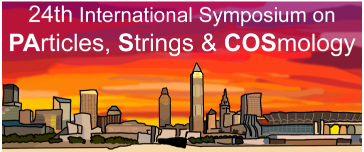

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Conservative Physics and New Physics for the Quantised Black Hole

June 4, 2018

What will the fundamental new principles be
in theories that would unify Einstein's
General Relativity with *Quantum Mechanics* ?

This would be the last major step for unifying physics.

I advocate an approach that keeps our basic steps as small as possible.

Approach: first ensure that the collapsed state – a black hole – is described such that it agrees with what most people would call *common sense*.

Observation: this can be done, but there are still obscure features that have to be clarified. In the mean time, we learn a lot.

For instance: *string theory does not give the right answers* – or rather: is *not fool-proof.*

There are 3 pieces of insight that are absolutely essential for understanding the quantum black hole.

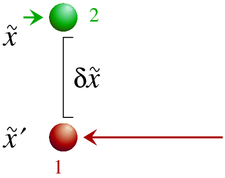
Two of these are merely consequences of good old, known physics and should be difficult to deny, but not noticing them leads to errors . . .

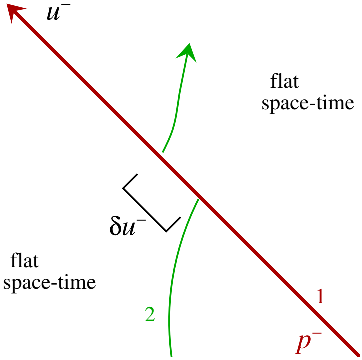
The third could be called new physics, but is almost inevitable.

But most investigators ignore these facts, while ignoring any one of my 3 observations leads to misunderstanding and confusion.

1, good old physics: The gravitational back-reaction:

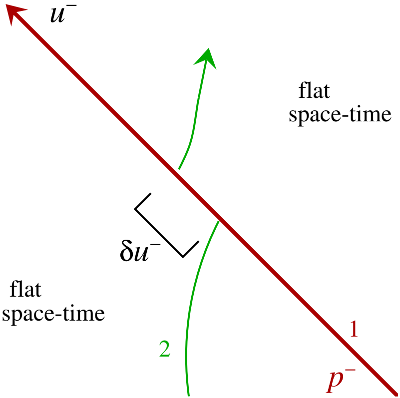
Calculate the *Shapiro time delay* caused by the gravitational field of a fast moving particle: apply Lorentz boost to the field of a particle at rest: let $m_0 \to 0\ ,\quad v \to c\ ,\quad p = \dfrac{m_0\, v}{\sqrt{1 - v^2/c^2}}$ fixed.





$$\delta u^-(\tilde{x}) = -4G\, p^-(\tilde{x}\,') \log|\delta\tilde{x}|\ .$$

P.C. Aichelburg and R.U. Sexl, J. Gen. Rel. Grav. **2** (1971) 303

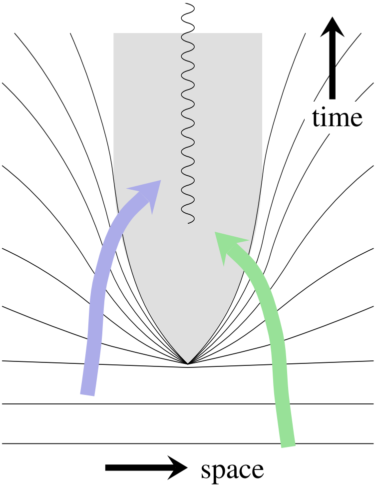


the geodesic of particle $\#\,2$ is broken because space-time is curved

(the two flat pieces are glued together with an $\tilde{x}$-dependent shift δu^-),

but we may also do as if particle $\#\,1$ drags particle $\#\,2$ along.

Then we can apply quantum mechanics as if space and time were still flat.

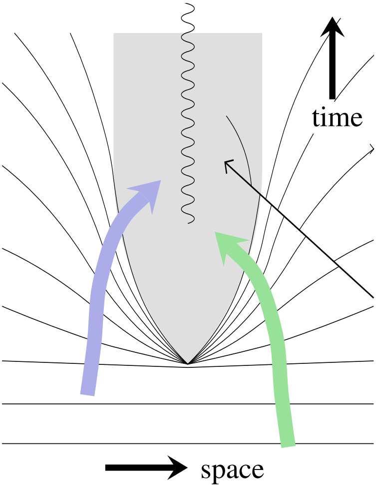


We see that this effect has drastic consequences for the out-going particles.

