TIFR Annual Technical Report (2015-16)

Department of Theoretical Physics

1. School / Centre / Department / Group

Department of Theoretical Physics

2. Highlights

A. Cosmology and Astroparticle Physics

- It was shown in a series of two papers that a self-interacting neutrino gas can spontaneously acquire a nonstationary pulsating component in its flavor content, with a frequency that can exactly cancel the "multiangle" refractive effects of dense matter.
- It was shown that photon jets can be distinguished from isolated photons by exploiting the fact that a large fraction of photons pair-convert inside the inner detector, and quantified this in the context a diphoton-like signal.
- Sterile neutrinos with secret interactions were studied and their viability in the light of constraints from observations of the microwave background and large scale structure was investigated. It was shown that two interesting regimes remained marginally viable.
- Sunyaev-Zeldovich effect fluctuations, which are integral of the pressure fluctuations in the intracluster medium (ICM) along the line sight, were detected using Planck data in the Coma cluster. This is a first such detection of pressure fluctuations in a cluster of galaxies with important implications for using galaxy clusters as a cosmological probe.
- A new method for separating the Sunyaev-Zeldovich effect from Carbon monoxide emission from Galaxy was proposed and applied to the Planck cluster catalog.
- Interaction of X-rays with the Galactic molecular clouds was studied and scattered X-rays were proposed as a probe of properties of the X-ray sources in the Galaxy as well as the structure of the interstellar medium.
- Prospects for looking for missing baryons in the Universe were studied using cross-correlation of distribution of galaxies with the Sunyaev-Zeldovich and X-ray power spectra of galaxies from their circum-galactic baryons. These cross-correlations in current and

upcoming surveys were shown to be the excellent probes of the nature, i.e. extent, evolution and energetics, of the circum-galactic medium.

B. Condensed Matter and Statistical Physics

- A new universality class of multicritical melting of three-sublattice order of easy-axis antiferromagnets with triangular symmetry was identified, and critical exponents computed.
- The critical density for the phase transition from the nematic to layered phase in a system of hard rectangles was studied analytically, and by simulations.
- A theory for optical lattice modulation spectroscopy in spin-orbit coupled Bosons was developed.
- A cold atom implementation of Bernal stacked bilayer honeycomb lattice with cold atoms was proposed and incommensurate spin-density wave instability in this system was investigated.
- A new formalism for critical behaviour near nonequilibrium Mott transitions in dissipative open quantum systems was developed in terms of non-Hermitian models invariant under parity (P) and time reversal (T) transformations. The nonequilibrium Mott transition was identified with PT symmetry breaking.
- The Berry phase mechanism for anomalous Hall effect was discovered in a strongly disordered two-dimensional magnetic semiconductor structure.

C. High Energy Physics

- A method based on Principal Component Analysis was presented to study event-by-event fluctuations in ultrarelativistic heavy-ion collisions; it revealed previously unknown subleading modes in the particle multiplicity as well as elliptic and triangular flows.
- A comprehensive "White Paper", quantifying the physics potential of the ICAL detector as obtained from realistic detector simulations, was completed.
- A new variable for analysis of hadronic jets in heavy ion collisions was proposed as a better tool to analyse the hot medium produced in these collisions.
- An invited review for physics undergraduates was written on QCD critical point.
- The ratio of the two flow scales in QCD, w_0 and $\sqrt{t_0}$ was found to be universal.

- Two explanations were proposed as explanations for the CERN diphoton excess reported in December 2015. One model proposed a solution based on a mixed Higgs-radion state of mass 750 GeV, which could be shown to decay exclusively to diphotons and dijets. The other proposed a solution based on a variant of the minimal supersymmetric Standard Model which has two extra scalars, of which one can be arranged to have the necessary properties.
- A monograph entitled "Particle Physics of Brane Worlds and Extra Dimensions" was completed for publication by the Cambridge University Press in its prestigious series "Cambridge Monographs on Mathematical Physics." This book is a comprehensive review of a highly current research topic which has come up in the last two decades.
- Bulk warped-scenarios as high-energy models of R-parity violating supersymmetry.
- Boosted tops in association with jets as a way of pinning down a KK-gluon at the LHC.
- The Cray XC-30 which delivers over half a Petaflop of computing power was installed in the Hyderabad data center of the Indian Lattice Gauge Theory Initiative in April 2015. It was ranked the 114th most powerful computer in the world in May 2015. It will be used to compute properties of the strong interactions, including phase transitions in the early universe, and other properties to be tested in collider experiments.

D. String Theory and Mathematical Physics

- Thermalization of local operators in integrable conformal models proved. Deconfinement model in AdS/QCD further extended to incorporate dynamical quarks.
- The dynamics of black holes in a large number of dimensions was demonstrated to reduce to the dynamics of a nongravitational membrane - roughly the event horizon of the black hole. The degrees of freedom of the membrane are its shape, charge density and a velocity field. Einstein's equations reduce to a set of initial value equations for the membrane variables. This development may be regarded as a precise version of the membrane paradigm of black hole physics.
- We used holography to find the dual description of a driven anisotropic fluid.
- Assuming that inflation occurs in an approximately de Sitter space, we use the Ward identities of conformal symmetry to obtain model independent constraints on three point scalar operators.

- We propose a new definition of the entanglement entropy of a finite spatial region of a lattice gauge theory.

- We further study the viscosity of anisotropic fluids using holography and demonstrate that the shear viscosity is can be parametrically smaller than the KSS bound in the limit of large anisotropy.

- We derive the general Ward identities for scale and special conformal transformations in a single field model of inflation.

- We study several aspects of Entanglement Entropy for Gauge defined in our earlier work, and explicate its properties.

3. Text

A. Cosmology and Astroparticle Physics

Self-induced temporal instability from a neutrino antenna

It has been recently shown that the flavor composition of a self-interacting neutrino gas can spontaneously acquire a time-dependent pulsating component during its flavor evolution. In this work, a more detailed study of this effect in a schematic model was performed. The linear and nonlinear results were found to be in good agreement in the linear regime, while a dramatic speed-up of the flavor conversions occurs in the non-linear regime due to the interactions among the different pulsating modes. It was shown that large flavor conversions can take place if some of the temporal modes are unstable for long enough, and that this can happen even if the matter and neutrino densities are changing, as long as they vary slowly.
[Basudeb Dasgupta with F. Capozzi (Padua U. & INFN, Padua), and A. Mirizzi (Bari U. & INFN, Bari)]

Photons, photon jets, and dark photons at 750 GeV and beyond

In new physics searches involving photons at the LHC, one challenge is to distinguish scenarios with isolated photons from models leading to photon jets. For instance, in the context of the 750 GeV diphoton excess, it was pointed out that a true diphoton resonance can be mimicked by a light pseudoscalar decaying to two collinear photons. Photon jets can be distinguished from isolated photons by exploiting the fact that a large fraction of photons pair-convert inside the inner detector. In this note, this discrimination power was quantified, and a study of how the sensitivity of future searches differs for photon jets compared to isolated photons was made. It was also investigated how these results depend on the lifetime of the particle(s) decaying to the photon jet. These results will be useful, more generally, in any new physics search involving hard photons.

