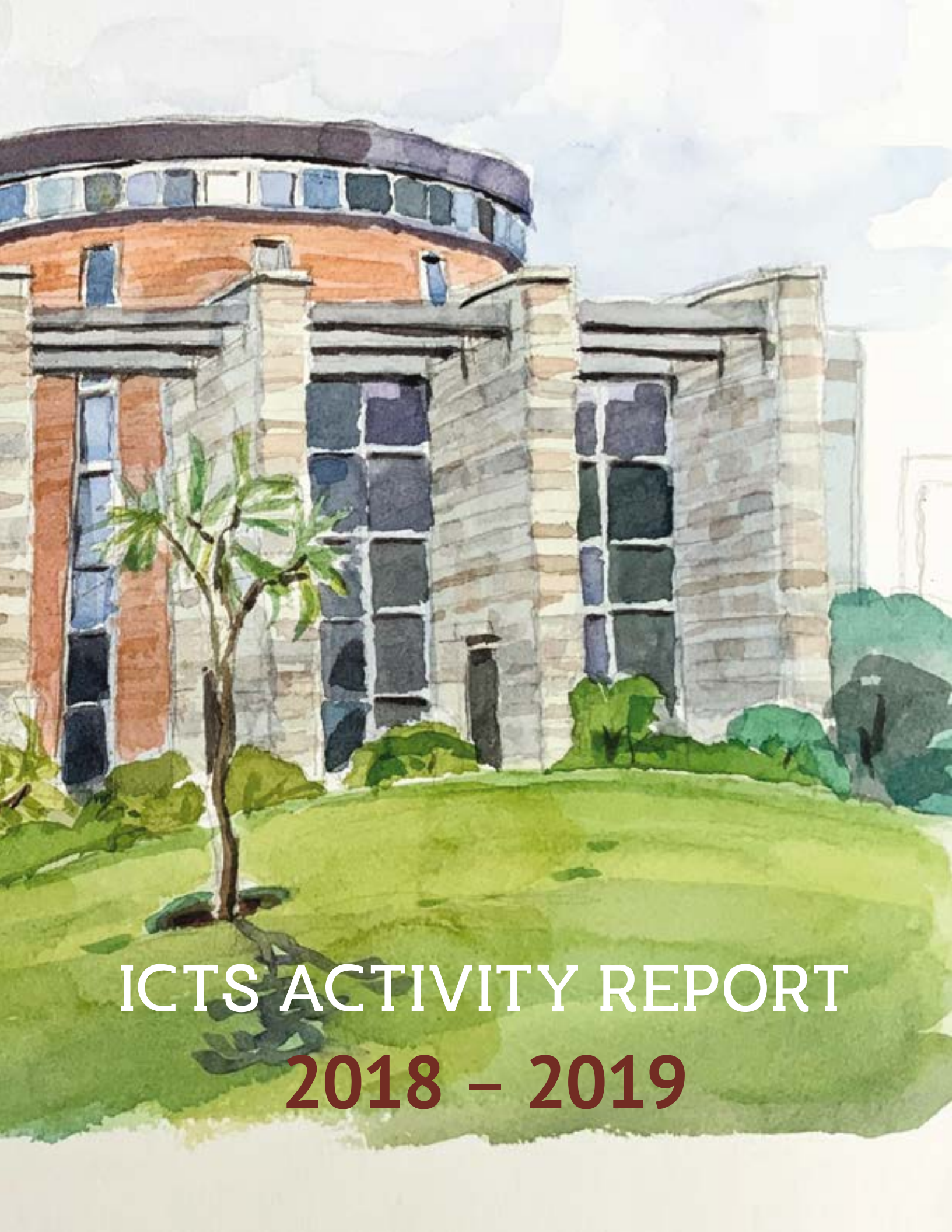


ICTS ACTIVITY REPORT

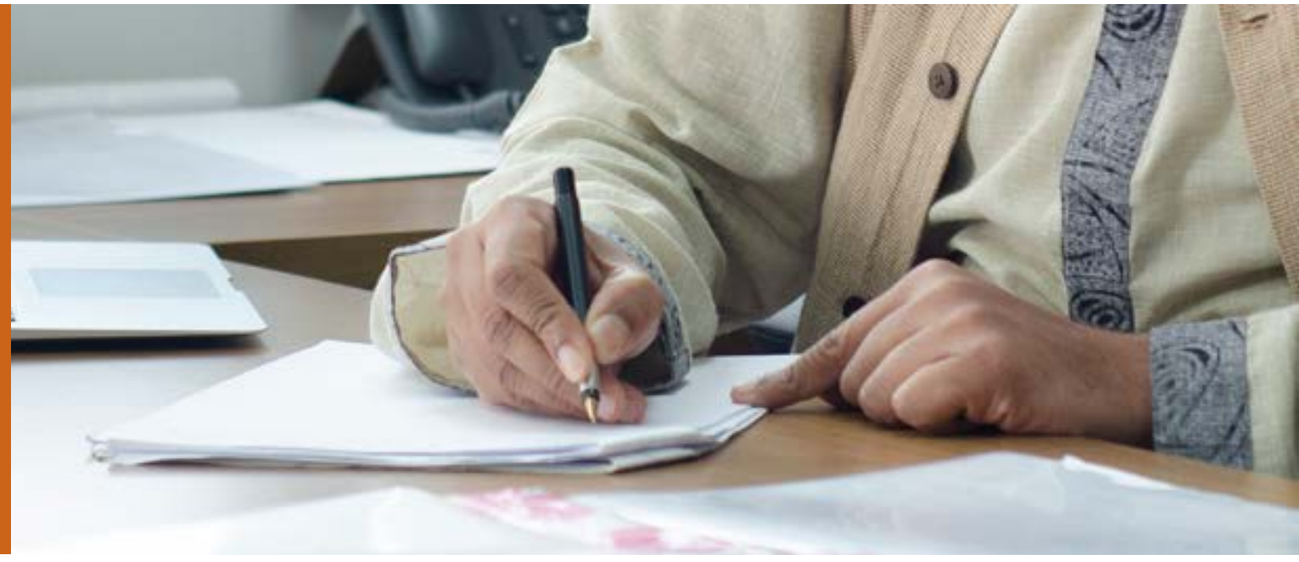
2018 – 2019

CONTENTS

Cover illustration
Water colour on paper by KENGO HIRACHI *(The University of Tokyo)*, speaker at the ICTS program *Cauchy-Riemann Equations in Higher Dimensions*. Visit www.ms.u-tokyo.ac.jp/~hirachi/ to see more of his work.

Editorial team – Ananya Dasgupta, Renu Singh
Design – Juny K. Wilfred

DIRECTOR'S REPORT



"That taste and style have so much to do with one's contribution in physics may sound strange at first, since physics is supposed to deal objectively with the physical universe. But the physical universe has structure, and one's perceptions of this structure, one's partiality to some of its characteristics and aversion to others, are precisely the elements that make up one's taste. Thus it is not surprising that taste and style are so important in scientific research, as they are in literature, art and music"

Chen Ning Yang

Yang brilliantly expresses his insights into the role of "taste and style" in scientific discovery, in unlocking the hidden patterns in nature. These are characteristics that define a personality, which as the word itself indicates, we usually associate with a person. Nevertheless, I like to believe that institutions, too, manifest personalities and can be associated with signature tastes, styles and themes. In fact, the very presence of diverse individuals in an institution affords the scope for this personality to be multilayered and multifaceted in ways that any one individual can rarely be.

ICTS is now in its teens and even as it grows in size, it is also rapidly developing its own multifaceted personality. Ensuring that intellectual growth happens without sacrificing a broad underlying unity of vision, is a key challenge for us. It has therefore been rewarding to see that the multiple research themes that have emerged in the last few years are not fragmented tunes but are instead building to a polyphony that harmonises.

Nothing illustrates this better than the growth of mathematical areas at ICTS in the last three years. ICTS has strived to go beyond the traditional binaries of 'pure' and 'applied' which needlessly force the richness of mathematical thought into judgemental silos. At the same time, we wanted to create a home for emerging themes that are likely to be central to mathematics and the theoretical sciences in coming years.

We have therefore been very fortunate to recruit top notch faculty in probability theory, geometry & mathematical physics as well as in the dynamics of complex systems. They have brought to ICTS not only their strong core disciplinary expertise - it is also combined with a vigorous intellectual engagement with other areas such as statistical physics and complex systems, fluid dynamics, string theory and computer science. Many of the latter are topics already represented and thriving at ICTS and the resulting mix has been a very fruitful one.

The ICTS Indian Monsoon Initiative is a novel product of such an engagement. It brings together multiple physics, engineering, meteorological and mathematical expertise at ICTS as well as partner institutions like TIFR-CAM and the Indian Institute of Tropical Meteorology, Pune. It combines a sophisticated data driven mathematical modelling approach (Markov Random Fields) on large scales with underlying fluid dynamical cloud simulations on smaller scales. I expect to see powerful new insights come out of this initiative to tackle a highly complex dynamical system which is at the same time an issue of critical importance to India.

In coming years, areas we plan to focus on include, quantitative and computational biology, computer science, quantum condensed matter physics as well as other branches in mathematical sciences, while also nurturing existing groups at ICTS. Living up to its slogan of "Science without Boundaries," ICTS is weaving a tapestry with its brilliant faculty as the multicoloured strands which gives the whole a unique personality. After all, isn't it a bit like what we have in India itself? - A unique collective genius emerging from diverse streams of language, faith and culture.

JUNYK, WILFRED

The ICTS scientific personality is woven not only by its faculty, its bright students and postdocs but also by the invigorating stream of visitors and faculty associates we host from around the globe. Our program activities have also hugely multiplied in numbers as you will see in this report. We now have a biannual call for program proposals which are evaluated by a program committee of top experts from across the country reflecting ICTS as a resource for the entire scientific community. Program slots at ICTS have become extremely sought after and despite stretching our facilities and staff to the limit, we are able to accept just about half of the excellent proposals we receive. It only underscores the unmet need that was there for an ICTS!

In the ICTS tapestry I must highlight the invisible threads which keep everything together and give it a warm human texture - our incomparably dedicated administrative and technical support staff. If our programs are successful and our visitors keep coming back again and again to ICTS it is because our staff go far beyond the call of duty to make everything function in a seemingly effortless manner. Few people see behind the scenes, the multiple challenges that have to be overcome day after day.

We have had unstinted backing from the members of our management board and our international advisory board, for the growth of ICTS. Multiple individuals across the globe responded generously to our inaugural ICTS endowment drive. Without this and the continuing support of the Infosys Foundation as well as the Simons Foundation, ICTS would not have had the wherewithal to aim for the stars. A warm thank you to all of you!

I hope this report will give you a snapshot of ICTS' early teens personality. More importantly, through your engagement and support, we seek to shape a unique taste and style at ICTS which can peer deeper into the mysteries of the universe.

Rajesh Gopakumar
Bengaluru (Bangalore), October 2020

P. S. - *Even as this report was being compiled, the covid-19 pandemic was upon the entire planet and delayed the finalisation. ICTS has successfully moved much of its academic and outreach activities online. Like with so many other challenges, "Hum honge kaamyab - we shall overcome."*

JUNY K. WILFRED

ICTS AT TEN
and
INTERNATIONAL REVIEW

ICTS at Ten

In January 2018, ICTS celebrated its 10th year with a scientific gathering. *ICTS at Ten* was an opportunity for us to reflect on our journey thus far, plant the seeds for new initiatives and to pursue our dreams with renewed enthusiasm. We heard broad perspective talks from a galaxy of distinguished researchers on subjects ranging from Quantum Gravity, Astrophysics, Statistical Physics and Physical Biology to Theoretical Computer Science and Mathematics. There was an associated public lecture by Robbert Dijkgraaf, followed by a panel discussion, on the theme of the *'Usefulness of Useless Knowledge'*. The 2017 Nobel Prize winner in Physics, Kip Thorne, delivered the first VISHVESHWARA LECTURE SERIES and Hirosi Ooguri gave a public lecture where he explained the science behind the film, *'The Man from the 9 Dimensions'*, which takes us from the microscopic world of elementary particles to the macroscopic world of the universe, and to its beginning – the Big Bang.

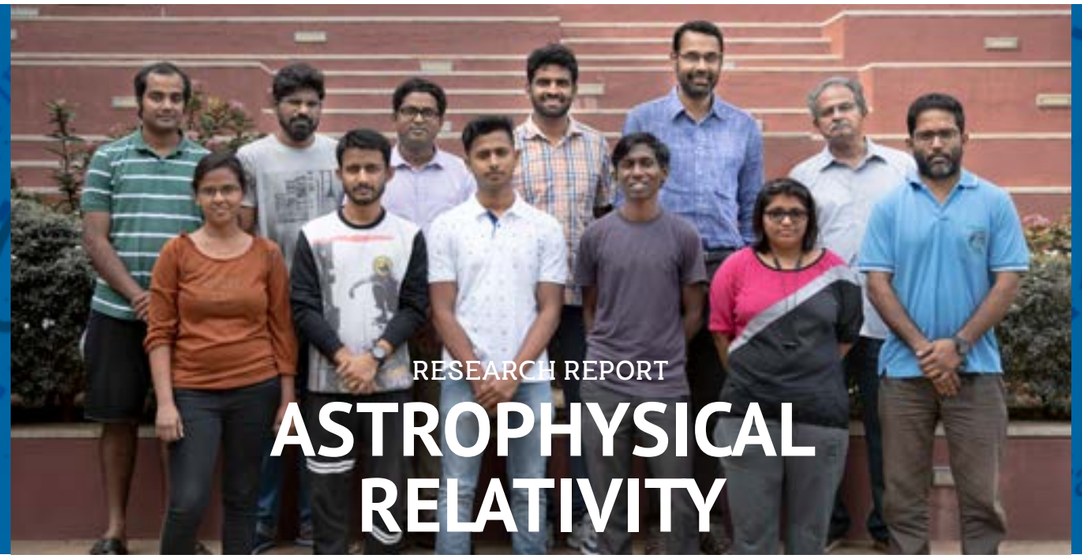
International Review

During January 11-13, 2018, ICTS was reviewed by an international committee for the first time. It was a comprehensive review of all aspects of the Centre – research, programs, graduate program, outreach, administration and infrastructure. The review committee was chaired by Curtis Callan *(Princeton University)*. The other members were Beverly K. Berger (LIGO, Caltech), Bertrand I. Halperin *(Harvard University)*, Itamar Procaccia *(Weizmann Institute)*, Kavita Ramanan *(Brown University)* and Ashoke Sen *(HRI)*. The international committee of experts convened for a three-day meeting, after which they presented their observations and recommendations.

The full report can be read at https://www.icts.res.in/sites/default/files/ICTS-Review-Report-2018.pdf.

Members of the international review committee. *(L → R)* BEVERLY K. BERGER *(LIGO, Caltech)*, CURTIS CALLAN *(Princeton University)*, BERTRAND I. HALPERIN *(Harvard University)*, ITAMAR PROCACCIA *(Weizmann Institute)*, KAVITA RAMANAN *(Brown University)*, ASHOKE SEN *(HRI)*.

RESEARCH @ICTS



RESEARCH REPORT

ASTROPHYSICAL RELATIVITY

FACULTY

Parameswaran Ajith ◈ Bala Iyer *(Simons Visiting Professor)*

POSTDOCTORAL FELLOWS

Apratim Ganguly ◈ Md Arif Shaikh ◈ Shasvath J. Kapadia ◈ Kanhaiya Lal Pandey ◈ Gayathri Raman ◈ Rahul Kashyap ◈ Haris M. K. ◈ Sumit Kumar

STUDENTS

Ajit Kumar Mehta ◈ Abhirup Ghosh ◈ Soummyadip Basak ◈ Aditya Vijaykumar ◈ Srashti Goyal ◈ Parita Mehta

RESEARCH REPORT

Parameswaran AJITH

The recent discovery of gravitational waves (GWs) has opened up a fundamentally new observational window onto the Universe. **Parameswaran Ajith's** research spans several aspects of GW physics and astronomy, such as modeling of GWs from binary black holes by combining analytical and numerical relativity, and probes of strong gravity and astrophysics using GW observations.

The detection of GWs from binary black holes and the extraction of source parameters are performed by comparing the data with theoretical templates of the expected signal waveforms. Ajith pioneered one of the two existing approaches (the phenomenological method) for constructing waveform templates describing the full inspiral, merger, and ringdown of binary black holes by combining analytical calculations in GR with large-scale numerical-relativity simulations. Waveforms constructed using this method are widely used in LIGO-Virgo data analysis. Now that GW observations are becoming precision probes of gravity and astrophysics, it is important to characterize the systematic effects in our GR-based waveform models. In collaboration with former student V. Varma, Ajith characterized the systematic errors due to neglecting the higher-order modes of the gravitational radiation from binary black holes. The group, led by grad student A. K. Mehta, also constructed accurate waveform templates that model the effect of higher-order modes.

The availability of waveform templates describing different modes of the radiation allowed them to formulate a test of the "no-hair" nature of binary black holes (i.e., to see if a binary black hole system in quasi-circular orbits is completely described by the masses and spin angular momenta of the black holes) based on the consistency between different spherical harmonic modes (work involving S. Dhanpal, A. Ghosh, T. Islam, A. K. Mehta, and B. S. Sathyaprakash). This is analogous to the tests of the "no-hair" theorems for isolated black holes based on the consistency of their quasi-normal modes. Such a test can distinguish, in principle, a binary system comprising exotic compact objects from binary black holes. The group also developed another method for constraining the parameter space of exotic compact objects from constraints on their tidal deformation (work led by postdocs N. K. Johnson-McDaniel, A. Mukherjee and R. Kashyap).

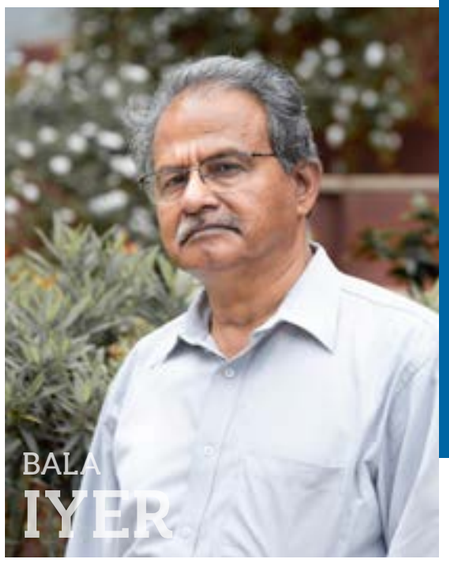
Another exciting new area of Ajith's research is the gravitational lensing of GWs. Ajith and collaborators developed a method for identifying strongly lensed binary black hole merger events in the LIGO-Virgo data and performed the first search for lensing signatures (work led by grad student A. Mehta and postdoc K. Haris). Although no lensing signatures have been detected so far, the first detection is expected in the next few years. Their ongoing work suggests that observation of a

strongly lensed binary black hole merger would enable the identification of the host galaxy of the merger, and allow interesting new tests of GR through the accurate extraction of GW polarizations.

In another work, led by postdocs R. Kashyap and G. Raman, they asked whether the recently found optical transients kilonovae can be standardized, analogous to the standardization of Tye 1a supernovae (so as to use them as standard candles for distance measurements). This was motivated by the several parallels that exist between these two types of optical transients. While a satisfactory answer to this question can only be provided by future kilonova observations, employing theoretical models they explored whether there is any ground for harboring such expectations. They found that theoretical light curves of kilonovae show remarkable correlations despite the complex underlying physics. This presents a possibility of future observations to allow observers to standardize these light curves and to use them for local distance measurements.

RESEARCH REPORT

Bala IYER



Gravitational-Wave Amplitudes for Compact Binaries in Eccentric Orbits at the Third Post-Newtonian Order

Bala Iyer in collaboration with Y. Boetzel, C. K. Mishra, G. Faye and A. Gopakumar, computed the tail contributions to the gravitational-wave mode amplitudes for compact binaries in eccentric orbits at the third post-Newtonian order of general relativity. They are combined with the previously available instantaneous contributions and the post-adiabatic corrections computed in the present work to fully account for the effects of radiation-reaction forces on the motion. The resulting waveform in the small eccentricity limit is compared to the quasi-circular one and shown to be in perfect agreement.

Gravitational-Wave Amplitudes for Compact Binaries in Eccentric Orbits at the Third Post-Newtonian Level

The non-linear memory contributions to the gravitational wave amplitudes for compact binaries in eccentric orbits at the third post-Newtonian level was computed by Iyer with M. Ebersold, Boetzel, Faye, Mishra and P. Jetzer. Combining these results with the previously computed instantaneous and recently computed tail contributions we get the complete 3PN accurate waveform in terms of the standard post-Newtonian parameter and the time eccentricity in the quasi-keplerian representation.

FACULTY

Amit Apte ◈ Anirban Basak ◈ Riddhipratim Basu ◈ Rukmini Dey ◈ Pranav Pandit ◈ Vishal Vasan

POSTDOCTORAL FELLOWS

Shibi Vasudevan ◈ Saibal Ganguli ◈ Mohamd Saleem Lone ◈ Sumanto Chanda ◈ Arideep Saha ◈ Adway Mitra ◈ Sajini Anand P. S. ◈ Nachiketa Mishra ◈ Manoj Kumar ◈ Anish Mallick ◈ Varun Dilip Thakre ◈ Amit Chandra Vutha

STUDENTS

Anugu Sumith Reddy ◈ Mukesh Singh Raghav ◈ Kohinoor Ghosh ◈ Manisha Goyal ◈ Pinak Mandal ◈ Shashank Kumar Roy ◈ Srikanth B Pai

RESEARCH REPORT

Amit APTE

The two main themes of the research of the dynamical systems group, led by Amit Apte, were data assimilation and monsoon modelling.

