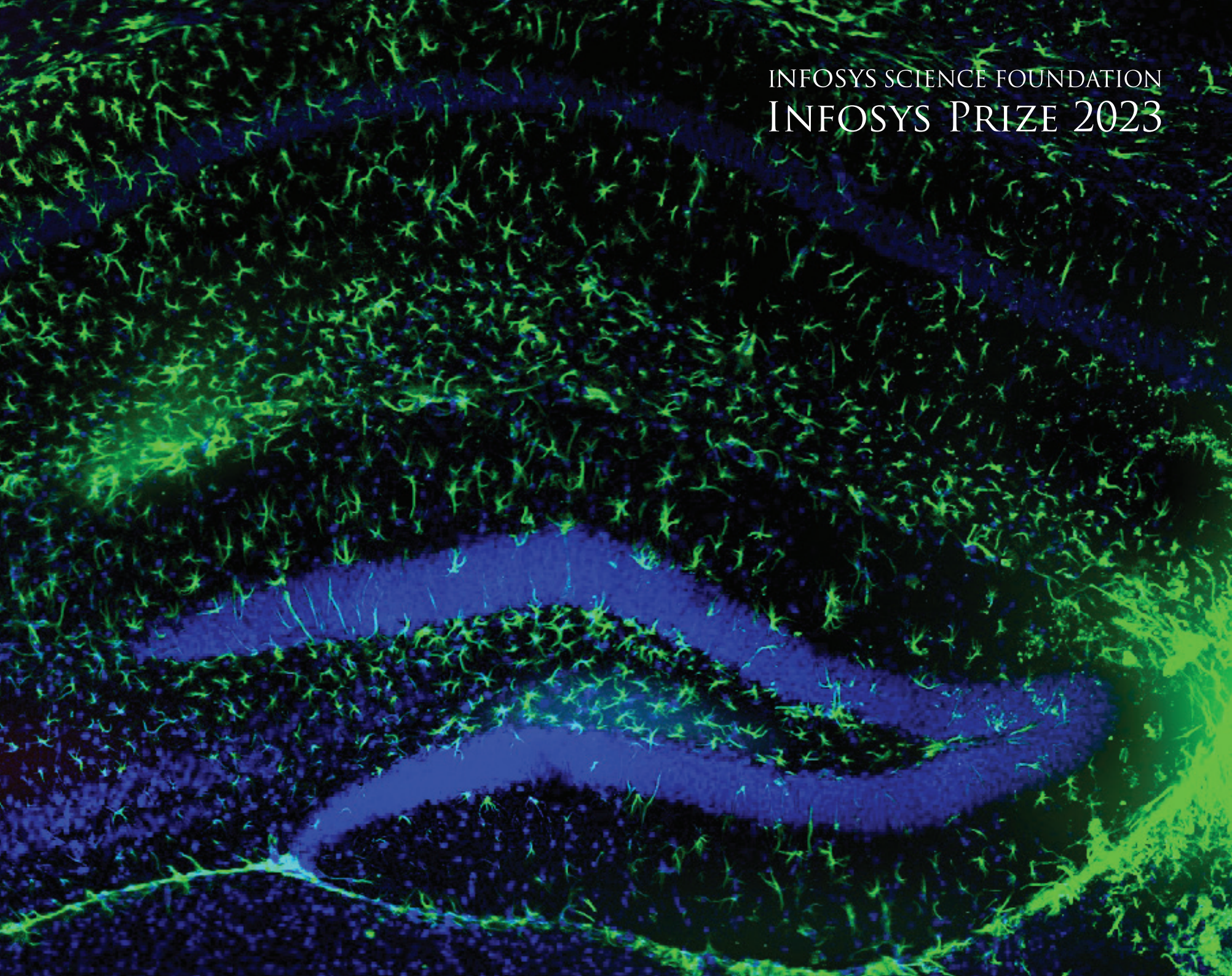
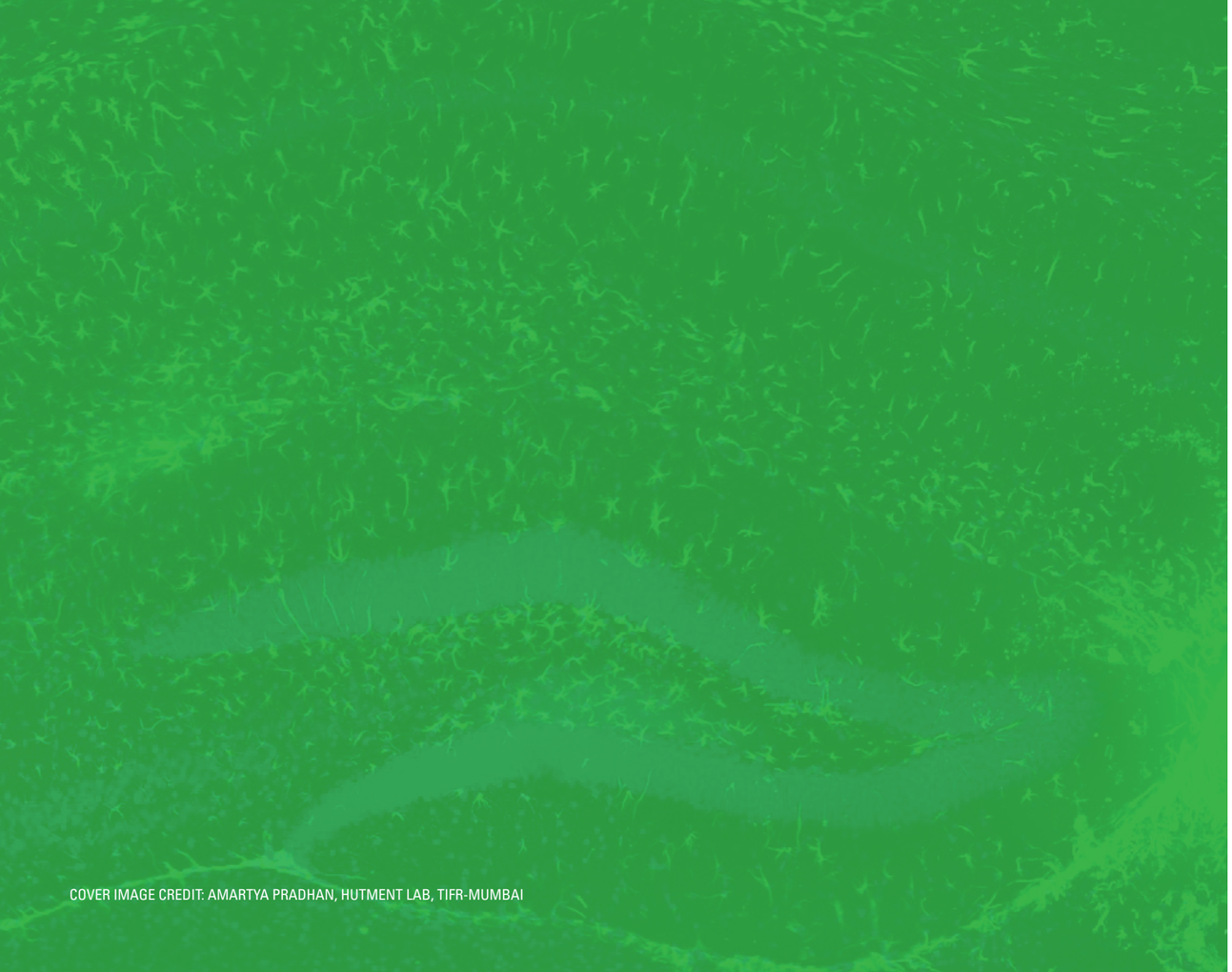


INFOSYS SCIENCE FOUNDATION

Infosys Prize 2023



COVER IMAGE CREDIT: AMARTYA PRADHAN, HUTMENT LAB, TIFR-MUMBAI

STARGAZING IN THE HIPPOCAMPUS

Carl Sagan once famously said, "The cosmos is within us. We are made of star stuff. We are a way for the universe to know itself." What one of the great scientific minds of the 20th century meant by that was that human bodies (and everything else on earth) are constituted of the same raw materials that made up long dead stars. The origin of humanity lies in the origins of the universe itself. Sagan tried to show us that we are but a tiny part of the vastness—a blip in geological time. In a very elemental way, we are an inextricable part of the planet we live on and by extension the universe in which that planet exists.

