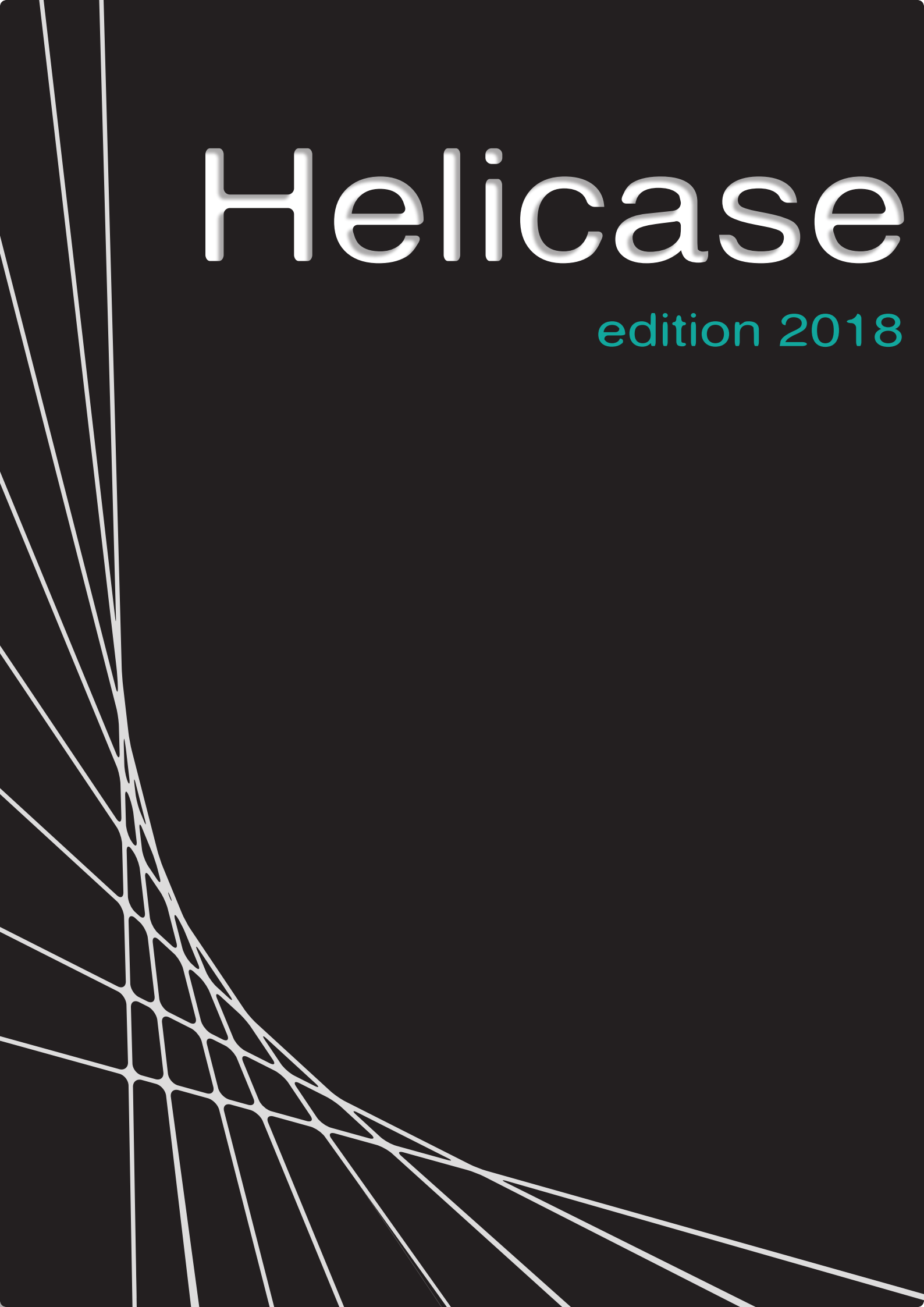




Helicase

edition 2018

HELICASE

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edition no. 3



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Editors' Note

It is with great joy that we present to you the long awaited third edition of Helicase, the bi-annual Science Club Newsletter.

This was possible largely due to the efforts of Sriram Raghunath, 3rd year BS-MS. We would like to use this opportunity to thank Prof. Sachin Jain, for his time and assistance. We would also like to take up this opportunity to thank Prof. M. S. Santhanam for his valuable ideas and advice. We would also like to thank Prof. Neeraja Dashaputre, the faculty coordinator of the Science Club.

Putting together a magazine is a team effort and this would not have been possible if not for our team of editors, Akshay Nair, Purva Joshi, Saismit Naik, Amruta Swaminathan, Kasturi Lele and Shriya Hirve, the previous team of editors, Sriram Raghunath, Bhargavi Parthasarathy, Anjana, Anwesh Bhattacharya, Vishrut Patel, Vikram Ravindranath, Janani A, Nivedhika Kannan, and our designers Shivangi Patel and Ishwari Mulkalwar.

We hope we have been able to deliver to your expectations of the newsletter.

We hope to continue this celebration of science through Helicase and look forward to seeing many more editions of it in the future.

Chief Editors,
Sanjana. M and Devadharsini. S

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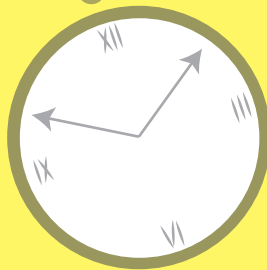
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Unraveling the Ends

Gaurav Joshi, a 2nd year BS-MS student of IISER Pune, gave a brief talk titled 'Telomeres and their role in genome integrity and cancer' on 11th February 2016. The speaker started off with a remark about the rise in cancer rates and the insights that telomeres can provide about cancer development and risk. He then proceeded to talk about the build-up of current knowledge of telomeres through the work of Leonard Hayflick, Paul Moorhead and Alexi Olovkinov. This was made possible by the initial discovery of the structure of DNA by Watson and Crick, and how it replicates by Meselson and Stahl.

The speaker described to the audience the Hayflick limit. It is the limited number of times a normal human cell is permitted to divide, after which cell division stops. Upon reaching this point, apoptosis kills the cells that are undividing. This overthrew Alexis Carrel's prevalent hypothesis that "all cells explanted in culture are immortal..." In 1961, Hayflick and Moorhead experimentally established the Hayflick limit as a credible theory. And about a decade later, Alexi Olovkinov described the end-replication problem that arises as a natural consequence of the way DNA replicates - a section at the end of the chromosomes is lost during each cycle of replication. The repetitive nucleotide sequences found at the ends of chromosomes are known as telomeres, and they shorten with each round of cell division.

Telomeres were considered inert for almost twenty years after the discovery of DNA structure. The speculations made by Muller and McClintok in the 1930s regarding the role of telomeres in the protection of chromosomes and preventing them from fusing or degrading were substantiated by Elizabeth Blackburn and Jack Szostack in 1982, when they demonstrated the ability of telomeres to protect the chromosome ends (using *Tetrahymena* telomeres transferred into yeast). It is seen that the loss of some bases at the end of one strand of DNA causes looping across the two strands that comprise a DNA molecule. This causes issues such as the prevention of detection and interaction with enzymes. It is now known that telomeres prevent this by capping the ends of chromosomes through association with 'shelterin' proteins. Subsequently, the enzyme telomerase was discovered by Blackburn and Greider in 1985. Telomerase, a ribonucleoprotein, adds the repetitive sequence 5'-TTAGGG-3' to the 3' end of telomeres. The telomeric sequences are non-coding and thus protect the essential gene sequences from getting lost during replication. Telomere shortening can occur without repercussions only until up till a critical point (as suggested by the Hayflick limit) past which it can result in genome instability.

Following this, the focus of the talk shifted to the cases where apoptotic response fails to take place in cells past the Hayflick limit. In the words of the

speaker, “The shortening of telomeres beyond the critical point, if not detected by the apoptotic machinery, leads to formation of open chromosomal ends which can fuse with other chromosomes or undergo recombination”. Besides the loss of essential genes close to the ends, there can also occur a fusion of the sister chromatids leading to a sort of bridge formation. This breaks in the next division only to fuse again and on and on. This ‘bridge- break- fusion’ cycle is only one of many instances of chromosomal instability possible due to shortening of telomeres.

The talk concluded with a succinct description of the role of telomerase biology in cancer development and ageing. It has been observed that telomerase levels in cancerous cells are markedly higher than

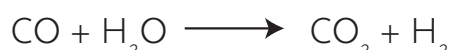
those in normal cells. These high telomerase levels are acquired through random mutations. This is what enables cancerous cells to overshoot the Hayflick limit. Telomerase activity (exhibited in humans only in embryonic cells) is lost progressively as stem cells differentiate, and therefore the lengths of the telomeres shorten with age. Thus ageing can be accelerated through factors that promote telomere degradation such as oxidative stress. A novel method of cancer therapy that has been born out of this knowledge is the class of drugs designed to inhibit telomerases by binding to the RNA sequence of telomerases with the oligonucleotide sequence of the drug. This has shown a lot of promise in its early stages. The talk thus ended on a note of hope.

-Rajaditya Das

DESIGNING MATERIALS FROM BULK TO NANO TO STORE CLEAN HYDROGEN ENERGY

“Storage of Hydrogen energy is one of the most exciting and active areas of present research”, said Prof. G. P. Das in his talk on 12th February 2016, while reminding that we have come all the way from the high carbon past to the low carbon future. He discussed the top 10 challenges we are facing today, with energy being at the top. To give all 10 billion people on the planet the level of energy prosperity people in the developed world are used to (couple of kilowatt-hours per person), we would need to generate 60 terawatts around the planet, the equivalent of 900 million barrels of oil per day. He thus illustrated how energy is the key to solving the rest of our problems from water to population explosion.

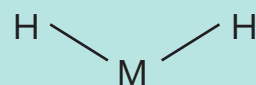
What makes H₂ unique as a source of energy is that it can be produced from different renewable routes and liberates a large amount of energy per unit weight during combustion. Thus, it is environment friendly and the heat energy can be easily converted to electricity by fuel cells.



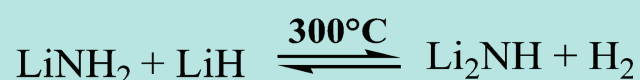
The above equation shows how energy is produced in a hydrogen fuel cell. It involves the conversion of CO to CO₂ (which is less toxic) and also the conversion of H₂O to H₂ which liberates energy.

With the above example, he explained that the production of H₂ is not a major problem. But storage of H₂ is, because it requires either physisorption, chemisorption or molecular-chemisorption. Out of these three processes, as physisorption forces are too weak and chemisorption forces too strong, molecular-chemisorption is the most suitable for storage, where H₂ remains as a dimer.

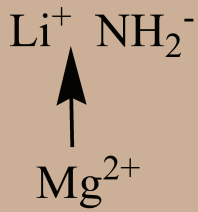
Prof. Das informed the audience that several methods have been developed for the solid state storage of H₂, examples of which are metal probes, different hydrides like AlH₃, MgH₂, TiH₂, and transition metals. Transition Metals dissociate the H-H bond to H⁺ and H⁻.



where M is the transition metal. Apart from hydrides and transition metals, Alkali metals like magnesium can also form bonds with H₂ and help in accessing stored H₂ through desorption (a phenomena whereby a substance is released from or through a surface). One of the synthesis procedures for H₂ is:



The only problem is the temperature. 300°C is too high for any practical purposes. One of the ways to decrease the desorption temperature is to include Mg²⁺.

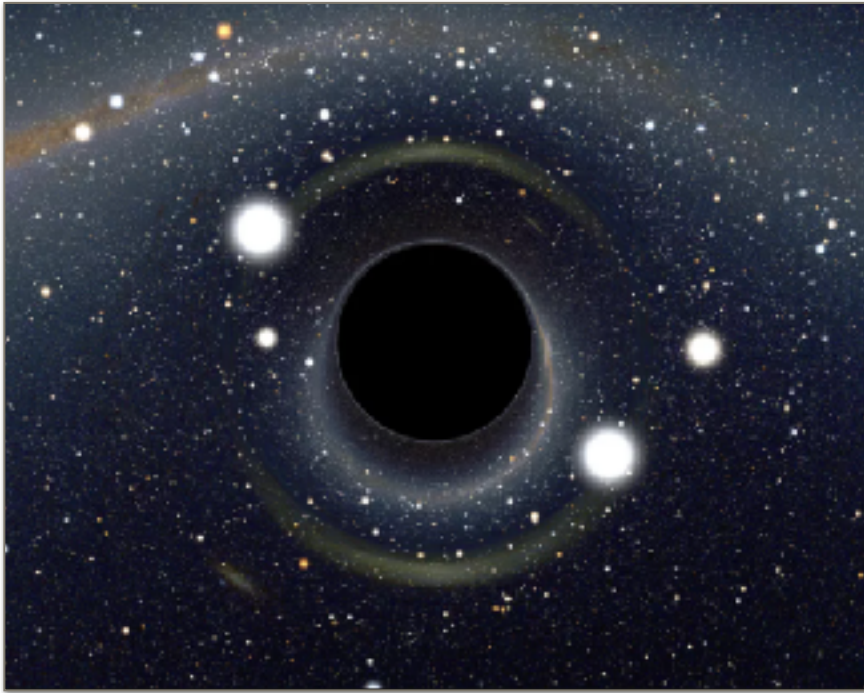


Prof. Das then elucidated how this insertion of Mg²⁺ weakens the bond between Li⁺ and NH₂⁻, thereby decreasing the desorption temperature. He also showed the plot of H₂ desorption v/s temperature by varying the percentage weight of Mg²⁺ which revealed that an increase in percentage weight of Mg²⁺ would decrease the desorption temperature to as low as 370K, and that too for just 30% Mg²⁺. He also stated that recent advances in this field use Ti⁺ decorated Boron-Carbon-Nitrogen (BC₄N) nano composite as the probe for H₂ storage.

Prof. G.P. Das concluded his illuminating lecture on hydrogen energy by stating, “Water is what the environment wants from Hydrogen.”

-Pranavi Reddy

General Relativity and the Future of Gravitational Wave Astronomy



September 14, 2015 was a momentous day for the scientific community, and humanity at large, owing to the first direct detection of gravitational waves that provide evidence for black holes and a binary black hole system. The concept of gravitational waves, which remained in doubt for long, was one of the last predictions made by Einstein's widely acclaimed general theory of relativity. The theory demonstrates how gravity can be considered to be a 'curvature' of space-time, which implies that gravitational waves are ripples in space-time. To discuss the same, the Science Club at IISER Pune organised a series of two student talks

on 17th february 2016 where Rameshchandra Ammanamanchi first discussed relativity and how it predicts the existence of gravitational waves, followed by Anup Singh who described the detection of gravitational waves, the detectors themselves and their future.

Ramesh began his talk by describing how local flat space might be curved globally. If an ant were walking on an apple towards its stem, it would locally be found walking on a straight path, but for an observer outside, it would seem as if the ant was 'attracted' to the stem of the apple, even though there is no physical force that is responsible

for this attraction. Ramesh illustrated that gravity could be thought of as simple geometry! He then went on to talk about why gravity cannot seem to be a ‘curvature’ of just space, but instead of space-time.

Ramesh stated one of Einstein’s experimentally verified assumptions that the speed of light is constant for any observer. From this, one can show that two observers may not agree on the simultaneity of events, and thus on time intervals, speeds, and distances! This sounds absurd, but it has been rigorously tested and verified by experiments. The only things that two observers can agree upon are the speed of light and the space-time interval, which has one temporal and three spatial components. That is why space-time is the basis for the fundamental geometry of the universe. Ramesh proceeded to explain the ‘equivalence principle’, which states that one cannot perform any experiment to distinguish between a uniform gravitational field and a uniformly accelerating frame of reference. Thus, a frame that is freely falling under a gravitational field is identical to one which is at rest in a gravity-free space. After a few logical steps, one can arrive at the conclusion that gravity is not a force, but the curved geometry of spacetime. Before discussing the implications of this model, Ramesh explained some

mathematical concepts like metrics and geodesics. Using these, he elaborated on Einstein’s field equations that relate energy density to the curvature of space-time, and thus predict gravitational waves. With this, Ramesh concluded his part of the talk following which Anup took over to discuss the first detection of the waves, and the future of gravitational wave astronomy.

Anup began by describing non-spherically or cylindrically symmetric accelerations, from which gravitational waves arise. The objects which have such accelerations are supernovae, non-spherical spinning stars and black hole mergers. He further talked about the instruments used to detect them. Since gravitational waves are very feeble, scientists and engineers have developed very sensitive instruments to detect them (LIGO, or Laser Interferometer Gravitational-Wave Observatory), which work on the principle of interference of light. A laser beam is split into two, which are sent down the arms of an interferometer where they undergo multiple reflections and then interfere. When there is no disturbance, the laser beams interfere destructively. However, when a disturbance affects the arm length, the interference is no longer destructive. Thus, this highly sensitive instrument can extract a lot of data from the noise-filled readings obtained. The merger of two black holes, the source of the waves, was detected

independently by two LIGO detectors, one in Louisiana and the other in Washington. More LIGO detectors would greatly increase the detection frequency and accuracy of detection, thus enabling gravitational waves to add to the information obtained from the currently used electromagnetic spectrum. India, being geographically the farthest from the current detectors, is a prime location for building one of these observatories. Anup then demonstrated how the sensitivity would increase after the addition of LIGO-India.

Anup then explained why one should study gravitational waves and what further insights into the universe one may gain by this.

Firstly, they can be employed as a means for the rigorous testing of the theory of general relativity. Gravitational waves are also currently one of the only ways to directly detect and confirm black holes.

Scientists can now use gravitational waves as a new tool to probe into the mysteries of not only black holes, but also the very beginning of the universe, when the dense and violent nature of the universe purportedly created primordial gravitational waves. Perhaps this is the answer to studying the elusive dark matter as well! Anup concluded by saying that the use of gravitational waves as a tool to observe our universe will help physics advance to its ultimate aim of finding the Theory of Everything.

-Rahul Poddar



Science Day 2016

Every year, IISER Pune celebrates National Science Day on the 28th of February to mark the discovery of the Raman effect by Sir C.V. Raman.

The events of the day kicked off in the morning with the second Linus Pauling Memorial Quiz, an initiative by the Quiz Club of IISER Pune. The quiz was open to all students from 8th to 12th standards. The prelims questions were based on a diverse assortment of topics, from recent ones such as the Zika virus and gravitational waves to Turing machines and even lightsabers. The quiz finals included rounds such as 'Infinite Bounce', Visual Connect and Rapid Fire. The team from Vikhe Patil Memorial School bagged the first position.

There was an exhibition of books on varied topics, conducted parallel to the quiz. Disha, the social initiatives club of IISER Pune also conducted an exhibition, but of old journals, magazines and textbooks.

A major event of the day was 'From Basic Science to Social Benefit' a series of talks by eminent scientists expanding upon the role of basic science research in the society. The first talk was 'From Raman to Remedies' delivered by Dr. Chandrabhas Narayana from JNCASR Bengaluru. He started his talk by explaining Raman scattering. Sir C.V.

was the first to detect inelastic scattering, and this gave rise to Raman spectroscopy, and its applications in medical diagnosis and therapy. Dr. Chandrabhas further discussed his own research in which the Raman effect is applied to identify and distinguish between different kinds of HIVs.

The second talk titled 'From Microwaves to Mobiles' was by Dr. Bhas Bapat of IISER Pune. The talk began with a discussion of the early research in electricity and magnetism carried out by legendary scientists like Coulomb, Faraday, Gauß, Ampère and Maxwell, and went on to breakthroughs made in solid state physics and quantum mechanics that have led to the miniaturisation of the now-ubiquitous mobile phones.

The third talk, 'From Darwin to Diabetes' was by Dr. Nishad Matange, also from IISER Pune. He described the contributions of evolutionary theory and genetics research in the development of commercially produced insulin. Insulin used to be extracted from the pancreas of pigs, but this was hopelessly impractical. With the onset of recombinant DNA technology, which has its foundations in genetics, the human insulin gene was cloned into E. coli and thus commercial production of human insulin became possible.

The final talk was titled 'From Primes to Privacy', delivered by Dr. Jaikumar Radhakrishnan from TIFR Mumbai. He highlighted patterns in prime numbers and explained applications of projective planes of prime order in communication technology and about how prime numbers can be used for error correction. The talk concluded with a description of how prime numbers were used for erasure coding which is very

relevant to today's age of cloud computing.

The talks endeavoured to deliver the message that curiosity fuels and drives basic science. Areas of science that do not have any immediate foreseeable applications are not to be disregarded. The speakers thus made their case that society should support research in basic science. All in all, the talks were a fitting end to a memorable Science Day.



