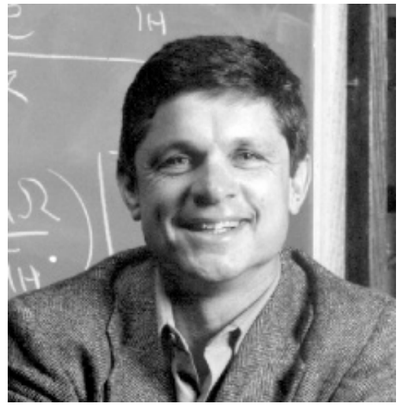

Black Holes, Holography and Strings
July 30-31, 2015

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Black Holes, Holography and Strings

A Celebration of the Science of
Andrew Strominger

Harvard University

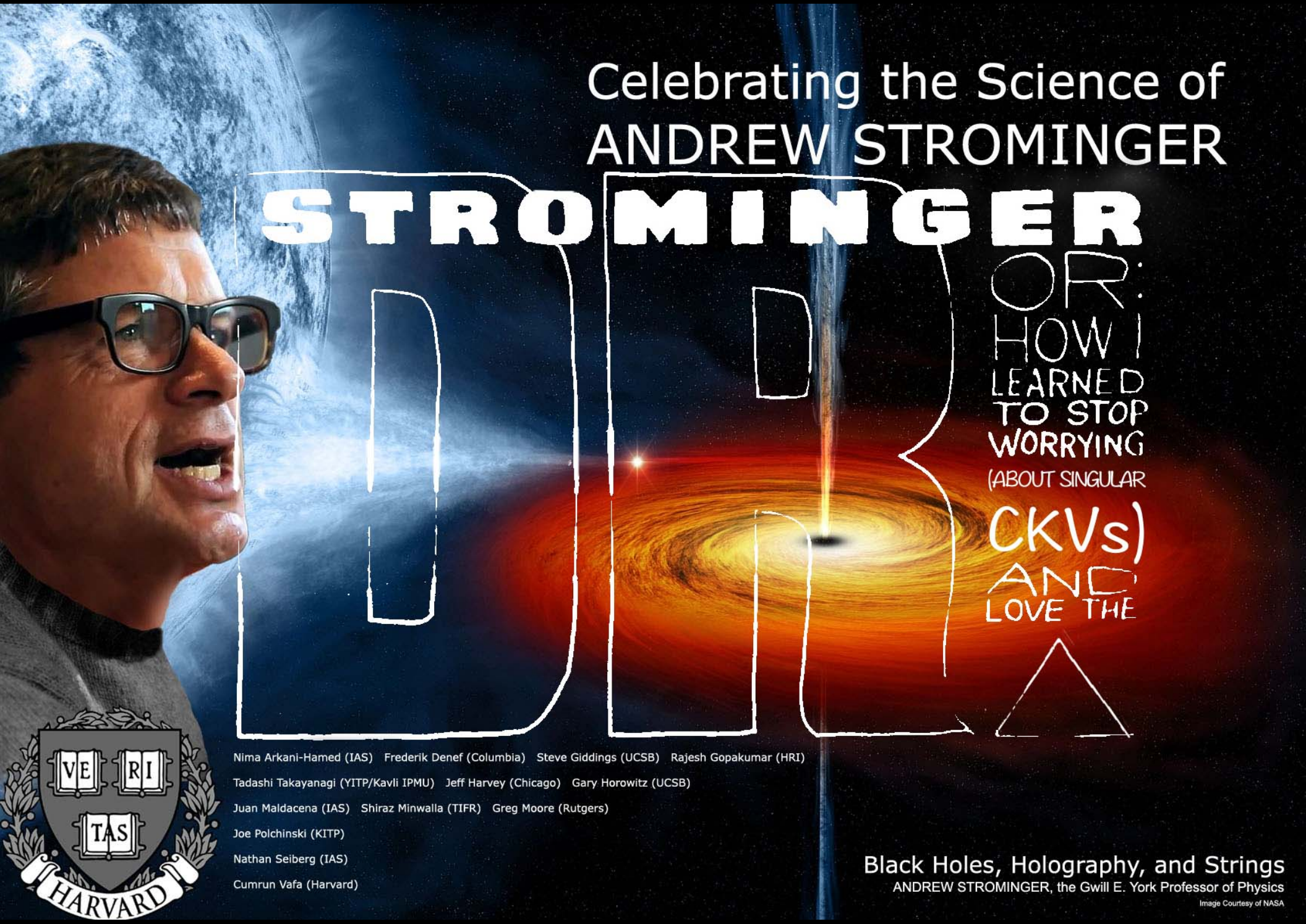
Department of Physics

July 30-31, 2015

(Photo: H. Ooguri)

This conference aims to bring together a diverse group of physicists and educators whose career paths have intersected with Andy's and who share his passion for Physics.

In addition to talks scheduled for Thursday, July 30 and Friday, July 31, there will be a banquet on Thursday evening. Please see the conference schedule for more details.


Celebrating the Science of
ANDREW STROMINGER
STROMINGER
OR:
HOW I
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Nima Arkani-Hamed (IAS) Frederik Denef (Columbia) Steve Giddings (UCSB) Rajesh Gopakumar (HRI)
