Barnard / Nevis Summer Colloquium Series

What is a black hole?

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LEHMAN COLLEGE

Outline

- What is gravity?
- Black holes (theory)
- Black holes (astrophysics)

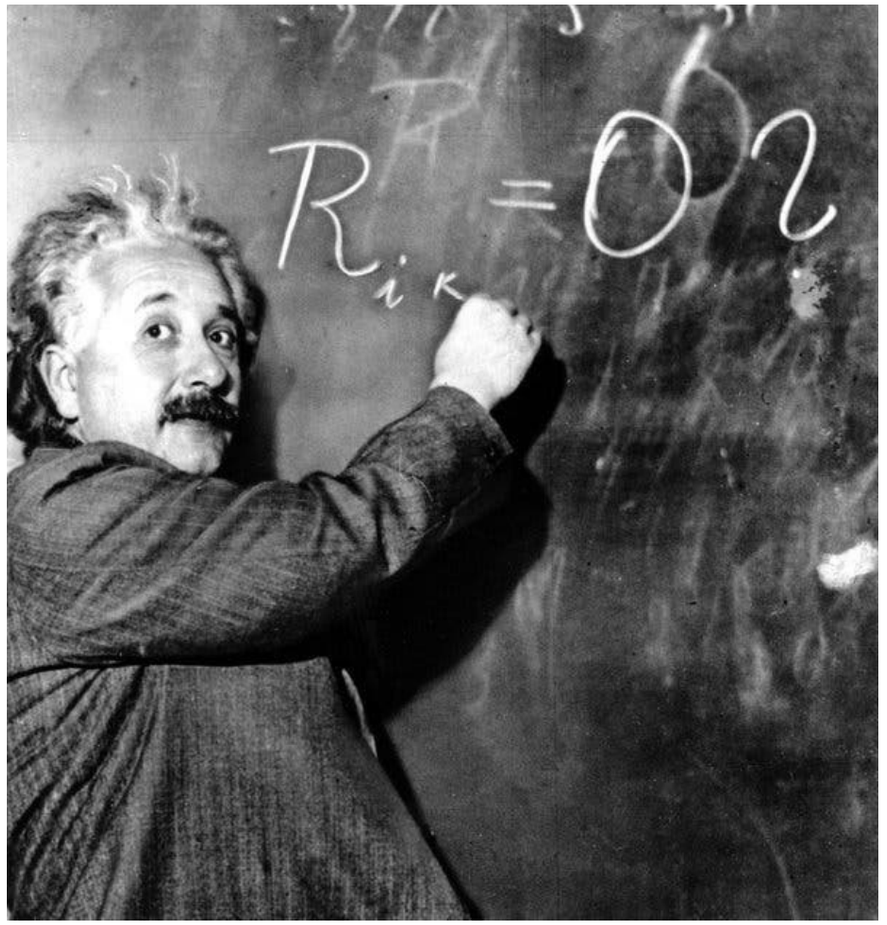
Time for questions in between, science careers at the end.

What is gravity?

Equivalence principle: all objects fall at the same rate in a gravitational field - even light! In free fall the effects of gravity disappear.

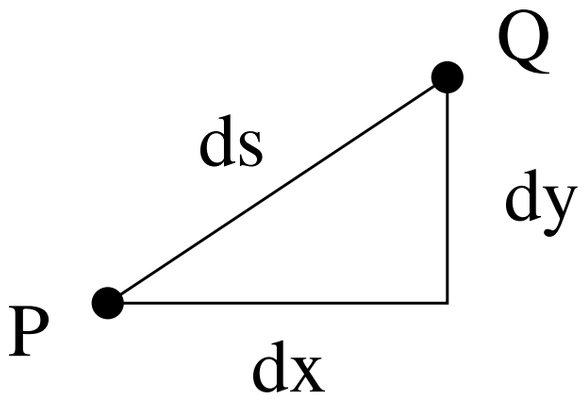
Einstein realized this meant gravity could be understood via geometry, as the bending and stretching of space and time.

(I'll say why later.)



Two-dimensional flat plane.

Distance between P and Q?



$$ds^2 = dx^2 + dy^2$$

(Pythagoras)

Three-dimensional flat space $ds^2 = dx^2 + dy^2 + dz^2$

Four-dimensional flat space-time

$$ds^2 = -c^2dt^2 + dx^2 + dy^2 + dz^2$$

"Minkowski space" - the geometry behind special relativity.

