Draft Article *(Transcripted)*

Mega Science Projects: Relevance of and for India

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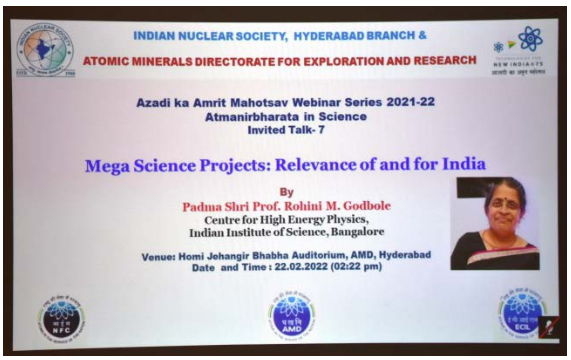
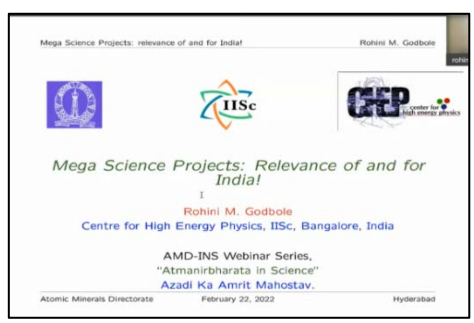


Introduction



Present day scientific research, in general can be classified into two broad classes, viz. (a) Basic research (curiosity driven) and (b) Applied Research (application driven). The later class involves applications to broaden available scientific knowledge to specific technological goals particularly in fields of defence, energy security, agriculture, environment, societal benefits etc. Expenditure incurred in such applied research projects are usually not questioned as they are linked to direct strategic or societal needs. In Indian context, there are a large number of such mega projects by Indian Space Research Organisation (ISRO), Department

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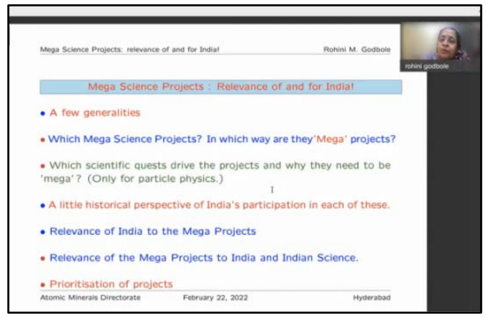
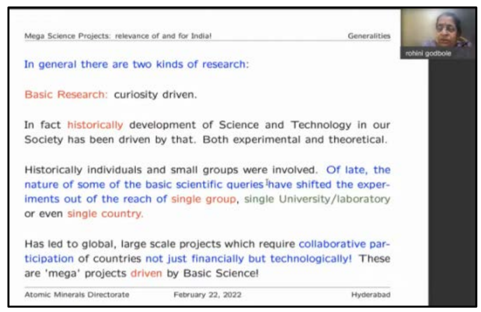
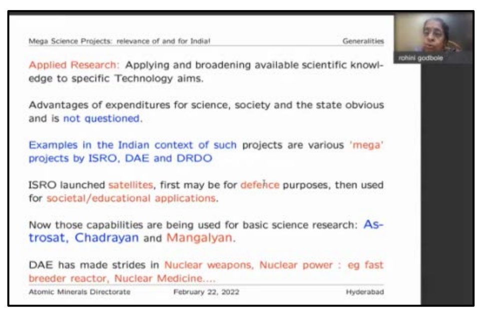
of Atomic Energy (DAE) and Defence Research and Development Organisation (DRDO) and we proud of the progresses made by them. ISRO launched satellites may be for defence purposes but they are subsequently also used for societal, educational and applications and now those capabilities are being used for basic science research such as *Astrosat*, *Chandrayan* and *Mangalyan*. DAE also has taken giant strides in nuclear power, weapons and technologies like fast breeder reactor other than material research, nuclear medicine and of course the projects related to artificial sun for fusion energy.



In contrast, the curiosity driven experimental or theoretical developments of Science & Technology in human society has actually been guided by basic research. Initially, few individuals or small groups were involved in such curiosity driven basic research but of late, the nature of some of the basic scientific queries demanded shifting of the experiments out of the reach of individuals, single laboratory, small groups, or even a single country.



This led to the launch of Mega Science Projects. Such projects, because of their technical complexities and requirement of large resources, state-of-the-art facilities, are manifestly multi-agency, multi-institutional and most often, involves international scientific cooperation. Mega-science projects are high-budget global experiments that involve thousands of scientists and make fundamental breakthroughs in science. These projects attempt to answer some of the most basic yet inexplicable questions of our universe, such as how the universe was born, what prompted the formation of stars and galaxies, and if there is life outside of earth. Indian science community is participating in many such projects like European Organisation for Nuclear Research (CERN)'s Large Hadron Collider (LHC); Facility for Antiproton and Ion Research (FAIR); India-based Neutrino Observatory (INO); International Thermonuclear Experimental Reactor (ITER); Laser Interferometer Gravitational-Wave Observatory' (LIGO); Thirty Meter Telescope (TMT) and Square Kilometre Array (SKA). This article discusses few of these Mega Science Projects with which India is associated, the scientific quests that drives these projects and their relevance to India and Indian science.



Indian participation in four major Global Mega Projects

The mega projects in which India is presently engaged or preparing to engage are designed to find answers to some curiosity questions related to basic sciences. Two such Mega projects, namely Large Hadron Collider (LHC) accelerator and indigenous Indian Neutrino Observatory

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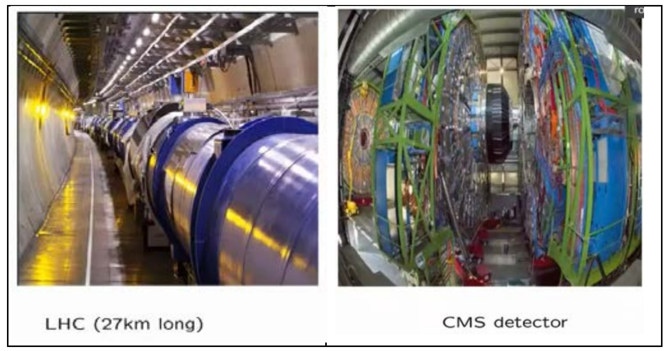
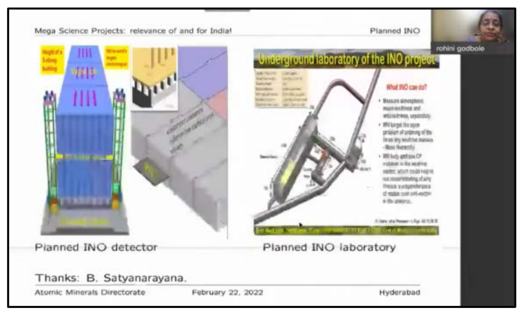
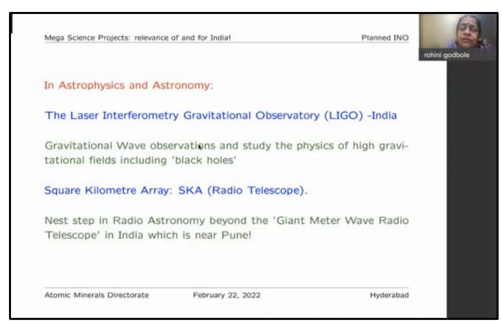
(INO) project, are based on particle physics where the high energy particle is actually the forefront of research. Besides, in Astrophysics and Astronomy, India is also embarking on the *Laser Interferometry Gravitational-wave Observatory (LIGO)* and *Square Kilometre Array (SKA, Radio Telescope)* in India.

