Title: Can we observe firewalls or fuzzballs?

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Abstract:

Can we observe firewalls or fuzzballs?

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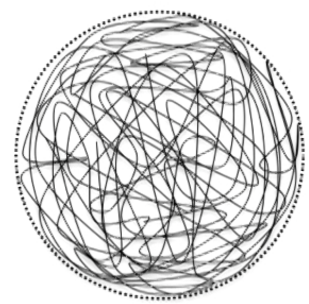
Quantum Black Holes in the Sky

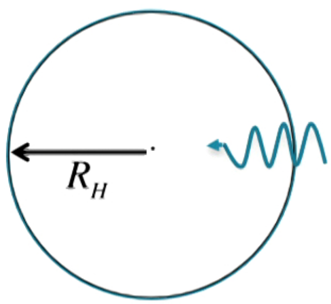
Perimeter Institute



arxiv:1711.01617

Classical Black Holes

- General Relativity says horizon region of a black hole is a vacuum state
  - Infalling observer won't experience anything when crossing the horizon



moves smoothly across the horizon

Hawking Radiation

- Black holes radiate thermally but the radiation is stretched to **infinity** with

$$T = \frac{1}{8\pi M}$$

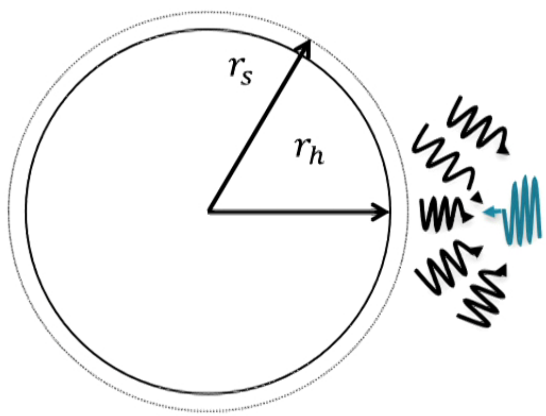
- Starting with vacuum, ending with radiation violates unitarity (information paradox)
- There is a monotonic increase in entropy due to entanglement of particle pairs, with one falling inside the horizon and the other one going to infinity

Firewall Argument

- Proposed by **A**lmheiri, **M**arolf, **P**olchinksi, **S**ully in 2013
  - (1) The information of the hole is radiated away the same way as any other black hole body (no monotonic increase in entropy)
  - (II) Consider a surface located at r_s (stretched horizon) which is $1\ l_p$ outside of horizon ($r_h = 2GM$) then for $r > r_s$ physics is described by Effective Field Theory

Firewall argument cont.

- If a shell is approaching r_s at speed of light then the stretched horizon can't respond to this shell until shell reaches r_s
- They concluded that an in-falling particle would see a firewall of radiation



Issue with Firewall construction

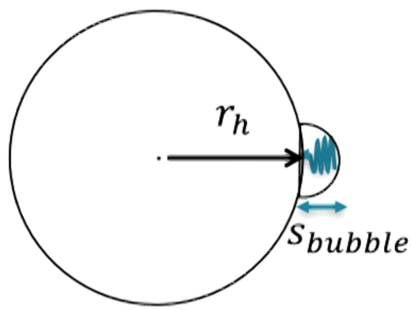
- (I) and (II) are in conflict with each other
  - (I) standard radiation, (II) $r > r_s$ EFT
- Why? Well consider a black hole of mass M. Using (II) anything at $r > r_s$ should behave according to 'normal physics'
- Consider collapsing shell of massless particles of mass ΔM. The shell will collapse all the way down to $r = r_s$ uhindered
- Horizon at $r_h' = 2G(M + \Delta M)$ but by (II) it must past 'without problem' through this region

Issue with Firewall construction

- But this information is trapped inside it's own horizon
- This violates (II) stating for at $r > r_s$ phenomena should obey normal physics since now recovering the information would violate causality
- Therefore the energy can not be radiated away from the surface to infinity in violation of (I)

Back-reaction of geometry

- Imagine an infalling particle of energy E



$$s_{bubble} = \left(\frac{E}{T}\right)^{1/2} l_p$$

$$T = \frac{1}{4\pi r_h}$$

'Modified firewall conjecture'

- Consider particle of energy E falling towards black hole of mass M
- At a certain distance s_{bubble} from the horizon, r_h, the particle **should** be swallowed up by a new horizon
- Quantum gravitational effects must arise at or before s_{bubble}

Modified firewall conjecture cont.

- For this we use Fuzzball construction where we get a tunneling into new fuzzball states right before reaching s_{bubble}
- Fuzzball **radiates** like a piece of coal
- Look for interactions in region $s_{bubble} < s$
- If $P_{int} \sim 1$ then we have a 'modified firewall'
    - In-falling particle interacts with radiation
- If $P_{int} \ll 1$ then we have NO modified firewall

$AdS_3 \times S^3$
CAUTION

Modified firewall conjecture cont.

