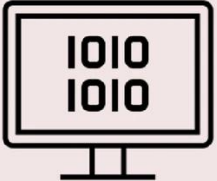
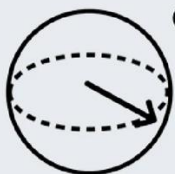
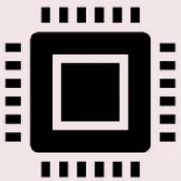
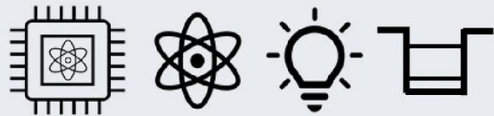


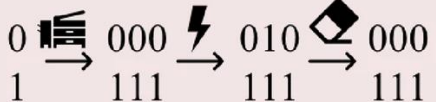



Building the Quantum Future: Hardware, Software, and Beyond

L Venkata Subramaniam

Classical vs. Quantum

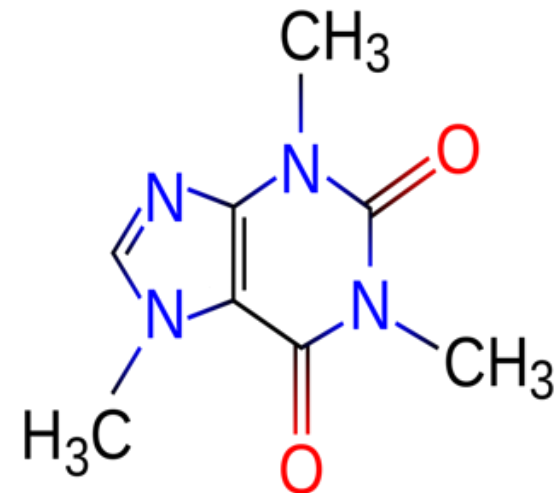
Classical Computer	Quantum Computer
<p>Bit</p> 	<p>Quantum bit (Qubit)</p> 
<p>Transistor</p> 	<p>Physical systems</p>  <p>Superconducting qubits, ions, neutral atoms, photons, quantum dots, etc.</p>
<p>$10^{-13} \sim 10^{-18}$</p>	<p>Error rate</p> <p>$10^{-2} \sim 10^{-4}$</p>
<p>Clock jitter, background radiations, etc.</p> 	<p>Source of error</p>  <p>Temperatures fluctuations, microwave/laser noise, environmental noise (electromagnetic fields), etc.</p>
<p>Copy & majority vote</p> 	<p>Error correction</p>  <p>Physical qubits → Logical qubit</p>

Computing with caffeine

If our best classical computers are so powerful, shouldn't we be able to perfectly simulate molecules and chemical reactions?

This would allow us to accelerate discovery of new compounds and processes for healthcare, materials, alloys, and sustainable energy creation.

Let's consider caffeine ...



Computing with caffeine

We would need approximately 10^{48} bits to represent the energy configuration of a single caffeine molecule at a single instant in a classical computer.

This is 1 to 10% of the total number of atoms in the Earth.

$10^{48} =$
1,000,000,000,000,000,
000,000,000,000,000,000,
000,000,000,000,000



Computing with caffeine

Although it's impossible to completely represent the molecular configuration of caffeine on today's most powerful super computers, we could represent it using 160 logical qubits.

IBM Quantum



It takes a long time to
develop new materials...

10-20+ years

Typical time from material identified in the laboratory to commercialization.

New material process development is constrained by a labor-intensive and time-consuming, trial and error process that must pass through multiple steps, i.e., new materials identification, process development, device development, and product qualification.

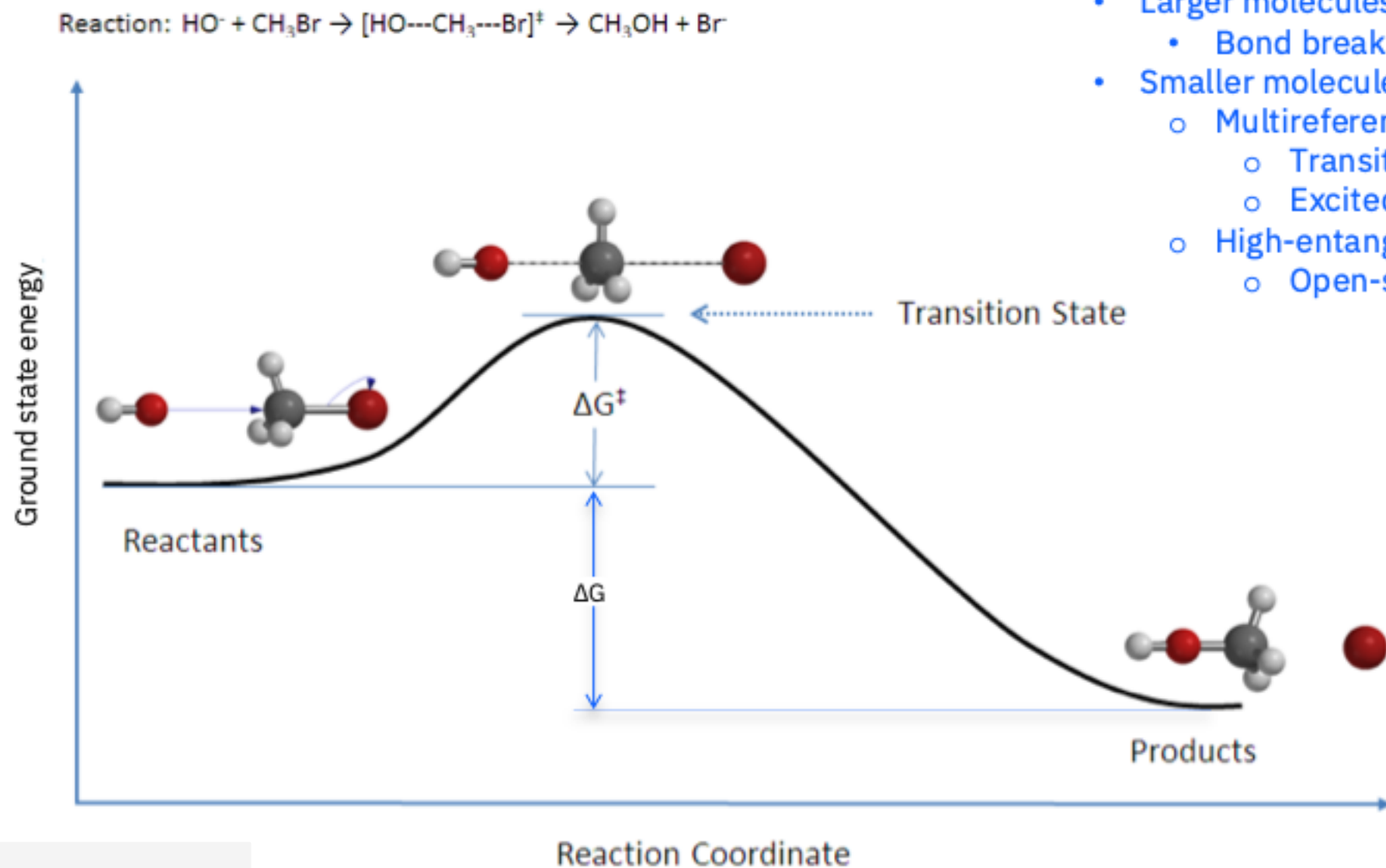
[Materials Genome Initiative | WWW.MGI.GOV](http://WWW.MGI.GOV)

Why can't classical computers model these use cases?

Example: reaction rates

Challenging for classical computers:

- Larger molecules
 - Bond breaking & formation
- Smaller molecules with
 - Multireference character
 - Transition metals
 - Excited states
 - High-entanglement
 - Open-shell systems



Shor's Algorithm

Shor's Algorithm is a **quantum algorithm** that can **factor large numbers efficiently**—something classical computers struggle to do.

It threatens RSA encryption, which relies on the difficulty of factoring large numbers. Shor's algorithm can break RSA in polynomial time using a quantum computer.

