विज्ञान एवं प्रौद्योगिकी विभाग
DEPARTMENT OF
SCIENCE & TECHNOLOGY

सत्यमेव जयते

National Quantum Mission

October 2025 I Vol. 01

DREAM 2047

National Quantum Mission (NQM)

R & D Momentum

NQM is explicitly designed to **"seed, nurture and scale"** scientific and industrial R&D, connecting academia, government and industry

Towards Self-Reliance

The mission aims to cut India's dependency on imported quantum-grade hardware, and foster domestic design, fabrication, and integration capabilities

Startups

Pushing the frontiers of quantum technology through innovation

Quantum Computing ■ Quantum Materials & Devices ■ Quantum Communication ■ Quantum Sensing & Metrology

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Editorial Introduction

THE REIMAGINED *DREAM 2047*

When **Dream 2047**, a popular science magazine, was first launched in 1998, its very name was a vision in itself. The year 2047 marked not just a distant date, it symbolized the centenary of India's independence and the aspiration for a self-reliant, innovative, and globally leading nation in science and technology.

Over the past decades, **Dream 2047** carved a unique space as a popular science magazine and earned wide acclaim for bringing science closer to people-making complex scientific ideas accessible, spotlighting scientific developments, and celebrating the achievements of Indian scientists and research. It inspired young minds, informed the public, and connected the world of science with societal progress.

Now, as India advances through a transformative era shaped by rapid developments in science, technology, and innovation, **Dream 2047** returns in a vibrant digital format-more dynamic, engaging, and aligned with the evolving needs of the knowledge society. This reimagined edition builds on the magazine's founding mission, while embracing the new realities of digital communication and the expanding scope of Indian science.

This first issue of the digital edition of **Dream 2047** marks the beginning of a new chapter-one that will explore fresh dimensions of science, technology, and innovation (STI) in India. Each edition will highlight new developments, emerging challenges, and key milestones shaping the country's scientific and innovation ecosystem.

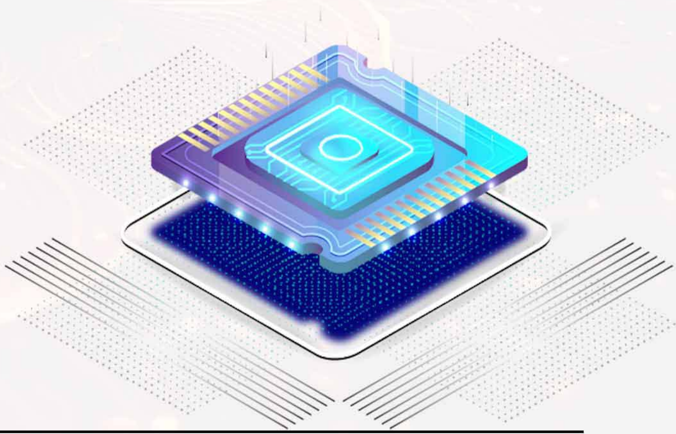
In this inaugural issue, we spotlight the National Quantum Mission (NQM), a landmark initiative in India's strategic push into frontier technologies. With transformative potential in computing, communication, and security, quantum technologies represent a critical domain of global competition and national importance. We chose to focus on NQM as it reflects India's aspiration to lead in next-generation technologies and reinforces the spirit of self-reliance, innovation, and scientific excellence that Dream 2047 embodies.

More than just a science magazine, **Dream 2047** is envisioned as a chronicle of transformation-a reflection of how scientific advancement is driving inclusive, sustainable progress across the country. It will continue to serve as a bridge between the scientific community and the public, enabling informed conversations and fostering greater public engagement with science.

As we turn the page to this new chapter, we welcome our readers-students, educators, researchers, innovators, and curious minds to be part of the journey. Share your thoughts, contribute your ideas, and help shape a publication that evolves with the spirit of the nation's scientific aspirations.

Dr Kinkini Dasgupta Misra
Editor

This Deepavali, let quantum leaps in science light the path to our technological future. From photons to qubits, may knowledge illuminate like never before...



FROM THE DESK OF
EDITOR-IN-CHIEF

A. Dhanalakashmi
Joint Secretory
Department of Science and Technology

It is with great pleasure and renewed purpose that we present the revived edition of **Dream 2047**, the popular science magazine of the Department of Science and Technology (DST), now in a dynamic electronic format.

As science and technology continue to reshape how we live, work, and interact with the world, the importance of effective science communication has never been greater. This digital platform aims to make cutting-edge ideas, transformative innovations, and scientific insights accessible and engaging for all citizens.

Since its inception, **Dream 2047** has represented a forward-looking vision—symbolising India's aspiration to become a self-reliant, scientifically empowered, and globally leading nation. As we move with determination towards Viksit Bharat @2047, the magazine's mission aligns more closely than ever with national priorities, serving as both a reflection of progress and a guide to the future.

The **Dream 2047** will serve as a window into India's vibrant and rapidly evolving Science, Technology, and Innovation (STI) landscape. It will spotlight developments across a wide range of disciplines, while also capturing the journeys of the people, institutions, and ideas that are shaping the frontiers of Indian science.

The magazine will offer a panoramic view of India's science and technology landscape against the backdrop of global developments. Readers can expect thought-provoking essays, engaging explainers on emerging areas, conversations with leading scientists and innovators, and evidence-based features that separate real progress from more promise. A special focus will remain on the initiatives of the Department of Science and Technology- its programmes, missions, partnerships, and milestones, keeping readers connected with the Nation's priorities and opportunities in emerging S&T.

Together, let us strengthen the foundation of a developed India by 2047—rooted in knowledge, driven by innovation, and guided by the spirit of inquiry.

Every great journey begins with a **DREAM**

Dr Anita Gupta
Head, Climate Energy and Sustainable Technology **(CEST)**
Department of Science & Technology

For India, that dream is to become a Viksit Bharat—a developed, confident, and self-reliant nation that uplifts every citizen and stands tall among the world's leading economies. At the heart of this journey lies the transformative power of science, technology, and innovation—forces shaping the nation's progress and redefining its global identity.

Dream 2047, the new magazine of the Department of Science and Technology (DST), celebrates this spirit of discovery and innovation. It tells the stories of young researchers breaking barriers, grassroots innovators turning ideas into impact, and entrepreneurs daring to imagine the impossible. Together, they include the creativity, curiosity, and courage that fuel India's scientific renaissance.

India's research and innovation story is deeply rooted in its people—the students in small-town laboratories dreaming big, the engineers developing local solutions with global relevance, and the scientists who look beyond horizons. Their collective pursuit of excellence reflects the essence of Atmanirbhar Bharat—self-reliance built on indigenous research and innovation.

Across sectors, science and technology are transforming how India works, lives, and sustains itself. From clean energy and sustainable mobility to digital governance and healthcare, Indian innovators are addressing challenges with global impact. New national missions such as the India AI Mission, Semiconductor Mission, National Quantum Mission, National Supercomputing Mission, NM-ICPS, MAHA EV Mission, and the Geospatial Mission are charting India's leadership in frontier technologies. Together, they aim to strengthen digital infrastructure, promote innovation-led growth, and position India as a key player in emerging global technology ecosystems.

From green hydrogen to advanced biofuels, from smart grids to next-generation materials for clean energy storage and conversion, innovation is steering India's transition toward a low-carbon, resilient economy. India's pledge to achieve net-zero emissions by 2070 is not merely an environmental goal—it represents a technological and economic revolution that will redefine industries and create new opportunities for startups, researchers, and entrepreneurs. The integration of Artificial intelligence, the Internet of Things, and Geospatial technologies is enhancing efficiency, strengthening climate forecasting, and building resilience against future challenges.

The upcoming **Emerging Science, Technology and Innovation Conclave (ESTIC 2025)**, scheduled for next month, reflects this vision. Conceived as a whole-of-government approach, ESTIC 2025 will bring together ministries, research institutions, industry, and startups on one platform to align efforts and amplify impact. It will serve as a launchpad for the next generation of researchers and innovators driving India's march toward Viksit Bharat 2047. The event also signals a shift in India's innovation ecosystem—from isolated projects to integrated missions, from incremental progress to transformative breakthroughs.

As India enters a decisive decade on its path to 2047, the convergence of innovation, sustainability, and inclusivity will shape its destiny. Scientists and engineers are working on solutions that not only advance technology but also ensure that India's development remains equitable and environmentally responsible. As we look ahead, let us continue to dream and envision a rising , resurgent and powerful India that leads with science, grows with technology, and shines with innovation.

Dream 2047 is more than a magazine—it is a movement of ideas, a reflection of the nation's pulse, and a reminder that innovation begins with imagination. It connects past visionaries with future pioneers, capturing India's confidence in exploring new frontiers—whether in deep tech, green energy, digital transformation, or human development. By communicating science in an engaging, accessible way, **Dream 2047** will inspire curiosity, foster scientific appreciation, and bridge the gap between policy and people.

Reviving Dream 2047:
Reclaiming India's Popular Science Voice

Dr Rashmi Sharma
Head NCSTC & SHRI Division
Department of Science & Technology

Dream 2047, a bilingual monthly magazine was a bold experiment in 1998 when most popular science magazines catered stakeholders in English or Hindi. This inclusive magazine reflected the linguistic diversity of India and anticipated today's discourse on the importance of multilingual science communication to bring science closer to people.

The magazine reached to schools, colleges, libraries, and science enthusiasts across the country with its stimulating content, explanatory articles, and reflective pieces. The rich and exhaustive resource of the magazine served as a skylight into contemporary science for students in smaller towns and ready classroom material for teachers. For aspiring writers, it was a platform to publish their first pieces. Above all, **Dream 2047** was an idea that science belongs to everyone, not just to laboratories and elite institutions.

India is currently undergoing a dynamic transformation in science, technology and innovation field. Emerging domains and a vibrant STI ecosystem is positioning the country as a global leader in frontier areas. The grassroots innovations and community-driven solutions in the country remind us that science is not only about frontiers of knowledge, but it also has everyday relevance. The roadmap of India to become a developed nation by 2047 revolves primarily around science and technology. Chandrayaan-3 and Gaganyaan, National Missions on Artificial Intelligence, Quantum, Supercomputing, Interdisciplinary Cyber Physical Systems, Green Hydrogen, Geospatial and many more such initiatives by the Government of India need to percolate down to the society.

A revitalized Dream 2047 can narrate this journey effectively with reliable source of information thus involving citizen to be part of this development story and scientific vision of "**Viksit Bharat@2047**." Revival and rejuvenation of Dream 2047 is therefore essential and timely, as the demand for clear, credible, and engaging science communication has become even more critical for trust building among people of the country. The opportunity is therefore immense to reimagine, reorient and restructure and build a more poweful tool of communication that not only informs but also invites dialogue through essays, interviews, features, and even personal reflections. By showcasing both the triumphs and challenges of science, it can nurture a culture of inquisitiveness and critical thinking.

The revival of **Dream 2047** builds on National Council of Science, Technology Communication's enduring commitment to making science accessible, and inspiring curiosity among all as enshrined in the Article 51A of the Constitution of India. It affirms that science is not an isolated pursuit, but a shared journey requiring the participation of scientists as well as common man. In an age of misinformation, having a reliable, thoughtful, and inspiring voice is indispensable. As we look ahead, **Dream 2047** must continue to be ambitious in scope yet accessible. It should capture the pulse of research while also reflecting the human stories behind it. It should give space to pioneering missions while also amplifying community-led solutions. Above all, it should continue to remind us that science is not only about equations, experiments, or innovations, but also about values- curiosity, honesty, humility, and service to humanity.

Marking this new beginning, the revived **Dream 2047** promises of once again becoming a platform where ideas take root, where dialogue flourishes, and where the aspirations of a developed India by 2047 are expressed through science. For students, teachers, researchers, policymakers, and citizens, it can be a guide, a companion, and a source of inspiration. For each of us, it can be a reminder that the dream of 2047 is not only about the destination, but also about the journey we take together.

Dr V. K. Saraswat
Padma Bhushan
Member, NITI Aayog
Former Director General, DRDO

Strategic Vision for Quantum Mission

In an exclusive exchange with Dream 2047, Dr V. K. Saraswat, Member of NITI Aayog and a key visionary behind India's National Quantum Mission, shares his insights on the strategic foundations of the country's quantum roadmap. He outlines the policy priorities, the drive for technological self-reliance, and the pivotal role of industry in shaping a robust quantum ecosystem. His perspective highlights India's ambitions to emerge as a global leader in the quantum revolution.

What is the strategic significance of the National Quantum Mission in the context of India's broader science and technology goals?

I view the National Quantum Mission (NQM) not as an isolated technology programme but as a strategic fulcrum that converts India's long-term science and technology ambitions into operational capability, resilient infrastructure, and sustained economic advantage. The mission, approved by the Union Cabinet in 2023 with an outlay of ₹6,003.65 crore, provides a clear fiscal and temporal envelope that allows us to plan multi-year platform builds, national testbeds, and human-capital pipelines.

Crucially, the NQM is explicitly designed to "seed, nurture and scale" scientific and industrial R&D across the full quantum stack – computing, communication, sensing and materials, so that India moves from being predominantly a consumer of specialised components and software to becoming a designer, integrator and exporter of quantum systems; that objective shapes our investments, hub selection and public-private engagement strategies. To achieve this transition, a hub-and-network architecture has been adopted: four thematic hubs and a constellation of technical groups are being established to concentrate expertise, provide shared cryogenic and nanofabrication facilities, and operate open testbeds that startups andindustry can use to de-risk product development and accelerate TRL transitions.

From a capability perspective, the mission has concrete deliverables – inter-city quantum key distribution (QKD) over long distances, satellite-enabled quantum links, multi-node quantum networks and development pathways for quantum processors and sensors, which anchor the programme in measurable outcomes; these deliverables map directly onto national priorities such as secure communications for critical infrastructure, quantum-assisted sensing for navigation and defence, and quantum-accelerated discovery in materials and chemistry. Finally, and perhaps most importantly for India's broader S&T goals, the NQM is meant to be catalytic: it strengthens supply chains (cryogenics, photonics, detectors, control electronics), creates credible long-term demand that will stimulate manufacture and standards adoption, builds an expanded talent pipeline, and provides a governance template for mission-mode science.

How do you see the NQM aligning with initiatives such as "Atmanirbhar Bharat" and "Digital India"?

The NQM aligns very organically with both Atmanirbhar Bharat and Digital India by advancing sovereign technological capacity while securing and strengthening our digital infrastructure. From the perspective of Atmanirbhar Bharat, NQM is designed to reduce India's reliance on imported quantum-grade hardware, such as cryogenic systems, detectors, lasers, and control electronics by enabling domestic capabilities in design, fabrication, and integration capabilities. We are ensuring that indigenous technology platforms are developed within India and made accessible to our startups and industry partners. This approach mirrors the larger Atmanirbhar Bharat philoophy – to of cultivatinge homegrown innovation, nurturinge local supply chains, and developing export-worthy products that contribute both to India's self-reliance and to its competitiveness in global technology markets.