The study of a new Markov random field model for Indian summer monsoon rainfall lead to identification of dominant rainfall patterns and improved description of active-break phases of monsoon. The group continues to explore various other statistical approaches to understanding patterns in other climatic variables such as cloud cover and winds.

In joint work with Mythily Ramaswamy and Didier Auroux, the group considered a multidimensional model of a compressible fluid in a bounded domain. They wanted to estimate the density and velocity of the fluid, based on the observations for only velocity. They built an observer exploiting the symmetries of the fluid dynamics laws. The main result is that for the linearized system with full observations of the velocity field, one can find an observer which converges to the true state of the system at any desired convergence rate for finitely many but arbitrarily large number of Fourier modes.

The group also focused on implementation of the hybrid ensemble Kalman particle filter for high dimensional quasi geostrophic model with Lagrangian data. The group also worked on using indistinguishable states to develop gradient descent algorithms for data assimilation in chaotic models such as the Lorenz equations and the Ikeda map. The work on the role played by the unstable Lyapunov vectors and exponents in controlling the asymptotic properties of the posterior filtering distribution.

The studies of the connections between nonlinear filtering theory and data assimilation problems were undertaken in collaboration with Anugu Sumith Reddy, Sreekar Vadlamani. The problem that they studied was the asymptotic proximality of the incorrectly initialised linear filter and correctly initialised linear filter (known as filter stability). The main contribution of the current work is deriving the stability of linear filter with zero system noise under the assumption of observability.

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RESEARCH REPORT

Anirban BASAK

Anirban Basak's research focuses on understanding various aspects of the spectra of sparse non-Hermitian matrices, such as their invertibility, condition number, and the sensitivity of spectral properties under small perturbations.

Analogous Problem for Sparse Random Matrices

The study of the smallest singular value and the condition number of large matrices was initiated in the 1940s when von Neumann and his collaborators used random matrices to test their algorithm for the inversion of large matrices. They predicted that the condition number of a random matrix should be of the same order as its dimension. For general random matrices, this prediction remained open for a very long time. It was proved only recently by Mark Rudelson and Vershynin about fifteen years ago. Basak, with his collaborator Rudelson, has investigated the analogous problem for sparse random matrices, and in particular sparse matrices with independent and identically distributed 0/1 entries. In a series of works, they establish a sharp transition of invertibility at the threshold n/n, where n is the dimension of the matrix under consideration. They also identify the primary reason for invertibility to be the existence of a zero row and column. The results on the smallest singular value are further strengthened to study the limit of empirical spectral measure of sparse non-Hermitian random matrices.

Non-Hermitian Toeplitz Matrices

In the second sequence of work, in collaboration with Elliot Paquette and Ofer Zeitouni, Basak considers non-Hermitian Toeplitz matrices. These are non-normal matrices and their spectra are often susceptible to small perturbations. To capture the instability of the spectrum one often studies the pseudospectrum, the worst-case behavior of the spectrum under perturbation. From a probabilistic point of view, it is more natural to study the spectrum under a 'typical' perturbation. In the literature, the latter goes by the name of 'regularizing' the non-normal matrix by adding some noise. Basak, with his collaborators, has studied the spectrum of non-normal finitely banded Toeplitz operators under an additive random perturbation. They show that the limit is universal, i.e. it does not depend on the law of the noise matrix, and it is the push forward of the uniform measure on the unit circle by the symbol of the infinite Toeplitz operator. His works further find the law of the outlier eigenvalues which turns out to be the zero set of some non-universal random analytic function.

RESEARCH REPORT

Riddhipratim BASU

During 2017-2019, the major focus of Riddhipratim Basu's research has been models of first and last passage percolation. Last passage percolation (LPP) on Z2, where one puts independent and identically distributed random weights on the vertices and studies the weight of the maximum weight path (called last passage time) between two far away vertices, is believed to be a canonical model in the KPZ universality class. A few of these models are exactly solvable (including the special case of exponential LPP) whereas other models like LPP with general weights or FPP are harder to study in absence of exact solvability. Basu's research in this period encompassed both exactly solvable models and beyond.

Exactly Solvable Models in KPZ Universality Class

Basu and co-authors have developed new geometric approaches in studying exponential LPP that has led to the resolution of several problems hitherto inaccessible via exact formulae. In two recent joint works (with Sarkar and Sly and with Ganguly, respectively), they proved optimal tails estimates for coalescence of semi-infinite geodesics and obtained exponents governing correlation decay in time direction, answering two open questions. In another work with Hoffman and Sly, Basu established the non-existence of bi-infinite geodesics in exponential LPP. Using the exact relationship between last passage time in exponential LPP to largest eigenvalues in certain Wishart matrices, Basu also investigated, in a joint work with Ganguly, the upper tail large deviation event (i.e., the passage time between two far away points being macroscopically larger than typical) and showed that the transversal fluctuation exponent changes from the characteristic 2/3 of KPZ class to 1/2. Moving beyond the exponential LPP, Basu also studied, in a joint work with Ganguly and Hammond, the fractal properties of the universal scaling limit, the so-called Airy sheet, started from a related model of Brownian LPP.

FPP and LPP Beyond Exactly Solvable Models

For LPP on Z2 with general weights, the question of understanding the behaviour of the path in the lower tail large deviation, i.e., when the optimal path is conditioned to have atypically small weight, was open for almost twenty years. In a joint work with Ganguly and Sly, Basu answered this question by showing that in the lower tail large deviation, the optimal path is delocalized with high probability, that is, it does not stay macroscopically close to any deterministic curve. In another joint work with Ganguly and Sly, Basu considered first passage percolation on Z2 where one studies the random metric obtained by putting independent and identically distributed non-negative weights on the edges, and study upper tail large deviation where the first passage time between two points at distance n, is macroscopically larger than typical. Under boundedness of edge weights, it was known that the probability of this event decays as exp(−Θ (n2)). However the question of the

existence of the rate function had remained open. Basu, Ganguly and Sly showed that under some mild regularity assumption, the rate function for upper tail large deviation indeed exists. Going beyond the Euclidean setting, in a joint work with Mahan Mj, Basu established some basic properties of first passage percolation on Cayley graphs of hyperbolic groups, and answered an open question regarding the growth of variance.

RESEARCH REPORT

Rukmini DEY

Rukmini Dey, in collaboration with Pradip Kumar and Rahul Kumar Singh, showed the existence of a maximal surface containing a given curve and a singularity.

With Rishabh Sarma and Singh, Dey obtained relations between certain Dirichlet series which result from a Euler-Ramanujan identity and Weirstrass-Enneper representation of a Scherk's minimal surface. They also obtained a functional equation for this Dirichlet series. With Kumar and Singh, Dey obtained the result that when two real analytic curves are 'close enough' there is a minimal surface interpolating them (translated, in general). Though the result is known, their notion of closeness and the proof is new. This is work in progress.

RESEARCH REPORT

Pranav PANDIT

Pranav Pandit's research lies at the intersection of symplectic geometry, (derived) algebraic geometry, higher category theory, and mathematical physics.

Categorical Kähler Geometry

The goal of this project is to formulate and study analogues of Kähler metrics in derived noncommutative geometry, and to prove an analogue of the celebrated Donaldson-Uhlenbeck-Yau theorem in this context. This is an attempt to mathematically formalize ideas appearing in string theory. Possible areas of application of our methods include stability structures on Fukaya categories, the geometry of various moduli spaces, mirror symmetry, extremal metrics on Kähler manifolds, and the theory of infinite-dimensional geometric flows in general. During 2019, Pranav Pandit and his collaborators continued to refine the ideas in order to apply them to the problem of proving a categorical Donaldson-Uhlenbeck-Yau theorem. The main result says, roughly speaking, that

if a k-linear category is equipped with a stability condition, then the generic fiber of a deformation of this category over the ring of integers in a non-archimedean field with residue field k inherits a natural stability condition.

Stability Structures on Perverse Schobers

The goal of this project is to construct stability structures on Fukaya categories using local-to-global methods. The main conjecture that Pandit and collaborators are trying to prove asserts that one can construct a stability structure on the Fukaya category with coefficients in perverse sheaf of categories (perverse Schober), starting from the data of a relative stability structure on the stalks of the sheaf. They have succeeded in giving a precise definition of the Fukaya category of a surface with coefficients in a perverse Schober. Pandit and his collaborators have also been able to demonstrate the main conjecture of the second project above in one example. This represents a major step forward in this project, and is the content of an evolving preprint.

Spectral Networks, Buildings, Stability Structures and non-Abelian Hodge Theory

The key idea of this project is to use the Gromov-Schoen theory of harmonic maps to buildings to develop an approach to higher Thurston-Teichmüller theory and WKB analysis, and to use this to study stability in certain Fukaya categories, and the asymptotics of the nonabelian Hodge correspondence. This work done by Pandit along with Fabian Haiden, Ludmil Katzarkov & Carlos Simpson is closely related to the theory of cluster varieties, and to Gaiotto-Moore-Neitzke's theory of spectral networks in high energy physics. During the period of the report, they have indicated a new approach to constructing hyperKähler metrics. This research avenue was explored, and some preliminary progress was made in this direction. This is work in progress.

RESEARCH REPORT

Vishal VASAN

Spatio-Temporal Pattern Identification in Monsoon Dynamics

In joint work with Rama Govindarajan, Amit Apte, Sreekar Vadlamani and Adway Mitra, Vishal Vasan proposed a model for monsoon precipitation dataset that identified 10 canonical patterns of rainfall over the Indian landmass. These ten patterns were sufficient to explain rainfall on more than 90% of the day. Moreover, they identified periods of active and break spells which characterise the Indian summer monsoon rainfall. Subsequently, with Arjun Sharma, they extended the analysis to model jointly cloud cover data and rainfall data. Their main conclusions were that eight daily spatial patterns each in rain and OLR, and seven joint patterns

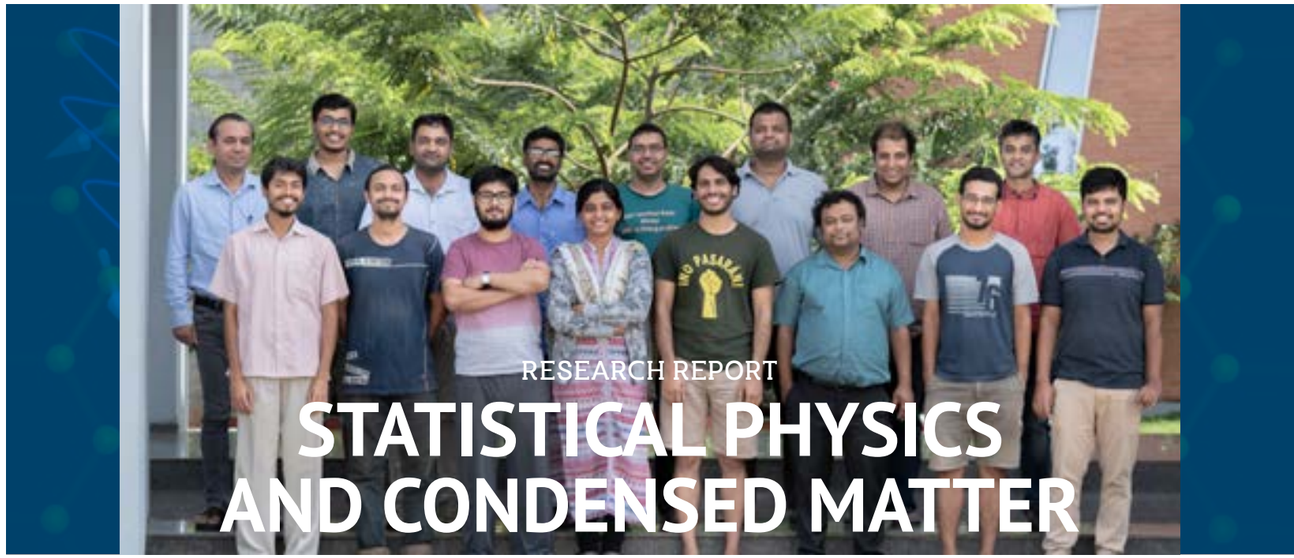
of rainfall and OLR, can describe over 90% of all days, and each pattern occurs on several days every season. The highest cloud cover days correlate well with highest rainfall days but with interesting departures. Based on cloud and rain behaviour the landmass may be classified into four regions.

KdV reduction in multi-component and driven-dissipative systems arising in BEC, nonlinear optics, exciton-polariton, etc.

In joint work with Manas Kulkarni and Swetlana Swarup, Vasan introduced a formalism to systematically derive effective theory equations describing the behaviour of multi-component Nonlinear Schrodinger equations. They rigorously analysed the system of equations describing necessary conditions (in terms of experimental parameters) to produce coherent stable pulses propagating. This formalism was then adapted to driven-dissipative systems governing exciton-polariton interactions (joint work with Urbashi Satpathi and Manas Kulkarni) yielding equally satisfactory results.

Applications and extensions of the unified transform method

The unified transform method was extended to be applicable to systems of linear PDEs. This is the first work to emphasize the role played by the discrete symmetries. Previous works had not understood their relevance and employed case-by-case analysis. The work showed the general nature of the arguments previously used (joint with B. Deconinck, E. Shlizerman and Q. Guo). With Rama Govindarajan and S.G. Ganga Prasath, Vasan successfully employed UTM techniques to produce an efficient numerical scheme to solve the famous Maxey-Riley equations for inertial particles in a fluid. This is the first work to make the Basset history term computationally tractable. Our work is also the first to produce analytical results for several important fluid cases. Last, they also established the counter-intuitive nature of the history term which is not just a pure drag, but may also accelerate the particle. In joint work with T. Trogdon and D. Smith, Vasan successfully employed the UTM formalism for a problem with moving interfaces as a model for understanding dispersive shocks. Their analysis indicates many of the qualitative features of dispersive shocks can be reproduced by a simple linear piecewise-constant differential equation explicitly showing the need for long-times to confirm nonlinear effects.



RESEARCH REPORT

STATISTICAL PHYSICS AND CONDENSED MATTER

FACULTY

Subhro Bhattacharjee ◈ Chandan Dasgupta *(Simons Visiting Professor)* ◈ Abhishek Dhar ◈ Manas Kulkarni ◈ Anupam Kundu

POSTDOCTORAL FELLOWS

Adhip Agarwala ◈ Abhishodh Prakash ◈ Urbashi Satpathi ◈ Amit Kumar Chatterjee ◈ Aabhaas Vineet Mallik ◈ Subhadip Chakraborti ◈ Arghya Das ◈ Amit Dey ◈ Pawan Nanda Kishore ◈ Priyanka ◈ Sambuddha Sanyal ◈ Saurish Chakrabarty

STUDENTS

Aritra Kundu ◈ Archak Purkayastha ◈ Animesh Nanda ◈ Avijit Das ◈ Varun Dubey ◈ Arnab Seth ◈ Monica Bapna ◈ Prashant Singh ◈ Basudeb Mondal ◈ Junaid Majeed Bhat ◈ Santhosh Ganapa

RESEARCH REPORT

Subhro BHATTACHARJEE

Subhro Bhattacharjee and collaborators explored concrete realisations of quantum spin liquids (QSL) and metals including non-fermi liquids (NFL) in strongly correlated electronic systems. They also characterised many-body chaos in strongly correlated classical many-body systems.

QSLs in Rare Earth Pyrochlores and Honeycomb Magnets

They explored possible QSLs in rare earth pyrochlores and honeycomb magnets. They focussed on two important issues regarding symmetry fractionalisation in QSLs and their possible quantum phase transition to magnetically ordered phases. In regards to the first issue, they showed concrete realisation of symmetry broken and symmetry protected topological phases can coexist with long range quantum entangled QSL in rare earth pyrochlores where we studied a uniform $U_{(1)}$ QSL with fermionic partons for rare-earth pyrochlores and tested its feasibility for candidate materials like $Yb_2Ti_2O_7$. The fractionalised ordered phase allows for a possible understanding of the diffuse neutron scattering candidate materials. In a related study developed a theoretical framework to study a Z_2 QSL on honeycomb lattice and its application to the candidate material α-$RuCl_3$. In regards to the quantum phase transition out of a QSL, they now understand a concrete realisation of it in context of experimentally relevant honeycomb magnets and show that the conventional Landau theory fails to describe such a phase transition. Currently, experimental detection of QSLs using spin-lattice coupling and other unconventional probes are being pursued. They have been actively collaborating with experimental groups in India and outside to explore the physics of disorder driven and lattice assisted QSLs.

Physics of NFLs

In regards to the physics of NFLs, Bhattacharjee and his collaborators realised one dimensional NFLs — the so called Tomonaga-Luttinger liquids (TLL) in microscopic models of intermediate algebra — where interactions allow continuous tuning of fermions to bosons. Their calculations reveal a rich phase diagram including a novel transition between two TLLs captured through their entanglement properties and not local order parameters. These phases and phase transitions can be experimentally relevant to fermionic cold atoms. Very recently, they explored the physics of strongly correlated kagome metals which have attracted much recent interest. Their calculations show that atomistically thin layers of a particular member of this family - Fe_3Sn_2 - can stabilise a novel topological Chern metal and/or topological superconductor and thus providing a new material platform of novel quantum matter. In a related development, at the crossroads of QSL and NFL, they

found a purely interaction driven gapless phase without well-defined quasi-particle excitations - akin to a NFL - in a honeycomb spin system under lattice-strain.

Spatio-Temporal Measures of Chaos

Bhattacharjee and his collaborators also showed quantitative connections between many-body spatio-temporal chaos and dynamics of strongly correlated classical many-body systems like spin systems and thermalised fluids — natural many-body chaotic systems. They quantified two complementary aspects of butterfly effect: the rapid temporal growth of the perturbation, and its simultaneous ballistic spread, as characterised by the Lyapunov exponents and the butterfly speed, respectively and show that the latter exist even in systems without ballistic modes. Further, they showed explicit connections between the above measures of spatio-temporal chaos and thermodynamic quantities such as temperature and transport coefficients such as diffusion in the correlated paramagnetic regime. Their findings raise fundamental questions regarding the semi-classical limit of the spin systems in context of the recent quantum bonds of chaos - a topic of our current research. Finally, they showed that their above quantification of chaos is rather general and applicable to a system of thermalised fluid.

RESEARCH REPORT

Chandan **DASGUPTA**

The origin of the rapid dynamical slowdown in glass forming liquids is a much debated issue. Chandan Dasgupta and his collaborators have carried out several investigations that address different aspects of this question. Growth of medium range crystalline order (MRCO) has been observed in various model systems to be associated with glassy behaviour. Such observations raise the question of whether molecular mechanisms for the glass transition in liquids with and without MRCO are the same. They have performed extensive molecular dynamics simulations of a number of glass forming liquids in two dimensions and shown that the static and dynamic properties of glasses with MRCO are different from those of other glass forming liquids with no predominant local order. In another study, they have developed a microscopic mean-field theory of the dynamics near the glass transition in terms of the pair structure of the liquid and shown that this theory can predict the correct dynamical transition temperature and the difference in dynamics of two systems that have very similar pair correlations.

Aging effects on the thermal conductivity of a model glass-forming system in the liquid and glass states have been studied using extensive numerical simulations. Dasgupta and his collaborators have shown that near the glass transition

temperature, the measured thermal conductivity decreases with increasing age. The thermal conductivity of the disordered solid obtained at low temperatures is found to depend on the cooling rate with which it was prepared, with lower cooling rates leading to lower thermal conductivity. Their analysis links this decrease of the thermal conductivity with increased exploration of lower-energy inherent structures of the underlying potential energy landscape.

Dasgupta has also studied the effects of 'activity' or 'self-propulsion' on the glass transition. Active matter consisting of self-propelled particles exhibits many interesting properties at high densities if the Pèclet number is large. The behaviour is particularly interesting in the limit of large persistence time, which we call 'extreme' active matter. For infinite persistence time, the liquid jams on lowering the active force below a critical threshold. As the active force is decreased with the persistence time fixed at a large value, the system goes through a phase characterised by intermittency before dynamical arrest at a low value of the active force.

To consider a different way of representing activity, Dasgupta and his collaborators have studied a three dimensional system of particles in which 'scalar' activity is introduced by increasing the temperature of half of particles (labeled 'hot') while keeping the temperature of the other half constant at a lower value (labeled 'cold'). The ratio of the temperatures of the two subsystems is considered to be a measure of the activity. From their simulations, they observe that the cold particles tend to phase separate at sufficiently high activity and they form a solid that exhibits a mixture of two close packed structures. The phase diagram of this system in the density-activity plane is determined.

They have carried out several studies of equilibrium and dynamic properties of strongly confined liquids. The structure and dynamics of a single component, monatomic Lennard-Jones fluid confined between two mica surfaces have been studied in order to investigate the effects of incommensurability arising from the crystalline structure of the mica surfaces and their separation. They have also investigated the thermodynamics and associated phase transitions of a water monolayer confined within a quasi-two-dimensional nanopore. An asymmetric nanopore constructed by combining a hydrophilic (hexagonal boron nitride) sheet and a hydrophobic (graphene) sheet leads to an ordered water structure at much higher temperatures compared to a symmetric hydrophobic nanopore consisting of two graphene sheets.

