Throwing Strings into Microstate Geometries

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Based on [2106.03841] with S. Hampton and Y.Li
Generalization of work by Martinec and Warner [2009.07847]

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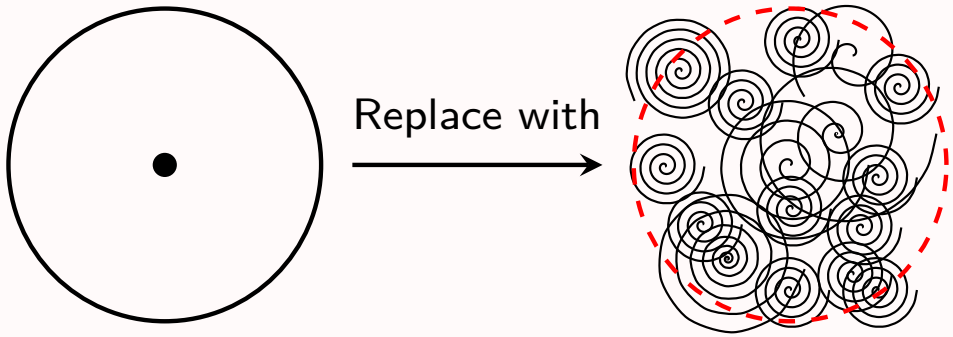
Contents

1. Introduction
2. Tidal Forces on infalling strings
3. Summary and Outlook

Introduction

Motivation – Black Holes

- New observational data
- Refinement of theoretical results – Information Paradox [Hawking;...]
- Resolution might involve new physics [Almheiri, Marolf, Polchinski, Sully;...] such as:
  - Firewalls [Almheiri, Marolf, Polchinski, Sully;...]
  - Islands, Wormholes, ... [Penington; Almheiri, Engelhardt. Marolf, Maxfield; ...]
  - Fuzzballs [Mathur, Lunin; Bena, Warner, ...]
- Fuzzballs: Take the microstate counting seriously [Strominger, Vafa; Sen; ...]
  There exist $e^{S_{BH}}$ explicit microstates with structure at the would-be horizon



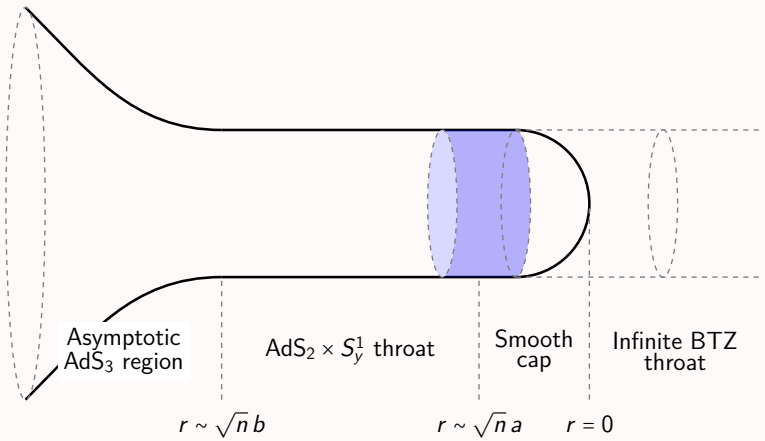
- A typical state might include arbitrary high-energy modes
- Arguments supported by constructions in string theory

Microstate Geometries

[Mathur, Lunin; Bena, Giusto, Martinec, Russo, Shigemori, Turton, Warner;. . .]

- Some microstates can be seen within (super)gravity: *Microstate geometries*: Smooth horizonless solutions within supergravity that have the same charges as the usual black hole
- Well studied example is D1-D5 system (can use AdS_3/CFT_2 duality): Microstates of the extremal D1-D5-P black hole – $(1, 0, n)$ superstrata

