TIFR Annual Technical Report (2017-18)

Department of Theoretical Physics

1. School / Centre / Department / Group

Department of Theoretical Physics

2. Highlights

A. Cosmology and Astroparticle Physics

- The first estimation of the hot circumgalactic medium (its extent, temperature and density profile) from a cosmological sample of galaxies observed in both SZ and X-Ray was made, and shown to solve the galactic missing baryon problem.
- A novel analytic model was constructed of the X-ray AGN-halo occupation distribution and prospects of constraining the AGN-halo connection with upcoming eROSITA satellite was demonstrated.
- The correlation of BCG radio luminosity and the feedback energy was made using joint data from GMRT and Chandra/ROSAT, showing conclusively for the first time that AGN feedback affects lower mass system more. Using a select sample of clusters observed in both X-Ray and SZ, the non-gravitational energy injection to the cluster, its dependencies on various cluster formation, dynamics, and cosmological physics was explored.
- A proposal for the next generation of astrometric mission to test LambdaCDM paradigm was submitted to ESA.
- New type of polarized and un-polarized anisotropic spectral distortions in the Cosmic Microwave Background from conversion of CMB photons into low mass spin zero scalar or pseudo scalar particles in the Galactic magnetic field were proposed opening a new window in which to search for new spin-zero particles.
- New interactions of neutrinos with dark matter in the early Universe were shown to enhance the small-scale power in the CMB B-mode power spectrum potentially providing a new probe of new neutrino and dark matter interactions complementary to scalar modes. It was shown that there is a potential degeneracy between new particle physics and new inflationary features both of which may modify the CMB B-mode spectrum.
- Neutrino oscillations in the deep regions of supernovae were explored using novel techniques, e.g., dispersion relations and exact mapping to other problems
- Unique signatures of multi-state inelastic dark matter scattering and annihilation, including new avenues for energy loss that affects dark matter halos, as well as non-perturbative

selection rules that can completely alter the annihilation phenomenology, were identified and shown to be observable.

B. **Condensed Matter and Statistical Physics**

- A new mechanism based on disordered Kosterlitz-Thouless criticality was proposed for the recently observed Vogel-Fulcher law for the finite temperature insulator transition in strongly disordered superconductor thin films.
- A graduate level textbook on the theory of electrons in normal metals, *Landau Fermi Liquids and Beyond*, was completed. The publishers are CRC Press, Taylor and Francis group.
- Exact solutions were obtained for a large class of non Markovian dynamics from Keldysh field theory
- A new protocol for braiding Majorana zero modes was proposed to implement topologically protected quantum computing.
- A theory-experiment collaboration within TIFR yielded evidence of rotational symmetry breaking in Landau level diagrams in ABA trilayer grapheme
- In a series of two papers, a theoretical framework was built to analyze stochastic systems conditioned on an empirical measure. This framework was applied to simple stochastic systems as well as to systems with interacting many degrees of freedom.
- A perturbation approach was introduced for theoretical analysis of fractional Brownian motion. Using this approach an exact result was obtained for generalization of three arcsine laws.
- An example of phase transition in one-dimensional system with short-range interaction was presented as a counter example to the folk-wisdom that phase transition cannot occur in such systems in equilibrium.
- An exact theoretical analysis and its experimental verification were presented for a dynamical phase transition out-side equilibrium and its connection to non-analytic large deviations function.
- Using a fluctuating hydrodynamics description it was shown that long-range correlations are generic in the non-equilibrium steady state of a wide class of diffusive systems.

C. **High Energy Physics**

- New possible effects of non-standard self-interactions of neutrinos on flavor conversions of supernova neutrinos were explored in a two-flavor framework.
- The ability of the proposed iron calorimeter (ICAL) detector at the India-based Neutrino Observatory (INO) to determine hadron shower direction was determined through simulations.

- We predicted the quantum numbers of recently discovered Ω_c baryons from Lattice quantum chromodynamics.
- We have initiated a program to study heavy tetraquarks states and our preliminary study indicated the presence of shallow double charm tetraquarks and deeply bound double bottom tetraquarks.
- Limit on the scale of non-commutativity of space was shown to be smaller than the current LHC limit for compositeness of quarks or electrons.
- A new method/tool is proposed (namely, an anomaly finder) that searches for new physics via identifying energy deposits in the detectors of a high energy collider (such as LHC) to be inconsistent with that of standard objects such as single photons, electrons, taus, QCD-jets, etc. The method paves a way to search for new physics in a model-independent fashion.
- The full set of Renormalisation Group Equations was derived in the context of Generalized Supersoft Supersymmetry. Upon solving these equations, a new way to solve cosmological issues associated with the lightest mass eigenstate of superparticle spectra in these models was discovered.
- We wrote down an effective field theory model for QCD near the chiral crossover region
- We calculated the Collisional and thermal dissociation of J/Psi and Upsilon states at the LHC
- A comprehensive study was made of the current constraints on mixed Higgs-radion states and the possibility of discovering them in the future runs of the LHC.

D. **String Theory and Mathematical Physics**

- Dynamics of near extremal black holes in four dimensional anti-de Sitter space was analyzed and was shown to be described by Jackiw-Teitelboim gravity in two dimensional anti-de Sitter space at low energies.
- Proposed a bulk dual to SYK model based on coadjoint orbits. Showed a 3-dimensional holographic origin of SYK model.
- An improved stress tensor for the membrane dual to the large D black hole motion was found, and shown to reproduce the thermodynamics and first order hydrodynamics of black holes and black branes exactly even at finite D.
- Tensor models that mimic the SYK model were studied; it was demonstrated that the Euclidean path integral that computes the finite temperature partition function of these theories has many more light modes than the similar SYK theories. A bulk interpretation of this observation was proposed.
- A new way to solve the system of conformal crossing equations was proposed. It was shown that the solutions are labeled by a representation of the conformal group.

- The space of not necessarily unitary conformal field theories with an abelian symmetry is shown to be a vector space.
- Asymptotic symmetry algebras for classes of three dimensional supergravities with and without cosmological constant were studied
- The entanglement for a state on linked torus boundaries in 3d Chern-Simons theory with a generic gauge group is studied and the asymptotic bounds of Rényi entropy at two different limits: (i) large Chern-Simons coupling k, and (ii) large rank r of the gauge group are computed
- The tree level four point scattering amplitude in 3d N=2 Chern-Simons theory coupled to a fundamental chiral multiplet is computed and shown to be dual superconformal invariant.
- A Complex Fermionic Tensor Model in general dimensions is studied. The model in d=2-epsilon has a fixed point whose spectrum is numerically computed. For 2<d<6, it was found that the model has a complex eigenvalue.
- The entanglement entropy in de Sitter space for a bipartite quantum field theory driven by axion originating from Type IIB string compactification on a Calabi Yau threefold (CY3) and in presence of NS5 brane is computed.
- Constraints imposed by channel duality and analyticity on tree-level amplitudes of four identical real scalars are worked out with the assumptions of a linear spectrum of exchanged particles and Regge asymptotic behaviour.
- An algorithm is developed to study the cosmological consequences from a large class of quantum field theories (i.e. superstring theory, supergravity, extra dimensional theory, modified gravity etc.), which are equivalently described by soft attractors in the effective field theory framework.
- Supersymmetric Bianchi attractors are constructed in N=2,d=4,5 gauged supergravity.
- Fermion localization in a braneworld model in presence of dilaton coupled higher curvature Gauss-Bonnet bulk gravity is discussed.

