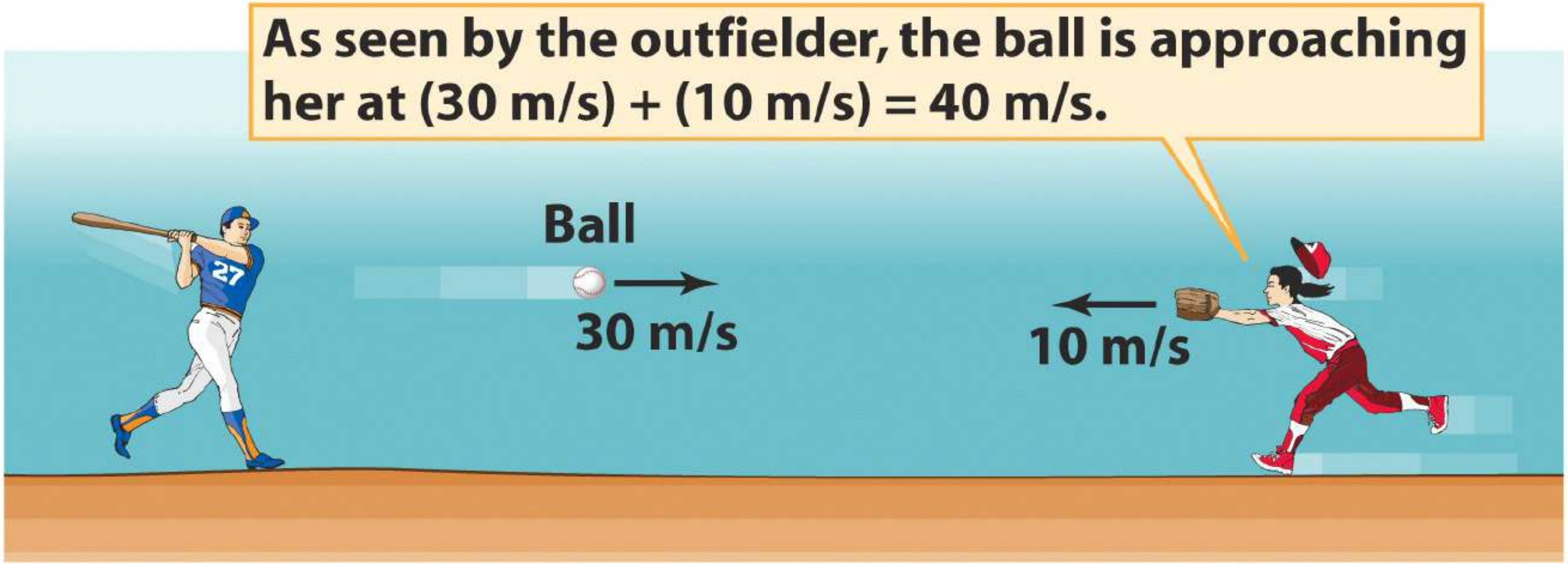
Black Holes

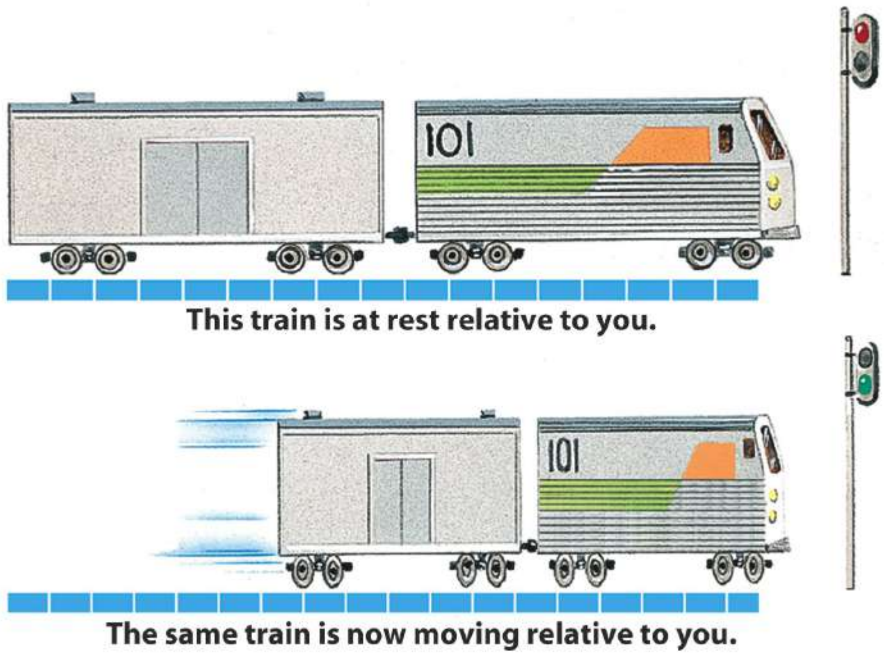
Chapter Twenty-Four

The special theory of relativity changes our conceptions of space and time

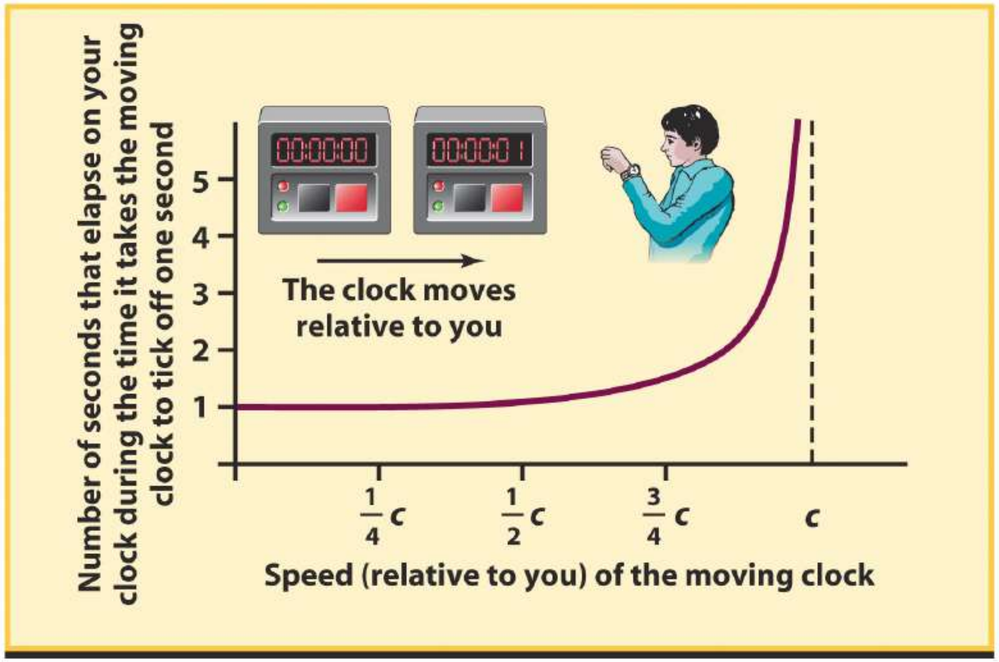


- This theory, published by Einstein in 1905, is based on the notion that there is no such thing as absolute space or time
- Space and time are not wholly independent of each other, but are aspects of a single entity called spacetime

An observer will note a slowing of clocks and a shortening of rulers that are moving with respect to the observer