$$J_L = J_R = \frac{R_y}{2} a^2 , \qquad Q_P = \frac{1}{2} n b^2 .$$

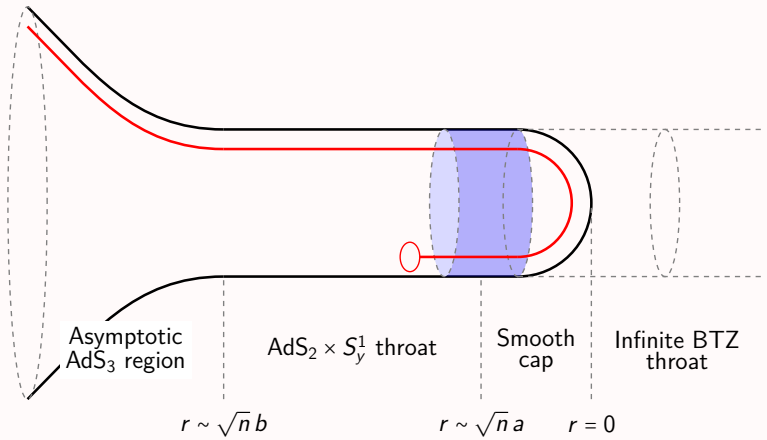


- Asymptotically $AdS_3 \times S^3 \times T^4$.

Tidal Forces on infalling strings

Previous Results

- The capped structure implies physics different from that of a classical black hole: for example gravitational echoes. [Bena, Heidmann, Monten, Warner]
- Capped geometries exhibit large tidal forces high up the throat. [Tyukov, Walker, Warner; Bena, Martinec, Walker, Warner]
- If the infalling probe is a massless string then tidal forces cause string excitations → String obtains mass. [Martinec, Warner]
- The resulting massive string gets trapped at the cap, but can emit low energy radiation that escapes to infinity.

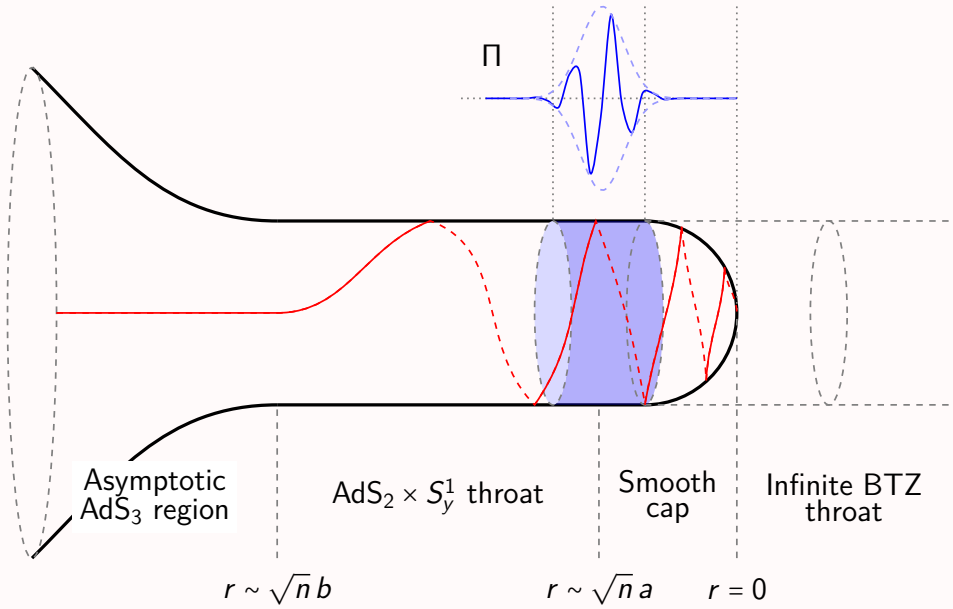


Stringy Probe

- We need full 10-dimensional string frame metric:

$$ds_{10}^2 \;=\; \Pi\left(\widetilde{ds}^2_{\mathrm{AdS}_3} \;+\; \widetilde{ds}^2_{S^3} \;+\; ds^2_{T^4}\right).$$

- Infall of a massless string – follows a spiralling null geodesic.



