1 TIFR Annual Report (2011-12) - Department of Theoretical Physics

2 Highlights

String Theory and Mathematical Physics

Holographic Wilsonian RG was generalized to fermions and applied holographic models of non-Fermi liquids, permitting the derivation of a low energy effective action proposed by Faulkner and Polchinski to describe non-Fermi liquids.

A holographic model of electroweak symmetry breaking was constructed. The system displays walking dynamics; its spectrum contains a light scalar, the dilaton, which is difficult to distinguish from the Higgs at low energies, in addition to towers of excited states.

A new proposal for the correct gravitational dual of deconfinement transition in Yang-Mills theory was made. A framework for relativistic superfluid hydrodynamics was developed, correcting errors in previous literature, and verified to be consistent with the AdS/CFT correspondence.

A new framework for constraining non-dissipative first derivative corrections to hydrodynamics - based on comparison with equilibrium partition functions - was developed.

The shear sum rule was obtained for the equations of hydrodynamics that follow from the AdS/CFT correspondence

Chern Simons theories coupled to fermions in the vector representation were solved in the Large N limit and their AdS/CFT dual conjectured.

The origin of the 2+1d novel Higgs mechanism was identified in a very general class of field theories and it was speculated that an analogue of it could occur in condensed matter or gravitational systems.

Extremal black brane near-horizon geometries which preserve homogeneity along the directions in which the brane extension were constructed.

The properties of extremal black branes in dilatonic gravity, especially the fermionic two-point correlators, were studied.

TEXT

String Theory and Mathematical Physics

Holographic Wilsonian flows and emergent fermions in extremal charged black holes

The formalism needed to study Wilsonian flows of fermionic operators using holography was developed and applied it to flows in extremal charged black hole backgrounds. Such backgrounds can be used to describe a non-Fermi liquid in the dual field theory, and are therefore of relevance to condensed matter systems. The existence of a Fermi surface may be deduced from the behavior of the retarded Green function of the fermionic operators, which develops a pole at a particular value of the momentum, the Fermi momentum. In earlier work an effective action was proposed [Faulkner, Polchinski, 2010], which reproduced the correct behaviour of the retarded Green function. This model was semi-holographic, in the sense that it consisted of a strongly coupled sector, described holographically, coupled to an extra fermion put in by hand. By studying the holographic Wilsonian RG for the fermionic operators, in the current work we derived the Polchinski - Faulkner effective action from first principles. We found that the strongly coupled sector is dual to the near horizon region of the black hole, while the extra fermion is emergent in the following sense: at the Fermi momentum, the double-trace coupling generated by the flow develops a pole in the frequency, which means that we have integrated out a massless mode (the emergent fermion) that should have been kept in the effective action. [Daniel Elander, Hiroshi Isono, Gautam Mandal, 2011]

A composite light scalar, electro-weak symmetry breaking and the recent LHC searches

A holographic model of electroweak symmetry breaking that exhibits walking dynamics was constructed. The model flows from a UV fixed point to an IR fixed point, with the scale of the kink corresponding to the end of the walking region. A hard cut-off in the IR

provides a crude model of confinement. Similar flows had previously been found in more sophisticated top-down models constructed from string theory. However, the current model is simple enough to permit the simultaneous computation of both the spectrum of spin-0 and spin-1 states, as well as the S-parameter, one of the precision electroweak parameters. The spectrum contains a set of parametrically light states that can be identified with the electroweak gauge bosons and a light dilaton, the mass of which is suppressed by the length of the walking region. This is followed up by a little desert, up to 2-3 TeV, where towers of resonances of the vector, axial-vector and scalar particles appear. The current model illustrates that using holography, it is relatively easy to construct models of electroweak symmetry breaking that satisfy the experimental constrains, and that contain a light scalar, the dilaton, which at low energies would be difficult to distinguish from the Higgs. [Daniel Elander, Maurizio Piai (Swansea), 2011]

Phase Structure of Holographic Gauge Theory

The phase structure of N D4 branes, wrapped on a temporal (Euclidean) and a spatial circle, was discussed in terms of the near-horizon AdS geometries. This system had been studied previously to understand four dimensional pure SU(N) Yang-Mills theory (YM4) through holography. In the standard treatment of the subject, the phase transition between the AdS soliton and the black D4 brane is interpreted as the strong coupling continuation of the confinement/deconfinement transition in YM4. We have demonstrated that this interpretation is not valid, since the black D4 brane and the deconfinement phase of YM4 have different realizations of the Z(N) centre symmetry and therefore cannot be the same phase. In the current work, an alternative gravity dual of the confinement/deconfinement transition was proposed in terms of a Gregory-Laflamme transition of the AdS soliton in the IIB frame, where the strong coupling continuation of the deconfinement phase of YM4 is a localized D3 soliton. This proposal offers a new explanation of several aspects of the thermodynamics of holographic QCD. As an example, a new mechanism of chiral symmetry restoration was found in the Sakai-Sugimoto model. The issues discussed in this paper pertain to gravity duals of non-supersymmetric gauge theories in general. [Gautam Mandal with Takeshi Morita (Crete)].

