
INFOSYS SCIENCE FOUNDATION
INFOSYS PRIZE 2022

MAN IN THE AGE OF MACHINE

The image on the cover is the result of human-AI collaboration.

This is how an algorithm reimagined Van Gogh's Starry Nights—in Varanasi, India.

What would Vincent make of it, one wonders.

Humans through the millennia have used art, music, and literature as self-expression and to describe the world around them. In recent years though, artificial intelligence has been both inspiration and medium for creating visual art, music, film, and literature. A few months ago, a piece of AI-generated art won a competition against human artists.

Is AI-generated art really art, then? Or is the algorithm a mere copycat?

AI-generated art can be dismissed as gimmicky. You could teach an algorithm to write like Charlotte Bronte and it could write you a few passages in the vein of Jane Eyre. But will we ever have an algorithm that does more than imitate Picasso's brushstrokes or mimic a Bach fugue? And what would that mean?

We have started playing around with something profound — something which goes to the essence of what makes us human. And it makes some of us nervous.

Between home robots that will soon anticipate our every need and an AI predicting the structure of every protein molecule, we are already living in a reality that was once science fiction. As with all new technology, there is an existential anxiety around AI. Besides being confronted with the hard problem of consciousness, this anxiety perhaps comes from living in an age when so much of technology is monopolized by a few and algorithms appear to be taking over our lives — from writing emails to music recommendations to compiling shopping lists. Add to this the very real danger of algorithms with the ability to generate and push false information, especially when they lead to real world unrest and violence.

Is it any wonder then that the age of AI is also the age of anxiety?

On the flip side is the potential of a world where man and machine collaborate and coexist. Together with humans, an algorithm compiles your favorite playlist, while another finds a cure for cancer and yet another discovers new planets.

Imagine that world.

Every technology holds in itself the ability to unleash great change. And everyone seems agreed that AI is possibly the most important development since electricity. As we find ourselves on a new frontier, it demands of us a better imagination which requires us to dig deep into the best of ourselves to forge a brave new world.

ENGINEERING & COMPUTER SCIENCE

The Infosys Prize 2022 in Engineering and Computer Science is awarded to Prof. Suman Chakraborty for his pioneering work in elucidating the interaction of fluid mechanics, interfacial phenomena, and electromechanics at the micro- and nanoscale. Using this understanding, he has helped to advance healthcare in resource-limited settings through the invention of novel low-cost medical devices for sensing, diagnostics and therapeutics.

SUMAN CHAKRABORTY

Professor, Mechanical Engineering, and Dean,
Research and Development,
Indian Institute of Technology, Kharagpur

Prof. Suman Chakraborty is a Professor of Mechanical Engineering, and Dean, Research and Development at the Indian Institute of Technology, Kharagpur. Prof. Chakraborty completed his undergraduate studies from Jadavpur University in 1996 and obtained his M.E. in Mechanical Engineering, and Ph.D. from Indian Institute of Science, Bengaluru in 2002. He joined IIT-Kharagpur the same year as assistant professor and became full professor in 2008. Chakraborty has received many accolades including the Shanti Swarup Bhatnagar Prize (2013), J.C. Bose Fellowship (2018), and the G.D. Birla Award (2020).

SCOPE AND IMPACT OF WORK

Prof. Suman Chakraborty's research explores the physics of fluid transport at very small length scales, ranging from nanometers to microns. At these length scales, the physics are dominated by the interaction of the fluid with surface structure and interfacial phenomena may dominate. When these new physics are combined with new modalities for fluid actuation, such as the use of electric fields, an exciting array of new technologies becomes possible. Microfluidic technologies are making a lasting impact on fields such as healthcare, energy, transportation, microelectronics and many others.

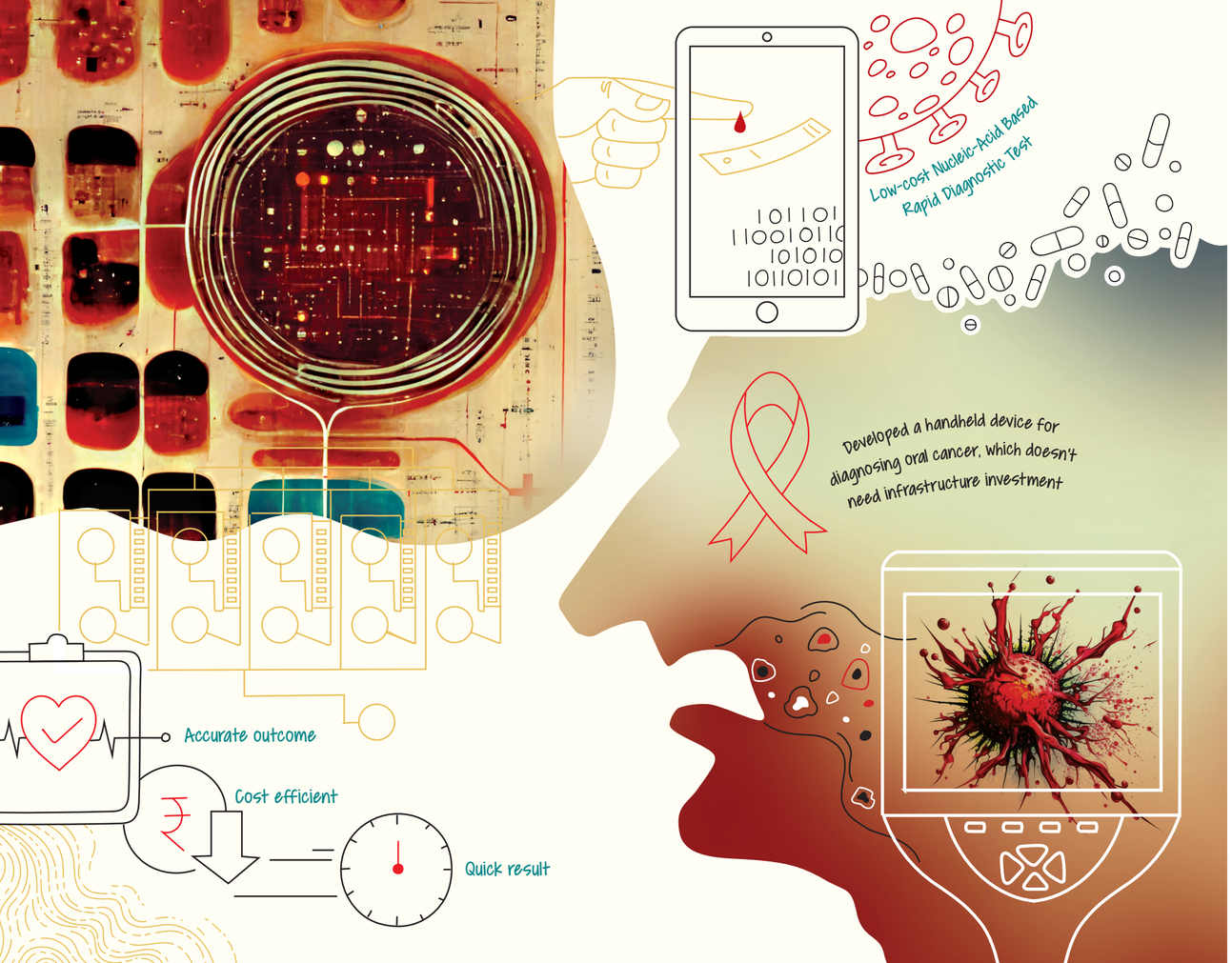
Prof. Chakraborty has investigated the behavior of fluids in nanoscale geometries, with a particular emphasis on the role of fluid confinement and interaction with boundaries. At very small scales, fluid-fluid and fluid-solid interactions are determined by molecular-level interplay and the atomistic details of surface structure. Chakraborty has demonstrated that these interactions lead to a variety of unintuitive physical phenomena not encountered at larger scales. For example, he has shown that hydrophobic surfaces may be tuned to selectively produce hydrophilic behavior by exploiting the molecular and ionic arrangements at the interface between fluid and solid. This understanding has opened up the possibility of switchable surface wettability without the necessity of elaborate and permanent surface functionalization techniques. Another significant contribution has been the investigation of novel modalities to induce and control fluid motion at the microscale, and the interplay of capillarity, rheology and electrical modulation in transporting fluids at very small scales. Deeper understanding of these physics enables the exploitation of new paradigms for electro-fluidic interaction, and for the interactions of fluids, surfaces and interfaces. It makes possible new functionalities such as controlled capillarity and wettability, electrokinetic flow control, novel electrically controlled rheologies, and the development of new generations of microdevices for biomedical and other applications. Suman Chakraborty has exploited his deep understanding of microscale flow physics in developing unique low-cost biomedical devices for use in resource-limited settings where trained personnel may not be available. These have included paper-based handheld devices for blood testing using very small blood samples, devices for the painless extraction of blood samples and for drug delivery, devices for the detection of antibiotic drug resistance, as well as devices for water quality monitoring and pathogen detection in ultra-dilute samples, among others.