Probability Etiquette Guide

K. Sriram, one of the last speakers in Science Club's student talk series in Spring 2016, presented a talk titled 'Probability etiquette guide - How to (mis)interpret probability and statistics', on 13th April, 2016. He said that his talk would deal with psychological biases present when analysing data, not mathematical ones. He began his talk by posing a question and requesting a volunteer from the audience to answer it. The answer led to him introducing the concept of Gambler's fallacy which states that 'if events we consider are independent, the result of one event does not affect the others.'

Post his next question, he introduced 'ANOVA' (Analysis of Variance), which is a statistical method used to analyse the means of two different groups, when stereotyping of the data is involved. He further added that stereotypes are generally formed due to outgroup homogeneity bias, illusory correlation and correspondence bias. His third question involved the choice of a road after considering two roads with different lengths and rates of

accidents. It was revealed that psychologically, if two or more risks are present, people are biased towards completely eliminating one of them, even if the reduction in overall risk is lesser. This is called the 'Zero Risk Bias'.

He then showed that, as the sample size increases, the probability of even improbable events increases very rapidly, by illustrating that the chance that two people in the audience share a birthday increases very rapidly as the number of people in the audience increases.

The final problem of the talk led to 'Bertrand's paradox', which arises because of the sample space not being specified. Sriram explained the paradox by illustrating the multiple answers one gets and the choice of the correct answer from them. He also conveyed that one must be aware of the set of assumptions one makes, which forms the null hypothesis.

He concluded the talk by talking about the representation of probabilities as logarithms of odds and a tongue-in-cheek excerpt from the Xkcd comics.

-Bhargavi Parthasarathy

THERMALISATION after QUANTUM QUENCHING

The last student talk of the semester was given by Shruti Paranjape, a 5th year BS-MS student. The talk was titled "Thermalisation after Quantum Quenching", which was also the topic of Shruti's fifth year thesis. Shruti talked about how quantum systems evolve after a sudden change in the Hamiltonian of the system.

As a large part of the audience was unfamiliar with these terms, Shruti first defined quantum quenching, which is a sudden change in a quantum system that causes it to go from one state to another. The motive of the talk was to see what happens after the quenching; whether or not the quantum system returns to equilibrium. Shruti considered the particular case of the system's mass going from m_0 to 0. But how can mass change? It is neither getting converted to energy nor escaping the system. It is just a theoretical construct. If we consider a line of electrons with different spins placed in a magnetic field, the effect of the magnetic field going from B_0 to 0 is mapped to the mass of a quantum harmonic oscillator going from m_0 to 0.

Shruti then explained why perturbation theory fails to model this system. Perturbation theory is used everywhere in quantum physics, from Zeeman and Stark effects to the hydrogen spectrum, as well as in quantum field theory. Hence any physicist would be tempted to treat the mass perturbatively. However, it is incorrect to do so. The reason perturbation theory works in other cases is that we consider only a small parameter to be changing, but in this case we are considering a change in mass as our parameter and we

have no scale to say whether or not this mass is small. Also, we don't necessarily want to deal with only small mass changes, but any finite mass change.

Shruti then gave an introduction to scalar fields. The Schrödinger equation is not symmetric in space and time; it has a second order partial derivative with respect to position but only a first order derivative with respect to time. This contradicts the special theory of relativity. Quantum field theory solves this problem of combining quantum mechanics and the special theory of relativity. Considering a quantised scalar field as an infinite set of quantum harmonic oscillators at each point in space-time and taking their continuum limit we arrive at a scalar field Hamiltonian that is symmetric in space and time.

A system is said to thermalise if expectation values of operators in the state mimic expectation values of the thermal ensemble asymptotically. To show the thermalisation of post-quench states we need to show that the system in the post-quench state follows a distribution as in statistical mechanics. The quantum system will be thermalised if the thermal expectation value is the linear sum of all states under a Hermitian operator. $(\sum \langle n | e^{-\beta H} O | n \rangle)$ It can be shown using cylindrical geometry (considering space along the axis of the cylinder and time along the circular perimeter) and conformal field theory that post-quench states thermalise.

This highly informative talk ended with an interactive question-answer session.

Where to PARK your SPACECRAFT

The Science Club talk on 22nd August 2016 by Anup Anand Singh was a great start to the semester. A crowd puller, it was based on the classic three-body problem, the realisation of chaos in it and its application in placing satellites at an appropriate position in space.

Anup tried to keep the talk simple, sparing mathematical rigour. He started with the story of the king who came up with a problem on his birthday, announcing a reward for the solver - "In an interacting n -particle system (gravitationally attracting), assuming that no two points are colliding, find the representation of the coordinates of each point as a function of time, which must be a series converging uniformly". It was an extension to the interesting two-body problem, extensively worked on by Newton and Kepler. This problem was very popular at that time because scientists wanted answers to questions such as whether or not the moon is in a stable orbit, whether it has any long term effect on the orbit of the earth and whether the earth will move into the sun or away into outer space if some extra force acts on it. As the general case is very complex, people like Henri Poincaré came up with a specific solution for the dynamics of the three-body problem. His work introduced the possibility of chaotic behavior in a deterministic system. But the orbit he predicted was unstable.

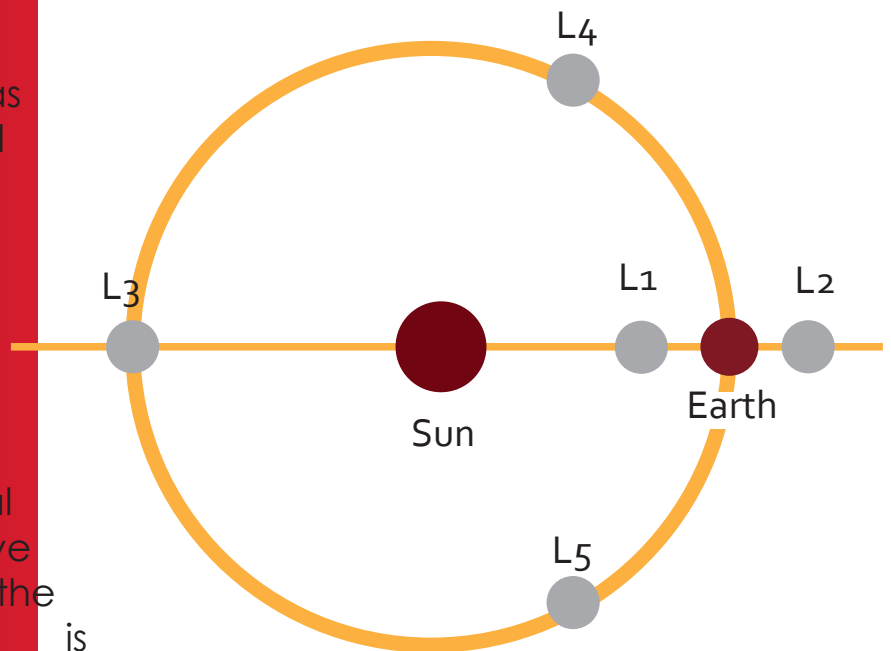
Anup quoted one of the fine interpretations of chaos as, "when the present determines the future, but the approximate present doesn't determine the approximate future." The fate of the system is extremely sensitive to the initial conditions. An infinitesimal deviation from the initial conditions would make the prediction of the future uncertain.

It is interestingly known as SICness (Sensitive to Initial Conditions) of the system. For example, while planning to send a spacecraft into space, we neglect many factors like impact due to other planets and their moons. As the initial conditions involve approximation, the three-body problem is chaotic. So, the intriguing idea is how to find suitable point(s) to place the body in space starting with approximate initial conditions.

Anup presented Poincaré's solution to the restricted three-body problem. As there is no analytic solution, it is solved numerically (by hit and trial method). The final solution is independent of the third mass ($m \ll M_{\text{sun}}$), giving five equilibrium points in space for the small body (i.e. the spacecraft) where it can manoeuvre without any fuel. These points - where the force of attraction between the two larger bodies and the spacecraft is equal to the centrifugal force experienced by it - are known as Lagrange points (L_i) and are the points to park the spacecrafts.

L_1 is a point between the earth and the sun, facilitating study of the sun without any interruption from the earth and the moon throughout the year. L_2 is a point similar to L_1 but in the opposite direction from the sun, suitable for studying deep space. L_3 lies at a point behind sun, opposite to earth's orbit, which would enable us to study solar dynamics, earth forecasts, and deep space. L_4 and L_5 are very stable points where dust and asteroids tend to accumulate. These could serve as points for future space colonies because of their proximity to earth.

Anup showed us different analytically simulated trajectories of systems like the Sun-Jupiter asteroid system, repetitive orbits of idealized planets, and the Pythagorean problem where the initial condition of the system corresponds to Pythagoras' theorem. He talked about the utility of nonlinear dynamics in diverse research fields. The talk was thus a great blend of nonlinear dynamics and astronomy applied to space exploration.



Does *each* Amino Acid *matter*?

The second talk of Science Club was organized on 1st September, 2016. The talk was given by Basila M A, who talked about how and why every amino acid mattered in a protein. She started the talk with the photo of a famous Caribbean writer, Gabriel Garcia Marquez, who suffered from Dementia. She then talked about Alzheimer's disease, a progressive degenerative brain disorder, which can be caused by a multitude of reasons. One of the many molecules implicated to be related to Alzheimer's is a lipoprotein found in some human cells. Lipoproteins are protein molecules which have a lipid attached to them. Their protein component is called as an apolipoprotein. An ApoE is a polymorphic protein containing two hundred and ninety-nine amino acids involved in lipoprotein metabolism and has 3 isoforms – ApoE2, ApoE3 and ApoE4. The three isoforms differ only in two amino acids, present at the 112th and 158th positions, yet have drastically different responses and affinities towards receptors. ApoE3 is the most common isoform found in humans, and out of all the isoforms, only its structure is known by NMR spectroscopy. ApoE4 is considered a major risk factor for Alzheimer's as its presence increases the chances of getting the disease by 50%.

The question addressed by the speaker in the talk was, "How does the difference in amino acids between isoforms affect their interactions with other molecules?" The problem could be tackled using three approaches: Structural Biology, Biochemistry or Computational Biology. The exact effects of the small changes in amino acids were not observable as the structures of the different isoforms were not known. The Biochemical approach was done by quantifying the free energy of denaturation of the two isoforms. Due to the difference of amino acids, the interaction between the two domains may be different, affecting how these protein isoforms unfold. The C-terminal domain of the protein unfolded before the N-terminal domain, and this is measured by adding a denaturant and observing the progression of denaturation using tryptophan fluorescence or using circular dichroism spectroscopy.

During the denaturation of the protein as a whole, only the C-terminal and N-terminal free energy aspects were looked at. The C-terminal has only one α -helix while the N-terminal has four. As a consequence, the C-terminal denatured at only 1 M concentration of the denaturant while the N-terminal denatured at 2 M of the same.

The speaker gave an analogy of a house of cards falling down due to removal of one card, with the unfolding of one part of the protein affecting another. This was tested by comparing the denaturation of the normal N-terminal domain and a Tryptophan-mutant form of the protein. It was observed that Trp-mutant protein unfolds more easily than the normal N-terminal domain, suggesting presence of cooperative unfolding. The speaker stressed on how the change of just two amino acids affected the whole structure of a protein in crucial ways.

This led to a change in the affinity of the molecule to its binding receptor which can lead to further changes, one of which might be crucial for the onset of a complex disease. She also noted that Alzheimer's can be studied at different levels, and many aspects of the disease still make for active research areas. The best part of the talk was in the end, when we saw how a general biological problem is approached and solved.

-Shreya Lakhera

Nobel Evening 2016

On 19th October 2016, the Science Club of IISER Pune organised the ‘Nobel Evening’, a series of short talks presented by eminent scientists on the Nobel Prizes awarded in the year 2016. The C.V. Raman Auditorium saw a huge number of eager students and faculty waiting in anticipation to learn more about 2016’s Nobel awardees and their achievements.

The first talk was given by Prof. Sunil Mukhi about the Nobel Prize in Physics, awarded to David J. Thouless, F. Duncan, M. Haldane and J. Michael Kosterlitz, ‘for theoretical discoveries of topological phase transitions and topological phases of matter’. What they discovered was a new type of phase transition in 2D systems. In normal 3D systems, we see a sudden shift from randomness to long-range order at temperatures below a certain threshold temperature but in most lower-dimensional systems, this model does not apply. Thus, ideally, no phase transitions or long-range order should be found in 2D or 1D systems, which is clearly contrary to what actually happens at low temperatures. Thouless, Haldane and Kosterlitz found topologically stable lattice configurations called vortices and anti vortices which occur in pairs and cause quasi-long-range order in 2D systems at low temperatures. The topological phase transition is caused by the binding and unbinding of these vortex-antivortex pairs. This finding has the potential to

have major implications in future research.

The second talk was delivered by Prof. Nagaraj Balasubramanian about the Nobel Prize in Physiology and Medicine. This Prize was unique since it was awarded for the work of an individual scientist, Yoshinori Ohsumi, ‘for his discoveries of mechanisms for autophagy’. The word autophagy comes from two Greek words, ‘*auto*’ meaning ‘self’ and ‘*phagy*’ meaning ‘to eat’. Therefore, unsurprisingly, autophagy is the process by which cytoplasmic cargo is bound in double-membrane vesicles and delivered to the lysosomes for degeneration. Autophagy was first described in the early 1950s, but it was not until the 1990s that Ohsumi used baker’s yeast (*Saccharomyces cerevisiae*) to find the fifteen genes that control autophagy. He accomplished this by developing yeast cells that lacked vacuolar proteases and found that autophagic bodies accumulated in the vacuoles when yeast was grown in a nutrient-lacking medium. Later, signalling pathways which effectively regulate autophagy were also found. This discovery is of paramount importance as autophagy is one of the underlying fundamental processes of the cell and may have the potential to cure neurodegenerative diseases and cancers. The third and final talk was delivered by Prof. Pinaki Talukdar about the Nobel Prize in Chemistry, which was awarded to Jean-Pierre Sauvage, .

Sir J. Fraser Stoddart and Bernard L. Feringa, 'for the design and synthesis of molecular machines'. In 1983, Sauvage made the first molecular machine, catenane, by linking two cyclic molecules together using a metal atom. One ring could rotate independently of the other enabling the molecule to function as a machine. Prof. Talukdar illustrated this effectively using physical models of these molecules. In 1991, molecules called rotaxanes were synthesised which comprised of a ring threaded on a molecular axle. This ring could move from one station (point) on the axle to another. Using this, Stoddart was able to build a molecular elevator.

In 1999, Feringa made the first unidirectional molecular motor. In 2005, he succeeded in placing the motor on a metal surface, and in 2006, he made a light-driven molecular motor that could rotate material 10,000 times its size. Later, in 2011, he made a molecular 'nano-car' that moved with its wheels' rotation.

In conclusion, as a tribute to Bob Dylan, the winner of the Nobel Prize in Literature in 2016, two students of IISER Pune gave a heart-touching performance of 'Knockin' On Heaven's Door'. The Nobel Evening of 2016 thus turned out to be an enlightening and enjoyable experience.

-Kasturi Lele and Amruta Swaminathan



a hands-on introductory workshop

On the 23rd of October 2016, a one-of-a-kind workshop was organised by the Science Club of IISER Pune. It was conducted by Mr. Ramandeep Singh who is passionate about educating and spreading awareness about the various uses of Arduino.

The workshop took place at the lecture hall complex and comprised a limited number of entries on a first come, first served basis. It was directed at introducing students to open-source electronic platforms based on integrated hardware and software technologies. The participants used Arduino boards to create and control electronic circuits. The software used Python as the programming language, which made usage and following of instructions easier.

The workshop started off with a couple of demonstrations - of the working of robotic joint types, and a functioning miniature humanoid robot. It aimed at teaching the participants how to

manipulate circuits to create gadgets that can interact with the real world in terms of acting as a proxy or a tool, using the Arduino software which was freely available online. The participants began to experiment with the Arduino board starting with a very simple circuit. They put together a couple of resistors and an LED on a breadboard, with the aim of turning the LED on and off.

Then, they edited the program to turn the LED on and off periodically with a time period of their choice. The participants then moved on to learning how to set up alarm systems and implement already available programs for the same. They also learnt that one could integrate all these programs to make systems with more complexity.

The workshop was reported to be very helpful and no one realised how the three hours of the workshop flew by.

-Surabhi K S

UNDERSTANDING THE FUNDAMENTAL LOKI

This semester's third Science Club talk was given by Abhishek Das, a BS-MS fourth year student who specialises in physics and biology and was titled "Understanding The Fundamental 'LOKI'". The talk, given the catchy title and the interesting nature of the topic, attracted a fair and diverse number of students. The talk drew its inspiration from Norse mythology. It etched a correlation between "Loki", a Norse god famous as the ultimate shapeshifter, and a cell, that smallest structural and fundamental unit of life which undergoes morphogenesis in various stages to ultimately determine the fate of the organism. The talk devoted time to the role of morphogenesis in disease before shifting focus to the mechanobiological aspects of cell morphogenesis by using some basic ideas from fundamental physics and pattern formation. The speaker began his talk by stating that changes in cell size, polarisation in the cell and cell migration cause the "shape-shifting" in cells. The speaker then talked about cell microbiology and the function of cytoskeletal elements like actin filaments, microtubules and intermediate filaments as tiny molecular motors within cells that work together with other structural players to coordinate critical cell shape changes.

Abhishek then pointed out the fact that one of the major applications of this research topic is to help understand cancer metastasis, the spread of cancer cells to new areas of the body. He then spoke about how cell growth and cell morphogenesis are governed by the mechanical properties of the actin and microtubule filaments along with biochemical gradient patterning. He also mentioned the experimental techniques used to measure elasticity constraints, namely Traction Force Microscopy, Optical Tweezers, Adhesive Micropatterning Array and Atomic Force Microscopy. Moving on to the core aspects of the talk, Abhishek introduced the Cellular Potts model that helps us determine the direction in which cells will move using Boltzmann weights (which are based on probability). Cellular Potts model is a lattice-based computational technique used for morphogenesis simulations. It models the cell as a deformable object where cell-shape is the result of the combination of internal and external forces which act upon it. Other factors included are cell-cell adhesion forces along with cell-substrate adhesion forces and different signal transduction networks governing the motility of cells. As put by the speaker, Cellular Potts

model basically just looks at the energy of the system and gives us a number that we can associate with the shape. The CPM formalism, based on energy minimisation, allows us to integrate these forces acting at mesoscopic scales into a predefined Hamiltonian. He then talked about the Hamiltonian that will be used for the Potts model and explained the physical interpretation of terms like surface tension, area, Young's modulus and perimeter. The energy that we get from the above Hamiltonian is used in the Potts model to predict cell shape.

Desiring to introduce a chemical gradient which gives a pre-patterning inside the cell (thereby giving a spatial localisation to the chemicals according to the cell shape changes), Abhishek put forward the concept of Reaction-Diffusion Patterning, talking about it with regard to the simulations. Having got everyone a hang of the topic, Abhishek then turned to his own research on the simulation of early cell differentiation during neurite outgrowth using a Cellular Potts Model. The main motive of his project is to improve upon existing models of cell shape dynamics using insights from detailed models of microtubule-motor and actino-myosin mechanics. He then proceeded to explain in further detail about the simulations. In the simulations, we start with an initial shape, input the parameters, calculate the Hamiltonian, and check if it satisfies the acceptance criteria. In case it does, the shape gets updated and new parameters are calculated. These iterations are

performed again and again till there is no further update in the cell shape. In accordance with this, Abhishek then showed us one of his simulation programs in which he started off with a square cell and executed the above algorithm on it. We saw that after many iterations this square cell shape shifted to a circular cell, thus depicting the talk in a nutshell.

Hence, the 2-D model provides a proof of concept for the mechanical forces that are in play during cell growth and cell motility and helps us in identifying key components of such processes along with the quantification of the forces acting on the cell at a given moment of time, and helps to model the dynamic process of shape determination (helping in shape prediction without prior knowledge of final shape).

Finally, the speaker elucidated the future applications of the topic. This model, an implementation of the Cellular Potts Model, if achieved, will allow the evaluation of the shapes obtained to mimic the neurite outgrowth in stem-cell and PC12 cell differentiation. It will also improve our understanding of the mechano-chemical basis of cell shape and provide testable predictions for experimental validation. Moreover, it will give us an insight into the cellular movement during cancer metastasis. The talk was followed by an interactive question-answer session where all the topics were expanded on and discussed, providing a fitting end to an extremely informative session.

-Bhavesh Valecha

Blah Fest – K’16

During Karavaan ’16, on the 5th of November, the Science Events team organised Blah Fest – an event where students from IISER and outside competed to come up with the most absurd, far-fetched hypothesis to account for an everyday observation.