RESEARCH REPORT

Abhishek **DHAR**

Exact Results for Trapped Gases with Long-Ranged Interactions

Several models of trapped interacting gases in one dimension were studied, such as the coulomb gas, the plasma gas, the log-gas and the Calogero-Moser system. For these

systems, the exact profile of particle density was computed using a new field theoretic approach. In some cases, exact correlation functions and distributions of individual tagged particles were obtained. One of the aims of the study was to identify universal features.

Quantum Dynamics Under Repeated Measurements

A problem of fundamental interest is the effect of repeated measurements on the dynamics of a quantum system. In earlier work from this group, it was shown that the dynamics of such a system can be described by the so-called quasi-Zeno dynamics. It was also shown that this dynamics is non-unitary and can be effectively described by two different non-Hermitian Hamiltonians. This result has been used to understand the problem of the distribution of detection times, at a fixed detector site, of a free quantum particle.

Propagation of Perturbations in Magnetic Systems

A well-known model for magnets is the so-called Heisenberg spin system. How do perturbations propagate in this system? This question was studied for the one-dimensional classical Heisenberg chain, by looking at the form of space-time correlations and the spread and growth of chaos in this system. The results were understood using the framework of Hydrodynamics and interesting connections were discovered with the Kardar-Parisi-Zhang system which models surface growth.

Anomalous Heat Transport in Low Dimensional Systems

Several stochastic dynamical models have recently been developed to describe the motion of so-called “active” particles such as bacteria, vibrated granular particles and self-propelled particles. Examples include the Run and Tumble Particle model and the Active Brownian Particle model. Mathematically, the absence of detailed balance in the dynamics makes, even the problem of a single active particle quite challenging. For such systems, many exact and analytical results were obtained and some surprising qualitative features have been discovered.

RESEARCH REPORT

Manas KULKARNI

Particles with Long-Range Repulsive Interactions in External Confinement

Manas Kulkarni and his collaborators (S. Agarwal, A. Dhar, A. Kundu, S. N. Majumdar, D. Mukamel, G. Schehr and A. Kumar) studied the collective description of classical many-particle interacting systems. They developed a large-N field theory and computed analytically the average density profile. They considered the case of

both all-to-all-coupling and finite ranged interactions. Their analytical results are in excellent agreement with brute-force Monte-Carlo simulations. Given the fact that these family of systems are of broad relevance (to both theory and experiments), their findings are of paramount importance.

Engineering Indefinitely Long-Lived Localization in Cavity-QED Arrays

By exploiting the nonlinear nature of the Jaynes Cumming's interaction, one can get photon population trapping in cavity-QED arrays. However, the unavoidable dissipative effects in a realistic system would destroy the self-trapped state by continuous photon leakage. To circumvent this issue, Kulkarni and A. Dey showed that a careful engineering of drive, dissipation and Hamiltonian results in achieving indefinitely sustained self-trapping (localization). Although, their analysis is performed keeping cavity-QED systems in mind, their work is applicable to other driven-dissipative systems where nonlinearity plays a defining role.

Provable Bounds for the Korteweg-de Vries Reduction in Multi-Component Nonlinear Schrodinger Equation

Kulkarni, with S. Swarup and V. Vasan, studied the dynamics of multi-component Bose gas described by the Vector Nonlinear Schrödinger Equation (VNLS). Using a multi-scaling and a perturbation method along with the Fredholm alternative, they reduced the problem to a Korteweg de-Vries (KdV) system. This is of great importance to study more transparently, the obscure features hidden in VNLS. Importantly, before studying the KdV connection, they provided a rigorous analysis of the linear problem. They wrote down a set of theorems along with proofs and associated corollaries that shine light on the conditions of existence and nature of eigenvalues and eigenvectors of the linear problem. This rigorous analysis is crucial for understanding the nonlinear problem and the KdV connection. The results are expected to be relevant not only for cold atomic gases, but also for nonlinear optics and other branches where VNLS equations play a defining role.

Kardar Parisi Zhang (KPZ) Scaling in Non-Integrable and Integrable Classical Models

In collaboration with A. Das, H. Spohn, A. Dhar, K. Damle, D.A. Huse and C.B. Mendl, Kulkarni investigated spatio-temporal correlations in classical non-integrable and integrable spin chains. For the non-integrable case, they considered the classical XXZ model and show regimes where they found KPZ scaling. They explained it using the framework of nonlinear fluctuating hydrodynamics (NFH). To their surprise, they found that a classical integrable spin chain also has regimes in which it displays KPZ behaviour. The findings are along the lines of what was recently found in quantum integrable spin chains thereby providing strong evidence for a classical-quantum correspondence.

Phase Diagram and Non-Equilibrium Properties of Incommensurate Lattice

Models in Low Dimensions

Properties of incommensurate lattice models in low dimensions were investigated. In particular, in the well-known Aubry-Andre-Harper (AAH) model, an interesting sub-diffusive scaling (with system size) of non-equilibrium steady state current at critical point was demonstrated. A novel approach was introduced for probing the phase diagram. A detailed study of certain closed system quantities was made and hints of the anomalous transport was found. (with A. Purkayastha, S. Sanyal, A. Dhar).

Photon Statistics of a Double Quantum Dot Micromaser: Quantum Treatment

Kulkarni (with B. K. Agarwalla, D. Segal) developed an in-depth, rigorous understanding of recent experiments in Quantum dot circuit-QED systems. First, they used a semi-classical theory and study transmission spectroscopy. This approach allowed them to derive the masing threshold condition for arbitrary temperature and voltage bias, and expose microscopic principles required for realizing photon gain and thereby a photon amplifier. Next, by employing the quantum master equation approach they extended the Scully-Lamb quantum theory of a laser to the present setup, and investigated the statistics of emitted photons below and above the masing threshold as a function of experimentally tunable parameters. Although their focus was primarily on hybrid quantum dot circuit-QED systems, their approach was adaptable to other light-matter systems where the gain medium consists of a mesoscopic structure.

Quantum Dot Circuit-QED Diodes and Transistors

It was demonstrated that Quantum Dot systems coupled to circuit-QED architecture (QD-cQED) can be an excellent platform to realize devices such as diodes and transistors. Elastic and inelastic currents (electronic and heat) through a voltage-biased double quantum dot system with strong and ultra-strong electron-photon interaction are investigated. By employing a diagrammatic Keldysh non-equilibrium Green's function approach, it was found that the QD-cQED system displays remarkable charge and heat rectification effects which may provide a cutting-edge frontier for high performance thermoelectrics. The results demonstrate that QD c-QED systems can be a great candidate for novel quantum devices. (With J. Lu, R. Wang, J.Ren, J-H. Jiang)..

RESEARCH REPORT

Anupam KUNDU

Energy Transport in Low-Dimensional Open Systems

Starting from the Hamilton's equations of an interacting many-particle system, a nonlinear fluctuating hydrodynamics theory has recently been developed which turned out to be quite successful in describing various features of anomalous energy transport. However, the diffusion and the noise terms present in this theory are not derived from microscopic descriptions but rather added phenomenologically. Starting from microscopic description these hydrodynamic equations have been established with explicit calculation of the diffusion and noise terms in a one dimensional model of hard particle gas. The precise knowledge of the diffusion and the noise terms made it possible to predict a novel crossover from diffusive to anomalous heat transport. In a separate stochastic model of energy transport it has been shown explicitly that the Fourier's law gets replaced by a non-local linear response relation implying a non-local evolution equation (similar to fractional diffusion equation) for the temperature.

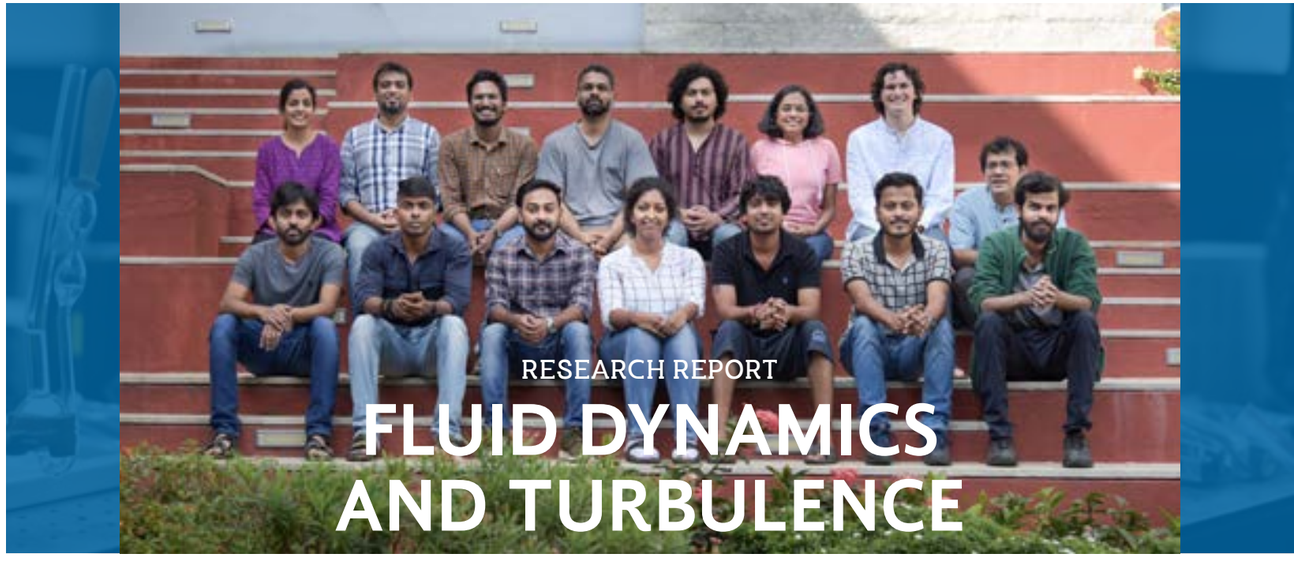
Study in Equilibrium Interacting Multi-Particle Systems

In the last decade, similar to the Gaussian distribution law, a new universal law called the Tracy-Widom distribution has emerged, which describes the typical fluctuations of the extremum of many strongly interacting random variables. This distribution has appeared in various seemingly unrelated interacting many-particle systems - indicating some kind of universality of this distribution. In a recent work, Kundu and his collaborators have shown a counter-example in a specific interacting system (1D Coulomb gas) where the fluctuations of the maxima are not describable by the Tracy-Widom distribution. System of many interacting particles in confining potentials has always been a subject of interest. In particular particles with power law repulsive interaction has recently attracted renewed attraction due to recent technological developments in cold atomic systems. On the theoretical side a large N (number of particles) field theory is crucial. In a few recent works they have developed a consistent field theoretic description of such models, both for infinite and finite range models. Counting statistics is one common observable to study in such a system, which shows interesting statistical fluctuations in the intermediate regimes between typical and large deviations. In the Ginibre ensemble, a detailed description of these intermediate scale fluctuations have been developed.

Interacting and Non-Interacting Stochastic Processes

Microscopic derivation of the effective erratic dynamics (Brownian) of a molecule in a solution at temperature T is an important problem and it still has not been achieved in a satisfiable form. Together with collaborators, Kundu has looked at this problem in the context of a single particle gas confined by a heavy but movable piston - a Szillard engine. In this problem, interestingly, it has been found that the relaxation of the particle in case of a fixed piston, is logarithmic with time in contrast to the

usual exponential relaxation. Secondly, when the piston is allowed to move, it turns out that the effective dynamics of the piston can be described by a suitable Langevin equation. In addition, we interestingly find study that the piston is never in equilibrium during the expansion step, contrary to the assumption made in the usual Szilard engine analysis - nevertheless the conclusions of Szilard remain valid. While Brownian particles describe many passive stochastic systems, Run and tumble particles (RTPs) have been proposed as the simplest model of an active particle which describes several phenomena in biological systems. Kundu and collaborators have studied the dynamics of such a particle in one dimension where we have obtained various probabilities like the occupation, the survival and the exit probabilities analytically. The behaviour of such particles are quite different from what exhibited by passive Brownian particles. They have recently shown that the '*ArcSine*' laws receive interesting modification in the case of RTP particles One of the important problems in biological systems is the intermittent search problems. Kundu's recent work investigates the time (called the local time density), the searcher, subject to resetting mechanism, spends around a particular position during the search process. His collaborators and he found interesting statistical features of this time. To investigate the effect of resetting mechanism on extended systems, they studied the behavior of a symmetric exclusion process (SEP) where the configuration of the system is reset to a step-like profile with a fixed rate r. They have shown that the presence of resetting affects both the stationary and dynamical properties of SEPs strongly.



FACULTY

Rama Govindarajan ◈ Samriddhi Sankar Ray

POSTDOCTORAL FELLOWS

Sangeeth Krishnan ◈ Sunil Bharadwaj ◈ Yogesh Prasaad Madras Sethuraman ◈ Priyanka Maity ◈ Jason Picardo

STUDENTS

Ritabrata Thakur ◈ Sumit Kumar Birwa ◈ S. Ganga Prasath ◈ Rahul Chajwa ◈ Rahul Kumar Singh ◈ Subhajit Sutradhar ◈ Sugan Durai Murugan ◈ Divya Jaganathan ◈ Mohit Gupta

RESEARCH REPORT

Rama GOVINDARAJAN

Particulate and Droplet Flow

There is an important open question in cloud evolution on how cloud droplets collide and coalesce to form raindrops. With Jason Picardo, Samriddhi Sankar Ray, Lokahith Agastya and S. Ravichandran, Rama Govindarajan showed (i) that three-dimensionality enhances clustering near caustics regions (ii) that a large number of collisions occur in very high strain regions, where few particles live.

With Vishal Vasan and Govindarajan, Ganga Prasath (Govindarajan's PhD student) completed the Basset-Boussinesq force study. This work has been highlighted in Focus on Fluids in the Journal of Fluid Mechanics (2019). We have for the first time (Vishal's idea) a way to handle this force without the need for unrealistic storage.

Instabilities in Stratified and Rotating Flows

When a channel is rotated, the Reynolds number for linear instability falls dramatically. With Sharath Jose, Govindarajan showed that the reason lies in the non-normality of the underlying stability operator in non-rotating flow. This finding can help understand instability in a wider class of flows.

Fluid-Structure Interactions

In collaboration with Narayanan Menon, Rajalakshmi and PhD student Sumit Birwa, Govindarajan showed that a solid sphere approaching a bottom plate at finite velocity through a viscous fluid makes physical contact with the plate before bouncing, whereas shallow water theory suggests that this will not happen. Work on flexible filaments on 3D geometries, on interactions between falling disks, and on settling of porous objects is nearing completion.

Indian Monsoon

This is a collaboration with Adway Mitra, Arjun Sharma, Amit Apte, Vishal Vasan and Sreekar Vadlamani. The Markov Random Field approach to describing the monsoon yielded successful first results. It was shown that ten spatial patterns over the Indian landmass are sufficient to describe the rainfall in 95 per cent of all monsoon days in the past 110 years. The transition matrices between these patterns enables a further classification into three families.

Bay of Bengal

With PhD student Ritabrata Thakur, in a collaboration with Jim Moum and Emily Shroyer, Govindarajan has shown that when fresh water arrives, and winds pick up in

the northern Bay of Bengal, the upper twenty metres of the ocean are well-mixed, but turbulence in the next few tens of metres are suppressed by over an order of magnitude. These measurements, made as part of this large Indo-US project, are likely the first measurements of turbulence in the Bay of Bengal.

RESEARCH REPORT

Samriddhi Sankar RAY

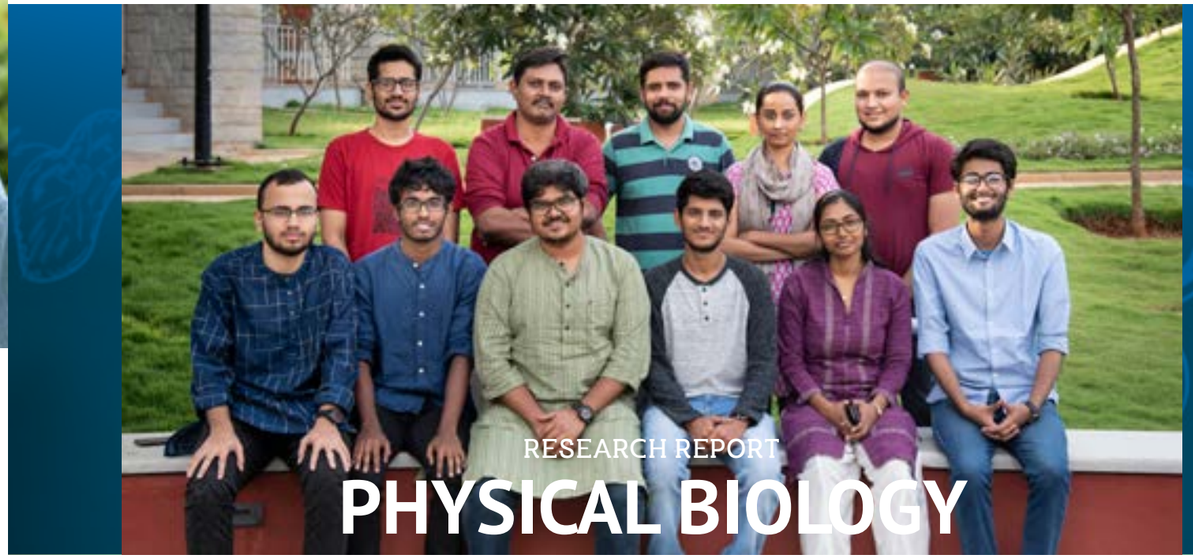
Samriddhi Sankar Ray's interests lie in various aspects of turbulence and turbulent transport in its many 'avatars.'

In the area of turbulent transport, Ray and his collaborators have studied the role played by the structures in the carrier turbulent flow in determining the statistics of particle collisions and coalescences. Furthermore, we made advances in understanding how large, initially spherical, droplets stretch, deform and eventually break in a turbulent flow. In this period, we also made progress in exploring the dynamics of orientation and gravitational settling of non-spherical, sub-Kolmogorov particles in three-dimensional flows. These particles mimic rather well, for example, ice crystals in cold clouds.

An important step in the group was to uncover the novel dynamics of extended objects, modelled through inertial (see enclosed figure) and inertia-less beads connected by elastic links. These objects, because of their elasticity, stretch well into the inertial range of turbulent flows, and, unlike non-interacting particles, are trapped in the vortices of the flow. Ray and his collaborators were able to understand this "*vortex pinning*" in terms of the dimensionality of the flow, the elasticity of the chains, and the inertia of the beads which form such chains.

Apart from turbulent transport, this period saw significant work in understanding the origins of intermittency and Lagrangian irreversibility for both isotropic and non-isotropic (rotational) flows. Some of these studies involved the method of Fourier decimation to isolate the effects of small-scale fluctuations and the role they play in the now-well established phenomenology of turbulence. Some of the ideas developed in the group on thermalised solutions of inviscid hydrodynamics were extended to dynamical systems, such as shell models, for both equal-time and dynamic structure functions.

Finally, they also studied classical analogues of the out-of-time-ordered correlators (OTOCs) for spin systems as well as in idealised, thermalised fluids. In particular, for the latter, they were able to construct models which showed that in the classical problem, the Lyapunov exponent associated with such decorrelators scale not only as the square-root of the temperature but also linearly with the effective degrees of freedom in the problem.



FACULTY

Vijay Kumar Krishnamurthy ◈ Shashi Thutupalli *(JOINTLY WITH NCBS)*

POSTDOCTORAL FELLOWS

Jemseena V. ◈ Pritha Dolai ◈ Sankaran Nampoothiri ◈ Debajit Goswami

RESEARCH REPORT

Vijay Kumar KRISHNAMURTHY

Vijay Kumar Krishnamurthy and his collaborators investigated the motion of a run-and-tumble particle (RTP) in one dimension. They found the exact probability distribution of the particle with and without diffusion on the infinite line, as well as in a finite interval. In the infinite domain, this probability distribution approaches a Gaussian form in the long-time limit, as in the case of a regular Brownian particle. At intermediate times, this distribution exhibits unexpected multi-modal forms. In a finite domain, the probability distribution reaches a steady-state form with peaks at the boundaries, in contrast to a Brownian particle. They also studied the relaxation to the steady-state analytically. Finally, they computed the survival probability of the RTP in a semi-infinite domain with an absorbing boundary condition at the origin. In the finite interval, they computed the exit probability and the associated exit times. They provided numerical verification of their analytical results.

Spontaneous pattern formation in Turing systems relies on feedback. But patterns in cells and tissues seldom form spontaneously - instead, they are controlled by regulatory biochemical interactions that provide molecular guiding cues. The relationship between these guiding cues and feedback in controlled biological pattern formation remains unclear. Here, Krishnamurthy and collaborators explored this relationship during cell-polarity establishment in the one-cell-stage Caenorhabditis elegans embryo.

