SUMMARY TALK

Strings 2013

끈이론
Seoul

JEFF HARVEY

I am indebted to the local organizers for the invitation to give the summary talk. It forced me to attend, and pay attention to, all of the talks. A task simultaneously exhausting and invigorating! And a personal thanks for the many wonderful introductions to Korea.

I apologize to the Gong show speakers and to Ed Witten. I will not review their talks

The talks at Strings 2013 were of extremely high quality, both in terms of the interest of the material presented and the clarity of the presentations.

Thanks then also to the speakers for making my job easier by giving such clear and enjoyable presentations.

More profound thanks than this are required and will be delivered by a higher authority following my talk.

I have tried to give equal attention to all speakers, but human nature being what it is, I may have done a less than perfect job at times. I offer the following as explanation.
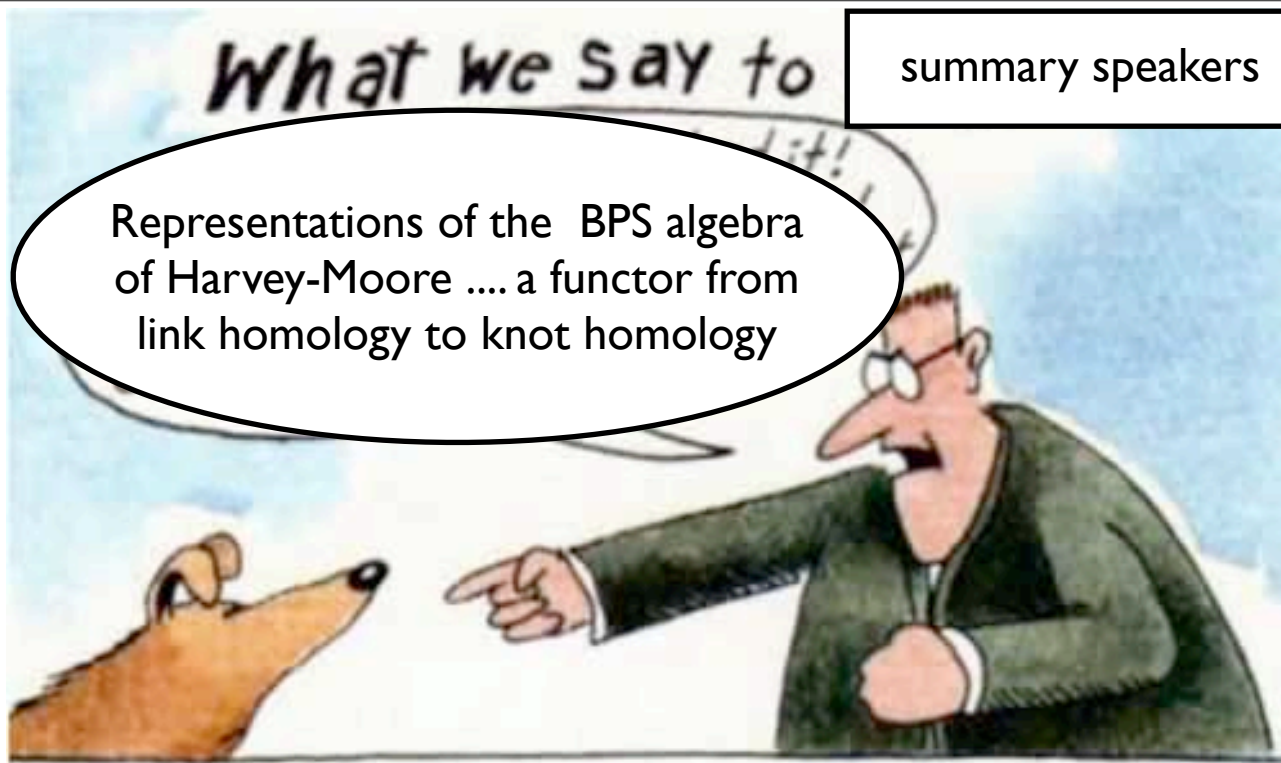
General Observations:

String theory is in many ways now a mature field, with well established results, streamlined techniques, and a significant body of knowledge into which new results must fit. Next year will mark the 30th year anniversary of the Green-Schwarz paper on anomaly cancellation!

