

Our Black Hole



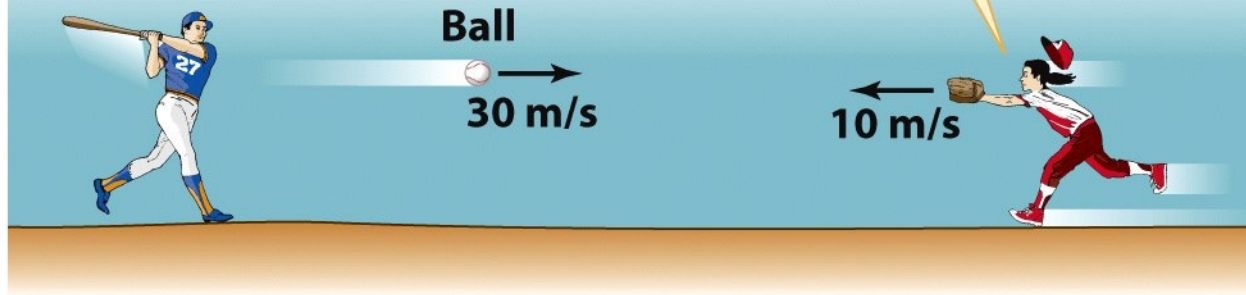
Daniel Thomas

Professor of Astrophysics

Head of School of Mathematics and Physics

University of Portsmouth

As seen by the outfielder, the ball is approaching her at $(30 \text{ m/s}) + (10 \text{ m/s}) = 40 \text{ m/s}$.



(a)

Incorrect Newtonian description:

As seen by the astronaut in the spaceship, the light is approaching her at $(3 \times 10^8 \text{ m/s}) + (1 \times 10^8 \text{ m/s}) = 4 \times 10^8 \text{ m/s}$.



Correct Einsteinian description:

As seen by the astronaut in the spaceship, the light is approaching her at $3 \times 10^8 \text{ m/s}$.

(b)

Figure 22-1

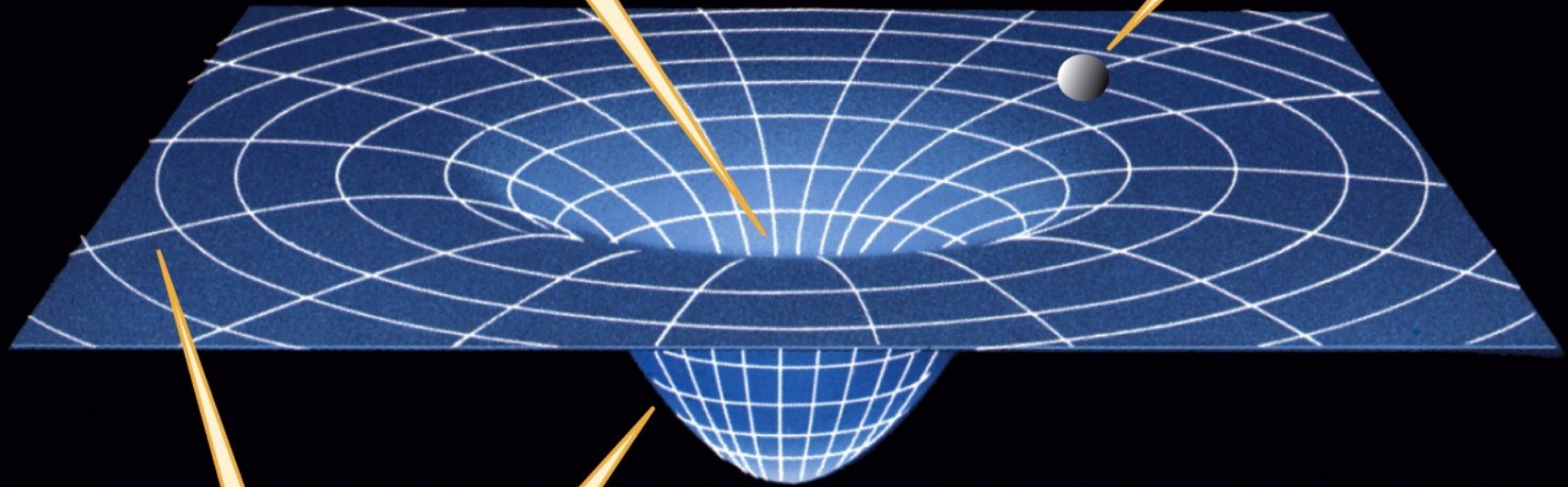
Universe, Eighth Edition

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The curvature of space-time

1. A massive object curves the spacetime around us.

3. In Einstein's picture of gravity other objects sense the curvature and are drawn into the "well."



2. Far from the object, spacetime is nearly "flat"; close to the object, the curvature forms a "well."

Figure 22-4

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Deflection of light

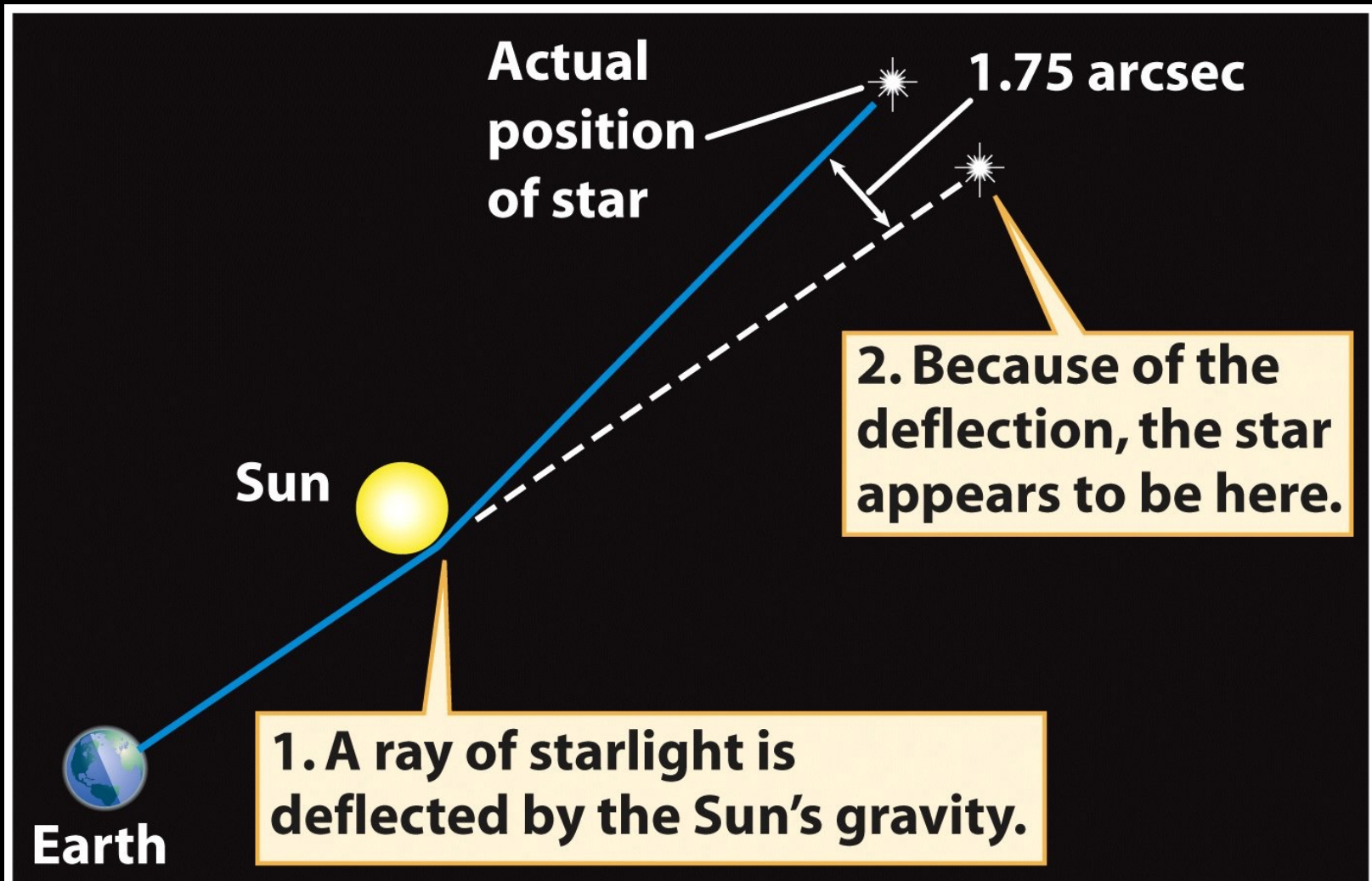
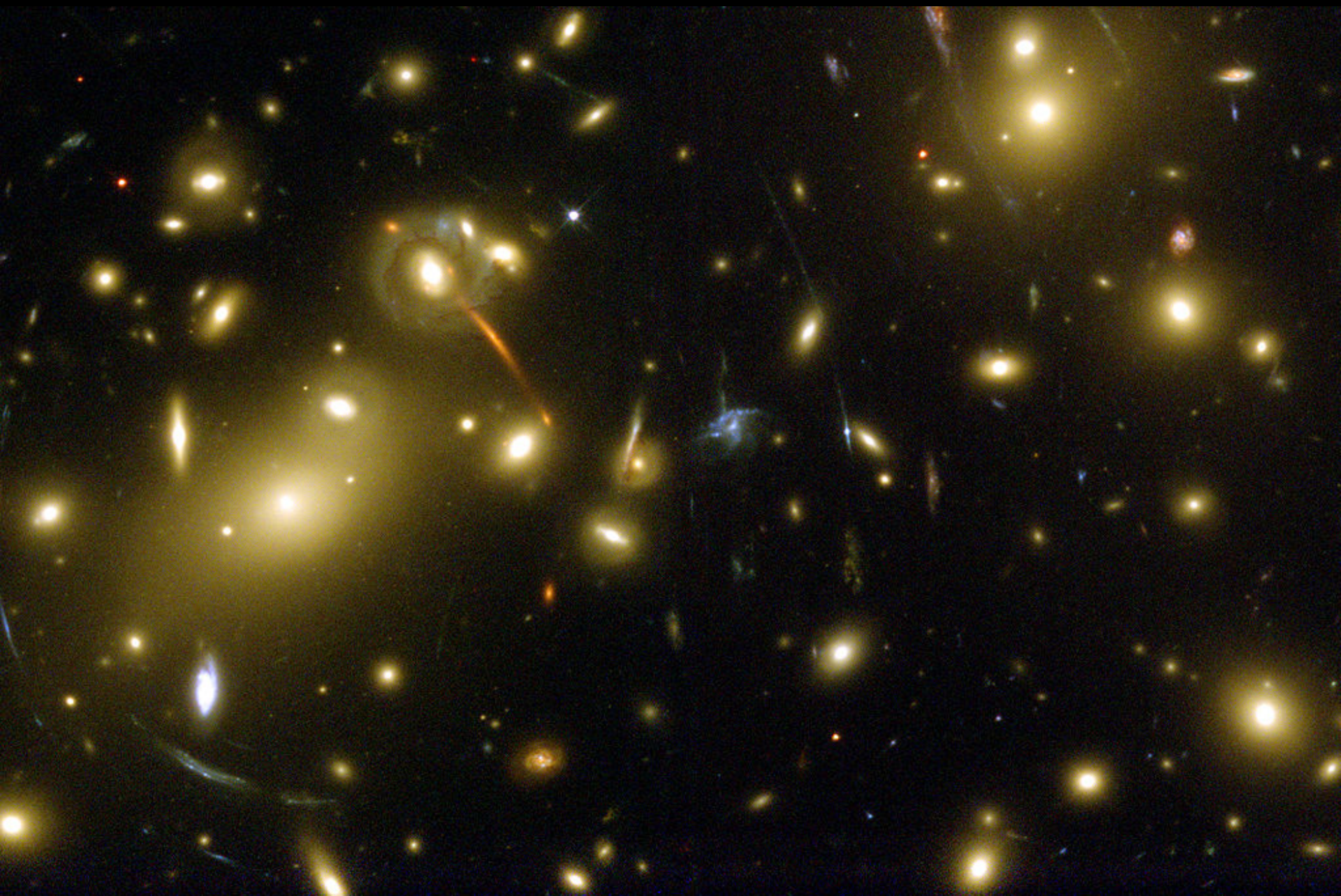


