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KERNEL

Editorial

What can we learn from tiny animals such as termites and worms? This issue of *Kernel* features an interdisciplinary team studying the termites that build imposing mounds on the IISc campus, and a neuroscience lab investigating a free-living roundworm for insights into animal movement.

Also included are stories on how “space bricks” can be made, how glass transforms into a crystal, and other recent research from IISc.

SMART BUILDING LESSONS FROM TERMITES

Termite mound in IISc (Photo: Alfred Daniel)

THE TOWERING TERMITE MOUNDS FOUND ACROSS THE IISc CAMPUS ARE INSPIRING BOTH ECOLOGISTS AND ENGINEERS TO MAKE IMPORTANT DISCOVERIES ABOUT SUSTAINABLE BUILDING

To an untrained eye, the huge termite mounds – mud structures scattered across the IISc campus – look nothing out of the ordinary. However, they are a treasure trove of information for ecologists and architects, who have been studying these complex structures for decades. “Not all termites build such mounds; these giant mounds are built by fungus-farming termites,” points out Renee M Borges, Professor at the Centre for Ecological Sciences, IISc. These termites cultivate fungi in their mounds, for which they need to maintain constant temperature and humidity inside. The abundance of these particular termites on the IISc campus (and in South India) was one of the main reasons why Borges decided to study them.

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Photo: Nikhil More

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Borges' lab has been investigating these termites as part of a larger goal to understand interactions between species. In an earlier study, for example, they discovered how the termites keep their fungus farms free of parasites. While soil scientists, architects and engineers have carried out studies on self-organisation, social behaviour, and heat and mass transfer inside a termite mound, few have tried to tease out how exactly these insects construct their homes, and what the internal structure looks like, she says.

To explore these questions, a few years ago, Borges decided to collaborate with Tejas G Murthy, Associate Professor at the Department of Civil Engineering. Murthy recalls how a lunch discussion about these fascinating systems piqued his interest, when a former colleague drew him in by casually mentioning that this could be "a cool granular mechanics problem". The discussions broadened afterwards and, along with PhD student Nikita Zachariah, they started asking more specific questions such as: how is the climate controlled inside a mound? How exactly do the termites build them? What gives the mound strength and stability? "No one was really looking from [both] an engineering and ecological perspective," says Borges.

Their work, however, wasn't without challenges, one of which was sample collection from inhabited mounds, says Zachariah. "I didn't want to destroy the mound to collect my sample and so had to build my own drilling machine for sample collection. This ensured that there was minimal damage to the mound." The researchers also had to replicate the conditions of the mound interior for termites that they housed in the lab. Moreover, in the field, the team also had to deal with some people who mistakenly feared these mounds thinking that they harboured snakes, or considered them as sacred sites. The team, therefore, had to put up notices on all their research mounds on the IISc campus.

In one of their first joint studies, published in *Scientific Reports* in July 2017, they investigated the physical, chemical and engineering properties of termite mound soils, and identified a unitary structure called a bolus (like a brick) that is used by the termites as the building block. These boluses come in two sizes that are produced by major and minor worker termites, the two worker castes (termites also have soldiers and reproductive castes). Big and small boluses are interspersed during mound building, which may contribute to tighter packing of the material. The team also investigated the range of materials which the termites choose to build their mounds with. "We concluded that a granular material in the presence of water and which has organic matter is ideal for mound building," says Murthy. In another study published in *Royal Society Open Science* in 2020, they found that what gave the mounds their great strength was a specific level of moisture content in the soil and consequent soil suction – how much negative water pressure it creates in the pores. In addition, to weather-proof the mounds, these termites mix the soil with their secretions. This is why these mounds don't wash away in the rain. "We thought that secretions from termites are key to the stability of these mounds; and that these secretions are applied to the soil. It turns out that suction creates this wonderfully strong soil fabric, essentially saving the requirement for a lot of the secretion, something that is evolutionarily beneficial to termites," says Borges.

The researchers also investigated the constitution of the mound itself and found it to be a bi-layered structure that has a more porous outer buttress and less porous (denser) inner shell, which enhances stability and also allows better ventilation. These results were published in *Scientific Reports* in August this year.