3. Text

A. Cosmology and Astroparticle Physics

X-ray and SZ constraints on the properties of hot CGM

Observations of stacked X-ray luminosity and Sunyaev-Zeldovich (SZ) signal from a cosmological sample of 80, 000 and 104,000 massive galaxies was used to constrain the hot Circumgalactic Medium (CGM) density and temperature. The X-ray luminosities constrained the density and hot CGM mass, while the SZ signal helped in breaking the density-temperature degeneracy. A simple power-law density distribution as well as a hydrostatic hot halo model,, with the gas assumed to be isothermal in both cases, were considered. It was shown that the mean hot

CGM profile goes as $r^{-1.2}$, which is shallower than an NFW profile. The hot CGM was estimated to contain 20 - 30% of galactic baryonic mass within the virial radii, and also broadly agreed with observations of the Milky Way. In a paradigm changing result, it was shown that the mean hot CGM mass is comparable to or larger than the mass contained in other phases of the CGM for L* galaxies. [Subhabrata Majumdar, Priyanka Singh (RRI), Biman B. Nath (RRI) & Joseph Silk]

AGN feedback with the Square Kilometre Array and implications for cluster physics and cosmology

AGN feedback is regarded as perhaps the most important non-gravitational process in galaxy clusters, providing useful constraints on large-scale structure formation. In view of upcoming data, particularly from radio surveys with next-generation facilities like SKA, along with major breakthroughs in X-ray sensitivity, high spatial and spectral resolutions, a review AGN feedback in galaxy clusters was presented along with its implications for future study of cluster physics and cluster cosmology. The current major issues regarding modelling of AGN feedback and its impact on the surrounding medium and the possible breakthroughs we can expect from the future multi-frequency SKA instrument was discussed. [Subhabrata Majumdar, Asif Iqbal (Kashmir University), Biman B Nath (RRI), Prateek Sharma (IISC), Ruta Kale (NCRA), Mahadev Pandge (Dayanand Science College, Latur), Somak Raychaudhury (IUCAA) & Manzoor Malik (Kashmir University)]

Correlations of the feedback energy and BCG radio luminosity in galaxy clusters

The excess entropy and the corresponding non-gravitational feedback energy ($E_{feedback}$) in the intra-cluster medium (ICM) was studied by considering a sample of 22 galaxy clusters using Chandra X-ray and NRAO VLA Sky Survey (NVSS)/Giant Metre-wave Radio Telescope (GMRT) radio observations. Moderate to strong correlation of the brightest cluster galaxy (BCG) radio luminosity (L_R) with the feedback energy and various other cluster thermal properties were found. It was shown conclusively that the active galactic nucleus (AGN) is more efficient in transferring feedback energy to the ICM in less massive clusters. Finally, the implications of the results with regard to feedback in clusters and cosmology were discussed. [Subhabrata Majumdar, Asif Iqbal (RRI), Ruta Kale (NCRA) & Biman B. Nath (RRI)]

Constraining the X-ray AGN halo occupation distribution: implications for eROSITA

The X-ray emission from active galactic nucleus (AGN) is a major component of extra-galactic X-ray sky. The X-ray luminosity function (XLF) and halo occupation distribution (HOD) formalism was used to construct a halo model for the X-ray emission from AGNs. Verifying that the two inputs (XLF and HOD) are in agreement with each other, the auto-correlation power spectrum in the soft X-ray band (0.5-2 keV) was computed due to the AGNs potentially resolved by eROSITA (extended ROentgen Survey with an Imaging Tele-scope Array) mission and the redshift and mass dependence of the power spectrum were explored. Studying the relative contribution of the Poisson and the clustering terms to the total power, it was found that at multipoles $l < 1000$ (i.e. large scales), the clustering term is larger than the Poisson term. The potential of X-ray auto-correlation power spectrum and X-ray-lensing cross-correlation power spectrum using eROSITA and eROSITA-LSST (Large Synoptic Survey Telescope) surveys, respectively, to constrain the HOD parameters and their redshift evolution were also forecasted. In addition, the power spectrum of the AGNs lying below the flux resolution limit of eROSITA was computed, which is essential to understand in order to extract the X-ray signal from the hot di use gas present in galaxies and clusters. [Subhabrata Majumdar, Priyanka Singh (RRI), Alexandre Refreiger (ETH Zurich) & Biman B. Nath (RRI)]

Excess entropy and energy feedback from within cluster cores up to r_{200}

The non-gravitational entropy injection profiles, $K(m_g)$, and resulting non-gravitational energy feedback profiles, $E(m_g)$, of the intracluster medium for a sample of 17 clusters were estimated using the joint data sets of Planck SZ and ROSAT X-Ray observations, spanning a large radial range from $0{:}2r_{500}$ up to r_{200}. The non-thermal pressure and clumping were included in the analysis since they become important at larger radii. The inclusion of non-thermal pressure and clumping resulted in changing the estimates for r_{500} and r_{200} by 10%-20%. It was shown that neglect of clumping leads to an under-estimation of $K \sim 300$ keV cm^2 at r_{500} and $K \sim 1100$ keV cm^2 at r_{200}. On the other hand, neglecting non-thermal pressure resulted in the over-estimation of $K \sim 100$ keV cm^2 at r_{500} and under-estimation of $K \sim 450$ keV cm^2 at r_{200}. Combining both, it was conclusively shown that for the sample as a whole, an entropy floor of $K \sim 300$ keV cm^2 is ruled out at 3-sigma throughout the entire radial range and hence strongly constraining all ICM pre-heating scenarios. Moreover, it was found that the average feedback energy per particle of $E \sim 1$ keV is also ruled out at more than 3-sigma beyond r_{500}. The robustness of our results w.r.t sample selection, X-Ray analysis procedures, non-radiative entropy modeling were demonstrated. [Subhabrata Majumdar, Asif Iqbal (Kashmir University), Biman B Nath (RRI, Bangalore), Stefano Ettori (INFN Bologna), Dominique Eckert (University of Geneva) & Manzoor A. Malik (Kashmir University)]

Theia: Faint objects in motion or the new astrometry frontier

In the context of the ESA M5 (medium mission) call, a new satellite mission, Theia, based on relative astrometry and extreme precision to study the motion of very faint objects in the Universe was proposed. Theia is primarily designed to study the local dark matter properties, the existence of Earth-like exoplanets in our nearest star systems and the physics of compact objects. Furthermore, about 15 % of the mission time is dedicated to an open observatory for the wider community to propose complementary science cases. With its unique metrology system and "point and stare" strategy, Theia's precision would have reached the sub micro-arcsecond level. This is about 1000 times better than ESA/Gaia's accuracy for the brightest objects and represents a factor 10-30 improvement for the faintest stars (depending on the exact observational program). In the version submitted to ESA, an optical (350-1000nm) on-axis TMA telescope was proposed. Due to ESA Technology readiness level, the camera's focal plane would have been made of CCD detectors but it is anticipated that an upgrade with CMOS detectors will be possible. Photometric measurements would have been performed during slew time and stabilisation phases needed for reaching the required astrometric precision. [Subhabrata Majumdar and the THEIA Collaboration]

Fast flavor conversions of supernova neutrinos: Classifying instabilities via dispersion relations

