Title: String Theory of Supertubes

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Abstract: The internal structure of extremal and near-extremal black holes in string theory involves a variety of ingredients â€” strings and branes â€” that lie beyond supergravity, yet it is often difficult to achieve quantitative control over these ingredients in a regime where the state being described approximates a black hole.Â The supertube is a brane bound state that has been proposed as a paradigm for how string theory resolves black hole horizon structure.Â This talk will describe how the worldsheet dynamics of strings can be solved exactly in a wide variety of supertube backgrounds, opening up the study of stringy effects in states near the black hole transition.

Thou shalt not put (ordinary) stuff at the horizon

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with

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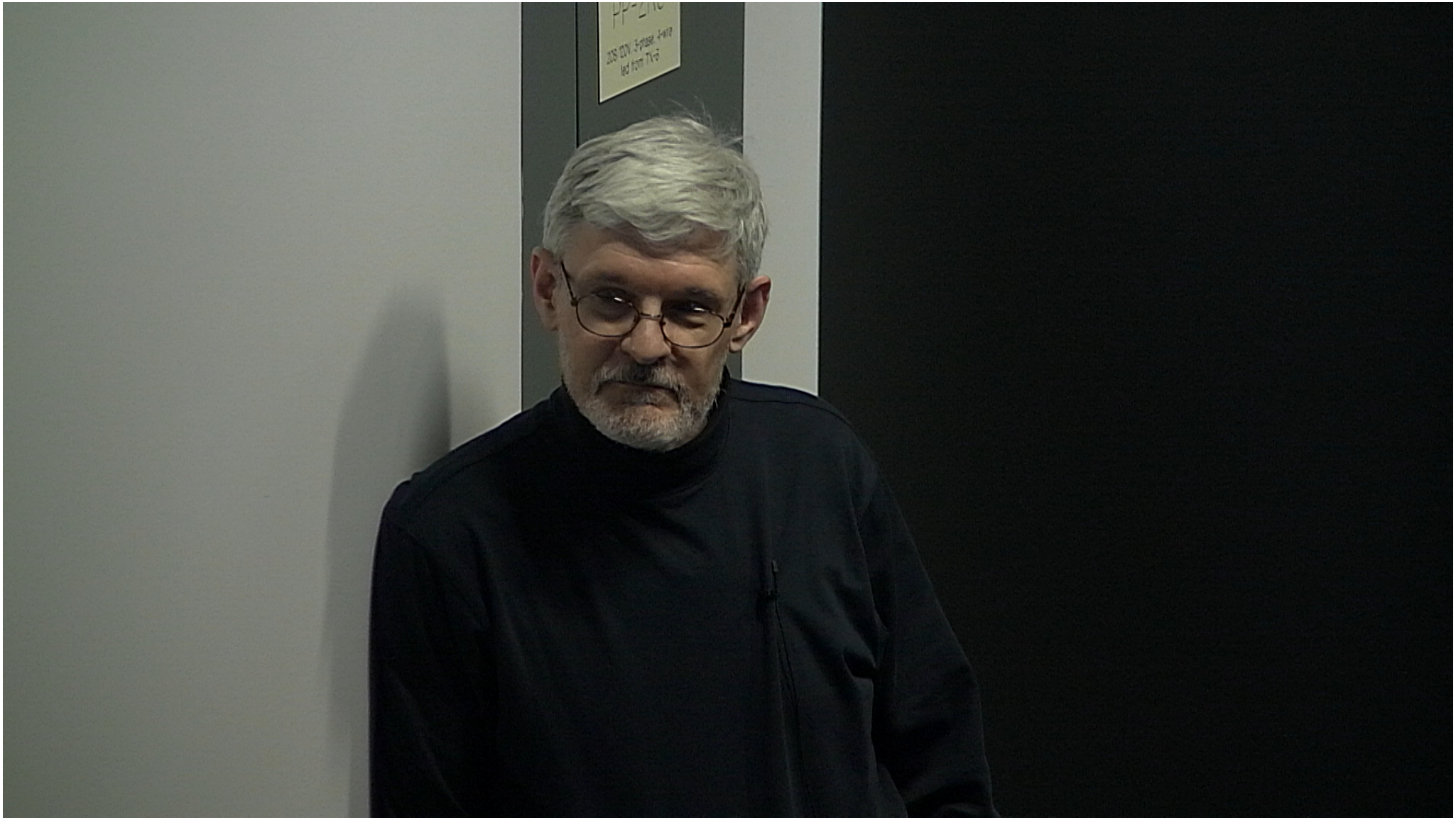
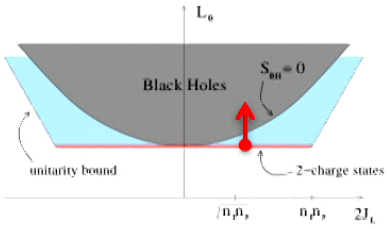
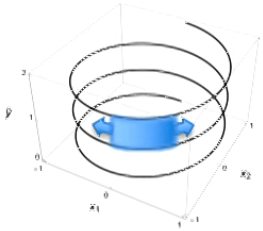