How about a curved 4-D space-time?

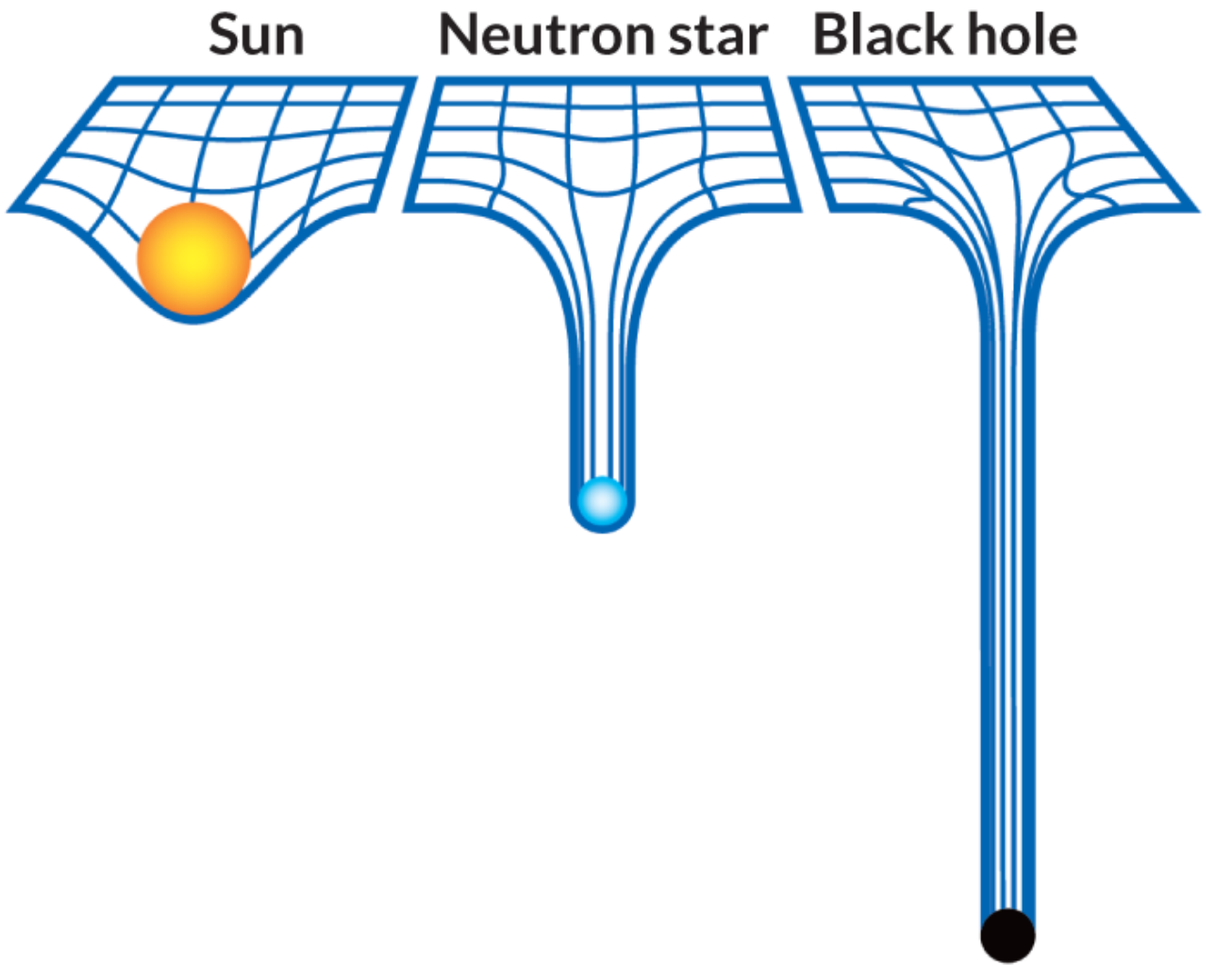
$$ds^2 = -\left(1 - \frac{2GM}{r}\right)c^2dt^2 + \frac{1}{1 - \frac{2GM}{r}}dr^2 + r^2d\theta^2 + r^2\sin^2\theta d\phi^2$$

"Schwarzschild geometry" - a non-rotating black hole of mass M

Questions?

