ICTS ACTIVITY REPORT

2020 – 2021

CONTENTS

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DIRECTOR'S REPORT

"Considering Mathematics as a metaphor, I want to stress that the interpretation of Mathematical knowledge is a highly creative act. In a way, Mathematics is a novel about Nature and Humankind. One cannot tell precisely what Mathematics teaches us, in much the same way as one cannot tell what exactly we are taught by War and Peace."

Yuri Manin

The eminent Russian mathematician and scholar Manin, in his essay "Mathematics as Metaphor", develops on the idea that mathematics is a specialised language of science which helps to *"enhance our imprecise imagination by the rigid logic of a mathematical reasoning."* He gives two examples to illustrate the point - the first being the Kolmogorov-Chaitin notion of complexity as usefully formalising of the nature of human knowledge. Similarly, the Arrow theorem in social choice captures some of the dilemmas of democratic decision making. Their value arises in their role as mathematical metaphors for broader philosophical and social issues.

This nuanced view lifts mathematics beyond both an unabashedly platonic or a narrowly utilitarian perspective by subsuming both. At ICTS, we celebrate mathematics in all its manifestations as a powerful medium that enhances the human imagination. In this process it enables us to uncover the hidden patterns of number and space as well as the physical and conceptual structures of the universe and life.

Theoretical physics and mathematics have had a particularly symbiotic relationship - with the latter providing a powerful language for the former which, in turn, often pushes the syntax and vocabulary of the latter in new directions. ICTS is proud to welcome to our faculty, Ashoke Sen, one of the world's foremost theoretical physicists, who has helped to push these frontiers. This last year also saw a strong push in the physics of complex systems with two exciting hires – senior condensed matter theorist Sumathi Rao and younger researcher Stithadhi Roy. Together with TIFR-CAM, we have made a joint faculty appointment to Jim Thomas, a researcher applying mathematics to the science of oceanography. This is part of ICTS' push in applying fundamental science to hard problems affecting climate at the global level.

An important area that has been a priority for me to grow at ICTS has been theoretical computer science - the mathematical discipline that gives unique insights into the nature of thinking and structural complexity. Besides the subject is seeing a unique synergy with physics as a new paradigm of quantum computing emerges. I am therefore very happy to report that senior computer scientist, Jaikumar Radhakrishnan, will be moving this year to ICTS from TIFR-Colaba, where he has successfully built a very dynamic group of young theorists. We will be looking forward to exciting growth in this direction at ICTS under his leadership.

Collectively, we need to think ahead to ensure India has a large pool of creative young people who will be at the fore of the mathematical progress that will define science and technology in the coming decades. We need to nurture systematic excellence in mathematical thinking in our schoolchildren, especially those who face barriers of opportunity. In many countries, beginning with Eastern Europe and Russia, and recently the US, a tried and tested model is that of creating Maths Circles. ICTS is spearheading a pan-TIFR effort to launch a movement to seed Maths Circles across the country. These will encourage a creative engagement with mathematics through problem solving and open-ended explorations, encouraging collaborations amongst a chosen peer group. We have launched an online version of such a circle aimed at children in classes 7-10, together with the School of Mathematics, TIFR-Mumbai and the Homi Bhabha Centre for Science Education (HBCSE-TIFR). This will be a template for future circles and we are partnering with a

JUNY K. WILFRED

number of other institutions so that 2022 should see a number of these underway. It is one of the new initiatives I am very excited about and which has huge transformational potential in the country.

The period of this activity report has been a tough one for the entire planet. Our academic members, especially students and younger researchers, had to face the challenges of working from home in difficult environments. The usual stresses of academia have been compounded by the lockdowns as well as the continuing uncertainty. ICTS has tried to provide academic as well as non-academic support in navigating these waters - a responsive and empathetic approach on ICTS' side is key to making members feel the institute has their back. I am so thankful for the cooperation of our members and the collective strength and wisdom that has enabled us to steer our way thus far. I specially want to laud our dedicated admin, scientific and technical staff who have worked tremendously hard to make sure that ICTS activities could proceed in a seamless manner.

ICTS pivoted very quickly to an online mode for its programs. The organisers of programs have been very flexible and have organised a number of very stimulating online versions of their originally scheduled programs. These have attracted large numbers of participants, not only from India but also from abroad and helped keep up the overall scientific morale. These online schools and workshops as well as some of our new outreach series (like Vigyan Adda and Cosmic Zoom) enabled many young researchers not to fall behind as they isolated at their homes away from scientific communities.

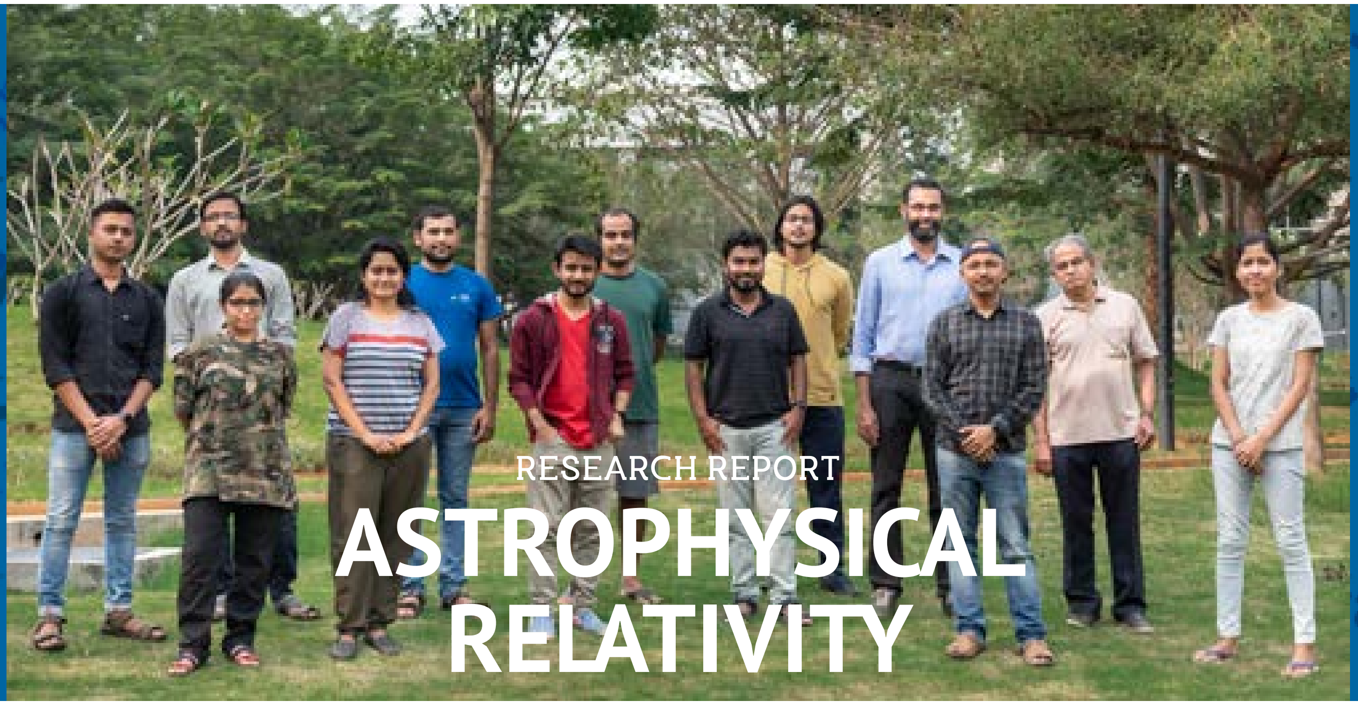
The committed backing for ICTS from the members of our management board and our international advisory board has been one of ICTS's great assets. Thanks to our online engagement with a wide community of international donors we have had a very good response to our 2021-22 fundraising drive. We plan to use the raised support to increase our outreach activities and professionalise their running through a dedicated team. We continue to receive the strong support of the Infosys Foundation as well as the Simons Foundation which has made all the difference. A warm thank you to all of you!

I hope this report will give you a window into the multifarious activities we were able to undertake as well as an idea of the exciting directions our researchers are taking. Do walk the path with us - this garden of the theoretical sciences will enchant you with its perfume.

Rajesh Gopakumar
Bengaluru, January 2022

JUNY K. WILFRED

RESEARCH
@ICTS



RESEARCH REPORT

ASTROPHYSICAL RELATIVITY

FACULTY

Ajith Parameswaran ◈ Pallavi Bhat ◈ Bala Iyer *(Simons Visiting Professor)* ◈ Prayush Kumar

POSTDOCTORAL FELLOWS

Shalabh Gautam ◈ Apratim Ganguly ◈ Shasvath J Kapadia ◈ Tushar Mondal ◈ Kanhaiya Lal Pandey ◈ Md Arif Shaikh

STUDENTS

Soummyadip Basak ◈ Uddeepta Deka ◈ Srashti Goyal ◈ Souvik Jana ◈ Aditya Kumar Sharma ◈ Mukesh Kumar Singh ◈ Aditya Vijaykumar

RESEARCH REPORT

AJITH Parameswaran

The discovery of gravitational waves (GWs) has opened up a new observational window onto the Universe. AJITH PARAMESWARAN's research spans several aspects of GW physics and astronomy. His current focus is on using this new astronomical tool to probe different aspects of fundamental physics, astrophysics and cosmology.

Ajith and collaborators developed a method to constrain the variation of the gravitational constant G over cosmic time using GW observations of binary neutron stars. If the value of G at the epoch of merger is significantly different from its current value, neutron star masses inferred from the GW observations will be inconsistent with the theoretically allowed range. Using the binary neutron stars observed by LIGO and Virgo, they put the first constraints on the time evolution of G in a cosmological epoch that is not probed by other observations.

Third generation GW detectors are expected to detect a large number of binary black holes to large distances, opening up an independent probe of the large scale structure using their clustering. This will be complementary to the probes using galaxy clustering – GW events could be observed up to very large distances although the source – localisation will be much poorer. Ajith and collaborators showed that the bias factor of the binary black hole population (with respect to the dark matter clustering) could be estimated well with a few years of observations of the next-generation detectors. This will help in identifying the type of galaxies that host binary black holes, thus shedding light on their origins.

Ajith and collaborators performed a search for the stochastic GW background from primordial curvature perturbations using LIGO Data. From the non-observation of the signal, they placed the very first GW-based constraints on the amplitude of the primordial power spectrum at these scales. They also put tight upper limits on the fraction of the Universe's mass in ultralight primordial black holes at their formation time.

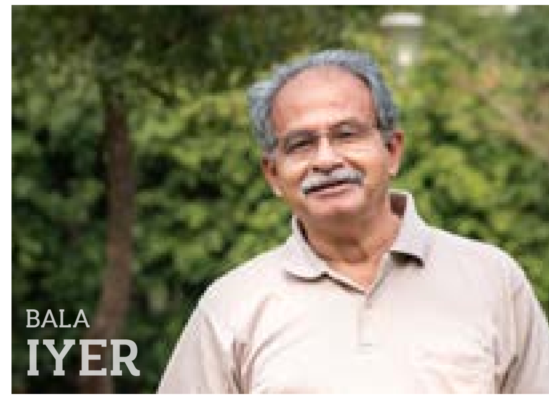
Ajith and collaborators showed that the GW early warning of neutron-star black-hole mergers can be significantly improved if we include the effect of higher modes of gravitational radiation in the search templates. This is because higher modes oscillate at higher harmonics of the orbital frequency, and will enter the detector band well before the dominant mode. Such an early warning will help the electromagnetic telescopes to slew to the location of the GW-event before the onset of the counterpart.

One major aspect of Ajith's current research is the gravitational lensing of GWs. Ajith and collaborators had earlier developed a Bayesian statistical method to identify strongly lensed GW signals in LIGO-Virgo data, and had performed the first search for lensing signatures in the GW signals detected by LIGO and Virgo. In their recent work, Ajith and collaborators used the non-observation of microlensing signatures in LIGO-Virgo events to constrain the fraction of dark matter in the form of compact objects in the high-mass regime.

Ajith and collaborators also developed a Machine Learning-based method to rapidly identify strongly lensed signals. This method achieves efficiencies comparable to that of the optical Bayesian method at a fraction of computational cost. They also showed how the observation of strongly lensed GW signals will significantly improve our ability to measure the polarization content of GWs, and hence enable a new test of General Relativity.

RESEARCH REPORT

Bala IYER



BALA IYER has been involved in the activities of the LIGO Scientific Collaboration (LSC) and the Gravitational Wave International Committee (GWIC).

Gravitational-Wave Physics and Astronomy in the 2020s and 2030s

The Gravitational Wave International Committee (GWIC) roadmap originally published a decade ago was re-examined and updated. An overview of Gravitational Waves (GW), the methods used to detect them and few scientific highlights from the past five years were first presented. This was followed by a survey of some outstanding scientific questions that can be answered with planned or envisioned future GW detectors. Future prospects for synergistic observations using GW and Electromagnetic (EM) observatories are next explored. The technological challenges to be overcome to build future GW detectors are finally highlighted.

RESEARCH REPORT

Pallavi BHAT

Saturation of Large-Scale Dynamo in Anisotropically Forced Turbulence

Turbulent dynamo theories have faced difficulties in obtaining evolution of large scale magnetic fields on short dynamical time-scales due to the constraint imposed by magnetic helicity balance. This has critical implications for understanding the large-scale magnetic field evolution in astrophysical systems like the Sun, stars and galaxies. Direct numerical simulations (DNS) in the past with isotropically forced helical turbulence have shown that large-scale dynamo saturation time-scales are dependent on the magnetic Reynolds number (Rm). PALLAVI BHAT's work showed that when the turbulence is forced anisotropically, the nonlinear (saturation) behaviour of the large scale dynamo is only weakly dependent on Rm. In fact, the magnetic helicity evolution on small and large scales in the anisotropic case is distinctly different from that in the isotropic case. This result possibly holds promise for the alleviation of important issues with positive implications for understanding large-scale magnetic field evolution as observed in astrophysical systems.

Large–Scale Dynamo in Periodic and Non–Periodic Domains

The conservation properties of magnetic helicity can constrain the nonlinear evolution of the dynamo. In an ongoing work with collaborators, Bhat has performed direct numerical simulations of the turbulent dynamo to investigate if employing open boundaries relaxes the constraint imposed by magnetic helicity conservation. They have found that in the open or non-periodic domain, a net magnetic flux (or system-scale fields) of significant strength arises but opposes the contribution from the resistive term. Overall, while the large-scale field evolution in the open domain does not seem to depict a strong Rm dependence within the range of values explored, the large-scale field strengths achieved are much smaller than those in the closed domain. Further, a net magnetic flux (or system-scale fields) arises which shows a negative trend with Rm.

RESEARCH REPORT

Prayush KUMAR

Eccentric Binaries

Both LIGO instruments and the Virgo detector have successfully completed three distinct observation periods (called "O1", "O2", "O3"). During these, tens of binary black holes have been found, ranging from a few $M_\odot$ to several tens of $M_\odot$. We have measured their spin angular momenta, giving credibility to the existence of an accretion phase in the mechanism of compact binary formation. Although relatively rarer, we have also observed a few more neutron stars since their first discovery (in the GW spectrum) in 2017. A common theme has so far been the orbital geometry of all these binary systems whose mergers were observed. Their orbits being nearly circular is a powerful indicator of the astrophysical surroundings these systems were born and evolved in. A strong alternate possibility is the formation of binaries that are dynamically formed in dense stellar environments where multi-body encounters are not unlikely. Such orbits will necessarily start out with some amount of eccentricity. Population synthesis studies show that it is quite possible that up to 10 per cent of all GW observations might come from eccentric binary mergers. Yet, they remain elusive and are yet to be observed. Much of PRAYUSH KUMAR's research over the past few years has been the quest to detect eccentric binaries and study them. This year he worked on (a) the source modeling of eccentric binaries, (b) developing a deep-learning based advance warning system for eccentric GW signals, and (c) exploring the intrinsic degeneracies between orbital eccentricity and other black hole parameters manifest in GW emission that hamper their respective measurement.

Numerical Relativity Code Development

The current generation of instruments, it appears that the loudest signals they observe consist of short signals with a few cycles of inspiral followed by a loud merger. Going forward with improvements to the ground-based detectors, and possibly more sensitive instruments coming up, there is ample need to model the late-inspiral and merger of compact binaries with extreme accuracy. Numerical Relativity is the only way we can achieve this goal.

The current generation of NR codes have all come up against their inherent limitations, that are borne out of choices made to discretize GR and MHD equations, perform parallel computation that can leverage modern supercomputers, and other such technological choices. Therefore, with the Simulating eXtreme Spacetimes (SXS) collaboration, Kumar has been working on a paradigm changing new NR code called SpECTRE for the past four years. Over the time Kumar and his collaborators have finalized the essential infrastructure and paradigm choices that this code will be based on. The code has been open source since the beginning (https://github.com/sxs-collaboration/spectre).

During the past year, Kumar contributed to the GR module of SpECTRE. He implemented some of the bulk terms of the generalized harmonic formulation of the Einstein evolution system as well as radiation absorbing boundary conditions for the same. As the code matures to be able to perform simulations of binary systems, we studied discontinuity-handling strategies (a.k.a. “limiters”) on simulations of magnetized neutron stars.

Astronomy with LIGO-Virgo Observations

Finally, the last major portion of Kumar’s research time was spent on working on projects of the LIGO-Virgo Scientific Collaboration (LVC). During their recently completed second and third observation runs, the Hanford, Livingston and Virgo instruments detected several binary merger events. As part of the collaboration, they studied these events to understand their properties, astrophysical origin and implications, and cosmological implications. These were published as a series of articles by the LVC over the year 2021, especially for the events recorded during O3. Kumar’s contribution here has been to the design and review of algorithms that infer the source properties of all these events, as well as to some of the waveform models used to detect these events.

