AdS/CFT in your everyday life

Hirosi Ooguri

Walter Burke Institute for Theoretical Physics, California Institute of Technology
and
Kavli Institute for the Physics and Mathematics of the Universe, University of Tokyo

Strings 2017, Tel Aviv

My first paper in the graduate school in Kyoto:

Prog. Theor. Phys. Vol. 73, No. 4, April 1985, Progress Letters

One-Loop Effective Potential in Anti-de Sitter Space

Takeo INAMI and Hirosi OOGURI*
Research Institute for Fundamental Physics, Kyoto University, Kyoto 606
**Department of Physics, Kyoto University, Kyoto 606*
(Received January 31, 1985)

A scheme is given to compute the one-loop effective potential in a general class of curved spacetimes which are homogeneous and globally static. The renormalized effective potential for scalar field theories in anti-de Sitter background is evaluated by this method. The computation based on the S^p background is disproved by demonstrating that this prescription does not respect the correct boundary condition.

Quantum effects in anti-de Sitter (AdS) space have recently been an important issue in connection with possible breakdown of supersymmetry.[1)~3)] AdS space, which emerges as a natural background geometry in supergravity and Kaluza-Klein theories, is homogeneous and globally static.[*)] These nice properties give this space a special role as a background spacetime.

dimensions $p \geq 2$) with a Lorentizian signature. M is isomorphic to a coset space G/H, where G is the isometry group of M and H is the isotropy group.

To construct a field theory on M, the function space $\mathcal{H}$ on M must be furnished with an inner product. A natural one for scalar fields is

6 months later ...

Invited talk at the 1985 Cambridge Workshop
"Supersymmetry and its Applications"
Cambridge, UK, 23 June-13 July, 1985

A FOND FAREWELL TO ANTI DE SITTER SPACE

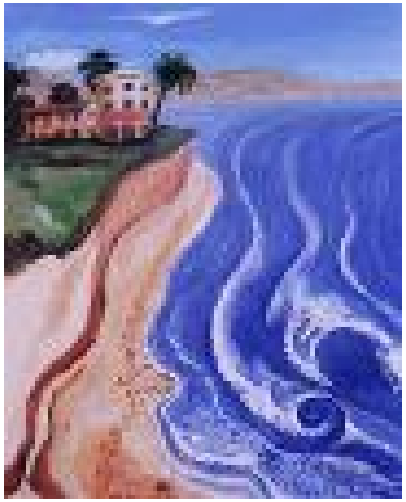
Daniel Z. FREEDMAN

For this and for other reasons the subject of AdS supersymmetry no longer seems as relevant to theoretical physics as it did three years ago, and I myself have decided that it is time to study something else. It is a decision made with some reluctance, because I find that the subject has intellectually attractive aspects.

I conjecture that these amplitudes share some of the properties of ordinary scattering amplitudes such as independence of the choice of interpolating field and gauge independence (in a gauge field theory). I suggest that these questions be studied as an open problem, although I cannot really foresee what application they will have.

12 years later ...

Strings '98



Conference Coordinators
Steve Giddings, Hirosi Ooguri, Amanda Peet, John Schwarz

INSTITUTE FOR THEORETICAL PHYSICS

Program on

Dualities in String Theory

January - June, 1998

Coordinators: M. Douglas, W. Lerche, and H. Ooguri

Speakers: Please give your transparencies to the ITP staff members in the front office (Rm 1102) for scanning. They will be returned promptly to your mailbox.

Time	Speaker	Title
1/26 2:00	Dr. Savdeep Sethi ITP & IAS	D-brane Bound State Redux
1/27 12:30	Dr. Nikita Nekrassov ITP & Harvard	Testing Seiberg-Witten Solution
1/28 10:00	Dr. Tom Banks Rutgers	The State of Matrix Theory[Audio]
2/3 1:00	Dr. Juan Maldacena ITP & Harvard	The Large N Limit of Field Theories and Gravity

SCIENCE

New Dimension in Dance: Thinking Man's Macarena

By GEORGE JOHNSON SEPT. 22, 1998

AT the Strings '98 conference this summer in Santa Barbara, Calif., physicists were so excited about a recent paper by Dr. Juan Maldacena, a Harvard theorist, that they danced in celebration. The lyrics, written by Dr. Jeffrey Harvey, a physicist at the University of Chicago, are a take-off on the 14-step version of the popular Spanish dance called the Macarena.