[Basudeb Dasgupta with J. Kopp (U. Mainz, PRISMA & Mainz U.), P. Schwaller (DESY)]

Temporal instability enables neutrino flavor conversions deep inside supernovae

It was shown that a self-interacting neutrino gas can spontaneously acquire a nonstationary pulsating component in its flavor content, with a frequency that can exactly cancel the multiangle refractive effects of dense matter. This can then enable homogeneous and inhomogeneous flavor conversion instabilities to exist even at large neutrino and matter densities, where the system would have been stable if the evolution were strictly stationary. Large flavor conversions, especially close to a supernova core, are possible via this novel mechanism. This may have important consequences for the explosion dynamics, nucleosynthesis, as well as for neutrino observations of supernovae.

[Basudeb Dasgupta with A. Mirizzi (Bari U. & INFN, Bari)]

Sterile neutrinos with secret interactions: lasting friendship with cosmology

Sterile neutrinos with mass around 1 eV and order 10% mixing with active neutrinos have been proposed as a solution to anomalies in neutrino oscillation data, but are tightly constrained by cosmological limits. It was recently shown that these constraints are avoided if sterile neutrinos couple to a new MeV-scale gauge boson A'. However, even this scenario is restricted by structure formation constraints when A'-mediated collisional processes lead to efficient active-to-sterile neutrino conversion after neutrinos have decoupled. In view of this, the viability of sterile neutrinos with such “secret" interactions was reevaluated. Their evolution in the early Universe was carefully dissected, and it was argued that there are two regions in parameter space - one at very small A' coupling, one at relatively large A' coupling - where all constraints are satisfied. Interestingly, the large A' coupling region is precisely the region that was previously shown to have potentially important consequences for the small scale structure of dark matter halos if the A' boson couples also to the dark matter in the Universe.

[Basudeb Dasgupta with X. Chu (ICTP, Trieste), J. Kopp (U. Mainz, PRISMA & Mainz U.)]

Sunyaev-Zeldovich (SZ) effect fluctuations and mass bias in Coma cluster

The SZ fluctuations in the intracluster medium (ICM) of Coma cluster was detected using Planck data. This is first such detection in any cluster and has very important implications for using the clusters as cosmological probes. The SZ fluctuations are an indirect measurement of turbulence in the intracluster medium which provided non-thermal support against gravity and is therefore a source of bias when using X-ray or SZ data to measure the mass of the cluster. In particular substantial non-thermal pressure support was found, implying hydrostatic mass bias $b_M = -15\%$ to -45% from the core to the outskirt region, respectively, much larger than previously expected. This mass bias is one of the main uncertainties in using clusters for cosmology and may be the cause of tension between cosmological parameter from primary CMB and clusters in Planck papers. It was demonstrated that we can estimate the mass bias accurately using the SZ data itself.

[Rishi Khatri with M. Gaspari (Princeton U.)]

Interaction of x-rays with the Galactic molecular clouds

The interaction of x-rays with the Galactic molecular clouds was studied. It was shown using the Monte-Carlo simulations that by studying the reflected X-rays from the molecular clouds we can learn about the internal structure of these clouds.

[Rishi Khatri with M. Molaro (Max Planck Institute for Astrophysics, Garching) and R. Sunyaev (Max Planck Institute for Astrophysics, Garching, & Space Research Institute, Moscow & Institute for Advanced Study, Princeton)]

An alternative validation strategy for the Planck cluster catalog and y-distortion maps

A very important contaminant in the Planck cluster catalog is carbon monoxide (CO) emission from Galactic molecular clouds. This work demonstrated and proved a new method of distinguishing between the CO emission and SZ signal and thus validate the clusters in the Planck catalog. One main result was that most of the unconfirmed clusters in the Planck catalog are likely to be molecular clouds.

[Rishi Khatri]

Using cross-correlation to probe cosmic baryons

The cross-correlation of distribution of galaxies, the Sunyaev-Zeldovich (SZ) and X-ray power spectra of galaxies from current and upcoming surveys were shown these to be excellent probes of the nature, i.e. extent, evolution and energetics, of the circumgalactic medium (CGM). A Fisher matrix analysis found that the gas fraction in the CGM can be constrained to a precision of $\sim 34\%$ (23%) by the SPT-DES and $\sim 23\%$ (14%) by the eROSITA-DES surveys in the presence (absence) of an unknown redshift evolution of the gas fraction. It was also demonstrated that the cross-correlated SZ-galaxy and X-ray-galaxy power spectrum can be used as powerful probes of the CGM energetics and potentially discriminate between different feedback models recently proposed in the literature; for example, one can distinguish a 'no AGN feedback' scenario from a CGM energized by 'fixed-velocity hot winds' at greater than 3σ.

[Subhabrata Majumdar with P. Singh (RRI), B. B. Nath (RRI), A. Refregier (ETH, Zurich) and J. Silk (IAP, Paris)]

Dark Energy Constraints from Planck CMB plus LSS observations

Plausible dark energy models, parametrized by multiple candidate equations of state, using the recently published Cosmic Microwave Background (CMB) temperature anisotropy data from Planck together with the WMAP-9 low-l polarization data and data from low redshift surveys was studied. It was shown that a clear tension exists between dark energy constraints from CMB and non-CMB observations when one allows for dark energy models having both phantom and non-phantom behavior; while CMB is more favorable to phantom models, the low-z data prefers model with behavior close to a Cosmological Constant. The results motivate construction of phantom models of dark energy, which is achievable in the presence of higher derivative operators as in string theory.

[Subhabrata Majumdar with D. Hazra (APCTP, Korea), S. Pal (ISI, Kolkata), S. Panda (IOP, Bhubaneshwar) and A. A. Sen (JMI, New Delhi)]

B. Condensed Matter and Statistical Physics

Condensate Formation in a Zero-range Process with Random Site Capacities

It is known that quenched disorder can strongly influence both static and dynamic properties of statistical systems. These effects were studied by analyzing a disordered one-dimensional lattice model of nonequilibrium transport, namely a zero-range process (ZRP) in which the maximum capacity of each site is a quenched random variable. The question of interest was the possible occurrence of a phase transition to a condensate phase, in which a single site holds a finite fraction of the particles. This is a quintessential feature of the normal (non-disordered) ZRP in which the capacity is unrestricted. An interesting interplay between interactions, modelled through hop rates, and randomness, modelled by the distribution of capacities, was found, and the exact conditions for condensate formation were determined. Interestingly, for a given realization of disorder, the condensate relocates on a small subset of sites with the largest capacities. The critical particle density was found to exhibit extremely large sample to sample fluctuations; the corresponding scaled distribution was shown to assume a Gaussian or a Lévy-stable form depending on parameter values.

