TIFR Annual Report 2005-06
THEORETICAL PHYSICS

String Theory and Mathematical Physics

Highlights

Work was continued on exact counting of black hole states and comparison with the quantum corrected macroscopic entropy.

A method was developed to exactly bosonize a system of finite number of non-relativistic fermions in one dimension, with applications to many problems in field theory, string theory and condensed matter physics including the classic Tomonaga problem of bosonization of non-relativistic fermions on a circle.

Gauge theoretic description of black holes was studied via the AdS/CFT correspondence, focussing on Yang Mills description of localized black holes, phase transitions between black holes and black strings, and the precise counting of supersymmetric states of N=4 super Yang Mills theory on a three-sphere in order to understand supersymmetric black holes.

Noncritical string theories were re-examined in a modern context in the light of D-branes and holography, and new results were obtained for their matrix descriptions, correlators and dualities. A new class of orientifolded, supersymmetry-preserving geometries in critical string theory was found.

Work was done on closed string tachyons and stringy small black rings.

A vector bundle generalization of Fay's trisecant identity was proposed.

The attractor phenomenon was found for non-supersymmetric extremal black holes under suitable conditions. Explicit examples in string theory were constructed including rotating geometries and a C-theorem applicable to the non-supersymmetric case was formulated.

Time dependent cosmologies were studied in string theory by constructing time dependent supergravity backgrounds which have Super-Yang Mills duals in the presence of time dependent sources.

The black hole-string transition of the ten dimensional small Schwarzschild black hole in anti de Sitter space times a five-sphere was described using the dual SU(N) gauge theory in the large N limit.

TEXT

Black hole entropy

The entropy of a black hole is of fundamental significance in a quantum theory of gravity because it involves all three fundamental constants of nature and offers very precise quantitative information about the quantum structure of gravity. Comparison of subleading corrections offers a nontrivial and precise test of string theory as a consistent quantum theory of gravity.

In a series of papers quantum corrections to the entropy of a class of black holes in string theory were investigated. It was shown that the entropy of these black holes can be explained in terms of the microscopic statistical counting to all orders in an asymptotic expansion. The macroscopic entropy itself arises as follows. The classical spacetime geometry of these states contains a null singularity and there is no black hole. Inclusion of quantum corrections covers the classical singularity with an event horizon and turns it into a black hole with a well-defined entropy. This result is of interest since it provides an example where quantum corrections to a null singularity in a classical geometry are crucial and result in correct macroscopic entropy. It is essential and possible to systematically take into account the quantum corrections to the geometry of the black hole and the Bekenstein-Hawking formula itself in agreement with the microscopic counting. [Atish Dabholkar with F. Denef, G. Moore (Rutgers) and B. Pioline (Paris)].

The above methods are applied to spinning 4D/5D black holes and 5D black rings [Atish Dabholkar, Ashik Iqbal and Norihiro Iizuka, and Masaki Shigemori, Caltech] and black holes in CHL orbifolds [Atish Dabholkar and Suresh Nampuri].

Exact Bosonization of a finite number of fermions

The old problem of bosonization of non-relativistic fermions in one space dimension was revisited. The motivation was the recent work on bubbling half-BPS geometries by Lin, Lunin and Maldacena (hep-th/0409174). After reviewing earlier work on exact bosonization in terms of a noncommutative theory, an action was derived for the collective field which lives on the droplet boundaries in the classical limit. The novel point of the action is that it is manifestly invariant under time-dependent reparametrizations of the boundary. It was shown that, in an appropriate gauge, the classical collective field equations imply that each point on the boundary satisfies Hamilton's equations for a classical particle in the appropriate potential. For the harmonic oscillator potential, a straightforward quantization of this action could be carried out exactly for any boundary profile. It was shown that for a finite number of fermions, the quantum collective field theory does not reproduce the results of the exact noncommutative bosonization, while the latter are in complete agreement with the results computed directly in the Fermi theory. [Avinash Dhar]

An exact operator bosonization of a finite number of fermions in one space dimension was derived. The fermions can be interacting or noninteracting and can have an arbitrary hamiltonian, as long as there is a countable basis of states in the Hilbert space. In the bosonized theory the finiteness of the number of fermions appears as an ultraviolet cut-off. Applications of this bosonization to the half-BPS sector of N=4 super Yang-Mills theory, the c=1 matrix model and the Tomonaga problem were briefly discussed [Avinash Dhar and G. Mandal with N. Suryanarayana, Perimeter Institute]