FACULTY

Amit Apte ◈ Anirban Basak ◈ Riddhipratim Basu ◈ Rukmini Dey ◈ Pranav Pandit ◈ Mythily Ramaswamy *(NASI Senior Scientist)* ◈ Vishal Vasan

POSTDOCTORAL FELLOWS

Sumanto Chanda ◈ Saibal Ganguli ◈ Akshay Goel ◈ Sharath Jose Mohamd Saleem Lone ◈ Poorna Narayanan ◈ Anantadulal Paul ◈ Arideep Saha ◈ Shibi Vasudevan

STUDENTS

Kohinoor Ghosh ◈ Manisha Goyal ◈ Prokash Kumar Kundu ◈ Pinak Mandal ◈ Srikanth B Pai ◈ Mukesh Singh Raghav ◈ Anugu Sumith Reddy ◈ Shashank Kumar Roy ◈ Bhanu Kiran S

RESEARCH REPORT

Amit APTE

In recent work, AMIT APTE and collaborators have proved a mathematically precise version of the statement that the span of the estimation error covariance matrices asymptotically (in time) tends to the subspace spanned by the unstable-neutral Lyapunov vectors. This work was continued to obtain stronger results about stability of linear and nonlinear filters. The main result is the almost sure convergence of the filter under the condition of uniform complete observability, as well as convergence in probability for the small noise limit. This is one of the first such results for deterministic, chaotic dynamical systems, which are widely used in practical applications in the earth sciences.These papers also contain a wealth of additional results about (i) a bound for the rank of analysis covariance, (ii) identifying the support of the asymptotic covariance in terms of unstable-neutral Lyapunov vectors, (iii) a bound on the rate of convergence of the eigenvalues in terms of Lyapunov exponents, (iv) relation to observability, as well as (v) asymptotic stability of the analysis covariance with respect to the initial condition.

In a recent work, Apte and collaborators revisited the classical question of equilibration of the Fermi-Pasta-Ulam-Tsingou (FPUT) system. The main novelty of their approach was that they considered averaging over initial conditions chosen from a narrow distribution in phase space, examining in detail the effect of the width of the initial distribution, and of integrability and chaos quantified by the Lyapunov exponents, on the time scales for thermalization. Somewhat surprisingly they also found that the ensemble averaging can lead to thermalization of the integrable Toda chain, though on much longer time scales. Relation of these results to Arnold diffusion is currently being investigated.

RESEARCH REPORT

Anirban BASAK

The primary focus of ANIRBAN BASAK's research, during the period of the report, has been on investigating spectral properties of non-Hermitian operators under disordered perturbations, and large deviation phenomena in sparse random graphs and matrices.

Spectrum of Non-Hermitian Toeplitz Under Random Perturbations

Over the last few years, Basak with his co-authors has been working on understanding spectral properties of non-self-adjoint operators under disordered perturbations. These questions are largely motivated by problems arising in the study of open quantum systems, pseudo-differential operators, and numerical analysis. Basak's research in this direction has mostly focused on the spectral behavior of generic random perturbation of finitely banded Toeplitz matrices. For example, one of his works shows that the empirical spectral measure of such matrices converges to the push forward of the uniform measure on the unit circle in the complex plane by the symbol associated with the limiting Toeplitz operator. Another work identifies the limit of the outlier (i.e. stray) eigenvalues to be the point process induced by the zeros of some non-universal (i.e. depending on the distribution of the random perturbation) random analytic function that depends on the winding number of the curve associated with the symbol. In a recent paper, he and his co-authors also show that when the strength of the perturbation is low the eigenvector corresponding to a typical eigenvalue must be localized resulting in a scarring phenomenon, and an absence of quantum ergodicity. They predict that eigenvectors corresponding to outlier eigenvalues must be multi-fractal and non-ergodic. In ongoing work, they aim to study the behavior of the eigenvectors when the strength of the perturbation is high. Simulations suggest that in this regime eigenvectors must be delocalized and should have a long-range autocorrelation.

Large Deviations for Sparse Random Graphs and Matrices

During the last decade or so there has been enormous interest in the study of large deviations for random graphs and matrices. A couple of prototype questions are the large deviations of the triangle counts in the Erdös-Rényi graph, and large deviations of the largest eigenvalue, and the empirical spectral measure of Wigner matrices. Basak and his co-author have recently solved the upper tail large deviations problem of the subgraph counts in sparse Erdös-Rényi graphs for all regular connected graphs in the entire localized regime. This work settled a well-known open problem in the area. In another work, he obtained the upper tail large deviations of the spectral radius the adjacency matrix of sparse Erdös-Rényi graphs for a certain regime of sparsity and showed that the upper tail probability can be asymptotically approximated by the solution of a mean-field variational problem. This work together with a couple of other works resolves the upper tail large deviations of the spectral radius of the adjacency matrix of sparse Erdös-Rényi graphs. Currently, he is working on the large deviations of the largest eigenvalue and the empirical spectral measure of diluted Wigner matrices.

RESEARCH REPORT

Riddhipratim BASU

RIDDHIPRATIM BASU's research during the period of the report primarily focussed on various models of planar random geometry, primarily exactly solvable models in the Kardar-Parisi-Zhang (KPZ) universality class and the Liouville quantum gravity metric on the complex plane.

In a joint work with collaborators, Basu considered the k-geodesic watermelon in planar exponential last passage percolation. For $1 \leqslant k \leqslant n$, the k-geodesic watermelon refers to the collection of k disjoint paths contained in a square of size n with maximal total weight. They studied the geometry and weight of the geodesic watermelon and obtained the exponents (in k) governing the fluctuations of the weight and the transversal fluctuation of the watermelon. These results generalise the classical case $k=1$.

Basu and collaborators considered the small ball probabilities for the geodesic in exponential LPP. Considering the geodesic between $(0,0)$ and (n,n) they estimated the probability that the geodesic lies within a $\delta n^{2/3}$ width strip around the diagonal and obtained the exponent governing the decay of this probability as δ becomes small.

With collaborators, Basu considered the environment seen from the infinite geodesics in Liouville quantum gravity on the complex plane. Under an appropriate scaling, they established the existence of a limiting environment rooted at a sequence of randomly chosen points on the unique infinite geodesic starting at the origin and obtained some basic properties of this limiting environment.

RESEARCH REPORT

Rukmini DEY

During the period of the report, RUKMINI DEY and collaborators worked on the Euler-Ramanujan formula, Dirichlet-series and minimal surfaces.

Dey and and collaborators worked on a research problem which studies coadjoint orbits and Kähler structure with some examples from coherent states. It is a semi-expository work (accessible to physicists) where the authors studied some examples of coherent states - the Weyl-Heisenberg group, $SU(2)$ and $S(1,1)$. They showed that in cases where the coadjoint orbit admits Kähler structure, the coherent states give a Kahler embedding into projective Hilbert space, whereas the squeezed states give a symplectic embedding, They also studied the geometric quantization of coadjoint orbit of $SUT(2, \mathbb{R})$. They gleaned out some general insights from these examples..

Dey and collaborators studied the pull back coherent states and squeezed states and their relationship to quantization. It is a semi-expository work, where authors define certain Rawnsley-type coherent and squeezed states. They showed that on an integral Kähler manifold these states satisfy some properties which are similar to maximal likelihood property, reproducing kernel property, generalised resolution of identity property and overcompleteness. This is a generalization of a result by Spera. They repeated this on a smooth compact manifold and showed that they satisfy similar properties. Finally they showed a Berezin -type quantization involving certain operators acting on a Hilbert space on a compact smooth totally real embedded submanifold of U of real dimension n where U is an open set in $\mathbb{C}P^{n-1}$

A problem involving interpolation by Maximal and Minimal surfaces was studied. In this work, Dey and collaborators showed two real analytic spacelike curves in Lorentz-Minkowski space $\mathbb{L}^3$ which are "close" enough in a certain sense, can be interpolated by a maximal surface using inverse function theorem for Banach spaces. Using the same method they showed that two real analytic curves in $\mathbb{R}3$ which are close enough can be interpolated by a minimal surface.

Dey and collaborators also studied a problem involving the finite decomposition of height functions of Minimal surfaces, Maximal surfaces, Time-like Minimal surfaces and Born-Infeld solitons. Using various techniques, like Euler-Ramanujan identities, Weierstrass-Enneper representations etc, they showed that the height function of these surfaces can be decomposed into height functions of scaled and translated surfaces of the same type.

RESEARCH REPORT

Pranav PANDIT

PRANAV PANDIT's research centered around the following themes at the intersection of derived geometry, higher category theory and mathematical physics:

Categorical Kähler Geometry

Derived noncommutative geometry was introduced by Kontsevich as a geometric framework in which to study topological string theory and homological mirror symmetry. In this flavor of noncommutative geometry, higher categories play the role of geometric spaces. Categorical Kähler Geometry is a long term research project that was initiated a few years ago by Pandit, in joint work with his collaborators, with the goal of developing a theory of Kähler metrics (and other differential-geometric structures) in the setting of derived noncommutative geometry. In this theory, Bridgeland stability conditions on triangulated dg-categories play the role of "noncommutative Kähler classes", and are viewed as analogues of Mumford's stability conditions in geometric invariant theory.

Building on their earlier work, Pandit and his collaborators have made progress on certain aspects of this ongoing multi-faceted project. They have discovered a refinement of the Harder-Narasimhan stratification in geometric invariant theory, and related this refinement to the asymptotic behavior of certain gradient flows. Another important development has been the formulation of a non-Archimedean analogue of King's theorem for quiver representations, which relates the stability of a representation to the existence of a metric satisfying an analogue of the Hermitian-Yang-Mills equation.

Extended Topological Quantum Field Theories

Extended topological quantum field theories (TFTs) play a central role in the description of condensed matter systems and in high energy physics. Mathematically, TFTs are defined as functors between certain higher categories. The cobordism hypothesis, which gives a complete classification of TFTs in all dimensions, is one of the great achievements of higher category theory. While this theorem is of tremendous theoretical significance, it does not provide explicit constructions of many TFTs of interest in mathematics and physics.

Dijkgraaf-Witten theory is a topological field theory associated with a finite group G. It is one of the simplest TFTs. In joint work with his student, Pandit has developed a model for double categories based on Segal fibrations. In ongoing work, this theoretical framework is applied to give mathematically rigorous and explicit constructions of extended TFTs of Dijkgraaf-Witten type. Applications of these constructions in the representation theory of higher groups are under investigation.

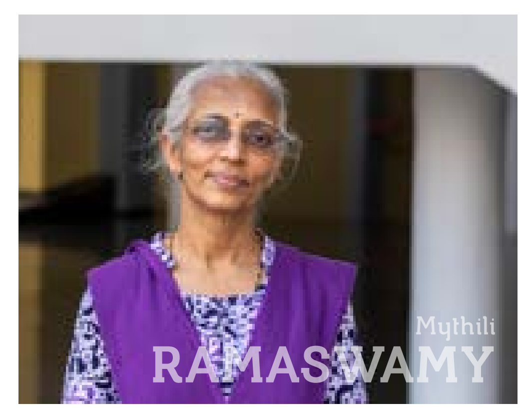
Ulrich Bundles in Noncommutative Geometry

Ulrich bundles are special vector bundles on algebraic varieties satisfying certain cohomological conditions. They first arose in commutative algebra, where they have many applications. In algebraic geometry, Ulrich bundles provide a measure of the complexity of an algebraic variety. In joint work, Pandit has extended the notion of Ulrich bundles to the realm of noncommutative geometry. Two types of noncommutative geometry were considered: Artin-Zhang noncommutative geometry, where abelian categories play the role of spaces, and Kontsevich's derived noncommutative geometry, in which spaces are represented by triangulated dg-categories. The classification of Ulrich bundles on noncommutative projective planes was investigated using a noncommutative analogue of Castelnuovo-Mumford regularity.

In the next phase of the project, the geometry of Ulrich bundles on Fano varieties will be studied using homological mirror symmetry and the theory of 'perverse sheaves of categories' (perverse Schobers).

RESEARCH REPORT

Mythily RAMASWAMY



MYTHILY RAMASWAMY and collaborators studied the controllability of the one-dimensional fluid-particle interaction model of the viscous Burgers equation and the point mass obeying Newton's second law. They proved null controllability (driving the system to zero state in finite time) for the velocity of the fluid and the particle and approximate controllability for the position of the particle with a control acting only on the particle. One of the novelties of this work is that this controllability result is achieved in a uniform time for all initial data.

Ramaswamy and her collaborators explored the numerical implementation of feedback stabilization of the two dimensional incompressible heat conducting fluid, modeled by Boussinesq equations. First the linearized system around an unstable stationary solution is stabilized by boundary feedback controls of finite dimension, applied on velocity and temperature, localized on parts of the boundary. This feedback control is computed by solving a Riccati equation of small dimension, associated with this system. Next, the linear feedback law is applied to the nonlinear model to locally stabilize the flow and its temperature. The numerical study matched well with the theoretical predictions.

Ramaswamy analysed the motion of a rigid body in a bounded domain filled with compressible isentropic fluid, with Navier-slip boundary condition at the interface and at the boundary of the domain. Along with her collaborators she proved the existence of a weak solution of the fluid-structure system up to collision. This is the first mathematical analysis of a compressible fluid-rigid body system where Navier-slip boundary conditions are considered.

RESEARCH REPORT

Vishal VASAN

VISHAL VASAN is interested in the theoretical and numerical analysis of partial differential equations as well as their applications. He has worked on a number of topics including cold atomic systems, waves in coastal regions, large-scale atmospheric dynamics and pattern-formation in biological systems. In the last two years he has worked on the following topics

Estimating the Ocean-Depth from Surface Waves

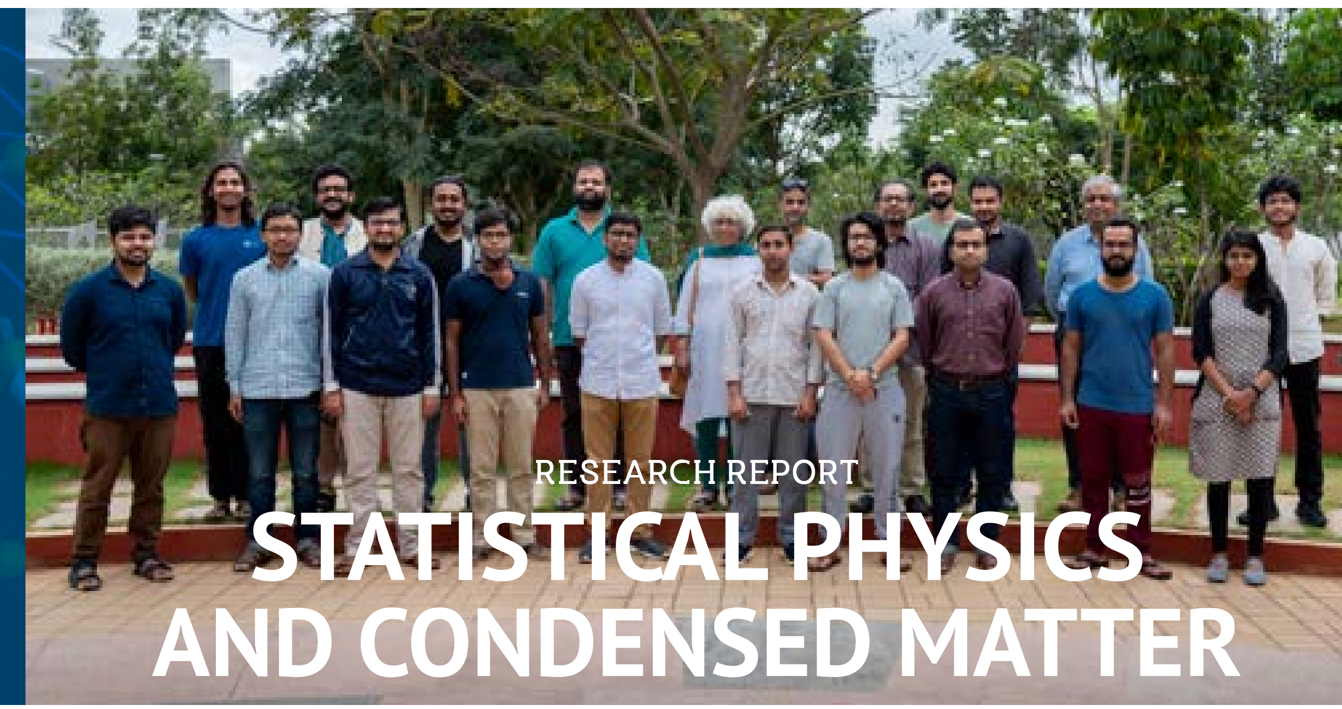
Ocean-depth measurement, i.e. determining the shape of the ocean-bed, is one of the most challenging oceanography problems both theoretically and practically. In joint work with collaborators and building on previous work done by Vasan and Deconinck, Vasan developed a new algorithm to determine the shape of the bottom of the ocean based solely on the shape of the time-evolving free surface. The mathematical context consists of estimating the bottom impermeable boundary to an inviscid, incompressible, irrotational fluid by analyzing an equivalent inverse problem for dispersive shallow-water wave models derived from the full set of equations governing the fluid flow. Their algorithm accurately recovered the bottom-boundary profile and surface velocities assuming a relatively inaccurate guess for the bottom boundary. Their work highlighted the main cause of the illposedness as well as the importance of careful modelling which can help address some of the illposed behavior. More recent work has established theoretical results for nonlinear convergence as well as an analysis of the effects of noise.

Impact of Frely Falling Liquid Containers and Subsequent Jetting.

When a container, partially filled with liquid, is dropped from a certain height onto a floor, it will undergo a sudden deceleration followed by a rebound. The free-surface meniscus at the moment the container impacts, leads to large radial pressure gradients forming a high-velocity surface jet. Vasan and collaborators reported experimental results and scaling analysis of jet formation showing the initial sudden deceleration phase alone can produce strong jets. This is the first work to establish that the jet-velocity scales with the geometric mean of the impact velocity and the meniscus-deformation velocity scale. Theirs was also the first study to reliably produce the second-jet phenomenon: the formation of a micro-sized second jet at the tip of the first jet formed upon impact. They showed the second-jet is not due to noise in the system but is a direct consequence of the initial state of the free-surface at the moment of impact. Indeed the second-jet velocity scales as a capillary velocity-scale and the radial contraction of cavity mouth follows a $t^{(1/2)}$ scaling law, a relation which has been observed in cavity-collapse problems showing the universal nature of the second-jet. This led to the proposal that the lab setup developed here as a useful model to study deforming fluid surfaces, jetting and subsequent droplet formation. The size of the droplets formed by the second-jet are orders of magnitude smaller than those formed by the first jet. This study could have implications for aerosolisation in more general contexts. A paper on this is currently under review.