Learning



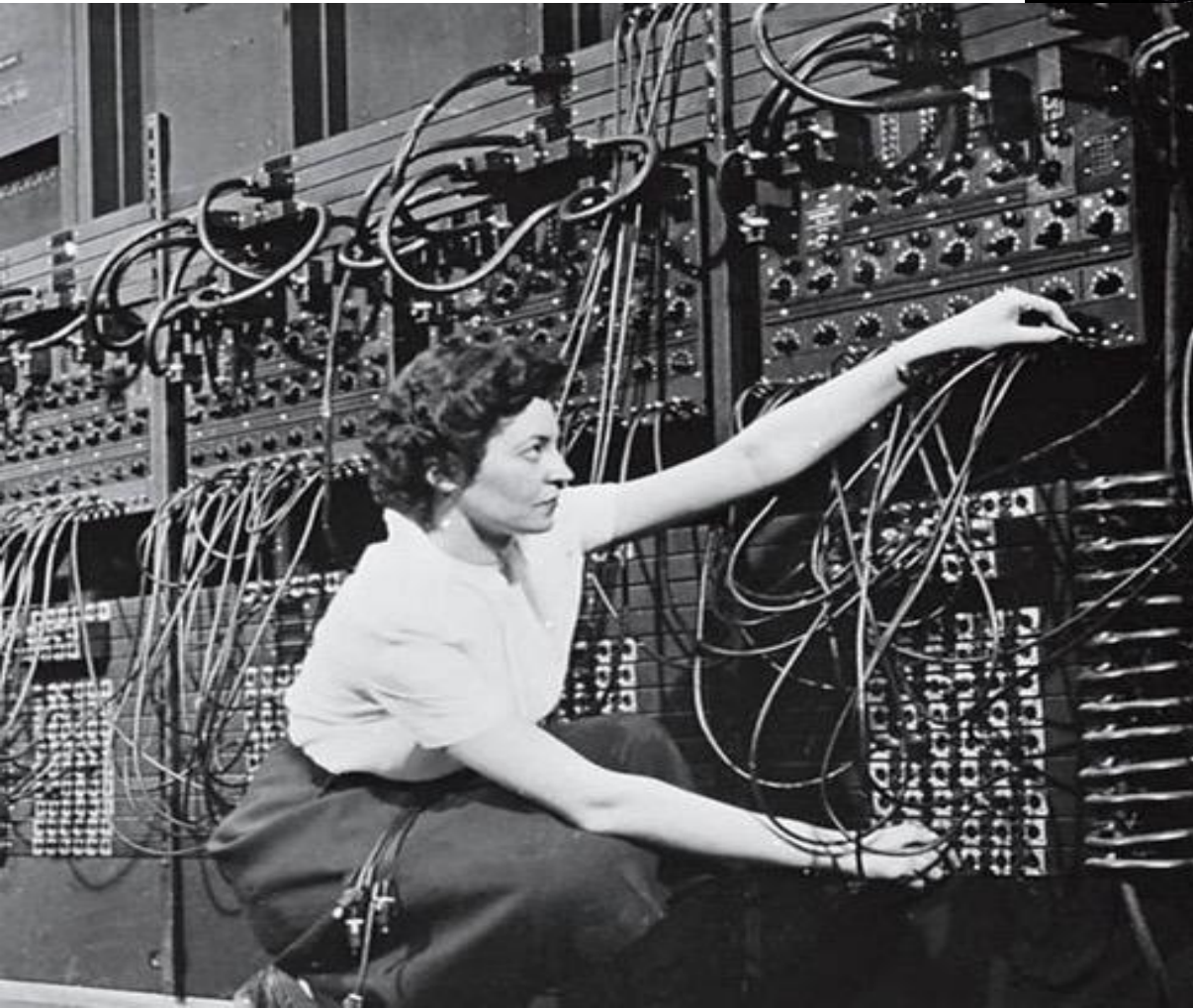
Cat



We are at beginning of new age of computation

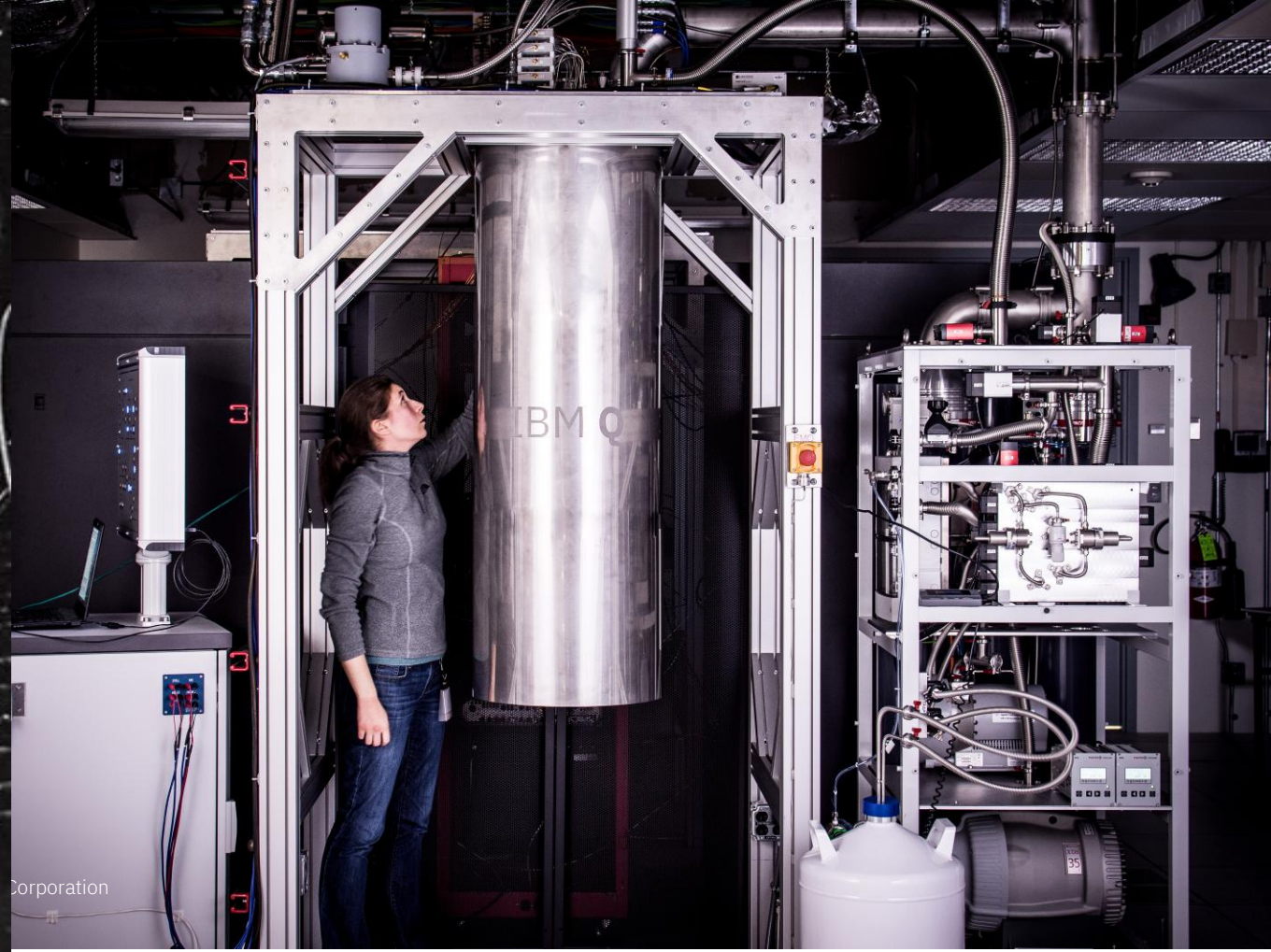
Colossus

First electronic digital programmable computing device



IBM Quantum

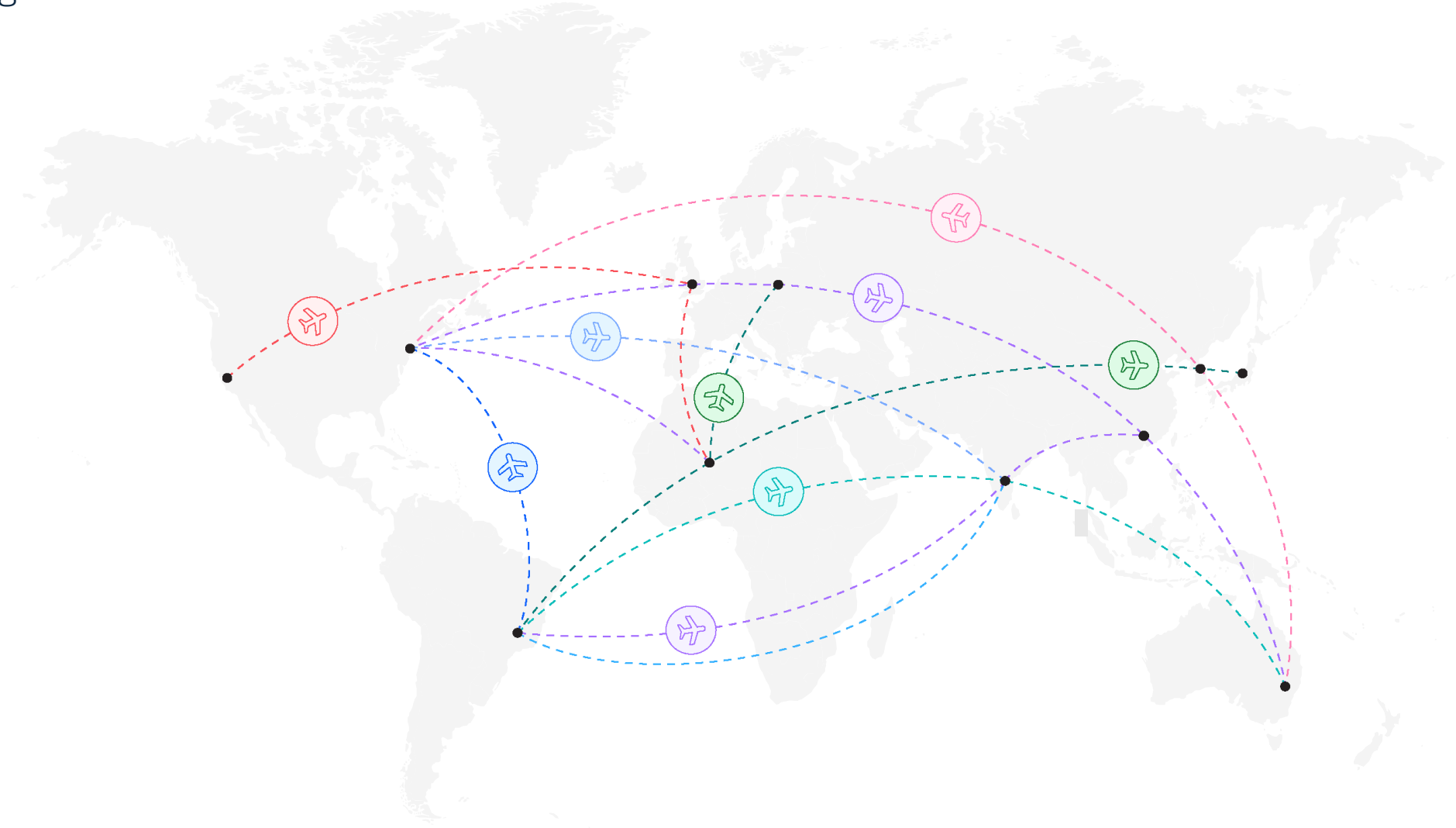
First universal quantum computing device made available to public



Quantum computing

The new wave of computing

- Potential to **Unlock** previously unsolvable problems with quantum computing, cutting computing time **from years to hours.**
- **A new paradigm** of thinking launches inventors into previously uncharted discovery territories with **new use cases.**
- **Accelerate** discovery through a **powerful** hybrid quantum- classical approach.