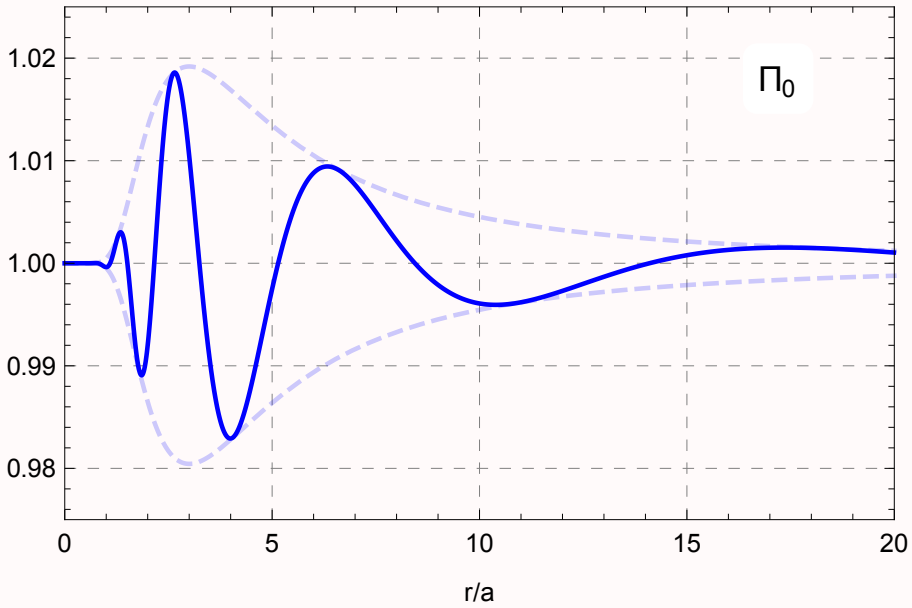
- Use Penrose Limit to analyse the quadratic neighbourhood of the geodesic

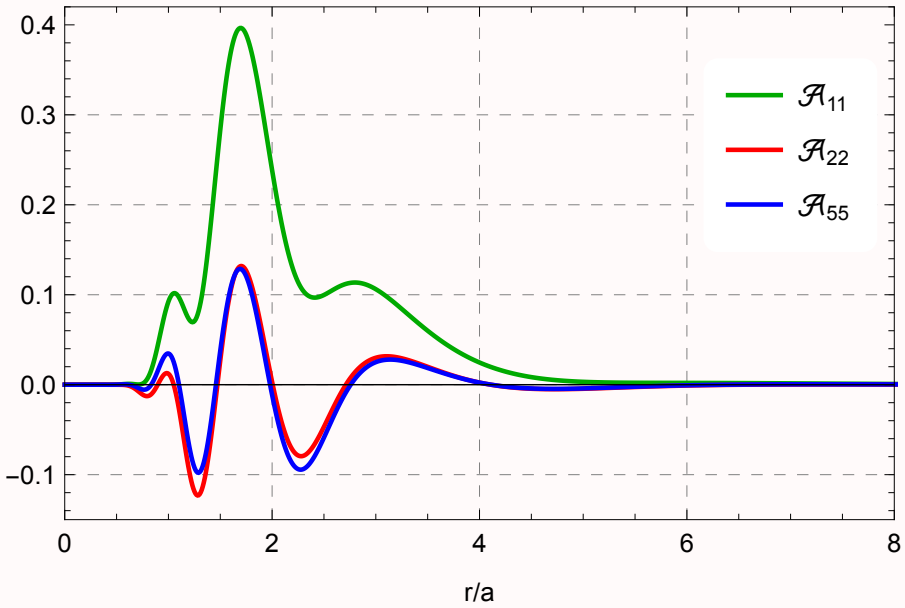
$$ds_{10}^2 \;=\; 2dx^+\,dx^- - \mathcal{A}_{ij}(x^-)\,w^i\,w^j\,(dx^-)^2 + \delta_{ij}\,dw^i\,dw^j\,.$$

Tidal Forces

- $\mathcal{A}_{ij}$ appears as a mass matrix in the equations of motion of the string modes in light-cone gauge

$$\partial_\tau^2 w^i + k^2 w^i + (\alpha' E)^2 \mathcal{A}_{ij}(\tau)\, w^j + ik\,\alpha' E\, B_{ij}(\tau)\, w^j = 0\,.$$





- Oscillatory behaviour of all $\mathcal{A}_{ii}$.
- Along y direction only compression.
- Along the S^3 *and* the T^4 both stretching and compression.
- Amplitude of $\mathcal{A}_{ij}$ scales with length of throat.

Summary and Outlook

Summary and Outlook

Summary

- Tidal forces along T^4: full 10D important.
- String alternately experiences stretching and compressing.
- Supports CFT intuition.

Outlook

- What is the exact fate of the string?
  - B-field contributions?
  - Resonances?
- Subleading effects in Penrose limit: Effects coming from the different sizes of S^3 and T^4.
- What is the precise dual of this result in the CFT? [see Shaun's talk]