Impacts of AdS/CFT in many areas of physics:

★ Strongly correlated systems in hadron physics
and condensed matter physics
★ Dynamics of (super)conformal field theories
and their perturbations
★ Models of elementary particles and cosmology
★ Topological strings
★ Liouville theory and other non-compact CFT's
★ Moonshines ★ F-Theory
★ Conformal bootstraps
★ Chaos ★ Complexity
★ . . . . .

Impacts of AdS/CFT in many areas of physics:

★ Strongly correlated systems in hadron physics and condensed matter physics

PRL **94,** 111601 (2005) PHYSICAL REVIEW LETTERS week ending 25 MARCH 2005

Viscosity in Strongly Interacting Quantum Field Theories from Black Hole Physics

P. K. Kovtun,[1] D. T. Son,[2] and A. O. Starinets[3]
[1]*Kavli Institute for Theoretical Physics, University of California, Santa Barbara, California 93106, USA*
[2]*Institute for Nuclear Theory, University of Washington, Seattle, Washington 98195-1550, USA*
[3]*Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L 2Y5, Canada*
(Received 20 December 2004; published 22 March 2005)

PRL **101,** 031601 (2008) PHYSICAL REVIEW LETTERS week ending 18 JULY 2008

Building a Holographic Superconductor

Sean A. Hartnoll,[1] Christopher P. Herzog,[2] and Gary T. Horowitz[3]
[1]*KITP, University of California Santa Barbara, Santa Barbara, California 93106, USA*
[2]*Department of Physics, Princeton University, Princeton, New Jersey 08544, USA*
[3]*Department of Physics, University of California Santa Barbara, Santa Barbara, California 93106, USA*
(Received 2 April 2008; published 14 July 2008)

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Received: *January 1, 2008*
Accepted: *January 25, 2008*
Published: *February 14, 2008*

Nonlinear fluid dynamics from gravity

Sayantani Bhattacharyya and Shiraz Minwalla
Department of Theoretical Physics, Tata Institute of Fundamental Research, Homi Bhabha Rd, Mumbai 400005, India
E-mail: sayanta@theory.tifr.res.in, minwalla@theory.tifr.res.in

Veronika E. Hubeny and Mukund Rangamani
Centre for Particle Theory and Department of Mathematical Sciences, Science Laboratories, South Road, Durham DH1 3LE, U.K.
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Impacts of AdS/CFT in many areas of physics:

VOLUME 83, NUMBER 23 PHYSICAL REVIEW LETTERS 6 DECEMBER 1999

An Alternative to Compactification

Lisa Randall*
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08543
and Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

Raman Sundrum†
Department of Physics, Boston University, Boston, Massachusetts 02215
(Received 15 July 1999)

★ Models of elementary particles and cosmology

PHYSICAL REVIEW D **66**, 106006 (2002)

Hierarchies from fluxes in string compactifications

Steven B. Giddings,[1,2] Shamit Kachru,[1,3] and Joseph Polchinski[1]
[1]*Institute for Theoretical Physics, University of California, Santa Barbara, California 93106-4030*
[2]*Department of Physics, University of California, Santa Barbara, California 93106*
[3]*Department of Physics and SLAC, Stanford University, Stanford, California 94305/94309*
(Received 3 May 2002; published 25 November 2002)

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Towards inflation in string theory

Shamit Kachru[1,2], Renata Kallosh[1], Andrei Linde[1], Juan Maldacena[3], Liam McAllister[1] and Sandip P Trivedi[4]

[1] Department of Physics, Stanford University, Stanford, CA 94305, USA
[2] SLAC, Stanford University, Stanford, CA 94309, USA
[3] Institute for Advanced Study, Princeton, NJ 08540, USA
[4] Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400 005, India

Impacts of AdS/CFT in many areas of physics:

PHYSICAL REVIEW D, VOLUME 70, 106007

Black hole attractors and the topological string

Hirosi Ooguri,[1] Andrew Strominger,[2] and Cumrun Vafa[2]
[1]*California Institute of Technology, Pasadena, California 91125, USA*
[2]*Jefferson Physical Laboratory, Harvard University, Cambridge, Massachusetts 02138, USA*
(Received 15 July 2004; published 19 November 2004)