European Organisation for Nuclear Research (CERN)'s LHC accelerator project is a fundamental physics experiment that enables sub-microscopic particles to collide at high speeds to explore the laws of nature which functions as the heart of matter. India has made some important contribution in the LHC tunnel and the LHC magnet. The Compact Muon Solenoid (CMS) detector is one of the experiments that happened in LHC. India has had some significant share in the construction of the gigantic sized CMS detector.



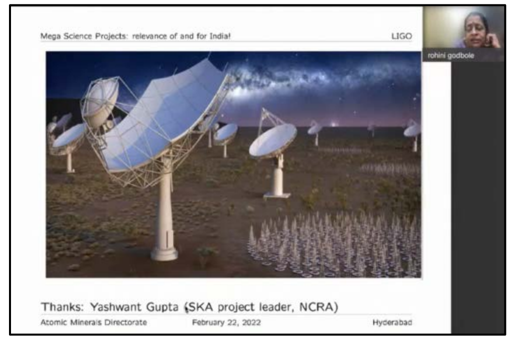
The INO, which is a home based and indigenous project that Indian physicists have thought about and are working on it very vigorously. The project is aimed at studying the properties and interactions of the elementary particle called neutrino, which are thought to have been the very first particles to escape from the Big Bang at high energies. Studying neutrinos can help better understand the astrophysical aspects of what happened in the very first moments of the Big Bang. The five floor building hosting the planned INO detector consists of multiple layers of low carbon iron sheets and in between these sheets there are the so called Resistive Plate Chambers (RPC) fast gaseous detectors which are indigenously designed and built in India. The underground laboratory of INO project will be in a 2-km long tunnel under a rock cover of about 1000 metres and is currently under construction in a cavern in mountainous terrain in Tamil Nadu. This is to isolate the lab from other types of cosmic rays, allowing highly sensitive detectors to study neutrinos.



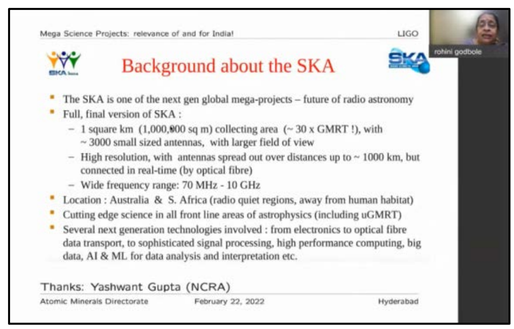


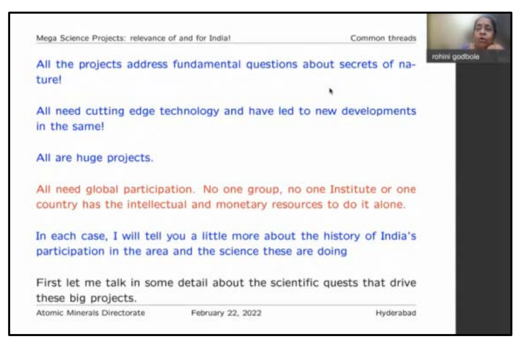
In the field of Astrophysics and Astronomy, India is also embarking on the *Laser Interferometry Gravitational-wave Observatory (LIGO)* for gravitational observations and study the physics of high gravitational fields including the one that of the 'black holes. LIGO observatories consist of two intersecting, perpendicular arms 4-km long each. At the intersection is a source of light that is split and travels through both arms. At either ends of the arms are mirrors that reflect the light back. When a gravitational wave hits the arms, space expands ever so slightly, throwing the light's wave out of whack. This disturbance can be observed and measured. Once a rough source area is located, telescopes operating on other wavelengths such as ultraviolet or infrared can then tune in and study the 'afterglow' of mergers. The more observatories are there, the better and quicker one can triangulate the location of the source event.

It is believed that about three minutes after the Big Bang, the universe began to cool, allowing protons and electrons to form neutral hydrogen. About 250 million years after the Big Bang, the first stars of the universe are likely to have formed, made mostly of lighter elements such as hydrogen and helium. This cosmological dawn before the star formation was dark and invisible, but was buzzing with radio signals. To see what happened when the first galaxies formed, the 13-nation led *Square Kilometre Array (SKA)* will probe radio signals from the past. This is next step in Radio Astronomy beyond the 'Giant Metrewave Radio Telescope (GMRT) radio telescope', in India which actually has been functioning for many decades near Pune, Maharashtra.



SKA is going to be mega version of this GMRT which is supposed to set up in Australia and South Africa because these are radio quiet regions away from human habitat and in fact it will take up a space with antennas spread out over a distance of about 1000 km. This is really huge area that will be covered but the whole point is that cutting edge science is really in the front line areas of physics where India has a lot of expertise. Several next generation cutting edge technologies viz. electronics to optical fibre data transport to sophisticated signal processing, high performance computing, and big data AI&ML for data analysis and interpretation etc. are involved, so Indian contributions in developing all these technologies will be of prime significance in the mega project.

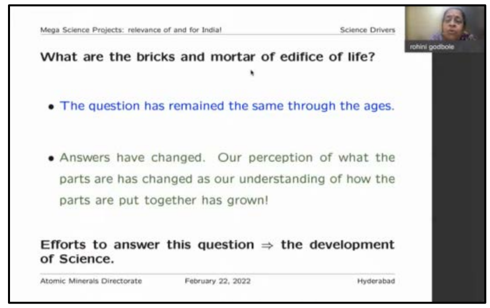




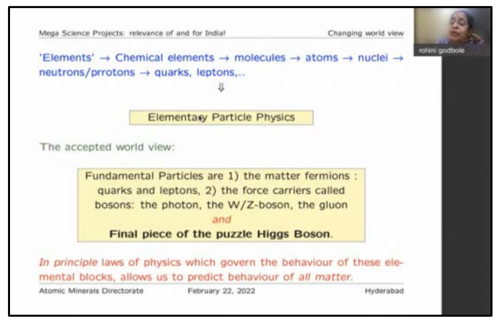
It is interesting to note that all these projects address the fundamental question related to the unknown secrets of nature. All these huge projects need global participation for development of the cutting edge technologies. No one group or institute or one country has the intellectual and monetary resources to do it alone.

What are the bricks and mortar of edifice of life?

This is the question that has been driving development of science in all centuries and the answers have been changing through times depending on our level of understanding and our perceptions. It started from the idea of the Greeks or the Indian sages who told about ‘Panchamahabutas’ to Mendaleev’s chemical elements and subsequently to molecules and then to atoms which we considered to be the fundamental particles. Further with the introduction and development of the concepts on nuclear physics, it was understood that even the nuclei is also not fundamental and there are the constituent neutrons and protons which are actually made up of quarks, leptons which as per the elementary particle physics are considered to be the fundamental objects of matter.

