IIT ALUMNI CENTRE
BENGALURU

saturday
WEBINAR

THE WEBINAR BOOK

VOLUME 1 | SEPTEMBER 2020

edited by
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preface by
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PREFACE

September 5, 2020

The IIT Alumni Centre at Bengaluru (IITACB) started a few years back and will soon have its own building in the Bommasandra area near Electronics City in Bengaluru. Our main goals are to provide a platform for the IIT alumni to network and come up with ways in which we all can contribute to the economy and the growth of India. We aim to be the facilitator for high end research projects between the IITs and the Industry as well as the government and the IITs.

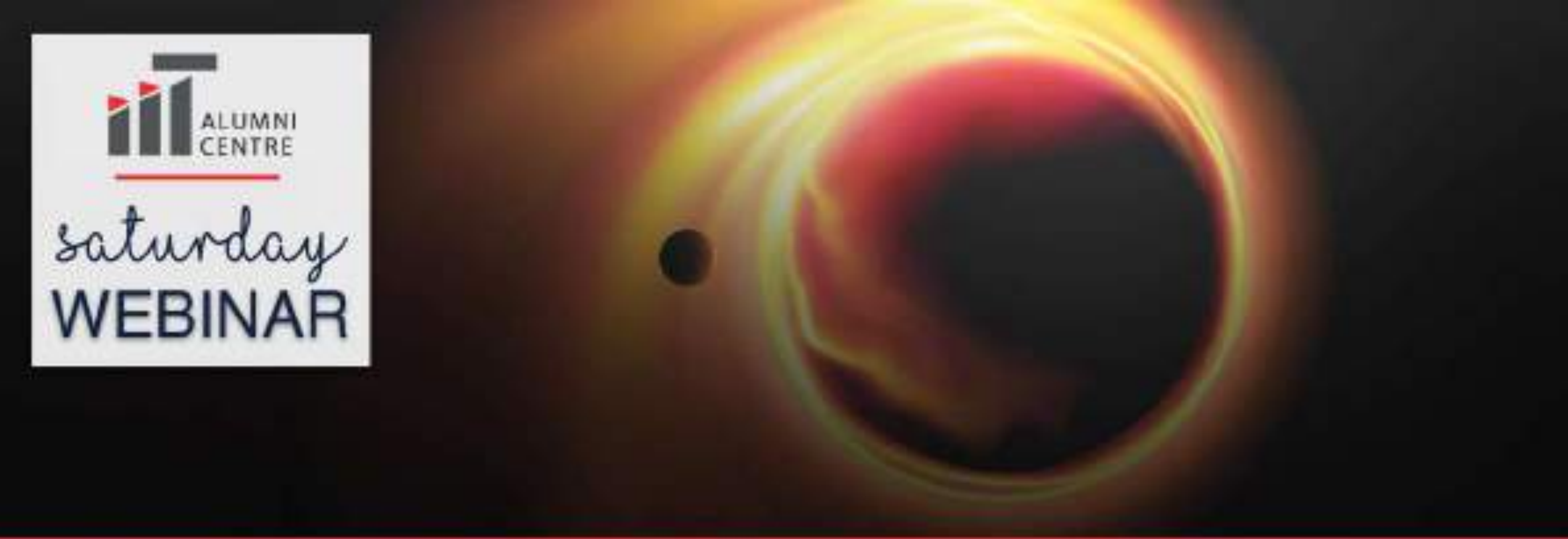
One of our regular activities was the Third Saturday Monthly Meet (TSMM), a networking event at which we had an IIT Alumnus give a talk on a topical area to the members and their guests. This was a very popular event and sadly we had to discontinue due to the Covid19 pandemic.

However, the lockdown offered an opportunity to plan virtual talks that got to be known as Webinars. We at IITACB started organizing Webinars and our first one was on April 18. Since then we have had 19 Webinars which are designed to share the excitement of what science and technology brings in our lives. The current pandemic has brought out the importance of science and why we all should listen to what it tells us. The talks have been on wide raging topics including the legacy of Stephan Hawking, water resources, materials, Covid related information, innovations in health and much more. We are delighted that all the Webinars were very well attended with numbers much higher than in TSMM talks and people from across the globe participating. The other important things of the Webinars is that a majority of the speakers and moderators have been IIT Faculty Members and Alumni. The IITACB champions of the Webinars were Ashok Kamath and Susheela Venkataraman with many others chipping in to make each Webinar an exciting event. All the Webinars are on the IIT Alumni Centre, Bengaluru Channel of YouTube, for those who missed attending them live.

We thought a logical next step is to document the Webinars into books for preserving the knowledge and for archiving them. We transcribed each talk with the authors correcting them, for which we are grateful to them. Ashok Kamath then took up the mammoth task of combining the talks and the slides, in cases where speakers had PowerPoint presentations. We are pleased to have the first volume ready for release on the auspicious Teachers' Day, September 5, 2020. We sincerely hope the readers will enjoy articles in the book.

(Ashok Misra)

President, IIT Alumni Centre, Bengaluru



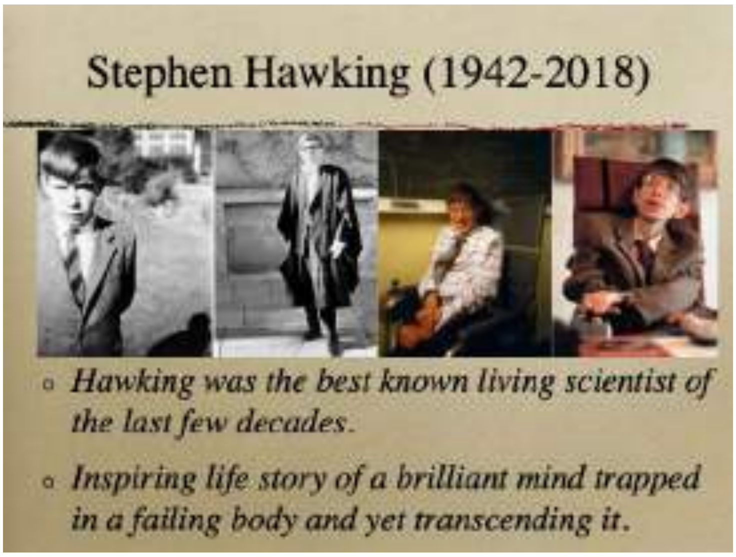
STEPHEN HAWKING'S LEGACY IN FUNDAMENTAL PHYSICS

PROF. RAJESH GOPAKUMAR | APRIL 18, 2020

Rajesh Gopakumar, born 1967 in Kolkata, India is a theoretical physicist and the Director of the International Centre for Theoretical Sciences (ICTS-TIFR) in Bangalore, India. He was previously a Professor at Harish-Chandra Research Institute (HRI) in Allahabad, India. Rajesh Gopakumar did his undergraduate degree in Physics from IIT Kanpur and went on to do his Ph.D. at Princeton University. After being a research associate at Harvard University he moved to Harish-Chandra Research Institute in 2001 as Associate Professor and then Professor. He was also a visiting long-term member at the Institute for Advanced Study, Princeton from 2001-2004. He is the recipient of the ICTP Prize - in honour of G. C. Wick (2006), the S.S. Bhatnagar Award (2009), the Swarnajayanthi Fellowship (2006), the J. C. Bose Fellowship (2015), the G. D. Birla Prize (2013) and the TWAS Prize in the Physical Sciences (2013). He is also a Fellow of the Indian Academy of Sciences, the Indian National Science Academy and the National Academy of Sciences, India. He was elected Fellow of the The World Academy of Sciences (TWAS) in 2015. He is a founding member (now alumnus) of the Global Young Academy (GYA).

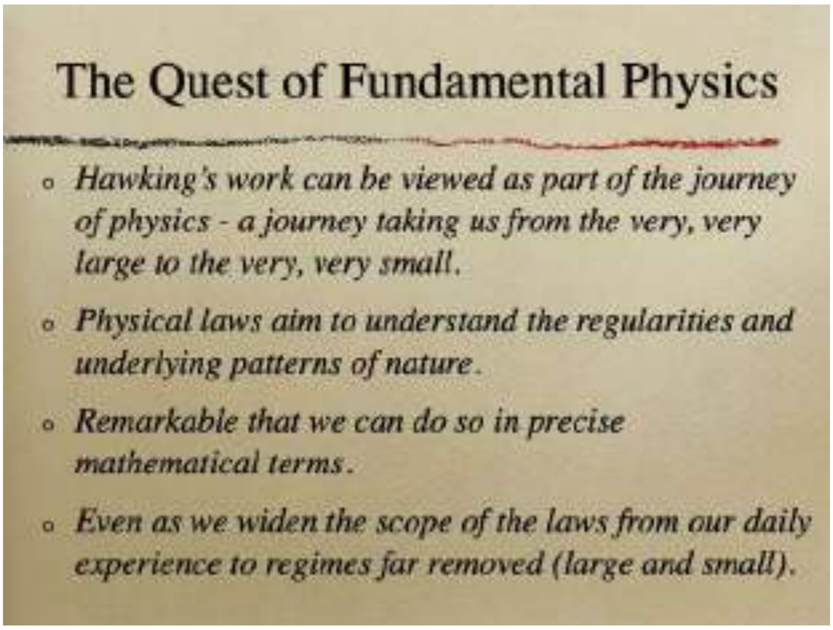
The Webinar was moderated by Dr. Aninda Sinha. Dr. Sinha is an associate professor at Center for High Energy Physics, Indian Institute of Science, Bangalore, India. He was awarded a Ramanujan Fellowship in 2010 and the Swarnajayanti Fellowship, instituted by the Department of Science and Technology, India. He received the Shanti Swarup Bhatnagar Prize for Science and Technology 2019 for his influential work on aspects of quantum field theory and string theory, in particular, on conformal bootstrap and entanglement entropy. Sinha is known for his work with Rob Myers on c-theorems in quantum field theories.

Lecture at IIT Alumni Centre, Bengaluru, by Dr. Rajesh Gopakumar, Director, ICTS-TIFR, Bengaluru, April 18, 2020.
Link to the webinar : https://www.youtube.com/watch?v=z7TPF51dHSE&list=PL0zMQ-70IHIX-df3u2Tto6dkKHCRC6iFL&index=19



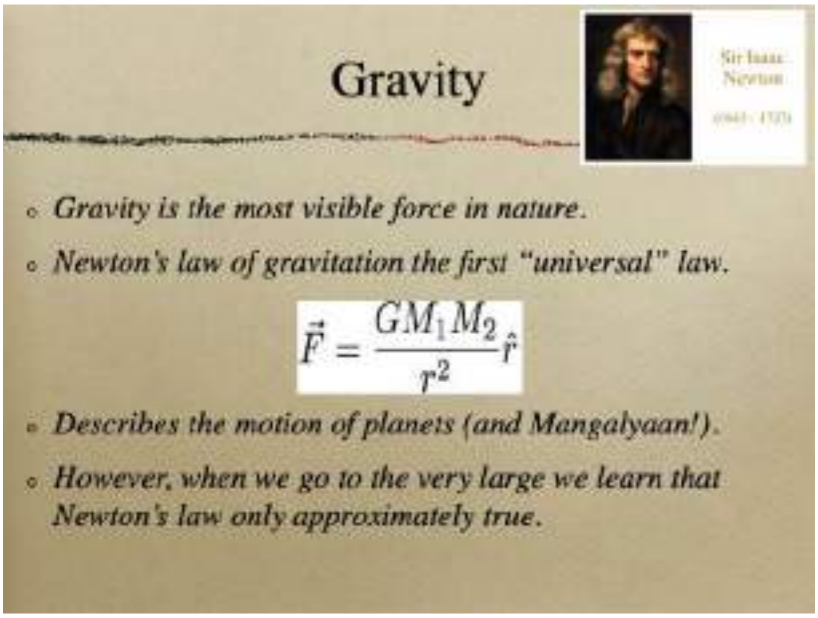
Stephen Hawking, as all of you have heard of, was probably one of the most famous scientists alive in the last few decades. His life story was particularly inspiring to people and actually giving this webinar, I was thinking that his story of brilliant mind inside his ailing body, yet overcoming these limitations is in some ways something we can particularly relate to, in our immediate circumstances of lockdown and isolation. Hawking's situation was an extreme version of this - the most self isolation a person can face - when your brain is active and creative and yet you are forced by circumstances to be cutoff in a direct way from everyone else. These are pictures of Stephen Hawking, at various stages of his life - in his childhood and then twenties and so on, there is no indication of his illness. But gradually there was the onset of the illness of amyotrophic lateral sclerosis or Lou Gehrig's disease. I won't talk about his life story as such, I will talk more about his scientific work.

In the context of modern physics, Hawking is famous not only for having overcome his limitations but for addressing profound questions of fundamental physics. His most important contributions which I will talk of are in the mid-seventies and are about properties of black holes and the Big Bang. It is these that I will talk about, particularly black holes. But again I can't resist making an observation in the context of these cosmic questions that Hawking spent most of his life wrestling with. It is a kind of metaphor for humankind in general while we are quarantined on this little planet, which is very nondescript planet in the solar system on the outskirts of the Milky Way Galaxy which itself is in a small corner of a very vast universe. Yet though all of us human beings are quarantined on this planet, we are able to transcend these limitations and explore the universe with our mind. This is something worthwhile to remember these days - that in the end the human mind can transcend some of these physical limitations and make inspiring journeys through the mind.



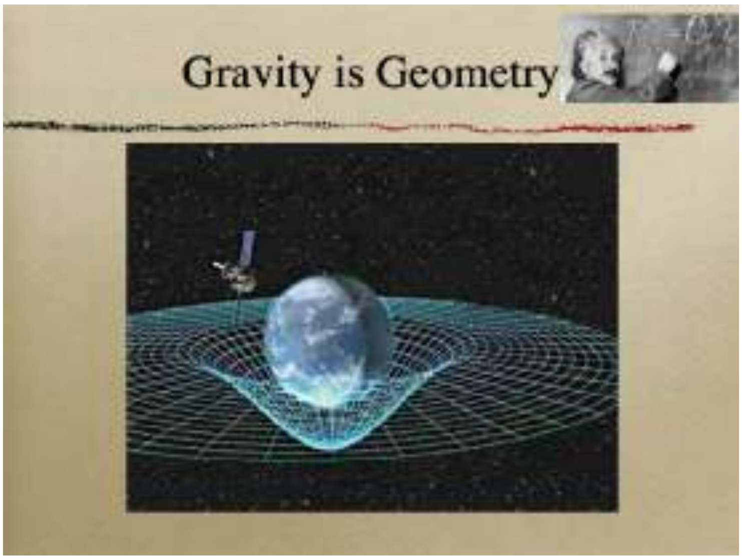
So Hawking's work can be viewed as part of the modern journey of physics, a journey taking us from the very, very large to the very, very small. I mentioned the large scales of the universe but interestingly understanding this will require us to also journey to very small scales. Let me put this in a larger picture. What is the aim of physics - physical laws aim to understand the regularities and underlying patterns in nature by figuring out how things fall and then how things move when you push them, pendulums that oscillate and so on and so forth. From basic phenomena around us, physicists first formulated the mathematical laws which we learn in school, in high school physics. This process of understanding the patterns of nature actually continues to hold even as we widen the scope of laws from far outside our experience to the very large and the very small that I was mentioning. It is quite remarkable that we have been able to capture these patterns in precise mathematical terms.

So that has been the quest of physics - to enlarge the scope of these laws and this is the journey which I will talk about. But I will focus on one aspect of this journey involving the force of gravity which is in one sense, the fundamental force that all of us know and feel in our bones. Gravity is, in that sense, the most visible force of nature - a tiny toddler while trying to make his or her first steps senses the force of gravity, and tries to overcome it. So it is something very ubiquitous that all of us encounter with and it was Newton's genius that he realized that one could formulate a law for this gravitational force and moreover applied it not only on earth but on a universal scale - the universe as he knew it at that time. This is the famous law of Newton which we all study in school, the inverse square law - so this is something you are all familiar with. I will remind you of the formula F= GMm/r^2. Here G is the Newton's constant strength of the gravitational force and M and m are the masses while r is the separation. This is the law which governs the planets in our solar system very well and in fact to this day space scientists like the ones who are designing trajectories for Mangalyaan and so on are using the Newton's laws. This works remarkably well within the solar system and in the environment we normally live which was the extent of Newton's understanding of universe.

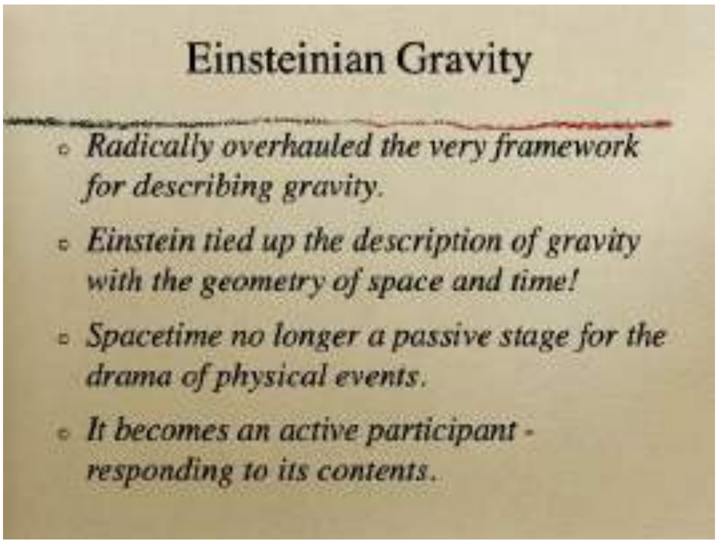


However this is no longer true when we go to the very very large - to the largest scales. As I said the solar system is in the outskirts of the Milky Way and the universe is immensely larger than the Milky Way. So what we learn is that in this vast universe there are extreme phenomena and Newton's law is actually only approximately true in many cases and in some extreme cases very far from accurate. Thus Newton's law of gravitation was a very successful law but it only applies within a certain domain. I will say a little bit more about what that domain is as we go along. But the important point to appreciate is that when one went from the terrestrial experience to the solar system, Newton was able to successfully expand our understanding to this bigger domain. However, physicists pushed it further and further and this what we have been doing.

The understanding that Newton had of the force of gravity was turned up on its head in some sense by Einstein who actually came up with a rapidly different picture of the force of gravity. What he actually said, if you want to encapsulate it in a slogan is that gravity is geometry. Let



me say a few words in explanation. What he meant to say is that the force that we see as the force of gravity is essentially a manifestation of the geometry of space and time. When there are massive bodies like in the picture here they affect the geometry around them. The matter curves the geometry in a particular, in a very specific, way such that objects moving in the vicinity of the earth like the satellite over here, feel this geometry and move according to the laws of motion on the curved geometry

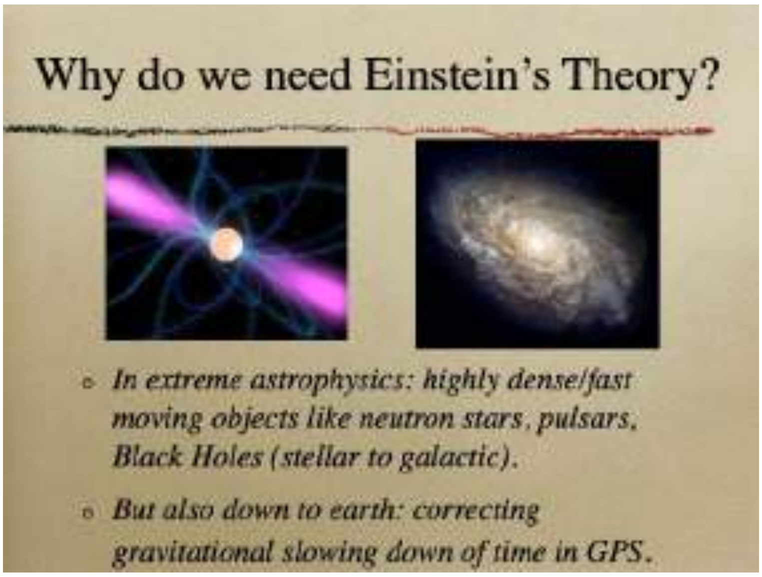


and those are the trajectories that we see. Those laws of motion in the curved geometry of spacetime actually appear to us like the elliptical or circular orbits which we normally find from Newton's laws. But here they arise from an entirely new perspective on gravity.

Moreover, quite remarkably Einstein gave precise equations for prescribing the geometry of the space time and he realized that in a certain limit you recover Newton's laws. But it is important to appreciate that this is recovered only in a certain limiting case. When things are more extreme, for instance when the velocities are very large - comparable to the speed of light - then Newton's laws are not a good description. Einstein's curved space geometry gives a more accurate picture and this has by now been experimentally verified in many instances, in many different situations. Thus Newton's law was, in some sense, expanded by Einstein.

Einstein overhauled the very framework for describing gravity and tied it up with geometry of space and time. One of the remarkable things here was that, and this is why Einstein was revolutionary, he brought about a completely different view of space and time. We normally view spacetime as some kind of passive stage on which all the other stuff happens. So space is what you perceive as up, down, top, left, right etc. - you think of all that as the setting on which all the physical events happen. Since Newton this is how physicists had formally treated it but Einstein realized that spacetime becomes an active participant because it interacts with the contents within the spacetime. The more heavy and more dense an object is, it curves the spacetime around it in a very specific way and so in that sense space time responds to the contents. It is as if you had a stage in which depending on what the actors on the stage were doing, the stage itself changes its mood or changes its colours - an interactive stage. So that was a very novel insight of Einstein to view space time in this way.

You might well ask that if Newton's law is good enough for sending satellites around the earth, spacecraft to Mars and other planets etc. then why do we need this Einstein's theory. As I said earlier, it is because, in this vast universe there are very extreme events which we, in our little boring corner of the universe, don't immediately encounter. Because, for instance, there are objects called neutron stars, pulsars, etc., which are very dense objects. A teaspoonful of neutron star material weighs as much as the Sun! So it is matter compressed to one of its most dense states. In such cases, you discover that Einstein's theory is the correct theory and not Newton's theory. Astrophysicists have measured and studied the physics in the environment of neutron stars, pulsars very extensively by now. They routinely find that when things are very highly dense, Newton's laws break down. Also, as I said earlier when things move very fast, at velocities comparable to the speed of light then again Newton's law of gravity breaks down. So there are many circumstances where the Newtonian description breaks down.



One of the most remarkable situations arise for black holes which I will talk more about very soon. Black holes arise at various scales in the universe. There are stellar black holes where black holes masses are a few times the mass of the Sun. In fact, it could vary from a couple of times to even about 30 or 50 times the mass of the Sun. Then there are galactic black holes which are typically found at the centre of galaxies. The Milky Way also has such a giant black hole at its centre and these have masses from a few million times the mass of the Sun to a few billion times the mass of the Sun. These are humungous black holes which have also now been detected. But we will come to black holes and their properties very soon.

I want to mention that you may think "OK, these are some extreme events in the universe" and merely objects of curiosity. But remarkably even "down to earth", Einstein's description of the curved geometry of spacetime means that there is an effect called the gravitational slowing down of time. This is a measurable effect when you go from the surface of the earth to a satellite which is a few thousand kms above the earth. There is a small time difference between the clocks on the satellite verses those on earth. And since all our modern GPS systems in our phones have to do with the signals sent from earth to satellites and their triangulation, if you want to pinpoint a location to an accuracy of even a few meters you need to take into account these corrections due to Einstein's gravitational slowing down of time. This is an effect that people have to actually take into account. So even something seemingly abstract at first has down to earth consequences.

Einstein's picture of gravity in terms of geometry has given us right now a very successful description of the universe and its evolution from the very early moments near the so called Big Bang to the present day. Thus at the very largest scales of the universe - the largest scales we have explored as species is about a million times the size of the Milky Way. Recall that the Milky Way itself is mind bogglingly large since the solar system itself is a tiny spec in the Milky Way. We are now talking of things a million times the size of Milky Way. In fact, the

Milky Way and other galaxies form clusters which in turn form super-clusters and so the universe is structured and textured at much bigger scales than we might have thought. And Einstein's theory gives a very good description of all this structure. So you might think "Great, to the extent we have managed to see in the universe to a very large scale we seem to have a good theory". Aren't we then done? Actually the answer is No. And this is one of the remarkable things in the journey of physics that one repeatedly sees (and as we have seen with Newton's theory for gravity itself). Einstein's theory itself throws up some puzzles and this is what I will come to the next. Maybe this is a good time for a short break and ask people if they have any quick things to clarify.

Q&A: Srinivasan Sekhar: What exactly is meant by space time curvature, in terms of equations and math? More precisely what does it mean that spacetime is curved by gravity.

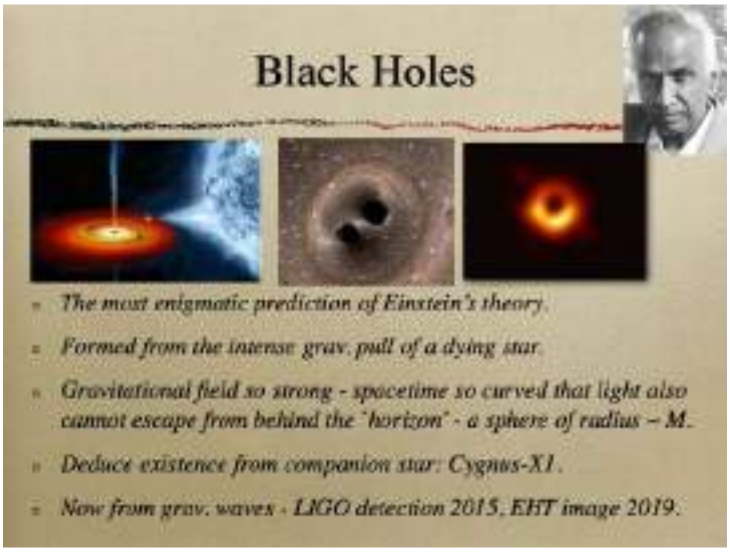
It is of course difficult to explain in a few words what it is like, but just to give you a rough picture, you know in two dimensions if you just take a piece of paper which is flat like this, you describe things in terms of Euclidean geometry. You have the sum of the angles of a triangle adding up to 180 degrees - all the things that you learned in high school geometry. But now if I curve this paper in some way and then I draw the analogue of triangles on it, the sum of the angles of the triangle actually will no longer be necessarily 180 degrees. It actually depends on whether the paper is positively curved like the surface of a sphere (in which case the sum is greater than 180 degrees). Or it can be negatively curved like the saddle of a horse in which case the sum can be less than 180 degrees. This is a case in two dimensional curved geometry which is easy to visualize. Now four dimensional geometry (of space and time) being curved is more difficult to visualize. But nevertheless it can be done in terms of equations very similar to those we use for describing two dimensional curvature. This generalization was done by the German Mathematician Riemann and there are precise equations which tell you how to describe the curvature in terms of the way you measure local distances - something called the metric. The curvature is defined in terms of taking second derivatives of the metric. This geometric curvature is what appears in Einstein's equations. They essentially relate this curvature to the energy (or equivalently the mass) in the space time. More precisely the mass density (or the energy density) determine the curvature. These are very precise equations and you can look them up in the internet or some introductory books on General Relativity. This is how one quantitatively describes the curvature and finds out how much curvature there will around a given body like the earth or the sun.

Q&A: Can you please explain about black hole jets?
I have not yet talked about black holes and probably not talked about black hole jets but I will be happy to answer later.

Q&A: Arvind: Are you saying, time on a GPS satellite time goes faster than on earth, that this could affect GPS accuracy? If so, how that is corrected further?

The clocks on earth go slightly slow compared to the clock on the satellite and you know exactly how much it is. It is roughly like one part in a billion. So knowing this you can correct for it.

So let me proceed. As I said, Einstein's theory is very successful but there are puzzles, and, black holes which I mentioned already really exemplify those puzzles. This is where Hawking's work will come to centre stage. Black holes are in some ways one of the remarkable predictions of Einstein's theory. They are one of it's most enigmatic predictions because even now, more than a century after the prediction, we have so far not understood its properties in detail. People are still trying to figure out the consequences of this prediction. In the universe out there you see these black holes which were at first simply a set of solutions of Einstein's equations. In astrophysics, people began to study what happens when a star



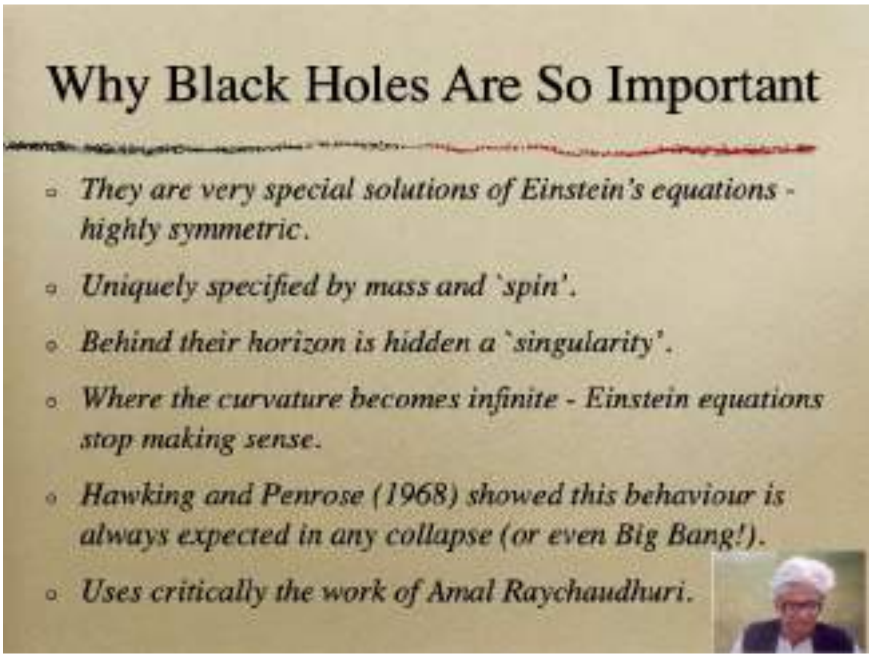
becomes so dense that there is nothing that can overcome its gravitational pull. Recall that since gravity is always attractive in the end it always wins over other forces. Now in a typical star like the Sun there are other chemical processes, nuclear processes going on which generate energy and therefore pressure which pushes the star out and balances this attractive pull of gravity. However, when stars burn out, when nuclear fusion processes extinguish themselves, then they eventually collapse. At first they collapse to things called white dwarfs and neutron stars but eventually - and this was first realized by Chandrasekhar - the gravitational field is so strong that probably nothing that we know can resists the gravitational collapse.

The end point of this collapse is likely to be something where the space time is so highly curved that even light cannot escape from beyond a certain radius. So in a sense, you can think of space time which curves into a kind of infinite or very long tube. I showed you earlier the picture of the earth sort of gently curving that space and you can imagine it is much more dramatic when things are very dense. Then the curvature would be so strong that light which tries to go in a straight line in that curved geometry will not be able to escape, it gets trapped inside. This is what happens in a black hole and you can mathematically understand this from the geometry of it's space and time. There is this region which will be important for us so please keep in mind that there is a region called the event horizon which you might have heard of. It is roughly a sphere of an area which is proportional to the mass of the object. Beyond or behind this horizon is the region from which the light cannot escape. In the simplest case it is a sphere of radius proportional to the mass and called the Schwarzschild radius. The Schwarzschild radius is the one behind which light cannot escape and this is why the name black hole arose.

Here is a picture of the region near a black hole which also shows some the jets that someone asked about. So you see the black sphere in the middle is an artist's impression of the tiny region beyond which light does not escape. People felt this was a possibility that could happen but it is of course very difficult to see something from which light cannot escape - it is almost an oxymoron. So people initially deduced the existence of these objects from cases like that shown in the picture. Here there are two objects - one is a star which seems to be losing matter which appears to be spiralling into some massive nearby object which must be very dense but not having much of a structure. This was first noticed in a particular star Cygnus X1 in the 1970s. Gradually people found more and more examples and grew convinced of their existence.

Remarkably enough, in the last five years we have seen more direct evidence of these black holes. The first is from gravitational waves detected by the LIGO laboratory - which can be a whole topic for another fascinating talk. The LIGO observatory detected gravitational waves that comes when two black holes collide and create ripples in space time which can be measured. These ripples show up in these very sensitive detectors. And then last year we had the so called Event Horizon Telescope (EHT) which was a radio telescope set up as a whole network of radio telescopes around the world which imaged the black hole at the centre of the M87 galaxy. This picture was a sort of rendition of that image, which was originally in the radio wave length. THE EHT folks could see a very clear evidence of structure which matched with what one predicts for the environment around the black hole.

I must say that all these developments are very remarkable because within 5 years you got this direct evidence of two very different kinds of black holes. The black hole that LIGO detected shows us stellar black holes. As I said these are in the tens of solar masses The picture from the Event Horizon Telescope is of a black hole at the centre of the galaxy and this particular one is a few billion solar masses. So we now have very direct evidence for both stellar and galactic black holes.



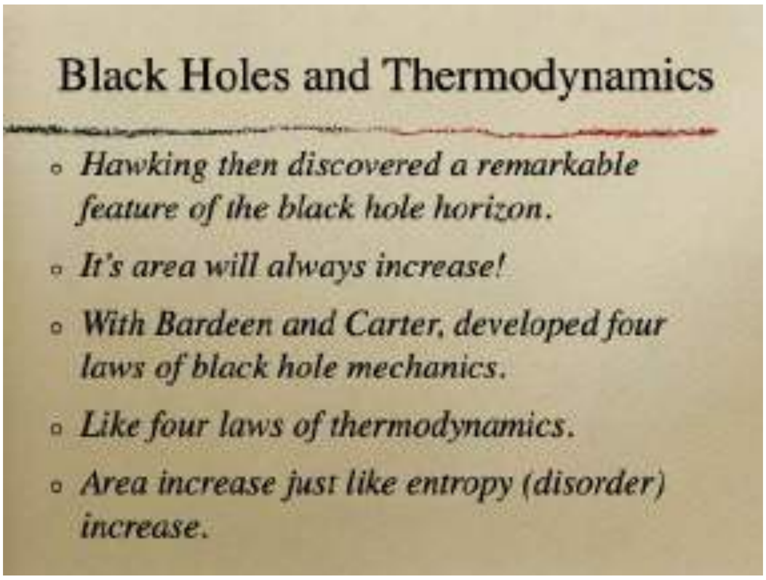
Why are these black holes so important? Firstly they are very special solutions, highly symmetric solutions of Einstein's equations. When I mean they are highly symmetric, that means they are completely specified once I tell you what the mass of the black hole is and how much it's angular momentum is i.e., how fast it is rotating. So just those two numbers essentially capture all the properties of the black hole, the geometry is completely specified once I know this and you can show that the black hole's geometry is unique. So we have these highly symmetric special solutions and moreover they have this funny region I mentioned - this event horizon beyond which light doesn't escape. Behind the horizon there is something even more puzzling called the singularity where spacetime essentially ends and people still don't completely understand it. It is a place where Einstein's equations breaks down. The curvature, which I mentioned earlier, becomes infinite and the equations stop making sense there. So Einstein's equation predict this solution which is very beautiful, has these very unique characteristics and which has been experimentally observed. But in some sense Einstein's equations also tell you that something must break down inside this black hole. We really don't understand what really happening in inside because there is bound to be a singularity.

People were very puzzled by this. But in the 1960s - this was even before black holes were experimentally detected - people felt that this is just some special solution of Einstein's equations. In any actual system which was actually formed from a star - a star is much more messy - it is not going to settle into some very symmetric object. So there was a feeling that the singularity is more a consequence of, or an artefact of, very special symmetric solutions. Hawking’s first work for which he became famous, is the work he did with Roger Penrose in his thesis in 1968 which shows that in any collapse generically you will have a singularity. In other words, this singularity is inevitable - Einstein's equations will inevitably develop a singularity when you let things evolve in time even in a messy real world situation. Even for the Big Bang, which also has a similar singularity, this fate is unavoidable. It has nothing to do with some very symmetric solutions - it will always be there.

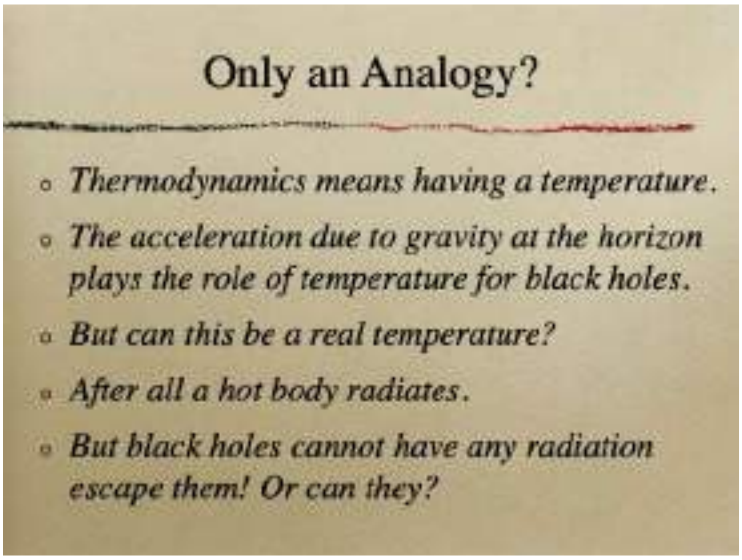
This was very eye opening and changed physicists’ way of thinking about the singularity and made people realize that you have to address this problem. Namely, that Einstein's equation stops making sense at some point and therefore there is a puzzle to understand. What does it mean that space time ends and there is a singularity. I want to mention here about an unsung hero of Indian science, Amal Raychaudhuri who taught at Presidency College in Kolkata - in fact he was a mentor for many brilliant physicists working in the country today. His work in the 1950s on something called the Raychaudhuri equation, which tells you that in gravity things must inevitably come together, was used by Hawking and Penrose in their works. You don't normally hear so much about Raychaudhuri in India but his seminal work even now continues to play a role even now in our understanding of Einstein's theory.

Hawking as I said came on the scene with a big bang, so to say, with his work on singularities. But he then focussed his attention on the black hole horizon - he actually realized that there were some remarkable features even for the black hole horizon. The singularity is after all something deep inside the black hole and you might not immediately access it. But the horizon is the interface of the black hole with the rest of the universe. That is the place where you see that there is a region beyond which light is not escaping. In other words that is the boundary of the accessible part of the black hole. What he realized is that Einstein's equations predict that the area of this horizon - this sphere at the Schwarzschild radius- will always increase - it can never decrease. So it can't happen that the black hole will split up into two smaller black holes which would mean the area will decrease. In fact black holes can only eat up each other like monsters. They keep increasing - they can never shrink and disappear, at least that is the consequence of the Einstein's equations. Hawking, together with two other physicists Bardeen and Carter, developed what they called the four laws of black hole mechanics which have to do with properties of the black hole horizon. The reason to call them the four laws of black hole mechanics is because there are four laws of thermodynamics and they noticed a very compelling analogy with these laws of thermodynamics.

This was, firstly, very strange. Perhaps many of you are more familiar with the laws of thermodynamics, which is something you might have studied as an engineer - all of us take courses on thermodynamics at IIT. These laws are the basis of heat engines. You may know about the first law of thermodynamics is essentially the law of conservation of energy. What will actually be important is the so called second law of thermodynamics which is something that you may also be familiar with. This is the law which essentially tells you that entropy, which is a thermodynamic concept, always increases in the universe. This is something all of us can relate to - we only see an increase in clutter as times goes by, in our home and offices, unless we put in an active effort to reduce the entropy. Of course, in that process you sweat a lot and the net entropy in the universe increases. Entropy is actually a precise technical concept which tries to capture this notion of disorder. One way to to view it is as the number of different configurations a system can take. So a high entropy system is one in which there can be many many different configurations giving rise to the same overall system. While a low entropy system is a very ordered system like a magnet in which all the individual atomic magnets are lined up. This is a very ordered state whereas when the magnet is demagnetised all the individual magnets can point any which way and is thus a highly disordered system. So entropy is measure of this disorder.



What Hawking observed was that the area increase theorem was a bit like the entropy increase theorem of thermodynamics. Of course such an observation is meaningless if it is only about one such thing. After all many things increase with time - my weight increases all the time. But that doesn't mean that your weight has anything to do with the horizon of a black hole. With Bardeen and Carter, Hawking found that the analogy also holds with the other laws of thermodynamics as well, such as the first law of thermodynamics is about conservation of energy. There were analogies to all the laws and thermodynamic concepts



which was quite remarkable. But at first glance this looks very strange because for thermodynamics you need to have a temperature. I just told you that all thermodynamic concepts have analogue with black holes. In fact if you took this analogy seriously, the acceleration due to gravity at the horizon would play the role of temperature of the black hole. This looks totally crazy. Why would the acceleration have anything to do with temperature? In what sense can it be a real temperature? And besides, a hot body which has temperature is radiating - it radiates and loses energy to its surroundings. But we have just been talking about black holes not being able to radiate, radiation is after all light or electromagnetic radiation which we asserted cannot escape black holes. So what is happening here? Maybe this is only some silly analogy without any deeper significance. In fact, Hawking believed that this was a silly correspondence though there were other people like Bekenstein who thought that it was really more than an analogy. Hawking therefore wanted to prove that it just can't make sense, so he investigated this question in detail. This will bring us to the last part of the story - on Hawking's greatest work.

Q&A: Nitish: How does black hole form reducing ... jets if nothing comes out of the lab? Does black holes have harmonic vibrations?

It is not coming out of the black hole, we can say that it is coming only from the environment around the black hole, not coming from the black hole. About the harmonic vibrations, I will talk about it a little later.

Q&A : Aditya: Is there any evidence to show conservation of mass does not hold in a black hole ?

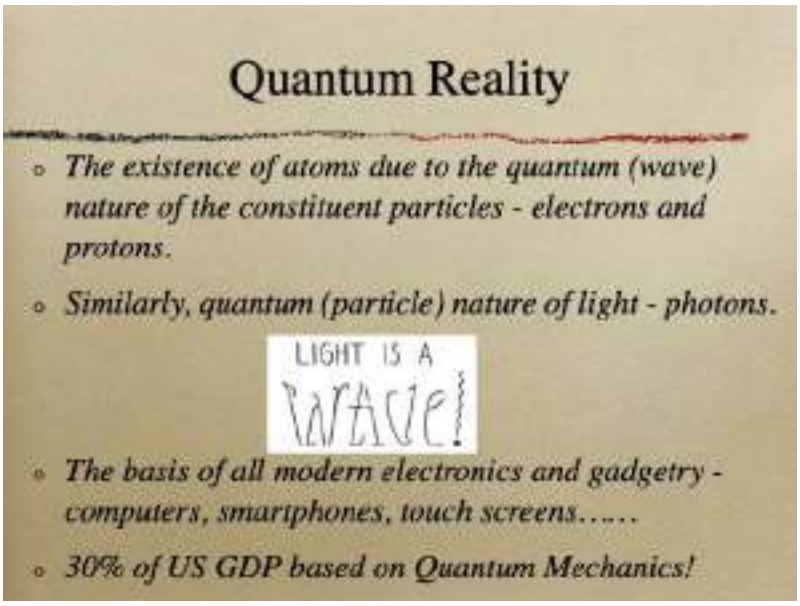
No, we don't see any evidence for that provided you understand this in terms of mass and energy which are interchangeable. In fact when those two black holes detected by LIGO collided, it was actually of one with 35 solar masses and the other 29-30 solar masses and the final black hole was 62 solar masses. So you might have thought mass is lost, but actually the three solar masses were carried away in gravitational radiation. You know that energy and mass are interchangeable by Einstein's relation and so if you take that into account, there is no evidence for any non-conservation.

Q&A: Nitish: I read in Hawking's book that if black hole A and black hole B combine, they will give a black hole C which has a larger area than black hole A and B individually - how and why? Is this the second law of thermodynamics?

Yes this is the second law of thermodynamics or black hole mechanics. You can actually work it out. I have actually given you most of the information needed for that. I mentioned that the radius of the horizon is proportional to the mass. So if you can imagine two bodies each of mass M and so is the Schwarzschild radius. The area is proportional to the square of the radius. Now you bring the two masses together, it becomes a black hole of two times the mass and if you works out its area you will see that it is twice the area of the original black hole. So the area is always increasing and you can work it out using the relation between the area and radius which is 4pi R^2 and the fact that the radius is proportional to the mass.

Q&A: Ashok Misra: Is it area or volume?
That is definitely one of the very remarkable features of this relation. That it is proportional to be area and not the volume and I will comment more below.

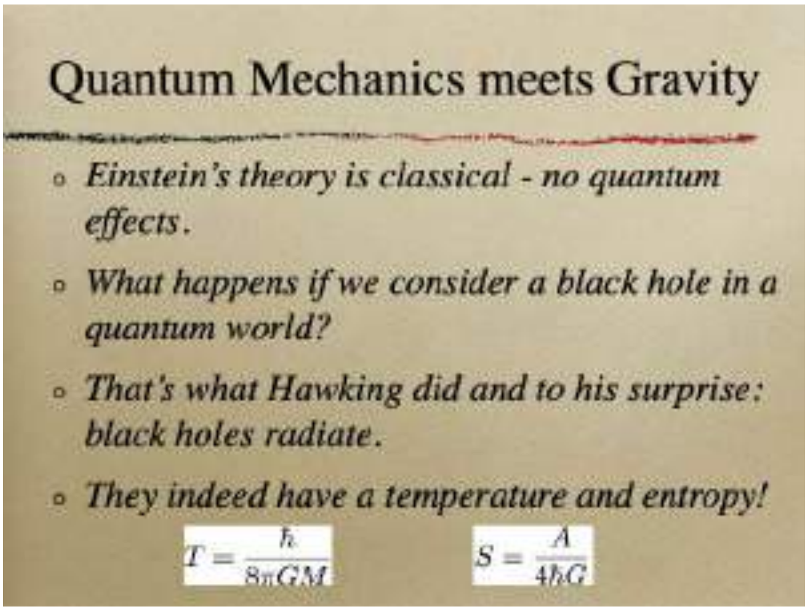
In trying to explain Hawking's most profound results, let me bring in a third component, another pillar actually of our understanding of modern physics which we have not talked about so far and you might have even wondered why. I talked. about Einstein's theory which is a so-called classical theory. Whereas we now know that there is a quantum nature that underlies all reality as we now understand it. In particularly the existence of atoms is due to the quantum nature or the wave like nature of the constituent particles namely, the electrons, protons, etc. This picture at the very small scale from the atomic scale downwards is something that we have now tested very well. We know that light also has a quantum nature and that is the origin of the term



photon coined by Einstein - it has a quantum particle like nature. Here is a little cartoon that illustrates this duality between waves and particles. If you read "particle" then you don't see "wave", if you read "wave" then you don't see "particle". it is a bit like that in quantum mechanics. This mystifying description in reality is really the underpinning of much of modern electronics and gadgets. The things that surround us: computers, smart phones, touch screens, GPS and lasers, all of them have their origin in the laws of quantum mechanics. If you didn't know the laws of quantum mechanics as we didn't before 1925, we wouldn't have had any of these objects. The underpinning of much of modern technology is quantum mechanics. In some estimation, 30% of the US GDP is based on the laws of quantum mechanics. So I just put that out there to bring home to people the importance of understanding the fundamental laws of physics from a purely pragmatic point of view.

This microcosmos - I haven't so far talked about the microcosmos - is where quantum mechanics applies most dominantly. In fact it governs all the other forces of nature: electromagnetic, radioactive and the strong nuclear interactions all the way to distances about a billion times smaller than an atom. So at the atomic scales and beyond when people wanted to describe phenomena they discovered the laws of quantum mechanics. Nowadays we test these laws in accelerators like at CERN. The circle that you see is a picture of LHC - an underground tunnel below that circle. This is this accelerator which was in the news for finding the Higgs boson. You can see the Geneva airport runway there to give you a scale of how big that collider is. This huge collider can actually probe distances right now all the way to a billion times smaller than an atom and the laws of quantum mechanics hold incredibly well all the way. This is, as I said, a pillar of our modern understanding of nature.

I told you about these two different things, one is gravity at very large scales and then quantum mechanics at the microscopic distances. They seem to be like worlds apart and indeed Einstein's theory is in some sense what we call as a classical theory, something like Maxwell's theory of electromagnetism which is a purely classical description. Einstein's theory is in some ways a complicated generalisation of Maxwell's equations. Maxwell's equations tell you what the electric and magnetic fields are once you have currents and charges. Einstein's theory tells you what the geometry is once you have masses and energy so mass and energy play the similar role as currents and charges. Just like the electric and magnetic fields, the geometry is described by a metric field. It is a classical description in terms of differential equations if you think of it mathematically - there are no quantum effects in it.



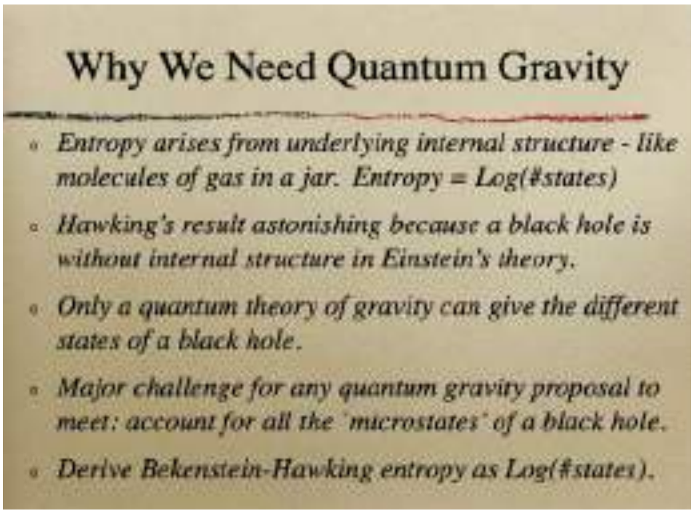
So one can now ask what happens if we consider black holes in a quantum world. This is what Hawking essentially did. You take a little baby step into the quantum world by asking what happens if the environment around the black hole is described by the laws of quantum mechanics. What would change from what one studied earlier? Hawking did this to try to disprove this idea of Bekenstein that black holes have entropy and can potentially radiate. He found to his surprise that a black hole indeed radiates. They have a temperature and an entropy. So this was a complete surprise. Bekenstein had proposed that there would be an entropy, but he didn't really think of it as having a temperature.

What Hawking found was that actually there is a temperature and gave a precise formula for this temperature and that is one of the equations I wanted to show. It is a very beautiful formula and is for the simplest kind of black hole. You might remember, I introduced the symbol G earlier as Newton's constant of gravitations - it is the basic underlying physical constant for gravity and M is the mass. Then there is this "h bar" which is actually Planck's constant in the numerator and this is a signature that it is a quantum effect. If this was not there, the temperature would be zero. So this is a purely quantum effect which is why Planck's constant, which is a measure of quantumness, enters into this formula. This is for the simplest kind of black hole and there is a similar formula for the entropy which actually turns out to be proportional to the area. Again, like we discussed, the area increase was behaving like the entropy and now Hawking is telling us that it is not just an analogy - the black hole does have an entropy which is given by a very precise formula. It is not just an analogy, there is a precise formula that tells you that the entropy of the black hole is equal to its area divided by the Planck's constant and this area is as I said proportional to the mass, square of the mass actually - so it is a very definite formula. So Hawking found that if you include quantum effects, black holes do have a temperature and radiate.

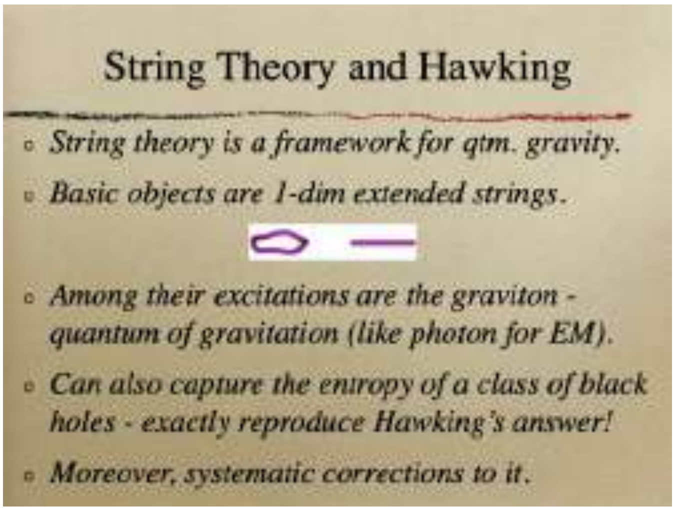
There are many things that are puzzling about this formula some of which were already raised. Entropy is something which normally arises from the underlining internal structure of a thermodynamic system. Like when there are molecules in a jar and you study their entropy in a thermodynamics course you realize that the entropy is proportional to the volume. More fundamentally this comes from the number of different states that the underlying gas molecules can occupy. Thus Hawking's result is astonishing for a number of reasons. Firstly, the fact that it is non-zero because as I mentioned earlier, the black hole in Einstein's theory has no internal structure. It is very unique, so you cannot say that it is like molecules of gas in a jar because then there are lots of molecules that can be moving all over the jar and that is why there are many different states the molecule can be in for a fixed volume. But for a black hole if I tell you it's mass and angular momentum then it is essentially in a unique state which is the solution of Einstein's equations. You would have thought the number of states is one and the logarithm of one is zero i.e. entropy should be zero. So it is surprising that there is a non-zero answer for the entropy that Hawking found.

That is surprise number one and surprise number two is that if it is non-zero, you would have thought it should be proportional to the volume like Ashok asked. But it is instead proportional to the area. Thus, it is again very puzzling because there is no thermodynamic system which we normally encounter in which the entropy is not extensive. Entropy always grows as the volume - the number of different states grows exponentially with volume and therefore the law will always be proportional to the volume. So Einstein's theory is unable to account for this quantum entropy. It is only a quantum theory of gravity - which describes gravity completely at the quantum level - which can give the underlying states of a black hole. Note that what Hawking actually found is a formula not by considering a full-fledged quantum theory of gravity. As I said he just considered what a black hole would do in a quantum environment but he didn't really study the black hole itself as a fundamentally quantum object. Only a full fledged quantum theory of gravity can do so and this is a challenge.

Hawking's formula therefore immediately throws up a challenge for a quantum theory of gravity which is to account for this very strange formula that the entropy is proportional to

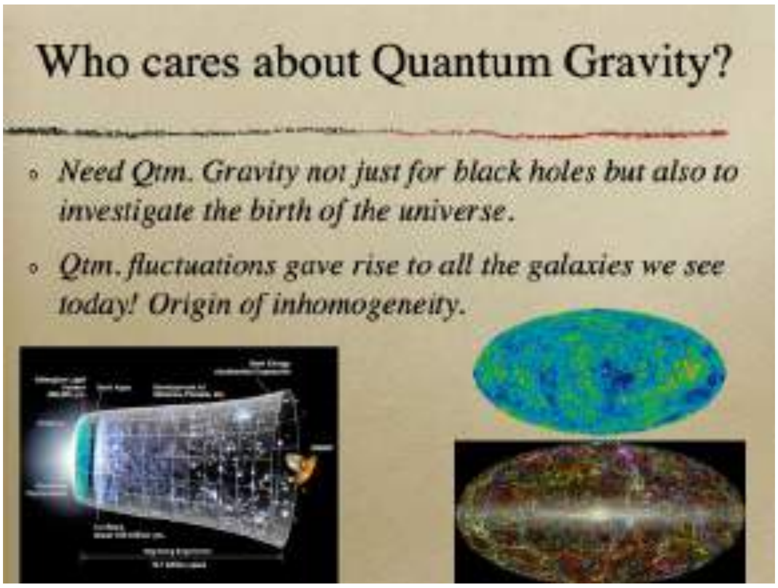


the area with this proportionality factor. And this has to come out from any viable quantum gravity proposal. To me it is a benchmark for seeing whether you have a viable theory of quantum gravity. It has to account for all these micro states of a black hole. We have to be able to count the number of different states, take its logarithm and account for this entropy. It is therefore a definite challenge - if you or I come up with a quantum theory of gravity, one of the first things what we need to do is to figure out whether we can reproduce this answer of Hawking from a microscopic point of view, namely by counting the microstates. Let me remind you that one of the successes of the atomic theory was in accounting for the entropy of gases and all the thermodynamics that we study. It is actually well described by the theory that gases are made of molecules. Similarly we need an atomic theory of gravity which will account for this entropy.

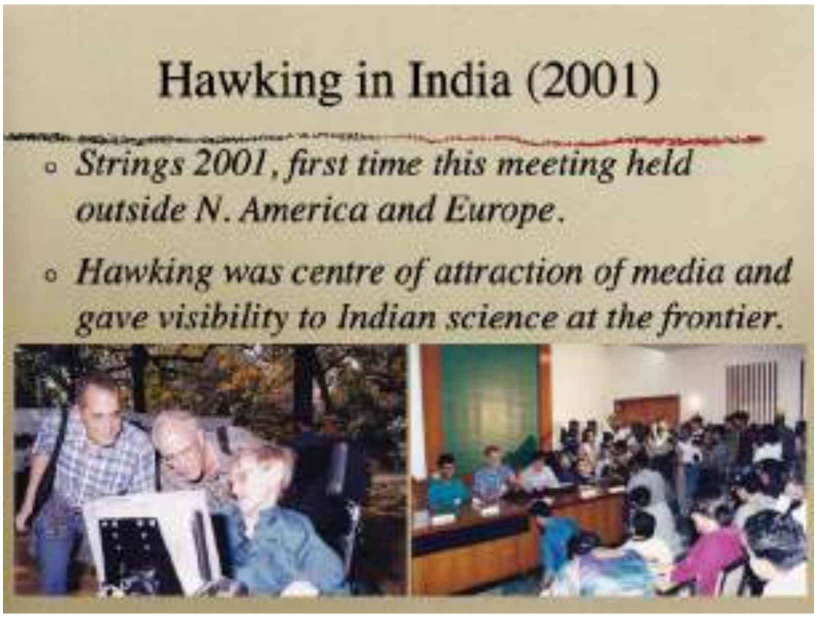


I will therefore say a little bit in the final closing section of this talk about String Theory. String Theory is a framework of quantum gravity in which the basic objects are one dimensional extended string like objects like close strings or open ended strings and among the early successes of String Theory was the fact that it could account for the quantum of gravitation and its interactions. Just like the photon is the quantum for electromagnetism, the graviton is the analogous quantum for gravity. This could be accounted for by String Theory and its interactions were of the right kind. But I think that the strong test that String Theory passed to be considered a viable theory of quantum gravity was that it could capture the entropy of a large class of black holes and exactly reproduce Hawking's answer with the factor of a quarter. Moreover, it predicts very systematic corrections which can also be compared. Hawking's formula is strictly speaking applicable for a very large black hole with a very large area. So there are corrections to that answer, which you can work those out and String Theory has been very successful in doing all that.

I have now told you the need for a quantum theory of gravity - that we need it to understand black holes - but you might think that is very special. Actually, it is also necessary to understand the birth of the universe. In some ways all the galaxies and everything we see today arose from initial quantum fluctuations at the time of the Big Bang. It is rather a remarkable fact that all the structure that we see in the universe today, both in terms of distribution of galaxies and in the cosmic microwave background, are coming from quantum fluctuations in this very early era. In the diagram on the left, you see it says quantum fluctuations at the early Big Bang and then the universe expanded and all the structure of the galaxies etc., arises from a magnification or amplification of those quantum fluctuations.



On the right hand side there are two pictures, the top picture is the picture of the anisotropy of the cosmic microwave background which again shows that there is an overall background of three degree Kelvin radiation coming from the relic of the Big Bang but there is inhomogenity as well. The brightest blue spots are the cooler spots and the yellow ones are the warmer ones - there is one part in hundred thousand inhomogeneity in those quantum fluctuations. Similarly the lower figure has to do with the distribution of matter, not radiation. Matter such as galaxies and their clusters that I mentioned and you see that the universe is not homogeneously populated. It has all these fibres and it looks like some neuronal structure. So this is the reconstruction of the universe, the distribution of matter in the universe at the largest scale and this is inhomogeneity again arising from quantum fluctuations. We therefore need to understand these quantum fluctuations better to have a full fledged understanding of the universe as it is today starting from the very early era. In a sense, we understand things quite well from a little after the Big Bang, so we assumes certain conditions just after the Big Bang, then you can follow through Einstein's equations fairly successfully but that very initial period that we don't understand well and that is where we needed a theory of quantum gravity.



Let me just close by just saying Hawking had come to India in 2001 for the String Theory Conference that was held in TIFR in Mumbai. This was for the first time that this prestigious meeting was held outside North America. It was testimony to the fact that India has a very strong presence worldwide in String Theory. In fact I would say that perhaps outside the United States, India has had the single most influential community in String Theory in any single country. So Hawking was there and this is the picture with two other stalwarts of Physics, David Gross and Ed Witten at TIFR. This is a picture of the press conference Hawking addressed at TIFR. You can see all the journalists are trying to get his picture. He was the centre of attraction and it had given lot of visibility to Indian science. We were trying to get him in 2015 to Bangalore at ICTS when we organized the Strings 2015 conference But unfortunately his health was failing and he couldn't travel and we couldn't have him here then. So let me end by an inspirational quote from Hawking:

"Remember to look up at the stars and not down at your feet. Try make sense of what you see and wonder about what makes the universe exist. Be curious. And however difficult life may seem, there is always something you can do and succeed at. It matters that you don't just give up"

As I said in the beginning, the fact that Hawking is an individual who could overcome the limitations of being in an extreme "lockdown state" to traverse the whole universe should inspire all of us - as mankind continues on its journey to unravel the mysteries of the cosmos.

Thank you very much.

Q&A: Prof. Sarit Kumar Das: While there is analogy of black hole dynamics with the laws of thermodynamics do we also have an analogy with convective radiative heat transfer.

Not in a very direct way, convection usually requires motion of particles and transfer of heat across regions. But there is an interesting analogy with hydrodynamics and this is also related to a question people asked about harmonics on black holes. If you throw some matter into a black hole, then what happens? Supposing I just go today and dump all my trash into a black hole. It will fall into the black hole and the black hole will vibrate initially, it will have oscillations and these are very specific modes called quasinormal modes. Then it will slowly settle down to a final state which is another black hole - slowly relax down to one of these states, in the process probably radiating some gravitational energy. These fluctuations that are there initially can be described as some kind of hydrodynamic ripples also. So there is an analogy to hydrodynamics which is after all the first deviation from thermodynamics or equilibrium.

Q&A: Srinivasan: Can an elementary particle be thought of as a black hole?

It is an interesting question. People have speculated on that because in a limited sense, particle-like black holes are specified by their mass and charge and angular momentum. But if they are in some sense black holes, they would be very tiny black holes. We haven't seen any structure of the elementary particles to the scales I mentioned earlier of one billionth of the size of an atom. We haven't seen any structure at that level. But there is also another problem which is that if you have very tiny black holes they radiate, the Hawking radiation is also higher because the formula, the temperature is inversely proportional to the mass. So when you have a small particle, the temperature is actually very high, it will very quickly radiate away. But on the other hand one has extremal black holes which do not radiate - there is therefore speculation but nothing very concrete yet.

Q&A: Sreekumar: How far generally is a black hole from its companion star?
There is no fixed distance, but it will be on the scales of solar system distances. It would depend on their masses, they would just be orbiting like a binary star around each other. By the way these black hole binaries which are orbiting around each other, they eventually spiral in. This is because of gravitational radiation. Unlike in Newton's theory, where two bodies can be spinning around each other forever and nothing will change - it's a stable system. In Einstein's theory, when two bodies are rotating around each other, they will radiate just like an accelerating charged particle radiates electromagnetic radiation. These accelerating massive objects, binary objects, will also radiate gravitationally and they will send off ripples and they will lose energy. When they lose energy they will come closer and spiral in and move faster and faster and finally they will merge. Similarly there can be binaries of a neutron star and black hole or a binary of neutron stars.

Q&A: Aditya: In the quantum world, don't the strong forces and electromagnetic forces overtake the forces of gravity. Why should gravity be what we are concerned with?
Of course this is what happens initially, that is what keeps white dwarfs, for instance, from collapsing. There is the strong force in the nucleus which generates a certain nuclear pressure in a neutron star which balances the gravitational force. But in the end when the density become higher what happens is that the quarks inside the neutrons also get liberated. When the density is very high they form what is called as plasma and in fact at very short distances

quarks have almost no force between each other. So that force is also not sufficient to hold up gravity. Electromagnetic force is overcome right at the beginning itself. That is much weaker but when things become of a nuclear scale, then at some point strong interactions also can be overcome. Gravity can be stronger and stronger as things come closer, whereas the strong interaction become weaker.

Q&A: What is the closest black hole to the earth, does it interact with the earth in any manner. I don't know in terms of the numbers and distances, I think Cygnus X1 must be one of the closest ones. There may be other candidates as people are finding new black holes. It could be of the order of tens of light years, or hundreds of light years. They wouldn't interact with the earth in a very direct manner. It is lucky for us, but actually as far as the outside of the black hole is concerned, it is no different from that of a star. You only feel the extreme gravitational pull when you are very close to the horizon. As far as the gravity far away is concerned, it is very much like that of a star of the same mass. So just like a star a few light years doesn't have any direct effect on us gravitationally, similarly if there was a black hole there as far as the gravity is concerned, it would have the same effect on us.

Q&A: Mr. Arvind is asking more details about the black hole jets. How does the mass escape the black hole,? You said it is the surrounding mass which escapes, not the black holes's mass. Can you elaborate.

Usually the black holes in astrophysics that you see have formed from collapsing stars or in binary systems, there is always additional matter around it which is in the process of falling inside. As these fall they get ionized and they get accelerated to very high speeds. They create magnetic fields, they interact with that and it is those that lead to jets. These are very complex phenomena but not so much to do with the black hole. They do require certain extreme features of black holes but it is ultimately a phenomenon of very complex magneto-hydrodynamics that leads to these jets. The peculiarly extreme geometry of the black hole and speed at which it is rotating do make a difference as the magnetic fields get twisted in a particular way. It is a fascinating topic of astrophysics but it is a complex phenomenon. It has to do with the matter around it, it is not the matter that has already fallen inside the black hole. So some of the matter doesn't fall in, some of it comes out through these jets. You might have heard of these words like quasars and so on - they are actually jets coming from the black holes in the centre of galaxies, like the picture I had shown. If you zoom out of that picture, if you go on the net and look at the picture and if you zoom out, you will see a jet coming out of that black hole in the galaxy M87 which is one of the prominent features of that galaxy. You see that jet but that is on a larger scale compared to this horizon scale.

Q&A: What is the implication of this entropy being proportional to the area. May be you can elaborate a bit on that now.

I didn't say much, but as I said there were two astonishing features of Hawking's formula. One was that it is not zero, the second was that if it is non-zero, why is it proportional to the area and not the volume. The fact that it is non-zero is something a quantum theory of gravity like String Theory can accommodate by counting the number of microstates that are there. But the surprising thing even in String Theory is realising that you get an answer proportional to the area which indicates that the number of degrees of freedom in this quantum gravity theory are far fewer than what you would have in a normal quantum theory of atoms that are described by interacting with electromagnetic force or other forces. For these other forces, the number of states is always growing exponentially with the volume and the entropy which was the logarithm of the number of the states is proportional to the volume. This is why entropy is extensive, but here somehow it grows slower because it grows only as an exponential of the area. So it is as if the number of degrees of freedom are effectively those of a theory living on the horizon of the black hole. It is about the degrees of freedom being somehow captured on the horizon of the black hole and not inside of it. So this idea has been developed by people now, it is now an understanding of quantum gravity itself as being what is called holographic. Because a hologram roughly does that. It is able on a two dimensional surface to capture the three dimensionality of an image. In special cases there is a precise understanding of how quantum gravity can be holographic in this sense. It can have a description which is effectively like on a one lower dimensional surface like the horizon itself.

I also wanted to address a small question by Ashok Misra, he asked why I talked about the area rather than the radius. It is only in the case of a spherical black hole we can very easily relate the area and the radius. The area is the more general formula which applies even for a very non-spherical black hole - when they are rotating, black holes are very non-spherical. So this area which counts the entropy can be on this holographic screen, this horizon, which is not necessarily spherical but it is one lower dimension compared to the black hole itself. So this is one of the facts that String Theory could account for the area, you could then understand why it is proportional to the area and this holographic picture has been successfully developed in the last 15-20 years.

Ashok Kamath: Final topic of discussion:

Aninda Sinha: Another thing that Hawking was very famous for is called the information paradox. I can tell you a story, when I was a student in Cambridge, Hawking sent out an email saying that he has solved some of the most profound problems in physics. We gathered in his meeting room in the basement. He comes and starts explaining "his solution to the information paradox". The information paradox, roughly speaking, tells you that either quantum mechanics or gravity has to give when you think in terms of black holes because either probability is not conserved when you think of black holes or gravity some how needs to be modified.

Ashok Kamath: There is a question in the Q&A, somebody is asking about this Hawking-Susskind debate - can you comment on that? What is the status of the information paradox, can you elaborate on that?

Hawking realized that the consequence of the black hole radiating is that it can eventually radiate into nothing. It can emit all its energy and evaporate just like water evaporates. Similarly, when it is radiating, the black hole is losing energy and the final mass can eventually go to zero. That seems very puzzling from the point of view of quantum mechanics because the final state seems to be a lot of radiation which is very formless or characterless. While the initial state that formed the black hole you would think has all the information on how the black hole was formed - maybe from a particular star, with a composition of different elements, carbon. nitrogen, oxygen and so on in different proportions. Where does all that information go if the final state is simply radiation. So this was the information paradox and there was no good answer for this for a very long time. String Theory came and there was a concrete example where you could study this question. Having accounted for the entropy you could study this question about what happened as the black hole radiated. People realized that it is not as simple as structure less radiation - people realized that there are probably going to be very subtle correlations in the radiation. So Hawking was unimpressed but at some point due to the understanding of this holographic principle Maldacena and others had given a potential way to resolve this Hawking information paradox. And Hawking seemed to agree with that which is why he in fact conceded the bet that he has with Preskill on this. He had believed that information is lost but at the end of his life he changed his mind and could see that perhaps it is not. In any case the current status is that, people believe that information is not lost. People are still finding more subtle versions of that paradox which people are trying to counter and it is still an evolving subject but by and large people believe that the information is not lost. They have a picture of how it would not be lost but a more mathematically precise way of seeing exactly how it is not lost is not there. There are recent developments which suggest ways with which you can make that precise. So this is a very active subject right now and I think a lot of people are trying to understand how precisely this paradox is evaded. The consensus is that it is indeed evaded.

Ashok Kamath: Thank you very much, Rajesh, before we conclude, would you mind telling us little bit about the kind of work happening in India now in the area of String Theory.

Sure, as I said, outside the United States, probably India has the most impact, not only in terms of numbers but also in terms of the influence of the work coming from India in shifting the frontiers of physics and this is happening at a number of institutions all over India. In Bangalore itself, both at CHEP and IISc., and at the ICTS where we are, we both have very strong active groups, also collaborate with each other as well, working on precisely these cutting edge questions on the information paradox, on the holographic principles and so on so forth. There are other groups in TIFR in Mumbai and Harishchandra Institute in Allahabad where we have Prof. Ashoke Sen who is probably the most distinguished scientist since independence from India. He has done pioneering work in String Theory. So there are now many active groups in many centres in India and I think they are contributing, they are really pushing the frontiers in the subject. Some of the topics that I raised over here are active areas of research in India and others too which I haven't had time to talk about but various other ways in which String Theory connects to particle physics and cosmology. Cosmology is the study of the very early universe, and String Theory people are trying to develop scenarios for understanding things like the multiverse. Particle physics beyond the standard model is a very active area. To unify some of these other forces, the electromagnetic, strong and weak interactions and combine them ultimately with gravity. There is a whole plethora of fundamental physics questions that are being explored in India.

PROF. SATYAJIT MAYOR & DR SHAHID JAMEEL I APRIL 25, 2020

Prof. Satyajit Mayor serves as Director of the National Centre for Biological Sciences, Bangalore. He is also the Director of the Institute for Stem Cell Biology and Regenerative Medicine (inStem) at Bangalore which has a focus on the study of stem cell and regenerative biology. In 2012, Prof. Mayor won the Infosys Prize for life sciences for his study of regulated cell surface organisation and membrane dynamics. Prof. Mayor studied chemistry at the Indian Institute of Technology Bombay and was awarded his Ph.D. in life sciences from The Rockefeller University, New York. He worked as a post-doctoral fellow at Columbia University, where he developed tools to study the trafficking of membrane lipids and GPI-anchored proteins in mammalian cells using quantitative fluorescence microscopy. Prof. Mayor is the recipient of several national and international awards such as the Wellcome Trust International Senior Research Fellowship, Swarnajayanti Fellowship, Shanti Swarup Bhatnagar Award and the JC Bose Fellowship.

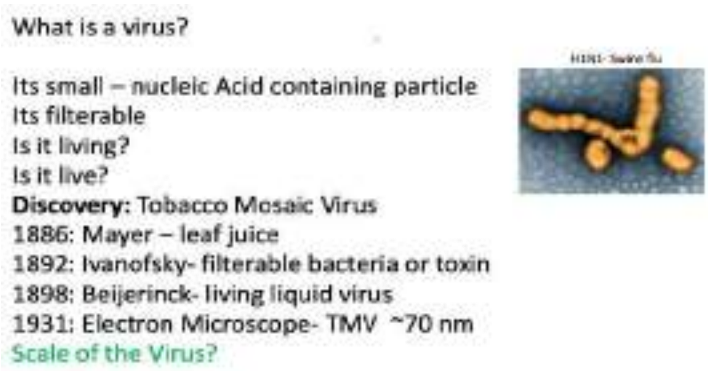
Dr Shahid Jameel has been the Chief Executive Officer of the Wellcome Trust/DBT India Alliance since April 2013. A graduate of IIT Kanpur, he did his PhD in Biochemistry from Washington State University (USA) and his postdoctoral work in Molecular Virology from the University of Colorado Medical School (USA). Prior to joining the India Alliance, Dr Jameel was Group Leader of Virology at the International Centre for Genetic Engineering and Biotechnology (New Delhi, India) for over 25 years, where his research focused on the hepatitis E virus and HIV. He has published over 120 peer-reviewed papers and served on various review and advisory committees of the Government of India and the World Health Organisation (WHO). Dr Jameel is a recipient of the Shanti Swarup Bhatnagar Award in Medical Sciences, which is India's highest mid-career research award. He is also a Fellow of the Indian National Science Academy, the Indian Academy of Sciences and the National Academy of Sciences, India.

Lecture at IIT Alumni Centre, Bengaluru, by Prof. Satyajit Mayor, Director, NCBS-TIFR, Bengaluru, and,
Dr. Shahid Jameel, Chief Executive Officer of the Wellcome Trust/DBT India Alliance

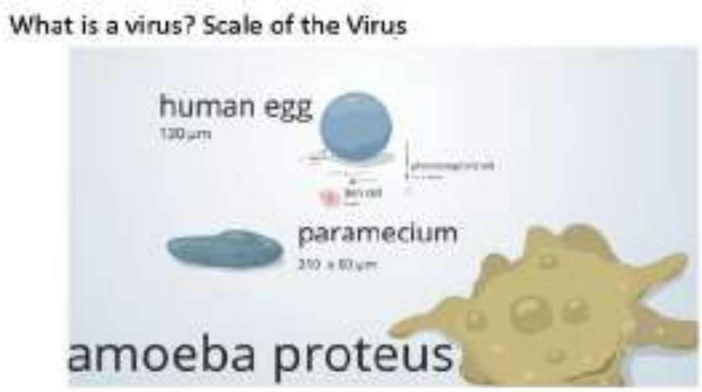
Link to the webinar : https://www.youtube.com/watch?v=3-1CsG-IprA&list=PL0zMQ-70IHlX-df3u2Tto6dkKHCRC6iFL&index=18

Dr. Satyajit Mayor:

First of all it is a great thing that the IIT Alumni Centre is organizing these talks this time. I think it is quite valuable input and information. Let me tell you a little bit about what is a virus, giving you some facts, more importantly figures about the virus in general and then about the cause of the pandemic Covid 19 - SARS-Voc-2 virus.

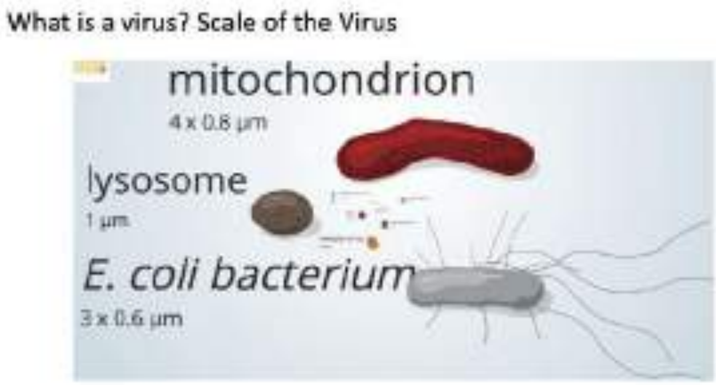


So, a virus itself is a very small particle, it is a nucleic acid containing particle. It is filterable because it will filter away through standard filters that remove bacteria, but viruses pass through. It is a collection of nucleic acids whether DNA or RNA and some proteins and sometimes it has a shell containing lipids which essentially envelops the virus. Often there is a question that is being asked, is it live? We have live virus and dead virus and here again live viruses are potentially infectious and dead virus is something that is not infectious. Very simply that is the question about whether the virus is alive or dead. Let us say, the virus itself is not a stranger to our knowledge. It was first discovered early when people were wondering what was this causing the tobacco blight and causing tobacco leaves to start turning yellow and Edolf and Mayer in 1886, put some juice from the leaf and transferred it in to the stem of another tobacco plant and discovered that we could transfer these leaves and then little later Ivanofsky found that we could filter this with a very fine filter we could block almost all bacteria but still the infectious agents could be transferred between one plant to the other and he thought that it is a filterable bacteria, that is why the term filterable. Then, it was in fact a little later that the term living liquid virus is found by Beijerinck and he found that the virus is not at all a living system, in fact it is a particle and it was visualized when the electron microscope first turned

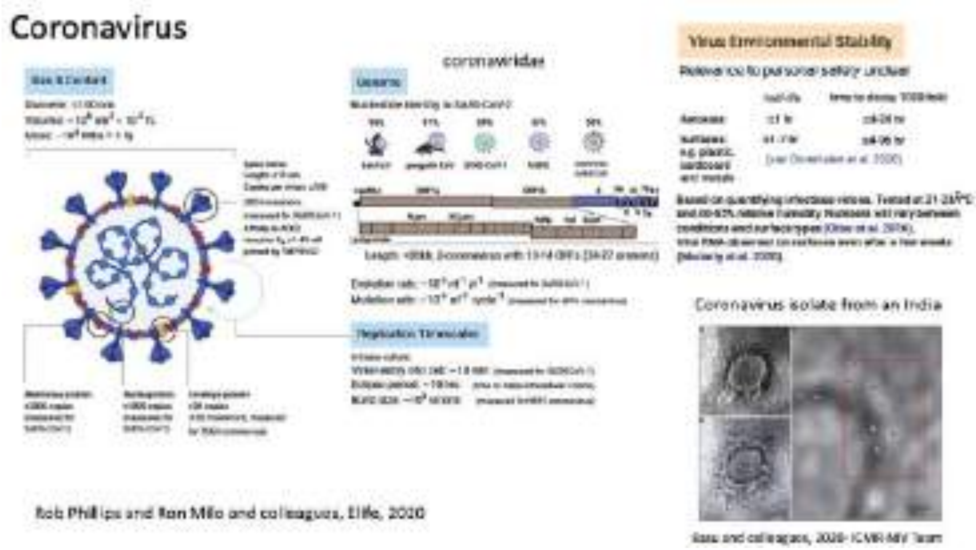


its gaze looking at biological systems and by the first thing that is discovered is the tobacco mosaic virus. And it was found that the tobacco mosaic virus size was 70 nm.

Now, I come back to the scale of the virus which again is an important parameter when you think about viruses because many of the features that we deal with today is because of its scale. So if you think about scale, here is on the left coffee bean and on the right grain of rice and right in the middle below is grain of salt of about half micron in length and further down the scale you have a human egg about 1/5th of a grain of salt, a paramecuim, amoeba proteus that we may know about and the photo receptor cell of the our eyes of the order of about a 100 microns. But the virus is still undetectable at these scales, where the scale here is 1/5th, as I said the human egg is 1/5th of a grain of salt. Further into the cell you see cell organelle like lysosome and mitochondrion and bacterium that is about say a micron or so at the bottom of the slide and viruses are now

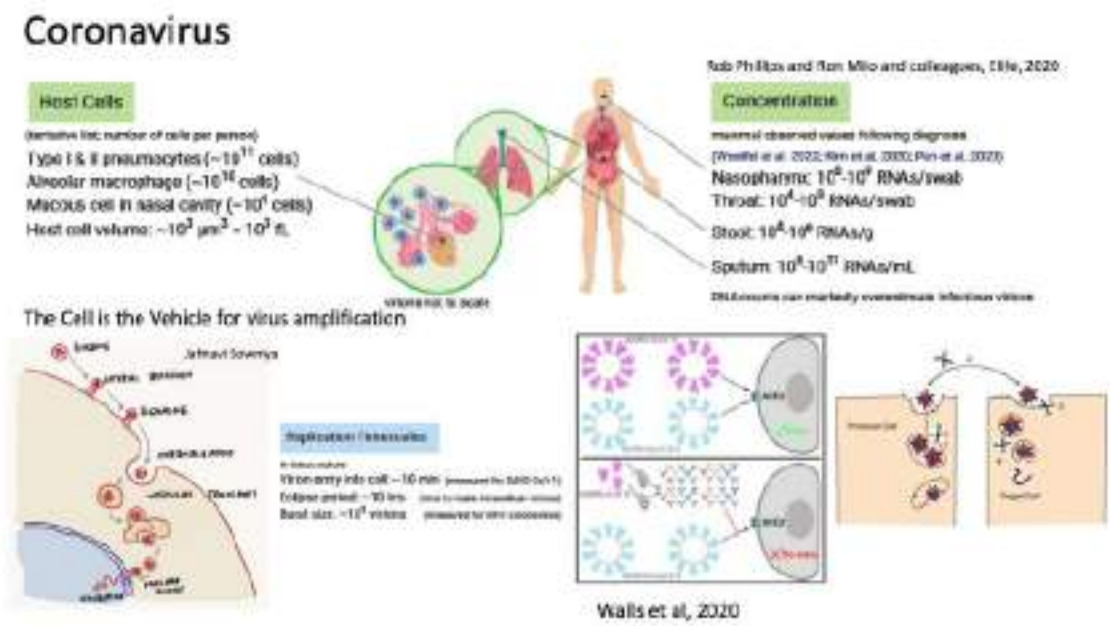


peppered in the middle. In this scale when you can begin to see bacteria, we can fantasize about make out the size of the virus. So, these viruses are in fact, that are here in the middle are on the scale of about few 100 nanometers to much much much smaller. In fact, here in this appropriate scale you can see an HIV virus and influenza virus, a hepatitis virus and the kind of viruses that my friend Shahid works on and a rhino virus. But the corona virus is not mentioned here - it comes in its full blown glory in the next page where I show you a corona virus in cartoon form on the left, and an image on the right of the screen taken from an Indian isolate by Dr. Basu & his colleagues at the National Institute of Virology in Pune. Here is electron micrograph of the corona virus which is depicted somewhat more clearly compared to the cartoon on the left, where it is a particle of about 100 nm in size with a

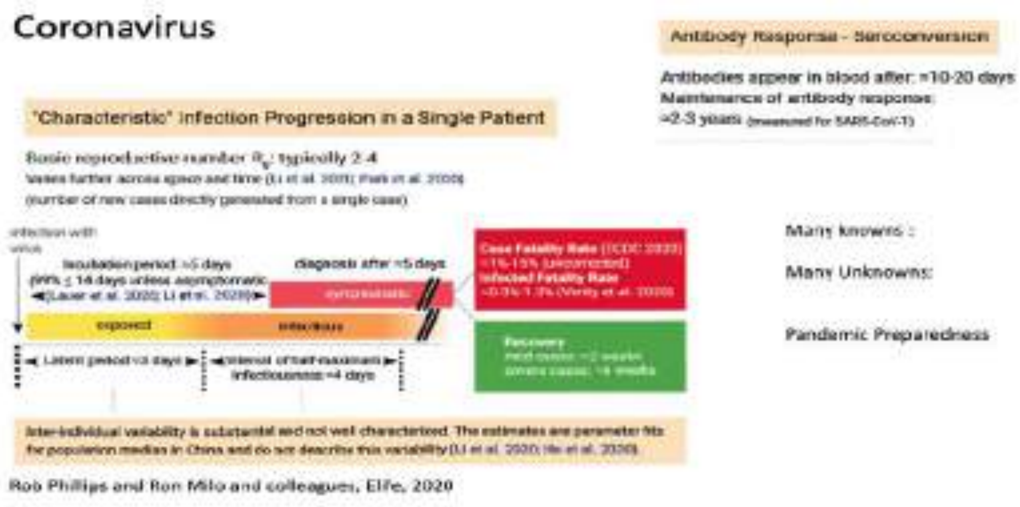


volume of about 1000th of a feptolitre, and mass of about a feptogram. So that is the numbers, but I can tell you about about the corona virus that we are dealing with today. It is an enveloped virus, it has a lipid membrane that surrounds its nucleic acid material, the nucleic acid material is in the centre of the virus, it is a positive strand RNA which means it can code directly for proteins and positive strand RNAs are covered or peppered by proteins that are called nucleic acids and the virus itself, on the outside presents, to the outside world as you will the protein which is of great interest to us, it is the protein that decides the specificity of the host. It is the protein called the spike, it is the protein which is this clover leaf like structure which has a strong domain, and a globular domain. Those domains face the outside in fact determine what cells or what species the virus is going to infect. That is so much to the structure of the virus. The genome of the virus, is as I mentioned, is a positive strand RNA. It is a RNA not a DNA. It is itself a part of a very large family of viruses called coronaviridae family of viruses and it has illustrious relatives most common and most candid about are the bat corona virus about which I will have something to say in a little bit and the bat corona virus happens to be highly homologous to the human corona virus being about 96% in sequence identity to the human corona virus. In fact, the human corona viruses are three in number, we have the SARS, MERS and others and those are also of very high homology to the corona virus family. The virus mutates incredibly fast, unbelievably fast, mutation rate every cycle of division of the virus, every time they duplicate, the RNA is about 30,000 kilobases and one in a million bases is when the virus mutates, that is actually extremely fast for any nucleic acid replication. The replication times of the virus are quite significant, for example virus enter the cells within 10 minutes and within 10 hours it produces several thousand of the variants. So these properties of the virus by the way, it has a small size, it has a membrane, it has nucleic acid captured there and covered in this proteinacius scope, make it also resistant to the environment that we find the virus in and when the virus is shed, for example, in the aerosol when you cough it can settle on surfaces and on the surfaces it can be live meaning it can be still infectious for a period, for a period between 1-

7 hours and in fact on plastic and on cardboard it can even be longer. Somehow, it seems to be inactivated on copper. So, the virus itself is not very unhappy at room temperature, even



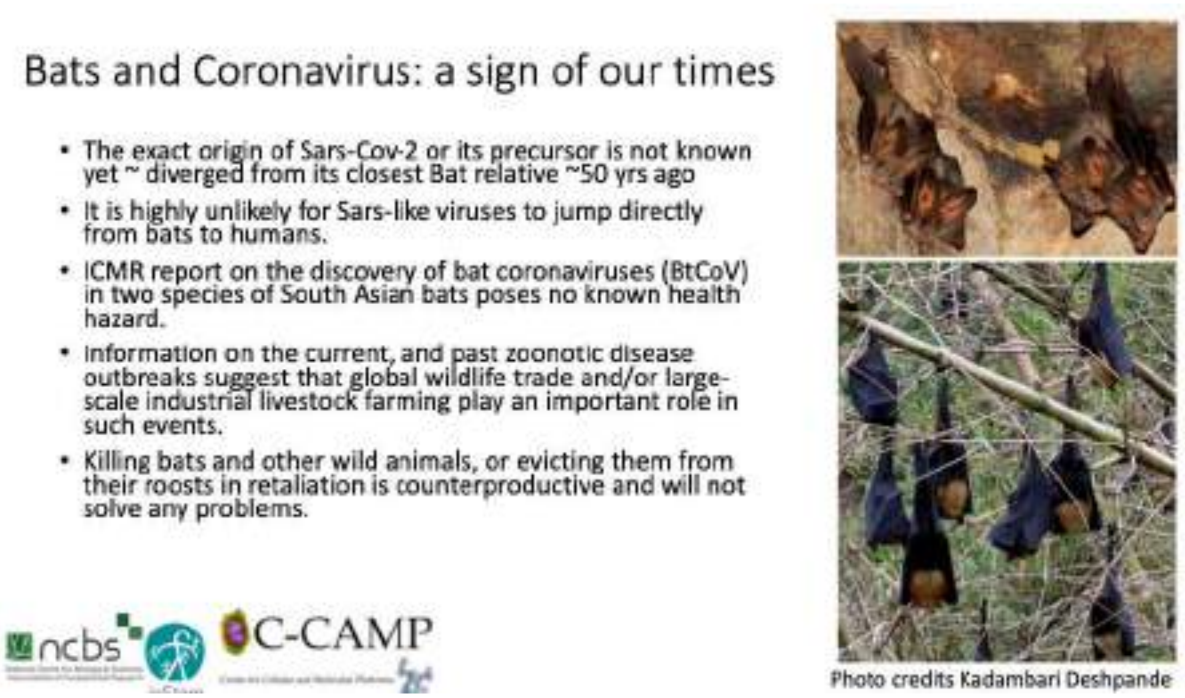
at 30 or 35 degrees because it seems to be proliferating as reported in places like Singapore and in various parts of India which are quite warm. So, the virus itself has properties that make it stable for such conditions, so that one has to take it with a pinch of salt in what has been talked about the heat or in summer slowing down this virus. Perhaps it will but not for the reasons it is unstable in this manner. So the corona virus again because it associates with various specific receptors on the surface of a cell and it can interact with the cells of our lungs, it can interact with the cells in our nose, in fact it also binds to very specific receptor that is on these cells and that is the reason why it is thought to be transmitted through the nasal, pharyngeal tract because there are cells in these tracts which can attract the virus in fact allowing it to enter the cells and very generally as shown in bottom slide, the virus when it associates with the cells binds to the receptor and it sometimes tickle the cells so that the cell can be prepared for its infection and the cell itself produces a vesicle which is what it does even in peace time even without the virus and this virus then piggy backs on these vesicles and gets into the cell where in now find the cell, in the cell and producing and then it jumps out of its vesicular carrier in to the juicy nutrient rich cytoplasm of the cell where it begins all its infections. Remember the virus is so small and itself doesn't have the capacity to multiply and replicate itself. It actually uses the entire hosts machinery to do that. It piggy backs on the hosts protein translational machinery and then it begins to produce many many more of its kind. In fact, as I mentioned here, it produces about within one single round of infection it can produce anywhere from a thousand to a million particles of its own kind which then burst out of the cell and can infect another cell. Remember the virus carries this information about its address, so when it bursts out since we already know the spike, like the protein is the information that directs it to a surface, people have begun to identify molecules and vaccines against the virus itself, these protein can in fact prevent the infection of the virus. There are now ongoing studies even at the Indian Institute of Science, Bangalore, right now which are directed towards producing reagents which could neutralize the virus at this stage. There are other ways, the virus doesn't just not enter the cell, it needs to be modified at the cell, needs to be clipped by the proteins in the cell, then it leads to produce and sent outside the cell, then it can infect the cell again and then again it is modified. Proteus inhibitors are another target of the virus. Now coming back to the panel shown on the top right, the concentration of the virus is relatively high in major cells in the stool, also it can infect the cells of our gut; therefore it can pass through stool, it can come through sputum and infect through your face, through your nose, and here you find significant amount of new virus particles, that is why isolating the virus in the nose and the throat is perhaps the most significant way of detecting this virus. The way to detecting the virus is by using components of the virus which are its RNA and its protein. This infection progression in a single patient is actually complicated, it takes about five days. This is going to be important when Shaheed talks about the pandemic of the virus and its latent period is about three days. But people are mostly asymptomatic in this phase, even infected but they remain asymptomatic and that is going to be real issue we have to deal with so testing the people who have the virus in them is going to be an extremely important task ahead. Testing them can only be done by exploring their RNA and the proteins that the virus uses, specially taken



from the nose and throat.   Now what happens when the virus infects an individual, is that you develop an immune response. In most cases those immune responses leads you to a recovery and again in terms of the infection progress of the virus, in this particular corona virus, it is very unclear how the immune response seem to be dealing with the virus. It take at least a week or 10 days before one begins to see antibodies in the blood and therefore, detecting the virus in your blood, by the time you detect antibodies in your blood with these rapid detection kits, it will be already 10 days into the infection and that may have generated a lot of infectious particles that can infect others in the meantime. Therefore, these rapid tests only tell you that you have been infected in the past and perhaps you are already cured of the infection. But of course, if the symptoms persist you are also still carrying the virus.   There are many knowns here and many unknowns and we need many of these things for pandemic preparedness and I think Shahid is going to talk about some of these things.