[Mustansir Barma with Shamik Gupta (Université Paris-Sud, Orsay, France, Università di Firenze, Italy, & Max Planck Institute for Physics of Complex Systems, Dresden, Germany)]

Singular ferromagnetic susceptibility of the transverse-field Ising antiferromagnet on the triangular lattice

A transverse magnetic field Γ is known to induce antiferromagnetic three-sublattice order of the Ising spins σ^z in the triangular lattice Ising antiferromagnet at low enough temperature. This low-temperature order is known to melt on heating in a two-step manner, with a power-law ordered intermediate temperature phase characterized by power-law correlations at the three-sublattice wavevector $\boldsymbol{Q}$: $< \sigma^z(\vec{R})\sigma^z(0) > \sim \cos(\boldsymbol{Q}.\vec{R})/|\vec{R}|^{\eta(T)}$ with the temperature-dependent power-law exponent $\eta(T) \in (\frac{1}{9}, \frac{1}{4})$. In this work, a newly developed quantum cluster algorithm was used to study the *ferromagnetic* easy-axis susceptibility $\chi_u(L)$ of an $L \times L$ sample in this power-law ordered phase. The results were consistent with a recent prediction of a singular L dependence $\chi_u(L) \sim L^{2-9\eta}$ when $\eta(T)$ is in the range $(\frac{1}{9}, \frac{2}{9})$. This finite-size result implies, via standard scaling arguments, that the ferromagnetic susceptibility $\chi_u(B)$ to a uniform field B along the easy axis is singular at intermediate temperatures in the small B limit, $\chi_u(B) \sim |B|^{-\frac{4-18\eta}{4-9\eta}}$ for $\eta(T) \in (\frac{1}{9}, \frac{2}{9})$, although there is no ferromagnetic long-range order in the low temperature state.

[Kedar Damle and S. Biswas]

Field-driven quantum phase transitions in $S=1/2$ spin chains

A valence bond solid (VBS) is a long-range ordered nonmagnetic state with broken lattice symmetries that can appear in certain quantum spin systems with competing interactions. Recent innovations in models and simulation techniques have enabled large scale numerical studies of these states and associated quantum phase transitions to the standard antiferromagnetic (Neel, for two or more dimensions) or power-law critical states (in one dimension). This work studied the VBS order and induced magnetization as a function of an external magnetic field in a one-dimensional extended Heisenberg model -- the J-Q_2 model -- using the stochastic series expansion quantum monte carlo method with directed loop updates and quantum replica exchange. It was found that the magnetization jumps to the fully polarized state (metamagnetism) for $q \equiv Q/J \geq q_{\min} = \frac{2}{9}$ where J represents the traditional AFM Heisenberg exchange and Q represents a competing four-spin interaction. An exact solution for $q = q_{\min}$, where the jump first appears, was found. It was found that two flipped spins on a fully polarized background behave as effectively noninteracting particles. For smaller values of q, two flipped spins repel, while for larger values, they attract.

[Kedar Damle with A. Iaizzi and A. Sandvik (Boston U.)]

Vacancy-induced low-energy states in undoped graphene

This work demonstrated that a nonzero concentration n_v of static, randomly-placed vacancies in graphene leads to a density w of zero-energy quasiparticle states at the band-center $\epsilon = 0$ within a tight-binding description with nearest-neighbour hopping t on the honeycomb lattice. It was shown that w remains generically nonzero in the compensated case (exactly equal number of vacancies on the two sublattices) even in the presence of hopping disorder, and depends sensitively on n_v and correlations between vacancy positions. For low, *but not-too-low* $|\epsilon|/t$ in this compensated case, we show that the density of states (DOS) $\rho(\epsilon)$ exhibits a strong divergence of the form $\rho_{1D}(\epsilon) \sim |\epsilon|^{-1}/[\log(t/|\epsilon|)]^{(y+1)}$, which crosses over to the universal low-energy asymptotic form expected on symmetry grounds $\rho_{GW}(\epsilon) \sim |\epsilon|^{-1}\, e^{-b[\log(t/|\epsilon|)]^{2/3}}$ below a crossover scale $\in_c \ll t$, $\in_c$ is found to decrease rapidly with decreasing n_v , while y decreases much more slowly.

[Kedar Damle with S. Sanyal (ICTS, Bangalore) and O. I. Motrunich (Cal. Insti. of Tech.)]

<u>Two-step melting of three-sublattice order in $S=1$ easy-axis triangular lattice antiferromagnets</u>

This work focused on $S = 1$ triangular lattice Heisenberg antiferromagnets with a strong single-ion anisotropy D that dominates over the nearest-neighbour antiferromagnetic exchange J. In this limit of small J/D, the low temperature ($T \sim J \ll D$) properties of such magnets were studied by employing a low-energy description in terms of hard-core bosons with nearest neighbour repulsion $V \approx 4J + J^2/D$ and nearest neighbor unfrustrated hopping $t \approx J^2/2D$. Using a cluster Stochastic Series Expansion (SSE) algorithm to perform sign-problem-free quantum Monte Carlo (QMC) simulations of this effective model, it was established that the ground-state three-sublattice order of the easy-axis spin-density $S^z(\vec{r})$ melts in zero field ($B = 0$) in a *two-step* manner via an intermediate temperature phase characterized by power-law three-sublattice order with a temperature dependent exponent $\eta(T) \in (\frac{1}{9}, \frac{1}{4})$. For $\eta(T) < \frac{2}{9}$ in this phase, it was found that the uniform easy-axis susceptibility of an $L \times L$ sample diverges as $\chi_L \sim L^{2-9\eta}$ at $B = 0$, consistent with a recent prediction that the thermodynamic susceptibility to a uniform field B along the easy axis diverges at small B as $\chi_{\text{easy-axis}}(B) \sim |B|^{-\frac{4-18\eta}{4-9\eta}}$ in this regime.

[Kedar Damle with D. Heidarian (U. of Toronto)]

<u>Sign-problem-free Monte Carlo simulation of certain frustrated quantum magnets</u>

This work introduced a Quantum Monte Carlo (QMC) method for efficient sign-problem-free simulations of a broad class of frustrated $S = 1/2$ models using the basis of spin eigenstates of

clusters to avoid the severe sign problem faced by other QMC methods. The utility of the method was demonstrated in several cases with competing exchange interactions.
Important limitations as well as possible extensions of the method were also flagged.
[Kedar Damle with F. Alet (CNRS), and S. Pujari (U. of Kentucky)]

Classical spin-liquid on the maximally frustrated honeycomb lattice

This work demonstrated that the honeycomb Heisenberg antiferromagnet with $J_1/2 = J_2 = J_3$, where $J_{1/2/3}$ are first-, second- and third-neighbour couplings respectively, forms a classical spin liquid with pinch-point singularities in the structure factor at the Brillouin zone corners. Upon dilution with non-magnetic ions, fractionalised degrees of freedom carrying 1/3 of the free moment emerge. Their effective description in the limit of low-temperature is that of spins randomly located on a triangular lattice, with a frustrated interaction of long-ranged logarithmic form. The XY version of this magnet exhibits nematic thermal order by disorder, which comes with a clear experimental diagnostic.
[Kedar Damle with J. Rehn (Max-Planck-Institut, Dresden), A. Sen (IACS, Kolkata), and R. Moessner (Max-Planck-Institut, Dresden)]

Quantum cluster algorithm for frustrated Ising models in a transverse field

This work introduced and characterized a new quantum cluster algorithm for quantum Monte Carlo simulations of transverse field Ising models with frustrated Ising exchange interactions. As a demonstration of the capabilities of this new algorithm, which works within the framework of the stochastic series expansion, it was shown that a relatively small ferromagnetic next-nearest neighbour coupling drives the transverse field Ising antiferromagnet on the triangular lattice from an antiferromagnetic three-sublattice ordered state at low temperature to a ferrimagnetic three-sublattice ordered state.
[Kedar Damle, S. Biswas, and G. Rakala]

Melting of three-sublattice order in easy-axis antiferromagnets on triangular and Kagome lattices