The contestants, over forty in number, ranging from first years to PhD students were all enthusiastic to test their creative and oratory powers. Each contestant was given three minutes to prepare their hypothesis, and three more to present it before the judges, fellow competitors, and the audience.

The observations given ranged from the most obvious, yet bewildering, such as “Why is red

associated with danger?” or “Why do people gossip?” to the most bizarre, like “Why are roses red and violets blue?”. Some participants just did their best to give the listeners a good laugh, while some others were most earnest and serious in their explanations.

However, each speaker proved to be more than a match for his/her topic, and presented delightfully weird hypotheses, well-substantiated with convincing graphs and diagrams. Points were awarded for the scientific plausibility and the effectiveness of the defense of the hypothesis.

The event ended with all those present speculating on and coming up with imaginative answers to why we hypothesise at all. Overall, Blah Fest proved to be a fun-filled experience for the judges, participants, and audience alike.

Science Standup Comedy – K'16

The Science Events team also organised another entertaining event on 6th November 2016, called 'Science Standup Comedy'. The participants were required to perform a standup routine for three minutes on any topic related to science. They were judged on the basis of their sense of humour as well as the science involved in their piece.

The high enthusiasm of the contestants was evident from the fun topics they had come up with to talk about, and their successful endeavors to provide the audience with a good laugh. One of the participants spoke about how professors often use video lectures and lasers to put the students to sleep. Another student kept the audience in stitches by describing how despite being in the fifth year, they sometimes had no idea what their professor was talking about, even when it had to do with their own research project.

As a result, Science Standup Comedy turned out to be a memorable event, and was thoroughly enjoyed by all.

-Amruta and Akhila



INTERVIEW

Prof. Sandip Trivedi

and

Prof. Shamit Kachru

Student:

[00:02](#)

Oh Great. So , so you guys have been working in the field for a long time. So what were your ideas? What are your inspiration behind your joining this field?

Prof. Shamit Kachru:

[00:18](#)

That, that's for me, is a complicated question., But probably my main inspiration is that when I was an undergraduate, uh, I was at Harvard, and at that time there were a number of very old and famous faculty, and there was one very young faculty member whose name was covering Boffa and the very old famous faculty seemed a little bit stuck and the young faculty member was very energetic and was working on things that were extremely mathematical and that was almost a mess with mathematician. So this matched my interests very well and the problems you're solving in physics though in the anti didn't release all of them had to do with the initial singularity in cosmology and uh, the derivation of why there are three dimensions of space and things that sounded very ambitious. And so, uh, I became interested in this both because he was asking very ambitious questions and was still energetic and also because it used the kind of mathematics that I found various, that'd be good.

Prof. Sandip Trivedi:

[01:14](#)

I do not. I came to string theory from particle physics, actually. And so when I was in college, in IIT Kanpur, I had professors who are particle physicists and they were really excited about the standard model. And this'll tell you how old I am, but when I was an undergraduate, you know, the experiment at CERN actually discovered the W and Z bosons that the model predicted. And it was very exciting. And then when I learned more in college about mathematics and Elia group theory, then I found that all of the known particles used to fit very beautifully into representations of Asu Five. And so Dan, etc. Etc.

And that all seemed very beautiful. And then when when I went to, around the time I finished my undergraduation, and I went to do my graduate studies and this new kind of string was discovered a little before that was called the heterotic string and the kind of symmetry structures that you know, people have been seeing in grand unified theories, these groups and so on came out so naturally in heterotic extremes it used to be taught that you don't understand standard model is very peculiar because at the particles are in what are called chiral representation does it handedness. If you take a picture of the standard model and you take its reflection, you will know which world you live in. Neutrinos and, and, and it was taught, it was very difficult to get that kind of matter out of theory which also contained gravity and some consistent way. But that was also shown not to be true at all. And so it just seemed like there was this hope to have grand unified theory. You were all done on particles of the world, came together with gravity in some beautiful, symmetry structure. And that kind of got me interested. And I think it still. I still am slightly partial to the heterotic corner of string theory for this reason. Sherman's actually work more on that than I have, but anyway. Um, I think we very far from that dream today, I think we feel that yes, there are many possible choices in string theory, other corners also very interesting. We don't understand which, if any of them has picked out by nature why and so on. But that's what got me interested in.

Student:

[03:39](#)

You mentioned the string theory. It fascinates a lot of young students and one reason is because it asks a lot of ambitious questions as you've said personally, when I were interested in the field of quantum gravity, and string theory and I would like to know what are the challenges one would face in this field, of course, in every field has its own set of challenges. Do you think, Are there any specific set of challenges in these fields?

Prof. Shamit Kachru:

[04:06](#)

I can give you a very general answer and then have a more specific list of questions that I would love to see answered before I die. Uh, first let me start with a very

general answer, which may now be a peculiar answer from the point of view of our community because I don't hear people talk about it. Um, but if you look at the history of, uh, of, of gravity, of researching gravity, einstein of course invented general relativity and he was a master of thought experiments. And so the way he thought of a lot of the things that he did, was through thought experiments. And so the lesson you might take from that is we should always follow thought experiments to lead us to, to correct thoughts about, about subjects that are difficult. But on the other hand, if you take a deeper look at the history of general relativity, although einstein was said to have, I thought experiments, the equations he was eventually led to with a lot of help from mathematicians. In fact, hilbert first wrote down the equations correctly where those of ramadi in geometry. And if you now look at the history of relativity subsequent to its discovery, uh, the Shortell black hole solution, you know, half of the talk to this conference has been about black holes. They lie at the center of many of our questions about gravity was written down in 1915. If you look at the conceptual understanding of the Shortell black hole solution between 1915 and 1940, everybody who tried to think about the solution conceptually said wrong things. Einstein didn't understand what the solution was. Shortell thought about it as to space time outside of the star. There was a horizon which people thought was a singularity. There's a singularity which we still don't understand today. It took 24 years until oppenheimer and his students understood what the nature of the horizon was. This was 1939. And then of course world war two happened and oppenheimer was distracted with more important things like bowling people. So, um, you know, it's interesting to me that on the one hand thought experiments were crucial and the other hand, once the mathematical structure was there, it didn't lie. And just understanding what that mathematical structure was telling you is what led to our understanding of black holes. Another example in the whole context, Hawking radiation discovered in [inaudible] 74, but it was discovered because of the

deep analogy between laws of thermodynamics and mathematical properties of the space of black hole solutions in relativity. There were worked out by mathematical relativists. So somehow having that structure there lead people to really work hard to interpret correctly what the physics is. And in cosmology, again, there are examples, the de Sitter solution where we probably think we live, we live in an accelerating cosmology. You can look at the history of the de Sitter solution. It was written down around a 1920 by a Belgian priest. Uh, Einstein thought the solution was extremely ugly. Einstein and de Sitter of both thought it described a static universe. In fact, it describes an accelerating, expanding cosmology. And what was right about it was the mathematics. So the mathematics was smart enough. They made you write down the solution. And eventually when people were smart enough mathematically to understand it, it taught us correct facts. Now in string theory, we have much less experimental reason to believe this theory. Even then, Einstein had to believe relativity though there too. There weren't a lot of experimental tests for almost 50 years. There were few, but with string theory, we have really no deep experimental reasons. We have conceptual reasons that reproduces gauge theory, gravity, you know the basic structures we've seen in physics, but we don't have experimental tests, but the other thing that we lack that I think is really important is this analog of Riemannian geometry that will tell us what the correct objects are and will force us to understand them even if we're too stupid at first with our thought experiments to even understand what the theory is telling us, and so I think we're missing a mathematical structure and I don't think. I think in the 1980s many people would've said that. I think today very few people would say that, but I think it's a central issue and I think the history of general relativity illustrates what a central issue it is. Just the confusion over very basic things. That now every first year student knows that it took Einstein, you know, 15 years to understand it. Um, so I think having a proper mathematics will be

important. That as to a list of questions, what are central questions that we would all agree on? A lot of them still centered around black holes. What, what is the nature of, of physics behind the horizon versus physics outside of horizon, how is it captured in holography? Which many of the talks to this conference has been about? Uh, what is the nature of the singularity where higher curvature terms would matter in string theory hasn't really resolved that issue. Similarly in cosmology, there's an initial singularity. What is the nature of that? Can string theory answer that kind of question? And then lastly, there are questions of productivity and experiment . I really had nothing to say.

Prof. Sandip Trivedi:
[08:27](#)

I think that's a very good answer. I don't know. I would say that we are almost certainly at a very preliminary stage, I would say in understanding of the structure of string theory. So I think that's true almost 70 mil understanding much more deeply in terms of a mathematical structure and perhaps more also in terms of its physical structure. But I would say one way to gauge how where we are in a state of understanding is if you even asked the first thing you'd like to ask our theory of quantum gravity, namely, okay, how does smooth spacetime emerge or does it emerge? When does it emerge? We are very far from being able to answer that question, right? That question goes, has another name. It's called the cosmological constant problem, right? Where is the cosmological, the cosmological constant is the scale on which spacetime determines the scale on which space time is crinkled out, right? If you have a theory where there's one natural scale, the Planck's scale you do nothing special, everything will be crinkled up on that scale. That would mean the cosmological constant would be at the planck scale. But we know that we live in a very smooth spacetime. And how does that space times emerge? Do they come out and string theory, we have no idea. We have an understanding of smooth space times, but with the extra symmetry like supersymmetry, which we know in our world are broken at a much higher scale and we do know spacetime way of smoothness on much larger

distance. So that's an example of a question with which I feel we can gauge how far we have come and, and, and so I think we have quite a long ways to go. A shaman says and much exploration to do. But you know, I do feel the reason I feel hopeful about string theory is that the kind of things which in physics we've grown to know and love as tests of theories, string theory does pass in our very crude understanding. For example, as I was telling you, the symmetries of string theory allow us to have the kind of matter we have in the standard model. This is not exactly trivial thing. um, and so there used to be a nogo theorem like this, you know, that in theory of gravity you can't have this kind of matter, string theory met that nogo theorem, then they used to be kind of logo theorem on, whether you can get an accelerating universe of the kind data tells us we live in again and there's a sort of logo theory that some worked that shaman and various other disreputable people did help to overcome and so on and so forth. So I think every time you know, the structure is yet to be understood, but there seems to be some very broad, consistent theoretical structure. They're broad enough to and robust enough to accommodate many nontrivial features of the real world. So that's why I think it's promising. But as Shamid emphasized, I think we have quite a ways to go in terms of understanding and uncovering it.

Student:

[11:23](#)

So this one is a bit different so Professor shamid you have been there in the us for almost all your life, you were born there and studied there and you have been in India for the last 16, 17 years, except for 15 years except for the that gap. So what do you think is a general difference between the scientific community and the way institutions work in the two countries?

Prof. Shamit Kachru:

[11:46](#)

So I think Sandip is actually much better qualified to answer because he's been part of institutions in both places and now he's deeply involved in running maybe the premier institution in theoretical physics in India or I can't say that to your one of the prettier, but I can give observations of course the countries are broadly

different there economic differences. But the central difference that I would say I see between the way american things were organized in and Indian things were organized and this is a difference that, that isn't really just due to economics due to the conceptualization of what training is and what a research institution is a, is that in America almost without exception, with very few exceptions, the sites were great research, uh, is, you know, it gets done and the sites where students are educated, are one and the same. So you don't the, your favorite american universities from us news and world report will be harvard or princeton or stanford. But, but, um, these are also places that, that, uh, you know, so the students come there because they get good reviews from us news. But also the faculty myself apart are our people who do good research and the students get infused immediately. Many of them as sophomores and juniors as an undergraduate, certainly graduate school, both students from the us and many students from abroad get get infused in that culture of research. Um, and, and so, um, there's a sort of a synergistic nature of the cutting edge of research. And the cutting edge of education, the best students automatically go to the places where the best researchers are doing their work. And in India, my, my very limited experience which comes just from theoretical physics, you know, I started coming to India for work as opposed to because my parents would bring me maybe in 1995 or six for the first time and a lot more after 2000 and the places I would go would be hri or he's trying to route or tifr or, or um, you know, there are these indian institute of science I went once. These are institutes that by and large at least until very recently existed so that a research faculty in isolation could do cutting edge research with no distractions, no students, no teaching, nothing to deal with. And for me that sounds ideal, but especially as I get older and lazier, I realized what a crucial role my students and postdocs play. And even getting me out of bed when we get into research time and from the point of view of students weaves an unfortunate situation where all these brilliant kids go to IIT . And I don't doubt

that there are great faculty at iit, but I've heard they have very high teaching loads and so the students are basically sequestered in the indian system from the leading researchers and vice versa until a much later stage. Um, okay. My own guess would be that that's not the best way for me to do my own work. And so it would not be the best way for the system to be organized. Uh, and that's a very solvable problem. All you have to do is stick the institutes in the middle of university campuses. Um, but that would be, I think the weeding sort of administrative difference I see between the cultures.

Prof. Sandip Trivedi:

[11:46](#)

Student:

[14:44](#)

Say again what your question was.

How different do you feel the scientific community under the main institutions function function of course, like in genral the perception towards science in the two countries or the way that dialogues happen between scientists at an american institute versus the one that the one India. So how do you thlnk they differ?

Prof. Sandip Trivedi:

[15:03](#)

So you've asked a couple of questions. So let me try to at least answer them a, break them up and answer them. What, what's the difference between the communities when you know, the indian scientific community I would say is still developing. I think the us scientific community is, is broad. It has, you know, people of very high quality or a large number of them, sustained, of course with a size of a shaman said funding and so on. So we're, I would say we're not at a compareable level in terms of the scientific effort in India, right? That's the first thing to acknowledge, but I think they are on an upward trend. I think, you know, if you compare the country today from where we were at the time of independence, you've already seen it. We have come very far and I think if we can sustain the kind of funding we have and actually grow it, you know, you should do better. India actually puts less than two percent of its gdp into science, science research and this is not a good thing. We must put at least about two percent. If you look at other asian countries, look at South Korea, Japan now look at China. They're

investing much more heavily in science and the reason is simple. You're living in a world where the growth of the economy is going to be coupled to how you make advances in science, how you make discoveries and so on. You've got to invest in science. So India continues on its upward path in terms of growing and scientific and technological infrastructure. I think we will come of age and ultimately hopefully get more comfortable. So that's in general terms where we are, right? Uh, in terms of you had other questions about how we function, I guess. Yeah. So I think Shamid brought up a very good point. I think I also feel this is a key point that, you know, when the scientific effort started. If you look at the Tata Institute itself, a fundamental research, we had research groups and the idea was that we would be more like a national lab or a research lab and teaching wasn't even there as part of our mandate. Then after some time it was realized that that's not a very good model because then what you have to do is create hierarchical groups. Some senior person dictates what some younger scientists do and that doesn't make any sense because in science often the best ideas come from the younger people in the older people are already too old, in a sense like me already. So that didn't make sense. And so you wanted a more sort of level of structure in terms of a research organization then who's going to do much of the work, right? If we reach this by themselves. So you need students. So that's a good reason to have students. Also students or even younger, they're you know creative ideas. Right. So, uh, so we went with that model but it was added on and it wasn't ideal. And so I think it's a good idea. TIFR itself, other research institutions like Shamid said should move towards a more teaching, a kind of orientation. But also we made a new beginning, especially at IISER, right? IISER was not exactly an attempt to correct that. The idea was the IIT model worked well but somehow the, it was more teaching oriented. Let's start something like the IITs but for science and also let's have the load teaching load at a point where really people should be able to do cutting edge research and that's the idea of IISER's we have five already, right?

Student:

[15:03](#)

Two more

Prof. Sandip Trivedi:

[16:34](#)

And two more are going to come. Plus the, iits are are, you know, being ramped up in terms of their research and so on. First of all, we're in the middle of the second biggest growth right? of scientific and technological institutions. Post independence. The government has said they'd be an iit in every state, you know, that's 22 iits, seven iisers. And if we manage this right, that's the challenge. We have to find the quality people manager, right? So make sure we get enough funding for this. Then I think, you know, we would have corrected to some extent, what shamid is saying we will put the bright students who are india's biggest asset. How does India compete with the us, with China? We have compared to China, much lower funding if you look at it and how do we compete? We compete because we have 300, million young indians, china has young students too. americans too, but this is our big strengths that we got to use that put them in contact with good research and so I think we will get there, but we managed things clearly. We can't fall prey. This is the major challenge today. We're also. I can be a little vocal about this. We are also in the midst of a of the meat of, I would say the most significant rethinking of science and its role in society today. Post independence because we were very lucky to have a visionary prime minister like nehru as our first prime minister, extraordinary person by any artistic and someone who clearly understood the importance of science in in a developing society, but also just the importance of irrationalism in thought and the fabric of society. Right, and that's very important actually. I'm very secular person and so. But what's happened is that today some of that thinking in terms of the role of science, should we invest in science for more short term returns or more longterm goals. That's being questioned a little bit. We have to make the case, you know again and again that actually even though science might give rewards in the long run, it's very important and I think the way I would like to say is that we, we need to, we can only be a society which is economically sustained in changing times if we not only build in India ,

manufacturing in India, but also invent and discover in India, if you don't have that part, you're not going to be sustainable. So that message has to go across and that's a big challenge for, for us, but if we can manage that, I think we can look forward to a better, bright future. I do.

Prof. Shamit Kachru:
[21:09](#)

Can I make two more comments? About what he said?

Two things I actually noticed that are quite different between America today and India today. A one he already listed, But I googled iiser today just to find out what the structure of the organization is. So as you said, there's seven iisers, but this one is from 2006. My guess is that means within a period of 10, 15 years, seven of these organizations have come up, all of them elite. All of them planning to hire many leading scientists. Uh, the number of iits was I think five when I was a kid and that's now going to be 22. So in a period of maybe 20, 30 years, India has added order 20 slash 25 elite scientific institutions. I have no complaints about american universities as a whole. But if you will get the derivative, the derivative in America has been, recently, very negative. You know, they're, they're real jewels of the american system. The university of California system, they discovered the cosmological constant. They have many of the first biggest telescopes. They, you know, they, they've just lead the way in so many ways and research. They have been facing huge cuts for 40 years in America, university of Wisconsin for the first time has started to do away with tenure. Now center has been a leading university. So I'm in a certain sense, the great american system of, of, of these universities and research institutes is under siege at a time when it looks like India has a very steeply positive derivative. I'm not happy to say that, but it's very noticeable. And it, it shows up in, if I was your age and I was a student in America, I would be thinking hard about whether science will offer me reasonable job opportunities. If I was your age and I was in India, I would, I'll say this a little rudely, but I think even if I'm only second rate, they're opening so many great universities, I'm going to get a job for sure and it makes a big difference because

that way also first rate. People who have a. Everyone's insecure will be very attracted into science. They won't have to worry that they're gonna spend all their years trying to prove Reiman hypothesis and not get a job and an America. That's a very realistic. The other thing which may go hand in hand with this is my perception of the public view of sciences that in India, it is still very rosy. That there is still deep interest in the public in the idea that fundamental basic questions can be answered, like the origin of the universe or you know, I'm not talking about politicians. I'm talking about the public and in America, both the politicians and the public have, have started to take a more jaundiced view toward science. Many issues that are very clear cut scientific are now political. Uh, evolution is a great example. Climate change is a great example. Um, I don't know to what extent this is going to be a longterm thing in America, but it's very disturbing and I think it is different between the two countries though. First, I know India, much less well,

Student:
[23:52](#)

So, uh, there have been several other approaches to quantum gravity to say, for example, loop quantum gravity, or the emergent gravity picture, that's also, there are many different approaches. And talking about the future in this area, what kind of progress are you guys expecting? Uh, where will it lead us to just seeing the coming few decades?