Overview

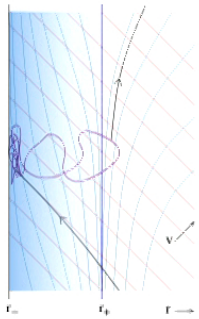


- Review of the 3-charge system
- Supertubes and phase structure

- A supertube spiral



- Decorating the supertube:
  Long string structure in the bulk



- Speculations on horizon structure

String Theory of Supertubes

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based on arXiv pubs:

1409.6017 (EJM)

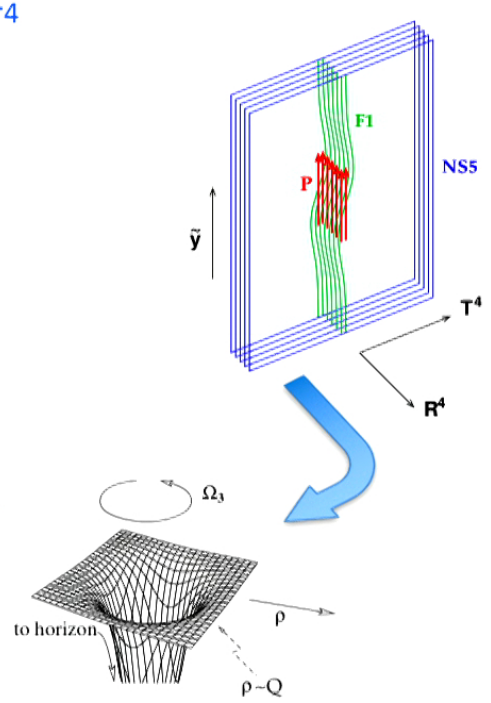
1705.10844 (EJM, Stefano Massai)

Branes, Geometry and Entropy

- Standard example of μstate counting (Strominger-Vafa '96):

  String theory compactified on $(S^1)_y \times T^4$

- Wrap n_1 **F1-strings** along $(S^1)_y$
- Wrap n_5 **NS5-branes** along $(S^1)_y \times T^4$
- Excite n_p **units of momentum P** along $(S^1)_y$



- The near-horizon geometry is $BTZ \times S^3 \times T^4$
- Dual to thermal ensemble in CFT_2