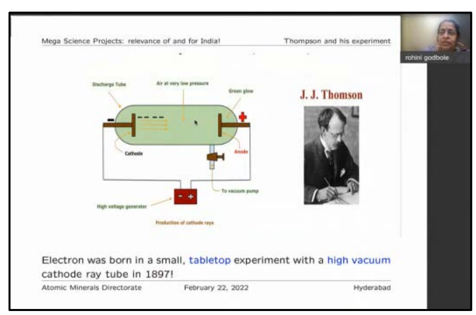


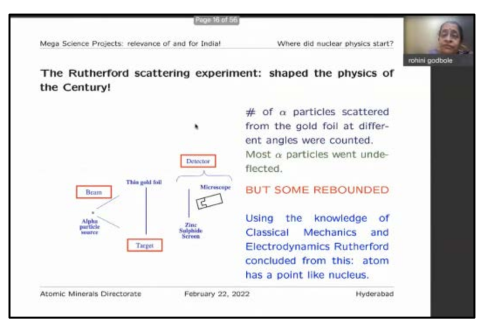
So, the fundamental objects are quarks and leptons, which are called matter fermions and they interact with each other through four fundamental forces and the force carriers are actually particles with integral spins namely, the *bosons* (spin quantum number is zero or an integer), *photon* (quantum of light/EM radiation), *W/Z-boson* (vector bosons), *gluon* (hypothetical massless subatomic particle), *Higgs Boson* (particle associated with the Higgs field) and the *graviton* (mediates the gravitation interaction). The laws of physics which govern the behaviour of these elemental blocks allow us to predict in principle, the behaviour of all matter in all conditions.



Changing concepts of particle physics

The story began in 1897 and the electron was born in a small table top experiment with a very high vacuum cathode ray tube in 1897. In a few years in 1911, Rutherford performed the scattering experiment, which shaped the physics of the century and helped in understanding the matter. In this simple experiment, alpha particles were made to scatter using gold foil and the scattered alpha particles arriving at different angles on zinc sulphide detector screen were observed to produce scintillation through a microscope in dark room. Using the then available knowledge of classic mechanics and electrodynamics, Rutherford concluded that atom actually has point like nucleus. So since 1911, nuclear and particle physicists have essentially done these scattering





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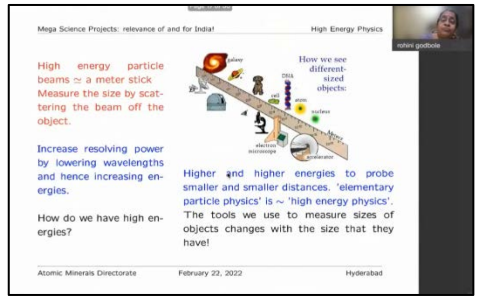
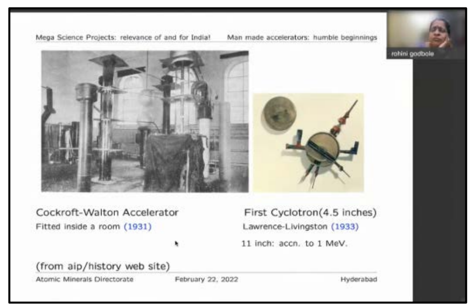
experiments where there is beam, target and a detector. By using higher energy particle beams one has actually been able to probe structure of matter at smaller and smaller distances.

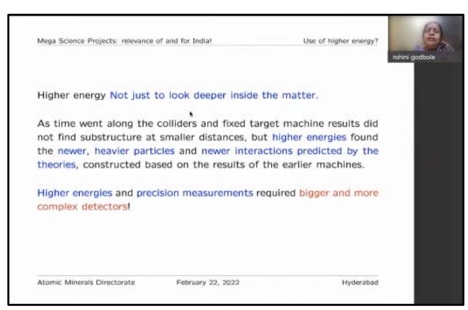
The scale of the object sizes and their distances decides the resolution required to view and analyse them. The meter stick **(Fig. 1)** represents how we see distances of objects of different sizes. To see galaxies the radio telescope are used, to see planetary objects, a telescope is good enough, to see dog or human being our eye has good resolution but to see a plant cell a higher resolution microscope is needed. Likewise, to see smaller objects of size of the order 10^{-8}, an electron microscope is needed but for viewing an atom of the order 10^{-10} m, a field electron microscope will be needed. For studying the sub atomic particles (10^{-16} to 10^{-18} m), the LHC accelerators serve as our microscope. So, the tools we use actually change with the object sizes and by increasing the energy or lowering the wavelengths, it is possible to increase the resolving power of the tools as this is how we have used the Giant Radio Telescope to accelerators like LHC, which actually looks at structure which is smaller than 10^{-16} m or even smaller 10^{-18} m.



The beginning was very humble. The first man made accelerator is Cockroft-Walton Accelerator which actually fitted inside a room, built in 1931. One version of Van de Graf generator is available in India for material science & nuclear science research in Delhi and Palatrons are available in Delhi and in DAE, Mumbai. By 1933, the First Cyclotron (small accelerator) was developed by Lawrence and Livingston, which was of 4.5 inches built and then another such Cyclotron of 11 inches size was developed which could accelerate particles to energy of 1 MeV. As life went on, accelerators needed to have more and more energy and they became much bigger. The Tevatron Van de Graf generator in Fermi National Laboratory, Chicago and the LHC tunnel with circumference of 27 km are the modern day accelerators for studying high energy particle physics.

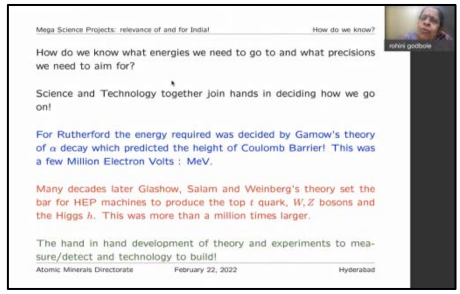


Need for bigger higher energy detectors



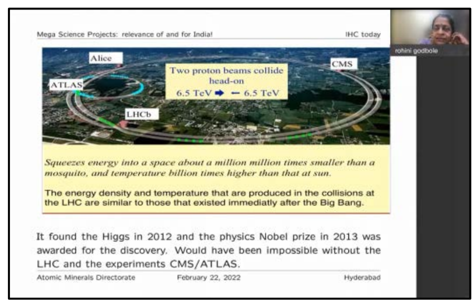
High energy accelerators are basically needed to look deep into the matter. But there is actually another aspect, as time went along, the colliders and fixed target machine results did not find any substructure at smaller distances, but higher energies actually found evidence for newer, heavier particles and newer interactions which were predicted by the theories. Accordingly, new devices were constructed based on the results of the earlier machines. So, these higher energies and precision measurements required bigger and more complex detectors like CMS detector.

Now the question is how do we know what energies we need to go to in these colliders and what precisions we need to aim for? This is where science & technology together join hands in deciding how we can go forward. For example, in case of Rutherford model, the high energy particle is required was actually decided by Gamow's theory of alpha decay, which said that the energy required to study nuclear processes needs to overcome the Coulomb Barrier and should be in the order of few Mev. This is the energy that the Cockroft-Walton or the Wilson small cyclotron accelerator produces.



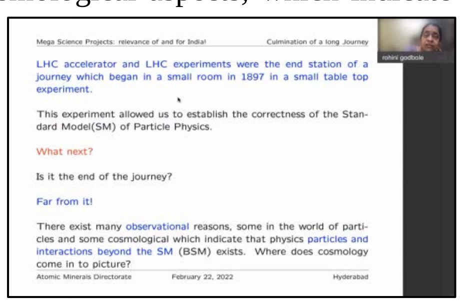
Few decades later, Glashow, Salam and Weinberg's theory set up the bar for higher energy physics (HEP) machines as they aimed to produce the top *t* quark *w*, *z* bosons and the Higgs *boson* so that their model could be tested and validated. The energy required for this was million times higher than the Mev, actually in Giga units.

