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SENSING MAGNETIC FIELDS WITH ATOMS

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FROM THE EDITOR

As we step into the vibrant third quarter of 2025, Quantum Vibes continues to explore the fascinating intersections of innovation, intellect, and imagination that are shaping the quantum future. This edition brings together thought leaders, breakthrough research, and global developments that underscore the rapid evolution of the quantum ecosystem.

In our *Expert Insights* section, we delve into “Sensing Magnetic Fields with Atoms” by Mr. Raghav Sah and Dr. G. Rajalakshmi from TIFR, who illuminate how atomic precision is redefining the frontiers of quantum sensing.

Inside the Minds section presents an engaging dialogue with Mr. Syamasundar Gopasana (Accenture), Dr. Marco Matters (Quantum Inspire) and Dr. Vivek Sinha (Quantum Inspire) — a conversation that navigates the human and technological dimensions of scaling quantum innovation in industry and research.

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As the quantum world accelerates toward realization, Quantum Vibes remains your companion in navigating its waves — connecting people, ideas, and possibilities that are shaping tomorrow’s quantum-enabled world.

Happy Reading !

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**SENSING
MAGNETIC FIELDS
WITH ATOMS**

**QUANTUM
TRANSPILATION
IN THE NISQ ERA**

Sensing magnetic fields with atoms

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1. INTRODUCTION

Magnetic fields are ubiquitous in our environment. These can range from those produced by the Earth that is in the micro-Tesla (μT) range to bio-magnetic fields that are in the femto-Tesla (fT) range. Measuring the strength and time variations in these fields gives us insight into the mechanisms that produce these fields. Magnetic sensing can be beneficial in a range of applications from geo-navigation to biomedical diagnostics. Accurate measurements of the Earth's magnetic field gradients can be used for GPS-free navigation [1, 2] while magneto-encephalography (MEG) [3, 4] and magneto-cardiography (MCG) [5, 6] study the magnetic fields from the body to understand brain and heart functions. Detection of magnetic anomalies in the environment can aid geological surveys like underwater surveillance.

To support these applications, a wide range of magnetometers are available, capable of detecting magnetic fields with varying sensitivities as summarized in figure 1. The choice of sensor depends on the operating environment and application requirements. SQUIDS and atomic magnetometers are the instruments of choice when sensitivities of the order of fT are required. However, in contrast to SQUIDS, atomic magnetometers are portable and do not require cryogenic operation. Another interesting property of atomic magnetometers is that they are self-calibrating — the measured signal depends only on the magnetic moment of the atom that is being used.

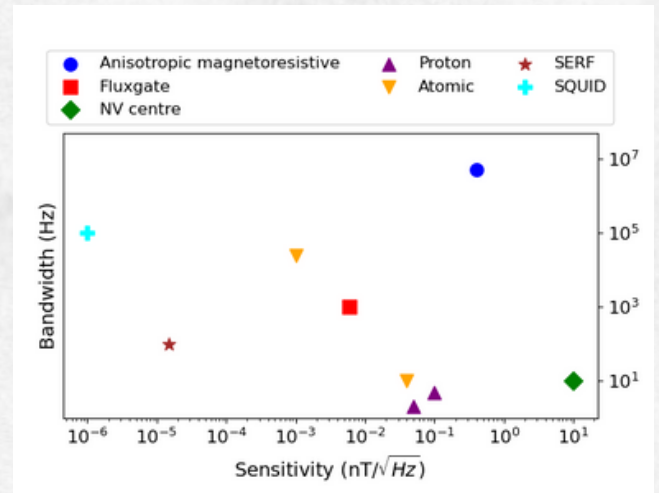


Figure 1: Different magnetometers with their sensitivity to magnetic fields and the upper limit of their frequency bandwidth of operation [7–15].

In this article, we focus on atomic magnetometers and present an overview of the working principle of atomic magnetometer based on magneto-optic rotation of light. We particularly address the factors that affect their sensitivity to magnetic fields and the bandwidth of operation. The principles are demonstrated using some experimental results from our lab.

Myth

Compasses always point exactly to the geographic north pole.

Fact

Compasses actually point to the **magnetic north**, not the **geographic north**. The difference between them is called **magnetic declination**, and it varies depending on where you are on Earth.

We start by introducing the experimental setup for the atomic magnetometer and explain the working principle. We then explain the selection/choice of light for an atomic magnetometer and later discuss the effect of such a light on the atoms under ambient conditions. The creation of atomic spin polarization and mechanism that lead to spin relaxation are explained. Later, we discuss the affect of magnetic field on the spin polarization of atoms and how light can be used to detect the magnetic field strength. We then discuss how various parameters affects the dynamic range and the sensitivity of the atomic magnetometer. Finally, we demonstrate how modulation of light can be used for sensitive magnetic fields measurements, even in the presence of a higher background field.

2. WHAT IS AN ATOMIC MAGNETOMETER?

Atomic magnetometers, as the name suggests, use atoms as the sensing element. Typical atomic magnetometers use alkali atoms like rubidium, potassium, and cesium because of their simple electronic structure. Alkali atoms with one valence electron have electronic energy levels closely resembling those of hydrogen atom. They have transition energies that can be conveniently excited by using optical sources. Nonlinear magneto-optic rotation (NMOR) based atomic magnetometers operate on the principle of the resonant Faraday effect. In this process, linearly polarized light, tuned to an atomic transition, experiences a rotation of its polarization as it passes through the atomic medium subjected to a magnetic field.

We employ a rubidium (^{87}Rb) vapor cell and a 780 nm laser, tuned to the atomic transition of rubidium, to construct our magnetometer. The laser beam is linearly polarized using a Glan-Taylor prism before passing through the (^{87}Rb) vapor cell. The polarization state of the transmitted beam is then analyzed with a polarimeter consisting of a Wollaston prism that separates the two orthogonal polarizations of light and a differential photo-detector setup that measures the difference in intensity between the two separated beams. The setup is

aligned such that, in the absence of a magnetic field, this difference is zero. When a magnetic field is present along the direction of laser propagation, the polarization of the light rotates, leading to a difference in intensity between the two orthogonal polarizations. This difference in intensity is measured and used to deduce the strength of the magnetic field. By tuning the frequency and intensity of the laser and the atomic number density, the response of the atomic system to the magnetic field can be optimized to achieve different sensitivity, bandwidth and dynamic range of operation. In this article, we will concentrate on atomic magnetometry techniques that allow for operation in ambient Earth field conditions.

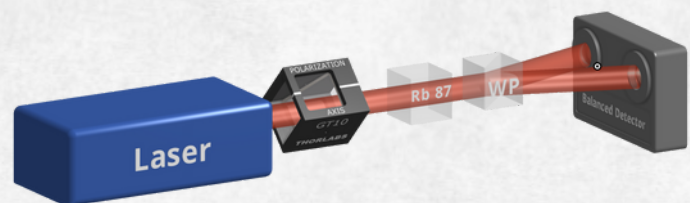


Figure 2: The basic setup for the atomic magnetometer. Laser light, tuned to the atomic transition of ^{87}Rb , passes through a Glan-Taylor Polarizer (GT) and then through the rubidium vapor cell. The transmitted beam is separated into two beams of orthogonal polarization by a Wollaston prism (WP), and the difference in their intensity is measured using a balanced photo-detector.

3. WORKING PRINCIPLE

A magnetic field can be detected through its influence on atomic magnetic moments. When an atom absorbs resonant light, its quantum state is modified, which, under appropriate excitation schemes, can create a net magnetic moment. In the presence of an external magnetic

field, this magnetic moment undergoes Larmor precession. This precession is imprinted onto the light beam, as measurable changes in its ellipticity and polarization. The aim of this section is to familiarize the reader with each of these processes and give an overall understanding of the working principle of using atoms to detect magnetic fields.

3.1 ATOM-LIGHT INTERACTION AND ATOMIC RESONANCE

To understand the interaction between light and atoms, it is useful to review the convention used in quantum mechanics and atomic physics. The discrete atomic energy levels are denoted by the spectroscopic notation - $n^{2S+1}L_J$, where n , $\vec{S}$, $\vec{L}$ and $\vec{J}$ correspond to the principal, spin, orbital (azimuthal) and total electronic angular momentum quantum numbers, respectively. The nucleus carries an intrinsic angular momentum $\vec{I}$, which couples with the electronic angular momentum $\vec{J}$. As a result, each spectroscopic level splits into hyperfine levels characterized by the total angular momentum quantum number, $\vec{F} = \vec{J} + \vec{I}$, that takes integer values ranging from $|J - I|$ to $|J + I|$. These hyperfine levels are associated with a spin quantum number m_F , that takes values ranging from $-F$ to F . In the absence of magnetic field, different m_F states, corresponding to a particular $\vec{F}$ state, are degenerate. Applying a magnetic field lifts this degeneracy, producing the Zeeman splitting of the states. The change in energy for each m_F state is given by $\Delta E = \gamma m_F B$, where γ is the gyromagnetic ratio denoted in Hz/T [16].

We consider a semi-classical description of the atom-light interaction in which light is treated as an electromagnetic wave. Linearly polarized light can be expressed as a superposition of left (σ^+) and right (σ^-) circular polarizations that carry an angular momentum of +1 and -1, respectively [17]. Conservation of angular momentum leads to the selection rules for allowed atomic transitions, $\Delta F = 0, \pm 1$ and $\Delta m_f = +1(-1)$ for left (right) circular polarization, with $F = 0 \rightarrow F' = 0$ being a forbidden transition [16].

In this treatment, it is convenient to use a complex refractive index to describe the effect on light after its transit through the atomic ensemble. Absorption is quantified by the

imaginary part of this complex index of refraction, while the real part describes the phase lag experienced by the propagating light. For light resonant with an atomic transition, absorption occurs over a finite frequency range determined by the natural linewidth (Γ_N). The imaginary part of the refractive index (absorption) exhibits a Lorentzian dependence on the frequency, whereas the real part (corresponding to phase lag experienced by light) has the characteristic dispersive profile, centered about the resonance frequency.

Now that we have the necessary tools, let us consider a simple example of light resonant with the $F = 1 \rightarrow F' = 0$ transition in the presence of a magnetic field. Choosing the propagation direction of light and the magnetic field axis to be along z-axis, and the linear polarization along the x-axis, the result in the atomic quantization to be along the z-axis, with F_z as the eigen state of the system. The effect of magnetic field can be captured by looking at the complex index of refraction for the σ^+ and σ^- components as given by the equation [18] below:

$$n_{\pm}(\Delta) = 1 + 2\pi\chi_0 \frac{\Gamma_N}{2(\Delta \pm m_F\gamma B) + i\Gamma_N} \quad (1)$$

where,

- $n_{\pm}$: Refractive index for σ^+ and σ^-
- χ_0 : Electric susceptibility
- Γ_N : Natural linewidth
- Δ : Detuning from resonance ($\omega - \omega_0$)
- m_F : Magnetic quantum number
- γ : Gyromagnetic ratio

The real and imaginary parts of the refractive index correspond to dispersion and absorption, respectively. In the absence of magnetic field the two circular components have the same refractive index due to the degeneracy of the states with different m_F . Magnetic field lifts the degeneracy between the states with different m_F values and the maximum absorption of the two circular polarizations of light occur at two different frequencies, and hence the corresponding dispersion is also centered about these frequencies as shown in figure 3a.

The result of this difference in dispersion is that the two circular polarizations exit the vapor cell at slightly different times. This leads to a relative phase difference between the two circular components of light, which translates to rotation in linear polarization as shown in figure 3b.

3.2 ROOM TEMPERATURE SYSTEM - DOPPLER BROADENING

The explanation of polarization rotation described above is strictly valid when atoms are probed at resonance within their natural linewidth (Γ_N). However, in practice, the absorption profile of atoms is much broader than Γ_N due to their thermal motion. Atoms possess a thermal velocity distribution governed by the Maxwell-Boltzmann law. For example, the root-mean-square velocity of ^{87}Rb atoms at room temperature is approximately 270 m/s, which is sufficient to cause a Doppler shift of the resonant frequency. As a result, an atom with a certain velocity may experience incident light that is off-resonant in the laboratory frame as resonant in its own rest frame. The probability of finding atoms at such velocities follows a Gaussian distribution. Consequently, the

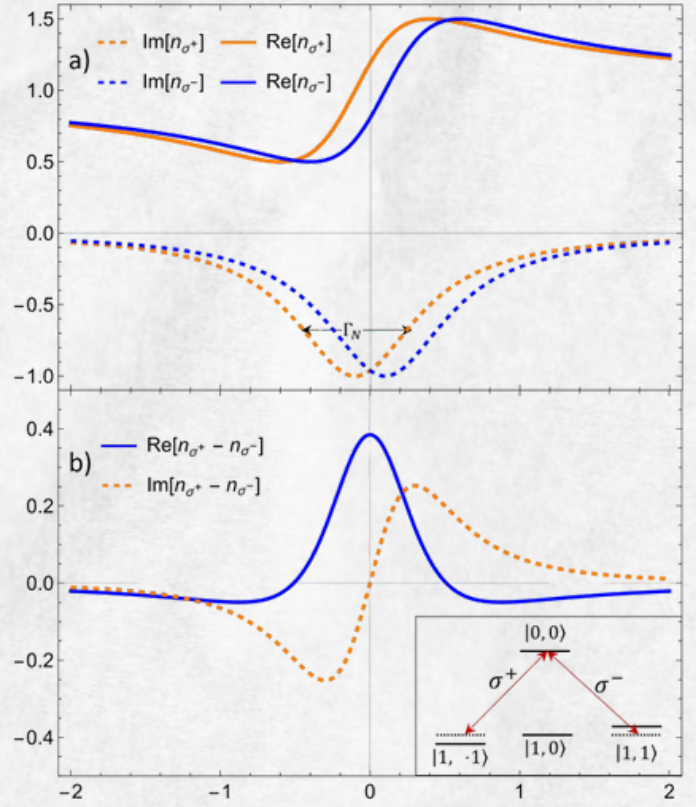


Figure 3: The inset shows a schematic of $F = 1 \rightarrow F' = 0$ transition driven by the two circular components of a resonant linearly polarized light. Left (σ^+) and right (σ^-) circular polarizations are shown by the red arrows. (a) The plot shows the behavior of $\text{Im}[n]$ (absorption, dotted curve) and $\text{Re}[n]$ (dispersion, solid curve) of the two circular polarizations with respect to detuning ($\Delta = \omega - \omega_0$) as per equation 1, for a magnetic field such that $\gamma B = \Gamma_N$. (b) The plot shows the variation of the polarization rotation and ellipticity with respect to detuning. They are induced due to the difference in the real (dispersion) and the imaginary (absorption) parts of the refractive indices of the two circular components, respectively. The value $2\pi\chi_0 = 1$ is used to plot the variation of refractive index with respect to detuning.

overall absorption profile as a function of frequency is given by the convolution of this Gaussian with the intrinsic Lorentzian natural linewidth, yielding the Voigt profile [19]. This broadening mechanism, known as Doppler broadening, amounts to about 500–600 MHz for ^{87}Rb at room temperature while the natural linewidth is about 6 MHz. As a result, even when the probe light is detuned from the exact atomic resonance, certain velocity classes of atoms remain resonant and contribute to polarization rotation of light in the presence of a magnetic field. Thus, while the magnitude of the rotation is reduced when compared to that in the absence of Doppler broadening, it extends over a much broader frequency range, as illustrated in figure 4, conserving the area under the two curves.

Taking all this into account, rotation in polarization occurs through the Doppler-broadened spectrum instead of the natural linewidth of the transition, (Γ_N) and it is clear from figure 4 that the maximum rotation of polarization occurs near the maximum absorption of light for absorption of light for the chosen D2 transition of ^{87}Rb . Now that we know what type of light to use to detect the magnetic field, let's see how the magnetic field affects the light.

3.3 INTERACTION OF ATOM WITH LIGHT IN THE PRESENCE OF MAGNETIC FIELD: SENSING MAGNETIC FIELD

The laser frequency is usually fixed such that the rotation in polarization of light is maximum (refer to fig. 4). A variation in the magnetic field along the direction of propagation of light leads to rotation in the polarization of light, (ϕ), as given by equation 2 [21] and plotted in figure 5.

$$\phi = \frac{2\gamma B_z / \Gamma}{1 + (2\gamma B_z / \Gamma)^2} \cdot \frac{l}{l_0} \quad (2)$$

where Γ is the spin relaxation rate, l is the physical length of the vapor cell, and l_0 is the specific absorption length. We will discuss the spin relaxation rate in the next section.