The image on the cover is from the laboratory of one of our laureates, and it shows the hippocampus that lies deep within our brains and is responsible for emotion, memory, and learning. At first glance the image looks like we are staring deep into space and those stars that shine on quietly with that sublime indifference that W.H. Auden wrote of so eloquently. It all seems so perfectly balanced, doesn't it? Like nothing could ever disturb the eternal equilibrium of something so complex. And yet, a tiny change in the hippocampus leads to anything from Alzheimer's and epilepsy to depression. And as with our bodies, so it is with the planet we live on. The whole is a sum of its parts and any change in one leads to an imbalance everywhere else.

Our embodied selves are deeply rooted in the heart of the universe. Not just us, but everything, living and even non-living. The world we live in is deeply interconnected. The fragile systems and cycles that keep the earth going as we know it are all connected to each other—all dependent on a fine balance. Disturbances in that balance, eventually lead to knock on collapses and the consequence of such collapse is often unpredictable.

The poet and essayist Mary Oliver once wrote of the interconnectedness of all things, "I would say that there exist a thousand unbreakable links between each of us and everything else, and that our dignity and our chances are one. The farthest star and the mud at our feet are a family, and there is no decency or sense in honoring one thing, or a few things, and then closing the list." If there is to be any hope for our species and for everything that lives on this beautiful planet of ours, we must respect its fragility and our own. We need to know our place fully and truly in it all.

SACHCHIDA NAND TRIPATHI

Professor, Joint Faculty in Civil Engineering and Sustainable Energy Engineering, Indian Institute of Technology, Kanpur, India

Prof. Sachchida Nand Tripathi was born in Varanasi, Uttar Pradesh. He obtained his B.Tech. from the Indian Institute of Technology, Benares Hindu University (1992), M.Tech. from the National Institute of Technology, Allahabad (1995), and Ph.D. from the University of Reading, UK (2000). After two post-doctoral stints at Bhabha Atomic Research Centre and Oxford University, he joined IIT-Kanpur in 2003, where he is a professor in the Department of Civil Engineering and Sustainable Energy Engineering. The Council for Scientific and Industrial Research of the Government of India awarded him the Shanti Swarup Bhatnagar Award for his outstanding contribution in the field of Earth, Atmosphere, Ocean and Planetary Sciences in 2014. Prof. Tripathi is an elected fellow of major sciences and engineering academies of the country and also holds the J. C. Bose Fellowship of the Department of Science and Technology.

ENGINEERING & COMPUTER SCIENCE

The Infosys Prize 2023 in Engineering and Computer Science is awarded to Prof. Sachchida Nand Tripathi for the deployment of large-scale sensor-based air quality network and mobile laboratory for hyper local measurements of pollution, data generation and analysis using artificial intelligence and machine learning for effective air quality management and citizen awareness, and for the discovery of new pathways of aerosols formation and growth that provide mechanistic understanding of haze formation.

SCOPE AND IMPACT OF WORK

Air pollution is one of the high priority problems in India. Mitigating air pollution requires a scientific understanding of the causes of pollution, its origin and sources. Measuring pollution and understanding its source requires networks of inexpensive sensors. Prof. S.N. Tripathi deployed such a sensor network in 1,400 locations, and a mobile laboratory to collect and transmit data automatically for analysis.

Prof. Tripathi applied greedy and genetic algorithms to find critical locations for sensor placement while meeting twin requirements of citizens' satisfaction and resource conservation. He used existing self-supervised Machine Learning (ML) techniques on vast data sets to develop correction factors for collocated and non-collocated sensors. The field data is further corrected by Graph Neural Networks (GNN) to fill missing values. Prof. Tripathi is using a range of techniques such as dynamic time wrapping and hierarchical clustering to figure out airsheds, which are defined as regions with similar air pollution patterns. This may help develop effective air quality management. The vast amount of data allows for in-field fault-detection of sensors, development of air quality forecasting systems, citizen awareness and understanding of disparities between rural and urban air quality.

One of the fundamental findings of Prof. Tripathi is that condensation of vapor drives the formation and growth of nanoparticles which quickly grow into sizes responsible for haze formation in Delhi, and it happens at night without photochemistry. We need such sensor networks and scientific understanding for proper mitigation of air pollution.

CITATION BY THE JURY

Prof. Sachchida Nand Tripathi has been selected as the winner of the Infosys Prize 2023 in Engineering and Computer Science for his fundamental research in the atmospheric aerosols including the mechanisms of winter haze formation. He showed that the key differences between Delhi and other places like Beijing are much faster particle growth rate in Delhi as it happens even at night without photochemistry. This finding is useful for mitigating air pollution.

Prof. Tripathi has also helped deploy large-scale sensor-based air quality network and mobile laboratory for hyper local measurements of pollution needed for effective air quality management and citizens awareness. A pilot scale plant built by Prof. Tripathi is being used by Indian atomic energy agencies for safety evaluation of their nuclear plants. The plant can also be reconfigured to measure aerosol leakage from chemical industries for environmental safety analysis.

Congratulations Prof. Sachchida Nand Tripathi for being selected as the winner of the Infosys Prize 2023 in Engineering and Computer Science. Your fundamental research and its deployment in the field has deepened the understanding of the winter haze formation in Delhi by characterizing precisely the atmospheric aerosols using the nanoscale single-particle analyzer. You have shown that carbonaceous aerosol deposition has caused the discoloration of Taj Mahal's marble surfaces. We need such scientific understanding to come up with proper mitigations.

Arvind

THE AIR THAT WE BREATHE

According to the World Air Quality Index Report 2023, there are an estimated 7 million deaths every year that can be directly attributed to air pollution. A WHO report says that environmental risks cause 12 per cent of the global disease burden, and air pollution ranks first. In November 2023, the government of Delhi sounded the alarm about a catastrophic fall in air quality, leading to school closures and advisories for citizens to remain indoors. The national capital was facing one of the worst environmental disasters unfolding as winter set in.

Air quality and its management has been a topic of intense discussion as more and more Indian cities face a crisis of air pollution. The factors that lead to the pollution caused by human activity are many including biomass burning, increased vehicular pollution, industrial emissions and others. The aerosols and their precursor gases from these pollutants then create haze which exacerbates the pollution. Air quality becomes important especially for vulnerable sections of the population such as the very young and the elderly, sections of the population with chronic illnesses and others. Trying to find solutions to such problems begins with understanding how the problem happens in the first place.

Prof. Sachchida Nand Tripathi's lab studied the process of haze formation in Delhi and how this differed from other cities in the world such as Beijing. What they discovered is that while in Beijing the aerosols forming the haze grew during the daytime in the presence of sunlight i.e. with photochemistry, in Delhi the growth took place in the night in the absence of photochemistry. Along with identifying how the haze particles worked, Tripathi then needed to identify the most polluted areas. This would help in increasing citizen awareness and implement better air quality management measures.

