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Growing old
Why and how

Harish-Chandra
From physics to maths

Light Combat Aircraft
Design and development

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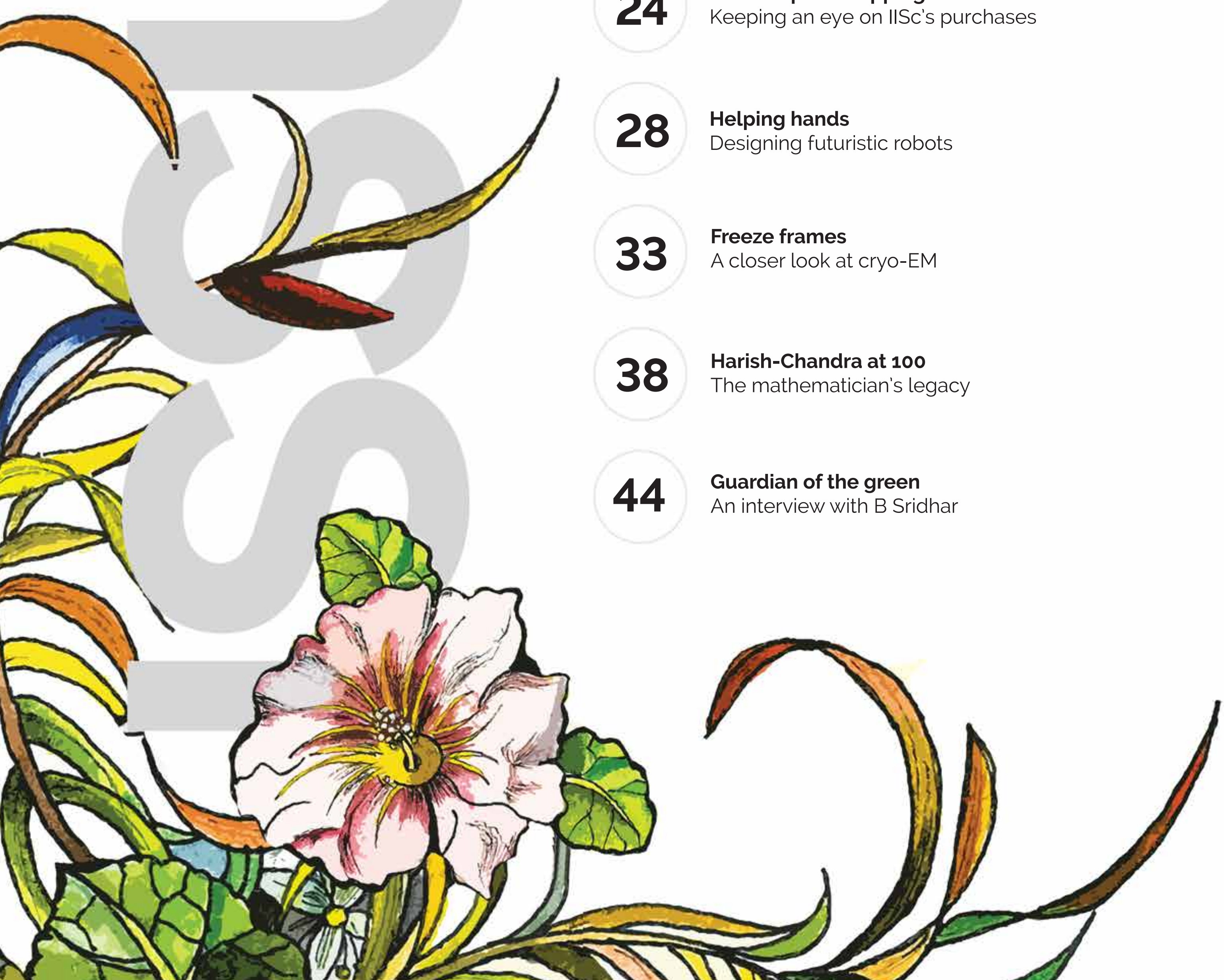
IN THIS ISSUE



Editorial

From bacteria to blue whales, almost all organisms age. Yet, this universal phenomenon has remained one of biology's biggest mysteries. In this issue of *CONNECT*, read more about the fundamental questions on ageing that scientists, including those at IISc, are investigating.

Another feature in this issue covers two different sides of the story surrounding the discovery of large lithium reserves in Jammu and Kashmir – the evolution of lithium technology as well as the environmental and social consequences of mining for the metal.

The story of how IISc's researchers and alumni went on to build India's space programme is well-known, but the Institute's contributions to the Light Combat Aircraft (LCA) are less known, a history that we highlight in this issue. 2023 marks the birth centenary of Harish-Chandra, one of the most influential mathematicians of the 20th century – we retrace his time at IISc and Cambridge to understand the circumstances under which he switched from physics to maths.

In campus stories, we speak to B Sridhar, who was in charge of IISc's nursery and greenery, as well as the famous flower show organised every year around Founder's Day. We feature a day in the life of Aparna Kandi, a deputy registrar who brings her navy experience and rigour to the methodical job of managing the Institute's purchases and stores. We also spent an exciting night with IISc's astronomy club, as they chased after celestial bodies in the Challakere campus.

In other stories, we describe an emerging microscopy technique enabling scientists to peer at proteins and life processes at resolutions never before possible, and visit several labs at IISc and ARTPARK building the next generation of robots that will work alongside humans in diverse settings.

Happy reading!

Team Connect

Bitasta Das, Karthik Ramaswamy, Malavika P Pillai, Narmada Khare, Pratibha Gopalakrishna, Ranjini Raghunath (Coordinator), Sandeep Menon

Contact

Email: connect.ooc@iisc.ac.in

Phone: 91-80-2293 2066

Address: Office of Communications,
Indian Institute of Science,
Bangalore 560 012

Website: http://connect.iisc.ac.in

Design: Magnetyz

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Chasing Stars

- Bitasta Das

Astrae, the astronomy club of IISc, recently embarked on an expedition to capture the Milky Way

Photo: Aloke Kumar and Kenil Ajudiya

The Milky Way galaxy

Dusk was just setting in and the early stars were twinkling when the bus carrying a bunch of students and faculty members rumbled into the Challakere campus of IISc, late one May evening. The visitors were part of Astrae, IISc's Astronomy Club, and they were on a special expedition. After a quick dinner at the dining hall, the team proceeded to the guest house where accommodation for their night stay was arranged. But they were not planning to sleep much that night – with telescopes in hand, they had come to this faraway campus, with its pitch-black night sky clear of aerosols, to catch a glimpse of our home galaxy: the Milky Way.

Astrae was founded in early 2018 by four undergraduate students: Yash Mehta, Ameya Patwardhan, Divij Mishra and Ashim Dubey. It started with small group discussions in hostel rooms, and looking at constellations from the terrace of their hostel building. The students gradually organised themselves into a club, which soon attracted members from different batches and departments. Lectures and star-gazing sessions were organised and a 4-inch telescope was borrowed from the defunct PhD astronomy club. The new club thereafter expanded its activities, inviting faculty members and PhD students to give talks on astronomy-related topics.

The visit to Challakere in May was Astrae's first expedition outside IISc's Bangalore campus. About 24 club members, which largely included undergraduate students, plus a few PhD students and postdocs, and their mentor Aloke Kumar, Associate Professor in the Department of Mechanical Engineering, were on this trip. Aloke's interest in astronomy developed during the long and monotonous lockdowns during COVID-19. He would observe the stars from his terrace, capturing them with his camera. After the lockdown, he shared snapshots from his newfound hobby with his undergraduate class. It was then that Kenil Ajudiya, a fourth-year undergraduate student, mentioned to him that they already had an astronomy club and that Aloke was welcome to join them. Kenil had just retrieved some telescopes that were in a deplorable state when the campus was desolate during the pandemic. He had taken them to the UG biology lab, and washed and cleaned them with Milli-Q water – water that is purified using reverse osmosis. Aloke's association with Astrae had begun from this point.

> ***The visit to Challakere in May was Astrae's first expedition outside IISc's Bangalore campus***

Quest to capture the Milky Way

The devices that were carefully carried to Challakere included an 8-inch Newtonian Reflector telescope with a Dobsonian mount, a 5-inch Schmidt-Cassegrain telescope, a single motor drive, and a DSLR camera. Besides these, the club also has a 6-inch Newtonian Reflector telescope. Named after its inventor, Issac Newton, the Newtonian Reflector telescope is a vital tool for astronomers. It chiefly operates with two mirrors, a primary and a secondary. The 8-inch Newtonian Reflector telescope was bought by the club with sponsorship from a startup, Kalam labs, and some contributions from Aloke, Kenil and another club member, Hemansh Alkesh Shah. The 6-inch telescope was found abandoned by someone in the hostel, so the club members decided to take and use it. The club also occasionally uses much of Aloke's personal equipment.

But just as the team prepared to set up the instruments on the terrace of the Challakere guest house, a drastic turn of events occured. It started raining heavily! The expedition now seemed like a washout.

The heavy showers did not, however, deter the spirits of the club members. They decided to stay awake the entire night and observe the sky after the rain stopped and the clouds cleared. They gathered mattresses, snacks and juice for the long night, and camped out patiently in the hall, one of them occasionally stepping outside to check the sky. It was past midnight when the rains stopped. The students were finally able to set up their instruments on the terrace. But the wait was still not over. The sky was covered with thick clouds.

Photo courtesy: Aloke Kumar

The expedition team

Finally, it was only at 3 am in the morning when the clouds slightly receded, giving a glimpse of the stars in the sky. The students got ready to take photographs of the galaxy; a smartphone was attached to the 8-inch telescope and the DSLR was mounted on the tripod. The team waited restlessly for the clouds to clear; some surveyed the sky with the help of an app called Stellarium to locate the direction of the constellations and the galaxy. In order to keep everyone busy during the long waiting period, Hemansh, a third-year undergraduate student and former convener of the club, gave an orientation on the night sky for the first-timers and hobby stargazers in the group. According to him, the ideal site to watch the night sky should be away from the city lights. Artificial lights in the city fill the sky with a diffused glow, called light pollution, which prevents proper viewing of the stars. A bright moon can also make it difficult to spot the stars, so a new moon or crescent moon is ideal.


Photo: Kalyanbrata Chandra

The long wait on the terrace to capture the Milky Way

The region of the sky visible at a particular time depends upon the viewer's position. This is due to the Earth's spherical shape and its rotation. However, if the sky is monitored throughout the night, a major portion of the total visible sky can be covered, leaving out only a small fraction that is closest to the Sun, and rises and sets with it. Hemansh adjusted the lenses of the telescope and showed the team several stellar bodies: the magnificent Messier 4 and Messier 80 – both globular clusters 6,000 and 30,000 light-years away respectively – and the Messier 13 or the Hercules globular cluster – 25,000 light-years away (a light-year is equivalent to about 9.5 trillion km). Globular clusters are stable, tightly bound clusters containing about a million stars. Besides these, Hemansh was also able to locate and show the group Messier 57 or the Ring Nebula, made up of leftover gases after a dying star blows out its outer layers. Other clusters that the team saw included Messier 20 or the Trifid Nebula, which is a region of gas actively collapsing on itself to create new stars, and Messier 24 or the Sagittarius Star Cloud, a region of the sky with an enormous density of stars.

But the students were yet to see what they had come all the way to Challakere for. The Milky Way still remained elusive behind thick clouds.

Then, at 4 am, the veil of clouds finally lifted, showing the shining stars fully. The telescope was adjusted, and the winsome Milky Way galaxy was finally visible. The team members took turns observing it, photographs were clicked, and an engaging discussion ensued upon its appearance. It was 5.30 am when a few members decided to catch some sleep; others preferred to go for a walk, exploring the vast campus. The expedition was finally a success.

Beyond the Milky Way

The visit to Challakere was the third major event that Astrae had organised in 2023 after CosmoGaze and CosmoExpo. CosmoGaze was organised in early February this year when a green-coloured comet hurtled past the Earth for the first time in 50,000 years. During the event, which was open to the public, the students also engaged in several discussions related to astronomy and showed visitors other objects like the Sun as well through their telescopes. Like the Challakere expedition, CosmoGaze too was initially racked with uncertainty. The crowd was losing hope as they were unable to locate the comet for a long time. But eventually, when it became visible, the whole crowd cheered!

CosmoExpo was an event held in April 2023 for middle school students, which featured talks by faculty members discussing their work and interest in astronomy, followed by observations of the sky.

Astrae's present convenors are Deep Bhowmik, Atharv Sagar Suryawanshi, Sahil Sibasish Nandi and Gaurav Niraj Rachh, all undergraduate students at IISc. Their responsibilities include scheduling talks on various topics related to astronomy, organising events to popularise astronomy among the public, taking care of logistics for these events, and coordinating with the mentor and the UG office for issues like funds for equipment and events. They are keen on building upon the efforts of the previous conveners – Kenil, Hemansh, Harshvardhan and Ekta – who had put in a lot of effort to generate interest among students attending the talks and observation sessions, and had also taught about 50 students how to handle telescopes. Chaya Karkera, a postdoc at the Centre for Nano Science and Engineering, who was also part of the Challakere trip, believes that it would be helpful to increase the participation of girl students in these sessions. She says, "The club can host or collaborate with schools to introduce these events and conduct quizzes about astronomy to generate interest and competitive spirit among young girls."

Aloke is confident that the club's activities will grow and expand in the future. A faculty committee consisting of himself as well as Nirupam Roy from the Department of Physics, Baladitya Suri from the Department of Instrumentation and Applied Physics, and Ranjan Laha from the Centre for High Energy Physics, is looking at setting up an Astro-Imagery facility and observatory at IISc's Bangalore campus, and an astronomy outreach programme at the IISc Challakere campus. An IISc alumnus living abroad, CK Manjunath, has also donated many sophisticated tools to the club.

One of the founders of the club, Ashim Kumar Dubey, who is currently pursuing his PhD at the Swiss Federal Institute of Technology, Lausanne, says that he continues to eagerly follow the activities of the club through social media. He is proud of the fact that his juniors have taken forward the efforts put in by the founders. The pictures of the Milky Way galaxy that he saw on the Instagram page of the club from the Challakere visit felt "like a true coming of age moment for the club."

For many in the club, like Hemansh, the night sky is a source of inspiration, "a perfect balance of mystery, beauty, and capacity." He says, "There are a lot of mysteries out there and beautiful objects to view. The fact that humans have managed to understand so much about them shows our capability."

Photo courtesy: Aloke Kumar

Participants and organisers at CosmoExpo, organised in April 2023

Live Long and Prosper

- *Ranjini Raghunath*

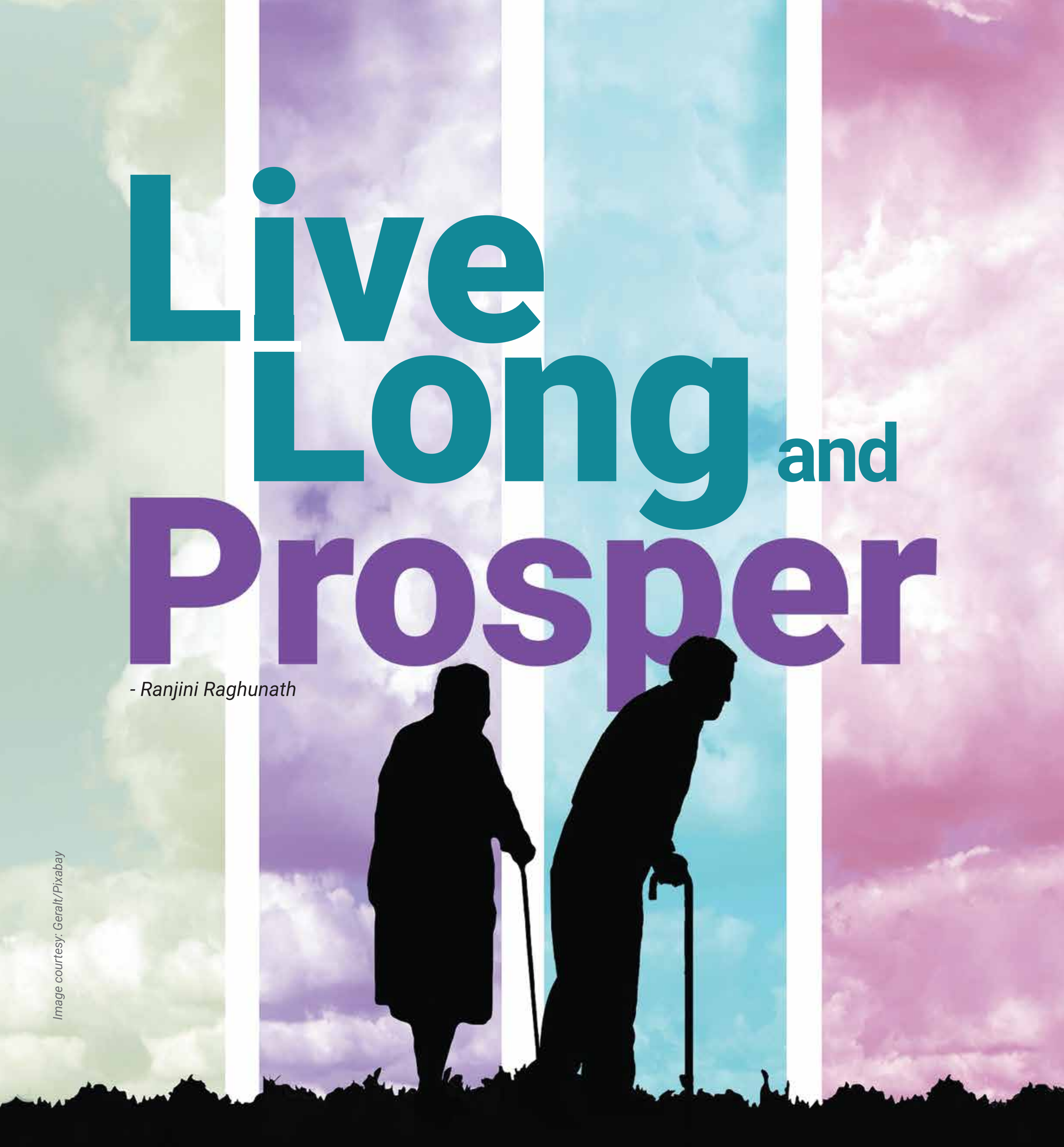


Image courtesy: Geralt/Pixabay

With a mushrooming elderly population, research on ageing is gathering steam

Among Greek myths, the tale of Tithonus is particularly tragic. Eos, the immortal goddess of dawn, fell in love with the mortal Tithonus, a prince of Troy. She begged Zeus, the ruler of Greek gods, to grant Tithonus eternal life, but forgot to ask for eternal youth. Tithonus grew older but did not die; over time, his body withered away, leaving him babbling, broken and bitter. He eventually shrank down into a cicada whose incessant cries are supposedly heard even today.

A century ago, people were lucky if they lived past the age of 50. Today, a large number of elderly people face a fate similar to Tithonus' – living longer but suffering from disease or poor health for decades.

"We have stopped falling off mountains in search of food. Wild animals are not killing us. Infectious diseases are more or less in control. But we are getting older," says Deepak Saini, Professor at the Department of Developmental Biology and Genetics (DBG), IISc. "Ask an audience how many want to live long, most will shout yes. Ask how many want to be old, perhaps none will answer."

With nearly 1.43 billion people, India's population just crossed China's to become the largest in the world. By 2050, every fifth Indian will be over 60 years of age, according to a UN Population Fund report. Chronic diseases like cancer, diabetes and Alzheimer's are on the rise among the elderly. "People usually retire by the age of 60-65, and most of them can live up to about 85. There's a very real pressure to identify what can be done to keep them healthy during those 20 years," explains Deepak. The idea of boosting one's "healthspan" – how long an individual lives in general good health – is now taking centre stage in debates raging around ageing.