★ Topological strings

JHEP
PUBLISHED FOR SISSA BY SPRINGER
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PUBLISHED: *May 7, 2015*

Resumming the string perturbation series

Alba Grassi, Marcos Mariño and Szabolcs Zakany
Département de Physique Théorique et section de Mathématiques,
Université de Genève, Genève, CH-1211 Switzerland

JHEP
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Entropy function and AdS_2/CFT_1 correspondence

Ashoke Sen
Harish-Chandra Research Institute,
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E-mail: sen@mri.ernet.in, ashokesen1999@gmail.com

Impacts of AdS/CFT in many areas of physics:

★ Strongly correlated systems in hadron physics
and condensed matter physics
★ Dynamics of (super)conformal field theories
and their perturbations
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★ Moonshines ★ F-Theory
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★ Chaos ★ Complexity
★ . . . . .

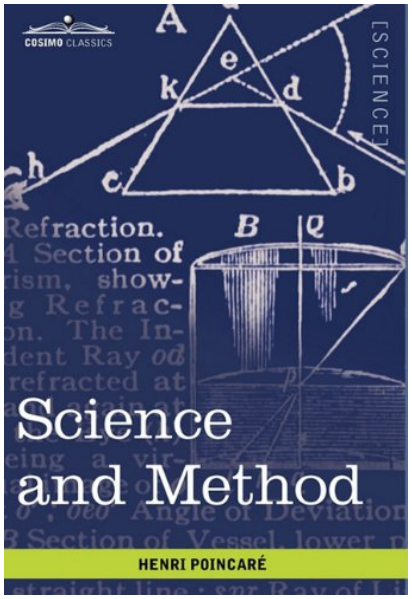
[*Plenary talks related to AdS/CFT*]

[*All plenary talks*]

Strings '98 44 %

42 %

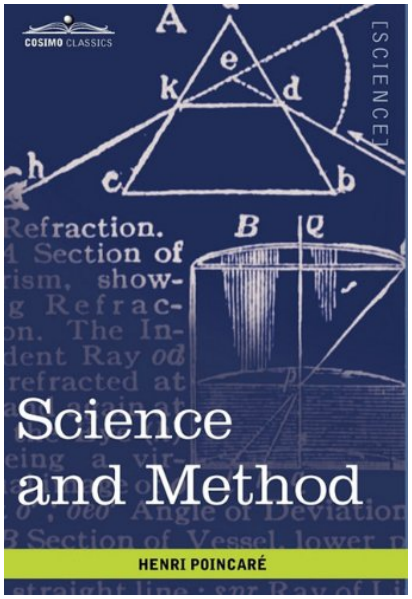
plus this special session



In this book, Henri Poincaré asked himself:

Why some research directions give large returns and others don't?

He suggests that scientists should devote themselve to research directions that give large returns.