Semilinear Partial-Differential Equations: Theory and Applications

The global wellposedness theory for semi linear PDEs is an active area of research. On the other hand, the local wellposedness is quite well-developed, at least for high-regularity solutions (sufficiently large so that the algebra property for the underlying function space is available). In ongoing work, Vasan and collaborators outline a framework wherein local wellposedness, numerical analysis and state-estimation problems are intimately tied together: progress in one problem, implies progress in the others. This framework grew out of a set of inverse problems Vasan and colleagues have been investigating, specifically state-estimation from partial observations. Observer models are a useful strategy to recover full-state estimation from partial observations. The aim of this project is to show via different applications, the mathematical connections between wellposedness theory and observability. In recent work, Vasan developed an observer for the Saint-Venant equations with Coriolis term to show that the vorticity field is sufficient to deduce the full system state: height and velocity field. Ongoing work implements an observer model for compressible Navier-Stokes wherein the observations are a passive scalar field.



RESEARCH REPORT

STATISTICAL PHYSICS AND CONDENSED MATTER

FACULTY

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RESEARCH REPORT

Subhro BHATTACHARJEE

SUBHRO BHATTACHARJEE and collaborators explored different aspects of two broad areas of the physics of correlated many-body systems: (1) Topological phases of quantum matter, and (2) Dynamics in correlated classical many-body.

Experimental Signatures of Unconventional Magnetic Ground States in Candidate Materials

A typical signature of frustrated magnets is lack of ordering till very low temperatures. The two candidate materials that were explored, in collaboration with two experimental groups, in context of their low temperature novel magnetic properties are: (1) The candidate Kitaev spin-liquid, Cu_2IrO_3, and, (2) the 50% diluted Triangular Lattice magnet Y_2CuTiO_6. In case of the former the efficacy of the spin-phonon coupling via Raman scattering was successfully investigated as a probe for fractionalised excitations of the Kitaev-QSL– the majorana fermions. The latter, it was pointed out, raises the interesting possibility of obtaining a dynamic correlated low temperature paramagnet driven by disordering of the magnetic network – via site dilution – that is usually known to give rise to spin freezing.

Unconventional Quantum Phase Transition in Magnetic Insulators

In search of unconventional continuous quantum phase transition in experimentally relevant magnetic materials, the phases and quantum phase transitions in the anisotropic Kitaev-Heisenberg-Γ magnet was investigated which presents a situation where the exactly solvable gapped Z QSl gives way to various magnetically ordered as well as trivial paramagnetic phases. The associated phase transitions are not captured via order-parameter only descriptions as they miss the non-trivial nature of the QSL including its topological order and fractionalised excitations – the bosonic Ising electric and magnetic charges. Starting with the microscopic systems and isolating the low energy modes as well as their non-trivial (projective) symmetry implementation, the nature of the associated phase transitions was successfully investigated to obtain the critical theories that describe such unconventional quantum critical phenomena.

In addition to the above, the role of disorder in the three dimensional amorphous topological insulators were investigated via the characterisation of ½ electronic charge of the dyon via the Witten effect.

Metallic Phases in Two Dimensional Flat Bands

The possibility of stabilising almost flat topological bands were investigated in – (1) bilayer-Kagome metals, and, (2) strain-induced zero Landau level of Kitaev QSL. In case of the former, a Chern metal is realised which appears to be relevant to the physics of binary intermetallic materials, M_3Sn_2 (M=3d transition metal) in general and Fe_3Sn_2 in particular. The natural instabilities of the Chern metal gives rise to a rich phase diagram that arises due to the interplay of topology and correlations. The latter case represents a novel implementation of half-filled Landau level physics, albeit in presence of time-reversal, and stabilises a correlated gapless phase similar to the composite fermi liquid in case of the Hamm effect, but with a completely different set of symmetry implementation. Therefore, the two above systems provide new platforms to stabilise novel correlated gapless phases.

Many-Body Chaos

Building on previous studies by the group, Bhattacharjee and his collaborators explored quantifying spatio-temporal chaos in thermalised fluids in three dimensions as described via the truncated Euler's equation to find the scaling of the Lyapunov exponent with temperature. Further, in a separate work, he studied the role of spontaneous symmetry breaking and the associated emergence of low temperature integrability in classical spin systems.

Emergent Elasticity in Amorphous Solids

The mechanical response of naturally abundant amorphous solids are not described by the conventional paradigm of broken symmetry that defines crystalline elasticity. In contrast, the response of such athermal solids are governed by local conditions of mechanical equilibrium, i.e., force and torque balance of its constituents. Bhattacharjee and his collaborators showed that these constraints have the mathematical structure of a generalized electromagnetism, where the electrostatic limit successfully captures the anisotropic elasticity of amorphous solids. The emergence of elasticity from local mechanical constraints offers a new paradigm for systems with no broken symmetry, analogous to emergent gauge theories of quantum spin liquids. Specifically, their U(1) rank-2 symmetric tensor gauge theory of elasticity translates to the electromagnetism of fractonic phases of matter with the stress mapped to electric displacement and forces to vector charges. The theoretical results are in excellent agreement with numerical simulations of soft frictionless disks in both two and three dimensions, and experiments on frictional disks in two dimensions.

RESEARCH REPORT

Chandan DASGUPTA

Active Matter

In simple models of active systems, activity is represented by a self-propulsion force with strength f and persistence time τ. CHANDAN DASGUPTA and collaborators studied the dynamics of a model active system with large values of f and τ. They found that in the limit of infinite τ and no thermal noise, the system undergoes a transition from a liquid-like phase to an athermal jammed phase as f is decreased. At intermediate values of the persistence time, a new intermittent phase is found to intervene between the liquid and the dynamically arrested phase. A detailed study

of this intermittent behaviour is in progress. They also extended a theory of the glass transition in active systems to large values of f and τ. In another study carried out in collaboration with several colleagues at ICTS, Dasgupta has shown that active particles moving on a line exhibit a universal form of single-file dynamics that does not depend on the details of the activity.

Dynamics of Glass-forming Liquids

Dasgupta and collaborators studied the relation between the dynamics and the configurational entropy of a model glass-forming liquid that interpolates between a three-dimensional liquid and a fully connected mean-field system in a continuous manner. Their investigation was motivated by the observation that the con_gurational entropy of this model liquid calculated using the usual thermodynamic integration method violates the relation between dynamics and the configurational entropy predicted in several popular theories of the glass transition. They calculated the entropy of the liquid using a different method and showed that the expected relation between the configurational entropy obtained this way and the relaxation remains valid. In a study of the time scales at which Fick's law of diffusion sets in, they considered two different Fickian time scales and showed that these two time scales are very different from each other and from the structural relaxation time, and their relation with the structural relaxation time is well-described by power laws with different exponents. In another study, Dasgupta and collaborators showed that the thermal conductivity of a liquid near the glass transition depends on its thermal history and this dependence can be understood in terms of the properties of the local minima of the potential energy explored by the system.

Non-equilibrium Phase Transitions

Dasgupta and collaborators studied the steady-state behaviour of a two-dimensional ferromagnetic Ising model that is out of equilibrium because the assumed dynamics does not obey the detailed balance condition. This model is found to exhibit a nonequilibrium phase transition as the variable that plays the role of temperature in the spin updates is decreased. The values of the critical exponents that characterize this continuous phase transition are found to be the same as those of the equilibrium Ising model in two dimensions. This model, therefore, provides an example of a non-equilibrium phase transition that is in the same "universality class" as the equilibrium Ising model. During this period, they also worked on the dynamics of sheared nematic uids, colloidal crystallites under external oscillation, and dielectric properties of water confined in a graphene slit pore.

RESEARCH REPORT

Abhishek DHAR

Connection Between the Atomistic and Hydrodynamic Descriptions of Matter

The blast problem corresponds to the phenomena where a huge amount of energy is released in a small part of an otherwise cold gas, as happens in a nuclear explosion or a supernova. How does this evolve in time? The evolution of the blast was studied by molecular dynamics and compared with the predictions of hydrodynamics. A surprisingly high level of agreement was noted and some important discrepancies were pointed out and these are currently being pursued. This work by ABHISHEK DHAR and collaborators constitutes one of the first direct comparisons, via simulations, of hydrodynamics and Newtonian dynamics. Another work explored the idea of quantifying the notions of irreversibility and the arrow of time in Hamiltonian systems. Through the simple example of free expansion of an ideal gas, the idea of Boltzmann's construction of an entropy function was explained. The main idea is that this entropy is well-defined for a single microscopic configuration and involves observing a system in a coarse-grained way. It was demonstrated that the entropy constructed this way shows increase with time and shows thermalization.

Transport of Particle and Heat Across Superconducting Wires

This was studied using the formalism of quantum Langevin equations. A general Landauer-type formula was obtained for the electrical and thermal conductance in terms of generalized Green's function. The formula was related to results obtained earlier using scattering approaches. Several physical implications were discussed, in particular new results were obtained in systems with multiple topological phases and new predictions were made for quantization of heat conductance. As a surprising spin-off, the results obtained in this work could be used in the completely different problem of phononic heat conduction in charged one-dimensional crystals in random magnetic fields. A new type of phonon Anderson-localization was observed and many exact results for the size dependence of heat conductance in this system was obtained.

Modeling the Covid-19 Pandemic

Dhar and collaborators made an attempt to see if one can use mathematical models to obtain predictions for the course of the covid pandemic in India. The problem is difficult because of the large number of unknown parameters, dependence on human social behaviour and the lack of precise data. The idea was to see if one can still obtain any insights from the models that might help policy makers. The work led to some new results that are expected to be useful in the general area of population dynamics.

Open Quantum Systems

This study investigated, in the most general setting, the structure of the nonequilibrium steady state density matrix of a system weakly coupled to thermal reservoirs. While the standard Redfield equation produces an accurate description, however, it does not ensure positivity of the density matrix and there has been a constant effort to arrive at so-called Lindblad descriptions which ensure positivity. This work explains the kind of constraints that need to be imposed on any attempted Lindblad description and shows explicitly that none of the existing Lindblad forms are able to satisfy these requirements.

Non-Hermitian Description of Quantum Systems with Quasi-Zeno Dynamics

Dhar and collaborators showed that there is a mathematically precise and physically meaningful limiting procedure, involving strong coupling of a quantum system and detector, to show that the dynamics of a quantum system subjected to repeated projective measurements can be exactly described by a non-Hermitian Hamiltonian.

RESEARCH REPORT

Manas KULKARNI

The Universal Spectral Form Factor for Many-Body Localization

MANAS KULKARNI and his collaborators studied correlations present deep in the spectrum of many-body-localized systems. An exact analytical expression for the spectral form factor of Poisson spectra can be obtained and is shown to agree well with numerical results. They also identified a universal regime.

Population Imbalance for a Family of Incommensurate Models with Mobility Edges

Kulkarni and collaborators investigated four generalizations of the Aubry-André-Harper model which possess mobility edges. They mapped out a phase diagram in terms of population imbalance and looked at the system size dependence of the steady-state imbalance. Their findings are an important step forward to understanding nonequilibrium phenomena in interesting models with incommensurate potentials.

Multilayered Density Profile for Fermions in a Rotating Two-Dimensional Trap

Kulkarni and his collaborators computed exactly the average density for N-spinless noninteracting fermions in a 2D harmonic trap rotating with a constant frequency and in the presence of an additional repulsive central potential. They found that in the large-N limit, the density has a rich and nontrivial profile with a hole at the centre of the trap and surrounded by a multilayered structure. They found a rich phase diagram..

Harmonically Confined Long-Ranged Gas in Presence of a barrier:

Kulkarni and collaborators computed exactly the average density of a harmonically confined Riesz gas of N particles for large-N in the presence of a barrier. They found various interesting regimes (effectively short-ranged, weakly long-ranged, strongly long-ranged) and a phase transition.

Dynamical Regimes of Finite Temperature Discrete Nonlinear Schrödinger Chain

It was shown that the discrete nonlinear Schrödinger chain (DNLS) at finite temperature has three different dynamical regimes (ultra-low, low and high temperature). The analysis presented is an important step forward towards the understanding of DNLS which is ubiquitous in many fields. The work also shows that the different methods used here can serve as important tools to identify dynamical regimes in other interacting systems.

Spatio-Temporal Spread of Perturbations in Power-Law Models at Low Temperatures

Kulkarni and his collaborators presented exact results for the classical version of the Out-of-Time-Order-Commutator (OTOC) for a family of power-law models consisting of N particles in 1D and confined by an external harmonic potential. Their findings are a step forward towards a more general understanding of the spatio-temporal spread of perturbations in long-range interacting systems.

Spatio-Temporal Spread of Perturbations in a Driven Dissipative Duffing Chain

Kulkarni and collaborators probed a driven-dissipative classical many-body system using the classical OTOC to investigate the spread and growth (decay) of an initially localized perturbation. They found three distinct types of dynamical behaviour (sustained chaos, transient chaos and non-chaotic region) as clearly exhibited by different geometrical shapes in the heat map. This analysis is an important step forward towards understanding nonlinear dynamics, chaos and spatio-temporal spread of perturbations in open systems.

Non-Analytic Non-Equilibrium Field Theory: Stochastic Quench of the Ising Model

By a combination of stochastic field theory and Monte Carlo simulations, Kulkarni and collaborators unveiled how the usual potential in the Landau-Ginzburg theory is deformed by nonanalytic operators of intrinsic nonequilibrium nature.

Emergence of Chaos and Controlled Photon Transfer in a Cavity-QED Network

Kulkarni and his collaborators developed optimal protocols for efficient photon transfer in a cavity-QED network. Their analysis is also significant in designing transport protocols aimed for nonlinear open quantum systems in general.

Emergent PT Symmetry in a Double-Quantum-Dot Circuit-QED Set-up

Kulkarni and collaborators showed that a non-Hermitian Hamiltonian emerges naturally in a double-quantum-dot-circuit-QED set-up, which can be tuned to the PT-symmetric point. The analysis also reveals the effect of quantum fluctuations on the PT-symmetric system. Their results pave the way for an on-chip realization of a potentially scalable non-Hermitian system with a gain medium in quantum regime, as well as its potential applications for quantum technology.

Particles Confined in Arbitrary Potentials with a Class of Finite-Ranged Interactions

A large-N field theory for a system of N-classical particles in 1D at thermal equilibrium was developed for the case where every particle is interacting with finite number of particles to its left and right. The intricate interplay between external confinement, pairwise repulsion and entropy was investigated. Given the fact that these family of systems are of broad relevance, these analytical findings are of paramount importance.

RESEARCH REPORT

Anupam **KUNDU**

In the last two years ANUPAM KUNDU's research has mainly involved studying the following topics/systems: single file systems, active particles, equilibrium properties of many particles interacting via power law potentials, spatiotemporal chaos in driven systems, temporal distributions in Brownian particles and non-instantaneous resetting.

Studies on Active Particle Systems

Active matter systems have been an active field of research for the last few decades. They consist of a collection of self-propelled particles or 'active' agents which consume energy from the surroundings at the microscopic level and transduce it into a systematic movement. While a collection of active particles display interesting phenomena, they exhibit intriguing properties even at a microscopic level. Kundu and collaborators have studied the single-file dynamics of three classes of active particles: run-and-tumble particles, active Brownian particles and active Ornstein–Uhlenbeck particles. At high activity values, the particles, interacting via purely repulsive and short-ranged forces, they observed an emergent scaling of the mean-squared displacement of a tagged particle for all the three models with identical scaling exponents and functions. In a later work they made an attempt to understand the tagged particle motion in a harmonic chain of particles driven locally by active noises. In order to understand sub-diffusive motion of tagged particles they, in a separate project, considered the effective dynamics of a run-and-tumble particle in inhomogeneous media. The sub-diffusivity exponent of the motion of the particle depends on the nature of the inhomogeneity.

Stochastic Resetting with Stochastic Returns Using External Trap

Most of the theoretical studies of stochastic resetting so far have focused on instantaneous resetting which is, however, a major impediment to practical realisation or experimental verification in the field. In this research work, Kundu and collaborators proposed a method of resetting which involves non-instantaneous returns facilitated by an external confining trap potential centered at the resetting location. Consequently the system reaches a non-equilibrium steady state. A general framework has been developed to study such a set up which helped us to compute this steady state as well as the approach to the steady state. In a specific example of a linear confining trap, they showed that the particle exhibits a dynamical transition in the form of cone spreading relaxation to the steady state. The general formalism developed in this work can be applied to more realistic return protocols, opening up a panorama of possibilities for further theoretical and experimental applications.

Particles Confined in Arbitrary Potentials with a Class of Repulsive Interactions

Understanding the properties of many particle systems interacting via long-range potential has been a subject of immense interest in both physics and mathematics. In recent work, Kundu and collaborators developed a large N field theory for a such a system in one dimension at thermal equilibrium in which N classical particles are confined by an arbitrary external potential and repel each other via a class of pairwise interaction potentials that decays as a power law with the separation between two particles. They considered the cases where every particle is interacting with d number of particles to its left and right where d can range from d=1 (nearest neighbour) to d=N (all-to-all coupling). Due to the intricate interplay between external confinement, pairwise repulsion, and entropy, the density exhibits markedly distinct behaviour depending on the range of interaction. From this field theory, one can analytically compute the average density profile for large N in these regimes.

Spatiotemporal Spread of Perturbations in a Driven Dissipative Duffing Chain

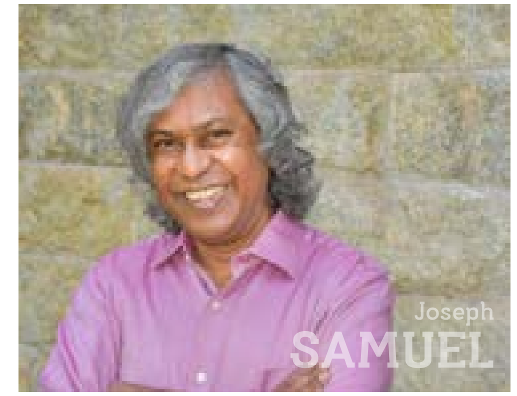
In this work, Kundu and collaborators studied chaotic properties in an open (no energy conservation) chain of Duffing oscillators (which is a classical many-body system) by measuring out-of-time correlator (OTOC). It was shown that OTOC serves as an excellent diagnostic to identify different dynamical regimes of this oscillator chain in presence of external drive and dissipation locally. The OTOC provides a clear demarcation of three distinct dynamical regimes where chaos is sustained, transient, and absent. This work provides extensive information about the degree of chaos which can be potentially used in areas like encryption devices, secure communications, and signal detection to name a few.