While air quality management is becoming a global issue, in resource-limited countries such as India, there are additional challenges. Prof. Tripathi placed air quality sensors chosen by algorithms. The locations were chosen keeping in mind resource conservation and citizen satisfaction. Starting with a few sensors, they eventually placed 1,400 sensors across the Indian states of Uttar Pradesh and Bihar. These sensors helped identify the worst polluted locations in these places.

The vast amounts of data from the sensors were analyzed using artificial intelligence and machine learning. Prof. Tripathi and his team identified areas known as airsheds, which are areas with similar patterns of air pollution. This data will help in the development of effective air quality forecasting systems, citizen awareness, exposure analysis for health assessment and understanding of differences in air quality in rural and urban areas.

It isn't just human beings and other living things who are affected by bad air quality and air pollutants. Prof. Tripathi was the first to prove that the Taj Mahal's pristine white marble was turning yellow because of the carbonaceous aerosols in the air from industrial emissions in the area. As a result of the study, policies were implemented to move industries away from the monument and protect an icon of India's cultural heritage.

JAHNAVI PHALKEY

Founding Director, Science Gallery Bengaluru, India

Dr. Jahnavi Phalkey is a highly accomplished historian of science and technology, filmmaker, and curator. She is currently the Founding Director of Science Gallery Bengaluru. Dr. Phalkey did her B.A. at Elphinstone College and got her M.A. from Bombay University with a gold medal (1995). After an M.Sc. in the Politics of Asia and Africa (1996) from the School of Oriental and African Studies, University of London, she completed her Ph.D. in the History of Science and Technology from the Georgia Institute of Technology (2007). Jahnavi Phalkey was formerly Senior Lecturer in History of Science and Technology at King's College London (2011 – 2018) and a Fellow at the Wissenschaftskolleg zu Berlin (2013-14) and has held numerous other visiting appointments and fellowships. Her major work is the celebrated book, *Atomic State: Big Science in Twentieth Century India* (2013) She is also the co-editor of *Key Concepts in Modern Indian Studies* (2015) and the director of the documentary film *Cyclotron* (2020).

HUMANITIES

The Infosys Prize 2023 in Humanities is awarded to the historian Dr. Jahnavi Phalkey for her brilliant and granular insights into the individual, institutional, and material histories of scientific research in modern India. Her book *Atomic State* (Permanent Black, 2013) and many articles insightfully braid the global history of science, especially nuclear science, with the anthropology of the postcolonial state to illuminate rich and textured histories of the everyday lives of science in India.

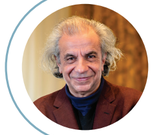
SCOPE AND IMPACT OF WORK

Dr. Jahnavi Phalkey's history of nuclear science research in twentieth-century India has creatively extended the scope of the global history of science to postcolonial contexts. It has productively shifted attention beyond the atomic bomb as a moment of postcolonial arrival for nation-states like India and Pakistan to reveal the complex institutional and material edifice of nuclear science research, and scientific research more broadly. The quality of her archival knowledge and research on these subjects is without peer. Her brilliant anthropology of science has emphasized the need to see the history of science as much a history of scientific ideas, as one of power, practice, and the nation-state. Dr. Phalkey's ongoing scholarship also emphasizes that the trajectories of the natural sciences, social sciences and humanities—from physics and nuclear science to the development of statistics and sampling, and the vocabularies therein—are an inextricably joint narrative of individual genius, institutional structures, and state policy; and she extends her canvas, in comparativist vein, from India to China.

Jahnavi Phalkey has skilfully marshalled these insights from her monograph and scholarly articles to boldly and passionately reimagine spaces and modes through which science can be communicated with the wider public. Her documentary film *Cyclotron* (2020) tells the story of the longest-running particle accelerator in India and the scientists who have worked with it. Underlying the creative exhibitions and activities she has organized as the Founding Director of Science Gallery Bengaluru is the vision of explaining to the wider public how complex science works. This vision sees the dissemination of science and the humanities together in order to critically root the histories and contemporary everyday practice of science and rationality in empirical practice and theoretical rigor, at a time when they are under obscurantist threat everywhere.

CITATION BY THE JURY

The Infosys Prize 2023 in Humanities is awarded to Dr. Jahnavi Phalkey for her brilliant insights into the individual, institutional, and material histories of scientific research in modern India. Her book *Atomic State: Big Science in Twentieth Century India* (Permanent Black, 2013), on the rise of nuclear science research in India, tells a deeply researched, methodologically innovative, and passionate story of institutions, individuals, and the state. It highlights how people, instruments, and ideas across local, national and transnational flows developed the edifice of scientific research in twentieth-century India. Dr. Phalkey skillfully braids the global history of science with the anthropology of the postcolonial state to reveal textured histories and everyday lives of science in postcolonial countries like India. Her revealingly granular scholarship illuminates the interface between technology, bureaucracy, educational policy and equitable access, revealing both macro and micro processes of knowledge production.



My warm congratulations to Jahnavi Phalkey for winning the Infosys Prize 2023 in Humanities, awarded to her for her brilliant history of the making of nuclear science in modern India that brings together individual narratives of ambition, effort, failure, and resilience with the institutional structures and state policy in which they are necessarily embedded; and critically excavates the human and material realm within which the history and contemporary practice of scientific research has taken place in India. Her pathbreaking scholarship is absolutely essential reading for scholars of knowledge production in India and beyond.

Akeel Bilgrami

SCIENCE DOES NOT HAPPEN IN ISOLATION

British India was partitioned in 1947 and new India's leadership in politics, industry and science looked for ways to shape a modern nation. India's independence came two years after the first use of atomic weapons towards the end of World War II. Many of us saw in the film *Oppenheimer* how cutting-edge research and state power was tightly knit together in the Manhattan Project. This changed the scale and budgets at which scientific research could be conducted. Another such moment was the launch of Sputnik by the Soviet Union in 1957—10 years after Indian Independence—which accelerated the race for cutting-edge dual-use technologies between the two superpowers. It is, therefore, of enormous significance that a new Indian state was being created in this time. Scientific research came to be deeply implicated in the making of state structures and, therefore, of defining state capacity in free India.

Dr. Jahnavi Phalkey is a historian of science. Her seminal book *Atomic State* traces the beginnings of experimental nuclear physics in India. How did India come to have infrastructures that could contribute towards nuclear capability? Was this trajectory inevitable? What were the motivations of those who pursued (or not) this goal? Who were the people involved in the unfolding of this history? What was happening in the world at large at the time?

Three eminent physicists Meghnad Saha, Chandrashekhar Venkata Raman and Homi Bhabha—and their students and colleagues—tried to build capacity for nuclear physics research in three laboratories—then in Calcutta, Bangalore and Bombay. This was a moment of transitions: of India from imperial rule to political independence; of experimental physics from tabletop small science to large systems and big science; and, finally, a world order that transitioned from European imperialism to the Cold War between two new super-powers—the United States and the Soviet Union.

Twenty-five years after the end of imperial rule, India became the first developing country to create a nuclear research infrastructure capable of developing a nuclear program with the peaceful nuclear explosions in Pokhran. Dr. Phalkey tells us how this became possible, why this was not inevitable, and why this came to be seen as necessary. She has used extensive archival research, ethnography, image archives, and studied the technology to write this history.

