The Institute of Mathematical Sciences, Chennai

Quarterly Report

October - December 2021

Highlights: research and events

String Theory

Various aspects of string theory in asymptotically anti-de Sitter (AdS) backgrounds in three dimensions were studied by Sujay K. Ashok and his collaborators. This was made possible due the fact that the two dimensional conformal field theory that describes string propagation in such backgrounds is a WessZumino-Witten model and hence exactly solvable. For the best studied (4,4) supersymmetric models, the one loop string amplitude was obtained and rewritten in a manifestly spacetime supersymmetric form in [Journal of High Energy Physics volume 2021, Article number: 7 (2021)]. These methods were extended to string-scale AdS models with reduced supersymmetry in [Journal of High Energy Physics, 05(2021), 024, 2021.], by means of novel theta function identities. In addition, the operator product expansion coefficients of supersymmetric (BPS) operators for backgrounds with at least (2,2) supersymmetry were determined in [Journal of High Energy Physics, 11(2021), 176, 2021.]. Finally, the study of string propagation in three dimensional black holes in asymptotically anti-de Sitter spacetime was initiated in [Preprint: 2112.08784].

Foundations of Quantum Mechanics

In the work done by Sibashish Ghosh and his collaborators [Phys. Rev. A, vol. 104, pp. 042608 (2021); published on 20th Oct., 2021], the action of qubit channels on projective measurements on a qubit state is used to establish an equivalence between channels and properties of generalized measurements characterized by bias and sharpness parameters. This can be interpreted as shifting the description of measurement dynamics from the Schrodinger to the Heisenberg picture. In particular, unital quantum channels are shown to induce unbiased measurements. The Markovian channels are found to be equivalent to measurements for which sharpness is a monotonically decreasing function of time. The effect of bias and sharpness parameters on various quantum correlations and on the corresponding energy cost of measurements is discussed. Self-testing protocols enable certification of quantum devices without demanding full knowledge about their inner workings. A typical approach in designing such protocols is based on observing nonlocal correlations which exhibit maximum violation in a Bell test. We show [arXiv preprint arXiv:2112.06595 (13th Dec., 2021)] that in Bell experiment known as Hardy's test of nonlocality not only the maximally nonlocal correlation self-tests a quantum state, rather a non-maximal nonlocal behavior can serve the same purpose. We, in fact, completely characterize all such behaviors leading to self-test of every pure two qubit entangled state except the maximally entangled ones. Apart

from originating a novel self-testing protocol, our method provides a powerful tool towards characterizing the complex boundary of the set of all quantum correlations.

Non-Perturbative Quantum Field Theory

A progress towards resolving a long-standing puzzle about the fate of anomalous axial U(1) symmetry for QCD with two light quark flavours in the chiral limit has been recently published as a peer-reviewed paper, authored by Sayantan Sharma and his collaborators Lukas Mazur and Olaf Kaczmarek in Physical Review D, 104, 094518 (2021).

Particle Interactions

Semileptonic flavor-changing neutral-current transitions with a pair of neutrinos in the final state are very accurately determined in the Standard Model (SM) and thus provide an accurate and sensitive probe for physics beyond the SM. Until recently, the poor tagging efficiency for the $B \to K^{(*)} \nu\bar{\nu}$ modes made them less advantageous as a probe of new physics (NP) compared to the charged lepton counterparts. The most recent Belle II result on $B \to K^{(*)} \nu\bar{\nu}$ uses an innovative inclusive tagging technique, resulting in a higher tagging efficiency; this together with previous BABAR and Belle results indicates a possible enhancement in the branching fraction of $B^+ \to K^+ \nu\bar{\nu}$. A reanalysis of the full Belle dataset together with the upcoming Belle II dataset is expected to result in a much more precise measurement of this mode. If the branching ratio is indeed found to be enhanced with improved measurements, this would provide an unambiguous signal of NP without uncertainties due to long-distance non -factorizable effects or power corrections (in contrast to $B \to K^{(*)} ll$). We have explored the possibilities of such an enhancement as a signal of NP within several scenarios, which can also explain some of the other tensions observed in neutral- as well as charged-current B decays. In an effective field theory approach, with the most general dimension-6 Hamiltonian including light right-handed neutrinos, we explore the viability of all scalar and vector leptoquarks, as well as the parameter space possible with a generic vector gauge boson Z′ model, assuming minimal new particle content. While being consistent with all data, correlations between the observed intriguing discrepancies in B decays are also obtained, which will discriminate between the various NP scenarios. (Thomas E. Browder, Nilendra G. Deshpande, Rusa Mandal, and Rahul Sinha https://doi.org/10.1103/PhysRevD.104.053007).

