INVENTING A BETTER TOMORROW



YEARS OF **IIT MADRAS IMPACT**

IIT Madras

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Message from the Director



IIT Madras stands today as a beacon of deep tech research and innovation in the country. The number and scale of sponsored and industry projects undertaken by its faculty have increased the visibility and impact of the institute. Further, the innovation ecosystem at IIT Madras sets a very high benchmark for academic institutes in India and globally.

IIT Madras has clearly emerged as a leader in the country, and in many aspects globally, with respect to its ability to undertake and deliver on high-impact projects. This is not a sudden evolution—over several decades, the pinnacle of excellence has been achieved by painstakingly putting together groups of high calibre faculty members and providing them the necessary support to carry out groundbreaking research. The institute is constantly aligning its policies and processes to enable its faculty to carry out their research unfettered.

Fundamental, translational and transformational research is going to be a key necessity as we prepare ourselves towards achieving the dream of making India a world leader and strive towards Viksit Bharat 2047. It is also important for us to pause and look back at the learnings from the past, which we can build upon to create an ecosystem that helps us get towards this goal. This compendium of impactful projects from IIT Madras in the last 25 years has been put together for this very purpose. It is by no means an exhaustive list of projects and technologies that have come out of IIT Madras but rather a collection of diverse projects that indicate how high quality research can lead to industrial growth.

V. Kamakoti




IC & SR
OFFICE OF
INDUSTRIAL CONSULTANCY
& SPONSORED RESEARCH

Message from the Dean IC&SR



The Office of Industrial Consultancy and Sponsored Research (IC&SR) manages all the externally-funded projects undertaken by IIT Madras faculty members. This includes project creation and management, legal frameworks, financial management, recruitment, industry engagement, procurement, intellectual property management, and technology transfer. The processes and policies of IC&SR have evolved over time according to the guidance provided by the Board of IC&SR, and ratified by the BoG of IIT Madras, as well as the extant financial and procurement policies.

At the current stage, IIT Madras has emerged as a leader nationally in terms of funding received on sponsored and industry projects. With the size of the projects, the complexity in terms of financial management and procurement has also increased. Additionally, as IIT Madras explores the evolving technology landscape, there have been several developments in the handling of IP and technology transfer matters. IC&SR has been striving to meet the ever-changing demands of modern-day research.

This compendium highlights the achievements of IIT Madras faculty members in the last 25 years through a presentation of the deep-tech research projects that were operationalised through IC&SR. While this is only the tip of the iceberg in terms of the scale of the projects at IIT Madras, the objective is to showcase the journey of research and innovation through a handful of projects that have had a major impact on industry.

This book is a testament to how an enabling institutional environment paves the way for high-impact research.

Manu Santhanam


Indian Institute of Technology
Madras



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Introduction

IIT Madras is the leading academic institution in the country. Started in 1959 with a collaboration with Germany (then the Federal Republic of Germany) as an engineering and technology institute that produced high-quality engineers, IIT Madras today has emerged as a leader in multiple fields spanning engineering, science, and policy. This is not only from the perspective of education and research but also in terms of innovation and industry impact. Apart from strong and rigorous academic programmes that are curated and managed through its 18 departments, several research centres and hubs have been created over the years, where the faculty and students of IIT Madras engage in projects of strategic significance to the nation. While there has been a steady stream of projects sponsored by various central and state ministries and departments, the scale of industry interaction is where IIT Madras leaves all other academic institutions behind. The IIT Madras faculty have emerged as solution providers and thought leaders and agents of change in the Indian engineering ecosystem.

This book provides a glimpse into some of the pioneering work undertaken by IIT Madras faculty members in the last 25 years. It focuses on how scientific projects could be translated successfully to impact creation in the industry and beyond. This is by no means a complete presentation—several other path-breaking projects and scientific initiatives at IIT Madras have not been included here—but rather a sampling of the scale of the research and innovation that are shaping the future of technology in the country.

These initiatives are organised into key thematic pillars—ranging from the foundational rigours of theoretical and experimental physics to the urgent demands of energy and sustainability—that highlight a commitment to both high-level discovery and practical, indigenous solutions. Other themes include the digital frontiers of artificial intelligence and advanced computing, the life-saving advancements in biology and healthcare, and the strategic developments within defence, electronics, and communications. Furthermore, the work details critical progress in the physical world, showcasing breakthroughs in advanced materials, transformative manufacturing techniques, and the modernisation of infrastructure and heritage conservation.

From the development of indigenous microprocessors and 5G testbeds to the sustainable restoration of water bodies and the implementation of 3D concrete printing, these projects represent a synergy of engineering excellence and social responsibility. Together, they form a roadmap of technical sovereignty and scientific curiosity, illustrating how focused academic research translates into global impact and national progress.

A History of IC&SR

The Centre for Industrial Consultancy and Sponsored Research, IIT Madras was set up in April 1973. It was initially known as the Industrial Consultancy Centre (ICC). It was created to act as a link between the institute and industry to ensure more effective utilisation by industry of the existing expertise and capacity in the various departments and laboratories.


Industrial Consultancy Centre

Newspaper clipping, 17 November 1973

The following is a sketch of the growth of IC&SR, by decade.

The 1970s: The "ICC" Era

The Deans of the ICC were known as Professors in Charge.

Leadership

- Prof. R.G. Narayanamurthi (first Professor in Charge, 1973-1975) and Prof. V.G.K. Murti (1975-1977) served under Director K.A.V. Pandalai.
- Prof. V.C. Venkatesh (Professor in Charge, 1977-1979) served under Director R.G. Narayanamurthi.

Major Milestones

- **1973:** First major sponsored projects managed
- **1977:** The institute's first patent filed
- **12th October 1979:** The first official IC&SR Board meeting held

Funding and Projects

- Rarefied Gas Dynamics Facility: Design and Development for Aeronautical Engineering (Rs.21.18 lakhs).
- Earnings: Annual earnings reached Rs.43 lakhs by 1975-1976


Prof. A. Ramachandran


Prof. K.A.V. Pandalai


Prof. R.G. Narayanamurthi


Prof. Hans Wagner, Advisor, ICC

The 1980s: Transition to IC&SR

This decade marked the official change in name to IC&SR and the formalisation of governance and intellectual property (IP) rules.

Leadership

- Prof. P.S. Rao (1979–1981) and Prof. J.C. Kuriakose (1981–1983) served under Director P.V. Indiresan. Prof. H.N. Mahabala (1983–1985) served under Directors P.V. Indiresan and L.S. Srinath.
- Prof. V. Radhakrishnan (1986-1990) served under Director L.S. Srinath.

Major Milestones

- **1980:** Formal intellectual property rules and consultancy guidelines introduced
- **1986:** The ISRO-IITM Space Technology Cell (STC) established
- **1987:** Industrial Associateship Scheme launched
- **1989:** Relationship Based Industrial Consultancy (RBIC) introduced

Funding and Projects

- Wave Energy Device: A landmark sea trial of a 150 kW device off the Trivandrum coast (Rs.3.88 crores)
- Advanced Tech in Communication: A major computer science program (Rs.1.68 crores)
- Growth: Sponsored projects jumped to Rs.6 crores by 1989.



Prof. P.S. Rao



Prof. J.C. Kuriacose



Prof. P.V. Indiresan



Prof. H.N. Mahabala



Prof. V. Radhakrishnan



Prof. L.S. Srinath

The 1990s: Infrastructure and Institutional Expansion

The focus shifted toward building dedicated physical infrastructure and managing large-scale national technology missions.

Leadership

- Prof. V.S. Raju (1990–1995) served as Dean under Director N.V.C. Swamy.
- Prof. K.V.S. Rama Rao (1995–1998) and Prof. S. Srinivasa Murthy (1998–2003) served under Director R. Natarajan. Prof. Srinivasa Murthy also served under Director M.S. Ananth.

Major Milestones

- **1994:** Dedicated IC&SR Building inaugurated
- **1995:** Technology Development Mission Projects managed
- **1996:** IGCAR-IITM Cell established

Funding and Projects

- Computational Fluid Dynamics (CFD): A dedicated centre (Rs.3.73 crores) established
- Growth: Sponsored funding reached Rs.10 crores during 1996–1997.



Prof. V.S. Raju



Prof. N.V.C. Swamy



Prof. K.V.S. Rama Rao



Prof. S. Srinivasa Murthy



Prof. R. Natarajan

The 2000s: The Mega-Mission Era

This period was defined by massive digital education drives and the establishment of high-tech research centres.

Leadership

- Prof. V. Kalyanaraman (2003–2006) and Prof. T.T. Narendran (2006–2009) served under Director M.S. Ananth.
- Prof. Job Kurian (2009-2012) served under Directors M.S. Ananth and Bhaskar Ramamurthi

Major Milestones

- Launch of NPTEL (Phases II and III), a massive digital education drive for the nation.
- Focus on nano-electromechanical systems (NEMS) and nanophotonics

Funding and Projects

- NPTEL (Phases II and III): Rs.96 crores
- NEMS & Nanophotonics Centre: Rs.49.46 crores
- Growth: In 2010–2011, sponsored research funding crosses the Rs.100-crore mark (Rs.117 crores).



Prof. V. Kalyanaraman



Prof. T.T. Narendran



Prof. M.S. Ananth



Prof. Job Kurian

The 2010s: Digital Transformation and Strategic Projects

This decade focused on Aatmanirbhar Bharat (self-reliance) and complete digitalisation of IC&SR's internal operations.

Leadership

- Prof. Krishnan Balasubramanian (2012–2018) served under Director Bhaskar Ramamurthi.
- Prof. Ravindra Gettu (2018–2022) served under Directors Bhaskar Ramamurthi and V. Kamakoti

Major Milestones

- **2016–2017:** Major national schemes like UAY and IMPRINT managed
- **2017:** IC&SR Data Centre set up
- **2019:** TULA, an in-house ERP software package for integrated project management and accounting, goes live

Funding and Projects

- NPTEL (Phase IV): E-content creation valued at Rs.303 crores
- Indigenous 5G Test Bed: Development of homegrown 5G technology (Rs.7.68 crores)
- Speech technologies: AI for Indian languages (Rs.50.65 crores)
- Establishment of Pravartak, Cyber Physical Systems Incubator, under NMICPS



Prof. Krishnan Balasubramanian



Prof. Bhaskar Ramamurthi



Prof. Ravindra Gettu

The 2020s: The Golden Jubilee and Beyond

The current era is marked by unprecedented financial growth and a leadership role in strategic national technology.

Leadership

- Prof. Manu Santhanam (2022 to the present) is serving under Director V. Kamakoti.

Major Milestones

- 2021-2022: Total IC&SR earnings cross Rs.1000 crores; currently at >1500 crores
- 2022: DRDO Industry–Academia Ramanujan Centre of Excellence (DIA-RCoE) established
- 2022-2023: The Centre for IC&SR was renamed as the Office of IC&SR.
- 16th February 2023: Golden Jubilee of IC&SR celebrated

Funding and Projects

- Establishment of 15 IoE Centres of Excellence
- Major sponsored projects: Lab-Grown Diamonds, from Ministry of Commerce; Quantum Communications Hub, from DST; CoE on AI in Education, Ministry of Education
- Industry funding (including consultancy and CSR) crossed Rs.1000 crores in 2024–2025
- IP filing and commercialisation: IP filing > 400 year on year for the past three FYs; cumulative tech transfer earnings reached > Rs.40 crores in 2023–2024
- Current scale: The centre now manages over 250 specialised professionals.



Prof. V. Kamakoti



Prof. Manu Santhanam

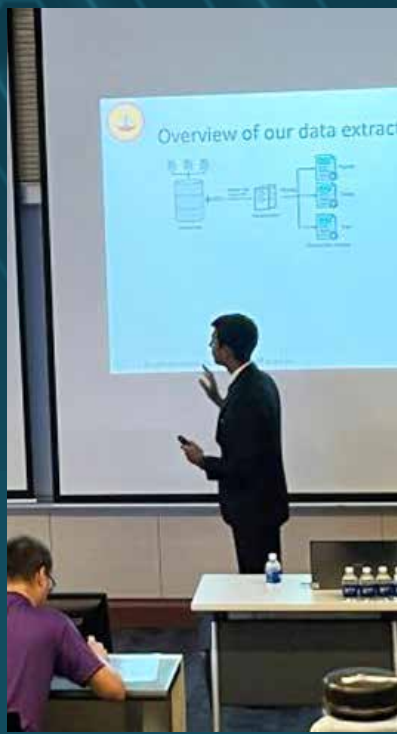


Advanced Materials and Devices

Alloy Design and Database Development Using Large Language Models

In the rapidly evolving field of materials science, data-driven approaches are transforming how researchers design and analyse alloys. At the forefront of this revolution is **Prof. Rohit Batra**, an expert in materials informatics, leading a groundbreaking project to develop the largest and most systematic alloy database in the world. Sponsored by DRDO, this initiative leverages large language models (LLMs) to extract and organise alloy composition and properties from an extensive corpus of scientific literature





Traditional alloy research relies on painstaking manual extraction of data from published papers a slow and labour-intensive process. Prof. Batra's project aims to automate this task using fine-tuned AI models, significantly improving efficiency and accuracy. The database will include mechanical, processing, corrosion, electrical, and biocompatibility properties of alloys, making it an invaluable resource for engineers, researchers, and industries worldwide.

The project has hitherto processed 10,000 of the over 100,000 papers published in the field over the last 25 years. Some 200,000 records have been extracted, covering 25,000 unique compositions. Unlike conventional AI models that are designed for general users, Prof. Batra's team employs retrieval-augmented generation (RAG) and prompt engineering to fine-tune LLMs specifically for alloy data extraction. This has boosted accuracy from 55% to an impressive 85–95%.

The database is designed for continuous enhancement, ensuring it remains a dynamic and evolving resource. It will allow users to search for alloys on the basis of desired properties or even train AI models to predict properties of new compositions. For instance, by analysing yield strengths of 5000 compositions, researchers can predict the yield strength of new alloys, unlocking new possibilities in materials engineering.

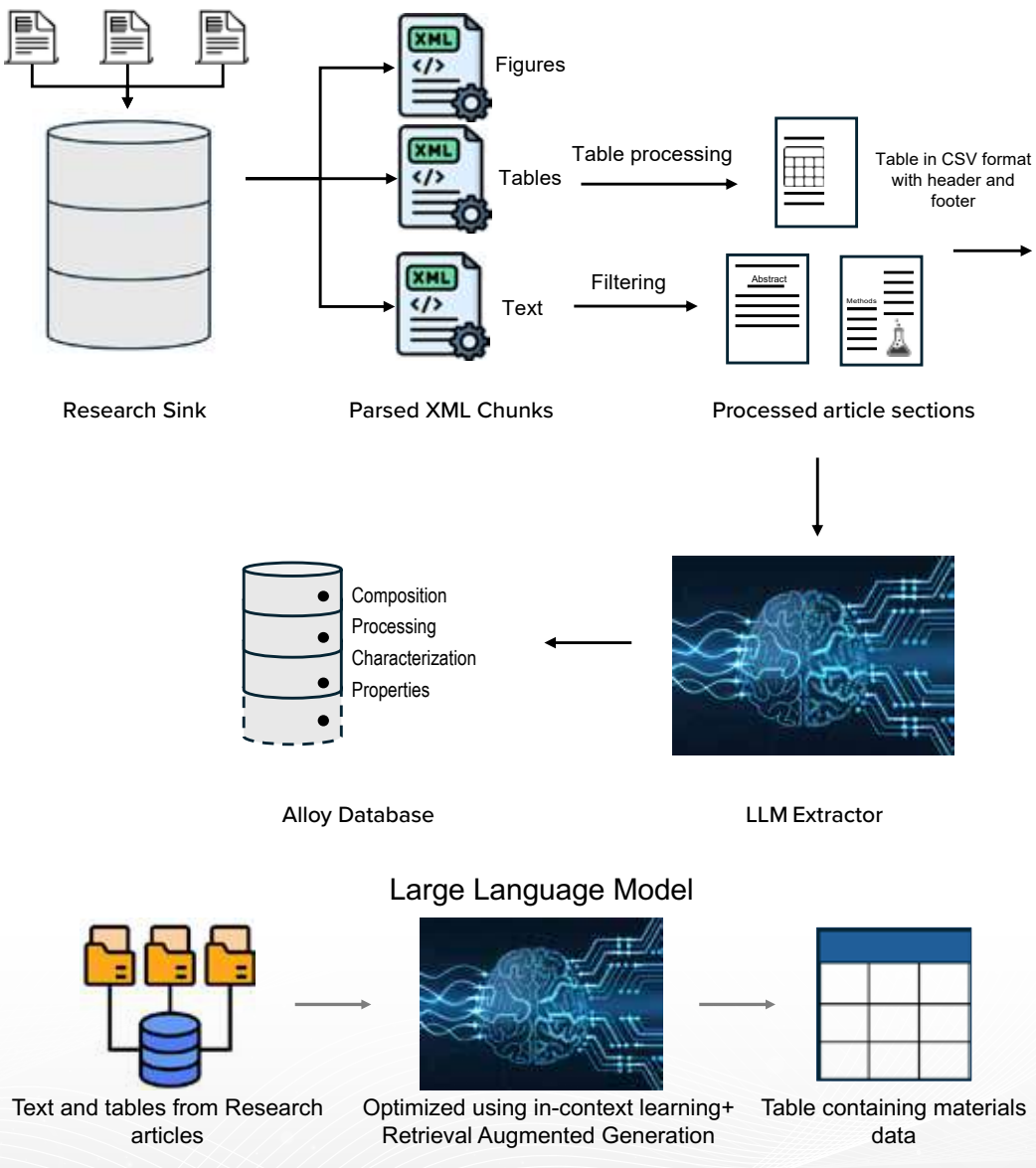
One of the project's key contributions is its ability to visualise data using Ashby plots, for instance, to study variations in strength and ductility. This approach enables researchers to identify trends and optimise alloy compositions for specific applications.

Prof. Batra's database is poised to become a cornerstone of materials research, joining the ranks of internationally recognised databases such as Materials Project (USA), NIMS (Japan), and European initiatives. Unlike these, however, Batra's database does not restrict itself to specific categories of computational or experimental database, making it universally applicable across industries, academia, and government research labs.

The project, spanning 2.5 years, is supported by a dedicated team comprising a Ph.D. scholar, an M.Tech student, a B.S. (Data Science) intern, and an undergraduate student funded by alumni. The team is refining the database, ensuring that the accuracy and usability of successive versions are improved.

As the project progresses, Prof. Batra plans to share reports, conference presentations, and illustrations to further enrich the database. In fact, an undergraduate researcher working on this project recently presented this work at the AI4X conference at Singapore. The ultimate goal is to make the database publicly accessible, fostering innovation and collaboration in alloy research.

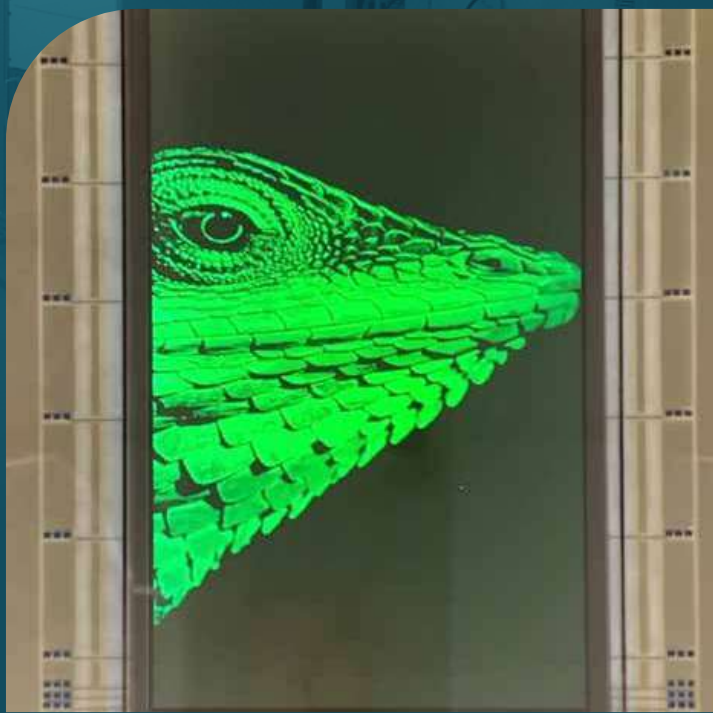
With AI-driven materials science gaining momentum, Prof. Batra's work represents a paradigm shift in how alloys are studied and developed. By harnessing the power of LLMs and data analytics, this project is set to redefine the future of materials engineering, paving the way for smarter, more efficient alloy design.



AMOLED Research Centre

The AMOLED Research Centre (ARC) aims to develop next-generation AMOLED displays for smartphones, tablets, watches and wearables. The centre is a national centre of excellence and is funded by MeitY, DRDO, and Tata Sons. The centre has researchers from various fields working on developing the displays. The centre consists of a state-of-the-art cleanroom which houses fabrication and characterization equipment.

Profs. Debdutta Ray and Soumya Dutta



This is the only centre in India which has the capability to develop smartphone-sized AMOLED displays. The center is working toward turnkey solutions by planning to develop, demonstrate, and deploy micro-factories for smartphone displays. The center is developing novel engineering techniques to utilise the concept of “economies-of-speed” rather than the current model of “economies-of-scale”. The ultimate goal is to maintain or improve unit fabrication times, with the concept of economies of speed allowing smaller mother-glass sizes during production. This will lead to a modular production system.

The ARC is located in the Electrical Engineering department of IIT Madras. It consists of cleanrooms with class 100 and class 1000 ratings. The major fabrication system is an OLED cluster where multilayer OLEDs can be grown with precise control of the growth parameters. The system has a state-of-the-art pixel patterning system which has been designed by an IIT Madras team. The system also incorporates a next-generation ultrafast growth and patterning technique, which is the key focus of study at this centre. The centre has facilities for device characterisation, where optoelectronic properties are studied. While the primary focus of the centre is to develop AMOLED displays, it also works on white OLEDs for lighting and TV and on organic photovoltaic devices.



IIT-Madras AMOLED research centre to fast track display innovations

Chennai, Dec 23:
The Indian Institute of Technology Madras (IIT Madras) has inaugurated the AMOLED Research Centre (ARC), a National Centre of Excellence dedicated to developing next-generation AMOLED displays for smartphones, tablets, watches, and other wearable devices.
The Centre, funded by the Ministry of Electronics and Information Technology (MeitY), Defence Research and Development Organisation (DRDO), and Tata Sons, is a significant step toward establishing a display manufacturing industry in India.
The ARC features a cutting-

S. Krishnan, Secretary, MeitY, inaugurates AMOLED Research Centre at IIT Madras campus.

The centre has demonstrated indigenously designed and fabricated state-of-the-art full-colour HD AMOLED displays (5.2”, smartphone size) for the first time in India.

The team at ARC is working on a novel patterning technique to create AMOLED displays. The new technique promises to lower capital expenditure for display manufacture. The aim of the centre is to create a technology which will enable the growth of modular display factories (micro-factories). The centre has capabilities of both current and next-generation growth processes. The centre currently focuses on small displays such as those used in tablets, smartphones, and watches. The centre actively supports the “Make in India” initiative.





Lab - Grown Diamonds

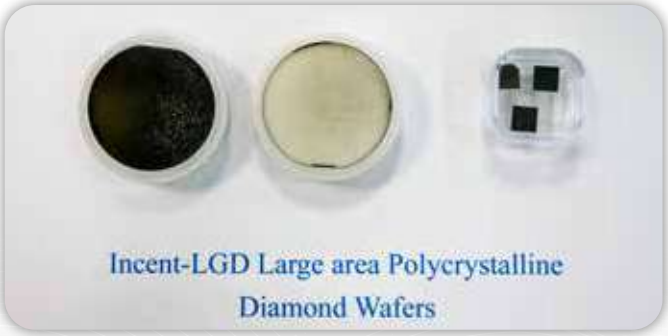
For over three decades, **Prof. M.S.R. Rao,** physicist at IIT Madras, has been at the forefront of research into advanced materials, from thin-film deposition for quantum electronics to the growth of synthetic diamonds. His pioneering work has positioned IIT Madras as a national leader in lab-grown diamond technology, with applications spanning industry, defence, space, and next-generation electronics.



Natural diamonds, formed deep within the Earth under extreme pressures and temperatures, are rare, expensive, and environmentally contentious. Industries that rely on diamond coatings—such as tool manufacture, defence, and aerospace—face high costs and limited supplies. Tungsten carbide dies, for example, wear out after repeated use, reducing efficiency and increasing expenses. At the same time, the global diamond market is dominated by monopolies, with natural mines nearing exhaustion. India, historically a hub for diamond cutting and polishing, needed indigenous capability to produce diamonds for both industrial and electronic applications.

Prof. Rao's journey began with a 30-crore project supported by the Department of Science and Technology (DST) and industry partners such as the Murugappa Group and Orchid Chemicals. This collaboration led to the creation of the Nano Functional Materials Technology Centre (NFMTC), a unique laboratory in India. Here, his team developed chemical vapour deposition (CVD) techniques to grow diamond films, extending the lives of drill bits and dies by 12–15 times.

The research expanded into defence and aerospace, producing diamond-coated seals for ship motors and components for ISRO. Beyond mechanical applications, Prof. Rao explored the electronic potential of diamonds. Unlike silicon, diamond is a superior insulator with exceptional thermal conductivity—five times that of copper—and can be doped with boron to become superconducting. Nitrogen-vacancy (NV) centres in diamonds enable quantum sensing and magnetometry, critical for quantum computing and precision mapping.

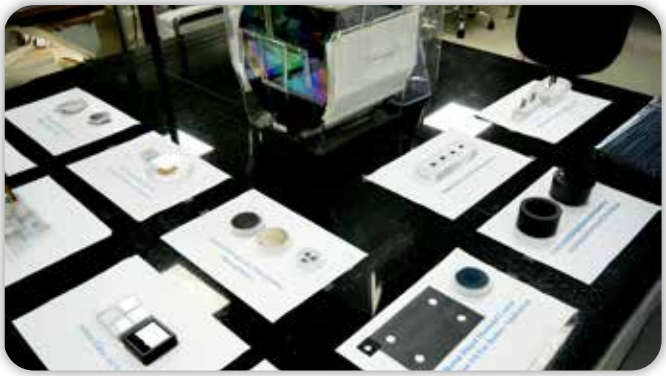


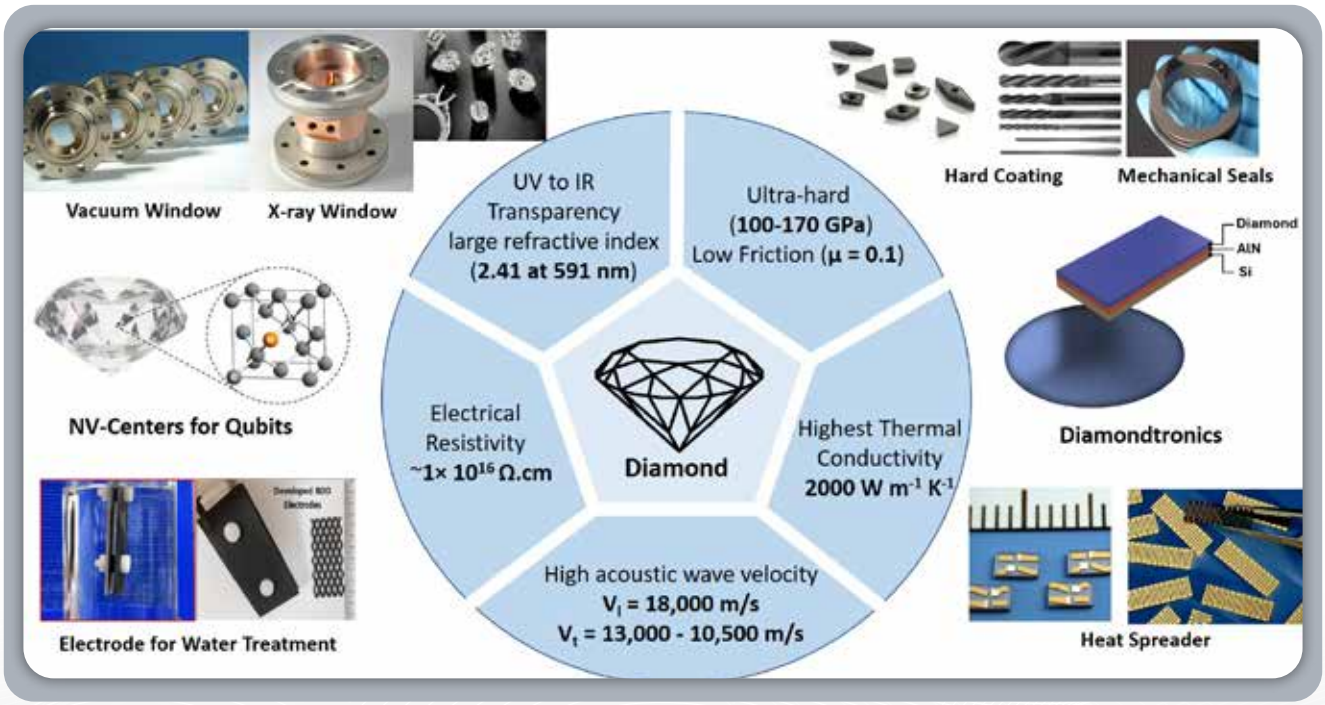
His team also investigated high-pressure high-temperature (HPHT) methods alongside CVD, developing indigenous equipment and solid-state microwave plasma generators. This dual approach allowed production of both jewellery-grade diamonds and electronic-grade wafers, the latter essential for “diamond-tronics”—a term coined to describe diamond-based electronics capable of operating at high voltages and frequencies.

The significance of this work was recognised at the highest levels. In 2023, the Finance Minister announced funding for a dedicated centre for lab-grown diamonds at IIT Madras during the budget session of Parliament. The initiative aligned with the Prime Minister’s vision of making India self-reliant (atmanirbhar) in advanced materials. With five principal investigators from the departments of physics, mechanical engineering, and electrical engineering, and a team of 100 staff members, the centre represents India’s first large-scale effort in this domain.

The outcomes have been remarkable. Diamond-coated tools now last far longer, reducing industrial costs. Defence and aerospace applications have benefited from corrosion-resistant, high-performance materials. In electronics, diamond wafers promise breakthroughs in high-frequency, high-power devices, radiation sensors, and quantum technologies. Two start-ups have already emerged from the programme, with more expected, ensuring revenue generation and global competitiveness.

Lab-grown diamonds are also environmentally sustainable and cost-effective, priced at close to one-third compared with natural diamonds. As global mines decline and monopolies weaken, India’s indigenous capability offers both economic and strategic advantages. Prof. Rao’s vision has transformed diamonds from luxury gemstones into quantum materials for the future, positioning IIT Madras as a hub for innovation in advanced materials.





Making Clinical Tests Affordable and Accessible

Is it possible to have advanced clinical tests for any disease at a community-level or primary healthcare centre? Can a drop of blood or urine be used to detect biomolecules at very low concentrations?

Why do most diagnostic tests still require complex laboratories, trained personnel, and long waiting times, even in an age of smart devices and instant information?

If rapid bedside diagnostics are so critical, why do only a few such technologies actually exist today?

Lead investigator:
Prof. V.V. Raghavendra Sai



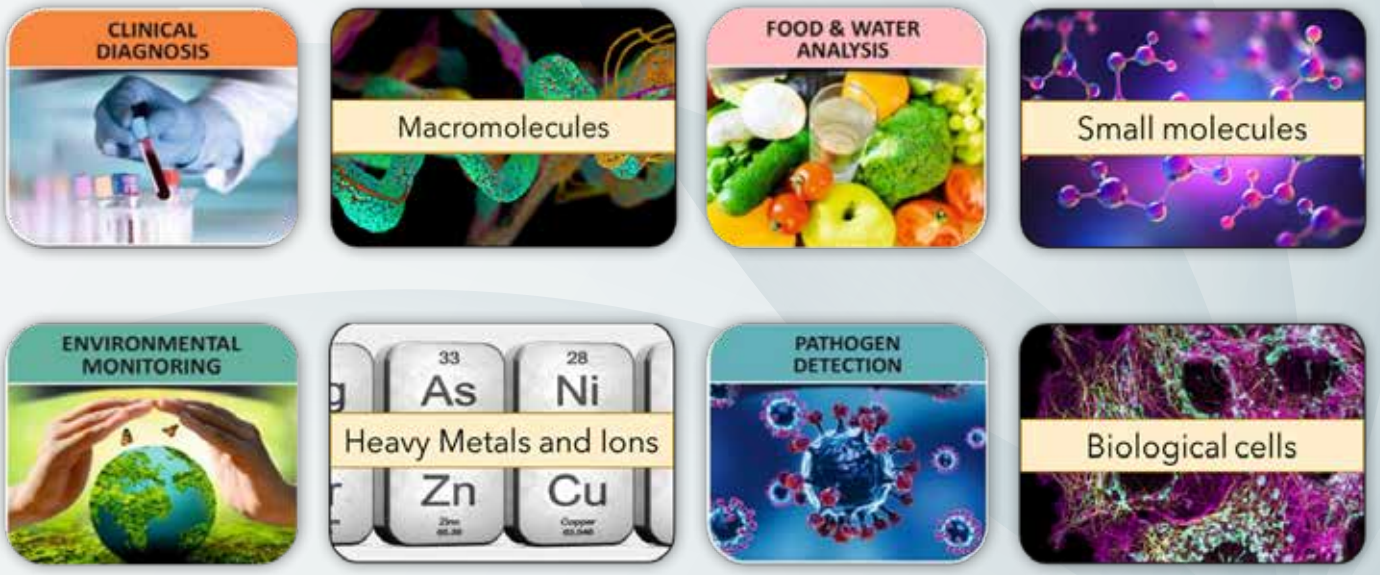
The answer lies in the challenge itself. True point-of-care (PoC) and near-POC sensing platforms capable of detecting ultra-low concentrations of biomolecules are rare, and those that have reached the market represent the outcome of decades of multidisciplinary research, rigorous validation, and technological refinement. It is within this landscape that the Biosensors Laboratory at IIT Madras, led by V.V. Raghavendra Sai, has emerged as a pioneer with the development of the U-shaped fibre optic sensor (UFOS)—a highly sensitive, rapid, and versatile sensing device designed to take advanced diagnostics beyond conventional laboratory settings. UFOS is built on the principle of evanescent wave absorbance sensing, offering exceptional sensitivity for real-time and precise quantification of biomolecules, toxins, and heavy metal ions. The platform has been indigenously developed and is low-cost, equipment-minimal, user-friendly, and scalable, making it particularly well suited for deployment in resource-limited settings for decentralised healthcare.

