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Research Scholars Association of Physics (RSAP)
IIT Bombay

INVITED TALKS

Astrophysical Recipes to Cook Merging Black Hole Binaries

Prof. Sourav Chatterjee

TIFR, Mumbai

The Nobel-winning discovery of gravitational waves (GW) from the mergers of binary black holes by the LIGO-Virgo collaboration has opened a new window to the universe. It is expected that ground-based detectors such as advanced LIGO, Virgo, Kagra, and in near future, Indian LIGO will make hundreds of such detections in the next few years. Upcoming and proposed detectors, including LISA and DECIGO will detect even more sources at different orbital frequencies. These detections very soon will allow us to study properties of merging black hole binaries as a population and interpret the astrophysical implications. But, how does nature make these extraordinary systems? I will review various astrophysical formation channels for merging binary black holes. I will also discuss a few detectable properties that can shed light on the formation channel of specific mergers.

Where are we heading to?

Prof. Gagan Mohanty

TIFR, Mumbai

The standard model of particle physics has been remarkably successful in describing almost all the experimental observations related to the basic building blocks of matter and fundamental interactions among them. However, there are a number glaring examples which one cannot explain within this theoretical framework. These include dark matter, matter-antimatter asymmetry and neutrino mass. While we have several proposals on the table, none of them has found any taker with the experiments at the Large Hadron Collider of CERN or elsewhere. This talk is an experimenter's perspective on the current status and what the future holds for us in this noble pursuit for the next fundamental layer of physics.

Unified theory and a tale of two vacuum energies

Prof. Urjit A. Yajnik

Department of Physics, IIT Bombay

The discovery of the Higgs boson is a long desired landmark of the Standard Model of Elementary Particle Physics. But it suggests the presence of cosmological vacuum energy of the order of 10^2GeV, which is completely contradictory to observations. "Running coupling constants" is an elegant feature of the gauge theories. It means the couplings of various fundamental forces are energy dependent and can unify at a very high energy scale. Again, the grand unified Higgs sector signals the presence of large vacuum energy. The very long life 13 billion years of our present Universe and its enormous scale 10^{26}m suggest that vacuum energy dominated near the unified scale of 10^{14} GeV–so called inflationary Universe – but this energy must have also dissipated – so called graceful exit from Inflation.

In an apparently different phenomenon, direct observations of the expanding Universe suggest we have vacuum energy of scale 3×10^{-11} GeV. All the ingredients needed to understand the fundamental forces in a unified framework seem to be in place yet the numbers have a mismatch by enormous orders of magnitude. Either our paradigm of Quantum Field Theory or of General Theory of Relativity, or both, could be in the need of serious revision. We hope for hints towards resolution from future high energy colliders and from improved precision in cosmology and strong gravity experiments.

Mechanics of a granular skin

Prof. Shankar Ghosh

TIFR Mumbai

Magic sand, a hydrophobic toy granular material, is widely used in popular science instructions because of its nonintuitive mechanical properties. A detailed study of the failure of an underwater column of magic sand shows that these properties can be traced to a single phenomenon: the system self-generates a cohesive *skin* that encapsulates the material inside. The skin, consisting of pinned air-water-grain interfaces, shows multiscale mechanical properties: they range from contact-line dynamics in the intragrain roughness scale, to plastic flow at the grain scale, all the way to sample-scale mechanical responses.

Anomalous collective behavior and physical properties of active matter

Prof. Nitin Kumar

Department of physics, IIT Bombay

Active matter is a collection of particles that operate out of equilibrium by converting external energy into motion. This simple definition of a new class of matter not only raises fundamental questions for physicists but also has the potential to uncover laws governing various natural and biological processes. For instance, the collective behavior of living organisms like birds, fish, etc., to cellular and subcellular processes like cell division and vesicular transport, fall under the category of active matter. In this talk, I will introduce two simple table-top experiments which are capable of imitating various complex features of active systems. The first system is a collection of millimeters-long granules placed on a vertically vibrating surface which faithfully mimics phenomena of flocking and trapping. The second system consists of a synthetic assembly of cytoskeletal biopolymers and molecular motors in the form of an active nematic liquid crystal. Here I will discuss how the defect dynamics and elastic properties can be tuned as a function of activity. These results open exciting opportunities in creating a new class of tunable materials that are active and perform tasks which are otherwise forbidden in conventional materials.

Interfacial Self-assembly of Soft Colloids

Prof. Dillip K. Satapathy

Soft Materials Laboratory, Department of Physics,
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The creation of self-assembled uniform monolayers of colloids at fluid interfaces and transforming them on to solid surfaces is not only crucial to fundamental science but also of utmost importance for soft nanotechnology. Here, we demonstrate a facile strategy which exploits the interface assisted self-assembly to obtain two-dimensional layers of soft colloids. Solvent-swollen submicrometer-sized hydrogel particles (microgels) with delicate hydrophobic - hydrophilic balance and sensitive to environmental conditions such as temperature/pH are used as soft colloids. The surface activity of the microgel particles, the interparticle interactions, and the kinetics of evaporation are tuned to generate a variety of novel two-dimensional structures, including monolayer coffee-rings, loosely packed uniform layers, and interconnected cell-like patterns with extraordinary richness and diversity. A smooth order-disorder transition in the self-assembled monolayers of soft colloids is identified by constructing Euclidean Voronoi diagrams. The viscoelastic nature of the soft colloid laden interface probed by using multiple particle tracking passive microrheology and its dependence on the crosslinking-density of microgels will be presented. In addition, the suppression of the "coffee-ring effect" for hard colloids in presence of microgel particles and the origin of the depletion zones observed in evaporative self-assembly will be discussed in detail.

High pressure and Raman Spectroscopy reveal new Topological Insulators and Topological Crystalline phases.