Conferences Organised

Teachers' Enrichment Workshop

Teachers' Enrichment Workshop on Complex Analysis and Number Theory during Dec 18 – Dec 31, 2021. This is a 3 weeks programme for college teachers. About 56 participants registered for the programme. The event is financially supported by NCM.

Conference Participation

Ashok, Sujay K.

Participated in the Indian Strings Meeting held at IIT Roorkee (online) during Dec 12 – Dec 17, 2021. Invited Speaker

Coimbatore Balram, Ajit

Participated in the Young Investigator's Meet on Quantum Condensed Matter Theory - 2021 held online (organized by NISER, Bhubaneswar) during Nov 16 – Nov 19, 2021. Invited talk

Gun, S.

Participated in the Pan Asian Number Theory Conference 2021-Kyoto held at RIMS, Kyoto (Online) during Dec 6 – Dec 10, 2021. Invited Speaker

Participated in the BRICS Mathematics Conference held at IISER Thiruvananthapuram (Online) during Dec 7 – Dec 10, 2021. Invited Talk

Mahajan, Meena B.

Participated in the 4th BRICS Mathematics Conference held at hybrid mode – IISER Thiruvananthapuram and online during Dec 7 – Dec 10, 2021. Gave a plenary talk titled "The complexity of formal proofs".

Participated in the 41st FSTTCS Conference held Online during Dec 15 – Dec 17, 2021. Gave a short presentation on the paper "On (Simple) Decision Tree Rank"

Mukherjee, Nayana

Delivered a talk on August, 2021 entitled "Reaction-diffusion systems: An overview" in BIOM: Recent Advances in Mathematical Biology (A one day National Level Webinar) at Karanjia Autonomous College, Odisha, India.

Srinivas, K.

Participated in the Second International Webinar on Recent Developments in Number Theory held at Online Mode, Organized by KIIT, Bhubaneswar. during Oct 1 – Oct 4, 2021. Delivered a talk with the title On the zeros of Riemann zeta-function and its analogues.

Participated in an International Conference on Class Groups of Number Fields and Related Topics held at Online Mode, Organized by KSoM, Kerala. during Oct 21 – Oct 24, 2021. Delivered a talk titled “Parametrized families of quadratic fields with n-rank at least 2”.

Sharma, Sayantan

Invited lecturer in the IV ALICE-India school on Quark-Gluon Plasma, organized by Bose Institute, Kolkata between Nov 8-20, 2021 (online). Gave 4 lectures on Standard Model of Particle Physics for beginning Ph. D. students. The lectures are available online in the following link. https://indico.cern.ch/event/1090153/timetable/

IMSc Outreach

Azadi Ka Amrit Mahotsav

The Institute of Mathematical Sciences (IMSc), Chennai, is celebrating the 75th anniversary of India's independence with a year-long calendar of popular scientific talks, a line-up of distinguished lecturers, public outreach programmes, exhibitions and educational initiatives.