Black hole theory - understanding Schwarzschild

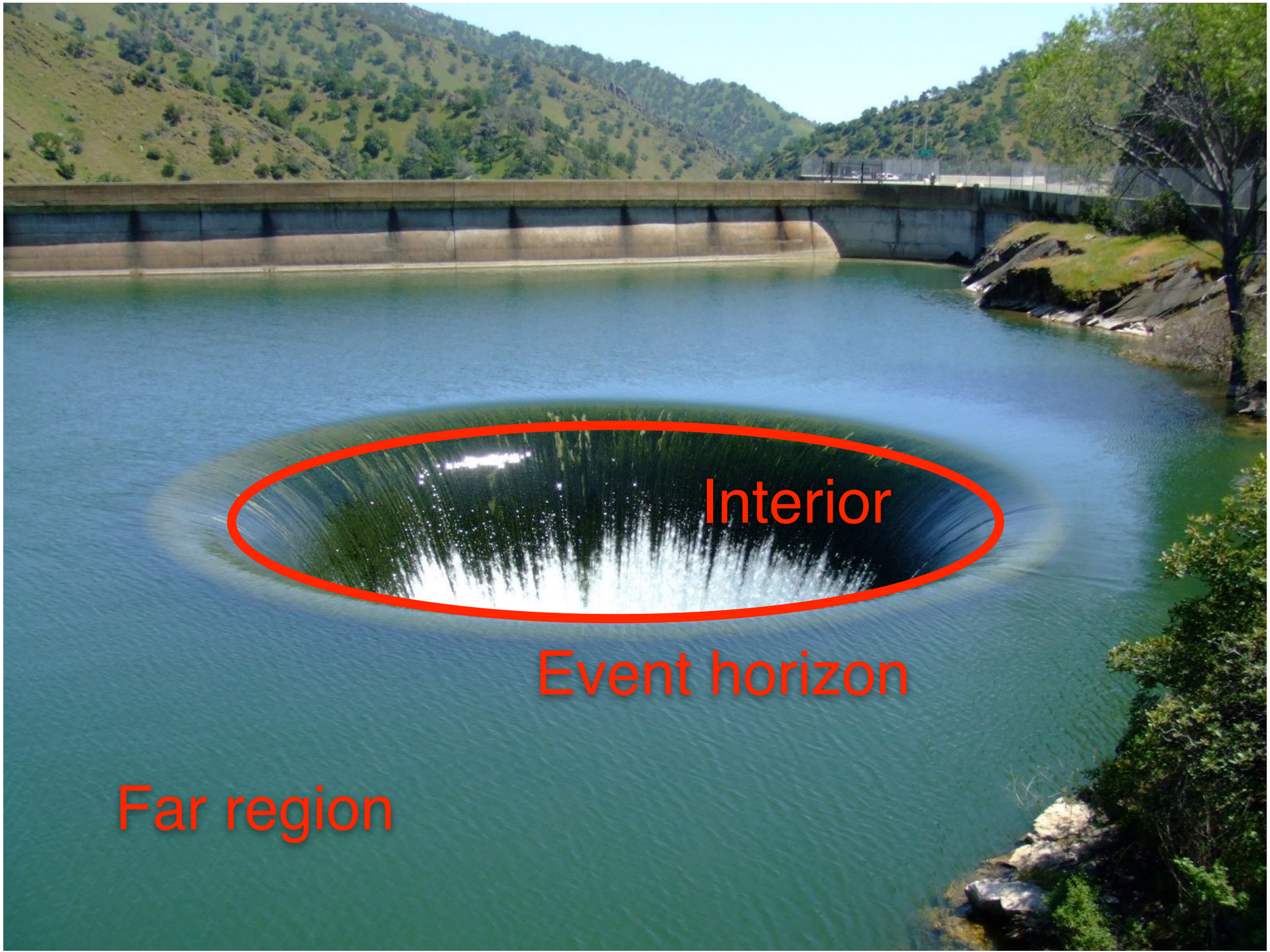
Anything with mass or energy will bend space-time.