But before I end, I would like to tell you about what we have been doing as a research community to tackle the virus itself. First of all in Bangalore, the Institute for Stem Cell Research and the National Centre for Biological Sciences came together along with C-CAMP to set up testing facilities to help expand the scale of the operations of testing. Testing is not a simple task, we need to take this virus, we need to then extract the RNA, and then amplify the RNA by various reverse transcriptase methods, enzymatic methods and then detect it in as a PCR and then that requires scaling. Since we now doing it we know exactly how it is, it takes 6-8 hours before one gets results after a single test and generate all the reports which needs at least 24 hours before one gets his first report. We need to have new technologies for enhancing testing. Here again, we are building in collaboration with IIT Bombay, a combinatorial pooling strategy by using compressed sensing using computer science-based methods to develop new ways for enhancing the testing capacity. Using the properties that we know about the virus, we are also building rapid diagnostic technology which can help to detect the virus right in the site of its production in your nose or in your sputum within 10 or 15 minutes. We hope these technologies come and to inhabit at our regular disposal very soon. That is what we really need in order to understand how people can begin move about very quickly. Disease and epidemiological modelling is very important for us to understand extremely unusual dynamics of the virus and its ability to carry itself and infect others and therefore that again become a very important programme that both the Indian Institute of Science and folks at the NCBS and others in various parts of the TIFR system. We are also finding new antivirals now based on the information I just told you about, how the virus infect the cells and the cells take up the virus which you can block the first step either by blocking the machinery that takes up the cell, the virus or by blocking the viruses that may be good antivirus very quickly especially if we explore available drugs that are already in the labs today. Here again a chemi-informatic analysis are turning out to be very very useful. The physical aspect of the virus allow us to develop the infection technologies and that's again something happening well. I think this pandemic has shown us us to come together of scientists to address this particular problem and nothing can stop us as long as we are able to collaborate and for that you need people who have that knowledge and created institutions that supports that and only then can we respond to such an emergency. I must say that precisely that is what is happening in your neighbourhood in Bangalore and also communicating these results and there is a wonderful website created by IISc and TIFR called www.covid-gyan.in, which I hope will continue in various forms to create this capacity to communicate scientific information.

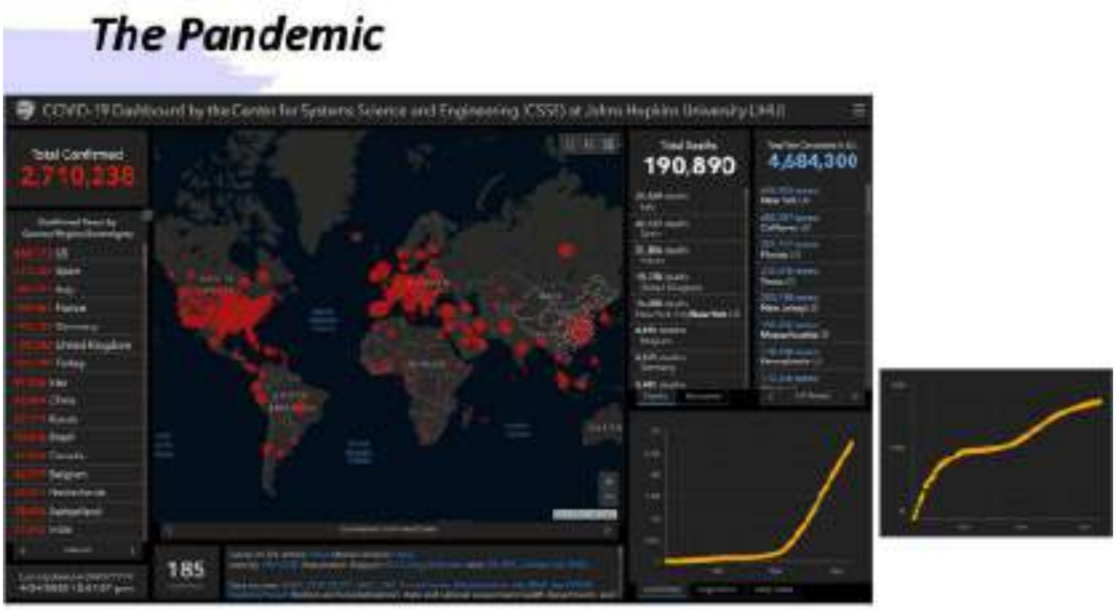
Before I end, I want to say something about where this virus could have come from and I am going to end with that. That people have been blaming this poor bat for corona virus. I must say that is really maligning the animal kingdom for this virus. The virus has come really from our tampering with the animal kingdom. It is highly unlikely for Sars-like viruses to jump directly from, bats to humans. The ICMR report on the discovery of bat corona viruses (BtCoV) in two species of South Asian bats poses no known health hazard. Information on the current, and past zoonotic disease outbreaks suggest that global wildlife trade and/or large-scale industrial livestock farming play an important role in such events. Killing bats and other wild animals or evicting them from their roots in retaliation is counterproductive and will not solve any problems. There have been very worrying reports both in the newspaper and in journals that the virus is actually directly originated from the bats.



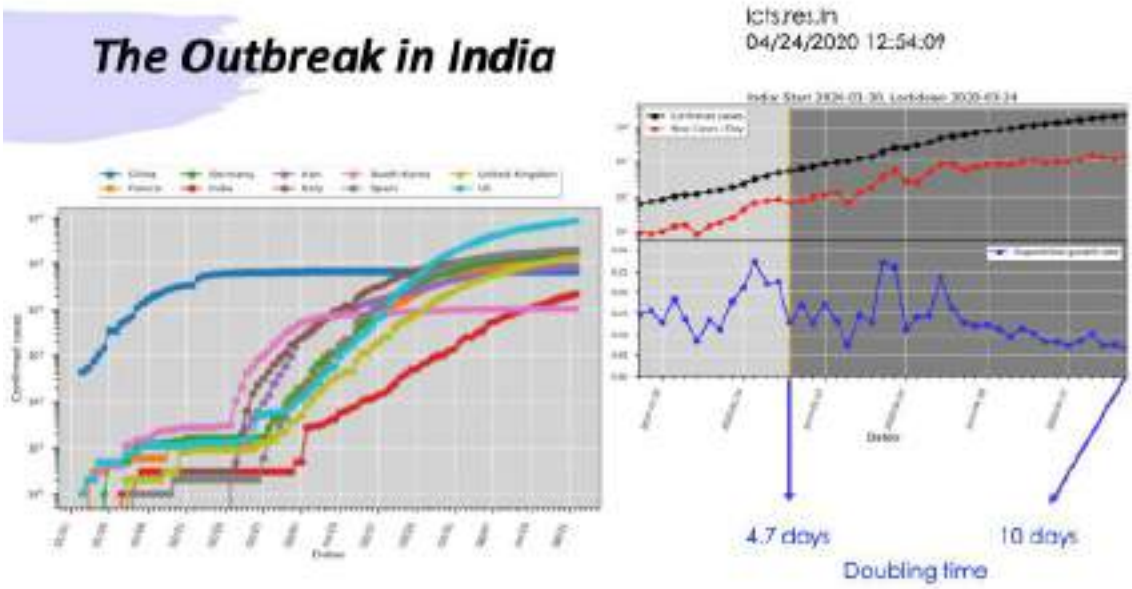
I end here by saying I really want to thank my laboratory colleagues helping me actually put together some of these presentations and colleagues in all over the world who send me information about the corona virus itself and latest information that we have about science behind the corona virus. I am sure Shahid is going to share much information on the happening on this pandemic. Thank you for this opportunity.

Dr. Shahid Jameel:

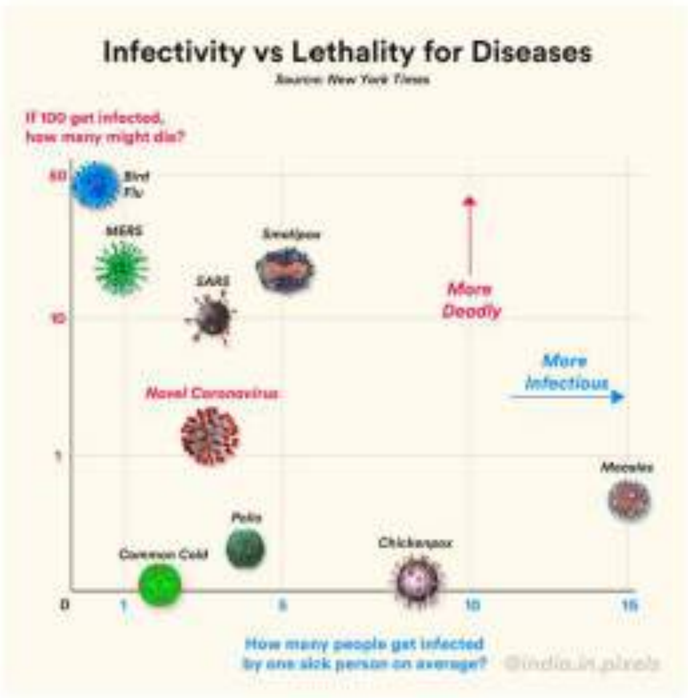
Good evening everyone. Jitu has already given you Virology 101, so let me go on from there and my talk is specially about the Covid outbreak and a little bit of the virology behind it,

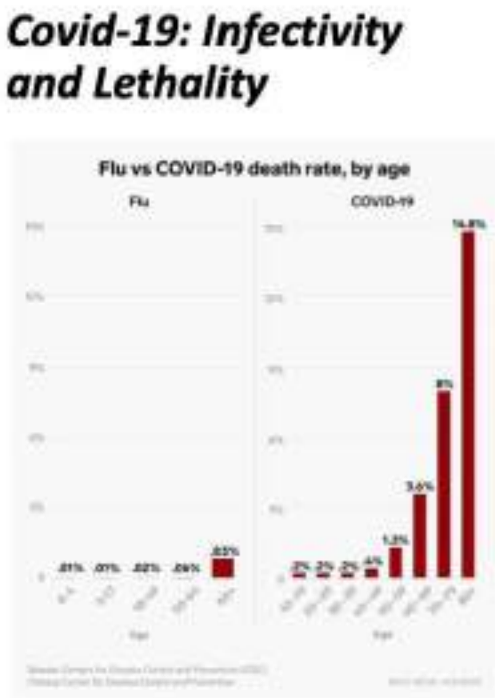


various mitigation strategies. At this time and this slide was made yesterday we now have almost 2.8 million confirmed cases around the world and the data today is that there are 196,000 deaths around the world. The ten top countries contribute 75% of the total caseload in the world. India has something like 23-25 thousand cases, I am not sure exactly how many are checked today and little over 600 deaths in India. As you know, this is a pandemic which means that it is all around the world, growing all around the world and there are 185 countries in the world that are currently affected by this outbreak. Just wanted to show you the growth curves. The yellow lines that you see on the left is a linear curve but the more important one is on the right which is plotted on a semilog scale and you can see that there are phases in the growth of this pandemic in the world so started with very steep slope and as China started levelling off, you see a levelling effort, then it is the entry of Spain, they took off and you again see a steep curve and finally you see the outbreak slowing down just a little bit now around the world since most of the big countries are beginning to slow down.



If you plot the outbreak in India on the left again on a semilog scale, India is show on the red line here, there are couple of countries in other colours, you will see that after the first case in India was detected on 30th of January, we remained relatively case free till about early March and then suddenly cases started appearing and the outbreak has been going up since that time. If you look at the lock down period which started around 25th of March, you see that there is a little bit of levelling off in the red curve towards the end but not very much but I show you on the right something called the new factor which is the rate of the growth of the outbreak. If you look at the rate at which the outbreak was growing, doubling time of cases, at the start of the lock down period, the rate of doubling of cases were 4.7 days. Today the rate of doubling is 10-10.5 days. So definitely the lock down has had an effect, the key question is what will happen after the lock down is lifted from the 3rd of May. Will there be a rise in cases or not? There are various epidemiological models that have been developed and one thing the models agree on is that there will be a spurt of cases after the lock down is lifted and therefore, there needs to be proper evidence based lifting of the lock down, evidence based decisions on whether the lock down should be nation-wide, should be state-

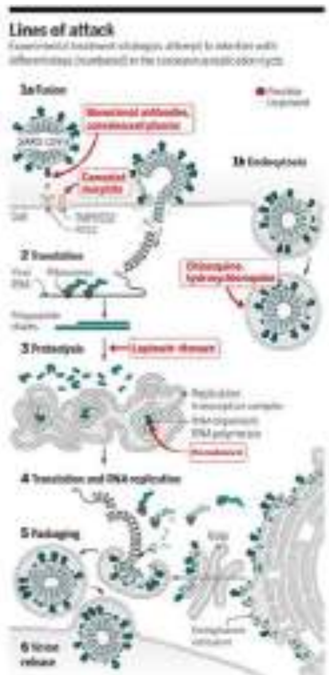




wide, whether it should be region specific. How do you identify hot spots, all these are challenges and all these challenges also go back to the testing methodologies that Jitu are talking about. The testing that is being used is artificia based testing which identifies caseloads whereas the rapid tests that are antibody based tests define population based numbers. So, we have to look at both of these in order to decide how to go forward.

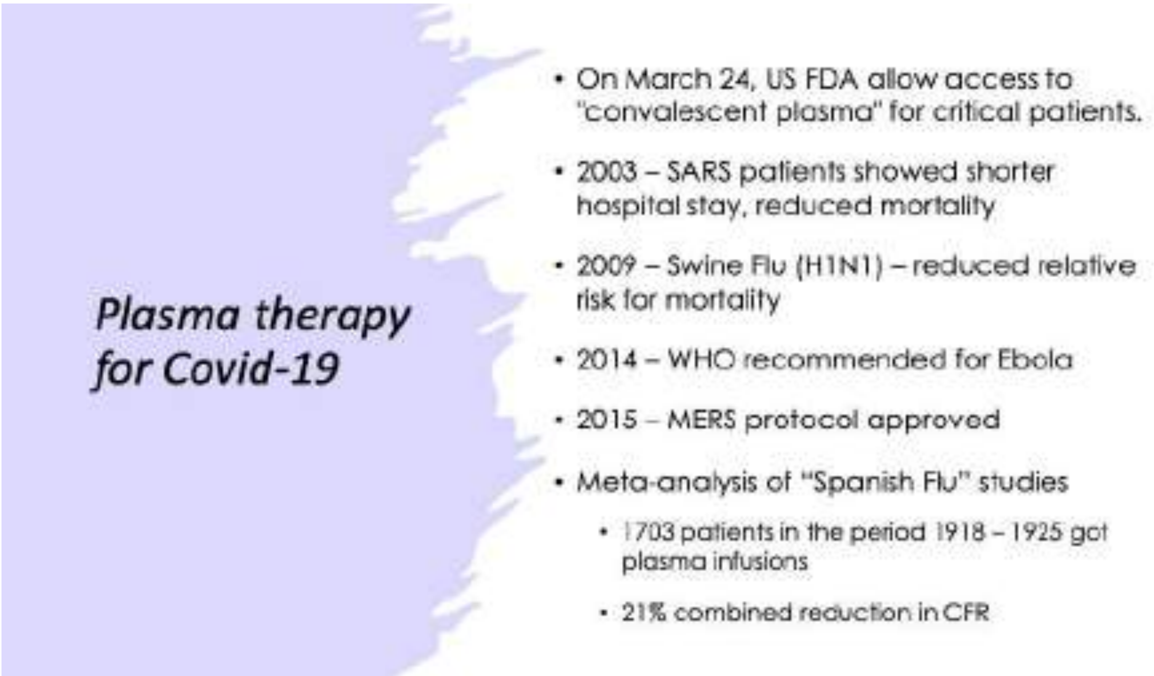
See next slide. On the left I show a comparison of infectivity vs. lethality of the viruses. You heard a lot about the factor called R0 which is the rate of transmission. How many people one person can infect on an average. If you look at an extreme example, measles virus. Measles virus, one infected person in a community will infect on an average 15 others. On the other hand, a common cold virus will infect only about 1-1.5 on an average. Bird flu virus even less, but bird flu had a very high lethality, almost killing 50% of people infected whereas measles, common cold they are fairly low on the mortality strip, common cold has a population-based mortality of only around 0.1%. What we are seeing for the novel corona virus, the SARS coronavirus too at this time is their R0 is somewhere around 2-2.5 but R0 is also not a static figure, it changes as the outbreak changes. Mitigation strategies bring about changes in R0 and that is why it reflects in the doubling point of the outbreak which I showed you previously. That's one thing about this virus and the other is that when you are measuring fatality, at this time we are only measuring case fatality meaning fatality in those cases we are identified to be positive based on PCR test. That is a selected population and not general population. Whereas there are people who have not been tested and therefore we would not know if any of them succumbed to the virus. There was a paper in Lancet a couple of weeks back and other studies also show that the population fatality rate of this virus is likely to be somewhere in the range of 0.5 to 0.6% which makes it about 5-6 times more lethal than your common flue but much less than SARS or other viruses that we have been talking about. So put that in to perspective when you think about the corona virus and there is a narrative built around people dying of this virus that we fail to recognize that even with the fatality rate of 3%, 97% people are recovering and this is something that is not being communicated very clearly. The entire focus is only people who are dying. Because death is a very finite thing, whereas people recover that is not kept track of very well, but also, I heard from others say that this is just a bad flu. It is not just a bad flu, because if you look at the figure on right, I show you flu mortality as a percent of age as a progression with age as well as covid as a progression with age and you see that covid rate rise rapidly in people who are old in people who have other co-morbidities. A lot of work is going on about the pathogenesis of this virus to figure out why people with diabetes, why people with blood pressure are also succumbing to this virus. It is understandable for somebody with impaired lung functions, COPD for example, chronic smokers are also succumbing, but why people with diabetes, why people with high blood pressure? So a lot of that work that is going on right now and thousands of papers are coming, every day that are being uploaded in open access archives So let us move on.

So, Let us come to treatments - both the principles and options. We heard a lot about hydroxychloroquine, and I will come to that in a minute. If you focus on the figure on your right, and this is also something that Jitu alluded to. There are steps in the virus life cycle that can be inhibited. So, when the virus attaches to the protein of the surface of the cell, this process can be affected by antibodies that are targeted to this interface, it can be



inhibited by small molecules that are targeted to this interface and this is really where plasma therapy would come in useful because plasma from recovered patients have antibodies that inhibit the attachment of the virus to the target cell. As the virus now moves into the cell it comes into an endosome into a corded pit and Jitu told you how the endosome acidification leads to the release of the viral genetic material in the cytoplasma of the cell and chloroquine is a molecule that prevents the acidification of endosomes, so presumably chloroquine could be effective at this stage and it is not a specific effect on this virus, many viruses that enter cells through this pathway have similar effects of chloroquine. Now once the RNA is released, the RNA has to be translated into proteins. This virus also translates its RNA into proteins. The proteins are made as large polyproteins, which are then processed by protease that are coated for by the virus itself and some of these protease can be targets for the antivirus. In fact some people have tried with limited success certain protein inhibitors have been used as HIV drug, Lopinavir, Ritonavir these are protease inhibitors that have been tried with limited success. Now the viral RNA also needs to be replicated to make more viral RNA into produce more viral particles and for this an enzyme which is RNA dependent called RNA polymerase or replicase is used. This enzyme is very special. It is very unique to these viruses, RNA viruses and this enzyme is missing from cells because as we know cells have no need to replicate their RNA whereas the virus has a RNA genome and it has a need to replicate that genome. So this enzyme is very special to viruses and inhibitors of these enzymes can also use that antivirus and this is the drug Remdesivir that we have been hearing about. Remdesivir was developed as a drug against Ebola, it was never really tried for Ebola but it is being tried in some trials.

Coming back to the left of this, I show you that famous trial that set off this hydroxychloroquine controversy. This was a small trial done in France, was never really published through a peer reviewed mechanism. It included only 36 patients, 16 of them remained in control, 14 of them were put on hydroxychloroquine and 6 of them were put on under a combination of hydroxychloroquine and an antibiotic called azithromycin and what this limited study show was that a combination of hydroxychloroquine and azithromycin leads to faster clearance of the virus from patients. That's all it shows and of course with clinical benefits. But since this was not a random controlled trial, a lot of people didn't believe in it and therefore two large trials are going on right now, one is called the solidarity trial which is going on by World Health Organization in which multiple countries are participating and the other is something called the accelerator trial which is being run by the Bill & Melinda Gates Foundation and MasterCard. The same group that showed this chloroquine effect has come out with almost a thousand patients. But again that study is problematic because (a) it has not been peer reviewed and (b) it is not a random controlled study. Similarly Remdesivir therapy is also common to some suspicion. The manufacturer of Remdesivir, Gilead Sciences is conducting a large trial. Some early data that has come out of the trial has shown that Remdesivir is not really working very well on the covid virus.



I will say little thing about plasma therapy. We hear not about plasma therapy these days, we are hearing appeals from Ministry of Health for people who have recovered from this disease in India to donate their plasma, all of this is happening. Plasma therapy is not a new concept at all. Plasma therapy has been tried for various things, even going back to the Spanish Flu of 1918, plasma from recovered patients was tried and a recent meta study from that period showed that plasma gave about 20% combined reduction in case fatality rates in the 1918 flu so almost a century back. On 24th March, US FDA allowed access to convalescent plasma and this really triggered of a race for plasma in the current situation.

But way back 2003 in the SARS case it was showed that the patients who were put on plasma from recovered patients showed reduced mortality and shorter hospital stay. It was used for 2009 Swine Flu outbreak around the world. WHO also recommended this for Ebola as well as for MERS. So there is a history to plasma therapy. Whether plasma therapy work will very well in this case or not we don't know but there surely some logistical issues here because what we have seen in the case of covid is that only those people who have severe disease are the ones who should make antibodies that are good enough to neutralize the virus. People who are asymptomatic or people who show mild symptoms don't make antibodies that are good enough to be used for plasma therapy. That immediately provides a bottleneck where people who have been very sick, we are asking them to donate plasma and that makes not a very practical situation.

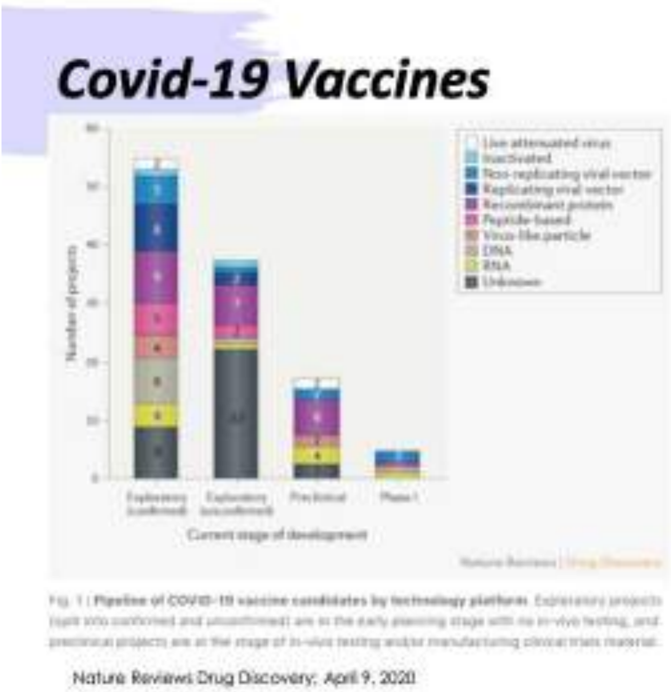


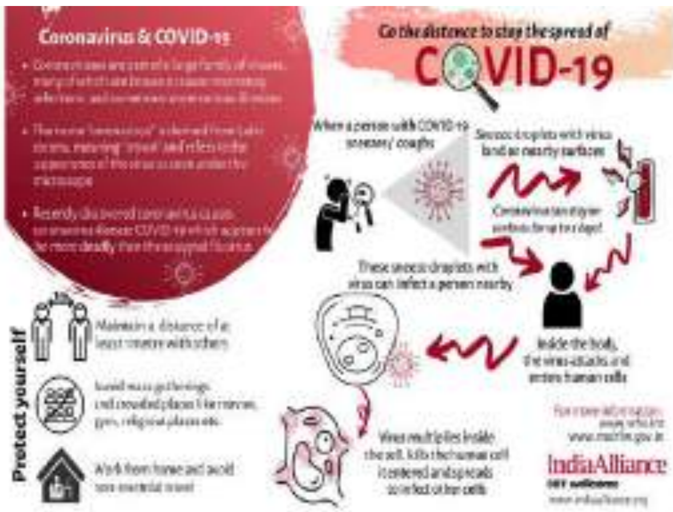
TABLE 1 | CLINICAL-PHASE VACCINE CANDIDATES FOR COVID-19

Candidate	Vaccine characteristics	Lead developer	Status
mRNA-1273	LNP-encapsulated mRNA vaccine encoding S protein	Moderna	Phase I (NCT04283461)
Ad5-nCoV	Adenovirus type 5 vector that expresses S protein	CanSino Biologicals	Phase I (NCT04313127)
INO-4800	DNA plasmid encoding S protein delivered by electroporation	Inovio Pharmaceuticals	Phase I (NCT04336410)
LV-SMENP-DC	DCs modified with lentiviral vector expressing synthetic minigene based on domains of selected viral proteins; administered with antigen-specific CTLs	Shenzhen Geno-Immune Medical Institute	Phase I (NCT04276896)
Pathogen-specific aAPC	aAPCs modified with lentiviral vector expressing synthetic minigene based on domains of selected viral proteins	Shenzhen Geno-Immune Medical Institute	Phase I (NCT04299724)

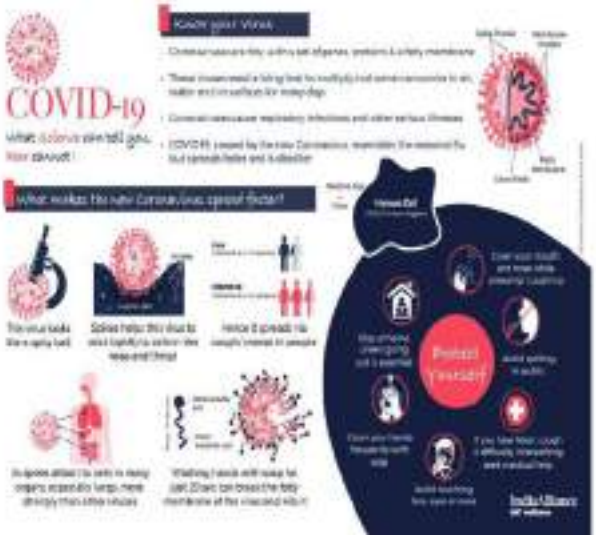
aAPC, artificial antigen-presenting cell; CTL, cytotoxic T lymphocyte; DC, dendritic cell; LNP, lipid nanoparticle; S protein, SARS-CoV-2 spike protein. Source: ClinicalTrials.gov website; WHO.

What you see now in the screen is a summary of Covid 19 vaccines that are being developed and are in trial and if there is anything that exemplifies how technology has really helped fight this disease it is this one slide. Barely two months into knowing the sequence of the virus, the first candidate vaccine was shipped from labs from a company to go into trials in humans and that is the Moderna vaccine which is in Phase-1 which has been done at NIH. There are five in total vaccines shown on the table on the right which are in Phase-1 clinical trials and I believe there is a vaccine from Oxford which has just gone into Phase-1 trial either yesterday or today. The figure on the left shows you how many vaccines are being developed today and at last count there were 115 different vaccines, 78 of them we know all about their development pathway, about 35, we know very little about the development and they use all kinds of platforms from live attenuated vaccines to inactivated vaccines to non-replicating viral vectors to to sub-unit vaccines, virus like particles, DNA, RNA, everything, all technologies are being harnessed to produce vaccines for covid. Earliest estimates for a vaccine to be available, the most optimistic estimates are six months but a realistic estimate is somewhere around twelve to eighteen months and don't forget that once a vaccine has finished testing, it also has to be produced at a level enough to be given to everyone who needs the vaccine.

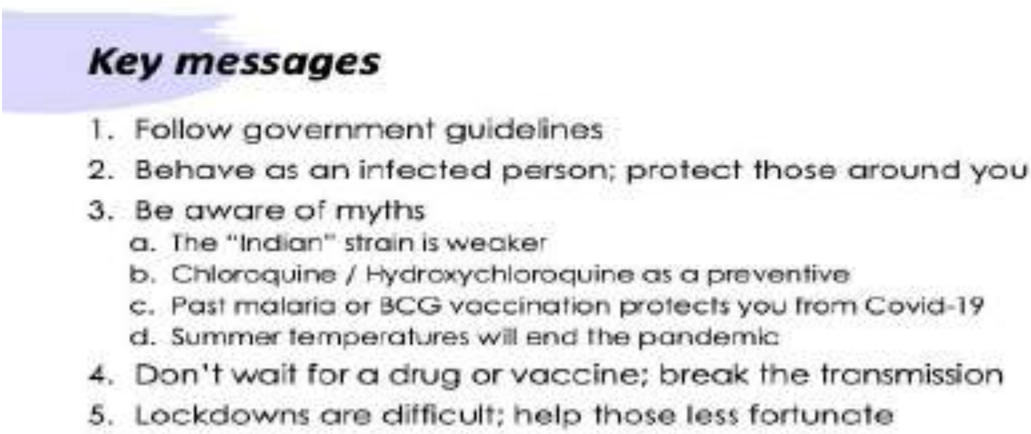
The next three slides are really some info graphic we have prepared to educate people about the virus, you don't have to look at them now, these are available from our website in multiple Indian languages and at last count we have translated it to about 12 languages. These are open



resource available to any one wants to take it and educate others.



I will finish with some key messages. The first message is that we need to follow the Government guidelines that is being given to us. We don't have a vaccine, we don't have a drug and about the only thing we can do to break transmission is to do what people calling social distancing, I prefer to call it physical distancing. So we need to follow that. Each one of us has to behave as an infected person, we need to protect people around us and that is



why it is simple cloth mask is good enough to protect everyone in the community. We don't need N95 masks. We don't need surgical masks, leave that to healthcare workers. They are in need of those masks, what we need is a simple cloth mask when we go out. There are also various myths floating around, some of these have been addressed, the first one is that the Indian strain is the weakest strain of the virus and when this myth started floating there was only one sequence available in the database from India and that was a patient who acquired the virus in Wuhan, China. So I don't how it suddenly became an Indian virus after it came into India. There is no evidence that the Indian strain or any strain of the virus is a weaker strain. We have to treat every strain as infectious , as capable of causing mortality.

The second is chloroquine or hydroxychloroquine can be used as preventive. Absolutely wrong. There is no case for using it as a preventive. Both US FDA has actually allowed it to go into trials and the trials are now showing that hydroxychloroquine is not showing any efficacy. Indian Ministry of Health has allowed hydroxychloroquine to be used as a preventive, as a prophylaxis in healthcare workers, but it is not a measure for the general population.

The third myth is that past exposure to Malaria or BCG vaccination prevents you from covid, again no evidence of this. In fact there are countries like UK that used to have BCG vaccination in childhood and they stopped only in the early part of this century. So there are lot of people in the population today in UK who have been vaccinated with BCG and you know about the outbreak happening in UK, that really says lot about this myth. Final one Jitu also addressed, summer temperature will end the pandemic, again there is no evidence. In fact when the virus is transmitting from person to person, it is going from body temperature to body temperature. There is no significant exposure to environmental temperatures. Finally, don't wait for a drug or vaccine, those are far away, we need to break the transmission today. Lockdowns are difficult, lockdowns are a luxury for the privileged, lockdowns are becoming a burden for the poor and it is the duty of each of us to help the less fortunate and take care of them.

Thank you and I will be happy to answer any questions.

Susheela Venkataraman: There are lot of questions. There are few questions on impact of the virus.

Q. What impact does the virus leave on the survivor?

A. At this time, it doesn't look like there is any long lasting effect based on people who have survived. It is unlike Dengue or Chikangunia that leaves a very bad ache in the joints, there is nothing like that. So in that respect it is more like a flu virus. Once gone, it is gone.

Q. Could there be a possible second wave in some patients who have already had it or could the virus be inactive for a while and again get activated in later point of time?

A: These are two questions, first is whether the same person who was infected with covid and recovered can be re-infected. It is possible and that really depends on the kind of antibodies that the person makes the first time when they get infected. If the infection is asymptomatic, if the infection is very mild, they don't make high quality antibodies and these antibodies don't last long enough, yes they can be re-infected. We haven't gone through the outbreak long enough to understand that. There is really no data on that.

The second is whether there will be a second wave in the population and yes that is also possible. It is possible that the virus may lie low for a while and then come up again when our flu season starts somewhere around November or December. There is distinct possibility of that and I really think that people are now also tuned to wear masks and physical distancing and it would be really prudent to really practice that at least for a couple of months if not for a year as we open our economy, as we open our working system.

Q. There are couple of questions on prevention. One of them is, can there be a device that can be put in through the nose or something which could either stop or neutralise the virus and similar question, if the corona virus grows in the nasal passage and grows would yogic practices like nethi help in prevention.

A: Certainly, anything that washes these passages is going to reduce the load of virus there. But remember the virus is not sitting on these cells. If you remember what Jitu showed you, the resident time of the virus on the cell is about 10 minutes and after that it enters the cell. So you can't really wash it off if it is inside the cell. So those things have limited value, but certainly from a good hygiene point of view it is crucial.

Q. What about the question on the device?

A. I don't know what sort of a device we put in while you are capturing the virus, may be something Jitu can look at. May be a little incinerator inside your nose to turn the virus off. It is an interesting idea.

Jitu: Something you could spray in to your nose as the US President said.

Q. How long it is going to take to create an effective drug? For the vaccine you indicated about 18 months, how long to create an effective drug take?

A: It depends on when the effective drug is discovered, none has been discovered so far. People are working, people are also working to repurpose other drugs. So any drug that is approved for something else is already safe ,has been tested in the population. Therefore, if one can show that there is an effect of this drug also on this virus, it could be immediately deployed. Lately there has been a lot of bioinformatics activity and lot of papers have gone on bio-archive. I know two from India, maybe there are more I haven't looked at, just by doing structure based modelling studies one group have shown that valproic acid, a metabolite of valproic acid is a tight binder of one of the viral proteins. Another group has shown that vitamin b12 is a very tight binder but whether this tight binder actually translates into a good drug or not that has been shown yet. So people are doing all kinds of work, re-purposing known drugs, taking molecules that have passed in Phase-1 and Phase-2, be safe but have not gone through Phase-3 for efficacy are also being tried at many pharma companies. But nothing really been out yet, at least in the public domain.

Q. There are questions on the epidemic per se. You have shown the infection rate as same as SARS, why this is reaching the stage of a pandemic now?
A. SARS was contained very quickly in Hong Kong and Mainland China. You have to actually go back to when this outbreak started in China to understand why the virus has become viral. It coincided very nicely with the Chinese New Year, when the outbreak happened. This was a time when people go back to ancestral lands, when people go back to families and they really took the virus along with them and those were very very fast spread early on. I believe that, that has really contributed to a really very fast take off of this outbreak but yes you are right, the transmissibility is no different from SARS-1.

Q. In the long run, will Covid-19 become history and if yes, how long you expect it to be?
A. It is very hard to make predictions especially about the future, but from all indications, the number of people infected around the world this is going to go exactly the way 2009 Swine Flu. It will become resident, it will become part of our daily lives. It will not go away. It will keep coming back in waves for some time, it will become endemic to the human population just like other human corona viruses. There are four other corona viruses that cause human disease, but they don't cause the kind of mortality, about 15 to 30% of your common cold is due to other corona viruses, yet you don't even notice them. I think once this virus becomes endemic to the human population, it will go the same way till a new one comes around.

Q. There are few questions on treatment and virus itself. One of them is, can we stop the verion exiting from an infected cell, in other words, can we direct it towards destruction by a lyseson?
Dr. Mayor: It is a good idea. It is something that in fact we are also trying to do. You see if we can stop the virus from exiting outside its carrier that brings it into the cell. When it gets into the cell, it is still encased in a membrane which is the basic carrier membrane. You can prevent the virus from exiting out of that, then the virus is literally consumed by the cell, it

will be destroyed by the lyseson itself. So there are ways in a bit diffusion process of the virus by blocking some of the proteins that are involved in the fusion process. That is the strategy that has been tried.

Shahid Jameel: Let me just add to that this idea is already in practise. There are drugs against influenza viruses, that block the release of influenza virus from an infected cell. then these are drugs that has been used for flu viruses. Yes it is certainly a viable strategy.

Dr. Mayor: I would make some points about drugs. A drug is that is going to be something that will be useful in the early stages. The virus actually produces many other consequences to the host. The drug against the virus alone may be only useful in the early stages. In the late stages we may need find drugs that prevent the destruction of the host cell.

Shahid Jameel: In the Solidarity trial, there are four arms to that trial and one of the arms is a molecule called beta interferon which inhibits the cytokine storm that one sees in covid. It is really the hyper-reaction of the body to the virus which essentially kills people instead of the virus by itself.

Q. There seems to be distinct effect on blood, primarily clotting microclots, how serious is this?

Shahid Jameel: This is something that has been noticed by physicians both in China as well as in New York that people who are dying of covid, a significant number of them have clotting abnormality. We don't know whether it is a direct effect of the virus on the blood or whether it is some indirect effect. But certainly clots can be dangerous, clots can move from site at which the clot is made, can go into the heart, which can lead to heart attack, it can move into the brain, it can induce a stroke, so clots are dangerous. This is the feature of this virus that has been seen but isn't really understood yet.

Q. Do aged cells which is the older population have a higher capacity to increase viral replication than cells of younger people?

Shahid Jameel: Well it is the age related mortality I don't think has to do with the amount of virus replicating in an individual. It has more to do with other morbidities, as you age you accumulate other morbidities. Most of us with age we develop high blood pressure, we develop tendency towards pre-diabetes, diabetes, we develop obesity, poor lung functions, we develop poor kidney malfunctions, all of this happens with age and don't think it has anything to do with the virus replicating more in older people. It is just that you accumulate morbidity in old age.

Q. Is there a link between an individual's DNA and the effect that the covid-19 has on them if they are infected.

A. Good question. We are an outbreak population and our DNA has polymorphisms which are linked to our response to various infections, linked to our response to various drugs, everyone doesn't reacts the same to a virus or to a drug and that is why some people show either no symptoms or very mild symptoms whereas others show severe symptoms. The virus is same and lot of it has to do with your genetics, absolutely.

Q. A follow up question: How much does obesity influence likely outcome for infected people, why and you may like to touch on another such factors as well.

Shahid Jameel: Obesity has been shown to be a risk factor in this case. I am not sure about the exact mechanisms but I believe there was some reports about virus also replicating in fat cells. I may be wrong. I really don't know whether there is a direct mechanistic link between the virus and obesity. It could simply be that obesity also makes you prone to other morbidities and therefore you are more at risk.

Q. This is a question for Dr. Mayer: Do covid genes have immuno-modulatory effects on host cells?

A. Covid genes when they are expressed themselves, they influence a huge range of molecules inside the cell. So, if for example, immune signalling is affected by an infected cell that will then affect the host's immune response to the covid infected cell. Prima facie covid itself does not infect immune cells. So the covid genes themselves are not going to affect the immune cells in a direct manner even though they can have indirect effect by influencing host, the proteins inside an infected cell to react to the immune system. We actually don't know, there has been no evidence so far that covid or the virus itself , in the immune cells but there have been some reports that generic cells might be picking up some of the viruses, generic cells that are cells that are part of the immune system and it is to be studied further.

Shahid Jameel : I just wanted to highlight two reports that I saw. One report from China which showed that the virus is able to infect t-cells and t-cells are a type of cell involved in developing immunity and compromise the function of t-cells and another report which has just come out yesterday I believe which shows that the virus induces the production of interferons which is normally what happens. But then interferon is also a modulator that increases the expression of a molecule called ACE2 on the surface of the cells and ACE2 is the receptor of the virus, so if you have more ACE2 on the surface of the cells, there will be more virus captured by the cells. So it is sort of like a positive feedback mechanism that seems to be operating there. This paper just came out yesterday.

Q. Here is question about ACE2 inhibitors: ACE2 Inhibitors commonly used for treatment of hypertension, are there any interfaces with both genetics of common diseases like hypertension.

Shahid Jameel: Yes, an ACE2 inhibitor will not necessarily inhibit the entry of the viruses well because the ACE2 inhibitor inhibits the function of the enzyme ACE2 whereas the virus will find into the ACE2 molecule on the basis of its structure. So unless the activity portion and binding portion overlap the ACE2 inhibitors are not going to have any effect as an antiviral and I believe that is the case that inhibitors like medicine Telma used for moderately high pressure which seems to have no antiviral effects.

Q. What can be concluded about the multi-organ dysfunctions caused by SARS Cov-2. Is direct effect of infection possible or might it arrive due to the prevailing underlying conditions of the patients or due to the treatment given to them?

A: So as Jitu was mentioning earlier, this happens because when the body reacts to the virus, sometimes the body overreacts. The body produces molecules called cytokines which attract certain kind of cells that are called phagocytic cells to the site of virus infection to clear the infection. However, the body overreacts and there is too much cytokines produced. That means too many cells to that site and that really creates a problem in the lung, in the alveoli where oxygen exchanges take place and also in the kidneys where the blood is filtered. So multi-organ failure essentially happens because of the cytokine storm. You can think of it like success happens in a bacterial infection, again success doesn't happen because the bacterium is directly causing it that is because of the body's over reaction to the pathogen. So it is mainly a host's response and again there may be an underlying genetics behind it, why some people react violently to an infection and others don't.

Q: Are Asthma patients highly compromised with respect to fighting the covid infection, young and old?

A: Yes. If something that will really help you is breathing exercises, yoga breathing exercises are wonderful to increase lung capacity. Normally we use only about 60-65% of our lung capacity. These exercises help us increase our lung capacity and especially if you are an asthmatic, those exercises could be very useful.

Q: Since virus is immune to the temperature, washing, boiling vegetables, fruits or keeping them in the sun etc. Is it a futile exercise or what other measure we should adopt to clean them.
A: Well the virus is not resisting to boiling but that is not a practical method, you can't boil yourself, but to destroy them from surfaces there are other methods, common household bleach, oxide, soap etc., the viral membrane breaks open, it is a lipid membrane, it breaks open if you do so.

Q: Is there severe under-testing happening in India and if that is the reason why our numbers don't look as high as they might be.
A: I won't say that there is under-testing now, but at one point, there was severe under-testing. You know, when we started testing we were testing only a thousand samples a day, now we are testing about 35,000 samples a day and the idea is really not to test everyone. The idea is to test in a targeted manner and test people who fall in certain risk groups. I mean, we can't possibly test everyone. If today you started testing one lakh people a day, it will take you 37 years to test everyone in the country. That is not a practical option. You really need to do targeted testing. So that is more important. The numbers in India are just low partly because we tested low but also partly because we caught it fairly early on. The real thing to see is what happens to numbers after the open up, that is the real thing to watch.
Dr. Mayor: The testing capacity has to match the specific targeted testing that we believe to be doing, till this opens up. Today, if the numbers are going up, I would say not because they may be doing far more testing and therefore one needs to think about the curves flattening which is a good sign. Once you open up, if we don't do targeted testing, in a manner where we are not limited by capacity, it will be very difficult to contain the spread of the virus in a timely manner. Now we will be going to deal with many many more sites which would become hot spots. So I think the testing capacity needs to go up. I must say that each

test costs nearly Rs.2000, so that material costs are high and are not cheap. And that's a challenge.

Q: There are reports of a new way of testing that has been developed at IIT Delhi which can test instantly. How does that work?
Dr. Mayor: Well, we have been discussing this rapid diagnostic testing. The test in IIT Delhi works on the ability to identify the RNA with a specific capture agent they have made. If that works, it will really really be a positive development. Now those tests can be done without going through this whole paraphernalia with PCR. There are few tests to go in IIT Delhi and hope it will be useful.

Shahid Jameel: I think it has been validated by the ICMR recently.

Q. How countries like South Korea able to flatten the curve well?
Dr. Mayor: This may because they were able test them very rapidly, quickly identify where the outbreaks are going to happen and isolate the people with the physical non-pharmaceutical interventions.
Shahid Jameel: That is pretty much it, South Korea tested very vigorously. I must also bring another element in here, we ignore in our own country but Kerala has been able to do. Kerala looked at this outbreak very quickly and was able to flatten the curve, say much better than anyone in this country. They didn't do anything special, I think what was key to Kerala was that while the rest of India treated it as a law and order problem, Kerala treated it as a public health problem. The State government gained the trust of the people, so people were self reporting, self quarantining, that is very very important in any outbreak like this. Unless you build trust in the system, it is not going to work. So I think it is very important for all of us in the rest of the country, to transition from a law and order problem into a public health problem. Policemen should not be guarding barriers, community should be self-policing

themselves and that will only happen when you build trust, when you provide for livelihoods, when you take care of them.

Q. There are a few questions on herd immunity, is that the best bet for us?

A. Herd immunity is developed in two ways, the first is through a vaccine, we vaccinate enough people in a population. so that the virus doesn't really survive in that population and the rate will depend upon transmissibility of the virus. For example, something like measles we need about 90+ percent people in a population be immune before the chain of transmission breaks whereas for something which has a low R0 such as say flu you need lower level, you need about 50-60% people in a population to be immune. For covid people is estimated, the range is very large, it is about 29-74% of the population has to be immune. Now there is no vaccine. How do you make people immune, the only other way to gain herd immunity is to have enough people to be infected so that they recover and they become immune but there is a danger to this. If the population mortality rate of covid is 0.5%, you can calculate how many people in India you will have to sacrifice before you can build up even 50% of population with immunity. No government, no public health system will allow that. So herd immunity is a theoretical concept at this time. Herd immunity is not practical concept at all. Even countries like Sweden, which have very good health care system all of that, just go an look at the mortality in Sweden compared to Norway which is next door. Sweden is propagating herd immunity, Norway is propagating isolation.

Q. Two more questions, one is: could the covid virus change its property according to the environment and next question is: post lock down what needs to be done.

Shahid Jameel: All viruses change in time, if you recall Jitu's slide, there is average mutation rate. And RNA virus mutate faster than DNA virus, simply because the enzyme that replicates RNA cannot correct mistakes where as the enzyme that replicates DNA can correct mistakes.

There is more mutations randomly introduced in RNA virus genomes. Some of these mutations get selected because a mutation may allow the virus to escape the immune response, it may allow it to attach better to cells, whatever. So that is the selection pressure, that is how the viruses evolve, that is how viruses change. The other concept to understand is that killing a host is not in the interest of the virus. A dead host does not allow the virus to go from one person to the another. A dead person does not cough or sneeze and therefore cannot transmit the virus. So the virus will have to mutate and adjust its virulence to a level where it infects and makes people just about sick enough to be able to transmit the virus but not too sick to kill them. As viruses evolve in populations, they do that. You see, when new viruses enter a population the mortality rates are high and as they remain in population the mortality rate goes down and that is part of the natural evolution of the virus. Evolution is something that we cannot imagine on a timescale of our lives. Influenza have been in human populations for hundreds of years. It is changing, they change in every season. This virus has been around for just a little while. The second question is about what should we do after the lock down. Difficult question. But I have a couple of points here. Firstly, when to raise the lock down? Whether the lock down in future are going to be state wise, region specific, or in certain hot spots, will all depends upon data. So any further decisions have to be made based on evidence, based on data. It should not be made based on the whims of an individual, or it should not be a political decision or otherwise, that is going to be a disaster. That is one, the second is we each one of us should consider ourselves infectious for a long time to come and therefore we must all consider wearing cloth masks in public and I would really advise to do this at least for the next couple of months if not till the end of the year. Third, is that we start treating this as a public health problem and not as a law and order problem, build trust, let people self-report, self quarantine, bring communities together that is how we will control the virus.

HOW ARE THE IITs CONTRIBUTING N TACKLING COVID-19?

PROF. SUBHASIS CHAUDHURI ; PROF. V. RAMGOPAL RAO
PROF. T. G. SITHARAM ; PROF. SARIT KUMAR DAS | **MAY 1, 2020**

Prof. Subhasis Chaudhuri (born 1963) is the Director at IIT Bombay. He is a former K. N. Bajaj Chair Professor at the Department of Electrical Engineering of the Indian Institute of Technology, Bombay. He is known for his pioneering studies on Computer vision and is an elected fellow of all the three major Indian science academies viz. the National Academy of Sciences, India, Indian Academy of Sciences,and Indian National Science Academy.He is also a fellow of Institute of Electrical and Electronics Engineers, and the Indian National Academy of Engineering.The Council of Scientific and Industrial Research, the apex agency of the Government of India for scientific research, awarded him the Shanti Swarup Bhatnagar Prize for Science and Technology, one of the highest Indian science awards for his contributions to Engineering Sciences in 2004.

Prof. V Ramgopal Rao is the Director of the Indian Institute of Technology, Delhi. He was a P.K.Kelkar Chair Professor in Department of Electrical Engineering, Indian Institute of Technology Bombay . Ramgopal Rao has more than 450 publications in various journals, and 43 patents in the areas of Electron devices and Nanoelectronics. Ramgopal Rao was the first elected chairman for the Indian Section of the American Nano Society. He is also the recipient of multiple prizes including the Swarnajayanti Fellowship Shanti Swarup Bhatnagar Prize , Infosys Prize, Techno-Mentor award from the Indian Semiconductor Association in 2009. and the IBM faculty award in 2007. He is a Fellow of IEEE, Fellow of the Indian National Academy of Engineering (INAE), Indian Academy of Sciences (IASc), National Academy of Sciences (NASI) and the Indian National Science Academy (INSA).

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Prof. T. G. Sitharam is the Director, Indian Institute of Technology, Guwahati, Assam He was a Senior Professor, Department of Civil Engineering, Indian Institute of Science, Bangalore, India (he is on deputation from IISc from July 01, 2019). He was formerly a Chair professor in the area of Energy and Mechanical Sciences at Indian Institute of Science (IISc). He was former founder Chairman of the Centre for Infrastructure, Sustainable Transport and Urban Planning (CiSTUP) at IISc, Bengaluru. Presently, he is the Honorary Professorial Fellow at University of Wollongong, Wollongong, Australia and Distinguished professor at Hankou University International Innovation Centre, China. He is the Chairman, Executive Council of Visvesvaraya Industrial & Technological Museum Bangalore India. He is the founder President of International Association for Coastal Reservoir Research (IACRR), registered in NSW, Australia. He obtained Ph.D. in Civil Engineering from University of Waterloo, Waterloo, Ontario, Canada (1991). Further, he served as a Research Scientist (for his post-doctoral work) at the Centre for Earth Sciences and Engineering in the Department of Petroleum Engineering, University of Texas at Austin, Texas, USA. He is the Chief Editor of international journal of Geotechnical Earthquake Engineering, (IJGEE), PA, USA. He is the Editor-in-chief, Springer Transactions in Civil and Environmental Engg series, Book Series, Singapore.

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PROF. SUBHASIS CHAUDHURI ; PROF. V. RAMGOPAL RAO
PROF. T. G. SITHARAM ; PROF. SARIT KUMAR DAS | **MAY 1, 2020**

Prof. Sarit Kumar Das, Director and Professor, Indian Institute of Technology Ropar, Punjab is currently on leave from Indian Institute of Technology Madras where he is a Professor with the Mechanical Engineering Department and served as Dean (Academic Research) in the past. After obtaining B.E (Mechanical) in 1984 and M.E (Heat Power) in 1987 from Jadavpur University, he completed his Ph.D degree in the area of Heat Transfer from Sambalpur University in 1994 and joined University of BW Hamburg, Germany where he did his Post-Doctoral Research in the area of Plate and Liquid Metal Heat Exchangers. He has published four books and more than 250 research papers. He is a recipient of the DAAD and Alexander von Humboldt Fellowship of Germany. He is a fellow of the Indian National Academy of Engineering and the National Academy of Sciences, India. He has been bestowed with several Awards such as "India Citation Award 2012" by Thomson Reuters and "Prof. K. N. Seetharamu Award & Medal for Excellence in Research" by Indian Society for Heat and Mass Transfer in the year 2006. He has also been awarded the Peabody Visiting Professorship at the Mechanical Engineering Department, Massachusetts Institute of Technology, Cambridge, USA, in 2011. He is the Editor-in-Chief of the International Journal of Micro/Nanoscale Transport and an Associate Editor of the journal Heat Transfer Engineering. His current research interests include heat transfer in nanofluids, microfluidics, biological heat transfer, nanoparticle mediated drug delivery in cancer cells, heat exchangers, boiling in mini/microchannels, fuel cells, jet instabilities, heat transfer in porous media, and computational fluid dynamics.

Prof. Ashok Misra: Good evening to all the panellists and good evening to all the participants who are taking part in this webinar. As Ashok Kamath mentioned, this is our 3rd webinar and we have a very powerful panel and a very exciting programme that we look forward to this evening. We have Directors of four IITs. We have Prof. Ramgopal Rao, Director, IIT Delhi; Prof. Subhasis Chaudhuri, Director, IIT Bombay; Prof. T.G. Sitharam, Director, IIT Guwahati; and Prof. Sarit Kumar Das, Director, IIT Ropar, the youngest of these four IITs (IIT Ropar). All of them have been in the news and we thought it will be nice for the general community specially the IIT alumni and friends of IITs to know what is going on. Many IITs are working to mitigate the Covid-19 pandemic in terms of diagnostics, vaccines, all kinds of thing you hear about it, in a way these IITs are contributing to the nation as I see it and hopefully some of these work will go to the world, useful to the work. Without delay let us start.

We will start with Prof. Ramgopal Rao of IIT Delhi.

Prof. Ramgopal Rao: Thank you Prof. Misra, thanks for organizing this, good evening to all of you. We are all actively participating in this IIT ACB platform. In fact, for IITs, when it all came to a standstill because of COVID, with no anticipation of any of this, it also became a kind of self discovery moment as well as an opportunity for disruption. Self-discovery and disruption are the two terms I would use to classify what exactly is happening in the IITs. I was recently looking at a compilation of COVID projects in all IITs, which were initiated in the last couple of months. I notice over 200 projects around COVID started in IITs by either the startups or the faculty in the Institute. Many of these technologies are now becoming available in the market. Almost every week a new finished product is getting introduced into the market. This is the self-discovery moment for all of us. Even I did not realize the depth of research at IIT Delhi and capability of our startups. When we closed down in the early March, while I was sending that notice to all the students and faculty, I also said that anyone working in the areas related to COVID can stay back and Institute will make all arrangements for their laboratories to be opened and for them to stay on the campus. So we encouraged students and faculty working in the COVID related areas to stay back and Institute also pitched in with funds. We internally funded many of these projects to the tune of a few tens of lakhs per project to meet their consumables and other requirements. With this arrangement, we soon saw about 20 research projects that got initiated in the Covid related areas at IIT Delhi. For example, there is a good group in the Kusuma School of Biological sciences at IIT Delhi, who were working on virus related research almost for twenty years and they soon shifted their focus to COVID 19. For the past almost three months they have been working day and night on Covid and have now come up with a very low cost detection system for Covid-19 from IIT Delhi which has got ICMR approval. Once the ICMR approvals were in place, we received more than forty expressions of interest, many pharma companies wanted to take this Technology and take it to market. We said we will follow a open license policy. We decided that instead of giving it to only one company, we will give a non-exclusive license to any company which meets our quality requirements and certain background requirements. With that arrangement, yesterday we signed an agreement with four companies and we will be giving it to many more companies which meet that criteria. We are confident that in the next three to 4 weeks, this detection assay is expected to be in the market and the cost will be around 500 rupees. Now it will be a very low cost detection assay, 100% accurate as certified by ICMR, and can detect virus if some one has been infected for even two days. This Technology is RT-PCR based and very accurate. That was a great moment for us and it has also got the necessary attention it deserves. Further, we have a very good textile department and in the textile department, every fifth faculty member now has got his/her own start up. For example, there is this Nanoclean start up from IIT Delhi for the nasal filters, for air pollution. They were working on filters which you can stick to your nostril and it filters the particles down to 99%. With a little bit of modification to their focus, they got into the market of PPEs. They have now set up a manufacturing plant which is able to produce one lakh masks per day in the Delhi NCR region. They are also setting up a plant where they are able to manufacture thirty thousand N95 masks per day. That’s the kind of a rampup they have been able to achieve in a matter of a month and for this, I should also give credit to government agencies. Because, when we wanted to do all of these, there were approvals required, there were permissions required to open these factories. MHRD was very supportive in taking up our matters with the concerned ministries. Now we are able to produce all of these masks indigenously. IIT Delhi also has an excellent high performance computational facility with about 2 petaflops capacity and we said any covid related project which requires modelling and requires HPC, they can write a proposal to us and we will make it available for free. We received around 15 proposals for use of HPC for covid related projects, we approved 9 of them. These nine projects are from researchers outside IIT Delhi. We also have research groups working on drug discovery for COVID. At IIT Delhi we were facing a huge problem with sanitizers. I casually told our Chemistry Department, why can't we make it in-house, why we need to struggle for sanitizers and within about 48 hours they prepared 50 litres of hand sanitizers meeting the WHO standards, the recipe of which we made available to whoever needs it. I think this is the kind of self-discovery moment for us. I am happy that, one year from now, when we look back and see in what way IIT Delhi contributed to the nation in these difficult times, we will be able to list out many innovations from our campus. We have kept that in mind very consciously and we are working towards getting these innovations to the market.

There is also a disruption that COVID has brought about in IITs. Online education has taken off in a big way now. Until now, we have always had a bit of resistance to integrate online methods into our regular curriculum. This has changed in a big way. I see suddenly over 300 courses being taught online. Other than the use of PowerPoint, I don’t think any new pedagogical tools have really found a wide spread use in education. But now, thanks to Covid, we are able to reach out to people through these online programmes and in IIT Delhi we are working on a kind of a platform where we want to launch some certificate programmes in areas like AI, ML, Data Sciences soon. We hope to reach out to tens of thousands of people through these online platforms. IIT model always has been to select a few through the world's toughest examinations and give them the highest quality education and at the end, a degree.

Huge entry barrier and almost a non existent exit barrier. But now we have an opportunity to turn this on its head. Admit a wide spectrum of people with widely varying backgrounds, provide them highest quality training and give them a certificate after throughly evaluating them. That would mean, anybody can now take IIT courses in a live classroom. We are now launching some of these major certificate programmes jointly with private companies in the educational space. We have got expressions of interest from at least eight private companies now which are in the education space and they will provide all the backend support for running these programmes. The job of faculty members is to just go there and deliver those lectures. Tutorials and other matters will be handled by the service partner. I think these are the kind of self discovery and disruptions that have happened in our institution because of covid. Even the governments have realized the importance of science now. I am pretty sure now that funding for science will grow post Covid. Thank you.

Q&A: Prof. Ashok Misra: Thank you Ramgopal, a couple of questions from the participants. Can you share the formula for the hand sanitizer and disinfectant with the public?
A: We shared it widely. It's available every where now. If somebody can send me a message, I can share it again.

Q: What is the role of IIT in tackling covid, you mentioned about it a little bit. What is the research scope of IIT to find solutions for this sort of a pandemic, as I look at it, some pandemic may come later so we need to develop ready solutions.
A: Internet of things is a platform which can network all the Covid Sensors and update the data on cloud. Covid detection requires assays, requires deep science. Our target is to introduce a million kits in the country, so that this testing problem will go away. One can connect these sensors with an IoT based platform for online monitoring and reporting purposes. One can also integrate these Sensors with the Arogya sethu app of government of India. Possibilities are endless.

Q: Can you commend on the accuracy of the detection kits, how accurate they are and how do you say that they are accurate?

A: The ICMR report is available on the web site. ICMR said that they have done large number of tests and their test report shows 100% accuracy. The good thing with the PCR based systems is accuracy but the bad thing is the cost. The way we have been able to reduce the cost is by using a probe free assay. The flourescent probes that PCR systems use, they are the most expensive components of the entire assay. I would expect the IIT Delhi kit to cost around Rs. 500 or 700 per test. Let's wait and see how it shapes out.

Q: Last question: In any how, going on by statistics, lots of reports coming, the numbers are doubling, are these accurate or statistics people are involved in it.

A: We have launched an online portal now called PRACRITI from IIT Delhi. This tool predicts district wise spread of covid on a weekly basis and uses advanced prediction algorithms. Information about all the ongoing COVID projects is available on the IIT Delhi website www.iitd.ac.in.

Q: Can private companies help IIT Delhi in the R&D programme, are they helping or what is your outreach now.?

A: That is a very good question. Many industries are now coming forward to support our research on COVID. Many activities are getting funded through the CSR activities. In fact industry is playing a very proactive role in our research right now and I am very happy to say that more than half a dozen industries have come forward and given us funds. We have a Dean of Corporate Relations office and they are also working very closely with the corporates.

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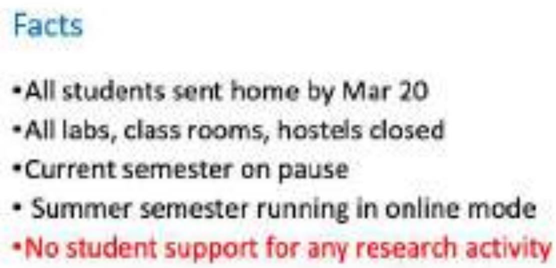
Prof. Subhasis Chaudhuri, Director, IIT Bombay:

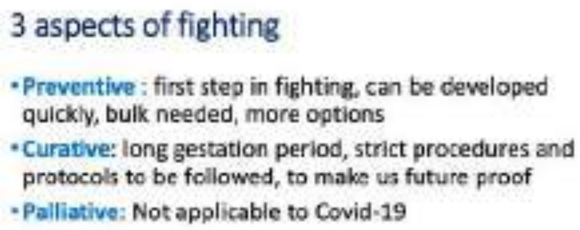
Thank you Prof. Misra, good evening to all the people here in the virtual world. It is a real pleasure to be talking to you. I will request Mr. Ashok Kamath to put up some slides I have prepared so that I could be more coherent in my talk.

As again Prof. Ramgopal Rao said, this was like all of a sudden and unlike IIT Delhi, we did not keep anybody in the campus, that is a big difference.

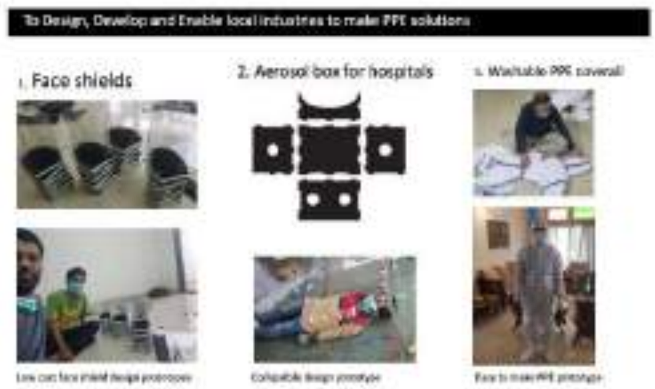


Please see the next slide. This is how we are fighting Covid-19. The basic facts are all students were sent home by March 20th, that was the last day students were there, only 70 or 80 of them are in the campus. All labs, hostels, class rooms are closed. Now current semester on pause. In between we declare summer vacations, so the summer semester is running now on online mode, for people so that they can make up and the key thing right now is that we have to realize when we say that what we all are doing, there is absolutely no student support for any research activity currently because those who need real lab support, they are not here in the campus.

When you talk about the fighting against Covid, actually there are three aspects to any kind of fighting like this. One is of course a preventive part, so which is like a first step in fighting, this is where the majority of the focus is, because it can be developed quickly but the bulk is required, we have more options to do this one. On the other hand the next thing which is



very important for all of us is the curative part, where usually we have a long gestation period, there are strict procedures and protocols to be followed and this is required supposing it comes back. This is where you start the thing but you don't see the result right now as it take longer. So I will be talking mostly about preventive part, little bit about activities owe have picked up on the curative thing. But of course for the third component for any medical issue is palliative which is not applicable for Covid-19. We don't have to talk about that.



One of the quickest thing, I am not talking about the mask or any kind of sanitizers that we have prepared here, we are talking about people from outside to take up that, for example, we provided a design so that somebody can very quickly take it up, for example, you see certain things like face shields are to be designed so that it can be done very quickly and they are very safe and at low cost. Hospitals, when you are checking particularly when you pick up swabs and all, these are dangerous for the people, for the health person, I mean for the worker, so some kind of an aerosol box to contain all those and the third thing is that if you are using PPE, many of them, we did not have enough at the beginning. All these we have made it and given to others so that they can actually start producing.

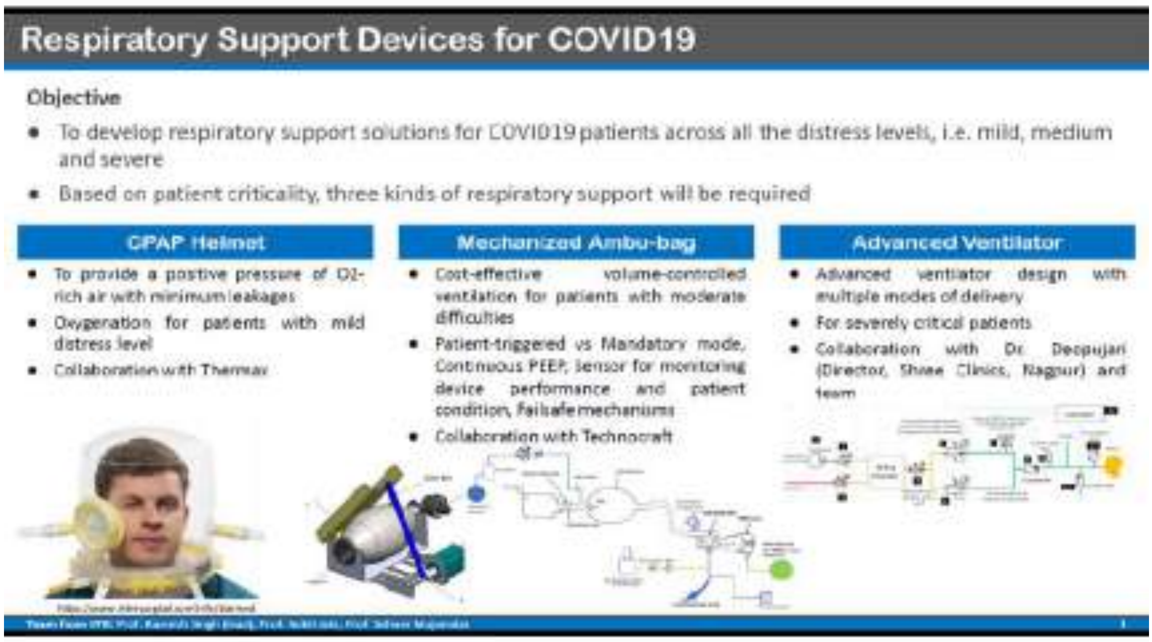
One of the common thing people talk about is killing the virus but what about so many things we just can't get rid of, for example, your valet, anything else that you use by touching outside. We actually got some disinfectant chamber designed, it has been actually tested. Of course we don't have access to the actual corona virus, but we got it done with E.Coli, Ebola, MS2 Phage and it do very well without damaging the things, for example you have mobile phones which may have thousands of bacteria and virus, so the question is how do you get it disinfected. We got it done.

There is another thing, if you realize, in the beginning people were talking about like a shower-chamber through which you pass through for disinfecting somebody, it is like a tunnel. But these are actually not safe and health authorities says that it should not be used. So we started working on something different, which is called phyto-formulations for walk through sanitizers, these are mostly means, a herbal paste, safe alternatives to chlorates.

Indian patent is filed, formulations developed, all formulations are food grade, GRAS approved, it is to be evaluated as aerosol sprays in tunnel, hand rub version is moisturising, safe to skin, and in depth evaluation remains. We are looking for some companies to pick it up so that we really want to do large scale kind of walk through sanitization for people and it can be done.

There is another one which is very well known that if you have certain special nano particles like silver and others, they have antiviral kind of properties. So we have actually been developing something where you can have very little bit of spraying of these particles on surfaces and you can kill all these viruses, do complete disinfection within two hours. We have had all the tests done and it can kill most of the viruses with very high accuracy. Of course, I must say that we could not do this test for the Corona virus as we don't have permission to do that.

There are other things, one aspect is the ventilator, CPAP machines. Some of our people in Mechanical Engineering and others are developing respiratory support solutions for Covid-19 patients across all the distress levels, i.e. mild, medium and severe. Based on patient's

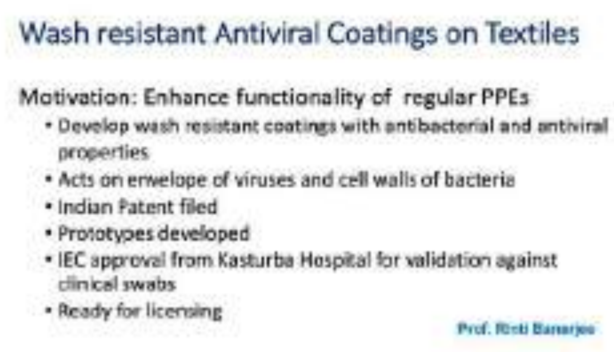


criticality, three kinds of respiratory support will be required. CPAP Helmet has been developed to provide a positive pressure of O2-rich air with minimum leakages; oxygenation for patients with mild distress level. This work is going on in collaboration with Thermax Ltd. Next one is Mechanized Ambu-bag, which is a cost-effective, volume-controlled ventilation for patients with moderate difficulties. It is patient-triggered vs mandatory mode, continuous PEEP, sensor for monitoring device performance and patient condition, with failsafe mechanisms, which is developed in collaboration with Technocraft Industries. Finally, the Advanced Ventilator, designed for multiple modes of delivery, specially for severely critical patients. This is in advanced stage of development, some more processes have to be done, before it is actually released and this is being developed in collaboration with Dr. Deopujari, Director, Shree Clinics, Nagpur and team.

The Biomedical Engineering Technology incubation Centre (BETiC) at IIT Bombay have already come up with a Ventilator, code name VI-SWAS, the model they have prepared as shown here, it is ready for absorption, they have signed a LOI with their industry partner, IITPL, Bangalore to supply 2000 ventilators.

Next one is the Ventilator RUHDAAR. This is something which we were not aware, our students no matter wherever they are, they are not in our campus. Two days back, it came out in the paper that one of our Masters design student, Mr. Zulqarnain in Kashmir has come up

with a ventilator called RUHDAAR which is a good ventilator design as being claimed which maintains all of these vital parameters required for a ventilator, it can control tidal volume, breaths/minute, and inspiratory : expiratory ratio, and the prototype is costing only Rs.10,000/-. That is also some interesting things some of our students are doing their own.



What happens is that in India, I was reading today in the newspaper, actually in Mumbai which is a hot spot, the amount of biomedical waste has gone up like the roof, we are thinking of how to actually get rid of biomedical waste which is a health hazard. So, can we design something like a wash resistant antiviral coatings on textiles, so that they can be reused. This is actually done by Prof. Rinti Banerjee and her team, any PPE you make out of this coating, they actually last even after twenty such washes; It enhances functionality of regular PPEs. They are wash resistant coatings with antibacterial and antiviral properties, it acts on envelope of viruses and cell walls of bacteria. Indian patent filed, prototypes developed and IEC approval received from Kasturba Hospital, Mumbai for validation against clinical swabs and it is ready for licensing.

Next is Biodegradable antiviral plastic Face Shields. Prof. Rinti Banerjee and her team have developed environmentally friendly alternatives to plastic based PPE. They are biodegradable biopolymer composites. Indian patent filed for biodegradable plastics for packaging. Prototypes available of biodegradable films. Antiviral properties of components being tested. Technology available for development of face shields/body suits.

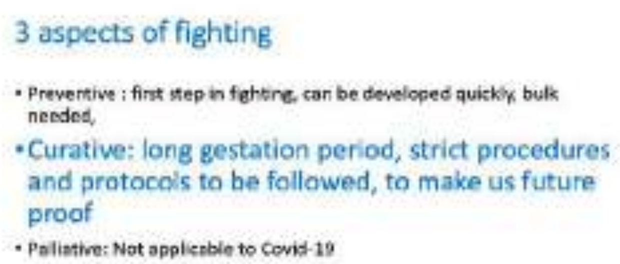
Somebody asked on IOT and others while Prof. Ramgopal Rao was talking. Here is another interesting thing. There is an app which is available in Google Play Store which is called Corontine. If somebody is suspected with covid and quarantined, he/she is registered in this App, if the person is violating the quarantine, it can track and trace the quarantined person. It is based on GPS and mobile signal. Developed by Hanawal & Ganesh, it allows geofencing and alert generation and being used in Odisha and Meghalaya. NITI Aayog is involved in developing this App and Deloitte is the industry partner for this App. Other States are also most welcome to use this App.

If you notice that now people are scared to go to hospitals. You don't know another person who is a Covid patient, asymptomatic or not. Also the doctors also don't want to come to hospital unless there is something very serious, but there are people who are suffering. We now have a system of online OPD. No need to visit OPD for non life threatening diseases. You can avoid exposure to Covid infection. Some of our faculty members lead by Prof. Kameswari Chebrolu of the Department of Computer Science have developed an online OPD, it is WhatsApp based, where you leave a message on WhatsApp, the OPD Doctor will call back, they will talk to you and would send you the prescriptions and this application is being used in big hospitals like, KEM Hospital, Kokilaben Ambani Hospital and in our own IIT

Hospital. You need not have to come to the campus for normal medical consultations, wherever you are, be safe and we will provide you the necessary medical support.

Other initiatives we are doing are Epidemiological prediction modelling, we have not been very successful, but some of the numbers are depending on lot of conditions, how good are all these model parameters, our colleagues along with the JNCASR are actually predicting at different places, in Mumbai, Bangalore or various places, what would be the requirement of health equipments, they are actually predicting the requirements. This is online and anybody can use these predictions. We do not have enough testing kits. We are also trying to develop pooled testing using sparsity based techniques and development of demand-supply match making platform for PPE.

Now we go into the next one which is the second portion of the curative part of it. This is a long term plan and some of the part we have started doing. There are three aspects of fighting. Preventive: first step in fighting, can be developed quickly, bulk needed. Curative: long gestation period, strict procedures and protocols to be followed, to make us future proof. Palliative care not applicable to Covid-19.



There are several projects, I took only few of them which are relevant. First one talks about an antiviral drug/molecule synthesis, coming out with some kind of a gel which you can put it close to your nose and inhale it, which goes inside your nose and that is suppose to kill the virus, this is some antibody based capture which is getting some good results and it will take time. It is a DST funded one year project and bioinformatic analysis completed. This project is carried out by Prof. Kiran Kondabagil, Prof.

Rinti Banerjee, Prof. Shamik Sen and Prof. Ashutosh Kumar of our Biosciences & Bioengineering Department (BSBE). The other one is identification of global metabolite biomarkers in Covid-19 infected patients for targeted therapy. This development work is done by Prof. Sanjeeva Srivastava of the BSBE Department, it is a DST funded one year project. IRB approval from Kasturba Hospital, Mumbai has been received and proteomics/metabolomics analysis of Covid+ve/Covid-ve patients have initiated.

Initially there have been claims that you put some prophylactics to help the immunity and others, so here is a antiviral very specific kind of prophylactics. Formulations developed as nutraceutical drinks and phytopharmaceuticals. This research work is headed by Prof. Rinti Banerjee of BSBE. FSSAI registration filed, strong antiviral and RNAse activity , pilot clinical trial being planned with partner hospitals. It is available for licensing and scale up.

Next is Nanosurf Technology. Aerosols for adult respiratory distress syndrome complications of Covid-19, a research project of Prof. Rinti Banerjee of BSBE. Aerosol formulations optimized and validated at laboratory level and in rat models. It significantly reduces cytokine storm; mortality. All ingredients are GRAS approved and is in discussion with Pharmaceutical GMP manufacturer MKPPL. Formulation validated and is ready for licensing.

We have a Covid related special task forces. One is for physically maintaining the campus where the Dy. Director (AIA) is the Head and for research, Dean (R&D) is in charge. Thank you, I will be happy to take any questions.

Prof. Ashok Misra: Lots of questions have come. For the participants if your question is not answered because the number is large, please feel free to write to the respective IITs and they will give a response I am sure.

Q. How easy is to get Covid sample for testing?

A. We were told that even if it is easy to get samples for testing, we should not go there, because it is very very contagious. So you need very special kind of chambers like at least BSL3 and also certain certifications and normally we would not encourage to do it unless you have very special protection gears and other things. These people are looking at getting only getting the RNA samples. It is very risky. It should be done only with NIV and ICMR guidelines should be strictly followed. I would say that some specialist should answer that question.

Q. Can we use the current research on Covid in general and be prepared for another which may come say three years from now. Is this an opportunity for us to develop larger research.

A. If you look at Professors, you have been Professors all through your life, if you are using google map for driving and suddenly you find that the road is closed, we simply take left or right and see is there any other way, we start exploring. So right now we are on that mode. So what happens that our people get trained on this process as Prof. Ramgopal Rao has said hopefully we are better prepared because the last major epidemic, I told it is about 100 years after something of a similar epidemic, so hopefully we are better prepared and we know how to handle it. We may not know exact solutions, but we know how to handle it and may be tweaking a current kind of thing we hopefully quickly get a vaccine or an antidote kind of a thing.

Q. Can you comment on the ventilators, are they as good as available now, are they cheaper and better.

A. It is cheaper for sure but whether better we have to check because you see the key thing is that these parameters are very very critical and the second thing is that you have to put them in a negative pressure chamber. Otherwise what happens your ventilator design is very critical, if you are putting them in a regular room and if there is a leakage you are jeopardising everybody else's health. So the entire ambiance has to be prepared. It is not only the ventilator even the leakage, the pressure monitoring. ICMR is very strictly monitoring, their protocol is very strict, they have the numbers, I don't know the exact numbers but I think the experts should know. What is important is that saving a little bit of money I would say. In the long run we will be damaging quite a lot.

Q. Along with the ventilators there is also talk about oxygenarators, are you looking at both together or in tandem or something like that.
A. The ventilator is the key aspect and what make it very complicated is actually also the negative pressure you have to put in there. Right now we are looking at getting a proper design that follows all the parameters so tomorrow, you can place it somewhere and do the proper testing. I know that our student has designed something which has come out in the paper but frankly speaking I don't have the details to say how safe it is.

Q. As we go forward, safety of industrial workers, that is where people come together, is there any research towards that aspect.
A. This is something very interesting. In certain areas we can have social distancing maintained and if you look at certain things in the software industry, it is possible. They are already talking about cutting down the office presence by 70-80% but there are certain areas where you need to have people and in manufacturing industry you have to be extremely careful that you place them properly so that there is no contamination so you have to have a new way of making sure our work site is good so that it is safe. I would go one step beyond that, see our work space may be safe in future but our living space in big cities like Mumbai if you see in Dharavi and other places, eight lakh people living in a small area, no space for them to do social distancing and due to this the condition is very bad. So I am more optimistic about the work space than the physical space that we live in.
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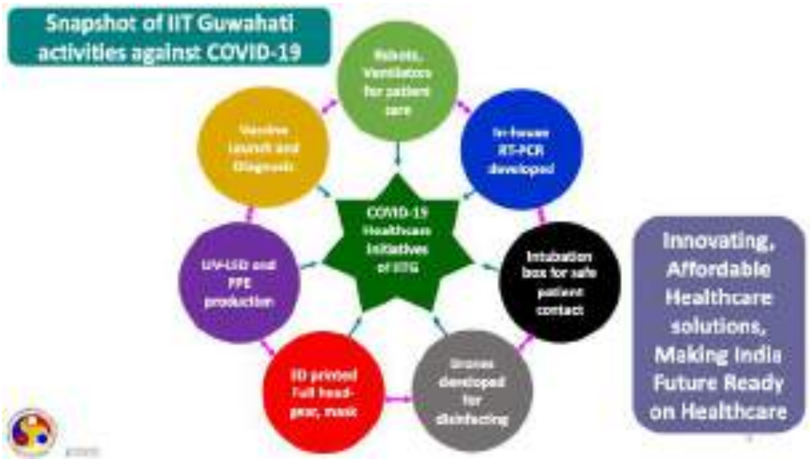
Prof. T.G. Sitharam, Director, IIT Guwahati:

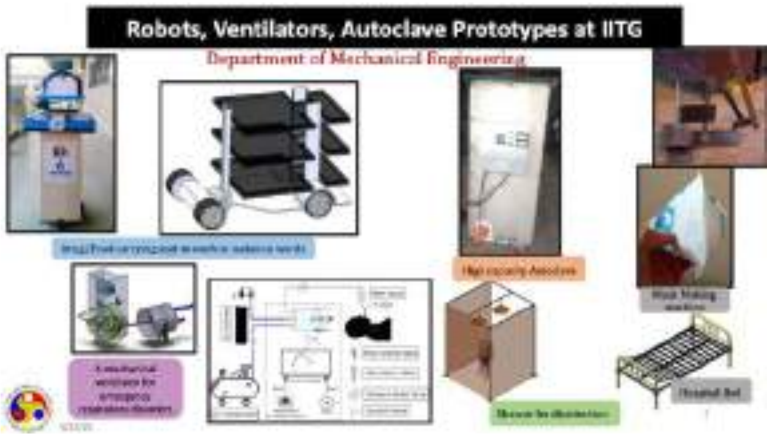
Good afternoon, thank you IIT Alumni Centre. Welcome to IIT Guwahati, which is celebrating it's Silver Jubilee this year and we have to actually cancel our alumni meet because we closed down all our academic, co-curricular and extra-curricular activities on 16th of May 2020 and also cancel our alumni meet which was scheduled on 20th May and our research conclave on 21-23rd May 20. All of that was cancelled because to Covid-19 and immediately on 16th, we created a disaster response team which have been constituted to look after both the prevention as well as mitigation of Covid-19 related issues in the campus with our Deputy Director as the Chairman and very big thanks to the team. Our campus is far away from the city and most of the Scientists and Professors live in the campus. So every issue including getting food, vegetables, grocery, meat/fish have to be sorted out. DRT team has done a fantastic job. Then we have started online classes immediately on April 4th, and more than 400 various courses are going online. we have started online yoga course for our students and faculty (they can attend these classes from their homes with their respective yoga teachers at IITG) through the Microsoft teams, which is going on very well everyday morning. We have done necessary steps for social distancing, strictly following Covid-19 protocols in the campus , which have been praised by all. Many of the students who got placements, only one company has withdrawn the job they offered and rest of the jobs are intact as on today. Our faculty and students are very generous, and they have donated one day salary to the PM Care Fund. We have collected more than Rs.35 lakhs from faculty, staff and students towards this cause. I am very happy to say that when the Guwahati Medical College Hospital informed that their RT-PCRs are not working and requested IIT Guwahati to kindly allow it's PCRs, our faculty members have very happily given two of our RT-PCRs for their use and I am very happy to tell you today that they are using our PCR machines for covid related testing. Student volunteers are providing food items regularly to the campus animals in this grave situation. Special thanks to Students Gymkhana Council.



Amid the Coronavirus outbreak in the country, IIT Guwahati has also joined the efforts of fast track research to deal with the pandemic. IIT Guwahati has contributed research in the fields of Epidemic pattern and disease, Ventilator, Hospital beds, 3 Layer fabric mask, Compostable Plastic Masks, Model the COVID-19 virus etiology using the tools of biophysics. Re-purposing of FDA drugs and exploitation of ancient Ayurvedic knowledge to discover novel inhibitors to block coronavirus propagation, Local Home Delivery Networks, Robot based Regular Health Monitor, Travel Tracker, Non-contact InfraRed (IR) Human Fever Tester, Testing kit, Disease Management Manual, Face Shields as an Effective Personal Protective Equipment etc.

Delivered products:

Affordable and sterile Viral Transport Media (VTM) kits, RT-PCR kits and RNA isolation kits have been developed jointly with RR Animal Healthcare Ltd. with inputs from GMCH. Large scale production of the kits has started and it will be delivered to test centres across the state. The quality of the are comparable to the best in the world. These kits have been developed at IIT Guwahati jointly with RR Animal Healthcare Ltd. with inputs from GMCH Govt. of Assam. Due to the huge demand for these kits and the high price associated with their timely procurement, the National Health Mission (NHM), Assam had approached IIT Guwahati for their development and procurement. The requested kits were already under development stage



The following products have already been developed and ready for manufacturing:
Mobile Robot for carrying drug/ food in COVID-19 Isolation wards, Mobile robot for medical waste disposal in the COVID-19 isolation wards, Face Shields for Medical professionals and security staffs, and Hand sanitizers.

The following products are under development and will be completed soon:
Shower for disinfection; Robot based screening unit (automatic temperature measurement), Ventilator, High capacity autoclave.

IIT Guwahati has taken the responsibility to contribute towards "Fight against Coronavirus" and is seeking solution(s) from the students community on measures that can be adopted on priority basis to tackle this pandemic crisis of any one of the broad objectives: ➢ Detection of infected persons, ➢ Precautions to halt its spread, ➢ Newer treatment approaches, ➢ Society impact, ➢ Behaviour changes, ➢ Disease outbreak pattern, ➢ Resources distribution, ➢ Transportation of goods, ➢ Migration of humans, ➢ Supporting health care workers, ➢ Supporting essential services, and, ➢ Any others appropriate. This competition was targeted to empower IITG students to conduct research to develop potential solutions to contain spread of coronavirus.

Marut Dronetech Private Limited, a startup, founded by IIT Guwahati alumni has developed and deployed drones for spraying disinfectant in public spaces to prevent Coronavirus. Marut Dronetech is working with the Government of Telangana and departments across the state to deploy drones for public safety applications.

Recently, Karimnagar Municipal Corporation, Telangana, had deployed customised drones of Marut Drones for spraying disinfectants in Mukarampur area of Karimnagar where 10 Indonesians and one local had tested positive for COVID-19. Disinfectants were also sprayed at District Collectorate, Municipal Corporation, District Hospital, Bus Station, Auto stand, markets, Police Commissionerate and Rythu Bazars.