When the spins have an energetic preference to lie along an “easy-axis", triangular and Kagome lattice antiferromagnets often develop long-range order that distinguishes the three sublattices of the underlying triangular Bravais lattice. This “three-sublattice order" melts in zero field *either* via a “two-step melting" transition, with an intermediate-temperature phase characterized by power-law three-sublattice order controlled by a temperature dependent power-law exponent $\eta(T) \in (\frac{1}{9}, \frac{1}{4})$ *or* via a transition described by the three-state Potts model. In this work, it was predicted that the uniform susceptibility to a small easy-axis field B diverges as $\chi(B) \sim |B|^{-\frac{4-18\eta}{4-9\eta}}$ in a large part of the intermediate power-law ordered phase (corresponding to $\eta(T) \in (\frac{1}{9}, \frac{2}{9})$, providing a thermodynamic signature of two-step melting. This work also demonstrated that these two generic melting scenarios are separated from each other by an interesting multicritical point with central charge $c_{\mathcal{M}} \in (1, \frac{3}{2})$. Numerical estimates of multicritical exponents were also obtained.

[Kedar Damle]

<u>Random Coulomb antiferromagnets: from diluted spin liquids to Euclidean random matrices</u>

This work studied a disordered classical Heisenberg magnet with uniformly antiferromagnetic interactions which are frustrated on account of their long-range Coulomb form, i.e., $J(r) \sim -A/\ln(r)$ in $d = 2$ and $J(r) \sim A/r$ in $d = 3$. This arises naturally as the $T \rightarrow 0$ limit of the emergent interactions between vacancy-induced degrees of freedom in a class of diluted Coulomb spin liquids (including the classical Heisenberg antiferromagnets in checkerboard, SCGO, and pyrochlore lattices) and presents a novel variant of a disordered long-range spin Hamiltonian. Using detailed analytical and numerical studies it was established that this model exhibits a very broad paramagnetic regime that extends to very large values of A in both $d = 2$ and $d = 3$. In $d = 2$, using the lattice-Green-function-based finite-size regularization of the Coulomb potential (which corresponds naturally to the underlying low-temperature limit of the emergent interactions between orphans), it was found that freezing into a glassy state occurs only in the limit of strong coupling, $A = \infty$, while no such transition seems to exist in $d = 3$. This work also demonstrates the presence and importance of screening for such a magnet. Additionally the spectrum of the Euclidean random matrices describing a Gaussian version of this problem was analyzed, and a corresponding quantum mechanical scattering problem was identified.

[Kedar Damle with J. Rehn (Max-Planck-Institut, Dresden, A. Sen (IACS, Kolkata), A. Andreanov, R. Moessner (Max-Planck-Institut, Dresden), and A. Scardicchio (ICTP, Trieste)]

Phase transitions in a system of hard rectangles

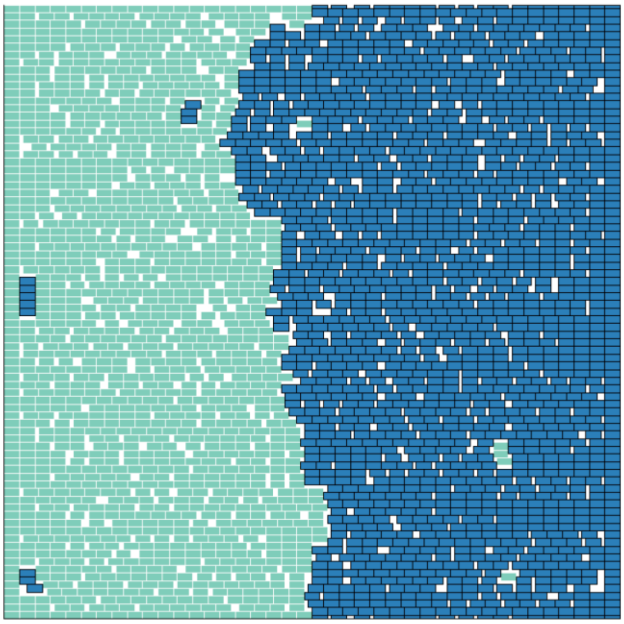

Figure 1: An interface between two differently ordered layered phases of 2 x 7 hard rectangles on the square lattice.

A system of $2 \times \ell$ hard rectangles on square lattice is known to show four different phases for $\ell \geq 14$. As the covered area fraction ρ is increased from 0 to 1, the system goes from low-density disordered phase, to orientationally-ordered nematic phase, to a columnar phase with orientational order and also broken translational invariance, to a high density phase in which orientational order is lost. Interestingly, simulations have shown that the critical density for the second transition ρ_2^* tends to a non-trivial finite value ≈ 0.73, as $\ell \to \infty$, and $\rho_2^* \approx 0.93$ for $\ell = 2$. We provide a theoretical explanation of this interesting result. We develop an approximation scheme to calculate the surface tension between two differently ordered columnar phases. For all values of d, these estimates are in good agreement with Monte Carlo data.
[Deepak Dhar]

Optical Lattice Modulation Spectroscopy for Spin-orbit Coupled Bosons

Interacting bosons with two “spin" states in a lattice show novel superfluid-insulator phase transitions in the presence of spin-orbit coupling. Depending on the parameter regime, bosons in the superfluid phase can condense to either a zero momentum state or to one or multiple states with finite momentum, leading to an unconventional superfluid phase. The response of such a system to modulation of the optical lattice potential was studied and it was shown that the change in momentum distribution after lattice modulation produces distinct patterns in the Mott and the superfluid phase and these patterns can be used to detect these phases and the quantum phase transition between them. Further, the momentum resolved optical modulation spectroscopy can identify both the gapless (Goldstone) gapped amplitude (Higgs) mode of the superfluid phase and clearly distinguish between the superfluid phases with a zero momentum condensate and a twisted superfluid phase by looking at the location of these modes in the Brillouin zone.
[Rajdeep Sensarma with S. D. Sarkar and K. Sengupta (IACS)]

Spin-Density Wave States in Biased Bilayer Honeycomb Lattice

An experimental setup using ultracold atoms was proposed to implement a bilayer honeycomb lattice with Bernal stacking. In presence of a potential bias between the layers and at low densities, Fermions placed in this lattice form an annular Fermi sea. The presence of two Fermi surfaces lead to interesting patterns in Friedel oscillations and RKKY interactions in presence of impurities. Further a repulsive Fermion-Fermion interaction leads to a Stoner instability towards an incommensurate spin-density wave order with a wave-vector equal to thickness of the Fermi sea. The instability occurs at a critical interaction strength which goes down with the density of the Fermions. It was found that the instability survives interaction renormalization due to vertex corrections and possible experimental signatures of this instability was discussed.
[Rajdeep Sensarma and S. Dey]

Berry phase mechanism of the anomalous Hall effect in a disordered two-dimensional magnetic semiconductor structure

