Title: Firewalls- A GR perspective

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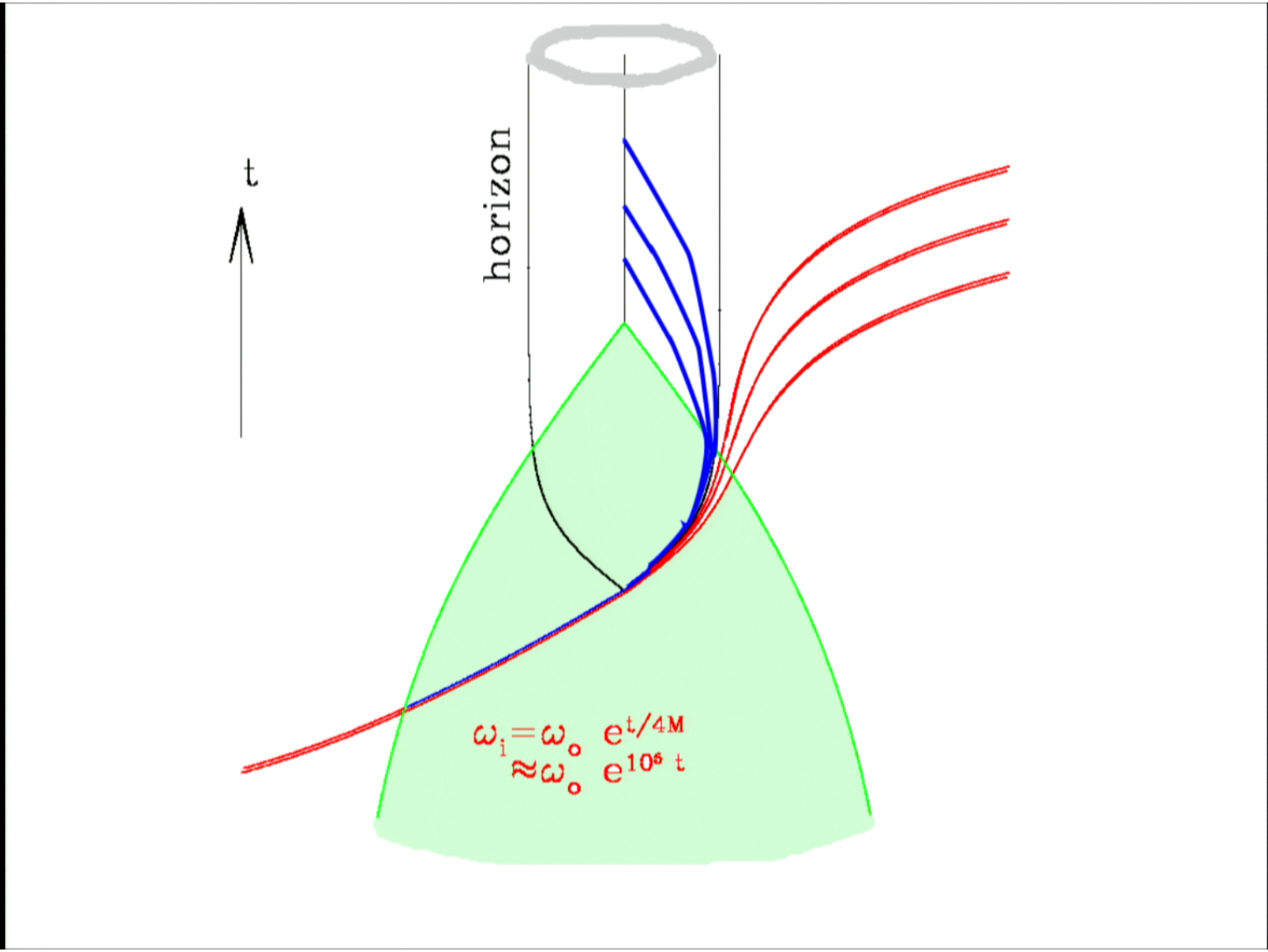
Abstract: This talk will examine the Firewall argument and a number of possible approaches to it, with a variety of simple examples to try to clarify various aspects of the arguments.

