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Hawking... the man, the myth.

- A serious and accomplished scientist (As we will see today)
- A popularizer of science (Is this a good thing or bad?)
- A role model for those facing adversity (Could any of you imagine doing what he did?)

I have little doubt that had he not been "interrupted" by ALS, he would have eventually moved on to be a champion of either LQG or String Theory.

But at the point in time of his most important work, there were really 2 well established frameworks for doing fundamental physics:
a) Non-gravitational QFT
b) Classical GR
Hawking's work centered on exploring the consequences of considering these together.
Note: Because he was not toying w/ more speculative ideas like QG, his results were accepted as major problems in theoretical physics. They were, as it turned out, ultimately addressed by ideas in QG, though not until developments some 30 years later!

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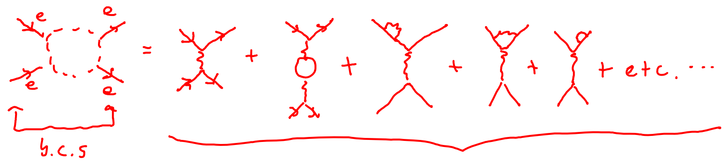
GR: $R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$ given $T_{\mu\nu}$ - (mass, energy, momentum) + b.c.s solve for $g_{\mu\nu}(x)$ - (geometry)

QFT: $\mathcal{L}_{QED} = \bar{\psi} \gamma^\mu D_\mu \psi - \frac{1}{16\pi} \eta^{\mu\alpha} \eta^{\nu\beta} F_{\mu\nu} F_{\alpha\beta}$

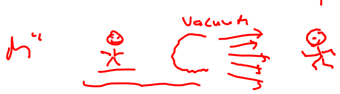


$\mathcal{M}_i$ for $e + e \to e + e$
↳ σ_i for $e + e \to e + e$
i indexes other outcomes, e.g. $e + e + \gamma + \gamma$

It is important to note that both of these frameworks were well-tested and widely accepted at the time of Hawking's work.

So what did Hawking do? He worked in the context of QFT on a curved spacetime. That is, he treated all matter + interactions (except for gravity) in terms of QFT, but
a) worked on a fixed (non-dynamical) curved geometry
b) introduced the effects of gravity in the standard way i.e. $\eta^{\mu\nu} \to g^{\mu\nu}$, $\partial_\mu \to \partial_\mu + \Gamma_\mu^i$.

One of the more pronounced results of this context is that the idea of what "vacuum" is becomes less clear. This can also be seen in flat spacetime if we consider not just inertial, but accelerating observers.



The Unruh effect

inertial observer sees nothing

accelerated observer sees thermal bath of particle radiation

Now where all of this gets interesting is for black holes...

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Gravity sucks... I mean it really sucks. Since it is "always" attractive, then if you put enough mass together it will pull itself into smaller and smaller sizes. Usually this is stopped by other "forces", E&M, Electron degeneracy pressure, Neutron degeneracy pressure,
But if the mass is too large, nothing can stop it and it is gravitationally collapsed to a point, i.e. a gravitational singularity.

Now most people get excited about the singularity, but truthfully this is really a prediction the GR breaks down and needs to be replaced by some QG to describe the singularity.

Where the money is at is in the formation of an event horizon. This is a region around the singularity where once an object enters, its only evolution is towards the singularity.

What is crucial about the event horizon is that the curvature is not necessarily huge. In fact an observer falling into a super massive BH, would probably not even realize when they enter the event horizon (in terms of tidal effects).

But this means that near the event horizon, Hawking could employ his QFT + GR hybrid to describe what is going on. His argument is technical, but there are two ways to intuit it..

a) 

b) Equivalence says replace $g \Leftrightarrow a$ and then use Unruh.

So in the end, black holes ain't black. They are emitting thermal radiation. The term thermal is important because it means the spectrum of emission depends only on the temperature T of the object (which Hawking also calculated).

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So black holes radiate ... so what?

For large black holes (which paradoxically have lower T and radiate more slowly) they will accrete matter (CMB at least) at a faster rate than they radiate, and so will live forever.

For microscopic black holes the radiation actually gives them a very short lifetime.

Of course for questions of principle, we could consider a large and very isolated black hole that will then eventually radiate itself away.

And here we find a problem.

Physics is full of conservation laws, i.e. the change in a quantity is explained by a flux through the area bounding the system. At times when these conservation laws seemed challenged, e.g. $N \to p + e$ the absolute conviction to uphold conservation has led to startling (though correct) steps:

One immediate consequence of a conservation law is that if system = everything (entire universe), then a conserved quantity is actually constant.

One such conserved quantity is "information." The conservation of information is reflected by the unitarity (or unitary evolution) of quantum systems (including QFT). It says that in the absence of wavefunction collapse (measurement) the time evolution can be reversed, e.g. pure states remain pure.

That is

These have the same M, but are different.
Information captures the differences.

What happens if we drop a spherical cow of mass M into a black hole? Well we can no longer see it, but the black hole will grow to a new size $M' = M_0 + M$.
However all we observe is M'. The rest of the information about our cow is lost to us.
Now that is in some sense okay since the black hole's interior is still part of spacetime, albeit invisible to us outsiders. So one could just as well say that the information is still there, just bound up inside the black hole.

But...

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Then consider when the black hole evaporates through Hawking radiation. Eventually the black hole, and anything in it is gone, and the only remnants are the radiation that poured out. But.. this is purely thermal! With T depending only on M!. The rest of the information seems to have been lost!

This conundrum led to a 30 year debate between 2 opposing camps.

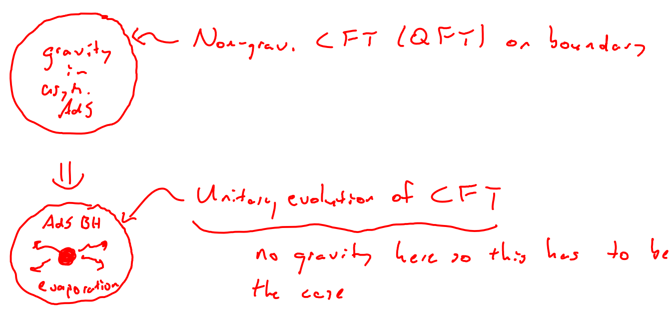
Hawking + Thorne: The story is correct, information is lost as is unitarity evolution.

Preskill + Susskind: Unitarity is preserved, this story has a flaw.

Many arguments were put forward (information supernovae, remnants) but all were refuted on various grounds.

Susskind, taking a cue from string theory, was convinced that the information was preserved, somehow (not lost in the singularity) encoded on the event horizon of the black hole. But this is odd since the information of 3D objects would need to be encoded on a 2D surface which implies some mechanism of holography.

This approach was given its most precise realization when in 1997, Maldacena put forward the AdS/CFT conjecture which states



AdS/CFT is a highly nonlocal, non-intuitive correspondence, so exactly how this works out on the gravity side took another seven years.

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In 2004 Hawking finally conceded the bet, agreed that information was not lost, and made a dramatic presentation of his explanation.

Hawking argued that the entire process of BH formation and eventual radiating away should be treated like an S-matrix calculation defined w/ the asymptotic states (which do not involve a BH):

Hawking's argument was essentially a generalization of a more concrete proposal by Maldacena a few years earlier in his "Eternal Black Holes in AdS" paper.