RESEARCH REPORT

Joseph **SAMUEL**

JOSEPH SAMUEL's research during the last two years has had the following themes:

Geometric Phase in Band Theory



This is ongoing research in which some geometric aspects of band theory in crystals are investigated. Samuel and collaborators studied the homotopically different ways in which the torus representing momentum space can be embedded in the quantum ray space. The objective was to understand the physical effects of topology that one can expect to arise from such systems. Some simple solvable models have been identified in this area.

Quantum Information and Quantum Computing

By repeated trials, one can determine the fairness of a classical coin with a confidence which grows with the number of trials. A quantum coin can be in a superposition of heads and tails and its state is most generally a density matrix. Given a string of qubits representing a series of trials, one can measure them individually and determine the state with a certain confidence. Samuel and collaborators showed that there is an improved strategy which measures the qubits after entangling them, which leads to a greater confidence. This strategy is demonstrated on the simulation facility of IBM quantum computers.

Closure Invariants in Radio Astronomy

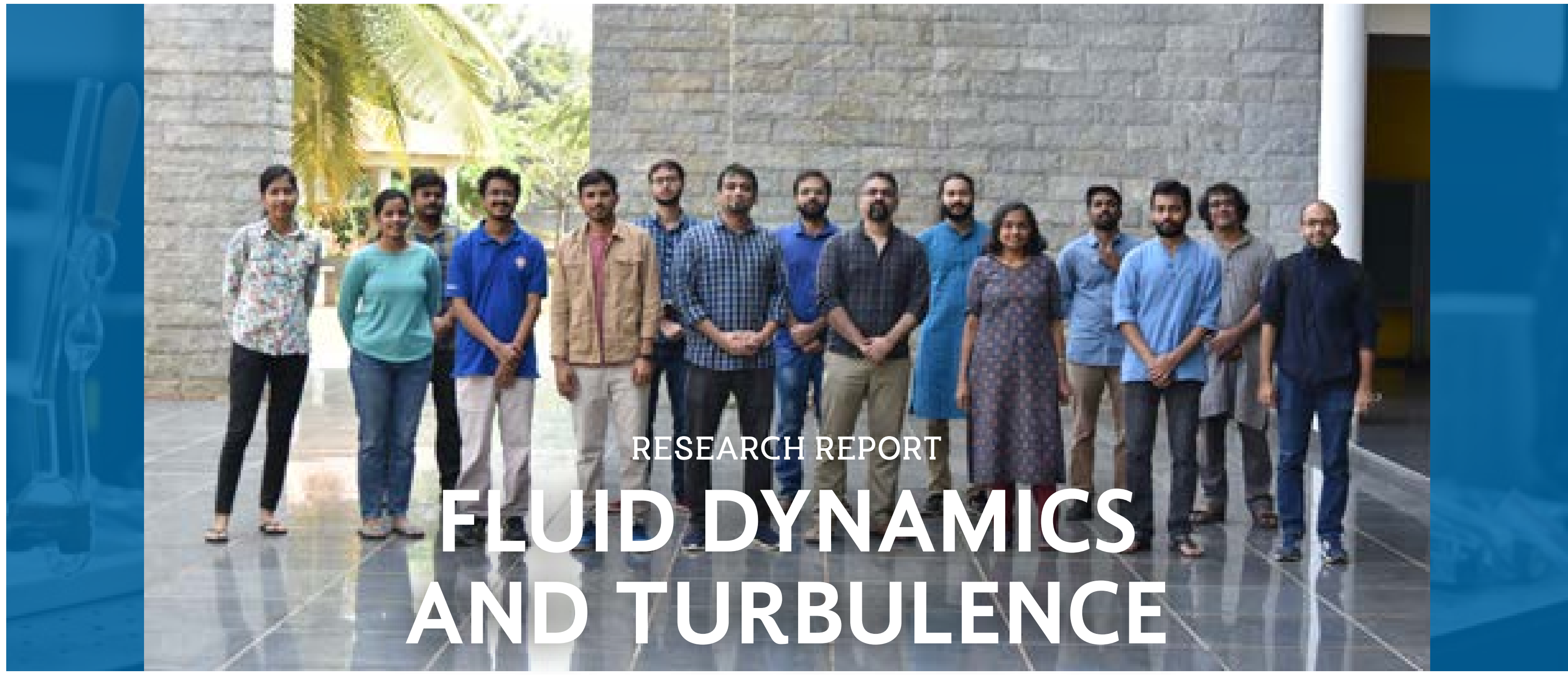
The discovery of magnetic fields close to the M87 black hole using Very Long Baseline Interferometry by the Event Horizon Telescope collaboration utilized the novel concept of "closure traces", that are immune to antenna-based corruptions. Samuel and collaborators took a fundamentally new approach to this promising tool of polarimetric interferometry. The corruption of measurements of polarized signals at the individual antennas are represented by general 2×2 complex matrices, which are identified with gauge transformations belonging to the group GL(2,C), so the closure traces now appear as gauge-invariant quantities. They applied this formalism to polarimetric interferometry and generalize it to any number of interferometer elements. This approach goes beyond existing studies in the following respects: (1) they did not need auto-correlations, which are susceptible to large systematic biases, and therefore unreliable (2) they used triangular combinations of correlations as basic building blocks (analogous to the "elementary plaquettes" of lattice gauge theory), and (3) they used the Lorentz group and its properties to transparently identify a complete and independent set of invariants. This set contains all the information immune to corruption available in the interferometer measurements, thus providing robust constraints which would be important in future interferometric studies.

Coherent States and Kahler Embeddings

It is well known that Coadjoint orbits of Lie groups admit a symplectic structure. Using geometric quantisation on the coadjoint orbits, Samuel and collaborators investigated whether these also admit a symplectic structure.

Optimal Control in Pandemics

During a pandemic, there are conflicting demands that arise from public health and socioeconomic costs. Lockdowns are a common way of containing infections, but they adversely affect the economy. Samuel and collaborators studied the question of how to minimize the socio economic damage of a lockdown while still containing infections. Their analysis was based on the SIR model, which they analyzed using a clock set by the virus. This use of the "virus time" permits a clean mathematical formulation of our problem. They optimized the socioeconomic cost for a fixed health cost and arrived at a strategy for navigating the pandemic. This involves adjusting the level of lockdowns in a controlled manner so as to minimize the socioeconomic cost.



RESEARCH REPORT

FLUID DYNAMICS AND TURBULENCE

FACULTY

Rama Govindarajan ◈ Samriddhi Sankar Ray

POSTDOCTORAL FELLOWS

Sunil Bharadwaj ◈ Sangeeth Krishnan ◈ Priyanka Maity ◈ Siddhartha Mukherjee ◈ Yogesh Prasaad Madras Sethuraman

STUDENTS

Rahul Chajwa ◈ Divya Jaganathan ◈ Saumav Kapoor ◈ Anup Kumar ◈ Sugan Durai Murugan ◈ Rahul Kumar Singh ◈ Ritabrata Thakur

RESEARCH REPORT

Rama GOVINDARAJAN

Dynamics of Bodies in Fluid

The dynamics of an ellipsoid in inviscid and viscous fluid is a classical problem. A theorem of Kozlov and Onishchenko states that the dynamics of ellipsoids of a certain geometry in inviscid flow is integrable. RAMA GOVINDARAJAN and her collaborators' analytical computations showed how the regions in phase space displaying chaotic orbits depend on the triaxiality of the ellipsoid, and on the ratio of fluid to solid density. Ellipsoids of rotation cannot display chaos, and we obtained an additional integral for them, namely the generalized angular momentum along the unequal axis. This makes their dynamics rather limited compared to that of a triaxial ellipsoid, though viscosity can make a spheroid execute chaotic motion at short time.

Cloud Flow

Through stability analysis, and by direct numerical simulations using the Megha code, Govindarajan and collaborators have proposed a mechanism by which mammatus clouds can form. As droplets from a cloud base descend under gravity, they evaporate, leading to a cooler and denser layer of air lying above warmer air, going unstable and giving bulbous structures. It was shown that the essential physics is already displayed in two dimensions, and the third dimension is only needed to obtain the rounded mammatus shapes.

Stability Studies

Laminar shear flows often display an extreme sensitivity in their stability properties to changes in geometry, heating etc. Govindarajan and collaborators showed that this happens because the eigenvectors are not orthogonal to each other, and so the resolvent norm is extremely sensitive to perturbations. In other words, a small change in geometry or the addition of a small level of rotation can provide a perturbed stability matrix, the convex hull of whose eigenspectrum can cross the neutral boundary.

By deriving a new Reynolds-Orr equation for viscosity stratified flow it was shown that disturbance growth in heated channel flow is dominated by nonlinear effects as opposed to an unstratified flow where all perturbation growth is instantaneously linear.

Indian Monsoon

Govindarajan and her collaborators had earlier shown that about 10 spatial patterns of daily rainfall are sufficient to explain over 90 per cent of all monsoon days in the past 110 years. They now studied combined patterns of OLR (outgoing longwave radiation) and rainfall. OLR is a proxy for convective clouds. As before, about eight patterns are sufficient to describe over 90 per cent of all monsoon days. They found many interesting features in these combined patterns. For example, a lot of South Eastern India is cloudy but dry during a significant part of the monsoon season.

RESEARCH REPORT

Samriddhi Sankar RAY

Collective motion is remarkably commonplace. While this is true for many organisms, the case of bacterial swarms - an intriguing class of spatio-temporally chaotic, out-of-equilibrium systems, called active turbulence - is subtle. Drawing parallels with hydrodynamic turbulence, such suspensions should be diffusive. However, recent experiments suggest that Lévy walks and super-diffusion does augment foraging in bacterial swarms. Surprisingly, its detection and understanding have eluded theoretical studies. SAMRIDDHI SANKAR RAY and group showed how such optimal strategies emerge and traced them to hitherto undetected patterns in active flows providing insights on how microorganisms exploit hydrodynamics as well as what sets animate active turbulence apart from inanimate classical turbulence. This work on active turbulence complements the group's study of flocking of microorganisms in turbulent, marine-like environments.

The group also explored many of the interesting questions related to thermalised fluids. In particular these were used, with the help of cross-correlators, to understand chaos in many-body systems by bridging equilibrium and dynamics through rigorous estimates of the temperature-dependence of the degree of chaos (Lyapunov exponent). By using finite-dimensional hydrodynamical equations, resulting in chaotic, thermalised flows, the Lyapunov exponent was shown to grow as square-root of temperature and linearly with the degrees-of-freedom underlining the universality of many-body chaos and its fundamental connection to equilibrium properties.

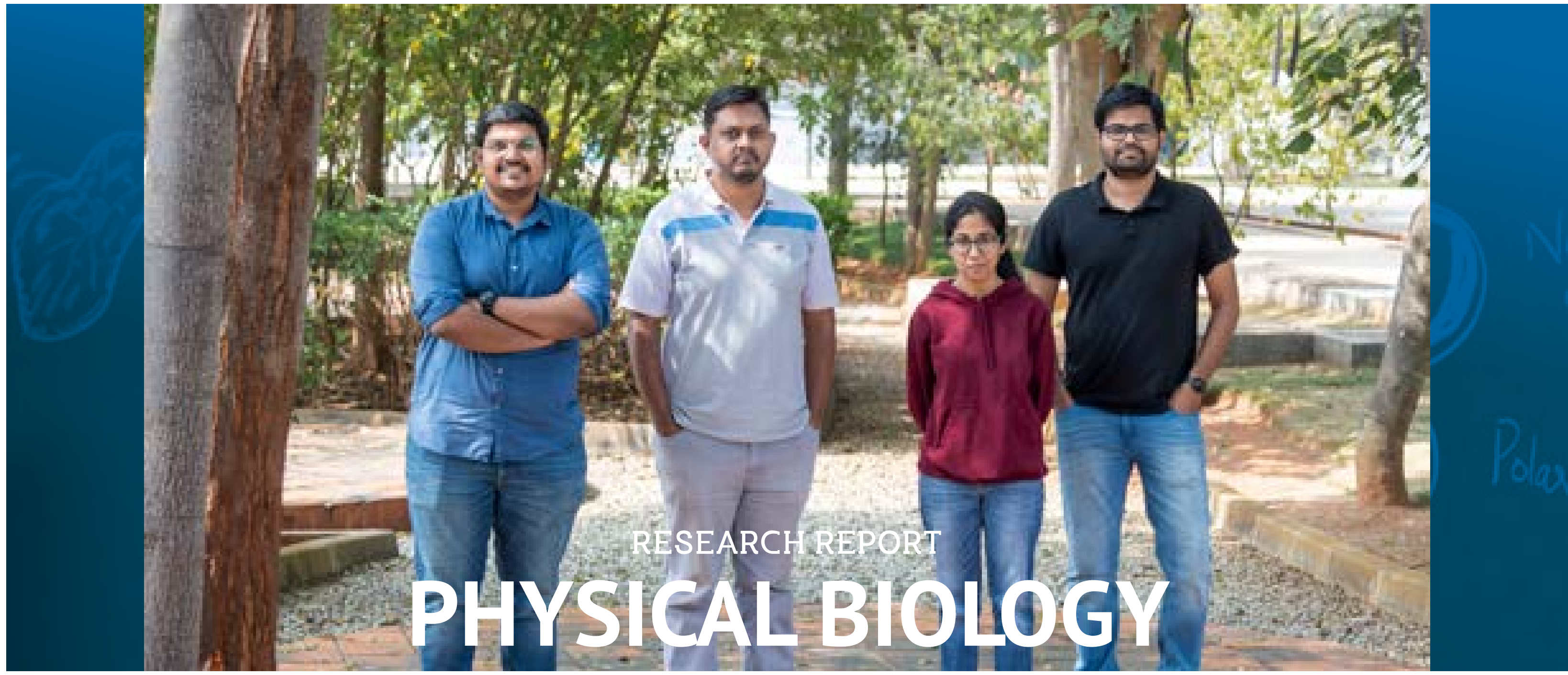
However, that solutions of finite-dimensional inviscid equations thermalise lead to other problems in the theory of turbulence. First, a numerical approach to predict finite-time blow-up of the Euler equation by measuring the width of the analyticity strip fails as the small-scales thermalise. Second, weak (dissipative) solutions of the Euler equation (Onsager's 1949 conjecture) are impossible to realise numerically. The group proposed a novel method - tyger purging - to prevent thermalisation without viscous regularisation. This method allows one to (1) recover dissipative solutions and (2) conjecture on possible finite-time blow-up in the Euler equation.

On more applied problems of turbulence, the group examined the dynamics of ice crystals in turbulence, accounting for both inertia and gravity. This remains the first concrete step towards quantifying Cirrus cloud characteristics which depend sensitively on the ice crystal orientation distribution. Clouds constitute the greatest uncertainty in the Earth-atmosphere radiation budget, and this work has implications towards estimating their contribution to the planetary greenhouse effect.

Turbulent flow, the archetypal non-equilibrium system, ubiquitous in nature and industry, is recognized as being strongly irreversible and intermittent; yet the physical connection between these two characteristic properties remains unclear. The group showed how Lagrangian measures of irreversibility are connected to the rather peculiar passage of tracers through zones of intense Eulerian dissipation. This study suggests that contrary to intuition, Lagrangian irreversibility is insensitive to intermittency.

Apart from these, there was considerable progress in understanding the statistics of the dissipation range in the Burgers equation and in rotating turbulence. While the former study used tools of analysis and asymptotics, the latter extended multifractal ideas to the case of rotating flows.

Finally, perhaps the area which received the most attention was the dynamics of chains (bead-spring models), ranging from those which are very small and hence mimic polymers, to long elastic ones which extend well into the inertial range of scales. While on one hand the group investigated the scission of polymers in turbulence - which is a fundamentally important question in basic sciences and industry - on the other hand there were the first reported results for a minimal model of elasto-inertial filaments and their unique sampling of the structures in a turbulent fluid.



RESEARCH REPORT

PHYSICAL BIOLOGY

FACULTY

Vijay Kumar Krishnamurthy ◈ Shashi Thutupalli *(Joint faculty with NCBS, Bengaluru)*

POSTDOCTORAL FELLOWS

Tuhin Chakrabortty ◈ Pritha Dolai ◈ Jemseena V. ◈ Sankaran Nampoothiri

STUDENTS

Aditya Singh Rajput

RESEARCH REPORT

Vijay Kumar KRISHNAMURTHY

Cytoplasmic dynein 1 (dynein) is the primary minus end-directed motor protein in most eukaryotic cells. Dynein remains in an inactive conformation until the formation of a tripartite complex comprising dynein, its regulator dynactin and a cargo adaptor. How this process of dynein activation occurs is unclear, since it entails the formation of a three-protein complex inside the crowded environs of a cell. Here, VIJAY KUMAR KRISHNAMURTHY and collaborators employed live-cell, single-molecule imaging to visualise and track fluorescently tagged dynein. First, they observed that only ~30% of dynein molecules that bound to the microtubule (MT) engaged in minus end-directed movement, and that too for a short duration of ~0.6 s. Next, using high-resolution imaging in live and fixed cells, and using correlative light and electron microscopy, they discovered that dynactin remained persistently attached to MTs, and endosomal cargo remained in proximity to the MTs and dynactin. Finally, they employed two-colour imaging to visualise cargo movement effected by single motor binding. Then they used these discoveries as the basis for a stochastic model incorporating dynamic motors binding to cargo located along MTs, and also developed a coarse-grained 3-state run-and-tumble particle (RTP) model for the cargo that quantitatively recapitulates the emergent statistics of cargo movement. Taken together, Krishnamurthy and collaborators discovered a search mechanism that is facilitated by dynein's frequent MT binding-unbinding kinetics: (1) in a futile event when dynein does not encounter cargo anchored in proximity to the MT, dynein dissociates and diffuses into the cytoplasm, (2) when dynein encounters cargo and dynactin upon MT-binding, it moves cargo in a short run. Several of these short runs are undertaken in succession for long-range directed movement. In conclusion, they demonstrated that dynein activation and cargo capture are coupled in a step that relies on the reduction of dimensionality to enable minus end-directed transport in cellulo, and that complex cargo behaviour emerges from stochastic motor-cargo interactions.