Prof. Chandrabhas Narayana

Chemistry and Physics of Materials Unit, School of Advanced Materials, JNCASR, Bangalore

There is a great interest in understanding and finding new Topological Insulators and has become important due to many uses of it in spintronic applications in future. Topological Transitions also are interesting to enhancing the thermoelectric applications of materials. High pressure provides an apt tool to understand the effect of strain in tuning the electronic topological properties of the materials. High pressure simulates the effect of chemical doping in achieving this in real materials. Electronic topological transitions are very well seen by angle resolved photo emission spectroscopy (ARPES). But to perform this the samples need to be freshly cleaved inside a ultrahigh vacuum and the surface is cleaned using Argon sputtering. The electronic band structure should be measured before the sample relaxes. In high pressure since the sample need to be bathed in a hydrostatic medium for applying the pressure, these procedures are near impossible at the present. Hence we need to find alternative methods to identify the topological transitions. Hence in this talk we will demonstrate that use of a combination of Raman spectroscopy, X-ray diffraction and DFT calculations could combined to identify the topological transitions under high pressure conditions. Raman spectroscopy is an inelastic light scattering measurements, which measure the vibrational properties of the molecules and lattice. Here there is a large interaction between electron and phonon (lattice vibration) and it is called the electron phonon coupling. These would affect the lifetime of the phonons and this manifests in the Raman spectroscopy as the anomalous changes in phonon frequency and phonon linewidth (which is directly influenced by lifetime of the phonon). X-ray diffraction helps us to know if these transformations in the Raman spectra are linked with any structural changes. If there are no structural transitions, these can be easily concluded originating due to electronic origin. In order to confirm that this is due to topological

transitions, one can do DFT calculations under pressure. This clearly gives the band overlaps in the electronic band structure and parity. Based on this one can easily find the Topological Transition under pressure. The talk will show using examples how this is achieved. The pressure induced topological quantum phase transitions (TQPT) in $TlBiS_2$ and 1T-$TiTe_2$ [1,2] are seen using this approach. We show the evidence of two isostructural electronic transitions in $TlBiSe_2$, deduced from the unusual electron-phonon coupling (A1g and Eg phonons) at ~0.5 GPa and ~1.8 GPa observed in the Raman scattering measurements. Our first principles density functional theory based electronic band structure, topological invariant Z2 and mirror Chern number nM calculations reveal that the phonon anomalies at ~0.5 GPa and ~1.8 GPa are related to the topological insulator and topological crystalline insulator (TCI) transitions, respectively. Both high pressure Raman and powder synchrotron XRD confirm a reversible first order structural phase transition of the rhombohedral phase above 4 GPa. We see that the effect of high pressure on transition metal chalcogenide 1T-$TiTe_2$, a prominent layered 2D system. Here, we have explored the topologically non-trivial and trivial quantum phase transitions at ~2 GPa and ~4 GPa with evidence of the minima in *c/a* ratio concomitant with the phonon linewidth anomalies of Eg and A1g modes. Between ~4 GPa and ~8 GPa, a transformation from an anisotropic 2D layer to a quasi-3D crystal network is noticed, which occurs due to increased interlayer Te-Te interactions (bridging) by the charge density overlap. In addition, we observed a reversible first-order structural phase transition from a trigonal ($P\bar{3}m1$) to monoclinic ($C2/m$) phase above 8 GPa. In order to show that all electronic transitions deduced from Raman and X-ray cannot be deduced to be TQPT, we have taken another example. We have investigated Raman scattering and synchrotron XRD measurements on InTe compound [3]. The pressure induced a semiconductor-to-metal transition in InTe is deduced from the phonon anomalies of A1g and Eg modes along with the decrease and anomaly in Raman intensities at ~3.6 GPa. In distinct pressure regime, the presence of strong anharmonic phonon-phonon interactions and electron-phonon interactions are noticed from phonons' peculiar behaviour. Our Raman scattering experiments up to ~19 GPa reveals the pressure induced structural transitions (B37 → B1 → B2) in InTe.

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Physics and technology with quantum materials

Prof. P.S. Anil Kumar*

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Quantum materials are materials that exhibit exotic electronic properties that are manifested due to reduced dimensionality, quantum confinement, topology of wave functions etc. Materials such as graphene, topological insulators, Weyl semimetals, spin-liquids etc. belong to this category and is widely investigated by condensed matter physicist and materials scientists in the past couple of decades. Among these, topological insulators are materials characterized by an insulating bulk and gapless metallic states on the sample surface. Electrical transport in three dimensional topological insulators occurs through spin-momentum locked topological surface states that enclose an insulating bulk. In the presence of a magnetic field, surface states get quantized into Landau levels giving rise to chiral edge states that are naturally spin-polarized due to spin momentum locking. Robust access to topological surface states has presented itself as a formidable challenge due to inevitable bulk doping that mires the effects arising from the topological surface states. In this lecture, I will demonstrate that surface states that are highly amenable to detection and control using electrostatic gating[1-7] if one uses bulk-insulating topological insulators. Here, we have also fabricated electrostatically defined n-p-n junctions[8] of bulk insulating topological insulator $BiSbTe_{1.25}Se_{1.75}$. I will also demonstrate how these fabrication technologies can be extended to get diverse devises such as edge-contacted topological insulator FETs and topological insulator/superconductor hetero-interfaces[9,10] opening up the possibility for further understanding of this new materials class.

*in collaboration with: A Banerjee, R Ganesan, BR Sekhar and Diptiman Sen

The work discussed here is covered in our following publications

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Art of Model Building in Quantum World

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World of quantum matter continues to challenge us with new experimental results and situations of increasing complexity and variety. During these happy encounters, contemplation and deep insights result in models. These mathematical models are caricatures of reality. They help us navigate the vast Hilbert space, without getting lost and discover new worlds. We will illustrate the art of model building using some models, including Majumdar-Ghosh model.

ORAL PRESENTATIONS

NuRIA: Numerical Relativity Injection Analysis of spinning binary black hole signals in Advanced LIGO data

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The advent of Gravitational wave astronomy has provided us with black holes much heavier than the ones observed using X-ray astronomy. But intermediate-mass black holes still now have largely remained elusive. After the end of the second observing run, the LIGO Scientific and Virgo collaboration presented more stringent upper limit on the merger rate based on a simulation study performed with non-precessing intermediate-mass black hole signal generated using numerical relativity simulation. In this talk, I discuss the results of the study which we conducted over a broad range of generically spinning numerical relativity injections to explore the sensitivity of two vastly different employed search techniques that are used by the collaboration for the search.
arXiv Number: 2002.10666

Optical follow-up of gravitational waves with India's first fully robotic telescope "GROWTH-India telescope" in LIGO O_3 a run.