The magnetometer exhibits a linear response within a range, which in our case was approximately $-1 \mu\text{T}$ to $1 \mu\text{T}$. This interval defines the effective dynamic range of the magnetometer and is determined by the spin relaxation rate, Γ . The slope of the polarization rotation curve within this region determines the amplitude of the signal for small magnetic fields. A steeper slope corresponds to a larger change in polarization rotation (ϕ) per unit applied magnetic field, thereby enhancing the magnetometer's signal towards a smaller magnetic field.

Having discussed the signal, we now turn to the noise sources that fundamentally limit the sensitivity of atomic magnetometers.

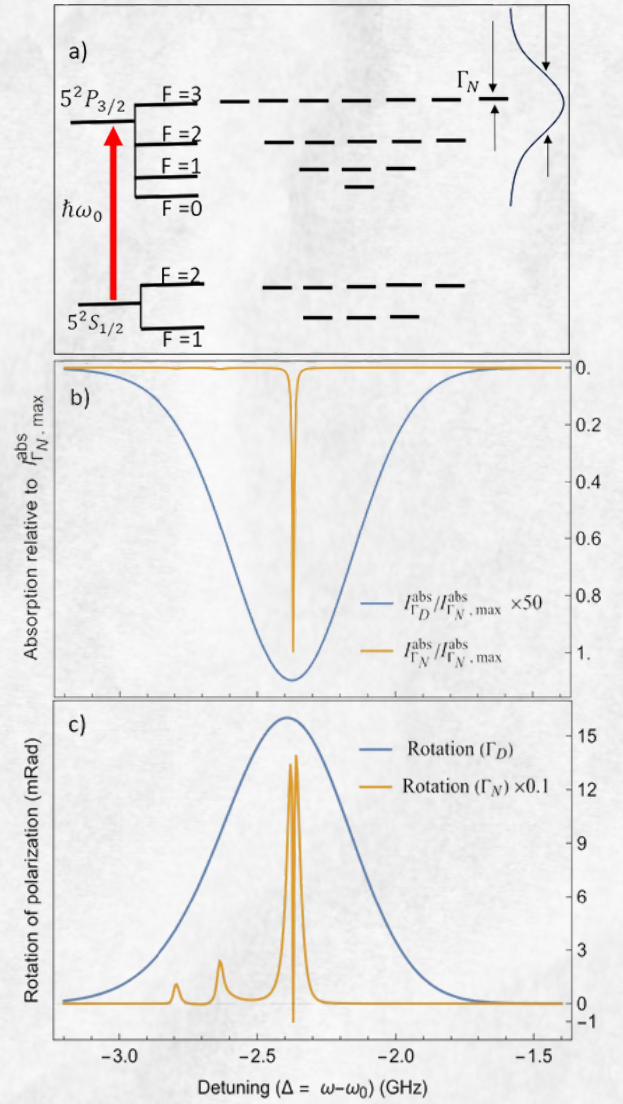


Figure 4: The energy level diagram of ^{87}Rb in a qualitative manner (not to scale) [20] is shown in (a). The energy gap between $5S_{1/2} \rightarrow 5P_{3/2}$, in the absence of hyperfine splitting is taken as $\hbar\omega_0$. The $5P_{3/2}$ level, after hyperfine splitting, is still seen as a single absorption band due to the Doppler broadening effect. The Doppler-free and Doppler-broadened variation of the absorption (b) and rotation of polarization of light (b) is shown by the orange and the blue curves, respectively, in the presence of $1\mu\text{T}$ of magnetic field. The plot is obtained by simulation of an ensemble containing ^{87}Rb with $600 \mu\text{W}$ of light with 8 mm beam diameter tuned to the D2 atomic transition of ^{87}Rb $5^2S_{1/2} F=2 \rightarrow 5^2P_{3/2} F'=1, 2, 3$. Note that the rotation and absorption due to Doppler broadening do not scale down proportionally.

The dominant noise contributions are:

- **Photon shot noise:** Lets say that, in a polarimetry measurement, the number of photons falling on each detector is N_1 and N_2 . The angle of polarization can be obtained by the

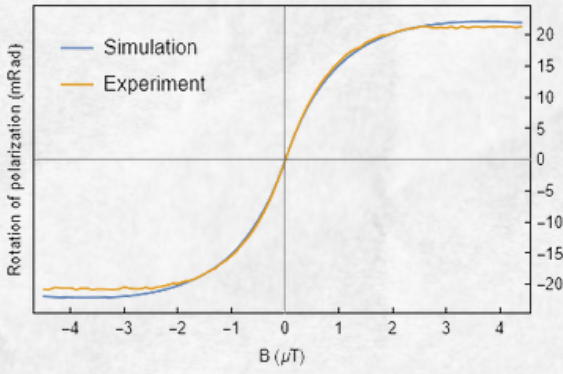


Figure 5: Change in the rotation of polarization when a magnetic field is applied in the direction of propagation of the laser. The simulation matches the result for a spin relaxation rate Γ of 18 kHz. A 0.6 mW laser light with a beam 0.8 cm wide, exciting 7.4×10^9 atoms/cc of ^{87}Rb over 1 cm length, were the parameters of the simulation. The laser frequency was set at the D2 transition of ^{87}Rb to obtain maximum rotation

formula $\phi = (N_1 - N_2)/(N_1 + N_2)$. In the balanced condition, when the number of photons falling on each detector is equal, let's say, $N_1 = N_2 = N_{ph}/2$. The fluctuation in the number of photons scales as $\sqrt{N_{ph}/2}$ and this represents the photon shot noise. Hence, the uncertainty in the measure of angle ϕ is given by $\sigma(\phi) = 1/2\sqrt{N_{ph}}$.

- **Spin projection noise:** According to the uncertainty principle, two non-commuting angular momentum components (e.g. $\hat{F}_x$ and $\hat{F}_y$) cannot be simultaneously measured with the utmost precision. In the system we described above, $\hat{F}_x$ and $\hat{F}_y$, are mapped to the polarization rotation and ellipticity of the transmitted beam. Hence, both spin components are measured simultaneously upon measuring ϕ . The uncertainty principle imposes a fundamental limit to the precision of measurement of ϕ , known as spin projection noise.

- **Quantum back-action noise:** Linearly polarized light exhibits fluctuations in the numbers of left and right circularly polarized photons. The atoms perceive these as a fluctuating effective magnetic field via the AC Stark effect [22, 23] and this is reflected as noise in the signal from the balanced photo-detector.

The smallest magnetic field that can be measured by the system depends on the optical rotation signal, ϕ , generated by the magnetic field that is fixed by the system parameters. This system response is calibrated by applying a known magnetic field. An unknown magnetic field can be measured as long as the signal due to the field is larger than the noise. Signal strength can also be enhanced by optimizing the parameters of the magnetometer. Some methods to improve the signal are:

- **Reducing the spin relaxation rate (Γ):** A reduction in the relaxation rate, Γ , leads to a steeper slope in the linear response region of the magnetometer, thus increasing the magnitude of the signal obtained due to a small magnetic field. However, reducing the spin relaxation rate also reduces the linear response region, reducing the dynamic range of the magnetometer. We will discuss this in the next section.
- **Increase in the atomic density:** By slightly heating the cell, the atomic vapor pressure in the cell can be increased, leading to a larger number of atoms interacting with light, and hence to a larger rotation in polarization of light. Although increasing the atomic density increases the signal, there is also an increase in the spin relaxation rate due to spin-exchange collisions.
- **Increase in illuminated volume of the cell:** Yet another way to increase the signal is to increase the length of the cell. Using a longer cell will result in a proportionally larger rotation of polarization of light. Although a smaller cell results in lower angle of rotation of polarization, it has a better spatial resolution. Similarly, increasing the diameter of the beam will also provide a larger signal - but this also reduces the spin relaxation rate (Γ), leading to a smaller dynamic range and the bandwidth of operation. The signal in this case will also be affected by inhomogeneities in the magnetic field across the length of the cell.

Although the signal from an atomic magnetometer can be improved by various techniques, these parameters are not independent, as explained above. Therefore, understanding and controlling spin relaxation processes becomes essential in optimizing magnetometer performance. In the next section, we discuss the various mechanisms of spin relaxation and its impact on sensitivity to magnetic fields.

3.4 OPTICAL PUMPING AND SPIN RELAXATION

In order to understand the atomic spin relaxation, we review how spin polarization is created via optical pumping. Consider a $F = 2 \rightarrow F' = 2$ transition. An $\hat{x}$ -polarized light propagating along the $\hat{z}$ direction, tuned exactly on resonance, excites the atoms to the higher energy state driven by the σ^+ and σ^- components, as shown in figure 6. Atoms decay to the ground state after excitation. Over many cycles of excitation and decay, a population difference is created among the Zeeman levels in the ground energy state. This is called atomic spin polarization. In this configuration, the ensemble is in an eigen-state of the $\hat{F}_x$ operator, and hence the population of atoms is in a superposition of the stretched state: the $+m_f$ and $-m_f$ states.

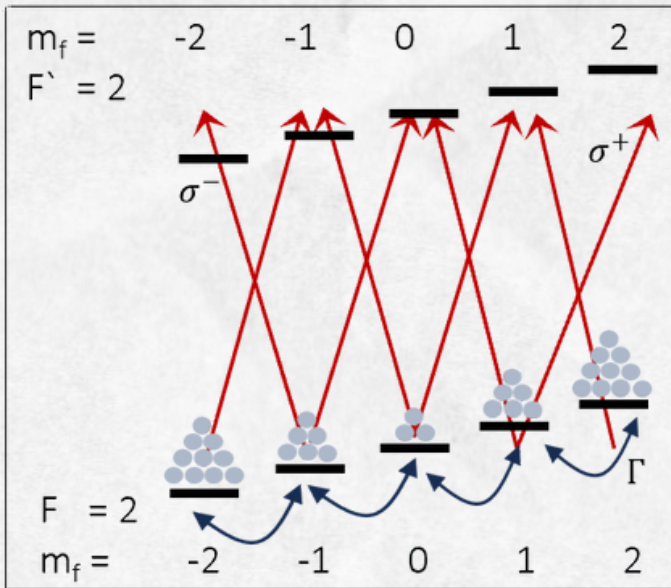


Figure 6: Linearly $\hat{x}$ -polarized light, composed of the two circular polarization (σ^+ and σ^-), drives a transition, $F = 2 \rightarrow F' = 2$, in the presence of a magnetic field. A population difference is created among the Zeeman sub-levels, known as the atomic spin polarization. Via the spin relaxation processes (Γ) (denoted by the curved arrows connecting the Zeeman sub-levels), this spin polarization comes to thermal equilibrium.

In the presence of a magnetic field ($B = B_0 \hat{z}$), spin polarized atoms undergo precession in the x-y plane with Larmor frequency $\Omega_L = \gamma m_F B_0$. At the same time, spin relaxation processes redistribute the spin populations toward thermal equilibrium, resulting in equal population in the Zeeman sub-levels. This reduces the magnitude of spin polarization. Due to a continuous drive by the laser creating spin polarization, spin precession due to the external magnetic field and spin relaxation, the atomic spin orientation reaches a steady state over time. The steady-state spin angular momentum of the atomic ensemble is at an angle from the polarization direction of light, which is also the initial spin polarization direction. The various spin relaxation mechanisms are summarized in table 1.

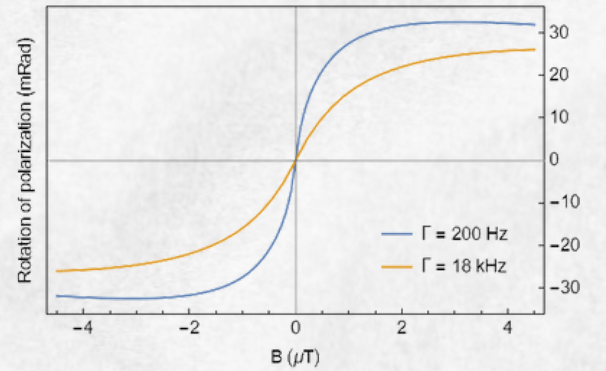


Figure 7: The plot shows the rotation in polarization of light obtained by simulation of system with the same parameters used in fig. 6, with two different atomic spin relaxation rates, Γ . The turning points on these curves are given by $\Gamma/2\gamma$.

If the spin relaxation is slow, the spin polarized atoms retain their angular momentum state, $|F, m_f\rangle$, for a longer duration, and the steady state is reached at a larger angle from the state prepared in the $\hat{x}$ direction. This leads to a larger rotation in the polarization of light. However, in this case, the atomic magnetometer saturates at a lower magnetic field, hence reducing the dynamic range. A comparison of the magnetometer response for two different relaxation rates is shown in figure 7. The turning point of the curve in figure 7 occurs at $B = \Gamma/2\gamma$.

Spin Relaxation Phenomenon	Description	Control Method
Wall collisions	As atoms hit the container walls, their spin polarization is lost to magnetic impurities in the wall [23]. Thus the thermal velocity and the cell geometry determine the spin relaxation rate due to wall collisions.	Using a larger cell increases the time before atoms collide with the walls. Also, coating the inner surface of the cell wall with paraffin and other special chemicals results in multiple bounces of atoms before their spin polarization is lost.
Transit through the illuminated volume	Atoms leaving the illuminated region are considered lost, as they usually return only after hitting the wall and losing their spin polarization. Hence, the thermal velocity of atoms in the cell and the illuminated volume of the cell determine the transit relaxation rate.	Enlarging the laser beam diameter allows atoms to remain longer in the illuminated region.
Spin exchange	Collisions between atoms with different spins redistribute populations among ground-state Zeeman levels, hence reducing the spin polarization.	Adding noble gases with zero angular momentum in the ground state (e.g., Argon) reduces alkali-alkali and wall collisions, preventing spin redistribution.

Table 1: Mechanisms of atomic spin relaxation and methods to control them.

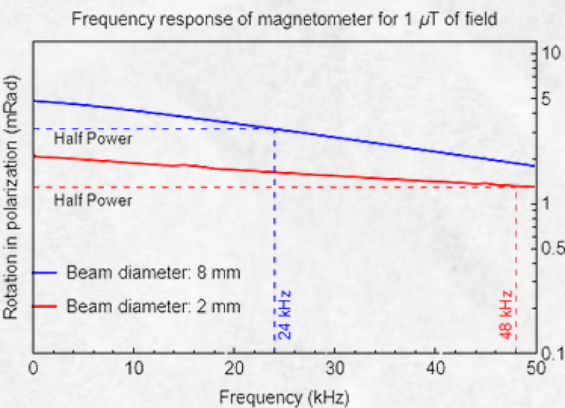


Figure 8: The plot shows the frequency response of the magnetometer for laser beams of two diameters obtained by the application of a magnetic field of amplitude 1 μT .

Another effect of the spin relaxation rate is on the bandwidth of operation of the atomic magnetometer. Higher spin relaxation rates allow the magnetometer to respond to a faster changing magnetic field. Figure 8 shows the experimental comparison of the frequency response of the magnetometer with two different spin relaxation rates, achieved by changing the diameter of the laser beam and hence the transit time of atoms through the beam (refer table 1). Using a laser beam with a smaller diameter reduces the time that atoms take to pass through the illuminated volume of the cell and hence increases the relaxation rate, which results in a larger bandwidth for the detection of the magnetic field. By optimizing the parameters of the system, we were able to attain a good bandwidth of 24 kHz with close to $1\text{ pT}/\sqrt{\text{Hz}}$ of sensitivity to the magnetic field.

4. IMPROVING THE RANGE OF ATOMIC MAGNETOMETER USING MODULATION

Until now, we had discussed the steady-state response of the system under continuous optical pumping, in the presence of a magnetic field. When the frequency or the amplitude of the laser is modulated, the system exhibits a resonance condition when the Larmor precession rate (Ω_L) matches the modulation frequency (ω_m) of the laser and this provides a way to measure small changes in magnetic field in the presence of a larger bias field.

When linearly $\hat{x}$ -polarized light is used to optically pump atoms into the eigen-state of the $\hat{F}_x$ operator, the atomic angular momentum is symmetric about the $\hat{x}$ axis. In the presence of a magnetic field, the atomic angular momentum precess by 180° , and come back to the initially prepared state, given that the spin polarization is still maintained. Hence, upon modulating the laser at a frequency (ω_m) much larger than the spin relaxation rate (Γ), there is a resonance condition at every $\omega_m = n\Omega_L/2 = n\gamma B/2$ where n is an integer. The factor of $1/2$ appears because the angular momentum of the atoms need only to rotate by 180° before the state again becomes an eigen-state of $\hat{F}_x$, which leads to a resonance. This is parametric resonance, as the modulation of the laser affects the strength of optical pumping and hence the extent of atomic spin polarization.