In a similar vein, in her documentary film *Cyclotron,* Dr. Phalkey tells the history of the world's oldest particle accelerator—an extraordinary machine and its ordinary story! The cyclotron was built in 1936 at the University of Rochester, New York. It was decommissioned and shipped to India in 1967 where it continues to function at the Panjab University, Chandigarh. The film is the story of science under constraints, science as a social enterprise as told through the humdrum of a life in experimental science.

At a moment when we celebrate the information technology revolution and the accomplishments of the Indian space program, it is imperative that citizens and new generations of scientists understand how and why science and engineering have grown in specific ways in India. History of science may provide a perspective to scientists and engineers about the developments in their own discipline. Equally, it may help them contextualize their place as knowledge-makers whose work has consequences for the world at large.

ARUN KUMAR SHUKLA

Professor and Sonu Agrawal Memorial Chair, Biological Sciences and Bioengineering, Indian Institute of Technology, Kanpur, India

Arun Kumar Shukla is Professor in the Department of Biological Sciences and Bioengineering at IIT - Kanpur. He completed his B.Sc. from Gorakhpur University, his M.Sc. from Jawaharlal Nehru University in New Delhi and his Ph.D. at the Max Planck Institute of Biophysics in Frankfurt, Germany. Prof. Shukla was a Research Associate and Assistant Professor at Duke University, North Carolina before joining the Indian Institute of Technology, Kanpur as an Assistant Professor in 2014. Prof. Arun Kumar Shukla is a Fellow of the Indian Academy of Sciences and the Indian National Science Academy. He is a recipient of many honors, notably the Shanti Swarup Bhatnagar Prize and a Senior Fellowship of the DBT Wellcome Trust India Alliance. In addition to his scientific leadership, as evident in his team's outstanding record of publications, he is a strong advocate for fundamental science and a committed mentor for Ph.D. students and other trainees.

LIFE SCIENCES

The Infosys Prize 2023 in Life Sciences is awarded to Prof. Arun Kumar Shukla for his outstanding contributions to the biology of G-protein coupled receptors (GPCRs), a key component of cell function. His studies have elegantly illustrated mechanisms that selectively activate signaling pathways downstream of GPCRs. These and other discoveries provide fundamental understanding of the context-dependent functions of GPCRs and suggest a new framework for the design of novel therapeutics.

SCOPE AND IMPACT OF WORK

The overarching theme of Prof. Arun Shukla's research is to understand the structure, function and regulation of G-protein coupled receptors (GPCRs), a fundamental component of cellular function. Cells—the basic architectural unit of our tissues and organs—communicate with each other to change their size, shape, and function. Misregulation of cell-cell signaling can result in developmental defects, cancers, heart diseases, and brain disorders. A crucial mechanism of signaling is through GPCRs, which are intricately involved in almost every physiological process in our body. Approximately half of currently prescribed medicines exert their therapeutic effects through these receptors, including therapeutics prescribed for hypertension, heart diseases and neurological disorders. Prof. Shukla's work has demonstrated that selectively engaging one of two major pathways downstream of GPCRs using specific activators, or agonists, may help minimize the side effects of commonly prescribed medicines. The concept of biased agonists that can direct GPCR signaling can also be harnessed to develop drugs for many human diseases.

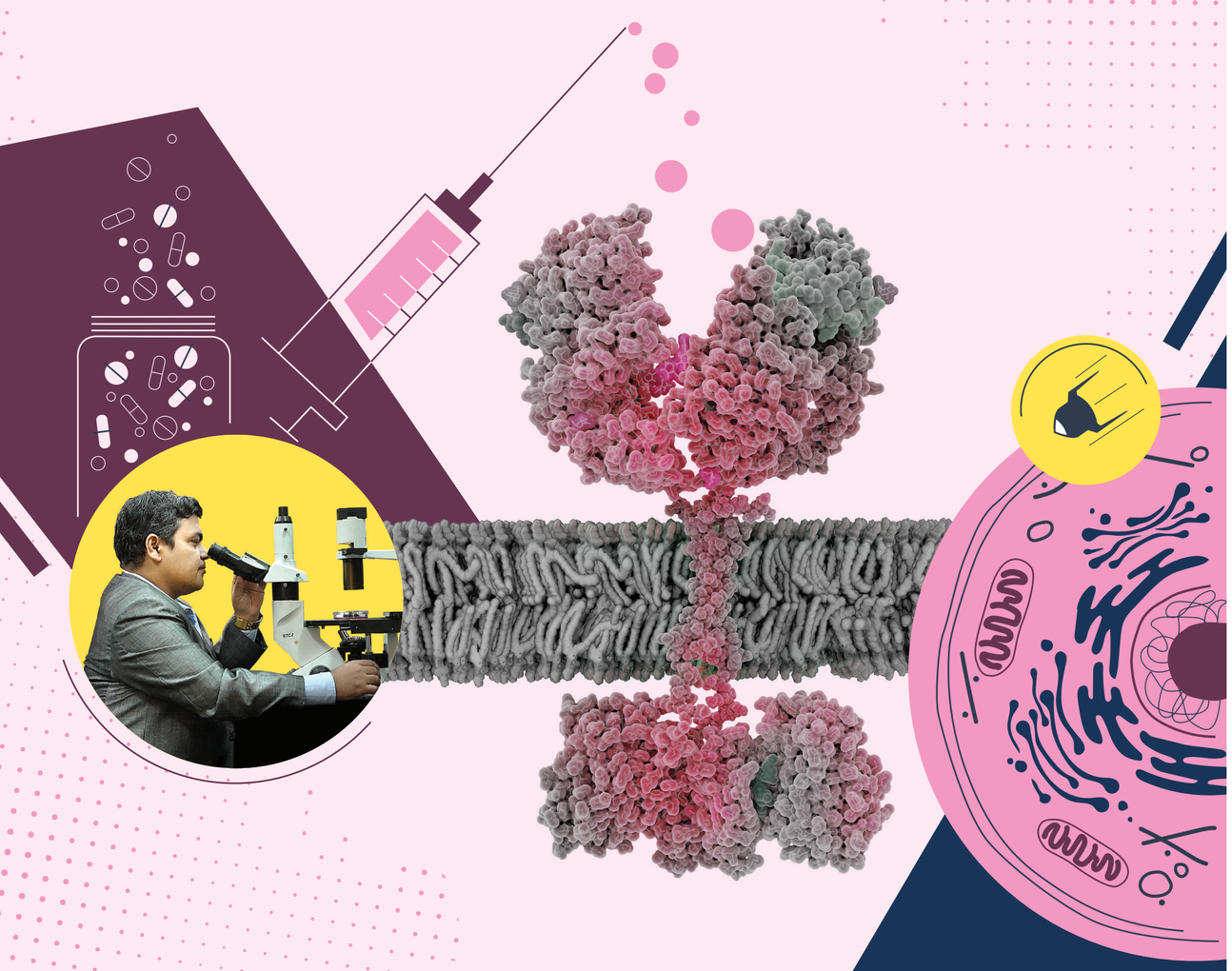
Arun Kumar Shukla has established a platform for synthetic antibody technology and successfully employed it to design sensors to probe GPCR activation, as well as modulators to control GPCR trafficking and signaling. These tools have far-reaching implications for illuminating novel aspects of GPCR biology. A central aspect of his research program is to understand the structural biology of membrane proteins such as GPCRs and their signaling complexes. His advocacy and leadership have led to the establishment of national facilities for cryo-electron microscopy, a technology that is vital for the progress of fundamental science in India.