Tadashi Takayanagi (YITP/Kavli IPMU) Jeff Harvey (Chicago) Gary Horowitz (UCSB)
Juan Maldacena (IAS) Shiraz Minwalla (TIFR) Greg Moore (Rutgers)
Joe Polchinski (KITP)
Nathan Seiberg (IAS)
Cumrun Vafa (Harvard)
VE RI TAS
HARVARD
Black Holes, Holography, and Strings
ANDREW STROMINGER, the Gwill E. York Professor of Physics
Image Courtesy of NASA

i) Weinberg – photon $\mathcal{O}(\frac{1}{\omega})$
ii) Weinberg – graviton $\mathcal{O}(\frac{1}{\omega})$
iii) Cachazo & Strominger – graviton $\mathcal{O}(1)$

Soft Factors

Memories ⟷ **Symmetries**

i) Liénard-Wiechert / Bieri & Garfinkle
ii) Zeldovich & Polnarev / Christodoulou
iii) Pasterski, Strominger, & Zhiboedov

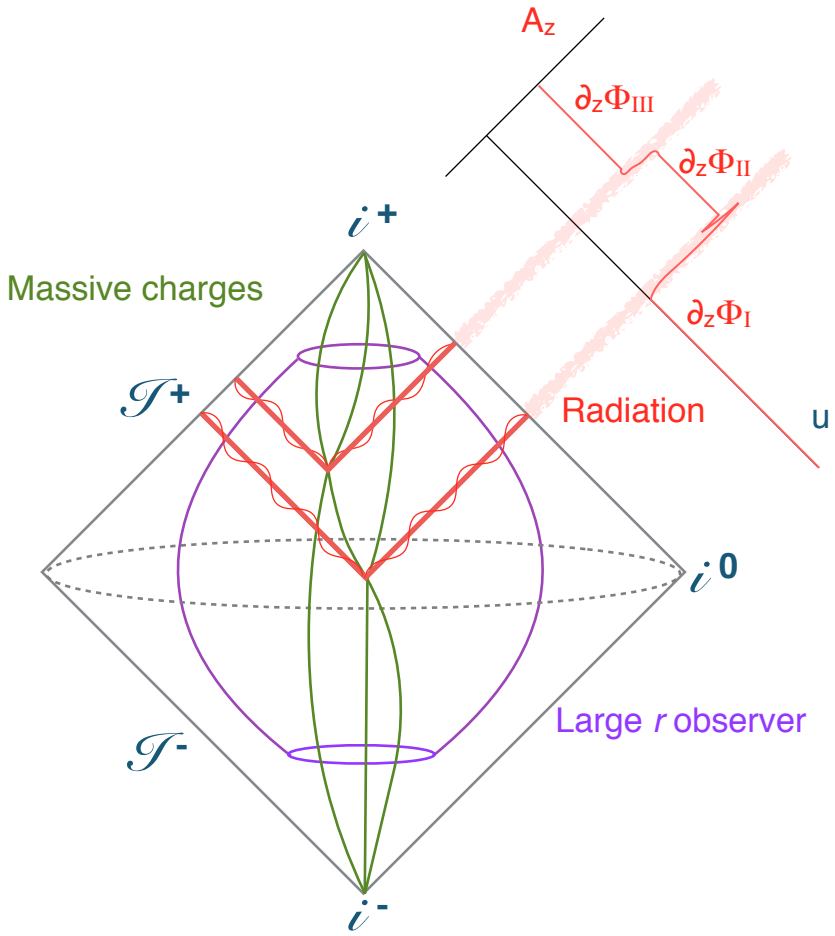
	(global)	(asymptotic)
i)	e-charge	large U(1)
ii)	p^μ	supertranslations
iii)	$J^{\mu\nu}$	superrotations