Very recently, a novel method has been proposed to investigate fast flavor conversions of supernova neutrinos, in terms of the dispersion relation for the complex frequency and wave number of disturbances in the mean field of the flavor coherence. A systematic approach to such instabilities, originally developed in the context of plasma physics, and based on the time-asymptotic behavior of the Green's function of the system was discussed. Instabilities are typically seen to emerge for complex frequency, and can be further characterized as convective (moving away faster than they spread) and absolute (growing locally), depending on k-dependent features. Stable cases emerge when the wavenumber (but not frequency) is complex, leading to disturbances damped in space, or when both are real, corresponding to complete stability. The analytical classification of both unstable and stable modes leads not only to qualitative insights about their features but also to quantitative predictions about the growth rates of instabilities. Representative numerical solutions were discussed in a simple two-beam model of interacting neutrinos. As an application, it was argued that supernova and binary neutron star mergers exhibiting a "crossing" in the electron lepton number would lead to an absolute instability in the flavor content of the neutrino gas [Francesco Capozzi, Basudeb Dasgupta, Eligio Lisi, Antonio Marrone, and Alessandro Mirizzi]

Fast Neutrino Flavor Conversion as Oscillations in a Quartic Potential

An analytical treatment of the simplest system that exhibits fast conversions was presented, and it was shown that the conversion can be understood as the dynamics of a particle rolling down in a quartic potential governed dominantly by the neutrino density, but seeded by slower oscillations. [Basudeb Dasgupta and Manibrata Sen]

New Dissipation Mechanisms from Multi-level Dark Matter Scattering

Multi-level dark matter with diagonal and off-diagonal interactions shows a rich phenomenology in its self-scattering. If the interactions are mediated by a particle that is less massive than the dark matter, Sommerfeld effect can lead to resonant enhancement of the scattering. For mediators lighter than the level separation, dark matter particles can up-scatter to excited states and de-excite by emitting these mediators. These cross-sections, both above and below the kinematic threshold were computed in a generic two-component dark matter model and the large inelastic cross-section as a result of maximal mixing between the two states was found. A new route for cooling of large dark matter halos and a new drag force between two colliding halos are identified and shown to arise purely from the inelastic scattering. [Anirban Das and Basudeb Dasgupta]

Selection Rule for Enhanced Dark Matter Annihilation

Multi-level dark matter with diagonal and off-diagonal interactions shows a rich phenomenology. A selection rule for enhancement (suppression) of odd (even) partial waves of dark matter co-annihilation or annihilation using Sommerfeld effect was pointed out. Using this, the usually velocity-suppressed p-wave annihilation was shown to dominate the annihilation signals in the present Universe. The selection mechanism is a manifestation of the exchange symmetry of identical incoming particles, and generic for multi-state DM with off-diagonal long-range interactions. As a consequence, the relic and late-time annihilation rates are parametrically different and a distinctive phenomenology, with large but strongly velocity-dependent annihilation rates, was predicted. [Anirban Das and Basudeb Dasgupta]

Fast neutrino flavor conversions near the supernova core with realistic flavor-dependent angular distributions

Using linear stability analyses and numerical solutions of the fully nonlinear equations of motion, a detailed study of fast conversions was performed, focusing on the region just above the supernova core and it was found that neutrinos travelling towards the core make fast conversions more generic, i.e., possible for a wider range of flux ratios and angular asymmetries. Using fluxes and angular distributions predicted by supernova simulations, it was found that fast conversions can occur within tens of nanoseconds, only a few meters away from the putative neutrinospheres. [Basudeb Dasgupta, Alessandro Mirizzi, and Manibrata Sen]

Polarized anisotropic spectral distortions of the CMB from photon-axion/scalar conversion

CMB photons can convert to axions or light scalar particles, as they propagate through the cosmos, in the presence of magnetic fields, resulting in a deviation of the CMB spectrum from a blackbody. The spectral distortions in the CMB photons from conversion (disappearance) to light spin-zero particles as they propagate through the galactic magnetic fields was calculated. It was shown that resonant conversion happens for axion masses between 10^{-14} and $5x10^{-13}$ eV giving rise to a polarized anisotropy pattern in the microwave sky (shown in Fig 2). The anisotropy pattern varies with particle mass and the polarization direction for scalar and pseudo-scalar particles is orthogonal to each other. Some inaccuracies in cosmological axion constraints in existing literature were pointed out. Un-polarized distortions from stochastic magnetic fields, in our Galaxy as well as in nearby voids, was also estimated. [Suvodip Mukherjee (IAP, Paris), Rishi Khatri, Benjamin Wandelt (IAP, Paris)]

Dark neutrino interactions make primordial gravitational waves blue

New interactions of neutrinos with dark matter were shown to significantly affect the evolution of the primordial gravitational waves and their imprints on the CMB B-mode polarization power spectrum. It was also shown that very generally there are two class of models having neutrino dark matter elastic scattering cross section either constant or with neutrino temperature dependence of T^2. Neutrino dark matter interactions were shown to enhance the CMB B-mode polarization power spectrum on small scales for modes with angular wavenumber $l>100$. Our results implied potential degeneracy with primordial (inflationary) gravitational wave power spectrum as well as a new window into neutrino physics from measurements of primordial B-mode polarization power spectrum of the CMB. [Subhajit Ghosh, Rishi Khatri, Tuhin Roy]

New viable region of an inert Higgs doublet dark matter model with scotogenic extension

We explored the intermediate dark matter mass regime of the inert Higgs doublet model, approximately between 400 GeV and 550 GeV, which is allowed by latest constraints from direct and indirect detection experiments, but the thermal relic abundance remains suppressed. We extended the model by three copies of right-handed neutrinos, odd under the built-in Z2 symmetry of the model. This discrete Z2 symmetry of the model allows these right-handed neutrinos to couple to the usual lepton doublets through the inert Higgs doublet allowing the possibility of radiative neutrino mass in the scotogenic fashion. Apart from generating nonzero neutrino mass, such an extension can also revive the intermediate dark matter mass regime. The late decay of the lightest right-handed neutrino to dark matter makes it possible for the usual thermally under-abundant dark matter in this intermediate mass regime to satisfy the correct relic abundance limit. The revival of this wide intermediate mass range can have relevance not only for direct and indirect search experiments but also for neutrino experiments as the long lifetime of the lightest right-handed neutrino also results in almost vanishing lightest neutrino mass. [Aritra Gupta, Debashis Borah (IIT Guwahati)].