But before we get to healthy ageing, we need to understand the process of ageing itself. When does ageing actually begin in the human body? Is ageing accelerated by genetic or environmental factors? Why do women live longer than men? Can we really reverse ageing? Scientists are only now beginning to find the answers to some of these questions. "We know so much and yet so little," says Deepak.

Why do we age?

In the 19th century, some people believed in a weird theory about why we age: Our bodies have a limited supply of "vital energy" assigned at birth that gradually depletes over time. The key to delaying ageing, they recommended, was to save as much energy as possible by refraining from "excesses and undue exertions", eating specific foods and practising abstinence.

While this theory has long been debunked, over the years, scientists have put forth dozens of more plausible explanations for why our bodies age.

Some scientists believe that our lifespan is set at birth and ageing unfolds in a "programmed" manner, controlled by genes turning on and off at specific times, or by the release of certain hormones.

The "wear and tear" theory suggests that just like a car, our body parts become rusty over time, mainly due to continuous assault by free radicals (unstable molecules that build up as a result of chemical reactions in the cell). A related theory suggests that a faster metabolism might be linked to quicker ageing. "The idea is that more free radicals are generated when burning more fuel. Therefore, the more the system's going to get injured," says Deepak. This might explain why excess exercise has sometimes been linked to faster ageing – a 2022 Harvard study of about 3,000 former football players found that their healthspans were shorter than the general population by nearly a decade, and they also appeared to develop arthritis and dementia earlier. "Exercise seems to keep you healthy but may not correlate with you living longer," Deepak adds.

> ***One theory is that ageing might be a defence mechanism against cancer***

The theory that most scientists are invested in, however, is that ageing might actually be a defence mechanism against cancer. Ageing cells have a curious property called senescence, triggered by stresses of different types. When we are young, our cells are able to repair injuries rapidly and cells beyond repair are quickly cleared out by the immune system. As we grow old, the immune system and the cell's repair machinery become weak, but stresses and assaults continue, triggering inflammation all over the body, creating a ripe environment for cells to turn cancerous. To avoid this, damaged cells switch to a limbo-like state called senescence in which they stop dividing – which is critical for cancers to form and spread – but continue to eat food, remain active and talk to other cells.

"The damaged cell neither wants to die nor does it want to become cancerous. It is in a finely tuned state where the cell just maintains its vital status without proliferating," explains Deepak.

But senescence can be a double-edged sword. As the number of senescent cells grows in the body, they start affecting other healthy cells, putting strain on the body's resources and reducing our ability to fight off infections. "Slowly, the equilibrium starts shifting towards a greater number of aged cells, and a lesser number of cells which can clear them out. Once this balance tips over, you enter into what is called physiological ageing," explains Deepak.

Ageing and the human body

When I started getting my first grey hairs at the age of 30, I was instantly jealous of my grandfather whose hair remained dark well into his sixties. Not all ageing individuals look alike, but there are some signs, like greying hair, that are more or less universal. Our skin starts to wrinkle. Our senses become weaker. Spicy foods suddenly become intolerable. Blood vessels become stiffer, making it harder for our hearts to pump blood. Bones become brittle and break easily. A weaker bladder makes us run more frequently to the restroom.

With age, our muscles also start losing mass and flexibility. Upendra Nongthomba, Chair and Professor at DBG, and his lab use fruit flies to study how muscle function breaks down over time. They have specifically been investigating the crosstalk between muscles and neurons at sites called neuromuscular junctions. Their experiments showed that flies with mutations that disrupt this crosstalk seem to age faster.

Upendra's lab has also been focusing on the build-up of protein aggregates in muscles with age. "Our muscle proteins are cleared out and renewed every few days. As you age, this clearance machinery will become faulty, so you will have increased aggregation." His lab is working with P Thilagar, Professor in the Department of Inorganic and Physical Chemistry (IPC), to develop artificial molecules that can break up these aggregates.

Another major change inside the bodies of older people is an increase in inflammation. Inflammation is the immune system's immediate response to injury or infection, which lasts up until the injury heals or the infection is treated. However, in older people, inflammation becomes chronic – it is constantly present at low levels and further exacerbates ageing, a condition called "inflammaging". Excess inflammation is dangerous and can greatly damage cells, but as people age, their ability to clamp down on inflammation becomes weaker. Deepak's lab has uncovered the role of a critical cell surface protein called CXCR4 involved in driving this inflammation. Targeting this receptor can potentially help control inflammation and allow ageing to happen at a normal rate, he explains.

But a high level of inflammation also seems to have a curious and counterintuitive benefit: It can help older people fend off infections. In an aged body, the immune system is already weak, and unable to quickly identify infected cells. "Inflammation is like an innate

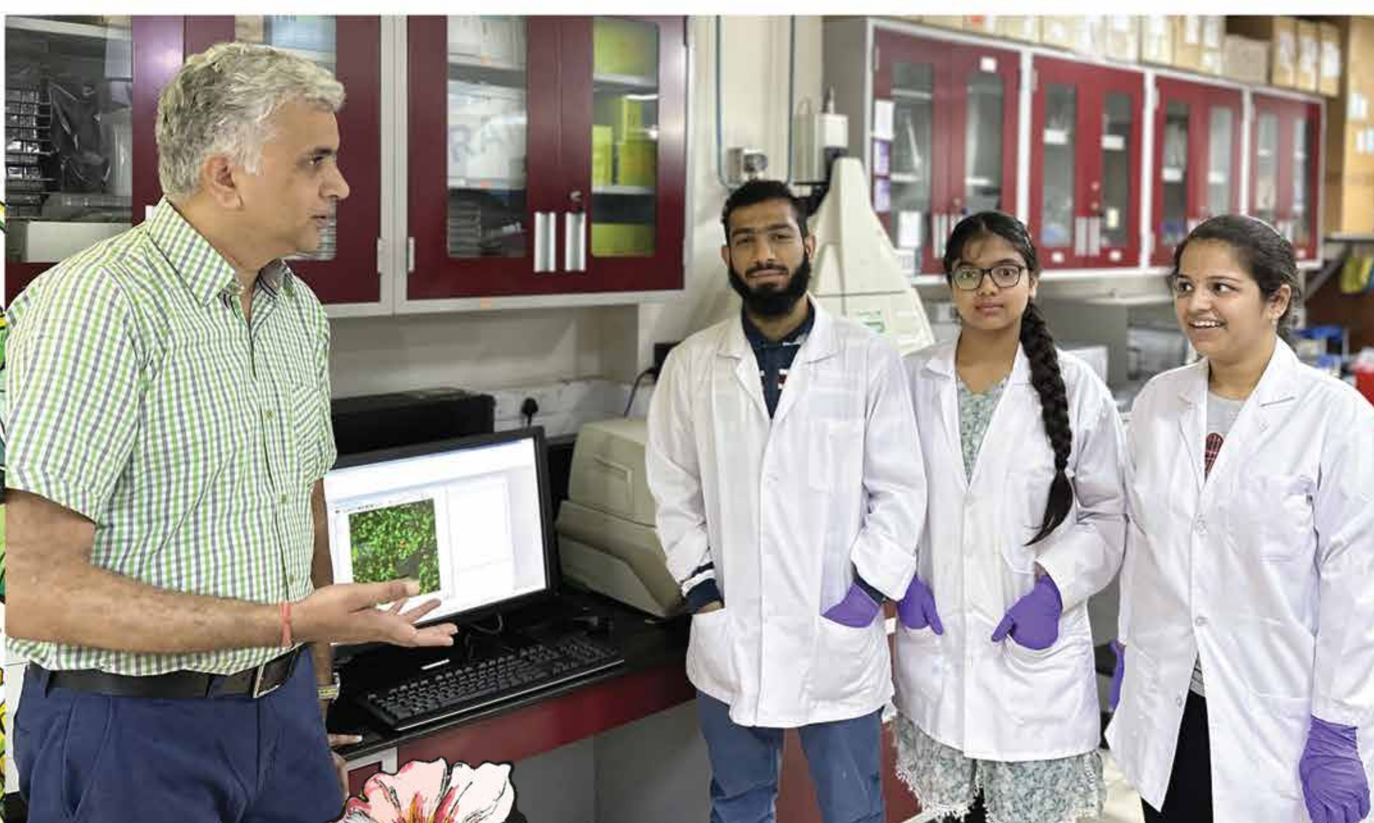


Photo courtesy: Deepak Saini

Deepak Saini with graduate students Siddiq, Nahid and Madhumita defence mechanism. Higher inflammation by itself can counteract infection," says Deepak. "We showed [in mice models] that in the case of at least two intracellular pathogens – *Salmonella* and *Mycobacterium* – the infection burden in aged animals is lower and it is mediated by enhanced nitrosative stress [overproduction of nitrogen-based free radicals] which goes up in ageing."

> ***A high level of inflammation can help older people fend off infections***

This may also explain why giving drugs that suppress inflammation to older people puts them at a higher risk of infections, according to Deepak. During COVID-19, for example, many doctors were probably not looking closely enough at what drugs older people were already taking, he says. "If they were co-morbid, they were definitely taking some drugs which might have suppressed their inflammatory response. This is one part we are actively exploring – to understand if the aged host's susceptibility [to infection] is altered because of the drugs we give them. That means we need to revisit therapy for the aged."

Ageing in the brain

Even in his seventies, my grandfather could reel off names of classmates and teachers from his middle school days. But not all older people are that lucky. People who develop dementia start losing their memory early on, becoming more and more forgetful with time, often not recognising their own family members. They start asking the same questions repeatedly, become confused and disoriented, and sometimes wander off on their own.

It is to study such neurodegenerative disorders that the Centre for Brain Research (CBR) was established on the IISc campus in 2015 with a philanthropic grant of Rs 225 crore from the founders of the Pratiksha Trust, Kris and Sudha Gopalakrishnan. Earlier this year, the Trust made a fresh commitment of Rs 450.27 crore spread over 10 years.

A large part of the research at the Centre has focused on understanding how the brain ages in a healthy individual. Under two long-term studies planned out over 10-15 years, one focusing on about 10,000 individuals living in the Srinivasapura Taluk (about 100 km from Bangalore) and the second on about 1,000 individuals in Bangalore city, researchers have been tracking how genetic, environmental and socio-economic differences shape brain ageing. Once a year, people recruited for the two studies are tested for dozens of biomarkers in their blood, get their genomes sequenced and undergo brain imaging scans. The data are then pooled together to build a comprehensive picture of how their brain health is changing every year. One of the reasons why Srinivasapura was chosen is because it is home to many mango orchard farmers who have lived in the area for generations with very few migrating away, making it easier to follow up with participants for years.

"We want to see the progression of ageing, and how multiple factors including comorbidities contribute to either healthy ageing or cognitive difficulty," says Ravi Muddashetty, Associate Professor at CBR. "This is a unique project in the Indian context and a rare one even globally." He adds that researchers at CBR have already collected a wealth of data from these studies and are currently analysing them.

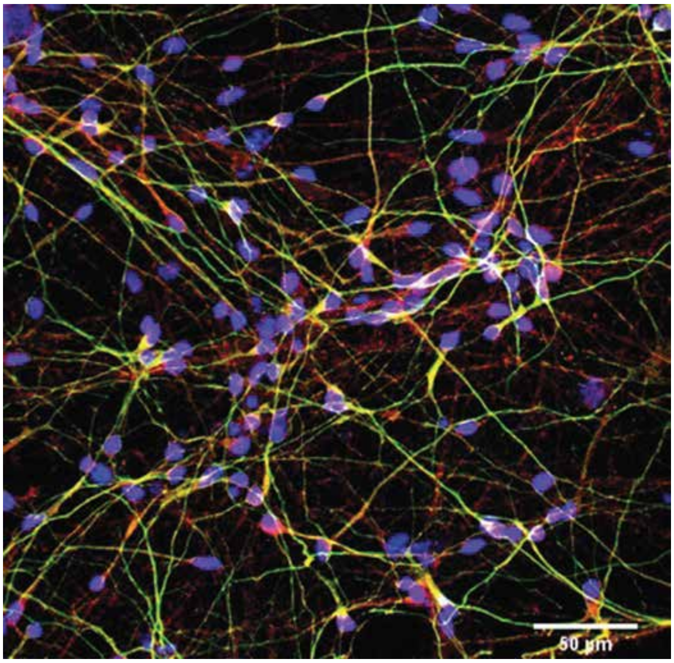
Apart from these large-scale studies, researchers like Ravi are also zooming in on cellular and molecular-level changes in the ageing brain. His lab is particularly tracking the connections between neurons that form and break down over time. When we are born, our brain has about 100 billion neurons, the most we will ever have in our lifetime. Right after birth, these neurons get busy forming connections with neurons in other parts of the brain and the body. This continues up until the age of 25-30. "By 30, you get what you can call an optimally functioning brain," explains Ravi. "From then onwards, every year, there may be some reduction in the number of connections the neurons make. We are studying what factors determine making and breaking or stabilising these connections."

> ***A large part of the research at the Centre for Brain Research has focused on understanding how the brain ages in a healthy individual***

As these connections deteriorate with age, brain functions like memory, learning and cognition slow down. Other changes also add up: Some parts of the brain start shrinking, blood supply gets reduced, and most importantly, aggregates of proteins begin building up in the brain – the hallmark of many neurodegenerative diseases like Alzheimer's and Parkinson's.

"Neurons are non-dividing cells. In a dividing cell, any malfunctioning proteins can be gotten rid of. But in the case of neurons, you can't have that function and there is a slow accumulation of mistakes," says Ravi. "This accumulation of misfolded proteins or aggregates leads to unhealthy ageing and diseases of cognition."

Image: Sarayu Ramakrishna



Induced pluripotent stem cell-derived neurons from familial Alzheimer's patient

There is also growing evidence that brain health may be influenced heavily by the trillions of tiny microbes that live inside our intestines – the gut microbiome. "The gut-to-brain axis is one of the new areas being studied extensively," Ravi says. "What we eat and the way we live determines our gut microbiome, which in turn has an influence on ageing."

Flies, worms and food

Studying ageing in humans is not easy because changes happen over decades. This is why scientists have turned to smaller animals like fruit flies and worms that have much shorter lifespans. "Usually, fruit flies live for close to 65-70 days. But we've developed mutant flies that can live up to 150 days, and also those with only half the lifespan, around 30-35 days," says Upendra. His team is able to track the growth of an entire organism from birth to death within a few weeks, and study how ageing unfolds.

Another model organism that has proved useful in ageing research is *C. elegans*, a tiny transparent worm that has a life span of two to three weeks. Many proteins in the worm have functions very similar to human proteins. "Its tissue structures are also similar," explains Varsha Singh, Associate Professor at DBG.

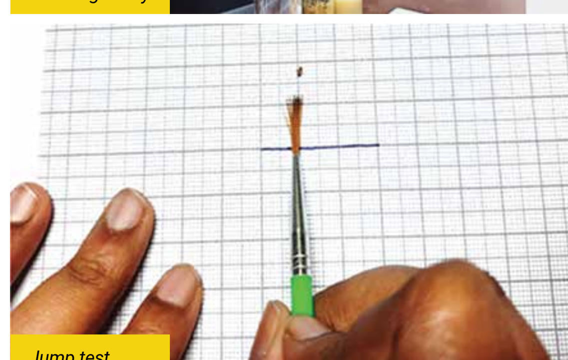
These flies and worms are helping Varsha and Upendra uncover exciting insights into the links between food, gut and ageing.

When Varsha began studying ageing in worms, a key question she was interested in was how the animal smells specific odours. To live longer and "produce more babies", the worm first needs to find the right food, and to find the right food, it needs to have a good sense of smell. "We started with a simple question: If we alter olfaction [the ability to smell] in *C. elegans*, do we see changes in how long the organism lives?" In their experiments, her team found that long-lived worms have a specific protein in their neurons that can "smell" a compound called 2-heptanone, emitted by bacteria that the worm needs to eat. The same smell is produced by some bacteria in our gut, like the ones that we take in with curd. The receptor protein for the smell is responsible for regulating lipid metabolism, which in turn is important for regulating lifespan in worms. Varsha and other researchers suggest that this protein is able to sense 2-heptanone released by microbes in our gut, and this sensing can therefore boost our health too.

Photos courtesy: Upendra Nongthomba

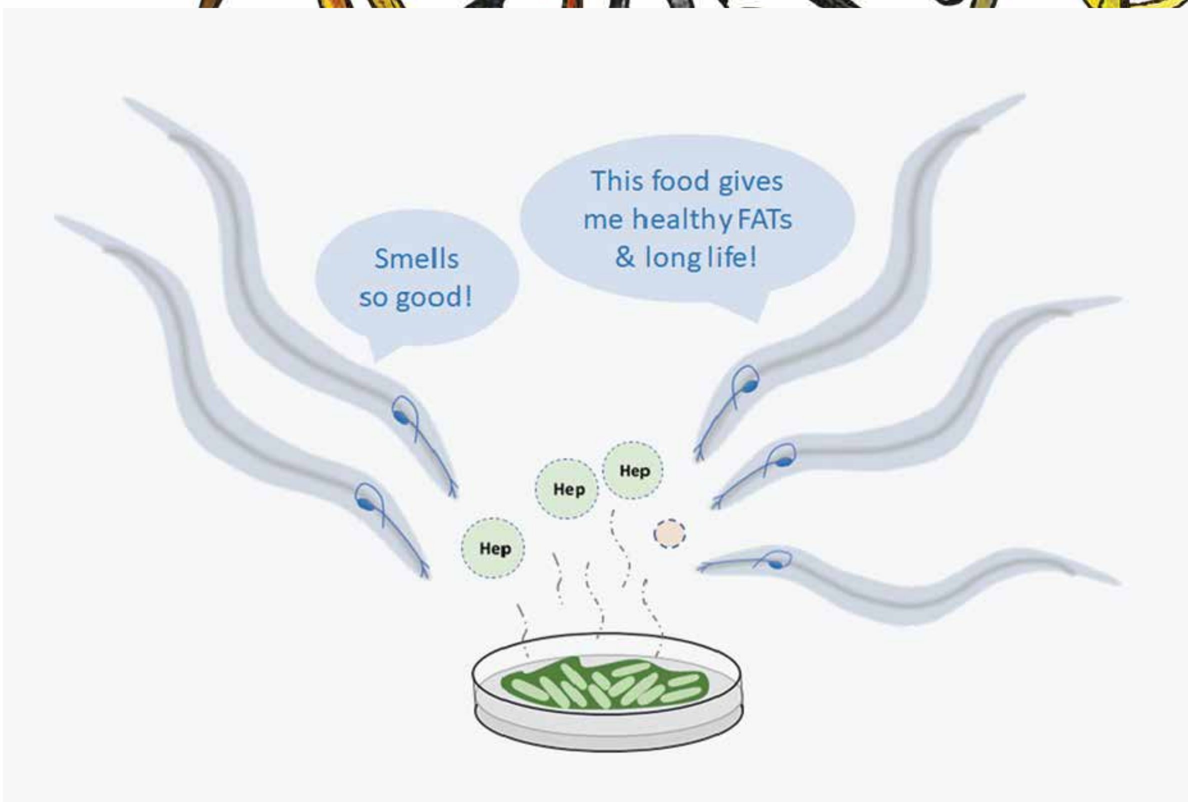

Flight test


Climbing assay


Jump test

Simple behavioural assays to measure healthspan in fruit flies

Illustration: Varsha Singh



Roundworms called C. elegans *choose foods based on certain smells, specifically foods that change the levels of healthy fats and promote longevity*

In addition, the same study by her team showed that short-lived worms lacked mono unsaturated fatty acids (MUFAs), the kind of fats found in foods like almonds. When these worms' diet was supplemented with MUFAs, they lived longer.

Such findings emphasise how the food we eat can influence health and lifespan. "For example, it is believed that in certain Scandinavian countries, people are longer-lived because they have lots of cabbage in their diet," explains Varsha. "The idea is that cabbage changes the gut microbiome, which produces something that will improve health."

