TIFR Annual Report 2007-08
THEORETICAL PHYSICS

String Theory and Mathematical Physics

Highlights

Exact Counting of supersymmetric dyonic black holes and comparison with the quantum corrected macroscopic entropy was carried out.

For supersymmetric dyons, a general formula for the curve of marginal stability was obtained. A key relationship between membranes in M-theory and D-branes in string theory was demonstrated via a novel Higgs mechanism.

The entropy of some large extremal non-supersymmetric black holes was calculated microscopically by showing that their charges can be made to lie in the Cardy limit after a duality transformation and small shifts.

Giant gravitons were quantized in three-dimensional anti de Sitter spaces.

A connection was established between long wavelength solutions of the classical theory of gravity in AdS_{d+1} and the Navier Stokes equations in d dimensions. A map (probably one to one) was constructed from the space of long wavelength solutions to Einstein's equations in AdS_{d+1} to the solution space of fluid dynamics in d dimensions. These results may prove important in understanding the dynamics of aspects of classical gravity as well as the dynamics of equilibriation in quantum field theories.

A proposal to introduce quark masses in the holographic model of a QCD-like theory by Sakai and Sugimoto was studied analytically as well as numerically.

A numerical study of the 0+1 dimensional reduction of a large N gauge theory was done using Monte-Carlo methods, with special attention to the GWW large N phase transition which has been argued to be dual to the black hole/string transition.

Singular cosmological solutions which have a gauge theory dual were studied. It was argued, using the gauge theory description, that in the light-like case the singularity is resolved and admits a continuation.

A description for N=2 supersymmetric Yang-Mills theory with fundamental matter in terms of twistor string theory was found.

TEXT

Counting of Dyonic Black Holes

Methods for counting dyons in N=4 string theories were developed. The partition functions of these dyons were found to be given in terms of Siegel modular forms. It was shown in several examples how to construct the modular forms and how to the extract degeneracies by contour integration. Several important questions pertaining to the physical interpretation of the degeneracy formula were addressed. In particular, it was show that the spectrum jumps across walls of marginal stability. Different choices of contours are correlated with the different regions of moduli space separated by the walls. [Atish Dabholkar]

Tachyon Condensation and Chiral Symmetry Breaking

The Sakai-Sugimoto model of chiral symmetry breaking was modified to take into account the open string tachyon which stretches between the flavour D8-branes and anti-D8-branes. The main reason to do this is the bi-fundamental coupling of the tachyon to fermions of opposite chirality which makes it a suitable candidate for the quark mass and chiral condensate parameters. Also, under suitable conditions, the tachyon may condense and so take the system far away from the perturbatively stable minimum of the Sakai-Sugimoto model. It was shown that the modified Sakai-Sugimoto model with the tachyon present has a classical solution in which chiral symmetry breaking coincides with tachyon condensation. The parameters corresponding to the quark mass and the chiral condensate were identified. The mesonic spectra were discussed and a Gell-Mann-Oakes-Renner like relation between pion mass, quark mass and the chiral condensate derived. The essential role of an ultraviolet cut-off in these analyses was discussed. Computing the chiral condensate required identifying flavour brane boundary counter terms for a holographic renormalization of cut-off dependent infinite terms. Our work naturally explains the parameter for asymptotic brane-antibrane separation as arising from the quark mass parameter. [A. Dhar and P. Nag]

Monte Carlo Studies of the GWW Phase Transition in Large-N Gauge Theories

The third-order Gross-Witten transition of the finite-temperature $N = 4$ SYM theory on S^3 was studied by Monte Carlo simulation. It was found that exhibiting this transition in the truncated but highly non-trivial gauge theory implies that in the vicinity of the critical temperature T_c, the system goes critical. The spontaneous breaking of the SO(6) R-symmetry was studied numerically. [Takehiro Azuma with Pallab Basu and Spenta R. Wadia)