The NQM fits together seamlessly with Digital India. Our digital public infrastructure today supports the backbone of India's governance, financial inclusion, healthcare delivery, and citizen services. Through the deployment of quantum communication networks, the NQM will introduce quantum-safe communication protocols into India's digital infrastructure, future-proofing it against emerging threats. This means that flagship platforms like Aadhaar, UPI, DigiLocker, and the broader array of Digital India services will transition into the post-quantum era with enhanced security guarantees.

You have often highlighted the need for developing indigenous quantum systems. What are the key areas where India must urgently reduce import dependency?

When we speak of indigenous quantum systems, it is about ensuring that India has sovereign ability to design, build, and scale technologies that will underpin both national security and economic competitiveness in the decades ahead. Today, there are several critical segments of the quantum technology stack where our dependency on imports remains high, and these are precisely the areas where the NQM is directing both resources and policy attention.

One such area is specialised hardware and cooling systems. Most quantum computers require extremely low temperatures, close to absolute zero, to operate. The advanced refrigeration units and associated hardware that make this possible are almost entirely imported today. If India can master these systems domestically, it will unlock the ability to build and expand our own quantum computers at scale

One such area is specialised hardware and cooling systems. Most quantum computers require extremely low temperatures, close to absolute zero, to operate. The advanced refrigeration units and associated hardware that make this possible are almost entirely imported today. If India can master these systems domestically, it will unlock the ability to build and expand our own quantum computers at scale.

Another important area is quantum communication devices. At present, we procure many of these from abroad, which not only adds cost but also creates strategic vulnerabilities. Developing these devices indigenously will be essential for deploying secure comunication links across the country.

> "We must also strengthen our capabilities in control systems and software, which are the brains behind quantum processors and communication setups. If we want to build 50-100 qubit systems or quantum-secure networks, we cannot afford to rely solely on imported control electronics or foreign toolchains.

And finally, the materials ecosystem from supercoducting films to specialised photonic chips is still at a nascent stage in India. Investing in domestic fabrication and advanced materials will ensure we have the foundation to innovate, rather than just assemble systems designed elsewhere.

India cannot be self-reliant in quantum without mastering the critical building blocks at home. The NQM is structured precisely to address these gaps.

What policy instruments or incentives can help Indian startups and industry build homegrown quantum technologies?

For Indian startups and industry to play a central role in building quantum technologies, we must recognise that quantum is not like conventional software, where innovation can be scaled with relatively low upfront costs. This field demands specialised equipment, long development cycles, and deep collaboration between science and industry. That is why policy instruments and incentives must be carefully crafted to lower risk, encourage investment, and provide assured pathways to market.

The first instrument is public procurement and assured demand. If government agencies, whether in defence, telecom, or finance, signal clear demand for quantum-secure communication systems, Quantum Random Number Generators (QRNG), or prototype processors, startups will have the confidence to invest. Long-term purchase agreements or pilot deployments funded by the NQM can provide this anchor demand and ensure that promising technologies move beyond the laboratory.

Second, we need shared infrastructure and testbeds. No single startup can afford dilution refrigerators, advanced photonics labs, or nanofabrication facilities on its own. By creating open-access national facilities under the

Mission, we de-risk the capital burden and allow startups to experiment and innovate without prohibitive costs.

Third, financial incentives and funding mechanisms are crucial. This includes matching grants for R&D, concessional credit lines for capital-intensive equipment, and tax incentives for firms investing in deep-tech. Linking the Mission with the Anusandhan National Research Foundation (ANRF) will also allow for to crowd-in of private capital and philanthropic funding alongside government resources, creating a much larger pool of support for quantum startups.

Fourth, we must think about standards and certification. Having a clear Indian reference standard for devices like QKD systems or QRNG will give domestic products credibility, both in international markets. Once standards are in place, Indian startups can integrate their products into telecom or IT networks with assurance, accelerating adoption.

Finally, regulatory flexibility will play an enabling role. For example, providing sandboxes that allow startups to test quantum-secure communication systems on telecom fibre networks or through satellite links under simplified approval processes will speed up innovation while keeping safety and security intact.

With these instruments in place, we can transform India's natural scientific strengths into globally competitive quantum enterprises that are homegrown and Atmanirbhar.

How can Indian industry become a meaningful partner in both technology development and fund sharing under the NQM?

For this, the industry has to move beyond the view that quantum is only a research plan for scientists and academics. Industry has to see itself as both a co-developer of technology and a co-investor in its growth. This begins with creating a clear articulation of use-cases that matter to different sectors. When industry sees tangible applications that connect directly to their business priorities, their willingness to invest in joint development automatically increases.

On the technology development side, the industry can bring complementary strengths that research institutions alone cannot provide. Large firms can scale prototypes into deployable systems, integrate quantum components with existing digital infrastructure, and ensure that technologies meet standards of reliability, cyber security, and user-friendliness. Startups can act as agile partners to translate cutting-edge lab research into products and services that the industry can pilot and scale. Joint R&D projects, co-innovation centres, and industry-funded PhD fellowships or postdoctoral chairs in quantum science could strengthen this collaborative pipeline.

Equally important is fund sharing. Unlike traditional IT, quantum requires patient, long-term investment that cannot be met by public funds alone. Indian industry can contribute not only through direct R&D investments but also by creating venture funds dedicated to deep-tech, supporting accelerators and incubators focused on quantum, and pooling resources through industry associations for collective infrastructure.

> **"The model could be similar to how the Indian semiconductor ecosystem is being developed, with government support reducing initial risks, and industry progressively stepping in as technologies mature. Public-private partnerships under NQM could even allow industry to co-own intellectual property, ensuring both financial stake and technology adoption.**

With such mechanisms, Indian industry will not remain a player on the periphery but will become a co-shaper of the mission, contributing both ideas and resources while positioning itself competitively in the emerging global quantum economy.

Are there successful models from other sectors (e.g., defense, space, semiconductors) that can be replicated for quantum?

Yes, India has several successful models from other strategic technology sectors that offer useful lessons for the quantum domain. Perhaps the most prominent is the space sector, where ISRO built a model of strong public investment in early-stage R&D, coupled with steady technology transfer to industry once systems reached maturity. For quantum, a similar pathway could work, The semiconductor mission offers another parallel, especially in terms of ecosystem creation.

Finally, the public-private innovation clusters built around biotechnology in India. Government support for biotech parks and incubators created fertile ground for startups and academia-industry collaborations. For quantum, establishing "Quantum Innovation Hubs" with shared infrastructure, mentorship, and funding access could replicate this success. Taken together, these sectoral experiences show that India has a strong history of nurturing high-risk technologies through state-led vision, industry partnerships, and ecosystem development. The NQM can borrow from these models, adapting their best features to suit the unique challenges of quantum technologies.

What role do you envision for institutions like IISc, IITs, and new quantum hubs in building India's long-term quantum capability?

Institutions like IISc and IITs will be central to building India's long-term quantum capability because they combine deep scientific research with the ability to train future talent. Their role will be to push the boundaries of fundamental knowledge, whether in quantum algorithms, new qubit materials, or error correction, and ensure that India is not just adapting global advances but contributing original science. Equally important is their role in shaping the next generation of experts. These institutions can design courses, labs, and research programmes to create that talent pipeline. The new quantum hubs, on the other hand, are designed to bridge academia and industry. By offering shared infrastructure, testbeds, and prototyping support, they can help translate lab research into deployable technologies and reduce risks for startups and industry partners. Over time, these hubs can become national anchor points, ensuring coordination, setting standards, and driving mission-oriented progress.

How can India ensure it retains top quantum talent and creates a globally competitive workforce in this domain?

A major challenge for any frontier technology is the global talent competition, and quantum is no exception. India will have to approach this in a multi-pronged way. First, we must create a research environment that is on par with the best in the world. That means sustained funding for laboratories and access to high-end infrastructure. Second, we need to embed quantum deeply into our education and skilling system. From introducing basic quantum concepts at the undergraduate level, to offering specialised Master's and PhD programmes, to setting up interdisciplinary centres that train students in physics, computer science, pipeline of talent. This also extends to creating reskilling opportunities for engineers and IT professionals who can pivot into quantum-related roles, expanding the talent base beyond traditional academia.can pivot into quantum-related roles, expanding the talent base beyond traditional academia. Third, retention is not just about salaries, but about opportunity. By fostering vibrant startups and industry linkages, we create attractive career paths within India that combine research with entrepreneurship and application. If young PhDs knows they can build a startup, access venture funding, or collaborate with industry leaders here, they will be far more likely to stay.

Finally, we must actively encourage global collaboration without brain drain. That means sending students and scientists abroad for training but creating strong incentives and pathways for them to return. The goal is to make India not just a source of talent for the world, but a hub where top global talent also wants to come and work.

How does India currently compare with other countries investing heavily in quantum technologies, such as the United States, China, or the European Union?

India today finds itself at a crucial but somewhat uneven stage compared to global leaders like the US, China, and EU. The US and China have been investing billions of dollars into quantum technologies for over a decade, with strong backing from both government and private industry. The US, for instance, has a highly networked ecosystem of universities, national labs, and Big Tech companies driving quantum computing research and commercial applications. China, meanwhile, has made quantum a national security priority, leading breakthroughs in areas such as satellite-based quantum communication and aggressively building indigenous hardware capacity. The EU, with its Quantum Flagship programme, has has created a coordinated, multi-country platform that integrates research, industry, and training in a long-term strategic way.

Source - @indiaDST

In India, the launch of the NQM is a significant and commendable step, but the scale of investment and maturity of the ecosystem still lags far behind the US and China. What India does have, however, is a strong pool of experts, a proven record in large science missions and an increasingly dynamic startup environment that could be mobilised towards quantum. Unlike the US and EU, India does not yet have a large industry footprint in quantum hardware, and unlike China, its efforts have not been explicitly tied to national security imperatives. Instead, India's approach has been more focused on academic capacity-building and early-stage infrastructure, with a view to gradually expanding into applications.

In short, India is a late entrant but a serious contender. The NQM signals intent to catch up by creating dedicated hubs, funding labs, and supporting startups, but for now, the cou try is still in the "capacity-building" stage rather than leading breakthroughs.

What would strategic autonomy in quantum computing and communication look like for India in the next 10 years?

In the next 10 years, strategic autonomy in quantum computing and communication for India would mean the ability to design, build, and operate quantum systems end-to-end without depending on foreign suppliers. On the computing side, this translates into indignous stacks for at least two qubit modalities, scaling to medium-sized processors with verified applications in materials discovery, optimisation, and secure computing. On the communication side, it means a quantum-secure backbone – long-distance fibre QKD across priority corridors, complemented by India's own satellite-to-ground links, protecting government and critical infrastructure.

Equally important, autonomy requires domestic supply chains for critical components such as cryogenic platforms, single-photon detectors, precision lasers, and control electronics, along with indigenous software compilers and verification tools. Finally, it's about institutions and talent; our hubs and industry partners must translate lab advances into deployable systems, backed by skilled manpower and certification regimes. Together, these positions enable India to operate independently, safeguard national security, and engage in global collaborations as an equal partner rather than a dependent.

What are the biggest challenges you foresee in executing the NQM effectively?

The NQM carries immense promise, but its execution will face a set of interlinked challenges. One of the foremost risks is fragmentation; if research efforts across IISc, IITs, and new quantum hubs operate in silos without effective coordination, India could lose both efficiency and global competitiveness. A second challenge lies in the talent pipeline; while India produces a strong base of physicists and engineers, retaining them in the country will be difficult if opportunities for funding, long-term career growth, and cutting-edge infrastructure remain limited compared to global centres. Another risk is over-reliance on imported hardware in critical areas.On the institutional side, quantum research is inherently high-risk and long-gestation, meaning bureaucratic delays, short-term evaluation cycles, or rigid procurement processes could stifle innovation. Equally, industry engagement may remain shallow unless specific incentives, co-funding mechanisms, and procurement guarantees are put in place to make quantum technologies commercially viable. Finally, there is the challenge of security; given the dual-use nature of quantum systems, safeguarding sensitive research against technology leakage or cyber espionage will be crucial. In summary, the mission's success depends not just on funding but on building a flexible, coordinated, and security-conscious ecosystem that can take risks and deliver at scale.

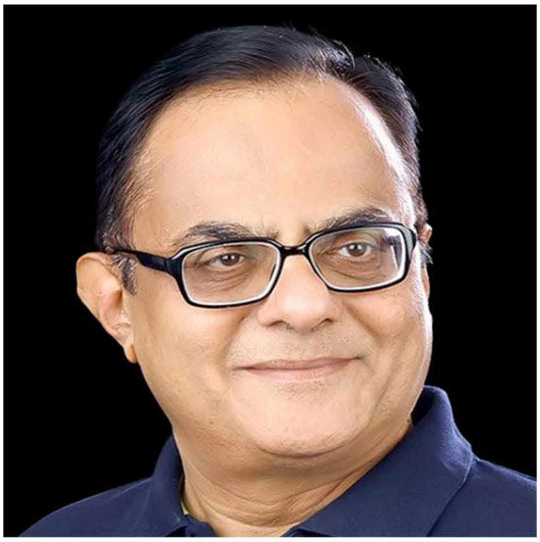
What are the biggest challenges you foresee in executing the NQM effectively?

Over the next three to five years, progress under the NQM can be recognised through a few visible and high-impact milestones. One of the earliest signals will be the creation of dedicated quantum hubs and centeres of excellence in leading institutions such as IISc, IITs, NITs, and other research clusters. These hubs will not just serve as advanced laboratories but also as ecosystems where students, researchers, startups, and industry can collaborate on real-world applications of quantum technology.

Another important milestone will be the launch of pilot projects and demonstrators. For instance, government and strategic sectors may begin to adopt quantum-based secure communication networks on a trial basis, or startups may showcase early versions of indigenous quantum devices. Even if these are not yet at full global scale, the act of demonstrating homegrown prototypes and testbeds will signal India's seriousness in building independent capacity.

Equally critical will be talent-related outcomes. The introduction of dedicated master's and PhD programmes, as well as training modules for engineers and industry professionals, will show that India is not only developing technology but also preparing the skilled workforce needed to sustain it.

Finally, a clear milestone will be the active involvement of industry and startups. This kind of public-private partnership will demonstrate that quantum is moving beyond labs into the larger economy. Together, these milestones will be the clearest indicators that India is transitioning from vision to tangible progress in quantum technologies under the NQM.



National Quantum Mission: Strategic Science for a Self-Reliant Future

Prof. Ajay Kumar Sood
Principal Scientific Adviser (PSA)
Government of India

India's National Quantum Mission (NQM) is more than a scientific initiative—it is a strategic leap toward global technological leadership. Steering this ambitious mission is Prof. Ajay Kumar Sood, Principal Scientific Adviser, whose leadership is shaping India's quantum future. In this special interview, Prof. Sood shares insights into the mission's goals, strategic significance, and thedeep scientific legacy that powers it.

What is the overarching vision of the National Quantum Mission, and how do its short-term goals (0-5 years) differ from its long-term aspirations (5-10 years and beyond)?

The overarching vision of NQM, or its long-term aspiration, is to place India "among the leading nations in the development of Quantum Technologies". And, this will be made possible by creating and nurturing a vibrant R&D and innovation eco-system in Quantum Technology (QT), and by accelerating QT-led economic growth, in the country.

