DTP Annual report 2013-2014

A. String theory and mathematical physics

1. Interpolating from Bianchi Attractors to Lifshitz and AdS Spacetimes

We constructed classes of smooth metrics which interpolate from Bianchi attractor geometries of Types II, III, VI and IX in the IR to Lifshitz or $AdS_2 \times S^3$ geometries in the UV. While we did not obtain these metrics as solutions of Einstein gravity coupled to a simple matter field theory, we showed that the matter sector stress-energy required to support these geometries (via the Einstein equations) does satisfy the weak, and therefore also the null, energy condition. Since Lifshitz or $AdS_2 \times S^3$ geometries can in turn be connected to AdS_5 spacetime, our results show that there is no barrier, at least at the level of the energy conditions, for solutions to arise connecting these Bianchi attractor geometries to AdS_5 spacetime. The asymptotic AdS_5 spacetime has no non-normalizable metric deformation turned on, which suggests that furthermore, the Bianchi attractor geometries can be the IR geometries dual to field theories living in flat space, with the breaking of symmetries being either spontaneous or due to sources for other fields. Finally, we showed that for a large class of flows which connect two Bianchi attractors, a C-function can be defined which is monotonically decreasing from the UV to the IR as long as the null energy condition is satisfied. However, except for special examples of Bianchi attractors (including AdS space), this function does not attain a finite and non-vanishing constant value at the end points. [Nilay Kundu, Rickmoy Samanta and Sandip P. Trivedi with Shamit Kachru (Stanford, USA) and Arpan Saha (IISc, Bangalore)]

2. Conformal Invariance and the Four Point Scalar Correlator in Slow-Roll Inflation

We calculated the four point correlation function for scalar perturbations in the canonical model of slow-roll inflation. We worked in the leading slow-roll approximation where the calculation can be done in de Sitter space. Our calculation used techniques drawn from the AdS/CFT correspondence to find the wave function at late times and then calculate the four point function from it. The answer we obtained agrees with an earlier result

in the literature, obtained using different methods. Our analysis reveals a subtlety with regard to the Ward identities for conformal invariance, which arises in de Sitter space and has no analogue in AdS space. This subtlety arises because in de Sitter space the metric at late times is a genuine degree of freedom, and hence to calculate correlation functions from the wave function of the Universe at late times, one must fix gauge completely. The resulting correlators are then invariant under a conformal transformation accompanied by a compensating coordinate transformation which restores the gauge. [Nilay Kundu and Sandip Trivedi, with Archisman Ghosh and Suvrat Raju (ICTS, TIFR, Bangalore)]

3. Dynamical entanglement entropy with angular momentum and U(1) charge

We considered the time-dependent entanglement entropy (EE) for a 1+1 dimensional CFT in the presence of angular momentum and U(1) charge. The EE saturates, irrespective of the initial state, to the grand canonical entropy after a time large compared with the length of the entangling interval. We reproduced the CFT results from an AdS dual consisting of a spinning BTZ black hole and a flat U(1) connection. The apparent discrepancy that the holographic EE does not a priori depend on the U(1) charge while the CFT EE does, is resolved by the charge-dependent shift between the bulk and boundary stress tensors. We showed that for small entangling intervals, the entanglement entropy obeys the first law of thermodynamics, as conjectured recently. The saturation of the EE in the field theory was shown to follow from a version of quantum ergodicity; the derivation indicates that it should hold for conformal as well as massive theories in any number of dimensions. [Gautam Mandal and Ritam Sinha, with Pawel Caupta (Department of Physics and Centre for Theoretical Physics University of the Witwatersrand, South Africa)]