> ***Such findings emphasise how the food we eat can influence health and lifespan***

Varsha and Upendra believe that some dietary supplements, including Ayurvedic and traditional medicine, might help boost health during ageing. Upendra has been testing some of these formulations in his lab. His team has found that a specific molecule present in pomegranate juice could help fruit flies remain healthy for longer. His experiments have shown that some salts and salt solutions described in Ayurvedic medicine can reduce gut leakiness in ageing flies by modulating gut bacteria. Upendra hopes that identifying and scientifically validating some of these compounds could lead to therapies that can counter or delay the symptoms of ageing. He adds that the department is also trying to set up a full-fledged centre that will not only focus on understanding the biology of ageing, but also develop therapies that can promote healthy ageing.

In recent years, many therapies have been proposed that claim to stop or reverse ageing. Some researchers have also been testing existing medicines like metformin (an antidiabetic medication) and rapamycin (an immunosuppresive drug) for their ability to counteract ageing-related complications. Countries like Saudi Arabia are reportedly spending a billion USD annually to develop treatments that can slow down ageing.

So far, however, anti-ageing therapy has remained a pipe dream. "People have found some [initial] success with a lot of molecules. Unfortunately, most of them have failed in controlled trials," says Deepak. "The only thing which works without any doubt is caloric restriction. It is the only known therapy which is known to extend lifespan across lifeforms – from worms to flies to mice to humans," he adds. "If we eat less, we burn less, and we tend to live longer."

Giving Wings to the LCA

- Debraj Manna

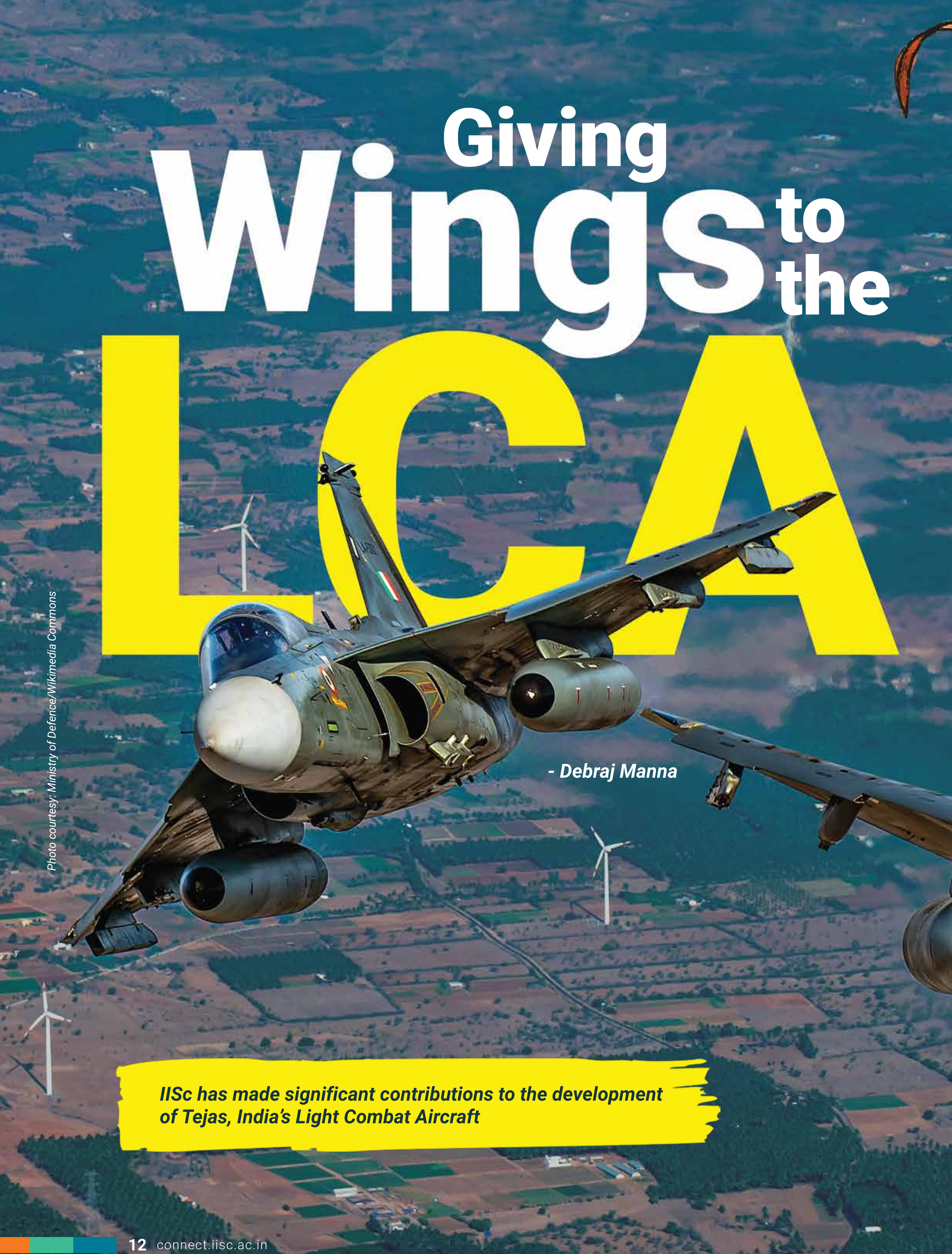


Photo courtesy: Ministry of Defence/Wikimedia Commons

IISc has made significant contributions to the development of Tejas, India's Light Combat Aircraft

In July 1940, during the early stages of World War II, the skies over Europe rumbled as the Luftwaffe, Nazi Germany's air force, launched a massive attack on Britain's Royal Army and Royal Navy. For months, the two sides battled fiercely until the British finally emerged victorious in what became known as the Battle of Britain. It marked a turning point in military aviation history, as it was the first major battle to showcase the power of fighter planes. As World War II continued, air superiority became crucial in many more battles. When the conflict finally ended in 1945, nations worldwide realised that the future of their defence would depend on fighter jets.

India, which became independent in 1947, was no exception, but unlike many other countries, it had a long way to go. Its military aviation journey began in 1953, when Hindustan Aeronautics Limited (HAL) designed and built the HT-2, a military trainer (currently on display at IISc). The HAL team was led by VM Ghatage, who had earlier served as the head of the newly established Department of Aeronautical Engineering, later renamed Aerospace Engineering (AE), at IISc. But India's first fighter bomber – HF-24 Marut – was built only in the 1960s. This too was made by HAL, in collaboration with Kurt Tank, a German aeronautical engineer.

Origin of the LCA

In the 1971 war against Pakistan, the Indian Air Force (IAF) relied heavily on imported jets like the Hawker Hunter – also displayed at IISc – MiG 21, and Canberra, besides the Marut. The war had an important lesson for India's military aviation: It needed to up its game. In the years that followed, however, attempts to upgrade the Marut failed because the West was unwilling to sell India a more powerful turbojet engine, says Duvvuri Subrahmanyam, Assistant Professor at AE. A plan to build a new aircraft called HF-25 did not take off either "because the Indian Government at that time was keen to procure the Jaguar aircraft (which it did in 1978)," he adds. One of those closely involved in both these still-born projects was Roddam Narasimha, who was then a Professor at AE.

'To emphasise the concept, I called it the Light Combat Aircraft'

Nevertheless, Narasimha persisted. "At the same time I started thinking about what would be a practical, affordable, useful aircraft project for India," he writes in a 2019 unpublished article. Now in the possession of AE, the article titled *My Encounters with DRDO: From the HF-24 to the LCA*, was written a little over a year before his death in 2020. In 1977, he came up with the idea of a new indigenous fighter jet, he writes. "We need to have something like 100-200 [of these] aircraft to make the project economically viable. It should have excellent point performance so that it could engage in combat with the best aircraft that might be available to our adversary (from one of its allies) but without the need for either a heavy payload or a long range," he states. Elaborating on his vision, he continues, "This should be effective in at least one of the two fronts that India has had to face. To emphasise the concept I called it the Light Combat Aircraft."

Narasimha took his idea to a group of aerospace researchers based in Bangalore: Satish Dhawan (Director of IISc and Chair of ISRO), Sitaram Rao Valluri (Director of National Aerospace Laboratories (NAL)) and Raj Mahindra (Managing Director (Design & Development) of HAL). "After a few discussion sessions it was concluded that it

was an excellent idea and worth pursuing," he adds. Then, in November 1978, following preliminary studies, Narasimha and Mahindra proposed the idea to IAF in a meeting at HAL.

IAF, during this period, relied heavily on the Soviet supersonic aircraft MiG-21, which was ageing; it needed a new fighter jet. According to Narasimha, IAF responded positively to his proposal but had concerns about the "performance estimates". To address them, Raja Ramanna, who had just taken over as the Scientific Advisor to the Defence Minister – and had discussed the idea with the IAF – suggested that Narasimha lead a delegation to aerospace companies in Europe to get their feedback about the LCA project. So, in 1981, a delegation comprising representatives of IAF, Defence Research and Development Organisation (DRDO), HAL, and NAL, along with Narasimha, left for Europe. It made several presentations, which according to Narasimha were well-received. The positive feedback made the IAF more optimistic about the LCA.

However, the Government of India needed more convincing. So, in 1983, they set up a committee under Valluri to carry out a detailed feasibility study on whether and how the programme could be implemented, according to the book *Radiance in Indian Skies - The Tejas Saga* by P Rajkumar and BR Srikanth. The committee also visited the same five aerospace companies in Europe. Based on their assessment, they produced a report which made a push for the LCA. "It was now time to place it before the Government, with the recommendation that the LCA project may be approved," writes Narasimha. Later that year, the LCA plan was approved. And on 2 July 1984, the Government established the Aeronautical Development Agency (ADA) in Bangalore to oversee the design and development of the LCA, with Valluri as its Director General.

Birth pangs

The first order of business for the ADA was to decide who would lead the design team. "We knew how to manufacture planes, but the big issue now was to actually design a fighter aircraft ourselves," says Srinivas Bhogle, former head of the Information Management Division at NAL. And for that, they needed a good aircraft designer. Valluri chose Mahindra for the job. But the appointment invited some misgivings. In their book, Rajkumar and Srikanth write about how some Members of the Parliament questioned Mahindra's appointment because they felt that this long-term project needed to be headed by a younger person. "Dr Valluri was, however, adamant that only Mr Raj Mahindra was the most competent person to head the project. No amount of persuasion by Dr [VS] Arunachalam [Director General of DRDO] could make Dr Valluri change his mind," they reveal. The controversy ended only when both Valluri and Mahindra resigned from their positions.

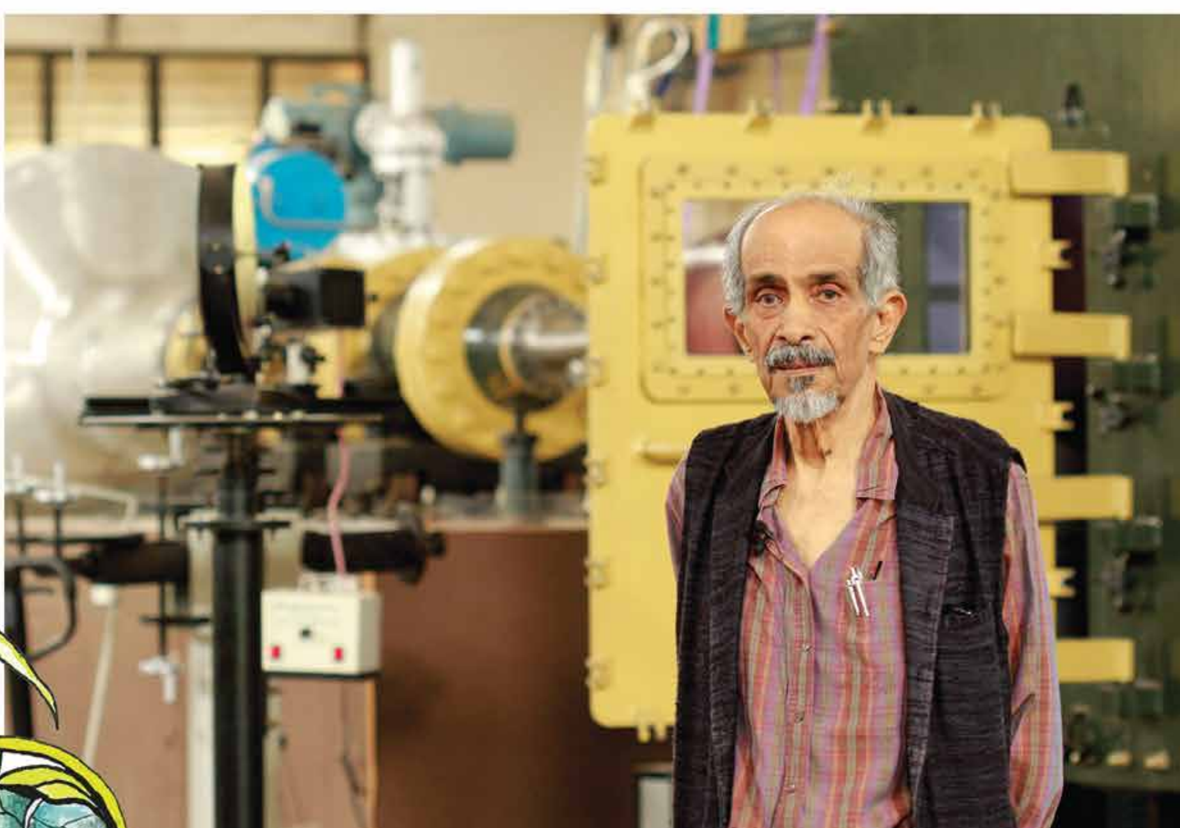


Photo: Souvik Mandal

Roddam Narasimha

Now, the project was again in need of a new head and designer. According to the book, feelers were sent to several eminent scientists and engineers including Narasimha and MA Ramaswamy, Professor at AE. But they declined. Finally, in December 1985, Kota Harinarayana, the then Director of the Aeronautical Development Establishment (ADE) in Bangalore, was asked to take over as the Programme Director of ADA and the Chief Designer of LCA. "When the offer came, my friends told me that the chances of success were 0.1%. They said there was a 99.9% chance that we would fail. I said, as there was at least a 0.1% chance, it was good enough for me to try – and I landed there," recalls Harinarayana, a veteran aerospace engineer who had worked at several organisations like the DRDO, HAL, and ADE.

Harinarayana's experience told him that the colossal task of building the LCA was not a single organisation's job. "I came from a background where I knew that if we all put our heads together, we could certainly succeed. My mindset was very clear – I knew we must work with our academic partners." Foremost on his list of potential academic partners was IISc's AE, his alma mater. "It was a top choice because it has always been one of the best in India, even today."

Materials research and airframe design

And it was to AE that Harinarayana turned for help with his first major task – to identify the material to be used for the body of the lightweight fighter aircraft. Aluminium, which is typically used to build planes, is heavy. To design the airframe, the LCA team, therefore, considered using composites like Kevlar, a synthetic fibre, and carbon fibre-reinforced composites, both of which are lighter than aluminium. The airframe includes wings, a vertical tail, a radome (a dome-shaped enclosure that protects the weather radar of a plane), and the fuselage. There is another significant benefit to using materials like carbon fibre composites, explains KP Rao, former Professor at AE who oversaw the use of composites in the LCA. "Aluminium or steel offer the same strength and stiffness in all directions. Superior strength and stiffness in desired directions can be achieved by using fibre-reinforced composites. It can be achieved by using carefully calculated and designed layering and fibre-orientation techniques. This leads to [a] reduction in weight which impacts fuel efficiency and performance of the aircraft."

IISc was involved even in the design of the airframe. The shape of a plane determines how air will flow around it, which in turn affects the forces acting on it when in flight – lift, the upward acting force; gravity, the downward acting force; thrust, the forward acting force; and drag, the backward acting force. So, ADA sought the help of computational fluid dynamicist Suresh M Deshpande, Professor at AE. Deshpande, who became the Chair of the Computational Fluid Dynamics Planning Committee, joined hands with AG Marathe (Assistant Professor at the Department of Mechanical Engineering (ME), IISc, now with IIT Bombay), Biju Uthup (alumnus of AE who had joined ADA) and other researchers from DRDO. Deshpande's team developed the computational fluid dynamics code for the design of the LCA intake duct, a bell-shaped funnel that provides a constant supply of air to the aircraft's engine. To achieve this, they worked extensively with two supercomputers: DRDO's PACE and Bhabha Atomic Research Centre's Anupam.

More LCA research at IISc

A versatile and manoeuvrable fighter plane like the LCA requires a sophisticated computer law to make it into what is known as a fly-by-wire aircraft. Bhogle illustrates why such a system is important: "Let's say that you're a pilot in a fighter jet and in any five-minute interval, you have to look at 20 variables. Out of these, about three or four are crucial, and you want your

Photo courtesy: Udaya Kumar

LCA outer shell being tested in the High Voltage Laboratory complete attention on them. So, if some of the workloads can be taken away from you, it becomes easier for you to focus your attention on the crucial tasks." This is done by an onboard computer which is the control system of a fly-by-wire aircraft. "It communicates the pilot's requirements to the aircraft's control surfaces. So, the pilot's request goes to the onboard computer, which worries about tolerance, safety, structural strength, and all those things. Then, after analysis, the computer tells you, 'OK, do it' or 'It can't be done.'" To help develop an advanced fly-by-wire system for the LCA, ADA knocked on the doors of IG Sarma, the founding Chair of the Department of Computer Science and Automation (CSA) at IISc. The computerised management of the LCA, which was developed by Sarma, is used in all indigenous aircraft even today.

Combat Aircraft," states IISc's 1993-94 Annual Report. "When the facility became ready, that was declared the best facility in the whole world because both high voltage and high current could be simultaneously created," says Harinarayana, describing the hangar built by Nagabhushana. "Even today, that facility is the backbone for [testing] all aircraft that are designed in India."

Research on lightning protection for the LCA is ongoing and is being carried out in the High Voltage Lab of Udaya Kumar, Chair of EE. "We have developed a unique model for quantifying the lightning attachment to aircraft. Further, an efficient method is being developed for evaluating the lightning current and electromagnetic field distributions in the aircraft after it is struck," he elaborates.


Photo courtesy: Udaya Kumar

Simulation of lightning attachment to scaled version of LCA

Yet another important innovation that was developed by IISc's AE Department for the LCA, called the Non-Destructive Testing (NDT) technology, allows for testing components or systems without permanently damaging or altering them. NDT was designed by CRL Murthy, who was also a Professor at AE.

The LCA underwent multiple tests at the open-circuit wind tunnel in the old building of AE, according to BN Raghunandan, its former Chair. Rajkumar and Srikanth write that Ramaswamy played a crucial role in the wind tunnel testing of the LCA. "He was a specialist in wind tunnel testing and made a big contribution to the development of the first aerodata set for the LCA. In addition, he conducted numerous reviews on aerodynamics at ADA."

The LCA, like all aircraft, would be vulnerable to lightning strikes when in flight. It is estimated that an aircraft is struck by lightning every 1,000 flight hours, the equivalent of one strike per aircraft per year. So, they need to be tested to determine whether they can withstand lightning strikes without malfunctioning. India lacked a sophisticated testing facility until GR Nagabhushana, former Professor in the Department of High Voltage Engineering, IISc (now a part of the Department of Electrical Engineering (EE)) and his team built the first artificial lightning test facility in India at the Centre for Airborne Systems (CABS), DRDO, in Bangalore for the LCA. "A lightning protection scheme has been configured for the radome of Light

IISc was also involved in several other aspects of the LCA project. Besides AE, ME, EE and CSA, departments that participated in LCA research included Civil Engineering, Physics, Supercomputer Education and Research Centre, and the Centre for Nano Science and Engineering.

Raghunandan argues that IISc has contributed to the LCA in yet another significant way. "The most important thing about IISc's contribution to the LCA programme is that we provided the manpower. That includes the late scientist Prof Roddam Narasimha, Dr Kota Harinarayana and many other well-known scientists who have all graduated from this department – some have got their PhDs and some their Master's degrees." Referring specifically to Narasimha's contribution, Joseph Mathew, the current Chair of AE, says, "Such a close involvement of an academician in the LCA project until its sanction is unique."