Figure 22-5

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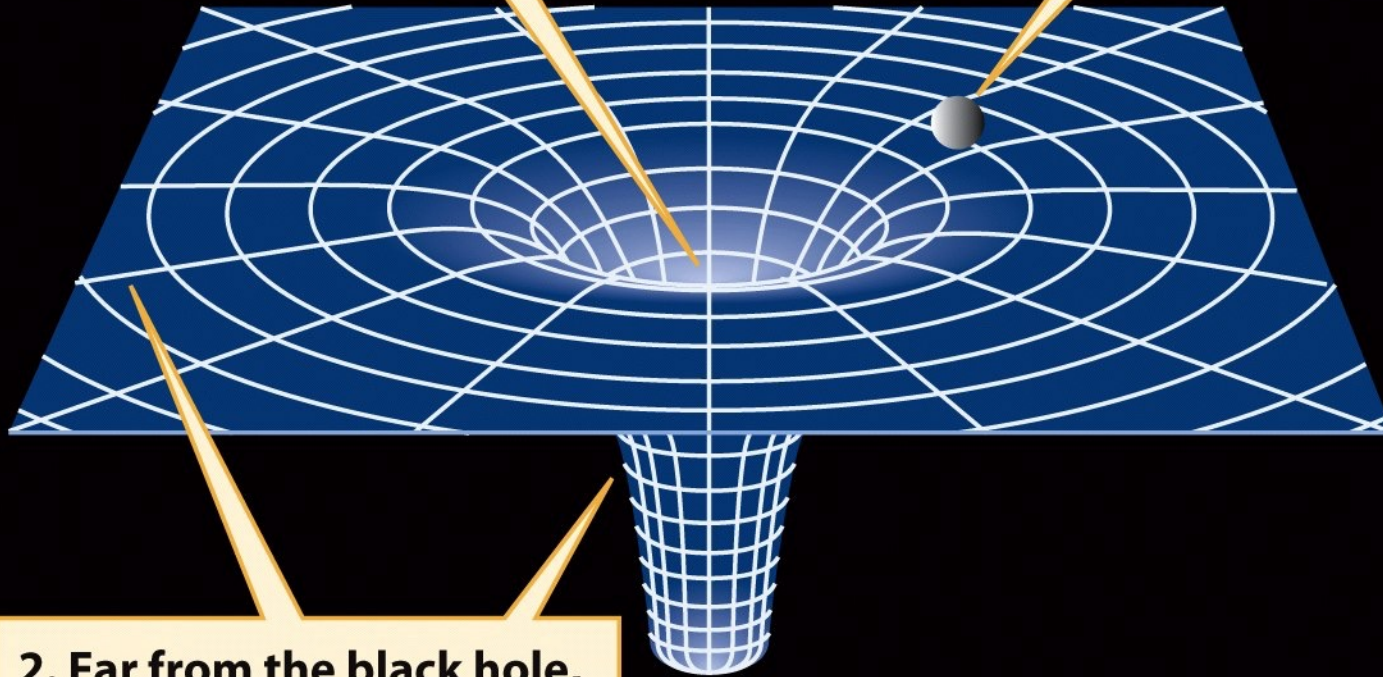
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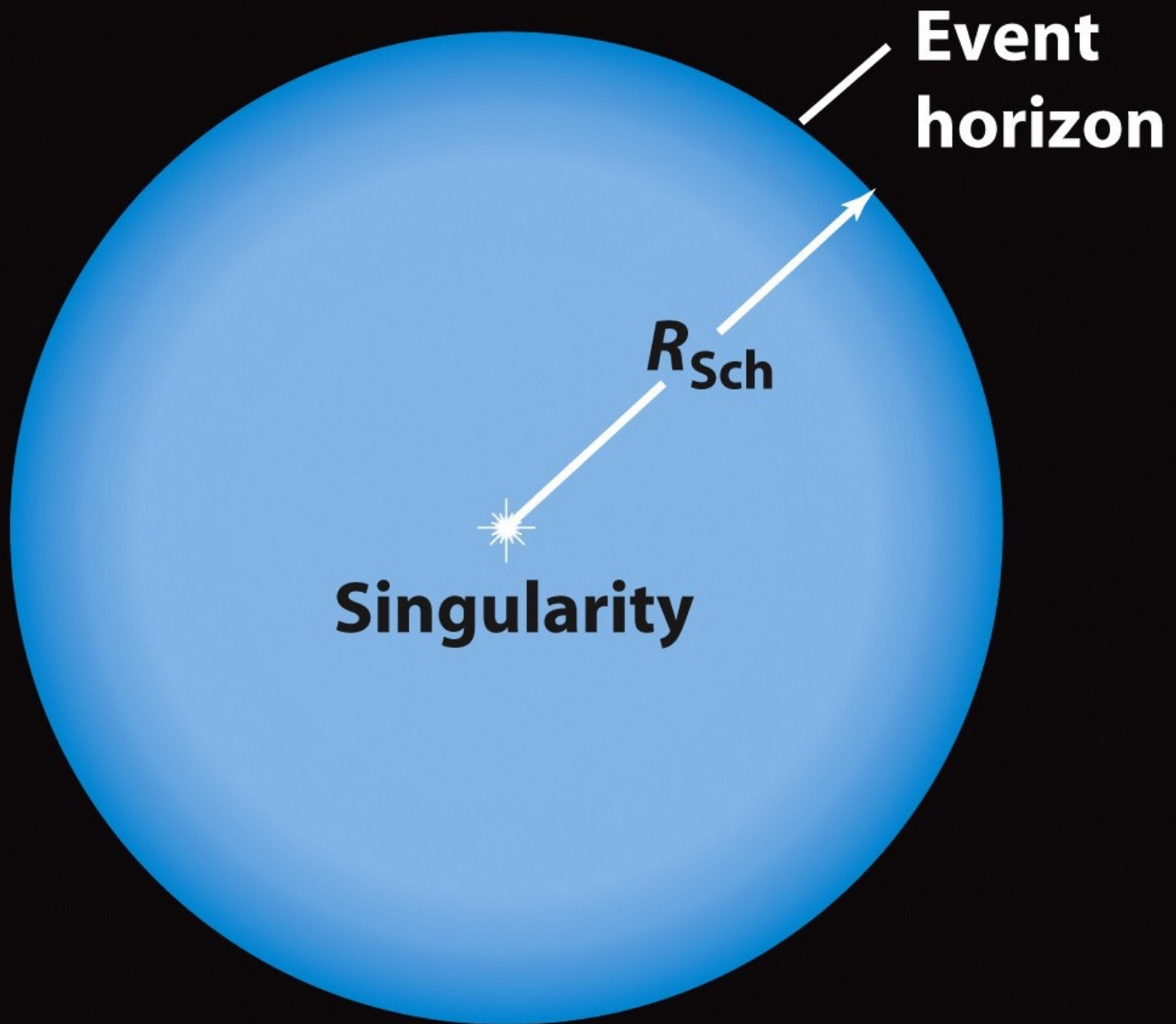


1. A black hole sharply curves the spacetime around it.

3. Objects that venture too close to the black hole cannot escape from the "well."



2. Far from the black hole, spacetime is nearly "flat"; close to the black hole, the curvature forms a "well" that is infinitely deep.