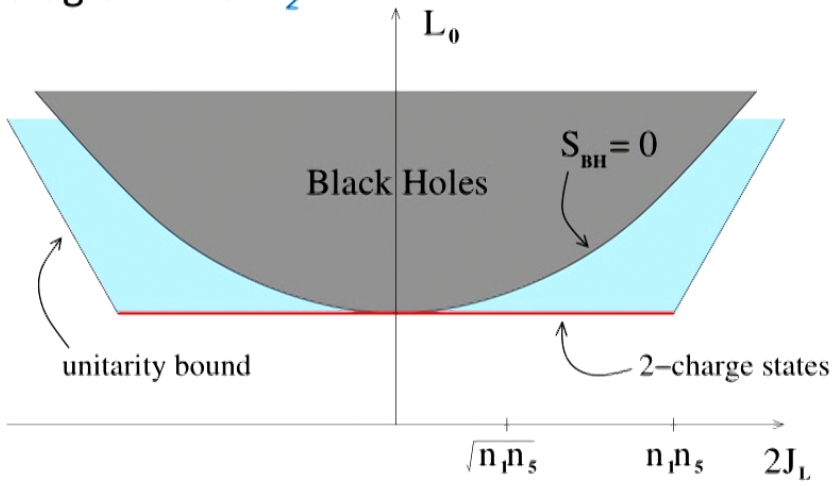
Branes, Geometry and Entropy

- In the near-horizon geometry $BTZ \times S^3 \times T^4$, the area of the horizon determines the semiclassical BH entropy

$$S_{\rm BH} = \frac{area}{4G} = 2\pi\sqrt{n_5 n_1 n_p - J^2}$$

effect of S^3 rotation

- The naïve phase diagram in CFT_2 :

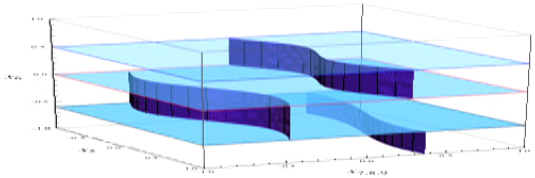


Branes, Geometry and Entropy

- In the near-horizon geometry *BTZ x S^3 x T^4*, the area of the horizon determines the semiclassical BH entropy

$$S_{\rm BH} = \frac{area}{4G} = 2\pi\sqrt{n_5 n_1 n_p - J^2}$$

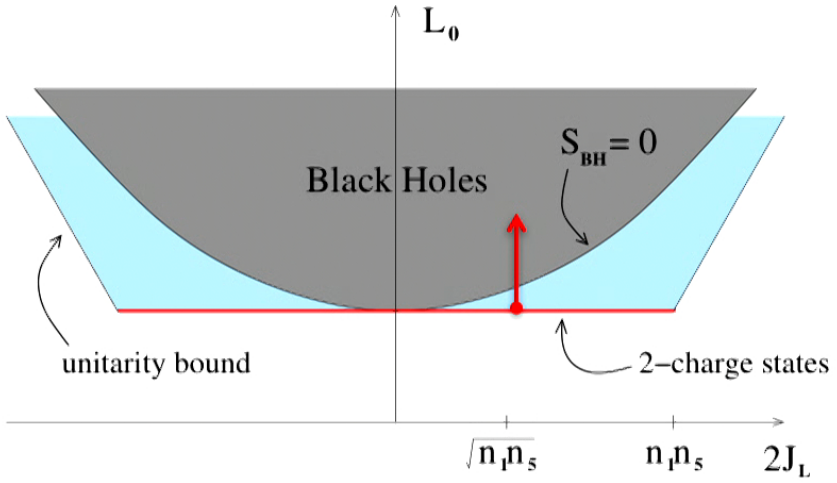
- In 1+1d CFT dual, get this same accounting via oscillator excitations in a *"long string"* sector



- Is this *long string* physics emergent in the near-horizon structure of this class of BH geometries on the gravity side? How to see it, since the naïve supergravity solution is featureless at the horizon scale?