Photo: Debraj Manna

Model of Tejas in the Department of Aerospace Engineering at IISc

Many academic institutions, besides IISc, and defence organisations also contributed to the development of the LCA, which continued through the 1990s. In September 1998, at the Jakkur Aerodrome in Bangalore, the first flight of a miniature model of the LCA was witnessed by some of the faculty members from IISc involved with the project, and representatives from defence establishments like HAL, DRDO, and NAL. "Satish Dhawan commented, 'Now I have the confidence that the LCA can fly,'" reminisces Raghunandan, who remembers this moment vividly even today. According to IISc's 1998-99 Annual Report, this model, built by SP Govindaraju, Professor at AE, had a span of 1.1 m, weighed 6 kg and reached speeds of up to 150 km/h.

From LCA to Tejas

Within a few years, India was finally ready with its LCA – a fourth generation all-weather, supersonic, multi-role, and fully digital fighter jet. More significantly, it was also the smallest and lightest in its class. The LCA prototype made its maiden flight on 4 January 2001, and was christened Tejas in 2003. It officially joined the IAF in 2016 when it became part of No. 45 squadron called the Flying Daggers. And in 2019, it received its final operational clearance.

HAL now produces the LCA Mark 1, Mark 1A, and the trainer variants. The LCA Mark 1 and Mark 1A are replacing the MiG-21s, MiG-23s, and MiG-27s from the IAF fleet. The LCA Mark 2 variant is under development and expected to replace MiG-29s, Mirage 2000s, and Jaguars. The Naval LCA (N-LCA) programme started in 2003, and in February 2023, the N-LCA made its maiden take-off and landing on the aircraft carrier *INS Vikrant*.

Besides giving India a state-of-the-art fighter aircraft, the development of the LCA has benefited the country in other ways. The technologies made for the LCA are being used in other initiatives like the HAL-Advanced Medium Combat Aircraft (HAL-AMCA), currently under development. "Before the project, our technology base was next to nil. After this project, we became among the top leaders in fighter aircraft technology," says Harinarayana.

Harinarayana adds that the LCA also serves as an example of how industry, academia and national R&D labs could work together towards a common goal – more than 300 companies, 40 national laboratories, and 25 academic institutions contributed to the effort. IISc's contribution, however, stands out. As a token of appreciation, ADA gifted IISc the first scale model of the LCA after its design was finalised. The mock model now sits proudly at the entrance of AE.

Debraj Manna is a PhD student at the Department of Biochemistry, IISc and a former science writing intern at the Office of Communications

Mining for White Gold

- *Aniket Majumdar*

Photo courtesy: Krzysztof Woźnica/Wikimedia Commons

India is betting big on lithium-ion batteries, but at what cost?

The CR2032 Li-ion battery, the most commonly used button cell in the world

In 1817, Johan August Arfwedson, a Swedish lawyer and mineralogist, was studying the mineral petalite in the laboratory of the renowned chemist Jacob Berzelius. His investigations revealed that the mineral mainly contained aluminium, silicon and oxygen. But around 4% of the composition could not be accounted for. Arfwedson also noticed that this missing part was chemically similar to sodium, potassium and other alkali metals. Confused with this result, he exposed the petalite sample to a flame, and the flame immediately turned carmine red, a colour never seen before in any flame test. Surprised by its chemical behaviour, Arfwedson named this newly discovered metal "lithium", derived from "lithos", the Greek word for stone.

The discovery of lithium went largely unnoticed until an Australian psychiatrist named John Cade started experimenting with this metal for treating bipolar patients during World War II. In 1950, he, along with colleagues Mogens Schou and Poul Baastrup, showed that a controlled dose of lithium could reduce the symptoms of bipolar disorder. This generated a sudden excitement for lithium. In the following years, chemists also began looking at its energy-storing capabilities, and companies started making batteries utilising this metal.

Lithium – often referred to as "white gold" – is a much more precious resource than fossil fuels. Only 22 million metric tonnes of lithium reserves are presently available worldwide, whereas, in 2020, the world's total oil reserves was estimated to be 236.29 billion tonnes. Most of the mineral is confined to the so-called Lithium Triangle – Bolivia, Argentina and Chile – which has more than 75% of the world's lithium reserves. Countries like India have, therefore, been importing lithium for decades.

But in 1996-97, India too struck gold, metaphorically. The Geological Survey of India (GSI) discovered the presence of large lithium reserves in Jammu and Kashmir. However, there were no serious attempts to explore them. Twenty-six years later, in 2023, the Ministry of Mines finally announced the presence of about 5.9 million metric tonnes of "inferred" lithium reserves in the same place in Reasi district. This was just two years after GSI reported the presence of around 1,000 metric tonnes of lithium reserves in the Mandya district of Karnataka.

"Lithium – often referred to as "white gold" – is a much more precious resource than fossil fuels"

Even though scientists and activists are worried about the environmental impact of mining such reserves, industries, especially those working on electric vehicles and energy storage technologies, are excited. And for good reason. If the Ministry's estimates are validated, then the net worth of the Reasi reserves alone can be as high as Rs 34 lakh crore, substantially cutting down India's spending on importing lithium, which was about Rs 9,000 crore in 2022. This may just be the tip of the iceberg, given the massive craze for transitioning to clean energy. And it certainly has a lot to do with the fact that lithium has now become the poster boy of the battery industry.

From clay pots to cellphones

In 1936, a German archaeologist named Wilhelm Konig was excavating a 2,000-year-old village called Khujut Rabu near modern-day Baghdad. During the excavation, he came across an unusual 5 inch-tall clay pot, which encapsulated a copper cylinder and had an iron rod suspended in the centre of the cylinder. The cylinder and the rod did not touch each other and were separated by an asphalt plug. Konig concluded that the pot belonged to the Parthian dynasty (from around 250 BCE) and that its structure resembled a very primitive form of electrical battery. Konig named the pot "the Baghdad battery" – the earliest battery known to humans.

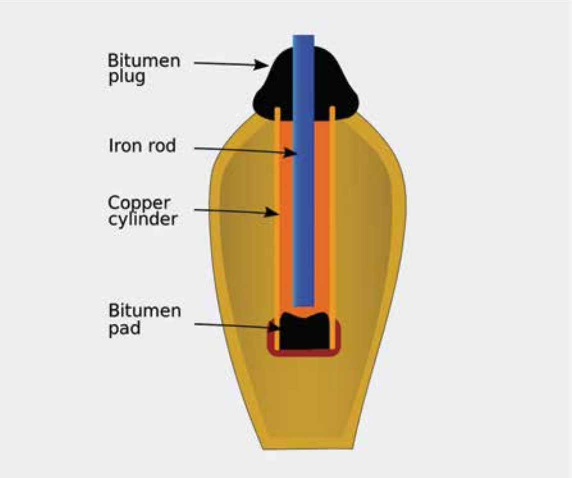


Image courtesy: Chatsam/Wikimedia Commons

An artist's impression of the famous Baghdad battery

In today's world, batteries play a crucial role in our lives. From the heavy lead-acid batteries used in buses and trucks to the tiny dry cells used to switch on our laser pointers, we have come up with several innovations in battery technology. As the world marches towards greener forms of energy, scientists believe that batteries are critical to the transition from non-renewable energy sources to renewable ones. "[Energy from] renewables is intermittently available; hence, it must be stored. At present, batteries are the most preferred choice for energy storage because they are modular, scalable and easily transportable," says

Naga Phani Aetukuri, Assistant Professor in the Solid State and Structural Chemistry Unit (SSCU), IISc. “Right now, there is sufficient reason to switch to renewables. However, this is limited by the availability of batteries with the necessary techno-economic attributes. The good news is that this transition to renewables plus batteries is inevitable in the years to come.”

The cost of production of energy from renewable sources like solar panels and wind turbines has gone down significantly in the past decade, but the need for storing renewable energy in batteries forces the net cost to increase by three to four times of that spent for generating power from coal, according to Naga Phani. Recent advances in lithium (Li) ion technology could enable the shift to green energy sources while still being economically viable.“Batteries today are consumables, and the one parameter that the consumer cares about the most is cost. The cost of ownership is expected to be much lower for lithium-ion batteries than any other battery in the market today,” adds Naga Phani. “Cheaper batteries also mean lower costs for green electricity.”

Photo: Dipen Biswakarma

Akshatha Venkatesh from Aninda Bhattacharyya’s lab assembling a lithium-ion battery in the glovebox under inert conditions

Today, Li-ion batteries are used abundantly in automobiles, mobile phones, laptops and other electronic devices. Compared to other types, these batteries last much longer and have a higher energy density – which means more energy storage while using a tiny amount of lithium. “Li-ion battery [technology] has made great strides. In 1991, a Li-ion module cost around USD 1,000 with a power output of 90 kWh, whereas today, the energy output has gone up to around 250 kWh with the cost coming down to less than USD 100,” says Aninda Jiban Bhattacharyya, Professor in SSCU and the Interdisciplinary Centre for Energy Research, IISc.

This enormous increase in cost-efficiency has a lot to do with the evolution of the chemical composition of the Li-ion battery over the years. And this change began just three decades back.

Mining, manufacturing and mass production

In 1985, a Japanese multinational company called Asahi Chemicals, led by scientist Akira Yoshino filed a patent demonstrating the first safely rechargeable Li-ion battery. This sparked a massive interest among companies like Sony and Panasonic, which were aiming to commercialise Li-ion batteries. Keizaburo Tozawa, the then Chairman of Sony Corporation, was excited about the prospects of this novel technology, but at that time, his company lacked the recipe to produce these batteries on a large scale.

Five years later, Sony took a giant step in the memory storage sector – shifting from tape recorders and cassettes to CDs (compact disks). During this transformation, Tozawa was visiting a company manufacturing unit and happened to come across the tape-recorder assembling equipment lying idle, waiting to be discarded. He had a sudden epiphany – the manufacturing process of these tape recorders and cassettes involved sprinkling a polymeric foil with magnetic nanoparticles. Tozawa immediately realised that the same technique could be used to coat Li-ion powders or inks onto metallic films and assemble Li-ion battery modules on a large scale. This procedure is still being followed for making Li-ion batteries, exclaims Naga Phani.

In 1991, Sony brought out the CCD-TR1 8 mm camcorder powered by commercialised Li-ion batteries, becoming the first company in the world to do so. And Yoshino, along with two other scientists, was awarded the Nobel Prize in Chemistry in 2019 for the development of Li-ion batteries.

The 1991 prototype had a graphite anode (negatively charged electrode) and a transition metal oxide-based cathode (positively charged electrode). Today, state-of-the-art Li-ion batteries available in the market primarily consist of cathodes made of lithium cobalt oxide or lithium iron phosphate. The most commonly used cathode consists of cobalt oxide, but it is costly and toxic. Therefore, researchers are working on finding a proper replacement for cobalt. “India is largely betting on lithium iron phosphate-based cathodes because they tend to be a lot safer to use. Continuous usage of a battery with lithium iron phosphate does not cause the electrolyte to heat up significantly, rendering the battery very stable even at temperatures as high as the average summer temperature in India. But there is a compromise – this has a lower energy density than the cobalt-based ones,” says Naga Phani.

A major problem with conventional batteries, in general, is that continuous usage leads to a strong heating effect, known as a thermal breakaway reaction, which can even result in an explosion. Li-ion batteries also use liquid electrolytes that are highly reactive and have low flash points (flash point is the lowest temperature at which the electrolyte starts combusting), which can also cause the battery to explode. In addition, these batteries have a non-conducting and polymer-based separator between the positive and negative electrodes, which reduces the battery's efficiency.

> *'The transition to renewables plus batteries is inevitable in the years to come'*

Ongoing research in Naga Phani’s lab aims to make Li-ion batteries safer and more compact by replacing the polymeric separator and liquid electrolyte with a solid-state electrolyte. To keep the battery light, the researchers have successfully replaced the carbonaceous anodes with solid-state lithium metal-based ones. These changes are expected to increase the energy density of the batteries by 30-40%. This could significantly lower the battery cost, thereby enabling the widespread adoption of batteries for green electricity.

Photo courtesy: Naga Phani Aetukuri

Akhila S from Naga Phani Aetukuri’s lab setting up batteries on a differential electrochemical mass spectrometer

Aninda’s group works on both Li-ion and beyond Li-ion chemistries. Over the years, the focus of their research has been to design alternative Li-storing anodes and Li-ion conducting soft matter (“solid-like”) electrolytes (cross-linked polymers, gels and viscous liquids). They have also proposed and designed carbonaceous materials like 2D (doped) graphene, nanostructures of transition metal oxides, sulphides, and tin alloys as alternatives to graphite. Their goal is to assemble Li-ion batteries with electrodes developed in-house along with multi-functional soft matter electrolytes. All these efforts are expected to lead to a more energy-efficient and cost-effective Li-ion battery module.

But the cost-effectiveness also depends on how much we must spend on getting raw lithium. In theory, the extraction of lithium is a straightforward process. In South America’s Lithium Triangle, for example, lithium is extracted from brine, a highly concentrated salt solution of lithium found in underground reservoirs or seawater. The brine solution is stored in evaporation tanks, and the lithium concentration of the brine is carefully monitored as the water evaporates. This gives an estimate of the amount of lithium that can be extracted from the brine solution. Adding sodium carbonate to the brine solution yields lithium carbonate, from which metallic lithium can be directly obtained and used in batteries.

But Aninda believes that the Reasi reserves might be present in the form of mineral ores, like spodumene and petalite. In that case, the mineral needs to be taken through a protocol of processes comprising crushing, roasting at very high temperatures (around 1200^{0}C) and acid leaching. "This entire process of lithium extraction from ores is cost- and energy-intensive (vis-a-vis extraction from liquid brine), demands heavy machinery, and the yield may still be low," says Aninda. "India does have the necessary infrastructure to mine and extract lithium, irrespective of the starting material; however, certain industry-compatible optimisations might need to be adopted."

Impact on ecosystems

While industry and government sources gear up to capitalise on the Reasi discovery, the presence of the reserves has also stirred up a socio-political and environmental storm. The area where the lithium reserves have been identified has large plots of agricultural land and a dense forest cover. The Chenab river also flows quite close by. Lithium mining can therefore pose a serious threat to these natural resources.

"[Mining] creates fragmentation in the forest habitat and hampers the movement of animals residing in that area," says Rajkamal Goswami, Fellow in Residence at the Ashoka Trust for Research in Ecology and the Environment (ATREE). He adds that mobilising and deploying heavy mining machinery and infrastructure can alter the landscape rapidly, which, in turn, can severely impact flora and fauna.

Rajkamal explains that among the most affected would be small creatures such as worms, spiders, snails and frogs. These animals do not move much in search of food or mates. Consequently, mining-related excavation can completely wipe out their populations.

The colour of the Lukha river in Meghalaya has turned deep blue due to excess growth of blue-green algae caused by dumping of pollutants from mining

Incessant dumping of chemical waste into the water can affect and kill fish. During the limestone mining boom in Meghalaya in 2007, Rajkamal recounts how a 4 km-long stretch of the Lukha river downstream from the mining site had “literally no fishes.” Birds and large mammals can travel large distances from the mining site. But this territorial displacement can cause drastic shifts in the ecosystem.

“Before 2007 [when the cement and limestone mining began], the forest cover in this region was much more than what it is now,” says a local official who works in a government organisation in Sonapyrdi, Meghalaya. “The Lukha river was the most affected – all the aquatic life in the river has vanished over the last 15 years.” Because of the large number of pollutants dumped into the river, the water has turned deep blue due to the excessive growth of toxic blue-green algae.

However, there are ways to minimise the mining-related damage to the ecosystem. For example, mining can be done across one small patch of land at a time, then shifting to another small patch, and so on – just like cultivating small tracts of land – instead of mining over a large area all at once. This allows the patch of land that has been mined some time to recover. “In developed countries, they plan the development of industries and infrastructure in such a way that they keep the resilience of the ecosystem in mind and phase out the extent of any possible disturbance to the level that it doesn’t affect the ecosystem critically,” adds Rajkamal. Every ecosystem has a threshold for the disturbance it can tolerate before collapsing or changing irreversibly. He believes that for the Reasi reserves, the authorities should similarly try to understand the natural systems and find the threshold. “If you are planning to dump lithium-associated waste into the water bodies, find the optimum dumping rate beyond which it will negatively alter the aquatic ecosystem balance. Beyond that rate, you will simply destroy the water body,” says Rajkamal.

Photo courtesy: Tackmon L Gympad and Kwilnis Suchiang

> *There are ways to minimise the mining-related damage to the ecosystem*

Large-scale unplanned mining can also disrupt the lives of the local villagers who depend on the forest and the local water bodies for their livelihoods. In some areas, many private land-owners are happy to sell their land to the government or industries for mining, especially when the land is not agriculture-friendly. But in most areas, like Meghalaya, for instance, local villages and communities have been cultivating common land for many years. Therefore, when limestone mining began in 2007, large scale appropriation of common land took place for excavation, and left the poor and marginal farming communities destitute and vulnerable.

“Unless there are strong policies in place for environment conservation, it will be difficult for the common man to save the planet through individual or collective action alone,” says Rajkamal.

Engaging and interacting with local communities, who might be directly affected by the mining at Reasi, even before the operations are planned, will also go a long way to ensure the mining is carried out safely and sustainably. But Rajkamal is sceptical. “Given how scarce lithium is,” he says wryly, “I don’t think these companies will allow any delay or obstruction to the immediate procurement of the mineral.”

Aniket Majumdar is an Integrated PhD student in the Department of Physics, IISc and a former science writing intern at the Office of Communications

From navy discipline to fiscal prudence

- Pratibha Gopalakrishna

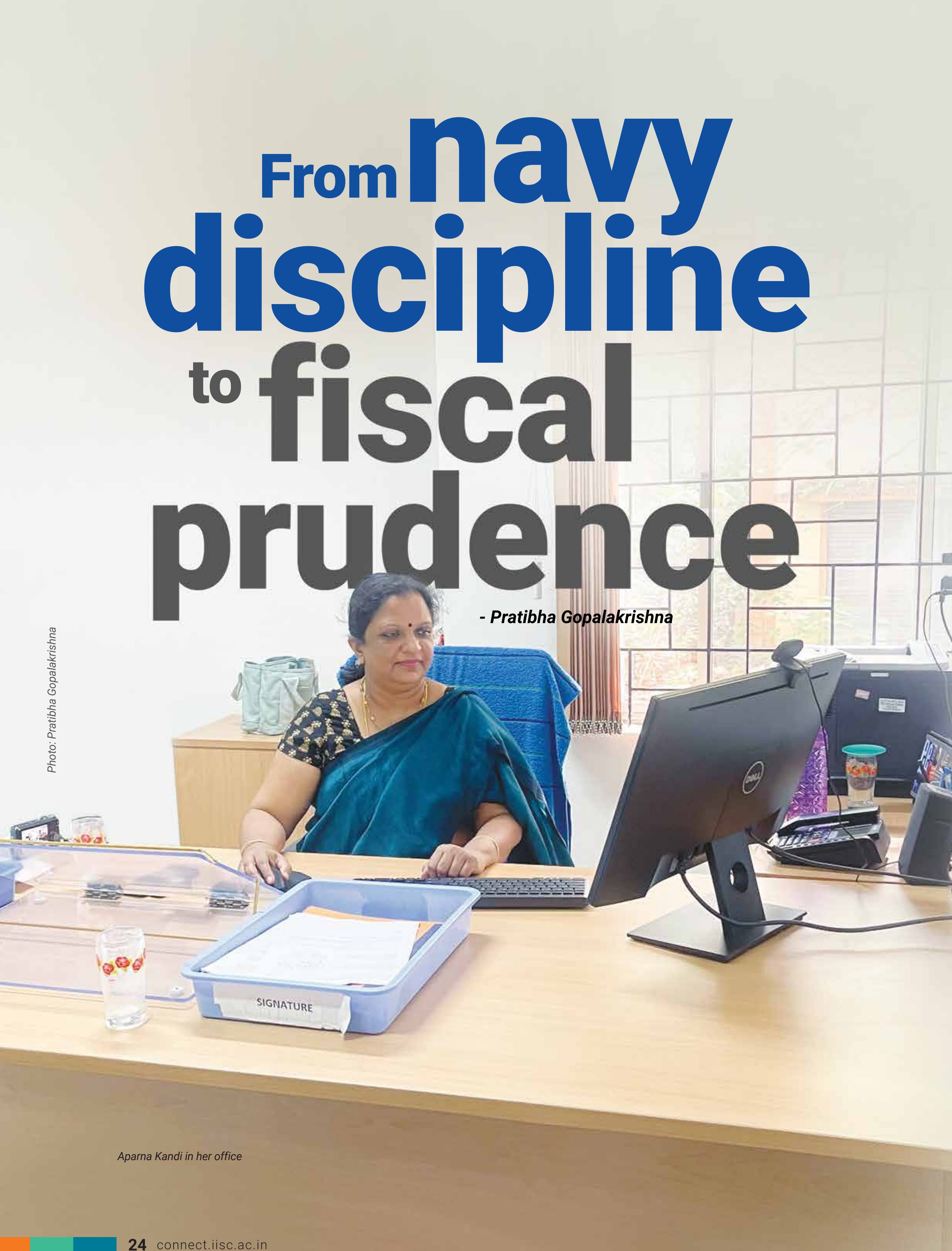


Photo: Pratibha Gopalakrishna

Aparna Kandi in her office

A deep dive into one day in the life of Aparna Kandi, a former navy officer and current Deputy Registrar

It is a quiet April morning at the pale cream-coloured administrative building at IISc, close to the main gate. On the ground floor are offices of the Finance and Accounts (F&A) section as well as the Purchase section. From outside, the latter looks empty but on passing through, people can be seen bent over their desks, softly clacking away at their computers. At the far end of the room are a few individual offices, one of which belongs to Aparna Kandi.