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The mergers of compact objects like binary neutron stars(BNS) & black hole - neutron star (BH-NS) are among the most energetic events in the universe. These events provide us a glimpse into some of the most extreme physical processes. Merger events of BNS and BH-NS are believed to be the key to solving several open questions in astrophysics - including the sites of formation of r-process elements, progenitors of short gamma-ray bursts (GRBs), the equation of state of ultra-dense matter, and can even provide an independent estimate of the Hubble constant. Advanced gravitational wave detectors are currently in their third observing

run. During its first-half run of O_3, LIGO has detected ten events with at-least one neutron star as a merger object. Six events out of these ten were geographically visible to us. We followed these events with GROWTH-India Telescope(GIT) in close collaboration with the GROWTH team. The uncertainty regions were huge for most of the events. Tiled or Targeted search modes were used to find the counterpart in optical regime depending on the parameters given by LIGO. Here, I present the details of the followup of GW events by India's first robotic telescope "GIT" and GROWTH collaboration.

Helical magnetic fields from Riemann coupling

Ashu kushwaha and S. Shankaranarayanan
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We study the inflationary generation of helical magnetic fields from the Riemann coupling with the electromagnetic field. Most models in the literature introduce non-minimal coupling to the electromagnetic fields with a scalar field, hence, breaking the conformal invariance. In this work, we show that non-minimal coupling to the Riemann tensor generates sufficient primordial helical magnetic fields at all observable scales. We explicitly show that one of the helical states decay while the other helical mode increases, leading to a net non-zero helicity. Our model has three key features: (i) the helical power-spectrum has a slight red-tilt for slow-roll inflation consistent with bounds from observations and free from backreaction problem, (ii) the energy density of the helical fields generated is at least one order of magnitude larger than the scalar-field coupled models, and (iii) unlike the scalar field coupled models, the generated helical fields are insensitive to the reheating dynamics.

Detectability of PMFs and the B-mode Polarization of CMB

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The existence of the primordial magnetic field (PMF) in the early Universe affects the evolution of cosmological perturbations and potentially leaves an imprint on CMB anisotropies. We look at the effects of the stochastic magnetic field of nano-Gauss strength on the Polarization of the CMB. The effect of magnetic fields is more evident in B-mode polarization than in case of temperature or E-mode spectra. We focus on the B-mode power spectrum, and show that the B-mode of CMB carry a distinct signature of the primordial magnetic fields. We use the BICEP2 and POLARBEAR data of B-mode polarization to show that the observations are in agreement with nonzero PMF cases, and hence, their presence cannot be ruled out. We also use the BICEP2 observations to constrain the primordial magnetic field. We provide a detailed analysis of the B-mode polarization of the CMB with primordial magnetic fields and possible implications for future CMB observations.

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Develop a Compact High Current Super-Conducting Linear Electron Beam Accelerator for Treating Industrial and Domestic Effluents

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The total volume of water on earth is about 1400 million of which only 2.5% is freshwater. The usable portion is less than 1% of all freshwater and only 0.01% of all water on earth [1]. Today's increasing population, urbanization, and industrialization is producing a lot of waste like carcinogenic halogenated hydrocarbons, human waste, effluents from industries. These effluents in India are discharged into river without any process moreover the usage of pesticides, fertilizers in agriculture are responsible for ground water impurities. The conventional treatments have often been found to be insufficient for purification because of carcinogenic byproducts and bacteria's mutation nature against chemicals.

So there is an urgent need for alternative purification methods for domestic and industrial effluents which should be economically beneficial, operationally robust and compact in size and can be duplicated and placed all along the water resources like rivers. The solution is that irradiation with high-energy electron beam can be used for water purification without any side effects like production of harmful byproducts. Radiation essentially works on the principle of radiolysis of water. It results in very reactive radical particles like reducing agents: Hydrated electrons, Hydrogen atom(H) and oxidizing agents: Hydroxyl radical(OH), Hydrogen peroxide). They removes organic impurities with radiation chemical reactions, colour by destruction of the double bonds, odour by opening up rings in aromatic compounds and disinfects the water by destroying the DNA of micro-organisms[2].

So our aim is to design a high current super-conducting linear electron beam accelerator with 40 kW beam power and 1 MeV beam energy to treat 1000 /day water for dose 2 kGy. The estimated cost is about 68 ₹ for 1 million litre per day. If the system is operated at 200 kW then the cost goes down 18 ₹ MLD. The average life of such facility is very long and recurring costs are moderately low. This will establish feasibility of large scale water treatment facility in India and make accelerator based facility a very prudent choice.

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Understanding long-range near-side ridge correlations in p−p collisions using rope hadronization at LHC energies

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The observation of long-range ridge-like structure in the near-side region of the two-particle Δη−Δφ correlations as measured by LHC experiments in high multiplicity p−p collisions indicated towards the presence of collective effects which are similar to that observed in p−A (nucleon-nucleus) and A−A (nucleus-nucleus) collisions. The two-particle correlation between the charged particles in Δη−Δφ for p−p collisions at $\sqrt{s}$ = 7 TeV and 13 TeV is studied using Pythia 8 event generator within the framework of final-state partonic color reconnection effects as well as the microscopic rope hadronization model. The rope hadronization relies on the formation of ropes due to overlapping of strings in high multiplicity events followed by string shoving. A near side ridge-like structure which is qualitatively similar to the observed ridge in data was observed for high-multiplicity events when the mechanism of rope hadronization (with shoving) was enabled.

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Measuring the polarization of boosted, hadronic W bosons with jet substructure observables

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Measuring the polarization of high energy W bosons is important for the study of many SM and BSM processes. In this work, we present a new technique for measuring the longitudinal and transverse polarization fractions of hadronic decays of boosted W bosons. We introduce a new jet substructure observable denoted as $p\theta$, which is a proxy for the parton-level decay polar angle of the W boson. We show that the distribution of this observable is sensitive to the polarization of W bosons and can therefore be used to reconstruct the W polarization in a model independent way. As a test case, we demonstrate the efficacy of our technique on vector boson scattering processes at the high luminosity LHC.

