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Science REPORTER

- ▶ India at CERN
- ▶ India-based Neutrino Observatory (INO)
- ▶ International Thermonuclear Experimental Reactor (ITER)
- ▶ Square Kilometer Array (SKA)
- ▶ Facility for Antiproton and Ion Research (FAIR)
- ▶ Thirty Meter Telescope (TMT)



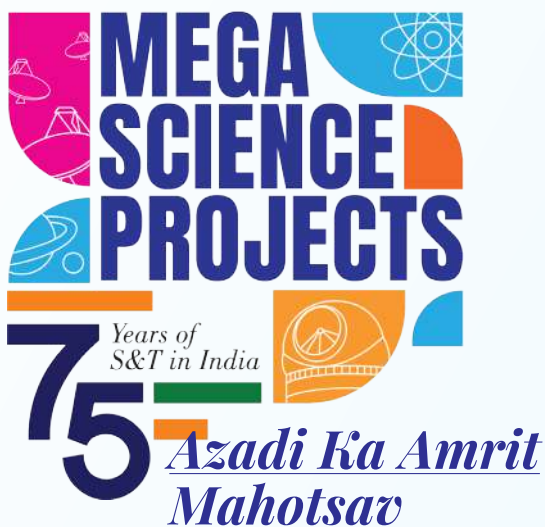
*Azadi Ka Amrit
Mahotsav*

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To ALL Winners!!!**

**The winning entries will be
published in *Science Reporter***





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THE AGE OF MEGA SCIENCE

DURING the past century, science has been increasingly becoming multi-disciplinary. And over the past decade, scientific endeavours have transformed into Mega Science projects. These projects seek to look deep into profound and intriguing questions that have been bothering humans or strive to provide solutions to some of the most complex problems that the world is grappling with. So, while some projects attempt to delve into fundamental questions such as how the universe was born, how the stars and galaxies were formed or if there is life outside of earth, there are also projects attempting to demonstrate alternate and feasible sources of clean energy.

Such projects are huge in terms of outlays and infrastructure that needs to be created and so manifestly become multi-institutional and multinational in nature, bringing the world scientific community together to work in a collaborative mode. The beauty of such Mega Science projects is that they not only empower and enable a deep-dive into confounding S&T problems, and make fundamental breakthroughs in science possible, they also spin-off technologies that find applications in several other walks of life.

The Government of India has been supporting participation of the Indian scientific community in several Mega Science projects appealing to the scientific curiosity of researchers. And so, after the Independence Day special issue of *Science Reporter* focusing on “75 Years of India’s S&T Journey”, once again in the series of *Azadi Ka Amrit Mahotsav* special issues that we have planned, *Science Reporter* brings to its readers another special issue, this time focusing on some of the Mega Science projects where India is an integral part. We are grateful that some of the experts at the helm of these projects acceded to our request to write about the projects.

And so, we have Dr Archana Sharma, Senior Scientist, CERN, Geneva, writing on India’s presence in various projects at CERN like ATLAS, LHC & ALICE and how India’s collaboration in the Compact Muon Solenoid programme also contributed to Peter Higgs and Francois Englert winning the Nobel Prize in 2013 for Physics.

Dr Vivek Datar, former Director of the India-based Neutrino Observatory (INO), along with Dr Indumathy and Dr Murthy of the Institute of Mathematical Sciences write about India’s effort in the worldwide hunt for neutrinos to understand issues of fundamental importance.

The International Thermonuclear Experimental Reactor (ITER) is slowly moving towards its goal of demonstrating the feasibility of controlled nuclear fusion as an alternate source of virtually limitless and clean energy. Dr Ujwal Baruah, Project Director of ITER-India, writes about the integral Indian participation in the project.

Dr Yashwant Gupta, Centre Director, National Centre for Radio Astrophysics, one of the participating institutes in the Square Kilometer Array (SKA) mega-project, tells us how this is an excellent opportunity for India to reap the benefits from next generation technologies and also enable Indian astronomers access to the best experimental radio astronomy facility of the future.

Dr Sibaji Raha, Former Director, Bose Institute & Raja Ramanna (DAE) Fellow, Indo-FAIR Co-ordination Centre talks about how Indian scientists and technologists have proved their mettle as expert collaborators in the international Facility for Antiproton and Ion Research (FAIR) project.

The Thirty Meter Telescope (TMT) project is looking for answers to some of the nuanced questions like, are we alone in the Universe and what would be the fate of the accelerating Universe, among others. Prof. B.E. Reddy, Programme Director, India-TMT along with Dr Ramya, Project Scientist, India-TMT Co-ordination Centre, tell us how the project will help Indian industry and science take a giant leap forward.

We do hope you enjoy reading this special issue.

Hasan Jawaid Khan

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It takes decades to build a once unfathomable machine like the LHC, and its experiments. India has been at the heart of it all. Mega Science projects and experiments like those at the LHC, HL-LHC and the future circular collider, among others, open avenues for other technologies and ideas to flourish.

THE CHARM OF MEGA SCIENCE *CERN & INDIA*

Dr Archana Sharma

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IT'S cold in Geneva. Hymns of the sanctimonious Large Hadron Collider (LHC) at CERN fill the air like white noise. Time churns again and particles are set in motion. They swirl like a subtle breeze, swallowing every ounce of energy that keeps them in motion.

There's a burning sensation around, not because something is on fire but because the excitement is filling the room and our skins can feel it. All eyes on screens, lip biting happens, someone starts clicking their wrists, staring begins. The gentle sound of experimental results appears. There are moments of palpable silence and then someone declares the opening of the abyss, the chasm in the heart of the world! This is a discovery! Of course, it's not as simple as it seems, it takes decades to build a once unfathomable machine like the LHC, and its experiments.

India has been at the heart of it all. In the sixties, India had an army of high energy physicists. It was also the decade of unprecedented scientific advancement in India. India was brimming with ideas. Most of these physicists were working at the Tata Institute of Fundamental Research (TIFR). It was, and still is, one of the most important centres of theoretical studies in Physics in the East. The first collaboration of CERN with India began in the sixties and has grown to be an extraordinary example of Mega Science Collaboration with a legacy of excellence.

The Nobel Prize in 2013 for Physics was given to Peter Higgs and Francois Englert "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider". The CMS India collaboration contributed to this discovery and has continued this excellent work over the last three decades.

Science, especially Physics, is enchanted by the recurrence of ideas. We continuously reevaluate and review our ideas and opinions. It's a spiritual process of some kind and every discovery comes as intermediary enlightenment. Lo and behold, and there is light!

It is perhaps of some value to admit that the obsession of humankind (mythology to modern physics) with light has not changed. It's the longest romantic relationship known to us. It has inspired us. Imagine a giant cosmic chest of drawers. Every age discovers one drawer and calls itself advanced. Well, we discovered more than ten but one must be modest. It's a gratifying thought.

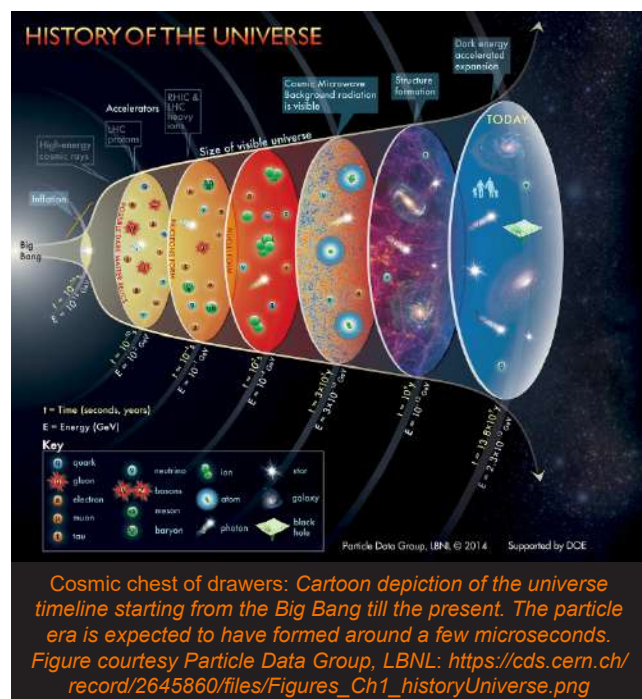
The universe begins at nothing. The word oblivion, which our peers in social science departments use to indicate unconsciousness or stupefaction, physicists around the world use this word to indicate the beginning, the moment of



India CMS Collaboration (Photo courtesy Prof. B. Choudhary)

creation. There is no agreement on the state of consciousness of the universe, we would like to think, if there's a conscious universe to which Roger Penrose would agree, the act of creation would have been a conscious decision. The befuddlement of these ideas is the pastime of lazy winter conferences of physicists and philosophers.

Since Roger Penrose was mentioned, thanks to him we know that the universe exploded from nothing. Something was created out of nothing. The speculation is that before this eruption, a minor glitch in maintaining quantum vacuum led to the creation of the first particle that expanded to maintain the action-reaction principle, and that led to everything else. Boom! You read that with a sound, didn't you? Everyone does.



All of us recount these memories of the universe several times every day. This is a physicist's day job and at the night we astound ourselves with the vastness of it. How can something this gigantic exist? Where does it exist? Why does it exist the way it does? How did it all begin?

Autumn is in her last days; followed by winter and then mud-soaked spring. The cycle goes on. It recurs several times in our lifespan. You must know of the story of a man who used to count his age in the number of springs he had witnessed. When asked how old he was, he replied, "I am seventy-eight springs beautiful." It's a romantic thought.

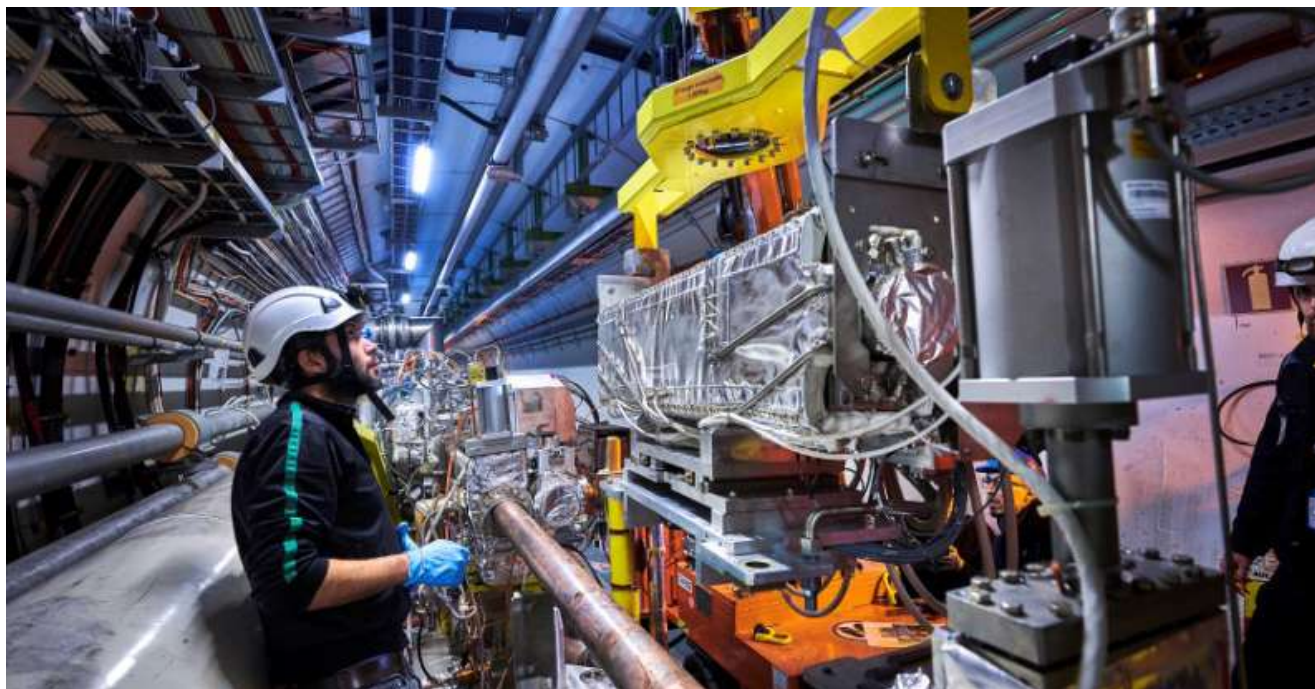
Two twentieth-century physical discoveries that changed the realm of physical reality were general relativity and quantum mechanics. We were awestruck for the first four decades of the twentieth century. In the fifties, we realized that particles can be of great help in understanding the microstructure of matter and then we discovered a dictionary worthy number of particles. One collision after another, one recurrence at a time, we started coming closer to the truth, the absolute truth (we are still far from knowing what it actually is, it sounds exciting when we say this), and then we discovered Higgs Boson! We now know what makes us heavier! You still have to exercise to lose weight; Higgs Boson can't be held accountable for the extra calories you eat.

It has been a century of ideas, maybe more than that when we started peeking into the intricacies of the material world. Our vision is somewhat of a hurdle in the path of our ambition to see everything. So, we invented new pairs of glasses, microscopes, telescopes, and several other instruments that had the capability to make us observe whatever we wanted to observe.

Physicists brazenly invented an oxymoron a few years ago. 'The largest microscope' or Large Hadron Collider is an instrument that helps us see, for the lack of better words, the microcosm elaborately. The LHC, as it is abbreviated, accelerates particles (such as protons, etc.) closer to the speed



The Large Hadron Collider and its four major experiments, clockwise from top left: ATLAS, CMS, LHCb and ALICE
<https://home.cern/science/accelerators/large-hadron-collider> <https://home.cern/science/experiments>



The High Luminosity LHC Project (<https://hilumilhc.web.cern.ch/>)

of light and then they are set on the path to collide. The rate of these collisions at LHC is about 40 million times per second!

These collisions produce billions of particles that are studied by extremely large experimental detectors that track them creating terabytes, petabytes of data. It would come as surprise but CERN has processed 99.9975% of all data produced from each collision. Computer scientists' hearts just skipped a beat. It's all right, take a breath.

This processing happens simultaneously actually. CERN's computing grid has a sophisticated code to decide which data to capture or discard that happens via constant vigilance through trigger systems that are designed to check every collision in the experiments. This cycle repeats itself when the experiments take data again.

As mentioned earlier, the realization that one could recreate the conditions of the beginning to study it in principle, led to the experimental setup of the LHC. The universe began as a hot soup of particles. It expanded to form structures, from atoms to stars were formed. Then it evolved to form large scale structures such as galaxies and superclusters. This expansion led to thermodynamic cooling and whatever we see right now is 13.8 billion years after everything began. So, the experimentalists are basically trying to traverse through time by creating that hot cosmic soup and then push the limit a bit backward in time. It's astonishing that the LHC can (and it has) reproduced that hot cosmic soup.

The thing about good food and good science is that we want more. The LHC will "run" (not run away) again in March 2022. That would be its third race and the stakes would be quite gigantic! We are expecting that the total number of collisions and rate will increase dramatically. This will be followed by the LHC's High-Luminosity era, which is scheduled to begin in 2027 and operate until the 2040s. This High-Luminosity era would be defined by increasing the luminosity of the machine (a measure of the focus of

the crossing beams of particles at the collision point) by ten times its design value. How very droll! It is only humorous to think of the abyss stepping out of nothingness (I laugh at it sometimes), standing in front of physicists and asking for a giant cheeseburger!

Setting up and running (not running away from) these experiments is also a humbling exercise. They also serve as an important opportunity to collaborate and learn from your peers. You would be interested in knowing that the experiments that help expand the sphere of human knowledge and scientific enterprise are also pinnacles of engineering innovation and industrial advancement. It was not long ago that the internet was invented at CERN to help physicists communicate and share data around the globe. The same thing you would use to find the right song or a poem for romantic purposes. Physicists did the same. They wanted to communicate the most heart-clenching moment of their life with their peers.

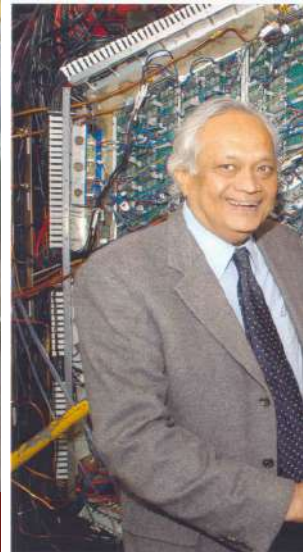
Physicists from India contributed to the making of several important experimental hardware such as the endcap hadron calorimeter and the development of the core software of the L3 experiment. The teams were involved in key physics research ideas at the CERN, such as the line-shape analysis, Higgs searches, quantum chromodynamics and b-quark physics.

Experts like Som Ganguly, Tariq Aziz and Sunanda Banerjee analyzed vast amounts of such information for electroweak interactions at the Large Electron-Positron Collider (LEP). The L3 results from the TIFR group contributed to precise W and Z measurements across all LEP experiments.

In the 1990s, The Raja Ramanna Centre for Advanced Technology (RRCAT) at Indore delivered hardware for LEP, and the Indian High-Energy Heavy Ion Physics Team contributed to the construction of the Photon Multiplicity Detector for the WA93 experiment at the CERN-SPS. In



Indian "corrector magnets" installed in LHC dipole magnets



Visit of Dr R. Chidambaram, Chairman, Atomic Energy Commission, India 4 October 1999



Honourable President Kalam visiting the SM18 magnet test facility at CERN and meeting with the Indian engineers from DAE (May 2005)

1991, an International Cooperation Agreement (ICA) between the Department of Atomic Energy (DAE) of the Government of India and CERN concerning the further development of scientific and technical cooperation in the research projects of CERN was signed. These developments paved the way for the Indian AEC's (Atomic Energy Commission) decision in 1996 to take part in the construction of the LHC and to contribute to the construction of the CMS and ALICE detectors.

In recognition of its contribution to the LHC construction, India was awarded the status of an Observer State in 2002. The success of the DAE-CERN partnership in the LHC has also led to a new cooperation on Novel Accelerator Technologies (NAT), which envisioned DAE's participation in CERN's Linac-4, SPL and CTF3 projects, as well as CERN's contribution to DAE's programs. India also contributes to the COMPASS, ISOLDE and nTOF experiments and operates two Tier-2 centers for the Worldwide LHC Computing Grid (WLCG).

Currently, India is a significant contributor to several experiments at CERN. Several Indian universities and institutes are members of one or two of the collaborative experiments. In addition to this participation, the Indian groups have also contributed in terms of design, development, fabrication and operation of several sub-detectors or detector components used in them. More than 150 Indian scientists

and students from India participate in various experiments at CERN.

From knowing the universe, to how to know the universe, and eventually what to do to keep up with the quest is a very long journey. It is uncharted territory. Hence collaboration is the only way to go for the future towards attaining sustainable development goals for our country.

India has made excellent progress by signing the Associate Membership at CERN on 22 November 2016 which consolidates the path for Indian collaboration at CERN, not only for the present generation of experiments and R&D but for the future projects that span decades. It is also an incredible opportunity for training our younger generation and create international leadership for the future.

MegaScience projects and experiments like those at the LHC, HL-LHC and the future circular collider (slated to start in 2040) among others, open avenues for other technologies and ideas to flourish. Let us talk about India. The Indian government led by Prime Minister Shri Narendra Modi has set a goal of making India a \$5 trillion economy by 2024-25. In addition to infrastructure, banking and agriculture, certain sectors have been prioritized to achieve the goal and drive employment opportunities.

Industries based on physics and mega science projects generate over 16 per cent of the total turnover in Europe,



Photon Multiplicity Detector (PMD) and Muon Spectrometer: Bikash Sinha Senior INSA Scientist (left) Team ALICE building the PMD (right)



Signing the associate membership for India on Nov 22 2016, DAE Mumbai, Fabiola Gianotti with DAE Chairman Sekhar Basu

surpassing contributions from financial services and retail sectors. Among all physics disciplines, High Energy Physics (HEP), given the gigantic scale, complex technology, and large-scale facilities, becomes a significant contributor.

Relevant state-of-the-art technologies were initially developed for fundamental research at institutions like CERN. It has happened time and again that technologies were improved and exclusive versions of techniques were made available for social use. There are several examples. The LHC Grid Computing involves algorithms that have numerous applications in banking, finance and weather forecasts. Data quenching technology built-in high-energy physics can be used in developing teaching aids as well as in safety monitoring. High Performance Embedded Computing (HPEC) systems can be used for several applications like the US Department of Homeland Security does in the aerospace and communications industry.

Sensors from High Energy Physics (HEP) have been used for 3D imaging of the body in medical diagnostics. Radiotherapy devices deliver cancer treatment by means of particle accelerators, also using positron emission tomography (PET) scanners that contain photon detectors based on crystals. The list is huge and this tells us that the road for India to utilize the mega science enterprise is to harness its existing academic and industrial expertise and combine it with the advanced experimental setups around the world. This would not be an unusual experiment. We have precedent. We

just need to take the plunge and move forward, and that is certainly the key learning of the pandemic too.

The medical sector has seen widespread adoption of developments in particle physics technologies. The more we can peer into how tiny particles zip around, the more we can utilize the same technology to peer into tiny processes in our bodies.

Over 1,500 positron emission tomography scanners have been built using crystal technology from HEP by GE healthcare at a cost of \$250,000-\$600,000 each, with which around 1.5 million PET scans are performed every year in the US.

The Medipix chip was developed as a side project for a tracking application in particle physics. Its potential quickly realized, the second generation of chip was licensed by the company PANalytical and is at the core of the PIXcel system, of which over 500 systems are currently being deployed worldwide. Low-dose high-precision 3D imaging applications for diagnosis using sensors developed in particle physics are in use. Proton and particle therapies are used in a large number of cancer treatment centres in the world, exploiting the IP from HEP.

Given the increasing incidence of cancer in India and the surrounding region, there is massive societal impact that can be delivered. This also forms the basis for a viable commercial model. A net benefit of approximately €1.6 billion has been projected in an equivalent European cancer treatment (accelerator-based) facility, over 10 years. Of course, for commercialization to take effect, a multi-disciplinary setting is needed where particle physics engages with other disciplines involving both academia and industry, and this must be enhanced and strengthened.

There is a need for international collaborations and networks and help to young people from our field, many of whom go into industry, to develop as entrepreneurs creating spin-offs and start-ups.

Industry is looking for talent from our community — let's help them find it. Medical, industrial and research applications of particle physics technologies are located at the nucleus for the spiral of development of a strong ecosystem that will deliver a benefit to India for decades to come, creating a vibrant particle physics community that will continue to grow, innovate and contribute to the economy.

Outreach and Education is extremely important in order to raise awareness about Mega science projects among the young talent in the country, to leverage training possibilities across the board in skill-building for the future for both academia and industry. The dream is to see the Indian flag flying high in all mega science projects, veritably at CERN!





INDIA-BASED NEUTRINO OBSERVATORY (INO) RESEARCH IN THE FRONTIERS OF HIGH ENERGY

Neutrinos are the second most abundant particles in the universe. But we know little about their fundamental attributes. A single experiment cannot probe all the properties of the neutrinos. It requires a complimentary worldwide effort to finally determine all the unknown parameters. The India-based Neutrino Observatory (INO) is an effort to join this worldwide hunt for neutrinos to understand issues of fundamental importance.

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Gold Fields in the 1950s. Starting at a depth of a few hundred metres, many points of observations were established at different depths ultimately reaching 2700 metres in the late 70s. Many important observations were made during its operation lasting four decades. An important discovery was the very first observation of neutrinos produced by cosmic ray interactions in earth's atmosphere in 1965 (Achar *et al.* 1965).

Proton decay experiments were mounted in the late seventies and early eighties; these detectors recorded some anomalous events, called Kolar events, which are yet to be understood. Unfortunately, the KGF underground laboratory had to be closed in the early nineties due to the closure of the mining operation itself. An opportunity to convert it into a national underground science laboratory was lost.

INO is a collective effort of many scientists working in many institutions in India to recover the pioneering spirit of KGF underground laboratories. The idea of creating an underground observatory in India was mooted during the Workshop on High Energy Physics Phenomenology (WHEPP) held in the Institute of Mathematical Sciences, Chennai in 2000. A working group report emphasised the need for such an observatory (WHEPP 2000). After many in-depth discussions, it was decided to pursue the goal of precision measurement of parameters related to neutrino properties, especially the masses, which are unknown even today. Thus began a totally indigenous R&D program carried out in more than

THE India-based Neutrino Observatory (INO) is an ambitious mega-science project which proposes to build an underground observatory for research in neutrino physics, in particular, and science in general. The project is jointly funded by the Department of Science and Technology and the Department of Atomic Energy with Tata Institute of Fundamental Research as the host Institute.

This underground observatory is to be known by the name Pottipuram Research Centre (PtRC). The main goal of the PtRC is to set up the observatory deep underground under a mountain near Pottipuram village in the Theni district in the state of Tamil Nadu. Just

as a telescope is set up in an area where there is less or no background light so that you can observe the sky clearly, neutrinos are best observed from underground labs; in fact, all neutrino labs around the world are located underground or under water/ice.

The INO project is the first of its kind since it is a completely indigenous project that involves significant interaction between scientific institutions and many industries small and big.

INO – The Beginnings

Many Indian scientists were pioneers in cosmic ray and neutrino physics. One of the earliest deep underground science laboratories was established in Kolar

20 institutions by nearly a hundred scientists.

One of the main goals is to build a large detector, an Iron Calorimeter (ICAL), to do cutting-edge research addressing the fundamental properties of neutrinos. When completed, the 51000-ton ICAL detector will be the largest magnetised detector in the world. While ICAL is built to explore the unknown properties of neutrinos and their antiparticles, the underground observatory offers space for experiments in other areas like material sciences, geology and biology where such clean background-free environment is useful.

The Ubiquitous Neutrinos

Neutrinos are the second most abundant particles in the universe (330 cm^{-3}) after the ubiquitous photons (440 cm^{-3}). They come in three types or flavours as they are commonly known, namely electron-neutrino, muon-neutrino and tau-neutrino. Each one of them is produced in association with the corresponding charged lepton and hence the prefix. The most abundant source of neutrinos on earth is the Sun in whose core the electron-neutrinos are produced in a series of fusion processes. In fact, the only direct proof of the mechanism of energy production in the Sun and other stellar objects comes from the detection of these neutrinos in the last fifty years.