Working as an interdisciplinary team has helped the researchers pursue such broad questions, says Borges. "[It is] not possible to tackle this as either a pure granular mechanics problem or as a problem of animal behaviour." Studying these termite mounds also has important implications for low carbon construction technologies and for the design of ventilation systems in buildings, says Murthy. "It is fascinating that without spending that much energy, earth structures which last for centuries can be made."

- Vaishalli Chandra

Photo: Divakar Badal

SPACE BRICKS FOR LUNAR HABITATION

USING BACTERIA AND GUAR GUM, RESEARCHERS AT IISc AND ISRO HAVE DEVELOPED A PROCESS TO BUILD "SPACE BRICKS" FOR LUNAR STRUCTURES

In what could be a significant step forward in space exploration, a team of researchers from IISc and the Indian Space Research Organisation (ISRO) has developed a sustainable process for making brick-like structures on the moon. It exploits lunar soil, and uses bacteria and guar beans to consolidate the soil into possible load-bearing structures. These "space bricks" could eventually be used to assemble structures for habitation on the moon's surface, the researchers suggest.

"It is really exciting because it brings two different fields — biology and mechanical engineering — together," says Aloke Kumar, Assistant Professor in the Department of Mechanical Engineering, IISc, one of the authors of two studies recently published in *Ceramics International* and *PLOS One.*

Space exploration has grown exponentially in the last century. With Earth's resources dwindling rapidly, scientists have only intensified their efforts to inhabit the moon and possibly other planets.

The cost of sending one pound of material to outer space is about Rs 7.5 lakh. The process developed by the IISc and ISRO team uses urea — which can be sourced from human urine — and lunar soil as raw materials for construction on the moon's surface. This decreases the overall expenditure considerably. The process also has a lower carbon footprint because it uses guar gum instead of cement for support. This could be exploited to make sustainable bricks on Earth too.

Some microorganisms can produce minerals through metabolic pathways. One such bacterium, called *Sporosarcina pasteurii,* uses urea and calcium via a metabolic pathway called the ureolytic cycle to form calcium carbonate crystals as byproducts. "Living organisms have been involved in such mineral precipitation since the dawn of the Cambrian period, and modern science has now found a use for them," says Kumar.

To exploit this ability, Kumar and colleagues at IISc teamed up with ISRO scientists Arjun Dey and I Venugopal. They first mixed the bacteria with a simulant of lunar soil. Then, they added the required urea and calcium sources along with gum extracted from locally sourced guar beans. The guar gum was added to increase the strength of the material by serving as a scaffold for carbonate precipitation. The final product obtained after a few days of incubation was found to possess significant strength and machinability.

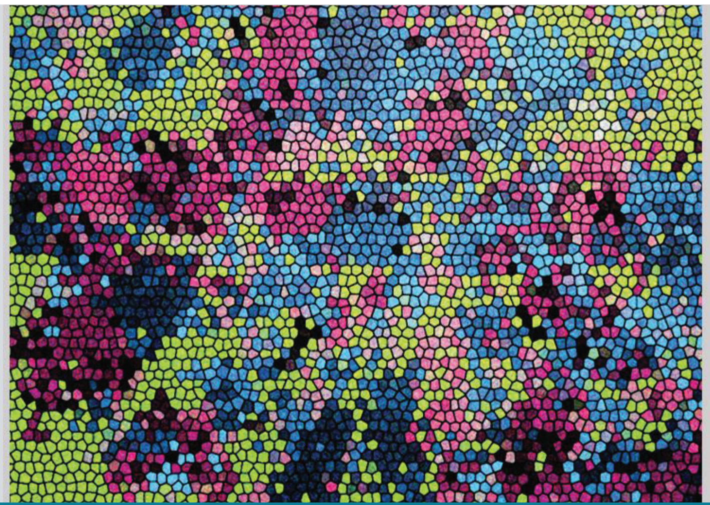
"Our material could be fabricated into any freeform shape using a simple lathe. This is advantageous because this completely circumvents the need for specialised moulds – a common problem when trying to make a variety of shapes by casting," explains Koushik Viswanathan, Assistant Professor in the Department of Mechanical Engineering, IISc, another author. "This capability could also be exploited to make intricate interlocking structures for construction on the moon, without the need for additional fastening mechanisms."