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New Physics through neutrino portal

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The Standard Model (SM) of particle physics has been successful in explaining nearly all the experimental findings below the electroweak scale. However the limitations that shadow its successes are not less. The non-inclusion of gravity and some theoretical questions like parity violation in weak interactions, baryon asymmetry of the universe, origin of neutrino mass, dark matter and dark energy restrain the model from being considered as the final theory. A major blow to the SM comes from the neutrino oscillation experiments which reveal that neutrinos have mass and they mix with each other [1, 2, 3, 4]. The fact that neutrinos do oscillate makes us wonder whether fundamentally they are Dirac or Majorana particles [5]. Among all the new theories the seesaw mechanisms namely type-I [6], type-II [7], type-III [8] that are the simplest extensions of SM seem appealing as they naturally provide mass to neutrinos. However these seesaw mechanisms link the sub-eV masses of neutrinos to a very high scale of right-handed neutrino mass making themselves unsuitable for experimental verification at colliders. The alternative is to study TeV scale seesaw models like inverse seesaw, extended seesaw, radiative seesaw which can be verified at current experiments. The seesaw mechanisms consider neutrinos to be Majorana particles and if neutrinos are Majorana in nature, they can mediate a very rare process in nature called the Neutrinoless Double Beta Decay ($0\nu\beta\beta$) [9]. The importance of this process in particle physics is far-reaching since it is the only process that can confirm the Majorana nature of neutrinos and total lepton number violation in nature once observed unambiguously. The current experiments on $0\nu\beta\beta$ decay process are still trying to finetune the bound on the life-time of the isotopes being decayed. Recent experiments like GERDA, EXO, KamLAND have given the most stringent lower bounds on the half-lives of the decay of various nuclei [10, 11, 12]. A promising theory beyond SM which gives

room to a right-handed neutrino naturally and aptly explains neutrino mass is the Left-Right Symmetric Model (LRSM)[13, 14, 15]. The gauge symmetry i.e. SU(2)L × SU(2)R × U(1)B−L × SU(3)C makes the model quite versatile to accommodate low scale seesaw mechanisms and DM candidates. Moreover the associated gauge bosons with this symmetry can give various new contributions to 0νββ decay process when studied at TeV scale (see refs. [16, 17, 18]). A major part of our work involves the study of various new physics contributions to 0νββ decay in TeV scale LRSM.

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Charged lepton flavour violating decays in a neutrino mass model with A_4 symmetry

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We study the charged lepton flavour violation in a popular neutrino mass model with A_4 discrete symmetry. This symmetry requires the presence of multiple Higgs doublets in the model and it also dictates the flavour violating Yukawa couplings of the additional neutral

scalars of the model. Such couplings lead to the decays of the neutral mesons, the top quark and the τ lepton into charged leptons of different flavours at tree level. The A_4 symmetry of the model leads to certain characteristic signatures in these decays. We discuss these signatures and predict the rates for the most favourable charged lepton flavour violating modes.

Nematics on Curved Colloidal Membranes

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Monolayers of rod like, chiral, colloidal molecules serve as a model system for studying open membranes with free edges. Experiments have shown that the temperature dependence of molecular chirality can be exploited to reduce the line tension of the open edges at low temperatures and thus promote curved membrane structures with more edges. I will discuss theoretical results on the 3D orientations of the rods, considered as nematics, on curved membranes.

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A Lamin Associated Chromatin Model for Chromosome Organization

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We propose a simple model for chromatin organization based on the interaction of the chromatin fibres with Lamin proteins along the nuclear membrane. Lamin proteins are known to be a major factor that influences chromatin organization, and hence gene expression in the cells. Our polymer model explains the formation of lamin associated domains, and for heteropolymers with sequence control, can reproduce observed length distributions of LADs. In particular, lamin mediated interaction can enhance the formation of chromosome territories as well as the organization of chromatin into tightly packed heterochromatin and the loosely-packed gene-rich euchromatin regions.

Electrostatic Interactions in polyelectrolyte brush on the spherical surface

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Polyelectrolytes (PEs) polymers exhibit electrostatic interactions because of the charged monomers in their structure. Electrostatic interactions in PEs are a topic of interest as they show interesting properties with changing external variables such as pH, temperature, salt valency, and salt concentration. DNA is one such natural polyelectrolyte that has a negatively charged backbone. Multivalent

ions are found to interact with the DNA backbone, thus inducing DNA-DNA attraction. At a high salt concentration in multivalent ions, DNA can also show charge reversal. We designed DNA-AuNP (gold nanoparticles) based BCC crystals to understand the effect of the different salt concentration and salt valency on the DNA chain length attached to the spherical surface. Small Angle X-Ray Scattering (SAXS) is an in-situ measurement used to understand the super-lattice BCC crystal of DNA-AuNPs. The experimental data is further explained using the modified Daoud Cotton model.

Self-assembly of anisotropic nanoparticles - lipid bilayer composite at the air-water interface

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The electrostatic interactions in confined geometry can lead to rich phases including fluid, gel and soft glasses which have applications in various biomedical fields. Herein, we present the self-assembly of model lipid membrane at the air-water interface and its interaction with zwitterionic anisotropic nanoparticles. The strength of electrostatic interaction at the air-water interface is controlled using different compositions of neutral lipid 1,2-dimyristoyl-sn-glycero-3-phosphocholine (DMPC) and cationic lipid dimyristoylethylammonium propane (DMTAP). The number density of zwitterionic anisotropic nanoparticle trapped in 2D confinement at the air-water interface exclusively depends on the strength of electrostatic interactions and exhibits glass-like or gel-like behavior. Structural changes in lipid membrane due to nanoparticle adsorption are monitored in-situ by studying surface pressure - mean molecular area isotherm and static/dynamic modulus using Langmuir Blodgett technique and ex-situ via atomic force microscopy measurements.

Unprecedently High Conduction of Triplet Exciton in Molecular Solids

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Exciton physics of singlets vs triplets are pretty distinct and in particular a notion is there in community that triplets are highly localized in polymeric semiconductors in comparison to their crystalline family of acene based molecular semiconductors. Here we studied the effect of polymer chain packing on triplet diffusion in the amorphous polymeric system which is known to have pretty efficient delayed fluroscence via triplet-triplet annihilation process. In order to understand the dark triplet exciton transport physics we designed a customized experimental technique to measure the triplet diffusion coefficient in the semiconductor system along lateral and transverse directions. We have used a unique method to trace the triplet dipole position in the emissive layer of light-emitting diode (LED) by solving the dyadic green function for the out-coupling and direct visualization of triplet by imaging technique. Results suggest the anisotropy is significantly higher in thinner films and as film thickness increases we get lesser anisotropic triplet transport. Moreover, we note that for thicker films triplet diffusion coefficient, surprisingly, approaches close to 10^{-3} cm^2 s^{-1} similar to reported values for Tetracene based thin-films. An independent temperature dependent DF studies further supports these results.