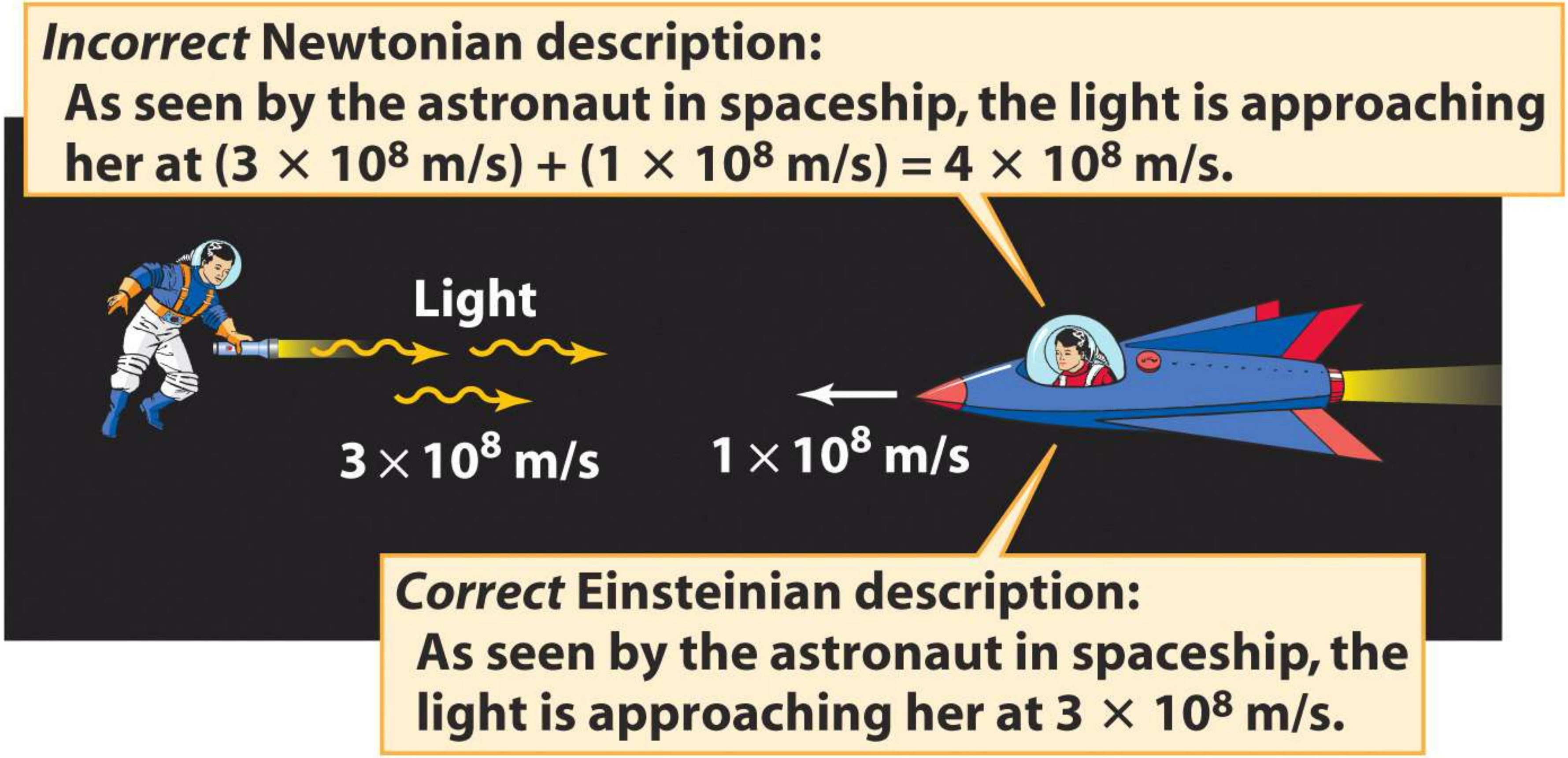
Length contraction

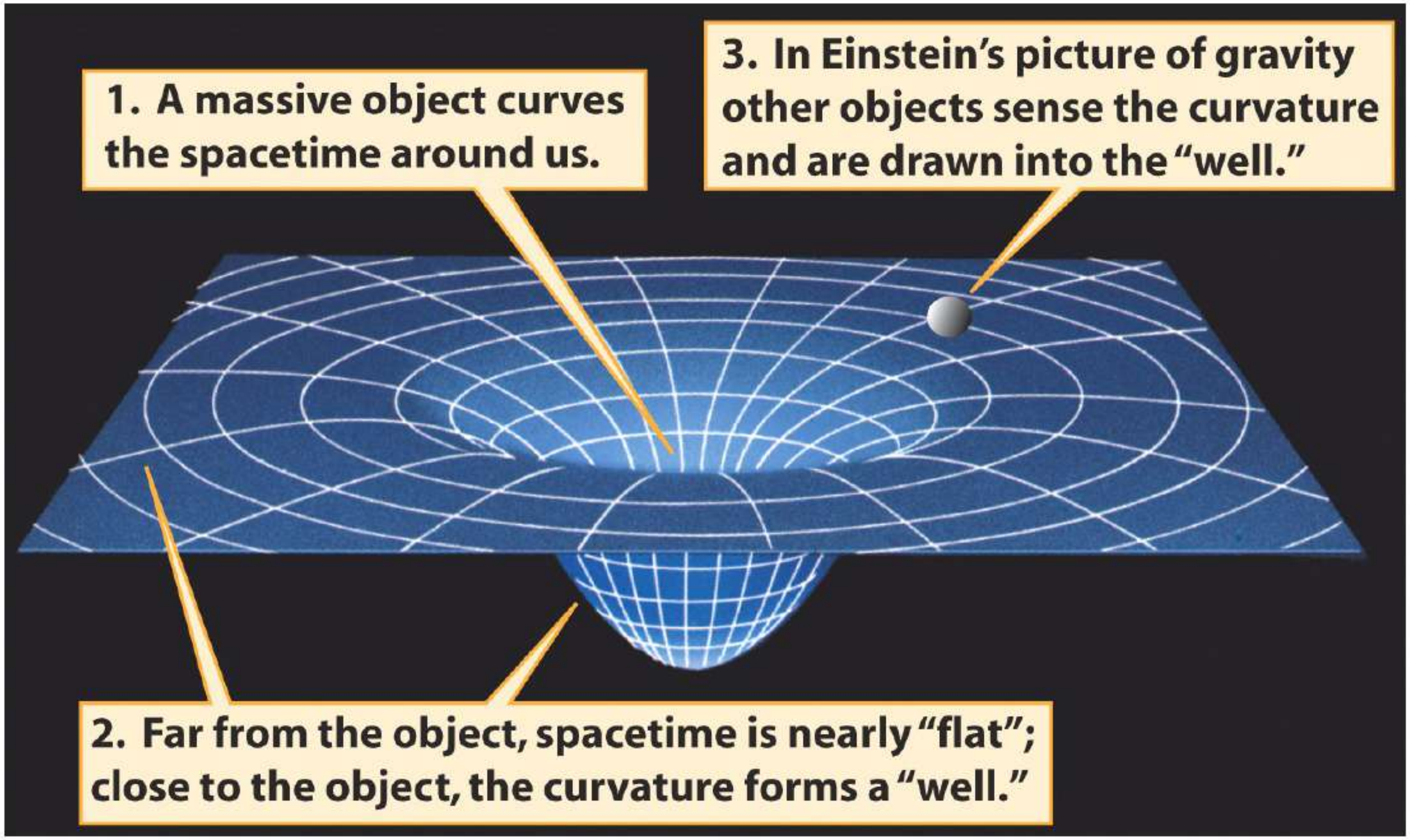


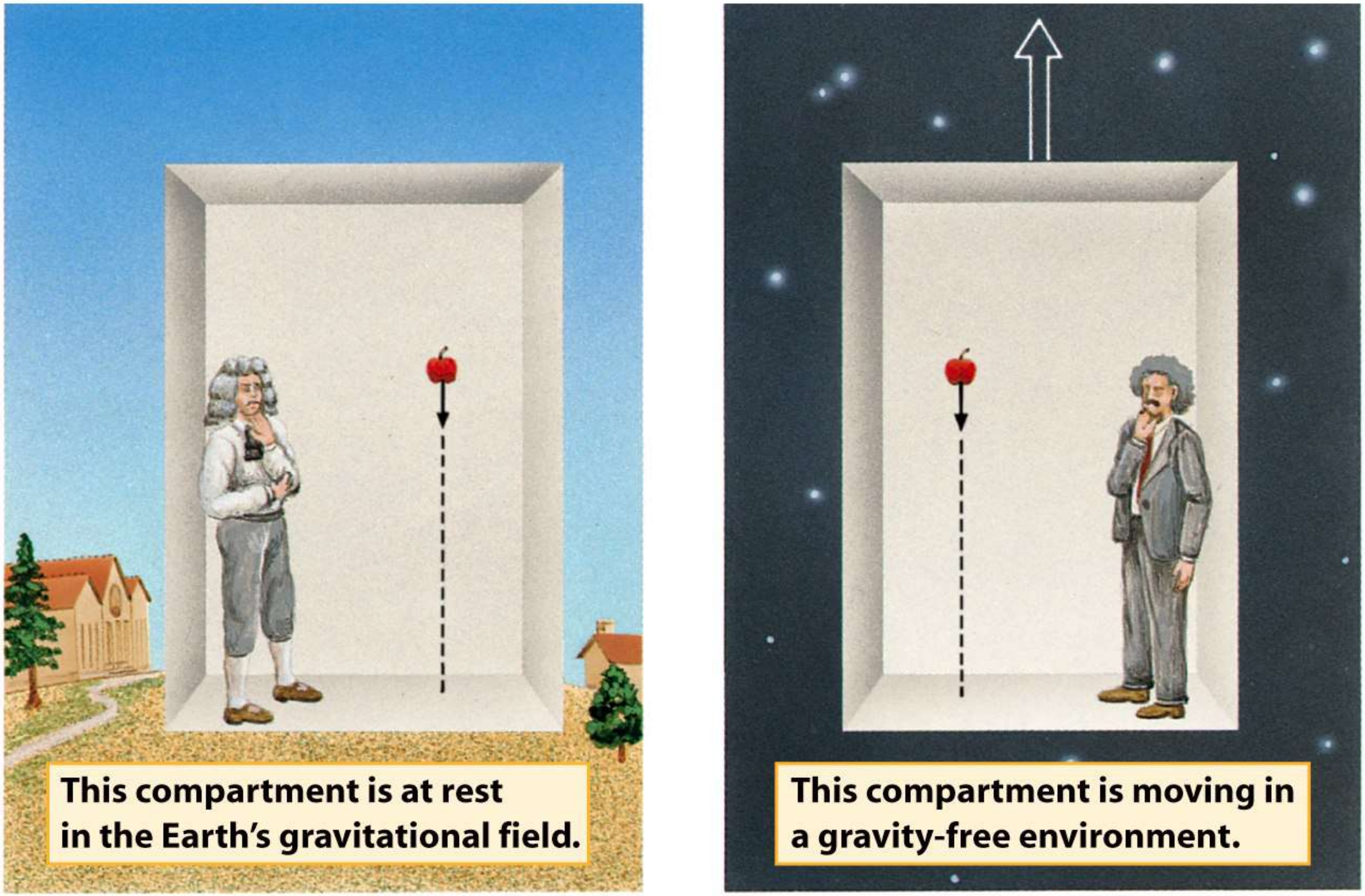
Time dilation

This effect becomes significant only if the clock or ruler is moving at a substantial fraction of the speed of light

The speed of light is the same to all observers, no matter how fast they are moving



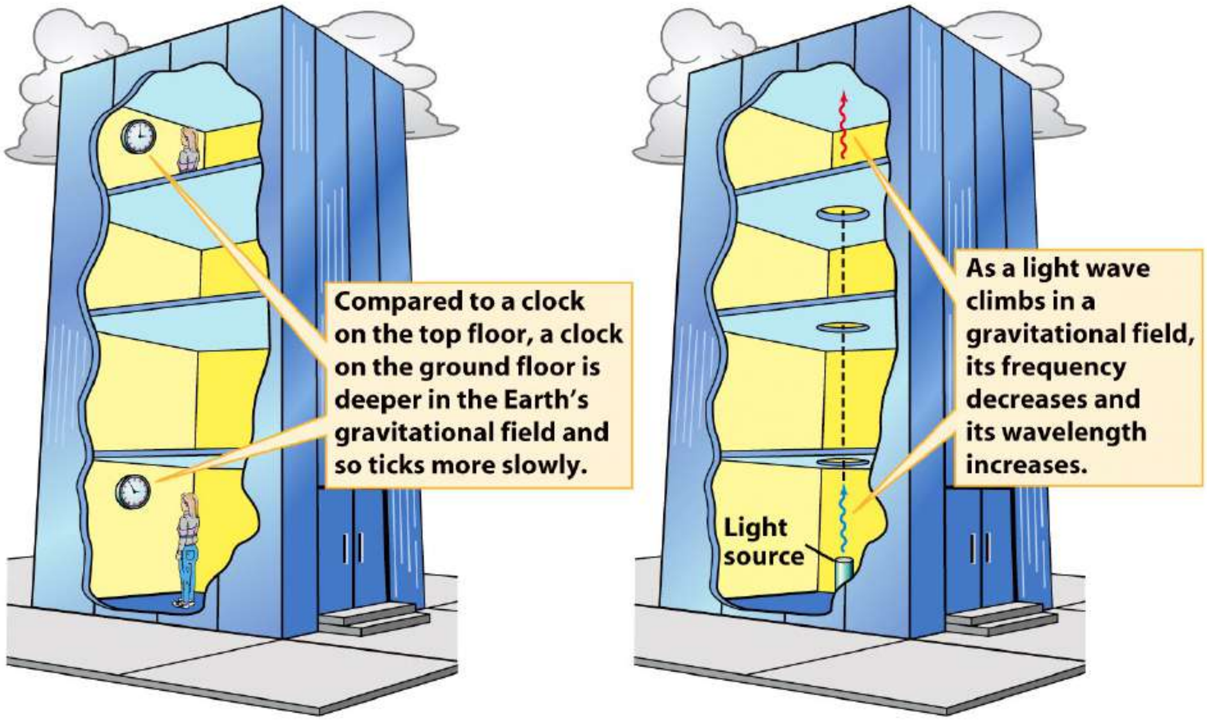

1. A massive object curves the spacetime around us.
