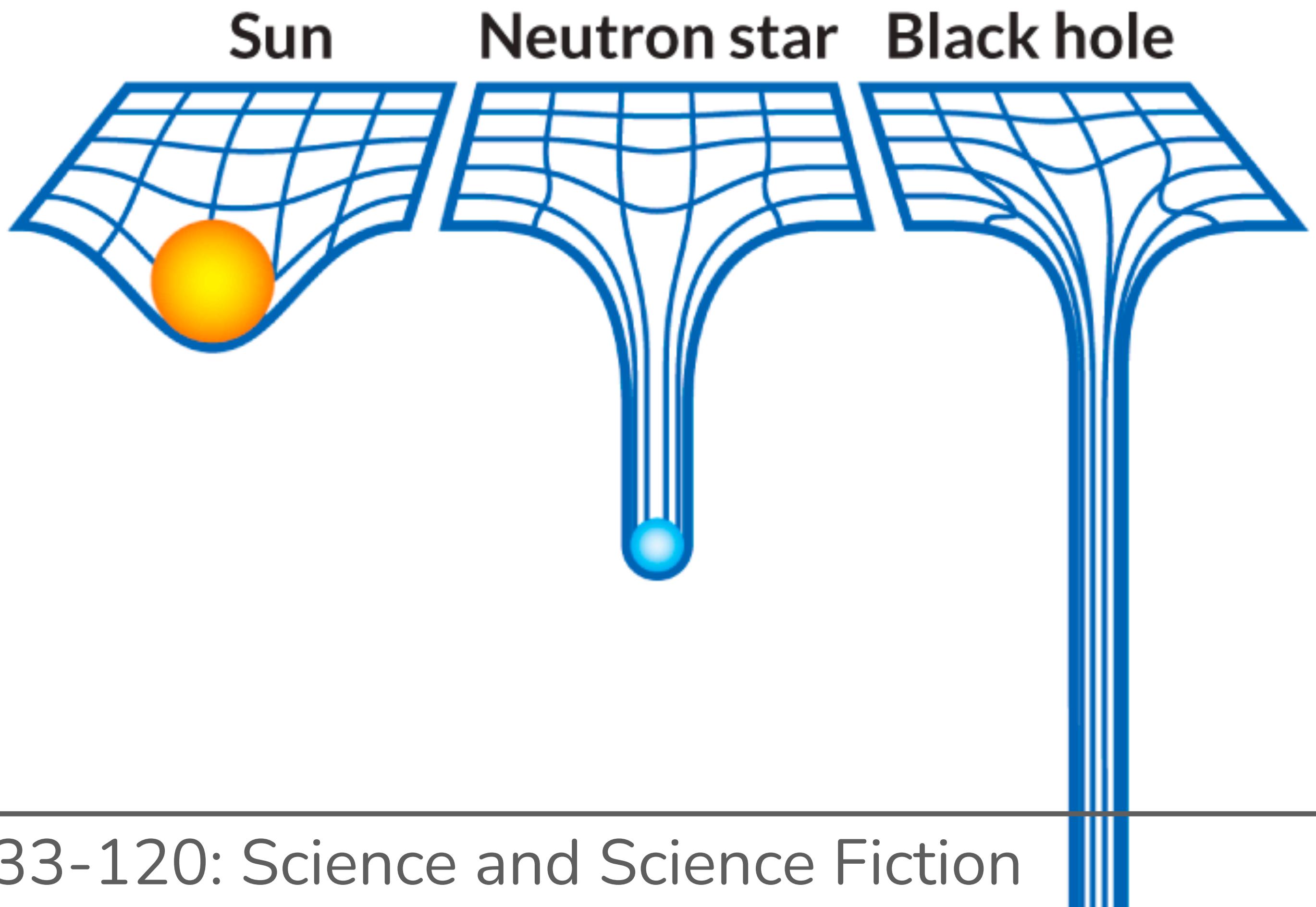


Announcements

- Problem 2 is due Feb 02 at 11:59pm
- Exploration paper 1 due **Feb 09**
- **Spacetime Team Project: due Feb 07**
 - Find your teams on Canvas then pick up your equipment in the Doherty Hall A301 suite of offices Jan 31 or Feb 2, between 12:15 and 4:30 PM, or Feb 5, between 10:30 AM and noon.
 - **NO CLASS ON MONDAY, Feb 5**