On a personal level, I find that coming face to face with the fact that I wrote papers 30 years ago (and more) introduces a certain amount of cognitive dissonance. This is something that I am sure the older generation understands, but the younger generation does not.

In a mature field there is a younger generation and an older generation. A quick inter-generational quiz:

For the younger generation (Ph.D in or after 1999): How many of these questions can you answer? What is the value of c for the tricritical Ising model and why is it an interesting model? What did Dashen-Hasslacher-Neveu do? What is harvmac?

For the older generation (Ph.D before 1999): What is a motive? What does categorification mean? Could you construct the following figure in Latex in less than 4 hours?

$\{5, 4, 6, 7, 8, 9\}$
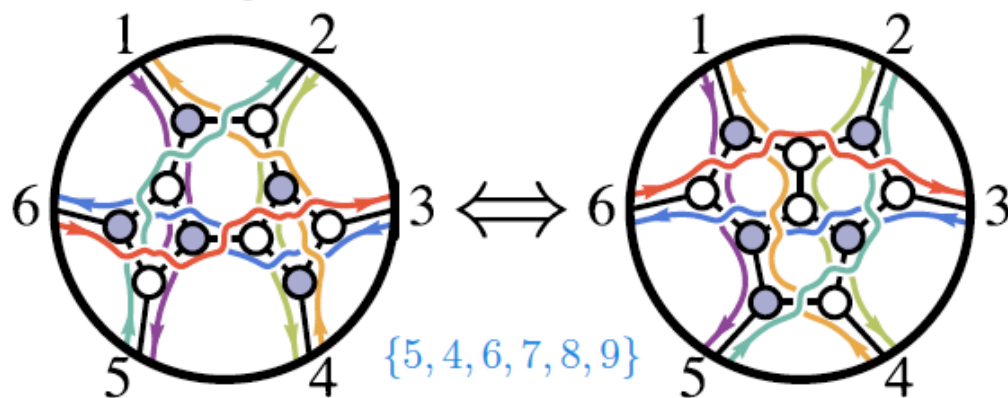
The study of supersymmetric gauge theory (D-branes) continues in a vibrant way, but there is also a gradual shift in emphasis towards the dynamics of M-branes. Many talks on Chern-Simons in d=3 and the (0,2) theory in d=6. M-theory still has much mystery but there is progress in unraveling these mysteries. Both CS w/ matter and (0,2) theory are remarkably rich.

String/M theory continues to be a fertile source for new mathematical ideas and structures with recent developments including the mathematics of BPS states such as wall crossing, applications of the (2,0) theory and M24 moonshine.

This is an era of string theory with a great diversity of ideas and applications, but with common techniques that include supersymmetry, AdS/CFT, brane dynamics, supergravity and other topics that for the most part have evolved from our increasing understanding of string theory.

Applications of gravity dualities (AdS/CFT, AdS/CMT, Fluid/gravity) are maturing, with more detailed models and more sophisticated analyses. These are not a panacea, but an interesting addition to the general toolkit of theoretical physicists that may lead to truly new insights into strongly coupled dynamics.

Supersymmetric Gauge and String Theory

Schwarz	Minwalla	Hartnoll	Arkani-Hamed	Yi
Seiberg	Klebanov	Horowitz	Skinner	Manschot
Break	Break	Break	Break	Break
Chair: Brink	Chair: Chaiho Rim	Chair: Eguchi	Chair: Larsen	Chair: Skenderis
Yin	Gaberdiel	Janik	Vieira	Moore
Kachru	Sungjay Lee	Strominger	Landsberg	Patanchon
Gukov	Morrison	Lunch &	Cvetic	Linde
Lunch	Lunch	Free Afternoon	Lunch	Lunch
Chair: Erdmenger	Chair: Henneaux		Chair: Jeong-Hyuck Park	Chair: Jaemo Park
Myers	Polchinski		Berman	Komargodski
	Harlow		Douglas	Jafferis
Takayanagi	Maldacena		Seok Kim	Pasquetti
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Rychkov	Silverstein		Vafa	Witten
Sen	Ooguri	16:30-17:00	Gong Show	Harvey

Seiberg: Careful study of the definition of susy gauge theory in the presence of line, surface defects and nontrivial topology. This leads to insights into possible new phases of gauge theory, somewhat analogous to the recently discovered topological insulator phases of certain CM systems.