3. In Einstein's picture of gravity other objects sense the curvature and are drawn into the "well."
2. Far from the object, spacetime is nearly "flat"; close to the object, the curvature forms a "well."



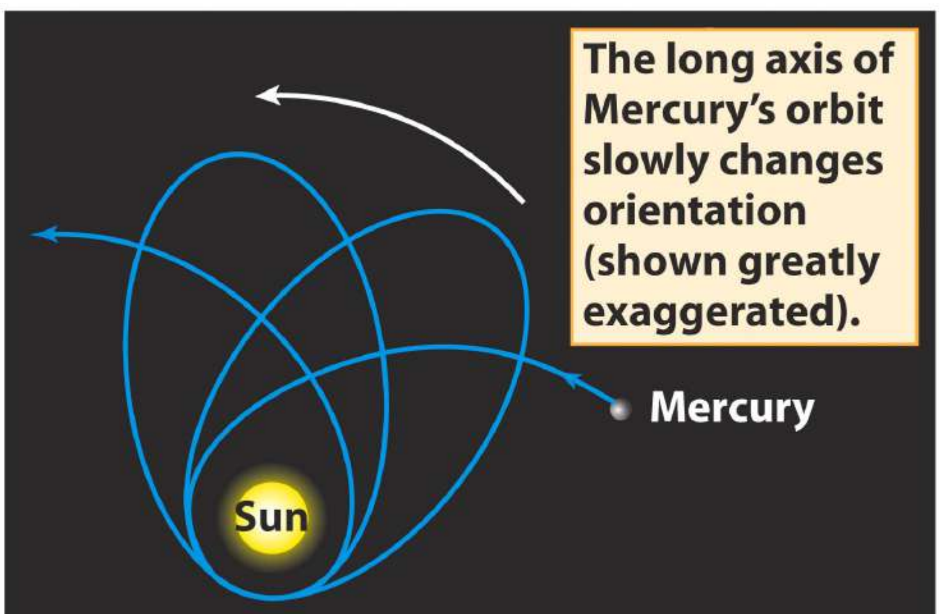
(a) The apple hits the floor of the compartment because the Earth's gravity accelerates the apple downward.

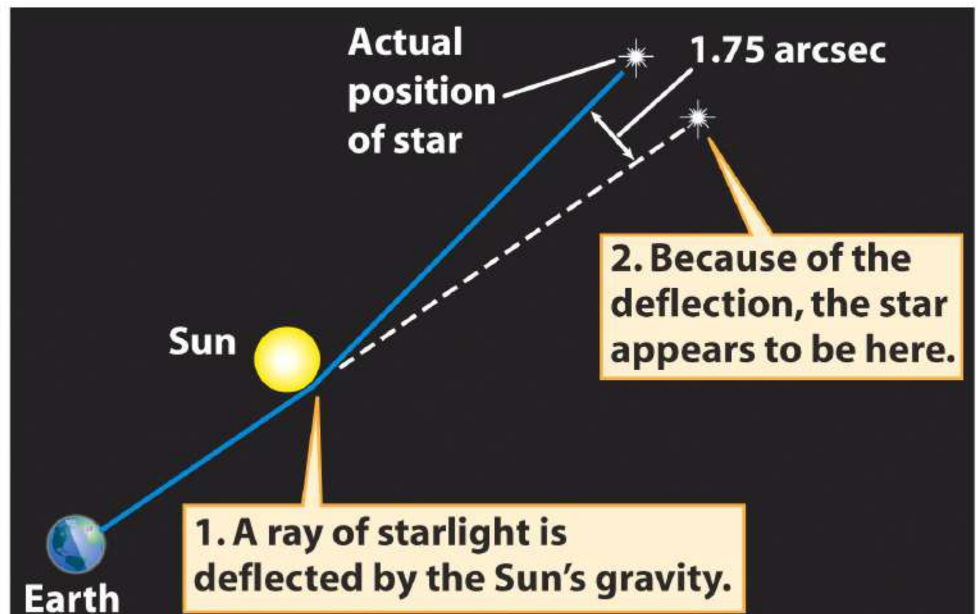
(b) The apple hits the floor of the compartment because the compartment accelerates upward.