The hand in hand development of theory and experiment continued and finally this journey has ended in LHC. It is the 'big ring', where India actually participated in building of the LHC accelerator. This colliding proton beams have 6.5 Tev. i.e 6,500 Gev (1 Gev =1000 Mev), which is six orders of magnitude from 1 Mev of Rutherford. This is the collider which has 6,500 Gev of protons hitting another beam of protons of 6,500 Gev and these beams actually intercepted at four points and one of the intersections was seen by the CMS detector and it found the Higgs Boson in 2012. Noble Prize in the field of Physics for 2013 was awarded for this discovery and this discovery would not have been possible without the LHC and the experiments CMS/ATLAS.

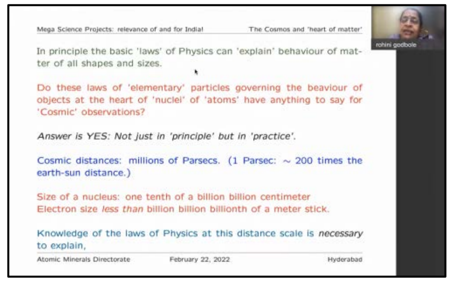


The gaps in understanding

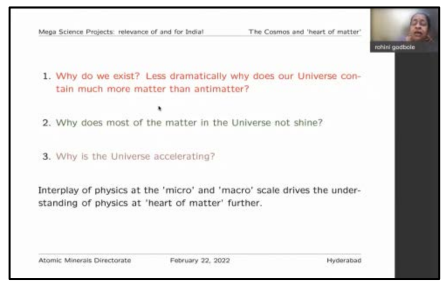
This LHC experiment has allowed establishing the correctness of standard model of particle physics but does it indicate that the journey is over? Fortunately not, as there are many observational reasons in the world of particles and some cosmological aspects, which indicate that there must be physics beyond the standard model, which means that particles and interactions beyond the standard model must exist. This is indirect indication from a lot of observed facts which is still un-explained.



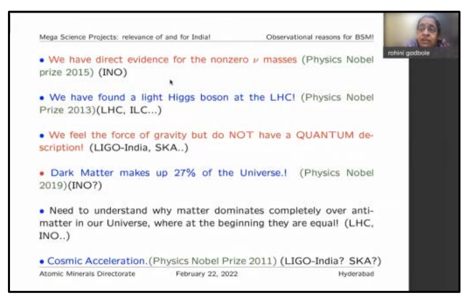
Now why does cosmology come into picture? The basic law of physics that we have studied in the last 100 years at the heart of matter can explain the behaviour of matter of all shapes and sizes. Now the next question was do these laws of elementary particles which govern the behaviour of object in the heart of matter have anything to say about the cosmic observations? And the answer is yes, not only in principle, but also in practice. Cosmic distances mean millions of parsecs (1 parsec = 200 times the Earth-Sun distance) and the size of nucleus, one tenth of a billion billion centimetre. The size of electron is not known yet, but we believe that electron ideally has no size and even if it has the size, it is less than billion billionth of a meter stick. The knowledge of the laws of physics at this distance scale is necessary to explain the physics that happens at distances of mega parsec or things that happened at the beginning of the universe.



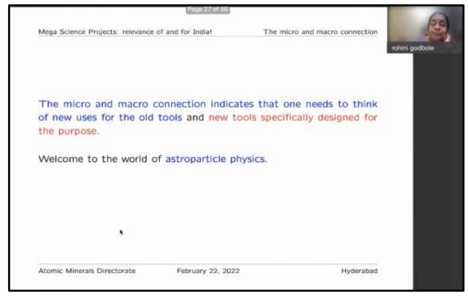
These knowledge of the laws of physics along with astrophysics and classical particle physics can help us to answer such questions like why do we exist? Why does the universe contain so much matter than antimatter? Why does most of the matter in the universe not shine? These are clearly not understood but, for sure there exists lot of matter in the universe, which we call the *dark matter* simply because it does not shine. Besides, there is clear evidence that the universe is accelerating but the source of acceleration is not understood. Our understanding of gravitational forces and laws of particle physics at the beginning of the universe are all extremely relevant in trying to get some understanding of the answers to these questions. So this interplay of the physics at the micro scale and the macro scale, which is actually the universe scale is now driving the understanding of particle physics.



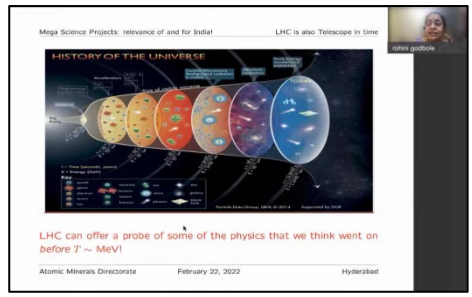
There are some observational reasons for going deep into the PSM (Physics Standard Model). One is that we have direct evidence for non-zero *v* masses for which Nobel Prize was awarded in 2015 and Indian Neutrino Observatory would be directly looking at this subject. We have *found a light Higgs boson at the LHC* and this was honoured by Physics Nobel prize in 2013 and both the LHC and International Linear collider (ILC) would actually be exploring the questions that are raised by the mass of the Higgs. We feel the force of gravity but the quantum description of the questions related to it are being investigated in the LIGO as well as in SKA. It is known that the dark matter makes up 27% of the universe and the related experiments were awarded with the Nobel Prize in 2019. Further experimentation is being done with INO and LHC for probing these matters. Some other experiments in the same line could directly explore and make India proud through significant experimental contributions to answer these very burning questions. We really do need to understand why matter dominates over anti-matter in our universe, where at the beginning



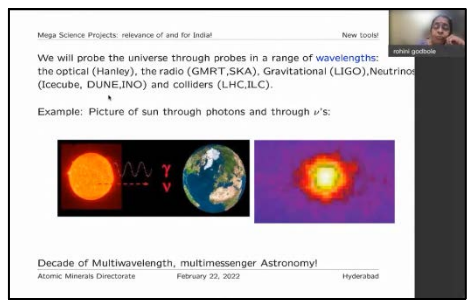
they are equal and both LHC and INO have possibilities of addressing some aspect of this question and then indeed the cosmic acceleration is something that both LIGO-India and SKA can explore. The Nobel Prize winning discoveries have answered lot of questions but also raised new questions, which might be answerable by the experiments performed in all these various mega projects.



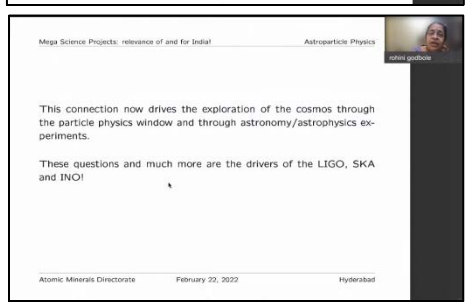
The micro and macro connection really indicates that we need to think of new users for the old tools and new tools which have been specifically designed for the purpose. This is the world of astroparticle physics and all the four mega projects under discussion are in this border line of general area of astroparticle physics.