## Firewalls-- What are the Possibilities?

Part of my talk is very  similar to Bardeen's talk on Tues.


t
horizon
$\omega_i = \omega_o \; e^{t/4M}$
$\approx \omega_o \; e^{10^6 \, t}$

Outgoing modes along the green line (ingoing stream)
Positive frequency modes (empty-- vacuum state)
Convert to modes travelling along red and blue characteristics-- calculate positive frequency for these

Bugoliubov transformations – Outgoing state is in Themal state-- entanglement between the red and blue modes. Trace out over blue modes-> red modes are in Thermal state.

For fluid, proportional to rate of change of c-v.
Black hole proportional to $1/8\pi M$-- mass of the black hole.

Ie Temperature is a function of the energy.

$$
\begin{aligned}
TdS &= dE = dM \\
T &= \frac{1}{8\pi M} \\
S &= \frac{1}{4}(4\pi(2M)^2)
\end{aligned}
$$

Black Holes have an entropy equal to 1/4 of the area of Horizon.

Black Holes emit radiation with high entropy even if black hole formed from low entropy.

When black hole evaporates (emits all its energy) is the radiation high entropy, or equal to original entropy of formation?

## Information Loss

Black hole created by collapse of a pure quantum state.

Black Hole evaporates ( $10^{63}\left(\frac{M}{M_\odot}\right)^3 \text{yr.}$ )

Radiation incoherent high entropy thermal radiation.

After black hole gone, radiation is high entropy and black Hole has transformed Pure state to high entropy state Without dissipation (energy same).

## Solutions?

Black hole does not form. (Motola, Visser, Mathur,....)

Thermal radiation because there is inaccessible region Behind horizon of black hole.

If horizon does not form, no inaccessible region, pure state remains pure.

[Motola, Visser-- somehow quantum effects cause any collapse to halt before the black hole is formed. Mathur—Fuzzballs-- the infalling matter is replaced by a quantum tangle of strings before horizon is formed

$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$

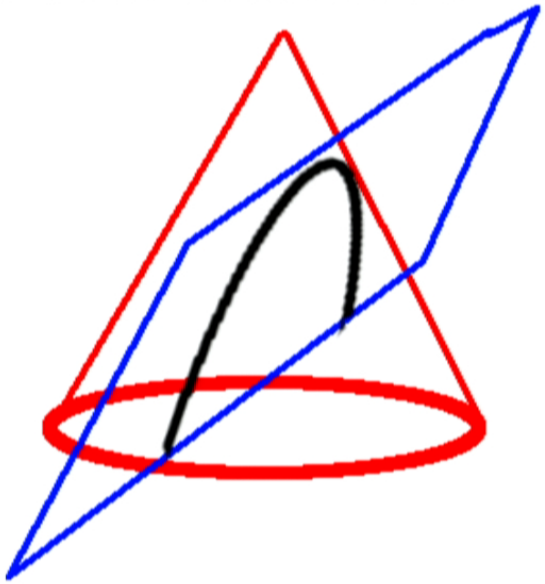
We can determine energy momentum tensor from metric.

Black hole formation far far from quantum regime-- even for solar mass black hole, radius of curvature of spacetime is 10's of Km. (and for galactic BH, 10millions of Km)

What must energy momentum tensor be like?

Solar mass collapsing toward horizon with velocity approaching speed of light. -- Must exert HUGE force to stop it.

Where is horizon?
Horizon defined by future behaviour of spacetime.
Apparent Horizon? (surface for which outward travelling light rays are parallel and inward are collapsing.)
Not a local property-- There exists milloions of “apparent horizons” in this room.



past null cone i intersectiion with null plane is an apparent horizon. --It just is not closed, and thus not what is usually called apparent horizon.

closing is a non-local feature.
How does collapsing body know ?

Energy, Decoherence and Black Holes

Peskin, Susskind, Banks- late 80s

If black hole loses coherence, then black hole must violate energy conservation.

Key assumption: The equations of motion of the density matrix is local in time.

$$\frac{d\rho_{ij}}{dt} = S_{ij}^{kl}\,\rho_{kl}$$

Markovian assumption. -- System has no memory except that in the density matrix.
System cannot remember how much energy emitted
Energy non-conservation-> Plank scale energy

Problem: Energy and decoherence unlinked.

$$\frac{p_1^2}{2m} + \frac{p_2^2}{2m} + \sum_i \epsilon_i s_i^z \delta(x_1 - x_2)$$

Two particles colliding when positions are same.
Collision strength depends on z component of a bunch of hidden spins.