Prof. Shamit Kachru:
[24:15](#)

My own view would be the sundip put on exactly the right question, which is this question of how one can get a large a large spacetime in a consistent theory of quantum gravity. And um, okay, so in string theory, the theory is very well developed and there's a clear answer for one way to get a large space time and that is you have a space time of supersymmetry and, and you choose the solution very carefully among a very large number of possible solutions of string theory so that it's very super symmetric. And then with no ambiguity, you've got a large space time that space time marina you can see the gravitons propagate and they obey the einstein equations and they can be coupled to a

maxwell fields and other generalizations called ph fields that appeared with the standard model and there could be chiral matter and many, many successes appear in that unrealistic framework. But, but it's unrealistic in a very theoretical way, controlled way. The theory is highly non trivial and it allows that to be the case in many other attempts to do quantum gravity, which I know much less well. Um, I don't see the analogous list of freedom and ingredients. So for instance, in a loop, quantum gravity, when you say we have these basic variables and then out of this spacetime omers, because we have the right kind of a, you know, I don't, I don't even know what the words they use are temps or network or string web or whatever the words are. Um, my first response to anybody who would say, here's my list of widgets. And out of this list of widgets, spacetime emerges and it's big. My question would be, there's something called the cosmological constant problem. It says that without any other ingredient, without some other wave of guaranteeing that space can be larger, the cosmological constant can be small. You'll almost never land on a small cosmological constant. And hence a large space. The curvature of space is tied to the cosmological constant. It must be very small for space to be in string theory. The most honest Answer to that, the one that's rigorous mathematical, he is okay, but with supersymmetry you can do it and everything's unambiguous. And then sundip and others did work on more slightly more speculative, but, but probably realistic situations where the theory allows you to still obtain large space by breaking so, but with some control, with parameters, and you have to worry about the parameters. Do you understand what it is that you're doing in attempts to get emergent gravity that don't have the superstructure of either supersymmetry or some way to tune the parameters that you can see? Um, I don't see how you'd ever get an emergent space. So for emerging gravity, which I think is a central question or the question of how, how large space emerges from some theory, the central question is going to be, how can you do this in a way that's even better than what we can do today in string theory?

Meaning get it in a way that our world is without supersymmetry, without evident dials. But Anyway, it's really theoretically convincing the work in string theory in this direction. It goes under the name of holography. There've been many talks here. The ones that try to get space out of some kind of quantum field theory by emergence still really lacked this key extra ingredient. We don't know how to do it without supersymmetry what supersymmetry we can do it, no problem, but that's been true since 1985 and without supersymmetry and doing it in a really hands on way where you see what it is that allowed the large space to emerge. I think we just haven't gotten there, but I think this is. I went to that example because I think other approaches to quantum gravity or much worse flooding that that is. They can't even do the analogs with supersymmetry. They don't have that freedom. It's not built into their way of thinking and so I think that's, that's what ties, you know, my interests to string theory as opposed to these other approaches.

Prof. Shamit Kachru:
[27:46](#)

what, what, what might be fine in the next few decades. Right. It's a good question. I, I will echo some of what Shamid says and you know, seeing that one of the remarkable developments in the past decade and string theory has been holography and what it has given us, is a deep understanding of at least a string theory or quantum gravity, and asymptotically anti de Sitter space, um, and uh, you know, we have needed all the crutches that string theory provided to come to that understanding of holography, we needed supersymmetry. We needed everything else to have confidence in that statement because it's a very nontrivial statement and all the crutches when necessary for us to be able to check to the limited, but nontrivial extent, you could check it and so on. But after you've checked it enough, you realize that you're looking at a principle which could have more general validity, right? so that's an example of how some of the structures in string theory which are present, which may not be present in the real world, can still help you, understand, deep facts about quantum gravity right now.

What I hope we really do in the coming decade is gain a deeper understanding of how spacetime emerges just in ads contexts, right? We think we have a non-perturbative definition in some cases, um, but we still don't have it totally satisfactory understanding of how this emergent phenomena actually are. The degrees of freedom are living, one less time dimension. They are gauged theories. How does it come out of that? How does this move based on come out of that? So I hope we will understand that we already have a set of criteria that must be met by a field theory for it to be dual to a large spacetime in anti-de Sitter space. Namely should be a conformal field theory. It's a spectrum. Should be of this type its central charge should be large, et cetera, et cetera. Do we have non supersymmetric field theories of that type we don't want today, but it's a question I think we may be able to answer it in a decade or maybe more people are developing tools to understand conformal field theories more deeply. We have many talks here, conformer bootstrap this and that. That will lead to a class of field theories about which we feel confident, so that may be a partial onsite won't be a full on. So because even given it, let's say someone handed you a field theory, met all the criteria. Okay. Still how has this emergent phenomena occur? You're not. You want to understand that a little bit better. So I think. I think there too. You know, we will make progress. There is some, some attempts, mayarah, all of these. I think they're very preliminary but okay. The they are attempting to try and understand this so I hope. I'm not sure, but I hope it will have no progress and if we can do that then of course we hope to go towards the kind of space that we live in and so on. How far we get. Who knows? Nature always seems to choose these very nontrivial and peculiar things. We could have lived in a dS space, much more exciting. Probably, multiverse. It has its own deep reasons, we will discover it in the next decade, maybe we will discover it in the next two decades. I think it's okay because I think we are on a useful track. You know, this is a useful track in which to try and ask about spacetime gravity and so on. We're clearly~ making some progress, but we are clearly, you know, before we connect to nature, there'll be many interesting results. That's okay.

Prof. Shamit Kachru:
[31:32](#)

Actually, can I get to make some quick comments? One is, It's a little embarrassing that there were both physicists. You you are three physics students? At no point did we mentioned experiments as being relevant to what happened in the next year. I'm myself starting in 1995. If you had asked me what would the world look like in 2015, I'd say lac has discovered supersymmetry. The cosmological constant is zero and there's a beautiful symmetry tied to supersymmetry that extends, it explains a lot of cosmological concepts here. Nineteen 98 or 99. The supernova data comes in. The cosmological constant is not only non zero, it's positive, which is inconsistent with exact supersymmetry 2012 to today. The lhc data comes in. Maybe they're super symmetry to factor of five higher than we thought. maybe a factor of 10 higher, maybe not until the pike scale. Maybe never. But, um, the world looks very different than what I thought it would look like. And this is certainly infected a lot of our thinking and the kinds of problems we work on. Um, it, there's every reason to think that this will happen for your generation. You know, the first black holes were coalescing black holes or just discovered that in the last year, even specifically in India, there will be a big project. Maybe we'll learn something very interesting from experiment about that. Uh, it's, it's hard to say where else surprises will come from because the things that surprised me were so far off my charts. I wouldn't have mentioned the cosmological constants of possible surprise. So. So that's one thing that should be said. And the other thing I want to say is beyond experiments. String theory has given faith too many of us practitioners through ties to mathematics. I think we were going to see a lot of more real advances in mathematics. And so I think it's fair to say string theory has so far led to zero Nobel prizes, but it has led to three fields medals in ways that the mathematicians who won the fields, metals with themselves acknowledged. I think there'll be more of that and I think it's great. It's what unfortunately for now is replacing experiment is giving a state.

Prof. Sandip Trivedi:
[33:16](#)

Yeah, I think that's a very good point. Again, you know, I didn't mention experiment. I think my own feeling is that primarily we will try to understand the th-, the theory theoretically, but I think it's a very good point. Then of course, experimentally the situation could become much more exciting. Gravity is a great example and maybe we even see gravity waves from the early universe. That could be very exciting. Maybe we see something else. Non-gaussianity...

Prof. Shamit Kachru:
[33:42](#)

We already did see them with just ensemble.

Prof. Sandip Trivedi:
[33:46](#)

We saw, you know, there was this experiment, the uh, what was it? The, uh, Bisah getting to see it, but that was not quite true. So yeah, but you know, maybe maybe in the future we do see it or maybe you see something in some non gaussianity, whatever. I think there could be all kinds of interesting surprises. It might tie in with our, with our understanding of string theory. The lhc experiment has so far, you know, only shown the predicted in a sense, but who knows, you know, for something I'm developing new methods of accelerating particles based on light lasers and so on, free electron laser, all kinds of lasers. This is an interesting area. Maybe they find a way to build know even higher energy machines that discover something and also the theoretical structures, um, which we find useful. Uh, for example, the ideas of entanglement and how it might be tied to space time. These are things people are only now thinking about but could be very central. They're also crucially tied to how people think about new phases of matter, condensed matter, physics. And so maybe there's a connection there of interest. So, so in this way, because of the interconnectedness of physics and of science, actually I should say mathematics. Shamir better qualified than I am to mention that he mentioned a quantum information theory, computer science. Maybe there'll be all kinds of interesting connections that could be very interesting.

New Speaker:

Thank you

events over the years

2018

MAKING THE SOUND VISIBLE

The Science Club and the Mathematics Club of IISER Pune jointly organised a talk titled ‘Making the Sound Visible’ on 18th January 2018. The speaker was Dr. Sudhir Jain who works in the area of nonlinear dynamics, from the Bhabha Atomic Research Centre (BARC), Mumbai.

Waves and oscillations have always been a topic of great fascination for physicists and mathematicians alike, and the theory of waves, their properties and the phenomena involving them occupy a central position in physics. Besides this, the beautiful patterns of circular ripples produced on a water surface exhibit the undeniable visual appeal of the world of waves. So, a talk such as this one, which nicely incorporated both, the theoretical and the visual aspects of wave phenomena, was definitely one which no one could afford to miss.

Dr. Jain started off by describing a 19th century experiment in which mesmerising and symmetrical patterns [figure at the end] are formed by sand sprinkled on a metal plate when the plate is vibrated by striking it with a violin bow. the frequency of vibration is

a violin bow. As the frequency of vibration is changed, the patterns spontaneously change and it is seen that they tend to get more and more intricate as the frequency is increased. The problem that was of interest to physicists was to calculate how the number of nodal domains changes with the frequency. Dr. Jain then went on to describe how this classical problem is related to the problem of periodic billiards trajectories for regions of different shapes. It is interesting to note that the billiards problem is something that has attracted a lot of researchers, particularly Maryam Mirzakhani, the only female Fields medallist till date, who unfortunately passed away in July 2017. The connection with billiards becomes more prominent when one considers quantum billiards, where the solutions of the Schrödinger equation display chaotic behaviour. What was striking about the talk was the fact that although a lot of sophisticated mathematics is employed in these topics, the speaker did an excellent job of conveying the underlying principles without completely obscuring the mathematics.

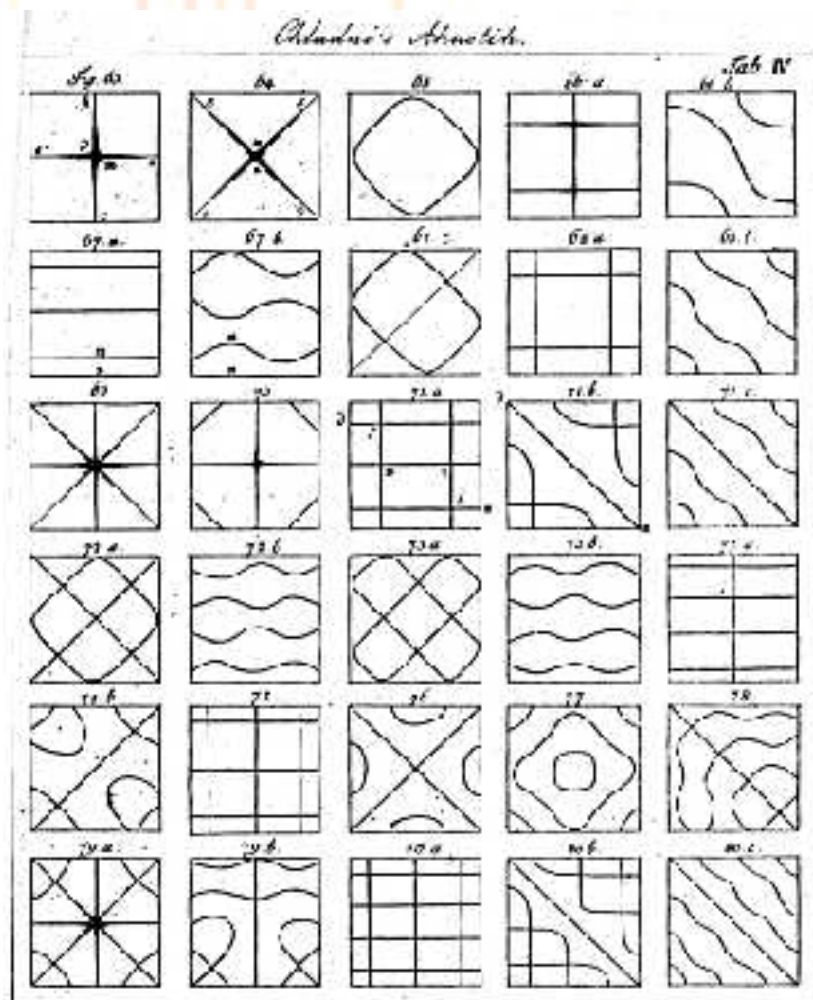
In the next part of the talk, Dr. Jain described a similar problem which goes by the name ‘Can you hear the shape of a drum?’ Posed by physicist Mark Kac, the problem is to determine whether hearing the frequencies produced by a vibrating drum can tell us the shape of the drum. This question was answered in negation in 1992. This problem has been generalised to different branches of physics and

mathematics, such as representation theory.

At the end of his talk, Dr. Jain left the audience with a few open problems whose answers are quite sought after by the physics community and directions to explore. He not just boggled the audience with a few questions but also left them with a lot of curiosity to venture into this fascinating area at the intersection of physics and mathematics.

-Ajith Nair

Figure from - Chladni, E. F. F., 1802, Die Akustik
(Breitkopf und Härtel, Leipzig)



TB or Not TB

On 8th February 2018, the Science Club organised a student talk, titled “TB or not TB - A Diagnostic Tool”. The talk was delivered by the IISER Pune iGEM team who won the silver medal in the iGEM competition. iGEM is a worldwide competition in synthetic biology.

The iGEM team emphasised the relevance of their project by elucidating the flaws in current diagnostic methods for tuberculosis. Most methods are not very accurate, and those which are accurate take a long time to detect TB. As a way of getting around this the iGEM team proposed a new, more accurate, more efficient, less time-consuming and biologically safer TB detection tool.

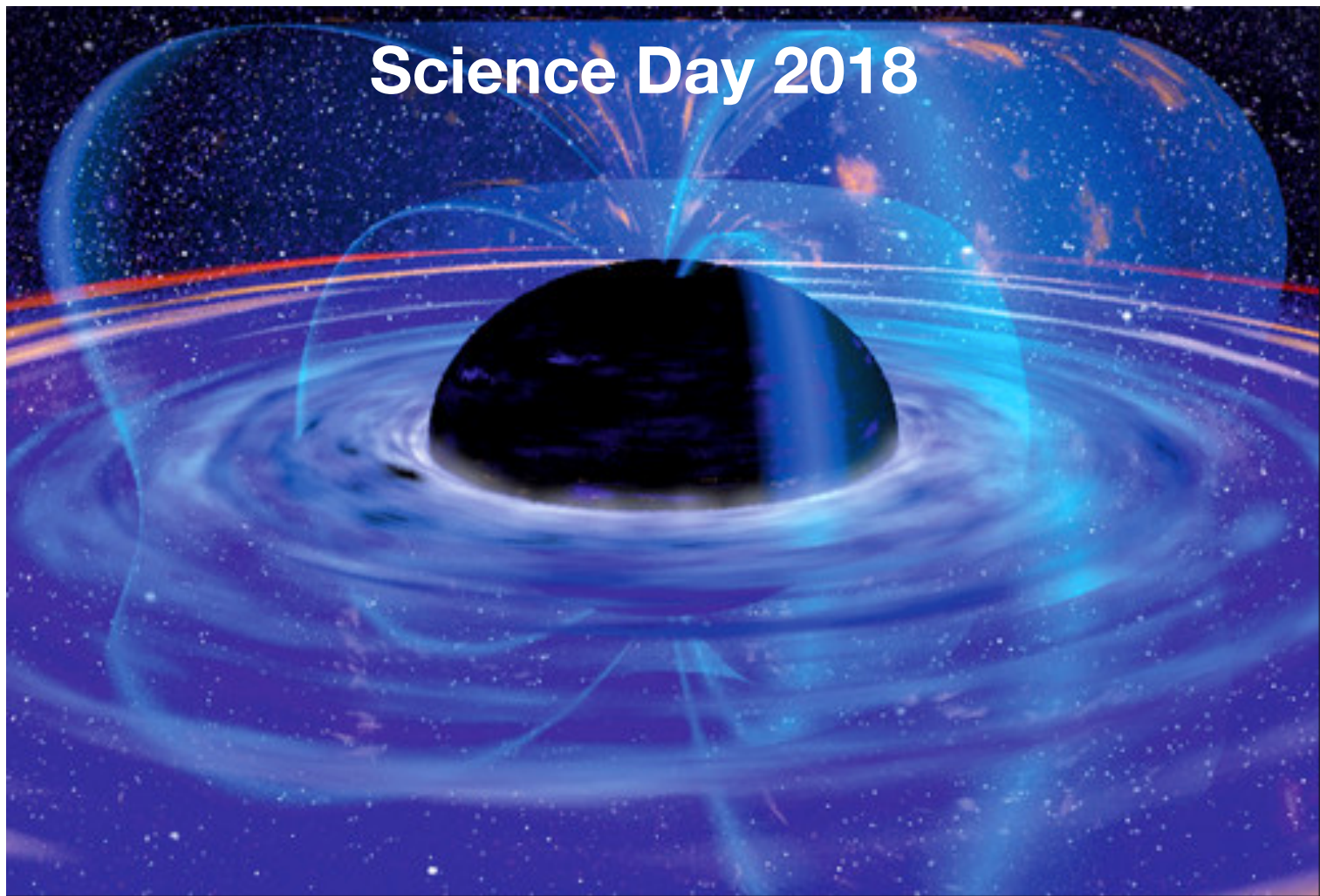
This tool consists of a Bacteriophage module, Hijack module, Detection module and Termination module. The Bacteriophage module involves collection of the patient’s sputum in a specially designed tube which contains growth nutrients and bacteriophages with engineered plasmids. The tube closes irreversibly so that bacteria cannot come out. The next module is the Hijack module which causes bacterial growth by altering their rate of division. For this, the iGEM team designed an oscillator containing DnaA (initiates replication), FtsZ (initiates cell division), and PolA promoter (whose working depends on the concentration of DnaA). The iGEM team used mathematical modelling to check the efficiency of Hijack module.

The Detection module consists detecting TB bacteria by a change in colour. The team explained that addition of a gene that confers a different colour on the bacteria can help detect their presence. The last module in this method is the Termination module. As the number of bacterial cell reaches a certain critical amount, the Termination module ensures the death of all bacteria. For this, the iGEM team proposed a killer gene which gets activated if the concentration of a certain protein exceeds a given threshold. This killer protein is formed by the presence of the corresponding gene on the plasmid itself. As the gene gets transcribed and translated, the protein is formed. Attaining the critical limit activates the killer gene which in turn forms proteins that kill the bacterial cells.

The IISER Pune iGEM team also mentioned their collaboration with IISc Bangalore, the All India iGEM Team Meet-up held by IISER Pune, and the sessions held with school and college students. The team concluded their talk by thanking their sponsors and guide professors.

-Rijyuta Nayan Kaabaadee

Science Day 2018



The first talk as a part of Science Day 2018 was given by Prof. R Shankar from IMSc, titled 'Emergence in condensed matter physics' and was attended by IISERites as well as school students who participated in the Pauling Memorial Quiz. It began on a simple note with a discussion on how complex systems have emergent properties and that they can't be studied by mere dissection, followed by a review of atoms and charge carriers - with emphasis on 'holes'. Prof. Shankar warned the audience that the 'holes' may be

mistook for antiparticles described by Paul Dirac. Then, he briefly explained the Hall effect that helps determine the type of charge on a current carrier by applying magnetic field over it. Experimentally, the Hall conductance in the quantum Hall setup was found to be quantised (discrete-valued). The idea of quantum vortices was able to explain the former, which may be visualised as a curl of the velocity field. These vortices allowed for charges that are fractions of electronic charge, e ! Prof. Shankar also shortly mentioned that the

above concepts and phenomena were further explored using theoretical and experimental ways, like the ideas of fractional charges, quasi-particles and composite fermions. They help to understand 'Strange Metals' as well as possibilities of high temperature superconductivity, which could be a boon for electronics and communication industry. The talk was concluded with a question session that involved questions on fractional charges and quantum vortices.

-Dinesh P R

SCIENCE DAY TALK

Prof. K P Mohanan delivered the third talk on Science Day, titled 'Constructing theories of the structure of language, species, and cultures'. The talk was conducted as an interactive classroom session, where the answers were motivated from the audience and their suggestions written down on the blackboard. He spoke about the need for one to understand the basis of widely accepted scientific theories, so that one can accept them not as dogma, but as a logical conclusion of the observations one makes.

First, Prof. Mohanan spoke at length about what exactly constitutes a theory, asserting that not only does it have to be logically coherent, but also have predictive power. The consequences of the theory may be testable by observational generalisations (or observations that have been reported by several people). Prof. Mohanan then gave the audience an example of scientific theory construction by constructing a theory that our sense of vision is caused by 'invisible rays that come out of our eyes'. He then asked the audience to find loopholes in the theory, and thus pointed out that unless we understand what exactly was wrong with an old, debunked theory, we cannot understand why the currently accepted theory works better. Using the debunked geocentric theory as a specific example, Prof. Mohanan also noted that the many of the predictions made by the geocentric theory match those made by the heliocentric theory, a fact that is glossed over in our dogmatic parroting of "the earth goes around the sun". He gave more examples from similar experiments that he had conducted with school students, undergraduates and postgraduates.