As another application of the above exact bosonization, the classic Tomonaga problem was discussed. In the case of N noninteracting fermions on a circle, the bosonized hamiltonian naturally splits into an $O(N)$ piece and an $O(1)$ piece. It was shown that in the large-N and low-energy limit, the $O(N)$ piece in the hamiltonian describes a massless relativistic boson, while the $O(1)$ piece gives rise to cubic self-interactions of the boson. At finite N and high energies, the low-energy effective description breaks down and the exact bosonized hamiltonian must be used. The connection between the Tomonaga problem and pure Yang-Mills theory on a cylinder was discussed briefly. In the dual context of baby universes and multiple black holes in string theory, it was pointed out that the $O(N)$ piece in our bosonized hamiltonian provides a simple understanding of the origin of two different kinds of nonperturbative $O(e^{-N})$ corrections to the black hole partition function [Avinash Dhar and G. Mandal].

Gauge-gravity duality with sixteen supersymmetries

An exact quantization of gravitational fluctuations in the half-BPS sector around $AdS_5 \times S^5$ background was discussed, using the dual super Yang-Mills theory and the exact bosonization discussed above. An exact computation of the three-point correlation function of gravitons for finite N shows that they become strongly coupled at sufficiently high energies, with an interaction that grows exponentially in N. However, even at such high energies a description of the bulk physics in terms of weakly interacting particles could be constructed. The single particle states providing such a description are created by our bosonic oscillators or equivalently these are the multi-graviton states corresponding to the so-called Schur polynomials. Both represent single giant graviton states in the bulk. Multi-particle states corresponding to multi-giant gravitons are, however, different, since interactions among our bosons vanish identically, while the Schur polynomials are weakly interacting at high enough energies [Avinash Dhar, G. Mandal and M. Smedback].

A new infinite class of supersymmetric backgrounds of type IIB string theory was found. These are associated to orientifold planes and thereby to excited states of the SO(N)/Sp(N) N=4 supersymmetric Yang-Mills theory. The geometries are in correspondence with free fermions moving in a harmonic oscillator potential on the half-line. Branes wrapped on torsion cycles of these geometries were identified in the Fermi fluid description. Besides being of intrinsic interest, it was proposed that these solutions may also occur as local geometries in flux compactifications where orientifold planes are present to ensure global charge cancellation. [Sunil Mukhi and Mikael Smedback]

An Index for Superconformal Field Theories.

The elliptic genus is an exceptionally useful object in the study of 2 dimensional supersymmetric field theories. On the one hand it is a sort of partition function over the set of all supersymmetric states. On the other hand there is a sense in which the elliptic genus is 'topological'; it cannot change under continuous variations of the parameters that define the theory. Because of this property it is often also computable.

In the present work, an analogue of the elliptic genus for 3+1 dimensional superconformal field theory is discovered. It is demonstrated that this index captures all information about supersymmetric states in the conformal field theory that is guaranteed to be protected by superconformal invariance alone, and so is, in a sense, the most general index for 4 dimensional superconformal field theories. The index is computed in the case of the $\mathcal{N} = 4$ Yang Mills theory and is shown to reproduce the index over supergravity states in $AdS_5 \times S^5$. This is a check of the AdS/CFT conjecture.

The index here receives contributions from states that preserve one or more supersymmetry (together with its Hermitian conjugate). Supergravity on $AdS_5 \times S^5$ has black hole solutions that preserve exactly one supercharge. It turns out that the effective density of states captured by this index for the $\mathcal{N} = 4$ theory is qualitatively different from the density of states from the Hawking-Bekenstein formula for these supersymmetric black holes. This implies that, unlike in other situations (e.g. AdS_3 and the D1-D5 system) the field theory index does a poor job of capturing states in the regime relevant to black hole physics. It thus appears that, in order to understand black hole physics, it is necessary to understand the full partition function over the supersymmetric states of Yang Mills theory (the index, which is a partition function weighted by some minus signs, is not sufficient). [Shiraz Minwalla, with J. Kinney (Princeton Univ.), J. Maldacena (IAS, Princeton) and S. Raju (Harvard)].