The theory of relativity predicts a number of phenomena, including the bending of light by gravity and the gravitational redshift, whose existence has been confirmed by observation and experiment

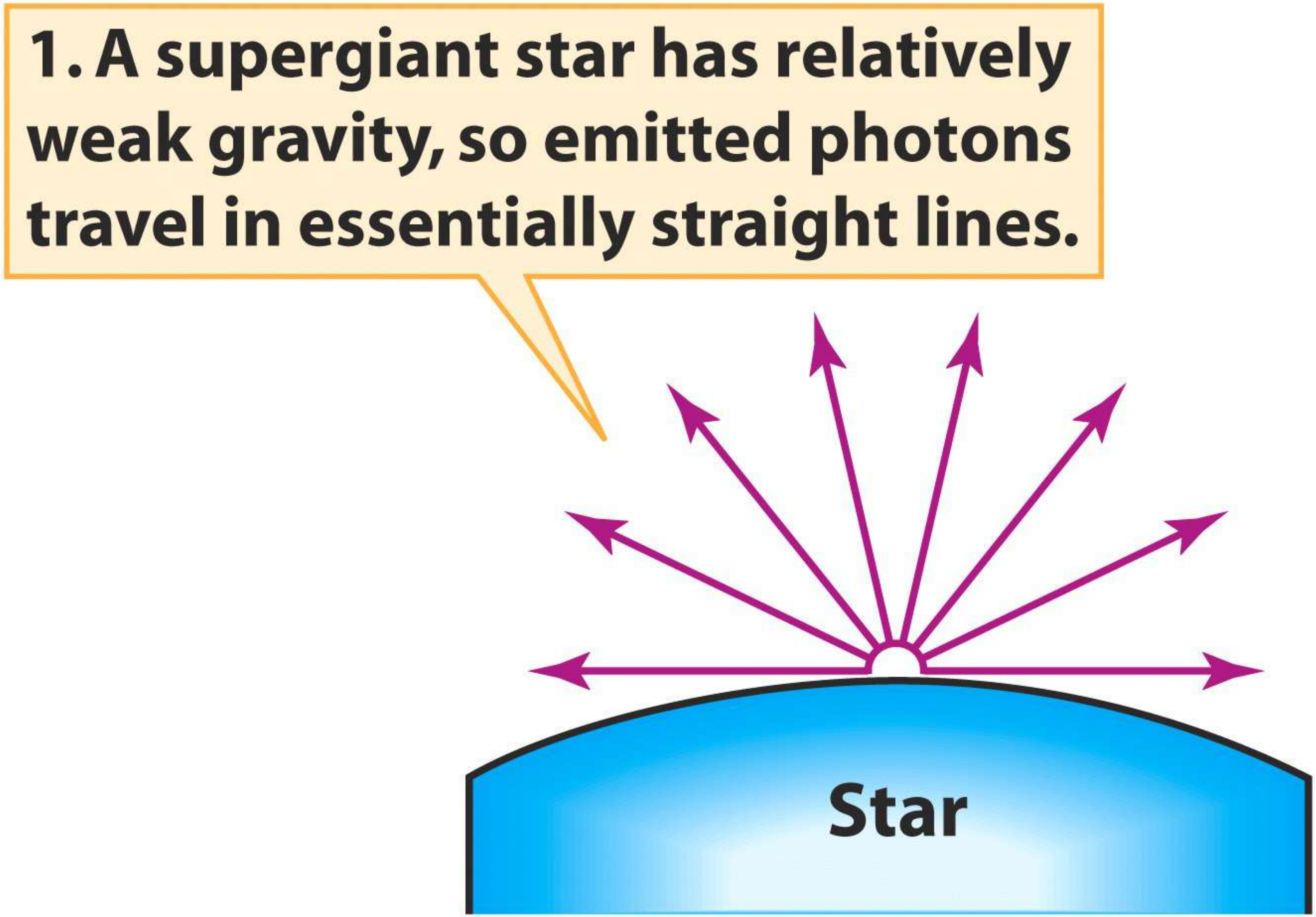


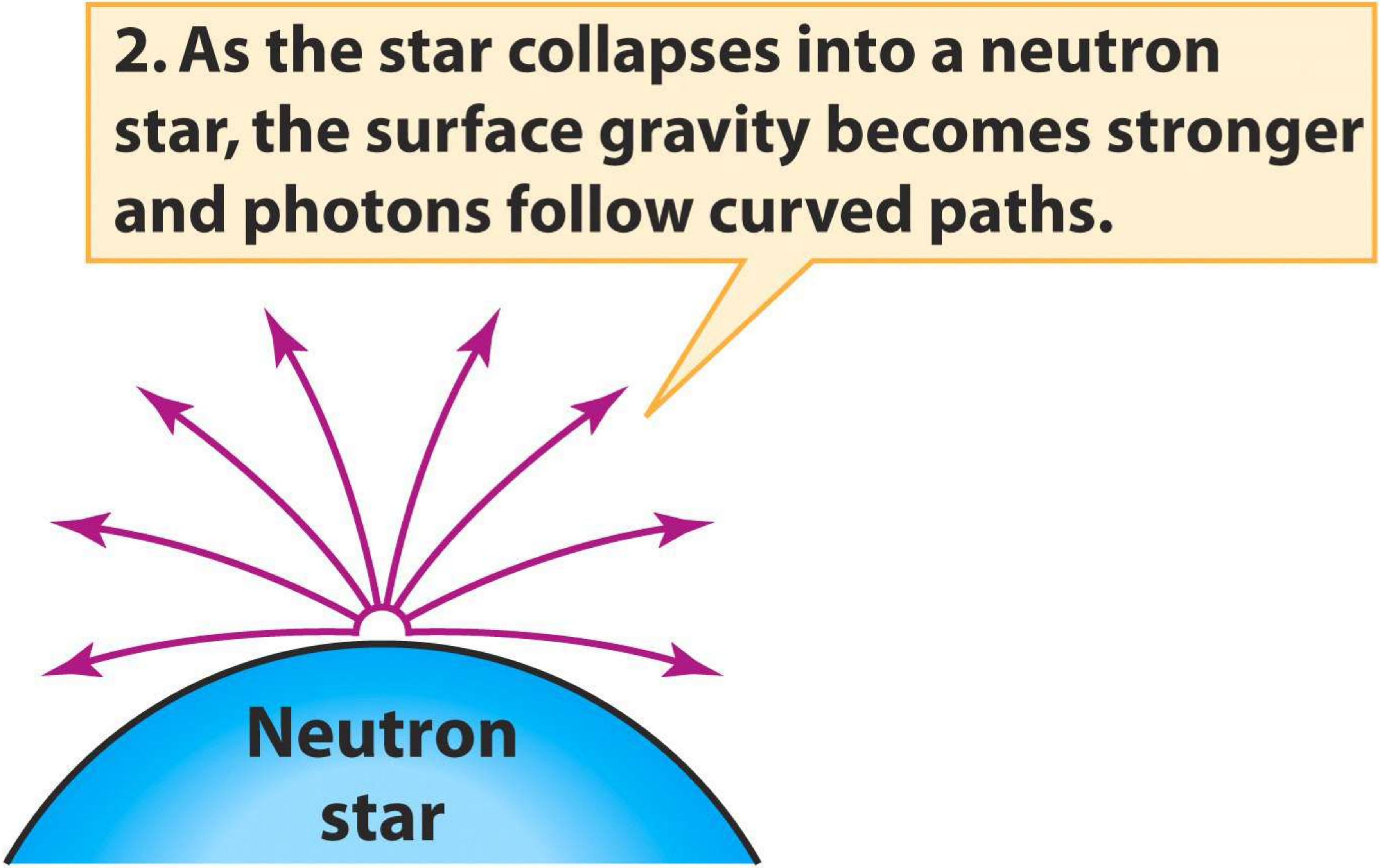
(a) The gravitational slowing of time **(b)** The gravitational redshift