Prof. Mohanan concluded the talk by asserting that as students became more and more 'educated', their ability to think for themselves diminishes, and that there is a need for a change in the education system at its most basic level.

-Kasturi Lele

A Brief History of Stephen Hawking

On March 22, 2018, the Science Club of IISER Pune commemorated the life of a legend through a public talk titled 'A Brief History of Stephen Hawking', delivered by Prof. Sunil Mukhi. Commencing the talk with a song by Pink Floyd featuring Hawking's electronic voice, Prof. Mukhi went on to describe the life and research of Stephen Hawking, and the Strings 2001 Conference where they interacted. The talk was seasoned with Hawking's sarcastic and hilarious quotes that were a defining feature of his personality.

After the song, Prof. Mukhi discussed Stephen Hawking's PhD thesis, a phenomenal piece of work in itself, which shed a lot of light on the history and the properties of the universe. The next few years of Hawking's research on cosmology changed physics forever. Prof. Mukhi gave a non-technical description of this work on singularity theorems and gravitational waves. He then went on to talk about Hawking's work on one of the most mysterious and elusive objects in the universe - black holes. One of the gems of Hawking's work was the concept of Hawking radiation (the radiation emitted by a black hole), which resolved an apparently paradoxical implication of the properties of black holes that seemingly violates the second law of thermodynamics - the black hole information paradox. While the second law of thermodynamics is not violated by black holes, it has been argued that as black holes radiate, eventually evaporating, the information which falls into a black hole is apparently lost forever. Hawking radiation seemed to be almost entirely thermal in nature, seemingly random and informationless, thereby giving back no information to the universe. Prof. Mukhi stated that this issue hasn't been completely resolved and Hawking had published a paper on this problem as recently as 2016.

Prof. Mukhi also talked about Hawking's personal life and his own memories of meeting Hawking when the latter visited TIFR Mumbai for the Strings 2001 Conference. He also talked about Hawking's views on varied topics ranging from religion and intelligent life to Brexit. Prof. Mukhi concluded his talk by narrating a series of funny incidents from Hawking's life and mentioning some of his comments that left the audience laughing at Hawking's rather distinctive sense of humour. To quote Prof. Mukhi, "And now we're near the end and I think it's a good thing to celebrate the life of this great person by laughing at his jokes; I think he would have liked it."

"Consideration of black holes suggests, not only that God does play dice, but that he sometimes confuses us by throwing them where they can't be seen."

- Stephen Hawking

-Adarsh Srinivasan and Shriya Hirve

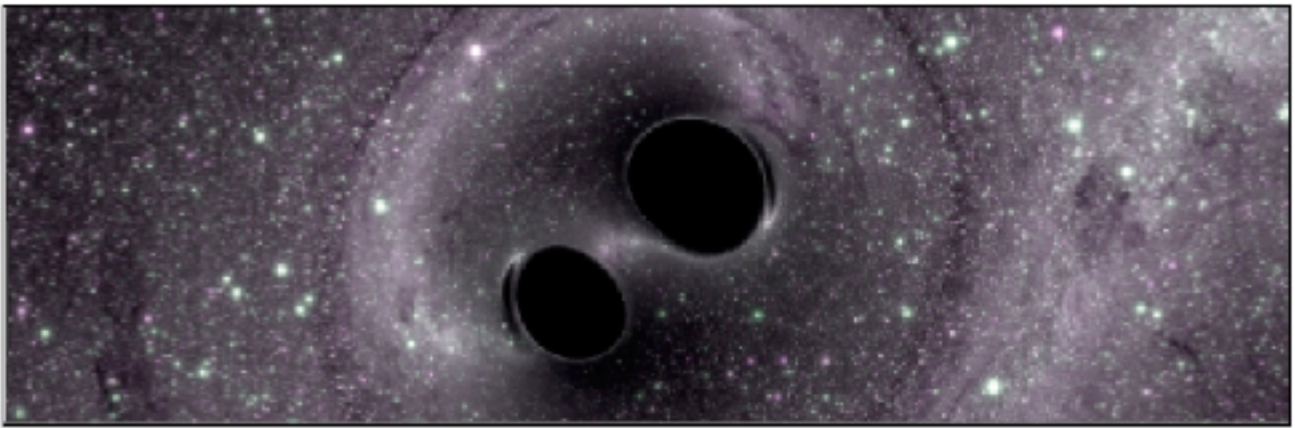


insight

The Era Of Gravitational Wave Astronomy

As Albert Einstein described in his general theory of relativity, gravitational waves propagate at the speed of light, filling the universe. They are created when a mass accelerates, for example when a pair of black holes rotate around each other. Einstein was

far, all sorts of electromagnetic radiation and particles, such as cosmic rays and neutrinos have been used to explore the universe. However, gravitational waves are direct testimony to disruptions in space-time itself. This is something completely new



convinced that it would never be possible to measure the characteristics of gravitational waves. On February 11, 2016, the Laser Interferometer Gravitational Wave Observatory (LIGO) announced that they had observed gravitational waves. By using a pair of gigantic laser interferometers, they measured a change of an order thousands of times smaller than an atomic nucleus, as a gravitational wave passed through the Earth. A little over two years after the first direct detection of gravitational waves by LIGO, the Nobel Prize committee awarded the 2017 Physics Prize to Rainer Weiss, Barry C. Barish, and Kip S. Thorne for "*decisive contributions to the LIGO detector and the observation of gravitational waves*", a project which ran for decades. Their results verified the general theory of relativity proposed by Einstein roughly a hundred years earlier.

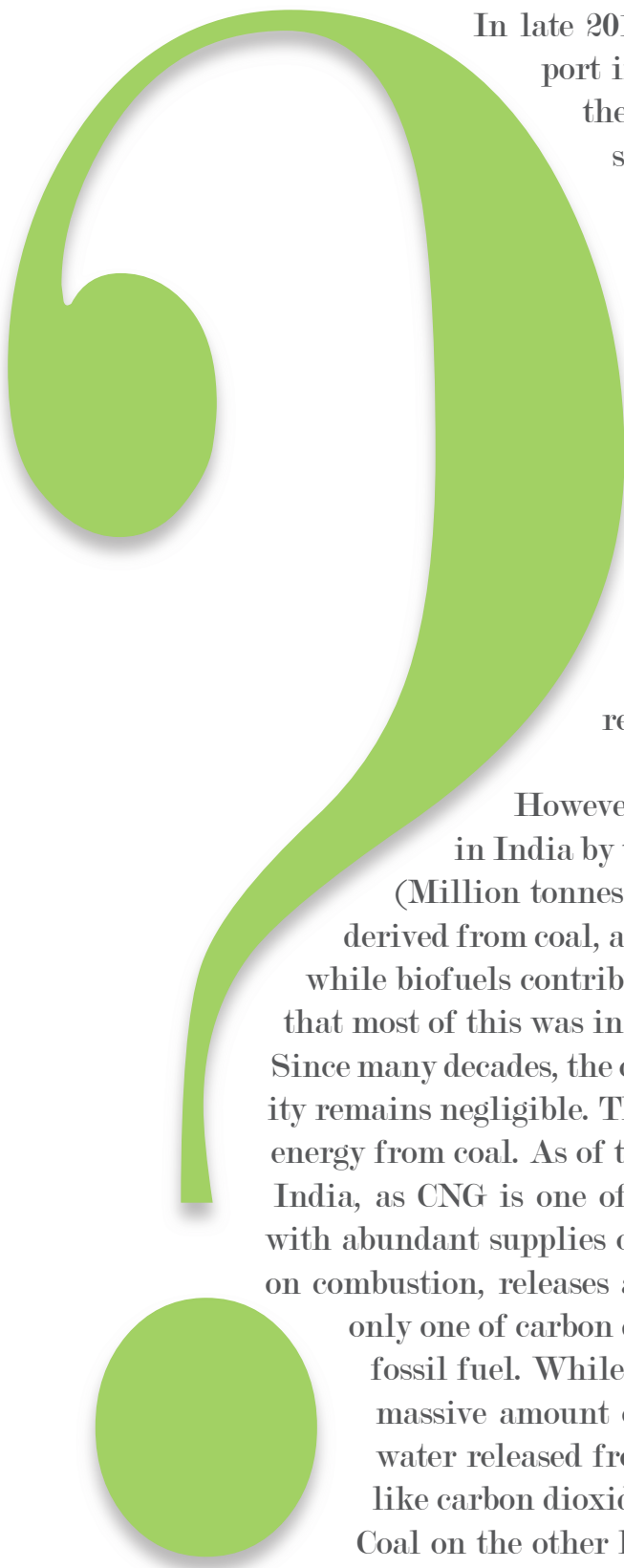
Gravitational waves are an entirely new way of observing the most violent events in universe and testing the limits of our knowledge. So

and different, opening up unseen worlds. A wealth of discovery awaits those who succeed in capturing the waves and interpreting their messages. Though the signals are extremely weak when they reach the Earth, they promise a revolution in astrophysics.

The proposed location for the third site of LIGO's detector is in India and has been named IndIGO (Indian Initiative in Gravitational Wave Observations). The addition of a new detector to the existing network will increase the expected event rates, and will boost the detection confidence of new sources. It will also serve as an opportunity for enthusiastic Indian scientists to work in the field of gravitational astronomy in their own country.

-Onkar Sadekar

Is zero emission really clean?



In late 2017, the Brihanmumbai Electrical Supply and Transport introduced zero emission city buses on select routes in the southern business district. BEST claims that this is a step forward in eco-friendly travel from the otherwise abundant compressed natural gas (CNG) operated vehicles. The Mumbai Metro Rail Corporation Ltd. suggests that the under-construction Line 3 of the Mumbai Metro will take around 4.5 lakh vehicles off the roads of Mumbai. This is touted by many as a big step towards curbing increasing vehicular air pollution. On a much bigger scale, the Indian Railways plans to completely electrify India's rail network, and to scrap diesel locomotives within three years. Apart from saving money spent on diesel, the Railways also suggests that this move will also positively affect the environment in terms of reducing diesel emissions.

However, a look at the percentage production of energy used in India by the various sources suggests otherwise. Of the 724 Mtoe (Million tonnes of oil equivalent) energy used in 2016, about 59% was derived from coal, an increase from the 44% of 775 Mtoe in 2013. Moreover, while biofuels contributed about 20% of the total energy consumed, we know that most of this was in the form of cooking fuel and other largely rural uses. Since many decades, the contribution of nuclear energy to the produced electricity remains negligible. This means that electrified transport is largely deriving energy from coal. As of today, coal is a bigger problem than diesel and CNG in India, as CNG is one of the cleanest hydrocarbon fuels and India is blessed with abundant supplies of it. The main component of CNG is methane, which on combustion, releases a whopping two molecules of water in comparison to only one of carbon dioxide - the best water to carbon dioxide ratio for any fossil fuel. While water is also a greenhouse gas in its vapour form, the massive amount of water on the planet makes it easier for the excess water released from emissions to be budgeted. Also, water is not acidic like carbon dioxide, which is absorbed by the oceans in large quantities. Coal on the other hand, is pure (rather, very impure) carbon. It is absolutely dehydrogenated and the major combustion product is carbon dioxide, along with healthy doses of carbon monoxide and sulphur oxides.



All this sums up to the fact that various government bodies and environmentalists are replacing vehicles which emit throughout their geographical reach with devices that do not emit as such, but whose working requires localised emissions that are far more toxic and cause global warming. The transmission losses of this coal derived electricity should also be carefully weighed against the transport costs of diesel and CNG.

However, in the long term, these efforts might actually pay off. Developed countries like France and Belgium derive between 50 and 70% of their energy from nuclear plants. While nuclear plants do pose a reasonable risk to neighbourhoods around the plant itself, emissions and warming at a global level are taken care of. India is blessed with the largest deposits of both thorium and uranium - fuels that cannot be neglected in an age of increasing awareness against global warming. Nuclear energy is also capable of providing energy at a constant rate to the grid (unlike solar energy), so the problem of fluctuating voltages which the grid is incapable of dealing with, takes care of itself.

Although its disadvantages are numerous, coal derived energy comes at a fraction of the cost of nuclear energy. With more and more evidence that the emissions of countries follow a Kuznets curve with respect to their prosperity, it is only foresight that prevents the Department of Atomic Energy and the Nuclear Power Corporation of India Ltd. from investing their huge funds into a massive nuclear power programme. In a few more decades, this investment will be inevitable. Today, the nuclear power bureaucrats bide their time in order to allow a rapidly growing India to access the cheap, albeit polluting energy derived from coal. In simpler words, electrification of transport today should only be bought with a promise to invest in alternative fuels tomorrow.

-Siddhartha Sohoni, with various inputs from Aritra Lahiri, Vikas Rastogi and Milind Sohoni.

BOUNDED GAPS BETWEEN PRIMES: MEANS TO AN END

The twenty-first century is undoubtedly an exciting time for those who follow prime numbers. Several mathematicians, either working in solitary spaces by themselves or as members of international collaborative teams, have put forth interesting facets of prime numbers that have evaded the most laborious efforts of the last two centuries. These developments cover various aspects of primes. In this article, we focus on one such aspect, namely, the gaps between consecutive primes.

Let us begin by listing the first few primes: 2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 47, 53, 59, 61, 67, 71, 73, 79, 83, 89, 97, 101, 103, 107, 109, 113, 127, 131, 137, 139, 149, 151, 157, 163, 167, 173, 179, 181, 191, 193, 197, 199, 211, 223, 227, 229, 233, 239, 241, 251, 257, 263, 269, 271, 277, 281, 283, 293, 307, 311, 313, 317, 331, 337, 347, 349 and so on.

In this list, there are a few things that we immediately observe. Firstly, other than 2 and 3, no two consecutive primes can differ by 1, or for that matter, by any odd number. The reason is that other than 2, a prime is necessarily an odd number and adding an odd number to another odd number yields an even number which is decidedly not prime. No rocket science there!

We also notice that the gaps between two consecutive primes seem to oscillate! For several pairs, we have a gap of 2 which gradually increases to 4, 6, 8, 10 and so on, but keeps jumping back to 2. This pattern seems to repeat itself several times, even in the limited list we have above, motivating the following questions:

- 1) As the primes grow larger and larger, can we have infinitely many pairs of consecutive primes with a gap of 2?
- 2) Does there come a stage beyond which the gaps increase and do not fall back to smaller numbers?
- 3) Can we predict how large the gaps can be at any stage? Can there be gaps much larger than the average gaps up to that stage?

The twin prime conjecture is the assertion that there are infinitely many pairs of consecutive primes with gap 2. This is a special case of the more general 1849 conjecture by the French mathematician Alphonse de Polignac. This general conjecture states that for any even number k , there are infinitely many pairs of consecutive primes with a gap of k . This

conjecture, if proved, would immediately address the first two questions (yes to the first and no to the second). The third question smoothes out the first two questions: if we do not have specific answers about gaps, can we say something "on average"? The philosophical question behind all of the above is whether the spacings between the primes behave like those between randomly generated numbers, or follow some pattern.

Mathematicians have grappled with the above questions in various ways, either by trying to understand them as special cases of a general phenomenon or by trying to formulate more precise conjectures from available data. It was only in 2005 that three mathematicians, Goldston, Pintz and Yildirim made a remarkable observation that brought us a little closer to solving the twin prime conjecture. They showed that there are infinitely many pairs of consecutive primes with gaps arbitrarily small relative to the average gaps between consecutive primes. The question that now remained was whether we could have infinitely many pairs with the absolutely smallest possible gap, namely, 2.

In 2013, a reclusive mathematician called Yitang Zhang from the University of New Hampshire made a giant stride in this direction: he announced that there is a number n less than 70 million such that there are infinitely many pairs of consecutive

primes with gap n . At first sight, to the layman, 70 million may come across as a ridiculously large bound. But that is not how the experts saw Zhang's theorem; instead, they recognised it as the first instance where an absolute and explicit bound had been found for infinitely many pairs of primes. Stunned and impressed by Zhang's first step, the mathematical community challenged itself to reduce the gap from 70 million to 2! Thus started the international Polymath8 project with several contributors, some of the notable names being Terence Tao and James Maynard. As of today, the bound has been reduced to 246. Is it just a matter of time before 246 can be brought down to 2? Or does 246 represent the limit that can be obtained using current knowledge? Will further reduction of the bound require completely new insights? We do not know.

While the mathematical community as a whole continues to attack the twin primes problem and will not be at ease until a complete answer is found, our understanding of the ideas and techniques behind the bounded gaps conjecture can widen in various ways. One such way is to understand and practise the technique well enough to apply it to other related problems. In other words, we concentrate on the means to the end rather than the end itself.

This is precisely what was done by a former student of IISER Pune from the BS-MS 2007 batch, (now) Dr. Akshaa Vatwani. In her Ph.D. thesis, Akshaa

asked an analogue of the twin prime question, for what are called Gaussian primes. Gaussian primes are prime numbers which can be written as a sum of two squares. For example, 5 can be written as the sum of the squares of 1 and 2. Similarly, 13 can be written as the sum the squares of 2 and 3. Akshaa pushed the techniques of Zhang, Tao and Maynard to show that there are infinitely many pairs of distinct primes of the form $a^2 + b^2$ and $a^2 + (b + h)^2$ where h is bounded above by 246, the same bound that has been found for gaps between infinitely many pairs of consecutive primes.

The journey towards proving the twin prime conjecture continues. And it is a demonstration of the principle that holds true for all human endeavours - it is not merely the destination that matters, but the knowledge that one gains and refines on the way.

- Kaneenika Sinha
Assistant Professor, Mathematics

WHERE ARE THE **BOUNDARIES** DEFINED?

The 2017 Nobel Prize in Chemistry was awarded to three biophysicists for their contributions to cryo-electron microscopy. Surprised? It is no longer possible to draw distinct lines between different disciplines.

With each passing year, it is only becoming more necessary to integrate concepts and techniques from “different disciplines” in order to understand the way the world works in greater depth. This is because the complexity that we are dealing with at the current depth can only be understood by studying the various aspects of phenomena and at different levels of organisation in systems, which requires expertise from different fields.

Unlike in the beginning of twentieth century, when scientists worked in isolation, we now see collaborative science. We are in need of new, cutting-edge technology and equipment, large computational power, and data analysts to analyse the huge amount of data that is being collected. This automatically demands collaboration among the sciences.

The systems approach to biology or the earth sciences is a shining example of interdisciplinary science. Common characteristics of complex systems are emergence, non-linearity, and feedback loops. The earth and climate sciences study systems with feedback loops and multiple interactions between their components. This calls for an interdisciplinary approach. For example, to find out how the Himalayas were formed, a knowledge of the chemistry of rocks, the physics of interacting bodies, the effect of life, and the mathematical tools to build models is needed, along with proficiency in experimental techniques.

The biology of systems poses a similar scenario. Various cellular functions are at the

confluence of many molecular signalling cascades, regulatory networks (which consist of feedback loops), cross-talk between pathways and more. To deal with these, powerful imaging techniques, data analysis, molecular biological experiments, mathematical models, and computational models are required.

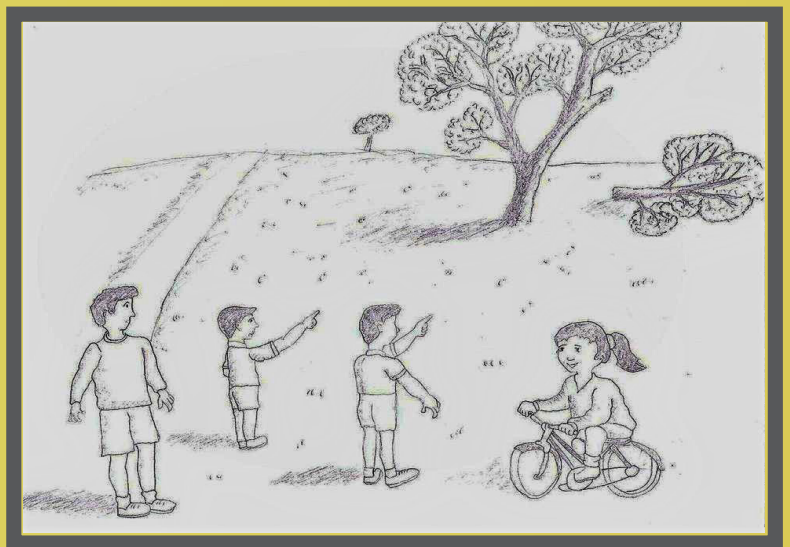
IDC or interdisciplinary courses are gaining popularity in renowned colleges and undergraduate schools. This marks a sort of shift in the paradigm of how we do science. At some level, the whole concept of having rigid boundaries between various disciplines just melts away. And the only question that remains is, “Where are the boundaries defined?”