A distinguishing feature of active particles is the nature of the non-equilibrium noise driving their dynamics. Control of these noise properties is, therefore, of both fundamental and applied interest. Krishnamurthy and collaborators demonstrated emergent tuning of the active noise of a granular self-propelled particle by confining it to a quasi one-dimensional channel. They found that this particle, moving like an active Brownian particle (ABP) in two-dimensions, displays run-and-tumble (RTP) characteristics in confinement. They showed that the dynamics of the relative orientation coordinate of the particle maps to that of a Brownian particle in a periodic potential subject to a constant force, in analogy to the dynamics of a molecular motor. This mapping captures the essential statistical characteristics of the one-dimensional RTP motion. Specifically, their theoretical analysis is in agreement with the empirical distributions of the relative orientation co-ordinate and the run-times (tumble-rates) of the particle. Finally, they explicitly controlled these emergent run-and-tumble like noise parameters by external driving. Altogether, their work illustrates geometry-induced tuning of the active dynamics of self-propelled units thus suggesting an independent route to harness their internal dynamics.

The actomyosin cortex is a thin film, containing actin filaments and myosin molecular motors, located beneath the plasma-membrane of eukaryotic cells. Active processes, driven by ATP hydrolysis, can generate mechanical forces in the cortex. Coordinated force-generation drives large-scale mechanical flows and orientation patterns. These flows can pattern proteins coupled to the cortex leading to the emergence of active mechanochemical patterns. In this review, Krishnamurthy and collaborators discussed physical approaches to understand force-generation and the concomitant patterns observed in the actomyosin cortex. They briefly outlined the hydrodynamic theory of active gels as applicable to the cortex and discussed its consequences. They speculated on the role of the actomyosin cortex in sculpting large-scale tissues and ended with an outlook for open problems.

Krishnamurthy and collaborators found an exact series solution for the steady-state probability distribution of a harmonically trapped active Brownian particle in two dimensions in the presence of translational diffusion. This series solution allowed them to efficiently explore the behavior of the system in different parameter regimes. Identifying "active" and "passive" regimes, they predicted a surprising re-entrant active-to-passive transition with increasing trap stiffness. Their numerical simulations validated this finding. They discussed various interesting limiting cases wherein closed-form expressions for the distributions can be obtained.

He also studied the single-file dynamics of three classes of active particles: run-and-tumble particles, active Brownian particles and active Ornstein–Uhlenbeck particles. At high activity values, the particles, interacting via purely repulsive and short-ranged forces, aggregate into several motile and dynamical clusters of comparable size, and do not display bulk phase-segregation. In this dynamical steady-state, Krishnamurthy and collaborators found that the cluster size distribution of these aggregates is a scaled function of the density and activity parameters across the three models of active particles with the same scaling function. The velocity distribution of these motile clusters is non-Gaussian. They showed that the effective dynamics of these clusters can explain the observed emergent scaling of the mean-squared displacement of tagged particles for all the three models with identical scaling exponents and functions. Concomitant with the clustering seen at high activities, they observed that the static density correlation function displays rich structures, including multiple peaks that are reminiscent of particle clustering induced by effective attractive interactions, while the dynamical variant shows non-diffusive scaling. Their study revealed a universal scaling behavior in the single-file dynamics of interacting active particles.

RESEARCH REPORT

Shashi **THUTUPALLI**

SHASHI THUTUPALLI's long standing interest in the dynamics of complex systems far from equilibrium, of which living systems are a quintessential example, naturally places his research at the interface of biology, physics and engineering. He develops

quantitative experiments combined with conceptual frameworks following two broad strategies: He directly probes biological complexity at different spatio-temporal scales, while developing simple physico-chemical systems that display the emergent dynamics of living processes. He is specifically interested in the material origin of the characteristics of living processes - his approach has been to recreate in the laboratory, the emergence of specific and observable processes of living systems to shed light on early evolution, the transitions therein and to inform us about the mechano-chemical fabric underlying the living state.

The key questions that drive Thutupalli's group are distinct, unified by their probing of the multiple facets of the complex organization of living systems through space and time: (i) what design features (with a specific focus on spatio-temporal organization) are required to create synthetic systems capable of displaying emergent computation, heritability and evolvability? (ii) what are the emergent dynamical patterns of interacting non-equilibrium active units/microbial species? (iii) what are the energetic budgets of living systems and how do such energetic requirements scale with size and across evolutionary transitions (e.g. uni--multicellular)? The group broadly takes two complementary approaches:

The group constructed de novo, synthetic mimics of living matter to study the minimal ingredients for self-assembly, replication, feedback, and evolvability. Thutupalli's group currently works with collaborators on problems related to the origins of life scenario and on aspects of synthetic self-replication. In other collaborations in this broad area, the group investigated stochastic dynamics in active matter.

The group also studied the impact of mistranslation on evolutionary outcomes in bacteria came to fruition with a first publication. The group continues its Max Planck Partner Group to study aspects of cellular energetics and responses to extreme perturbations and also continues to strengthen multiple other collaborations on these theme. This past year the members were invited to be part of a group interested in physical approaches to cellular bioenergetics, which held a meeting at KITP and summarised the emerging discussions in a perspective article.

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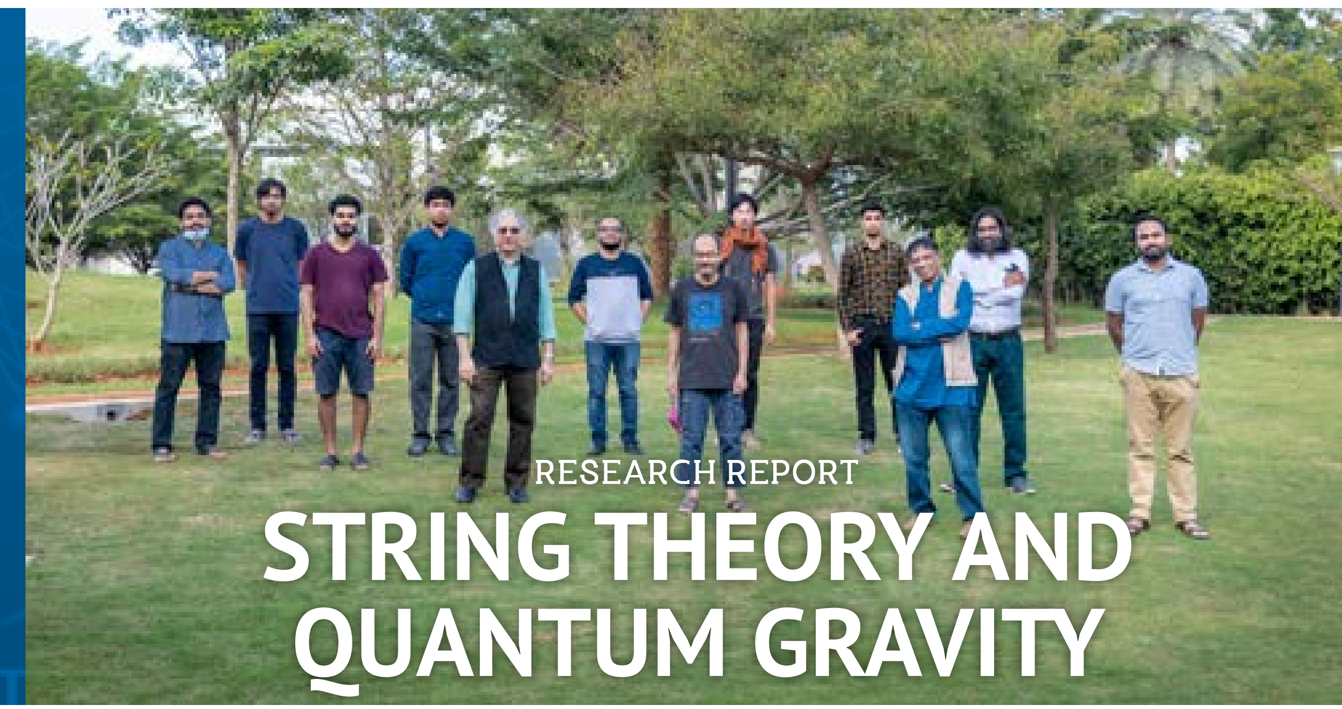


RESEARCH REPORT

STRING THEORY AND QUANTUM GRAVITY

FACULTY

Avinash Dhar *(Dean Emeritus and Visiting Professor)* ◈ Rajesh Gopakumar ◈ R. Loganayagam ◈ Suvrat Raju ◈ Ashoke Sen *(ICTS-Infosys Madhava Chair Professor)* ◈ Spenta R. Wadia

POSTDOCTORAL FELLOWS

Anupam A H ◈ Bidisha Chakrabarty ◈ Yogesh Dandekar ◈ Jewel Kumar Ghosh ◈ Victor Godet ◈ Athira P V ◈ Naveen Prabhakar ◈ Siddharth Prabhu ◈ Vishal M. Vijayan

STUDENTS

Tuneer Chakraborty ◈ Joydeep Chakravarty ◈ Soumyadeep Chaudhuri ◈ Chandramouli Chowdhury ◈ Sarthak Duary ◈ Chandan Kumar Jana ◈ Kasi Jaswin ◈ Vijay Kumar ◈ Aswin Parayil Mana ◈ Pronobesh Maity ◈ Priyadarshi Paul ◈ Shivam Sharma ◈ Omkar Shetye ◈ Pushkal Shrivastava ◈ Akhil Sivakumar

RESEARCH REPORT

Rajesh GOPAKUMAR

RAJESH GOPAKUMAR's work has aimed at giving a systematic derivation of the AdS/CFT correspondence (or gauge string duality) with the tensionless limit of the string theory as its starting point. In the last two years, he has intensely investigated the particular case of the AdS_3/CFT_2 correspondence where the tensionless limit is dual to a class of free (orbifold) 2d CFTs. A crucial finding was showing that the worldsheet correlators of the string theory reproduces the dual CFT correlators through a very unusual localisation on the worldsheet. It makes the equality of correlators on both sides manifest. This localisation was seen to originate from a twistor incidence realisation obeyed in the free field realisation of the string worldsheet CFT.

This worldsheet description was then generalised to one for the tensionless string dual to free maximally supersymmetric Yang-Mills theory. The worldsheet theory is now in terms of fields describing the twistor space of the dual 5d Anti de Sitter spacetime. A natural generalisation of the procedure for quantising these fields gives rise to a spectrum which is exactly that of the single trace spectrum of the free Yang-Mills theory. This opens the way to understanding the dual string theory in a controllable manner by starting from the small radius limit. In particular, this formulation naturally connects to the integrable spin chain description of planar super Yang-Mills at the interacting level.

These developments also tie well with a broad approach to reorganising the Feynman diagrams of the field theory into worldsheet contributions to the dual string theory. This was explicitly realised in the AdS_3/CFT_2 case where one sees that the field theory correlators naturally give rise to the Strebel differential that is the key object linking the two sides. This has also recently been generalised to the 5d AdS case where appropriate stringy twistor incidence relations imply twistor covering maps that realise a similar geometric picture in terms of Strebel differentials. In turn, the Strebel area of these worldsheets gives rise to the Feynman propagators of the field theory.

In another direction of work on the conformal bootstrap, a formalism was developed which writes (four point) correlation functions in a conformal field theory in a way which manifests the so-called crossing symmetry between all channels. This formalism was used to show how one can make a well defined expansion of such correlators in terms of what was dubbed Polyakov-Mellin blocks which in turn are closely related to Witten diagrams in Anti de Sitter space. In particular, certain ambiguities involving contact diagrams are fixed through the imposition of locality constraints. This potentially gives a lot of calculational power as a new analytic approach to the conformal bootstrap.

RESEARCH REPORT

R. LOGANAYAGAM

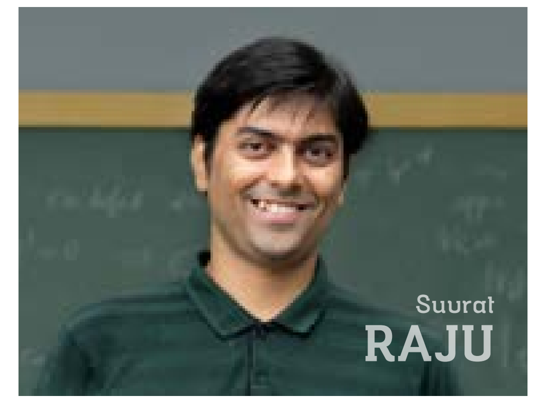
During the period of the report, R. LOGANAYAGAM has mainly focused on using AdS/CFT to construct and study open quantum field theories(QFTs), i.e., QFTs coupled to environments. The dissipation in such systems arises from modes falling into a black hole whereas the thermal fluctuations are modeled using Hawking radiation. Both these infalling as well as Hawking modes appear in two versions: one version in which the decay as well as fluctuations evolve and die fast (Markovian), another version in which the infalling as well as Hawking modes evolve slowly and are long-lived (non-Markovian). This corresponds to two qualitatively different versions of open QFTs that occur in real systems.

Loganayagam and collaborators developed a systematic way of treating the interactions between the dissipative infalling and fluctuating Hawking modes, using a recently proposed real-time (Schwinger-Keldysh) computational technique in AdS/CFT. They computed real time, finite-temperature correlation functions of the dual CFT and from it the influence functionals for a probe scalar couple to a CFT bath. They considered n-particle contact scatterings for arbitrary n and derived a sequence of fluctuation-dissipation type relations obeyed by the parameters of the resulting open QFT. They also derived a set of exact results for 2d CFT baths in this work.

In a set of two papers, they showed how the physics of fermionic fluctuations are correctly reproduced by studying fermionic Hawking radiation (the first without chemical potential and the second work is an extension to finite chemical potential). They showed that the scattering from the Schwinger-Keldysh geometry correctly reproduces the physics of the Pauli exclusion principle and the Fermi-Dirac statistics in these systems. This study opens up a way to construct and study fermionic open EFTs, especially that of non-fermi liquids, a subject of great relevance in solid state physics.

In a set of papers Loganayagam and collaborators addressed, for the first time, the question of long-lived fluctuations. The physics here is that of fluctuating hydrodynamics, or more precisely stochastic diffusion (the first work at zero density and the second work is an extension to finite density): they considered a long-lived diffusion mode along with the long-lived thermal noise that accompanies it. This is modeled by electromagnetic/gravitational waves decaying/Hawking-fluctuating about a black hole background. The challenge here is to separate out the short-lived modes: in the zero density case, this is achieved using symmetry considerations. In the non-zero density, one needs to diagonalise further to achieve such a separation. In either case, with judicious choice of variables, one can reduce the question to a set of decoupled scalar systems which can then be solved in small frequency/wave-number expansion. These works set up an array of tools which allows us to construct and study interacting, non-Markovian open QFTs using gravity.

In a separate work, Loganayagam and collaborators describe how to think about open quantum systems in the Heisenberg picture, i.e., in terms of time evolving operator algebras. The analysis is straightforward quantum mechanics but with a striking conclusion: an exact Heisenberg picture for an open quantum system can be given in terms of mixing/co-evolution of multiple image Heisenberg operators corresponding to every system observable. For a given system observable, the number of such image operators grows with the dimension of the environment Hilbert space. Nevertheless, they show that, a single system observable can be constructed, accurately upto arbitrary orders in the system environment coupling which contains the same information. The price they pay though is that this construction depends non-linearly on the state of the environment, and the operator product on such operators is no more the naive operator product but a deformed one.



RESEARCH REPORT

Suurat RAJU

Holographic nature of null infinity

SUVRAT RAJU and his collaborators made a significant advance towards understanding flat space holography. They were able to show that in a theory of quantum gravity in asymptotically flat space in four dimensions, all information on future null infinity can also be obtained from the past boundary of future null infinity. This work suggests a general principle about how quantum information is localized in quantum gravity that was later termed the “principle of holography of information” in a theory of gravity, a copy of the information anywhere on a Cauchy slice is also available near its boundary.

Holography from the Wheeler deWitt Equation and a Physical Protocol for Obtaining Information from the Boundary in Quantum Gravity

The principle of holography of information is not simply a formal statement about quantum gravity but has manifestations in perturbation theory. Raju and his collaborators explored these implications in asymptotically anti-de Sitter space. They showed that observers near the boundary of the AdS could, by means of an elegant protocol, obtain complete information about the bulk for low-energy states.

In a related paper, Raju and collaborators also established a link between two well-known but seemingly different approaches to quantum gravity. One approach involves the Wheeler-DeWitt (WDW) equation and has been used to understand gravity from a canonical perspective. The other involves the AdS/CFT correspondence that has been the focus of a significant amount of research in the past 25 years. Raju and his collaborators showed that a version of holography can be derived from the WDW equation. The precise result is that within perturbation theory, that two wave functionals that solve the WDW equation in AdS, and coincide at the boundary of AdS for an infinitesimal time interval, must coincide everywhere in the bulk.

Inconsistency of Islands in Theories with Long-Range Gravity and Information Transfer with a Gravitating Bath

In the recent literature, a significant amount of attention has been devoted to computing a Page curve for AdS black holes. These computations utilize the so-called "island proposal". However, Raju and collaborators showed that these computations are inconsistent in standard gravity and necessarily involve nonstandard theories of gravity, which include a nongravitational bath and massive gravitons. In a set of related papers, Raju and his collaborators showed that if gravity is turned on in the bath then the Page curve vanishes. Second, in a standard theory of gravity, where the Gauss law holds, Raju and his collaborators showed that the island proposal would be inconsistent.

Failure of the Split Property in Gravity and the Information Paradox and Lessons from the Information Paradox

In an ordinary quantum field theory, the "split property" implies that the state of the system can be specified independently on a bounded subregion of a Cauchy slice and its complement. The work above shows that this property does not hold for theories of gravity, where observables near the boundary of the Cauchy slice uniquely fix the state on the entire slice. This observation has important implications for the information paradox. The original formulation of the information paradox by Hawking explicitly assumed the split property and they followed this assumption to isolate the precise error in Hawking's argument. A similar assumption also underpins recent refinements of the information paradox by Mathur and AMPS. Finally the same assumption is used to support the common idea that the entanglement entropy of the region outside a black hole should follow a Page curve.

Raju showed that discarding this assumption leads to a robust resolution of the paradox. The review "lessons from the information paradox" summarizes this resolution in significant detail and also reviews other progress in our understanding of quantum aspects of black holes. .