Lee: Study of 2d susy gauge theory on S2 via localization and computation of exact partition function. Important application via GLSM to computation of Kahler potential of CY3 w/o mirror symmetry (see Morrison's talk).

Komargodski: General analysis of when and how one can formulate N=2 susy theories on three manifolds.

Pasquetti: Explored a connection between susy gauge theory and CFT via localization computations. Discussed connections between a flop symmetry of partition functions and conformal bootstrap.
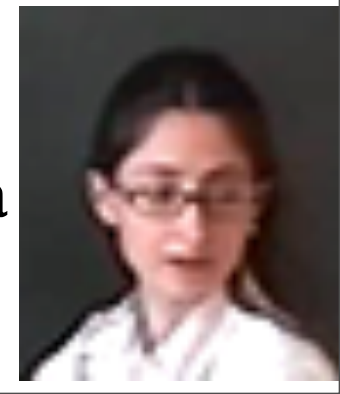
Twistors and Amplitudes

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Skinner: A fascinating reformulation of N=8 supergravity at tree level in terms of a string theory in twistor space. Extension to spacetime string theory and loops?
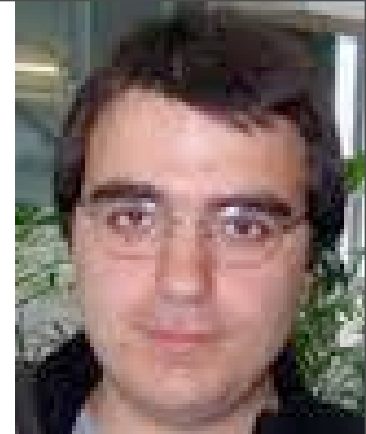
Vieira: Computation of nonperturbative Wilson line observeables in N=4 SYM via spectrum of flux tubes and transitions.
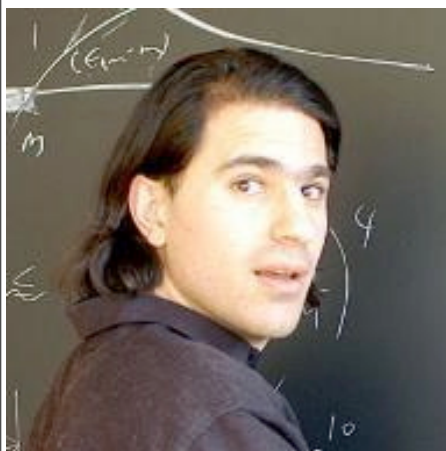
Arkani-Hamed: A program to make the Yangian symmetry manifest with emergent locality and unitarity, or life on and beyond the positive Grassmannian.

Higher Spin and Holography

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Klebanov: The low-energy limit of gauge theory coupled to massive matter (e.g. d=3 QED), Induced Gauge Theory, is dual to a higher spin Vasiliev like theory in AdS with modified b.c. Developed further evidence for this duality.

Gaberdiel: Discussed the duality between Vasiliev higher spin theory in AdS and weakly coupled gauge theory and its possible relation to standard AdS/CFT along with an extension to a new duality involving large N=4 SCA.

Applied AdS/CFT

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Hartnoll: Effective field theory of transport phenomena, focus on breaking of symmetry via irrelevant ops (Fermi liquids), relevant ops (insulators). AdS/CMT as source of new mechanism for pushing dof from IR to UV, O(1) anomalous dimensions.

Horowitz: Compute optical conductivity of holographic conductor and superconductor with lattice included exactly via numerical solution of Einstein-Maxwell and note striking similarities to intermediate scaling $|\sigma(\omega)| \sim \omega^{-2/3}$ measured behavior in BSCCO

Janik: Study derivative expansion of hydrodynamics via fluid/gravity duality. The expansion has zero radius of convergence, interpret singularities in Borel plane in terms of non-hydrodynamics modes.

Ooguri: Use AdS as guide to new phenomena, anomalous hydrodynamics and far from equilibrium response theory at order energy squared.

