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THEORETICAL PHYSICS

String Theory and Mathematical Physics

Highlights

Chiral symmetry breaking in a non-local Nambu-Jona-Lasinio like 4-fermi model, derived from the intersecting brane model of Sakai and Sugimoto in the weak coupling limit, was found to occur only above a critical value of the coupling. Numerical investigations showed, contrary to what had been suggested in the literature, that this feature persists even when the radius of the circle on which the D4-branes wrap is taken to infinity.

Microstate dependence of scattering from a two charge black hole was studied in a string theory model and the role of coarse graining in classical geometry was clarified.

Work was continued on the relationship between long wavelength asymptotically AdS gravity and fluid dynamics, to include gravity in arbitrary dimensions, to fluids forced by varying background metrics and dilaton fields, and to the non relativistic limit of fluid dynamics. A new investigation of field theory equilibration was started using the AdS dual gravity description. Equilibration turns out to map to the process of black hole formation, which was studied analytically, in certain regimes, obtaining quite surprising results.

The moduli space and dynamical properties of 3-algebra field theories proposed to describe M-theory membranes were obtained. The relation between membrane and D-brane field theories was exhibited and higher-derivative corrections to 3-algebra theories were computed using dualities and a novel Higgs mechanism.

Constraints on superstring moduli that enable "rare" dyon decays were obtained.

Cosmological singularities and fluid dynamics were studied using the AdS/CFT correspondence.

New symmetries of the standard Navier-Stokes equation were discovered. These form a 14 parameter Lie algebra which includes conformal transformations. The bulk viscosity in strongly coupled non-conformal hydrodynamics in 1+1 dim. was calculated using the AdS/ CFT correspondence.

Some new properties of emission from the D1D5 CFT were studied.

Work was continued on the computation of Hawking radiation as quantum anomaly. Higher spin bulk operators were constructed from boundary operators using gauge-gravity duality.

The fuzzy two-sphere structure of M2-M5 systems in ABJM membrane theories was elucidated. This appeared as the two-sphere base of a three-sphere, realised as a Hopf

fibration, that is wrapped by the M5-brane in M-theory.

TEXT

Intersecting branes and Nambu−Jona-Lasinio model

Chiral symmetry breaking was investigated in the intersecting brane model of Sakai and Sugimoto at weak coupling for a generic value of separation L between the flavour D8 and anti-D8-branes. It was found that for any finite value of the radius R of the circle around which the colour D4-branes wrap, a non-local Nambu-Jona-Lasinio (NJL) type short-range interaction couples the flavour branes and anti-branes. Chiral symmetry is broken in this model only above a certain critical value of the 4-dimensional 't Hooft coupling. This was theoretically argued and confirmed through numerical calculations of solutions to the gap equation. Moreover, numerically it was found that in simple ways of implementing the limit of large R keeping L fixed, do not lead to a consistent picture of chiral symmetry breaking in the non-compact version of the non-local NJL model. [Avinash Dhar and Parha Nag]

Microstate dependence of scattering from a black hole

An important result in the past decade has been the construction of microstates of black holes in terms of which the Bekenstein-Hawking entropy could be computed and the rate of Hawking radiation reproduced. In these calculations, a notion of coarse-graining was implicit. The scattering of a closed string mode off a two-charge D1-D5 system (whose strong coupling limit corresponds to a small black hole) was calculated in detail to understand the precise nature of the coarse graining involved and to see under what conditions the absorption cross-section displays sensitivity to the specific microstate. The results depend on several scales: the radius R of the circle on which the D1 branes are wrapped, the time scale T of observations and the width ΔE of the incident beam. It was found that an absorption probability proportional to time exists when $\Delta E \gg 1/T$. When $R\Delta E \gg 1$, the absorption crosssection was found to be *independent of the microstate* and identical to the leading semiclassical answer computed from the leading order classical geometry. For smaller ΔE, the answer depends on the particular microstate, which is examined for *typical* as well as for *atypical* microstates. The departure from the classical result was computed for these states both analytically and numerically. It was shown that in a certain parametric region, the departures are universal and have a geometrical analogue. [Gautam Mandal, with Sumit Das (University of Kentucky, Lexington, USA)].