This scheme is demonstrated using the same setup as shown in figure 2 and adding a laser frequency modulation along with a lock-in detection of the optical rotation signal at the modulation frequency. The laser frequency is kept at 240 MHz (f_{bias}) above the ^{87}Rb D_2 $F = 2 \rightarrow 3$ (f_0) transition and sinusoidally modulated by an amplitude of 177.5 MHz (f_{amp}) at $\omega_m = 2\pi \times 500$ Hz, leading to the laser frequency being modulated as $f(t) = f_0 + f_{bias} + f_{amp} \sin(\omega_m t)$. Modulating the frequency of the laser leads to the modulation of optical pumping efficiency. The frequency of the laser is modulated about a bias frequency such that modulation happens at the side of the absorption profile and hence the absorption change is almost linear across the modulation region.

The signal from the polarimeter is demodulated at ω_m and the in-phase (X) and out-of-phase (Y) components are measured and plotted in figure 9 while the magnetic field was swept across the resonance. At resonance, the in-phase component has the same slope at a bias magnetic field ($B = \Omega_L/\gamma = \omega_m/2\gamma$) as the slope around the zero magnetic field regime. This slope can be utilized to measure magneto-optic rotation of polarization at a larger bias field when the Larmor precession rate exceeds the spin relaxation rate. In this way, the high sensitivity of the atomic magnetometer can be taken advantage of even at larger bias magnetic fields leading to the working of the atomic magnetometer to achieve pico-Tesla level of sensitivity over the background magnetic field of the Earth.

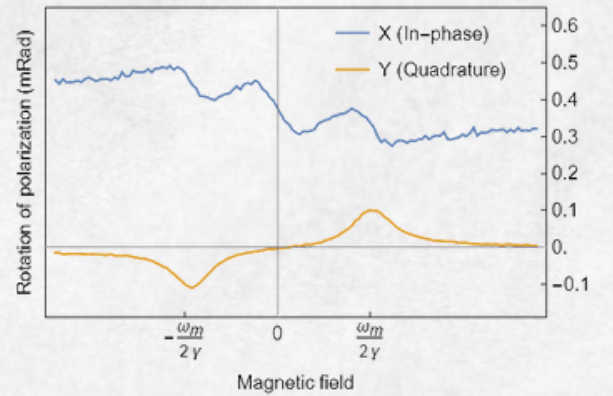


Figure 9: The in-phase (X) and out-of-phase components (Y) of the demodulated signal are plotted as the magnetic field is swept across resonance. The in-phase signal has a positive bias due to imbalance in the photo-detector signal when the magnetic field is absent.

5. CONCLUSION

We show the working principle of atomic magnetometry and how the magnetometer can be optimized to measure magnetic fields with a range of sensitivity. Also, we remark on the factors affecting the bandwidth of the magnetometer and explain a method to measure the magnetic field in the presence of large bias field using modulation technique. These techniques enable the development of a field-deployable magnetometer with a sensitivity of a few $\text{pT}/\sqrt{\text{Hz}}$ and a large bandwidth that can work in the background magnetic field of the Earth.

7. REFERENCES

1. Jukić, M. et al. Quantum sensing for magnetic-aided navigation in GPS-denied environments in Quantum Technologies for Defence and Security 13202 (2024), 23–37.
2. Muradoglu, M. et al. Quantum-assured magnetic navigation achieves positioning accuracy better than a strategic-grade INS in airborne and ground-based field trials. arXiv: 2504.08167 [quant-ph] (Apr. 2025).
3. Xia, H., Ben-Amar Baranga, A., Hoffman, D. & Romalis, M. V. Magnetoencephalography with an atomic magnetometer. Applied Physics Letters 89, 211104. issn: 0003-6951 (Nov. 2006).
4. Sander, T. H. et al. Magnetoencephalography with a chip-scale atomic magnetometer. Biomed. Opt. Express 3, 981–990 (May 2012).
5. Kamada, K., Ito, Y. & Kobayashi, T. Human MCG measurements with a high-sensitivity potassium atomic magnetometer. en. Physiol. Meas. 33, 1063–1071 (June 2012).
6. Sun, Y. et al. A Single-Axis Atomic Magnetometer-Based Mouse Magnetocardiography Measurement System. IEEE Transactions on Instrumentation and Measurement 72, 1–10 (2023).
7. Aerospace, H. HMC-1001 / 1002 / 1021 / 1022 Magnetic Sensors (Anisotropic Magnetoresistive magnetometer) https://aerospace.honeywell.com/content/dam/aerobt/en/documents/learn/products/sensors/datasheet/N61-2056-000-000_MagneticSensors_HMC-ds.pdf.
8. Xi'an Huashun Measuring Equipment Co., L. HSF-113 / 2H3-AAB Fluxgate Magnetometer (Fluxgate magnetometer).
9. Kumar, H., Dasika, S., Mangat, M., Tallur, S. & Saha, K. High dynamic-range and portable magnetometer using ensemble nitrogen-vacancy centers in diamond. Review of Scientific Instruments 95, 075002. issn: 0034-6748 (July 2024).
10. Shanghai Aidu Intelligent Detection Technology Co., L. ACZ-8 Proton Precession Magnetometer (Proton magnetometer) <https://www.aiduny.com/detail/content/id/427>.
11. Systems, G. GSM-19T Proton Magnetometer (Proton magnetometer) https://www.gemsys.ca/wp-content/themes/gemsystems/pdf/GEM_Proton_GSM_19Tfin.pdf.
12. Geometrics, I. G-882 Magnetometer (Atomic magnetometer) https://www.uniquegroup.com/wp-content/uploads/2022/08/G-882_Spec_Sheet.pdf.
13. Kurian, K. G., Sahoo, S. S., Madhu, P. & Rajalakshmi, G. Single-Beam Room-Temperature Atomic Magnetometer with Large Bandwidth and Dynamic Range. Phys. Rev. Appl. 19, 054040 (5 May 2023).
14. Quspin. QZFM Gen-3 Magnetometer (SERF magnetometer) <https://quspin.com/products-qzfm/>.
15. Schmelz, M. et al. Field-stable SQUID magnetometer with sub-fT Hz $1/2$ resolution based on sub-micrometer cross-type Josephson tunnel junctions. Superconductor Science and Technology 24, 065009 (Apr. 2011).

6. ACKNOWLEDGEMENT

Authors are thankful for the support of the Department of Atomic Energy, India, under Project Identification No. RTI 4007. Authors thank TIFR-H workshop facility and Rakesh Moodika for the 3D design and modeling of the compact version of the magnetometer. We also extend our thanks to Dr. George K.K.K. for helpful discussions.

7. REFERENCES

16. Sakurai, J. J. Modern Quantum Mechanics (Revised Edition) (Cambridge University Press, 2017, 1994).
17. Auzinsh, M., Budker, D. & Rochester, S. Optically Polarized Atoms: Understanding Light-atom Interactions (OUP Oxford, 2010).
18. Budker, D., Kimball, D. & DeMille, D. Atomic Physics: An Exploration Through Problems and Solutions isbn: 9780198509509 (Oxford University Press, 2004).
19. Foot, C. J. Atomic physics / 1st Ed. (Oxford University Press, UK, 2014).
20. Steck, D. A. Rubidium 85 D line data <https://steck.us/alkalidata/rubidium87numbers.pdf>. Aug. 2025.
21. Budker, D. et al. Resonant nonlinear magneto-optical effects in atoms. Rev. Mod. Phys. 74, 1153–1201 (4 Nov. 2002).
22. Seltzer, S. J. Developments in alkali-metal atomic magnetometry PhD thesis (Princeton University, New Jersey, Jan. 2008).
23. Budker, D. & Romalis, M. Optical magnetometry. English (US). Nature Physics 3, 227–234. ISSN: 1745-2473.

8. ABOUT



RAGHAV SAH

Raghav Sah is a Senior Research Fellow at the Tata Institute of Fundamental Research (TIFR) in Hyderabad, specializing in quantum sensing and magnetic field detection. He has achieved $1 \text{ pT}/\sqrt{\text{Hz}}$ of sensitivity towards detecting oscillating magnetic fields and is working on techniques to extend this sensitivity to static and slowly varying magnetic fields.

Previously, Raghav worked at the Defence Research and Development Organisation (DRDO) on quantum magnetometry with rubidium atoms and nonlinear optical processes.

He holds a Masters of Science (MSc) in Physics from the University of Madras and a Bachelor degree in Applied Science from PSG College of Technology.



DR. G. RAJALAKSHMI

Dr. G. Rajalakshmi is a Scientist at the Tata Institute of Fundamental Research (TIFR), specializing in gravitational and spin physics. Her research focuses on laser-cooled atoms, gravitational wave detection with LIGO, and nuclear magnetic resonance studies on spin-environment interactions.

She holds a PhD in Experimental Gravitation from the Indian Institute of Astrophysics (IIA), Bangalore, and was a member of the LIGO-India consortium. Her work also includes torsion balance experiments and exploring modifications to gravity at short ranges.

Dr. Rajalakshmi strives to develop experimental techniques that connect theoretical models with observable phenomena, advancing our understanding of fundamental forces.

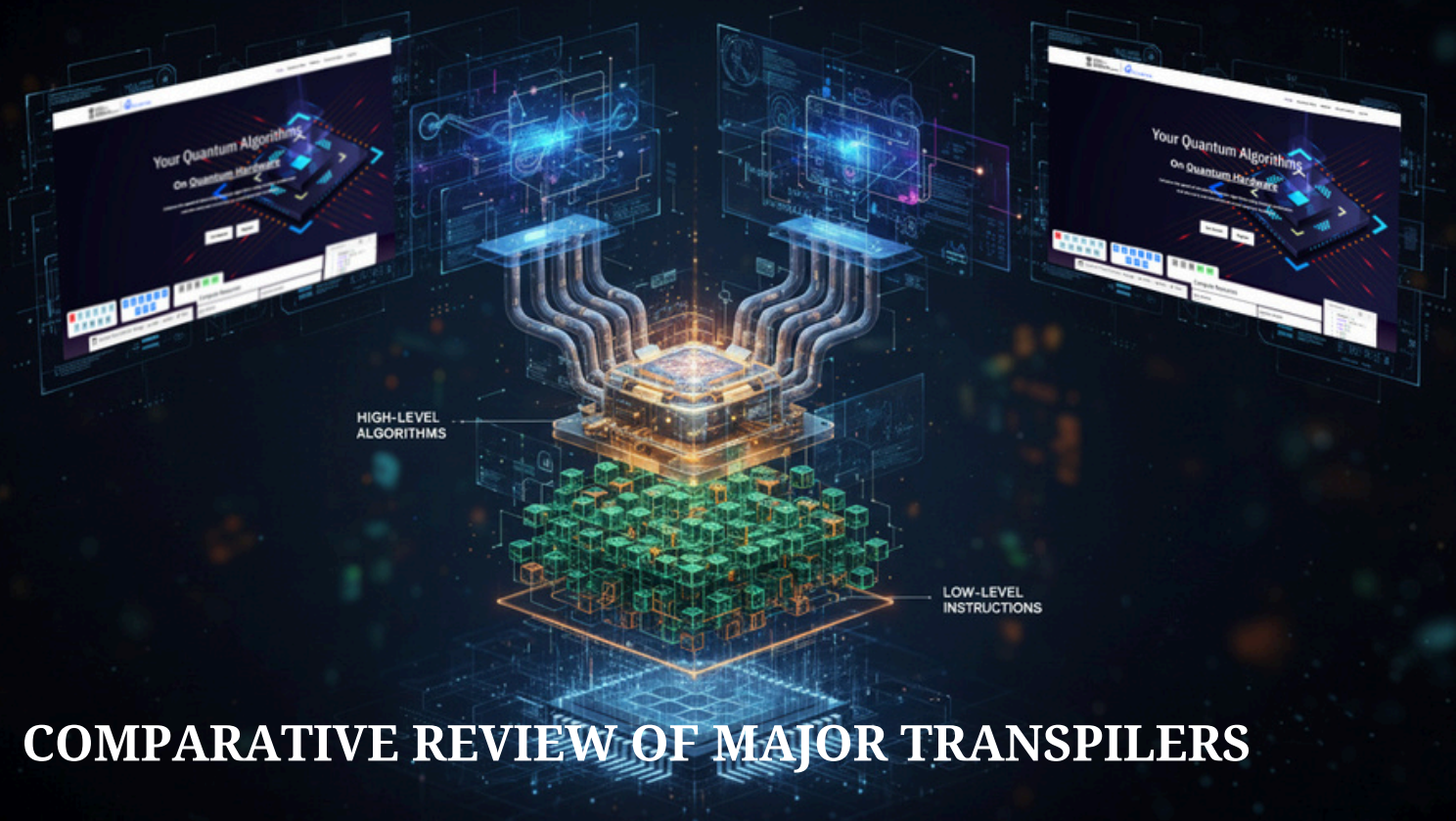
QUANTUM TRANSPILATION IN THE NISQ ERA: COMPARATIVE ANALYSIS AND IMPLEMENTATION IN QNIVERSE

VIKAS RAMASWAMY



Quantum **compilation** / **transpilation** refers to the process of converting high-level quantum algorithms or circuits into low-level instructions that satisfy the constraints of a particular quantum hardware. In practice, this involves transforming an abstract circuit – which might be described in a language like OpenQASM or a framework like Qiskit/Cirq – into a form executable on a specific device. Transpilation typically includes mapping logical qubits to physical qubits, decomposing gates into the device’s native gate set, and optimizing the resulting circuit to mitigate noise and minimize resource usage [1]. For example, IBM’s Qiskit defines transpilation as “the process of rewriting a given input circuit to match the topology of a specific quantum device, and/or to optimize the circuit for execution on present day noisy quantum systems.” [1]. This process is essential for bridging the gap between high-level algorithm design and the physical realities of quantum hardware, since quantum algorithms are often expressed without reference to any particular device’s connectivity or gate set [2].

A typical transpilation flow applies a sequence of **passes** to an intermediate representation of the circuit. In IBM’s Qiskit, for instance, a DAGCircuit graph is used as an intermediate form, and a PassManager orchestrates a pipeline of analysis and transformation passes (such as layout selection, routing with SWAP gates, gate synthesis, and optimization) [1]. Other frameworks use similar concepts: for example, Google’s Cirq provides transformer functions to rewrite circuits to use a specified hardware-native gate set [3]. Effective transpilation must respect hardware constraints (qubit connectivity, native operations) while also applying optimizations (gate cancellation, qubit reuse, scheduling delays, etc.) to improve fidelity on noisy devices.



COMPARATIVE REVIEW OF MAJOR TRANSPILERS

Several software frameworks provide quantum transpilation capabilities. The most widely used include IBM's Qiskit, Google's Cirq, Cambridge Quantum/Quantinuum's t|ket> (pytket), and Rigetti's Quilc (via PyQuil), among others. Each has its own design and strengths:

Qiskit is an open-source quantum SDK from IBM. Its *transpile()* function automatically runs a multi-stage pass pipeline (layout, routing, translation, optimization, scheduling) to target specific devices [1]. Qiskit uses heuristic routines such as the Sabre algorithm for qubit placement and routing, and allows configurable optimization levels (0–3) to trade compilation time vs performance [1]. It natively supports IBM superconducting hardware (e.g. heavy-hex lattices) and can be extended to other devices via its provider interface. Qiskit's transpiler is highly modular and widely tested; in one comprehensive benchmark it successfully transpiled all test circuits (100% of cases) even for restricted connectivities, although it sometimes produces higher two-qubit gate counts compared to the

others [2, 4]. Its widespread use and integration with IBM's cloud make it a de facto reference transpiler in many settings.

Cirq is a Python based framework developed by Google. Cirq emphasizes flexibility for custom hardware, especially Google's own processors and provides a library of transforms for circuit optimization. For example, Cirq's transformer rewrites a circuit to use only gates in a specified *CompilationTargetGateset()*, decomposing higher-level operations as needed [3]. Other built-in optimizers can merge single-qubit rotations, align gates into parallel "moments", and even insert echo pulses to mitigate noise [3, 4]. Unlike Qiskit's staged pass manager, Cirq often uses user-invoked transform functions to achieve similar goals.

T|ket> is a high performance compiler developed originally by Cambridge Quantum (now Quantinuum). It is language-agnostic (supporting OpenQASM, PyQuil, etc.) and emphasizes retargetability across many architectures [2]. The t|ket> compiler includes sophisticated placement and routing algorithms, circuit rewriting passes, and noise-aware optimizations. Its designers report that it "outperforms most competitors in terms of circuit optimization and qubit routing," often yielding circuits with fewer two-qubit gates or shallower depth for highly-connected topologies [2, 4]. In one end-to-end comparison targeting realistic device topologies, t|ket> produced the most efficient circuits (especially on dense connectivity), followed by Rigetti's Quilc, with Qiskit incurring a substantially higher two-qubit gate overhead [2].