The anomalous Hall effect (AHE) arises from the interplay of spin-orbit interactions and ferromagnetic order and is a potentially useful probe of electron spin-polarization, especially in nanoscale systems where direct measurement is not feasible. While AHE is rather well understood in metallic ferromagnets, much less is known about the relevance of different physical mechanisms governing AHE in insulators. As ferromagnetic insulators, but not metals, lend themselves to gate-control of electron spin-polarization, understanding AHE in the insulating state is valuable from the point of view of spintronic applications. Among the mechanisms proposed in the literature for AHE in insulators, the one related to a geometric (Berry) phase effect has proved elusive in past studies. The recent discovery of quantized AHE in magnetically

doped topological insulators - essentially a Berry phase effect - provides strong additional motivation to undertake more careful search for geometric phase effects in AHE in the magnetic semiconductors. Careful measurements were performed of the temperature and magnetic field dependences of AHE in insulating, strongly-disordered two-dimensional Mn delta-doped semiconductor heterostructures in the hopping regime, and the data analyzed for evidence of the Berry phase mechanism of AHE. The main find is that at sufficiently low temperatures, the mechanism of AHE related to the Berry phase is favoured.
[Vikram Tripathi with L. N. Oveshnikov, V. A. Kulbachinskii (Kurchatov Inst., Moscow), A. B. Davydov, B. A. Aronzon (Lebedev Inst., Moscow), I. V. Rozhansky, N. S. Avkeriev (Ioffe Inst., St. Petersburg) and K. I. Kugel (ITAE, Moscow)]

A Kondo route to spin inhomogeneities in the honeycomb Kitaev model

Paramagnetic impurities in a quantum spin-liquid can result in Kondo effects with highly unusual properties. In this context, the authors studied the effect of locally exchange-coupling a paramagnetic impurity with the spin-1/2 honeycomb Kitaev model in its gapless spin-liquid phase. The (impurity) scaling equations were found to be insensitive to the sign of the coupling. The weak and strong coupling fixed points were shown to be stable, with the latter corresponding to a noninteracting vacancy and an interacting, spin-1 defect for the antiferromagnetic and ferromagnetic cases respectively. The ground state in the strong coupling limit in both cases has a nontrivial topology associated with a finite Z2 flux at the impurity site. For the antiferromagnetic case, this result can be obtained straightforwardly owing to the integrability of the Kitaev model with a vacancy. The strong-coupling limit of the ferromagnetic case is however nonintegrable, and to address this problem, exact-diagonalization calculations were performed with finite Kitaev fragments. The exact diagonalization calculations indicate that the weak to strong coupling transition and the topological phase transition occur rather close to each other and are possibly coincident. An intriguing similarity between the magnetic response of the defect and the impurity susceptibility in the two-channel Kondo problem was also noted.
[Vikram Tripathi with S. D. Das (Bristol) and K. Dhochak (Weizmann)]

Parity-time symmetry-breaking mechanism of dynamic Mott transitions in dissipative systems

The critical behavior of the electric field-driven (dynamic) Mott insulator-to-metal transitions in dissipative Fermi and Bose systems was described in terms of non-Hermitian Hamiltonians invariant under simultaneous parity (P) and time-reversal (T) operations. The dynamic Mott transition was identified as a PT symmetry-breaking phase transition, with the Mott insulating state corresponding to the regime of unbroken PT symmetry with a real energy spectrum. The

imaginary part of the Hamiltonian was shown to arise from the combined effects of the driving field and inherent dissipation. The renormalization and collapse of the Mott gap at the dielectric breakdown was obtained and this was used to describe the critical behaviour of transport characteristics. The obtained critical exponent was found to be in an excellent agreement with experimental findings.
[Vikram Tripathi and H. Barman with A. Galda and V. Vinokur (Argonne)]

C. High Energy Physics

Principal Component Analysis of Event-by-Event Fluctuations

The method of principal component analysis was applied to the study of event-by-event fluctuations in ultrarelativistic heavy-ion collisions. This method brings out all the information contained in two-particle correlations in a physically transparent way. Multiplicity fluctuations and anisotropic flow fluctuations were studied using ALICE (LHC) data as well as a sample of events simulated using A Multi-Phase Transport (AMPT) model. In particular, elliptic and triangular flow fluctuations were studied as a function of transverse momentum and rapidity. This method revealed previously unknown subleading modes in both rapidity and transverse momentum for the momentum distribution as well as elliptic and triangular flows.
[R.S. Bhalerao and S. Pal with J. Y. Ollitrault (Saclay), and D. Teaney (Stony Brook)]

Collective Flow in Event-by-Event Partonic Transport plus Hydrodynamics Hybrid Approach

Complete evolution of the strongly interacting matter formed in ultrarelativistic heavy-ion collisions was studied within a coupled Boltzmann and relativistic viscous hydrodynamics approach. For the initial nonequilibrium evolution phase, A MultiPhase Transport (AMPT) model that explicitly included event-by-event fluctuations in the number and positions of the participating nucleons as well as of the produced partons with subsequent parton transport was employed. The ensuing near-equilibrium evolution of quark-gluon and hadronic matter was modeled within the (2+1)-dimensional relativistic viscous hydrodynamics.
[R.S. Bhalerao, A. Jaiswal and S. Pal)]

Wilson Flow with Staggered Quarks

Scale setting was examined for QCD with two flavours of staggered quarks using Wilson flow over a factor of four change in both the lattice spacing and the pion mass. The statistics needed to keep the errors in the flow scale fixed was found to increase approximately as the inverse square of the lattice spacing. Tree level improvement of the scales t_0 and w_0 was found to be useful in most of the range of lattice spacings explored. The scale uncertainty due to remaining lattice spacing effects was found to be about 3%. The ratio $w_0/\sqrt{t_0}$ is N_F dependent and its continuum limit was found to be 1.106 ± 0.007 (stat) $\pm$ 0.005 (syst) for \$$m_\pi w_0 \simeq 0.3$.

[Saumen Datta, Sourendu Gupta, and A. Lahiri with A. Lytle (Glasgow), and P. Majurmdar (IACS, Kolkata)]

Study of deconfinement transition with new order parameters

At finite temperatures, strongly interacting matter undergoes a transition to a deconfined plasma. We studied the transition for the theory with gluons, where we used the technique of flowing the gauge fields to define a new, renormalized order parameter. We also used the flow to calculate the renormalized Polyakov loop and the renormalized electric and magnetic gluon condensates. The condensates were found to have very interesting thermal dependence. The differential flow behavior of the electric and magnetic condensates was shown to act as a marker of deconfinement.

[Saumen Datta and Sourendu Gupta, with A. Lytle (Glasgow)]

Quantifying the physics potential of the ICAL detector at INO

A comprehensive “White Paper", quantifying the physics potential of the ICAL detector as obtained from realistic detector simulations, was completed. It described the simulation framework, the neutrino interactions in the detector, and the expected response of the detector to particles traversing it. The report outlined the analyses carried out for the determination of neutrino mass hierarchy and precision measurements of atmospheric neutrino mixing parameters at ICAL, and gave the expected physics reach of the detector with 10 years of runtime. The potential of ICAL for probing new physics scenarios like CPT violation and the presence of magnetic monopoles was also explored. This would be the first reference to go to for all future ICAL-INO-related publications.