The instability of intersecting fuzzy spheres

The classical and quantum stability of general configurations representing many fuzzy spheres in dimensionally reduced Yang-Mills-Chern-Simons models with and without supersymmetry was studied. By performing one-loop perturbative calculations around such configurations, it was shown that intersecting fuzzy spheres are classically unstable in the class of models conidered in this analysis. The large-N limit of the one-loop effective action as a function of the distance of fuzzy spheres was also studied. It was found that concentric fuzzy spheres with different radii, which are identified with the 't Hooft-Polyakov monopoles, are perturbatively stable in the bosonic model and in the D=10 supersymmetric model. [Takehiro Azuma with Subrata Bal (DIAS) and Jun Nishimura (KEK)]

Twistor Strings with Flavour

The tree-level description of a class of N = 2 UV-finite super Yang-Mills theories with fundamental flavour within a topological B-model twistor string framework was explored. The twistor dual of the Sp(N) gauge theory with one antisymmetric and four fundamental hypermultiplets was identified, as well as that of the SU(N) theory with 2N hypermultiplets. This was achieved by suitably orientifolding/orbifolding the original N = 4 set-up of Witten and adding a certain number of new topological 'flavour'-branes at the orientifold/orbifold fixed planes to provide the fundamental matter. The appearance of these objects in the B-model on $CP^(3|4)$ was further commented upon. An interesting aspect of the construction was that, unlike the IIB description of these theories in terms of D3 and D7-branes, on the twistor side part of the global flavour symmetry was realised geometrically. Evidence for this correspondence was provided by calculating and matching amplitudes on both sides. [C. Papageorgakis with J. Bedford (Queen Mary, University of London and CERN), and K. Zoubos (Queen Mary, University of London)]

Semiclassical Quantization of AdS(3) x S(3) using giant gravitons

The program of quantizing supersymmetric giant graviton configurations in various spacetimes was continued. All giant graviton configurations, i.e. probe brane configurations that preserve four supersymmetries were constructed, in (a) the extremal D1-D5 geometry, (b) the extremal D1-D5-P geometry, (c) the smooth D1-D5 solutions proposed by Lunin and Mathur and (d) global AdS(3) x S(3) x T(4)/K3. These configurations consist of D1 branes, D5 branes and bound states of D5 and D1 branes with the property that a particular Killing vector is tangent to the brane worldvolume at each point. It was shown that the supersymmetric sector of the D5 brane worldvolume theory may be analyzed in an effective 1+1 dimensional framework that places it on the same footing as D1 branes. In global AdS and the corresponding Lunin-Mathur solution, the solutions we described are 'bound' to the center of AdS for generic parameters and cannot escape to infinity. These probes were found to exist only on the submanifold of moduli space where the background NS B-field and theta

angle vanish. These probes are quantized in the near horizon region of the extremal D1-D5 geometry and the theory of long strings discussed by Seiberg and Witten is obtained. [G. Mandal, M. Smedback with S. Raju (Harvard U.)]

Hawking radiation and quantum anomaly

The dimensional reduction of black hole spacetime to r-t plane was considered and it was shown that Hawking radiation is a contribution of quantum anomaly for scale transformation or diffeomorphism in near horizon region (on r-t plane these two symmetries are essentially equivalent.). [T. Morita with S. Iso (KEK, Japan) and H. Umetso (Okayama Institute for Quantum Physics, Japan)

W-geometry

The study of W-geometry was further extended. The relationship of projective structures on a compact Riemann surface of arbitrary genus with holomorphic immersions in a certain grassmannian was elucidated. The immersions were found to be parametrized by projective structures, i.e. by one point functions of an energy-momentum tensor, and data reflecting the symmetries of the immersion. [A.K. Raina With I. Biswas (School of Mathematics, TIFR)]

Duality And The Cardy Limit

It was shown for Type IIA on $K3XT^2$, that a generic non-supersymmetric charge configuration can be brought to the Cardy limit after a duality transformation. More precisely, this can be done after possible small shifts in the charges. This result provides a microscopic understanding of the entropy of non-supersymmetric extremal black holes, in some region of moduli space. [S. Nampuri, P.K. Tripathy, S. P. Trivedi]

Time Dependent Cosmologies and Their Gauge Theory Duals

Some Cosmological solutions, which can be thought of as deformations of the $AdS_5 \times S^5$ backrgound in IIB string theory, were studied in further detail; along with their Gauge Theory Duals. The Stress tensor was calculated, and some aspects of the Gauge theory were elucidated. [K. Narayan, S. P. Trivedi with A. Awad and S. Das (Kentucky U.)]