Strong Coupling BCS Superconductivity and Holography

A holographic description of the microscopic theory of a BCS superconductor was investigated. Exploiting the analogy with chiral symmetry breaking in QCD, the Sakai-Sugimoto model of two D8 branes in a D4 brane background with finite baryon number was utilized. A new tachyonic instability was tentatively identified as the bulk analog of the Cooper pairing instability. Exact solutions of the non-linear Yang-Mills equations in flat space were presented , and shown to be present in the presence of an electric field. The holographic picture also suggests a dependence of T_c on the number density which is different from the usual (weak coupling) BCS dependence. [Nilanjan Sircar with S. Kalyana Rama (IMSc), Swarnendu Sarkar (Delhi U.), B. Sathiapalan (IMSc)]

Bianchi Attractors: A Classification of Extremal Black Brane Geometries

Extremal black branes are of interest because they correspond to the ground states of field theories at finite charge density in gauge/gravity duality. The geometry of such a brane need not be translationally invariant in the spatial directions along which it extends. A less restrictive requirement is that of homogeneity, which still allows points along the spatial directions to be related to each other by symmetries. It was demonstrated that, in $4+1$ dimensional space time, such homogeneous black brane solutions are classified by the Bianchi classification. Large new classes of homogeneous but anisotropic extremal black brane horizons, which could naturally arise in gauge/gravity dual pairs. were found. [Nilanjan Sircar with Norihiro Iizuka (CERN) , Shamit Kachru (Stanford) , Nilay Kundu (TIFR), Prithvi Narayan (TIFR), Sandip P. Trivedi (TIFR)]

Constraints on Hydrodynamics from Equilibrium Partition Functions

The thermal partition function of quantum field theories on arbitrary stationary background spacetime, and with arbitrary stationary background gauge fields was studied in the long wavelength expansion. It was demonstrated that the equations of relativistic hydrodynamics are significantly constrained by the requirement of consistency with any partition function. In examples at low orders in the derivative expansion it was demonstrated that these constraints coincided precisely with the equalities between hydrodynamical transport coefficients previously derived from the local form of the second law of thermodynamics. In particular the results of Son and Surowka on the chiral magnetic and chiral vorticity flows were

recovered starting from a local partition function that manifestly reproduces the field theory anomaly, without making any reference to an entropy current. It was conjectured that the relations between transport coefficients that follow from the second law of thermodynamics agree to all orders in the derivative expansion with the constraints derived in this work. [Shraz Minwalla, Sachin Jain and Tarun Sharma with Nabamita Banerjee (Utrecht), Jyotirmoy Bhattacharya (IPMU), Sayantani Bhattacharyya (HRI)]

2 dimensional hydrodynamics from partition functions

The study of hydrodynamic transport coefficients from partition functions was further strengthened by investigations of the equilibrium partition of parity violating charged fluids in 1+1 dimensions at zero derivative order. In this case as well it was shown that the results thus obtained are consistent with local form of the second law of thermodynamics. [Sachin Jain and Tarun Sharma]

Hairy Black Holes and Solitons in AdS_5

A mix of analytic and numerical methods were used to exhaustively study a class of asymptotically global AdS solitons and hairy black hole solutions in negative cosmological constant Einstein Maxwell gravity coupled to a charged massless scalar field. The results depend sensitively on the charge 'e' of the scalar field. The solitonic branch of solutions studied hit the Chandrashekhar limit at finite mass at small 'e', but extended to arbitrarily large mass at larger 'e'. At low values of 'e' no hairy black holes exist. At intermediate values of 'e' hairy black holes exist above a critical charge. At large 'e' hairy black holes exist at all values of the charge. The lowest mass hairy black holes is a smooth zero entropy soliton at small charge, but a (probably) singular nonzero entropy hairy black hole at larger charge. In a phase diagram of solutions, the hairy black holes merge with the familiar Reissner-Nordstrom-AdS black holes along a curve that is determined by the onset of the superradiant instability in the latter family. [Shiraz Minwalla with Oscar J.C. Dias (Saclay), Pau Figueras (Cambridge), Prahar Mitra (Harvard), Ricardo Monteiro (Copenhagen), Jorge E. Santos (Santa Barbara)]