[Amol Dighe with the ICAL-INO Collaboration]

Unravelling Medium Effects in Heavy Ion Collisions with Zeal

Since the seminal proposal of Bjorken in 1982 of using energy loss of fast particles and the related jet-quenching as a probe to study the nature of the hot medium formed in heavy ion collisions, a lot of experimental and theoretical studies have enriched our understanding of the medium produced in relativistic heavy ion collisions. For instance, R_{AA} obtained from the ratios of single particle inclusive transverse momentum (p_T)-spectra of nucleus-nucleus (AA) to that of suitably normalized proton-proton (pp) spectra shows a large suppression at RHIC and at the LHC. Arguing it to stem from the leading particle in the corresponding jets, this has been identified as the shining example of jet quenching by the medium, especially since no such suppression in seen in ratios constructed for pA collisions.

LHC has now produced exciting results on reconstructed jets in heavy ion collisions, showing almost uniform suppression compared to pp collisions as a function of the jet transverse momentum. QCD based models using either strong or weak coupling pictures seem capable of explaining the data, obscuring its full potential to enhance our understanding of the hot medium. We proposed a new observable, called zeal, to analyze events with jets in heavy ion collisions. It measures how a thermal medium affects the multiplicity and distribution of energetic particles in a jet, and is therefore more discriminating than R_{AA} of the leading partons. Its advantage is that it weighs the energetic partons more heavily and hence is particularly sensitive to the processes that lead to the energy loss of the leading partons. For frequent medium induced bremsstrahlung with several gluons carrying a tiny fraction of the energy of the leading partons, the peak of the zeal distribution should move towards lower zeal values unlike the case where induced bremsstrahlung is rare and the emitted gluons carry significant fractions of the energy of the leading partons. Using few known models for energy loss and jet quenching, we demonstrated its capability to distinguish the physics of these models, thus splitting their degeneracy to some extent.
[Rajiv Gavai and Rishi Sharma with A. Jain (IISER, Bhopal)]

The QCD Critical Point : An Exciting Odyssey in the Femto-World

Strongly interacting matter, which makes up the nuclei of atoms, is described by a theory called Quantum Chromodynamics (QCD). A critical point in the phase diagram of Quantum Chromodynamics (QCD), if established either theoretically or experimentally, would be as profound a discovery as the familiar gas-liquid critical point discovered in the nineteenth century. Due to the extremely short lived nature of the concerned phases, novel experimental techniques are needed to search for it. The Relativistic Heavy Ion Collider (RHIC) in USA has an experimental programme which can fit the bill to do so. Theoretical techniques of Lattice QCD, which is QCD defined on a discrete space-time lattice, have provided glimpses into where the QCD critical point may be, and how to search for it in the experimental data. An invited brief

overview of the theoretical and experimental attempts was written for “Contemporary Physics" journal of Taylor & Francis, UK.
[Rajiv Gavai]

Charmed-bottom mesons from Lattice QCD

We present ground state spectra of mesons containing a charm and a bottom quark. For the charm quark we use overlap valence quarks while a non-relativistic formulation is utilized for the bottom quark on a background of 2+1+1 flavour HISQ gauge configurations generated by the MILC collaboration. Results are obtained at three lattice spacings: 0.12, 0.09 and 0.06 fermi in a box size of about 3 fermi. While the pseudoscalar mass of B_c^* meson is known, nothing is known for mesons of other quantum numbers. We predicted that the hyperfine splitting between the vector and pseudoscalar B_c^* mesons is 55(3) MeV, which will be helpful for the future discovery of vector B_c^* meson. We are also studying the leptonic decay constants of such mesons.
[Nilmani Mathur with M. Padmanath (University of Graz, Austria)]

Radion Candidate for the LHC Diphoton Resonance

A mixed Higgs-Radion state was proposed as an explanation for the (now defunct) CERN diphoton excess reported in December 2015. Tuning of the mixing parameter to the ‘conformal point', where the heavier mixed state decouples from most Standard Model fields led to an elegant explanation of the observed facts, provided one allows for the existence of an extra generation of vectorlike fermions on the IR brane.
[Sreerup Raychaudhuri, D. Bardhan, D. Bhatia, A. Chakraborty, U. Maitra, and T. Samui]

Diphoton Resonance at 750 GeV in the Broken MRSSM

The MRSSM or the R-symmetric version of the minimal supersymmetric Standard Model is a useful construct which allows the possibility of very heavy gluinos without forcing the squarks of the third generation to become correspondingly heavy. This model also contains two scalars, of which one has dominant decays into diphotons. It was shown that if this scalar has a mass of 750 GeV, it could explain the (now defunct) CERN diphoton excess reported in December 2015.
[Sreerup Raychaudhuri, A. Chakraborty, and S. Chakraborty]

A Detailed Analysis of Flavour-changing Decays of Top Quarks as a Probe of New Physics at the LHC

If direct evidence for new physics eludes the LHC, one can still look for new physics effects through virtual particle exchanges in loop-induced processes. One of the most interesting of these is the flavour-changing decays of the top quark, which is extremely rare in the Standard Model. In

a detailed study, the conditions on a new physics model which ensure an enhanced rate for this decay were determined, and illustrated by comprehensive studies of the constrained minimal supersymmetric Standard Model, with and without conservation of R-parity.
[Sreerup Raychaudhuri and D. Bardhan, with G. Bhattacharyya (SINP, Kolkata), D. Ghosh (Weizmann Inst.), and M. Patra (Boskovic Inst., Zagreb)]

R-parity violation in warped GUT scale Randall-Sundrum Framework

A bulk Randall-Sundrum type warped extra-dimensional model is invoked at the GUT scale to provide a high-energy completion to a TeV-scale R-parity violating supersymmetric model. This turns out to be a predictive framework of R-violating supersymmetry with distinctive and testable low-energy predictions.
[K. Sridhar and A. M. Iyer with B. C. Allanach (Cambridge U., DAMTP)]

Kaluza Klein Guon+jets associated production at the LHC

Models of warped extra dimensions are viable and consistent with precision electroweak measurements only if the Standard Model particles are localised in the bulk. Electroweak precision also places strong constraints on bulk warped models but by either invoking a bulk custodial symmetry or by deforming the bulk metric it is possible to have testable models with gauge boson Kaluza-Klein modes within the reach of the LHC. Of these the Kaluza-Klein excitation of the gluon is the most interesting; yet given that it is about 2-3 TeV in mass it seriously challenges collider searches at the LHC. It is suggested that searching for the KK gluon in association with hard jets may provide a better search strategy and will be very useful in pinning down this signal. A complete simulation of the Kaluza-Klein gluon + associated jet process has been carried out.
[K. Sridhar and A. M. Iyer with F. Mahmoudi (Lyon U. & CERN) and N. Manglani (Mumbai U.)]

Status of the MSSM Higgs sector using global analysis and direct search bounds, and future prospects at the High Luminosity LHC

In this paper, we searched for the regions of the phenomenological minimal supersymmetric standard model parameter space where one can expect to have moderate Higgs mixing angle (α) with relatively light (up to 600 GeV) additional Higgses after satisfying the current LHC data. We performed a global fit analysis using updated data (till December 2014) from the LHC and Tevatron experiments. The constraints coming from the precision measurements of the rare b-decays are also considered. It was found that low M_A (≤ 350) and high $\tan\beta$ (≥ 25) regions are disfavored by the combined effect of the global analysis and flavour data and in the allowed regions Higgs mixing angle $\alpha \sim$ 0.1-0.8. Existing direct search bounds on the heavy scalar/pseudoscalar and charged Higgs bosons masses and branchings at the LHC were also studied.