IITG is leaving no stone unturned in making the country self-reliance (Atmanirbhar Bharat Abhiyan) as mentioned by Honourable Prime minister and IITG is fostering relations with industry in healthcare products manufactured in Assam. IT Guwahati continues developing affordable and innovative products to fight COVID-19. he Institute community and its alumni are taking up the challenge to convert this time of crisis into an opportunity to serve society and will continuously work to contribute to the masses in this time of pandemic so that vital products that are necessary for hospitals, offices, schools and colleges, private establishments to keep the population safe and secure are readily available at a reasonable cost. I congratulate all the innovators and incubatees of Technology Incubation Center (TIC) of IITG. I thank once again IIT-ACB for giving me a chance in this panel discussion. If there are any questions, I will be very pleased to answer the same.

Prof. Misra: What about the 2020 students who may lose jobs, may or may not get jobs due the Covid pandemic effect.

Prof. Sitharam: As I told you earlier, at IIT Guwahati only one company has withdrawn i.e only two students as of now. So far there is no other job withdrawal at IIT Guwahati. But we are ready with even another round of interviews by the middle of June/July for the students who lost the jobs. At the same time, there are few companies who came forward to offer jobs for the students who lost the jobs. I have written to every company personal letters from the Director's Office, saying that this is difficult time, please don't withdraw whatever offers made. We are working with our CCD Coordinator, talking to the industry who are ready to offer jobs to the people who lose the job and now luckily 2-3 students from one company have lost the jobs. That is the good news about it. I would also like to add here that we have started online internships for the students. That was also very successful and many companies have come forward to offer internships, sitting at their home they chase their data and files and the students are working from home for their internships.

Q. Prof. Misra: One question is about antimicrobial coating for vaccines, are there any side effects, are you considering their side effects.
A. I think I am not the right person to answer that question because which is a more of a science based question you have asked me, but any way I will discuss with the investigator, Prof. Biman Mandal. But I will try to tell you that five companies have come forward to use this technology and it was demonstrated it, they were using in hand and these scientists are using themselves without any side effect which shows that it is perfect.

Q. Does IIT Guwahati want to collaborate with nearby institutions beside the Covid-19 pandemic. Are you open to working with such institutions, that is the question?

A. As soon as I joined in last July, we have actually tied up with North East institutions whether it is a private institution or a government institution, even NITs because we are the only IIT within 8 States of the North East. We had a conclave of all the North East NITs, eight NIT Directors at IIT Guwahati and we offered them to work with us jointly. As I told you, E&ICT Academy at ITTG has already set up online courses for teachers at all NIT's and practicing professionals in all 8 states (through NKN networking). We are also working with the government institutions in Guwahati, medical schools, medical hospitals, So IIT Guwahati is making all efforts to work closely with the institutions in North East.

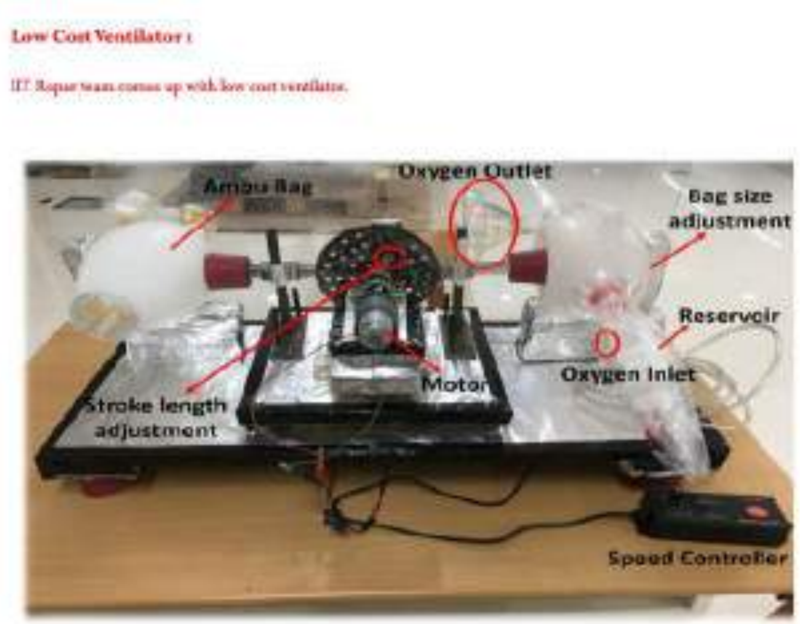
Thank you so much Prof. Sitharam, now over to Prof. Sarit Das.

Prof. Sarit Kumar Das, Director, IIT Ropar:

Last but not the least, IIT Ropar, so some of you have gone through the books of Chetan Bhagat, he started Five Point Something and then gone to Two States and then went to One Night, then went to Half Girlfriend. Every time you see becoming half, from five to two to one to half. I think the IIT experience the way we are following is also going exactly the same way. You see the first two IITs are 50+ years of experience and the next one IIT Guwahati is 25 years and then come IIT Ropar it is 12 years, just half and half. As you know, we are the youngest and that is actually exciting thing for IIT Ropar because we have got lot of young people and these young people, young faculty members are getting so excited that things are happening at IIT Ropar and I will come to that in a minute. Before that let me tell you about the point Prof. Ramgopal Rao has brought up which is the new way of learning. In fact what we are offering, we have not just loaded more than 2000 lectures but we are giving different platforms to different faculty members so that in future how we can use these different platforms for different kinds of courses interactions that will be tested now. In fact what Prof. Rao said is very relevant, we may have a model in which people can take some credits from IIT Bombay, some credits from IIT Delhi, some credits from IIT Ropar and then demand that I have got all credits and give me a degree and that may be possible in the days to come. On 21st of May we are launching an AI based programme with a university in Taiwan, Carton University in Canada and a company in Hyderabad, a certificate in AI and Machine Learning. So this is what is going on in the newer IITs also and this is really exciting and probably the old picture of education may change.

Now I would like to share the works are being done. Immediately after this Covid-19 crisis, the faculty members themselves made a WhatsApp group and they decided what are the things they can work on. There was nothing from my side, you please understand, in a small new IIT with 170 odd faculty members , 25 groups started working on different technologies and the most important thing that I would like to share is the point that we are just not working on those technologies and making designs, for everything after design they are making prototype, they are looking at technology readiness, they are working with hospitals, health centres,industries and implementing all of them and you will see that in a minute from different technologies that we are working.

This is the one thing which was previously shown. It is Ambu bag based system of ventilation.



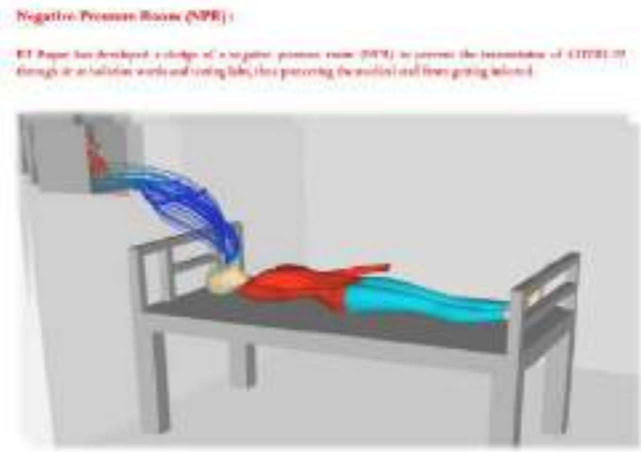
This is very important for ambulances, where patients are to be transported for one hour, two hours. It is a portable ventilator, a mechanical automatic system in ambulance, at the same time the patients can be transported and the same machine can ventilate them and they have also put sophisticated electronics in terms of sensing etc., which can automatically control the system of ventilation and we are implementing it in two ambulances right now. This is the electronics of that, it is sensing the oxygen situation and all. Then the next one is a very simple thing. These days, you bring vegetable, you bring everything and then you need to

sanitize them, otherwise you don't know what is coming with that. IIT Ropar has prepared a sanitizing device based on UV-C germicidal irradiation technology to disinfect groceries, vegetables, packages and personal belongings. This is a simple trunk shaped device, easy to fabricate, convenient to operate and chemical-free procedure for sanitization. In the literature which is there, UV light of a particular frequency kill Corona virus, corona virus in general and so it was fitted with that particular lamp, if you keep it for 20 minutes, you can see the reflector there, aluminium reflector. You can keep things which you cannot wash such as currency notes and keep it there for 20 minutes, it will be disinfected. Now the interesting thing is, the DGP of Karnal, she phoned us when she came to know about this, she said -" Can we use it." We gave them the technology, how to make it, they themselves assembled it, made and in 70 police stations in Karnal division. This is being used by all police personnel who are going to Covid affected places and coming back and they are sanitizing their belongings. Punjab Government has also recently taken it from us.

The next one is very important, we call it Medi-Sarathi. We developed autonomous vehicles called Medi-Sarathi for delivery of samples and medicine for Covid patients. It consists of two prototypes: One is Drone System to curtail Covid infection in `touch me not' environment and the second one is RC Trolley System to curtail Covid-19 infection in `touch me not' environment. Jointly developed in partnership with PGIMER, Chandigarh. It completely eliminates human intervention and reduces risk of infections to paramedics. Prototypes are completed; currently looking for industry partners for large scale commercialization. In Chandigarh, the PGI, which is one of the top most hospitals, is a designated Covid Hospital and one of their Wing is a Covid Wing in which it is very difficult for people to go, because you will be in PPE and all that and even after that there are infections. Our people are working with the PGI people and we have built this Drone system and the delivery system and this is going to the Covid Ward and in fact this has been tested. In PGI, from next week onwards we are going to imply these kinds of things, that is what I am saying, we are not just designing, we are building and working with the doctors in the hospitals to deliver the whole thing. This is the thing we call Medi-Sarathi, two of them, one is the ground based system, another is the drone based system.

The next one there I want to show is a very interesting thing. You have seen that they are screening people by putting the gun like thermometer. From thermometer, just by seeing temperature you can actually understand nothing. If a person has temperature it doesn't mean he has covid. So this is an intelligent system, called Intelligent Infrared Vision System, where various symptoms of covid are integrated, i.e. the temperature, breathing, the oxygen level, the fatigue, everything is integrated in one system and adjusted and is now being tested. This can scan like that in the airport just like metal detector, you can go through this they will integrate all the parameters together, use artificial intelligence and show whether this is likely to be a covid patient. This is the one developed by Dr. Ravibabu.

The other thing is this box, this is a containment box for protecting frontline healthcare workers. It allow it to be converted into a negative pressure chamber by connecting the vacuum from the wall-gas supplies. This is now being utilized in Government Hospital, Ludhiana and other general hospitals. Aerosol elements of the patients actually infecting our health workers, this containment box create negative pressure so that the things cannot go out, it can only come in. The latest model of it , we have tested that such that the negative part is optimal, we made it optimal so that the person doesn't feel suffocation or loss of oxygen.



The next one, which is very important, which is Low Cost Negative Pressure Cabins. A low cost (Rs.5000/-) isolation cabin for Covid-19 patients based on CFD simulations has been developed and building it now in PGI, Chandigarh. We are also building a negative pressure ambulance, negative pressure means the air cannot go out without filtering but air from outside can come in through leakages as a result of that infection will not go out. The cabin is designed to ensure no recirculation or aerosols and droplets generated by covid-19 patients in the cabin.

Next is a mobile chamber. The concept is that they use it exclusively for mobile testing being used in South Korea. In South Korea, the testing was so successful, they have mobile units, they went everywhere. Now in these red zone, it is very difficult for health workers to go, bring it to the lab and then test, so it can be done there if negative pressure mobile units are there and we are bringing such kind of vehicle, we are building it right now. This is the negative pressure one.

Next is this Mathematical predictive model. Analysis of incidence curves of 9 countries including India, China and US. A combination of two factors can significantly predict a country's incidence curve of Covid-19: the number of days between the date of first reported case and implementation of social distancing, and the percentage of the country's population affected at that time. The lockdown efficacy has been measured by using satellite data of nitrogen dioxide.

Every day, every channel shows one model. We found that these models are simple car feeding. Have anybody done the kind of research for these models, our Mathematics group has done that and what they have done is very interesting. Their finding is at what stage the lock down was done and what is the quality of lock down, is there the activity of 10%, 20% or 30%, the spread depends on that. How they did it. They took from NASA, the nitric oxide shows, how much of vehicles and industries are there in an area and then they correlated that to the covid data of 9 countries and then they came out with predictions, they said long term predictions are not possible, but they predicted the cases of India, China and US. In fact 10 days ahead of 15th of April, they predicted that on 15th of April will be 13400 plus and it was about 12900. So what they are able to say actually is nitric oxide is an indicator of how this week's spread, you can predict on the basis of nitric oxide.

The other one is, Dr. Puneet Goyal our Computer Science Department has put one Sampark-o-meter Application. He was working before hand. How this app works: Day-1: A is an asymptotic infected person, B and C groups represent people who came in contact with A.

Day-2: A falls sick and is now symptomatic (shows symptoms). Authorities are able to trace and quarantine the C group. Most in B and C group used App and self isolated. Day-3: People in group B & C falls sick, but as they had taken timely precautions and notified the authorities, they had broken the chain. The infection rate is reduced!!

Probably this application and Arogya Sethu was developed in parallel. Arogya Sethu is of course government sponsored it and it is being used. There are certain features in this Sampark-o-meter, because the progression is with base and in Arogya Sethu there is a problem. The problem is your contact can be traced only from the time that your app is downloaded. Where you were before that? Because 14 days before you could be an infected but that is not traceable. But this is a system in which they have made arrangements so that even before hand wherever you travelled, the data it can be traced. We are trying to contact the Arogya Sethu people so that we can include these kind of features.

Features additional to Aarogya Setu:

Distinctive features: App enables users to include the location data for the time when the app was not even installed. Location visualisation and Risk estimation (0-5 scale) as and when user wants. Early assessment can help timely break the chain. WebApp support to visualize and/or create location history for non-smart phone users. Helpful for Govt. officials to digitize and upload covid patients location data. Explain of risk assessment score to the user for one's re-verification. It facilitate assessing the risk for even others, not having the app or smart phone, using Google Takeout data or WebApp support.

Next is certain conceptualized design, we call it Wardboyt. What happens, when the direct health workers, such as doctors and nurses, they have to go to the affected patients, but they are well trained. But the problem is with ward boys and others who are not very well trained, even PPE is given they do not appropriately use it and get infected. So can we use these kind of a robot for delivering food medicine, etc. This is a line robot and in fact this idea, MHRD you know through their Mega Online Challenge `SAMADHAN', in that 2500 entries were there and this Wardbot actually was one of the top ten. We are now building prototypes of this robot.

The next one is shoes, anti-microbial coating kind. What we have done, our people changed from anti-microbial to anti-viral and we are testing it now. It is currently in testing stage.

The final one that I would like to share you is a Doffing Station - The Doffing Chamber. In the hospitals, the greatest problem is health workers getting infected. Suppose a health worker go to a covid patient, he leaves the PPE outside, now people outside got infected. Now where he leave the PPE, the point from where the infection will start. Now we have designed and building in PGI Chandigarh, the doffing where we use three things, one is non-alcoholic disinfectant spray, the next one is UV light and then negative pressure. Everything combined, we make a doffing chamber in which the health worker after treating the patient, they go to the doffing chamber, leave those things and they themselves get disinfected and all the articles get disinfected and come out of that chamber. He can go out of that because of the negative pressure. We have designed it, bought the materials and we are building it.

I could end by saying, you know in the last 20-25 days, all these young people who are doing this work, they never asked "Sir, we need money." But, " Sir, money is fine but can you arrange a curfew pass for me? Can you talk to the Dy. Commissioner so that I can go to the supplier and bring the necessary materials so that I can build it?" So, I am seeing a tremendous synergy developed and I am sure this is happening in other IITs as well in all the 23 IITs. I think we will be different people post covid time but another thing is we were known to be academic kind of researchers, that we do some deep research and publish in some journals and happy with that . Now Covid has put focus on doing something for the society, bringing a product, given it to the people, given it to the industry and I think that is the greatest opportunity which has come which IITs have started utilizing and in future they will be upholding this. Thank you very much.

Prof. Misra: Thank you Prof. Das, few questions to you.

Q. What is the pay load of the Medi-Sarathi you were talking about.

A. It is 3 kg, i think.

Q. You talked about UV Sanitizers, it is being tested and tried for Covid-19 work.

A. No, actually this is tested for other Corona viruses but not Covid-19 in specific. All other evidences indicate, whatever is there in literature it should also work for Covid-19.

Q. What is the role of robotics in this pandemic.
A. About hospital robotic we are talking about for a long time, but it has not really come up. When we are talking about hospital robotics to a PGI doctor, he says no, no, no, I could go personally and I want to see the patient, now that has changed. They themselves are asking now, can you give us a robotic arm, can you give us a robotic vehicle which can go there, because everybody understand the danger.

Q. How can nano-particle technology be used for detected covid patients and so on.
A. One of the things almost everyone said is it is the nano-coating, antiviral coating kind of a thing. Another thing which is there is called superhydrofobic surfaces. Like lotus leaf, you make the surfaces such that anything, any droplets touches it, it falls immediately, it doesn't stick to that surface. that is another way of repelling the droplets, because covid is known to be a droplet kind of infection. These are two ways we can do it. Covid virus can stay on the surfaces, and if we can coat the surfaces with the anti-viral coatings, then the chances are less as it says the virus remains live for 2 hours or 3 hours, it depends on the surface. What is interesting and what has been found in covid is that they stay maximum on plastic surfaces and minimum on copper surface. This is found out. So our age old everything is coming back. Doing namaskar, in our homes, always we have to keep our shoes outside and before having food you wash your hands and now use copper vessels for drinking water, everything thing is coming back to us, whatever are our traditions that are coming back and seems to be correct.
Prof. Misra: Good, now let me ask you one questions, this is our plastic man. Having said this, now home delivery of things are taking place, everything is coming in plastic.
A. Yes it is dangerous. I will tell you one thing, I was told by a doctor that one of the worst that these institutes do is we buy new furniture and new furniture is packed in plastics, at

home also we get it, and we think it is new we don't unpack it. I will keep the plastic cover still. That is the most dangerous thing.

Prof. Sitharam: IIT Guwahati has developed a bio-plastic, degradable in a normal temperature within six months. You know, Prof. Kathiyal who developed this and is already in a scale which is scalable. We can manufacture that, we are working with NRL to make that in tons.

Prof. Misra: Thank you Prof. Das. I have a few questions which is a general kind of variety. Are IIT alumni association collaborating in fund raising for Covid related projects. Prof. Ramgopal, you can answer this?

Prof. Ramgopal Rao: Many of our IIT alumni are coming forward, there is a major initiative started by PanIIT alumni for alumni networking under Covid point of view. there is lot of work that is happening, in fact I just now saw a picture that they have launched a bus, the bus will go all over and do more tests and I have also offered them IIT Delhi test kits. There is little bit of networking happening to contribute to the cause.

Q. Subhasis, will the funding for covid affect the funding for other projects. At one time, all the funding was going for Nano, and now it is happening like that for Covid.

A. This definitely happening, there is little bit of skewing of funding because this is more urgent but in general, what happens, no matter even I not being a Nano person, I survives, the rest of the people also survives, there will be other sources of funding.

Q. How to engage Ph.D. students during lock down period. Students, are they contribute from home or are they allowed to go the labs, if they are on campus.

A. For us in IIT Bombay, since it is closed, we are not allowing but somebody does something very specific and urgent, then they have to take a permission and if they are happen to be in Mumbai and they have to move to the campus and with permission, we allow. This is if they need lab access, but if somebody doing some computational work, they can do it from home and the Professors are keeping tab of the student.

Q. In Guwahati, how are you managing well.

A. Most of our labs are closed. We have only around 50 students on campus. Only Covid-19 related ones are open. Some of our faculty, some of them who are in biology they keep running the labs. All others are working from home. Some of our workshops are open for doing covid related works.

Prof. Sitharam: We are engaging students in a different way, for example, day before yesterday, we had a research methodology webinar and about 400 research scholars from our Institute and other 200-300 students from outside institutions attended and we brought speakers from outside and the students were excited about that. Research scholars who are ready with their seminars and doctoral committee meetings all these are happening over web.

Prof. Ramgopal Rao: We had our Senate meeting involving 200 faculty held online and in fact the attendance was better as it was held online.

Prof. Subhasis Chaudhuri: Actually I am busier than normal times, working lot more than I used to earlier.

Q. What would be the long term impact on education, how do you see 19-20, 20-21 batch and so forth. Will it be going to affect the classes etc.

Prof. Das: Let me tell you, short term we are forced to do certain things, today only we have taken a decision that we would go for the end semester exam online for final year students. These things we are pushed into, probably it may emerge something which I put it this way. A very great thinker who passed away a couple of months back, Clayton Christensen who was a Professor of Harvard, he was a propagator of disruptive innovation and he said about education, this education system of a university in which you come for three years, five years, this system is existing for the last 500 years. But this is going to be challenged. People will ask why should I go for a complete course when I don't need it. I need only a part of it, why should I take a programme which is designed by somebody else. Why shouldn't I design my own learning and these concepts will come. I am sure, some of these concepts are going to come in future.

Prof. Misra: Ramgopal, I will ask you the one last question. People are suggesting that IIT should also work on socially relevant health projects, it could be a multi disciplinary involving humanities and social sciences and the bio people, so on and so forth. How do you respond to that.

A. We must do that, we are doing it, we can do more. There are lots of multidisciplinary projects within IITs but what is missing is inter-institutional projects aren't many, for example there are certain strengths here, there are certain strengths in another Institute. We haven't really been to that sort of an expertise, that is probably something we need to do more often and at IIT Delhi, I can imagine at least 200 faculty members working with outside their departments, we have various schemes to encourage that. Within the Institute these are now happening on a much larger scale compared to let us say ten years ago. When I started at IIT Bombay ten years ago, having a project where there are four or five faculty involved was very difficult to even think of. Everybody was within the department, within the group. But some of those things happened at IIT Bombay ten or fifteen years ago, but now many projects happening across the Institute.

Prof. Misra: Thanks to all of you, Prof. Ramgopal Rao, Prof. Subasis Chaudhuri, Prof. Sarit Das and Prof. Sitharam, taking the time to show us what is going on at your respective IITs, I am sure very good working is going on in all IITs, as Ashok Kamath said we have to restrict to reasonable number of panellists to take this webinar forward. Thank you so much for the excellent presentation and we will put it on youtube very soon so that others can also see it. I would also like to acknowledge the help provided by the respective alumni associations for spreading the news about these webinars especially the alumni associations of IIT Delhi, Bombay, Guwahati and Ropar and I think this is the way we will proceed to put forward. Thank you and have a good evening.

DIAGNOSTIC TESTING FOR COVID19

DHANANJAYA DENDUKURI I MAY 2, 2020

Dhananjaya Dendukuri is Chief Executive Officer & Co-Founder of Achira Labs, a pioneering technology company focusing on point-of-care medical diagnostics. Dhananjaya returned to India with his passion for engineering and belief that technology development for underserved markets must be done locally.

Achira's ACIX is India's first microfluidics-based platform for point-of-care diagnostics. Achira received the National Technology Award for new technologies (biotechnology) in 2016. Dhananjaya has received MIT's TR35 award and the Senturia Prize at MIT.

He received his PhD in Chemical Engineering from MIT, an MASC in Chemical Engineering from the University of Toronto and a B.Tech in Chemical Engineering from the Indian Institute of Technology, Madras where he received the 'Institute Blue'. Outside of work, Dhananjaya enjoys running through the leafy parts of Bangalore and playing the Carnatic violin.

The webinar was moderated by Prof. Rohit Srivasatava, IIT Bombay

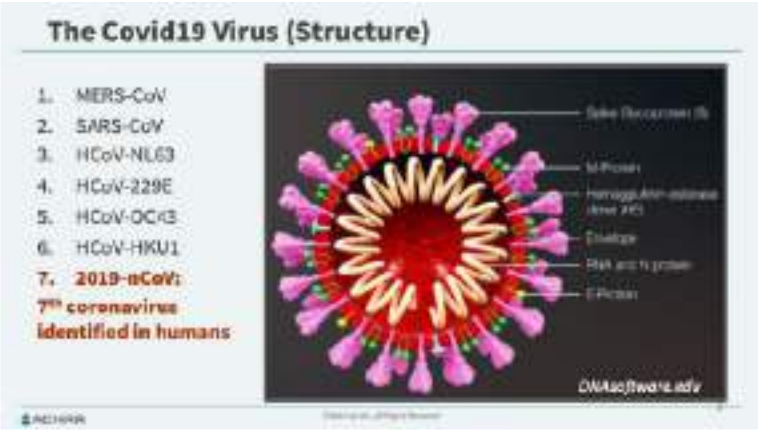
Talks at IIT Alumni Centre, Bengaluru, by Dr. Dhananjaya Dendukuri, Chief Executive Officer & Co-Founder of Achira Labs & Prof. Rohit Srivastava, Head, Dept. of Biosciences & Bioengineering, IIT Bombay

Link to the webinar : https://www.youtube.com/watch?v=gA7LqCyqpgg&list=PL0zMQ-70IHlX-df3u2Tto6dkKHCRC6iFL&index=16

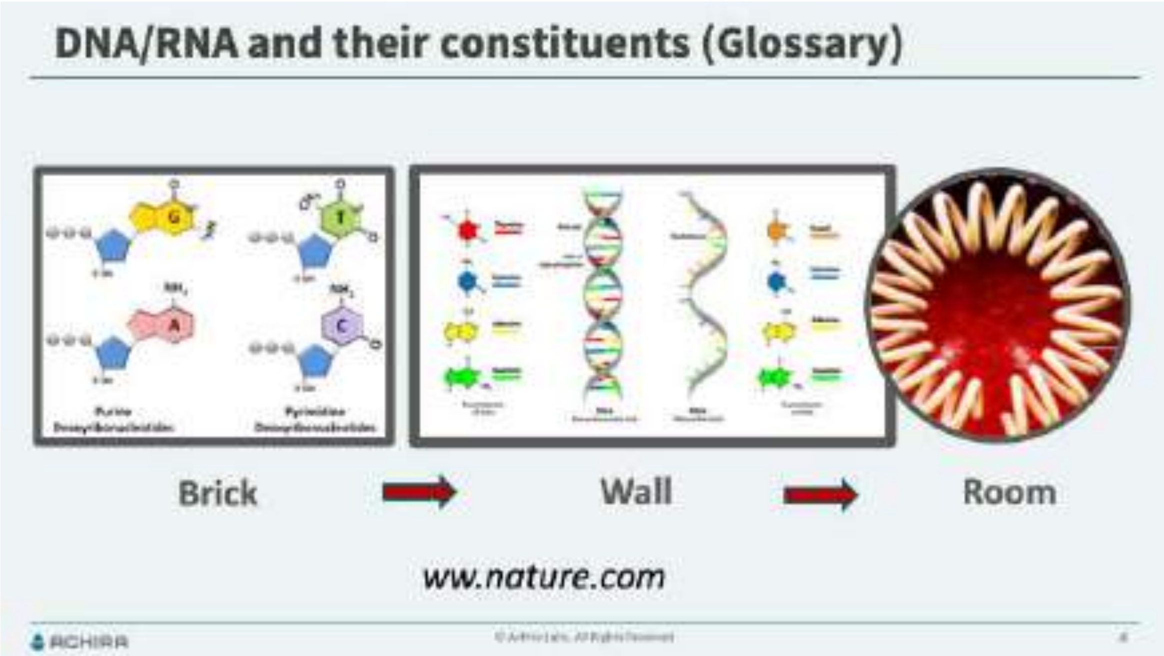
Dr. Dhananjaya Dendukuri:

Thank you Ashok Kamath and Susheela Venkataraman for having give this talk. I am very honoured to be here. It is interesting coming from the Diagnostic world talking about all of these things right now because so many of these terms like RTPCR, immunoassay, immunoglobulin and so on have suddenly become part of the popular imagination in a way none of us in this field would have imagined before. Suddenly diagnostic testing has come to the forefront, because of the Covid-19 crisis and I really like the opportunity to talk about this today. What I am going to do today is to give you an overview of the kind of diagnostic tests that are being done for Covid and for some of you who are very educated about the mechanics of how these tests work, this might seem very simplistic and be about things that you already know but for a lot of people who don't know about the details of the diagnostics, I will try to explain lot of details about how these tests are actually being made and what the pros and cons are and hopefully elicit some discussion from all of you because this is the topic everyone is interested in today about the testing for Covid and what the good tests are. I structured the talk in the following way. I am going to give you, since it is science heavy talk, lot of jargon in biology, it is important to understand that at the basic level. I am going to explain a few terms before actually beginning my talk and then discuss really the key types of diagnostic tests that are for Covid-19, the molecular gene test and the antibody antigen test and then talk about how

these tests are developed, what sort of platforms are used in the labs to test. That is the flow of the talk.

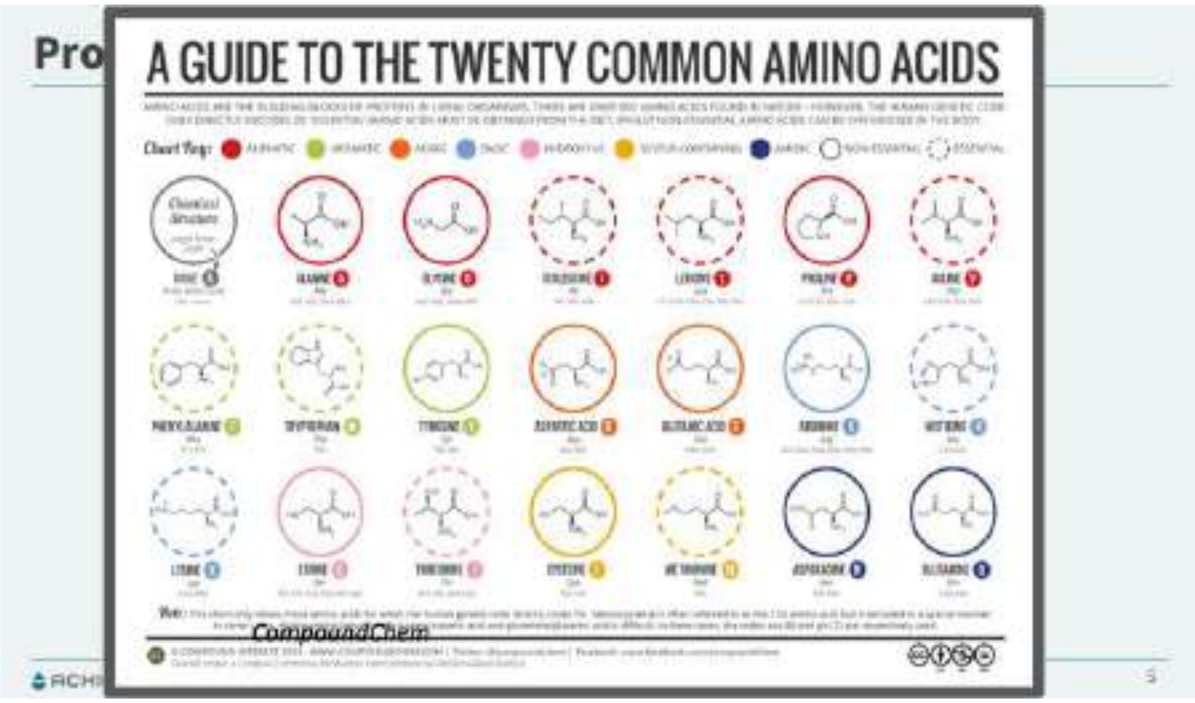


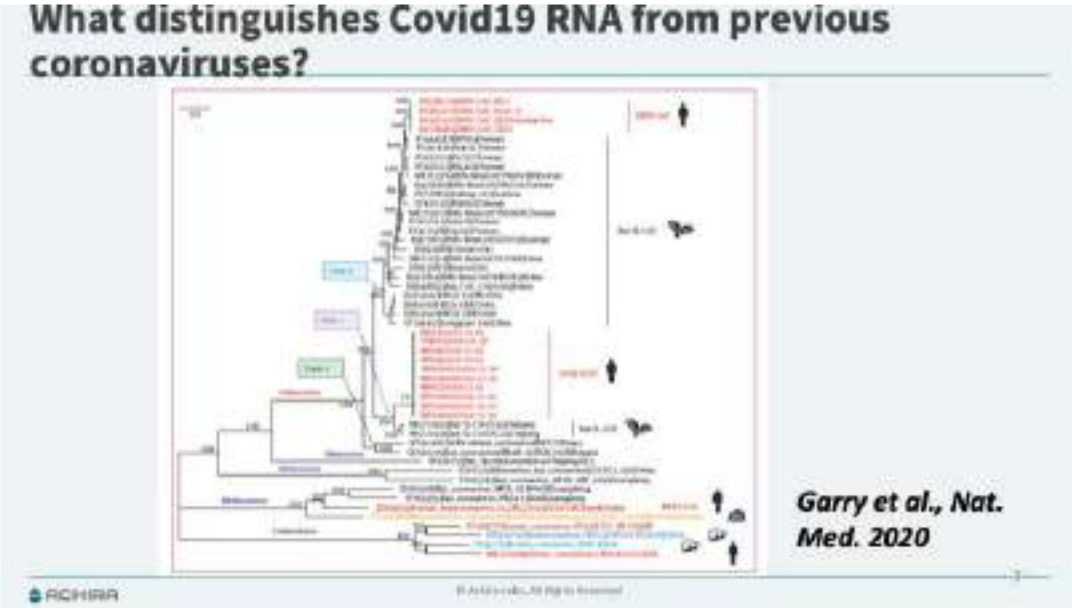
I will start with the picture of virus that everybody has seen in one form or the other. The thing I am going to state here is that the Covid-19 is actually the seventh of the Corona viruses identified in human beings, so lots of corona viruses are out there in bats, pangolins and animals. Covid-2019 strain is the seventh strain of the corona virus that has actually infected human beings. Most prominent previous one of course was the earlier SARS, again there has been MERS a few years ago and there is even being slightly less infectious common colds for example which is also counted as corona viruses amongst this list. As the name indicates when it comes from the Sun Corona and that is actually because of this spike like structure that very distinct to these corona viruses. In this cartoon view, you can see this pink spikes and this is actually a protein on the exterior surface of the virus and that really gives a distinct name Corona Virus. All these have spike proteins. In addition to that there are few other important structural aspects of these viruses. You can see inside this string like structure, that is really RNA, which is the genetic core of the virus and the RNA is encapsulated inside something called the N protein and there are a few other structural proteins which are important for this virus to function, including the envelope protein - E and the Membrane protein - M. So it is important to understand exactly what RNA is, what protein is in terms of actually designing some of these tests. I am going to spend little bit of time on that. All of us know that there are the four building blocks of the DNA at least: A, G, C & T, shown here are the four molecule blocks or the bricks from which a more complex DNA strand is built.



So here on this slide I am showing you DNA which deoxyribonucleic acid and also RNA which is ribonucleic acid. So the main difference between the two is that you have instead of a Thymine inside the building block of the DNA replaced by something called Uracil in the RNA. and that makes RNA a single-stranded virus as opposed to DNA, which is a double stranded polynucleotide. This Covid-19 virus is a RNA virus, it means you have an RNA like this that is about 30,000 bases long. You could imagine a really long sequence of UGCTS 30000 bases long, that is what encapsulated inside this virus here. So the analogy again is that the bricks are the nucleotides, imagine sort of a wall .... the structure DNA, RNA and then all that encapsulated into a much larger body which is the virus here.

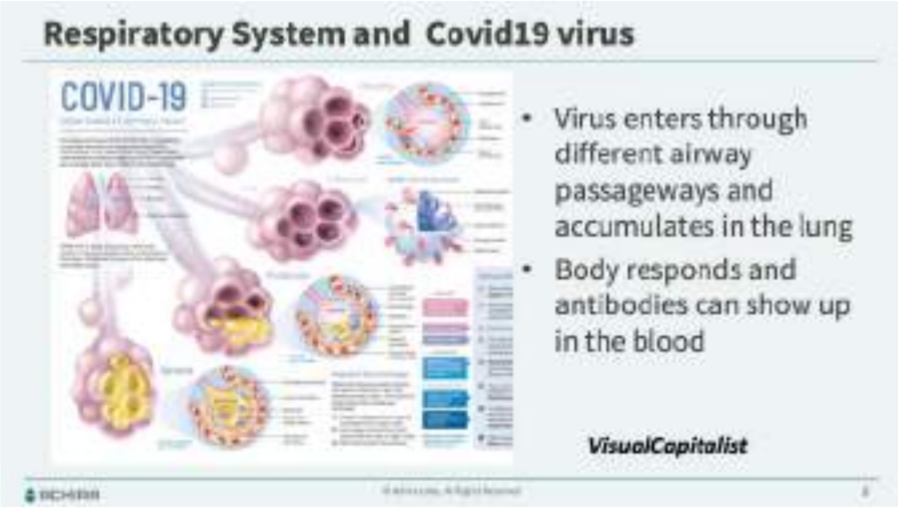
Another term which very important as diagnostics testing is concerned something called Polymerase Chain Reaction (PCR) which won a Nobel Prize actually and is almost 35 years old today. But the principle behind it is quite simple, and actually works so amazingly. What it does is basically exponentially amplifies the DNA using enzymes that are present naturally. So we all know the DNA is the key to life and the body is able to continuously copy and replicate cells by copying and replicating DNA. To take over that machinery to do a polymerase chain reaction, if you start here with a DNA molecule, shown here as double standard DNA. It is something called 5-prime end but if you start with one copy of double standard DNA, and you add what is called primers shown here in pink, it just uses the building blocks the nucleotides and puts it together in certain chemistry. You can actually just go from one copy to two to four and eight and so on to the power N as you keep these cycles. That is really the power of polymerase chain reaction is that you are able to exponentially amplify a small number of DNA or RNA to start with and produce enormous number of copies of it. So the Polymerase Chain Reaction, the PCR is the name that keeps coming up. The thing to know about really is that you can exponentially amplify these nucleotides. The other sort of jargon thrown at you to begin with is the other important macro molecule. The virus has proteins of course and protein are composed of amino acids and there are twenty amino acids, so you have four nucleotides to make up DNA, RNA but you have twenty building blocks to make amino acids and it not important to know everything about what those are but it is important to know that each of those actually come with a simple code A, G, I, L



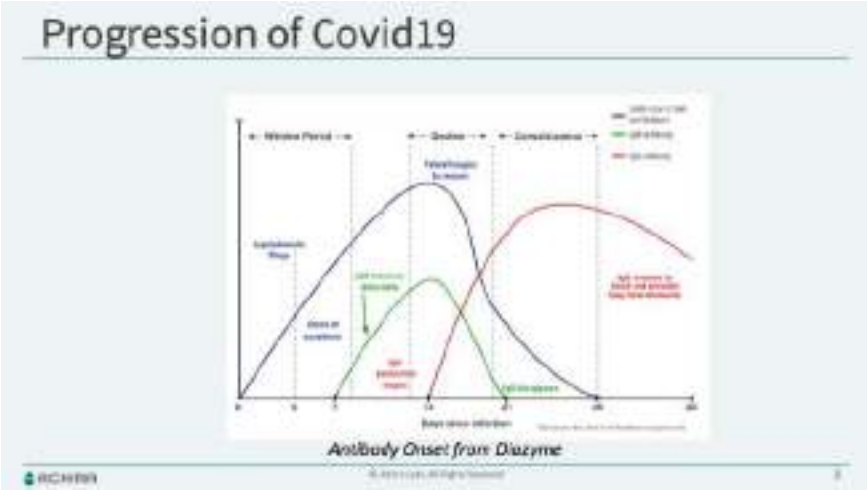


etc. So you can basically mention a strand through entire sequence of these amino acids. Amino acids have a more complicated superstructure, so if you have a string of amino acids like the one shown in the picture, actually then into such complicated ribbon like, sheet like structures which then go on to becoming something like a spike like thing. So again the analogy of the building blocks, the amino acids going all the way to quite a complex macromolecular structure despite protein. Again this structure and exactly how it binds to cells in our body and so on is obviously very important the way the virus infects, even in production of antibodies. This is a little bit of terminology before actually to get to the diagnostic part of it in my talk.

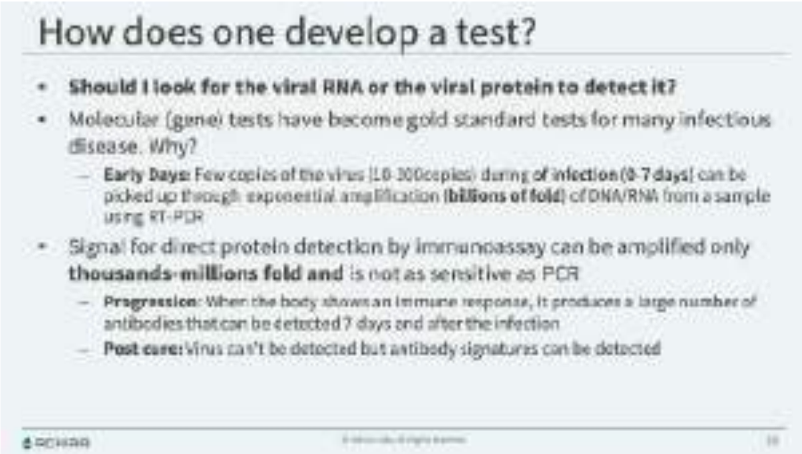
What is this Corona virus and how it is related to all other corona viruses around. So this is a family tree much like our own family trees. You can see here the sequences shown here in red are the 2018 Corona virus and sequences shown on top are the SARS Corona virus. It is actually only 80% similar if you compare all the nucleotide sequences , in the end it is 80% similar to the corona virus. It is much closer to some bat corona viruses not yet seen in humans, it is isolated from bats. There is also the MERS Corona virus, the other corona virus you can see in this genetic tree, family tree of these viruses in some ways to each other. In fact the same spike protein, M protein, the E protein, sequence of those actually changed from virus to virus. So what happens when someone unfortunately get infected by the Covid-19.



This is just a picture of your lungs and really as you get the lunch has this .... like structure to the end you have these alveoli which is where gas exchange actually happens in your blood and lungs. You breath in air, you want oxygen to actually go into your blood stream to take away carbon dioxide, that is what shown here and these alveoli contains some important cells, type 2 alveolus cells which the virus actually binds to ACE2 on type II alveolus cells. That is how it attacks the lungs. The virus gets into the lung it gets all the way here, you can find to the ACE2 on type II alveolus cell and actually the building up of fluids with breathing and things could get much worse severe problems for the people. The point I would really like to mention here is that virus is present inside your lungs. This is what I guess you all know. So what happens when you go through a Covid-19 infection. Shown here is actually progression of three important molecules. One is just the viral RNA, the virus itself shown here in blue lines, you can imagine it is keeping increasing over time and then the patient begins to recover it kinds of falls off, because these numbers that average of typical numbers, in better and worse cases ..... Within about seven days of the virus actually entering somebody's system, you could actually start the antibody production which is part of your immune response and this actually first comes up as an IgM i.e. immunoglobulin M, so this is an antibody that is released is made by your own body to combat the virus which is shown in green, it peaks and then falls off and then we have shown here in red is the immunoglobulin G which is what is critically confers long term immunity. We will see that there are some complications associated with Covid-19, but typically this IgG actually confers long time immunity

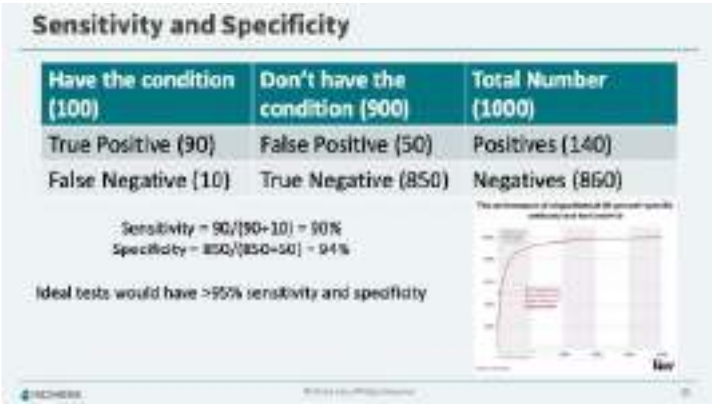


and builds up say 14 days and onwards and actually maintain quite a steady presence in your blood sometimes even years after you passed that infection. So this is sort of the progression of different parts of virus and antibodies inside your system. So you could imagine, if you are someone who just know all these information right now, and you said ok, I need to develop a test for Covid, the two obvious things you could do that look for protein and the virus as a protein I showed you earlier, or you could look for the RNA of the virus or the molecular test, unfortunately the name molecule, everything I guess is a molecule. But molecular test has a specific meaning in diagnostic test that refers to nuclear tier testing. DNA, RNA tests are molecular tests. These tests have become the gold standards for infectious diseases, why is that because in the early days of infection. When we go back this graph a little bit, in this 0 to 7 days of infection, you may have very very small numbers of copies of the virus (10-100 copies) can be picked up through exponential amplifications

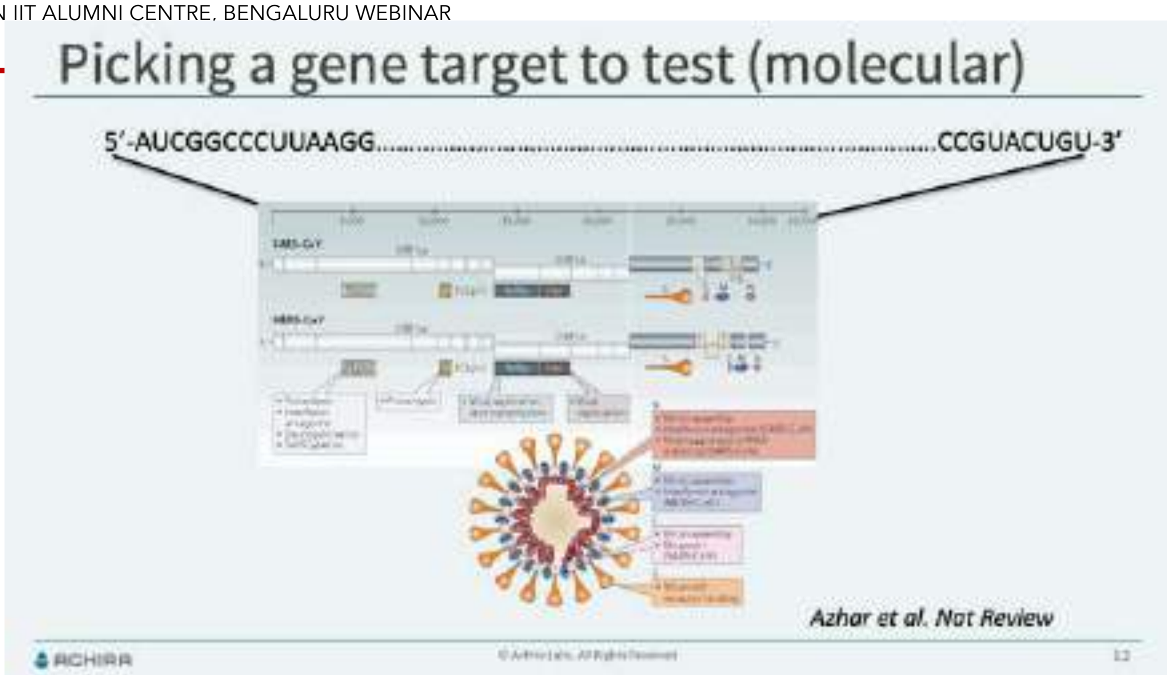


(billions of fold) of DNA/RNA from a sample using RT-PCR. So you can't pick up something small as 10 or 100 copies by itself. The only way you can do is by amplifying it say a billion fold, that is exactly what PCR does. So you could go suddenly from 10 to 100 copies to billions of molecules of RNA and that is what is detecting by using RT-PCR. You could in theory also a protein, so let us say you have the S protein or A protein of the virus, you could detect it directly but the problem here is that you can't amplify a protein like RNA or DNA that is the limitations to chemistry and because of that reason it is preferred specially in case of an infection do a molecular test and lot more sensitive. However, as the disease progresses your body start producing this amplified antibody response and for each copy of the virus you could be producing thousands of copies of these antibodies, so that actually can be picked up quite easily which is why seven days or so after you can pick up a lot of antibodies with the traditional detection of the viruses. The final point, on post cure stage, virus can't be detected but antibody signatures can be detected. You can see that both these molecular gene tests as well as the antibody tests have their own use.

Some more terminology that is important to define diagnostics, this is sensitivity and specificity, this is very very important because these terms are used very hugely so given this terms of a very small example, let us you have a 1000 people in a population you have studied and 100 of them actually had Covid alright, you have 1000 people to begin with a 100 Covid positive patients, so 900 of them don't have Covid. You have a test which is picking up 90 out of those 100 people and classifying them as being positive to Covid but it also falsely

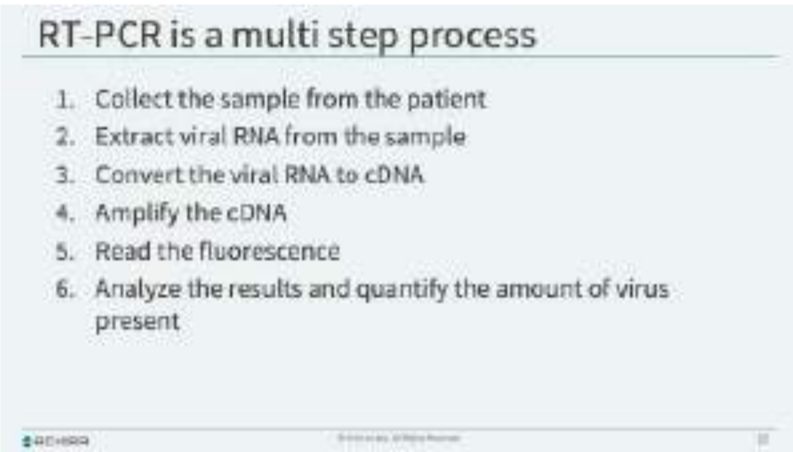


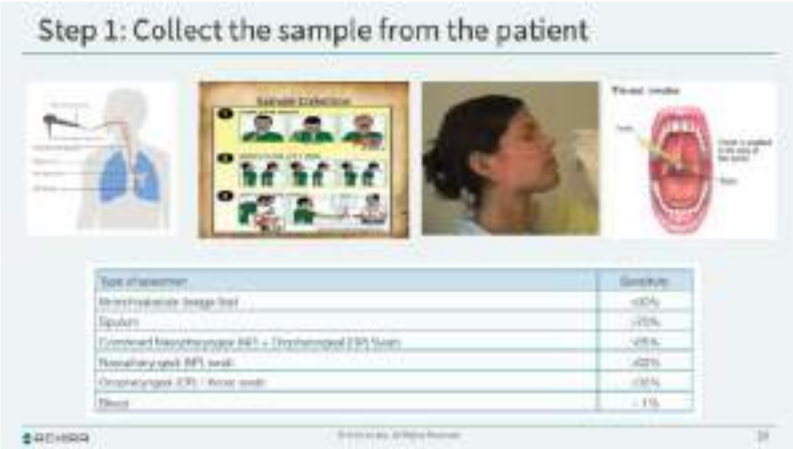
classify those 100 of them as negative, ten false negative. Of the 900 people that don't have Covid you classify 850 people correctly as being negative but you classify also 50 of them as falsely positive. No diagnostic test is perfect as you could imagine and you always have these kinds of tables that you would do on a population study. Definitions of sensitivity and specificity like here quite simple to understand, 90/(90+10) that is 90% sensitivity and specificity really is how many people you correctly classify as being negative, that is 850/(850+50) that is 94% specificity. The ideal tests would have say, 95% sensitivity and specificity but right now in fact many of the tests of public don't have this kind of performance but when it is a hurry to get something out, lot of test out there on the public don't have this kind of performance. If you give tests enough time then you will get these kind of performance mentioned. Another term that is very important in addition to sensitivity specificity, is something called positive predictive value. As you can see from these numbers, there is a fairly large number of people that are false positive, at a population left, 50 out of a population of 900 think they have Covid, they don't, although the test is 95% specific. So the other important thing is actually something that is positive predict value which is if you are classified as positive what is the chance you actually have the disease, correct and that is different from 90%, to say that actually 90/140 that is closer to 60 or 70%. That is very important specially at low level, if you only have 1% of the population that actually has the disease you could end up with positive predictive value a much lower than 90%. So this is very important for planners and epidemiologists and so on to understand the value of a positive test.



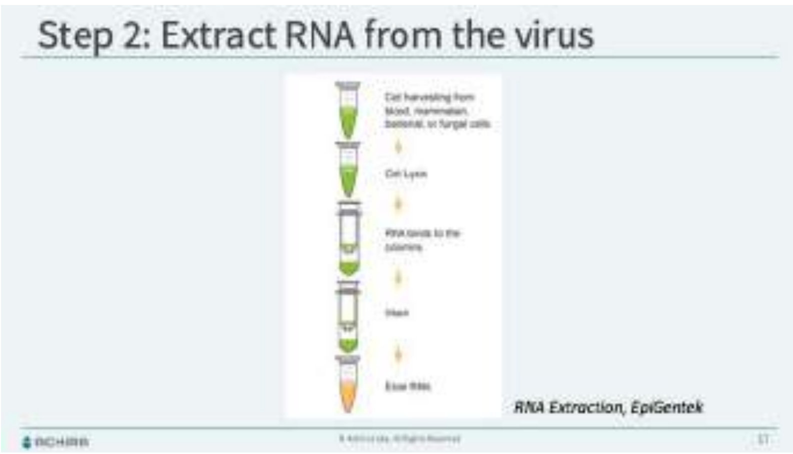
So let us go to a little bit more technical detail now about how we would actually design one of these molecular tests. Let us assume that you want a very sensitive early detection to happen, correct. So you want to pick a gene or set of genes that you would like to test. So here I have a very condensed view of the genome of the Covid. So you have about 30000 base pairs and here shown 5'-AUCGGCCCUUAAGG, some random sequence just to show you how that should be arranged inside that.

What people have found, so now Corona virus cases have been studied for 15 years and quite a people know, as I said they share many of these features, they share this spike protein, they share this share is M protein they share this E protein and so on. So might decide that you might actually target let us say this spike protein. You want to detect the gene for this spike protein as your PCR test. You might wanted to do the spike protein, M protein and E protein tests. So some of the good PCR tests actually are trying to detect all three of them, not one of them. If our target any one of them, the next thing that you do is actually design a molecular assay, do that and as I said earlier, the way to do this is by using a very standard PCR kind of chemistry, there is a variant called TaqMan Chemistry for these kind of assays where you have primer as I showed here. So this is your original strum and a small detail I missed is that you have to convert the RNA into DNA. once you do that you have this strand of DNA and you have this priming sequences shown here. You have to forward a reverse primer that is actually bind to the DNA and you have also these TaqMan probe find somewhere in the middle of that and we will come to that. The sequences of these primers released by the US-CDC, China and Germany. This is just to give you an idea. This is something honestly that anybody with a computer sitting at home could actually generate their own primers. It is not that difficulty with sort of bio-informatic tools that are available to us today. It is about finding a sequence that binds very specifically to part of your gene and then let the DNA polymer do the rest of the job built that gene all over. So these are the three primers were released by the US-CTC and they took back this one actually and it has been not a very good one and causing some false positive results. They are sticking with N1 and N2. You can see that people are used to genes, so the US-CTC is recommending N-gene, Germany is recommending E-gene, N-gene and the RdRpg. So there is different way do the same thing and all comes back to which of the genes and the virus you want to amplify, 1 or 2 or 3 or all of them together. So that is what is done. RT-PCR actually stands for Reverse Transcription Polymerized Chain Reaction, as I mentioned to you earlier, you actually starts with an RNA and not a DNA. You need this small step of actually making the RNA into DNA that is called reverse transcription. So what you

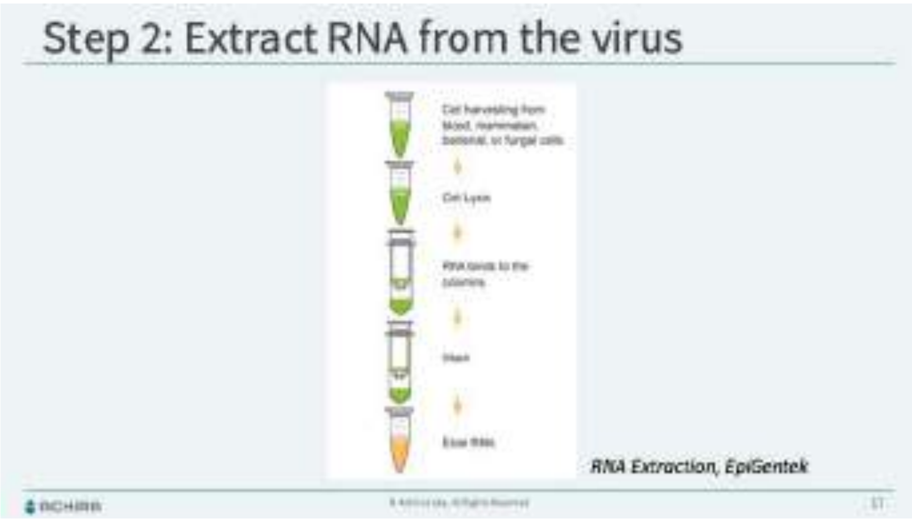




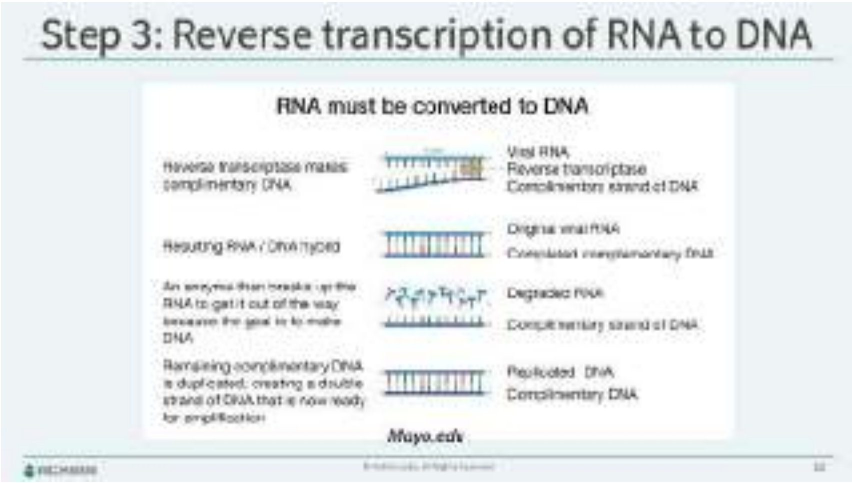
do is you first collect the sample from the patient, then you extract the virus from that sample, then you convert this viral RNA to DNA, then you amplify the DNA as I said earlier and that is converted into a fluorescent signal which I will tell you a little bit, then you analyze those results to tell how much virus is actually inside the patients sample. Look at each of these steps a little more closely. This is something very very important and I am not talked about it much. How you collect sample from patients. Here I have four different sport from which you can collect samples for Covid-19. The first one here is called the bronchoalveolar lavage. Sounds a little painful basically but you have to stick a tube inside somebody's lungs and pull out that fluid which is humiliating especially if the patient is in ICU and so on, imagine that this is the only way to get the sample from them. This is bronchalveolar lavage. The other is sputum. Sputum is basically getting people to cough out from their lungs the sputum .Then you have nasopharyngeal (NP) swab, basically insert swab on someone's nose and you collect samples from there and you have



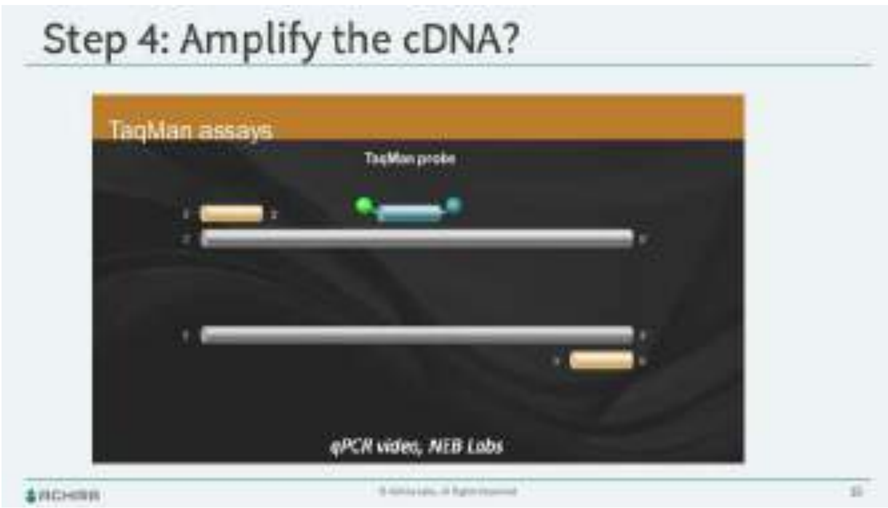
oral swab which is the easiest thing, you have to stick a swab into somebody's mouth and the back of the mouth might contain some virus and you pick it up. So, one of the important point to not here is these swabs are special purpose designs, they are not like the ones you normally use. These swabs would very drizzling and they actually have the ability to pick up as much viruses as it can. Even something like the swab has to be optimized, you can't just use any material for it. It is important what the swab is and how it stands. In one of the slid here, it was only a couple of companies in the world actually making this swab and you can imagine they are completely run out of them. So one important point I would like to make in this table, this is from an actual RT-PCR test that has been performed at our clinic. Depending on the sample that you take the sensitivity of the test actually changes. This is very very very important because what it says is that you might have the best test in the world amplifying the gene of doing very sensitive detection and so on, but if you messed up in terms of how you collect the sample then no good test can save you. This is what is called a pre-analytical error. So you can see the Bronchoalveolar lavage ..... because it is all the way to the lungs has the highest sensitivity and the oral swab actually has quite poor sensitivity >32%. So it is very important in terms of how you take swabs from patients, this is something that is being done from people's homes, camps and wherever training people to do it properly is also very very important.



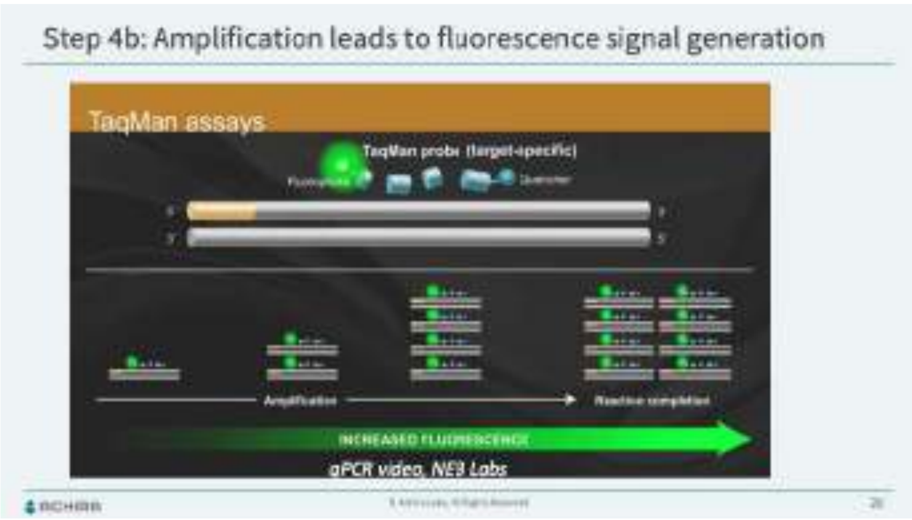
The next step after you collect that swab is you put it into some medium which actually inactivate the virus immediately that is obviously very important because it is a very infectious sample and from that medium, you need to extract the RNA. So what that means is you have to break open all the cells there including the human cells, viral cells etc.,

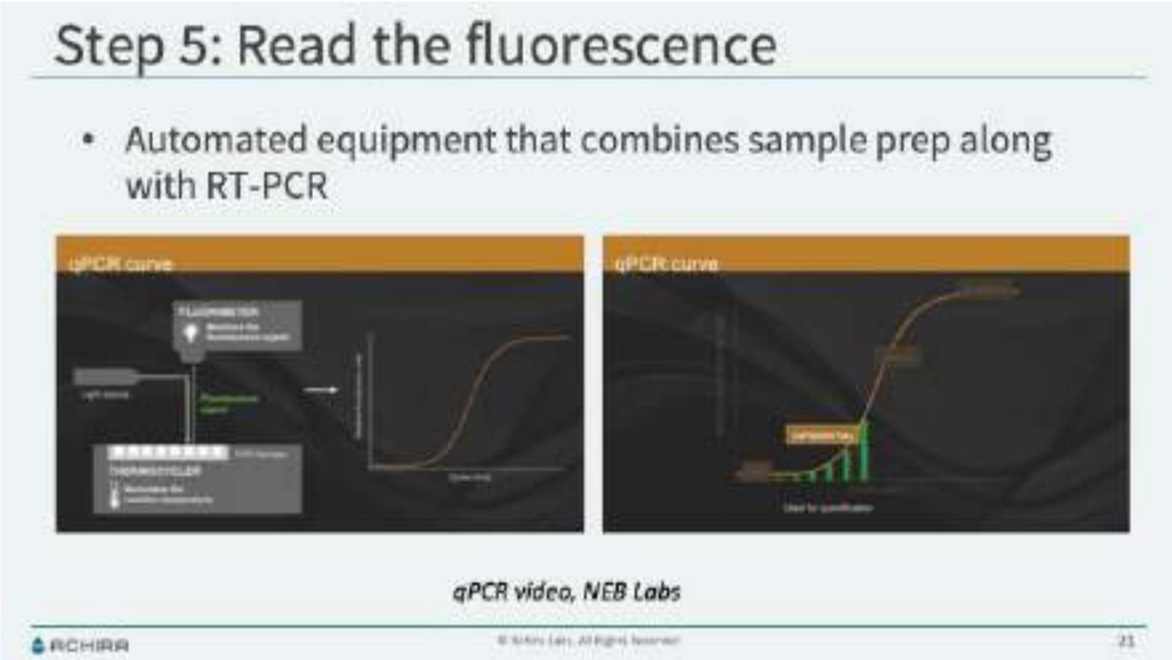


that is called lysis in cells, so you break open all of that and then release the RNA and you release not just the RNA, you release DNA and all sorts of things, you might have a bunch of human cells there that will release it's own DNA. There are these columns that actually will bind very specifically to the RNA from the virus as shown here and then you actually wash of all of the other stuff which might be various contaminants, cellular debris and so on and you wash it off and you elude or remove the RNA rather from that column and that is your starting material for the PCR. These are very very important steps and these are done in a large lab in a very automated way where you have the liquid handling robots basically doing these sequence of steps and actually producing this eluted RNA.

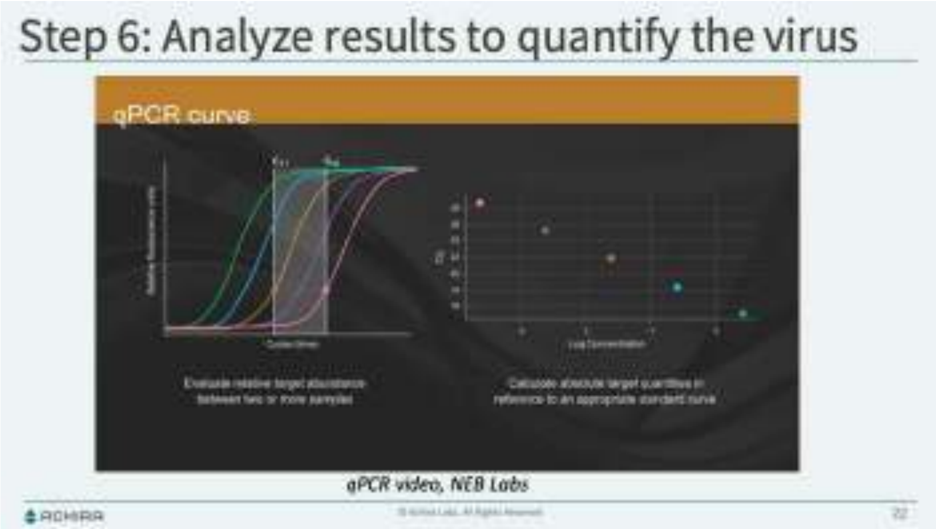


The next thing that you do is actually like as I said earlier, run these TaqMan assays and it is quite simple as I said earlier you have to reverse transcribe the viral RNA to DNA and then run this amplification reaction. The important thing to note here is that in addition to these primers shown here, you also have this TaqMan probes. TaqMan probe is a very special molecule, it has a fluorescent marker at one end that is something called quencher at the other end. So when it is in its normal stage, it is not fluorescent, because quencher actually prevents this molecule from fluorescent. But when you run this polymerization reaction, what happens is that the DNA polymerise which is the molecule that actually makes your DNA and there is a special something called Taq polymers that is used over here, it is a heat sensitive polymerise that comes from a special thermos of particles that is found in a hot spring many years ago it is an important molecule because it functions at high temperatures unlike polymerizations in our own body. But what it does is as the polymerise form this complementary strand of DNA. It leaves of this fluorescent molecule creating fluorescence and as you amplify right now 1 to 2 into 4 to 8 shown here you keep increasing this amount of fluorescence. That is very very important and this amplifier product where fluorescence can be detected by an instrument, there is thermo cycler and a fluorimeter, combination of these two can actually pick up the fluorescence and the fluorescence has this S shaped kind of

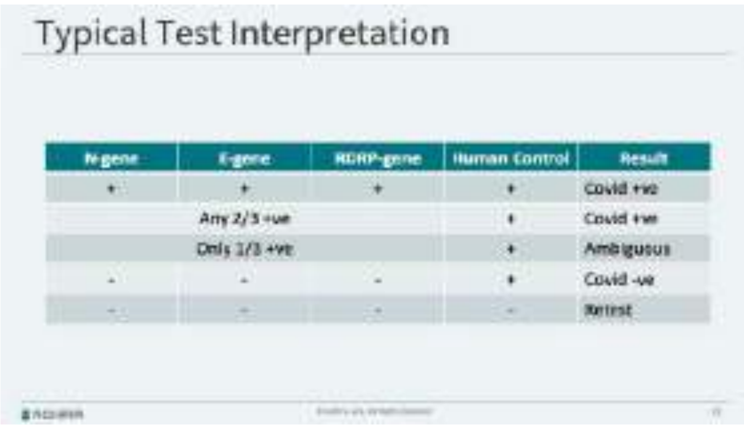




signal and there is a kind of a lag face, an exponential growth face and eventually flattops. So all of these is done automatically so what you do actually is run a number of cycles where actually you do a combination of re-nurturing and annealing DNA means is the DNA actually its double standard form at a low temperature i.e. 50-60 degree Celsius is heated up to 95 when the bubble standard form separates in to single standard form and that allows you to then actually create more and more templates which you can then anneal and copy as you go along. This is actually few RT-PCR term and what you do when you are setting up these instruments is actually you make certain calibrations curve where you have put in different number of virus copies. So you artificially spike in let us say 10, 1000, 10000 virus copies and each of those will have a different float that looks something like this. You can imagine one with the lowest concentration of virus will actually take the longest number of cycles to amplify where as the one with the highest number of viruses particle to start with will amplify quite fast. In between you have the intermediate concentrations. You can use that to make a calibration curve like this. So, when you run an unknown sample that will give you some shape like right here that will allow you to say how many copies of the virus were in that ......



This is the quantitative PCR reaction and this is how you use a calibration curve and then calculate how many virus copies there are inside a know patients sample. So this is a very typical test interpretation let us say that you have a test looking for N-gene, E-gene and the RDRP-gene. In fact this is a very standard one I think and this is the one being used right now in India, this is RNA dependent, RNA polymerate, it is another viral gene that is present. So if you had all three as positive you would then classify that patient as Covid positive and you would also always run a human control, you know that you are extracting your DNA and RNA correctly.



When more complicated cases are let us say when 2/3 of them as positive and only 1/3 of them are positive, you might come up with some chart like this where when you say 1/3 is positive you might say ambiguous and of course if all three genes are negative gene control positive is a negative result because none of the viral genes are amplified only the human genes which you expect to be from a sample that coming out of a human are positive and if all are negative, then it is a problem with your test protocol and you need to retest.

So this is your very typical molecular tests and how they are interpreted. May be this might be a good point actually pause because next part of the talk is about the immuno acid ....

Prof. Rohit Srivastava: Let me ask you ask you few questions put up by the participants.
Q. Was 1917, 1919 Spanish Flue a Corona virus.
A. I don't believe so, it was a different class influenza.
Q. When you were discussing this slide-12, on Sensitivity, Specificity, Positivity, Negativity, there was a question, is it the same as concordance amongst positive and negative. I don't think the question was complete, I guess, there is another question, within sensitivity 90/140, specificity 850/860.
A. So the way that sensitivity is calculated, may be I will go with the logic again. Sensitivity basically is all of the true positives as measured by some gold standards, right. Let us say in this case a Technician looked at their symptoms, just CT and so on, this person is 100% Covid positive, right and if you know the information, and those hundred patients you run your tests on, how many of them is it picking up, that's sensitivity cases.
Q. How about specificity.
A. I guess specificity is sort of the inverse where people who don't have Covid, same way you have in mind, 900 people in the population that don't have Covid measured again by some gold standards. Key point is these are true, 900 out of true number of negatives, known by some dual standards and you are only classifying 850 of those 900 accurately and you are classifying 50 of them wrongly as being positive although they are negative. So that is where you have specificity comes from, 850/900.

Q. *When you went to this RT-PCR slide, we started talking about the reverse transcription process, there is a question which says how does RT-PCR distinguishes virus RNA from other RNA.*

A. Let us say, the person is infected with three different strains of a virus, may be Covid-19 and some other virus, say common cold. The thing is that you could also extract that RNA, if you have the Covid-19 RNA and the common cold RNA but your primers will be specific only to pick up your Covid-19 genes and not the common cold genes, that is where the specificity arises.

Q. *What type of fluorescence molecules are used in the taqman probe.*

A. There is an entire family of these, again these are all sort of very closely held chemistries made only by few companies in US and China. So there these names like hex, tet, pam etc. at different wavelengths spanning the entire UV based 200 per ...... You have different combinations of taqman dyes and quencher probes and again a great knowledge build in India build out of those companies because certainly it is big problem, so I guess that's going back to the basics. By the way, Rohit, somebody has answered here that one company in Chennai called Kriya Medical is actually started to manufacture these swabs.

Q. *This reverse transcription, what is reverse in it.*

A. What is reverse in it, I guess, you are going from RNA to DNA and so there are enzymes which actually do that in fact there is an enzyme called reverse transcriptase that I am showing you in this slide here. So you have this reverse transcriptase which actually makes DNA from RNA and the reason that is important to do is that all of these chemistries work very nicely for DNA so this sort of any annealing denaturing chemistry is work very nicely for DNA and hence it is important to go from RNA to DNA rather than like doing it directly.

Q. *There is lot of questions around this fact that if the virus mutates what will happen to the RT-PCR tests. You have to change something in that.*

A. That is a very good question, I think the short answer to that question is if it doesn't mutate too much, you probably will be fine and but if there are significant changes and you happen to be picking up that gene, let us say the N-protein gene of mutates in fact by the way it is much more likely that the spike protein mutates, it is well known right now that the spike protein is very very variable and that is the smart part of the virus in some sense that is continuously figuring out and optimizing itself and so which is probably why many of the PCR tests are going for the more conserved genes like the N and EG gene but even those could mutate. These viruses mutate every cycle. So it is important to keep track of it, I think there are few genomes now published from India by the way. I was hoping to share some of that but it was not enough time but it will be important to keep track of that through sequencing studies and if there are significant changes coming and those will get published and uploaded into this NCBI database, then you have to change your primers effectively to kind of catch those changes.

Q. *How easy is it to change primers.*

A. I think it is quite easy, probably the more difficult part is knowing when the virus has mutated and how many strains there are and that kind of thing is probably more difficult to actually know. But in principle doing the primers for someone who is experienced at this is quite straight forward.

Q. *I was also hearing that the virus has already started mutating, so we are seeing different viruses and sequences of the virus now. There was a study from Pune which has identified* *four or five of these which one is the prominent one which is showing up in all samples but there are other ones as well.*

There are other questions, some of them will come to when you start discussing the antibodies and their testing. The question on the RT-PCR, does sensitivity by source of sample which is nasal or oral meaning more PCR cycles can compensate.

A. That is a very good question, the answer is that not beyond a point so for instance the number of cycles that is commonly accepted as a sort of upper limit is about 37 or 38. If you do more cycles, you have the risk of amplifying other things which are contaminants and so on and so that is the kind of quite a strict number of cycles there so people would not if they don't see the virus and say 37 cycles you would not go beyond that.

Prof. Rohit Srivastava: A question from my side: you talked about this RT-PCR, there is also something called RT-RT-PCR, right, the room temperature one, so what is that or the lamp assay, now proposed as an alternative.

A. I purposely didn't talk about that so that I do not confuse people too much. RT-PCR I talked about is, you could call it the reference standard of the most mature technology and in fact nearly all the labs that we all know are running this technology, so I chose talk about, but what Rohit talked about the LAMP method, it is called the loop-mediated isothermal amplification. That is a very interesting technology that does not involve thermo cycling and thermo cycling means you need more complicated instrumentation to keep maintaining these two different temperatures, whereas in LAMP you could amplify by just keeping it say 60 degree Celsius. So people are actively looking at LAMP to make these tests also and to my knowledge I don't know how many commercial LAMP tests are already out but there certainly are going to be some coming in the next few months because it could be made a lot simpler with LAMP.

Q. *We are also seeing many of these and the reason I asked this question was that you are into the same diagnostics and we are seeing several companies now propose a LAMP assay , you know an affordable LAMP device because an RT-PCR costs about three and half lakh rupees. So it may not be feasible to put an RT-PCR in all of these primary health care centres, that could be a way forward.*

A. Absolutely Rohit, by the way the RT-PCR by the way is nothing less that Rs.10-12 lakhs.

P*rof. Rohit Srivastava: I know, I was thinking of really cheap version you could get.*

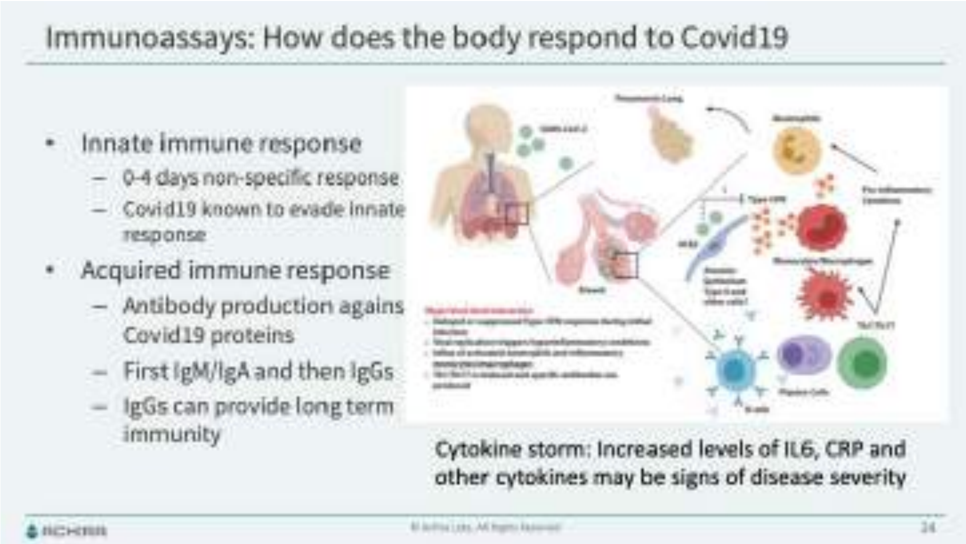
A. You are absolutely right, I think if you could get a thermo cycler or a LAMP reaction going, nothing like it ideally a multiplexed lamp that is able to pick up two or three of these genes would be great in the Indian context as a fast and quick and dirty amplification and as a nucleic acid test.

Q. *Is a normal PCR machine is able to amplify Covid-19 RNA.*

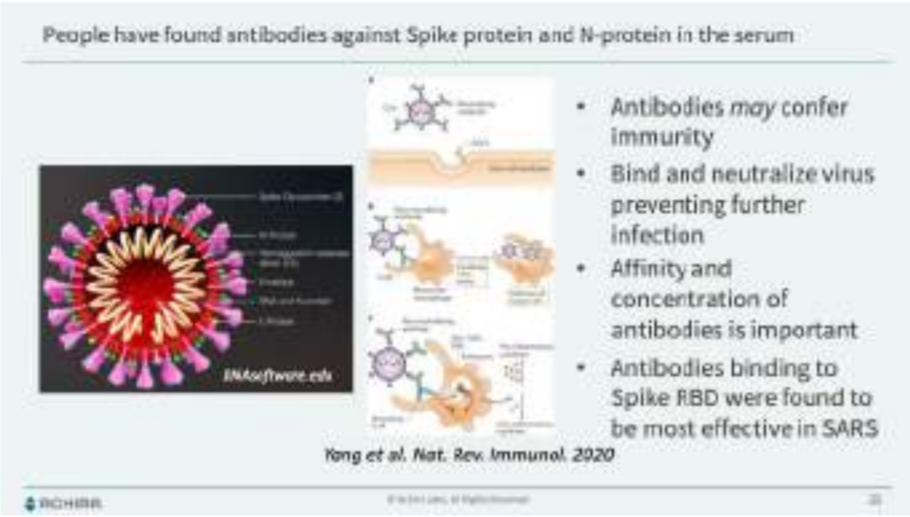
A. A normal machine can amplify it but it cannot do a quantitative PCR. the whole point about a qPCR what I showed here is that you can actually get this sort of a profile. This S-shaped profile which is important to quantify the number of virus copies that exist. You can't do that with a regular thermo cycler or a regular PCR machine, that is the only endpoint, you can't keep measuring at every point.

Prof. Rohit Srivastava: There are several questions which you can answer later, but now I think you can go back to your lecture presentation.

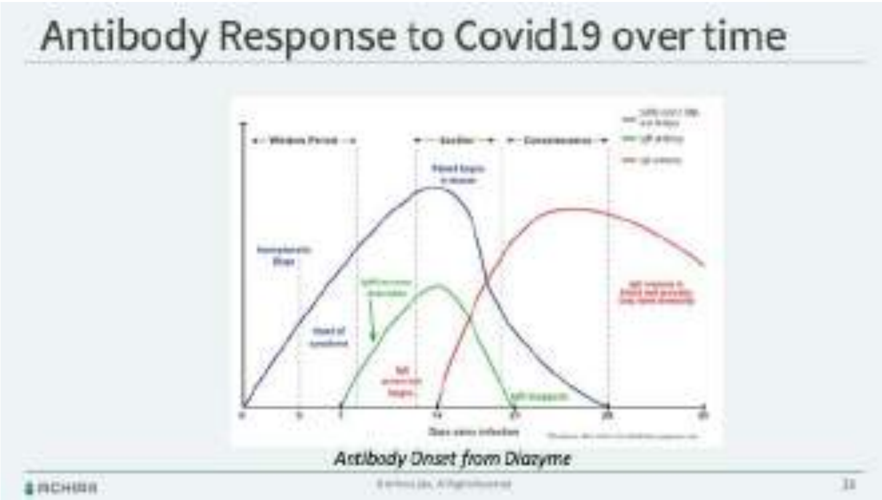
Dr. Dendukuri: Now, I will move to the immunoassay part. We just went to the molecular and now were are going to the immunoassay protein test. First of all it is important to know a little bit about the immune response in the body, there is something called the innate immune response and then there is something called the acquired immune response. The inner immune response is the first thing your body does right like so even your skin or other protective mucosal barriers all of this s part of that and it prevents virus or other known bacteria or other things from entering your body and even when they do happen to enter there are sort of non-specific things that happen to where you know bugs are chewed up and so on so that is all part of your innate response. Now what is known by the way is that this covid-19 is obviously very clever virus and is able to evade the innate immune response and that is an important part if it is being so effective it is actually able to get away from your standard immune response, which is why let us say somebody you know passes a cold in a week or so they are not able to do that with covid because of its ability to evade this and some of these things are honestly being understood as we speak. People don't know exactly why but it is able to evade what is called the IfN gama response that is seen during initial infection, but after that you have the acquired response where your body is figuring out what this virus is you know that it has got this spike protein, it has got this N-protein and your body starts generating antibodies and antibodies



are very specific molecules that are made by B-cells in your body that actually bind to these viral antigens. So antibody binds to antigen, antigen comes from the virus. So your body will start making the antibodies against very specific viral antigens which could be the N protein, it could be the S protein, it could be E protein and it could be any of these. So your body starts making antibodies against all of these things and like I said earlier what the body does actually is it first start making IgM and actually also in this case some thing called IgA so these come on first and then effectively your body is optimizing its immune response and once it kind of understands effectively the virus better, you than get this IgG which is shown here in red. So the IgM is in green and IgG is in red so both of these are part of your acquired immune response the IgM as I said earlier goes away and the IgG stays on typically. Now I am coming back to this slide, I think I put a picture of the virus here again just to mention to you that you have got all of these proteins right and the virus buy the way we gets chewed up inside your body. So it releases all of its constituent proteins inside your body so your body is able to sample the different parts of the virus and generate antibodies against even something inside here like the N protein and because there is a lot of this N protein become a favourite you could say to actually make and you will see a lot of antibodies against the N protein. One thing I would like to mention about antibodies which is very important here in the context of immunity and such questions, so here on top I am showing you a picture of ideally what we would like an antibody to do, so this neutralizing

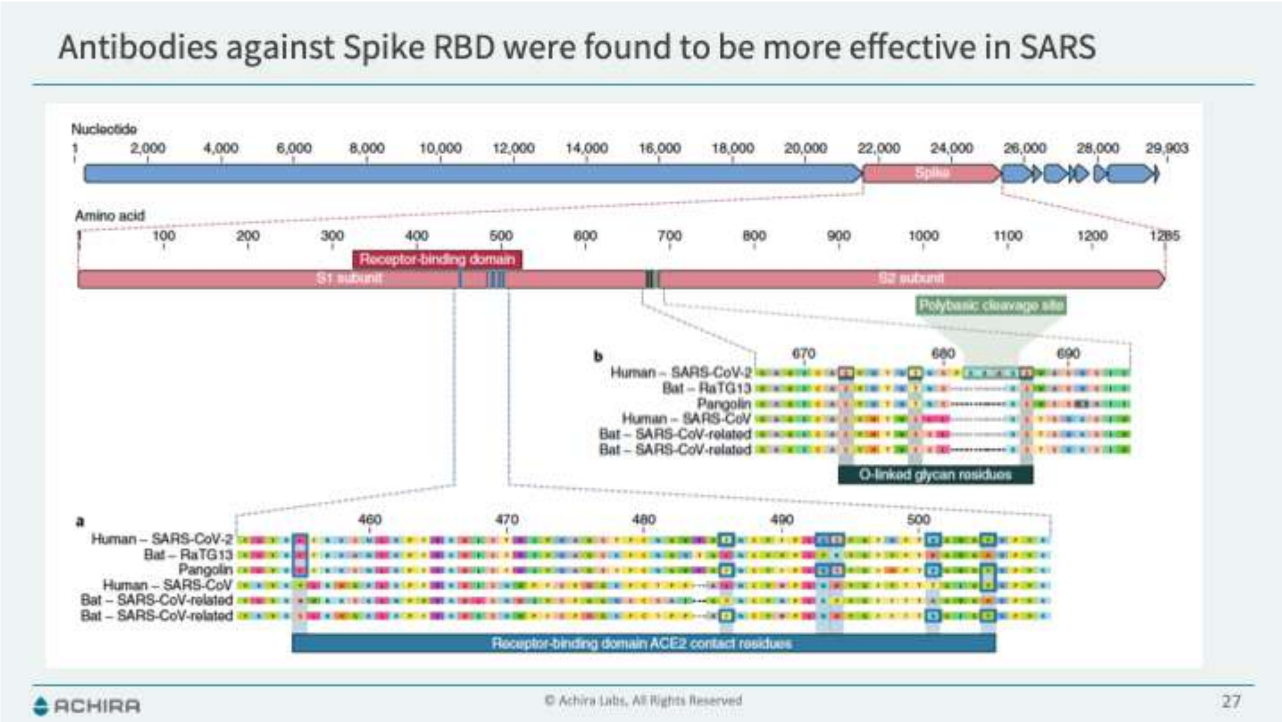


antibody as the name indicates will bind let us say to this all the spikes on a certain virus and prevent it from binding to the ACE2. This is what you would hope the antibody would do and that actually would count as conferring immunity but what is not known right now is if this what is exactly happening. We are hearing stories of people getting re-infected and so on and there are known cases in past where you have things where antibodies are generated but not enough of them are generated or they don't have enough affinity, affinity is simply how strongly the antibody will bind to say the spike protein. So if your antibody exists but it is not strongly binding enough that might not be good enough to actually give you immunity so there are all these second and third order question that need to be answered. One thing that is interesting from the literature is that the antibodies binding to the spike protein receptor binding domain RbD that is the part of the spike protein that binds to the ACE2 in your cells were found to be the most effective in cells and this is not surprising in some sense because that is what the virus is using to bind to your cells, so if your body is able to generate an antibody against that receptor binding domain it is going to be more likely to prevent the covid from binding to you the least so these kind of questions again are being answered in more detail as we speak.