...But win by changing
the complexity

- How long does it take to multiply 2048 bit integers?
 $p * q = N$

How long does it take to factor 2048 bit integers? $N = p * q$

- Classical Cost of multiplication:

~0.0025s

- Quantum Cost of multiplication:

~75.0000s

Classical Cost of factoring:

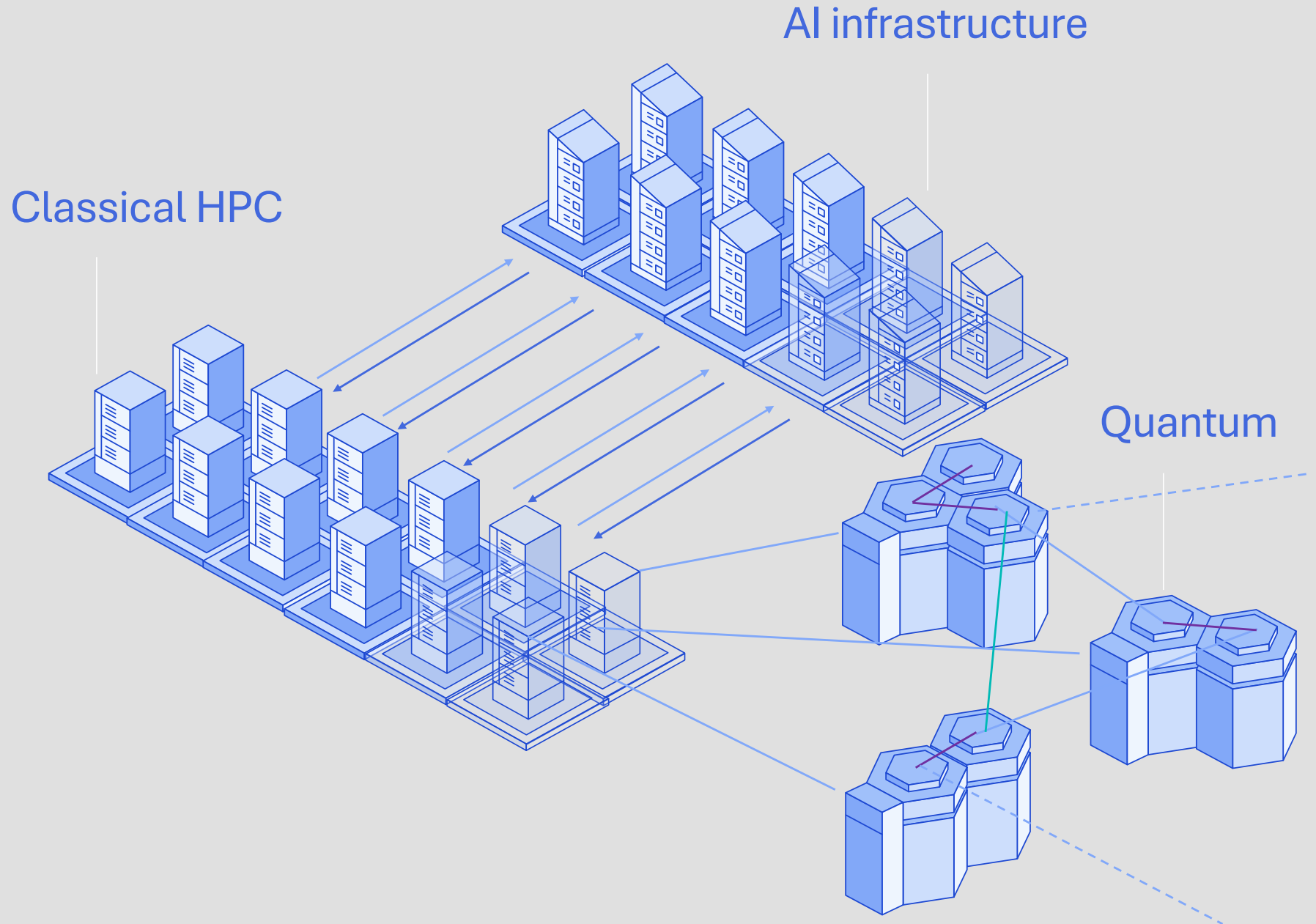
~4.7 billion CPU years

Quantum Cost of factoring:

~8 hours

Quantum is a component in the future of advanced computing

- In the future, quantum will integrate with other components, including AI, to enhance the overall capability of our computational tools.
- Each tool is best suited for certain types of tasks, and all will work together to solve the hardest problems that face society today.