Chern Simons theory with Vector Fermions

Three dimensional conformal field theories described by U(N) Chern-Simons theory at level k coupled to massless fermions in the fundamental representation were studied. By solving a Schwinger-Dyson equation in lightcone gauge, the exact planar free energy of the theory at finite temperature on R^2 as a function of the 't Hooft coupling lambda=N/k was computed. Employing a dimensional reduction regularization scheme it was found that the free energy vanishes at |lambda|= 1; the conformal theory does not exist for |lambda|> 1. The operator spectrum of the theory was analysed via the anomalous conservation relation for higher spin currents. It was shown in particular that the higher spin currents do not develop anomalous dimensions at leading order in 1/N. An integral equation whose solution determine all correlators of these currents at leading order in 1/N was presented and explicit perturbative results for all three point functions up to two loops were also computed. A lightcone Hamiltonian formulation of this theory where a W-infinity algebra arises was developed. The maximally supersymmetric version of our theory is ABJ model with one gauge group taken to be U(1), demonstrating that a pure higher spin gauge theory arises as a limit of string theory. [Shiraz Minwalla, Shiroman Prakash, Sandip P. Trivedi, Spenta R. Wadia with Simone Giombi (Harvard) and Xi Yin(Harvard)]

A Theory of Superfluid Hydrodynamics

The most general form of the equations of relativistic superfluid hydrodynamics consistent with Lorentz invariance, the Onsager principle and the second law of thermodynamics at first order in the derivative expansion was presented. Once parity is violated, either because the U(1) symmetry is anomalous or as a consequence of a different parity-breaking mechanism, the presented results deviate from the standard textbook analysis of superfluids. The general equations of superfluid hydrodynamics presented in this paper require the specification of twenty parameters (such as the viscosity and conductivity). In the limit of small relative superfluid velocities a seven parameter set of equations was found. In the same limit, the AdS/CFT correspondence was used to compute the parity odd contributions to the superfluid equations of motion for a generic holographic model and the results were verified to be consistent. [Shiraz Minwalla and Jyotirmoy Bhattacharya with Sayantani Bhattacharyya (HRI) and Amos Yarom (Princeton)]

Three dimensional superconformal Indices

Recent progress in superconformal indices in three dimension was reviewed: three dimensional superconformal indices can be exactly computed by using localization method including monopole contribution, and can be applied to provide evidence for mirror duality, AdS_4/CFT_3 correspondence and global symmetry enhancement of strongly coupled gauge theories. It was suggested that the global symmetry enhancement does not occur in a finite rank of gauge group if the 3d gauge theory includes non-diagonal monopole operator. This was confirmed by calculating a superconformal index in a specific 3d quiver gauge theory. [Shuichi Yokoyama]

Higgs mechanism and topological mass

Chern-Simons gauge theories in 2+1 dimensions with multiple gauge fields exhibit novel properties that were analysed in some detail, with a focus on the possibility of a non-propagating Chern-Simons field acquiring a massless propagating mode via a Higgs mechanism. This novel Higgs mechanism is revealed as a variant of topological mass generation and shown to arise only when Chern-Simons and mass matrices are not simultaneously diagonalisable. Some analogue of the NHM could occur in theories of condensed-matter systems similar to those exhibiting the fractional quantum Hall effect, as well as in 2+1 dimensional gravity [Sunil Mukhi]

Dilatonic Extremal Black Branes

The thermodynamics and transport properties of a large class of dilatonic extremal branes were analysed. The behaviour of a fermionic field in these background was also analysed and the behaviour of the fermionic correlators in the dual theory was extracted. Depending on the parameters involved this behaviour an be of Fermi-Liquid or Non-Fermi liquid type. [Sandip Trivedi, Nilay Kundu with Nori Iizuka(CERN) and K Narayan (CMI)]

Shear sum rules, AdS/CFT

The shear sum rule was obtained for the $\mathcal{N} = 4$ Yang-Mills, gauge theory of the M2-branes and M5-branes all at finite chemical potential. It was shown that at finite chemical potential

there are additional terms in the sum rule which involve the chemical potential. These modifications were shown to result from the presence of scalars in the operator product expansion of the stress tensor which have non-trivial vacuum expectation values at finite chemical potential. [Justin R. David, Sachin Jain, Somyadip Thakur]

The one-loop corrections to the masses of strings in the near-flat-space limit was computed using field-theoretic instead of solitonic and integrable structures. The results obtained open the way to a two-loop calculation. Various finite-size corrections were computed using Luesher formulae. Some earlier obtained results were recovered, and also heavy modes of the worldsheet theory (which are absent in the integrable picture) are described by bound states in the mirror theory. [Michael Abbott, with Per Sundin (Cape Town), Ines Aniceto (Lisbon) and Diego Bombardelli (Porto)]