Escape velocity

$$E_{\text{kinetic}} + E_{\text{potential}} = 0$$

$$\frac{1}{2}mv^2 - \frac{GmM}{r} = 0$$

$$\frac{1}{2}mv^2 = \frac{GmM}{r}$$

$$v_{\text{escape}} = \sqrt{\frac{2GM}{r}}$$

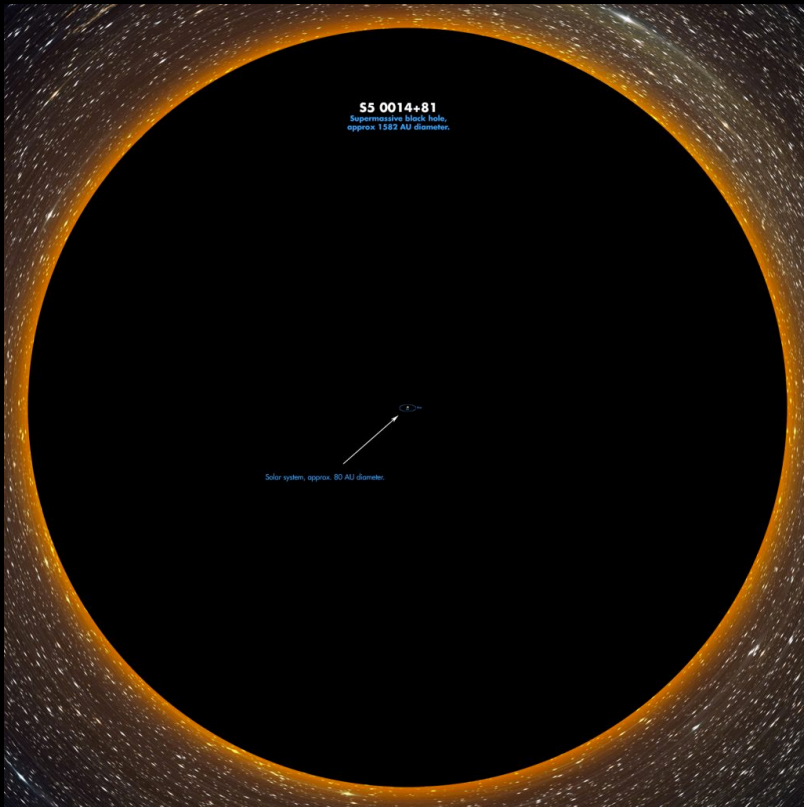
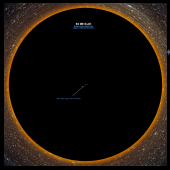
The radius of a black hole

$$v_{\text{escape}} = c$$

$$c = \sqrt{\frac{2GM}{R}}$$

$$R = \frac{2GM}{c^2}$$

The larger the black hole, the smaller the gravity at its Event Horizon!

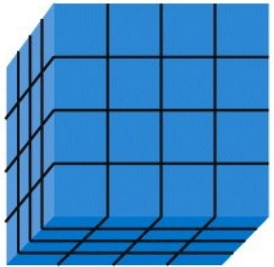


$$R = \frac{2GM}{c^2}$$

$$g = \frac{GM}{R^2} \\ = \frac{4GM}{c^4}$$

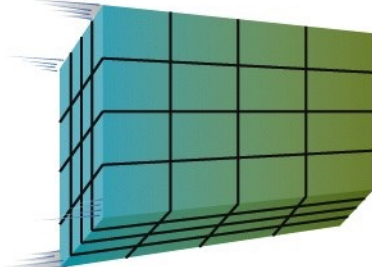
Falling into a black hole

Probe far from black hole

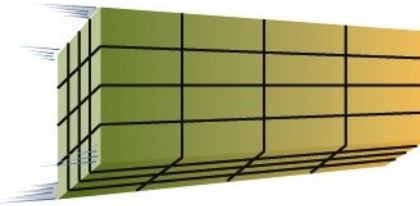


(a)

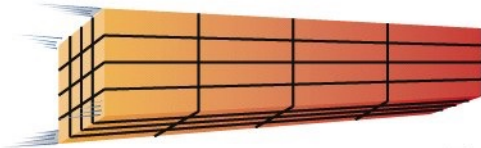
Probe approaching black hole



(b)



(c)



(d)

Black hole
Event horizon

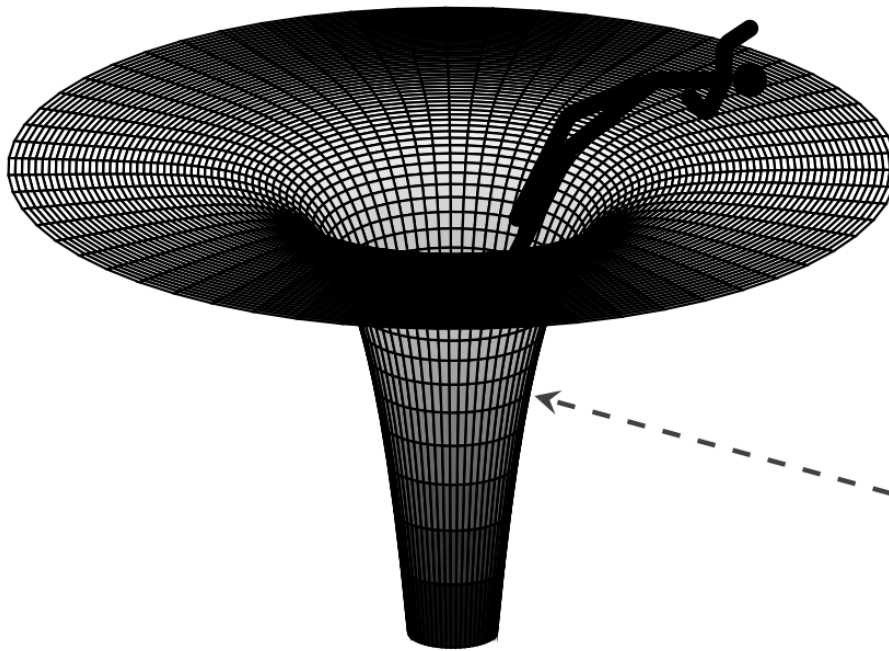
Figure 22-22

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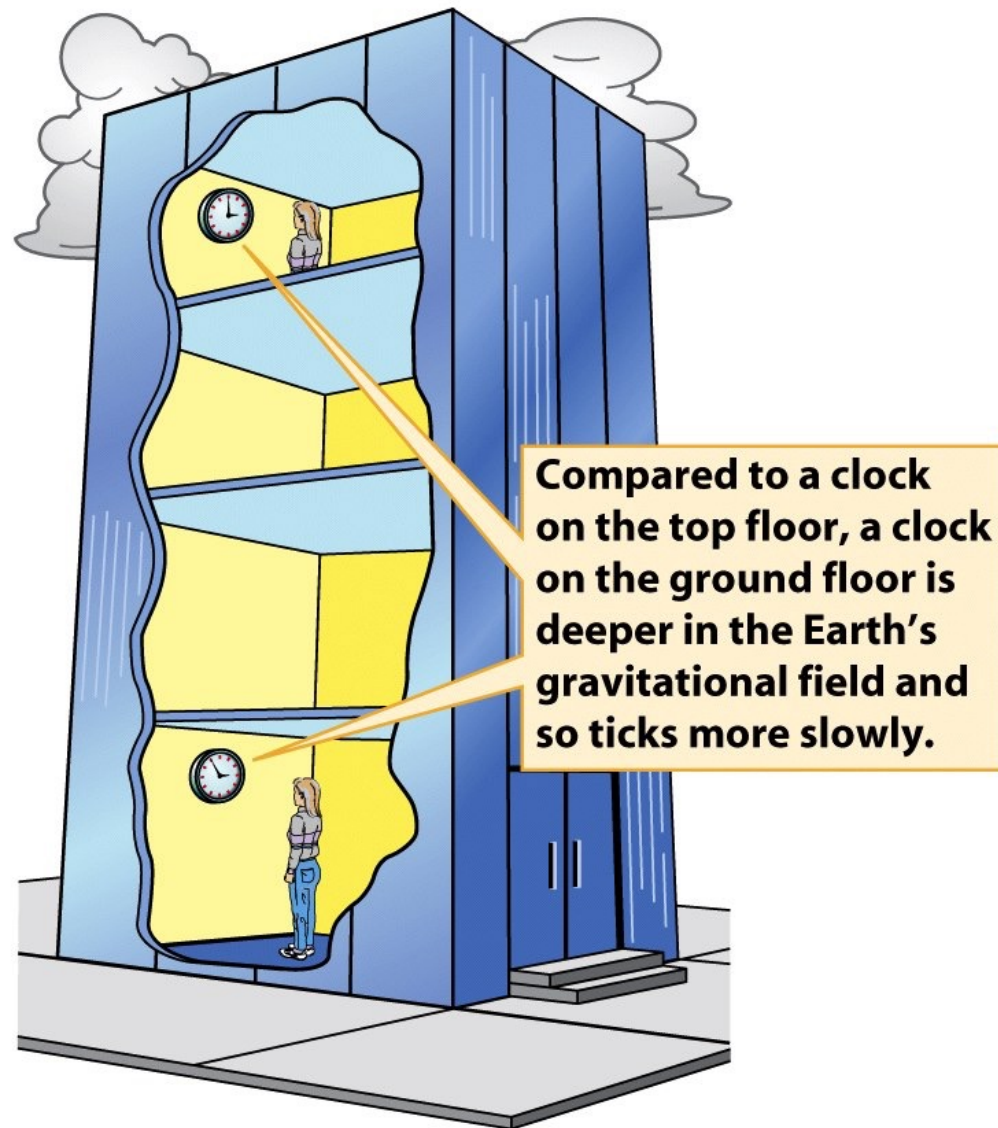
Falling into a black hole