The effect increases exponentially with time.

The in-particles leave their 'footprints' in the out-particles.

This changes everything!



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How to avoid doing this wrong? Easy. This is my

observation # 2 (plane old physics):

Just notice that the math simplifies enormously if you expand the in-going momentum $p^-(\theta,\varphi)$ and the shifts of the out-going particles, $u^-(\theta,\varphi)$ in spherical harmonics, $Y_{\ell m}(\theta,\varphi)$.
Let $\Omega=(\theta,\varphi)$,

$$u^\pm(\Omega)=\sum_{\ell,m}u_{\ell m}Y_{\ell m}(\Omega)\ , \qquad p^\pm(\Omega)=\sum_{\ell,m}p^\pm_{\ell m}Y_{\ell m}(\Omega)\ .$$

$$[u^\pm(\Omega),\, p^\mp(\Omega')] = i\delta^2(\Omega,\,\Omega')\ , \quad [u^\pm_{\ell m},\, p^\mp_{\ell' m'}] = i\delta_{\ell\ell'}\delta_{mm'}\ ;$$

$$u^-_{\rm out} = \frac{8\pi G}{\ell^2+\ell+1}p^-_{\rm in}\ , \quad u^+_{\rm in} = -\frac{8\pi G}{\ell^2+\ell+1}p^+_{\rm out}\ ,$$

$p^\pm_{\ell m}$ = total momentum in of ${}^{\rm out}_{\rm in}$-particles in (ℓ, m)-wave ,

$u^\pm_{\ell m}$ = (ℓ, m) - component of c.m. position of ${}^{\rm in}_{\rm out}$-particles .

Use: $$\psi(u) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} {\rm d}p\, e^{-ip}\,\hat\psi(p)\ ,$$

when going from $u^\pm$ basis to $p^\mp$ basis and back. Note that this mixes positive and negative values for the light cone coordinates $u^\pm$, so that regions I and II get quantum mechanically mixed, only then the Fourier transform is unitary.

Observe: we have a single quantum variable u and its associated momentum p at every ℓ, m.

Different (ℓ, m) values decouple (only secondary, higher order effects might mix different ℓ and m).

And then you discover that still something is not yet right:

The 'footprint' drags some out-particles to a place inside the hole.

There, the footprint cannot be observed.

The math works such that the information seems to re-appear intact, *but in the other black hole!*

Particles in one black hole are *quantum mechanically entangled* with those of the other.

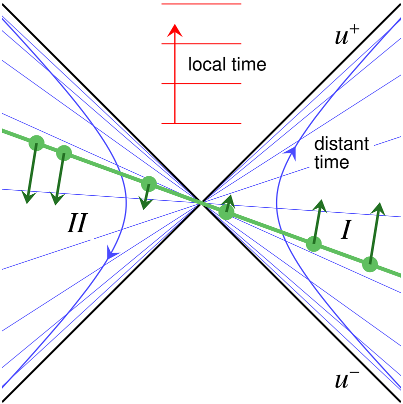
Therefore, some investigators propose that we have to consider entangled pairs of holes.

This would not unify them with ordinary forms of matter.

and it is wrong: the grav. back reaction causes non-local interactions between these 2 black holes.

There is a much better solution!

The footprint extends from one side of the black hole to the opposite side. What enters at one side, emerges, entangled, as a footprint on both sides.



The center point of this diagram is the 'edge' or *horizon* of the black hole, where time (blue lines) stands still.

Region *I* is the outside world. Region *II* was always thought to be the 'inside' of the black hole. Our better solution is that the black hole ...

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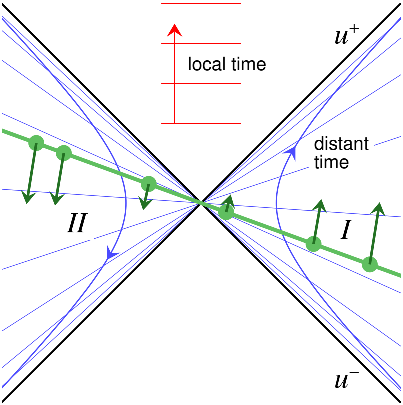

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Region *I* is the outside world. Region *II* was always thought to be the 'inside' of the black hole. Our better solution is that the black hole . . .