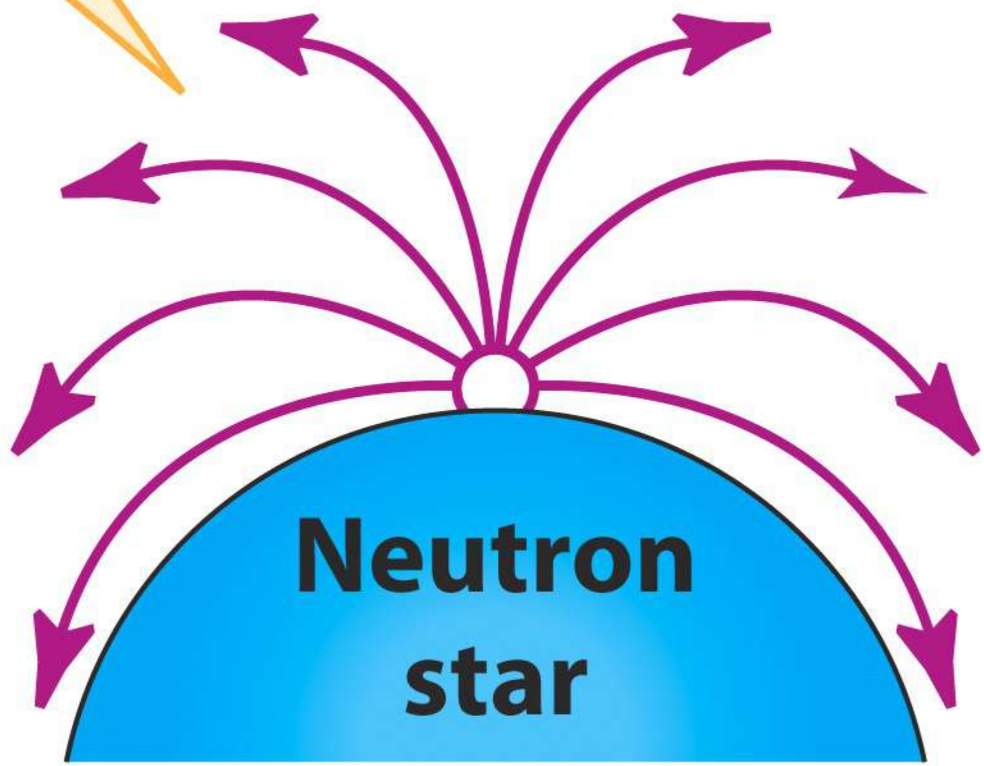


The general theory of relativity predicts black holes

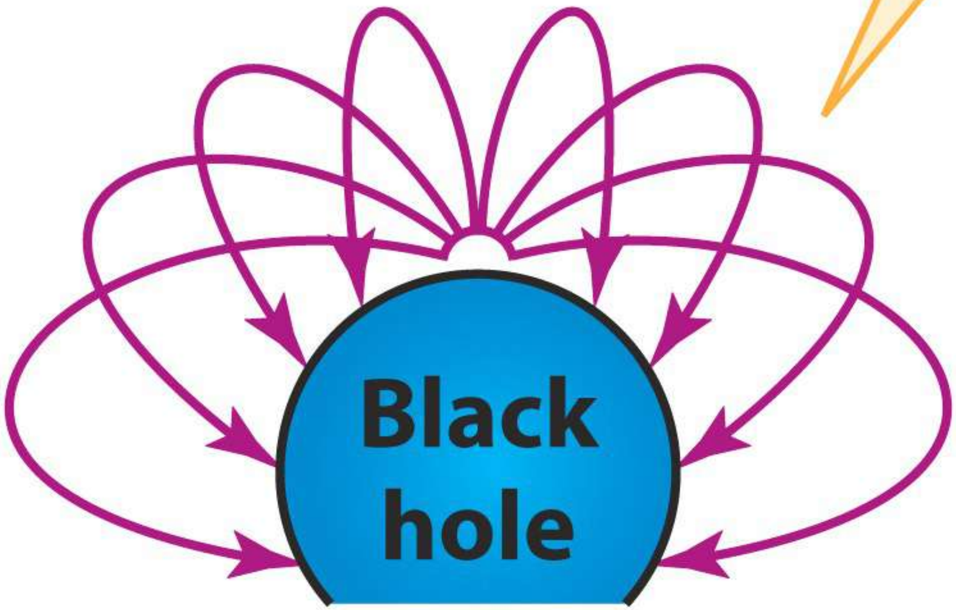


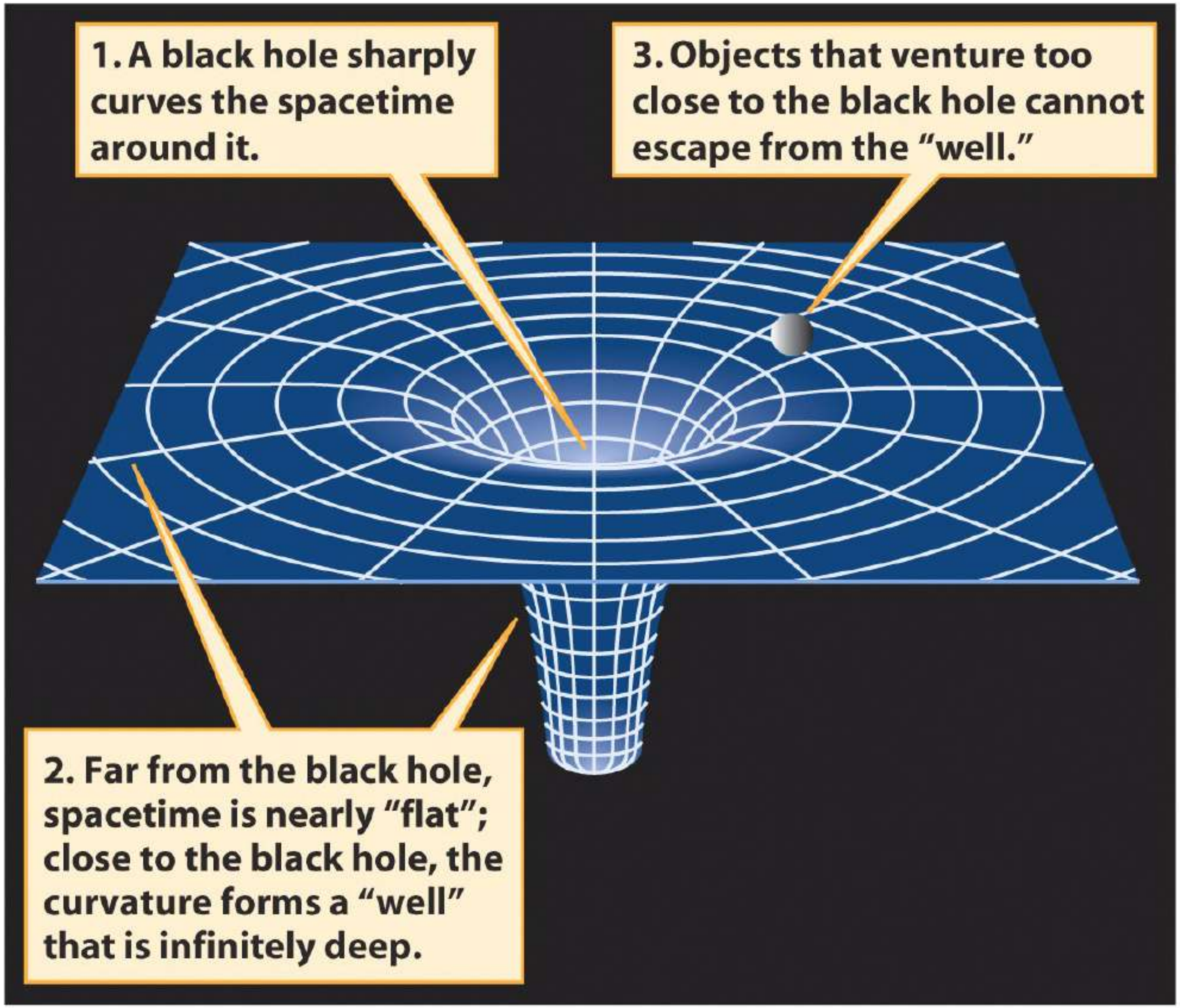

2. As the star collapses into a neutron star, the surface gravity becomes stronger and photons follow curved paths.
Neutron star

3. Continued collapse intensifies the surface gravity, and so photons follow paths more sharply curved.



4. When the star shrinks past a critical size, it becomes a black hole: Photons follow paths that curve back into the black hole so no light escapes.