CITATION BY THE JURY

Prof. Arun Shukla has made far-reaching contributions to our understanding of G-protein coupled receptors, with a focus on understanding their activation, signaling and regulation. GPCRs are one of the most important classes of drug targets. Prof. Shukla's research has refined the conceptual framework of pathway-selective activation in GPCRs. His group has discovered a novel GPCR signaling mechanism demonstrating that even partially engaged receptor-effector complexes can mediate downstream signaling. This discovery challenges the longstanding notion in the field of GPCR biology that complete engagement of signaling effectors with GPCRs is a prerequisite for their functions. His laboratory has shown that even a single change on a GPCR can make a decisive contribution to its coupling with other proteins and its activation. His group has provided the GPCR community with important research tools that demonstrate the feasibility of skewing GPCR signaling in desired directions.

On behalf of the jury, I congratulate you on receiving the Infosys Prize 2023 in Life Sciences. Your groundbreaking work on G-protein coupled receptors, or GPCRs, has discovered mechanisms by which the structural biology and biophysical properties of the receptors couple to downstream processes. Your group has shown how GPCR signaling can be specifically engineered, an important discovery that can enable the design of novel drugs.

Mriganka Sur



DESIGNING SAFER MEDICINES FOR ALL

According to a recent WHO report an estimated 1.28 billion adults aged 30–79 years worldwide suffer from hypertension. Medications used to control hypertension work by targeting specific areas in the cell. However, these life-saving medications can have several unpleasant side-effects. Not just hypertension, but medications used for many other conditions can have these side-effects and make individuals reluctant to take them. How can vital drugs for hypertension and other conditions such as heart disease, asthma, and schizophrenia be made safer with minimal side-effects?

The answer lies in the biology of a component of living cells called G-protein coupled receptors or GPCRs. Many drugs used to treat hypertension and other conditions are typically designed to target GPCRs. Prof. Arun Shukla is a structural biologist who works on the biology of G-protein coupled receptors (GPCRs), a key component of cell function. Around half of currently prescribed medicines for hypertension work through these receptors.

What are G-protein coupled receptors? All living cells keep their fundamental functions going by moving 'information' within the cell, and from within the cell to the outside and vice-versa. This constant 'trafficking' of information is carried out by protein molecules called 'receptors'. Among these are the G-protein coupled receptors that reside on the surface of the cell that respond to various external signals. GPCRs are the largest and most important of these receptors as they carry out several important functions of the cell that are important for the human body. GPCRs help to regulate several important functions in the human body such as sensations, growth, and hormone responses. In addition, many drugs that are used to treat various conditions such as mental disorders, cancer, hypertension and cardiac conditions are designed to target GPCRs. Researchers estimate that between one-third and one-half of all marketed drugs act by binding to GPCRs. Therefore, a deeper understanding of how GPCRs function can help design drugs that are effective and have minimum side-effects.

Prof. Shukla's laboratory has utilized a platform for synthetic antibody technology and leveraged this to develop sensors to probe the functions of GPCRs. Using combinatorial biology and directed evolution, Prof. Shukla created tiny 'nanomachines'. Using these nanomachines, Shukla has determined that even a single change in GPCR can make a difference in how it couples with other proteins and gets activated. Data from Arun Shukla's research can help design better drugs that are precise in how they target cells. This will also help reduce side-effects for those who are prescribed these medicines for chronic conditions.

BHARGAV BHATT

Fernholz Joint Professor, Institute for Advanced Study and
Princeton University Gehring Professor, University of Michigan , USA

Prof. Bhargav Bhatt has been the Fernholz Joint Professor at the Institute for Advanced Study and Princeton University since 2022. He has been on the faculty at the University of Michigan as Gehring Professor, since 2014. He obtained his Ph.D. from Princeton University in 2010, and his B.S. in Applied Mathematics from Columbia University in 2005. He was born in Mumbai and studied until high school there.

Prof. Bhatt's work has been recognized by a number of prestigious prizes: Clay Research Award (2021), New Horizons Prize in Mathematics (2021), Nemmers Prize (2022). He was a Plenary speaker at the International Congress of Mathematicians in 2022.

MATHEMATICAL SCIENCES

The Infosys Prize 2023 in Mathematical Sciences is awarded to Prof. Bhargav Bhatt for his outstanding contributions to arithmetic geometry and commutative algebra. Bhatt's fundamental work on prismatic cohomology (joint with Peter Scholze), his work around the direct summand conjecture in commutative algebra, introduces new ideas and powerful methods in an area at the heart of pure mathematics.

SCOPE AND IMPACT OF WORK

Prof. Bhargav Bhatt's two main research areas are *p*-adic geometry (in the shape of *p*-adic Hodge theory) and commutative algebra. Prof. Bhatt has made groundbreaking contributions to both areas and his research has revealed completely unexpected relationships between the two, showing that the deepest questions in both have surprising and very close connections. The theory of prismatic cohomology of Bhatt and Scholze represents a truly fundamental discovery in arithmetic algebraic geometry, which will eventually be part of the standard toolkit of every mathematician working in the area. It has already attracted a huge amount of attention and given rise to many applications. Prof. Bhatt is at the forefront of these developments. He is among the top leaders in arithmetic algebraic geometry worldwide. Prismatic cohomology is the right theory of *p*-adic cohomology of *p*-adic schemes which unifies all the previously existing theories and sheds new light on the structure of those. Much work by mathematicians over the past five decades can now be viewed retrospectively as steps toward the Bhatt-Scholze theory of prismatic cohomology

CITATION BY THE JURY

Prof. Bhargav Bhatt is an internationally renowned expert in arithmetic algebraic geometry and commutative algebra. He has made fundamental contributions to both subjects. Prof. Bhatt is at the forefront of a revolution in *p*-adic geometry. For each prime p, there is a *p*-adic geometry, with a very different flavor from the geometry of the real world we live in. Despite this difference, *p*-adic geometry has found spectacular applications in solving famous conjectures in number theory, like the Mordell conjecture and Fermat's Last Theorem. One of Bhatt's significant mathematical contributions is his introduction (in joint work with Peter Scholze) of the theory of prismatic cohomology. He has applied these developments to solve longstanding problems in commutative algebra.

I would like to congratulate Bhargav for winning the Infosys Prize 2023 in Mathematical Sciences. His work has produced some of the most exciting and impactful mathematics done anywhere in the world over the last decade. His work on prismatic cohomology has introduced a powerful set of methods in p-adic geometry. And there is so much more to come!

Chandrashekhar Khare

THE SHAPE OF THINGS

Prof. Bhargav Bhatt works in two areas of mathematics — algebraic geometry and number theory. The fundamental objects of study in algebraic geometry are the solution sets of systems of polynomial equations. These can be studied using the dual perspective of equations (algebra) or spaces of solutions (geometry). It is one of the biggest fields in math which has seen a great deal of research in the last 60 to 70 years. In particular, algebraic geometry has deep applications to solving problems in number theory—the branch of mathematics concerned with properties of whole numbers and arguably the oldest topic in mathematics.

The bulk of Prof. Bhatt's work lies in a discipline called p-adic geometry, which lies at the intersection of algebraic geometry and number theory. Given a prime number p (for example, take p to be 3), the German mathematician Kurt Hensel, in the 19th century, introduced an alternate number system, the *p*-adic numbers, that is sometimes more useful than standard (real) number system for tackling problems in algebraic geometry and number theory.