B. Condensed Matter and Statistical Physics

From Continuous transitions to Metamagnetism in 2 dimensional JQ Model

Using a combination of quantum Monte Carlo (QMC) and exact methods, the field-driven saturation transition of the two-dimensional *J-Q* model was studied. For small values of *Q*, the saturation transition is continuous, and is expected to be governed by zero-scale-factor universality at its upper critical dimension, with a specific form of logarithmic corrections to scaling (first proposed by Sachdev et al. [Phys. Rev. B 50, 258 (1994)]). Results conforming to this expectation were obtained, but the logarithmic corrections to scaling do not match the form predicted by Sachdev et al. It was shown that the saturation transition becomes first order above a critical coupling ratio (*Q*/*J*)min and is accompanied by magnetization jumps---metamagnetism. An exact solution for (*Q*/*J*)min using a high magnetization expansion was obtained, and confirmed the existence of the magnetization jumps beyond this value of coupling using quantum Monte Carlo simulations. [K. Damle, A. Sandvik and A. Iaizii (Boston University)]

Realization of Multi-mode Superconducting Circuits as multiple qubits

Inter-qubit coupling and qubit connectivity in a processor are crucial for achieving high fidelity multi-qubit gates and efficient implementation of quantum algorithms. Typical superconducting processors employ relatively weak transverse inter-qubit coupling which are activated via frequency tuning or microwave drives. This work proposed a class of multi-mode superconducting circuits which realize multiple transmon qubits with all-to-all longitudinal coupling. These "artificial molecules" directly implement a multi-dimensional Hilbert space that can be easily manipulated due to the always-on longitudinal coupling. The basic technique to analyze such circuits was described, and used to compute the relevant properties and discuss how to optimize them to create efficient small-scale quantum processors with universal programmability [Tanay Roy, Madhavi Chand, Sumeru Hazra, Suman Kundu, Kedar Damle, R. Vijay]

Competing electronic phases in the topological crystalline insulator Pb(1-x)Sn(x)Te

The four topologically protected electron bands on the (001) surface of the crystalline topological insulator Pb(x)Sn(1-x)Te include two containing Type-II van Hove singularities, accessible at relatively small values of doping. Bloch states corresponding to electrons in these bands have nontrivial Berry phases that effectively impart a momentum dependence to the interparticle interactions in a given band. Using a “multipatch” parquet renormalization group scheme, the authors studied the effect of repulsive electron interactions on the competition of different electronic phases on the (001) surface when the chemical potential is tuned to the vicinity of the van Hove singularities. Over a wide region of parameter space of repulsive interactions, it was shown that a chiral p-wave superconducting phase is favoured. In a subsequent paper, the authors studied the effect of a finite magnetization on the electronic phase competition. Implications for experiment were discussed. [V. Tripathi, S. Kundu]

Scaling universality at the dynamic vortex Mott transition

A clean way to observe a dynamic Mott insulator-to-metal transition (DMT) without the interference from disorder and other effects inherent to electronic and atomic systems, is to employ the vortex Mott states formed by superconducting vortices in a regular array of pinning sites. In this joint experiment-theory effort, the authors studied the critical behaviour of the vortex system as it crosses the DMT line, driven by either current or temperature. They found universal scaling with respect to both, expressed by the same scaling function and characterized by a single critical exponent coinciding with the exponent for the thermodynamic Mott transition. A theory for the DMT was developed based on the parity reflection-time reversal (PT) symmetry breaking formalism. It was found that the nonequilibrium-induced Mott transition has the same critical behavior as the thermal Mott transition. These findings demonstrate the existence of physical systems in which the effect of a nonequilibrium drive is to generate an effective temperature and hence the transition belonging in the same universality class as the temperature driven transition.
[V. Tripathi, M. Lankhorst, M. P. Stehno, F. Coneri, H. Hilgenkamp, A. Brinkman and A. Golubov (Twente), N. Poccia (Harvard), A. Galda, T. Baturina and V. Vinokur (Argonne), and H. Barman (TIFR & IMSc)]

Power Law Tails in non-Markovian Dynamics of Open Quantum Systems

The dynamics of open Bosonic and Fermionic systems coupled linearly to thermal baths were investigated in this work using Keldysh Field Theory. It was shown that the dynamics of a system of bosons (fermions) linearly coupled to a noninteracting bosonic (fermionic) bath falls outside the standard Markovian paradigm if the bath spectral function has nonanalyticities as a function of frequency. In that case, the dissipative and noise kernels governing the dynamics were shown to have distinct power-law tails. The Green's functions show a short-time "quasi"- Markovian exponential decay before crossing over to a power-law tail governed by the nonanalyticity of the spectral function. Exact solutions were found for a large class of non-analytic baths and it was shown that the power law tails are easier to observe at strong system bath coupling in unequal time correlators. It was shown that the power law tails were perturbatively robust to inter-particle interaction. [R. Sensarma, A. Chakraborty]

Braids and phase gates through high-frequency virtual tunneling of Majorana zero modes

Braiding of non-Abelian Majorana anyons is a first step towards using them in quantum computing. In this work a protocol was proposed for braiding Majorana zero modes formed at the edges of nanowires with strong spin-orbit coupling and proximity-induced superconductivity. The protocol uses high-frequency virtual tunneling between the ends of the nanowires in a trijunction, which leads to an effective low-frequency coarse-grained dynamics for the system, to perform the braid. The braiding operation is immune to amplitude noise in the drives and depends only on relative phase between the drives, which can be controlled by the usual phase-locking techniques. It was also shown, how a phase gate, which is necessary for universal quantum computation, can be implemented with our protocol. [R. Sensarma, P. Gorantla]

Landau level diagram and the continuous rotational symmetry breaking in trilayer graphene

Sequence of the zeroth Landau levels (LLs) between filling factors -6 and 6 in ABA stacked trilayer graphene (TLG) is ambiguous because it depends sensitively on the non-uniform charge distribution on the three layers of ABA-TLG. Using the sensitivity of quantum Hall (QH) data on the perpendicular electric field E and magnetic field B, in an ultraclean TLG sample, experimental data and theoretical modeling was used to quantitatively estimate the non-uniformity of the electric field and determine the sequence of the zeroth LLs. Anticrossings between some LLs differing by 3 in LL index were observed, and were explained as a result of the breaking of the continuous rotational to C_3 symmetry by trigonal warping. Some fractional quantum Hall (FQH) states at low magnetic field were also observed in this sample. [R. Sensarma, Biswajit Datta, Hitesh Agarwal, Abhisek Samanta, Amulya Ratnakar (CEBS, Mumbai University), Kenji Watanabe (NIMS Japan), Takashi Taniguchi (NIMS Japan)and Mandar M. Deshmukh (DCMP-TIFR)]

Large deviations conditioned on empirical measure

In studies of stochastic processes, an important question deals with characterization of fluctuations conditioned on an empirical measure. Such conditioned processes have been studied in probability theory and computer science. Their relevance in Physics comes from thermodynamic ensembles and their generalization in non-equilibrium stationary state. In two long papers, we looked into stochastic processes when conditioned on an empirical observable, *e.g.* time integrated current. The first paper presented a formal analysis of conditioned Markov chain and Langevin dynamics. The second paper dealt with generalization of our framework to fluctuating hydrodynamics fields, in particular, application to systems of interacting many degrees of freedom. The results were verified by exact solution of few non-trivial microscopic models of interacting particles. [Tridib Sadhu, Bernard Derrida (College-de-France, Paris)]

Generalized arcsine law for fractional Brownian motion

The three arcsine laws for standard Brownian motion are well known pedagogical results in the theory of stochastic process. For a Brownian motion starting at the origin, and evolving during time T, one considers the following three observables: (i) the time t_+ the process is positive, (ii) the last time t_{last} the process visits the origin, and (iii) the time t_{max} it takes its maximum (or minimum). All three observables have the same cumulative probability distribution expressed as an arcsine function, hence the name arcsine law. We studied how these laws change for the fractional Brownian motion, which is a non-Markovian generalization of the Brownian motion. Using a tedious and challenging calculation we obtained generalization of all three arcsine laws. The theoretical results were supported (see Figure 3) by extensive numerical simulations, which itself was challenging due to its non-Markovian nature. [Tridib Sadhu, Kay J Weise (Ecole Normale Supérieure, Paris)]