Approximately about 70 billion electron neutrinos pass through every square centimetre of area on earth. In addition, neutrinos are produced in our own atmosphere when the cosmic rays from outer space, mainly protons, interact with atoms in the upper atmosphere. This interaction produces both electron and muon type neutrinos as also their antiparticles. Copious amounts of neutrinos are produced in a matter of few seconds when a supernova explosion occurs. While there are other natural sources of neutrinos, they are also produced in nuclear fission reactors and during beam-target interactions using an accelerator.

Despite their ubiquitous nature, we know little about their fundamental attributes. Both solar and atmospheric neutrino experiments [SuperK, SNO] have shown that the neutrinos exhibit a curious property called oscillations. Even though a neutrino is produced in a particular flavour state, electron neutrino as in the case of the Sun, part of the flux may be converted to other flavours during propagation. Such a property is possible if the flavour states are superpositions of mass eigenstates with slightly different masses.

Quantum mechanics tells us that the changes in phase during propagation are controlled by the energy and hence the mass. If there are distinct mass eigenstates, in the superposition, the mixing changes with time giving rise

to the phenomenon of oscillations. This also means that neutrinos must have non-zero masses. However, we do not know their masses, or even the mass ordering.

Furthermore, because they are electrically neutral fermions, neutrinos may in principle be their own antiparticles. If so, this opens a window to new physics beyond the standard model of particle physics. The main reason for lack of precise knowledge about neutrinos is their extremely weak interaction – the strength of the neutrino interaction is at least a trillion times smaller than the electromagnetic interactions, say of electrons. This makes detection of neutrinos extremely difficult.

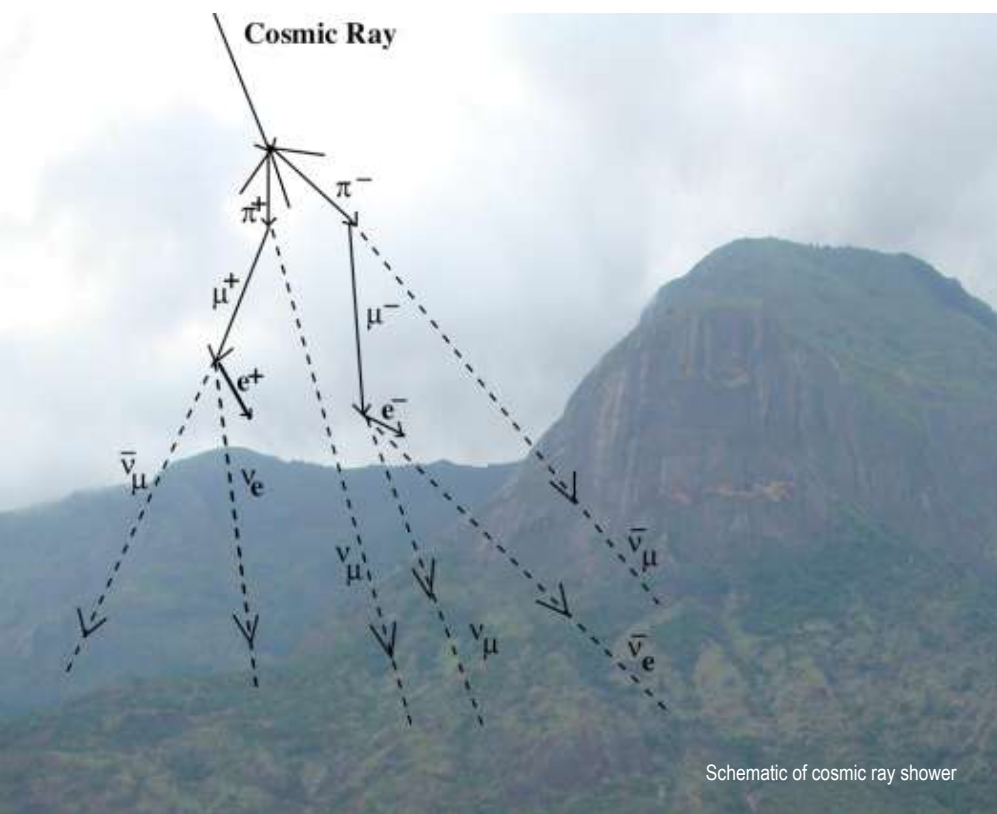
One way of overcoming these difficulties is to build detectors that are massive (increasing probability of interaction) and locate them deep underground to reduce the background to increase the signal-to-background ratio for neutrinos. Almost all the neutrino experiments are therefore located deep underground employing massive detectors. Even then, a single experiment cannot probe all the properties of the neutrinos. It requires a complimentary worldwide effort to finally determine all the unknown parameters.

The ICAL experiment at INO is an effort to join this worldwide hunt for neutrinos to understand issues of fundamental importance.

ICAL Detector at INO

The main detector at INO is the magnetised iron calorimeter detector (ICAL), which is designed to detect atmospheric muon-neutrinos. The detector consists of 151 layers of iron plates covering an area of $48\text{m} \times 16\text{m}$. There are three modules each covering an area of $16\text{m} \times 16\text{m}$. Copper coils are used to energize and magnetise the iron plates to produce the desired magnetic field of 1.5 Tesla in the central portion of the detector.

Between the layers of iron are housed the active detector elements called Resistive Plate Chambers covering almost the whole area. These RPCs are a sandwich of two sealed glass plates with gas flowing on the



Schematic of cosmic ray shower

inside. Whenever a charged particle passes through the RPC, it ionises the gas leaving behind its signature which is recorded in a digital form using suitable electronics. The total mass of the detector is about 51000 tons.

When a muon-neutrino (muon-antineutrino) produced in the atmosphere enters the detector, occasionally it will interact with the iron nucleus producing a negatively (positively) charged muon which leaves its signature in the form of a track created by an ionization trail in many layers of RPC detectors. Because the iron plates are magnetised, the track bends in opposite directions depending on the charge of the muon. Thus, the detector can measure the energy from the length of the track, momentum from the bending as well as the charge of the particle. Hence the name calorimeter.

Upgoing muons can be distinguished from down-going muons through the time sequence of events in the RPCs, which have the necessary nanosecond timing capability. The detector is most sensitive to muons since they are minimum ionising particles which leave longer tracks in the energy range of few hundred MeV to about 15 GeV or more.

ICAL is the only large detector which is capable of distinguishing events caused by neutrinos and

antineutrinos proposed at present. This allows a clean measurement of the mass ordering of neutrinos apart from precision measurement of many parameters associated with the property of neutrino oscillations. Previous experience shows that in any such large experiment, serendipitous discoveries cannot not be ruled out.

Research and Development

Building a large detector like ICAL requires serious R&D towards the development of all the components of the detector. This was carried out by the members of the collaboration spread over more than twenty institutions by nearly a hundred scientists and students. Starting from a 30cm-by-30cm RPC in the early 2000s, the R&D for the full

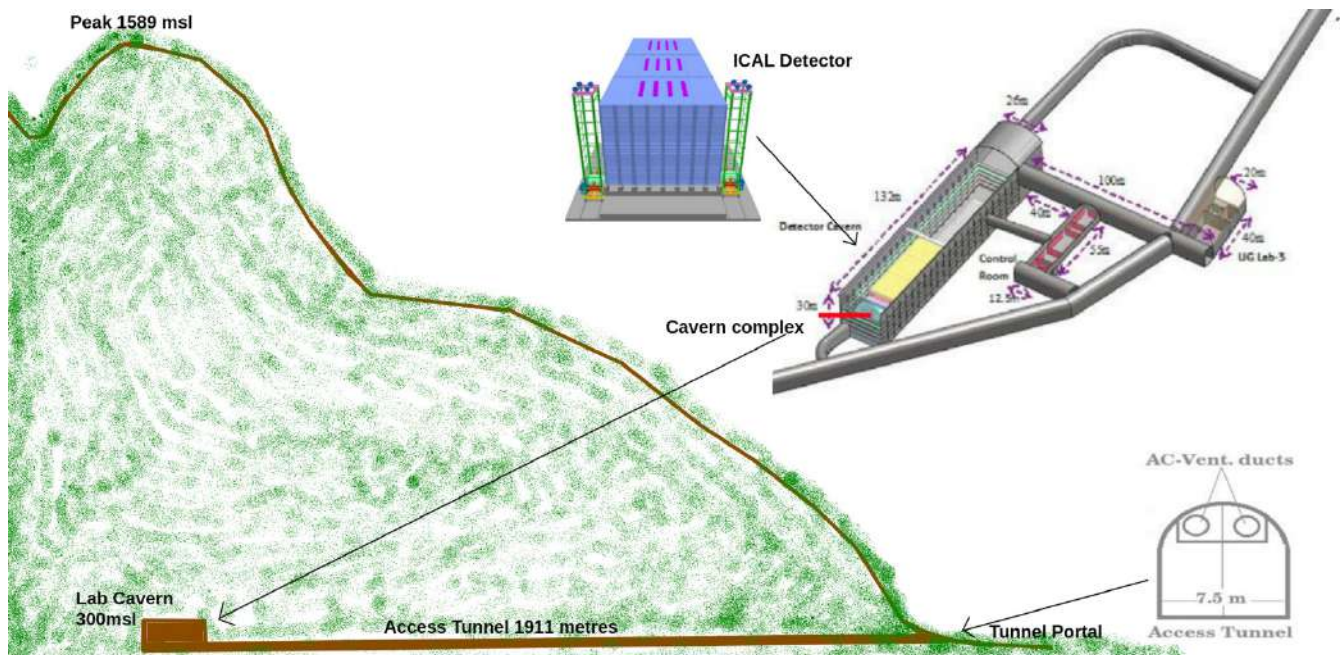
scale 2m by 2m RPCs are now complete including the development of glass type, gas systems and the electronics.

A small magnetised iron calorimeter was first tested at VECC in Kolkata. An 85-ton 1/200 scaled down version of the 17 kton ICAL module (of which there will be 3), mini-ICAL has been built and is operating at the transit campus of INO at Madurai.

A larger 700-ton ICAL prototype is being built at the Inter Institutional Center for HEP (IICHEP) in Madurai. This will be capable of testing all the components of ICAL like low carbon steel plates of the final size, the RPC loading trolley, about 320 RPCs, larger closed loop RPCs gas systems and the electronics and data acquisition system. This will also serve as a test bench for



Mini-ICAL detector at INO transit campus, Madurai



Schematic of mountain showing horizontal tunnel, its cross sectional view, caverns and ICAL



Participants in the 2019 collaboration meeting of the INO at TIFR, Mumbai

the 28,800 RPC detectors that will be required to populate the ICAL detector and will see a throughput of 320 per week over a period of 3-4 years!

Eventually, since the detector is so large, all the components will have to be manufactured in medium and large-scale industries. Already many industries are making the gas units as well as glass plates to the required specifications. The Indian industry has also shown interest in the manufacture of low carbon steel with a saturation magnetic field of 1.8 Tesla. The manufacture and testing will be streamlined in parallel to the construction schedule.

R&D is also in progress for two other proposals. The neutrino-less double beta decay experiment using ^{124}Te is being explored by the Tin-Tin collaboration spread over many institutions. This experiment is designed to test the nature of the neutrino – whether it is like any other lepton with a separate antiparticle or is it its own antiparticle – a question of fundamental importance.

Yet another proposal for which R&D is in progress is the search for the Dark Matter particles called Dark Matter at INO experiment (DINO). The group involved has already mounted a small-scale experiment testing the

detectors at a depth of 550m in the Jaduguda uranium mines.

Human Resource Training

Such a mega project requires human resources on a large scale. It is an on-going program in many IITs and Universities since 2000. A graduate training program (GTP) was started in 2008 specifically to train students skilled in doing experiments, simulations and phenomenological calculations. All the students were required to go through the course work involving all the three aspects. Till date about 30 students have graduated with Ph.D. from the Homi

Bhabha National Institute (HBNI), a deemed-to-be University of the DAE, and more than 15 students have graduated from IITs and Universities pursuing INO related studies. Many of these students are now doing post-doctoral research at leading institutions around the world. Some are already faculty members in leading institutions in India.

Location of the Observatory

The underground facility, known as the Pottipuram Research Centre (PrRC), will be located in the Bodi West Hills range of the Western Ghats in the



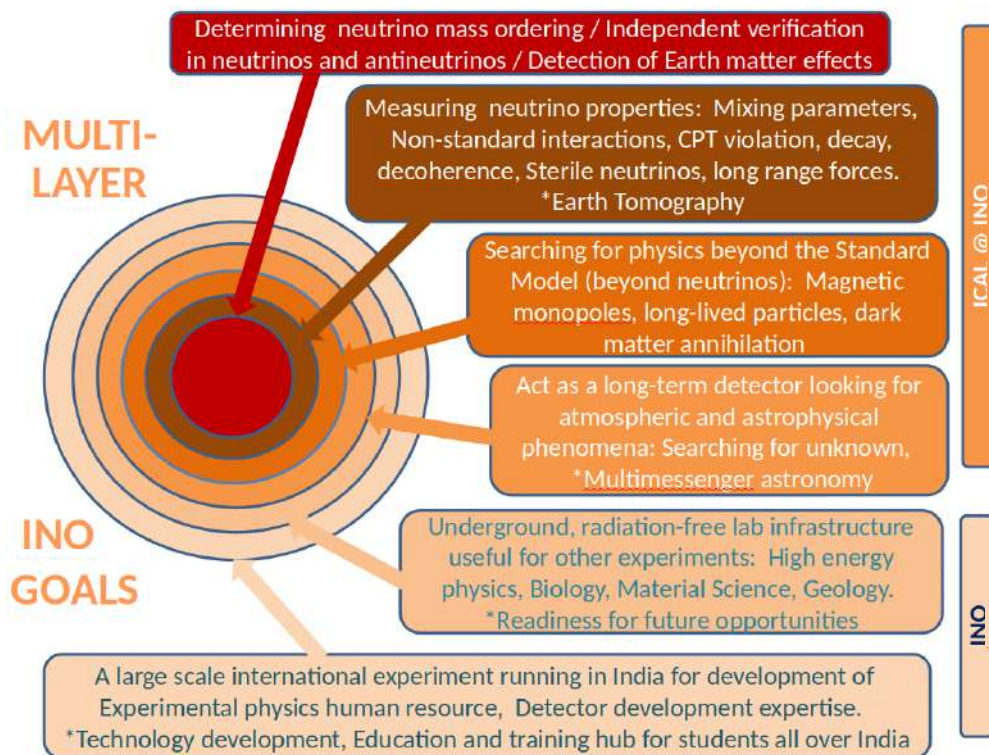
View of the INO mountain showing shrubs and lack of any tree

Pottipuram panchayat area in the Theni district of Tamil Nadu. The location was chosen after a detailed survey of more than ten possible sites following suggestions from the Forest Department, engineers of Tamil Nadu Electricity Board and the Geological Survey of India after consultations with ecologists. Apart from the physics requirement, factors like environment, ecology, rock quality for tunneling, availability of water/power and access played a role in the choice of the location.

The observatory will be located under the peak 1589 msl which is reached by a horizontal two-way tunnel of length 1910 meters (shortest among all the sites surveyed) and width 7.5 meters. The tunnel portal is located at the edge of a 66-acre revenue land which has been allotted by the government of Tamil Nadu free of cost for INO project. The tunnel begins in the revenue land and goes under the reserve forest until the observatory located at a vertical depth of 1289 metres below the peak. A large cavern of length 132 meters, 26 meters wide and 31 meters high will be carved to host the large ICAL detector. In fact, the dimensions are such that two such detectors may be mounted in future still leaving enough space for some smaller experiments.

Two small caverns are to be constructed to house other experiments like TinTin and the DINO and possibly other experiments requiring smaller space. The construction of the tunnel and cavern is expected to take about three years after which the first module of the detector will be assembled *in-situ*. It is expected that the data taking will begin about five years after the construction begins. The infrastructural aspects like water, power and access are being handled by various departments of the state government.

In addition to the underground observatory PtRC, the project envisages building an Inter-Institutional Centre for High Energy Physics (IICHEP) in Madurai devoted to the design and testing of all the components of the ICAL detector. While this is the initial goal, it is expected to grow into a dedicated centre for detector development and human resource



Pictorial representation of the goals of the INO project

training centre for many projects in HEP, Nuclear Physics, Astrophysics, etc. IICHEP is already functioning in Madurai from a transit campus. About 32 acres of land has already been purchased for the purpose from the Tamil Nadu government where the construction is about to begin for the Centre.

INO – Research in the Frontiers of High Energy

INO is a mega basic sciences project which aims to build one of the world's most massive, magnetised detector to do research in the frontiers of high energy physics. Any such large indigenous basic sciences project has immense technological implications which will serve the larger interests of the society in the long term. The detector R&D and the engineering infrastructure needed for the project has already generated an industrial interface. This will have a cascading benefit over time. As in any large scientific project, technology development goes hand-in-hand with the development of science.

The project is not in any way harmful to the people, land or environment in the Pottipuram area.

The scientists involved are conscious of being accountable to the public and propose to employ the best practices available. The scientific community has an obligation to carry out research in a safe and eco-sensitive manner.

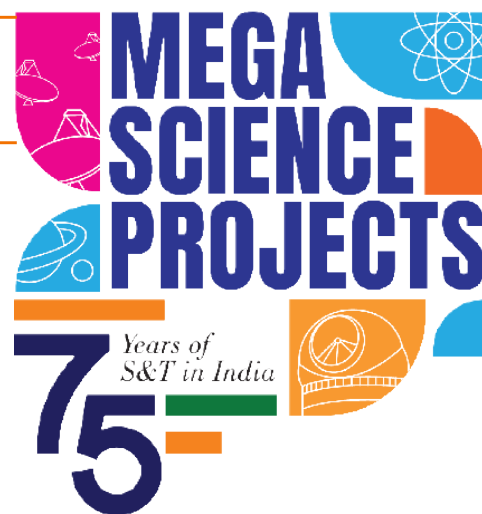
The underground observatory PtRC at Pottipuram along with the IICHEP in Madurai, will galvanise interest among students in science, and the scientific process, which is so critical to the nation now in its 75th year after independence. The future of science in the country demands setting up such indigenous mega-projects through which both science and technology development is possible along with local area development. This project can set an example for future mega-projects, being the first such efforts.

In the future, it may develop into an international facility as is common in such large scientific ventures. INO is enthusiastically supported by the International community as evidenced by the public statements of internationally acclaimed scientists including many Nobel Laureates in Neutrino Physics.



International Thermonuclear Experimental Reactor

Indian Participation in ITER



After almost a decade and a half of participation in ITER, ITER-India is slowly moving towards its goal of achieving self-reliance in the area of fusion-related S&T development. Successful and timely delivery of 4 out of the 9 committed systems to ITER has helped India stand tall and proud on an international platform.

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ITER, ‘the way’ in Latin, is one of the most ambitious, technologically complex mega-science projects in the world. The objective of the International Thermonuclear Experimental Reactor (ITER) is to demonstrate experimentally the feasibility of controlled nuclear fusion as an alternate source of virtually limitless and clean energy. Nuclear fusion is the process that has been powering our sun and stars since ages. If successful, it will lay the path for the world and India to address in a novel and noble way the ever-increasing energy demand for future generations.

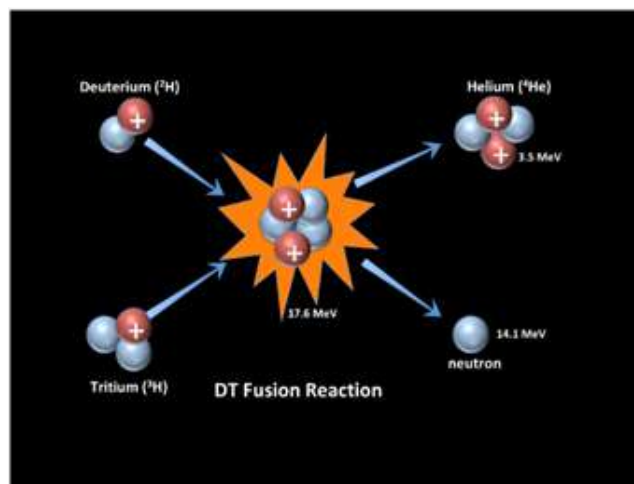


Figure 1: Schematic of D-T Fusion Reaction

When the nuclei of the two isotopes of Hydrogen, Deuterium (D) and Tritium (T), fast enough to overcome the Coulomb repulsion (both nuclei being positively charged), collide they fuse together to convert into a Helium nucleus and a neutron (Figure 1). The mass of the reactants slightly exceeds the combined mass of the products with the mass difference being released as energy following $\Delta E = \Delta mc^2$, the famous formula of Einstein. Each reaction produces 17.6 MeV of energy, 14.1 MeV of the neutron and 3.5 MeV of

the He-4 nucleus. The energy generated can be converted into heat and finally, electricity, see Figure 2.

Deuterium is available from seawater and Tritium can be generated within the reactor by blankets containing lithium salts. Barely a gram of gaseous fuel is within the reactor at any given time (e.g., the input and exhaust are approximately same at 30 milligrams/sec of D or T for a 1000 m³ reaction volume). The yield of the D-T fusion reactions is the highest and requires temperatures in excess of 100 million Kelvin. At such temperatures, the matter is fully ionized (and known as plasma, the 4th state of matter).

One of the most popular ways to demonstrate and establish nuclear fusion in the laboratory is by confining plasma in a very strong magnetic field produced in a donut shaped machine called the Tokamak. The history of Tokamaks dates to the 1950s with the design of the first device proposed by Andrei Sakharov and Igor Tamm. The first reports on plasma with a temperature of 11.6 million Kelvin came in from T-3 Tokamak, Moscow in 1968. Since then several machines like Joint European Torus (JET) in UK, 1973; Princeton Large Torus (PLT), 1975; the Tokamak Fusion Test Reactor (TFTR), Princeton USA, 1976; ADITYA in India, 1986; JT-60 in Japan, 1985; Tore Supra in France, 1988; ASDEX in Germany, 1991, and so on have been commissioned worldwide.

The first success related to demonstrating 11 MW of fusion power from DT reactions was reported from TFTR USA in 1993. In 1997 JET in the UK reported 16 MW of fusion power. ITER is the largest Tokamak to be built, using insights from all such experiments. New tokamaks, the KSTAR in South Korea (2008) and the EAST in China are contributing to the physics of high-temperature plasmas for long-pulse operation.



Figure 3: Site of ITER, world's largest scientific collaboration in France

The ITER Collaboration

The first step towards ITER was set in motion at the Geneva Superpower Summit in November 1985, when the idea of a collaborative international project to develop fusion energy for peaceful purposes was conceived. The collaboration expanded later to include seven members, viz., European Union, USA, Russia, Japan, China, Korea and India (Figure 3).

ITER is located at Saint-Paul-Lez-Durance, in the south of France. Industrial capability and Indian domestic effort in Fusion Research were the stepping stones for India being invited to join this prestigious scientific collaboration. EU, being the host contributes 45% of the project; all other members including India contribute 9.09% of the project. In-kind contribution from participating nations is a key feature of ITER whereby industries from all members have the opportunity to develop key technologies for future reactors.

All members shall have full access to the Intellectual Property generated from construction and operation of ITER. Indian participation in ITER gives us access to the gains of a Mega Science Project, as it would have been impossible for any one member to construct such a large and complex project on one's own.

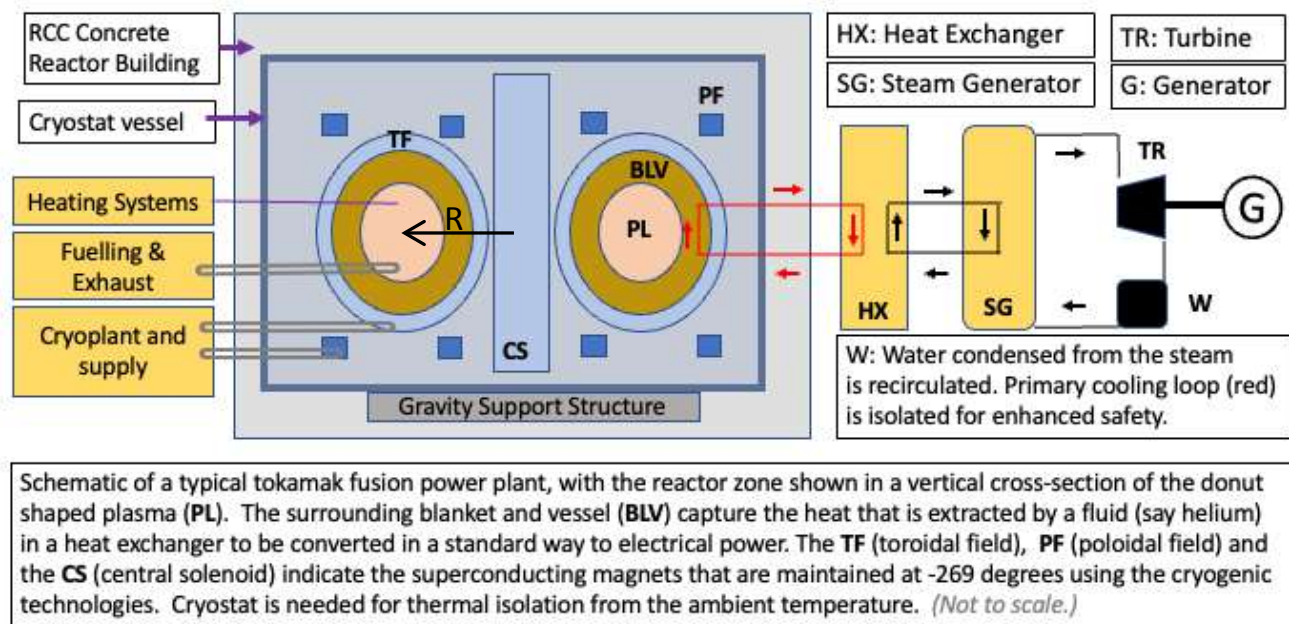


Figure 2: Schematic of a Tokamak Fusion Reactor Plant

Goals of ITER

ITER aims to build and demonstrate the following to lay the foundations for tokamak-based fusion power plants:

- To produce 500 MW of fusion power from 50 MW of input heating power $Q \geq 10$.
- To sustain fusion through internal heating, i.e., self-sustained reaction.
- To demonstrate the feasibility of producing tritium, as well as heat-extraction to mimic a real fusion power plant environment.
- To control the plasma and fusion reactions to establish the safety of a fusion device.
- To test technologies such as heating, control, diagnostics, cryogenics and remote maintenance to bridge the gap between today's smaller-scale experimental fusion device and fusion power plants of the future.