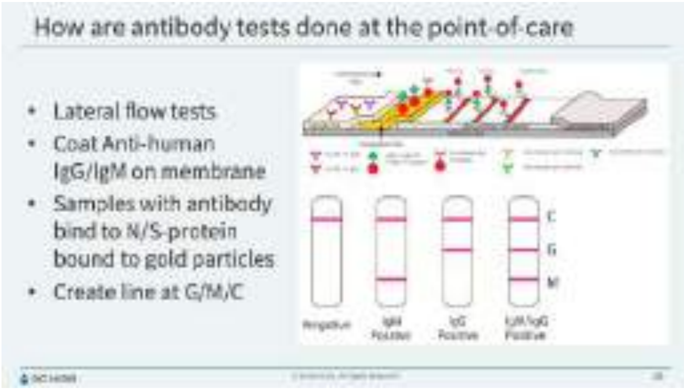


Antibodies against Spike RBD were found to be more effective in SARS. We spoke about this a bit, but I want to repeat this point again so here is actually a view of the spike protein.

This is a view of the genome again I talked about earlier about 30000 base pairs and shown here in pink is the spike protein. So the spike protein actually has about 1200 amino acids

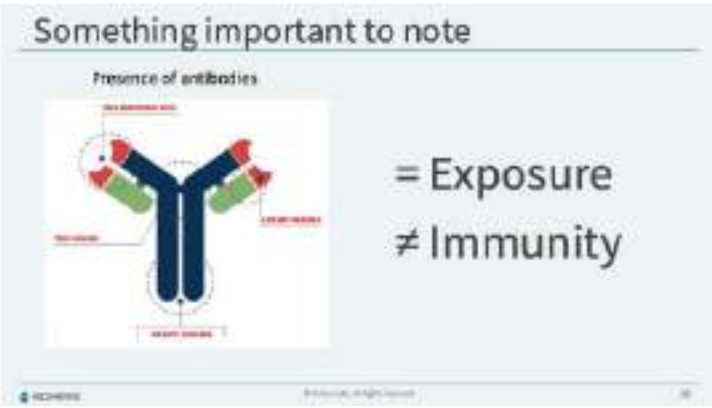


so small detail that I am skipping here is you are going from nucleotides to proteins here and every three nucleotides effectively makes one amino acid so that is why you have a reduction in number here but you ignore that for a second you have 1200 amino acids making this spike protein and in fact as you all know there is a lot of conspiracy theories going on right now about where this virus is emerged from and was it man-made and so on and so forth and one of the strongest pieces of evidence that it is not man-made, it is actually coming from the spike protein and I think the most experienced biologists believe that this is not man-made because when they study this spike protein very closely what they have found and I am showing that sequence right here. This is a sequence of amino acids, it reads P, R, R, A, R and if you go back to the table I have showed earlier you can use that to find out exactly which amino acids those are and I can tell you R is arginine and it is a basic amino acid. So it is well know that this is a poly basic cleavage site that is something which has multiple basic amino acids together is actually the virus is using an enzyme in your body called furin to kind of cleave it and allow it to enter your cells. So this particular sequence is very very important and also this receptor bind domain here is very important. These are two in this 1200 amino acids of the S-protein, these two are very critically important to the functioning of the virus and if you see here, there are these blue things receptor binding domain residues, so you can see one, two, three, four, five and six. These six actually come together because this is not a linear here but imagine it folds together like a string these can actually all come much closer to each other and they form a pocket and that pocket actually helps it bind to this ACE2. Now what people have found is that the pocket is very crucial to this virus and it matches exactly with something seen in pangolins, so that is where this whole bat-to-pangolin theory has come from, that is a combination of a bat and a pangolin virus especially this receptor binding domain which gives it this ability to bind very nicely to ace 2 can't have been created by man effectively. This needs to explore parameter space of such a large amount that you cannot imagine human experiments effectively coming up with this. It is only natural selection that could come up with this combination of nice receptor bind pocket that was not predicted previously by say computation. So this is the short answer to why people believe this is not a man-made virus. But any way we will come back to our diagnostics here for a second. So I think these receptor binding domains again even from an antibody point of view are very important, you want your antibody to go and bind to these very same molecules so that it gives it that ability to block the virus effectively. So how would you do this immunoassay. The principle is very simple, you isolate the spike protein or the N protein of the virus and that's what's shown here as capture antigen so that is actually coated on a surface on a plate here so this is an ELISA plate here on the right and on the bottom surface of this you coat this N protein or the S protein, now as your body is actually recognizing these things, a patient that is actually been exposed to the virus will have antibodies inside them and these antibodies are typically shown as these y-shaped molecules. These antibodies will actually then bind very specifically to that spike protein let us say this here and then you have another secondary antibody which has got an enzyme on it which produces a colour and that is simply so that you can actually detect this binding event so this antibody recognizes this antibody (see the slide) and then produces a colour change so the more blue you are the more amount of antibody you have in this plate and that is actually read by some spectrophotometer and then you can say how much IgG or IgM so these molecules could be either IgG or IgM and you could actually quantify this on an ELISA plate reaction like this, so just again what you need as the reagents for this test are actually the viral proteins the spiked protein or the N protein and these are made in the lab by effectively taking again the cDNA that is the DNA of the virus putting it inside an e-coli or an insect or some other species and actually culturing it in the lab and making large amounts of the viral protein without actually needing the virus itself. So this is a very standard technique that is used in molecular biology and you want to make large amount of protein so that is what people are doing and there are large number of companies out there already making these S and N proteins which have been made in E. coli or something and they are supplying them to people who want to make tests.

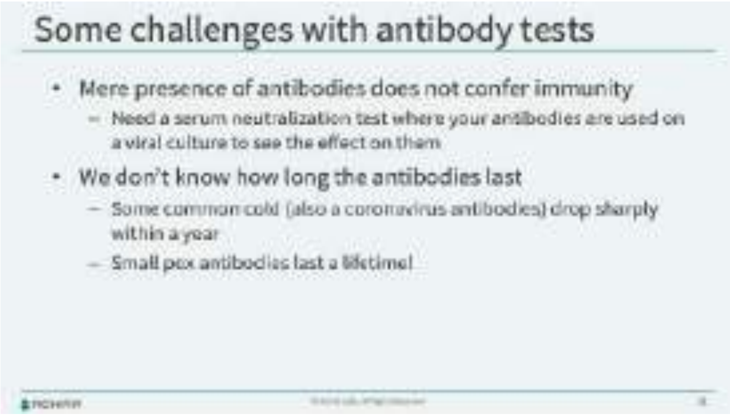


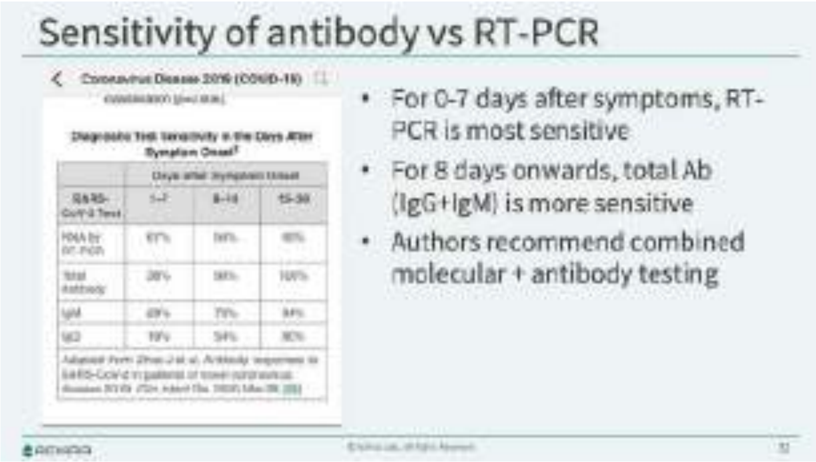
The other kind of tests that has got a lot of attention is the rapid tests and the rapid tests obviously have a lot of value especially in the Indian context because they can be done very simply at home by a relatively untrained operator with a finger stick of blood so that is why people are rightly attracted to the idea of rapid tests, they don't need instruments also. The rapid tests also work on a similar principle to the ELISA, you basically have this N-protein or the S-protein of the virus which is coated with some dye and that dye is usually some gold particle that shows up as pink and then you add your sample there your sample contains antibody which will bind to this N or S protein because you have antibodies against it and that complex migrates downstream where it bind to this anti-human IgG, anti-human IgM and produces a line like this so very much like the home pregnancy test. So the components of the ELISA and the rapid tests are the same you nee the spike protein or the N protein and you need the anti-human IgG and the anti-human IgM and that creates a line and in fact you could do some nice thing where you say it is only IgM positive, may be it is an early infection and in it is IgM and IgG you could say that it is a 14-15 day infection, if it is only IgG, you could say that you have passed the infection and you have retained it. This is how typically people do this and that there are some complications again with covid and that in theory at least would be how these tests would work.

Here is the important point, I think right now people don't know if exposure to the virus actually means you have acquired immunity, for most other viruses like that is true but with covid-19 there is a lot of confusion and doubt about this and hence the fear that just because you have been exposed and just because you have generated antibodies it does not mean that you have actually acquired immunity. This is really, if I had to say one point in this presentation that you should all take away that is all that is the most important point that exposure not necessarily equal to immunity and at this point we don't know, may be it does but we don't know, there are lot of details we don't know at this point. So how do we actually deal with that, how do

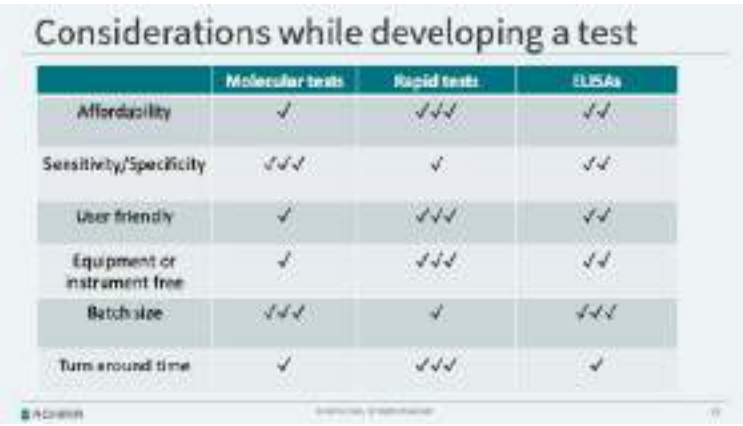


we improve these antibody tests? So the mere presence of the antibodies does not confer immunity. So what actually helps you understand that and this is done in a lab and it can't be done routinely right now is something called a serum neutralization test where you collect the antibodies from a patient and then you grow the virus in a culture and you see if those antibodies are actually able to neutralize the virus which as you can imagine is some sort of really proof-of-the-pudding that your antibodies are actually getting rid of the virus. But this is obviously a test that cannot be done very easily in a widespread way but lot of researchers are doing studies like this in labs right now to determine exactly which antibodies confer this neutralization which is the key point in terms of being able to get immunity and the other thing we don't know is how long the antibodies last. So with these corona viruses and even with SARS people have seen that unlike let us say smallpox where once we have all been vaccinated it lasts a life time literally 90 years or so but with these corona viruses it seems like these IgG levels rise, then drop and then they get sort of insignificant levels after few years and may be for some people it might be a few months we don't know all these question, so how long does the immunity actually lasts even if you have it and unless we know that again, the same question comes back that can you give this immunity passport when you don't know how long the immunity lasts. So these are some of the challenges that need to be solved with antibody tests and being able to draw conclusion that they actually give you ability. So what is the summary of all this, I would say in some sense this is a study in China where they used RT-PCR and you can actually see the sensitivity even from day one to seven is 67% is





not that great honestly for RT-PCR and again these are tests that have been developed in a hurry and so on they are probably be getting better and better as we speak but the interesting thing to take away from this table is that they when they measure the antibody which is the IgG plus IgM especially after day eight they got good sensitivities by measuring antibodies. In fact as the body probably started clearing the virus, the sensitivity by RT-PCR started dropping but you had really good sensitivity by antibody, so right now what you can say is an antibody test done well can tell you whether somebody has got the virus has been exposed to the virus but it cannot tell you about the immunity at this point. So the authors recommend, I think it is become sort of a lot of people who are experts are saying that some combination of PCR and antibody tests is the ideal protocol going forward to determine all the answers that we need as a society.



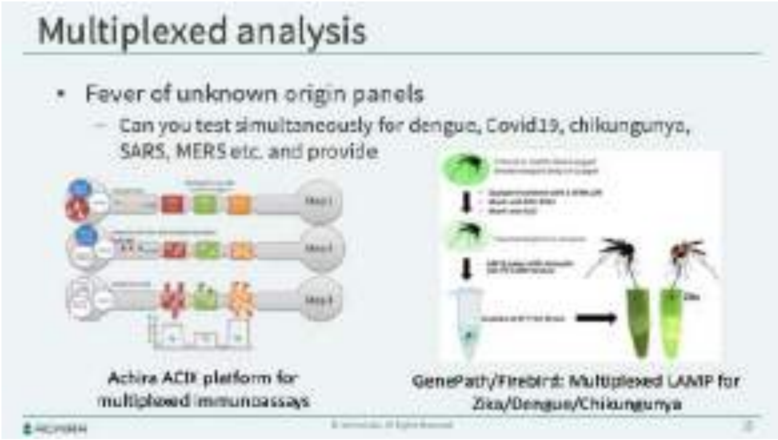
So here is a table to quickly understand, I guess all of these tests against each other how they stack up so affordability, we want this to be really cheap so molecular test don't score very well there, the RT-PCRs are expensive, they are Rs.4500/-

each in India and even the reagents can be quite expensive and on the other hand rapid tests score high because they are quite cheap and you can make them in the millions quite fast. ELISAs are somewhere in between, sensitivity, specificity obviously like I have mentioned at the beginning of my talk the molecular tests are the best especially early on in the infection, they can catch it better than anything else. Rapid tests not so good in terms of being user friendly, again rapid test score because they could be done by say, Asha Workers or not so trained technicians out in the field could run these, a molecular test need fancy labs and you want to protect from contamination and all these kind of things, making it equipment or instrument free that is again something the rapid test score very well on because you could just read it visually the RT-PCR obviously needs quite a fancy equipment to run but there are some other considerations like batch size like you in a context like this you want to be running thousands and tens of thousands of tests, now things like ELISAs and molecular tests have very nice automated instruments built to run this like factory production, literally thousands of tests a day automated like 24/7, where as rapid tests you got to have that person who is trained who has got to go, take your samples etc. etc., so that batching is a little bit more difficult to imagine happening there, around time these can be as fast as 15 minutes so they score well, these tests need at least an hour if not more. So there is a lot of trade-offs here which I have tried to summarize in this table.

The next thing that I want to talk about is just some important trends going forward. Ideally you want to combine best of both worlds and Rohit already talked about lamp but if you could do basically LAMP or something which enables point of care PCR tests, so you don't need a fancy lab but you can do this PCR test and get its sensitivity but in a much more distributed location like a slum or a smaller nursing home or whatever then you would have

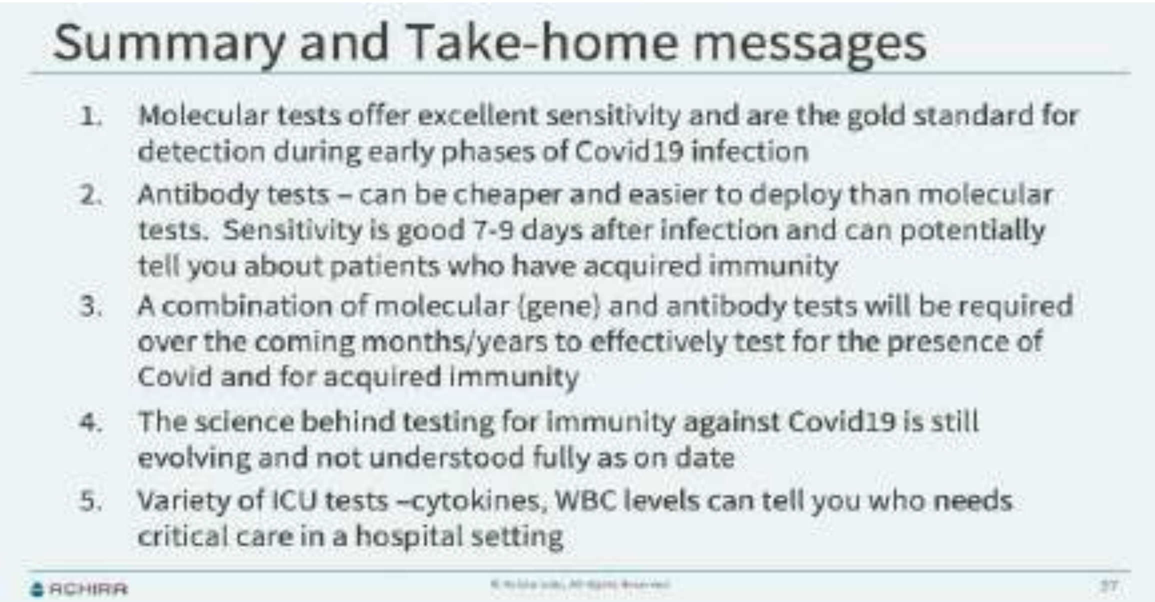
a lot of advantages. The Abbot now, I think many of you probably read this, they have an excellent platform and I would like to make a small point here. It is not like Abbot made this in three months. Abbot now has been around for the last five years detecting influenza in the US. They made a Covid test on that very fast which is pretty incredible but the point to note here is unless you have invested the time and years and effort into making a working platform, this takes honestly a decade to do, then you don't at a time like this suddenly have this platform available to actually do testing. So that is an important point. Here in India we have our own company Molbio Diagnostics, Goa which has the platform called TrueNat and I believe some States are already procuring this which is also a point of care molecular test that can be done without access to very fancy lab facilities. So we have an India company that has got a PCR test that can be point of care.

Coming to my own company, Achira, going forward one of the things that we feel is going to be very important is can you simultaneously test dengue, covid-19, Chickungunya, SARS, etc. sort of a fever of unknown origin panel and you can just imagine that this is going to be very relevant in six months or may be years from now that people have some sort of fever or some sort of overlapping symptoms, they are scared they don't know what it is. Can you do



a multiplexed panel that is simultaneously detect for everything that is exactly the kind of things that we do so we have a multiplex immunoassay platform that could do multiple detections at the same time. So may be can we do all of these together as a kind of thing that we are looking at. We also have other people like there is a company in Pune I know that has a multiplexed lamp where they did zika, dengue, Chikungunya together and this is again something which can bring lamp and multiplexing together for sort of point of care applications. So I think a lot of things to look forward to in terms of new developments. The other important point is that post vaccination even once the vaccine is developed whenever that is, we will have to test whether the vaccine is effective because likely it will work for some people not work for everybody and so on and the only way you will know if the vaccine is working is by measuring again antibodies. So these tests will continue to be important even through that phase once you have developed the vaccine. So I would like to summarize the talk at this point.

Number 1, molecular tests offer excellent sensitivity and are the gold standard for detection especially during the early phases of the Covid-19 infection, so zero to seven days I think nothing better than a molecular test in terms of sensitivity. the antibody test can be cheaper and they can be easier to deploy like the rapid tests the sensitivity is very good if you are talking about seven to nine days and after infection and they can also potentially again I stress that again potentially tell you about patients who have acquired immunity once we get the reagents right going forward. So ideally a combination of the two molecular gene test and the antibody test will be required in the coming months and years to effectively test both for covid presence and for acquired immunity. The science behind testing for immunity is still evolving and not fully understood, so I think WHO actually came out with a statement last week saying we don't know basically know. You have to wait to know when we can say that such and such tests will actually test for immunity we don't yet know. Last thing I would like to mention is this is really about testing for the virus and immunity but in addition to these, there is a whole bunch of other diagnostic tests that are very crucial especially in the ICU setting you have all probably heard of something called the cytokine storm which happens in patients who are critically ill where your body is basically fighting the infection but basically going berserk and being able to test the elevation of these cytokines in people's blood samples doing it fast could help identify critical patients in ICU setting and people who need care urgently. So there is a bunch of other tests like that are also very relevant I would say in the Covid19 testing scenario beyond just testing for virus and immunity. So with that I would stop and pause here and we can take forward the discussion.



Prof. Rohit Srivastava: Thank you Dhananjay, very interesting talk. Let me ask you some questions that have been posed in the Q/A and then I can ask you some of my own questions.
Q. There is a question which says somebody likes your multiple tests that can do multiple causes, the fever test panel that you said. Is this commercially available now.
A. No it is in development stage, that is something that we will have to put a bunch of things together still the hope is that to have something like that in a few months.

Prof. Rohit Srivastava: I think that is a wonderful way forward because many companies are now investing in doing these multiple detection because it might lead to a wider platform technology than what we currently have.

Q. *There is a question that says that we know that viral particles have been detected in other organs like kidney etc., so are there tests to detect virus using different tests that targets other organs. One is can you use blood to blood serum plasma for an antigen based testing.*
A. In theory yes, that you could directly detect the virus but this goes back to a point I made at the beginning of my talk which is that if you only have a few copies of virus around unless you have a tremendously sensitive technique which is able to identify just a few copies of the protein you will not likely pick it up. The DNA, RNA tests are different because of the PCR's ability to amplify the reaction. there are sort of cutting edge protein technologies that are trying to get to these kinds of femtomolar very low concentrations but they are not very widely easily available at this point. So it would be a tricky thing but I think an exciting thing if it worked.

Prof. Rohit Srivastava: I think it is difficult, my perspective is that the virus when it appears in the blood is already too late then, you should have picked it up much earlier. But going back on a different thread here: you talked about antibody based rapid tests. What are these antigen based rapid tests?

A. The antigen based rapid tests will start with the swab samples and try to detect the viral protein directly after lysing the virus, again if you have enough copies of virus. Somebody who has an acute infection or whatever, you might even pick it up like that directly, direct antigen tests.

Prof. Rohit Srivatava: This is something that South Korea tried out and had a lot of success. I had a chat with Dr. Swarup also regarding this and she was very excited that if somebody can make these rapid antigen based tests and these are sensitive and specific to the numbers that is what we want them to be, then this would be the way forward for all these testing kiosks that South Korea did and was able to contain the infection really well.

A. No doubt, if we can demonstrate that performance there is no doubt because now you are directly detecting the virus, you are not disrupting the response of the antibodies, so if you can do that there is no doubt that, that would be very exciting test.

Prof. Rohit Srivastava: May be your company could have a look at it.

A. Absolutely, thank you for the suggestion.

Q. Do the ELISA test and the three strip home test work on the same antibody detection technique, I guess you answered that.

A. Broadly yes.

Q. *In order to test large group of people for Covid-19, is it possible to test 10 people all together, so all of them are negative, you can economize on the test and you can finally isolate the positive, pooling.*

A. I think pooling is something certainly on the molecular tests, it is pooling is already done routinely done in India for blood banking, because when we want to test for HIV, Hepatitis B and C, those tests are also very expensive, so it is often blood bags samples are pooled before being tested. I think 10 at a time is quite common. Now antibody test being pooled is something that I think a little bit more complicated than the molecular testing.

Prof. Rohit Srivastava: I agree. One question I had, you talked about this IgM and IgG which is showing you a long term kind of a response, so is this so if somebody gets and IgG response in the rapid test, does this show a response to other corona virus infection or particularly the Covid19?

A. That is a very important question actually. You need to demonstrate in your testing protocols that it is not doing that in order to say you have a good test and I think these are exactly the kind of things that are probably not being done right now in a hurry to push out products that people are not testing for all these because there are like I showed you earlier, lot of sequence homology in the S-protein, let us say between the earlier SARS virus and the Covid-19, so it is possible that there could be antibodies that are cross-reacting in that case and you don't have to go and this is where it will come down to getting your reagents right, making those reagents very specific to Covid-19 will be the key here.

Prof. Rohit Srivastava: I guess all these antibody based tests and the antigen basis raising the right kind of antibodies, the monoclonal antibodies and their purity is a really crucial thing. Even for the antibody based test you will need anti-human IdP or the anti-human or the anti-human IgM.

A. We are talking about the direct antigen test, but those are quite routinely available and those are not considered problematic reagents. We will have to get the MmS protein right but the human IgG and anti-human IgG are not quite routinely available.

Q. *Strand Life Sciences have a role to play in this using bioinformatics, I guess this will.*

A. Anybody who is, obviously Strand is one of the leading companies in India in terms of doing lab testing now and I guess they develop their own tests and so on and I am sure they would be able to add a lot of value better to them .

Q. *Can we use gene editing techniques targeting the RbD.*

A. Are you referring to CRISPR and so on? I think there are people doing R&D on using CRISPR to do it, so I think the CRISPR which is not clear to me at least yet, right now is whether it can avoid amplification. The painful part in some sense of PCR is like the amplification. If CRISPR is able to avoid amplification and still detect then it would be great but whatever I have seen so far of the CRISPR methods is that they also need the amplification to happen first and then it is sort of CRISPR is used to do the read out which I feel is less exciting but CRISPR has the potential to get rid of the amplification which would be great.

Prof. Rohit Srivastava: You, sitting in some of these committees, we have come across several companies which have put forward this CRISPR based tests and hopefully one of them will have solutions soon. There is another question to you, your company has been working a lot with micro fluidics, you have a terrific set up there and how do you make a rapid test on micro fluidic platform?

A. In some sense, the test principle is not going to fundamentally change. You need a surface on which you put antigen or antibody, you need a flow to happen, you need a detection reagent and then you need to pick it up. The way I think about it is you should use microfluidics to do something which lateral flow cannot, because you can't beat a lateral flow at it's own game. Producing cheap tests for IgG an IgM and for doing that on a micro fluidics platform, I don't how much value honestly it will add, but the kind of thing that I suggested earlier being able to do much bigger multiplex panels may be being able to do direct antigen testing by being more sensitive. Those are the areas that I would say if the microfluidics can help that will add true value over and above what already exists.

Prof. Rohit Srivastava: In fact you know, I was thinking Dhananjay, why not do something for the LAMP protocol, combine your micro fluidics with that.

A. Absolutely, that would be a great idea too if you can. I was only thinking about the amino acid right now, but absolutely if you can do a lamp and make a cartridge which can hold a chamber, heat it up at 60, hold it for this.

Prof. Rohit Srivastava: That is the plan that your company should do, in fact explore. There was a question in which somebody asked, some of you know that the antibodies are taken out from a recovered patient, what all parameters are checked before giving it to another patient.

A. This plasma therapy stuff. I should say that I am not a Clinician and I don't want to say something which is slightly controversial and evolving topic. So I would prefer to defer on that question.

Prof. Rohit Srivastava: Going back again to the cost of these tests, right now the RT-PCR tests as you said are costing about Rs.4500/- and somebody is asking is these rapid tests are available at affordable rates in India.

A. Probably the price at which the rapid tests are being sold to the labs would be on the order of Rs.500 to 600 rupees right now and so to pay to the patient it might be say Rs.1000 or 1500 rupees, it should be a lot lower honestly. there is a lot of commercial activity in this space and you can imagine because of the demands and so there is a lot of market economics which have taken over things. I think ideally we should have a lot cheaper like 100 rupee type testing available from us, but it is little bit of market economics at work right now also and demand-supply shortages.

Prof. Rohit Srivastava: There is a question from Prof. Misra, how would you rate the quality of testing in India compared to that in Western nations.

A. Prof. Misra, why do you want to get me into trouble. I think, honestly anybody who is, I think the ICMR has got great labs, we have got these RT-PCR machine set up and we have got gold standard kits, so I think may the numbers of tests we all feel should go up, but the tests that are going on itself, especially if they have passed all of those strictest standards in terms of measuring their sensitivity, specificity, I see no reason to disbelieve them.

Prof. Rohit Srivastava: All of us are waiting for this Covid-19 to finally go away and we really don't know when it will but how long do you think we are going to see before a vaccine comes up.

A. That is a very controversial question right now and I am sure all of you are following the news, there is a company called Moderna which has promised the US government that they will have a vaccine in two months or something like that. Slightly unproven technology which is basically an mRNA based vaccine, effectively the spike protein that we talked about earlier will be made, you will make that inside your body, train your body to make that spike protein and then the body will respond to that. that is the strategy the US is going after effectively and Moderna company was just given a $483 million emergency grant. It is absolutely crazy but a lot of people in China are also trying and BIRAC is also looking at a number of interesting facts. I don't know enough about the vaccines honestly, I am only commenting and reading other people's stuff.

Prof. Rohit Srivastava: I think that covers everything that people ask you and it was a wonderful talk Dhananjay but more importantly we got a feel of what is happening and then what are the possibilities. Let me once again congratulate you on what your company has been able to do in the past and we hope that you will be able to come out with a much more sensitive, specific and affordable panel that you just described in the near future. Thank you Dhananjay.

Dr. Dhananjay: Thank you, thanks very much Rohit, I appreciate it and thank you for the wonderful moderation.

ALUMNI CENTRE

saturday WEBINAR

INDIA RUNNING OUT OF WATER OR WATER RUNNING OUT OF INDIA?

PROF. T. G. SITHARAM I MAY 9, 2020

Prof. Dr. T. G. Sitharam is the Director, Indian Institute of Technology Guwahati (IITG) and formerly a KSIIDC Chair Professor in the area of Energy and Mechanical Sciences at Indian Institute of Science (IISc), Bengaluru. He is the Chairman, Research Council, CSIR-Central Building Research Institute (CBRI), Roorkee, Honorary Professorial Fellow at University of Wollongong, Australia & Distinguished professor at Hankou University International Innovation Centre, China. He has obtained his Bachelors in Civil Engineering from University of Mysore, Master's in Civil Engineering from Indian Institute of Science; Ph D in Civil Engineering from University of Waterloo, Canada and post-doctoral from University of Texas at Austin, USA. He has guided 31 Ph D students,30 masters students and large number of post-doctoral students.

He was associated with 3 startup companies at IISc. He has executed 150 consulting projects, and has 5 patents, > 500 publications, 12 books to his credit. H-Index is 42 and I-10 index 107 in Google scholar. He is the chief editor of International Journal of Geotechnical earthquake Engineering and Editor-in-Chief of Springer Transactions in Civil and Environmental Engineering.

Lecture at IIT Alumni Centre, Bengaluru on May 9, 2020

Link to the webinar : https://www.youtube.com/watch?v=_fT5oE6HOeE&list=PL0zMQ-70IHlX-df3u2Tto6dkKHCRC6iFL&index=15

IIT ALUMNI CENTRE

saturday WEBINAR

INDIA RUNNING OUT OF WATER OR WATER RUNNING OUT OF INDIA?

PROF. T. G. SITHARAM I MAY 9, 2020

Prof. Shuqing Yang is the associate Professor at School of Civil, Mining and Environment and Engineering, University of Wollongong and director of Coastal Reservoir Research Centre at the University of Wollongong, Australia. He is also one of the founders of International Associational for Coastal Reservoir Research (IACRR). He received his BEng and MEng from China, and PhD from Nanyang Technological University, Singapore. He was a pioneer researcher and designer for the Three-Gorge-dam, China, the largest inland dam in the world.

After that, he has shifted his research from rivers and inland dams to coastal lakes, and he involved a research project of water pollution in Lake Pontchartrain, New Orleans, USA. In Singapore, he started his research on coastal reservoirs which shows that in Singapore the desalination plants and Newater plants are unnecessary if coastal reservoirs are properly designed. He also helped to initiate a coastal reservoir for Shanghai city, one of the largest cities in the world, whose water supply now fully depends on the Qingcaosha coastal reservoir in the Yangtze Estuary.

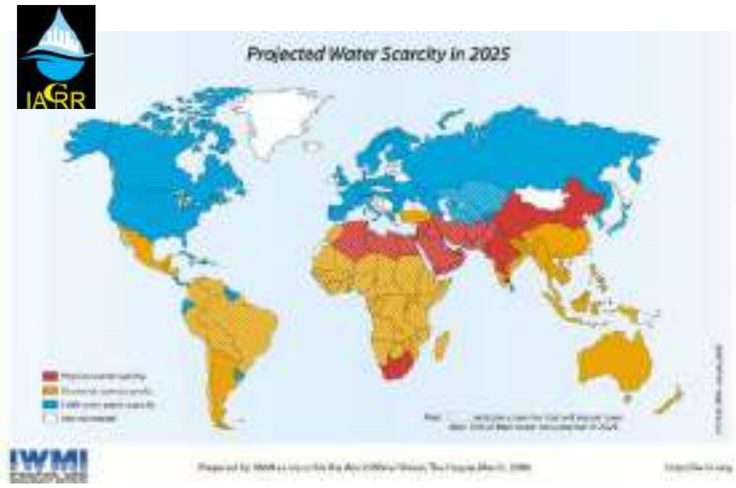
Ashok Kamath: Good evening, I am the Secretary of the IIT Alumni Centre, Bengaluru. We have been hosting this weekly webinars for the past month on every Saturday and very encouraged by the response we have seen. Today we had almost a 1000 people registered to join this webinar. Today's topic is very fascinating. Prof. T.G. Sitharam the Director of IIT Guwahati comes up with the very solid punch line, India is not running out of water in fact water is running out of India. It is time for us to pause and think what that means, I am sure Prof. Sitharam will be able to guide us through all of that. In today's climate, after Covid 19, water is the most important thing and we need to pay attention to it. We have the pleasure of having Prof. Shu-Qing Yang from the University of Wollongong, Australia. Both Prof. Sitharam and Dr. Yang are highly accomplished scholars and they will talk about coastal reservoirs and take us through all the technologies that are there and what we should be doing both in India and around the world would be the theme of today.

Prof. T.G. Sitharam: Good evening to all of you. First of all thanks to IITACB Bengaluru for inviting me to present this webinar. I can see already large number of participants have logged in. I would also like to thank Prof. Shu-Qing Yang from the University of Wollongong, who has joined this session as a moderator all the way from Australia. Thank you so much to all of you for giving this opportunity to deliver a talk on water during this Covid 19 pandemic. I request all of you to stay home and stay safe and maintain social distance and beat the corona virus.

As you all know, water stress has caused countries around the world to consider ways to mitigate the impact of increased population and climate change. Today my talk is on Water Scarcity to Security. The global risk perception survey conducted by 900 recognized experts by the World Economic Forum reports that the highest level of societal impact for the next 10 years will be the water crisis and also we are already seeing large number of movement of people from urban areas because of Covid 19, going to the villages. Our country is a village centric country. We have more than six lakh villages. I will briefly touch upon the

SDG sustainable development goals and India's water resources and that is my punch line "India is not running out of water, actually water is running out of India". That means lot of water is actually joining the ocean during the four months of monsoon. I will also touch upon traditional water harvesting structures, rain water harvesting techniques, underground dams and coastal resevoirs. As you all know, both myself and Shu-Qing started the International Association for Coastal Reservoir Research, registered in Australia, we have a large number of industries and individuals who have joined us to create awareness and I will also show you later, recently even United Nations has also listed in their official document on the topic of coastal reservoir and our first book is also coming up by Elsevier Publications with seven authors within a month's time. I will be presenting some case studies of the coastal reservoir and I will conclude my talk with ideas and innovations on this topic. Sustainable development goals - all the countries in the world have signed to alleviate poverty, the 17 goals, and if you

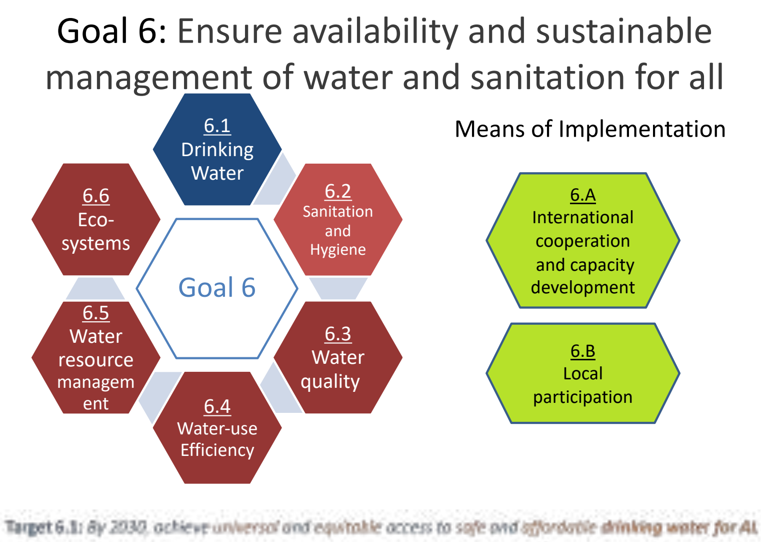
look at it carefully all of them have a tinge of water that is what is basically integration. For these sustainable development goals, actually we have only 10 more years left with us because they have signed the agreement in 2015 and by 2030 we have to fulfil these goals. Most of the States have taken this as a challenge. India, with the target of US $ five trillion economy in 2024, starting with a disastrous Covid 19 affected time, it is very necessary to think very big when seeking to make a difference for the whole India. This transformation would not come or would not be possible with simple modest plans. In this modest planning, we have to include Mission Water and I will tell you that the Mission Water will play a major role in India which is a village centric economy, more than six lakh villages and also lot of industries are in semi-urban areas, particularly the medium and small scale industries are in semi-urban areas. Now we



Interesting to note Coastal areas (both in India and China) only Economic water scarcity!!

are seeing the reverse migration from urban areas to villages at least for the time being, we should wait and watch whether they will come back to our cities. This change can happen only when water is available at plenty, with water energy food nexus in play. So we have to understand the water energy nexus very clearly.

If you look at the goal 6 of the SDG goals, very clearly ensure availability of sustainable management of water and sanitation for all. On 1st of January 2016, the 17 sustainable development goals of 2030 agenda for the sustainable development adopted by the world leaders at a historic UN summit in September 2015 that means we are only left with 10 more years as I told you earlier. The sustainable development goals are a universal call to action to end poverty, protect planet and to ensure that all people enjoy peace and prosperity. So in this water is going to play a major role and this to achieve by 2030 a universal and equitable access to safe and affordable drinking water for all is also a great challenge particularly in India. The



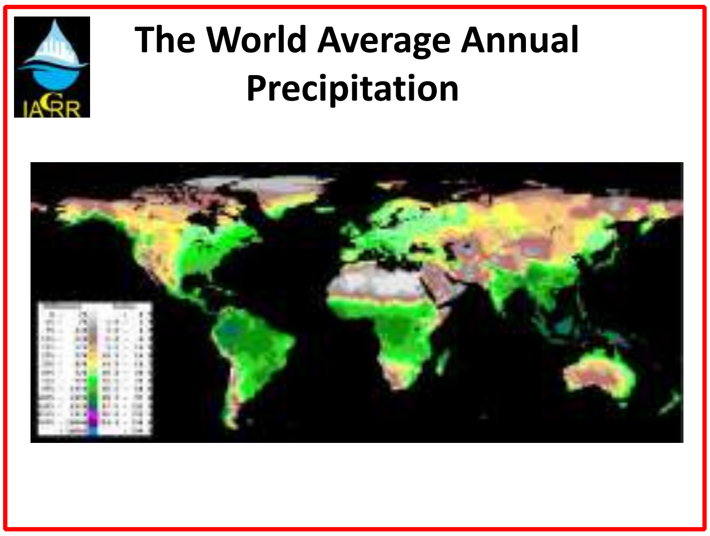
Sustainable Development Goals (SDG)

- Each goal is important in itself and "WATER" is critical –
- SDG 6 - Measures To Overcome Water Shortage

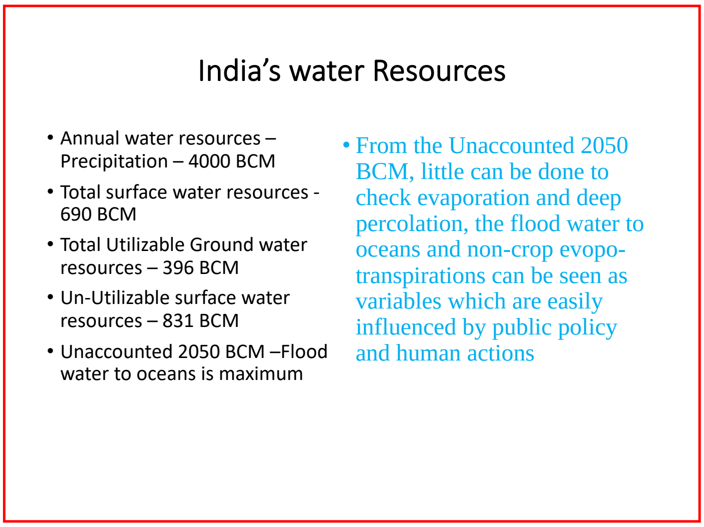
Move from shortage to Water Security

all Member States to develop as soon as practicable ambitious national responses to the overall implementation of this Agenda

role of these Member States is to work together to encourage all member States to develop as soon as practical ambitious national responses to the overall implementation of the agenda of the goal. If you look at it, each goal is important in itself and water is very critical among all these SDG6 and it moves from water shortage to water security. We are hearing almost every day in newspapers till the Covid 19 pandemic, water is running out, Chennai is running out of water and all our cities are running out of water. What I would like to remind you us time immemorial, many of us from small villages and towns in India, we have seen our woman folk carrying water on head but we never realized there is a shortage.



Suddenly when Chennai ran out of water, Bengaluru ran out of water, we are thinking that there is a need for water security, water shortage and we need to do something about it. So we never woke up when there was shortage when our women folk was carrying water on their head, just for a pot of water. Every day they have to walk 10 kms to fetch water. So in this direction, the United Nations member States have taken a practical and ambitious goal of implementing this agenda. So let me take you through the world average annual precipitation. This is a picture which clearly shows you, if you look at the area shown in green, that is where more than thousand millimetres annual average precipitation. So if you can see both China and India, majority of the area in the green sector, which clearly indicates we have thousand millimetre or more rainfall, but projected water scarcity in 2025 by the IWMI shows that in India most of the northern part is shown as red that means basically physical water security and also most of the other portion of the coastal area are in economic water security zone. If you look at China, it is only in economic water security. So what it clearly says is that cost of water becomes an important part of decision making.



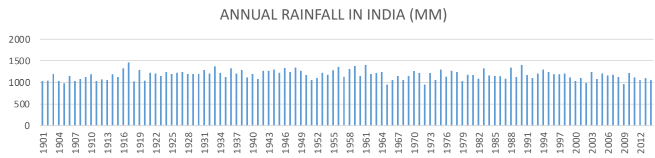
Let me take you through the India's water resources. We have only one source of water that is rain fall. So though the precipitation we receive four thousand billion cubic meters of water and total surface water sources if you count something like 690 million cubic meters of water. So we have unaccounted of almost like 2000 billion cubic meter of water. Where is it going, it is basically flood water. From the unaccounted 2050 BCM, little can be done to check evaporation and deep percolation, the flood water to oceans and non-crop evopo-transpirations can be seen as variables which are easily influenced by public policy and human actions. I will show you some more details as we go along from the unaccounted 2000 billion cubic meter water, what we need to do is to check a little bit of evaporation and deep percolation and then whatever the flood water which is going to the ocean, these are three aspects which actually account to this more than 2000 BCM.

Story of India: We have more than 400 rivers in total with 25 basins, out of that major river systems are seven and if you look at it, the majority of them discharge water to the Bay of

Bengal. Total surface runoff is more than 77%. Indo-gangetic is the third largest discharge in the world (which basically is the area where the IWMI shown entire thing showing red), east and west flowing rivers from Western Ghats where we have large number of rivers which are only 100-150 km long, directly flows into the Arabian sea. The two fantastic drainage systems India has, one is Himalayan and other is Peninsular drainage system. Government of India is aware of these issues so they have started a new water power ministry (ministry of jal Shakti) in 2019. Complements to them, but still we need to do a lot of thing. Also, I will touch upon the river linking issue in a little while.

Story of India

- 400 rivers in total – 25 basins
- Major river systems – 7 – Most of them discharge to Bay of Bengal (total surface runoff 77%)
- Indo-Gangetic -3rd largest discharge in the world
- East and West flowing rivers – Western Ghats
- Himalayan and Peninsular Drainage system
- New JalaShakti (water power) 2019. formerly water resources, river development and Ganga rejuvenation
- River linking



So if you look at the annual rain fall in India this is the picture which shows the data for 1901-2013 here, not even one year we have gone below thousand mm average rainfall. Due to curiosity, I just looked at the 2013-2020 data, it is much more than 1000 mm, i.e. 1200 to 1300 mm for your information. So this rainfall in India when we have 1000 mm and above, how we can call it shortage. What is happening to this water which is coming through the

Runoff of Indian Rivers

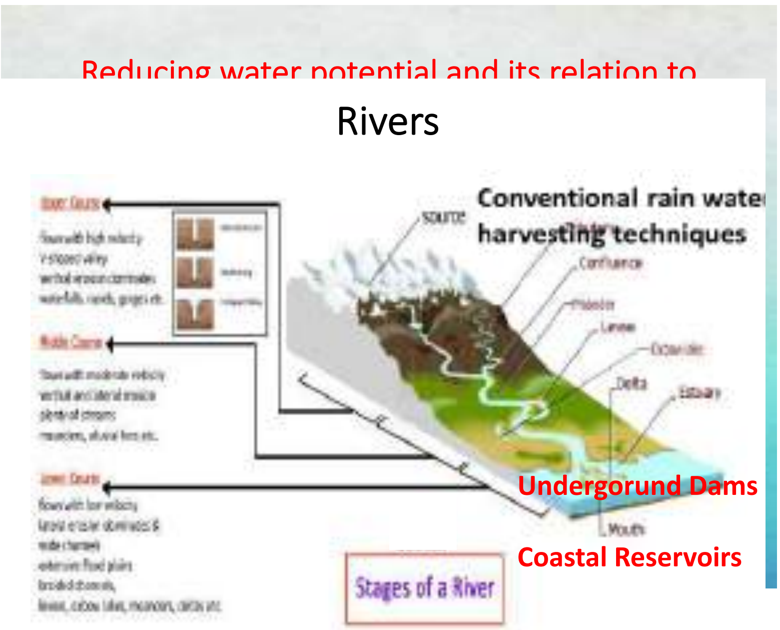
7 Major river systems

- Huge discharges – all of this happens in 3 to 5 months of monsoon
- Majority of rivers join Bay of Bengal
- West flowing rivers – not utilised much – western ghats – lengths of rivers are about 100km long
- Flow rates are much higher than major rivers listed here

More than 400 rivers

basin	Drainage km2	Average Discharge M3/sec
Indo-gangetic basin	1635000	38000
West flowing rivers	1165000	6600
Godavari	310000	3500
Krishna	258000	2200
Mahanadi	141000	2100
Narmada	100000	1500

precipitation. So we have seven major river systems if you look at the runoff of the Indian rivers, the huge discharges all of this happens in 3-5 months of the monsoon. Majority of rivers flowing to the Bay of Bengal and most of these west flowing rivers which I talked about from almost like the Gulf of Kutch to the Kerala coast, all of them, 100-120 rivers, going through the Western Ghats, most of them with very clean water flowing into the Arabian Sea. The flow rates are much much higher than major rivers listed here in the western Ghat area. So you can look at some of the average discharges, they are very large. What is happening ? Why this large volume of water is simply flowing, it is because we have simply transformed the landforms. In the past, we had lot of trees which we cut/killed all of them. So nature used to recharge the surface water through these trees and roots but today due to deforestation, siltation and soil erosion, we have lost the capacity to store water. So you can visualize that when a heavy rain takes place in Benguluru and big cities, large amount of water gets accumulated and flow away to the rivers and then to the ocean. So deforestation, increased soil erosion, have reduced resident time of water in the different layers of the earth (ground water) which makes the entire water just moving towards the ocean through the drainage pattern.

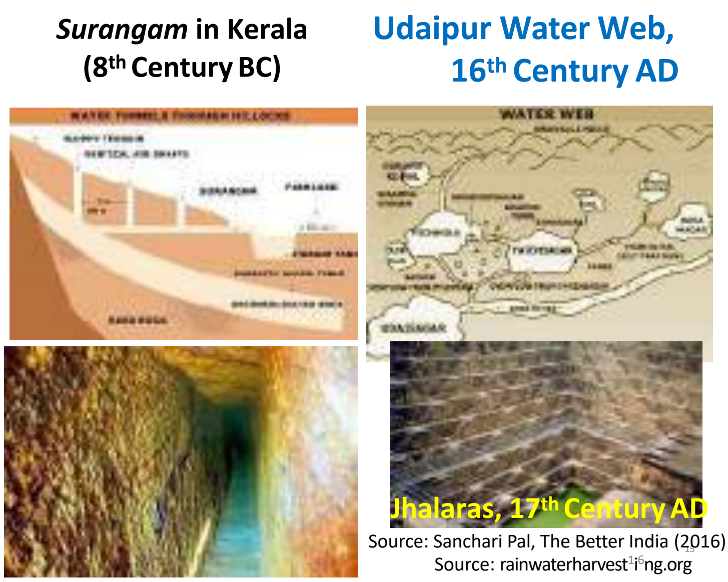


Let me take you through how our Indian rivers are, basically in most places except leaving Indo-Gangetic plain rivers (which are fed by snow melt water), they have source in the mountains and then they will be joining in the confluence and basically come down the hill and slowly flow in to the sea. These stages of the river, we can divide them in to three courses, Upper Course, Middle Course and Lower Course. Upper course flows with high velocity though v-shaped valley, vertical erosion dominates with water falls, rapids, gorges, etc. Middle course flows with moderate velocity, vertical and lateral erosion, plenty of streams, meanders, alluvial fans, etc. Lower course flows with low velocity, lateral erosions dominates and wide channels, extensive flood plains, braided channels, levees, oxbow lakes, meanders, deltas etc. Why I am highlighting this is, please remember most of our dams are constructed either in the middle course or in the upper course. So in the middle course, lots of our dams are located, conventional rain water harvesting techniques can be adopted over there. What I wanted you to concentrate is that in the lower course, nothing much has been done. What I am looking at the water management at last mile the entire catchment area water is available to you. For example, imagine while you taking bath, you try to catch water, in the body or in the head, you get a very little quantity of water, where as at the bottom at the toe, you get the entire water. Similar things happen here. We need to look at Underground dams and coastal reservoirs and downstream management of the river courses.

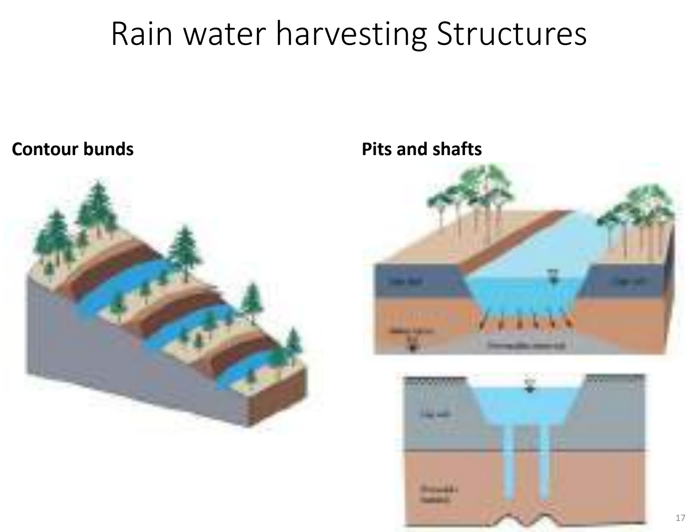
India's traditional water harvesting structures: India is very rich in this understanding. If you go and see Tankas in Rajasthan, Khadin or Dhora in Western Rajasthan, Bavadi in Gujarat and Rajasthan, they know how store the water. they also knew the cycle of water. Monsoon come only three months or four months and then it goes off to dry season. They have understood that they have to store water. they have built these water storage structures. I would like to show you some of the other water harvesting structures: check dams or diversion weirs built across rivers, a traditional system found in Maharasthra, their presence raises the water level of the rivers so that it begins to flow into channels. They are also used to impound water and form a large reservoir, where a bandhara was built across a small stream, the water supply would usually last for a few months after the rains. They are known differently in local languages, Cheruvu in Chitoor and Cuddapah Districts of Andhra Pradesh, they are reservoirs to store run off water. Cheruvu embankments are fitted with thoobu (sluices), alugu or marva or kalju (flood weir) and kalava (canal).

Next is the traditional Bengal's Inundation channel a few months after the rains where they used to cut the embankment to the fields so that they can get a crop, so the cut in the embankment to use the water for crops.

Over a period of time, we have forgotten the utilization of the flood water and also storage structures. See the Khooni Bhandara ia also a network of well like structures, inter-connected through an underground tunnel. These are existing ones in our country. We can also look at the network of tunnels, Surangam in Kerala and



Udaipur water web, all of these are inter-connected underground tunnels for passage / storage of water. So technical knowledge was there during those times. Over a period of time, we have resorted to only large dams. So let me also take you to the other rainwater harvesting techniques. We have started adopting very recently the check dams, nalah bunds, contour trenches, percolation tanks, soak pits, subsurface dykes, sand dams, infiltration wells, injection wells, water pools, subsurface dams or underground dams or sand dams and coastal reservoirs. The major disadvantage in some of these structures, is that you need to still pump water because they are stored underground. One good thing is very difficult to contaminate these water bodies because the entire water is below the ground. But what happened in many cities, they started putting more bore wells and that is why the ground water is going very deep. So you need to actually augment this rainwater harvesting technique in our urban areas. In some of these rain water harvesting structures: you can see the contour bunds, which try to reduce the lateral flow, horizontal flow of the water so that there is enough time to get in and sink into the underground, then water penetrated

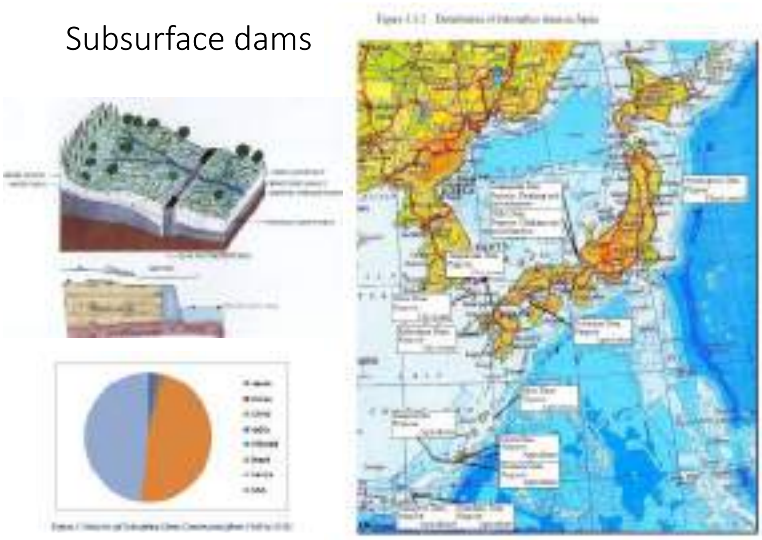


underground creates an underground water storage. In many of the underground storage structures, we need to augment storage. When the rainfall comes, we should allow it to go down rather than naturally flowing laterally on the surface. So right now most of the water is going through and joining finally to ocean.

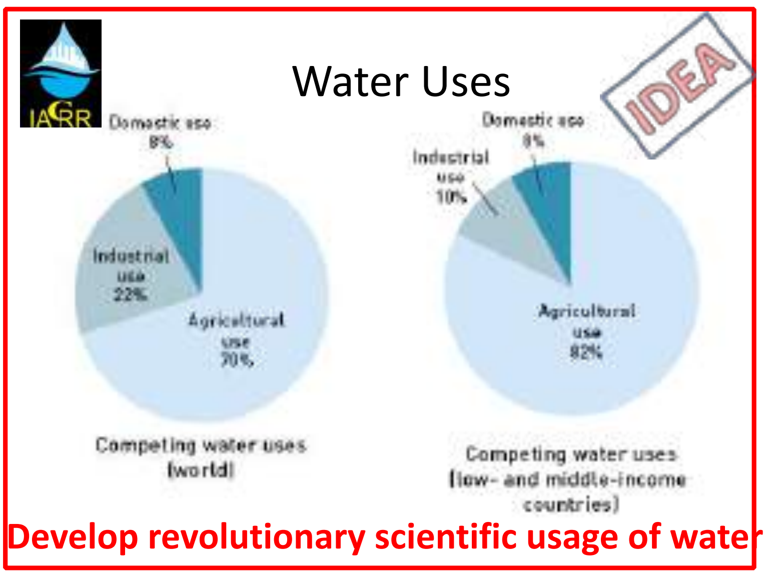
Some of the simple projects actually can be done and it doesn't mean that it is not being done . In some of the areas in the country it is being done at few locations but not still very popular. Similarly, with recharge wells. See some of these pictures are of AOL, which I was actually associated with some of the scientists who are working with villagers. The Art of Living(AOL) has adopted many towns and villages in Karnataka and other states for rejuvenation of rivers, which augments rain water harvesting.

Another important thing is afforestation. So it basically prevents soil erosion, accelerate water infiltration, attracts water molecules to the gravity zone, enhances water retention through capillary action and a long term permanent solution for water problem. Please remember, you need to start planting trees. So in IIT Guwahati, we made it a point that every student who joins actually plants a tree and takes care for four years.

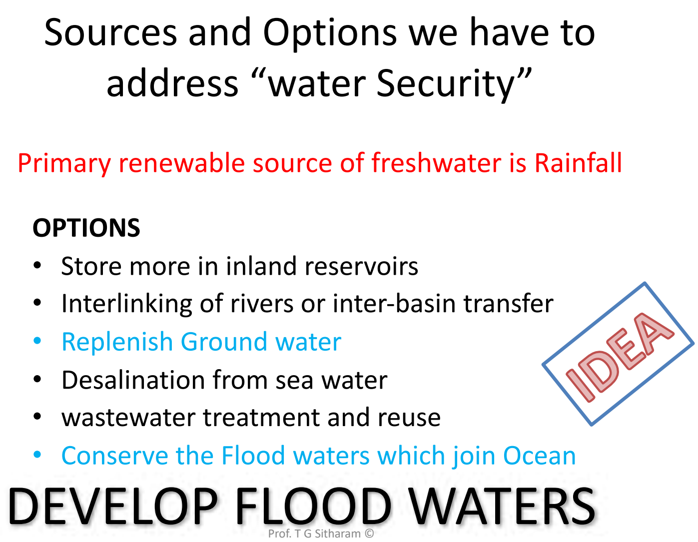
Underground dams : what are these underground dams. the surface dam which stores water above the ground level which is open to the sky, there is evaporation losses and many other things but what happens is this is under the ground level. you can also create an underground dam that dams up ground water flow, stores in the pores of the stratum and uses ground water in a sustainable way. Further more, a facility for preventing saltwater intrusion is also included to definition of the underground dam. In a wide sense, it is called as underground dam including reservoir area. In other words underground dam reserves the ground water in the hard porous soil. So this dam basically intercepts the ground water flow and store ground water in the underground. Another important thing is, if it is close to the coastal area, it also stops the saltwater intrusion into the fresh water zone so the fresh water is very clearly isolated and stored for future use. In rainy or no rain season, we have to maintain the water level. During no rain season, that is the time we need to use the stored water when rain god is not pleasing us. So this kind of dams, Japan has adopted in large numbers. They are also very safe in the point of earthquake or tsunami. it need not be only in the river course, it could even to a large extent to store water and what you need to build is a diaphragm wall /cut off wall cutting off the water flowing into the ocean.



Interlinking of rivers are the challenges faced by the Indian river basins. What we are trying to do is interlink rivers like linking Ganga to Kaveri. Water is basically a State subject; Centre is only supposed to manage the interstate disputes. Lot of interstate disputes are going on legally. Interlinking of rivers not a good solution. We are also creating a lot of environmental damage. The great challenge to optout of linking rivers is both from the environmental consideration and also cost consideration.



I would like to show you one more idea, as we talked about a lot of water uses. So if you look at how the water is used in the world as well as in the low and middle income countries like India and China, agriculture is the major user of water, 82-90% of the water, we are actually using is for agriculture, for production of food. Also majority of our dams are also used for power generation, so if you look at that there is a really clear nexus between water, energy and food. So if you look at this picture much more carefully, the domestic use and industrial use is of this entire water is about 10%. It is not a different scenario in the developed world, only the industrial use will be little over 22% but domestic is same. So what I am trying to say is if you are able to teach our farmer the water consumption reduction techniques (how to really consume water in their farms very efficiently), like we can learn from Israel, lot of technologies in water conservation whether it is drip irrigation, micro irrigation, etc. then we can save large quantity of water. You might be hearing the advertisement in the media, saying while you are brushing your teeth please close your tap, that is very insignificant in number and definitely it should be done but what we need to do at the same time is that we have to teach our farmers to use water resources very efficiently then the quantity of water we could save be much more than what we are consuming in the entire domestic sector.



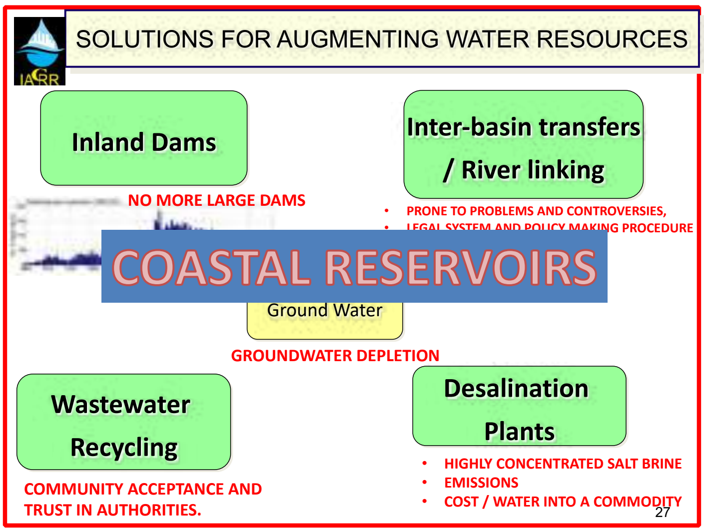
I already talked about that interlinking of rivers, which is very great challenge for India, particularly through inter-basin transfers. Indeed, we need to store more water in land, in such a terrain, reservoirs are already silted and we have to look at the replenishment of ground water.

Desalination from sea water, this is the one foolish thing, I sorry to use this word. We are allowing the fresh water to flow in the monsoon in to the ocean and using desalination process take it back and clean it up. This is a beautiful science. However instead of using desalination, we need store the rain water. Desalination of sea water is also not a safe method to practice, may be because once you remove the salt from water and wherever you deposit the concentrated salt water, mostly that area (almost 2-3 kms where you discharge the salt water from the desalination plant) there will not be any aquatic life. So there is lot of challenges for desalination of sea water. It may be good for Saudi Arabia and Israel, where the rain fall is very low but not for a country like India.

Coming to the waste water treatment and reuse, there are lots of options for us. This is a fantastic thing we can do, but many times because of operational challenges this is not done. Second is the taboo, so I think India with the kind of culture we will never drink the treated waste water what we call grey water. This will have to be done and this water can be used for industrial purpose.

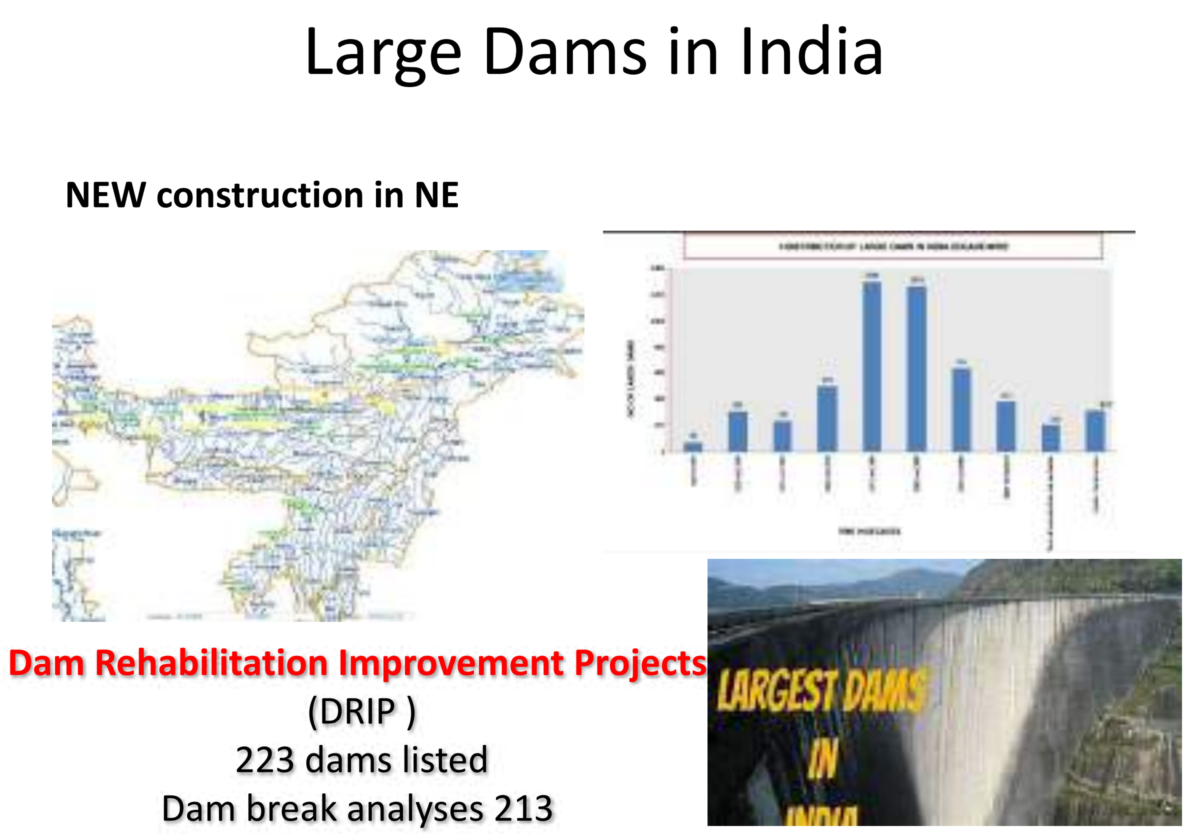
Finally, what I will be focussing on is the flood water flowing into the ocean. So all these options such as inland dams, inter-basin transfers/river linking, waste water recycling, desalination plants are very great challenges. So conservation of flood waters is one such option, which will be provide solutions for our water resources.

Before going to the coastal reservoirs, let us look at what has happened in the surface water storage in India and how we have tackled the augmentation in storage of surface water. We shifted our focus to large dams when compare to smaller recharging structures and storage.

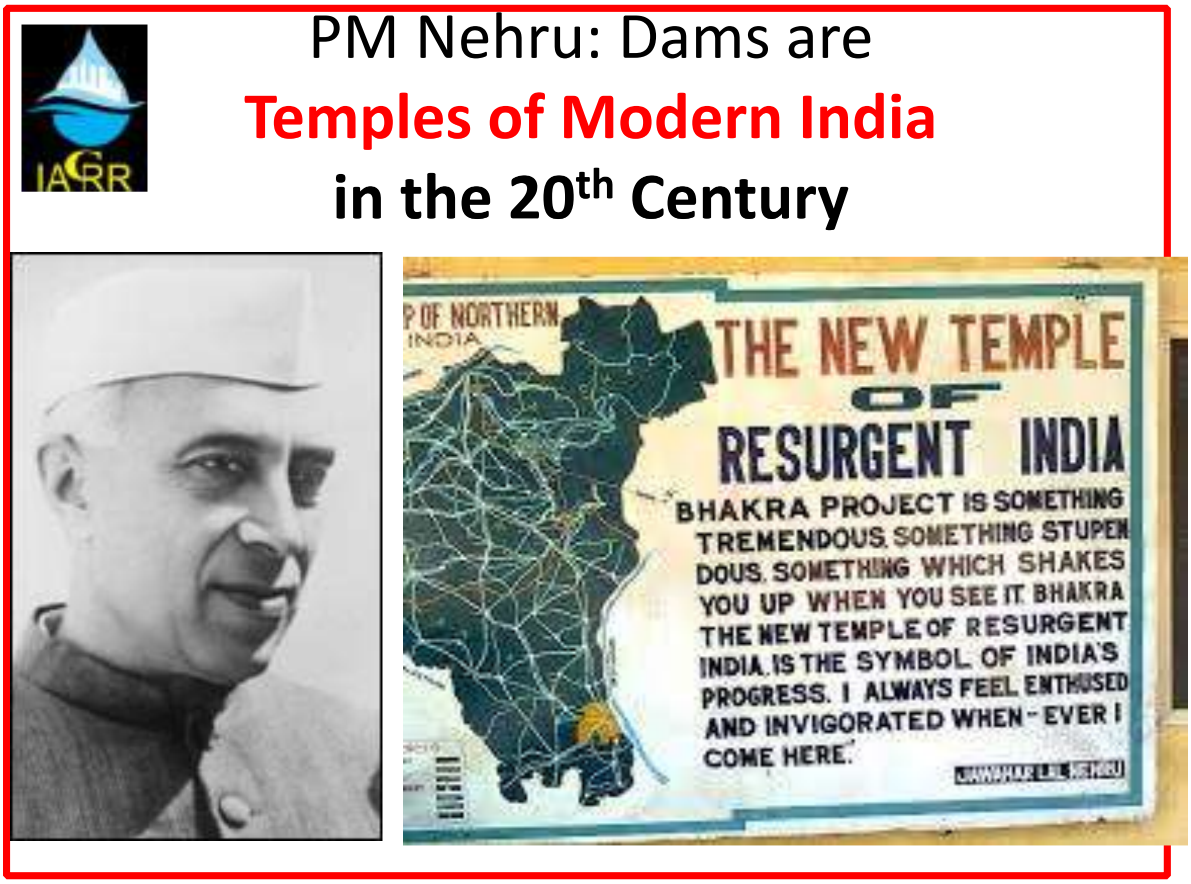


When we got independence in 1947, we had 300 large dams and since independence, we have built 5204 dams and 437 large dams are under construction. Today with more than 5700 large dams, India ranks third in the world in dam building, after USA and China. But how much of water we are storing in these dams, we are only storing less than 10% of the average annual rain fall received in this country. If you look at the dams, majority of them are in Maharashtra, can you believe it, in just three years back Maharashtra used trains to transfer water. Now having almost 5700 large dams, still we have a shortage.

So what I am highlighting is “actually there is no shortage of water, there is a shortage of storage”. We need to

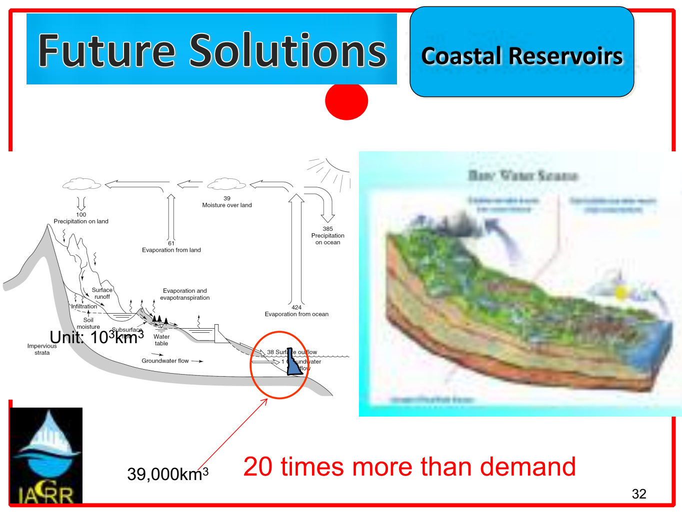


really improve this storage. But , we are trying to do that with large dams and we are looking even now where to build our dams. We are building dams, large number of them in North East which is actually zone-5 as per the earthquake zonation. So these large dams are coming up in earthquake areas and becoming potential threats. So if you look at the dam distribution in India, we have built large number of dams during 1970 to 1990. From 1980 to 1990, we have built around 2000 dams, almost four thousand dams built upto year 1980. Now, we have come up with dam rehabilitation and improvement projects with the help of world bank. Why we have come out with this concept, because most of these large dams are concrete dams and they are leaking. But the life of the concrete dams is about 100 years and after that we have to remove them. None of these concrete dams can survive for more than 100 years. So if you look at the future, where from our grand or grand-children are going to drink water from? These large concrete dams, we have constructed survives only for 100 years. This is the question we need to ask. I would like to highlight is in the dam rehabilitation improvement project funded by the World Bank, we have so far carried out dam break analysis for 213 dams and 223 dams were listed for repairs and other things. So we do not have sufficient money to take up all the dams for rehabilitation. What our former honourable Prime Minister Nehru ji said in 1962, "Dams are Temples of Modern India". When he inaugurated the Bhakra Nangal project in 1962, he said



the modern temples of India are going to be dams, That is where we have focussed and we have done fantastically well compared to the whole world. But look at our dams now, Where is going to be the next temple, where is our new temple in the 21st century?. So we have not left with any space actually, we have completely covered the entire India by building dams, we are now building dams in the North East. So future solutions would be, I feel time is ripe to go back to smaller surface storage structures. As the population increased and people move, we have all started looking at the dams and I think now the population have almost touched 1.3 billion people then we have to look at new outbox ideas for our storage.

Something very close to the coastal area, we can store 20 times more water than the demand. Near the coast, there is lot of things which we can do because already the river water velocities are smaller, so it is very easy compared to the dam constructing in upstream, where the velocities will be very high so we have to build structures to withstand that kind of pressure. But when you come closer to the coast, there will be less pressure on these materials used for construction of dams, so it is much easier to build. So this is what we are looking as the future solution i.e. "coastal reservoirs". Our first book by Elsevier, on "Sustainable Water Resource Development Using Coastal Reservoirs", coming out by next month, both myself and Prof. Shu-Qing Yang are the authors and other contributors are Roger Falconer, Muttucumaru Sivakumar, Brian Jones, Sreevalsa Kolathayar and Lim Sinpoh. This book is going to be released in the month of August, 2020.



Now, I will take you through some of the advantages of the coastal reservoir vs. large dams. Inland reservoir is limited in land, unlimited in the sea. It will not be only in the sea, it will be closer to the coast and it can be on

Coastal Reservoir Vs Large dams

item	Inland Reservoir	Coastal Reservoir
Dam-site	Limited (gorge)	Unlimited (in the sea)
Dam design	High pressure	Low pressure but with wave surge
Seepage	By pressure difference	By density difference
Pollutant	Land based	Land-based + seawater
emigrant cost	High	No
Water supply	By gravity	By pump

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land. For inland dams, seepage will be the pressure difference, but for coastal reservoirs it is the density difference. The issue of pollutant is there in land based reservoir and in case of Coastal reservoir it is land based plus seawater ingression. One major issue we need to solve is the pollutant problem in Coastal reservoir. Any way we have to handle the pollutant issue, whether it is inland reservoir or the coastal reservoir. IN coastal reservoir, we don't displace any people. Water supply is by gravity in the coastal reservoir, we don't have much option other than pumping. Let us look at how many coastal reservoirs are existing already in the world. Netherlands built Afsluitdijk in the Ijsselmeer in 1932 for flood control measures, India has built Thanneermukkom bund in Kerala in 1974 for agriculture; South Korea has built two coastal reservoirs, Sihwa, 1994 for tidal energy and Saemanfgeum, 2010 for land reclamation and fresh water; Hong Kong built its Coastal reservoirs (Shek Pik, 1968; Plover Cove and High land for fresh water); Singapore has built Marina Barrage in 2008 for fresh water and United Kingdom built its Cardiff Bay Barrage, 1987 as a fresh water lake. So coastal reservoirs, what we are

Coastal Reservoirs - Existing

Country	Name	Purpose
Netherlands	Afsluitdijk in the Ijsselmeer, 1932	Flood control
India	Thanneermukkom bund, 1974	Agriculture
South Korea	1. Sihwa, 1994 2. Saemanguem, 2010	Tidal energy Land reclamation and fresh water
Hong Kong	1. Shek pik, 1968 2. Plover cove 3. High land	Fresh water
China	1. Qingcaosha, 2011 2. Chenhang, 1992 3. Baogang, 1985	Fresh water
Singapore	Marina barrage, 2008	Fresh water
United Kingdom	Cardiff Bay Barrage , 1987	Fresh water lake

Planning Stage: 1. Pluit Reservoir Revitalization Project, Jakarta, Indonesia
2. Kalpasar project, Gulf of Kambhat, Indian Water Project, Gujarat
3. New York , USA

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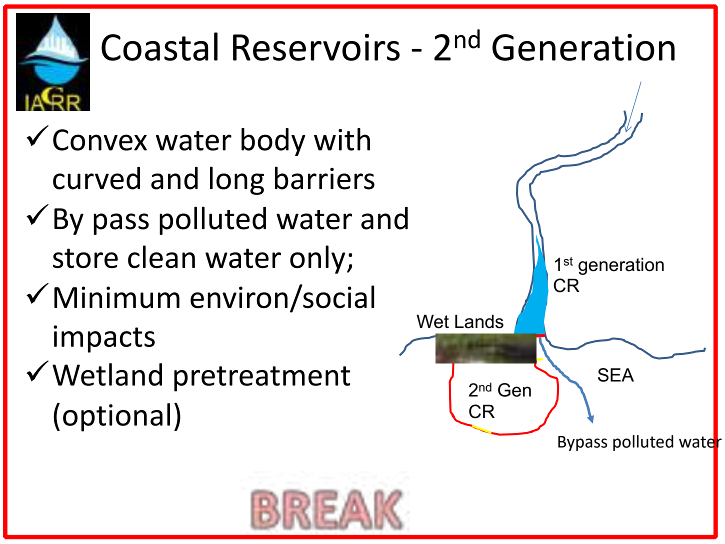
recommending is the second generation not the first generation coastal reservoirs. What is the first generation coastal reservoir? First generation is basically blocking the river mouth entirely. In that way you are collecting all the pollutants also there, that is not a good idea. What we are talking about is during the monsoon, the clean water can be diverted to a reservoir outside the mouth of the river. When the water quality is good, you can divert the water to the coastal reservoir and when water is dirty, it can bypass and go out into the sea. The second generation coastal reservoir is a convex water body with curved and long barriers and bypasses the polluted water and stores only clean water. Minimum environmental and social impacts because our fishermen can get inland, and we are not stopping any fishermen from going into our rivers and river transportation can also happen. We can also create a wetland pre-treatment before allowing flood water to enter the coastal reservoir. Many new wetlands can be created through this approach.



I will take a break here and I will let Prof. Shu-Qing to highlight some points and then I will continue with my case studies. Thank you very much.

Prof. Shu-Qing Yang: I would like to thank Prof. Sitharam for the wonderful presentation. He mentioned something from the history, India, from UN endeavour, so many other issues related to CR . This reminds me a story. He says there is sufficiency in the world for a man's need but not for man's greed, yes this is Mahatma Gandhi's teaching. From today's presentation, we know this is true in water scarcity. Thanks to Prof. Sitharam, you told us that India can solve the problems and we need to change our mind. Thank you very much, you opened our mind, the water problem is so important for everybody. Now I have some questions to ask you on behalf of the audience. These two questions you can answer together.

Q. How flood water can be controlled from reaching the ocean so a maximum utilization may be possible. Another question, if we reduce water discharge into the ocean, for flood water resources development and flood disaster mitigation, can we link both of them together, use your idea.

A. First of all let me tell you that there is apprehension that we are going to stop entire water, there is no way, humanly impossible to stop and store all the flood water running into ocean. We can only do with all our big plans may be another 3-4% of the water resources available. So far we taken almost 70 years to build 5600 dams and we have increased our storage may be about 3% to about 8%, so that means 8% of the precipitation which falls on our ground. We might go from 8% to may be about 11 to 12% with coastal reservoirs and underground dams. First of all that means, we are not stopping the entire water which is flowing through the river, we are only taking this very small portion, 3 to 4% to store, that itself is a very large quantity of water, that is almost like 1000 billion cubic feet of water in total. What I am trying to say is we are not really going to stop all the water that is flowing into the ocean and also with second generation coastal reservoirs, one more beautiful thing is happening. All the sediment which rivers carry also will join the ocean, so we are not stopping the sediments as well, so that it means salts which are supposed to join the ocean is also not stopped and we are allowing, so there is no environmental damage. I hope I answered both the question.

Q. Next question is, for improving national water security, there are many water technology, but its application in practice is always behind people's expectation. For proved technologies like coastal reservoirs/underground tanks, how to convert our dreams into practice from government's policy to implementation in a short period.

A. Why the policy of implementation is taking lot of time?. We need to look at that, because India is a democratic country and also water is a State subject. For example, if Karnataka and Andhra Pradesh wants to build a dam, they need to take permission from the Karnataka State, so upper riparian State has to permit and also there must be an agreement between the two States for water sharing, which will take a lot of time because I will tell you, Karnataka is still fighting for 10 TMC of water with Goa State and for 10 TMC water with Tamil Nadu. Karnataka is fighting every year, when the summer comes water is becoming a major issue. However, Flood water stored in coastal reservoir is nobody's water which is joining the ocean. We try to store this flood water so actually the litigations between the States will come down, that automatically saves a lot of time. So we need to look at this in that context of interstate disputes we are having because of water sharing agreements between the States. Similarly, the water which is going underground which also belongs to each State, so increasing water ingress into the ground and storing in coastal reservoir are the better options than building large dams that stops water completely. Using CR and underground dams, I think the interstate disputes can reduce, and further as these will not involve large displacement of people and villages, implementation becomes much faster.

Prof. Shu-Qing Yang: Thank you Professor Sitharam, this reminds me what the Singapore PM said, he said: every other policy has to bend at the knees for our water survival , so this means all our other policies are now less important than our water development, it is looks like a king. .

Prof. Sitharam: I would like to highlight the Shanghai experience. Shanghai city has built a coastal reservoir, you can see at the right side bottom of the slide, so this is the coastal reservoir what Shanghai city has built in the Yangtze River delta. This is a second generation coastal reservoir. Through, wet land water enters into the coastal reservoir and this is one of the unique second generation coastal reservoir constructed in the world. Prof. Yang was involved in some portion of the decision making of this reservoir location, design and construction. CR supply water to the Shanghai city and almost 60% of the citizens of Shanghai citizens get water from this coastal reservoir. We can clearly see that Shanghai is able to do that. Construction of CR was started in 2008 and completed the construction in 2010. City started pumping fresh water from this CR, without resorting to desalination. They could complete all the work in 4-5 years time. But imagine, Sardar Sarovar Dam, when it was started construction and how many years they took?. I remember very clearly, Sardar Sarovar Dam foundation was laid in 1961, took form in 1979, construction started in 1987 and finally the construction was completed in 2017. This dam planning and construction in India has taken 55 years and this clearly shows there is some serious issues of interstate dispute, environmental damage, displacement of people, submergence of towns and villages. So large dams in interior land are not the solution. Any way we have built it now. I think we need to look at the future as we are saying whatever

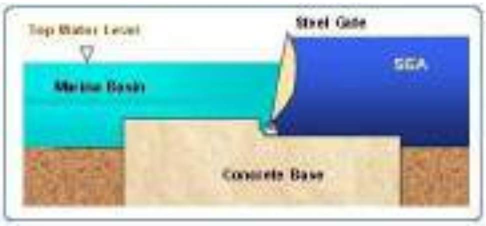
storage we have created with large dams is so small and this is not enough for the increasing population of India. So we need to really look at villages and towns which doesn't have enough drinking water, the water doesn't come to their homes, to really fulfil this dream and to become a five trillion dollar economy we need to do focus on Mission Water. This "mission water" will allow us to increase our food production. This will also increase our energy production and thus water-energy nexus we need to solve.

So let us look at some of the case studies of the coastal reservoir. Netherlands constructed the Afsluitdijk coastal reservoir in 1933, see the picture, this is the dam they created having six lane highway on the top of the dam. You can see the dam wall is facing a very rough sea. Today, the dam has really become a fresh water reservoir. They constructed it not for storing fresh water they constructed for flood control and to save the villages from the rough sea and created large fresh new land. Because of a coastal reservoir, you can create a new land which has been developed well now. Basically the Afsluitdijk in the Ijsselmeer, Netherlands is constructed with the objective of flood control but it holds fresh water and new reservoir was created which acts like a buffer between

Netherlands and the Wadden sea. Major CR in the Netherlands was constructed between 1927 and 1932 and running from Den Oever on Wieringen in North Holland province, to the village of Zurich in Friesland province. A length of 32 kilometres and a width of 90 meters (300 ft), at an initial height of 7.25 metres (23.8 ft) above the sea level.

Hong Kong scenario: In 1960s, the condition was just like Indian villages, people were bringing water in pots so you can see that water was a difficult to fetch in 1963-64 in Hong Kong and they were practicing water rationing. Sea water was used for flushing at that time. Construction of large freshwater reservoirs in Bays in Hong Kong was constructed in 1957 to 1963, then what happened is, Hong Kong decommissioned the desalination plants in 1975. Hong Kong is a very small city actually, they built up coastal reservoir, you can see the picture, they simply built a small dam and stored water. These are all first generation coastal reservoirs. Similarly in Singapore, in 2007-2008 Marina Barrage was constructed, which has a dam of 350 meter length across the canal.

HOW DOES THE BARRAGE WORK?



Nine numbers of 26.8-metre-long hydraulically operated steel crest gates, will be built across the 350m wide Marina Channel to keep out sea water.

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- Most impressive smart project to date in Singapore
- Greatest advancements in water management technology.
- May 2016 report - protecting Manhattan from storm surges, New York City's Economic Development Corporation

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Marina Barrage

Marina Barrage stretches across the mouth of a wide channel.

Most expensive real estate in Singapore — tall office towers, a conference centre, hotel and shopping complex and the popular Gardens by the Bay botanic garden, all built after the dam went up in 2008.

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A concrete tilting dam across the mouth of the Marina channel was constructed with a catchment area of 10000 ha. The salt water storage area became fresh water reservoir and today it provides 10% of inland water needs of Singapore. This barrage stops rain water flowing into the sea and stops sea water coming in. This is also a first generation coastal reservoir. The hydraulically operated steel crest gates you can see (in all nine) of 26.8 metre long and also there are huge under water pipes through which the excess rainwater flows into the sea. There are huge pumps which pumps excess rain water during high tide time. Marina Barrage stretches across the mouth of a wide channel. It has the most expensive real estate in Singapore, tall office towers, a conference centre, hotel and shopping complex and popular gardens by the Bay, botanic garden, all built after the dam came up in 2008. So you can see how the area has been transformed after this barrage was built. This is the most impressive smart project to date built in Singapore. It has received superior achievement award from American Academy of Environmental Engineers (AAEE). The picture on the left side below is before the construction of the barrage in 2005. Here in this project, a deep sea fishing harbour is developed to protect the displaced fishermen from the area due to the barrage construction.

Deep fishing Harbour

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Saemangeum Seawall, Korea

The seawall was officially open to the public on April 27, 2010.

- 400 sq km area reclaimed
- fresh water reservoir of 117.6 km2
- Rest is reclaimed land to house a population of 680 000.
- the world's longest man-made dyke, measuring 33 kilometres (21 mi).

average width of the sea wall/earth dam is 290 metres (it is 535 metres at its widest) and the average height is 36 metres (54 metres highest)

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Saemangeum Seawall

Saemangeum is an estuarine tidal flat on the coast of the Yellow Sea in South Korea.

- The Saemangeum lay at the mouths of the Dongjin & Mangyeong Rivers, on the coast of Jeollabuk-do
- just south of the estuary of the Geum River.

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Similarly Saemangeum Seawall was constructed in Korea located on the southwest coast of the Korean peninsula, is the world's longest man-made dyke, measuring 33 kilometres, runs between two headlands, and separates the Yellow Sea and the former Saemangeum estuary. Average width of the sea wall/earth dam is 290 metres, 535 metres at its widest and the average height is 36 metres (54 metres highest). The seawall was officially open to the public on April 27, 2010. It has

Saemangeum Seawall

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reclaimed 400 sq. km. area, with freshwater reservoir of 117.6 km2, reclaimed land is housing a population of 680000. You can see from the picture how the dam is constructed which is almost like ground level, one side is sea water and other side is the fresh water, this is also a first generation coastal reservoir.

The Saemangeum dykes has Sluice Gates. Saemangeum Garyeok Sluice Gate is 870 feet long and 66 feet wide and has 8 sluice gates. The gate's function is to control the water level to prevent the flood with the ebb and flow of the tides. Second 540 m wide sluice gate will then

Sluice Gates

Saemangeum Garyeok Sluice Gate is 870 feet long and 66 feet wide and has 8 sluice gates. The gates function is to control the water level to prevent flood with the ebb and flow of the tides.