The *PLOS One* study, conceived by Rashmi Dikshit, a DBT-BioCARe Fellow at IISc, also investigated the use of other locally available soil bacteria in the place of *S. pasteurii.* After testing different soil samples in Bangalore, the researchers found an ideal candidate with similar properties: *Bacillus velezensis.* Just a vial of *S. pasteurii* can cost Rs. 50,000; *B. velezensis,* on the other hand, is about ten times less expensive, the researchers say.

The authors believe that this is the first significant step towards constructing buildings in space. "We have quite a distance to go before we look at extra-terrestrial habitats. Our next step is to make larger bricks with a more automated and parallel production process," says Kumar. "Simultaneously, we would also like to further enhance the strength of these bricks and test them under varied loading conditions like impacts and possibly moonquakes."

- Rohini Murugan

Image courtesy: Rajesh Ganapathy



DEVITRIFICATION DEMYSTIFIED

SCIENTISTS AT JNCASR AND IISc HAVE VISUALISED HOW GLASS TRANSFORMS INTO A CRYSTAL FOR THE FIRST TIME IN EXPERIMENTS

Glass is amorphous in nature – its atomic structure does not involve the repetitive arrangement seen in crystalline materials. But occasionally, it undergoes a process called devitrification, which is the transformation of a glass into a crystal – often an unwanted process in industries. The dynamics of devitrification remain poorly understood because the process can be extremely slow, spanning decades or more.

Now, a team of researchers led by Rajesh Ganapathy, Associate Professor at the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), in collaboration with Ajay Sood, DST Year of Science Chair and Professor at IISc, and their PhD student Divya Ganapathi (IISc) has visualised devitrification for the first time in experiments. The results of this study have been published in *Nature Physics.*

"The trick was to work with a glass made of colloidal particles. Since each colloidal particle can be thought of as a substitute for a single atom, but being ten thousand times bigger than the atom, its dynamics can be watched in real-time with an optical microscope," says Divya Ganapathi. "Also, to hasten the process we tweaked the interaction between particles so that it is soft and rearrangements in the glass occurred frequently."

In order to make a glass, the team jammed the colloids together to reach high densities. They observed different regions of the glass following two routes to crystallisation: an avalanche-mediated route involving rapid rearrangements in the structure, and a smooth growth route with rearrangements happening gradually over time.

To gain insights into these findings, the researchers then used machine learning methods to determine if there was some subtle structural feature hidden in the glass that decides beforehand which regions would later crystallise and through what route. Despite the glass being disordered, the machine learning model was able to identify a structural feature called "softness" that had earlier been found to decide which particles in the glass rearrange and which do not.

The researchers then found that regions in the glass which had particle clusters with large "softness" values were the ones that crystallised and that "softness" was also sensitive to the crystallisation route. Perhaps the most striking finding emerging from the study was that the authors fed their model pictures of a colloidal glass and it accurately predicted the regions that crystallised days in advance. "This paves the way for a powerful technique to identify and tune 'softness' well in advance and avoid devitrification," says Ajay Sood.

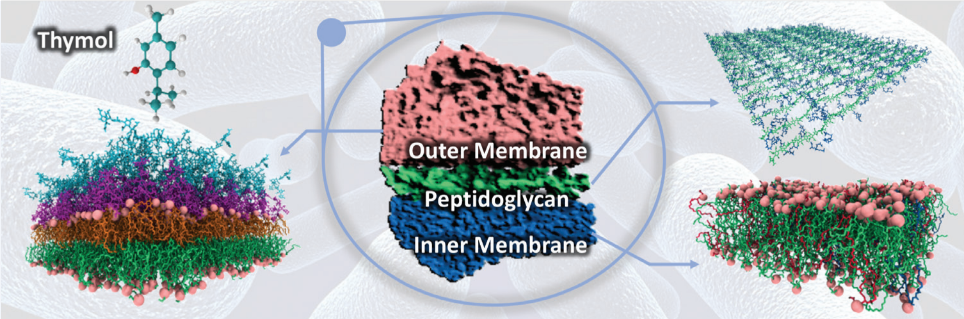
Understanding devitrification is crucial in areas like the pharmaceutical industry, which strives to produce stable amorphous drugs as they dissolve faster in the body than their crystalline counterparts. Even liquid nuclear waste is vitrified as a solid in a glass matrix in order to safely dispose of it deep underground and prevent hazardous materials from leaking into the environment.