Branes, Geometry and Entropy

- Recent work on microstate geometries adopts a strategy that starts with a (supersymmetric) rotating 2-charge (**NS5**-**F1**) brane configuration (not the μstate of a macroscopic BH), and decorates it with coherent (not thermal) momentum excitations to move into the BH regime:



BPS Microstate Geometries

- All 2-charge BPS µstate sources (w/$n_p = 0$) generate explicitly known nonsingular supergravity solutions called ***supertubes***
  (Mateos-Townsend '01, Lunin-Mathur '01)

- The typical such geometry has large stringy corrections
  (EJM-Sahakian '99, Lunin-Mathur '01)

- The foundation upon which 3-charge μstates are built is the collection of 2-charge supertubes, so it pays to understand the latter in as much detail as possible, especially when they are stringy

BPS Microstate Geometries

- Ideally we would like an exactly solvable worldsheet CFT for the supertube, and remarkably, *this can be achieved!*
- The worldsheet theory is a gauged WZW model (a CFT based on current algebra symmetries) for the group quotient

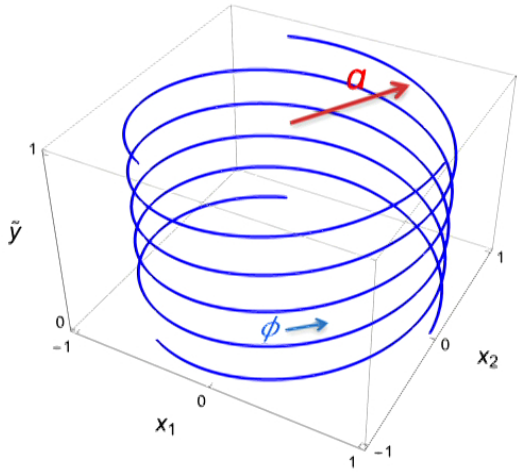
$$G/H = \left(\frac{\mathbb{R}^{1,1} \times SL(2,\mathbb{R}) \times SU(2) \times \mathbb{T}^4}{U(1)_L \times U(1)_R} \right)$$

- By varying the embedding of H into G, one finds a variety of supertubes: NS5-P, NS5-F1, as well as spectral flows thereof (including the nonsupersymmetric "JMaRT" geometry)
- Null gauged WZW models appear to be a valuable tool to explore near-horizon structure.

Supertubing

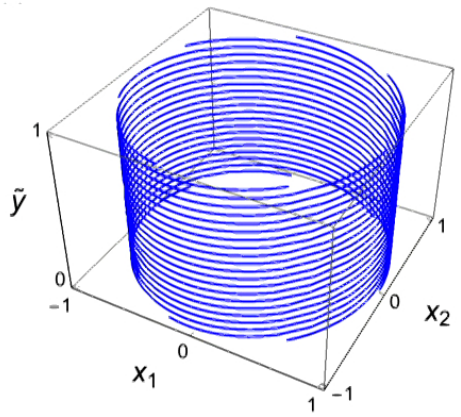
- A particularly simple class of configurations: Round rotating NS5-P supertubes exciting a single harmonic of the scalars parametrizing the brane embedding:

$$X^1 + iX^2 = a \exp\left[\frac{ik}{n_5}(t + \tilde{y}/\tilde{R})\right]$$



Fivebrane "hidden structure"

- There is a rich *"fine structure"* in the source geometry which is invisible to supergravity because it is non-perturbative in the string tension α'

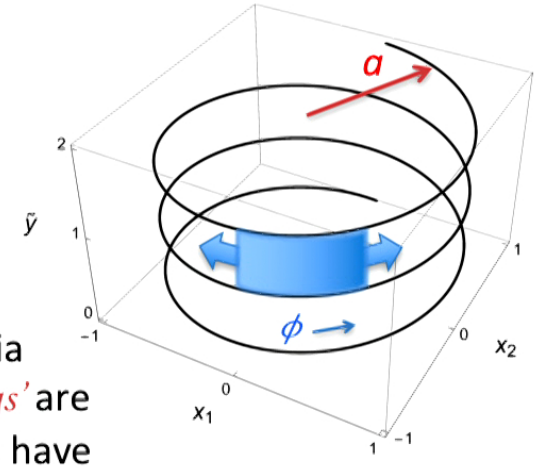


- Recent constructions of (superstratum) microstate geometries wiggle the smeared geometry. Expect a rich variety (and entropy) of stringy excitations of the fine structure of the source . . . far exceeding the variety of supergravity excitations.