Forced Fluid Dynamics from Gravity

The computations of arXiv:0712.2456 were generalised to generate long wavelength, asymptotically locally AdS_5 solutions to the Einstein-dilaton system with a slowly varying

boundary dilaton field and a weakly curved boundary metric. Upon demanding regularity, the solutions are dual, under the AdS/CFT correspondence, to arbitrary fluid flows in the boundary theory formulated on a weakly curved manifold with a prescribed slowly varying coupling constant. These solutions turn out to be parametrised by four-velocity and temperature fields that are constrained to obey the boundary covariant Navier Stokes equations with a dilaton dependent forcing term. The stress tensor and Lagrangian was explicitly evaluate as a function of the velocity, temperature, coupling constant and curvature fields, to second order in the derivative expansion and demonstrate the Weyl covariance of these expressions. The event horizon of the dual solutions to second order in the derivative expansion was also construct, and the area form on this event horizon was used to construct an entropy current for the dual fluid. As a check of the constructions the exactly known solutions for rotating black holes in global AdS_5 in a boundary derivative expansion were expanded and perfect agreement was found with all the results upto second order. Other simple solutions were also found of the forced fluid mechanics equations and their bulk interpretation were discussed. The results obtained may aid in determining a bulk dual to forced flows exhibiting steady state turbulence. [Sayantani Bhattacharyya, R. Loganayagam, Shiraz Minwalla, Suresh Nampuri, Sandip P. Trivedi, Spenta R. Wadia]

Superconformal Indices for N=6 Chern Simons Theories

A dual gravitational description for a family of superconformal Chern Simons theories in three spacetime dimensions were recently proposed by Aharony, Bergman, Jafferis and Maldacena. A one loop computation was performed that determines the field theory superconformal index of this theory and compared it with the index computed over the Fock space of dual supersymmetric gravitons. In the appropriate limit (large N and large k) a perfect match was found. [Jyotirmoy Bhattacharya, Shiraz Minwalla]

Conformal Nonlinear Fluid Dynamics from Gravity in Arbitrary Dimensions

A recent work to construct a map from the conformal Navier Stokes equations with holographically determined transport coefficients, in d spacetime dimensions, to the set of asymptotically locally AdS_{d+1} long wavelength solutions of Einstein's equations with a negative cosmological constant, for all $d > 2$ was generalized. The simple explicit expressions for the stress tensor (slightly generalizing the recent result by Haack and Yarom (arXiv:0806.4602)), the full dual bulk metric and an entropy current of this strongly coupled conformal fluid, to second order in the derivative expansion, for arbitrary $d > 2$ was found. The well-known exact solutions for rotating black holes in AdS_{d+1} space in a manifestly fluid dynamical form was also rewritten, generalizing earlier work in d=4. To second order in the derivative expansion, this metric agrees with the general construction of the metric dual to fluid flows. [Sayantani Bhattacharyya, R. Loganayagam, Ipsita Mandal (HRI, Allahabad), Shiraz Minwalla, Ankit Sharma (IIT Kanpur)]

The Incompressible Non relativistic Navier Stokes equation from Gravity

The equations of relativistic hydrodynamics reduce to the incompressible Navier-Stokes equations in a particular scaling limit was noted. In this limit boundary metric fluctuations of the underlying relativistic system turn into a forcing function identical to the action of a background electromagnetic field on the effectively charged fluid. It was demonstrated that special conformal symmetries of the parent relativistic theory descend to 'accelerated boost' symmetries of the Navier-Stokes equations, uncovering a possibly new conformal symmetry structure of these equations. Applying the scaling limit to holographically induced fluid dynamics, gravity dual descriptions of an arbitrary solution of the forced non-relativistic incompressible Navier-Stokes equations were found. In the holographic context it was also found that simple forced steady state shear solution to the Navier-Stokes equations, and demonstrate that this solution turns unstable at high enough Reynolds numbers, indicating a possible eventual transition to turbulence. [Sayantani Bhattacharyya, Shiraz Minwalla, Spenta R. Wadia]