The authors believe that this study is a significant step forward in understanding the connection between the underlying structure and stability of glass. "It is really cool that a machine learning algorithm can predict where the glass is going to crystallise and where it is going to stay glassy. This could be the initial step for designing more stable glasses like the gorilla glass on mobile phones, which is ubiquitous in modern technology," says Rajesh Ganapathy.

The ability to manipulate structural parameters could usher in new ways to realise technologically significant long-lived glassy states.

- Gouri Patil (with inputs from the authors)

Image: Pradyumn Sharma



ASSESSING BARRIERS IN BACTERIAL MEMBRANES

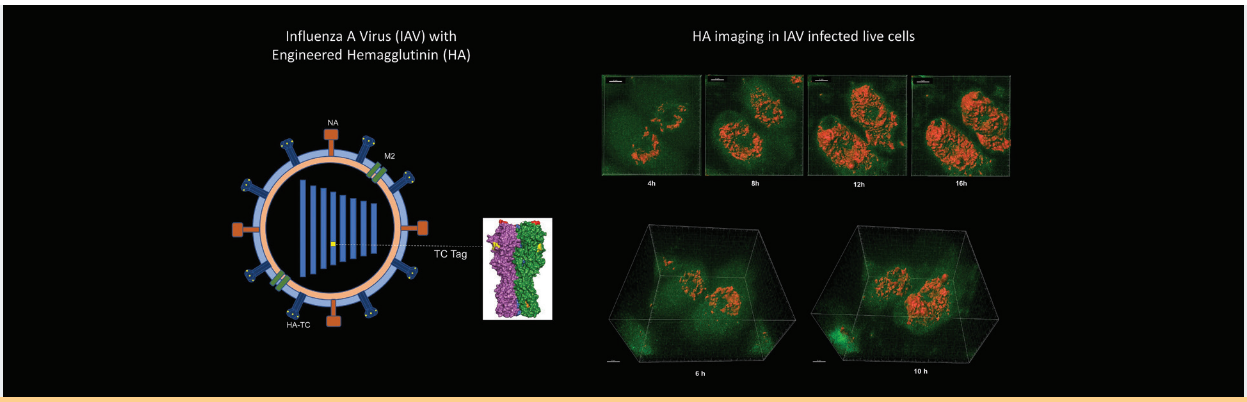
Researchers from the Departments of Chemical Engineering and Physics, along with Unilever R&D, have developed improved laboratory and computer models to understand how antibacterial compounds can penetrate bacterial membranes. In one study, using lipid mobility as a marker for entrance of thymol – an antibacterial molecule used in personal hygiene products – the group revealed the location of barriers present in the membrane. They found that increased phospholipid content in the outer membrane allowed thymol to penetrate it.

In another study, they developed a simplified molecular model of the membrane's peptidoglycan layer, which is expected to reduce the computational effort by several hundred-fold. Using this model, small molecules such as thymol were found to rapidly pass the peptidoglycan layer.

The studies illustrate the ability to recreate models that can be used to test the passage of small molecules through complex bacterial membranes. This opens up the possibility of screening potential antibiotics, and the development of novel drug molecules to combat bacterial infections.