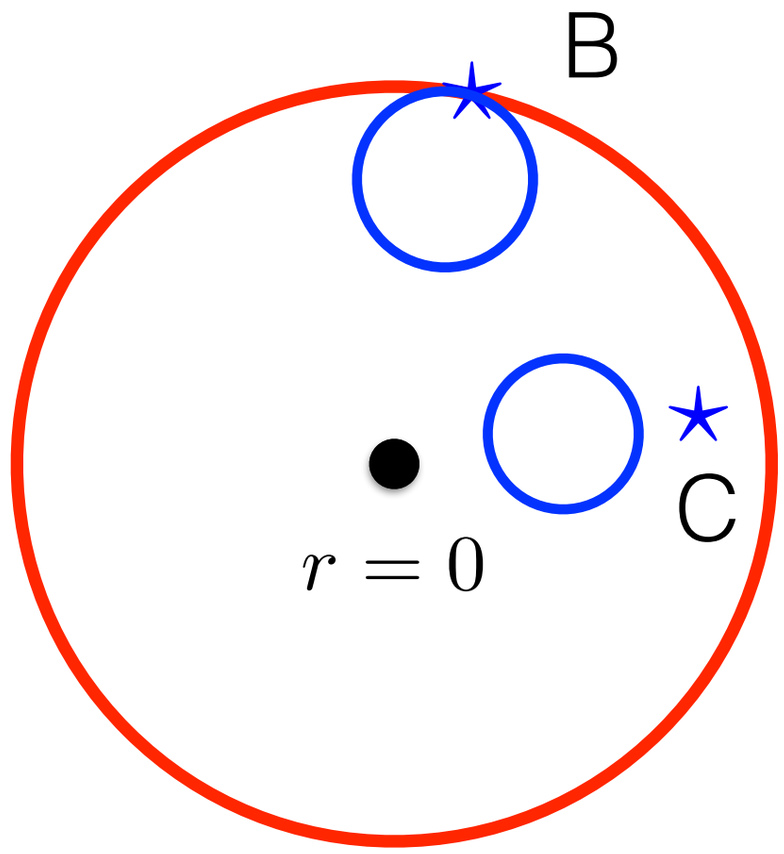
Why curved space-time?

Zoom in on a small region and you won't notice that space-time is curved (geometry => Equivalence Principle!).

Even better - you should think of space as moving in toward the center of the black hole.



Imagine flashes of light set off at different places.