They quantified the strength of two feedback systems that operate during polarity establishment: feedback between polarity proteins and the actomyosin cortex, and mutual antagonism among polarity proteins. They characterized how these feedback systems are modulated by guiding cues from the centrosome, an organelle regulating cell cycle progression. By coupling a mass-conserved Turing-like reaction-diffusion system for polarity proteins to an active-gel description of the actomyosin cortex, they revealed a transition point beyond which feedback ensures self-organized polarization, even when cues are removed. Notably, the system switches from a guide-dominated to a feedback-dominated regime well beyond this transition point, which ensures robustness. Together, these results reveal a general criterion for controlling biological pattern-forming systems: feedback remains subcritical to avoid unstable behaviour, and molecular guiding cues drive the system beyond a transition point for pattern formation. This work was published in *Nature Physics*, 15, 293 (2019).

The cell cortex, a thin film of active material assembled below the cell membrane, plays a key role in cellular symmetry-breaking processes such as cell polarity

establishment and cell division. Here, Krishnamurthy presented a minimal model of the self organization of the cell cortex that is based on a hydrodynamic theory of curved active surfaces. Active stresses on this surface are regulated by a diffusing molecular species. They showed that coupling of the active surface to a passive bulk fluid enables spontaneous polarization and the formation of a contractile ring on the surface via mechanochemical instabilities. Krishnamurthy and collaborators discussed the role of external field in guiding such pattern formation. Their work reveals that key features of cellular symmetry breaking and cell division can emerge in a minimal model via general dynamic instabilities.

RESEARCH REPORT

Shashi THUTUPALLI

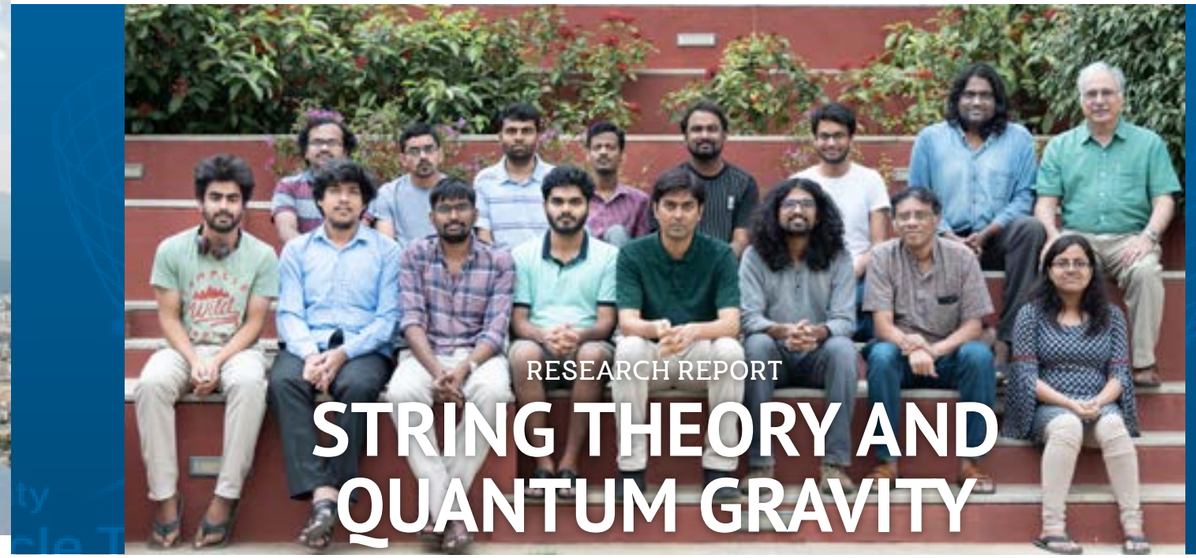
Shashi Thutupalli's research program aims for a broad understanding of the origins and organization of living systems. His is an interdisciplinary group combining experimental and theoretical techniques drawn from physics, engineering and biology. Broadly, their research program comprises two approaches:

Construct de novo, synthetic mimics of living matter

These studies serve as a kind of synthetic biology from a physical perspective and are likely to shed light on early evolution and the transitions therein. They are also likely to throw up new solutions that might be useful in engineering and biotechnology. Thutupalli and collaborators study the minimal ingredients for self-assembly, replication, feedback, and evolvability. Currently, their focus is on self-assembly in active systems, particularly towards understanding self-replication and origin of life scenarios.

Probe the physical basis of organization in cells

This represents a kind of physical biology which will allow us to quantitatively identify the broadly universal features of cellular organization. The group has multiple research projects along these lines in which they investigate a) energy flows and budgeting in living systems, b) transitions to dormancy and chemical reactions in crowded environments and c) cellular phenomenological growth and death laws.



FACULTY

Avinash Dhar *(DEAN EMERITUS AND VISITING PROFESSOR)* ◈ Pallab Basu *(TILL NOVEMBER 2018)* ◈ Rajesh Gopakumar ◈ R. Loganayagam ◈ Suvrat Raju ◈ Spenta R. Wadia

POSTDOCTORAL FELLOWS

Bidisha Chakrabarty ◈ Siddharth Prabhu ◈ Vishal M. Vijayan ◈ Jewel Kumar Ghosh ◈ Yogesh Dandekar ◈ Prithvi Narayan ◈ Victor Ivan Giraldo Rivera ◈ Junggi Yoon ◈ Anosh Joseph ◈ Alexandre Serantes ◈ Pinaki Banerjee ◈ Swapnamay Mondal

STUDENTS

Pushkal Shrivastava ◈ Soumyadeep Chaudhuri ◈ Sudip Ghosh ◈ Vijay Kumar ◈ Aswin Parayil Mana ◈ Prateek Mukati ◈ Rajeev Ranjan ◈ Chandan Kumar Jana ◈ Akhil Sivakumar ◈ Joydeep Chakravarty ◈ Pronobesh Maity ◈ Sarthak Duary ◈ Kasi Jaswin

RESEARCH REPORT

Avinash DHAR

Black hole formation in an exactly solvable model of gravity

A precise understanding of black hole formation and evaporation is key to the information puzzle. In this context, exactly solvable models provide valuable insights into the real problem (which has so far proved to be technically too difficult to solve). The SYK model, which is perhaps the simplest holographic model of quantum gravity and black holes, provides an important example of this type within the context of AdS/CFT correspondence. It is a quantum mechanical system of fermions which is solvable at strong coupling. In the present work, **Avinash Dhar** (with Adwait Gaikwad, Lata Kh Joshi, Gautam Mandal and Spenta R. Wadia) modeled matter collapse by a deformed SYK model with a sudden quantum quench in the deformation parameter. As in the undeformed case, the deformed system also permits a low energy description in terms of pseudo Nambu Goldstone modes. The bulk dual is characterised by gravitational collapse with a bulk matter stress tensor whose value near the boundary shows a sudden jump at the time of the quench. The resulting gravitational collapse forms a black hole if the deformation parameter Δ exceeds a certain critical value Δ _c; if Δ is less than Δ _c, a horizonless geometry is formed. In the black hole case, the resulting Hawking temperature is given by a fractional power T_bh ∝ (Δ − Δ _c)^1/2, which is reminiscent of the `Choptuik phenomenon' of critical gravitational collapse.

RESEARCH REPORT

Rajesh GOPAKUMAR

Deriving the AdS_3/CFT_2 Correspondence

Rajesh Gopakumar has been developing further on the long term theme in his research of deriving the AdS/CFT correspondence expanding around the tensionless limit with some success. He has focussed on the case of AdS_3/CFT_2 which is relatively more tractable. In this direction Gopakumar uncovered a novel tensionless limit for 3-dimensional AdS backgrounds in the presence of NS-NS flux (with M. Gaberdiel and C. Hull). With Gaberdiel, he studied this limit in further detail and found a rather surprising relation between the spectra at this special point and that of the apparently different point which is described by a conventional symmetric product orbifold. Recently, with Lorenz Eberhardt and Gaberdiel, Gopakumar showed in a precise way how this comes about by showing that the worldsheet description of this background at this special point has a rather remarkable truncation of the spectrum which leads to it matching with the orbifold CFT. They have moreover, recently shown how the correspondence actually works at the level of arbitrary correlation functions

by making manifest the equivalence of the correlators of the worldsheet AdS_3 string theory with those of the dual (symmetric orbifold) CFT_2. This opens the way for a precise understanding of the tensionless limit of a string theory.

Conformal Bootstrap in Mellin space

Another direction Gopakumar has pursued recently is a very novel way of understanding conformal field theories using a new approach that combines techniques from string theory, specifically gauge-string duality ('Witten Diagrams') and the mellin representation. This has already yielded surprising new results for systems relevant for studying real world phase transitions. In recent work Gopakumar and his collaborators (Apratim Kaviraj, Kallol Sen and Aninda Sinha) have solved some of the main technical challenges in implementing this program and also refined our understanding of our formalism. This opens the way for a number of applications.

RESEARCH REPORT

R. LOGANAYAGAM

During the period Jan 2018-Dec 2019, R. Loganayagam's work involved three major themes: first was to understand the conceptual basis of entropy production in a formalism where hydrodynamics is thought of as a Wilsonian effective theory. The second theme was to develop local, dissipative effective theories that can capture the physics of out of time order correlations. The third theme concerns developing a real time (Schwinger Keldysh) formalism within gravity.

The first work was motivated by the following conundrum: the standard Wilsonian effective theories exhibit currents only when there is an exact symmetry and a conservation law associated with them. The presence of an entropy current in hydrodynamics however seems to violate this expectation: there does not seem to be an exact symmetry or a conservation law to guarantee its existence in long distance effective theories of hydrodynamics. In previous work, Loganayagam and collaborators Felix Haehl and Mukund Rangamani had argued that there is in fact an exact symmetry in these theories (related to thermal translations in a superspace) which guarantee the presence of an entropy current. This leads to an apparent contradiction: presence of an exact symmetry suggests a conservation law whereas it is well-known that the entropy is not conserved. In a series of two papers they resolved this puzzle by studying the conservation law implied by this symmetry. Their conclusion was as follows: while the net entropy in superspace is conserved, the entropy in physical space is produced by virtue of it flowing in the superspace directions. This inflow is non-zero only when appropriate superspace components of the field strength are turned on. The mechanism for entropy production is thus analogous to the picture for 't Hooft anomalies in field theories.

The second set of works are broadly driven by the recent attempts at understanding the physics behind out of time ordered correlations in open quantum systems. Whereas effective theories describing time ordered correlations have been known for over a century (since the work of Langevin, Einstein and Smoluchowski on a particle in Brownian motion), we do not have a similar understanding of out of time ordered correlations. In a series of works with Soumyadeep Chaudhuri, Chandramouli Chowdhury and Bidisha Chakrabarty, Loganayagam developed a systematic formalism to write down a dissipative effective theory for out of time ordered correlations in a system coupled to thermal bath. They managed to delineate general principles that should be obeyed by such an effective theory which was then illustrated in detail within a particular example. Crucial in this regard is a treatment of non-linear dissipation and fluctuation as well as the relation between the two. To study these, it was necessary to invent a formalism that extends the standard Kubo formula to out of time ordered correlations.

Regarding the third theme, in a work with Bidisha Chakrabarty, Joydeep Chakravarty, Soumyadeep Chaudhuri, Chandan Jana and Akhil Sivakumar, Loganayagam has tackled the question of how to develop a real time (Schwinger Keldysh) formalism within gravity, using the simple example of a Brownian particle with non-linear dissipation and fluctuation. On AdS side, this corresponds to studying a trailing string in the black brane background. For the first time, they were able to show how to deal with Hawking radiation in the presence of interactions: including the physics of the outgoing Hawking modes scattering against the ingoing modes. Crucial technical ingredients in this work are the use of a gravitational Schwinger Keldysh geometry as well as an effective parameterisation of the Hawking modes using the time reversal isometry.

RESEARCH REPORT

Suvrat RAJU

Localization of Quantum Information in Quantum Gravity

In the past two years, a major theme of Suvrat Raju's research has been to understand how quantum information is localized in quantum gravity, and how this can reveal the presence of subtle nonlocal effects in quantum gravity. This work has revealed an unusual and interesting picture: it suggests that, in a theory of quantum gravity, if one specifies all quantum mechanical degrees of freedom outside a bounded region, this automatically fixes all degrees of freedom inside that region.

Raju has developed this theme in a number of papers.

Most recently, together with Alok Laddha (of the Chennai Mathematical Institute),

ICTS graduate student Pushkal Shrivastava, and postdoctoral fellow, Siddharth Prabhu, Raju was able to make this idea precise in a theory of massless particles in asymptotically four dimensional spacetimes. Quantum gravity is often studied using toy models, but Raju and collaborators believe this recent work is exciting since it marks a step towards understanding how effects of quantum gravity in our own world.

This work also has implications for black holes. More specifically, the so-called black hole information paradox is framed as a question about how quantum information is *"recovered"* when a black hole forms and evaporates. Their work suggests that, in quantum gravity, the information is always accessible outside the black hole!

Fuzzballs and Internal Structure of Black Holes

With ICTS graduate student, Pushkal Shrivastava, Raju also examined the so-called fuzzball proposal for black holes. This proposal suggests that black hole interiors are very different from the conventional picture. Rather than being relatively-featureless, the fuzzball proposal suggests that black holes should be replaced by microstate geometries, with a rich structure near the putative horizon that stores information about how the black hole was formed.

Their previous work indicates that such a picture is unnecessary to resolve the information paradox. But, they were also able to show that such a picture runs into trouble with general constraints from statistical mechanics. Their result can be explained in simple terms. In a system with a large number of degrees of freedom, almost all quantum states are effectively indistinguishable. They showed that this contradicts the notion that different black hole microstates must have distinct geometric features.

Inner Horizons of Black Holes

Charged and rotating black holes can have a second horizon in their interior, which is called an inner horizon. The inner horizon is theoretically interesting because it is also a Cauchy horizon; classically, it is impossible to predict what happens beyond that horizon. Therefore the existence of such a horizon creates problems for determinism. Determinism suggests that given complete initial data, one should be able to evolve it uniquely into the future, but this idea appears to fail in the presence of inner horizons.

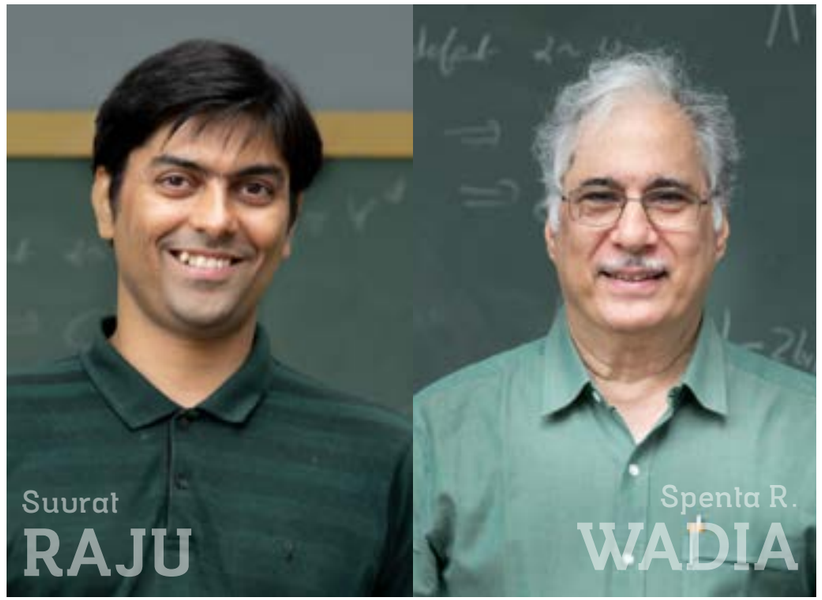
It is commonly believed that inner horizons are unstable against classical and quantum fluctuations, and so they will not really exist for a physical black hole. With Kyriakos Papadodimas and Shrivastava, Raju developed an innovative and simple test to examine the stability of inner horizons.

Their test confirms that, in most physical settings, quantum fluctuations will destabilize the inner horizon.

Relativistic Correlators at Large Spacelike Momenta

With Souvik Banerjee, Papadodimas, Prasant Samantray and Shrivastava, Raju also studied the behaviour of thermal correlation functions in a relativistic field theory in the limit where the spatial momenta of the insertions is taken to be large but their frequencies are kept small. They found that, in this limit, the correlators were bounded by a beautiful geometric quantity: the exponential of the radius—measured in units of the temperature — of the smallest hypersphere that could accommodate the polygon formed by the momenta.

This bound was already important in their study of fuzzballs, but it may also be useful in determining whether a theory has a holographic dual or not.



RESEARCH REPORT

Spenta R. WADIA

One of the important questions in gravitational physics is to provide a description of black hole formation, which is an inherently far from equilibrium process. This process is in a sense the reverse of the process of black hole evaporation and can be regarded as a version of `information loss'. This is because even if the collapsing matter is in a pure state, when it forms a black hole the information about the initial pure state appears to be lost, and the black hole behaves like a hot body having temperature and entropy. Hence a pure state appears to evolve to a mixed (thermal) state. There appears to be information loss even though quantum mechanics conserves information.

The Sachdev-Ye-Kitaev (SYK) model of randomly interacting real fermions provides a microscopic theory to study black hole physics in AdS_2 spacetimes. The idea is that under a sudden perturbation (a quantum quench) a pure state can evolve to a pure state with thermal properties for a large class of operators. Spenta Wadia and his collaborators demonstrated that in the SYK model this evolution can be exactly calculated and they predicted a critical threshold for black hole formation, with an associated Choptuik scaling exponent for the temperature of the asymptotically thermalised state. The Choptuik type scaling exponent here is ½.

Ongoing work includes the modeling of Hawking evaporation of the black hole in the SYK model.

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CONSORTIUM

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RESEARCH

ICTS ASSOCIATES

ICTS ASSOCIATES

ICTS has been emboldened by the participation and involvement of several eminent, world-class scientists, with various activities of the Centre. They form the wide group of ICTS Associates.

ADJUNCT FACULTY

Ravi S. Nanjundiah
Director, Indian Institute of Tropical Meteorology, Pune
Monsoon Physics, High-Performance Computing (HPC), Algorithms for Visualization, and Big-Data Analytical Techniques

INFOSYS VISITING PROFESSOR

Abhinav Kumar
Stony Brook University
Number Theory, Algebraic Geometry, Combinatorics and Discrete Geometry

ICTS VISITING PROFESSOR

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Computational Complexity Theory, Computational Number Theory and Algebra

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Sumilan Banerjee
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Urna Basu
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Shailesh Chandrasekharan
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Probability and Mathematical Physics

Prayush Kumar
Cornell University
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Bipin Kumar
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Cloud Micro-physics and Numerical methods

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Tapan Mishra
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Arun Paramekanti
University of Toronto, Canada
Quantum Condensed Matter Theory, Solid State Physics, Ultracold Atomic Gases

Jahnavi Phalkey
Founding Director, Science Gallery Bengaluru
History of Science and Technology, Public Engagement with Science

Thara Prabhakaran
Indian Institute of Tropical Meteorology, Pune
Cloud Microphysics and Atmospheric Boundary Layers

Shiroman Prakash
Dayalbagh Educational Institute, Agra
String Theory, Gauge Theories and Quantum Information

Sujatha Ramdorai
University of British Columbia, Canada
Algebraic Theory of Quadratic Forms, Arithmetic Geometry of Elliptic Curves, the Study of Motives and Noncommutative Iwasawa Theory

Kabir Ramola
TIFR, Hyderabad
Statistical Mechanics, Soft Matter, Disordered Systems, Stochastic Processes

Sanjib Sabhapandit
Raman Research Institute, Bengaluru
Statistical Physics

Tridib Sadhu
TIFR, Mumbai
Statistical Physics

B. S. Sathyaprakash
Pennsylvania State University and Cardiff University
Gravitational Physics & Cosmology

Anand Sengupta
IIT Gandhinagar
Gravitational-Wave Physics and Astrophysics

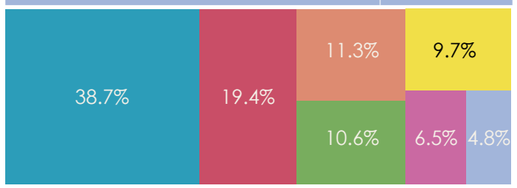
Ramachandran Shankar
The Institute of Mathematical Sciences, Chennai
Condensed Matter Physics, Glaciers and Climate

Dario Vincenzi
CNRS, Université Côte d'Azur
Nonlinear Physics, Fluid Mechanics

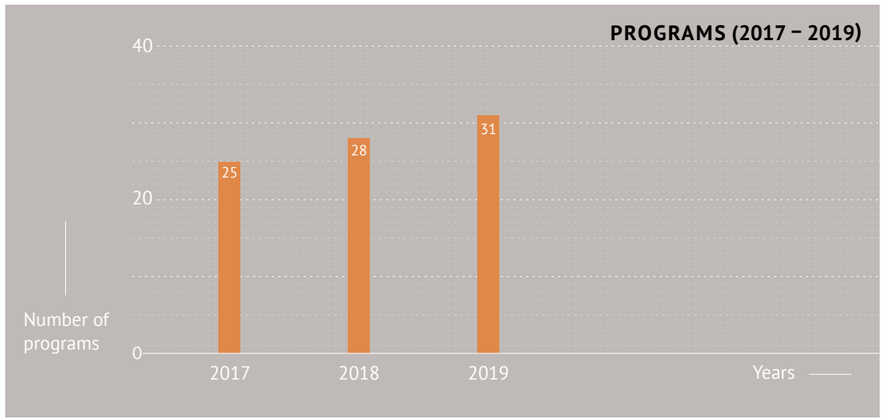
PROGRAM ACTIVITIES
@ICTS

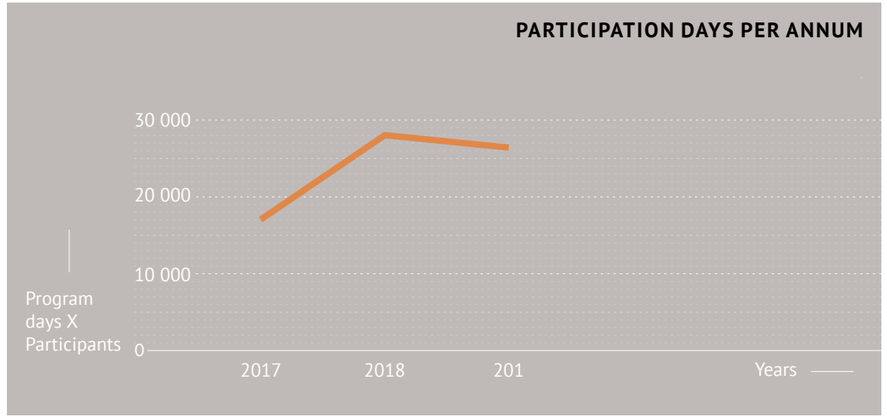
Since its inception in 2007, organizing programs has been one of the primary activities of ICTS. So far, ICTS has organized a total number of 239 programs of varying sizes. Programs can be long (6–12 weeks or longer), short (2 weeks or more, but less than 6 weeks) or mini (usually about 1–2 weeks in duration). Discussion meetings are shorter and can be held even over one day. Each year, an average of nearly 1200 researchers from India and abroad participate in our activities amounting to nearly 17000 annual participant-days. The number of programs per annum has been increasing steadily since 2015 reflecting on their popularity and demand. During the period ranging from January 2018 to December 2019, ICTS hosted 33 programs and 26 discussion meetings.