Given this long-term aspiration of NQM, a list of deliverables has been carefully worked out as its milestones as a function of time. These are all very well-known by now and are available at the NQM website. So, I will not repeat these. I would only add that these have been decided after carefully mapping the national capabilities in different sectors of QT (or in different verticals of NQM). Overall, a realistic and graded progress chart has been worked out.

What mechanisms are in place to ensure that the NQM integrates seamlessly into India's larger Science, Technology, and Innovation ecosystem and allign with Atmanirbhar Bharat?

Very simply put, QTs will give us exponentially fast computers, secure information communication systems, and extremely sensitive sensors. Exponentially fast computers and secure information communication systems will have direct bearing on the functioning and security of our huge digital and communication infrastructure in both civilian and defence sectors that we have set up in the last decade or so. NQM thus is completely aligned with Digital India goals.

Given the sensitive nature of QTs, and their importance for national security, they will in all likelihood be proprietary or highly guarded technologies. Every nation will have to perforce develop it for guarding its strategic autonomy.

Atmanirbharta is not going to be a choice in this domain, it will be a necessity. So, NQM will manifestly assist in India's march towards an Atmanirbhar Bharat. Atmanirbharta, as well as NQM's dream of positioning India among the leading nations in QTs globally, will necessarily require promoting Make in India, Startup India, etc. This naturally brings me to the second part of your question. Given the complex and multidisciplinary nature of QTs, it is a must to bring all capable players in our science, technology, innovation and industrial ecosystem together to make India competitive in this fast-growing and highly-competitive field. NQM has been consciously structured to make this a reality.

The mission brings together academia, national labs, and industry. From a policy and governance perspective, how is the collaborative ecosystem being structured to ensure efficient coordination and translation of research into deployable technology?

Picking up from what I just said, collaboration among academia, national labs and industry is a must given the multi-disciplinary nature of QTs. NQM has incorporated this aspect into the mission design and management right from the start. Let me explain it briefly. The Mission itself is designed in the Hub-Spoke-Spike Model, with one national hub looking after each of the four verticals of QT, viz. Quantum Computing, Quantum Communication, Quantum Sensing and Metrology, and Quantum Materials and Devices.

Each Hub and Spokes are themselves Technical Groups comprising some of the most competent groups in various institutions in the country aiming to achieve specific goals of the Mission. So, inter-institutional collaboration has been built from the beginning, ensuring that all necessary and available expertise is available to deliver the goals of the Mission on time. Each hub will also mentor or collaborate with startups, industry and international partners as well. NQM has also extended initial financial support to startups, and the RDI Fund is expected to facilitate industrial forays into this "deepest-tech" area easier. Coming to Mission Management, the apex-level decision-making will rest with the Mission Governing Board (MGB) and MTRC (Mission Technology Research Council). A nodal Mission Coordination Cell (MCC) in DST will look after the overall operational aspects of the Mission.

> "Atmanirbharta is not going to be a choice in this domain, it will be a necessity. So, NQM will manifestly assist in India's march towards an Atmanirbhar Bharat.

Most of the day-to-day management, however, has been decentralized in the four hubs for their respective verticals. The four hubs have been created as Sec.8 companies in some of the best institutions in the country led by a Hub Governing Board (HGB). While the initial steps were taken by the MCC, it is expected that the operational work will soon get decentralized making it quicker and more responsive to the special needs of the four verticals, while reporting to MTRC and MGB. Thus, a very well-defined structure has been put in place to ensure collaboration among academia, national labs and industry under NQM.

Quantum Technologies are now central to strategic global competition. How does the NQM position India in the international quantum landscape, and what steps are being taken to ensure both global scientific collaboration and technological sovereignty with safeguarding national interests in this emerging field?

Yes, as I just said, QTs are crucial for the strategic autonomy of any nation today. So is it for India. And, NQM has adopted a very realistic and graded approach after a careful SWOT analysis of the national QT eco-system. Given the massive expansion and adoption of digital infrastructure and services in the country, security of our information and communication infrastructure is of paramount importance. Luckily, we are doing quite well in this domain, especially in fibre-based QKD systems. We have already developed such systems and demonstrated them in both civilian and strategic domains. Implementation of globally accepted PQC frameworks and development of our own protocols are also under way.

Roadmaps for building a Quantum-Safe Ecosystem in India have also been released. In free space QKD, progress is also being made by ISRO and several institutions, but there is catching up to do. In case of Quantum Computing, we have considerable catching up to do in qubit fabrication, but we have strength in application software development and quantum literate manpower. To capitalize on this strength, NQM is arranging for time on globally-available quantum computers. There is considerable scope to become a global supplier of electronics for quantum computers, and that is being emphasized to our industry.

Quantum Sensing and Metrology is globally a relatively guarded domain because of the dual use nature of quantum sensors. So, we have no option but to develop on our own. Our academic and research institutions have taken up this challenge and a very focused attempt is being made to achieve self-sufficiency in this. In Quantum Materials and Devices, India has considerable strength – thanks to decades of research funding under SERC/SERB/ANRF, Nano Mission, and other similar programmes of other agencies.

NQM is consciously trying to marshal this strength to develop novel materials and devices specific to the other three verticals so that NQM is able to distinguish itself from other general capability-building programmes of the government. In all these domains, industrial participation is being promoted and international collaborations are being forged to effectively fill the gaps in knowledge, test-beds etc. And, needless to say, national interest is the fundamental principle guiding all of NQM activities.

Coming to the Science of Quantum Technology, what makes quantum technology fundamentally different from classical digital technologies? Could you explain, in layman's terms, how quantum mechanics enables capabilities like quantum computing or secure communication?

There is enormous literature, even popular literature, available on this. For the sake of completeness, let me however try to explain it very briefly. Classical digital technologies are all based on 'bits' of information. Each bit can take one of two values 0 and 1 (that is, exist in one of these two states). One can for simplicity think of these as OFF and ON states of an electrical switch. All classical digital technologies are built by putting such bits of information together to perform different functions.

A 'quantum bit' or 'qubit', with two possible distinct states (such as an electron with spin UP or spin DOWN), can also exist in a 'superposition' of the two states. That means, it can exist in any of these two states simultaneously with different probabilities. Two qubits can exist simultaneously in any of 22 states, three in any of 23 states, and so on. So, for N qubits, we have an exponentially large (2N) computational space. This leads to exponentially fast computing power. One can do new types of computation which were extremely difficult (even impossible) for a classical computer.

'Superposition' is a fundamental property of quantum systems. For secure communication in classical digital systems, we rely on cryptographic protocols like RSA which cannot be broken in any reasonable time by even the fastest classical computers.

Quantum computers, however, with their exponentially fast computing power, can break such cryptographic systems. This was Peter Shor's discovery. Quantum mechanics, however, gives us a foolproof way out. If someone tries to read what is contained in an information being carried by a quantum system, the very act of reading will disturb the system and will be discovered. This is the very nature of quantum 'measurement', and this basically stems from the extreme sensitivity of quantum systems with respect to any disturbance. This is something that is intrinsic to the very physical nature of quantum systems and does not depend on clever mathematical cryptographic schemes. There is yet another property of 'entanglement' of quantum systems (related to superposition) which can also be exploited in QTs. So, basically, three fundamental properties of quantum systems—"superposition", "entanglement" and "measurement"—form the basis of all QTs. These have no parallel in classical digital technologies.

You've emphasized that quantum science did not arrive suddenly, but is the result of over a century of foundational research. Could you briefly walk us through the evolution of quantum mechanics — from Planck's hypothesis to the modern quantum revolution — and why this historical understanding matters today?

Yes, I have always emphasized this point. Starting with the Planck's hypothesis in 1900 (published in 1901), Einstein's explanation of the Photoelectric Effect, and followed by the works of Heisenberg, Schrodinger, Neils Bohr, Max Born, our own SN Bose, Paul Dirac, von Neumann, Enrico Fermi and others, the fundamental principles of Quantum Theory got established over a 25-30 year period in the early 1900s. This gave physicists the tools to analyze the behaviour of matter at atomic or sub-atomic scales. This was followed by revolutionary developments and discoveries in nuclear physics, particle physics, condensed matter physics, low temperature physics, astrophysics, optics and so on, along with enormous developments in associated instrumentation. We first acquired the ability to tailor the properties of materials, moving from the semiconductor to the nano revolution. And finally developed tools and understanding to engineer quantum systems per se. So, the development of QT is roughly a 125-year long story.

Richard Feynman's paper on Quantum Computing is itself of 1982. Realization of such things had to wait for development of appropriate technological tools. This story is too well-documented for me to repeat, but I keep on saying this to dispel the belief that QT has suddenly come up from nowhere. It is the culmination of a long series of 'eureka moments' in physics and engineering. In fact, this is true of any science and technology. Remember that Nano Science and Technology was also foreseen by Richard Feynman in 1959, but appeared as a real technology only by 2000s.

You've described today's advances as part of the "Second Quantum Revolution". How do you distinguish this phase from the first, and what scientific breakthroughs have made it possible to move from quantum theory to real-world engineering?

Quantum Theory tells us how matter behaves at the atomic and sub-atomic dimensions—atoms, molecules, etc. When such constituents of matter get together to form matter at macroscopic scales, their individual quantum properties in some sense get "averaged out" to give the materials their various properties.

In the First Quantum Revolution, we learnt how to manipulate or modify such macroscopic matter systems to give them the desired properties or functionalities. Semiconductors are a classic example from this era, ushering in the modern electronics era, the great digital and solar energy revolution etc.

In the Second Quantum Revolution, however, we are 'engineering' small quantum systems like atoms, photons (single or very small collections of them) themselves to impart to them the functionality that we desire. These are very small and sensitive systems and such capabilities had to wait for development of revolutionary technological developments like lasers, laser cooling, sophisticated microscopies, etc. to become a reality. Being very small, the quantum nature of such systems are not yet averaged out, so the wave-particle nature of matter is itself being exploited in the Second Quantum Revolution.

Yes, being small and fragile, such systems are very sensitive to noises and perturbations of all kinds, and taming them is one of the greatest challenges in QT.

India has a unique historical connection to quantum physics through Satyendra Nath Bose. How do you see Bose's contribution—particularly Bose-Einstein Statistics—continuing to influence modern quantum science? And how is the NQM building on this foundational Indian legacy?

Yes, India has a proud position in the history of development of foundational principles of Quantum Theory, courtesy the work of Satyendra Nath Bose (SN Bose). Bose-Einstein Statistics, developed first by SN Bose for photons and extended by Einstein for atoms, marks the beginning of Quantum Statistics. Today, we know that there are two kinds of particles in Nature, 'bosons (named after SN Bose)' carrying integer spin, and 'fermions (named after Enrico Fermi)' carrying half-integer spin. Bose-Einstein Statistics tell us how a collection of bosons behave. It is as fundamental a discovery as that. This leads to exotic phenomena like superconductivity, superfluidity, Bose-Einstein condensation, etc. It is clear that Bose's contribution was a defining moment for Quantum Theory, and continues to be crucial for designing QT systems. Regarding the second part of your question, I would only say that science is universal, and Bose's contribution is so fundamental, that NQM cannot have any exclusive path exploiting this discovery separate from the whole world. Yes, it imparts NQM a great sense of pride that Bose will remain an indelible landmark in the history of QT, no matter how many times it is written!

The NQM focuses on atomic clocks, magnetometers, superconductors, single-photon sources, and topological materials. Why are these components so critical, and what breakthroughs do you foresee in these areas in the next few years?

Atomic Clocks with improved accuracy are important for accurate time keeping in GPS systems, for example. This, you can imagine, will find wide-ranging applications, in both civilian and strategic sectors. Similarly, magnetometers are of great use in navigation, NMR, geophysical prospecting and exploration, archaeology, ordnance and weapons detection and so on. Single photon sources are crucial for quantum communication applications. It is, therefore, clear why the NQM focuses on these important devices as these are crucial for national security also. NQM has also listed the desired accuracy to be reached by the end of the Mission.

Superconductors and topological materials are important from the point of view of qubit fabrication. There already are commercial quantum computers based on superconducting qubits; and Microsoft has already unveiled its Majorana chip based on topological materials. Any breakthroughs in the underlying materials science will impact qubit fabrication paradigms. The jury is still out on the best possible qubit fabrication pathway. Given the materials and nano science strengths in the country built over decades of R&D funding by SERC/SERB/ANRF and other agencies, NQM aims at very focused attempts on developing novel materials for more promising devices.

Quantum science often seems abstract or inaccessible to the public. What is being done to raise awareness and literacy around quantum technologies, especially among students and early-career researchers across disciplines?

Quantum science is abstract even for most scientists, because the underlying concepts are quite different from our day-to-day experience with 'classical' systems. However, ever since the arrival of QTs on the scene, I think there is a deluge of information available in the open domain for all kinds of audiences. We are also contributing by way of popular talks, articles, etc. Our special issue of Vigyan Dhara is yet another attempt; so will be your issue of Dream 2047. Regarding QT-literacy, our SWAYAM and NPTEL portals have added several courses, in addition to the numerous courses on the internet by prominent institutions and companies like IBM.

As another concrete step, NQM has designed courseware for BTech and MTech to be adopted through AICTE. With research funding under NM-ICPS and QuEST earlier, and now under NQM, large number of students and researchers have been supported for research.

The fact that we received 384 proposals for Technical Groups, out of which 17 involving 152 scientists have been supported, itself shows that our HRD efforts have started giving results. It is estimated that there are about 100 more scientists who are also actively involved in QT research.

The NQM has a strong focus on materials research—superconductors, semiconductors, topological materials. From a policy and scientific leadership perspective, how critical is this area in achieving hardware independence?

We have just discussed this aspect. It is easy to visualize that materials form the basis of QT hardware. Fabrication, packaging, associated electronics, software etc. are other important aspects. Ability to produce QT-relevant materials will clearly be crucial for achieving hardware independence, so very necessary in this domain with strong strategic overlap. And, development of new and novel materials will give us scientific, technological and competitive edge. While designing NQM, we were acutely aware of the importance of developing indigenous capabilities in materials, should this come under cloud in an unexpected strategic environment. That is why, Quantum Materials and Devices form an important vertical, supporting all the other three pillars. As I mentioned, luckily India has strong capabilities in materials research. So, that is good news.

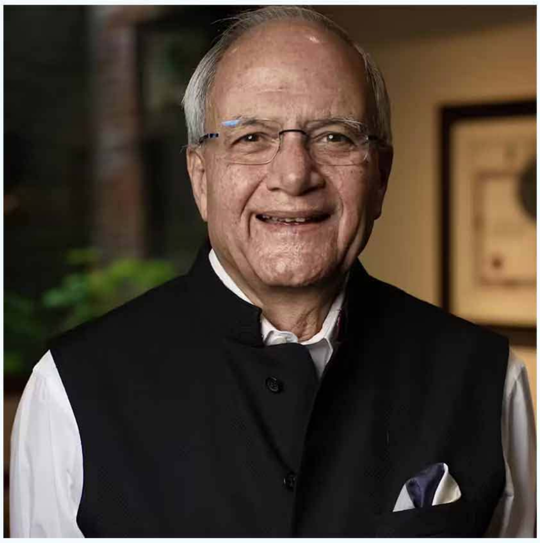
The UN has declared 2025 as the International Year of Quantum (IYQ) Science and Technology. How can India leverage this platform to both showcase its progress and forge meaningful global partnerships in the quantum domain?