Aparna is one of four Deputy Registrars in the administrative section. In 2021, after 10 years of working at F&A, she was put in charge of overseeing all purchases at the Institute as well as the Central Stores.

Today, Aparna's first meeting is with colleagues in F&A at 9 am, to discuss the transfer of a 40-year-old piece of research equipment to another institute. She is part of the committee that overlooks the entire process and paperwork involved.

In one corner of Aparna's office sits a monitor with multiple displays of live video feed from security cameras. Each display focuses on a particular portion of what looks like a scrapyard containing old machines. Managing the scrapyard on campus takes up a big chunk of her responsibilities. When Aparna joined the office, she had cameras set up around the area to keep an eye on the material in the scrapyard.

"Scrap" is the term given to all the old, obsolete equipment at the Institute that are no longer in use or in working condition, from old computers to scientific equipment like fume hoods – used for ensuring safety in chemistry and biology labs. Aparna explains that these obsolete items also have some value, and their parts – like the copper wiring or magnets – are auctioned off via the central government's MSTC e-portal.

At the Purchase section, one of Aparna's main responsibilities is managing purchase committees, which are set up every time a faculty member wants to buy equipment for their lab. This committee oversees the entire purchase process, and includes that faculty member, the Chair of their department, another faculty member from a different department who has similar equipment, and a purchase officer – usually Aparna.

Central government rules require that before the purchase of any expensive machinery, a tender has to be circulated to local business vendors (called domestic tendering). If the bidders don't qualify, then the tender document is sent to the Ministry of Education (MoE) for approval, after which it is opened up for international bidders. It is Aparna's job to guide the faculty members throughout this process. Which is why on this day, she asks Puja Choudhury, the administrative assistant in her office, to collate the Global Tender Enquiry (GTE) documents – all tender requests that need to be sent to the MoE on the 10th of every month.

Her current job may involve procuring research equipment, but growing up, dinner table conversations at Aparna's house usually revolved around acquiring weapons and warships.

From sea to IISc

Photos courtesy: Aparna Kandi

Aparna during her Navy days

Most of Aparna's family members had served in the armed forces. Even though she was part of an army family, nobody initially expected that she would join too. "I was very happy in the world of Enid Blyton," she explains. But eventually, after completing her engineering in electronics and communication, she applied to the Service Selection Board (SSB).

The five days-long SSB exam consisted of physical tests, group discussions, personal interviews and group tasks. Psychologists observed the candidates' behaviour and interactions with others. On passing the exam, she was sent to Mandovi, Goa, for six months of training. "It was very, very tough," Aparna says. The training also strengthened her spirit, she adds. After completing her training, Aparna worked as a Short Service Commission Officer in the Indian Navy for 12 years. By then, she had two children and wanted to put down her roots in one place for their education. She, therefore, handed over her papers, moved to Bangalore, and joined IISc in 2012.

Aparna says that her training and experience in the armed forces helped her tremendously during the first wave of the pandemic. When the first COVID-19 lockdown was announced in March of 2020, it was the yearly closing period at F&A. Aparna was told 'come hell or high water' to office and close the financial records for that year. She called other colleagues, but couldn't reach many of them. Some of them were reluctant to come. Others managed to come to the office, but were stopped and some were even roughed up by the police. Aparna points out that everyone was scared because so much about the virus was unknown. Her family was also worried about her going to the office. "After three days, I built up courage. All those days in the navy had trained me to fight a war with a known enemy. But I had never fought a war with an unknown enemy."

So, she marched to her office, broke open locks on the drawers, took out the papers, and started clearing all the bills. Those first few weeks were difficult, as everything was delayed or slowed down, from clearing cheques at the bank to even getting petrol for her bike to come to the office. Her experiences during the pandemic as well as in the navy have helped her become rigorous and meticulous in her work, she says.

> ***She welcomes the challenge of taking charge of something she is not familiar with***

At IISc, officers like Deputy Registrars are appointed at different administrative offices irrespective of their background. In Aparna's case, she comes from an engineering and military background but was asked to take charge of finance and purchase-related operations – all alien areas to her. Not one to be discouraged, she took them all in her stride and used them as opportunities to learn and improve her skills. She welcomes the challenge of taking charge of something she is not familiar with, she explains, keeping herself updated by reading a lot in her spare time. She points to some of the books on the office shelf behind her chair – titles that include *Swamy's Compilation of General Financial Rules* and *Manual for Procurement of Works*.

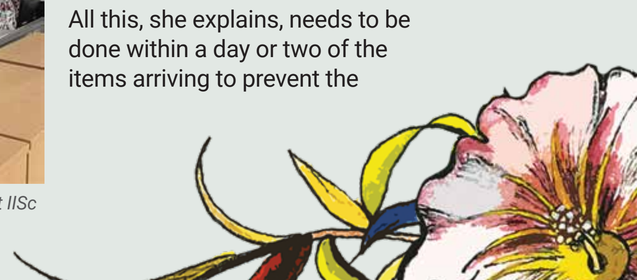
Around mid-day, as Aparna steadily works on clearing papers and bills, she gets a phone call from one of the faculty members who wants clarity on customs clearance – a procedure required for importing any goods into the country. It needs several documents to be prepared and submitted to the customs department, in order to ensure that no illicit or restricted goods enter the country. The central government collects taxes and duties on every item that is imported. As a scientific research institution, IISc has a tax exemption certificate called the DSIR certificate, based on which the Institute only pays 5.5% of the entire customs duty.

The person who called Aparna wants to know if an outside agent – someone not under contract with the Institute – can get a tax exemption for the imported goods if they claim it on behalf of IISc, to which Aparna politely says that it is not possible. Fielding such calls is a part of Aparna's routine. IISc has a Customs House Agent (CHA) or a clearing agent who works on the Institute's behalf to clear the customs duty on any purchase from countries outside India. The vendor who supplies the equipment intimates both the purchase office and the clearing agent when the item is going to arrive at the airport, so that they can prepare the documents and the payment for clearing customs duty.

All this, she explains, needs to be done within a day or two of the items arriving to prevent the

Photo: Pratibha Gopalakrishna

The Purchase section at IISc



Institute from being fined. Then, the purchase office makes sure that the item is transferred to the respective department without any damage. "This has to be done with a lot of due diligence – for example, noting down the right item description and numbers – everything has to be clear so that we don't incur any penalty from customs," she says. The items imported can be anything from scientific equipment to perishable items like proteins, viral samples and reagents (these are stored in dry ice and need to be shipped within 48 hours) to lab mice, radioactive materials, and chemicals.

Aparna stays in the campus quarters opposite the Department of Electrical Communication Engineering. She drives her lavender Scooty pep back home at 1.30 pm every day for a quick lunch. Today, this consists of lemon rice (Chitranna) and curd rice with a side of tomato chutney and mango pickles. On this day, her two daughters are also home during lunch. Aparna's elder daughter is making dosas for herself; she offers some to Aparna. This daughter is really keen on joining the armed forces after completing her engineering – just like her mother. The younger one has just finished her 10th board exams.

Keeping alive a legacy

Back to work at 2.30 pm from her lunch, Aparna starts going through the tender requests that faculty members have submitted via the SAP portal. There is a flurry of activity in the afternoon as administrative assistants Rakesh V and Mareena Jerson come into her office to verify older documents that are stored in the cupboards, as well as to get clarity from Aparna for stock verification. Aparna elaborates that stock verification is an annual operation during which all items at IISc's Central Stores are reviewed.

The Central Stores building is located beyond the old physics building, on the corner where Gulmohar Marg and the Students' Council road intersect. This was once the most happening place in the Institute, Aparna recalls. It was a centralised procurement centre from where all items were bought for the entire Institute and distributed to relevant departments. This included office consumables, electrical hardware, chemicals, and furniture. That was 10-15 years ago. As the Institute expanded, individual departments and faculty members got more funding, and therefore started procuring items themselves.

Today, Aparna keeps the Central Stores open by stocking office consumables such as copy paper, pens and other stationery, and files and folders for administrative departments. She has streamlined the purchase process for the stores and made it mandatory to buy items only through the GeM portal, an online central government marketplace built to ensure efficiency and transparency. She also sends broadcast emails about the items available in the stores to all departments every two weeks so that people can send in their requests.

The GTE report reaches Aparna's inbox around 3.30 pm and she verifies it. After the pandemic, all approvals and signatures are online, enabled by Adobe Acrobat software. So, all she has to do is digitally sign the document, and after a final check, she emails it to the Director and the Dean of Administration and Finance (A&F) for their signatures.

Photo: Pratibha Gopalakrishna

Rakesh V, an administrative assistant, hands a file to Aparna for approval

At 4 pm, Aparna joins a virtual meeting of a purchase committee that has been set up to help an assistant professor in the Division of Biological Sciences purchase equipment for his lab. They are joined by two other faculty members in the same division, one of whom has similar equipment in their lab. The assistant professor who wants to purchase the equipment proceeds to open the three bids received from potential vendors. Each bid has two separate parts – technical and financial. The technical bid contains the specifications of the equipment that the bidder owns, whereas the financial bid lays out the pricing.

The faculty member reads out the technical specifications and lets the committee know if those specifications match the tender put out by IISc. Only if the technical specifications match, the financial bid would be opened. In this way, they go through the three bids and at the end, none of them meet the criteria for the specifications listed by IISc. They wrap up the meeting, concluding that the tender will need to be sent out again.

At 4.30 pm, the signed GTE document is sent off to the MoE. Today has been a relatively busy day at the office, Aparna says. As is her custom, she wraps up work around 5 pm, clears her desk, and leaves the office to ride her Scooty back home, where she will spend the evening taking a stroll with her daughters.

I, Robot

- Shrivallabh Deshpande

Photo courtesy: Mukil Saravanan

Clockwise from L-R: Siri Dupaka, Saravanan Murugaiyan, Darren D'souza, Jayesh Prakash and Sushmita S working on collaborative and social robots in Abhra Chowdhury's lab at CPDM

Researchers at IISc and ARTPARK are building robots that will soon become an integral part of human environments

The *Terminator* movies and several science fiction books have painted a picture of robots as mostly evil overlords bent on wiping out humanity. The reality is that although robots have evolved significantly in the last few decades, we still have a long way to go before – if at all – robots acquire anything closely resembling human intelligence. There is no denying, however, that robots are now woven tighter than ever into the fabric of human society. From ancient Egyptian water clocks to Boston Dynamics' obstacle-jumping Atlas, robots have come a long way.

"The definition of robot evolves over time," explains Shishir Kolathaya, Assistant Professor at the Robert Bosch Centre for Cyber-Physical Systems (RBCCPS), IISc. The first industrial robot called Unimate, for example, was simply a manipulator arm that moved die castings on an assembly line and welded them to car parts.

"To understand what a robot is, you have to understand why it was required," says Abhra Roy Chowdhury, Assistant Professor at the Centre for Product Design and Manufacturing (CPDM), IISc. He explains that machines have existed for centuries, but the transformation from machine to robot happened as the machines became more and more human-centric.

The development of robots is scattered across many timepoints in history, but there is a common underlying theme to why they were needed – to relieve humans of dull, messy and dangerous tasks like digging the earth, handling hazardous substances and detecting landmines in a battlefield. Since the industrial revolution, robots have largely occupied factory floors, doing monotonous, repetitive tasks on the assembly line. But today's – and tomorrow's – robots are ones that will have a more profound impact on our lives, like driverless cars and robotic nurses.

Out in the real world

At Abhra's lab in CPDM, his students are working on ways to improve how humans and robots collaborate with each other, especially in complex real-world settings such as smart industries, healthcare facilities, construction sites, offices and homes. "We are focused on integrating robots with human [environments]," says Jayesh Prakash, a research assistant in the lab working on collaborative robotics. One of the areas they are focusing on is how communication between robots and humans can be improved so that humans find it safer to work alongside robots. This is especially important in factory floors where human-robot interaction is unavoidable. For example, Abhra's lab has shown that some robots can be programmed to perceive and interpret human gestures to communicate with another robot in order to carry out a package delivery task in a smart industry set-up.

Jayesh explains that imparting the robots with intelligence and the ability to be keenly aware of their environment will go a long way towards making human-robot interaction safe.

The lab is also interested in precision robotics. Saravanan Murugaiyan, a PhD student, is working on improving the immensely challenging technique of stereo electroencephalography – an invasive procedure that involves passing an electrode into deep regions inside the brain in order to record electrical signals. He is exploring a futuristic application: Developing tiny, flexible robots that will travel through the brain, instead of surgically inserting electrodes, to not only record signals but also potentially perturb the brain tissue if needed. If he is successful, such robots could be used to treat symptoms of epilepsy, for example.

> ***Students are working on ways to improve how humans and robots collaborate with each other, especially in complex real-world settings***

Another challenging environment where robots complement human activity is a construction site. A typical day there is abuzz with the activity of both machines and humans. Into this dynamic scene, Kalaivanan K, a PhD student, is hoping to introduce a robot that will help with tasks like bricklaying, working alongside humans. Shravan Shenoy, a project student in the lab, is looking at making the handling of electronic waste safer by using machine learning and computer vision to build robots that can segregate the waste, so that humans can avoid handling these potentially toxic materials. Mukil Saravanan, another research assistant, seeks to improve the communication between humans and robots beyond just physical controllers. With the advent of Brain-Robot Interfaces (BRI), it is now possible for humans to control robots wirelessly by using a sensor that records our brain's electrical activity – almost like mind control. He says that such seamless connections between humans and robots would be quite useful in a place like a factory floor.

From automated to autonomous

While Abhra's robots work alongside humans within the same space, in another part of the IISc campus, at RBCCPS, researchers in Bharadwaj Amrutur's lab are focusing on connecting humans and robots that are not even in the same room.

"The idea is that the robot is in a location where the person physically cannot go … but [we can] get tasks done through the robot," explains Bharadwaj, Professor and Chair of RBCCPS.

This kind of "tele-robotics" or remote control of robots can prove useful in a range of situations, from operating in areas that are physically hazardous for humans – like an underground mine or deep seawater – to more innocuous but monotonous tasks like watching over a patient. The scenario becomes much more than just observation when the robot has the ability to interact and manipulate the objects in its environment.

For example, if a robot is helping to care for a patient in a hospital, it may at some point need to open a pill bottle and give it to the patient safely. "Physical dexterity [of robots] is a state-of-the-art research problem with challenges in the physical construction of the robot's arms with appropriate sensors, actuators and materials, as well as the algorithms to allow safe and effective manipulation and interaction with soft and fragile physical objects like humans," explains Bharadwaj.

He adds that the goal is to go beyond robots mimicking human actions strictly – to have them share the cognitive burden of executing tasks. These span the gamut of low-level planning for tasks to high-level reasoning as well as understanding humans' intentions and plugging any holes in their commands like any average human assistant would do. As an example, a doctor doing rounds in a hospital through a robotic avatar would navigate between patient beds not by driving the robot, but by voice commands like "Let's go to Lata next," or "Now I need to see Lata". Modern AI's large language models like ChatGPT have advanced enough to enable translation of such high-level commands to detailed robot and computer actions involving looking up a patient's bed location in the hospital's database, and planning and safely navigating to the patient's bed. Current research focuses on developing techniques to have robots extract the intent from human speech and evolve a safe plan to achieve it.

Bharadwaj is also leading AI Robotics and Technology Park (ARTPARK), a not-for-profit company started by IISc in the year 2020. ARTPARK was established to provide a viable mechanism to translate the lab-level research in robotics and autonomous systems into products for the market. ARTPARK is developing a general tele-operation testbed to enable technopreneurs to explore different commercial applications and solutions of robotics and AI technology. One such application is developing a virtual museum tour through the deployment of "telepresence" robots at the Visvesvaraya Industrial and Technological Museum in Bangalore, says Sridatta Chatterjee, Product Lead at AHAM Robotics, a pre-venture at ARTPARK.

The museum would like to enable its virtual visitors – who currently visit their web portal and see static images of various exhibits – to instead experience a real-time tour via telepresence robots. With this approach, the visitor can be virtually present in the museum space as well as move about and 'see' the exhibits through the robots' cameras. In addition, the visitor can interact with any other visitors and museum staff who are present there at that time. The museum hopes that this will enrich the experience for such visitors and in fact they might be able to increase their revenue by charging a small fee.

This activity was born out of the experience gained by Bharadwaj and others when they worked on Asha, a robotic avatar nurse developed in collaboration with TCS and Hanson Robotics – a Hong Kong-based engineering and robotics company – for an international competition in 2020. Asha was an assistive robot that could aid a nurse in a distant location to provide patient care via tele-operation. "[The Asha project] triggered us to go along this whole journey of teleoperation and telepresence," explains Bharadwaj.

Photo courtesy: AHAM Robotics, ARTPARK

AHAM Robotics' telepresence robot

Another pre-venture at ARTPARK contributing to developing robotics hardware is Gati Robotics. "The idea ARTPARK had was to build our own humanoid robot. So, when we started the journey, we realised that we will have to make a robotic arm first; that came down to making more than six robot joints even before the arm could be a possibility," explains Kaushik Sampath, pre-venture lead at Gati Robotics. The task is extremely challenging as it requires the development of a robotic joint actuator – a device that helps the robot move with high precision and torque – from scratch. "Gati is all about making the building blocks for robotics from the ground up," explains Kaushik. Building an actuator is a truly interdisciplinary challenge, adds Ashish Joglekar, pre-venture lead at Gati Robotics, because it needs expertise in not just mechanical engineering, but also power electronics, controls, embedded systems and other domains.

Image courtesy: Kaushik Sampath

Exploded view of fully integrated robotic joint actuator

Small leaps, giant gains

Walking around the IISc campus, you might sometimes see a small four-legged robot making its way around, trying to navigate different terrains, from pavements to concrete roads. The robot, called Stoch, was one of the first projects started at RBCCPS.