SUBJECTS	NO OF EVENTS
Mathematics and Computer Science	24
Condensed Matter and Statistical Physics	12
Astrophysics and Cosmology	7
Quantitative Biology	6
Others	6
Climate Sciences and Fluid Dynamics	4
High Energy Physics	3



Total Participation	**4210**
Total Participation days	**53492**
Indian participation	3238
Foreign Participation	972
SPEAKERS	
Indian	774
Foreign	643
GENDER	
Female	1417
Male	2793
STUDENTS AND POSTDOCS	
Indian	1798
Foreign	263





YEAR	2017	2018	2019
Number of programs	25	28	31
Participation days	18057	28007	26238

(Left) JUAN MALDACENA, GAUTAM MANDAL, SPENTA R. WADIA interact with morsing artist BHARADWAJ R. SATHAVALLI during the *'AdS/CFT at 20 and Beyond'* discussion meeting. *(Right)* MARINA LOGARES *(Complutense University of Madrid)* presents her research talk during the *Moduli of bundles and related structures* program.


SHANTARAJ S.


IPSITA HERLEKAR

PROGRAMS

ICTP–ICTS Winter School on Quantitative Systems Biology
3–20 December 2019 ♦ *Organisers* – Buzz Baum, Guillaume Salbreux, Stefano Di Talia and Vijaykumar Krishnamurthy

Thermalization, Many body Localization and Hydrodynamics
11–29 November 2019 ♦ *Organisers* – Dmitry Abanin, Abhishek Dhar, Francois Huveneers, Takahiro Sagawa, Keiji Saito, Herbert Spohn and Hal Tasaki

Group Algebras, Representations and Computation
14–23 October 2019 ♦ *Organisers* – Gurmeet Kau Bakshi, Manoj Kumar and Pooja Singla

Smooth and Homogeneous Dynamics
23 September–4 October 2019 ♦ *Organisers* – Anish Ghosh, Stefano Luzzato and Marcelo Viana

Perfectoid Spaces
9–20 September 2019 ♦ *Organisers* – Debargha Banerjee, Denis Benois, Chitrabhanu Chaudhuri and Narasimha Kumar Cheraku

Multi–scale Analysis and Theory of Homogenization
26 August–6 September 2019 ♦ *Organisers* – Patrizia Donato, Editha Jose, Akambadath Nandakumaran and Daniel Onofrei

Advances in Applied Probability
5–17 August 2019 ♦ *Organisers* – Vivek Borkar, Sandeep Juneja, Kavita Ramanan, Devavrat Shah and Piyush Srivastava

Cauchy–Riemann Equations in Higher Dimensions
15 July–2 August 2019 ♦ *Organisers* – Sivaguru, Diganta Borah and Debraj Chakrabarti

Summer School on Gravitational Wave Astronomy
15–26 July 2019 ♦ *Organisers* – Parameswaran Ajith, K. G. Arun and Bala R. Iyer

Mathematical and Statistical Explorations in Disease Modelling and Public Health
1–11 July 2019 ♦ *Organisers* – Nagasuma Chandra, Martin Lopez–Garcia, Carmen Molina–Paris and Saumyadipta Pyne

Bangalore School on Statistical Physics – X
17–28 June 2019 ♦ *Organisers* – Abhishek Dhar and Sanjib Sabhapandit

Summer Research Program on Dynamics of Complex Systems
15 May–12 July 2019 ♦ *Organisers* – Amit Apte, Soumitro Banerjee, Pranay Goel, Partha Guha, Neelima Gupte, Govindan Rangarajan and Somdatta Sinha

Summer School for Women in Mathematics and Statistics
13–24 May 2019 ♦ *Organisers* – Siva Athreya and Anita Naolekar

The Myriad Colorful Ways of Understanding Extreme QCD Matter
1–17 April 2019 ♦ *Organisers* – Ayan Mukhopadhyay, Sayantan Sharma and Ravindran V

Probabilistic Methods in Negative Curvature
11–22 March 2019 ♦ *Organisers* – Riddhipratim Basu, Anish Ghosh and Mahan Mj

Algebraic and Analytic Aspects of Automorphic Forms
25 February–7March 2019 ♦ *Organisers* – Anilatmaja Aryasomayajula, Venketasubramanian CG, Jurg Kramer, Dipendra Prasad, Anandavardhanan UK and Anna von Pippich

Preparatory School on Population Genetics and Evolution
4–10 February 2019 ♦ *Organisers* – Deepa Agashe and Kavita Jain

Universality in Random Structures: Interfaces, Matrices, Sandpiles
4 January–8 February 2019 ♦ *Organisers* – Arvind Ayyer, Riddhipratim Basu and Manjunath Krishnapur

Cosmology – The Next Decade
3–25 January 2019 ♦ *Organisers* – Rishi Khatri, Subha Majumdar and Aseem Paranjape

School on Cluster Algebras
8–22 December 2018 ♦ *Organisers* – Ashish Gupta and Ashish K Srivastava

(Clockwise from top-left) Participants of the '*School on Cluster Algebras*' held in December 2018 ◊ SATYA N. MAJUMDAR *(CNRS, Universite Paris-Sud)* and URNA BASU *(RRI, Bengaluru)* at ICTS during the *X^th Bangalore School on Statistical Physics* ◊ Participants of the program, *Multi-scale Analysis and Theory of Homogenization* held in August 2019 ◊ The discussion meeting, *The Future of Gravitational-Wave Astronomy,* was organized in celebration of the work of Indian gravitational-wave (GW) physicist BALA IYER, in August 2019 ◊ Participants of the discussion meeting *Education Systems in South Asia: Present Status and Future Evolution*

The 2nd Asia Pacific Workshop on Quantum Magnetism
29 November–7 December 2018 ♦ *Organisers* – Subhro Bhattacharjee, Gang Chen, Zenji Hiroi, Ying–Jer Kao, SungBin Lee, Arnab Sen and Nic Shannon

Winter School on Quantitative Systems Biology: Learning and Artificial Intelligence
12–23 November 2018 ♦ *Organisers* – Antonio Celani, C. Mathys and D. Zoccolan

Entropy, Information and Order in Soft Matter
27 August–2 November 2018 ♦ *Organisers* – Bulbul Chakraborty, Pinaki Chaudhuri, Chandan Dasgupta, Marjolein Dijkstra, Smarajit Karmakar, Vijaykumar Krishnamurthy, Jorge Kurchan, Madan Rao, Srikanth Sastry and Francesco Sciortino

Summer School on Gravitational–Wave Astronomy
13–21 August 2018 ♦ *Organisers* – Parameswaran Ajith, K. G. Arun and Bala R. Iyer

Integrable Systems in Mathematics, Condensed Matter and Statistical Physics
16 July–10 August 2018 ♦ *Organisers* – Alexander Abanov, Rukmini Dey, Fabian Essler, Manas Kulkarni, Joel Moore, Vishal Vasan and Paul Wiegmann

Bangalore School on Statistical Physics – IX
27 June–13 July 2018 ♦ *Organisers* – Abhishek Dhar and Sanjib Sabhapandit

Dynamics of Complex Systems 2018
16–30 June 2018 ♦ *Organisers* – Amit Apte, Soumitro Banerjee, Pranay Goel, Partha Guha, Neelima Gupte, Govindan Rangarajan and Somdatta Sinha

Non–Hermitian Physics – PHHQP XVIII
4–13 June 2018 ♦ *Organisers* – Abhishek Dhar, Andrew Houck, Manas Kulkarni, Bhabani Mandal, Vijayaraghavan Rajamani, Avadh Saxena and Miloslav Znojil

Summer School for Women in Mathematics and Statistics
7–18 May 2018 ♦ *Organisers* – Siva Athreya and Anita Naolekar

Living Matter
16–26 April 2018 ♦ *Organisers* – Vidyanand Nanjundiah and Olivier Rivoire

Third Bangalore School on Population Genetics and Evolution
05–17 March 2018 ♦ *Organisers* – Deepa Agashe and Kavita Jain

Nonperturbative and Numerical Approaches to Quantum Gravity, String Theory and Holography
27 January–3 February 2018 ♦ *Organisers* – Poul H. Damgaard, Masanori Hanada, Anosh Joseph, Loganayagam R, Aninda Sinha and Toby Wiseman

Kavli Asian Winter School (KAWS) on Strings, Particles and Cosmology 2018
8–18 January 2018 ♦ *Organisers* – Minxin Huang, Sangmin Lee, Sungjay Lee, Loganayagam R, Suvrat Raju, Tadashi Takayanagi, Masahito Yamazaki and Gang Yang

DISCUSSION MEETINGS

Novel Phases of Quantum Matter
23 December 2019-2 January 2020 ♦ *Organisers* – Adhip Agarwala, Sumilan Banerjee, Subhro Bhattacharjee, Abhishodh Prakash and Smitha Vishveshwara

Astrophysics of Supermassive Black Holes
17-19 December 2019 ♦ *Organisers* – Parameswaran Ajith, K.G. Arun, Suchetana Chatterjee and Bala R. Iyer

Sphere Packing
31 October-6 November 2019 ♦ *Organisers* – Mahesh Kakde and E.K. Narayanan

The Future of Gravitational-Wave Astronomy
19-22 August 2019 ♦ *Organisers* – Parameswaran Ajith, K. G. Arun, B. S. Sathyaprakash, Tarun Souradeep and G. Srinivasan

Education Systems in South Asia: Present Status and Future Evolution
1-3 August 2019 ♦ *Organisers* – Rekha Pappu, Padma Sarangapani and Leena Chandran Wadia

Edge dynamics in topological phases
10-14 June 2019 ♦ *Organisers* – Subhro Bhattacharjee, Yuval Gefen, Ganpathy Murthy and Sumathi Rao

Before the global pandemic COVID-19 forced the country to lockdown, some of India's best-known mathematicians were in ICTS-TIFR to attend a program on *Moduli of Bundles and Related Structures*. The inaugural lecture of the Madhava Lecture Series was also delivered during this time by P. P. Divakaran. We took the opportunity and organized a discussion session to record the early days of the School of Mathematics at TIFR, its culture of excellence and the history of the path-breaking work on vector bundles by M. S. Narasimhan and C. S. Seshadri. The people present were M. S. NARASIMHAN, M. S. RAGHUNATHAN, P. P. DIVAKARAN, SPENTA WADIA, RAJESH GOPAKUMAR, CARLOS SIMPSON, RUKMINI DEY and PRANAV PANDIT. C. S. SESHADRI joined the discussion via video conference from Chennai. C. S. Seshadri passed away in July this year.

(Clockwise from top-left) Participants of the discussion meeting *Gauge Theory Ideas for Number Theory* ♦ ALESSANDRA BUONANNO *(Albert Einstein Institute, Germany)* presents her talk during the program *The Future of Gravitational-Wave Astronomy* ♦ *Mathematics At TIFR - A Discussion Session*

Thirsting for Theoretical Biology
3-7 June 2019 ♦ *Organisers* – Vijaykumar Krishnamurthy and Vidyanand Nanjundiah

Workshop on Algebraic Complexity Theory
25-29 March 2019 ♦ *Organisers* – Prahladh Harsha, Ramprasad Saptharishi and Srikanth Srinivasan

Monsoon Day
24 February 2019 ♦ *Organisers* – Amit Apte, Rama Govindarajan and Vishal Vasan

Air-Sea Interactions in the Bay of Bengal from Monsoons to Mixing
18-23 February 2019 ♦ *Organisers* – Eric D'Asaro, Rama Govindarajan, Manikandan mathur, Debasis Sengupta, Emily Shroyer, Jai Sukhatme and Amit Tandon

Indian Statistical Physics Community Meeting
14-16 February 2019 ♦ *Organisers* – Ranjini Bandopadhyay, Abhishek Dhar, Kavita Jain, Rahul Pandit, Sanjib Sabhapandit, Samriddhi Sankar Ray and Prerna Sharma

The Theoretical Basis of Machine Learning
27-29 December 2018 ♦ *Organisers* – Chiranjib Bhattacharya, Sunita Sarawagi, Ravi Sundaram, SVN Vishwanathan

Gauge Theory Ideas for Number Theory
17-21 December 2018 ♦ *Organisers* – Rajesh Gopakumar and Minhyong Kim

Surface Group Representations and Projective Structures
10-21 December 2018 ♦ *Organisers* – Krishnendu Gongopadhyay, Subhojoy Gupta, Francois Labourie, Mahan Mj and Pranab Sardar

The Fargues-Fontaine Curve: Insights from Perfectoid Spaces and P-Adic Hodge Theory
26 November-8 December 2018 ♦ *Organisers* – U.K. Anandavardhanan and Sujatha Ramdorai

Complex Algebraic Geometry
1-6 October 2018 ♦ *Organisers* – Indranil Biswas, Mahan Mj and A. J. Parameswaran

Quantum Fields, Geometry and Representation Theory
16-27 July 2018 ♦ *Organisers* – Aswin Balasubramanian, Saurav Bhaumik, Indranil Biswas, Abhijit Gadde, Rajesh Gopakumar and Mahan Mj

Geometry and Topology for Lecturers
16-25 June 2018 ♦ *Organisers* – C. S. Aravinda and Rukmini Dey

AdS/CFT at 20 and Beyond
21 May-2 June 2018 ♦ *Organisers* – Pallab Basu, Avinash Dhar, Rajesh Gopakumar, R. Loganayagam, Gautam Mandal, Shiraz Minwalla, Suvrat Raju, Sandip Trivedi and Spenta Wadia

RAD@Home Discovery Camp
7-13 May 2018 ♦ *Organisers* – Ananda Hota, Chiranjib Konar and Sravani Vaddi

Pressing for Progress: A Discussion Meeting on the Gender Gap in Physics
22 March 2018 ♦ *Organisers* – Prajval Shastri

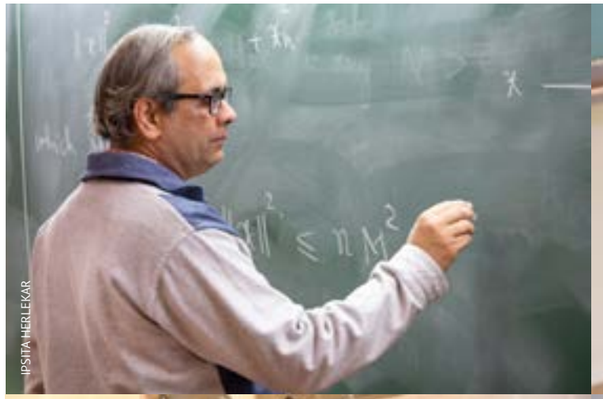
Analytic and Algebraic Geometry
19-24 March 2018 ♦ *Organisers* – Indranil Biswas and A. J. Parameswaran

Indian Statistical Physics Community Meeting 2018
16-18 February 2018 ♦ *Organisers* – Ranjini Bandyopadhyay, Abhishek Dhar, Kavita Jain, Rahul Pandit, Sanjib Sabhapandit, Samriddhi Sankar Ray and Prerna Sharma

Turbulence from Angstroms to Light Years
20-25 January 2018 ♦ *Organisers* – Rama Govindarajan and Shravan Hanasoge

ICTS at Ten
4-6 January 2018 ♦ *Organisers* – Rajesh Gopakumar and Spenta R. Wadia

Algorithms and Optimization
2-3 January 2018 ♦ *Organisers* – Prateek Jain and Nisheeth K. Vishnoi



(Clockwise from top-left) D. S. RAMANA *(HRI, Allahabad)* delivers a lecture during the *'Workshop on Additive Combinatorics'* ◊ PARONGAMA SEN *(University of Calcutta)* presents her talk during the *7th Indian Statistical Physics Community Meeting* ◊ VARUN BHALERAO, POONAM CHANDRA, G. C. ANUPAMA, KENTA HOTAKEZAKA in a panel discussion on 'Multi messenger astronomy' during the program, *The Future of Gravitational-Wave Astronomy* ◊ Participants of *Living Matter* program held in April 2018 ◊ From the presentation by the National Education Policy committee

INFOSYS-ICTS CHANDRASEKHAR LECTURE SERIES

Entanglement and Topology in Quantum Solids
Speaker – Ashvin Vishwanath *(Harvard University, USA)* ♦ 23 December 2019

Metamaterials and Topological Mechanics
Speaker – Tom Lubensky *(University of Pennsylvania, USA)* ♦ 24 June 2019

X-Ray and Microwave Cosmology
Speaker – Rashid Sunyaev *(Space Research Institute of the Russian Academy of Sciences, Moscow; Max-Planck Institute of Astrophysics, Garching; IAS Princeton, USA)* ♦ 17 January 2019

Order, Disorder and Entropy
Speaker – Daan Frenkel *(University of Cambridge, UK)* ♦ 28 August 2018

Nature's Optics and our Understanding of Light
Speaker – Michael Berry *(Melville Wills Professor of Physics (Emeritus) at the University of Bristol, UK)* ♦ 11 June 2018

Quantum Mechanics and the Geometry of Spacetime
Speaker – Juan Maldacena *(IAS Princeton, USA)* ♦ 24 May 2018

Computing Reality
Speaker – David B. Kaplan *(University of Washington, USA)* ♦ 31 January 2018

S. Chandrasekhar's Fluid Dynamics
Speaker – Katepalli Raju Sreenivasan *(Dean of NYU Tandon School of Engineering; The Eugene Kleiner Professor for Innovation in Mechanical Engineering; Professor of Physics (Faculty of Arts and Science); Mathematics (Courant Institute of Mathematical Sciences), USA)* ♦ 22 January 2018

Symmetries, Duality, and the Unity of Physics
Speaker – Nathan Seiberg *(IAS Princeton, USA)* 8 ♦ January 2018

INFOSYS-ICTS RAMANUJAN LECTURE SERIES

Some Open Questions about Scaling Limits in Probability Theory
Speaker – Sourav Chatterjee *(Stanford University, USA)* ♦ 14-18 January 2019

Some New Results On Rationality
Speaker – Claire Voisin *(College de France)* ♦ 1 October 2018

ABDUS SALAM MEMORIAL LECTURES

Networks and Mycobacterium Tuberculosis
Speaker – Shekhar C. Mande *(Director General of the Council of Scientific and Industrial Research (CSIR) & Secretary, Department of Scientific and Industrial Research (DSIR), Govt of India)* ♦ 30 April 2019

DISTINGUISHED LECTURES

Residual Intersections in Geometry and Algebra
Speaker – David Eisenbud *(Director, Mathematical Sciences Research Institute, and Professor of Mathematics, University of California, Berkeley, USA)* ♦ 10 December 2019

Computational Complexity in Theory and in Practice
Speaker – Richard M. Karp *(Professor Emeritus, Electrical Engineering and Computer Science, University of California, Berkeley, USA)* ♦ 18 October 2019

Lyapunov Exponents, From the 1960s to the 2020s
Speaker – Marcelo Viana *(IMPA, Brazil)* ♦ 24 September 2019

Falling/Rising Styles of Gravity/Buoyancy-Driven Disks
Speaker – Jacques Magnaudet *(CNRS & University of Toulouse, France)* ♦ 4 September 2019

The Making of High-Precision Gravitational Waves
Speaker – Alessandra Buonanno *(Albert Einstein Institute, Germany)* ♦ 19 August 2019

A Golden Age in Physics: Heavy Ion Physics at High Energies
Speaker – Rob Pisarski *(Brookhaven National Laboratory, USA)* ♦ 10 April 2019

Three Lectures on Machine Learning
Speaker – Sanjeev Arora *(Princeton University and IAS*

Princeton, USA) ♦ 12-13 February 2019

Quantum Inflation in the Planck Era and Beyond
Speaker – J. Richard Bond *(CITA, University of Toronto, Canada)* ♦ 15 January 2019

Topological Quantum Matter, Entanglement, and a 'Second Quantum Revolution'
Speaker – Duncan Haldane *(Sherman Fairchild University Professor of Physics, Princeton University, USA)* ♦ 11 January 2019

Topics in Quantum Chaos (An Infosys Prize Lecture)
Speaker – Nalini Anantharaman *(IAS Princeton, USA and University of Strasbourg, France)* ♦ 3 January 2019

From Bits to Qubits: A Quantum Leap for Computers
Speaker – Susan Coppersmith *(University of Wisconsin-Madison, Wisconsin, USA)* ♦ 26 September 2018

Mysteries of the Higgs Boson
Speaker – Michael E. Peskin *(SLAC, Stanford University, USA)* ♦ 17 April 2018

Symmetry in Quantum Gravity
Speaker – Hirosi Ooguri *(Fred Kavli Professor of Theoretical Physics and Mathematics, Director of the Walter Burke Institute for Theoretical Physics, Caltech; Principal Investigator, Kavli IPMU, The University of Tokyo and President, Aspen Center for Physics)* ♦ 15 January 2018

The SYK Model (Kavli Distinguished Lecture)
Speaker – David Gross *(KITP – University of California, Santa Barbara, USA)* ♦ 8 January 2018

INFOSYS-ICTS TURING LECTURE SERIES

Active Processes in Cells and Tissues
Speaker – Frank Julicher *(Max Planck Institute for the Physics of Complex Systems, Dresden, Germany)* ♦ 9 December 2019

The Power of Sampling
Speaker – Peter W. Glynn *(Stanford University, USA)* ♦ 14 August 2019

Evolutionary Dynamics and Diversity in Large Populations
Speaker – Daniel S. Fisher *(Stanford University, USA)* ♦ 8 March 2018

VISHVESHWARA LECTURES

In January 2018, ICTS introduced a new lecture series, celebrating the life and work of C.V. Vishveshwara – a pioneer in black hole physics and science outreach in India. The Vishveshwara Lectures will be delivered by leading scientists who have also contributed greatly to communicating science to the public.