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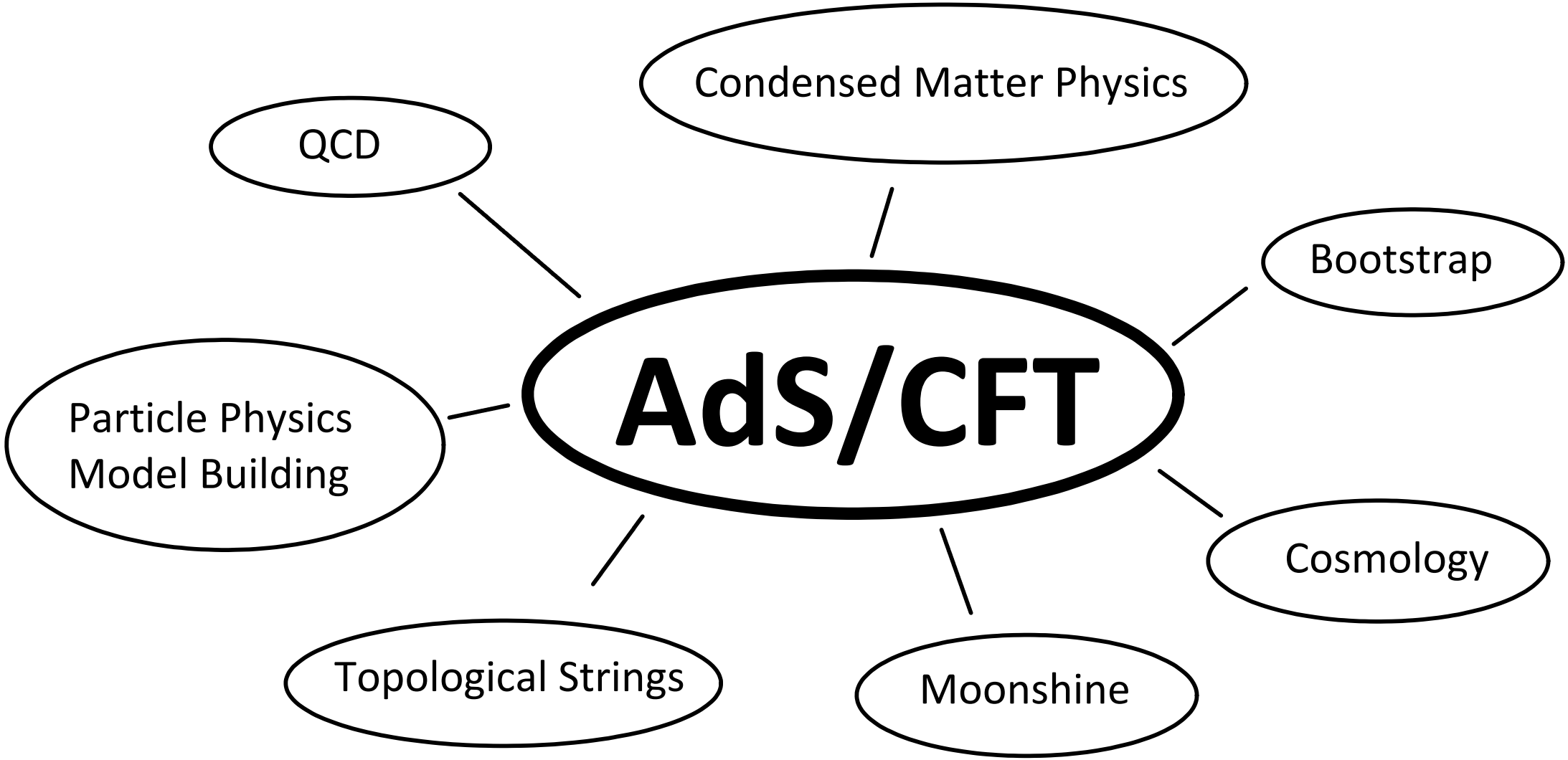
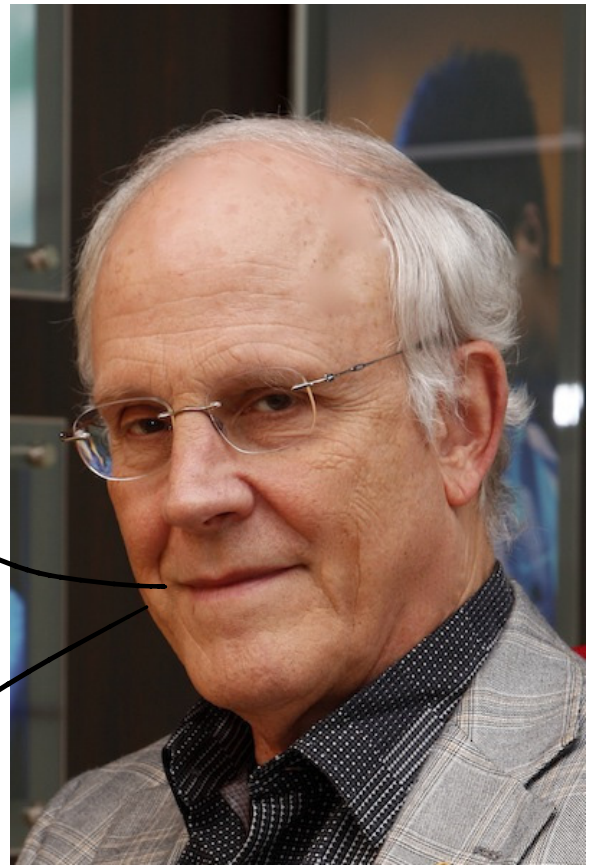
"as these sciences developed, we have recognized more clearly
the links which unite them
.....
the map of universal science
.....
the nodal point of the St. Gotthard
from which there flow waters
that feed four different basins."

