Secret of the Wings: Nanostructures on a Dragonfly

Debanuj Chatterjee (Marie Curie Postdoctoral fellow at CNRS, University of Lille, France)

Dragonflies are one of the marvels of natural creation. The secrets of their flight dynamics, mate selection, predation, and visual information processing are all awe inspiring. During a trip to Puri in India, I had an interesting encounter with a group of dragonflies. A few of their pictures revealed some hidden mysteries about the nanostructures present on their wings. In this article we use scientific knowledge to develop a peeping hole into those hidden mystries.

It was the summer of 2017 when we visited Puri, a coastal city, in eastern India. On the fall of evening, the beach side road was bustling with tourists as my parents hopped from one shop to another, testing their price negotiation skills with the local shopkeepers. While my parents were busy in their shopping spree, I was having a fun time clicking pictures of some beautiful handcrafts in a souvenir shop, with my camera. While clicking one of those pictures, something interesting caught my attention. I found out that some of the items hanging near a bright light bulb outside the shop had become a playground for stray dragonflies. This species of dragonfly is also known as the globe skimmer (_Pantala flavescens_) due to its long migratory flights [1]. Around a hundred of them swirled in a chaotic yet mesmerizing dance, basking in the warmth of the incandescent bulb. It was quite serendipitous to discover such a gathering of one of my favorite insects, the dragonfly, while I had a camera in my hand. Before continuing with the story, I cannot resist a brief digression to explain why dragonflies are my favorites as an insect species.

First of all, dragonflies are beautiful, with their large colorful compound eyes and their aerodynamic bodies, perfectly designed for flight (see some of my shots in Fig. 1). Additionally, dragonflies can control the flapping of their four wings independently, allowing them to take off vertically, fly in any direction—including forward, backward, right, left—and hover with unmatched precision. Moreover, while hunting, they can predict their prey's trajectory and make fine adjustments to their own, in real-time all while airborne. The secrets of their flight dynamics, mate selection, predation, and visual information processing are all awe inspiring, making me feel the true ingenuity of Mother Nature.

That evening, instantly I found myself capturing hundreds of close-up shots of these incredible insects. While taking these shots, I observed something very striking. In one of the shots, when I looked closely on the wings on the display screen of my camera, I noticed the insect's wings had a faint opaque blueish pattern (see Fig. 2 (a)). It was quite surprising for me, because I always thought dragonflies had transparent wings. Then I had a look with my bare eyes at those insects. Yes, their wings were transparent to my naked eye. What, then, was that bluish pattern that my camera was displaying on the wings? Trying to answer this question I came across one of those feelings where I realized scientific research is no short of being in the shoes of a detective, trying to solve a case where the answer is apparently omnipresent, yet invisible to the common eye (pun intended). After thinking for a while on this, I had a closer look at some of the other images of dragonflies I captured the same day. I found out that in some of those images, the blue pattern was visible, while it was not present in the rest. For example, in the shot shown in Fig. 2 (b), we do not see the characteristic pattern clearly as seen in Fig 2 (a). In fact, the lower right wing in Fig. 2 (b) seems completely transparent. So, what was going on?

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The first clue came when I noticed that the blueish pattern appeared when the line joining the light source and dragonfly's wing was at certain angles to the line joining the wing and the camera lens (see Fig. 3). Does it ring a bell? The first thing that came to my mind was Mie scattering. Mie

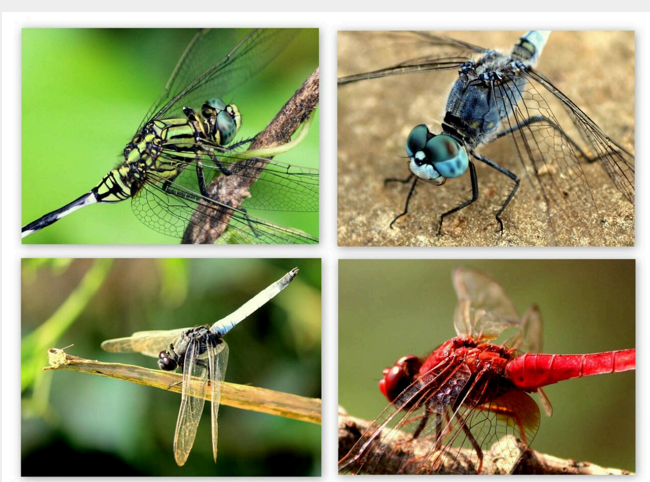

Fig 1: Shots of colorful dragonflies.

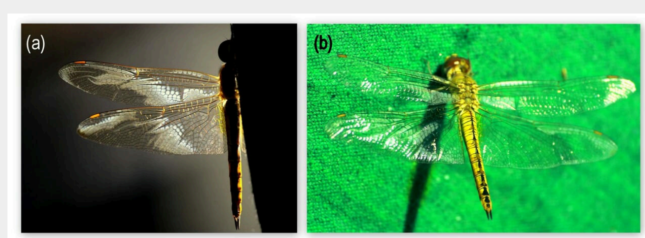

Fig 2: Two different shots of a dragonfly (*Pantala flavescens*) from two different illumination angles.

scattering describes how a small particle (typically dielectric) scatters incident light in different directions. The amount of scattering depends on the angle by which it is being scattered. In other words,when a small dielectric particle is illuminated by a beam of light, it scatters varying amounts of light at different angles. Also, an important aspect of Mie scattering is that it is efficient when the wavelength of the light is of the same order of magnitude as the size of the illuminated particle. Thus, if this blueish pattern on the dragonfly's wing was due to some small structures present on the wings of the dragonfly, those structures must have been similar in size to the wavelength of the incoming light (visible spectrum : 400 nm to 700 nm). In this case, the incoming light was in the visible spectrum, with wavelength ranging from 400 nm to 700 nm. I immediately remembered, a professor at IISER Kolkata once told us in our classes about nanostructures found in the feathers of a peacock. He said that a peacock's blue color does not come from pigment but instead results from light scattering by nanostructures. The same principle applies to some species of blue butterflies. Could the dragonfly's wings be exhibiting a similar phenomenon? It was time to find out!

To investigate further, I turned to Google Scholar. I found a few papers that studied the structure of dragonfly wings and to my surprise I found ample evidence of the presence of nanostructures on their wings [2,3]! In fact, dragonfly wings contain nanoscale pillars, ridges, and pores composed of chitin, often combined with a thin wax coating. An example is shown in Fig. 4, where an atomic force microscopy image from [3] is shown, indicating multiple nanoscale layers (see arrows) and a "ripple wave morphology" (see circular region).

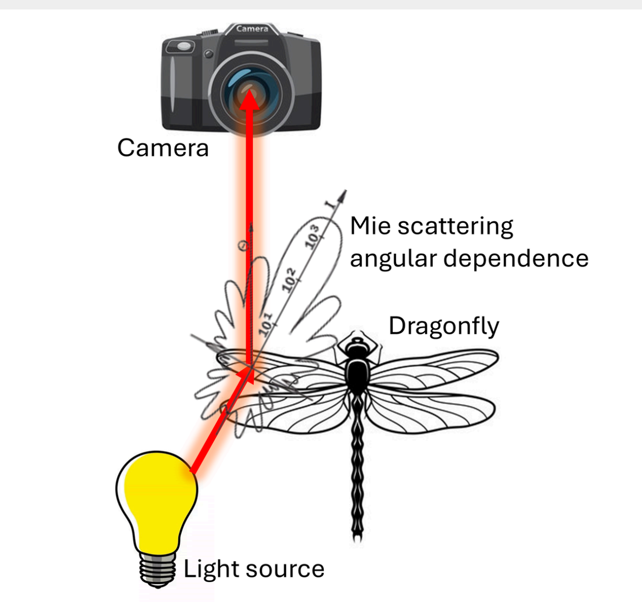

Fig 3: Illustration of angular illumination of the dragonfly's wing and the angular strength of Mie scattering.

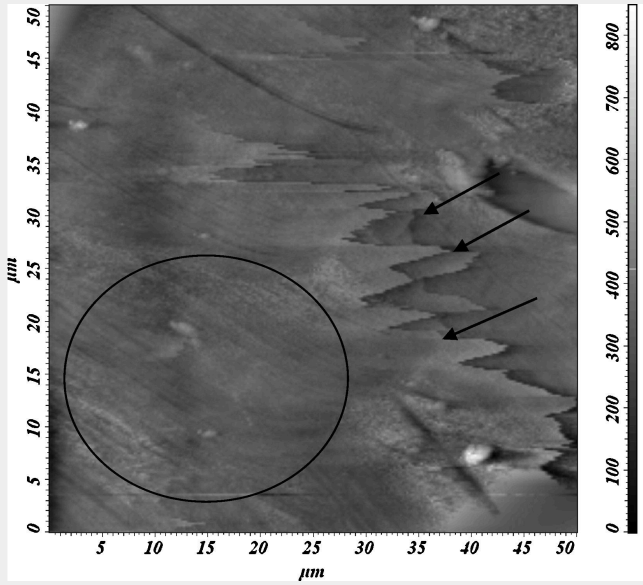

Fig 4: Atomic force microscopy image of a dragonfly's (*Sympetrum vulgatum*) hind wing, depicting a multilayer arrangement. Reproduced from [3].

But then shouldn't the dragonfly wings look blue all the time, like peacocks, rather than only from a particular angle? Maybe not. Here I remembered that those faint blue colors on the dragonfly's wings were not conspicuously visible to my bare eyes. I could only see them through the camera. This might suggests that these colors were outside the visible range of my eyes but detectable by my camera.The Canon EOS 1200D camera I used has a CMOS sensor which is capable of detecting wavelengths from approximately 350 nm to 1000 nm, though infrared wavelengths are often filtered out optically. As a result, the camera can detect wavelengths slightly beyond the blue end of the visible spectrum. This suggests that the scattered light had a spectral signature just outside the visible range but still within the CMOS sensor's detection band. Interestingly, a paper suggested that non-iridescent, angle-dependent color formation can occur at wavelengths between 350 nm and 500 nm due to electromagnetic resonances caused by the random aggregation of silica nanostructures [10]. However, whether this is the same mechanism for the dragonfly wings, needs to be verified through a detailed scientific investigation. Another interesting question that came to my mind was about the visibility of these patterns to other dragonflies. It is true that humans cannot see shorter than 400 nm wavelength on the blue side, but what about the visible range of dragonflies? It turns out that dragonflies have a particularly sensitive vision in the wavelength range of 300 nm to 500 nm [4,5], and body and wing colours carry important visual cues influencing their behaviour [5]. Which means one dragonfly should be able to see the patterns on another one. Perhaps this is why they were hovering around the bright light source, where they can see those structures in its aesthetic eminence. Or maybe those nanostructures play a role in their mate selection? In fact, research on the structural properties of the wings of a dragonfly witnessed a boom in the past decade. The wings' nanostructures revealed anti-bacterial properties [6,7], opening potential application avenues in biofilm design for medical implants [8] or even in the food processing industry [9]. In a world of emerging technologies, I strongly believe in the potential of the dragonflies to inspire the next generation of biomimetic innovations.

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From a BS-MS student to an Independent Scientist: My Academic Journey

Sayan Choudhury (HRI Allahabad, Prayagraj)

Sayan Choudhury, an alumnus from the first batch of IISER Kolkata talks about his academic journey in this article. He reminisces about his education and research experiences at IISER, and his trajectory beyond IISER: first, as a PhD student and a post-doctoral fellow in the USA, and now as a faculty member at HRI. The article concludes with a message for current students.

I have very clear memories of the summer of 2006. I had just graduated from high school and was exploring options for the future. I had been fascinated by Physics in school and wanted to pursue it further. At that point, an advertisement for IISER appeared in the newspaper and I applied. After a round of counseling, I was allotted a seat at IISER Kolkata. During the counselling session, we were told about the vision of IISER. One of the big points that was emphasized was that science was becoming increasingly interdisciplinary, and the coursework at IISER would embrace this interdisciplinarity. I found this pitch very attractive and decided to join IISER.

The IISER journey: A walk down memory lane

Being the first batch at an Institute is a unique experience. For starters, there's no Fresher's welcome! However, at the same time, we received immense support in pursuing various kinds of projects. From the very beginning, the importance of getting involved in research was emphasized to us. Our lab courses had a project component, where we worked in groups on some experiments that we designed. This was a fascinating experience – we learnt to design problems, work in groups, and present our results. The courses were also very interesting at that time. Since, we had very few permanent faculty members, we were often taught by Professors from research Institutes in Kolkata. These professors often had a very different view on what should be taught to undergraduates, and consequently, we were exposed to several advanced topics. For instance, the first Biology class was a discussion about Daniel Koshland's article entitled 'The seven pillars of life'. In the third or fourth Biology class, we learnt about Ludwig Boltzmann and his entropy formula: We had a biology quiz where we were asked to design a question and then answer it. We were taught the RSA algorithm in the first semester Maths course by one of India's leading cryptographers. It was fascinating and motivating! The courses continued to be very interesting throughout the 5 years of my stay.