The following are the distinguished and popular lectures organized during period

IMSc Distinguished Lectures

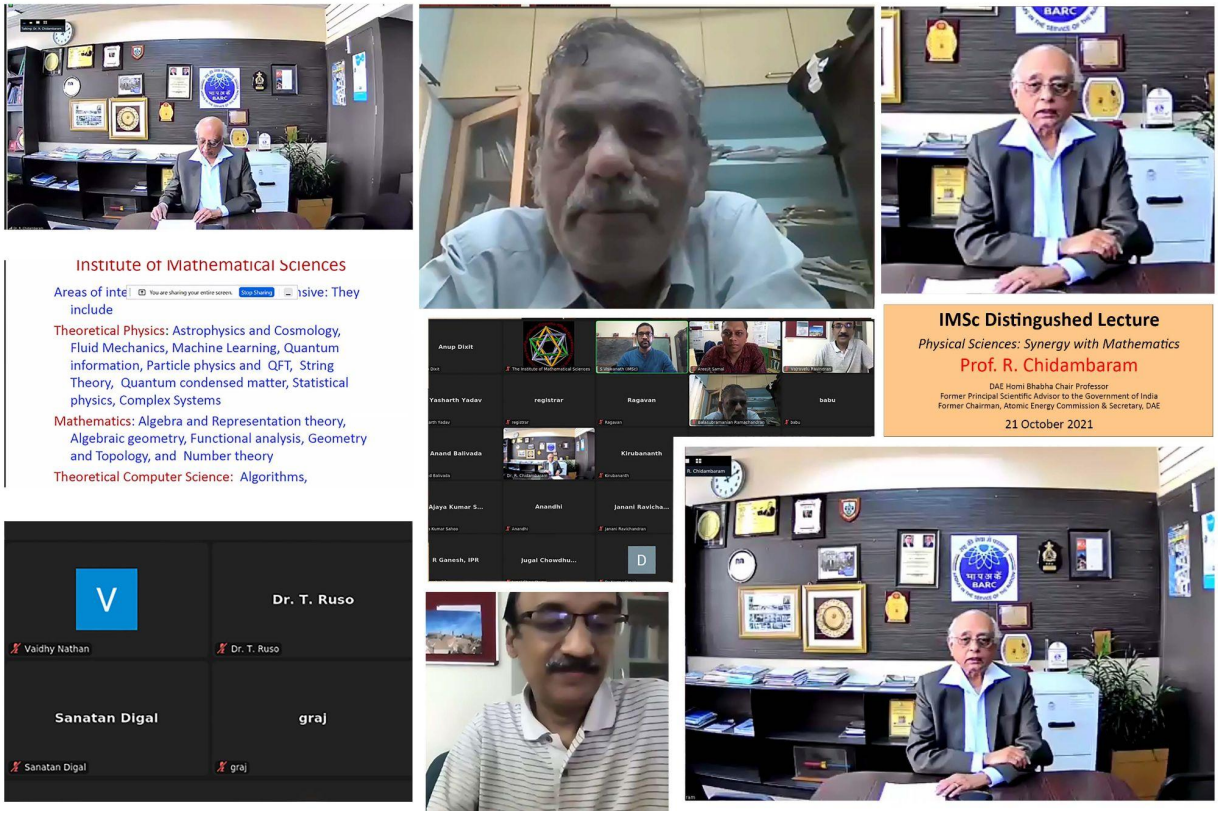
1. **Physical Sciences: Synergy with Mathematics**

   Speaker: **Prof. R. Chidambaram,** DAE Homi Bhabha Chair Professor, Former Principal Scientific Adviser to the Government of India, Former Chairman, Atomic Energy Commission & Secretary, Department of Atomic Energy.

   Date & Time : 21 October 2021, 11:00 AM - 12:00 PM

   Abstract: Physical Sciences and Mathematics are very closely linked, from high energy physics to condensed matter physics and chemistry. Mathematics is used widely in other areas like nuclear reactor design, artificial intelligence and cyber security. Computational Mathematics is also playing an increasingly important role.