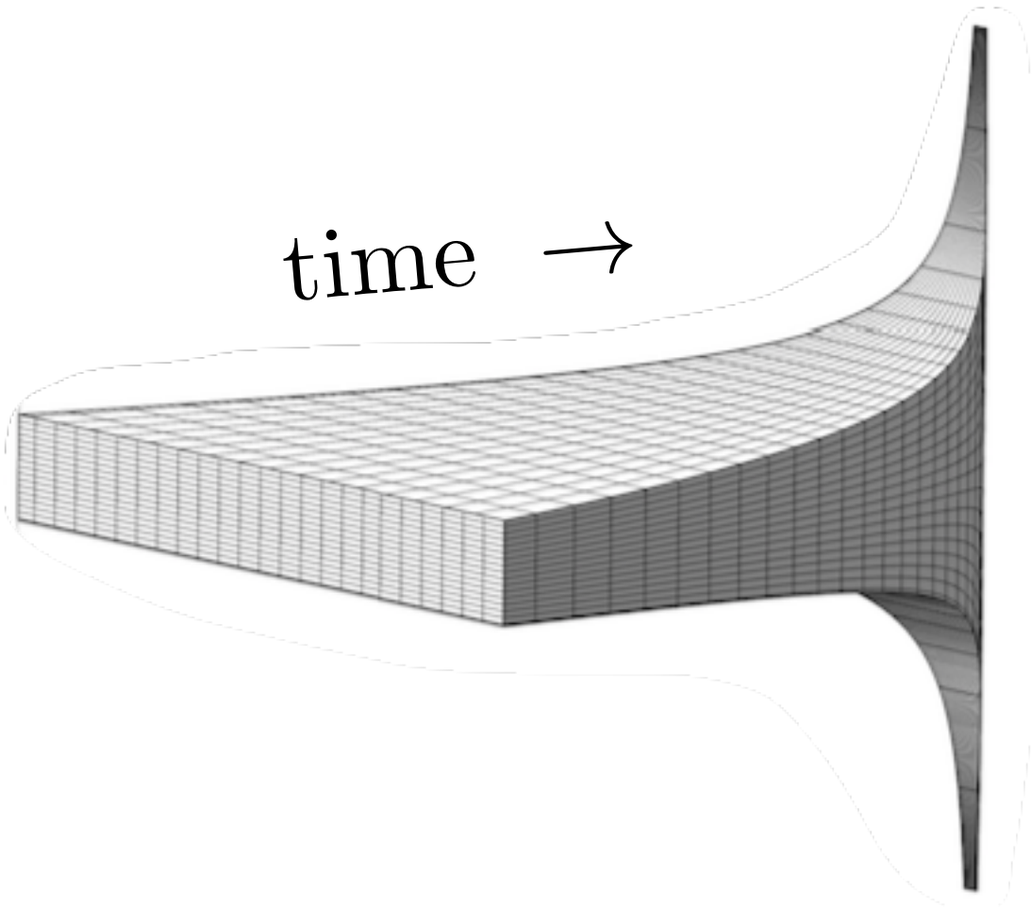
A spreads out

B falls in, but part stays on the event horizon

C just falls in

Anything inside the horizon will end up at r = 0.

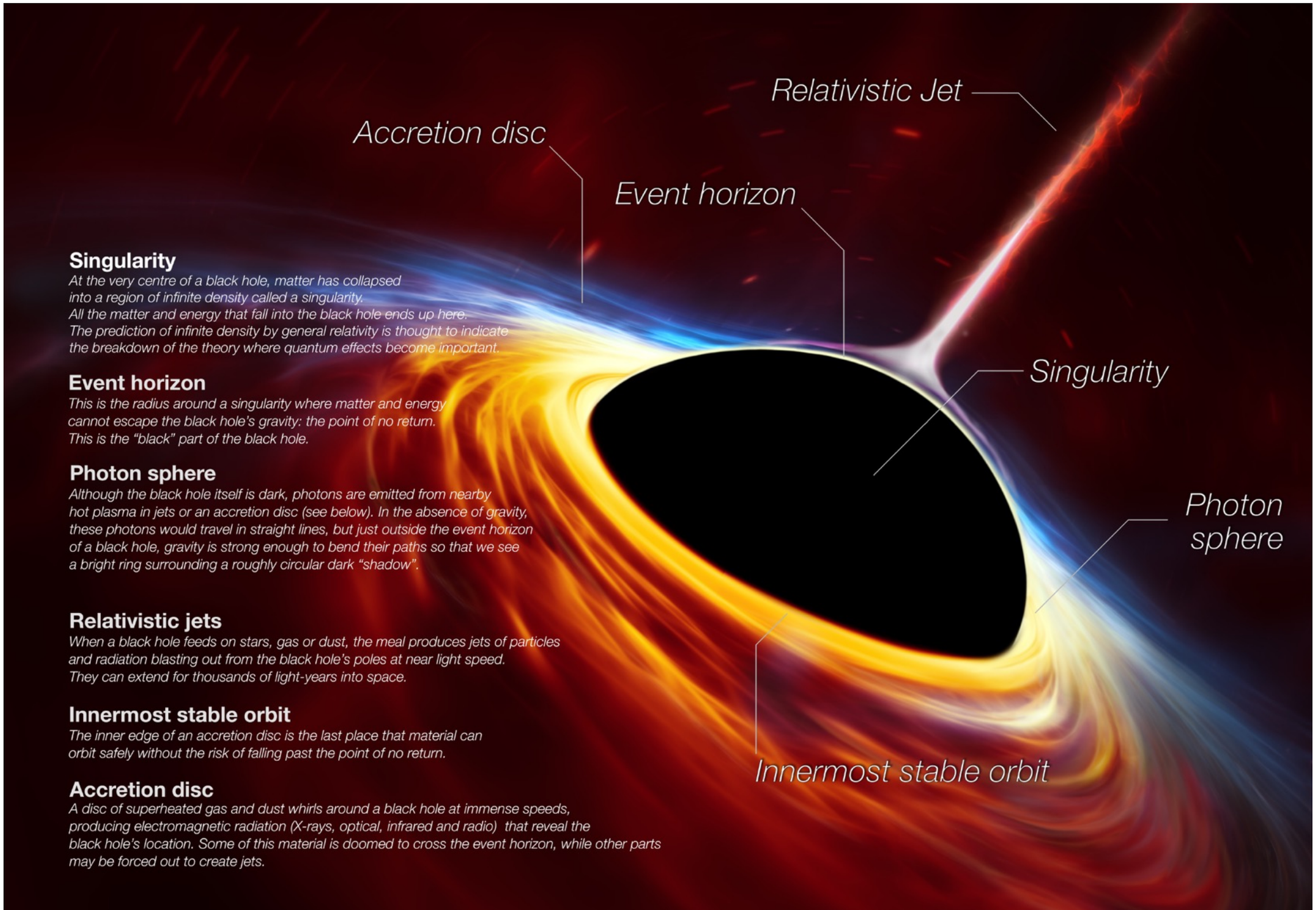
Once you're inside the horizon r = 0 isn't located relative to you in space. Instead it's in your future. It's a singularity where time ends.