However, this higher optimization cost can also lead to longer compilation time, and $t|ket\rangle$'s routing routines are known to scale less favorably for very large circuits. $t|ket\rangle$ is widely used in industry benchmarks and is accessible via its Python package (pytket).

QUILC is an optimizing compiler for Rigetti's Quil language. It is integrated into the PyQuil framework and translates abstract Quil programs into native Quil instructions that respect a hardware's gate set and connectivity [6]. The compiler can perform rewiring (qubit mapping), inserting

SWAPs, and decomposing gates so that the output is executable on a Rigetti QPU. For example, pyQuil provides `quil_to_native_quil()` and `native_quil_to_executable()`, making the compilation transparent to the user [6]. In benchmarks, Quilc generally performs well on Rigetti's architectures, often second only to $t|ket\rangle$ in gate-count optimization [2].

Other notable tools include AWS Braket's SDK (which leverages Qiskit and other compilers for hardware backends), Microsoft's QDK/QIR (for targeted hardware via the Q#

language), and academic compilers like BQSKit and StaQ. Each has specialized features (e.g. pulse-level compilation in Braket or ZX-calculus optimizers), but Qiskit, Cirq, $t|ket\rangle$, and Quilc cover the current primary landscape. In general, no single transpiler is universally best: trade-offs exist between optimization quality, compilation time, and device support. Benchmark studies show, for instance, that $t|ket\rangle$ typically yields very low two-qubit depth on all-to-all connected tests [4, 7], while Qiskit has the most complete feature set and easiest integration with cloud devices.

Although the considered benchmark may vary based on updates by the respective platforms.

QNIVERSE'S TRANSPILATION AND COMPILATION STACK

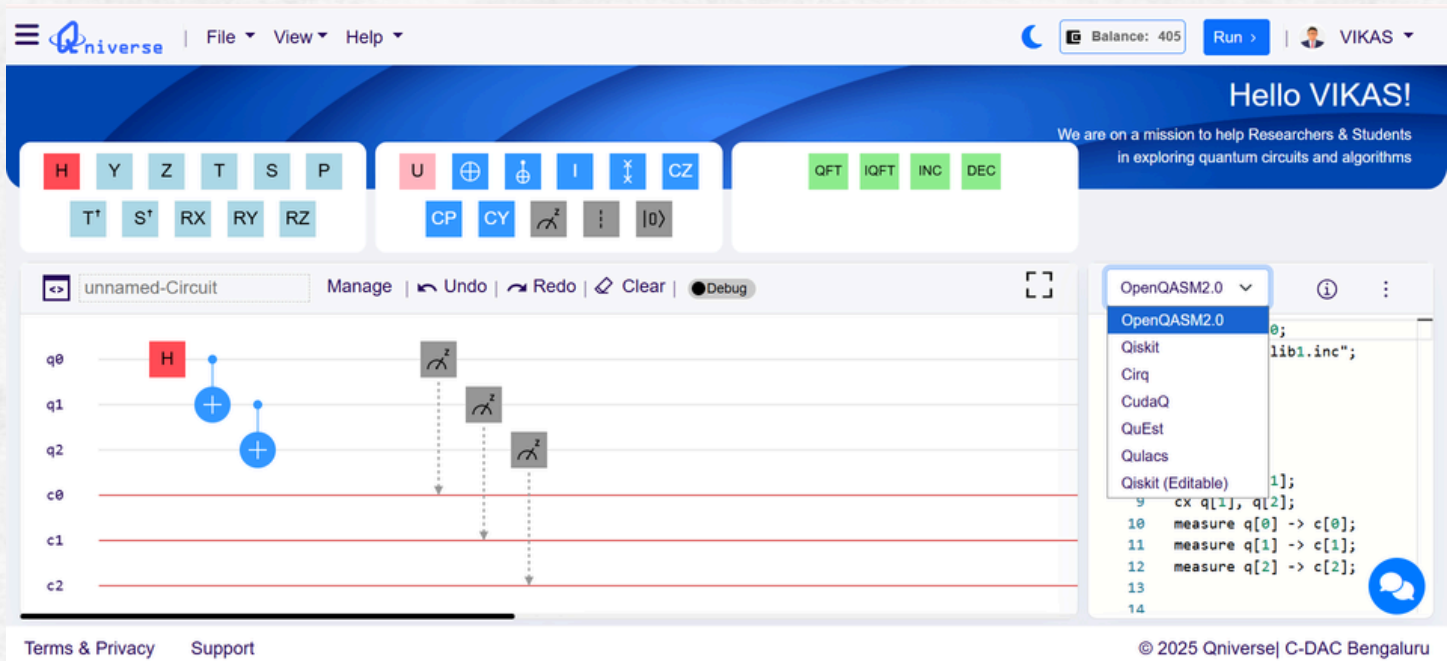


Fig 1: Qniverse circuit composer with integrated transpiler

Qniverse is a unified quantum computing platform developed by Quantum Technology Group, C-DAC Bengaluru to facilitate circuit design, simulation, and execution across heterogeneous resources [8]. Its transpilation/compilation framework is designed to “code once, execute on multiple platforms” [8]. Key aspects of Qniverse’s stack include:

- **Multi-language support:** The Qniverse code editor and SDK support several circuit description formats. It provides real-time code generation in OpenQASM and high-level frameworks such as Qiskit, Cirq, Qulacs, CudaQ and QuEst [8]. Users can visually build circuits via a drag-and-drop interface, and the system automatically produces the corresponding QASM 2.0, Cirq, or Qiskit, etc., supported code. Likewise, existing QASM 2.0 code can be imported and will be instantly reflected in the visual composer. This interoperability means the Qniverse transpiler must accept circuits in QASM 2.0 and convert between representations internally [8].
- **Integrated Transpiler:** Qniverse includes an automated transpilation pipeline that adapts circuits to different execution backends[8]. Qniverse’s transpiler “efficiently converts quantum circuits into formats supported by various simulation frameworks (Qiskit, Cirq, CudaQ, etc.) and transforms them into optimized instruction sequences compatible with different quantum hardware architectures (IBMs superconducting, Quantum Inspire’s Starmon and Tuna 7)” [8]. Qniverse also integrates Superstaq (Infleqtion) hardware which “acts as an advanced compiler that bridges the gap between high-level quantum algorithms and the unique characteristics of different hardware” by applying device-aware optimizations [8]. Thus, Qniverse can leverage state-of-the-art, hardware-specific optimization.
- **Hardware Integration:** Qniverse connects to multiple quantum backends. It currently supports IBM Quantum devices (e.g. ibm_brisbane, ibm_torino, ibm_kingston, etc.,) and Rigetti’s ankaa-3 [8], via Superstaq, and can target other QPUs with their native gates [8]. Qniverse also provides access to Starmon-7 and Tuna-5 QPUs via Quantum Inspire’s API to its premium users. Qniverse handles the final translation into device-specific instructions and queues the jobs. The platform provides seamless hardware connectivity and HPC acceleration on CPUs, GPUs, FPGAs, and vector units [8]. Internally, Qniverse uses the published coupling maps and gate sets of each device to perform qubit mapping and to decompose gates into the device’s basis. For instance, Starmon-7 and Tuna-5 devices require inserting SWAP gates for non-neighbor two-qubit interactions; Qniverse’s built in unified transpiler automatically takes care of this routing without needing any user intervention.

Our Complete
Quantum Ecosystem



Powerful Circuit Builder



Simulate on Accelerators



Run on Quantum Hardware



Algorithm Implementations



Integrated Transpiler



Modular Libraries

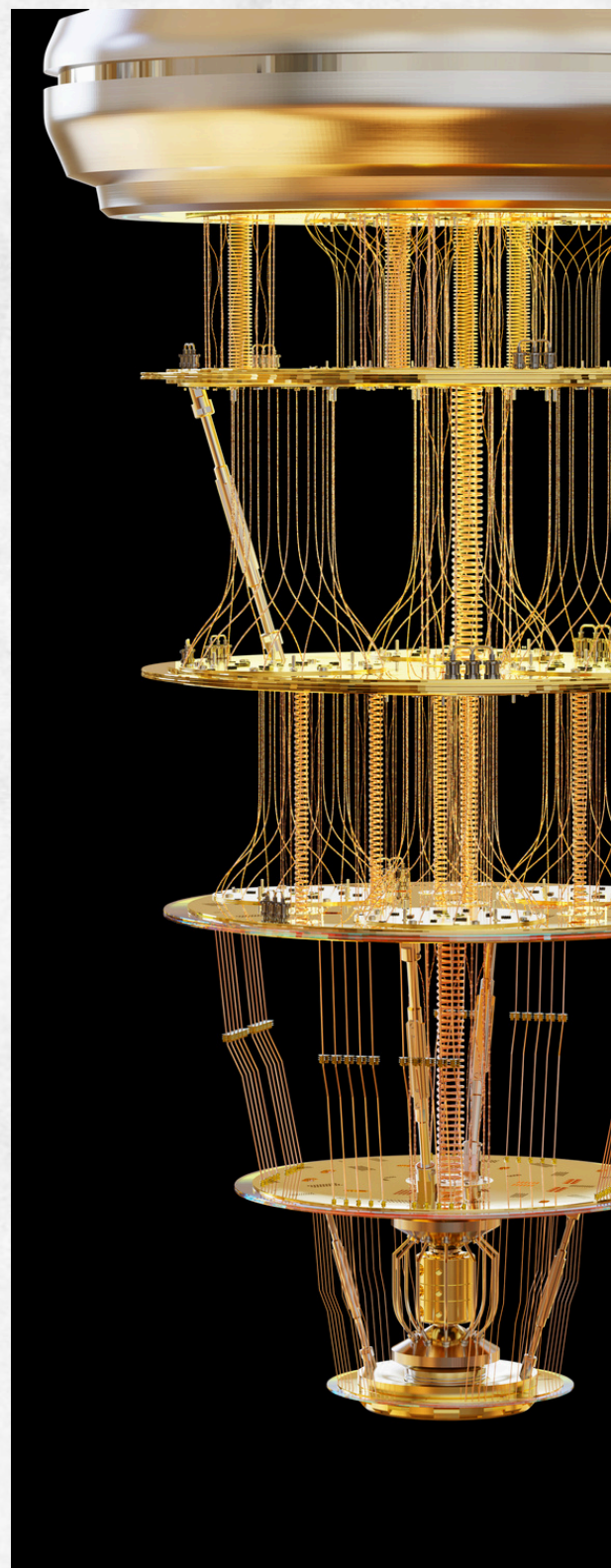
- **Optimization and Gate Decomposition:** Qniverse's compiler passes includes advanced circuit optimization libraries (e.g. merging rotations, gate cancellations) and offers modular libraries for building custom circuits. The platform performs optimized instruction sequences [8] and Quantum Inspire's device-informed compilation [8] implies that Qniverse's transpiler performs aggressive low-level optimizations. These would include decomposing arbitrary gates (from QASM or high-level circuits) into the minimal sequence of hardware-native one-qubit and two-qubit gates, and re-synthesizing fragments to reduce depth (similar to the Optimize1qGates or multi-qubit unitary synthesis passes in Qiskit). The system also supports custom gates defined by users, which must be decomposed into the hardware set.
- **Qubit Mapping and Routing:** Qubit mapping (assigning logical qubits to physical addresses) is a critical challenge. Qniverse solves this for each backend. For example, Qiskit's VF2 or Sabre algorithms iteratively place qubits and insert SWAPs to respect the device graph [1], while t|ket> uses optimal-path routing with fidelity heuristics [2]. By leveraging these tools, Qniverse offers reduced two-qubit depths and device-aware scheduling.
- **Architecture-Aware Compilation:** Qniverse's stack is architecture-aware by design (it supports multiple device types and bases its transformations on each device's specifics) [8]. It also enables users to run simulations on ideal (noise-free) backends (state-vector simulators or density matrix simulators on CPUs and GPUs [8]) for debugging before execution on QPUs.

In summary, Qniverse offers a comprehensive transpilation framework that unifies multiple front-end languages and back-end devices. Its features include cross-platform code generation [8], drag-and-drop circuit building, real-time debugging, and an integrated compiler pipeline with multi-hardware support. It also provides JupyterLab integration and uses HPC resources (CPU/GPU) for fast simulation [8].

CHALLENGES IN QUANTUM TRANSPILATION

Despite advances, many challenges remain in quantum transpilation, especially on NISQ devices. Key open problems include:

- **Hardware Heterogeneity:** Different quantum architectures (superconducting, ion-trap, photonic, etc.) have wildly different gate sets and connectivity. A compiler must adapt to each topology and native operation set. While Qniverse supports multiple platforms [8], the rapid emergence of new devices (e.g. 3D ion traps, neutral-atom arrays) means transpilers must continually update gate libraries and mapping algorithms. Ensuring portability of optimized circuits across such diverse hardware remains difficult.



- **Qubit Mapping and Routing Complexity:** Finding an optimal mapping of logical qubits to physical qubits (minimizing added SWAPs) is NP-hard. Heuristic methods (Sabre, $t|ket\rangle$ algorithms) work well in practice, but there is no guarantee of minimal overhead. This mapping must also consider topology-aware optimizations and may interact with gate synthesis.
- **Noise-Adaptive Compilation:** Real devices suffer from decoherence and gate errors that vary across qubits and time. An ideal transpiler would use calibration data (error rates, cross-talk) to place critical qubits in the best physical locations and schedule noise-cancelling sequences.
- **Dynamic and Adaptive Circuits:** Recent developments like OpenQASM3 and mid-circuit measurements enable dynamic circuits with classical feedback. Transpiling such circuits (with loops or conditionals) is more complex. Qniverse's current GUI and SDK focus on static circuits (up to 6 qubits in the visual composer [8]). Supporting dynamic circuits would require significant enhancements to the compiler and execution engine (for example, injecting classical control), which is an open challenge.
- **Standardization and Interoperability:** The quantum software ecosystem still lacks a single standard IR. While OpenQASM2 is common, QASM3 and QIR are emerging, and various frameworks use their own formats. Qniverse mitigates this by supporting multiple front-ends [8], but future updates may need to embrace new standards fully.
- **Scalability and Performance:** As circuits grow larger, compilation time and memory use become significant. Benchmark studies show that some compilers (e.g. BQSKit) can be extremely slow for large inputs [4, 7]. Balancing compilation effort vs circuit quality (as in Qiskit's optimization levels) is crucial. Qniverse's integration with CDAC's HPC resources provides support for simulating 40+ qubits. Ensuring fast, memory-efficient transpilation for such large-scale quantum circuits remains an ongoing goal.

Qniverse addresses several of these challenges by design. Its unified platform abstracts away the heterogeneity of tools: users compose circuits once in the interface, and the integrated transpiler targets different frameworks and hardware under the hood [8]. The availability of powerful classical accelerators (CPUs, GPUs & FPGAs) for simulation and computation [19] helps explore larger or more complex circuits during development. Finally, the platform's unified transpiler allows developers to implement their quantum algorithms without worrying about the constraints of target hardware. However, some challenges remain unaddressed and are under active research. For instance, Qniverse does not currently support any noise-model-based routing or calibration-aware placement. Likewise, dynamic circuits are not featured in the GUI, so adaptive compilation is likely limited. In future work, Qniverse will incorporate real-time calibration data or support OpenQASM3 constructs to tackle these issues. In summary, while Qniverse provides a comprehensive and feature-rich transpilation stack [8], the broader challenges of NISQ compilation (noise, scale, heterogeneity) continue to motivate further development in the field.

Visit www.qniverse.in to explore the fascinating world of quantum technology and experience the platform firsthand. The future of computing has arrived — and Qniverse is at the forefront, driving breakthroughs and innovations that will define the years ahead.