RESEARCH REPORT

Spenta R. WADIA

Current Algebra, a U(1) Gauge Theory and the Wess-Zumino -Witten Model

In this paper SPENTA WADIA demonstrated that current algebra with anomalous terms in terms of a U(1) gauge theory, in the space of maps M from S1 into a compact Lie group corresponding to the current algebra. The Wilson loop around a closed curve in M is shown to be the Wess-Zumino-Witten term. This discussion enables a simple understanding of the non-Abelian anomaly in the Schrodinger picture of quantum field theory.

Evaporating Black Hole in 1+1 Dimensions

In the past few years there has been important progress in the resolution of the information paradox of black hole physics. This progress is primarily because the time dependent von Neumann entropy of the black hole and radiation system has a geometric formula that was shown to obey the Page curve.

Another way to approach the resolution of the information puzzle is to study the problem of BH evaporation is by solving the real time dynamics of the Sachdev-Ye-Kitaev (SYK) model which in the low energy limit is holographic to 2-dim gravity. To absorb away the Hawking radiation the SYK model is coupled to a QFT.

Wadia and collaborators studied the SYK model at large N and low energy, coupled to a CFT2 via operators that include a relevant operator of dimension ½. Initially both systems are described by a pure state density matrix in the product Hilbert space of the SYK model and CFT2 . The initial density matrix of the SYK model describes a black hole in 2-dim gravity at low temperature. The evolution of the density matrix is naturally described in the Schwinger-Keldysh (SK) formalism. Since they integrated over all histories of the CFT2 they arrived at a non-local Feynman influence functional in terms of two copies of the SYK degree of freedom.

Wadia and collaborators have numerically solved the coupled system in the SK 'classical limit' and have verified that most of the energy of the initial SYK black hole state is lost to the bath on a long time scale. In the gravity dual there remains a geometry without a horizon.

RESEARCH REPORT

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Technical University of Munich, Germany
Condensed Matter Physics

Dario Vincenzi
CNRS, Université Côte d'Azur
Numerical Modeling and Fluid Dynamics

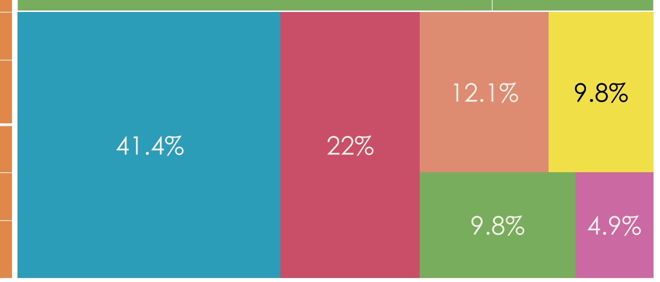
(Top to bottom) Ashoka University trustees' visit to ICTS ◊ Republic Day celebrations on campus in January 2021 ◊ Tree planting on campus

PROGRAM ACTIVITIES

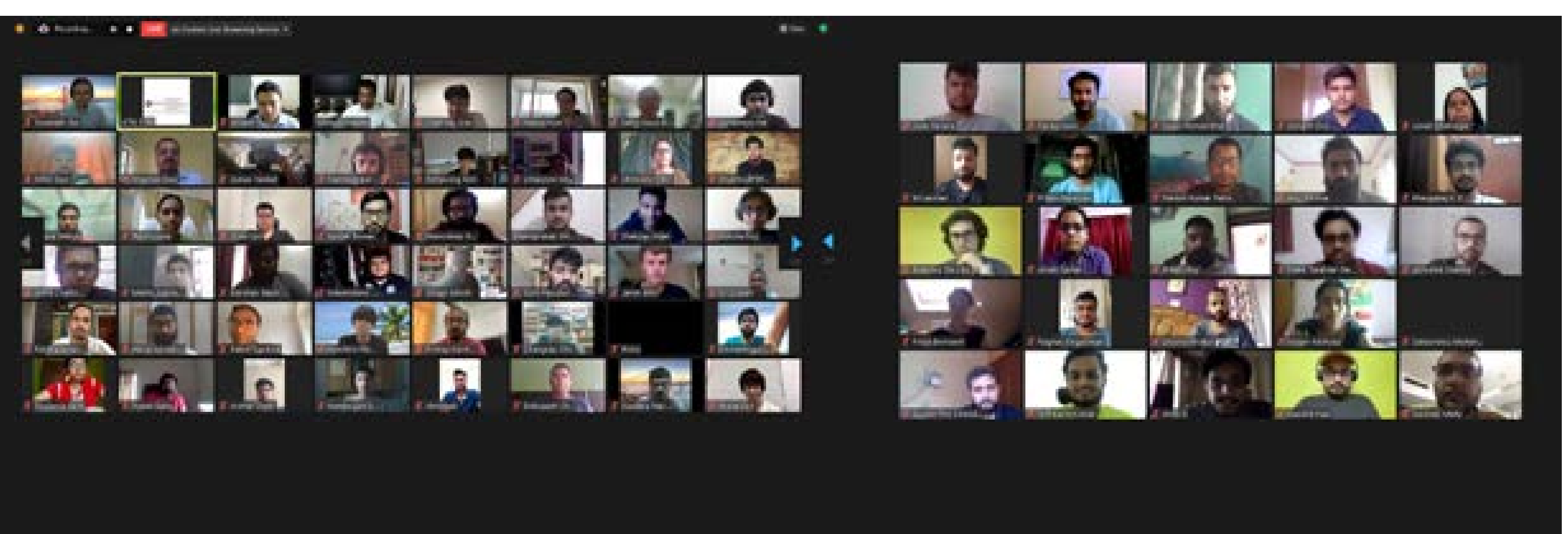
@ICTS

Total Participation	**4621**
Total Participation days	**32442**
Indian participation	3040
Foreign Participation	1581
SPEAKERS	
Indian	253
Foreign	453
GENDER	
Female	996
Male	3625
STUDENTS AND POSTDOCS	
Indian	2138
Foreign	738
Offline discussion meetings	7
Offline programs	3
Offline discussion meetings	8
Offline programs	23
Total	**41**
Upcoming in December	**2**

SUBJECTS	NO: OF EVENTS
Mathematics and Computer Science	17
Condensed Matter and Statistical Physics	9
Astrophysics and Cosmology	5
Quantitative Biology	4
Climate Sciences and Fluid Dynamics	2
High Energy Physics	4



Due to the Covid-19 pandemic and the restrictions that ensued, a few programs and discussion meetings in 2020 had to be cancelled. The first online program, on Gravitational Wave Astrophysics, was held in May 2020. Since then 24 programs and nine discussion meetings have been successfully organised on the online platform. Here are details of a few important programs and discussion meetings.



PROGRAMS

ICTP-ICTS Winter School on Quantitative Systems Biology ♦ 6-17 December 2021

This was the tenth school in the series on Quantitative Systems Biology, held alternatively at Trieste and Bengaluru. The aim of this school is to provide scientists with a broad exposure to quantitative problems in the study of living systems. This year, the school focused on Sensori-motor control. The two-week school began with a brief introduction to neuroscience, including electrical properties of neuronal membranes and single neuronal biophysics. Questions like how circuit dynamics emerge in diverse circuits using invertebrate and vertebrate model organisms as well as questions in population coding, variability and stochasticity and plasticity were covered. Students were then introduced to applications of quantitative tools to neuroscience data sets such as whole-brain imaging data sets or behavioral clustering data sets.

Quantum Fields, Geometry and Representation Theory 2021 ♦ 5-23 July 2021

The broad theme of this meeting was the intersection of quantum field theory and geometric representation theory, to build on an attempt to foster synergistic interactions between the mathematics and physics communities in India and across the world. The program included several mini-courses and research talks. The talks were spread over two time windows to enable participation from all over the world.

Summer School for Women in Mathematics and Statistics ♦ 14-25 June 2021

The Summer School for Women and Statistics was aimed at helping young students gain broader exposure to problem solving skills in mathematics and statistics at the undergraduate level. The school also included seven popular lectures covering topics such as 'Groundwater and Us', 'Mathematical Models for Infectious Diseases', 'What is the Geometry of the Universe', and others.

Probabilistic Methods in Negative Curvature ♦ 1-12 March 2021

This program was the second in a series of meetings focused on the interface between hyperbolic geometry, probability and ergodic theory. The topics discussed in this meeting were percolation on general background geometries and invariant random subgroups. The program consisted of seven mini-courses, each comprising 2-4 lectures.

Advances in Applied Probability I ♦ 4-8 January 2021

Applied probability has seen a revolutionary growth in research activity, driven by the information age and exploding technological frontiers. In this six-day program on advances in applied probability, leading researchers from the field conducted short courses in emerging areas, including statistical learning theory, high dimensional computation, Monte Carlo methods, discrete probability, percolation and empirical methods in probability. The program included sixteen research talks.

Turbulence: Problems at the Interface of Mathematics and Physics ♦ 7-18 December 2020

The interest in turbulent flow goes back many centuries, but progress has been very slow until recently from the point of view of ab initio theory (starting from the Euler or Navier-Stokes equations). Recently, there has been an important advance in the ab initio mathematical understanding of turbulence. The time is right to bring together a wide range of specialists for a new assault on the turbulence problem. This two-week program, first introduced participants to new developments, followed by specialized talks by leading experts and then focused discussions between them to make progress on the solutions of the challenging problems here.

Recent Developments in S-Matrix Theory ♦ 20-31 July 2020

Scattering amplitudes have played a central role in quantum field theory since its inception. Recent years have seen a remarkable advance in our understanding of scattering amplitudes, both for theoretical and phenomenological purposes.

This program brought together researchers working in scattering amplitudes, IR physics and asymptotic symmetries and mathematics, with the goals of reviewing recent progress with both pedagogical lectures and research talks, strengthening connections between areas of mathematics and physics relevant to these topics and inspiring further progress and collaborations among the participants.

List of programs

ICTP–ICTS Winter School on Quantitative Systems Biology
6–17 December 2021 ♦ *Organisers* – Vijaykumar Krishnamurthy, Venkatesh N. Murthy, Sharad Ramanathan, Sanjay Sane and Vatsala Thirumalai

Elliptic Curves and **the Special Values of L–Functions**
2–7 August 2021 ♦ *Organisers* – Ashay Burungale, Haruzo Hida, Somnath Jha, Ye Tian

Quantum Fields, Geometry and **Representation Theory 2021**
5–23 July 2021 ♦ *Organisers* – Aswin Balasubramanian, Indranil Biswas, Jacques Distler, Chris Elliott, Pranav Pandit

ICTS Summer School on Gravitational–Wave Astronomy
5–16 July 2021 ♦ *Organisers* – Parameswaran Ajith, K. G. Arun, Bala R. Iyer, Prayush Kumar

Bangalore School on Statistical Physics – XII
28 June–9 July 2021 ♦ *Organisers* – Abhishek Dhar, Sanjib Sabhapandit

Summer School for Women in Mathematics and **Statistics**
14–25 June 2021 ♦ *Organisers* – Siva Athreya, Purvi Gupta, Anita Naolekar, Dootika Vats

Online School and **Discussion Meeting on Trapped Atoms, Molecules** and **Ions**
10–22 May 2021 ♦ *Organisers* – Bimalendu Deb, Sourav Dutta, Saikat Ghosh

Non–Hermitian Physics
22–26 March 2021 ♦ *Organisers* – Manas Kulkarni, Bhabani Prasad Mandal

Probabilistic Methods in Negative Curvature
1–12 March 2021 ♦ *Organisers* – Riddhipratim Basu, Anish Ghosh, Mahan M.J.

Dualities in Topology and **Algebra**
1–13 February 2021 ♦ *Organisers* – Samik Basu, Anita Naolekar, Rekha Santhanam

Nonperturbative and **Numerical Approaches to Quantum Gravity, String Theory** and **Holography**
18–22 January 2021 ♦ *Organisers* – David Berenstein, Simon Catterall, Masanori Hanada, Anosh Joseph, Jun Nishimura, David Schaich, Toby Wiseman

Advances in Applied Probability II
4–8 January 2021 ♦ *Organisers* – Vivek S. Borkar, Sandeep Juneja, Kavita Ramanan, Devavrat Shah, Piyush Srivastava

Statistical Biological Physics – **From Single Molecule to Cell**
7–18 December 2020 ♦ *Organisers* – Debashish Chowdhury, Ambarish Kunwar and Prabal K Maiti

Turbulence – **Problems at the Interface of Mathematics** and **Physics**
7–18 December 2020 ♦ *Organisers* – Uriel Frisch, Konstantin Khanin and Rahul Pandit

Winter School on Quantitative Systems Biology – Quantitative Approaches in Ecosystem Ecology
30 November–18 December 2020 ♦ *Organisers* – Antonio Celani, Jacopo Grilli, Simon Levin and Matteo Marsili

Recent Developments Around p–Adic Modular Forms
30 November–4 December 2020 ♦ *Organisers* – Debargha Banerjee and Denis Benois

Less Travelled Path of Dark Matter – **Axions** and **Primordial Black Holes**
9–13 November 2020 ♦ *Organisers* – Subinoy Das, Koushik Dutta, Raghavan Rangarajan and Vikram Rentala

Physics of the Early Universe – An Online Precursor
31 August – 3 September 2020 ♦ *Organisers* – Robert Brandenberger, Jerome Martin, Subodh Patil and L. Sriramkumar

Knots Through Web
24 – 28 August 2020 ♦ *Organisers* – Rama Mishra, Madeti Prabhakar and Mahender Singh

Compact Stars and **QCD 2020**
17–21 August 2020 ♦ *Organisers* – Manjari Bagchi, Sarmistha Banik, Sudip Bhattacharyya, Prashanth Jaikumar, V. Ravindran and Sayantan Sharma

Zariski–Dense Subgroups and **Number–Theoretic Techniques in Lie Groups** and **Geometry**
30 July 2020 ♦ *Organisers* – Gopal Prasad, Andrei Rapinchuk, B. Sury and Aleksy Tralle

Recent Developments in S–Matrix Theory
20–31 July 2020 ♦ *Organisers* – Alok Laddha, Song He and Yu–tin Huang

Bangalore School on Statistical Physics – XI
29 June–10 July 2020 ♦ *Organisers* – Abhishek Dhar and Sanjib Sabhapandit

Gravitational Wave Astrophysics
18–22 May 2020 ♦ *Organisers* – Parameswaran Ajith, K. G. Arun, Sukanta Bose, Bala R. Iyer, Resmi Lekshmi and B. Sathyaprakash

Fourth Bangalore School on Population Genetics and **Evolution**
27 January– 7 February 2020 ♦ *Organisers* – Deepa Agashe and Kavita Jain

Workshop on Additive Combinatorics
24 February–6 March 2020 ♦ *Organisers* – S. D. Adhikari and D. S. Ramana

Topics in Birational Geometry
27–31 January 2020 ♦ *Organisers* – Indranil Biswas and Mahan Mj

DISCUSSION MEETINGS

Celebrating the Science of Giorgio Parisi ♦ 15-17 December 2021

The 2021 Nobel Prize in Physics was awarded to Giorgio Parisi of Sapienza University of Rome 'for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales.' Gorgio Parisi continues to make pioneering contributions in several areas of statistical mechanics, quantum field theory, disordered and complex systems. During this discussion meeting, experts helped understand the scale of Parisi's work in all these areas as well as placed them in the context of the outstanding questions of today. Giorgio Parisi also delivered the ICTS Distinguished Lecture.

Topological Aspects of Strong Correlations and Gauge Theories ♦ 6-10 September 2021

The topological properties of quantum field theories are responsible for several exotic phenomena occurring over many length scales, from nano-materials to the early universe. The techniques used by the condensed matter and the high energy communities to address such problems are, at least superficially, quite different. In this me eting the two groups came together to understand the techniques currently in use and to develop a common ground. The aim of this meeting was to introduce graduate students and postdoctoral fellows to open problems and challenges.

List of Discussion Meetings

Celebrating the Science of Giorgio Parisi
15–17 December 2021 ♦ *Organisers* – Chandan Dasgupta, Abhishek Dhar, Smarajit Karmakar and Samriddhi Sankar Ray

Hunting SUSY @ HL–LHC
22–26 November 2021 ♦ *Organisers* – Satyaki Bhattacharya, Rohini Godbole, Kajari Majumdar, Prolay Mal, Seema Sharma, Ritesh K. Singh and Sanjay Kumar Swain

Workshop on Inverse Problems and **Related Topics**
25–29 October 2021 ♦ *Organisers* – Rakesh and Venkateswaran P Krishnan

Topological Aspects of Strong Correlations and **Gauge Theories**
6–10 September 2021 ♦ *Organisers* – Rob Pisarski, Sumathi Rao, Soeren Schlichting and Sayantan Sharma

Hydrodynamics and Fluctuations – Microscopic Approaches in Condensed Matter Systems
6–10 September 2021 ♦ *Organisers* – Abhishek Dhar, Keiji Saito and Tomohiro Sasamoto

Multi–scale Analysis – **Thematic Lectures** and **Meeting (MATHLEC–2021)**
15–19 February 2021 ♦ *Organisers* – Patrizia Donato, Antonio Gaudiello, Editha Jose, A.K. Nandakumaran, Daniel Onofrei

Thirsting for Theoretical Biology
11–22 January 2021 ♦ *Organisers* – Vaishnavi Ananthanarayanan, Vijaykumar Krishnamurthy, Vidyanand Nanjundiah

Extreme Nonequilibrium QCD
5–9 October 2020 ♦ *Organisers* – Ayan Mukhopadhyay and Sayantan Sharma

Zero Mean Curvature
7–15 July 2020 ♦ *Organisers* – CS Aravinda and Rukmini Dey

7th Indian Statistical Physics Community Meeting
19–21 February 2020 ♦ *Organisers* – Ranjini Bandyopadhyay, Abhishek Dhar, Kavita Jain, Rahul Pandit, Sanjib Sabhapandit, Samriddhi Sankar Ray and Prerna Sharma

Moduli of Bundles and Related Structures
10–14 February 2020 ♦ *Organisers* – Rukmini Dey and Pranav Pandit

Geometric Phases in Optics and Topological Matter
21–24 January 2020 ♦ *Organisers* – Subhro Bhattacharjee, Joseph Samuel and Supurna Sinha ♦

Fluids Day
20 January 2020 ♦ *Organisers* – Rama Govindarajan, Samriddhi Sankar Ray and Gaurav Tomar

Foundational Aspects of Blockchain Technology
15–17 January 2020 ♦ *Organisers* – Pandu Rangan Chandrasekaran

Statistical Physics of Machine Learning
6–10 January 2020 ♦ *Organisers* – Chandan Dasgupta, Abhishek Dhar and Satya Majumdar

DISTINGUISHED LECTURES

Putting Order into Disorder – An Application to the Chronology of my Works
Speaker – Giorgio Parisi *(Sapienza University, Rome, Italy)* ♦ 16 December 2021

A Scientific Summary of the 2021 Nobel Prize in Physics
Speaker – John Wettlaufer *(Yale University, USA & Nordic Institute for Theoretical Physics, Sweden)* ♦ 2 November 2021

Statistical Mechanical Ensembles and Typical Behavior of Macroscopic Systems
Speaker – Joel Lebowitz *(Rutgers University, New Brunswick, USA)* ♦ 13 July 2021

TMC DISTINGUISHED LECTURES

Applying Physics to Mathematics
Speaker – Tadashi Tokieda *(Stanford University, USA)* ♦ VIDEO RELEASE – 7 July 2021; INTERACTIVE SESSION – 20 July 2021

On the MLC Conjecture
Speaker – Mikhail Lyubich *(Stony Brook University)* ♦ VIDEO RELEASE – 4 June 2021; INTERACTIVE SESSION – 23 June 2021

FOUNDATION DAY LECTURES

The Future of Our Universe
Speaker – Ashoke Sen *(ICTS-TIFR, Bengaluru)* ♦ 27 December 2021

Generalized Hydrodynamics
Speaker – Herbert Spohn *(Emeritus of Excellence, Technical University of Munich, Germany)* ♦ 26 December 2020

INFOSYS-ICTS TURING LECTURE SERIES

Artificial Intelligence – Success, Limits, Myths and Threats
Speaker – Marc Mézard *(Director of Ecole Normale Supérieure - PSL University)* ♦ 6 January 2020

INFOSYS-ICTS RAMANUJAN LECTURE SERIES

Exploring Moduli
Speaker – Carlos Simpson *(Université Nice-Sophia Antipolis, France)* ♦ 10-14 February 2020

INFOSYS-ICTS STRING THEORY LECTURES

Modular Theory and QFT
Speaker – Nima Lashkari *(Purdue University)* ♦ 3-5 February 2020

OUT REACH
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The COVID-19 pandemic forced cancellations of many outreach programs. However, ICTS was able to promptly adopt the online platform and organise several lectures and other activities.