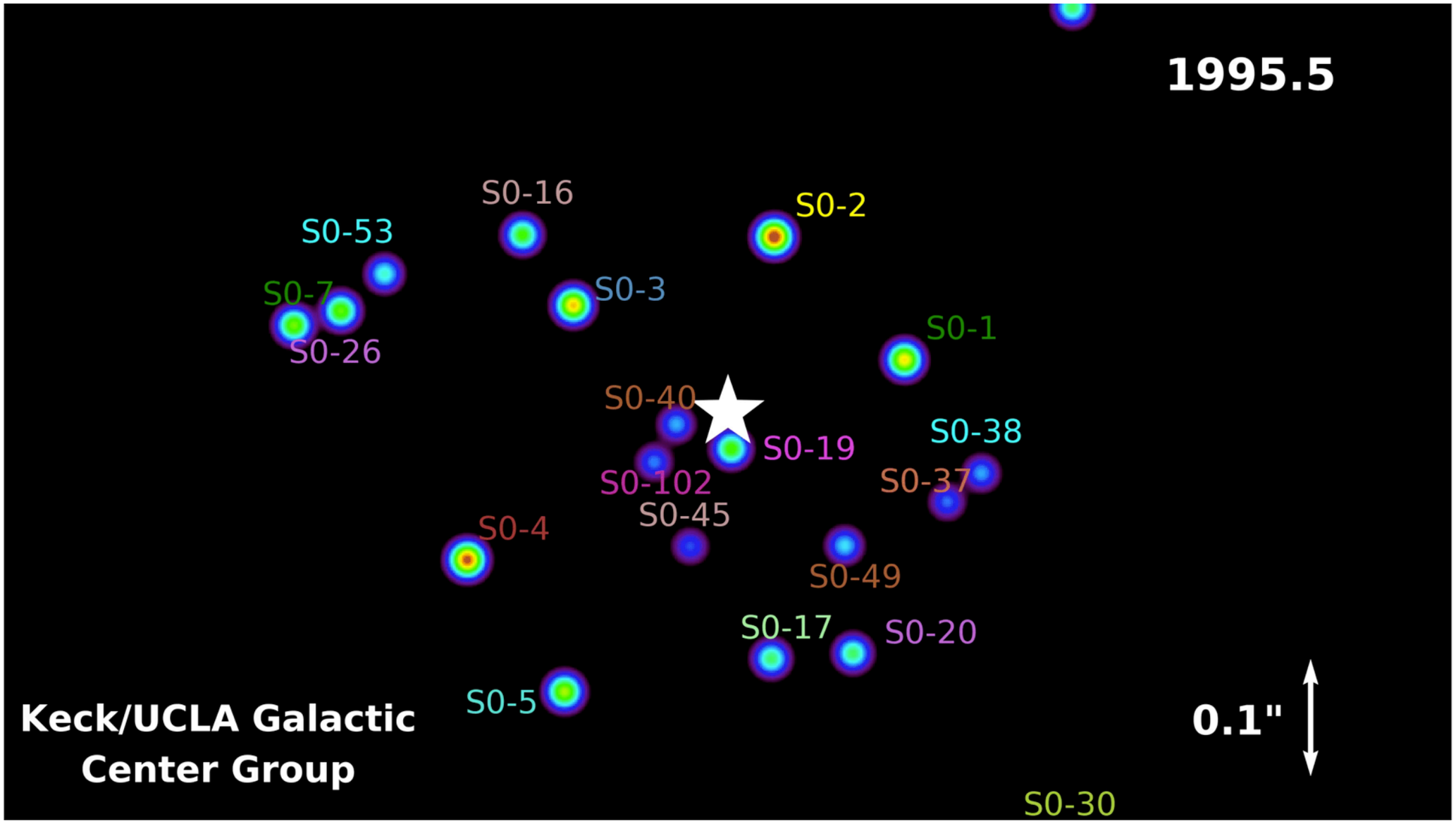
Questions?