The most remarkable application of AdS/CFT is Sean Hartnoll's discovery of the

Holographic insultor

- **Objective**: realize a new type of localization. Main input from holography is that operators get O(1) anomalous dimensions.

- **Bulk action**:

$$S = \int d^5x \sqrt{-g} \left(R + 12 - \frac{1}{4}F_{ab}F^{ab} - \frac{1}{4}W_{ab}W^{ab} - \frac{m^2}{2}B_aB^a \right) - \frac{\kappa}{2} \int B \wedge F \wedge W.$$

Insult

I am enclosing two tickets to the first night of my new play; bring a friend... if you have one.

G.B. Shaw to W. Churchill

Dual Insult

Cannot possibly attend the first night; will attend second, if there is one.

W. Churchill to G. B. Shaw

Insult

You, Mr. Wilkes, will die either of the pox or on the gallows.

The Earl of Sandwich to John Wilkes

Dual Insult

That depends, my lord, whether I embrace your mistress or your principles.

John Wilkes to the Earl of Sandwich

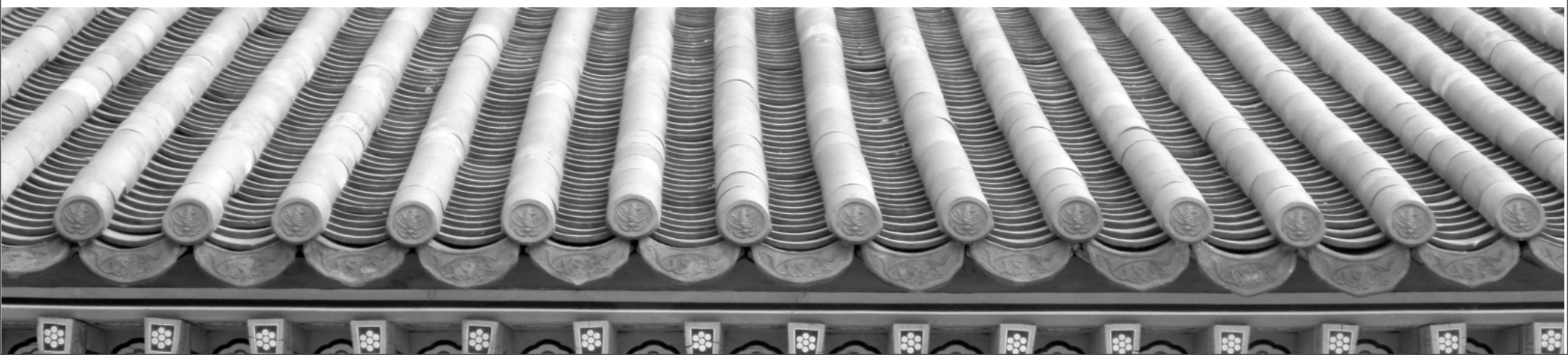# Another application: Holography/RG Flows/Entanglement

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Myers gave a beautiful review of the developments over the last several years growing out of the proposal of Ryu and Takayanagi for the AdS dual computation of entanglement entropy and the connection to RG flows, c-theorem and a-theorem.

Takayanagi gave a fascinating analysis of a holographic model of a local quench that proposed relations between information and energy and involved the notion of an entanglement temperature.

M theory, M5, M2 branes, and the (0,2) theory.

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Douglas: Why the (0,2) theory is hard, survey of various approaches, and discussion of an approach through d=5 reduced theory with instantons as particles and monopoles as strings (there is an interesting issue involving the instanton scale size I do not understand)

Vafa and Kim: Different approaches to computations of the superconformal index.

Localization of (2,0) on S5xS1 vs. an approach via the elliptic genus of M-strings, i.e. M2 suspended between M5 branes.
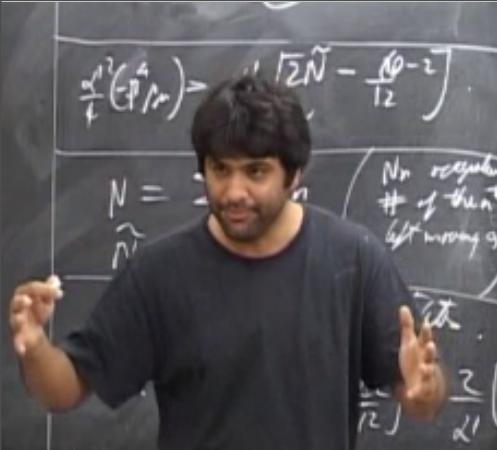
Minwalla: large N, 3d CS theories with fundamental matter have a rich dynamical structure. Studied dualities (rank-level, Giveon-Kutasov) and finite temperature behavior. Vasiliev bits=String bits??