CITATION BY THE JURY

The Infosys Prize is awarded to Prof. Suman Chakraborty for deepening our understanding of fluid mechanics at micro- and nano-scales, and for applying this knowledge to develop a new generation of low-cost medical devices. Prof. Chakraborty has achieved numerous important breakthroughs in our understanding of how fluids behave at very small scales, and how this behavior may be exploited to achieve effects not accessible at larger scales. His investigations of the interaction of interfacial structure, hydrophobicity, rheology and external fields has led to the discovery and elucidation of a variety of rich physical phenomena only occurring at the nanoscale. Furthermore, Suman Chakraborty has used his expertise in microfluidics to develop a variety of sensing, diagnostic and therapeutic medical technologies with the potential to significantly transform healthcare in resource-limited settings.

"Prof. Suman Chakraborty is that rare researcher who combines the highest quality fundamental research with the translation of research into practical use. I am particularly impressed that Prof. Chakraborty's work has the potential to expand inexpensive healthcare options in India and across the world and am so proud that such deep and impactful work originated entirely in India. Congratulations Prof. Chakraborty!"

- Arvind



The age of microfluidics: From point-of-care to extreme point-of-care

It is often said that we live in the Digital Age. But it wouldn't be too far-fetched to say that this is also the Age of Microfluidics. The discipline of microfluidics developed in the 1980s and since then it has grown in leaps and bounds. The study of how fluids move and function in the tiniest of channels is called microfluidics. Fluids tend to move differently in smaller tubes than they do in larger pipes. And this has important implications for how we understand everything from drug delivery in the human body to diagnostics.

These special properties of fluid behavior in small channels are being exploited to develop new cutting-edge diagnostics and treatment. Microfluidics is the basis of creating benchtop on-chip systems that mimic human physiology. The development of pharmaceuticals and diagnostics can be prohibitively expensive. However, on-chip systems can help reduce costs considerably while providing accurate results. Using microfluidics in diagnostics and treatment has the advantage of making these interventions cost efficient, quick, easy to use, and accurate. Prof. Suman Chakraborty has made important advances in microfluidics, and taken the concept of point-of-care diagnostics to extreme point-of-care diagnostics using his knowledge and findings. During the COVID-19 pandemic, Prof. Chakraborty and his collaborators developed a Nucleic Acid-Based Rapid Diagnostic Test which helped in quick detection of infectious diseases. Based on their study of capillary action of fluids, Chakraborty and his team also devised the Finger-Prick Blood on Paper Strip which is an extremely low-cost diagnostic test that can measure glucose, lipid profile, hemoglobin from a simple pinprick size blood sample, which can be analyzed using a smartphone app. Such a device has the advantage of being widely accessible.

Prof. Chakraborty has used microfluidics to develop a handheld device for diagnosing oral cancer. This device uses thermal imaging to detect changes in blood flow in human tissue thus detecting changes that may indicate tumors. The reason that oral cancer was the focus was because this is a common ailment due to tobacco use. Around 1 million people die of oral cancer annually in India. Lack of access to early detection and diagnosis exacerbates the problem. The device doesn't need specialized training to use and doesn't need infrastructure investment. In initial testing, the device has demonstrated an impressively high 97% accuracy and has passed Phase-1 clinical trials. If rolled out, it could prove to be a game changer for rural areas with no access to healthcare or medical personnel and has the potential to save millions of lives.

HUMANITIES

The Infosys Prize 2022 in Humanities is awarded to the legal scholar Prof. (Dr.) Sudhir Krishnaswamy for his insightful understanding of the Indian Constitution, especially his carefully argued account of the importance of the landmark 'basic structure doctrine' adopted by the Supreme Court in 1973 that guides and constrains various efforts to amend it, while also ensuring its stability in the face of executive and legislative outcomes in India's political life.

SUDHIR KRISHNASWAMY

Vice Chancellor and Director,
Department of Professional and Continuing Education, National Law School of India University, Bengaluru

Prof. Sudhir Krishnaswamy studied at the National Law School of India University in Bengaluru, where he obtained his B.A. L.L.B (Hons.) degree. He then went to Oxford University as a Rhodes Scholar, where he obtained a B.C.L. degree and a D.Phil. in Law in 2009.

Prof. Krishnaswamy has taught at Pembroke College in Oxford University and at Columbia University, and in India he has taught at West Bengal National University of Juridical Sciences and at Azim Premji University before being appointed Vice Chancellor of the National Law School of India University, Bengaluru in 2019. Krishnaswamy has been an important voice as a public intellectual, engaging in civil society debates and shaping and guiding legal policy, especially in Karnataka, where he has also been the founding member of the Alternative Law Forum and a founding trustee of the Centre for Law and Policy Research.

SCOPE AND IMPACT OF WORK

In a democratic polity, the domain of the law consists not only of ordinary legislative outcomes and the various clauses of a constitution, but also fundamental assumptions and ideals that a nation has adopted, sometimes without explicit and detailed articulation. The Supreme Court, in its decision in *Kesavananda Bharati* (1973) and other cases declared these latter assumptions and ideals to constitute 'the basic structure' doctrine. Prof. Sudhir Krishnaswamy's great achievement in his major book, *Democracy and Constitutionalism in India* (Oxford, 2009), is to elaborate the theoretical underpinnings, the legitimacy, and the unfolding significance of this doctrine, showing how it emerges by a very careful reading, not only of cases that have evolved in a nation's legal history, but also by an interpretation of the debates in the Constituent Assembly, and indeed during the many deliberations during India's freedom movement as it geared itself to acquire statehood.