[A. Chakraborty with B. Bhattacherjee (IISC, Bangalore), and A. Choudhury (Harish-Chandra Res. Inst.)]

Status of the 98-125 GeV Higgs bosons scenario with updated LHC-8 data

We studied the possibility of having the lightest Higgs boson with mass M_h = 98 GeV to be consistent with the 2.3σ excess observed at the LEP as well as the heavier Higgs boson (H) with mass $M_H \sim 125$ GeV to be consistent with the combined 7 and 8 TeV LHC data. We scanned the minimal supersymmetric standard model parameter space and then imposed constraints coming from flavour physics, relic density of the cold dark matter as well as direct dark matter searches. We also studied the possibility of observing the 98 GeV Higgs boson in vector boson fusion process and associated production with W/Z boson at the high luminosity ($3000\ \text{fb}^{-1}$) run of the 14 TeV LHC.

[A. Chakraborty with B. Bhattacherjee (IISC, Bangalore), M. Chakraborti, U. Chattopadhyay, and D. K. Ghosh (IACS, Kolkata)]

Probing $(g-2)_\mu$ at the LHC in the paradigm of R-parity violating MSSM

The measurement of the anomalous magnetic moment of the muon exhibits a longstanding discrepancy compared to the Standard model prediction. In this paper, we considered the framework of effective supersymmetric theory with relevant R-parity violating operators. Such a framework provides substantial contributions to the anomalous magnetic moment of the muon while satisfying constraints from low energy experimental observables as well as neutrino mass. In addition, we pointed out that the implication of such operators satisfying muon $(g-2)$ are immense from the perspective of the LHC experiment, leading to a spectacular four muon final state. Finally, we proposed an analysis in this particular channel which might help to settle the debate of R-parity violation as a probable explanation for $(g-2)_\mu$.

[A. Chakraborty and S. Chakraborty]

Looking for lepton flavour violation in SUSY at the LHC

We consider models of supersymmetry which can incorporate sizeable mixing between different generations of sfermions. We probe the lepton flavour violating (LFV) vertex originating from decay of heavier neutralino and identify a distinct and unambiguous combination of the tri-lepton final state which include a lepton pair with same flavour and same sign (SFSS) in addition to a pair with opposite flavour and opposite sign (OFOS)

[M. Guchait, A. M. Iyer, and R. Samanta]

The 750 GeV diphoton resonance as an sgoldstino: a reappraisal

Out of the many proposals offered as an explanation to the reported 750 GeV resonance, one of the attractive proposals was the sgoldstino. This proposal was made by three separate groups. We took a closer look at the explanation in realistic models of gauge mediated supersymmetry breaking. We concluded that there is a lot of difficulty in such an explanation, coming from several diverse lines of reasoning.

[D. Bardhan with P. Byakti (IISC, Bangalore), D. Ghosh (Weizmann Inst.), and T. Sharma (Weizmann Inst.)]

D. String Theory and Mathematical Physics

Thermalization studies in quantum field theory and gravity: Local thermalization in integrable models and higher spin black

In recent years quantum quench experiments conducted in cold atom systems have shown thermalization in integrable systems. Theoretically this apparent oxymoron has been understood as part of the general story of "subsystem thermalization", described by the time development of pure excited states of a system such that the reduced density matrix of a subsystem approaches that in a thermal state. In the present work, this has been rigorously shown for a general class of conformal integrable models for a general class of initial states. The final 'thermal' state is a generalized Gibbs ensemble (GGE), defined by the infinite number of conserved charges characterizing the initial excited state. The approach to equilibrium is exponential; the relaxation rates are explicitly computed in perturbation in the chemical potentials. In cases where the the GGE have an AdS/CFT dual description, in terms of a new class of three dimensional black hole solutions (in a higher spin generalization of Einstein gravity), the phenomenon of relaxation of perturbations to the GGE quantitatively match the decay of scalar perturbations to these black holes.

[Gautam Mandal, R. Sinha and N. Sorokhaibam]

Thermalization studies in quantum field theory and gravity: Mass quench in two dimensions and exact results:

Free massive scalars and fermions are subjected to a fast quench (time dependence) and the resulting time development of various observables are theoretically studied. Analytic results are obtained for specific time-dependence of the mass function. Late time behaviour is shown to be consistent with the results described above in the perturbative regime of chemical potentials. In

the nonperturbative regime, all chemical potentials are shown to be important; in particular the late time behaviour is affected by operators of arbitrary high dimensions.
[Gautam Mandal and N. Sorokhaibam with S. Paranjape (IISER, Pune)]

AdS/QCD and deconfinement:

In an earlier work, it was shown (G.Mandal and T.Morita, 2011) that the conventional gravity dual description of deconfinement transition in four dimensional Yang-Mills theory was phase separated from the actual deconfinement transition line. A new gravity dual description was proposed in that work which was free from this problem. In the present work, the Mandal-Morita model is extended further to include the effect of dynamical quarks.
[Gautam Mandal]

A Membrane Paradigm at Large D

$SO(d+1)$ invariant solutions of the classical vacuum Einstein equations in $p+d+3$ dimensions are studied. In the limit $d\to\infty$ with p held fixed we construct a class of solutions labelled by the shape of a membrane (the event horizon), together with a ‘velocity' field that lives on this membrane. We demonstrate that our metrics can be corrected to nonsingular solutions at first sub-leading order in d if and only if the membrane shape and ‘velocity' field obey equations of motion which we determine. These equations define a well posed initial value problem for the membrane shape and this ‘velocity' and so completely determine the dynamics of the black hole. They may be viewed as governing the non-linear dynamics of the light quasi normal modes of Emparan, Suzuki and Tanabe.
[Shiraz Minwalla, R. Mohan, and A. Saha with S. Bhattacharyya (Indian Inst. Tech., Kanpur), A. De (IISER, Pune)]

Unitarity, Crossing Symmetry and Duality in the Scattering of $N=1$ Susy Matter Chern Simons Theories

We study the most general renormalizable $N=1$ $U(N)$ Chern-Simons gauge theory coupled to a single (generically massive) fundamental matter multiplet. At leading order in the `t Hooft large $N$ limit we present computations and conjectures for the $2\times 2$ S-matrix in these theories; our results apply at all orders in the `t Hooft coupling and the matter self interaction. Our S matrices are in perfect agreement with the recently conjectured strong weak coupling self duality of this class of theories. The consistency of our results with unitarity requires a modification of the usual rules of crossing symmetry in precisely the manner anticipated in arXiv:1404.6373, lending substantial support to the conjectures of that paper. In a certain range of coupling constants our S

matrices have a pole whose mass vanishes on a self dual codimension one surface in the space of couplings.
[Shiraz Minwalla, K. Inbasekar, S. Mazumdar, and V. Umesh with S. Jain (Cornell U.), and S. Yokoyama (Technion)]

Chern Simons Bosonisation along RG Flows

It has previously been conjectured that the theory of free fundamental scalars minimally coupled to a Chern Simons gauge field is dual to the theory of critical fundamental fermions minimally coupled to a level rank dual Chern Simons gauge field. In this paper we study RG flows away from these two fixed points by turning on relevant operators. In the 't Hooft large N limit we compute the thermal partition along each of these flows and find a map of parameters under which the two partition functions agree exactly with each other all the way from the UV to the IR. We conjecture that the bosonic and fermionic RG flows are dual to each other under this map of parameters. Our flows can be tuned to end at the gauged critical scalar theory and gauged free fermionic theories respectively. Assuming the validity of our conjecture, this tuned trajectory may be viewed as RG flow from the gauged theory of free bosons to the gauged theory of free fermions.
[Shiraz Minwalla with S. Yokoyama (Technion)]