Second 540 m-wide sluice gate will then remain open after sea wall closure for a year or two with greatly reduced water exchange and tidal-range

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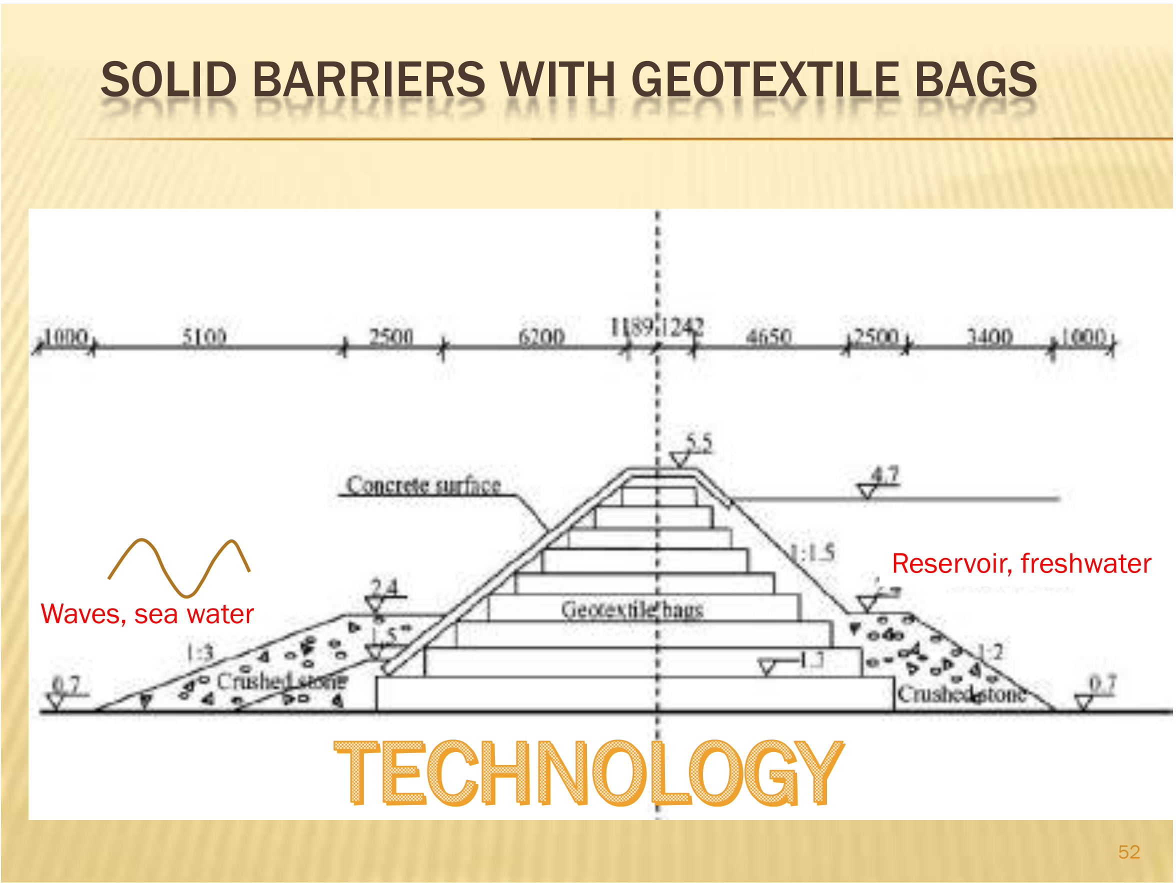
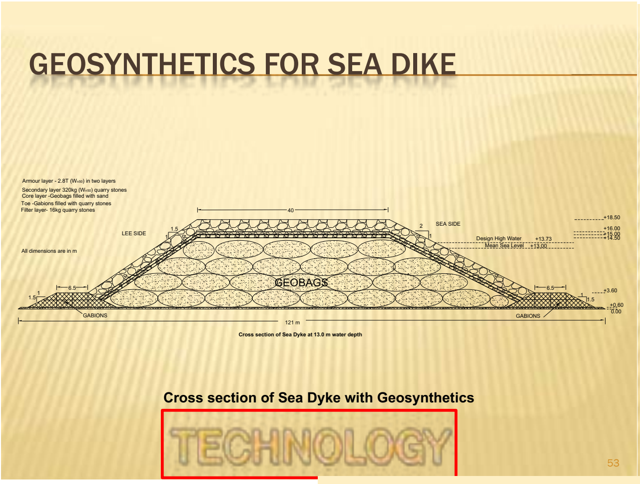
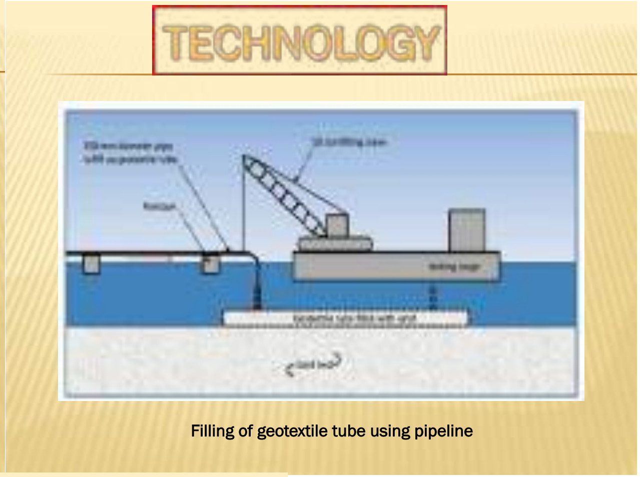
remain open after sea wall closure for a year or two with greatly reduced water exchange and tidal range.

We are propagating the concept of the second generation coastal reservoir where the entire river mouth is not blocked and you only take water when water is in plenty particularly during monsoon type of conditions. There are new innovations and technologies to build the dyke in coastal environment. These solid barriers with geo-textile bags are a new innovative technique to construct the dykes. Saemangeum dykes are built using geo-textile bags by using the material in the ocean, i.e. same sand silt could be packed into geo-textile bags and you can start constructing and put a concrete surface and the dam is ready. These have the

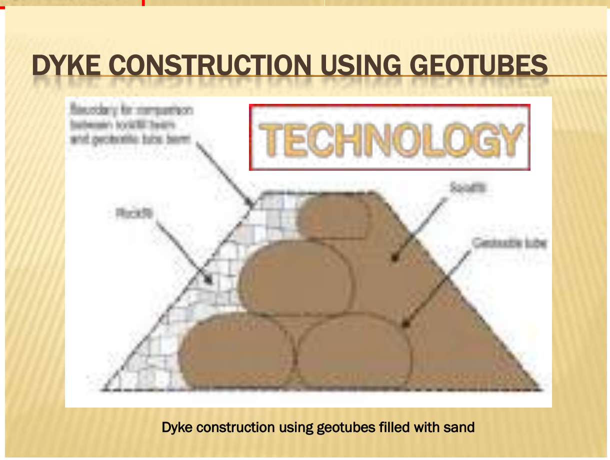




Cross section of Sea Dyke with Geosynthetics

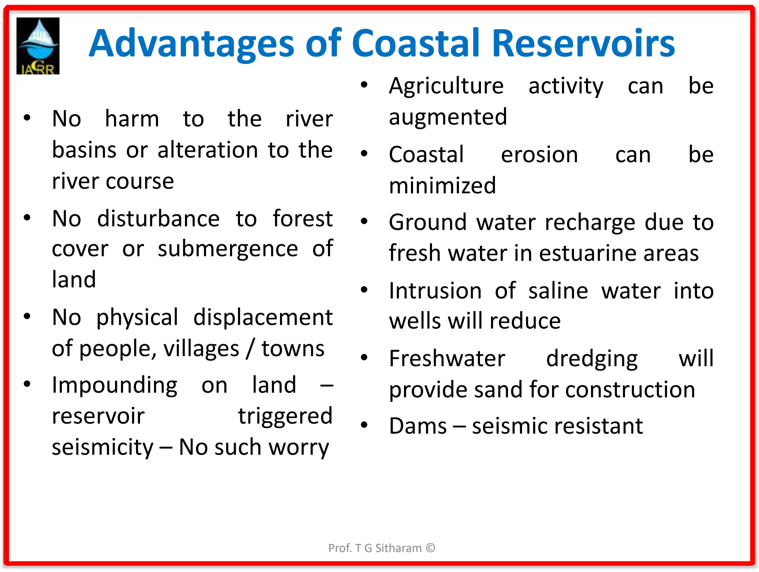


Filling of geotextile tube using pipeline

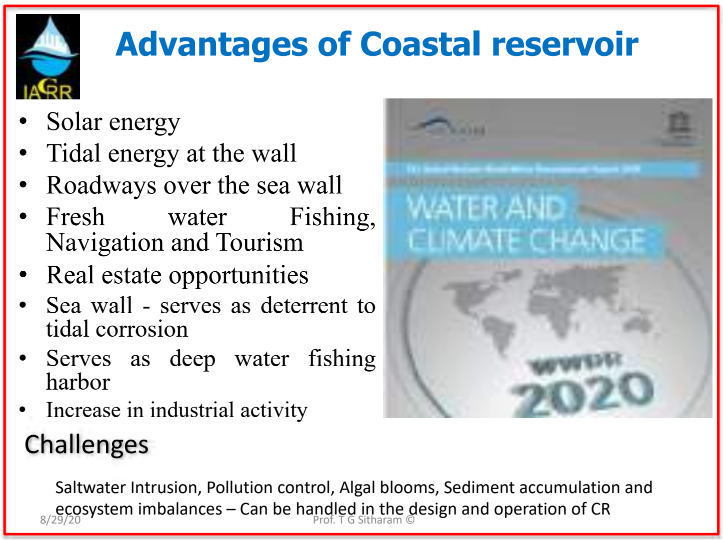


Dyke construction using geotubes filled with sand

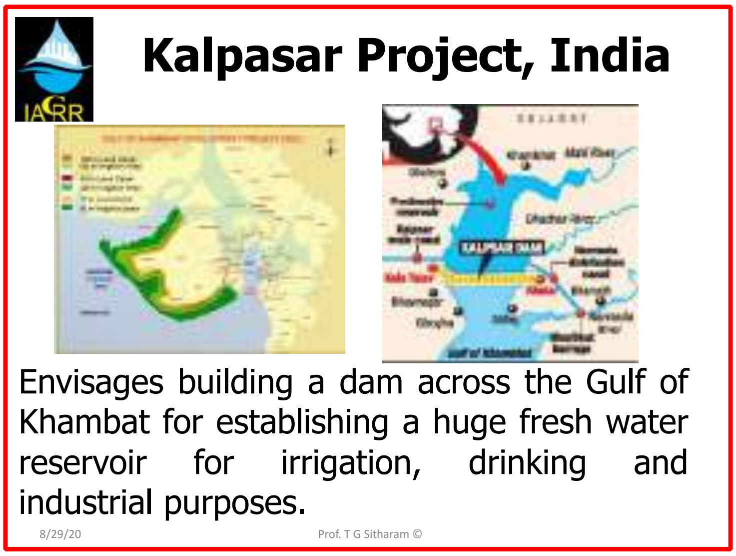
geosynthetic sea dyke cross section of geosynthetic bags, one side is the ocean and one side is fresh water. The geobags are filled up with sand & silt from ocean floor into the geotextile tube using the pipeline and pump into this geotextile tube. The geotextile has small pores capable of retaining the injected materials and allowing water, due to a greater permeability, the flow out of water during the pumping phase. In addition, the geotextile, as well as the seam, is highly strong, to resist the high tensions occurring during the hydraulic filling and maintain its geometrical shape.



Advantages of Coastal Reservoirs: No harm to the river basins or alteration to the river course because we are at the lowest part of the river where it joins the ocean. No disturbance to forest cover or submergence of land. No physical displacement of people/villages/towns. In many of the large dam constructions, the delay is happening because of displacement of people, villages and towns. Through this technology it will not really disturb any forest cover. No displacement of people, impounding on land - no reservoir triggered seismicity issues. For example, Koyna Dam has triggered a large number of earthquakes, no such problems here. Since it will be in the coastal area, coastal erosion can be minimized, ground water recharge due to fresh water from estuary areas can be increased, infusion of saline water into wells can be stopped. Agriculture activity can be augmented. Freshwater dredging will provide sand for construction. Dams - seismic resistant. We can also generate solar energy, we can put solar panels on our reservoir also as the depth of the coastal reservoir will be 10-15 meters deep, we can actually put a lot of solar panels, generate solar energy, generate tunnel energy, we can construct roads over the sea wall, fresh water fishing, navigation and tourism, real estate opportunities and sea walls serves as deterrent to tidal corrosion, and it can serve as



the deepwater fishing harbour and overall it can increase in industrial activities which will provide new opportunities. These are the advantages but there are disadvantages also. If you adopt the first generation coastal reservoir, salt water intrusion, pollution control algal blooms, sediment accumulation and ecosystem imbalances would be the issues. All of these we strongly believe can be handled in the design and operation of the coastal reservoir. Recently, UN brought out a document on water and climate change, they have clearly mentioned that putting a coastal reservoir is a clearly affordable option in this book. You can go to the United Nations website and look at this document. Coastal reservoir has been put as one of the other alternative option, which was not there earlier, so our idea has been recognized by the UN. India has also done a thought process in this direction. They have already identified one project near the Gulf of Khambhat, Gujarat called Kalpasar Project, 64 km long dam across the Gul of Khambhat connecting Ghogha in Bhavnagar with Harsot in Bharuch District.. You can see the website or Kalpasar project. It is to the north of Mumbai and south of Surat, which was planned by Honourable Prime Minister Modi, when he was CM of Gujarat. The Kalpasar project envisages building a dam across the Gulf of Khambat for establishing a huge fresh water reservoir for irrigation, drinking and industrial purposes. They have also planned set



The Kalpasar Project envisages building a dam across the Gulf of Khambat for establishing a huge fresh water reservoir for irrigation, drinking and industrial purposes.

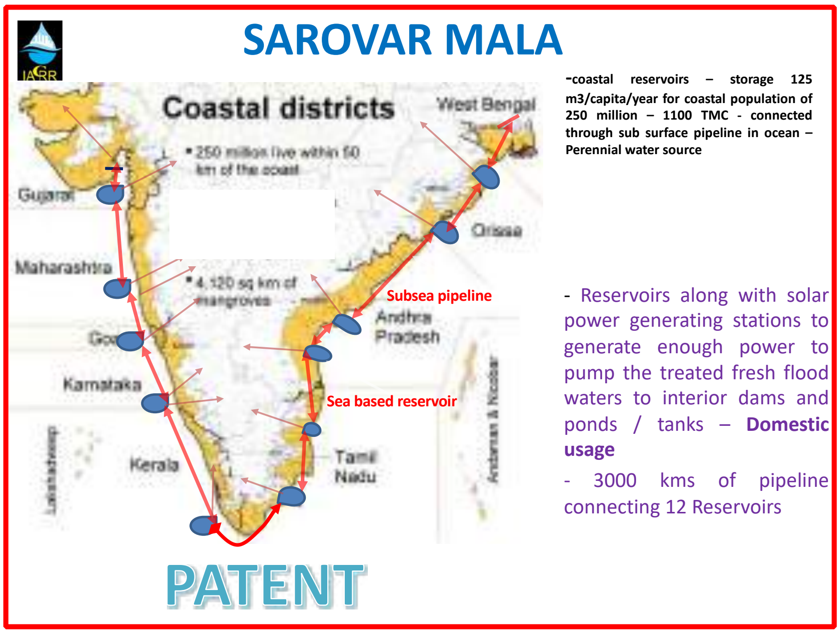
A 10 lane road link will also be set up over the dam, greatly reducing the distance between Saurashtra and South Gujarat by 225 km

Gross storage of 16,791 million cubic metres of water

64 km long dam across the Gulf of Khambhat connecting Ghogha in Bhavnagar with Hansot in Bharuch District.

60

of contour canals to connect basically Bharuch to Bhavanagar from this reservoir and it will resolve the water woes in Saurashtra and Kutch region. A 10 lane road link will also be set up over the dam, greatly reducing the distance between Saurashtra and South Gujarat by 225 km. Gross storage of this coastal reservoir/dam would be 16791 million cubic metres of water, which will be the largest reservoir in India.



My bigger idea with coastal reservoirs is as follows: If we can build small coastal reservoirs all across India's long coastline and connect them through sea/subsea pipeline, 3000 kms of pipeline connecting some 12 reservoirs, storage of 125 m3/capita/year for coastal population of 250 million - 1100 TMC - connected through sub surface pipeline in ocean - perennial water source can be created. Such reservoirs along with solar power generating stations can generate enough power to pump the treated fresh flood waters to interior dams and ponds/tanks or for domestic usage. With this idea of "Sarovar Mala"TM, continuous availability of water can be ensured even if there is scarcity of rainfall in a particular year. I call this concept "Sarovar Mala"TM and even applied for a patent on the concept. We need to increase the storage of water as our population is increasing and we need more and more water for domestic usage, irrigation and food production.

Conclusions

- **India is not running out of water, but water is running out of India**
- Desalination is expensive and environmentally not sustainable;
- Underground dams will augment Ground water resources
- Cost of Coastal reservoirs vs alternative water diversion schemes is much lower

Adopt Coastal Reservoirs and Underground dams along with ground water recharge techniques

To conclude my talk today, as I already said earlier, India is not running out of Water as I have shown earlier. We have 1000 mm average annual rainfall, which is a huge quantity of water (amounting to 4000 billion cubic metre of water). But, we are now able to store close to 690 billion cubic metre of water, so even if we can create 400-500 billion cubic metre of water storage, it would suffice India's needs. So India is not Running out of Water, but Water is Running out of India. Desalination is very expensive and that is not recommended for our country. It is really a foolish idea to allow fresh water to join the ocean and then take it back again, clean it up with high power costs, huge environmental damages to the surroundings of the desalination plants. This idea is environmentally not sustainable. Underground dams is a very good idea which will augment ground water resources, which you can actually do but this cannot get a large quantity of water storage in some locations. We can increase the rain water harvesting systems at local areas. When we need large quantity of water storage, then we should go for coastal reservoirs. If we can adopt coastal reservoirs and underground dams along with ground water recharge techniques through rainwater harvesting, India water problems will be solved. We have done a feasibility study for a coastal reservoir project for the Government of Karnataka, Bangalore Water Supply and Sewage Board (BWSSB). We have demonstrated that cost of constructing a coastal reservoir near Mangalore is feasible and it is much cheaper than the alternative water diversion schemes and construction of large dams. I would like to end with a quote, "Adopt coastal reservoirs and underground dams, and water recharge techniques which will save us for the future". Unless we increase the storage of water inland for the benefit of the mankind we will not be able take up developmental activities, industrialization, agriculture.

I would like to welcome all of you to become member of IACRR (International Association for Coastal Reservoir Research), which is also holding the first international conference on Coastal Reservoirs from 20th to 23rd April, 2021 in Nanjing, China. Hohai University is holding this conference jointly in collaboration with IACRR, for which I am the President, Prof. Shu-Qing Yang is the Secretary. We welcome all of you to IACRR and also to the conference. Thanks to IITACB for giving this opportunity for me to share my ideas. Thank you one and all for patiently listening to my lecture and if there any questions, I will take. Thank you very much.

Prof. Shu-Qing Yang: Thank you Prof. Sitharam, wonderful presentation. This reminds me Martin Luther King's voice many years ago, he said, I had dream. Now our dream I can see is "Sarovara Mala" for the people and to our next generation. They will enjoy beautiful life in future with CR around them. I have some questions from the audience.

Q. River interlinking is an important proposal for an agricultural country like India. Can you compare coastal reservoir and river interlinking, how to supply sufficient water for agriculture in inland areas.

A. Interlinking of rivers idea came up in 1970 with a concept on national water Grid by Mr. KL. Rao, to link Ganga to Kaveri. Are you able to do that even today, no. The problem is our terrain is very difficult, so we have hills and mounts which makes it very difficult and also due to large population, in all these projects we have to displace people, if you are going for interlinking of rivers and dams/barrages. Lot of environmental damages, we are going create. Second question is: where is the money? it needs lot of money because we have to pump the water at some places (lift irrigation have to be done). This is difficult and costly. It is possible where if both rivers are in the same area and nearby. Krishna and Godavari rivers can be linked as they are nearby rivers. Some of these projects have happened and some other projects will never happen. Also today with the environmental damage and also with the kind of population density we have, I think interlinking of rivers we need to forget. Secondly, interlinking of rivers becomes difficult because of interstate disputes. Each State says this is my water share, even though you are able to link it, most of the canals which are linked will go dry because for example, one State will not leave water to other State and this is the challenge after constructing with large investment. The upper riparian states will never allow the water to go when they don't have enough water, they will allow when they have plenty of water, that means when monsoon comes they want to leave the water but not in summer. This challenge actually puts river linking projects to back burner. Many river linking projects have gone to back burner because of shortage of money, litigations, cost and environmental damage. But today we are looking at the downstream river management using coastal reservoirs and underground dams. It is actually storing the flood water, which is going to the ocean. It is nobody's water. Each State is going to have it's own small reservoir, in our concept of “Sarovar Mala TM project”. They could also collectively work together, and connect the coastal reservoirs along the coast. So Sarovar Mala TM can be created without damaging the environment. At this time, it is only a concept. It really require lot of work to be done both scientifically, technologically, and collectively. We need to debate, understand and select these locations for these coastal reservoirs. This is a very initial picture of a strategy. The interlinking of rivers and interlinking of large dams has shown many negative effects. We need to look at and concentrate on something new idea. As I highlighted earlier that the concrete is also a material, which lasts for about 50 to 100 years. We need to look at a new material and may be geosynthetic gives you that kind of a hope. We have seen in National Highway projects that more and more reinforced earth flyovers are being used.

Q. How your proposal take the need of hydroelectric power in a dam. Dams in up and the middle reaches can generate electricity or green energy, its environmental cost of the dams is to change the river and the sear flow causing significant damage for the downstream. Can coastal reservoir technology also bring us the green energy?

A. For the hydro power, we have already constructed large dams for four to five decades. We are only taking on the utilization of monsoon bounty flood water, which is now simply flowing into the ocean. If you are thinking what would happen to our future generation of power, as I showed very clearly my coastal reservoir can generate non-conventional power like solar, wind power, wave energy etc. We have to look at ways of generating large quantity of power using solar, wind energy and of course wave energy. The coastal reservoir water will be still water, we can put wind mill, solar panels, as the water depth is very small. We can place the floating solar panels and windmills with foundations in shallow still waters of CR.

Q. Can coastal reservoirs mitigate the flood disasters like the one happened in Kerala post 2018 flood.

A. Now we are creating a pathway for river flood water, which can be directly stored into the coastal reservoir. So in flood control, these reservoirs will also help. It will not only allow you to save good quality water flowing into the ocean but also acts as a buffer for storage and do the flood control measure. We need study the feasibilities and then go for the implementation plan and locate these CR;s for doing the job of flood control.

Q. In Chennai, most of the population residing near the coast have suffered heavily from tsunami and are now facing problems of sediments after the last tsunami. Will the coastal reservoir help to control tsunami.

A. I am saying, we cannot control tsunamis, however, coastal reservoir will work as a buffer. So coastal reservoir will definitely act like a buffer with it's still water and it will help in controlling most of the tsunami effects, but may not eliminate it completely and sometimes tsunami might flood the reservoir with salt water, all that we have to learn and handle as we go along.

Q. Chennai city faces floods and also water scarcity, is coastal reservoir feasible in Chennai to store its flood water for water resources?

A. It is not a simple thing to answer. We need look at the detailed feasibility study of how much water is going out of the city, where we can store, and how we can do it including cost and construction considerations. But we have done this for Mangalore city for example. For Mangalore city, we wanted to store 50 TMC of water very close to the coast of Mangalore and we demonstrated that it is feasible through the river Netravati alone. Unfortunately they are going for desalination when you have 400 TMC of water joining the ocean every year, if you look at the last 100 years data, through Netravati river alone near Mangalore, 400 TMC of water is simply joining the ocean every year during the four months of monsoon and the quality of water is reasonably good during monsoon and such water we are allowing it to flow in to the ocean and planning to taking it back and try to clean that up by using desalination techniques. Putting desalination plants at Mangalore City is not a wise decision, when we can create a small coastal reservoir. We went to a coastal town of Mangalore and we saw fishermen have created small fresh water ponds in their yard that clearly demonstrate that our people are very smart enough to show that they need to store water for use in summer.

Q. In your opinion, which river has the chance to apply the CR technology first in India.

A. As I told you we haven't looked at the entire country, we have looked at one or two locations, at Mangalore there is a clear availability and Godavari there is a clear availability. Arthur Cotton as early as in 1800s argued with British and built the barrage and today East Godavari and West Godavari districts are rice bowls of India. He basically used the flood water storage in this barrage, directed this water into the fields and used it for agriculture and today he has been remembered like a god in Godavari district. Arthur Cotton is the greatest agriculture engineer of British India. He has informed the British Govt at that time, that one day's water outflow from Godavari river to the Bay of Bengal is equivalent to one year outflow of river Thames in England, that is valid even today during monsoon. Every year this is the same scenario. Krishna river water we have reasonably used very well, but not Godavari river.

Q. Up to what extent we can meet the India's future water need through coastal reservoirs compared to existing surface dams or vice versa and also mention about the cost benefit aspect

A. Please understand whatever large dams, etc. we have constructed for the surface water we have to maintain them well and look after them well. The idea of coastal reservoir and Sarovar mala is a futuristic one. We need to look at coastal reservoir as a new generation out of the box idea and we have to augment more ground water using underground dams and conventional rain water harvesting techniques which we have completely forgotten once we started building large dams. We have to actually revive all the rain water harvesting techniques (discussed in this presentation). We still need to create additional storage of water, because our population has exponentially grown and now we are becoming an industrialized nation. For any industry to survive, water is critical. All industries require large amount of water. Many large companies from different parts of the world are coming to India and we need to provide them land and enough water. If you go on building interior large dams taking away the valuable land (because of submergence of villages and downs in the back water), then where from will we give land for the industries. So we need to save the land we have and create new land for industries. We need to come up with innovative plans for storage of water. This innovative storage of water that is what I am looking at which is very essential for India to become world leader in another 30-50 years. Unless we adopt a "mission water", a strategy to store water at right places and right locations we cannot be hosting large number of industries. Second point: In majority of our coastal towns, the population is increasing and thus we need water, to augment food and energy production in these coastal towns. The proposed coastal reservoir will supply water to them. Third point: Due to climate change, our rain fall is actually shifted to coastal areas. Kerala got flooded in the recent rains during the last monsoon. Similarly, Mangalore get large amount of rainfall > 5000 mm. If average rainfall is 1000 mm, coastal areas of India would get almost close to 3000 to 5000 mm rain fall. Is not wise to store water which is available to you at the toe of river catchment?. We have built dams inland and found that there is no rainfall behind these dams due to climate change aspects. Due to climate change issues, rainfall pattern has changed and now shifted to coastal areas, so we need to look at coastal reservoir as a solution. So with these three points i.e., availability of land, the climate change aspects and where the water is available are to be pursued rigorously to increase of storage.

Q. Is India working on the concept of second generation coastal reservoir, if not why?

A. I have already shown you that the Government of India have already planned in the Gulf of Khambhat. If you go to Kalpasar website, they have already called for tender for geotechnical investigation. So Gulf of Khambat is going to be the largest coastal reservoir once constructed. I have already shown you the modified plan, they are going to build a large reservoir, there in part of that will be salt water and half of that will be a fresh water reservoir, the height of the reservoir won't be too high so that it will protect the livelihood of the fisherman and the salt manufacturers by allowing part of proposed dam to have salt water storage. Only one part will be used for fresh water reservoir. Now they have called for tender for geotechnical investigation. If you look at the details, Thanneemukkom bund and several of the water reservoirs in Kerala fall under the coastal reservoirs. But maintenance is a major issue, so we need to need to do much more quality work in maintaining these coastal reservoirs, which we have constructed in Kerala and also what we are going to construct in Gujarat. I think there is a good possibility even in the other coast because large number of rivers are dumping large amount of flood water to the sea, one can create second generation coastal reservoirs to store the flood waters.

Prof. Shu-Qing Yang: Thank you Prof. Sitharam, from your lecture it is very clear that India is not running out of water and water is running out of India, the message is true for other countries, for Indonesia, for China, etc. We don't have water shortage, the shortage of storage is the problem, that is a very important message for everybody and in future most of the people live in the coastal area and future generations will drink water from coastal reservoirs. Thank you attendees from all over the world for attending today's webinar.

Prof. Sitharam: When I made this presentation in Australia in a workshop and showed you the “Sarovar Mala Concept”, many of you came up with the Sarovar Mala concept for Australia, Malaysia, Taiwan, and China. This means that the concept of connecting coastal reservoirs immediately caught an eye among all the researchers across the world. You need to share and publicize this aspect as the Secretary of IACRR.

Dr. Susheela Venkataraman: Thank you Prof. Sitharam for the wonderful journey you took us on water storage solutions from century ago and brought us to where we are today, clearly the solutions lye in thinking differently and thinking out of the box and today you talked us through what those solutions could be. So thank you very much, I think judging by the number of questions the interest is extremely high and there are a lot of thoughts that are going into these ideas. We probably need to do yet another session to address all the question that we have. So some point of time, we look forward to having both of you and

Prof. Shu-Qing with us on a different discussion. Thank you Prof. Shu-Qing, we really appreciate you for taking time to be with us.

Prof. Shu-Qing Yang: It is my pleasure, as I said I am an Indian also.

Dr. Susheela Venkataraman : When I talked to Prof. Shu-Qing, he said I feel as an India and not a foreigner. Thank you for being with us in the webinar.

ALUMNI CENTRE

saturday WEBINAR

ENABLING HIGH TECHNOLOGY WITH MATERIALS SCIENCE

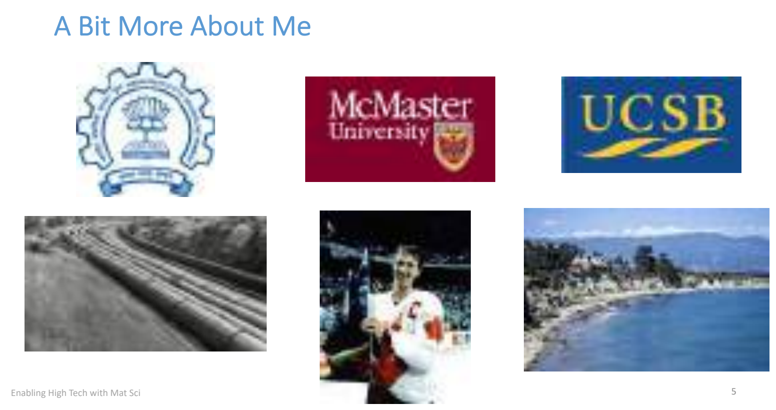
DR. KAUSHIK VAIDYA I MAY 16, 2020

Dr. Kaushik Vaidya has been a student of Materials Science since 1983. He studied the subject for a decade in the academic environs at IIT Bombay, McMaster University, and UC Santa Barbara. He feels he is fortunate to be learning the nitty gritty of materials development for the real world at University of Minnesota, Applied Materials, General Electric R&D, and Bloom Energy for the last 27 years. He has constantly sought to apply foundations of Metallurgy, Ceramics and Glasses to develop materials for the new economy.

Prof. Udayan Ganguly received the B.Tech. degree in Metallurgical Engineering from the IIT Madras, in 2000 and M.S. and Ph.D. degrees in Materials Science and Engineering at Cornell University, Ithaca, NY, in 2005 and 2006 respectively. He has authored/co-authored 50+ journals, 90+ conferences and 25+ patents (applied/granted). His research interests are in semiconductor device physics and processing technologies for advanced memory, computing, and neuromorphic systems. He works to augment national semiconductor manufacturing capability at Semi-Conductor Labs, Chandigarh, for which he has won the Dr. PK Patwardhan Technology Development Award 2018.

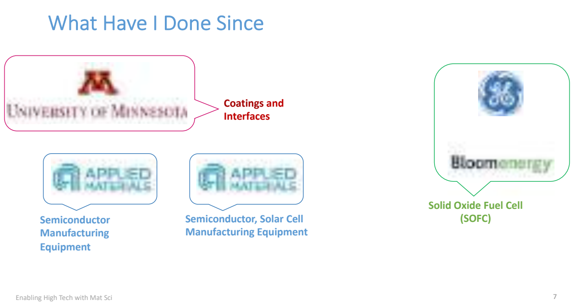
Kaushik J. Vaidya: We are going to talk about enabling high technology with material science. This is my background and this is what I learned and this is what I have been doing for the last three decades. The agenda for this presentation is, I will start with a little bit about my background and would tell what we are going to cover here. I am going to tell you what a material scientist does and what is material science, this will be followed by a case study, in my professional career starting 1995 and we will cover two other topics which are that of commercialization of the technology and science as well as volume manufacturing and I will end it with a couple of slides on what India should do and what is going to be the main takeaway from this presentation.

Just a little bit about me, I was born and brought up in Mumbai, for those familiar with the city, I am from a suburb called Vile Parle where I studied for 17 years and then went to IIT Bombay and did Metallurgy for four years and then studied at McMaster University, Canada and then to UC Santa Barbara for four years and currently settled in Bangalore. On the right image you see my home location on google map. It just tells you how technology has evolved, you know people in those days in 60s and 70s were travelling by train and stations were the way to go, to identify the suburb, now it is Google Maps, just an example of how technology is impacting our lives.



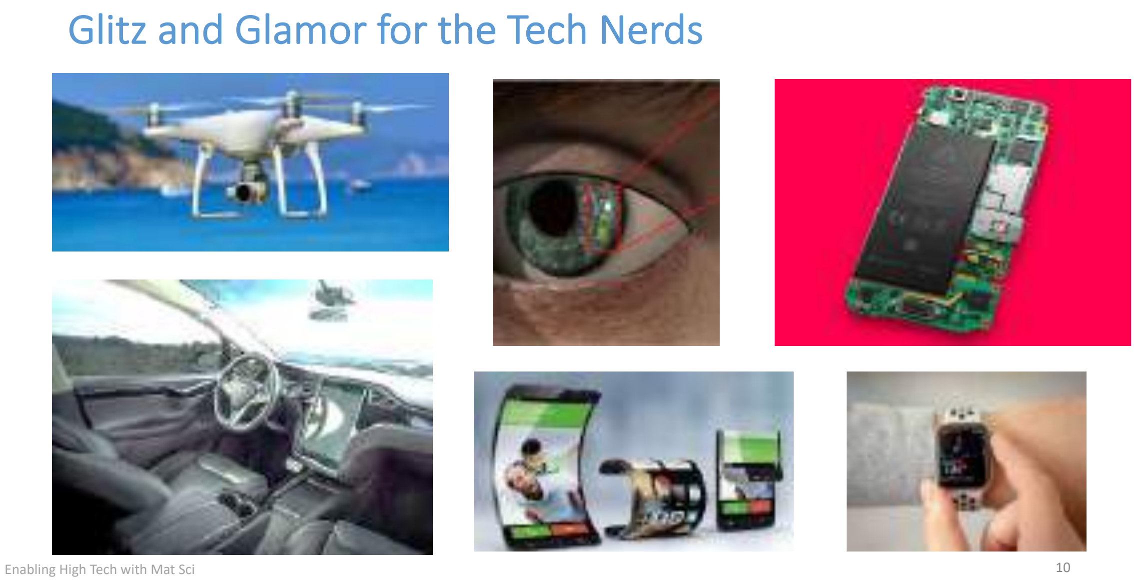
All of you will agree with me that it is not just studies that we do in classroom, there are a lot of other learning opportunities making us a well-rounded human being, they are summarized in the next slide. Those who studied there in IIT Bombay now would recognize what we would call the pipeline road the one behind the hostels, I was staying in hostel those years and used to go jogging and running up this place. In Canada, I started liking ice hockey. So this pic is of a guy named Wayne Gretzky and him lifting Canada cup in 1987, my first year at McMaster, and then the last photo on the right is Santa Barbara. Again I mean what can I say, it is sunshine and the campus is right on the beach. So that is just an introduction about me and now I will tell you what I have been doing since graduating in 1993. I was at University of Minnesota till 1995 following that I was with Applied

Materials from 1995 to 2001 and came back to India in 2001, joined with GE Research and worked there little over three years till Nov 2004. Then worked for a start-up called Bloom Energy from 2004 to 2005 and I re-joined Applied Materials late 2005. Since then I have been at our office in Bangalore. Starting my stint with GE, we have been located in Bangalore.



Next slide is just a very top view of whatever I have done in my professional career, for example University of Minnesota, in two phases at Applied Materials (during the six years in Santa Clara and last fourteen and half years in Bangalore). I have been working on developing semiconductor or semiconductor and solar cell manufacturing equipment and you will see these connects that the equipment bring through the whole high technology and specifically on semiconductors in the rest of the presentation. In GE and Bloom Energy I worked on something called a Solid Oxide Fuel Cell (SOFC), this is not exactly renewable but it is an electrochemical source for generating electricity. Why are we here? Right, so we are here to understand what is high technology, what role materials play in enabling this high technology and then how do you commercialize something and what India can do.

So I thought what is the best way to introduce the topic of high technology and as you see next slide, there is a bunch of images, so first is all of us who are like tech

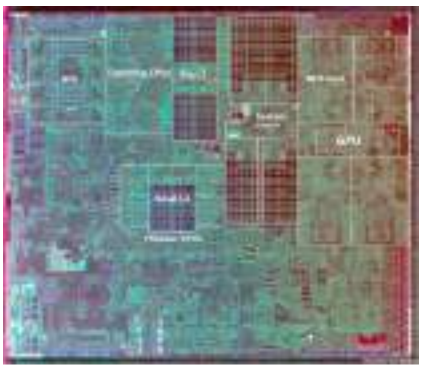


nerds, high tech is like glitz and glamour for us and every time a new gadget comes, every time a new device comes, we all want to know more about it, we all want to know the features and as a father of a 21-year old, I can tell you this understanding is very much easy to the next generation, they are far ahead of people in 40+ age group. The other message I want to convey or communicate in this

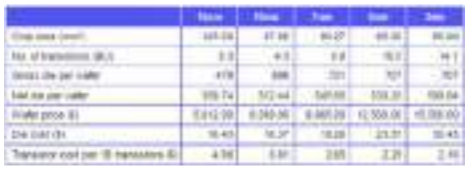
presentation is it may seem like magic that a mobile phone can do as much as it does but it is not all magic, I will show you images on how it all comes together and end the section with a sneak preview what is enabling all this. What I have is a bunch of images of what high-technology is, so in the present parlance it includes drones, it includes electric cars which may be self-driving, it includes foldable displays, a watch, that is also like a health diagnostic tool, also includes the image in the centre which is an eye and this is an eye that can help a person with high blood sugar in ways that we cannot think and then on the top right you have both the smart phone and the cover. So in the present talk, all of these are high-tech products in the 21st century but in the present talk I will go on focusing on smart phone, what this is if you take apart the latest iPhone 11, now what do you see here on the left I have what are all the chips so you see those squares or rectangle pieces, those are what we call as integrated circuits or chips. In the middle, the two black rectangles are the display and on the top right you have the cameras and there are three of them and on the bottom you have the battery. This is all what makes up all of your iPhone in terms of the hardware, you have the chips of the integrated circuit that does your calculation, stores your memory helps you make phone calls and then you have the display which is again pretty high-tech, pretty fancy both in terms of resolution and in terms of being able to detect things just beyond what you see on the screen and then you have pretty advanced camera and then the image quality is now controlled both by the hardware which is the camera hardware as well as the software and behind all of this is a powerful battery which has again its own set of material science enablers. So I am not going to touch upon display or the battery or the camera but for the purpose of this presentation I will take you through the bottom, middle and left portion of this slide which is the integrated circuit. I wanted to communicate that it may seem like there are discrete elements which make iPhone or any other gadget do what it does and in this particular presentation we will be covering the memories or the logic, the integrated circuits which go into the heart of the iPhone.

If you see the next slide, I am calling it what's behind the scene and I will be spending

What's Behind the Scene ?



Die Block Comparison (mm²)		
SoC	Apple A13	Apple A12
Process Node	TSMC N7P	TSMC N7
Total Die	98.48	83.27
Big Core	2.61	2.07
Small Core	0.58	0.43
CPU Complex (Cores & L2)	13.47 (9.06 + 4.41)	11.16 (8.06 + 3.10)
GPU Total	15.28	14.88
GPU Core	3.25	3.23
NPU	4.64	5.79
SLC Slice (SRAM+Tag Logic)	2.09	1.23
SLC SRAM (All 4 Slices)	6.36	3.20



https://wccftech.com/apple-5nm-3nm-cost-transistors/

https://www.techinsights.com/blog/apple-iphone-11-pro-max-teardown

https://www.anandtech.com/show/14892/the-apple-iphone-11-pro-and-max-review/2

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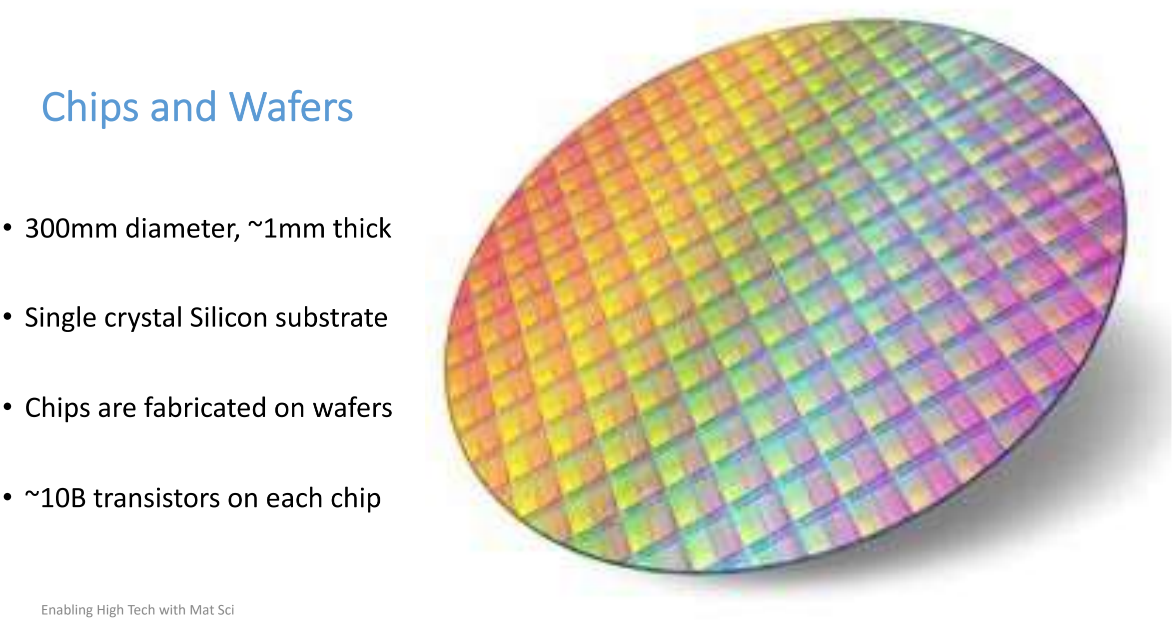
a few minutes on this slide. The square looking thing is what we call microprocessor or the A13 which is the heart of the iPhone in the middle table you will see here, it says Apple A13 and it compares it to Apple A12 and right under that it says TSMC and thin wafers. TSMC is Taiwan Semiconductor Manufacturing Corporation, this is their animation on it again as the size of different die which are on this device. Then the table on right, it just compares what are your technology nodes, what is the chip size and how many transistors are on this particular device so if you see in the second row, it says number of transistors billion unit; so for a five or a seven nanometre node we are going to have up to 10 billion transistors and that should give you a sense of how many transistors each chip has and what is the size of each of those and what is the number of dies per wafer we have. It also has parameters such as what is the price of the die and what is the transistor cost per million transistors. This is not just technology or scaling or getting down to the nanometre dimension, there is also the economics of it. The economics is what kind of makes or breaks and we will cover this in the subsequent slides but the message I wanted to communicate through this is we are truly developing these products with nanometre scale precision, nanometre scale manufacturing, there are literally millions of transistors in a chip and the die cost itself is coming down because we are putting a lot of transistors per die.

Next slide is on Chips and Wafers, this is again for those who are not familiar with this



field. We call it a wafer, what it really is a 300 mm slice of silicon, it is a single crystal silicon about 1 mm thick and chips are fabricated on these wafers and if you see the colour disk on the right what it communicates is the repeat layers and each one of this is as I mentioned in the previous slide, we have about 10 billion transistors in each, so if you just think about it for a minute we are starting with a slice which doesn't have any layers any films any coatings on top and then and after about 1800 process steps, we are converting it into a piece of silicon which has these dies which has this billions of transistors, the cost to set up one of these factories I will cover in the subsequent portion. This is what I do, this is what my colleagues do at work, this is what Prof. Udayan does when he designs the circuits, when he designs these chips to make this integrated circuit to make these devices. I wanted to spend just a couple of minutes giving you a very top level view of how it comes together. So we covered the gadgets, we covered high tech products, we covered smart phone as an example, we told you there are chips like A13, also told you what is actually inside A13, how many transistors, what is the size of each of them. Now we are going to tell you how each of these transistors are made at a very top level. The whole process of fabricating these chips involves very sophisticated material science, it involves hundreds of unit processes, it involves integration, packaging and it involves sophisticated characterization process. One of the ways you look at material science is you start with what you studied in Chemistry during your school days and you say what is the foundation, one of the ways of looking at the foundation, the other way to look at it is what are the different materials, crystalline and amorphous or glassy and the third element is how do you characterize, how do you make these things, this impulse to make this in difference and what is the role of nanotechnology. I briefly touched upon the fact that we are truly working on five nanometre and ten nanometre, I will show you what those dimensions are in a minute just to set the context.

Materials Science in 10min

- Periodic Table
- Crystalline & amorphous materials
- Processing and characterization
- Metals, Ceramics & Glasses, Polymers, Composites, and Semiconductors
- Thin films
- Nanotechnology

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Next slide is just revising the college class, I say this because this is your periodic table, what I would like to highlight is the elements on the right, silicon element that

Periodic Table

- Classification based on atomic number, atomic weight
- Often used as guide for materials selection, alloy formation, and doping.
- Can be considered as one of the foundation of Materials Science

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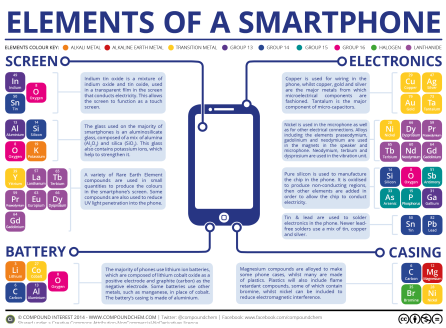
makes number 14, more of the phosphorus, silicon is the semiconductor, it's property is mainly that its electrical properties can be changed in a controlled manner, opening it with small amount per billion, or less, of elements such as phosphorus. There are other elements of periodic table which are dear to material scientists and we will see that in the next slide.

Periodic Table (Contd.)

- Touch screen, Battery, Electronics (chips) and Casing use specialized materials.
- Bulk materials, thin films manufactured using atomic precision.
- Selective doping, surface and interface control are key for reliable performance.



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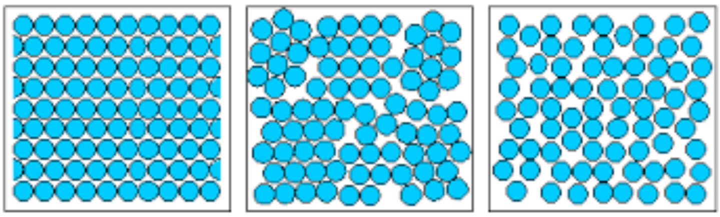
Again I will go back to the smart phone example. So when you look at the smart phone, you have screen, you have battery, electronic chips and casing using specialized materials. What this slide shows here is what are all the elements of a smart phone. In electronics, not only do we have metals which are copper, silver, gold, platinum, we also have bunch of different levels which go into making the chips, we have selective doping, surface and interface control which are key for reliable performance. That just tells you how much of knowledge, how much of experience is needed to make the latest A13 or any other chips that is required. In addition to that you also have a screen which has its own materials, battery which is nowadays lithium-ion and then you have the casing. You don't see any of these, nobody tells you what is inside the phone but next time you use your phone I hope you have a sense of appreciation how much of technology goes into building a device like this.

Crystalline & Amorphous Materials

- Periodic arrangement is the determinant.
- Metals, Ceramics & Glasses, and Polymers exhibit all 3 types of arrangements.
- Atomic arrangement affects properties, end application.
- Can be considered as one of the foundation of Materials Science



Single crystal — Periodic across the whole volume.

Polycrystal — Periodic across each grain.

Amorphous solid — Not periodic.

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The next slide is about Crystalline and Amorphous Materials. This is a very very top level view about materials as I mentioned, there are two classes mainly crystalline and amorphous, it has to do with periodic arrangement of atoms, molecules, in some cases that is the determinant on whether something is crystalline or amorphous there. There are different classes here as well, metals, ceramics, glasses and polymers, and each of these material class can be made amorphous or crystalline depending on how you process it. The other thing which I would like to bring up here is that the whole set of materials and their arrangements at the atomic level is another foundation of material science just as periodic table was.

Materials Processing, Characterization

- Plethora of techniques, technologies available to process materials.
- Technologies often developed, selected for specific end applications.
- Diffusion bonding, and additive manufacturing (3d printing), and selective doping are emerging technologies.
- Modern characterization techniques allow mapping atoms to detecting cracks in large structures.

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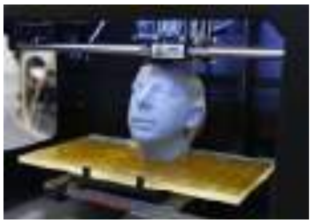

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Next is about materials processing and characterization. I will not spend too much time on this but this is how you make materials. There are thorough techniques and technologies, what I have shown here is 3D printing kind of things which takes you back to mission impossible movies but people are using 3D printing or additive manufacturing for doing something really unique in several industries.

Nanotechnology & Thinking Small

There's Plenty of Room at the Bottom

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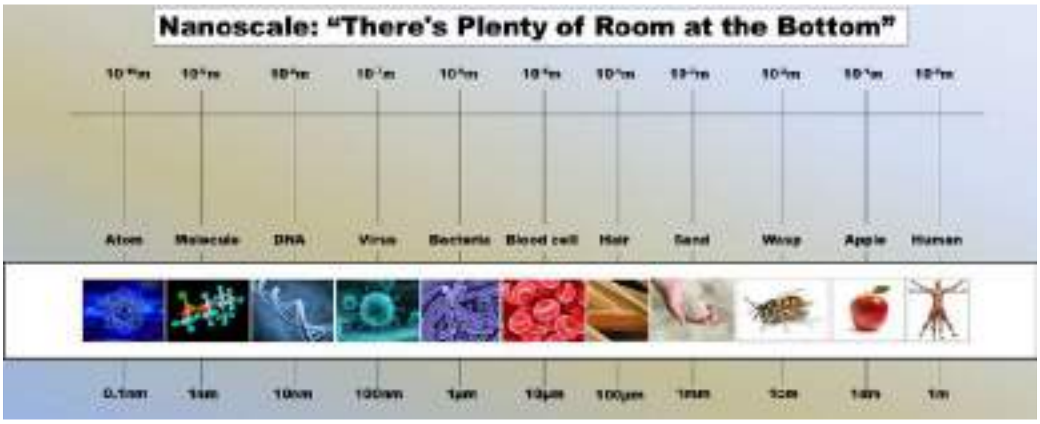
The whole field of semiconductor manufacturing was envisioned more than sixty years ago by Prof. Richard P. Feynman, who was a Professor of Theoretical Physics at Caltech. He had a seminal work done in a paper published `There's Plenty of Room at the Bottom'. I will be happy to share this semi-technical paper with you but his main findings or sort of look into the crystal ball, well there is plenty of room as is being able to mediate is being able to move atoms and believe it or not in 60 years since he published the paper, 65 years since he did the work, all of this is coming to fruition now. You will see in subsequent slides, we do many plate's work of 1 nanometre, 3 nanometre, 5 nanometre scale devices. The message again here is almost everything is high tech, science leads and then technology follows, commercialization of the technology is where materials science plays huge role.

Nanotechnology – Length Scale



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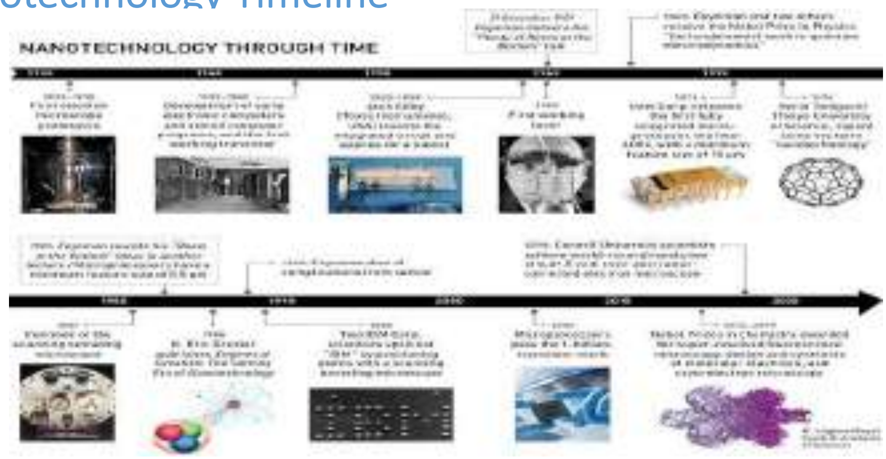
This slide, those who are not familiar with nanometre, this is just a landscape, on the right side it just says human 1.8 meter tall, about 6 feet, and as you go to the left you see the size, the length scale, is shrinking, you have 100 nanometre virus size; but the dimensions that we are talking about is a lot smaller than a virus, even smaller than a DNA strand. DNA strand is of the order of 10 nanometre and when we talk about one nanometre, we are truly talking about molecules just as a reference, typical size of an atom is about 3 Angstroms, so when we talk about 5 nanometre we are talking about between 15 to 17 atoms, how do you arrange them, how do you move them, how do you modify them, deposit or selectively remove extra and more importantly how do you see them. Did you have some pretty sophisticated microscopes and other technological tools to characterize these devices and you will see that in the next slide.

Nanotechnology Timeline



https://www.osa-opn.org/home/articles/volume_30/july_august_2019/features/still_plenty_of_room_at_the_bottom/

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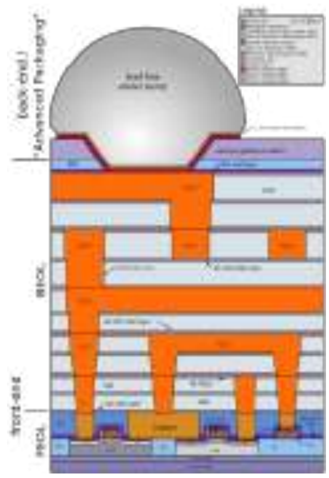
I just call this as Nanotechnology Timeline. If I mention here, it all started with Prof. Feynman's lecture — there is plenty of room at the bottom — which was in late fifties and then Intel started bringing their chips to market in early 70s and since then there was work done on carbon. This term nanotechnology was coined by a Professor Taniguchi of Tokyo University. Another big development was in the field of characterization where scientists developed something called as an STM which is scanning tunnelling microscope, researchers at IBM use that and if you see here in the timeline, in 1989 they actually spelled out this word "IBM" by positioning atoms using scanning tunnelling microscope. Since then as you know there is no looking back and almost in 2005 we had the first microprocessor or a first chip which had a period transistor and in 15 years since we are today we have 10 million chips with 10 million transistors. So if you think in terms of time scale, if you think in terms of what it takes, and what it takes to commercialize, it is phenomenal that we have made the progress we have and continue to go down that path. You will see some of these roadmap items in the subsequent slides.

Thin Films

- Deposition, removal, and patterning of thin films is fundamental to semiconductor processing.
- Thin films range in dimension from few atoms to 1000s of atoms.
- Thin film processing is carried out in vacuum, using a variety of chemicals, materials and energy sources.
- Manufacturing of semiconductor chips involve the use of various thin films on Silicon substrate.



https://www.extremetech.com/computing/235842-globalfoundries-announces-new-7nm-finfet-process-full-node-shrink

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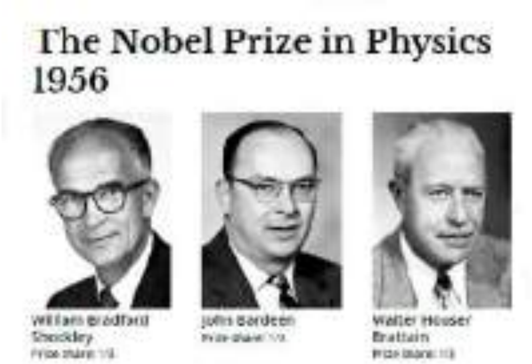
I will end it here with portion and say that this is how thin films and materials come. The deposition, removal and patterning of thin films is fundamental to semiconductor processing. Thin films range in dimension from few atoms to 1000s of atoms. Thin film processing is carried out in vacuum using a variety of chemicals, materials and energy sources. Manufacturing of semiconductor chip involves the use of various thin films on silicon substrate. If you see the image, there are three words, first it says FEOL and then it says BEOL and then it says back-end or advanced packaging, so FEOL is front end of the line, this is where transistor and first pair of first metal connection are made and you have BEOL which is your back end of the line and now we have to put up seven line levels of BEOL or interconnect and at end you have lead free solder bump. So if you look at a cross section image, the action or the movement of electrons in working of the transistor happens at the FEOL level, this is where you truly have nanometre scale dimensions; after that you go into the BEOL where you basically transport the electrons generated in the active or transistor region and you take it to the outside in this package. Package area is where you make connection. I just want to say that front end of the line, in back end of the line is where most of material science and the technology can make impact, and it is where I have been working during my career.

Next slide is about what is a memory cell and I will also cover solar cell after a break but I want to give you a glimpse of what is the memory cell. The original transistor

Transistor



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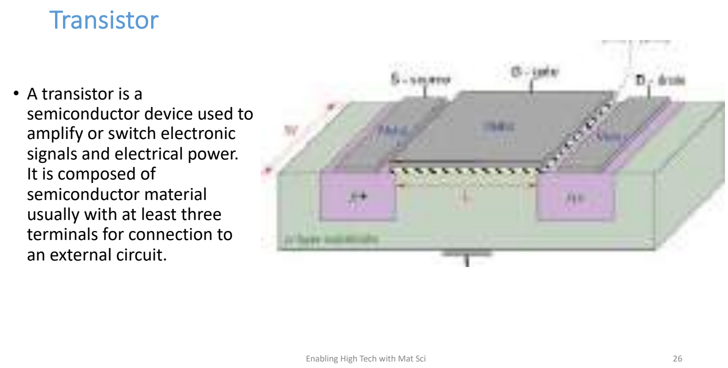
was invented by gentlemen here John Bardeen, William Bradford Shockley and Walter Houser Brattain who got Noble Prize for it. This was a very clunky looking device, this is their original germanium transistor so germanium also can be used under certain conditions but this was mid to late forties and since then doped Silicon is the material of choice for transistor technology.

Next slide is again a very basic view of the transistors like I said it is nothing but a



semiconductor device which can be used for amplification (or switch) in electronic devices. It is composed of semiconductor material usually with at least three terminals for connection to an external circuit. One neat thing about the transistor in this particular case, I am showing you an example of what is known as a Field Effect Transistor (FET) where the dielectric is metal oxide. In what you see here is a single crystal p-type substrate that is doped with phosphorus or n-type dopants, you have Silicon Oxide which is dielectric, and then you put metals on it. What are the challenges and how do you define the areas you make sure that there is isolation between the N doped and P doped regions, how do you do your circuitry so that you can pack as many transistors as possible. That is where the design and materials creativity meets technology.

Next slide shows the Transistor timeline, transistor is celebrating it's 70th year, I can send these slides to you and you can study this in detail.

Transistor Timeline

https://www.electronicsweekly.com/news/first-transistor-created-70-years-ago-the-device-that-changed-the-world-2017-12/

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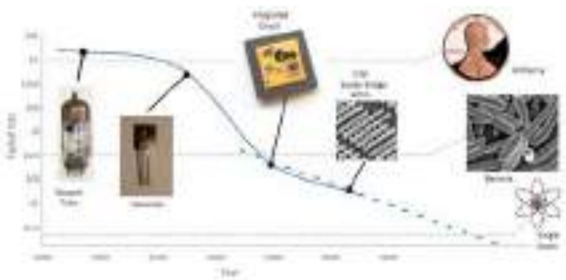
Next slide is about Transistor Size Evolution, it is important because if you see here this is your dimension, the x-axis is the time line; on the y-axis, the typical size and this is of course on the log scale, so the whole integrated circuits and the Intel 22 nanometres came may be 15 years ago but since then this line just continues to go down and then we are almost at single atomic layer critical dimension or we will be in a decade from now when we are dealing with anywhere between 3 and 7 nanometre in volume production. Again, another illustration of how complicated these are getting and how much of returns you get if you do it right.

Transistor Size Evolution



https://theglobalscientist.com/2014/04/07/the-next-big-step-in-computers-what-can-physics-offer-us/

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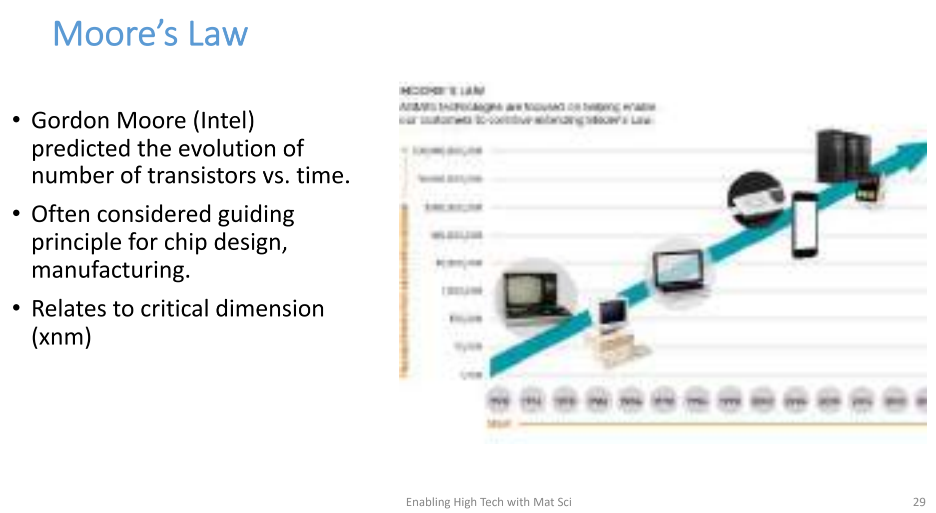
Next slide again is something known as Moore's Law. Gordon Moore (Intel) predicted

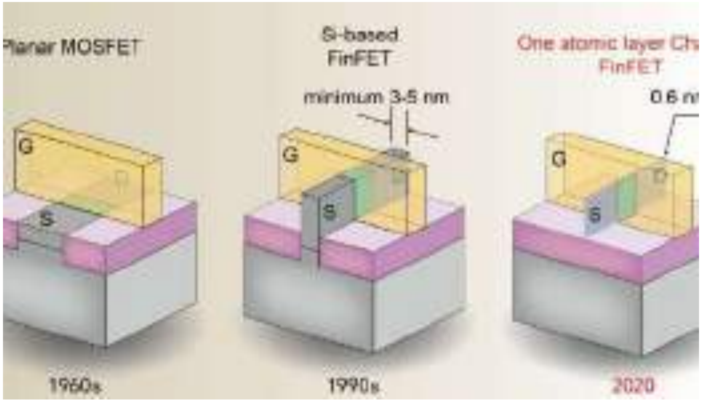


the evolution of number of transistors vs. time. It is often considered as guiding principle for chip design and manufacturing. It relates to critical dimension (x nm). This again is timeline and the number of transistors as I say we shrink the size or the length dimension we get these transistors into three-dimensional structure so from 2D to 3D, it is one of the change that happened and there has been lot of evolution in materials and designs we do but I like this because it just graphically shows how it evolved from PC to smart phone, now to medical devices integrated in a watch and everything is moving to access, now a days that is challenge and an opportunity for us. So Moore's law is nothing but sort of prediction based on his knowledge and his experience of how the number of transistors will double almost every 18 to 24 months.

I wanted to give you another view of how the transistor has evolved from a planar to a 3-dimensional silicon based on what do we do into a one atomic layer. So if you

Transistor Evolution

- Miniaturization of critical dimension
- Increasing complexity in volume manufacturing.
- Rapid advances in unit processes and process integration.
- Up to 1800 process steps to make a chip



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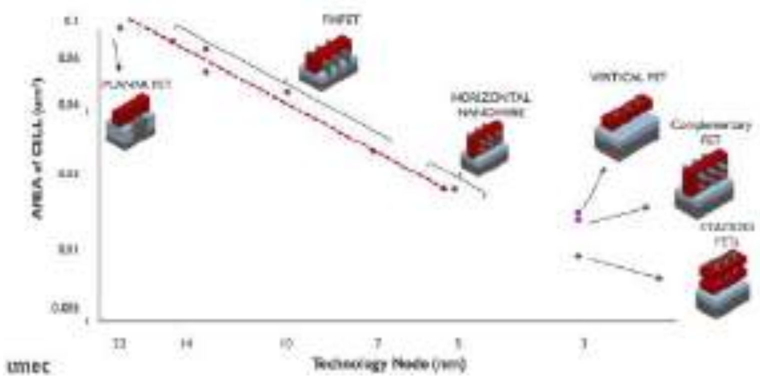
see here from 1960s to 1990s to 2020 what has increased is the complexity and as I referred to earlier we have up to 1800 process steps in some of these advanced chips as we consider size ranging from say 3 to 5 to 7 nanometre for the most critical dimension.

Now we go to the next slide, same thing, how are we going to do it. We call it technology node, how we enable this is something that is my employer, Applied Materials' and their customers are working on.

Technology Node Trend



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We did cover High Technology products, we did cover elements of the product which is a smart phone and a A13 chip, we did cover what goes into this A13 chip and how many transistors and we did cover the role played by device technology and materials.

I want to summarize the three main takeaways for you to think about in next few minutes before we change gears and get into the next part of the lecture.

1. High Technology Products are Pervasive.
2. Materials are Unseen Enablers of High Technology Products.
3. Advances in Nanotechnology are Accelerating Materials Development.

Munch on

1. **High Technology Products are Pervasive.**
2. **Materials are Unseen Enablers of High Technology Products.**
3. **Advances in Nanotechnology Accelerating Materials Development.**

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Prof. Udayan Ganguly: *Thanks Kaushik, I think you are doing really well on time, things are quite interesting, there were a couple of questions. One of them was about particle sizes, so a question was about how to make very small particles for example, chemists can make about hundred nanometre particles with hydrothermal or thermal processes but what would be methods to make particles at 3 to 10 nanometres. So I thought that this would be a good time for you to respond, what sort of control we have now in the semiconductor world.*

A: A couple of things, in semiconductor world especially when it comes to fabricating integrated circuits particle defects are extremely undesirable because these can be yield killers, we don't want them on the wafers or the substrate but I see other applications for nano-particles and then we have been using for example there is something known as a core-shell structure. So you have a core which can be kind of a sacrificial and then on top of that you do deposition, then you remove the core selectively. So that is one way you can have your particles approaching nanometre one of the process used for doing this is what we call Atomic Layer Deposition (ALD) It is also used to deposit coating some particles of that landscape and there are applications not only in semiconductors but in energy storage as well as in pharmaceutical. ALD and some of the other hydrothermal synthesis, this is something you talked about, combustion synthesis is other for forming nano sized particles.

Prof. Udayan Ganguly: I also think that it is important to highlight that particles are also of a gross unit of material, if you look at a semiconductor device like a transistor the gate length which are printed by control is about 10 nanometres. It is not only that people can make particles, they can write small designs on the particles today. Of course I think there are ways to make these particles as electrically charged as I was saying so I think we are in terms of technology control there are lots of ways to do it, the question is what is the application and where is money in the application.

Dr. Vaidya: It is all about commercialization.

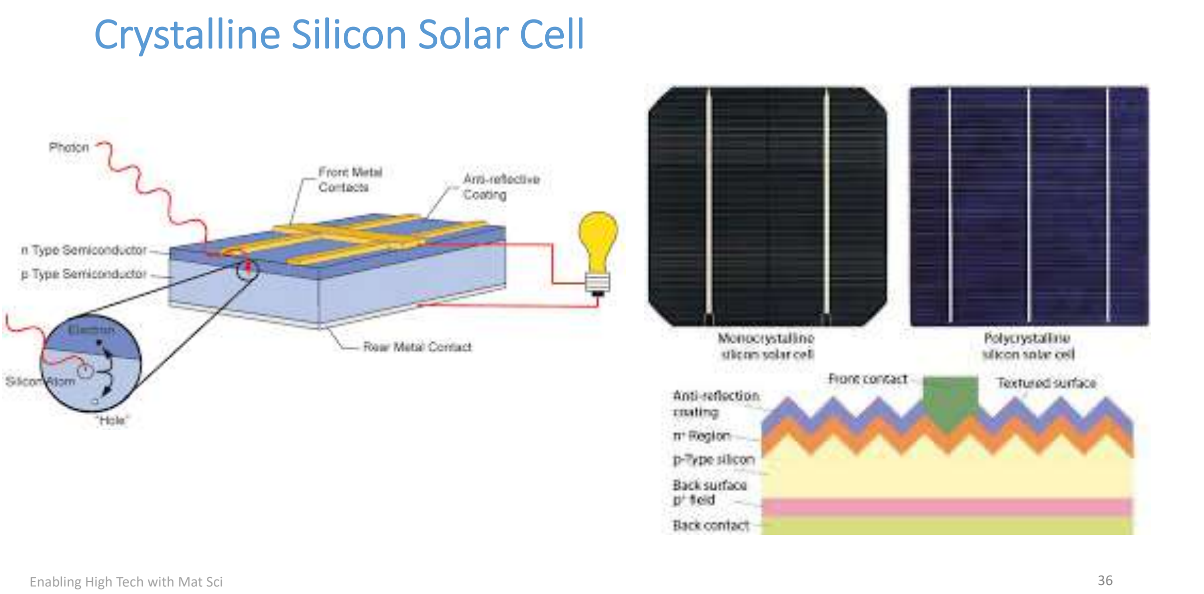
Prof. Udayan Ganguly: Another comment that came in is that there is this whole thrust on materials recycling and in the time of Covid when some of us who are lucky to have gardens, we are trying to compost and make our gardens. In the semiconductor world there must be a need to recycle because materials of course are scarce. I think it will be a good question to address.

Dr. Vaidya: In the electronic industry, if you look at the semiconductors, what we don't see is at the nanometre level, but there is plenty of metals like copper, platinum and at the very back end even gold and silver. There are companies who have benign chemistry to strip, remove and recycle and reclaim at least some of the transition and precious metals. What doesn't get so that is number one, number two is the whole industry is now moving away from Lead (Pb), so you look at the back end soldering or any other elements that you need to join them at the gross level, there are Lead free solders. So recycling, reclaim and using it, doing it with chemistries which are known. It is happening but it can't be done because if you just look at this smart phone as an example, literally there are hundreds of millions of smart phones which are manufactured and sold every year and the useful life of all is about 5 years, everyone updates their phone and then what happens to the one which you had already and lot of these smart phones, if you tear it apart, in addition to the plastic and that screen all the integrated circuits that are in the recycle and at least the materials mainly the metallic elements are reclaimed for other applications. Good question, but there is need for being creative in developing chemistries which do a better job and do it more efficiently than what is being done now.

Prof. Udayan Ganguly: This is a good segway to the next part of your talk. You may continue and we will have another set of questions to be answered. There are some questions that have been posted that we have not addressed. Some of the questions we will take up once the talk is done and there is more of a discussion.

Dr. Vaidya: One thing which I did not cover is how much electricity is required. We all talk about the latest and greatest social media app and a large number of population that is using social media. There was some statistics which I read on how many uploads are there on YouTube or Instagram and you have to imagine all of these data that is being generated is stored somewhere. It is stored in massive server farms and the server farms need electricity that is point number one, so the electricity demand increases as the adoption of semiconductor and the adoption of high-tech gadgets increases. And point number two, at the technical or technological level, lot of heat is generated in all these, so the whole way of dissipating heat not only within a chip but even within a server farm, it is going to take lot of creativity. Number three, if you keep burning coal for electricity, we will have the whole debate on global warming, ozone layer, etc. So lastly it may be a kind of a parallel development. Two main sources of renewable energy are wind energy and solar, so I thought it is a continuation of this theme of semiconductor and specifically on silicon based semiconductor. What else can we learn regarding the use of materials? We can go to the next slide.

I will give you a basic glimpse of Solar Cell and specifically I will cover Crystalline Silicon Solar Cell. So just as you have variety of different types of integrated circuits, some based on silicon some based on 3-5 or 2-6 compound semiconductor, in solar cells also you have both organic and inorganic, within the inorganic portion of solar cell, it is crystalline and thin-film solar cells, there are CIGS solar cells and the whole range of technology and materials when it comes to solar cells. In terms of adoption, I would say about 95% of the solar cells and modules that are used in the world based on the same exact crystalline silicon that is used to develop pure integrated circuits and chips.

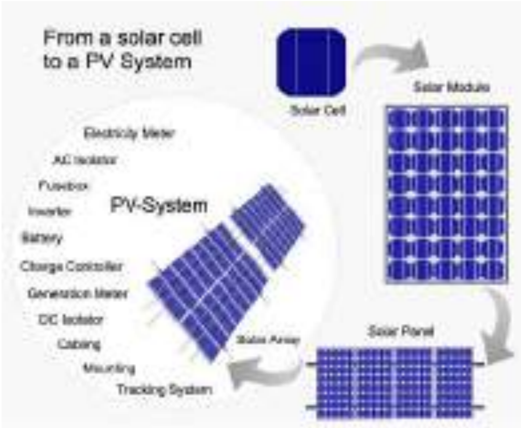


In the next ten minutes or so, I will cover the basics, same doping, same Silicon and phosphorous used to make integrated circuit, also used to make solar cell the same passivation and the silicon nitride layer in this case is used and what is different is the metallization scheme and as Udayan and I were discussing, metallization is far more complicated for an integrated circuit but for a solar cell it is screen printing using silver or silver aluminium alloys. I will touch upon that as well and we will talk about integration.

The genesis of this is what is known as photoelectric effect. This was done by Albert Einstein who won a Nobel Prize for this in 1905 and what he observed was in this one of the alkali metal I think it was testing with potassium at that time where above a

Photovoltaic Energy Value Chain

- 156mm x 156mm, ~0.5mm thick Silicon substrate.
- Typically, 4 Watts per cell
- 60 to 72 cells per module.
- Roof-top (few kW) to Megawatt scale installations
- Technological advances across the value chain



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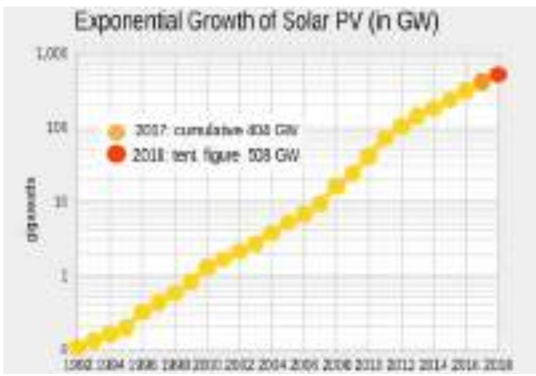
certain wavelength above a certain frequency it was emitting electrons. That is how we call this term photoelectric effect. Thanks to photon which generates electricity. In the next slide, I will show you how this happens. Silicon as you know is an indirect band gap semiconductor; so in a certain range, it includes visible spectrum as well, silicon does generates electricity using photoelectric effects and what you see here in slide on the right are two squarish looking things so the black is called mono-crystalline silicon solar cell and the bluish looking square piece is called polycrystalline or multi-crystalline silicon solar cell and the cross section view is what you see here again might say you started with a bulk silicon, deposit layers, pattern layers, region you form a junction, on top you form what is known as an Anti-Reflection Coating (ARC) layer and then you put the metal contact so the lines you see here, two lines on the left, three lines on the right and then you have very fine lines under those that is what is called as the metallization and the grid lines.

I will show you in the next slide, how the whole system is coming together. Some of you may have seen and these days even rooftop solar is picking up but it all starts with a single 156mm x 156mm slice of silicon substrate, it can be single crystal or multi crystal about half mm or now a days it is even getting thinner, each silicon solar cell typically, 4 watts per cell, between 4 to 5 watts. What they do is the amount of electricity is not enough, so they combine these cells and form what is called as the module, this rectangle which is combined if they do a series and parallel connection of anything between 60 to 72 cells and each module these days generate about 300 watts. Then you take these modules what is not in the panel and people who have roof top solar cells for generating electricity for use for their own residence anywhere between 1 to 5 kilowatt on the rooftop. In addition to that there is also these solar farms which generate 10s to 100s megawatts. So to rooftop is ok, you can have one, three may be five kilowatt worth of solar panels but when you are talking about solar farms where you are generating about 300 megawatt, you need much more than solar panels, you need your isolator, you need your controller, battery, inverter and eventually lot of these farms feed electricity to the grid. So there is a whole infrastructure on that as well, and current government and when Mr. Modi was Chief Minister of Gujarat, he was a big proponent of using solar electricity and that has definitely contributed to present scenario where the usage of photovoltaic power plant now in a place like Germany a lot more renewable are used between solar and wind but in India also renewables have seen increasing market share for the last five years or so.

Solar Electricity Adoption

- Rapid adoption during the last decade.
- Improvement in technology, affordability.
- Reliability, low performance degradation for 25 years.
- Modular, scalable, and can be grid connected.



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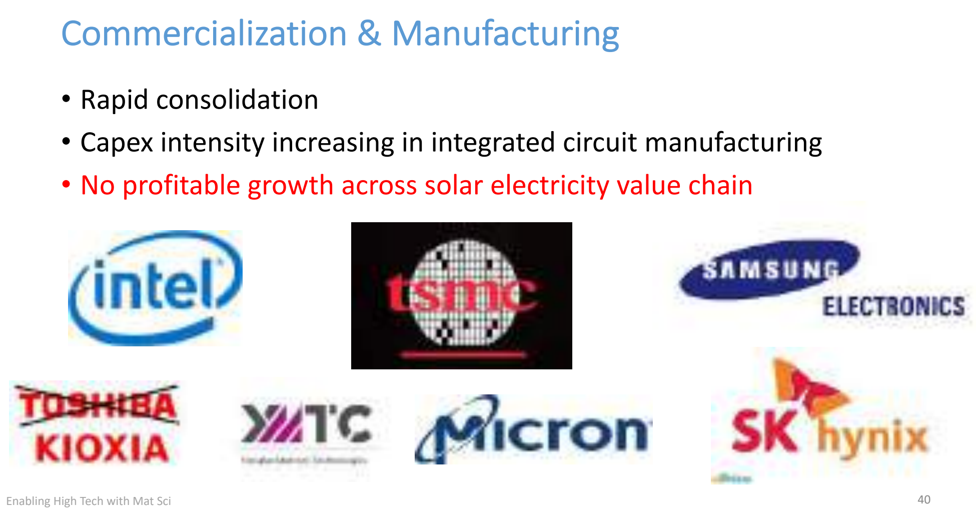
In the next slide, I am again showing the Solar Electricity Adoption. This is again the log scale on the y axis, we are on the x axis. Total cumulative solar installation, solar photovoltaic this is in giga watt which is 10 to the power of 9. Giga watt is a thousand megawatt and again if you see here variety of reasons, first there is improvement in technology, there are subsidies which has made it affordable as well as this is now demonstrated beyond a doubt that if the panel or if the module is made right using quality materials and manufacturing processes, this will last easily for 25 years with about 10% reduction in performance over the length of time and the other good thing is it can be sort of grid independent mode. So again this is an example where the use of silicon has led to a fundamental shift in the way people look at electricity. So silicon is the same silicon, say used as a semiconductor or say the substrate, use of material science to process, to deposit layers, to pattern it, and to do metallization. So people did install the solar cell 25-30 years ago mostly in US and now thinking of recycling it with the chemistries and processes that are developed so that the aluminium and silver that is used can be reclaimed, but in India we are several decades away from that requirement.

In the next slide, I am going to change the theme a little bit. So just to recap we covered on gadgets, we covered about high-tech products, technologies, two examples, two case studies, one is integrated circuit space and the other is on renewable energy.



Now I am going to talk about what does it take to commercialize and to make it now again in parallel to other if you look at say what automobiles is an example there are lot of car manufacturers may be 30-40-50 years ago and now it is really shrunk to may be 10 to 15 across the globe and we see the same thing happening in semiconductor. So two or three parameters or factors affecting that. First it is about volume and scalability because the profits the investment require are increasing. The profitability also increases if you are in all segments of the value chain right from making substrates or silicon, there is a term called IDM, Integrated Device Manufacturers and you will see in the next slide who those are and how large corporations they are so if you see this again as I mentioned, there is consolidation now of these logos that I have here which most of you are familiar with Intel or

Chip Manufacturing

Taiwan Semiconductor Manufacturing Co. (TSMC), which manufactures processors and other chips for Apple, AMD and many other firms, has confirmed that it will build a **$12 billion chip fab plant** in Arizona. The company will utilize its **latest 5-nanometer manufacturing technology,** with the capacity to build **20,000 silicon wafers per month**. As expected, construction will be subsidized by the US government and the plant will create 1,600 high-paying jobs. The US government has been reportedly been in talks with TSMC for months, according to an earlier report from the *WSJ*.

A sticking point had been the high cost of building the plant. TSMC chairman Mark Liu told the *NY Times* last year that since it's more expensive to operate in America than Taiwan, the company would require major subsidies. There's no report yet on how much money the US government will pour into the plant.

In the United States, TSMC currently operates a fab in Camas, Washington and design centers in both Austin, Texas and San Jose, California.

The Arizona facility would be TSMC's second manufacturing site in the United States.

TSMC is a massive contract manufacturer for numerous fabless chip makers. It builds AMD's CPUs, Apple's A13 processor for the latest iPhones and iPads, the Qualcomm processors used in Android devices and the chips used in both NVIDIA and AMD GPUs. Even companies with their own fab plants like Intel and Texas Instruments outsource some production to TSMC.

The company is well ahead of other manufacturers including Intel, **having commenced risk production for 5-nanometer manufacturing technology. It will reportedly use that process to build Apple's next-gen A14 chip,** which should increase performance but also increase costs, according to *Wccftech*. Intel, meanwhile, has only just moved on to 10-nanometer manufacturing and still isn't building its high-performance 10th-generation chips using the tech. (The only company currently matching TSMC's tech is Samsung, which focuses more on memory production.)

The White House has also reportedly been trying to convince Intel to build its upcoming chip fab plants stateside. According to the *WSJ* and *NYT* reports, the US Defense, Commerce and other departments are concerned about outsourcing chip supplies to other countries, especially China. Experts believe the US needs to invest a lot more in the sector, much as Taiwan, China, Israel and other nations have done.

TSMC addressed that issue in its press release, implying that the government needs to step up. "US adoption of forward-looking investment policies to enable a globally competitive environment for a leading edge semiconductor technology operation in the US will be crucial to the success of this project," the company wrote. "It will also give us the confidence this and other future investments by TSMC and its supply chain companies will be successful."

Construction will commence in 2021, with production targeted to start in 2024.

Enabling High Tech with Mat Sci https://www.engadget.com/tsmc-12-billion-chip-plant-arizona-083518143.html 41

Samsung or Micron. TSMC is what we call as a foundry as it stands for Taiwan Semiconductor Manufacturing Corporation. We at Applied Materials develop and sell to these companies so they are our customers, the names at the bottom you may or may not have heard of – SK Hynix which is a Korean chip manufacturer or Toshiba which is now known as Kioxia. These are all the companies which have survived, lot of others have gone into oblivion because they couldn't compete and the dimension shrunk and the investments, the capex went into billions. So this is only semiconductor for integrated circuits whether it is communication or memory application. On the solar side, it is a little different for a semiconductor used in devices and gadgets and high tech products people are willing to pay money. The challenge with solar electricity or photovoltaic electricity is the end product is still electrons and electrons can be generated from hydroelectric plant or from burning coal or from a variety of other ways, so people's appetite to pay money for solar electricity has not changed, they still want the same units per rupees per unit pricing and as a result what has happened is there is no profitable growth across the whole solar area. Companies have attempted to be profitable, companies have survived or they have reduced their capex when there is money in solar farm and downstream application. So that is one area which is different between semiconductors used in high tech products and semiconductor used in renewable energy and I will give you one example in the next slide which shows how much investment is required. This announcement was just made yesterday, so if you see this you will see what it takes to form the latest and greatest manufacturing facility for semiconductors.

Next slide is about Chip Manufacturing. This announcement just came as I said yesterday. This is a Taiwan based company, TSMC (Taiwan Semiconductor Manufacturing Co.) which is going to set up a manufacturing facility in Arizona in US and what I have highlighted here is the text of interest. So if you see here, the first number to remember is a 12 billion dollar chip fabrication plant. One billion is about 7500 crores. Number two, they are going to use this fabrication facility to make five nanometre manufacturing technology; we looked at the transistors and how they are shrinking, so TSMC is in my estimation based on what we know, it is the first one that is going to be setting up a five nanometre on volume scale. They have also come and say that this facility will build twenty thousand silicon wafers per month or equivalent devices and as I said each wafer has up to 400 dyes or chips so this is a very serious volume, number one, and number two, if you see the second or third paragraph, TSMC is a massive contract manufacturer for numerous fabulous chip makers such as Apple, AMD, Qualcomm. Earlier people used to send their chip design to a foundry like TSMC yet they would make it in Taiwan and ship the chip back but now they are coming closer to where the fabless companies are. Intel is not fabless but some of the other companies like Qualcomm and other are examples for this. The fourth paragraph what it says here is having commenced this production for five nanometre manufacturing technology, it will importantly use that process to build Apple's next generation A14 chip. So if you just thought that A13 chip and iPhone 11 just came, think again because when they launched iPhone 11 and the technologists, scientists and engineers at Apple were already working on an A14, they probably have the design done and now they are working with TSMC or another contract manufacturer to commercialize this product. The last highlighted item is that the construction will commence in 2021, with production targeted to start in 2024. So again there is a three year time line where it takes you to set up a green field fab and then get into a phase producing 20000 wafers per month. Two or three key takeaways here is our customers, Applied Materials' customers, are already planning, they have brisk production of five nanometre manufacturing so as I said 5nm which is 16 atom thick, this is going into mass production in next couple of years. There the linkage is very strong between manufacturer like TSMC and their customer which is Apple and their supplier which is Applied Materials and this is what keeps this whole product engine going, every two to three years they say refresh cycle, every two to three years there are some new features and almost every year people are uploading more images and data as and when doing more computation so until that continues, this technology advances now going beyond five nanometre to three and two nanometre, this is the way and this industry and all the products that are supported by this.

Next are probably my last few slides. We talked about all this but what can India do in this. India has only one what we call fab which is owned by the Government of India, in Punjab, SCL – Semiconductor Complex Limited and they do develop chips mainly for space programme and also some of our advanced chip requirement for other applications of the Government of India and they are not even close to 20,000 chips per month, they are talking may be few hundreds in first few months. So I have my thoughts on what India can do and to enable this use of material science and productization of high-tech.

Thoughts on High Tech Product Development in India

- Parallel Efforts in Short Term, Tactical Areas and Long Term, Strategic Wins.
- Move up the Value Chain while Establishing the Supplier, Manufacturer Ecosystem i.e. Broaden Capabilities Beyond Product Design, IT, and Software.
- Product Development Focus Across Industry, R&D Labs, and Academia.
- Application Oriented Research in Materials Science to Lead the Way e.g. Simulation & Analysis Driven Materials Development.
- Develop National Policy on Materials for Critical Infrastructure, and Security.

Enabling High Tech with Mat Sci 43

Next slide is about some thoughts on what India can do to advance high tech products to advanced materials and to truly go from an IT country or software country, we are moving into product design. So in Bangalore and other places, almost all the chip companies, whether it is Intel, Samsung or even Global Foundries, we have our Qualcomm, they have their design house, they are building some serious capabilities, in IT we did some complicated variety of software and as we move closer and closer to product design, mainly in semiconductor area, we think of next, what is next, we need to be moving up on this value chain and one of the way to get to this thinking both sort of tactical as well as long term strategies. Right now, I can confidently say that hundred percent of the chips that are used in India, the integrated circuits are coded and nobody makes it in India, the demand increases the supply is almost zero. So what we need to do in India is not necessarily copy them, invest 10 billion dollars and have the latest chip technology. What we need is a combination of technical investments starting may be at the back end and packaging and in parallel do enough cutting edge research and that cutting edge research will come when we have collaboration between industry R&D lab and academia. In this context, I can do may be a 30 second plug, you know that my employer Applied Materials is working with IIT Bombay in this area. Prof. Ganguly and Prof. Lodha and even previously Prof. Vasi were very helpful in guiding us, focus and prioritize on this. This three way collaboration between industry, R&D labs and academia is the way to go, we have to take kind of measures, we have to be smart when we quest, may be one area we can start with is this simulation and analysis for development of materials, together. So on the technical side, we can use our knowledge of materials to predict and improve on the yield, how many good chips you get on a wafer, we can use algorithms, we can use learnings based on maths and material science to predict how many good chips will come out and that adds tremendous value to the industries in the world and in the long term, we need to think what is our national policy on materials for critical infrastructure and security. You can always get hardware from Huawei or someone else, there are enough players in this area but we need to think what is in it, for us we need to think is this part of our national infrastructure and it is critical for us. I will leave it at that something to think about in terms of having national policy on materials, something to think about how can we have this three way collaboration and then how can we be tactical as well as thinking long term strategic wins. So this is my kind of concluding thoughts on what it will take to have high tech product developments and what role material science will play.

Next is my concluding slide. What are the three takeaways. What we learned in the last hour or so is that:

Three Takeaways

- Materials Science is a Key Enabler for High Technology Products.

- Investment in Materials Development Required
  (i) As a Strategic Infrastructure, National Security Imperative
  (ii) To Make the Most of the Development in IT, Software and Product Design.

- Multidisciplinary Collaboration Across Industry, R&D Labs, and Academia Needed for ~10 Years to Develop and Demonstrate World Leading Competencies in Materials Science.

Enabling High Tech with Mat Sci 44

Materials Science is a Key Enabler for High Technology Products.

Investment in Materials Development is Required.

(i) As a strategic Infrastructure, National Security Imperative

(ii) To make the Most of the Development in IT, Software and Product Design.

