Quantum Clones in the Interior of a Black Hole

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Verlinde^2 Symposium

July 14 2022

Version 2

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- String theory (the Verlindes' first passion)
- Loop Quantum Gravity
- Asymptotic Safety in Gravity
- Quadratic Quantum Gravity
- Stochastic Gravity (another Verlinde proposal)

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To my opinion, we are too frantically trying to repeat successes of the past. This may seem to be the correct attitude . . .

But in the past, we made a number of mistakes. These mistakes were crucial for our successes then, but today they may be standing in our way.

Now, what is crucial, is *precision and logical accuracy*

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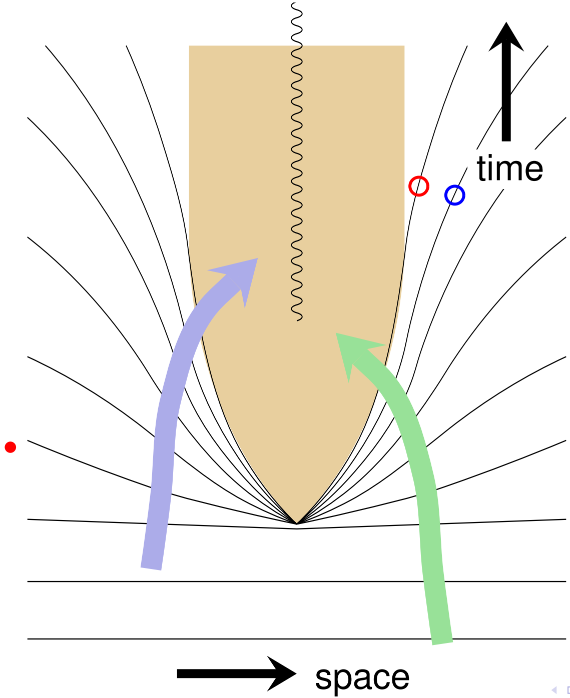
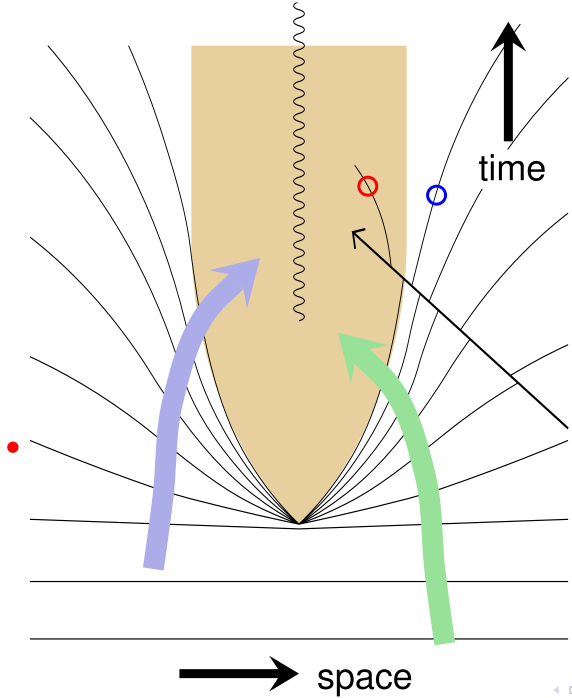
Black holes contain a region of space-time where particles boosted to infinite Lorentz contraction meet. New physics is required to understand what is going on.

Quantum gravity has to be reformulated to allow application in black holes. String theory is not fool-proof; string theories allow investigators to make the same mistakes as any other approach.



Shapiro shift



Shapiro shift

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Particles crossing the BH horizon seem to disappear, dragging along with them all information they carry.
But all known physical systems appear to obey unitary Schrödinger equations. Perhaps black holes are exceptions, which means we understand very little about them.
But we can also search for equations such that their Schrödinger equations do conserve probabilities (i.e., they are unitary).

All that is needed is a little work with some insight.

Let me explain (in words and in equations) how this goes:

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After initial collapse, a black hole quickly attains an almost stationary state. Schwarzschild Metric in a spacetime (r, t, θ, φ):

$$\begin{aligned} \mathrm{d}s^2 &= \frac{1}{1-\frac{2GM}{r}}\mathrm{d}r^2 - \left(1-\frac{2GM}{r}\right)\mathrm{d}t^2 + r^2\mathrm{d}\Omega^2 \ ; \\ \Omega &\equiv (\theta,\, \varphi) \ , \\ \mathrm{d}\Omega &\equiv (\mathrm{d}\theta,\, \sin\theta\, \mathrm{d}\varphi) \ . \end{aligned}$$

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Go to Kruskal-Szekeres (or 'tortoise') coordinates $x,\ y,$ defined by

$$x\,y = \left(\frac{r}{2GM} - 1\right) e^{r/2GM} \quad ;$$

$$y/x = e^{t/2GM} \quad .$$

$$\mathrm{d}s^2 = \frac{32(GM)^3}{r}\, e^{-r/2GM}\,\mathrm{d}x\,\mathrm{d}y + r^2\mathrm{d}\Omega^2 \quad .$$

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For every point (r, t, θ, φ), there are *two* points in these new coordinates: with every (x, y, θ, φ) there is also $(-x, -y, \theta, \varphi)$.