Radiation $\Rightarrow \triangle$
Memory

Measurable observable:

- Finite energy flux
- Propagating to $r >> r_s$

- Far-field $\frac{1}{r^n}$ fall-offs
- $= 0$ @ $u \to \pm\infty$
  $\neq 0$ generic u
  $\int du... \neq 0$



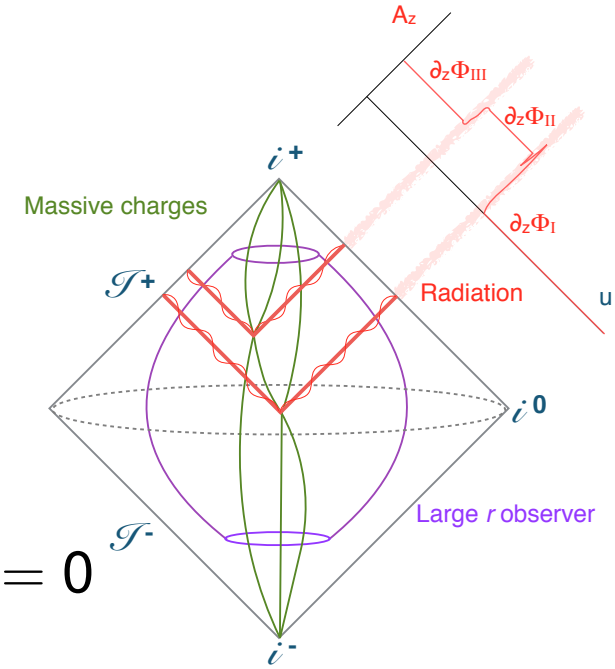
Radiation $\Rightarrow \triangle$
Memory – Symmetry

- Memory $\equiv \int_{-\infty}^{\infty} du\ f_{rad}(u)$
  - measure finite net effect
  - observer anywhere on S^2

- $O(u) \equiv \int_{u_0}^{u} du'\ f_{rad}(u')$
  - $\text{Mem}_{eff} = O(u_f) - O(u_i)$ s.t. $f_{rad}(u_{i,f}) = 0$

    $u_f \neq \infty$ How long should I wait?

    $u_i \neq -\infty$ Did something happen before?



