Black holes in the quantum universe: perspectives and observational prospects

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Some basic points:

1) There is now a broad view in the quantum gravity community that consistency of BHs with quantum mechanics requires modification to GR+local QFT *at horizon scales* (or larger) of a big BH.

2) There is not (yet) consensus about what this new physics is.

3) This is, of course, extremely interesting given new observational windows to near-horizon physics: GW + VLBI.

Tests for this new physics??

To elaborate:

The problem in a nutshell:

GR+LQFT, via Hawking's calculation, imply BHs build up entanglement with their environments ("missing information")

If a BH disappears at the end of evaporation, this then violates QM (unitarity) (apparently very bad — also leads to drastic violation of E conservation)

[Banks, Peskin, Susskind]

Planckian remnant scenarios do not appear viable (though dissent among panel): *unbounded production instabilities*

[Preskill; hep-th/9304027, hep-th/9412159, Susskind]

"Obvious" way out: information must escape a BH, while it is *macroscopic*

Forbidden by locality principle of QFT, *but* the least radical proposal

Implies new physics beyond LQFT+GR, "reaching out past the horizon"

Outline of scenarios:

1) **Massive remnant** [hep-th/9203059]

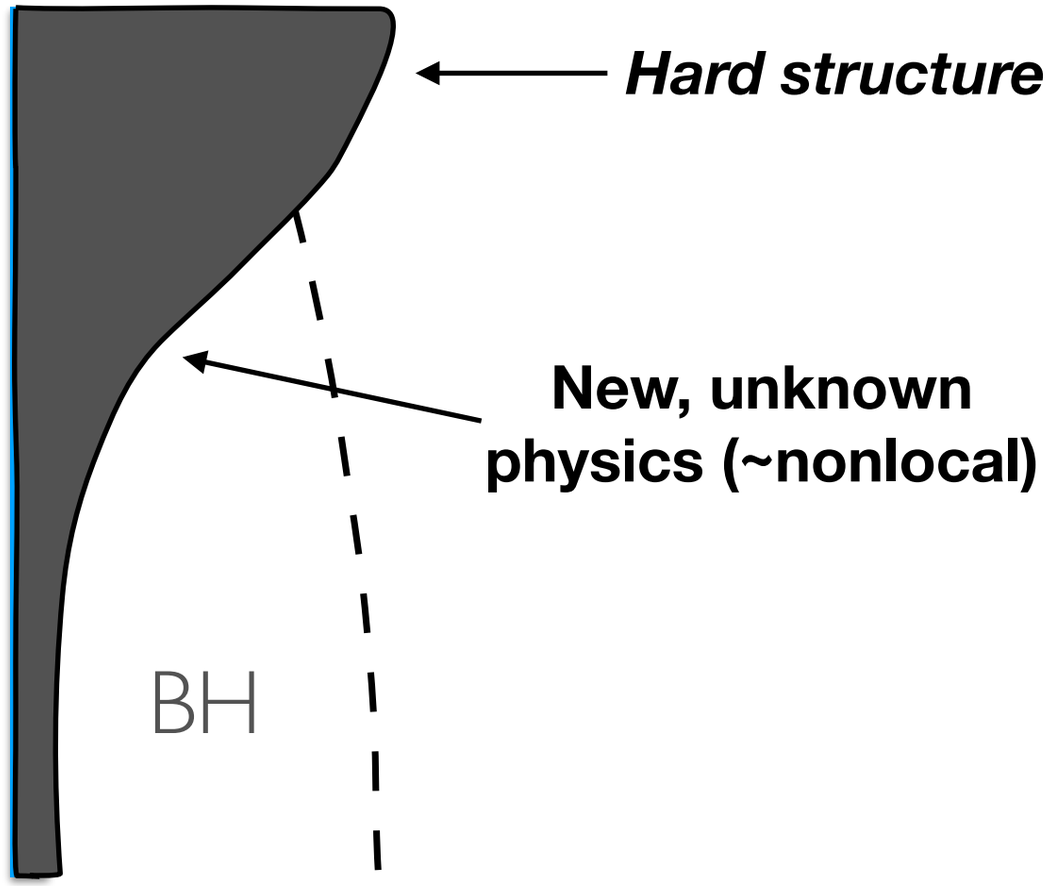
e.g.: Gravastar [Mazur/Mottola]