REFERENCES

1. IBM Quantum. Transpiler (latest version). IBM Quantum Documentation. Retrieved from <https://quantum.cloud.ibm.com/docs/en/api/qiskit/transpiler>
2. Cowtan, A., Dilkes, S., Duncan, R., Krajenbrink, A., Simmons, W., & Sivarajah, S. (2020). $t|ket\rangle$: A retargetable compiler for NISQ devices [White paper]. Cambridge Quantum Computing. https://cqwbkpro.s3.eu-west-2.amazonaws.com/wp-content/uploads/2021/10/27144214/200324_CQ_Tket-A-Retargetable-Compiler-for-NISQ-Devices.pdf
3. Google Quantum AI. `cirq.optimize_for_target_gateset`. Cirq Documentation. Retrieved from https://quantumai.google/reference/python/cirq/optimize_for_target_gateset
4. Bittel, L., et al. (2024). Benchmarking the performance of quantum computing software. arXiv preprint arXiv:2409.08844. Retrieved from <https://arxiv.org/html/2409.08844v1>
5. Google Quantum AI. Circuit optimization, gate alignment, and spin echoes. Cirq Tutorials. Retrieved from https://quantumai.google/cirq/tutorials/google/spin_echoes
6. Rigetti Computing. The Quil compiler. pyQuil 4.16.1 Documentation. <https://pyquil-docs.rigetti.com/en/stable/compiler.html>
7. ADAC Institute. (2025). The role of quantum computing in advancing scientific high-performance computing: A perspective from the ADAC Institute. arXiv preprint arXiv:2508.11765.
8. Qniverse v1.2.1 2025. Quantum Technology Group, C-DAC Bengaluru. <https://qniverse.in/>

ABOUT

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Vikas Ramaswamy is a Project Engineer at CDAC, Bengaluru, working in photonic quantum simulation and quantum transpilers. He is a BE graduate from VVIET, Mysuru. He is passionate about bridging theoretical quantum models with practical implementations through scalable simulation and software innovation.



Inside the minds

Mr. Syamasundar Gopasana
Accenture

TECHNOLOGY INNOVATION
SENIOR MANAGER

Specializing in Quantum Computing & HPC

A WORLD ECONOMIC
FORUM FELLOW

Published author & Led award
winning quantum innovations

CUTTING-EDGE
RESEARCH

His team's work in reinsurance
optimization achieved an
industry-first breakthrough,
improving decision-making by
30% with large-scale scenario
data.



EXCLUSIVE INTERVIEW

“The true power of quantum computing lies in translating complex business problems into solutions that create measurable, transformative outcomes.”

Inside the minds

With Mr. Syamasundar Gopasana

Where does Accenture see the first tangible business value emerging for enterprises using quantum technologies? How do you balance the hype vs. reality in quantum when advising clients and collaborators?

Accenture sees the first tangible business value for quantum technologies across three areas:

Quantum Computing

We're seeing early traction in industries like finance, life sciences, energy, aerospace, and automotive where classical systems struggle with complex problems. We've delivered successful experiments in portfolio optimization, credit scoring, bond hedging, drug discovery, and grid optimization. Currently, we're working with clients to scale these solutions and explore new use cases. To balance hype with reality, we use a Quantum Business Experiment Framework that guides clients from ideation to PoC and scalability. We validate quantum advantage using real-world data and apply quantum-inspired algorithms for near-term impact while preparing for future hardware maturity.

Quantum Sensing

There are early wins in healthcare and aerospace, where precision and stability of results are key. Quantum magnetometers are enabling non-invasive cardiac diagnostics, and gravimeters are improving navigation and geophysical surveys. We're working with sensor manufacturers on miniaturization and integration and applying AI to enhance data interpretation.

Quantum Security & Communications

Enterprise adoption is already underway in financial services and telecom industries, driven by the urgency to prepare for post-quantum threats. We're helping clients with crypto agility assessments and implementing quantum-safe techniques such as post-quantum cryptography (PQC), quantum random number generators (QRNGs) and quantum key distribution (QKD).

“

Accenture's approach is grounded in delivering real client value through practical implementation, ecosystem collaboration, and strategic foresight.

Inside the minds

With Mr. Syamasundar Gopasana



Our Next Generation Computing team works across industries to ensure quantum solutions are scalable, secure, and tailored to real-world needs

How is Accenture accelerating the transition of quantum technology from a prototype stage to full-scale production for its enterprise clients?

Accenture takes an end-to-end approach to move quantum computing from experimentation to enterprise-scale impact. It includes:

- **Strategic advisory:** Helping clients define quantum readiness goals aligned with their business strategy.
- **Use case engineering:** Identifying high-impact problems where quantum can outperform classical methods.
- **Technical enablement:** Building quantum software stacks that integrate with classical infrastructure using cloud-based platforms.
- **Talent development:** Training quantum software engineers and domain experts to bridge the gap between theory and enterprise application.

Our Next Generation Computing team works across industries to ensure quantum solutions are scalable, secure, and tailored to real-world needs. While full-scale production implementations remain limited (e.g., using quantum annealers), we're seeing progress in quantum hardware, algorithms, and software innovation that will drive future adoption. We're ensuring clients are prepared to capitalize on these advancements.

Inside the minds

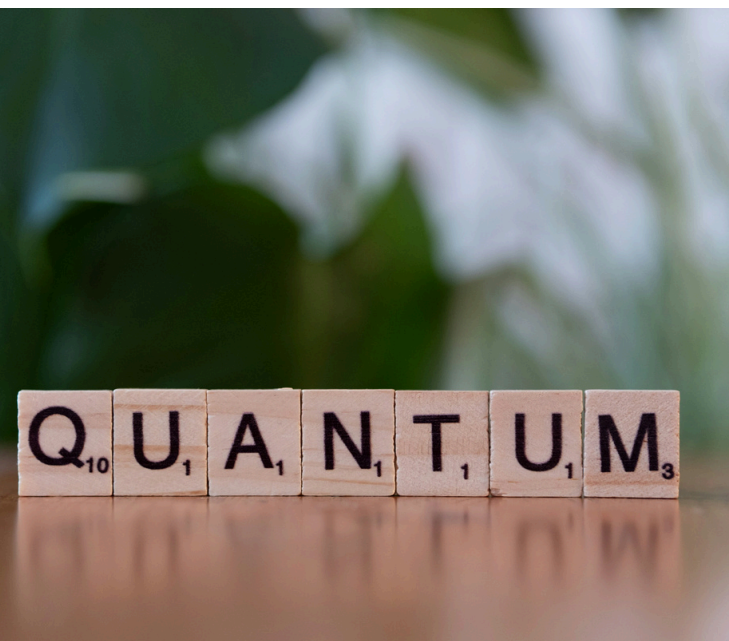
With Mr. Syamasundar Gopasana



Our goal is always to ensure that the technology serves the business need, not the other way around.

What key differentiators do you prefer to see in quantum technology vendors from an evaluation standpoint, and why?

Accenture is focused on delivering client value. When evaluating quantum technology vendors, our priority is to bring the best-fit tools and solutions to solve our client's most pressing problems. We assess vendors based on their ability to integrate into enterprise environments, scale effectively, and contribute meaningfully to real-world outcomes. Our goal is always to ensure that the technology serves the business need, not the other way around.



Could you tell us about your projects under the India National-level ‘Challenge to be Quantum Ready’ contest, and their impact on India’s quantum ecosystem?



Accenture’s India Labs team has been actively participating in the “Challenge to be Quantum Ready”, a national-level initiative hosted by I-HUB Quantum Technology Foundation of IISER Pune in collaboration with NVIDIA and supported by DST, NM-ICPS, and the National Quantum Mission. We were provisioned with 200 compute hours on NVIDIA A100 GPUs to explore quantum-inspired and emulated solutions for real-world problems.

We’ve contributed to two impactful projects:

Efficient Simulation of Quantum Boltzmann Machines (QBM)

Led by Dr. Srikumar K. Subramanian, the team simulated a 20-qubit system on a single GPU, surpassing the 12-qubit benchmark in current literature. We’ve achieved significant speed-up over CPU-based methods using custom CUDA code in Julia, efficient memory management, and hand-coded gradient operations.

Scalable Credit Card Fraud Detection Using Quantum-Inspired ML

Led by me and Swatantra Singh, this project applied quantum-inspired and GPU-accelerated models to detect fraudulent transactions. Using the BankSim dataset, we achieved impressive results on small qubit systems. We’re now scaling to larger datasets using Quantum SVM with Kernel Estimation, cuTensorNet-powered tensor networks, and GPU-accelerated classical machine learning models.

These initiatives reflect our commitment to “building in India, building for the world”, and demonstrate how industry-led R&D can accelerate quantum readiness, inspire new talent, and shape the future of applied quantum science.

Inside the minds

With Mr. Syamasundar Gopasana

Global Quantum Policy Frameworks



Given your experience in co-authoring reports with the World Economic Forum—how do you think India's strides in quantum technologies are helping shape global quantum policy frameworks and influencing international cooperation?

As an industry fellow of the World Economic Forum, I engage with global experts, including those from India, to distil insights into white papers and reports. India's quantum journey is not only self-fulfilling but also a model for the Global South.

While India entered the quantum race later than others, it's now charting a bold course through the National Quantum Mission (NQM). We're seeing thematic hubs, targeted startup funding, national challenges, and a strong push for talent development. We've showcased these initiatives in global publications and events to help shape international cooperation and policy frameworks.

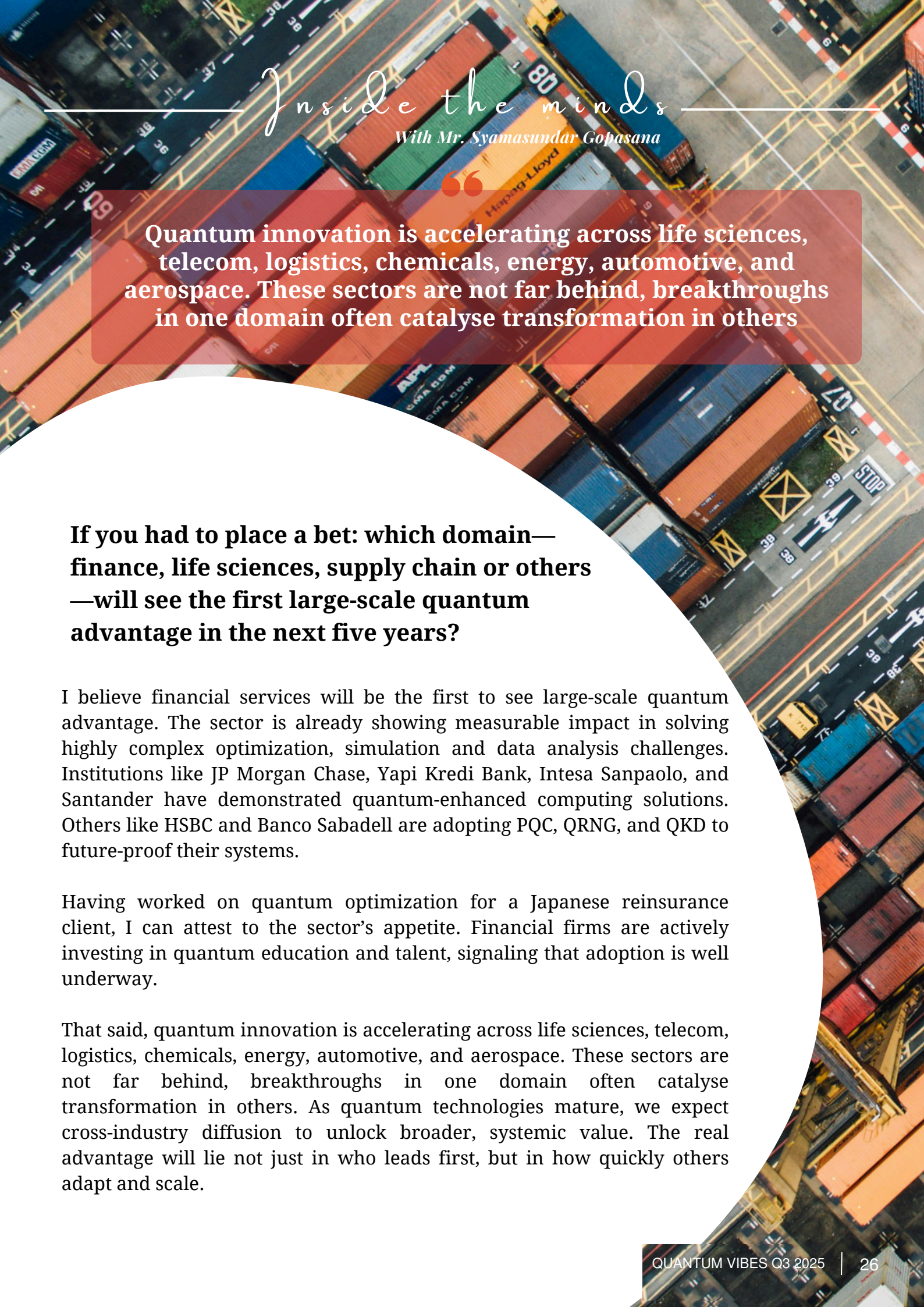
Highlights from the report he co-authored

Quantum computing has the potential to transform portfolio optimization, risk modelling, and fraud detection, with an estimated \$622 billion in value creation by 2035. Most applications are in pilot or proof-of-concept phases, with early case studies from leading banks showing promise.

Quantum sensors like atomic clocks provide ultra-precise timing for high-frequency trading. While current use is limited, various quantum sensors could enhance ESG reporting and sustainable investing by providing highly accurate environmental data.

To address quantum-enabled cyber threats, financial institutions should adopt PQC, QKD and QRNG. A "defense-in-depth" approach combining quantum-resistant and quantum-native technologies is essential, with early deployments already underway.





Inside the minds

With Mr. Syamasundar Gopasana

Quantum innovation is accelerating across life sciences, telecom, logistics, chemicals, energy, automotive, and aerospace. These sectors are not far behind, breakthroughs in one domain often catalyse transformation in others

If you had to place a bet: which domain—finance, life sciences, supply chain or others—will see the first large-scale quantum advantage in the next five years?

I believe financial services will be the first to see large-scale quantum advantage. The sector is already showing measurable impact in solving highly complex optimization, simulation and data analysis challenges. Institutions like JP Morgan Chase, Yapi Kredi Bank, Intesa Sanpaolo, and Santander have demonstrated quantum-enhanced computing solutions. Others like HSBC and Banco Sabadell are adopting PQC, QRNG, and QKD to future-proof their systems.

Having worked on quantum optimization for a Japanese reinsurance client, I can attest to the sector's appetite. Financial firms are actively investing in quantum education and talent, signaling that adoption is well underway.

That said, quantum innovation is accelerating across life sciences, telecom, logistics, chemicals, energy, automotive, and aerospace. These sectors are not far behind, breakthroughs in one domain often catalyse transformation in others. As quantum technologies mature, we expect cross-industry diffusion to unlock broader, systemic value. The real advantage will lie not just in who leads first, but in how quickly others adapt and scale.

Inside the minds

Marco Matters is the Program Director at Quantum Inspire. He holds an MSc and PhD in Applied Physics from Delft University of Technology, where he conducted research in the Quantum Transport group under the guidance of Professor Hans Mooij.

Marco Matters
Program Director,
Quantum Inspire
(TU Delft / QuTech)

"Quantum Inspire democratizes quantum computing — giving researchers, educators, and innovators free access to real quantum hardware."

A pioneer in bridging science and strategy, Marco co-founded several Philips internal start-ups.

Marco Matters brings together the precision of a physicist and the vision of a technology leader.



Dr. Marco Matters

Could you start by giving us a brief overview of the Quantum Inspire Platform and why it is a significant step in advancing quantum computing research and innovation?

Quantum Inspire is a cloud-based quantum computing platform developed by QuTech in the Netherlands. It provides users with (free) access to quantum processors and simulators through an intuitive online interface.

Key features



Real quantum hardware access

Users can run quantum algorithms on actual quantum chips based on different type of superconducting qubit technologies developed in Europe.

Classical simulators upto 37 qubits

Includes classical quantum simulators (up to 37 qubits) for testing and development without needing real hardware and a Rydberg emulator

Programming tools

Supports programming in (c)QASM ((common) Quantum Assembly Language), as well as integration with Qiskit and PennyLane SDKs.

Educational resources

Offers extensive documentation, tutorials, and examples, making it accessible for students, educators, and researchers.

From simulation to superconducting — Europe's quantum power at your fingertips.

Inside the minds

With Dr. Marco Matters

Significance in advancing quantum computing:

European innovation

Quantum Inspire is one of the first platforms to offer quantum hardware developed entirely in Europe, promoting technological independence. It has helped create a vibrant ecosystem of companies, universities and knowledge institutes, that worked together to advance quantum technology in the Netherlands and in Europe.

Open access & Educational Impact

It democratizes quantum computing by providing free access to quantum technology for researchers, educators, and developers worldwide.

Serves as a valuable resource for teaching and training the next generation of quantum scientists and engineers.

Support for Research & Development

Facilitates experimentation with real quantum devices, accelerating algorithm development and innovation.

Quantum Inspire is a significant step toward making quantum computing more accessible, fostering innovation, and supporting Europe's strategic presence in the global quantum technology race.