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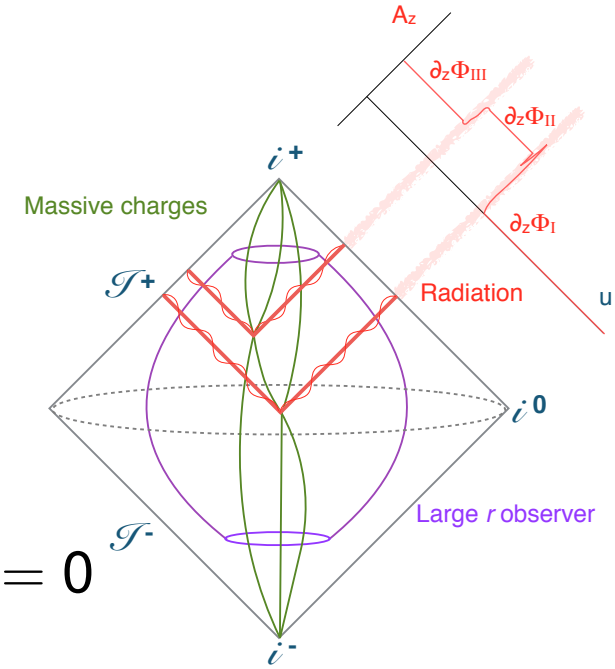

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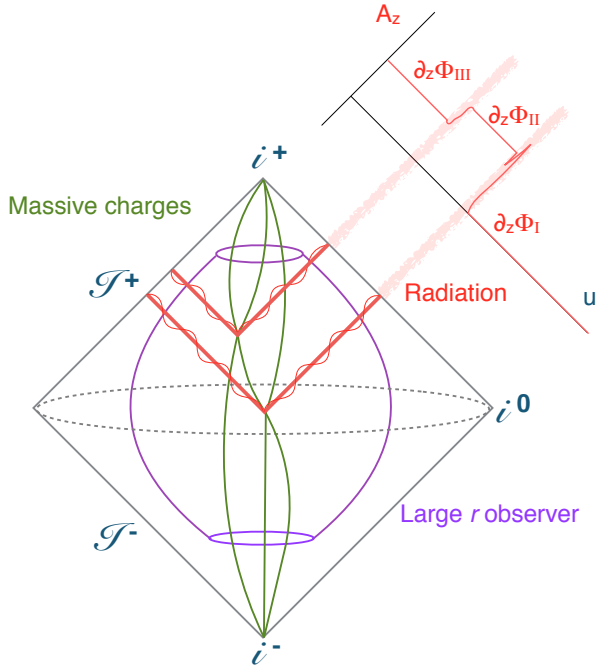
Consistency of fall-off conditions allowing radiation

$\Leftrightarrow$

local on S^2 shift in baseline value of O

Radiation $\Rightarrow \triangle$
Memory – Soft Factor

- Memory $\equiv \int_{-\infty}^{\infty} du\, f_{rad}(u)$
  - measure finite net effect
  - observer anywhere on S^2

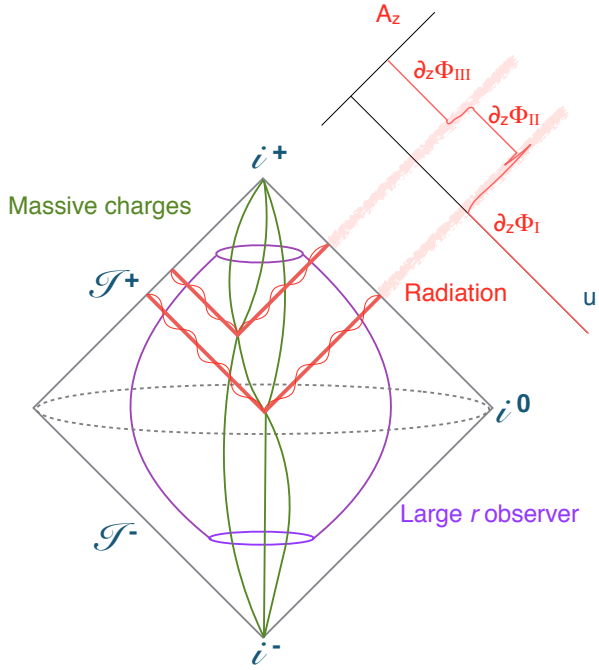


- $\int_{-\infty}^{\infty} du \ldots \leftrightarrow \lim_{\omega \to 0}$
  - ex. F.T. takes step function $\rightarrow$ pole