Multidisciplinary Collaboration across Industry, R&D labs, and Academic needed for ~10 years to develop and demonstrate world leading competencies in Materials Science.

This is the missing link for India to be a powerhouse in how we can through materials enable differentiated high-tech products. It is not going to be easy, it will involve multi disciplines across various segments and it is going to take at least 10 years. I know several IITs and you who are working on it. It will take 10 years of focused collaboration to have world leading competencies in material science. So I will end with that. Thank you and I am sharing this with you for almost an hour, thanks for this opportunity, thanks for spending your Saturday with me and if you would like to get in touch, this is my email/phone number (Vaidya.Kaushik@gmail.com, 9900500112).

Prof. Udayan Ganguly: Thanks Kaushik for this really exciting discussion. There are some questions, there are lots of questions in fact and clearly because the talk has found some resonance. One of the questions is that there is Moore's Law, because when semiconductors rise, let us put more memory, faster processors in everybody's house and everybody's phones, but there is a fear that Moore's laws is coming to an end. So what next is the question and would electronics still be important or do you think it is not going to freeze out right. I would request your thought on that.

A: Udayan, ideally you are more qualified than me probably to answer this. I will give you a response from the user perspective, may be then you should add the science perspective. From the user perspective, as I mentioned 5 nanometre is going to be coming online in next 2-3 years. I think there is still a lot of mileage that can be forced on number one, our customers, TSMC in some sense in the world is already having process flows for 3 nanometre, so 5 to 3 itself is work in progress. The other thing that has happened is going to be simpler and I believe just the silicon based semiconductor and the creativity of packaging the 3D structures using materials and technologies like selective etch and atomic layer deposition, this industry will survive, this industry will give us high tech products for next I would say 10-15 may be 20 years. I don't have that as a concern. What is next, I think Udayan is better qualified but what I know people are talking about III-V, II-VI based semiconductors, people are talking about compound semiconductors and then the latest is the quantum computing. I will let Udayan elaborate but from a manufacturing or mass adoption of personalization point of view Moore's law is going to be with us for at least 15 to 20 years.

Prof. Udayan Ganguly: Kaushik has presented a robust perspective, there is a road map and the road map has a materials position based on logic, so if you want to process microprocessors there is a path. In memory, Moore's law is an economic or of historical rule and it is pushed by requirement, so everybody has this sort of unquenchable thirst for computing and memory, more memory than computing probably. In that sense people are already saying that look I don't need to make my devices smaller, I can go 3D and which is what you are showing. I can keep making things more complex and still pack more functions in the same space. One of the things that I think may be added is AI. So while quantum computing is technically a very important idea, the proof that it works has still a lot of science to be done. In AI, the algorithms are developed and they work on existing processors but you need a server farm to do AI. But if you look at the original inspiration of the AI which is your brain, it works on a cup of tea and it is like you know it is portable so if you look at the computing sort of benchmark that we have to go to it exists and it is a million times better than what today chips can provide. There is a lot to be done on various aspects of adding sensors, adding actuators, adding different kinds of fuzzy computing which today is not necessarily things that are touched upon by standard processors. So, right, that it will be very interesting to sort of see things; actually Moore's law provides some sort of guarantee that you know future scale things get better but now there will be a much more multifaceted development in materials, algorithm, circuits and so on and so forth which cannot be written down but that doesn't mean that it won't happen.

Mr. Kaushik Vaidya: I can just add one thing, it doesn't necessarily have to shrink to 5 or 3 nanometre. There is a whole host of applications inside which is called IOT, Internet of Things, that would need chips that would need devices which are not latest and greatest. Second is, chips required for communication, third is automobile – transportation, cars are going to be the nextsmart phone in terms of semiconductor usage. These days sensors alone, may be 30-40% of car, are going to be silicon based semiconductors. Fourth is amplification of power is already gallium nitride, silicon carbide as I said you can combine high power and high temperature chips which are required. The last is sensors, sensors are required everywhere that will keep this whole semiconductor industry and the key to manufacture affordable, scalable and profitable for companies that are doing this. So even if Moore's law may be doing out this other applications which not necessarily need the latest apparatus, will keep the semiconductor industry going way beyond next two decades. I am sure that materials will change but the need for technology and the need for material science will remain for foreseeable future.

Prof. Udayan Ganguly: In fact you know I just got a comment from Prof. Misra to comment on what is happening in IIT Bombay. IIT Bombay, like every other IITs, lots of things are happening. One of the thing that my group works on is we are working on making neurons and synapses out of silicon, this is something that is really close to manufacturing and it also enables a completely different way of computing. We also have a lab which is able to do this which is where what Kaushik was talking about where we have this collaboration with Applied Materials. That is my sort of short pitch for you, interesting things happening at IIT Bombay and at least one of them there are lots and lots of others, so I will delve into another comment and I think you talked about it. India has a lot of fabless companies and that is the huge strength, we are definitely producing about thirty percent of the design content. A fab or manufacturing and technology development, be it solar, be it standard logic memory that is where you have also pointed out is a weakness. What you think of the hopes of having fabs work in India. Do you think it will be economically viable, do you think we have time to catch up because we already are at 5 nanometre node, we are pretty much close to some very cutting edge technology and need lots of investment, should we invest there in the highest, the most bleeding edge of technology? So what would be your India sense and you also talked about the government's position, that would be good for us to have a more detailed discussion on before we conclude.

Mr. Kaushik Vaidya: My views on this is there is no point in having an isolated fab. If you look at Taiwan or if you look at China or any other country, it is a whole ecosystem. Even if you want to invest 10 billion dollars it is just not scalable and it may not be profitable given where the rest of the world is. So India should be doing its own semiconductors, we have to be smart and we are to be sure where do we want to invest. For example SCL in Chandigarh, it is doing what is needed for its customers, and for Government of India for other applications. We can have clusters like that where we don't necessarily need to be importing, we do bits and pieces which are enough for our needs and then we don't need to be a bleeding edge all the time. I don't see why we cannot be working on investing in it. So if I can draw a parallel from the automobile sector we have companies making cars, may be they are not necessarily make the value chain for others. Other industry is Pharma, i.e., ecosystem in generics. So there are parallels where we can learn from and say given the requirements and given where we are in terms of our budget and our capacity to invest where should it be. I personally don't believe in having 10 billion dollar fab. My personal view is we start with computation, be smart in design and as you said we do know design competency, a pilot line not necessarily of 7 or 5 nanometre node but trailing edge and then have entrepreneurs set up a profitable set up. I can give you example from solar, over last ten years, several solar companies try to make sense and it did not go because they just couldn't compete on a global scale.

Prof. Udayan Ganguly: This is a very interesting point. India has had a policy on electronics from 2011 that was may be the second policy on electronics and in 2019 they revised it and came up with the next version of it and India has been playing, toying with the idea of getting fabs; we all pitched in and the cost of import is not abating. We pointed out right in the beginning, everything, every piece of electronics we import, what we use is imported, so the cost is increasing and there have been proposals like the Atomic Energy Commission or Space Commission which are important commissions of India to have an Electronics Commission which would have an independent budget to oversee this. In fact a very important IIT alumnus and IIT Professors are pushing this agenda. From that perspective, there is also this whole commercial position, but also a strategic position in that India always has an option of being or can be denied technology. On that perspective SCL has existed and there are also some other small R&D efforts, but a bigger fab is definitely or a few fabs are definitely important, analog or digital or whatever, MEMS. So what you think is the Applied Material's push on this? Can you talk about some of those positions that would be an interesting thing for this group because while we are talking general technology, there is also lot of lobbying that we do.

Mr. Kaushik Vaidya: Yes, we have, you know my colleague actually based in Delhi and he is head of government affairs and we are doing our bit to make sure that the manufacturing takes off and it survives and it thrives as I said we are in one segment of this which is the equipments and making it production for high volume manufacturing scale but there is this whole ecosystem, cleanrooms, chemicals, all the other abatements, everything else that comes together. Just having the equipment may be 60-70% of the fab but the other 30-40% needs to happen and as an employee if I can say yes, we would be happy to participate in this venture whether it is more than Moore's kind of application or maybe we can even start with 65nm or 45nm, we don't need to start at the cutting edge but I agree with you, we need to start at something which is of relevance to us from an infrastructure and a security point of view and eventually we need to build on it and if I again draw parallels to the automobiles, there are examples and there are learnings which we can apply from that industry. Now we would be happy to discuss more on that.

Prof. Udayan Ganguly: I think it is a good point for us; let me also mention some interesting new developments. You know, when I came back to India in 2010, we started trying to lobby for IMEC like R&D centre and people who want to understand technology, it is an important idea in terms of how technology moves from labs, extend and the way it does and people who are in it, like Kaushik would know this like the back of his hand, is that it goes from the lab to a place like an R&D centre which mocks up manufacturing, try to demonstrate lab ideas at this manufacturing scale, look there are 20 lab ideas and out of that only two of them are manufacturing worthy, meaning that they meet reliability specs, they meet production specs, the mitigation challenges and with an existing baseline. It is not that you create a new technology and it works, it has to fit into some sort of plan of the existing world. In that space, from 2011 we have been trying to do this lobbying and in 2019, we have got a proposal accepted to create what is called a detailed project report for an R&D centre, so it will be a midway between a full fab and what we have in IIT Bombay and IISc. and other IITs which have sort of fabs which are lab level ideas and vet them for manufacturing. A report is due in next eight months and the questions are what sort of technologies, for example power electronics, infrastructure management or high voltage switches, gallium nitride or silicon carbide for very high power antennas. These are not silicon but they are very related. Today there is Covid, so one of the thing people can do is silicon based assays which are automated micro fluidic channels which can get very small amounts of samples of liquids. So the question for us is how do we do that and there is a mandate from the Government of India which is the Principal Scientific Advisor's Office to create a blueprint for such an organization. It will be in a membership mode. Some members and you collaborate on the research based collaboration and when it becomes competitive you take it out. Indian government agencies will benefit from it by cost-shared R&D. Everything will make sense once we have either manufacturing, more significant amount of technology or design which are coming out of this that is interesting. In that set up what you think the companies which are fabless, how does Applied Materials integrate with a fabless company, you may comment on it, may be even Susheela can comment on it as she is from that background.

Mr. Kaushik Vaidya: Very encouraging news. I can tell you we work a lot with the foundries, yes IMEC is a R&D partner and we continue to work with them and TSMC works very closely with fabless companies but there are two areas that you touched upon. First is, does it make sense for us to work with the firms? Does it make sense for us to work with a mediator? I think now it is about Siemens but Cadence and Synopsis or one of them. I think in terms of improving the learning rate and shortening their product development cycle, it does make sense for an equipment manufacturer. But we have to be a little bit careful because then it gets into a bit of a territorial situation also. We have to strike a balance and we want to make sure that all four elements do it which is your Foundries, such is TSMC or fabless companies, the chip design houses and the EDA companies which are for design, we should all be partnering together and making sure that development time cycle is reduced. So four way collaboration between fabless company, EDA company, foundry and equipment manufacturer, will definitely help in accelerating.

Prof. Udayan Ganguly: Thanks Kaushik, I also wanted Susheela to comment on this in terms of ecosystem and materials to lab and then fab, so may be Susheela, you can put your comments.

Dr. Susheela Venkataraman: Thanks Udayan, one of the discussions that we have had in the past and we had spent quite a bit of time today talking about the need for collaboration and need for scale and so on and one of the development that has taken place is the IITs becoming centres that are setting up shared facilities that help everyone, industry, academic, research, etc. and IITACB, our organization also sits in a space where we can bring all of these different groups together. For example, you mentioned fabless design and it would be great to have a shared centre that allows people to come in and do their fab design without necessarily investing in a cadence or whatever you know, software that is required for it, so these are great developments and personally I am very hopeful that people will see a lot of excitement in the space of electronics and materials.

So let me take this opportunity to thank both for this very engaging discussion this evening. In February, we had this industry-IIT Conclave and several of the topics or themes that came up today were discussed there too. One of the key issues that came up for discussion that day was materials and today we have looked at electronic materials and we gone into it with a lot of detail starting with generic discussion around why it is important; electronics just pervades everything that we do. It has been really fascinating to kind of drill right through to the bottom to almost the atomic level and really understand what electronics is about.

Thank you very much Kaushik for having demystified that magic what you called that magic and helping us understand what goes behind it and Udayan, thank you very much for very insightful discussions and I am thankful to both of you having taken this on very readily and for the audience thank you for being here and thank you for your questions, it all helped in terms of building the quality of this discussion. So thank you. We know, we haven't been able to answer every question but Kaushik has given you his email and please feel free to reach out to him. Today we touched on electronics but hopefully some talks down, we will look at materials and other areas as well, we do have these seminars-webinars every weekend so please do keep a look out and we look forward to seeing you all there. Once again thank you very much and Namaste.

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MR. SANJAY MASHRUWALA & PROF. ABHAY KARANDIKAR I MAY 23, 2020

Mr. Sanjay Mashruwala did his B. Tech (Mech) from IIT-Bombay, batch of 1971, and his M.S. (Engg) from the University of Texas, Austin, batch of 1973. Upon completion of his studies, he returned to India and joined NRC Limited, Mohone, Maharashtra, when their Nylon Tyrecord plant was under construction. He worked on various activities including Operations, Maintenance and Expansion. He worked with NRC Limited from 1975 to 1981.He joined Reliance Industries Ltd, in 1981 for their first Polyester Filament plant handling activities starting with planning, engineering, construction and operation. Subsequently, he has been associated with almost all RIL projects, including Hazira polyester and Petrochemicals, Jamnagar Refineries and both telecom ventures. He is now the Managing Director, Reliance Jio Infocomm Ltd., RCP, Navi Mumbai.

Prof. Abhay Karandikar is the Director of IIT Kanpur. Earlier, he was the Dean (Faculty Affairs) and the Institute Chair Professor in the Department of Electrical Engineering at IIT Bombay. Prof. Abhay Karandikar received his M.Tech. and then a Ph.D. in electrical engineering from IIT Kanpur in 1988 and 1994,respectively. He was the Chairman of the Telecom Standards Development Society of India (TSDSI), India’s standards body for telecom, of which he is also a founding member. He has also served as the coordinator of Tata Teleservices IIT Bombay Centre of Excellence in Telecommunications (TICET) and the National Centre of Excellence in Technology for Internal Security. Prof. Karandikar's current research interests include frugal 5G and rural broadband, device to device communication, software defined networking, network function virtualization and 5G core network, and quality of service and resource allocation in wired/wireless networks.

Lecture at IIT Alumni Centre, Bengaluru on May 23, 2020

Link to the webinar : https://www.youtube.com/watch?v=NNWxewF87ow&list=PL0zMQ-70IHlX-df3u2Tto6dkKHCRC6iFL&index=13

MR. SANJAY MASHRUWALA & PROF. ABHAY KARANDIKAR I MAY 23, 2020

Arnob Roy is a co-founder and Chief Operating Officer at Tejas Networks. He has over 30 years of experience in developing products in the domains of Telecom, Networking, Semiconductors and Electronic Design Automation. Prior to Tejas, he has held senior engineering management positions at Synopsys Inc., and Cadence Design Systems. At Tejas, Arnob has been responsible for leading high performance teams for development, manufacturing and sales of leading-edge Optical Transmission and Data Networking products, which have been deployed in over 60 countries world-wide.

Arnob Roy holds a Masters' Degree in Science in Computer Science from the University of Nebraska, Lincoln, USA and a Bachelor's Degree in Technology in Electronics and Communication Engineering from the Indian Institute of Technology, Kharagpur.

Lecture at IIT Alumni Centre, Bengaluru on May 23, 2020

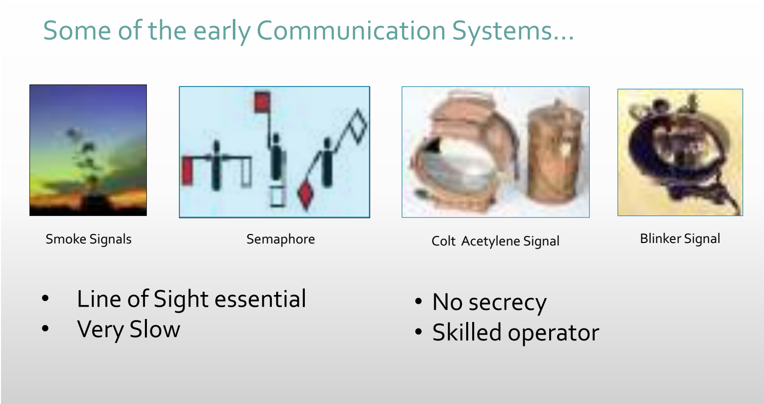
Link to the webinar : https://www.youtube.com/watch?v=NNWxewF87ow&list=PL0zMQ-70IHlX-df3u2Tto6dkKHCRC6iFL&index=13

Mr. Ashok Kamath: Today we have an interesting and fascinating topic of current interest, which is 5G telecommunication. We are privileged to have two very outstanding people in this area. First is Mr. Sanjay Mashruwala, Managing Director, Reliance Jio Infocomm Ltd. and they are very much in the news. Sanjay is a graduate of IIT Bombay and went to UT, Austin to do his Masters and came back to India and since 1981, he has been with Reliance. The other speaker is Prof. Abhay Karandikar, Director, IIT Kanpur, who did his Masters and Ph.D. from IIT Kanpur and then taught for a very long time at IIT Bombay before going back to his alma mater as the Director. Prof. Karandikar was also the Chairman of the Telecom Standards Development Society of India, in fact the Founding Chairman and continues to be very actively involved in it and is probably India's leading expert on 5G Technology. To help us do the moderation, we have been fortunate to have Arnob Roy, Founder and COO of Tejas Networks and he is Bangalore based and very active, specially on communications, and he is going to moderate this session.

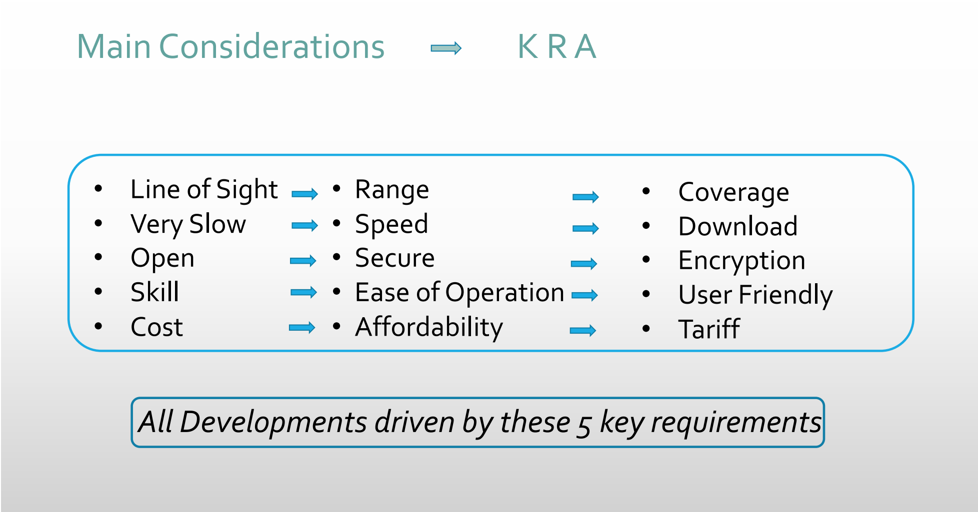
Mr. Sanjay Mashruwala: Good evening,

The moment humans figured out how to communicate, through hand signs, gestures or speech, they also realized need to communicate beyond visual or shouting distances. Given the degree of technology, options were limited. While they did develop some tricks, there were severe limitations.

Lecture at IIT Alumni Centre, Bengaluru on May 23, 2020
Link to the webinar : https://www.youtube.com/watch?v=NNWxewF87ow&list=PL0zMQ-70IHlX-df3u2Tto6dkKHCRC6iFL&index=13



For transmitting signals over a longer distance beyond smoke signals, essentially methods used for distant communication, or what we now call Telecommunication have changed, the consideration of the limitations have not changed. Of course, the words we use to describe these have changed over the years. So, as technologies were developed and evolved, these points have been always remained 'key' result areas. While new methods evolved, they had obvious limitations of distance, security, speed and convenience and ease and so on. Really speaking if you talk about communication there are five major KRAs or considerations that people have. Today, we call these parameters Coverage, Download speed, Encryption, User Friendliness and of course Tariff. As we go over the development, we would see how these five key requirements have improved over the period.



Path to Technology Based Solution – Telegraph

- Voltaic cell by Alessandro Volta, Italy in 1800
- Electricity and Magnetism by Hans Christian Oersted, Denmark in 1820
- Electromagnet by William Sturgeon, Britain in 1825
- Electromagnetic induction by Michael Faraday, Britain in 1831 and independently by Joseph Henry, USA in 1832
- The first commercial electrical telegraph developed by Sir William Fothergill Cooke and Sir Charles Wheatstone, patented in May 1837, used a number of needles on a board that moved to point to letters of the alphabet. This system was installed in the British railway network.

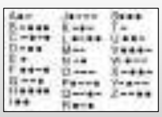
Early steps in the development of modern communication technology started, was with discovery of electricity, after that magnetism and so on and so forth over the years till eventually in 1837 the first telegraph was developed to convey the signals over longer distance. The first models were not really a very good to work with, we could not call it as simple or user-friendly model and naturally it did not become very common or popular. The credit for creating really common and commercial system for telegraphy goes to Samuel Morse who patented his invention in 1837. This technology breakthrough happened when he came up with concept of digital communication using just two symbols – dash and dot. Of course, at that time, it was not called "digital".

Morse Telegraph

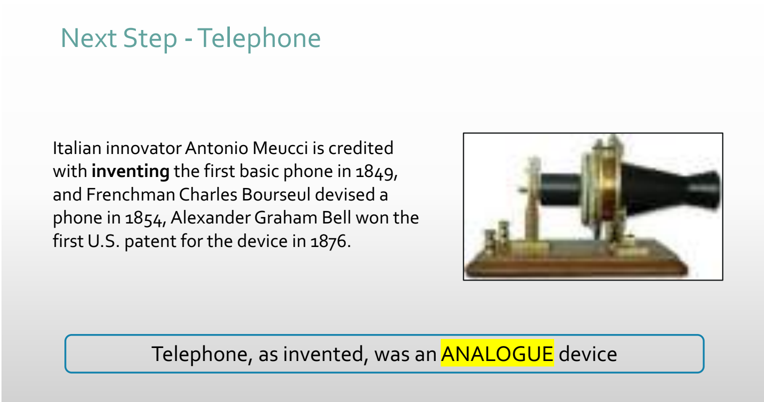
Independently, a different type of telegraph developed and patented in the United States in 1837 by Samuel Morse, Leonard Gale, and Alfred Vail.

—	DASH	1
•	DOT	0

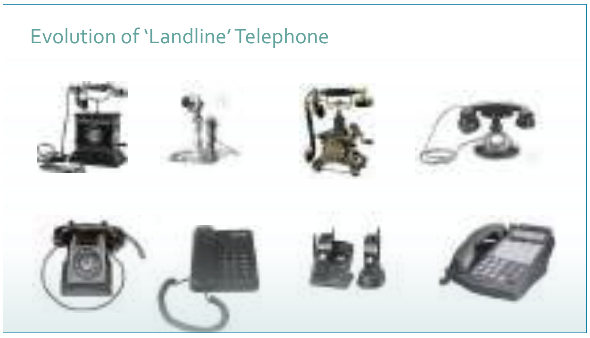
First Truly DIGITAL communication

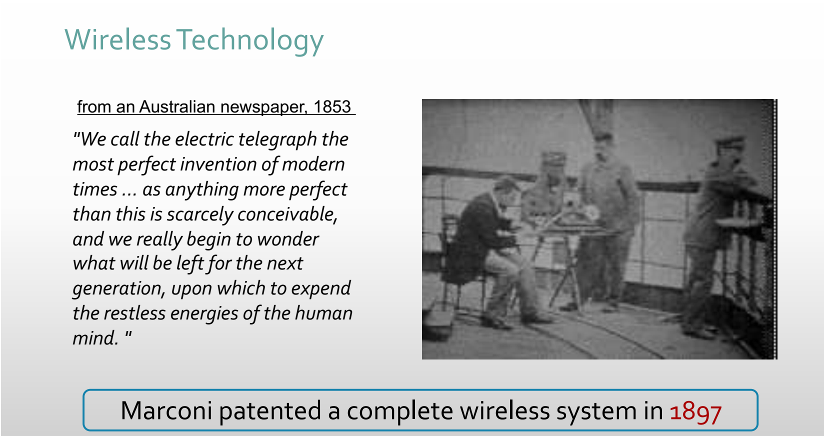


The technology improved and thus we could send signals over longer distance, the speed improved as also security. Everybody could not simply go and see or hear what you are trying to convey. Still, it was not very user friendly and the cost was very high. As the time progressed, people started working on technology for conveying information over voice rather than telegraphic signals. Parallel activities were happening on both sides of Atlantic, to invent, what became known as telephone. Again, though number of people demonstrated this technology. Italian inventor Antonio Meucci is credited with inventing the first basic phone in 1849, and Frenchman Charles Bourseul devised a phone in 1854. However, Alexander Graham Bell won the first US patent for the device in 1876, so he is credited with the invention of telephone.



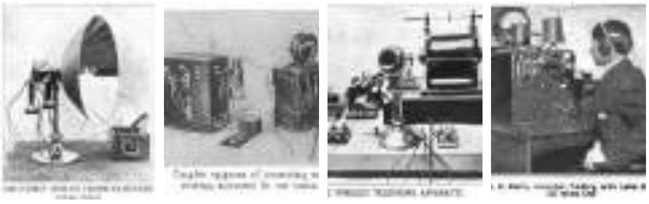
Now over the years, the telephone technology has continued to improve and so symbolically we could show how the telephone instruments changed, shape and size in this slide. The same thing was happening at the back end, what was then called the telephone exchange. Starting with operator assisted calls, electro-mechanical exchanges, Strowger, Cross Bar, Electronic and so on. The technology improved not only in terms of the speed of dial or ease of communication, but also in terms of distance. From intercity to intra-city, national to international dialling etc., services continued to evolve.





While all these were happening, other technologies were also being developed, such as wireless. So, in 1897, wireless and telegraph technology were put together to create a wireless telegraph system so that now you could send signals to places which could not be connected by wire. Then, it was natural that this technology would be extended to voice as well and so evolution to wireless telephones. It was very logical. But the equipment were rather large and complex even for limited capabilities. Lot many more technological developments in various fields had to happen before the next step could be taken. Some of these were, development of electronics starting from vacuum tubes to transistors, integrated circuits, large scale integrated circuits, microprocessors and so on. This also led to development of digital technologies, covering computers, micro and embedded processors, development of various programming techniques and languages.

Early Wireless Telephone Apparatus



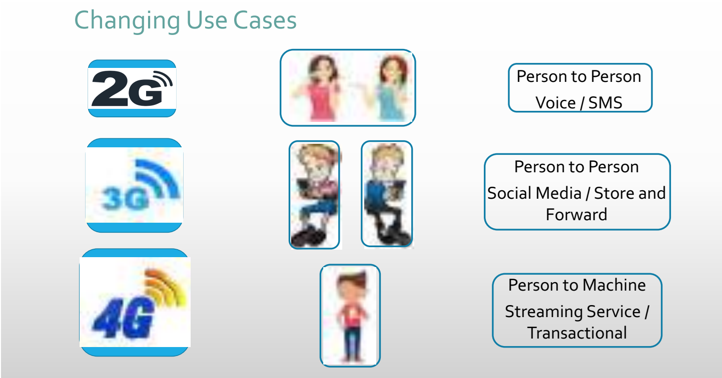
As all these technologies came together, it was possible to create something which was more practical that today we call mobile telephony. The first mobile telephone was demonstrated in 1973 (Motorola Dynatec) but it took quite some time before commercial service could be rolled out and that service became really popular. That service came to be known as 2G. And today, nobody remembers the first-generation telephone service. It took some more time before commercial 2G became common in 90s but that was also the time when the computers and internets were developing rapidly and demand was to find a way to transmit mobile data in addition to mobile voice. 1G Analogue Cellular Network – AMPS was developed in Japan in 1979 and USA in 1981. 2G Digital Cellular Network – GSM and CDMA developed in Europe in 1990.

Mobile Phone Service

- First Mobile call with Motorola Dynatec – 1973
- 1G Analogue Cellular Network - AMPS - Japan 1979, USA 1981
- 2G Digital Cellular Network - GSM and CDMA – Europe 1990
- 2.5 G – CDMA 2000 1X / GPRS / EDGE - 1998
- 3G Packet Switched Network - WCDMA / HSDPA – Japan 2001
- 4G Native IP Network – LTE - 2010

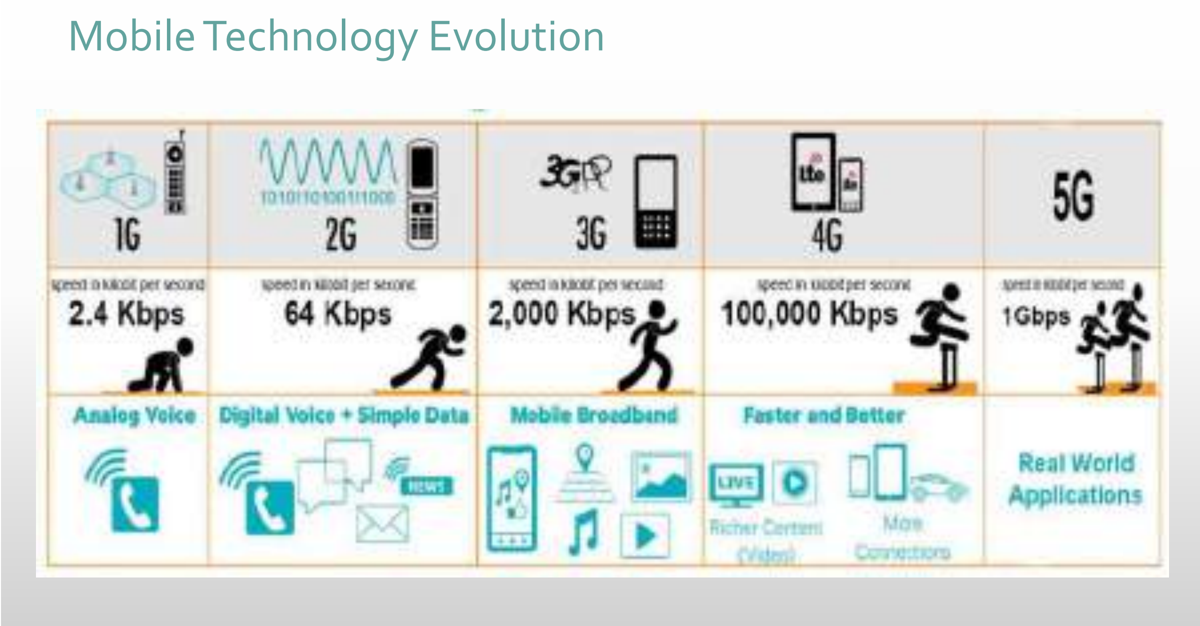
But 2G was a technology which was essentially developed for voice. So, data had to be pushed on to that technology and 2.5G was developed in the late 90s where you could transmit little bit of data on the mobile services. This was improvised with 3G Packet Switched

Network which could transmit greater amount of data but was essentially an extension of 2G. So thereafter a completely new technology had to be evolved and that become known as 4G which essentially native IP based network was, focussed mainly on data and not on voice.



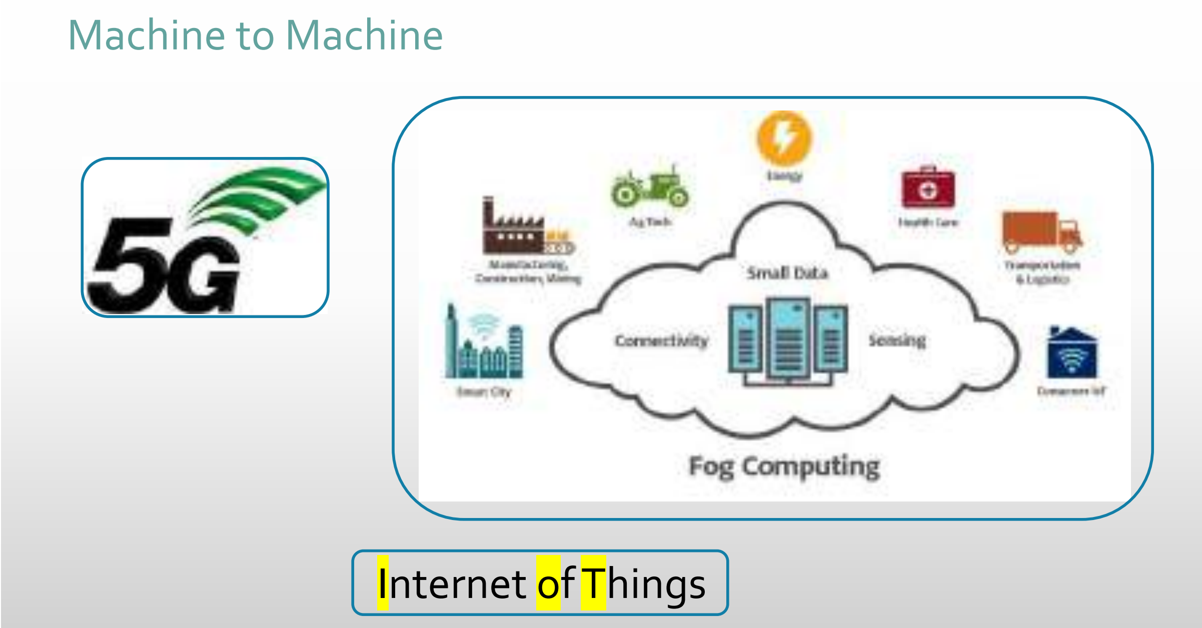
In the days of 2G technology, phones were essentially used for person-to-person communication, one person talks and the other person listens in real time and as the technology progressed, in addition to voice 3G now could handle data and that is where people started using social media like Facebook and WhatsApp where you could create something, a message, some content, a voice recording etc. and send it to one or more person but it didn't have to be consumed at the same time. It could be stored and then consumed as it was convenient but still this is between two people.

Then 4G came in. Things changed, where one didn't need anyone at the other end to communicate with. One could simply use smart phone and interact with a machine - with the computer. This is when streaming services like YouTube and others transactional services like banking, trading, e-learning etc. started developing.



So now we have come to a stage where it is no longer person to person, it is person to machine. The slide shows what has changed at a glance, from 1G to 5G. Obviously the data speed went up from really small insignificant numbers to much higher speed for 5G, and it could go even beyond that. And, in terms of applications, starting from simple analogue voice, moving on to digital voice + little bit of data, then, broadband for faster and better streaming, and other services, everything continued to evolve and till we come to 5G.

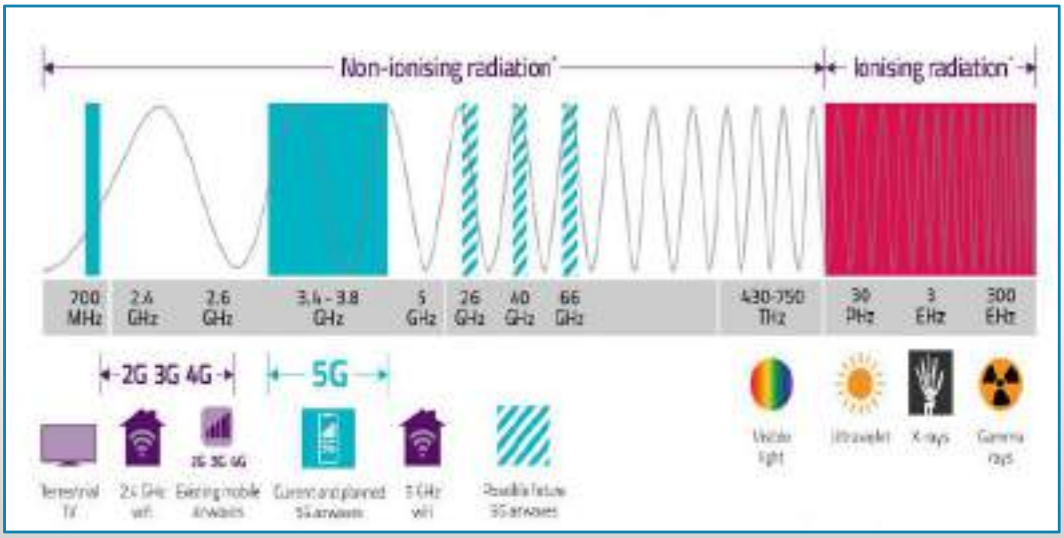
5G concepts are getting to a stage where you don't even need one person for communication such that communication is completely between machine-to-machine, one machine communicating to another machine, which is what we call Internet of Things. Things, that is, machines talking to each other over Internet. As for the applications, it could be used anywhere or everywhere, specifically in manufacturing, agriculture, energy, health and so on. So 5G is really enabling more and more of automation. Obviously, it will be used for the usual phone activities, that we do with 2G, 3G, 4G but there is much more that can be done with 5G.



5G also uses radio signals. Now as we talk about radio, we have to consider spectrum and before we talk about 5G spectrum, let us talk about the electro-magnetic spectrum. Electromagnetic spectrum spreads over wide range starting from lower end at kilohertz level used for ultra-long radio waves and going beyond radio waves to visible light, ultraviolet, x-ray and gamma ray. So for 5G, the spectrum which is proposed to be used is broadly classified into two groups, sub-6 GHz and mm Wave meaning frequency beyond 24 GHz. In near future, what we may look forward to is 5G services in the sub 6 GHz range. Talking about sub 6 GHz frequencies, services of 2G, 3G and 4G also use the spectrum in this range as also Wi-Fi. 5G technology can be utilise any spectrum starting from 700 MHz in various bands and also newer spectrum between 3300 and 3600 MHz being released by the Government.

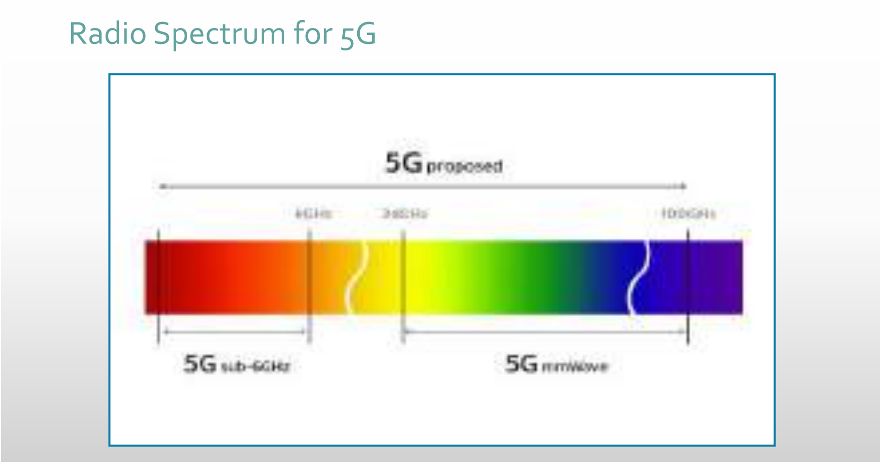
There are two consideration about the radio spectrum; radio propagation (distance that can be covered) and penetration (in buildings).

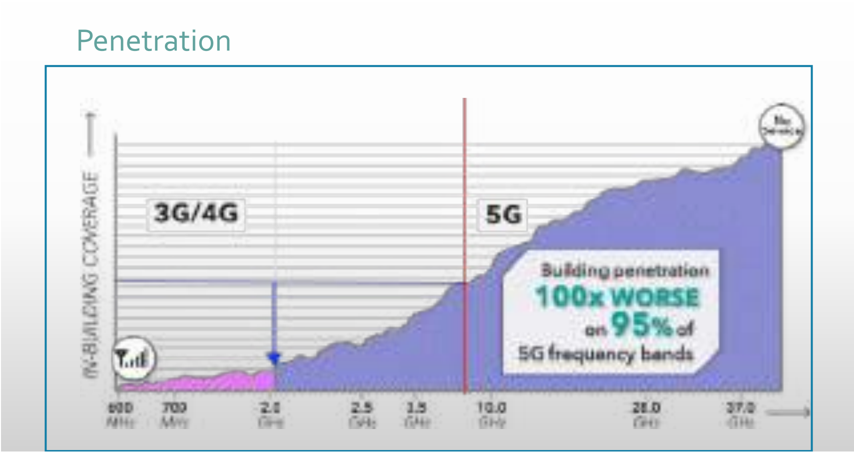
Electro Magnetic Spectrum



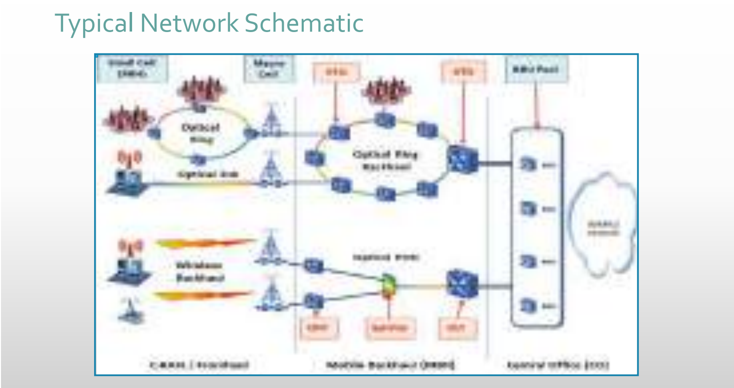
As the frequency of the radio wave increases, the penetration and the propagation range reduces. This is because as frequency starts going up, the absorption of the radio signals increases till it is no longer usable. When we consider 5G, penetration becomes a major issue that needs to be addressed. Other issue is propagation meaning the distance over which a signal can travel. Again, as the frequency increases, the distance becomes smaller and smaller. So when we use mm wave, the distance to which the signals could travel also becomes shorter.

In a traditional 2G, 3G, 4G technologies, a Macro Cells are deployed which is typically a tower with an antenna mounted on the top. The signals can reach up to 4 or 5 kms, though at higher frequencies and dense urban areas, this could be as low as 300 m.





But cells used for 5G cannot send the signals beyond may be 100 metres and that is why we would end up needing large number of antennas that are called small cells. This is like a street light illuminating road. We need multiple street lights along the length of the road to make sure it is illuminated fully. So these small cells could be mounted on top of the street light pole or any other pole or as convenient but definitely not too far from the user. So, for 5G we need far more cells installed closer to where users are expected to be. These small cells would receive the signals from individual users, aggregate them and pass them on to the central servers where the signals could be processed. In a larger area like Mumbai city, we would need multiple solutions deployed outside as also inside the buildings. All these signals have to be aggregated together, transmitted over optical links and then processed. That is a simple description what a 5G network looks like.



So where would 5G be used for? Now 5G cannot be of any use unless we have all the other supporting technologies developing at the same time. Many of these technologies are not directly related to 5G but they would greatly depend on 5G and 5G commercialisation would be greatly depend on them. Potentially, 5G could be used to connect almost everything that you are familiar with amongst each other and with central system. Many of these applications are still being perfected, from mobile phones, drones-based technologies, location based services, entertainment, satellite communication, health, ecommerce. That is where IoT solutions comes in and that is where real utility 5G begins but having done that, there is already talk about 6G. What would 6G be.

That is something probably worth talking about in some future seminar.

Thank you.

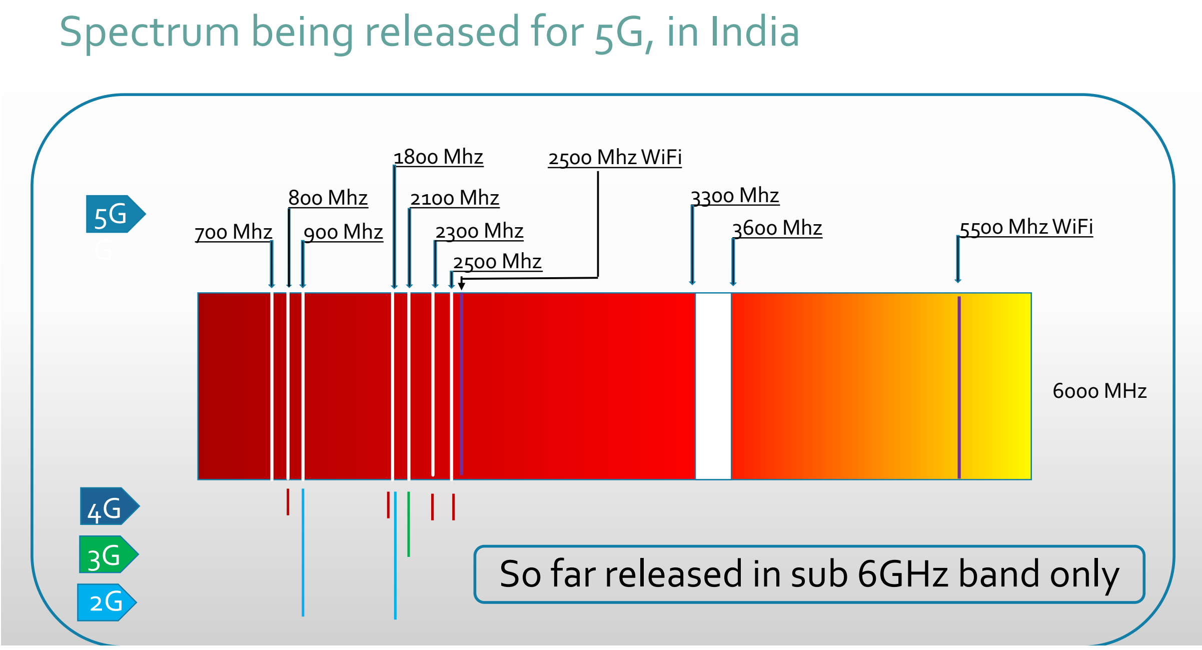
Q&A:

Mr. Arnob Roy: When will 5G be launched in India and what are the important steps that will happen before that.

Mr. Mashruwala: One of the questions would be when the auction of the spectrum will happen. When the spectrum auction happens, issue is when would this technology be practically usable and commercially worthwhile to implement. That requires development of many other technologies and applications that can profitably use 5G services. This means devices and gadgets, appliances like autonomous cars, health equipment, and so on. These are also getting developed right now in a variety of ways. So 5G as a technology might be around but to make it available to people in a practical form would take time as all these things develop, capabilities improve, cost will become more and more affordable. It will take a few years, starting probably next, that 5G equipped devices become common place just like smart phones are common today.

Mr. Arnob Roy: What frequency band will be initially launched in India.

Mr. Mashruwala: Basically, frequency band which would be used, existing bands which are being used, some of those could be used for 5G, like 700-800 MHz, going up to 1800-2100-2500 MHz and then possibly some bands beyond 3000-3600 MHz. Those are the bands which will be used for now, till a few years later when we get into millimetre wave lengths.



Mr. Arnob Roy: How do you feel the evolution of different area in India with 5G across broad band connectivity, machine to machine communication? How are the applications evolving in India?

Mr. Mashruwala: 5G, like any evolving technology needs two or three drivers to make it successful. One of that, which is much more relevant in the developed economies, is the cost. Whether those technologies are able to reduce the cost of performing a specific activity. Obviously mechanisation and automation is one big part of this. Now big motivation of cost reduction is autonomy – decisions being taken by machines through artificial intelligence. Autonomous car is a typical example where, by eliminating a driver one can reduce cost.

Some of other drivers work for 5G in the developing economies. Drivers which are much more relevant in India compared to elsewhere are education, health, entertainment. These are much more important in day-to-day life in India for variety of reasons and these are the areas where the first 5G applications would happen. Similarly, applications related to remote security. These are the area where early use of 5G. One more area where 5G is going to be useful is in factory floor automation, for coordination, machine fault diagnostics or autonomous machine operation etc. In India, this too will happen but probably sometimes later because it may not be economically justifiable as easily as it would be in the western countries.

Mr. Arnob Roy: Do you see any impact on the environment due to 5G or is it harmful?

Mr. Mashruwala: That is the question which is always asked. As I said the 5G frequencies are not any different than 2G, 3G or 4G. We think anything in excess could be harmful, even the sunlight in the excess is harmful, like you don’t want to go and stand in the sun forever. Similarly, anything, any radiation in the excess can be harmful but the question is, are the mobile tower radiations or for that matter, all of the wireless radiation that is in air - not only from mobile telephony but also from radio and TV, microwaves and so many other things, are they strong enough to be harmful? As yet, there is no evidence scientific evidence to show that these radiations are harmful to human beings or any other form of life - insects or birds or vegetation or anything. I do not believe that radio waves cause any harm. Radio waves have been around for more than hundred years and we have not seen any significant effect on any life form. And 5G radio waves are like any other radio waves, there is nothing different about it.

Mr. Arnob Roy: Now 5G is coming and a number of technologies are going to develop, what would be your advice for start ups and companies who are interested in leveraging in India?

Mr. Mashruwala: I feel that 5G technology would require fresh way of thinking about automation, about data collection, data analysis and what one can do with that. Then at the end of that, this is going to be what is the cost benefit, what is the practicality and how do you commercialize this and that is not a very easy question to answer because there are whole lot of variables and whole lot of technologies involved. Like my last slide showed, whether this cloud computing, edge computing, block chain, AI, all these technologies have to develop, so it is a vast field. Which area one wants to develop is something which is quite open. So I don't thing in a short sentence one could come up with a very quick answer.

Mr. Arnob Roy: Thanks a lot Sanjay for a very detailed and very interesting presentation.

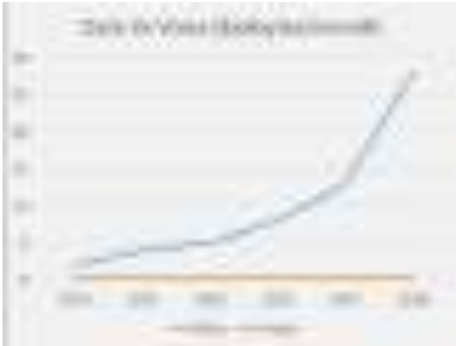
Ashok Kamath: We will have more questions and answers after Prof. Abhay Karandikar's presentation. Now I would request Prof. Karandikar to start.

Prof. Abhay Karandikar:

Thank you very much. Sanjay in his talk has given an excellent background from the older communication days up to 5G. This has made my task a bit easier. I will provide more technical details on 5G and will be happy to take questions during the question time. Sanjay has rightly mentioned that there has been a significant growth in mobile

Mobile Networks – Where is it headed?

- Huge Growth in Mobile Usage
- 7.9 billion mobile subscriptions world-wide
- 6 billion mobile broadband subscriptions
  - Year-on-year growth of 15%
- Mobile Data - Primary Growth Area
- Lower ARPU



Courtesy : Ericsson Mobility Report Dec 2019

Mobile Network Evolution – From Voice to Data
Data brings diversity of Use Cases

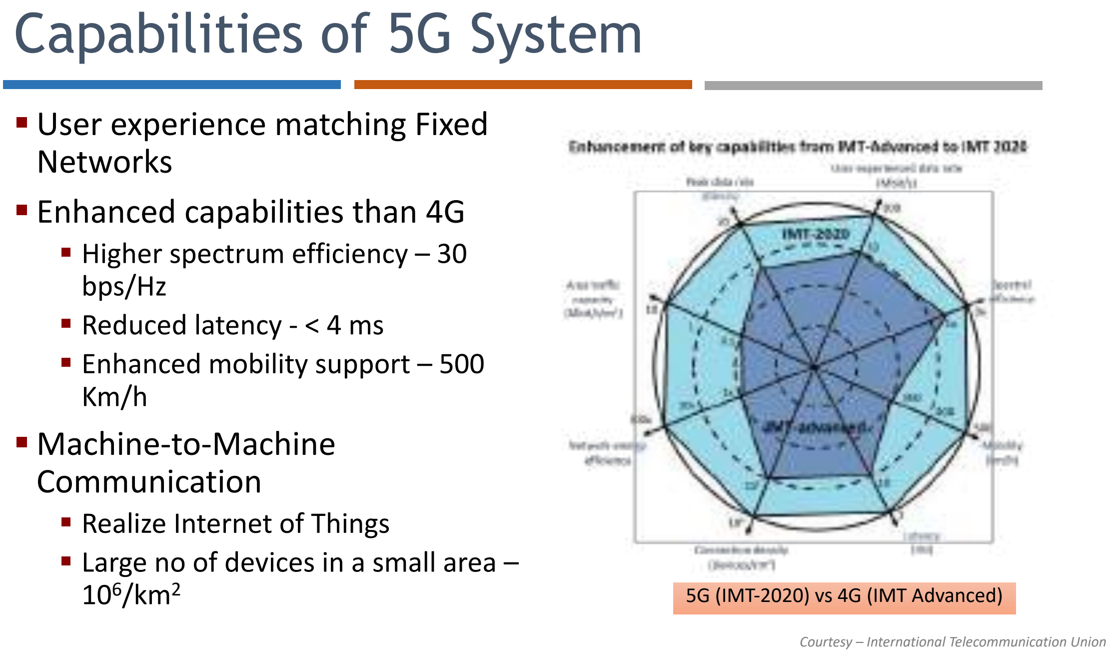
subscriptions world-wide. There are 6 billion mobile broadband subscriptions and there has been year-on-year growth of 15%. Increasingly, the traffic is now entirely moving from voice-to-data. The mobile data has also been primary growth area in India in the last five years or so. On the other hand, with growth in data, there has also been a concern for lower ARPU for telecom operators.

5G Key Use Cases

Huge Diversity of Applications - Not supported by 4G

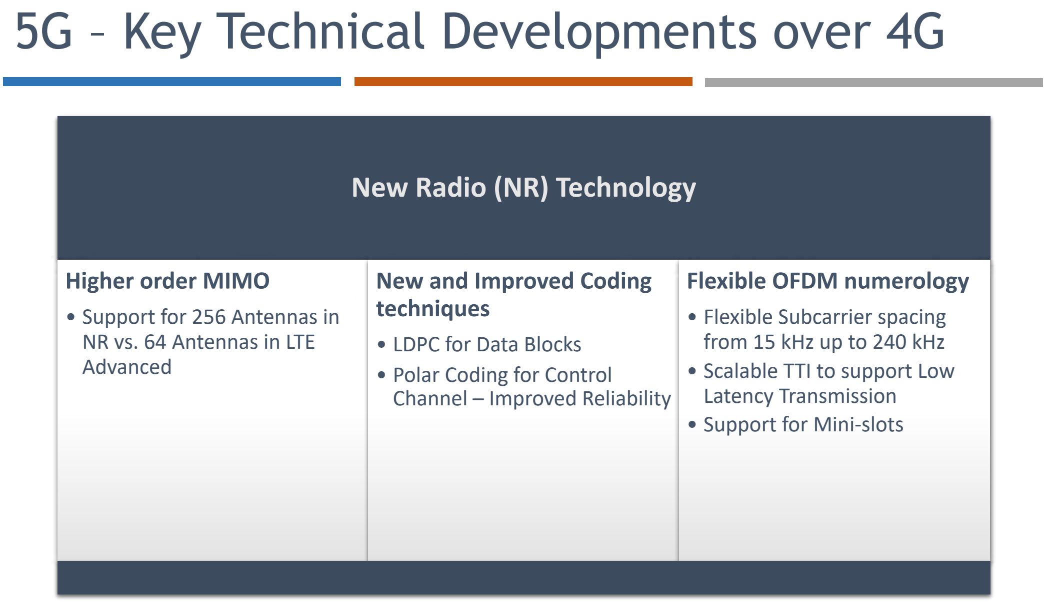
Courtesy – IEEE/International Telecommunication Union

5G is bringing a paradigm shift. There are three key use cases of 5G. One of them is of course our normal mobile broad band use case with enhanced throughput to Gbps and it is called Enhanced Mobile Broadband (eMBB). The other two important use cases are Ultra-high Reliable Low Latency (uRLLC) and Massive Machine Type Communications (mMTC). These use cases result in the huge diversity of applications which were not supported by previous generation technologies, such as 4G which primarily supports mobile broadband. Significantly enhanced capabilities than those



of 4G would be possible in 5G, say, in terms of spectral efficiency which can go up to as high as 30 bps/Hz, very low latency (less than 4 ms) and very high speed mobility support up to 500 km/h. While the telecom technology enabled human to machine communication, in 5G we could actually enable machine to machine communication, connecting very large number of devices in a very small area with a density of $10^6/km^2$. The slide illustrates some of the IMT 2020 (ITU nomenclature for 5G) parameters in comparison to IMT-Advanced 4G. This slide also demonstrates the enhancement of the key capabilities that are going to occur in 5G in terms of peak data rates, user experience, traffic capacity connections, network energy efficiency etc.

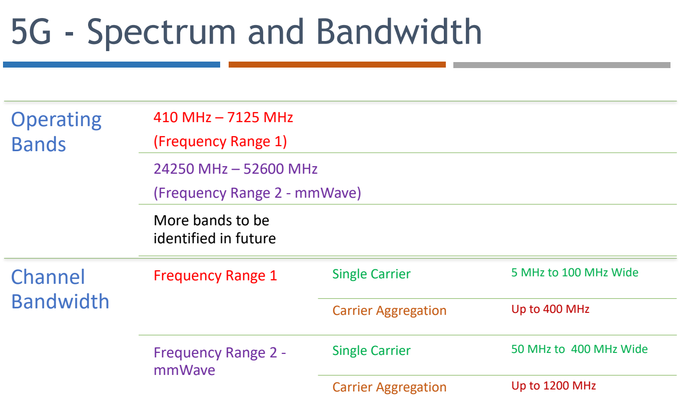
How do you attain the above enhancements in 5G? 5G achieves many of its capabilities with a completely new radio interface called- 5G New Radio (NR). It has been often



asked in many forums whether you would require a new base station and a new phone for accessing 5G services. The answer is: Yes, you would need a new base station and a new phone to access 5G services. There are some key technical developments over 4G for some of the enhanced capabilities. One of the important aspects of the new radio technology is the support for higher order MIMO. For example, 5G provides support for 256 antennas in NR versus 64 antennas in 4G LTE-Advanced specially in millimeter wave spectrum band. 5G radio interface also has new and improved coding techniques and follows flexible OFDM numerology. OFDM is also used in LTE but 5G NR enables flexible subcarrier spacing from 15 KHz to 240 KHz. 5G also has new spectrum bands such as mm-wave frequencies from 24 GHz which were actually not used in 4G technology. 5G radio also has larger carrier bandwidth and we could use

bandwidth ranging from 5 MHz to almost as high as 400 MHz (if you are operating in the mm-Wave). In the sub-GHz band also, it is possible to use carrier bandwidth of 50 MHz or 100 MHz.

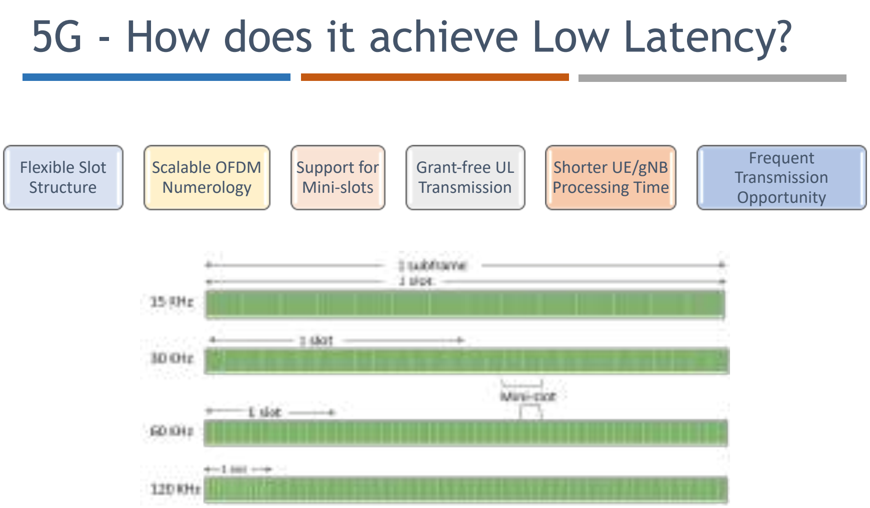
The third paradigm shift that has occurred in 5G is increasing softwarization of the networks. Unlike specialized hardware elements in 3G and 4G, the core is completely going to be software running on the commodity off-the-shelf hardware. 5G core network architecture employs software defined networking and network function virtualization. In 5G, there are primarily two spectrum bands, one below sub-6 GHz


5G - Spectrum and Bandwidth

Operating Bands	410 MHz – 7125 MHz (Frequency Range 1)		
	24250 MHz – 52600 MHz (Frequency Range 2 - mmWave)		
	More bands to be identified in future		
Channel Bandwidth	Frequency Range 1	Single Carrier	5 MHz to 100 MHz Wide
		Carrier Aggregation	Up to 400 MHz
	Frequency Range 2 - mmWave	Single Carrier	50 MHz to 400 MHz Wide
		Carrier Aggregation	Up to 1200 MHz

which are the same frequency

band widely used in 3G and 4G, but there are other frequency bands which is called FR2 that is the mm-wave. In FR2, the coverage is going to be limited and therefore the mm-Wave band primarily may be deployed for creating 5G hot-spots while the sub-6 GHz, like 3 GHz or 700 MHz, frequency band may be used to provide larger coverage. Thus, 5G spectrum band provides a combination of larger coverage and at the same time enables hot-spot with the mm-Wave frequency bands. As I already said, we can go up to the carrier bandwidth of 400 MHz while carrier aggregation in mm-Wave can provide a bandwidth of 1.2 GHz as well. As a result, users will be able to experience an order of magnitude higher throughput than what is possible today in 4G.

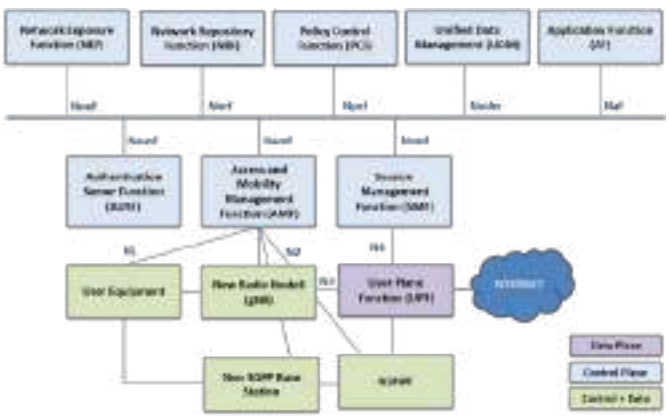


Another important feature in 5G system is extremely low latency. This is needed in some applications, for example in vehicle to vehicle communication. Of course, self-driving car may be a more futuristic application, but it is very likely that 5G could be deployed for vehicle to vehicle communication called as V2X communication. In V2X communication scenario, the data rate may not be high but the latency or response time needs to be extremely low. Similarly, in applications such as robot based surgery, we need a very low latency in order to take the action faster. Low latency and high throughput are often contrasting requirements in wireless communications. To achieve this, many innovations have been done in 5G technology. These include framing structure with flexible time slots where the entire transmission time interval is divided into slots just like in 4G but these slots can be further sub-divided into mini-slots as well. As a result, if an urgent data is to be sent, mini-slots could be used. Typically, in wireless communication, a user is able send data by first making a request and then transmitting in the scheduled slot when the request is granted by the base station. However, in 5G, a grant-free transmission is also possible to send some data urgently. Similarly, several innovations have been done to reduce the processing times, thereby enabling the low latency.

3GPP 5G - SDN & NFV based Network Architecture

- Separate Control Plane and Data Plane Functions
  - Data Plane and Control Plane Functions separated thru standardized interface
  - Both in Core and Radio Access Network (RAN)
- Control Plane Functions in Core Network (CN)
  - Access & Mobility Management Function (AMF)
  - Session Management Function (SMF)
  - Other Function e.g. Authentication Server Function (AUSF) etc
- Data Plane Function in Core Network
  - User Plane Function (UPF)
- Control Plane Function in RAN
  - gNB-CU (Centralized Unit) Control Plane
- Data Plane Function in RAN
  - gNB-CU User Plane
  - gNB-DU (Distributed Unit)

3GPP 5G - SDN & NFV based Network Architecture

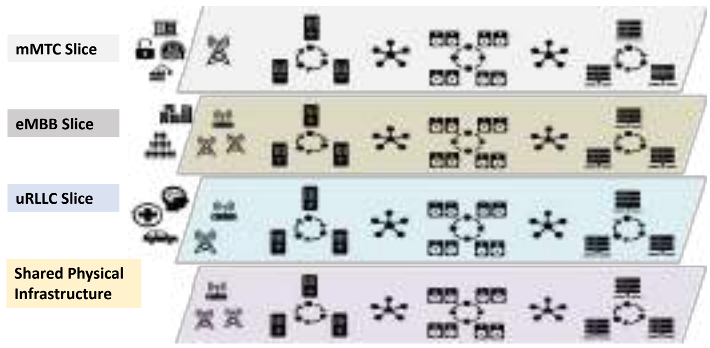


3GPP System Architecture: Courtesy TS 23.501

The third important innovation that has happened in 5G is the use of Software Defined Networks (SDN) and Network Function Virtualization (NFV). In 4G, both control plane and data plane are tightly coupled, but SDN paradigm separates control and data planes in 5G. For example, the control plane functions in 5G core are AMF, SMF and so on as illustrated in the slide. The figure illustrates SDN and NFV based 5G core network architecture elements. The separation of control and data plane nodes enables the scaling of networks by the operators in a very efficient way. Most of these are software nodes running on commodity hardware. The softwarization of the core networks also enables the scaling of the networks in a much faster way than those of 3G or 4G networks where we require specialized hardware elements.

Network Slicing – Enabled by SDN & NFV

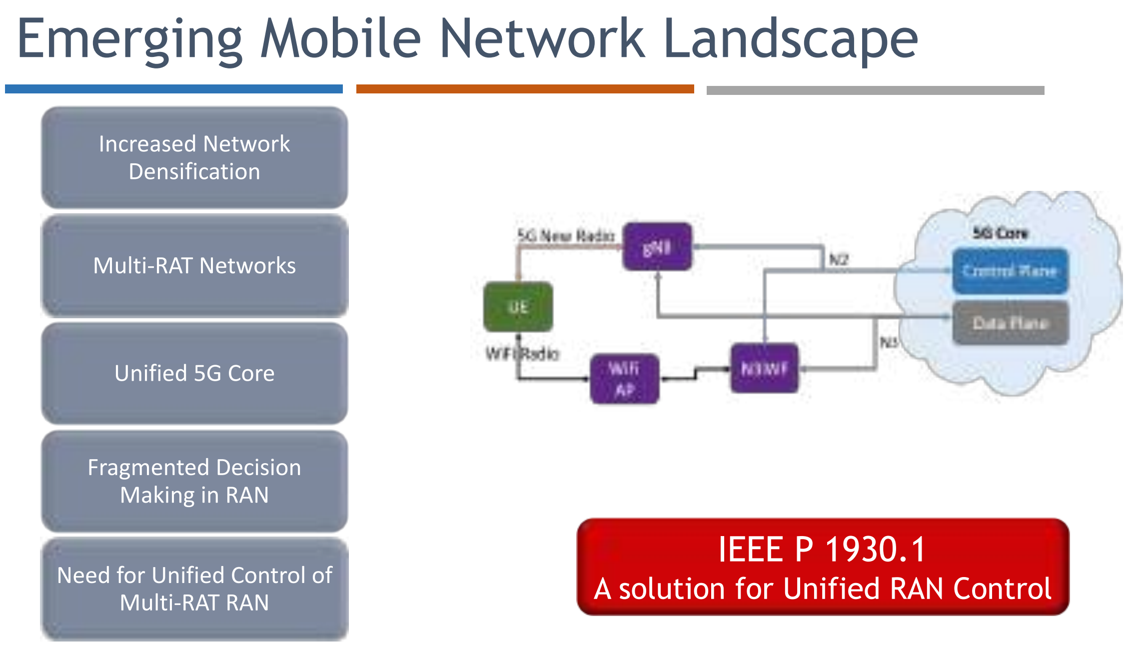
- Network Slicing
  - Multiple Virtual Networks over shared infrastructure
- Different Slice - Different Service



5G also uses the concept of Network Slicing. Network Slicing is nothing but deploying virtual networks over the same physical infrastructure. Thus, in 5G network, operators would be able to create different slices for different services. For example, one could create a slice for machine to machine communication, a slice for broadband communication, a separate slice for intelligent transportation, a slice for health care based network and so on. These slices could be configured with different parameters for quality of services. If an operator who wishes to deploy various applications in diverse areas, such as transportation, agriculture, health care, etc., with various quality of services, then these can be created by slicing the network in scalable fashion.

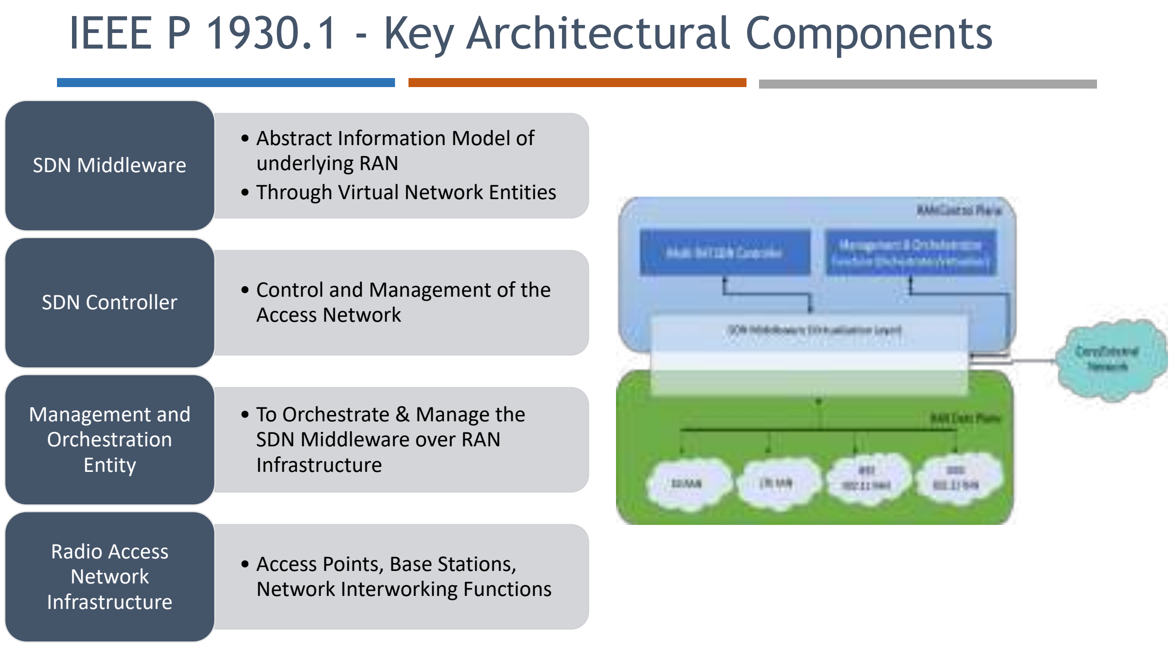
Now, let me also discuss how 5G can be used to address the rural broadband connectivity issue. While India has witnessed significant increase in mobile broadband communications, still about 700 million do not have broadband connections as of today. There is still large addressable mobile broadband market particularly in tier 2 cities and villages.

Historically, in the developed market, the broadband was primarily enabled through wired communication infrastructure, such as Fibre, DSL, etc. In emerging markets, like in India, the mobile phone has been one of the primary phones for majority of the population as the wired telephone penetration is not significant. Not only for voice communication, but the mobile is now also becoming the primary access device for accessing the Internet in India. Fiber to the home penetration is also limited in India. Thus, while cellular technology emerged in the Western world primarily to address mobility but in emerging markets such as in India, cellular technology has become the primary source for voice as well as for broadband access. The existing and emerging cellular mobile communications standards have focussed on urban usage scenarios.



For example, key targets for 5G standard are 20 Gbps throughput, 1 ms latency and 500 km/h mobility. The evolution of cellular mobile communications has not considered variations in use cases scenarios across regions and countries. The challenges and characteristics of rural connectivity have not been factored in specifications and design.

We need to really rethink 5G in terms of requirements for addressing rural connectivity. Some of these are low cost backhaul solutions, limited mobility support, energy efficient solutions and large coverage area support. For example, in terms of mobility support, we don't need very high speed mobility like 500 km/h but what we really need is high throughput with limited mobility. We also need energy efficient solution. For example, in India where we don't have 24/7 electricity supply at all locations, we need energy efficient solutions even for base stations and network nodes. We also need large coverage area support in rural setting.



To address the typical India rural setting requirements, TSDSI has proposed Low Mobility Large Cell (LMLC) as part of IMT 2020 test configuration. You may recall that eMBB is one of the configurations of 5G-IMT 2020. LMLC has been proposed as part of rural eMBB. This addresses the specific scenarios of our country of large coverage area with low mobility but at the same time requiring high throughput. Our group also is also leading an IEEE standards project P2061. This standard is working on defining a network architecture for low mobility but is highly energy efficient. One of the instances of architecture comprises of small cells

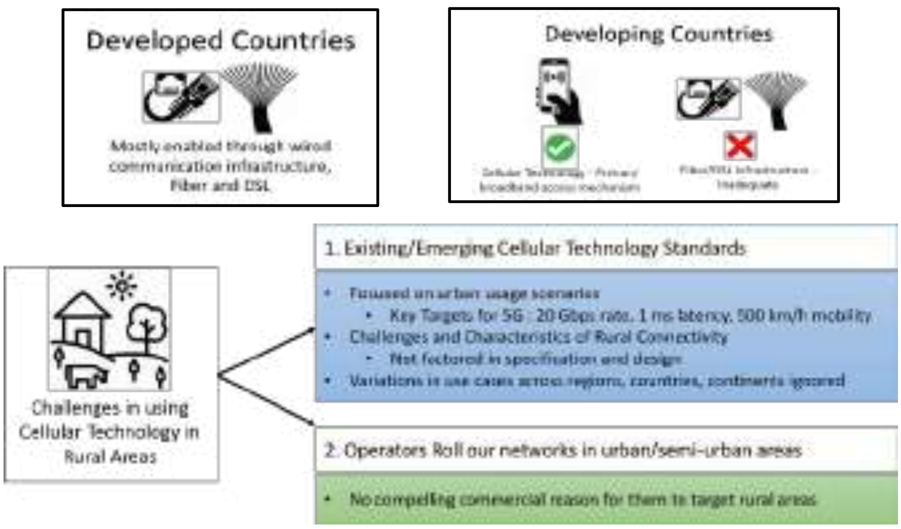
(WiFi hot-spots as high speed access points) which are backhauled using wireless middle mile to optical point of presence.

Rethinking 5G Requirements for Rural Areas

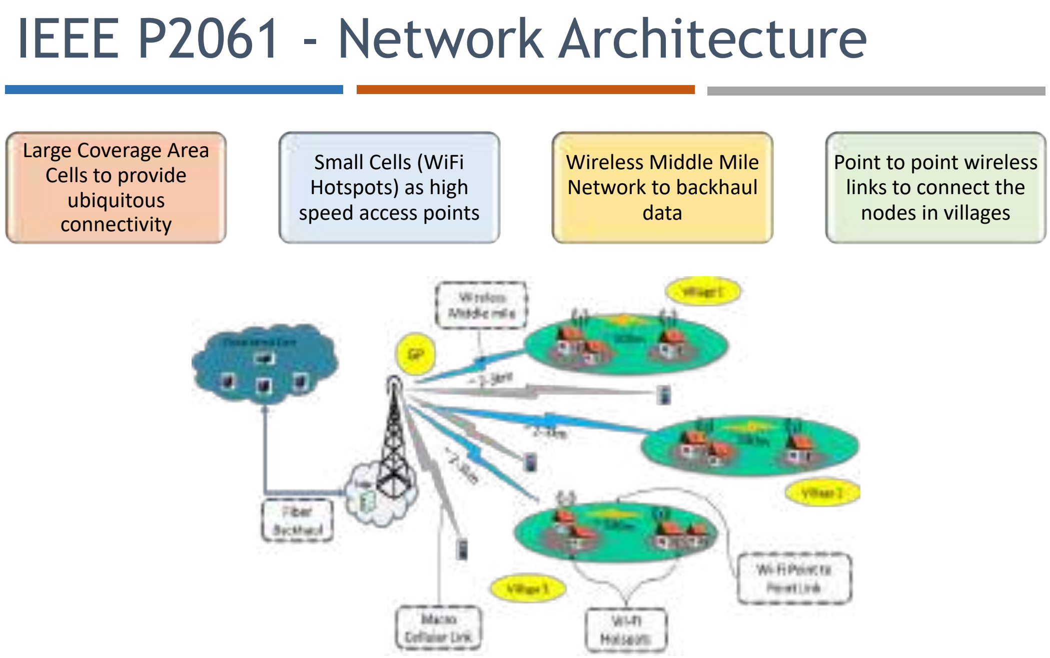
- Low cost Solution
  - Low Cost Backhaul Solutions - Wireless backhaul instead of Fiber
  - Lower Spectrum Cost
- Limited Mobility Support
  - Mobility required but not very high speed
  - Small no of vehicles in Rural Areas
- Energy efficient solution
- Large coverage area support

The above two examples indicate that we have taken Indian requirements to the international standards bodies to incorporate our specific use cases in global standards.

Internet/Broadband Access- How is it enabled?



I would like to briefly touch the case of increased network densification as well. In the emerging mobile landscapes, 5G is going to co-exist with 4G. Operators are deploying WiFi hot-spots as well. Thus, multiple radio access technologies get deployed in the network. In such as Multi-RAT network, the decision making remains

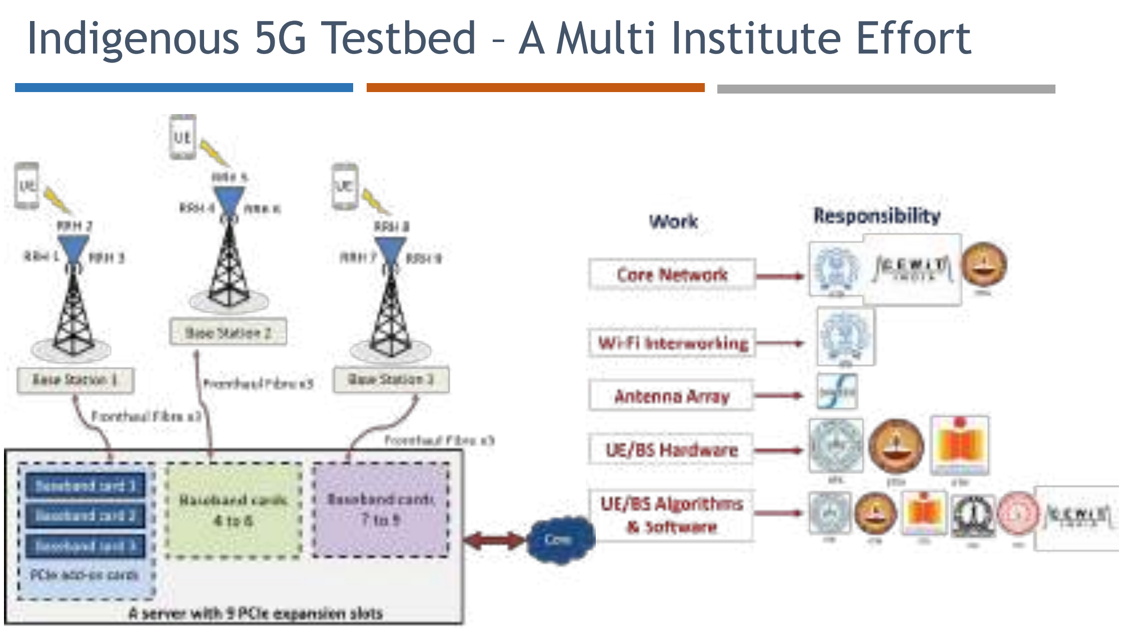


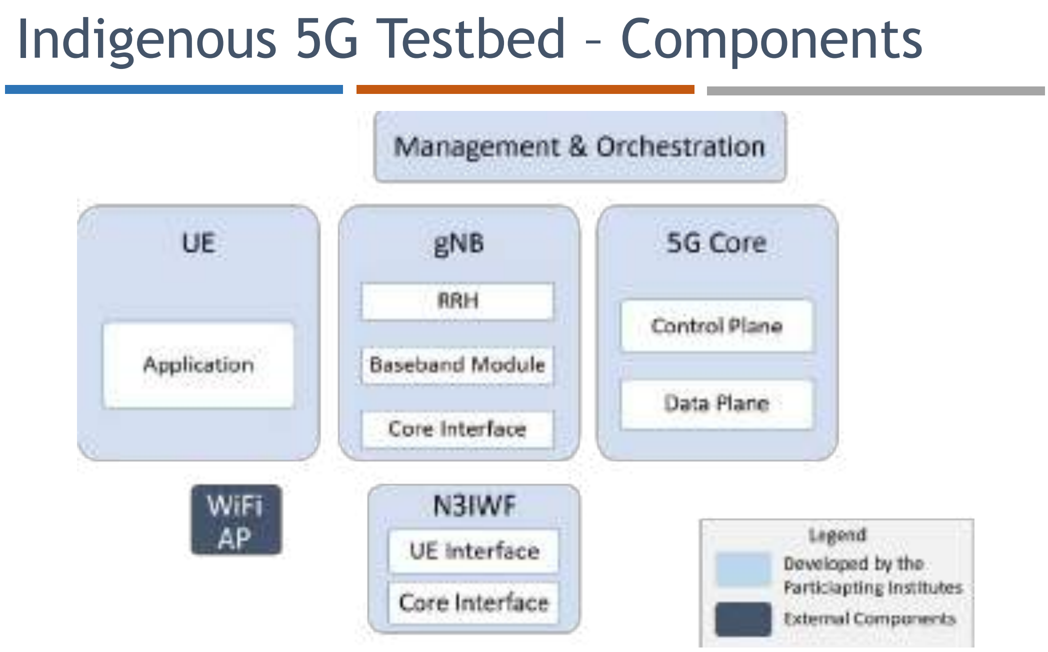
fragmented in radio access network (RAN). For example, WiFi access points may be controlled by a WiFi controller and so on. There is a need for a unified control of these multiple radio access technologies. IEEE P 1930 provides solutions for a unified RAN control. A Multi RAT SDN controller in the cloud through an SDN middleware can control all the radio access technologies through virtualizations. Thus, whether it is a 5G base station or a 4G base station or a WiFi access point, each could be virtualized.

Indigenous 5G Test Bed

- A Multi-Institute Project
  - To Enhance 5G Capabilities in the Country
- Goals
  - Enhance 5G R&D Capability in the Country
  - Boost Product Design and Manufacturing
  - Increased Participation in Global Forums/Standardization
  - Encourage telecom Product Start ups
- End-to-End 5G Testbed to develop
  - User Equipment
  - 5G NR Radio Node - gNB
  - 5G Core
  - WiFi – Interworking Support

While we are contributing to the 5G standards, a PanIIT effort is also going on in developing the indigenous 5G test bed. Globally, we believe that 5G deployment is likely to be delayed as a fall out of Covid19. This gives an opportunity for Indian organizations and companies to develop the technology and deploy indigenous network in India. 5G Test-bed is a multi-institute project. The goals are essentially to enhance the R&D capabilities in the country, boost the product design and manufacturing and of course encourage and incubate telecom start-ups. This is an end to end test-bed where we are developing the prototype of a user equipment (UE) the prototype of a 5G NR gNB and 5G core with support of WiFi access point. This is a joint effort between IIT Bombay, IIT Madras, IIT Kanpur, IIT Hyderabad, IISc Bangalore, Centre for Excellence in Wireless Technology in Chennai, SAMEER and CDoT. Our team in IIT Bombay is developing software based 5G core network prototype and we hope that by the end of this year or early next year, we will have many components of this 5G test-bed ready which could go for field trial.

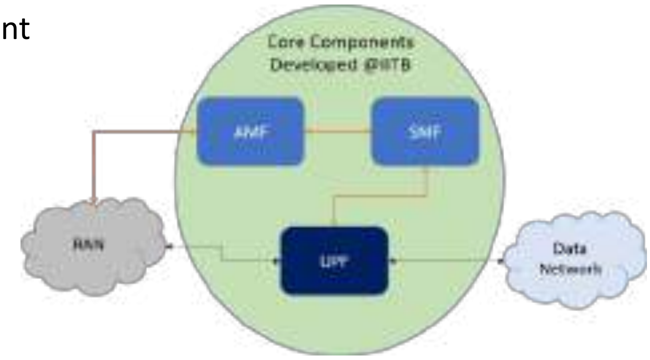




To summarize, with the 5G networks, we are going to have multiple use cases like enhanced broadband, machine type communication and low latency applications. This technology is also going to be very useful in the Indian context for enhancing the

IITB 5G Core

- Registration, Authentication, Security
- Data Path Configuration
- User Data Forwarding between RAN and External Data Networks
- Mobility Management
- Policy Enforcement



performance of mobile broadband. As observed earlier, mobile broadband is a primary broadband for most Indian subscribers and therefore high throughput itself would be a good application driver as most Indian homes are not having access to fibre to the home. Finally, increasing softwarization also gives an opportunity for the Indian companies and the Indian institutions to leapfrog into developing the prototypes as you don't need very specialized hardware or specialized chips to develop the technology as was the case in 3G and also to some extent in the 4G. Thus lies a big opportunity both for development as well as deployment. Thank you very much.

Mr. Arnob Roy: Thank you Abhay, I have a bunch of questions summarized across different questioners. Part of questions are with respect to Abhay and rest are for both Abhay and Sanjay. Of course, you have answered the questions about the areas of research going on in IITs and other academic institutions in India, you mentioned the test-bed and development of the new radio and the core and other things, would you like to summarize the work that is going in IITs, academic institutions or other areas would you like to highlight.

Prof. Karandikar: 5G test-bed compliments the difference capabilities in different institutions, for example, the radio technology is being developed by IIT Madras and IIT Kanpur. In fact the base band is being developed at IIT Kanpur and RF is being developed at IIT Madras, then the core is being developed by IIT Bombay. Similarly, the antennas etc. are being developed by SAMEER. This effort is using the complimentary expertise that exists at different institutions.

Mr. Arnob Roy: Another question was, if 5G can work in the sub-GHz band, then why do we need 5G in mm-wave band.

Prof. Karandikar: That is a good question. There is always a trade-off between coverage and capacity. In the lower frequency band we can get a good coverage, but then the band width is limited. Since the band width is limited, we will not be able to achieve that high data rate. The peak data rates or even the user experienced data rate will be somewhat limited. On the other hand, in mm-Wave, because of the penetration and propagation characteristics the cell size will be limited, but since we are talking of 24 GHz and so on, the carrier band width could be very large. In fact, with carrier aggregation, we can go up to 1 GHz of band width and with 1 GHz of band width we can get 20 Gbps kind of throughput. But with the 20 Gbps kind of throughput, cell size will be limited. Hence, mm-Wave will be used for hotspots, while 700 MHz bands or 800 MHz bands can be used for covering a large area for providing vehicular type of mobility.

Mr. Arnob Roy: Next question was around the topic you addressed about hot-spots, what would be role of WiFi especially new technology like WiFi C with respect to 5G especially for hot-spots, how would they coexist?

Prof. Karandikar: The WiFi will also coexist with 5G. In 5G, one can control the quality of service very tightly, therefore the premium application which require very tightly controlled quality of service, you obviously would go for the 5G kind of applications. For example, very tightly controlled low latency applications like AR, VR or vehicle to vehicle communications where you require guaranteed quality of service then you go for technologies like 5G and so on. But where you need best effort high throughput then I think one can go for WiFi hot spots. As I already mentioned, we are going to see multiple radio access technology coexisting. The operators are not going to throw away their 4G investments and their 4G base stations, so that is going to remain; WiFi hot spots are also going to be there when you need best effort broad band. We are likely to have the multiple radio access technologies coexisting.

Mr. Arnob Roy: There is a question around the effort to allocate mm-Wave 24 GHz and higher spectrum band, there is also use for many other applications such as automotive, radar and so on. Have the frequency bands been allocated taking care of the other applications?
Prof. Karandikar: Well, unfortunately in India we are having this problem. 24.25 to 27.5 GHz band has been assigned as the 5G band by both 3GPP and ITU. I believe that DoT is working with our space agencies, ISRO and also with defence forces to address the coexistence issue. Currently, I think the likely scenarios for the operators in India would be to get 3GHz band particularly from 3.3 to 3.6 GHz.

Mr. Arnob Roy: Has ITU accepted our recommendation for Low Mobility Large Cell?

Prof. Karandikar: Yes, it is a part of the rural eMBB scenario of IMT 2020.

Mr. Arnob Roy: You described how 5G achieves low latency, is there a fundamental limit to latency? How low it can get and what constrains that?
Prof. Karandikar: The fundamental limits really come from the wireless channel. For example, in optical fibre we can go up to terabits, but in wireless from few Kbps we have now been able to achieve few Mbps and perhaps will go to few Gbps. The low throughput is primarily

because of the very notorious characteristics of the wireless channel where we have multipath and so on. Similar issues exist for the latency where in order to reduce the slot structure to address low latency operation, you also need to ensure tight synchronization. This puts a limitation.

Mr. Arnob Roy: What are the security concerns around 5G across the world regarding 5G requirements?

Prof. Karandikar: The security concerns over the wireless are similar whether it is for 3G or 4G or 5G and the standards have addressed this by defining various protocol and encryption techniques. Of-course, nothing can be fool-proof. Applications also ensures end to end security by using their own encryption or protocol mechanism. Finally, there is always a trade-off between the security and flexibility. In order for certain applications to really deploy and run some level of security at the application level is also needed.