To explain Hensel's creation, note that the notion of distance in our world relies on the usual notion of sizes of numbers; for instance, in the more familiar number system, the distance from 0 to 6 is smaller than the distance from 0 to 9. Hensel observed that there is an alternative (*p*-adic) way to measure distances: in the *p*-adic world, a number is closer to 0 if it is more divisible by p. For instance, in the 3-adic world, the distance from 0 to 9 is smaller than the distance from 0 to 6 since 3 divides 9 twice but it only divides 6 once. In this way, for each prime number p, Hensel built the *p*-adic numbers; work of various mathematicians in the last century then expanded on Hensel's creation to build a new geometry: *p*-adic geometry. While different from standard geometry and initially counterintuitive, *p*-adic geometry has found spectacular applications in solving important conjectures in mathematics such as Fermat's Last Theorem and the Mordell conjecture.

Bhargav Bhatt has made fundamental contributions to *p*-adic geometry by providing new techniques for understanding p-adic spaces. More precisely, Prof. Bhatt (with collaborators Matthew Morrow and Peter Scholze) introduced a theory called prismatic cohomology, which provides a novel way to "measure holes" in *p*-adic spaces. This theory unifies all previously known cohomology theories in the *p*-adic world and sheds new light on their relationship; it can be regarded as a *p*-adic counterpart of the classical work of W.V.D. Hodge in the 1930s in classical geometries. Despite being relatively recent, the theory has already found applications in the solution of longstanding questions in algebraic topology and commutative algebra.

MUKUND THATTAI

Professor, Biochemistry, Biophysics and Bioinformatics,
National Centre for Biological Sciences, Bengaluru, India

Mukund Thattai is a biological physicist and professor at the National Centre for Biological Sciences (NCBS) of the Tata Institute of Fundamental Research in Bangalore. In 2004, Prof. Thattai obtained his Ph.D. from the Massachusetts Institute of Technology. He joined NCBS in the same year.

Thattai helped establish the Simons Centre for the Study of Living Machines at NCBS. Under his leadership, it has emerged as one of the important centers internationally for work at the interface of biology and physics. He was instrumental in setting up the ICTP-ICTS Winter School on Quantitative Systems Biology as well as the Simons-NCBS Monsoon School on the Physics of Life, which for over a decade have attracted hundreds of ambitious students and postdocs to this interdisciplinary area. In all these ways, Prof. Thattai has helped nurture a new generation of computational biologists and put India on the map in a rapidly growing and exciting field. Mukund Thattai has guided three Masters-by-Research and nine Ph.D. students, who have gone on to become group leaders, physician scientists, and industry researchers internationally, including at EMBL Heidelberg, the University of Warwick, and Brown University.

PHYSICAL SCIENCES

The Infosys Prize 2023 in Physical Sciences is awarded to Prof. Mukund Thattai in recognition of his groundbreaking contributions to evolutionary cell biology. He has explored the origins of endomembrane organelles, shedding new light on how they emerged from ancient, primordial cells.

SCOPE AND IMPACT OF WORK

One of biology's central mysteries is how a modern-day cell with its complex network of organelles evolved from a primitive, or archaeal, cell that had none of these structures. Data has emerged suggesting that the symbiosis of bacteria and archaeal cells led to a "proto-eukaryote", a prototype for a modern-day cell, but one that lacked internal membranes or endomembranes. Cells as we know them today harbor an array of membrane-bound compartments, called organelles, that work collaboratively to ferry cargo into, around and out of the cell. How did so many kinds of organelles emerge and how did they form networks amongst themselves as we see in modern cells?

Prof. Mukund Thattai's work combines molecular biophysics with DNA sequence information to metaphorically go back, deep in time, to reconstruct a physical picture of how new organelles evolved. He pinpointed that the evolution of vesicle trafficking proteins can lead to the emergence of new endomembrane organelles. Injecting ideas from statistical physics and information theory into rich bioinformatics, he has studied how organelle networks within cells evolved. Thattai showed that the unique organization within the Golgi was an inevitable consequence of the basic flows of vesicle traffic within the cell.

CITATION BY THE JURY

The Infosys Prize 2023 in Physical Sciences is awarded to Prof. Mukund Thattai for his work that has expanded our understanding of one of biology's central mysteries: the emergence of complex cells. Prof. Thattai has studied a problem lying at the crossroads of cell biology and evolution using powerful tools from physics and computer science. His groundbreaking contributions include his work on the emergence of eukaryotes from prokaryotic ancestors, the origin of hallmark eukaryotic traits such as mitochondria and the vesicle trafficking system, and the evolution and function of the Golgi apparatus.

Your efforts to understand how organelle networks arose and evolved from primitive cells that had no organelles, have seeded a new area in evolutionary cell biology. Your findings related to how the organization of organelle networks came to be, by considering them as natural information processing systems, are both pioneering and profound. We have recognized these brilliant achievements with the Infosys Prize. Congratulations Mukund Thattai!

Shrinivas Kulkarni

EXPLORING THE PHYSICS OF LIFE

Living organisms are built from molecules that obey the laws of physics, so it is inevitable that the threads of biological and physical research often intertwine. Ever since the light microscopes of Antonie van Leeuwenhoek and Robert Hooke uncovered the cellular basis of life in the 1600s, instruments based on physical principles have revealed how cells are organized at the smallest scales. In the early 1900s J. C. Bose conducted pioneering electrical recordings on plant cells. In the 1950s George Palade studied the architecture of animal cells using the electron microscope and discovered the ribosome. In the same period X-ray crystallography allowed Linus Pauling and G. N. Ramachandran to solve protein structures and led Watson and Crick to discover the DNA double helix.

Ideas from physics have also stimulated the formulation of biological principles. Physicists such as Max Delbruck and Seymour Benzer, deeply influenced by Erwin Schrödinger's 1944 book *What is life?* helped establish the field of molecular biology. Their work contributed to the discovery of the genetic code. Importantly, this has not been a one-way street. Physicists and engineers have always been inspired by the amazing things cells can do at the smallest scales. Richard Feynman's 1959 lecture "There's plenty of room at the bottom", considered to be the start of nanotechnology, was influenced by his explorations of biology in Delbruck's laboratory.

The molecular biology revolution has generated a "parts list" of the biomolecules that underpin life. Yet, we still know very little about how cells actually work. The question of how random interactions between biomolecules could lead to such precise cellular architecture and dynamics is what attracted Prof. Mukund Thattai, originally trained as a physicist, to the life sciences. Thattai studies one of the central mysteries of biology—the question of how complex eukaryotic cells emerged from simpler prokaryotic ancestors.

There are three distinct types of cellular life on Earth—prokaryotic bacteria and archaea, lacking nuclei; and nucleated eukaryotic cells, including those that make up plants and animals. Originally there were only prokaryotes. Eukaryotes arose about two billion years ago, from within a symbiotic population of bacteria and archaea. The bacteria eventually took up residence within the archaea, becoming what we now call mitochondria. These ancient hybrid cells were the first eukaryotes.

Present-day eukaryotes use an active transport network to move material around the cell. Small carriers called vesicles move molecules between large membrane-enclosed compartments called organelles, just as trucks ferry specific cargo between warehouses in a city. Prokaryotic cells don't have such a transport system. Thattai pioneered the application of tools from physics and computer science to study how biomolecular interactions generate this cell-scale transport network. He has combined biophysical models with genome sequence information to 'go back in time', probing how vesicles and organelles may have arisen in the earliest eukaryotes.

Mukund Thattai's discoveries provide a quantitative foundation for the emerging field of evolutionary cell biology and have contributed to our understanding of the diversity of cellular life.