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Correlation of Nano-morphology with Structural and Spectroscopic Studies in Organic Solar Cells

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The nano-morphology of bulk heterojunction blends based on poly[[4,8-bis[(2-ethylhexyl)oxy]benzo[1,2-b:4,5-b']dithiophene-2,6-diyl][3-fluoro-2-[(2-ethylhexyl)carbonyl]thieno[3,4 b]thiophenediyl]] (PTB7) blended with [6,6]-phenyl-C_{71}-butyric acid methyl ester ($PC_{71}BM$) is systematically varied by varying the volume fraction of the solvent additive 1,8-diiodooctane (DIO) from 0 vol% to 20 vol% in the casting solution. With increasing addition of DIO, the photoluminescence (PL) from the blend is reduced; however, a relative increase in PL from 750 nm onwards is observed for blends with 20 vol% DIO. As quenching of the blend PL is related to the donor/acceptor (D/A) interface, structural characterizations in real-space (microscopy) and *k*-space (diffraction) are performed to unravel the morphology of blend systems to correlate nano-morphology with photophysical and charge transport processes. Blends prepared with 0 vol% DIO form

large phase separated domains of PCBM, hundreds of nanometres in diameter. With the addition of 3 vol% DIO the size of PCBM domains is supressed resulting in a more mixed morphology due to the selective dissolution of DIO in $PC_{71}BM$. On the addition of up to 20 vol% of DIO, the film becomes rougher with a finer interconnected morphology due to polymer aggregation, which contrasts with previous reports. Electron transport lengths measured by scanning photocurrent microscopy (SPM) are found to increase with the addition of up to 3 vol% DIO associated with the break-up of the large $PC_{71}BM$ aggregates, while the hole transport length is found to increase on adding DIO up to 20 vol% due to aggregation of polymer chains. The structural results are found to be in good agreement with the PL quenching and the transport lengths. This work represent a unique set of results systematically examining the effect of nano-morphology on structural and opto-electronic properties of PTB7: PCBM blends on the addition of solvent additive DIO, which has implications beyond the system studied.

Monitoring in-depth soil moisture for advanced agriculture application

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A facile approach to determine in-depth soil moisture is developed using capacitive graphene oxide (GO) sensor. The array sensor probe (GO-ASP) having dimensions $22 \times 4 \times 0.5\ cm^3$ is embedded with a series of five microsensors (scalable according to the need).

The measurement electrodes were designed in a interdigitated manner having 8 pairs of comb-like shape fingers with 100 nm thickness and 90 μm spacing. It has been observed that, for black soil, all the microsensors displayed response in the range of 500-550% when soil water content is varied from 3.2-55.5%. The GO-ASP shows fast response and recovery time of 140 s and 20 s, respectively, for 10% soil moisture samples. Soil moisture profile have been monitored upto the scale of 20 *cm* depth using the fabricated design. Indepth soil moisture profiling shows a maximum difference of ±2.4% when compared with standard oven-drying method. The lump formation effect in soil mass showed a maximum difference of ±4% for GO-ASP array. This robust and low cost GO-ASP with high sensitivity is promising for technological advances in agricultural application.

Spin-gapless Semiconducting Nature in Co-rich $Co_{1+x}Fe_{1-x}CrGa$

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Spin gapless semiconductors (SGSs) are an interesting class of materials which bridge the gap between semiconductors and half-metallic ferromagnets. This class of materials shows band gap in one of the spin channels and a zero band gap in the other [1]. The structural, electronic, magnetic, and transport properties of Co-rich SGS $Co_{1+x}Fe_{1-x}CrGa$ are investigated using both theoretical and experimental techniques. The key advantage of Co-rich samples $Co_{1+x}Fe_{1-x}CrGa$ is the high Curie temperature (T_C) and magnetization, without compromising the SGS nature (up to x = 0.4), and hence our choice. The quaternary Heusler alloys $Co_{1+x}Fe_{1-x}CrGa$ (x = 0.1 to 0.5) are found to crystallize in LiMgPdSn-type structure having space group $F\bar{4}3m$. The measured Curie temperature increases from 690 K (x = 0) to 870 K (x = 0.5). The obtained T_C for x = 0.3 (790 K) is found to be the highest among all previously reported SGS materials. Observed

magnetization values follow the Slater-Pauling rule [2, 3]. Measured electrical resistivity, in the temperature range of 5–350 K, suggests that the alloys retain the SGS behavior up to $x = 0.4$, beyond which it reflects metallic character. Unlike conventional semiconductors, the conductivity value (σ_{xx}) at 300 K lies in the range of 2289 S cm^{-1} to 3294 S cm^{-1}, which is close to that of other reported SGS materials [4, 5]. The anomalous Hall effect is comparatively low. The intrinsic contribution to the anomalous Hall conductivity increases with x, which can be correlated with the enhancement in chemical order [6]. The anomalous Hall coefficient is found to increase from 38 S cm^{-1} for $x = 0.1$ to 43 S cm^{-1} for 0.3. Seebeck coefficients turn out to be vanishingly small below 300 K, another signature of SGS [5]. Based on these observations, these alloys are found to be promising for room temperature spintronic applications, with enhanced T_C, magnetic properties, and SGS nature [7].

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Study of skew scattering dominated anomalous Hall effect in Si/Ni multilayers

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The devices produced by the nanofabrication techniques have laid the foundation of the spintronic (spin electronics) devices. The giant magnetoresistance (GMR) and the anomalous Hall effect (AHE) have been more extensively studied in magnetic multilayers. The present paper deals with the skew scattering dominated AHE study in Si/Ni multilayers. The study is performed by preparing a series of $[Si(t_{Si})/Ni(30Å)]_{20}$ multilayers at ambient temperature using DC magnetron sputtering process. The structural and microstructural studies suggest that effective crystallites size increases with a decrease in t_{Si}. The cross-sectional TEM data reveals that the Si/Ni multilayers with $t_{Si} \leq$ 10Å are of discontinuous form. The magnetotransport parameters such as saturated anomalous Hall resistance, anomalous Hall coefficient and Hall sensitivity are found to gradually increase within 100Å $\leq t_{Si} \leq$ 30Å and then sharply increase till t_{Si} = 10Å due to the surface and interface scattering effects. These parameters decrease when t_{Si} further reduces down to 5Å which is beyond the percolation threshold. The maximum enhancement of about 33 times in anomalous Hall resistance and 24 times in anomalous Hall coefficient are found at t_{Si} = 10Å. The skew scattering is the dominant mechanism that is responsible for the AHE phenomena in the Si/Ni multilayers. The results are useful for their possible applications of AHE based devices in potential and sensing technology.