Plasma Balls in Large N gauge theories

It has long been believed that confining large N gauge theories are dual to weakly coupled string theories. The string duals possess an exponential tower of long lived excitations that map to glueballs. However, at least some perturbative string theories also possess long lived excitation - black holes - at energies of order $1/g^2$. In the present work it is argued that such configurations have analogues in a class of confining gauge theories. In particular one argues for the existence of plasma balls – meta-stable, nearly homogeneous lumps of gluon plasma at just above the deconfinement energy density – in a class of large N confining gauge theories that undergo first order deconfinement transitions. Plasma-balls decay over a time scale of order N^2 by thermally radiating hadrons at the deconfinement temperature. In gauge theories that have a dual description as a theory of gravity in a warped geometry, it is proposed that plasma-balls map to a family of finite energy black holes localized on the 'IR brane'. In the same work a conjecture is also presented for the qualitative nature of black holes in such backgrounds, and have numerically constructed such black holes, in a class of warped backgrounds. These black holes turn out to have novel properties (in particular their temperature tends to a constant in the large mass limit) that match precisely with the properties of plasma-balls. These black holes shrink as they decay by Hawking radiation; towards the end of this process they resemble ten dimensional Schwarzschild black holes, which are proposed in this work as dual to small plasma-balls.

The above work may find 'practical' applications in the study of the physics of localized black holes from a dual viewpoint. Fop example: in some examples the production of a plasma-ball in high energy hadron-hadron collisions, and its subsequent decay by hadronization, is dual to the production of a black hole in high energy graviton-graviton scattering, and its subsequent decay by Hawking radiation. As the first of these processes is manifestly unitary, the second must be as well. It is possible that this connection could be pursued further to draw more detailed lessons for the nature of the Hawking radiation (i.e. hadronization).

As a second application, it is argued that one of the most striking features of black hole physics - the universally absorptive nature of black holes - is crucially tied to a feature of the hadronic parton distribution function in those gauge theories that is absent in asymptotically free theories. It follows that while black hole like configurations continue to exist in at least some warped geometries with curvatures of order string scale (those that are dual to gauge theories at small λ) they have qualitatively different dynamics from their large λ cousins. In particular they are no longer black.[Shiraz Minwalla, with O. Aharony (Weizmann Inst.) and T. Wiseman, (Harvard)].

Phase Transitions in Yang Mills Theories on Tori

An exhaustive study is made of the phase structure of large N Yang Mills theories on Tori. This natural generalization of the study of Plasma balls reported above is of interest for several reasons. First, a T^d has d independent noncontractable loops. In Euclidean space the Wilson line around each of these spatial loops is as important to the dynamics as the Polyakov line. Consequently gauge theories on Tori have several order parameters, opening out the possibility of a much richer phase structure than their counterparts on spheres. Secondly phase transitions involving clumping of eigenvalues of spatial Wilson loops, sometimes have dual interpretations as Gregory- Laflamme type phase transitions (between black holes and black strings), a gravitational phenomenon that has evoked considerable interest over the last few years. [Shiraz Minwalla, with K. Papadodimas, J. Marsano, T. Wiseman (Harvard). O. Aharony (Weizman Inst.) and Van Raamsdonk (British Columbia).]

The study of the phase structure of large N Yang Mils on Tori theories employs several different techniques in different regimes of parameter space. When all matter fields are very massive compared to the scale set by the gauge coupling (more precisely, when $m^{4-d} \gg \lambda$, where m is the mass scale of the matter fields, d is the dimension of space-time and $\lambda \equiv g_{YM}^2 N$ is the 't Hooft coupling), the gauge theories involved are weakly coupled since the massless gauge field has no dynamical degrees of freedom and may reliably be analyzed in perturbation theory. Already in this analytically tractable regime one finds sharp phase transitions and a rich phase structure. Outside this perturbative regime, the phase diagram can be constrained by the requirement that they reproduce well known results in special limits. The strong coupling behavior of maximally supersymmetric Yang-Mills theories may be analyzed using generalizations of the AdS/CFT correspondence. Finally, it is sometimes practical to employ Monte Carlo simulations to supplement the information from our other techniques. Employing all these methods, it becomes possible to present a reasonably complete picture of the phase diagram of these systems. As mentioned above, some of the phase transitions studied also have gravitational duals. For example, the phase transition in maximally supersymmetric Yang-Mills theory on T^2 is holographically dual to a Gregory-Laflamme black hole/black string phase transition in type II string theory. [Shiraz Minwalla with J. Marsano and T. Wiseman (Harvard) and O. Aharony (Weizmann Inst.)].