Phase transition in one-dimensional system with short-range interactions

There is a misconception, widely shared amongst physicists, that the equilibrium free energy of a one-dimensional model with strictly finite-ranged interactions, and at non-zero temperatures, cannot show any singularities as a function of the coupling constants. We presented an instructive counter-example. We considered thin rigid linear rods of equal length 2L whose centers lie on a 1-d lattice, of lattice spacing a. The interaction between rods is a repulsive soft-core interaction, having energy U per overlap of rods. We showed that the equilibrium free energy per rod $\mathcal{F}(\kappa=L/a)$ has an infinite number of singularities, as a function of κ (see Figure 4). [Tridib Sadhu, Deepak Dhar and Sushant Sarlay (IISER, Pune), and Juliane U. Klamser (Ecole Normale Supérieure, Paris)]

Dynamical phase transition in a non-equilibrium steady state

Many recent works show phase transitions in the path-space measure in the non-equilibrium steady state of interacting particle systems. Drawing parallel with equilibrium phase transitions one may ask: are these phase transitions related to a non-analytic state function, similar to free energy? In one of the simplest setting of a single Brownian particle in a circular trap we analytically showed that the system undergoes a dynamical transition in the optimal paths, and the transition was related to non-analyticity of large deviations function of the particle position. The non-analyticity and the transition was then observed in an experimental realization of a diffusive bead confined in a circular potential generated in an optical tweezer setup. [Tridib Sadhu, Harsh Jain and Shankar Ghosh (DCMPMS-TIFR)]

Multi-time correlation in driven diffusive system

Multi-time correlation of fluctuating quantities plays an important role in statistical mechanics. For example, within linear response theory, response function is expressed in terms of two-time correlation of the fluctuating observable. Using a variational formulation, we presented a systematic analysis of multi-time correlations of current in general diffusive systems out-of-equilibrium. A corollary of the work is an electrostatic correspondence providing an effective description of generic long-range correlation in non-equilibrium steady state, encompassing a large class of older works. In addition, the work presented a formal solution for the large deviation of density in non-equilibrium steady state of general diffusive systems. [Tridib Sadhu]

C. High Energy Physics

Non-standard self-interactions of supernova neutrinos

New possible effects of non-standard self-interactions (NSSI) of neutrinos on flavor conversions of supernova neutrinos were explored in a two-flavor framework. Flavor-preserving NSSI were shown to lead to pinching of spectral swaps, and an overall suppression of bipolar oscillations. Flavor-violating NSSI were shown to cause swaps to develop away from a spectral crossing or even in the absence of a spectral crossing. NSSI could then give rise to collective oscillations and spectral splits even during neutronization burst, for both hierarchies. [Anirban Das, Amol Dighe, and Manibrata Sen]

The standard linear stability analysis was shown to give rise to linearly as well as exponentially growing solutions in the presence of NSSI, and hence, to lead to “fast” oscillations at r ~ 10 km. In the intersecting four-beam model, it was pointed out that flavor-violating NSSI can lead to fast oscillations even when the angle between the neutrino and antineutrino beams is obtuse, which is forbidden in the Standard Model. This leads to the new possibility of fast oscillations in a two-beam system with opposing neutrino-antineutrino fluxes, even in the absence of any spatial inhomogeneities. The long-time behavior of fast and slow flavor conversions was explored by solving the full non-linear equations of motion in the four-beam model numerically. [Amol Dighe and Manibrata Sen]

Hadron direction reconstruction at INO-ICAL

The ability of the proposed iron calorimeter (ICAL) detector at the India-based Neutrino Observatory (INO) to determine hadron shower direction was determined through simulations. The directions of hadron showers in charged-current interactions were reconstructed using the orientation matrix method, while for neutral-current events, the raw-hit method was used which did not need knowledge about the interaction vertex. [Moon Moon Devi, Amol Dighe, D. Indumathi, and S. M. Lakshmi]

Ω_c baryons

We presented the ground and excited state spectra of Ω_c baryons with spin up to 7/2 from lattice quantum chromodynamics with dynamical quark fields. Based on our lattice results, we predicted the quantum numbers of five Ω_c baryons, which have recently been observed by the LHCb Collaboration. Our results strongly indicate that the observed states $\Omega_c(3000)$ and $\Omega_c(3050)$ have spin-parity $J(P)$=1/2(−), the states $\Omega_c(3066)$ and $\Omega_c(3090)$ have $J(P)$=3/2(−), whereas $\Omega_c(3119)$ is possibly a 5/2(−) state. [Nilmani Mathur, M. Padmanath of University of Regensburg]

Tetraquark states

We presented preliminary results from a lattice calculation of tetraquark states in the charm and bottom sector of the type $ud\bar{b}\bar{b}$, $us\bar{b}\bar{b}$, $ud\bar{c}\bar{c}$ *usbb*, *udcc* and $sc\bar{b}\bar{b}$. These calculations were performed on N_f=2+1+1 MILC ensembles with lattice spacing of a=0.12fm and a=0.06fm. A relativistic action with overlap fermions was employed for the light and charm quarks while a non-relativistic action with non-perturbatively improved coefficients is used in the bottom sector. Our preliminary results provide a clear indication of presence of energy levels below the relevant thresholds of different tetraquark states. While in double charm sector we found shallow bound levels, our results suggest deeply bound levels with double bottom tetraquarks. [Nilmani Mathur, P. Junnarkar]

Baryon spectra

We presented preliminary results on the light, charmed and bottom baryon spectra using overlap valence quarks on the background of 2+1+1 flavours HISQ gauge configurations of the MILC collaboration. These calculations were performed on three different gauge ensembles at three lattice spacings (a ~ 0.12 fm, 0.09 fm and 0.06 fm) and for physical strange, charm and bottom quark masses. The SU(2) heavy baryon chiral perturbation theory is used to extrapolate baryon masses to the physical pion mass and the continuum limit extrapolations are also performed. Our results are consistent with the well measured charmed baryons. We predicted the masses of many other states which are yet to be discovered. [Nilmani Mathur, S. Mondal, and M. Padmanath (University of Regensburg)]

Probing non-commutativity of space

Non-commutative (NC) space-time geometry arises naturally in the context of string theory. An obvious question to ask is whether observational constraints can be placed on the scale of non-commutativity (measured in m^2). It has been argued earlier that Lamb shift measurements in

Hydrogen can potentially reveal this scale while others have argued that no such effect is possible since proton and electron have equal and opposite charges. On the other hand, proton is made up of quarks with 2/3 and -1/3 charges, suggesting an effect may be possible at some scale. Examining quantum electrodynamics in NC-space, and for composite proton operator, it was shown that i) any charge g for a fermion is allowed provided the basic QED coupling is g, but no other multiples of g are permitted, thus only up (2/3 charge) or down (-1/3) is possible but not both and ii) composite operators do not have a simple transformation which can be attributed to effective total charge of the composite particle. This places limit on the scale of non-commutativity to be smaller that current LHC limits for compositeness. It also suggests that a substructure at still smaller scales is needed if NC-geometry is to be a physical reality. [R. V. Gavai, P. S. Ghoderao (IIT Mumbai), P. Ramadevi (IIT Mumbai)]

<u>Study of Quarkonia in QGP using effective field theory</u>

Quarkonia are some of the most important probes of the medium created in relativistic heavy ion collision experiments, but it is still difficult to get quantitative predictions of its behavior in quark-gluon plasma from QCD. A combination of effective field theory techniques with nonperturbative determination of their coefficients from QCD may allow us to make reliable theoretical calculations for such systems. As part of this ongoing project, I have estimated decay width of heavy quarkonia in the plasma. [Saumen Datta]

<u>Quark number susceptibilities and equation of state at finite mu</u>

Direct numerical studies of nonperturbative QCD at finite baryon chemical potential mu are not possible. A method employing Taylor expansion in mu, suggested from TIFR, has turned out to be the most successful method for calculations at finite mu. The coeffiecients of such expansion, quark number susceptibilities (QNS), are important experimental observables in their own right. As continuation of the finite mu program in TIFR, We are studying QCD on fine (Nt=12) lattices with two flavors of dynamical quarks with the aim of calculating the QNS. Combining with earlier results on coarser lattices allows us to calculate the continuum equation of state at finite mu and make an estimate of the location of the critical point in QCD phase diagram. [Saumen Datta, R. Gavai and S. Gupta]

<u>A Universal Framework for Finding Anomalous Objects at the LHC</u>

There are examples aplenty where new physics (NP) gives rise to anomalous objects, which cannot be classified as any of the standard-objects (such as isolated-photons, leptons, and QCD-jets). The need for a generic method/tool capable of finding the unexpected cannot be understated.