Mr. Arnob Roy: Why do we need larger number of towers and base stations in 5G?

Prof. Karandikar: Towers depend upon two factors: the frequency band and the coverage. If we go for mm-Wave frequencies, then obviously as the cell sizes are small and if you need large number of hot spots then you would need that many towers. If you go for lower frequencies then you can cover a large area and you may need lesser towers. Towers are also needed if subscriber density is very high. You need to break a geographical area into a number of cells. In fact, the whole concept of cellular technology enables you to what we call as a frequency reuse. Thus, the same frequency can be reused in the neighbouring cells and so on and that is how you can cover a greater number of subscribers. Otherwise for example, in case of TV tower, you have just one tower which could broadcast to a large number of users. But when you need two way communication and you want a greater number of subscribers to be connected, then you need to create these number of cells. The number of towers depends upon the coverage, subscriber density and the frequency band on which

you are operating and typically an operator needs to do careful RF and capacity planning and that determines how many number of towers and what would be the location of these towers.
Mr. Arnob Roy: I am addressing the next set of questions to Sanjay, however, you can chip in whenever necessary. Sanjay, how can 5G be useful in making mobile broadband affordable, especially for economically weaker sections of population, specially in rural areas?
Mr. Sanjay Mashruwala: As Abhay said, if you have a larger bandwidth, then you can carry more data and if you don't need that much data per user, then you could have more number of users, share the same amount of data that is coming to it. 5G is capable of handling larger quantity of data, larger amount of data. Obviously to that extent per user cost of data per mile per user cost would be lower. The technology has matured and it is not in the initial stages where the developmental cost is high. If you look at it the cost of data per GB or per MB in the early days of 2.5G, then with 3G and 4G, it has been continuously coming down and that is the reason why technology makes it more efficient to transmit the same amount of data. For the same cost larger amount of data spread over larger number of users, the cost per user comes down.

Mr. Arnob Roy: We seem to be going late in terms of 5G deployment with respect to the rest of the world. Do you see any economic impact of that?
Mr. Sanjay Mashruwala: Actually, we are not late, it is a question of what you call late and what you call early. Today, China is way ahead of us in using electric cars, or Europe or USA. We are still getting into the electric cars. Similarly, 5G and many other technologies some of the other nations or some of the economies are in it. It is not necessarily late, it is a question of few years here and there, except over all development that is required, not just months in case of 5G. As I said we are also talking about various other technologies that have to develop, the entire ecosystem has to be developed around and obviously depending on different levels of economy, different level of local needs, different level of technical as well as economical development these things could be somewhat different in one country to another. I don't think it is necessarily any disadvantage.

Mr. Arnob Roy: What would be the advantages for 5G which could motivate the operators to deploy quickly and widely as possible?

Prof. Karandikar: I don't think the killer apps really come up when the deployment happens. When people start using the network, then newer applications actually get developed. As I already said that enhanced mobile broadband itself will be a killer app for most of the Indians. I think Sanjay has also mentioned that tremendous amount of data gets generated when the network speed increases and deployment of technologies like block chain, artificial intelligence etc. could also drive many new applications and use cases which even we cannot think of today.

Mr. Arnob Roy: How is the massive MIMO, multiple number of antennas are going to help in 5G? what is the benefit of that?

Prof. Karandikar : Massive MIMO simply increases the multiplexing gain and that is why you can increase the throughput. The real question is: "why can't we use this Massive MIMO in 400 MHz, 500 MHz"? Actually what happens is that the antennas are typically proportional to the wave length. So when the frequency is high, wavelength is small and therefore the size of the antenna will be small. Therefore, you can have larger number of antennas and you can have more number of antennas even on your cell phone on a higher frequency band. Thus, it becomes feasible to have multiple antennas in mm-Wave band.

Mr. Arnob Roy: One last question to Sanjay: with deployment of 5G, are we going to see a much improved quality of service as far as the data experience is concerned?

Mr. Sanjay Mashruwala: Quality of service, particularly, is the issue of reach of the signal where the user is, which I talked about the penetration and propagation part. A lot of that is debated by physical limitations in being able to get an antenna close enough to the user or get the signals penetrate all the way where the user is, that challenge can actually been marked with higher frequency and that is where the question of small cells and large number of small antennas being all over the place comes in which is obviously a large physical exercise and activity to be able to go and install these antennas, get the power to the antennas, get the fibre to the antenna and so on. But yes, technically once we are able to do that, the quality of service will surely improve which is actually true for anything, just not 5G, 4G, 3G or any equipment.

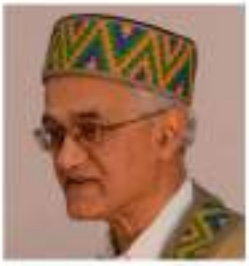
Mr. Arnob Roy: Thank you Sanjay, thank you Abhay. Susheela you can take over.

Dr. Susheela Venkataraman: Than you Arnob, thank you to all of the people today and absolutely fascinating session, particularly many of the audience have been quite surprise to know that a telephone is something headed to evolve at some point of time. Today we learnt that 5G is a whole new technology, it is not an incremental change from things that we already know, we learnt about softwarization and a lot of the pieces that go to creating 5G. We saw that 5G is not just about wireless technology but also about a whole new set of technologies that go along with it and it is all about an ecosystem that has to work together very well. We have looked at the question of why 5G is important to India especially from the point of view of access to who do not have access and it is very very heartening to note that international standards organizations and the international standards relating to 5G are taking on board the recommendations and the needs of countries such as ours. We saw there are many new opportunities for developmental, implementation interventions and we also saw there are many business opportunities that are going to arise as a result of the implementation of 5G.

Thank you all very much, Sanjay thank you, Prof. Abhay Karandikar thank you ever so much and Arnob thank you very much for holding the whole session together. Many thanks to our audience. All of your questions have made it interesting for us to host this seminar. As Ashok said, we do have a webinar every Saturday, please do look out for them and join us. Once again thank you all.

CHALLENGES IN CREATING A GLOBAL INSTITUTE IN A REMOTE AREA

PROF. TIMOTHY A. GONSALVES I MAY 30, 2020



Timothy A. Gonsalves

B.Tech. (Electronics) IIT-Madras; M.S. (Electrical Engg) Rice University, Houston; Ph.D. (Electrical Engg) Stanford University, California. Joined the Department of Computer Science & Engg, I.I.T., Madras as an Assistant Professor in 1989, rose to Professor and Head of the Department.

Cofounder of the TeNeT Group of IIT-Madras, founding Director of NMSWorks Software Ltd, n-Logue Communications Ltd, Nilgiri Networks Ltd and the IIT-Madras Rural Technology Business Incubator (IITM RTBI).

Since January 2010, the Founding Director of the Indian Institute of Technology Mandi in Himachal Pradesh, also Professor in its School of Computing & Electrical Engineering. Led the initiative to increase female BTech students in IITs from 8% to 20%.

Interests: Education for engineers of the future. Design and performance of computer and telecom networks. With emphasis on innovative and low-cost product and technology development for Indian and international industry. Fostering software development in small towns and rural areas. Guided/co-guided 5 PhD and 26 MS research scholars.

Led or advised the software system design for product/technology development in telecom area. Commercially-successful products include Nova thin-clients, Grammateller Rural Automatic Teller Machine, corDECT Broadband Wireless Local Loop System, CygNet Network Management System for telecom, BlueBill telecom billing software and the LAN-T trainer kit for colleges. Sold in India and several foreign countries.

Webinar at IIT Alumni Centre, Bengaluru on May 30,2020

Link to the webinar : https://www.youtube.com/watch?v=yMCJCTPPOf8&list=PL0zMQ-70IHlX-df3u2Tto6dkKHCRC6iFL&index=12

CHALLENGES IN CREATING A GLOBAL INSTITUTE IN A REMOTE AREA

PROF. TIMOTHY A. GONSALVES I MAY 30, 2020

Prof.M.S.Ananth

Prof. Ananth graduated from the AC College of Technology with a gold medal In Chemical Engineering. He obtained his Ph.D degree In Chemical Engineering in the area of Molecular Thermodynamics from the University of Florida, USA In 1972 and joined IIT Madras as a faculty member in the same year. He held various senior positions and served as Director of IIT Madras from Dec 2001 to July 2011. He was one of the key persons associated with the preparation of The Strategic Plan of IITM - Vision 2010. Prof. Ananth was a Visiting Professor at Princeton University and University of Colorado (USA) and in RWTH, Aachen (Germany) and a Visiting Scientist in ICT, Mumbai, Aspen Tech and the National Institute of Standards and Technology (USA). He has taught a wide range of courses in Chemical Engineering and has been consistently rated an excellent teacher. His research Interests are In Molecular Thermodynamics and Mathematical Modelling. He has several publications in and is a reviewer for several international journals. He has been a consultant for several industries in India. He has been awarded the Herdillia Prize for "Excellence in Basic Research" in Chemical Engineering by the IIChE and the R.W. Fahien Alumni Award for "Distinguished Professional Contributions" by the University of Florida. He is a Fellow of IIChE and INAE. He was Member of the Scientific Advisory Committee to Cabinet and of the National Manufacturing Competitiveness Council (2008-2011).

He is responsible for setting up the IITM Research Park, the first University-based Research Park in India. He is the architect and the first national coordinator of the National Programme on Technology Enhanced Learning (NPTEL). NPTEL has created over 800 video and web courses for free use by all the engineering colleges In the country. In December 2011, I&EC Research published the Ananth-Festschrift Issue consisting of over 75 technical contributions from former students and chemical engineering colleagues in honour of "Professor M.S. Ananth, leading researcher, gifted teacher and visionary leader of higher education in India".

Webinar at IIT Alumni Centre, Bengaluru on May 30,2020

Link to the webinar : https://www.youtube.com/watch?v=yMCJCTPPOf8&list=PL0zMQ-70IHlX-df3u2Tto6dkKHCRC6iFL&index=12

Prof. Ashok Misra: Good evening to all of you, those who are attending the webinar of IITACB, Bengaluru. I am Ashok Misra, I am the president of the IIT Alumni Centre, Bengaluru, IITACB for short. Just to give you a little brief about IITACB, it was set up about 10 years ago, and we are trying to be the facilitators for the high end projects to flow from the industry to IITs and in this endeavour we have held several workshops and held a very successful IIT-Industry conclave in February. While we are following up the recommendations of the conclave, the Covid 19 hit the world and we all went into a lock down. We turned this into an opportunity and we started our webinar series on topical areas and we had several webinar, seven to be exact, you can go to the youtube and look at them but most of them have been in technical areas ranging from Covid to Materials to 5G and many many more to follow.

Today, we are having a different kind of a webinar and let me first introduce the people who will be on this webinar, two stalwart Directors of the IIT system. We have Prof. Timothy Gonsalves who is the Founder Director of IIT Mandi and he was concurrently a Professor in the Department of Computer Science at IIT Madras where he also was involved in a few start-ups. The Moderator for us today is my very good friend and contemporary, another retired director from the IIT System. We were Directors of IITs around the same time, Prof. M.S. Ananth, former Director, IIT Madras. I would rate both Timothy and Ananth as the two very entrepreneurial Directors. As you will see, IIT Mandi was set up in a very remote area 400 kms beyond Delhi in a place called Kamand which is actually as remote as you can get. People talk of locational disadvantage. Today you will see how Timothy has converted that disadvantage into an opportunity and the wonderful things he has done.

Ananth set up the first ever IIT Research Park at Madras which is flourishing. They had a one five-six storey building, I don't remember the area is sq.ft. and the second building is coming up, a leader in that manner. So I am very privileged to have both Timothy and Anand on this webinar today. Ananth, of course, I have visited a few times and even I had a chance to visit, it is something to go and see for yourself and then believe it. Before I hand it over to Timothy for his presentation, a few housekeeping matters. Whatever the comments you want to give to the panellists or the other participants please put it in the chat box. All your questions should be brief, one liners/two liners in the Q&A box and Prof. Ananth will take care the questions at the end or after presentations by Timothy. I must also mention here that these webinars have been very successful, we have over 500 registrants almost routinely, today we have over 500 registrants for this webinar. With these few introductory remarks, we from IITACB welcome Timothy Gonsalves and Ananth to this seminar. Over to you Timothy.

Prof. Timothy Gonsalves: Thank you for the introduction. Prof. Ananth, do you want to say anything at this point?

Prof. Ananth: I just want to set the background. I want to say that the university today still has many of the characteristics that renaissance thinkers thought of, that is the basis, but basically they were looking at research and teaching and what has happened in recent times is that the intellectual property rights have become very important and therefore innovation has become very important and since the university has always been the source of innovation, that is another important aspect and social relevance has become important because the tax payers don't want to support systems that are not relevant to them. So, I think Timothy is going to cover all these, we look forward to hearing from Timothy about what he did at Mandi and how he integrated all the requirements of the university into a beautiful landscape. I must say that Timothy went there because of the hills, he has a love for hills. Over to you Timothy.

Prof. Timothy Gonsalves: Thank you, let me just share this screen. Thank you Prof. Misra and Prof. Ananth. Thanks for the introduction. As Prof. Ananth has mentioned, I came to Mandi the first time in January 2010, in fact that was my first visit to Himachal. I had taken up the job of

Director of this new Institute without knowing what the place was like except that it was in the mountains, and I come from the mountains in Tamilnadu.

If you look at the temples of learning in India, in the ancient period, often we went for wisdom to the Himalayan mountains, maybe to a remote river bank, someone sat under the banyan tree to get inspiration for learning, for wisdom. Now, in modern India on the other hand if you look at the temples of learning, the IITs, leading universities, almost all of them are in crowded, polluted cities, they are in cities that are today infected by Covid. The question is: can this change or should it change? In fact, this was a question we asked ourselves when we were starting IIT Mandi.

I will talk a bit about the genesis, what the location is, I will talk about the strategy we adopted and then I will take you through some of the developments of IIT Mandi in a few areas in education, in research, in connect to society and so on. And at the end I will share with you some of the outcomes of our journey over the past 10 years.

Back in 2008-09, the Government decided to start eight new IITs, and one of them was allotted to Mandi in Himachal. The location chosen was a 500-acre site near the village of Kamand on the left bank of the Uhl river. This village had a population of under 200 at that time. The 500 acres consisted of 200 acres Animal Husbandry farm and 300 acres of forested mountain slopes. Himachal itself is a peaceful state with a very high human development index (HDI) which is the 3rd highest in India, it has a low population of 7.4 million people and 90% of this is rural. In fact Himachal has the highest percentage of rural people in the country. The economy of the state is largely agrarian. There are some pockets of industry, mainly pharma industry, tourism, cement and of course there are a few pockets of education over here.

What you see here is the IIT campus on the banks of the Uhl river. The campus stretches from the lower right corner along the river and the flat green area you can see is the Animal Husbandry farm and then it goes around the mountains to the left center. This is another view, you can see a few stables and not much else over here.

The challenges that we faced, as did all the other IITs, was of course how to hire and retain good faculty and staff, how to attract good students and starting without anything to equip the labs and library, get research funding, get industry to come for placements and so on and also to construct a campus, a fully residential campus, with academic buildings, residential buildings, sports facilities, etc. etc. Some of the specific challenges we have over here which are different from the other IITs is that our campus is a 45 minute drive from the nearest small town, Mandi, which had a population of just about 40,000 people, the road goes over a steep mountain pass with a 1,500 foot gorge on one side which is fine for the people from Himachal, but people from the plains of India find that it is scary. The nearest major city is Chandigarh. There is 6-7 hour journey by road to get to Chandigarh.

Now what this means is that if a faculty member at IIT wants to attend say a one hour meeting, it takes about two days of travel to go to Delhi, Bombay or Bangalore, have the meeting and come back. In addition to this, Himachal has a lot that people from the rest of India are worried about: cold winters, mountains, landslides, wild animals - leopards, bears and so on. There actually aren't any leopards here to worry about, but the fear is there. The more serious problem is the lack of an ecosystem. When a faculty member joins an Institute, s/he comes with a family. He/she wants good schools for the children, spouses want jobs and elderly parents would need medical care. All of this was not present over here. Many people felt that out of the eight new IITs that were started, IIT Mandi was fated to be at the bottom, to be number eight always. We, from the first, did not believe that, and we set out to prove them wrong.

So what is the strategy that we should adopt to become a leading research university around the world? One obvious idea is to copy or clone one of the old IITs. It is tempting, because that is an existing model. Take IIT Madras for example, you see it has a fancy main building and a lot of banyan trees and, of course, it is doing very well in academic respects, also. However, when we looked at it ten years ago, the IITs while they were excellent in India, they were still falling short in many measures compared to some of the best global universities.

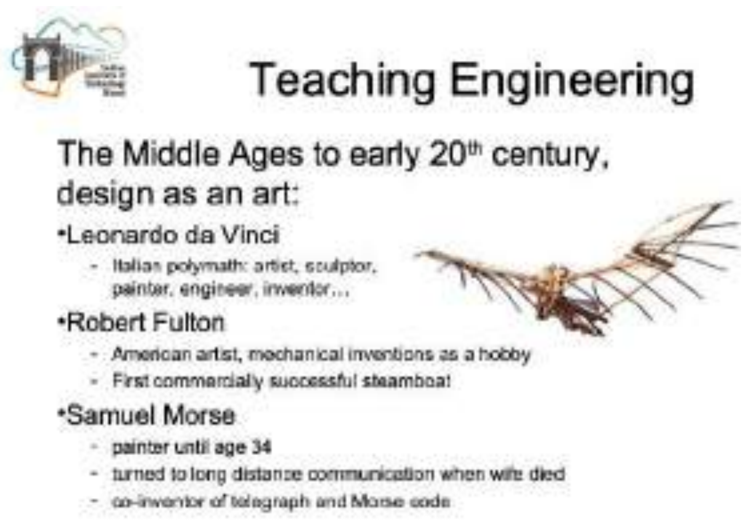
So we said, let us look outside India for examples, so we studied a number of leading research universities in North America and Europe, in Singapore. We looked to see if they have characteristics that helped them achieve prominence. We found that some of them are very small, some of them are large, some are largely undergraduates, some are largely postgraduates, some are private, some are public. There seemed to be very little in common. One thing that we did find is that all of them have a strategy of working for the local and the national needs and national priorities. This comes in different ways, in some cases like in Caltech, some of the national labs are run by the university. In other cases, there is industry nearby as in Stuttgart, and the industry brings in the national priorities and needs. So this is something that we realised - the path to technological excellence

is through working on local, regional and national problems, and fortunately India is a country with very large number of problems, which is very good for engineers, there is a lot for us to solve.

So the strategy that IIT Mandi chose was to focus on a few areas to try to become among the best in the world in those and pick areas that are of regional relevance and national relevance, which meant the Himalayan region and in India as a whole. Because if you take the problems of our region, we live here, we understand the problems and we are likely to come up with the best solutions. Being a small new institution, we decided that we needed to build strong partnerships with like-minded institutions both in India and outside India, educational institutions and industry. Also, the problems of society are inherently interdisciplinary, the solutions do not fit within narrow academic disciplinary branches, so we decided that we would try to foster a culture and an organization, academic and so on that cut across disciplines. And finally, we believed that IIT Mandi has a strong advantage in this location. So we decided, we should exploit that.

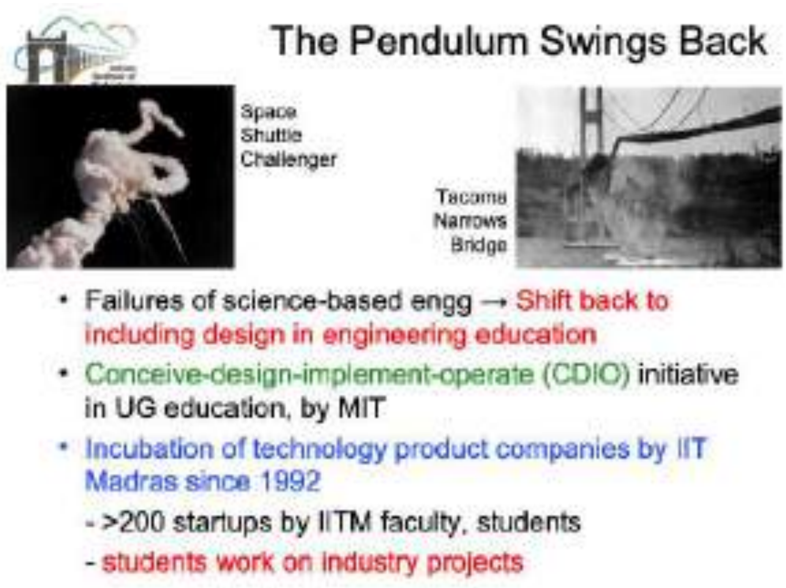
IITs are perhaps best known for the undergraduate programme, they are reputed for excellence in teaching, we are also known for research. So the first thing we looked at was the B.Tech. programme and at that time in 2009, one batch of B.Tech. students, 97 students had already been admitted, so that was the first priority. So as I said, we could have copied the curriculum of one of the older IITs, I came from IIT Madras, IIT Roorkee was the mentor IIT, but we decided instead let us have a fresh look at engineering education and figure out what we should be doing to educate the students who are going to be working for the next 30-40 years.

So we first decided to look backwards. Looking at engineering over the last 700 years, for a long time engineering was more of an art. If you see some of the leading engineers, people like Leonardo Da Vinci, Robert Fulton who developed the steamboat, Samuel Moss who developed the Telegraph. These people have transformed society through their technology and products that they developed. None of them were engineers or scientists, they were artists, painters and so on, and they took up engineering as one of their many activities and were extremely successful. So for a long time, teaching of engineering was akin to apprenticeship an engineer would focus on skills, a student would go to a skilled engineer in order to acquire the experience and the wisdom of the master. Engineering design was often done using tables, design rules and so on which were written down. Some might have been calculated, some came from the experience of the master engineers.



Before World War-II, in teaching of engineering there was some teaching of science but again it was largely lip service. During World War-II, the influence of science and engineering really grew a lot, there were a number of war time developments, radar, sonar, radio, code breaking encryption and tremendous use of operations research for logistics and, of course, the Manhattan project for developing the first nuclear bombs where some of the leading physicists of the western world were involved. So governments and the public and the universities realized that science could make a big difference to engineering.

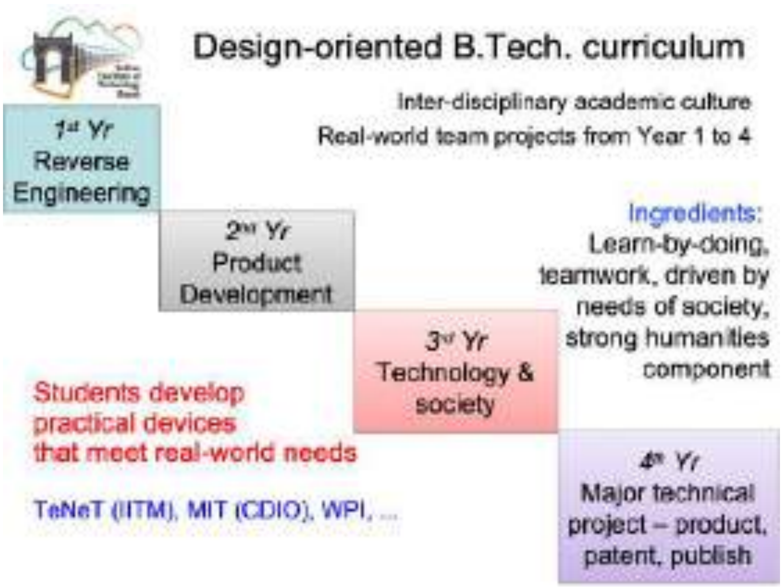
Towards the end of the second world war, Vannevar Bush who was the science advisor to the US President wrote a report called `Science the Endless Frontier'. In the 45 page report that he submitted to the president, he made a very strong case for government funding of basic science research and he pointed out that basic science research drives applied science and engineering. In fact, this view was bought by the US government and governments elsewhere and by the universities, and there was very generous funding from the national science foundation and US military to research universities like MIT, Stanford and so on. So then the curricula in these universities for the undergraduates changed drastically and became very much science-based so there was much more dependence on doing analysis, mathematical modelling, computer simulation and so on and with less hands-on practice.



Interestingly, a few countries particularly Japan, Germany and Netherlands retained a strong emphasis on practice in their engineering education, while bringing in some science base also. So with this science base, there was a tremendous flowering of technology and technology-based products and things were going very well. But then there were also some disasters, some problems. For instance, the Tacoma Narrows bridge in Washington State collapsed when there was a 70 km/hr wind, the space shuttle Challenger exploded during takeoff due to a faulty O-ring seal and all the crew members were killed. These are some of the failures of engineers who were perhaps too much science based and did not have enough practical experience.

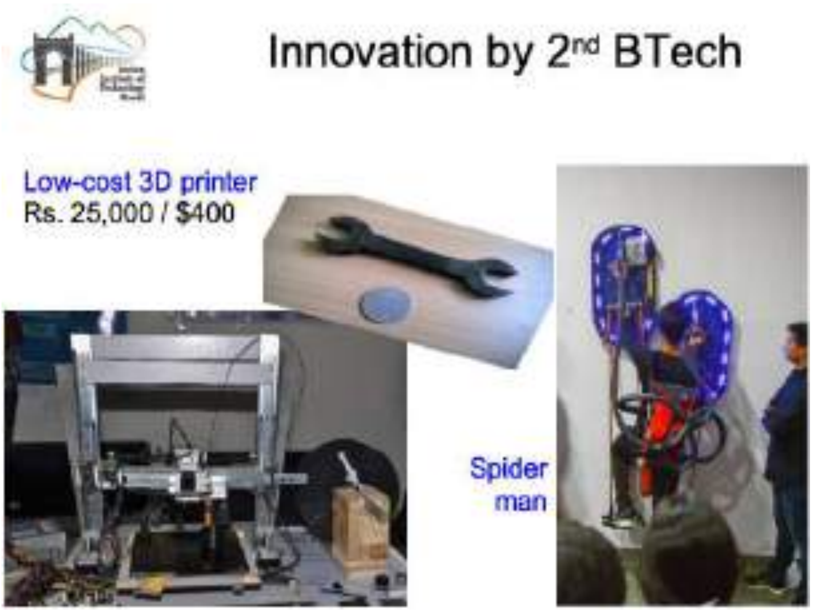
So the pendulum of engineering education started to swing back. At MIT there was an initiative called Conceive-Design-Implement-Operate (CDIO) for giving undergraduate students hands-on experience in product design. At IIT Madras in around 1992, a number of faculty started the TeNeT Group (Telecommunication and Computer Networking Group) and started developing technology for immediate use in the area of telecommunications. Over the last two decades, IIT Madras faculty and students have started over 200 startups and have developed a wide range of products and technologies in these. One of the key things over here was that in addition to their studies, a number of interested undergraduate students and masters students and even Ph.D. students started to work on these industrial projects along with the faculty. So there was in a sense a team of the IIT faculty, the students and industry working together to develop technology.

Given all these experiences and studies, we decided at IIT Mandi to have an undergraduate curriculum that was very much based on and emphasized learning through projects throughout the four years. Students would take up real-world problems, they would work in teams, in interdisciplinary teams in order to solve problems, they would deliver solutions to customers in society and so on.



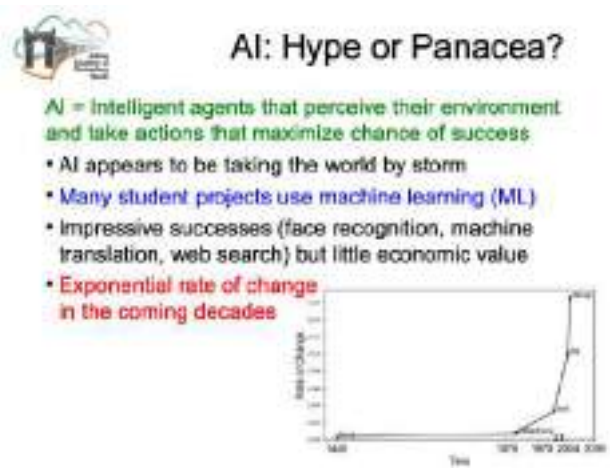
So if you look at our curriculum, in the first year students do reverse engineering They dismantle existing products, understand how they work. And in the second year, they work on product development. They have to build a prototype based on some idea of theirs. In the third year, they go out into society and do essentially a market survey, and in the fourth year they do the traditional major technical project. So they get experience on all aspects of the work that an engineer would do in a product oriented design company.

To give some examples, during the second year all the undergraduate students, all second year BTech students have to do a design practicum, they have to choose a problem of society and within one semester they have to design a solution for that, build it and show that it works, in an Open House, all with a budget of Rs. 25,000/-. What you see on the right here is an automated cooker made by a batch, a group of five or six 2nd year undergraduate students. The ingredients are fed in at the top, the recipe is fed in the microcontroller, the ingredients are chopped up and then fall into the frying pan. They get cooked, and the dish comes out at the end. Other teams of students have worked on things like voice-controlled wheelchairs, intelligent drip irrigation where the irrigation is controlled by the amount of moisture in the soil, clothes dryers that work in the monsoon and so on.



What you see on the left here is a 3D printer. We had bought a 3D printer for about Rs. 12 lakhs. These students, in three months, built a 3D printer at a cost of Rs.25, 000/-, and the spanner you see in the centre is printed by their 3D printer. On the right hand side, is a spiderman outfit which a batch of students made using a couple of household vacuum cleaners and some tubes from a scooter.

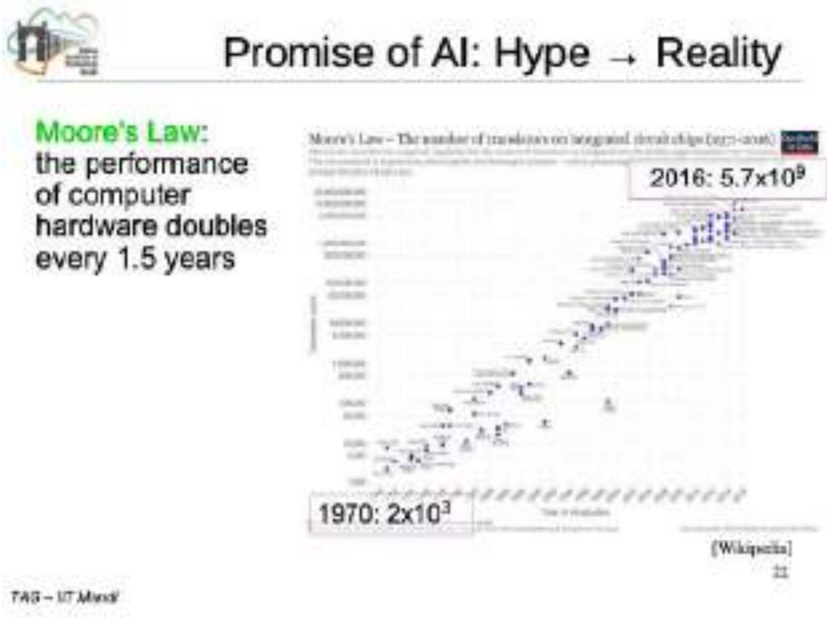
One thing that we found when our students work on these projects is that many of them started to use machine learning, to use Python programmes, and to do fairly sophisticated kinds of programming in their second year project. They would be a bit surprised to see how easy it was to have automatic control and so on by using existing available Python libraries. Now this



machine learning is actually a part of artificial intelligence. There is a lot of AI that has been in the news for quite a while, and we are told that AI is going to be the solution to almost all problems. Now there have been some successes of AI such as face recognition in Facebook, web search, machine translation and so on. At the same time if you look at a country like India, there has been relatively little economic value if you look at our GDP and for most people there has been relatively little impact of AI on their lives so far. And in fact, some studies that have been done even in the West have found that most AI based startups have not made much money.

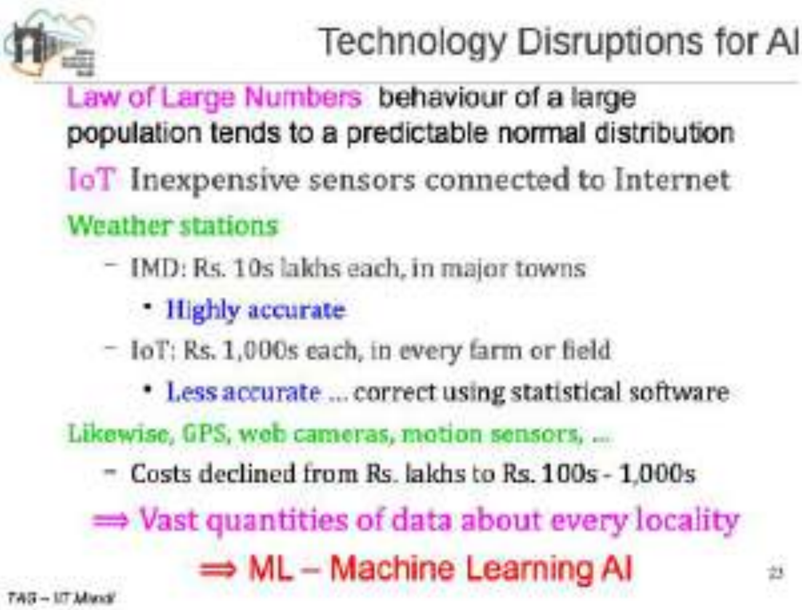
So the question is, there is this AI bandwagon and as an educational institution, as an IIT should we get on to it or should we not? This was something that we were grappling with a few years ago. One thing that we looked at is that AI has become more successful because of changes in computing technology and communications and so on. So we did an informal survey of some recent disruptive technologies. For example, if you look at things going from the printing press in the 15th century to telephone, the Internet, Facebook and Whatsapp. Now the rate at which these disruptive technologies appear globally has been shrinking as time goes forward. So essentially, what we see is that the rate of change in society is growing exponentially. Essentially what that tells is that even though AI may not have been doing very well in the past, in the next 10 or 20 years, it is likely to do very well.

Lecture at IIT Alumni Centre, Bengaluru on May 30, 2020
Link to the webinar : https://www.youtube.com/watch?v=yMCJCTPPOf8&list=PL0zMQ-70IHlX-df3u2Tto6dkKHCRC6iFL&index=12



Now of course AI depends on certain computing power and computing power has been driven for the last 45 years by an empirical law called Moore's law. In 1970, an integrated circuit had about 2,000 transistors on it. By 2016, an integrated circuit had about 5.7 billion transistors on it. If you look at the rate at which the computer performance, the performance of computer hardware has been doubling, everyone and half years it has been doubling for the last 50 years and this trend doesn't show any signs of coming to an end. Every little while someone predicts that we are reaching the limits of technology and innovative engineers find some way to get round it. So we expect that Moore's law will continue to operate for the next 10 to 20 years.

When you look at machine learning, machine learning essentially works sort of like human learning in that we take data from existing systems and find some patterns in that data and then use these patterns to handle new scenarios and to predict for the future. This is based on something called the law of large numbers from statistics in which the behaviour of a large population tends to a predictable normal distribution. Now one of the technologies that



supports machine learning is the Internet of Things (IoT). Machine learning requires data and the internet of things is a set of inexpensive sensors connected to the internet by which we can get data. For instance, take the IMD, the Indian Meteorological Department. Until recently it spent maybe tens of lakhs for each weather station. And since they were so expensive, they could be install ed only in major towns like district headquarters may be with a distance of 50 kms or so between them. With the Internet of Things, one can build a weather station with a few thousand rupees, it becomes feasible to have a weather station in every farm or field. It may be less accurate, but with a very large number of weather stations, we can actually correct for these inaccuracies.

Similarly, if you look at other sensors like GPS, web cameras, motions sensors, etc. etc., the costs have declined from lakhs of rupees to just a few hundreds or thousands of rupees. So what this means is that now we have a vast amount of data available, and there is going to be much more and more data available about every locality, about every person, every system, every mechanism and so on. This means that machine learning which is one part of AI is becoming much more useful and much more likely to be beneficial in the near future.

So a number of faculty at IIT Mandi, seeing this trend, have been applying machine learning to practical problems. A few years ago some faculty in Computer Science and Electrical Engineering teamed up with a private company called Aindra in Bangalore, a medical instrumentation company. They spoke to doctors in some hospitals about the needs of cancer patients, and they realised that there was a need for automating the detection of cervical cancer cells from some images that are taken. So this device that you see here was released by Aindra Pvt. Ltd., Bangalore, it is a portable scanning device which can scan for cervical cancer, and the software algorithms in this are based on machine learning developed here at IIT Mandi. Similarly, faculty are using machine learning to help mobile operators and telecom networks. Here again you see that we have faculty, students and industry working together to come out with useful innovations for society.

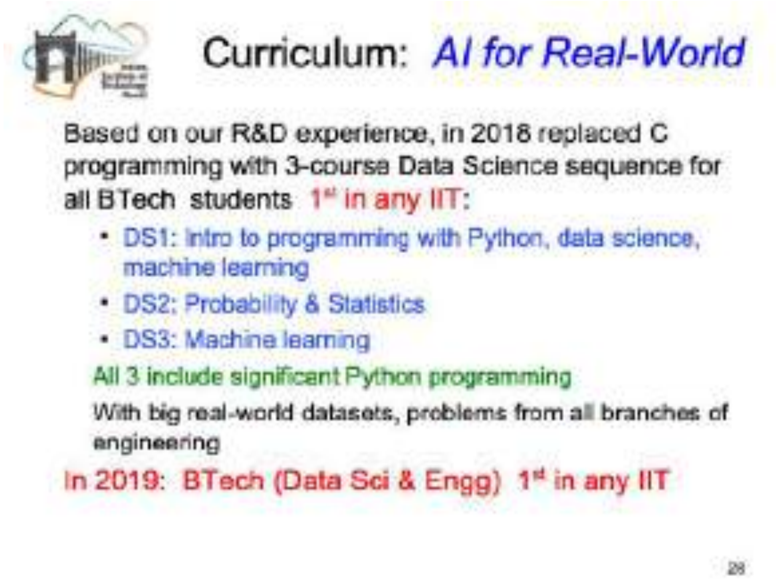
Now, in the Himalayas, landslides are a problem, particularly during the monsoon season, and many lives are lost due to landslides. If a landslide could be predicted even a few minutes in advance, traffic could be stopped or houses could be evacuated and lives would be saved. Typically landslide monitoring systems cost lakhs of rupees. Two faculty at IIT Mandi along with some of their students have developed an inexpensive landslide monitoring system using low cost sensors and machine learning. This is available at the cost of Rs. 20,000/- per system, and it

has been installed in a number of places in Himachal and has been able to detect and give early warning of some landslides already. This is another example of how AI can actually be used to help the society.

A third area where our faculty are working on applying AI to help society is in agriculture. If you look, traditionally a farmer decides on how to manage the crop, when to plant, how much fertilizers to give, when to apply pesticide and so on based on knowledge of market price etc. which has been gathered over many years. Now the problem today is that the traditional patterns are being disrupted, firstly by globalization where there is free import and export of agricultural produce which affects the prices and demand and secondly climate change which affects the growing pattern so that the experience of a farmer's father and grandfathers may not be useful.

So here what we are working on at IIT Mandi is a project called the FarmerZone^{TM}. This is funded by the Department of Biotechnology, and it is a national project. Over here, we collect data from many sources, agriculture related data from farmers, from the fields, we collect weather information, we collect information about seed varieties and so on. Market information is collected, cold storage information and so on. All this is put into a big cloud based data repository and then machine learning or data science algorithms are applied to advise the farmer when to plant, what to plant, when to fertilize and so on and so forth. This particular project which has partners from India, UK and US is being led by IIT Mandi on behalf of Department of Biotechnology. Currently, we are working with potato farmers and eventually this will extend to over 20 major crops around the country.

What we have seen over here is that out of the many different aspects of AI, machine learning is something that can be applied in the real world, that can actually give value to society even today, and certainly it will tomorrow, also.



On our experiences with R&D, in 2018, two years ago we decided to replace the C programming that has been taught to all our B.Tech. students with a 3-course sequence on data sciences using Python programming. This is the first time any IIT has done this. So all our undergraduate students whether in Computer Science, Civil Engineering or Electrical Engineering go through an introduction to Python and machine learning in their first semester, in the second semester they learn probability and statistics again with a lot of lab work using Python, and in the third semester they apply this to machine learning, again with Python. In all of these three courses they work on real world problems, problems taken from all branches of engineering they work with big data sets of millions of records. In a few weeks after joining IIT Mandi students are able to process such large data sets. Last year, we decided that we would start a B.Tech. programme in Data Science and Engineering. Data Science essentially is at the confluence of machine learning, computer science, computer systems and mathematics and statistics. This is the first such B.Tech. programme in any IIT.

So what I have given you is an overview of our undergraduate curriculum which is project based and where the undergraduate students work on research problems and the research that our faculty do that feeds back into the curriculum of the undergraduate students. Now in order to take all this work to society, we need to have industry, and Himachal is a State with very little industry. So in 2016, we set up IIT Mandi catalyst, a technology business incubator in order to foster high tech industry in this area. Over the last three to four years, Catalyst has obtained about 23 crores of funding from different sources, it has supported over 75 startups and some of these have won awards and so on. It is doing quite well and trying to build up an industrial ecosystem around IIT Mandi and in Himachal.

Another important aspect as Prof. Ananth mentioned in his introduction, society today is no longer willing to just fund IITs just for education, society expects to get returns from IITs and this is something important for us to pay back to Indian society for setting up the IITs. It is also important for engineers to understand society because engineers build technology and products for society so

they need to understand the society. IIT Mandi is an elite institution and located here in this very serene rural setting and of course our vision says that we should work for the rural area, also. In fact our B.Tech. curriculum has about 12-25% of the courses of the credits in Humanities.

We also have an unusual project that I will talk about. It is the interactive socio-technical practicum (ISTP). So our students study local society and to our surprise, they also learn from local society. There is often a tendency for people to come from big cities in the plains to look down on villagers in the mountains and think that they are inferior primitive people, but they actually find that these are very sophisticated people, and the students are able to learn from the villagers. So during the third year, our undergraduates do this unique project where they go out into the villages and they study the impact of new technologies on the villages. For instance they look at how the medical officer of the district keeps track of the supply of medicines in remote villages. And they ask, can modern technology, SMS, mobile networks and so on be used for this. What is the quality of milk, what are the needs of rural women and so on. These are many kinds of projects that are studied by our students and at the end they come up typically with a technology impact report.

Now one of the interesting developments here was that the faculty who worked on some of these projects found that the rural women had aspirations for education, for business

opportunities and so on. So they set up a society called EWOK, Enabling Women of Kamand to help rural women to start businesses and further educate themselves. Interestingly, here was one example where IIT faculty and students started out thinking that business for rural women meant making handicrafts. It turned out that the rural women don't want to make handicrafts, they want to learn English, they want to operate computers, they want to do something more modern. So EWOK has now started fostering such businesses.

In other work for the local area, we have a biodiversity research lab which is working on medicinal plants of this region, and some of these are being commercialized in the form of herbal tea. A group of faculty from Electrical Engineering, Mechanical Engineering and Economics are working on developing electric autos that will work in hill states. A faculty of Physics is working on developing some economical ways of utilizing dried pine needles which are the problems in the forests over here.

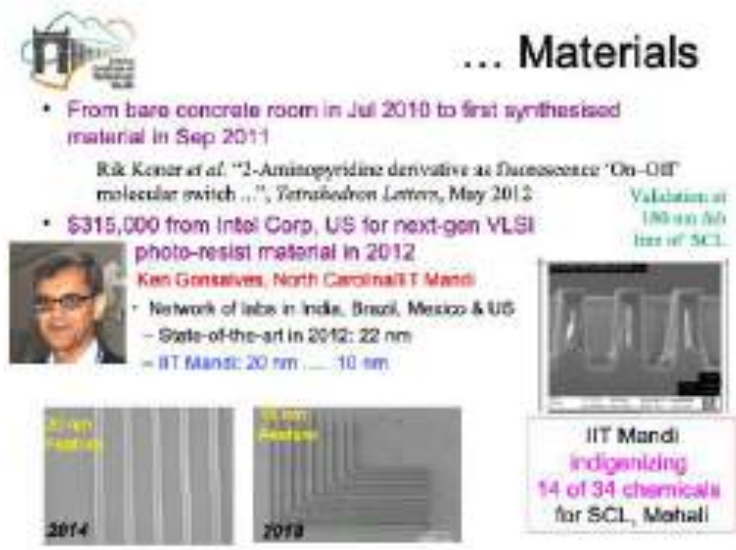
So you can see that these are just a few examples of R&D for the Himalayan region by our faculty, in fact 1/3rd of IIT Mandi faculty are working on problems of the Himalayan region and about 15% of the funding that they have received is for these projects. To give you an example, an indication of the desire to work for the society, when COVID came up, within the last couple of months our faculty have submitted or started over 20 projects to tackle different aspects of

COVID. EWOK has helped local women to make face masks, and these are being used in IIT and also being sold in the region.

IITs have to make a name globally and so not only do we work on local research problems we also work on global R&D. One area I will touch on is Advanced Materials. When we started out trying to decide on what kind of research to do over here, some people said you are in a remote location, you should focus on theoretical research, don't try to set up sophisticated labs, it is very difficult to do such things in the remote place and so on and so forth. We had an Emeritus Professor, Prof. Subrata Ray from IIT Roorkee who was advising us and he was originally a physicist who became a material scientist and he said don't listen to this, good research requires experiment and theory. Go ahead and set up very good research labs.

We followed his advice and spent over Rs. 100 crores over the last ten years on setting up very good research labs. These labs are shared institute facilities which are open to anyone in the institute, to make sure that they are well utilized. That is a very good cooperative culture. In fact, this helps students to work together, also.

The first experimental chemists were hired in July 2010, and we gave them some empty rooms to do their research, and within 18 months they had bought the equipment for doing the research, hired and trained Ph.D. students. The first material synthesized in IIT Mandi was in September 2011, and a paper was published on this by May 2012.



Also in 2012, our faculty got a very prestigious project from Intel in the US to develop next generation VLSI photo resist material. This was driven by a very unusual person, Ken Gonsalves who was in North Carolina State University and he came as a visiting faculty to IIT Mandi. He has a network of labs and collaborators in different part of the world. The faculty at IIT Mandi were able to do better than state of the art of 22 nanometres in 2012 and you can see in 2014 they had fabricated materials here at 20 nanometres and by 2018 had gone down to 10 nanometres. This research has now been used by SCL Mohali in their endeavour. An unusual spin-off of this advanced materials research is that one of our faculty here was working on solution-blown nanofibres for the last year or two. When the COVID crisis came, he realized that he could make a membrane material from these nano fibres which results in very low cost N95 masks. He is now looking for some industry that can commercialize this.

Now I will move on to our campus which is one of the unusual, unique aspects of IIT Mandi. As mentioned, we were also the first of the new eight IITs to start using our own campus. This is because

Lecture at IIT Alumni Centre, Bengaluru on May 30, 2020
Link to the webinar : https://www.youtube.com/watch?v=yMCJCTPPOf8&list=PL0zMQ-70lHlX-df3u2Tto6dkKHCRC6iFL&index=12

we took a very different approach to campus development. Most of the new universities take the approach of planning the entire campus, constructing all the buildings, and then after several years when everything is ready, then shift to the new campus. This approach has a couple of problem. One is the buildings are only a small part of the campus and sometimes we find they are not the most important part. Secondly, during those several years when the institute is functioning from a transit campus, faculty put down roots in some nearby city, their families get comfortable there, and they are reluctant to move to the new campus.

So what we did is that we had an incremental approach of saying let us build one building and start using it as soon as it is ready and then build more buildings and use them as and when they are ready. So this helped us to develop the campus, to refine the design of the buildings and also to set up all the essentials that are needed in a residential campus like shops, supply of milk, a good campus school, social gatherings, etc. etc. The result is that today 98% of the faculty live on campus even though it is in such a remote place.

So we had a three-pronged strategy: first, make use of the existing stables and so on that were here when we came; second, we used pre-engineered technology to quickly construct some buildings; and then, have the major construction with permanent concrete steel buildings. So in June 2011, this showed a stable with a few horses, nine months later we had renovated this stable and installed our first sophisticated instrument, an x-ray defractometer. In May 2012, we had an industry conclave over here, as you can see in the stable which housed horses just nine months earlier. By September 2012 our first new building was ready and the first batch of B.Tech. students shifted to the Kamand campus. We also used some low cost LGSF, light gauge steel frame, technology and so on.

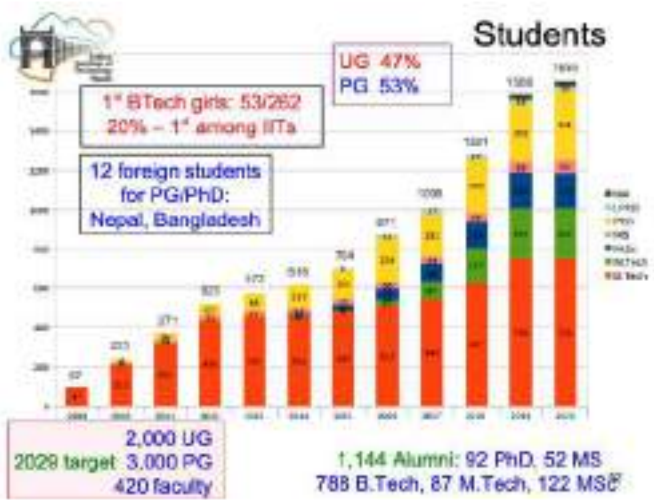
By 2015, almost all our students were on campus, and many faculty had shifted here. By January 2020, as you can see in the foreground is what we call the South Campus and the left middle is the North Campus, these have about 1.4 lakh square meters and 1655 students, and this campus is fully functional. It is also a very liveable campus because the amenities in it have been developed over the past six to eight years so that whenever you want whether it is an ATM machine, you want medical care, school, go hiking, play games and so on, it is all available and all working very well.

These are some of the activities on our campus: the faculty and staff families get together periodically and cook some exotic meals; our students go hiking into the mountains in the snow, they go down to the river and there are various other such activities.

What I have shown you so far is some of the developments, some of the stories that we have gone through over here in the undergraduate curriculum, in socially relevant research and activities and in some advanced technology and also our campus development.

This is only a small fraction of what has been going on at IIT Mandi. There is lot more, but not enough time to cover everything.

But now the question we come back to is the original question. If you recall when we started people said that we would be number eight out of the eight new IITs and we would be following all the others, so what is the reality today after 10 years? We see that IIT Mandi has taken leadership nationally and in the IIT system in several initiatives. In 2016, we led an initiative to increase the number of female students joining BTech in the IITs, as then IITs had only 8% female students in B.Tech. Thanks to the initiative of IIT Mandi by which we introduced the supernumerary scheme, all IITs now have doubled to 17% and IIT Mandi is leading the pack with 20.2% in 2019. As I mentioned we were first of the eight new IITs to develop a new campus. We have a very good relationship with German universities and thanks to that in 2018 the Ministry of Human Resource Development decided to initiate the SPARC programme for academic collaboration with other countries, IIT Mandi was chosen as the nodal institute for Germany, one of the leading countries. When DBT wanted to set up the FarmerZone Project, a



very prestigious national project, they selected IIT Mandi as the lead institution for this. So we are leading in several aspects.

Individually also, last year, one of our young Assistant Professors, Dr. Manu V. Devadevan won the Infosys prize for Humanities. This is perhaps the most prestigious academic prize in India and normally it goes to more senior researchers and academicians. Looking at our students strength, because after all IITs important role is training students, as you can see we have grown steadily from 97 students in 2009-10 to 1,655 students and the number of PG students has risen from being 100% undergraduate we now are now only 47% undergraduate and 53% PG. We also have a significant number of foreign students and we have graduated seven batches of alumni. Ultimately IIT Mandi will have about 5,000 students.

Everyone talks about ranking these days, so how do we do in ranking? We look at the Indian Government's National Institutional Ranking Framework (NIRF). As an engineering institution, nationally we are number 20, and among all the 23 IITs, we are number 13, among the 8 new IITs we are number four in 2019 and in Himachal we are number one. So you can see that when we compare ourselves to the other new IITs in various respects we are nowhere number eight, in some places we are number one in some places we are near the top.

Performance Measure	National	Rank: All 23 IITs	Rank: 8 new IITs	Himachal
Engineering (NIRF)	20	13	4	1
Overall (NIRF)	44	11	2	1

Our alumni have been getting good placements right from the first batch. They have joined companies and got admitted in universities similar to where the alumni of older IITs go. Some of our students have done very well. Nitesh Kumar is a B.Tech. student at IIT Mandi. While being a B.Tech. student he participated in international para-badminton and so far has won 13 gold/silver/bronze medals for India. Last year, a team of second year B.Tech. students won the ACM-W National Hackathon. They competed against about 180 other teams which consisted mostly of senior undergraduate and PG students, and these second year students from IIT Mandi won this. So what we see is that IIT Mandi has made a name for itself nationally and our faculty and students are achieving laurels and are doing very well on par with some of the other IITs, sometime even better than them.

So what are the lessons from a journey over the past 10 years? Some of the lessons are firstly success depends on people depends on outstanding faculty and outstanding students supported by very good staff. Now, how do we attract and inspire people? The way we have done it is to define some compelling USPs and follow these, provide a supporting environment for these. The USPs in our case are project based learning, working for society, boundary-less academics not having disciplines and departments based on disciplines, and a strong ethos in the institute of working cooperatively to solve large problems. Many of our young faculty and our students also, I am proud to say, have bought into these and worked very hard in order to achieve the laurels that I have mentioned. We have capitalised on our location advantage and in the first decade of our existence, we have taken the lead in some areas nationally. In the coming decades and the next few years, I am sure that IIT Mandi will become a leader globally, thanks to our hard working and exceptional faculty, students and staff and also a lot of well-wishers from elsewhere who have helped us in this journey.

Thank you for your attention. We can open it up for discussion and questions.

Prof. Ananth: Thanks very much Timothy, that was a wonderful talk. I think everybody enjoyed it and we will open now the questions but I think Prof. Ashok Misra wants to say something.

Prof. Misra: Timothy, what a wonderful talk, you took us to the beautiful campus of Mandi which I have been to when you were inside the campus. When you are inside the campus, you see mountains all around. It's not a valley, it is like a bowl, it is like you have seen in the movie, Shangri-la, it is like the Shangri-la I have seen in real life. So it is a fantastic campus.

I had a chance to interact with the faculty and students and as you saw from the presentations they are all very enthusiastic, very happy to be in this location because it provides not just education but so many other things which other locations would not provide. It is very impressive that some faculty members have won laurels, in humanities, very prestigious awards like the Infosys award and so on.

Timothy touched upon just for the viewers a little bit about his international collaboration, and I can tell you there are some very strong, meaningful collaborative programmes with some leading universities in Europe and the United States and if you talk to those faculty members, they are very, very enthusiastic about interacting with IIT Mandi. The remote location turned into an advantage.

Lots of first as I see, something to emulate, and as you heard him, locational disadvantage for IIT Mandi, where it is in the hills, the first one to move into their own campus amongst all the new IITs. I mean the others were in metropolitan cities and so on. What is the other thing that I saw is that it is probably the only IIT which is spending so much time on the development of the local people and their needs which is remarkable which is what we need for an inclusive India. And lastly a number of start-ups, 75 is very, very impressive for where you are located. So thanks again and over to Ananth.

Prof. Ananth: I have half a dozen questions. The first question is, first of all the large number of people appreciating the beauty of the campus although you didn't quite show them the full beauty, maybe you should take a video as well. One of the questions is that somebody wants to know is, did IIT Mandi destroy the beauty of Himalayas by building a college there. This is the usual question about development versus environment.

Prof. Gonsalves: To answer this, this is something that troubled me when the first time when I came here. I came over the mountain and saw this beautiful valley, my God, how am I going to build an institute here for 5,000 people and not destroy it. So the first thing that we did is that we commissioned an environmentalist, Dr. Ranjit Daniels to do a study on the campus and prepare an ecological management plan in 2010 which has now been published and is available here in the links you can see in this slide and you can read it. So essentially what he did, this plan showed us how we could develop the place without destroying the environment, keeping the environment. And we have followed this. Also one of the mandates we gave to the architects was that we would like IIT Mandi to look like a Himachal village. And when we look at it from a distance, they have managed to do that fairly well.

During the construction, there has been of course lot of digging of the soil and so on. Every year for the past few years we have our students plant a thousand or more trees on the campus and so if you look at our South Campus particularly, it is very green now and within four to five years the whole campus will look a bit more like it used to look earlier. So we have certainly tried to minimize the impact on the area. Our faculty are also working on things like solid waste management, biogas generation and other such green types of research.

Prof. Ananth: There is a question that is really addressed to other IITs but I think you can try and answer that. The question is: Have other IITs learned from IIT Mandi and have they implemented some the socio-tech approaches developed there.

Prof. Gonsalves: The IIT system is something where we all learn from each other and we copy each other, there is lot of peer pressure and so on. To give you a couple of examples of things that have been done. In IIT Madras, I think 2-3 years ago they have introduced something in their first year curriculum which is very similar to our reverse engineering and some of the faculty from there had come here and seen our reverse engineering project. IIT Bombay, I hear that the Electrical Engineering Department has implemented a second year project in it’s curriculum. We have also copied some others.

Prof. Ananth: Incidentally Ranjit Daniels also advised IIT Madras.

Prof. Gonsalves: Yes.

Prof. Ananth: How difficult was it to convince the first batch of students about the new curriculum.

Prof. Gonsales: Convincing them about the curriculum was not really difficult. What was more difficult was convincing them to come here the first place. In the first year they were admitted even before the campus was identified. So for the first year they were in IIT Roorkee, and I think some of them hoped that they would spend four years in IIT Roorkee and graduate from there. So when they came here some of them were very happy to be here in the mountains, some were disappointed.

I have to say that many of them took up the challenge during the first few months. Three first year students came up to my office and said “Sir, we have developed a website”. They opened their laptop and they showed me the website, I looked at it, made a few comments and a few days later that went live as the first IIT Mandi website, and in fact that website was used and managed by students for a number of years.

Likewise, when we wanted to hire faculty, at that time all applications were through hardcopy in all the other IITs. We decided that let us make it online. I spoke to some second year students who were studying databases, and one of them said I will do it for you. And within a few months, he had developed an online faculty application form which has been used to hire all our faculty since then, and in fact it has been used by some other institutions also. So the Pioneer Batch got tremendous experience, and many of them chose to take advantage of it.

Prof. Ananth: What measures have you taken to attract young and bright faculty, what specific measures have you taken to attract them.

Prof. Gonsalves: Specific measures: one is, of course, having the USPs and being very clear that for instance at IIT Mandi we don’t have departments, we have broad schools. So a person who graduates from a Chemistry Department, over here joins the School of Basic Sciences and is not known as a chemist at all, but is free to talk to physics people, to talk to biology people, to guide them and teach courses for them and so on. So this interdisciplinary ethos is something that many people do find attractive.

We have done some things since it is a remote place, people cannot find houses off campus, we have made all the faculty houses on campus a uniform size - three bedroom. So even a young Assistant Professor the moment he or she joins gets a three bedroom flat which is again something that is not there in other IITs. We have a fairly generous faculty research fund which the Institute gives about Rupees one lakh per year, seed grant, etc.

Another decision that we have taken back in 2013 I think, we started the school for children on campus and the faculty has a lot of input into running that school, so they are quite happy with it. It is now a CBSE-affiliated school. So we have done these measures to try to attract faculty to come here. One of the things that we started doing fairly early is to hold interviews on our campus so that when people come for the interview they realise whether they like the place and are happy to come.

Prof. Ananth: There is one concern about the syllabus and that is introducing such practical courses, project oriented courses so early takes away from education at the early stage. Doesn't the strategy of focusing on products throughout the curriculum compromise the development of strong fundamental and theoretical concepts at such nascent state for students learning.

Prof. Gonsalves: There are two answers to that, one is that we don't compromise, we have healthy loads of rigorous theory in our classes in maths, physics, chemistry and theoretical courses in their discipline and so on. It just goes hand in hand with the practical. Also one of the reasons why we started this route is that when students come into IIT, they have spent the last three years focusing on theoretical study of mathematics and chemistry and little else. So we wanted to get them to overcome this disadvantage that they have where they have not done practical work, hands-on work for a number of years which normally children do during school.

The other thing is that by working on practical projects right from the beginning our students develop excitement and that excitement stays with most of them through their four years. With the traditional engineering curriculum, students come in excited and then for the first year or two they are given only theoretical subjects, and they tend to get a bit burnt out and bored by the time they get to the more interesting things. So we don't compromise on their education and if you look at the jobs that our students take up, the universities they go to for higher studies, they are doing very well over there.

Prof. Ananth: One of the things that you did that wasn't particularly noticed was the fact the you have 15% of humanities courses, a high percentage. Of course, I welcome that, in fact the original renaissance thinkers also thought so. They thought you needed both the natural and social sciences in order to produce anything in terms of unity and knowledge. So how did you manage to convince your faculty that 15% of the curriculum should be humanities. You know we didn't succeed in IIT Madras, we ended up with 7%.

Prof. Gonsalves: I think I had the advantage of two things. One is young faculty who came in here being young were more open to change and doing things differently. Secondly, we had a few senior faculty from other IITs including IIT Madras, IIT Roorkee and so on who perhaps in the parent institution they were not able to bring about changes. They came here and helped us to make those changes. Of course, they also brought their experience and their wisdom of having taught for 10 or 20 years, so they helped make sure that our young faculty did not make serious mistakes in the curriculum.

Prof. Ananth: There is one comment that the Director at IIT Mandi seems to have quite a lot of independence overall to lead the Institute. Is that true? Actually, I must say that the IIT system itself gives you lot of freedom. But the question here I think you can answer. Question is, does your remoteness give you more independence.

Prof. Gonsalves: First of all the IIT system does have tremendous, especially academic, independence and autonomy. And even financially, if we bring in money for projects and so on, then we have a lot of freedom in how we use that. We get money from donations, etc., where again we have freedom. I think the remote location did help a bit because if we do something unusual we are kind of below the radar and people in Delhi and other places probably don't notice it until it is too late. In IIT Delhi, to try something, it would be much more nervous. So being remote also helped.

Prof. Ananth: One of the participants wants clarification on your method that says build new shift and so on. How does it actually work in practice.

Prof. Gonsalves: Well, the way it works in practice is that, for instance, we gave a contract for constructing some 56 buildings including a dozen academic buildings and 40 odd residential buildings, hostels and so on. Now what we did with this 56 buildings is that we identified a set of academic and residential buildings which are almost contiguous and asked the contractor to deliver those first. As soon as those were delivered, we occupied them and they were partly isolated from the rest of the construction site though there is a little overlap. So we staged the construction in such a way that we could occupy it, and the construction would continue in other parts of the campus.

Prof. Ananth: Another question is, in India they can see the role of the Central Government but what is the role of the State Government in continuous improvement of the institute. Does it play a role? What is your interaction with the State Government?

Prof. Gonsalves: The State Government plays a role in two ways. One is they provide the infrastructure of the region, the roads, the police force, electricity and so on. And the other more important way that the State Government plays a role is that the they are essentially customers for our research and development and faculty work quite closely with many State Government agencies such as the Forest Department, the PWD, Irrigation, Public Health and so on. So they help us to define the problems of the region and then to solve it. We have also over here formed a group called "PRAYAS" which is a forum of the citizens and administration of Mandi district and IIT Mandi. So PRAYAS is essentially a vehicle by which we can learn about the problems and challenges faced by the people and help them to come up with good solutions.

Prof. Ananth: Don't you have interaction through the socially relevant projects.

Prof. Gonsalves: We certainly have a lot of interaction there. Since we are working on a number projects in agriculture, through that again we interact with the State Government departments as well as with the farmers in the locality.

Prof. Ananth: There is a question on the curriculum which says what did you sacrifice when you introduced project based learning, essentially can you discuss the things that were deleted from a conventional curriculum.

Prof. Gonsalves: What we did is that, we took the core in the discipline and we reduced that. Typically the discipline core in most of the older IITs perhaps about 40 to 50 credits, we made ours 30 to 35 credits. So we reduced it there, and we gave students a little more of free electives, so that those who are passionately interested in their discipline can take it in their discipline, those who want can take the free electives in something else, either some other discipline or the humanities.

The other thing which we also realised is that as engineering education is developing, the undergraduate degree is becoming more of a basic degree, and so we want breadth over there and specialization more and more is being done at the master's level. So that is the view we take, unlike for instance earlier when I did my five year B.Tech., we were highly specialized by the end of the BTech itself. Also many engineering students after getting B.Tech., they work on something other than their discipline. A person who has a B.Tech. in electrical engineering may work in EE for a little while, then in computer science, then perhaps into management and may be even start writing books or novels or something after some time, so we believe that a broad based foundations is what is more important.

Prof. Ananth: There is a bit of interdisciplinary in that. I think all enjoyed your talk really and I also want to thank IITACB for doing this wonderful job of webinars because the response really has been phenomenal and I think over all people have enjoyed especially during this lock down period, they have enjoyed the webinars. So thank you very much,Timothy for a wonderful talk.

Meanwhile, I see that Manas Thakur has already sent the panelists a YouTube link of a video of your campus! Let me hand this over to Susheela now.

Dr. Susheela Venkataraman: Thanks very much Prof. Ananth, thank you very much Prof. Gonsalves. Today it has been a wonderful talk taking us through a journey of converting an absolutely idyllic mountainside into an equally idyllic campus and the wonderful work that is being done. Just a few takeaways that I would take back out of this session, Prof. Ananth started by saying that a University is a centre of research, teaching and innovation and also it needs to be socially relevant. Through your talk, Timothy you told us exactly how IIT Mandi has achieved all of that and is doing all of that. When you talked about the challenges, you said we benchmarked against the best not just in India but across the world and that obviously is the reason we have an absolutely world-class campus at Mandi today.

A few of the key basic tenets that you have used while setting up this institute, absolute focus, partnerships, interdisciplinary working and culture and also engaging with the local community. It is already also very interesting to hear, you say that engagement has resulted not just in businesses and other contributions to the local society but also very interestingly learning from the people which the students can take back with them and apply in their own careers and lives that is absolutely fascinating. You also talked about boundary-less learning and what that means to the students because all of us end up doing lots of other things than what we studied at IITs. So this has been wonderful, thank you ever so much for your talk today, for your time.

Prof. Ananth, thank you very much, it has been very valuable listening to your point of view as well. Prof. Misra, thank you for leading and bringing in your comments to this. To our listeners, we will be uploading the video into the IITACB youtube channel, please do subscribe to it, our lectures are uploaded there, please do look for it and please do join us every Saturday, same time. We have some very interesting talks lined up for you. Thank you very much.

WHY WE SHOULD CARE ABOUT TURBULENCE IN CLOUDS

PROF. RAMA GOVINDARAJAN | JUNE 6, 2020

Rama Govindarajan is an Indian scientist specialized in the field of Fluid Dynamics and is currently a Professor at International Centre for Theoretical Sciences (ICTS) Bengaluru. Prof. Govindarajan is a recipient of the Shanti Swarup Bhatnagar Award for the year 2007. She did her undergraduate degree (B.Tech.) in Chemical engineering from IIT Delhi, in 1984. She got her master's degree (M.S.) in Chemical Engineering, from Drexel University, Philadelphia, United States, in 1986. Her doctoral degree (Ph.D) thesis is on the subject of Aerospace Engineering from the Indian Institute of Science Bangalore, in 1994. She worked in Post-Doctoral Research, in Dept. of Aeronautics, Caltech during 1994.Of the many awards that she has received so far, the most notable is the Shanti Swarup Bhatnagar Award for the year 2007 for her "original contributions to the understanding of instabilities in shear and non-parallel flows, flow entrainment, turbulent transition and small-scale hydraulic jumps". She was also awarded with the Young Scientist award of 1987 and Outstanding scientist award of 1996 given by the National Aerospace Laboratories. She received the CNR Rao Oration award of 2004 at JNCASR Bangalore.

Jason Picardo is a professor at Dept. of Chemical Engineering, Indian Institute of Technology Bombay. He did his BTech Chemical Engineering, VIT University, Vellore, PhD from the Department of Chemical Engineering, IIT Madras and a Post-doc, Int. Centre for Theoretical Sciences from TIFR in Bangalore. His research interests include Fluid dynamics, Pattern formation, Turbulence, Reduced-order modelling. He won the Fulbright-Nehru Doctoral Research Fellowship (2015-2016) and the IIT Madras Institute Research Award (2015).

Lecture at the IIT Alumni Centre, Bengaluru on June 6, 2020

Link to the webinar : https://www.youtube.com/watch?v=9SbaYZzZjCQ&list=PL0zMQ-70IHlX-df3u2Tto6dkKHCRC6iFL&index=11

Mr. Ashok Kamath: Welcome to our continuing series of Saturday Webinars. Today we have a webinar on a topic "Why we should care about turbulence in clouds". We have a real cloud scientist, Prof. Rama Govindarajan, who is the senior Professor at ICTS, TIFR, Bengaluru. Her research has always been on Fluid Mechanics. We have mistaken Fluid Mechanics as the study of droplets, particles and fluids and on the dynamics of clouds themselves. I am sure she will be able to tell us what we didn't know about the Indian monsoon which ideally brings in a lot of attributes and a great deal of sorrow. Rama is a graduate of IIT Delhi and then did her Ph.D. from IISc., Bangalore and then did post-doctoral fellowship at Caltech. She has got many many awards and the SS Bhatnagar Prize is one of them. Moderating for her is Prof. Jason Ryan Picardo, Department of Chemical Engineering, IIT Bombay. Jason did his doctorate from IIT Madras and did his post-doctoral fellowship at ICTS in Bangalore and currently a faculty at IIT Bombay. Over to you Rama.

Prof. Rama Govindarajan: Thank you Ashok, thank you Susheela.

Good evening everybody. We are going to talk today about why we should care about turbulence in clouds and here I put two pictures which are very indicative of our daily life now. So on the top there is a picture of a cloud at sunset which is a monsoon cloud seen in Bangalore over the last few days. We see this every day and monsoon is a part of our everyday life nowadays. On the bottom is a picture with a person in a mask. This is Mona Lisa of course, with a mask, and this has become a very very standard thing in our life nowadays. We will discuss why turbulence is connected to both these things and will talk about the connection

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between them. One thing that worries us now is how we are going to reduce the spread of Covid infection and this is a hot topic with already a very large number of publications come out. Now obviously a lot of people are studying about masks and estimating how well you protect yourself and others if you wear a mask, whereas in our discussion we will not talk about masks at all. The reason is that we would like to go back to a life without masks, back to social occasions, classrooms, and all the crowded situations where it would be very nice to live without a mask. Our aim is to understand when we can go without masks.

In both rain and Covid, we are talking about falling droplets. So at the base of a cloud here, this is a droplet, we will talk about a always as the radius of the droplet, it starts with initial radius a0 and then as it falls it is evaporating, it is falling through dry air over here beneath the cloud, it is evaporating so water vapour escapes out of this object and it therefore becomes smaller as it drops. Now here you see an image of a sneeze line made by droplets from human coughing. This is an actual human coughing, they have taken a picture with time lapse so that you see the track of each droplet that is coming out during the cough. This is also about falling droplets, so whether it is a cough, whether it is sneeze, whether it is loud talking: like I am doing right now, you can have lot of droplets coming out of a person's mouth. Not all these may be relevant for Covid infections but we are interested in this thing in general to understand how droplets can carry not just covid but all kinds of infections. So this and clouds are what I want to talk about today. Now in both of these, there is a competition between evaporation and the speed with which the droplets fall down.

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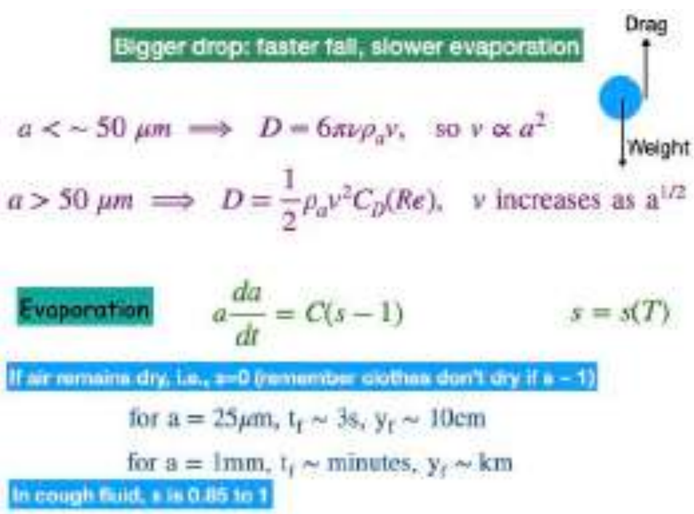
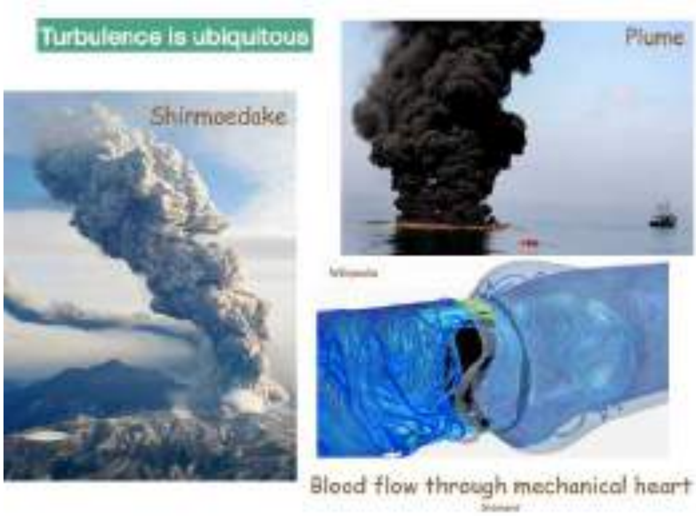
So we all want rain in the monsoon, so we don't want all the tiny drops evaporating before they hit the ground. In that place evaporation is an undesirable thing and we want all droplets to fall to the ground. Whereas we want the opposite in cough droplets. We want every droplet to evaporate if possible, so that they don't fall on the ground or other surfaces, which other people can then touch and catch the infection. When they are airborne, if they evaporate that is good for us. I don't know if this is established yet but apparently in dry air viruses don't survive for too long. This is the contradiction between clouds and cough droplets. The dogma in this is that if a droplet is very small it is going to evaporate before it falls, so we don't have to worry about small droplets in the context of covid. If they are big droplets they fall before they evaporate because big droplets fall pretty fast as they come down. So then we don't have to worry about evaporation in this context. We are going to challenge especially the first assumption that small droplets evaporate before they fall. They may not fall very fast but their evaporation may be a lot slower than we thought. This is one of the places where turbulence will come in.

When you have a bigger drop you have a faster fall and slower evaporation. Here I have got this diagram which shows a force balance on a tiny little droplet. It could be from a cough or

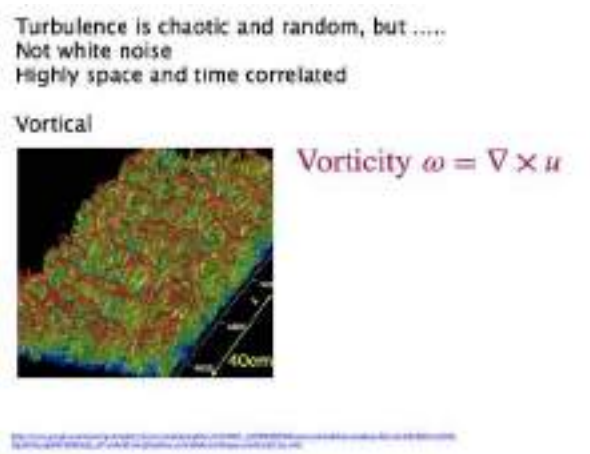


it could be a droplet inside the cloud. It is usually in steady state, or quickly comes to steady state, so its net (buoyancy-reduced) weight, which is pushing downward, is equal and opposite to drag, which is acting upwards. This drag is given by two different formulae, one for very very small drops which are less, then 50 micron in size (a micron is a millionth of a metre), and there are 1000 microns in a mm. So these are very very small drops. If the radius is ~50 microns, then the drag is given by this formula called the Stokes formula for drag, so this is v which is the vertical velocity of the droplet. So when it comes to a steady state, we know the weight of the droplet is the volume of the drop times the density of water, and I neglected the buoyancy term here since the droplet is much heavier than air, a thousand times heavier than air. So you have this as the formula 6π**ν**av where **ν** is the kinematic viscosity, it doesn't matter if you don't follow what it is. It is the friction that air gives to the droplet, it stops the droplet from accelerating while falling down, it gives a resistance and then **ρ**a is the density of air. If you equate drag to weight in the formula you get that the velocity of this droplet is proportional to the radius squared. So all that we need to understand here is that if the droplet doubles in radius then it falls four times faster, that is what happens to smaller droplets. They fall faster and faster as their size increases. What happens to bigger droplets? Bigger droplets, they also fall faster as their size increases but their velocity increases lower as a square root of the size as they fall. This is basically how drag acts and then no need to remember this formulae, the idea is just to say that they falls and faster and faster as their size increases. Now, how does this falling time compete with evaporation time. So the formula for evaporation is given by the Clausius-Clapeyron equation, doesn't matter what it is but after few steps of algebra, you actually derive that for a small the rate at which `a' changes, (i.e., da/dt which is the time derivative of the droplet size) is proportional to the super-saturation. So s is the saturation vapour pressure and s-1 is the super saturation. We all knew that on a rainy day, clothes will not dry very easily and that is because the air already has so much water vapour in it that there is no way for more water vapour to escape from the clothes on to the air. So because of that if s = 1, that means if the air is saturated, then the radius of the droplet will not change whatsoever and your clothes will not dry at all. C is a constant, it doesn't matter what it is now. If the air is totally dry you have s=0, and the droplet can evaporate reasonably fast. `s' is a function of temperature, so we know that on a cold day clothes don't dry very fast, while on a hot day clothes dry very fast. If the temperature is higher, the s value is higher, that means more water vapour can escape into the air than at cold temperatures. Thus basically the same story as clothes can be told about droplets. All we need to know is if s = 1 or s is close to 1, a droplet will not evaporate and it may even grow if s is greater than 1. Water vapour from the atmosphere can come and condense on this droplet, and it can grow and grow as it happens in a cloud. Now let us just talk about how far this droplet will go from the base of a cloud or from a coughing person. I just told you some facts are not important for the discussion, they just convince you that there is this competition between falling and evaporation, and which happens faster. And then we can use these formulae and may be even fancier versions of these formulae to decide what happens to droplets of different sizes. We are interested especially now in cough droplets. So if somebody is coughing without a mask on, and without covering their mouth with their elbow or any such thing, then how bad is it going to be for everybody around them. This is the basic question being asked. So here a 25 micron droplet, which is a very very tiny droplet, will evaporate in about 3 seconds in dry air and it will move a total distance of about 10 cms which is much less than the prescribed distance of metres. Then in 3 seconds it will vanish and then I don't have to worry. It will go only that distance before it evaporates, but remember that air may not always be totally dry. So when somebody's coughing, if all these droplets are of this order, I don't have to worry if the air is bone dry. Now for a 1 mm droplet, everything changes. It can live for many many minutes. In fact it lives more than minutes and it can actually travel kms. If you now talking about clouds, you can have a rain drop which is of 1 mm there at the base of a cloud, which is about some kms above us, and it will reach the ground practically un-evaporated. So rain drops above 1 mm or so are going to reach the ground very very comfortably without losing much of themselves. When droplets come out of your mouth, when you are coughing, into air that has an s of somewhere between 0.85 to 1.00 (so that means the rate of evaporation is low), this is bad news for us.

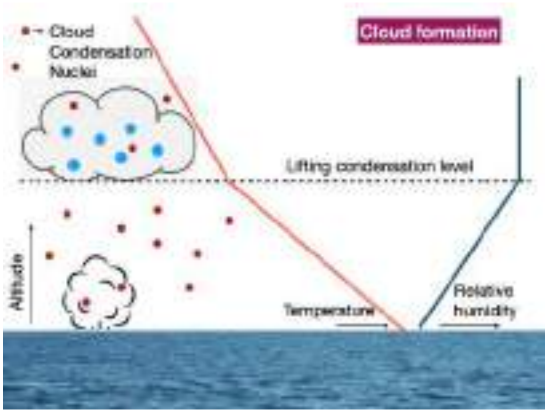
Now let us talk about this coughing again and we will talk about projectile motion. When I am coughing, the fluid being expelled out has a forward velocity of about 3 m/s. So my 25 micron droplet can actually be a free rider on this. It may not die within 10 cms. It can travel 1 m or more even if the surrounding air is totally dry. The air being expelled from the mouth has some wetness, and while the droplet is encompassed within this expelled fluid, it experiences a wetter surroundings, and therefore a slower evaporation. In the next couple of slides, we are going to talk about turbulence. A big (1mm) droplet falls at about 10 m/s, so it will fall to the ground within a horizontal distance of 50 cm, when I am coughing with a forward speed like this (3m/s), and it can contaminate the surface on which it falls. But fortunately we don't expel too many 1 mm droplets while coughing. Also I should mention that even talking loudly expels many droplets, and on whether coughing is worse than talking loudly, the jury is still out. So there too droplets will fall to the ground, so I should talk softly always hence. Now we will talk about turbulence, briefly moving away from talking about droplets. Whenever you have a flow, and by a flow I mean the motion of any fluid (a liquid or gas). So when we have a blob of fluid moving, if the length scale is large, then almost always it is turbulent. So turbulence is all around us, turbulence is ubiquitous, we don't often



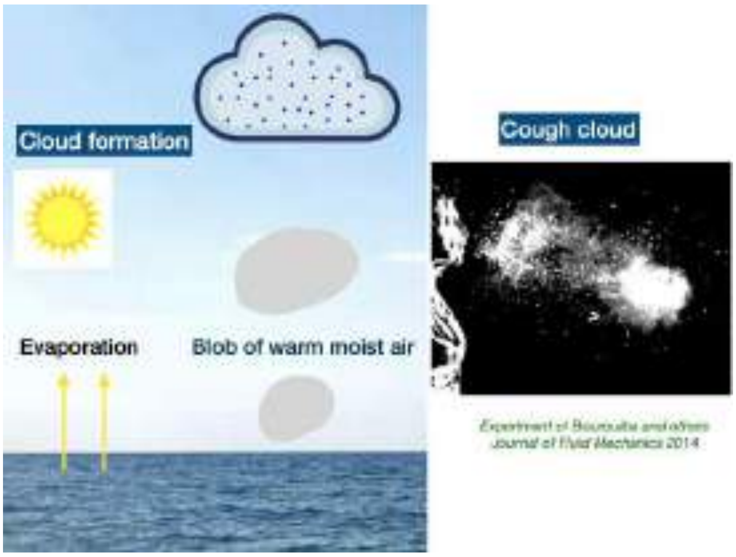
see it, like here are a few instances where we can actually see the turbulence, here something is burning and a lot of dust and smoke is being carried onto the surrounding air along with the turbulence. So you see how very complicated this flow is, it is not like a smooth flow. In the Earth system, whether it be a river or air in the atmosphere, flow is almost always turbulent. In the ocean too there is a lot of turbulence and only rarely we see it, like here is a volcano and its eruptions, again a lot of ash is going into the atmosphere, so we are able to view it. In other situations we cannot view it unless we do some special experiments for visualising, but believe me turbulence is everywhere. Even when I am talking now there is turbulence in front of my face. In fact all of you are sitting still but the air above your head is turbulent, because you are warmer than the surroundings and a plume is rising above you, if only you could see turbulence you can see it absolutely everywhere. This is a simulation of a blood flow through a mechanical heart, and you can see that the path that the blood flows in is extremely turbulent. So turbulence is a state the flow is in. It is very counterintuitive because from Newton's second law we know that the force on a body is equal to mass times acceleration. For example if I throw a cricket ball, I expect the cricket ball to go in a projectile motion according to how I throw it, and due to gravity, or expect a spin or swing according to what I try to do. I don't expect it to walk backward, make rotary motion out of nowhere and do all of this. But that is what fluid does. Fluid is still obeying Newton's Law of motion, so on an average it is going forward in the direction in which it is being pushed, but it wastes a lot of kinetic energy performing random motions that are sometimes backwards, sometimes forwards, but on an average forward. This is because different portions of the fluid apply forces on each other and the instantaneous force on a given blob of fluid may not be forward. Motion is extremely chaotic, practically impossible to predict. Turbulence is an extreme example of chaos and when you look at it, it is very random but it is different from other random processes. For example, it is not white noise, it is highly space- and time-correlated --- that means if I know something about turbulence at one place I can actually tell on an average what is going on at other places in the vicinity and at future and past times, and if you want me to describe turbulence in one word, I would say it is `vortical'. This photo that you are seeing here is actually just flow past any plate. So suppose you switch your fan on and your table is sitting there, your bed or something is sitting there, then this is what the flow looks like on it. This is what the flow looks like on an aircraft wing, very close to the table, one cm or half a cm from the table. So you can see that there is a lot of structure to it, it is not complete arbitrary jitter, so here you have this pattern of what are known as horseshoe vortices. So in these red regions this quantity called the vorticity (and don't worry if you can't understand what this curl is, vorticity is the curl of the velocity vector here), is very high. So all that it means is that rotational motion is very high in these places which are marked red and very low in the places which are marked blue and intermediate in the regions which are marked green. So in any flow, any turbulent flow, this place has got vorticity extremely high, this place is where the vorticity is lower and the places where the vorticity which is extremely high are often organised into tubular structures. Like here you see it a tubular structure and everything around this tube is rotating, so the whole tube itself is spinning around extremely fast and it has an effect on everything else, it makes everything



else spin and gets distorted by everything else going on as well. It is an extremely complicated thing that is going on.



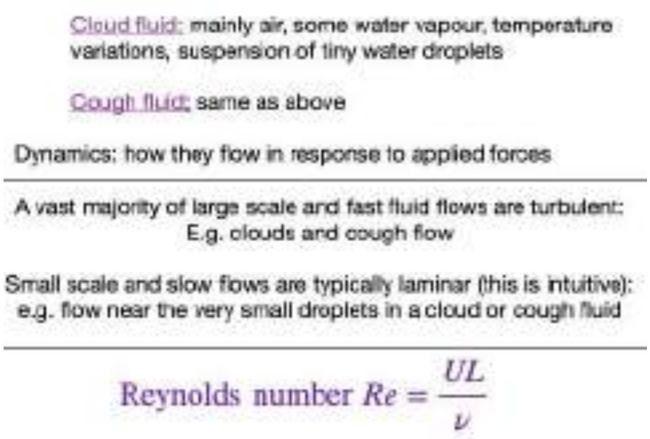
Now let us talk about cloud formation. We will return to turbulence but we will talk about cloud formation now. Here is a puff of air, above a wet surface. The puff contains water vapour which is evaporating from the surface due to high temperature. Here the sun is shining and because the surface is very wet this puff of air is taking with it some humidity. It is carrying along with it some water. As it rises through the atmosphere, it goes past little aerosol particles, which are these things you see in red on screen. Everywhere in the atmosphere you have aerosol particles. So first, why is this puff climbing up? It is climbing up mainly because this little puff of wet air is warmer than its surroundings. Also water vapour is lighter than air but that contribution is very small. The main contribution to it being less dense is that it is warmer. So it is lighter and any puff that is lighter would rise through the air. So this is the initial part of cloud formation. Such cloud formation is going on on the ground all the time except that we cannot see it on a normal day. We cannot see it because we have no way of visualizing it. The temperature in the surrounding atmosphere as it rises, keeps falling. You know that when we are flying in an



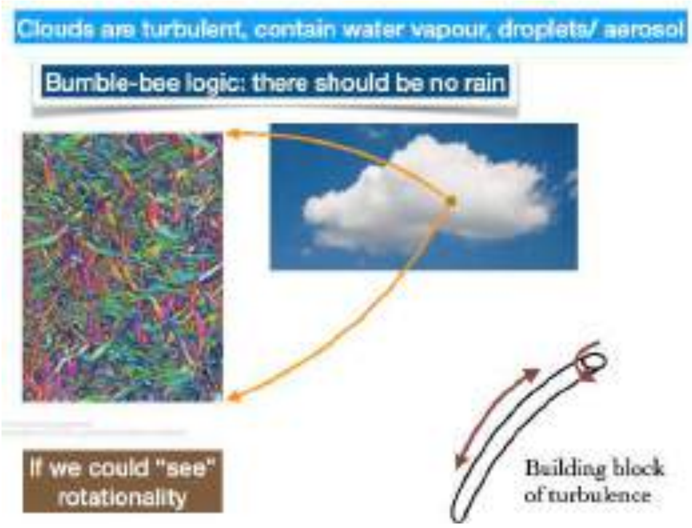
aircraft the temperature outside is -40 degree and so the temperature falls as you go up and up in the atmosphere, and we will see in a minute what that does. The relative humidity in the puff typically keeps going up because the temperature is going down. So at this puff rises and rises it is carrying a lot of wetness, its relative humidity is increasing, until a height where it reaches s = 1, that means its humidity is equal to saturation. Above this it gets super saturated and you start seeing tiny little droplets of water condensing on to these aerosol particles. You see these droplets condensing on to the aerosol particles. So if you did not have the aerosol particles you would never get any condensation. So that is basically why you need aerosol. Aerosols are thus called cloud condensation nuclei and so a cloud forms. So this gives a basic idea why a cloud forms. Once the water droplets are formed, you start seeing this white object. You see this white object because of the way the water droplets scatter light.