Black hole – string transition

The black hole-string transition of the small Schwarzschild black hole of $AdS_5 \times S^5$ is discussed using the AdS/CFT correspondence at finite temperature. The finite temperature gauge theory effective action, at weak *and* strong coupling, can be expressed entirely in terms of constant Polyakov lines which are $SU(N)$ matrices. It is shown that the phase of the gauge theory in which the eigenvalue spectrum has a gap corresponds to supergravity saddle points in the bulk theory. The third order $N = \infty$ phase transition is identified with the black hole-string transition. This singularity can be resolved using a double scaling limit in the transition region where the large N expansion is organized in terms of powers of $N^{-2/3}$. The $N = \infty$ transition now becomes a smooth crossover in terms of a renormalized string coupling constant, reflecting the physics of large but finite N. Implications of the results are discussed for the resolution of the singularity of the Lorentzian section of the small Schwarzschild black hole. [Spenta Wadia, Pallab Basu with M. Marino and L. Alvarez-Gaume (CERN)]

Non-critical Strings

The relationship between different matrix descriptions of finite-temperature noncritical strings was found. The Normal Matrix Model that describes c=1 string theory was shown to be equivalent at self-dual radius to the Kontsevich-Penner (KP) model of this string theory. Macroscopic loop expectation values in the former model were related to condensates of the closed string tachyon, and a new form of open-closed duality was proposed involving the description of extended branes in terms of inverse determinants. [Anindya Mukherjee and Sunil Mukhi]

An investigation was initiated into two outstanding open problems in noncritical string theory: demonstrating T-duality, and understanding black holes.The starting point was a systematic study of correlation functions of momentum modes, as a function of the radius and to all orders in string perturbation theory. The Normal Matrix Model was found to be a powerful calculational tool and used to obtain new combinatoric formulae for the 2n-point functions of unit momentum modes. These can be used, assuming T-duality, to compute the vortex condensate dual to black holes. These results are also sufficiently detailed and extensive to provide a good test of T-duality, once computations in the nonsinglet sector are successful in computing the other side. Further work in this direction has addressed analogous questions in nonperturbatively well-defined type 0 noncritical strings. [Anindya Mukherjee and Sunil Mukhi]

Nonsupersymmetric conifolds and topology change

Nonsupersymmetric conifold singularities were studied via closed string tachyon condensation, showing that they are nonsupersymmetric orbifolds of the supersymmetric conifold. These exhibit flip transitions mediating mild dynamical topology change: the 3-cycle deformation is obstructed here by the quotient structure suggesting that there is no strong topology change in these geometries [K. Narayan].

Time-dependent cosmologies

Generalizations of AdS/CFT to time dependent cosmologies and their duals were considered. An infinite family of deformations of AdS/CFT was found, some of which exhibit null cosmological singularities. The holographic gauge theory duals were investigated. [K. Narayan and Sandip Trivedi with Sumit Das and Jeremy Michelson (Univ. of Kentucky, Lexington)]

Non-supersymmetric attractors

It was shown that the attractor mechanism can work without needing to invoke supersymmetry. The attractor mechanism is an intriguing process originally found in extremal black hole solutions of N = 2 supergravity. In these solutions the values of moduli fields, which can take on arbitrary values at asymptotic infinity, are drawn to fixed values at the horizon determined solely by the charges carried by the black hole. The attractor mechanism ensures that the entropy of the black hole, is unaffected by the asymptotic values of the moduli. Up till this work, the attractor mechanism had only convincingly been demonstrated in the context of supergravity. [Kevin Goldstein, Norihiro Iizuka, Rudra P. Jena, Sandip P. Trivedi]

In related work, a monotonic c-function was found for black holes in four (and higher) dimensional theories of gravity coupled to gauge fields and massless scalars. At the horizon the c-function takes on the value of the entropy of the black hole. [Kevin Goldstein, Rudra P. Jena, Gautam Mandal, Sandip P. Trivedi]

Conformal field theory

Work on revision of book on Virasoro algebra continued. A vector bundle generalization of Fay's trisecant identity was proposed. [Ashok Raina]