PUBLIC LECTURES

The **Public Lecture Series** and **Einstein Lectures** were all held online. The online version of the monthly talk **Kaapi with Kuriosity** was renamed **Kuriosity during Kuarantine**. A new lecture-symposium series **Technology & Cosmic Frontier** from the Office of the Principal Scientific Advisor, Government of India and ICTS was also organised. The first lecture in this series was delivered by Rana Adhikari and Nobel Laureate Kip Thorne on August 19, 2021.

A new outreach lecture series named **Vigyan Adda** was introduced. Through this new forum scientists from ICTS and other similar institutes and universities can explain their work to broader audiences, or engage with the public on scientific and mathematical topics of interest. The target audience for this series is undergraduate and graduate students of science, and members of the public with a basic background in science.

A new lecture series, named after the 14th century mathematician and astronomer Madhava, was established. The **Madhava Lectures** are delivered by eminent scholars of history of mathematics, science and technology.

An interesting talk **A Scientific Summary of the 2021 Nobel Prize in Physics**, by John Wettlaufer was organised on November 2, 2021. Wettlaufer is part of the Nobel Prize Committee for the Physical Sciences. In December 2021, a virtual discussion meeting, **Celebrating the Science of Giorgio Parisi,** was organised, which also featured an **ICTS Distinguished Lecture** by 2021 Nobel Laureate in Physics, Giorgio Parisi.

On the occasion of International Women in Mathematics Day, a talk and an interactive session by mathematicians Radhika Ganapthy *(IISc)* and Purvi Gupta *(IISc),* **Two Mathematicians, Their Work & Career Experiences** was conducted on May 15, 2021.

COSMIC-ZOOM

A major outreach initiative named **CosmicZoom** was launched in April 2021 (https://cosmic-zoom.in/). This virtual exhibition was aimed at taking visitors for a trip through the Cosmos – both through the smallest and largest scales in the Universe. The exhibition was designed to engage with a wide range of visitors – starting from school children to university students. This three-week long exhibition featured virtual tours and 17 events, hosting several vibrant scientists sharing the excitement of their science with the audience in interactive and engaging sessions. These included lectures, interactive sessions with labs and observatories, workshops for children, and conversations with researchers. The exhibits covered a wide range of topics, including astronomy, particle physics, quantum phenomena, cell biology, forests, search for extraterrestrial life, toys, climate, insects, marine life and ecology.

MATHS CIRCLE INDIA

ICTS is leading a pan-TIFR effort to seed Maths Circles for talented middle school students across the country. To establish proof of concept, ICTS has conducted four online Maths Circle India sessions since October 29, 2021. Three of the interactive sessions were conducted by Pranav Pandit, Divya Jaganathan, Abhishodh Prakash and Srikanth Pai. One was conducted by Ashutosh Roy Choudhury, Biswajit Nag, Niladri Patra, Arkamouli Debnath, Roktim Mascharak and Amitava Bhattacharya. The **Maths Circle India** is a new initiative launched with a view towards identifying mathematically inclined students at an early stage, honing their aptitude and mathematical skills, and exposing them to the joy of doing mathematics. The Maths Circle involves a group of carefully selected students, who meet online once in two weeks on weekends for a few hours to discuss carefully chosen mathematical explorations. The explorations and course material are curated by active researchers in Mathematics and the sessions are led by PhD students and postdoctoral researchers with an aptitude for communication and pedagogy. The long term goal of this initiative is to foster the creation of a network of Maths Circles across India, and to create and curate resources for these communities of mathematics students and teachers.

The main logo and icons for various subject sections in the onlince science exhibition COSMICZOOM

SCIENCE OUTREACH IN SCHOOLS

As part of our Science Outreach in Schools, ICTS has selected 21 government schools in the vicinity of Hesaraghatta (where ICTS is located) to distribute library and experiment kits. ICTS has received a formal consent from the Block Education Officer, North Bengaluru for this initiative. On November 13, 2021, ICTS conducted a day-long, hands-on, in person teacher training session for science teachers from these 21 schools and introduced them to the kits. The distribution of the kits was completed in November 2021. The aim is to follow up with more teacher training sessions and feedback from students.

COVIDGYAN

Members of the ICTS Outreach committee were also deeply invested in the **CovidGyan** initiative, making contributions to content writing, translation, and infographics. CovidGyan is a multi-institutional effort and has a partnership of various institutions of Tata Institute of Fundamental Research, Mumbai and centres affiliated to National Centre for Biological Sciences, TIFR Hyderabad, Homi Bhabha Centre for Science Education, International Centre for Theoretical sciences, along with Indian Institute of Science, Tata Memorial Centre, Vigyan Prasar and IndiaBioscience. It is an initiative of community engagement and serves as a hub to bring together a collection of resources in response to the COVID-19 outbreak. The CovidGyan website is available in 12 Indian languages. The CovidGyan team consists of scientists, students, science communicators, designers and illustrators and professionals from various institutes volunteering their time towards presenting the public with a variety of resources, including articles, podcasts, infographics, conversations with experts etc. A few examples of the resources available on the CovidGyan website are:

- *Daily Gyan*
  Infographics to create awareness about Covid-19 and the ways of preventing catching the infection are shared each day.
- *Daily Vigyan*: City scale epidemic simulator to observe the pattern of spread of Covid -19 in select Indian cities, developed by Indian Institute of Science's Centre for Networked Intelligence, Robert Bosch Centre for CPS in collaboration with the School of Technology and Computer Science TIFR.
- A nineteen-part graphic novel by Arvind Ramanathan and Sonia Sen, titled *'Bharath and Fatima learn about Covid -19'*.
- Wellness sessions addressing some of the mental health and lifestyle issues that might be experienced by people during lockdown and long durations of social isolation.
- Sci-fi story writing competition and a poster designing competition for students of the Atomic Energy Education Society's school and college network in Mumbai region https://covid-gyan.in/community . The theme of this competition revolved around life during the COVID-19 pandemic. The entries are now being reviewed.

ONLINE MOVIE SCREENINGS

The film **Secrets of the Surface: The Mathematical Vision of Maryam Mirzakhani** was screened on May 16, 2020. This was part of the international celebration of Women in Mathematics Day, held on May 12, also Maryam Mirzakhani's birthday. Filmed in Canada, Iran and the United States, the film examines the life and mathematical work of Maryam Mirzakhani.

The film **Cyclotron** by Jahnavi Phalkey was screened on September 27, 2020. The film screening was accompanied by a panel discussion between Jahnavi and Shiraz Minwalla *(TIFR, Mumbai)*. Cyclotron is a film about the world's oldest functional particle accelerator and the people who keep it running today.

Some of the inforgraphics created for public awareness, as part of the Covid-GYAN initiative

List of Kuriosity During Kuarantine Lectures

To Paint the Lily, Mathematically
Speaker: L. Mahadevan *(De Valpine Professor of Applied Mathematics, Professor of Organismic and Evolutionary Biology, Professor of Physics, Harvard University)* ♦ 12 December 2021

Autism and "Astro"logy: New Insights From Recordings in Human Brain Cells
Speaker: Sumantra Chattarji *(Senior Professor, NCBS-TIFR, Bengaluru & Visiting Professor, Simons Initiative for the Developing Brain, University of Edinburgh, UK)* ♦ 7 November 2021

Science of the Indian Kitchen
Speaker: Krish Ashok *(Author of 'Masala Lab')* ♦ 17 October 2021

The Art and Science of Secret Messages: Some Glimpses
Speaker: Geetha Venkataraman *(Dr. B. R. Ambedkar University Delhi, Delhi)* ♦ 19 September 2021

Quantum Matters
Speaker: Arindam Ghosh *(Indian Institute of Science, Bengaluru)* ♦ 29 August 2021

Metallurgical Heritage of India
Speaker: Sharada Srinivasan *(National Institute of Advanced Studies, Bengaluru)* ♦ 25 July 2021

Can We Learn From Insect Societies?
Speaker: Raghavendra Gadagkar *(Indian Institute of Science, Bengaluru)* ♦ 20 June 2021

The Neutrino Story: From Impossible Dreams to Unreachable Stars
Speaker: Srubabati Goswami *(Physical Research Laboratory, Ahmedabad)* ♦ 23 May 2021

Scientific Approaches to Understanding the Past
Speaker: Parth R. Chauhan *(Indian Institute of Science Education and Research, Mohali)* ♦ 25 April 2021

What's in a Diet?
Speaker: Anura Kurpad *(St John's Medical College, Bengaluru)* ♦ 28 March 2021

Why is Climate Change a Wicked Problem?
Speaker: Raghu Murtugudde *(University of Maryland and Indian Institute of Technology, Bombay)* ♦ 21 February 2021

Symmetries of Nature and Nature of Symmetries
Speaker: Rohini M. Godbole *(Indian Institute of Science, Bengaluru)* ♦ 24 January 2021

Kolam: A Western Perspective
Speakers: Claudia Silva *(Photographer & Videographer)* and Oscar Garcia-Prada *(Institute of Mathematical Sciences, Madrid)* ♦ 13 December 2020

Can forests in India influence rainfall?
Speaker: Jagadish Krishnaswamy *(Ashoka Trust for Research in Ecology and the Environment, Bengaluru)* ♦ 22 November 2020

Cosmic Whisper from Binary Black Holes
Speaker: Archana Pai *(Indian Institute of Technology, Bombay)* ♦ 18 October 2020

Agents of Change: The Role of Catalysts in the Modern World
Speaker: Shobhana Narasimhan *(Jawaharlal Nehru Centre for Advanced Scientific Research, Bengaluru)* ♦ 26 September 2020

A Life of Resonance with Quantum Matter: P.W. Anderson (1923-2020)
Speaker: Ganapathy Baskaran *(Professor Emeritus, The Institute of Mathematical Sciences, Chennai, Distinguished Professor, Indian Institute of Technology, Chennai, and Distinguished Visiting Research Chair, Perimeter Institute for Theoretical Physics, Waterloo, Ontario, Canada)* ♦ 23 August 2020

Soft and Squishy Materials and How to Think About Them
Speaker: Gautam Menon *(Ashoka University and IMSc)* ♦ 19 July 2020

Automating Mathematics?
Speaker: Siddhartha Gadgil *(Indian Institute of Science, Bengaluru)* ♦ 17 May 2020

List of Vigyan Adda Talks

The Finite Part of Infinity
Speaker: Joseph Samuel *(RRI & ICTS-TIFR, Bengaluru)* ♦ 24 October 2021

Steven Weinberg: The Physicist and his Physics
Speaker: Rohini M. Godbole *(Indian Institute of Science, Bengaluru)* ♦ 2 September 2021

Heading Towards Turbulence
Speaker: Rama Govindarajan *(ICTS-TIFR, Bengaluru)* ♦ 15 July 2021

Phases of (Quantum) Matter
Speaker: Subhro Bhattacharjee *(ICTS-TIFR, Bengaluru)* ♦ 15 June 2021

Hundred Years of Gravitational Lensing
Speaker: Parameswaran Ajith *(ICTS-TIFR, Bengaluru)* ♦ 28 February 2021

Black Holes and the Reversibility of Time
Speaker: Suvrat Raju *(ICTS-TIFR, Bengaluru)* ♦ 22 December 2020

List of Einstein Lectures

Physics of Life
Speaker: Vijaykumar Krishnamurthy *(ICTS-TIFR, Bengaluru)* ♦ 21 November 2020

Order and Patterns in Randomness
Speaker: Abhishek Dhar *(ICTS-TIFR, Bengaluru)* ♦ 28 February 2020

List of DD Kosambi Lectures

Emperor Ashoka – History, Memory, Memorialization
Speaker: Nayanjot Lahiri (*Professor of History at Ashoka University)* ♦ 16 January 2020

List of Public Lectures

Technology & Cosmic Frontiers
Speakers: Kip S. Thorne *(2017 Nobel Laureate and Richard P. Feynman Professor of Theoretical Physics (Emeritus), Caltech, USA)* and Rana Adhikari *(Caltech, USA)* ♦ 19 August 2021

List of Madhava Lectures

The Man who Invented Calculus: The Life and Work of Madhava
Speaker: P. P. Divakaran *(Formerly professor of physics at TIFR, Mumbai)* ♦ 14 February 2020

GRADUATE PROGRAMS AND TRAINING

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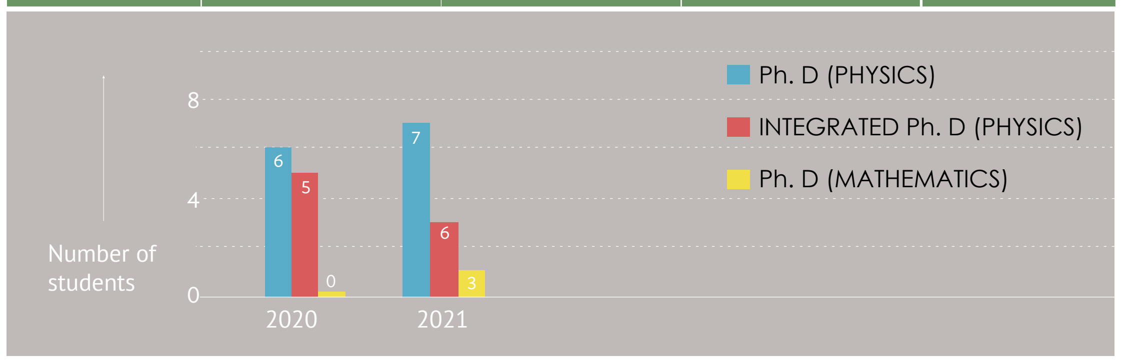
GRADUATE PROGRAMS

The graduate program at ICTS provides intense training to young graduate students for years of research. During 2020-2021, 27 students joined the ICTS graduate program – 13 in physics, 11 in integrated physics and 3 in the mathematics program.