AdS/CFT is a St. Gotthard Pass in physics



I would ask you to focus on
a few important lessons that
we (not just your own work) have
learned from gauge/gravity duality
and **a few hopes** for what
we may learn in the future.



To me, one of the most important aspects of AdS/CFT has been that it gives a **UV complete definition of quantum gravity**.

(1) It gives a non-perturbative definition of string theory in some backgrounds.

(2) It has enabled us to ask deep questions in gravity and to seek answers in CFT.

(3) It has taught us what are possible and are not possible in quantum gravity.

The relation between **information** theoretical concepts in CFT and **geometric** concepts in AdS has taught us many lessons.

Eternal black holes in anti-de Sitter

Juan Maldacena

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) intersects
$^{d-1} + S^{d-1}$.
two circles
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lary CFT is
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ction on the
$= \mathcal{H}_1 \times \mathcal{H}_2$
denote the full Hilbert space consisting of two copies of the Hilbert space of the CFT. The wavefunction $|\Psi\rangle \in \mathcal{H}$ is

$$|\Psi\rangle = \frac{1}{\sqrt{Z(\beta)}} \sum_n e^{-\beta E_n/2} |E_n\rangle_1 \times |E_n\rangle_2 \,. \qquad (2.3)$$

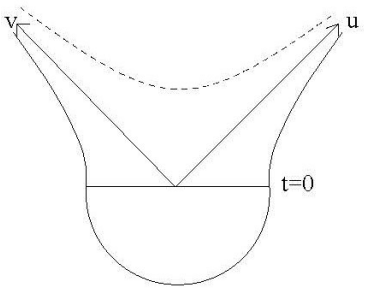
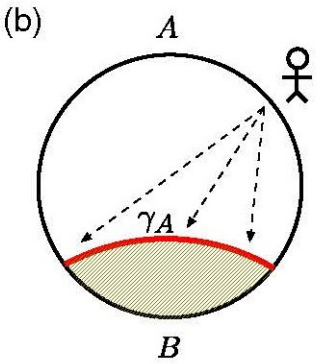


Figure 3: The Hartle-Hawking-Israel wavefunction can be thought of as arising from gluing half the euclidean geometry at $t = 0$ to half the lorentzian geometry. Over each point on this diagram there is a sphere S^{d-1}.

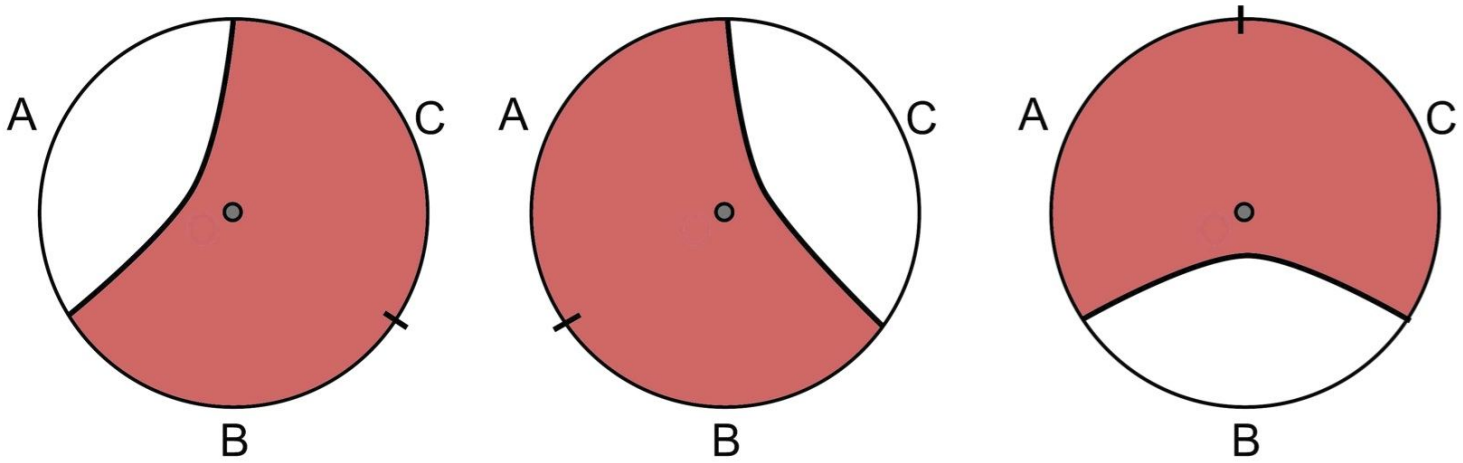
PRL **96,** 181602 (2006) PHYSICAL REVIEW LETTERS week ending 12 MAY 2006