"We started with a simple plastic prototype: Stoch 1, in 2018," says Shishir, who leads the project at the Stochastic Robotics Lab (SRL) in RBCCPS. The lab works on both theoretical and applied aspects of robotics. The Stoch project started in 2017 under the leadership of Bharadwaj, Shalabh Bhatnagar, Professor in the Department of Computer Science and Automation; and Ashitava Ghoshal, Professor in the Department of Mechanical Engineering, as a foray into the domain of walking robots.

"There are [only] a handful of labs around the world which build their own research-quality legged robots," says Manan Tayal, PhD student at SRL. The advantage of building a robot instead of buying one, he explains, is that researchers have the freedom to try new things, like the flexibility to modify the design without worrying about copyright or losing warranty. But legged robots are quite complex to design. For example, imagine that a robot has to turn a single motor. This is pretty straightforward. Now imagine that it has to turn 12 motors at the same time and that too in a specific manner and not independent of each other – this is what a legged robot needs to do to move around.

Photo courtesy: Stoch Lab, IISc

Legged robots like Stoch are meant for use in applications that require locomotion over unstructured and rough terrain

Before deploying the robot on any terrain, the lab runs simulations in which computer programs use the power of machine learning to develop strategies for how to utilise the motors efficiently on different terrains. The simulations help visualise imaginary terrains, angles and other scenarios that the robot needs to navigate so that it can help the researchers develop hardware and parts that are more suitable to environmental conditions in the real world. The project has come a long way since inception, having evolved into Stoch 2 and a more recent Stoch 3, which is a stronger and faster version capable of walking outdoors as well. The broad goal of the Stoch project is to create a truly autonomous legged robot platform that can be successfully deployed in real-world environments to carry out logistics operations, surveillance tasks and similar applications.

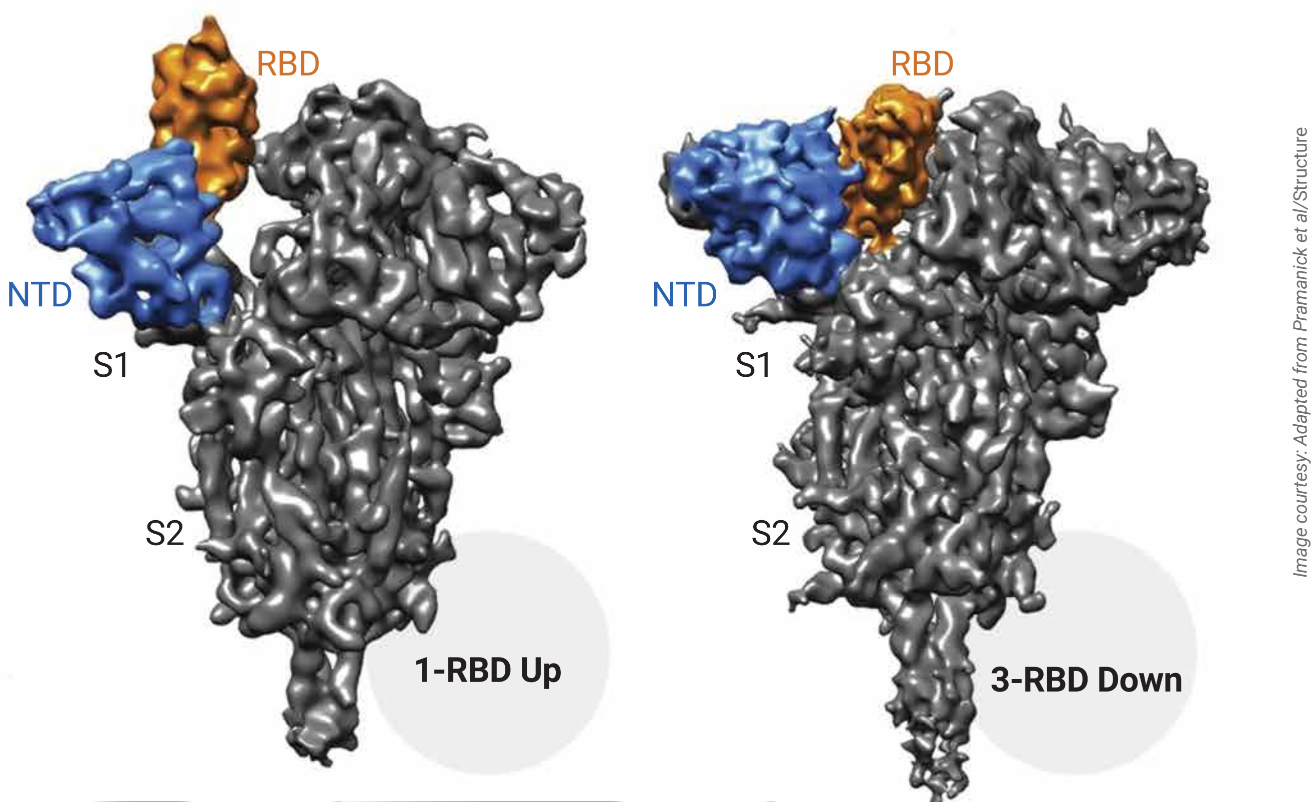
Another pre-venture at ARTPARK that is also working on legged robots is Chirathe Robotics. It began with the idea of applying the insights gained from studying and developing legged robots at RBCCPS to industrial problems. Factories, for instance, have staircases and narrow passageways which humans navigate without difficulty, but they present a challenging terrain for robots. Robots with wheels might struggle over such uneven surfaces, but legged robots can navigate and carry loads over such terrain more easily. "The way we solve these problems is to imagine ourselves in place of the robot and think how we would plan and approach the situation," explains Aditya Sagi, co-founder, Chirathe Robotics. "We need to carefully plan the motion in highly complex environments with rough terrain and obstacles." Chirathe Robotics is developing quadruped robots and the control strategies required to enable advanced locomotion capabilities in them.

As robots become more useful in a variety of settings, it is becoming harder and harder to imagine a future without them. No wonder Sophia, the humanoid robot created by Hanson Robotics, said at the UN General Assembly in 2017: "I am here to help humanity create the future."

Shrivallabh Deshpande is a PhD student at the Centre for Neuroscience, IISc and a science writing intern at the Office of Communications

Taking cold snapshots of life

- *Prarthana Ghosh Dastidar*



Cryo-EM, an emerging technique, is allowing scientists to better zoom in on cells and molecules

3D rendering of the SARS-CoV-2 spike protein obtained by Cryo-EM

"Like any living organisms, we are a bag of water, formed from billions of cells which all are small bags of water. Since air is not transparent to electrons, an electron microscope must operate under vacuum – which means that any observed biological specimen must be dry." This opening line of the Nobel lecture given by Swiss biophysicist Jacques Dubochet in 2017 perfectly sums up the problem in using electron microscopy to observe biological specimens.
Most of us are familiar with the upright microscopes we used in schools to peer inside a tissue sample mounted on a glass slide. These microscopes need a source of light – which is either sunlight or a lamp. An electron microscope operates on fundamentally similar principles to those of light microscopes, except for one key difference – instead of visible light, electron beams are used to visualise the object. The reason for using complicated electron beams where simple light could have done the trick is resolution – the ability to distinguish between two closely situated points. One nanometer (nm) is one-billionth of a metre, and the resolution of a light microscope is about 200 nm. This is good enough to distinguish large organelles (compartments) inside the cells. But an electron microscope has a far higher resolution. At 0.1 nm, it is good enough to distinguish between individual atoms.

When we think of a microscope, what comes to mind is looking at a section of a leaf or an animal tissue under its lenses. The use of a microscope is fundamental to the study of biology, and naturally, having the resolving power of an electron microscope would provide insights at an atomic level. But it took a very long time for an electron microscope to be commonly used to visualise biological specimens. Any part of a living organism is at least 70% water. And as Dubochet says, electron microscopes need to be operated in vacuum, devoid of any moisture. This makes biological specimens fundamentally incompatible for studying under an electron microscope – locking away the secrets of life at an atomic and molecular level from the scientists. This is the reason that although the electron microscope was developed in the 1930s, for a long time it was only used to look at atomic details of inanimate materials, like various metal alloys.

It wasn't until over half a century later, in the 1990s, that scientists around the globe began to use it routinely to look at molecules – mostly proteins – that shape our life. This change came about through the development of a revolutionary new technique of sample preparation which led to the term – "cryogenic electron microscopy" or Cryo-EM for short, for which Dubochet, alongside Joachim Frank and Richard Henderson, won the Nobel Prize in chemistry in 2017.

Bringing electron microscopy to biology

Visualising biological specimens with an electron microscope came with a myriad of problems. First, as mentioned earlier, an electron microscope must be operated in vacuum and these specimens don't hold up very well in vacuum due to their high water content. Secondly, biological samples are fragile. The high energy electrons would collide with and potentially destroy them – and hence they can only be observed under a very low energy electron beam. This significantly affects the quality of the image obtained. It took our three laureates years of work to overcome these challenges.

Photo: Prarthana Ghosh Dastidar

A modern plunge freezer device for flash freezing Cryo-EM samples at the Advanced Centre for Cryo-Electron Microscopy, IISc

Dubochet was the person responsible for the "cryo" in Cryo-EM. He was the one who developed a special method of sample preparation that allowed biological samples to be examined by an electron microscope. One workaround to the problem of having moisture-rich samples would be to freeze them. But water, upon freezing, forms ice crystals, where the molecules are well structured in a cage-like fashion. Such ordered ice crystals form a barrier to the passage of electron beams. Dubochet used liquid nitrogen to flash-freeze biological samples suspended in liquid ethane. Doing this freezes the samples so fast that water molecules do not have time to form highly ordered ice crystals, and instead, they form a disordered glass-like structure, which allows the electron beams to easily pass through. Flash-freezing also solves the problem of having any free moisture in vacuum. It also preserves the biomolecules in near-original condition, allowing scientists to look at biological processes frozen in time.

As mentioned earlier, biological samples have to be subjected to the lowest energy electron beam to ensure sample integrity. This means that plenty of processing post-microscopy is required to obtain a sharp, high-resolution image. Enter Joachim Frank, whose image processing algorithms made it possible to compile 2D pictures of a protein taken using Cryo-EM and build a sharp 3D structure with details at atomic levels.

Richard Henderson was the first person to successfully generate an image of a protein, a bacterial pigment called rhodopsin, using an electron microscope, and he kept refining his technique till he obtained a protein structure with the same resolution as that obtained using another popular method – X-ray crystallography.

Catching proteins in action

Since the development of Cryo-EM techniques, their most widespread use has been to look at proteins and characterise their structures. But structural biologists already had other tools like X-ray crystallography and Nuclear Magnetic Resonance (NMR) at their disposal to do exactly that. So, what was special about this new technique? First, both X-ray crystallography and NMR require huge quantities of the protein whose structure is to be determined, which can be a bottleneck in research, while Cryo-EM requires a very small amount. Secondly, Cryo-EM allows scientists to capture snapshots of protein structures while they are carrying out biological processes inside cells, which is not possible with either of the other techniques, as they require proteins to be purified from the rest of the cell. Having Cryo-EM as a tool at their disposal, it has become possible for scientists to understand how protein structure changes as it interacts with drugs, pathogens, and other molecules inside the cell.

While X-ray crystallography and NMR still remain popular techniques, Cryo-EM is rapidly becoming more and more commonly used

While X-ray crystallography and NMR still remain popular techniques, Cryo-EM is rapidly becoming more and more commonly used, thanks to the development of better image processing software, more stable microscopes, improved back-end support, improved cameras to capture images and so on. In 2020, the 10,000th protein structure determined by Cryo-EM was deposited in a prominent database for protein structures.

Photo: Prarthana Ghosh Dastidar

A transmission electron microscope at IISc's Cryo-EM facility

Cryo-EM has become particularly popular for determining structures of membrane proteins. Each of our cells is bound by a double-layered membrane made of molecules called lipids. This lipid membrane is often interrupted by proteins embedded in it. Proteins in the membrane may form channels that allow molecules from outside to enter the cell, or receptors that interact with "signalling" molecules that provide the cell with information about the external environment. Such membrane proteins are particularly difficult to purify in large quantities as they prefer living in the water-free environment of the lipid bilayer and are not easily soluble in water. Cryo-EM is a good tool not only to decipher the structures of these proteins, but also to understand how their structures change, and how the proteins interact with other molecules. Some of the molecular movements and interactions that have been understood using Cryo-EM include the transport of water or ions inside cells, and the effects of drugs and pathogens on a cell. Being able to answer such questions provides crucial insights into how biological systems work.

Cryo-EM in India

It was 2017 when Dubochet, Frank and Henderson were recognised for their accomplishments with a Nobel Prize. The following year, in 2018, two Cryo-EM facilities opened their doors right here in Bangalore – one housed at IISc and the other at the National Centre for Biological Sciences (NCBS). The primary goal of these facilities was to expose the faculty and student researchers of their respective host institutes to the latest frontiers in Cryo-EM. The facilities also provide training and guidance, and allow academic and industrial researchers from other institutes to use them as well.

The Cryo-EM facility at IISc was established with efforts led by Somnath Dutta, Associate Professor at the Molecular Biophysics Unit with the help of Raghavan Varadarajan, the then MBU Chair. Somnath's journey in cryo electron microscopy has been long, adventurous, and enjoyable, he says – starting from his PhD days at the National Institute of Cholera and Enteric Diseases (NICED), Kolkata. He studied under the supervision of retired faculty member AN Ghosh who pioneered the use of this technique in India, back in the 1990s, with the help of one of the first cryo-electron microscopes in the country. For his PhD, Somnath was studying toxins from cholera bacteria when he saw a structure like a "bead necklace", under the electron microscope. That was the beginning of his lifelong fascination with electron microscopy. "I enjoy imaging and photography a lot, and Cryo-EM allows you to take images at a microscopic level," says Somnath. When he joined the Institute in 2016, he was interested in looking at drugs that interact with bacterial toxins in the biological membrane. Cryo-EM would have been an extremely useful technique for this purpose, however, at that time IISc did not have this facility. Due to his persistent efforts, he explains, the Advanced Center for Cryo Electron Microscopy became operational two and a half years down the road.

Photo: Parthana Ghosh Dastidar

A 300kV transmission electron microscope used in NCBS for Cryo-EM

These days, multiple labs, both within and outside of IISc, use this facility to elucidate structures of proteins, or to peer into cells at an atomic resolution. It is also used by researchers in the pharma industry who study drug interactions at molecular levels to gain approval for commercialising their product from regulatory bodies like the Central Drugs Standard Control Organisation (CDSCO). As for Somnath himself, his lab is mostly interested in studying secretion systems of bacteria, bacterial toxins and other membrane proteins. In some of the recent studies published by his group, they have determined, visualised, and characterised the structure and function of biological macromolecules involved in host-pathogen interactions, which are associated with infectious diseases including SARS-CoV-2 and tuberculosis, using Cryo-EM techniques.

Around the same time that the facility was planned to be set up at IISc, Vinothkumar Kutti Ragunath, faculty member at NCBS, was working with his colleagues to set up a similar facility at his institute in 2017-2018. Like the facility at IISc, this one too is open to researchers across the country. Students using the facility also get the opportunity to obtain hands-on training in using the electron microscopes. “Students should be confident in using the instrument beyond merely collecting data,” believes Vinoth. His own journey with Cryo-EM also started during his PhD days at the Max-Planck Institute of Biophysics, Frankfurt. At that time, he too was primarily interested in looking at membrane proteins. He recalls that among the techniques available at that time, crystallisation of membrane proteins was a difficult endeavour. The proteins would often go into inclusion bodies (clumps) or express very little, and it was often difficult to purify in large quantities. One of the many advantages of single particle cryo-electron microscopy is that it does not require crystallisation and is easier to perform with lesser quantities of protein. His group currently studies various membrane proteins and enzymes using Cryo-EM.

> ***From only a handful of labs using this technique in the 1990s and early 2000s, to having fully operational world-class facilities in multiple institutions today, Cryo-EM has come a long way in India***

From only a handful of labs using this technique in the 1990s and early 2000s, to having fully operational world-class facilities in multiple institutions today, Cryo-EM has come a long way in India. Vinoth attributes this rise in popularity to a “series of developments happening in the background starting from early 2000s to 2011-12,” most prominent of which is the development of better detectors and algorithms that can capture and analyse the electrons when they hit the sample.

Beyond proteins

Cryo-EM is not used solely to determine protein structures, it is also being used by many scientists to look at samples of intact cells – a process called cyto-tomography. As Somnath remarks, “electron microscopy is first and foremost an imaging technique,” and it should be used as one – to go beyond determining atomic structures and start investigating the bigger picture.

Cyto-tomography has been used to look at tiny viruses infecting cells, at biological processes, like cells internalising water and ions through channels on the membrane, or how drug molecules interact with organelles inside cells at single molecule resolution, and more. It can be used to visualise how different molecules interact with each other in cells, what kinds of changes cells undergo when they are dividing or are under attack by a pathogen, and what different structures look like inside the cell. It can also be used in tandem with light microscopy, where staining with light microscopy would give us the exact location of a molecule or organelle, and looking at the same position in cells using cryo electron microscopy would give us a more detailed understanding of the processes going on in that location.

Despite all its advantages, Cryo-EM suffers from some serious limitations. First, since samples have to be frozen, it is impossible to image live cells. Second, there is a lower limit to the size of protein that can be determined by Cryo-EM – anything less than the size of 60 kilodalton has a low signal-to-noise ratio, and hence a clear image cannot be obtained. But with the improvement of detectors and better computational programs, it may become possible in the future to obtain structures of smaller proteins. For now, a clever workaround to this problem is to tack on a larger molecule to the small protein of interest, and then obtain the structure of the whole complex. The structure of the smaller protein can then be deduced from that information.

“Thirty years ago, my group presented a model of a virus floating in immobilised water, showing details as small as 35 Å. Nowadays, cryo-electron microscopists are nearly routinely achieving 3.5 Å. Thirty years later, a resolution 10 times better, a volume 1,000 times smaller; this is truly an impressive achievement,” Dubochet had remarked in his Nobel lecture. He ended by saying, “At 3.5 Å resolution, atoms are visible. We see chemistry, how the atoms are arranged in the molecules, how the disease changes the arrangement. Perhaps we will find which drug disentangles the aggregates that make a brain senile … Colleagues, cryo-electron microscopists, you have a good tool at your disposal; make the best of it!”