The technology follows a simple “dip-and-detect” assay format using affordable instrumentation. The decladded, U-shaped sensing region of the fibre—functionalised with specific chemical or biological receptor molecules—is immersed directly into the sample containing the target analyte. Light from a low-cost LED source is guided through the fibre, with a significant fraction extending beyond the core as an evanescent field that interacts with the sample. The optical losses due to the optical absorption by the chromophoric nanoreceptors or reporter labels for the chemical biological analytes of interest are measured using a photodetector at the other end of the probe. The change in light intensity is directly correlated to the analyte concentration, enabling real-time, rapid, and highly sensitive detection. The evanescent field of the core modes interacts directly with the analyte, leading to a change in intensity of light that is directly related to the concentration of the analyte in the sample. The approach supports label-free or minimally labeled assays, making it ideal

for immunoassays and nucleic acid assays targeting proteins, hormones, DNA, RNA, and other clinically relevant biomolecules. With turnaround times typically in the 10–30 minute range, UFOS is especially suited for PoC diagnostics.

The versatility of the UFOS platform has been demonstrated across high-impact healthcare applications, including screening for pre-eclampsia and ultrasensitive detection of infectious diseases such as COVID-19 and tuberculosis. Beyond healthcare, the UFOS technology has been successfully applied to food and environmental monitoring, including endotoxin detection and mycotoxin analysis, such as detection of ochratoxin-A in food products and heavy metal ions in water samples, highlighting the strength of a single platform that addresses multiple societal and industrial needs.

Prof. Sai's research has attracted substantial funding from various government, institutional, and international agencies. Key organisations that have supported the work on optical biosensors include IIT Madras itself and Government of India agencies such as the Department of Science and Technology (DST), Indian Council of Medical Research (ICMR), and Science and Engineering Research Board (SERB). International support has come from sources such as the Indo-German Science & Technology Centre (IGSTC), which funded a project for water-borne pathogen detection, the US–India Science & Technology Endowment Fund (USISTEF), and Indo-Norway and Indo-UK projects. The IGSTC project has been recognised as an indigenous technological innovation, funding the design and development of multiplexed and near-POC devices that have been licensed to US- and India-based startups and an Indian diagnostic company and aligned with the Aatmanirbhar Bharat vision and the Make-in-India initiative, emphasising indigenous innovation and scalable manufacture. The technology is designed to meet the World Health Organization's stringent ASSURED criteria—affordable, sensitive, specific, user-friendly, rapid, and equipment - free thereby underscoring its potential to utilise high-quality diagnostics, enable timely decision-making at the bedside, and extend reliable testing beyond conventional laboratories into resource-limited communities and homes.



Understanding Coatings of Soft Materials over Permeable Surfaces

A research team led by **Prof. Sreeram K. Kalpathy** has taken a closer, detailed look at something most people rarely think about—how liquids spread and settle on permeable/porous surfaces. From paints on walls to coatings on contact lenses and electronic materials, these processes are far more complex than they appear. The work sheds new light on how "soft materials" like liquids, polymers, and particle suspensions behave when applied to real-world surfaces.

In everyday life, surfaces are rarely perfectly smooth or solid. Many materials—such as paper, textiles, and even certain medical devices—are porous, meaning they contain tiny openings that allow liquids to seep in. This seemingly small detail can dramatically change how coatings form and perform. Recognising this, the research team set out to understand how coatings behave when applied to such imperfect surfaces.

One of their most notable breakthroughs revisits a classic scientific model from the 1940s that predicts how thick a coating film will be when a surface is dipped into a liquid and pulled out. Until now, this model assumed the surface was completely solid and non-porous. The team extended this theory to account for porous materials, revealing that permeability significantly alters how coatings form. Their findings, published in a leading scientific journal, have already influenced other international research studies in areas ranging from fibre coatings to architectural monuments to advanced sensing technologies.

To make their work more practical, the researchers developed simplified models that help predict coating outcomes under different conditions. These models take into account factors such as the porosity of the material, the specific type of flow behaviour exhibited by the liquid, and how quickly the coating process is carried out. Importantly, the approach works not only for simple liquids but also for complex materials like polymers, which are widely used in flexible electronics and medical devices.

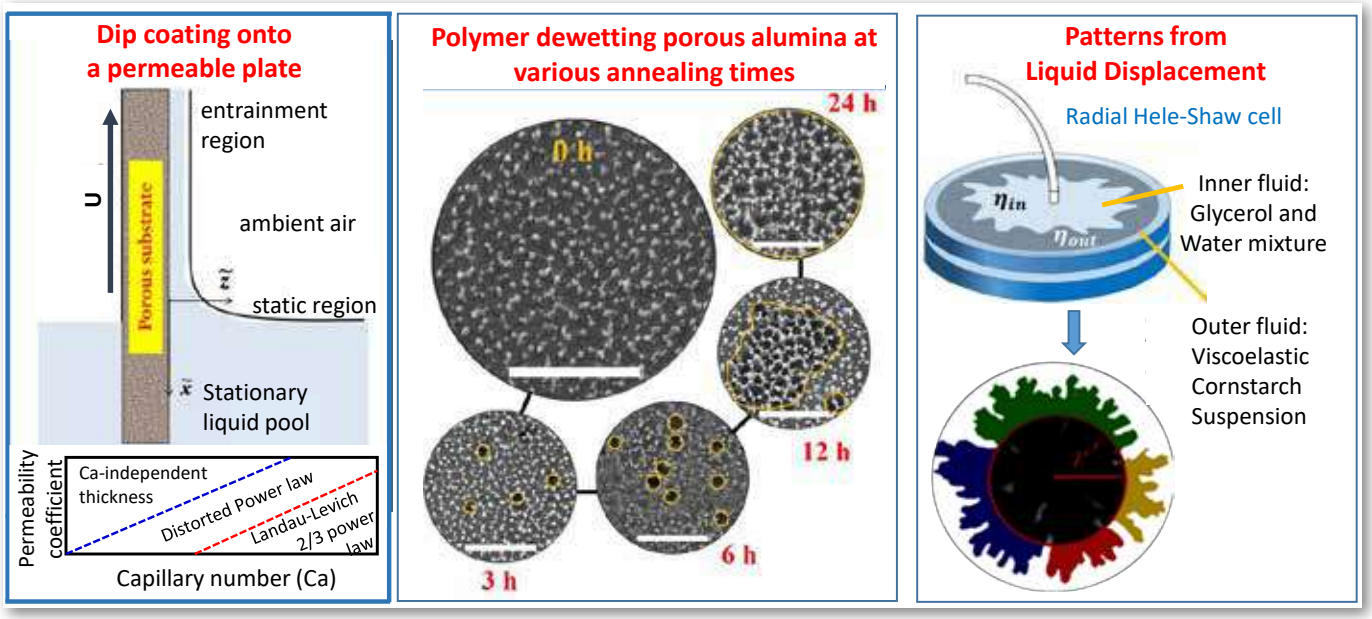
The team also explored coatings made from tiny particles suspended in liquids, such as silica. By carefully adjusting properties such as pore size and liquid composition, they demonstrated how to achieve smooth, uniform coatings with high coverage—an essential requirement in many industrial applications. In addition, they studied how thin polymer films behave on porous surfaces, including how they sometimes break apart or form uneven patterns, a phenomenon known as dewetting.

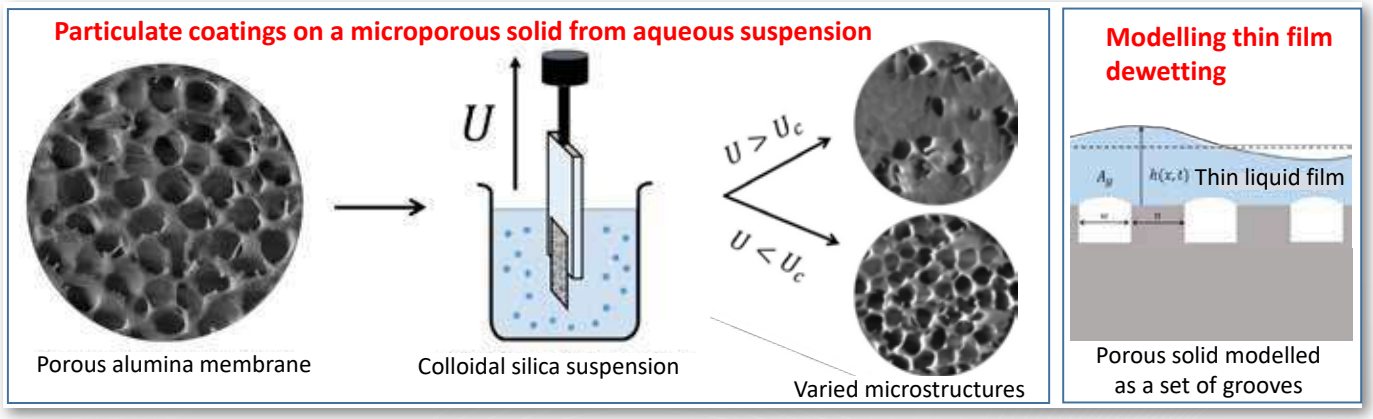
Another focus of the research was a widely used industrial technique called spin coating, where liquids are spread across a surface by spinning it at high speed. This method is commonly used to create thin films for electronic devices. The researchers discovered that the final quality of these films depends heavily on how quickly the process unfolds, rather than just the inherent compatibility of the materials. Even when materials should mix well, uneven structures can still appear if the process is not carefully controlled—an insight that could help improve devices like solar cells and sensors. The study also highlights the

importance of post-processing techniques. Heating, or “annealing,” was found to improve the uniformity and stability of coatings on porous surfaces. However, timing is critical—too much or too little heating can lead to defects such as holes in the film. This finding provides valuable guidance for industries aiming to produce reliable, high-quality coatings.

In a collaborative effort with the Raman Research Institute, in Bangalore, the team turned its attention to how fluids move through porous materials. They investigated a striking phenomenon known as “viscous fingering,” where one fluid pushing another creates intricate, finger-like patterns. By adjusting properties such as viscosity and elasticity, the researchers showed how these patterns can be controlled. This has practical implications for industries that handle complex fluids—such as food processing (sauces, chocolates, etc.) and personal care (lotions, for example)—where smoother and more efficient flows can improve product quality and manufacturing efficiency.

Overall, this body of work highlights how a deeper understanding of coatings on porous materials can lead to better products and processes across a wide range of industries. What might seem like a simple act—applying a coating—turns out to be a finely balanced interplay of physics, materials, and process conditions. Thanks to this research, that balance is now better understood, opening the door to smarter and more effective technologies in everyday life.





The Shakti Microprocessors

India is one of the world's largest importers of electronics, consuming vast quantities of microprocessors without producing its own (circa 2010). **Prof. V. Kamakoti**, of IIT Madras, recognised the strategic vulnerability this posed. Microprocessors are the "brains" of modern devices, and imported chips could potentially harbour hidden backdoors or leak sensitive information. His vision was clear: India needed to design and manufacture her own secure, indigenous microprocessors to ensure technological sovereignty and compete globally. The Shakti project was born from this vision. Prof. Kamakoti's rationale was that true security could only be achieved if the architecture itself was designed indigenously.



Reverse engineering a chip is notoriously difficult. Therefore, the only way to guarantee trust was to build from the ground up. The initial goal was to create processors for domestic consumption, at the same time positioning India as a global competitor in semiconductor design.

The Ministry of Electronics and Information Technology (MeitY) provided the initial funding for the project. This support allowed the team to experiment with processor design, verification, and validation, while building the necessary ecosystem of software and hardware tools. Work began around 2014 at the RISE Lab, IIT Madras, now renamed the Pratap Subrahmanyam Centre for Digital Intelligence, Secure Hardware and Architecture (PS-CDISHA). The project leveraged India's only semiconductor foundry, the Semiconductor Laboratory (SCL). in Chandigarh, which has 180-nm technology capabilities. The team also collaborated with international foundries such as Intel for manufacturing the microprocessor in the advanced 22-nm process technology.

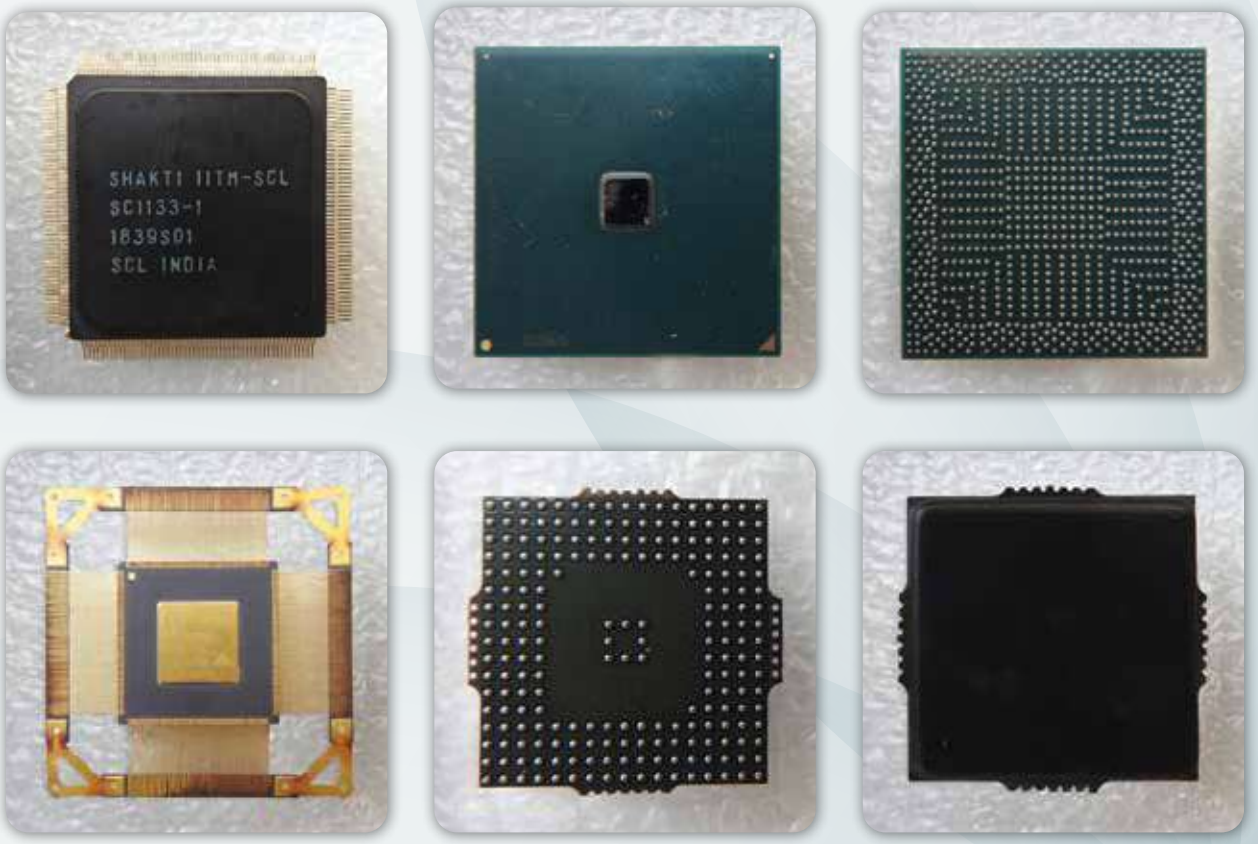
The Shakti family of processors was designed using the open-source RISC-V Instruction Set Architecture (ISA), pioneered by UC Berkeley in 2012. IIT Madras, recognising its potential to free India from the expensive licensing fees associated with proprietary ISAs such as ARM and Intel's x86, was one of the founding members of the RISC-V consortium. For hardware description, the team chose Bluespec, a high-level hardware description language that compiles down to Verilog (current industry standard), enabling faster and more efficient design cycles.

The first tape-out occurred in 2017, producing the Shakti C-Class CPU, aimed at industrial applications. This was followed by the E-Class, designed for low-cost embedded systems. The team also developed in-house PCB designs, system software, and application software to ensure end-to-end

integration. Work is in progress on the I-Class, a high-performance processor intended for mobile devices. Other products under development are ShaktiMAAN, a hardware accelerator for machine learning, and a low-energy neuromorphic accelerator for efficiently executing dual-sparse mixed-precision spiking neural networks.

Agencies such as ISRO, DRDO, and Bharat Electronics Limited (BEL) have begun adopting Shakti processors for different applications and have expressed interest in collaborating on future tape-outs. Beyond government use, Shakti has catalysed a wave of semiconductor startups. InCore Semiconductors, based in IIT Madras Research Park and Bangalore, is building RISC-V IPs and SoCs, which can be licensed by product companies to develop RISC-V based solutions. Mindgrove Technologies, likened to Qualcomm in ambition, has demonstrated end-to-end processor development by building India's first commercial-grade high-performance microcontroller, with built-in security, for IoT and embedded systems. Other startups, such as Vyoma Systems, Shakra Innovations, Drutam Technologies, SecurWeave, and SecurSi Technologies, provide products and services spanning the entire RISC-V hardware, software, and security ecosystem.

Looking ahead, the team is preparing for tape-outs of out-of-order processors and machine learning accelerators, a foundational requirement for high-performance computing applications. Shakti's influence is expanding beyond academia, with potential applications in automotive electronics and smart devices worldwide.





Steam Oxidation Test Rig for Ultra-supercritical Power Plants

Thermal power plants are the backbone of electricity generation in India. But conventional systems face challenges of high fuel consumption and significant carbon emissions. The advanced ultra-supercritical (AUSC) technology was envisioned to address these challenges. AUSC promised a great improvement in efficiency, by up to 48%, compared with the existing plants. At the same time, it would reduce carbon dioxide output. The operating conditions of AUSC would be extreme, and researchers needed to identify materials capable of withstanding these conditions. **Prof. V.S. Sarma** initiated the development of a specialised steam oxidation test rig to evaluate candidate materials under the environments of AUSC plants.

Thus the journey of Prof. Sarma's research began with the pressing need to modernise India's thermal power infrastructure.

The central problem addressed by his project is to ensure that the materials used in the high-temperature, high-pressure components of AUSC power plants are durable and reliable. Super-heaters and re-heaters are critical to the performance of these plants. These components must resist oxidation and corrosion over long service lives. Without proper testing, they may fail prematurely, which would jeopardise the efficiency and safety. Prof. Satyanarayanan Seshadri, within the scope of a DST-funded project, has designed and fabricated a rig that tackles the issue. It does this by simulating steam oxidation conditions up to 750°C and 400 bar and enables alloys and coatings to be evaluated. The rig can also be used for other industrial environments where there are similar harsh conditions: in hydrocarbon extraction, biofuel production, and chemical synthesis.

The project was supported through R&D initiatives aligned with India's national energy goals.

The rig that Prof. Satyanarayanan Seshadri and his team fabricated is equipped with heating and stirring facilities and precise system controls to regulate the temperature and pressure. The rig was used to expose specimens of austenitic stainless steel 304HCu, Alloy 617, and FeAl coatings to steam at 230 bar and 700°C for 1000 hours. Their oxidation behaviour was analysed. Significant differences in weight gain and oxide scale thickness were found between fine-grained and coarse-grained specimens. The tested specimens were characterised using X-ray diffraction (XRD), which provided insights into the oxide formation mechanisms involved. The prospects of commercialisation and adoption by industry are promising, with discussions under way.

The steam oxidation rig provides a platform for screening materials used in AUSC power plants. The ability to simulate a range of conditions, up to those encountered in AUSC plants, makes the versatile system applicable across industries, from biofuel extraction to chemical processing. Nationally, the technology contributes to India's mission of reducing carbon footprints and advancing sustainable industrial practices. Ultimately, the rig not only strengthens India's energy infrastructure but also positions the country as a leader in high-temperature materials research.


TEST IN
DO NO

Ultrathin Films for Electrocatalysis

Prof. Satyesh Kumar Yadav first became acquainted with a thin-film deposition system (magnetron sputtering machine) during his undergraduate studies at IIT Roorkee. Such systems are used to coat surfaces with ultrathin (nanometres) layers of metals such as gold and platinum or oxides such as silicon dioxide and alumina. These layers need to be very thin because the material properties change significantly at the nanoscale. Their electronic, optical, or catalytic behaviour can be finely controlled. Ultrathin films find application in semiconductors, sensors, and catalysis. For instance, they are central to chip manufacturing, where precise control of coatings at the atomic scale determines performance.



Lam Research, a major chip-equipment manufacturer, approached Prof. Yadav to seek explanations for the remarkable behaviour of Zn-doped Ru ultrathin films. Having trained extensively in atomic-level simulations during his doctoral and postdoctoral work in Connecticut and Los Alamos, Prof. Yadav has developed strong intuition into an atomistic view of materials. provided a crucial insight into the phenomena.

While simulating the behaviour of ultrathin films, he envisioned a new opportunity to manipulate them. This is when he decided to set up a magnetron sputtering facility to deposit ultrathin films. He built an experimental facility at IIT Madras using seed funding of ₹ 45 lakhs from IC&SR. In 2020, he acquired a deposition system that was identical to the one he had used at Roorkee.

Prof. Yadav's research combines atomistic modelling and experiments to understand interfaces of nano-heterostructures. Prof. Yadav and his team created ultrathin-films of platinum on silicon wafers, with a zinc adhesion layer in between. These films, when tested under harsh acidic conditions, proved to be remarkably stable. Prof. Satyesh Kumar Yadav's research on ultrathin zinc–platinum films has significant implications across science, industry, and sustainability. They are used in microelectronics, fuel cells, and catalytic converters, for example. By demonstrating that stable catalytic layers can be deposited at nanometre thicknesses, the work directly addresses the challenge of reducing the amount of expensive noble metals such as platinum in various applications. This cost-effectiveness is crucial for scaling up hydrogen production technologies, where platinum is a key catalyst but is traditionally used in large, costly amounts.

The durability of the platinum layers in highly acidic conditions means they can be deployed in real-world electrolysis systems without rapid degradation. By extending electrode lifespan and reducing replacement costs, the coatings improve the viability of hydrogen as a clean fuel.

Beyond energy, Prof. Yadav's research impacts the semiconductor industry. Ultrathin films at metal–oxide interfaces improve charge transfer and heat dissipation, tackling persistent problems such as overheating in mobile devices. By combining atomic-level simulations with experimental validation, Prof. Yadav has created a model of interdisciplinary innovation. His work advances academic understanding and provides industry with practical, scalable solutions.





Artificial Intelligence, Advanced Computing

AI4Bharat

India speaks more than 1500 tongues and recognizes 22 official languages, yet digital technologies that power everything from mobile banking to legal transparency overwhelmingly favour English and a few dominant regional languages. In 2019, a Supreme Court plea to translate judgements into multiple vernaculars laid bare the absence of AI models capable of handling this diversity. Backed by the EkStep Foundation and Nilekani Philanthropies, and steered by **Prof. Mitesh Khapra** at IIT Madras, AI4Bharat set out not just to translate judicial rulings but to build a foundational open-source language-AI ecosystem for all of India's scheduled languages and beyond.



At the core of AI4Bharat is an unparalleled data-collection effort, undertaken in its capacity as the Data Management Unit for Bhashini, the MeitY-funded national language mission. Over 1893 field workers fanned across more than 144 districts, capturing 20,000 hours of speech (12,000 hours fully transcribed) and curating hundreds of millions of text sentence pairs. Manual recordings—driven by community trust and dialectal authenticity—complemented large-scale mined corpora from news archives. To orchestrate quality at this scale, the team built Shoonya, a multi-layer text-annotation platform, and enhanced the Karya mobile app for real-time speech validation and demographic tracking. This two-pronged approach ensures that even languages such as Kashmiri, Bodo, Manipuri, Sindhi, and Santali—historically starved of digital resources—now boast structured, high-quality datasets.

Armed with this rich corpus, Prof. Khapra's team engineered state-of-the-art AI systems: automatic speech recognition (ASR) for all 22 scheduled languages, machine translation (MT) covering every one of the 253 language pairs linking those tongues with English, and text-to-speech (TTS) voices for each of the 22 languages. By pioneering model-compression and optimisation techniques, they made real-time on-device inference feasible for resource-constrained settings. Rigorous training-validation loops, tailored to capture code-mixing, yield translation and ASR accuracy that rival global benchmarks while running efficiently on modest hardware.

Behind each AI4Bharat service lies the AI4X Stack, a modular infrastructure co-developed with the EkStep Foundation. It integrates diverse models, automates complex workflows, and scales to handle millions of daily inferences. AI4Bharat's open models power Bhashini's real-time speech translation and transliteration services, democratising access to government portals, helplines, and grievance systems. The Supreme Court's SUVAS platform has translated more than 31,000 judgements into

regional languages. In education, AI-driven reading and numeracy tutors (ALL and AXL) bolster learning in Taminadu. and Sarvam AI leverages the datasets for generative chatbots in local languages, while the Kisan e-Mitra chatbot answers farmers' subsidy and agronomy queries—benefiting over 6.5 million users. NPCI's voice-enabled UPI payments and NCERT's e-Jaadui Pitara learning app further illustrate how inclusive AI reshapes daily life.

An open, collaborative future backed by MeitY, philanthropic partners like Rohini and Nandan Nilekani, and global tech collaborators, AI4Bharat champions an "AI for all" ethos. By open-sourcing every dataset and model, it eliminates training-cost barriers for startups, researchers, and governments. This public-good approach not only cements India's leadership in multilingual AI but offers a replicable blueprint for other linguistically diverse regions, from Africa to Southeast Asia.

AI4Bharat transforms language from a barrier into a bridge, ensuring that India's digital future speaks in every mother tongue.



Centre for Responsible AI

The Centre for Responsible AI (CeRAI) at IIT Madras is a leading interdisciplinary research centre located in the Global South, dedicated to advancing both the technical and policy dimensions of responsible AI. CeRAI stands out globally as one of the few institutions that integrate fundamental and applied research with policy development to promote the ethical, fair, and accountable deployment of AI systems.



A visionary leadership

At the helm of this transformative journey is **Prof. Balaraman Ravindran**, the founding head of the Wadhwani School of Data Science and AI and CeRAI. Prof. Ravindran is a global authority in the field, his influence extending to the United Nations, where he serves on the Independent International Scientific Panel on AI.

Under his guidance, CeRAI has become a thriving ecosystem with over 12 Principal Investigators who lead research projects and set the Centre's research agenda; research leads, who oversee specific research areas and mentor junior researchers; policy analysts, who examine the policy implications of AI and contribute to policy development; and junior researchers, who conduct research and contribute to CeRAI's publications and events.

The Centre's strategic path is paved by a scientific advisory board of eminent global experts and a governing council that ensures every research breakthrough translates into meaningful societal impact.

Supported by a powerhouse consortium including Google, Ericsson, the Gates Foundation, and Roche, CeRAI continues to bridge the gap between what AI can do and what it should do.

Dimensions of research

CeRAI's work is organised into four pillars: Technical Research, Policy Research, Education and Outreach, and Advisory Roles. Its research themes - Safe AI, Making AI Understandable, and AI and Society-tackle the most pressing questions of the AI era.

- Technical Integrity: Researchers at CeRAI are evaluating the readiness of large language models (LLMs) specifically for the Indian context, ensuring these systems are not only high-performing but culturally equitable.
- Sectoral Innovation: From creating AI agents that interact naturally with humans to investigating life-saving applications in healthcare and transformative tools in law and education, the Centre is building AI that serves the public good.
- Policy and Governance: By advising government bodies on data privacy and algorithmic bias, CeRAI helps formulate the governance structures that will keep AI safe and trustworthy.

Global impact: The India AI Impact Summit 2026

The Centre's role as a "knowledge partner" was most visible at the India AI Impact Summit 2026 at Bharat Mandapam, New Delhi. In the months leading up to the summit, CeRAI hosted pivotal pre-summit events

on AI governance and human capital, setting the stage for international dialogue.

A landmark achievement was the launch of the Global South Research Network for Trustworthy AI. This initiative fosters Global South collaboration, ensuring that the unique priorities of developing nations are represented in the global AI safety conversation.

CeRAI in numbers

The Centre's contribution is reflected in its rapid growth and output:

- 12 peer-reviewed research papers and 14 influential policy papers
- 26 major events conducted and 18 op-eds in leading publications
- 6 prestigious awards recognising its contributions to the field

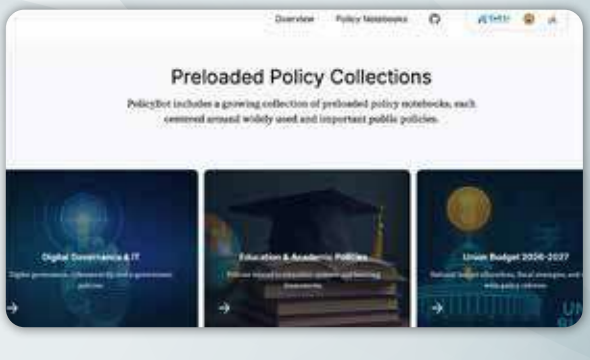
Through these efforts, CeRAI aims to shape standards, frameworks, and best practices for responsible AI, ensuring that technological advancements benefit society at large.











IIT Madras OpenMP Compiler Framework (IMOP)

Compilers are the invisible engines of modern computing, translating human-readable programs into machine code. While global projects such as GCC and LLVM dominate the landscape, their complexity often makes it difficult for researchers to experiment with new optimisation or program analysis techniques. To address this challenge, **Dr. Aman Nougrahiya and Prof. Krishna Nandivada** at IIT Madras developed the IIT Madras OpenMP Compiler Framework (IMOP)—India's first openly available compiler framework, recognised internationally by the OpenMP Research Board.

IMOP was conceived to simplify the process of analysing and optimising OpenMP programs written in C. Traditional compilers can be cumbersome when handling long programs that stretch to thousands of lines, and even small modifications must be made with extreme care. IMOP functions as a source-to-source compiler: it takes an OpenMP program as input, applies analyses and optimisations, and produces another OpenMP program as output. This design avoids reinventing the wheel while providing a flexible platform for innovation.

Prof. Krishna explains that IMOP provides value in distinct ways:

1. For compiler writers: IMOP makes it convenient to implement new optimisations and program analysis techniques without having to understand all the existing passes of optimisations and analyses in the compiler. This design choice is termed "Homeostasis". Unlike GCC or LLVM, where additions can be cumbersome, IMOP's innovative Homeostasis framework lowers the barrier to experimentation.
2. For end users: Programs can be compiled using IMOP, which applies both its own optimisations and those already present in GCC/LLVM. The performance improvements vary depending on which IMOP optimisations are invoked. The team has found measurable gains in specific contexts.
3. For writers of new compilers: The design decisions of the IMOP framework can work as foundational basic-blocks for the design and implementation of future compilers.

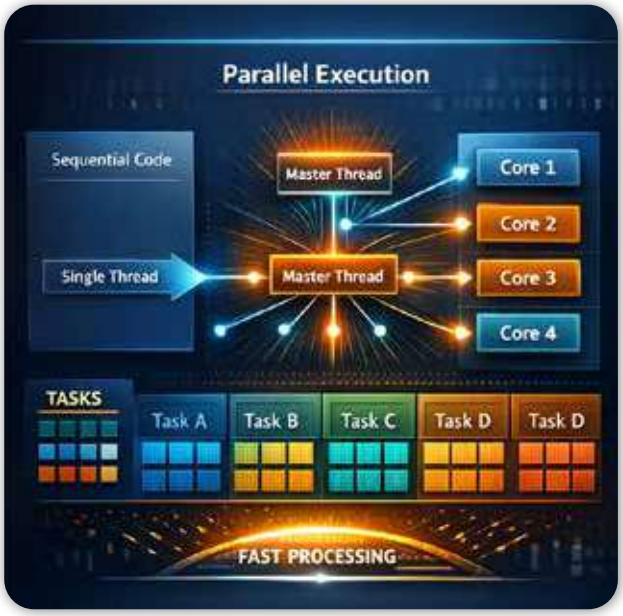
Work on IMOP began around 2015, with the framework taking shape in 2016 and the alpha version released in 2021. The project was developed entirely within IIT Madras's Computer Science Department, with major contributions from students such as Aman Nougrahiya, who implemented key research topics. Other students have since expanded the framework

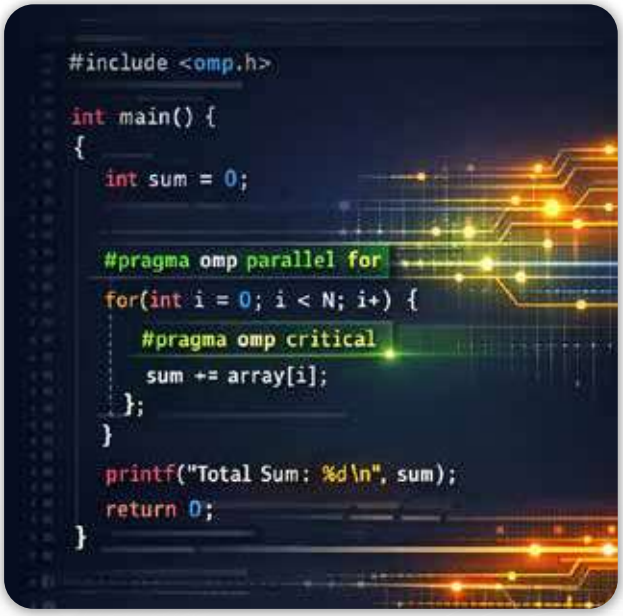
with new components. Tutorials are available online, and the project is actively maintained on GitHub, where associated research papers are also listed.