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Electron-phonon interaction in Lead-Free Double Perovskite $Cs_2AgIn_{1-x}Bi_xCl_6$

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Recently, lead free all-inorganic double perovskites have revolutionized the photovoltaic research, showing promising light emitting efficiency and tunability via modification of inherent structural and chemical properties. Carrier-lattice interactions via Fröhlich mechanism is known to be the dominant scattering mechanism, dictating carrier mobility near room temperature for these compounds. In this talk, I will give a brief introduction on electron-phonon coupling via Fröhlich mechanism. Next, I will discuss our theoretical study on the variation of carrier-lattice interaction and optoelectronic properties of $Cs_2AgIn_{1-x}Bi_xCl_6$ double perovskite nanocrystals with varying alloying concentrations. In addition to introduction of parity allowed direct optical transition, we observe a noticeable increase in hole mobility with small Bi alloying, attributed to valence band maxima acquiring Bi-s orbital characteristics, thus increasing its dispersive nature.

Synchronization of Dissimilar Quantum Systems

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Detecting and measuring synchronization of classical systems has been an important area of research in nonlinear dynamics for decades [1-3]. Regardless of the exact nature of the studied classical system, be it a collection of fireflies, heart cells or firing neurons in

the brain, the equations of motion generate trajectories in phase space which enable us to compute an appropriate measure of synchronization. Quantification of synchronization in quantum systems, on the other hand, does not immediately present such a unified and intuitive approach. Different measures have been introduced to study quantum synchronization [4-7], but they are specific to the systems under study. In our work, we present a unified information-theoretic measure of synchronization, based on distance-like measures to the set of limit-cycle states. This measure captures synchronization dynamics in all previously studied systems such as quantum analogs of anharmonic oscillators, few-level atoms, and coupled oscillator networks, generalizing several previously proposed information-theoretic measures. Furthermore, the new measure allows us to discuss the synchronization of disparate physical systems such as coupled hybrid quantum systems.

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POSTERS

Singlet ground state in the alternating spin-1/2 chain compound $NaVOAsO_4$

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We present the synthesis and a detailed investigation of structural and magnetic properties of polycrystalline $NaVOAsO_4$ by means of x-ray diffraction, magnetization, electron spin resonance (ESR), and ^{75}As nuclear magnetic resonance (NMR) measurements as well as density-functional band structure calculations. Temperature-dependent magnetic susceptibility, ESR intensity, and NMR line shift could be described well using an alternating spin-1/2 chain model with the exchange coupling $J/k_B \simeq 52$ K and an alternation parameter $\alpha \simeq 0.65$. From the high-field magnetization measured at $T = 1.5$ K, the critical field of the gap closing is found to be $H_C \simeq 16$ T, which corresponds to the zero-field spin gap of $\Delta_0/k_B \simeq 21.4$ K. Both NMR shift and spin-lattice relaxation rate show an activated behaviour at low temperatures, further confirming the singlet ground state. The spin chains do not coincide with the structural chains, whereas the couplings between the spin chains are frustrated. Because of a relatively small spin gap, $NaVOAsO_4$ is a promising compound for further experimental studies under high magnetic fields.

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Photoinduce quasi-2D to 3D phase transformation of organic-halide perovskite nanoparticles

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Organic halide perovskite nanoparticles (NPs) have excellent photoluminescence (PL), high PL quantum yield (QY), direct band-to-band transition with significant absorption coefficients (~10^5 cm^{-1}), small excitonic binding energy (76 meV), high carrier mobility, long charge-diffusion length, etc. This makes hybrid halide perovskite nanoparticles ($CH_3NH_3PbX_3$ where X=Cl, Br and I) the most promising candidate for various optoelectrical applications. Various experimental reports have illustrated that $CH_3NH_3PbBr_3$ NPs belongs to an analogue of Ruddlesden–Popper phase which consists of two-dimensional perovskite-like slabs interleaved with cations. General formula of Ruddlesden–Popper phase is $A_{n+1}Pb_nBr_{3n+1}$ for a single catanionic system which can be represented as $A_{n-1}A'_2Pb_nBr_{3n+1}$ for double catanionic compound, where A is $CH_3NH_3^+$ and A' long-chain organic cations which are taken as a surfactant during the synthesis of perovskite NPs such as oleylammonium cations ($C_{18}H_{35}NH_3^+$). "n" is thickness of the perovskite, i.e. the number of continuous octahedra which are stacked together in the perovskite structure. For a complete 3D perovskite form, $n=\infty$ and for a complete transformation to 2D perovskite, n=1. In between n=2 to 4, they are known as quasi-2d perovskites; and after $n \geq 5$ it starts behaving like a 3D (or bulk) perovksite.

Herein, we have shown the photo-induced phase transition from quasi-2D to 3D $CH_3NH_3PbBr_3$ perovskite NPs. In this work, we successfully synthesized quasi-2D $CH_3NH_3PbBr_3$ nanoparticles