Weak Field Black Hole formation in Asymptotically AdS Spacetimes

The AdS/CFT correspondence was used to study the thermalization of a strongly coupled conformal field theory that is forced out of its vacuum by a source that couples to a marginal operator. The source was taken to be of small amplitude and finite duration, but was otherwise an arbitrary function of time. When the field theory lives on $R^{d-1,1}$, the source sets up a translationally invariant wave in the dual gravitational description. This wave propagates radially inwards in AdS_{d+1} space and collapses to form a black brane. Outside its horizon the bulk spacetime for this collapse process was systematically constructed in an expansion in the amplitude of the source function, and takes the Vaidya form at leading order in the source amplitude. This solution is dual to a remarkably rapid and intriguingly scale dependent thermalization process in the field theory. When the field theory lives on a sphere the resultant wave either slowly scatters into a thermal gas (dual to a glueball type phase in the boundary theory) or rapidly collapses into a black hole (dual to a plasma type phase in the field theory) depending on the time scale and amplitude of the source function. It was found that the transition between these two behaviors is sharp and can be tuned to the Choptuik scaling solution in $R^{d,1}$. [Sayantani Bhattacharyya, Shiraz Minwalla]

Membranes in M-theory

The moduli space for the Bagger-Lambert 3-algebra field theory proposed to describe multiple membranes in M-theory was obtained. It was conjectured that the theory describes two M2-branes on a class of "M-folds" that generalise familiar orbifolds in string theory. It was shown that in the limit of very large rank of the orbifold group, one recovers compactified M-theory via a mechanism similar to "deconstruction" in gauge theory. In this limit the M2-branes were shown to reduce to D2-branes [Sunil Mukhi and Costis Papageorgakis, with

Jacques Distler (Texas Univ.) and Mark van Raamsdonk (Univ. of British Columbia, Canada)].

Starting from maximally supersymmetric Yang-Mills theory in 3 dimensions and using a duality transformation, it was shown how to obtain the ghost-free Lorentzian 3-algebra theory proposed to describe M2-branes. This derivation implied that the latter theory was equivalent to Yang-Mills on-shell, but exhibited superconformal invariance off-shell [Bobby Ezhuthachan (HRI, Allahabad), Sunil Mukhi and Costis Papageorgakis]. Incorporating higher-derivative corrections to lowest nontrivial order, the same duality was used to derive the Lorentzian 3-algebra theory along with a set of derivative corrections. It was found that these corrections could be expressed entirely in terms of intrinsic 3-algebra quantities: the 3-bracket and covariant derivatives. It was conjectured that the derivative corrections were in some sense universal for all 3-algebras [Sunil Mukhi with Mohsen Alishahiha (IPM, Iran)]. The novel Higgs mechanism was used to determine the leading higher-derivative corrections to the Bagger-Lambert field theory. The result agreed with the universality conjecture. Extensions of this procedure to ABJM field theory were also explored [Bobby Ezhuthachan (HRI, Allahabad), Sunil Mukhi and Costis Papageorgakis].

Rare dyon decays

The complete set of constraints on the moduli of a class of superstring compactifications that permit "rare" marginal decays of supersymmetric dyons were obtained for the first time. The constraints were analysed in several cases and extended to multi-particle decays [Sunil Mukhi and Rahul Nigam].

W geometry

Earlier results in W-geometry had included results proving an equivalence between the assignment of a projective structure on a Riemann surface and immersions of a Riemann surface in complex projective space. This study was extended to the case of a Riemann surface embedded in a complex grassmannian. An equivalence was established between such immersions and the specification of a projective structure and an equivalence class of flat orthogonal group connections on the Riemann surface, equivalence being defined by their giving rise to isomorphic flat projective bundles. [A.K. Raina With I. Biswas]

Gauge Theories with Time Dependent Couplings and their Cosmological Duals

The N=4 super Yang-Mills theory was considered in flat 3+1-dimensional space-time with a time dependent coupling constant which vanishes at t=0, like $g_{YM}^2 = t^p$. In an analogous quantum mechanics toy model it was found that the response is singular. The energy diverges at $t = 0$, for a generic state. In addition, if $p > 1$ the phase of the wave function has a wildly oscillating behavior, which does not allow it to be continued past $t = 0$. A similar effect

would make the gauge theory singular as well, though nontrivial effects of renormalization could tame this singularity and allow a smooth continuation beyond $t = 0$. The gravity dual in some cases is known to be a time dependent cosmology which exhibits a spacelike singularity at $t = 0$. The results, if applicable in the gauge theory for the case of the vanishing coupling, imply that the singularity is a genuine sickness and does not admit a meaningful continuation. When the coupling remains nonzero and becomes small at $t = 0$, the curvature in the bulk becomes of order string scale. The gauge theory now admits a time evolution beyond this point. In this case, a finite amount of energy is produced which possibly thermalizes and leads to a black hole in the bulk. [Sandip Trivedi with Sael Awad (Kentucky U. & British U. in Egypt), Sumit R. Das (Kentucky U.), Suresh Nampuri and K. Narayan (Chennai Math. Inst.)]