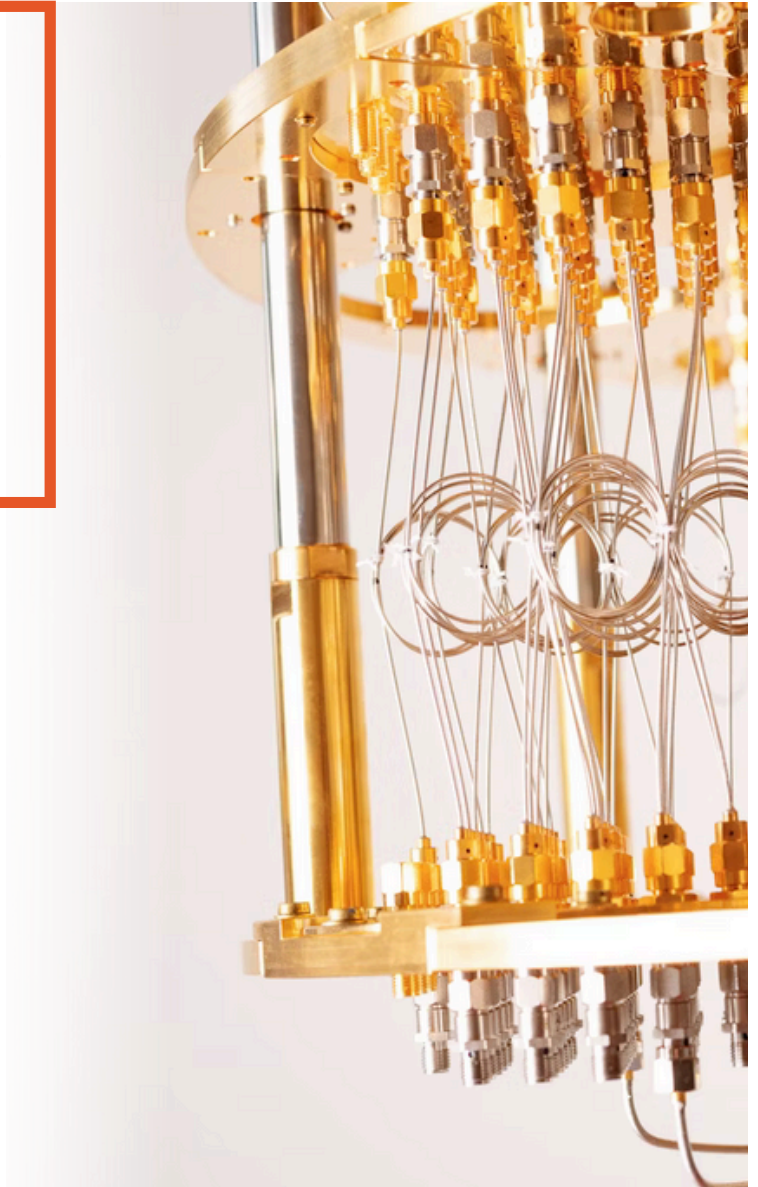
In your view, what attributes of the Delft ecosystem render it distinct in the field of quantum technology when compared to other initiatives worldwide?

The Delft quantum ecosystem's uniqueness comes from its decades-long development, QuTech's (part of Delft University of Technology) academic excellence and commitment to create value and spinoffs, its engineering culture, and a collaborative, "full-stack" development approach that emphasizes an open-architecture system and fosters a specialized supply chain for quantum components, rather than solely focusing on building a complete quantum computer in-house.

Here are the key factors contributing to its uniqueness:

Integrated ecosystem and decades of development

Delft has cultivated a thriving community of researchers, engineers, and entrepreneurs over decades, becoming a leading global hub for quantum technology.



QuTech

The mission-driven institute QuTech is at the heart of this ecosystem, focusing on quantum computing and the quantum internet and pushing

Engineering culture & facilities

The area's strong engineering culture, combined with top-tier facilities like the House of Quantum, attracts and supports the necessary talent and infrastructure.

Inside the minds

With Dr. Marco Matters



Open-architecture & full-stack approach

Rather than developing quantum computers entirely in-house, QuTech and its partners focus on building interoperable systems and developing individual components like specialized electronics, cabling, and detectors, strengthening the Dutch quantum supply chain.

Large talent pool

Delft benefits from a deep reservoir of innovative and multidisciplinary talent, including a steady supply of highly trained scientists and engineers from Delft University of Technology.

Strong industry-academia partnership

The ecosystem thrives on the close collaboration between academic research and industry partners, accelerating the transition from fundamental research to practical, real-world applications.

**Building the future of quantum through collaboration
— interoperable systems and cutting-edge components
powering the Dutch quantum supply chain.**

With your extensive background at Philips and now at QuTech, what lessons from DeepTech innovation and commercialization do you see as most relevant to the advance quantum technologies?

“

Investments in DeepTech offer significant potential but also have serious challenges, like long development timelines, high technical risk, a need for substantial upfront funding with uncertain market potential and smaller exit opportunities. This is also the case for quantum technologies, including quantum computing. Some of these risks can be mitigated by initially focussing not on the full end product, but on the key components of a quantum computer. In this way, the growing R&D market can be served and at the same time advances – technological as well as economic - are realized by working together. Still, significant and longer term support from public funding is needed to bridge the gap to private funding from investors. This way of working has been successfully adopted so far by the Delft ecosystem, with most of the companies creating revenue ‘from day 1’.

Inside the minds

With Dr. Marco Matters

How do you envision Europe's role in the global race for quantum innovation, and how does Quantum Inspire contribute to strengthening that position?

Europe plays and will play a significant and strategic role in quantum innovation, both in excellent scientific research and technological innovation. With coordinated public funding, international collaboration and academic excellence, Europe is one of the front runners in quantum research and technology. Although large corporate investments are limited in comparison to e.g. the US, Europe has managed to create several thriving ecosystems, consisting of world-class universities and research institutes, combined with a growing numbers of new start-ups and successful mid-size quantum tech companies.

Quantum Inspire, a full stack quantum computer that was built with many ecosystem partners in an “Airbus” like approach, plays three important roles to strengthen Europe's position in quantum technology

Freely accessible public quantum computer (with different qubit technologies and simulators) to make quantum computing available to a broad audience and train students.

An R&D vehicle for new innovation in quantum (computing) technology and for expanding and strengthening the ecosystem.

A testbed for development of quantum application and system software.

Inside the minds

With Dr. Marco Matters

Looking ahead, what is your long-term vision for Quantum Inspire, and how do you see it shaping science, industry, and society in the years to come?



“

By continuously improving and expanding its functionality, Quantum Inspire, will continue to play the roles described above and significantly contributing to innovation in quantum technology and creating value of quantum in society.

”

 **Quantum Inspire** - By QuTech

Inside the minds

Dr. Vivek Sinha

TECHNICAL PROJECT MANAGER

in Quantum Computing at QuTech, TU
Delft.

**Driving Quantum
Advancement at QuTech**

THE QUANTUM VISIONARY BUILDING BRIDGES ACROSS DISCIPLINES

Research bridges quantum chemistry,
clean energy, and advanced computing.

“

What excites me most is how Quantum Inspire now bridges hardware scale-up with advanced software to unlock real-world quantum applications.

”





Inside the minds

With Dr. Vivek Sinha

**Can you tell us about your role at QuTech?
What kind of projects do you lead?**

At QuTech I work as a project manager in the quantum computing division. I work closely with the DiCarlo lab. My main responsibility is leading the management and strategy of the HectoQubit (HQ) consortium.

“

We follow an ambitious roadmap to scale superconducting quantum computers using an open-architecture approach. We make the quantum computers widely accessible via the Quantum Inspire platform for research and education.

Inside the minds

With Dr. Vivek Sinha

The HQ consortium includes QuTech (coordinator), TNO, and four Delft-based quantum computing start-ups: Qblox, Delft Circuits, Orange Quantum Systems, and QuantWare. The HQ consortium, funded at the national level through the National Growth Fund via Quantum Delta NL (QDNL), runs in close synergy with the European flagship program OpenSuperQPlus (OSQ+).

I am also an elected member of the project management team of the OSQ+ consortium where I contribute to the operations, steering and road mapping activities.

In addition to hardware scale-up, I actively work with Dr. M. Matters in the day-to-day management, steering, and operations of the Quantum Inspire platform.

Quantum Inspire is not just a platform, but also a learning ecosystem. How do you see it inspiring and training the next generation of quantum scientists, engineers, and entrepreneurs, and what excites you most about Quantum Inspire?

In 2020, when the quantum computing ecosystem in Europe was still at an early stage, we were the first to place a quantum computer online. Over the past five years we have prioritized ecosystems development over vertical technology growth. Quantum Inspire served as an incubator, training quantum scientists, engineers, and entrepreneurs, and helped seed a strong quantum supply chain.

With Quantum Inspire 2.0, we have not only completed a major overhaul of both the software and hardware stacks, but also shifted our strategy. QI now serves as a testbed for developing quantum components. What excites me most is how hardware scale-up, combined with advanced software, will accelerate the development of real-world quantum applications via Quantum Inspire.

Inside the minds

With Dr. Vivek Sinha

Leading the HectoQubit consortium, what lessons have you learned in managing collaborations among startups and research partners in the quantum ecosystem?

In the HQ consortium each partner contributes a key layer. QuantWare builds quantum chips, Qblox develops control electronics, Orange QS provides automated (re)calibration, tune-up software, and the quantum operating system, Delft Circuits develops flexible cryogenic I/O, TNO works on quantum compilers, and the Quantum Inspire team develops the SDK and cloud connection. The DiCarlo lab acts as systems integrator and leads quantum error correction efforts. Leading the HectoQubit (HQ) consortium taught me important lessons about managing collaboration between startups and research partners.

“

Building a quantum ecosystem isn't just about technology — it's about aligning diverse visions, iterating together, and celebrating progress through trust, transparency, and shared purpose.



Inside the minds

With Dr. Vivek Sinha

The first lesson is that commitment to a shared vision is critical. Our shared goal is to strengthen the Dutch quantum ecosystem's global leadership. We do this by scaling up cloud-connected superconducting quantum computers in an open-architecture framework. All partners specialize at their tasks. But the final integrated system needs to be more than just a sum of parts. We need clear interface definitions and often have to work outside our area of specialization. Commitment to a shared vision motivates us to look beyond task-based contributions and invest in the bigger picture.

The second lesson is about iterative, test-driven approach. Open-architecture integration required significant change management across all layers of the stack. Having rigorous sub-component testing helps refine and simplify interfaces. Repeated cycles of testing, feedback, and adjustments also helps build trust while improving overall system quality.

Inside the minds

With Dr. Vivek Sinha

The third lesson is to celebrate small milestones and keep the momentum going. Upgrading the first-generation Starmon-5 system on Quantum Inspire 2.0 was an important step before moving to the open-architecture Tuna-5 system. We made sure to celebrate these milestones not just with the members of the project board but with the entire team of researchers, engineers, managers and support personnel. Each upgrade provided clear benefits to both our partners and the users of Quantum Inspire, and strengthened the cohesiveness of our team.

A fourth lesson is about proactive communication with contextual alignment. The HQ project regularly presents the researchers with new scientific challenges. It is important to get the scientific insights productized and assimilated in our workflow with commercial partners. While all of us share the same goals, we see different opportunities in the same challenge. Progress in such a diverse scenario requires a lot of open communication, steering and contextual alignment.

“

Finally, trust and transparency, supported by robust IP agreements, are essential. When challenges are visible early, we solve them together, share knowledge, and make progress - whether toward scientific breakthroughs or commercial deep-tech goals.

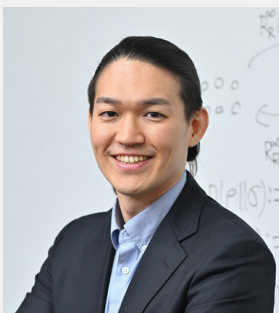
Dr. Vivek Sinha



THEORY OF QUANTUM COMPUTATION, COMMUNICATION AND CRYPTOGRAPHY (TQC) 2025

The 20th Theory of Quantum Computation, Communication and Cryptography (TQC) conference took place on 15–19 September 2025 at IISc Bengaluru, with pre-conference tutorials on 13–14 September. Led by Local Chair C. M. Chandrashekar (IISc) and Program Chair Bill Fefferman (University of Chicago), the event marked its 20th anniversary by bringing together global researchers, industry leaders, and students highlighting India’s growing role in quantum research and innovation.

Keynote Talks and Invited Speakers



Hayata Yamasaki
(The University of Tokyo ,
Japan)



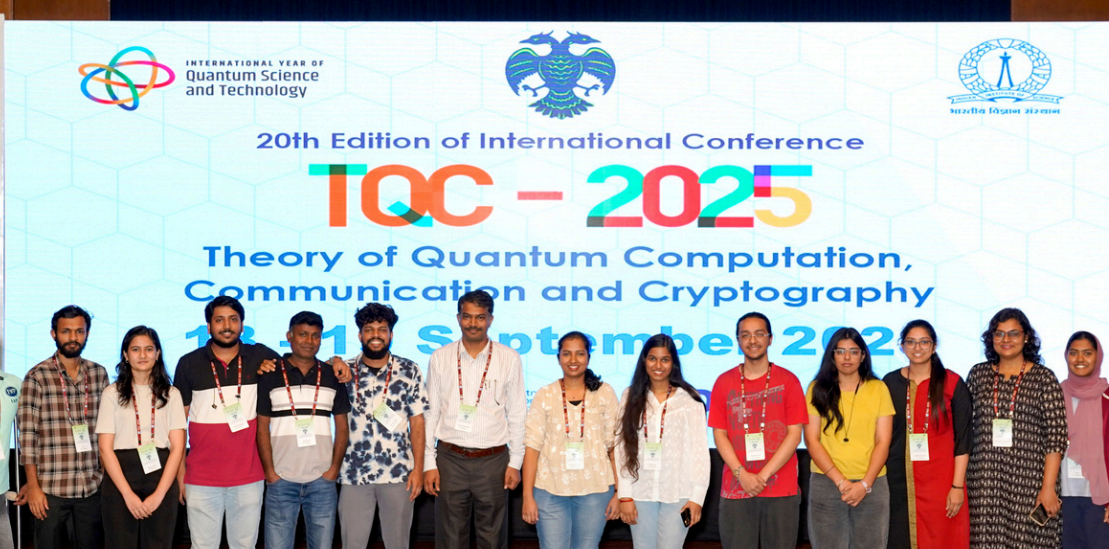
Stacey Jeffery
(CWI, Amsterdam,
Netherlands)



André Chailloux
(INRIA, France)



Rajendra Kumar
(IIT Delhi, India)



20TH EDITION. FIRST TIME IN INDIA. AT IISC, BENGALURU.

The 20th edition was hosted in India for the first time. It was hosted in India, in the same year designated as the International Year of Quantum Science and Technology by the United Nations. Around the time India's National Quantum Mission is launched, it is very exciting.

The event highlighted India's growing leadership in quantum science, showcasing advances in scalable error correction, stronger quantum cryptography, and deeper links between theory and applications. Hosted by IISc with national support, the conference marked a milestone for global quantum dialogue, blending rigorous research, industrial relevance, and cultural richness.

Pre-conference tutorial participants attracted about 100 students & researchers.

345

Participants

400

Submissions

80

Talks

160

Peer-reviewed Posters

28

Participating Countries

TQC 2025

Quantum Waves of Appreciation

“

**Dattatreya
BITS Goa**

My experience at TQC was very valuable. The talks gave me clear insights into the latest work in quantum computing, and I really appreciated the chance to interact with both speakers and other participants. The conference created a friendly and collaborative atmosphere, and I came away with new ideas and useful connections. I'm thankful to the organizers for making it such a well-run and inspiring event.

”

“

**Dale Jacobs
Tufts University, Boston**

The TQC conference was a lot of fun. I learned a lot of things, attended some great talks, got to see some friends and meet new people. The excursions were a lot of fun, and I hadn't seen monkeys before, so that was cool.

”

“

**Simon Apers
Université Paris Cité**

I very much enjoyed the conference this week. It was quite amazing. I love India and Bangalore and I love the institute. So thanks a lot for everything.

”

“

**Sigurd A. L. Storgaard
University of Copenhagen**

I very much enjoyed the conference. Lots of interesting talks and nice people and good food and overall just a very pleasant experience.

”

“

**Toshishiro Yada
University of Tokyo**

My experience in TQC was great. I could attend talks on various topics, for which usually I didn't get the opportunity otherwise. Also I was able to meet many people in the poster session where I presented my work. I made strong relationships with attendees. It was a good experience overall.

”

“

TQC is purely an academic activity to discuss and exchange theoretical knowledge in the fields of quantum computing, Communication, and cryptography ended on a highly appreciative note from all participants.