- For this we use Fuzzball construction where we get a tunneling into new fuzzball states right before reaching s_{bubble}
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Fuzzball paradigm

- Horizon is **replaced** by an object (fuzzball) that radiates directly from **surface** like a piece of coal (this solves the information paradox)

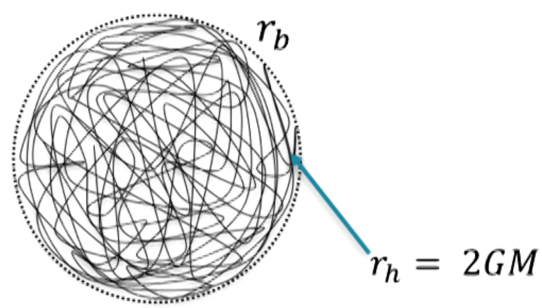
- Can observations distinguish a traditional hole from a fuzzball
  - Does infalling particle interact with emerging radiation? (**firewall** of radiation) $P_{interact} \sim 1$
  - Can particle emerge from reflecting off radiation or off the fuzzball surface?

Fuzzball Geometry

- Assume we have a fuzzball (long vibrating closed string) with no charge or rotation, roughly spherical in shape; outside of the fuzzball surface we have the metric

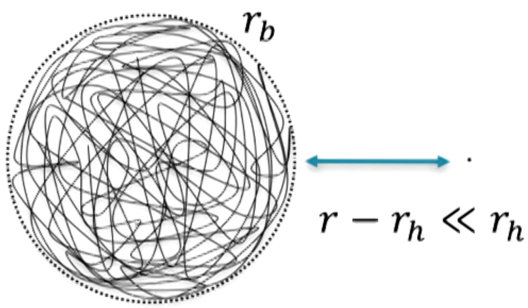
$$ds^2 = -\left(1 - \frac{2GM}{r}\right)dt^2 + \frac{dr^2}{\left(1 - \frac{2GM}{r}\right)}dr^2 + r^2 d\Omega_2^2$$

- Fuzzball boundary at $r_b = 2GM + \epsilon$ where $\epsilon \sim \frac{l_p^2}{GM}$ (**tight fuzzball**)
- Giving proper distance $s \sim l_p$

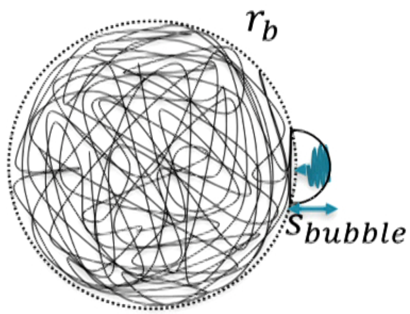


Near horizon scattering

- Perform particle scattering in near horizon region
$$r - r_h \ll r_h$$
  - In this region we assume radiation is isotropic
- Corresponds to a proper distance
$$s \sim r_h^{1/2}(r - r_h)^{1/2}$$
- Consider local **orthonormal frame** (Schwarschild frame) so that metric is locally flat



Scattering outside of s_{bubble}



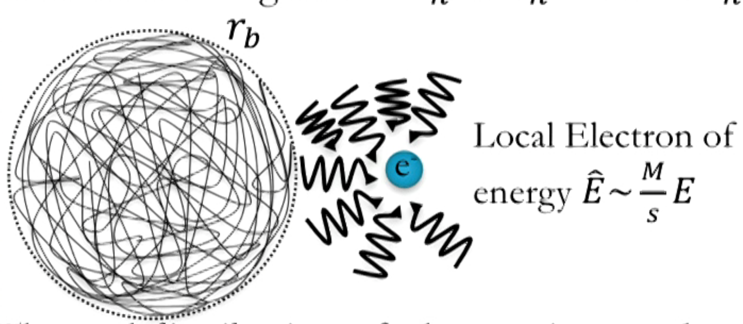
$$s_{bubble} = \left(\frac{E}{T}\right)^{1/2} l_p$$

- For $E > T$, $s_{bubble} > l_p$
- Fuzzball picture – tunneling into new fuzzball states ensues right before particle reaches s_{bubble}
- Ask if particle sees a firewall within region $s_{bubble} < s$