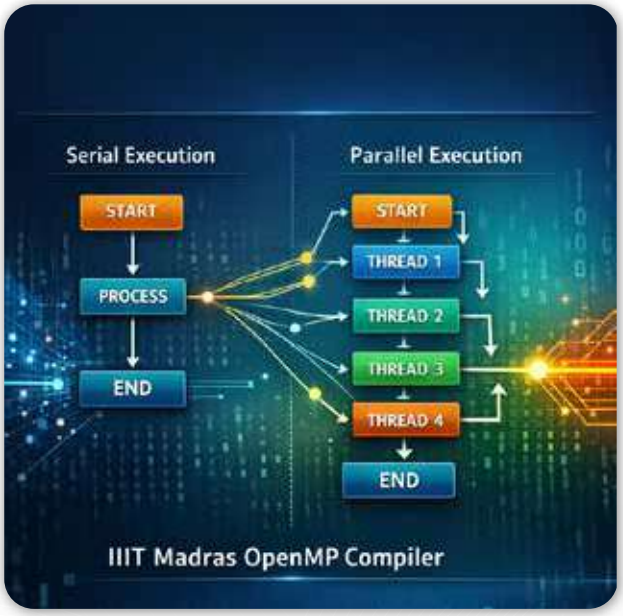
IMOP reflects IIT Madras's commitment to advancing computer science research. Supported by institutional funding and academic collaboration, it has achieved international recognition: the OpenMP Research Board lists IMOP among compilers contributing to the global ecosystem of parallel programming tools.

Although Prof. Krishna estimates IMOP's current usage at around 10 on a scale of 100—primarily within academia—the framework's impact lies in enabling research scholars to experiment with new ideas more easily than with existing compilers. As compilers evolve, IMOP stands as a pioneering Indian contribution to the global research community, lowering barriers to innovation and strengthening India's presence in advanced computing.

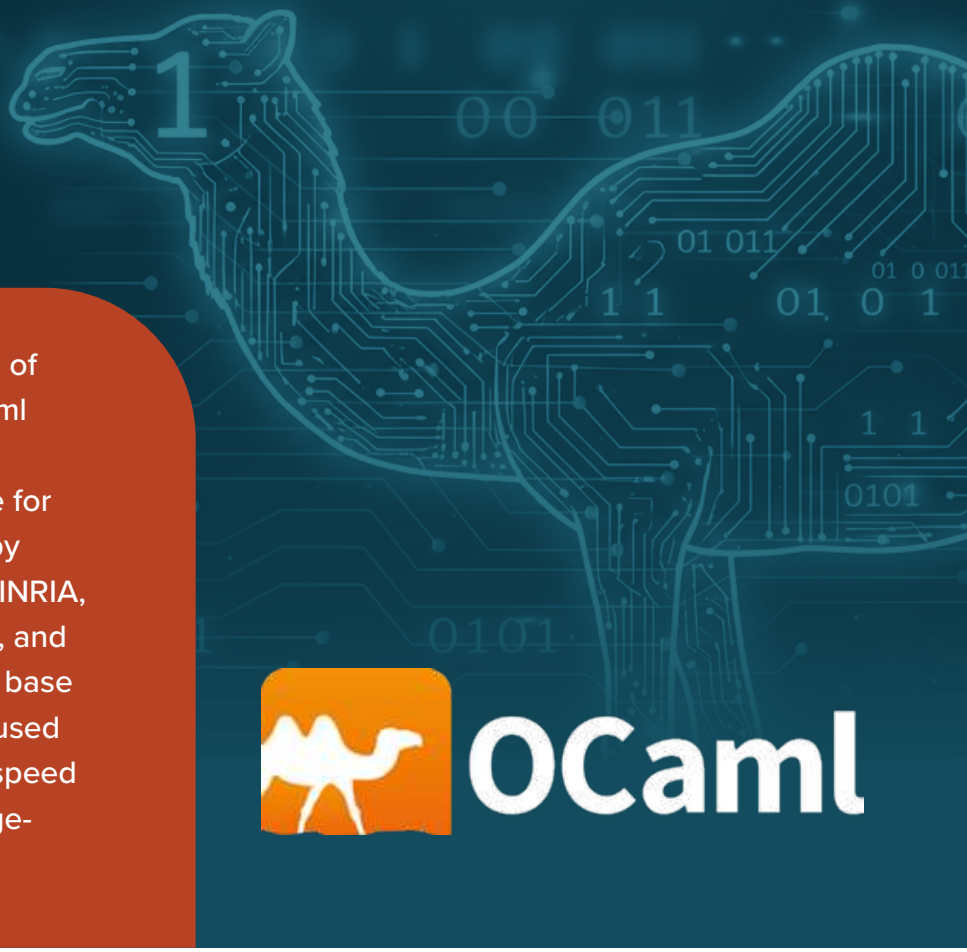








Multicore OCaml



Prof. K.C. Sivaramakrishnan, one of roughly 25 core developers of OCaml worldwide, led the Multicore OCaml effort that modernised the language for parallel hardware. OCaml, created by Xavier Leroy about 30 years ago at INRIA, is valued for reliability, performance, and expressive power. Although its user base is small (under 50,000), it is widely used in domains where correctness and speed are critical—finance, aerospace, large-scale computing.

The Multicore OCaml work addressed a clear problem: mainstream hardware shifted from single-core CPUs to chips with many cores, but OCaml's runtime and language primitives were designed for sequential execution. The project's purpose was to provide safe, efficient language-level support for parallelism so that OCaml programs could exploit multicore processors without sacrificing the language's guarantees on safety and determinism—crucial for high-assurance applications such as fintech and blockchain systems.

Prof. Sivaramakrishnan began core development on Multicore OCaml in Cambridge in 2014, collaborating closely with other members of the OCaml Labs initiative. His contributions included designing and implementing language primitives and runtime changes that act like composable "Lego blocks" for concurrency—building blocks that let programmers express parallel tasks while preserving memory-safety and predictable behaviour. In 2019 he moved the initiative to IIT Madras, continuing development, testing, and integration work there. At IIT Madras he guided implementation, performance engineering, and correctness validation, helping adapt the runtime scheduler, garbage collector, and language interfaces to multicore execution. His role combined hands-on systems programming with coordination across the small global OCaml core team.

The project at IIT Madras received funding from the Tezos Foundation, a blockchain organisation that emphasised the need for fast, reliable execution in fintech and smart-contract platforms. This support enabled sustained engineering work, benchmarking, and the refinement necessary to make Multicore OCaml production-ready for performance-sensitive domains.

Multicore OCaml materially broadened OCaml's relevance on modern hardware. By introducing safe parallel primitives and a compatible multicore runtime, the work enabled existing OCaml code bases to scale on multicore servers without rewriting for low-level threading or risking subtle concurrency bugs. For fintech and blockchain applications—areas where Tezos and other stakeholders operate—this meant faster transaction processing, more responsive services, and stronger correctness guarantees

under concurrent load. More broadly, Multicore OCaml strengthens the language's attractiveness for systems programming, high-assurance applications, and research, helping retain a specialised but influential user community and ensuring OCaml can continue to serve domains that demand both speed and reliability.

Multicore OCaml is now used in production at many companies, including Jane Street, whose trillions of dollars of notional trading volumes go through the system that matured at IIT Madras.

Prof. Sivaramakrishnan's stewardship—spanning design, implementation, and ecosystem advocacy was central to delivering a multicore-capable OCaml that aligns with contemporary hardware trends while preserving the language's foundational guarantees.

```
type _ eff += Fork  : (unit -> unit) -> unit eff
type _ eff += Yield : unit eff

let fork f = Effect.perform (Fork f)
let yield () = Effect.perform Yield

(* A concurrent round-robin scheduler using
 * effect handlers *)
let run main =
  let run_q = Queue.create () in
  let enqueue k = Queue.push k run_q in
  let dequeue () =
    if Queue.is_empty run_q
    then ()
    else Effect.Deep.continue (Queue.pop run_q) ()
  in
  let rec spawn f =
    (* Effect handler => instantiates fiber *)
    match f () with
    | () -> dequeue ()
    | exception e ->
        ( print_string (Printexc.to_string e);
          dequeue () )
    | effect Yield, k ->
        ( enqueue k; dequeue () )
    | effect (Fork f), k ->
        ( enqueue k; spawn f )
  in
  spawn main
```



Engineering Human Performance using an AI-Powered Eye Tracking System

The landscape of work and the workplace is undergoing a sea change across industries, brought about by the adoption of new technologies such as digitalisation, robotics, IoT, AI/machine learning, and virtual, augmented, and mixed reality. The induction of these advanced technologies is motivated by the desire to overcome common human limitations and worker frailties (such as human behavioural biases and attention tunnelling). However, integrating such technologies leads to fundamental changes in the human–technology relationship and introduces new challenges and failure modes (for example, over-reliance on technology). Recent statistics indicate that human attention and behaviour challenges, such as fatigue and disengagement, cause ~80% of transportation accidents and US$8.8 trillion in global productivity losses annually.

The research group of **Prof. Rajagopalan Srinivasan** and **Prof. Babji Srinivasan** at IIT Madras focuses on engineering the performance of humans in the context of human–technology partnerships. Specifically, their group has developed a patented multi-screen eye-tracking solution (ParvAI Focus) that gives actionable science-based insights about the cognitive behaviour of humans from eye gaze data. By embedding ParvAI Focus across control rooms, training simulators and operational dashboards, users have gained unprecedented visibility into operator alertness, training effectiveness, and user engagement, enabling faster decision-making, proactive safety interventions, and continuous performance improvement. The technology has been licenced to a startup that emerged as the winner in the AI, DeepTech, and Cyber category at the 2nd Startup Mahakumbh in 2025, underscoring its impact in AI-powered eye tracking analytics and the domain of human–machine collaboration.

To drive real-world impact, the IIT Madras research team has partnered with India's leading research and development agencies—ISRO, NIOT, NPOL (DRDO), the Airports Authority of India, and multinational firms to advance astronaut training, submersible interfaces, human–machine interaction systems and to validate ParvAI Focus in high-stakes environments. By identifying lapses before they cascade into accidents, the root causes of millions of annual workplace injuries and fatalities are addressed and team performance is improved, fostering overall well-being. In operations where unplanned downtime and human error can cost tens of millions per incident, ParvAI Focus delivers rapid ROI. By slashing error-related stoppages, shortening training cycles, and enabling data-driven optimisation for human–machine interaction systems, organisations achieve measurable productivity gains through smoother turnarounds and optimised system readiness. Through real-time monitoring of operator attention and cognitive load, ParvAI Focus proactively prevents human error-driven incidents such as chemical leaks and unsafe discharges that pose significant risks to soil, water, and air quality. Its precise gaze analytics enable data-driven refinements to human–machine interfaces, streamlining control sequences and eliminating redundant actions. The result is a marked reduction in energy consumption and material waste, reinforcing sustainable, environmentally responsible industrial practices.











Biology, Medical and Healthcare

Cancer Genome

At IIT Madras, **Prof. S. Mahalingam** has embarked on a mission to decode the cancer genome landscape in India. His work seeks to identify biomarkers that can aid in early detection, track disease progression, and predict treatment response. The ultimate purpose is to enable precision medicine-designing therapies tailored to the genetic profile of Indian patients. A major milestone in this journey is the **development** of Bharat Cancer Genome Atlas, for breast cancer, which now serves as an **open access** foundational database for researchers and clinicians. Building on this success, Prof. Mahalingam's team is expanding their **focus** to pancreatic, liver, and colon cancers and childhood leukaemia, aiming to create a comprehensive genomic map of the cancers most prevalent in the country.

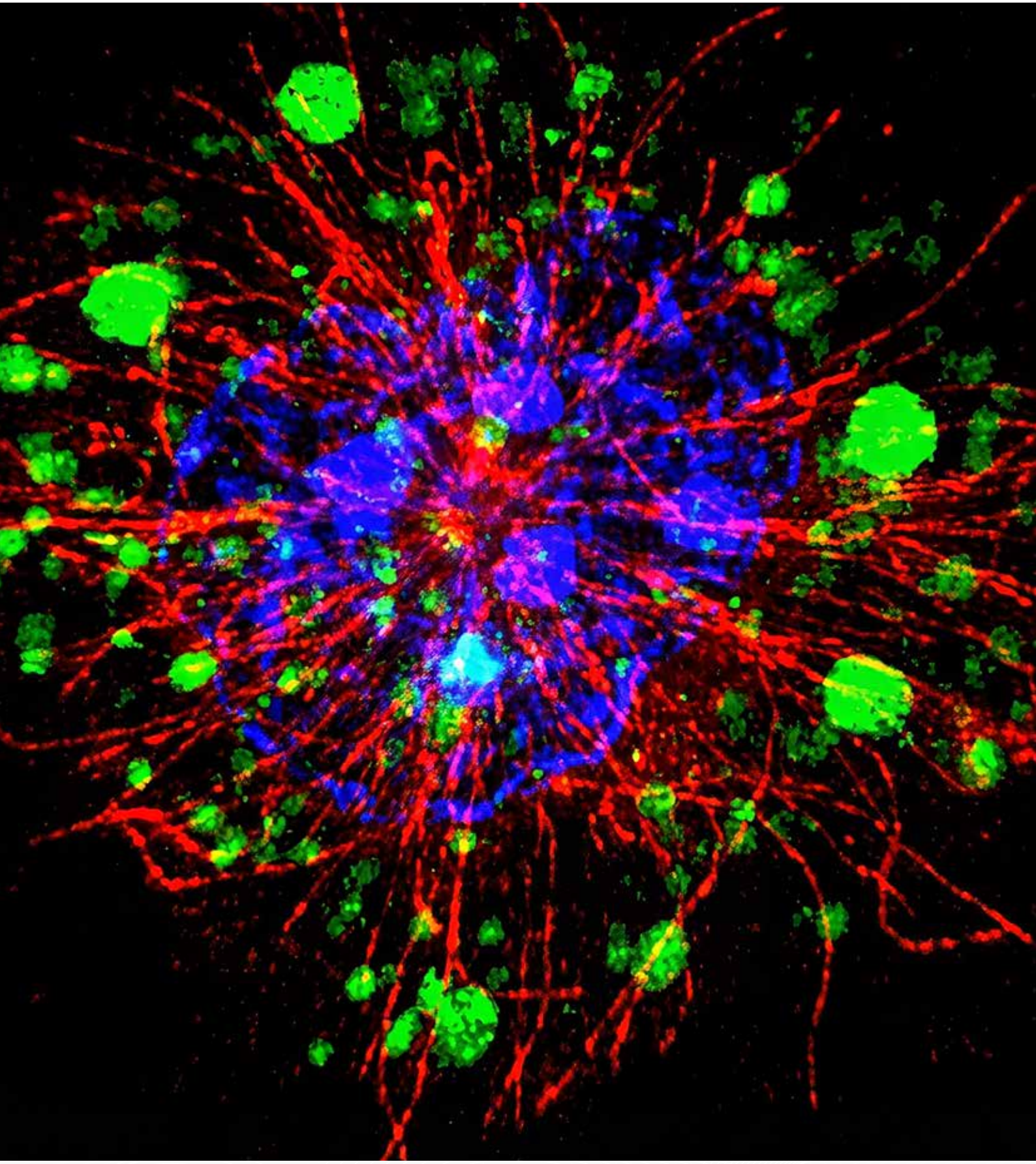
Central to the research is the National Cancer Tissue Bank, India's first community-based biobank. With contributions from ***10 hospitals-including KK Child's Trust, JIPMER, Chennai Breast Clinic, Kumaran Hospital, Rajiv Gandhi Government Hospital, Dr. Rela Medical Centre, and Southern Railway Headquarters Hospital***-the initiative has already collected around 7000 patient tissue and blood samples, stored in liquid nitrogen. The biobank has capacity for up to 200,000 specimens, ensuring long-term growth.

The team is also developing organoid models-lab-grown miniature versions of tumours-to study cancer evolution and treatment response. These models form the basis of a personalised treatment platform, allowing clinicians to tailor therapies to individual patients. Alongside laboratory work, Prof. Mahalingam's group is engaged in social outreach programmes, ***such as cancer awareness and screening in Tamilnadu, Maharashtra, and Haryana and HPV vaccination for girls aged between 9 and 19, with plans to expand nationwide***. Regional cancer patterns further guide their efforts: oral cancer dominates in the Northeast, diet-related cancers are common in Kerala, and breast and gastrointestinal cancers are prevalent in southern states.

The biobank has received significant support from the Department of Science and Technology (DST), underscoring the national importance of the project. ***In addition, a state-of-the-art next-generation sequencing (NGS) facility, funded by Karkinos Healthcare India, and a dedicated leukaemia research facility, funded by Hyundai Motors India***, expand the scope of the cancer research infrastructure. With advanced tools such as next-generation sequencers and molecular imaging systems, the project is well-equipped to accelerate genomic discoveries.

Prof. Mahalingam's work is already yielding results. ***The genomic data and biobank resources are being used to develop biomarkers for early detection and intervention, helping to identify individuals at risk***. By enabling region-specific screening and personalised treatment, the initiative promises to reduce cancer mortality and improve patient outcomes. Research papers are being published, and the continuous growth of the biobank ensures that future studies will have access to an unparalleled resource.

The vision is clear: to transform cancer care in India by harnessing genomics for timely, targeted, and effective interventions, ultimately changing the trajectory of one of the country's most pressing health challenges.



Hyperthermia for Cancer Treatment

Hyperthermia—raising tumour temperatures to 40–45°C—has emerged as a potent adjunct to chemotherapy and radiotherapy, boosting cancer-cell kill rates by roughly 20%, with minimal added toxicity. Since 2018, **Prof. Kavitha Arunachalam's** team at IIT Madras has been engineering an indigenised ultrasound-guided phased-array microwave hyperthermia system tailored for resource-constrained settings. Their goal: deliver focused, image-driven heating to tumours for 1-hour treatments in prone patients, with ergonomics, safety, and cost-effectiveness built from the ground up.

In Europe, hyperthermia devices are used routinely that cost upwards of US$2.5 million and often rely on bulky MR thermometry. India faces a twofold challenge: high import costs and a paucity of MR scanners outside major metros. Recognising this gap, Prof. Arunachalam secured funding from DST under the IMPRINT2 scheme in 2019 to develop a 50-W prototype with focused-microwave phased-array technology, typically used for defence research, for hyperthermia treatment delivery. She began validating treatment with 3D tissue phantoms. In parallel, she carried out device ergonomics studies with ethics approval in volunteers, ensuring comfortable face-down positioning during 1-hour hyperthermia treatment sessions.

Phase I work paired ultrasound imaging with low-power microwave applicators to localise and monitor tumour temperatures.

Building on the success of Phase I, students are now advancing to Phase II with CSR donation from SBI General Insurance Private Limited, through the Office of Alumni and Corporate Relations, IIT Madras: a fully programmable, steerable 200-W microwave phased-array applicator. In partnership with MSME industries, they are designing a custom high-power microwave amplifier capable of driving the antenna elements at an optimally chosen ISM band for the end medical application. Each channel, driven by an embedded FPGA system, delivers up to 200 W, enabling fine spatial-diversity steering and reducing hot-spot volumes. A patented two-step workflow incorporates on-table 3D ultrasound: first, obtaining patient consent and performing the scan; second, automated tumour-location mapping driving beam-steering algorithms that adjust microwave intensity to each patient anatomy. Real-time thermometry is derived from ultrasound backscatter, replacing MR for monitoring, as well as avoiding ionising-radiation burdens.

To ensure broad accessibility, the system eschews MR dependence, targeting implementation in Tier 2 and Tier 3 hospitals. It will potentially be used to treat large numbers of patients in government and NGO-run hospitals, where late-stage cases are prevalent.

The team is consciously integrating electromagnetic-compatibility compliance (IEC, FCC, ISM-band licensing) into hardware layouts. Thermal-management innovations push the microwave

amplifier efficiency to 80%, while joint-development agreements with industry partners aim to localise component supply chains, which is critical, given that SAC, ISRO, and DRDO all compete for limited high-power microwave semiconductor stocks.

Prof. Arunachalam's platform promises to elevate the standard of care in India by combining affordability, portability, and proven efficacy. Hyperthermia administered 15–30 minutes post-radiation or alongside chemotherapy can sensitise tumours without adding systemic side effects. The team has completed pre-clinical phantom and safety studies and is poised to launch pilot clinical trials within the year. Beyond clinical oncology, their modular phased array architecture holds promise for ablative therapies (RF, microwave, high-intensity ultrasound) for localised tumours requiring temperatures above 70°C.

By indigenising high-precision hyperthermia with image guidance, IIT Madras is charting a path for democratised cancer care: an open-access, low-footprint device that brings a 20% boost in treatment efficacy to hospitals nationwide, far beyond the reach of imported systems.





Indian Gestational Age Models

Accurate estimation of gestational age is the cornerstone of obstetric care. Determining when a foetus will reach full term, or risk pre-term delivery, guides everything from scheduling antenatal interventions to legal definitions of permissible abortion. Globally, most ultrasound machines rely on the Hadlock formulas, developed in the 1990s from a Texas cohort of Caucasian pregnancies. Yet in India, maternal nutrition, genetics, and healthcare access differ substantially, undermining Hadlock's precision. The error margins, of five to eight days, in later trimesters can translate into mistimed treatments, inadequate supplementation, and skewed public-health metrics. Compounding the challenge, nearly half of Indian mothers skip recommended antenatal reviews. Against this backdrop, **Prof. Himanshu Sinha**, of IIT Madras, set out to create India-specific gestational age (GA) models calibrated to the nation's unique maternal–foetal profiles.



The project began in 2018 under Grand Challenges India, which is a collaborative initiative between the Government of India and the Bill & Melinda Gates Foundation. Through a knowledge-integration grant, IIT Madras's Centre for Integrative Biology and Systems Engineering (IBSE), established in 2015 to tackle biological questions with engineering rigour, brought data-science expertise to the Translational Health Science and Technology Institute (THSTI), Faridabad. Under the leadership of Dr. Shinjini Bhatnagar, THSTI had already built GARBH-Ini, a rich database on pre-term births. Leveraging that registry, Prof. Sinha's team devised two quadratic regression formulas tailored to Indian ultrasound measurements.

1. *Garbhini GA-1 (first-trimester model)*: Input, crown–rump length (CRL) in centimetres; output, estimated gestational age in weeks; performance, accuracy comparable with that of Hadlock's first-trimester formula, validating CRL's universality even across diverse nutritional backgrounds.

2. *Garbhini GA-2 (late-trimester model):* Input, head circumference (three axes), abdominal circumference, and femur length—dimensions influenced by both genetics and maternal health; calibration, using each pregnancy's Garbhini GA-1 date as the "Gold Standard GA" to anchor later ultrasound readings; performance, a mean error of just one day demonstrated, versus 5.8–7.6 days for Hadlock's late-trimester formula, when tested on cohorts in Gurgaon and Vellore.

Throughout the development, the team addressed data sparsity and within-population variability. They collaborated with radiologists and obstetricians/gynaecologists and factored in their inputs and

regional differences were uncovered between north and south Indian centres.

Prof. Sinha's India-specific GA models carry far-reaching implications:

Clinical precision. More accurate due dates mean timely antenatal care and scheduling, nutritional and clinical interventions, and enhance foetal growth monitoring, directly reducing pre- term morbidity and mortality.

Public health surveillance. With the National Family Health Survey often limited by low antenatal uptake, Garbhini GA-1 and GA-2 offer robust backbones for national prevalence estimates of pre-term births.

Scalable solutions. Building on success in two cities, the team has secured funding for a nationwide study spanning seven civilian and private hospitals. A total of 4000 women will contribute ultrasound data, further refining the models and accounting for India's demographic and ethnographic mosaic.

Beyond immediate patient care, this work exemplifies how cross-disciplinary partnerships-bridging academic engineering, clinical biology, and global-health funders-can generate context-aware technologies. The study also emphasises the importance of utilising India-specific data to develop tools and technologies that enhance the accessibility and affordability of healthcare for the people of India. As Prof. Himanshu Sinha's gestational age models gain clinical adoption, India stands poised to lead in precision maternal health, ensuring expectant mothers receive care calibrated not to foreign norms but to their own diverse physiologies.



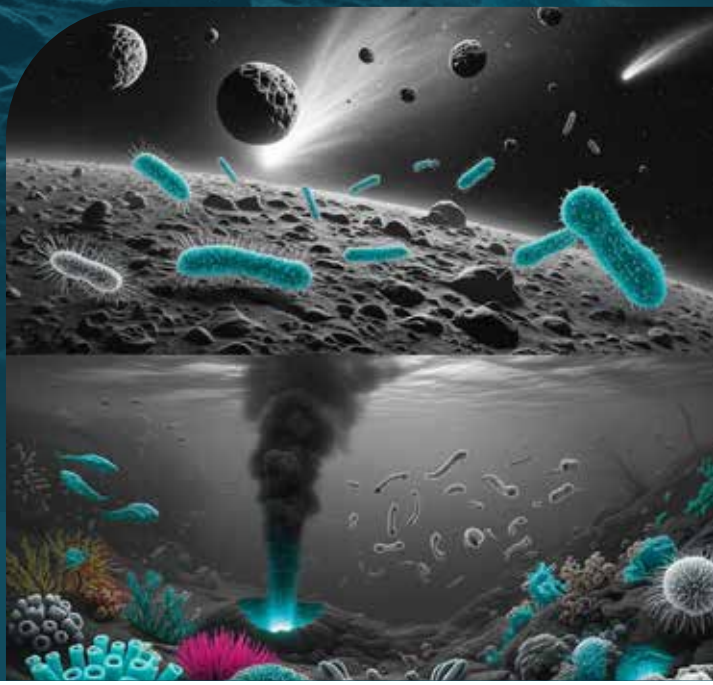






Microbiome

Microorganisms pervade every corner of our planet, from human gut tracts and hospital wards to ocean depths and outer space. Yet a lot of what we know about bacteria comes from species we can culture in a lab, and a large fraction of microbes are invisible to traditional methods. Since 2020, **Prof. Karthik Raman** has led a systems biology-driven effort at IIT Madras to chart parts of this hidden biodiversity, unravel microbial interactions, discover new species, and harness beneficial microbes to tackle challenges in health, industry, and beyond.



At the heart of Raman's work is metagenomics-sequencing all the DNA present in a microbial community to identify which species are there, infer their functions, and predict their relationships. In collaborating with national and international experts, his team has assessed the microbiome from a range of environments, including spacecraft clean rooms, bus-stand benches, hospital wards, sea vents, and even metro handrails, by extracting and analysing total DNA. Using advanced computational pipelines, they discovered novel microbes: one such discovery was Tigheibacillus, a new bacterial genus found in NASA's Mars 2020 spacecraft assembly facility (SAF), defined from sequence signatures.

Once the community composition is mapped, Prof. Raman's group applies systems-level modelling to ask, Which microbes promote each other's growth, and which curb competitors? By reconstructing metabolic networks in silico, they predict whether Microbe A secretes some metabolites beneficial to Microbe B—and propose experiments to validate these dependencies. This pipeline unites hypothesis generation with lab testing, closing the loop between data and discovery.

Prof. Raman's collaborative work spans leading-edge research at NASA's Jet Propulsion Laboratory to pioneering efforts in India's deep-sea exploration, reflecting an orbit-to-ocean approach to advancing science and technology. With former JPL microbiologist Kasthuri Venkateswaran, his team has analysed microbial snapshots from the International Space Station (ISS) and spacecraft assembly facilities over 18 months, offering insights into microbial colonisation patterns in space and their effect on planetary protection and human space flight. They recently published their findings about multidrug-resistant Enterobacter strains thriving in the ISS environment.

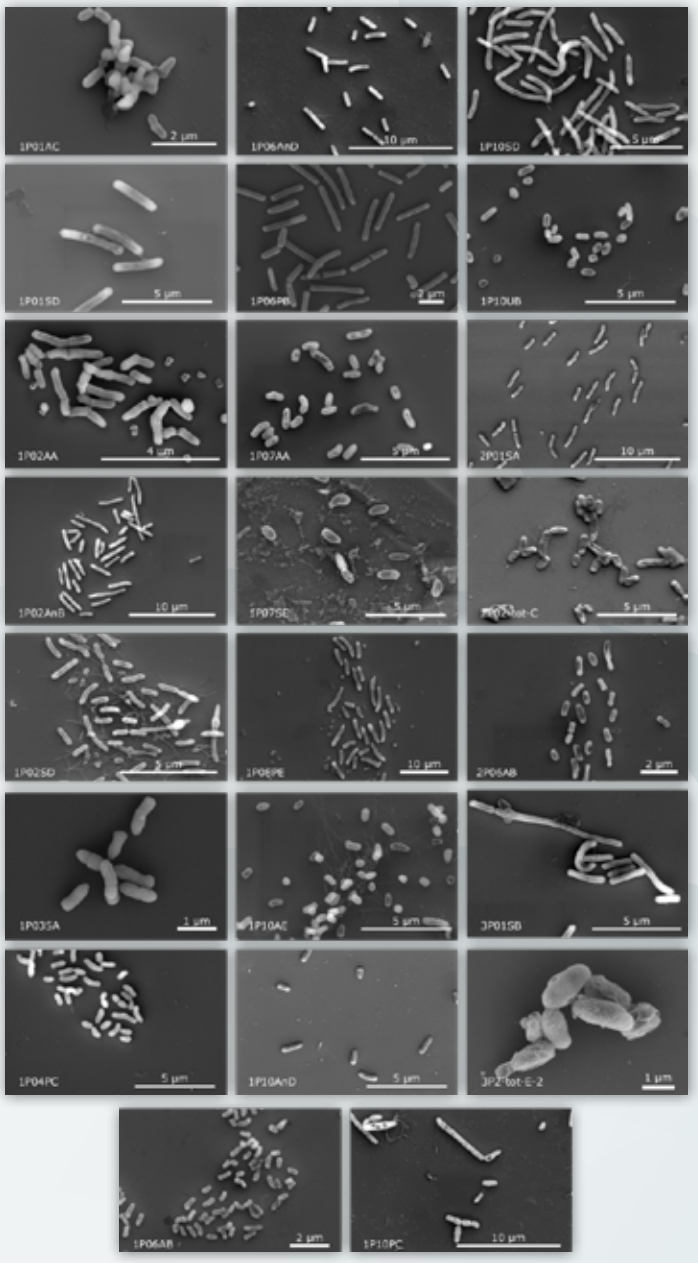
A partnership with Wisconsin-Madison examines deep-sea hydrothermal vents, off the Gulf of California. There, microbes that metabolise sulfur under extreme temperature gradients offer blueprints for biotechnology. Back home, a collaboration with NIOT is building insights into coral-reef probiotics-an approach already tested in the Red Sea to revive bleaching corals. Students have catalogued microbial loads at Chennai Metro stations, IITM bus stands, and the institute hospital, laying the groundwork

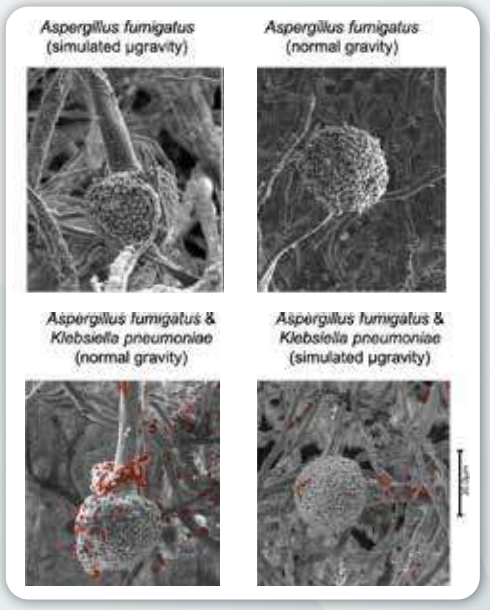
for microbial surveillance and potential outbreak detection.

Understanding microbe–microbe interactions opens doors to replacing harsh chemical disinfectants with microbes or milder chemicals that modulate microbial growth. Prof. Raman's lab is exploring how beneficial bacteria can be strategically employed to mitigate pathogens in urban built environments or even in animal guts.

Beyond fundamental research, Prof. Raman's vision is to engineer minimal, function-specific microbiomes—from human gut symbionts to environmental consortia—tailored for industrial bioprocessing, environmental remediation, and human well-being. By combining high-throughput sequencing, computational modelling, and wet-lab validation, his group is forging a new discipline of predictive microbiome engineering.

As microbiomes shape medicine, manufacturing, and space exploration, Raman's systems-biology framework provides an exciting paradigm: map every genome, model every interaction, and engineer microbial communities that serve humanity's greatest challenges, across the Earth and into the cosmos.







The Herbalife - IITM Plant Cell Fermentation Technology Lab

The Indian Institute of Technology Madras (IIT Madras) has entered into a partnership with Herbalife International India Pvt. Ltd. under their Corporate Social Responsibility (CSR) initiative. The collaboration aims to establish the Herbalife–IITM Plant Cell Fermentation Technology Lab at IIT Madras, a state-of-the-art facility focused on developing sustainable, high-quality herbal ingredients. Under this collaboration, a pilot-scale facility for plant cell fermentation will be established, which will be a first-of-its-kind dedicated facility to facilitate plant cell fermentation for producing high-quality herbal products at scale. This initiative aims to drive innovation in wellness, nutraceuticals, and Ayurveda, contributing to a healthier future.