Prof. Krishnaswamy's work in legal theory extends to a wide range of other topics, such as the workings of India's Supreme Court, the nature and extent of the trust that public opinion has for the Indian judiciary, the relations between social justice and the courts, and the newly emerging field of horizontal rights — that is, rights that are not, as is usually conceived, rights against states, but against private individuals as well. In all these writings, Krishnaswamy's intellectual prowess is everywhere evident and, taken together with his writings on the Constitution, it amounts to a very impressive and lasting contribution to the subject that cannot be ignored by serious students of Indian law.

CITATION BY THE JURY

Prof. Sudhir Krishnaswamy's writings on the Indian Constitution are a significant contribution to our understanding of India's framework of governance since independence, with broad philosophical implications for how the realm of law relates to parliamentary politics and, thus, to the ideals of democracy. This is a notable achievement produced with great theoretical sophistication, detailed research, and acute analysis and argument. Prof. Krishnaswamy's work extends to a range of other areas of the law, including the workings of the Supreme Court of India, to all of which he brings his considerable intellectual power. Prof. Krishnaswamy, who has been a Rhodes Scholar and has taught at universities both abroad and in India, is also making a name for himself as a skillful leader and administrator, currently holding the position of Vice Chancellor of India's pre-eminent institution of legal education, the National Law School of India University, Bengaluru.

"My warm congratulations to you, Prof. Krishnaswamy, on being awarded the Infosys Prize 2022 in Humanities. I greatly admire the analytical power with which you have elaborated the significance of 'the basic structure doctrine' for the Indian constitution and its unfolding history in independent India. I hope very much that this award will spur you to new heights of scholarly achievement. "

– Akeel Bilgrami

One doctrine to rule them all

A constitution is a set of fundamental principles and laws according to which a country is governed. The constitution defines the main institutions of the country and the relationship between those institutions. It also sets limits on the exercise of power by the branches of government while also setting out the rights and duties of citizens.

A constitutional amendment is the act of modifying sections of the constitution. While constitutions remain mostly inviolable, as nations progress and change, there is need for constitutions to reflect those changes. However, in most countries constitutional amendments require involved and stringent procedures.

The Constitution of India was adopted by the Constituent Assembly of India (which was assembled to frame the constitution) in 1949 and came into effect in 1950. In India, proposed constitutional amendments are governed by the 'basic structure doctrine', the idea that changes cannot violate its basic features.

Prof. Sudhir Krishnaswamy is a scholar of constitutional law. Prof. Krishnaswamy's scholarship examines the Indian Constitution in depth and analyzes how it influences governance and the democratic ideals of the Indian polity. Krishnaswamy has written extensively on the basic structure doctrine of the Indian Constitution and how the understanding of the basic structure of the constitution came about.

In 1972, the case of *Kesavananda Bharti vs Kerala* came before the Supreme Court of India. In the case, the head of a Hindu monastery in the southern Indian state of Kerala challenged the state government's attempts to restrict its ownership and management of land belonging to the monastery. The government attempted to do this using its land reform acts. When the case eventually appeared before the Supreme Court, it decided that while the institutions of the government have wide powers and could restrict elements like property rights, they did not have the power to destroy the fundamental features or 'the basic structure' of the constitution.

The basic structural elements of the constitution that the Kesavananda judgment listed are supremacy of the constitution, democratic and republican form of government, federal character of the constitution, separation of power, individual freedom, among others. The basic structure doctrine is used by the Supreme Court of India to review any proposed amendments to the constitution to ensure that the parliament doesn't overstep when making those amendments.

Prof. Krishnaswamy analyzes the significance of the basic structure doctrine and how its theoretical basis lay in the debates of the constituent assembly that framed the document and in a careful examination of Indian legal history.

Besides his work on basic structure, Prof. Krishnaswamy has done extensive work in other areas of legal theory such as the functioning of the Supreme Court, what social justice means and whether the courts can deliver it, and recently also horizontal rights, that is the rights against individuals and not just public entities or the state.

Prof. Sudhir Krishnaswamy's scholarly work on legal theory and jurisprudence helps us better understand independent India's constitution and its judiciary, governance framework and legislative outcomes that have far-reaching consequences.

LIFE SCIENCES

The Infosys Prize 2022 in Life Sciences is awarded to Prof. Vidita Vaidya for her fundamental contributions to understanding brain mechanisms that underlie mood disorders such as anxiety and depression, including signals engaged by the neurotransmitter serotonin in causing persistent changes in behavior induced by early life stress and the role of serotonin in energy regulation in brain cells.

VIDITA VAIDYA

Professor and Chairperson, Department of Biological Sciences, Tata Institute of Fundamental Research, Mumbai

Vidita Vaidya is Professor of Neurobiology in the Department of Biological Sciences at the Tata Institute of Fundamental Research, Mumbai. She received her Ph.D. from Yale University in 1998 and did postdoctoral research at the Karolinska Institute and Oxford University before joining TIFR in 2000. Prof. Vaidya is an elected fellow of the Indian National Science Academy, the Indian Academy of Sciences and the National Academy of Sciences, India. She has received the National Bioscientist Award (2012), Shanti Swarup Bhatnagar Award (2015), the J.C. Bose Fellowship (2021), and a Nature award for excellence in mentoring (2019).

Prof. Vaidya's record of scientific leadership includes serving on the boards and scientific advisory committees of several institutes including the National Centre for Biological Sciences and the National Brain Research Centre. She serves on the Council of Scientists, Human Frontiers Science Program, and is a reviewing editor for eLife and senior editor for the European Journal of Neuroscience.

SCOPE AND IMPACT OF WORK

Mental health is fundamental for human well-being and productivity. Our mental health is affected by mood disorders such as anxiety and depression, but the mechanisms that alter brain function and cause these disorders are not well-understood. In humans, early life stress can lead to anxiety and depression in adulthood. The focus of Prof. Vidita Vaidya's work is to understand the molecular and cellular mechanisms that contribute to mood disorders, with an emphasis on the function of serotonin, the neurotransmitter associated most closely with regulation of mood.

After establishing a credible animal model for depression based on early life stress, Prof. Vaidya's laboratory has shown that an imbalance in serotonin mechanisms, via different receptors with different G-protein-based signaling systems, is an important contributor to stress-induced anxiety and depression. Manipulating these signaling pathways during brain development can influence mood-related behavioral changes extending into adulthood. She has shown that the effectiveness of antidepressants in altering behavior may relate to the growth of new neurons and processes together with changes in gene expression in critical brain regions such as the hippocampus.