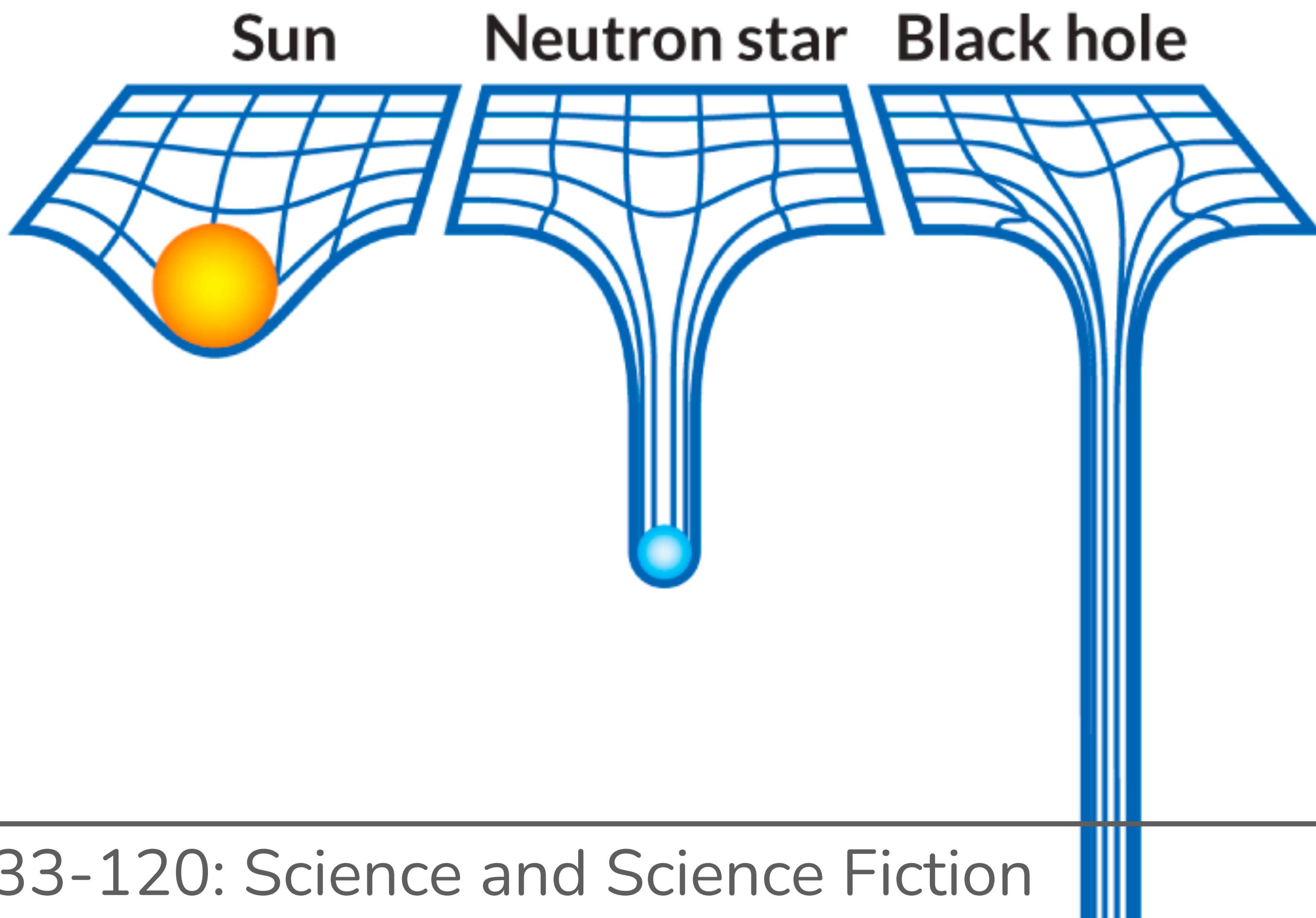
Black holes



Hawking radiation

- ▶ First introduced by Hawking in 1974
- ▶ Particles created near the horizon are not reabsorbed and cause evaporation
- ▶ faster for lower masses
- ▶ Masses of up to 10^{12} kg will evaporate within age of Universe

Black holes



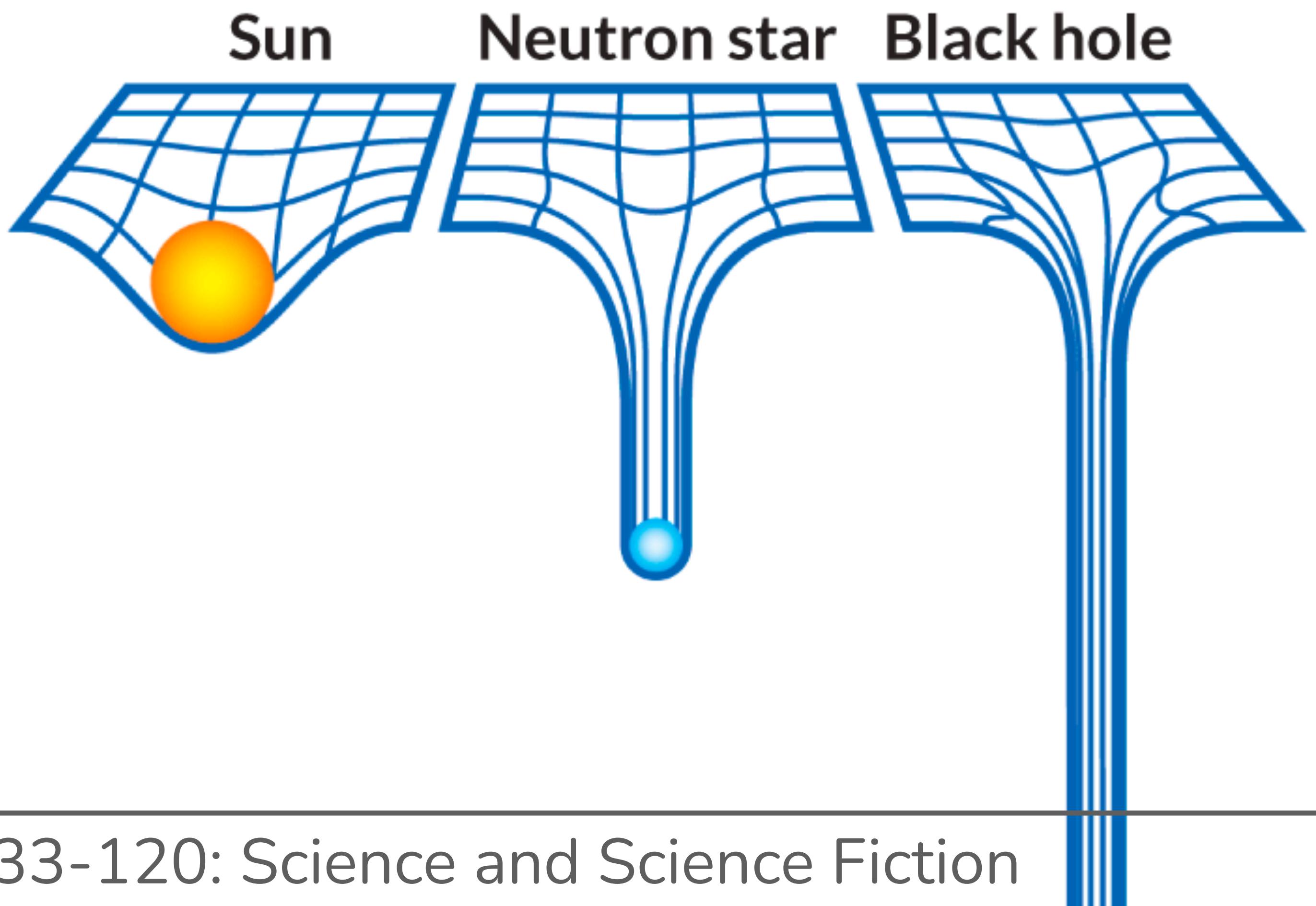
Schwarzschild radius

$$r_s = \frac{2Gm}{c^2}$$

radius that defines
the event horizon for
any mass

not the “actual radius”