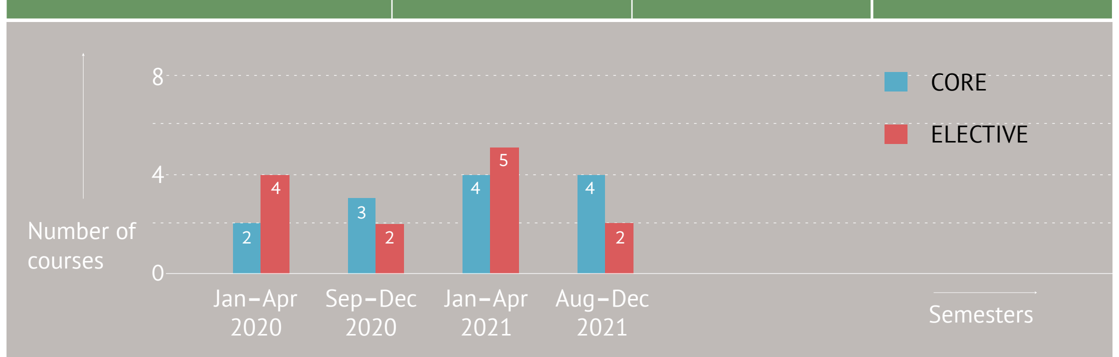
NUMBER OF STUDENTS JOINED PER YEAR

YEAR	PHYSICS		MATHS	TOTAL
	Ph.D. (Physics)	Integrated Ph.D. (Physics)	Ph.D. (Mathematics)	
2020	6	5	0	11
2021	7	6	**3**	16
TOTAL	13	11	3	27



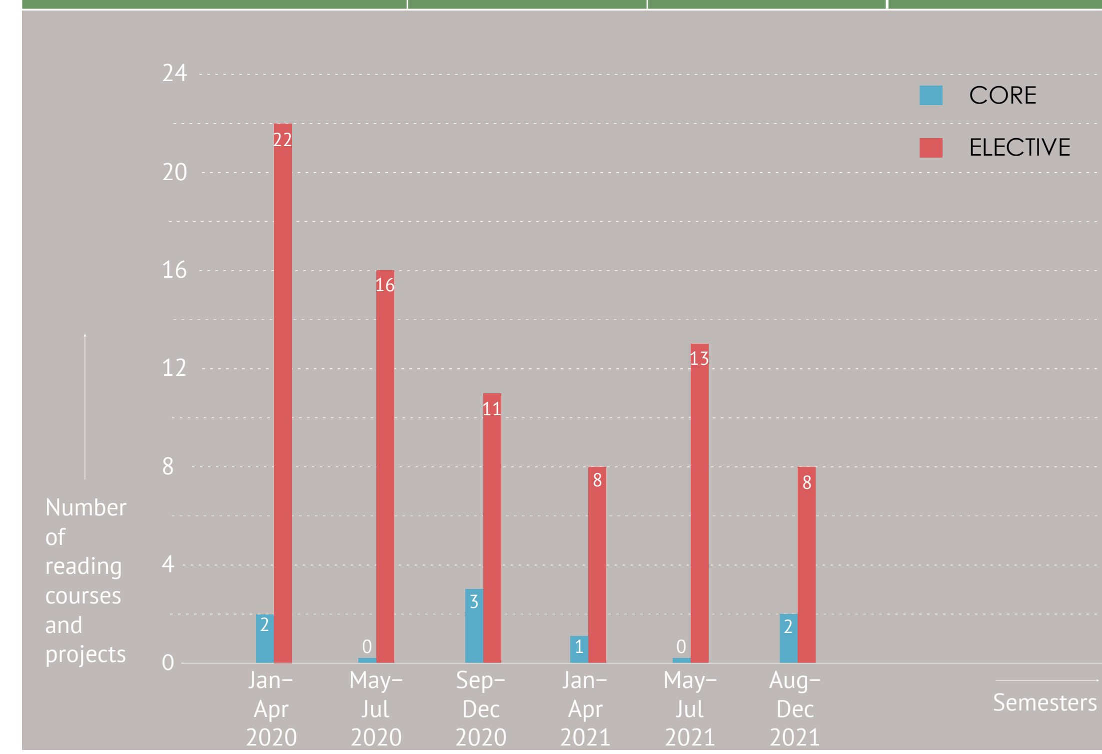
CORE AND ELECTIVE COURSE

SEMESTER	CORE	ELECTIVE	TOTAL
Jan – Apr 2020	2	4	6
Sep – Dec 2020	3	2	5
Jan – Apr 2021	4	5	9
Aug – Dec 2021	4	2	6
TOTAL	13	13	26



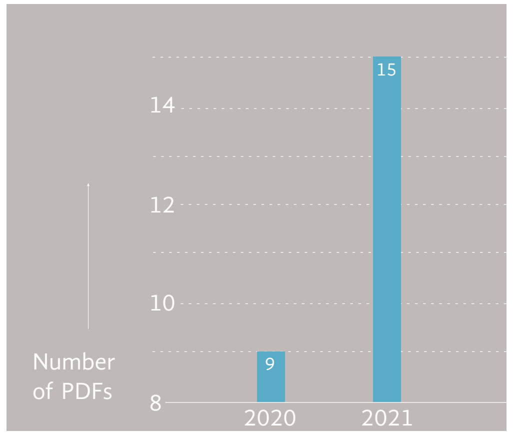
READING AND PROJECT COURSE

SEMESTER	READING	PROJECTS	TOTAL
Jan – Apr 2020	2	22	24
May – Jul 2020	0	16	16
Sep – Dec 2020	3	11	14
Jan – Apr 2021	1	8	9
May – Jul 2021	0	13	13
Aug – Dec 2021	2	8	10
TOTAL	8	78	86



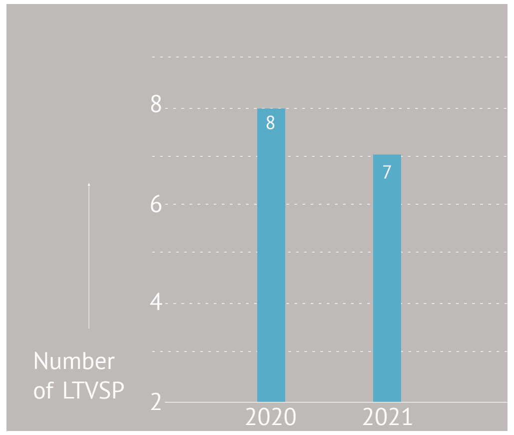
POST DOCTORAL FELLOWS

YEAR	PDFs
2020	9
2021	15
TOTAL	24



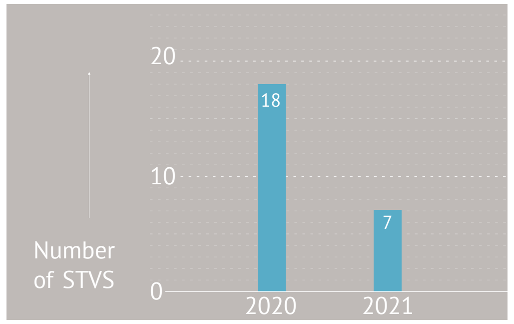
LONG TERM VISITING PROGRAM (LTVSP)

YEAR	LTVSP
2020	8
2021	7
TOTAL	15



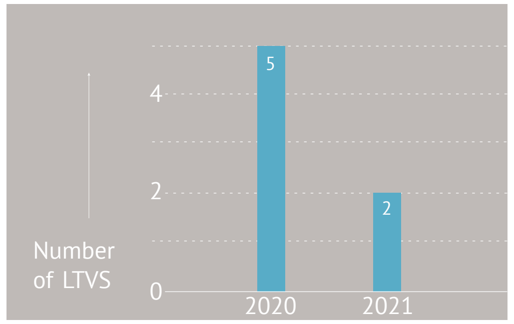
SHORT TERM VISITING STUDENTS (STVS)

YEAR	STVS
2020	18
2021	7
TOTAL	25



LONG TERM VISITING STUDENTS (LTVS)

YEAR	LTVS
2020	5
2021	2
TOTAL	7



STAFF @ICTS

STAFF

The administrative, scientific and technical support at ICTS is excellent and proactive. They provide assistance to faculty, postdoctoral fellows and students and well as visitors, in organizing programs, lectures and seminars. They contribute to maintaining the best possible environment for research.

ADMINISTRATION

Jenny Burtan
Project Assistant *(Establishment)*

Abhijit De
Administrative Officer

Raghu DS
Project Assistant *(Purchase & Stores)*

Roshini George
Project Administrative Coordinator

Rajesh Gopakumar
Centre Director *(ICTS-TIFR)*

Kavyashree H. A.
Admin Assistant *(Temporary)*

Rama Iyer
Consultant

Veena Iyer
Project Scientific Administration Coordinator

Johana Jerusha
Admin Assistant *(Faculty Secretariat, Temporary)*

Ramya M.
Project Accounts Assistant

Jeeva M.
Faculty Secretariat

Aruna Mahendarkar
Administrative Coordinator *(Programs and Activities)*

Anupama Murali
Admin Assistant *(Programs and Activities, Temporary)*

Gayatri N.
Administrative Assistant *(Programs and Activities)*

Manjunath P
Administrative Assistant B *(Accounts and Finance)*

Ashwini P.
Accounts Assistant *(Temporary)*

Basavaraj S. Patil
Project Assistant *(Front Desk)*

Pavana R.
Admin Assistant *(Academic Office, Temporary)*

Yashas R.
Purchase & Stores Assistant *(Temporary)*

Divya R.
Admin Assistant *(Programs and Activities, Temporary)*

Suresh R.
Project Manager *(Services and Health Promotion Centre)*

Sunitha Ravikumar
Project Assistant *(Accounts)*

Gouthami S.
Admin Assistant *(Academic Office, Temporary)*

Chetan Savanth
Purchase & Stores Assistant *(Temporary)*

Nithya Seshadri
Accounts Assistant *(Temporary)*

Renu Singh
Project Scientific Officer and Executive Assistant to Centre Director

Madhulika Singh
Administrative Officer C *(Accounts and Finance)*

Rajalakshmi Swaminathan
Administrative Assistant *(Purchase)*

Mahindra V.
Project Manager *(Facilities and Services)*

Shalini V.
Project Assistant *(Academic Office)*

SCIENTIFIC AND TECHNICAL ADMINISTRATION

Ikbal Ahmed
Scientific Assistant B *(Labs)*

Berty Ashley
Consultant

Arun B.
Scientific Assistant *(AV, Temporary)*

Harshith B. S.
Project Scientific Assistant

Ananya Dasgupta
Consultant

Hemanta Kumar G.
Project Scientific Officer 'C' *(HPC)*

Mohan G.
Engineer *(Civil)*

Anupam Ghosh
Project Coordinator *(Outreach)*

Ipsita Herlekar
Science Communication Coordinator

Mohammad Irshad
Scientific Assistant *(IT/AV)*

Anuradha G. Kotabagi
Project Librarian

Samhitha Kottamasu
Consultant *(Exhibition Designer)*

Chandan Kumar
Project Engineer *(Electrical)*

Naveen Kumar L. C.
Scientific Assistant *(AV)*

Rifat Naaz
Scientific Officer C

Gobinath M.
Project Assistant *(IT)*

Deanish M. A.
Scientific Officer C *(Web, Temporary)*

Kusuma Manjunath
Technical Trainee *(IT/Web, Temporary)*

Deepak R.
Project Assistant *(IT)*

Srinivasa R.
Scientific Officer - In-charge *(IT)*

Muhammad Rayees
Scientific Assistant *(Labs, Temporary)*

Parul Sehgal
Scientific Officer *(Resource Development and Societal Engagement Wing)*

Shantaraj S. K.
Scientific Assistant *(AV)*

Deepali Shewale
Project Scientific Officer *(Academic Office)*

Prashanth Kumar V.
Scientific Assistant *(IT, Temporary)*

Juny K. Wilfred
Consultant

AWARDS AND RECOGNITIONS

Ajith Parameswaran

- Awarded the inaugural TWAS-CAS Young Scientist Award for Frontier Science in the Physical Sciences by The World Academy of Sciences (TWAS). This award recognizes outstanding young scientists from developing countries. Ajith received the honour *'for his pioneering contributions to the development of phenomenological models of gravitational-wave signals from coalescing binary black holes.'*

Amit Apte

- Awarded one of the exclusive VAJRA grants from the SERB of the Department of Science and Technology. The grant enables international collaborators over a period of three years. He will be holding this grant jointly with Amarjit Budhiraja of the University of North Carolina.

Anirban Basak

- Received the Feinberg Graduate School Postdoc Prize from the Weizmann Institute, Israel, for his postdoctoral research on Random Matrices.
- Received an honourable mention in the Bernoulli Society New Researcher Award, of the Bernoulli Society for Mathematical Statistics and Probability, in recognition of his outstanding work in the fields of Mathematical Statistics and Probability.
- Awarded the INSA Medal for Young Scientists (Mathematics), 2021. The prestigious medal is awarded by the Indian National Science Academy (INSA) to young scientists in recognition of notable contributions to any branch of science and technology.

Riddhipratim Basu

- Awarded the INSA Medal for Young Scientists (Mathematics) for 2020. Basu works on different aspects of probability theory including stochastic growth models, interacting particle systems, random matrices and random graphs and large deviations.
- Awarded the 2021 NASI Platinum Jubilee Young Scientist Award for his contributions to probability theory. Riddhipratim's interests are specifically in first and last passage percolation, interacting particle systems and models of self-organised criticality.

Subhro Bhattacharjee

- Received the prestigious Swarnajayanti Fellowship of the Department of Science and Technology, Govt. of India, in the physical sciences category. The Swarnajayanti Fellowship is awarded to a selected number of promising and exceptional young scientists to enable them to pursue basic research in frontier areas of science and technology.
- Publication with former ICTS postdoctoral fellow Adhip Agarwala (in collaboration with Johannes Knolle and Roderich Moessner) titled *Gapless State of Interacting Majorana Fermions in a Strain-induced Landau Level* was selected as 'Editors' Suggestion' in Physical Review B. Editors' Suggestions are prominently displayed on the journal website and are chosen for their clarity as well as important and interesting work.
- Received a VAJRA grant of SERB as co-PI with Tanusri Saha-Dasgupta of SN Bose National Centre for Basic Sciences, Kolkata. Their proposed work is titled *'Tuning Quantum Materials with Strain.'* This grant will host Arun Paramekanti of the University of Toronto as the overseas VAJRA Faculty.

- Received the Quantum Materials grant under the NanoMission special project and includes researchers from IISc, IACS, TIFR-Mumbai and other research institutions in the country, Department of Science and Technology

Abhishek Dhar

- Elected Fellow of the Indian National Science Academy (INSA). Dhar works in the area of statistical physics and his current research interests include anomalous heat transport in low-dimensional systems, understanding the connection between microscopic dynamics and hydrodynamics, developing formalisms for open quantum systems, the time of arrival problem in quantum mechanics and active matter physics

Rama Govindarajan

- Elected Fellow of the Indian National Science Academy (INSA). Rama has contributed over many different aspects of fluid mechanics, including instabilities in viscosity-stratified flows and the ubiquitous multiphase flows involving the dynamics of bubbles, drops and particles in fluid.

- Selected for the prestigious Kirk Distinguished Fellowship of the Isaac Newton Institute, Cambridge. She will be participating in their semester long program on the *"Mathematical Aspects of Turbulence"* in 2022. The Kirk Distinguished Fellowship is given to field leaders from under-represented groups within higher mathematical research with the hope to 'address the historical gender imbalance that persists within science.'

Vijay Kumar Krishnamurthy

- Part of a global cohort of interdisciplinary researchers who have been awarded a prestigious Templeton Foundation Grant to investigate new conceptual frameworks for understanding *'Agency, Directionality and Function' in living systems*. Vijay and ICTS senior associate, Vidyanand Nanjundiah, are part of the project *'Cellular Agency in Multicellular Development and Cancer'* led by Stuart Newman of New York Medical College.

Manas Kulkarni

- Selected for a Rutgers Global International Collaborative Research Grant, with collaborator Jedediah Pixley. The aim of the grant is to develop a formal pipeline between Rutgers University and institutions around the world for collaborative research that makes a significant contribution to advancing a particular field of study. Kulkarni and Pixley aim to address open problems in quantum many-body physics in general and many-body systems localized far away from equilibrium in particular.

- Received the SERB MATRICS Grant. SERB MATRICS Grants are given by the Department of Science and Technology, Government of India, for research in theoretical sciences for a period of three years. The SERB MATRICS grant will support Kulkarni's new project titled *'Dynamics and spatio-temporal spread of perturbations in integrable models',* which will investigate the nonlinear dynamics, spatial spread and temporal growth (or decay) of perturbations in integrable models and the effect of breaking integrability.

- Received one of the exclusive VAJRA grants, as co-PI with Abhishek Dhar, given by the Science and Engineering Research Board (SERB) of the Department of Science and Technology, Govt. of India. The proposed work is titled, *'Hydrodynamic Behaviour of Low-Dimensional Systems.'* Herbert Spohn of Technische Universitat Munchen, Germany, will be the overseas VAJRA faculty.

- Publication, in collaboration with J.H. Pixley (Rutgers University), titled *'Universal Spectral Form Factor for Many-Body Localization,'* was selected as Editors' Suggestion in the journal Physical Review Research (Letter).

- Selected as Bengaluru's Young Achiever in Science by a leading Kannada newspaper *Prajawani*.

Anupam Kundu

- Publication, with ICTS graduate student Prashant Singh, titled *Local Time for Run and Tumble Particle* was highlighted as the Editors' Suggestion in journal Physical Review E.

- Publication, in collaboration with ICTS post-doctoral fellow Amit Kumar Chatterjee and Manas Kulkarni, titled *'Spatiotemporal spread of perturbations in a driven dissipative Duffing chain: An out-of-time-ordered correlator approach'*, in the journal Physical Review E, was highlighted as the 'Editors' Suggestion'

Samriddhi Sankar Ray

- Awarded the new prestigious SERB-Science and Technology Award for Research (SERB-STAR). The SERB-STAR is instituted by SERB to recognize and reward outstanding performance of Principal Investigators of SERB Projects. The award is given to young researchers for stellar performances in frontier areas of science and engineering.

- Elected member of the National Academy of Sciences, India (NASI). Ray works at the interface of non-equilibrium statistical physics and fluid dynamics. In particular, his research interests lie in fundamental and applied problems of turbulence and turbulent transport.

- Received the SERB MATRICS Grant. This grant will support his new project titled *'Understanding the Origins of Intermittency in Turbulent Flows,'* which will look at examining the role of triadic interactions in the observed non-Gaussian statistics of small-scale structures in turbulent flows.

- Publication, with ICTS postdoctoral fellow Siddhartha Mukherjee and PhD student Rahul K. Singh (in collaboration with Mart, titled *Anomalous Diffusion and Levy Walks Distinguish Active from Inertial Turbulence* was highlighted as Editors' Suggestion in Physical Review Letters. The work was also featured in the APS Physics Magazine.

Vishal Vasan

- Selected an associate of the Indian Academy of Sciences. Vasan's work is in the field of partial differential equations and their applications. His work balances theoretical and applied aspects of these equations employing a mix of analysis, numerical methods and asymptotics. He has worked on problems arising in water-waves, oceanography, and Bose-Einstein condensates and more recently, he is interested in mathematical tropical meteorology. Vasan's primary mathematical interests are the analysis of partial differential equations, stability theory and inverse problems.

- Received the SERB MATRICS Grant. This grant will support his new project titled *'Spectra of Differential Operators and the Unified Transform Method.'*

Rahul Chajwa *(Former ICTS graduate student)*

- Received the TAA-Geeta Udgaonkar Award (2021) for the best thesis in physical sciences within TIFR. Rahul's thesis, titled *'Driven Stokesian Suspensions: Particle Anisotropy, Effective Inertia and Transient Growth'* is based on experimental and theoretical work under the supervision of Rama Govindarajan (ICTS), Naraynan Menon (University of Massachusetts, Amherst) and Sriram Ramaswamy (IISc).

Bikram Pain *(First year I-PhD student)*

- Awarded the gold medal by the Indian Association of Physics Teachers (IAPT) for his stellar performance in the National Graduate Physics Examination (NGPE-21).

Archak Purkayastha *(Former ICTS graduate student)*

- Awarded the prestigious Marie Skłodowska-Curie Actions Individual Fellowship for his research proposal towards developing *a thermodynamically consistent microscopic theory which allows numerically exact description of noisy out-of-equilibrium mesoscopic quantum devices*.

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(Top to bottom) Various cultural programmes organised and performed by the ICTS family

All photographs – SHANTARAJ S.

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