

# Black holes aren't black

A half century after the discovery of Hawking radiation, we are still dealing with the quantum puzzle it exposed.

By Claire Lamman

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Presenting the black hole:  
a region where space falls  
faster than light.

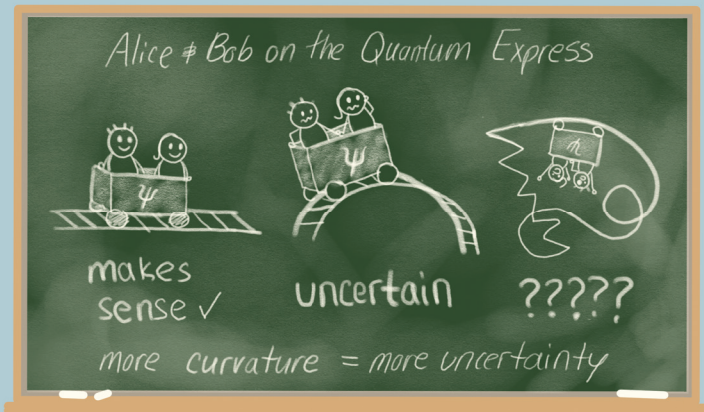
*Once you pass the  
event horizon,*

*the central singularity becomes  
your unavoidable future.*

This is famously inescapable!

## But quantum physics tangles the classic story.

In 1974, Stephen Hawking applied quantum field theory to the spacetime metric of the event horizon.

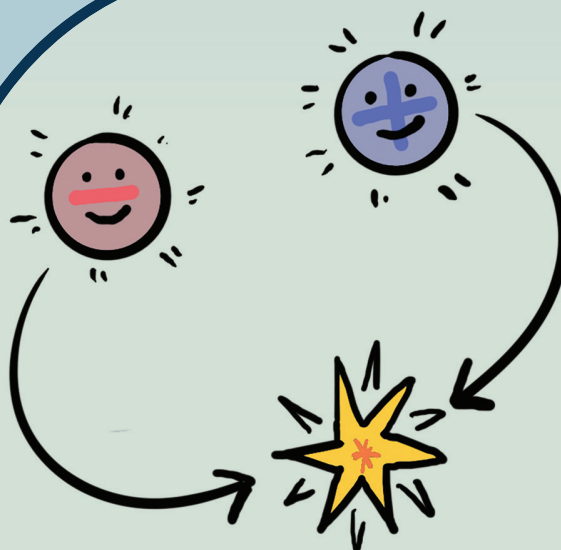


Describing a field under the quantum framework works fine in a flat spacetime.

But in very curved space, like around a **black hole**, you end up with an uncertainty in the local energy density.

Uncertainty causes weird effects near the event horizon. Hawking showed how quantum fluctuations allow energy to escape from a black hole, a process now known as Hawking radiation. He described this **heuristically** with virtual particle-antiparticle pairs, here represented with  $\ominus$  and  $\oplus$ :

Normally, the particles annihilate each other soon after being created.



But near the event horizon, one can fall through it.

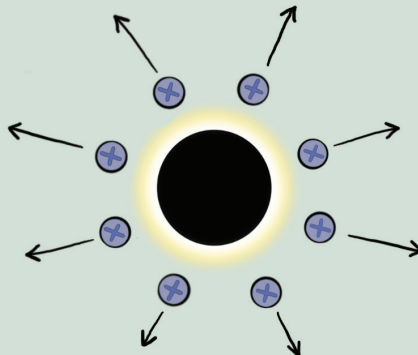
*As the virtual particle falls into the black hole, it becomes real!*

What happens to the other particle and its energy?



*It lost its sibling and is now free to escape!*

*This process happens many times, and bits of energy radiate from the event horizon.*



*The full physical picture is a bit more complicated, but the net result is the same: A black hole loses energy and faintly glows.*

# Black holes aren't black!

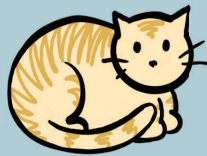
*Instead, they emit blackbody radiation.*



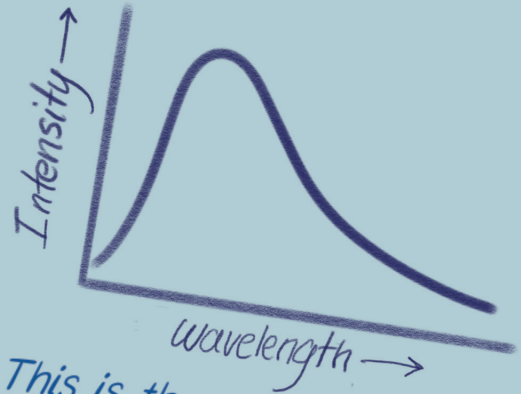
The Sun, 5800 K



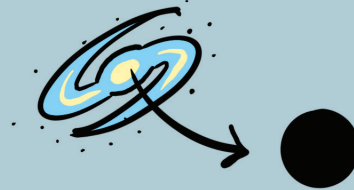
A campfire, 800 K



A cat, 312 K



*This is the same form of radiation that is emitted by other objects that create heat.*



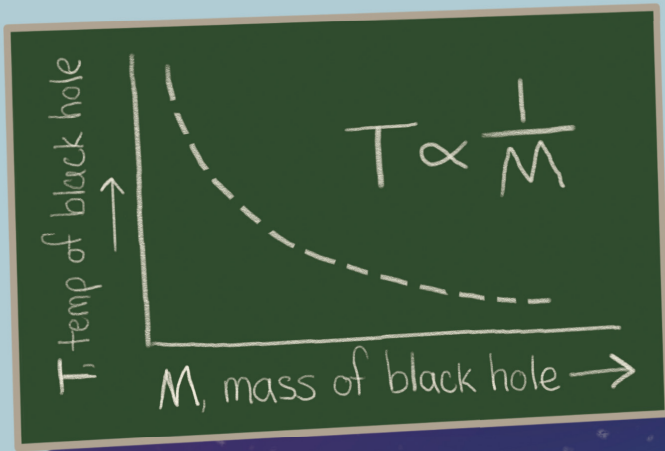
Sgr A\*,  $10^{-14}$  K

These all have a temperature, including black holes!