- Shatarupa Sarkar (with inputs from the authors)

Image courtesy: Viruses/Shashank Tripathi



NOVEL METHOD FOR LIVE IMAGING OF INFLUENZA INFECTION

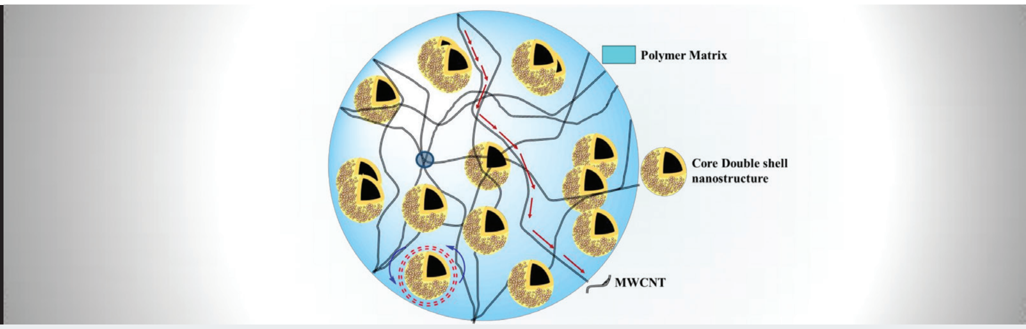
Subtypes of Influenza A viruses (IAV) cause the "flu" in birds and some mammals, including humans. Influenza hemagglutinin (HA) is a glycoprotein on the surface of these viruses that binds to the membranes of host cells to enable viral entry, and thus plays an important role in infection.

Scientists have extensively studied this protein's structure and synthesis. However, little is known about how HA moves through the network of organelles inside the host cell and reaches the membrane. Live imaging of HA in IAV-infected cells can enable such studies. Researchers in different countries, including Shashank Tripathi at the Centre for Infectious Diseases Research, have collaborated to develop a new method to enable the visualisation of HA in infected cells.

This technique involves engineering a recombinant virus which has a tetra cysteine tag that emits fluorescence in the presence of biarsenic dyes, and can be rapidly detected. This method can be used to study IAV infection even after viral fusion with the host membrane, and could aid the discovery of antiviral drugs.

- Samira Agnihotri

Image: Yudhajit Bhattacharjee



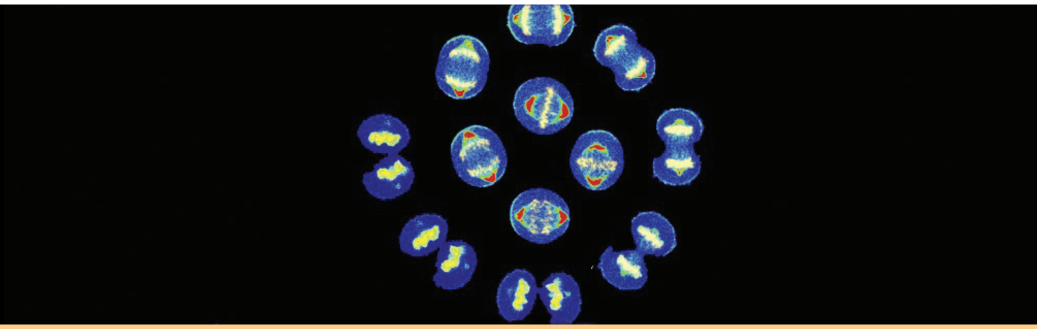
ROBUST NANOSTRUCTURES FOR EMI SHIELDING

Electro-magnetic interference (EMI) is a persistent issue that plagues modern electronics as it is the main source of noise, disrupting circuits. The efficiency and robustness of existing EMI shielding materials are quite low, which makes them ill-suited for high-end electronics. To overcome this, researchers in the Department of Materials Engineering designed a novel nanostructure involving a polymer and a blend of nanocomposites. They incorporated a conducting carbon nanosphere (CNS) as the core and iron oxide (Fe_3O_4) and silica (SiO_2) as shell materials to develop a core-dual-shell nanostructure. Multiple nanocomposites were integrated in a polymer matrix of polyvinylidene fluoride, resulting in EMI shields with highly effective architectures.

The team designed and compared many core-shell configurations and found that CNS@SiO_2@Fe_3O_4 showed maximum attenuation of incoming electromagnetic radiation – a remarkable 99%. These nanostructures were also effective in blocking UV radiation up to 99.9%. The material is also durable at high temperature and under mechanical stress, making it suitable for flexible electronics.