- $e^{iq\cdot x} = e^{-i\omega u - i\omega r(1-\hat{x}\cdot\hat{q})} \leftrightarrow \hat{x} = \hat{q}$
  - $\mathcal{A}_\mu(x) = e \sum_{\alpha=\pm} \int \frac{d^3q}{(2\pi)^3} \frac{1}{2\omega_q} [\varepsilon_\mu^{\alpha *} a_\alpha(\vec{q}) e^{iq\cdot x} + h.c.]$

Radiation $\Rightarrow \triangle$
Memory – Soft Factor

- Memory $\equiv \int_{-\infty}^{\infty} du\, f_{rad}(u)$
  - measure finite net effect
  - observer anywhere on S^2



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Long-time integration at large distances probes low frequencies at the same angle

Details
Soft Factor – Symmetries

- null infinity
  - relevant leading radial behavior of $\mathcal{A}_\mu, g_{\mu\nu}$
    - ex. Bondi Gauge and BMS as ASG for asymptotically flat spacetimes

$$ds^2 = -du^2 - 2dudr + 2r^2\gamma_{z\bar{z}}dzd\bar{z} + 2\frac{m_B}{r}du^2 \qquad \left[z = e^{i\phi}\tan\frac{\theta}{2} \quad \gamma_{z\bar{z}} = \frac{2}{(1+z\bar{z})^2}\right]$$

$$+\left(rC_{zz}dz^2 + D^z C_{zz}dudz + \frac{1}{r}\left(\frac{4}{3}N_z - \frac{1}{4}\partial_z(C_{zz}C^{zz})\right)dudz + c.c.\right) + \ldots$$

  - order of limits and stationary phase
- constraint equations
- expectation value

Details
Soft Factor – Symmetries

- null infinity
- constraint equations
  - first-order in ∂_u e.o.m's
    $\nabla^\nu \mathcal{F}_{\nu\mu} = e^2 j_\mu$

    $$j_u \quad \Rightarrow \quad \partial_u A_u = \partial_u (D^{\bar{z}} A_{\bar{z}} + D^z A_z) + e^2 j_u$$

    $G_{\mu\nu} = 8\pi G T^M_{\mu\nu}$

    $$G_{uu} \quad \Rightarrow \quad \partial_u m_B = \frac{1}{4}\partial_u \left[D_z^2 C^{zz} + D_{\bar{z}}^2 C^{\bar{z}\bar{z}} \right] - T_{uu}$$

    $$\partial_{\bar{z}} G_{uz} - \partial_z G_{u\bar{z}} \quad \Rightarrow \quad \mathrm{Im}[\partial_{\bar{z}} D_z^3 C^{zz}] = 2\mathrm{Im}[\partial_u \partial_{\bar{z}} N_z + \partial_{\bar{z}} T_{uz}]$$

  - $m = 0$ scatterers + symmetric in/out radiation + in/out matching $\Rightarrow \mathcal{S}$-matrix Ward identities
- expectation value

Details
Soft Factor – Symmetries

- null infinity
- constraint equations
- expectation value
  - use soft behavior $\langle out|a_-(q)\mathcal{S}|in\rangle = \left(S^{(0)-} + S^{(1)-}\right)\langle out|\mathcal{S}|in\rangle + \mathcal{O}(\omega)$ and constraint equations to get observables (memory effects) with:

$$\langle \mathcal{O}_{mem}\rangle|_{in\to out} \sim \frac{\langle out| : \mathcal{O}_{mem}\mathcal{S} : |in\rangle}{\langle out|\mathcal{S}|in\rangle}$$