Could we detect the glow from a black hole?

*Maybe.*

*The uncertainty in energy density at the event horizon, and thus emission, is related to the curvature of spacetime.*



*Smaller black hole  
= more curvature  
= more uncertainty  
= more emission*

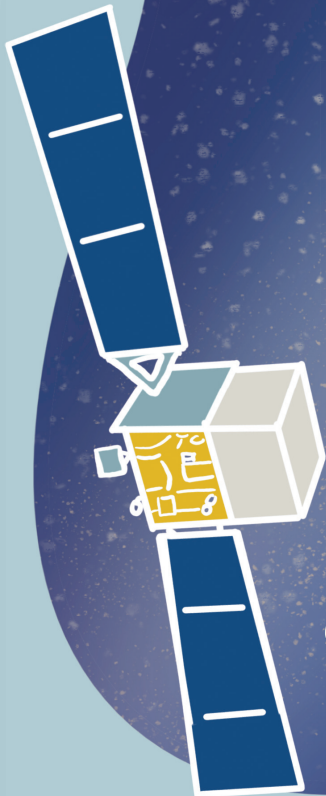
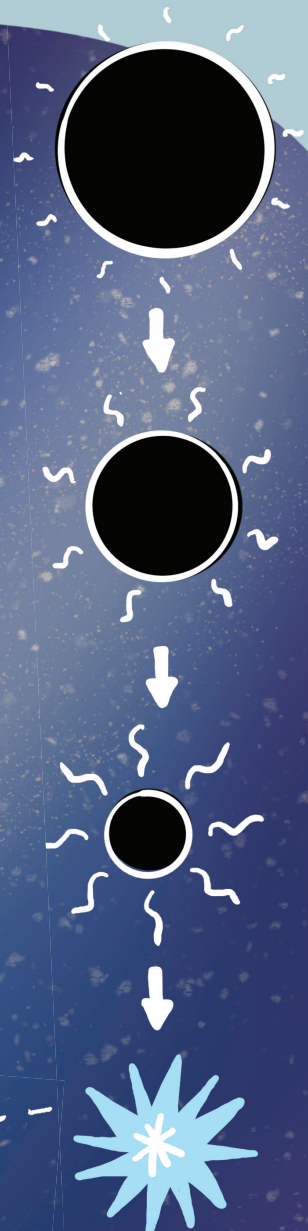
A black hole that's not getting fed will get smaller ...

and smaller ...

and emit more and more radiation.

Eventually, it will die in a burst of high-energy radiation!

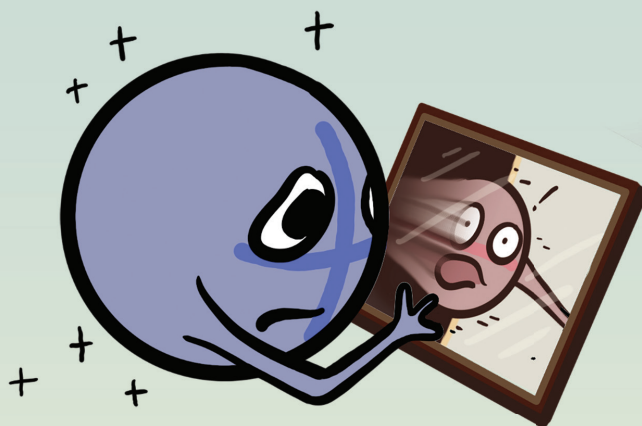
*For primordial black holes, this evaporation will take about as long as the age of the universe. The Fermi space telescope is searching for the faint signs of black hole deaths.*



But if black holes die,  
we have a problem.

*What happens to everything inside them??*

Let's revisit the particle  
lost to the singularity.  
Its sibling has not  
forgotten about it, as  
they are entangled!



The lost particle has information about the  
state of the particle pair. Hawking believed that  
black holes destroy this information, which  
violates a core principle of quantum mechanics.

*It contradicts unitarity: The initial state of  
a system can be determined from its final  
state. This is impossible if information about  
an initial state is destroyed.*

This is known as the **information paradox**.

All three things, as we currently understand them, cannot be true at once:

1) General relativity

2) How black holes work

3) Quantum mechanics

What's the solution?

This is very robust.

Maybe black holes don't actually destroy information. (But this is hard to show!)

Maybe unitarity is wrong. Maybe quantum theory must be revised.

Why might a human, safely away from any black holes, care?

It can help us understand why you're even around to wonder this!

Our universe began in an extremely dense state in which quantum mechanics dominated. We can't replicate this on Earth, but black holes give us present-day laboratories to explore similar conditions.

Hawking radiation is a clear example of a clash between general relativity and quantum theory, but it is also a process that can be explained only through the application of both. The solution to the black hole information paradox could be the key to describe our universe under a unified framework.

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