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

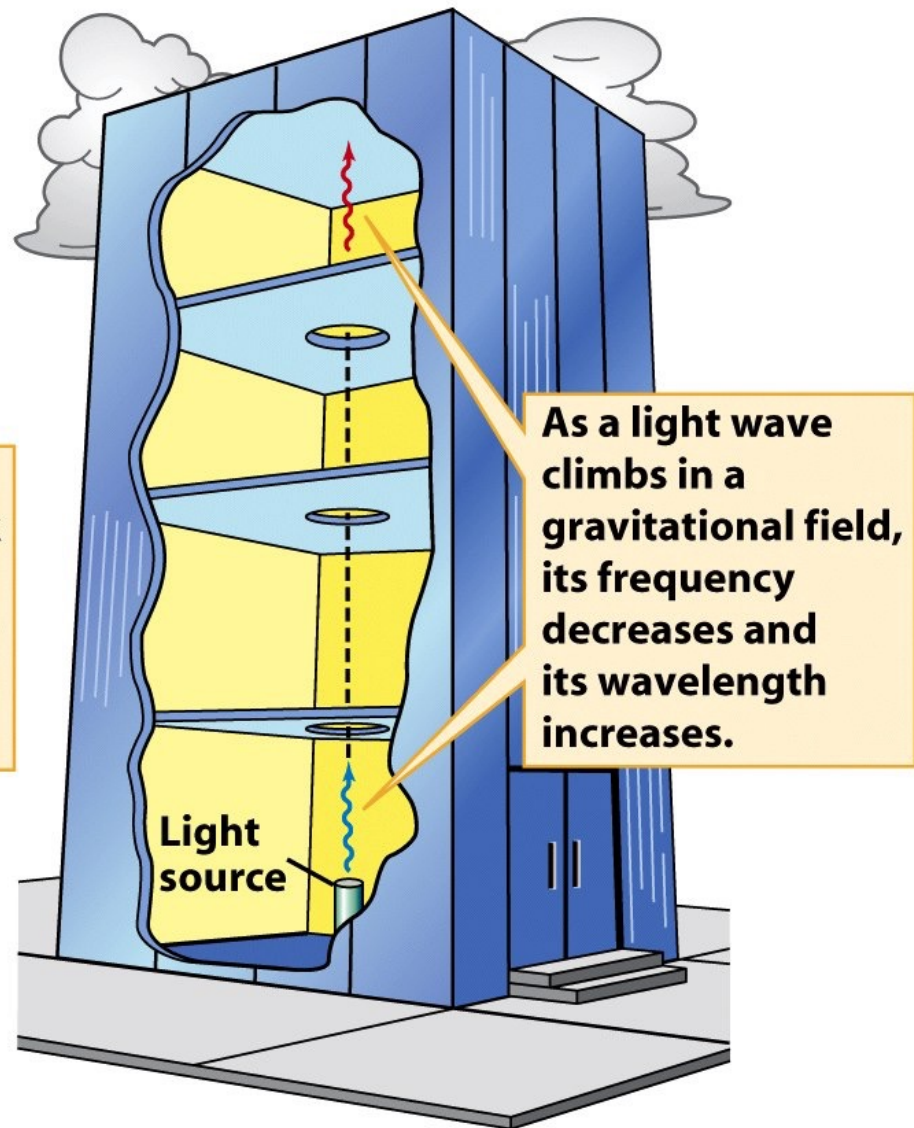


$$|\Delta F_{grav}| = \frac{2GMmd}{r_0^3}$$

$$r_{Horizon} = \frac{2GM}{c^2}$$



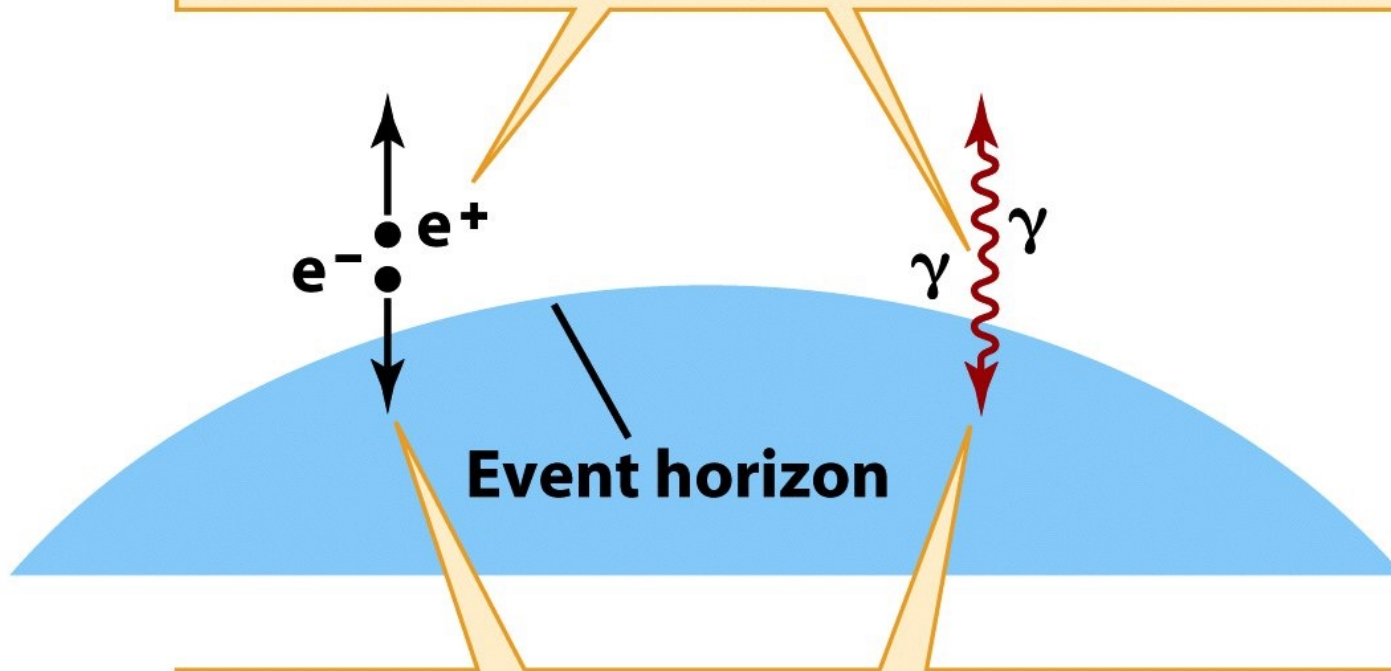
(a) The gravitational slowing of time



(b) The gravitational redshift

1. Pairs of virtual particles spontaneously appear and annihilate everywhere in the universe.

2. If a pair appears just outside a black hole's event horizon, tidal forces can pull the pair apart, preventing them from annihilating each other.

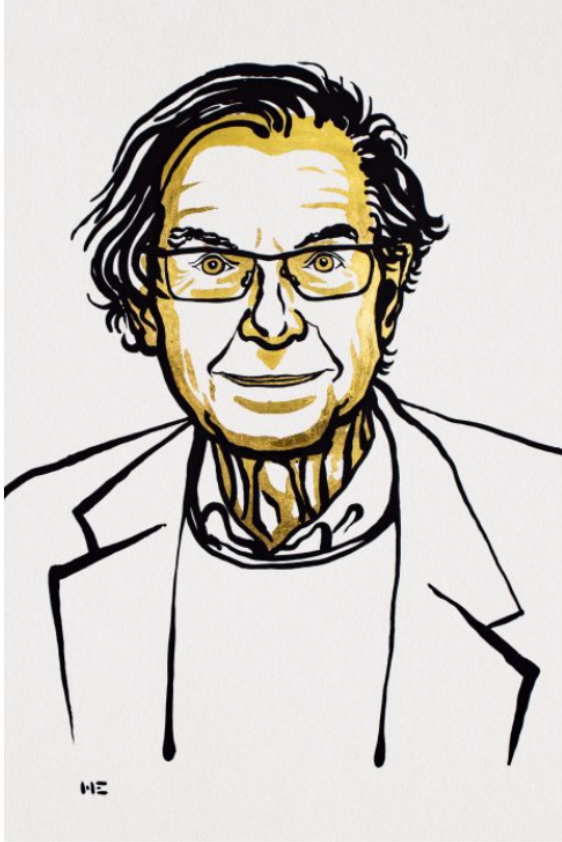


3. If one member of the pair crosses the event horizon, the other can escape into space, carrying energy away from the black hole.

The Milky Way



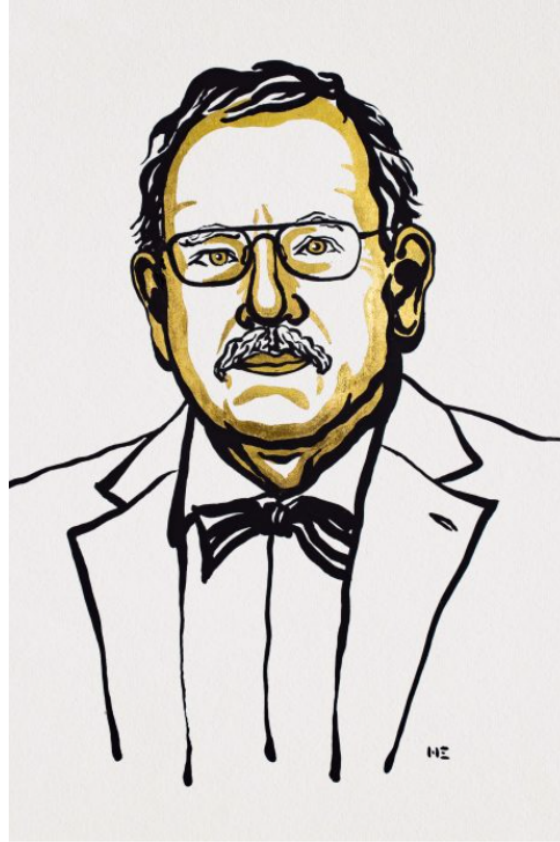
The Nobel Prize in Physics 2020



Ill. Niklas Elmehed. © Nobel Media.

Roger Penrose

Prize share: 1/2



Ill. Niklas Elmehed. © Nobel Media.

Reinhard Genzel

Prize share: 1/4



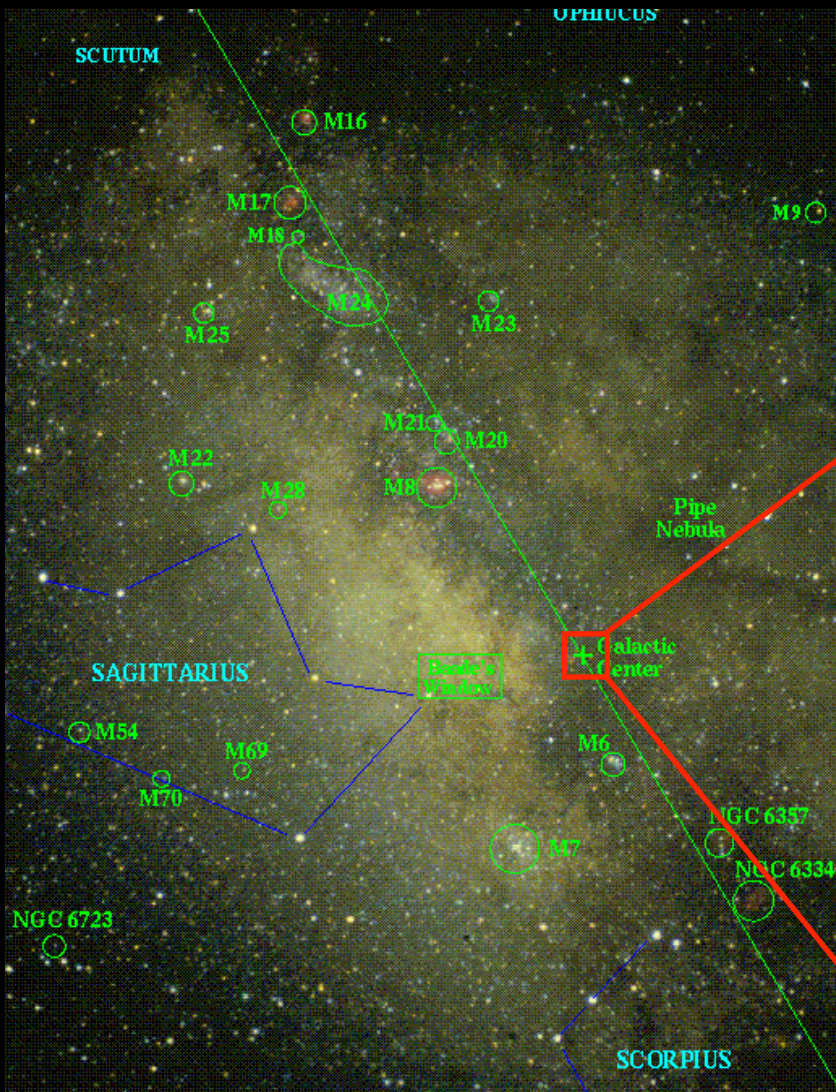
Ill. Niklas Elmehed. © Nobel Media.