Prof. C. M. Chandrashekar, IISc



IEEE QUANTUM WEEK

📍 Albuquerque

Over 1760
Participants

31 August - 5 September

Featuring

Keynotes
Papers
Tutorials
Workshops
Posters

Though not the official theme, quantum error correction (QEC) emerged as a central focus. In today's NISQ era of noisy devices, QEC is critical, and sessions highlighted scalable surface and LDPC codes, improved decoding, syndrome extraction, and noise modelling. Discussions emphasized collaboration, mentorship, and shared expertise to drive progress toward logical qubits and large-scale, fault-tolerant processors.

Covering

Algorithms
Applications
Distributed
computing
Error correction
HPC
QML
Photonics
Networking
System software



C-DAC Team at IEEE QUANTUM WEEK 2025

The poster session showcased cutting-edge projects, including India's MAQAN: Metro Area Quantum Access Network by C-DAC and IIT Madras, presenting the country's first fibre-based multi-party Quantum Key Distribution (QKD) network for secure communications.

Keynotes featured Nobel Laureates David Wineland and William Phillips on atomic computing and the history of quantum physics. From industry, IBM's Jay Gambetta outlined software for quantum advantage and error correction's role, while PsiQuantum's Pete Shadbolt shared the company's vision for a fault-tolerant quantum computer. Other notable speakers included Zach Yerushalmi (Elevate Quantum), Prineha Narang (UCLA/NQCP), Chetan Nayak (UCSB/Microsoft Azure Quantum), and Sam Stanwyck (NVIDIA).

Exhibits from major players highlighted the growing ecosystem: Q-CTRL (qubit performance), Classiq (algorithm design), Quantum Machines (control), SpinQ (educational devices), Quantinuum (fault-tolerant systems), IonQ (trapped-ion hardware), IQM (superconducting processors), River Lane (optimization software), Zurich Instruments (precision control), Maybell Quantum (scalable hardware), Zero Point Cryogenics (cryogenic systems), and Liquid Instruments (research tools).

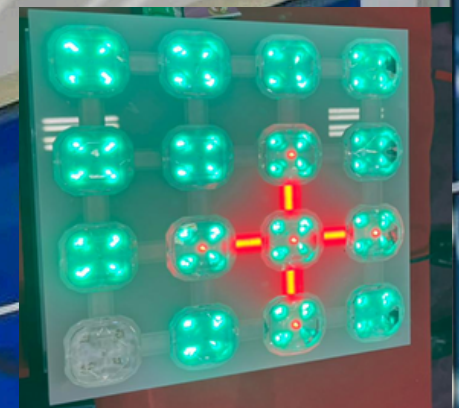
The conference reaffirmed QEC as central to the quantum future, highlighting collaboration, mentorship, and innovation as drivers toward practical large-scale quantum computing.



A. Quantinuum H2 Trapped Ion Quantum Processor.



B. Ion Q's Trapped Ion Quantum Processor.



C. Diamond Spin Quantum Processor developed by Fujitsu in collaboration with QuTech



D. Control electronics solution from nVent SCHROFF for superconducting Quantum Processors.



E. Time Tagger series from Swabian Instruments for photonics based quantum applications.



F. Control electronics solution from Quantum Machines for superconducting Quantum Processors.

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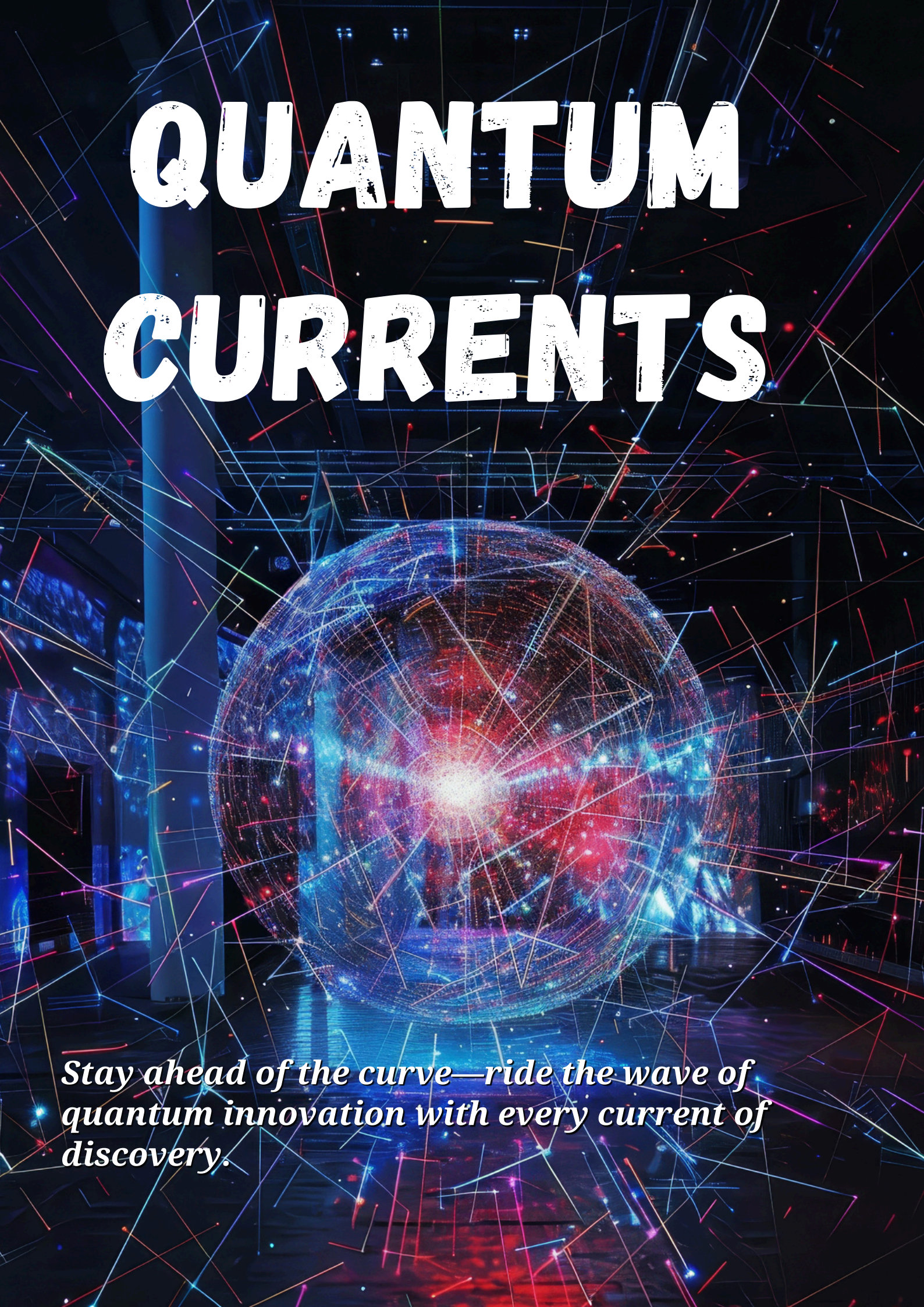
080-2509 3400
quantum-outreach-blr@cdac.in

Contact Us



CDAC Bangalore

QUANTUM CURRENTS

The background of the entire image is a dark, futuristic space filled with a dense, chaotic network of thin, glowing lines in various colors (blue, red, green, yellow, purple). These lines crisscross the frame, creating a sense of a complex, interconnected system. In the center of the image is a large, spherical object that appears to be a globe or a data sphere. It is covered in a grid of these glowing lines, with a bright, multi-colored core (red, blue, yellow) that radiates light. The sphere is surrounded by more of these lines, some of which are thicker and more prominent. The overall effect is one of high-tech, quantum computing, or data visualization.

Stay ahead of the curve—ride the wave of quantum innovation with every current of discovery.

QUANTUM CURRENTS

Entangled with Today's Quantum News

Noise Brings Quantum Surprise from Indian Scientists

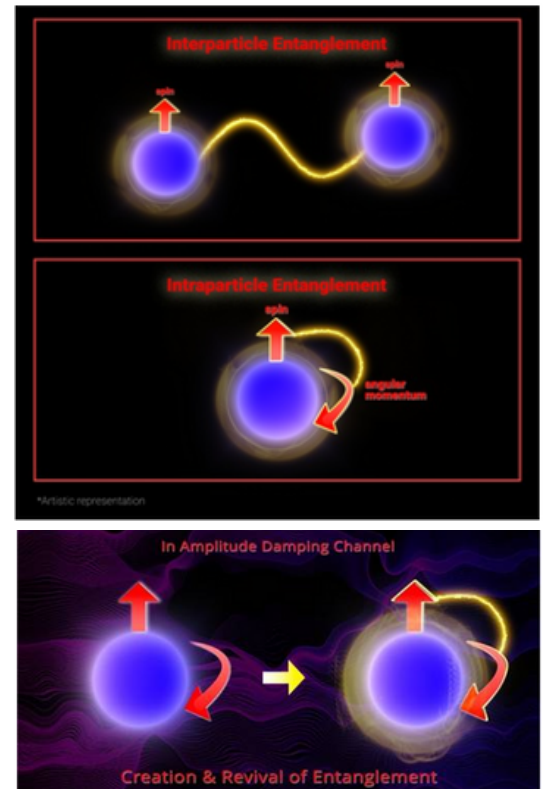
14 JUL 2025

SOURCE : PIB

The conclave brought together global experts on quantum key distribution (QKD), quantum satellite communication, and entanglement-based secure channels. Technical sessions emphasized the transition from laboratory testbeds to scalable networks, including terrestrial QKD fiber backbones and satellite-to-ground quantum links.

India's National Quantum Mission outlined its roadmap for building metropolitan QKD networks, satellite payloads, and indigenous single-photon detectors. Interoperability, standards, and post-quantum cryptography (PQC) integration were also highlighted as key research challenges.

Researchers analytically showed that amplitude damping noise can generate intraparticle entanglement between degrees of freedom such as path and polarization. Concurrence was derived as a closed-form function of damping strength, revealing non-monotonic entanglement dynamics.



Third International Quantum Communication Conclave

23 JUL 2025

SOURCE : PIB

The conclave brought together global experts on quantum key distribution (QKD), quantum satellite communication, and entanglement-based secure channels. Technical sessions emphasized the transition from laboratory testbeds to scalable networks, including terrestrial QKD fiber backbones and satellite-to-ground quantum links.

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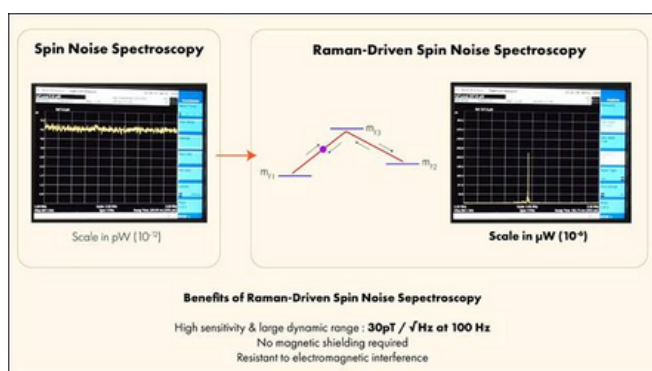
A Quantum Leap in Magnetometry

23 JUL 2025

SOURCE : PIB

The RDSNS method measures magnetic fields by detecting spin noise in rubidium atoms, using Raman scattering to upconvert noise spectra into an accessible range. This removes the need for active pumping or shielding, traditionally required in SERF magnetometers.

The prototype achieved ~ 30 pT/ $\sqrt{\text{Hz}}$ sensitivity at 100 Hz, with robustness against stray fields and vibrations. Future improvements include squeezed-light injection for sub-shot-noise performance and MEMS integration for compact deployment.



Parliament: Incentivising R&D in Private Sector

23 JUL 2025

SOURCE : PIB

The government outlined schemes such as weighted R&D tax deductions, collaborative grants with academic institutes, and support through missions like NQM for deep-tech areas including quantum computing, sensing, and communication.

Emphasis was on creating technology-transfer pipelines from research labs to startups. Industry-led consortia will be eligible for co-funding in areas like quantum hardware, photonics, and PQC software stacks.

Quantum India Bengaluru 2025

23 JUL 2025

SOURCE : BIO SPECTRUM

Over 1000 delegates participated in technical sessions covering superconducting qubits, trapped ions, photonic processors, and quantum error correction codes. Industry demos highlighted QRNGs, quantum simulators, and PQC software stacks.

The event also launched initiatives for training 10,000 quantum professionals by 2030. Investors and government agencies discussed scaling startups from prototype to deployable products in quantum sensors and secure communication.

MeitY Whitepaper on Quantum-Safe Cybersecurity

23 JUL 2025

SOURCE : PIB

The whitepaper provides a transition plan from RSA/ECC-based encryption to lattice-based and code-based PQC algorithms, while parallelly deploying QKD where feasible. It discusses hybrid cryptographic protocols combining PQC with symmetric-key primitives for near-term security.

It also recommends indigenous development of QKD hardware (sources, detectors, random number generators) and integration into critical sectors like banking and defense networks. Pilot testbeds in Delhi and Bengaluru were showcased.



Karnataka's \$20B Quantum Economy Plan

23 JUL 2025

SOURCE : ET

The state aims to establish dedicated quantum parks with cryogenic facilities, photonics fabs, and HPC-quantum integration labs. Bengaluru's cluster will focus on superconducting qubits, photonics, and PQC software.

A workforce development plan includes setting up quantum engineering programs in universities. The state also announced incentives for quantum startups working on quantum cloud services and advanced sensors.

ICEQSM 2025 Kolkata Conference

23 JUL 2025

SOURCE : TOI

ICEQSM 2025 sessions included quantum algorithms for optimization, materials for topological qubits, and photonic quantum simulators. Keynote speakers emphasized the convergence of quantum science with condensed matter research.

Workshops demonstrated software frameworks for simulating bosonic systems and hybrid quantum-classical optimization. The conference positioned Kolkata as a rising hub for theoretical and experimental quantum research.

High energy triggers atomic collaboration, paving path for next-generation quantum devices

22 SEP 2025

SOURCE : PIB

In a breakthrough in Indian quantum science, researchers have discovered that when atoms are energized to extremely high states, they cease acting individually and begin interacting intensely, causing their response to light to become distorted. This marks the first global demonstration of interaction-induced distortions in Rydberg atomic signals at such high energy levels, and could be pivotal in developing future quantum computers, sensors, and communication systems.

IIT Madras Licenses Silicon Photonics QRNG

23 JUL 2025

IIT Madras licensed a silicon photonics-based quantum random number generator (QRNG), which exploits photon path superposition and beam splitter randomness for entropy generation. Integration on a silicon chip ensures scalability and CMOS compatibility.

The licensed design provides true randomness validated by NIST tests and can operate at multi-Gbps speeds. Such QRNGs are essential for PQC, QKD systems, and secure IoT applications.



SOURCE : PIB

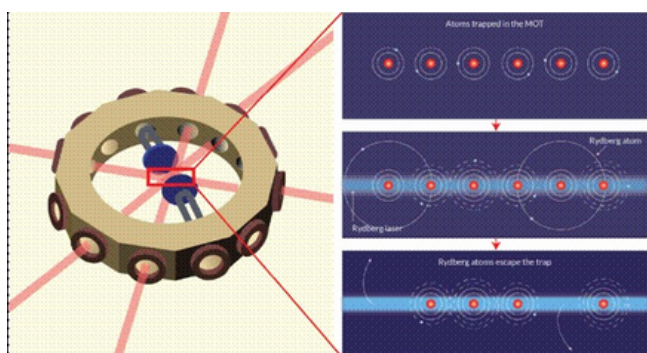
Rigetti & C-DAC MOU on Hybrid Systems

23 JUL 2025

SOURCE : GLOBENEWSWIRE

CDAC and Rigetti announce that they have signed MOU for accelerating superconducting qubit research, where Rigetti will provide superconducting quantum hardware, while C-DAC contributes HPC scheduling, compilers, and classical-quantum interface layers. The focus is on hybrid workflows where quantum kernels are embedded in classical HPC simulations.

The project will evaluate co-simulation for materials modeling and machine learning benchmarks. It also explores developing a middleware layer for scheduling quantum and classical jobs within India's HPC centers.



An artistic representation of the Rydberg excitation in the trapped cold atom set-up

IBM & AMD: Quantum-Centric Supercomputing

SOURCE : QUANTUM INSIDER
26 AUG 2025

IBM and AMD will co-design heterogeneous systems combining QPUs with CPUs and GPUs in tightly coupled nodes. The effort targets workloads like quantum chemistry, machine learning, and combinatorial optimization.

Research includes developing memory hierarchies optimized for quantum-classical data exchange and new scheduling algorithms for hybrid execution. This positions quantum not as a peripheral but as a core element of future exascale systems.