In this paper, we propose one such anomaly-finder, which simply is a collection of vetoes that eliminates all standard-objects up to a pre-determined acceptance rate. Events containing anomalous objects can be identified as a candidate for NP. Subsequent offline analyses can determine the exact nature of the event, paving a robust way to search for NP scenarios in a model-independent fashion. Further, since the method relies on learning only the standard-objects, for which control samples are readily available from data, one can build an analysis in entirely data-driven ways. [Tuhin Roy, Amit Chakraborty and Abhishek Iyer]

Charting Generalized Supersoft Supersymmetry

In the context of supersoft supersymmetry, I recently proposed new solutions to the μ-problem, color breaking problem, and too-large a T parameter, via a new class of operators (namely, NR-operators), built using the D-vev of a real spurion. In this work we point out that the last remaining issue associated with supersoft spectra (namely that a right-handed (RH) slepton is predicted to be the lightest superpartner, rendering the setup cosmologically unfeasible) can be addressed. NR-operators generate a new source for scalar masses, which can raise the RH-slepton mass above bino due to corrections from renormalisation group evolutions (RGEs). In fact, a mild tuning can open up the bino-RH slepton co-annihilation regime for a thermal dark matter. By deriving the full set of RGEs, we show that a completely viable spectra can be achieved. [Tuhin Roy, Adam Martin (University of Notre Dame) and Sabysachi Chakraborty].

Collisional and thermal dissociation of J/Psi and Upsilon states at the LHC

We presented new results for the suppression of high transverse momentum charmonium [J/Psi,Psi(2S)] and bottomonium [Upsilon(1*S*),Upsilon(2*S*),Upsilon(3*S*)] states in Pb+Pb collisions at the Large Hadron Collider. Our theoretical formalism combines the collisional dissociation of quarkonia, as they propagate in the quark-gluon plasma, with the thermal wavefunction effects due to the screening of the $Q\bar{Q}$ attractive potential in the medium. We found that a good description of the relative suppression of the ground and higher excited quarkonium states, transverse momentum and centrality distributions is achieved, when comparison to measurements at a center-of-mass energy of 2.76 TeV is performed. Theoretical predictions for the highest Pb+Pb center-of-mass energy of 5.02 TeV at the LHC, where new experimental results are being finalized, are also presented. [Samuel Aronson (UCSB), Evan Borras (UCSB), Brunel Odegard (UCSB), Rishi Sharma, Ivan Vitev (LANL)]

Effective Field Theory Models for warm QCD

Using only global symmetries of QCD, we set up an effective model of two flavors of quarks at finite temperature near the crossover, including all possible terms up to dimension-6. We first treat this in mean field theory. Then we investigate low-energy fluctuations around it up to one-loop order in fermions below the crossover. Static correlation functions of pions and the crossover temperature, both measured on the lattice, completely suffice to fix all parameters of the theory. We examine predictions of this theory, including those for thermodynamic quantities. The results are encouraging. In particular, the pion decay constant as a function of the temperature is an independent prediction and matches well with the lattice observations. [Sourendu Gupta, Rishi Sharma]

Current constraints on mixed Higgs-radion states and the possibility of discovering them in the future runs of the LHC

Light radions constitute one of the few surviving possibilities for observable new particle states at the sub-TeV level which arise in models with extra spacetime dimensions. It is already known that the 125 GeV scalar discovered at CERN is unlikely to be a pure radion state, since its decays resemble those of the Standard Model Higgs boson too closely. However, due to experimental errors in the measured decay widths, the possibility still remains that it could be a mixture of the radion with one (or more) Higgs states. We used the existing LHC data at 8 and 13 TeV to make a thorough investigation of this possibility. Not surprisingly, it turned out that this model is already constrained quite effectively by direct LHC searches for an additional scalar heavier than 125 GeV. We then made a detailed study of the so-called 'conformal point', where this heavy state practically decouples from (most of) the Standard Model fields. Some projections were then made for the future runs of the LHC. [Amit Chakraborty, Ushoshi Maitra, Sreerup Raychaudhuri, Tousik Samui]

D. String Theory and Mathematical Physics

The Dynamics of Near-Extremal Black Holes

We analyse the dynamics of near-extremal Reissner-Nordström black holes in asymptotically four-dimensional Anti-de Sitter space (AdS4). We work in the spherically symmetric approximation and study the thermodynamics and the response to a probe scalar field. We find that the behaviour of the system, at low energies and to leading order in our approximations, is well described by the Jackiw-Teitelboim (JT) model of gravity. In fact, this behaviour can be understood from symmetry considerations and arises due to the breaking of time reparametrisation invariance. The JT model has been analysed in considerable detail recently and related to the behaviour of the SYK model. Our results indicate that features in these models which arise from symmetry considerations alone are more general and present quite universally in near-extremal black holes. [Pranjal Nayak, Ashish Shukla, Ronak M Soni, Sandip P. Trivedi, V. Vishal]

An Action for and Hydrodynamics from the improved Large D membrane

It has recently been demonstrated that black hole dynamics at large D is dual to the motion of a probe membrane propagating in the background of a spacetime that solves Einstein's equations. The equation of motion of this membrane is determined by the membrane stress tensor. In this paper we `improve' the membrane stress tensor derived in earlier work to ensure that it defines consistent probe membrane dynamics even at finite *D* while reducing to previous results at large D. Our improved stress tensor is the sum of a Brown York term and a fluid energy momentum tensor. The fluid has an unusual equation of state; its pressure is nontrivial but its energy density vanishes. We demonstrate that all stationary solutions of our membrane equations are produced by the extremization of an action functional of the membrane shape. Our action is an offshell generalization of the membrane's thermodynamic partition function. We demonstrate that the thermodynamics of static spherical membranes in flat space and global AdS space exactly reproduces the thermodynamics of the dual Schwarzschild black holes even at finite D. We study the long wavelength dynamics of membranes in AdS space, and demonstrate that the boundary `shadow' of this membrane dynamics is boundary hydrodynamics with a definite constitutive relation. We determine the explicit form of shadow dual boundary stress tensor upto second order in derivatives of the boundary temperature and velocity, and verify that this stress tensor agrees exactly with the fluid gravity stress tensor to first order in derivatives, but deviates from the later at second order and finite D. [Yogesh Dandekar, Suman Kundu, Subhajit Mazumdar, Shiraz Minwalla, Amiya Mishra, Arunabha Saha.]