- *Gouri Patil*

Image courtesy: Sachin Kotak lab



TUG-OF-WAR BETWEEN TWO ENZYMES DRIVES SPINDLE FORCES IN CELL DIVISION

When eukaryotic cells divide, thread-like structures called spindle fibres help pull a copy of the replicated chromosomes into each daughter cell. The forces responsible for this pulling should be generated at the right time to ensure error-free cell division. In animal cells, a protein called NuMA plays an integral role in this process.

One of the ways that cells regulate such proteins is by adding or removing phosphate groups. When NuMA is dephosphorylated at an amino acid residue called T2055, it localises to the cell cortex where it helps anchor the motor protein, dynein, essential for generating spindle forces. However, enzymes like Cdk1 can block its localisation by phosphorylating NuMA.

Very little is known about the dynamics of these two processes. Researchers from the Department of Microbiology and Cell Biology have now identified and characterised the subunit (B55γ) of an enzyme called PP2A responsible for dephosphorylating NuMA at T2055. The researchers suggest that a tug-of-war between Cdk1 and PP2A-B55γ regulates cortical NuMA levels.

As low levels of B55γ are linked to prostate cancer, future research will attempt to unravel the role of spindle formation in cancer progression.

- *Rohini Murugan*

Photo courtesy: Sarah Iqbal

WHAT A WORM CAN TEACH US ABOUT HOW ANIMALS MOVE

KAVITA BABU'S LAB IS INVESTIGATING THE MOLECULAR MECHANISMS THAT UNDERPIN ANIMAL MOVEMENT

Before her passing, Veronica Rodrigues, one of India's most well-known neurobiologists, mentored dozens of students — not just her own but also several undergraduate students from around the country who spent their summers in her lab at the Tata Institute of Fundamental Research (TIFR), Mumbai. In 1996, Kavita Babu was one of them.

Kavita was then a BSc student at St. Joseph's College, Bangalore, majoring in Physics, Chemistry, and Mathematics. "I really enjoyed the summer there, working on fruit fly biology, especially the genetics," she recalls. The experience had such a profound influence on her that she decided to become a biologist.

After her undergraduate degree, Kavita joined a Master's programme in biotechnology. At that time, on the advice of Rodrigues, she talked to William Chia, a fruit fly biologist at the Institute of Molecular and Cellular Biology in Singapore, about the possibility of working with him. After her first year, she left her Master's programme and went on to do her PhD with Chia in developmental biology.

But her love for genetics and neurobiology, which she was exposed to in Rodrigues' lab, eventually led her to pursue neurogenetics for her postdoctoral research at the Massachusetts General Hospital in the United States.

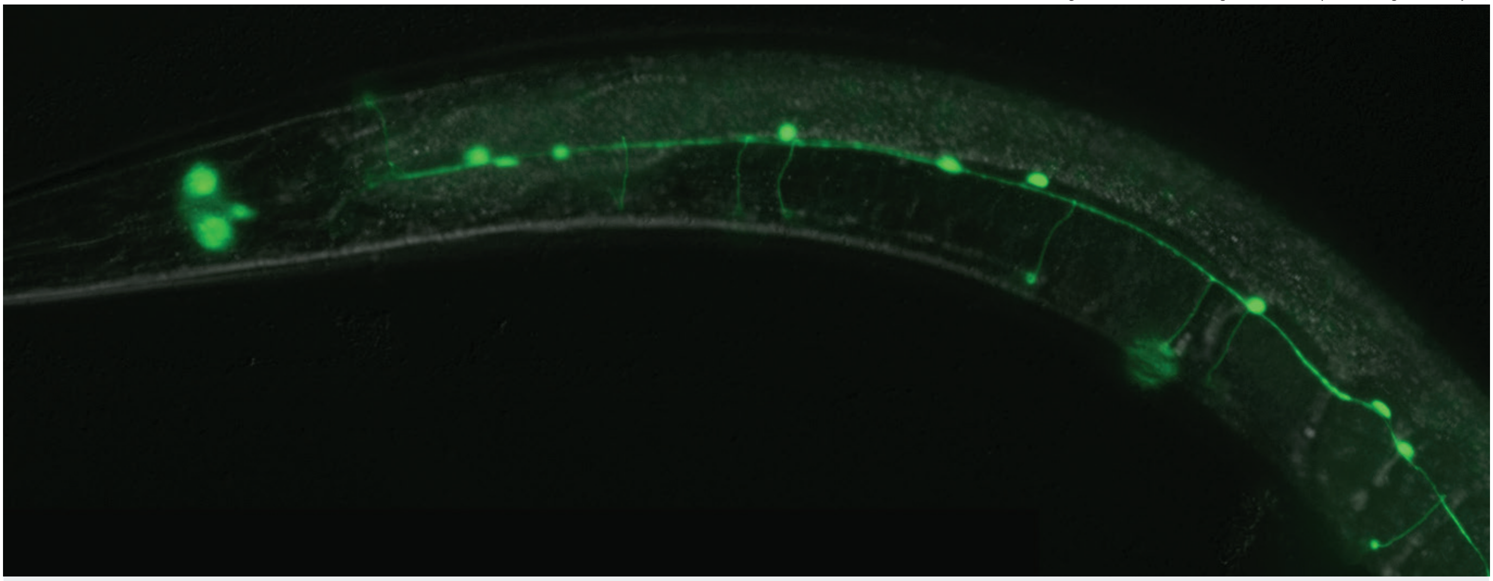
In 2011, Kavita moved back to India as a faculty member at the Indian Institute of Science Education and Research (IISER), Mohali, where she set up her own lab. But after having spent more than seven years up north, she wanted to come back to South India, and so applied to IISc. And in 2019, she joined the Centre for Neuroscience (CNS) at IISc as an associate professor.