Fuzzball [Mathur …]

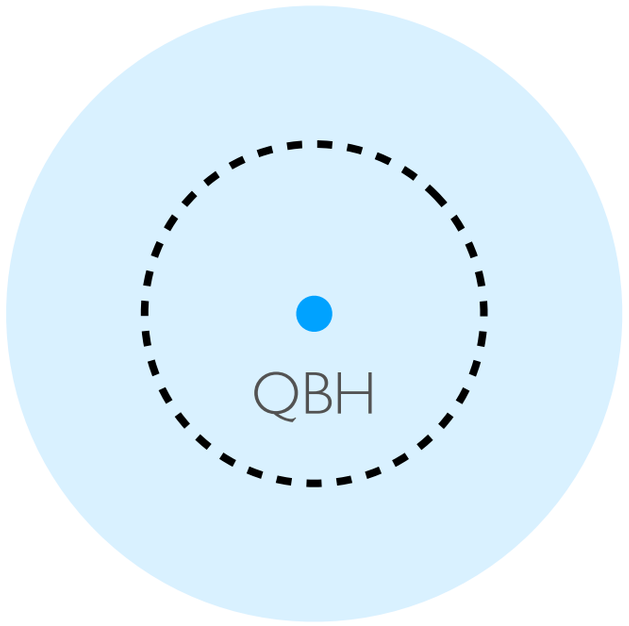
Firewall [AMPS]

Planck star [Rovelli/Vidotto]

(variant: BH never forms)



2) **Soft gravitational atmosphere**



3) **More radical nonlocalities (ER=EPR, etc.)**

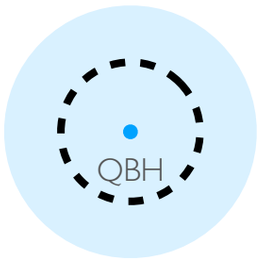
Soft gravitational atmosphere: [1401.5804, 1701.08765, + antecedents]

Key postulates:

1. Quantum mechanics holds (sufficiently generalized)
2. Existence of quantum subsystems, e.g. BH + environment (approx.?)
3. Correspondence with LQFT
4. Universality of new effects (~gravity!)

Imply interactions between internal state of BH, and environment: necessary to transfer information (postulate 1!)

Simplest version, respecting 4: ~ "state dependent metric fluctuations"



$$H_I = \int dV\, H^{\mu\nu}(x)\, T_{\mu\nu}(x) \qquad g^{\rm eff}_{\mu\nu} = g^0_{\mu\nu} - H_{\mu\nu}$$

Operator, depending on BH state
Support in "atmosphere"

How large?

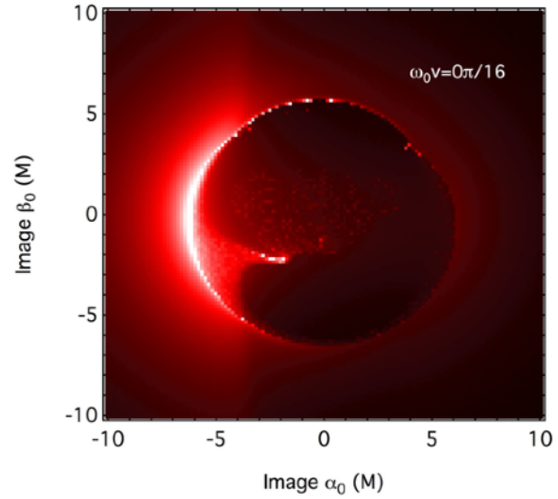
$\langle H_{\mu\nu}\rangle \sim 1$ **clearly sufficient** **"soft, strong"**

interestingly, $\langle H_{\mu\nu}\rangle \sim e^{-S_{bh}/2}$ **also sufficient: quantum argument, relying on large # BH states** **"soft, weak"**