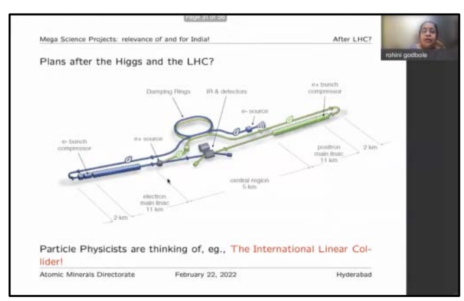


The LHC beam goes deep inside the structure to probe the matter and in fact it also serves as telescope in time because the discoveries of the LHC can also be used to actually probe what happened at the beginning of the universe. The universe is believed to have formed after 10^{-4} sec after the big bang and today 13.8 x 10^{-9} years after the big bang we are experimenting with the LHC to know more about what happened in this early universe. India is participating in the experiments to probe the period in the history of the universe. So, this is really the interplay between what happens at the heart of the matter and what happened at the beginning of the universe billions of years ago and what is happening today at the distances of millions of mega spaces.



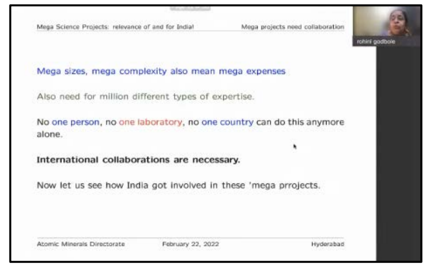
Scientists will now have the opportunity to probe the universe through a range of wavelengths through the optical telescope at Hanley, the Giant Metrewave Radio Telescope (GMRT), SKA, gravitational waves (LIGO), neutrinos (INO) and the colliders (LHC and ILC). So this is the decade of multi wavelength, multi messenger astronomy. A schematic representation of a photograph of the sun as taken by photons is shown **(Fig. 2)** in comparison to another photograph of sun taken by neutrino observatory. As the sun generates energy it also generates neutrinos and neutrinos get detected on the earth. Experiments with neutrinos provided us a lot of insight into the laws of particle physics and the physics of the neutrinos and these giant detectors are of great help in this decade of exploration. This connection actually drives the exploration of the cosmos through the





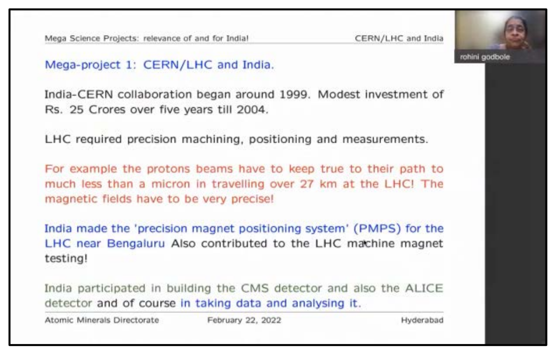
particle physics window as well as through astronomy and astrophysics experiments. There are plans after Higgs and LHC and particle physicists are thinking of what is called the International Linear Collider (ILC), which will be an electron particle collider and all are actually quite excited.

These mega science projects are not only mega in sizes, complexity and expense but also require multidisciplinary expertise. Therefore, no one person, laboratory or country can do this alone and international collaborations are absolutely essential. An account of review of India's participation in four of these mega projects is as follows:

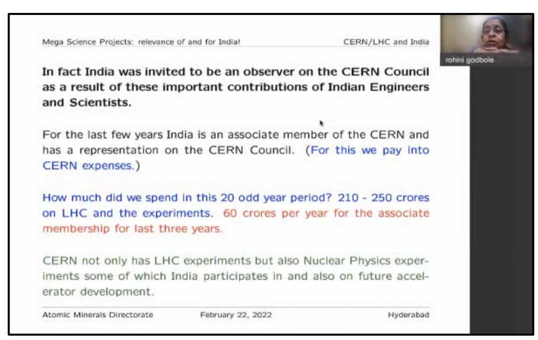


1. Mega-Project 1: CERN/LHC and India

India- CERN collaboration started in 1999 and was modest investment of Rs. 25 crores over five years till 2004. LHC requires precision machining, precision positioning and precision measurements. Precision is very important as the protons beams will have to keep true to their path to much less than a micron in travelling over distance of 27 km travelling at the velocity of light. So the magnetic field, which keeps the protons in their path, has to be very precise. India contributed in making the Precision Magnet Positioning System (PMPS) for the LHC at Bengaluru. Indian scientists and engineers from BARC have contributed to the LHC machine magnet testing. India participated in a big way in building the CMS detector as well as the A Large Ion Collider Experiment (ALICE) detector in taking the data and analysing it.

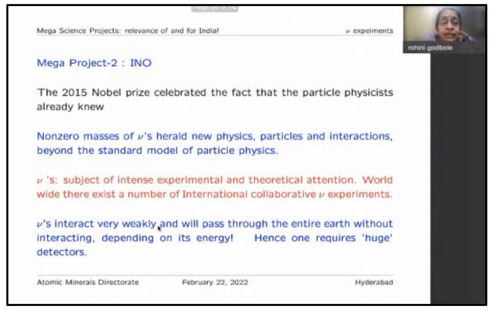


India was invited to be an observer on the CERN (European Council for Nuclear Research) council as a result of these important contributions of Indian Engineers and Scientists. Over the last few years India is an associate member of the CERN and has a representation on the CERN council. For this we pay into CERN expenses very small fraction. In this project, for over of 20 odd years period, India has spent about 210-250 crores for LHC and the experiments. Out of this, 60 crores per year has been for associate membership for the last three years. CERN not only has LHC experiments but also has Nuclear Physics experiments and some of them are in nuclear medicine, which is of interest to India. There is accelerator driven energy programme on how to create energy and how to build reactors where there is a good progress and India is also participating on future accelerator development and this part has been possible because India is an associate member.

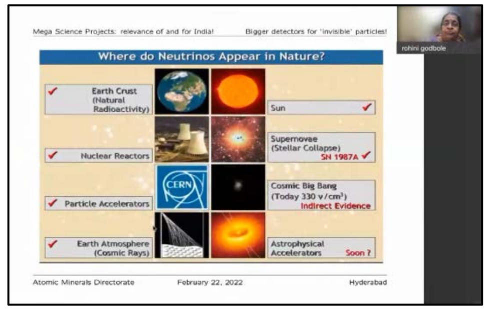


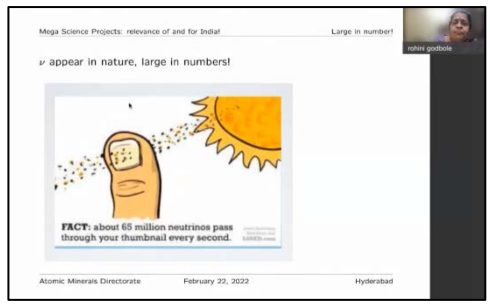
2. Mega Project-2: Indian-based Neutrino Observatory (INO-India)

The 2015 Nobel Prize celebrated the fact that neutrinos have masses but this is something that particle physicists already knew for 20 years. The non-zero mass of velocity (*v*) actually heralded new physics, particles and interactions beyond the standard model of particle physics. So neutrinos (*v*) is right now the subject of intense experimental and theoretical attention. Worldwide there exist a number of international collaborative neutrino related experiments. Neutrinos interact extremely weakly so they pass through the entire earth without interacting depending on their energy. Since neutrinos can pass through the entire earth with being detected, it really requires very big detectors.