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.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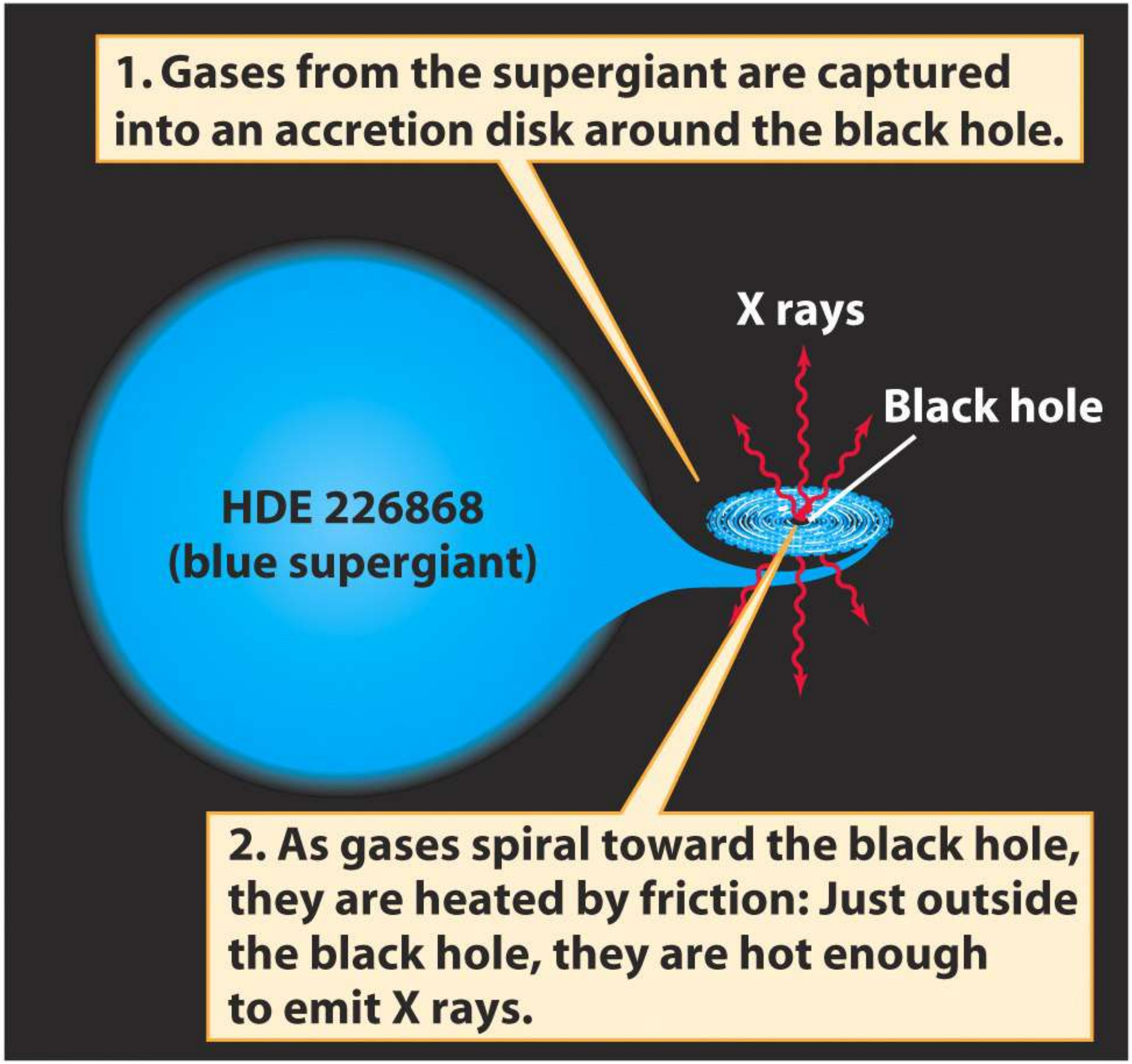
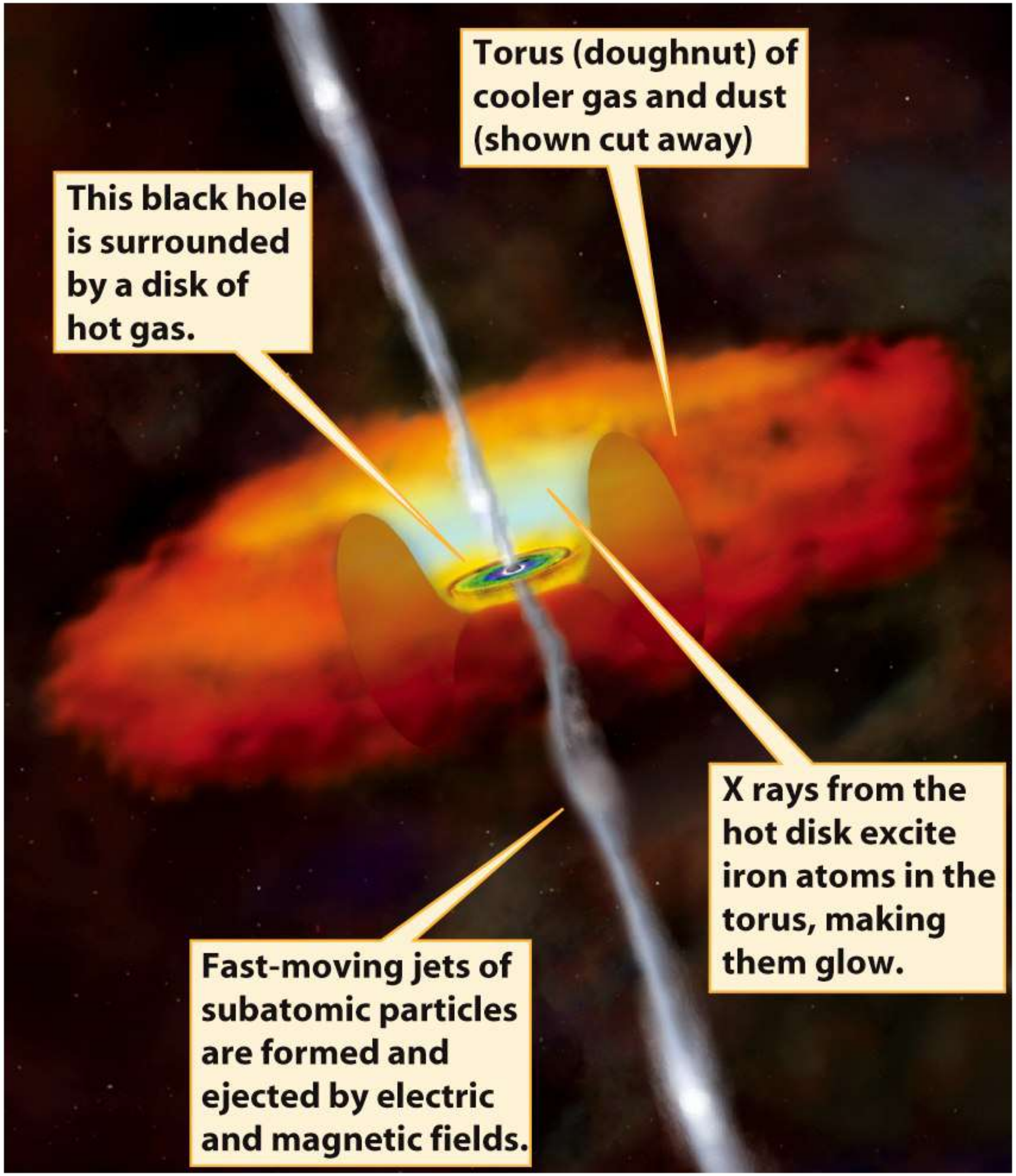
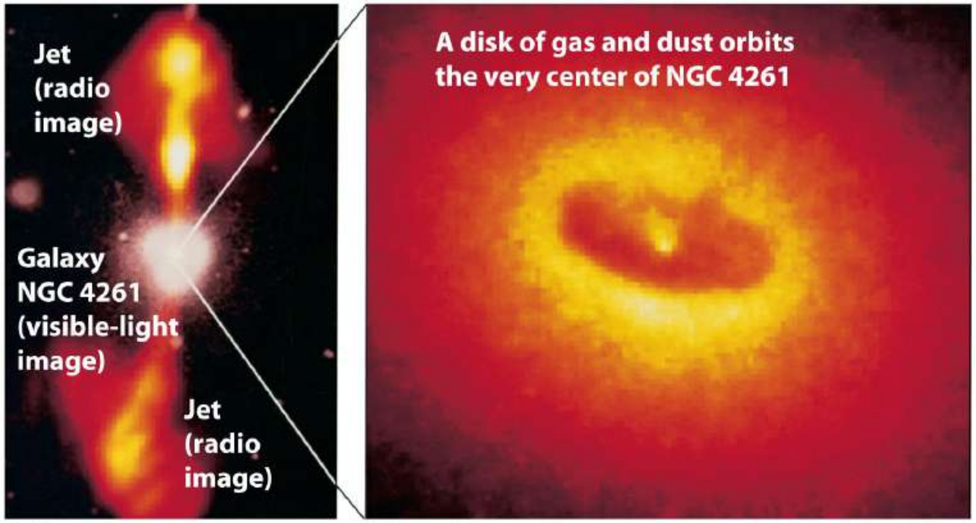