Prarthana Ghosh Dastidar is a PhD student in the Department of Microbiology and Cell Biology, IISc and a science writing intern at the Office of Communications

How a Physicist Became a Mathematician

- *Kaustubh Roy*

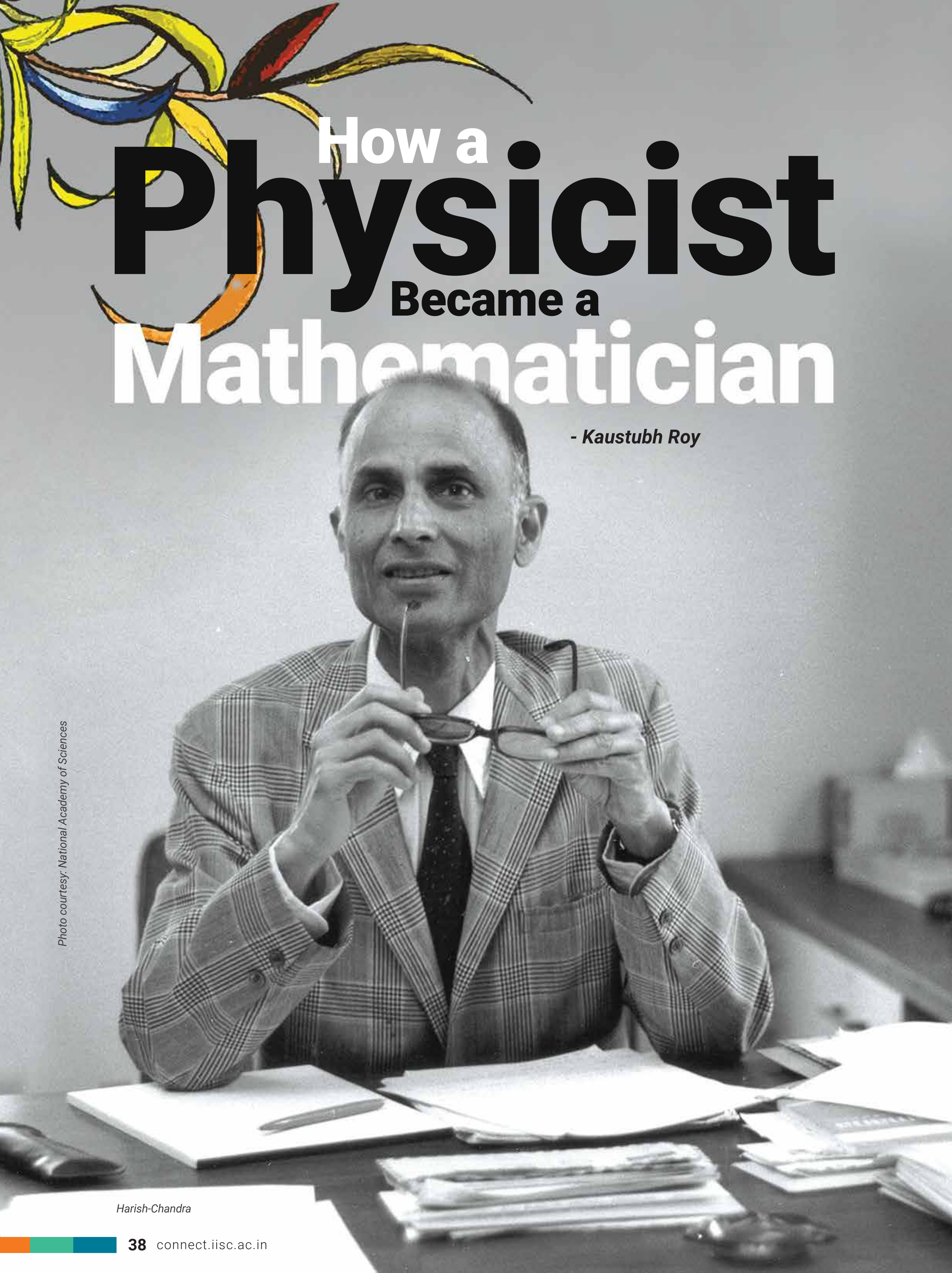


Photo courtesy: National Academy of Sciences

Harish-Chandra

2023 marks the birth centenary of the influential mathematician Harish-Chandra who spent two important years at IISc

"The book of nature is written in the language of mathematics," declared the Italian astronomer and physicist Galileo Galilei in an essay titled *The Assayer* published in 1623. Mathematics is an indispensable tool for physicists who strive to uncover the secrets of nature. The bond between the two subjects has always been strong – be it calculus developed by the English physicist Isaac Newton in his effort to understand the physics of flow and motion, or imaginary numbers discovered by the Italian mathematician Girolamo Cardano which proved indispensable in the formalisation of quantum mechanics centuries later.

Although the two subjects are closely related, they have vastly different goals and approaches. Physics, a modern science, cares more about understanding matter and its behaviour using theories, experiments, models, and observations, while mathematics, a much older discipline, is more concerned with abstract quantities, spaces, structures and ideas using purely logic and reasoning. This dichotomy, perhaps, is why physicists and mathematicians have different priorities and temperaments, and do not often switch teams. There are instances of mathematicians moving to physics, mostly to address theoretical questions for which they are trained. However, not many physicists give up their day job to ply their trade as "pure" mathematicians, barring a few.

One such exception is Harish-Chandra. Having started out in theoretical physics, he subsequently became one of the greatest modern mathematicians from India. He revolutionised representation theory and harmonic analysis of groups – fields that would grow into major topics of interest in the latter half of the 20th century. In his biography of Harish-Chandra, the Abel Prize-winning mathematician RP Langlands says this about Harish-Chandra's contributions: "It is difficult to communicate the grandeur of Harish-Chandra's achievements and I have not tried to do so. The theory he created still stands – if I may be excused a clumsy simile – like a Gothic cathedral, heavily buttressed below but, in spite of its great weight, light and soaring in its upper reaches, coming as close to heaven as mathematics can."

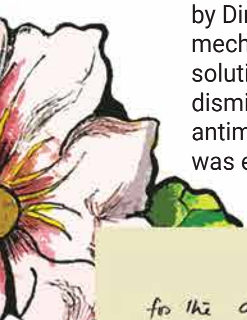
But under what circumstances did Harish-Chandra switch to mathematics? It is rumoured that, while once on a walk with the renowned physicist Freeman Dyson at Cambridge, Harish-Chandra, then still in physics, said, "I am leaving physics for mathematics. I find physics messy, unrigourous, elusive." The story seems to suggest that his decision to switch to mathematics was somewhat sudden. However, his transformation into a mathematician was far from abrupt.

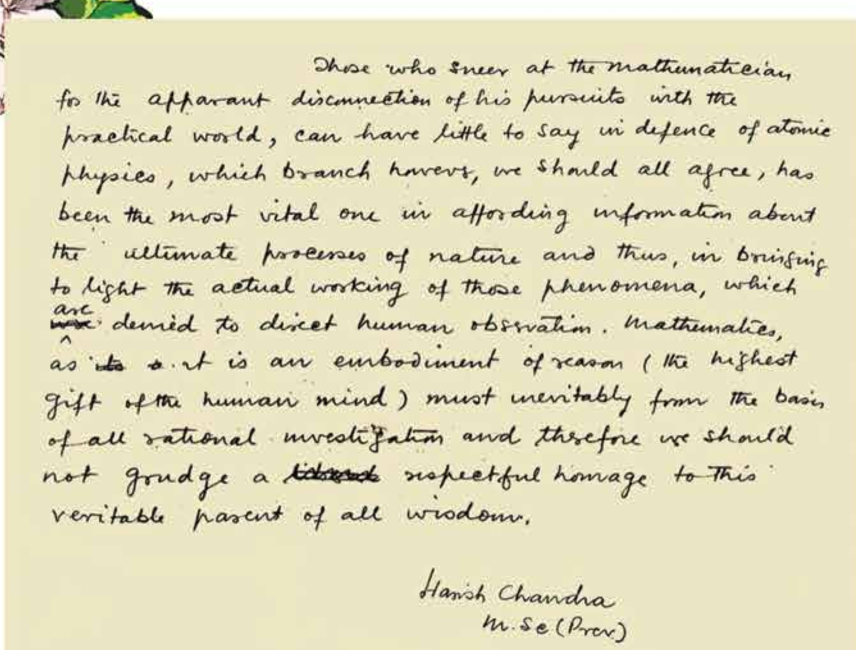
A crush on math at Allahabad University

Harish-Chandra – he spelt his name with a hyphen after a mistake by a copyeditor at the *Proceedings of the Royal Society* – was born in 1923 in Kanpur, Uttar Pradesh. He was conspicuously precocious and successful in school, writes Roger Howe in a brief memoir about the mathematician published by the National Academy of Sciences, USA in 2011. "He graduated from Christ Church High School at 14, from intermediate college in Kanpur at 16, received the BSc from the University of Allahabad at 18, and the MSc at 20. On his MSc exam, in physics, he received first place in the state of Uttar Pradesh, with a perfect written examination, which earned him gold medals."

As an undergraduate student, Harish-Chandra once stumbled upon physicist Paul Dirac's book *Principles of Quantum Mechanics* at the university library. He was "immediately fascinated by it", he writes on the occasion of Dirac's 80th birthday, perhaps a harbinger of the significant role Dirac would play in his life later both as a mentor and a friend. During his Master's at the same university, Harish-Chandra's brilliance caught the eye of his teacher, the celebrated physicist and Head of the Department of Physics, KS Krishnan. Krishnan, according to Langlands, was delighted by his student's passion for learning. "He encouraged Harish-Chandra in every possible way, lending him books like Hermann Weyl's classic text, *Raum-Zeit-Materie*." But even as Harish-Chandra was pursuing physics, he seems to have developed an interest in mathematics and a respect for mathematicians. This is revealed by a handwritten manuscript of Harish-Chandra's, titled *Algebra of Operators*, in which he presents some results on mathematical operators and matrices, and contextualises their use in quantum mechanics. Equally pertinent is his view of mathematics in the introduction, where he calls it "the mother of all sciences". He even admonishes the "thoughtless scientists" who just treat it as a tool and do not give it the respect it deserves.

CS Aravinda, Professor of Mathematics at the Tata Institute of Fundamental Research – Centre for Applicable Mathematics (TIFR-CAM) and the Chief Editor of the mathematics magazine *Bhāvanā*, believes that this manuscript hints at a deep-rooted love for mathematics in Harish-Chandra from the very beginning. "Harish-Chandra felt that the workings of physical phenomena can possibly be explained in the language of mathematics, sometimes even before the discovery of the actual phenomena," he says. "He thought of mathematical expression as a definitive way to try and uncover the hidden processes of nature." It is likely that Harish-Chandra was inspired by recent scientific discoveries predicted by mathematics, such as the Dirac equation, formulated by Dirac in 1928 to incorporate relativity into quantum mechanics. The equation had seemingly erroneous solutions with negative energies, but instead of dismissing them, Dirac posited these solutions as antimatter – a new form of matter whose existence was experimentally confirmed four years later.





Those who sneer at the mathematician for the apparent disconnection of his pursuits with the practical world, can have little to say in defence of atomic physics, which branch however, we should all agree, has been the most vital one in affording information about the ultimate processes of nature and thus, in bringing to light the actual working of those phenomena, which ~~was~~ are denied to direct human observation. Mathematics, as ~~its~~ it is an embodiment of reason (the highest gift of the human mind) must inevitably form the basis of all rational investigation and therefore we should not grudge a ~~[illegible]~~ respectful homage to this veritable parent of all wisdom.

Harish Chandra
M.Sc (Prev)

Image courtesy: Vijay Thiruvady

A page from Harish-Chandra's manuscript titled Algebra of Operators *written when he was a Master's student*

During his postgraduate degree in Physics, Harish-Chandra's excellence was noticed by another scientist – Krishnan's own mentor, CV Raman, who was his examiner. Raman, then the Chair of the Department of Physics at IISc, had several research interests, including the physics of vibrations of Indian drums such as the tabla and the mridangam. For the final exam, he included a bonus question about vibrations of the mridangam, expecting most students to skip it. It was therefore a pleasant surprise to him that Harish-Chandra solved the question in full. Raman awarded him a full score, even though he left the other questions unanswered, according to Aravinda.

Harish-Chandra's love for mathematics during this period is corroborated by his batchmate, Rajendra Singh, fondly referred to as Rajju Bhaiya, who went on to become an eminent mathematician himself. In a retelling of Bhaiya's stories by Yatindra Singh, a close family friend, Singh recalls that Harish-Chandra would be engrossed in mathematics even when he was running a temperature. It was only when he rested that his fever troubled him, writes Singh.

As Harish-Chandra was finishing his Master's, it became clear to Krishnan and Raman – both experimental physicists – that the young graduate was drawn to theory. So, they suggested that he work with Homi J Bhabha, the nuclear physicist who headed the Cosmic Ray Research Unit at IISc. Harish-Chandra heeded their advice and moved to Bangalore.

Flirting with math at IISc

At that time, Bhabha was in his third year at the Institute, having just received the Adams Award for his groundbreaking thesis titled: "The theory of elementary physical particles and their interactions". He was a rising star in Indian science – he had just been made a Fellow of the Royal Society and the Indian Academy of Sciences. At IISc, he dabbled in both theoretical and experimental aspects of nuclear and particle physics.

Harish-Chandra's time with Bhabha was brief – a mere two years, from 1943 to 1945 – and not many accounts of his life survive from this time. The Institute's archives, however, provide an extensive record of Harish-Chandra's work here.

The 1943-44 Annual Report of IISc says: "A paper by Prof Bhabha and Harish Chandra 'On the theory of point particles' which is being published in the *Proceedings of the Royal Society* has established a very important theorem … A paper by Mr Harish Chandra on 'The removal of the self-energies of point particles' … gives a general solution to a problem of some importance and is also being published in the *Proceedings of the Royal Society*."

The trajectories of point particles in time and space was one of the two topics that Harish-Chandra worked on with Bhabha while at the Institute. The other topic was that of relativistic wave equations, possibly motivated by work Dirac had published at that time. Although no papers were published that year on physics, the Annual Report refers to two colloquia conducted by him on the subject.

> ***'Harish-Chandra felt that the workings of physical phenomena can possibly be explained in the language of mathematics, sometimes even before the discovery of the actual phenomena'***

The Report also mentions 12 lectures that Bhabha delivered as part of a course he offered that year: The Theory of Finite Groups. These lectures may well have been Harish-Chandra's first formal introduction to the subject of groups, a topic that he would later dedicate his life to. Taken together, the account of his work during his first year at IISc paints a picture of a physicist still fresh in the field, but filled with a deep mathematical curiosity and perhaps a nebulous idea of his true calling.

The 1944-45 Annual Report shows Harish-Chandra emerging as a theoretical physicist in his own right, publishing many more papers as a single author. While he continued his work on point particles and scattering with Bhabha, Harish-Chandra published two papers which were more mathematical. One of them, titled *Algebra of the Dirac-Matrices*, possibly inspired by Bhabha's colloquia on the same subject a year ago, delves into the algebraic properties of the Dirac matrices, a set of objects discussed in the context of the Dirac equation. Another paper was on the σ-symbols, a class of objects associated with transformations of the Lorentz group. These papers were independent of his work with Bhabha.

Just as Harish-Chandra was finding his feet as a theoretician, Bhabha's proposal to the Sir Dorabji Tata Trust to set up the Tata Institute of Fundamental Research (TIFR) was accepted, and Bhabha turned his attention to his new project. TIFR was eventually established in Bombay (now Mumbai) in 1945. The year also marked Harish-Chandra's final year at IISc, after which he moved to Cambridge University, having been accepted by Dirac as a research student.

It is not clear whether Harish-Chandra himself was inclined to make the move or whether he was encouraged to move by Bhabha, also an alumnus of Cambridge. Rajat Tandon, Professor at the University of Hyderabad and nephew of Harish-Chandra, suggests that the former may have been the case. "The impression I had was that Harish-Chandra was not very fond of Homi Bhabha. He felt that Bhabha had very little contribution to their joint papers. But that," he adds, "is not unusual for a youngster to feel."

Courting math at Cambridge

At Cambridge, point particle physics was one of Dirac's research interests, a subject that Harish-Chandra was well-acquainted with. Even having just arrived at Cambridge, he was already grappling with the thought of switching lanes to mathematics, as expressed in a letter to Bhabha written a few months after arriving in England. In the letter, he tells Bhabha that besides attending his lectures on quantum mechanics (lectures that he would promptly abandon), he was also "attending all advanced lectures in pure mathematics", titled "'Theory of Numbers', 'Functions of a Real Variable' and 'Linear Algebras'". Towards the end of the letter, he adds: "I am getting more and more interested in pure mathematics and perhaps after I have learnt enough of it I might change over to it." It was perhaps fortunate that the primary focus of Harish-Chandra's research at Cambridge and what would be his doctoral thesis was a fairly mathematical topic – classifying the irreducible representations of the Lorentz group.

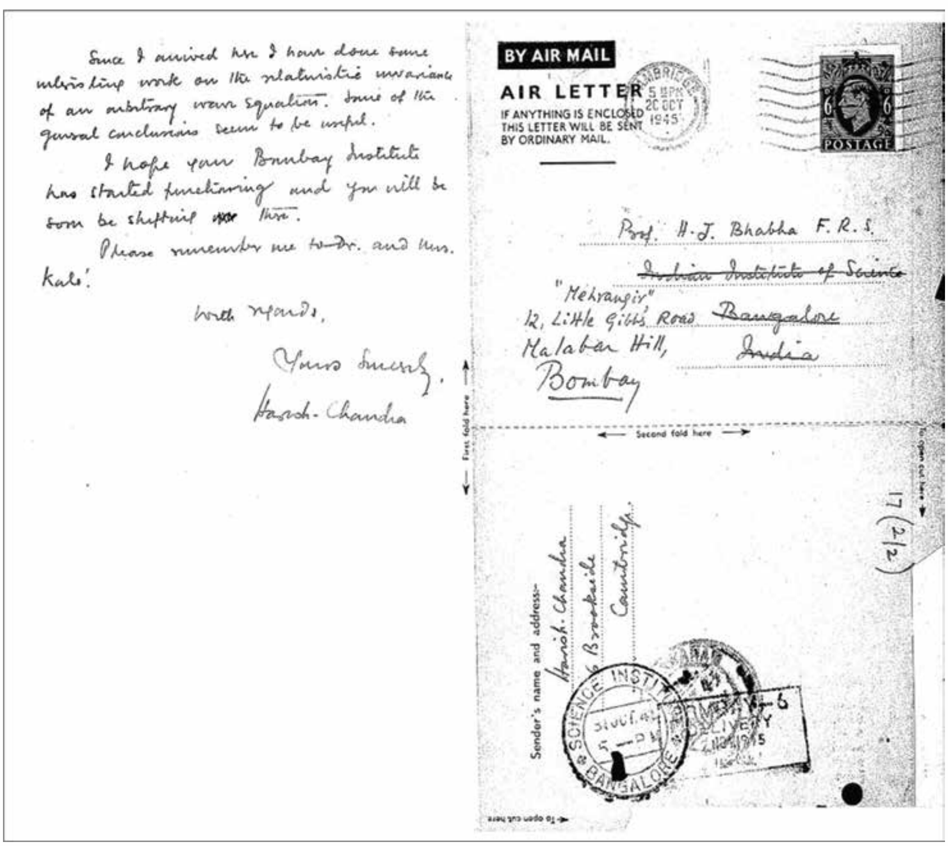
In mathematics, a group is a collection of elements that can be combined in a certain way, called an operation. Groups are used in many different areas of mathematics, such as algebra, geometry, and number theory, and help us understand the properties of objects and structures in mathematics.

> ***At IISc, Harish-Chandra was a physicist still fresh in the field, but filled with a deep mathematical curiosity and perhaps a nebulous idea of his true calling***

A representation of a group is a way of associating each element of the group with a matrix or transformation, such that the group operation is preserved. Representations allow us to handle groups, a rather abstract mathematical concept, more concretely. They are of physical significance as well, since they often correspond to observable quantities, particularly for the Lorentz group – a group that encodes the structure of Einstein's special relativity.

N Mukunda, former Professor at the Centre for Theoretical Studies at IISc, explains the meaning of irreducible representations: “The idea of an irreducible representation is a representation that cannot be broken down into smaller pieces, in a qualitative sense.”

By studying irreducible representations of a group, one can gain valuable insights about the group itself. But, for the Lorentz group, finding these representations is not as straightforward, as Mukunda points out. “There are two types of representations [of the Lorentz group]: finite dimensional ones, like the ones that correspond to the location of the object in space and time, or the ones that correspond to the energy and momentum of the object. All of these are non-unitary. The unitary representations have to necessarily be infinite dimensional.”


Since I arrived here I have done some interesting work on the relativistic invariance of an arbitrary wave equation. Some of the general conclusions seem to be useful.

I hope your Bombay Institute has started functioning and you will be soon be shifting there.

Please remember me to Dr. and Mrs. Kale.

With regards,

Yours sincerely,

Harish-Chandra

BY AIR MAIL

AIR LETTER

IF ANYTHING IS ENCLOSED THIS LETTER WILL BE SENT BY ORDINARY MAIL.

POSTAGE

Prof. H. J. Bhabha F.R.S.

~~Indian Institute of Science~~

"Mehrangir"

12, Little Gibbs Road ~~Bangalore~~

Malabar Hill, ~~India~~

Bombay

Sender's name and address– Harish-Chandra, 6 Brookside, Cambridge.