Unraveling the Nature of Supermassive Black Holes
Speaker – Priyamvada Natarajan *(Yale University, USA)* ♦ 20 December 2019

Exploring the Universe with Gravitational Waves: From the Big Bang to Black Holes
Speaker – Kip S. Thorne *(Feynman Professor of Theoretical Physics at Caltech, USA) Kip Thorne won the 2017 Nobel Prize for Physics.* ♦ 11 January 2018

D.D. KOSAMBI LECTURES

The ICTS D.D. Kosambi Lectures are delivered by eminent scholars in the social sciences, the arts and the humanities. The eminent mathematician and statistician Damodar Dharamanand Kosambi made pioneering and foundational contributions to the methods and study of ancient Indian history. He was the first professor of mathematics at the Tata Institutional of Fundamental Research (1946–62).

A Paean to Learning to 'See'
Speaker – Tarun Khanna *(Harvard Business School, Harvard University, USA)* ♦ 25 November 2019

The Fissures of Modern Hinduism: Religion and Historiography
Speaker – Pratap Bhanu Mehta *(Vice–Chancellor, Ashoka University, Sonepat)* ♦ 24 May 2018

INFOSYS-ICTS STRING THEORY LECTURES

In October 2018, the ICTS-Infosys String Theory Lectures were introduced. The String Theory Lectures are delivered by leading physicists in current areas of research in string theory as well as closely related areas influenced by developments in string theory. These lectures start at a level suited to a beginning graduate student and advance to current open ended research problems in these topics.

Baryons, Determinants and Integrability at Large N
Speaker – Shota Komatsu *(IAS Princeton, USA)* ♦ 14–16 October 2019

A Modern Take on the Information Paradox and Progress Towards its Resolution
Speaker – Ahmed Almheiri *(IAS Princeton, USA)* ♦ 30 September–3 October 2019

The Fishnet Model – a Playground for Large N Holography
Speaker – Amit Sever *(Tel Aviv University, Israel and CERN, Switzerland)* ♦ 24–26 June 2019

Integrability in Planar AdS/CFT, Yangian Symmetry and Applications
Speaker – Niklas Beisert *(ETH Zurich, Switzerland)* ♦ 13–15 May 2019

3D Gravity, Chern-Simons Theory, and Wilson Lines
Speaker – Alejandra Castro *(University of Amsterdam, Netherlands)* ♦ 1 March 2019

The Analytic S-matrix Bootstrap
Speaker – Alexander Zhiboedov *(Theory Division, CERN, Switzerland)* ♦ 29–31 January 2019

Musings on Entanglement Entropy in String Theory
Speaker – Raghu Mahajan *(Princeton University, USA)* ♦ 21–24 January 2019

4D Supersymmetric Dynamics from 6D
Speaker – Sergei Razamat *(Technion, Israel)* ♦ 11–13 December 2018

Aspect of De Sitter Space
Speaker – Dionysios Anninos *(King's College London, United Kingdom)* ♦ 29 October–1 November 2018

(Clockwise from top-left) RICHARD M. KARP *(Professor Emeritus, University of California, Berkeley)* delivers ICTS Distinguished Lecture ◊ SUSAN COPPERSMITH *(University of Wisconsin-Madison)* delivers ICTS Distinguished Lecture ◊ MARCELO VIANA *(IMPA, Rio de Janeiro)* delivers ICTS Distinguished Lecture during the program, *Smooth and Homogeneous Dynamics* ◊ DUNCAN HALDANE *(Princeton University)* delivers ICTS Distinguished Lecture

OUT REACH @ICTS

PUBLIC LECTURES

Delivered by eminent visitors, the public lectures are an integral part of ICTS's outreach program. These lectures bring exciting new developments in science to the general public and play an important role in engaging students and civic society at large on issues of modern science.

Big Bang, Black Holes & Gravitational Waves
Speaker – Abhay Ashtekar *(Institute for Gravitation & the Cosmos and Physics Department, The Pennsylvania State University, USA)* ♦ 21 August 2019

(Un)seen at last: the black hole in M87
Speaker – Rajaram Nityananda *(Azim Premji University, Bengaluru & former Director of NCRA-TIFR, Pune)* ♦ 29 April 2019

What is Common Between Falling Cats and the Quantum Hall Effect?
Speaker – Alexander Abanov *(Stony Brook University, New York, USA)* ♦ 10 August 2018

Chandra. The Journey of a Star
Speaker – Giuseppe Mussardo *(SISSA, Trieste, Italy)* ♦ 3 August 2018

Black Holes and the Structure of Spacetime
Speaker – Juan Maldacena *(IAS Princeton, USA)* ♦ 25 May 2018

Can Evolution be Understood Quantitatively?
Speaker – Daniel Fisher *(Stanford University, USA)* ♦ 6 March 2018

The Science of the Man from the 9 Dimensions
Speaker – Hirosi Ooguri *(Fred Kavli Professor of Theoretical Physics and Mathematics, Director of the Walter Burke Institute for Theoretical Physics, Caltech; Principal Investigator, Kavli IPMU, The University of Tokyo and President, Aspen Center for Physics)* ♦ 14 January 2018

The Usefulness of Useless Knowledge
Speaker – Robbert Dijkgraaf *(IAS Princeton, USA)* ♦ 7 January 2018

EINSTEIN LECTURES

The Einstein Lectures were inaugurated in 2015 and have become very successful over the years. These lectures cover a wide spectrum of topics in physics and related areas. Speakers are selected with the date, venue and the nature of the audience in mind – ranging from early-career scientists to internationally eminent ones. During the duration of this report, ICTS has organised 13 Einstein Lectures.

Faint Strains of the Gravitational Wave Symphony and the Dawn of Multi-Messenger Astronomy
Speaker – Bala Iyer *(ICTS-TIFR, Bengaluru)* ♦ 25 November 2019 ♦ *Venue* – E.M.S. Seminar Complex, University of Calicut

Black Holes and Holography
Speaker – Amin Nizami *(Ashoka University, Sonepat)* ♦ 22 October 2019 ♦ *Venue* – I-View Studio, Department of Civil Engineering, NIT Jalandhar

Millisecond Pulsars – The Born-again Pulsars
Speaker – G. Srinivasan *(Retired from Raman Research Institute, Bengaluru)* ♦ 21 October 2019 ♦ *Venue* – ICSR Main Auditorium, IIT Madras, Chennai

The Revolutionary Concept of 'boundary layer' and its prevalence in aeronautics
Speaker – Sourabh S. Diwan *(IISc, Bengaluru)* ♦ 11 October 2019 ♦ *Venue* – MBA Seminar Hall, Acharya Institute of Technology, Bengaluru

String Theory and Strong Interactions
Speaker – R. Loganayagam *(ICTS-TIFR, Bengaluru)* ♦ 26 September 2019 ♦ *Venue* – School of Sciences, Center for PostGraduate Studies (CPGS), Jain Deemed-to-be University, Bengaluru

Dawn of new astronomy – How Einstein can take from Planck to Hubble
Speaker – B. S. Sathyaprakash *(Bert Elsbach Professor of Physics at The Pennsylvania State University, and Professor of Physics at The Cardiff University)* ♦ 2 March 2019 ♦ *Venue* – Dr H Narasimhaiah Multimedia Hall, National College, Bengaluru

Searching for Einstein's Biggest Blunder
Speaker – Subhabrata Majumdar *(TIFR, Mumbai)* ♦ 27 January 2019 ♦ *Venue* – Lecture Hall, IIT Guwahati

Is the Universe Geometric or Algebraic?
Speaker – Minhyong Kim *(University of Oxford, UK and KIAS, South Korea)* ♦ 21 December 2018 ♦ *Venue* – Main Auditorium, Christ University, Bengaluru

Space-Time and Gravity – From Newton to Hawking and Beyond
Speaker – Spenta R. Wadia *(ICTS-TIFR, Bengaluru)* ♦ 8 October 2018 ♦ *Venue* – Bipin Chandra Pal Seminar Hall, Assam University, Silchar

The Fascinating World of Turbulent Flows
Speaker – Samriddhi Sankar Ray *(ICTS-TIFR, Bengaluru)* ♦ 24 August 2018 ♦ *Venue* – Dayananda Sagar College of Engineering, Kumarswamy Layout, Bengaluru

Einstein's Messengers
Speaker – Parameswaran Ajith *(ICTS-TIFR, Bengaluru)* ♦ 14 June 2018 ♦ *Venue* – Indian Institute of Technology Mandi, Kamand

Stephen Hawking's Legacy in Fundamental Physics
Speaker – Rajesh Gopakumar *(ICTS-TIFR, Bengaluru)* ♦ 24 April 2018 ♦ *Venue* – Infosys Campus, Electronic City, Bengaluru

In Brightest Day and Blackest Night
Speaker – Rana Adhikari *(Professor of Physics, Caltech, USA)* ♦ 20 February 2018 ♦ *Venue* – Library Auditorium, BMS College of Engineering, Bengaluru

KAAPI WITH KURIOSITY

Kaapi with Kuriosity is held every month and is organised by ICTS in collaboration with the Jawaharlal Nehru Planetarium and other educational institutions in Bengaluru. The aim of these lectures is to impart scientific knowledge and discoveries to the public, in an informal setting. They are easily accessible to school and college students, families and working professionals interested in science. ICTS has organised 24 Kaapi with Kuriosity lectures during December 2017-December 2019.

150 Years of Entropy
Speaker: William Bialek *(Princeton University, USA)* ♦ 21 December 2019

Will Tigers Survive the 21st Century
Speaker: Uma Ramakrishnan *(NCBS, Bengaluru)* ♦ 10 November 2019

NALINI ANANTHARAMAN *(IAS Princeton, USA and University of Strasbourg, France)* delivers ICTS Distinguished Lecture (an Infosys Prize lecture)

(Top to bottom) HIROSI OOGURI *(Fred Kavli Professor of Theoretical Physics and Mathematics, Director of the Walter Burke Institute for Theoretical Physics, Caltech; Principal Investigator, Kavli IPMU, The University of Tokyo and President, Aspen Center for Physics)* greeted by SUDHA MURTHY during his public lecture ◊ UMA RAMAKRISHNAN *(NCBS, Bengaluru)* during her *Kaapi with Kuriosity* lecture ◊ URBASI SINHA *(Quantum Information and Computing (QuIC) laboratory at Raman Research Institute, Bengaluru)* during her *Kaapi with Kuriosity* lecture

Elementary Arrangements
Speaker: Arnab Bhattacharya *(TIFR, Mumbai)* ♦ 20 October 2019

Thinking Ecologically about Indian Cities
Speaker: Harini Nagendra *(Azim Premji University, Bengaluru)* ♦ 22 September 2019

The Culture of Science
Speaker: Jayant Narlikar *(Emeritus Professor, IUCAA, Pune)* ♦ 18 August 2019

A Mathematical Adventure in Immunology
Speaker: Carmen Molina-Paris *(School of Mathematics, University of Leeds, UK)* ♦ 7 July 2019

Quantum Technologies
Speaker: Aditi De *(HRI, Allahabad)* ♦ 16 June 2019

A Few Examples How the Science of Complex Systems Changes Our View of the World
Speaker: Stefan Thurner *(Science of Complex Systems, Medical University of Vienna)* ♦ 26 May 2019

Symmetry and the Laws of Nature
Speaker: Umesh Waghmare *(JNCASR, Bengaluru)* ♦ 14 April 2019

How Fish Swim?
Speaker: Jaywant H. Arakeri *(IISc, Bengaluru)* ♦ 17 March 2019

The Tau of Ramanujan
Speaker: Eknath Ghate *(TIFR, Mumbai)* ♦ 10 February 2019

Our Amazing Universe: Astronomical Revelations and New Mysteries
Speaker: Francois R. Bouchet *(Institut d'Astrophysique de Paris, France)* ♦ 20 January 2019

States of Matter
Speaker: Deepak Dhar *(Visiting Faculty, IISER Pune)* ♦ 9 December 2018

Life and Motion, One Molecule at a Time
Speaker: Roop Mallik *(TIFR, Mumbai)* ♦ 18 November 2018

Science, the Fulcrum for Social and Economic Change
Speaker: K. VijayRaghavan *(Principal Scientific Adviser to the Govt. of India)* ♦ 14 October 2018

A Finite Discussion on the Infinite
Speaker: Tanvi Jain *(Indian Statistical Institute, New Delhi)* ♦ 9 September 2018

Making Things, Doing Science
Speaker: Arvind Gupta *(Children's Science Center, IUCAA - former)* ♦ 19 August 2018

The Discrete Charm of Geometry
Speaker: Alexander Bobenko *(Technical University of Berlin)* ♦ 22 July 2018

How quantum physics democratised music: a meditation on physics and technology
Speaker: Michael Berry *(University of Bristol, UK)* ♦ 10 June 2018

Black Holes and Steam Engines
Speaker: Joseph Samuel *(Raman Research Institute, Bengaluru)* ♦ 27 May 2018

Towards Life in a Jar
Speaker: Zorana Zeravcic *(ESPCI Paris, France)* ♦ 22 April 2018

Endless Forms Most Beautiful
Speaker: Shannon Olsson *(NCBS-TIFR, Bengaluru))* ♦ 25 March 2018

Fascinating world of photons, superposition and entanglement
Speaker: Urbasi Sinha *(Raman Research Institute, Bengaluru)* ♦ 25 February 2018

Black Holes
Speaker: Ramesh Narayan *(Thomas Dudley Cabot Professor of the Natural Sciences at Harvard University and Senior Astronomer at the Smithsonian Astrophysical Observatory)* ♦ 21 January 2018

VISHVESHWARA LECTURES

Through the Vishveshwara Lecture Series, ICTS celebrates the life and work of C.V. Vishveshwara – a pioneer in the black hole physics and science outreach in India. Vishveshwara lectures are given by leading scientists who have also contributed to communicating science to the general public.

Unraveling the Nature of Supermassive Black Holes
Speaker: Priyamvada Natarajan *(Yale University, USA)* ♦ 20 December 2019

Observing the Birth of the Universe
Speaker: Lyman Page *(James S. McDonnell Distinguished University Professor in Physics, Princeton University, USA)* ♦ 22 January 2019

Exploring the Universe with Gravitational Waves: From the Big Bang to Black Holes
Speaker: Kip S. Thorne *(Feynman Professor of Theoretical Physics at Caltech, USA & 2017 Nobel Laureate in Physics)* ♦ 11 January 2018

SCIENCE OUTREACH IN SCHOOLS

ICTS volunteers regularly visit schools in Bengaluru to demonstrate science concepts using toys made with everyday objects and materials. The aim of this activity is to inculcate logical, creative thinking and encourage the students to come up with innovative experiments with day to day material. Activities such as these will dispel the fear of science and math among students, making space for an engaging and fun way of learning. There have been 9 school visits organised in 2018-2019. The visits made so far have been to Nagenahalli Government School, Hessaraghatta Government School and Ananya Public School.

ICTS-NIAS MATH CIRCLE

In 2019, the maths circle was launched in cooperation with the National Institute of Advanced Studies, Bengaluru. It is one of the first math circles in India with a view towards identifying mathematically gifted students at an early stage and honing their aptitude and mathematical skills. The idea is to expose students in classes 7-9 to the joy of mathematics, and its prevalence in the world around us by emphasizing the empirical roots and far-reaching empirical consequences of beautiful mathematical ideas. The maths circle also creates a peer group of children with a shared passion for mathematics. The maths circle meets every

other week at NIAS with an intense 3-4-hour session on mathematical exploration with trained facilitators. One of the innovations of our maths circle is that the webpage has a challenge set of problems which we encourage children to solve and upload problems. There have been 4 maths circle meetings so far.

OTHER OUTREACH ACTIVITIES

There were several other events organised by ICTS as part of their outreach activities during the period January 2018-December 2019.

- **Special Colloquium by Mansi Kasliwal** *(Caltech)* ♦ 13 December 2019
  The colloquium was attended by 41 students from Govt. Science College, Palakkad, Kerala as part of their educational tour

- **Special Colloquium by Patrick Brady** (LIGO Spokesperson) ♦ 31 July 2019
  The colloquium was attended by many astronomy enthusiasts from Bengaluru.

- **Visit by undergraduate students** ♦ 3 July 2019
  45 JBNSTS Scholars (undergraduate students from Science, Engg., Medical) from West Bengal visited ICTS as part of their research institute visits

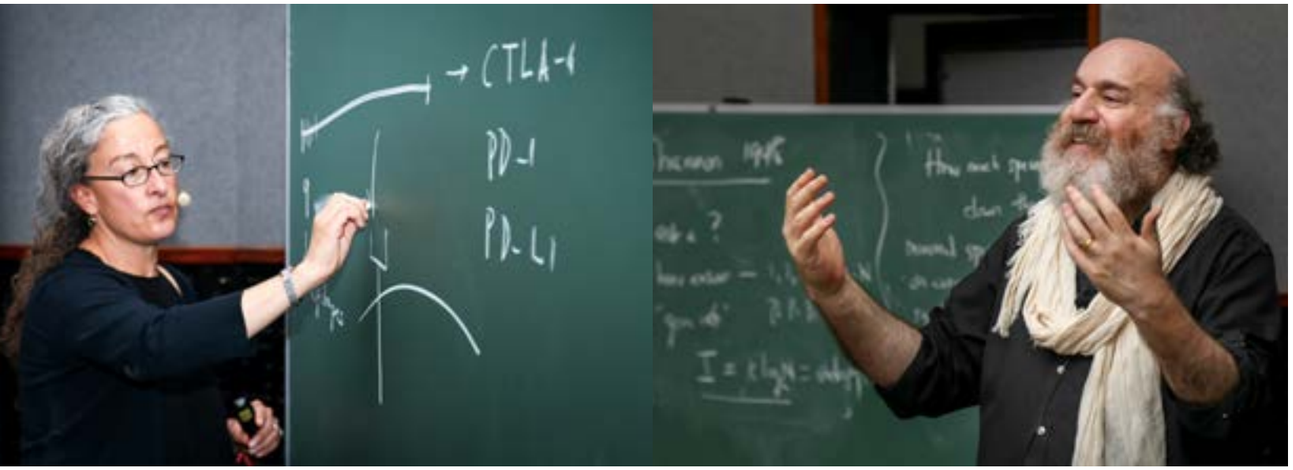
- **Screening of the film *Wild Karnataka*** ♦ 11 January 2019
  Exclusive screening and interaction with the director.

- **Visit by school students** ♦ 29 January 2019
  St. Joseph's Boys High School students (Grade 9) visited ICTS.