Melonic O(N)^(q-1) models

It has recently been demonstrated that the large N limit of a model of fermions charged under the global/gauge symmetry group O(N)^(q−1) agrees with the large N limit of the SYK model. In these notes we investigate aspects of the dynamics of the O(N)^(q−1) theories that differ from their SYK counterparts. We argue that the spectrum of fluctuations about the finite temperature saddle point in these theories has (q−1)^(N^2/2) new light modes in addition to the light Schwarzian mode that exists even in the SYK model, suggesting that the bulk dual description of theories differ significantly if they both exist. We also study the thermal partition function of a mass deformed version of the SYK model. At large mass we show that the effective entropy of this theory grows with energy like E lnE (i.e. faster than Hagedorn) up to energies of order N^2. The canonical partition function of the model displays a deconfinement or Hawking Page type phase transition at temperatures of order 1/lnN. We derive these results in the large mass limit but argue that they are qualitatively robust to small corrections in J/m. [Sayantan Choudhury, Anshuman Dey, Indranil Halder, Lavneet Janagal, Shiraz Minwalla, Rohan Poojary]

Currents and Radiation from the large D Black Hole Membrane

It has recently been demonstrated that black hole dynamics in a large number of dimensions D reduces to the dynamics of a codimension one membrane propagating in flat space. In this paper we define a stress tensor and charge current on this membrane and explicitly determine these currents at low orders in the expansion in 1/D. We demonstrate that dynamical membrane equations of motion derived in earlier work are simply conservation equations for our stress tensor and charge current. Through the paper we focus on solutions of the membrane equations which vary on a time scale of order unity. Even though the charge current and stress tensor are not parametrically small in such solutions, we show that the radiation sourced by the corresponding membrane currents is generically of order (1/D)^D. In this regime it follows that the 'near horizon' membrane degrees of freedom are decoupled from asymptotic flat space at every perturbative order in the 1/D expansion. We also define an entropy current on the membrane and use the Hawking area theorem to demonstrate that the divergence of the entropy current is pointwise non negative. We view this result as a local form of the second law of thermodynamics for membrane motion. [Sayantani Bhattacharyya (IIT Kanpur), Anup Kumar Mandal (IIT Kanpur), Mangesh Mandlik, Umang Mehta (IIT Bombay), Shiraz Minwalla, Utkarsh Sharma (IIT Bombay), Somyadip Thakur]

Two-dimensional quantum gravity dual to SYK/tensor models

The Nambu-Goldstone (NG) bosons of the SYK model are described by a coset space Diff/SL(2,R), where Diff, or Virasoro group, is the group of diffeomorphisms of the time coordinate valued on the real line or a circle. It is known that the coadjoint orbit action of Diff naturally turns out to be the two-dimensional quantum gravity action of Polyakov without cosmological constant, in a certain gauge, in an asymptotically flat spacetime. Motivated by this observation, we explore Polyakov action with cosmological constant and boundary terms, and study the possibility of such a two-dimensional quantum gravity model being the AdS dual to the low energy (NG) sector of the SYK model. We find strong evidences for this duality: (a) the bulk action admits an exact family of asymptotically AdS2 spacetimes, parameterized by Diff/SL(2,R), in addition to a fixed conformal factor of a simple functional form; (b) the bulk path integral reduces to a path integral over Diff/SL(2,R) with a Schwarzian action; (c) the low temperature free energy qualitatively agrees with that of the SYK model. We show, up to quadratic order, how to couple an infinite series of bulk scalars to the Polyakov model and show that it reproduces the coupling of the higher modes of the SYK model with the NG bosons. [Gautam Mandal, Pranjal Nayak, Spenta R. Wadia]

Solving conformal crossing equation

The conformal crossing equation puts very stringent constraints on the conformal data. We formulate it in way that makes the conformal symmetry more transparent. This allows for generalization of the crossing equation to arbitrary Lie group G. Using the crossing equation for SU(2) as a toy model, we find infinitely many solutions to the G-crossing equation. In particular, when G is specialized to the conformal group SO(d+1,1), we get infinitely many solutions to the conformal crossing equation. [Abhijit Gadde]

Vector space of conformal field theories

It is argued that the space of not necessarily unitary conformal field theories with abelian symmetry forms a vector space over complex numbers. This is done by formulating the CFT consistency condition as factorization of the n-point function of a certain chosen operator. As a corollary we can construct a non-unitary conformal theory in any dimension. [Abhijit Gadde, Indranil Halder]

S-Matrix Bootstrap for Amplitudes with Linear Spectrum

We worked out constraints imposed by channel duality and analyticity on tree-level amplitudes of four identical real scalars, with the assumptions of a linear spectrum of exchanged particles and Regge asymptotic behaviour. We reduced the requirement of channel duality to a countably infinite set of equations in the general case. We showed that channel duality uniquely fixes the soft Regge behaviour of the amplitudes to that found in String theory, (-s)^(2t). Specialising to the case of tachyonic external particles, we used channel duality to show that the amplitude can be any one in an infinite-dimensional parameter space, and presented evidence that unitarity doesn't significantly reduce the dimension of the space of amplitudes. [Pranjal Nayak, Rohan Poojary, Ronak Soni]

Asymptotic Symmetries of 3d Extended Supergravities

We studied asymptotic symmetry algebras for classes of three dimensional supergravities with and without cosmological constant. In the first part we generalised some of the non-Dirichlet boundary conditions of AdS_3 gravity to extended supergravity theories, and computed their asymptotic symmetries. In particular, we showed that the boundary conditions proposed to holographically describe the chiral induced gravity and Liouville gravity do admit extension to the supergravity contexts with appropriate superalgebras as their asymptotic symmetry algebras. In the second part we considered generalisation of the 3d BMS computation to extended supergravities without cosmological constant, and showed that their asymptotic symmetry algebras provide examples of nonlinear extended superalgebras containing the BMS_3 algebra. [Rohan Poojary, Nemani Suryanarayana (IMSc)]

Entanglement in Chern-Simons theory with generic gauge groups

We study the entanglement for a state on linked torus boundaries in 3d Chern-Simons theory with a generic gauge group and present the asymptotic bounds of Rényi entropy at two different limits: (i) large Chern-Simons coupling k, and (ii) large rank r of the gauge group. These results show that the Rényi entropies cannot diverge faster than lnk and lnr, respectively. We focus on torus links T(2,2n) with topological linking number n. The Rényi entropy for these links shows a periodic structure in n and vanishes whenever n=0 (mod p), where the integer p is a function of coupling k and rank r. We highlight that the refined Chern-Simons link invariants can remove such a periodic structure in n. [Siddharth Dwivedi (IIT Bombay), Vivek Kumar Singh (IIT Bombay), Saswati Dhara (IIT Bombay), P. Ramadevi (IIT Bombay), Yang Zhou (Fudan University), Lata Kh Joshi]