Tokamaks in India

India's quest with fusion dates back to the vision of Dr Homi J. Bhabha who, while presiding at the "Atom for Peace" conference in 1955 in IAEA, Geneva said, "*I venture to predict that a method will be found for liberating fusion energy in a controlled manner in the next two decades.*"

A firm roadmap of the Indian fusion research program was seeded by Dr Vikram Sarabhai in 1970 which got stronger recognition with the launch of the Plasma Physics Program at the Physical Research Laboratory (PRL), Ahmedabad in 1982. Under the leadership of its founder, Late Prof. P.K. Kaw, India's first Tokamak called ADITYA was commissioned in 1989 at the Institute for Plasma Research, Gandhinagar, Gujarat.

ADITYA (Figure 4) is a small tokamak producing about 0.4 m³ of Hydrogen plasma and has been extensively used to make significant contributions in understanding of plasma



Figure 4: ADITYA Tokamak at Institute for Plasma Research, Gandhinagar, Gujarat



Figure 5: SST-1 Tokamak at Institute for Plasma Research, Gandhinagar, Gujarat

behaviour in its over 30 years of operation. Generation of intermittent disruptions in plasma was first reported from experiments in ADITYA which is a major subject in fusion plasma experiments even today.

Parallel to experimental efforts and learnings on ADITYA, Indian domestic R&D moved forward to build its second tokamak using superconducting magnet coils to achieve steady-state condition with operational pulse length goal of 1000s and christened as Steady-state tokamak (SST-1). The building of SST-1 also provided a platform to address several technologies indigenously and develop the capability to design and build complex systems, e.g., large-sized superconducting magnets, high power radio-frequency heating system, large neutral beam injectors, cryogenic systems, complex power electronic converters, large vacuum systems, high heat load bearing divertors, R&D for handling high heat-flux, etc.

The Indian Vision

The two tokamaks, ADITYA and SST-1, are being used for innovative research. By joining ITER, Indian scientists and engineers have the opportunity to work and get trained on an actual fusion reactor as part of the international team and learn the physics and technologies to build our own reactors in future. In parallel, it is also important to ensure timely deliveries of in-kind contributions to ITER meeting all quality requirements. The in-kind equipments included several state-of-the-art or first of its kind technologies, many of which needed considerable development efforts.

In order to pursue the above vision a project named ITER-India was created within the Institute for Plasma Research with the following objectives:

- Deliver the systems and equipments that are Indian in-kind contribution to ITER, meeting required quality and standards of the International project.
- Conduct necessary R&D in areas, where necessary, for the in-kind deliveries.
- Work with Indian industry to complement their abilities for Indian deliveries.
- Interaction with academia and industry for developing the R&D in fusion relevant areas.
- Develop and maintain knowledge from ITER.

Table 1: Indian in-kind Contributions to ITER

Functionality	Key features	Present status
Package 1: The Cryostat		
Secondary nuclear boundary and a vacuum jacket around ITER's superconducting magnets and the whole Tokamak.	30 m tall, 30 m wide, world's largest ultra-high vacuum vessel made from stainless steel. Several segments, machined in India, assembled at ITER, special techniques developed for welding and inspection and meet tolerances.	100% manufacturing and delivery of all segments (M/s L&T Hazira), last shipment left Indian shores in November 2020. Cryostat base section of 1250 ton is the first component installed.
Package-2: In-Wall Shielding		
Shielding from neutrons and other radiation to the outside of Tokamak	Assembly of 8000 blocks consisting of 72000 plates of various shapes, sizes and tolerances made of Borated Steel.	100% delivery of shield blocks completed from the works of M/s Avasaralla technologies Bangalore and M/s L&T, Hazira.
Package 3: Cryogenic Systems		
Supply cryogenic fluids and gases at temperatures as low as -269°C to superconducting magnets, cryopumps and other auxiliary systems	Multi-pipe vacuum jacketed insulated cryoline of diameters ranging from 25 mm to 700 mm developed for the first time in India. Insulation is designed to transport liquid with minimal losses with an allowed temperature rise of 1°C. Lines meet French nuclear standards.	100% delivery of such lines which include 4 km running length of cryolines and 6 km length of warm lines for return gases completed. Facilities at M/s INOXCVA, Vadodara, augmented to achieve the target. Installation of these lines currently underway at ITER site
Package 4: Component Cooling Water System & Heat Rejection System		
To remove the heat generated from Tokamak and its auxiliary systems using water circulation during operation.	Avg. 510 MW, heat rejection capacity, Peak 1200MW, 10 cells of Cooling Tower, 14 Plate type Heat Exchanger of 70 MW each, 6 Air cooled Chillers: 450 kW each, approx. 8 km of pipelines, seismic qualification for nuclear site.	100% delivery of components completed with the help M/s L&T and several other participating industries, e.g., M/s Kirloskar, M/s Paharpur, etc. The installation of the 500 MW cooling tower completed at ITER.
Package 5: Ion-Cyclotron Heating System		
To supply 20 MW of heating power to the plasma, 36-60 MHz frequency.	A unique solution of using two amplifier chains of 1.5 MW established. A wide band of frequencies 36-60 MHz and over 2000 seconds of operation. World's highest powered Radio Frequency (RF) sources.	Extensive prototype development and experimentation carried out in the RF test bed at ITER India laboratory achieving the target power. Delivery is needed in 2 nd phase of ITER operation.
Package 6: Electron Cyclotron Heating System		
Auxiliary systems used during plasma start up and for localized plasma heating to the tune of 20 MW	Requires development of 1 MW, 170 GHz gyrotron tubes capable of operating for 1000 s.	Test bed preparations under way to establish the performance of gyrotron source system.
Package 7: Diagnostic Neutral Beam System		
A dedicated neutral beam system used to measure the Helium (product of fusion reaction) content in the plasma.	100 kV, 60 A hydrogen (negative) ion beams focused at 21 m and with divergence < 7 mrad. Several parts need to tolerate very high heat exposure.	R&D is in progress, 35 keV, 2 A Hydrogen (negative) ion beams from RF based single driver source (ROBIN) and plasma generation in an indigenous two driver TWIN completed. A unique test bed INTF being set up. CuCrZr material and several manufacturing technologies developed. Large vacuum vessel, 4.5 m dia, 8 m long with double-sealed dull-top opening manufactured by M/s Vacuum Techniques, Bangalore.

Package 8: Mega-Watt level Power Supply Systems		
Required to operate the radio frequency and beam systems at ITER	Indigenous development of 10 kV 120 A, 90 kV 70 A, 10 kV 60 A power supplies, 1 MW, 200 kW 1Mhz generators for RF ion source of the NB system. Indigenous technology developed during SST-1 has become useful for ITER as well.	90 kV, 70 A power supply system indigenously developed and supplied to RFX Padua by M/s ECIL, being used at present. Dual output voltage power supply developed and currently used on Ion-Cyclotron Heating System testing.
Package 9: Diagnostics Systems		
Used to measure parameters and diagnose ITER plasma	Includes X-ray crystal spectroscopy, electron cyclotron emission spectroscopy, charge exchange recombination spectroscopy and upper port structure for holding diagnostic equipments.	Fourier transform spectrometer developed to establish in vacuum attenuation, development of boron carbide (B4C) material with Indian industry. Final design of the diagnostics underway.

As a 9.09% stakeholder in the ITER frame, the Indian contributions to ITER are in the form of nine procurement packages (Figure 6) – some of these are engineering intensive while others in addition to engineering also require developmental R&D.

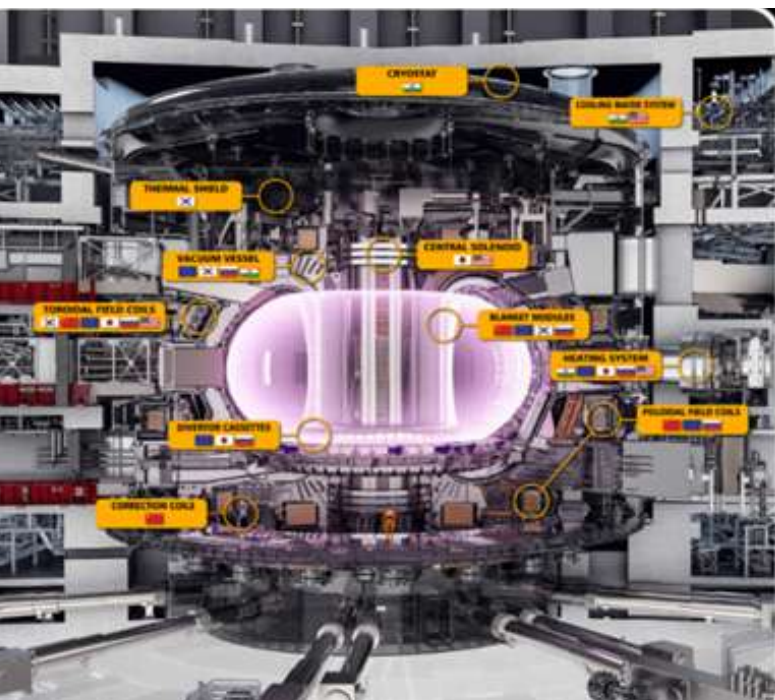


Figure 6: In-kind contributions to the core ITER reactor from various member nations

Beyond ITER

Should the experiments at ITER demonstrate the goals, the next step would be to move towards building a tokamak fusion reactor plant to produce electrical energy to the electricity grid.

Nearing a decade and a half of participation in ITER, ITER-India, IPR is slowly but continuously moving towards its goal of achieving self-reliance to the extent possible in the

area of fusion-related science and technology development. Successful and timely delivery of 4 out of the 9 committed systems to ITER has helped India stand tall and proud on an international platform. The supplied products have been certified to meet the quality norms required for components performing at a European Nuclear site.

During the course of these developments, several industries have upgraded their products line or facilities to facilitate the deliveries and also achieve the desired recognition on an international platform. The hand-holding and transfer of knowledge database of experts from several national research institutes and centres of excellence like BARC Mumbai, RRCAT Indore, TBRL Chandigarh, NPCIL, NFTDC Hyderabad and several IIT's has helped in addressing areas where capabilities didn't exist in the Indian industry.

Innumerable small scale prototype developments, relevant tests and their scaled-up versions have been established which now can be used by the industry to take up new challenges in these areas. Technologies and databases in several areas still need to be further pursued in the quest for achieving self-reliance within a time frame in which ITER successfully demonstrates experimentally that nuclear fusion is achievable and economically viable.

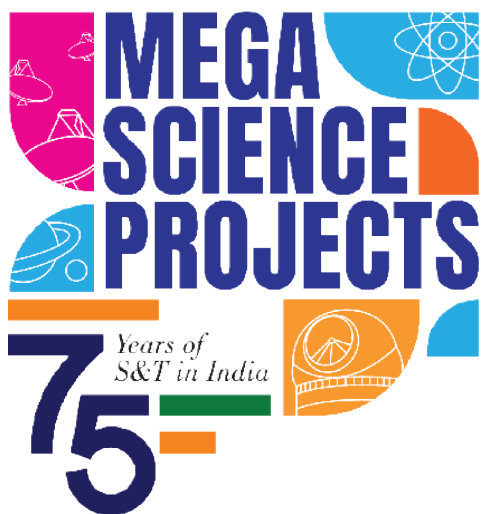
Operations in ITER are expected to start in a few years from now. Indian scientists and engineers must prepare themselves for participation in the experimental phase of ITER to learn the art of operating the machine and its auxiliary systems and to interpret the extensive physics database that will be generated during operations and move towards demonstrating its goals.

With the knowledge from ITER, we must now prepare for the logical next step of producing thermonuclear fusion reactions on the Indian soil using our learnings and a collaborative framework involving Universities, Industries and Research Institutes in the true sense of pride in this 75th year of our Independence.



SQUARE KILOMETER

ARRAY *RADIO ASTRONOMY OBSERVATORY OF THE FUTURE*



India's participation in the Square Kilometer Array (SKA) mega-project is an excellent opportunity for India to showcase its S&T capabilities on the global stage, while reaching the benefits from the development of next generation technologies, and guaranteeing Indian astronomers the right of access to the best experimental radio astronomy facility of the future.

Dr Yashwant Gupta

Centre Director

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Artist's composite illustration of what the SKA1-Mid and the SKA1-Low telescopes would look like, against a backdrop of the night sky view. (Credit: SKA Observatory)

THE Square Kilometer Array (SKA) Observatory (<http://www.skatelescope.org>) is a global project that aims to build the next generation, state-of-the-art radio telescope, for addressing a wide variety of cutting-edge science goals, ranging from the birth of the Universe to the origins of life. At present, 12 nations, including India, are participating in this mega-science project, and some more are expected to join shortly. The SKA is expected to revolutionise radio astronomy, while driving the growth of many important new state-of-the-art technologies.

Though the first ideas to build a large radio astronomy facility like the SKA were put forward in the early 1990s, the formal project work started around 2012 with the setting up of the SKA Organisation in November 2011. Given the size and complexity of the full SKA, a decision was taken that the SKA should be built in two phases. The first, SKA1, would comprise ~10% of the final collecting area of the telescopes, but would still be significantly better than any existing facility; and the second phase, SKA2, comprising the remainder, would follow once the first phase was working.

After an extensive search for suitable sites to locate the SKA observatory, remote and radio-quiet areas were identified in Australia and South Africa, and it was agreed to locate the low-frequency component of the observatory (SKA1-Low) in Australia, and the higher-frequency component (SKA1-Mid) in South Africa. Both Australia and South Africa have established precursor telescopes on the two sites, which has proved useful to test and prepare the sites for eventually locating the SKA there. Further, it was decided to have the operational headquarters of the SKA in the UK – at Jodrell Bank, near Manchester.

The detailed design of the SKA1 was carried out during 2014 to 2020 by a set of nine core design consortia authorised by the Board of the SKA Organisation. Each consortium reflected the international nature of the SKA partnership with institutes from around the world contributing to the design effort. After a bridging phase where useful prototyping activities have been carried out since 2020, the SKA project now is set to transition into full-fledged construction phase by the end of 2021.

A new governance vehicle – an Inter-Governmental Treaty Organisation, called the “SKA Observatory (SKAO)” – that came into being from March 2021, has replaced the SKA Organisation and will oversee the construction of SKA1 and the subsequent operations and possible further expansions of the project over the next few decades.

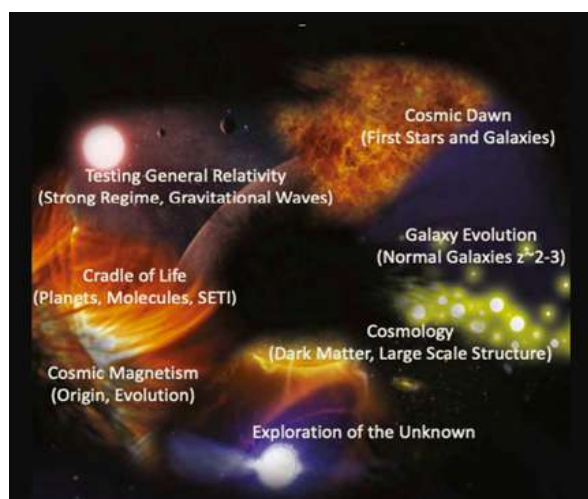
Science Potential of SKA

Since the initial definition of the SKA, the science case for the SKA has developed and evolved significantly in several steps, with the two volume compendium *Advancing Astrophysics with the Square Kilometre Array* (SKA Science Team, 2015) providing the latest and most comprehensive coverage of the vast range of science that the SKA will be capable of.

Some of the main science goals for the SKA are as follows:

1. Detect the first stars and galaxies that formed in the early Universe.
2. Trace the evolution of galaxies from their earliest formation to the current stage.
3. Study the large scale structure of the Universe, probing dark matter and dark energy.
4. Understand the distribution and structure of magnetic fields in the Universe and their influence on its evolution.
5. Test existing theories of gravitation in extreme environments such as close to black holes, using pulsars as probes.
6. Detect low frequency gravitational waves, which are complementary to gravitational waves detected by LIGO type observatories.
7. Study the formation of planets around nearby stars, detect complex molecules that are precursors to life, and scan for signals from extra-terrestrial intelligence.
8. Last, but not the least, make serendipitous discoveries! This always happens whenever a new telescope much more powerful than any existing facility comes into operation.

The science goals form the basis for deciding the technical specifications of the SKA1, and the broad design. One such key parameter is the frequency range of the SKA1, which needs to be roughly 50 MHz to 14 GHz, to meet all the science goals. This broad range is split between the SKA1-Low (50 to 350 MHz) and SKA1-Mid (350 MHz to 14 GHz). Furthermore, given that the low frequency range is better covered with dipole antenna arrays (rather than dish antenna arrays), the SKA1-Low design is based on the use of stations of log-periodic dipole antennas, while the SKA1-Mid design utilises the more traditional dish antennas, though of a special design.



Mosaic illustrating the main science goals of the SKA
(Credit: SKA Observatory)



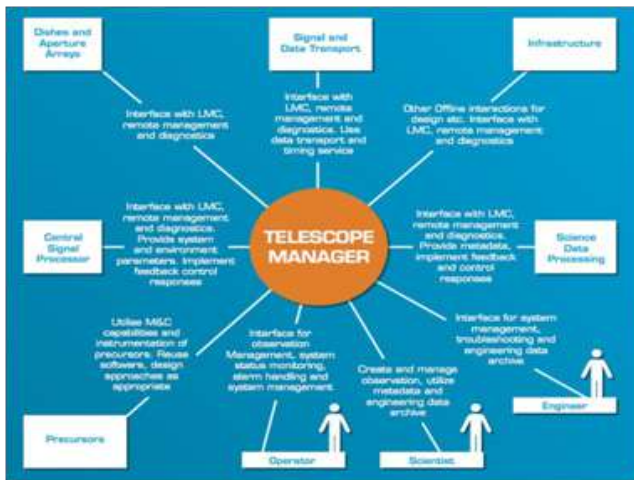
Artist's impression of SKA1-Mid antennas in the central core region of the array.
(Credit: SKA Observatory)

Next, the number of antennas required in SKA1-Mid (and their layout), as well as the number of dipole antenna stations in SKA1-Low (and their configuration), are determined to meet the requirements of sensitivity, angular resolution and quality of the images required by the key science drivers. This leads to a configuration where there are to be a total of 197 dish antennas in SKA1-Mid, spread out over distances up to 150 km, located in the Karoo region of the Northern Cape of South Africa. For SKA1-Low, there will be as many as 131,072 low-frequency dipole antennas arranged in 512 stations, each having 256 dipoles, and spread out over around 65 km in the Murchinson shire region of Western Australia.

The radio waves received by the antennas of SKA1-Low or SKA1-Mid are processed by sophisticated, low noise electronics receiver systems, connected to the receiving elements. For SKA1-Low, the signals from dipoles at each

station are combined in appropriate fashions using high speed digital circuits, to generate the net signal from each station. These signals from antennas/stations are then transmitted over an extensive network of optical fibres to central processing facilities at each site, where they are further processed in sophisticated digital signal processing hardware to generate the specific data products required for deriving the different science results.

The total data flow through the SKA1-Low and SKA1-Mid telescopes, as well as the total signal processing and computing capability required to process the data are truly phenomenal. Even after that, the final data products to be recorded for offline analysis by the astronomer will result in massive data storage requirements, which will be distributed in regional data centres around the world in member countries of the SKA.



Illustrating the role of Telescope Manager in the SKA design. The Telescope Manager provides the 'nervous system' of the SKA, controlling and monitoring every aspect of the telescopes' performance.

India's Participation in SKA

India, with its strong tradition in radio astronomy research and building of facilities such as the Giant Metrewave Radio Telescope (GMRT) near Pune, has been an active participant in the SKA project since the initial days (<http://www.ncra.tifr.res.in/ncra/skaindia>). In fact, one of the earliest concepts for a large radio observatory of the class of the SKA came from the radio astronomy group in India, led by Prof. Govind Swarup, in the early 1990s. When the SKA Organisation was formed in 2012, India joined as an Associate Member, and became a Full Member in October 2015.

India has contributed actively to the design phase of the SKA, working in three different work packages, including a leadership role in the Telescope Manager work package. Indian scientists from the National Centre for Radio Astrophysics (NCRA) led a consortium of seven SKA member countries for the design of the Telescope Manager system, which will be the controlling nerve centre and brains behind the functioning of the entire SKA observatory. It was the first design consortium to complete and submit the final design, as early as mid-2018. In the ongoing bridging phase, Indian contributors are continuing to build up on these activities with early prototyping efforts.



India joins the SKA Organisation as a Full Member – signing ceremony at Mumbai, India on 5th October 2015, with Prof. Philip Diamond (SKA) and Dr R.K. Sinha (DAE)

The Indian astronomy community has built up a strong case for using the SKA for carrying out cutting-edge science, and also contributed to SKA precursor facilities. Several Indian scientists are members of the International Science Working Groups for the SKA, including leadership roles in some of these groups. Besides, SKA India Science Working Groups which have been formed in 2014 have been working on developing the science case and enhancing the potential user base within the country. Their activities range from carrying out theoretical studies and modelling, to using the existing facilities like the GMRT for conducting research and investigations that will prepare the scientific community to make the best use of the SKA when it is ready. National level SKA workshops have been held in conjunction with the annual meeting of the Astronomical Society of India, for almost every year from 2014 onwards. India also hosted the international SKA Science Meeting in 2016.



First version of the Indian science case for the SKA published in a special issue of the *Journal of Astrophysics & Astronomy* in December 2016.

In order to organise all the SKA related activities in India under a common umbrella consisting of all interested organisations within the country, the SKA India Consortium was formally launched in February 2015 at NCRA, Pune. Today, with more than twenty institutions from all over the country (including colleges, universities and major research organisations) signed up as members, the SKA India Consortium is playing a major role in enhancing India's ability to participate effectively in the SKA project, both in technical and scientific spheres. The overall guidance to the SKA activities in India is provided by the high-level SKA India Steering Committee constituted by the Government of India.

For the construction phase of the SKA, India is poised to play a lead role in the production of the Observatory Monitor and Control system, which is an expanded version of the Telescope Manager, with additional features and capabilities added to the scope. India is also going to play a significant role in the building of the digital electronics needed for the signal processing at the SKA1-Low stations, and will also



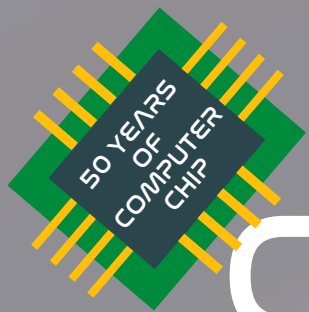
Locations of the SKA India Consortium member organisations as of early-2021 (in pink background), as well as other organisations (names in light green background), who have contributed to the Indian science case for the SKA.

be contributing to the construction of the radio frequency electronics for one of the bands of the SKA1-Mid antennas. In addition to these direct contributions to the SKA project, India will also be building a SKA regional data centre in the country, that can host a significant portion of the data products from the SKA1, for easy access of the SKA data by the Indian astronomy community.

The SKA is a truly next generation multi-country collaborative project for astronomy and science in general. It is also a major driver of several next generation technology developments. With the construction phase recently launched, the SKA1 is expected to become fully operational towards the end of this decade and should produce transformational science for decades to come.

The benefits from Indian participation in the SKA are many fold. On the science front, it will allow Indian astronomers direct access to the best facility in the world in the future. On the technology front, it provides an opportunity for research organisations and industry to contribute at (and learn from) the highest levels of technological developments. It will drive growth of technologies within the country in several key areas, ranging from antennas and electronics to data and software, including areas like artificial intelligence and machine learning. The SKA project can also be used in a big way to spur interest in science, engineering and technology in the country, especially in the student population.





CHIP-ING IN!

Indian Contributions to the Chip - A 'Sangam' of Talent

Anand Parthasarathy

November 15 marks 50 years since the first computer chip was announced. Here's the untold story of the Indians who, over five decades, have contributed to the development of the microchip.



IN its 15 November 1971 issue, an American trade journal, *Electronic News*, carried a large display advertisement with the banner: “Announcing a new era of integrated electronics.... A micro-programmable computer on a chip!” It came from a recent entrant into the electronics arena, just three years old, named Intel.

The company had recently taken up a job for a Japanese company, the Nippon Calculating Machine Corporation, to develop a set of chips to fuel its new Busicom desk calculator, with a printer. Intel engineers Ted Hoff, Frederico Faggin and Stan Mazor worked with the client’s representative, Masatoshi Shima to shrink the originally planned 12 chips into 4 – a central processing unit (CPU), a read-only memory, a random access memory and a register for in-out operations —together called, MCS-4 for microcomputer system.

Having delivered the chips to Busicom, Intel offered their Japanese client a deal: “We’ll give you a discount on the price of the chips, if we can keep the rights to the design and sell them in markets where we don’t compete with you.” The client agreed – and Intel separated the CPU chip and offered it to the world as the Intel 4004, the world’s first microprocessor, commonly called the microchip. It contained 2,300 transistors and worked at 740 kHz. Today, microchips of the same class – like an Intel Core i9 – contain about 2 billion transistors and run at 5-6 GHz, that’s nearly 10,000 times faster. Their size has shrunk too – and they consume typically 5000 times less energy than the Intel chip of 50 years ago.

While Intel became the world’s biggest maker of microchips for computers, innovation in chip design has not been at Intel alone.

Microchip: Early Milestones

In 1979, Motorola entered the market with its 6800 series of chips and used a single 5-volt DC power supply, instead of a dual supply, that brought down the cost for computer makers. In 1974, Texas Instruments introduced a self-contained computer-on-a-chip, the TMS 1000, combining processor, memory and input/output operations on a single slab of silicon. By 1983, TI developed the first Digital Signal Processor or DSP chip. In 1975, another entrant, AMD, offered a concept called ‘bit slice’ – chopping up a task between chips so that they worked faster and generated less heat.