Berman: Try to develop an "extended geometry" approach to M theory with manifest T-duality following earlier approaches to doubled and generalized geometry.

Jafferis: Showed that the (2,0) theory (M5-branes) on a squashed S3 leads to CS theory with complex gauge group. This has interesting connections to AGT correspondence.

Firewall Debate

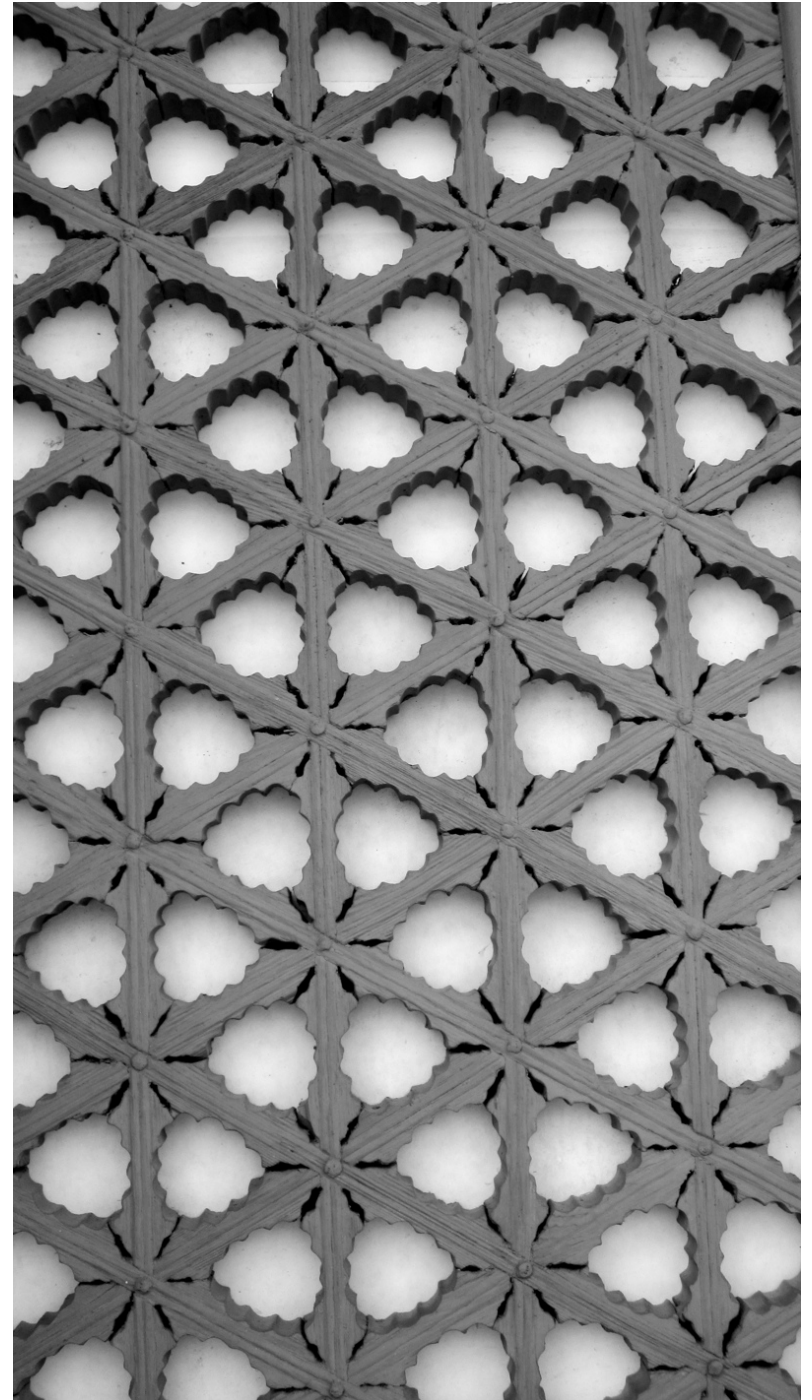| Schwarz	Minwalla	Hartnoll	Arkani-Hamed	Yi
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Joe: There are firewalls!!