4. Figures

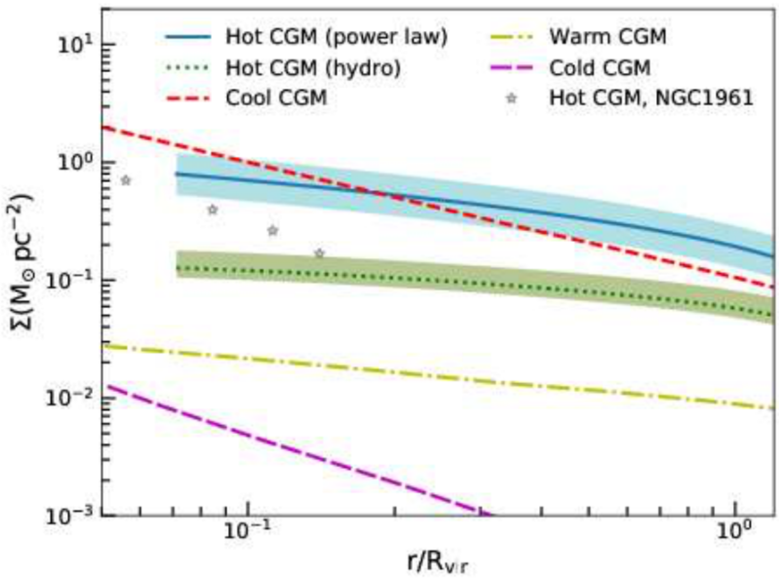

Fig: 1: A new synthesis of CGM mass density results showing the 'hot-CGM' phase to be the dominating phase in the CGM. The new estimates of the amount of hot CGM, from a cosmological sample of galaxies, can potentially fill in the remaining gap to solve the galactic missing baryon problem. (Page 4-5 **X-ray and SZ constraints on the properties of hot CGM)**

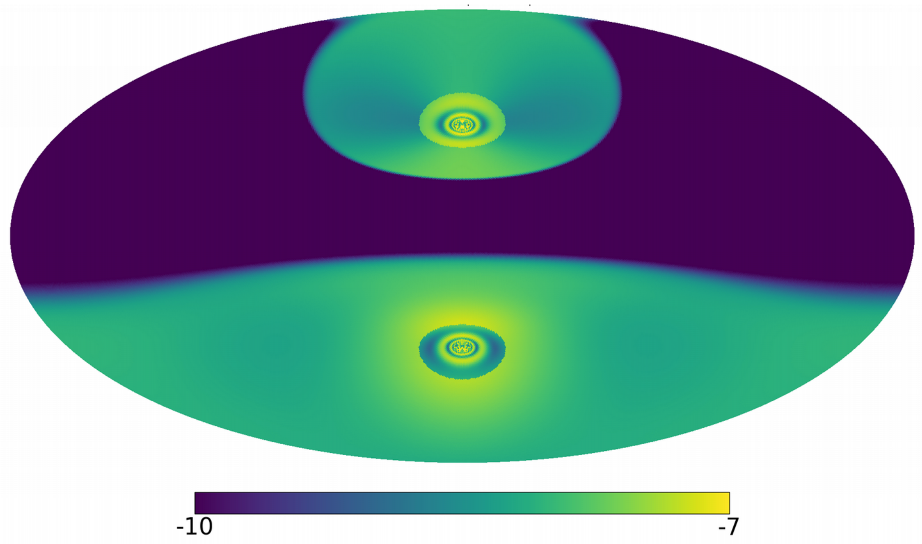

Fig 2: Expected polarized anisotropy pattern in the CMB maps for photons mixing with axions or light scalars with mass 5x10^{-13} eV for resonant conversion of photon to new spin-zero particles in the Galactic magnetic field. (Page 9 **Polarized anisotropic spectral distortions of the CMB from photon-axion/scalar conversion)**

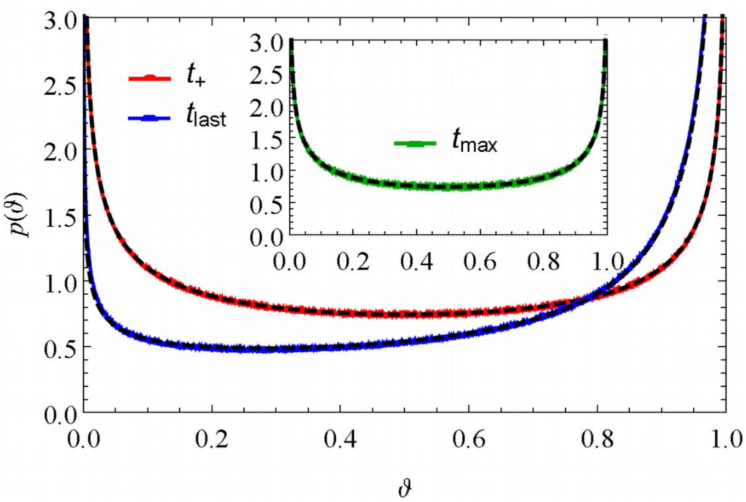

Fig 3: Comparison of theoretical results of the three probabilities to their numerical simulation results. (Page 13 **Generalized arcsine law for fractional Brownian motion**)

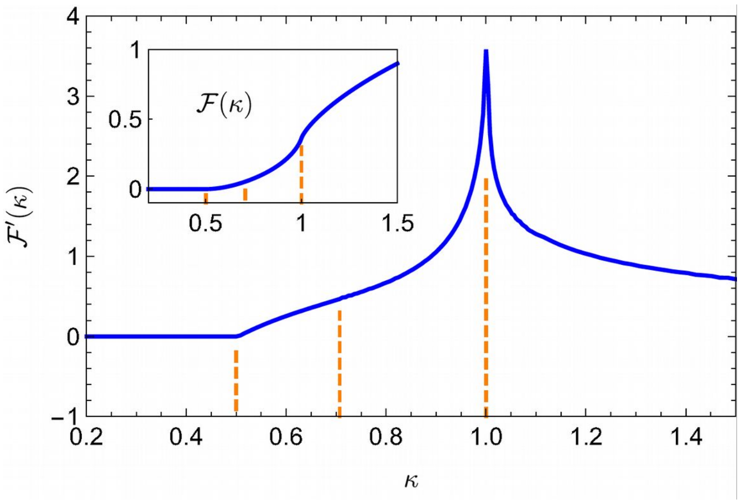

Fig. 4 Singularity in the derivative of free energy Ƒ'(κ). (inset: shows the free energy) (Page 13 **Phase transition in one dimensional system with short range interactions**)

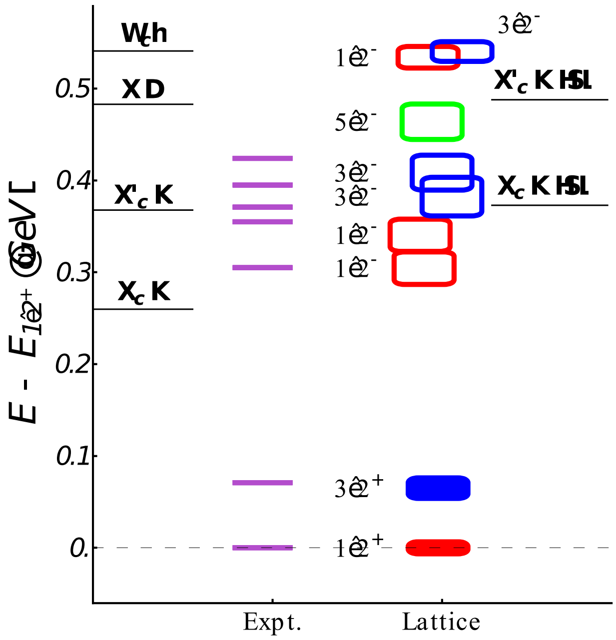

Fig. 5 Charm spectroscopy, (page 15-16 **Baryon spectra)**