   Video Link : https://youtu.be/YMaGYw3yrgQ



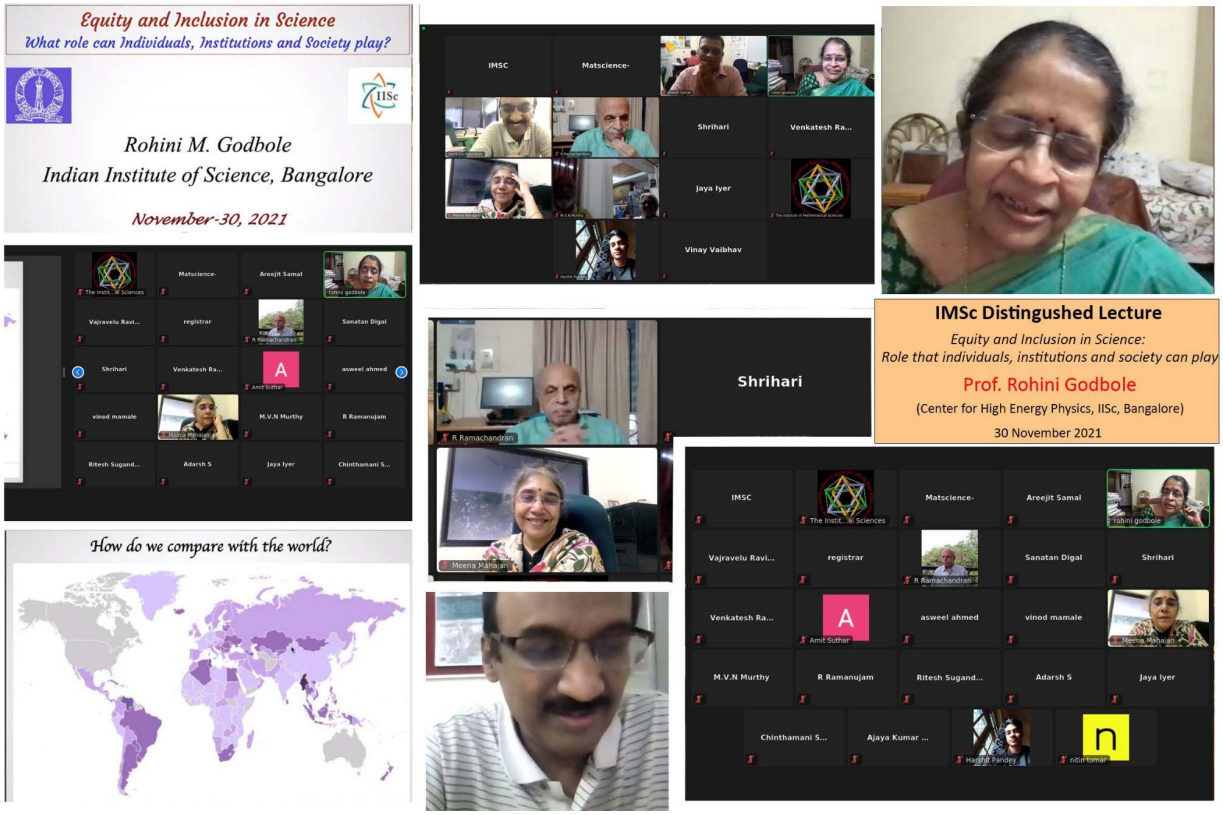
2. **Equity and Inclusion in Science: Role that individuals, institutions and society can play**

Speaker: **Prof. Rohini Godbole**, Centre for High Energy Physics, Indian Institute of Science, Bengaluru

Date & Time: 30 November 2021, 16:00 hrs - 17:00 hrs

Abstract: I will discuss in this talk why it is essential to have equity and inclusion in the practice of science and how it benefits science as well. I will specialise to some extent, to case of Gender inequity. I will then review the Equity and Inclusion discussions in the Science, Technology and Innovation Policy released recently - STIP-2020 and the measures suggested therein. I will end by commenting what all of us, individuals, institutions and society can do in this context.

Video Link : https://youtu.be/01mo2A8bEuU



3. **Online Bipartite Matching and Adwords**

Speaker: **Prof. Vijay Vazirani,** Distinguished Professor, University of California, Irvine, USA

Date & Time : 15 December 2021, 10:30 AM - 11:30 AM

Abstract: Over the last three decades, online bipartite matching (OBM) has emerged as a central problem in the area of Online Algorithms. Perhaps even more important is its role in Matching-Based Market Design. The resurgence of this area, with the revolutions of the Internet and mobile computing, has opened up novel, path-breaking applications, and OBM has emerged as its paradigmatic algorithmic problem. In this talk, we will discuss a simple optimal OBM algorithm and its generalization to the notoriously hard Adwords problem. We will also provide a broad overview of the area of Matching-Based Market Design and pinpoint the role of OBM.

Video Link : https://youtu.be/PZ8oRce-zEU

IMSc Popular Lectures

1. **Lecture on the Nobel Prize in Physiology or Medicine 2021 : Sensing Heat and Pressure**