Andrea Ghez

Prize share: 1/4

The centre of our Galaxy

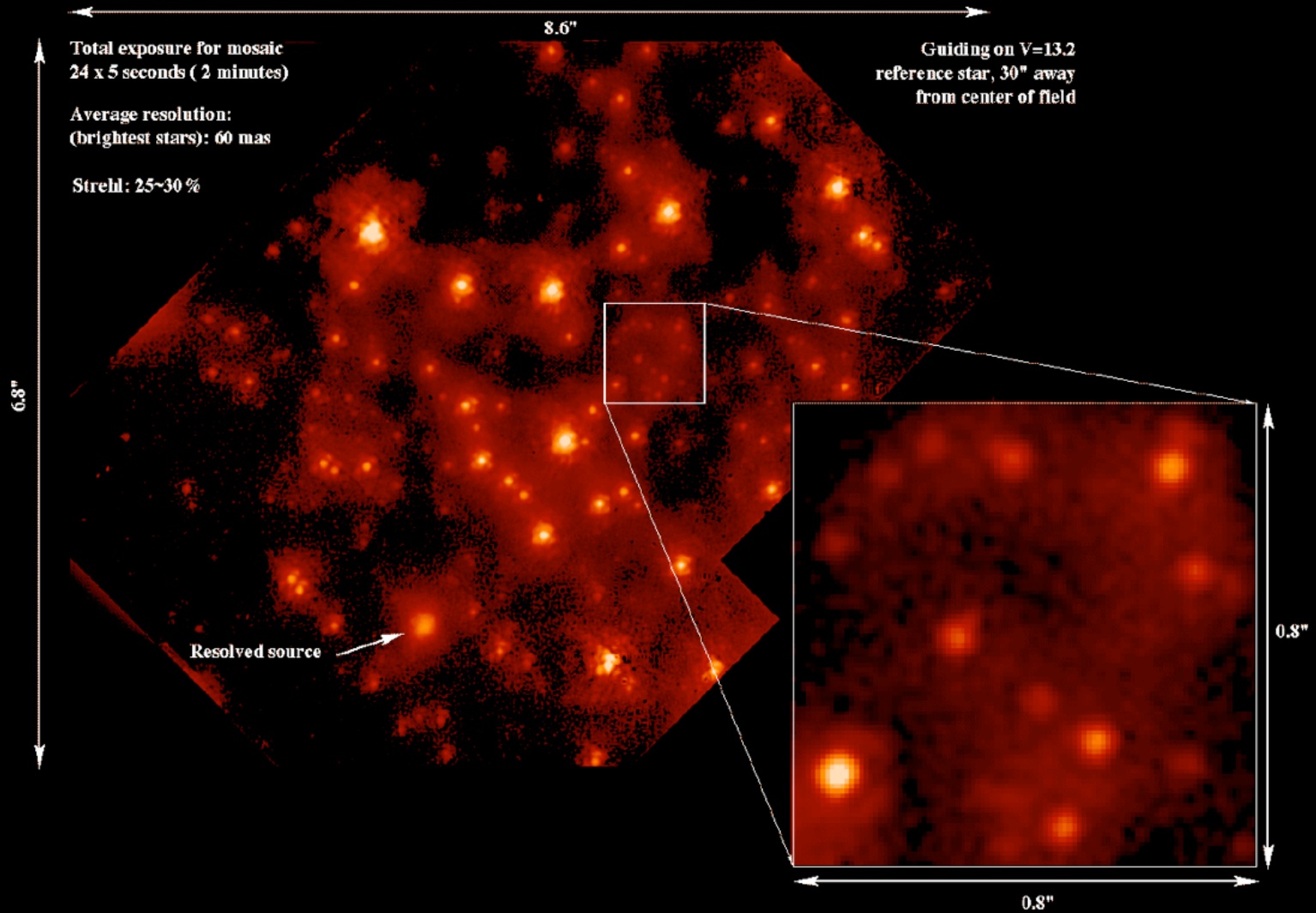
- 10 by 15 degrees
- View to centre blocked by dust
- Baade's window is dust free



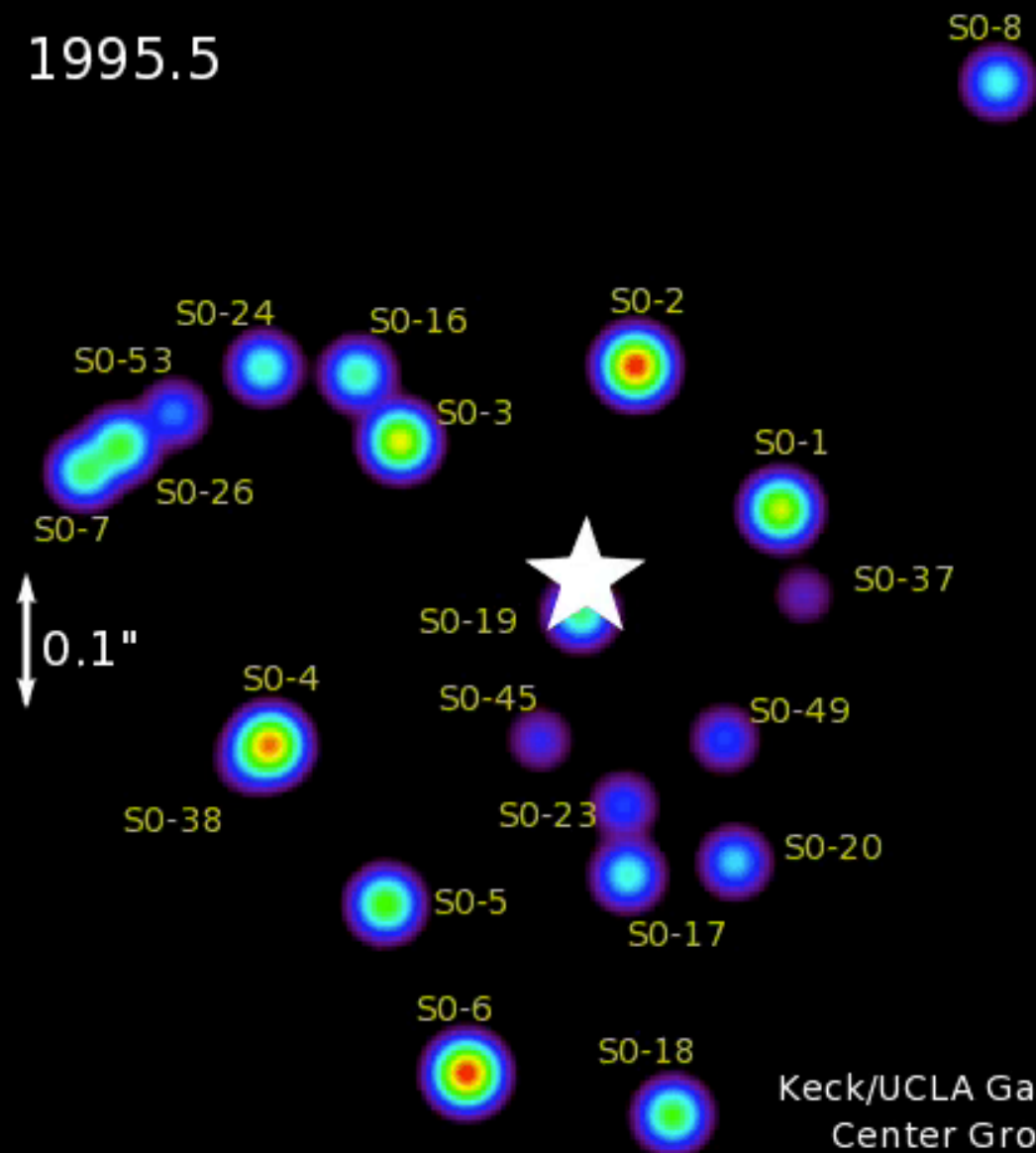
0.5 x 0.5 deg in IR (NOAO)



Zooming in...