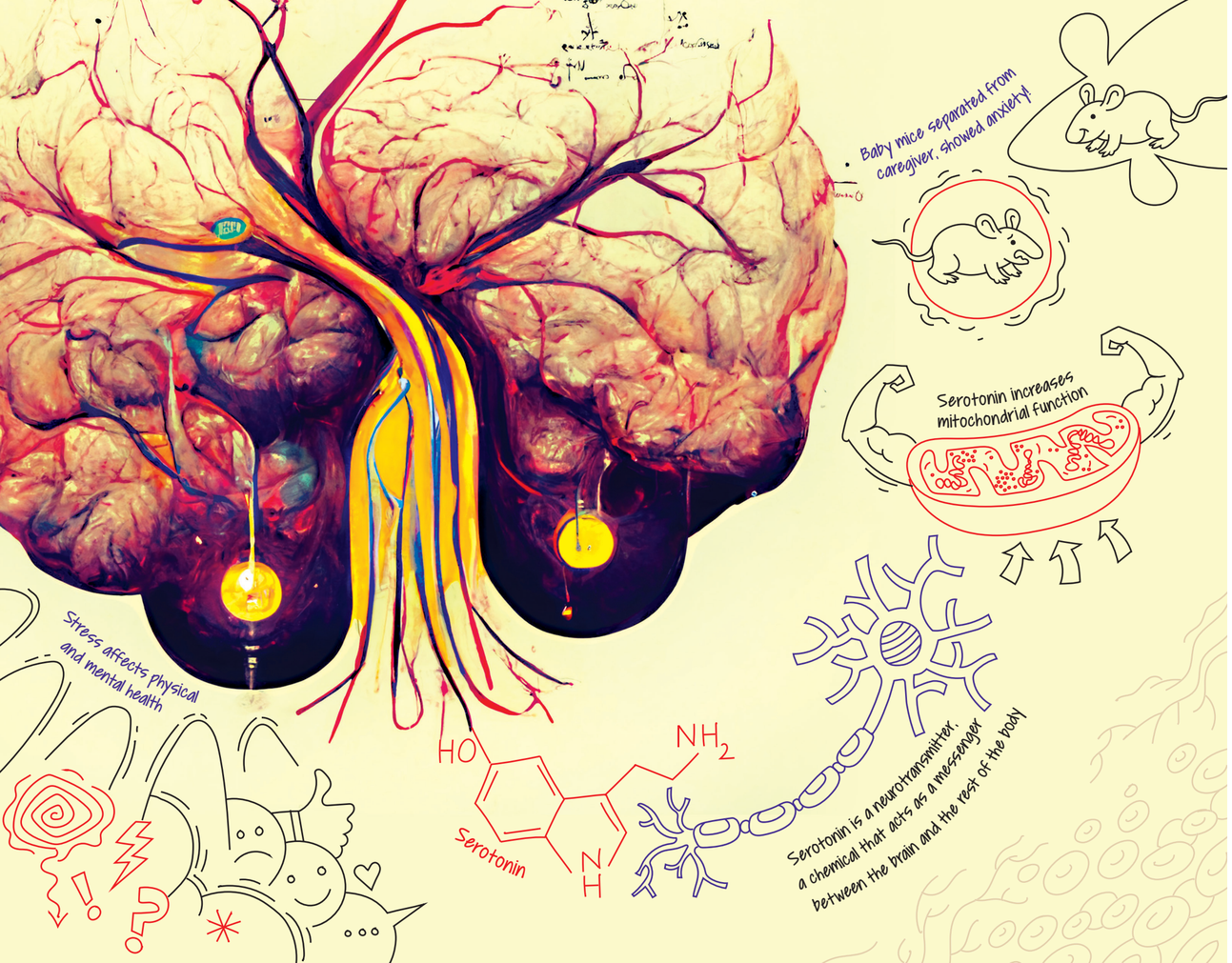
Vaidya's findings demonstrating a role for serotonin signaling in making new mitochondria and enhancing mitochondrial function in neurons establishes a connection between neurotransmitter activity and cellular energy regulation. This work provides a new way to understand the effects of serotonin and has the potential to yield novel approaches to therapeutic treatments for psychiatric or neurodegenerative disorders.

CITATION BY THE JURY

Prof. Vidita Vaidya has made important contributions to understanding the neurobiology of mood disorders. Such disorders crucially affect mental health, but the underlying brain mechanisms remain poorly understood. Prof. Vaidya's work has focused on mechanisms downstream of serotonin, the most important neurotransmitter linked to mood disorders. She has provided evidence for persistent alterations in the brain in animal models of depression, mainly arising from early life stress, caused by an imbalance between different serotonin receptors and their intracellular signals which ultimately leads to long-lasting behavioral changes. Prof. Vaidya's laboratory has described adaptive changes in brain structure and function that arise in response to chronic antidepressant treatments, and a novel mechanism of serotonin action through enhancing mitochondria production and cellular energy-regulating pathways. These findings can lead to new therapeutic strategies for a range of psychiatric and other brain disorders.

"On behalf of the jury, I congratulate you on receiving the Infosys Prize 2022 in Life Sciences. Your pathbreaking work on the neurobiology of mood disorders has revealed fundamental mechanisms by which serotonin signaling affects brain states underlying anxiety and depression. Your analysis of how early life stress impacts serotonin function promises to yield novel strategies for reducing the burden of psychiatric disorders and improving mental health."

– Mriganka Sur



More than a feeling

A few years ago, the National Health Service in the UK started 'social prescribing' to improve health. Social prescribing encouraged patients to be out and about and be involved in their communities. Activities such as gardening, forest bathing, a game of bingo were all part of social prescribing. This was official recognition that health (mental and physical) is affected by several factors including social isolation. Evolution has ensured that our brains are wired to respond to our environments in specific ways. And those responses have effects on mind and body.

At this point we are all familiar with the many terrible ways that stress can affect physical and mental health. Prof. Vidita Vaidya believes that how we cope with stress will determine how we live and how we will die. The chemical we now call serotonin has been known to scientists for more than a century. In the 1950s, scientists discovered the presence of serotonin in the human central nervous system. Serotonin is a neurotransmitter, a chemical that acts as a messenger between the brain and the rest of the body. It is responsible for mood modulation, learning, memory, and several biological functions in the human body. And serotonin production is boosted by many of the activities relating to social prescribing. The role of serotonin on brain function and behavior has been known since the 1950s. But how and what that role was on brain mechanisms was unclear — until now.

Prof. Vaidya's work involves studying the brain mechanisms that lie behind changes in emotional behaviors and mood disorders, and how serotonin determines these behaviors.

Using mice, Vaidya and her team, determined that early life stress has a role to play in mental health disorders such as anxiety and depression in adults. How they did this was by separating baby mice from their mothers and then studying their behavior over time. Many of the babies in later life exhibited anxiety-like behavior. The team discovered that the behavioral change is because of changes to serotonin receptor function in the brain. They then tweaked serotonin receptors in the baby mice using a genetic toolkit to see what would happen. Sure enough, they saw changes in behavior in the mice.

Importantly, the team also made a discovery about serotonin's role in energy production in nerve cells or neurons. Neurons are some of the longest lived cells in the human body and they consume a lot of energy. About 20% of energy produced by the body is used up by the brain. Energy production in all cells in our body is controlled by tiny organelles in the cells called mitochondria. Prof. Vaidya and her collaborators discovered that mitochondrial function is regulated by serotonin. Increased serotonin meant increased mitochondrial function, boosting energy production in the neurons.

Prof. Vaidya's discoveries have enormous clinical implications. The function of serotonin in boosting energy production has particular relevance for the aging brain and in neurodegenerative disorders. Vaidya's findings about how early stress affects mental health in adults has implications in how we understand and treat mental health disorders such as anxiety and depression.