μ-states and phase structure

- Low-energy dynamics on (nearly) coincident NS5's is governed by *'little string theory'*. For instance, Maldacena showed that NS5 thermodynamics is the Hagedorn thermodynamics of little strings.

- On the Coulomb branch of separated NS5's, *'little W-strings'* are D2-branes stretching between NS5's (or in the T-dual NS5-F1, D3-branes wrapping KK-dipole cycles)

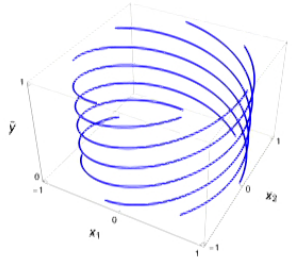


- Supertubes separate the fivebrane source via transverse excitation, thus the *'little W-strings'* are heavy; the supertube ground state does not have huge entropy, but excited states are highly entropic

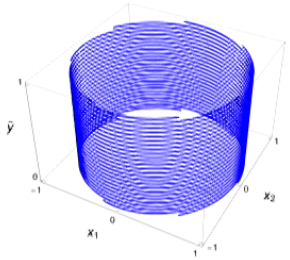
μ-states and phase structure

- A *W-brane* pinned between successive windings of the fivebrane helix has monodromy allowing parametrically soft excitations – due to the large winding, open strings live on a k-fold cover of the ϕ circle.

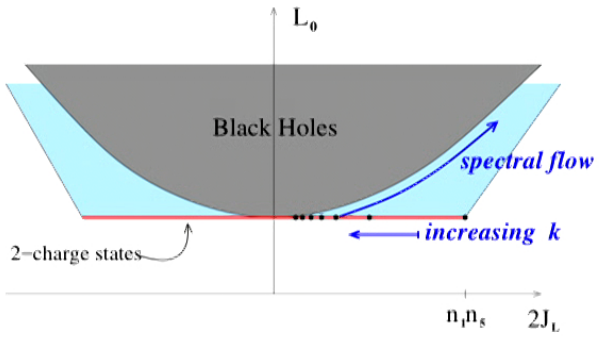
- One expects these *W-branes* to be precursors of the 'long string sector' which arises in the BH regime of the ***spacetime*** CFT dual to AdS_3.
  The "long string sector" of the CFT is a particular class of little strings.



k = 5



k = 25



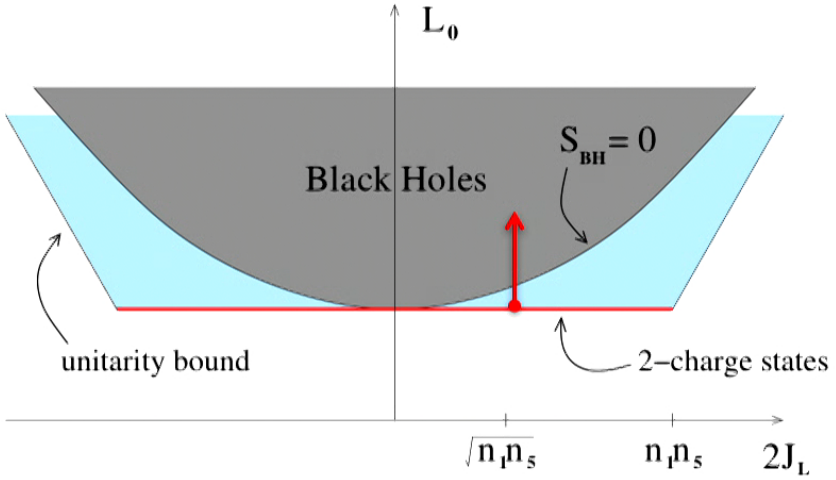
the emerging picture:

- Supertubes approaching BH transition: Angular momentum supports smooth but stringy Coulomb branch fivebrane configurations; W-branes wrap topology at the bottom of the throat, become light near the BH threshold, and are expected to dominate entropically in the BH regime, often thought of as the Higgs branch of the underlying brane dynamics.