Black holes

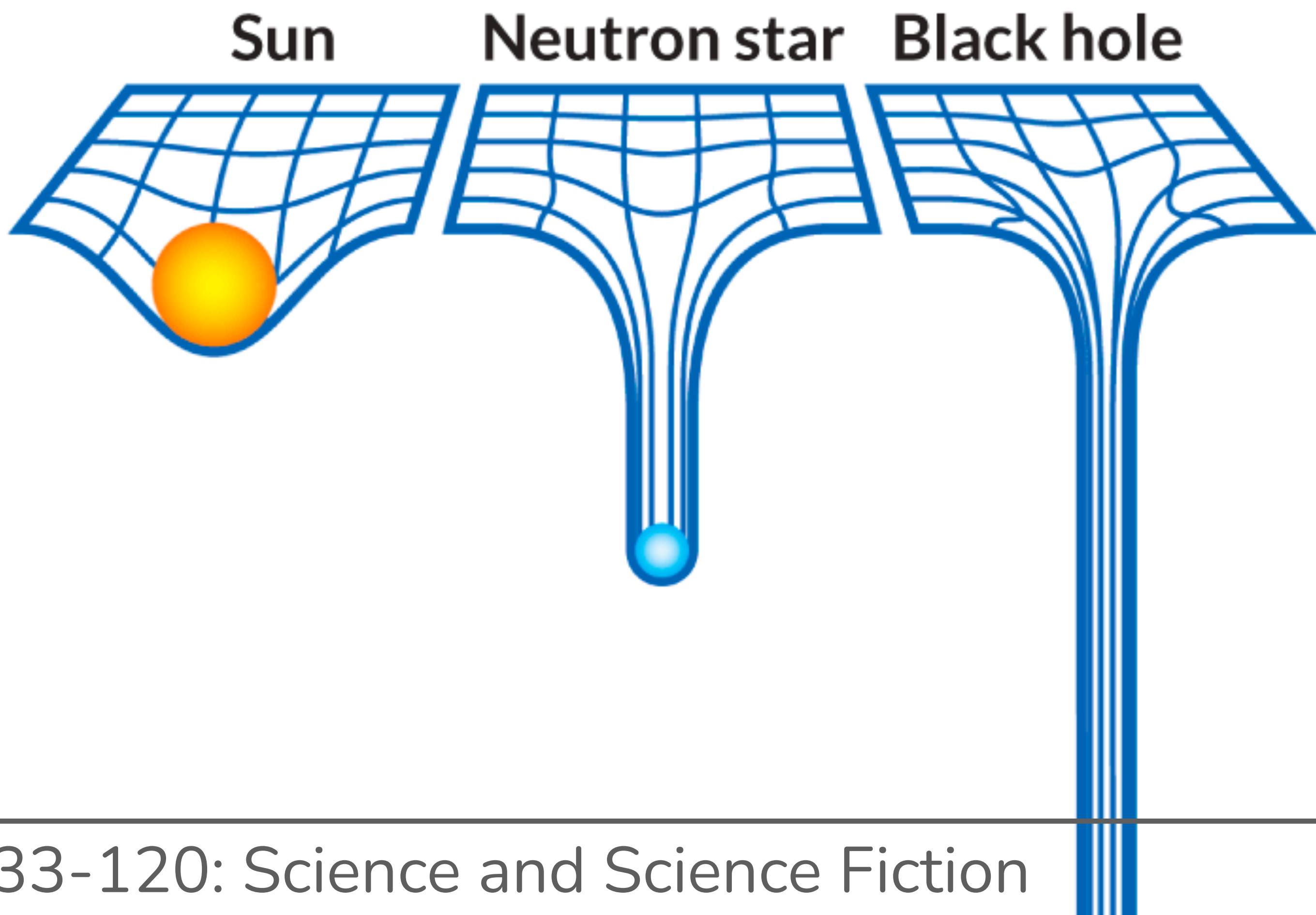


Schwarzschild radius

$$r_s = \frac{2Gm}{c^2}$$

radius at which
contained mass
undergoes complete
gravitational collapse

Black holes



Schwarzschild radius

$$r_s = \frac{2Gm}{c^2}$$

Gravitational time dilation

$$t = t_\infty \sqrt{1 - \frac{2Gm}{rc^2}}$$

$$t = t_\infty \sqrt{1 - r_s/r}$$



Despicable Me

Directed:

Chris Renaud

Pierre Coffin

Universal (2009)



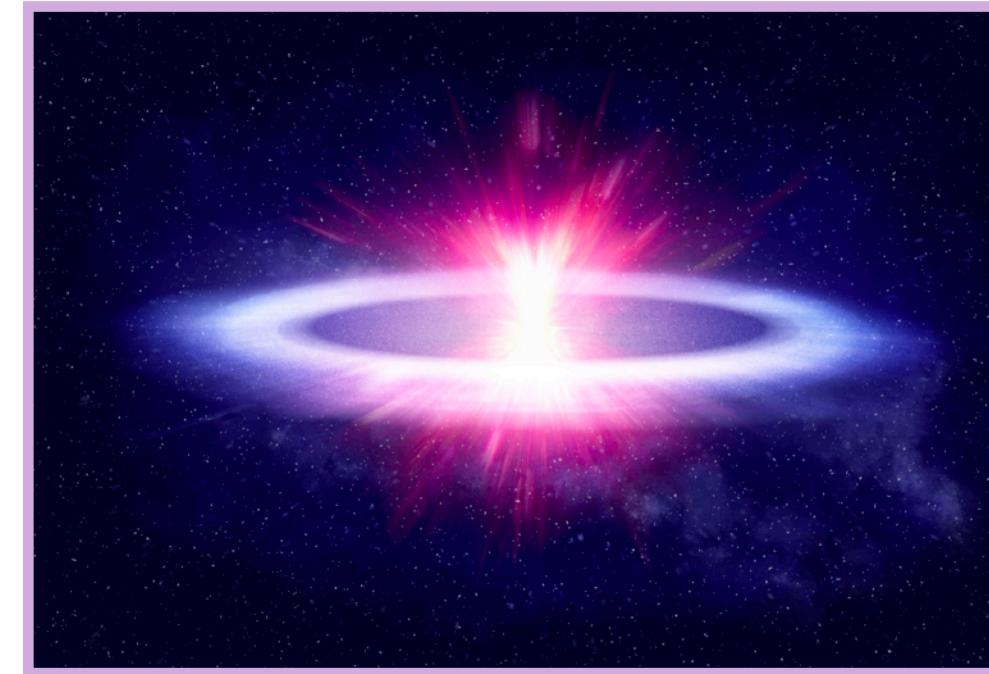
Inspiration for problem 3

What happens if
you shrink the
Moon down to the
size of a grapefruit?