The MoU for this collaboration was signed on 7 February 2025, in the presence of **Mr. Ajay Khanna**, Managing Director of Herbalife India, and **Prof. Ashwin Mahalingam**, Dean-Alumni and Corporate Relations, IIT Madras.

The project is led by **Dr. Smita Srivastava** (Biotechnology) as the Principal Investigator, with the support of eminent subject matter experts **Prof. Madhulika Dixit** (Biotechnology) and **Dr. Nirav Bhatt** (WSAI). The team also includes Co-principal Investigators **Dr. Karthik Raman** (WSAI) **Dr. Muraleedharan K.M**. (Chemical Engineering), **Dr. Meiyappan Lakshmanan** (Biotechnology), and **Dr. Madivala G. Basavaraj** (Chemical Engineering), bringing together interdisciplinary expertise to drive sustainable herbal innovation.

The Herbalife-IITM Plant Cell Fermentation Technology Lab is envisioned as a pioneering centre to advance research and innovation from early-stage concepts (Technology Readiness Levels (TRL) 2-3) to commercially viable solutions (TRL 7-8).

The lab focuses on three major verticals:

(1) the sustainable production of herbal raw materials and phytochemicals using bioreactors, enabling consistent, high-yield production without reliance on seasonal or geographical factors;

(2) phytochemical characterisation, extraction, and purification to ensure the quality, safety, and efficacy of active plant-based compounds; and

(3) the production of high-quality germplasm and starting plant material to support scalable biomanufacturing. These objectives align with the broader vision of transitioning research “from lab to market” by creating a robust pipeline for product development and commercialisation.

The key activities include pilot-scale plant cell fermentation for tech transfer and validation, supporting industrial-scale production of herbal ingredients. The lab will also drive capacity building through manpower training and industry-focused skill enhancement programmes, nurturing the next generation of biotech professionals.

The key outcomes of the facility will also include intellectual property creation and licensing, joint technology development with industry partners, and fostering innovation through high-risk, high-reward “blue sky” research. The facility will serve as an innovation engine for spinoffs and start-ups, further enriching India’s bioeconomy.

With these integrated efforts, the facility will help in building a fostering ecosystem driving innovations in the realm of plant cell fermentation-based biomanufacturing, aligning well with the Bio-E3 policy of the Government of India for making India a hub for biomanufacturing and contributing to India’s vision of becoming a leader in biomanufacturing and Atmanirbhar Bharat.



Indigenous Ultrasound Scanner Development

Ultrasound machines are essential tools in hospitals and clinics. Yet their high cost and modest performance slow down their spread in many parts of India. Imported, entry-level devices often trade image clarity and speed for price, while premium scanners remain out of reach for smaller healthcare centres. With no home grown alternative, advanced ultrasound applications arrive late and at a premium, leaving rural and budget-conscious providers with limited options

Recognising this challenge, **Prof. Arun K. Thittai** and his team at IIT Madras set out in 2017 to rethink basic ultrasound design. Their goal: build a machine that delivers sharp images and fast frame rates without expensive hardware. Early work focused on computer modelling and lab experiments, funded through internal grants and national fellowships. By 2019, the lab had moved from simulations to a working prototype that used clever signal patterns to capture clear pictures deep inside the body.

Traditional ultrasound scanners fire focused beams one at a time, adjusting each beam to "look" at one spot before moving on. This method works but limits how quickly machines can refresh their images. Prof. Thittai's team invented a way to send broad, diverging waves and then piece together those echoes with smart software. The result is an image that stays in focus all the way from shallow to deep tissue. Additionally, the frame rates are more than double what conventional scanners achieve.

To prove their design, the researchers tested wire and tissue-mimicking phantoms (model objects that simulate human anatomy) and even scanned volunteers' biceps. Compared with a standard machine, the new prototype produced crisp outlines of tiny structures, nearly tripling at the same time the real-time frame rate. These encouraging outcomes led to journal articles and set the stage for further refinement under real-world conditions.

Apart from having an early spinoff, Sonolight Imaging Innovation, incubated at IITM Research Park, Prof. Thittai's lab is now exploring partnerships with other industry players. They have assembled a complete package: core patents, software toolkits, printed-circuit-board designs, and custom probe interfaces. Interested manufacturers can license the technology, tap into ongoing joint-development support, and accelerate product launch by 5 years compared with starting from scratch.

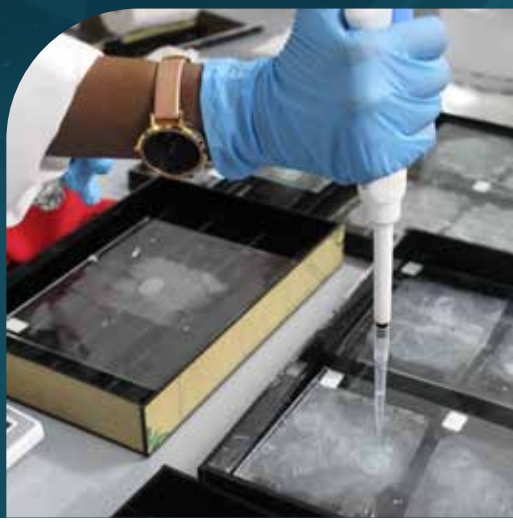
By cutting hardware costs and leaning on software for enhancements, Prof. Thittai's indigenous scanner offers a practical solution for small clinics, rural hospitals, and mid-tier healthcare centres. Doctors will gain access to high-quality images, which are crucial for everything from prenatal check-ups to emergency trauma assessment, without the premium price tag. As pilot clinical studies wrap up and regulatory filings move forward, Prof. Thittai's vision of democratised ultrasound could soon become reality, empowering practitioners nationwide with home-grown innovation.


Velosen E10
Sani-Cloth Plus

Cell-Resolution Mapping of Whole Human Brains

Lead investigator: **Prof. Mohanasankar Sivaprakasam**

IIT Madras launched its cutting-edge Brain Centre in 2022 with seed support from Kris Gopalakrishnan and the Office of the Principal Scientific Adviser (PSA), GoI, to power a large-scale multi-disciplinary effort in the fields of science, technology, computing, and medicine and to map human brains at the cellular level. Its vision is to become a globally leading R&D centre for human brain research with transformative impact in neuroscience and neurotechnologies



The Sudha Gopalakrishnan Brain Centre has developed a world-class brain imaging technology that processes whole human brains into high-resolution digital 3D images. These unique 3D images of human brains of different types and ages provide an unprecedented high-resolution view of human brains that reveal cellular-level details across the entire brain. This is the first time such large-scale human brain image data have been generated at this resolution across the entire brain. These data are being shared with and studied by globally leading brain researchers for neuroscience discovery leading to medical applications.

The Centre is driven by 15+ IITM faculty members and a 200+ research and technical staff with expertise in neurobiology, biomedical instrumentation, systems engineering, large-scale computing, machine learning, molecular biology, and bioinformatics, and over 20 leading doctors from leading medical institutions in the country in areas of infectious diseases, neuroimaging, neurology, neurosurgery, neuropathology, neuroanatomy, psychiatry, neonatology, foetal medicine, and forensic medicine.

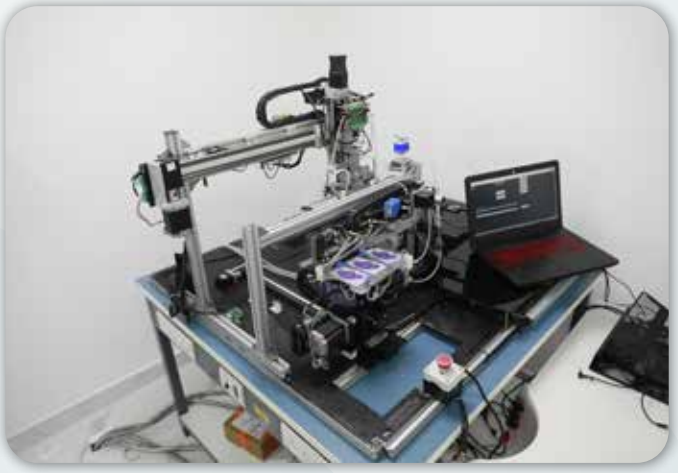
Recently, the Centre released results of the second trimester human foetal brain ("DHARANI"), advancing the state-of-the-art by over 10×. It is the first time India has generated such high-quality human brain data and has made them publicly available as a global resource. This has garnered significant global visibility and appreciation, including a detailed editorial by the oldest neuroscience journal in the world, titled "India Gets a Seat at the Table of Human Brain Cartography".

This first-of-its-kind research platform and datasets have drawn the participation of over 20 leading brain researchers from institutions in the US, Germany, Croatia, Romania, South Africa, and Australia, who are now collaborating closely with the IITM Brain Centre and serving as visiting faculty members at IITM.

The Centre is supported by the Kris and Sudha Gopalakrishnan, Azim Premji's Premji Invest, Prem Watsa (Fairfax), Prema Srinivasan Charities, Tata Trusts, Hindalco, Fortis Hospitals, Agilus Diagnostics, Gates Foundation, Dr. Reddy's Labs, Johnson Lifts, Rajan Anandan, Sharad Sanghi, Hemendra Kothari Foundation, AMM Foundation (Murugappa Group), Krishnan Care Beyond Bound Trust, Davos Alzheimer's Collaborative, and HSBC.

The Centre is in a unique position to attain global leadership by imaging 100+ human brains across different age groups and diseases and generating the largest set of human brain maps, which will serve as a global reference for decades to come.











Defence Applications



Extending the Range of Artillery Shells

Artillery has always been central to battlefield dominance, with commanders striving to strike at greater ranges before the enemy can retaliate. While missiles offer long-range capabilities, they are complex, costly, and less survivable. Guns, on the other hand, remain the preferred option due to their simplicity, cost-effectiveness, and ease of deployment. Yet, traditional gun systems face a technological ceiling in terms of range. **Prof. P.A. Ramakrishna** of IIT Madras has been at the forefront of research aimed at breaking this barrier, pioneering work that could redefine artillery effectiveness for the Indian Army.



The Indian Army, recognising the limitations of existing artillery systems, sought innovative solutions to extend the range of conventional shells without compromising their lethality. Through the Army Technology Board, a project was awarded directly to IIT Madras under Prof. Ramakrishna's leadership. The goal was ambitious: to explore the application of ramjet propulsion in artillery shells, a concept never before realised in full-scale operational ammunition.

Traditional methods of increasing gun range, such as adding more propellant or lengthening barrels, have reached practical limits, often at the cost of stability, mobility, and deployability. Ammunition improvements like Extended Range Full Bore (ERFB) projectiles, base bleed concepts, and rocket-assisted projectiles have pushed ranges incrementally, but even the most advanced 155 mm ERFB base bleed shells plateau at around 24 km.

Prof. Ramakrishna's team turned to the ramjet principle, an air-breathing propulsion system. Unlike rockets, which carry both a fuel and an oxidiser, ramjets ingest atmospheric air as the oxidiser, combining it with a fuel-rich propellant to generate thrust. Artillery shells, with their high muzzle velocities, naturally achieve the Mach 2 speeds required to initiate ramjet combustion. This innovation promises a 60–100% increase in range compared with existing methods, potentially revolutionising tube artillery.

In recent trials at the School of Artillery, in Deolali, IIT Madras successfully tested ramjet-assisted shells. These tests validated both internal ballistics (within the gun) and external ballistics (post-launch).

Tests were conducted at Pokharan Field Firing Ranges in December 2025, to demonstrate the increase in range with this ammunition

The project's funding and support came directly from the Indian Army through the Army Technology Board, underscoring the strategic importance of the research. The Army also provided the artillery guns for testing, ensuring that the experiments were conducted under realistic battlefield conditions. This collaboration highlights the synergy between academic research and defence requirements, with IIT Madras serving as a hub for cutting-edge military innovation.

If successful, this will mark the first time globally that a conventional existing artillery shell has been fitted with a ramjet engine to extend its range. The implications are profound: Indian artillery units could engage targets at nearly double the current distances, significantly enhancing battlefield flexibility and deterrence. Importantly, the lethality of the shell remains uncompromised, ensuring that extended range does not come at the cost of effectiveness.









Electronics and Communications

India's Indigenous 5G Testbed

Profs. Radhakrishna Ganti and Bhaskar Ramamurthi

The Indigenous 5G Testbed is a national research and development initiative aimed at building India's own end-to-end 5G communication system. The project brings together eight leading academic and research institutions: IIT Madras, IIT Kanpur, IIT Bombay, IIT Delhi, IIT Hyderabad, the Indian Institute of Science, Bengaluru, and the R&D organisations SAMEER and CEWiT.



Launched in 2019, the project is funded by the Department of Telecommunications (DoT), with support from the Ministry of Electronics and Information Technology (MeitY), under the Government of India's Aatmanirbhar Bharat initiative. Its objective is to design, build, and validate a fully functional 5G system using largely indigenous intellectual property, while remaining compliant with global standards.

IIT Madras played a central role in this national effort and was responsible for designing the hardware and software of the physical layer and integrating the complete end-to-end 5G system—bringing together radio units, baseband processing, core network functions, and network management into a unified and operational platform. This system-level integration enabled seamless collaboration across partner institutions.

A defining feature of the project is that the system was built primarily by research scholars, postdoctoral fellows, and research associates, with students forming the core development team. From physical-layer algorithms and FPGA-based radio design to protocol implementation, system integration, and deployment, the work was carried out entirely within the academic ecosystem, demonstrating the capability of Indian universities to deliver deployable systems.

Within the IIT Madras campus, the 5G Testbed has been deployed across multiple locations for experimentation under real operating conditions. The platform was formally inaugurated in May 2022 as part of India's national 5G mission. Soon after, Ashwini Vaishnaw, Union Minister of Electronics and Information Technology, successfully tested a 5G voice and data call on the indigenously developed network at IIT Madras.

Beyond the campus, the testbed has been deployed and operationalised through training and field installations at the IIT Kanpur campus, the Indian Railways Institute of Signal Engineering and Telecommunications (IRISET), Hyderabad, and the Military College of Telecommunication Engineering (MCTE), Indore. Technology developed under this initiative has also been transferred to Tejas Networks, Bengaluru, for further development and commercial deployment.

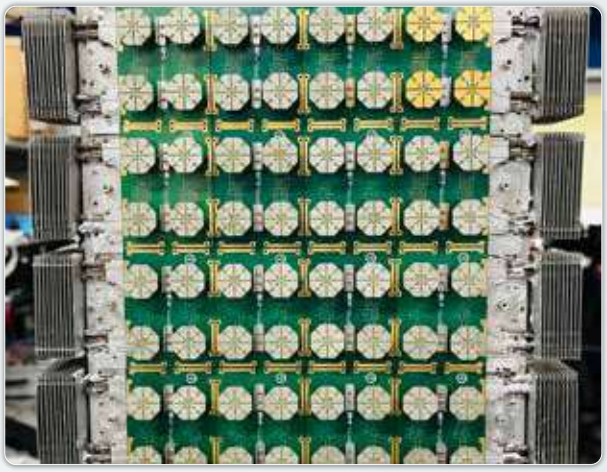
The testbed enables experimentation using real radios, real mobility, and realistic impairments such as interference, synchronization errors, and hardware non-idealities. It has demonstrated peak throughputs of approximately 1.2 Gbps and functions as a continuous source of real-time system data for measurement-driven research. Its openness allows fine-grained logging and debugging at all layers, enabling startups and companies to validate physical-layer and core-network algorithms efficiently.

Building on its 5G foundation, the platform now supports next-generation research including centimetre-level localization, interference studies, and real-time integration of AI and machine learning models for receiver algorithms. The effort has resulted in multiple research publications and patent filings, underscoring its academic and translational impact.

Built largely by students and researchers, India's Indigenous 5G Testbed demonstrates how academic innovation can deliver real-world, deployable wireless systems.









Advanced Optical Communication Testbed

The Advanced Optical Communication (AOC) Testbed, led by **Prof. Deepa Venkitesh** at IIT Madras, is India's pioneering initiative to build indigenous, next-generation optical communication systems. Supported by the Department of Telecommunications through the Telecom Technology Development Fund (TTDF), the project has already achieved global firsts, including the deployment of a Multicore fiber Testbed for underground and aerial installations, the first of its kind in the world.



Fiber optic communication has become the backbone of modern digital infrastructure, powering high-speed internet, 5G networks, and data centers. Recognizing its critical role in enabling smart cities, IoT applications, and real-time connectivity, the Government of India launched the AOC Testbed under the Digital India and Atma Nirbhar Bharat missions. The Department of Telecommunications envisioned this project as a way to achieve self-reliance in optical technologies while positioning India as a thought leader in the optical communication systems.

The consortium project is led by IIT Madras, with IIT Delhi, IIIT Delhi, ERNET, and industry partners such as Sterlite Technologies, SASMOS, Signalchip, filters, amplifiers, optical combs, turbulence-resistant free-space optics, networked LiFi, RF fronthauls, interoperable quantum key distribution (QKD), and predictive network modelling. These efforts have already resulted in 18 patents and 63 research publications, reflecting the rapid pace of innovation. As Prof. Deepa Venkitesh notes, the project's collaborative framework has produced prototypes, solutions, and products in record time, demonstrating the strength of India's academic–industry partnerships. Also, the team has been contributing to Indian and International standards organizations.

The AOC Testbed is more than a research facility it is a national platform for local product development, performance testing, patent creation, and standard

Signaltron, SFO Technologies, and Quanfluence as the consortium members. This ecosystem ensures that academia, industry, and R&D institutions work together to create homegrown solutions for India's future networks.

The AOC Testbed focuses on both fiber optic and free-space optical communication, developing innovative subsystems and solutions that scale capacity from gigabits per second (Gbps) to petabits per second (Pbps). Its modular infrastructure supports real-world experimentation, with fiber ducts available for researchers and vendors to lay their own fiber and test equipment.

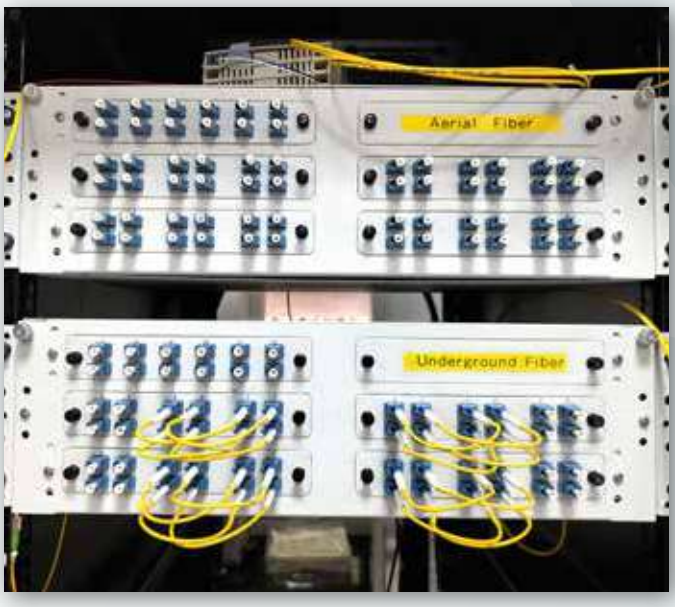
A landmark achievement is the Multicore Fiber Testbed at IIT Madras, the world's first facility to deploy multicore fiber for both underground and aerial installations. This breakthrough quadruples transmission capacity without increasing weight or volume, making it a game-changer for high-capacity networks. The testbed also includes spare ducts for future expansion, ensuring scalability.

Research spans 19 focus areas, including optical and optoelectronic devices, transceivers, optical setting. By fostering indigenous technologies, it reduces reliance on imports and strengthens India's position in global optical communication.

Equally important is its role in training the next generation of optical engineers, equipping students and researchers with hands-on experience in cutting-edge systems. The open-access model ensures that academia and industry alike benefit from shared knowledge and infrastructure.

With its readiness announced at the TTDF symposium, the multicore fiber testbed marks a significant milestone in India's journey toward self-reliant, high-capacity communication networks. By enabling experimentation at scale, the project lays the foundation for future-proof digital infrastructure that supports 5G, smart cities, and beyond.

The Advanced Optical Communication Testbed exemplifies how visionary leadership, collaborative ecosystems, and indigenous innovation can transform India's digital future. It is not just a technological milestone but a strategic step toward ensuring that India leads in the global race for next-generation communication systems.







Centre for RF, Analog and Mixed-Signal ICs

Profs. Shanthi Pavan and Nagendra Krishnapura

Background and Purpose

The Centre for RF, Analog and Mixed-Signal ICs (CERAMIC) at **IIT Madras** emerged from the institute's long-standing leadership in analogue circuit research and its deep industry partnerships. Led by distinguished faculty members of the Department of Electrical Engineering, the Centre was set up to address a critical skills gap: India lacked enough indigenous expertise in high-performance analogue and mixed-signal circuit design, particularly for data converters, RF front-ends, and serialiser/deserialiser (SERDES) links. The purpose was three-fold:

- To cultivate worldclass talent trained in the end-to-end IC design cycle (from concept to fabricated chip)
- To conduct cutting-edge research in high-impact analogue and mixed-signal technologies
- To strengthen industry–academia collaboration by solving real industrial problems.

What the Centre does

- The Centre's research and training objectives span several key technology verticals:
- High-performance data converters.Continuous time ΔΣ and pipelined ADCs, incremental ΔΣ modulators, targeting ultra-low power and high resolution for communication systems and sensor interfaces
- RF IC components. Compact, low-phase-noise oscillators and tunable synthesisers targeting next-generation wireless applications
- High-speed serial links (SERDES). Low-power architectures for 56 Gbps and above aimed at data centres and bandwidth-intensive systems

The Centre oversees the TI–IIT Madras M.S. by Research programme a fully sponsored 3-year course combining 1 year of coursework and 2 years of internship at TI India. Students complete rigorous IC design from simulation to fabrication using industry-grade CAD tools (Cadence/Mentor) and foundry interfaces, often producing chips that go on to be published or showcased at premier venues such as ISSCC and IEEE journals. Research associates and Ph.D. candidates also collaborate on industrially relevant problems, frequently under dual supervision from IIT and TI engineers.

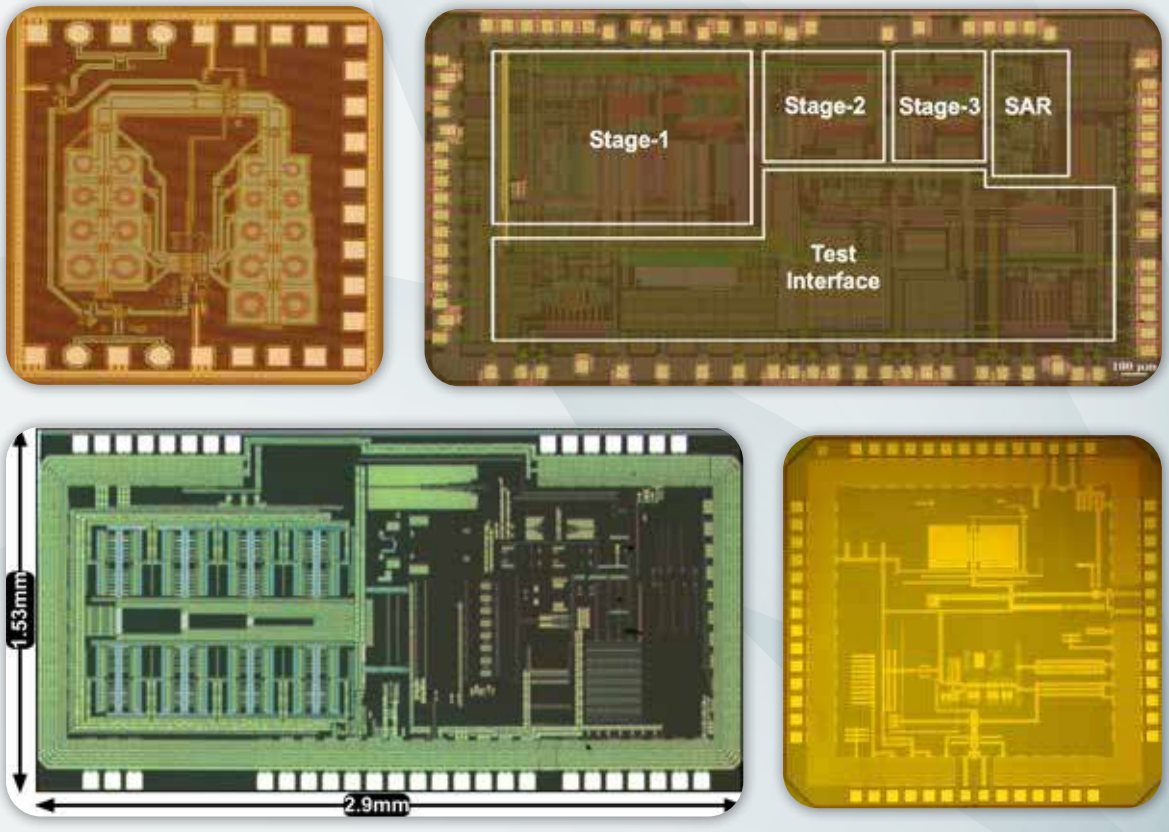
Impact

The Centre has had remarkable national and international impact in talent development, publications, and ecosystem building:

- Manpower. The M.S. programme—with stringent selection and industry mentorship—is widely recognised as the "dream programme" for analogue VLSI aspirants across India. Alumni have gone on to faculty positions at IIT Delhi, Kanpur, and Hyderabad, as well as leadership roles at TI and other semiconductor firms.

- Research outputs. The Centre accounts for most of India's papers in the IEEE Journal of Solid-State Circuits over the last 20 years—a clear indicator of its dominance in analogue/mixed-signal scholarship. It is the only Indian group to publish at ISSCC.
- Industrial relevance. M.S. students work on real industry-sourced challenges—ranging from precision converters and amplifiers for EVs to mixed-signal processing for medical and automotive systems—and often design their own ICs that advance the state of the art.
- Ecosystem leadership. The Centre's model—blending top-tier research, industry internships, chip fabrication, and publication success—has become a benchmark for India's semiconductor strategy. It has demonstrated that India can match global analogue VLSI standards and serve as a talent hub for OEMs and fabless design firms alike.
- Pedagogy. The Centre has set the gold standard for analogue/mixed-signal education in India, with its rigorous coursework, hands-on chip design labs, and close industry integration. Its alumni have transformed both academia and industry. It has been providing free online access to cutting-edge educational material in the area for almost 20 years.

In sum, CERAMIC plays a pivotal role in India's semiconductor ecosystem. It provides the critical bridge between theory and industrial deployment, nurtures elite analogue-IC talent, and delivers breakthrough research in technology domains key to India's ambitions in AI, 5G, IoT, and more.



Centre for NEMS and Nanophotonics

The MEMS and Microelectronics Programme has been sustained by IIT Madras along with sponsored research for the last 40 years and was part of the Interdisciplinary Research Programme (IDRP) introduced by IITM in 2002. The Photonics Programme was especially started in 2001 with an initial grant from IITM alumnus Gururaj Deshpande, Chairman of Sycamore Networks, USA, and has grown successfully, with several significant achievements to its credit. In 2011, generous funding was received from MeitY to set up the Centre for Nanoelectromechanical Systems and Nanophotonics (CNNP), addressing two important branches of nanotechnology, nanoelectromechanical systems (NEMS) and nanophotonics, which are closely related to developments in nanoelectronics.

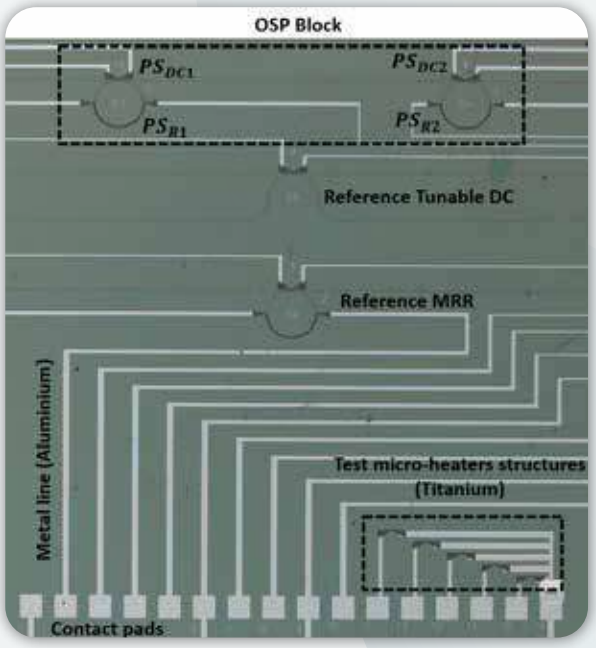
Profs. Nandita DasGupta and Enakshi Bhattacharya

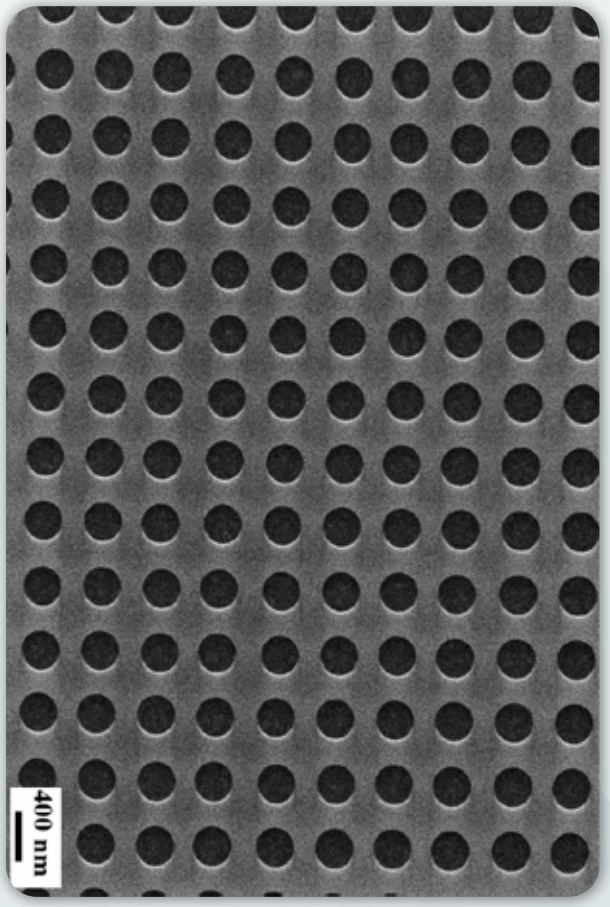
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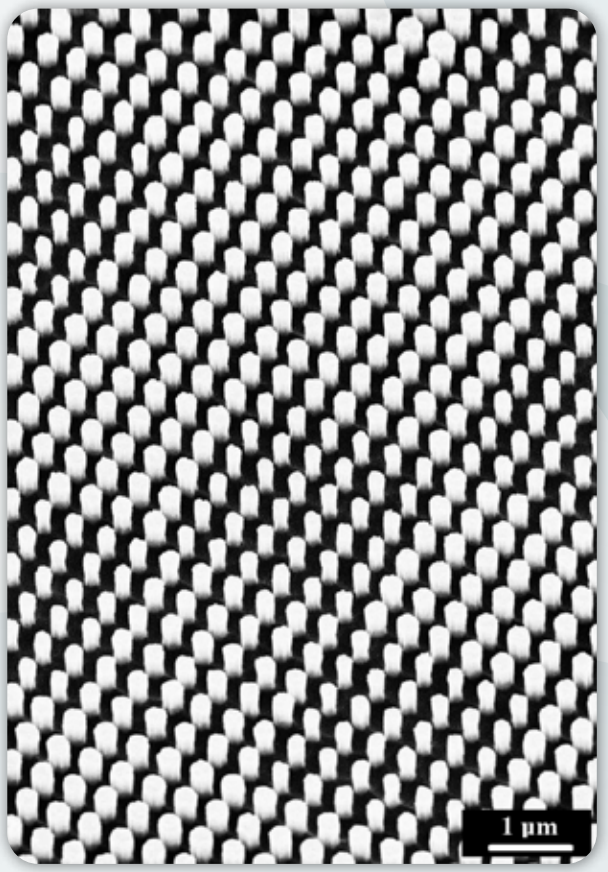
The CNNP team have successfully set up nanofabrication and characterisation facilities in an approximately 5000-square-foot Class 1000 clean room space at IITM, including a Class 100 space for lithography. Through the research and development in the first phase, they realised a major part of their work leading to various components such as RF switches, sensors, membranes, lamellar gratings, silicon photonics devices, and resonators. In the second phase of funding, received jointly from MeitY, DST, and IITM, under the NNetrA programme, they augmented the facilities and focused on systems based on these sensors and components. The facilities added and expertise generated during the first phase of the CNNP enhanced the capability to work in the areas of NEMS and nanophotonics and brought in participation from many allied departments. Collaboration with faculty members specialising in material engineering, biochemistry, mechanical engineering, and instrumentation and circuits has enabled the Centre's work towards systems building. CNNP is now planning for a third phase in which to take this activity forward.