Fig 1: First year Chemistry lab at the Salt Lake Campus of IISER.

In this context, I must mention that a major highlight of my IISER experience was the approachability of our professors. it was a common sight to find young BS-MS students engaged in discussing science with senior professors at the local tea stall. These interactions played a significant role in our development as scientists. Another cherished tradition was special Saturday morning seminars, where faculty members would present accessible `colloquium style' talks on some cutting-edge topic. Through these interactions, courses, seminars and projects, I found that learning and doing science was great fun. On a side note, Inquivesta was conceptualized during our time, but the first edition took place after we left. A science fest was a unique proposition and there were a lot of spirited debates about the name of the event, but that's a story for another day.

Research experience at IISER

I was lucky to get opportunities for getting involved in research from the summer of my second year. During that summer, I was exposed to quantum information theory and performed some calculations on the entanglement entropy of cluster states. After the summer, Prof. Prasanta Panigrahi encouraged me to write up my results and submit it to Prayas: Student Journal of Physics. Writing this paper was a very enriching experience and it gave me a lot of confidence. Eventually, I ended up doing a more serious project with Prof. Panigrahi and our results were published in J. Phys. A. I also went for internships to other Institutes – SINP (as an Undergraduate Associateship Program), IISER Mohali (IAS Summer Fellowship) and the Georg-August University at Gottingen (DAAD Fellowship). These experiences exposed me to several other directions of research, and I finally decided that I wanted to work on a project in Condensed Matter Physics for my MS thesis.

I thoroughly enjoyed my final year at IISER. We needed to take very few courses that year, and the emphasis was

Fig 2: The first Science Day celebrations at IISER in 2010.

primarily on the MS thesis. I worked with Prof. Siddhartha Lal and Prof. Prasanta Panigrahi for my thesis. Siddhartha had just joined IISER then and I was his first student. Siddhartha treated me as a bona-fide graduate student, and we had long and intense discussions on my MS thesis project. My project started as an exploration of the dynamics of Bose-Einstein condensates in one-dimensional optical lattices. I learnt about a lot of things – from the Gross-Pitaveskii equation to Luttinger liquids. As we delved deeper, we found that we needed to borrow ideas from non-linear dynamics to proceed further, and we roped in Prof. Anandamohan Ghosh for discussions. Even though, we never wrote a paper to disseminate these results to a broader audience, I am very proud of my MS thesis. We finally graduated in May 2011. Unfortunately, our convocation happened much later (probably 2013) and I missed it. However, I cherish all my memories of IISER Kolkata. It was a wonderful time!

Academic life beyond the BS-MS at IISER

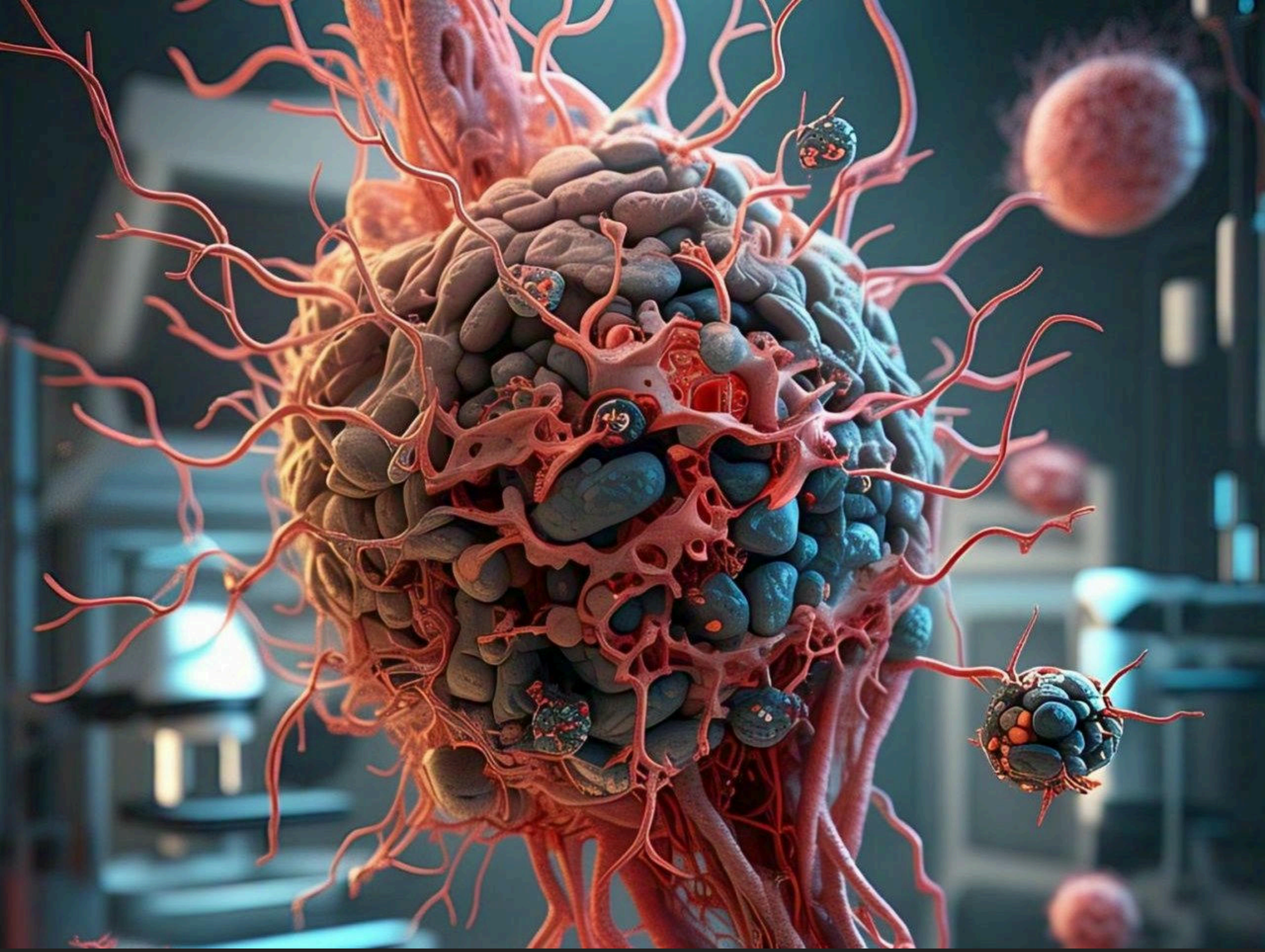
After graduating from IISER, I went to Cornell for my PhD. Cornell has perhaps one of the most beautiful campuses in the world and I had a great time there. There were waterfalls on campus and the seasons were gorgeous. My IISER education kept me in good stead during my PhD and I had the opportunity to work with and learn from wonderful people like Prof. Erich Mueller and Prof. Jim Sethna. I obtained my PhD in 2017 and headed to Purdue University for my Postdoc. Amongst other things, I collaborated with another IISER-K alumnus, Rishabh Khare on a project during this period, and we wrote a paper together. After Purdue, I joined the University of Pittsburgh as a post-doctoral fellow. Interestingly, at Pittsburgh I worked with Prof. W. Vincent Liu, whose early papers on quantum chaos had been very important for my MS thesis. Finally, I joined HRI Allahabad as a faculty member in October 2022. The different positions I have taken up in my career have come with their own set of challenges and rewards. Out of these, my current role of a professor is probably the most satisfying and difficult. I am immensely grateful to my professors who have taught and mentored me, and now as I teach and mentor young students, I sincerely hope that I am able to share the joy of doing science with them.

Fig 3: The first batch of IISER students after a visit to the Variable Energy Cyclotron Center.

Message for current IISER students

IISER Kolkata is poised to step out of its teens and enter the second decade. An Institute is known not only for the quality of research and teaching, but also for the success of its alumni. Despite its relatively young age, IISER-K has already produced a significant number of alumni who have established themselves in academia and industry. Our alumni have become faculty members and academic group leaders, established companies, and achieved success in corporate jobs. Current IISER students should tap into this network. Whether you are wondering about applying for a PhD/Post-doc/Faculty position or thinking of establishing a start-up, the alumni network can be a powerful resource who can help you. So, don't be shy about asking your seniors for help even if you don't know them personally. I wish you all the very best for your journey!

Sayan Choudhury is a theoretical physicist based at HRI Allahabad. He is an alumnus of the very first batch of IISER Kolkata (06MS). He can be reached at sayanchoudhury@hri.res.in



Brain on Overload: Unlocking Hope for Rare Diseases Through Cellular Cleanup

Tisha Dash (Department of Biological Sciences, IISER Kolkata)

Neurodegeneration in Mucopolysaccharidosis VII (MPS VII) remains poorly understood. A recent Drosophila study reveals that β-glucuronidase deficiency disrupts autophagy and mitophagy, leading to mitochondrial dysfunction, energy depletion, and neuronal apoptosis. Remarkably, resveratrol rescues mitophagy and prevents ATP loss, highlighting a druggable axis linking lysosomal impairment to neurodegeneration in MPS VII.

When you think of waste management, the last thing that comes to mind is the human brain. Yet, deep within our cells, an intricate system works tirelessly to clear out damaged or unnecessary components, ensuring the smooth functioning of critical processes. But what happens when this cleanup system breaks down? For individuals with Mucopolysaccharidosis VII (MPS VII), a rare genetic disorder? This failure triggers a cascade of devastating events, culminating in severe brain damage and early death.

Lysosomal Storage Disorders and Neurodegeneration: Revisiting the Molecular Underpinnings

Mucopolysaccharidosis VII (MPS VII), also known as Sly Syndrome, is a rare autosomal recessive Lysosomal Storage Disorder (LSD) caused by mutations in the GUSB (Glucuronidase Beta) gene, which encodes β-glucuronidase (β-GUS), a key enzyme in the catabolism of glycosaminoglycans (GAGs). The deficiency of β-GUS leads to the accumulation of undegraded or partially degraded GAGs within lysosomes, resulting in widespread cellular dysfunction and multi-systemic manifestations [1][2]. Clinically, MPS VII presents with a broad spectrum of phenotypes, including skeletal deformities, hepatosplenomegaly, cardiovascular complications, and progressive neurodegeneration [3]. Notably, neurological symptoms such as cognitive impairment, motor dysfunction, and sensory deficits highlight the impact of lysosomal dysfunction on the central nervous system [4][5].