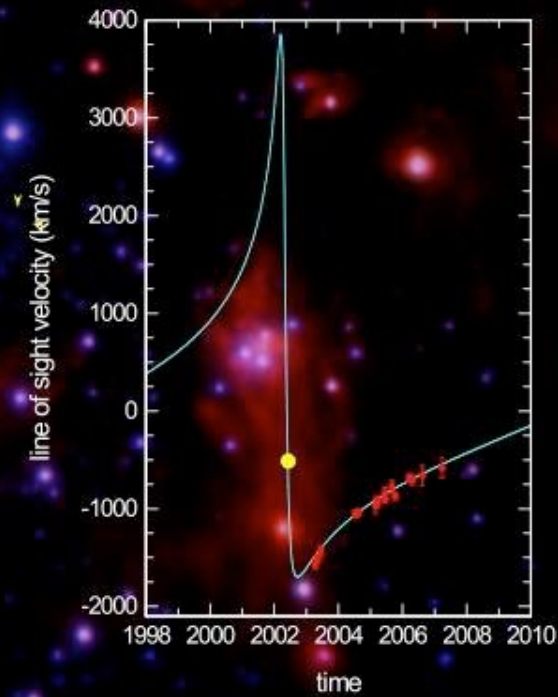
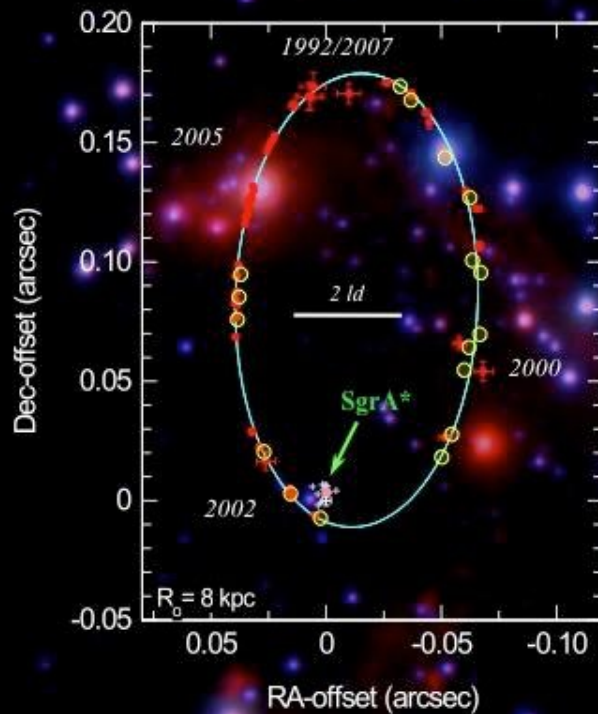
1995.5



Keck/UCLA Galactic
Center Group

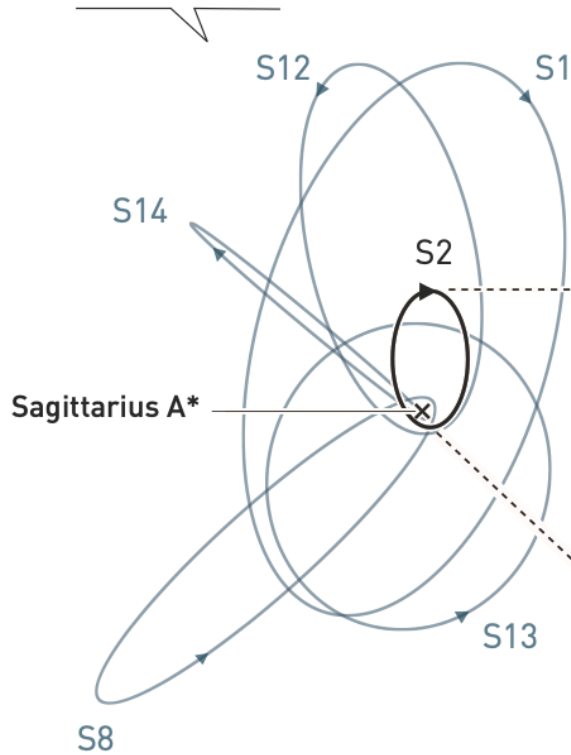
15 years of tracking stellar orbits

MPE (VLT)
Univ. California Los Angeles (Keck)

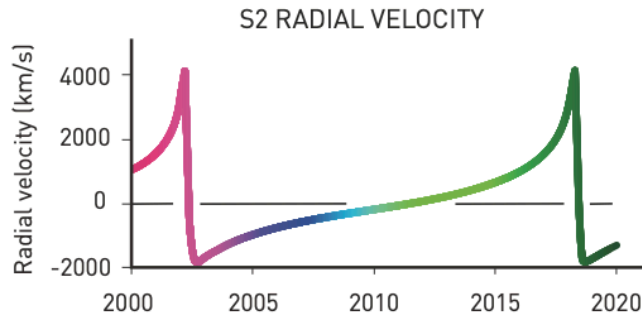
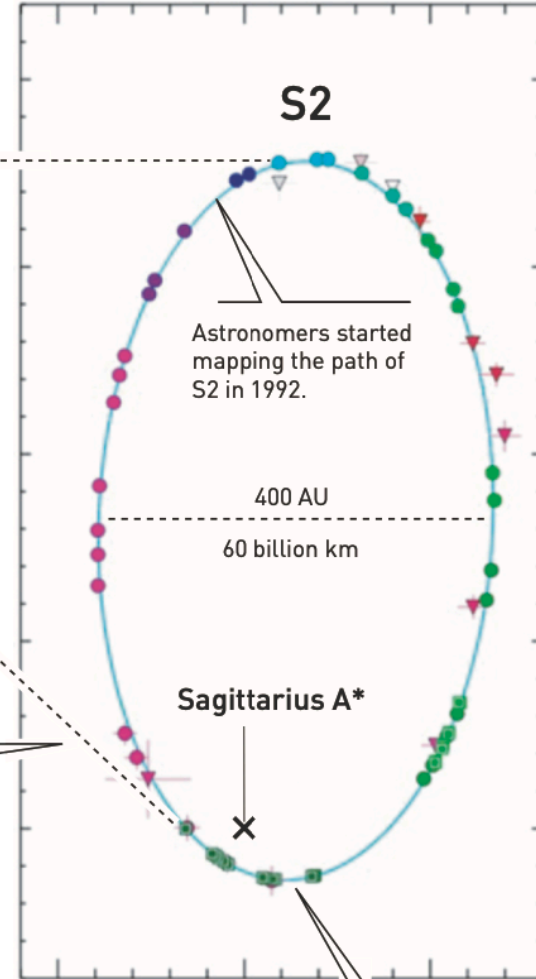


Schödel et al. 2002, 2003, Ghez et al. 2003, 2005, Eisenhauer et al. 2003, 2005, Gillessen et al. 2007

Some of the measured orbits of stars close to Sagittarius A* at the centre of the Milky Way.



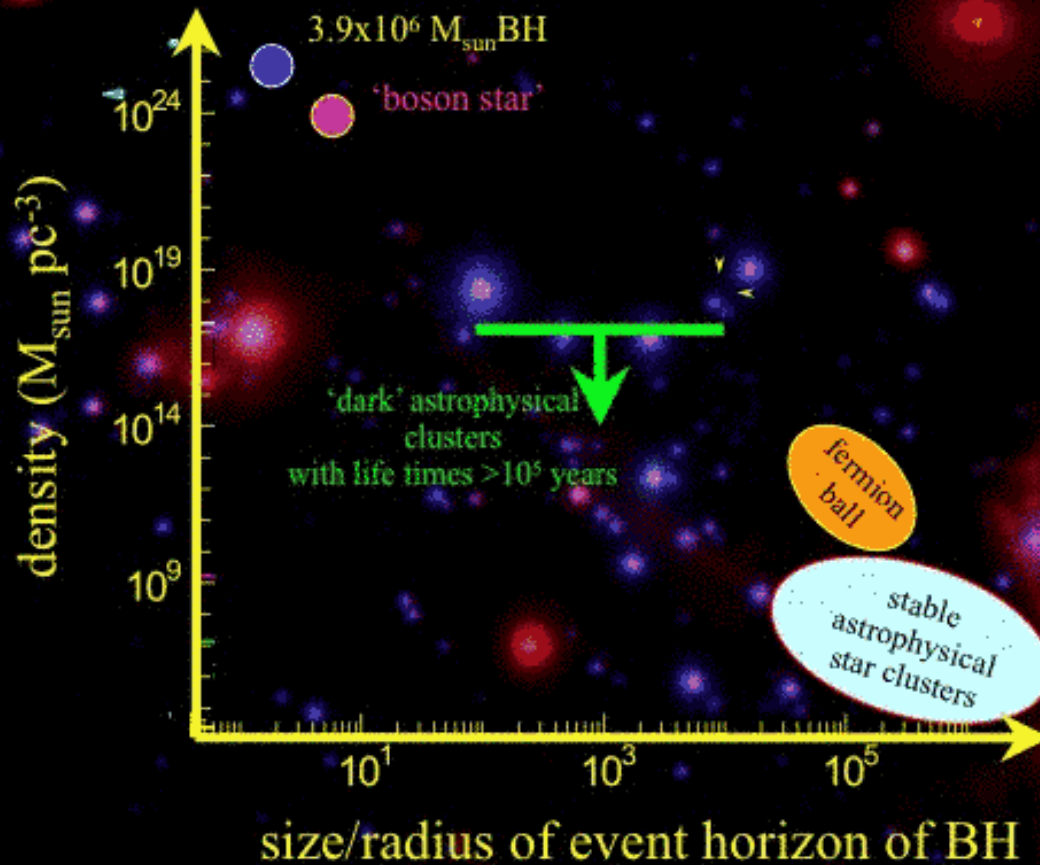
Astronomers were able to map an entire orbit of less than 16 years for one of the stars, S2 (or S-02). The closest it came to Sagittarius A* was about 17 light hours (more than 10,000 million kilometres).



The S2 star's radial velocity increases as it approaches Sagittarius A* and decreases as it moves away along its elliptical orbit. Radial velocity is the component of the star's velocity that is in our line of sight.

Closest to Sagittarius A* (in 2002 and 2018), S2 reaches its maximum velocity of 7 000 km/s.