Investment in quantum computing is accelerating at an unprecedented pace

Accelerating adoption and usage

48%

Customer spend CAGR¹

\$42B

Global investment²

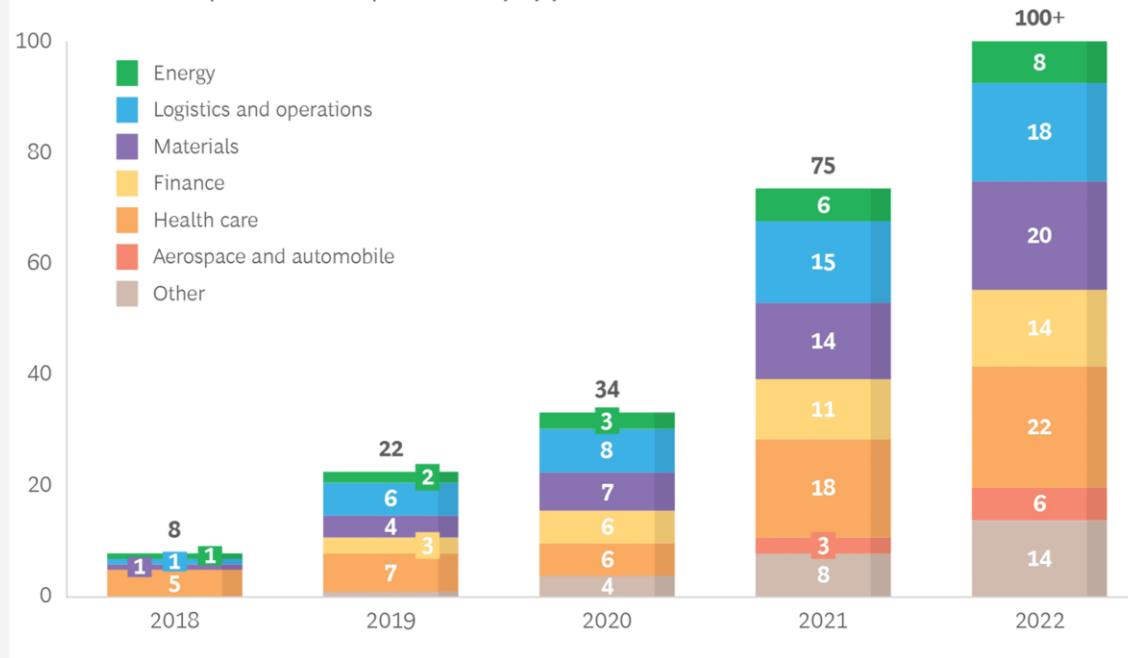
80%

Increase in expected investment by users³

3x

Enterprise use case activity 2020–2022⁴

Number of active proofs of concept in industry by year



Source 1: IDC, IDC’s Worldwide Quantum Computing Forecast: 2023–2027: Surfing the Next Wave of Quantum Innovation,” IDC #US49198322, 2023.

Source 2: McKinsey & Co., “Steady progress in approaching the quantum advantage,” 2024.

Source 3: BCG, “Why users should start building [quantum] capabilities now,” 2022 Q2B Conference.

Source 4: BCG, “Quantum Computing Is Becoming Business Ready,” 2023.

Computationally complex problems exist across almost every industry.

Banking

- Fraud monitoring
- Portfolio optimization
- Risk simulation
- Customer analytics
- Time series forecasting

Automotive

- Battery material design
- Material design
- Mobility as a Service
- Quality control
- Self-driving and ADAS
- Production optimization

Chemicals

- Sustainable products
- Low-carbon manufacturing
- Resilient supply chains
- Process optimization
- Asset health

Life sciences

- Efficient drug research and development
- Clinical trials
- Tractable protein folding
- Call-centric therapeutics
- mRNA

Healthcare

- Accelerated diagnoses
- Personalized interventions
- Adherence to drugs
- Biomarkers
- Image processing

Logistics

- Global logistics optimization
- Disruption management
- Routing optimization
- Predictive maintenance
- Forecasting

Public services

- Security/safety
- Multimodal transport
- City resource planning
- Disaster management
- Fraud detection in tax and social

Insurance

- Catastrophe modeling
- Precise customer profiling
- Efficient risk management
- Optimized pricing of premiums

Electronics

- Faster product design
- Circuit defect identification
- Process optimization
- Production optimization
- Quality control

Airlines

- Forecasting and revenue
- Irregular operations
- Network planning
- Safety and maintenance
- Hyper-personalization

Energy and utilities

- Energy trading
- Optimization of energy grid
- Renewables system design
- Energy forecasting
- Hyper-personalization
- Asset health

Aerospace

- Material discovery
- Aircraft design
- Asset health
- Corrosion and material interaction
- Fuel efficiency

Oil and gas

- Emissions reduction
- Reservoir simulation
- Virtual flow meters
- Subsurface modeling
- Failure prediction

Telecom

- Network optimization
- Network anomaly detection
- Contextual customer segmentation
- Cybersecurity network

Mercedes-Benz

Materials discovery and manufacturing optimization

Mercedes-Benz and IBM have published a series of papers demonstrating progress toward using quantum computers to model material systems, including lithium-sulfur, that are relevant to advancing the performance of batteries.

The teams are also exploring applications in manufacturing defect analysis and product recommendation.

- Journal of Chemical Physics 154.13 (2021): 134115.
- Nature 567.7749 (2019): 491-495.
- arXiv:2004.00957



“Developing and perfecting these hypothetical batteries could unlock a **billion-dollar opportunity.**”

Benjamin Boeser
[Former] Director of Innovation Management
Silicon Valley at Mercedes-Benz R&D America

Higher manufacturing uptime

Business imperative

The uptime of the production line is one of the most important metrics in manufacturing. When the production line is interrupted, costs continue to accrue, while product is not produced.

Current state

Fault detection and classification (FDC) suffers from high false positive rates. Data is often difficult, time-consuming, and expensive to obtain. This is particularly true for highly imbalanced datasets, such as FDC, where the ratio of non-faults to faults can exceed 10,000:1.

Business value exploration

Quantum machine learning models have demonstrated higher accuracy on smaller datasets.



Gate scheduling optimization

Optimizing large combinations of cargo and passenger traffic among the planes, gates, personnel, and the air traffic flows originating and terminating at an airport helps airlines to control costs and reduce inefficiencies.

Delta and IBM partnered to explore the application of quantum computing to airline gate-scheduling quadratic assignment problems (QAP).

The team applied the variational quantum eigensolver (VQE) with a new space-efficient quadratic unconstrained binary optimization (QUBO) algorithm that maps a k -coloring problem to a lower number of qubits.

<https://arxiv.org/abs/2111.09472>

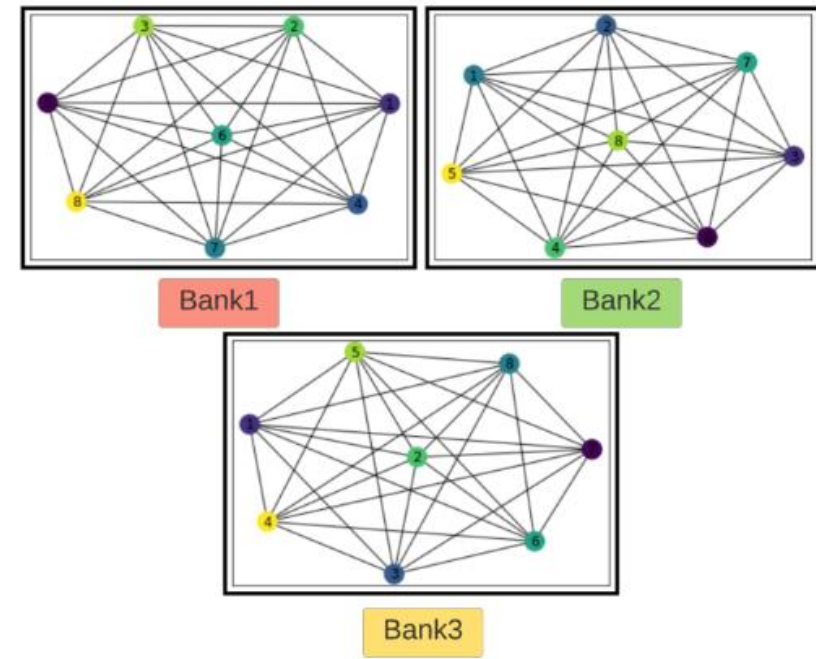


Figure 4 Quantum simulation results for 24 flights and eight gates. The graph successfully colored by the applying the efficient embedding technique.