Despite advancements in enzyme replacement therapy (ERT) with vestronidase alfa, the treatment remains inadequate in addressing neurological manifestations due to the inability of the recombinant enzyme to cross the blood-brain barrier[6][7]. This limitation highlights the urgent need for alternative therapeutic approaches that target the molecular mechanisms underlying neurodegeneration in MPS VII. Emerging evidence suggests that lysosomal dysfunction disrupts essential cellular clearance pathways, particularly autophagy and mitophagy, which are vital for maintaining neuronal homeostasis[8][9][10]. Autophagy ensures the degradation of damaged proteins and organelles, whereas mitophagy selectively eliminates dysfunctional mitochondria, thereby preventing excessive reactive oxygen species (ROS) production and bioenergetic failure [11]. In the context of LSDs, defective lysosomal activity may impair mitophagic flux, leading to mitochondrial dysfunction, ATP depletion, and neuronal apoptosis—hallmarks of neurodegeneration observed in MPS VII and related disorders [12]

Leveraging Drosophila as a Neurodegeneration Model: A Key Insight

In a landmark study, a team of scientists led by Professor Rupak Datta from the Indian Institute of Science Education and Research Kolkata, India, has uncovered a crucial link between cellular waste accumulation and brain cell death in MPS VII [13]. Using a fruit fly model, *Drosophila melanogaster*, they've shed light on how dysfunction in a process called mitophagy—the selective disposal of damaged mitochondria —leads to an energy crisis in neurons, ultimately causing neurodegeneration. This discovery holds promise for new treatments and highlights the intricate process of cellular maintenance that keeps our brains healthy. Notably, the research demonstrated that MPS VII flies exhibit a marked reduction in dopaminergic neurons, indicative of neuronal loss. Additionally, impaired mitophagic clearance of damaged

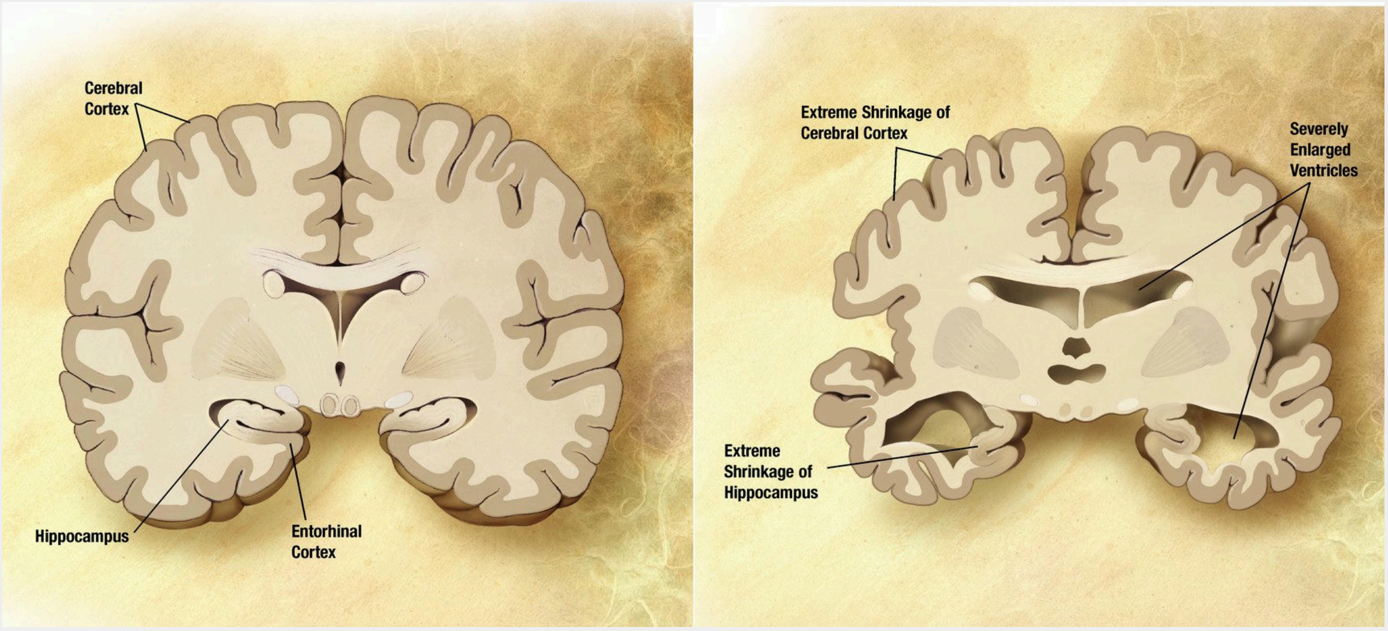


Fig 1: Credit: Garrando (Wikipedia)

mitochondria was observed, with these dysfunctional mitochondria accumulating in the neurons and causing increased oxidative stress and reduced ATP production. Transmission electron microscopy (TEM) imaging revealed the presence of swollen mitochondria with abnormal cristae, supporting the claim of mitophagy defects. The study also showed increased lipofuscin accumulation and multilamellar bodies, further evidence of defective lysosomal clearance mechanisms. Despite the robustness of these findings, they raise an important question: How well do these insights translate into the complexities of human neurodegeneration? In particular, can we bridge the gap between the accelerated pathology in Drosophila and the long-term, multifactorial neurodegenerative processes in humans?

In this study, the authors investigated the molecular link between lysosomal dysfunction, mitochondrial impairment, and neurodegeneration, aiming to delineate the cellular and molecular defects driving mitochondrial accumulation and neurodegeneration in CG2135 (β-GUS homolog) knocked-out flies. They focused on the autophagy-lysosomal pathway to determine whether defective mitophagy contributes to mitochondrial dysfunction and neuronal loss. Their findings reveal a significant impairment in mitophagic clearance due to autophagy defects, leading to an energy crisis in the brain that ultimately triggers apoptotic neurodegeneration. Moreover, they demonstrate that pharmacological activation of mitophagy using resveratrol restores mitochondrial function and prevents neuronal loss, highlighting its therapeutic potential for neurodegenerative LSDs.

The use of Drosophila to model MPS VII is a strategic choice, one that takes advantage of the fly's well-characterized dopaminergic neurons and its genetic simplicity. The study showcases how these neurons, which mirror critical features of human neurodegeneration, undergo age-dependent degeneration due to impaired lysosomal function and subsequent mitochondrial damage.

Fig 2: caption

Whole-mount brain immunostaining confirmed a loss of dopaminergic neurons in aged CG2135−/− (mutated – knocked out) flies, mirroring neurodegenerative phenotypes observed in Parkinson's disease (PD). While the accelerated rate of neurodegeneration in Drosophila provides an efficient platform for studying cellular pathology, it raises concerns about the generalizability of these results. The lifespan of flies is significantly shorter than that of mammals, potentially skewing the observed rate of neuronal loss. Nevertheless, the conserved nature of key cellular processes, particularly those involved in autophagy and mitochondrial function, offers a strong rationale for using the fly as a model. Future studies should aim to track the progression of neuronal damage in more complex mammalian systems to validate whether the temporal patterns observed in Drosophila hold in longer-lived organisms.

Defective Autophagy-Lysosomal Clearance & Impaired Mitophagy in MPS VII

Autophagy is the cell's way of cleaning up and recycling unwanted materials, including damaged organelles. Mitophagy, a specialized form of autophagy, targets malfunctioning mitochondria for degradation. In the MPS VII model, both processes were impaired. The accumulation of defective mitochondria, which failed to produce enough energy, led to an ATP crisis in neurons. This energy deficit triggered apoptosis, or programmed cell death, contributing to the observed neurodegeneration. Markers of autophagy, such as Atg8a-II and Atg1, were significantly reduced, and damaged components like mitochondria accumulated in the brain. This is where things get particularly interesting. Not only was general autophagy impaired, but a specialized form called mitophagy —responsible for clearing damaged mitochondria—was also defective.

The research emphasizes the central role of defective mitophagy in driving neurodegeneration in MPS VII. The accumulation of damaged mitochondria due to impaired mitophagic clearance leads to oxidative stress and a progressive decline in cellular function, which is reminiscent of the mitochondrial dysfunction observed in Parkinson's disease (PD) and Alzheimer's disease (AD). The study showed

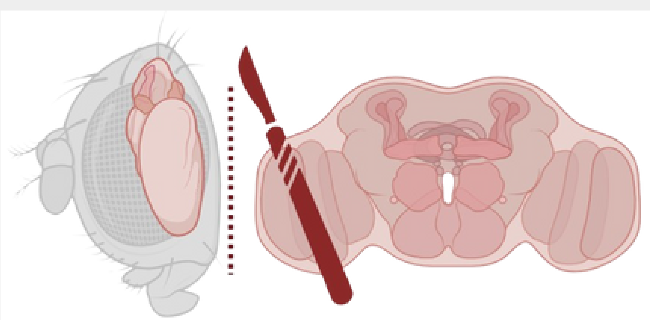


Fig 3: caption

that enhancing mitophagy using resveratrol (a known SIRT1 activator) improved mitochondrial clearance and rescued dopaminergic neurons from degeneration. Yet, there is an opportunity to consider more precise, mitophagy-specific therapies, such as those targeting the PINK1/Parkin pathway. If enhanced mitophagy alone could reduce the accumulation of depolarized mitochondria, then this approach may offer more targeted therapeutic outcomes compared to global autophagy activation. Exploring this concept in MPS VII and similar diseases may reveal novel therapeutic strategies for not just LSDs but other neurodegenerative conditions as well.

Resveratrol Treatment: A Therapeutic Intervention

A major highlight of the study was the demonstration that resveratrol, a natural compound found in red wine and certain plants, treatment could rescue mitochondrial and neuronal defects in CG2135−/− flies. Resveratrol-treated flies showed increased survival under starvation conditions and restored Atg1 transcript levels, indicating improved autophagy initiation. These findings suggest that resveratrol exerts its neuroprotective effects by enhancing mitophagy and restoring mitochondrial function. However, additional studies are needed to determine whether resveratrol acts solely through SIRT1 activation or involves other pathways such as AMPK signaling or direct modulation of lysosomal activity.

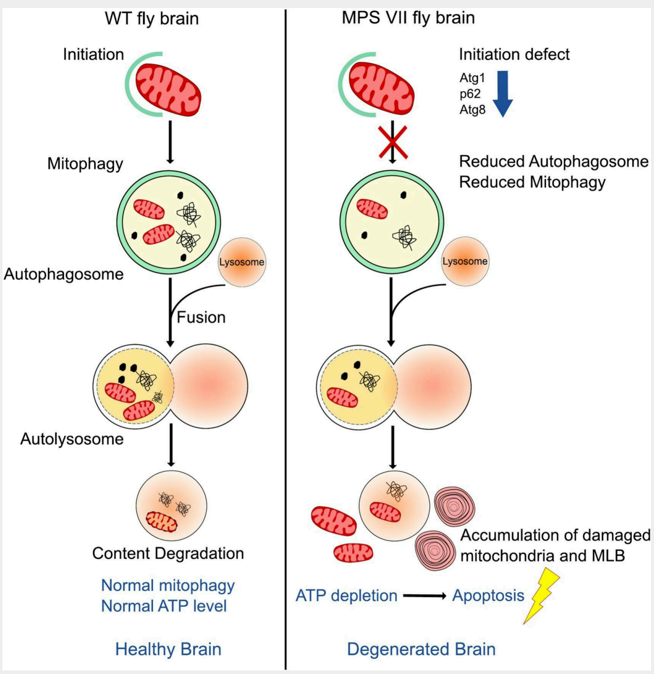


Fig 4: Schematic representation of the mechanism of neurodegeneration in the MPS VII fly. In the wild type (WT) fly brain, a healthy mitochondrial pool is maintained by the clearance of the damaged mitochondria through properly functional mitophagy. This mitochondrial quality control helps in maintaining normal brain ATP levels. Autophagy deficiency in the MPS VII (CG2135/) fly brain led to mitophagy defect, causing the accumulation of damaged mitochondria. This resulted in depleted ATP levels, triggering apoptotic cell death in the MPS VII fly brain. Adapted from [13]

Broader Implications: Connecting the Dots to Other Neurodegenerative Disorders

While the study centers on MPS VII, the findings have far-reaching implications for understanding neurodegenerative diseases more broadly. Conditions such as PD, AD, and ALS share a common theme of defective autophagy and lysosomal dysfunction, which contributes to the accumulation of cellular waste, including damaged mitochondria. The research demonstrated that both mitochondrial dysfunction and autophagic blockade play crucial roles in the pathophysiology of MPS VII, reinforcing the idea that these pathways are central to a wide range of neurodegenerative disorders.

Concluding Thoughts: A Roadmap for Future Research

In conclusion, this research provides critical insights into the role of mitophagy in MPS VII and its broader implications for neurodegenerative diseases. The study's results underscore the importance of defective autophagy and mitophagy in neuronal degeneration, showcasing both the value and the limitations of Drosophila as a model for human neurodegeneration. The next step should be to validate these findings in mammalian models to better understand their translational potential. Ultimately, the concept of enhancing cellular clearance mechanisms, whether through compounds like resveratrol or novel mitophagy-specific agents, holds promise for treating not only MPS VII but also a wide spectrum of neurodegenerative disorders.

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Tisha Dash is a final-year BS-MS student currently pursuing her Master's thesis in the Membrane Trafficking and Copper Metabolism Lab at IISER Kolkata, under the guidance of Dr. Arnab Gupta. Her research focuses on understanding cellular signaling pathways involved in copper homeostasis. Beyond the lab, Tisha is passionate about painting, dancing, and making her voice heard through spirited debates at Model United Nations conferences. She is deeply interested in bridging science with societal impact and storytelling.

The Cora Ball - Protecting Millions of Ocean Acres by The Second

Sharanya Chatterjee

Washing your blue shirt might seem harmless, but it can release microfibres that harm ocean life. Microfibre pollution—from textiles, hair, and pet fur—poses a growing threat to marine ecosystems. The Cora Ball, inspired by coral reefs, uses hydrodynamics to trap these fibres during laundry, reducing pollution by up to 31%. Praised by marine biologists and environmentalists, Sharanya Chatterjee takes you through the journey through her article showing a simple yet effective household solution to this global issue.