- The long string phase emerges as the BH threshold is crossed on the phase diagram

Coulomb dominated

Higgs dominated

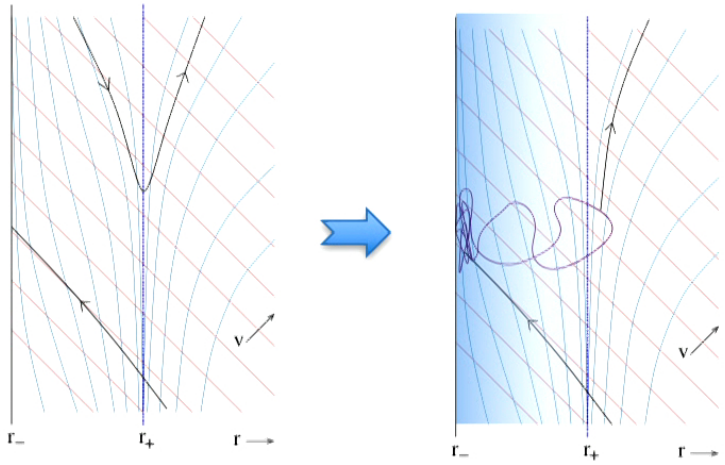


the emerging picture:

- The geometrical regime of smooth "capped throat" geometries is separated from the BH regime by a phase transition that is similar in many respects to the standard paradigm of gauge/gravity duality
- At weak coupling, this is "deconfinement" of nonabelian brane dof's
- These dof's lead to a breakdown of the supergravity approximation
- We are starting to see this structure on the gravity side of the duality
- The new dof's ***are*** the entropic dof's of the BH.
- ***The scale of their quantum wavefunction is the horizon scale***

Paradox lost?

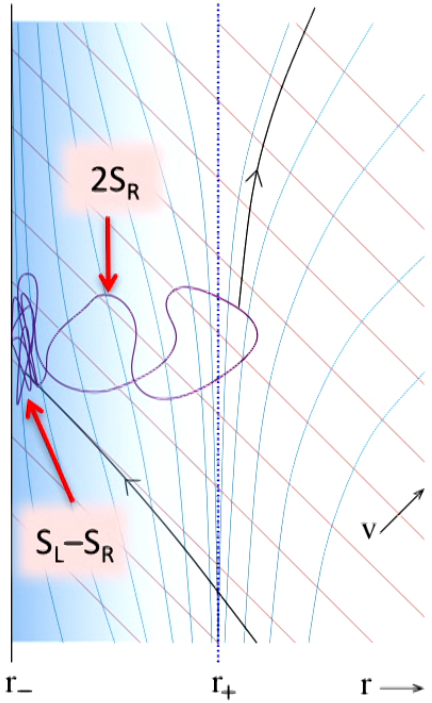
- The incoherent Hawking process is replaced by *coherent* emission from long/little strings, so long as you don't trace over their dof's:



Long strings remain coherent at the horizon scale because they are at their correspondence point (Horowitz-Polchinski '96), with n_5 times smaller tension. The horizon scale is the scale of the long string wavefunction. We hope to see the formation of this scale from the structure of Coulomb branch W-branes

μ-states and phase structure

- Effective geometry (esp. causal structure) seen by probes is the result of tracing over the long string dof's
- Unlike the RG where high energy dof's are slaved to low energy dof's, here one is throwing away info – long string excitations are extremely *soft* as seen from far away
- The *inner horizon is singular* even in GR, and extremal BH's are a bit degenerate: $r_+ = r_-$
- What happens to an infalling probe in nonextremal μstates is essentially a question of the response function of the brane matter



μ-states and phase structure

- Possible long string response functions:
  - Could be stiff – a firewall
  - Could be soft – fuzzball complementarity

- Conjectures:
  - The response function is soft for local probes at $r > r_-$; local EFT is valid.
  - The inner horizon is a stiff wall
  - The BH interior $r_- < r < r_+$ is in a mixed phase, with both geometrical (Coulomb) and entropic (Higgs) dof's