Energy conserved-- After collision all energy is in the particles
Momentum conserved-- depends only on diff. of positions

Initial state of the spins are x spin eigenstates.

$$Y = \frac{x_1 + x_2}{2}; \qquad y = x_1 - x_2$$

$$H = \frac{P_Y^2}{4M} + \frac{p_y^2}{2m} + \sum_i \epsilon_i s_i^z \delta(y)$$

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## Energy conservation and decoherence consistent

Need energy degeneracy.

# ADS/CFT

Supersymmetric gravity-- 11D

Anti-Desitter space near infinity

$$ds^2 = \left(1 + (\frac{r}{r_0})^2\right) dt^2 - \frac{dr^2}{\left(1 + (\frac{r}{r_0})^2\right)} - r^2 d\Omega^2_{(3)} - r_0^2 d\Omega^2_{(6)}$$

Time to infinity for massless fields is finite

$$t = \int_0^\infty \frac{dr}{1 + (\frac{r}{r_0})^2} = r_0$$

If the spacetime is assymp. anti-deSitter, then conformal Yang-Mills Supersymmetric theories on the 4-D boundary at infinity are `equivalent' to gravitational theories in the interior.

Not entirely clear what this means.

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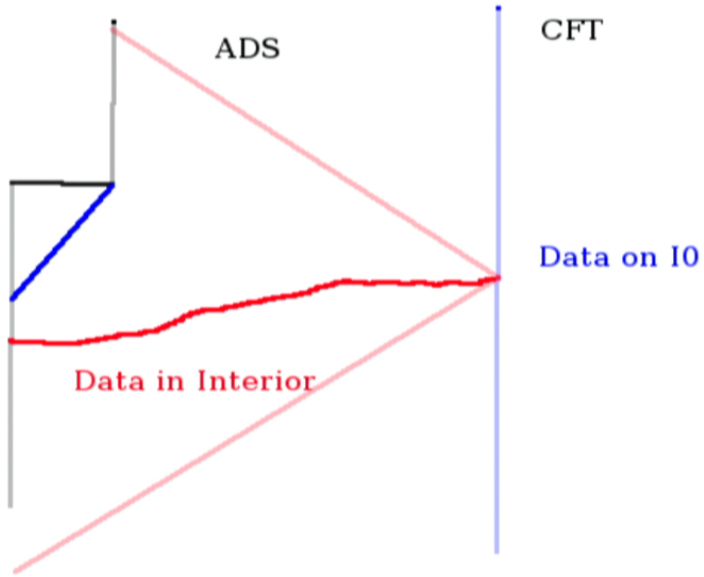
Interpretation: Since the YM conformal theory is “unitary”
if the initial state is pure state, then the final state must be

If the intial state corresponds to an “interior” gravity which
is a pure state, and the final corresponds to an
interior gravity which is the state long after a black hole
has evaporated, then those must also be “unitary”.

Can boundary see inside a black hole interior?
Bag of gold. Firewall?
Einsten Rosen bridge demands two “infinities”.