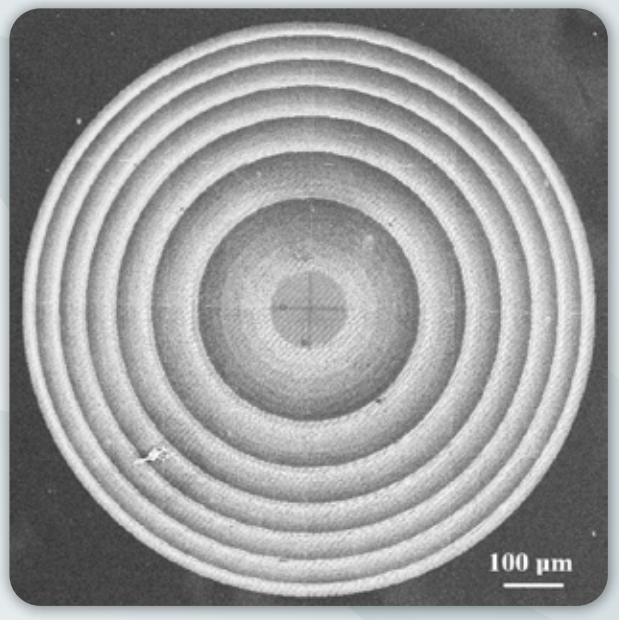
Currently, about 25 faculty members and more than 75 research scholars from different departments of IIT Madras are associated with CNNP/NnetrA. Twelve patents have been granted/filed in the last 5 years. Transfer of technology to a few companies has been carried out or initiated. Also, one start-up (Petra Biosystems) is going to commercialise a product developed as a part of a NNetra project. A few more start-ups are in the offing.

Thus CNNP/NNetrA is doing a very important job of carrying out cutting-edge research as well as training manpower in the important areas of micro/nano electronics, NEMS, and nanophotonics. This is particularly crucial in view of the thrust given by the Government of India towards the India Semiconductor Mission.


OSP Block
PS_{DC1}
PS_{DC2}
PS_{R1}
PS_{R2}
Reference Tunable DC
Reference MRR
Metal line (Aluminium)
Test micro-heaters structures
(Titanium)
Contact pads


400 nm


1 µm


100 µm



Indian National Users Programme (INUP)

Prof. Shanti Bhattacharya, along with her fellow coordinators, **Profs. Deleep R. Nair and Ananth Krishnan**, has played a pivotal role in advancing the Indian National Users Programme (INUP) at IIT Madras, providing researchers across India access to world-class semiconductor and photonics fabrication facilities. Her leadership has transformed simulation-based studies into hands-on innovation, fostering publications, patents, and even start-ups.

INUP, funded by the Ministry of Electronics and Information Technology (MEITy) since 2011, was designed to bridge a critical gap in India's research ecosystem. For decades, smaller colleges and universities lacked access to fabrication facilities, which limited their work to simulations that often failed to reflect real-world conditions. INUP sought to change this by opening up the sophisticated laboratories of IITs—including IIT Madras, IIT Bombay, and IIT Guwahati—to external researchers.

At IIT Madras, the programme is anchored in the Department of Electrical Engineering, where around 20 faculty members contribute to its execution. Specifically, it runs out of or uses the Centre for NEMS and Nanophotonics (CNNP), at IIT Madras. This centre has expensive, state-of-the-art equipment for semiconductor and photonic device fabrication. Researchers outside the IIT system can apply online, receive proposal guidance from IIT Madras staff members, and have their stay and equipment usage funded. This inclusivity has made INUP one of India's most impactful national research initiatives.

Prof. Bhattacharya, a leading figure in applied optics and photonics, has been instrumental in shaping INUP's vision of "ideas to implementation." Her expertise in diffractive optics, meta-optics, and optical MEMS has guided the programme's emphasis on practical fabrication and characterisation. She has coordinated training modules, ensured the fine-tuning of project proposals, and facilitated collaborations between IIT Madras and external institutions.

Her leadership emphasises capacity building, ensuring that participants not only learn theory but also gain hands-on experience in device fabrication. This approach has elevated the quality of research output from smaller colleges, enabling them to publish in high-quality journals and secure patents.

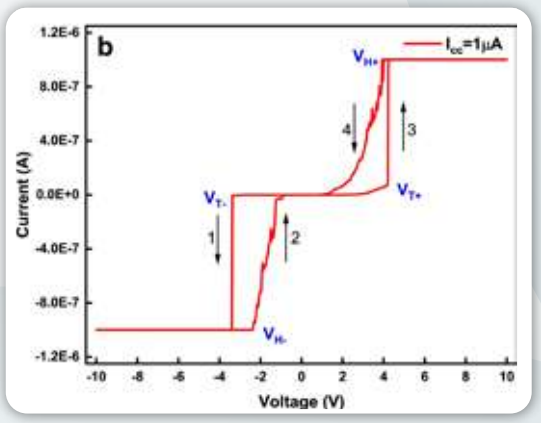
INUP, at IIT Madras, mandates regular training programmes in semiconductor photonics. Each year, three to four courses are conducted, both online and in-person, with up to 150 participants per batch. Graduates of these courses qualify for a 2-week hands-on programme, in which they fabricate devices such as solar cells, sensors, and optical coatings.

Participants are encouraged to submit short-term projects—from coating materials to characterising devices. These projects often involve deposition of materials such as silicon nitride, chosen for their electrical and optical properties, on glass. The devices are rigorously characterised, ensuring that participants gain end-to-end exposure to fabrication workflows.

The programme has yielded over 30 publications, numerous patents, and several doctoral theses authored by researchers from smaller institutions. It is notable that IIT Madras faculty members are not listed as co-authors, underscoring the programme's commitment to empowering external researchers.

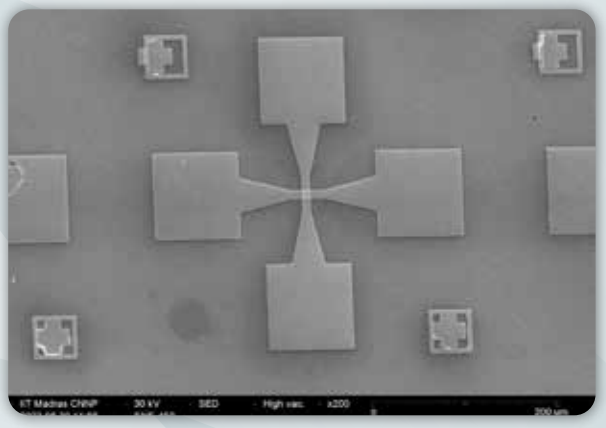
One participant has even launched a start-up, demonstrating INUP's potential to catalyse entrepreneurship. Devices fabricated under the programme include microscopic sensors for detecting proteins in urine, which serve as disease indicators, and solar concentrators, developed by Mr. Kumaravel of the Central Electronic Centre (CEC), IIT Madras. These innovations highlight the programme's societal relevance, extending as they do beyond academia into healthcare and renewable energy.

Through INUP, Prof. Shanti Bhattacharya has democratised access to advanced fabrication facilities, enabling researchers from across India to move beyond simulations into tangible innovation. By fostering collaboration, training, and hands-on experimentation, she has ensured that the programme not only uplifts academic research but also drives industrial engagement and entrepreneurial ventures. INUP at IIT Madras stands as a model of how national programmes can transform scientific capacity, with Prof. Bhattacharya's vision at its core.









New VLSI Architectures for Image-Based Robotic Path Planning

Efficiency and energy conservation are critical for mobile robots that rely on batteries. They must balance motor power consumption and computational needs.

'New VLSI Architectures for Image-Based Robotic Planning' is the title of a project led by **Prof. K. Sridharan** between 2003 and 2006. This project was sponsored by the Department of Science and Technology. Previously, in his doctoral work, at Rensselaer Polytechnic Institute (USA), Prof. Sridharan had focused on algorithmic robot-motion planning, using personal computers (PCs) to drive motors. In the DST-supported project, he sought to move beyond traditional computing approaches to custom hardware solutions. He explored how emerging hardware technologies could be used to transform robotics, particularly in mobile platforms with energy constraints. Prof. Sridharan's main aim was to investigate whether field programmable gate arrays (FPGAs) could replace PCs in robotic systems

FPGAs are integrated circuits that allow designers to build custom processing systems for performing specific tasks. FPGAs had become commercially available in the late 1990s. They held the promise of improved efficiency and reduced energy consumption.

Prof. Sridharan and his team explored the use of FPGA-based architectures in robotic path planning. Using VERILOG-HDL, VHDL, and other hardware description languages, they developed digital designs that could be prototyped on FPGAs and later migrated to application-specific integrated circuits (ASICs). The project enabled robots to handle inputs from multiple ultrasonic distance sensors simultaneously through parallel processing. As a result, robots could take real-time decisions to avoid collisions—namely, turning left or right or reversing—without the need to handle interrupts triggered by sensor input or to store sensor data in buffers excessively.

Another focus of the project was to experiment with geometric mapping techniques, such as Voronoi diagrams. These helped robots maintain a distance from walls and other obstacles. The team embedded the algorithms directly into hardware. The responses of the system were faster, and the energy costs were lower compared with traditional software-driven platforms.

Beyond navigation, broader applications of FPGA-based architectures in robotics were highlighted by the work. For instance, systolic arrays—parallel processing structures realised on FPGAs—were shown to be effective for image-based tasks. This served as the groundwork for later projects, including video stabilisation for defence applications. Between 2012 and 2014, Prof. Sridharan worked in collaboration with the Defence Research and Development Organisation (DRDO) to stabilise video captured by robots traversing uneven terrain. FPGAs

enabled smoother transmission of visual data from remote environments by compensating for vibrations using image-processing algorithms.

The DST project established that FPGAs could serve as superior alternatives to PCs that offered speed and adaptability. Prof. Sridharan and Panakala Rajesh Kumar documented the outcomes in a book, *Robotic Exploration and Landmark Determination, disseminating the findings to the academic and engineering communities.*

Prof. Sridharan's work also paved the way for emerging fields such as social robotics: rapid sensor-based responses could help provide geriatric care, such as by handling fall-related events.





Silicon Photonics

In today's technological landscape, the convergence of connectivity, computing, control, and sensing defines progress. With the advent of 5G/6G networks, artificial intelligence, and advanced computing systems, the demand for ultra-fast, energy-efficient, and scalable solutions has become critical. Silicon photonics now stands at the forefront, a field that harnesses the speed and bandwidth of light to overcome the limitations of traditional electronic systems. **Prof. Bijoy Krishna Das** is a leading expert in this field, whose sustained research since 2006 played a key role in IIT Madras securing funding from the Ministry of Electronics and Information Technology (MeitY) to establish a Centre of Excellence dedicated to silicon photonics.

The Centre for Programmable Photonic Integrated Circuits and Systems (CPPICS) was launched in January 2021 at the Department of Electrical Engineering, IIT Madras, Chennai. CPPICS is dedicated to advancing programmable photonic integrated circuits (PPIC) using CMOS-compatible silicon photonics technology.

The centre was established with seed funding of ₹ 3078 lakhs (US$4.4 million) from MeitY, supplemented by ₹ 325 lakhs (US$0.5 million) in-kind contributions from IZMO Microsystems, Bengaluru and ₹ 1175 lakhs (US$1 million) from IIT Madras.

The centre boasts state-of-the-art facilities for silicon photonics chip design, wafer-scale fabrication with indigenous IP portfolios (in collaboration with foundry partners), and world-class testing infrastructure.

CPPICS is committed to building national capability in silicon photonic chip manufacturing and strengthening India's photonics ecosystem to serve both domestic and global needs. The centre's immediate focus includes microwave and quantum photonics applications, such as advanced photonic processors for digital and analogue transceivers (data centres and 5G/6G applications), scalable optical quantum computing processors, chip-level quantum key distribution circuits, and AI photonic processors.

CPPICS has achieved much in a short time. The centre has recently completed transfer of technology (ToT) worth ₹ 1 crore (US$120K) of a full-stack, field-deployable quantum random number generator (QRNG) module for security applications to Indrarka Tech. Pvt. Ltd., with an international presence (QcoreSecure). CPPICS is now on the cusp of completing its 200-mm silicon photonics PDK with associated IP blocks, laying the foundation for scalable photonic manufacturing and advanced system integration. CPPICS has built a fibre array unit attachment (FAU) tool indigenously, and multiple patents have been granted or are in the pipeline. Team CPPICS has been also engaged in developing electronic photonic design automation (EPDA) tools that are currently reaching their maturity level.








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UPI: From Research to Reach

An IIT Madras story in mobile payments

The Unified Payments Interface, or UPI, has a story of significant contributions from IIT Madras.

The seeds of mobile-based payments were sown in 2005, when the Reserve Bank of India (RBI) released a vision paper focused on democratising retail payments. The goal was to make financial transactions simpler and accessible to everyone. By 2007, the rapid penetration of 2G networks, reaching approximately 700 million users, created a fertile ground for leveraging mobile phones for financial transactions.

In 2009, IIT Madras embarked on a groundbreaking project to build a universal mobile payment system. The initiative was spearheaded by **Profs. Ashok Jhunjhunwala, Timothy Gonsalves, and Gaurav Raina**, who recognised the transformative potential of mobile payments. Prof. Ashok Jhunjhunwala was the first Chairman of the Mobile Payment Forum of India (MPFI), and in 2010, Prof. Gaurav Raina became the Principal Investigator for the project from IIT Madras.

Laying the groundwork

IIT Madras played a key role in establishing the technical foundation for mobile-based payments in India. The system required stringent standards for interoperability, security, performance, and privacy.

The first milestone in this journey was the development of the Immediate Payment Service (IMPS), launched in 2010. IMPS marked a significant step by offering bank-based transactions that were both affordable and convenient.

The next step was to put the convenience of IMPS in mobile phones. This was done first by implementing the USSD channel *99#. This channel works across all handsets, smartphones, and more basic phones, enabling funds to be sent or received. To meet these demands, IIT Madras helped develop the USSD platform's protocols. The USSD-based system proved invaluable, especially for users of regular mobile phones.

Important research contributions from IIT Madras also came before mobile payments were launched. The work of students such as Deepti Kumar and Praveen Chandrahas, guided by professors at IIT Madras, helped shape the thinking and standards related to interoperability, mobile payment architectures, and the protocols that eventually formed the foundation for IMPS and later UPI.

From launch to scale

By 2013–2014, affordable smartphones and widespread 3G networks further facilitated the adoption of mobile-based payment solutions.

In 2016, UPI was launched. The Immediate Payment Service (IMPS) had already laid the initial groundwork for UPI. IMPS enabled push-based transactions, in which a user paid another user, and UPI enabled



push–pull functionality, allowing a user to send money and to request money from another user. The defining moment came with the launch of the payment app Bharat Interface for Money, or BHIM, by the Government of India. It really took off in 2017, with virtual payment addresses, QR codes, and mobile apps.

The adoption of UPI was not without challenges, including building robust merchant and user ecosystems. The success of UPI hinged on building user trust while ensuring accessibility.

Prof. Gaurav Raina was elected the Chair of the MPFI in 2017. The COVID-19 pandemic later acted as a catalyst for the adoption of UPI. Enhanced by Aadhaar integration and the creation of bank accounts, UPI soon became a cornerstone of financial transactions in India.

A national system with global reach

Countries that have adopted UPI include Bhutan, Nepal, the UAE, Singapore, France, Mauritius, and Sri Lanka. Many countries around the world are now exploring the idea of adopting UPI. As of early 2026, UPI powers more than 80% of all digital retail payment transactions in India. Today, UPI accounts for about 50% of the world's real-time payment transactions, by volume.







The story on film

www.upistory.com

Wireless Local Loop

In the late 20th century, India's telecommunications system relied heavily on copper-based telephony. Though effective, copper lines were costly to install and maintain, especially in rural areas with sparse populations or difficult terrain. Each line supported only a few connections, making per-user costs high and limiting penetration. The need for a more economical, scalable solution was urgent.

IIT Madras, in collaboration with Analog Devices, pioneered the Wireless Local Loop (WLL) project to address this challenge. The copper in the "last mile" was replaced with wireless technology: base stations were used to communicate wirelessly with subscriber terminals. These terminals mimicked landlines, allowing seamless calling while integrating with existing exchanges. This hybrid approach reduced costs but retained the familiarity of traditional telephony. Thus WLL promised faster deployment, lower costs, and improved rural connectivity.

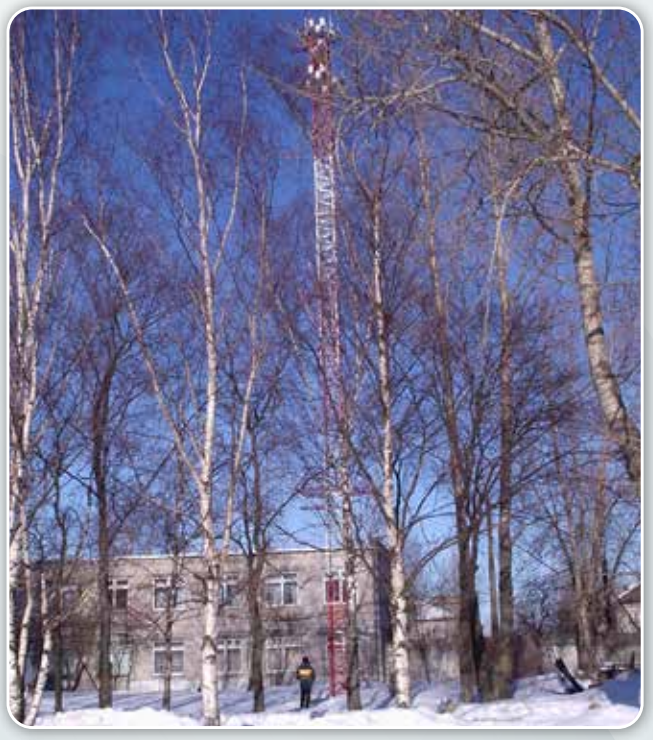
The vision was led by **Profs. Ashok Jhunjhunwala, Bhaskar Ramamurthi,** and **Timothy Gonsalves**. Partnering with Analog Devices provided financial backing and semiconductor expertise. The resulting system, called corDect, comprised wireless exchanges, base stations, and subscriber terminals. The project gave rise to Midas Communications, incubated at IIT Madras's TeNet Lab. With a team of professionals, assistants, and scholars, Midas developed a semiconductor-based WLL system. A pilot inside IIT Madras and across Chennai installed 20 base stations, serving hostels and about 100 users. This proof of concept demonstrated technical feasibility and significant cost savings. Midas adopted a sustainable revenue-sharing model inspired by C-DoT, ensuring financial viability while fostering innovation.

The first major breakthrough came when the Department of Telecommunications placed an order for 25,000 lines for MTNL in Delhi and Bombay. This success was followed by international expansion, with WLL systems exported to more than 20 countries, including Italy, Tunisia, Madagascar, Sri Lanka, Bangladesh, Brazil, and Fiji. Collaborations with public sector entities such as TCIL and the granting of manufacturing licenses to companies like HFCL, Shyam Telecom, ITI, and ECIL further strengthened the project's reach. As demand grew, Midas shifted its manufacturing operations to Adyar and later Perungudi to cope with delayed royalty realisations. Significant orders followed, including Reliance Communications' 1000-site deal and a ₹250-crore order from BSNL, cementing WLL's place in India's telecom landscape.

As the telecommunications sector evolved, Midas faced new challenges. The rise of mobile phones and the widespread hype around WiMAX disrupted traditional WLL systems. Despite their technological edge, these market shifts proved difficult to navigate. Global telecom priorities increasingly moved towards mobile and Internet-based solutions, leaving indigenous projects such as Midas struggling to stay relevant after 2008.

The WLL project remains a landmark in India's telecom history. It built domestic capacity for complex systems, nurtured engineering leadership, and laid the groundwork for later advances in 4G and 5G. By addressing rural connectivity and setting global benchmarks, WLL left an enduring legacy of innovation and collaboration.






RECARGA DE





Reliable Covert Sat-Com (RCS) System

Lead investigator: Prof. K. Giridhar

Covert wireless communications are employed by the defence forces to ensure that the voice or message that is being transmitted over the air is not "seen" or is not observable by an adversary who wants to eavesdrop into the call. Classically, we refer to such wireless links to have a low probability of intercept (LPI) and a low probability of detection (LPD). Such covert wireless links have been in use by the defence forces of the world for several decades, and they invariably use the concept of direct sequence spread spectrum (DSSS) as the waveform of choice. When this DSSS is combined with code division multiple access (CDMA), we refer to such an approach as DS-CDMA.

Geo-stationary, or geo-synchronous, satellites (GSATs) from ISRO, placed around 36,000 kilometres above India, today provide voice and data coverage to outdoor users in nearly any location, including inland waterways and the seas near the coasts. IIT Madras was approached by one of the DRDO labs to design and develop a covert point-to-multipoint system which would connect 32 nodes anywhere within the Indian land mass to one another using GSAT links. Since these 32 nodes were to be used by VVIPs, covert waveforms where the received signal power (of the adversary interceptor or even at the intended receiver) is at least 10 times weaker than the noise power at the antenna port was desired by DRDO. Moreover, for a given transponder bandwidth on the ISRO GSAT, 32 calls had to be supported reliably with a minimum bit rate of 4.8 kbps per voice call, even in the presence of multipath delay spread, which can severely distort the signal due to reflections from tall buildings or mountains.

The Telecom and Wireless Sensing (TelWiSe) group in the Electrical Engineering Department at IIT Madras has designed distinct covert waveforms for both the forward link and the reverse link, and this custom solution handsomely exceeds the specifications given by the DRDO lab for both these links.

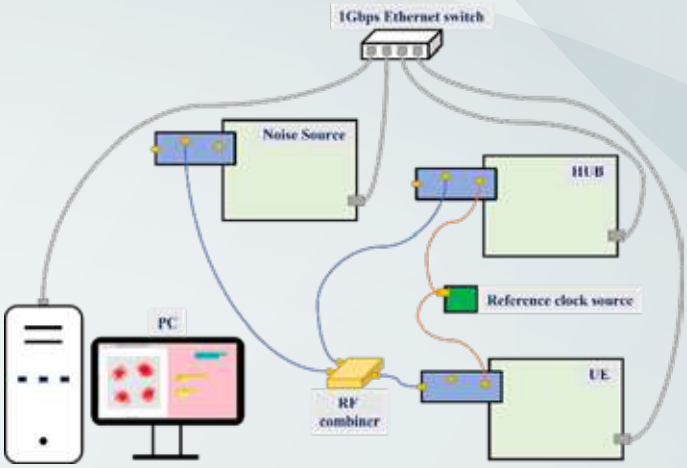
The reliable covert sat-com (RCS) system designed by the TelWiSe group has the following highlights: (a) The intended receiver was able to reliably recover even a signal that was 30 times weaker in power compared with the noise power. (b) All the 32 nodes could support a 7.2 kbps data rate. (c) For the forward link, a single-carrier block-modulated (BM) DS-CDMA waveform was used where all the 32 nodes were served with a mix of orthogonal Walsh-Hadamard spreading codes and a pseudo-noise (PN) scrambling code. The BM-DS-CDMA waveform enables low-complexity optimal receivers at the mobile nodes even in the presence of multipath interference since the frequency domain equalisation in the receiver restores orthogonality before the de-spreading operation. (d) For the reverse link, several unique contributions were made in the waveform design, code mapping choices based on loading, and the receiver-side processing to ensure low-complexity algorithms.

In summary, the RCS solution designed and developed by IIT Madras between 2019 and 2022 can be utilised to provide highly secure covert wireless links between 32 VVIP nodes over any outdoor spot in the country. The efficacy of these modern waveforms and algorithms was demonstrated on the prototype equipment, and a patent for the spread-IFDMA signal has been filed.


INDIA
States and Union Territories
PAKISTAN
CHINA (TIBET)
NEPAL
BHUTAN
BANGLADESH
MYANMAR (BURMA)
SRI LANKA
International Boundary
State/UT Boundary
Country Capital
State/UT Capital


INDIA
States and Union Territories
PAKISTAN
CHINA (TIBET)
NEPAL
BHUTAN
BANGLADESH
MYANMAR (BURMA)
SRI LANKA
International Boundary
State/UT Boundary
Country Capital
State/UT Capital


Noise Source
UE
Forward Link setup
HUB


1Gbps Ethernet switch
Noise Source
HUB
Reference clock source
PC
RF combiner
UE

Experiential Technologies

Work at the Experiential Technology Innovation Centre (XTIC), IIT Madras is reshaping how immersive technologies are conceived, built, and deployed. XTIC, led by **Prof. M. Manivannan,** has been positioned as India's first dedicated hub for research and product innovation in virtual reality (VR), augmented reality (AR), mixed reality (MR), and haptics. XTIC has a bold vision of making India the "XR corridor of the world, by 2040, just as the country became the IT corridor of the world.



Prof. Manivannan's efforts are rooted in the idea of extending India's IT legacy into immersive technologies. XTIC aims to establish the country as the global hub for XR. This involves creating an XR-Superhighway. This is comprehensive infrastructure of innovation centres, training facilities, and manufacturing hubs. Prof. Manivannan's emphasis on indigenous intellectual property and hardware development marks a strategic shift from India's traditional role as a services provider to becoming a global technology leader.

Frugal VR

Among Prof. Manivannan's most distinctive contributions is the concept of frugal VR. Recognising that costly headsets from global giants are inaccessible to most Indians, XTIC is developing extremely affordable XR tools that run on everyday smartphones and low-cost hardware. This approach democratises immersive technology, enabling students, engineers, and ordinary users to participate in the XR ecosystem. By championing frugal innovation, Prof. Manivannan ensures XR is not a luxury but a tool for education, healthcare, skilling, and public service across the Global South. This was the theme of the annual event of XTIC 2025 "XR for Global South", inviting leading corporates and startups to brainstorm on democratising immersive tech for education, healthcare, skilling, and public-service applications across emerging economies.

Perception engineering

Beyond affordability, Prof. Manivannan has been pioneering the field of perception engineering, a human-centred approach to XR. Instead of focusing solely on devices and graphics, this discipline focuses on how humans perceive through vision, haptics, audition, balance, and cognition. The goal is to engineer scientifically grounded perceptual illusions that feel real and comfortable, even using constrained hardware. This unique foundation allows XTIC to design XR systems that are both frugal and deeply immersive, setting it apart from labs that prioritise hardware.

National and global collaborations

Prof. Manivannan's work extends beyond academia into national policy and global standards. Through initiatives such as Consortium for VR/AR/MR Engineering (CAVE) and the Metaverse India Policy

and Standards (MIPS) Committee, XTIC unites startups, industries, and government to shape India's XR ecosystem. Prof. Manivannan's collaborations with ISRO's Human Space Flight Centre highlight XR's potential in measurement of functional anthropometry for astronaut training and space mission simulations, embedding immersive technologies in India's space programme.

Talent Development and Ecosystem Building

A strong believer in capacity building, **Prof. Manivannan** has leveraged platforms such as NPTEL to train thousands of students in XR fundamentals. His course "Foundations of Virtual Reality" blends neuroscience, physiology, and perceptual psychology with XR design, reflecting his emphasis on scientifically grounded illusions. Through the Academic Associates Programme, Prof. Manivannan is extending XR education into Tier-2 and Tier-3 institutions. Thereby he is ensuring that immersive technologies are not restricted to elite campuses.









Energy and Sustainability



Turning Agricultural Waste into Advanced Polymers

At IIT Madras, **Prof. K. Chandraraj** and his team, in collaboration with **Prof. Arnepalli Dali Naidu**, are pioneering a remarkable transformation, converting agricultural waste into high-performance thermoset polymers. This innovation not only addresses the environmental challenge of crop residue burning but also creates sustainable materials for emerging industries such as electric vehicles (EVs).



The journey began with research into producing second-generation (2G) ethanol from non-edible agricultural residues like rice straw and wheat straw. Unlike first-generation ethanol, derived from sugarcane, 2G ethanol taps into crop stubble that is otherwise burnt in fields, contributing to severe air pollution.

Prof. Chandraraj and his research associate, **Dr. Shereena,** developed a patented an organosolv pretreatment process using a green organic solvent. This method preserves carbohydrates while removing lignin, enabling efficient ethanol production. Importantly, the process is effluent-free, ensuring minimal environmental impact. The use of the green organic solvent adds another layer of sustainability to the overall biorefinery process since pretreatment is a prerequisite.

The breakthrough came when the team realised that the same process could yield phenolic resins, a class of thermoset polymers. By adding organic acids and curing the resultant material, they produced a polymer with exceptional properties:

- Lightweight
- Fire-resistant
- Electrically insulating
- Antioxidant

These qualities make the resin ideal for applications in battery insulation for EV packs, where safety and efficiency are paramount. Unlike conventional materials such as Teflon or fibre-reinforced plastics (FRP), which are incinerated after use, the new thermoset offers a cheaper, eco-friendly alternative.

Initially, Dr. Shereena's start-up, Chrissron Biomass Solutions, explored the idea of producing wall and roof panels. However, the scale of production required for such applications proved challenging. The focus then shifted to insulating separators for EV batteries, a niche yet high-demand market.

The resin can be produced from any non-edible plant material, ensuring flexibility in raw material sourcing. Moreover, the process requires no specialised equipment, making it accessible for decentralised production units.

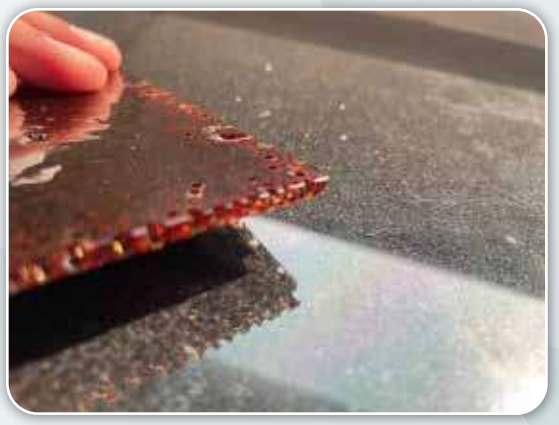
The implications of this work are profound:

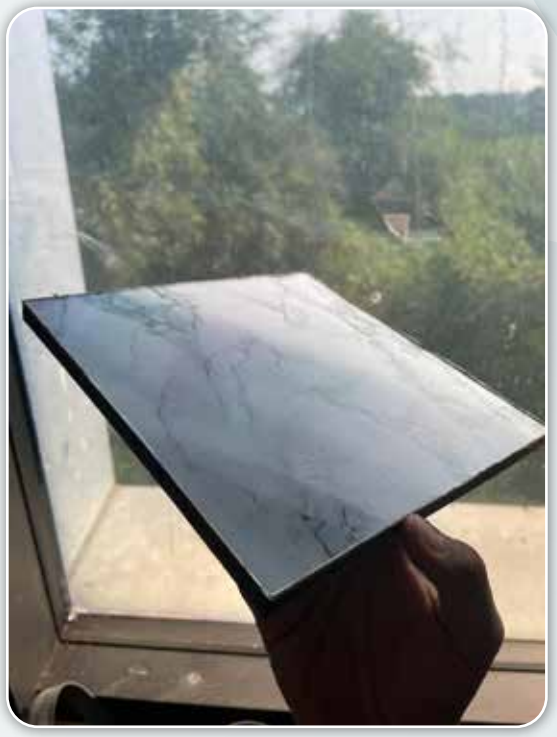
- Circular economy: By valorising agricultural waste, the project promotes resource efficiency and reduces pollution from stubble burning.
- Sustainability: The use of a green solvent and the effluent-free processing minimise the environmental footprint.

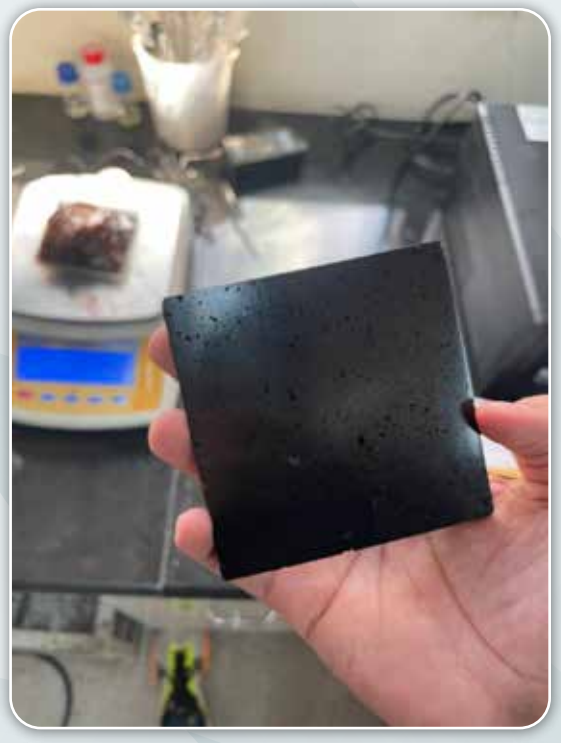
- Energy transition: Providing safer, cheaper insulation materials for EV batteries supports India's push toward clean mobility.
- Versatility: Beyond EVs, the thermoset shows promise in thermal and soundproofing applications in interior constructions, expanding its market potential.

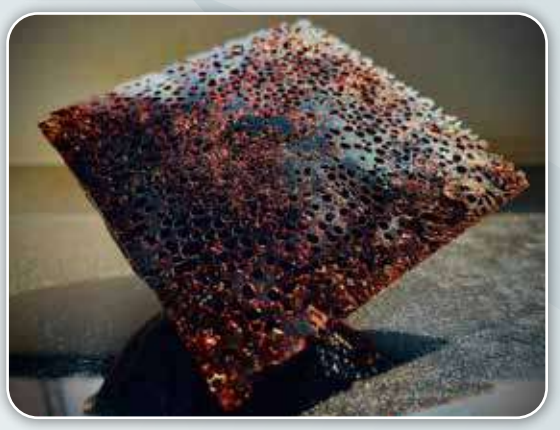
Prof. Chandraraj's research exemplifies how biotechnology can bridge agriculture and advanced fuels and materials science. By turning waste into value-added products, the work not only addresses pressing environmental issues but also strengthens India's innovation ecosystem.