NQM, as well as several State Governments, are regularly organizing conferences, etc. and will continue to do so. Similarly, forging global partnerships to supplement or complement our efforts is also an ongoing and important component of the Mission. UN's IYQ lends added visibility to all these efforts, which is obviously quite important.

As the Principal Scientific Adviser, what is your long-term vision for India's place in the global quantum landscape? What milestones should we aim for over the next decade to establish ourselves not just as participants, but pioneers in this space?

As you know, NQM was one of the Missions suggested by the Prime Minister's Science, Technology and Innovation Advisory Council (PM-STIAC), and my Office and I have been intimately involved with the formulation and approval of NQM. So, my vision is very similar to the stated vision of NQM. And, that is, to place India among the leading nations in QT globally. The milestones over the 8 years of the NQM have also been laid down very clearly.

> "In a fast developing and highly competitive field like QT, realistically, I can only say it will be our endeavour to achieve self-sufficiency in aspects relevant for our economic and strategic autonomy, become technologically competitive in some segments of various verticals, and possibly make some pioneering contributions to materials and algorithmic aspects of QT.



NQM: Transforming India's Science and Innovation Future

Dr Ajai Chowdhry
Padma Bhushan
Chairman, Mission Governing Board,
National Quantum Mission

At the heart of the National Quantum Mission (NQM) lies a dynamic and collaborative framework-bringing together leading research institutions, cutting-edge start-ups, public R&D laboratories, and industry leaders from across the country. The establishment of four specialized Technology Hubs (T-Hubs), supported by a network of Technical Groups, marks a significant milestone in India's science and innovation landscape.

In this exclusive exchange, Dr. Ajai Chowdhry, Chairman of the Mission Governing Board, responds to a set of questions that shed light on how the NQM is poised to impact key sectors, India's current standing on the global quantum map, and what lies ahead for young innovators eager to contribute to this transformative journey.

The NQM encompasses a wide scope-quantum computing, secure satellite-based quantum communication, inter-city QKD networks, quantum sensing and cloaking, and advanced quantum materials. Which of these domains do you anticipate will show significant progress in the near term, and what factors will drive this momentum?

I anticipate that in the near term, specifically in the next 3 to 5 years, inter-city QKD networks, along with quantum sensing and cloak technologies, are likely to demonstrate the most significant advancements within the broader objectives of the NQM. The application of QKD through fibre-optic links is relatively well understood and has already been validated in test environments in a pilot carried out by the Centre for Development of Telematics (C-DOT). We have the existing telecommunications infrastructure available to support QKD over fibre networks, with clear use cases in banking, defence, and data centres. Moreover, the NQM places a strategic emphasis on national security and critical infrastructure, where QKD is ideally aligned.

Given that the first system will support 6 qubits, how will it be utilised - in research, algorithm a, and for training purposes? How is the phased quantum hardware roadmap (6 to 1000 qubits) being aligned with software and algorithm development in parallel?

The deployment of a 6-qubit quantum system at Tata Institute of Fundamental Research (TIFR), Mumbai represents a strategic foundational step — not merely a hardware achievement. This system will be employed to assess hardware stability, noise models, gate fidelities, and to develop and test noise-resilient quantum algorithms on real hardware. Furthermore, the 6-qubit system can serve as a training resource for practical quantum programming, circuit design, and debugging. The phased quantum hardware roadmap (ranging from 6 to 1000 qubits) under India's NQM is intentionally is synchronised with software and algorithm development to guarantee that:

1. Software capabilities progress in tandem with hardware advancements,

2. Use-case development remains relevant at every phase, and

3. A cohesive national quantum ecosystem comprising hardware, software, algorithms, and talent is established.

From your perspective, where does India currently stand in the global quantum technology ecosystem? How will the NQM transform India from a technology follower into a global leader in quantum science and innovation?

India is currently assuming an increasingly significant and strategically advantageous position within the global quantum technology landscape. Historically, it has been a follower in the realm of quantum hardware; however, India is now making a determined shift towards becoming a global contributor and potential leader, with the NQM serving as the driving force. Furthermore, India is collaborating with other countries thereby enhancing access to expertise, facilitating joint research, and establishing hardware testbeds.

> **“ The NQM is designed to develop sovereign quantum systems, encompassing everything from cryogenic control to quantum algorithms and satellite-based communication. If this comprehensive capability is achieved, it will enable India to dictate its own innovation path rather than relying on imports or adaptations.**

The NQM focuses on four clearly defined verticals: Quantum Computing, Quantum Communication, Quantum Sensing and Metrology, and Quantum Materials & Devices. This clarity facilitates targeted resource allocation, establishes measurable objectives, and promotes vertical-specific intellectual property generation, thereby minimizing the dilution of effort.

Quantum sensing and precision timekeeping are often seen as niche scientific pursuits. How can these be leveraged for broader economic gains, improved public services, and advancements in national infrastructure?

Indeed, quantum sensing and precision timekeeping have historically been regarded as specialized, laboratory-focused fields. However, this perception is rapidly evolving. These technologies are currently at a pivotal moment, presenting real-world applications that can significantly influence economic growth, transform public services, and modernize national infrastructure.

With four major Technology Hubs supported by 14 Technical Groups across 17 States and 2 Union Territories, how does this "hub–spoke–spike" model foster regional innovation ecosystems and ensure inclusive, pan-India participation?

The hub–spoke–spike model established under the National Quantum Mission (NQM) aims to utilize regional strengths, encourage inclusive innovation, and create a distributed quantum ecosystem throughout India's varied landscape. This model promotes regional innovation ecosystems and guarantees inclusive participation across India in the following ways:

- Decentralisation of research and development prevents any single centre from dominating quantum research. Various regions contribute to different sectors, resulting in innovation that is genuinely pan-India.

- Tailored regional focus allows each spoke to specialise in quantum subfields pertinent to local industry and academia.

- Inclusive talent development involves institution from 17 states and 2 UTs, thereby providing opportunities for women and underrepresented groups through local outreach, as well as students from tier-2 and tier-3 cities, along with adaptations in regional languages and curricula.

- Industry linkages and startups enable regional clusters to attract local startups and MSMEs into the quantum ecosystem.Being close to industry hubs facilitates technology transfer and commercialisation.

Are there dedicated funding models, incubation frameworks, or public–private partnership (PPP) mechanisms under the NQM to accelerate the journey from lab-scale research to market-ready quantum technologies?

The NQM acknowledges that the transition from laboratory-scale quantum research to commercially viable technologies necessitate more than mere funding - it requires a well-organised ecosystem that includes dedicated funding models, incubation support, and strong PPP mechanism. The NQM designates specific grant programmes for proof-of-concept and prototype development, scale-up and technology validation, as well as collaborative projects that connect academia with industry. Funding is typically milestone-based, which ensures accountability and phased advancement.

Beyond industry and academia, how is the mission working to embed quantum technologies into public-sector use cases - such as secure government communication, disaster forecasting, or precision agriculture?

The NQM affirm that the adoption of quantum technologies by the public sector is crucial — not only for demonstrating their impact but also for establishing trust, scaling operations, and gaining a national strategic advantage. The NQM is focusing on the development and implementation of inter-city QKD networks that connect government agencies, defence establishments, and critical infrastructure. Pilot projects are currently in progress with various national agencies such as DRDO, ISRO, and the Ministry of Electronics & IT.

You've emphasized that manpower development and support for quantum startups are two critical pillars for the success of NQM. What specific strategies or initiatives are being planned to nurture a skilled quantum workforce and create a vibrant startup ecosystem that can drive innovation and commercialization in this frontier field?

The development of human resources and support for startups are fundamental elements of the NQM's approach to establishing a sustainable quantum ecosystem in India. To cultivate a skilled workforce, specialised courses in quantum science and engineering have been created at the undergraduate, postgraduate, and doctoral levels across various universities. The rolling call for proposals launched by the four Thematic Hubs will provide startups with access to laboratories, quantum hardware testbeds, mentoring, and business development assistance. Moreover, seed and early-stage funding will be available through these Thematic Hubs.

India is planning to launch a quantum satellite within the next 2-3 years for secure quantum communication. How will this satellite enhance India's capabilities in secure communication, and what potential impact could it have on national security, public safety, and international collaborations?

India's forthcoming quantum satellite mission represents a transformative advancement in secure communication, significantly enhancing the nation's strategic and technological prowess. The satellite will facilitate space-to-ground QKD, enabling the transfer of cryptographic keys with complete security grounded in the principles of quantum physics. In contrast to traditional encryption methods, QKD is resistant to hacking or interception, guaranteeing unbreakable encryption for sensitive communication. The satellite serves as a reliable node that connects various ground stations, establishing a nationwide quantum-secured communication framework.

What role will the partner Ministries and Departments play in advancing innovation and R&D in the quantum domain under the NQM?

Various partner Ministries and Departments play a vital role in fostering quantum innovation and research and development across different sectors. Their participation guarantees that quantum technologies are developed in conjunction with national priorities, integrated into essential applications, and transitioned from laboratory settings to practical use effectively.

Source - @indiaDST

Prof. Abhay Karandikar
Secretary,
Department of Science & Technology

Charting India's Quantum Leap

India's National Quantum Mission (NQM) is rapidly taking shape under the visionary leadership of the Secretary, DST. In this exclusive feature, Prof. Karandikar shares insights ontranslating vision into action and placing India at the forefront of the quantum revolution and discover how NQM aligns with the nation's self-rliant, innovation-driven future.

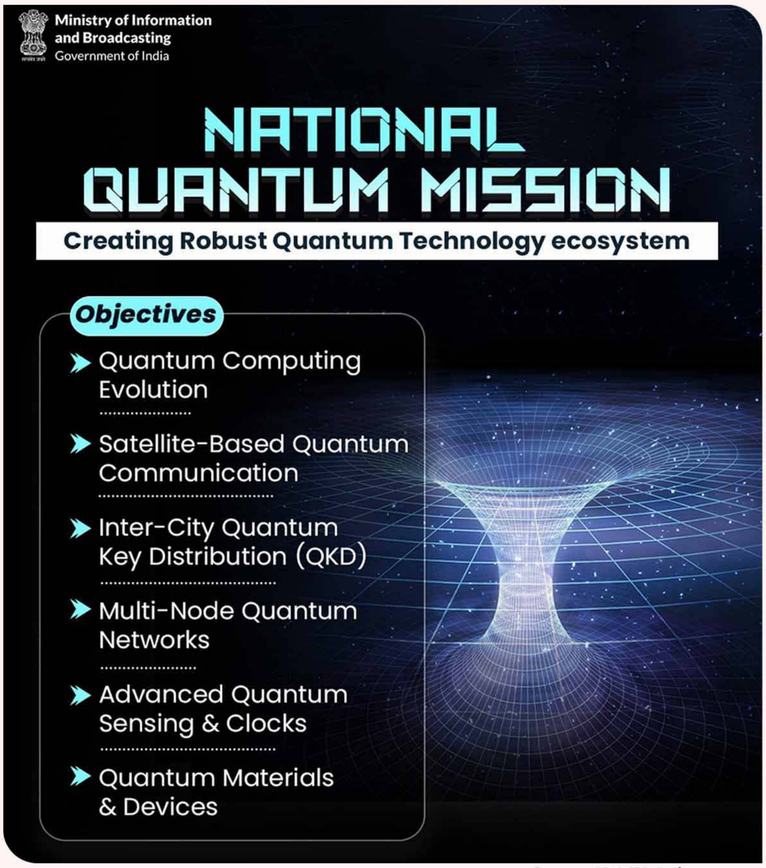
National Quantum Mission's Rapid Movement from Conception to Cabinet Approval

The Union Cabinet approved the National Quantum Mission (NQM) on 19 April 2023, at a total cost of Rs. 6,003.65 crore for eight years. The Mission aims to seed, nurture, and scale up scientific and industrial R&D and create a vibrant and innovative ecosystem in Quantum Technology (QT). This will accelerate QT-led economic growth, nurture the country's ecosystem, and make India one of the leading nations in the development of Quantum Technologies & Applications (QTA).

The speed at which NQM progressed was the result of a clear vision and strong alignment across government, academia, and industry. DST had been engaging with the scientific community for years to map India's strengths in quantum technologies. Extensive consultations and white papers laid the groundwork, enabling a well-structured proposal that could be approved swiftly. We ensured ambition was matched by realism — combining global benchmarking with India's specific needs in computing, communication, sensing, and materials.

Overall Implementation Strategy and Thematic Hubs

NQM follows a hub-and-spoke model with four Thematic Hubs (T-Hubs) established at leading institutions — each focused on quantum computing, quantum communications, quantum sensing & metrology, and quantum materials & devices. These hubs are linked through common governance mechanisms, including the Mission Governing Board



Source - X_MIB India

and Mission Technology Research Council, ensuring parallel progress in all domains.

On 30th September 2024, Four Thematic Hubs were officially launched:

- Quantum Computing at IISc Bengaluru
- Quantum Communication at IIT Madras in association with C-DOT
- Quantum Sensing & Metrology at IIT Bombay
- Quantum Materials & Devices at IIT Delhi

The hubs are designed to drive technology development, nurture human capital, promote entrepreneurship, and enhance international collaboration. Each hub also has a Governing Board with representation from academia, industry, and government to align national priorities.

Coordination of Stakeholders and Integration of Outcomes

The Mission is guided by a Mission Governing Board chaired at the highest level, ensuring strategic oversight and alignment with national priorities. Each of the four Thematic Hubs functions as a consortium of technical groups, bringing together 152 researchers across 43 premier institutions nationwide. These consortia integrate academia, R&D laboratories, and industry partners, with industry involvement built in from the beginning to enable co-development and rapid translation of research outcomes.

To strengthen this ecosystem, joint reviews and stakeholder consultations are conducted, ensuring that research outputs are not only of the highest scientific calibre but also ready for industrial deployment and critical national applications. This framework effectively transforms academic excellence into tangible, deployable technologies for the nation.

Facilitating Seamless Coordination through:

- **Common Review Committees**
- **Regular Inter-hub Workshops**
- **Joint MilestoneTracking**
- **Startup Support Mechanisms**

Crucial Stakeholders in the Early Phase

In the initial years, academia and startups are most critical. Academia anchors fundamental R&D and talent creation, while startups bring agility and innovation. Industry and strategic sectors are being engaged in parallel, but the early momentum depends on seeding a strong pipeline of ideas and demonstrators through academic labs and entrepreneurial ventures.

Recognising that quantum technologies are still in their nascent stage and require substantial investment, NQM formulated exclusive guidelines to effectively onboard and support startups. Eight promising startups have been supported in the area of quantum technologies. A rolling call for startups is also active, offering continuous support to early-stage ventures working in all four verticals of quantum technologies—thus nurturing India's growing quantum innovation ecosystem.