(thickness is n=2) via hot injection method. This quasi-2D $CH_3NH_3PbBr_3$ perovskite nanoparticles have cubic phase as confirmed from the XRD studies; which is also supported by the SAED investigations. Emission peak at 450 nm, 467 nm, 473 nm, and 525 nm belongs to n=2, 3, 4 and 5 thicknesses, for a layered $CH_3NH_3PbBr_3$ NPs. Excitonic Bohr radius of $CH_3NH_3PbBr_3$ nano particles is found to be 2 nm, and the thickness of a single layer of $PbBr_6^{4-}$ octahedra is 5.9 Å. As the layer thickness decreases, $CH_3NH_3PbBr_3$ perovskite NPs moves to quantum confinement regime, which is governed by the blue-shift in the emission peak of $CH_3NH_3PbBr_3$ nanoparticles. Room temperature steady-state emission and absorption investigations show a systematic change in the thickness of the perovskites as a result of continuous photon irradiation (340 nm, UV light source). As the phase shifts away from the quantum confinement regime, bandgap of the compound changes from 2.72 eV to 2.2 eV. XRD patterns show a continuous decrease in the full-width half maxima, which indicates that the thickness of the perovskite NPs is increasing. In order to support our claim, density functional theory (DFT) based ab-initio calculations were performed on layered $CH_3NH_3PbBr_3$ structure to validate the change in band gap due to the quantum confinement effect. Due to the organic molecule surrounding of the Pb-Br octahedra, the role of van-der-Waal's interaction becomes significant in the surface slab and this has been included in the calculations. With more accurate Heyd-Scuseria-Ernzerhof (HSE) exchange correlation functional, the band gap is found to vary from 2.79 eV to 2.29 eV, for 2-5 layered $MAPbBr_3$ perovskite nanoparticles, which matches exceptionally well with the observed experimental trends. Our observations are both important for the understanding of spectral emission shift in hybrid perovskites and for an eventual future development of efficient perovskite LEDs.

Carrier density modulation of thin gold film using electrolytic gating

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Electrolytic gating is a powerful technique to modulate density of charge carriers in high carrier density samples, having two dimensional carrier density as high as high as ~10^{17} cm^{-2} [1]. For example the conductivity of a thin film of gold, ~10-100 nm thick can be modulated by an ionic liquid gate, which is not possible by any insulated (solid state) gate. For any practical insulator material, the dielectric breakdown voltage limits the capacitance to a maximum of ~ 10^{11} carriers/Volt. The ionic liquid gating technique enables us to get into unexplored regions of the phase diagram in a variety of materials. Modulation of carrier concentration of thin gold film (~ 100 nm) using this technique are shown.

The relative sizes and coplanar layout geometry of the gate electrodes and the channel plays a significant role in the behavior of the device. For example, we find that the gate electrode needs to have a much larger area than the channel. We used N-N-diethyl-N-(2-methoxyethyl)-N-methylammonium bis(trifluromethylsulfonyl)-imide(DEME-TFSI) as an ionic liquid on 100 nm thin gold hall bar patterned onto a Si/ SiO_2 substrate. The IL DEME-TFSI forms a nano gap capacitor at the interface of sample and IL [3]. We show that, surface charge densities (n_{2d}) as high as ~7.6 x 10^{15} cm^{-2} can be modulated. The typical gate voltages are however limited to ~1 volt. This density is close to the carrier density of a hypothetical monolayer of a monovalent metal with a typical lattice constant of few Angstroms. This technique has the potential for field effect control of properties of degenerate semiconductors, thin films of metals and surface states of some materials.

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Low Band Gap Lead Free Mixed Valence Gold halide perovskites

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Synthesis of eco-friendly as well as stable perovskite-family absorber material is the prime need for the photovoltaic applications. Among the perovskite family, organo–inorganic lead halide perovskites have shown a tremendous growth in this regard, by achieving extraordinary power conversion efficiency from 3.8% to over 22% in just a decade. However, the short-term stability and the lead toxicity of these compounds has been a big pitfall for their practical use in photovoltaic devices. On the other hand, double perovskites $A_2B^IB^{III}X_6$ (where A = Cs, B^I = Ag, Cu, Au, B^{III} = Bi, Sb, Au and X is halide), are very popular among researchers looking for new lead-free material design of hybrid lead based perovskites. The chemical composition and the optical properties of these materials could be tailored by the anion exchange at B or X site. In this work, experimental results are presented to demonstrate the anion exchange in $CsAuCl_4$ resulting in $Cs_2Au^IAu^{III}I_6$ with the benefit of ideal band gap in the range of 1.1-1.5 eV. Also, the resulting compound remains unaltered under light, heat and humidity for more than 6 months.

Magnetic properties of the $S = 1/2$ coupled spin-chain compound $Ba_2Cu_2Te_2P_2O_{13}$

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We present the synthesis and characterization of polycrystalline $Ba_2Cu_2Te_2P_2O_{13}$ (BCTPO) via x-ray diffraction, magnetic susceptibility, heat capacity, and 31P Nuclear Magnetic Resonance (NMR) measurements. BCTPO crystallizes in a monoclinic structure with Cu2+ ions forming coupled chains. In magnetization [$M(T)$] measurements, a broad maximum is observed around 53 K. A sharp anomaly is seen around 4 K in the heat capacity [$CP(T)$] data, indicative of the onset of long range order (LRO). The 31P NMR line-shift tracks the spin susceptibility. The inferred isotropic and axial components of the hyperfine coupling constant are $Aisohf \cong 3635$ Oe/μB and $Aaxhf \cong 479$ Oe/μB, respectively. The 31P NMR spin-lattice relaxation rate ($1/T1$) shows a sharp upturn around 4 K, as was seen in $CP(T)$, signifying the onset of LRO.

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Quantum phase transitions with realistic superconducting qubits

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The strong interaction between a system and environment degrees of freedom in quantum impurity systems give rise to several interesting physics such as, quantum phase transition, generation of non-classical nature of light. However, experimental approach to this high coupling regime still facing a lots of challenges. We studied theoretically more promising system of arti_cial atom made from electronic components. Variational theory and numerical renormalization group (NRG) methods are implemented on a dissipative quantum system of superconducting qubits coupled to a bath of harmonic oscillators. We study ground state and dynamical properties of the system and calculate the system parameters as a function of coupling strength. From the results we observed that there is no quantum phase transition in transmon regime, therefore the system remains in delocalized phase. An unexpected behavior of spin-coherence is observed in that limit which makes the system more phase coherent.

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Out of equilibrium chiral higher order topological insulator on a π-flux square lattice

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One of the hallmark of bulk topology is the existence of robust boundary localized states. A d dimensional topological system hosts d - 1 dimensional surface states, which is known as the first order topological phase. The first order topological insulators (TI's) are classified based on three non-spatial symmetries such as, the time reversal, the particle-hole and the sublattice or chiral symmetry. Recently, this idea has been extended to higher order topological systems with boundary modes that are localized in lower dimensions such as in the corners or in one dimensional hinges of the system. The higher order topological insulators (HOTI's) are protected by the crystalline (spatial) symmetries, e.g., the inversion, the mirror reflection or the four-fold rotational symmetry or space-time symmetries. Generalization of TI's and HOTI's in the presence of time dependent Hamiltonian realized via periodic (Floquet) drive has also been developed.