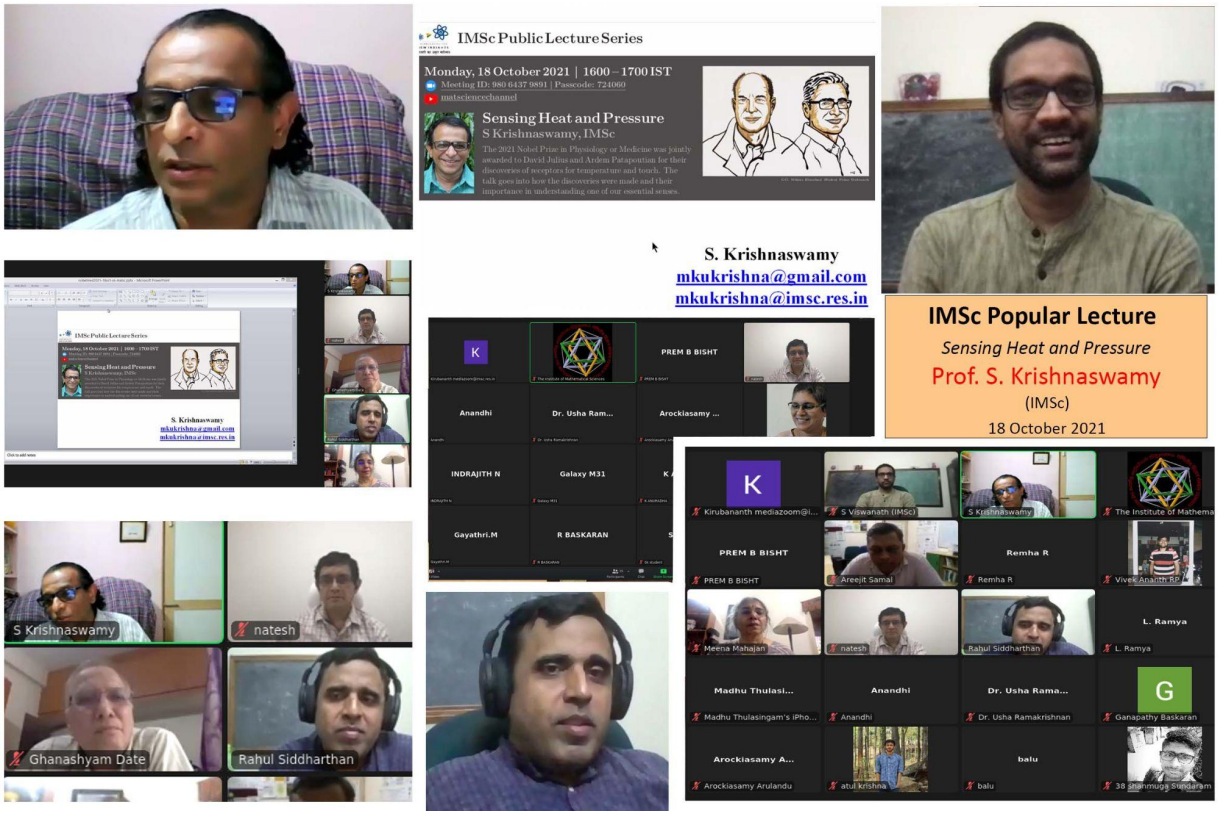
   Speaker: **Prof. S. Krishnaswamy**, Visiting Professor, Computational Biology Group,

   The Institute of Mathematical Sciences (IMSc), Chennai

   Date: 18 October 2021, 16:00 hrs - 17:00 hrs

   Abstract: The 2021 Nobel Prize in Physiology or Medicine was jointly awarded to David Julius and Ardem Patapoutian for their discoveries of receptors for temperature and touch. The talk goes into how the discoveries were made and their importance in understanding one of our essential senses.