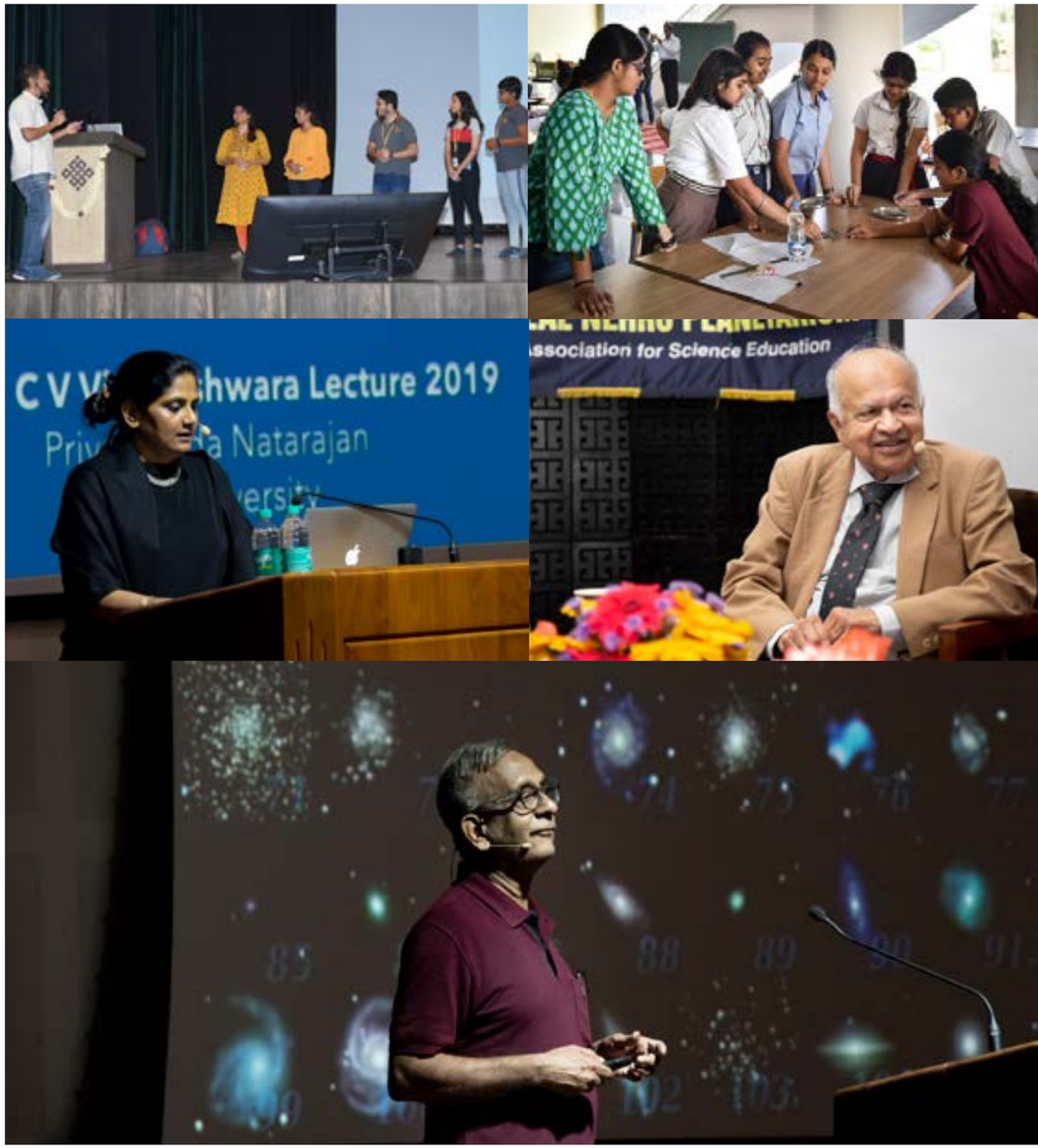
- **Visit by math, arts and design school students** ♦ 20 June 2018

- ***RAD@home*: Citizen Science** ♦ 13 May 2018
  One-day event as part of the Discussion Meeting *RAD@Home Discovery Camp*. Forty participants received initial training towards becoming citizen-scientists or e-astronomers.

- **Blood Moon observation from ICTS** ♦ 31 January 2018
  Viewing of the total lunar eclipse, organised for the ICTS-TIFR community and local children from Shivakote.



CARMEN MOLINA-PARIS *(University of Leeds, UK) (left)* and WILLIAM BIALEK *(Princeton University) (right)* were speakers at *Kaapi with Kuriosity* lectures.



(Clockwise from top-left) ABHISHEK DHAR delivers Einstein Lecture at REVA University, Bengaluru ◊ *ICTS-NIAS Maths Circle* is a new initiative in Bangalore launched with a view to expose students to the joy of mathematics, and its prevalence in the world around us by emphasizing the empirical roots and far-reaching empirical consequences of beautiful mathematical ideas ◊ JAYANT V. NARLIKAR *(Emeritus Professor, IUCAA, Pune)* during the *Kaapi with Kuriosity* lecture ◊ RAJARAM NITYANANDA *(Azim Premji University, Bengaluru)* delivers ICTS Public Lecture ◊ PRIYAMVADA NATARAJAN *(Yale University)* delivers Vishveshwara Lecture

GRADUATE PROGRAMS AND TRAINING

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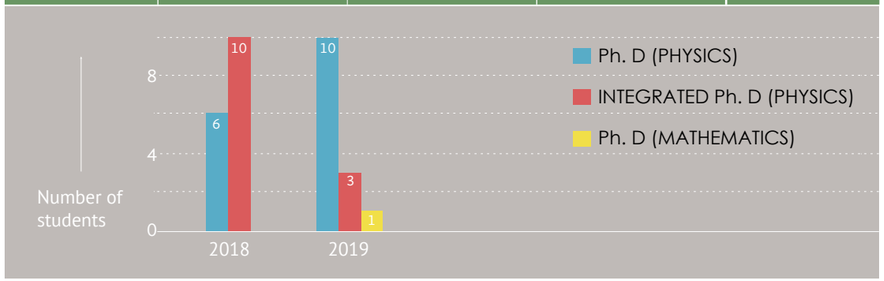
GRADUATE PROGRAMS

The ICTS has been deeply involved in training graduate students for years of research. In the past two years, 30 students joined the graduate program. 16 joined the physics programs, 13 the integrated physics program and 1 joined the mathematics program.

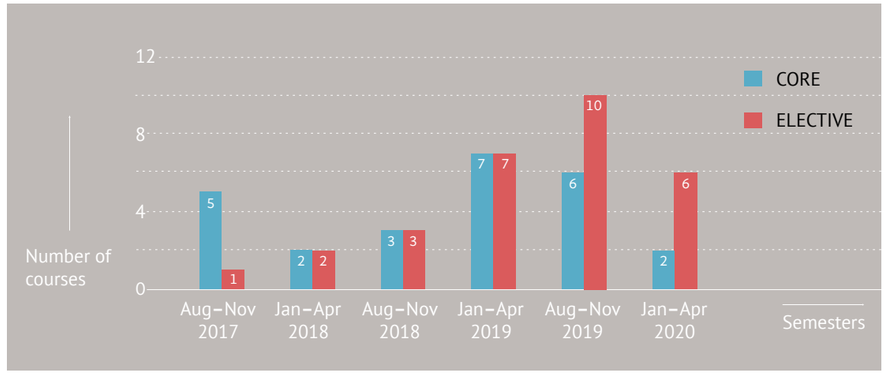
NUMBER OF STUDENTS JOINED PER YEAR

YEAR	PHYSICS		MATHS	TOTAL
	Ph.D. (Physics)	Integrated Ph.D. (Physics)	Ph.D. (Mathematics)	
2018	6	10	-	16
2019	10	3	1	14
	16	13	1	30



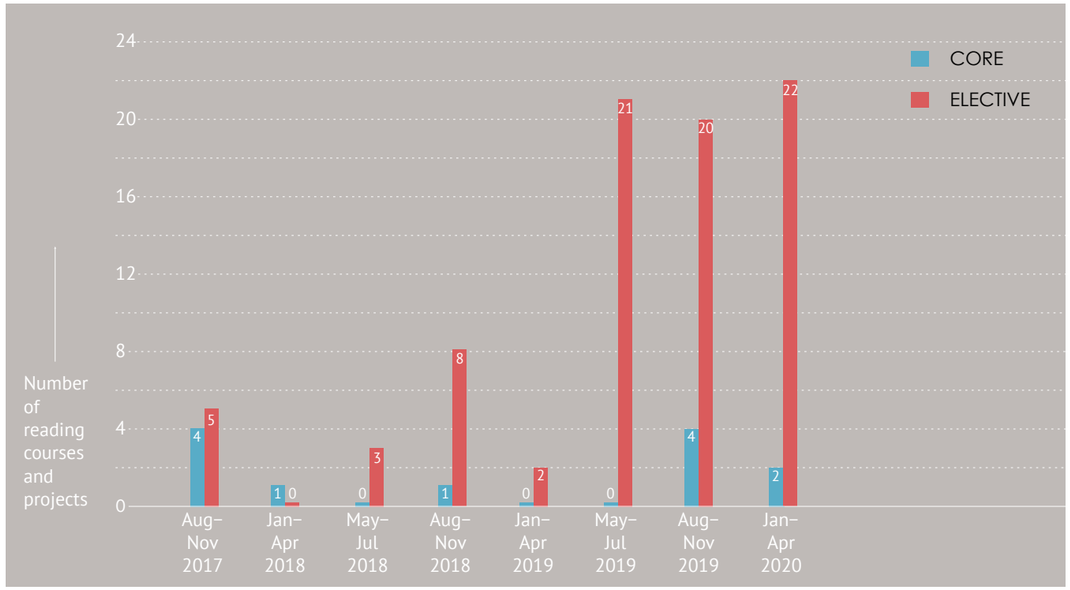
CORE AND ELECTIVE COURSE

SEMESTER	CORE	ELECTIVE	TOTAL
Aug – Nov 2017	5	1	6
Jan – Apr 2018	2	2	4
Aug – Nov 2018	3	3	6
Jan – Apr 2019	7	7	14
Aug – Nov 2019	6	10	16
Jan – Apr 2020	2	6	8
			54



READING AND PROJECT COURSE

SEMESTER	READING	PROJECTS	TOTAL
Aug – Nov 2017	4	5	9
Jan – Apr 2018	1	0	1
May – Jul 2018	0	3	3
Aug – Nov 2018	1	8	9
Jan – Apr 2019	0	2	2
May – Jul 2019	0	21	21
Aug – Nov 2019	4	20	24
Jan – Apr 2020	2	22	24
TOTAL	12	81	91

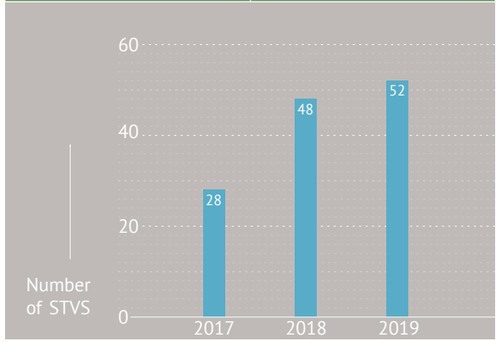


LONG TERM VISITING PROGRAM (LTVSP)

YEAR	PDFs
2017	13
2018	12
2019	11
TOTAL	36

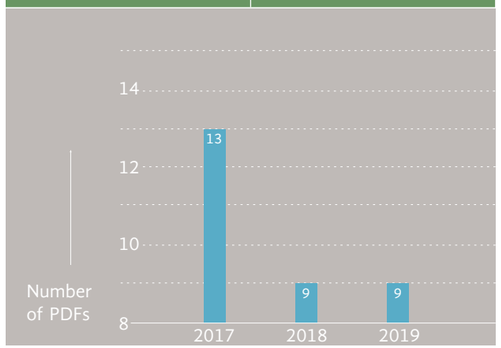
SHORT TERM VISITING STUDENTS (STVS)

YEAR	PDFs
2017	28
2018	48
2019	52
TOTAL	128



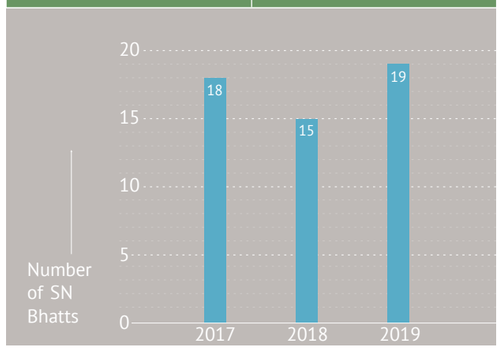
POST DOCTORAL FELLOWS

YEAR	PDFs
2017	13
2018	9
2019	9
TOTAL	22



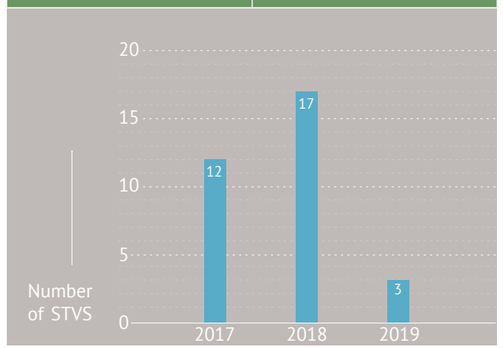
S. N. BHATT MEMORIAL FELLOWSHIP

YEAR	PDFs
2017	18
2018	15
2019	19
TOTAL	52



LONG TERM VISITING STUDENTS (STVS)

YEAR	PDFs
2017	12
2018	17
2019	3
TOTAL	32



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 in maintaining the best possible environment for research.

ADMINISTRATION

Jenny Burtan
Project Assistant *(Establishment)*

Abhijit De
Administrative Officer

Rajesh Gopakumar
Centre Director *(ICTS-TIFR)*

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

Rama Iyer
Consultant

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

Ramya M.
Project Accounts Assistant

Jeeva M.
Administrative Assistant *(Academic Dean's Office)*

Aruna Mahendarkar
Administrative Coordinator *(Programs and Activities)*

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

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

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)*

Deepali Shewale
Project Administrative Officer

Renu Singh
Project Assistant *(General Administration)*

Madhulika Singh
Project Accounts Officer

Rajalakshmi Swaminathan
Administrative Assistant *(Purchase)*

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

SCIENTIFIC AND TECHNICAL ADMINISTRATION

Arun B.
Project Trainee *(AV)*

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, Temporary)*

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)*

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Scientific Assistant *(AV, Temporary)*

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Scientific Assistant *(IT, Temporary)*

Juny K. Wilfred
Consultant

CAMPUS

@ICTS


ICTS
International Centre for Theoretical Sciences
Tata Institute of Fundamental Research

The ICTS campus, located in Hesaraghatta village in North Bengaluru, is self-contained and includes academic housing and recreational facilities. It is equipped with a modern library, state-of-the-art computing and networking infrastructure, lecture halls with enough capacity for meetings with hundreds plus participants, an auditorium, recreation spaces, childcare facilities and comfortable living quarters for staff and visitors.

The campus is spread over 72,400 square metres. The architectural plan was drawn by Venkatramanan and Associates of Bengaluru, in close consultation with the academic members of ICTS and the project management group from the Department of Atomic Energy (DAE), Government of India. The vital task of managing the construction project and associated processes was executed by a team of engineers from the Directorate of Construction, Services & Estate Management (DCSEM) of the DAE. B. N. R. Prasanna, project engineer (BW) of DCSEM had played a key role in the supervision of the project while the JMC Projects (India) Ltd. had been responsible for the construction.

AUDITORIA AND MEETING ROOMS

ICTS provides a platform for researchers working on diverse subjects to congregate during high-quality programs of varying durations. These highly interactive sessions endorse research areas that are especially contemporary, important and intellectually challenging. ICTS's expansive facility provides a perfect ambience for this. The auditoriums, lecture halls, seminar rooms, meeting and many discussion rooms can cater to any type of event, whether it is a meeting for two, a round table for 10 or an event for 300. The foyers are ideal to put up posters, exhibits, discussion corners etc. While the design of the auditoriums blends well with the architecture of the buildings, they are also fully equipped with state of the art audio-visual systems for recording and broadcasting, air conditioning, wireless internet and steeply raked seating arrangement.

CLASSROOMS

Apart from meeting rooms, the centre also has two classrooms. The 36-seater Feynman lecture hall and Chern lecture hall are equipped with blackboard, projection facility and Wi-Fi. The e-conference facility of ICTS has facilitated scientists of other premiere institutes to participate in interactive meetings or to deliver a lecture. The live telecasting facility has allowed students and scientists from all over to view the events organized in ICTS.

Every lecture hall at ICTS is well equipped with audio-visual media like large projection systems with full HD LCD and Laser Projectors, HD cameras for capturing lectures, DSP (Digital Signal Processor), live audio & video mixer etc.

On-premises video recording and live streaming facility is provided in all the lecture halls. A centralized on-premises video portal for archived material and a YouTube channel, both of which allow everyone to go back and revisit lectures.

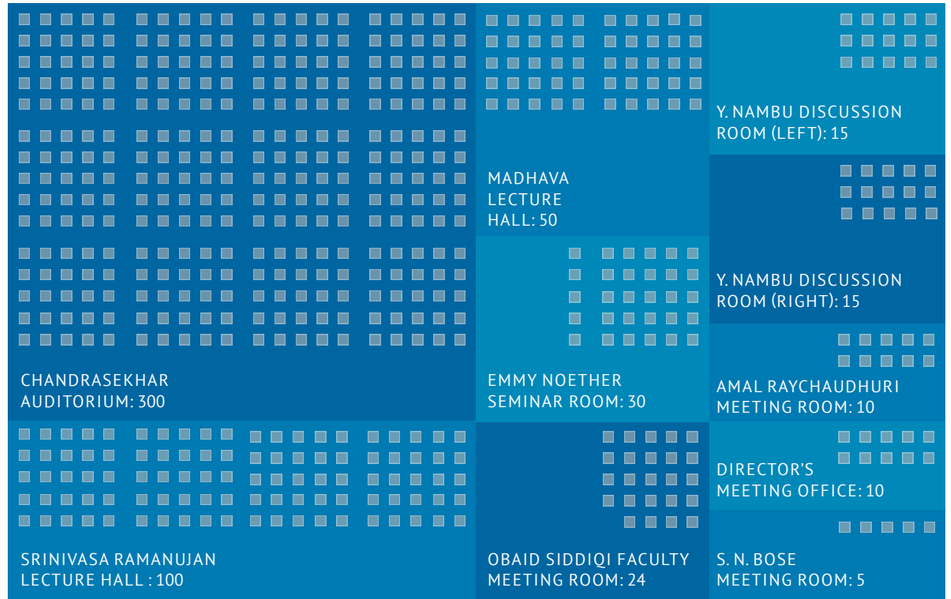
Video conferencing facility in all the lecture halls with minimum 2 Ceiling mount PTZ HD camera and multipoint video conference up to 64 video site people plus content. Touch panel based control panel is also available in all the lecture halls.

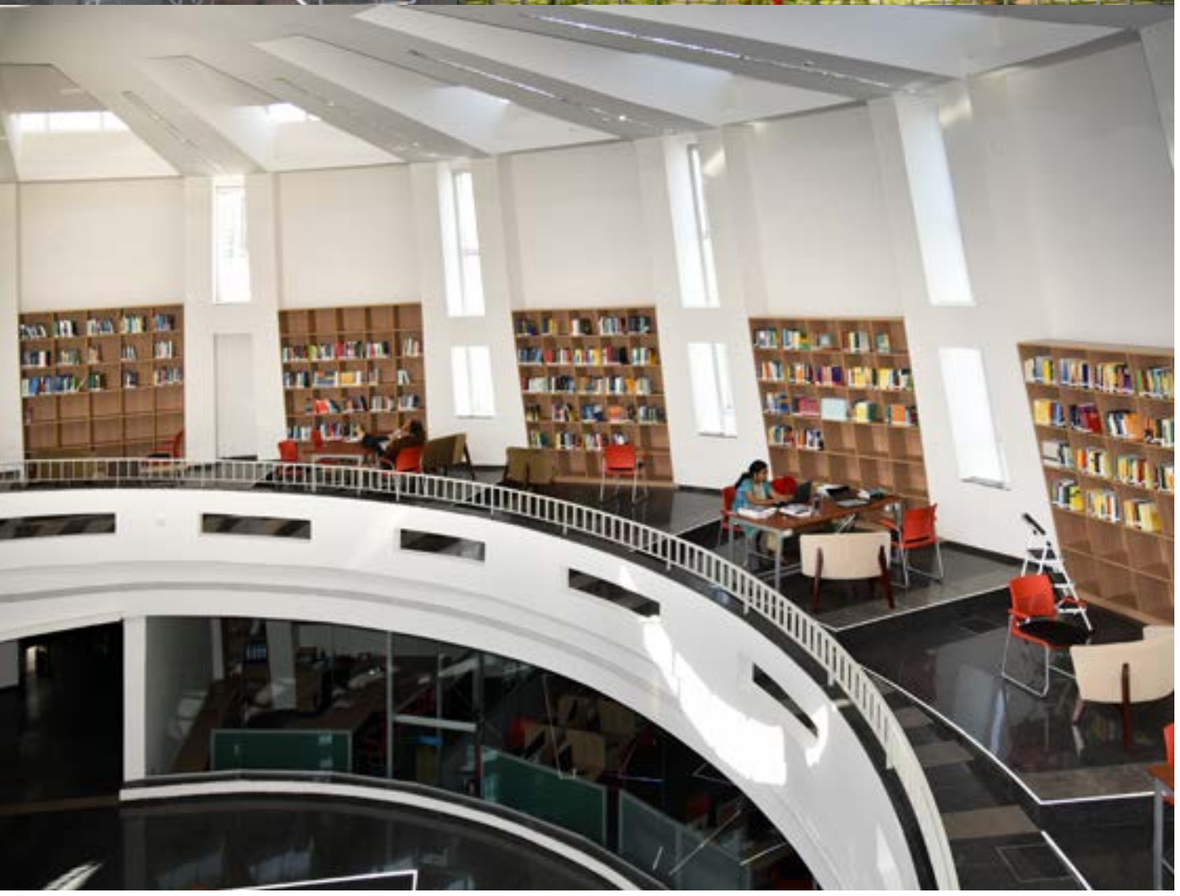
ACADEMIC BLOCK

The academic block is segregated into the four blocks. The Homi Bhabha Block that houses the Director's Office provides the leadership and administrative direction to the full range of responsibilities and tasks for effective functioning of the institute.