A Charged Membrane Paradigm at Large D

We study the effective dynamics of black hole horizons in Einstein-Maxwell theory in a large number of spacetime dimensions D. We demonstrate that horizon dynamics may be recast as a well posed initial value problem for the motion of a codimension one non gravitational membrane moving in flat space. The dynamical degrees of freedom of this membrane are its shape, charge density and a divergence free velocity field. We determine the equations that govern membrane dynamics at leading order in the large D expansion. Our derivation of the membrane equations assumes that the solution preserves an $SO(D - p - 2)$ isometry with p held fixed as D is taken to infinity. However we are able to cast our final membrane equations into a completely geometric form that makes no reference to this symmetry algebra.
[Shiraz Minwalla and M. Mandlik with S. Bhattacharyya (Indian Inst. Tech., Kanpur), and S. Thakur (Indian Inst. Tech., Kanpur)]

Quantum gravity effect in torsion driven inflation and CP violation

We have derived an effective potential for inflationary scenario from torsion and quantum gravity correction in terms of the scalar field hidden in torsion. A strict bound on the CP violating θ parameter, $\mathcal{O}(10^{10}) < \theta < \mathcal{O}(10^{9})$ has been obtained, using Planck+WMAP9 best fit cosmological parameters.

[S. Choudhury with B. K. Pal (IUCAA, Pune), B. Basu (ISI, Kolkata), and P. Bandyopadhyay (ISI, Kolkata)]

Constraining brane inflationary magnetic field from cosmoparticle physics after Planck

In this work, I have studied the cosmological and particle physics constraints on a generic class of large and small field models of brane inflationary magnetic field in case of RSII framework. I also establish a direct connection between the magnetic field at the present epoch and primordial gravity waves, which give a precise estimate of non-vanishing CP asymmetry in leptogenesis and baryon asymmetry in baryogenesis scenario respectively. Further assuming the conformal invariance to be restored after inflation in the framework of RSII, I have explicitly shown that the requirement of the sub-dominant feature of large scale coherent magnetic field after inflation gives two fold non-trivial characteristic constraints- on equation of state parameter and the corresponding energy scale during reheating epoch. Finally giving the proposal for avoiding the contribution of back-reaction from the magnetic field I have established a bound on the generic reheating characteristic parameter, to achieve large scale magnetic field and further apply the CMB constraints as obtained from recently observed Planck 2015 data.

[S. Choudhury]

Hysteresis in the Sky

Cosmological hysteresis has interesting and vivid implications in the scenario of a cyclic bouncy universe. This, purely thermodynamical in nature, is caused by the asymmetry in the equation of state parameter during expansion and contraction phase of the universe, due to the presence of a single scalar field. When applied to variants of modified gravity models this phenomenon leads to the increase in amplitude of the consecutive cycles of the universe, provided we have physical mechanisms to make the universe bounce and turnaround. This also shows that the conditions which create a universe with an ever increasing expansion, depend on the signature of $\oint pdV$ and on model parameters.

[S. Choudhury and S. Banerjee]

Reconstructing inflationary paradigm within Effective Field Theory framework

In this work my prime objective is to analyze the constraints on a sub-Planckian excursion of a single inflaton field within EFT framework. For a generic single field inflationary potential I have derived the most general expression for the field excursion in terms of various inflationary observables. By explicit computation I have reconstructed the structural form of the inflationary potential within EFT. I also provided two simple examples of Effective Theory of inflation- inflection-point model and saddle-point model to check the compatibility of the prescribed

methodology in the light of Planck 2015 and Planck 2015 +BICEP2/Keck Array data. Finally, I have also checked the validity of the prescription by estimating the cosmological parameters and fitting the theoretical CMB TT, TE and EE angular power spectra with the observed data.
[S. Choudhury]

Effective Field Theory of Dark Matter from membrane inflationary paradigm

In this work, we have studied the cosmological and particle physics constraints on dark matter relic abundance from EFT of inflation in case of RSII model. We establish a direct connection between the dark matter relic abundance and primordial gravity waves in the present work. We have explicitly shown that the membrane tension, bulk mass scale, and cosmological constant, in RSII membrane plays the most significant role to establish the connection between dark matter and inflation, using which we have studied the features of various mediator mass scale suppressed EFT “relevant operators" induced from the localized s, t and u channel interactions. Further we have studied an exhaustive list of tree-level Feynman diagrams for dark matter annihilation within the prescribed setup and to check the consistency of the obtained results, further we apply the constraints as obtained from recently observed Planck 2015 data and Planck+BICEP2+Keck Array joint datasets. Using all of these derived results we have shown that it is possible to put further stringent constraint on r within, $0.01 \leq r \leq 0.12$\$, for $< \sigma v > \approx \mathcal{O}(10^{28} - 10^{27})\text{cm}^3/s$.
[S. Choudhury with A. Dasgupta (IOP, Bhubaneswar)]

COSMOS-e'-GTachyon from String Theory

In this work, our prime objective is to study the inflationary paradigm from GTachyon living on the world volume of a non-BPS string theory. The tachyon action is considered here is getting modified compared to the original action. One can quantify the amount of the modification via a power q instead of 1/2 in the effective action. Using this set up we study inflation from various types of tachyonic potentials, using which we constrain the index q within, $1/2 < q < 2$, Regge slope, string coupling constant and mass scale of tachyon, from the recent Planck 2015 and Planck+BICEP2/Keck Array joint data. We explicitly study the inflationary consequences from single field, assisted field and multi-field tachyon set up. For single field and assisted field case we derive-the inflationary flow equations, new sets of consistency relations and the field excursion formula. We also put constraints from the temperature anisotropy and polarization spectra, which shows that our analysis is consistent with the Planck 2015 data. Finally, using ΔN formalism we derive the expressions for inflationary observables in the context of multi-field GTachyons.
[S. Choudhury with S. Panda (IOP, Bhubaneswar)]

S-duality invariant perturbation theory improved by holography

We studied the anomalous dimensions of unprotected low twist operators in the four-dimensional $SU(N)$ $N = 4$ supersymmetric Yang-Mills theory. We constructed a class of interpolating functions to approximate the dimensions of the leading twist operators for arbitrary gauge coupling τ. The interpolating functions were consistent with previous results on the perturbation theory, holographic computation and full S-duality. We use our interpolating functions to test the recent conjecture by the $N = 4$ superconformal bootstrap that upper bounds on the dimensions were saturated at one of the duality-invariant points.

[S. Thakur with A. Chowdhury (Harish-Chandra Res. Inst.), and M. Honda (Weizmann Inst.)]

4. Figure / Photograph Captions

The picture of Cray XC-30 which delivers over half a Petaflop of computing power was installed in the Hyderabad data center of the Indian Lattice Gauge Theory Initiative in April 2015. It was ranked the 114th most powerful computer in the world in May 2015. It will be used to compute properties of the strong interactions, including phase transitions in the early universe, and other properties to be tested in collider experiments.