National Semiconductor had the distinction of launching the first 16-bit processor as well as the first 32-bit processor. Intel’s 80486 processor in 1989, the first to cross 1 million transistors on board, was so powerful for its day that users called it “mainframe on a chip”. Motorola responded a year later with the 68040, which was even faster.

In the 1980s, a virtually unknown British company Acorn Risc Machine or ARM, offered efficient Reduced Instruction Set Computing (RISC) with highly optimised instruction sets that allowed very small devices like mobile phones to harness computing power. Soon ARM cores were in 10 billion

devices worldwide. (The company was acquired by NVIDIA, last year).

In 1987, Sun Microsystems improved on RISC with what it called Scalable Processor Architecture and SunSparc became the *de facto* chip for servers. In 1997, when a computer fuelled by 480 IBM chips called Deep Blue, beat Grand Master Garry Kasparov in a game of chess, the microchip had entered another era – artificial intelligence.

The saga continues into the 21st century – but over the decades, one fact emerged: Indians have contributed significantly at every stage of the microchip’s five-decade saga. Much of this innovation has taken place in the development labs of the major global chip companies. But a fairly recent development has seen many processor achievements coming from Indian academia and government institutions – addressing the special needs of India.

Indian Contributions at Intel

The name of Vinod Dham finds an honoured place in the history of Intel. A B.E. in Electrical Engineering from Delhi College of Engineering, Vinod went to the US in 1975 to study solid-state physics. He joined Intel in 1979, where he first worked on the 386 and 486 chips leading the development of the Pentium processor — at the time, the most complex microprocessor ever built, with 3 million transistors, executing 100 million instructions per second. He was hailed as the “Father of the Pentium Chip” and went on to become Vice President and head of the Intel Microprocessor Group. Vinod is also credited as the co-inventor of Intel’s first Flash memory technology that flows in every USB data stick.



Vinod Dham, ‘Father of the Pentium’

In his early years at Intel, Vinod Dham had the opportunity to mentor another young Indian who joined the company in 1988, after completing his basic engineering degree at the Manipal Institute of Technology and then obtaining an M.S. in Computer Science from the Illinois Institute of Technology in Chicago (US). The fresh graduate joined the 30-strong development team of the Intel 486 chip. His specific role was design verification of the 486 and as was Intel practice, his initials as well as those of his teammates are etched in tiny letters on every 486 chip. He went on to work on the CPU architecture of the Pentium as part of Dham’s team, before returning to India in 1991. Today, that engineer is the Minister of State for Electronics and Information, in India’s central council of ministers – Rajeev Chandrasekhar.

Another Indian – Avtar Saini – began his Intel career as a circuit designer for the 386 chip and a logic designer for the 486. A B.E. in Electrical Engineering from the Victoria Jubilee Technical Institute, Mumbai, Avtar earned his M.S. from the University of Minnesota, before joining Intel in 1982. In 1989, he became co-leader of the Pentium design team,



Rajeev Chandrasekhar:
from Intel chip
designer to India's IT
Minister

where he worked to manage the design and helped transition it to production. By 1994, Saini was General Manager of the Microprocessor division at the Santa Clara plant of Intel and helped manage Intel's transition to the next 64-bit architecture for microprocessors like Itanium. By then, he had earned 5 patents in microprocessor design. Avtar returned to India in 1996 as Director of its South Asia operations and over the next five years was responsible for setting up Intel's first India Development Centre in Bengaluru, which was to become a nodal agency for crafting Intel's enterprise microprocessors like the Xeon. The India team has validated, tested and supported every Xeon release for over a decade. By 2008, when Intel launched the Xeon 7400 series, the world's first ever processor with six computing cores, code named Dunnington, the product was almost wholly designed in India. Said an Intel statement at the time: "The Intel India team planned and executed end-to-end design activities including front-end design, pre-silicon logic validation and the back-end design for Dunnington, transitioning the entire Intel Xeon



Avtar Saini helped Intel
transition
to 64-bit computing

family to Intel's 45 nm manufacturing process." In 2007, Intel took up, largely as a technology demonstrator, a chip with 80 computing cores, enabling a computer built with such a chip, to process at 1 teraFLOP or one trillion floating-point instructions per second. The work was done jointly by Intel teams in Oregon (US) and Bengaluru. The India team of 20 engineers, headed by Vasantha Erraguntla, contributed about 50% of the work consisting of logic, circuit and physical design. The teraflops research chip, as it was named, was readied in a record 20 months. When the technical paper about 80-core was published, 8 of the 12 co-authors were Indian.

An Osmania University, Hyderabad, B.E. graduate and a Masters in Computer Engineering from the University of Louisiana, Vasantha joined the company in the US, 1991. She led the Bengaluru design lab of Intel for seven years from 2004, before moving back to the US to join Intel's architecture group and later headed its market solutions group and strategy programme till June 2016.



Vasantha Erraguntla led
the India team
behind the 80-core chip

When the then Intel CEO Paul Otellini showcased the company's exciting new chip powered by solar energy alone, at the Intel Developer Forum in 2016, he called on stage the scientist who headed the development – Sriram Vangal. The device Sriram unveiled was the Near Threshold Voltage Core, running at a very low voltage near the threshold required to

power its transistors, and still capable of running Windows on a computer. This low power was provided by a tiny solar panel on the face of the chip.

A B.E in Electronics Engineering from Bangalore University, Sriram obtained an M.S. in Computer Science from Nebraska-Lincoln and a PhD from Linkopings University in Sweden. For the last 25 years, he has been with Intel and is now Principal Research Scientist at the Portland (Oregon) centre, where his interests cover areas of low-power circuits and tera-scale computing. The solar chip is not yet a product for the market.



Sriram Vangal led the development of the first solar-powered chip

Texas Instruments

The first international technology company to set up an India-based software design centre in Bengaluru in 1985 was Texas Instruments. Within five years, it was involved in the development of application-specific products and soon included TI's flagship digital signal processors. The development team was led by Srinu Rajam, an M.Tech in Computer Science from the Indian Institute of Science, who came over to TI Bengaluru from Wipro in the year it was formed. In 1995, Srinu's team developed the first ever DSP that was completely made-in-India. It was named 'Ankur'. Internationally in TI's catalogue, it was called C2000.

In 1995, Srinu Rajam was designated Managing Director of TI India—a rare accolade for an Indian in a multinational in those days. The India team entirely developed TI's first modem chip for Asynchronous Digital Subscriber Lines (ADSL). Srinu continued to lead innovation at TI for six years and then had a choice – move to TI USA or leave. He chose to work for India. Six other TI colleagues decided likewise and in 2001 moved together to co-found a startup, Ittiam, where they would exploit their core competence in DSPs – but on their own terms. The company continues to thrive as a major generator of Indian intellectual property in signal processing and image processing areas.

Meanwhile, Indian engineers at TI India continued to deliver total solutions to the parent company: an audio process named 'Malhar' and a media chip, "Zeno". In 2003, TI India engineers developed the world's first single-chip solution for high-speed modems used for broadband communications. It was, said Vivek Pawar, then head of TI's Broadband Silicon Technology Centre in Bengaluru, a huge challenge to realise both analogue and digital circuits on the same chip. But the confluence of technologies worked – so they called the chip 'Sangam'!

In August 2005, TI celebrated 25 years of its India development centre. Global Chairman Tom Engibous flew down from Dallas, Texas to mark the occasion and unveiled the latest innovation at the centre: the first-ever cellular mobile phone completely built in India using a TI-designed single-chip cell phone solution for low-cost handsets. “We’re not just making dreams possible. We’re making them practical,” said then India Managing Director Biswadip ‘Bobby’ Mitra. One of the longest serving employees of TI India, Bobby joined when the Bengaluru centre opened in 1985 and after 12 years heading the India operations, he moved to the US to steer TI’s Industrial Systems. Today he heads TI’s worldwide smart manufacturing initiatives.

AMD: India hand in ‘Second Coming’

Indian engineers are said to have played a key role in the resurgence of AMD in recent years after a long dull period. AMD chose Hyderabad to house one of its two India development centres in 2008 and within two years, engineers there had crafted 2 AMD processors: ‘Ontario’ and ‘Zacate’, which served the market for low power chips for notebooks, smartphones, etc. The 80-member India team developed the chips “from drawing board to motherboard”, explained then India Managing Director Dasaradha Gude, calling it a ‘defining moment’ for the India team.

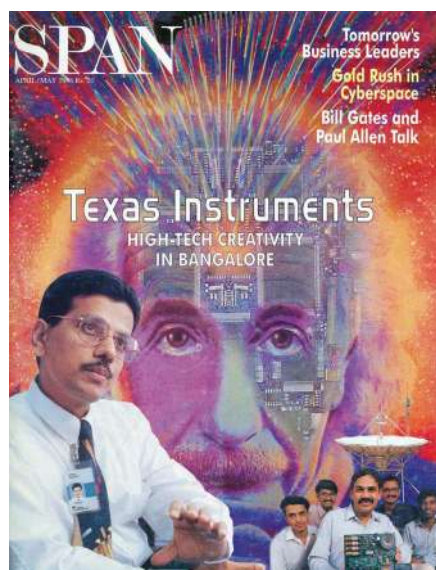
Similar was the story in 2011 when AMD inaugurated a new era in computing by merging general purpose and graphical processing in the same chip. The so-called Fusion chip family was built from concept to foundry tape-out (the design that is fed to the silicon foundry) by AMD engineers in Hyderabad and Bengaluru.

More was to come. “The team in India played a key role in designing AMD’s latest Zen processor core that’s behind the company’s revival,” AMD’s chief technology officer, Mark Papermaster told the *Times of India* on a visit to India in 2018. It triggered AMD’s return to high-performance computing in desktops with its Ryzen chips and in datacentres with server processors that it calls EPYC.

EPYC has seen Indian engineers play a major role in its development. Its 3rd generation, code-named Milan, launched this year, stakes claim to being the world’s fastest chip for server applications. Key hardware and software came from India and the latest iterations of EPYC have seen some of the world’s fastest supercomputers built with the processor – as they vie to launch a new age of Exaflop computing (An exaflop means one million-trillion calculations per second, or 1000 petaflops). “The India team contributed majorly to the success of the Milan EPYC,” Jay Hiremath, Corporate Vice President, Platform and Software engineering at AMD India is quoted in a July 2021 story in *Times of India*. And they achieved it last year while challenged by the Covid lockdowns.

NVIDIA and ARM: Made for each other

In 2005, NVIDIA opened its India design centre in Bengaluru and its engineers here have contributed to the company’s nForce wireless media and communications processors. NVIDIA has



Srini Rajam and his team at Texas Instruments featured on a 1996 magazine cover

a strong presence in graphical processing units. Today the company’s mantra is: If my GPU can do it all, why do you need a CPU?

Its acquisition of the UK-based ARM last year has created a computing behemoth and between ARM and NVIDIA they fuel many of the supercomputers in the world’s TOP 500 rankings. Since ARM already had large teams working in Bengaluru and Noida, the combo of these two companies in India makes for a powerful task force for NVIDIA to create the next leap in GP-GPU or General Purpose Graphical Processing Units.

IBM: POWER-ful Contribution

IBM has had a development team in India since 1996, starting as part of Tata Information Systems Limited and later functioning in Bengaluru as the India Systems Development Lab (ISDL). Uniquely among IBM R&D centres, the India lab works on all three of the company’s hardware verticals: the Z mainframes, the POWER processors and the storage solutions.

IBM’s flagship processor family, POWER, fuels high-performance machines like servers and workstations. The most recent in the series is POWER 10, launched last year – and much of the development happened in India.

“We are pretty much involved with all aspects of the processor, handling everything from chip development to physical design, the electronic design automation that goes into designing these complex chips, validation of the chips, and building the world’s first enterprise-scale 7 nm processor,” Akhtar Ali, Vice President and head of ISDL, has been quoted saying at *IndiaTimes.com*.

He also revealed that the India team actually improved IBM’s internal design tools by adding Artificial Intelligence features. IBM’s Indian engineers received 900 patents in just one year – 2019 – in the thick of POWER 10 development, second only to the US team.

Made-in-India – For India

Except for a few government plants, chip fabrication remains at academic-scale

India's active semiconductor fabrication units are mostly dedicated to serving strategic government sectors. What was formerly India's first fab, Semiconductor Complex Limited, in Chandigarh, since 1983, was converted into the Semi-Conductor Laboratory (SCL) under the Department of Space in 2006. It serves as an in-house resource for design, development, fabrication, assembly and testing of semiconductor devices and Micro Electro-mechanical systems (MEMS). The Defence Research and Development Organisation (DRDO) meets its own needs for military semiconductor devices with two facilities: the Semiconductor Technology & Applied Research Centre (STARC) at Bengaluru and the Gallium Arsenide Enabling Technology Centre (GAETEC) at Hyderabad.



Microprocessor assembly and packaging at SCL Chandigarh



Prof. V. Kamakoti with the team at IIT Madras that developed the Moushik chip

In recent years, there has been a tangible thrust in academia into developing microprocessors tailored for India's special needs:

- Researchers at IIT Madras have developed a microprocessor – 'Shakti' – that could be used for low power applications like mobile phones. It was claimed to be India's first RISC processor and initial quantities were produced in 2018 in an Oregon (US) plant after which it was manufactured at SCL Chandigarh, using the 180-nanometre fabrication technology. Lead researcher, Prof. V. Kamakoti said the product could address the need for customisable cores for many make-in-India projects. The Shakti family has grown to three chips, the latest being 'Moushik', released in October 2020.
- Another microprocessor designed, developed and manufactured in India was AJIT, crafted at IIT Bombay in 2019 by a 9-person team headed by Prof. Madhav Desai. Sample quantities were again manufactured at SCL, Chandigarh. Both projects were supported by the Ministry of Electronics and Information Technology (MEITY) but have not transited to commercial scale.
- IIT Kanpur also has an ongoing programme of research and development of silicon and organic-based materials at its semiconductor Device Fabrication.

The Fab-ulous Option

A large fab or fabrication unit for the manufacture of microchips and memory devices has long been an Indian dream – as yet unfulfilled. Multiple initiatives from the government over the last 20 years to woo major global players to locate a fab in India failed to bear fruit – the steep capital cost of setting up a fab, around \$ 6 billion to 7 billion, was one reason.

Many argued that such investment would make no sense, when most of the world's chip design was 'fabless', with designs or 'tapeouts' sent to fabrication giants like Taiwan Semiconductor Manufacturing Company (TSMC) which has nearly 565% of the world's chip making business. Leading Indian semiconductor designers like Saankhya Labs and Accord Software & Systems have made their global reputations, outsourcing fabrication to fabs who offer the best deal.

But the severe Covid-induced shortage of chips in recent months, that has seen many automobile and cell phone assembly lines in India shut down temporarily, has driven home the message that an India-based fab or two could be a strategic necessity. The government is now said by non-official sources, to have offered an incentive of 1 billion dollars to any entity willing to set up a fab in India. It has sought expressions of interest from interested players and hopefully this time there might be a few takers.

In August this year came a surprise announcement: "The Tata group has already set up a business to seize the promise of high-tech manufacturing for electronics." It looks like the current crisis of chip shortage may end up as the opportunity that evaded the fab business for so long.

From Micro to Macro

Recent months have seen product announcements, at two ends of the microchip manufacturing spectrum

A US Artificial Intelligence company, Cerebras Systems, recently unveiled the second edition of its Wafer Scale Engine (WSE-2), which is the size of a dinner plate – and the world's largest computer microchip. Macro rather than micro would be the right word for it.

The processor packs in 2.6 trillion transistors, each about 7 nanometers wide (one nanometer is one-billionth, that is 1/1,000,000,000th of a meter) and configures them into 850,000 computing units or cores that would typically work together on AI applications. The logic for packing so many cores into a single slab of silicon is that otherwise, researchers would have to combine that many separate processor chips adding to interconnects and delays. An article in the *New Yorker* of 20 August 2021 entitled *The World's largest computer chip* provides an update that lay readers can understand.

The smallest microchip commercially available today is IBM's Power 10 processor, released in August last year and manufactured for IBM by Samsung. It also uses 7-nanometre technology and packs 18 billion transistors into a chip that is about 2.5 mm across and fits on a fingernail.



Even smaller chips are on the way. Scientists at Columbia University, New York, announced that they had developed a microchip that is 0.1 mm cubed in volume and is small enough to be implanted into a human using a hypodermic needle and can measure body parameters. For example, a surgeon performing a critical operation might inject a few such microchips into the patient and then use an ultrasound scanner to communicate with the chips to check on the status of vital parameters. The researchers described their work in an article entitled *Application of a sub-0.1-mm³ implantable mote for in vivo real-time wireless temperature sensing*, on 7 May 2021, in *Science Advances*.

Biggest and smallest microchips: Left: Dhiraj Mallick, Vice President, Engineering and Business Development, Cerebras Systems, holds the world's largest computer chip, the WSE-2. Right (top): The tiniest microchip in production, the IBM Power 10. Right (bottom): The implantable chip developed by Columbia University seen in a magnified view, on the tip of a hypodermic needle

Earlier this year, IBM announced a major breakthrough in chip design: the first to be fabricated to 2-nanometre fabrication standards. Compared to current 7 nm technology this promises to deliver 45% better performance, a 75% lower energy use. The shrinking in physical design allowed IBM to cram 50 billion transistors on a chip smaller than a fingernail. What does it mean for the rest of us? A smartphone's battery would last four times as long; a laptop would work at much zippier speeds.

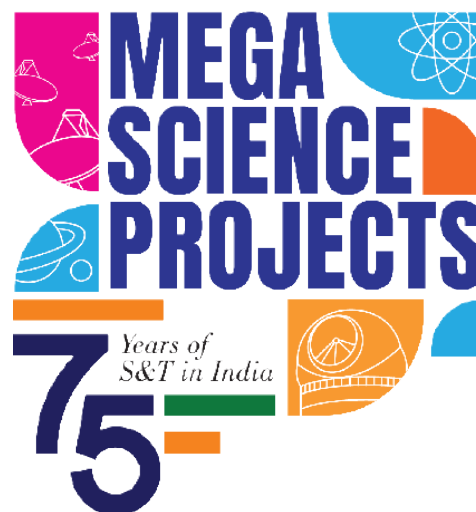
Mukesh Khare, IBM Vice President for hybrid cloud research says cloud data centres would be the biggest beneficiaries: they now consume a whopping 1% of the

world's energy. The 2 nm chip is as yet a proof of concept and may not reach the market for another two years. But anyone who bets that IBM's India-based engineers will be contributing key intellectual property to this chip too, is unlikely to lose. Because, through the 50-year history of the microchip, regardless of company or geography, there is in almost every new product, a little bit of Indian innovation.

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INDIA ^{AT} FAIR

The Universe in the Laboratory



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THERE is a famous quote from Einstein – “The strangest thing about the Universe is that it is understandable”. The human intellect understands the Universe through scientific investigations, explorations and logic; no part of it, however large or small, escapes our attention and our quest for the physical laws governing all aspects of the Universe comprises the ultimate intellectual endeavour.

Over the past several decades, the consensus has emerged that there are four types of fundamental interactions in Nature, which explain all the physical processes occurring in the Universe. The extremely short-range strong force operates between quarks and gluons, the fundamental constituents of atomic nuclei; the weak force too is short-range, but much weaker in strength compared to the strong force. It can change the electromagnetic charge of particles, leading to the phenomenon of radioactivity. The electromagnetic force is of infinite range, governing chemical and atomic interactions, thus dominating the processes of everyday life. The fourth force is the gravitational interaction, responsible for planetary, stellar, galactic and supergalactic dynamics, the science of the very large.

The strong, the electromagnetic and the weak forces all have an underlying quantum field theoretical framework, called gauge theories; for gravitation, however, a consistent quantum theory still eludes us. Arriving at such a theory and combining all the four interactions within one consistent quantum theory is the holy grail of physics.

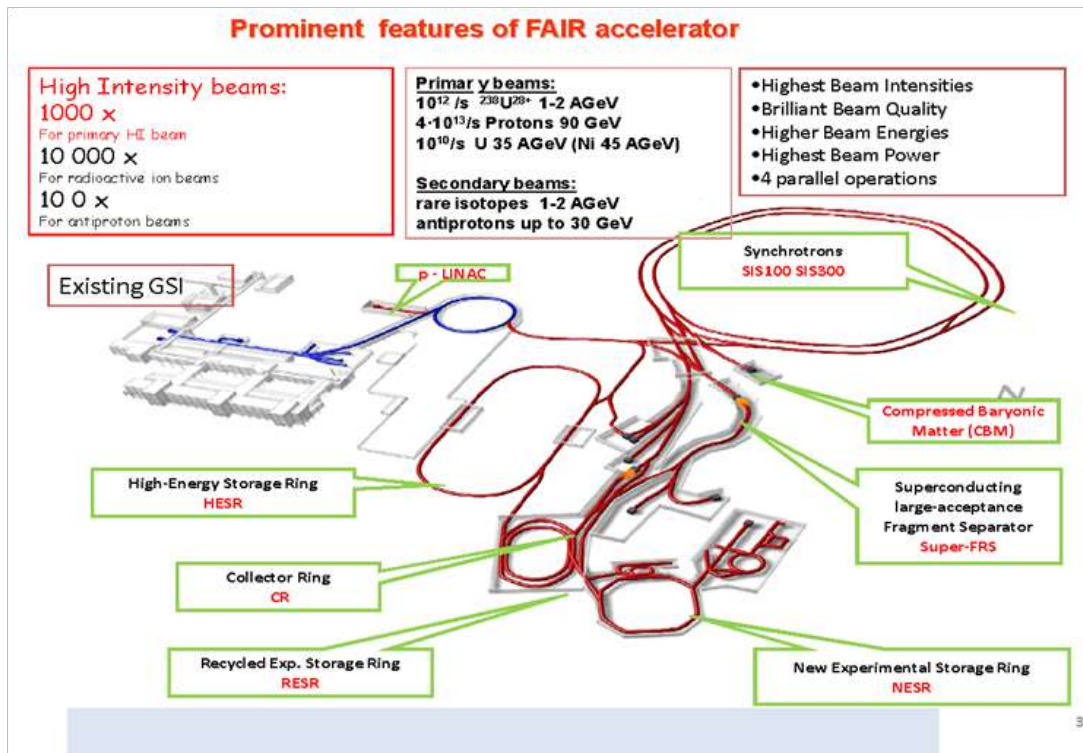
Another driving force in modern science is to understand the multitude of very rich structures that exist within these

India is no longer looked upon as the menial supplier of low-end materials for the upcoming international Facility for Antiproton and Ion Research (FAIR). Our scientists and technologists have proved their mettle as expert collaborators and it is a matter of pride that India is looked up to as a leader in FAIR. This reputation has been painstakingly built up over the past decade.

fundamental theories, study their interplay, explore the limitations of applicability of these theories and look for signs of new physics beyond our current understanding. The upcoming international Facility for Antiproton and Ion Research (FAIR) at Darmstadt, Germany will provide a unique opportunity to carry out world-class experiments elucidating salient features of all the four domains; it is thus at least four, if not more, accelerators rolled into one, a unique futuristic machine of unparalleled scope and promise.

NextGen Accelerator

FAIR is the next generation accelerator for fundamental and applied research, providing an array of ion and antiproton beams for a variety of experiments in all the four fundamental interactions and their interplay. It is currently under construction at the campus of the GSI Helmholtzzentrum fuer Schwerionenforschung (GSI Helmholtz Centre for Heavy Ion Research) at Darmstadt, Germany. The choice is driven by the design of the accelerator, which builds on the existing synchrotron SIS18 as the feeder to the new workhorse of FAIR. (The term SISxx designating the accelerator probably needs a little explanation for the general reader. SIS is the acronym of Schwerionensynchrotron, heavy ion synchrotron



in German and the numerals denote the rigidity of the accelerator in GV.)

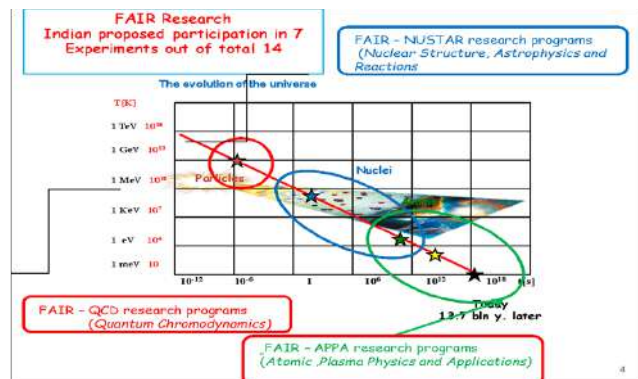
The heart of FAIR is the fast-ramping, superconducting heavy ion synchrotron SIS100, with a proton linac for the production of antiprotons, a variety of storage rings for storing various cooled ions and antiprotons, and the Superconducting FRagment Separator (SFRS) for production and clean identification of secondary ions (short-lived). The uniqueness of FAIR lies in:

- Covering beams of all ion species and antiprotons
- Unprecedented high intensity and quality
- A availability of beams at several experimental sites

The goal of FAIR is to study the structure and evolution of matter at microscopic as well as cosmic scales – hence the sobriquet ‘*THE UNIVERSE IN THE LABORATORY*’.

The original plan was to make provisions for two synchrotron tunnels, SIS100 and a bigger SIS300. However, for reasons of economy and on the basis of international agreement, it was decided to focus on a Modularised Start Version (MSV) which is restricted to SIS100. The goals of FAIR are distributed in four scientific pillars, each with its own focus, though often overlapping goals. These four primary pillars are:

- Atomic, Plasma Physics & Applications (APPA)
- Compressed Baryonic Matter (CBM) → (C.B.M.)
- NUClear STructure, Astrophysics & Reactions (NUSTAR)
- (Anti)Proton ANnihilation at DArmstadt (PANDA)

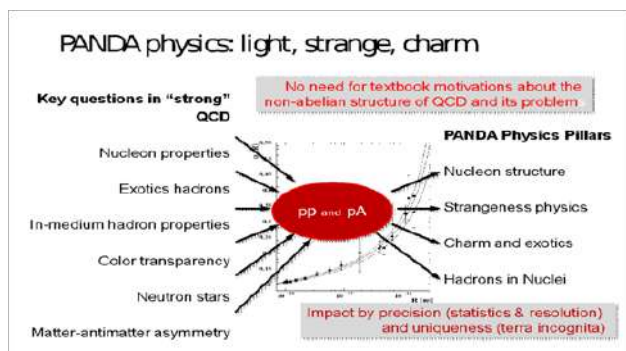


While the focus is on fundamental studies, the practical and technological spin-off is of utmost importance. Applications play a major role in the planning of activities, present and future – both short and long term.