Table 1 Comparison between the standard QUBO and the efficient embedding approaches

	Standard Embedding	Efficient Embedding
# Qubits	$n \times k: 25$	$n \times \log(k): 15$
Circuit Depth	29	19
Run-time (sec)	5569.84	395.48

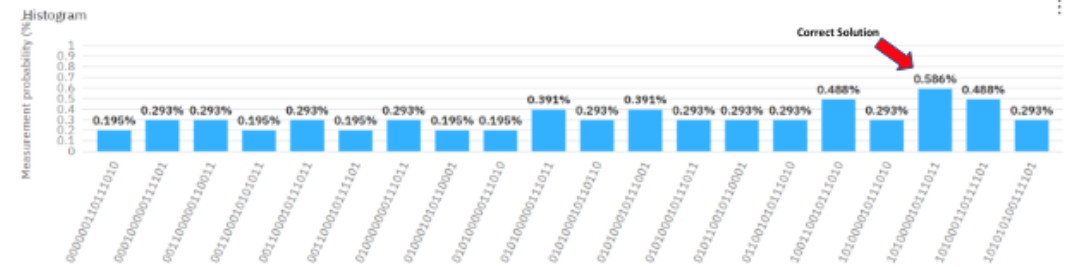


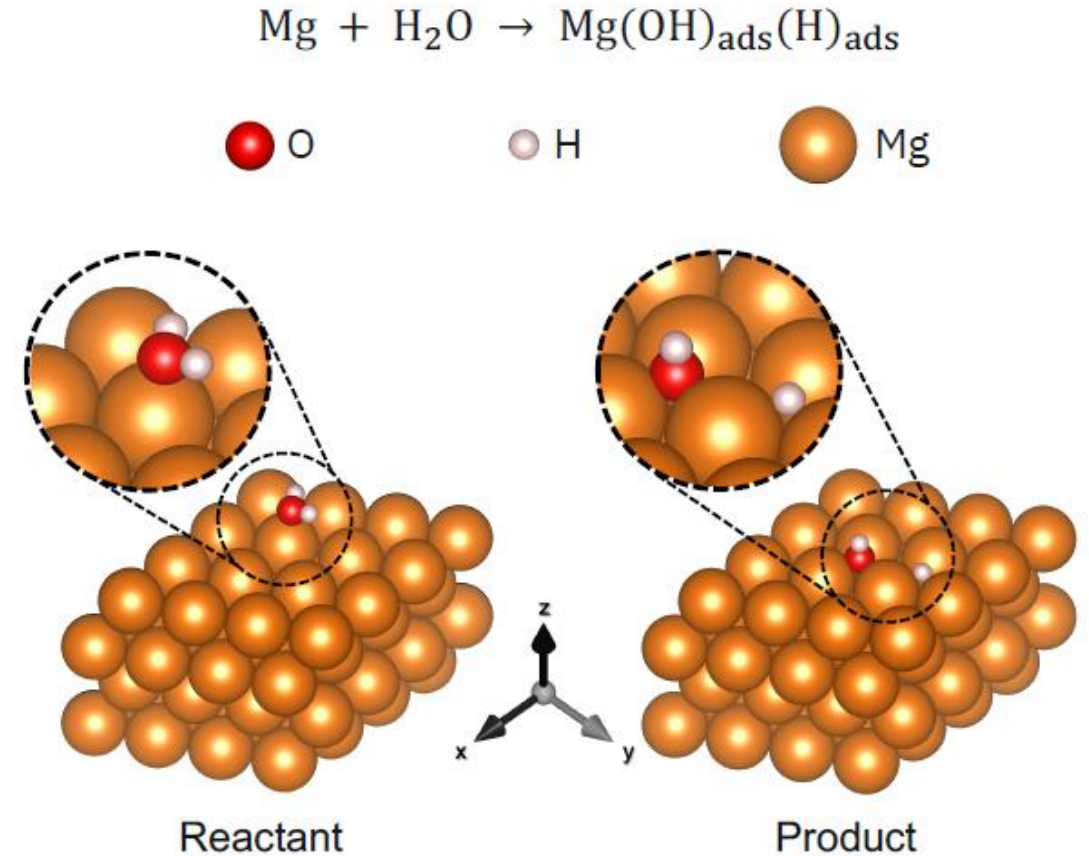
Figure 6 Hardware results with the measurement probabilities for a bank with eight flights and eight gates.

New materials qualification

IBM and Boeing model corrosion reactions for magnesium, the lightest structural metal

Magnesium has the potential to improve the weight of critical aerospace structures. However, magnesium reacts with water and corrodes readily.

IBM simulated the reaction of water with magnesium to better understand its reaction mechanisms to explore the possibility of lighter, higher-performance aerospace structures.



Exoplanet discovery

Business imperative

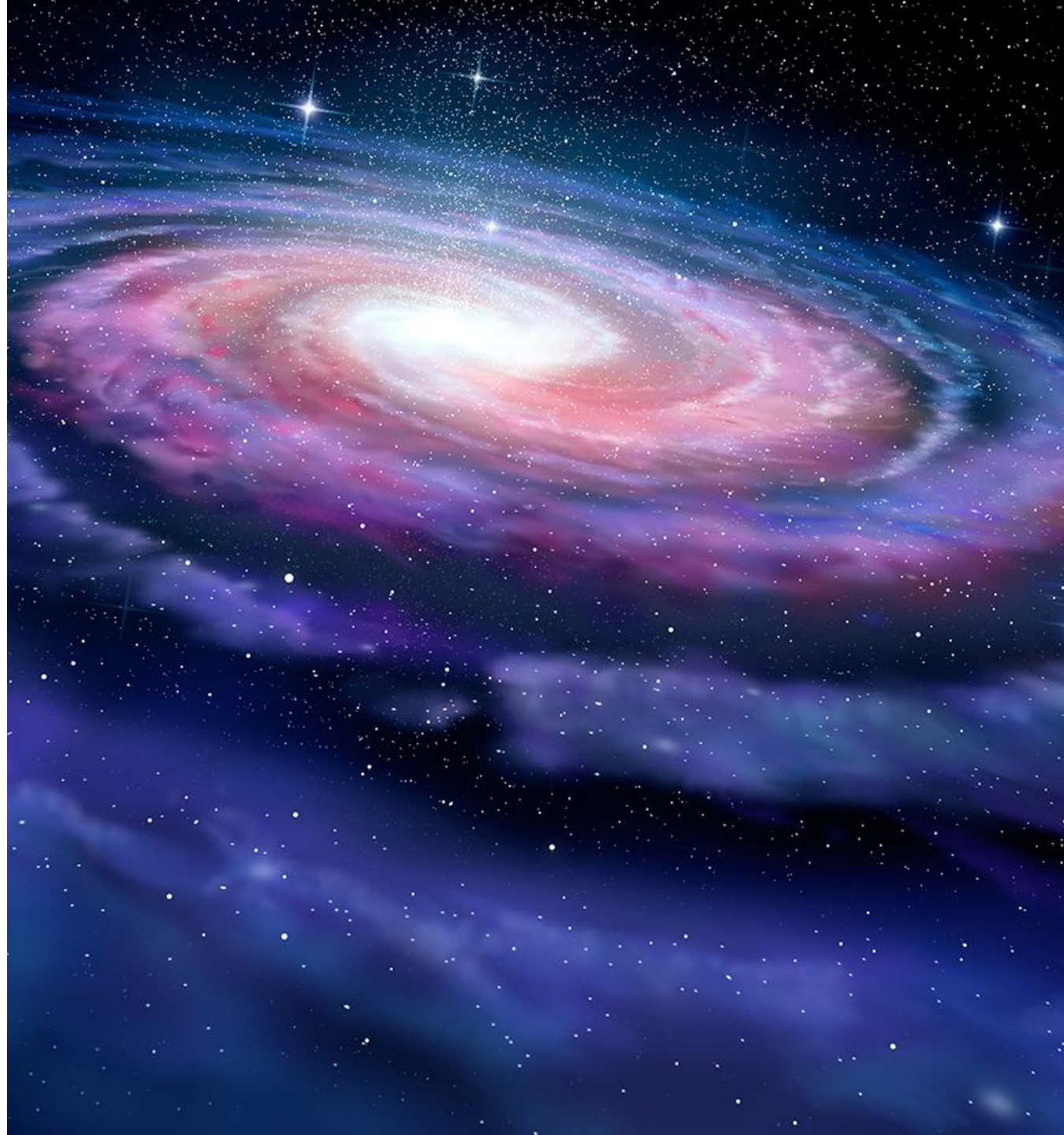
With new and advanced telescopes, data in astronomy is growing at a fast pace. Conventional methods to discover exoplanets that involve human judgment are not efficient and are prone to variability depending on the investigating expert.

Current state

Commonly used data analysis techniques for exoplanet detection with the transition method produce many false positives in the case of noisy data. These false positives must be reviewed manually.