Holographic Derivation of Entanglement Entropy from the anti–de Sitter Space/Conformal Field Theory Correspondence

Shinsei Ryu and Tadashi Takayanagi
Kavli Institute for Theoretical Physics, University of California, Santa Barbara, California 93106, USA
(Received 8 March 2006; published 9 May 2006)



Reconstruction of bulk local operators and its applications



Banks, Douglas, Horowitz, Martinec (1998); Hamilton, Kabat, Lifschytz, Lowe (2006);
Papadodimas, Raju (2013); Headrick, Hubeny, Lawrence, Rangamani (2014);
Almheiri, Dong, Harlow (2014); Lin, Marcolli, Stoica + H.O. (2014);
Jafferis, Lewkowycz, Maldacena, Suh (2015); Dong, Harlow, Wall (2016);
Engelhardt, Horowitz (2016); Kabat, Lifschytz (2017); Faulkner, Lewkowycz (2017); ...

Swampland Question

Given an effective theory of gravity, how can one judge whether it is realized as a low energy appropximation to a consistent quantum theory with **ultra-violet completion**, such as string theory?

Constraints on Symmetry in Quantum Gravity

Two well-known conjectures:

(1) **No global symmetry** in quantum gravity.

(2) If a low energy effective theory of quantum gravity contains a compact gauge group G, there are **physical states in every finite-dimensional unitary representations** of G.
If G = U(1), all charges consistent with the Dirac quantization condition appear. [Completeness Hypothesis]

Standard argument for

No global symmetry in quantum gravity:

If there is global symmetry G, we can combine a large number of G-charge matters to make a **black hole in an arbitrary large representations of G**.

Let it Hawking-radiate, keeping black hole mass > the Planck mass.

Since the Hawking radiation is G-blind, the black hole still contains the large reprentation of G with the number of states **exceeding the Bekenstein-Hawking entropy** formula.

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How about discrete groups?

e.g., Z_2, where only the only faithful representation is 1 dim.

How about higher brane charges?

It is desirable to have an argument that applies to any symmetry.

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These conjectures can be sharpened and proven in AdS/CFT.

Harlow: 1510.07911, Harlow + H.O.: in progress

Global Symmetry

We sharpen our requirements:

(1) Symmetry should map a local operator to a local operator.

(2) Symmetry action should be faithful on the set of local operators.

(3) For a set of open disjoint subspaces of the Cauchy surface:

$$U\left(g, \bigcup_i \mathcal{R}_i\right) = \prod_i U(g, \mathcal{R}_i)$$

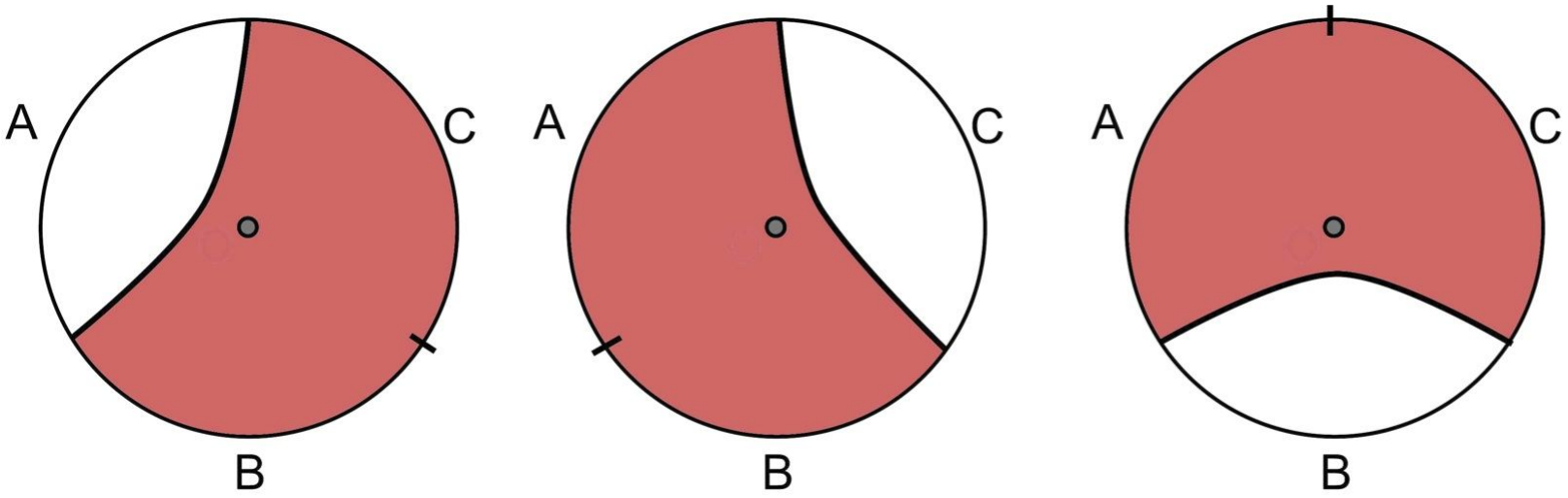
Noether theorem implies (1) + (2) $\Rightarrow$ (3).

With the *split property*, (3) holds for discrete symmetry also.

Buchholz-Duplicher-Lungo (1989)

Gauge theory can also have the split property by adding degrees of freedom in UV.

Let us apply the entangement wedge reconstruction.



Global symmetry in AdS is inconsistent with local structure of CFT.

If a gravitational theory in AdS has global symmetry G, there must be a bulk local operator that transforms faithfully into another local operator at the same point.

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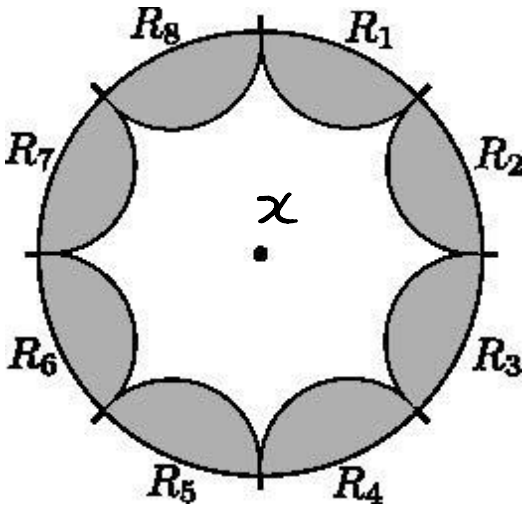

Symmetry generator,

$$U(g) = \prod_i U(g, R_i)$$

commute with the local operator at x in the bulk.

Contradiction

With the precise definition in AdS, we are able to ask what are possible and not possible in quantum gravity.

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Is the **weak gravity conjectutre** derivable?

Arkani-Hamed, Motl, Nicolis, Vafa: hep-th/0601001

★ WGC seems a generic phenomenon for emergent gauge fields.

Harlow: 1510.07911, Harlow + H.O.: in progress

★ The sharpened version of WGC would eliminate non-SUSY AdS supported by fluxes and may put constraints on types and masses of neutrinos in the Standard Model of Particle Physics.

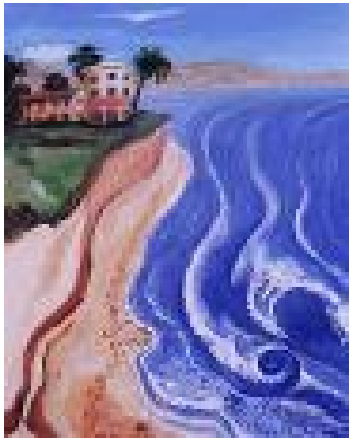
Vafa + H.O.: 1610.1533
Ibanez, Martin-Lozano, Valenzuela: 1706.05392

With the precise definition in AdS, we are able to ask what are possible and not possible in quantum gravity.

The UV/IR connection may imply surprising **IR predictions** on observable phenomena from **UV completion** of quantum gravity.

Quantum gravity can be made more relevant to our everyday life.

Thank you, AdS/CFT !



Strings '98

1997 20th ANNIVERSARY 2017