The development of thermoset polymers from agricultural residues at IIT Madras represents a paradigm shift in sustainable materials engineering. What began as an effort to produce 2G bioethanol has evolved into a technology with far-reaching industrial applications. With academic rigour, entrepreneurial drive, and a commitment to sustainability, Prof. Chandraraj and his team are charting a path where India's agricultural waste fuels the future of clean energy and advanced manufacturing.









AquaMAP
Centre for Water Management and Policy

A vision flowing into reality. As India faces growing water stress, AquaMAP Centre for Water Management and Policy, at IIT Madras is offering a bold, solutions-driven response. Established in 2022, AquaMAP's grand mission is to turn proven research into large scalable solutions that ensure water security across India for generations. It brings together leading minds, cutting-edge technology, and deep field engagement to solve real-world water problems.



The centre was made possible through seed funding by visionary IIT Madras alumni Dr. Parasuram Balasubramanian and Mr. Krishnan Narayanan. AquaMAP boasts a multidisciplinary team of 20+ experts, which includes stalwarts like **Profs. Ligy Philip** (Lead), **T. Pradeep, Balaji Narasimhan, Indumathi Nambi and Sridharakumar Narasimhan**. Together, they form a unique think-and-do tank, reshaping India's water future. AquaMAP receives critical support from the Office of the Principal Scientific Adviser to the Government of India and from the vast network of IITM alumni.

Transformative projects.

In just 3 years, AquaMAP has launched several impactful initiatives.

1. Rural Wastewater Management: In Muthur, Karnataka, AquaMAP, with support from IBM, built a nature-based wastewater collection, treatment, and reuse system requiring no electricity or chemicals. This is co-purposed as a public park. This effective model for rural wastewater management is now being replicated across 1000 villages by the state government, with AquaMAP support. The Office of the PSA wishes to replicate this model in other states.
2. Holistic Rural Development: In four villages in Nagapattinam, AquaMAP partnered with Chennai Petroleum Corporation to upgrade water systems, build 420 sanitation facilities, treat grey water, revive ponds, and empower women and youth—earning national CSR honours, including the Golden Peacock Award.
3. Smart Rural Water Supply: Responding to issues of equitable service delivery, water quality assurance, and reducing the public health risks in rural areas, AquaMAP is helping several villages in Erode and Chikkaballapura districts integrate IoT into their water supply systems for automatic pump operation, water quality monitoring, and chlorination. These efforts are being supported by CSR funds as well as NTU Singapore.
4. Neer Pasanam' for Smarter Irrigation: To help farmers use water efficiently, AquaMAP, with support from IBM, developed a mobile app that combines weather, soil, and crop data to guide irrigation decisions. Piloted in Tamil Nadu, it is now evolving with AI and farmer feedback.

Beyond projects. AquaMAP supports national initiatives and partners with well-known organisations such as ASCI, Art of Living, and WELL Labs. It has advised the Chennai Metropolitan Water Supply and Sewerage Board on urban water reuse, has trained engineers nationwide, and leads WASH efforts under the Manthan platform of the Government of India. It has provided comprehensive advice to Water Company of Odisha on all issues related to water quality assurance and water safety plans. Through programmes such as the Carbon Zero Challenge, AquaMAP mentors students and start-ups innovating in water technology and prepares youth for global platforms such as the Stockholm Junior Water Prize.

AquaMAP is more than a research centre—it is a catalyst for change. With your support, we can scale impactful solutions and ensure water is managed wisely, justly, and sustainably across India.











Heliostat for Solar Tracking



Prof. Tiju Thomas and his doctoral student **Adithyan TR** are advancing solar technology by addressing one of the most pressing challenges of our time: providing clean water and sustainable energy by harnessing the vast power of the sun.

Solar radiation at the Earth's surface has an intensity of about 1000 W/cm^2, commonly referred to as "one sun." While this energy is abundant, its direct use in solar distillation is limited. A basic solar still typically produces only around 3 kilograms of purified water per square metre per day. Prof. Thomas's project aims to improve this efficiency by concentrating solar energy and using advanced materials, thereby increasing water yield and making solar distillation a more viable solution for communities facing water scarcity.

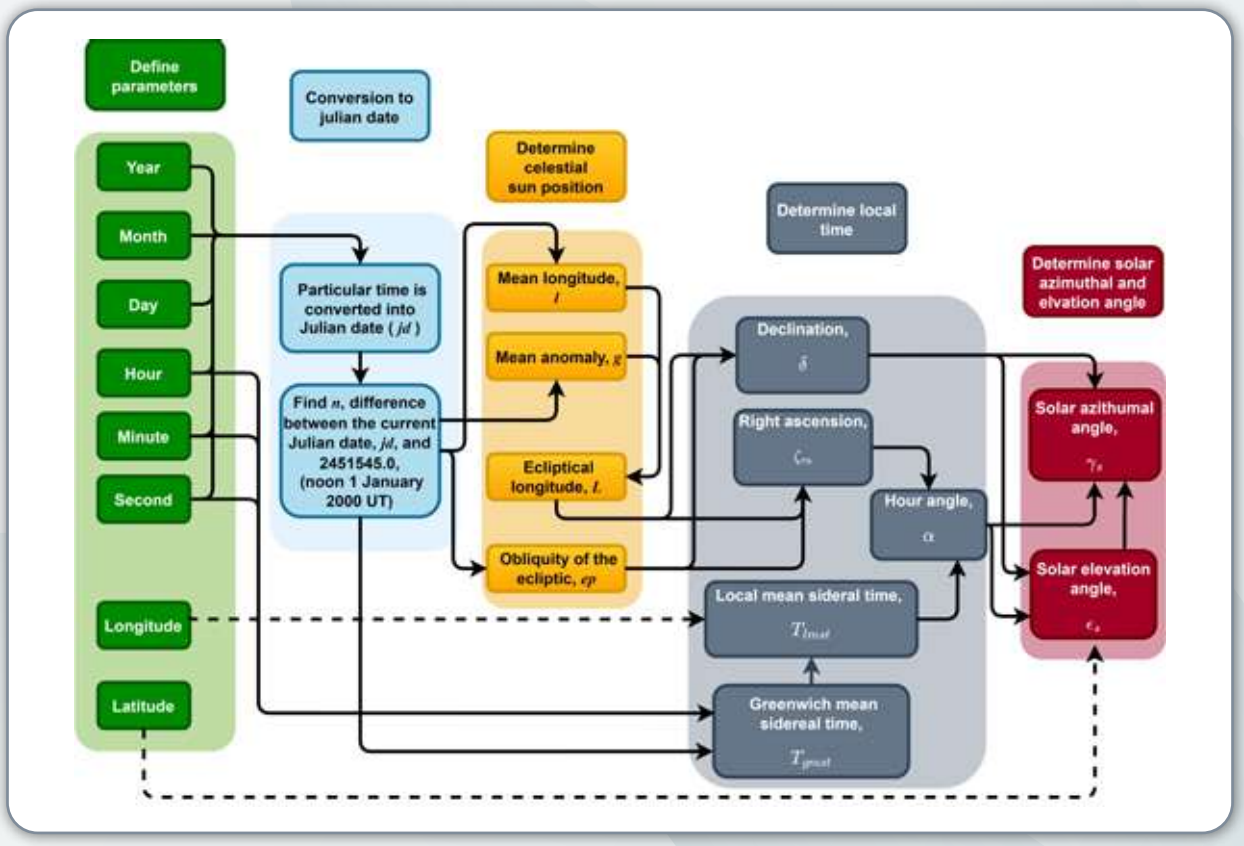
The centrepiece of the project is a heliostat, which is a device that uses mirrors to track the sun and redirect its rays to a fixed point. The design of Prof. Thomas and Adithyan employs eight small mirrors that follow the sun's movement and focus light onto a reflector, which then directs the concentrated energy to a target on the ground. This system raises the solar intensity to two or three suns, significantly enhancing the distillation process. With this setup, water production rises to about 4 kilograms per square metre per day, a notable improvement over conventional stills.

Adithyan brought prior training in mechanical engineering to the project. The team also explored the use of solar concentrators and nanoparticles to increase water heating efficiency. By raising the temperature of the water by 14%, these enhancements further boost distillation performance. In parallel, the group is investigating solar membrane distillation using advanced graphene membranes. These membranes promise higher efficiency and durability, opening new possibilities for scalable water purification systems.

The heliostat project is supported by IIT Madras's Institute Research Council (ICSR) under the Exploratory Research Project (ERP) scheme. This funding framework encourages faculty members to pursue bold early-stage ideas that can lead to transformative technologies. The ERP support has enabled Prof. Thomas and his associates to prototype the heliostat, conduct experiments, and prepare publications and outreach materials. The project also benefits from collaborations with colleagues working on related areas such as hybrid energy storage and environmental sensors, creating a multidisciplinary ecosystem around sustainable technology. Prof. Tiju Thomas invites people to reach out to him for collaboration in the field of renewable and solar energy.

The impact of Prof. Thomas's heliostat research is multifaceted. On a practical level, it enhances the efficiency of solar distillation, offering a low-cost, renewable method to produce clean water in regions where conventional purification is difficult or expensive. By integrating graphene membranes and nanoparticle-based heating, the system pushes the boundaries of what solar distillation can achieve, potentially transforming rural water supply and disaster relief operations.

Beyond water, the heliostat exemplifies how solar tracking and concentration can be applied to broader energy systems. It demonstrates the potential for hybrid solutions that combine solar power with advanced storage technologies, paving the way for resilient, decentralised energy infrastructure. The project also contributes to India's larger sustainability goals, aligning with national priorities in renewable energy and resource management.









Kotak IIT Madras Save Energy Mission

Lead investigator :
Prof. Satyanarayanan Seshadri

The Kotak IIT Madras Save Energy Mission (KISEM) has evolved into one of India's most impactful academia–industry collaborations in the areas of industrial energy efficiency and decarbonisation. Anchored at IIT Madras, it has grown from a single-centre initiative into a nationwide network across 10 IITs (IIT Bombay, IIT Ropar, IIT Gandhinagar, IIT Guwahati, IIT Indore, IIT Hyderabad, IIT Kanpur, IIT Jodhpur, and IIT Kharagpur), enabling a strong pan-India presence with region-specific interventions.

Since its inception in 2018 as the Industrial Energy Assessment Cell (IEAC) at IIT Madras and its expansion in 2022 with CSR support from Kotak Mahindra Bank across other IITs, KISEM has focused on addressing energy inefficiencies primarily in MSMEs and in large-scale industries through structured energy assessments and actionable interventions.

Measurable impact at scale

As of FY 2025–26, KISEM has achieved the following:

- 514 detailed energy audits across 30+ sectors delivered
- 5277 Energy Conservation Measures (ECMs) recommended
- ₹ 341 crores worth annual energy cost savings recommended
- 42,760 metric ToE of annual energy savings
- 4,05,100 metric tonnes of CO_2 emission reduction potential identified

Implementation effectiveness

- ~42% real-time implementation of recommended ECMs
- ~15–20% energy savings achieved by industries on average

Driving net-zero, SDGs and national energy efficiency

- Supports India's 2070 net-zero goal and NDCs through reduced industrial energy intensity and MSME decarbonisation
- Enables adoption of energy - efficient technologies and sustainable industrial growth
- Contributes to SDGs 7, 9, 12, and 13
- Exclusive partner to BEE under the ADEETIE Scheme
- Delivers MRV audits for MSME energy efficiency interventions
- Facilitates interest subvention to accelerate technology adoption
- Leads workshops and stakeholder engagement to drive cluster-level impact

Capacity building, industry enablement, and cluster outreach

- KISEM has developed a strong ecosystem to build technical capacity and accelerate adoption of energy efficiency across industries through:
- Training and certification of students, engineers, and industry professionals

- Creation of a pipeline of energy auditors and sustainability experts
- Enabling industries to institutionalise energy management practices
- Conducting targeted dissemination workshops across industrial clusters such as textiles, foundries, and process industries, in collaboration with state-level industry bodies and associations
- Accelerating technology adoption at cluster scale through demand aggregation

KISEM Energy Audit Tool

The KISEM Energy Audit Tool is a pioneering advancement in industrial efficiency, serving as a one-of-a-kind in-house tool. Developed by IIT Madras under KISEM. it replaces manual, labour-intensive audits with a streamlined, end-to-end digital process-from walk-through assessments to GHG emission analysis.

The tool standardises energy audits across sectors using 25+ pre-built utility modules and built-in algorithms, ensuring accurate data collection, performance analysis, and techno-economic evaluation. The tool transforms a once-cumbersome procedure into an agile, comprehensive digital platform that delivers instant, actionable reports.

A scalable model for industrial decarbonisation

With over ₹ 40 crores in CSR funding and a growing portfolio of paid industrial engagements, KISEM demonstrates a financially sustainable and scalable model. Its integrated approach combining technical rigour, digital tools, policy alignment, and on-ground implementation is transforming how industries view energy: from a compliance requirement to a strategic driver of competitiveness.









Restoration of Lakes and Water Bodies

Prof. Indumathi Nambi has brought Chennai's forgotten water bodies back into the public imagination—not through beautification but through science-led, community-rooted restoration. Her work goes beyond cleaning water. It is about restoring balance in a holistic way—reviving ecosystems to function naturally and sustainably within the fabric of an urban landscape.

In 2018, when unprecedented rains inundated the sprawling Siruseri-SIPCOT office campus of Tata Consultancy Services (TCS), the company turned to IIT Madras for answers. Under Prof. Nambi's guidance, a comprehensive hydrological assessment was carried out: mapping historic lake locations, charting groundwater levels and stormwater drains, and studying the subsurface hydrogeology. What emerged was a familiar but neglected pattern-silted lake beds had lost storage capacity, lakes once connected in a cascading chain were effectively isolated, and drains designed for routine monsoons were overwhelmed by what hydrologists term a "100-year storm."

Armed with data, Prof. Nambi's team proposed a four-pronged restoration: de-silting to reclaim dead storage, enlarging and realigning storm drains, hydraulically linking the lake cascade so that the inflow could reach downstream basins, and installing sluice gates for controlled releases during peak runoff. With government approvals in place and CSR funding from TCS, the implementation was entrusted to Pitchandikulam Forest Consultants (PFC). Over two seasons, PFC removed nearly 100,000 m^3 of sediment and sculpted it into earthen mounds within each lake. These mounds, swiftly colonised by native tree species, now stand as miniature islands that both stabilise lake edges and serve as roosts for birds. The once-barren basins now hold water year-round, the SIPCOT campus remains flood-free even during heavy downpours, and routine maintenance has been reduced to simple visual checks. The success has been measured quantitatively (there is a 20–30% increase in the combined water storage, and the avian diversity has surged) and qualitatively (a new educational hub is being developed by PFC and a partner agency where students and citizens can learn about wetland hydrology, the local biodiversity, and recharging groundwater).

Building on that success, Prof. Nambi turned her attention to Chitlapakkam–Sembakkam, a densely built suburb where 24 wastewater-laden drains once choked a shallow lake. Years of urban runoff had smothered open water with hyacinths and other macrophytes, deprived it of dissolved oxygen, and turned its margins into informal landfills infused with heavy metals. Recognising that a conventional sewage plant would be too costly and maintenance-intensive, her team recommended an in-situ constructed wetland system. In this design, modular shallow basins planted with emergent macrophytes and colonised by nutrient-cycling bacteria treat up to 75% of the inflow's nitrogen and phosphorus load before it rejoins the main lake. Buffer gardens of native species around the lake not only filter surface runoff but also create green corridors for pollinators. Capping and isolation of heavy metals and legacy sediments has been proposed, which will allow natural microbial processes to gradually immobilise or transform contaminants over time.

Prof. Nambi's lake-restoration portfolio exemplifies how targeted, science-driven interventions can revive urban water bodies into self-sustaining ecosystems. By drawing on field-based assessments, practical design solutions, and a deep understanding of how urban ecosystems behave, this approach has brought flood resilience, improved water quality, biodiversity revival, and stronger community connections—all without depending on energy-intensive infrastructure. As Chennai—and other Indian metros—grapple with growing water stress and urban flooding, Prof. Nambi's work offers a blueprint for turning underused blue spaces back into functional, living landscapes.





Humanities and Arts



Aviation English Language Proficiency Training

On 12 November 1996, two aircraft, a Saudia Boeing 747 and a Kazakhstan Airlines Ilyushin Il-76, collided in the air above Charkhi-Dadri, 100 km west of Delhi, in Indian airspace. All 349 people on board the two aircraft were killed in the accident. This was the world's deadliest mid-air collision. Investigations revealed that insufficient English language proficiency (ELP) had contributed to the occurrence of the accident: the crew of one of the planes had failed to maintain the correct altitude because they had not interpreted the instructions provided by air traffic controllers (ATCs) as they should have.

AIRPORTS AUTHORITY OF INDIA

This was not the first time in the world that language had had a role in air accidents. Over 800 people had lost their lives in just three incidents previously. Multiple near-misses and minor incidents were being reported annually. The Charkhi-Dadri collision prompted the International Civil Aviation Organisation (ICAO) to make ELP training mandatory for ATCs across all member states. The language provisions came into effect in 2003. By 2008, all ATCs (and pilots) had to demonstrate the ability to speak and understand the language used for radiotelephony communications.

To implement this requirement in India, the Airports Authority of India (AAI) turned to the Humanities Department at IIT Madras in 2020. **Prof. Rajesh Kumar** led the project to equip ATCs with uniform spoken English skills. The aim was to ensure that there is clarity in interactions with pilots from diverse linguistic backgrounds for the safety of all. The Humanities Department, IIT Madras, is recognised for its expertise in applied linguistics and communication. It is notable that IIT Madras was chosen over other language institutions to lead the national training programme. IIT Madras trained ATCs in communication. It developed training materials for the AAI for their new recruits and training programmes. The project also involved training the trainers in different parts of the country for this purpose.

The greatest number of instructions issued to a flight are during take-off and landing. There had to be no possibility of miscommunication during these critical phases.

The first training workshops were conducted in Chennai, for the South Zone, and in Delhi, for the North Zone. Training materials were prepared in advance that were tailored to the specific challenges faced by ATCs. Each workshop ran for five consecutive days. There were intensive 8-hour sessions led by experts from IIT Madras and invited specialists. Every operator underwent this mandatory training, which was essential for his or her certification. A train-the-trainer programme was launched at the same time. The selected participants came from across India, including the Northeast, Kashmir, and Gujarat. They would subsequently conduct workshops regularly in their zones. Refresher workshops were also instituted. These would ensure that ATCs reinforced their skills multiple times during their careers.

The project was funded entirely by the Airports Authority of India, with an allocation of approximately ₹ 1.8 crores.

This initiative has not only fulfilled an international mandate but has also contributed to ensuring the safety of millions of passengers flying through Indian airspace. Prof. Rajesh Kumar's project has standardised English communication across ATCs. The creation of a cadre of certified trainers has ensured continuity. Rarely does an academic project achieve such concrete nationwide influence.


APPROACHING RUNWAY 27 - CSMIA (BOM)
PROFICIENCY
TRAINING
IN PROGRESS
AVIATION PHONES
NOTE: LOCAL AIRPORT CALLOUTS
MUST BE PRACTICED.
LISTEN AND RE
CLEARANC


DGCA AVIATION SAFETY
DGCA AVIATION SAFETY
ICAO LANGUAGE SCALES
FOR DGCA INDIA

Infrastructure, Housing, Heritage



Bitumen and Modified Binders for Transportation

Worldwide and in India over 95% of highways and runways are constructed using bituminous materials. These materials form the top two layers of the pavement structure, providing essential load-bearing and surface functions.

Bituminous roads offer enhanced driving comfort and reduced vehicle noise. When engineered properly, they are capable of withstanding high traffic loads and extreme weather conditions.



Bitumen is a by-product of petroleum refining, derived from the vacuum tower bottom through fractional distillation of crude oil. Its properties depend heavily on the crude source and the refinery process. As with many natural resources, crude oil-essential to road construction-is finite. This underscores the urgency of adopting sustainable recycling technologies for existing pavements.

At IIT Madras, **Prof. J. Murali Krishnan** and his team are addressing the critical challenge of extending the service life of bituminous highways while reducing energy consumption and raw material use. Their focus is on cold recycling, a process that reuses aged bitumen and aggregates at ambient temperatures.

Given that cold recycling standards in India are still evolving, Prof. Krishnan, in collaboration with internationally recognised experts, has developed a mix design procedure tailored to Indian conditions. The resulting mixture is not only practical for execution but also resilient under India's harsh weather, heavy axle loads, and low-speed traffic conditions.

In a major real-world application, IIT Madras partnered with Cube Highways, Ingevity, and L&T to reconstruct the Ghaziabad-Aligarh toll road, covering 120 km. The project successfully reused around 500,000 tonnes of material and demonstrated that large-scale cold recycling can meet structural performance requirements.

Currently, Prof. Krishnan is working with the Kerala Highways Research Institute (KHRI) on an 8-km pilot stretch under the "Recycle Kerala" initiative. This project goes beyond material and structural design: it includes developing operational SOPs, conducting on-site training for state PWD engineers, and implementing a 3-year post-monsoon performance monitoring plan.

Looking ahead, Prof. Krishnan leads an Indo-German research project co-funded by the governments of India and Germany. The collaboration, with TU Dresden as the academic partner, focuses on maximising the reuse of aged pavement materials. The project's central aim is to explore whether bitumen ageing can be reversed, with findings intended to inform international standards and practices.




L&T







Concrete 3D printing

The Department of Civil Engineering at IIT Madras, led by **Prof. Manu Santhanam**, along with colleagues **Profs. Benny Raphael and Koshy Varghese**, has been conducting research in 3D concrete printing.

3D printing in construction adapts additive manufacturing principles to build structures layer by layer. Unlike conventional methods that rely on standardisation, 3D printing enables mass customisation, allowing homes and buildings to be tailored to individual needs. In India, where housing is both a critical asset and a pressing social need, this technology offers a pathway to affordable, rapid, and personalised construction. Recognising this potential, IIT Madras established the IMPRINT—IIT Madras Printability Lab in 2017, with seed funding from the institute and in technical collaboration with Tvasta, a startup incubated at IIT Madras. The lab's mission was to develop materials, machines, and methods that make 3D concrete printing viable for real-world applications.

The journey began with the development of a bench-top printer capable of producing 25-cm-high components, which was used to study material strength and printability. In 2018, Tvasta created an R&D printer that could print modules up to 50 cm in height. This printer was successfully used to construct a single-storey cabin. The following year marked a significant leap: with funding from Larsen & Toubro (L&T), Tvasta scaled up to an industry-level printer capable of producing 1.5-m-tall elements. This printer was used to build a toilet block complete with plumbing fittings, showcasing the practicality of the technology.

In 2020, the team achieved a landmark by constructing India's first 3D printed house, at IIT Madras. Wall panels were printed off-site and assembled on campus, with the entire project completed in just 21 days. Subsequent years saw further demonstrations, including a toilet block in Jaisalmer, a bus shelter at Godrej's Vikhroli (Mumbai) campus, and the striking Ananta Shiras monument in Chennai. In 2024–25, the group undertook the construction of a G+1 3D printed building as an extension to the Bose–Einstein Guest House, at IIT Madras.

The success of this initiative has been underpinned by strategic funding and partnerships. Initial seed support came from IIT Madras, while industry backing from L&T enabled scaling to commercial-level printers. Collaborations with organisations such as India Cements further expanded the scope of demonstration projects, ensuring that the technology was tested in diverse contexts and environments.

Beyond demonstration structures, IIT Madras has made significant contributions to the science of 3D concrete printing. These include:

- Developing systematic methods for mixture proportioning to balance contradictory rheological properties
- Designing tests to evaluate early-age behaviour and ensure printability
- Conducting multi-scale mechanical characterisation to study the effects of layering
- Leading efforts in standardisation and contributing to international guidelines
- Innovating with unconventional binders and waste materials to enhance sustainability
- Applying computer vision to stability assessment and topology optimisation inspired by nature

The work at IIT Madras has positioned India as a leader in digital construction. By reducing construction time, enabling customization, and incorporating sustainable materials, 3D concrete printing addresses critical challenges in housing and infrastructure.


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Tvasta




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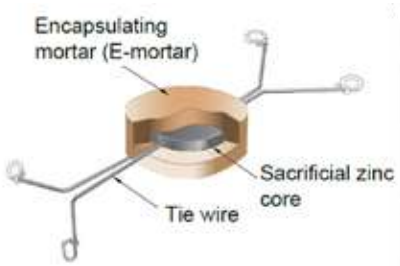

tvasta



Advancing Concrete Durability

The corrosion of reinforced concrete (RC) structures represents a critical but often overlooked economic challenge. **Prof. Radhakrishna Pillai's** research at IIT Madras addresses this challenge.

Co-investigator: **Prof. Ravindra Gettu**

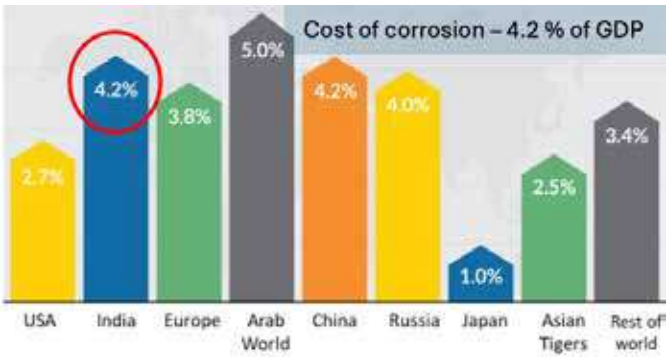


India is witnessing a construction boom in RC structures, with a targeted corrosion-free service life of 100+ years. However, many of them are exposed to aggressive environment, leading to early deterioration due to corrosion. As a result, repeated repairs and maintenance are carried out to prolong the lives of these structures. According to the IMPACT Report (2016) by NACE International, the total cost of corrosion of India is about 4.2% of the overall GDP. About 50% of this is contributed by the corrosion of various RC structures. This highlights the need for durable solutions in RC structures to mitigate environmental and economic impacts. To effectively estimate and extend the service life of RC structures, it is essential to assess corrosion risks during the construction phase and implement corrosion control strategies during the repair phase.

Since 2015, Radhakrishna Pillai's team is popularising galvanic cathodic protection (GCP) to extend the service lives of corroding concrete structures to beyond 20–25 years. Seeing the potential growth in this market, many new anodes were being introduced into the market, and the selection of anodes was becoming challenging. Hence, the group developed a test method (namely, the GAP Test) to assess the service lives of anodes and select suitable anodes for specific applications. Such selected anodes were used to repair the 1.2 km long chajja (sunshade) of Rashtrapati Bhavan, in New Delhi. The service life extension was 50 years. IIT Madras is also involved in promoting similar durable repairs in many other structures in India.

Durability/corrosion assessment

A multi-scale understanding of the electrochemical activities at the interface between the concrete and the metallic reinforcement is needed to assess the durability of RC. Towards obtaining this understanding, Ph.D. projects are being conducted from atomistic modelling to laboratory experiments to field assessments. Also, the group is promoting the specification of Mx–Dy concretes instead of the conventional Mx concretes (M40, M50, etc.). Here, Dy = ρ (the surface resistivity of concrete), which can be the quality control parameter for routine inspections at sites.

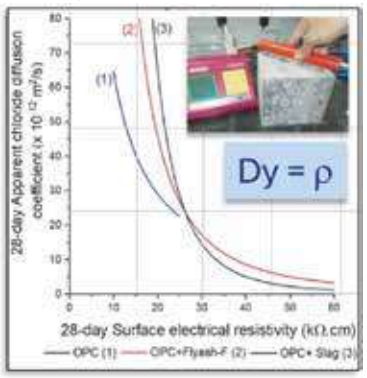


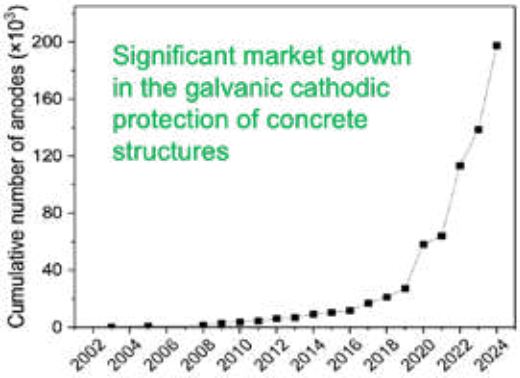




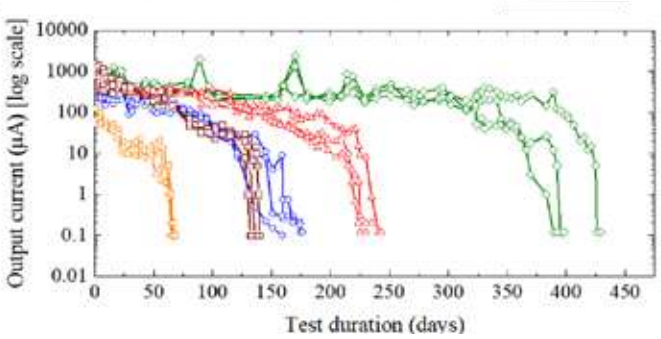


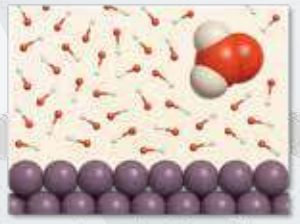
Mx–Dy concrete specification



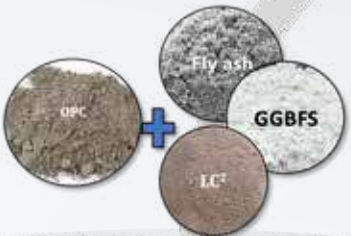


Use GAP Test to select galvanic anodes





Assessing steel passivation with corrosion inhibiting admixtures & superplasticizers



Understanding corrosion of steel in various low-clinker binders



Developing galvanized rebars with crack and corrosion resistance





Detecting corrosion of strands in prestressed concrete structures



Understanding the effect of steel–concrete interfacial characteristics on corrosion

Assessing the Safety of Dams and Developing the Capacity of Dam Engineers

Lead investigator**: Prof. Subhadeep Banerjee**

India has a vast network of over 7000 dams, representing critical infrastructure. In response to the National Dam Safety Act of 2021, which requires that major dams older than 50 years be assessed for safety against earthquakes and floods, IIT Madras and MNIT Jaipur initiated an ambitious pilot project. This project, funded by the Government of Maharashtra, is focused on a pilot study of earthen, concrete, and masonry dams. These are seven of Maharashtra's more than 3100 dams, the greatest number in any state, making it a priority region for ensuring public safety and robust infrastructure management.

Over the last eight months, multidisciplinary teams from IIT Madras and MNIT Jaipur have been actively engaged in deploying an integrated assessment approach. The teams have focused on four key areas: seismic and flood hazard analysis, vulnerability studies, exposure evaluations, and overall risk assessments. Historical seismic event records and flood data have been collected from established catalogues to form a baseline for the assessment. These data feed into probabilistic computational models. Numerical model are being developed to simulate the structural response of the dams under various stress conditions. The models will be verified through measurements in the field.

Preliminary inspections have allowed the teams to perform detailed visual assessments. There were challenges such as remote dam locations, harsh weather conditions, and extended travel distances. The visits prompted the updating and redrawing of existing dam plans using modern drafting tools since many of the original plans do not meet current engineering requirements.

The project is also undertaking practical experiments aimed at understanding the dynamics of dam performance. For example, controlled tests involving the incremental opening of dam gates have been executed to assess how water release in degradation scenarios could affect downstream areas. Such experiments are integral for developing emergency response protocols. Extensive field data are to be collected and the methodologies are to be refined continually for real-world conditions.

The pilot project stands to have a far-reaching impact on dam safety management in India. Its methodology—integrating advanced computational models with practical field assessments—is expected to become the standard for dam safety evaluation throughout the country. As the project progresses, it will generate a risk categorisation system that distinguishes between dams that are safe and those that require urgent remedial measures. The insights obtained will not only direct immediate safety interventions but will also inform the development of comprehensive emergency plans to mitigate the impacts of potential dam failures or leak scenarios.

This project has a robust capacity-building component for dam engineers. The project enhances technical competencies by exposing senior engineers to state-of-the-art assessment techniques. A team of engineers from the Department of Water Resources, Maharashtra, participated in a sensitisation programme conducted at IIT Madras in June 2025.

Findings and refined methodologies will be documented and disseminated over the next three years. Similar projects are expected to be conducted in other states. The project promises to substantially elevate safety associated with dams across the country and ensure the protection of vital water resources.











Glass Fibre Reinforced Gypsum (GFRG) Panels

Glass fibre-reinforced gypsum (GFRG) panels are prefabricated light-weight hollow panels, first invented in Australia in 1990 (under the trade name Rapidwall). They are suitable for faster construction of affordable buildings on a large scale. These load-bearing panels are manufactured from calcined gypsum plaster, glass fibres, and some special additives added to improve the moisture resistance.

The randomly distributed glass fibres, of length 300–350 mm, provide tensile strength to the otherwise brittle gypsum plaster. The cavities of the panels are filled with reinforced concrete for structural applications to improve the axial in-plane and out-of-plane load-bearing capacity.

In 2003, **Profs. P.K. Aravindan, Devdas Menon, and A. Meher Prasad** visited GFRG buildings and a factory in Australia. Subsequently, studies were conducted at IIT Madras to assess the suitability of the panels for use in India, where, unlike Australia, seismic loads play a significant role in structural design. Manuals on design, construction, and waterproofing of GFRG buildings were also prepared under the aegis of the Building Materials and Technology Promotion Council (BMTPC), Ministry of Housing and Urban Affairs, Government of India.

The research and development work on GFRG panels in India was steered by IIT Madras through six Ph.D.s, supported by research grants from the Department of Science and Technology (DST) and the Indo-French Centre for the Promotion of Advanced Research (IFCPAR). The extension of the use of panels from structural walls to other structural elements, such as floor slabs, staircase waist slabs, and parapets, is a key contribution from the R&D efforts at IIT Madras. Studies were also done on the use of panels in stilted construction, as infill walls, focusing on enhancing the durability and sustainability aspects for adapting the panels to the Indian construction industry.