The Problem of Microfibers

The news flashes across the television screen one fine morning: The proportion of aquatic life affected due to microfiber pollution is currently at 100 million; the number rises everyday! You pause to look for a second with the laundry in your hand, maybe turn the volume up. As you load the clothes in the washing machine, turn the knobs, you shake your head at the state of the times, even telling your toddler that climate change should be fought against. However, do you pause as you chuck that blue shirt into the machine and wonder what the enemy looks like? Well you don't have to look that far. The blue shirt and millions like it, or in other words, any kind of textile and fibre are one of the primary reasons for *microfiber pollution*.

Synthetic textiles, which are made up of polyester, nylon, acrylic and other fibres, almost singly contribute to **engineered micro-plastics** in the ocean, accounting for 35 percent of the total volume. These microfibers are released from fabric, which can be as small as three microns, a thirteenth the width of a single strand of your hair, are too small for water treatment plants to remove.These invisible minions make their way into the ocean at large scale, allow organic pollutants like DDT and PBTs to attach, and **accumulate in the bodies** of the aquatic life like fish, and its consumers like birds and humans, becoming more and more toxic with increasing concentrations. According to a researcher at the University of Plymouth, up to 700,000 micro-fibres can shed from a 6 kg household load of textiles. And thus every time you chuck that skirt in for a wash, you plot for death of aquatic life across an acre of ocean.

Rachel Miller and The Cora Ball

So what is the way out? Should we go back to the Stone-Age and live off bark skin and leaves and discard textiles totally? Well that might be a nice way to spend a summer afternoon but definitely isn't practical enough for today's life. However, a certain **Rachel Miller** wasn't ready to sit with her hands on her lap. A marine archaeologist and a windsurfing instructor went to help clean up an island off the coast of Maine in the north-east of the US in 2009. There had been a heavy storm, and she found the beach covered in debris, most of which was washed-up fishing gear. And that made the film-roll click into place and Rachel made up her mind to make a difference – prevent plastics from ever reaching the ocean. And that brings us to Miller's big reveal – the **Cora ball**. While it looks something you will buy to your kid from a toy shop, it does more than it shows. Cora Ball's surface is made up of coral-like stalks which trap microfibers while water flows through it. Coral reefs and sea anemones have tentacles with surface adhesion properties on the surface, mechanical

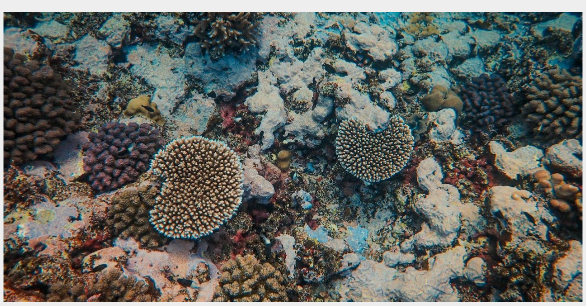

Fig 1: Coral Structures in the ocean. Miller's team found inspiration in nature, specifically the structure of coral, to design Cora Ball, which captures microfibers while allowing water to flow through. Coral's unique anatomy guided their design. [Photo by Francesco Ungaro]

Fig 2: Cora Ball prevents fiber shedding from clothes, extending their lifespan and reducing microplastic pollution in our waterways. The Cora Ball's hydrodynamics are inspired from the motion of Coral Reefs to trap food particles from the ocean water

Fig 3: Rachel Miller — A visionary environmentalist driven by a passion for ocean conservation. She has a bachelor of arts in anthropology (underwater archaeology) from Brown University 1993 and is a USCG Captain with an endorsement for auxiliary sail.

Fig 4: The Cora Ball team, from the left: Brooke Winslow, James R. Lyne and Rachel Miller. Rachael, James and technical designer Brooke Winslow joined together to create Cora Ball and launched on Kickstarter in 2017

motion of which helps to filter and trap food particles from ocean water. Inspired from the same, the Cora Ball's stalks deploy turbulence and speed fluctuation hydrodynamics which makes the circulating water **filter out the microfibers**.

The Cora Ball is easy to use as well. You have to put it into the washing machine along with the laundry and as your clothes get washed the Cora Ball **traps the microfiber** breaking off from the textiles as well as hair stuck to the clothes from the circulating water and stores it in its complex branching morphology. And as you open the lid, you take the Cora Ball out with the pollutants including textile fibre and shed fur and hair stuck to it .

Impact

The Cora Ball can be easily cleaned by parting the stalks and removing the fibre mass and discarding it into the trash. The Cora Ball also doesn't have to be cleaned every day. The fibres need to be removed only when it becomes a sizeable mass. With the Cora Ball you ensure that microfibers do not get carried to water bodies and prevent harm to the aquatic life and the ecosystem as a whole. Later the Cora Ball is to be cleaned and becomes ready for future use again. Miller claims that even if **just 10% of US households** used the Cora Ball it would prevent an equivalent of 30 million water bottles from washing into public water bodies every year. It reduces microfiber pollution by 31% as the numbers suggest. Although it is not yet available in every country including India but Miller and her team aspire to soon turn over this fact and make Cora Ball available to combat micro-fibre pollution globally.

Be it London's Imperial College or Miller's own Rozalia Project, people miles apart work in unison to reduce microfibers from entering the sea. This blue ball which works wonders shows how ingeniously one can make a small difference every day, through the simplest of mechanics. What started as a one-room project is in the BBC news today, with a potential of saving millions of lives. And with this words of Fullerene come to mind, "The only way to predict your future is to design it." Happy wondering!

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Sharanya Chatterjee is a second year student of IISER Kolkata and an aspiring researcher who is passionate in the field of neuroscience, developmental biology and its manifestations. She believes in responsible research facets. Habitually reads 'maybe nots' as 'maybes'.

In Conversation with Dr.Chandra Shekhar Sharma

Swarnendu Saha (IISER Kolkata)

What does it take to become a professor at an IIT before even defending your PhD? In this captivating conversation, Prof. Chandra Shekhar Sharma from IIT Hyderabad shares his unconventional academic journey, the evolving landscape of Indian higher education, and the pivotal role of young scientists in shaping research and policy. From navigating academia without a postdoc to leading global scientific communities, his insights challenge traditional career trajectories. He also unpacks how IIT Hyderabad's innovative curriculum is redefining interdisciplinary education and fostering entrepreneurship. Whether you're an aspiring researcher or just curious about the future of science in India, this dialogue offers invaluable lessons on ambition, adaptability, and making an impact!

SS: Good afternoon sir. I am Swarnendu Saha from team InScight and it is nice to have you here. I plan to discuss some of your scientific background, your scientific journey and your journey with the INYAS. So to start with, where do you come from and how did you reach here? Where you are today?

CSS: Hi. I am Chandra Shekhar Sharma, currently Professor in Chemical Engineering at IIT Hyderabad and I did my B. Tech from Aligarh Muslim University (AMU) in Chemical Engineering itself. In fact, I did my doctoral studies directly after the B. Tech.

So, I didn't do my master's. After my Bachelor's, I did a job for almost a year in one of the CSIR labs. During that time, there was a special program on CSIR research internship. So, that is how I was in CSIR, National Metallurgical Laboratory in Jamshedpur, for almost a year in 2004.

And since then, I joined the PhD program at IIT Kanpur directly after B. Tech and completed PhD in 2010 and immediately after finishing the PhD, I joined IIT Hyderabad as a faculty in the department of chemical engineering. In fact, it was kind of a rare occasion when I received the faculty position offer from IIT Hyderabad without even formally submitting my PhD thesis.

SS: Really ?

CSS: Yeah, so, I mean, I got the faculty position offer in May 2010, while I submitted my PhD thesis in October 2010. And in December finally, I joined the institute and I defended my PhD after four months. So, I defended my PhD thesis after 2011, but I started guiding a PhD student from January 2011. So, that is how it was. (laughs !)

And yeah, I think it is a long journey now. I mean, it has been almost 14 years in IIT Hyderabad and now I am currently a professor there for the last two years. So, that is my professional journey. I joined the Indian Young Academy of Sciences(INYAS) as a member in 2017. This was the third batch because when the INYAS, was founded in 2014 and first batch of membership was in 2016 and then 79 joined. And later I became the chair of Indian Young Academy of Sciences from 2020 to 2022. Then I also became a member of Global Young Academy in 2020 and that is where I currently represent Global Young Academy as its co-chair. And this is only the second time that India has been honored with the co-chair, our founding chair of INYAS Dr. Anindita Bhadra being the first one. She was also the first co-chair from India for the GYA and I am the second co-chair now for the Global Young Academy for 2024 to 2025.

Fig 1: Prof. Sharma did his PhD at Indian Institute of Technology (IIT) Kanpur directly after his B.Tech

Meanwhile, after becoming professor at IIT Hyderabad in 2022, I was then assigned the responsibility of a Dean of Research and Development, which I just completed in my two years tenure. So, I think that is my scientific and professional and leadership journey so far.

SS: So, sir, the first thing that struck me was that you joined IIT before completing the PhD. So, you did not have a post-doc period?

CSS: No, absolutely not. For a post-doc, as I said, I did not even submit my thesis.

SS: So, from a student like me who is going for a PhD, we always think if we have to find food in academia, research academia, it is a long journey. People tell us, if I have been frank, it is a long journey. So, from there, standing out as a rare example before us; how did it happen and how does it feel?

CSS: I consider myself lucky because, between 2008 and 2010, many new institutions were being established. In particular, the eight new IITs (Indian Institutes of Technology) started in 2008, and each of them was aggressively seeking to expand and recruit qualified faculty members. During this time, I was about to complete my PhD, so I decided to apply. To be honest, I thought, 'Let me apply and see what happens.' Generally, in India, by the time you apply, get shortlisted, and are called for an interview, it takes almost a year.

Assuming that it would take a while for the interview call to come, hopefully after I submitted my thesis, I decided to apply. However, things moved much faster than I expected. Within three months of submitting my application, I received the interview call. I was interviewed in March, and by May 1st, I was offered a faculty position. Of course, it was a conditional offer, subject to the completion of my PhD. But I think that's how things turned up, favorably. I believe I made the right decision to join immediately after my PhD. The experience I gained in those initial years, setting up my lab and building my team, was just as valuable as any postdoctoral experience could have been.

SS: My next question would be if you look back as an IIT student and today as an IIT teacher, what similarities and differences are defined because you are from an IIT which

needs no introduction, the IIT comfort. But frankly speaking, you are now in IIT which is much newer compared to even 50 years, not even 25 years. So, I mean what legacy IITs have for the previous seven IITs. So, I mean what differences and similarities do you find and then from the fun point, from the bench to the chair, How do you just change direction?

CSS: I think it's an interesting question because I was a PhD student at IIT Kanpur and then joined a new IIT that was still in the process of being established at the time. So, yes, there are a lot of differences, as well as similarities, and I would consider both aspects.

Of course, when you come from an established IIT like IIT Bombay, you have certain advantages: the reputation of the institute, the guidance from well-established professors, and the legacy that the institute creates. These advantages are definitely there when you come from older IITs.

However, when I reflect on my journey at IIT Hyderabad over the past 14 years, where I've graduated 17 PhD students—many of whom are now faculty in various IITs—I see both sides. While my students, as graduates of a new IIT, did not have the legacy or institutional reputation, they gained something equally valuable. If they worked on challenging problems, published quality papers, and most importantly, had access to the R&D infrastructure that these new institutes provide, they were at an advantage in certain ways.

For instance, at IIT Hyderabad, we have state-of-the-art research facilities, which in some cases, may even surpass those of older IITs. This infrastructure provides a significant edge, so if students are working on the right problems and publishing quality research, they can compensate for the disadvantage of institutional legacy.

Not only in my group, but I have seen many PhD students from IIT Hyderabad, even after 16 years, securing faculty positions not just in IITs but also in top institutions globally.

Fig 2: Prof. Sharma was a visiting research scholar at the UC Irvine

This clearly indicates that even as a newer institute, IIT Hyderabad has its own advantages.

I believe one should focus on the positive aspects rather than worrying about what can't be changed. Yes, IIT Hyderabad is 16 years old now, but that's something beyond our control. What we can control is how we leverage the best facilities, the new campus, and the positive research environment to do better science and better research, so we can be just as competitive as graduates from any other IIT.

SS: These days, we often discuss interdisciplinary work, especially in fields like basic sciences or, in my case, applied sciences. I had the opportunity to do an internship at IIT Roorkee, and I also spent a few days at IIT Kanpur and one day at IIT Delhi. When you look at the older IITs, they have many departments, schools, and research centers, and each of them often works independently, as they should. But the challenge is that, with the sheer number and diversity of these units, it can sometimes become difficult to achieve a truly holistic approach.