Early Milestones and Quick-impact Projects

The Mission has three phased timelines — 3 years, 5 years, and 8 years. The major objectives include development of intermediate-scale quantum computers with 50–1000 physical qubits using platforms such as superconducting and photonic technologies, alongside establishing satellite-based secure quantum communications between ground stations across 2000 km within and outside India. The Mission also focuses on developing high-sensitivity magnetometers in atomic systems and atomic clocks for precision timing, communications, and navigation, while supporting the design and synthesis of advanced quantum materials including superconductors, novel semiconductor structures, and topological materials for device fabrication.

Support for Quantum Startups

The NQM is dedicated to fostering a vibrant and robust startup ecosystem for advancing India's aspirations in quantum technologies. By nurturing innovation and entrepreneurship, NQM aims to create a thriving environment where startups can flourish, contribute to cutting-edge research, and develop transformative quantum solutions.

Mechanisms to Ensure Effective Research-to-industry Transfer and Workforce Development

A key mandate of the Thematic Hubs under NQM is to foster translational research, ensuring that innovations and prototypes emerging from laboratories are systematically advanced into deployable technologies for industry and strategic sectors.

To further strengthen this pathway, two dedicated calls were launched on 11th May 2025 — one on **Quantum Algorithms** to accelerate the development of application-oriented solutions, and another on establishing **Undergraduate Teaching Laboratories** in

Source- @indiaDST

Quantum Technologies to build hands-on capacity in young talent.

These initiatives are designed to directly bridge research outputs with industry requirements while simultaneously nurturing a skilled workforce for India's growing quantum ecosystem.

Creating a Robust Talent Pipeline

- B.Tech Minor in Quantum Technologies was launched on 24th December 2024. Nearly 2000 faculty members have already been trained through Faculty Development Programmes.
- M.Tech programme in Quantum Technologies was launched on 28th August 2025, designed to create advanced talent pipelines with deep expertise in quantum computing, communication, sensing, and materials.
- Dedicated course books, lecture series, and teaching laboratories are under development to ensure wide accessibility.

Quantum-Safe Ecosystem Initiative

A Concept Paper for the Quantum-Safe Ecosystem in India has been developed. It outlines the risks posed by quantum computing to existing encryption standards and emphasizes the need to transition to Post-Quantum Cryptography (PQC). The paper recommends:

- **Formulation of National PQC Standards**
- **Creation of Regulatory and Compliance Frameworks**
- **Promotion of Indigenous R&D in Quantum-Safe technologies**

This ensures India's long-term cybersecurity resilience against emerging quantum threats.

Benchmarks for Success

These are directional rather than rigid, given the evolving nature of the field. They include:

- **Establishing Strong Domestic Capabilities**
- **Training Manpower at Multiple Levels**
- **Advancing Research Infrastructure**
- **Vibrant Startup Ecosystem**
- **Sustaining Industry Participation**

The true measure of success will be India's ability to build sustained capacity and remain a significant global player, rather than any single numerical target.

India's long-term Vision in the Global Ecosystem

Beyond the 8-year horizon, India aims to be among the top three nations globally in quantum technologies. The vision is for India not just to be a user, but a creator and exporter of quantum solutions in secure communications, advanced computing platforms, and novel sensing applications.

> **"By 2047, India's quantum ecosystem is envisioned as a pillar of Viksit Bharat, enabling self-reliance, security, and technological leadership.**

National Quantum Mission: Steering India into the Quantum Age

India has consistently demonstrated its ability to harness emerging technologies for national growth and global leadership. Continuing this trajectory, the Government of India launched the National Quantum Mission (NQM) in April 2023 with an outlay of ₹ 6,003 Crore for eight years, a bold step towards securing the nation's place in the rapidly evolving quantum revolution. With quantum technologies poised to transform communication, computing, sensing, and materials research, this mission aligns seamlessly with India's vision of becoming a **Viksit Bharat by 2047.**

Dr J V B Reddy

Head, National Quantum Mission
Department of Science & Technology

T-Hubs announced to Lead India's Quantum Revolution, September 2024

Mission with a Vision

At its core, the mission seeks to harness the power of quantum technologies- an emerging domain with transformative potential in computing, secure communication, sensing, and materials science. By developing quantum computers ranging from 50 to 1000 physical qubits on various platforms, including superconducting and photonic technology, India envisions breakthroughs that could redefine problem-solving in areas where classical computers fall short. Equally ambitious are the mission's goals in quantum communication. Secure communication channels covering over 2000 km of long-distance fibre and satellite-based links between ground stations will be developed. These efforts are set to revolutionise information security and establish India among the few countries advancing in quantum encryption and communication.

Another crucial component of the mission is the development of quantum sensors and atomic clocks, which have wide-ranging applications in navigation, precision measurements, and national security. By investing in these areas, NQM not only strengthens India's scientific foundation but also enhances its strategic capabilities. The four hubs of quantum serve together as the mission's backbone, driving research, nurturing human capital, and promoting entrepreneurship while fostering international collaborations.

Startups and Innovation

Recognising the role of startups in translating deep science into deployable solutions, the NQM has actively onboarded entrepreneurs. Dedicated guidelines were formulated to support early-stage ventures in this emerging domain, and eight promising startups have already received support. These enterprises are exploring areas ranging from quantum-safe communication to indigenous quantum hardware, strengthening India's position in the global quantum startup ecosystem.

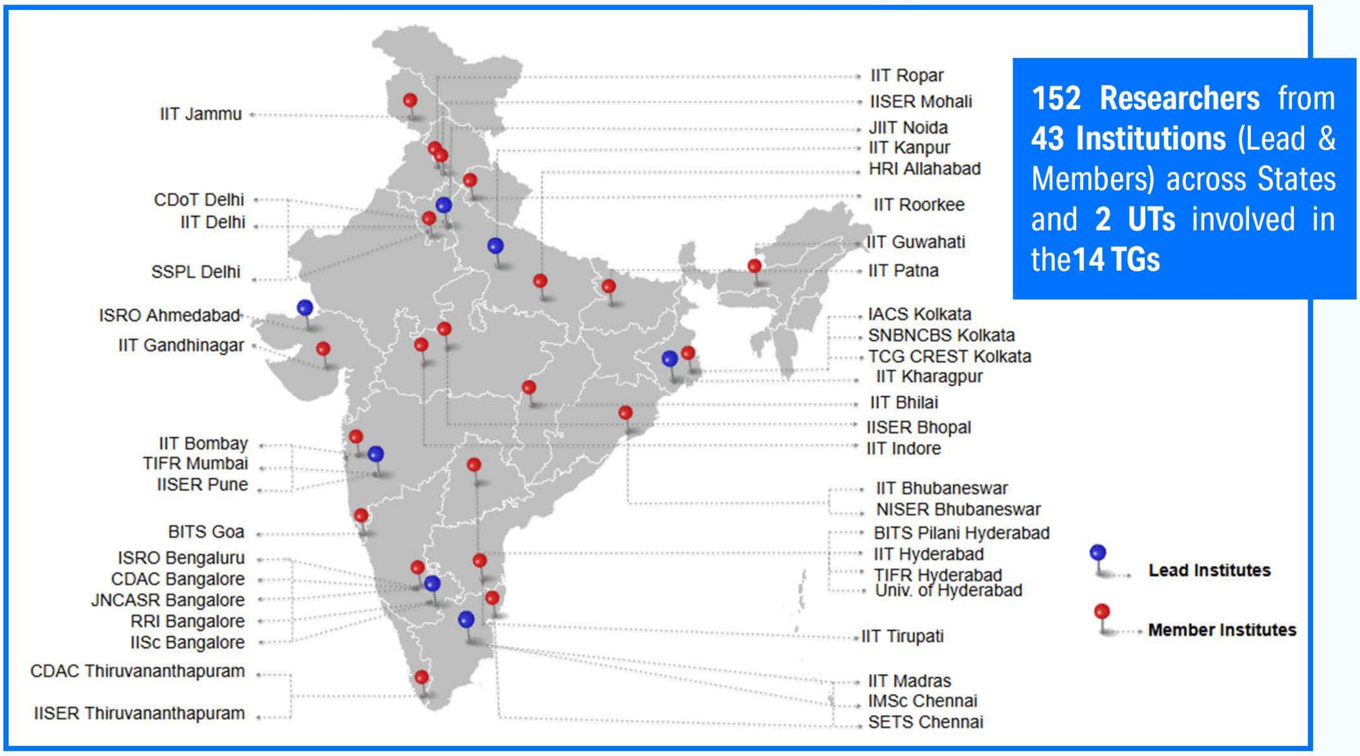
With the world moving rapidly towards a quantum-driven future, NQM places India at the forefront of this revolution. The mission is expected to generate not only new knowledge but also a wave of skilled professionals, cutting-edge startups, and global collaborations, ultimately strengthening India's position in the international quantum landscape.

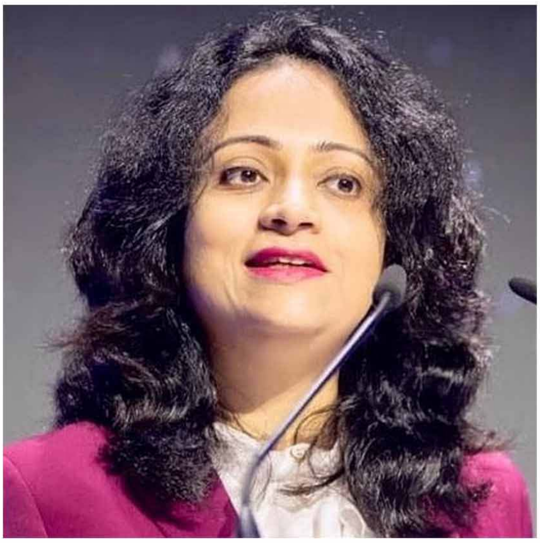
Future Roadmap

The mission has charted an ambitious roadmap. Dedicated calls for quantum algorithm research and undergraduate teaching laboratories are underway, alongside a rolling call for startups to ensure continuous engagement with innovators.

These efforts are designed not only to strengthen India's domestic capabilities but also to integrate the country into the global quantum technology race.

Four Thematic Hubs Institutions supported under NQM





India's Quantum Moment: From First Principles to Field Deployments

Reflections from leading the QuIC Lab at RRI Bengaluru - on how first principles turned single-photonphysics into secure networks, new computing pathways, and a nation-scale talent engine.

Prof. Urbasi Sinha
Physicist, Raman Research Institute, Bengaluru
Driving Advancements in Quantum Information and Quantum Computing

The Physics of Trust: A Revolutionary Bet

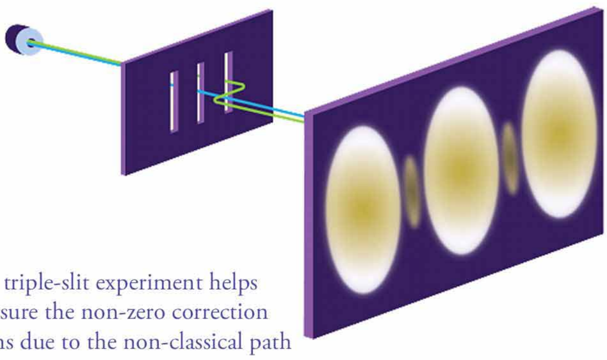
When I established the Quantum Information and Computing (QuIC) Laboratory at the Raman Research Institute in Bengaluru, I made a decision that would reshape India's quantum destiny: to trust physics over promises. While the world chased quantum headlines, we chose to chase quantum truth-the precise, unforgiving mathematics and physics governing single photons in their most vulnerable states.

This wasn't just scientific philosophy; it was a strategic rebellion. At a time when quantum technologies were drowning in hype, QuIC became India's anchor to reality. We would build nothing that we couldn't certify, deploy nothing that we couldn't guarantee, and claim nothing that we couldn't measure with precision that would turn our harshest critics into believers.

Today, our quantum communication links operate with reliability that surprises even sceptics. Our Quantum Random Number Generators (QRNGs) are poised to secure financial networks across continents through QuSyn Technologies-a start-up. The world has taken notice. India, led by QuIC&'s foundations-first philosophy, has become the country that others are starting to study to understand how to build quantum technologies that actually work. Our work at QuIC has influenced international thinking on global quantum policy.

When Physics Becomes Engineering Magic

Superposition Reinvented: While quantum textbooks treat superposition as settled science, we discovered it wasn't. Under realistic electromagnetic conditions-the kind that exists everywhere including pristine laboratories-superposition exhibits correction terms that nobody had measured before. These weren't academic curiosities; they were engineering necessities. Ignoring such corrections risks introducing systematic errors into quantum sensors, communication links, and computing architectures. By quantifying these effects, QuIC provided the community with a firmer foundation for building reliable quantum technologies.



The triple-slit experiment helps measure the non-zero correction terms due to the non-classical path of photons

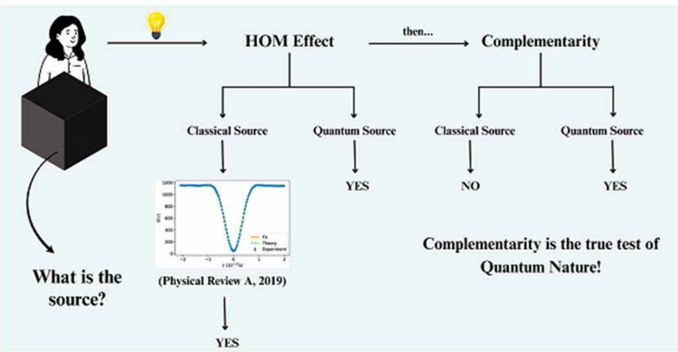
The Most Rigorous Quantum Proof Ever

Our simultaneous violation of both the Leggett-Garg inequality and its Wigner variant using single photons created what experts call the most watertight demonstration of quantum nonclassicality ever achieved for a single photon. We closed every loophole that sceptics had identified over 30 years of quantum experiments. This was not only a scientific achievement - it also set a benchmark for single-photon quantum technologies. Looking ahead, the protocols we developed could serve as the basis for certifying whether future quantum devices are genuinely quantum.

The Optical table set-up that aided in the realization of the loop-hole free experiment to generate random numbers, using the Leggett-Garg inequality

Hong-Ou-Mandel Alchemy

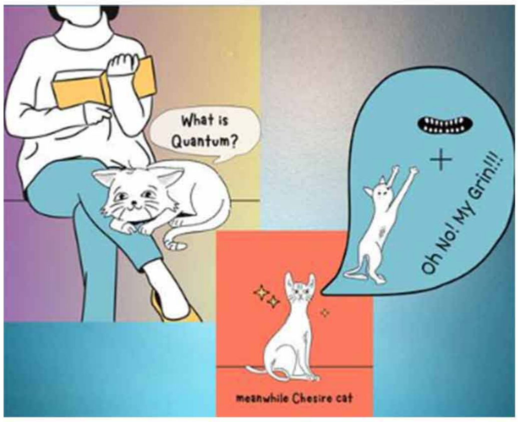
The Hong-Ou-Mandel effect - two identical photons refusing to separate at a beam splitter - had become quantum optics most trusted phenomenon. Until we showed it could be faked. By deliberately creating classical light that mimicked HOM behaviour, we taught the quantum community to distinguish genuine quantum magic from clever classical tricks. The protocols born from this work provide practical tools for calibrating quantum devices and help ensure that claimed quantum effects are genuinely validated.