The feasibility of the technology was demonstrated by constructing a two-storeyed building at the IIT Madras campus in 2013. Since then, GFRG panels have been used in several private and government projects, including four-storeyed hostel buildings at IIT Tirupati campus. These were awarded the GRIHA Council Award 2018 under the category Green Buildings for adopting GFRG as a sustainable construction material. The increased use of panels has led to the publication of two Indian Standards, IS 17400 and IS 17401, to support design and construction using GFRG panels.

Right from the introduction of the panels in India, IIT Madras has been actively involved in each step, including research studies, organisation of training programmes, preparation of manuals and design codes, and offering technical support to designers and contractors. It is believed that these efforts have been instrumental in bringing academic research to industrial applications, for the public good.







Conservation of Heritage Structures

The National Centre for Safety of Heritage Structures (NCSHS), at IIT Madras, emerged in response to a long-standing need for rigorous engineering expertise in heritage conservation. Prior to its inception, institutions such as the Archaeological Survey of India (ASI) and various state Public Works Departments (PWDs) frequently consulted IIT Madras on structural matters related to heritage buildings.



The Civil Engineering Department and ASI had even engaged on overseas projects in Cambodia, including Angkor Wat, where balancing ecological and cultural preservation was highly challenging. Lacking the required internal engineering capacity, these organisations required sustained support. Recognising this gap, IIT Madras submitted a proposal in 2012 to the Ministry of Culture and the Ministry of Human Resource Development (now Education), aligning with national efforts to integrate technology and cultural preservation. The proposal secured ₹ 12.5 crores in funding, leading to the creation of the first such ministry-funded centre in the country.

Since its establishment, the NCSHS has built advanced experimental and computational infrastructure and engaged deeply in research and outreach. It has become a national hub for scientific inquiry into the structural and geotechnical aspects of heritage buildings, awarding multiple Ph.D.s and developing specialised instrumentation. One of its major strengths is its dual approach—balancing laboratory simulations with real-world consultation. For example, it conducted pioneering weathering studies using salt spray chambers with simulated wind conditions to understand the damage faced by coastal monuments such as those at Mahabalipuram and Konark.

The centre's expertise has been critical in providing advice for landmark projects such as the restoration of a 12th-century temple at Thukkachi, Tamilnadu, under a tripartite agreement involving the HR&CE Department, the temple, and IIT Madras. This project was selected for the 2024 UNESCO Asia-Pacific Award of Distinction for Heritage Conservation from 52 projects received from the Asia-Pacific Region by UNESCO Bangkok. In the case of the fire-damaged Meenakshi Amman Temple, Madurai, the NCSHS played a key role in avoiding unnecessary demolition by scientifically demonstrating that much of the original structure could be retained. The centre also identified sources of compatible materials.

The role of the NCSHS goes beyond individual projects. In 2023, it entered into a memorandum of understanding with the ASI to train ASI engineers in scientific conservation. Accredited by the National Monuments Authority (NMA), the centre is authorised to conduct heritage impact assessments—a crucial step for urban development near protected monuments. Any intervention should be minimally invasive, reversible where possible, and sensitive to the material and the intrinsic value of heritage elements such as inscriptions and sculptures.

Twelve years since its inception, the NCSHS has influenced policy, improved safety standards, and filled critical gaps in heritage conservation across India and Southeast Asia. From recommending scientific and structural safety-centric approaches to heritage conversation to building capacity through research, its impact is both technical and cultural. With over 3600 nationally important protected monuments and many more at state and municipal levels, the work of the NCSHS is vital in ensuring that India's rich architectural legacy endures for future generations.

One alumnus has carried this mission forward by founding a company dedicated to heritage preservation.

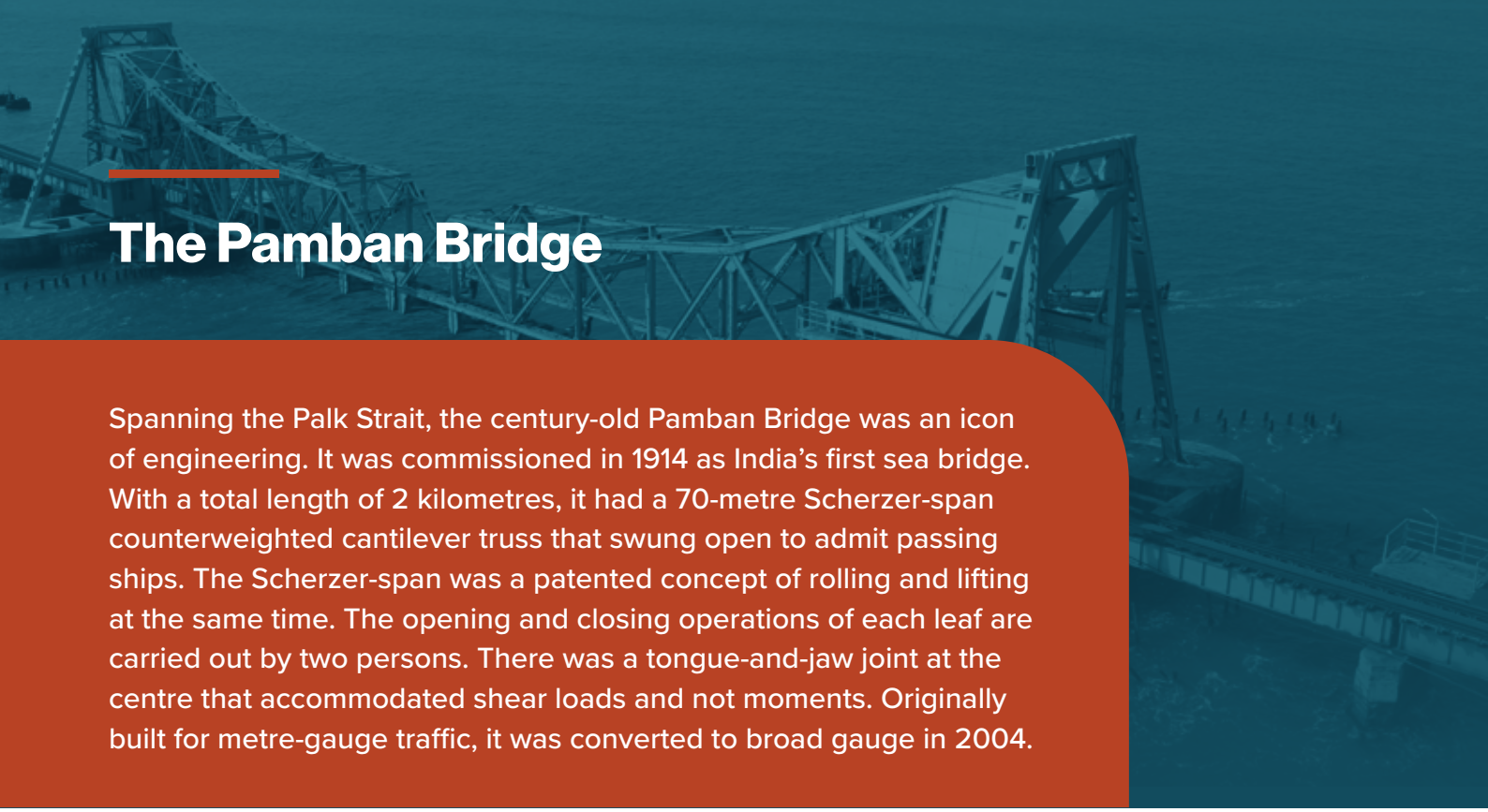
The NCSHS stands today as a research centre devoted to thoughtful, science-based conservation. It is headed by **Prof. Arun Menon**. Co-investigator: **Prof. C.V.R. Murthy**











The Pamban Bridge

Spanning the Palk Strait, the century-old Pamban Bridge was an icon of engineering. It was commissioned in 1914 as India's first sea bridge. With a total length of 2 kilometres, it had a 70-metre Scherzer-span counterweighted cantilever truss that swung open to admit passing ships. The Scherzer-span was a patented concept of rolling and lifting at the same time. The opening and closing operations of each leaf are carried out by two persons. There was a tongue-and-jaw joint at the centre that accommodated shear loads and not moments. Originally built for metre-gauge traffic, it was converted to broad gauge in 2004.

The bridge performed its service in one of the most corrosive environments in the world. Around its centenary year, the trains were operated at just 10 kilometres per hour on the single track due to corrosion issues. Incremental retrofits proved insufficient, and ultimately construction began on a new double-track bridge with higher limits.

Lives and freight on the ageing span of the old bridge, which was under stress, had to be safeguarded during its final years of service. Indian Railways turned to the Structural Engineering Group at IIT Madras, under **Prof. U. Saravanan.**

Beginning in August 2020, the IIT Madras team outfitted the Pamban Bridge with a dense network of sensors: 84 strain gauges to track member deformations, 40 accelerometers at the nodes of the truss to capture vibration signatures, and 10 thermocouples to log temperature for sensor health checks. Two field-hardened data-acquisition cabinets transmitted the raw time series to a cloud server, enabling continuous remote surveillance. This instrumentation package formed India's most comprehensive real-time monitoring system on a live railway bridge.

The strain gauges were tuned to detect axial stresses in all loaded members, and they issued alerts automatically whenever member strains approached predefined safety limits. The accelerometers logged acceleration time histories of the traffic-induced vibrations, flagging anomalous shifts in amplitude or frequency that potentially indicated structural damage. Though the temperature readings did not directly drive safety decisions, they validated the integrity of the electronic sensors in the fluctuating marine environment.

For 28 months—from 17 August 2020 to 22 December 2022—the IITM analytics engine parsed terabytes of sensor data in real time. Maintenance warnings were despatched routinely as corrosion and fatigue cycles took their toll. Only when strain surges breached thresholds did the system trigger train-stoppage advisories. This occurred three times over the monitoring period, and potential calamities were avoided. In late 2022, with the corrosion too advanced for cost-effective repair, the bridge was retired. The new structure was opened subsequently.

Parallel research at IIT Madras demonstrated how field-collected acceleration data alone can underpin continuous condition assessment. Vaibhav Gupta and Prof. Saravanan analysed over 1000 train passages between March–July 2021 and March–July 2022, extracting parameters such as root-mean-square acceleration, Arias intensity, characteristic intensity, and cumulative absolute velocity. Linear trends in these metrics closely mirrored retrofitting records, validating vibration-based health indicators as efficient proxies for damage detection without halting operations.

Looking ahead, the Structural Engineering Group at IIT Madras, under Prof. Saravanan, is developing scalable algorithms for ageing highway bridges, where complex loading from lane indiscipline complicates health assessment. They envision cloud-based platforms built in collaboration with CDAC Thiruvananthapuram that concurrently monitor thousands of spans nationwide.

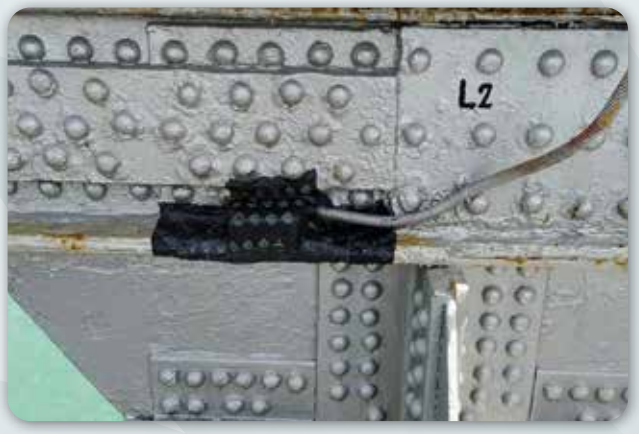
Meanwhile, a Chennai-based Trimble team is integrating drone-borne crack inspection: automated aerial surveys will flag hotspots for follow-up instrumentation, closing the loop between visual and sensor-based evaluations.

The team headed by Prof. Saravanan has also charted a path for the future of smart, resilient bridges across India.













RBG Labs - Centre of Excellence for Road Safety

Designing Safer Mobility for a Viksit Bharat@2047

Lead investigator:
Prof. Venkatesh Balasubramanian

Roads carry millions across India every day—toward livelihoods, education, opportunity. Yet every day, 435 lives are lost, with over 1.5 lakh deaths annually.

This shows that road safety is not peripheral to sustainable development, it is central to it.

To address this, the Centre of Excellence for Road Safety (CoERS) was established at RBG Labs, Department of Engineering Design, IIT Madras.

With initial funding from the Ministry of Road Transport and Highways (MoRTH), it works towards India's commitment to growth, mobility, and safety as pillars of Viksit Bharat@2047.

From rehabilitation to the road: The RBG Labs story

RBG Labs began where engineering meets the human body. Its earliest work centred on the objective evaluation of human factors across modes of transportation and lean manufacturing—asking how people move, how they are injured, and how systems could be designed to protect.

From this foundation grew structured methodologies, products, and intellectual properties. The lab's training programme Visionary Leaders for Manufacturing (VLFM) paved the way for under Make in India's human capital development initiative.

In a deliberate shift, the same human-factors lens—applied with a first-principles approach—turned towards the road—why crashes happen, how systems fail, and what the data show.

A think tank for safer futures

Meaningful impact demanded a complex but coordinated system. That conviction shaped the RBG Transportation Safety Framework—oriented toward a single goal of zero fatalities.

It operates through focused avenues:

- Human factors–based engineering for Infrastructure, vehicle, and occupant safety
- Data-driven emergency care systems like TAEI
- Cognitive and behavioural engineering for safer driving

Cutting across these are the Suzhal Management System (SMS), for operational excellence, RBG Innovation Paradigm (RIP), for structured problem-solving, and deep domain expertise—together supporting Viksit Bharat's shift toward data-driven governance.

Translating research into safer roads

Over the years, CoERS has built practical, scalable systems integrating crash data, human behaviour, infrastructure design, and emergency response, serving as a technical knowledge partner for MoRTH and governments at state and district levels—bridging science, policy, and on-ground implementation for evidence-based problem-solving.

At the heart of this work is the 5E Model.

A pathway for data-driven road safety

Every system CoERS built was built for a reason—to make data work for people.

These systems further developed the Road Safety Survey Application, which enabled audits of over 1000 kilometres of roads nationally—each gap identified, each intervention validated through data.

Strengthening behaviour, enforcement, and emergency care

Safer infrastructure must be matched by stronger behaviour, enforcement, and post-crash systems. CoERS addresses all three:

Scientific crash investigation using Root Cause Analysis Matrices translates crash data into actionable enforcement insights.

Zero Accident Day and school-based programmes nurture a culture of safety from an early age

The Trauma Care Preparedness Level (TPL)—developed by IIT Madras, evaluating hospital readiness, response timelines, and infrastructure gaps—is now being adopted by MoHFW for national trauma preparedness mapping.

Building national capacity for road safety

With systems and data, lasting change depends on people. Capability and capacity building form a core pillar of CoERS's mission.

Anchored in design thinking, CoERS has trained stakeholders across sectors—road safety audits, crash investigation, trauma care preparedness, and activity-based learning for young minds—building self-reliant road safety ecosystems.

Key initiatives like Data-Driven Hyperlocal Interventions (DDHI) and Sadak Suraksha Mitra (SSM) empowered district administrations to identify high-risk locations, prioritise interventions, and monitor outcomes across agencies.

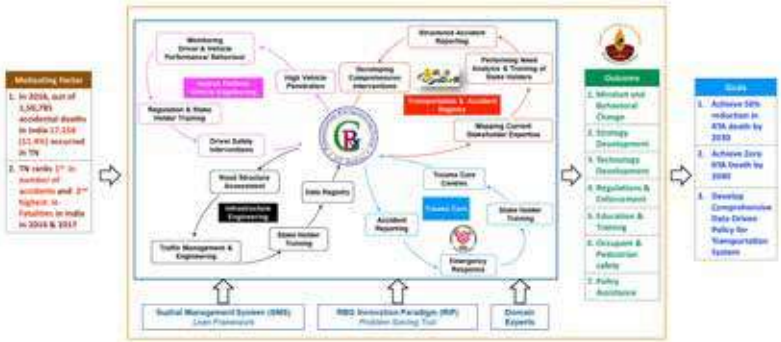
Safer roads, stronger India

Every journey on an Indian road is life in motion. The centre's work continues—rooted in science, guided by empathy, and strengthened through collaborations.

CoERS is building a future where mobility, growth, and human life advance together—an essential foundation for a Viksit Bharat@2047.











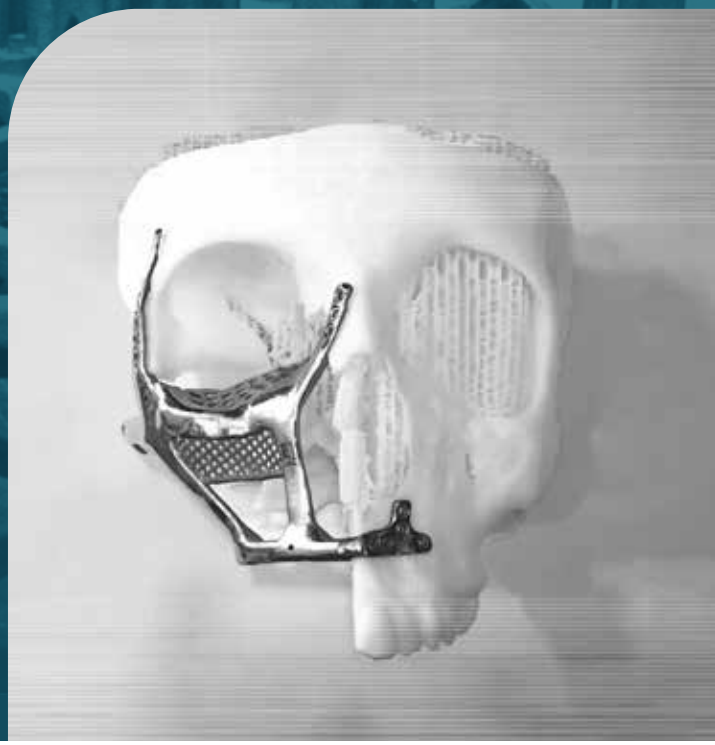


Manufacturing



Redefining Metal Manufacturing

For decades, the way metals were shaped in India's factories followed a familiar and largely unchanged pattern. Whether it was forging tools/dies on an automotive shop floor, a surgical implant in a hospital, or a high-performance aerospace bracket, the process relied on large metal blocks, long machining hours, substantial material wastage, and production cycles stretching into weeks or even months. As global industries began demanding faster turnaround, lighter structures, and highly customised components, this conventional manufacturing paradigm increasingly revealed its limits.



At Indian Institute of Technology Madras, **Prof. Murugaiyan Amrithalingam** set out to challenge this status quo. His work focuses on metal additive manufacturing, popularly known as metal 3D printing, not as a futuristic curiosity but as a robust and industrially viable alternative to traditional metal fabrication. His vision has been to move metal additive manufacturing from laboratory demonstrations to reliable shop-floor adoption.

While metal 3D printing offers unprecedented design freedom, early efforts were limited by serious technical hurdles. Internal porosity, residual stresses, microstructural inconsistency, and high production costs made industries hesitant to deploy additively manufactured parts in critical applications. Prof. Murugaiyan's research addressed this trust deficit at its root. Rather than simply printing components, his work focused on uncovering the fundamental science behind defect formation, laser–powder interaction, rapid solidification, and process control, laying the foundation for repeatable, economical, and qualification-ready manufacturing.

One of the most compelling success stories from his work is the LPBF-based fabrication of forging punches, a component long considered unsuitable for additive manufacturing. Conventionally, forging punches are machined from oversized tool-steel billets, resulting in nearly 30–45% material loss and lead times of 3–4 weeks. Prof. Murugaiyan and his team demonstrated that the same punches could be produced as a near-net-shape component using metal 3D printing, drastically reducing downstream machining. Through systematic optimisation of laser parameters and post-processing heat treatments, the additively manufactured punches achieved densities exceeding 99.5% and hardness comparable with conventionally produced tools. The impact was decisive: material waste reduced by ~50%, manufacturing cost lowered by 25–35%, and lead time compressed to under 8–9 days. These components reached TRL 6–7, overturning long-held assumptions about additive manufacturing in tooling.

An equally powerful demonstration of impact is found in Prof. Murugaiyan's work on patient-specific biomedical

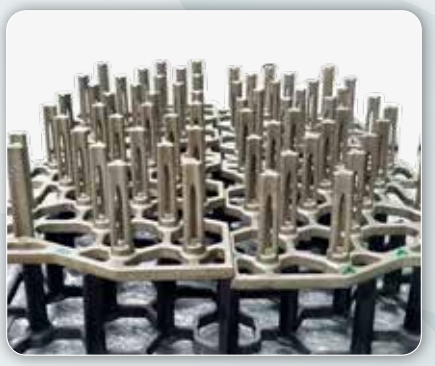
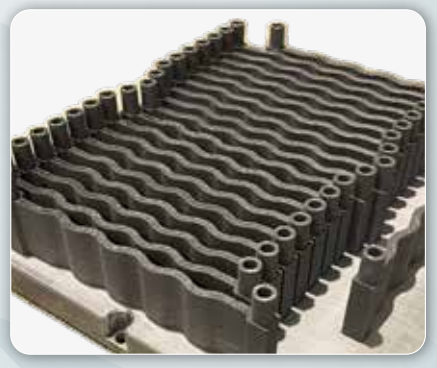
implants. Traditional implants are manufactured in standard sizes, often forcing surgeons to compromise during implantation. By integrating medical imaging with metal 3D printing, his research enabled the fabrication of implants precisely tailored to individual patient anatomy. This digital-to-implant workflow reduced production timelines from several weeks to less than a week, delivering 70–80% lead-time reduction, 20–30% cost savings, 40–50% reduction in weight, and improving fit and functional outcomes. These implants achieved TRL 6, highlighting strong translational potential.

Beyond applications, Prof. Murugaiyan has made significant advances in new alloy development specifically tailored for additive manufacturing, recognising that most conventional alloys were never designed for the extreme thermal cycles of laser-based processing. His research focuses on developing next-generation alloys for biomedical and tooling applications, where printability, defect resistance, and performance reliability are critical. His work on composition optimisation and process–microstructure relationships has improved printability, reduced cracking susceptibility, and expanded the material ecosystem available to industry.

His research also addresses sustainability through repair and life extension of high-value components using Laser/Arc Directed Energy Deposition. By rebuilding worn dies and moulds instead of scrapping them, his team demonstrated a nearly 2× extension in component life and 40–60% reduction in replacement costs, offering a compelling solution for cost-sensitive sectors.

Equally central to his mission is manpower development and industry readiness. Through hands-on training, industry-driven research projects, and close collaboration with manufacturing partners, Prof. Murugaiyan has helped build a skilled workforce fluent in the entire additive manufacturing workflow from design and materials to process control and qualification.

Supported by government grants, institutional funding, and industry partnerships, his work has delivered far more than publications and patents. It has produced qualified processes, new materials, industry-ready components, and trained professionals accelerating India's transition toward advanced manufacturing and a future-ready industrial ecosystem.





Advanced Manufacturing Technology Development Centre

In an era of rapid technological evolution, the Advanced Manufacturing Technology Development Centre (AMTDC), serves as a dynamic platform for research, innovation and skill development in advanced manufacturing technologies. This centre stands as a unique Centre of Excellence in machine tools and production technologies. It was established in 2016, as a not-for-profit society—a collaborative effort between industry, academia, and government, at IIT Madras Research Park, by **Prof. N. Ramesh Babu,** of IIT Madras, with a broad vision of building a translational research centre to innovate core technologies relevant to the capital goods sector. Its mission is (1) developing commercially viable technologies as import substitution, (2) building high-quality human resources in manufacturing, and (3) incubating new ideas/technologies and businesses for assisting MSMEs/SMEs.

The centre focuses on the development of core technologies in domains such as (1) mother machine tools and machining technologies, (2) industrial robotics and automation, and (3) digital and smart manufacturing to bring self-reliance into diverse sectors.

The precursor to AMTDC was the development of a high precision cylindrical grinder in partnership with Micromatic Grinding Technologies Pvt. Ltd, during 2012–2016.. Subsequently efforts were made to transfer the technology to the industry partner for commercial exploitation. The experience gave the confidence to take up 11 technology development projects under the Capital Goods (CG) scheme launched by the Ministry of Heavy Industries, in 2014, in partnership with industry partners. Notable contributions of AMTDC include technologies across different domains of advanced manufacturing.

- Development of multi-tasking machines, high- precision grinders, and ultra-precision micromachining centres.
- Design and development of articulated robots, spindle and axis drives, tailored to the manufacturing needs of India.
- Pioneering efforts in smart manufacturing including 'Automation of Grinding Process Intelligence (AGI), translation of machines into high precision machines with 'Thermal Compensation Systems' that leverage the concepts of IoT, data analytics, and Industry 4.0 technologies.

The centre has not only developed the technologies with a team of faculty, trained engineers, and researchers but also established state-of-the-art facilities in advanced manufacturing along with advanced software. With these resources and expertise, the centre supports many MSMEs, start up and incubatees in translating ideas into commercially viable products.

The extensive collaboration with multiple industry partners, in smart manufacturing projects, made the centre to establish 'Smart Manufacturing and Digital Transformation Centre (SMDTC)' with a goal of enabling many MSMEs/SMEs to get ready for digital and smart manufacturing transformation.

Another noteworthy initiative of AMTDC is the establishment of the technology innovation platform (TIP) known as 'kite': knowledge integration for technology enrichment. It is built using the concepts

of graph databases and reasoning with an intent of connecting the different stakeholders of manufacturing.

The centre has filed more than 15 patents and three copyrights on the technologies built indigenously. These contributions span the defence, aerospace, healthcare, and capital goods sectors. AMTDC is shaping the next generation of engineers into innovators by nurturing the talent through internships, skill development programmes, and international collaborations. AMTDC thus has a pan-India impact.

Prof. Ramesh Babu's leadership has earned him accolades including the Lifetime Achievement Award at the AIMTDR Conference, the Fellowship of the Indian National Academy of Engineering, and the Fellowship of the Andhra Pradesh Academy of Sciences. His work showcases how academia can drive industrial transformation to position India as a global leader in advanced manufacturing.











Centre for Non-Destructive Evaluation (CNDE)

The Centre for Non-destructive Evaluation (CNDE) at IIT Madras, led by **Prof. Krishnan Balasubramanian**, stands at the forefront of India's mission to master diagnostics and asset-integrity monitoring through in-house innovations. Established in 2001 to bridge critical gaps in non-destructive evaluation (NDE) and asset-health technologies, CNDE was charged from day one with addressing India's over-dependence on imported solutions. When the centre was launched, over 85% of the NDE technologies servicing the defence, energy, and aerospace sectors came from abroad, burdened by high costs, poor service, and long lead times. CNDE set out to develop affordable, robust Indian alternatives—solutions tailored to local challenges yet primed for global applicability.



NDE uses similar physics as medical diagnostics: acoustics, ultrasound, radiography, electromagnetics, infrared. These methods are used to inspect and evaluate the integrity of materials, components, assemblies, and products. Inspection contributes to approximately 15% of the life-cycle costs of critical products. NDE is applicable from cradle to grave of an engineered product.

CNDE has collaborated extensively with industry across the asset life cycle: from quality checks during manufacturing to life-extension assessments of ageing infrastructure and real-time safety monitoring. Analogous to healthcare diagnostics, CNDE's techniques reveal hidden flaws in machines. For instance, large numbers of components must be inspected rapidly and reliably in electric vehicles and auto-engines. Acoustic emissions provide vital data needed for doing this, pinpointing valve wear, piston friction, or oil degradation.

Continual innovation is required to keep pace with technological change—new materials are used, engine designs evolve, and operating environments grow increasingly harsh (extreme heat, corrosion, radiation). CNDE leverages robotics, sensor fusion, and multi-modal inspection strategies to stay ahead. It refines ultrasonic probes, develops diffraction-pattern imaging for micro-cracks, and engineers drone-based and underwater robotic inspection and information platforms. These solutions are designed to be cost-effective.

Technologies born at CNDE have enabled payload checks on space missions, inspections of supersonic combat aircraft, and validation of missile system.

Research at CNDE balances fundamental science with market relevance. It solves local problems, fuels strategic ambitions, and earns global acclaim by marrying deep academic research with agile

industry partnerships. A large number of publications and doctoral theses have emerged from the centre. A significant part of its efforts is focused on industry-driven problems, rapid lab-to-market commercialisation, and strategic national missions.

The spin-off ventures of CNDE are a testament to its entrepreneurial ecosystem, collectively employing 1500 high-tech professionals, including many working abroad, and serving some 500 client companies worldwide. Dhvani Research and Development Solutions,, incubated at IIT Madras in 2010, builds fully automated electro-mechanical systemsfor defence, aerospace, manufacturing, and automotive Industries; Planys Technologies deploys tethered robots that replace divers for hull and subsea inspections; Dhvani Inspection Technologies detects corrosive pits in offshore oil rigs; Detect Technologies was the first in the world to use drones for assessing the remaining life of tanks in petrochemical plants; Xyma Sensors measures furnace temperatures up to 1200°C; and a more recent spin-off, Dhvani AI, fuses ultrasound, thermal, and X-ray data into unified defect maps. One startup even delivers 20-micron-precision dent mapping for aircraft and automobile bodies in just five seconds—transforming maintenance turnaround times.

CNDE's work also underpins critical research in residual-stress measurement. The US Air Force, for instance, employs CNDE's electromagnetic and ultrasonic inverse methods to gauge subsurface compressive stresses introduced by shot-peening. Assessment is needed to ensure aircraft longevity since protective stresses decay after a few five years.

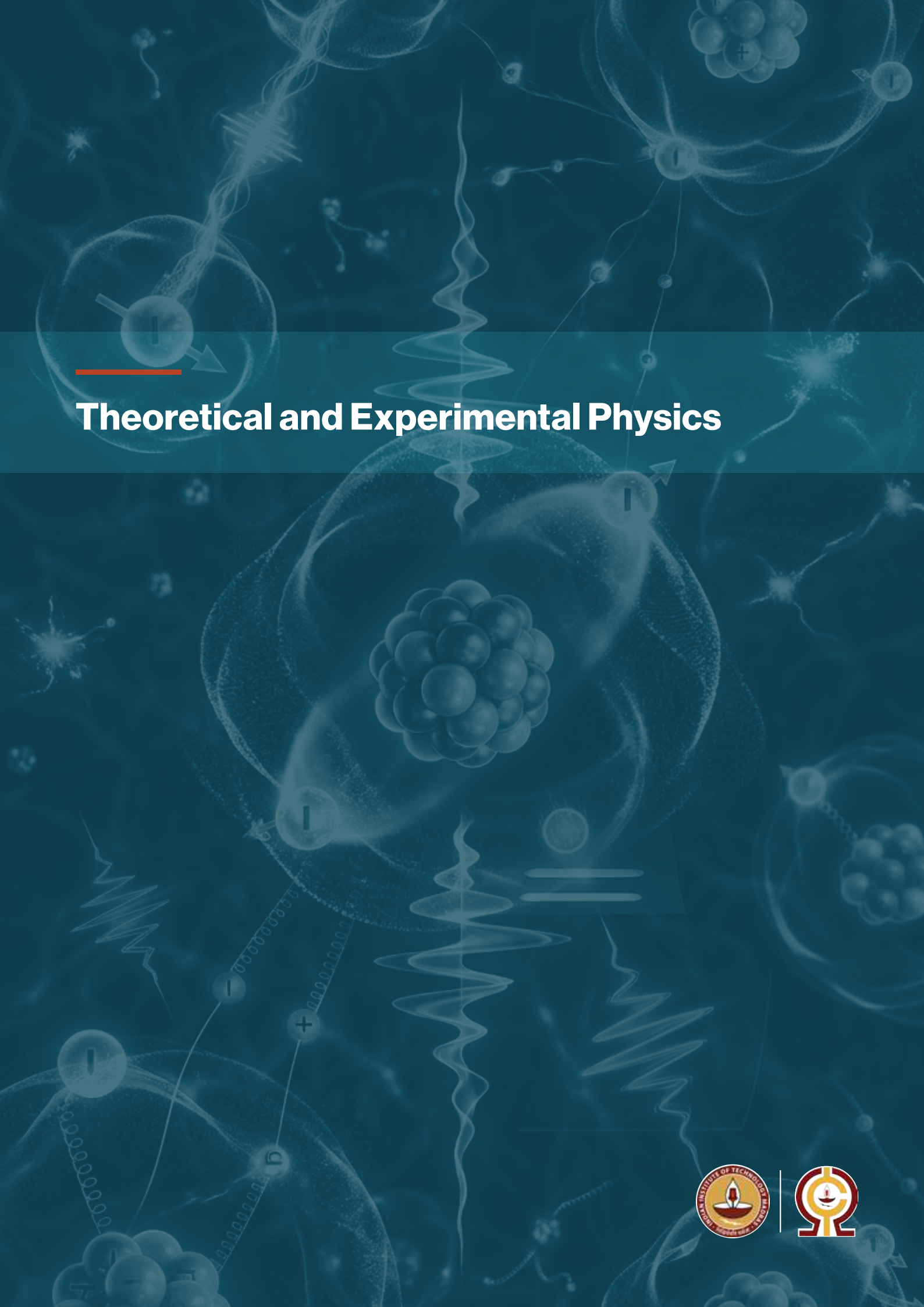
Indian and international refineries, power plants, and defence foundries integrate CNDE-derived sensors and machines into real-time monitoring of shells, tank barrels, and rocket motors during manufacture.