-Sahiti Chebolu and Onkar Sadekar

enigmatic entropy

One day, my seven-year-old son Richu was playing with his friend Loy, a year senior to him, in the garden downstairs. Tani, a five-year-old girl, was riding her bicycle. IISER students were playing in the adjacent football and basketball fields. It was a nice orderly atmosphere. Suddenly, we heard a cracking sound. One branch of a roadside tree fell on the ground. People went rushing towards it. There was some raucous noise. Fortunately, nobody got hurt, except that for a brief moment, the orderly peace was slightly perturbed. Richu was engrossed in his own endeavour to kick the football over the fence and did not notice what happened. So he called Loy and asked, "Hey Loy, what just happened?" Loy, being a connoisseur of classical thermodynamics, replied, "There was a sudden increase in entropy. But now, it has decreased again". Tani was just passing by. She, being an inquisitive girl, asked, "Do you

mean that entropy increased and decreased? But, I heard that it always increases!" Loy said, "Increase in entropy comes with two conditions: first, the process needs to be non-equilibrium and spontaneous, and second, the increase of entropy is appropriate only when we consider



both the system and its surroundings".

Richu said, "What is the system and what are the surroundings here?"

Loy said, "System is what we observe. For example, in today's event, the system was our premises whereas the surrounding was everything else, such as the environment. To bring things back to normal, some people needed

do some work, which converted their internal energy as heat to the environment. The tiny gas molecules picked up the heat and thus entropy got increased without our notice."

Tani then came up with another brilliant question. She asked, "Does it mean that entropy of the universe will always increase no matter what we do?"

Loy said, "Indeed! The entropy of the universe is a non-conserved quantity that always increases for every process happening within it. For anything to happen within the universe, its internal energy does some work. If the work is done in a non-equilibrium way, then some heat gets generated, increasing the entropy of the surrounding. You see heat and entropy are related. Since internal energy and temperature are related, the work done at the expense of the internal energy also reduces the temperature. You know, our universe was very small and very hot (hundred nonillion Kelvin) initially. Now, it has expanded to thousands of light years and cooled down to just 2.7 Kelvin."

"Then how about taking the heat from the environment and doing work?" Richu asked.

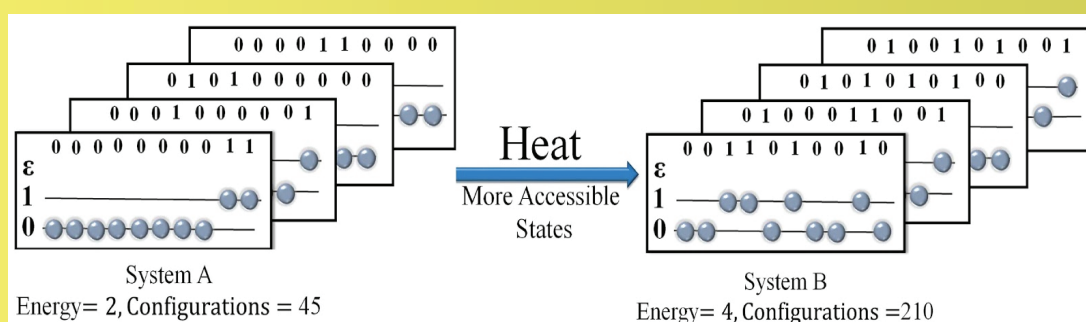
Loy said, "The problem is that heat flows only from a region of high temperature to a region of low temperature.

Therefore, one can get some work done only till an engine reaches the same temperature as the surrounding. So the engine will run for only one step without increasing the entropy. If you want continuous work being done by a machine, then Sadi Carnot showed in the seventeenth century that entropy would increase."

Tani now asked, "By the way, one thing is not clear. What is the role of entropy and why does it matter?"

Loy replied, "The entropy is important because any change will take place only along the direction of increasing entropy. Why? I don't know."

Ayush was away for the whole time. He saw these people in conversation and came running, "Hey guys! What are you doing?" All of them said, "We are discussing entropy".



Ayush said, "Oh! That's so simple. It is nothing but a measure of possible configurations that a system can assume". For example, when we heat system A, it becomes system B.

Since system B has more configurations than the system A, it has higher entropy.

Oh! I forgot to tell you that Ayush, the little eight-year-old, is a specialist of the statistical approach of thermodynamics.

Ayush said, "Entropy increase is favourable because entropy is a probabilistic measure. Entropy increases because the number of possibilities increases."

Richu asked, "Do you mean to say that the tree fell down just because it was more probable to fall down?"

Ayush said, "Yes!"

Richu, being a person of sound classical mechanical background, was puzzled. He dissented, "I thought that the fall of the tree or anything for that matter should be due to gravity. Where is the entropy coming into the picture? If something falls down, potential

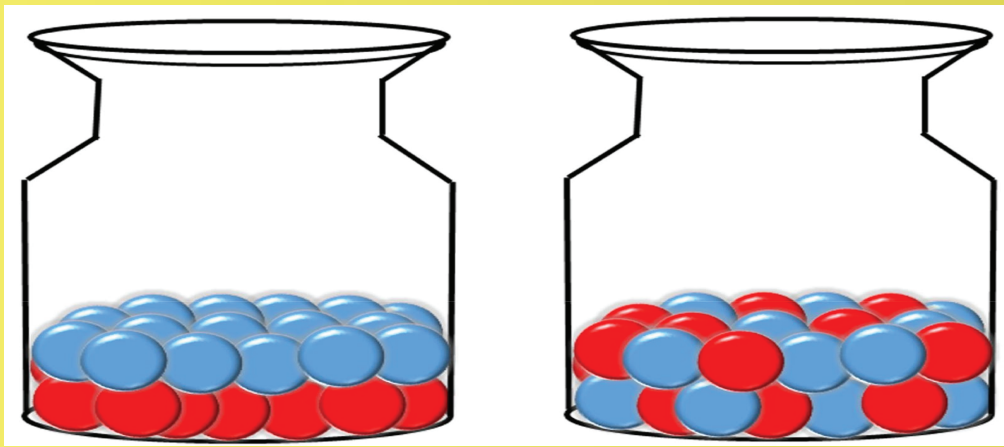
energy decreases and therefore it is more favourable."

Ayush replied, "Then you must know that potential energy gets converted to kinetic energy and the kinetic energy finally gets dissipated to the environment as heat." Richu agreed.

Ayush said, "Where does the heat go? This heat allows particles to access higher energy states, thus increasing the number of possible configurations the particle can take. That's what we regard as the increase in entropy."

"Wait for a second!", everybody shouted at once. "You are not making sense. What has randomness got to do with more accessible states?"

Ayush then explained, "Take, for example, a jar of blue and red colored marbles. If you place them in such a way that all the blue marbles are at the bottom, and all the red ones are at the top, then you would say that the entropy of the jar is low. You will say that it is less random. I will say it is because there is only one way to do so. Now, if you mix the marbles, then suddenly there are so many possible ways to mix them. We call it a



random mix of red and blue particles. You will then say that entropy is high. I say that the number of possible configurations of this state (the mixture of blue and red particles) is high, so is the entropy. However, if you pick up a specifically mixed jar, then again there is only one way to do so and the entropy is again low. Therefore, assuming that the marbles are continuously mixing (which happens only for small molecules at normal temperature and pressure), we say that the entropy is high. It is the POSSIBILITY that matters. If you keep a particular randomly mixed jar of blue and red marbles, it will remain in that state forever. Therefore, the entropy of that particular state is low (in fact, zero)."

Ayush then told them that the person who proposed such a relation between number of possibilities and entropy was an Austrian physicist, Ludwig Boltzmann, although nobody believed him at that time.

"The number of accessible states lets us think of entropy at the molecular level," Ayush explained, "Let's take a small gas particle like a marble but with a radius of $3 \text{ \AA}$ inside a cubic box of length $10 \text{ \AA}$. This particle will move continuously in the box due to temperature.

Remember the relation, $\frac{1}{2} mv^2 = kBT$. So higher the temperature, higher is the velocity. Heavier the particle, lower is its velocity, at a fixed temperature. Therefore, a big particle like a football will not seem to move on its own, but a molecule will. This apparent movement results in entropy production. We call this translational entropy. One can show that if the box becomes bigger, entropy will be higher because of many more possible places inside the box where the particle can go."

Richu said, "Philosophically, then it means that higher the number of possibilities, higher will be the entropy". Ayush continued, "This entropy is also higher

when the temperature is higher or mass is higher. Rest of the quantities do not matter."

Tani asked, "Are there kinds of entropy other than translational entropy?"

Ayush said, "Yes. If there are two particles and both the particles are moving all across the box, entropy will certainly be double. Now imagine that these particles collide and get glued together. Will there be entropy loss? Now it becomes a diatomic particle, much like two H atoms combining to form H_2 . These two particles were moving independently. Now there is only one particle. So, certainly there will be a loss in the translational entropy. However, new types of entropy such as rotational and vibrational entropy will emerge because this diatomic particle can now rotate and also vibrate, unlike a monatomic particle. Therefore, when two monatomic particles coalesce, three translational motions give rise to one vibrational and two rotational motions. Each of these motions will contribute to entropy. However, vibrational motions having higher frequency will contribute to lower entropy due to lesser probability of accessing some states."

"So, is any movement associated with entropy?", Tani asked after a long time.

Ayush said, "Almost. Entropy is an attribute to the overall motion. If the particle moves all throughout the box, there is only one value for the entropy. We cannot assign different entropy values depending on the position of the particle in the box. Entropy has one measure of all the possibilities combined."

When Ayush had finished his class on the entropy contribution, everybody agreed that they finally got what entropy is in a tangible and quantitative way. They now wanted to know where and how it is applicable. Both Ayush and Loy exclaimed that entropy has sealed our fate.

Tani exclaimed, "How?"

Ayush said, "We know that we are going towards an increase in entropy, i.e., randomness. However, the existence of life requires perfect order and harmony among several processes. Therefore, the increase in entropy signifies that we are going towards chaos where no life would be possible at some point. Entropy drives all the chemical processes in nature. We may find that energy is playing a role, but overall, for the universe,

entropy is the only deciding factor. Also, entropy has a significant role in folding of proteins that are tiny little machines in our body. For the protein to fold quickly, hydrophobic collapse is required. Hydrophobic collapse is the collapse of particles that don't like water. This increases the entropy of water, and thus favours the process. In fact, Arnab uncle had shown us that each water molecule around hydrophobic collapse has higher entropy than the water molecules which are farther from it. He proposed a method to calculate entropy of water as a function of distance from atoms and molecules."

Richu said, "Papa has done something like that? Pretty cool, huh!"

Ayush said, "Moreover, using his own method, he showed that even water molecules inside a single protein cavity can possess different entropy!"

Loy said, "That's not possible. Water will always exchange and they are in dynamic motion. We can only say that entropy of system A is something and entropy of system B is something. How can we find out the contributions of the subsystems?"

Ayush said, "It can be done using computational methods. Since one can tag each and every particle's movement during a simulation, it is possible, given an advanced technique, to identify the entropy of each and every particle. Doing that precise calculation, Arnab uncle showed that particles near a hydrophobic or charged particle have lower entropy. As it goes far away from it, it attains a standard value. For the bigger hydrophobic particle, however, entropy is higher than that of pure water. Thus, there is a hydrophobic crossover, a signature of entropy driven collapse of hydrophobes."

Suddenly, I heard a shouting, "Papa, get up! I will be late for school." I woke up from the profound "entropic" dream to find Richu all ready for school, and I rushed to take him to the bus. Today his entropy will really be high from the fun and games planned for the day. I could not help thinking though whether we would ever be able to fathom the enigma of entropy, which is all about probability that itself, depends on possibility. How do we understand why possibilities are higher in a spontaneous process? If somehow the possibilities become less, will entropy start going down? Peter Theodore Landsberg says, "It has been suggested that

thermodynamic irreversibility is due to cosmological expansion.” So it means that entropy increase is favourable because of the expansive nature of the present universe. Does it mean that entropy will go down in another cycle of the universe? Who knows?

-Arnab Mukherjee, Chemistry Department

Picture courtesy: Debasis Saha, Ph.D. student, chemistry department

Why are rubber bands elastic?

Ever wondered what causes a rubber band to regain its shape when you stretch it? Sure, it is because of something called elasticity, but where does this elasticity come from? What causes elasticity?

We have learnt in school that solids are elastic in the sense that they are like springs, which means that if you deform them, they will regain their original shape. Now, do all solids behave like springs? The spring-like behaviour originates from the bonds that exist between the molecules of these solids. These molecules are in an equilibrium between the attractive and repulsive forces. The attraction is mainly due to the force between negatively charged electrons and positively charged nuclei whereas the repulsion is due to

particles having the same charge. Figure 1 shows how the effective potential generally looks as a function of the separation between the atoms. The separation corresponding to the minimum value of potential energy is the most stable position for the atoms or molecules of the solid, and is called the equilibrium distance. Now, when you try to stretch a wire or compress a block of metal, it's this equilibrium you are trying to destabilise. As a result, the material exerts an equal and opposite restoring force and returns to its original shape.

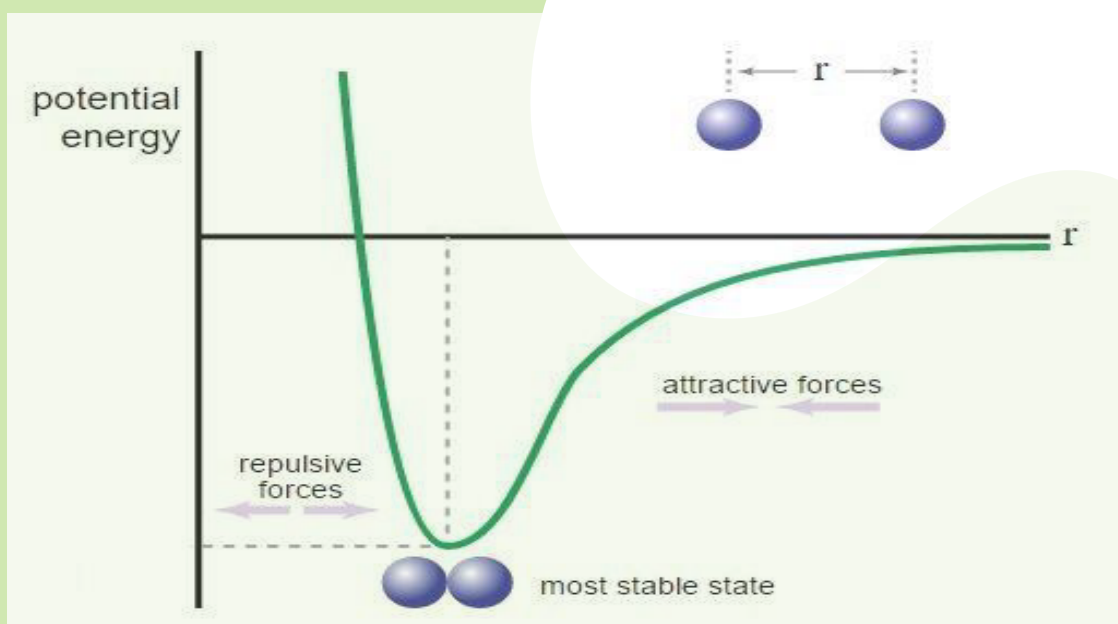


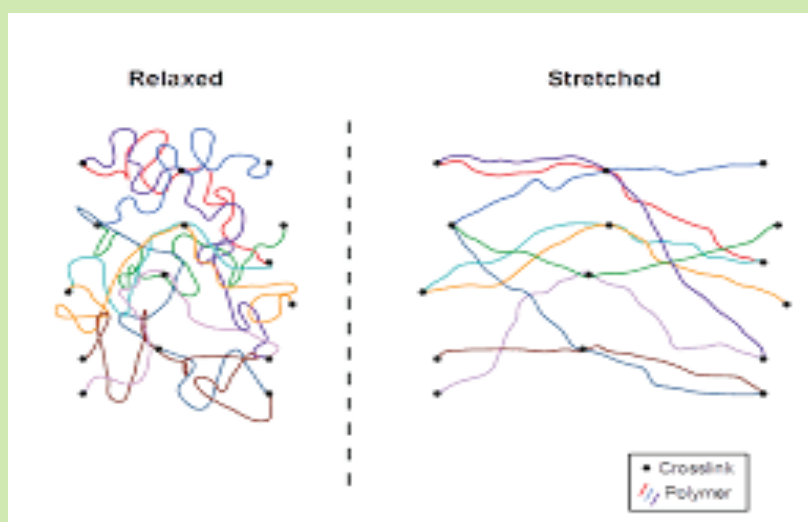
Figure 1

Speaking of rubber bands, they basically are long cross-linked chains of polymers. A rubber band, as we all know, regains its shape if stretched and released. We can say that it resists deformation. However, a rubber band resists deformation for reasons completely different from those for rigid materials. Polymers are mischievous chains; they like disorder (thanks to the second law of thermodynamics!). At thermodynamic equilibrium, these chains prefer to be jumbled, squiggly and intertwined. This occurs in order to maximise the entropy of the chains, as maximum entropy corresponds to the least energy configuration. (Analogously, you can think of these chains as earphone wires. They prefer to get entangled in your pockets.) Now, when you deform this maximally disordered state by stretching the rubber band, you essentially try to straighten these jumbled polymers. Trying to straighten translates to trying to bring order to our system. Now, the arrangement of these disordered chains in any ordered fashion requires energy, which, in the language of thermodynamics, means that any process that involves lowering of entropy has to have a positive change in free energy. In other words, energy must be supplied to

the system. This makes it energetically unfavourable for a polymer to attain an ordered configuration. Thus, the polymer tends to resist any deformation we induce. We can interpret this resistance as a restoring force generated within the polymer. The existence of this restoring force makes the material behave elastically.

And hey! That is why rubber bands are elastic.

Unlike rigid materials which store the energy within themselves in the form of potential energy, elastic polymers immediately release the energy in the form of thermal energy. When you stretch a rubber band, the work you do is spent on ordering the polymer chains, and it immediately appears as heat, once released. You can even test this yourself by holding a rubber band between your lips. Stretching causes heating of the rubber band and release causes cooling. Thus, the ability of a rubber band to do work depends only on the entropy-change considerations. This is remarkably similar to an ideal monatomic gas since, in both cases, the ability to do work comes entirely from thermal energy and not from any stored potential energy. Think about it!



- Saurabh Talele



World Mosquito Day

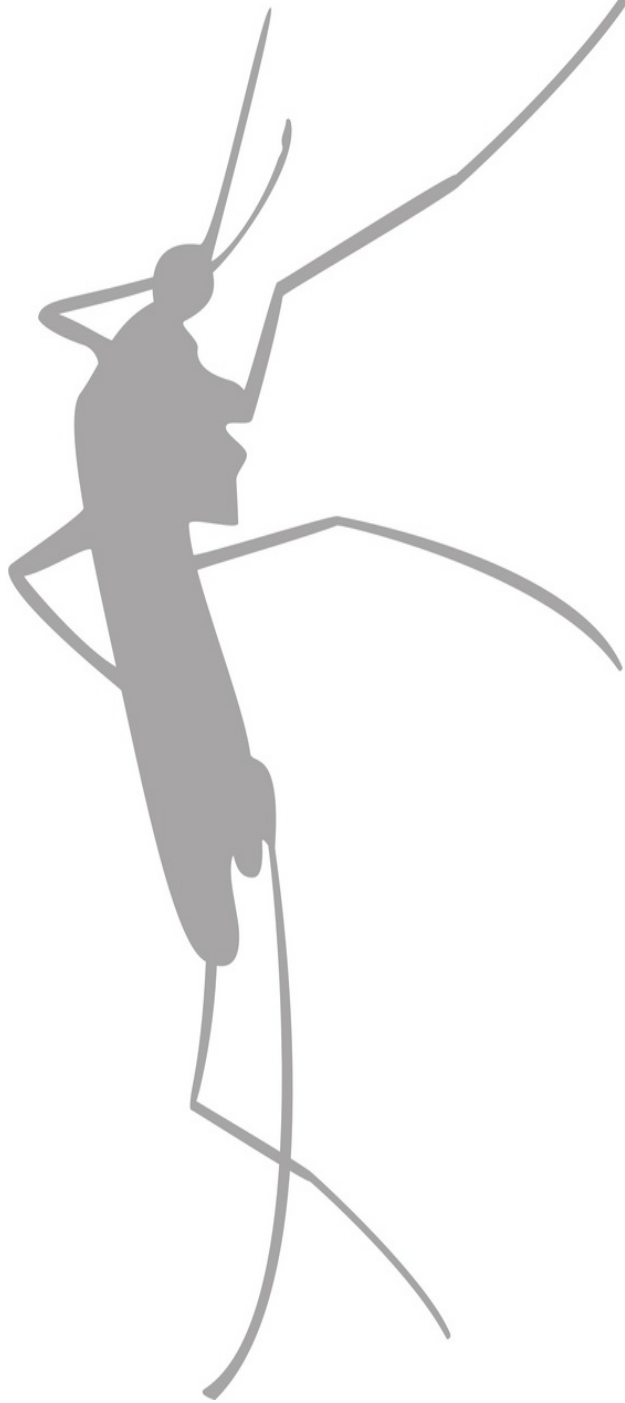
Malaria is one of the deadliest diseases to afflict mankind. Multiple wars have been lost and entire cities have bitten the dust due to malaria; it has changed the course of our history in more ways than we can fathom. With scientific advancements in the past century, malaria has been controlled and even eradicated in most developed countries, but it continues to be a major killer in the developing nations in Asia and Africa. World Mosquito Day is celebrated every year on the 20th of August to commemorate Sir Ronald Ross' discovery in 1897 that the female *Anopheles* mosquito is responsible for transmitting malaria in humans. Sir Ronald, a physician in the Indian Medical Services, suspected that the malarial parasite was transmitted by the bite of infected mosquitoes, and his hypothesis was confirmed when he observed the parasite in a stomach tissue sample from a female *Anopheles* mosquito. Sir Ronald dedicated his entire life to research on malaria and was awarded the Nobel Prize in Physiology or Medicine in 1902 for his exceptional efforts.