In this work, we show that the higher order topological states can be engineered in nonequilibrium where the equilibrium model does not possess any symmetry protected topological states. Unlike the other works, where the Floquet HOTI phases are protected by the space-time or the combination of both time reversal and four fold rotation or by the mirror symmetries, in this work we show that an emerging chiral symmetry generated through Floquet driving, can also protect a dynamical HOTI. By using both exact numerics and an effective high-frequency Hamiltonian obtained using the Brillouin-Wigner perturbation theory we probe these topological states in a π-flux square lattice. Furthermore, we show that the localized corner modes in our model are robust against a chiral symmetry preserving perturbation. Finally, we

identify a two dimensional topological invariant from the winding number of the corresponding sublattice symmetric one dimensional model in symmetry class AIII.

Evaporative self-assembly of gold nanorods

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Evaporative self-assembly involves the evaporation of solvent molecules and utilizes fluid dynamics to form order structures. Gold nanorods have two modes (longitudinal and transverse) of surface plasmon resonance. Order self-assembly of gold nanorods will help in innovative uses in applications such as biomedicine, biosensing, detection and many more. We use the evaporative self-assembly technique to assemble the gold nanorods because this technique is simple, inexpensive, easily controllable helps in designing a complex structure in a scalable manner. The coffee-ring effect, which is an instance of evaporative self-assembly, is caused by capillary driven flow. This outward capillary flow drags the particles towards the edge of the drop and deposit in a ring-like pattern. Particles are arranged along the perimeter of the ring in order manner depending on different parameters such as particles shape anisotropy, the surface morphology of substrates, suspension concentration. Our study involves the understanding of the dynamics of the coffee-ring effect and the formation of order structures by the evaporative self-assembly method. Here, we examine the effect particles shape anisotropy on the final deposition pattern lead by the coffee-ring effect.

ECHO IN SMALL WORLD NETWORKS

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Large populations of globally coupled or uncoupled oscillators have been recently shown to exhibit an intriguing echo behavior [2,3], wherein a system is perturbed by two successive pulses at times T and $T+\tau$ inducing a spontaneous increase in the order parameter at the given times. These two provoked increments in the order parameter are followed by an unprovoked spontaneous increment in the order parameter at time $T + 2\tau$ termed as echo. In this work, the effects of network topology on the emergence of an echo are explored. Two principal network parameters namely average degree and network randomness are varied for this purpose. The networks are rewired to increase randomness in the network connections using the Watts-Strogatz algorithm to generate small world networks [4]. Thus, the whole span of networks ranging from a regular ring to a completely random network is explored. The average degree of the underlying connectivity, starting from nearest neighbor connections is also monotonically increased and its effects on the echo behavior are analyzed. We find that for rings with low average degrees and high coupling strengths, a discernible echo is not observed. Remarkably, echo re-emerges in the presence of sufficient randomness in the connections for such networks. For a regular ring network, increasing the average degree post a critical value also yields a transition to echo behavior. However, for completely random networks echoes are present in networks of all average degrees. This suggests that randomizing connections can induce echoes in systems even when the average degree of connections is very low. Another subtle feature arises for intermediate randomness, where the system exhibits a non monotonic dependence of the echo size on average degree.The echo size was found to be minimum at an intermediate value of the average degree. Lastly we consider the influence of dynamically

changing links on the echo size and demonstrate that time-varying connections destroy the echo in low-average degree networks, while the echo persists under dynamic links in high average degree networks. Therefore, our results clearly demarcate the class of networks that are robust candidates for exhibiting echoes, as well as provide caveats for the observation of echoes in networks.

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LIPID MONOLAYER ASSEMBLY AT LIQUID-LIQUID INTERFACE

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Abstract: In the present work, we have focused on the study of the in-situ adsorption dynamics of lipid monolayer formed at liquid-liquid interface. Different composition of cationic lipid 1,2 dimyristoyl-3-trimethylammonium-propane (DMTAP) and zwitterionic lipid 1,2-dimyristoyl-sn-glycero-3-phosphocholine (DMPC) were used in the sub-phase for monolayer formation at the

liquid/liquid interface. The adsorption dynamics of different lipid composition at various concentrations are studied by measuring interfacial surface tension using Langmuir Blodgett technique. Lipid molecules organize via self-assembly process at the interface, i.e., hydrophilic heads stay in the polar solvent and hydrophobic tails in non-polar solvent to minimize the activation energy. The interfacial surface tension exhibits cross-over behavior with increase in lipid concentration in the subphase, which shows interesting structural phenomena. The formation of lipid monolayer at the interface via self-assembly process highly depends on the DMTAP: DMPC ratio. The ex-situ structural characterization of the monolayer is done using AFM via transfer of lipid monolayer to solid silicon substrate. The future goal of this work is to understand the in-situ structural morphology of lipid film formed at interface and their dynamics using confocal microscopy.

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ROTATIONAL SYNCHRONIZATION OF CAMPHOR RIBBONS IN DIFFERENT GEOMETRIES

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The experiments performed on multiple camphor ribbons are presented. The camphor ribbon, is a rectangular size paper with

camphor infused in its matrix. The camphor ribbon moves on the surface of water, due to the surface tension gradient introduced by the camphor layer on the surface on water [1] [2]. To allow rotational motion only, the ribbons were pinned at one the end [3]. Experiments were performed on three, four and five camphor ribbons. Three and four ribbons were placed on linear and closed geometry but the five ribbons were placed only on star geometry. In different geometries, the ribbons were observed performing rotational synchronization in all the possible configurations. However, in the frustrated geometry like in triangle, some configurations are restricted, and, hence were not observed experimentally. The synchronization was observed only between neighbor ribbons placed at the pivot to pivot distance l, less than twice the length of the single ribbon. The camphor layer around one ribbon interacts with the camphor layer of second ribbon, which leads to the chemical coupling between the camphor ribbons [2][3]. A numerical model, using the interactions between the ribbons as Yukawa interaction was simulated [3]. The simulations were qualitatively able to reproduce the experimental findings.

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