   Video Link : https://youtu.be/C9F5o7DSD8s



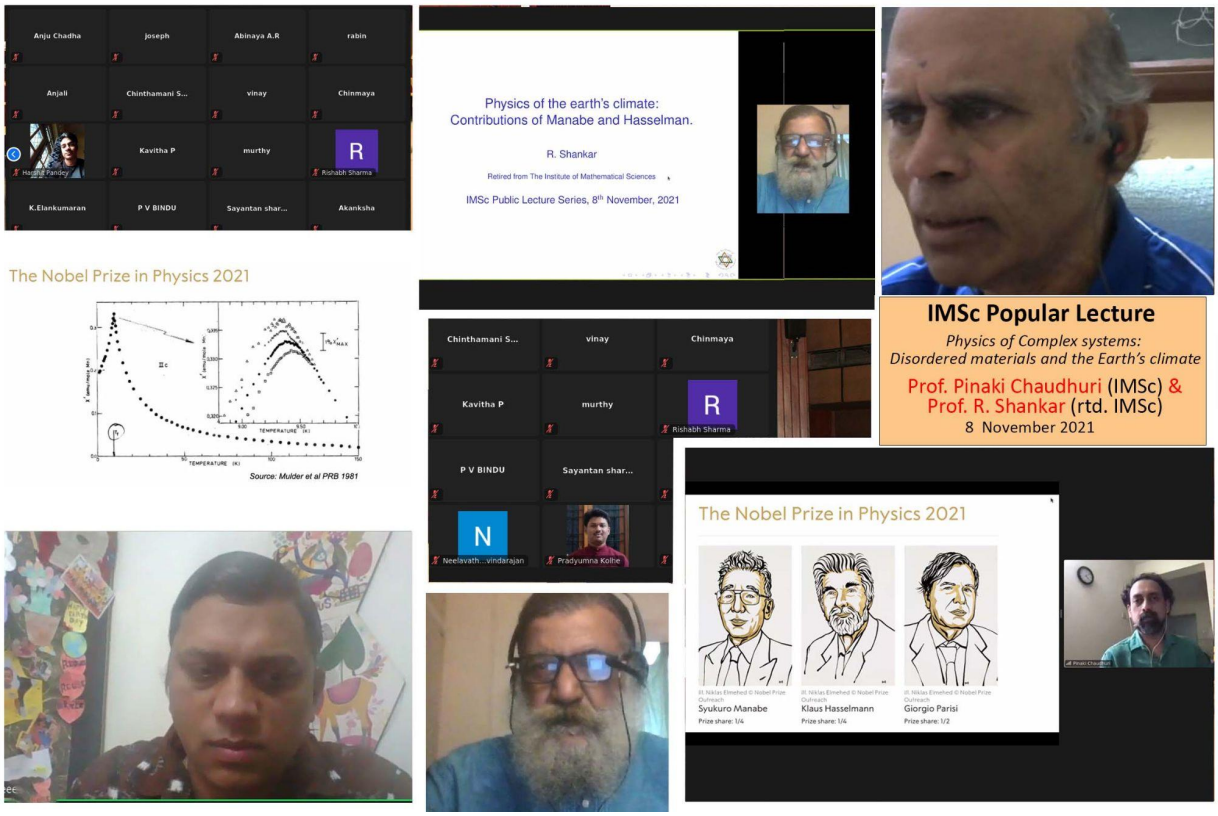
2. **Lecture on The Nobel Prize in Physics 2021 : Physics of complex systems: disordered materials and the earth's climate**

Speaker: **Prof. Pinaki Chaudhuri and Prof. R. Shankar** The Institute of Mathematical Sciences (IMSc), Chennai, India

Date: 8 November 2021, 16:00 hrs - 17:00 hrs

Abstract: The 2021 Nobel Prize for Physics was awarded “for groundbreaking contributions to our understanding of complex systems”. One half of the prize is awarded to Giorgio Parisi, for discovering hidden patterns in disordered complex materials. This first half of this talk will discuss these findings and how they have permeated to understand other physical problems and phenomena in other scientific domains. The other half of the prize is shared by Syukuro Manbe and Klaus Hasselmann for their contributions to the physics of climate science, a specific complex system, in another scientific domain, namely the Earth’s climate. A specific complex system, in another scientific domain, namely the Earth’s climate. The second part of the talk will outline the historical evolution of ideas and discoveries in climate physics and attempt to describe the significance of their contributions in this context.

Video Link : https://youtu.be/TS-llCjzJrc



3. **Playing games during a pandemic: Mathematical modeling for public health**

Speaker: **Prof. Sitabhra Sinha,** The Institute of Mathematical Sciences (IMSc), Chennai, India

Date: 26 November 2021, 16:00 hrs - 17:00 hrs

Abstract: Using the language of game theory, we explore how individual responses to public health measures for containing pandemics constrain their effectiveness. Even when the benefits of such measures-which may involve vaccination or non-pharmaceutical interventions such as quarantining or mask-wearing - may appear obvious, individuals upon weighing the risk of infection against the cost(s) of adopting such measures, may decide not to conform. Not surprisingly, the course of the epidemic will itself depend on the collective aggregate of such individual decisions, with less-than-complete adherence bringing about multiple resurgences of the epidemic.

This event was also to felicitate Prof. Sitabhra Sinha who was awarded the prestigious Prof. P.C. Mahalanobis National Award 2021.