KARUNA MANTENA

Professor, Political Science, Columbia University, USA and Co-Director,
Conference for the Study of Political Thought

Karuna Mantena is Professor of Political Science at Columbia University and co-Director of the Conference for the Study of Political Thought. Prior to joining Columbia, she was Associate Professor in the Department of Political Science at Yale University and Visiting Assistant Professor in the Government Department at Cornell University. Prof. Karuna Mantena studied at Essex University and the London School of Economics and received her Ph.D. from Harvard University in 2004.

Mantena has received numerous honors and awards, including the Elizabeth Adiseshiah Award, the Balzan Skinner Fellowship, the Gaddis Smith International Book Prize, and the Senator Charles Sumner Prize for the best dissertation at Harvard.

Karuna Mantena is a prolific researcher and her book, *Alibis of Empire: Henry Maine and the Ends of Liberal Imperialism* (Princeton University Press, 2010), is widely cited and celebrated for its originality.

SOCIAL SCIENCES

The Infosys Prize 2023 in Social Sciences is awarded to Prof. Karuna Mantena for her groundbreaking research on the theory of imperial rule, and the claim that this late imperial ideology became one of the important factors in the emergence of modern social theory. Her book and related papers are landmark publications in political theory with implications for all social sciences.

SCOPE AND IMPACT OF WORK

Prof. Karuna Mantena is an outstanding scholar and political theorist, having published numerous papers and books, which are widely cited in the literature in political science, with implications for related disciplines, ranging from moral philosophy to political economy. Her book, *Alibis of Empire: Henry Maine and the Ends of Liberal Imperialism* (Princeton University Press, 2010), is an impactful work that helps us understand that the dramatic shift in imperial policy, following the 1857 rebellion in India, was not a straightforward reaction to this traumatic event but legitimated by a new ideology of indirect imperial rule that was carefully crafted by the ingenious conceptual work of thinker-administrators such as Henry Maine. The purpose of the Empire from then on was no longer to civilize the 'natives' and prepare them for self-rule, as suggested by liberal thinkers like Mill, but instead marked by a custodial conservatism, an ideology that remained paternalistic but left Indian communities to run their own internal social (private) affairs. For Maine, the goal of imperial rule must be to preserve customary forms of legal and social practice through codification of the rule of law. The public and political sphere, on the other hand, must remain in the hands of imperial powers. By making this change from direct to indirect rule, the empire found a perfect alibi to perpetuate itself: The 'natives' were not capable of self-governance, or what Gandhi later called "Swaraj".

Several of her papers constitute major contributions to political theory. 'Another Realism: The Politics of Gandhian Nonviolence', *American Political Science Review* (2012) provides a consequentialist interpretation of nonviolence. By moving away from the conventional deontological explanation, she opened new avenues for analyzing non-violence as a political instrument.

CITATION BY THE JURY

The Infosys Prize 2023 in Social Sciences is awarded to Karuna Mantena, Professor of Political Science at Columbia University, for her ground-breaking research on the theory and ideology of imperial rule, and their implications for action on the ground. Her claim, that the late imperial ideology witnessed on the ground in India became one of the most important contributory factors in the emergence of modern social theory, has received a lot of attention and scrutiny. Prof. Mantena's book *Alibis of Empire: Henry Maine and the Ends of Liberal Imperialism* (Princeton University Press, 2010) is a landmark study with implications that go beyond normative political theory and sheds light on the moral responsibility of groups. In other work, she examined the role of Gandhian nonviolence in terms of consequentialist ethics. This has been influential and prompted others to engage in the debate.

Congratulations to Karuna Mantena for winning the Infosys Prize 2023 in Social Sciences. As we zeroed in on her from among a highly talented group of contestants for this year's prize, it turned out to be a wonderful experience for me and my jury colleagues, as we read and came to grips with Prof. Mantena's creative approach to examining age-old questions concerning political power and nonviolence, and the underlying ideologies and mechanisms that shape them. Her work has influenced researchers in different fields of the social sciences and I hope it will contribute to better policymaking in India.

Kaushik Basu

POLITICAL IDEAS AND POLITICAL PRACTICE

Prof. Karuna Mantena is a political theorist who traces the connections between political ideas and political practice: how ideas and theories emerge in moments of political crises and how they inform and are transformed through political practice.

Was the British Empire a liberal empire? To what extent did it aspire to modernizing Indian society and preparing Indians for self-government? *In Alibis of Empire: Henry Maine and the Ends of Liberal Imperialism*, Prof. Mantena shows these commitments to be much more fragile and never as dominant as they seem in retrospect. *Alibis of Empire* focuses on a pivotal moment, the aftermath of the 1857 rebellion, in which liberal ideas of civilizing native society were largely abandoned as an alternative vision of empire took hold. Conservative strategies of indirect rule, which viewed the rapid transformation of Asian and African societies as difficult and dangerous, flourished. The work of legal scholar Henry Maine was a key driver of this ideological change. Armed with new racial and cultural theories that highlighted the custom-bound nature of traditional society, imperial administrators sought to preserve and codify its practices and institutions, with long-standing repercussions. Protecting traditional society from disintegration proved to be a perfect alibi for empire to perpetuate itself and defer self-government.

In current work on Gandhi, Mantena continues to explore how ideas are born and evolve in relation to events in the world. Gandhi was unique amongst modern thinkers in the extent to which he generated theory through political action. Karuna Mantena details how satyagraha was invented and developed in response to crisis, failure, and criticism. Most important were the outbreaks of violence—what Gandhi called his 'Himalayan miscalculations'—tha accompanied his first experiments in mass satyagraha, the Rowlatt Satyagraha and the Non-Cooperation movement. These setbacks pushed Gandhi to better understand the impulses towards violence in politics, and refine satyagraha so that it could temper them.

By examining such moments of theory-building, Prof. Mantena shows satyagraha to be much more than a way to inject morality into politics. Satyagraha was disciplined political action, which in Gandhi's view, was more effective than traditional politics or violence for overcoming oppression and securing social change. To understand and assess the plausibility of this claim, Prof. Mantena reconstructs Gandhi's implicit theory of politics, especially what he took to be the challenges to political persuasion, such as the psychological dimensions of conflict that lead to recalcitrance and retrenchment.

That violence can compromise and undermine political ends remains a recurring blind spot of modern political imagination. Myriad political actors—from imperial policy makers, populist leaders, to revolutionary movements—assume that force leads to compliance. As Gandhi warned, and as the history of empire demonstrates, more often it leads to resistance and reaction. And when societies become habituated to force, universal moral and political values become most fragile.

JURY CHAIRS

ENGINEERING & COMPUTER SCIENCE

ARVIND
Jury Chair

Prof. Arvind is the Johnson Professor of Computer Science and Engineering, Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology. His work was instrumental in the development of dynamic dataflow architectures and associated parallel programming languages. He developed the Bluespec language for the synthesis and verification of large digital systems. Prof. Arvind has received numerous awards and honors and they include IEEE Charles Babbage Outstanding Scientist Award (1994); Distinguished Alumnus Award, IIT-Kanpur (1999); Outstanding Achievement Award, University of Minnesota (2008); and IEEE Computer Society Harry H. Goode Memorial Award (2012).