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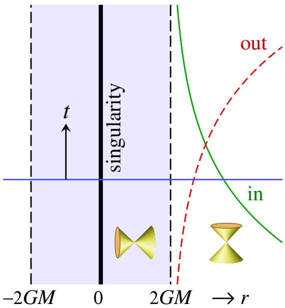
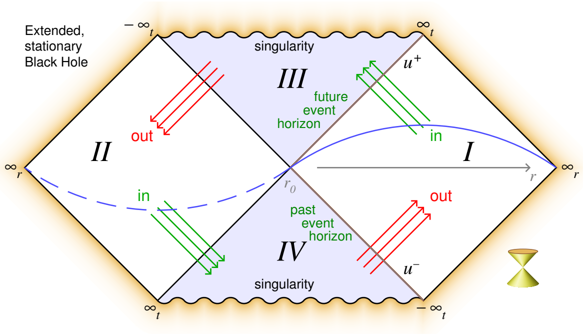
Schwarzschild

KS





In Schwarzschild coordinates (left) you see one outside region and one inside region (blue)

In the more regular Kruskal-Szekeres coordinates(right) you see two outside regions and two inside regions (blue)

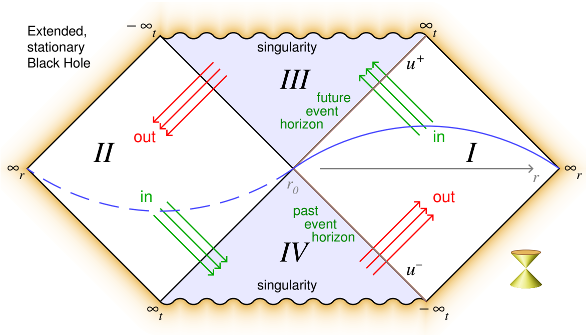
The Shapiro effect.

$$\delta u^- = G\, p^- f(\Omega,\, \Omega') \quad \text{with} \quad (1-\Delta_\Omega)\, f(\Omega,\, \Omega') = 8\pi G\, \delta^2(\Omega,\, \Omega')\ .$$

Partial waves: $$\delta u^-_{\ell m} = \frac{8\pi G}{\ell^2+\ell+1}\, p^-_{\ell m}\ .$$

This gives algebra: $$[u^+,\, u^-] = i\lambda\ , \qquad \lambda \equiv \frac{8\pi G}{\ell^2+\ell+1}\ .$$

Therefore, u^- is the Fourier transform of u^+. In only one dimension.

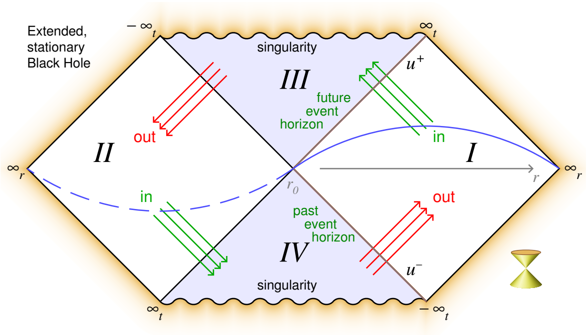


The Fourier transform is unitary,

but only if

$$-\infty < u^+ < \infty$$
$$-\infty < u^- < \infty$$

and this would give information loss!



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We need a unitary mapping from the interval $[0,\ \infty]$ to $[0,\ \infty]$.

But this is easy. Use: Fourier transform maps even functions onto even functions and odd onto odd !

The fact that we may use only even functions means that:

The data in region II are identical to the data in region I.

They are *clones* of one another.

It is often thought that region *II* represents the 'inside' of the black hole. Now, we see that it is a quantum clone of region *I*. Regions *III* and *IV* are the inside. More precisely:

$$\psi_{II} = \psi_{I}^{*}$$

Solve the equations with the *constraint* that the wave functions in *I* and *II* are the same !

Calculations: this appears to give a unitary evolution law!

N. Gaddam, S. Kumar, C. Ripken

The complex conjugation, $\psi \leftrightarrow \psi^*$, requires further discussion.

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Congratulations Erik & Herman