Complementarity is the true test of Quantum nature!

Measurement Beyond Measurement

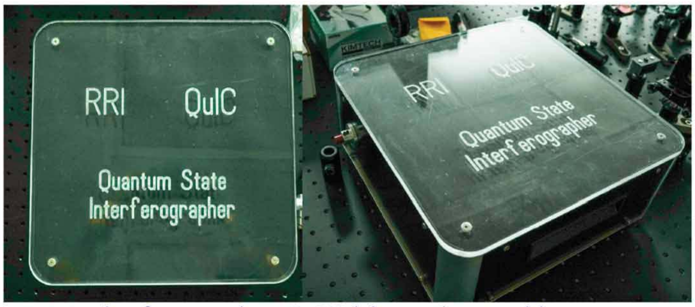
Standard quantum measurements can only access a fraction of quantum information. We worked on techniques to measure the unmeasurable - quantum observables that traditional physics said were impossible to access. These methods reveal how quantum states evolve in ways that were previously invisible, creating diagnostic capabilities that turn black-box quantum devices into fully transparent systems.



A cartoon representing the Quantum Cheshire Cat Effect, which we observed unambiguously for the first time in our lab
Credits: Mehak Layal, PhD Student, QuIC Lab, RRI

The Alchemy of Translation

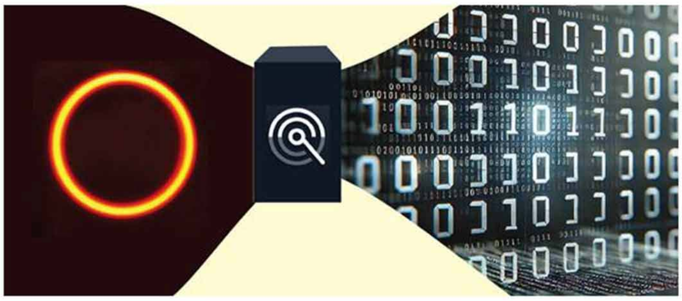
Quantum Diagnostics Revolutionized: Traditional quantum state characterisation requires thousands of measurements---utterly impractical for real systems. Our interference-based method, published in Physical Review Letters, 2020, delivers complete quantum diagnostics with minimal measurements. It is like having an MRI for quantum states, instantly revealing everything you need to know about system health. This method is increasingly being evaluated as a diagnostic option for quantum networks and shows strong potential for widespread use.



An example of one work at QuIC lab translating table-top experiments to a product tool-box

Randomness That Physics Guarantees

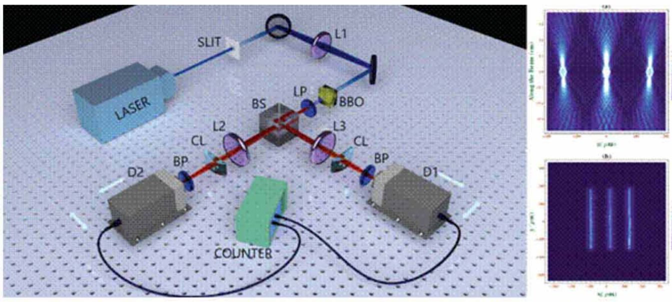
True randomness isn't just unpredictable - it is certified by the laws of physics themselves. Our compact QRNGs produce randomness so pure that even hypothetical future technologies couldn't predict it. Through QuSyn Technologies, these devices are transitioning from research prototypes to commercial products positioned to protect critical infrastructure as quantum- safe cryptography becomes essential.



Work at QuIC Lab at RRI bridging the route from a single photon source (left) to the generation of truly random numbers (right)

Photonic Computing, Indian Style

Rather than replicating western quantum computing architectures, we have leveraged India's strengths in photonics to explore high-dimensional quantum information processing (QIP). Our work encodes information in light's spatial structure, enabling demonstrations of information density beyond conventional qubit approaches. These efforts are best understood as building foundational components such as sources, encodings, and characterisation methods that could, in the long term, support photonic quantum computing architectures suited to India's ecosystem. While much progress remains, these building blocks mark essential steps toward eventual applications in quantum computing.



Schematic of the experimental setup for the higher dimensional photonic QIP platform. On the right, the simulated and experimentally measured images of the higher dimensional encoding at the non linear crystal plane are shown.

The Human Revolution

QuIC has become more than a laboratory - it's a quantum talent forge. Students arrive eager to learn textbook quantum mechanics and graduate as quantum engineers who can make the impossible routine. They learn to push noise floors to their fundamental physical limits, transform quantum paradoxes into practical design rules, and package delicate optical systems into devices robust enough for field deployment.

The launch of QuSyn Technologies exemplifies our philosophy: innovations don't remain trapped in academic papers but transform into products that change the world. This start-up represents a new paradigm where foundational quantum research directly feeds commercial innovation, creating a virtuous cycle where market demands inform scientific priorities and scientific breakthroughs enable market transformation.

When QuIC alumni join other institutions or launch their own companies, they carry with them not just technical knowledge but a culture of precision, a commitment to foundations, and an ability to bridge the gap between what physics permits and what engineering delivers.

Infrastructure That Astonishes

The progression of India's quantum communication capabilities reads like science fiction becoming science fact:

2020: India's first end-to-end free-space quantum key distribution, achieving security metrics that surpassed international benchmarks. Our end-to-end simulator now patented-revealed why other systems failed by modeling imperfections that purely theoretical analyses missed.

2021: The first building-to-building entanglement link in India's atmosphere, conquering synchronization challenges, background noise, and atmospheric turbulence.

2023: Quantum communication between stationary sources and moving receivers, complete with precision pointing and tracking that opens the gateway to satellite quantum networks.

Each breakthrough built upon QuIC's foundational discoveries: superposition corrections that prevent systematic errors, nonclassicality certification that guarantees quantum behaviour, HOM protocols that enable accurate calibration, and measurement techniques that reveal what is happening inside quantum systems.

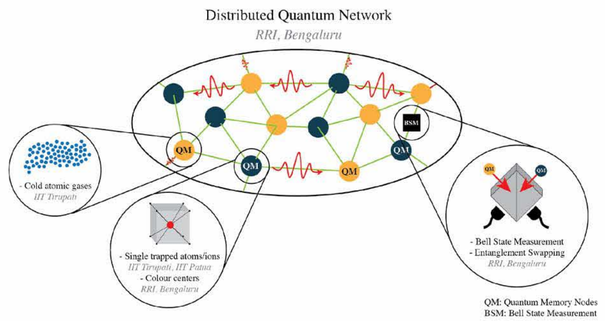
The Next Quantum Revolution

The coming five years will witness quantum technologies moving from impressive demonstrations to operational infrastructure that citizens depend upon. Campus and city quantum networks will employ calibration protocols pioneered at QuIC, with continuous verification through our interference-based diagnostics ensuring reliability. Satellite quantum communications will employ space-qualified payloads developed using QuIC methodologies,supported by ground stations optimized for performance under real atmospheric conditions. Crucially, these efforts now advance under the umbrella of the National Quantum Mission(NQM), which provides the institutional framework and scale to transform individual breakthroughs into deployable national infrastructure.

NQM: Architecting India's Quantum Future

My involvement with NQM extends from its concetion to its current implementation. As a member of the draft project report committee that outlined the roadmap, I helped shape its strategic vision. Today, I lead one of its most ambitious technology groups: quantum entanglement distribution and photonic repeater networks.

This collaborative project brings together a consortium of India's leading institutions - IIT Tirupati, IIT Patna, Harish-Chandra Research Institute Prayagraj, and IISER Mohali - each contributing expertise ranging from cold-atom quantum memories to repeater theory and error-correction protocols. At QuIC, we anchor the effort by developing diamond - vacancy–based quantum memories and custom entangled photon sources precisely matched to various memory specifications.



The specific areas QuIC Lab at RRI Bengaluru will lead under the National Quantum Mission

Credits: Dr. Arijit Sharma, IIT Tirupati

Our near-term goal is to demonstrate entanglement swapping across these nodes and to build India's first synchronous quantum repeater network. A particularly-significant milestone will be the integration of different memory technologies - such as portable DLCZ systems with SPDC-based sources - showing that heterogeneous quantum memories can operate together within the same network.

Beyond proof-of-concept, we will steadily advance diamond-vacancy–based quantum memories toward higher technology readiness levels, laying the groundwork for domestic manufacturing and eventual deployment. This collective effort represents a coordinated national step toward the infrastructure needed for a scalable quantum internet.

Vision 2047: The Quantum Bharat

By centenary of India winning its freedom, the country will have a sovereign quantum communications fabric-integrating terrestrial fibre and satellite links - that protects critical systems while enabling secure collaborations across institutions, industries, and borders. Foundational work on high-dimensional photonic encodings and hybrid quantum memories will have matured into practical platforms co-developed with India's photonics and semiconductor manufacturing strengths. We hope that the methodological frameworks developed at QuIC nonclassicality certification, error-budget methodologies, and calibration standards - will serve as global references for building reliable quantum infrastructure.

QuIC's journey from a single laboratory to a catalyst within the NQM embodies more than technological achievement - it represents a philosophy of development. Yet the deeper transformation lies in how we as a community approach the unknown: comprehending before commercialising, writing playbooks before writing patents, and training scientists to question as much as to build. This philosophy has already moved quantum communications from laboratory curiosity to early field deployment, advanced QRNGs toward protecting real networks, and established measurement protocols that will form the quality benchmarks for future industries.

As India's quantum story accelerates toward 2047, it carries a lesson that extends beyond quantum mechanics: nations that master first principles will shape the technologies of tomorrow, while those that chase shortcuts will spend decades catching up.

> **"The quantum revolution has begun, and it speaks with an Indian accent**

Harnessing Quantum Sensing Frontiers

Prof. Kasturi Saha
Associate Professor, IIT Bombay
Distinguished Researcher in Quantum Sensing, Imaging and Metrology

The Story of PQuest Lab and QMet

When I think about the second quantum revolution, I see it not as an abstract concept but as a daily reality in my laboratory. The principles of quantum mechanics, once confined to textbooks and thought experiments, are now tools in our hands, shaping devices that can probe the world in ways classical physics never allowed.

At IIT Bombay, through PQuest Lab (Photonics and Quantum Enabled Sensing Technology Laboratory) and our broader initiative QMet, I have been fortunate to lead a team dedicated to pioneering advances in quantum sensing.

Quantum sensors are distinct from classical counterparts because they leverage quantum coherence and entanglement - non-classical correlations that serve as highly sensitive probes of environmental perturbations.These resources enable measurements of magnetic fields, gravitational acceleration, time, and rotational motion with sensitivities that surpass the standardfields, quantum limit achievable by conventional devices. The spectrum of applications is broad: compact atomic clocks for precision timing and navigation, imaging systems capable of penetrating scattering media, quantum gravimeters for subsurface exploration of mineral and hydrocarbon deposits, and nanoscale biosensors capable of detecting biomarkers at ultra-low concentrations. The key challenge, however, is translating these laboratory-scale demonstrations into scalable, field-deployable instruments, which requires innovations in device engineering, noise mitigation, and interdisciplinary integration.

> **“Our journey began in 2017, when I established PQuest Lab in the Department of Electrical Engineering. My vision was to explore the extraordinary properties of Nitrogen-Vacancy (NV) centers in diamond.**

When the PQuest Lab in the Department of Electrical Engineering was established, my vision was to explore the extraordinary properties of nitrogen-vacancy (NV) centers in diamond. These atomic-scale defects act as quantum sensors, capable of measuring magnetic fields, temperature, strain, and electric fields with exquisite sensitivity, all at room temperature. What makes NV centers special is their versatility and stability, which allow us to engineer practical sensing platforms while pushing the boundaries of fundamental physics.

One of our proudest achievements has been building India's first Quantum Diamond Microscope (QDM). Unlike a traditional optical microscope, which shows us images of cells or structures, this instrument creates spatial maps of magnetic fields. For the first time in India, we could see how currents flow through a semiconductor chip or how a neuron's firing generates a tiny magnetic pulse. In 2020, our group demonstrated tiny magnetic pulse.

In 2020, our group demonstrated video-rate imaging of neuronal activity, proving that this tool could capture the rapid and dynamic nature of neural signals.

We have recently advanced this work to include three-dimensional imaging of current-carrying circuits as well as realistic imaging of neuronal potentials. The applications extend far beyond neuroscience.

Working closely with TCS Research, we are adapting the QDM for non-destructive testing of microchips. Instead of breaking open a circuit to look for flaws, we image its magnetic fields, which could potentially reveal functionality and faults at microscopic scales. This led to our first patent and, soon after, a second one for extending the imaging technique into three dimensions. This progress is a crucial step toward quantum-enabled diagnostics for the semiconductor industry.

An MoU was signed between QMET Tech Foundation, the Quantum Sensing and Metrology Thematic Hub at IIT Bombay, June 2025

One of our current research directions is to extend the QDM beyond static magnetic field mapping toward sensing alternating magnetic fields (AC fields). This development is essential because many technological and material phenomena are inherently dynamic, requiring high temporal resolution and phase-sensitive detection. We have demonstrated that by synchronizing the optical and microwave control of NV centers with the frequency of applied oscillating fields, the QDM can measure both the amplitude and phase of AC responses. This enables frequency-resolved imaging of magnetic susceptibilities in materials such as permalloy disks, providing insights into how quickly they respond to external stimuli—an important parameter for spintronic devices and magnetic memories.

Beyond condensed matter physics, AC-capable QDMs hold promise for semiconductor diagnostics, where circuits often operate under alternating currents, allowing imaging of current pathways and switching dynamics under realistic conditions. We are also pursuing the integration of AC sensing with three-dimensional reconstruction techniques, which would enable volumetric mapping of time-varying magnetic fields in layered circuits and complex materials. Together, these advances will transform the QDM from a static field imager into a dynamic analyzer of magnetic phenomena, significantly broadening its scope for both research and industrial applications.

While the QDM represents the cutting edge of laboratory instrumentation, we are equally invested in developing compact, portable quantum sensors. My students and I have designed handheld NV-based magnetometers that simplify the electronics and signal processing, making the devices easier to operate and cheaper to build. These sensors bring quantum precision out of the lab and into real-world settings. They are already being evaluated for strategic uses, from navigation in GPS-denied environments to defense-grade surveillance.

Our work also spans into the biosciences. By embedding nanodiamonds into living cells, we can measure how the coherence of the NV centers is affected by the cellular environment. This offers us a new way to detect early signs of disease or to monitor stem cell health. In collaboration with colleagues in life sciences and physics, we are using this method to study cellular aging and mechanisms underlying cancer. This is an exciting intersection of quantum technology and biology, opening a door to diagnostic methods that combine physics and medicine. We are advancing our work by integrating the ability to sense both temperature and magnetic fields within the same platform. This dual capability enables us to capture a more complete picture of the environment surrounding the NV centers, as many processes involve coupled thermal and magnetic dynamics. In materials research, heating effects often accompany magnetic transitions, while in semiconductor testing, thermal signatures can reveal

"The applications extend far beyond neuroscience. Working closely with TCS Research, we are adapting the QDM for non-destructive testing of microchips. Instead of breaking open a circuit to look for flaws, we image its magnetic fields, microscopic scales.

hotspots linked to current flow. Additionally, by using nanodiamonds inside biological cells, we can simultaneously monitor local temperature and magnetic field variations, providing unique insights into cellular processes and their micro environments.