Electron-Photon scattering

- Electron-photon scattering

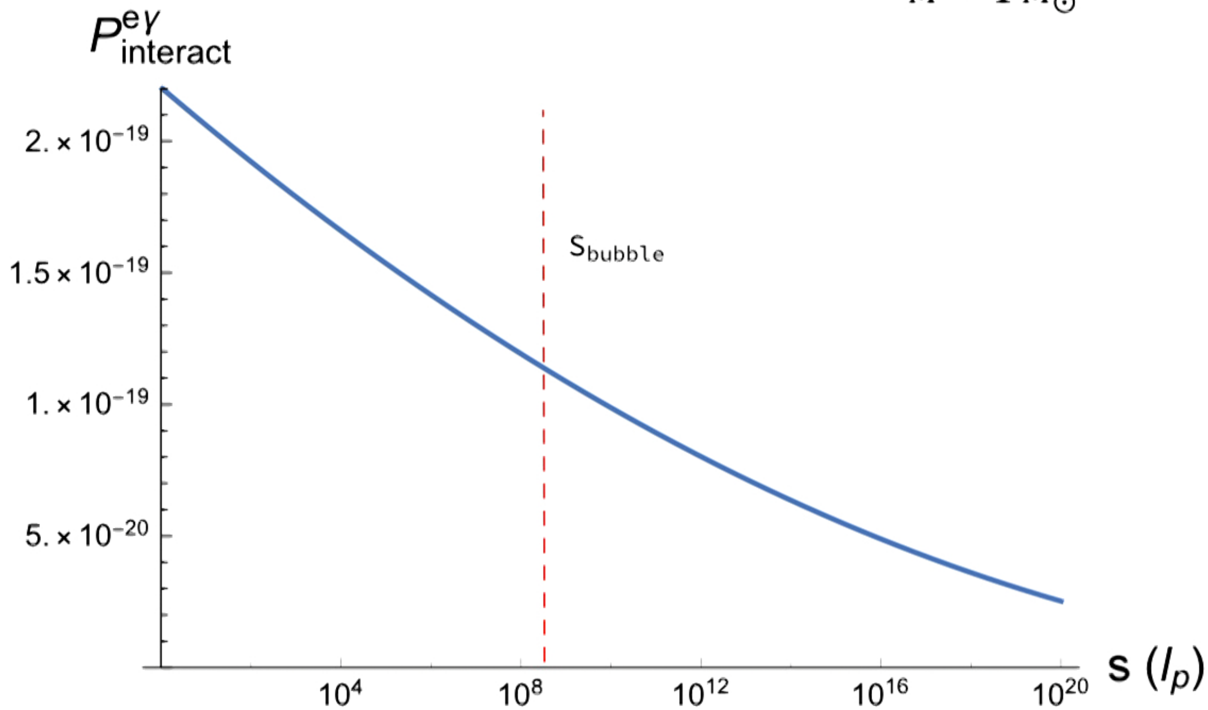
Near horizon region $r - r_h \ll r_h \Longrightarrow s \ll r_h$



Thermal distribution of photons in **near horizon** region with local temperature $\hat{T} \sim \frac{1}{s}$

Interaction Probability for electron-photon scattering

$E = m$
$M = 1\, M_{\odot}$

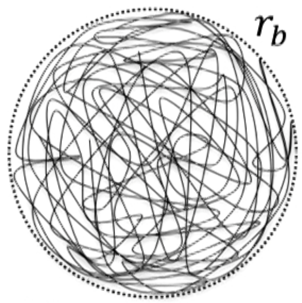


Probability never reaches ~1
There is NO FIREWALL!

Bin et. al.

Consider Scattering of low energy photon off of electron gas

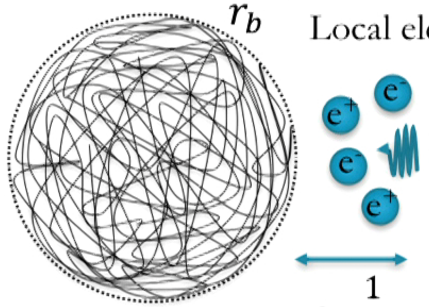
$s_{bubble} \lesssim l_p$ (inside of fuzzball surface)



Photon energy $E \sim T$

Near horizon region

r_b Local electron/positron gas at threshold $\hat{T} \sim \frac{1}{m}$ at $s \sim \frac{1}{m}$



Local photon energy $\hat{E} \sim \hat{T}$

$s \sim \frac{1}{m}$

found that $P_{int} \sim \alpha^2$ where $\alpha = \frac{1}{137}$ and $P_{emergence} \sim \frac{1}{(mr_h)}$

$\Rightarrow P_{backscatter} = P_{int} P_{emergence} \ll 1 \; for \; M = M_{\odot}$; $P_{reflection} \ll 1$

Summary

- AMPS argued to exchange vacuum at horizon with stretched horizon (presence of firewall)
- Firewall argument could be violated due to backreaction of infalling particle on on geometry
- We proposed a modified firewall argument
- Computed P_{int} and found that $P_{int} \ll 1$ for $s > s_{bubble}$
- NO MODIFIED FIREWALL!
- Found that low energy photons scattering off positron electron gas gave $P_{backscatter} \ll 1$ and $P_{reflection} \ll 1$

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