APPA

For the next decade and beyond FAIR offers novel, worldwide unique research opportunities and challenges with large discovery potential for the interdisciplinary research fields of APPA, which will contribute significantly to the very first experiments at FAIR (CRYRING, APPA cave, HESR).

Rapid technological advances in fields like laser, optics, X-ray detectors, and biomedical application implies a permanent scrutiny and update of the experimental methods and setups proposed by APPA. R&D is still needed. Focused, continuous research at the current GSI facilities is of utmost importance for the success of the FAIR project.



The coming into being of FAIR

After almost a decade of brainstorming and rigorous international discussions and bargaining, the international non-profit company FAIR was founded on 4 October 2010, on the basis of a multi-government agreement, the so-called convention of FAIR.



At present, there are 10 partner countries and the number is expected to grow in the near future. India is the third largest shareholder, after Germany and Russia. The initial cost estimate was 1.2 billion Euro, of which India agreed to pay 36 million Euro, all in 2005 prices, appropriately adjusted for inflation. Of these 36 million, 9 million Euros as cash, to partially defray the construction costs and the rest 27 million was in kind, for the accelerator as well as the experiments.

The initial timeline envisaged a completion date of 2018, with a year or two of installation, calibration, etc. However, even before construction could start, the nuclear accident at Fukushima happened, which resulted in the imposition of severely strict safety guidelines, leading to the need for major redesigning (with concomitant cost increase and several years' delay, unfortunately). Yet, safety could never be compromised! All the partner countries agreed to take the bit between their teeth and fight to keep the project on course.

Then, the ground breaking for the construction of FAIR took place on 4th of July 2017 and construction began in earnest. And it has been a marvel to see how rapidly the construction has progressed. The SIS100 tunnel has been dug, the concrete work completed and the many other important milestones have been achieved either ahead of schedule or on time. There is no point in showing a picture of the construction site; it would be out of date before this article reaches the reader! The readers may enjoy the pictures updated regularly on the FAIR website.

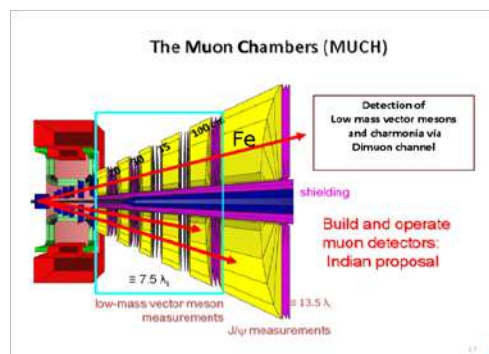
As already mentioned, the original timeline was completion by 2018. Due to various reasons, the project was considerably delayed. Thus the original objectives needed to be re-examined – whether they still remained valid, relevant and internationally competitive in spite of this delay. The Joint Scientific Council (JSC) of GSI & FAIR, under the Chairmanship of the present author, had the task of critically looking at all the prospects, and advise the Council of FAIR about the ground reality, in an open and objective fashion. The JSC took up this task in earnest during 2018-2019 and came up with the unanimous conclusion that not only were the scientific goals of FAIR still valid and current but in fact, they became even more pressing and challenging than had been anticipated a decade ago.

With such steady progress towards the completion of the FAIR project, the interest of the international community is once again picking up. At the latest count, there are about 4000 scientists from about 50 countries in 5 continents who are involved in planning experiments at FAIR. India is one of the major users of FAIR, with approximately 400 full-time scientists from 40+ Indian institutions and universities involved in FAIR-related studies.

Of the four scientific pillars, India has presence in all of them to varying degrees. Indian commitments to C.B.M. and NUSTAR are indeed very critical and sizable.

At CBM, the major responsibilities include:

- Detector stations for MUCH (the MUon Chamber, the mainstay for the detection of dileptons [Both Gas Electron Multiplier (GEM) and Resistive Plate Chamber (RPC)]).
- Cooling mechanism
- Physics analysis; Computations.
- Broad based phenomenology of QGP diagnostics, heavy flavour propagation and collective phenomena.
- Effective models (PNJL, ZM and others for high density).
- Machine learning for charged track analysis.



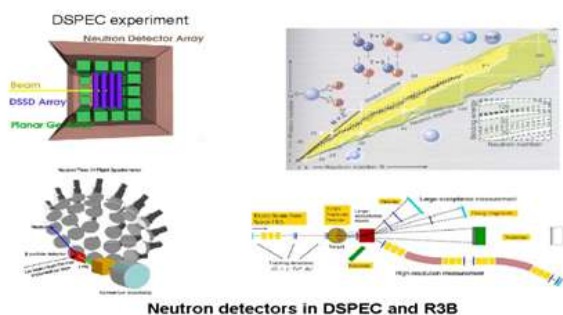
At NUSTAR, India participates in a major way in more than one sub-project.

In addition to contribution to the scientific collaborations, India is also contributing to the construction of the accelerator complex in an unprecedented manner, which is adding to the technical capability in the country at the cutting edge. For



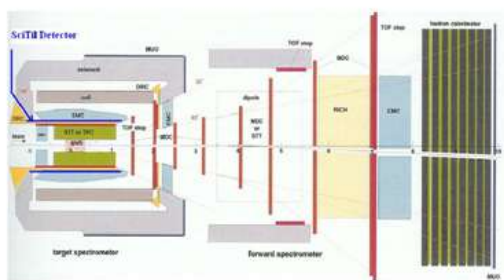
This is a picture of a high current power converter designed by the engineers of VECC, RRCAT and ECIL, manufactured at ECIL and installed at FAIR after successful factory acceptance and site acceptance tests. The technical challenge involved in the design and manufacture was considerable but Indian industry came through with flying colours, in the face of initial scepticism of European experts. 170+ power converters have already been shipped to FAIR, with orders for many more now under completion.

Indian participation at NUSTAR experiment



Neutron detectors in DSPEC and R3B

Indian participation in PANDA



Si-PM based scintillator detector for TOF, Luminosity monitor

example, a superconducting quadrupole magnet of great complexity was designed by the scientists at the Variable Energy Cyclotron Centre, Kolkata, which received praise for technical excellence from the world experts. For financial reasons, and lack of indigenous infrastructure, India excused herself from building the magnet in India, but agreed to

provide technical supervision to FAIR in the manufacture of the magnet designated for the Low Energy Branch (LEB) of the NUSTAR collaboration. India got a substantial amount of financial credit from FAIR for this work.

Two prototypes of the highly challenging HEBT Vacuum chambers have been made and shipped to FAIR. They have passed the rigorous acceptance tests and production clearances have been obtained. Given the extremely high luminosity, the design of the beam catcher was a major challenge which foxed the experts of the FAIR engineering design team. India undertook the challenge and the scientists of CMERI, Durgapur produced the solution.

Examples like this are many; it can be safely claimed that India is no longer looked upon as the menial suppliers of low-end materials. Our scientists and technologists have proved their mettle as expert collaborators!

The recent progress at FAIR has indeed been exemplary. While the initial delay in the project could not be entirely made up, the current pace has instilled full confidence in the community for a start of experiments within a few years. The interest among the scientists is palpable, the Indian community being no exception. It is a matter of pride for us that India is looked up to as a leader in FAIR. This reputation has been painstakingly built up over the past decade. It is now the responsibility of the new leaders to live up to the international expectation. It must be realised that it takes long and hard work to build the reputation; failing to honour commitments in a time-bound manner is the surest way to ruin it in no time. All of us must be extra vigilant against such an eventuality.



Thirty Meter Telescope

Unraveling Mysteries of the Universe



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Indian astronomers and engineers have joined the International community to build the Thirty Meter Telescope (TMT), which will help Indian industry and science take a giant leap forward. Building TMT will answer some of the nuanced questions that still remain unanswered, like: Are we alone in the Universe? What is the nature of extra-solar planets? How did the first stars and galaxies form? What would be the fate of this accelerating Universe (the Dark-energy conundrum)?



A rendering of the TMT on Mauna Kea, Hawaii. Photo credits: TMT Observatory.

“The great advances in science usually result from new tools rather than from new doctrines”
- Freeman Dyson

WHEN the human minds marvelled at the beauty of the night sky, they started building tools to probe deeper into the Universe. The tools initially simple, over time have become more and more sophisticated and complicated to build. A simple optical telescope which Galileo Galilei used just needed two simple lenses; a simple Newtonian Telescope needed few mirrors and a lens, which could be produced by the efforts of one or two individuals. A modern day optical telescope and its back-end instruments need the collaborative efforts of many engineers and scientists. This process has not only enriched both science and technology but has also benefitted society in ways that were never envisaged.

Currently, telescopes are being built across the entire range of electromagnetic spectra, each region posing its own technological and scientific challenges. Near and Far Infrared instruments need advanced cryogenics, while radio and submillimeter instruments need to be protected from radio interferences produced by humans, large optical telescopes need darker skies with minimal atmospheric turbulence (which owing to other advances in human development have become far and few), and the list goes on. Building of these instruments, testing them, deploying them and using them is now a highly collaborative effort involving teams of scientists and engineers from multiple countries. The Thirty Meter Telescope and its back-end instruments, in which India is a partner is one such prodigious effort.

India's indigenously built largest optical telescope until now has been the 2.3 m Vainu Bappu Telescope at Kavalur, Tamil Nadu, and with international collaboration the 3.6 m Devasthal Optical Telescope at Devasthal, Uttarakhand established recently. However, across the world, efforts are on to build far larger telescopes like the 30 m telescope, 39 m European Extremely Large Telescope (ELT) and 25 m Giant Magellan Telescope (GMT). Realising this, Indian astronomers and engineers have now joined the International community to build the Thirty Meter Telescope (TMT), which will help Indian industry and science take a giant leap forward.

Building TMT will answer some of the nuanced questions that still remain unanswered, like: Are we alone in the Universe? What is the nature of extra-solar planets? How did the first stars and galaxies form? What would be the fate of this accelerating Universe (the Dark-energy conundrum)? These pertinent questions need better and larger telescopes and technology.

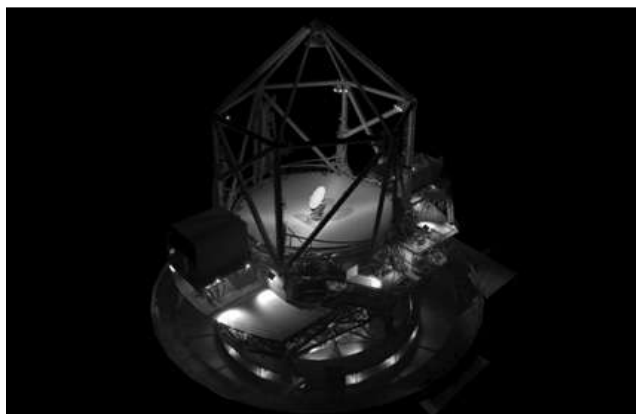
In this endeavour, India, Japan, China, Canada, and the University of California and Caltech in the US have come together to build the next generation's most versatile telescope, the TMT. India is a 10% partner in this project.

TMT will be a powerful Optical-Infrared astronomical observatory with a large primary mirror of diameter 30 m, having a light-collecting area of 664.2 sq m. It will collect light

that is sensitive to the atmospheric windows in the wavelength range of 0.31-28 μm . The three prime technological capabilities of TMT that will shape the future of astronomy are 492 mirror segments that will act as one mirror of 30 m in diameter, precision control of each of these segments and Adaptive Optics (AO) technology.

The capability of a telescope is measured based on resolving power, light-gathering power and sensitivity which is defined as the minimum signal that a telescope can distinguish above the random background noise. The sensitivity of TMT will be 81 times better than the current largest ground-based telescopes. The Adaptive Optics (AO)-assisted capability enables TMT to resolve objects by a factor of three, better than the existing 10 m class telescopes and 12 times better than the Hubble Space Telescope (HST). TMT, with its AO capabilities, can resolve structures as small as 25 km at a distance of Jupiter. At the distance of the Moon, TMT can resolve structures that are as small as 13 m, while comfortably sitting on the Earth.

Some parts of the pertinent questions mentioned above, like the phenomenon of dark energy, discovering life elsewhere in the Universe, and exploration of exoplanets can be addressed with TMT. TMT along with its back-end instruments would take images and spectra of the farthest and faintest objects in the Universe. It would be able to directly image earth-sized extrasolar planets that are within the habitable zone of their parent star up to a distance of 457 lightyears or 4.3×10^{15} km from us. It is capable of detecting the presence of bio-markers like CO_2 , H_2O , methane, carbonate-silicates, abiotic- O_2 etc. which are some of the signatures of life in these extra-solar planets. TMT along with its adaptive optics system would aid in discovering streams of things beyond our current imagination.



Picture shows the primary mirror, secondary mirror (on top), tertiary mirror (ellipsoid at the centre). Photo credits: TMT International Observatory.

Adaptive Optics Technology

The turbulence in the Earth's atmosphere is disadvantageous to astronomers as it blurs the image taken from the ground telescope. However, the Adaptive Optics (AO) technology has overcome this drawback using real-time calculations of the distorted wavefront, computer-controlled deformable mirrors that correct these distorted wavefronts and provide a sharp

image as good as the one obtained from the sky. AO allows the astronomers to observe finer details of much fainter and farther astronomical objects which are otherwise impossible from the ground.

Powerful lasers are beamed into the Earth's upper atmosphere (90 km) which creates artificial star spots that can be used for distortion corrections. The AO facility of TMT is called NFIRAOS (Near Field InfraRed Adaptive Optics System) and uses both natural stars and laser guide stars for AO corrections. AO technology is applied only to the near-IR region; for the visible wavelength region, it is extremely complex to estimate and apply corrections in real-time.

Mirror Segments and Precision Control

The 30 m primary mirror, M1 as we call it, forms the heart of the telescope. It is a segmented mirror consisting of 492 hexagonal mirror segments each with a size of 1.44 m from edge-to-edge of the hexagon and 45 mm thick. The mirror segments are made from Clearceram glass, which is a zero coefficient of expansion glass. The goal is to produce all the M1 segments accurately, quickly and economically, achieved by a unique technique called Stress Mirror Polishing (SMP) that achieves surface accuracy of the mirror within 20 nm Peak-to-Valley and without any subsurface damage. This technology has been well tested and successfully implemented for the Keck telescope (which has 36 segments) by the University of California and Caltech, US (Lubliner 1980).

However, as the number of segments increases (in this case 492), the complexity in making them work cohesively increases manifold. The workshare of segment production is shared between the partners as shown in the Figure below. India will be producing 86 of the 492 segments at the newly

built facility called ITOFF (India-TMT Optics Fabrication Facility), at one of the IIA campuses. The SMP polished mirror segment will then be sent to perform Ion-beam Figuring (IBF) for further etching and polishing reaching an accuracy of 2 nm Peak-to-Valley.

The primary Mirror Control System (M1CS) is responsible for maintaining the overall shape of the assembled mirror segments caused by temperature, gravity, disturbances from wind, seismic vibrations and vibrations that are observatory generated. The M1CS performs this task with the help of three major mechanical structures, namely, Segment Support Assembly (SSA), Actuators and Edge sensors, all working in a closed-loop. India is producing all the required numbers of Edge sensors, Actuators and SSAs for the TMT project.

Edge sensor is the most critical component in controlling the displacement of segments. It is a pair of glass piece, polished and coated with 0.5μ micron gold over 0.05μ chromium coating; consisting of a drive half mounted on one segment and the receiver half mounted on the neighbouring segment. Each sensor measures a combined change in the relative height of the two adjacent segments and in the dihedral angle between the two adjacent segments. The relative displacement, tip, and tilt of the segments measured by edge sensors would be relayed to the actuators. India will be producing all 3284 edge sensors for the TMT.

Actuators perform the precision correction for the segments' tip-tilt and piston errors measured by edge sensors. The precision actuator is designed to meet an RMS tracking error as small as 4.5 nm and is designed to meet a travel range of 5 mm. Each mirror segment will be driven by three actuators – altogether 1476 actuators are required to keep all the segments aligned. Prototyping of these soft actuators has

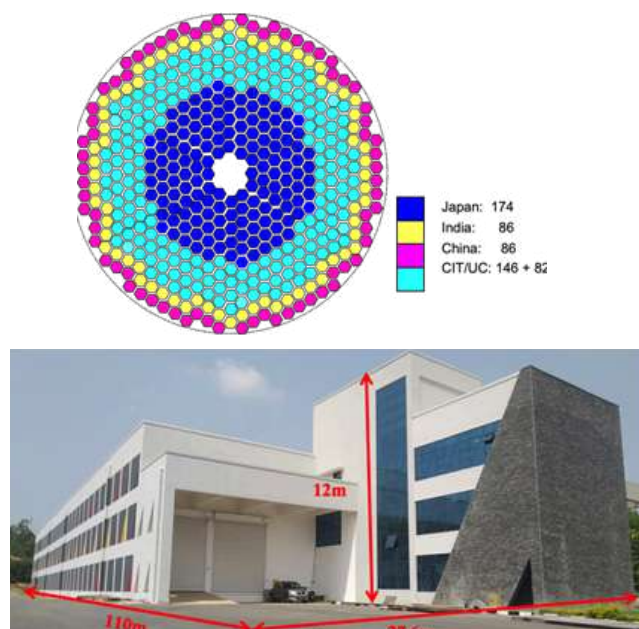
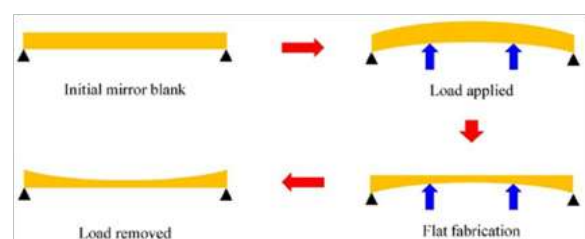


Figure shows the primary mirror segment arrangement. The yellow ring represents the 86 number of segments to be manufactured by ITCC at ITOFF. IIA building (below).



Schematic diagram shows steps involved in Stress Mirror Polishing. Photo shows polishing and Hex-cutting of a practice mirror blank — photocenterica, Bengaluru Credits: S. Sriram, IIA, ITCC

been successfully achieved with Indian vendors. All 1476 actuators will be produced in India.

Each mirror segment is mounted on a support system called the Segment Support Assembly (SSA). Each segment requires one SSA and a total of 492 (+82 spares) SSAs completes the primary mirror control system along with edge sensors and actuators. SSA helps in releasing the stress on the mirror segment that occurs not only due to gravity, but also due to the weight of the mirror segment. Whiffletree arrangement spreads the load across the mirror segment in proper proportions to avoid any distortion in the shape of the segment which in turn would result in the degradation of the image quality of the telescope. India will be manufacturing all the 574 SSAs.

Designing Back-end Science Instruments

India is playing a significant role in design and construction of one of the back-end instruments, WFOS (Wide-field Optical

software. India also contributed to the end-to-end optical design analysis to study the performance of the instrument.

Developing Key Software Systems

India is responsible for developing and delivering some of the principal software systems for the TMT. These include the Observatory Software (OSW), Telescope Control Software (TCS), WFOS instrument controls and Data Management System (DMS). Common Software (CSW) forms the backbone of the software architecture that provides a publish-subscribe communication infrastructure between the principal components of the software system and is completely developed in India.

For AO-assisted science observations, a catalog of natural guide stars across the sky with their parameters to the required accuracy, in infrared, does not exist. Construction of such an Infra-red guide star catalog is also the main contribution from India to the TMT.

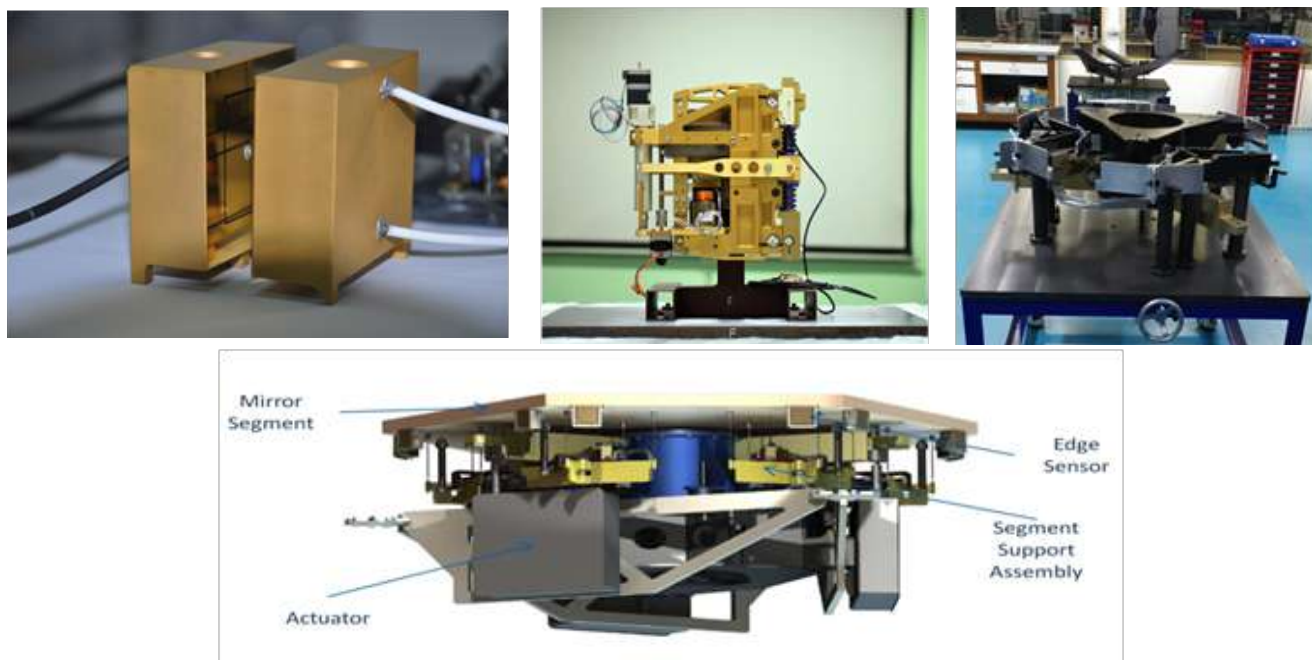


Figure shows a pair of edge sensor, actuator and SSA being assembled at the L&T, Coimbatore. Schematic of single mirror segment along with its support structure is also shown. Photo credits: Kamphues, F., TMT Observatory; Deshmukh, P., Kumar, K., ITCC

Spectrograph). This multi-object spectrograph and imager are designed to operate in the near-UV, visible and near-IR (0.31-1 μ) wavelengths. It is capable of performing multi-slit, multi-object spectroscopy of the faintest sources with multiplexing capabilities of 50-100 objects per observation. The spectrograph is split into two colour channels spanning 310-550 nm and 550-1100 nm passbands allowing for several observing modes (imaging, low to medium resolution) to cater to a wide variety of science scenarios. Some of the key subsystems that

India is developing for WFOS are the grating exchange system, camera rotation system, filter exchanger, calibration system, electronics integration and the instrument control

TMT is currently in the pre-construction or design phase and will enter into the construction phase in 2024-2025 and the project is expected to be completed by 2035. The most preferred site to build TMT is on the dormant volcano Mauna Kea, on the island of Hawaii, US. TMT observatory has also selected the Observatorio del Roque de Los Muchachos (ORM), in La Palma, on the Canary Islands (Spain) as an alternate site to build TMT. The experience gained in developing precision technologies, building instruments and managing large projects will be useful when India starts to build such projects of its own.



HOW MUCH DO YOU KNOW ABOUT MEGA SCIENCE PROJECTS?

1. Name the three main institutes constituting the Thirty Meter Telescope-India (TMT-India).

- IIT Bombay, Raman Research Institute (RRI), National Centre for Radio Astrophysics (NCRA)
- Indian Institute of Space Science and Technology (IIST), Tata Institute of Fundamental Research (TIFR), IIT Kharagpur
- Birla Institute of Science & Technology (BITS), IIT Indore, Indian Institute of Space Science and Technology (IIST)
- Aryabhata Research Institute for Observational Sciences (ARIES)
Indian Institute of Astrophysics (IIA)
Inter-University Center for Astronomy and Astrophysics (IUCAA)



Image credit: <https://tmt.iap.res.in/>

2. Accelerator centre for one of the world's biggest projects for research — Facility for Antiproton and Ion Research (FAIR) — is under construction at

- South of France at the Cadarache site
- GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany
- Bodi West Hills (BWH) in Theni district, Tamil Nadu
- Dudhala village in Hingoli district, Maharashtra



Image credit: <https://fair-center.eu/>

3. Name the project which is a global effort to construct the world's largest radio telescope over one million square metres of collecting area.

- International Thermonuclear Experimental Reactor (ITER) project
- India-based Neutrino Observatory (INO) project
- The Square Kilometre Array (SKA) project
- Laser Interferometer Gravitational-wave Observatory (LIGO-India) project



<https://www.skatelescope.org/>

4. Name the project that aims to make the long-awaited transition from experimental plasma physics to full-scale electricity-producing fusion power stations.

- ITER (International Thermonuclear Experimental Reactor) project
- Square Kilometre Array (SKA) project
- India-based Neutrino Observatory (INO) project
- Laser Interferometer Gravitational-wave Observatory (LIGO-India) project

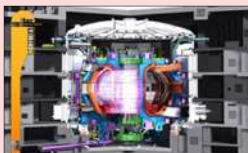


Image credit: www.iter.org

5. International Thermonuclear Experimental Reactor (ITER) will be the largest fusion device which will work onconcept.

- Stellarators
- Beam-target fusion
- Pyroelectric fusion
- Tokamak

6. “Tokamak” is a Russian acronym and stands for.....