Astrophysical black holes

stellar mass

$\sim 3 - 500 M_{\odot}$



Direct collapse of “normal” massive stars

intermediate mass

$\sim 500 - 10^5 M_{\odot}$



Direct collapse of earliest generation of stars

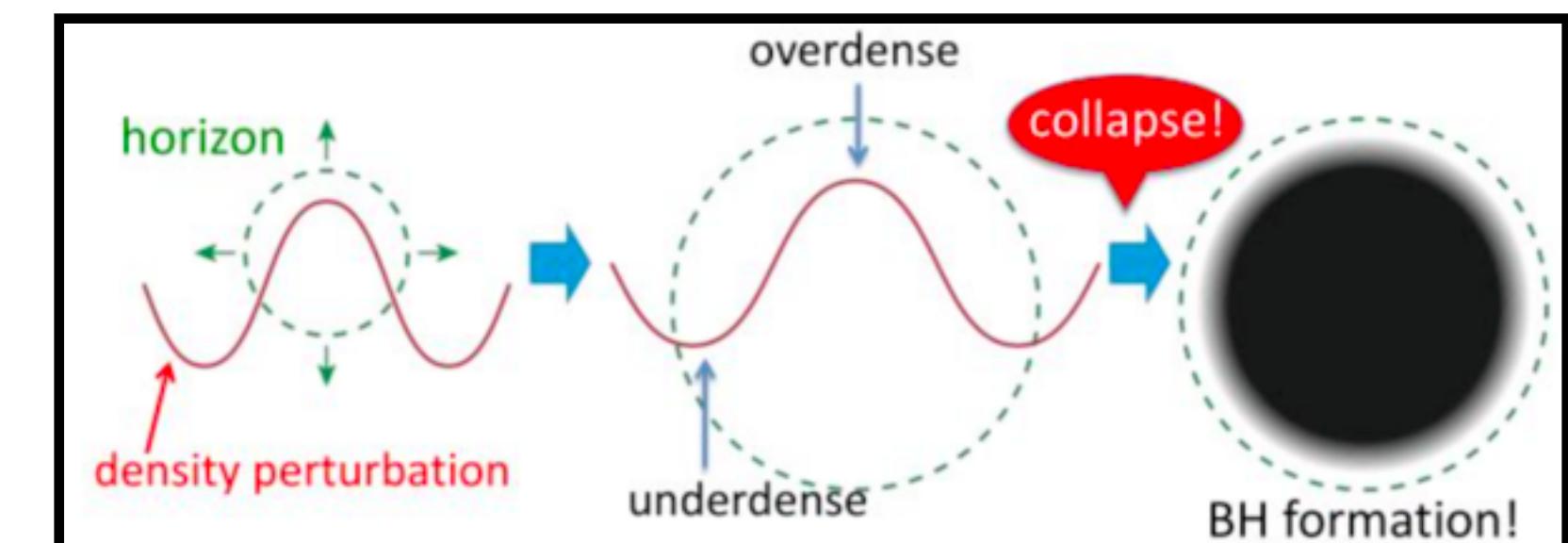
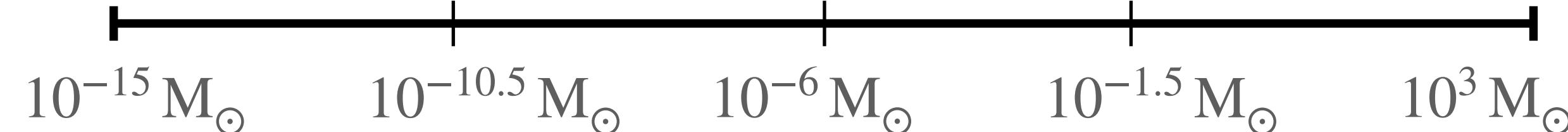
(Super)massive

$\sim 10^5 - 10^9 M_{\odot}$



Repeated mergers facilitated through galaxy mergers or gas accretion

primordial black holes





Star Trek

Directed:
J.J. Abrams

Paramount (2009)



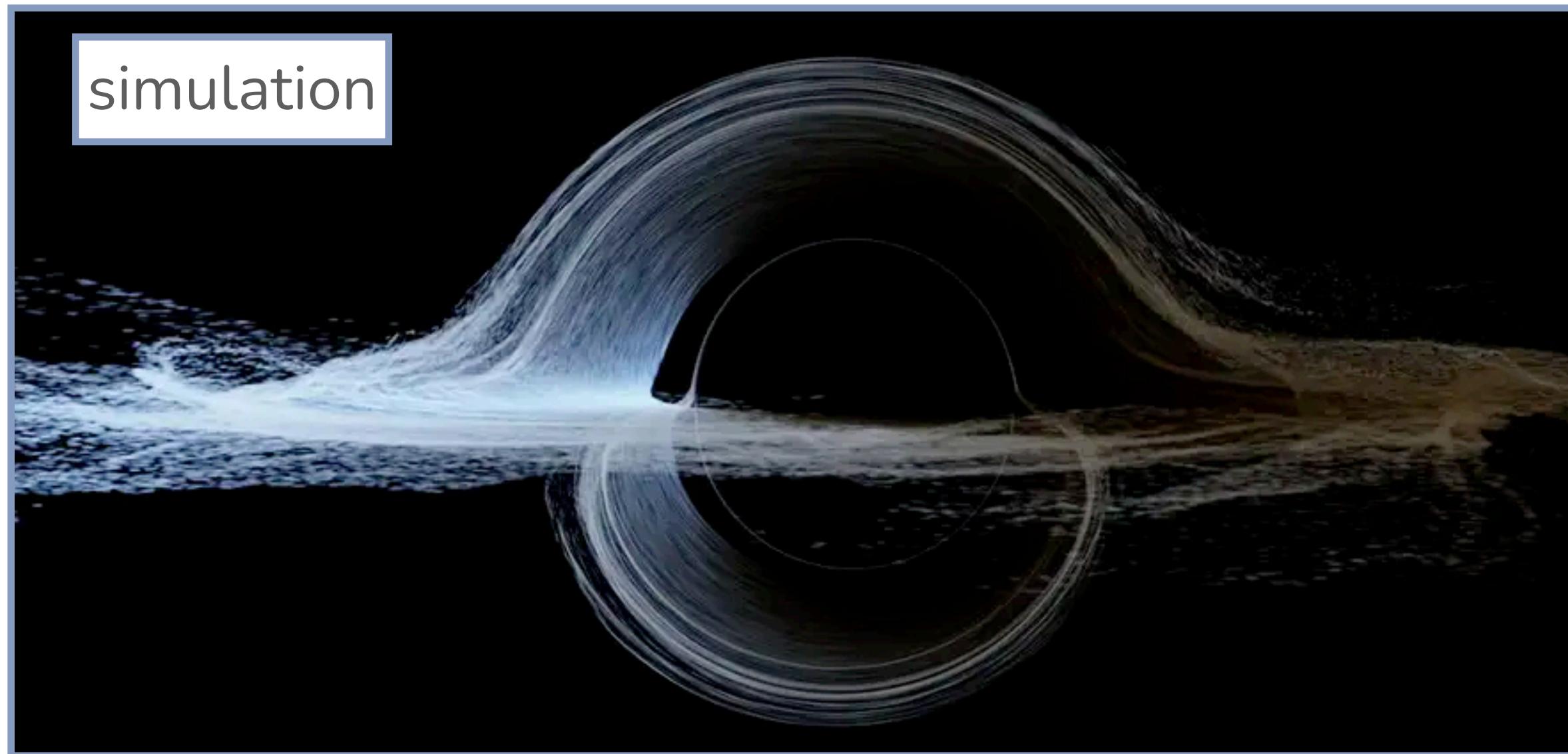
Star Trek

Directed:
J.J. Abrams

Paramount (2009)