Black holes (astrophysics)

Astrophysical black holes are usually spinning, and they often have accretion disks. Artist's image:



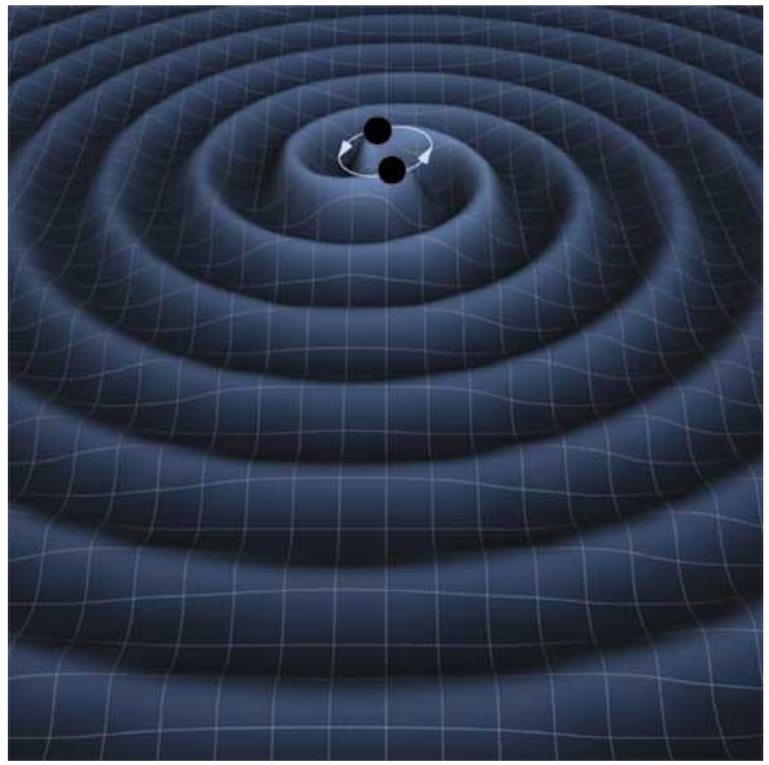
Black holes really exist! We've tracked stars orbiting the black hole at the center of our galaxy.



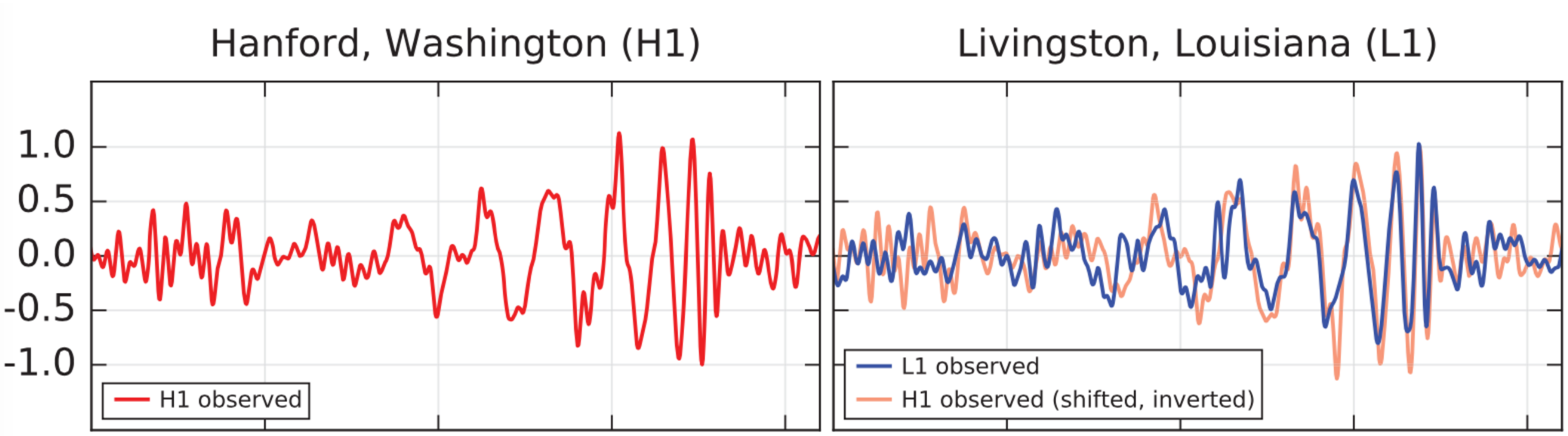
UCLA / Keck group

Central object has 4 million times the mass of the sun.