- Toroidal Chamber for Magnetic Coils
- Toroidal Chamber with Magnetic Coils
- Toroidal Coil with Magnetic Chamber
- Toroidal Magnetic Chamber

7. In which year the Government approved the INO (India-based Neutrino Observatory) project?

- January 2015
- February 2017
- March 2016
- July 2018

8. Where is the proposed underground site for the India-based Neutrino Observatory (INO) lab located?

- Dudhala village in Hingoli district, Maharashtra
- Darmstadt, Germany
- South of France at the Cadarache site
- Bodi West Hills (BWH) in Theni district, Tamil Nadu



Image credit: www.ino.tifr.res.in/ino/

9.is the site to host the International Thermonuclear Experimental Reactor (ITER).

- Bodi West Hills (BWH) in Theni district, Tamil Nadu
- South of France at the Cadarache site
- Dudhala village in Hingoli district, Maharashtra
- GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany



Image credit: www.iter.org/org/ITERinFrance

10. Mega-science project Laser Interferometer Gravitational-wave Observatory-India (LIGO-India), is jointly funded by which of the two organisations?

a. DBT and MoES
b. CSIR and ISRO
c. DoS and DBT
d. DAE and DST



Image credit: www.ligo-india.in/about/

11. Marking the landmark discovery in 2017, LIGO discovered which waves when two neutron stars smashed together?

a. Gravitational Waves
b. Longitudinal Waves
c. Transverse Waves
d. Electromagnetic Waves



Image credit: www.ligo.caltech.edu/

12. Fundamental physics research organisation in Europe CERN is a French acronym that stands for.....

a. European Council for Nuclear-fission Research
b. European Centre for Nuclear-fusion Research
c. European Council for Nuclear Research
d. Council of European for Nuclear Chemistry Research



13. On _____, Department of Atomic Energy (DAE), entered into a co-operation agreement with CERN, which was followed by a protocol for collaboration in Large Hadron Collider (LHC) on _____.

a. 28 February 1991, 27 February 1996
b. 28 March 1991, 29 March 1996
c. 28 February 1992, 27 February 1997
d. 22 March 1992, 27 March 1997

14. Which countries are involved in the consortium responsible for building of TMT?

a. Australia, Brazil, Italy and Russia
b. France, Switzerland, North Korea and Sweden
c. Canada, China, India, Japan and the USA
d. South Korea, United Kingdom, Belgium and Finland



Image credit: tmt.org

15. As part of its contribution, the Department of Science & Technology (DST) and the Department of Atomic Energy (DAE), Government of India, have jointly formed ITCC (India-TMT Coordination Centre), which is situated at.....

a. Indian Institute of Space Science and Technology (IIST)
b. Indian Institute of Astrophysics (IIA)
c. Tata Institute of Fundamental Research (TIFR)
d. National Centre for Radio Astrophysics (NCRA)

16. Name the nodal institute from India for overseeing activities related to SKA.

a. Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune
b. Indian Institute of Astrophysics (IIA), Bengaluru
c. Aryabhata Research Institute of Observational Sciences (ARIES), Nainital
d. National Centre for Radio Astrophysics (NCRA), Pune



Image credit: www.ncra.tifr.res.in/ncra/main

17. In which year did India become an associate member of the European Organisation for Nuclear Research (CERN)?

a. 2015
b. 2016
c. 2017
d. 2018



Image credit: home.cern/news/

18. India formally joined the International Thermonuclear Experimental Reactor (ITER) Project in which year?

a. 2002
b. 2003
c. 2004
d. 2005



Image credit: www.iter-india.org/

19. 'Vigyan Samagam', a valuable addition to the India International Science Festival (IISF) programme-2019, showcased the Indian science community's participation in how many mega-science projects?

a. Five
b. Six
c. Seven
d. Eight



Image credit: vigyansamagam.in

20. In which four cities this mega science exhibition was hosted in a caravan mode?

a. Hyderabad, Chennai, Pune and Jaipur
b. Mumbai, Bengaluru, Kolkata and Delhi
c. Delhi, Bhopal, Kanpur and Nagpur
d. Ranchi, Visakhapatnam, Chennai and Chandigarh

Answers:

1.d 2.b 3.c 4.a 5.d 6.b 7.a 8.d
9.b 10.d 11.a 12.c 13.b 14.c 15.b 16.d
17.b 18.d 19.c 20.b



**80 YEARS OF
IMPACT**

**Council of Scientific &
Industrial Research**

Leather for Employment



THE leather industry occupies prominence in the Indian economy because of its massive potential for employment, growth and exports. The leather and footwear industry directly employs approximately 4.5 million people, with more than 30% being women.

Established in 1948, CSIR-Central Leather Research Institute (CLRI), Tamil Nadu, has interwoven its research efforts to meet the training needs of industry since the time industry was operating in the cottage sector. Realising the significance of this synergy, the University of Madras handed over the Department of Leather Technology to be housed at CSIR-CLRI. CSIR-CLRI employs Science and Technology to develop society through a strong connection of the academy, research and industry, hosting the trinity model. The Institute's education, training and skill development initiatives nurture human resources and enable the percolation of the cutting-edge technologies developed at CSIR-CLRI into the industry.

The latest in the list includes technologies like waterless chrome tanning process, electro-oxidation based zero wastewater discharge, smart leathers, compost for agricultural applications, product for dry tanning, high-value collagenous products and activated carbon from trimming and fleshing

wastes, preservation-cum-unhairing process and biogas for energy conservation. The transfer of such technologies to the leather and leather product industries (existing and startups) has contributed directly to an increase in the existing employee base and new job creation.





CSIR-CLRI has also developed technologies for culling out wealth from waste, including combining banana fibres and leather scrap and exotic leather products from chicken feet skins (poultry waste). These interventions have been disseminated *via* training programmes.

CSIR-CLRI has always led the nation in skill development programmes at the primary level. Around 9390 artisans have been trained pan India since 2006 in association with sponsoring organisations like National Scheduled Castes Finance and Development Corporation and Gujarat Rural Industries Marketing Corporation Limited, and 3703 artisans trained by Central Footwear Training Institute have been assessed for skill training. More than 80% of primary level candidates are placed every year in wage/self-employment, with around 5% of candidates taking up entrepreneurship (individual/Self-help Groups).

Under the Leather Technology Mission, CSIR-CLRI has revived the traditional Kolhapuri chappal industry in the Athani leather cluster of Karnataka through technological intervention and training support, benefitting around 250 artisanal families.

CSIR-CLRI is the programme implementation unit (tannery sector) under the Indian Footwear Leather and Accessories Development Programme, Department for Promotion of Industry and Internal Trade (formerly DIPP), Government of India and has contributed to the creation of jobs for 9272 skilled workforces from 2017 to 2021. During the 11th and 12th five-year plans, CSIR-CLRI functioned as the National Monitoring Unit to monitor the human resource activities sponsored by the DIPP, monitoring around 5.5 lakh candidates pan India.

Probing into high-end skilling requirements, more than 3400 Indians have undergone professional training from CSIR-CLRI in the form of Diploma, PG Diploma and industry-oriented executive courses (standardised and tailor-made) – 30% of these candidates are entrepreneurs generating employment and the rest occupy prominent positions in the industry.

CSIR-CLRI organises various academic programmes — BTech (Leather Technology), MTech (Leather Technology/ Footwear Science and Engineering) and MS by research in collaboration with Anna University. Having stepped into the Platinum Jubilee Year, more than 2000 candidates have completed their BTech/MTech programmes to date through this academic partnership.

Today, the industry's absorption of CSIR-CLRI trained technologists is close to 100% of the supply. CSIR-CLRI has also turned out more than 450 Doctoral candidates in leather and allied sectors in association with Anna University, Madras University and Academy of Scientific and Innovative Research. Today, 50% of the Indian Leather Industry is being managed by CSIR-CLRI alumni. They command a 1 in 3 ratio of the global supply of tertiary level workforce in the leather industry.

Augmenting the capacity of national and international training institutions in leather and leather products has always been on the agenda of CSIR-CLRI. More than 450 citizens from 65 countries (including 14 countries of Africa) have been trained at CSIR-CLRI, carving an international research-cum-skill ecosystem. The Leather Industry Development Institute (LIDI) in Ethiopia on a twinning mode is a classic example. It has led to the growth transformation of the leather sector in Ethiopia.

CSIR-CLRI has successfully registered 8 of its PG Diploma, Diploma and executive courses under the National Qualifications Register. It is the first Laboratory among CSIR to obtain such accreditation and issue accredited skill certificates for its Skill Development Programmes under the National Skill Development Agency. CSIR-CLRI is also an assessor and endorsing body for the Leather Sector Skill Council (LSSC).

CSIR-CLRI pledges to continue its journey keeping in mind its motto of “doing better today than yesterday, forever”, and building lives from the bottom.

Adapted from the CSIR Blog (<https://www.csir.res.in/csirblog-success-stories>)

Integrated Municipal Solid Waste Disposal System (i-MSWDS)



MSW Management Pilot Plant towards Zero Waste
CSIR-CMERI Colony

WITH ever-increasing population and urbanisation, the country is facing a huge challenge in waste management. The volume of waste is projected to increase from 62 million tonnes at present to about 165 million tonnes by 2030. Dumping of garbage at the current rate without any treatment would require about 1240 hectares of landfill area per year and with projected generation of 165 million tons of waste by 2030. Setting up landfills for 20 years with 10 m height will require 66,000 hectares of land. This necessitates the importance of scientific solid waste management in today's context.

Waste-to-energy is an option for sustainable solid waste management and it is the need of the hour to realise its potential as one of the most significant future renewable energy sources. Studies suggest that the MSW generated in India mostly consists of a large fraction of organic wastes (40-60%). Unscientific waste disposal practices in landfill sites produce Greenhouse Gas (GHG) emissions and other air pollutants. Methane emitted from landfills is one of the most important contributors to GHGs.

Scientific and most popular techniques for the disposal of wet waste include composting and bio-methanation plants. As per information available for 2013-14, compiled by CPCB, municipal authorities have so far only set up 553 compost & vermicompost plants, 56 bio-methanation plants, 22 RDF plants and 13 Waste-to-Energy (W to E) plants in the country. Many of these plants have experienced failure due to several issues related to the segregation of waste, low calorific values

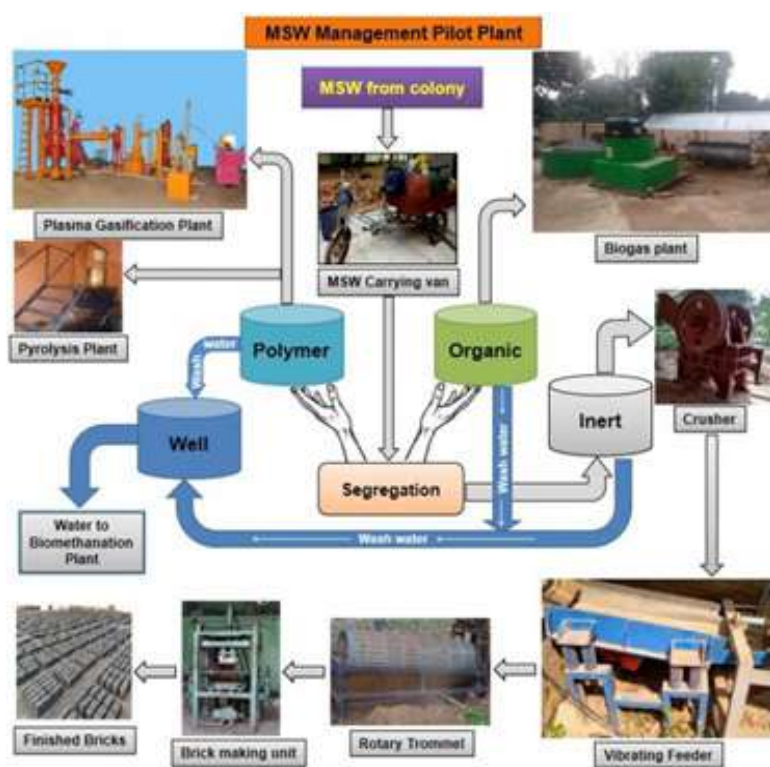
of the waste and challenges in the operation and maintenance of the plants (CPCB 2013-14).

The CSIR-CMERI (CSIR-Central Mechanical Engineering Research Institute), Durgapur, has developed an integrated Municipal Solid Waste disposal system (*i*-MSWDS) for disposal of solid waste in a scientific way in line with Solid Waste Management Rules (SWM) 2016 prescribed by the Union Ministry of Environment, Forests and Climate Change (MoEF&CC), Govt of India.

The integrated municipal solid waste disposal system starts with the mechanized segregation of solid waste. The mechanized segregation system segregates solid waste into metallic waste (metal body, metal container, etc.), biodegradable waste (foods, vegetables, fruits, grass, etc.), non-biodegradable (plastics, packaging material, pouches, bottles, etc.) and inert wastes (glass, stones, etc.).

The bio-degradable component of the waste can be decomposed in an anaerobic environment popularly known as bio-gasification. In this process, biogas is liberated through the conversion of organic matter. The biogas has a typical volumetric composition of 55-60% methane and 35-40% CO₂ with traces of moisture and other impurities such as hydrogen sulphide and it can be used as fuel for cooking purposes. The gas can also be utilised in gas engine for the generation of electricity.

The residual slurry is good organic manure and utilised as fertilizer. The organic waste is also converted to compost in



a natural process known as vermi-composting by introducing earthworms. The vermi-compost is utilised in organic farming.

Biomass waste such as dry leaves, dead branches, dry grass, etc. is disposed of by first shredding it to a suitable size followed by mixing with the slurry of the biogas digester. This mixture is feedstock for briquette, which is utilised as fuel for cooking. These briquettes are also being utilised in gasifier for the production of syngas which is a mixture of mainly carbon monoxide and hydrogen. The syngas has a calorific value equivalent to that of biogas and hence can be utilised in gas engine for generation of electricity. The ash produced from burning of briquette is mixed with cement and water in an appropriate proportion for the production of bricks which are used for construction work.

The polymer waste consisting of plastics, sanitary waste, etc. is being disposed through two main processes i.e. pyrolysis and plasma gasification. In the pyrolysis process, the polymer waste is heated to a temperature of 400-600°C in an anaerobic environment in presence of a suitable catalyst. The volatile matter from the polymer waste comes out as a result of heating which on condensation gives pyrolysis oil. Different heating mechanisms such as solid fuel-based, liquid fuel-based and gaseous fuel-based in standalone mode or combined mode have been developed for carrying out the process.

The pyrolysis oil is termed as Petro Alternate Fuel (PAF). The crude pyrolysis oil after purification can be used in industrial boilers, generators, etc. for heating/power generation purposes. The non-condensed syngas from the pyrolysis process is fed to the gas engine for the generation of electricity. The solid residue known as char is mixed with the biogas slurry for the production of briquette. These briquettes

are being utilised for heating the reactor of the pyrolysis process thereby making the process self-sustainable in terms of fuel.

The polymer waste or sanitary items are also disposed of utilising high-temperature plasma. The plasma gasification process converts the waste into syngas which can be utilised for the generation of electricity. The residual ash is mixed with cement for the preparation of bricks.

The Construction and Demolition (C&D) waste is crushed in a jaw crusher and then segregated in different sizes in the trommel. The fines are mixed with cement and water in appropriate proportion. The prepared mixture is then filled in the mould cavity of brick press. Then it is being pressed using hydraulic press to give it a proper shape and compaction. The bricks are cured to achieve the desired strength. Finally, the prepared bricks are tested for engineering properties. The ready bricks are being used as construction materials. The oversized crushed materials are used as aggregate in PCC road making.

CSIR-CMERI has already installed an MSW Management Pilot Plant in CMERI Colony where day-to-day waste generated at CMERI Colony is being processed aiming towards a “Zero Waste CSIR-CMERI Colony”. No waste has been discarded from the Colony in the last two years. The CSIR-CMERI MSW Management Technology is completely energy sustainable. The Cyclic Model of Waste Processing facilitates this energy sufficiency of the MSW Technology.

CSIR-CMERI steadily envisions a ‘Zero-Landfill’ and a ‘Zero-Waste City,’ by possibly espousing a business model for the MSMEs whereby individuals can deliver their household wastes to the garbage collectors who are incentivized for delivering the wastes to the MSW facilities. This will give the necessary enthusiasm for the citizens of a city to participate in waste management efforts.

CSIR-CMERI organises three-day workshops on handling of municipal solid waste and legacy waste. Programmes such as these are intended to raise the awareness levels of young minds on waste management and skill them with appropriate know-how on advanced and indigenously developed MSW Technologies.

The MSW management technology involves the participation of the local community in the operations and maintenance of the technology, thereby empowering the community with the necessary skills for employment opportunities. A decentralised model of waste processing also helps reduce expenditure on transportation thereby saving valuable resources on fossil fuels, which are both import-dependent and pollution-causing. Indirectly it will also have consequences on reducing medical expenses and protect mankind against toxic gases and wastes.

CSIR-CMERI has already installed and commissioned biogas plants of different capacities at different locations in West Bengal. In addition, CSIR-CMERI, Durgapur, is engaged in providing waste management solutions to CRPF Group Centre, Amrawati and PHE Department, Govt of Manipur.

Adapted from the CSIR Blog (<https://www.csir.res.in/csirblog-success-stories>)



CSIR Young Scientist Awards 2021

The “CSIR Young Scientist Awards” are given to Young Scientists (below 35 years of age) in the CSIR system to promote excellence in various fields of science and technology. The awards are given every year in the following fields:

- ▶ Biological Sciences
- ▶ Chemical Sciences
- ▶ Earth, Atmosphere, Ocean and Planetary Sciences
- ▶ Engineering Sciences
- ▶ Physical Sciences (including instrumentation)

Each award consists of a citation, a cash prize of rupees fifty thousand and a plaque. CSIR Young Scientist Awardees are also entitled to a research grant of rupees five lakh per annum for a period of five years and an honorarium of rupees seven thousand and five hundred per month till the age of 45 years.

Here are the prize winners of the CSIR Young Scientist Awards 2021 talking about what fetched them the award this year.

BIOLOGICAL SCIENCES

Mechanisms of Gene Regulation Genetic & Epigenetic Factors



Dr Divya Tej Sowpati

The CSIR Young Scientist Award for the year 2021 in Biological Sciences has been awarded to Dr Divya Tej Sowpati of CSIR-Centre for Cellular and Molecular Biology,

Hyderabad, for his outstanding contributions to understand the mechanisms of regulation of gene expression using genomic technologies.

DNA present within cells, collectively known as the genome, is the instruction manual read by the cellular machinery to live and function. Hence, all the complexity and variation seen in life on earth is encoded in the genome, written in a language of four letters – A, T, G, C. A lot of research has been done in understanding how the genome encodes traits that we observe, also known as phenotypes. However, the functions of a large part of the genome still remain unknown. Our lab is interested in understanding such functions, and we study this at two levels.

First, we ask how changes in the genome among individuals of a species (for example humans) can give rise to changes in phenotypic outcomes, particularly in the context of health and disease. Work towards this includes sequencing either healthy individuals (to understand the scope of natural variation in populations), or individuals with specific disorders (to understand the genetic basis of the disorders), or studying existing genome data to mine differences in their sequences.

The second vertical of our work studies phenotypic variation within the individual. All cells in a complex multicellular organism have developed from a single-celled zygote, and therefore share the exact same genome. But we know that all cells are their unique selves, performing different functions in the organism. For example, a neuron forms synapses with other neuronal cells and responds to environmental and chemical stimuli, whereas liver cells specialize in metabolism, and muscle cells join other muscle cells to form myotubes that are the core components of muscle fibers. If the genome is the instruction manual of life, how is it that different cells are reading different “chapters” of the manual to achieve their unique functions? To put it more objectively: how can one genome give rise to multiple phenotypes? This is possible because the cells can “bookmark” the instructions that are relevant to their function. The bookmarks are nothing but chemical modifications known as epigenetic modifications that happen either on the DNA or on proteins around which the DNA is wrapped. We study epigenomes (collection of epigenetic modifications) to understand how heterogeneity arises from the same genome, or how cells and organisms respond to environmental stimuli.

I would be focusing here on a subset of our work in the first vertical, on DNA repeat elements known as microsatellites.

Microsatellites

Only ~1.5% of the human genome is made of genes, which code for the functional units of the cell called proteins. The rest of the genome makes up what is known as the non-coding DNA. Previously thought to be “junk” DNA, we now know that the non-coding DNA plays important roles in regulation of how the coding DNA is expressed. Out of the many elements that make up the ncDNA, repeats comprise a large percentage. Repeats, as the name suggests, are DNA elements that show high sequence similarity with each other. They can be divided into two major groups: tandem and interspersed. Interspersed repeats are where the similar sequences are disrupted by other non-repetitive sequences, whereas tandem repeats are formed by motifs repeating right next to each other.

Microsatellites are a class of tandem repeats where short motifs (1-6 nucleotides) of DNA are repeated over and over again, as shown in the example in Figure 1. Microsatellites add variation to individuals within a species because their length is polymorphic – the number of times a motif is repeated is highly dynamic within populations. This happens because of the way DNA polymerase, the enzyme that replicates DNA, behaves when it encounters microsatellites. Due to their intrinsic polymorphic nature, microsatellites have found several usages in fields like genotyping and forensics. For example, the routinely used test for resolving parental conflicts using DNA fingerprinting relies on length

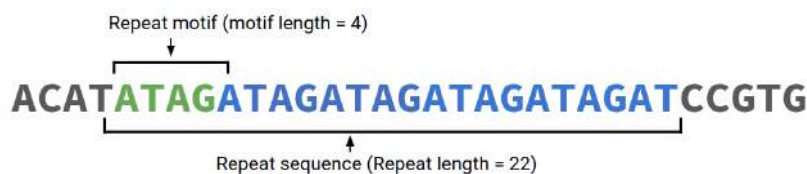


Figure 1: An example of a tetramer (4-nt motif) repeat of the motif ATAG. The entire repeat sequence is highlighted in blue, whereas the repeating motif is highlighted in green

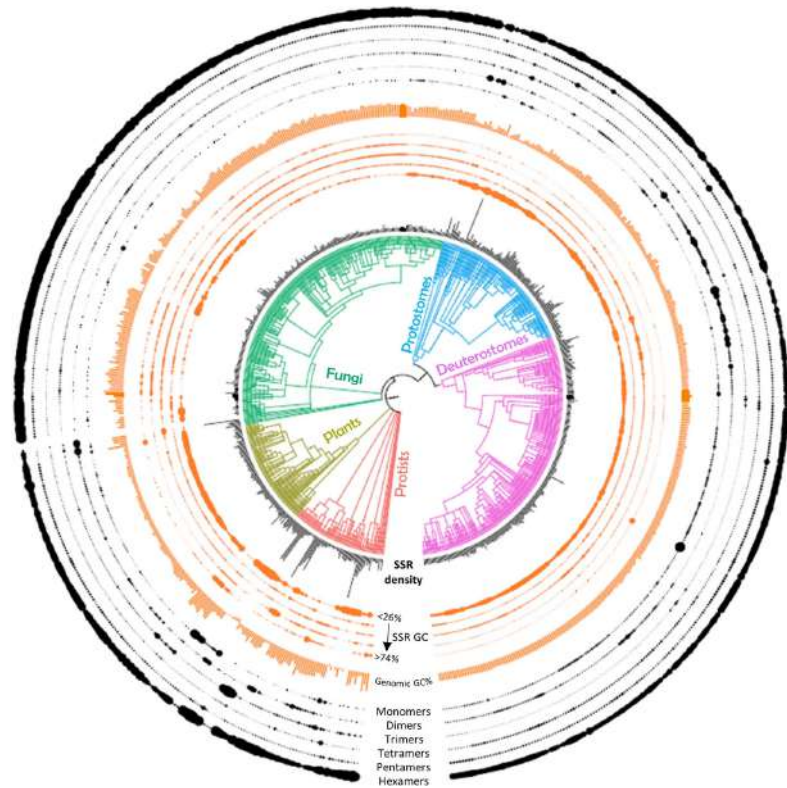


Figure 2: Phylogenetic tree representation summarizing attributes of microsatellites analyzed from 715 eukaryotic genomes. The clade nodes are colored based on the 5 groups used in this study. Black bars (the innermost track) around the organisms represent the microsatellite density (how frequently microsatellites are found, normalized to the genome size) in each organism. The orange tracks microsatellite GC% in each organism (the innermost orange track represents the relative enrichment of motifs with $\leq 25\%$ GC, while the outermost orange track represents $\text{SSR GC} > 75\%$) and the middle three tracks represent intermediate GC ranges. The size of each dot on the track (representing each organism) indicates the amount of SSRs present in that GC range. The orange bars represent the genomic GC content. The black tracks show the distribution in each organism based on the motif size of the repeat (the innermost black track represents monomers while the outermost black track represents hexamers). The size of each dot on the track (representing each organism) indicates the proportion of SSRs present in that motif size range

polymorphisms of microsatellites. However, work in our lab focuses on something more fundamental: the origin and function of microsatellites, with a special focus on their roles in regulation of gene expression.

When we first set out to work on microsatellites a few years ago, we realized that the computational tools that existed to identify microsatellites in a genome either lacked in speed or accuracy. Hence, analyzing these elements from a large number of genomes was impractical. To this end, we developed a novel algorithm that uses set membership theory to accurately identify all perfect microsatellites without compromising speed. This tool, which we called PERF (stands for a recursive acronym “PERF is an Exhaustive Repeat Finder”), could process the entire human genome (3 billion bases or 3 gigabases) in 7 minutes, compared to the previous best which was taking a couple of days.

Using PERF, we could study these elements in all genomes that were sequenced so far. We also developed a database called MSDB (MicroSatellite DataBase), to host the microsatellite data that we generated from all genomes. MSDB is by far the largest collection of microsatellites, with information of more than 5.2 billion elements mined from more than 46000 genomes. Unlike traditional databases which display such vast information in tables that are cumbersome

to read and comprehend, we also built a responsive web UI that enables users to access this information in a user friendly layout as interactive charts and tables. MSDB is openly accessible at <https://data.ccmb.res.in/msdb/>.