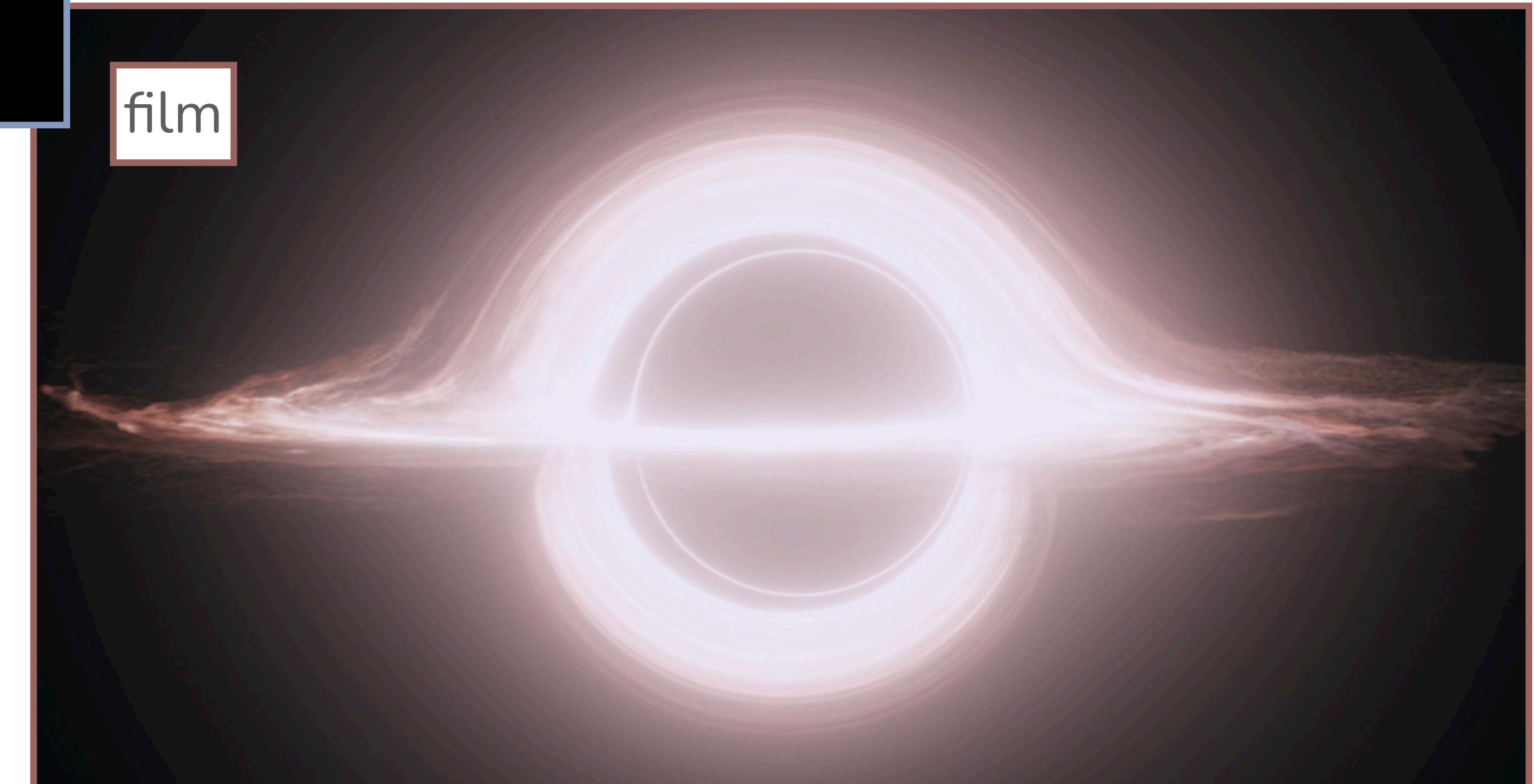
Travel into a black hole is **NOT** a way to travel in time

Astrophysical black holes in Science Fiction



A collaboration between scientists,
led by Kip Thorne, & artists!
Only changed the symmetry,
brightness, and smoothing

“Gargantua” in Interstellar is the
most faithful representation of a
black hole in film to date



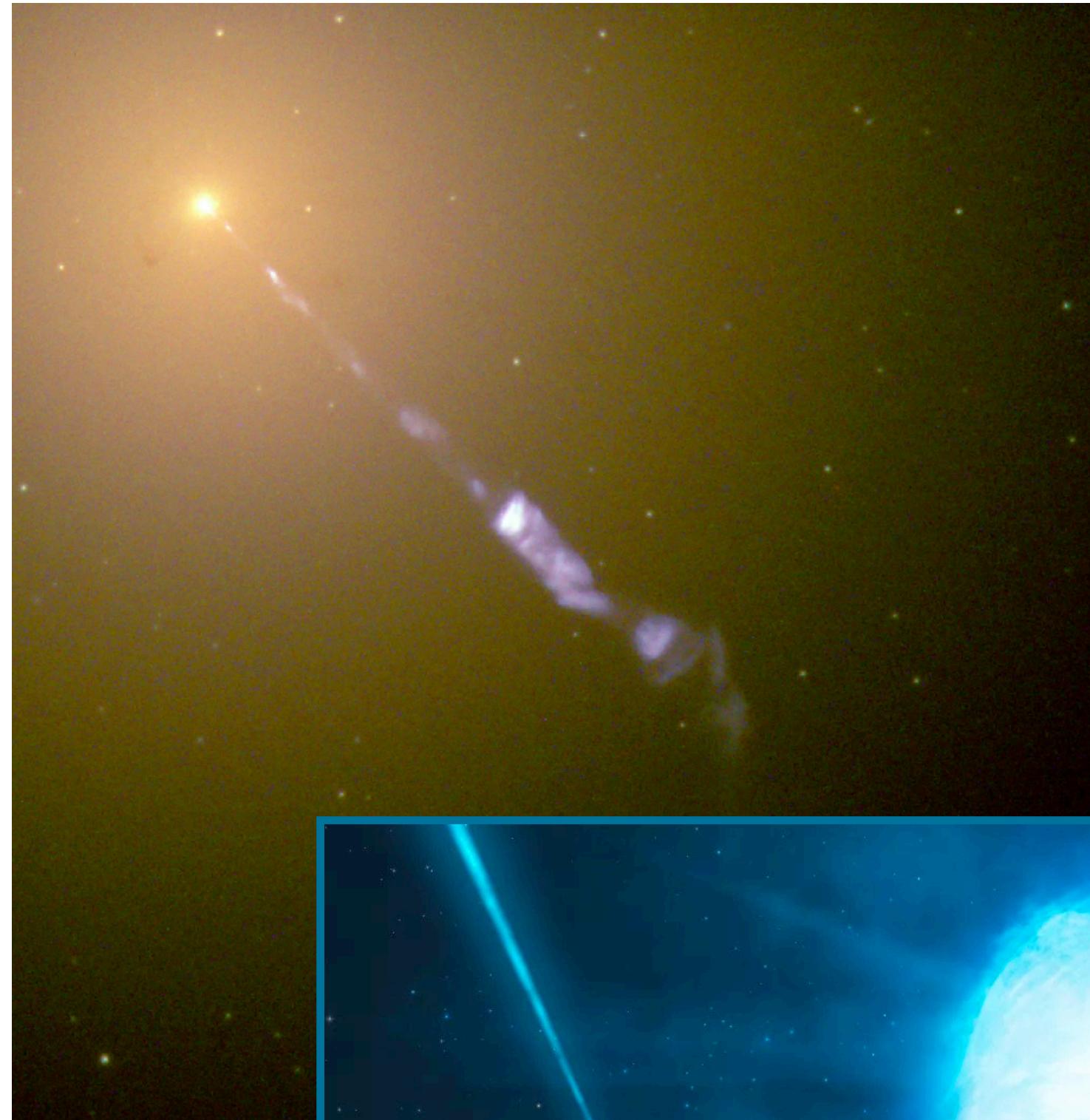


Interstellar

Directed:
Christopher Nolan

Warner Brothers
(2014)