  - ex. E&M soft factor and mode expansion:
    $S_p^{(0)\pm} = eQ\frac{p\cdot\varepsilon^{\pm}}{p\cdot q} \quad p^\mu = m\gamma(1,\vec{\beta}) \quad \Delta A_z = -\frac{e}{4\pi}\hat{\varepsilon}_z^{*+}\omega S^{(0)+}$
    agree with constraint:
    $-\frac{e}{4\pi}\lim_{\omega\to 0}\omega[D^z\hat{\varepsilon}_z^{*+}S_p^{(0)+} + D^{\bar{z}}\hat{\varepsilon}_{\bar{z}}^{*-}S_p^{(0)-}] = -e^2\frac{Q}{4\pi}\frac{1}{\gamma^2(1-\vec{\beta}\cdot\hat{n})^2}$
  - When $m \neq 0$, view constraint eq. as giving A_u in terms of free data A_z. But $A_u \Leftrightarrow$ Coulomb field, set by $in \to out$.

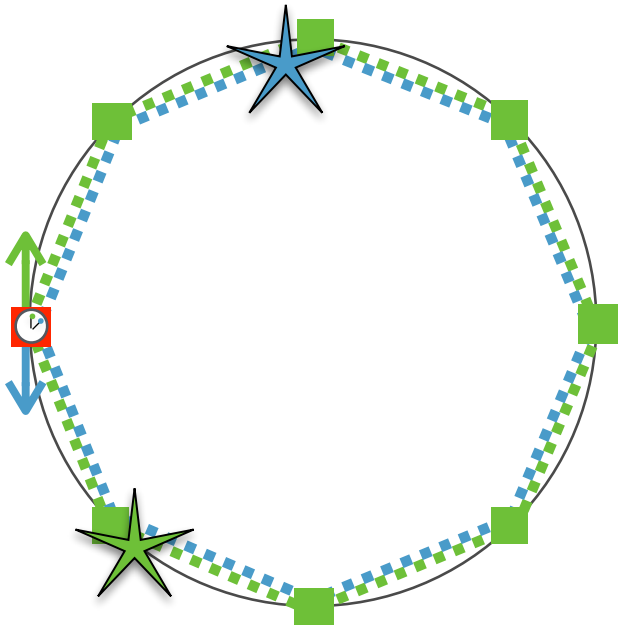
Applications

- BH hair?
- M_4 holography?
- SCET?

Applications

- BH hair?
  - arbitrary S^2 dependence from boosted monopoles vs. higher multipole of localized static configuration
- M_4 holography?
  - $CFT_2 \subset M_4$ on $S^2_{in/out}$ at $\cap$ of lightcone from origin and $\mathcal{I}$
  - Superrotation extension of BMS ASG
- SCET?
  - Freedom to Lorentz transform jet directions (RPI) versus angular momentum flux causing observer rotation (Spin Memory)

Spin Memory



- Subleading graviton soft factor related to $J_{\mu\nu}$
  - $S^{(1)-} = -i \sum_k \frac{p_{k\mu} \varepsilon^{-\mu\nu} q^\lambda J_{k\lambda\nu}}{p_k \cdot q}$
  - subleading $\leftrightarrow \int du...$ vs. $\int du \partial_u ...$
- Superrotation vector fields allow local CKVs
  - $\xi^+|_{\mathcal{I}^+} = Y^{+z}\partial_z + \frac{u}{2} D_z Y^{+z} \partial_u + c.c.$
  - can locally match to different Λ near a set of points on the S^2
- Spin Memory Effect
  - chiral observable projects out transitions associated with supertranslations
  - rotation of geodesic ring, or in fixed-z frame cumulative delay of counterrotating beams: $\Delta^+ u = \frac{1}{2\pi L} \int du \oint_{\mathcal{C}} \left(D^z C_{zz} dz + D^{\bar{z}} C_{\bar{z}\bar{z}} d\bar{z} \right)$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Thursday, July 30

Registration and Continental Breakfast

8:00 AM	**Registration** | Lyman Lobby **Continental Breakfast** | Jefferson Library
9:00 – 9:10 AM	**Welcome** | Jefferson 250 Opening remarks by Stephen Shenker (Stanford)