Observational approaches:

VLBI: EHT

e.g. soft, strong gravitational atmosphere

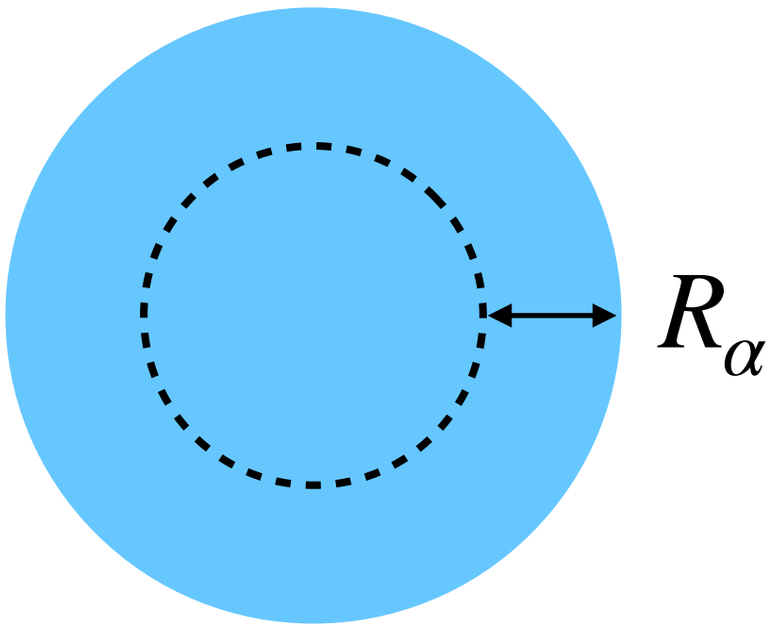


[SG/Psaltis, 1606.07814]

or, potentially, in massive remnant scenarios

Gravitational waves: Exciting prospect!

Schematic parameterization: **[1602.03622, 1703.03387]**

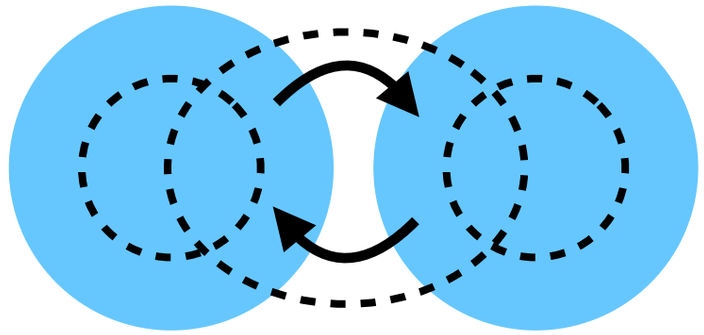


L: hardness scale ($L \lesssim R_\alpha$)

(also, strength, …)

(related discussion: Cardoso, Pani)

2 challenges:



1) Need full nonlinear evolution for GW signal, comparison with GR!

Not yet detailed proposals, for *any* scenario

hard ~ NS [1602.03622]

2) Gravitational "obscuration" of deviations

(Contrast: "echoes:" no final BH)

An approach to 1), beginning to test 2): effective metric, stress tensor

$$\langle G_{\mu\nu}[g^{\rm eff}]\rangle = 8\pi G\langle T^{\rm eff}_{\mu\nu}\rangle$$

WIP, with simple model T's, with Koren and Verastegui (bright UCSB students)

Discussing GW simulation tests, w/ Lehner, Neilsen

(see also work on Boson stars, etc. …)

Also: Soft, weak: likely altered absorption

EMRIs (LISA): back to "geodesic" probes…, ~VLBI