

Title: Research Talk 2 - Burns holography

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Abstract: I will describe a complete, top-down example of celestial holography, based on recent work with Costello and Paquette. Our duality relates certain models of self-dual gauge theory and conformal gravity, placed on an asymptotically flat four-dimensional spacetime called Burns space, to a two-dimensional chiral algebra living on D1 branes in a topological string theory on twistor space.

Burns holography

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Work with K. Costello & N. M. Paquette

- ▶ Celestial holography: quantum gravity in asymptotically flat spacetimes is dual to a CFT on the celestial sphere

[Strominger '17]

[Pasterski, Pate, Raclariu '21]

- ▶ This talk: build an explicit example on *Burns space*

Costello, Paquette, AS

[PRL 061602]

[2306.00940]

- ▶ Main takeaway: in our example

[Costello, Paquette '22]

$$\text{Celestial holography} = \text{Twisted holography} + \text{Twistor strings}$$

- ▶ Twistor space of $M =$ projective 2-spinor bundle

$$S^2 \rightarrow Z \rightarrow M$$

[Penrose '67]
[Atiyah, Hitchin, Singer '78]

- ▶ **Main trick:** for $M = \text{Blowup}_0(\mathbb{C}^2)$ with “Burns metric”

$$Z \simeq \text{SL}_2(\mathbb{C}) + \text{boundaries}$$

[LeBrun '91]
[Pontecorvo '92]

- ▶ Recycle holography for B-model on deformed conifold

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$$\text{SL}_2(\mathbb{C}) \simeq \text{AdS}_3 \times S^3$$

[Costello, Gaiotto '18]
[Bonetti, Rastelli '16]
[Dijkgraaf, Vafa '02]

- ▶ KK reduce along S^2 fibers of $Z \rightarrow M$

- ▶ Burns metric is a Euclidean signature, asymptotically flat, Kähler metric that is scalar-flat (but not Ricci-flat)

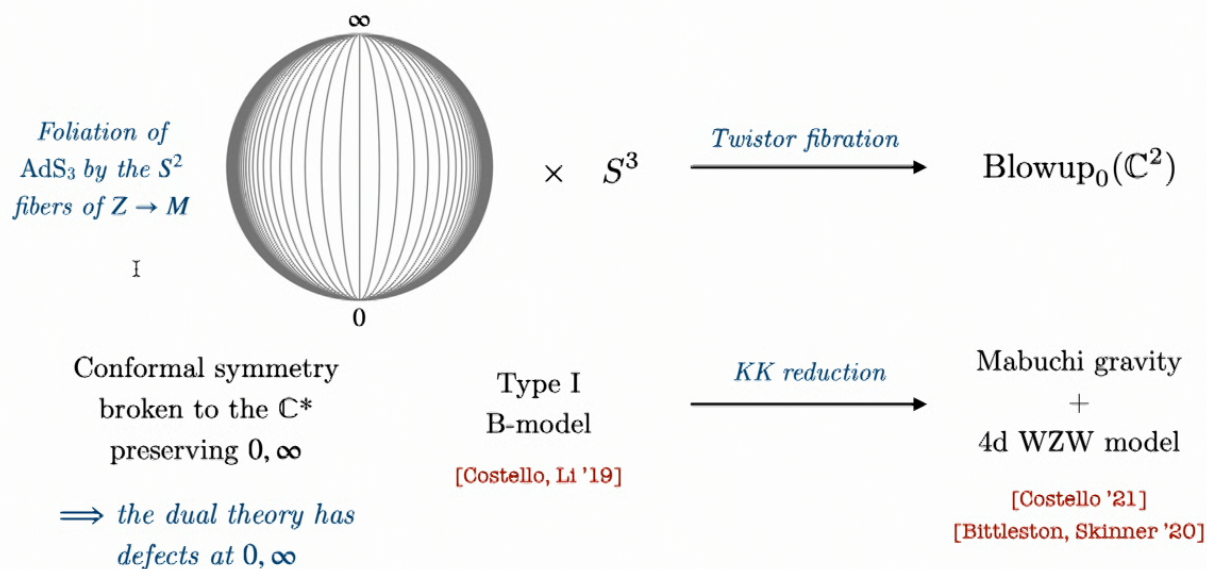
Kähler potential

$$K = |u|^2 + N \log |u|^2$$

$$u_i \in \mathbb{C}^2 - 0$$

[Burns '86]

[LeBrun '88]