We further performed an in-depth analysis of microsatellite data from more than 700 eukaryotic genomes to study their patterns. Our analysis revealed that while simple and unicellular organisms showed diversity in their microsatellite content, that of complex and heterogeneous organisms was highly constrained. This helped us converge on a subset of repeats that have been under constant evolutionary selection pressure, indicating their probable important regulatory roles in the genomes. A summary of this work is provided in Figure 2.

A natural sequent of our work is to understand how the subset of microsatellites that were “refined” in due course of evolution develop polymorphisms within a species. Previous work from other labs has also indicated that the length polymorphisms of these elements can affect the expression of nearby genes. Given the pervasive availability of population-level genomic data, our current goals are to utilize these data to study length polymorphisms of microsatellites at population scale. Unlike the reference human which is 3 gigabases, a population scale genome is 30 times larger, at around 100 gigabases (this is done to increase the confidence with which we can identify variations in an individual, the details of this is beyond the scope of this article). Hence, even the speed of PERF was not enough to study population scale genomes – mining them in a thousand genomes would take 210 minutes per genome $\times 1000 = 5$ months.

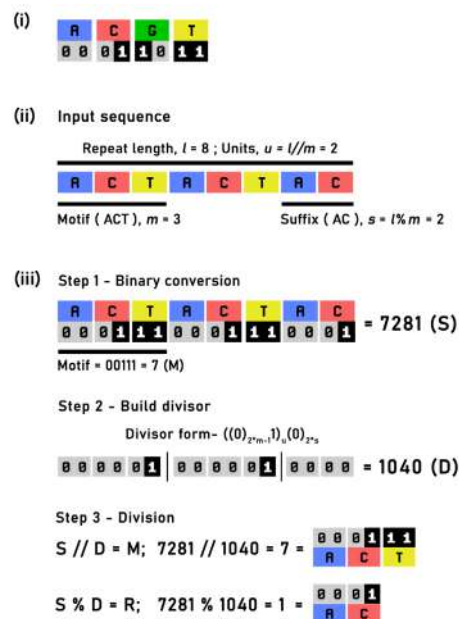


Figure 3: i) 2-bit representation of each nucleotide. ii) Example repeat sequence of ACT motif ($m=3$) with 2 complete units ($u=2$) and a suffix of 2 bases ($s=2$). iii) Binary representation of the repeat sequence generates a number denoted by S, which here is 7281. The binary representation of the motif, ACT, yields the number 7 and is denoted by M. The divisor (D) is built based on the lengths of the repeat, the motif and the suffix and is of the numerical form $((0)_{2^m-1})_u(0)_{2^s}$. The value of D is 1040 here. The division of S with D yields a quotient, which is 7, equal to binary representation of the motif and the remainder equals binary representation of partial suffix.

So, we developed another algorithm for efficient and ultrafast identification of microsatellites. This works on a mathematical property that exists in an alternative representation of DNA sequences called the 2-bit format. In computers, each letter/symbol is typically encoded as 8 binary digits or bits. However, as DNA's language needs just 4 letters, DNA sequences can be encoded in just 2 bits, effectively reducing the storage needs by 4-fold. In this alternative representation, tandemly repeated DNA sequences conform to a unique arithmetic division rule, as explained in Figure 3. Our tool DiviSSR (pronounced divisor) is able to leverage this property and has brought down the time required to process the data by 15 times. We are further improving this algorithm to make it multi-threaded, which will enable us to analyze multiple datasets in parallel.

COVID19 Genomics

Viruses, like all organisms, constantly acquire new changes in their genome as part of their natural evolution within their hosts. Most of these changes are inconsequential or downright disadvantageous for the virus, and hence will be selected against. However, once in a while, they acquire changes that offer them an advantage compared to those which do not carry that change. The novel coronavirus, called SARS-CoV-2, mutates once every two weeks as it passes from host to host. Tracking the evolution of this virus allows us to identify variants that may be more transmissible, cause more severe COVID-19, bypass existing immunity (both natural and vaccine-driven), or escape detection by diagnostic tests. In addition, it allows us to conduct a molecular surveillance to understand the spatio-temporal dynamics of how the cases are spreading.

Though we did not work on viral genomes before the pandemic, our basic understanding of genomics enabled us to contribute towards studying SARS-CoV-2 genomes. When the entire nation geared up for a lockdown in March 2020, we were working 20 hours a day to set up viral genome sequencing in our laboratories. Our team was one of the first in the nation to standardize SARS-CoV-2 sequencing, with first data sets coming out as early as the first week of April. Since then we went on to sequence thousands of viral genomes, and we are currently part of the nationwide SARS-CoV-2 genome sequencing consortium called INSACOG. In addition to sequencing, our team also developed and standardized pipelines for analysis of this data.

In May 2020, we analyzed and identified a novel clade (evolutionarily shared group of sequences) of SARS-CoV-2, which we called the A3i clade, which was responsible for the initial outbreak of COVID-19 in India. We also studied the host response to COVID-19 at a gene and molecular level. This study showed that genes involved in viral defense got activated in COVID-19 patients, whereas those involved in sensing smell and taste got deactivated – correlating well with clinical symptoms of COVID-19.

We also developed a web resource named GEAR19 (Genome Evolution Analysis Resource for COVID-19) that tracks all Indian SARS-CoV-2 genomes deposited publicly, and displays them on an interactive web portal. GEAR19 is accessible at <https://data.ccmb.res.in/gear19>. Our further

work on COVID-19 was on re-infections (the same individual getting infected multiple times with genetically distinct strains of SARS-CoV-2), breakthrough (post-vaccination) infections, screening international passengers for variants of concern, growth advantage analysis on the globally prevalent Delta variant, and so on. Using a skillset that we developed over several years, we are glad we got a chance to contribute to a problem that has become a global menace.

Dr Divya Tej Sowpati is a Scientist at the CSIR-Centre for Cellular and Molecular Biology (CSIR-CCMB) Hyderabad. He is currently leading COVID-19 genomics at CSIR-CCMB. Email: tej@ccmb.res.in

Developing Next-generation Insecticides for Sustainable Agriculture



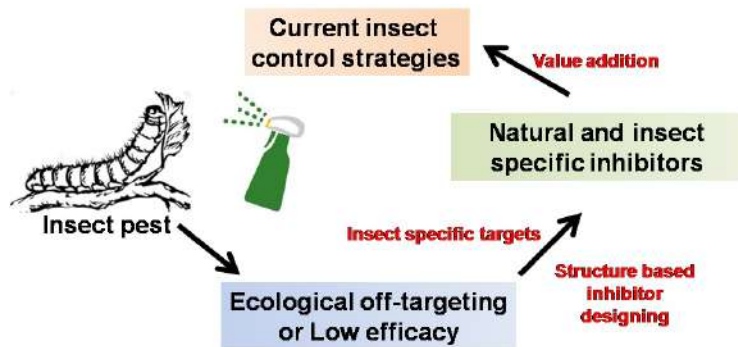
Dr Rakesh Shamsunder Joshi

The CSIR Young Scientist Award for the year 2021 in Biological Sciences has been awarded to Dr Rakesh Shamsunder

Joshi of CSIR-National Chemical Laboratory, Pune, for his significant contributions in the understanding of neglected insect metabolisms and targeting them to provide a sustainable alternative to existing pest management.

A PART from its direct impact on global temperature, sea level, and overall environmental changes, climate change has several indirect implications too. For instance, due to increase in greenhouse gases overall carbon to nitrogen ratio (C:N) of plants has increased, making plants more vulnerable to insect attacks. Increased temperatures have also led to ramping up of insect metabolism, increasing their food intake and leading to rapid increase in reproduction rates and the average number of generations per year. This scenario has converted several insects into pests of different crops. In addition to causing direct harm to plants, insect pests are vectors for several bacterial and viral plant diseases.

India ranks second worldwide in agriculture productivity and contributes around 17-18% to the country's GDP. Almost



Schematic of our group research work theme depicting the need for new insect controlling methods

60% of the Indian population depends on agriculture for livelihood. Total crop loss caused by insect attacks ranges from 30 to 40%, depending on the severity of the attack. This loss is estimated at around USD 70 to 80 billion each year, causing socio-economic difficulties for farmers.

Application of various insecticides and transgenic plants with insect resistance or tolerance are successful in mitigating insect attacks. However, most existing insecticides are highly reactive molecules that can interact with natural resources and pollute them. Besides, insecticides can have similar but unintended toxic impact on non-targets as well. Therefore, it is vital to identify and validate insect pest-specific metabolisms or processes and block these targets using natural molecules.

In my doctoral research work, I identified and validated peptides and small molecules as effective inhibitors of insect gut protease. Upon bioassay, it was observed that all these molecules exhibit a significant negative impact on larval growth, survival rate and other nutritional parameters.

In the quest to identify insect-specific targets for cidal molecule development, we focused on pathways involved in insect metamorphosis, development and peculiar behaviour like feeding or foraging. An insect's lifecycle goes from eggs to larva to pupa, finally converting into an adult moth. After moth formation, these insects can spread across the habitat. This process of metamorphosis, development and flight needs energy reserve. So, when an insect goes to pupa formation, it reserves an ample amount of energy in reserve sugar, trehalose.

Trehalose serves as primary circulatory sugar. It is synthesized in a specialized organ called the fat body through trehalose phosphate synthase (Tps) and trehalose phosphate phosphatase (Tpp). When energy is required, this trehalose is broken down into two glucose molecules by an enzyme called trehalase. Trehalose synthesis has predominantly occurred in invertebrates, but higher vertebrates don't possess the ability to synthesize trehalose. Also, trehalase is expressed in higher eukaryotes only upon a defect in the excretory system. Hence, these enzymes are lucrative targets to devise insect control methods.

My group gathered significant insights on the structure-functional characteristics of Lepidopteran trehalases. We solved the crystal structure of the ligand-free and ligand-bound form of trehalases, which enabled us to delineate the conformational changes accompanying ligand binding in trehalases. We identified several conserved residues and their importance in enzyme activity. Many of these identified residues form part of signature motifs and other conserved sequences in trehalases. The structure analysis thus led to the assignment of the functional role to these conserved residues. This information can be further explored for the design of effective inhibitors against trehalases. This study generated structural information about species-specific molecular features of trehalase to screen natural sugar analogues, followed by structure-based inhibitor designing.



Dr Rakesh Joshi group at CSIR-NCL – From left; Rakesh Joshi, Meenakshi Tellis, Vikram Nichit, Aruna Patil, Sharada Mohite, Yogita Patil, Deepti Wagh and Bhagyshri Chaudhari

We identified fungal metabolite, Validamycin A, whose product Validoxylamine A is a structural analogue of trehalose as a potent inhibitor of *Helicoverpa armigera* (devastating lepidopteran pest) trehalase. Ingestion of Validamycin A resulted in impediment of *H. armigera* growth and developmental defects. Treated larvae showed a concentration-dependent decrease in reproduction. When we used this molecule as a value addition to existing bio-pesticides, relatively high insect mortality of *H. armigera* was observed on tomato plants sprayed with a combination of Validamycin A with *Azadirachta indica* (neem) and *Pongamia pinnata* (karanj) oil as compared to the individual treatments.

We are also studying differential trehalose distribution from the site of synthesis (fat bodies) and to the energy-striving tissues or organs like muscle or testis. Trehalose synthesis and transport are crucial processes for carbohydrate homeostasis and the energy demand-supply equation. We are trying to understand the process of trehalose synthesis, breakdown, uptake and discharge in insects. We have found that inhibition of trehalose synthesis or degradation causes defect in ecdysis (skin formation during metamorphosis) and wing development. Due to which insects are not able to come out of the pupal chamber and die untimely. We are searching for natural molecules to halt these insect-specific and vital processes by translating this research into the field.

Our group hopes to make further efforts in understanding insect biology and devising new bio-control methods to contribute to the aim of sustainable agriculture. We intend to apply cutting-edge agricultural research to improve the country's agrarian productivity scenario. I strongly feel that India's first Green Revolution was nearly 60 years ago; it is now time to work towards a second one.

Dr Rakesh Joshi is a Biochemist working on the exploration of developmental and metabolic pathways of insects. He is currently a Scientist at the CSIR-National Chemical Laboratory (CSIR-NCL), Pune where he is working on the exploration of insect-specific metabolic and developmental pathways. He aims to use the obtained information to design next-generation insect control molecules to devise a sustainable pest management strategy.

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Expanding the Limits of Bioinspired Nanocatalysts



Dr Amit Ashok Vernekar

The CSIR Young Scientist Award for the year 2021 in Chemical Sciences has been awarded to Dr Amit Ashok Vernekar of CSIR-Central Leather

Research Institute, Chennai, for his significant contributions in the area of bio-inspired chemistry, focusing on engineering crystal systems that impart enzyme-like functions to nanomaterials, and its applications in chemistry and biology.

CURRENTLY, at CSIR-CLRI, my group is focusing on imparting catalytic properties of monomeric and multimeric enzymes to inorganic heterogeneous and atomic-scale materials for multiple applications. The team also investigates the abiological reactions of enzymes for sustainable catalytic applications.

Biomimetic chemistry is an emerging area of research wherein desirable superior biological properties are imparted to synthetic chemical systems for use in various applications such as catalysis, food processing, diagnostics, therapeutics, and drug delivery. One such biological entity, a complex molecular machine that fascinates scientists the most is an enzyme. Enzymes are nature's super catalysts that carry out various biochemical reactions in living organisms with extreme specificity and tremendous efficiency.

In nature, metalloenzymes have a unique yet complicated role in their niche ecological environment such as activation of small molecules, regulation of Reactive Oxygen Species (ROS), combating oxidative stress, and transformation reactions. Interesting examples to point out are the conversion of methane to methanol by methanogens by breaking the strong carbon-hydrogen bond and nitrogenase enzyme that splits the inert dinitrogen triple bond to make ammonia. This superiority of enzyme performance with much ease has driven the curiosity amongst researchers to investigate their structural features, delineating mechanisms in detail by understanding intermediates and complex coordinating environment at the active site.

Enzymes are produced by organisms and have low stability outside biological systems. Scientists have used enzymes directly for various reactions but their expensive expression, extraction, purification, and low shelf-life limit their widespread usage. An enzyme mimic deals with these limitations by fabricating a small molecular system that can exhibit desired properties of enzymes. In this aspect, the term "artificial enzyme" was coined by Prof. Ronald Breslow.

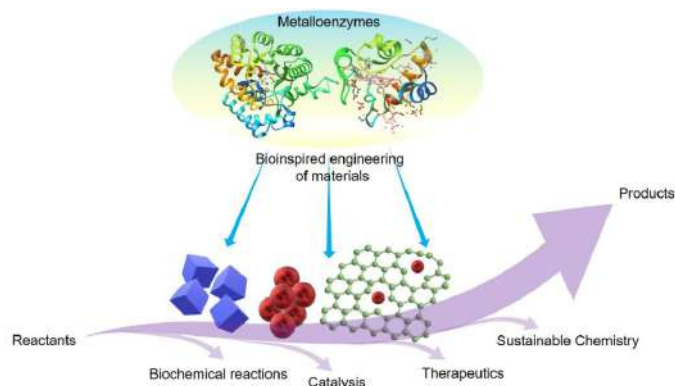
The study of artificial enzymes does not necessarily aim to copy the entire natural enzyme system, but focuses on exploring the different features of their active site. The diverse nature of enzymes to catalyze the reactions which are otherwise non-trivial has become a guiding light in tackling the current challenges related to sustainable development.

Research and development in the field of artificial enzymes has escalated to the next level of mimics, nanozymes. Nanozymes are well regarded as surrogates of enzymes for mimicking enzymes' active catalytic site and have gained rapid popularity for serving as a simple alternative of enzyme mimic without the need for constructing a complex protein framework. Over the last few years, a large variety of nanozymes have been reported related to peroxidases, oxidases, hydrolases and some antioxidant enzymes.

Imparting enzyme-like catalytic properties to heterogeneous catalytic systems and atomic-scale materials without compromising the efficiency, specificity and selectivity of the reaction is a highly challenging task. To fill this gap in the area of enzyme mimetic research, my team is implementing the fundamentals of bioinorganic chemistry to tune the selectivity and specificity of nanozymes by engineering the crystal structure and the core of heterogeneous materials.

While designing the next-generation nanozymes, our team observed that through structural engineering of the heterogeneous materials, the catalytic function can be highly tuned to work under physiologically relevant conditions. This phenomenon is very rare and is highly crucial for redox nanozymes that are often active at acidic pH. We found that the inductive effect in the crystal system alters the chemistry occurring at the surface of the nanozymes.

In another related study, we constructed an amorphous material that catalytically generates hydrogen from solid chemical hydrogen storage sources, following a shift in the kinetics to Michaelis-Menten. Hydrogen is considered a fuel of the future that can sustainably drive the wheel of development. Currently, the widespread usage of hydrogen is limited by the unavailability of appreciable catalysts and economical hydrogen storage material.





Dr Amit Ashok Vernekar with team members

Our research group is focused on designing bio-inspired materials as catalysts for hydrogen generation reactions. We observed that the peculiar property of multimeric enzymes called “cooperativity or allosterism” can be brought into solid heterogeneous materials. Allosterism refers to the increased affinity of binding of substrate to the active sites at the distant position when the first substrate molecule binds one active site that alters the structure of the enzyme. Such enzymes have a strong feedback mechanism and have an upper hand in controlling the reactions. A notable example includes metallohydrogenases responsible for the activation of hydrogen and proton reduction. Designing a heterogeneous catalyst with such allosteric properties is an intricate task and several attempts to bring in such a property into heterogeneous materials have failed. To date, only a few molecular catalysts are known to exhibit allosteric effects.

Our team observed that the addition of a fraction of one type of metal into the matrix of alloys induces electronic effects in the system that leads to electronic cooperativity during the catalysis. While it is difficult for the solid catalyst to alter the shape upon binding of one substrate molecule to the active site, we observed that the catalyst communicates electronically, exhibiting electronic cooperativity and generated hydrogen from solid chemical hydrogen storage sources.

As the field of bioinspired nanocatalysts is in its infancy and the reported catalysts face issues with biocompatibility, selectivity, catalytic efficiency, etc., we believe that through this research we will be able to tackle these challenges to expand the limits of usage of bioinspired nanocatalysts. The concept of altering crystal structures for inducing enzyme-like function in the nano and atomic-scale materials may open up new avenues that may have potential applications in several industrial reactions, biochemical reactions, therapeutics, energy and sustainability.

Dr Amit Ashok Vernekar is a Scientist at the CSIR-Central Leather Research Institute (CLRI), Chennai.

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website: <https://sites.google.com/view/av-laboratory/home>

Unique Sensing Platform for Electrochemical Detection of Biomarkers

Dr K. Giribabu



The CSIR Young Scientist Award for the year 2021 in Chemical Sciences has been awarded to Dr K. Giribabu of CSIR-Central Electrochemical Research Institute, Karaikudi, for developing a unique

sensing platform for the electrochemical detection of several biomarkers by interfacial tuning of immiscible liquid-liquid junctions. This way of fabrication of non-enzymatic biosensor using biogenic amines has profound implications in designing early warning systems for medical diagnostics and food degradation.

I STARTED my research career as Scientist in 2017 focusing on developing electrochemical and optical sensing platforms for non-redox molecules (food spoilage markers) and small biomarkers. My initial work was on developing sensing methodologies for simple aliphatic biogenic amines, a unique class of organic molecules known for its role in various physiological processes and frequently discussed in the field of sensors as they act as biomarkers and food spoilage markers.

The common biogenic amines are dopamine, histamine, serotonin, putrescine, cadaverine, spermine, spermidine, tryptamine, etc., and among these molecules, aliphatic biogenic amines remain highly distinctive due to their electro-inactive nature – it is very challenging to detect them. Aliphatic biogenic amines (putrescine, cadaverine, spermine and spermidine) are also referred as polyamines. Putrescine stems from Latin word *putrescere* which indicates putrid smell (foul odour).

In earlier times, structures of these polyamines were not elucidated and putrescine and cadaverine were collectively referred as ptomaines. Spermine and spermidine were first isolated as corresponding phosphate crystals from human semen by Antonie van Leeuwenhoek in 1678 and are responsible for the characteristic odour of semen. In modern times, these polyamines have received significant attention owing to their link with food spoilage marker and cancer

biomarker. These polyamines are ubiquitous in nature and regulate cellular metabolism in eukaryotic cells and stabilize the helical structure of nucleic acids.

Spermine is the precursor for biosynthesis of hypusine, an uncommon amino acid found only in protein (eIF) 5A (eukaryotic translation initiation factor 5A). In (eIF) 5A, the region around hypusine plays a key role in functioning of (eIF) 5A and hypusine is produced in body by enzyme Deoxyhypusine synthase which breaks down spermine to putrescine and gets converted into hypusine.

The levels of these polyamines increases abnormally in case of uncontrolled cell proliferation which results in tumor development and cancerous growth formation. Therefore, levels of these polyamines in body can act as cancer biomarkers. Abnormal spermine and spermidine levels in urine indicate formation of prostate cancer in men. Prostate cancer is a major health concern and leading cause of cancer among men. Early detection of prostate cancer is nearly impossible since it requires digital rectal examination where the doctor inserts a finger into the rectum. Other methods such as testing prostate specific antigen in blood are not available in all diagnostic labs.

Putrescine and cadaverine are found in poorly stored protein rich foods such as meat, dairy products, etc., due to bacterial action on amino acids present in it. In food industry, nitrite salts are common preservatives and if putrescine reacts with these nitrite salts, it leads to the formation of nitrosoamines, a well-known carcinogen. Therefore, readers might understand the need for sensing these biogenic amines.

We have recently developed a colorimetric method for sensing of putrescine and cadaverine using ninhydrin as the reagent. Usually, colorimetric methods were termed as semi-quantitative analysis, but it has high reliability for rapid detection. Ninhydrin chemistry itself is not a stranger in colorimetric analysis, it reacts with amino acids to give intense purple colour (Ruhemann's purple) which is routinely used in forensic analysis for labelling fingerprints. The developed method has been employed for the detection of putrescine and cadaverine in fish samples and will be highly useful in detecting the early spoilage of fishes.

Detecting these polyamines through electrochemical sensors is challenging as they are inert and require enzymes

(diamine oxidase, putrescine oxidase, cadaverine oxidase) to sense these molecules. Enzymes are proteins which uniquely and selectively bind with a specific molecule resulting in a byproduct. Like any other biomolecule, these enzymes have to be handled with the utmost care as enzymes are sensitive to external factors such as temperature, and moisture.

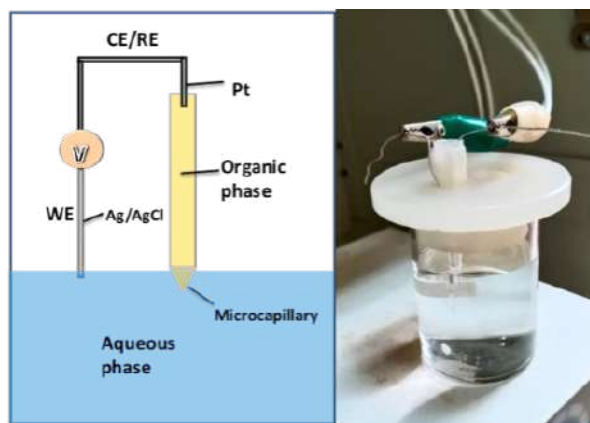
Non-enzymatic sensors have been seldom explored for these polyamines as they are exceptionally inert with no inherent redox properties. So, my challenge was to develop an electrochemical based sensor without any enzymes (i.e., non-enzymatic). To address this challenge, traditional electrochemistry is of little use as polyamines are inert and so we decided to turn our attention towards unconventional electrochemical approach as sensing strategy -- this was the onset for developing the unique liquid-liquid interfacial electrochemical approach.

We noticed that polyamines have two characteristic features: i) Exist as cationic form in physiological pH and ii) Form aggregates with phosphate groups to form macrocyclic polymer known as Nuclear Aggregates of Polyamines (NAPs). Taking advantage of these features, we first developed an ion-pair facilitated electrochemical sensor for which we used electropolymerised neutral red as sensor substrate. In this sensor system, phosphate ion which we used as buffer provided the phosphate that acts as a bridge between polyamine and neutral red molecule – this facilitated the non-enzymatic sensing of putrescine and cadaverine.

Though the link between polyamines content such as spermine and cadaverine with prostate cancer has been established, it failed to receive attention because researchers relied on Prostate Specific Antigen (PSA) in human serum to determine the growth of prostate cancer as it is easy to measure the amount of PSA with RT-PCR than measuring polyamines with an enzyme based sensor. Among these polyamines, putrescine and cadaverine are considered as biomarkers for prostate cancer or other tumorous growth and it is necessary to differentiate them. Conventional electrochemistry and other detection methods fail to differentiate them. A helping hand is offered from a lesser known part: Interface between Two Immiscible Electrolyte Solution (ITIES) or the liquid-liquid interface electrochemistry.

We can find the liquid-liquid interface model at places such as oil droplets floating over water; in liquid-liquid interfacial electrochemistry, we control the size of oil (organic phase) to a few micrometres in diameter by using a glass tip and connecting both the phases to an electrochemical workstation. Different molecules have different pKa (just as our fingerprints), resulting in different Galvani potential across the interface. We utilise this strategy for sensing of putrescine and cadaverine. (Note: The difference between putrescine and cadaverine is only a single methylene group).

At present motivated by the opportunities provided by challenges in sensing of non-redox molecules, we are currently working in electrochemical discrimination of similar amino acids of clinical importance.



Pictorial ITIES representation and ITIES electrochemical cell with a micropipette

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EARTH, ATMOSPHERE, OCEAN & PLANETARY SCIENCES

Recovery of Strategic U from Non-conventional Secondary Sources



**Dr Shilpi
Kushwaha**

The CSIR Young Scientist Award for the year 2021 in Earth, Atmosphere, Ocean and Planetary Sciences

has been awarded to Dr Shilpi Kushwaha of CSIR-Central Salt and Marine Chemicals Research Institute, Bhavnagar for her innovative research on the extraction of Uranium from secondary sources such as seawater and acidic effluents using crystalline thin films and polymer nanorings.