*"...With tears and toiling breath,
I find thy cunning seeds,
O million-murdering Death."*

(This is a fragment of a poem written by Sir Ronald following his discovery the malarial parasite in *Anopheles* mosquitoes)

Since ancient times, people have used herbal extracts to cure those afflicted with malaria. Both quinine and artemisinin, two of the most effective antimalarial drugs in use today, owe their discovery to traditional medical knowledge. Quinines were derived originally from the bark of the Cinchona plant, which was used by Native Americans to cure fevers. Artemisinin was discovered in the 1970s by Tu Youyou, a Chinese pharmaceutical chemist, who screened Chinese herbs for their potential antimalarial action. Tu's groundbreaking discovery fetched her the Nobel Prize in Physiology or Medicine in 2015.

According to the WHO, approximately half the world's population is at risk of contracting malaria. India features among the countries that are the worst affected by this disease. The mortality due to malaria in India was about 0.8 million per annum in 1947. To control this lethal epidemic, the Indian government started the National Malaria Control Programme in 1953. This program, though initially successful, soon faced setbacks due to shortages in the availability of DDT, rapid unregulated industrialisation, and resistance developed by malarial parasites. By the '90s, malaria was no longer just a rural disease; it had diversified to affect people from all walks of life. Even today, malaria is a leading cause for death amongst the poor in India.



Today, the WHO and different governments of the world are working hand in hand to control and eradicate malaria. To prevent transmission of malaria, the WHO actively helps in providing mosquito nets to families and spraying walls of homes with insecticide. Early detection and treatment and control of mosquitoes through chemical and biological means are the major strategies our government has adopted to combat malaria. The government is also collaborating with local communities to maintain hygiene and prevent mosquito breeding. However, if we wish to eradicate the ever-evolving threat that is malaria, more targeted and dedicated efforts are required.

The WHO has developed the Global Technical Strategy for Malaria 2016-2030 to address the challenges the world faces in the control and eventual eradication of malaria. The strategy, adopted in 2015, sets ambitious but achievable goals for 2030, which include reducing incidence of malaria and malaria mortality rates by at least 90%, eradicating malaria in at least 35 countries and preventing a resurgence of malaria in all countries that have been made malaria-free.

There are numerous pressing scientific challenges we need to address before we can successfully eradicate malaria. Research is being carried out to develop cheaper and more efficient diagnostic tools. Scientists are studying the life cycle of malarial parasites to develop targeted treatments that can control the transmission of malaria. We also need to

study non-falciparum malarial parasites like *P. vivax* in more detail. Malarial parasites are gradually developing drug resistance, which poses a major challenge to the pharmaceutical industry. Due to global warming and climate change, it is predicted that incidence of malaria will rise in the 2050s. Now, more than ever, dedicated efforts are required on the part of scientists to combat the malarial menace.

On 20th August 1897, Sir Ronald Ross made a path-breaking discovery that would mark the beginning of the war against malaria. Today, as we wage this war more fiercely than ever, it is time for some of us to follow in his footsteps.

- Sriram Raghunath



Since the birth of Wi-Fi the world has changed quite radically. Wireless data connectivity could not have been better, as we enjoy the fruits of this accidental discovery - that data can be transferred via variations in the intensity of electromagnetic waves. Nearly sixty percent of the global internet traffic makes use of Wi-Fi, but it has still proven to be unreliable at times - with its speed faltering and cases where the security can easily be compromised. Li-Fi is a new technology that surpasses Wi-Fi in terms of data transfer capabilities and versatility.

Li-Fi or Light Fidelity is a term coined by its inventor, Prof. Harald Haas, Chair of Mobile Communications at the University of Edinburgh. It basically uses the same principle as Wi-Fi, but uses the visible spectrum of electromagnetic waves rather than the radio waves that Wi-Fi uses. Well, so what's the difference?

To begin with, Li-Fi has achieved greater speed, hovering around the gigabytes per second regime in laboratory experiments. Since visible light has almost 10000 times

higher frequency than radio waves, it has a higher number of oscillations per second. So, more data can be transmitted via a light wave per second than via a radio wave and a higher data transfer rate can be achieved. Moreover, the raw material of information transfer is light, which is more easily available and that would be instrumental in providing a cheap source of internet connectivity.

As Prof. Harald explains in a talk, Li-Fi makes use of a standard LED bulb for transferring data. Just connect it to a small machine that can stream internet data like a router and voila! You get a huge speed of data transfer from just an ordinary LED bulb. Since LED is a solid state electronic device, its intensity can be changed rapidly. So we can switch between the on and off states crucial to any data transfer at a very high frequency that is undetectable to the human eye. Thus, an ordinary house lighting system can give us a stable internet connection with a high transmission rate, while also serving its purpose of lighting up a place. It has been found that diffused light from a light source or dimmed light can also achieve decent



decent speeds of about 70 Mbps, so a direct line of sight is not essential for the functioning of Li-Fi.

Now the final thing that is left is the detection of subtle changes in the amplitude of the light made by the streaming device. A photo-detector is good enough for this purpose, but as Prof. Harald goes on to demonstrate in yet another of his talks, a solar cell can also be used for the same. So, if a device has solar cells integrated into it, it can receive data from a light source fitted with a Li-Fi device, thus obtaining internet connectivity while being charged. This would be a step closer to the “Internet of Things”, a world where all electronic devices interact with each other and exchange data via network connectivity between them. For example, sensors on a bridge can send signals regarding its structural damage or household items can be controlled using just a mobile phone.

Li-Fi network is highly localised, and is hence hard to penetrate for hackers. Since light cannot penetrate through walls, it provides a highly secure network. Each LED light source will need its own Li-Fi streaming device, which may be costly initially, but would provide cheap internet connectivity for common use in the long run. One can also fit a street light with a Li-Fi streaming device to get a high-speed hotspot instantly.

Li-Fi can even be used underwater, where radio waves get damped hugely. Cars on roads can communicate with each other, which can lead to development of anti-collision systems in the near future. Remote places can get internet connectivity from just the light of a lamp post. Thus the possibilities of improvements in technology and life are far-reaching with the introduction of Li-Fi commercially. Even though the task is still under progress, we can hope to see Li-Fi being used widely everywhere in the not so distant future.

Sources:

- i. https://www.ted.com/talks/harald_haas_wireless_data_from_every_light_bulb
- ii. https://www.ted.com/talks/harald_haas_a_breakthrough_new_kind_of_wireless_internet

-Saswata Nayak

BEKENSTEIN

Hawking radiation is the radiation emitted from a body from which, by definition, no radiation can escape. This sounds weird, doesn't it? By the end of this article ought to sound a little less weird.

A black hole is a region of space that has a gravitational field so strong that no particle, not even light can escape it. In 1971, Stephen Hawking (Misner, Thorne and Wheeler, 1973) used general relativity to derive the horizon area theorem, which states that *"the total horizon area in a closed system containing black holes never decreases."* Now, consider the second law of thermodynamics: *"the total Boltzmann entropy of a closed system never decreases,"* where the Boltzmann entropy is defined as the logarithm of the number of ways in which you can alter the system without altering its overall properties. Don't these two seemingly unrelated theorems sound similar? They certainly did to Jacob Bekenstein, who in 1972 proposed that the surface area of a black hole is a measure of its entropy. This insight was also due to the fact that classical black holes do not follow the second law of thermodynamics. A classical black hole can be uniquely described by its mass, charge and angular momentum, says the famous 'no-hair theorem'. So if you throw an object into a black hole, all of that object's information would be irretrievable and hence destroyed. This would imply a decrease in the entropy of the system, which is a violation of the second law of thermodynamics. So, a generalised second law of thermodynamics was proposed by Bekenstein, which said that the sum of the entropy of the exterior of a black hole and the black hole entropy never decreases. Black hole entropy was defined as the area of the horizon of the black hole divided by the square of the Planck length, where the Planck length is $(hG/2\pi c^3)^{1/2} = 1.6E-32$ cm. This 'correction' to the second law would prevent the loss of entropy since a mass dumped in the black hole would increase the surface area of the black hole a bit, and this would balance the decrease in the entropy.

Stephen Hawking was initially against this idea as he felt that this was a misuse of his horizon area result. Bekenstein's advisor John Wheeler said, "Black hole thermodynamics is crazy, perhaps crazy enough to work." Hawking's argument was that something with entropy must have some temperature associated with it, and something with temperature must radiate heat and particles with a characteristic spectrum associated with that temperature. But a black hole cannot give out radiation as it is a region from which nothing can escape.

The debate came to an end when Hawking discovered, using quantum mechanics, that black holes do emit radiation and that the spectrum of this radiation corresponds exactly to the radiation associated with entropy, as proposed by Bekenstein. So Bekenstein was right after all. Hawking proposed a mechanism for this radiation which involved applying quantum field theory on curved spacetime. According to quantum mechanics, vacuum is not 'empty' but contains virtual particles (particle-antiparticle pairs) continuously getting created and destroyed. When these fluctuations happen near a black hole, the negative energy-carrying member of a particle-antiparticle pair falls into the black hole, decreasing its mass, while the other (with positive energy) escapes the horizon and is seen as radiation emitted by the black hole.

Today this radiation is called the Bekenstein-Hawking radiation and its discovery is one of the great achievements of physics. Along with this, the black hole information paradox and the holographic principle are ideas which came to be due to the brilliant insights of Bekenstein, and have been intriguing theoretical physicists for the past four decades. These are ideas which can play a big role in combining the two incompatible theories in physics, namely, quantum mechanics and general relativity, and pave the way to a unified theory of quantum gravity.

Biological Lasers – Alive and Emitting

By Prof. G. V. Pavan Kumar

*Laser, laser burning bright,
In the lab, through the night
What immortal ideas
Could frame thy emission process?*

-modified from William Blake's 'The Tiger'

‘Light Amplification by Stimulated Emission of Radiation’, or LASER, is a light source which is ubiquitous in the world around us. They are extensively used in scientific laboratories to study phenomena spanning various length scales, from astronomy to sub-atomic particles. A laser has three vital characteristics: monochromaticity, coherence and directionality, which make them unique emitters of light. Unlike conventional light sources such as tube-lights, lasers carry relatively large amounts of energy in a confined volume, and hence can propagate over longer distances and interact strongly with matter. These properties of lasers have not only made them a fascinating topic of fundamental research, but also a critical component in various applications.

Vital Quest:

Almost all the lasers that have been produced are made of abiotic matter, that is, matter without life. An interesting question to ask is: can we create a laser out of a living system, such as biological cell?

The answer is YES. In 2011, two optical physicists, Malte C. Gather and Seok Hyun Yun, then at Harvard Medical School, came up with an interesting experiment ^[1]. They transfected green fluorescent proteins (GFP) inside a human embryonic kidney cell, placed the cell between two high-quality mirrors, and optically pumped the cell with blue pulsed light (see Figure 1(a)). Interestingly, this experiment resulted in lasing action at a wavelength of around 513 nm from various parts of the biological cell (see Figure 1(b)), leading to the synthesis of a biological laser. The green laser light originated from the transfected GFP within the cell, which essentially acted as a gain media inside an optical cavity. The emitted light had rich spatial structure as evidenced in Figure 1(b), and this structure depended on the local distribution of the GFPs. This is the first report, to my knowledge, where a living system such as a biological cell has emitted laser light, and has created tremendous ‘excitement’. One may ask what the uses of such a system are.

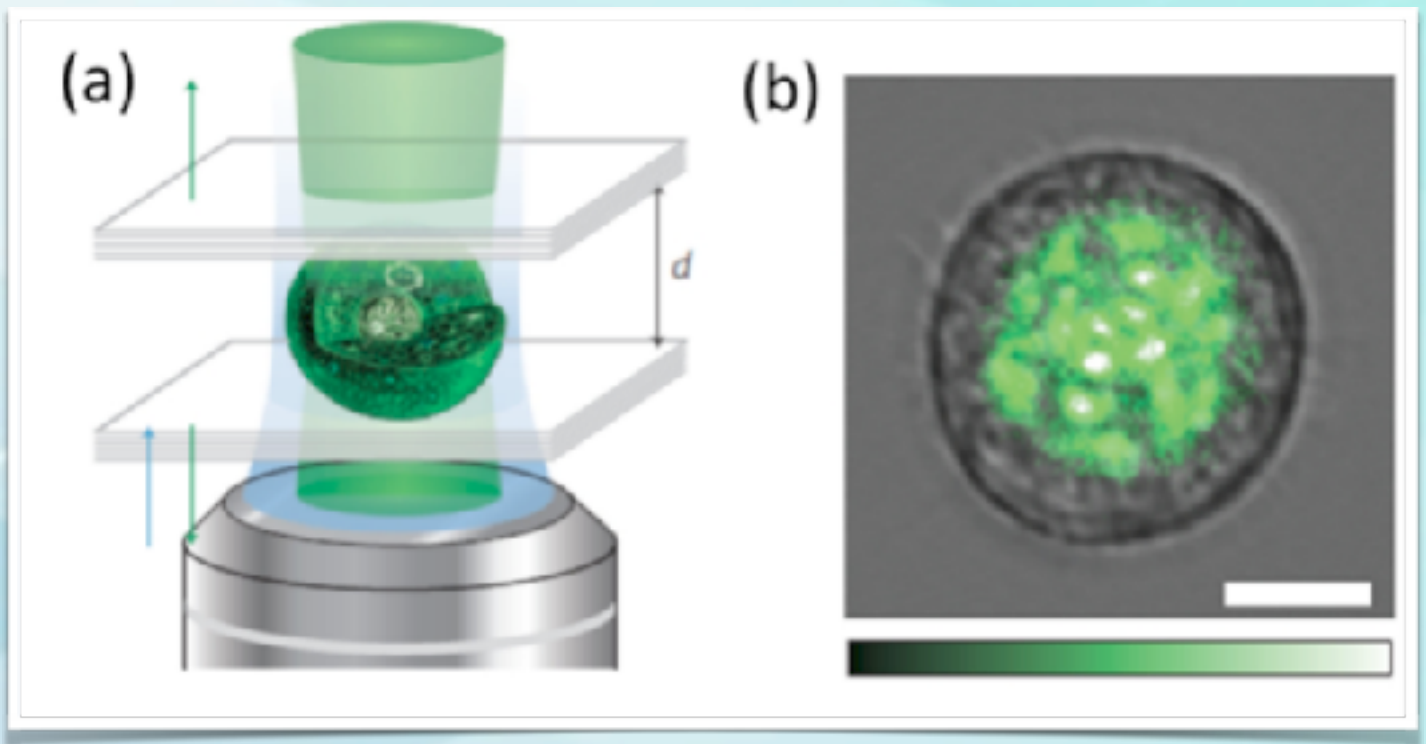


Figure 1: (a) Experimental schematic to realise a biological laser. The system consists of a human embryonic kidney cell transfected with GFP. This cell was placed between two high quality mirrors separated by a distance ‘d’ (representing an optical cavity). The cell was optically pumped by blue pulsed light (wavelength 465 nm). This resulted in laser emission from the cell. (b) Optical image of a lasing human embryonic kidney cell. The green light (wavelength ~ 513 nm) emanating from the cell is the laser light. The scale bar is 5 μm and the colour bar represents increasing intensity from dark to light shade. Figures reproduced with permission from *Nature Photonics*, 5, 406-410 (2011).

Bright Future:

The research on biological lasers is in its infancy. There are many interesting prospects of such lasers and below I outline a few of them.

- They can act as localised sources of light and heat, which may further drive certain mechanical, thermal and chemical reactions in the organelles and compartments of a cell.
- If placed in an appropriate location within living systems, biological lasers can be harnessed as light sources in biomedical applications, where the reach of certain surgical instruments is constrained.
- The emanating light is due to stimulated emission, which has a narrow spectral width. In contrast to spontaneous emission, which is the phenomenon behind conventional light emitters, lasers have very narrow spectral widths, and hence can be utilised for spectral multiplexing and discrimination of species inside a cell.

Voyage Ahead:

There are still many unexplored aspects of a biological laser. Below I mention three of them, each from a different viewpoint.

- From the optical physics viewpoint, a biological laser can be treated as an optical cavity with a randomly-scattering gain medium. It would be interesting to explore the localisation and propagation of light in such a randomised medium inside a living system.
- From the viewpoint of chemistry, it is interesting to ask if one can design and synthesise molecules or nano-materials which can be placed inside a cell such that it leads to efficient self-lasing without external stimuli.
- From the biological viewpoint, it is vital to know what the fate of a cell will be if it keeps emitting laser light. Specifically, it would be interesting to know how cells can adapt to an inbuilt laser source. Furthermore, if a cell with a biological laser divides, will it carry over its ability of lasing to the next generation?

As with all the interesting inventions and discoveries, biological lasers have opened many interesting questions for exploration. It has room for contribution from various branches of science and technology, and may open new avenues by bringing together biology and laser photonics. Let me conclude by quoting Feynman [2]:

“...A biological system can be exceedingly small. Many of the cells are very tiny, but they are very active; they manufacture various substances; they walk around; they wiggle; and they do all kinds of marvelous things - all on a very small scale. Also, they store information...”

Well, Mr. Feynman, now they can even emit laser light!

References:

- [1] “Single-cell biological lasers” Malte C. Gather and Seok Hyun Yun, *Nature Photonics*, 5, 406-410 (2011).
- [2] “There’s plenty of room at the bottom”, by Richard P. Feynman, *Engineering and Science magazine (Caltech)*, vol. XXIII, no. 5, February 1960

Endless Cycle

It's an endless cycle,
Oh an endless cycle,
Creation after destruction,
Order out of chaos,
One after the other,
Another after the other,
In an endless cycle,
Oh, an endless cycle.

A chicken comes out of an egg,
And an egg out of a chicken.
Whether the egg came first
Or the chicken came first,
Is a debate that goes on,
On and on, on and on,
Like the chicken comes out of the egg,
And the egg out of a chicken,
In an endless cycle,
Oh, an endless cycle.

A tree stands tall and proud,
Then things tall and proud stand on it.
We advance with destruction,
And destruction advances with us,
Until into ash, these things finally burn,
And out of ash, they will then be reborn,
And it's all an endless cycle,
Oh, an endless cycle.

It's all a loop,
A loop that loops unto itself,
A snake that bites its own tail,
An ouroboros life tale,
And there's no way out of this,
As the way out is an end,
And it's an endless cycle,
Oh, an endless cycle.

But why look for the way out,
When one can look out of the way
To advance without nature's bliss,
And advance in bliss with nature
instead?
We need to take care of each other,
And all we need is taken care of,
In a beautifully endless cycle,
Oh, an endless cycle!

Though life goes away in death,
The dead give a way for new life.
One is all and all is one,
And life, like everything else,
Is an endless cycle,
Oh, an endless cycle,
And it goes on,
On and on, and on and on.

-Janani A

*The foolish man seeks happiness in the distance; the wise
grows it under his feet.
-Julius Oppenheimer*

HAPPINESS.