Business value exploration

Quantum machine learning methods may help improve the classification accuracy of exoplanet candidates and reduce the rate of false positives.



RBI panel to examine quantum technology risks in financial sector



Photo: AFP

ANDHRA PRADESH'S BLUEPRINT FOR QUANTUM INNOVATION

Andhra Pradesh is taking a bold leap into the future with India's first state-led Quantum Valley initiative. Through the Amaravati Quantum Valley Declaration, the state has laid out a time-bound roadmap to build a full-stack quantum ecosystem—spanning research, infrastructure, talent, and startups, aimed at making Amaravati a global hub for quantum innovation by 2035.

Vision Statement

- By 2035, Amaravati aims to become a globally competitive centre for quantum science and technology.
- First Indian state to publish a formal, time-bound

Talent Development Goals

- Launch of Amaravati Quantum Academy under Integrated Quantum Skilling Ecosystem.
- Train: 200 quantum specialists in



Tamil Nadu to put quantum computers in hands of students, startups

Maharashtra govt to roll out quantum and deep-tech policies; cabinet to give nod soon: Devendra Fadnavis

Ready for quantum computing initiative in Uttar Pradesh: Yogi

Gujarat govt signs MoU with Innogress to establish India's first quantum technology park

AI NEWS

Karnataka Forms Quantum Task Force to Drive State's Quantum Technology Ambitions

The 16-member panel will guide policy, infrastructure development, and ecosystem growth as Karnataka seeks to establish itself as India's leading quantum technology hub.

NQM



विज्ञान एवं प्रौद्योगिकी विभाग
DEPARTMENT OF
SCIENCE & TECHNOLOGY



1. Announced in 2020
2. Cabinet approval in 2023 with budget of Rs 6000 Crores (approx. \$ 750 M)
3. Launch of Hubs – Sept 30, 2024
4. Rolling call for startups
5. 100 quantum labs set up



startups

Algorithms of National Importance

Hardware Manufacturing

Academia-Industry

Research and Development

Translational Research

Product Development

Technology Day Special: Inside India's National Quantum Mission

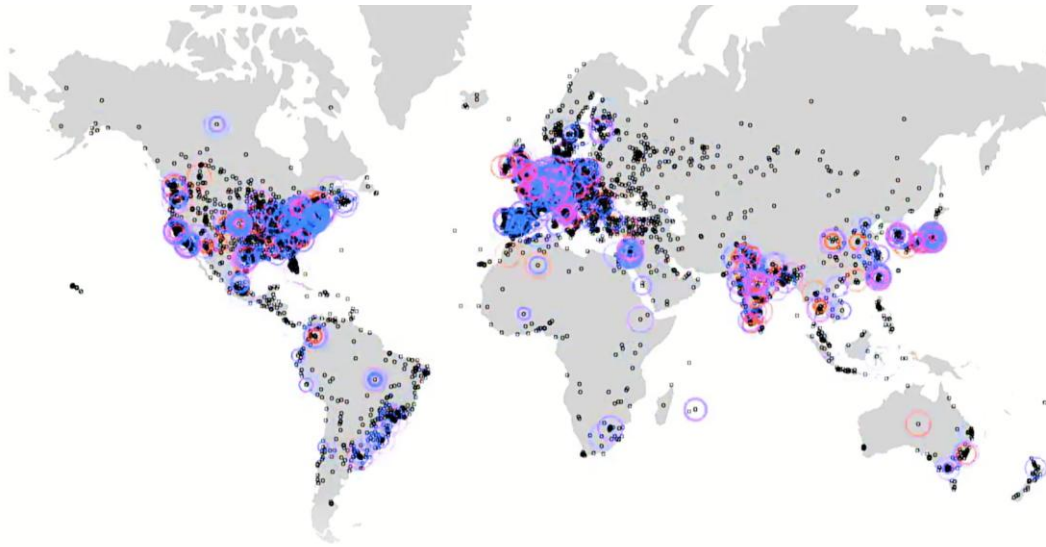
Rohit Chintapali | May 11, 2024

Technology Day # National Quantum Mission (NQM) # quantum technology # IBM # IIT Madras

The National Quantum Mission (NQM) aims to establish India as a key contender in the global quantum technology landscape, an area where over 30 governments have already pledged more than USD 40 billion in funding across a decade