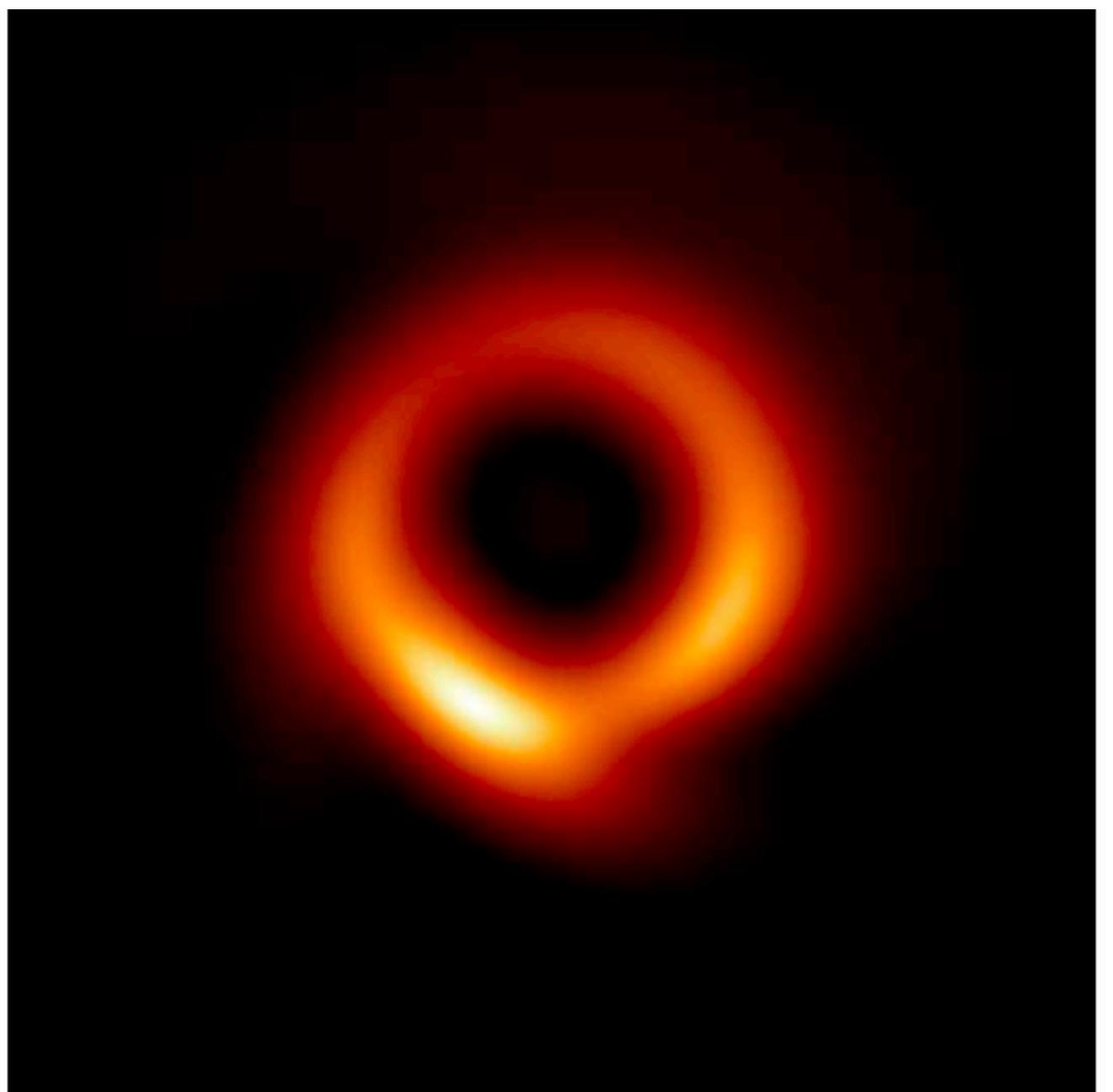
Observing astrophysical black holes



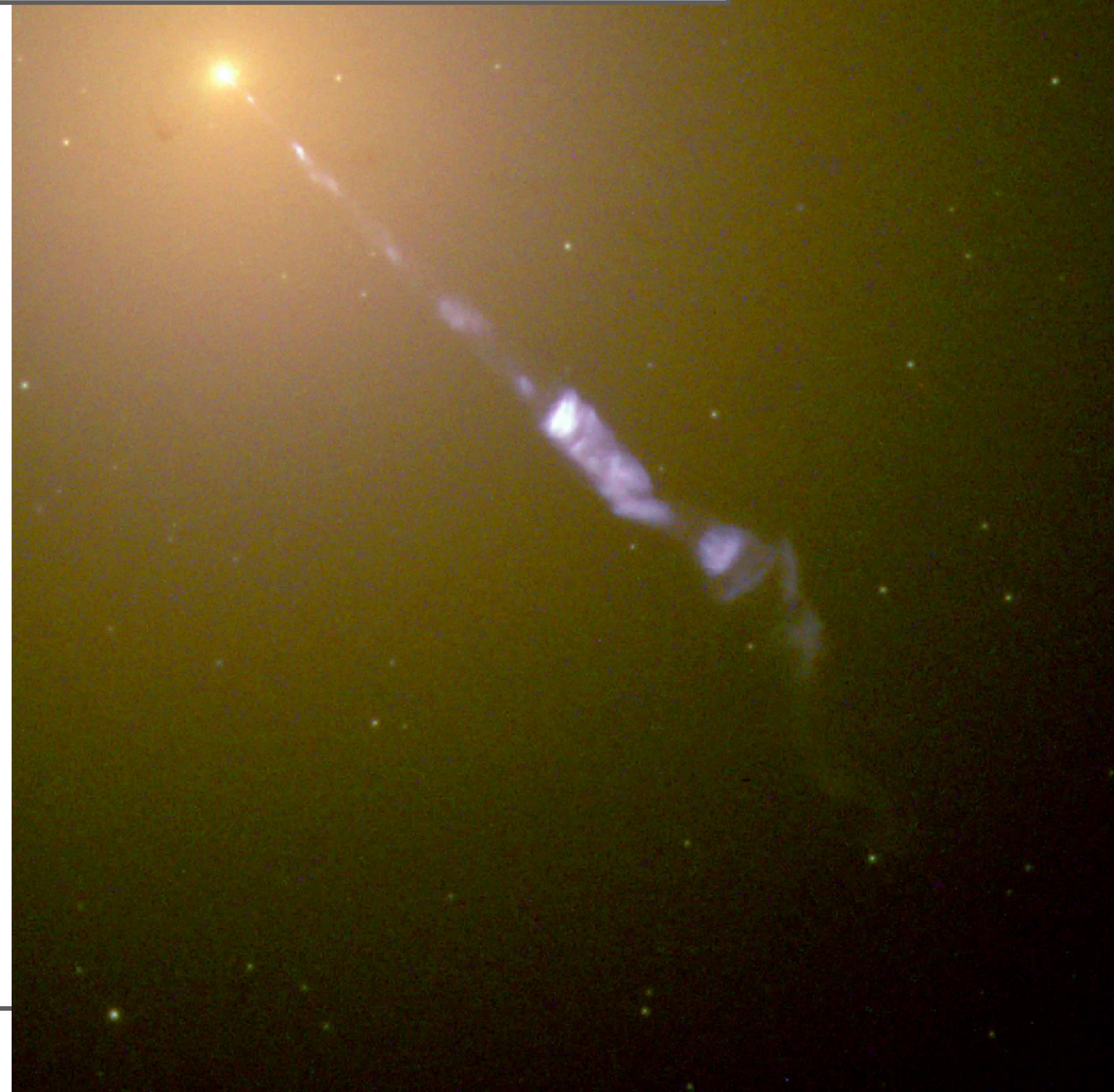
Until 2016, the vast majority of known black holes were discovered by their inferred presence due to accretion of gas