Happiness is defined as a subjective enjoyment of life. Humans try to seek happiness in their life. We even plan our future accordingly to satisfy us by sacrificing the happiness put forward to us now, and this can be explained by a scientific perspective. We all have many ways to find our happiness, but the choice for happiness is skewed due our adaption of human brain to the ancestral environment.

Our brain is also designed for (and adapted to) the conditions in our ancestral environment, and the fundamental theory of evolutionary psychology says that brain perceives and responds to the current environment as if were the ancestral environment. It logically follows that the factors that influence the idea of happiness or satisfaction can also come under the ancestral environment, which in this case is the savanna of Africa. Thus, this is known as the 'savanna principle'.

According to the Savanna Principle, the human brain is adapted to solve the problems which affect the survival of human population that recurrently occurred in the different domains of life throughout our evolutionary history. Hence the population (general domain) is adequate to solve such problems or derivatives of such problems with solutions from the ancestral environment (e.g. incest, social exchange, and infant care). This psychological adaptation has been regulated using a 'reward system' (by controlling hormones responsible for different emotions). That is why we feel satisfied or happy when we successfully overcome such problems.

Friendship is also a factor for happiness. People try to have friends and spend more time with them, hence their social interaction increases. The knowledge that we matter to each other and desire to share and amplify good news satisfies basic psychological needs. In earlier days, hunter-gatherers lived in a group of about 150 individuals, and they needed social interactions to survive the harsh situations of life by cooperating. Hence we can assume that people feel pain and distress when ostracised mostly because the friendship ties and alliance was important for the survival and reproductive success of ancestors. But in the present scenario we try to have

friends just because we biologically intended to feel satisfaction by interaction, as friendship is no more directly involved with reproductive success and survival rate.

Similarly, population density is a major factor for happiness. According to studies people living in rural areas (less population density) are happier than people in urban areas. People tend to feel uncomfortable when they are in a crowded place, because in our ancestral society the number of members per group was around 150-200, as the neocortex ratio of modern people says that we can have a healthy social interaction with 155 people at maximum. If this number was exceeded, groups tended to divide into two groups. Thus, people tend to have difficulty keeping cooperation and reciprocity in large groups. Studies say that this trait is present in modern society. The modern world has higher population density than the past, hence when we try to understand this in perspective of our ancestral environment, we tend to have decreased happiness in our life.

There are many other factors that influence happiness, but friendship and population density have a huge hand in it. We tend to feel life satisfaction if we have better friendships and less populated environments. So happiness is conceptually a trait rather than emotion in human population.

-Sooraj Das

References:

1. Li et al, 2016, British Journal of Psychology
2. 'Quality-of-life and Happiness: Not quite the same', 'Happiness in Society', 'What we know about Happiness', 'Advances in Understanding Happiness', 'Is Happiness a Trait?', Ruut Veenhoven

THE BOY *who cried* MMR

***Reconsider* the story of 'the boy who cried wolf'. What would it be like if he was believed? What if people suffered due to a constant fear of wolves? What if I told you that scientific research told us that we live in such a world? Would you believe me? Let me tell you a story.**

On February 28th, 1998, the MMR vaccine (vaccine against measles, mumps and rubella) controversy started with the publication of (now fraudulent) research paper in the medical journal The Lancet, authored by a group led by Andrew Wakefield, now-discredited physician and the architect of perhaps the most damaging medical hoax of the last 100 years and the latest anti-vaccine movement. On March 25th, 2016, "*Vaxxed: From Cover-up To Catastrophe*", an anti-vaccination documentary directed by Andrew Wakefield made the news refueling the debate regarding whether or not MMR vaccine causes autism-spectrum disorder, once again.

"Wakefield conjured a non-existent medical condition to ascribe these symptoms to and changed the accounts and numbers as well to make it scary."

The fact of the matter is that the overwhelming cold-hard evidence against Wakefield's claim failed to put the 18-year-old heated dispute to bed. Why? Because scientists are not good at telling bedtime stories. Just consider how much the first grim tale told by Wakefield in 1998 still scares Millennial parents against the "dangerous" vaccination. It was an early report, not a study or a randomised trial, that told the story of 12 children, 9 of which had symptoms of stunted development and 8 of those 9 had parents who believed that their children developed the symptoms that no parent would hope to see in their child, after giving them the MMR vaccine. Wakefield conjured a nonexistent medical condition (read: the fairy-tale monster) 'autistic enterocolitis' to ascribe these symptoms to and changed the accounts and numbers as well to make it scary. A horror fiction of 8 fearful parents authored by a proven fraud, debunked by dozens of scientific studies and retracted by The Lancet and 10 other co-authors, wasn't just junk science, but was a lie. A lie which has caused thousands of children across North America and Europe to suffer from measles and some to eventually die.

One of the alternate narrative of research is a 2012 systematic review of the Cochrane database including 5 randomised controlled trials (RCTs), 1 controlled clinical trial (CCT), 27 cohort studies, 17 case-control studies, 5 time-series trials, 1 case cross-over trial, 2 ecological studies, 6 self controlled case series studies involving in all about 14,700,000 children (!) and assessing effectiveness and safety of MMR vaccine concluded that despite there being some safety issues, a causal

Now, I can cite a social experiment done in 1975 demonstrating some of these facts, or 82-page long assessments of risk communication of vaccines, or studies (even randomised trials) that show how when confronted with contradictory beliefs we become more entrenched with our own. But I won't, for the same reasons that explanations of Bayes' theorem cannot console a worried parent and Mythbusters do not publish statistically significant conclusions. Scientific method can tell us what to

“Scientific method can tell us what to believe, but more often than you think, it makes it harder for us to believe it.”

link between autism and MMR vaccines cannot be established. And this by no means covers the ground in research done in order to debunk the hoax; this is one of the most researched medical topic ever. Yet, all the evidence was inadequate to sway the non-believers and caused the whole debacle to last this long. The scientific communication failed when they tried to fight 12 anecdotes with 14.7 million data points. This reveals fundamental facts about human cognition: how we evaluate information, weigh risks and fears, and how disabled we are at thinking probabilistically but instead think in terms of anecdotes.

believe, but more often than you think, it makes it harder for us to believe it. Instead, I choose to relate this ludicrous incident of how scientific researchers might have unknowingly aggravated a controversy which directly led to hundreds of fatalities. So, when we encounter a believer in 'the boy who cried wolf', we should not start yelling about confidence values in a sheep being a sheep, and instead tell a story.

- Vishrut Patel

Rube Goldberg Machine

In 2016, as part of Karavaan, we displayed a Rube Goldberg machine. The basic aim of a Rube Goldberg machine is to do a very simple thing in a very convoluted way. It is a contraption that is deliberately over-engineered to perform an elementary task in a complicated fashion, generally making use of a chain reaction. It was a great pleasure for me to be a part of the team that designed and built it.

The theme for Karavaan 2016 was 'Alice in Wonderland'. So, the idea was to build a Rube Goldberg machine with each stage of Alice's story represented by one module of the machine. This would depict Alice's journey through Wonderland as a series of chain reactions. Like most things, this was easier said than done. But when I signed up for this, I definitely did not anticipate the amount of effort we would have to put into it. I am not going to bore you with all the details of the model, but instead I will describe the challenges and hurdles that we faced while building it.

We started thinking of the design and ideas about three weeks before Karavaan and started the actual machine-building a fortnight before the event, in one of the undergraduate biology labs. The model was made almost entirely of cardboard, paper cups, old PVC tubes and other waste materials. Building it was really daunting and challenging work.

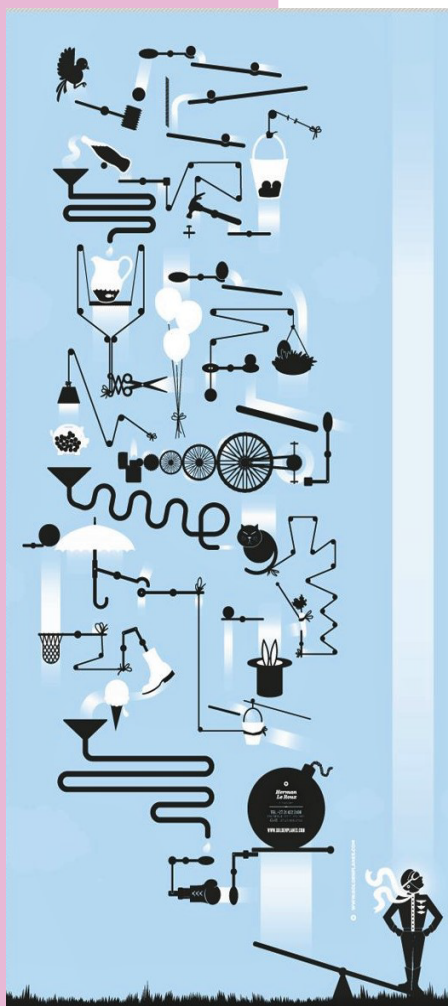
We had to be extremely precise in our measurements and timing. A few centimetres off and the entire thing would refuse to work. In addition to this, friction was the

devil. We spent a good portion of two weeks only trying to reduce friction in several modules so as to ensure smooth running of the machine, especially in the part depicting Alice falling into the 'Mad Tea Party'. The first module, involving Alice (depicted by a metal ball) falling down the rabbit hole was the hardest part. We had to measure the lengths and angles right down to the last millimetre and degree. We had also originally planned a module depicting the hookah-smoking caterpillar using dry ice and balloons. However, due to several reasons, including the non-availability of dry ice, we had to scrap it and replace it with a module involving Jenga, and a pack of cards that

was arranged to form a 'K', so that they fell one after another like dominos.

Well, I am not much of a crafts or cut-and-paste person, and rarely before in my life have I held a pair of scissors. But it was a new and fun experience for me to work hands-on for this. Working with the Rube Goldberg machine-making team taught me many things - such as the value of dedication and teamwork, and most importantly, how to work efficiently in the last minute!

-Adarsh Srinivasan



PRECISELY!

your story in six words

Enzyme structures, increase my Dopamine levels.

-Harsha Gouda, BS-MS student, Chemical Biology

Toil is temporary, publication is permanent.

-Shubham Chhajed, BS-MS student, Biology

I, alone, work in groups everyday.

-Dilpreet Kaur, Post-Doc, Group Theory

“Scientist, eh?” smiled Satan. God cringed.

-Satirth Dey, Faculty, Evolution

Dispute, verify: words we live by.

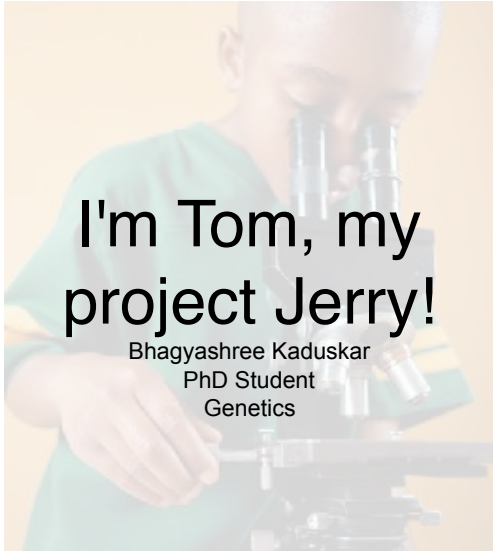
-Sourabh Dube, Faculty, Experimental Particle Physics

Perovskites- Lead - poisoning- break- long break!

-Rohithkumar Jadkar, BS-MS Student, Physics

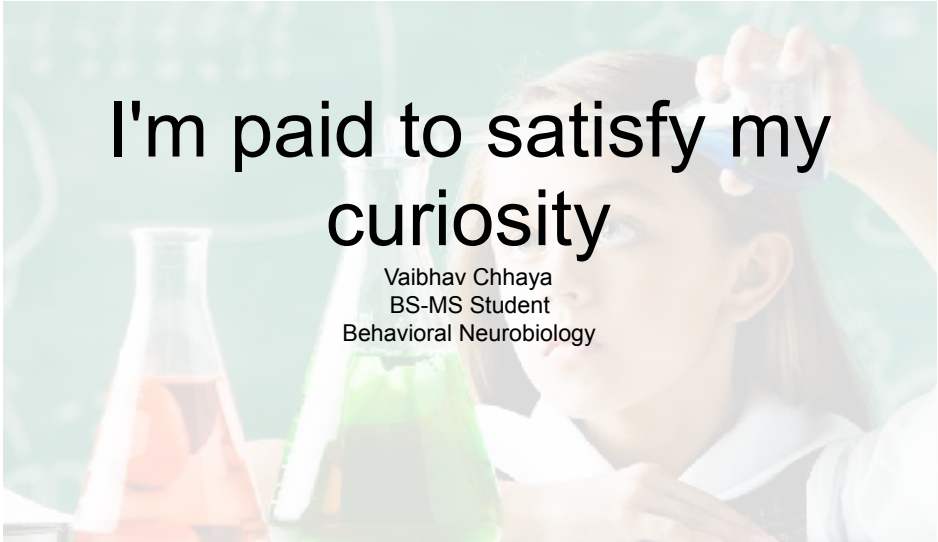
Routine frustration, infrequent happiness, sporadic ecstasy.

-Lokavith Agasthya, BS-MS Student, Fluid Dynamics



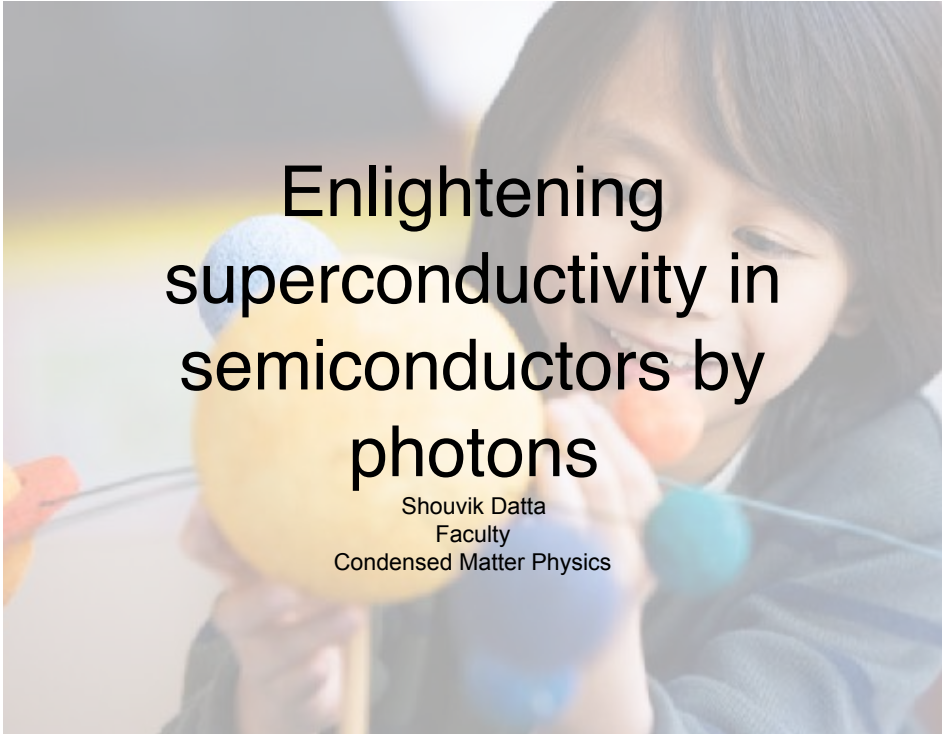
I'm Tom, my
project Jerry!

Bhagyashree Kaduskar
PhD Student
Genetics



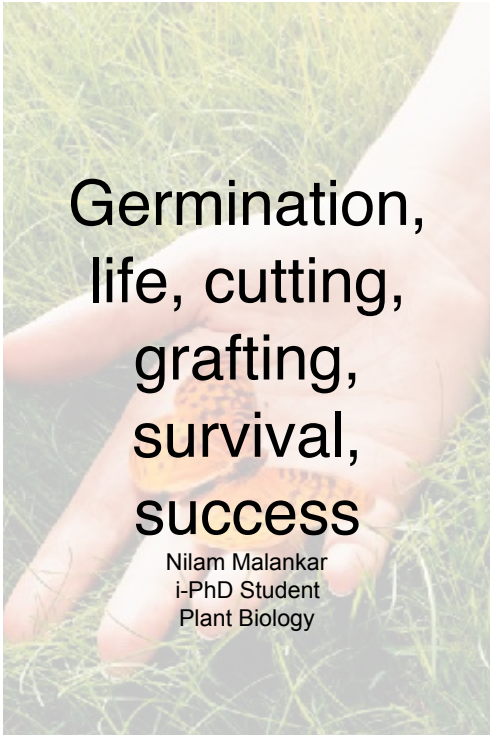
I'm paid to satisfy my
curiosity

Vaibhav Chhaya
BS-MS Student
Behavioral Neurobiology



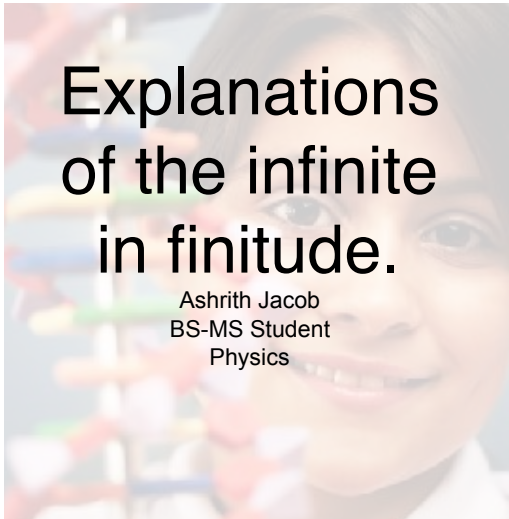
Enlightening
superconductivity in
semiconductors by
photons

Shouvik Datta
Faculty
Condensed Matter Physics



Germination,
life, cutting,
grafting,
survival,
success

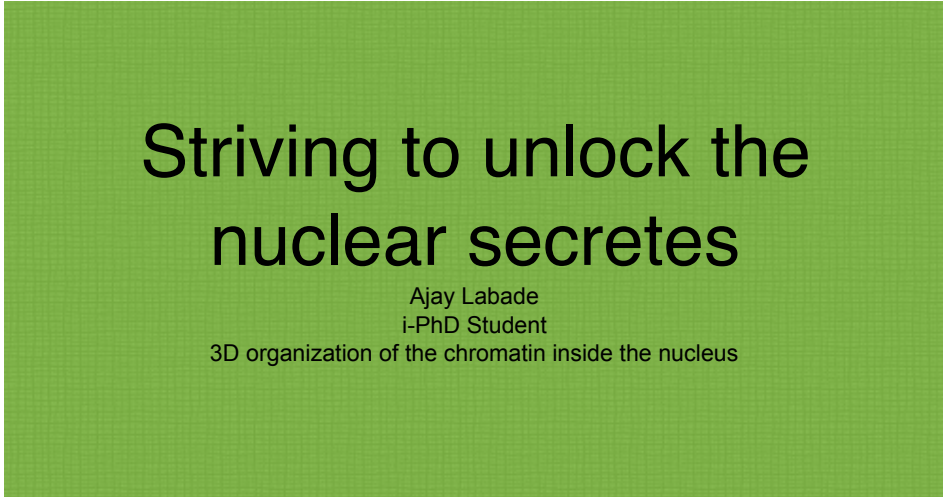
Nilam Malankar
i-PhD Student
Plant Biology



Explanations
of the infinite
in finitude.

Ashrith Jacob
BS-MS Student
Physics

Precisely!



Striving to unlock the
nuclear secretes

Ajay Labade
i-PhD Student
3D organization of the chromatin inside the nucleus

precisely!

My flies' life is more happening!

*Avani Koparkar, BS-MS Student,
Biology*

EAT not. SLEEP not.
REPEAT calculations.

*Arindam Bhattacharjee, i-PhD Student,
High Energy Physics*

Evolving flies and counting
them. Loop.

*Sudipta Tung, PhD Student,
Experimental Evolutionary Biology*

Next night, the sky
looked same.

*Disha Patil,
Project Assistant,
Glacier Modelling*

Denatured by problems,
renatured by experiments

*Swapnil Bodkhe, BS-MS Student,
Antibiotic resistance*

Finding paths on
boundaries
of disciplines.

*Mohan Karra,
BS-MS Student*

Enjoyable frustration of
fighting bad science.

*Milind Watve, Faculty,
Common Sense in Science*

Peer into stars by
hearing starquakes!

*Anvesh Bhattacharya,
BS-MS Student,
Astero-seismology*

He gave me rose.
I dissected.

*Shruthi Bharadwaj,
BS-MS Student*

Sorting developmental
biology the Maktub's way.

*Shivani Bodas,
i-PhD Student, Biology*

HELICASE

2018

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