4. Double Trace Flows and Holographic RG in dS/CFT correspondence

Maldacena's work on the gauge-gravity duality works between a conformal field theory (CFT) in d dimensions and string theory in d+1 dimensional anti-de Sitter (AdS) space. If there is a similar correspondence between de Sitter space (dS) and a CFT, time evolution in the bulk should translate to RG flows in the dual euclidean field theory. Consequently, although the dual field is expected to be non-unitary, its RG flows will carry an imprint

of the unitary time evolution in the bulk. We examined the prediction of holographic RG in de Sitter space for the flow of double and triple trace couplings in any proposed dual. We showed quite generally that the correct form of the field theory beta functions for the double trace couplings is obtained from holography, provided one identifies the scale of the field theory with $(i|T|)$ where T is the 'time' in conformal coordinates. For dS(4), we found that with an appropriate choice of operator normalization, it is possible to have real n-point correlation functions as well as beta functions with real coefficients. This choice leads to an RG flow with an IR fixed point at negative coupling unlike in a unitary theory where the IR fixed point is at positive coupling. The proposed correspondence of Sp(N) vector models with de Sitter Vasiliev gravity provides a specific example of such a phenomenon. For dS(d+1) with even d, however, we found that no choice of operator normalization exists which ensures reality of coefficients of the beta-functions as well as absence of n-dependent phases for various n-point functions, as long as one assumes real coupling constants in the bulk Lagrangian. [Gautam Mandal, with Diptarka Das and Sumit Das (University of Kentucky, Lexington, USA)]

5. Chern-Simons theories

- Phases of large N vector Chern-Simons theories on $S^2 \times S^1$: The thermal partition function of level k U(N) Chern-Simons theories on a two sphere interacting with matter in the fundamental representation was studied in the t Hooft limit with the t' Hooft coupling denoted by λ. In several specific theories we computed the holonomy potential as a function of λ. Level rank duality of pure Chern-Simons theory was used to demonstrate the equality of thermal partition functions of previously conjectured dual pairs of theories a a function of the temperature. The partition function was reduced to a matrix integral over holonomies. The summation over ux sectors quantizes the eigenvalues of this matrix in units of $2\pi/k$ and the eigenvalue density of the holonomy matrix is bounded from above by $1/2\pi\lambda$. The corresponding matrix integrals generically undergo two phase transitions as a function of temperature. For several Chern-Simons matter theories we were able to exactly solve the relevant matrix models in the low temperature phase, and determine the phase transition temperature as a function of λ. At low temperatures our partition function smoothly matches

onto the N and λ independent free energy of a gas of non renormalized multi trace operators. We also found an exact solution to a simple toy matrix model; the large N Gross-Witten-Wadia matrix integral subject to an upper bound on eigenvalue density. [S. Jain, S. Minwalla, T. Sharma, T. Takimi, S. Wadia and S. Yokoyama]

- Chern-Simons duality: The thermal free energy was computed for all renormalizable Chern Simons theories coupled to a single fundamental bosonic and fermionic field in the 't Hooft large N limit. Our results were used to conjecture a strong weak coupling duality invariance for this class of theories. The conjectured duality reduces to Giveon Kutasov duality when restricted to $\mathcal{N} = 2$ supersymmetric theories and to an earlier conjectured bosonization duality in an appropriate decoupling limit. Consequently the bosonization duality may be regarded as a deformation of Giveon Kutasov duality, suggesting that it is true even at large but finite N. [S. Jain, S. Minwalla and S. Yokoyama]

  Explicit computations and conjectures for $2 \to 2$ scattering matrices were presented in large N *U(N)* Chern-Simons theories coupled to fundamental bosonic or fermionic matter to all orders in the 't Hooft coupling expansion. The bosonic and fermionic S-matrices map to each other under the recently conjectured Bose-Fermi duality after a level-rank transposition. The S-matrices presented in this paper may be regarded as relativistic generalization of Aharonov-Bohm scattering. They have unusual structural features: they include a non analytic piece localized on forward scattering, and obey modified crossing symmetry rules. We conjecture that these unusual features are properties of S-matrices in all Chern-Simons matter theories. The S-matrix in one of the exchange channels in our paper has an anyonic character; the parameter map of the conjectured Bose-Fermi duality may be derived by equating the anyonic phase in the bosonic and fermionic theories. [S. Jain, S. Minwalla, T. Sharma, T. Takimi, S. Wadia and S. Yokoyama]