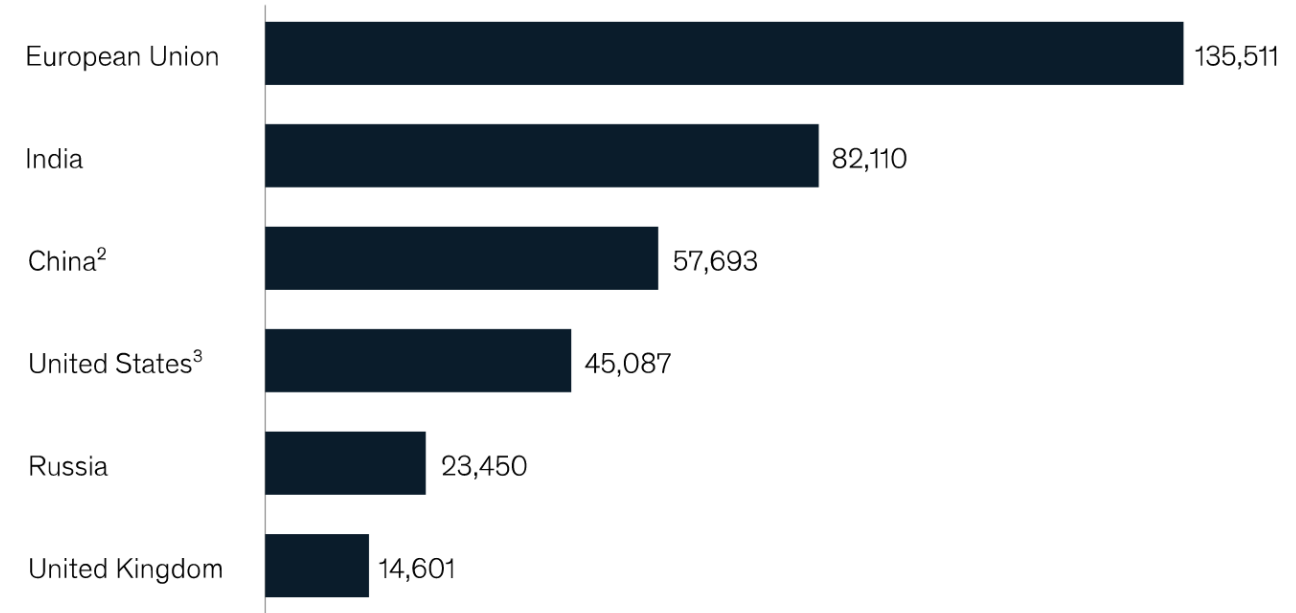


India's core strength: Talent



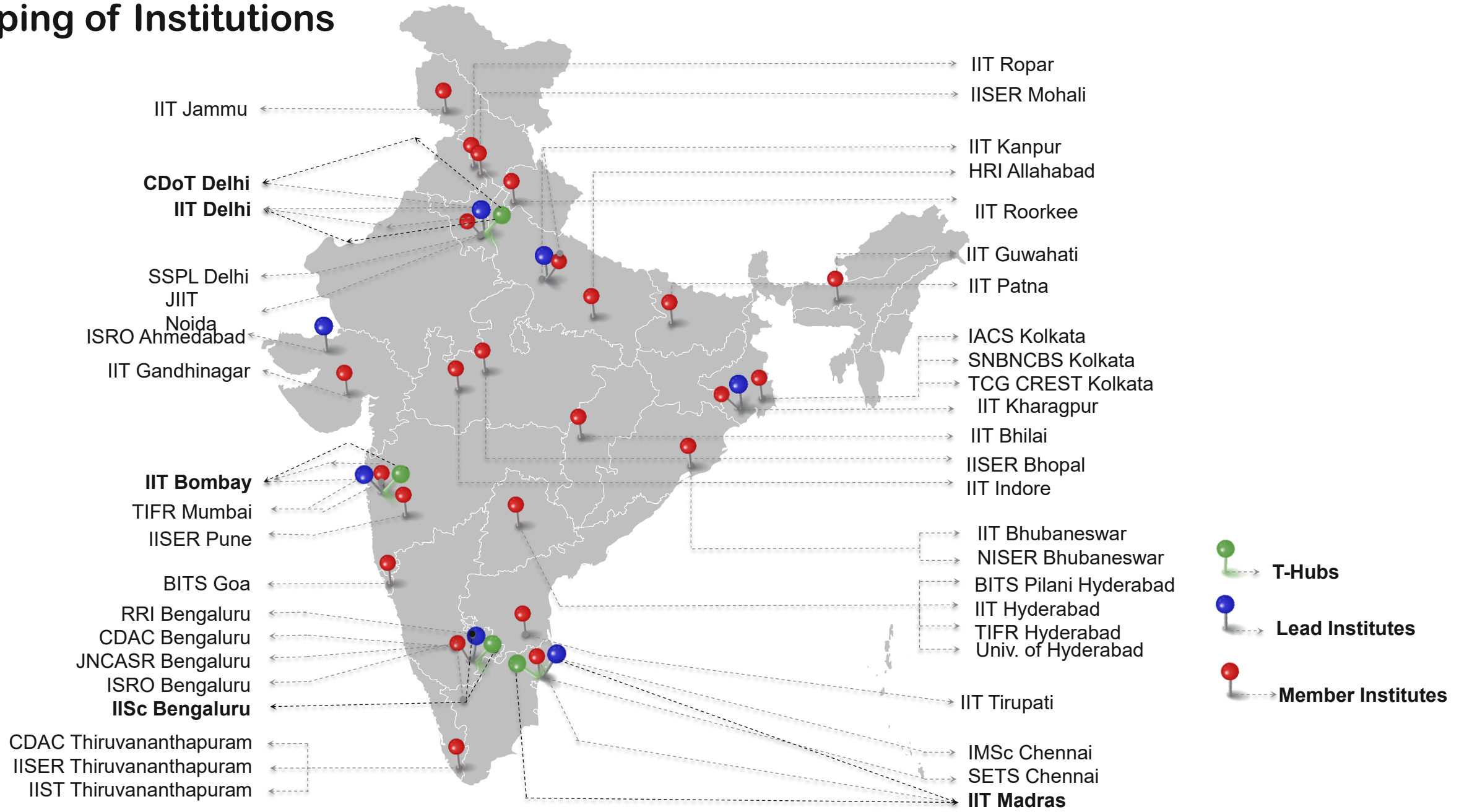
Among the highest users of IBM Quantum Computers

Absolute number of graduates in quantum technology-relevant fields, 2020¹



McKinsey Report lists India as having high talent

Mapping of Institutions



• 43 Institutions (Lead & Member) from 17 states and 2 UTs involved in the 17 proposals

Department of Commerce Announces Letters of Intent With 9 Companies for \$2 Billion to Accelerate U.S. Leadership in Quantum Computing

France Adds €1.55 Billion For Quantum And Semiconductor Development

भारत सरकार
GOVERNMENT OF INDIA
विज्ञान एवं प्रौद्योगिकी मंत्रालय
MINISTRY OF SCIENCE & TECHNOLOGY

BRICS
INDIA 2026

विज्ञान एवं प्रौद्योगिकी विभाग
DEPARTMENT OF
SCIENCE & TECHNOLOGY
(DST)

CALL FOR INTERNATIONAL RESEARCH PROPOSALS

BRICS STI FRAMEWORK PROGRAMME 2026

7th Coordination Call for Multilateral R&D Projects

Collaborate with leading researchers and institutions from India, Brazil, China, Egypt, Iran, Russia, and South Africa to address global challenges through scientific collaboration.

ELIGIBILITY

- Academic Institutions, Universities
- National R&D Laboratories
- DSIR-SIRO Recognized R&D Institutions

Consortium Requirement: Minimum participation from **3 BRICS Countries**

THEMATIC AREAS

1. WATER SYSTEMS & CLIMATE RESILIENCE	Water resources, treatment, reuse, resilience to water hazards and data-driven approaches.
2. HIGH-PERFORMANCE COMPUTING, AI & QUANTUM TECHNOLOGIES	HPC & AI infrastructure, LLMs, quantum computing, sensing & secure information technologies.
3. RENEWABLE ENERGY & SMART POWER NETWORKS	Solar energy, smart grids, sector coupling, energy efficiency & low-carbon pathways.
4. BIOTECHNOLOGY, DIGITAL HEALTH & PRECISION MEDICINE	Advanced biotech, genomics, AI-assisted discovery, personalized medicine, digital health & telemedicine.
5. CLIMATE-RESILIENT AGRICULTURE & FOOD SYSTEMS	Resilient crops, precision agriculture, sustainable fisheries, aquaculture & food quality monitoring.
6. ADVANCED MATERIALS, NANOMATERIALS & SUSTAINABLE TECHNOLOGIES	Functional & smart materials, energy materials, nanomaterials, bio-materials & resilient systems.

FUNDING SUPPORT (INDIA - DST)

Up to **₹1 Crore** per Indian Project Partner

PROJECT DURATION
2-3 YEARS

Equipment cost up to 30% of budget. Support for manpower, consumables, travel, contingency & overheads as per DST norms.

IMPORTANT DATE
SUBMISSION DEADLINE
03 JULY 2026

APPLY THROUGH
DST e-PMS PORTAL
<https://onlinedst.gov.in>

PARTICIPATING FUNDING AGENCIES

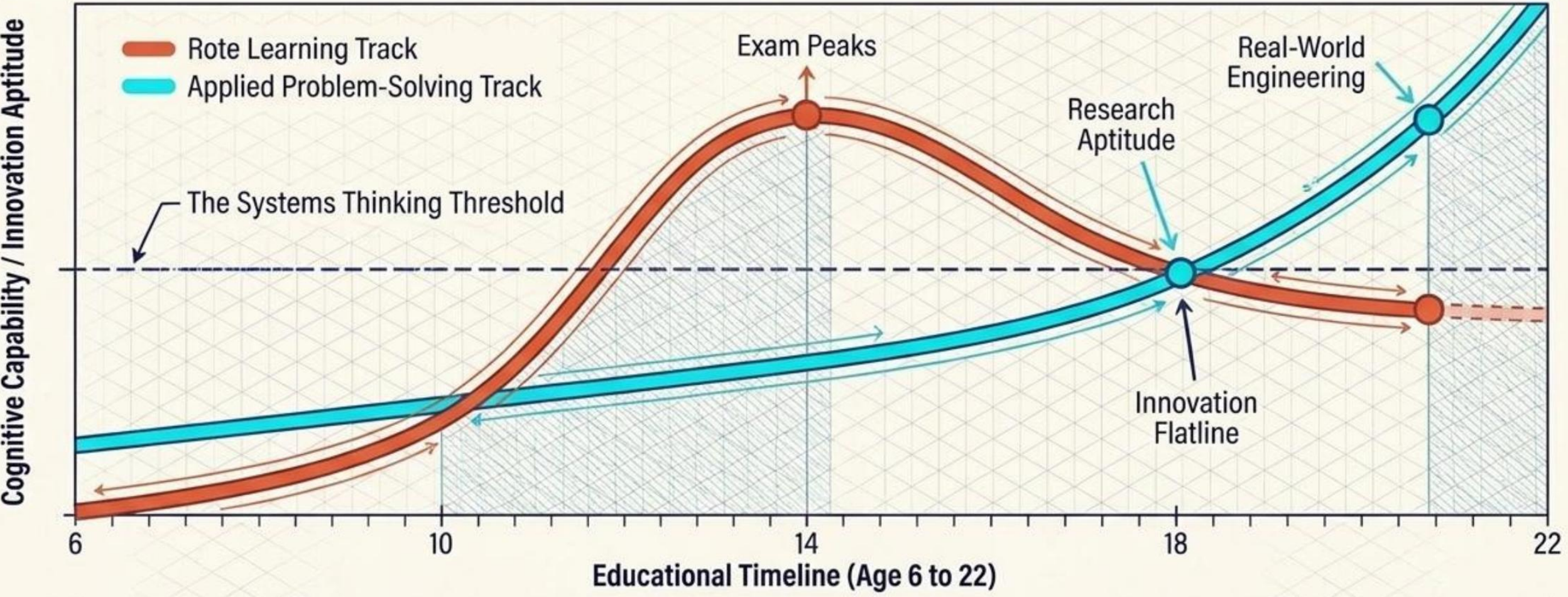
BRAZIL CNPq	CHINA MOST NSFC	EGYPT STDF	INDIA DST	IRAN INSF	RUSSIA MSHE RCSI	SOUTH AFRICA NRF
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OPPORTUNITY TO BUILD GLOBAL RESEARCH PARTNERSHIPS AND DELIVER HIGH-IMPACT INNOVATIONS FOR SUSTAINABLE DEVELOPMENT