We've detected gravitational waves from black hole mergers.



LIGO collaboration



And we've made a millimeter-wave image of the black hole accretion disk at the center of the galaxy M87.

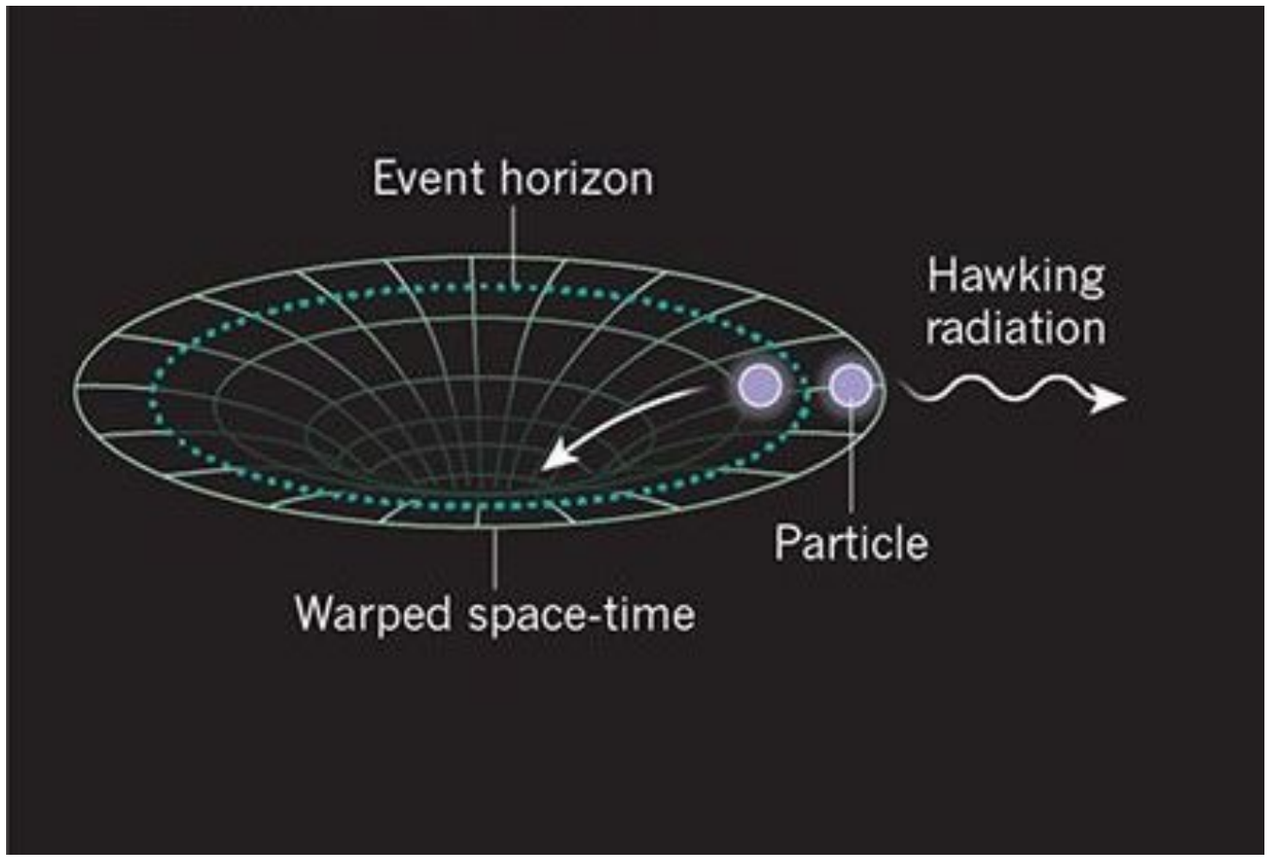
EHT collaboration

Thank you!

Quantum effects

It's not quite true that nothing can escape from a black hole.

Quantum effects - the uncertainty principle - mean that black holes emit long-wavelength thermal radiation.



But all information about what fell in to make the black hole appears to be lost.