We are also building hybrid quantum systems that combine NV centers with microwave cavities. A cavity enhances the interaction between spins and microwaves, improving sensitivity and allowing us to explore phenomena like superradiance in a solid-state system at room temperature. This work not only promises better sensors but also paves the way toward integrating quantum sensing with quantum communication and computation.

Students have been central to every breakthrough at PQuest Lab. From developing algorithms that simplify magnetometry to developing state of the art hardware for quantum sensing, their contributions are at the core of our success. Watching them build experimental setups from scratch, tackle challenges, and present their findings at international forums has been one of the most rewarding aspects of this journey.

Beyond our laboratory walls, QMet Tech Foundation was created under the aegis of the National Quantum Mission as the T-Hub on Quantum Sensing and Metrology at IIT Bombay. The hub comprises of 40 Principal Investigators from 15 institutes across the country. As Project Director for the mission's sensing hub, I see QMet as a bridge connecting academia, government, and industry. Our aim is to ensure that the technologies we develop - whether portable magnetometers, either atomic or NV-center-based, photonics-imaging tools, or chip diagnostic devices - can be translated into deployable solutions that strengthen India's scientific and technological landscape. QMet also plays a catalytic role in entrepreneurship and human resource development. By supporting startups focused on quantum sensing, QMet aims to provide access to technical expertise, laboratory infrastructure, and mentorship that help early-stage ideas grow into viable technologies. This ecosystem will not only accelerate the translation of research into market-ready solutions but also nurture a new generation of innovators. At the same time, QMet is focusing on training students and young researchers, ensuring that India builds a strong talent pipeline capable of driving the country's quantum sensing industry forward.

Looking ahead, my focus is on scaling these technologies. We are working to develop a chip-scale magnetometer, enhance the resolution of the QDM, develop adaptive optics for widefield NV imaging, and integrate sensors into hybrid networks. Each of these directions brings us closer to practical applications: chip manufacturers who need reliable diagnostics, doctors who need new imaging modalities, or defense agencies that require precise navigation systems. The opportunities are vast, and the science is just beginning to unfold.

“Our aim is to ensure that the technologies we develop whether portable magnetometers, either atomic or NV-center-based, photonics-imaging tools, or chip diagnostic devices can be translated into deployable solutions that strengthen India's scientific and technological landscape.

The vision of PQuest Lab and QMet is centered on transforming quantum science into technologies that directly address societal and industrial needs. What once were abstract concepts such as using diamonds as quantum sensors are now evolving into practical tools capable of imaging hidden defects in microchips, detecting the weakest magnetic signatures in materials, and monitoring subtle changes in biological systems.

In the near future QMet will play a pivotal role in building a national ecosystem for quantum sensing, accelerating the journey from prototypes to deployable platforms. By fostering collaboration between academia, industry, and startups, QMet will not only support the creation of new technologies but also ensure the development of skilled human resources to sustain innovation. This integration of fundamental research with entrepreneurship and training will help establish India as a leader in quantum sensing applications across healthcare, defense, and advanced manufacturing.

Dr. L. Venkata Subramaniam
IBM Quantum Ambassador,
IBM Research India
Research Leader in AI & Quantum Computing Technologies

India's Quantum Leap:
From Utility to Quantum Advantage

The first quantum revolution of the 20th century changed the world in ways we now take for granted. Mastery over quantum mechanics to control electron behaviour led to semiconductors, which power every computer and smartphone; lasers, which drive communication networks and medical technologies; and MRI, which transformed healthcare diagnostics. These breakthroughs created entire industries and became the invisible backbone of modern life.

We now stand at the early stages of the second quantum revolution, where instead of passively exploiting quantum phenomena, scientists and engineers are actively controlling quantum states to perform tasks impossible with classical physics. This revolution promises breakthroughs in computing, communication, sensing, and materials science that could dwarf the impact of the first. Among these, quantum computing stands out as the most transformative — a technology that may soon be capable of solving problems that even today's fastest supercomputers cannot. From simulating molecules for new medicines to optimizing supply chains and energy grids, quantum computing promises to redefine the boundaries of innovation.

For India, this moment is especially significant. With the launch of the National Quantum Mission (NQM), the rise of deep-tech startups, state-led programs, and collaborations between academia and industry, the country is positioning itself not merely as a participant but as a leader. The choices made now in talent development, applications and algorithms, and adoption will determine how India will be able to shape the future of the quantum world.

India's Talent and Software Advantage

India's greatest strength lies in its vast pool of software engineers, among the largest in the world. For decades, this workforce has powered the global IT industry, building platforms and solving computational problems at scale. Now, as quantum computing matures, this

Quantum computing offers a unique opportunity to channel this capability into a new paradigm. Developing algorithms, error mitigation strategies, and hybrid quantum–classical workflows requires exactly the skills that Indian engineers excel at. Global progress shows that early advantages are coming not from bigger hardware alone but from smarter software, HPC integration, and algorithmic innovation that make today's systems useful.

For India, the barrier to entry is therefore lower than many assume. Industry does not need to wait for "perfect" quantum computers. Instead, companies can begin today by:

- **Launching utility-scale pilots in pharmaceuticals, materials, logistics, and finance, for example.**
- **Developing domain-specific algorithms in support of complex business needs.**
- **Partnering with industry leaders, startups and universities to co-create applications.**
- **Building in-house quantum software expertise through training programs.**

> "By mobilizing its talent and encouraging industry adoption now, India can position itself at the centre of the transition from today's utility scale, to advantage. If harnessed effectively, India's workforce could become a leading source of the global quantum application layer.

From Utility to Advantage

The global quantum journey is unfolding in stages, with quantum advantage - when a quantum computer can run a computation more accurately, cheaply, or efficiently than a classical computer. - rapidly approaching. Importantly, quantum will not replace classical computing but work alongside it in hybrid workflows.

Utility (today): Current systems, while noisy, can reliably perform computations at ascale beyond brute-force classical methods, and are beginning to show scientific value when paired with classical supercomputers. Pilot projects in drug discovery, optimization, and materials science are already underway. Error mitigation techniques make these early systems usable.

make these early systems usable.

Advantage (By 2026): The point where quantum systems outperform by classical alternatives on meaningful tasks, validated by reproducible benchmarks. The IBMRoadmap indicates credible demonstrations will be available by 2026, and India should aim to contribute its own use-cases in healthcare, logistics, finance, energy, and other industries important to the country's economy.

Large-Scale Fault-Tolerance (by 2029): Fully error-corrected machines, built on logical qubits, capable of reliably executing 100 million+ quantum gates - thousands of times more powerful than today's quantum computers - could be available before the end of the decade. The groundwork laid during the utility and advantage phases will pave the way here.

For India, engaging now in utility use-cases is essential. Each successful pilot delivers value and builds expertise, preparing the ecosystem to attempt advantage-level demonstrations. When fault-tolerant computing arrives, the nation's fluency in utility and advantage will lead the standards and reap the greatest benefits.

Building Quantum Skills and Awareness

To realize this vision, talent development and awarness must match global technical progress. While researchers push the frontiers, the broader ecosystem of students, engineers, entrepreneurs, and policymakers needs structured opportunities.

Education: AICTE and DST have launched India's first UG Minor in Quantum Technologies, embedding quantum learning into engineering curricula. DST is also funding quantum teaching labs across universities.

Upskilling: Software engineers and data scientists can transition into quantum programmers and algorithm designers, creating a new class of professionals ready for pilots. NPTEL courses and community-led efforts like the Qiskit Summer School and Qiskit Fall Fest support this shift.

Public Engagement: Events such as the Amaravati Quantum Valley Hackathon, which engaged 20,000+ students, demonstrate the appetite for hands-on learning and grassroots innovation.

Collaboration: Stronger ties between academia, startups, and enterprises will accelerate learning and generate applications tailored to India's needs in agriculture, healthcare, governance, and climate.

Just as India's IT boom was powered by a skilled workforce, the quantum era will depend on how

Quantum for National Priorities

For India, the promise of quantum computing must be tied to societal impact. The National Quantum Mission can ensure that breakthroughs address the country's most pressing needs:

Healthcare & Pharma: Simulating molecules to accelerate affordable drug and vaccine discovery.

Agriculture: Optimizing crop planning and supply chains to boost resilience and sustainability.

Energy & Climate: Designing new materials for clean energy and carbon capture.

Logistics & Infrastructure: Streamlining freight, air traffic, and urban mobility.

Governance & Security: Enhancing secure communication, disaster management, and resource allocation.

By aligning quantum research with national priorities, India ensures that progress benefits millions while establishing a distinctive global identity.

Building a Quantum Innovation Ecosytem

Beyond skills and pilots, India needs an ecosystem that allows ideas to move quickly from research labs to real products and companies. Just as the IT revolution was accelerated by software parks and incubation hubs, the quantum era will require a similar enabling environment to drive quantum products made in India.

Key elements of such an ecosystem include:

Incubators and Accelerators: Dedicated programs to support quantum startups in developing algorithms, software platforms, and domain-specific applications.

Venture Capital and Government Funding: Risk capital that allows young companies to experiment and scale without being constrained by long R&D cycles.

Industry–Academia Consortia: Joint centres where universities, enterprises, and government labs work together on problems of national and global importance.

Access Infrastructure: Cloud-based quantum systems and open testbeds where students, researchers, and startups can test their ideas at low cost.

With such an ecosystem in place, India can ensure that breakthroughs don't remain locked in academic journals but translate into deployable products, applications, patents, and companies that create jobs and global impact.

Vision 2030: India's Quantum Roadmap

If executed well, by 2030 India could stand among the world's leaders in quantum computing, not just as a user but as a co-creator of applications and standards.

1. Lead in Quantum Software

• Train thousands of engineers via the UG and PG Programs in Quantum Technologies, NPTEL programs, and global initiatives like Qiskit Summer School and Qiskit Fall Fest.

• Build global open-source tools for hybrid quantum–classical computing.

2. Demonstrate Quantum Advantage Pilots

- Deliver breakthroughs in drug discovery, logistics, energy, and finance.
- Scale grassroots innovation through hackathons like Amaravati Quantum
- Valley Hackathon, ensuring students transition from ideas to prototypes.
- Tie pilots to national priorities in healthcare, agriculture, and climate.

3. Prepare for Fault-Tolerance

- Expand university labs to give hands-on experience in algorithms and applications.
- Contribute to the global effort in error correction and logical qubits.

• Build pathways from education to employment, onnecting UG minors, hackathon winners, and trained professionals into startups, labs, and government projects.

4. Quantum Products that Power the World

• Develop exportable quantum products — software libraries, optimization platforms, simulation engines, and algorithm suites — that become part of the global stack for research, industry, and education.

• Enable Indian startups and enterprises to launch domain-specific quantum applications (e.g., for pharmaceuticals, fintech, climate modelling) that serve both domestic and international markets.

• Position India as a hub for quantum product platforms, where enterprises worldwide can access quantum solutions built in India.

Looking Ahead

The first quantum revolution largely passed India by, as semiconductors and lasers were pioneered elsewhere. The second, however, offers a chance not just to catch up but to lead.

With millions of software engineers, a goverment-backed mission, and an emerging ecosystem of startups and research hubs, India has the ingredients to build a globally significant presence.

By focusing on utility today, advantage tomorrow, and fault-tolerance in the future, India can ensure it becomes not just a consumer but a shaper of the global quantum landscape. If seized, the decade from 2025 to 2035 will be remembered as the period when India made its quantum leap.

IBM Quantum System 2

Eight Startups Supported Under NQM

Marking a major step in India's quantum journey, eight pioneering Startups have been selected and supported under the National Quantum Mission (NQM) and the National Mission on Interdisciplinary Cyber-Physical Systems (NMICPS). These Innovators are pushing the frontiers of quantum technology across computing, communication, sensing, and materials.

QPiAI India Pvt. Ltd.
Bengaluru, is working on building a superconducting quantum computer.

QNu Labs
Bengaluru, is developing secure quantum communication networks.

Quanastra Pvt. Ltd.
Delhi, is developing advanced cryogenic detectors.

Quan2D Technologies
Bengaluru, is advancing superconducting single-photon detectors.

QuPrayog Pvt. Ltd.
Pune, is innovating optical atomic clocks in quantum sensing and metrology.

Prenishq Pvt. Ltd.
IIT Delhi, is creating precision diode-laser systems.

Dimira Technologies
IIT Mumbai, is focusing on indigenous cryogenic cables.

Pristine Diamonds Pvt. Ltd
Ahmedabad, is producing diamond materials for quantum sensing.

Together, these Startups are set to accelerate India's capabilities in quantum research, industrial applications, and technological self-reliance, paving the way for the nation to emerge as a global leader in this transformative field.

QpiAI

Full-Stack AI & Quantum Innovation

QpiAI, based in Bengaluru, is revolutionizing the way industries solve complex problems by merging Artificial Intelligence with Quantum Computing. Recognized under India's National Quantum Mission, the startup has developed India's largest superconducting quantum computer (25 qubits) and integrated it into a high-performance computing environment, creating a scalable quantum data center.

The startup's solutions span hardware, software, and applications, including quantum computers for research and education, SDKs and simulators for developers, and industry-specific platforms for logistics, drug discovery, matrials science, and optimization.

QpiAI's technology is already delivering impact: its logistics platform reduced route distances by 60%, cut vehicle usage by 47%, and solved European routing scenarios 72× faster, while its optimization engine accelerated automotive design simulations 96× faster using 10× less compute. Through collaborations with enterprises, QpiAI enables organizations to harness AI + Quantum technologies and drive innovation across sectors.

QpiAI Indus 25 Qubits Quantum Computer at QpiAI Bangalore Center

QNu Labs

Building the World's First Quantum-Safe Heterogeneous Network

Incubated at IIT Madras Research Park in 2016, QNu Labs, is at the forefront of quantum-safe cybersecurity, positioning India as a global leader in quantum cryptography. In 2018, it launched Quantum Key Distribution (QKD), marking India's presence on the global quantum map. Key milestones include winning the iDEX Open Challenge 2.0 in 2022 with a 150-km QKD system for the Army; building a Hub-and-Spoke QKD network under the NSCS grant; developing a quantum-secure VPN using its QRNG product and NIST-shortlisted PQC algorithm, deployed at MCEME and MCTE in 2023–24; and delivering 25 QKD systems to the Indian Navy in 2024.