Image courtesy: CS Aravinda

A 1945 letter from Harish-Chandra to Homi Bhabha

In 1945, Dirac published a paper that sought out these infinite-dimensional unitary representations of the Lorentz group, asserting that they may be of particular importance in physics. Harish-Chandra essentially solved the problem between 1945 and 1947, identifying and categorising the full list of unitary irreducible representations. This work, in essence, set the course for the rest of his life’s work in representation theory. More importantly, however, was the realisation he attained about physics as a whole. “I became aware that my work on the Lorentz group was based on somewhat shaky arguments … I once complained to Dirac about the fact that my proofs were not rigorous and he replied, ‘I am not interested in proofs but in only what nature does.’ This remark confirmed my growing conviction that I did not have the mysterious sixth sense which one needs in order to succeed in physics … ,” writes Langlands quoting Harish-Chandra.

Cementing the relationship at Princeton

Dirac took Harish-Chandra along as an assistant to the Institute of Advanced Study at Princeton in 1947. By this time, besides believing that he did not possess the “mysterious sixth sense” to do physics, Harish-Chandra was also increasingly disillusioned with it. At Princeton, he would write just one paper in physics, which would also be his last on the subject. Taking no breaks, he seamlessly switched from physics to mathematics, publishing his earliest papers in the latter subject in 1949.

Once Harish-Chandra made the switch, a topic that attracted his attention was Lie groups, of which the Lorentz group is an example. His interest was also spurred by Claude Chevalley, a lecturer at Princeton and a major inspiration for his work. Harish-Chandra would publish papers in the coming years on Lie groups and their associated Lie algebras, gaining an insight unparalleled by many, even seasoned mathematicians. His work culminated in his award-winning paper on the representations of semi-simple Lie algebras – a paper that lays out results and methods that are now considered standard in the field. This revolutionary work marked the beginning of his professional foray into mathematics, one that would continue for the rest of his life.

Photo courtesy: Lily Harish-Chandra

Lily Harish-Chandra

Clearly, it was at Princeton that Harish-Chandra made a clean break with physics and became a pure mathematician. And it was at Cambridge that his relationship with mathematics flourished. But it was at IISc that he delved seriously into mathematics for the first time. Harish-Chandra's stint at the Institute was significant for another reason. He met his wife here. "[At IISc], he spent the first six months lodging with old friends from Allahabad, Mrs H Kale, who had been his French teacher at the university, and her husband Dr GT Kale, a botanist who had moved to Bangalore to take up duties as librarian at the Institute," writes Langlands. It was during his stay with the Kales that Harish-Chandra met their daughter, Lalitha – Lily to her family and friends – whose hand he asked for in marriage on a visit to Bangalore in 1953.

For his contributions to mathematics, Harish-Chandra received several honours. "In 1973, he was elected a fellow of the Royal Society. The Indian Mathematical Society awarded him the Srinivasa Ramanujan Medal in 1974, and he was elected a fellow of the Indian National Science Academy and the Indian Academy of Sciences in 1975," writes Howe. In 1981, just after he became a US citizen, he was also elected to the National Academy of Sciences.

Even though Harish-Chandra kept himself fit – he liked taking long walks and was disciplined about his diet – he was prone to heart attacks. He experienced his first attack when he was only 46. After surviving three more, he died when he suffered his fifth heart attack on 16 October 1983. His ashes were scattered in Princeton and in the Ganga in Allahabad (now Prayagraj). The same year, a conference had been planned for his 60th birthday, but instead it was held as a memorial, Howe adds.

One of Lalitha's and Harish-Chandra's children, Premala, imbibed her father's love for nature and is now a professor in condensed matter physics at Rutgers University, USA.

On the occasion of Harish-Chandra's 70th birth anniversary, she said at Allahabad University: "[My father] always retained a childlike fascination, a youthful wonder for the natural world. Most of all he was a man of many dreams, only some of which he was able to fulfil. The realisation of these dreams and more is now up to us."

Kaustubh Roy is an undergraduate student at IISc, and science writing intern at the Office of Communications

Seasons in the sun

- *Kavitha Harish*

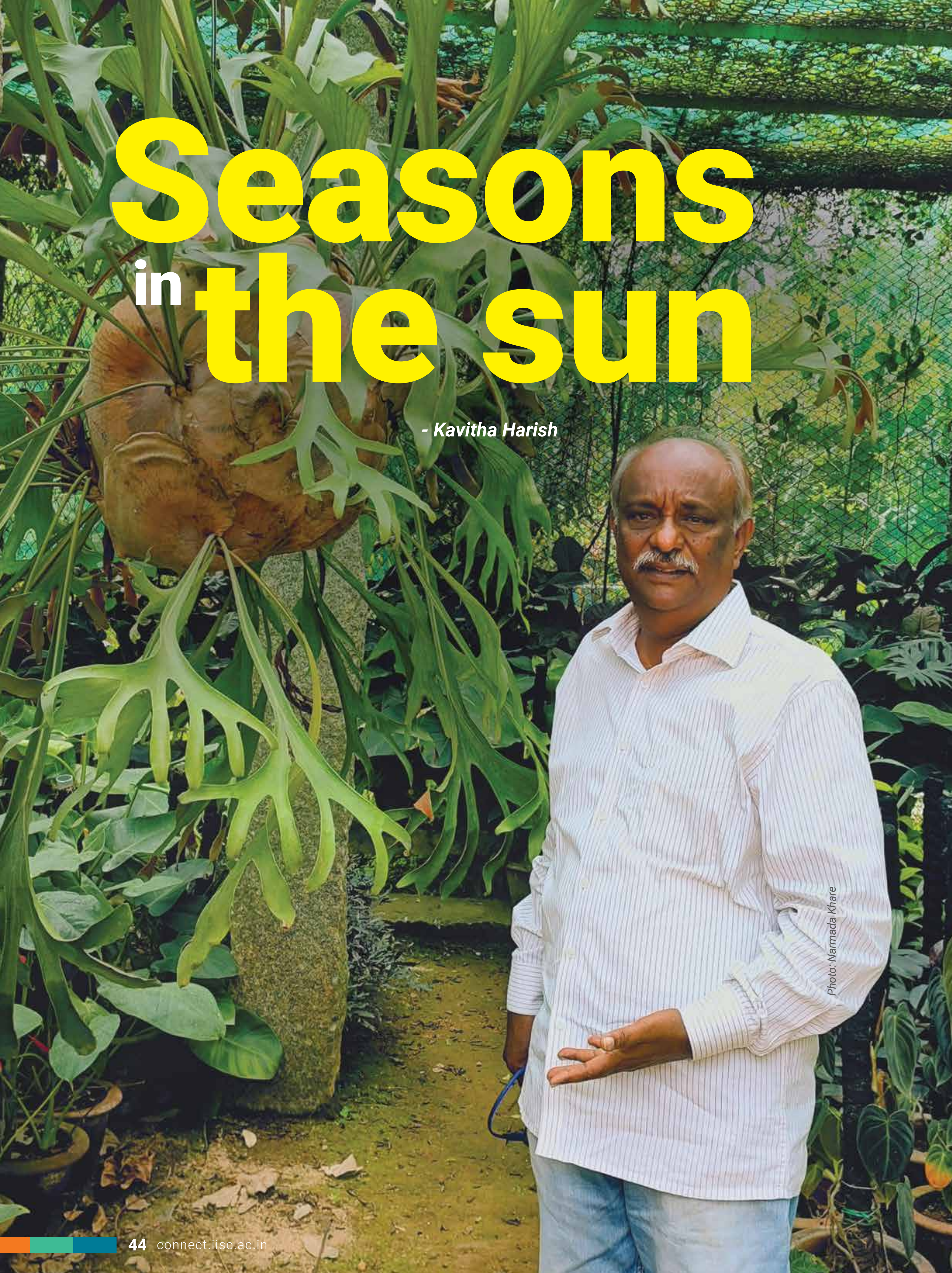


Photo: Narmada Khare

B Sridhar joined IISc in 1986 soon after he received his Master's degree in Horticulture from the University of Agricultural Sciences (UAS), Bangalore. For 36 years – until he retired in 2022 – he was in charge of the Garden and Nursery Unit at the Institute, and was responsible for maintaining the greenery on campus. He also conceived and oversaw the popular annual flower show – held during Open Day and Founder's Day – in front of the Main Building. Sridhar now keeps himself busy with animal husbandry on his farm in the outskirts of Bangalore.

Did you have an inclination towards gardening before joining IISc? What led you to a career in horticulture?

I come from a family in Bangalore that had a large property near Goods Shed Road, Ranasinghpete. Our ancestors were landlords, and our land was situated near the City Railway Station. Unfortunately, the British Government acquired most of our land to construct railway tracks. Consequently, my family relocated to Wilson Garden, which was near Lalbagh. It was during this time that I developed a passion for plants and trees. I used to spend several hours during my holidays and weekends walking, sitting, and reading in Lalbagh, which indirectly motivated me to pursue a degree in horticulture later in life.

Initially, I was keen on studying medical science, but I could not secure a spot due to insufficient marks. I attempted to enroll in a veterinary course and later turned to dairy technology. However, my friends warned me against joining the first batch of dairy technology citing the lack of job opportunities and the uncertainty surrounding the course's recognition. Eventually, I chose to study agriculture, specifically horticulture, which was a more popular and promising course at the time. I completed both my BSc and MSc in Horticulture from UAS, and obtained a state-level rank. I also obtained the 14th rank at the national level.

What were your early days at IISc like?

I joined IISc as a Supervisor in 1986. At the time of my joining, Prof CNR Rao was the Director, and I was the only person with the necessary qualifications to manage the Garden and Nursery Unit. I had started my PhD when I joined, but, unfortunately, I was not given permission to finish it.

The Garden and Nursery Unit was there before I joined, but it was a small unit. Initially Mr BS Nirody was the horticulturist and he introduced many flowering trees and creepers like bougainvillea, roses, butter fruit, and so on. Later, Mrs Dhawan [Nalini Dhawan, daughter of Nirody] took a lot of interest, informally, in nursery plants, especially Rex begonia and ferns.

Mr Nirody was followed by Mr Iyengara and then Mr Murthy. Though he was not qualified, Murthy had professional working experience at Pilani [Birla Institute of Technology and Science Pilani]. After Murthy, I was the only one professionally qualified for this position. I remember that Murthy was more like a gardener as he gained his experience through working in various places. I was given various tasks by Murthy, who took me to various places and explained what to do. He had his own style of communicating. But my disposition was different. My approach was a bit more formal and systematic. Though I was just 24 years old, I was in charge of 71 permanent staff who were older than me.

After I took over, I introduced both exotic and native species, and successfully covered the whole campus with trees using a scientific approach right from selection of seeds, to planting and nurturing them. This ensured the establishment of healthy trees with good flowering throughout the year, so that they attracted many insects and birds.

Over the years, the Institute nursery ended up with a large collection of plant species. It also became a plant introduction centre. We generously donated seeds and saplings to many botanical gardens and forest departments in the country.

Photo: Bharti Dharapuram

Nursery at IISc

How did you maintain the greenery on campus?

My responsibility was to ensure greenery on campus. I put into practice many things I had learnt as a student and as a horticulturist at IISc. Throughout my 36 years of service, I never took any time off except for four days for my wedding. I also worked on weekends.

Photo: Narmada Khare

Sridhar has grown a wide variety of plants including this climber at the Nursery

We used to procure fertilisers at a low cost, but their prices increased over time, and people began stealing them. To avoid theft, I decided to make fertilisers myself. I requested a tractor from CCMD [Centre for Campus Management and Development] and got one. It was very old, but we repaired it with the help of existing hands, and it is still in good working condition. We collected dried leaves and converted them into enriched leaf manure using EMC technology and earthworm casting manure. I contacted my friend Dr [HN] Chanakya [former faculty member, Centre for Sustainable Technologies] for help. He guided me on how to convert them into fertiliser. I bought microbial cultures from different places, such as UAS Dharwad, and arranged for cow dung from a milk colony.

Unlike small plants, trees require a strong root system and good soil structure. To improve the soil [quality], we added natural microbes, which helped in the fixation of nitrogen and worked against fungal and bacterial infection; thus, our trees are healthy and in good shape. We maintained flowerpots using this technique and continued using it for years. We stopped buying fertilisers from outside and relied only on organic manure made in-house and using natural methods.

I also constructed a digester without any financial assistance from the Institute. I used materials such as 60 bags of cement that someone donated, and stones collected from different locations to build the tank with the help of a mason I hired.

I developed a sprayer that we used to spray all over campus. To enhance its efficacy, I added 10 types of microbes, including nitrogen-fixing bacteria, phosphorus-soluble bacteria, potassium-mobilising bacteria, zinc-soluble and antifungal agents. In particular, during the 1990s, when a fungus attacked the Gulmohar trees, chemical treatment proved ineffective. I then added *Trichoderma* [soil fungus] and *Pseudomonas* [soil bacterium] to the slurry and sprayed the trees, even though it was a somewhat costly and smelly process that drew complaints from some people. Nonetheless, I persisted, encouraging my colleagues to spray the tree trunks for two to three hours every day. I was pleasantly surprised to see that the fungus which attacked the trees disappeared and the trees became healthy as a result of this treatment. It is a memory that I will cherish forever.

I planted two types of bamboo near the canals near CAOS [Centre for Atmospheric and Oceanic Sciences] to use them to support small trees and for various other uses.

I must also add that I had good moral support from IISc's Directors in the maintenance of campus trees. They extended all possible infrastructure facilities.

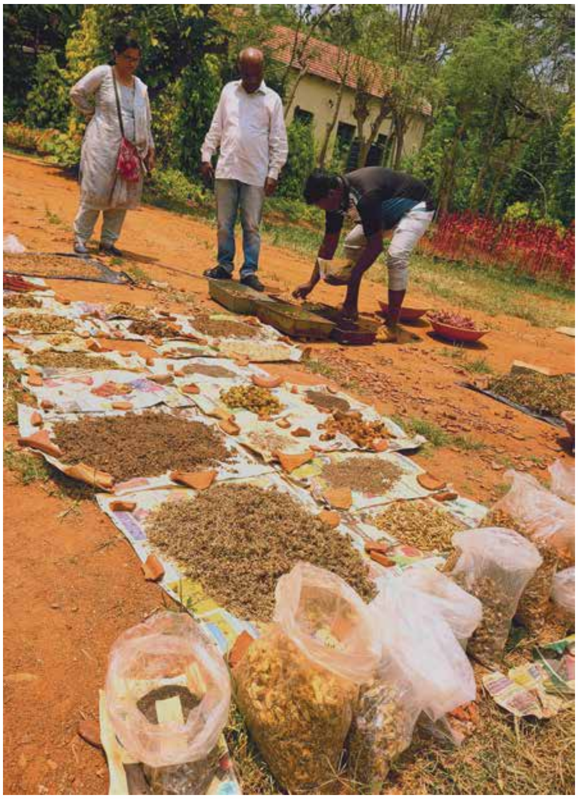
I used to involve myself in every [development] project, right from the selection of site to its design and execution, so that there was minimum damage to trees. We saved many trees by transplanting them or redesigning the plan to save rare species. Thus, the trees are safe and healthy.

Photo: Narmada Khare

Sridhar treated fungus on the Gulmohar trees with a special concoction he developed

I don't believe that having more certificates necessarily means greater qualifications; with basic knowledge and a passion for hard work, one can learn anything and excel.

Photo: Narmada Khare



Sridhar looks at the rich haul of seeds harvested after the annual flower show

You were also in charge of the annual flower show that we have on our campus during Founder's Day. How did you prepare for it?

The concept of growing flowers in pots and arranging them during Founder's Day was originally my idea. I had previously visited many affluent residences in Sadashivnagar [suburb in IISc's neighbourhood], such as the house of Ramakrishna Hegde [former Chief Minister of Karnataka] or Dr Rajkumar's [noted Kannada actor] house, as well as AVM [film] production houses, where I was given the opportunity to decorate [their gardens] with flowerpots. While doing this, I realised that I could also decorate the Institute where I work. I discussed this with my colleagues, and we decided to honour our founder, JN Tata, in front of his statue during Founder's Day. We started doing this in 1986.

To prepare for the Founder's Day event, we used the best seeds available, which required planning well in advance. We assigned one person to collect and maintain the seeds, another person to nurture them, and a third person to oversee their growth. We had to be aware of when to plant the seeds and how long it would take for them to bloom, which could range from 50 to 190 days. We also had to prepare for unexpected rain in October and November, which could cause fungal diseases. We developed methods so that we could manage the seeds for another 20 years.

We standardised our storage and developed techniques for open-pollinated seeds, which were not available anywhere else in Bangalore. We had trained our team to arrange flowerpots for any event, and we knew how to multiply our crops.

We used our techniques to develop the croton plant, an Indo-American hybrid, which was difficult to obtain. When we contacted the provider for a sample, they were reluctant to give it to us for free, but we eventually purchased one. We used our techniques to multiply it, and within three years, we had a large crop. When the provider learned of our success, they came to visit and asked how we did it, but we kept our techniques a secret.

Initially, my budget was Rs 50,000 to 60,000 and I would get an advance of Rs 3,000. I used this to purchase fertilisers and materials for arrangements. I would change the arrangement of flower pots for each year, and this was noticed by the Tata Group.

Overall, we can be proud that our team worked diligently to develop high-quality seeds, standardised our techniques, and arranged flower pots for various events with precision and creativity.

Photo: Bharti Dharapuram

Flowerpots being prepared for Founder's Day

What should the Institute do to preserve its greenery?

With the rise of new building constructions, a multitude of plants and trees are disappearing. To prevent this loss, we must thoroughly investigate the root systems of trees and prioritise the preservation of large ones, such as the banyan tree, which can live for hundreds of years. Before deciding to cut down mature trees that have grown for many years, we should carefully consider the consequences. Trees cannot speak for themselves.


Photo: Bharti Dharapuram

Sridhar and his staff during the 2016 flower show

We have many different species of trees. They require different kinds of approaches to ensure that they are healthy. For example, the Gulmohar trees planted in the area are exotic and not native to the region. The reason for choosing these non-native plants is to enhance beauty and provide a pleasant atmosphere through their attractive blooms and for their ability to cool the surroundings. Additionally, these trees are beneficial for soil fixation. However, they are weak and prone to falling, as seen during incidents of tree falls on cars during electric cabling work. To avoid damage to the roots during such activities, proper coordination with the horticulture office is necessary, and the roots should be treated accordingly. It is essential to have the appropriate training and supervision to take care of these trees. Also, as trees age, various changes can occur, including in their leaves and root systems. So, we need to take all this into account to ensure that they remain healthy.

What keeps you busy these days?

After dedicating 36 years to my profession, I was mentally prepared for a change in my life. As of 31 July 2022, I retired from my position at IISc and decided to pursue my interests in developing cattle feed for cows. I noticed that milk production in our country is much lower than that of western countries, and people in villages often depend on earnings from milk. Therefore, it's essential to increase the quantity and quality of milk production.

During my time at the Institute, I observed that cattle were not getting enough food. I sought advice from faculty members in related areas to improve my knowledge in developing this business. Through campus interaction, I met with Prof RM Medhamurthy from MRDG [Molecular Reproduction, Development and Genetics], and we discussed ways to improve breeding and milk production. He explained that our country is lagging by 100 years in this field. Initially, I purchased a few cows, but I had to sell them since I could not manage them. I realised that it requires a lot of training to take care of these animals, and one must physically spend time with them daily. Prof Medhamurthy had told me that I would need to dedicate myself completely to learning about the field. So, following his advice, I decided to dedicate myself to this service after my retirement.

Currently, I do animal husbandry on six acres of land in Lakkenahalli near Kunigal [about 35 km from Bangalore]. I travel to my farmhouse every day to tend to the animals. For the past 20 years, I have also been growing nut crops on my farm.

With input from Malavika P Pillai and Narmada Khare

Kavitha Harish is Personal Assistant to the Assistant Registrar (HR, Council)

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