Video Link : https://youtu.be/rzA1kYqbonw

4. Coping with Intractability Using Parameters

Speaker: **Prof. Saket Saurabh,** The Institute of Mathematical Sciences (IMSc), Chennai, India

Date: 13 December 2021, 16:00 hrs - 17:00 hrs

Abstract: One of the greatest achievements in theoretical computer science is the development of NP-completeness theory. NP-completeness theory provides a solid and convincing foundation for the study of computationally intractable problems. However, the theory does not make obsolete the pressing need for solving these hard problems because of their practical importance. Many approaches have been proposed, including polynomial-time approximation algorithms, randomized algorithms, and heuristic algorithms. The focus of this talk will be another approach to cope with NP-completeness, namely, fixed-parameter tractability (FPT for short). The talk will be in the form of a story -- accessible to most.

This event was also organized to felicitate Prof. Saket Saurabh who was awarded the prestigious Shanti Swarup Bhatnagar Prize (SSB) for Science and Technology 2021, in Mathematical Sciences.

Video Link : https://youtu.be/e6gJCvbQbkc

Threads on Twitter

Some of our events / research activities have received wide coverage among the public through our official twitter page. Few of them are listed below:

1. https://twitter.com/ManavAtlas/status/1452903823400333312

   Prof. Areejit Samal, Faculty, Computational Biology Group, gave a talk on "A phytochemical atlas of Indian medicinal plants for harnessing traditional knowledge", organised by MANAV- The Human Atlas Initiative on 11 November 2021.

2. https://twitter.com/IMScChennai/status/1468174412230782976

   IMSc announces a lecture series by **Prof. Michel Waldschmidt,** Sorbonne University on "Multivariate Lidstone Interpolation" for graduate students and researchers.

3. **Member publications on IMSc twitter handle**

   Disorder in cellular packing can alter proliferation dynamics to regulate growth

   The mechanisms by which an organ regulates its growth are not yet fully understood, especially when the cells are closely packed as in epithelial tissues. We explain growth arrest as a collective dynamical transition in coupled oscillators on disordered lattices. As the cellular morphologies become homogeneous over the course of development, the signals induced by cell-cell contact increase beyond a critical value that triggers coordinated cessation of the cell-cycle oscillators driving cell division. Thus, control of cell proliferation is causally related to the geometry of cellular packing.

   https://twitter.com/IMScChennai/status/1462108972006055937

   Phototaxis in Cyanobacteria: From Mutants to Models of Collective Behavior

   Cyanobacteria rely on photosynthesis, and thus have evolved complex responses to light. These include phototaxis, the ability of cells to sense light direction and move towards or away from it. Analysis of mutants has demonstrated that phototaxis requires the coordination of multiple photoreceptors and signal transduction networks. The output of these networks is relayed to type IV pili (T4P) that attach to and exert forces on surfaces or other neighboring cells to drive “twitching” or “gliding” motility. This, along with the extrusion of polysaccharides or “slime” by cells, facilitates the emergence of group behavior. We evaluate recent models that describe the emergence of collective colony-scale behavior from the responses of individual, interacting cells. We highlight the advantages of “active matter” approaches in the

study of bacterial communities, discussing key differences between emergent behavior in cyanobacterial phototaxis and similar behavior in chemotaxis or quorum sensing.

https://twitter.com/IMScChennai/status/1463511989930496001

Morphogen-regulated contact-mediated signaling between cells can drive the transitions underlying body segmentation in vertebrates

We propose a unified mechanism that reproduces the sequence of dynamical transitions observed during somitogenesis, the process of body segmentation during embryonic development, that is invariant across all vertebrate species. This is achieved by combining inter-cellular interactions mediated via receptor-ligand coupling with global spatial heterogeneity introduced through a morphogen gradient known to occur along the anteroposterior axis. Our model reproduces synchronized oscillations in the gene expression in cells at the anterior of the presomitic mesoderm as it grows by adding new cells at its posterior, followed by travelling waves and subsequent arrest of activity, with the eventual appearance of somite-like patterns. This framework integrates a boundary-organized pattern formation mechanism, which uses positional information provided by a morphogen gradient, with the coupling-mediated self-organized emergence of collective dynamics, to explain the processes that lead to segmentation.

https://twitter.com/IMScChennai/status/1464255033348820993