MATHEMATICAL SCIENCES

The Infosys Prize 2022 in Mathematical Sciences is awarded to Prof. Mahesh Kakde for his outstanding contributions to algebraic number theory. Prof. Kakde's deep work on the noncommutative Iwasawa main conjecture, his work on the Gross-Stark conjecture (with Samit Dasgupta and Kevin Ventullo), and his work on the Brumer-Stark conjecture (with Samit Dasgupta), resolves outstanding conjectures at the heart of modern number theory.

MAHESH KAKDE

Professor, Department of Mathematics,
Indian Institute of Science, Bengaluru

Mahesh Kakde has been working at the Indian Institute of Science, Bengaluru since 2019 as Professor of Mathematics. Prior to that, he was at King's College London. Prof. Mahesh Kakde did his B. Math. from Indian Statistical Institute, Bengaluru, and went on to complete his Ph.D. at the University of Cambridge in 2008, specializing in number theory. During his Ph.D., and shortly afterwards, he contributed essentially to Iwasawa theory. Prof. Kakde's proof of the "Noncommutative Iwasawa Main Conjectures over Totally Real Fields" subsequently became the subject of conference proceedings dedicated to the topic. Kakde was a Simons Visiting Professor, at The Centre de Recherches Mathématiques (CRM), Montreal, in 2020. Along with Samit Dasgupta, he delivered an invited talk titled "On the Brumer-Stark Conjecture and Refinements" at the International Congress of Mathematicians in 2022.

SCOPE AND IMPACT OF WORK

Prof. Mahesh Kakde's early work in his thesis and soon after made a decisive contribution to the main conjecture of non-commutative Iwasawa theory for the Tate motive. It used an insightful and ingenious combination of algebraic techniques and more analytic techniques drawn from the theory of modular forms. This has been a hallmark of his subsequent work as well.

Main conjectures in Iwasawa theory have played a huge role in modern number theory. Ideas from Iwasawa theory were a key inspiration for Wiles's proof of Fermat's Last Theorem. Prof. Kakde's work since his thesis has been in the area of Iwasawa theory and related areas and thus at the center of current work in algebraic number theory.

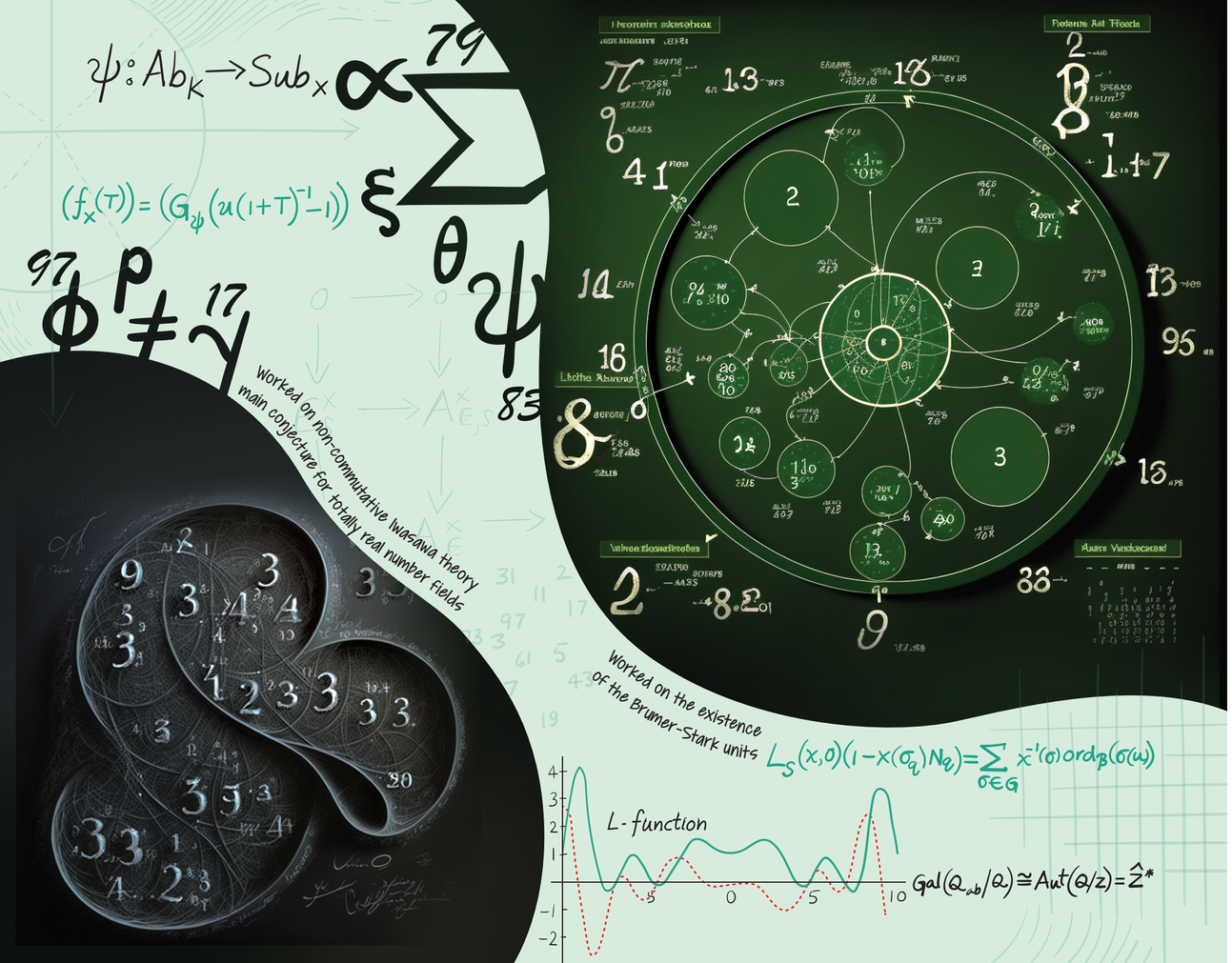
Kakde's work on the Gross-Stark conjecture (with Dasgupta and Ventullo) resolved an outstanding conjecture about leading terms of abelian p-adic L-functions and their relation to determinants made from units when the p-adic L-function vanished to order greater than one. This had been thought out of reach by experts in the area. A deepening of the ideas of this work, that again involved a deft combination of algebraic insights and a beautiful use of higher congruences between modular forms, led Prof. Kakde and Dasgupta to their landmark proof of the Brumer-Stark conjecture. This has led them to explicit p-adic constructions of units in abelian extensions of number fields, thus making a contribution to Hilbert's 12th problem.

CITATION BY THE JURY

The relation between certain analytic functions called L-functions and prime numbers and other objects of interest in number theory emerged in the 19th century. Dirichlet's proof of the infinitude of primes in arithmetic progression using Dirichlet L-functions is an early instance of this relation. Beginning in the middle of the 20th century, p-adic analytic variants of these L-functions for prime numbers p have played a distinguished role in algebraic number theory. Iwasawa theory posits a deep relation between p-adic L-functions and arithmetic objects of interest to number theorists. Prof. Mahesh Kakde's work on special values of p-adic L-functions and their relation to class groups and units of number fields resolves several outstanding conjectures in the subject. The methods used in his work (some of it joint with Dasgupta and Ventullo) are intricate and hinge on a deep study of congruences between modular forms.