At CNS, Kavita's lab studies a tiny, free-living roundworm called *Caenorhabditis elegans,* better known as *C. elegans.* Because it has a relatively simple body plan and is transparent, it has become an important animal model for biological studies.

There's another good reason why biologists like Kavita are fond of *C. elegans:* the invertebrate has about 20,000 genes (compared to about 25,000 in humans), many of which are "conserved", she says. Understanding conserved genes and the proteins they code for — those that have not changed over the course of evolution — allows researchers to draw conclusions about the origin and evolution of biological traits.

Kavita is interested in understanding the neurogenetics underlying how these worms move. "I don't know if you have seen a worm moving. It is essentially a sinusoidal movement like in a snake," she explains. "What are the molecular mechanisms that allow this worm to move as it does? Allow it to stop as it does? Allow it to move backwards? Make turns?" In order to understand

C. elegans neurons marked with green fluorescent protein (Image: Vina Tikiyani)



the mechanism of locomotion, her lab is addressing two broad questions.

The first is how neurons communicate with each other to facilitate movement. To answer this question, she and her students are studying the role of small proteins called neuropeptides sent out by neurons during signalling.

The second question that intrigues Kavita is how neurons communicate with muscle cells. She believes that the answer to this question might lie in the role of specific molecules at the synapse — the chemical junction between two neurons and between a neuron and a muscle cell — called cell adhesion molecules. She also wants to know whether these molecules have other functions in the pre- and post-synaptic phases of signal transmission required for muscles to contract.

In her quest to understand animal locomotion, Kavita and her students have made several significant discoveries. For instance, her PhD student Shruti Thapliyal has shown that a cell adhesion molecule called CASY-1 signals at the neuromuscular junction and is required for the release of GABA, an inhibitory neurotransmitter.

Two of her other students, Pallavi Sharma and Vina Tikiyani, have worked on a set of molecules called claudins that are present on the outermost layer of cells of an organism. When claudins are disrupted, it leads to disruption of these layers, sometimes leading to cancer. "We wanted to look at whether claudins are expressed in neurons and whether they actually function in neurons," states Kavita. Their research has characterised two claudins, both of which are expressed in neurons and present at the synapse. "These claudins," she continues, "are required to maintain post-synaptic receptors at the neuromuscular junction."

For her research contributions, Kavita has already received several awards like the Janaki Ammal National Women Bioscientist Award and Innovative Young Biotechnologist Award. She is happy with the recognition that has come her way but is quick to point out that science is a team sport. "It is important to realise that at the end of the day the awards were won not only because of my work, but because I have a fantastic set of people working with me in the lab."

- *Shatarupa Sarkar*

Kavita Babu with her lab members (Photo: Siju Surendran)

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