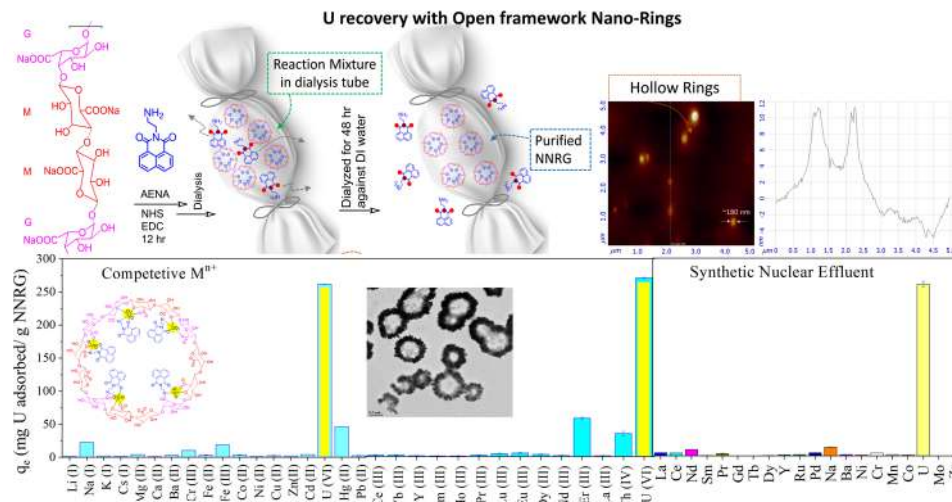
NUCLEAR energy is considered an ideal source for meeting the 2°C target of the Paris Agreement, as it has a higher capacity factor to generate baseload electricity with virtually no greenhouse gas emissions. However, the conventional sources of Uranium (U) are finite and projected to last the next 100 years. Being the workhorse of nuclear energy, the recovery of Uranium from various non-conventional secondary sources is necessary.

So, what are these non-conventional secondary sources? Resources with less concentration of Uranium which are economically not beneficial to explore – Uranium extraction from natural sources like seawater; and Uranium recovery from anthropogenic sources like mine tailings, synthetic nuclear effluents, and contaminated water. These non-conventional sources of Uranium have the potential to make it a sustainable source of energy. However, recovery of Uranium from such secondary sources containing ultralow concentration of Uranium, in the presence of other competing ions of similar charge and size, along with high salinity gradient makes it an economically challenging process.

Material design plays a critical role in defining Uranium recognition and extraction capacity, and the rate of Uranium extraction from secondary sources. Designing the Uranium selective adsorbent involves a few important considerations, such as the incorporation of Uranium selective functional groups, density and uniform distribution of functional groups, surface area, and diffusivity to maximize the availability of active sites, along with retaining its chemical and hydrolytic stability.

Previous work favours the adsorption-based scavenging material as the preferred methodology for Uranium extraction and enrichment, rather than solvent extraction-based processes. Based on the higher affinity for Uranium, adsorbents are typically derived using amidoxime, amide, imidazole, organophosphorus, and calixarene, phosphonic acid/phosphazene derivatives for developing reasonably efficient scavengers.

Besides, nano-materials have distinct benefits – one such advantage is that they have higher surface area providing maximum exposure of water to the material. Porosity is another significant parameter in the design of an adsorbent



because it allows diffusion of adsorbate through the adsorbent material.

In our work, for Uranium recovery from acidic effluents, nanostructured polymeric materials functionalized with appropriate receptors have opened up newer possibilities for designing a reagent that shows analyte-specific recognition and efficient scavenging of an analyte. Higher active surface area, morphological diversity, synthetic tuneability for desired surface functionalization, and the ease of regeneration of nanostructured material for further use have provided such materials with a distinct edge over conventional reagents.

Use of biodegradable polymeric backbone has an added significance owing to the recent concern over the impact of polymer on the environment. Functionalization of biodegradable sodium alginate with AENA (6.85 % grafting) led to a unique open framework nano-ring (NNRG) morphology. These nano-rings (NNRG) yield the maximized surface area for the molecular scavenger.

Uranium extraction from seawater (UES) is an emerging process and an archetype of Blue Economy towards sustainable development. Seawater contains 1000 times more amount of Uranium distributed worldwide (~ 4.5 billion tons of U in seawater), and has the potential to change the nuclear energy production scenario. Recently, there is a surge in the development of nano-materials and their implementation in UES, mostly from research groups in China. They have reported tremendous advancements in the UES efficiencies from < 6 mg/g (upto 2015) to ~ 17.45 mg/g (2020).

Recently, we prepared Uranium selective single component Hydrogen bonded Organic Framework ($^{CSMCRI}HOF-1$) of phenoxy-imine synthons. The innovative design of porous $^{CSMCRI}HOF-1$, with extended conjugation of pyridyl and phenoxy-imine moieties offers suitable binding site for Uranium. The excellent stability of $^{CSMCRI}HOF-1$ in aqueous, acidic, basic, saline and high ionic strength medium, makes it robust.

Besides, this strategy maximizes the surface area, and ease of applicability for large scale UES, and it can be implied in general for preparing large area thin films of HOFs for various applications. We hope these results will ignite more research interest towards exploration of phenoxy-imine modules for constructing new HOFs, and simplify the fabrication of HOF thin films and membranes, for leveraging the multitudes of applications focused on catalysis, separation, energy storage, coating, composite and sensing.

Our focus is towards improving the Uranium recovery and reducing the cost component. We are working on another synergistic aspect, by exploiting the seawater and other secondary source for symbiotic recovery of energy minerals along with Uranium.

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ENGINEERING SCIENCES

Indigenization of Printed Electronics: From Materials to Devices

Dr Achu Chandran



The CSIR Young Scientist Award for the year 2021 in Engineering Sciences is awarded to Dr Achu Chandran of CSIR-National Institute for Interdisciplinary

Science and Technology, Thiruvananthapuram for developing printed electronic materials and devices for strategic and societal applications.

THE global electronics sector is shifting towards flexible and wearable technology. In order to address the reliability issues of conventional wired electronics, printed electronics technology is widely adopted in consumer and strategic electronic systems, where a variety of devices can be printed directly on to rigid or flexible substrates. In addition, the integration of various electronic components has become easy owing to the progress in printing technology. Also, the technology ensures reduction in form factor of electronic systems, enabling more compact and reliable electronic devices.

The printed electronic technology has been used in a galaxy of applications in the electronic sector especially in the fabrication of solar cells, touch screens, healthcare devices, OLED displays, printed RFID tags, etc. As per IDTechEx, the market of printed electronics is currently worth \$41.2 billion USD and is estimated to reach \$74 billion USD by 2030.

In India, the demand for affordable electronic materials and printed components is very high. Unfortunately, more than 90% of electronic components are being imported in the country. In recent times, a surge in demand is seen in the areas of advanced printed technologies, high quality conductive inks and energy efficient electronics. Thus, indigenization of flexible and printed electronics is critical for our country. So, we at CSIR-National Institute for Interdisciplinary Science and Technology (NIIST), Thiruvananthapuram are in the

process of developing electronic grade materials for printed electronics especially, customized substrates, functional inks/paste and devices out of these.

My journey with printed electronics started at CSIR-Central Electronics Engineering Research Institute (CEERI), Pilani in 2016, where I joined as scientist in the Advanced Packaging Group, under Smart Sensors Area. At CEERI, we were mainly working on Low Temperature Co-fired Ceramics (LTCC) technology. LTCC is a multi-layered advanced ceramic technology in which we can print circuits, components and devices in each layers of ceramic tapes at green stage (before firing) and can stack them together to make a complete device or system after sintering at elevated temperatures. Using LTCC technology, we have fabricated printed electronic devices and structures for customized sensor packaging, thick-film sensor electrodes, gas sensor modules and micro-hotplates.

Packaging of sensors is very important and crucial to realize its optimal performance. At CEERI, we were involved in conceptualizing the design strategy and development of advanced techniques for customized packaging of smart-sensors. Using LTCC technology, we have successfully packaged various MEMS devices and microsensors fabricated in-house at CEERI including field effect transistors, pressure sensors, inertial sensors and gas sensors. Most of these customized packaging solutions were done for strategic sector agencies of our country (ISRO, DRDO and BARC).

We were also actively involved in the design and fabrication of thick film based sensor electrodes for chemical and bio-sensing applications. In 2016, DRDE, Gwalior approached us for indigenously developing printed sensor electrodes for the detection of malaria and dengue, which otherwise they were importing. We have developed two batches (300 numbers each) of one-time use, printed sensor electrodes meeting all the user specification and handed over to DRDE, which is a significant import substitution activity. CSIR-CEERI has recognised our team by awarding 'Foundation Day Award' for the excellence in services and process innovation category for this achievement in 2019.

We also developed affordable carbon monoxide (CO) sensor module based on printed technology using off-the-shelf sensors for masses. The module is capable of detecting CO gas above 100 ppm level in the environment.

Another important activity which we have carried out using LTCC technology is the design and fabrication of application-specific thick-film microhotplates. These hotplates find applications in strategic as well as domestic sectors. Micro-hotplate works on Joule's heating principle, which is also known as resistive heating technique. We have developed various versions of LTCC micro-hotplates and the latest one is named as LTIVA (LTCC with Interconnects through Vertical Access).

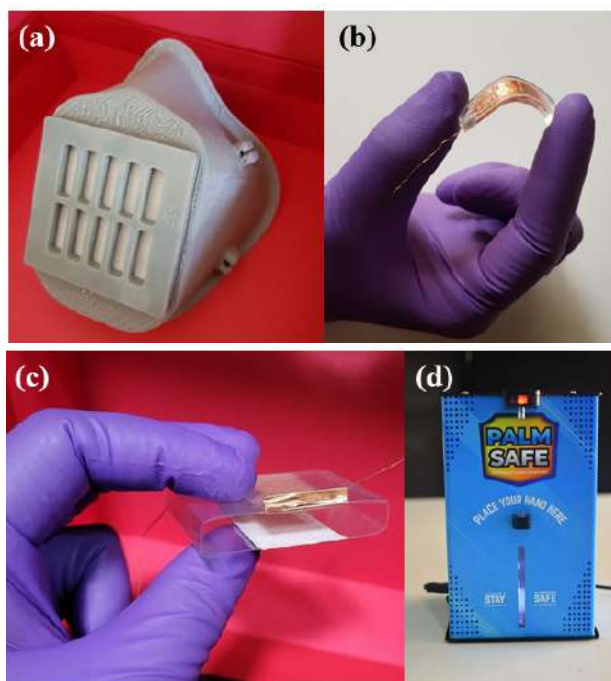
LTIVA hotplate has a size of 3.2×3.2 mm with printed platinum heating element which reaches a temperature of 300°C by merely consuming less than 1 W power. The novel interconnection technology provided a stable operation of these hotplates upto 600°C. The printed hotplate technology has been inducted by DRDO for use in their micro-farming

units installed at extremely low temperature and high altitude centres at DIHAR, Leh and Chang La, which is 18000 feet above sea level. These hotplates were successfully integrated with micro-farming units developed by DRDO to provide ambient temperature inside the unit. Micro-farming is a technique used for the germination and growth of highly nutrient rich plants in a confined environment even when outside temperature is less than -5°C -- their target is to supply ready-to-eat plants for army jawans living in cold deserts. The temperature inside the micro-farming unit has been maintained at 20°C using battery operated printed hotplates, which are less power consuming and highly reliable than conventional coil heaters. We were able to successfully germinate nutrient rich seeds of methi and raddish developed by DRDO, within 3 days inside the unit.

While working in the area of printed electronics, the major bottleneck which we faced was the availability of electronic-grade customizable substrates and printable inks. We realized that majority of the materials for printed technology are being imported in India, even though there is a huge market available within the country. In 2019, I moved to the Materials Science and Technology Division of CSIR-NIIST. Here at NIIST, we have a strong group of researchers working in the area of electronic-grade materials for printed electronics. The dream of 'complete indigenization of printed electronics' became a reality with my association with materials chemists and physicist of NIIST. We together developed customized substrates, functional inks and printed devices such as, flexible heaters, nanogenerators and tactile sensors. We could tune the desired device performance by tailoring the properties of electronic substrates and inks.

All types of electronic grade printable inks including conductive, resistive, dielectric and piezoelectric inks have been developed with custom properties by our team at NIIST along with compatible substrates such as LTCC, polymer-ceramic composites and flexible substrates. The very first device was an all-printed flexible heater on plastic substrate using customized carbon nanotube (CNT) ink. A room temperature curable CNT ink has been formulated using a conductive polymer additive (PEDOT:PSS) for the first time. This conductive polymer has provided an avenue to tailor the conductivity of the ink along with binding and surfaction properties. The wearable heater device has produced a maximum temperature of 136°C by merely consuming 137mW/cm² electric power. In addition, the heater device is very fast responding with an on-off time of 10 seconds. Such types of heaters can have a galaxy of applications in wearable electronics and thermal therapy.

During the Covid-19 pandemic, we utilized the knowledge of printed heater technology for developing a self-sterilizing fabric heater for use in face masks and PPE. The motivation behind this was a report on the WHO website stating that 'heat at 56°C kills the SARS coronavirus at around 10000 units per 15 min'. Also, recently it was reported that the time for SARS-CoV-2 virus inactivation was reduced to 5 minutes if the temperature is elevated to 70°C. Against this background, we developed a low power consuming (<0.25 W/cm²) self-sterilizing fabric heater using an in-house prepared conductive



Technologies developed by Dr Chandran and his team: (a) Self-sterilizing fabric heater integrated stopgap face mask; (b) Flexible piezoelectric nanogenerator; (c) Triboelectric nanogenerator and (d) Smart touch-free sanitizer dispenser

silver ink printed on polyester substrate. The fabric heater has been integrated with a stop-gap type face mask and has demonstrated its capability for complete annihilation of pathogens at 120°C by resistive heating using a 5V power supply. A patent on this technology has been filed – it has immense commercial potential in the smart textile industry and personal protective equipment.

The printed fabric heater technology is effective against all types of pathogens including SARS-CoV-2 as the device achieves standard sterilization temperature (120°C) in a few seconds. The face mask integrated with fabric heater can be reused after sterilization by connecting to a mobile phone charger or a 5V power bank. In addition, the fabric heater finds applications in light-weight smart fabrics for cold deserts such as jackets, coveralls, gloves, shoes/socks, etc. and also in medical applications such as warm band-aids for thermal therapy.

We also developed a smart touch-free smart hand sanitizer dispenser (“Palm Safe”) technology by addressing the issues in the current sanitizer dispensers available in the market. Main problems in current dispenser technology are false triggering, wastage of sanitizer liquid, no preset dispensing volume and mounting issues owing to infra-red sensor position. Our technology with novel line-of-sight sensor design has been licensed to M/s Tachlog Pvt. Ltd, Trivandrum. This ‘Palm Safe’ technology has been included in ‘CSIR Technologies for Covid-19 Mitigation’ by CSIR.

We are also working in the area of green mechanical energy harvesting devices and tactile sensors. In the era of internet of things and connected smart sensors we need self-powered technologies that are sustainable and eco-friendly.

We can have battery-less sensors and other electronic gadgets in the near future powered by nanogenerator technology.

Among the mechanical energy harvesting techniques, piezoelectric and triboelectric nanogenerators are promising candidates especially for self-powered device applications. They can scavenge mechanical vibrations from the surroundings and convert it into effective electricity. We have developed a lead-free piezoelectric printed nanogenerator based on potassium sodium niobate ink, which generates upto 15V from single finger tapping force of 3 N. Triboelectric nanogenerators (TENG) are upcoming candidates in this area, where contact electrification between two triboelectric layers along with the electrostatic induction enables conversion of mechanical energy into electricity. We at NIIST have recently developed a facile spring-assisted TENG based on two polymeric materials, which are far apart in triboelectric series of materials (PVDF and PMMA) and demonstrated powering various electronic gadgets using gentle finger tapping force.

Currently, we are into the development of an ‘electronic-skin patch’ for giving a sense of touch to robots and also for health care applications. In this efforts our sister laboratory CSIR-CEERI and two Indian industries (M/s Tachlog pvt. ltd and M/s Zealous endeavour pvt. ltd.) are on-board with us. Thus, our journey towards a ‘self-reliant India in strategic and societal electronics’ is in progress with the indigenization efforts in flexible and printed electronics.

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Role of Lignocellulosic Biomass in Decarbonisation



Dr Bhavya B. Krishna

The CSIR Young Scientist Award for the year 2021 in Engineering Sciences is awarded to Dr Bhavya B. Krishna of CSIR-Indian Institute of Petroleum, Dehradun, for her substantial work

on devising strategies for the effective utilization of lignocellulosic biomass using thermochemical conversion processes.

GLOBAL warming has led to increased heatwaves, precipitation leading to floods, droughts, etc. This has led to the worldwide call for reducing greenhouse gas emissions by slowly transitioning towards renewable sources of energy. The world is moving towards the goal of decarbonisation by the mid of this century i.e. around 2050. Decarbonisation is the reduction of carbon dioxide emissions through the use of low carbon power sources, achieving a lower output of greenhouse gases into the atmosphere.

The term sustainable energy is usually attached to solar, wind, tidal, hydrothermal and biomass energies due their renewable nature. However, globally, the move towards electrification of transport systems has gained momentum. The hydrogen mission has also gained considerable focus along with electrification of several processes. While light duty transport vehicles can use electricity to power them, liquid fuels are still required until complete transition to electric/hydrogen vehicles for heavy-duty transport systems, shipping and aviation industry.

Biomass is the only source of renewable organic carbon that can produce fuels (liquid/solid/gaseous), chemicals and petrochemical feedstocks in this transitional scenario to supplement fossil-derived resources. First generation bio-fuels are produced from edible biomass leading to the problem of food vs. fuel in certain situations. Second generation bio-fuels are produced from biomass that is non-edible in nature and third generation bio-fuels are produced from algal biomass. The National Biofuels Policy framed in 2018 by the Government of India mandated 20% bio-ethanol blending in petrol by 2030 and 5% bio-diesel blending with High Speed

Diesel (HSD). The target for 20% bio-ethanol blending has been preponed now to 2025 showing the government's intent to move towards renewable and clean energy sources.

India is primarily an agricultural country and it produces large quantities of crop residues. There is still surplus biomass available even after consumption of fodder. Around 22% of the country's geographical area is also covered by forests leading to forest residues and forestry activity wastes. The bio-diesel programme leads to the generation of huge amounts of defatted cakes which cannot be used as poultry feed. There are several terrestrial invasive species as well that cause depletion of soil nutrients. All these feedstocks fall under the umbrella of lignocellulosic biomass. These domestic residual/waste biomasses are capable of supplementing India's organic carbon requirement in a renewable and sustainable manner.

Aquatic biomass can either be algae, microalgae or macroalgae which are a good source of several important compounds such as nutraceuticals and can also be used for the production of fuels. Aquatic weeds are also found to grow in water bodies leading to reduction of dissolved oxygen and depletion of nutrients leading to eutrophication. These aquatic weeds also need to be removed and converted to useful products.

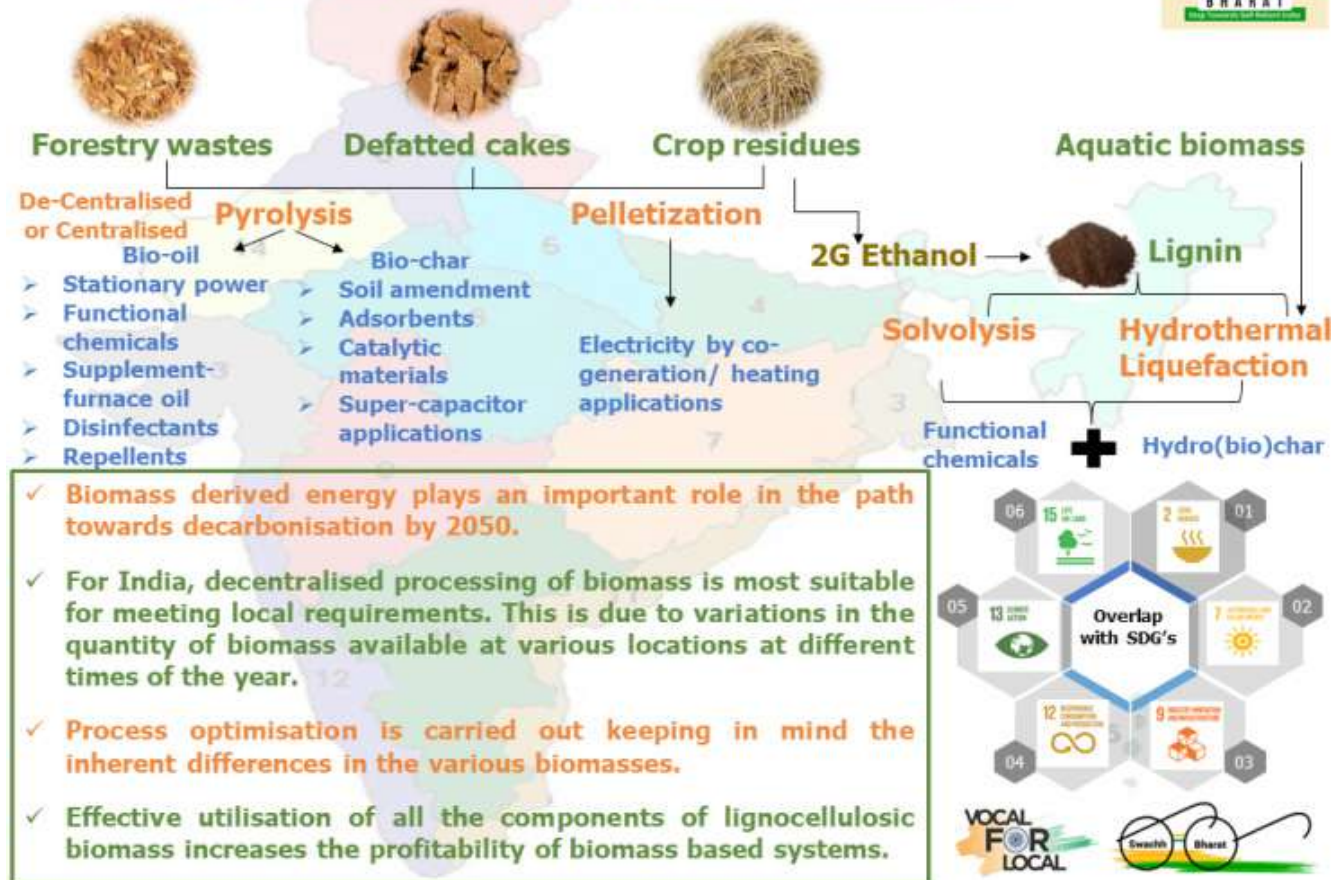
Several kinds of lignocellulosic biomass are available across our country – their quality and quantity varies from region to region in different times of the year. The estimated demand of biomass by 2050 is around 600 MMT and estimated availability is around 900 MMT well within the requirement. In this scenario, research has been focused on the valorisation of biomass for the production of fuels/chemicals/energy.

During my 10 years of research, I have worked with several kinds of domestic renewable carbon sources, namely, crop residues, forestry wastes, defatted oilseed and algal cakes, invasive terrestrial and aquatic species, etc. Pyrolysis process parameters have been optimised for different categories of biomass. The detailed physico-chemical characterisation of the products has helped in understanding the basic decomposition mechanism and the structure-activity relationships in catalytic systems. Certain biomass feedstocks are rich in moisture content and hence, hydrothermal liquefaction processes have been employed. Huge amount of lignin is produced as waste/by-product from the pulp and paper industry and 2G ethanol industry. Solvolysis processes are being developed to produce high value functional chemicals/potential petrochemical feedstocks from lignin to utilise its aromatic backbone.

The main focus of the research has been on the effective utilisation of renewable organic carbon content present in the biomass to supplement the fossil resources. Biomass conversion will help in producing hydrocarbons in a sustainable manner – they are now produced from fossil resources after several steps of functionalisation. The processes have been developed keeping in mind that biomass conversion units are best suitable in decentralised mode of operation due to the associated issues of low-density biomass transportation over long distances and storage issues for long duration.

The most preferred method for solid biomass utilisation at present is through pelletisation. The biomass pellets are used for electricity generation directly and also through

Devising Strategies & Solutions for Effective Utilisation of Domestic Renewable Carbon Resources



co-generation. These pellets can also be used in domestic cooking or industrial (direct or indirect) heating applications. Subsequently, these pellets can also be pyrolysed using the mobile pyrolysis unit. The major products from thermochemical biomass conversion are bio-oil and bio-char and several local applications are being developed for the same. The usage of bio-oil/blends is being extended for stationary power applications, supplement for furnace oil, source of functional chemicals, disinfectants, topical veterinary ointments, snake repellents, anti-termite, anti-fungal and wood borer repellent applications, etc. Bio-char on the other hand, can be used as soil amendment to increase the soil fertility, water retention and in turn, crop yields. Other high value applications for bio-char are as catalyst supports/catalysts, adsorbents, water treatment, supercapacitor applications, etc.

Globally, efforts are being undertaken to eliminate the traditional usage of biomass for cooking. Heavy industries that are energy intensive will be partially supplemented with the heat from biomass in the form of pellets/briquettes. In industries like steel making biomass can be directly used. There will be utilisation of waste or domestic carbon resources for the production of electricity or for heating applications.

An assessment of biomass availability and its characteristics across the country has been carried out. It has

been observed that there is a wide variation in the quality of the biomass available in different parts at different times of the year. These supply chain issues need to be sorted out to ensure regular availability of biomass at a particular location to decrease the risk associated with bio-refineries. A dynamic database which maps the availability to the biomass characteristics is the need of the hour. This will help in strategically mapping the biomass resources to the end target applications for various locations.

My target is to effectively utilise all the components of biomass and devise strategies for implementing biomass processing units across the country for the overall development of the nation. Depending upon the end target requirement, the developed processes of pelletisation, pyrolysis or solvolysis will be considered for implementation. This will also help in providing additional income to farmers, reduce stubble burning, generate local employment opportunities, strengthen the Swachh Bharat mission, produce import substitutes, etc.

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