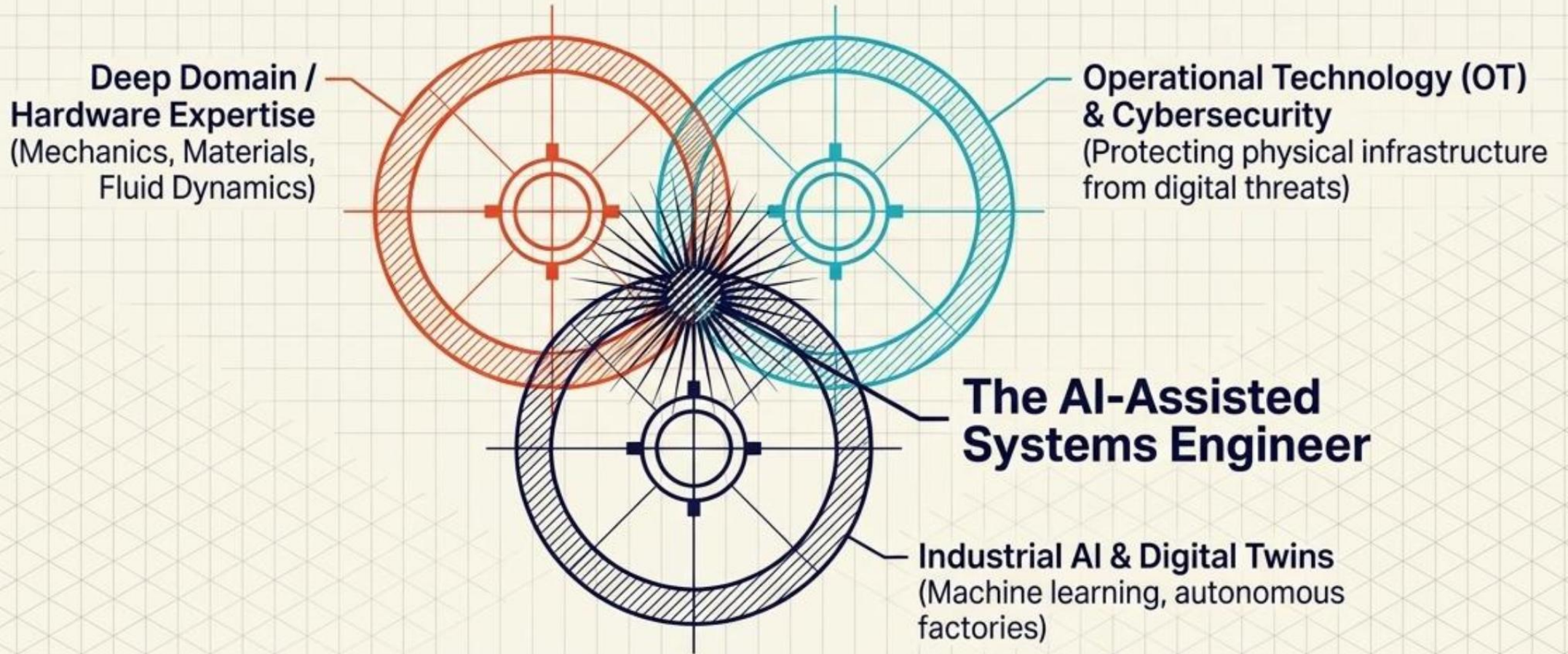
For queries, please contact:
Dr. Arindam Bhattacharyya, Scientist-F
Department of Science & Technology (DST)
Email: arindam.bhattacharyya@nic.in

Department of Science & Technology (DST)
Ministry of Science & Technology, Government of India
[f](https://www.facebook.com/IndiaDST) [in](https://www.linkedin.com/company/india-dst) [ig](https://www.instagram.com/india_dst) [@IndiaDST](https://twitter.com/IndiaDST)

Traditional pedagogy produces early exam performance but flatlines innovation aptitude.



AI does not replace core engineers; it superpowers those with deep physical domain expertise



By 2030–2040, pure **software roles** will face heavy automation, while **human+AI engineering collaboration** requiring real-world physical understanding will command the highest premium.

Quantum Reference Facilities

Two Made in India Open-Access
Hardware Quantum Computers
launched on World Quantum Day,
April 14, 2026



Amaravati 1S



Amaravati 1Q



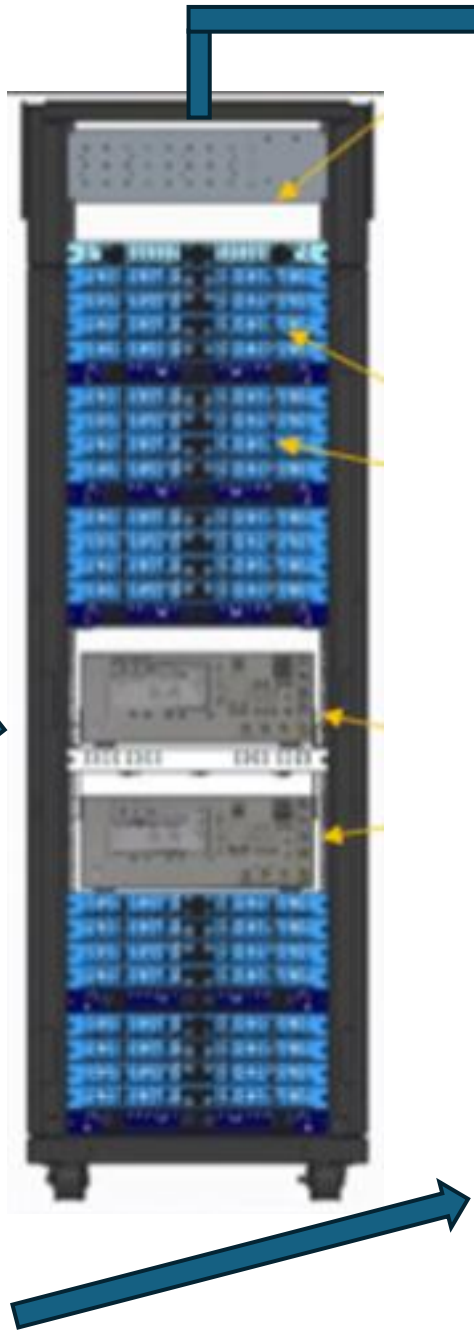
Sugam Kumar, (IUAC, Delhi)

5.
Qute Electronics
Precision Power Modules

Santu Sardar (DRDO)
Control Electronics

6.

Qbit Force
Bharat Quantum
7. Reference Facilities



1. Vijayaraghavan (TIFR), Vibhor Singh (IISc Blr)
3D and 2D Processors



2. Vijayaraghavan (TIFR)
Josephson Parametric Amplifier

3. Dipti Gupta (IITB)
Dimira
Cryogenic Flex Wiring

4. Dilution Refrigerator
Qbit Force and Amber



Bharat Quantum Reference Facilities

- Two Fully functional quantum computers
- All major components made in India: Processor, Readout Resonator Chip, Josephson Parametric Amplifier, Control Systems, Dilution Fridge, Precision Current and Voltage Sources, Experimental Flex Cables.
- Open-access hardware enabling use as reference quantum systems
 - Enabled for testing all quantum components
 - Scalable up to 100+ qubits

Accelerate Quantum hardware manufacturing

Manufacture components

Manufacture Quantum Computers

Control Systems

Processors

Precision Power Sources

Amplifiers

Cryogenic Components

Dilution Refrigerator

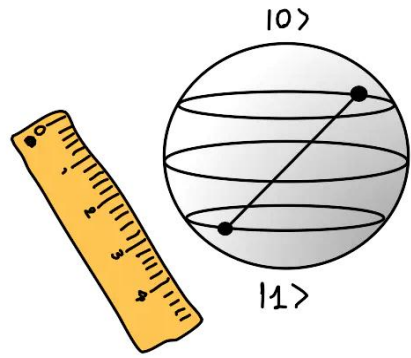
Integrate

Test and Refine

Bharat Quantum Reference Facility







Thank you!

In quantum, the sky is not the limit, it is just the starting point. 🧪 🚀