"I would like to congratulate Mahesh for winning the Infosys Prize 2022. His work on the main conjecture of non-commutative Iwasawa theory, on the Gross-Stark conjecture and on the Brumer-Stark conjecture has had a big impact on the field of algebraic number theory. His work makes important progress towards a p-adic analytic analog of Hilbert's 12th problem on construction of abelian extensions of number fields."

– Chandrashekhar Khare



Towers of infinite possibility

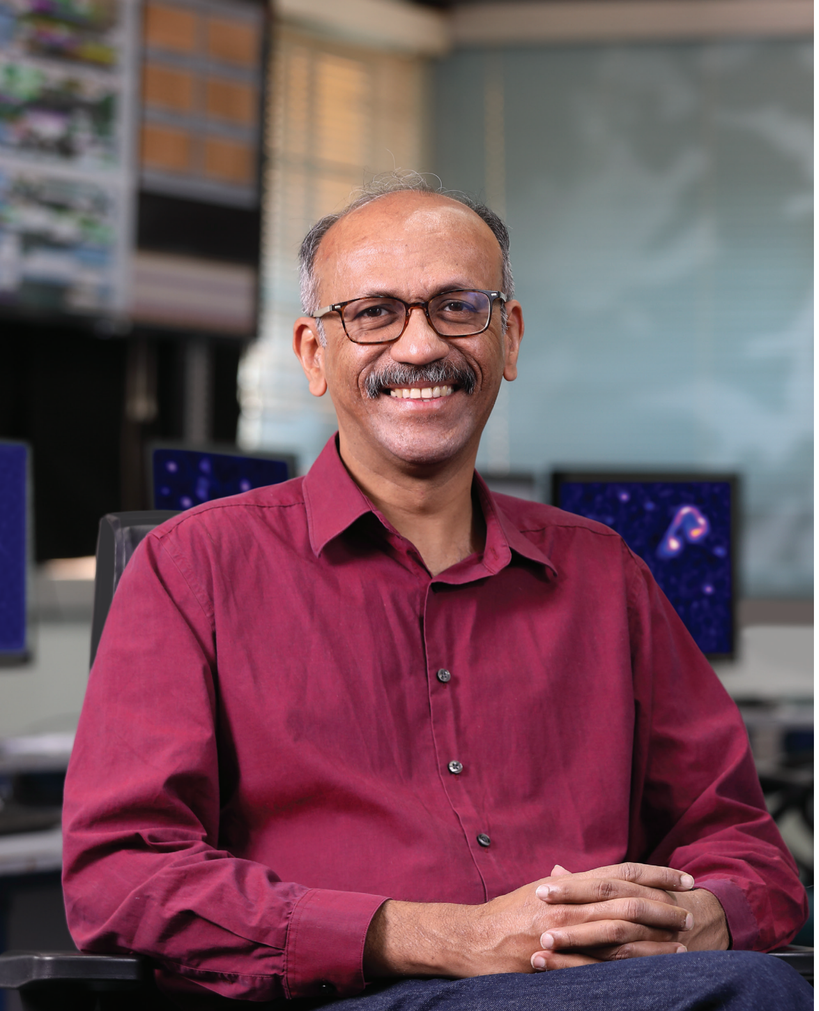
In 1900, the International Congress of Mathematicians was held at the Sorbonne University in Paris. At the conference, David Hilbert, a German mathematician, presented 10 unsolved (at that time) problems in mathematics. Hilbert's hope was that significant progress would be made toward solving these problems by future generations of mathematicians. In 1902, Hilbert's full set of 23 unsolved problems was published (in English translation) in the *Bulletin of the American Mathematical Society* by the American mathematician, Mary Frances Winston Newson. These 23 problems set the course for much of mathematical research undertaken in the 20th century and beyond. Over the next few decades, mathematicians from around the world proceeded to work on Hilbert's problems.

Prof. Mahesh Kakde is a number theorist who works with algebraic number theory. Prof. Kakde's work makes important contributions to Hilbert's 12th problem.

Number theory has several conjectures, which as the name suggests are statements with no proofs yet. Among the conjectures that Prof. Mahesh Kakde has worked on, he is particularly known for his deep study and contributions to the Iwasawa main conjecture. Modern algebraic number theory has many conjectures relating analytic objects, namely L-functions, with arithmetic objects such as ideal class groups. Iwasawa theory, first formulated by the Japanese mathematician Kenkichi Iwasawa in the 1950s, has played a crucial role in the development of modern algebraic number theory. It is a systematic tool for proving conjectures relating L-functions to arithmetic objects. A precise relation between the two is codified in Iwasawa main conjecture. Generalizing the work of Andrew Wiles from the 1980s, Prof. Kakde proved the non-commutative Iwasawa theory main conjecture for totally real number fields.

In the 1970s, Harold Stark and Armand Brumer posited the existence of certain numbers whose logarithms are related to values of L-functions. These special numbers, known as Brumer-Stark units, also turned out to have applications to explicit class field theory or Hilbert's 12th problem. In the 1980s, Benedict Gross used p-adic numbers as a way to obtain more information about Brumer-Stark units. In 2006, Samit Dasgupta refined the work of Gross and conjectured a p-adic formula for the Brumer-Stark units.

In one of the most exciting developments in algebraic number theory Mahesh Kakde and Samit Dasgupta resolved these conjectures, firstly, by proving the existence of the Brumer-Stark units, and then by proving the conjectured formula of Dasgupta. Besides having significant impact on number theory, the theorems led to an effective formula for computation of Brumer-Stark units and may have real-world applications in the field of cryptography.



PHYSICAL SCIENCES

The Infosys Prize 2022 in Physical Sciences is awarded to Prof. Nissim Kanekar for his study of galaxies in an era, the so-called "high noon" period, in which stars were being formed at a maximum rate. Separately, his careful astronomical investigations have placed the strongest limit on possible secular variation of the fine structure constant and the electron-to-proton mass ratio.

NISSIM KANEKAR

Professor, National Centre for Radio Astrophysics,
Tata Institute of Fundamental Research, Pune

Prof. Nissim Kanekar is an astronomer and professor at the National Centre for Radio Astrophysics (NCRA) of the Tata Institute of Fundamental Research in Pune. In 2000, Prof. Kanekar obtained his Ph.D. from the University of Pune working on the then newly-commissioned Giant Metrewave Radio Telescope (GMRT). He held a NOVA postdoctoral fellowship in the Netherlands, and then Jansky and Max-Planck postdoctoral fellowships in the United States.

Nissim Kanekar, working with a Ph.D. student, Aditya Chowdhury, and Prof. Jayaram Chengalur, focused on the detection of atomic hydrogen in the distant universe which was the primary motivator for the building of the GMRT. Kanekar's research is characterized by a thorough understanding of GMRT, stochastic and systematic noise. It is his deep understanding that lies at the heart of this success in studies of cosmological hydrogen and constraining variation of fundamental constants. Prof. Kanekar's recognitions include the Ramanujan and the Swarnajayanti Fellowships received in 2009 and 2015 respectively.