ORNL Quantum-HPC Software Stack

29 AUG 2025

SOURCE : ORNL

Oak Ridge National Laboratory initiated a study to define a software stack integrating quantum accelerators into HPC systems. It includes compiler layers, resource schedulers, and programming abstractions.

The goal is to make hybrid workloads where quantum subroutines are invoked within HPC simulations seamless for users. Target domains include materials discovery, cryptography, and AI acceleration.

HSBC, IBM Demonstrate Quantum Boost in Bond-Trading Efficiency

24 AUG 2025

SOURCE : IBM QUANTUM

In a pioneering collaboration, HSBC and IBM have revealed the first empirical evidence that quantum computing can enhance algorithmic bond trading. By combining quantum processors with classical computation, their hybrid model achieved up to a 34 % improvement in predicting trade completions compared to traditional classical methods.

Remarkably, these gains were obtained using today's accessible quantum hardware (IBM's Heron processors), suggesting that quantum advantage in financial services is not just theoretical but may be within reach for real, production-scale systems.

USC Demonstrates Quantum Speedup

16 JUL 2025

SOURCE : IBM QUANTUM

Using IBM Quantum processors, USC researchers solved variants of Simon's problem, achieving exponential speedup relative to classical algorithms. Circuit optimizations and error mitigation were key to implementation.

The experiment validated quantum advantage in a setting where classical algorithms provably scale exponentially, marking progress toward real-world demonstrations of superpolynomial speedups.

Proteins as Qubits

20 AUG 2025

SOURCE : QUANTUM INSIDER

Researchers showed that protein structures can host quantum states, effectively functioning as qubits. This suggests biological molecules could enable quantum information processing at room temperature.

Potential applications include quantum biosensing and hybrid biophotonic quantum devices. The work also raises questions about whether biological systems naturally exploit quantum effects.

Caltech unveils record-breaking 6,100-qubit atomic array

24 SEP 2025

SOURCE : CALTECH EDU

Researchers at Caltech have engineered the largest ever quantum array by trapping 6,100 neutral atoms using optical tweezers, a milestone that pushes the boundary of scalable quantum computing.

Despite scaling up so dramatically, the team preserved exceptional coherence maintaining superposition for around 12.6 seconds and operated individual qubits with ~99.98 % accuracy, showing that high fidelity and high scale need not be mutually exclusive.

IBM opens India Client Experience Centre in Mumbai and backs Maharashtra's quantum push

13 AUG 2025

SOURCE : IBM NEWSROOM

IBM has inaugurated its new India Client Experience Centre in Mumbai, positioning the facility as a collaborative hub where IBM experts, enterprise clients and partners can co-create technology solutions across AI, hybrid-cloud, data, automation, cybersecurity and quantum computing. In parallel, the company signed a Letter of Intent (LoI) with the Maharashtra government to support the state's quantum ecosystem via workshops, skills development, and joint innovation projects. The move signals IBM's intent to ramp up quantum-technology adoption in India as part of broader national-technology goals.



Cisco Quantum Labs unveils software stack and networking for distributed quantum computing

25 SEP 2025

SOURCE : CISCO BLOG / CISCO RESEARCH

Cisco Systems has announced the launch of its Quantum Labs research facility and a prototype “quantum entanglement chip” designed to network quantum processors together, enabling distributed quantum-computing architectures. Their stated aim is to accelerate the arrival of practical quantum-networking and quantum-data-centre infrastructure, moving what was once considered decades away into a nearer 5-to-10-year timeframe. The software stack includes development kits for quantum-network simulation and control.

Alice & Bob Surpasses Bit-Flip Stability Record

25 SEP 2025

SOURCE : ALICE & BOB NEWSROOM ALICE & BOB

Alice & Bob, a quantum-computing startup specialising in “cat qubits”, has announced a major milestone: their latest design, the “Galvanic Cat” qubit, achieved **bit-flip times of between 33 and 60 minutes** (≈ 44 minutes average) under a 95 % confidence interval, during idle operation. This shatters their own previous result of about 430 seconds (~ 7 minutes) achieved in 2024, and even exceeds their 2030 target of 13 minutes for bit-flip stability.

According to the company, the experiment was conducted at a mean photon number of 11 in the resonator, and also included demonstration of a Z-gate on the same qubit with ~ 94.2 % fidelity in 26.5 ns. The significance: bit-flip errors (logical $0 \leftrightarrow 1$ flips) are a foundational error mode in quantum hardware, and reducing them so substantially means less overhead for error-correction codes. Alice & Bob claim that by virtually eliminating bit-flips, their architecture could reduce hardware requirements by up to $\sim 200\times$ compared with conventional qubit approaches.

QuEra and collaborators present algorithmic fault-tolerance breakthrough for quantum computing

24 SEP 2025

SOURCE : PRESS RELEASE FROM QUERA COMPUTING

QuEra, together with researchers from Harvard University and Yale University, announced a new fault-tolerance framework titled “Low-Overhead Transversal Fault Tolerance for Universal Quantum Computation”, published in Nature. This introduces the concept of “Algorithmic Fault Tolerance” (AFT) which cuts the runtime overhead of error correction in quantum algorithms by factors of $10\text{-}100\times$ in simulations. The research leverages neutral-atom quantum architectures which operate at room temperature and offer flexible connectivity and shows that by using transversal operations and correlated decoding, one can reduce the time spent on syndrome-extraction rounds (normally proportional to code distance d) to just one round per logical layer. This promises a faster path to scalable fault-tolerant quantum machines.

Date and Venue

December 9–13, 2025

Manipal Institute of
Technology (MIT),
Bengaluru, Karnataka,
India

Highlights

- 100+ Sessions
- 200+ Speakers
- 2000+ Delegates
- 500+ Academicians
- 200+ Exhibitors
- 5000+ Attendees
- 15+ Countries



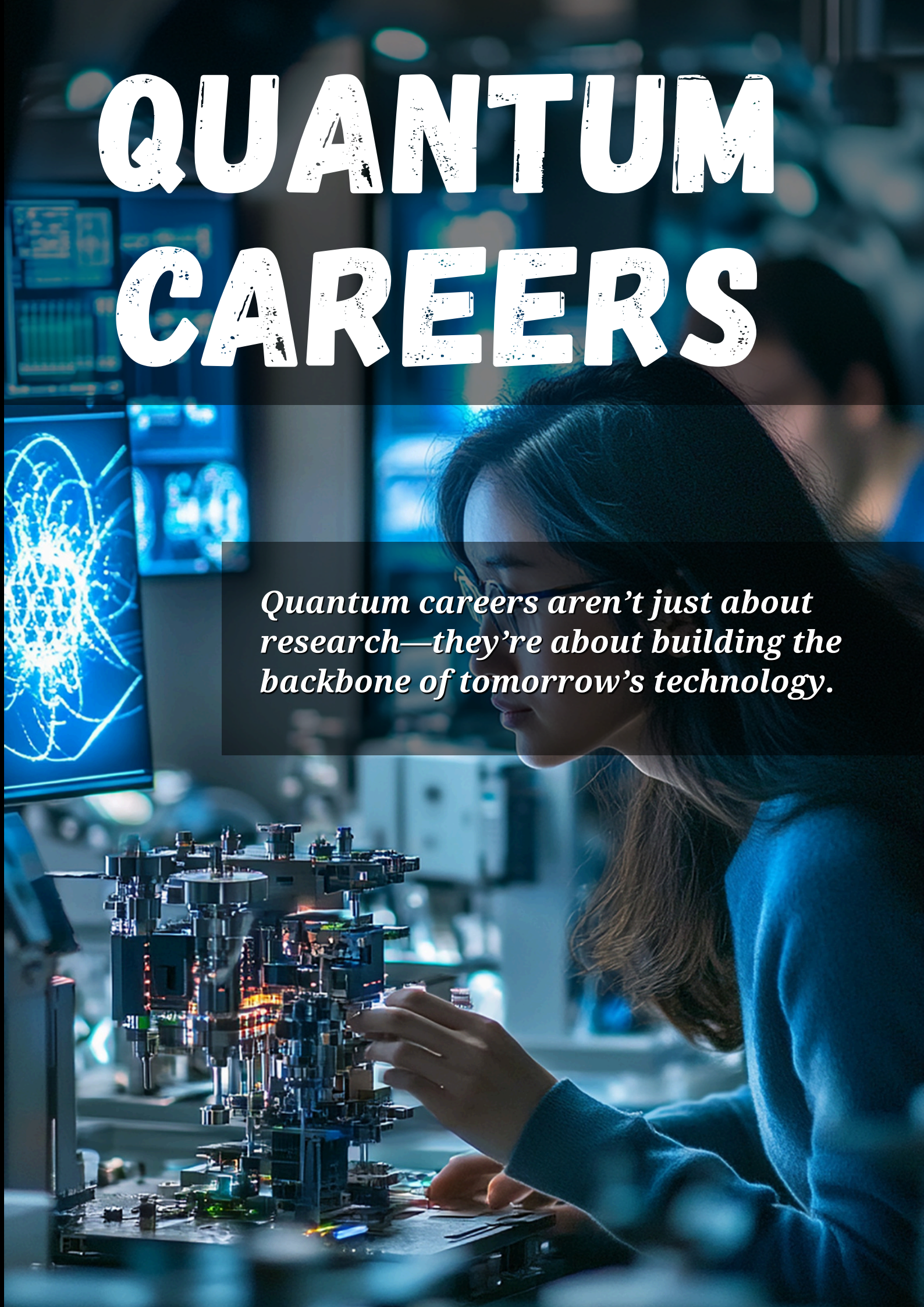
**SUPER
COMPUTING
INDIA 2025**

<https://sci25.supercomputingindia.org/>

Key Themes

- Quantum Computing
- High Performance Computing (HPC)
- Artificial Intelligence

QUANTUM CAREERS

A woman with long dark hair, wearing glasses and a blue sweater, is focused on adjusting a complex, multi-layered quantum device. The device features various metallic components, lenses, and glowing orange and yellow lights. In the background, a computer monitor displays a blue-toned image of a complex, branching network, possibly a quantum circuit or a biological structure. The overall scene is dimly lit with a strong blue color cast, creating a high-tech, futuristic atmosphere.

Quantum careers aren't just about research—they're about building the backbone of tomorrow's technology.

1 IQM Quantum Computers Quantum Hardware Engineer (Junior/Mid)  Finland, Espoo	2 D-WAVE QUANTUM Software Developer (Hybrid-Service)  Canada: Remote USA: Remote	3 D-WAVE QUANTUM Service Engineer II  Canada, British Columbia, Burnaby	4 UNIVERSITY OF AMSTERDAM PhD Position in Quantum Compilation  Amsterdam, Netherlands
5 Q-CTRL Federal Lead Research Scientist, Silicon Qubits  USA, California, Los Angeles	6 CDAC Various contractual positions  Chennai, Mohali, Hyderabad, etc.,	7 CDAC Project Engineer - Post Quantum Cryptography  Bengaluru	8 QMET TECH Project Senior Technical Assistant  IIT Bombay
9 Raman Research Institute Research Associate I Research Associate II Research Associate III  Bengaluru	10 QMET TECH Project Scientist III - Adaptive Optics  IIT Bombay	11 ALICE&BOB Quantum Algorithms Scientist  France, Paris	12 QUANTINUUM Research Software Engineer - Quantum Software  United Kingdom, Cambridge
13 Oak Ridge National Laboratory Postdoctoral Research Associate - Integrated Photonics  Finland, Espoo	14 LAWRENCE BERKELEY NATIONAL LABORATORY Postdoctoral Scholar - Quantum Benchmarking & Simulation (AQT/NERSC)  USA, California, San Francisco	15 QUANDELA Electronic Technician / Electrical Operation Support // Technicien Électronique / Electrical Operation Support  France, Massy	16 XANADU FPGA Design Engineer (Hybrid)  Canada, Ontario, Toronto

CONFERENCES

1 OCT 20 - OCT 24 100 Years of Quantum Waterloo, Canada	2 NOV 2 - NOV 5 IEEE Int. Conf. on Quantum AI (IEEE QAI 2025) Naples, Italy	3 NOV 4 - NOV 5 Quantum Science & Technology: The First 100 Years London, UK	4 NOV 7 - NOV 7 UK National Quantum Showcase London, UK
5 NOV 12 - NOV 13 SPIE Quantum Catalyst Boulder, USA	6 NOV 16 - NOV 21 QTML 2025 Singapore	7 NOV 18 - NOV 18 Quantum Dot Day 2025 Cardiff, UK	8 NOV 18 - NOV 21 qLIFE Wollongong, Australia
9 NOV 20 - NOV 22 XPANSE: Beyond Exponential Abu Dhabi, UAE	10 NOV 24 - NOV 26 QSSC2025 Melbourne, Australia	11 NOV 24 - NOV 28 Quantum Many-body Systems Workshop Vienna, Austria	12 NOV 24 - NOV 28 Gordon Godfrey Workshop Sydney, Australia
13 DEC 01 - DEC 05 AIP Summer Meeting Wollongong, Australia	14 DEC 04 - DEC 08 Quantum Foundations, Technology and Applications (QFTA-2025) IISER Mohali, India	15 DEC 09 - DEC 11 Q2B 2025 Santa Clara, USA	16 DEC 09 - DEC 13 SCI: Supercomputing India 2025 Bengaluru, India

**List of selected publications in Quantum Technologies during
July to September 2025**

Deterministic carving of quantum states with Grover's algorithm <i>July 2025</i>	Physical Review A, 112(1), 012621 <i>Nagib, O., Saffman, M., & Mølmer, K. (2025)</i>
Observation of anomalous information scrambling in a Rydberg atom array <i>July 2025</i>	Physical Review Letters, 135(5), 050201 <i>Liang, X., Yue, Z., Chao, Y. X., Hua, Z. X., Lin, Y., Tey, M. K., & You, L. (2025)</i>
Review of distributed quantum computing: from single QPU to high performance quantum computing <i>August 2025</i>	Computer Science Review, 57, 100747 <i>Barral, D., Cardama, F. J., Diaz-Camacho, G., Faílde, D., Llovo, I. F., Mussa-Juane, M., ... & Gómez, A. (2025)</i>
Practical introduction to benchmarking and characterization of quantum computers <i>August 2025</i>	PRX Quantum, 6(3), 030202 <i>Hashim, A., Nguyen, L. B., Goss, N., Marinelli, B., Naik, R. K., Chistolini, T., ... & Blume-Kohout, R. (2025)</i>
Full Characterization of Genuine 17-qubit Entanglement on the Superconducting Processor <i>August 2025</i>	Physical Review Letters, 135(7), 070801 <i>Hu, C. K., Wang, Y., Zhou, Y., Liu, C., Xie, G., Zhou, R., ... & Yu, D. (2025)</i>
Practical advantage of classical communication in entanglement detection <i>September 2025</i>	Physical Review Letters, 135(13), 130805 <i>Xing, W. B., Lv, M. Y., Zhang, L., Guo, Y., Weilenmann, M., Wei, Z., ... & Wang, Z. (2025)</i>
Verifiable blind quantum computation for two types of clients via iterated gate teleportation <i>September 2025</i>	Physical Review A, 112(3), 032603 <i>Wang, Y., Dai, Q., & Li, Q. (2025)</i>
Entangled measurement for W states <i>September 2025</i>	Science Advances, 11(37), eadx4180 <i>Park, G., Hofmann, H. F., Okamoto, R., & Takeuchi, S. (2025)</i>

CROSSWORD



Down

1. Transformation that preserves inner products and quantum probabilities.
2. Operator that represents total energy and drives time evolution.
5. Property of occupying multiple basis states at the same time.
6. Quantum algorithm that factors large integers efficiently.
9. Protocol that transmits a quantum state using entanglement.
10. Nonlocal correlation where measuring one particle affects another.
11. Quantum error type flipping 0 to 1.
12. Physicist who formulated the uncertainty principle.
13. The lowest-energy state of a quantum system.
15. Smallest unit of quantum information, can be 0, 1 or both.

Top 10 early solvers will be featured in the next edition of

QUANTUM VIBES
MAGAZINE!

Across

3. Particle of light commonly used to carry quantum information.
4. Black-box function queried by quantum algorithms to identify solutions.
7. Technology using zero-resistance circuitry commonly used for qubits.
8. Quantum algorithm giving a quadratic speedup for unstructured search.
14. Process that forces a quantum state to a definite outcome.
16. Principle that forbids perfect copying of an unknown quantum state.
17. Algorithm that finds a hidden period (secret string) of a function.
18. Vector space where all quantum state vectors live.
19. Grover step that inverts amplitudes about their average.
20. Auxiliary qubit used to assist computations or store temporary data.

Share your Crossword solution with us at

✉ quantum-outreach-blr@cdac.in

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