. . . *has no inside*.

Region *II* is the *other side*, or 'antipode of region *I*'.

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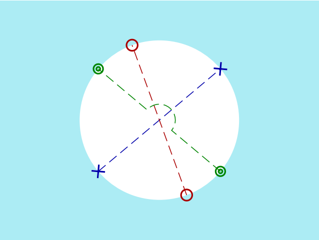
However, time there runs backwards.

Black emptiness: blue regions are the accessible part of space-time; dotted lines indicate identification.



The white sphere within is *not* part of space-time. Call it a 'vacuole'.

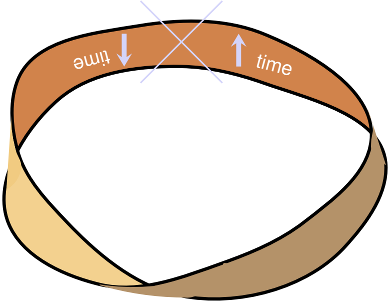
At given time t, the black hole is a 3-dimensional vacuole. The entire life cycle of a black hole is a vacuole in 4-d Minkowski space-time.

Space coordinates change sign at the identified points

– *and also time changes sign*

(Time stands still at the horizon itself).

A timelike Möbius strip



Draw a spacelike closed curve:
Begin on the horizon at a point
$r_0 = 2GM\ ,\ \ t_0 = 0\ ,\ \ (\theta_0, \varphi_0)$.
Move to larger r values, then travel to the antipode:
$r_0 = 2GM\ ,\ t_0 = 0\ ,\ (\pi - \theta_0, \varphi_0 + \pi)$.
You arrive at the same point, so the (space-like) curve is closed.

Now look at the environment $\{\mathrm{d}x\}$ of this curve. Continuously transport $\mathrm{d}x$ around the curve. The identification at the horizon demands

$$\mathrm{d}x \leftrightarrow -\mathrm{d}x\ , \quad \mathrm{d}t \leftrightarrow -\mathrm{d}t\ ,.$$

So this is a Möbius strip, in particular in the time direction.

The Fourier transform in $x, \ p$ space is non-local:

$$\langle x|p\rangle = \frac{1}{\sqrt{2\pi}}\, e^{ipx}$$

But if we write $x = \sigma_x\, e^{\varrho_x}$ and $p = \sigma_p\, e^{\varrho_p}$, where σ_x and σ_p are signs $\pm$, then the relation becomes:

$$\begin{aligned} \langle \varrho_x, \sigma_x | \varrho_p, \sigma_p \rangle &= \frac{1}{\sqrt{2\pi}}\, e^{\frac{1}{2}(\varrho_x + \varrho_p) + i\sigma_x\sigma_p\, e^{\varrho_x+\varrho_p}} \\ &= F(\varrho_x + \varrho_p,\, \sigma_x\sigma_p)\ . \end{aligned}$$

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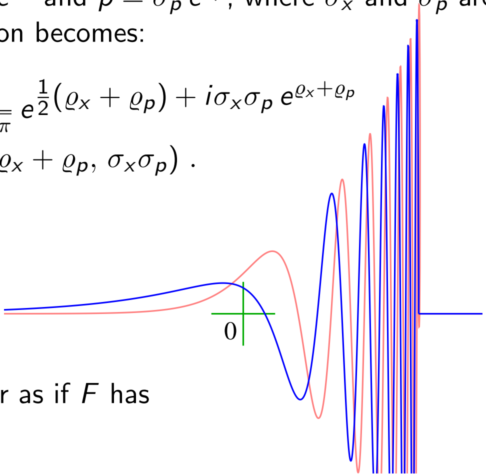
$F(x, +)$:



In practice it will appear as if F has a finite support.

We now have all ingredients to tell how the variables $u^{\pm}(\Omega)$ and $p^{\pm}(\Omega)$ evolve in time. *These are the microstates.* We were forced to impose and accept the antipodal identification.

Clearly, black holes tell us something about the topology of space and time. How this affects the interactions among the elementary particles is not at all understood.

But we are working on it

Extended notes on web:

http://www.staff.science.uu.nl/~hooft101/lectures/GtHBlackHole_2018.pdf

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THE END