SCOPE AND IMPACT OF WORK

Prof. Nissim Kanekar is an observational radio astronomer and best known, thanks to his deep understanding of methodologies, for his ability to make delicate but definitive measurements. The Infosys Prize 2022 in Physical Sciences is given for his pioneering detection of atomic hydrogen at cosmological distances and for constraining possible temporal evolution of two fundamental constants of physics.

Following the Big Bang, the universe was filled rather uniformly with hydrogen and helium. However, at the present time, the universe consists of concentrations of stars (a.k.a. galaxies). How the universe went from a gas-rich universe to one with galaxies is, not surprisingly, a frontier topic in astronomy. This question motivated the Giant Metrewave Radio Telescope in India and is the basis for the James Webb Space Telescope and the Square Kilometer Array.

Stars are born out of the gas, and galaxies which are collections of stars, are held together by the gravity of matter. Working with colleagues Aditya Chowdhury and Prof. Jayaram Chengalur, Prof. Kanekar detected atomic hydrogen at a redshift of 1.3, corresponding to a look back in time of eight billion years. In this epoch, gas appears to be converted to stars at a furious rate. The depletion of gas in turn reduces star formation and thus, neatly explains the dominance of stars over gas in our own galaxy at the present time. The detection was made possible by a brilliant approach which took advantage of redshifts obtained by optical astronomers and "stacking" the radio data.

CITATION BY THE JURY

The Infosys Prize 2022 in Physical Sciences is awarded to Prof. Nissim Kanekar for his investigations of the build-up of galaxies and observational constraints on secular variation of fundamental physical constants. The growth of galaxies since the Big Bang is a frontier problem in astronomy. Using the Giant Metrewave Radio Telescope, Prof. Kanekar and his colleagues traced the store of hydrogen gas as a function of their age. They found that eight billion years ago galaxies had more gas relative to stars. Copious star formation led to a rapid decrease of the hydrogen store. This finding nicely explains why present-day galaxies are dominated by stars. Separately, Kanekar, via radio astronomical observations, has placed the strongest limit on possible secular time variation of the fine structure constant and the electron-to-proton mass ratio. In both cases, the signals are weak and it is Prof. Nissim Kanekar's deep understanding of radio astronomical telescopes and methodology that were key to the success of his research programs.

"The detection of atomic hydrogen at "cosmic noon" is a landmark finding and a tribute to your exacting work and persistence, the GMRT and its architect, Govind Swarup. Your limits on invariance of fundamental constants stand high. We have recognized these two achievements with the Infosys Prize. Congratulations Nissim Kanekar! "

– Shrinivas Kulkarni

It all started with a big bang

The universe may end with a whimper as the poet said, but it began with a bang. And for a few hundred million years after the Big Bang, the universe was a place mostly filled with hydrogen and helium. It was a place in which stars and galaxies were beginning to form out of those gases.

Prof. Nissim Kanekar has been observing the vast expanses of space and trying to look back to a time 10 billion years after the Big Bang. What he found was fascinating. The period Prof. Kanekar and his collaborators studied is called the cosmic noon, when the star formation activity in the universe was at its peak.

Kanekar and his colleagues found that as the universe aged further, the hydrogen gas in galaxies was eaten up in star formation and galaxies were not able to acquire more gas from their surroundings. And so, the star formation activity in the universe slowed down. The universe as we know it now is a much quieter place than it was 10 billion years ago.

How did the team look so far back in time you may wonder. They used the Giant Metrewave Radio Telescope (GMRT). A radio telescope is an instrument used to detect radio waves from celestial objects. Radio telescopes use antennae to pick up signals from objects that are millions of light years away, much as one would use a radio to tune into a particular station. The signals are then interpreted using computer programs.

The GMRT, located a couple of hours outside the western Indian city of Pune, is an array or group of 30 telescopes. Nissim Kanekar and his colleagues measured the presence of atomic hydrogen gas in galaxies eight to nine billion years ago by studying the redshifted 21 cm line from these galaxies. This famous "spectral line" is redshifted to longer wavelengths due to the expansion of the universe, similar to the Doppler shift of train whistles when a train is moving away from us.

The team detected the presence of atomic hydrogen in galaxies at redshifts of 1-1.3 using the GMRT. This indicated that they were looking at galaxies as they were eight to nine billion years ago, a time when gas was being converted to stars at far higher rate than today. Galaxies also contained much more gas at those epochs relative to stars, but the gas was rapidly consumed in the process of star formation. As the amount of hydrogen gas in galaxies reduced, the rate of star formation reduced as well.

Prof. Nissim Kanekar's discoveries provide part of the answer to what was going on at cosmic noon, that has long fascinated astronomers. Separately, his studies have also yielded the best limits today on changes in two 'fundamental constants', the fine structure constant and the proton-electron mass ratio, two of the fundamental parameters that describe why our universe is the way it is.

SOCIAL SCIENCES

The Infosys Prize 2022 in Social Sciences is awarded to Prof. Rohini Pande for her outstanding research on subjects of key importance, including governance and accountability, women's empowerment, the role of credit in the lives of the poor, and the environment. Her empirical findings, based on diverse methodologies, offer major promise and potential for policy design in emerging economies, including India.

ROHINI PANDE

Henry J. Heinz II Professor of Economics and
Director, Economic Growth Center,
Yale University, New Haven

Rohini Pande is Henry J. Heinz II Professor of Economics at Yale University and Director of their Economic Growth Center. Educated at St. Stephen's College, Delhi (B.A.), Oxford (M.A.), and London School of Economics (Ph.D.), Prof. Rohini Pande held a chaired professorship at Harvard and, prior to that, was at Columbia and Yale. Prof. Pande has been a visiting professor at many leading universities and institutes, including Chicago, Stanford, and London School of Economics.

In 2018 Prof. Pande received the American Economic Association's Carolyn Shaw Bell Award for furthering the status of women in the economics profession. She was a Rhodes Scholar (1992-4), and is a Fellow of the Econometric Society and a member of the American Academy of Arts and Sciences. Pande has served on the editorial boards of several major journals, and on the boards of top research institutes in development economics.

SCOPE AND IMPACT OF WORK

Prof. Rohini Pande is an outstanding applied economist. Her work shows command over all modern empirical methods for finding or creating exogenous variation in the data and thereby achieving identification of cause and effect: Natural variation from policy reforms, field experiments, creative use of administrative and survey data and structural estimation. Much of her research focuses on India, a significant proportion is about gender issues. The questions are motivated by India's key challenges, such as governance, institutions and the functioning of democracy, women's empowerment, credit constraints for the poor and, lately, the environment. Her work is of outstanding quality and has appeared in leading journals, such as *American Economic Review, Econometrica*, *Quarterly Journal of Economics*, and *Science*.

In work studying the effect of mandated representation of women and marginalized groups in local government, Prof. Pande finds that the mandates improved the chances of such candidates winning elections even after the mandates were lifted, and had significant role model effects on younger generations' aspirations and educational attainment. Furthermore, exposure to female politicians reduced gender stereotypes.