In contrast, for newer IITs like IIT Hyderabad, if someone unfamiliar with the institute looks at its website, they may notice that the number of faculties, centers, and departments is relatively smaller. The facilities might seem fewer compared to the older, more established IITs. In light of this, what is your opinion on this situation? How do you think the newer IITs manage to stay competitive and successful despite these differences?

CSS: From my own experience at IIT Hyderabad, I can confidently say that being a new institution, we definitely have certain advantages. For example, at IIT Hyderabad, we've introduced several innovations in both academics and research. Let me share a few examples.

In academics, we don't follow the regular semester system. Instead, we've divided the semester into three segments, and most of our courses are not semester-long. We call this approach *fractal academics*. The idea behind it is to introduce emerging areas of study to students, especially in the B.Tech program, without the limitations of traditional credit systems. For instance, we break down certain courses into smaller modules, which allows us to free up credits for more advanced courses.

In the traditional system, there are core courses like electrical engineering or computer science, which might not be as relevant today. We minimized these courses and introduced more new, interdisciplinary ones. Additionally, we give students the flexibility to dive deeper into subjects of their interest, something not typically possible under conventional semester systems.

This approach helped us revamp our curriculum, addressing new challenges while providing students with greater flexibility in choosing their courses based on their interests.

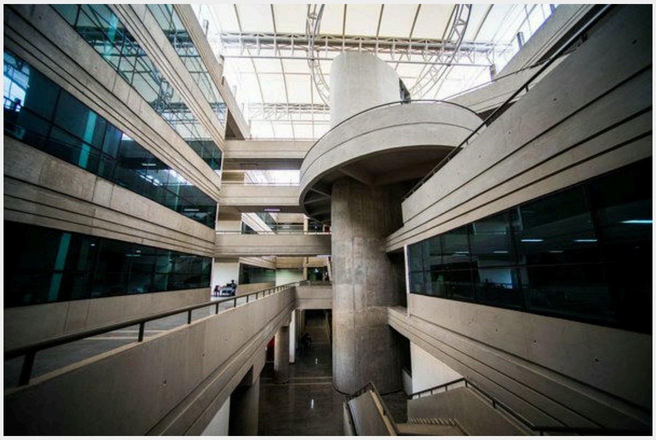


Fig 3: Prof. Sharma joined as a faculty at Indian Institute of Technology (IIT) Hyderabad in the department of Chemical Engineering even before formally submitting his PhD thesis

We've also introduced several new initiatives focused on interdisciplinary research. For example, in our PhD program, we have an interdisciplinary track where two faculty members from different departments collaborate on a project. The students join a center for interdisciplinary programs and work under the joint supervision of two professors. These students are not bound to any specific department, which promotes more collaboration across disciplines. This model is different from the traditional co-supervision approach, where one professor is primarily responsible. Both faculty members are equally responsible for guiding the student.

Such initiatives would have been challenging to implement in older IITs due to their more rigid systems. Being a new institution without legacy constraints has allowed us to experiment with innovative ideas in both academics and research.

SS: Sir, you are saying that the IIT Hyderabad design is meant mainly for the manufacturing industry.

CSS: Yeah.

SS: So, should we term that as core subject or non-core?

CSS: It's a B.Tech program, a complete B.Tech program in Computer Engineering.

SS: When I was about to join an institute, we were giving JEE Mains, JEE Advanced, and NEET exams. During that time, we were asked mainly which subjects we were interested in. Given the variety of subjects, the first screening often came down to whether the subject was considered 'core' or 'non-core.' To me, core subjects meant electrical, mechanical, and civil engineering, while the rest were seen as non-core. Some people believed core subjects would always have a lot of job opportunities because they're foundational, while others argued that those are outdated, relics of the past.

In today's world, people often say that yesterday belonged to Electrical Engineering and today belongs to fields like Quantum Computing and Artificial Intelligence. Considering this shift, IIT Hyderabad is introducing a program aimed at the manufacturing industry and is ranked third in innovation. This challenges the traditional view that everything is shifting to electronics or online industries. From that perspective, how do you see the future of core vs. non-core subjects? Do you think the boundaries between them are becoming more blurred, or is there still a clear distinction?

CSS: I think saying that everything will be online or AI-based is not entirely accurate. In my opinion, there are core areas like the manufacturing industry that cannot be overlooked. The Government of India's vision to make India a 'Viksit Bharat' by 2047 is built around this idea. If we look at any developed country—like the US, Germany, or Japan—they all have strong manufacturing industries at their core. No country can truly develop without focusing on this sector.

With all due respect to the IT sector, we cannot become a superpower or a developed nation just because of it. The manufacturing industry needs to grow. Initiatives like 'Make in India,' 'Digital India,' and others are focused on this very sector. For example, the government has already launched the Semiconductor Mission, with plans to manufacture semiconductor chips in India within the next few years. But here's the question: where do we have the skilled manpower for this?

This brings me to IIT Hyderabad's perspective. Two years ago, we started a B.Tech program in IC Design and Manufacturing. We're the only IIT to have introduced this program, with a view to meeting the future demands of the semiconductor industry. I'm happy to share that the All India Council for Technical Education (AICTE) has recognized our initiative and adopted our curriculum for this program. As a result, last year, over 100 engineering colleges across India began offering

Fig 4: Prof. Chandra Shekhar Sharma's Carbon Laboratory, IIT Hyderabad

similar B.Tech programs.

So, if we aim to develop the semiconductor manufacturing industry, we need to prepare our engineers accordingly. Right now, we lack skilled professionals in this domain. This is why we introduced this specialized B.Tech program in semiconductors.

SS: Now the question comes that the manufacturing industry needs experts that the UG course is making. Now the fact is that, if we come out of academics, India is a country whose borders are very fine with very good neighbors (smiling!!). So we have to spend a good amount on defense. India is a country which has a huge number of stomachs to fill. So we need agriculture and then agriculture based industries. India is a country to feed, we have to export. So there has to be stuff that has to be exported. Now, are those students capable enough to go to any industry that requires them or still they are tailored for some specific?

CSS: When we talk about this B.Tech program in computational engineering or the manufacturing industry, it's not limited to a specific sector. It can cater to multiple sectors like defense, healthcare, and agriculture, which are crucial today. With the rise of AI, it's important to understand that AI is a tool, but it needs to be applied with subject knowledge. For instance, to apply AI in healthcare, you must have a background in healthcare, or in agriculture, a basic understanding of agriculture is essential.

B.Tech programs in computer science provide knowledge in software, hardware, and programming, but they often lack the depth in core subjects. This program, which combines core subject knowledge with computational and AI tools, offers a much stronger foundation for future jobs, especially in the manufacturing industry.

At IIT Hyderabad, we recognized the importance of AI early on. We were the first institute in India to introduce a B.Tech in AI and, globally, we were the third after Carnegie Mellon and Stanford. Our vision is broader, and that's why, alongside the B.Tech in semiconductors and computational engineering, we also introduced the B.Tech program in AI.

This AI program isn't just about computer science or AI faculty. We involved experts from various departments like biotechnology, chemical engineering, materials science, and mechanical engineering, who are conducting AI-related research. AI today is highly interdisciplinary, and its effectiveness increases when combined with subject-specific knowledge. For instance, industries often look for AI expertise in specific sectors like pharma or defense, and that's where we need people with both core knowledge and AI skills.

SS: My next question may not come across positively, but given the global scenario and specifically the current situation in India, we've been hearing that IIT Bombay is considered the most coveted institute, followed by IIT Kanpur, IIT Kharagpur, and IIT Delhi. In recent years, it's been observed that about 70-80% of students are getting selected for IIT Bombay, while the rest are not, which seems very concerning. This situation feels unacceptable in our society. While it's understood that not everything can be 100% distributed, the fact that IITs have always been seen as paragons of excellence, and are now seeming to fall short, raises a question.

Do you think this decline is due to the changing global landscape, or is it that the brightest minds are no longer choosing to stay in India? Or, is it that IITs themselves are not producing the best anymore? How do you interpret this situation? It's not something that's viewed positively, whether at the government level, among students, peers, or industry.

CSS: See, I think we need to look at this scenario from a broader perspective. When we talk about placements, the 70-80% you mentioned doesn't mean that the remaining 20% aren't doing anything. Over the past 5 to 10 years, there has been a significant rise in startups, many of which are led by our youth, including B.Tech students. At IIT Hyderabad, for example, there are students in their second or third years running their own startups and even employing others. This highlights that not all students who don't get placed in traditional jobs are without opportunities.

The landscape has shifted. Many students are now pursuing entrepreneurship, higher studies, or unique career paths that don't always fit the traditional placement model. While the number of students opting for higher studies has reduced over the years, it's a positive shift, especially after addressing the brain drain concerns. The focus is no longer just on finding a job after B.Tech or pursuing higher studies.

Even for those completing a Ph.D., the mindset has evolved. It's no longer just about joining academia; there are opportunities in R&D, science administration, science communication, and science journalism, which are becoming more attractive career paths.

So, if we look at this from a broader perspective, I believe no IIT graduate is without a career path. The options are more diverse than ever before.

SS: You have been Dean R&D.

CSS: Yes.

SS: So you have been in academic administration. The fact is that being a professor just with his students and lab and being in the administration, how do the two chairs differ?

CSS: I believe there's a difference of opinion regarding the timing of transitioning into science administration. Some say one should focus on research early on and move to administration later in their career. However, my perspective is different. Through my experience with INYAS, I've realized that young scientists often face challenges that are best understood and handled by their peers. If you identify issues that you feel strongly about, I believe you should step into administration, rather than blame the system or the seniors. By doing so, you can make a positive contribution and help bring about change.

When I became a professor, my director asked me to take on the role of Dean of R&D at IIT Hyderabad. At the time, we had over 2,000 projects, and this number has grown to nearly 4,000. Managing this growth came with significant challenges, especially given the changing policies and funding sources. For me, administration became a full-time job, but it didn't negatively impact my research. In fact, I published more papers than I had in previous years, largely due to the 14 years I spent in the lab earlier in my career.

I had support from postdocs and senior PhD students, which helped balance both roles. I prioritized administration during weekdays but dedicated weekends and evenings to my research. My students were supportive, knowing the demands of my administration role, which I greatly appreciated.

Being involved in administration, especially as Chair of INYAS during the pandemic, gave me a broader perspective, which in turn made me a better researcher. Even as a researcher, you need leadership skills to manage diverse teams. My experience in administration helped me develop those skills. While you must prioritize one role over the other at times, I believe these two aspects—research and administration—are complementary, and being involved in both can make you a more well-rounded professional.

SS: And now, I will give you a small problem to solve. What you told me is two months, two and a half months long.

Fig 5: Meeting with ISRO chairman Dr. Somanath to strengthen the research cooperation between IIT Hyderabad & ISRO, with Prof. Chandra Shekhar Sharma

Let's imagine a scenario: A student from Central University of South Bihar gets an opportunity to work at IIT Hyderabad. He dedicates around two and a half months, working diligently on computational tasks and basic research, while also continuing his studies back at the university. By the end of August, he completes his work, and by December, a paper is fully ready for submission. By God's grace, he gets the chance to present this paper at a conference in Germany.

However, there's a catch. The university, being less lucrative compared to IITs, might not have the funds to support his travel. Moreover, since he is an undergraduate, he is not eligible for SERB or similar research funding programs.

Given that he is not an IIT student, how can he secure the money required to travel?

CSS: Yeah, I think you have a very valid point. And I totally support this, that we should have a more structured way of supporting those students.

And this number is not very big, but I think this is very important. So, I mean, thanks for bringing this point, highlighting this point. And I totally agree with that.

And well, right now, I am not in that. But yes, I think whenever I will get an opportunity to look into this matter from the institute point of view, or maybe at the national level, where I am part of some committees, I will definitely try to come up with some structured policy. Or maybe something like from the science academies, where we can have some kind of financial allotment for such students, undergraduate students to present their work, because you are right, that there are structured programs for the opportunities for the PhD students, but not for the undergraduate students.

So, but I agree, I mean, this has to be looked into. And it is more like a policy matter. But given the kind of discussions and given the kind of focus these days on undergraduate research, I am sure very soon we should be having this thing in place, at least at an institute level. So, that is what I can say right now.

SS: Can you please explain briefly what INYAS and GYA are?

CSS: See, INYAS, it stands for Indian National Young Academy of Sciences. It was established in 2014 by the senior academy, Indian National Science Academy, which is one of the oldest academies in the country. So, they came up with the idea in 2014 that young scientists should be having a separate exclusive platform where their voices can be heard, where they can also get some chances to network among the young scientists and also importantly contribute towards the science outreach, science promotion.