Hydrodymamics of the D1 brane

The hydrodynamic properties of strongly coupled SU(N) Yang-Mills theory of the D1-brane at finite temperature were studied in the framework of gauge/gravity duality. By isolating the quasi-normal mode corresponding to the sound channel for the gravitational background of the D1-brane the bulk viscosity was evaluated. It was found that the ratio of the bulk viscosity to the entropy density is $1/4\pi$. This ratio continues to be $1/4\pi$ also in the regime when the D1-brane Yang-Mills theory is dual to the gravitational background of the fundamental string. The analysis shows that this ratio is equal to $1/4\pi$ for a class of gravitational backgrounds dual to field theories in 1+1 dimensions obtained by considering D1- branes at cones over Sasaki-Einstein 7-manifolds. [S.R. Wadia and M. Mahato, with J. David (CHEP, Indian Inst. of Science, Bangalore).]

Emission from the D1D5 CFT

Traditionally the aspect of AdS/CFT studied is that there is a dual description of gravitational processes in AdS in terms of a non-gravitational CFT. Certain geometries have a core AdS region and an outer asymptotically flat space time. These two regions are separated by a neck region. The procedure to explain the interaction of the core region with the rest by replacing the core region with a CFT and finding the vertex operator for absorption/emission was worked out. The difference from traditional uses of AdS/CFT is that an explicit formula was found to calculate absorption into/emission out of the CFT. It was further shown that this results in the correct emission rates from certain geometries found earlier. [Borun D. Chowdhury with Steven G. Avery (OSU), Samir D. Mathur (OSU)]

String spectra near some null cosmological singularities

Cosmological spacetimes with null Kasner-like singularities are constructed as purely gravitational solutions with no other background fields turned on. These are shown to be

anisotropic plane-wave spacetimes by coordinate transformations. The classical string modes can be solved for exactly in these time-dependent backgrounds making it possible to analyse the spectrum of string modes. A detailed study of the near singularity string spectrum, (time-dependent) oscillator masses and wavefunctions was carried out. It was found that for string modes with finite oscillation number, lower compared to a cutoff specified by an infinitesimal regularization of the vicinity of the singularity, the classical near-singularity string mode functions are non-divergent for various families of singularities. For these modes it was seen that an infinite set of oscillators become massless as they approach the singularity. Furthermore, it was found that a tower of string modes of ultra-high oscillation number, compared to the cut-off, which propagate essentially freely in the background. The resulting picture suggests that string interactions are non-negligible near the singularity. [K. Madhu with K.Narayan]

Hawking Radiation and Quantum Anomaly in AdS(2)/CFT(1) Correspondence

Since two dimensional gravity is described by conformal field theory, simple relation can be found between local operator in the bulk and (almost local but) non-local operator in the boundary. By using this correspondence, it was shown that Hawking radiation in the bulk can be explained as anomalous property of the boundary operator. [Takeshi Morita]

The precise derivation of Hawking radiation through gravitational anomaly called Robinson-Wilczek method was also studied and their mistake was found. Modification of their derivation was proposed and it was shown that the contribution of the trace anomaly is necessary to derive the radiation through the gravitational anomaly. [Takeshi Morita]

The fuzzy two-sphere structure of ABJM membrane theories

The structure of M2-M5 systems in ABJM membrane theories was investigated. This involved a fuzzy three-sphere in M-theory, realised as a fuzzy Hopf fibration for finite number of M2-branes N. When N is large, this becomes the usual smooth three-sphere. For small ABJM coupling the base of the Hopf fibration becomes a two-sphere in IIA string theory and the fibre can be identified with the M-theory circle. Studying the action for small fluctuations from the M2 worldvolume also reveals such a structure by being recast into an abelian 5d Lagrangian on a sphere times 2+1 d flat space. It was also explained why the usual covariant fuzzy three-sphere of Guralnik and Ramgoolam cannot arise in the context of ABJM. [C. Papageorgakis]