The gas is either supplied by the centers of galaxies (above) or donated from stellar companions (below)

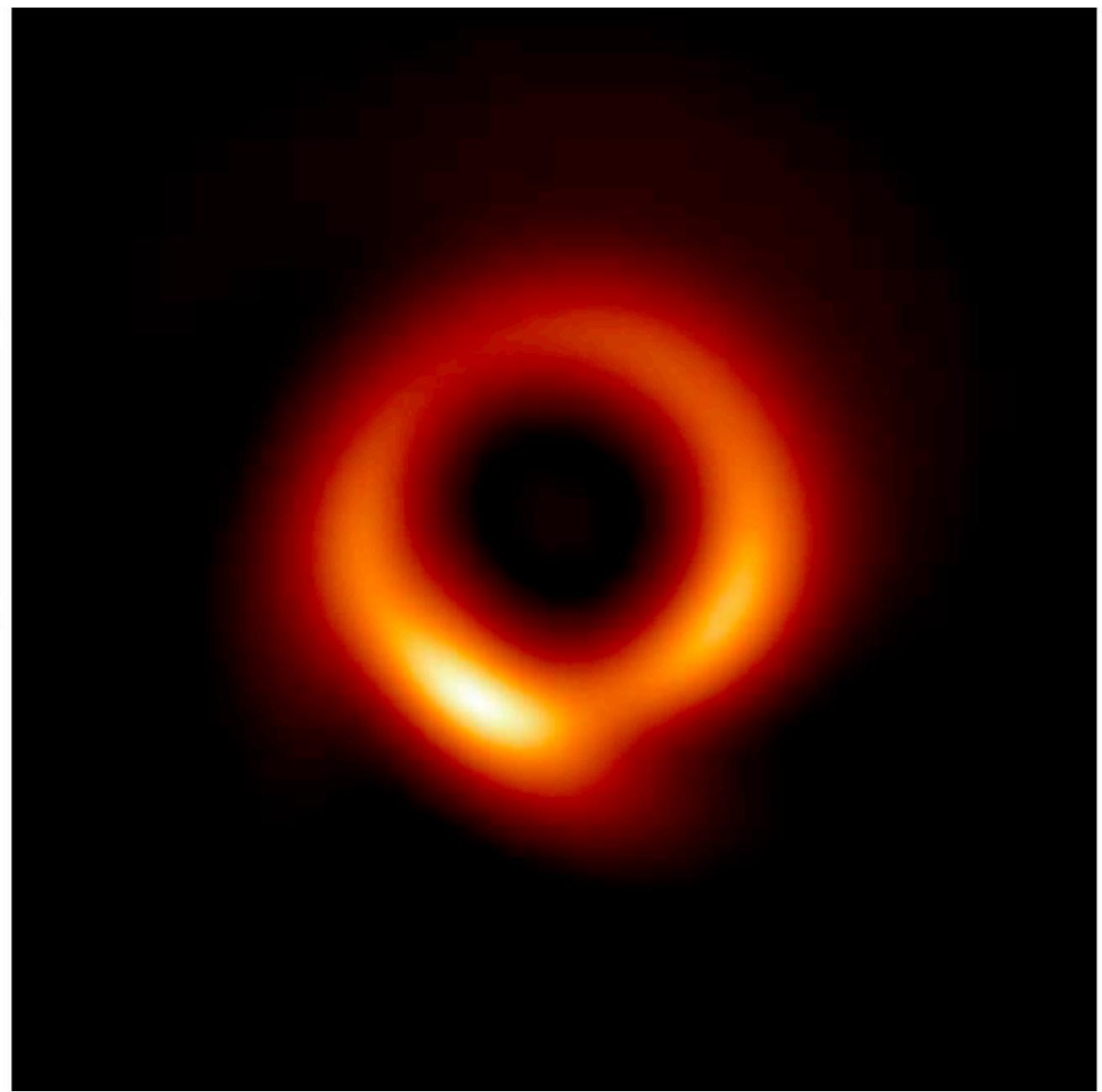
Observing astrophysical black holes



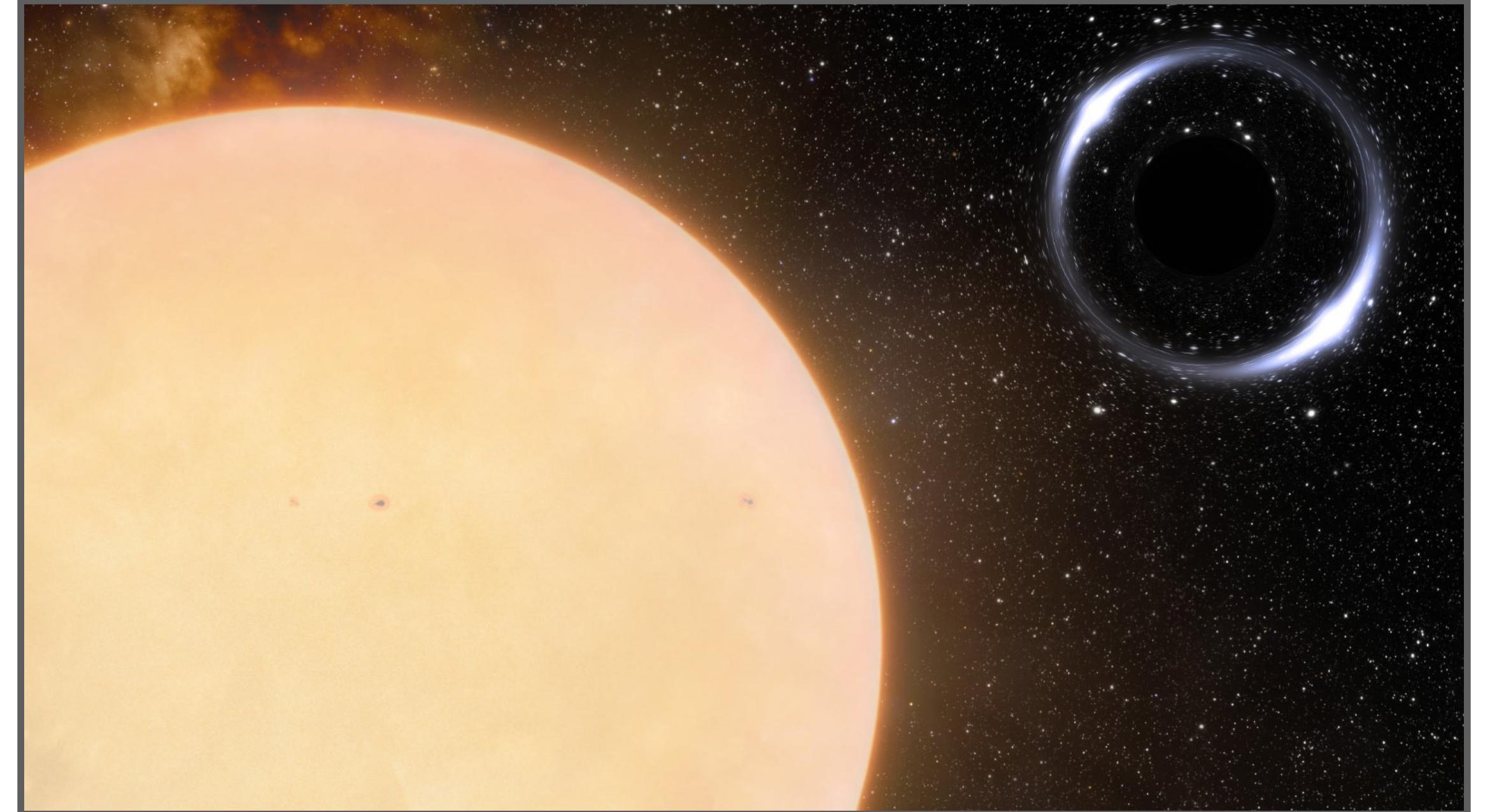
In 2019, the Event Horizon Telescope published the first *image* of M87, a $10^9 M_\odot$ BH in the center of a galaxy



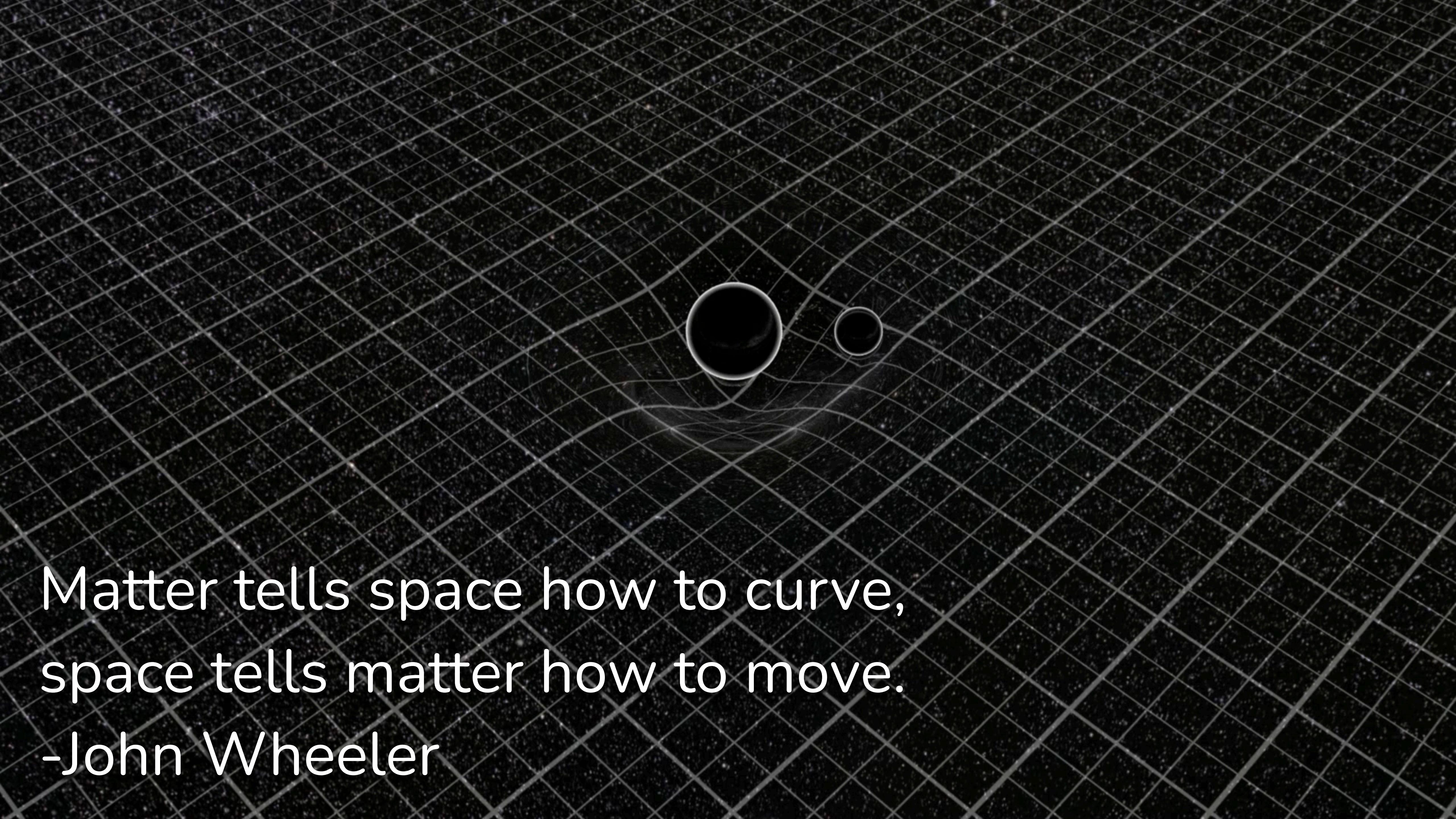
Observing astrophysical black holes



In 2019, the Event Horizon Telescope published the first image of M87, a $10^9 M_\odot$ BH in the center of a galaxy



In 2023, the Gaia satellite discovered two $10 M_\odot$ BHs by tracking the motion of their stellar companions:
Gaia BH1, Gaia BH2



Matter tells space how to curve,
space tells matter how to move.

-John Wheeler