That is how this young academy was established in 2014 and I came to Kolkata for this media meeting of INYAS, which is

Fig 6: INYAS's Mid Year Meeting (MYM-2024) and Technical Symposium on 'Empowering Young: Leveraging Science and Technology for Sustainable Development' on 26 September, 2024 at IISER Kolkata

now celebrating its 10th year, because 2014 and this is 2024. And in the last 10 years, INYS activities, if you see, I think we have done exceedingly well.

Coming to the Global Young Academy, this is also like another young academy, but it is having a global nature. It is connected with more than 100 countries and it is headquartered in Germany. It is supported by the German Academy of Sciences, Leopoldina, administratively and partially financially as well.

And as I said, Global Young Academy has representatives or membership from more than 100 countries. So, obviously, the perspective of the issues of young scientists in the Global Young Academy is much broader.

SS: As a professor or scientific administrator, do you think the problems I've presented can be controlled, partially addressed, or alleviated within the academic system? Specifically, if we focus on the "young" demographic, including undergraduate students (and even postgraduate students or PhDs), who often face challenges despite some funding opportunities—how can we address these issues? Is there a way to encapsulate or reform these community-based systems to better support them?

CSS: Especially when you look at the Indian National Academy of Sciences (INSA) during my tenure as chair from 2020 to 2022, my major focus was to expand the Academy's activities in Yash to encompass a broader understanding of young scientists. We started this initiative in 2014, and at that time, the focus was primarily on school students. However, we gradually expanded the scope of our activities.

If you look at today's situation, we have several flagship events that cater to different segments. We are focusing on school students, rural teachers, and training those teachers to further educate their students. We also have programs for PhD students, postdocs, and early career researchers—what we often refer to as *"young scientists"*. Additionally, we've introduced separate flagship events specifically for women scientists, covering various stages of their careers, from college to PhD to postdocs.

Over the past five to six years, we've significantly expanded our activities. As I've mentioned, there's still a lot more to be done. I'm confident that in the coming years, we will continue to grow and become a strong voice for young scientists. When I say *"young scientists"*, I'm referring to everyone from school students to independent early career researchers.

With such a wide target audience, our initiatives have been impactful, but of course, there's always room for improvement. These academies are dedicated to supporting young scientists, and yes, there is an age limit for participation, but we are continuously working to ensure inclusivity and broader representation.

SS: Apart from these in the very basic nature or the mode of operation, how does the Indian Academy of Science, Indian National Science Academy and the third National Science Academy, the three in Delhi, Allahabad and Bangalore are different from INYAS ?

CSS: As I mentioned earlier, our mandate primarily focuses on young scientists, which, for us, includes everyone from school students to college students, to PhDs, postdocs, and early career researchers. In contrast, INSA (Indian National Science Academy) in Delhi has a mandate that is more centered on the international representation of Indian scientists on the global stage. We also have the National Academy of Sciences, which focuses primarily on science outreach, especially in schools. The Indian Academy of Sciences, on the other hand, operates more as a publication space.

When we look at these three academies, what was missing was a dedicated focus on young scientists. This is where INYAS came in and bridge that gap. When we started, we were advised by senior academies not to overlap with their programs, which was completely fine. I believe there was enough room and sector for us to work in, and we've been able to effectively address the needs of this space.

This is where INYAS stands out. When we talk about the fellowships from these other academies, they typically go to very senior scientists—50+ years old, I'd say. Of course, they bring invaluable experience and wisdom, but to execute visions and turn them into reality, you need energy, you need enthusiasm. And that's where young scientists come in. This is the distinct difference that INYAS brings compared to the other academies.

SS: Okay. So, I will come out of the jargon and basic question, why did you become a scientist? You could have become something else.

CSS: Yes, you're right. If I look back, I can say that throughout my life, I always had an inclination toward academics. By academics, I mean being a scientist or a professor. That's what I wanted to pursue. I had a deep interest in chemistry during my +2, as many students do, and like most of them, I thought that chemistry and chemical engineering were quite similar fields. But, as I later learned, that's not quite true!

When I was doing my +2 at Aligarh Muslim University (AMU), I would pass by the chemical engineering department, and it was like a dream to study in that department. That's when I decided to pursue chemical engineering at the B.Tech level in AMU. At the time, my parents weren't very supportive, as chemical engineering wasn't considered as prestigious as mechanical or electrical engineering. I had the option to switch to mechanical or electrical, but I decided to stick with chemical engineering, and I think it was the best decision I made. When you make your own decisions, you put in extra effort to make them work.

It was during my time in chemical engineering that I found my true interest in academics. After completing my B.Tech, I was clear that I wanted to pursue a PhD, so I didn't go for a master's. When I got the opportunity to work at the CSIR lab in the National Metallurgical Laboratory (NML), I thought it would be great exposure to research, which would complement my PhD aspirations.

Once I was in the PhD program, I was still focused on academia. However, I never imagined at that time that I would be joining the academic staff at an IIT. By the time I was 30 or 40, I started looking into post-PhD opportunities. Working at IITs showed me that academics and research are deeply interconnected. Although my primary interest was always in teaching, I developed a strong interest in research as well. I believe IITs are the best place where one can balance both academic teaching and research. I got the opportunity to do this for three years, and it was a very fulfilling experience.

Fig 7: Prof. Sharma did his B.Tech in Chemical Engineering at Aligarh Muslim University (AMU)

SS: You mentioned that your goal was always to pursue academics. However, in India, a long-term career in academics is often not considered very lucrative. What made you choose it? What were the consequences of that choice for you?

CSS: Yes, absolutely. You're right. When I completed my B.Tech and shared that I wanted to pursue a PhD, my family wasn't very supportive, to be honest. Especially, as you mentioned, coming from UP, the typical expectation after completing BTech was to get a job. And that's what most of my BTech friends did.

I graduated in 2003, and it was the time when the IT sector was booming. Companies like Infosys would come to campus for mass recruitment drives. It was the perfect time to secure a job, but I never attended any placement sessions in my life.

Looking back, one thing that truly shaped my career is that I started making my own decisions about my future right after 10th grade. I was very clear about my path. After 10th, I was in the state board, and then I joined Aligarh Muslim University. There, I had to choose between mathematics and biology. I was sure I wanted to go for mathematics because I had a strong interest in it.

In +2, my inclination towards chemistry became even stronger, and that's why I decided to pursue chemical engineering. While my parents weren't supportive of chemical engineering—mainly because it wasn't as well recognized for job prospects—I stood firm in my decision. Again, I took ownership of my choice and committed to it, despite the challenges.

Similarly, when I decided to pursue a PhD, my parents weren't in favor of it either. Yes, there was resistance, but I knew I could handle it because I was confident in my decision. Clarity of thought, especially at an early stage, is crucial. It's something that's been incredibly helpful to me in my career.

SS: In your PhD, you had funding, right?

CSS: Yeah. And it was nothing, it was so less as compared to my other batchmates who did jobs after B.Tech. Okay. They were earning much higher than what I used to get as a stipend in the PhD.

SS: But you didn't have to take money from your parents?

CSS: Yes, that's true.

SS: And you had the occasion of being a teacher, at least getting appointed before you got the PhD degree in hand. So, that was some kind of answer to anyone who is questioning you.

CSS: Well, I wouldn't say it was wrong, because when I look at it from a family perspective, I can now relate as a father of three daughters myself. Parents are always looking for the safest and least risky path for their children. In that sense, they are right from their perspective, just as I was right from mine. It's a matter of how you convince them, and before you can do that, you need to convince yourself first.

That's where clarity of thought and self-confidence become crucial. If you're not clear about your decision, you won't be able to convince others. I was able to convince my family, though it took time. Eventually, they were fine with it, but yes, there was initial backlash.

SS: Okay, so, last question, any final comments for the students and readers?

CSS: See, based on my own experience, my own journey, I must say that two things, one is *follow your dreams*, follow your passion.

And secondly, have the clarity of thoughts in mind as early as possible because if you are confused, you will not be able to give your 100%. So, and to bring that clarity, you have to be aware of your surroundings. Like what is going on? What are the career options?

And these days, there are so many non-conventional career options that are emerging. And if you follow your passion, if you follow your dreams in that line, I think you will do much better.

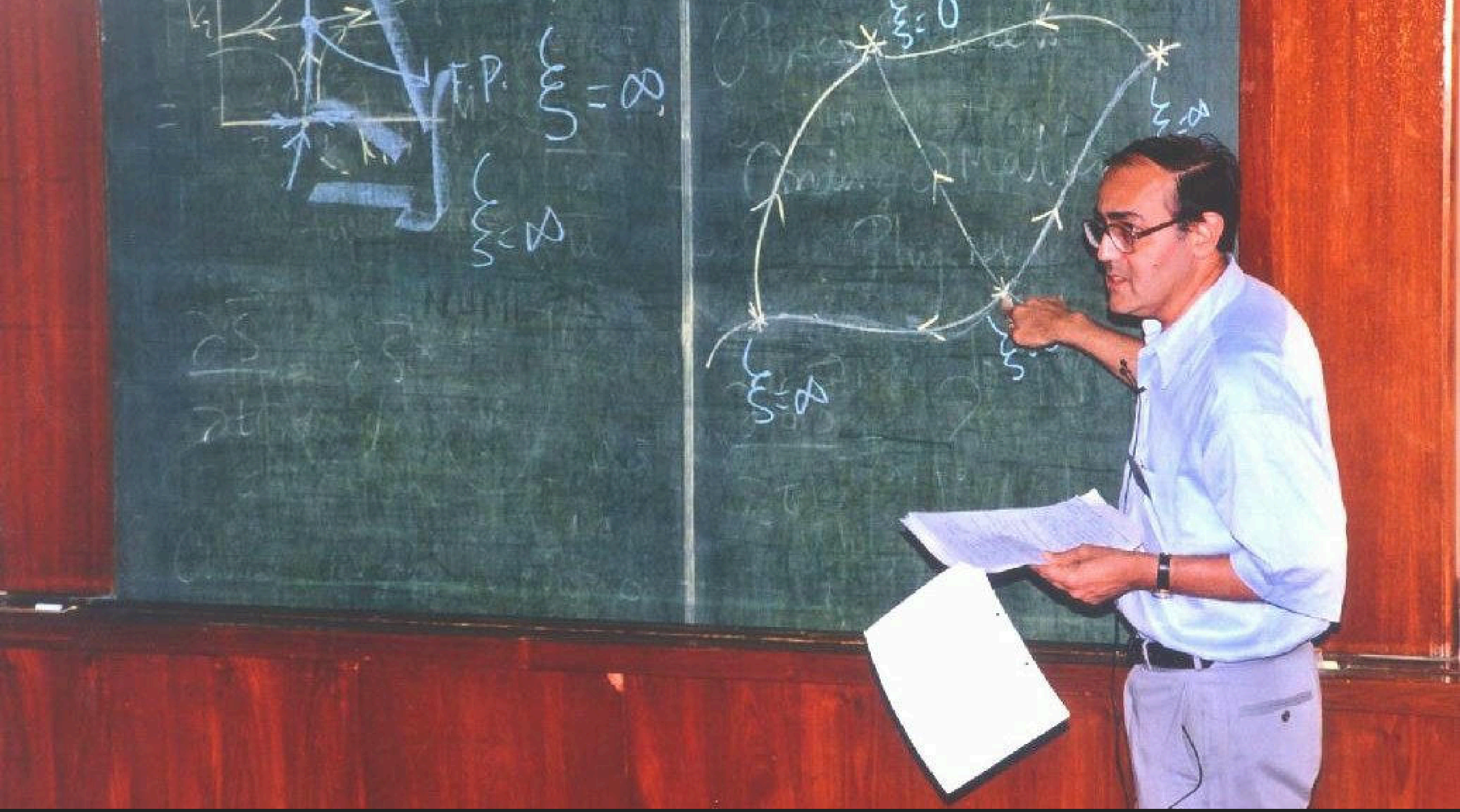
So, I think the first thing is to have clarity. Second, once you have clarity, follow it, follow your passion, follow your dreams. At a certain point of time, you may have to go against your peers, your parents, so be it.

I am sure that if you follow and you are successful in that, I am sure of the chances and obviously the parents and others will also be in line with that. So, that is what I would say.

SS: Thank you, sir. It was nice talking to you.

CSS: Thank you.