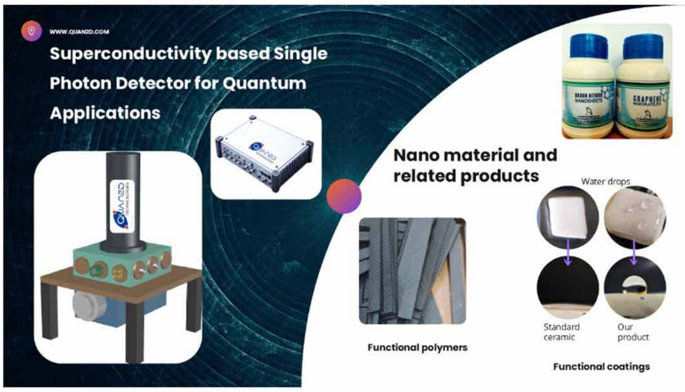
QNu's flagship products- Tropos (Quantum Random Number Generator), Armos (QKD), and QShield (quantum-secure SaaS platform), are already deployed across defence and strategic sectors, including DRDO, WESEE, BEL, and the Indian Army.

Selected under the National Quantum Mission, QNu is developing the world's first end-to-end quantum-safe heterogeneous network, integrating free-space QKD, indigenous components (SPDs, encryptors, QHSM), and a software-defined QKD controller, showcasing India's leadership in next-generation quantum communications.

Quan2D Technologies

Emerging from nearly two decades of pioneering research in quantum and materials science, Quan2D Technologies, Bengaluru is a deep-tech startup focused on superconducting nanowire single-photon detectors (SNSPDs) and scalable nanomaterial platforms. The startup bridges laboratory breakthroughs to industrial-scale deployment, with a strong emphasis on indigenous development, affordability, and global competitiveness. Leveraging expertise in quantum device technology and advanced materials, Quan2D is building foundational infrastructure for India's quantum future, aligned with national missions and poised to make a global impact in next-generation quantum technologies.

Quan2D's core products include SNSPDs, which offer high detection efficiency, ultra-low timing jitter, and modularity for plug-and-play applications in strategic sectors, and scalable nanomaterial synthesis platforms, developed through indigenously fabricated processes and protected by two patents, providing affordable high-quality 2D nanomaterials for Indian infrastructure creation.



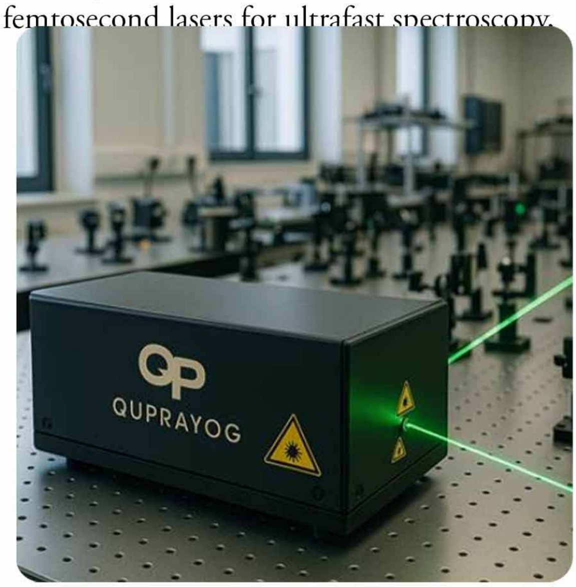
These technologies have significant real-world applications. SNSPDs serve as ultra-sensitive, low-noise detectors for quantum communication, imaging, and sensing, while the scalable nanomaterial platforms enable high-quality 2D nanomaterials for nano/micron-scale devices, electronics, biosensing, composites, and coatings.

Quan2D has received notable recognition and support, including the Biotechnology Ignition Grant (BIG) 2022 from BIRAC–DBT, the Elevate 2024 Startup Award from the Government of Karnataka, and the National Quantum Mission Startup Award 2024. The startup has also garnered media coverage across platforms, including Doordarshan Chandana.

QuPrayog

Leading India's journey into advanced quantum instrumentation, QuPrayog based in Pune is a deep-tech startup founded by scientists for scientists. It develops indigenous femtosecond lasers, optical frequency combs, and atomic clocks, bridging accessibility and affordability gaps in research labs, industries, and next-generation technology.

The startup is currently developing cost-effective and reliable femtosecond laser systems, optical frequency combs, and prototypes of use-case specific atomic clocks, addressing critical dependencies on expensive imports. QuPrayog's technologies have wide-ranging applications: femtosecond lasers for ultrafast spectroscopy, semiconductor research, medical imaging, materials processing, and drones; optical frequency combs for time-frequency metrology, secure satellite communication, advanced telecommunications, and microfabrication; and atomic clocks for GPS independence, secure military communication, satellite navigation, and precise financial transaction time-stamping.



Key achievements include securing seed funding under the National Quantum Mission from IHUB (DST, IISER Pune), incubation at IIT Madras and IISER Pune, and expanding collaborations with deep-tech and space-tech startups for next-generation navigation, secure communication, and satellite subsystems.

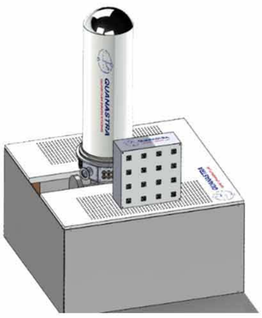
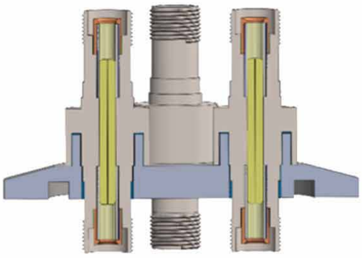
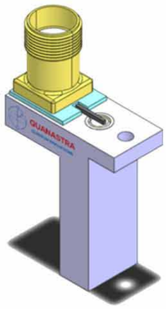
Quanastra Pvt. Ltd

Quanastra Pvt. Ltd, Delhi is an Indian deep-tech startup advancing indigenous capabilities in superconducting photon detection, thin-film optics, and cryogenic engineering. Founded with the vision of becoming a global leader in photon detection and quantum hardware, the startup develops infrastructure to support next-generation quantum and photonics technologies. Quanastra bridges fundamental research and industrial-grade solutions by offering superconducting nanowire single-photon detectors (SNSPDs), cryo-electronic systems, quantum-grade thin-film coatings, and advanced photonic devices, strengthening India's position in the global quantum ecosystem.

Its product portfolio includes high-performance SNSPDs with cavity-enhanced designs, fractal nanowires for polarization independence, photon-number-resolving architectures, and mid-infrared detectors for advanced communication and sensing. Scalable cryogenic systems and cabling solutions enable plug-and-play platforms from compact tabletop units to rack-mounted multi-channel systems.

These technologies impact multiple domains: quantum communication (secure QKD networks and satellite communication), quantum computing (high-efficiency qubit readout), bioimaging and sensing (single-photon-level imaging), photonics and AI/ML hardware, and scientific instrumentation (single-photon cameras, high-resolution spectrometers, and astronomical instruments).

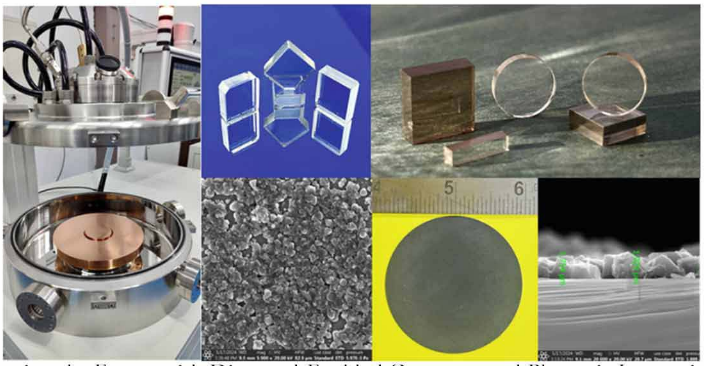
Recent achievements include collaborations with TIFR Hyderabad for high-uniformity wafer-scale thin-film deposition, RRCAT Indore for thin-film mirrors and NbN thin-films, the development of a small-scale prototyping facility with cleanroom and labs, and obtaining the export/import license.


Pristine Diamonds

Established at the intersection of academia and deep-tech innovation, Pristine Diamonds at IIT Delhi specializes in engineering high-purity, low-defect lab-grown diamonds for advanced technologies. Using Microwave Plasma Chemical Vapor Deposition (MPCVD) systems, the startup precisely controls plasma chemistry, growth kinetics, and in-situ diagnostics, translating diamond's exceptional thermal, optical, and quantum properties into devices for photonics, power/RF electronics, and quantum technologies.

Pristine Diamonds' quantum-grade diamonds, engineered with nitrogen-vacancy (NV) centers, form the foundation for quantum computing, spin-based quantum sensing, and secure quantum communication networks. Designed for enabling long coherence times, high spin stability, and precise optical addressability, our quantum-grade diamonds will provide the building blocks for scalable quantum architectures. For classical applications, the startup produces polycrystalline diamond thin-film coatings on silicon, sapphire, MgO, and SiC, offering unmatched thermal conductivity and phonon transport. Its diamond optical windows, capable of withstanding extreme photon flux and high-energy radiation, extend the performance of high-power lasers, X-ray optics, and advanced photonic instruments.


Shaping the Future with Diamond-Enabled Quantum and Photonic Innovation

NQM HIGHLIGHTS

The National Quantum Mission **(NQM)**, approved by the Union Cabinet on 19 April 2023 with a total outlay of **₹6003.65 crore** for **eight years**, aims to seed, nurture, and scale up research and innovation in **Quantum Technologies (QT)**

A thriving **quantum startup ecosystem** has emerged, with NQM supporting **eight startups.** Notably, **QNu Labs** created **QShield** (quantum security platform) and **QpiAI** commercialized India's first **quantum computer**

The Mission envisions making India a global leader in Quantum Technologies and Applications **(QTA)** by developing intermediate-scale quantum computers **(50–1000 qubits),** secure quantum communication links over **2000 km**, and **advanced quantum networks**

A dedicated Call for Proposals on **Quantum Algorithms** and a Call for Proposal for setting up Undergraduate Teaching Laboratories in **Quantum Technologies** was officially announced on **11th May 2025**

Beyond computing, NQM focuses on **high-precision magnetometers, atomic clocks, and quantum materials** such as **superconductors** and topological structures for **future technologies**

AICTE launched dedicated **B.Tech Minor** and **M.Tech programmes** in Quantum Technologies, training nearly **2000 Faculty members** through FDPs

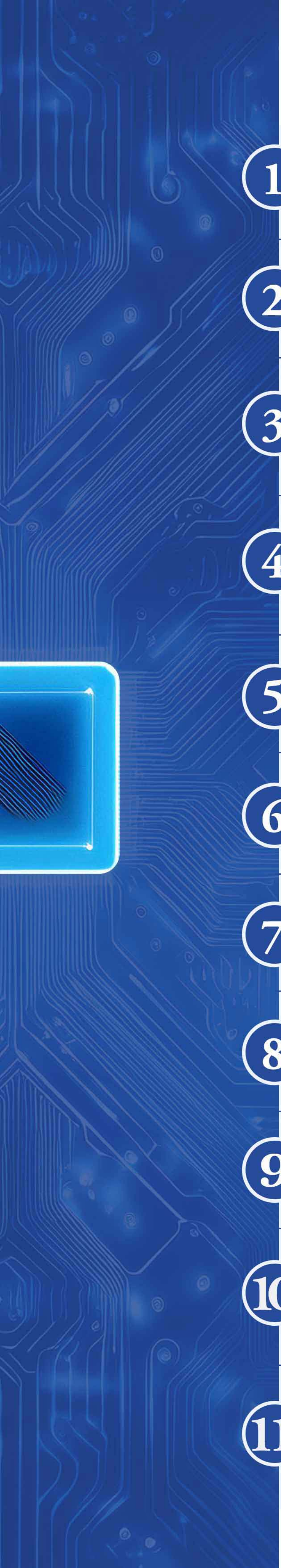
India launched **QSim (first cloud-based simulator)**, built a **7-qubit** superconducting prototype **(TIFR)**, and unveiled **QpiAI-Indus**, a 25-qubit full-stack quantum computer, placing India among **leading nations**

To strengthen R&D, four Thematic Hubs (T-Hubs) have been established:

Quantum Computing – IISc Bengaluru
Quantum Communication – IIT Madras (with C-DoT)
Quantum Sensing & Metrology – IIT Bombay
Quantum Materials & Devices – IIT Delhi

Ensuring future cybersecurity resilience, a Concept Paper on **India's Quantum-Safe Ecosystem** has also been developed. It outlines a national framework for adopting **Post-Quantum Cryptography (PQC)**, emphasizing indigenous standards, regulatory support, and research towards building a secure digital future in the **quantum era**

NQM organized a **two-day Quantum Awareness Programme**, "Quantum Quest 2025", at IIT Kanpur, engaging **750 students and faculty** in exploring the emerging frontiers of **quantum technologies**



Quantum **Glossary**

1

Quanta

The smallest **discrete units** or packets of a physical quantity, such as **energy** or **light**

2

Atomic Clocks

Atomic clocks keep time by measuring the **electromagnetic signals** emitted by electrons in **atoms** as they change energy levels

3

Qubit

A unit of computing information that is represented by a **state of an atom** or **elementary particle** (such as the spin) and can store multiple values at once due to the principles of **quantum mechanics**

4

Superposition

It is a fundamental concept in **quantum mechanics**, describing the condition in which a quantum system can exist in **multiple states** or configurations simultaneously

5

Quantum Materials

Materials with unique quantum properties used for the development of advanced quantum processors and devices

6

Entanglement

A mysterious link between two **particles** where changing one instantly affects the other, no matter how far apart they are

7

Quantum Computing

Harnesses quantum properties like **superposition** and entanglement to perform calculations far beyond the capabilities of **classical computers**

8

Quantum Supremacy

The milestone where a **quantum computer** outperforms the best classical **supercomputer** for a specific task

9

Quantum Internet

A future communication network using quantum entanglement for **ultra-secure connections**

10

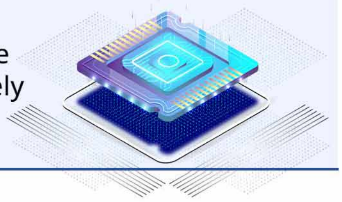
Quantum Communication

Quantum communication Research develops **ultra-secure communication** channels and global networks by leveraging the phenomena of **quantum information**

11

Quantum Sensors

Quantum sensors are measuring instruments that use **quantum mechanical principles** to carry out extremely precise **measurements**



Upcoming Event

The Emerging Science, Technology, and Innovation Conclave (ESTIC)

Date:
3-5 November, 2025

Venue:
Bharat Mandapam, New Delhi

The Emerging Science, Technology, and Innovation Conclave **(ESTIC)** is India's premier STI platform, bringing together ministries, innovators, and global visionaries across health, education, agriculture, energy, space, electronics & IT, environment and more.

A flagship annual event, ESTIC fosters collaboration, celebrates disruptive innovation, and drives forward the vision of "Viksit Bharat 2047", featuring 11 key thematic areas, deeptech showcase and poster sessions, bringing together more than 100 eminent speakers; 3,000 participants; & representation from young scientists, innovators, and entrepreneurs across the country.

This transformative platform will showcase cutting-edge research, deep-tech breakthroughs, and thought-provoking discussions with Nobel Laureates, global experts, policymakers, and emerging leaders - igniting a new era of scientific leadership.

For more details:
https://estic.dst.gov.in/

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