Plasma Rings in Large N Gauge Theories

Solutions to the relativistic Navier-Stokes equations that describe the long wavelength collective dynamics of the deconfined plasma phase of N=4 Yang Mills theory compactified down to d=3 on a Scherk-Schwarz circle and higher dimensional generalisations were

constructed. The solutions are stationary, axially symmetric spinning balls and rings of plasma. These solutions, which are dual to (yet to be constructed) rotating black holes and black rings in Scherk-Schwarz compactified AdS(5) and AdS(6) have properties that are qualitatively similar to those of black holes and black rings in flat five dimensional supergravity. [Shiraz Minwalla with Subhaneil Lahiri (Harvard U.)]

Large Rotating Black Holes in Fluid Dynamics

The AdS/CFT correspondence was used to argue that large rotating black holes in global AdS(D) spaces are dual to stationary solutions of the relativistic Navier-Stokes equations on $S^{(D-2)}$. The equation of state of this fluid was determined from the thermodynamics of non-rotating black holes, and then used to construct the nonlinear spinning solutions of fluid mechanics that are dual to rotating black holes. In all known examples, the thermodynamics and the local stress tensor of the solutions were found to be in precise agreement with the thermodynamics and boundary stress tensor of the spinning black holes. The fluid dynamical description apply to large non-extremal black holes as well as to a class of large non-supersymmetric extremal black holes, but is never valid for supersymmetric black holes. These results yield predictions for the thermodynamics of all large black holes in all theories of gravity on AdS spaces, for example, string theory on $AdS(5)xS^5$ and M theory on $AdS(4)xS^7$ and $AdS(7)xS^4$. [Sayantani Bhattacharyya, R. Loganayagam and Shiraz Minwalla with Subhaneil Lahiri (Harvard U.)]

Nonlinear Fluid Dynamics from Gravity

Black branes in AdS5 appear in a four parameter family labeled by their velocity and temperature. After promoting these parameters to Goldstone modes or collective coordinate fields – arbitrary functions of the coordinates on the boundary of AdS5 – Einstein's equations together with regularity requirements and boundary conditions was used to determine their dynamics. The resultant equations turned out to be those of boundary fluid dynamics, with specific values for fluid parameters. The analysis carried out, was perturbative in the boundary derivative expansion but is valid for arbitrary amplitudes. This work may be regarded as a derivation of the nonlinear equations of boundary fluid dynamics from gravity. As a concrete application an explicit expression for the expansion of this fluid stress tensor including terms up to second order in the derivative expansion, was found.[Sayantani Bhattacharyya and Shiraz Minwalla with Veronika E. Hubeny, Mukund Rangamani (Dhurham U.)]

Fluid Dynamical Entropy from Gravity

Spacetime geometries dual to arbitrary fluid flows in strongly coupled N=4 super Yang Mills theory have recently been constructed perturbatively in the long wavelength limit. It was

demonstrated that these geometries all have regular event horizons, and the location of the horizon was determined order by order in a boundary derivative expansion. Intriguingly, the derivative expansion allows one to determine the location of the event horizon in the bulk as a local function of the fluid dynamical variables. A natural map from the boundary to the horizon using ingoing null geodesics can be defined. The area-form on spatial sections of the horizon can then be pulled back to the boundary to define a local entropy current for the dual field theory in the hydrodynamic limit. The area theorem of general relativity guarantees the positivity of the divergence of the entropy current thus constructed. [Sayantani Bhattacharyya, R. Loganayagam, Gautam Mandal, Shiraz Minwalla, Takeshi Morita with Veronika E. Hubeny, Mukund Rangamani (Durham U.) and Harvey S. Reall (Cambridge U.)]

Superconformal Indices in 3, 5, and 6 dimensions

A trace formula for a Witten type Index for superconformal field theories in d=3,5 and 6 dimensions was presented, generalizing a similar recent construction in d=4. A detailed study of the decomposition of long representations into sums of short representations at the unitarity bound was performed to demonstrate that our trace formula yields the most general index (i.e. quantity that is guaranteed to be protected by superconformal symmetry alone) for the corresponding superalgebras. Using the dual gravitational description, this index was computed for the theory on the world volume of N M2 and M5 branes in the large N limit. The index was also computed for recently constructed Chern Simons theories in three dimensions in the large N limit, and it was found that, in certain cases, it undergoes a large N phase transition as a function of chemical potentials. [Jyotirmoy Bhattacharya, Sayantani Bhattacharyya, Shiraz Minwalla with Suvrat Raju (Harvard U.)]