A schematic diagram of Cygnus X-1

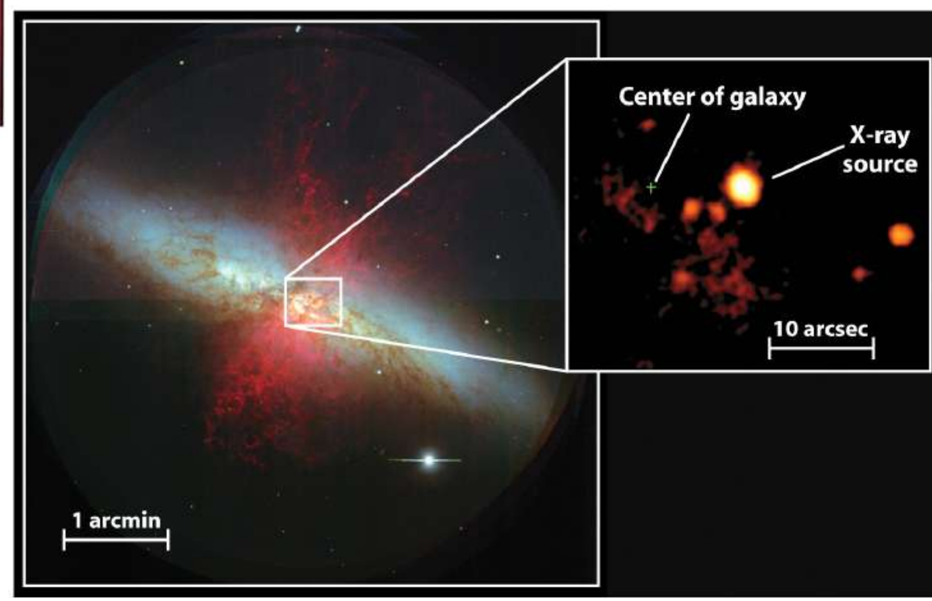
An artist's impression of Cygnus X-1


Torus (doughnut) of cooler gas and dust (shown cut away)
This black hole is surrounded by a disk of hot gas.
X rays from the hot disk excite iron atoms in the torus, making them glow.
Fast-moving jets of subatomic particles are formed and ejected by electric and magnetic fields.

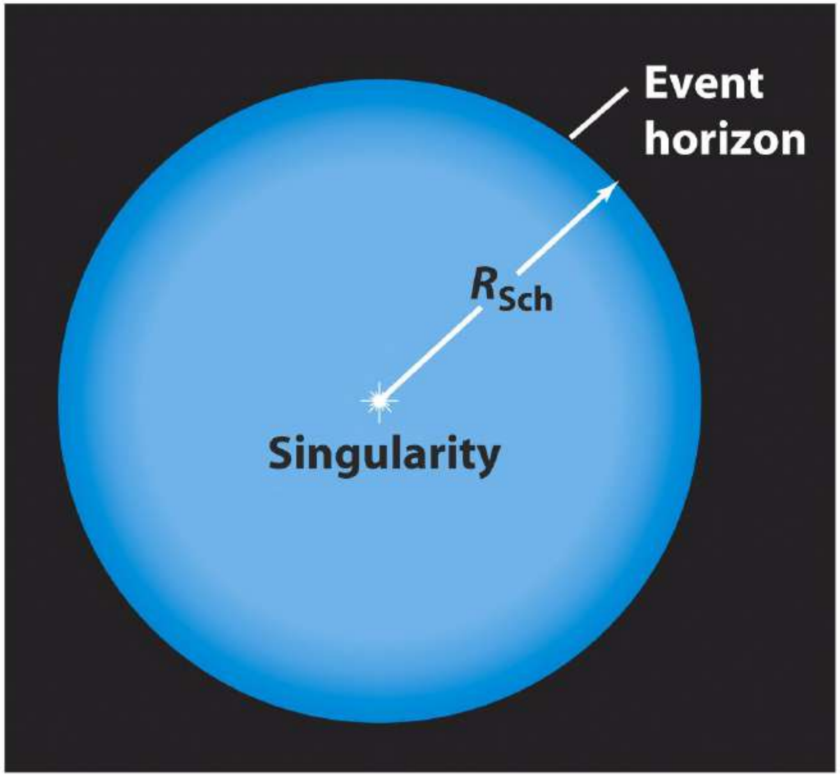
Supermassive black holes exist at the centers of most galaxies

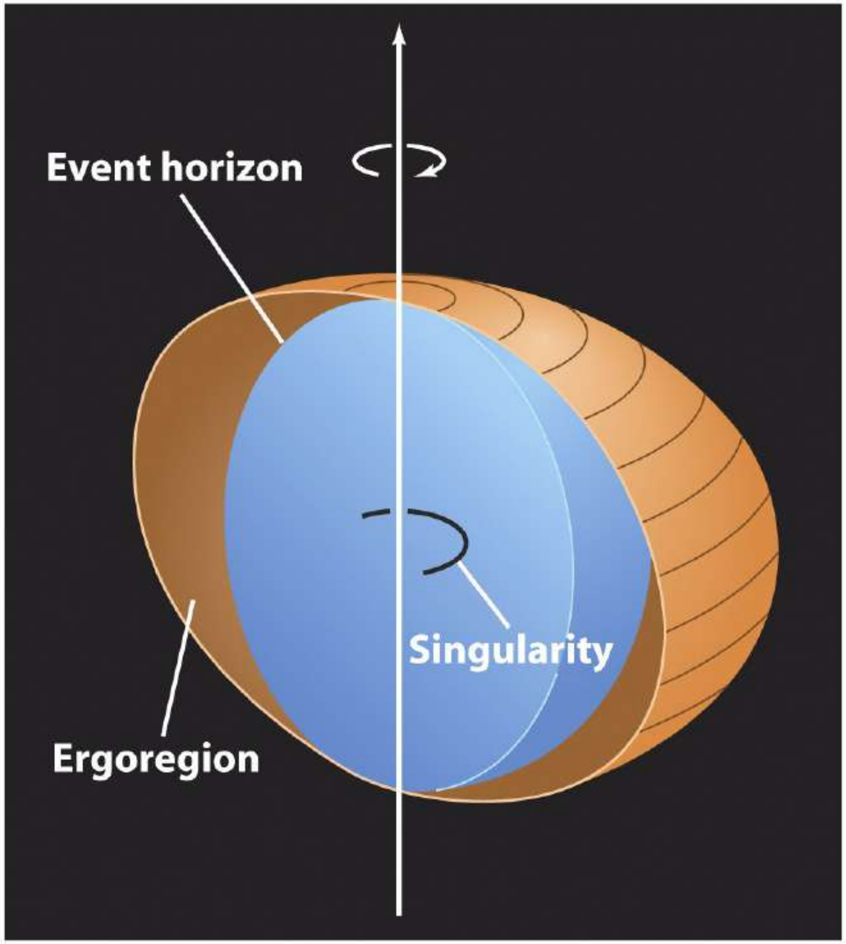


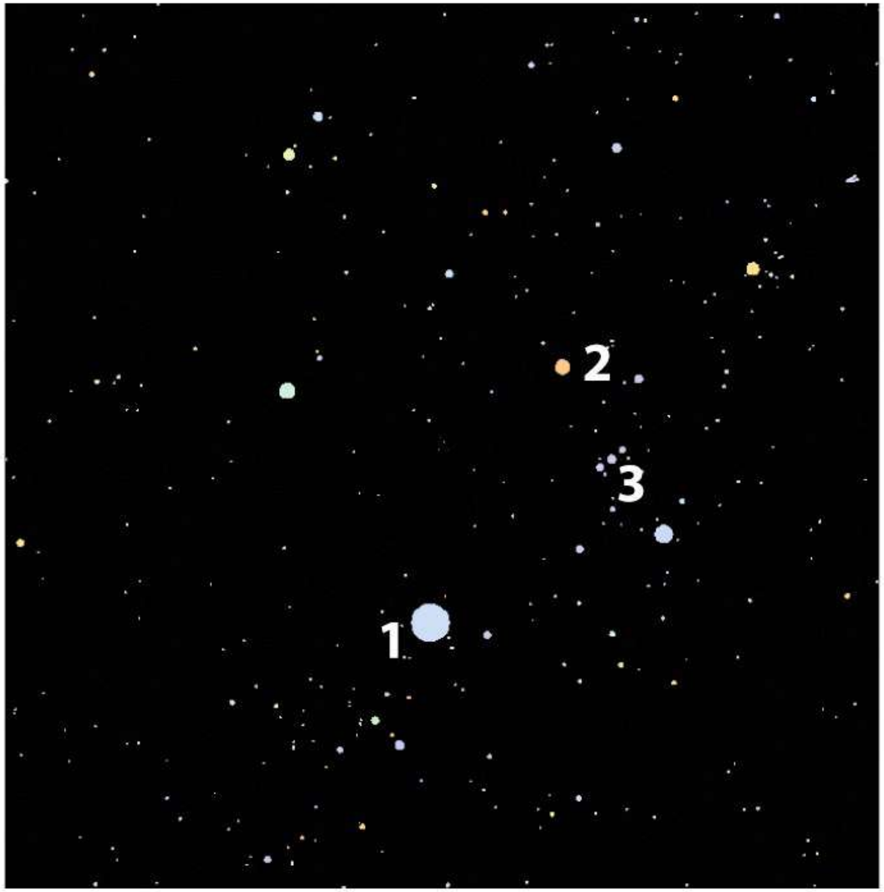
(a) Galaxy NGC 4261 (b) Evidence for a supermassive black hole in NGC 4261