CNDE is composed of faculty from several departments at IITM including **Prabhu Rajagopal** and **Abhishek Saini** (Mechanical Engineering Department), **Manu Santhanam, Vivek Samu** and **Tarun Naskar** (Civil), **Balaji Srinivasan** (Electrical), **S. Ramaprabhu** and **C.V. Krisnamurthy** (Physics), and **Kavitha Arunachalam** (Engineering Design). CNDE also is supported by several industry advisors and a consortia (NCNDE) comprising of industrial partners.









Theoretical and Experimental Physics

The CMS Collaboration at CERN

From a bold vision in late 2013 to an enduring partnership that will extend well into the 2040s, **Prof. Prafulla Kumar Behera** has steered IIT Madras into the heart of particle physics research at CERN. His efforts have transformed a modest proposal into one of the institute's flagship international collaborations, elevating IIT Madras onto the global stage and offering generations of researchers unprecedented opportunities.

Planting the seed of collaboration

The journey began when Prof. Behera recognised that IIT Madras could make a meaningful contribution to the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider. With guidance from Professor R. Nagarajan, then Dean of International and Alumni Relations, and support from the Indian consortium at TIFR, Prof. Behera secured the first approvals required to join the collaboration. By early 2014, the CMS collaboration welcomed IIT Madras as a full member, marking the start of a new era in the institute's research portfolio.

Funding ambition and technical upgrades

Prof. Behera led the drafting of a detailed proposal to the Government of India, initially seeking a budget of ₹ 3 crores for work on the silicon tracker and high-granularity calorimeter upgrades. This proposal laid out IIT Madras's commitments: design work, component fabrication, and data analysis for the Phase-2 CMS upgrade. Approval came swiftly, and by 2022 the Ministry of Finance had sanctioned an additional ₹ 12 crores to support the extended detector enhancements, ensuring that CMS would maintain peak performance beyond its original 10-year run.

Building a thriving research ecosystem

Under Prof. Behera's mentorship, the Indian contingent within CMS has grown from 10 members to a vibrant cohort of over 40 scientists, 100 Ph.D. students, postdoctoral researchers, and engineers. Two faculty members and 12 IIT Madras doctoral candidates now conduct research on CERN's accelerator campus, collaborating alongside peers from Germany's KIT, US national laboratories, and other leading institutions. A detector module fabricated at IIT Madras's Physics Department holds pride of place within CMS, a testament to the institute's manufacturing precision.

Recognition and impact

IIT Madras's contributions have already borne fruit. One of Prof. Behera's doctoral students received the prestigious CMS award for outstanding analysis of Higgs boson decay channels. In a milestone moment, the Indian CMS team shared in the 2025 Breakthrough Prize in Fundamental Physics—a US$1 million award that the DAE and DST hailed as on par with the Nobel Prize. Directed back into fellowships and research grants, these funds are catalysing the next wave of scientific breakthroughs and strengthening IIT Madras's Ph.D. programmes.

Cementing global partnerships

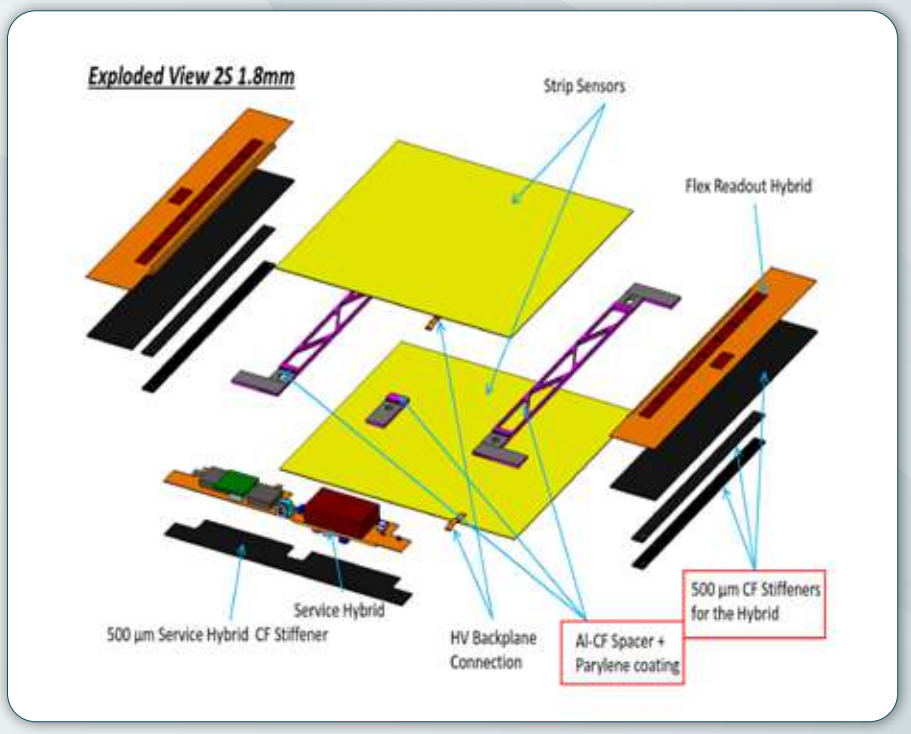
Beyond CMS, Professor Behera's success has spurred cross-disciplinary ventures. A direct memorandum of understanding with CERN has paved the way for computer science faculty members to initiate RISC-chip development projects, and the ICSR's strategic funding facilitated high-level visits by the Dean and Director of IIT Madras to CERN in late 2024. These missions have reaffirmed IIT Madras's status as a full member of CMS experimental collaboration. IIT Madras is one of only a handful of Indian institutes to hold that distinction.

A vision for the future

With a new consortium proposal of ₹ 190 crores under review and India's commitment as a CHF 10 million Associate Member of CERN, Prof. Behera's leadership is setting the stage for decades of discovery. Regular 6-monthly reviews and 5-year funding renewals will sustain CMS activity until 2040, offering IIT Madras students experiences on par with those at top global universities. IIT Madras remains at the frontier of humanity's quest to understand the universe.







Detecting Out-of-Plane Rotations at High Resolution in Optical Tweezers

Optical tweezers are scientific instruments that use a highly focused laser beam to hold and move microscopic and sub-microscopic objects, such as atoms, nanoparticles, droplets, cells, and even single molecules, in three dimensions. They mimic the action of mechanical tweezers by exerting piconewton-scale forces on the trapped objects. Optical tweezers have long been used to trap and manipulate microscopic particles to carry out studies of translational motion and in-plane rotations.

Prof. Basudev Roy has initiated a pioneering exploration of out-of-plane rotational dynamics. These involve motions perpendicular to the trapping plane. His purpose is to extend the capabilities of optical tweezers to detect these rotations with high temporal and orientational resolution. By doing so, he aims to probe the mechanical properties of biological systems at the nanoscale, including membranes, cytoplasm, and organelles. This work bridges fundamental physics and biophysics. It aims to offer new insights into how cells function and how diseases alter their mechanics.

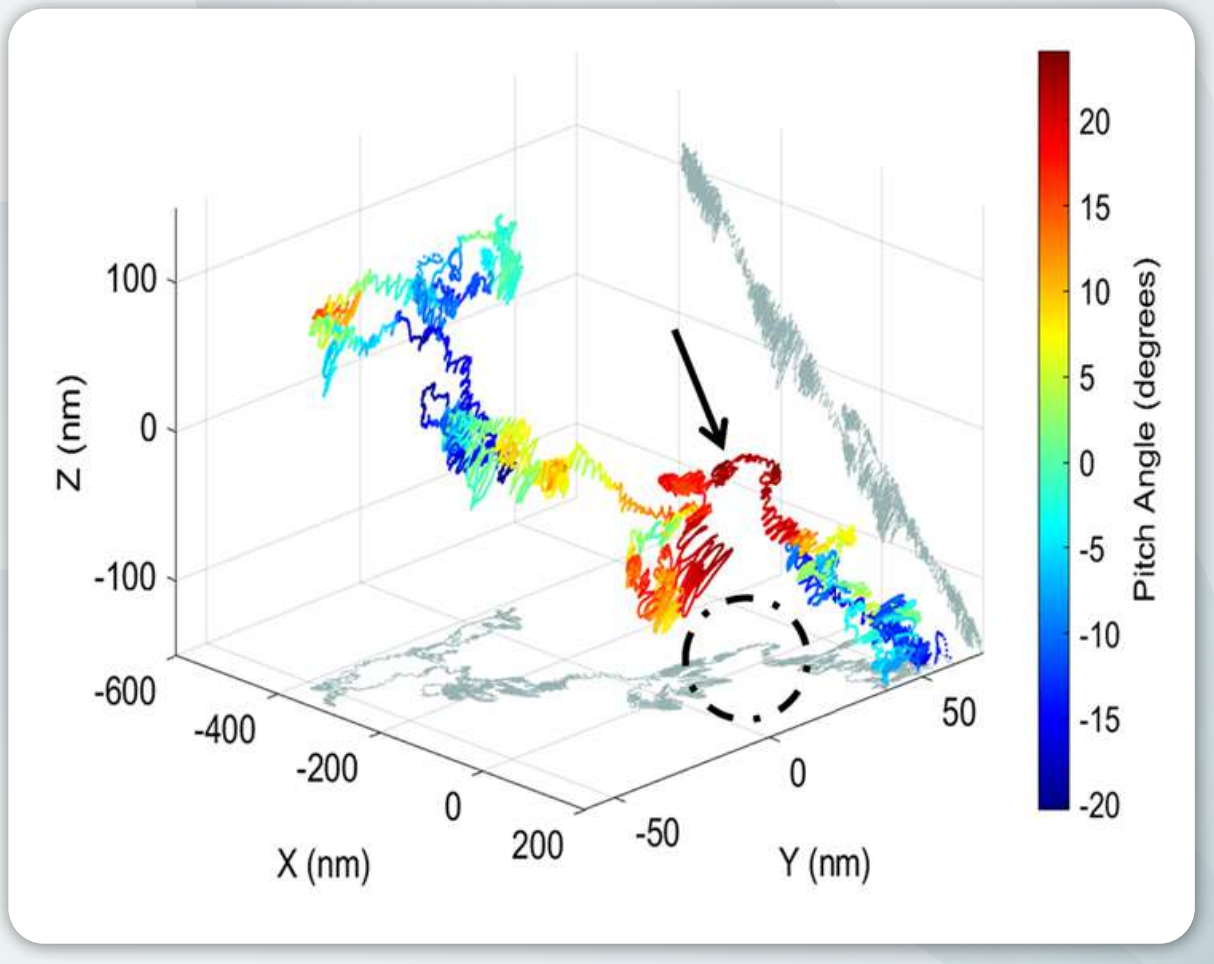
Prof. Roy's project is supported by the India Alliance Intermediate Fellowship. It is jointly funded by the Wellcome Trust (UK) and the Indian government's Department of Biotechnology. Prof. Roy has been able to establish advanced optical tweezers facilities at IIT Madras. Both commercially obtained equipment and facilities built in-house have been installed. Simulations and experimental studies have been carried out.

Prof. Roy's experiments involve trapping optically anisotropic particles, such as birefringent droplets in water, using polarised light. The electric field of the light aligns these particles, allowing precise measurement of their translational and rotational motion. The diffraction limit is bypassed through advanced photodetection. Thus Prof. Roy's team can detect subtle out-of-plane rotations at high resolution. These measurements reveal critical properties of cell membranes. These properties include bending rigidity, membrane tension, and cytoplasmic viscosity.

Around 20 research papers have resulted from the work. Submissions are being made to high - impact journals.

The research has studied vibrations of particles on membranes, providing quantitative data on mechanical forces within cells. Translational and rotational dynamics have been measured for different particle geometries; round objects remain a challenge for future exploration. Applications extend to studying protein transport within cells and understanding how mechanical changes contribute to diseases such as Parkinson's disease, Alzheimer's disease, and hypertension. For example, altered rigidity in endothelial cells lining blood vessels can be detected. This offers clues to how hypertension develops and how drugs might alleviate it.

By expanding the scope of optical tweezers, Prof. Roy's work opens new avenues for studying cellular mechanics. The insights obtained into disease mechanisms enable early diagnosis and support drug discovery. The project contributes to the understanding of neurodegenerative diseases and vascular conditions. Prof. Roy's research into optical tweezers offers both fundamental knowledge and potential applications in healthcare.



Superfluidity in Neutron Stars

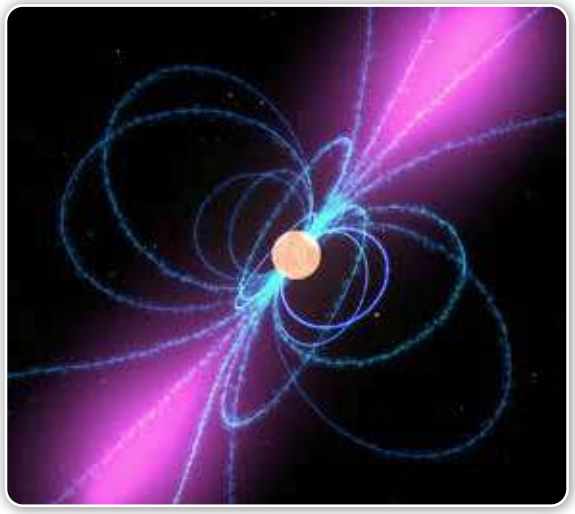
Neutron stars, which are born at the end of a core collapse supernova, are fascinating objects. Most of them are highly magnetised and are born rotating, with their axis of rotation tilted with respect to the magnetic axis. They are observed by the emitted electromagnetic radiation from the magnetic poles, which reaches us in pulses, and hence these stars are also dubbed pulsars.

The typical masses range from 1.3–2 solar masses, with densities of the order 1011 to 1014 g/cm3. While the star matter is held together by gravity, its detailed structure is determined by the strong force, which is short-ranged. The star therefore has terrestrial nuclei in the outer layers, which become subsequently neutron-rich radially inwards, until the neutrons can no longer be bound, thereby resulting in a lattice of quasi-nuclei interspersed with a sea of neutrons that forms an ultracold gas. This gas which exists in the inner layers of the crust is supposed to be a superfluid, as evidenced by the occurrence of pulsar glitches, which are sudden small increases in the star's rotational frequency. Furthermore, a superfluid neutron gas is needed to explain the observed thermal evolution of middle-aged stars. Although the idea of a superfluid neutron gas was postulated in the early 1960s, a consistent microscopic description of this phase has been elusive, partly due to the complicated interaction between neutrons as well as due to the extreme sensitivity of the pairing gap, which is the central quantity of interest to the many-body approximations made.

The project, "Pairing in Neutron Star Matter with Renormalization-Group Based Low-Momentum Interactions", funded by IFCPAR/CEFIPRA, was an Indo-French project that was executed by **Dr. Sunethra Ramanan,** IIT Madras, India and Dr. Michael Urban, IJC Lab, Universite Paris-Saclay, Orsay, France. The goal of this project was to obtain a consistent description of the superfluid phase using the state-of-the-art renormalisation-group (RG) based effective interactions. The RG-based approach to effective interactions has allowed the advancement of ab initio nuclear structure calculations for over two decades. Together with Mr. Viswanathan Palanippan, the calculation of the equation of state of the ultracold gas of neutron gas was carried out within the framework of Bogoliubov many-body perturbation theory (BMBPT). The formalism was tested on a system of ultracold atomic gas of fermions [1]. This work uses a perturbative approach made possible by the state-of-the-art effective interactions between neutrons which circumvents the numerically expensive resummations that are carried out traditionally.

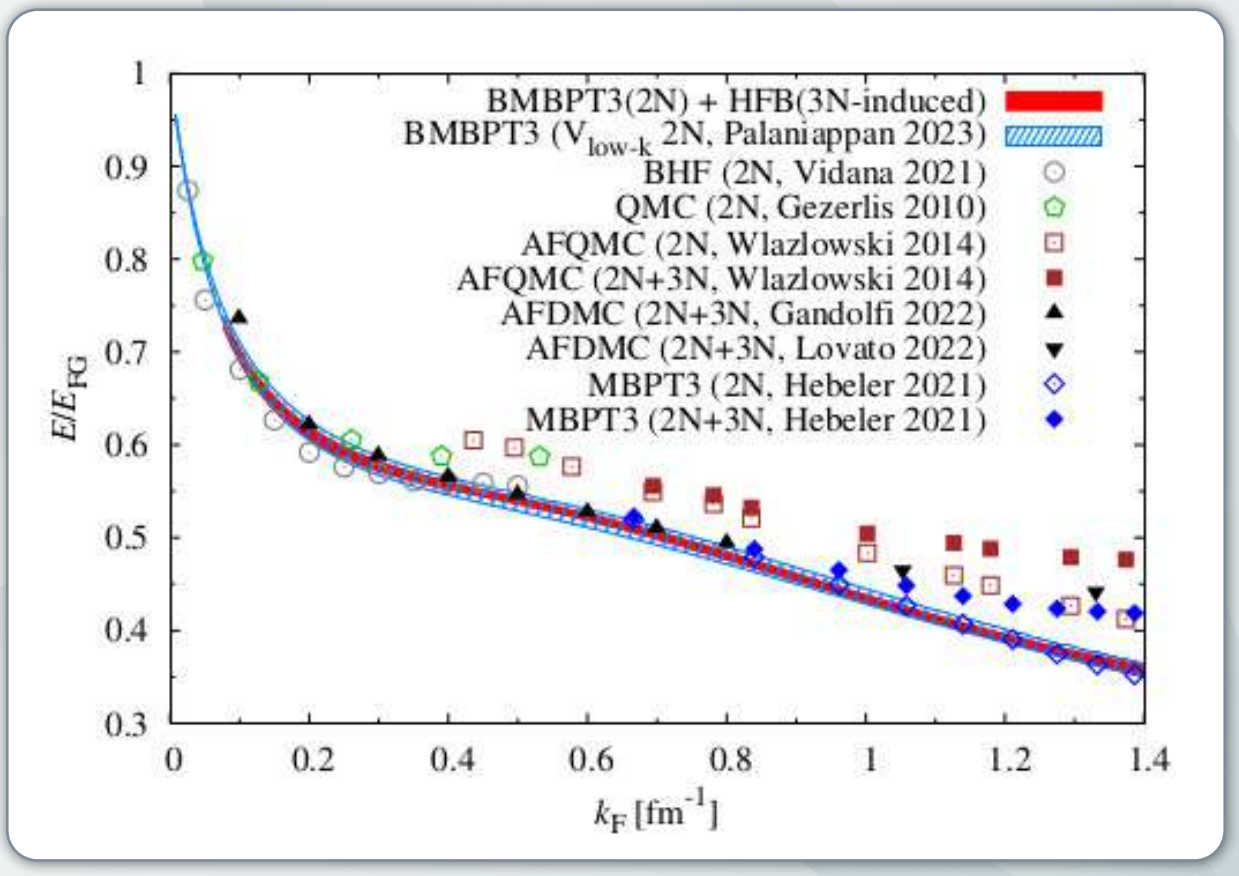
The main result of the work, highlighted in the accompanying plot by the shaded blue (2023) [2] and the improved red (2025) [2] curves, is in agreement with time-honored ab initio approaches such as Quantum Monte Carlo. The shaded region (in blue and red) gives the extent of theoretical uncertainties. Both the results were published in Physical Review C, with the 2023 paper [2] being highlighted as

'Editor's suggestions'. This work is part of a bigger initiative of obtaining a consistent description of low-density matter as present in stars, which is one of the research directions of the group of Dr. Sunethra Ramanan.



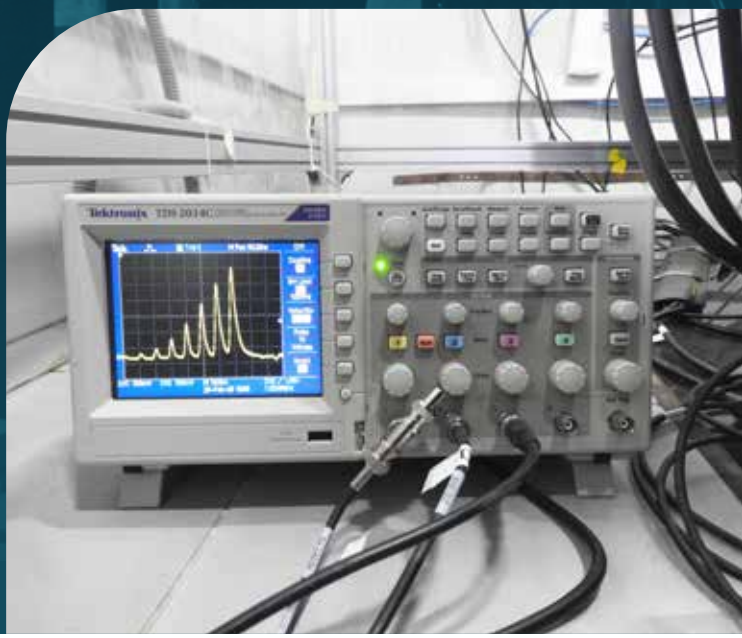
References

1. S. Ramanan and M. Urban, Phys. Rev. C 98, 024314 (2018).
2. V. Palaniappan, S. Ramanan and M. Urban, Phys. Rev. C 107, 025804 (2023).
3. V. Palaniappan, S. Ramanan and M. Urban, Phys. Rev. C 111, 035803 (2025).



Projects of Prof. Sivarama Krishnan

The research initiatives led by **Prof. Sivarama Krishnan** in the Department of Physics at IIT Madras revolve around the fundamental and applied study of light–matter interactions. These projects originate from both a deep scientific curiosity about how photons interact with matter at the atomic scale and a pressing national need to advance technologies in medicine, semiconductor manufacturing, and quantum science. They reflect a balance between individual research pursuits and contributions to India's broader scientific and technological landscape.



At their core, the projects seek to understand physical processes at the atomic and sub-atomic levels, linking the structure of materials with their optical properties. This line of inquiry is motivated by the recognition that X-rays and optical radiation play crucial roles in diverse fields. Hard X-rays are indispensable in medical diagnostics and therapy, while soft X-rays are central to semiconductor fabrication. Lasers, meanwhile, are increasingly used to modify surface properties of materials, enabling tailored functionalities in optics, electronics, and nanotechnology. The origin of this work lies in the need to develop indigenous expertise in these areas, ensuring that India remains competitive in high-technology domains such as chip-making, nanodevice inspection, and radiotherapy.

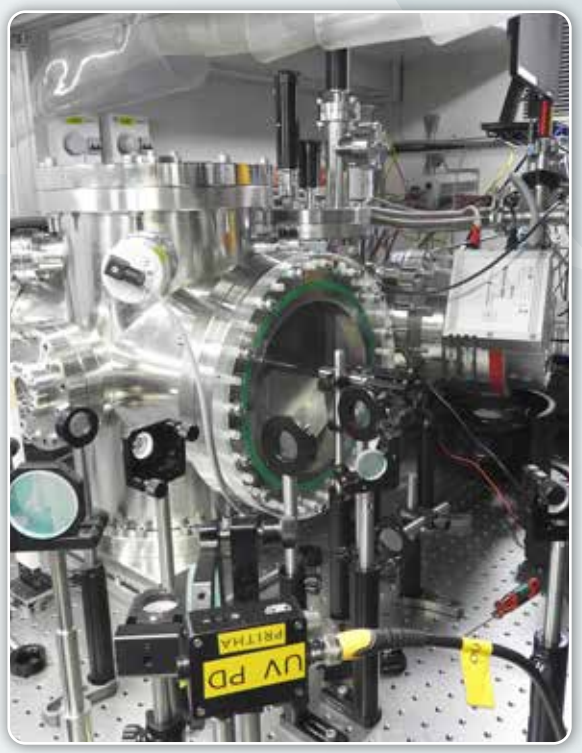
Prof. Krishnan's research spans several interconnected themes. One major strand investigates how X-rays, both hard and soft, interact with materials at the nano and sub-nano scales. This includes studying radiation damage, secondary processes triggered by high-energy photons, and their controlled application in radiotherapy, in which living systems are deliberately exposed to radiation for therapeutic benefit. Another strand focuses on semiconductor and chip fabrication, in which soft X-rays are harnessed for patterning and inspecting nanometre-sized devices. This work contributes to metrology and measurement techniques that are essential for modern electronics. Alongside these efforts, Prof. Sivarama Krishnan has explored the use of lasers to alter surface properties of materials, opening pathways to new applications in optics and nanotechnology. His interest in quantum and ultrafast processes led to the establishment of the Ultrafast Interactions Laboratory at IIT Madras, a facility designed to probe femtosecond-scale dynamics and quantum phenomena. This laboratory provides a platform for studying ultrafast light–matter interactions and supports the development of novel quantum technologies.

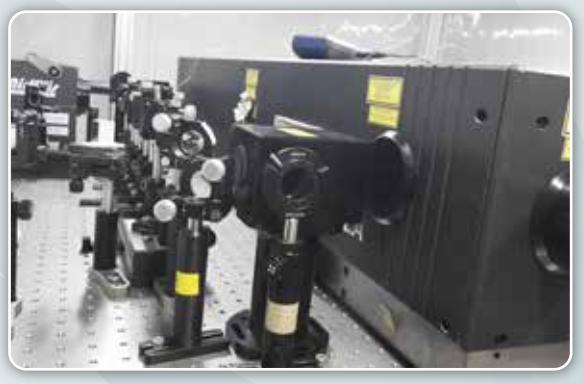
Funding for these projects comes through a combination of individual research grants and national programmes. Given their strategic importance, especially in semiconductor technology and medical applications, the work aligns closely with India's science-and-technology priorities. Support from government agencies such as the Department of Science and Technology and the Department of Atomic Energy, along with collaborative industry partnerships, ensures sustained backing for both fundamental research and translational applications.

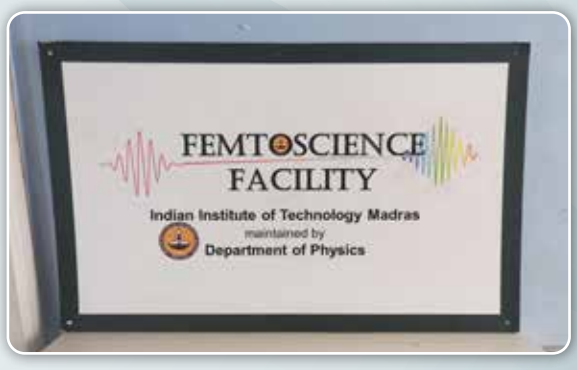
The impact of Prof. Krishnan's projects is multifaceted. Scientifically, they deepen our understanding of light–matter interactions at atomic scales, contributing to global knowledge in physics and materials science. Technologically, they enable advances in chip-making, nanodevice inspection, and radiotherapy, directly supporting critical industries and enhancing India's self-reliance in high-technology sectors. Nationally, the projects address strategic needs in healthcare and electronics, reinforcing India's capacity to innovate in areas vital for economic and social development. Educationally, the Ultrafast Interactions Lab provides cutting-edge training for students and researchers, nurturing the next generation of physicists and engineers.









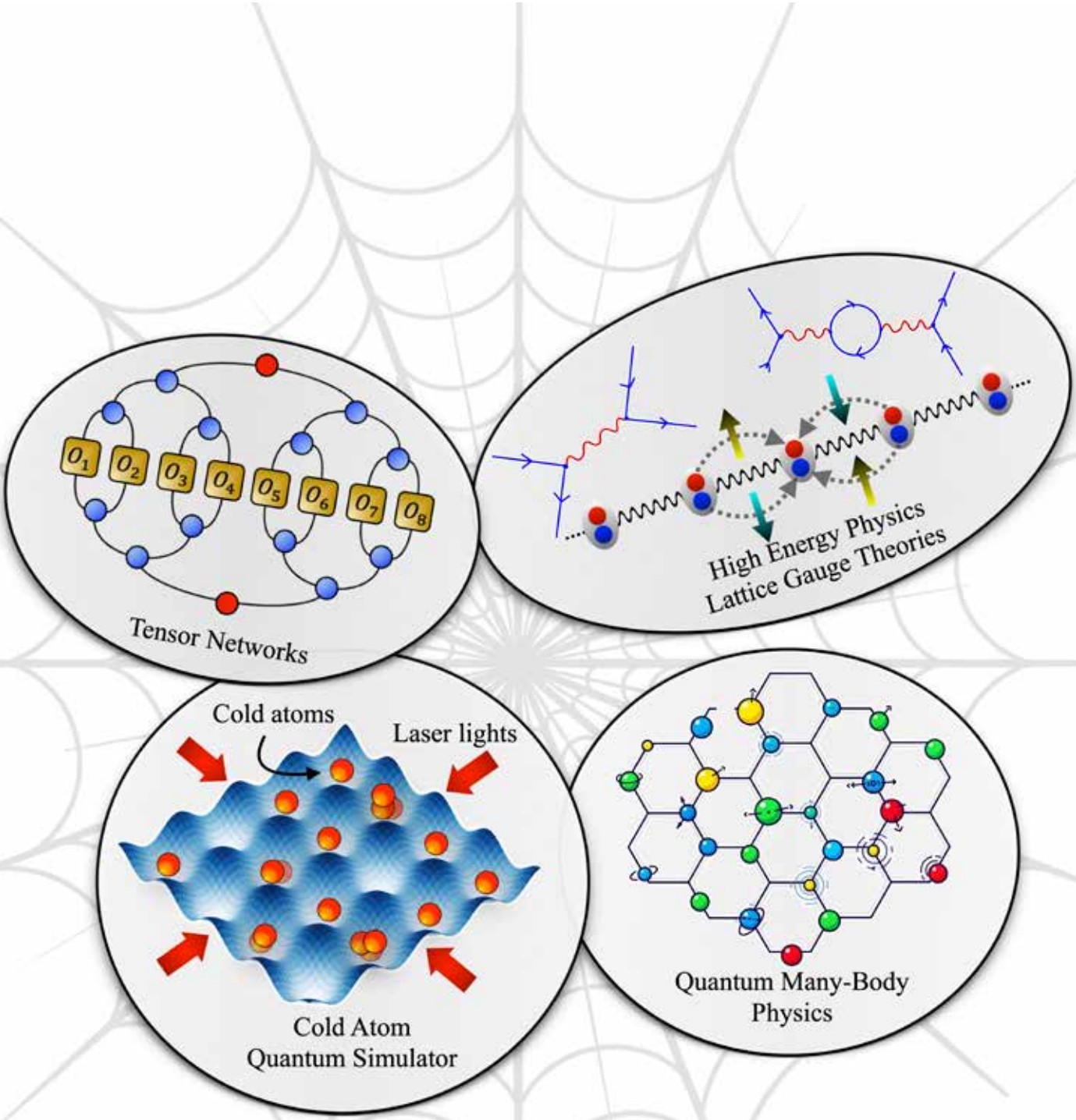


Quantum Research

One of the deepest mysteries in modern science is how the laws of quantum mechanics at the microscopic level give rise to the complexity that we observe in the world around us. This is the essence of quantum many-body physics: how do countless quantum particles, each following strange and unintuitive rules, come together to produce the rich collective behaviour of matter? From superconductors and magnetic materials to the interiors of neutron stars, these systems often show that more is not just more, but different (see "More Is Different" by Philip W. Anderson, https://www.science.org/doi/10.1126/science.177.4047.393). **Prof. Titas Chanda's** research is driven by the goal of understanding such emergent phenomena, where the whole behaves in ways that cannot be predicted simply by looking at the parts. These are not just academic puzzles, they are central to emerging technologies such as quantum computing, advanced material design, and even our understanding of nature itself. But unlike classical systems, the complexity of which grows steadily with size, quantum systems become overwhelmingly complex very quickly. Even a small number of interacting quantum particles can lead to situations too complicated for any classical computer to fully track. This makes exploring and predicting the behaviour of a quantum many-body system an enormous challenge.

One promising way forward is to build artificial quantum systems that can mimic others, allowing us to study their behaviour in a clean and controlled setting. This idea, first proposed by Richard Feynman back in 1982, has come to life in the form of quantum simulators, particularly those built from ultracold atoms, cooled to just billionths of a degree above absolute zero. Using finely tuned laser fields, these atoms can be arranged in optical lattices that replicate the structure of real materials, giving us a unique window into quantum many-body physics. Prof. Titas Chanda's theoretical work plays a key role in understanding and predicting what these synthetic systems can reveal. To carry out such investigations efficiently, he develops and uses tensor network methods—a class of computational tools that simulate quantum systems by exploiting patterns in their internal structure. These methods allow us to explore complex regimes that would otherwise remain out of reach with conventional procedures.

What excites Prof. Chanda most is that these tools, originally developed to understand quantum materials, are now beginning to shed light on some of the deepest questions in particle physics—the science of nature's most fundamental building blocks. His current project, supported by the Anusandhan National Research Foundation (ANRF) under the Prime Minister's Early Career Research Grant (PMECRG), explores how tensor networks and quantum simulators can be used to investigate interactions between elementary particles and fundamental forces in entirely new ways. Traditional methods often fail when quantum fields interact strongly or evolve in real time—precisely the situations where these new tools of quantum technologies excel. By bridging quantum many-body physics with high-energy theory, Prof. Chanda's research focuses on simplified models of particle physics to explore phenomena such as quark confinement, the formation of exotic bound states, and particle collisions. These systems of particle physics, once thought to be accessible only through massive particle accelerators or abstract theories, are now within reach of these new approaches. His project aims to explore them through detailed theoretical simulations using tensor networks and by proposing experimental setups where their behaviour could be recreated, visualised, and possibly even tested in tabletop quantum systems. It is a step toward making the invisible rules of the universe just a bit more tangible.


O_1 O_2 O_3 O_4 O_5 O_6 O_7 O_8
Tensor Networks
High Energy Physics
Lattice Gauge Theories
Cold atoms
Laser lights
Cold Atom
Quantum Simulator
Quantum Many-Body
Physics

Further Information

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