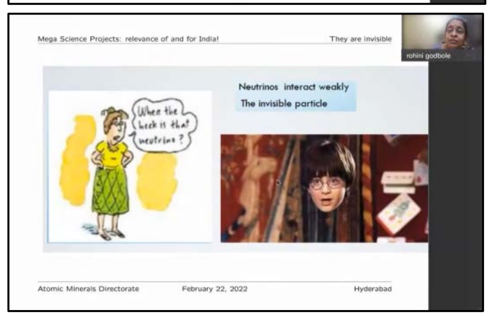


Neutrinos appear everywhere in nature. They come from sun, supernovae, cosmic big bang, in the blazers which are the astrophysical accelerators, earth's crust due to natural radioactivity, the nuclear reactors, particle accelerators and earth's atmosphere. INO will be engaging itself in experiments with neutrinos that come from cosmic rays. These neutrinos appear in nature in large numbers and the neutrino flux coming from the sun can be calculated to find out that about 65 million neutrinos pass through your thumbnail every second but they interact weakly and are invisible particles like 'Harry Potter' wearing the cloth of invisibility.

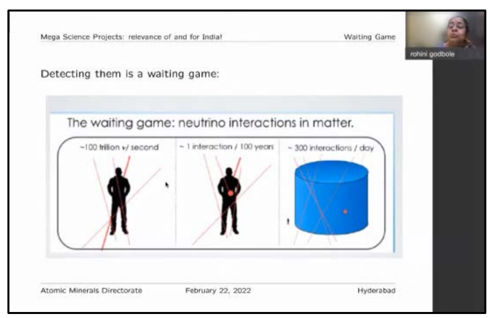




Detection of these neutrinos is a waiting game as out of about 100 trillion neutrinos hitting a human body sized detector, only 1 interaction is expected to be detected in ~100 years. So, detection of these neutrinos is only possible through huge detector which is much bigger than the human being. Such neutrino experimentation facilitates detection of about 300 interactions/day out of some 100 trillion interacting neutrinos.



India has been part of this waiting game long ago. One of the first detections of atmospheric neutrinos was in Kolar Gold Mine in India in 1965. This is the very first detection of atmospheric neutrinos. But many things happen other than neutrino interactions in these detectors and in fact at much bigger rates. To get rid of these interferences we need to go deep underground under the



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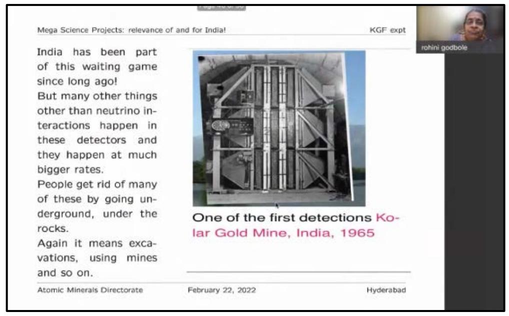
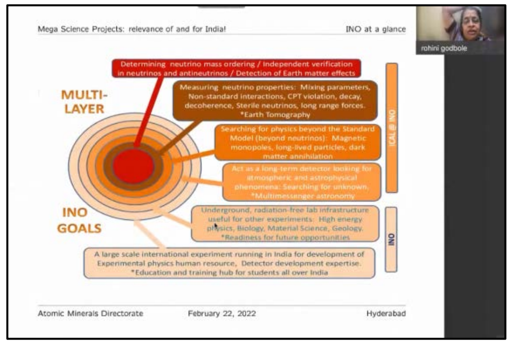
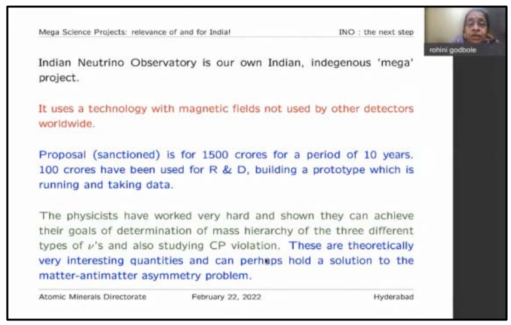
rocks in deep mines and so the detector was placed in deeper levels of Kolar mine as early as 1964.

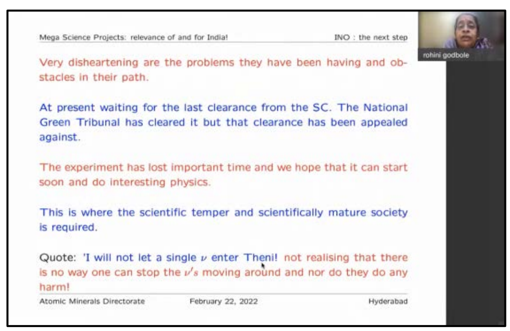


INO could actually have many goals in science and all these goals are multi messenger astronomy, underground radiation free lab which can be used for other experiments like dark matter detection experiments. This is the large scale international experiment in India which can actually develop experimental physics human resource, detector development expertise and it can be actually a particle physics education and training hub for students all over India. This is our own indigenous mega project, which uses technology with magnetic fields which other detectors have not used worldwide. So, we have an edge even now but the edge is fast disappearing because it was proposed 10 years back and granted sanction at that time but, out of the grant of 1,500 crores only 100 crores have been used for R&D and building a prototype, which is running and taking data in Madurai. The physicists have worked very hard by completing pilot experiments to demonstrate the determining quantities of the detector and shown that the desired goal of determination of mass hierarchy of the three different types of neutrinos and studying CP violation can be achieved. These are theoretically very interesting quantities and can perhaps hold a solution to the matter-antimatter asymmetry problem.



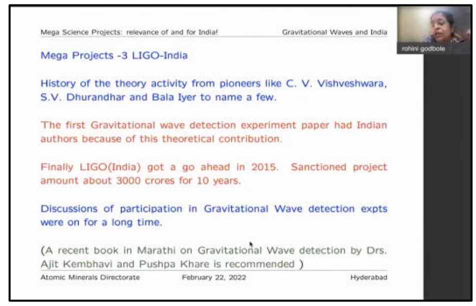


Unfortunately, it is very disheartening that the experimentalists are facing legal obstacles as presently they are waiting for the clearance from the Supreme Court after the National Green Tribunal had cleared the project four years back. The experiment has lost important time and we hope that it starts soon and does interesting physics. It is important to work towards developing scientific temper and scientifically mature society as this is required if we want this mega project to be a reality.