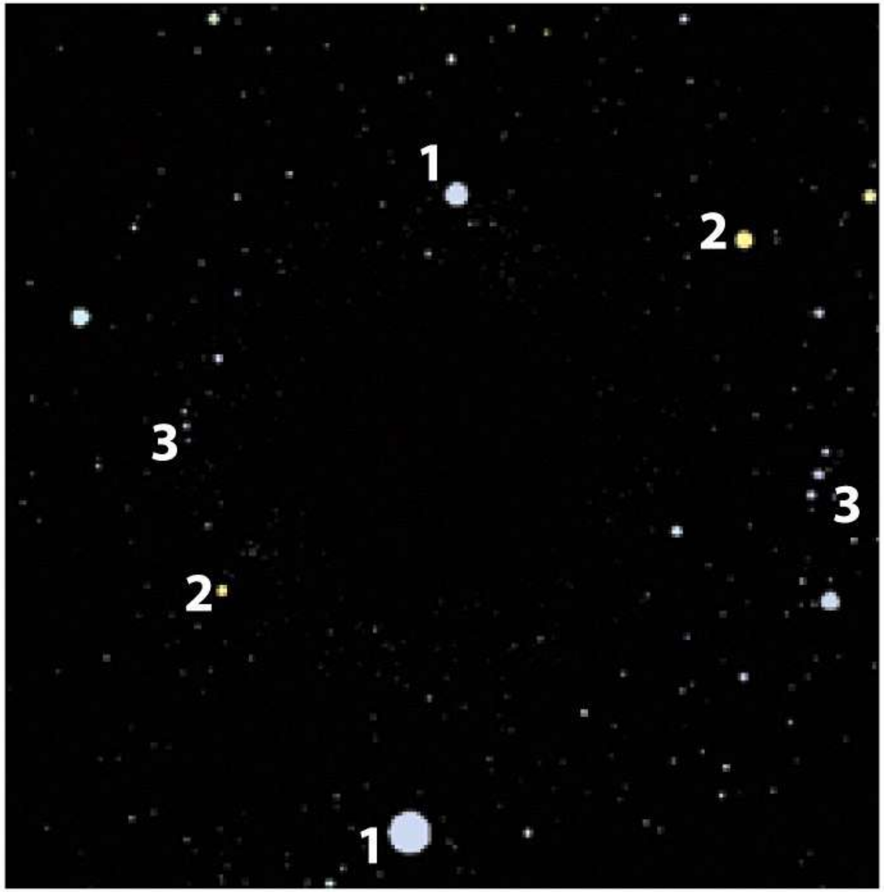
These are detected by observing the motions of material around the black hole


Event
horizon
R_{Sch}
Singularity


Event horizon
Singularity
Ergoregion

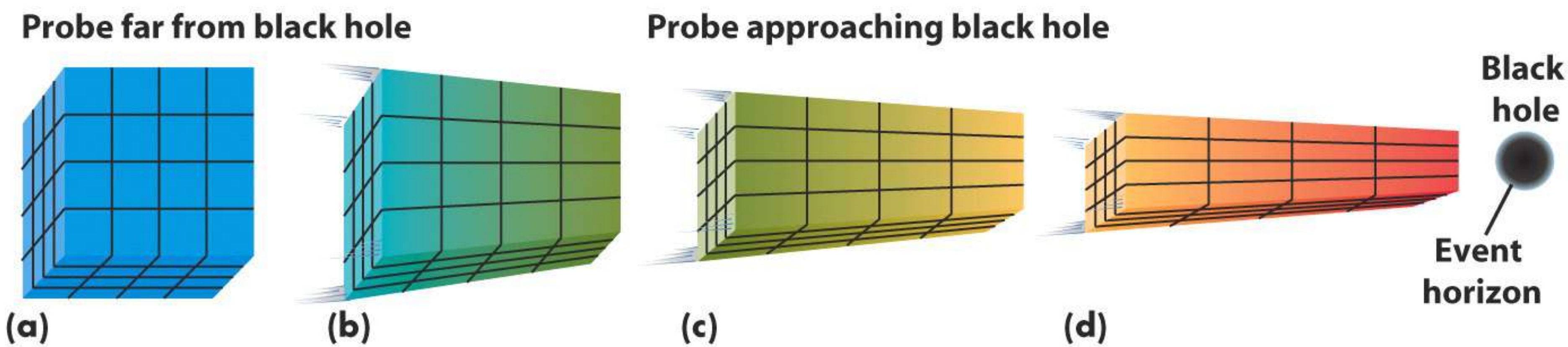


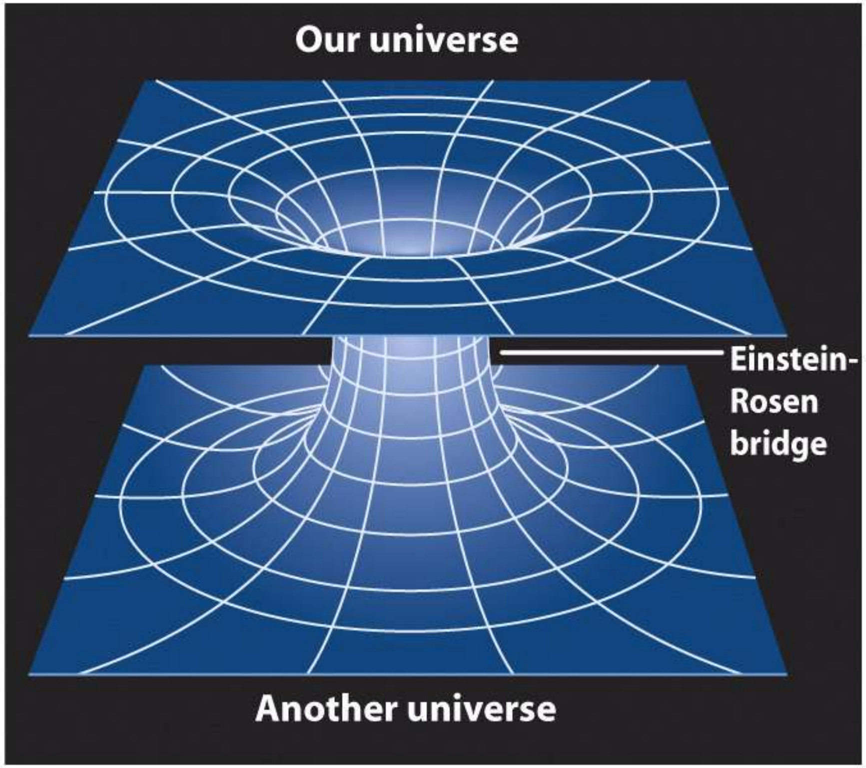
(a) Looking directly toward the black hole from a distance of 1000 Schwarzschild radii: Note positions of stars 1, 2, and 3.

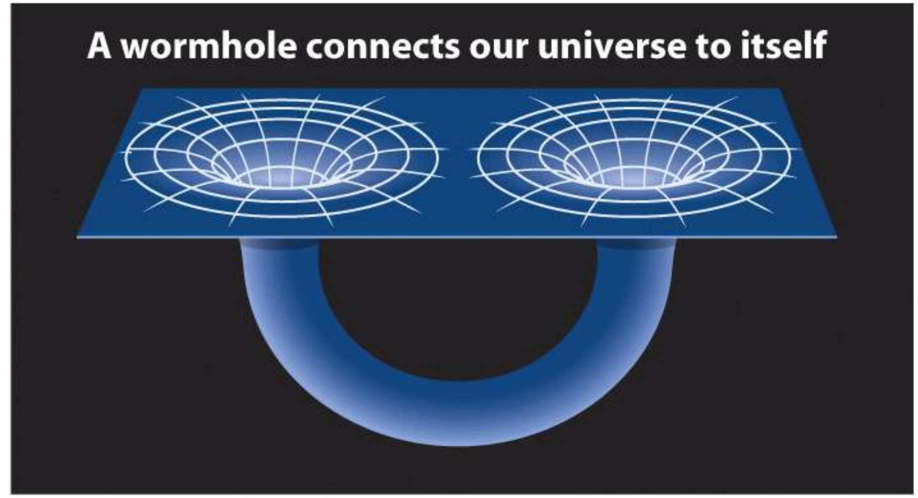


(b) Looking directly toward the black hole from a distance of 10 Schwarzschild radii: Light bending causes multiple images.

Falling into a black hole is an infinite voyage







- Could a black hole somehow be connected to another part of spacetime, or even some other universe?
- General relativity predicts that such connections, called wormholes, can exist for rotating black holes

Black holes evaporate