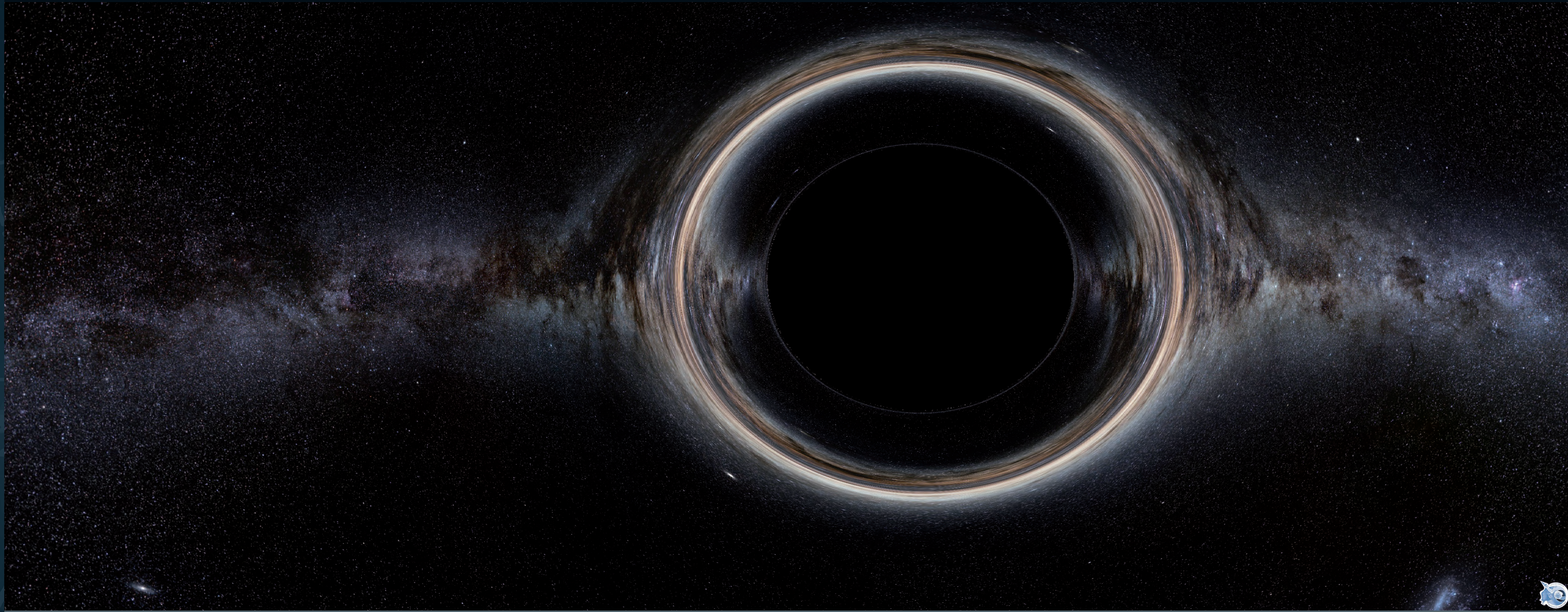
Black holes, the dark heart of General Relativity

General Relativity predicts the existence of black holes. They are regions where spacetime is so distorted that not even light can escape from them; this is what makes them appear “black”.

Black holes are very simple objects: we don’t need more than their mass and rotation velocity to know everything about them. In comparison, to accurately describe the Sun, we would need more information than any computer is currently capable of storing.



Visualisation of the Black Hole at the Centre of the Milky Way
(visualisation: ESA Advanced Concepts Team (Alexander Wittig, Jai Grover) - [CC BY IGO] ; Milky Way background: ESO (S. Brunier) - [CC BY 4.0.])

How compact should an object be to become a black hole?

	High school student	Earth	Sun	Sagittarius A* black hole
Mass	~ 50 kg	~ 10^{24} kg	~ 10^{30} kg	~ 4 million solar masses
Black hole radius	~ 10^{-26} m	~ 9 mm	~ 3 km	~ 12 million km

Falling into a black hole:

Imagine that your crazy cousin decides to jump into a black hole.

What will your cousin see while falling?

» When still outside of the black hole, she will see strange optical distortions, due to light bending.

» She will notice nothing unusual happening when entering the black hole.

» Once inside, as she goes deeper, she will be stretched in some directions and squashed in others until she gets completely spaghettified and eventually ripped apart – first her limbs, then her cells and her atoms: everything.

What will you see from a safe distance?

» As time passes, you will see her moving more slowly, and the fall will appear to proceed increasingly in slow motion. However, this does not mean that she won’t fall into the black hole.

» You will actually lose sight of her before she reaches the black hole. This is because the light from objects falling into a black hole gets dimmer and dimmer: they become invisible very quickly.

1916 — First black hole solution

K. Schwarzschild
(P.D. [CC])

Schwarzschild finds the first solution of Einstein’s equations: a black hole that does not rotate.

1939 — Black holes as corpses of stars

R. Oppenheimer
(Dpt. Energy, O. Public Affairs - [WC])

Oppenheimer and Snyder show that the gravitational collapse of very massive stars is unstoppable and forms black holes.

1963 — First rotating black hole

R. Kerr
(Melirius [CC BY-SA 3.0])

Kerr finds the first solution of Einstein’s equations describing a rotating black hole.

1972 — Black hole thermodynamics

S. Hawking
(NASA)

Building on the work of Bekenstein, Hawking suggests that black holes behave much like a pot of boiling water.