Morning Lectures | Jefferson 250

Session Chair: Michael Green (Cambridge)

9:10 – 9:50 AM	*Bell Inequalities and Cosmological Correlators* by Juan Maldacena (IAS)
9:50 – 10:30 AM	*Chaos in the Black Hole S-Matrix* by Joe Polchinski (KITP)
10:30 – 11:00 AM	**Coffee break** | Jefferson Library

Session Chair: Raphael Bousso (Berkeley)

11:00 – 11:40 PM	*Black Holes and Moonshine* by Jeff Harvey (Chicago)
11:40 – 12:20 PM	*A Membrane Paradigm at Large D* by Shiraz Minwalla (TIFR)

Lunch

12:20 – 2:20 PM	**BBQ Lunch** | Jefferson Courtyard

Afternoon Lectures | Jefferson 250

Session Chair: Igor Klebanov (Princeton)

2:20 – 3:00 PM	*Sailing into a Black Hole with Andy* by Steve Giddings (UCSB)
3:00 – 3:30 PM	**Coffee break** | Jefferson Library
3:30 – 5:00 PM	**Student Talks** | Jefferson 250 **Session Chair: Hirosi Ooguri (Caltech)** *TBA* by Dionysis Anninos (IAS) *Causality and the Conformal Bootstrap A* by Thomas Hartman (Cornell) *3D Gravity and String Universality* by Alexander Maloney (McGill) *Holographic Entanglement for Chern-Simons Terms* by Gim Seng Ng (McGill) *Dr. Strominger or: How I Learned to Stop Worrying (about singular CKVs) and Love the Triangle* by Sabrina Pasterski (Harvard) *Supersymmetry Constraints on String Dynamics* by Xi Yin (Harvard)

Evening Banquet | Knafel Center, 10 Garden St.

6:30 – 10:00 PM	**Cocktail Reception and Banquet:** *Dress Code: 'Physics casual'*

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Friday, July 31

Continental Breakfast

8:00 AM	Continental Breakfast | Jefferson Library

Morning Lectures | Jefferson 250

	Session Chair: David Morrison (UC Santa Barbara)
9:00 – 9:40 AM	*F-theory and 5d Spinning Black Holes* by Cumrun Vafa (Harvard)
9:40 – 10:20 AM	*Measuring the Elliptic Genus* by Greg Moore (Rutgers)
10:20 – 10:50 AM	Coffee Break | Jefferson Library
	Session Chair: Herman Verlinde (Princeton)
10:50 – 11:30 AM	*Anomalies, Conformal Manifolds, and Spheres* by Nathan Seiberg (IAS)
11:30 – 12:10 PM	*Gravity Dual of Information Metric* by Tadashi Takayanagi (Kyoto & IPMU)

Lunch

12:10 – 2:00 PM	Buffet Lunch | Jefferson Library

Afternoon Lectures | Jefferson 250

	Session Chair: Erik Verlinde (Amsterdam)
2:00 – 2:40 PM	*The Higher Spin Square* by Rajesh Gopakumar (ICTS Bangalore)
2:40 – 3:20 PM	*Towards Emergent Time* by Nima Arkani-Hamed (IAS)
3:20 – 3:50 PM	Coffee Break | Jefferson Library
	Session Chair: Robbert Dijkgraff (IAS)
3:50 – 4:30 PM	*Fun with Fermions* by Frederik Denef (Columbia)
4:30 – 5:10 PM	*An Extremal Black Hole Surprise* by Gary Horowitz (UCSB)

Additional Information

Extra Collaboration Space: Jefferson 453 and HETG Lounge
Late Registrations: Jefferson 453

Wireless Networks: "eduroam" or "Harvard Guest"

Useful Phone Numbers:
Cambridge Taxi Cab (617) 649-7000
Cambridge Taxi (617) 718 - 4000