Daniel: Does not compute!!!!

Juan: Entanglement = Geometry

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|+\rangle_A \otimes |-\rangle_B + |-\rangle_A \otimes |+\rangle_B)$$
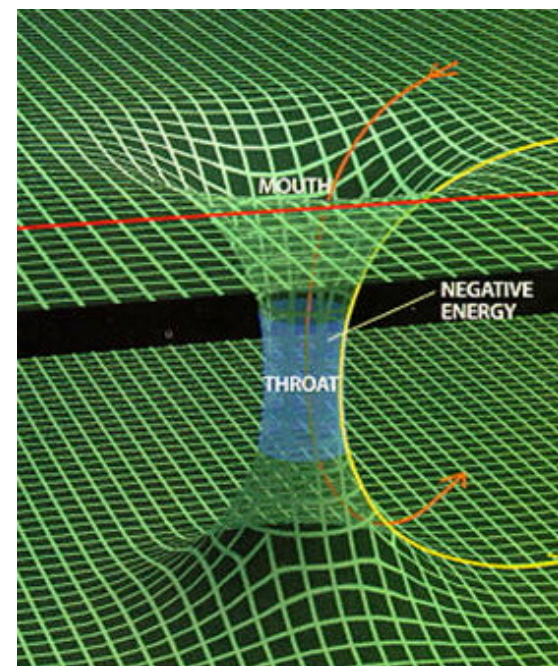
Everyone: While AdS/CFT gives a general argument for unitary BH formation and evaporation, we do not yet have sufficient control of bulk locality to see in detail how this happens and what it implies.
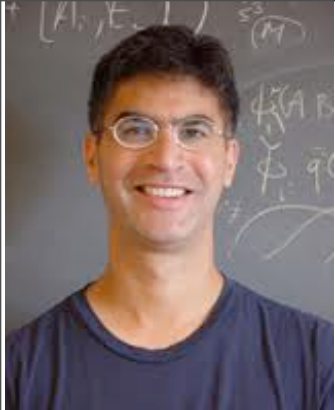
It seems there is a real problem, but that its resolution requires a tractable model which captures the essential physics. It is remarkable how long this problem has resisted an explicit solution.

Mathematics and String Theory

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Kachru presented evidence for the extension of M24 moonshine to N=2 heterotic string compactifications, and by N=2 string duality, to counting of Gromov-Witten invariants.

Morrison: How to count curves (GW invariants) without using mirror symmetry via a new approach to the quantum Kahler potential.

Gukov: Heterotic class, a program to establish links between two difficult subjects: 4-manifold theory and the (0,2) theory, extending previous work on 3-manifolds.

String Theory, Cosmology and Inflation

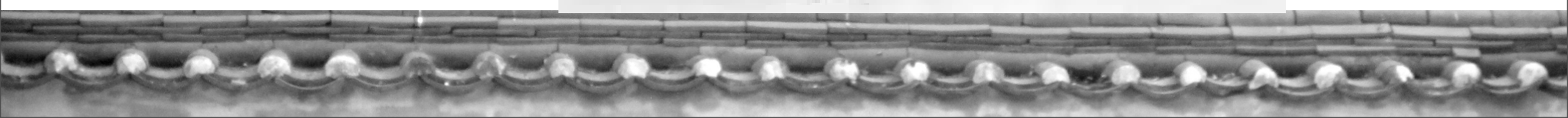| Schwarz	Minwalla	Hartnoll	Arkani-Hamed	Yi
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Silverstein: Fixing moduli in string compactifications can lead to deSitter and inflationary potentials. Described a search for, and features of, simple, tractable models.