Fig 8: Prof. Chandra Shekhar Sharma with his lab group (CARBON Laboratory, IIT Hyderabad)



In Conversation with Prof. Mustansir Barma

Swarnendu Saha (IISER Kolkata)

What sparks a lifelong passion for physics—and what does it take to lead one of India's premier scientific institutions? In this rich and wide-ranging conversation, Prof. Mustansir Barma opens up about his journey from a curious schoolboy writing letters to textbook authors to becoming a celebrated physicist and the founding director of TIFR Hyderabad. He reflects on the essence of randomness, the beauty of phase transitions, the art of asking questions, and the quiet power of effective leadership.

SS: Good morning sir. I am Swarnandu Shah from InScight. First things first, are you from Bombay?

MB: Yeah, I was born in Bombay. For the last 9 years or so, I have been at TIFR Hyderabad.

SS: You studied at St. Xavier's College, Mumbai, if I am not wrong, after which you went to the United States.

MB: Yeah, I went to the State University of New York at Stony Brook.

SS: I would like to know how you reached the position you are today, in the academic sphere. Were you inspired by your family, or was it more of an accident?

MB: Yeah, so it's like this. I had an interest in physics. I want to tell you about my school days because I will tell you about an incident from my school days.

What happened is that we had a textbook on light and there was a statement there that if you have two parallel mirrors and a candle in between, you will get an infinite number of images. Now, I sort of found that not quite right in that light has a finite speed of propagation. So, if we put the candle there, there would be reflection from one mirror to the other and soon.

So, the number of images will keep increasing in time but in a very short time, there will be no image because the light has not gone and come back. I wrote to the author. At that time we were in the 1950s, this was an English book. So, this person was in England. I wrote to him and he wrote back a nice letter saying that he is glad that I read my books and think about what is written and he sort of agreed with me that in a finite time, you won't have an infinite number of images.

So, that incident sort of sparked my confidence and then there were many other things in school and college. So, I really wanted to take up physics. Now, when I told this to my parents, my father was actually quite supportive for various reasons. When he was young, he had done engineering but he was asked to step into the family business because his father passed away. So, he had a sympathy for people who wanted to do academics. So, that is how I have done it.

SS: Now, coming to science, you work in statistical physics. When I as a layperson hear the word random, I do have some idea of what that means. But to a practising physicist such as you, what does randomness really mean?

MB: Randomness means to me the same thing that it means to everybody else. Something that is not predictable because it could be this way or that way. There are options and there might be different probabilities or different options so that you cannot be sure which one will happen.

So, that is what I would say is the characteristic of randomness. You are not sure of what will happen in time.

Randomness in space, we all have an intuitive idea - things are scattered without any pattern or arrangement, you know. So, my idea of randomness is the same as anybody else's, I think.

SS: So, if we could find out a mechanism to determine which one is going to be picked, then do you think this concept of randomness will become redundant?

MB: Not in such a sweeping sense but it is also true. See, there could be some things that are intrinsically random like nuclear decay which involves beta particle emission - from one emission to the next, it is truly random. There are other things which are effectively so random that you, I mean, well, which are effectively very well described as random.

For instance, when you toss a coin, you know it will end up as heads or tails and the question is why do we think of it as equally probable? Well, that is because actually as we know the laws of physics including, I mean, involving classical mechanics should determine exactly what the outcome would be - either heads or tails. But it is complicated enough that effectively indeed it is a random process.

So, what I am trying to say is that things that are complicated though intrinsically described by deterministic equations will effectively be random. People should use effective descriptions and the reason is very simple - because they are simpler. Any description that is simpler is good and useful and certainly, effective randomness is an example.

SS: I understand. My next question relates to how we traditionally learn about phase transitions in school. We are

Fig 1: Mustansir Barma accepting the INSA (Indian National Science Academy) medal for Young Scientists in 1980. [Source TIFR H]

taught that given a temperature and pressure, ice changes to water, and water changes to vapor as temperature increases. However, we often overlook the role of pressure. While temperature is the primary factor we focus on, a slight change in pressure near the triple point—even while keeping the temperature constant—can prevent a phase transition from occurring. The fundamental idea remains that once a certain boundary is crossed, a phase transition takes place.

MB: That's an interesting point. When we talk about phase boundaries, particularly the transition between liquid and vapor, we see that this boundary terminates at a critical point. However, the solid-liquid boundary behaves differently—it does not end at a critical point but rather continues indefinitely. The reason lies in symmetry considerations.

Liquid and vapor phases share the same symmetry—both are homogeneous and isotropic. This allows for the existence of a critical point where the phase boundary terminates. However, the solid phase has a fundamentally different symmetry. In a solid, atoms are arranged in a structured manner, meaning it breaks continuous translational symmetry. This broken symmetry prevents the solid-liquid transition from terminating at a critical point because, if it did, one could theoretically move around the phase diagram and bypass the phase transition entirely, which is not physically possible.

A particularly fascinating case is water under high pressure. Unlike many other substances, water exhibits multiple solid phases, meaning that at very high pressures, the phase diagram becomes highly complex, with over 10–11 different solid phases discovered so far. Each phase is separated by its own phase boundary, creating a web of phase transitions rather than a simple linear boundary.

This concept of symmetry-driven phase behavior is fundamental in statistical physics and quantum mechanics, and it was originally formulated by Lev Landau. His argument explains why phase boundaries can terminate at a critical point only if the phases involved share the same symmetry—as seen in the liquid-vapor transition. However, for solid-liquid transitions, where symmetry fundamentally differs, such a termination is not possible.

SS: Let me try to understand this from a different angle. You mentioned earlier that in theory, for a very short time interval after I place the candle, there is no image of it on the mirror. In the same way, if I consider the system over a very short time interval, there will be a region where the phase is morphing. Can you please explain or help me visualize what exactly is happening there?

MB: Well, the first thing is that you must understand what is meant by this temperature, pressure phase diagram and what it is referring to is phases which have reached equilibrium. So, the diagram with pressure and temperature and so on applies only to equilibrium phases of matter. Now, equilibrium is a state which is reached in principle if you wait very very long - you have to wait really long for a system to reach equilibrium and for example, if you change the temperature, it takes some time for the system to equilibrate.

So, the diagram, that phase diagram applies only to phases and systems which are actually in equilibrium. The moment you say that you do something and for a time, short or you know finite time, the system may or may not have reached equilibrium in that time, it probably would not, I mean it is a very short time and so this diagram on its own will not apply, but the fact is that as time goes by, you will indeed transit to the other phase. So, the question you ask is actually very interesting and a matter of current research. How do you accomplish a phase transition, how does one phase change to another in time? The answers are also very nice and finally, very simple.

So, there are regions with phase 1 and regions of phase 2 and these are small if the time is low. As time passes, these regions grow, they are still not very very large, but they are bigger than they were and you can define if you like a typical droplet size. So, as time passes, that size increases.

When that size reaches the size of a container, you actually will finally reach equilibrium. So, that is the way one can imagine it.

SS: Thank you. My next question is about administration. You have served as the Director of Tata Institute of Fundamental Research (TIFR). How do you see the difference between a non-scientist administrative role with regular responsibilities and the role of a director, in a scientific institution?

MB: These two roles are very different, yet they are interconnected. As a director, my responsibilities extended across various aspects of the institute.

Fig 2: The then Prime Minister of India, Dr. Manmohan Singh, unveiled the foundation stone of the new TIFR Hyderabad campus in October 2010. [Credit: Mohd. Yousuf, The Hindu]

First and foremost, there is a responsibility towards the faculty, as well as the entire staff—administrative personnel, technical teams, gardening staff, and so on. The director oversees the well-being of everyone in the institute. Even small but meaningful changes, such as installing an air conditioner in a driver's cabin, can make a difference in creating a better working environment.

While these are administrative tasks, the director plays a crucial role in academics. The responsibility is not to dictate but to help define the direction the institute should take in research and education.

Personally, I found that the biggest support in this role came from two sources, i.e.,The Faculty – They are central to the institution, and their collaboration is crucial for the institute's growth and The Council of the Institute – In the case of TIFR, the council was chaired by Ratan Tata (which, though incidental, is notable). The council played a key role in providing critical oversight and guidance. It met four times a year and functioned similarly to a Board of Governors (BOG) in other institutions.

The director also has an external-facing role—securing funding and engaging with government bodies. Since TIFR operates under the Department of Atomic Energy, I had many interactions with government officials and funding agencies.

This is very different from the role of a researcher. As a researcher, I would be happy to teach, mentor a small group of students, and work on problems at a blackboard with chalk in hand. That is where my personal comfort lies. But a director's job is different.

One of the biggest challenges in leading an academic institution is managing highly talented, independent-minded individuals. Academics are known for their strong opinions, and everyone believes they are right—and often, they are, in different ways. The challenge for a director is to bring these different viewpoints together to shape a collective vision for the institution.

So yes, being a director is a very different experience, but fortunately, it is also a fulfilling one.

SS: How do you evaluate the present condition of academia in various countries - for science in general and research in particular? I don't have a more specific question regarding this, so I would just like to hear your thoughts on this.

MB: To assess the current situation, we must compare it with the past. So, I'll share my perspective by comparing today's scenario with the time when I returned to India from the United States.

I came back in 1976 and joined TIFR, first as a postdoc and later as a permanent faculty member. If I focus on physics, particularly condensed matter physics, the research environment back then was very different from what it is today. At that time, there were very few active research groups in India. It is difficult to imagine today, but back then, you could count all the major groups on your fingers—probably no more than ten. It was a challenging time, but also exciting in its own way. The DAE Solid State Physics Meeting was one of the very few academic gatherings in the country. Since there weren't many conferences, this meeting became the central hub where almost everyone working in condensed matter physics in India would come together. Travel was very different too. There were no frequent flights, so we relied on trains for travel. I remember collaborating with a researcher in Roorkee while I was in Bombay—and every interaction required significant logistical effort.

SS: Do you mean IIT Roorkee?

MB: There was no IIT in those days—it was the University of Roorkee. But yes, the same place.

Back then, travel was very different. To visit Roorkee, I would take the Dehradun Express, which slowly made its way through Delhi and reached Roorkee in about 36 hours. Today, that seems unimaginable—there were no direct flights, no quick alternatives, but we managed. We took trains all over the country, and that was just how things were.

Of course, that's not the main point. The real point is how different the academic landscape was. There were very few researchers, but it was still very enjoyable. We communicated by letters—no email, no instant messaging. And in some ways, that was actually a good thing. When you wrote a letter, you had time to think before responding. Today, emails create an expectation of immediate replies—within a couple of hours at most. But back then, you could take a week to reply, reflect on ideas, and engage more deeply. Compared to those days, things today are much faster and more interconnected. Collaborations are no longer limited by geography—they happen online, across institutions, and even across continents.

Fig 3: STATPHYS – Kolkata IX (2016): Abhishek Dhar, Sanjib Sabhapandit, Mustansir Barma, Sakuntala Chatterjee, Shamik Gupta. [Source TIFR H]

If I focus on my field, statistical physics, the transformation has been incredible. Today, India has one of the largest statistical physics communities in the world. That didn't happen overnight—it took years of meetings, training, holding schools, and community-building efforts. One of the best examples of this is the Annual Community Meeting, organized by the International Centre for Theoretical Sciences (ICTS) in Bangalore. It is a completely open forum, where everyone—no matter how senior or junior—gets just 10 minutes to speak. The idea is to foster inclusivity and ensure that everyone contributes.

Another major initiative by ICTS is the Annual Summer School, where they bring in top international speakers. Around 80–90 students participate each year, getting exposure to some of the best minds in the field. It's not just about learning from experts—it's also about impressing them with the quality of Indian research. There's no doubt that the research scenario in India has evolved dramatically. Opportunities have multiplied, and the landscape is far richer than before.

I once wrote about this in an article titled "An Evolving Landscape" for the Indian Association of Physics Teachers magazine. But that's beside the point—I'm happy to share these thoughts again because the transformation of science in India is something worth celebrating.

SS: What do you make of the present scenario regarding research funds in India?

MB: Research funding has its challenges. Due to the budget cycle, sometimes funds are not released exactly on time, but such delays have not been severe enough to disrupt the entire system. It is not as though salaries are suddenly cut in half or research is completely halted.

The government has been generally supportive of science—sometimes more, sometimes less. All institutions have aspirations: they want to grow, expand into new areas, and accommodate more students. However, it is not always possible for the government to support everything at the desired scale.

That said, if I compare today with the 1970s, the situation has greatly improved. Back then, traveling abroad to attend conferences was not possible frequently—perhaps once in a few years, not every year as it is for many researchers today.