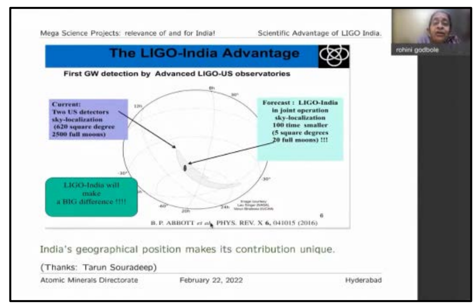


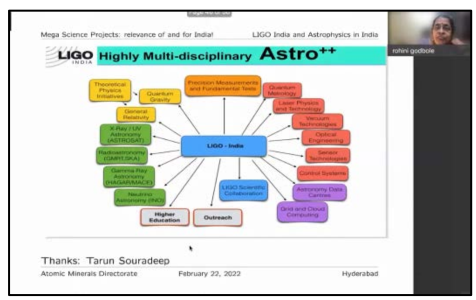
3. Mega Project-3: Laser Interferometry Gravitational-wave Observatory (LIGO-India)

The Laser Interferometer Gravitational-Wave Observatory (LIGO) - India is a planned advanced gravitational-wave observatory to be located in India as part of the worldwide network, whose concept proposal is now under active consideration in India and the USA. The history of theoretical activity of LIGO (India) started from pioneers theorists like C.V. Vishweshwara, S.V. Dhurandhar and Bala Iyer. The research paper on first gravitational wave detection experiment had Indian authors and this paper was quoted in the Nobel Prize. LIGO (India), a consortium of gravitational-wave physicists is planning to set up advanced experimental facilities for a multi-institutional observatory project in gravitational-wave astronomy to be located near Aundha Nagnath, Hingoli District, Maharashtra, India. The project has been given go ahead in 2015, and a sanction project amount is about Rs 3000 crore over a period of 10 years. There are lot of popular books on Gravitational Wave detection and a book in Marathi written by Dr. Ajit Kembhavi and Pushpa Khare, astrophysicists is recommended.



The LIGO (India) has a special advantage. The advanced LIGO observatory at USA actually detected gravitational waves and Nobel Prize was awarded for that. The USA based LIGO observatory has two detectors which can actually localize in the sky the region from where the regional waves came. But, if we had LIGO-India operative at that time, it would have been able to locate it in the small region as shown **(Fig. 3)** thereby increasing the capability of better localising the sources of gravitational waves in the sky. India's geographical position is actually what makes the contribution really unique. This is again a highly multi-disciplinary activity which is going to contribute to the development of theoretical physics, general relativity and in quantum gravity as well as neutrino astronomy (INO) in India. This project has lot of synergy with other Mega projects viz. GMRT, SKA with ASTROSAT and can help India grow in the front of cutting age technology.

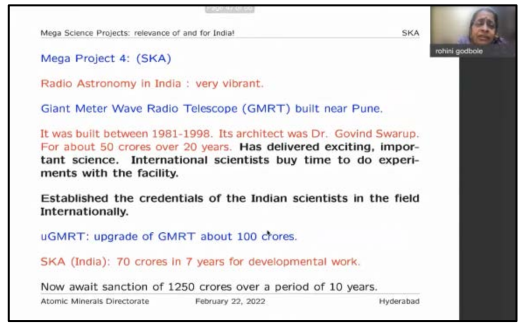




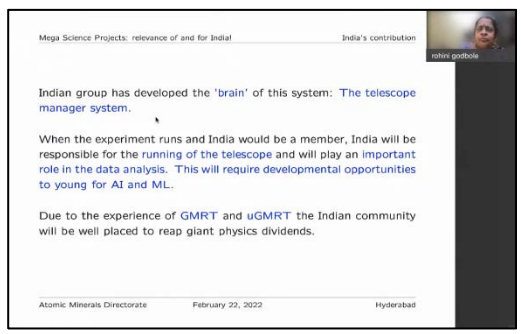
4. Mega Project 4: Square Kilometre Array (SKA)

The Square Kilometre Array (SKA) project is an international effort to build the world's largest radio telescope, with eventually over a square kilometre (one million square metres) of collecting area. The scale of the SKA represents a huge leap forward in both engineering and research & development towards building and delivering a unique instrument, with the detailed design and preparation now well under way. As one of the largest scientific endeavours in history, the SKA will bring together a wealth of the world's finest scientists, engineers and policy makers to bring the project to fruition. Whilst 14 member countries, including India are the cornerstone of the SKA, around 100 organisations across about 20 countries are participating in the design and development of the SKA. World leading scientists and engineers are working on a system which will require two supercomputers each 25% more powerful than the best supercomputer in the world in 2019, and network technology that will see data flow at a rate 100,000 times faster than the projected global average broadband speed in 2022. The SKA will be able to conduct transformational science, breaking new ground in astronomical observations. SKA scientists have focussed on various key science goals for the telescope, each of which will re-define our understanding of space.

The SKA mega project is actually just a next step the Giant Metrewave Radio Telescope (GMRT). Dr. Govindswaroop, a pioneer in radio astronomy in India, was behind the concept, design and installation of the GMRT built in 1981-1998 near Pune, Maharashtra. This was built for about Rs 50 crores over 20 years and delivered exciting and important science. International scientists right now buy time to do experiments with the same facility. It has also established credentials of the Indian scientists in the field. The facility presently requires upgrade costing about 100 crores. GMRT has been path finder for SKA (India) project and so far India has spent about Rs 70 crores in 7 years for developmental work related to SKA. Besides, sanction of additional Rs 1000 crores which will be spread over period of 10 years, is now awaited.

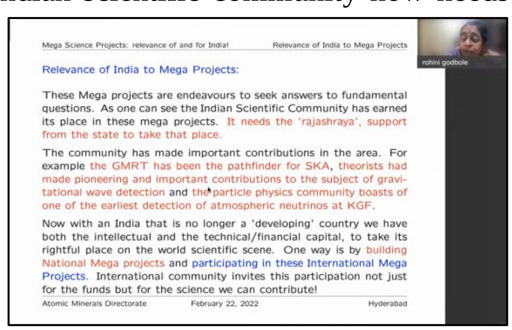


As regards the Indian contribution in this mega project, Indian groups are actually helping develop the brain of this project, the telescope management system and guiding data collection from different antennae and put them together in real-time. When the experiment runs, India would be a member and shall be responsible for running of the telescope and will be playing a very important role in data analysis. This means developmental opportunities for the young for AI and Machine Learning and so on and so forth. Due to our experience of GMRT and upgraded GMRT, the Indian community will be well placed to reap all giant physics dividends out of this.



Relevance of India to the Mega Projects

Indian physicists have a pedigree and have experience to contribute to these mega projects in the endeavour to seek answers to fundamental questions. Indian scientific community now needs 'rajashraya' support from the State to take that rightful place in these international mega projects. The community has made an important contribution in the area. GMRT has been the pathfinder for SKA, theorists had made pioneering contributions to the subject of gravitational wave detection and the particle physics community boasts of one of the earliest detection of atmospheric neutrinos at the Kolar Gold Field (KGF). Neutrinos physicists are keen on building mega physics facility in India where outsiders can



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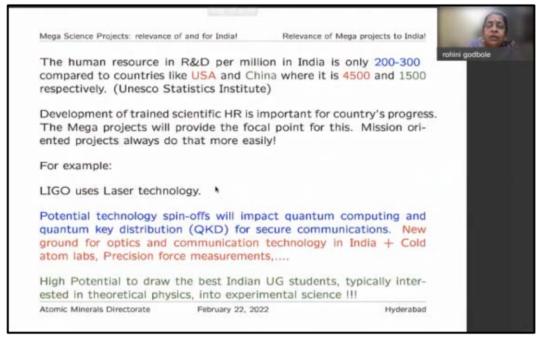
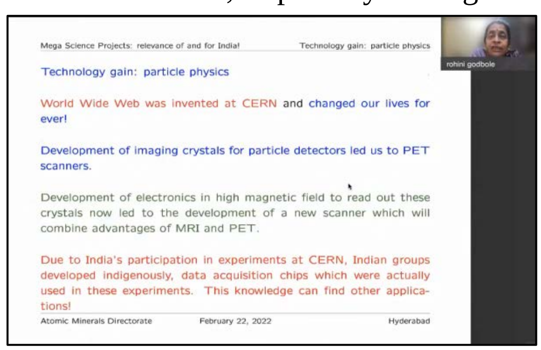
come to reap advantages of this facility. India is no longer a developing country as we have both the intellectual, technical and financial capital. India can take the right place after the 75 years of independence by building national mega projects like INO and participating in the international mega projects. The international community is now inviting our participation not just because of funds but for our capability and expertise in science and technology.