We discussed this cloud formation in the previous slide where we said there is blob of warm moist air and as it climbs up till it becomes a cloud. The process is similar to and different from flow expelled during a cough but I will come to that. The puff increases in volume due to a thing called entrainment which we will be discussing. Now this is a cough cloud. You know, if a person coughs out a small volume of air, the volume that the cough fluid occupies become bigger and bigger as it goes downstream and this can be both good and bad. It is bad because even if you are not in the line of sight of the coughing person you can get infected. That is the bad news, the good news is that as this blob grows and grows it is entraining outside air into it and therefore as the outside air comes in it becomes dryer and dryer. So the total humidity of the expelled fluid goes down and so the droplets evaporate faster.

Now let us summarise. What is a cloud fluid? A cloud fluid is mainly air, overwhelmingly air, it also has a small amount of water vapour, it has temperature variations because of variable droplet condensation there is latent heat driven out, wherever there is evaporation there is evaporative cooling and also a cloud moves through an atmosphere with temperatures changing as a function of height. In cough fluid, your body is warmer than the surroundings, typically, except on a hot summer day and so you are expelling this warm fluid, within which there is a suspension of tiny water droplets, which cools as it moves, just by exposure to the outside air. A cough fluid is exactly same as a cloud fluid, they both contain the same ingredients, the dynamics of how they respond to forces is very similar therefore. They are both turbulent as we are going to discuss, and so it turns out that whatever methods we employ to study a cloud fluid, we can employ to the study cough fluid. When I say dynamics I just mean how the flow conducts itself in response to outside applied forces. Now, a very vast majority of large length scale and fast fluid flows are turbulent, as I said turbulence is ubiquitous and two good examples are clouds and cough flow. Now on the other extreme, if you have a very very small scale flow like a microflow and it is very slow, then these flows are typically laminar. Laminar flow is more like an intuitive kind of straight line flow where fluid just moves into the direction in which you are applying pressure. So all kinds of strange things like in turbulence are not happening. This flow is also important for us because very small droplets in a cloud



or even in a cough fluid do not see turbulence. The smallest vortex that occurs in a turbulent flow is about a mm and these droplets are most often smaller than that, they range from a micron in size to hundreds of microns. So they see very streamline flow near them. This is the strange thing: you see laminar flow at the tiny length scales, when you zoom in and zoom in into a turbulent flow. So for those who are interested, there is a ratio called the Reynolds number which is the inertia (which is measured by a typical velocity scale multiplied by a typical length scale) divided by kinematic viscosity, and the higher and higher this is the more and more flow is prone to turbulence. In air, the kinematic viscosity is 10^{-5} m^2/s whereas the U and L are in m/s and hundreds of meters. So the Reynolds number is a very very big number. Whenever you have a big Reynolds number, you most often have turbulence. Clouds are very turbulent because the Reynolds number is about a 100 million, plus they contain water vapour, water droplets and aerosol particles. But when you fly through a cloud, you already know it is turbulent, the pilot tells you to wear your seat belt and you know that this powder-puff-looking innocent thing you see from the ground can actually throw you here and there, even if you are in a big aircraft. You know that when you look out of the window you don't really see large amount of water droplets, so you get an instinctive feeling that a cloud is very dilute in water droplets, so if it is very dilute and the droplets are all 10 micron in size, by bumblebee logic (and I will tell you what bumble-bee logic is) there should be no rain.



In other words, based on a simple calculation there should be no rain, but turbulence is going to make it rain. This is what a small portion of cloud looks like, so you can “see” rotationality, or vortical structures. These vortical structures are the building blocks of turbulence.

Lecture at IIT Alumni Centre, Bengaluru on June 6, 2020
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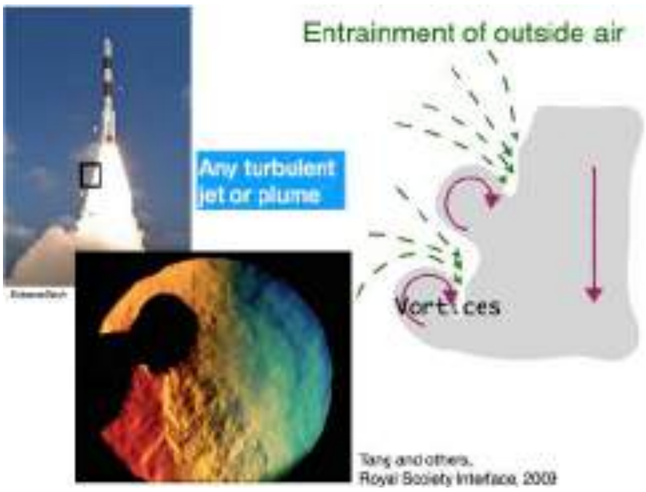
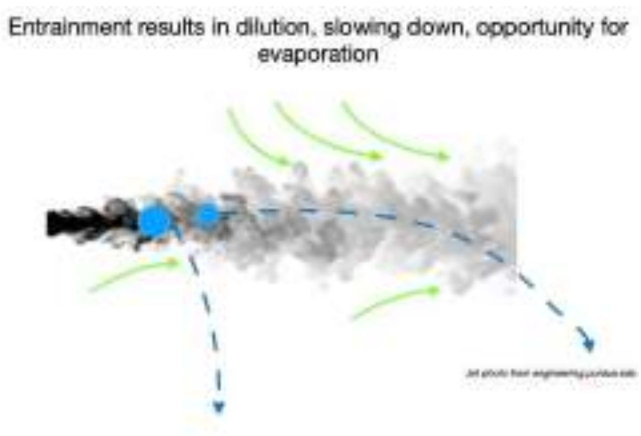
Now we will talk about another very important property of turbulence, which is entrainment. All of us have seen images like this, this is an ISRO rocket taking off, you can see turbulent flows behind them which are in the form of jets. You will always see an opening angle, a very clean and constant opening angle. So if you zoom into a particular portion, the fact that there is an opening angle is telling you that outside air is being included in this, because this is incompressible flow which is expanding at it goes down. It is actually pulling air which was not moving before and now forcing that air to move. Here I put a little rectangle which looks like this if you zoom into it. There are these big vortices and also many small vortical structures which effectively pull in outside air by collecting the outside air by a rotary motion into the jet flow. Thus outside air is entrained or sucked into the turbulent flow and then it starts moving with the flow. This is a very very important thing. The same thing is happening to the flow from a person coughing in the picture. It is being visualised by a schlieren image which basically is a visual technique based on small changes in refractive index (due to changes in temperature), and you can "see" what we cough out. The same thing is happening there. In all of these it is very important that outside air is being pulled in and the fact that outside is being pulled in results in dilution, so here you see a jet was very black in colour which is now diluted. Droplets and whatever else it is carrying are diluted in number or





concentration. Also it is sharing its momentum with freshly recruited outside fluid which is being pulled in, so it is actually slowing down on an average. Everybody is sharing their momentum, more things are moving and they are moving slower than before and this provides, fortunately or unfortunately for us, the opportunity for evaporation. So small droplets go along with the jet and fall to the ground at greater distances. For bigger droplets, gravity wins.

Prof. Jason: Thanks for the very nice first half of the talk, the audience have been appreciating the talk and they could follow it very clearly. There are couple of questions, one viewer would like to know something about transpiration as it relates to evaporative processes in formation of clouds.

Prof. Rama: Transpiration is an important part of the formation of clouds. So that is why we really need forests. If we cut down all our forests we will be losing out on a lot of water that could go back into the atmosphere. That is basically what I would like to say: we need to increase our forest cover and conserve our forest cover because apart from direct evaporation over the oceans and evaporation from lakes and rivers and some moisture on the soil, transpiration is crucial for us.

Prof. Jason: There is a question about the picture of the opening angle of the rocket's exhaust. Are these hot gases compressible and why should we think of them incompressible.

Prof. Rama: When the rocket just takes off, flow behind it may be taken to be incompressible but when the Mach number of the rocket approaches or crosses one then things become compressible. But right in the beginning its speeds are low. So every time speeds are low, you can actually derive this in fluid mechanics, you can show that air behaves like an incompressible fluid or any fluid behaves incompressible. So the velocity of sound is 300 m/sec of that order in air. If you move at a speed much lower than that you can think of yourself as being in incompressible surroundings.

Prof. Jason: Another viewer would like to know what happens to the virus when the droplets eventually evaporates.

Prof. Rama: I have been trying to ask many experts this question, so one thing you have to appreciate is that my entire experience with cough droplets dates back to April. I am veteran of few months in this area, so I have been interviewing/ discussing with people who know better. From what I gathered, it looks like they don't exactly know but they seem to believe that if the virus is dry and in the air it will become dysfunctional very soon. So they feel that we need not worry about the viruses that are dry and dispersed in the air. That is point number one, point number two: we can say from a fluid mechanical angle: due to turbulence these virus particles are dispersed over quite some distance and normally I cannot get infected by breathing in one or two virus particles. I have to breath in viruses in numbers of the order thousand, as I am told by the experts. So if I do not breathe in an entire droplet, I guess I am relatively safe.

Prof. Jason: There is one interesting question regarding the influence of air-conditioning on the survival of droplets in rooms, whether the turbulence and additional circulation generated by the AC is important and whether that will cause the droplets to live longer. Also one has to think about the humidity change.

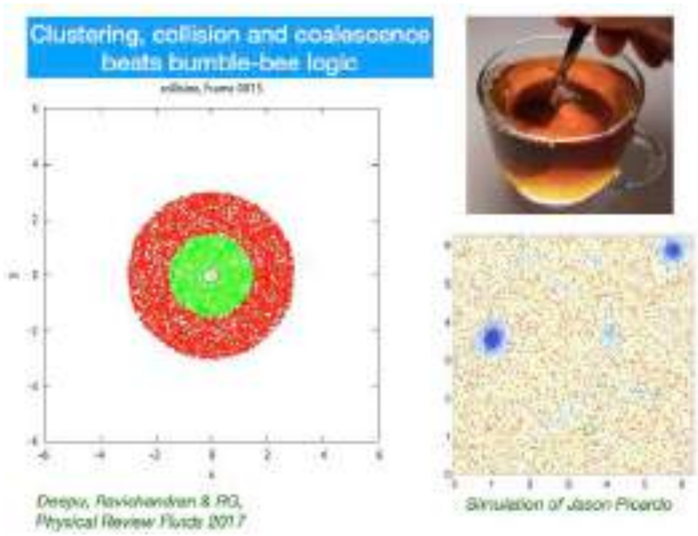
Prof. Rama: That is correct, it is a combination of how the air is circulating and what the humidity is. In a typical AC room the humidity is maintained at 60%, droplet evaporation is slowed down somewhat but not impossibly slowed down. You still have some evaporation taking place. At the same time, if air is circulated inside a closed room, if there is no free exchange with the outside air, and this can very quickly circulate all the droplets across the entire room If a person is coughing in one place and you are one meter away, and you think that you are safe, that many not be right. Within a few seconds droplets would be all over the entire room and that can be dangerous. Secondly, the droplets can get sucked into the ventilation system and viruses can go from one room to another. This can be bad news in places like hospitals where the same air is circulating. So there are a lot of factors but personally I feel that an open window is brilliant, compared to AC.

Prof. Jason: This 6 feet radius idea is quite nice and there is a lot to understand then and revise that possibly.

Prof. Rama: Exactly, and my second part of the talk is about that.

Prof. Jason: Rama, please carry on and we can pick up questions later.

Prof. Rama: Now we are going to talk about what turbulence does. We talked about one thing that turbulence does: which is, it entrains outside air. Another funny thing it does is to cluster droplets, and we'll see what it does in a minute. I will now explain what bumble-bee logic is: if you remember I had said that by bumble-bee logic, there should be no rain. Basically when we started studying aerospace engineering, we were told about this thing called bumble-bee logic, where every aerospace engineer knows that given a bumble-bee's shape, size and everything we know that it cannot fly by all logic. The only lucky part is that the bumble-bee doesn't know this, so it flies. So rain is something like that: by normal logic it shouldn't rain. So we are very very lucky that the rain doesn't know this and it happens. The reason for that is turbulence, and here I show you a cup of tea where somebody put sugar in it and is trying to stir it. We know that the minute we put in turbulence namely stir it, the sugar is going to mix all over the tea. So there is going to be a homogenous distribution of sugar and we can drink sweet tea in a few seconds as opposed to: if I kept it extremely still and



Lecture at IIT Alumni Centre, Bengaluru on June 6, 2020

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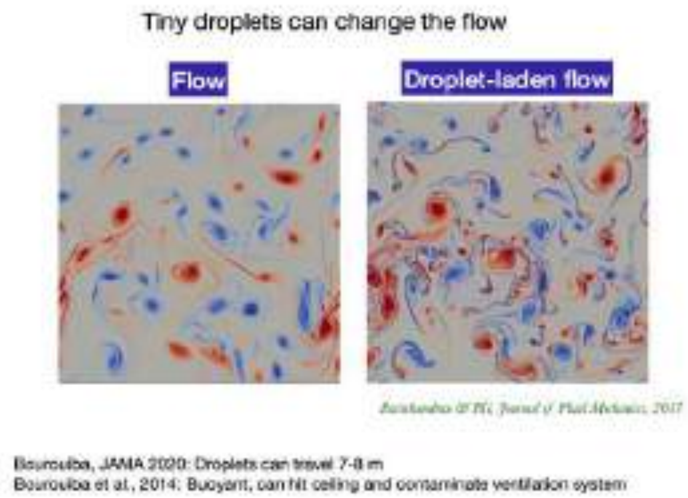
then it would take four months for this tea to become sweet on the top layer. That is what turbulence does, it mixes. We think of turbulent mixing and this simulation you see has been performed by Jason, who you just heard conducting this talk. He is a very good collaborator of mine, and is kind enough to provide this simulation, there you see little droplets who are living in a vortical flow, as I run this movie you see that droplets leave the vortical regions and they collect in these "strain" regions. So wherever there is a lot of rotationality there are no droplets there. So turbulence is demixing these droplets and putting them in certain parts of flow and in this left hand side what is this movie is showing is that basically as they go out of the vortex they have many chances as compared to before to cluster, that means they are coming much closer together than the average dilution tells you. And because they are now much closer to each other and due to other reasons they collide a lot. Jason is an expert on this and he can tell you a lot about it. Because they collide with each other they coalesce and become bigger and bigger droplets. Very quickly due to turbulence you have a large number of big droplets which then can fall down due to gravity very fast and this is how you get rain. In a cough situation we don't quite know what it is happening. Here too all the droplets must be getting centrifuged out of vortices same as in a cloud, but nobody has done a clean simulation to my knowledge. Then the fact that these droplets are centrifuging out feeds back into the flow itself. This we have shown to be happening in the context of cloud which should be happening in the context of cough as well, and this should result in very quick destruction of the turbulent flow. This should be helpful from the cough point of view. Normally if you imagine a bacterium in the ocean you will see that a big wave comes and pushes the bacterium to where it likes but the bacterium



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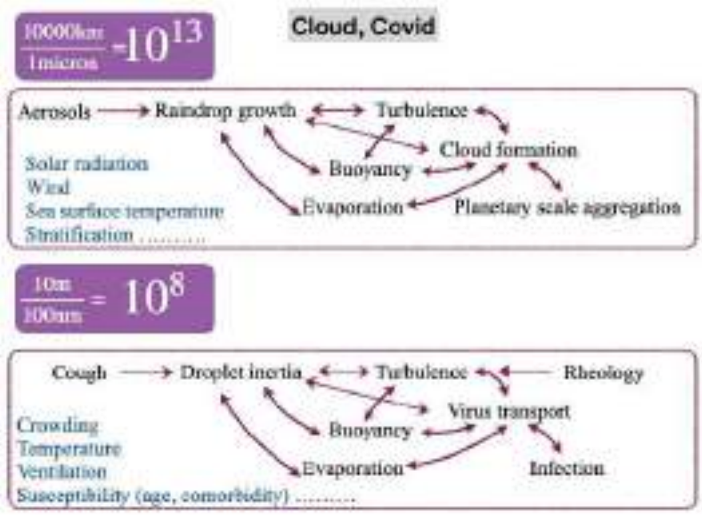
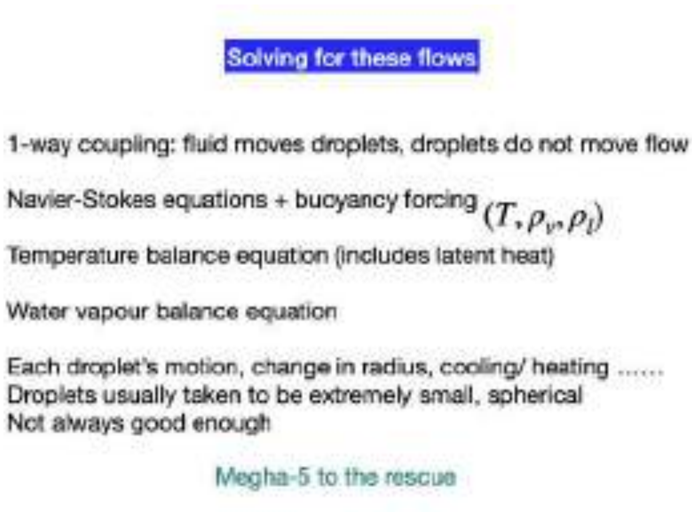
cannot do anything to the ocean. But here are these tiny micron size droplets, actually pretty dilute suspension of them, which are actually affecting back the flow due to phase change. This is due to the fact that they are evaporating and condensing and this feeds back on the turbulence and creates these tiny very strong vortices which then dissipate energy very fast. So the turbulence dies fast. There is this very recent paper by Bourouiba and which challenges the prescription of a one meter distance as safe. Jason has just brought this up, is a one or two meter safe for people? So she has shown very clearly that droplets can travel 7-8 meters (this is in the American Medical Association journal) and turbulence has got a very important role to play here. In an earlier paper, she and her colleagues have argued that because of us being warmer than our surroundings, especially when we are sitting in an AC room (our body temperature is 98 degree Fahrenheit and the surroundings could be at 60 or something like that) the air we eject is buoyant. So when I cough the air I expel lifts up, going upwards and carries droplets and everything it contains with it, and due to turbulence droplets are clustering and moving with the turbulence and this can hit the ceiling very quickly. This is in more detailed response to a question that was asked. It can thus contaminate the ventilation system, so it can actually enter the tubes in the air-conditioning ducts and create problems over there.

Everything we talked about till now tells us that both clouds and cough have things to do with each other and they are extremely complicated systems so there are lot of physics. We don't understand all this physics, we don't have a way of nailing down their interactions, making predictions, we are not there yet in both of these. I am not going to read it out, but I have shown in this slide how a lot of different kind of physics and different interactions take place in both these flows. Some of those are similar in a cloud and in a cough: you have



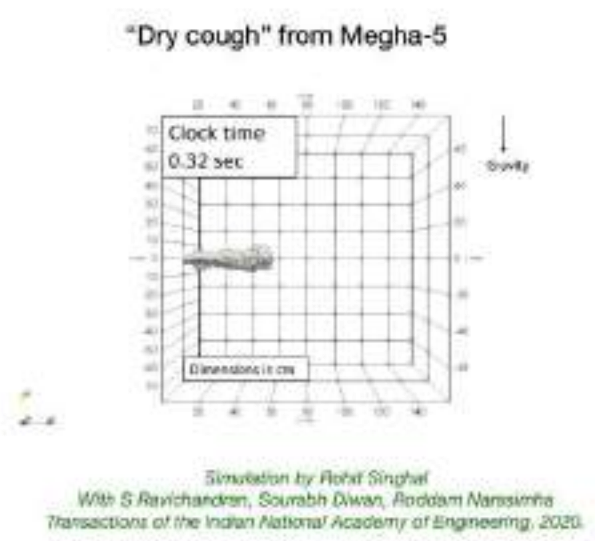
droplets, turbulence, buoyancy, evaporation in both but then we have new questions about how viruses multiply in this environment, how they sustain themselves in this environment, how they reach the place they need to reach to create an infection. Moreover cloud fluid is Newtonian, i.e., we may treat water and air as simple fluids, but mucous is a very complicated fluid. So its behaviour can depart from that of simple fluids. We may have to do proper simulations and experiments to understand what this (which goes under the name of rheology) does to the cough fluid. Similarly there are many other things in a cloud like solar radiation, wind, the sea surface temperature, stratification the way the temperature goes down with increasing height in the atmosphere, all these things change the behaviour of the cloud locally. In a cough flow there are other aspects which can actually determine who is infected and who is affected by that infection. So we need not just fluid mechanics, but a whole lot of other things like biological studies to go together with it even to understand what one cough does. What make things very difficult for us is the range of scales. If I want to understand everything about clouds, we know that aerosol particles and little droplets are 1 micron big, we know that the cloud is on a planetary scale. This is a mind boggling 13 orders of magnitude separation and it is very difficult for one study to encompass all these scales. This is not too different in a cough. We still have many orders of magnitude just to understand this spread of one cough. To include biology into the simulation, we will need to at least resolve a virus particle, which is about a 100 nm if I remember right. So there are many orders of magnitude here as well.

How do we solve these. We have understood that it is a very complex problem but want now to solve them to the point where we are making predictions. We are going to do many approximations and then solve it. The first approximation is that we will say that there is only a one way coupling: the fluid moves the droplets but the droplets do not move the fluid back.



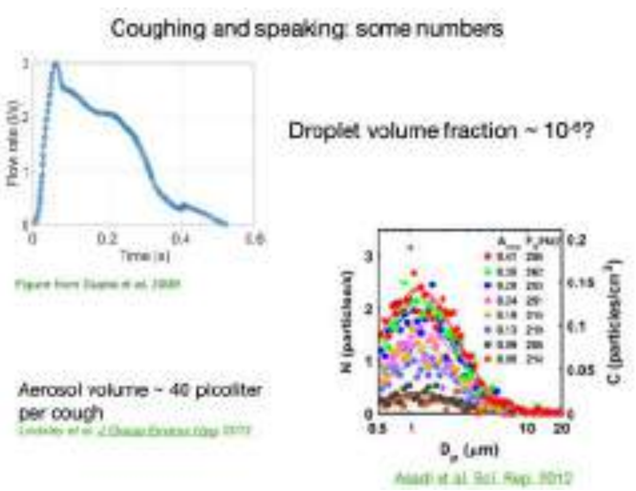
They are very tiny droplets which cannot affect the fluids. This can be a bad approximation sometimes. Now we solve the Navier-Stokes equations which are nothing but Newton's second law. And in the Navier-Stokes equation we need to add forces due to buoyancy. Buoyancy comes from temperature changes which come from latent heat when evaporation and condensation take place. Then the Navier-Stokes equations are also affected by how much water vapour there is, and how much liquid water there is. So all these things force the flow in a certain way. Indirectly these droplets, although they do not move the flow directly, change the way the flow moves. To estimate this we then have to solve a temperature balance equation to know the temperature everywhere, to put back into the Navier-Stokes. We also have to solve the water vapour balance equation to put it back into the Navier-Stokes. So this is already a mind boggling set of equations. On top of that is the billions and trillions of droplets in a cloud and even in a cough. If you want to solve for each droplet's changing radius how it heats and cools its surroundings: we are going to assume that they are very small and spherical. These two assumptions can be bad also but then we may need to solve the flow inside each droplet. With all these assumptions we may make simulations of a part of a cloud, or of a cough. The simulation package we used is called Megha-5, it is developed by Roddam Narasimha's group and in particular by S. Ravichandran who belong to my group earlier and is now in Nordita, Stockholm. There are other such codes elsewhere in the world but not that many who solve all these things in this way.

In a cloud, for flow alone, we have such a big range of scales and since we are talking three dimensional flow we need 10^{30} grid points. So when we want to solve for the flow, we want to break the region up into the grids and solve the equations within each. Here I have taken the smallest scale in the flow to be a mm (not a micron, remember) and even then there is no way that in the foreseeable future any computer can solve for a cloud flow. Much less can it follow each droplet, or make a detailed grid around each droplet at the micron scale. We use a lot of simplifications which could give some errors in the results and this we have to be realistic about because that is what the state of the art can do right now, whereas in a cough you can actually resolve the entire flow, but there too you may not be able to resolve each droplet. You can make approximations for the droplets and you can actually get reasonable answers. We don't have those reasonable answers yet but we are working towards this, and many many other groups in the world are now working towards this. I show you here a sample simulation our work, so here is the velocity, here is the temperature and here is liquid water, all coming of a little nozzle. This is a model cloud you can say. Initially there is no liquid water in the surroundings because the air is dry. The flow is fast here and slow there and the temperature is cool there due to evaporation and hot here. This is the liquid water content.



This looks more like what a real cloud will look like, it will go up there and settle down. This is just an example of the power of Megha-5 to solve for these flows. We have done this simulation just this month on a dry cough, we haven't included the phase change (evaporation and condensation) yet but this is just a sample. This simulation was done by Rohit Singhal. It is a collaboration with S. Ravichandran, Sourabh Diwan and Roddam Narasimha. So here is what the simulation looks like. You can see how the turbulence is spreading. In fact in this particular example it is dividing into two. You can see that the droplets can dry faster and many other things can happen and we will see that in future simulations hopefully.

Now, this is just to show you some numbers for coughing and speaking but I won't dwell on that because different publications give different values which are sometimes different by an order of magnitude. So we have to do more, clearly the world has to do more study to understand about coughing and speaking. The typical cough expels this kind of volume of air when the cough proceeds, the cough lasts half a second and the droplet volume fraction can be anywhere between 10^{-7} and 10^{-4}, you see wildly different values being given for this in the literature. The aerosol volume, that means the dry volume of what is left over after evaporation, probably the virus and other things left over after everything has dried out, is very very small, about 40 picolitre. So we know that a very very small volume of virus can infect us. This shows that different volumes of speaking eject different numbers of droplets. So this is the diameter of the droplets and this is the number which is ejected per unit time when you talk. This slide is just to give you an idea of where the field is. Before I end, I just want to say that there are many other beautiful questions apart from this: the Indian monsoon question which I couldn't talk about today at all but we were talking about an individual cloud, then we were talking about simulations there. So there is very nice cloud formation called Mammatus clouds, it



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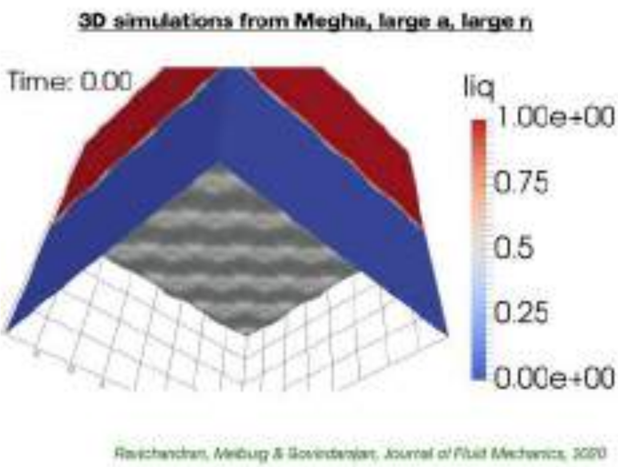
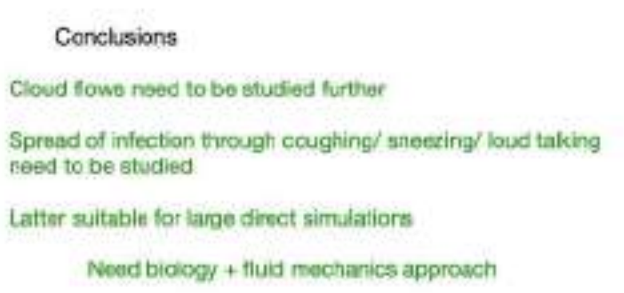
happens a lot over Nepal, Himalayas, it happens a lot in different parts of the world. There is a variant called Asperitas clouds. Those who are interested in it can go and look it up. It is the first time a new cloud has been identified in more than half a century and this was identified in 2016. This is an example over Vishakhapatnam in 2018. We gave a theory for why a Mammatus cloud forms. We did some simulations with Megha-5, which give these bulbous clouds, (this is a model simulation without noise) very beautifully these bulbs of Mammatus formed. This was just accepted last week in the Journal of Fluid Mechanics, 2020. This is just to give you an aside about how thousands and thousands of problems need simulations of this kind and also theory and calculations, experiment, a whole variety of studies and it is my hope that some of that will be done in India.



I conclude by saying that we know something about clouds but they really need to be studied further. This spread of infection with so many things we don't understand is another thing we need to study. So these two things (cloud flows and spread of infection through coughing/sneezing/loud talking) can be studied through fluid mechanical methods. For cloud flows we are not yet there in terms of resolving every scale and everything very correctly so we have to use models or semi-empirical methods to solve for cloud flows, whereas the latter: coughing/sneezing, etc. you can actually solve for the flow through large direct simulations. Here too you need a very large number of parallel computers (a large number of computers working in parallel to solve this) but it is feasible with present day computers and the important thing is to tie up biology and fluid mechanics so that we can solve this problem. One general thing you see is that in cloud flows you need everybody from atmospheric scientists to oceanographers to fluid mechanicians, all kinds of people including plant scientists, (remember the a question on transpiration) and all kinds of people, all scientists coming together to solve this problem. Similarly for understanding covid we would epidemiologists and a whole variety of people with different expertise. We need a very big interdisciplinary approach. So this is about what I was planning to tell you. I hope you liked what I said. Thanks for your attention and I ask Jason now to take over.



Prof. Jason: Before I go to the further questions, I would like to appreciate how your talk has shown the analogy between coughing on the one hand and formation of clouds, two phenomena at first glance that are very different and with different scales and have implications for us and yet as you have shown, the underlying physics seems to be quite similar and I think this brings out one aspect of the beauty of fluid mechanics, kind of phenomena underlying different things quite similar.

Let us start with the question related to the difference between them. In the simulations that you showed a cloud on the one hand and cough the way the jet forms quite different and the spreading angle, the entrainment seem different. Could you comment on that.

Prof. Rama: This is just one example of how clouds form. So you see that if I average it out, there is a kind of growing angle but that is not very evident, part of the reason is that we are not able to reach very high Reynolds numbers in this. So if we could go to even higher Reynolds numbers we see a clear angle but still you can see some kind of angle forming already in this thing especially in the velocity plot. To tell you the truth, we need to do many more simulations, this is a preliminary result to understand what is happening. In fact I don't understand why this particular thing is dividing, but it may have to do with the fact that there is a temperature difference and gravity and also there are walls. So there is a wall here as opposed to a periodic box. We need to do more to answer that question. It does look very different. But here too you can see some kind angular spread. You can see the basic idea of entrainment.

Prof. Jason: Another question about entrainment. You had mentioned earlier that entrainment causes dilution, dilution helps evaporation using more dry air. What is the role of that in a cloud, initial part of warm air gets diluted, will that impact the formation of cloud.

Prof. Rama: That is a beautiful question and one that has not been answered yet. It is an open question and many PhDs need to be done on that. Basically the point is that suppose you consider this as the beginning of the cloud and you assume that this is the vertical direction. Suppose this was the beginning of the cloud where there is a lot of water vapour and then as you go downstream dry air comes in. Suppose this happens in a cloud then there would be no rain. In actual fact the entrainment angle is very small, practically zero in a cloud. So the angle is way way smaller than what you see behind a rocket which is launching or something like that. Nobody knows why the angle is that small, let me put it that way. Basically we know that given the amount of water vapour that reaches the top of the cloud, the angle must be small. Roddam Narasimha has made some experiments to show that that this angle is actually close to zero in a toy model of a cloud but I don't think anybody has measured it in a real cloud.

Prof. Jason: Would one be prone to infections in Mumbai or in Delhi. As a way to ask essentially what is the role of the ambient humidity and temperature on the way the jet would spread and how long the virus stops with the mask.

Prof. Rama: The point about the temperature per se in one place being warmer than in another place, I read things and I am saying this as a lay person that the virus dies at high temperature and so temperature itself is enough to kill it but I don't know whether it is true or false as there is lots of contradicting evidence on that but the other point about relative humidity is very easy to answer. Because in a drier environment droplets evaporate faster so you are safer in a drier environment. In a wetter environment droplets are going to live longer and therefore be carried forward, even small droplets can actually give infection. There are so many other factors, but humidity is one of the factors.

Prof. Jason: Next question is regarding the role of masks. Does fluid dynamics tell us something about whether the mask would be effective especially the simple cloth masks people use.

Prof. Rama: there are many many fluid dynamics studies on masks and the final consensus is that they are very effective. Nobody is disputing that they are effective, but to what extent they are effective: that can be a question. For example, some fluid mechanical simulations show when the mask is on that the air escapes from above and below, so there is a small number of droplets which are escaping through the sides but that is much much lower than when no mask is on. An N95 mask does much better than a cloth mask. So it is like what you intuitively expect.

Prof. Jason: So does the mask have a role for the person who may be coughing as well as for the bystander.

Prof. Rama: Yes. There are lots of people designing cheap masks and there are a lot of things going on there.

Prof. Jason: One technical question from a person who is from fluid dynamics, the question is, in the case of a cough it seems like a situation of decaying turbulence, whether a cloud is decaying?

Prof. Rama: Technically the cloud is not quite in decaying turbulence. The reason is that there is input of energy into a cloud. Even a cough that way is not completely in decaying turbulence because you would call something decaying turbulence if its kinetic energy started with a number and just went down and down. In a cloud there is a way for the kinetic energy to go a little bit up: at first the potential energy is greater. Since it is lighter than the surroundings, and it climbs, it is losing potential energy, which can get converted to kinetic energy. In a cough also there is a small amount that happening because droplets are undergoing phase change and latent heat is exchanged. So chemical energy is being converted to potential energy by phase change and this potential energy can then get converted to kinetic energy. So there is a small amount of induction of kinetic energy but on the whole it is overwhelmingly decaying. A cloud also decays after a while but the amount of energy injected into it is larger than otherwise. If you in fact keep a movie camera on your terrace you can see that clouds do decay.

Prof. Jason: There is a question related to clouds and the role of pollutants on the formation of clouds. How increasing pollution would affect cloud formation.

Prof. Rama: So they are asking how pollutants affect cloud formation. The consensus among a lot of atmospheric scientists now is that as you increase the number of aerosol particles in the atmosphere, you have more condensation, more cloud condensation nuclei as I mentioned, you have more places for water droplets to condense. You have many more droplets, but because you have so many more droplets, very soon all the water vapour is used up in these droplets and they don't grow very big. So in a cleaner environment you have fewer and larger droplets and in a dirtier environment you have many more and smaller droplets and so the chance of rain is lower in a dirtier environment. There are counter examples to all of these arguments because there are so many other processes happening at the same time.

Prof. Jason: Is cloud seeding is in some sense related to this, the idea is to supply aerosols directly to clouds. This is also something that we don't fully understand.
Prof. Rama: We know it works but we don't fully understand it. When you know that a cloud is very supersaturated and in a clean environment and therefore not raining, you can actually trigger rain by seeding,

Prof. Jason: There is another question from a person who is wondering whether what we have understood about clouds so far, whether this has been incorporated into our meteorological predictions.

Prof. Rama: Some amount of it has been incorporated in to big climate models but for the most part that lies in the future. A lot of people are trying to do many different things, one is to go into real clouds and measure them, also they are trying to make cloud like things in the lab and they are trying to do simulations not of the direct variety that I talked about today but these things called large eddy simulations which are actually solve the Navier-Stokes in the large scale and do something empirical for the small scale. So they are doing that kind of thing and in the world there now are quite a few of these codes which are running quite well and hopefully they will improve feedback into climate models and that will help in predictions. Right now clouds are a big source of error for all these predictions.

Prof. Jason: Another question is regarding the chemistry of these aerosols, whether these things are incorporated in fluid dynamic models and what are their roles.
Prof. Rama: They typically are not, so it will be nice if some small-scale simulations are done to understand what things like hydroscopic behaviour, water repellent behaviour bring into the fluid mechanics. I mean in big turbulence simulations these are typically not incorporated.

Prof. Jason: There is a question regarding the variation of cloud formation physics and therefore rain experience pattern in different parts of India, essentially they want to know differentiation topography and local weather in different parts of India, all these effects and whether this can be understood little bit.

Prof. Rama: We know some broad things, even in high school we learned that there is a windward side and leeward side of a mountain. We know that the Himalayas and western ghats give us rain, so the basic summary here is that every time you have winds that are coming together at the level of the ground and then when things converge, when winds come together you get a climbing so you get what is called a convection and every time this happens water vapour is carried from the ground up and so the presence of a mountain aids, in that it helps take the flow upwards and you can get rain over there. So topography, local conditions, transpiration, forest cover, all these local things make a huge difference to cloud formation and also to rainfall.

Prof. Jason: This question goes back to the importance of studying clouds as a collective system where we have a lot of work to do.

Prof. Rama: That is probably a very big open question and very important one.

Prof. Jason: You may give some advice to the audience especially students who are interested in going for climate studies. What could be different ways for students to work in this area.

Prof. Rama: If somebody wants to enter this area, then there is something for everybody. A person with an undergraduate degree in history can study the monsoon, a person who has studied geography has so much potential to study problems of this kind and I don't think they are limited by background and in particular if they studied physics or any of the engineering subjects, may be computer science, a computer science person can solve this problem in a different angle. You can actually teach yourself the basic physics, you can study the fluid mechanics, in fact it is a pity that fluid mechanics is not a core subject in many physics curricula as well. So if you are coming from a physics background you need to teach yourself a bit of fluid mechanics before you are able to go ahead. Most other people can actually hop into this and there will be something for them, of course for biologists and everybody.

Prof. Jason: Thanks a lot Rama, I thing with this you covered most of the questions and I would like to thank all the viewers for many interesting questions and for their attention. With that I will hand it over to Susheela.

Dr. Susheela Venkataraman: Thanks very much Rama and Jason for your time and the session today. In my mind I could never imagine that the fluffy things in the sky the virus could have so much in common. Today you have really taken us through exactly how these things do have a lot of commonality and it was a very imaginative topic and obviously a very imaginative talk by you. During the IIT-Industry Conclave, a couple of months ago, we had a lot of themes repeatedly about the importance of cross disciplinary collaborations in work that has to be done through cross disciplines and today you given us an example of exactly how that happen between something that has to do with a pandemic and clouds. Obviously that same theme goes across many other things like rocket science and similar concepts. Thank you for that, it was brilliant and it was very nice to understand why this kind of cross disciplinary thing inculcating that amongst us to show this is so important. Dr. Abdul Kalam used to talk about this repeatedly, he used to say why developing the scientific temper amongst everyone is so important for our country to become a leader and as part of our mission in IITACB, we believe that it is important to take topics of science and technology to the lay person as well the person who specializes in that area and today you have a done a fantastic job of bringing the ideas of fluid mechanics and really explaining how it matters in every day concepts and everyday happening. Really speaking, we take so much for granted, processes that go on around us, the phenomena that happen around us, we take all of that for granted, but behind that is solid science and you really demonstrated how that works. I think the best way of describing today's session came from what one of our viewers said, I wish you had been teaching us at IIT Delhi in the 70s because for the first time after all these years I have understood something of fluid mechanics. So congratulations to Rama, I think you have done a phenomenal job and Jason thank you so very much for doing such a brilliant job of moderating and pulling the questions together. We had so many questions and it was lovely tide them together to bring out themes that evolve from there. Our viewers, thank you all for participating. Thanks for the questions. Thank you everybody.

INNOVATION AND ITS APPLICATIONS IN HEALTH

MR. PARAG SAXENA I JUNE 13, 2020

Mr. Parag Saxena was a Director of the Indian Institute of Technology, Bombay's Heritage Fund as well as a Trustee of the Bharatiya Vidya Bhavan. He co-founded two private equity investment management firms, Vedanta Management and New Silk Route, over a decade ago with commitments above 2 billion U.S. dollars. Over the span of his 35-year career, he has been part of investments in companies that have created hundreds of thousands of jobs and that have an aggregate market value exceeding $500 billion as of June 2018. Mr. Saxena has been named multiple times to the Forbes' Midas List which ranks the best global investors. He has raised billions of dollars of capital in both private and public markets around the world. He has led or been a part of over 80 healthcare venture investments in the areas of pharma-biotech, digital health, medical devices, hospital management and health insurance over three decades. Mr. Saxena has served on committees advising the Prime Minister of India on foreign direct investments, and the Planning Commission of India on venture capital.

Dr. Jayesh Bellare is the 'Institute Chair Professor' of Chemical Engineering at the Indian Institute of Technology, Bombay. He is an elected Fellow of the National Academy of Science, India, the Indian National Academy of Engineering, The Maharashtra Academy of Sciences, and the Electron Microscopy Society of India. He did his B.Tech in Chemical Engineering from IIT Bombay, a PhD in Chemical Engineering and Materials Science from University of Minnesota, USA, and Post-Doctoral work at UMass Amherst and M.I.T., USA. He was the first Head of IITB's Department of Biosciences and Bioengineering. He is a consultant to several industries, advisor to many Government panels and institutions, and has served on the board of directors of two companies. He has numerous publications, patents and awards to his credit.

Lecture at the IIT Alumni Centre, Bengaluru on June 13, 2020

Link to the webinar : https://www.youtube.com/watch?v=zpGt8sLssHk&list=PL0zMQ-70IHlX-df3u2Tto6dkKHCRC6iFL&index=10

Prof. Ashok Misra: Good evening to all the participants who are joining from India and a very good morning to those who are joining us from USA. I am Ashok Misra, President of the IITACB, Bengaluru, which we established a few years ago and we are building a unique centre of its kind with our own brick and mortar building. It is about two-third ready but we hit a roadblock because of covid-19. If everything goes well we would start functioning from our new building from next year. This unique centre has the vision to facilitate interactions between the IITs and Industries to get projects from the industries for the IITs and also to organize workshops which are of industries' interests. In addition, of course, we will have networking between alumni of various IITs. We are very proud to say that 16 IITs have already joined as partner in our work, unique venture of the IIT Alumni Centre, Bengaluru, IITACB for short. Recently we held the first ever IIT Industry Conclave in Bengaluru. It was a very successful event with a lot of excellent recommendations that came, however the follow up is slow due to Covid but we are now moving forward slowly. In the meantime, due to this Covid lock down we thought about some new things to do, so we launched the webinar series on topical subjects and they have been very, very successful. Registrations have been picking at 1000 and above for one of them and routinely there are more than 500 registrations.

Today's webinar is the tenth in the series and it also marks the first webinar with the speaker from USA, Mr. Parag Saxena. It is my pleasure to introduce Parag Saxena whom I have known for about 20 years. He did his B.Tech. in Chemical Engineering from IIT Bombay, after which he went to the US for his Masters followed by an MBA from Wharton. I first met him in New York when he hosted a meeting of the IIT alumni at his home and this was very soon after I took over as the Director of IIT Bombay. He has been a great supporter of his alma mater, IIT Bombay, especially in these days. He later built his investment career from Citibank and in 35 odd years that he has been in the venture capital and private equity space, betting on early companies like Starbucks and Imogen. He has been on the four Midas list of top investors multiple times. The companies in which his firm led investments are today worth over 500 billion dollars and employ hundreds and thousands of people. He has obviously

contributed greatly to the economy. He is a very caring human being willing to help anyone who asked for it at all times. His great attribute is that he is equally at ease with world leaders as well as with aspiring school students from distant rural neighbourhoods. His cultural coefficient is amongst the top percentile, a prerequisite for leadership.
Aside of all this he is a lover of Shakespeare, watches tennis very much and pursues yoga with the same passion as bridge and cricket. He has been a mentor to many alumni and young entrepreneurs. He handholds them till they can run on their own, a great supporter for start-ups. He is a strong supporter of both art and sciences.
Now it is my pleasure to introduce Prof. Jayesh Bellare who is also a Chemical Engineer. By coincidence, Parag, Bellare and myself are all Chemical Engineers. So you will see what we Chemical Engineers can do. He is the Institute Chair Professor at IIT Bombay, also an alumnus of IIT Bombay, he is a fellow of NASI and INAE and the Electron Microscopic Society among many others. His expertise is in Cryo-electron Microscopy, Nano-medicine, Biomedical devices and implants and regenerative medicines. He has received numerous awards including the Lifetime Achievement Award of the Government of India, Ministry of Ayush, the President award of Electron Microscopy Society of America, the ICI award for the most outstanding chemical engineer by the Indian School of Chemical Engineers, and the NASI-Reliance Platinum Jubilee Award for application oriented research. He will be moderating the session today which will be on the lines of fireside chat with of course on presentations and so on. So let me kick off the proceedings by asking Parag to tell us about his background, his professional journey which has taken him from chemical engineering of IIT Bombay to where he is today. With this I hand over the proceedings to Parag and Jayesh and Jayesh will conduct it from here.

Mr. Parag Saxena: Ashok, thank you for that wonderful and warm introduction. My mother could not have a better job, but let me get to my background. So like many people on this

like I am an alumnus of IIT Bombay and I put together a few slides. My education is from three places, the first the most important was from IIT Bombay, I still recognize the Main Building, and I went from there to West Virginia. Many people ask why West Virginia: it was a combination of being able to afford it, they offered me an assistantship and that was enough for me. It was also the shortest programme; my main interest was an MBA. Here I could get my MS done in just two semesters, since my real objective was the MBA later and then I worked a little while which will tell you in a second and then moved on to Wharton as Ashok said, did my MBA. So to tell you a little about my work experience, the crucial milestone in my career was when I finished my MS from West Virginia I looked for a job as a Chemical Engineer and one of the opportunities that I have was to work in Becton Dickinson. If you don't know Dickinson, they are the world's leaders in making needles and syringes, they have more than 85% of the worlds share. they also invented the vaccutainer and had the patent to it and dominate the world in that. The vaccutainer actually was a brilliant piece of engineering design and it is the product I worked on and contributed too. I don't now whether you can see in these tubes there is a residue at the bottom of the tubes, and when I joined Dickinson, one of the big challenges was having in separating red blood cells from plasma. For l the most popular tests, the most frequent tests that are done, I am sure everyone on this webinar today has had a blood drawn

test done by the most common tests that measure for example glucose, cholesterol, sodium and so on. To do that we need plasma separated from blood cells, so blood is drawn into one of these tubes and first brilliant part of this was to switch from the syringe. Before this, blood was drawn by a syringe so that there could be a little error by the phlebotomist who drew the blood and then depending upon what the purpose of the rest was different reagents was mixed into it. Another source of potential error was because you had to get a precise measurement of the reagent. So here what happened was that they did a vacuum so a precise amount of blood was drawn in to the tube, the reagent was pre-done and then the part that I contributed to the residue that I want to talk about here is this residue was designed so that it's specific gravity is between red blood cells and plasma. It is the jelly at the bottom of the tube in the beginning but when you have centrifugal force and all these tubes are put into a centrifuge after the blood is drawn to separate the red blood cells from the plasma. So they are spun in a centrifuge and so the red blood cells go to the bottom and because of the specific gravity of this gel is between those two it forms an impenetrable barrier which resumes its jelly nature at the end; a beautiful elegant solution, over two billion tests like this are sold today. So the one thing for me was my home paper, which is only an IIT Bombay term, that is the glorified B.Tech. thesis we had; it was on the rheology of non-newtonian fluids, it was precisely designed to be able to help in the design of this gel and a very very satisfying thing for somebody at the beginning of their career. What that did for me, though, was it got me into the field and I went and visited hospital after hospital that was adopting this new tube. It replaced the solutions that existed before and I got a picture of health care, a picture of how and why people buy one product versus another what their problems in the lab, the mess that occurs when one of these tubes breaks inside a centrifuge and the recurring problems. It gave me a real perspective and an interest in the broader scheme of health care at the very very micro level. It also gave me a great view of the United States in visiting hospitals over the three years that I had worked with Dickinson, I visited the 46 of the 50 American States, more than most of my American colleagues. So I came away from Dickinson with a knowledge and a love for heath care which stays with me to this day. I went to Business

School as I said, I joined a consulting firm briefly but then the real change in my life was when I joined Servico which offered me a job at the end of my MBA but not the one that I wanted, I wanted one in a venture capital unit and I started it as the low man on the totem pole, the junior most person but probably the most excited and happy person in the team because it is what I wanted to do. That was in May 1983, so I joined Citi and then I had a bit of mixed luck being that the person who had recruited me left in September that year and all of a sudden I didn't know I had a future there or not and whether in fact I could pursue a venture capital career or not but I had a very prized possession. I had a calling card which said Citicorp which was a global famous name at the time City was a dominant commercial bank well known around the world. It was a great calling card, it enabled me to raise my first fund, the grand sum of 13 million dollars but then luck favoured me and did extremely well and so I continued with that in a career that eventually steps along the way but I think they are less important. I started my own firm, the unusual thing of starting two firms, one focused on the Indian subcontinent, new route and the other Vedanta capital which is from where we do a lot of the health care companies that I hope we will cover today. I said that health care is something that I liked from the beginning and I had the pleasure, the privilege of leading personally leading most of all the investments and I say this because these investments were all done by my firm not by me personally and they were always done as a team; in fact everything I have done in my life has depended upon a team around me. I say that because it is important to remember that individually we may think we do it all but it is really the team, these slides that you see we started building them yesterday morning and if it wasn't for a team of four or five people around me they wouldn't be here this morning because I certainly couldn't have put them together in the few hours that we did.

So amongst the only early investments that we had and I pointed this for a reason was Amgen. Amgen today is the world's largest biotechnology company, I learned a great deal from George Rathmann who was it's founder. George is a unique person who started three companies each of these was worth well over a billion dollars over a period of time. Amgen today is worth over two hundred billion dollars and George was its Chairman and CEO, and I learned a tremendous amount from him, but I also pursued the love of health care with companies like that and a few later Celgene which recently Bristol-Myers bought by paying $74 billion for it and again it was a clever idea, Bristol-Celgene early on in the early eighties made the discovery which learned in chemistry, perhaps high school students today, I leant it at IIT Bombay that optical isomers can have very different behaviour and they found a drug which was extremely dangerous as one isomer but the other isomer has a great application in cancer and is actually a multi-billion dollar drug today for cancer, and that was the first thing that Celgene, the first product that Celgene brought to the market. We led the sole investment in that company, the only people that had the courage to put up the money when they need it badly. I invested in Celgene twice, once in 1986, second time in 1997 when we were the only investor. I put up Oncotype here because I was thinking about how Oncotype came much later so this is well after recombinant DNA had established itself but you are all familiar with PCR and Oncotype was a clever idea that built on that but their brilliant innovation was a different insight. What Oncotype does, their first test, they are many now, but their first tells a women who has already had breast cancer whether or not she should go in for chemotherapy. It is both expensive and a painful decision because chemotherapy is a many-month process that is going to remove all the hair from your head, it is going to leave you vomiting, uncomfortable, unhappy, should you have it or not. Protocol at that time, which seemed extremely logical, was that if the woman was of greater than a certain age, doctors believed, and their young colleagues especially, probably believed that they die anyway from something else, so there was no point putting her through a course of chemotherapy. So what they did was, they didn't give chemotherapy to those patients, or if the node was bigger than a certain size they gave chemotherapy if it was smaller they didn't. In a clinical study that Oncotype did, they showed that throwing darts was better than this completely logical-sounding supposition. The importance of data was established brilliantly by this.

The other great innovation which I loved was to prove that its test was effective to the FDA what they had to do was to show that a women didn't get cancer, 10, 15, 20 years later. How do you show that you don't get cancer, you do a test and wait for 20 years, that is one way to do it but that would take a long time. They came up with a brilliant alternative; the National Institute of Health stored samples and stores them in formaldehyde. They went back and looked at samples that were more than twenty years old and discovered a way to recover DNA even though it had the sample had been in formaldehyde this was a challenge and that was generally accepted that you can't do it, but this company genomic health figured out how to do it. They then took this greater than 20 years sample and sent to the FDA, we will predict blind, give us the samples blind, we will tell you which people who went on to have cancer and they proved that with a 99.9% confidence ratio statistically so that they showed that the test was a factor. So it is a wonderful insight using technology but also using the system, and I say that because it is a combination of technology but also understanding the real world and making solutions work within it.

As Ashok mentioned, we had as a firm the privilege of being an early investor in Starbucks when I met Howard Schultz, he said, we will never have more than a dozen stores, this is an apprentice business. We all know now Starbucks today has tens of thousands, 24000 stores within 76 countries. When we make this company the bet the challenge was whether or not people who drank coffee and paid $3 for it in the State of Washington and the City of Vancouver in Canada the only two locations that Starbucks existed then. Was this a phenomena that existed there only or was this a phenomena that would be able to come everywhere. Would we all love Espresso? Today we know we all do, right in India we go to the Coffee Day nearby or something like that, Gloria Jean's for a coffee, tea or whatever. So at that time, we didn't know this. In the late 1980s it wasn't clear that this phenomenon would capture consumer behaviour.

Similarly, would people shop at Costco? When we invested there was one store and today there is hundred of these stores, 785 at the time that we found the data for this or MetroPCS which was a pioneer in they said people would make many more phone calls and would buy our service even though there are many other competitors out there. We have a different model and MetroPCS came up with this model of providing unlimited bandwidth, unlimited roaming for a fixed fee, the figure that people would be attracted to that model and there was a large enough number of them. So it wasn't a technological breakthrough but it was understanding consumer behaviour and switching to that and MetroPCS today is a company with order of magnitude a hundred billion dollar value in its current avatar which is as T-Mobile and parlayed that brilliant idea with many adventures along the way over a 20 year period to a leader globally. I think I will stop there on the things that affected my background.

Prof. Jayesh Bellare: Very good Parag, thank you for that insight, it is obvious that you have really had a very impactful investment profile by being able to pick up the right things. It is obvious that your entire career really has been devoted to funding, nurturing and assisting innovation, so in a broader sense can you share with us what really is the key that drives innovation and your identification of those.

Mr. Parag Saxena: In my experience, the way I would summarize is that all of innovation is driven by three really important changes. There are lots of things that have happened but the three things that accelerated innovation the most are changes in regulation because regulation is very powerful yet vague, and when regulation changes, it spawns a whole stream of innovation, people come up with ideas to benefit from the regulation which can be deregulation or can be regulation that tries to push something, it can be either one of them. The second thing is changes in technology which we are familiar with and I think the one that most people think that technology is the biggest driver but in fact regulation is huge and I will give you some examples of each of those two and then the third thing which is normally the slowest driver of change, is changes in consumer behaviour. For people to adopt the MetroPCS model, it took 10 years for them; for MetroPCS to take away share from the leaders, AT&T and Verizon, took 10 years, and for Starbucks to convert people to buying $3 espressos instead of $0.50 coffees from the corner store also took years. So the consumer behaviour is the slowest to change normally, but circumstances change and that is the wonderful thing about the investment business, you keep learning. I have learnt greatly in the last few months and I will come back and share that with you.

I said regulatory change, so I will give you a great example. For a long time, Alexander Graham Bell's company, AT&T, would be the invention symbol out there, the great genius created a great company and created a great research organisation, Bell Labs. I am sure there are people on this webinar who have actually worked at Bell Labs, Bell created that, and Bell, the company, stayed and stayed as a near-monopoly, they had to satisfy certain demands that the government had, which was to provide service, so even though there was a person a mile away from any switch box, five miles away from any switch box, they had to get service, and AT&T had to provide and that they gave them a monopoly for a long period of time. But then the government decided that they would break that monopoly. Some companies had already started it find little loopholes at the edges at the margin of regulation in the United States and then the Telecommunications Act of 1996 did a great deal of deregulation. Till then we had the familiar phone that those of us who are over fifty of age will definitely recognize as the only phone that they knew for most of their lives before it changed widely the Bakelite phone that you see here but the telecom act of 1996 changed two things it enabled new people to come in and manufactured both instrumentation as well as the switches, the equipment that goes behind this and also deregulated service so that it permitted new people to come into services and that reverberation went all over the world. So you see it not only in India but you see it all over the world, so it spun off a number of companies in the US but it also spun off here, so I was watching with interest, as I am sure all of you were, as Reliance Jio raised the staggering sum of ten billion dollars in a month during Covid, so it was an astonishing thing that they were able to do at this point in time. It goes back to the deregulation that started the States. People said: hey this works and in fact the consumer benefits, and

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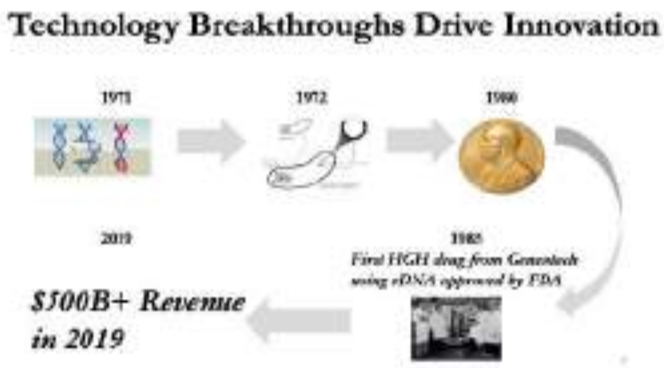
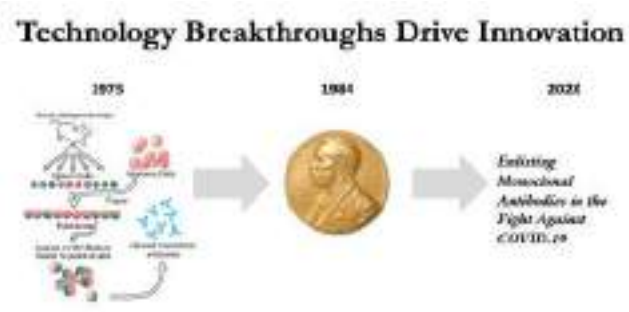
governments around the world started to permit non-government or non-monopoly organization to do it. I said that technology is the other thing that drives innovation I have several examples. Shockley and two of his colleagues came up with a transistor in 1947 as all of us know he won the Nobel Prize for that in 1956 and the first major company, there were others like National Semiconductor, the first major one that came out of that was Intel Corporation, which was founded in 1968 and here was a company that was going to make transistors by the million today. It spawned other deep foundry manufacturers who said hey we can take this to a different level of mass production and now of course the use of the IC is completely ubiquitous. It is there everywhere we don't even think about where it is the two symbols I used here, one which would be familiar to all, of course is the mobile phone and perhaps less familiar but a clear example of what this has taken us to is the Tesla car which really another long term outgrowth of that growth. But the thing to take away from here is that year 1947, so 20 years later in 1968, you started to see the use of ICs in a huge fashion, twenty years to go from a science breakthrough of the discovery of the transistor to its mass production and the use where every one of us is in some way starting to use ICs in the first way. I saw a clever cartoon recently that if the safety pin was invented today it would probably have two ICs in it.



Other technology breakthroughs and those in the area that I work on in particular: Paul Berg in 1971 published first paper on DNA splicing, he came up with this brilliant idea that I can take the DNA from living thing A and put it into species B, if I can get species B to multiply rapidly I will produce the product from species A quickly and this idea is an idea that is used and multiplied today. Gene splicing was the idea that then became popularized by Lawyer and Born at Stanford. Then after the UCSF breakthroughs that popularized that idea, Berg won the Nobel Prize in 1984 for his brilliant breakthrough and then just five years after he won the Nobel Prize all fourteen years from the time of the science breakthrough, just fourteen years from 1971, you saw the first approval of a drug Genentech, one of the major companies which is now part of Hoffman La Roche, they paid nearly a hundred billion dollars for this company created the first product from recombinant DNA, just a few years later 2019, today over half a trillion dollars of revenues come from recombinant DNA. So stop and think about that a science breakthrough in 1971, the first product in 1985 so fourteen years later and then in three decades, you are seeing a business that is half a trillion which will quickly cross a trillion dollar in the value. So technology is clearly a huge driver of innovation. Another innovation which I think we will see a huge amount, Kohler and Milstein from Cambridge created monoclonal antibodies. They found a way to uniquely attach one antibody to something which people then parlayed into different kinds of tests, the first really popular test that occurred from this in the early 80s was a test for pregnancy which you could just use urine to figure out whether or not you were pregnant, so does an extremely convenient test today, that same idea is used across a large number of diseases and one of the goals for people in Covid is to try and find a test that works off a monoclonal antibody so that you could do something very very simply and when that breakthrough comes through that my hope here on the slide that in 2021 perhaps we will have quick test for Covid.



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Thinking of Covid, vaccine is the other place where technology is huge in this area so that what began as an idea in 1796 with Jenner with vaccines, he injected a small 12 year old boy, the FDA anywhere in the world today strongly forbid something that, but he took some residue from a pox infection that a milkmaid had, put it on a little kid, I think many of us know the story that eventually led to the first vaccine in 1921, which is the BCG vaccine, so that all the scourges that occurred in the prior century, rabies, cholera, tetanus, typhoid, bubonic plague, many of these no longer occur because now every three years or so we have a new vaccine so that today we have 50 new vaccines for diseases and we are desperately looking for one for covid and I hope that in 2021 we will have one for covid. So regulation drives innovation, technology drives innovation, I used few examples there and the third thing is that consumer behaviour but this is normally the slowest driver of change. In consumer behaviour, you first had the ancient market places, the Agoras in Greece and they go back to 800BC that is where trading occurred and then we had mom and pop shops and then Harrods in 1826, the first Harrods store was created and we all know of it and then department stores concept was created and then we started to optimize that. Walmart came up with the idea of having huge choice, huge volume but really low prices. Costco adopted a format of that, made you a member of it and then the Big-Box revolution expanded in different ways, Starbucks was a form of that, Amazon takes another access to that and provides you with convenience but this as basically taking consumer behaviour and giving you cost and

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convenience as the two axes but again this is not what something you do quickly. Even today, Kirana stores or Corner stores or the Bodega here exists because our behaviour hasn't completely gone away and we don't do all our shopping online so it is something that happens and takes a period of time. Consumer behaviour changes are the slowest but those are the three drivers - regulation, technology and consumer behaviour.

Prof. Jayesh Bellare: May I ask you a question related to what you just said. Changes in consumer behaviour are often post facto, so to speak, but those changes are the ones that you as an investor and innovator have to anticipate. So taking the examples Walmart and Costco, how did you get the insight into changes in consumer behaviour or the expectation of consumer behaviour before perhaps even the consumer knew about it?

Mr. Parag Saxena: So in the end this is always a gamble, this is but a probabilistic gamble. So like most things that we have to do where we are taking some element of risk. So I think all of us know the story that when the first test of the atomic bomb went off, all the scientists working on the Manhattan project weren't absolutely sure they will destroy earth in that process right, so they were taking a gamble even though it was a very very thought out experiment by the smartest physicists on the planet. So the same thing in a much less dramatic, much less important way is what we do. So when we looked at Starbucks, it was terrific coffee, it was wonderfully served, the risk was, was this something that the climate of the Pacific Northwest which is a rainy climate, gloomy most days, was that something that would translate to the rest of the country. Would convenience and cost be important enough to people? These are the important things in the consumer world, of course, and sometimes they are thrust upon us. You can survey, and we do it, so there are very good surveys that you can do, you can actually take group of people, you can model those people so that they are a microcosm of society, there are even cities that people think of as the model cities so that you will see that people that start new products. When you see a Hindustan Lever or a Procter & Gamble start a new product you will find that they won't start in the biggest market, they won't begin with New York city, they won't begin with Mumbai, they will begin with a small place which they view as a model because they have learnt that through sophisticated marketing. In the venture world you do the same thing, right, and so one important thing I want to say, I want to say this to entrepreneurs, potential entrepreneurs who are out there, always take data, it is very easy to believe that the idea that you have must be one that everyone believes, but I learnt early in my career that my own instinct was often wrong and that it was really important to get data from others and ideally data from people who were not like me, people who didn't think like me, people who didn't have my background. So in fact I was in a company recently and I was looking around at the people and I said, you know what is wrong with this, we are all engineers here. So when you are all engineers, you have a certain perspective and that is not the world and so you need to design your surveys with people that represent the audience that you are eventually going to go after and you need to ask those questions and be guided by that data, but in the end you are always going to take a gamble. I don't take away, and I know that there are some naysayers, I don't take away from the people who believe that they have an idea and the world just hasn't understood it yet. Yes, there are such people but I think those are people who are one in a hundred million may be one in a billion. When you have somebody like a Steve Jobs or a Mark Zuckerberg, completely convinced that their model is something that everybody needs even though it is generally a leap from what was there before that is a hard model to follow. You should believe that you are going to be as good at cricket as leaders such as Sachin Tendulkar or Virat Kohli before you believe that your belief is going to capture the idea and have as many followers.

Prof. Jayesh Bellare: I think that is a great answer. I hope there are some more Steve Jobs amongst us but you have to take voice of the consumer with enough interest, with enough weightage. Parag, you talked to us about a few healthcare related investments that you have made and promoted. Can you give us some more examples, some more insights into the health care scenario. Let us limit this first to the pre-covid era, we will get to cover covid in a moment, but in the pre-covid era, what? And then perhaps after covid dies out and the new normal sets in, we can talk about that later, but in pre-covid era what have been your feelings and views about the healthcare scenario?

Mr. Parag Saxena: For some time now, one of the things I felt that there are two major problems with healthcare globally, one problem is access, everybody doesn't have equal access to good quality healthcare and that is one issue and the second issue is that we have a huge set of technological breakthroughs which I talked about earlier today, the analysis of the human genome, the available data science and the combination of those things leads you to something that you say, hey listen, we need to rethink healthcare and for those that do not have access, data science provides a huge step forward because there is a great deal that we can do with data science and where we can do it of course is wellness. I think we all, those of us who are educated, instinctively know that wellness is the way to go, prevention is the way to go. So not having diabetes type-2 is the best way to never have diabetes type-2 because diabetes type-2 is a lifestyle disease, we bring it on ourselves because we don't eat properly, we bring it on ourselves because we take too much stress on, we bring it on ourselves because we don't treat high blood pressure, we don't exercise, right. We know all these things; we know them to a greater extent. My children are much more thoughtful about exercising than I am, my children are much more thoughtful about eating carbohydrates or not eating carbohydrates than I am. That is one thing, there is that awareness that we have and so pre-covid, wellness is something that is extremely important but it is still at the

periphery, it is still with the more educated with the early adopters, it is not something that everyone believes but there is an opportunity using data science to convince everybody. Given the growth in less expensive telephones and our ability to distribute these cellular telephones everywhere, we can provide knowledge to people that don't have it. Because the challenge for somebody who is diabetic the next step for someone who knows that they shouldn't have carbohydrates is ok, tell me what I can eat, it is not enough for me to know that I shouldn't eat what I call the white devils, white flour, white rice, sugar but I need to know what I can eat instead, it needs to be easily available, it needs to be inexpensively available and so that is something that we can do and nutrition is a concept that we can provide and particularly where money is scare. In the developing world the idea of promoting wellness is the way to go and data science is the way to use it and by data science I mean when we see somebody not following that, when we somebody who has a high salt diet and has hypertension, reminding that person o not have things which have salt and telling them that when you have a spoon full of pickle, you are eating two days of salt probably will educate them so that they will pause before they have that spoon of pickle, that is the opportunity before us. For the wealthier world, prices still have to come down. There is biomedicine where genomic sequencing will lead us to more sophisticated very precision medicine driven solutions for individuals but costs still have to come down. Today that is still more the rich world, but just as a point of interest I will tell you, in my firm Vedanta, we are building one of the largest bio-banks in the world in India with the idea of treating diseases in India much less expensively than we are doing today as we get a genetic profile of more and more people and are able to find aberrations in their genomic profile that create diseases. For example, in 150 million hilly tribe people we have a materially different mix of blood related diseases like Thalasemia, sickle cell anaemia, absence of factor 8 and so on and so we are able to do that and over time this cost will come down from it, it is already come down lot, the first genome cost of three million dollars to do, of course that was a sample of one today we can do it for about $600 but I think that the cost has to come down something like $10 before it becomes a mass usable thing and that is the vision I think for healthcare. You got to use the availability, the vast availability of data and the ability to process it to provide digital health solutions for access to health and that will create wellness which reduces the need to take care of people. We don't really today have a healthcare system, we have sick care system, we need to change it and we need to change our mindset to a healthcare system.

Prof. Jayesh Bellare: Parag, we know you are a Yoga enthusiast amongst other things, so do you have any comments on the somewhat touchy subject of looking at traditional and alternative systems of medicine within the healthcare system?

Mr. Parag Saxena: In fact I have been working on a project where in the scheme of wellness, there are many things we know and there are some things that we know going up in India which today have been scientifically proven. We have clinically proven using double blinded samples with things such as, I will given you two examples that everybody in India knows and we see globally which is the isolation of the active gene from neem. We know that neem seems to have something because insects don’t attacks trees which are helped by neem right and we use neem to brush our teeth and we seem to be able to keep bacteria away from our mouth by doing that. Similarly we know that from haldi, turmeric, there is something in there turns out is curcumin which prevents inflammation and that is something now which is widely proven and the use of turmeric has become very broad. So I am always amused when I go to a coffee shop and I see that one of the things I can add is a little bit of haldi or turmeric into my coffee or whatever, I have it in my meals all the time. I think that as you know we have in the system of Ayurveda, we have that in the system of Yoga, in the end breathing is the most important thing, pranayama is the most important thing and our ability to breathe and sadly as we know in covid, we finally die from pulmonary fibrosis, we finally die from the inability to breathe in, it feels as if every breath that we are taking is coming through a vast body of water, every breathe and we can't do it any more. Ventilators can't support us but breathing and yoga exercises supports that and if we were to build these thing in I think we would build wellness extremely well.

Prof. Jayesh Bellare: Thank you Parag, perhaps that leads into the million or billion dollar question of the current circumstances and how the current covid pandemic has affected things, and what is your prediction for the post-covid scenario.

Mr. Parag Saxena: The two things that happen, the obvious thing that happened with covid are that the digital health accelerates and what used to be a corner case something that we tried because it wasn't ideal now becomes massively useable and there is a large number of people who will continue to use behaviour and so this will help particularly in the use of virtual applications such as doctor visits which can be done. So just to give you a statistic that I saw in a McKinsey report in the last couple of days, 70% of doctor visits during covid have been done virtually. That probably tells what can be done, three quarters of all cases don't really need people to go there and don't need people to physically meet a doctor because they have been able to find a way to do that. In India, we have in Bangalore actually we have a company called DocsApp which is also a pioneer in the telehealth space and has done this but what I think we will find is that many many more things, I know of

companies that are working on doing your eye exam through your telephone so that your doctor can do your eye exam removing another need for you to go to an optometrist or an ophthalmologist and you can do this on your own. That will accelerate but the impact of covid goes far beyond this because covid is going to change behaviour in many many ways. I will pause for a second, this is a little bit like what we have encountered before: for people in the IT industry, in the year 2000, there was this huge fear that when we changed the year 2000, a lot of computer programmes would run awry and there was a huge burst of conversions that took place and huge amount of business that firms like Azim Premjis' and Infosys and TCS and so on all had. Today I think covid-19 is going to be reason why there is digital form of transformation that takes place because what covid has done is it has taken us at a very rapid speed and all of sudden we have gone from having in the pre-covid people that would do were the early adopters but the visionaries but the providers of the technology were those that were providing game changing technology. When you went to make a sale to this hospital what you had to show them was and what you had to come away with was for the hospital or the doctors to say, yes I believe what you believe, but it was a difficult sell. During covid all of a sudden it has changed hospitals now say we need what that solution that you have, do you have a digital health solution for me. I need that solution today, so what is going to happen post covid is what used to be your earlier doctor, people at the fringe, people who bought the first thing and everything will now become mainstream customers because during covid they have been forced to do a variety of things so that business will transform completely. I think about how many people in my office really need to travel as much as they travel before, I myself was on a plane two days a week, three days

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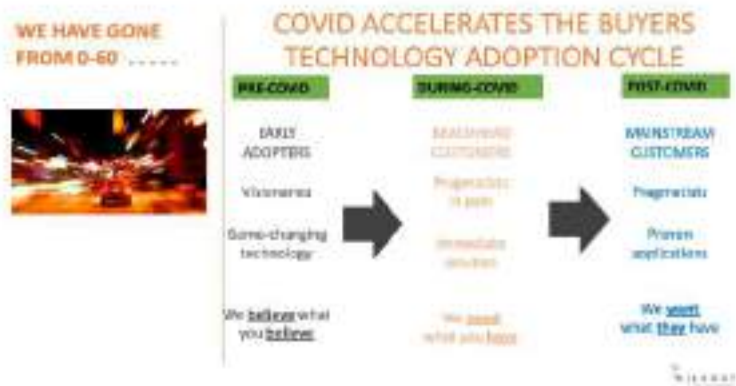
a week going somewhere to meet somebody. Now I think there are many of those meetings that I can cut out and I can just do them over video conference as we are doing this webinar today and indeed every day I probably do 3, 4 meetings using one of the various video conference services, so I think that behaviour will change completely which means that other things have to happen, so for example, on Thursday mornings I do a forma of yoga with a teacher who happens to be in Spain and I do it with one other person who takes the class with me, a former General in the Indian Army who lives in Pune and so it is the three of us, the teacher, the General and me and so we do it over zoom and I use my computer to blow up the image on a large TV screen so that I can see myself on that easily and see my teacher and I noticed the lag between the Bluetooth image from my computer to the TV screen so it tells me that has to get a lot better. We know the obvious ones, security, everything in computer security has to get better if you are going to use conferencing much more. Zoom had many failures for example that we are familiar with, so security, so that is a much bigger transformation than just healthcare but within healthcare we are going to see this. I saw an estimate recently by somebody who said that 2.3 trillion dollars will be spent on the changes of making things available that we realized because of covid, we need to have done and that deals with communication that most basic need with the security of being able to make it



happen with the payment process that we have with the forces that now will change education because as we think about this you know IITs, colleges, schools, how much more will be forced online and for how long because I don't think covid is going to go away tomorrow. I think that is here in this current form for at least one more year from today before we have the three things that we need. We need a quick inexpensive test, we need several drugs that work or several vaccines that can take care of the population in expensively and that transformation now has started and post covid you are going to have a lot of applications that you didn't have before this.

Prof. Jayesh Bellare: I guess so, would you hazard a time line for those solutions the one relating to covid of course?

Mr. Parag Saxena: Around the globe people are rapidly doing that, I am sure that people are thinking about solutions to these various problems and we are going to start seeing them in months, I am talking about the solutions to communications issues, improving those to security issues to improving those things I haven't thought about at all, improving those to providing education, so companies like the inefficiencies that are highlighted whether in healthcare whether to enable you to work from home whether to make supply chains more resilient. Covid has highlighted each of those, so Coursera, many people here may taken a course from Coursera but viewed it as a kind of an interesting curiosity course. Coursera has been around for many years but now covid has accelerated Coursera so that all of a sudden Coursera becomes a viable thing and I expect that what they will be looking at and saying is what more can be offered. I just use Courera as an example that many people know but there are many other services that provide classes online, so this will get accelerated through covid, these are things that are happening, these are ideas that we must come up with just now. Our own version in India we have adopted Arogyasethu, the bridge to health, it must be used for many more things, it cannot stop at just covid, here is an opportunity to use broadly for many other things, to use it for nutrition, to use it for chronic

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disease, this is an opportunity to expand and we should leap at that opportunity whether through Arogyasethu or through other ways.

Prof. Jayesh Bellare: You mentioned education. You and I are fellow IITians: we both attended IIT Bombay, and this event is in the IIT Alumni context; they are the sponsors of this webinar. The IIT residential milieu was a fantastic place and it continues to be. So what will happen to that? Will it suffer, thanks to remote teaching?

Mr. Parag Saxena: I think that maybe so till we come with a vaccine, speaking specifically of covid, and we should come up with faster solutions to newer situations, because our bad luck may be that covid comes back in a worse fashion; and good luck would be that it comes back in a better fashion, that it is a strain that we can handle because we had this strain and we do in fact have a herd immunity but the unlucky thing will be that yes the residential thing may be lost. Jayesh, you are an IITian like I am, in fact both of us from IIT Bombay, those wonderful years when I went, it was a five year programme, those wonderful five years that you spend there and the community that you come with are of course both the most wonderful parts of your life but besides that they are also an incredible piece of learning. We don't just discuss what happened in the Physics class that day or the Applied Mechanics class that day. We also discuss the Sartre book that we read or whether we believe in Karl Marx on what are the failings of capitalism or whether the Rubaiyat of Omar Khayyam is something that we should read or not and that milieu as you say must not be lost. We must find a way to do that. One of the great books I read, many of you may have read it, Sapiens, the brilliant idea that he came up with was that homo-Sapiens is much successful even though as a percentage of brain to body mass, we are smaller than Neanderthal. Neanderthal brains actually bigger, but why did they not succeed, he said communication is what made us succeed and what we have is the communication, the staying together, living in dormitories together with each other and the learning from each other, the camaraderie from each other that is a crucial part of human being and people have understood that in many many different ways. That is why email was such a successful quick app, that is why Facebook is such a successful app. Going back to your question, we must find a way to restore; that does mean that our health care effort must be stronger in coming up with a vaccine that enables us to get together quickly, it must come up with several different drugs, no single drug works on everybody. Even the simplest of things aspirin, I need aspirin you need Tylenol, acetaminophen, instead of salicylic acid and that is not including the corner case of migraines.

Prof. Jayesh Bellare: Allow me to ask this question more pointedly, would you hazard a guess on the vaccine and the timeline for those?
Mr. Parag Saxena: I don't think that we can have a vaccine that can be broadly used on the population is safe and effective for at least one more year, so in my view any normalcy as we knew it in 2019 cannot return before 2022 as a full year. At some point in 2021 we may start to see that.

Prof. Jayesh Bellare: You have had the good fortune of advising governments, not just entrepreneurs and innovators, you have been advisor to governments in India, in the US. What is your recommendation under current situation for public policy and regulations?
Mr. Parag Saxena: There is a lot of things that we have gone into and I have actually put together with the team, as part of the team, we put together a large number, 47 different recommendations, but if I was to think of the two things that are the most important thinking about this from one that is common everywhere but something that I put particularly before Indian governments and I talked about this to both the Manmohan Singh government as well as I had a discussion with Prime Minister Modi about this is that one thing we need really badly is a bond market and I won't go too long into this but at the headline level, it is extremely important for efficient borrowing because it lowers the cost of interest to the borrower and it increases the rate of interest received by the lender for any level of risk. So at any given level of risk, if it is a high risk then high interest of course must be paid and must be earned by the lender. What this does is it gives us a system that we do not have efficiently, in India we have a very small bond market, this must grow a thousand fold, there have been

great steps taken recently because one crucial thing and this is a technical point but one crucial thing for a bond market to be successful, you must have good efficient bankruptcy proceedings. A lender must know that there is recourse if they lend. Then, Jayesh, you will take your money from something safe and lend it with something that is a little more risky because you are getting a higher rate of interest for it. That is what a bond market does, just as stock prices have different prices relative to their earnings depending upon the risk and the growth that they offer. Similarly, the bond market does that but it is an alternate one with huge availability. I have a long list of points, I won't go through them. The second point is about countries which need capital for investment, and there is no country that does not need capital for investment, should make it attractive for investors by eliminating taxes, which also eliminates any regulation related to them; the gains made by the draw of capital into the country will be far more. I don't know how many people on this call know that if you are not living in the US, I know some of you on the call on this webinar from the US, but if you are not a US person and you invest in the US, say you buy IBM stock tomorrow or Google stock tomorrow and sell it at a profit, what is the tax that you owe? Is it 10%, is it 50%, is it 0? The answer is 0, zero. The US government is not interested in taxing you, why? They are happy that you provided capital so that Google or that $0.10 stock could go public here. Alibaba could go public here, a Chinese company, that is why I say that it could go public here, you provided capital to a Chinese company through the US market, that will provide jobs, will provide liquidity and the taxes that arise from those jobs will exceed the tax that I can get from you, the investor. India needs this investment capital much more, so my biggest single recommendation other than to help the creation of a bull market is to simplify or eliminate taxes. I couldn't have more things I could speak on regulation but time is short.

Prof Jayesh Bellare: Let us go to one burning question. Amongst our audience are many talented entrepreneurs, many students who are embarking on their careers, some of them thinking of entrepreneurship, some of them faculty like me who are wondering about getting their innovations out there. So can you give us some suggestions on the key qualities and strengths, especially of fresh graduates and young entrepreneurs, to successfully convert their ideas from execution to impact and influence, both commercially as well as perhaps socially.

Mr. Parag Saxena: I think there are old adages we hear growing up, it is just that as you grow older you learn that more adages turn out to be true, so at age 20 we can't figure out why our parents aren't smarter at 50; various adages that our parents had and the advice they gave us was much smarter than anything we learned anywhere else, so the old adage of "focus" is one of the really important things: not to try to do too many things but if you find one things that does well, keep doing it, keep doing it, keep doing it so that if you really find a problem, that you have solved that problem. So our old adages I would say everyone knows the story of Dronacharya and Arjuna. He was giving the Archery class and first asked his students what each would see when he wanted him to shoot a bird and he said, well I see the sun, I see the branches, I see the clouds and so on, he goes student by student and when he comes to Arjuna, Arjuna said I see only the eye of the bird and Arjuna of course is the greatest archer because he had that focus. It is also important to know when you have conviction to recognize that when you have looked at the data, you have looked and you have seen a pattern. Pattern recognition is a crucial thing and there is a little bit of a gift in that in recognizing pattern recognition you can do it because you do it over and over again. You can do it because you have an instinct for it. I use a different adage for that, we also know the story of Lord Nelson, when he was asked to withdraw on his ship he took his blind eye and put in to the telescope and he said I see no order to withdraw and he charged on regardless. So sometimes there are times that you have to follow and pursue your instinct and go ahead with that but don't fool yourself, don't kid yourself that you should not look at the data, data is really important, it is really available inexpensively and in vast quantity today. So I would say to use that. I would say one more thing which I learned and I like to believe that I am the originator of this phrase in one version or another. Ideas are a dime a dozen, ... har ek ko idea hai, lekin karnevala ... . So execution is one in a million, we have lots of ideas and we all say I had that idea too but doing it is really tough and the step to execution is really something that separates most people because that is where you are dealing with the difficult steps that you are going through.

Prof. Jayesh Bellare: Well you mentioned conviction, so let me ask you here, I am sure there must have been a few occasions when you were convinced of a bet you were going to make, an investment you are going to make with a start-up and it didn't work out. So can you tell us about one or two of your best failures and what you learned from it.
Mr. Parag Saxena: I have had many many failures and luckily some of them were early in my career and so I learned a great deal from them. I will tell you one because it contradicts what I have just said. Very early in my career, I met a guy called Bob Swanson who was two years older than me and his experience was at Citicorp, also a banker, he left Citicorp to start a company. He started a company and he told me about his company and I said to myself this guy is two years older than me, he has got a biotechnology company and he is a banker. I would not give me, Parag, any money to start a biotech company why am I going to give this guy. He knows less than I know, I am at least a chemical engineer with the masters degree and I worked with Dickinson, so I don't fund this company. That guy was Bob Swanson who went on to create Genentech, the first creator of recombinant DNA product, human growth hormone then the creator of insulin and many many products till Herceptin recently. A company that has sales of tens of billions of dollars today. The lesson it taught me was the following. When an idea is new, when a field is new like biotechnology or google with its founders then what you need actually is a young person not burdened, not burdened by historical ideas, experience is actually a liability in such a case. That was a valuable lesson that I held with me and then now if I see a company which is another company in health care, where somebody is coming up with a digital health solution, if they are not using data, I know they are probably making a mistake but it is a completely different way of looking at something then I will say well may be they know something that I don't because I do not have the experience, I do not have the vision said that they have. The same thing is true often when there is gamification of things and people come up with the solution with gamification.

As a 65 year old I do not have the perspective of the 25 or 35 year old who knows how that is going to appeal to people differently and I look to the younger people on my team to advise me on something like that. So what I have learned is go to someone who knows more about that experience set than Parag, you do, and I think the lesson is that very often people are going to come up with things that you are not the right guy to judge but you probably know somebody that is the right person to help you with solving that problem, understanding that data.

Prof. Jayesh Bellare: Parag, your interests are very side, tennis to bridge to cricket to Shakespeare to astronomy and so on. Many activities occupy you, so some hints on time management, how do you break up your time, how does this feed your innovations.

Mr. Parag Saxena: If I had a regret and if there is a message which I had to give, and I did say this in Goa, where there was an IIT Bombay driven meet recently, and you know there were 1500 of us there and one thing I said to people is: really take care of your health, don't let that priority move out and you will regret later because there are things that you won't be able to do because you did not take care of wellness. One thing I will say: wellness is important, the second I will say is about the other interests in your life: don't neglect them because the reason to be successful at number one is to find a right balance, so I have always managed to maintain a little bit of stargazing, a little bit of astronomy and you know in our life times we have had tremendous joy to see theory after theory of Einstein being proved in practice has been a phenomenal thing for us and so it has been a wonderful thing to see, so you have got to give time for stuff. Never stop reading, not just things relevant to your work or your betterment but read things that are just fun, just fiction.

Prof. Jayesh Bellare: Can I ask you then what is the top of your reading list and how you actually read now: are you still a fan of paper or are you totally electronic.

Mr. Parag Saxena: Jayesh, again I am 65 year old so the hardbound book is still the way I go. I normally have 2-4 books with me at a time, one I am enjoying and I recommend highly, is one of William Dalrymple's books, who has done a phenomenal job of learning Urdu and Persian and telling us a great deal about our own history, one of the things that I regret is the education I had didn't tell me much about the Peshwa Kingdon and how vast it was and I would love to learn about that. In fact in the entertainment world I would love to put together a series of TV serials on stuff that happened in Indian history that I don't know. What was Ashoka's kingdom really like in the 3rd century BC because it spanned Afganisthan, Kalinga, Bengal down all the way to the southern border, all but five southern states today. I love to know more about that history, Dalrymple does a great job of that but the other things I am reading right now, I always keep nearby something in poetry, sometimes Shakespeare, right now for me I mentioned this the Rubaiyat of Omar Khayyam. I have taken up bridge again, covid has been a great helper in helping me play bridge and so a book called Lemon Salt which only will be interesting to people who are interested in bridge. By the way bridge is known to be the one thing that postpones Alzheimer's. So those of who are 50 or greater and now thinking about things like as I am or you should be thinking about that.

Prof. Jayesh Bellare: Great, thank you very much Parag for those thoughts, I have been interspersing some questions from the audience all along but there are a few in the Q&A box which I would like to ask. One of the questions asked is about global versus local, what is your investment advice, what is your investment profile with respect to global companies or meeting local demand.

Mr. Parag Saxena: I think people should always start companies that deal with local issues because you are going to be best equipped at dealing with local issues. When I look at a project that comes to me, every company is a project rather than a investment, I look at the experience set of person that is coming to me, is this something that they understand really well; that matters more than whether I understand it well, because they are always going to know more than I do and you are always going to know local issues better and then you can step out and do something globally. Look at very very successful companies, they always start something locally, whether it is Starbucks first starting in home Seattle or Amazon first starting with just books locally in a few locations and then expanding, now Amazon is a dominant competitor all over the world but to get that well, they first got it right in books then they got it right in their own country, then they got it right elsewhere. So always local first, solve the problem that you understand really well, make sure it truly is a paying point for a number of people and then expand it.

Prof. Jayesh Bellare: One last question, Parag, what you think is the next science breakthrough or the current science breakthrough that is going to lead into mass production of tomorrow.

Mr. Parag Saxena: I think the science breakthrough that we have already that should be developed is the dream of manufacturing one thing for one person, so Henry Ford's brilliance was that he got the idea of mass production and that idea that assembly line production has enabled costs to come down and many people have done that, but today the way we can with what computers do for us, we can make one thing so that the shirt that is made for Parag or the shoe that is made for Parag can be a sample of one, done extremely cheap and I think the opportunity and the science is completely there, is that we have the ability to do this one for one. Before we jump off that particular one, I am going to use that question to do one more thing if my slides are still visible, say that covid is actually just a canary and the scare that we have had from covid is a very small scare compared to the much bigger problem of climate change which we continue to ignore. Climate change is going to lead us to a problem and a situation much worse than what we have today and we are going to end up with a problem that we will not be able to solve just by sitting at home because hurricanes will be taking the roofs of our homes, what we have seen, we saw we had a cyclone in India recently, you ain't seen nothing yet.

Prof. Jayesh Bellare: Great, thank you so much Parag, we have several questions still pending in the Q&A box, but I am sorry the time format doesn't allow us to continue. So I sincerely thank you and I hand over now to Susheela.

Dr. Susheela Venkataraman: Thank you very much, it was an extremely interesting session. As I am sure everyone believes, 20 years ago y2k was a game changer and in many ways that was what shaped software industry and the Indians software services industry and what we heard from you today is that today 20 years later we are at another inflection point where you see this as an opportunity just as much as there are issues around it and you have given us a lot of insights today in terms of what kind of changes it is going to bring about, the opportunities for technology and how digital is going to be so dominant in our lives going forward, the kind of new things that are going to emerge and are going to get nudged because of the situation we are in. You talked about the fact that there are three situations that are needed in making big changes, the change in regulation, technology and consumer behaviour and then we went on to talk about a very wide range of subjects today, it has been a very interesting talk, you even talked about the fact that we are going to move from looking at diseases to focus on wellness and how traditionally Indian systems are going to have a role to play in all of that. It has been an extremely interesting talk and Jayesh I must thank you for having led us and through this whole discussion today by bringing out so many different aspects of Parag's career and life and interests and there was one big takeaway from today's session Parag, is that we need to look at ourselves holistically care about our health and ourselves and make sure that our interests are given just as much importance as a career and a work and everything. So with that thank you very much once again. I think this was absolutely an inspiring session, thanks to both you Parag and Jayesh to all of our viewers today, thank you for participating, we tried our best to answer questions, I am sure there are many more, we will see if we can bring Parag back another time. Once again both Parag and Jayesh, thank you.

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This Book would not have been possible without the help of so many friends of IITACB. Thank you all.

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