Is SgrA a black hole ?*



Genzel et al

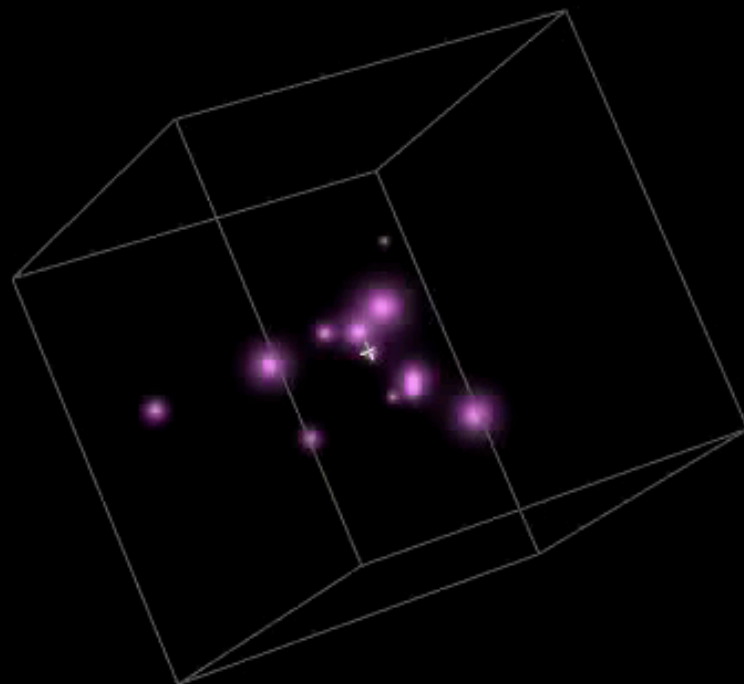
Is SgrA a black hole ?*



Genzel et al

Year: 1995.0

The Acceleration of Stars Orbiting
the Milky Way's Central Black Hole



Data: Andrea Ghez, Jessica Lu (UCIA)

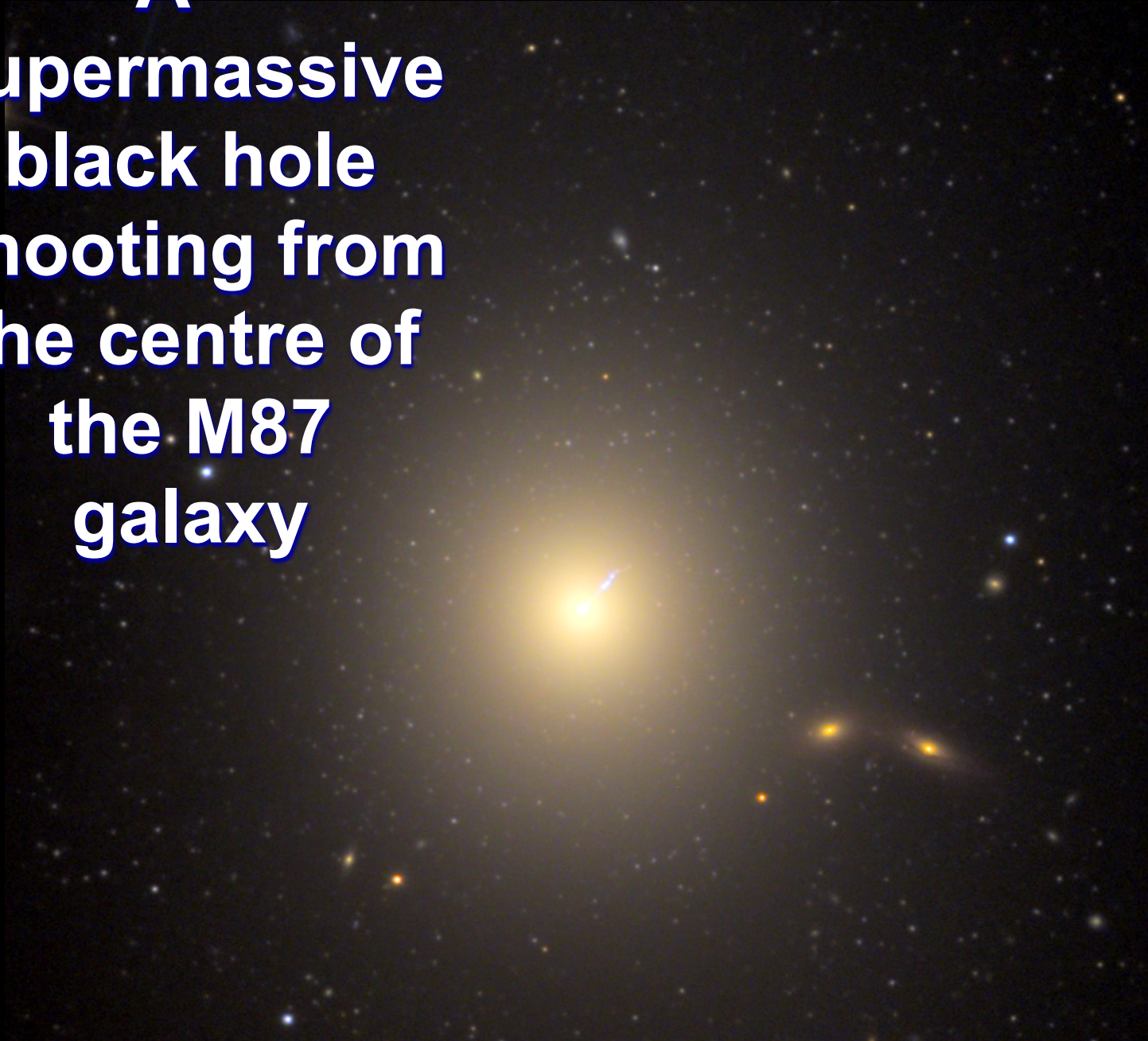
Visualization: Dinoj Surendran, Randy Landsberg,

Mark Subbarao (UChicago / Adler / KICP)

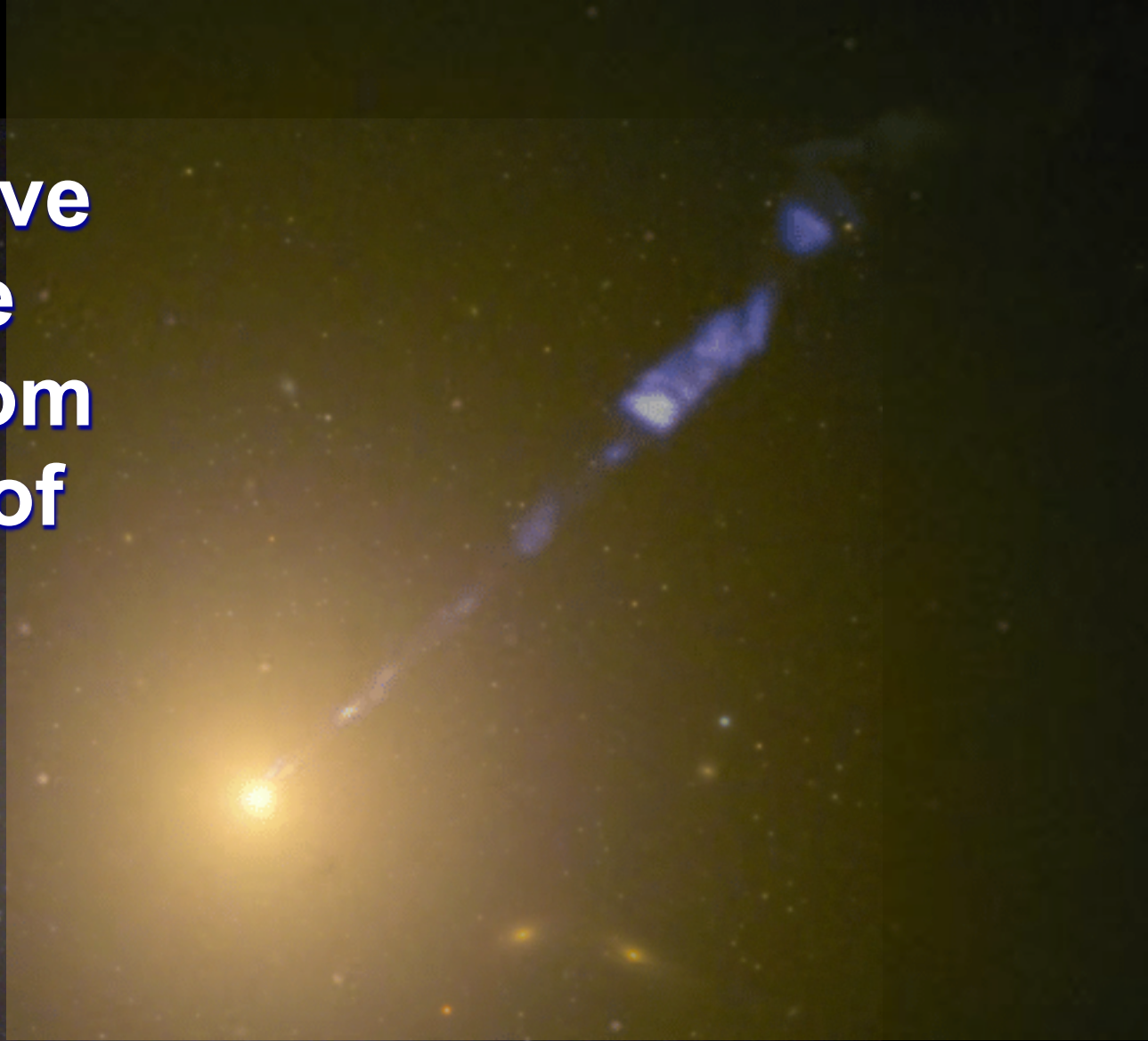


UCLA/Keck Galactic Center Group

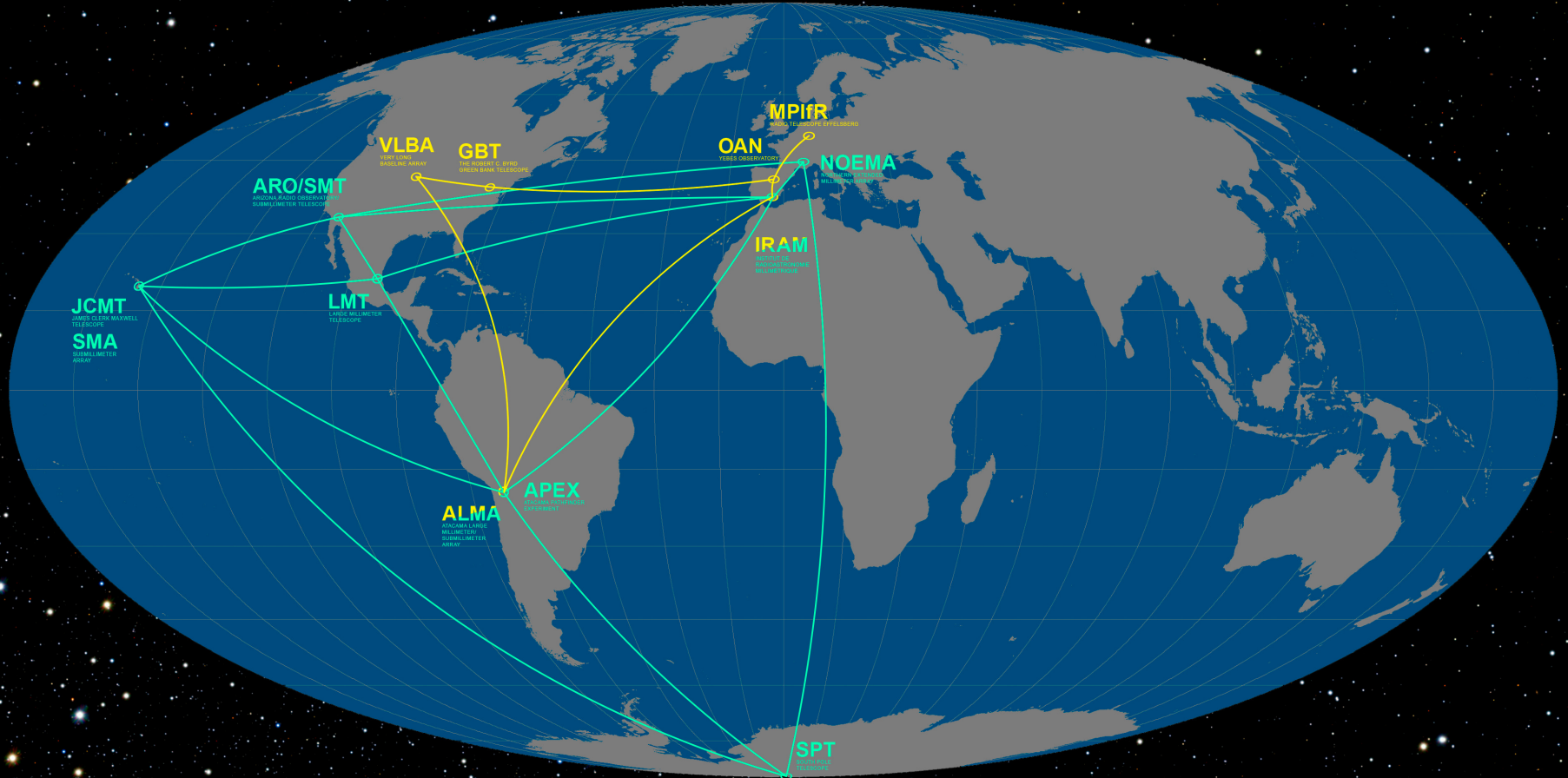
**A
supermassive
black hole
shooting from
the centre of
the M87
galaxy**