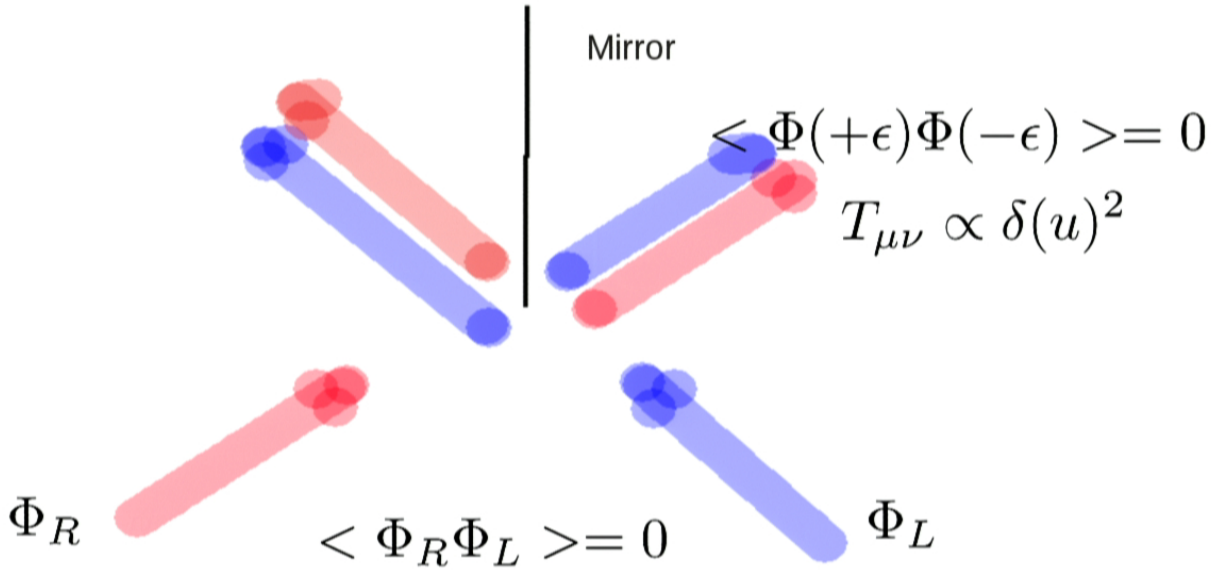
Mapping almost certainly non-local in time.




What is the mapping from Boundary theory to interior?-- Cannot select out special spatial surface-- must be same for for any choice of spatial surface in interior.-- "Constants of motion in interior". But we know from closed universe, this cannot describe full dynamics (changes) inside.

Decoherence and Stress energy Tensor
1+1D massless scalar field

Mirror which is switched on




$$u = t - x \qquad v = t + x$$

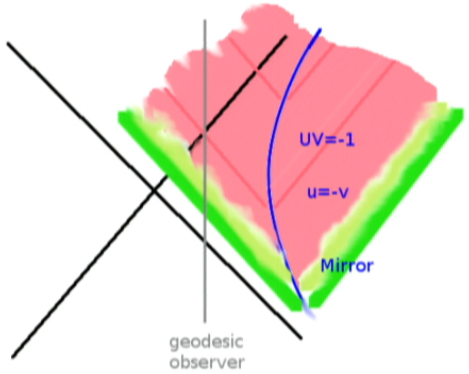
$$< AB > \equiv < AB + BA >$$

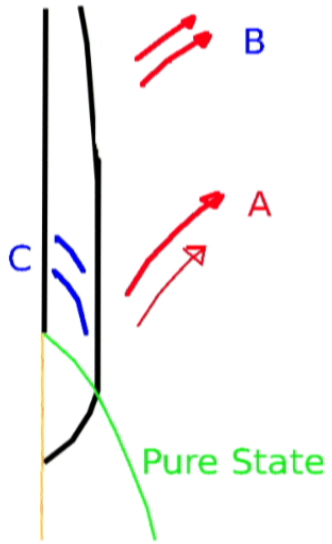
Loss of coherence across horizon leads to “firewall” -- Strong flux of energy along horizon (either inside or straddling horizon)

(Side note-- Can look at accelerated sponge.

$$(\partial_t^2 - \partial_x^2)\Phi = \delta(\sqrt{x^2 - t^2} - \rho_0)\epsilon(\tau)(\Phi(t,x) + \Psi(\tau,0))$$

$$(\partial_\tau^2 - \partial_y^2)\Psi = \delta(y)\epsilon(\tau)(\Phi(t(\tau,\rho_0), x(\tau,\rho_0)) + \Psi(\tau,y))$$






A-- mixed state emitted by black hole

A-C needs to be (relatively) pure state to have smooth energy along horizon

A-B needs to be pure state (Black Hole “Unitarity”)

Cannot have all three. (Subadditivity of entropy)

2) If C is same as B, then A can be in pure state with both

Frolov, Bardeen, Hayward, ...

$$ds^2 = \begin{cases} \left(1 - \frac{2M(v)r^2}{r^3+2M(v)r_0^2}\right) dv^2 - 2dvdr - r^2(d\theta^2 + sin(\theta)^2 d\phi^2) \\ \left(1 - \frac{2\tilde{M}(u)}{r}\right) du^2 + 2dudr - r^2(d\theta^2 + sin(\theta)^2 d\phi^2) \end{cases}$$

Eddington Finkelstein Vaidya metric (match along r=3M(v) and r=3$\tilde{M}$(u)) Outgoing pos energy, ingoing negative. Mimics energy mom tensor in Hawking process

Metric is “deSitter” for r near r0 (Planck scale).