Comments on quantum and classical supersymmetric states in Yang Mills

The problem of counting 1/16 BPS states of N = 4 Yang Mills theory was formulated as the enumeration of the local cohomology of an operator acting on holomorphic fields on C^2. Aspects of the enumeration of this cohomology at finite N were studied, especially for operators constructed only out of products of covariant derivatives of scalar fields, and compared with the result for the states obtained from the quantization of giant gravitons and dual giants. The holomorphic fields that entered the conditions for supersymmetry were physically interpreted semi-classically by deriving a set of Bogomolnyi equations for 1/16-BPS bosonic field configurations in N = 4 Yang Mills theory on R^4 with reality properties and boundary conditions appropriate to radial quantization. An arbitrary solution to these equations in the free theory was shown to be parameterized by holomorphic data on C^2 and was found to lift to a nearby solution of the interacting Bogomolnyi equations only when the constraints equivalent to Q cohomology are obeyed. [Shiraz Minwalla with Lars Grant (Harvard U.), Pietro A. Grassi (INFN, Italy) and Seok Kim (Imperial college, London)]

Entropy Current in Conformal Hydrodynamics

In recently reported work the energy-momentum tensor for the N=4 SYM fluid was computed, up to second derivative terms, using holographic methods. This investigation proposed an entropy current (accurate up to second derivative terms) consistent with this energy-momentum tensor and made explicit its relation with the existing theories of relativistic hydrodynamics. As a first step, a Weyl-covariant formalism was developed which simplifies the study of conformal hydrodynamics. This naturally lead to a proposal for the entropy current of an arbitrary conformal fluid in any spacetime (with d¿3). This proposal translates into a definite expression for the entropy flux in the case of N=4 SYM fluid. The formalism developed in this work was compared with the conventional Israel-Stewart formalism. [R. Loganayagam]

Dyons in The $N = 4$ Theory

The mass formula for dyons in N=4 superstring compactifications was used to derive general curves of marginal stability. It was shown that possible decays are of two types: one type of decay, into half-BPS states, takes place across domain walls in moduli space, while all others take place on hypersurfaces of codimension greater than 1. A kinematical analogy was proposed that illuminates the difference between the two types of decay and provides a new understanding of marginal stability curves using familiar results in particle physics. A relationship was found between the mathematics of Farey sequences and Ford circles in number theory and curves of marginal stability for dyons. [Anindya Mukherjee, Sunil Mukhi and Rahul Nigam]

M2 Branes and D2 Branes

The supersymmetric Bagger-Lambert field theory proposed to describe multiple membranes in M-theory was studied. A novel Higgs mechanism was discovered due to which the non-dynamical (Chern-Simons) gauge fields in this action turn into conventional Yang-Mills gauge fields on D-branes, providing a crucial test of the proposed action. [Sunil Mukhi and Costis Papageorgakis]

The GWW Transition

In the study of the small ten-dimensional Schwarzschild black hole, the black hole to string transition is an important problem. In this work, a possible identification was made between the Gross-Witten-Wadia (GWW) type third-order large-N phase transition in the boundary gauge theory and the string-black hole transition in the bulk. The existence of the GWW transition was demonstrated by Monte Carlo simulation in the zero mode bosonic action of the finite-temperature $\mathcal{N} = 4$ SYM theory on S3. Exhibiting this transition in the truncated

but highly non-trivial gauge theory implied that in the vicinity of the critical temperature Tc, the system goes critical, and the fluctuations give rise to universal formulas. [L. Alvarez-Gaumé, P. Basu, M. Marino, S.R. Wadia, Eur. Phys. J. C 48 (2006) 647, hep-th/0605041]. We also discussed the issue of SO(6) R-symmetry breaking. [(Takehiro Azuma, Pallab Basu and Spenta R. Wadia]