Unfortunately, there is small problem. The human resource (HR) in Research and Development (R&D) per million in India right now is only 200-300 which in USA is 4,500 per million and in China it is 1,500 per million (UNESCO Statistics Institute). The development of trained scientific HR is very important for country's progress. The mega projects actually provide the focal point for this development of human resource and mission oriented projects. Strategic organisations like DAE, DRDO, ISRO have contributed to focussed development of human resource. For example, LIGO uses laser technology and India has the potential to become a leader in this technology. The potential technology spin-offs will impact quantum computing and quantum key distribution for secure communications. Technology development in optics, communication, cold atom labs, precision force measurements, etc. is essential and will be useful and contribute to progress in pure science. These will also help to draw the Indian undergraduate students typically interested in theoretical physics into the experimental science because the questions that the experimental science is asking are very fundamental.



Technology gain through Mega Projects

Technology gains through Mega Projects are also very important. For example, the invention of World Wide Web (WWW) at CERN has changed our lives forever, especially during the pandemic during the last two years. It has been the lifeline for academics, enterprises and professionals. Development of imaging crystals for particle detectors led us to PET scanners. Likewise, development of electronics in high magnetic field to read out these crystals now led to the development of a new scanner which will combine advantages of MRI and PET. So, human health initiatives too got benefitted from such mega projects. Due to India's participation at CERN, Indian groups have developed indigenously data acquisition chips, which were actually used in these experiments. This knowledge can find other applications in other technological area in India.



Technology gains from esoteric basic science also needs mention in this context. General theory of relativity is essential for GPS. In response to a question by William Gladstone about *'utility of new-fangled blue sky research on electricity'*, Michael Faraday remarked- *'Sir, one day you will*

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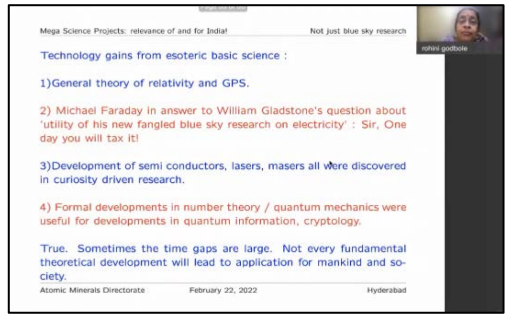
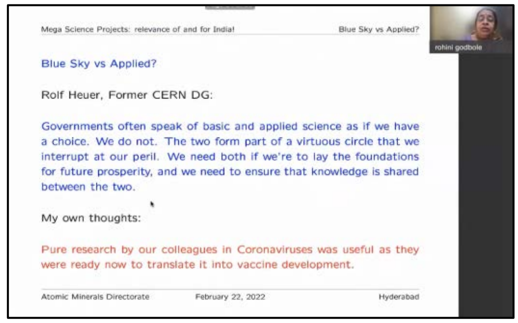
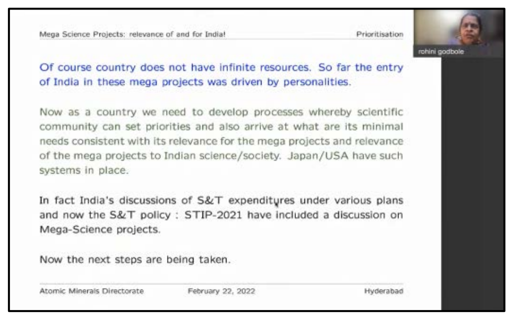
tax it'. Development of semiconductors and lasers are very important technology and were all discovered in curiosity driven research. Formal developments in number theory/quantum mechanics were useful for developments in quantum information and cryptology. It is true that in most cases the time gap between basic science development and their technological applications are very large and not every fundamental theoretical development leads to application for mankind and society, but since the potential is always there, one needs to be patient.



Conclusion

It is a common debate whether to focus on Blue Sky research or on applied research. The Former CERN, DG once remarked that governments often speak of whether to support R&D on basic science or applied science, but the fact remains that we do not have a choice. Basic and applied science form part of a virtuous circle that we interrupt at our peril. Focus and investment on both is essential to lay the foundations for future prosperity. We need to ensure that knowledge is shared between basic and applied sciences. In this regard it is worth citing that the basic research on the corona virus (SARS-CoV-2) structure, virology, replication diagnosis/testing etc. was extremely useful as they got translated into vaccine development within a short time of few months. India's participation in mega projects at home and abroad is critical for our 'Atmanirbharta' and national prosperity.





Of course our country does not have infinite resources and so far in India entry to all the mega projects has been driven by visionary scientists and personalities. It is high time now that system and policies are set right so that the community can make a decision, set priorities and arrive at what are the minimal needs consistent with India's relevance for the mega projects and relevance to the mega projects to Indian science and society. Such systems are in place in developed countries like Japan, USA and several other European countries. In fact India's discussions on budget for the S&T expenditure under various plans and the S&T policy (STIP- 2021) have included discussion on Mega-Science projects in the same way and steps are taken in the right

directions. The future of basic research in India appears bright, but we have a long way to go with high hopes and focussed goals to reach the end of these projects.

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About the speaker

Padma Shri Prof. Ms. Rohini Godbole was born in 1952 in a small town close to Pune, Maharashtra. Prof. Ms. Godbole obtained her bachelor's degree in physics, mathematics and statistics from Sir Parshurambhau College, University of Pune, and subsequently did M.Sc. from the IIT, Mumbai, and PhD in 1979 in theoretical particle physics from the State University of New York at Stony Brook. She joined Tata Institute of Fundamental Research, Mumbai as a visiting fellow in 1979 and then she was Lecturer and Reader at the Department of Physics, University of Bombay from 1982 to 1995. She later joined the Centre for High Energy Physics, Indian Institute of Science, Bengaluru in 1995 and since then, she is continuing at IISc, Bengaluru post her superannuation in July 2021. She has authored more than 150 research papers; many of which have some of the largest citation indices in her area.

Apart from her work in academics, Prof. Ms. Godbole is also a much sought-after communicator of science, often delivering talks to young students, scholars and scientists on everything physics. She is also an avid supporter of women pursuing careers in science and technology, and along with Ram Ramaswamy, edited the book Lilavati's Daughters, a collection of biographical essays on women scientists from India. Prof. Godbole is part of the International Detector Advisory Group (IDAG) for the International Linear Collider in the European research lab, CERN. She is the Chair of the Panel for Women in Science initiative of the Indian Academy of Sciences.

Prof. Ms. Godbole is a proud recipient of India's Civilian Award Padma Shri for the year 2019, for her outstanding contributions in science and technology. She was awarded fellowship of National Academy of Sciences, India (NASI) in 2007 and fellowship of Academy of Sciences of the Developing World, TWAS in 2009. Besides, she was also conferred with Satyendranath Bose Medal of Indian National Science Academy in 2009, Ordre National du Mérite by the French government and honorary doctorate from IIT Kanpur in 2021. She is currently associated with Centre for High Energy Physics, Indian Institute of Science, Bangalore as an honorary professor.