In a highly cited paper on bank expansion in rural India, Pande finds that this significantly reduced rural poverty, without affecting urban poverty, through increased deposit mobilization and credit disbursement by banks in rural areas. Her work on microfinance has helped better understand the role of repayment flexibility, the importance of social interactions and the extent to which within-household dynamics may limit returns to capital for female entrepreneurs.

In a paper examining why Indian children are significantly shorter than ones in many even poorer countries, Prof. Pande finds a steep downward slope in heights across birth order, and pins this down to cultural preference for a healthy eldest son.

CITATION BY THE JURY

Prof. Rohini Pande is a productive and versatile economist. Her work is globally recognized and highly regarded, and covers many areas of vital interest to India: Democracy and governance; mandates for greater political representation of women and marginalized groups; women's empowerment and family issues; greater rural access to, and information about, financial institutions; microfinance and credit availability for the poor; and the environment.

Prof. Pande conducts this research using multiple types of data – administrative and survey – and employing different methods to identify causal effects – from naturally occurring variations from policy reforms to randomized field trials. Her findings are published in top journals in economics and also in general interest journals. They have important lessons for governance, institutions and development policies. Rohini Pande has received several honors and prizes. The Infosys Prize should serve to inspire all young Indian researchers, and women in particular.

"Rohini Pande, the winner of this year's Infosys Prize in Social Sciences, is one of the world's leading economists undertaking empirical research on a remarkable range of topics of importance to developing nations. Rohini's creativity, grit, and prolific research output are not only of great value to all emerging economies, including India, but an inspiration for young economists venturing into the exciting world of research.Congratulations Rohini."

– Kaushik Basu

Poverty, inequality, and the climate emergency

The most pressing economic question of our time, particularly in lower middle-income countries like India, is how to sustain the economic progress that has lifted hundreds of millions of our fellow citizens out of poverty in recent decades without exceeding planetary boundaries and risking natural disasters that threaten to reverse that progress.

Prof. Rohini Pande is a development economist working at the intersection of poverty, inequality, economic growth, and climate change. She examines how the structures of political and social institutions can empower or disempower different groups, as well as how those institutions can be improved to allow for greater efficiency, inclusion, empowerment, less inequality, and more effective environmental regulation.

Prof. Pande is interested in the microeconomics of policy-making—the details of the millions of small interactions between individual citizens, and between those citizens and state and non-state institutions—that create our economic environment. She analyzes these interactions using a wide variety of economic tools, including political economy models, observational data and analysis of natural experiments and randomized experiments.

Pande has worked extensively on issues of urban air pollution and the climate transition. Rohini Pande and her collaborators have worked with state governments to launch India's first particulate emissions market, and they are now building on that work to help inform India's carbon market proposals.

Across the world, women face discrimination in the workplace, in politics, and in the family, forcing them to endure worse economic and welfare outcomes than men of the same social status. A large part of Prof. Pande's work focuses on improving the economic and political status of women. She has worked on issues of gender and political representation, financial access and entrepreneurship.

Prof. Pande and her colleagues discovered that when quotas for women are established in political institutions, the election of female candidates changed gender stereotypes such as beliefs about women's competence, aiding the election of more women in the future.

Pande's work emphasizes the social and private returns to improving women's ability to enter the workforce, and to manage their own finances. She and her collaborators find that microfinance schemes where credit is provided to those who would otherwise not have access to it significantly improved outcomes, where clients are allowed to delay repayment. They also found that enabling direct deposit of wages into women's own bank accounts helps them enter and stay in the labor force and promotes more progressive gender norms. At the macro level, Prof. Pande and collaborators show that expansion of banks across rural India help reduce poverty.

Examining the institution of the family, she and her colleague have identified son preference as a cause of some of the malnutrition and stunted growth faced by India's children; families tend to seek sons and then give more to their first son, and less to others.

Prof. Pande's work demonstrates the vital importance of strong and effective institutions to a healthy democracy that wants to ensure welfare and opportunity for all its citizens.

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

Jitendra Malik
Arthur J. Chick Professor Department of Electrical Engineering & Computer Science, University of California, Berkeley and Director of Research, Facebook AI Research, Menlo Park, USA

Jayathi Y. Murthy
President, Oregon State University, USA

Ashutosh Sharma
Institute Chair Professor, Department of Chemical Engineering, Indian Institute of Technology, Kanpur, 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

Clare Harris
Professor of Visual Anthropology, School of Anthropology and Museum Ethnography Curator for Asian Collections, Pitt Rivers Museum, University of Oxford, UK

Partha Mitter
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Sanjay Subrahmanyam
Distinguished Professor and Irving and Jean Stone Endowed Chair in Social Sciences, University of California, Los Angeles, USA

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, the American Association for the Advancement of Science, The World Academy of Sciences, and the Indian National Science Academy.

JURORS

Scott V. Edwards
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Gagandeep Kang
Professor, Department of Gastrointestinal Sciences, Christian Medical College, Vellore, India

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

Ronald Vale
HHMI Vice-President and Executive Director, Janelia Research Campus, USA

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

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. He was an invited speaker at the International Congress of Mathematicians, held at Hyderabad in August 2010. In 2012, Prof. Khare was elected as a Fellow of the Royal Society.

JURORS

Mahan Mj
Professor, School of Mathematics, Tata Institute of Fundamental Research, Mumbai, India

Sylvia Serfaty
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Avi Wigderson
Herbert H. Maass Professor, School of Mathematics, Institute for Advanced Study, Princeton, USA

Andrew Wiles
Royal Society Professor of Mathematics, University of Oxford, UK

Physical Sciences

SHRINIVAS KULKARNI
Jury Chair

Shrinivas Kulkarni is the George Ellery Hale Professor of Astronomy and Planetary Science at the California Institute of Technology (Caltech), USA. His primary interests are the study of compact objects (neutron stars and gamma-ray bursts) and the search for extra-solar planets through interferometric and adaptive techniques. He serves as the Interdisciplinary Scientist for the Space Interferometry Mission (SIM) and is co-Principal Investigator of the Planet Search Key Project (also on SIM). He has been awarded the Alan T. Waterman Prize of the NSF, a fellowship from the David and Lucile Packard Foundation, a Presidential Young Investigator award from the NSF and the Helen B. Warner award of the American Astronomical Society and the Jansky Prize of Associated Universities, Inc. He was also elected a Fellow of the American Academy of Arts and Sciences (1994), Fellow of the Royal Society of London (2001) and Fellow of the National Academy of Sciences (2003) and foreign member of the Royal Netherlands Academy of Arts and Sciences (2016). In 2017, he won the Dan David Prize for his contribution to the emerging field of Time Domain Astronomy.

JURORS

Rana Adhikari
Professor of Physics, California Institute of Technology, USA

Yamuna Krishnan
Professor, Department of Chemistry, The University of Chicago, USA

Milind Purohit
Dean of Faculty Affairs, Okinawa Institute of Science and Technology Graduate University, Japan

Tejinder Singh Virdee
Professor of Physics, Imperial College London, UK

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

Haroon Bhorat
Professor of Economics and Director, Development Policy Research Unit, University of Cape Town, South Africa

Ashwini Deshpande
Professor of Economics, Ashoka University, India

Avinash Dixit
John J. F. Sherrerd '52 University Professor of Economics Emeritus, Princeton University, USA

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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 e valuates the a chievements 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.

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