JURORS

Kaushik Bhattacharya
Howell N. Tyson, Sr., Professor of Mechanics and Materials Science; Vice Provost Department of Mechanical and Civil Engineering, California Institute of Technology, USA

Dhananjay Dendukuri
CEO & Co-Founder, Achira Labs Pvt. Ltd., India

Jayathi Y. Murthy
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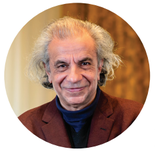
Ashutosh Sharma
Institute Chair Professor, Department of Chemical Engineering, Indian Institute of Technology, Kanpur, India

Sunita Sarawagi
Institute Chair Professor, Computer Science and Engineering, Indian Institute of Technology, Bombay, India

HUMANITIES



AKEEL BILGRAMI
Jury Chair

Akeel Bilgrami is the Sidney Morgenbesser Professor of Philosophy and Professor, Committee on Global Thought, Columbia University. He is the author of the books *Belief and Meaning, Self-Knowledge and Resentment,* and *Secularism, Identity, and Enchantment* and is currently writing a book on Gandhi's philosophy as well as a longer work on the nature of practical reason. At Columbia he has been the Chairman of the Philosophy Department from 1994-98, the Director of the Heyman Centre for the Humanities from Dec 2003-2010, and the Director of the South Asian Institute from 2013-2016. He was elected Cullman Fellow at the New York Public Library, held the Radhakrishnan Chair in India, visiting professorships at Oxford University and Yale University, and has been the recipient of fellowships and grants from the Mellon Foundation, Ford Foundation, National Endowment of the Humanities, as well as the Luce Foundation. He is also the President of the Trustees and the Executive Editor of The Journal of Philosophy.

JURORS

Prachi Deshpande
Associate Professor of History, Centre for Studies in Social Sciences, Kolkata, India

Partha Mitter
Emeritus Professor, History of Art, University of Sussex, UK

Kavita Singh
Professor, School of Arts and Aesthetics, Jawaharlal Nehru University, India

David Shulman
Professor Emeritus, Hebrew University, Jerusalem and Member of the Israel Academy of Sciences and Humanities, Israel

LIFE SCIENCES

MRIGANKA SUR
Jury Chair

Mriganka Sur is the Newton Professor of Neuroscience; Director, Simons Center for the Social Brain; and Investigator, Picower Institute for Learning and Memory, at the Massachusetts Institute of Technology. He was head of the MIT Department of Brain and Cognitive Sciences for 15 years. The McGovern Institute for Brain Research was founded under his leadership. At MIT, Sur received the Hans-Lukas Teuber Scholar Award in the Brain Sciences (1997), the Sherman Fairchild Chair (1998), and the Newton Chair (2008). He is an elected Fellow of the Royal Society (UK), the US National Academy of Medicine, the American Academy of Arts and Sciences, and the Indian National Science Academy.

JURORS

Scott V. Edwards
Chair, Organismic and Evolutionary Biology, Professor of Organismic and Evolutionary Biology, Curator of Ornithology, Museum of Comparative Zoology, Harvard University, USA

Jane Langdale
Professor of Plant Development, University of Oxford, UK

K. VijayRaghavan
Emeritus Professor and Former Director, National Centre for Biological Sciences, India

Gagandeep Kang
Director, Enterics, Diagnostics, Genomics and Epidemiology-Global Health, Bill and Melinda Gates Foundation, USA

Anjana Rao
Professor, La Jolla Institute for Immunology, USA

MATHEMATICAL SCIENCES

CHANDRASHEKHAR KHARE
Jury Chair

Chandrashekhar Khare is Professor & David Saxon Presidential Term Chair in Mathematics, University of California, Los Angeles, USA. He is a number theorist and works on the connection between modular forms and Galois representations. Prof. Khare's work with Jean-Pierre Wintenberger gave a proof of a celebrated conjecture of J.-P. Serre in the subject. He has received a number of honors and awards in recognition of his work. Khare received the Humboldt Research Award in 2011, Cole Prize in 2011, Infosys Prize in 2010, Guggenheim fellowship in 2008, Fermat prize in 2007, and the INSA Young Scientist Award in 1999. In 2012, Prof. Khare was elected as a Fellow of the Royal Society.

JURORS

Hélène Esnault
Einstein Professor (Emeritus), Institute of Mathematics, Free University, Berlin, Germany

Meena Mahajan
Professor, The Institute of Mathematical Sciences, Chennai, India

Siddhartha Mishra
Professor, Department of Mathematics, ETH Zürich, Switzerland

Dipendra Prasad
Professor, Department of Mathematics, IIT-Bombay, India

PHYSICAL SCIENCES

SHRINIVAS KULKARNI
Jury Chair

Prof. Shrinivas Kulkarni is George Ellery Hale Professor of Astronomy and Planetary Science at the California Institute of Technology and Former Director of the Caltech Optical Observatories. Prof. Kulkarni' s primary interests are the study of compact objects (neutron stars and gamma-ray bursts) and the study of the interstellar medium. His notable awards include the Alan T. Waterman Prize of the US National Science Foundation, the Helen B. Warner award of the American Astronomical Society and the Jansky Prize of Associated Universities, Inc. Prof. Kulkarni is a Fellow of the Royal Society of London, member of the National Academy of Sciences of United States, a Fellow of the Indian Academy of Sciences, and Foreign Member of the Royal Netherlands Academy of Arts and Sciences. In 2017, he won the Dan David Prize for his contribution to the emerging field of Time Domain Astronomy.

JURORS

Yamuna Krishnan
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Ramamurti Shankar
Josiah Willard Gibbs Professor of Physics, Yale University, USA

Spenta Wadia
Infosys Homi Bhabha Chair Professor and Founding Director, International Centre for Theoretical Sciences of TIFR, India

Srivari Chandrasekhar
Scientist, CSIR-Indian Institute of Chemical Technology, Hyderabad, India

SOCIAL SCIENCES

KAUSHIK BASU
Jury Chair

Kaushik Basu is Professor of Economics and the C. Marks Professor of International Studies at Cornell University. He is a former Chief Economist and Senior Vice President of the World Bank. Prior to joining the World Bank, he served as Chief Economic Adviser to the Government of India. A Fellow of the Econometric Society, he has published widely in the areas of Development Economics, Industrial Organization, Game Theory and Welfare Economics. His books include *Analytical Development Economics* (1997), *Prelude to Political Economy: A Study of the Social and Political Foundations of Economics* (2000), *Of People, Of Places: Sketches from an Economist's Notebook* (1994), *Beyond the Invisible Hand: Groundwork for a New Economics* (2011), *An Economist's Miscellany* (2011), and *The Republic of Beliefs* (2018). In May 2008, he was awarded the Padma Bhushan by the Government of India.

JURORS

Gopalkrishna Gandhi
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Mamta Murthi
Vice President for Human Development, World Bank, Washington DC, USA

Andrew Willford
Professor of Anthropology, Cornell University and Chair of Cornell's Institutional Review Board, USA

Sonalde Desai
Distinguished University Professor, Department of Sociology, University of Maryland, USA; Professor and Centre Director, NCAER-National Data Innovation Center, New Delhi, India

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THE INFOSYS SCIENCE FOUNDATION

The Infosys Science Foundation, a not-for-profit trust,was set up in 2009 by Infosys and members of its Board, with the objective of encouraging, recognizing, and fostering world-class scientific research connected to India. We do this primarily through the Infosys Prize, which is awarded to researchers and scholars in six categories: Engineering and Computer Science, Humanities, Life Sciences, Mathematical Sciences, Physical Sciences and Social Sciences. A jury comprising eminent leaders in each of these fields evaluates the achievements of nominees against the standards of international research, placing the winners on par with the finest researchers in the world. The prize consists of a gold medal, a citation, and a purse of US $100,000. In keeping with our mission of spreading the culture of science, we also partner with educational institutions to host lectures featuring Infosys Prize laureates and jurors aiming to spark curiosity and inspire the next generation of scholars. The Foundation creates conversations around science and society, engaging with various sections of the community, through talks, initiatives, workshops and training. Log on to www.infosysprize.org to know more.

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