Research funding today is better than in the past, but a judicious allocation of resources across institutions and researchers would have a huge impact. In the grand scheme, the amount allocated to fundamental science is still minuscule, but it does not mean that simply increasing the budget is the solution.

If we can ensure that financial support is given in an effective and strategic manner, India can progress by leaps and bounds.

SS: Should we question everything, or should we only ask the right questions?

MB: Question everything. There is no such thing as questioning rightly or wrongly. How do you even know if a question is right or wrong until you define it and explore the answer?

In science, answers are not the main thing. The question is paramount. The true essence of science lies in asking the right questions, pushing boundaries, and challenging assumptions.

SS: Having completed a major portion of your academic life and having become an Emeritus Professor, what do you consider to be your biggest contribution to science, TIFR, and the students?

MB: One of my most significant contributions as a Director of TIFR was initiating and playing a key role in the formulation and partial execution of the new TIFR campus in Hyderabad. It is a very large campus, seven times the area of the TIFR campus in Mumbai. It holds enormous potential, and if it reaches its full realization, it will be a game changer—not just for TIFR, but for the entire country.

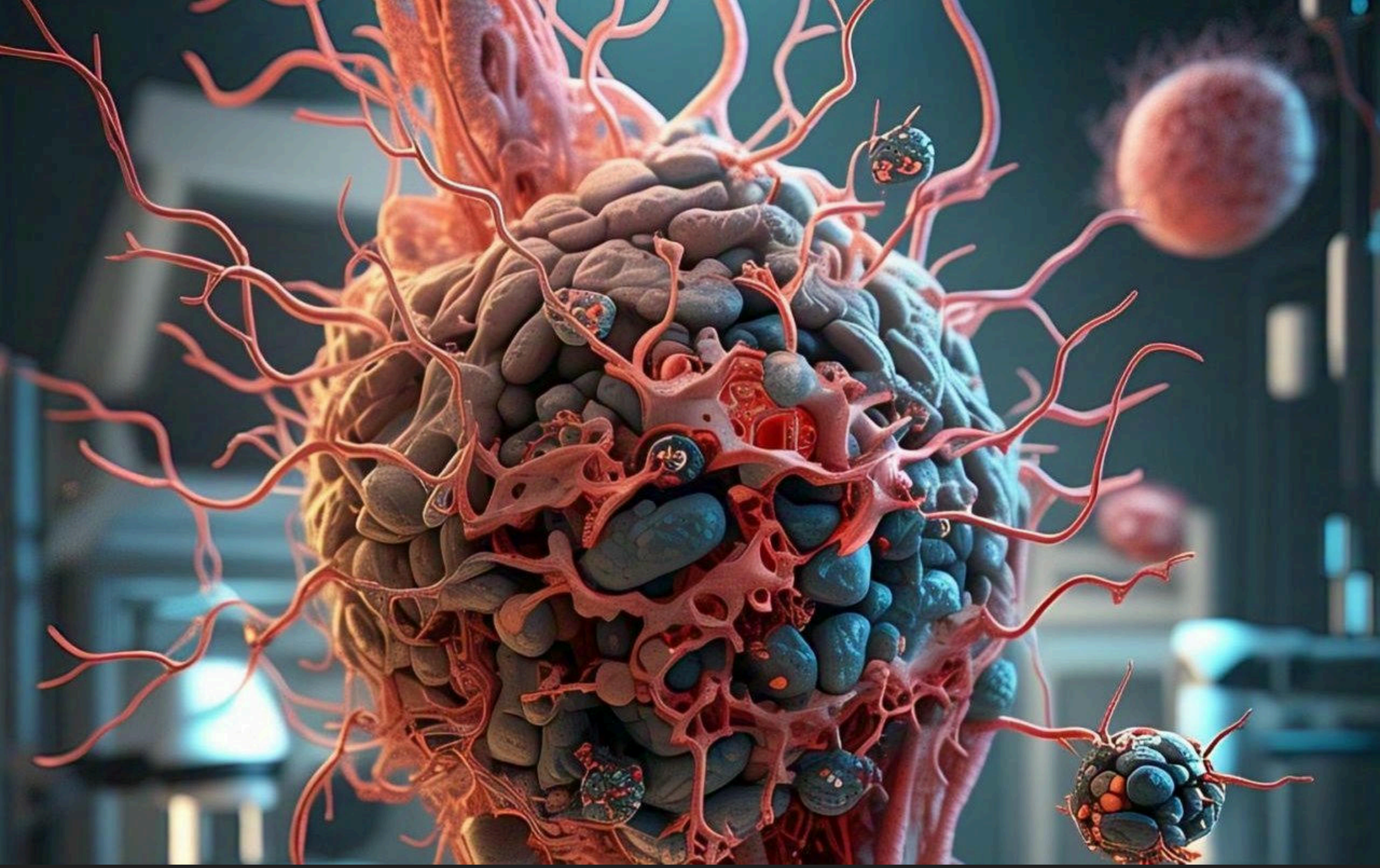
Progress is happening, though not at the speed we initially envisioned. Time has inflated, as is often the case with large-scale projects. But in the long run, this does not matter, because we hope that this institution will last for hundreds of years.

Seeing the plans I helped initiate now being executed is a source of immense satisfaction and pride for me.

SS: Thank you, sir. It was a pleasure speaking with you.

MB: Thank you very much.

Fig 4: Mustansir Barma delivering an invited talk at the International Institute of Physics, Brazil, on "Entropy, Order and Fluctuations", in January of 2020. [Source IIP]



InScight Digest

Simplified summaries of recent research articles in science. Intended to give a feel for what's happening at the frontiers.

Earth has its own electric field weaker than a pencil battery

Collinson, G.A., Glocer, A., Pfaff, R. et al., Nature 632, 1021–1025 (2024)

Contributed by **Chitradeep Saha (CESSI, IISER Kolkata)**

Our planet Earth also has a global electric field – as fundamental as its gravity and magnetic fields. Researchers have successfully measured this electric field for the first time. The quest started over half a century ago when a steady stream of outgoing plasma particles was detected near the Earth's poles. Theories have been proposed and refined over time to understand this peculiar phenomenon. Peculiar. Because the temperature of the outflowing plasma is too cold to evaporate due to solar radiation. Therefore, existing knowledge of global energy fields failed to explain it. Alternatively, the existence of an independent, electric field was hypothesized. However, more mature technology was required to make precise measurements and test the hypothesis. The research team flew a suborbital rocket through the arctic skies that touched the exosphere while sampling various ionospheric properties. The photoelectron spectrometer onboard detected a minute change in electric potential of 0.55 volts – less than that of a standard AA battery – across an altitude range of ~500 km, confirming the existence of such a global electric field. Due to an asymmetric gravitational pull on the lighter electrons and heavier ion cores, charge separation occurs in the atmosphere. The Coulombic force partially counteracts this charge separation; the associated electric field is ambipolar, as it works in both directions. The net effect of this global ambipolar field is to puff up the atmosphere, lifting some ions high enough to escape through the polar caps and giving rise to polar winds.

Mapping Strain in Laser-Written Diamond Waveguides Using Optically Detected Magnetic Resonance

Phys. Rev. Applied 22, 024055 (2024)

Contributed by **M. Sahnawaz Alam (RWTH Aachen University, Germany)**

Color centers in diamond, such as the nitrogen-vacancy (NV) center—which consists of a nitrogen atom adjacent to a vacancy in the carbon lattice—are renowned for their exceptional quantum properties, making them ideal candidates for applications in nanoscale sensing and quantum information processing at room temperature. However, NV centers often suffer from low contrast in experiments, which hampers their performance and limits practical applications. Integrating NV centers with laser-written optical waveguides enhances the coupling of light to these quantum systems, facilitating more efficient manipulation and readout of their states. This integration addresses the low-contrast issue by improving the interaction between NV centers and light. However, the process of laser writing photonic structures inherently introduces strain into the diamond lattice. This strain can alter the electronic and spin properties of the NV centers, affecting their performance and the fidelity of quantum operations. Until now, the full impact of this strain on defect centers has not been thoroughly understood. In our combined experimental and theoretical study, we demonstrate that optically detected magnetic resonance (ODMR) spectroscopy—a technique commonly used to probe the spin states of NV centers—provides sufficient information to fully characterize the spatial distribution of strain within laser-written diamond waveguides. Remarkably, this characterization is possible even without the application of an external constant magnetic field. Our findings present an accessible and non-invasive tool for mapping strain in diamond-based photonic devices. By utilizing ODMR spectroscopy, researchers can gain detailed insights into strain distributions, enabling the optimization of device fabrication processes and the improvement of quantum device performance. This advancement is a significant step forward in the development of diamond- based quantum technologies, potentially impacting a wide range of applications from high-precision sensing to quantum communication and computation.

GWTC-3: Compact Binary Coalescences Observed by LIGO and Virgo during the Second Part of the Third Observing Run

R. Abbott et al., Phys. Rev. X 13, 041039 (2023)

Contributed by **Swarnendu Saha (CESSI, IISER Kolkata)**

This paper, “GWTC-3: Compact Binary Coalescences Observed by LIGO and Virgo during the Second Part of the Third Observing Run”, is an excerpt from the third Gravitational Wave Transient Catalog. The report was published in December 2023 in the journal Physical Review X that reports on observation of gravitational waves by the LIGO, Virgo, and KAGRA for the second half of the period of the third observing run. The interval covered is from November 1, 2019, through March 27, 2020. Our very own Professor Rajesh Kumble Nayak has been a part of this team from IISER Kolkata.

The paper also lists 35 new gravitational-wave events detected during that period, all the result of a "compact binary coalescence" in which pairs of black holes or neutron stars orbit ever tighter until they eventually merge. This brings the number of gravitational-wave detections across three observation runs to 90. Most of the events in the catalog arise from the merger of black holes, which can be pretty large, but this observing run also marks the first definite identification of neutron star–black hole (NSBH) mergers. Curiously, however, no BNS mergers were confirmed during this period.

The researchers selected these signals with advanced algorithms and data calibration, estimating probabilities for each event to be of astrophysical rather than noise artifacts. As there is always some inevitable noise, the probability for these signals to be due to a non- astrophysical origin is estimated to be around 10-15%. All the data are made available in the public domain for use by the community through the Gravitational Wave Open Science Center. The expanding dataset from GWTC-3 gives unparalleled insight into the properties and behaviors of black holes and neutron stars, offering unique insights into the population in the universe and providing informative input into the theory governing their formation, structure, and evolution.

Strange Metal and Quantum Spin Liquid in Heavy-Fermion Material: An Array of Exotic Phases

Hengdi Zhao et al., Phys. Rev. Lett. 132, 226503 (2024)

Contributed by **Abhirup Mukherjee (IISER Kolkata)**

Strange metals and spin liquids constitute deviations from the "standard model" of condensed matter physics. For most of the twentieth century, metals were believed to be smoothly connected to non-interacting electrons at low- energies (the so-called Landau's Fermi liquid theory), and insulators and superconductors were believed to arise from spontaneous symmetry breaking (the ground state does not have all symmetries of the Hamiltonian). Violations of these ideas were observed in the 1980s, a notable example being the discovery of high-temperature superconductivity in copper oxide materials. The strange metal phase of the copper oxides, while being a metal, displayed a linear-in- temperature resistivity, in contrast to the quadratic-in-temperature resistivty of Landau Fermi liquids. Due to the large transition temperature of the material and the proximity to an electronic-correlation driven Mott insulator, Phillip Anderson hyppthesised that the ground state of the Mott insulator was close to a "spin liquid", where the system does not settle into any particular configuration (in contrast to the symmetry-broken insulators) but keeps shifting (in the sense of a quantum superposition) between various configurations.

 While these exotic phases typically emerge in different materials, the authors of the present work have experimentally realised these exotic phases in crystals of the material Ba4 Nb1-xRu3+xO12, where x is the hole- doping concentration. By tuning the doping concentration, the material undergoes transition from a heavy strange metal phase to a heavy Fermi liquid phase to finally a spin liquid phase. The "heaviness" arises from the fact that these are heavy-fermion materials in which the inter-electron interactions increase the "inertia" of the quasiparticles. Other results suggest that the excitations in all three phases are described by spinons - spin-1/2 charge-neutral objects. These spinons are fractionalised excitations (to see why, recall that flipping a spin from -1/2 to 1/2 creates a spin-1 excitation). At the heart of these exotic phenomenon in this material is the underlying triangular lattice that leads to geometric frustration (it is not simple to obtain an energy-minimising configuration of spins on this lattice) and the emergence of novel elementary excitations (the spinons). Such a material provides a wonderful platform to realise and study these highly-correlated phases of matter.