The theory on Burns space

- ▶ $\mathcal{K} = K + \rho$
- ▶ $\mathfrak{g} : \text{Burns space} \rightarrow \text{SO}(8)$

[Mabuchi '86] [Donaldson '85] [Nair '91]
 [Losev, Moore, Nekrasov, Shatashvili '95]
 [Ooguri, Vafa '91] [Yang '77]

$$S_{4d} = \int_M \text{Ric}(\mathcal{K}) \wedge \partial\mathcal{K} \wedge \bar{\partial}\mathcal{K} + \int_M \partial\bar{\partial}\mathcal{K} \wedge \text{tr}(\mathfrak{g}^{-1}\partial\mathfrak{g} \wedge \mathfrak{g}^{-1}\bar{\partial}\mathfrak{g}) - \frac{1}{3} \int_{M \times [0,1]} \partial\bar{\partial}\mathcal{K} \wedge \text{tr}(\tilde{\mathfrak{g}}^{-1}d\tilde{\mathfrak{g}})^3$$

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- ▶ Eoms: $R(\mathcal{K}) = 0$
 $F^-(A) = 0, \quad A = -\bar{\partial}\mathfrak{g}\mathfrak{g}^{-1}$
- ▶ The Wess-Zumino term imposes quantization of N .

The celestial chiral algebra

- ▶ Theory of N D1s + 8 D5s + O5 in twistor space of \mathbb{C}^2 [Costello '21]
- ▶ $\text{Sp}(N)$ gauge theory with $\text{SO}(8)$ flavor symmetry [Costello, Li '19]

$$\text{D1-D1} \quad X_{iab}(z) \in \mathbb{C}^2 \otimes \wedge^2 \mathbb{C}^{2N} \quad X_{iab}(z) X_{jcd}(w) \sim \frac{1}{z-w} \varepsilon_{ij} \varepsilon_{a[c} \varepsilon_{b|d]}$$

$$\text{D1-D5} \quad I_{ra}(z) \in \mathbb{C}^8 \otimes \mathbb{C}^{2N} \quad I_{ra}(z) I_{sb}(w) \sim \frac{1}{z-w} \delta_{rs} \varepsilon_{ab}$$

Weight $(\frac{1}{2}, 0)$ bosons

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Defect boundary conditions

$$X \sim 1/z \text{ at } z = 0, \infty$$

$$I \sim 1/\sqrt{z} \text{ at } z = 0, \infty$$

“Ramond puncture”

Most general poles consistent with regularity of bulk-brane couplings (Koszul duality)

[Costello, Paquette '20, '22]

[Paquette, Williams '21]

Testing the duality: an example

- ▶ Gauge invariant operators:

Soft currents

[Strominger '21]
[Guevara, Himwich, Pate
Strominger '21]

$$J_{rs}[k, l](z) = I_r X_1^{(k)} X_2^{(l)} I_s$$

dual to soft modes of
4d WZW on Burns space

Hard states

$$J_{rs}(\omega, z, \bar{z}) = I_r e^{\omega z (X_1 + \bar{z} X_2)} I_s$$

- ▶ Planar correlator without defects reproduces 2-pt amplitude of Hawking, Page & Pope '80.

$$\langle J_{pq}(\omega_1, z_1, \bar{z}_1) J_{rs}(\omega_2, z_2, \bar{z}_2) \rangle = -\frac{N}{z_{12}^2} J_0 \left(\sqrt{4N\omega_1\omega_2 z_1 z_2 \frac{\bar{z}_{12}}{z_{12}}} \right) \text{tr}(\mathbf{t}_{pq} \mathbf{t}_{rs})$$

Further tests & future directions

- ▶ Collinear limits match chiral algebra OPEs at 0th and 1st order in N .
- ▶ (Tree) amplitudes enjoy enhanced conformal symmetry in z , so are conjecturally computed by the chiral algebra without defects.
- ▶ Form factors are in 1:1 correspondence with correlators built from nonzero defect 1-point functions.
- ▶ Is there a dual of Witten's supersymmetric twistor string?
Can we venture beyond self-dual sectors?
[Witten '03]
[Costello, Paquette '20]
- ▶ Are there multi-centered generalizations of our duality?
[Gaiotto, Budzik '22]
[Hartnoll, Policastro '04]
[Donaldson, Friedman '89]
- ▶ Can we discover dualities for self-dual Einstein gravity?
[Skinner '13]
[Bittleston, Heuveline, Skinner '23]