Apparent Horizons $r \approx 2M - \frac{r_0}{2M}, \quad r \approx r_0 + \frac{r_0^2}{4M}$ until

$$M^2 < \frac{27}{16} r_0^2$$

Problem? Inner Horizon—Mass inflation

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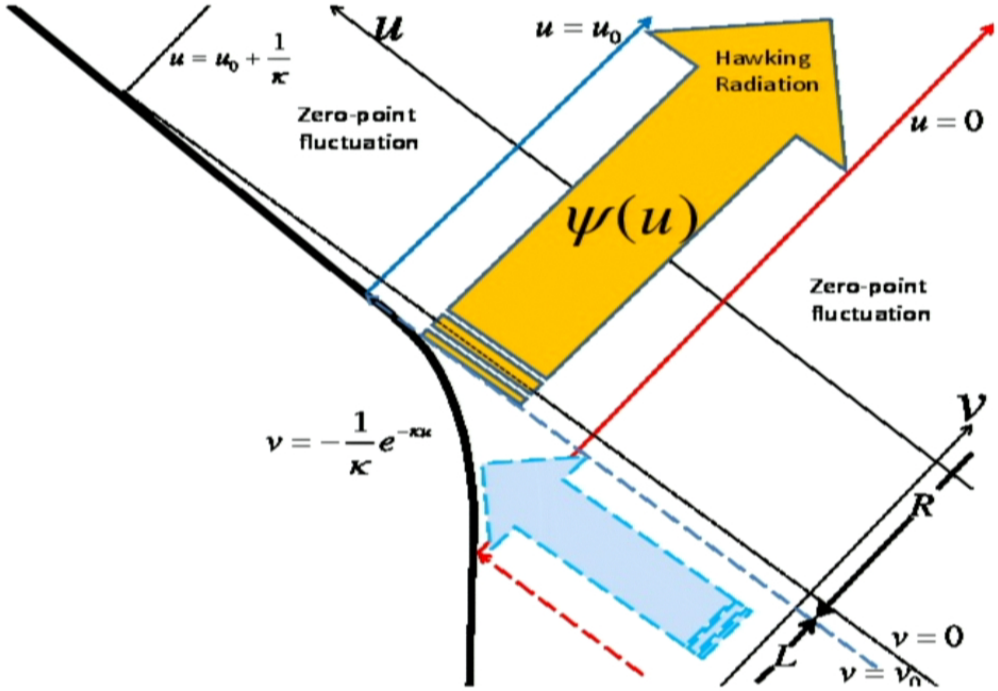
# Wilzeck- 1990s-- moving mirror in 1+1D Model for black hole (Hotta, Schuetzhold, Unruh)



Other issues.

A) Where are particles created?

Dumb hole models and energy==> Particles created well outside horizon (around r=3M)

In 1+1D Massless black hole model $T_{\mu\nu}$ Positive flux to infinity, negative flux into black hole

$$
\begin{aligned}
ds^2 &= x d\tau^2 - \frac{1}{x} dx^2; \quad x < 1 \\
ds^2 &= d\tau^2 - dx^2; \quad x > 1 \\
\Box\Phi + \epsilon\delta(x)\Phi &= 0
\end{aligned}
$$

Black holes still manage to surprise us and make us think, and realize we do not know much.

Is firewall argument reasonable?
Does ADS/CFT really mean what naive interpretation says it does? Does it see behind horizon? Does it simply refer to those degrees of freedom of gravity that are “diffeomorphism invariant” (constants of the motion)

How does one look at time development ?

Can all of information lost inside black hole be carried out by vacuum fluctuations?

Is there a singularity in the center of black hole and information and matter simply drops off the edge of the universe? [No evidence except prejudice that this is not true.]