The Abdus Salam Block houses faculty offices, program and graduate cell and about 10 visitors' offices. The Harish-Chandra Block and G N Ramachandran Block also house faculty offices, offices for students and post-doctoral fellows in addition to classrooms and lecture rooms. There is fully furnished office space reserved exclusively for visiting researchers. Each visitor office has the facility to accommodate up to four visitors.

Auditoria, Meeting Rooms and Capacity





PANINI LIBRARY

The library (Scientific Information Resource Centre, SIRC) is the most distinctive structure on campus with its interior spiral ramp leading to a dome that resembles the exterior of the magnificent Guggenheim Museum in New York. The primary aim of SIRC is to develop, organize, preserve and deliver information and scholarly resources for the ICTS community. SIRC presently has a collection of more than 2000 books covering the subjects as Astronomy and Astrophysics, Condensed Matter Physics, Mathematics, String Theory and Physical Biology. It subscribes to a number of peer reviewed journals covering the above mentioned subject areas.

SIRC also provides access to more than 300 online journals. SIRC has access to some of the important e-journals like, Journal of Fluid Mechanics, Soft Matter, Physical Review A, E, Physical Review Applied, Reviews of Modern Physics, Journal on Scientific Computing, Journal on Matrix Analysis and Application, Journal of Applied Mathematics, SIAM Journal on Mathematical Analysis, etc. It has access to full text databases such as Annual Reviews, IOPScience Extra, SIAM and Bibliographic Databases, such as MathSciNet. SIRC also subscribes to magazines and newspapers of general interest. SIRC provides photocopying, inter-library loan and reference services. Library uses KOHA Software (An open source Integrated Library System) that supports all in-house activities of the Library. The Library has RFID (Radio Frequency Identifier) based Automation system and Circulation system- KIOSK (Self Check-in/Check-out). The database of the entire library acquisition is being updated on a regular basis along with details of recently acquired books. Also, the Library has a WebOPAC facility under which all the bibliographic details of the library collection can be accessed from the internet 24x7 on all weekdays by the users.

GUEST HOUSE

The residential block of the campus houses apartments and guest houses. The Guest house complex has three buildings named after the major rivers of north India that have housed some great ancient civilizations. While Brahmaputra and Sutlej blocks are three floors high and have 24 rooms each, Indus is four floor high and has 23 rooms, 3 suites and a reception. Although not run like a hotel, the ICTS guest house facility provides all the essential services with highly subsidized tariff. Hygiene and comfort is taken with utmost care.

All the blocks are equipped with a small pantry that has a water purifier, a fridge and an oven; a discussion room with writing board and sofas; and a small dining room. The laundry facility of each block has two washing machines, a dryer and an iron box with an ironing board.

We also have special rooms under Director's Discretionary Quota in Ajanta Guest house located slightly away from the guest house block and in the housing block. The latter are fully furnished apartments with one bedroom and two bedrooms. The Guest House is maintained with the help of 12 housekeeping staff.

RESIDENTIAL COMPLEX

The campus includes academic, housing and recreational facilities. The centre has three housing blocks with apartments named after the three major rivers of south India: Cauvery, Narmada and Godavari. Each block is four floors high and has a total of 26 apartments.

FIRST AID CENTRE

The ICTS campus is a well-equipped basic first aid centre, managed and maintained by Manipal Hospital. The first aid centre functions as the primary health centre. Two doctors (day and night time), a senior medical officer and two nursing staff are present at the centre. The first aid centre offers outpatient consultation services with a small pharmacy with general medicines given according to the doctor's advice.

The centre also conducts regular health talks and consultation by various specialists with the help of Manipal Hospital. The centre also offers free confidential counselling service through an independent support group called Parivartan to all members.

CHILD CARE FACILITY (CCF)

ICTS CCF is a day-care centre for ICTS employees' children as well as all our visitors. It caters to the age groups of 6 months to 12 years. Its pedagogical concept is based on the principles of montessori to promote individual development of each child. All children are engaged in activities like poem recitation, storytelling and playing with educational toys. It employs a coordinator and an assistant teacher.

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CAFETERIA

The Cafeteria is situated adjacent to the recreation block. The staff endeavours to cater to a diverse mix of palates and visitors can choose between a variety of ethnic and intercontinental cuisines at subsidized rates. With a seating capacity of more than 150, the cafeteria is shared by students, staff and faculty.

Kaapi Korner - ICTS also has a Coffee Kiosk which dispenses a range of beverages and snacks from 8 am to midnight. Located in the lower ground floor of the academic block, it is a popular place for informal discussions.

SPORTS AND RECREATION CENTRE

There is a wide range of excellent sports facilities on campus. The sports complex includes a well-equipped gymnasium equipped with spacious locker rooms for men and women, as well as facilities for indoor sports such as badminton, squash, table tennis, foosball, carrom, chess along with provisions for outdoor sports including volleyball and basketball. The swimming pool is the pride and joy of this campus, supervised by lifeguards and treated to maintain the very highest standards of cleanliness and safety. The sports committee is very active in conducting exciting matches and tournaments of badminton, cricket, football and many more.

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IT INFRASTRUCTURE

TURING HALL (ICTS DATA CENTRE)

The ICTS Data Centre can currently accommodate a computing capacity of about 150 TFlops comprising about 12 racks of High Performance Computing hardware and can be expanded up to 400 TFlops.

Architectural, Civil and Interiors
The Data Centre is built in the area of about 2500 Sq. Ft. with raised floor in the DC, 450 mm high. Fire rated full height gypsum partitions, entry doors and emergency exit doors. Isolated PHE room for Heat exchangers and piping terminations and in-room electrical 7 Closed Loop Cooling (CLC) systems are used to optimize airflow management and space utilization. The racks are designed to accommodate 1000 CPU cores per rack with a cooling output up to 30 KW per rack. Power & UPS Power Input line from Emergency panel i.e DG: 2X 500 kVA, Secondary line: 200 kVA. Modular UPS with N+1 configuration & horizontal modularity upto 800kVA Safety, Security System: The data centre hosts the Honeywell Morley IAS fire detection system, Novec based fire suppression system, Water leakage detection system and a Rodent repellent system.

COMPUTING FACILITY

LIGO Tier-3 Grid Computing Center - Alice
The LIGO Tier-3 Grid facility is the 1536-cores HTC cluster. This cluster is composed of 98 nodes. Of the ninety eight, two are head nodes and all others are execution nodes. This is a heterogeneous cluster with each node consisting of 32 processing cores with hyperthreading enabled and 64 GB RAM per node. The cluster nodes

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are connected using Gigabit ethernet switches. The cluster has a Network Attached Storage of 150 TB capacity and archival storage of 200 TB on disk.

The High-Performance Computing Cluster - Mowgli
Mowgli is a 488 core HPC cluster, composed of 26 rack mounted nodes, located in the ICTS data center. Of the twenty six, one is a head node and all others are execution nodes. This cluster is a heterogeneous cluster composed of two types of nodes, 16 nodes with 32-cores, 64 GB RAM each and 16-nodes with 48-cores, 96 GB RAM each with hyper threading enabled. Cluster nodes are connected using Infiniband HBAs through a Mellanox QDR Interconnect switch. The cluster has a Network Attached Storage of 55 TB (RAID5) and a Network Attached archival Storage of 75 TB capacity usable after RAID.

The High-Throughput Computing Cluster – Mario
Mario is a 512-cores HTC cluster from Dell. This cluster is composed of 33 nodes. Of the thirty-three, one head node and all others are execution nodes. This is a homogeneous cluster with each node consisting of 16 processing cores and 64 GB RAM per node. The cluster nodes are connected using 10 Gigabit Ethernet switches. The cluster has a Network Attached Storage of 150 TB capacity and archival storage of 200 TB on disk.

The High-Throughput Computing Cluster – Tetris
Tetris is a 1536-cores HTC cluster from HPE. This cluster is composed of 98 nodes, installed in the ICTS data center. Of the ninety-eight, two head nodes and all others are execution nodes. This is a homogeneous cluster with each node consisting of 32 processing cores with hyperthreading enabled and 64 GB RAM. The cluster nodes are connected using Gigabit Ethernet switches. The cluster has a Network Attached Storage of 200 TB capacity usable after the RAID and archiving Storage of 250 TB on disk.

The High-Performance Computing Cluster - Contra
The latest addition to the ICTS HPC facility is the 2048-cores Intel cluster. This cluster is composed of 64 nodes, installed in the ICTS data center. Of the sixty-four, one head node and all others are execution nodes. This is a homogeneous cluster with each node consisting of 64 processing cores with hyperthreading enabled and 192 GB Main Memory. The cluster nodes are connected using Intel Omnipath switches (3:1 blocking). The cluster has a Network Attached Storage of 500 TB capacity usable after the RAID and archiving Storage of 550 TB on disk.

NETWORK INFRASTRUCTURE

The ICTS network infrastructure is a vast web of cables, switches, and wireless access points that serve one purpose: to get the information and files you need to use the computer as quickly as possible. ICTS's fibre backbone is designed on hybrid topology, which includes start and ring topology.

ICTS Campus network architecture is a converged architecture to carry voice, video and data; it is a hierarchical topology which segments the network into building blocks simplifying operation and increasing availability. This approach creates a flexible network on which new services can be easily added without major redesign. It also delivers separated traffic, balances load across devices and simplifies troubleshooting.

INTERNET ACCESS

Wi-Fi Campus
ICTS believes in keeping the students/faculty up-to-date with the latest and greatest. The campus is thus completely Wi-Fi enabled & boasts an extensive internet bandwidth. Registered students/faculty are given individual Logins to access the campus internet services on any of their registered devices.

LABORATORIES

ICTS has two research laboratories – the KS Krishnan Lab and the JC Bose Nonlinear Dynamics Lab. In both the labs, rigorous mathematics are combined with careful experiments to discover new phenomena as well as to look at potential applications in engineering and applied sciences.

JC Bose Nonlinear Dynamics Laboratory
One of the experiments conducted in JC Bose Nonlinear Dynamics Lab facilitates the study of the formation of patterns in free surface incompressible fluid flows and, understand formation of coherent structures and transport in oceanographic contexts. The specific project focuses on the resonant interaction of water waves, from shallow to deep regimes, so as to analyze the evolving vertical patterns.

Additionally, experiments are conducted in which the phenomenon of jet formation, arising due to instability of the surface under extreme accelerations are studied. The high levels of acceleration are achieved by forcing the container to free-fall before rebounding of a metal block. The jets are then captured using high-speed imaging. The phenomenon is universal due to curvatures of the water surface in the containers.

Besides the research lab, the JC Bose labs also houses a teaching lab for core and elective lab courses.

K.S. Krishnan Lab
The K. S. Krishnan lab is designed to study fluid-structure interactions, perform table top experiments on the interface of fluid mechanics and condensed matter. The lab has 3 optical tables and appropriate opto-mechanics, 3 DSLR cameras, state of the art 3D printer and several sundry electronic and mechanical equipment. There is an on-going effort to design and develop innovative experiments for graduate

students. A lab for doing experiments in fluid dynamics and non-linear dynamics is under development.

POWER HOUSE AND ELECTRICAL FACILITY

ICTS is dedicated to following the green energy campus norms and sourcing a considerable portion of its energy requirement through renewable energy. This block houses an installed capacity of solar energy at 32 kWp which can be extended up to 1MWp in future. ICTS is also generating electricity at 3.0 KW through a conventional wind turbine installed at a height of 36 meters. The solar generation and wind generation together generates 35 KW which is approximately 8 percent of current electricity consumption. ICTS is also maintaining a three tier backup system to meet the critical load requirement during grid failure.

WATER SUPPLY

The centre has an efficient implementation plan for water and sanitation. Our goal has been to provide an integrated, sustainable, equitable and clean water supply and sanitation service. ICTS is a zero discharge campus and is registered under Green Rating for Integrated Habitat Assessment (GRIHA) which makes it essential for installation of Sewage Treatment plants. The design for elevated reservoir, underground reservoir, emergency reservoirs were drawn after an exhaustive water mapping based on the consumption requirements, provision for future expansion and to minimize wastage. The per day consumption of water approximately 1.30 lakhs litres.

SEWAGE TREATMENT PLANT

The centre has installed a new generation packaged sewage treatment Plant (NGPSTP) of 11.50 cubic meters per day capacity which helps in maintaining the zero discharge from the campus. STP maintains water parameters in the usable zone and the treated water is being reused for horticulture in the campus. This system comes with a compact installation which does not need any open air treatment of water. Treated water is being used for horticulture usage across the campus. It is a modular based STP and hence plant capacity can be increased as load increases in the coming future.

SOLAR WATER HEATER SYSTEM

A solar tube water heater system is also there for meeting the hot water requirement in residential, cafeteria and recreational areas of campus. The total installed capacity for hot water is 15000 litres per day and it reduces electricity consumption considerably.

HVAC PLANT

The centralized chiller system has been installed at ICTS having a capacity of 4X120 TR to meet the HVAC requirement on campus inclusive of standby systems. It is a water cooled system and serves the purpose of the air conditioning requirement of the

campus. This facility operates 24X7. In addition, this unit also feeds chilled water to the data centre along with many installed AHU in various locations in addition to split ACs.

GREEN ENERGY

Wind Mill
ICTS is registered under Green Rating for Integrated Habitat Assessment (GRIHA) and has invested in the renewable energy facility. This facility meets a 2 percent of the total power requirement in a green way. A 3.0 KW wind turbine generates almost up to 5-7 KWH of energy per day. ICTS has received the Highest Environment Rating Certificate.

Solar electricity
A solar photovoltaic system in the campus of capacity 32 kWp solar generates up to 120-130 kWh electricity per day. This is an on-grid solar power generation system.

SUPPORTING INFRASTRUCTURE

Shuttle Service
ICTS offers a safe, reliable and convenient transit option between the campus and sister institutes located in the city. These shuttles ply roughly hourly until midnight. This service is operated on a subsidised and non-profitable basis. The routes and schedules are approved by the committee to cater to the needs of students and staff. The routes and schedules are made available on the ICTS website. Any changes in the schedule are alerted through emails. ICTS also provides on-demand transport service at nights and for emergencies.

Security
The security office offers a range of unarmed guards for the security and maintenance of the campus. 36 experienced guards including supervisors provide a seamless service in the day today activities of the centre. Their scope of responsibilities includes building and event guarding, security in night shuttles and access control management and more. All Entry & Exit points are manned by security personnel. Only registered students and staff members can enter/exit the campus premises. The newly added CCTV system and alarms form a part of the latest technology allowing to respond as promptly as possible to any situation.

Housekeeping
The Centre is committed to being a model of sustainability, environmentally-friendly practices wherever possible. This service has provided substantial employment to the surrounding villagers. Our housekeeping maintenance strategies seek to reduce carbon footprint while also decreasing the level of chemicals present in the cleaning products. The housekeeping crew consists of 35 personnel.

Day Worker Facility
The centre has put in a special effort to provide the contractual workers with a safe and supportive environment, empower them with job skills and improve their socio-economic conditions. The Day Worker Facility provides an informal recreational ambience that one can enjoy after a day's hard labour. This facility is equipped with clean restrooms, beds, and significantly subsidized cafeteria. The recreational room is further equipped with television, carrom boards and magazine racks.

Landscape and Garden
Despite having a relatively small campus, ICTS has embarked on developing 59 per cent of the total area into a green, sustainable open landscape. The centre has procured 2000 varieties of saplings from the forest department for this initiative including a small section of medicinal plants. Extensive green space, water body, landscaped lawns, and open courtyards will be created to develop a tranquil and ecologically friendly environment. The amphitheatre, gazebos and pergolas will add to the architectural beauty of the campus while promoting various formal, informal, academic and cultural interactions. A crew of 16 gardeners have been deployed to maintain this initiative.

Miscellaneous
- An ATM banking facility is available on the campus.

- The ICTS campus ensures a barrier free access for the differently abled and elderly with ramps in every block, lifts and special washrooms. The Srinivasa Ramanujan Lecture Hall also has provision to accommodate seating with a wheelchair.

AHMED ALMHEIRI *(Institute for Advanced Study, Princeton) (left),* speaker at *ICTS-Infosys String Theory* Lecture series, interacts with members of the *String Theory and Quantum Gravity* research group.

JUNY K. WILFRED

AWARDS AND RECOGNITIONS

P. Ajith
- Awarded the 2019 N. R. Sen Young Researcher Award of IAGRG (Indian Association for General Relativity and Gravitation).

Adhip Agarwala
- PhD thesis titled *'Excursions in Ill Condensed Quantum Matter: From Amorphous Topological Insulators to Fractional Spins'* was selected by Springer and published under the Springer thesis series. Adhip is currently a postdoctoral fellow at ICTS-TIFR. He was a PhD student at IISc, Bengaluru.

Riddhipratim Basu
- Selected as associate of the Indian Academy of Sciences. This is a recognition for promising young researchers below the age of 35.

Chandan Dasgupta
- Awarded the SERB Distinguished Fellowship by the Department of Science and Technology (DST), Government of India.
- Awarded the prestigious Satyendranath Bose medal of the Indian National Science Academy (INSA).

Rukmini Dey
- Awarded a Core Research Grant (CRG) of the SERB as Principal Investigator by the Department of Science and Technology, Govt. of India.

Avinash Dhar
- Awarded the 2018 Tata Institute of Fundamental Research Alumni Association (TAA) Excellence Award.

Abhishek Dhar
- Elected Fellow of the National Academy of Sciences, India, in recognition of his distinguished contributions to the field of statistical physics.

Abhirup Ghosh *(Former ICTS graduate student)*
- Selected among top 100 entries at the Augmenting Writing Skills for Articulating Research (AWSAR) Award 2018, organised by the Department of Science and Technology (DST), Government of India.
- Received an 'honourable mention' for the 2018 Braccini Thesis Prize by the Gravitational Wave International Committee (GWIC).

Rajesh Gopakumar
- Received the IIT Kanpur Distinguished Alumnus Award (DAA) 2019. The Distinguished Alumnus Award is the highest award given by IIT Kanpur to its alumni in recognition of their outstanding achievements.

Bala Iyer
- Awarded an honorary doctorate by Central University of Karnataka.

Manas Kulkarni

- Awarded the research grant by CEFIPRA (Indo-French Centre for the Promotion of Advanced Research)
- Awarded the SERB Early Career Research Award by the Department of Science and Technology (DST), Government of India.

Anupam Kundu

- Selected associate of the Indian Academy of Sciences. This is a recognition for promising young researchers below the age of 35.

Archak Purkayastha *(Former ICTS graduate student)*

- Received an '*honourable mention*' for the 2019 Geeta Udgaonkar Award for the best PhD thesis in physical sciences at the Tata Institute of Fundamental Research, Mumbai.

Suvrat Raju

- Awarded the 2019 ICTP Prize. He shares the prize with Basudeb Dasgupta from TIFR, Mumbai. The ICTP Prize is given annually by The Abdus Salam International Centre for Theoretical Physics (ICTP) Trieste, Italy, to recognise outstanding contributions made by physicists under 40 years of age, from developing countries.

Samriddhi Sankar Ray

- Received the Dr. A. P. J. Abdul Kalam Cray HPC Award for 2019 for his contributions in using numerical simulations to understand turbulence and turbulent transport from the point of view of statistical physics.

Shashi Thuthupalli *(Joint faculty with NCBS)*

- Awarded a Young Investigator Grant from the Human Frontier Science Program (HFSP).

Vishal Vasan

- Selected for membership of the National Academy of Sciences, India.

ICTS-TIFR won the *'Best Ornamental Garden'* award, for the third time in a row. The award is presented by the Mysore Horticultural Society, Lalbagh.

(Photographs on the right, clockwise from the top) From *A performance of Duets and Solos*–cultural event organised by Nrityagram - The Dance Village ◊ *A Cultural Evening by Abhinava Dance Company* on the occassion of ICTS Foundation day (26 December) 2019 ◊ ANOOR VINOD SHYAM (mridangam), AMIT NADIG (flute), MATHUR R. SRINIDHI (violin), BHARADWAJ R SATHAVALLi (morse) perform at a cultural event ◊ Music event by RAFIQUE KHAN (Sitar) and MUTHU KUMAR (Tabla) ◊ SHARMILA ROY with SEWLI BASU and RAJNARAYAN BHATTACHARYA presents *The Story of a Life in movement with Songs of Joy, of Resistance, and of Commitments*

All photographs – SHANTARAJ S.

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RTI Cell
Medical Committee
Childcare Cell
General administration and HR Planning & Management Committee
ICTS Standing Physical Verification Committee
Grievance Cell
Engineering Services committee
Cafeteria and Canteen Committee
Housing Cell
Transport and Security Committee
Local Purchase Committee
Tender Opening Committee
Sports and Recreation Committee
Cultural Committee
Anti-Ragging Committee
Resource Development and Societal Engagement Wing
Cell for Prevention and Resolution of Sexual Harassment of Women at Workplace

(Top to bottom) ICTS Cultural Day programmes and other cultural events by members of thet ICTS familty

All photographs — SHANTARAM S.

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