Linde: Models of chaotic inflation based on the idea of broken (super) conformal invariance. This leads to the following model:

Experiment or
Triumph of the Standard Models

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Landsberg: The LHC has performed beautifully, leading to the discovery of the Higgs boson and gradually improving limits on BSM physics as well as measurement of expected SM signals (e.g. direct CP violation in Bs decays. We all eagerly await data from new runs at 14 TeV.
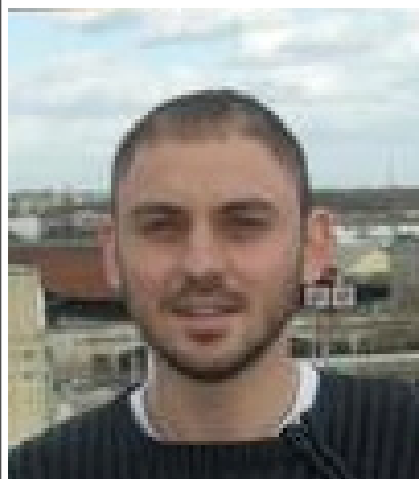
Patanchon: The amazing story of measurements of CMB spectrum, culminating in recent PLANCK data. This is perhaps the most dramatic development in the last 30 years, the evolution of cosmology into a precision science and confirmation of a standard Lambda CDM model.

68.25% Dark energy, a Universe 13.819 GB years old

New approaches to old problems

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Rychkov: revival of the conformal bootstrap approach and a detailed numerical implementation of bootstrap principles. "If it is mathematically well defined you can put it on a computer, if it is not you just have to solve it"

Strominger: Inspired by holography and a reinterpretation of Weinberg's theorem due to Maldacena, extend the BMS analysis of asymptotic symmetries to gauge theories with massless matter. Suggests a connection to affine Kac Moody algebras level $k \sim 2/g_{YM}^2$
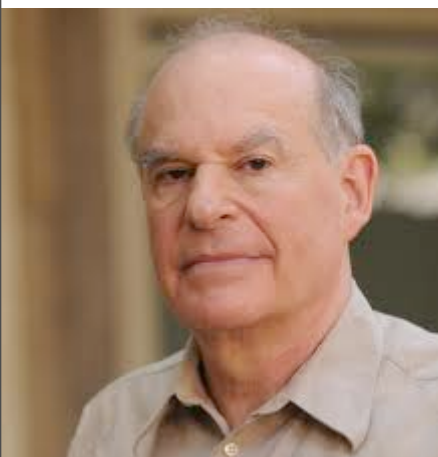
Schwarz: A modern point of view on the classic story of the SL(2,Z) symmetry of IIB string theory and the origin of the (2,0) theory.

Sen: Like any good perturbation theory, string theory perturbation theory diverges. In some situations we can use S-duality to derive asymptotic expansions at weak and strong coupling. An interpolation method is developed to predict the values of certain physical quantities at intermediate coupling.

Cvetic: How to deal with the mathematical subtleties of U(1) factors in F-theory. Who would have imagined that the Mordell-Weil group of an elliptic curve could have implications for string phenomenology?

Mirjam Cvetic

BPS-ology

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Yi: A beautiful overview of wall crossing of BPS states from the early days to the latest developments giving a physical interpretation and check of the KS wall-crossing formula. The full extension to N=2 string theory and BH states looks like a great adventure.
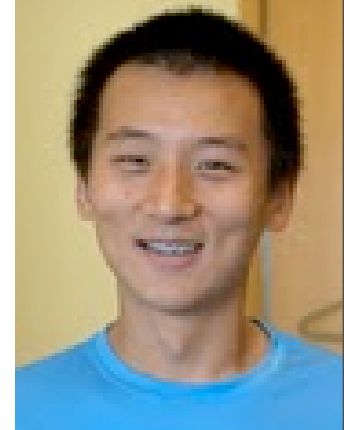
Yin: Study of 1/16 BPS states in N=4 SYM and a sharp puzzle in comparing to the entropy of large BH in AdS5.

Manschot: Study BPS bound states of fundamental BPS states via quiver dynamics with new improvements on both Coulomb and Higgs branches.

Moore: News on the spectrum of BPS states in N=2 susy gauge theory. Four talks in one!! Wins AWARD for cleverest slide!!! Man with questionable Motives !!!!!

Thanks for all the wonderful talks and stimulating conversations. My apologies to anyone whose work I have inadvertently omitted or misrepresented!

THE

END

None of us can stand other people having the same faults as ourselves.   -Oscar Wilde