**A
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black hole
shooting from
the centre of
the M87
galaxy**



The Event Horizon Telescope



The first 'image' of a black hole

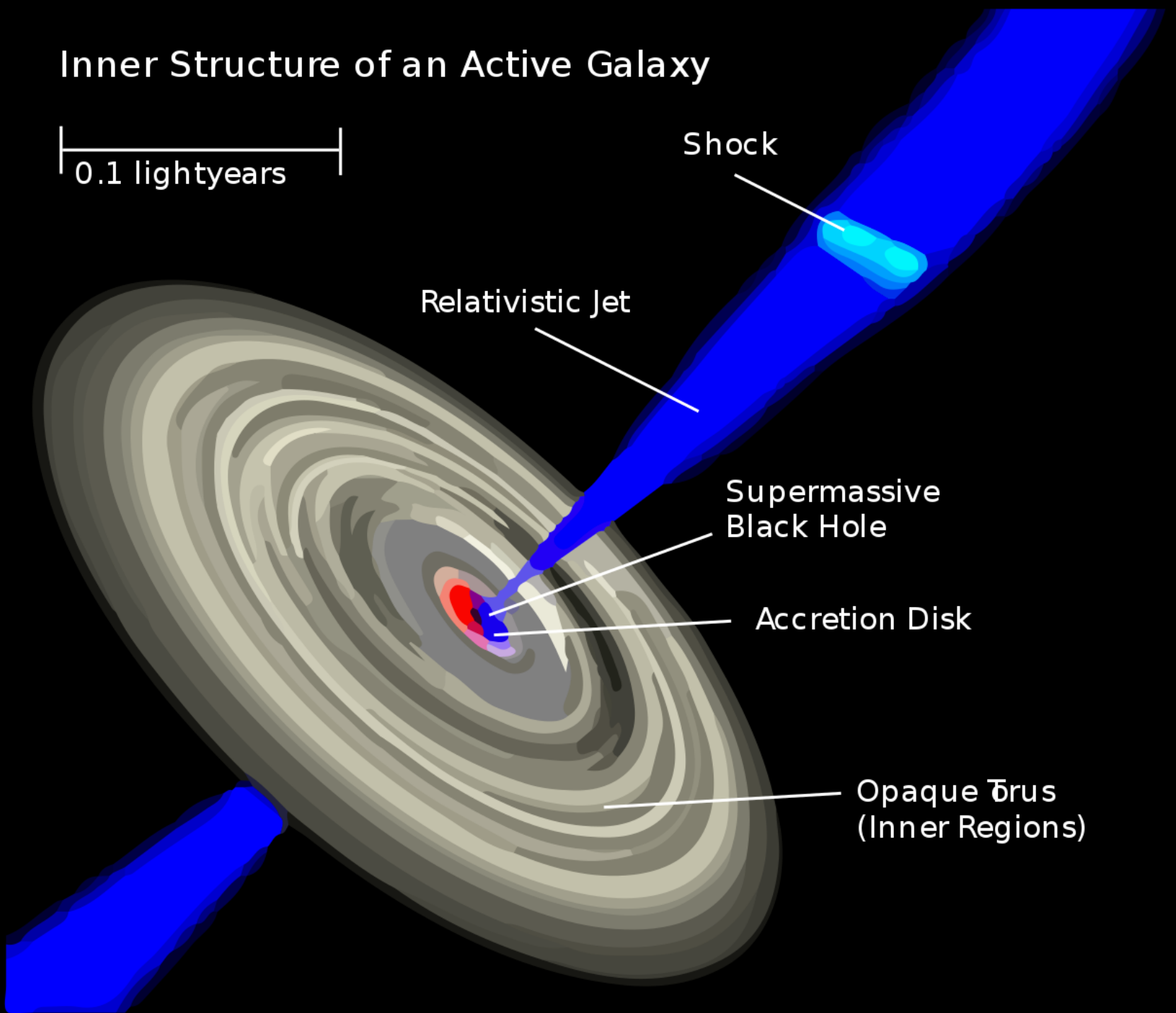


Supermassive black holes



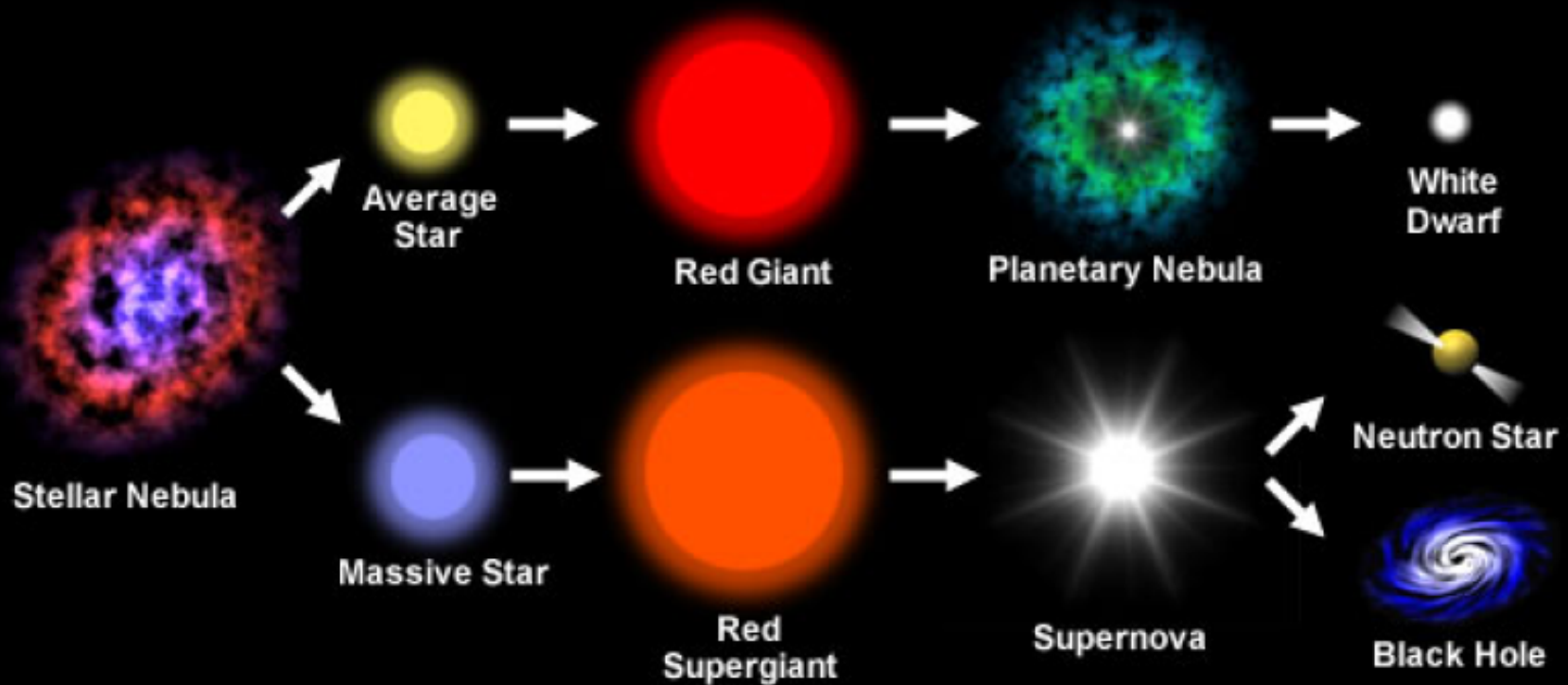
Inner Structure of an Active Galaxy

0.1 lightyears



Some stars end up as black holes

Life Cycle of a Star



Exploding stars leave black holes behind



Gravitational Wave Observatories watch black holes merge!





Distribution of matter in the Universe

A visualization of the cosmic web, showing a complex network of dark matter filaments and clusters. The filaments are colored in shades of purple and blue, while the clusters are highlighted in yellow and orange. A horizontal scale bar at the top left indicates a distance of 1 Gpc/h.

1 Gpc/h

Millennium Simulation

10,077,696,000 particles

Distribution of matter in the Universe

($z = 0$)

The image shows a simulation of a dark matter field with several black holes. The background is a gradient of red and orange, with a bright yellow-white glow in the center. Three black holes are visible: a large one in the upper left, a smaller one in the upper right, and a pair of black holes in the lower right. Each black hole is surrounded by concentric, glowing rings, representing gravitational waves or the accretion of dark matter. The text is centered over the image in a bold, white font with a blue outline.

**Primordial black holes may form the
mysterious Dark Matter!**