Today

- Black Holes
- The Milky Way
  - Galactic Structure
  - The Interstellar Medium
  - Star Formation
  - Stellar Populations

Homework 5 due next time

Black Holes

A ***black hole*** is an object whose gravity is so powerful that not even light can escape it.

Some massive star supernovae can make a black hole if enough mass falls onto the core.

Escape Velocity

A black hole is an object so compact that its escape velocity exceeds the speed of light.

$$V_{esc} = \sqrt{\frac{2GM}{R}}$$

The key is size as much as mass.

$$V_{esc} = c$$

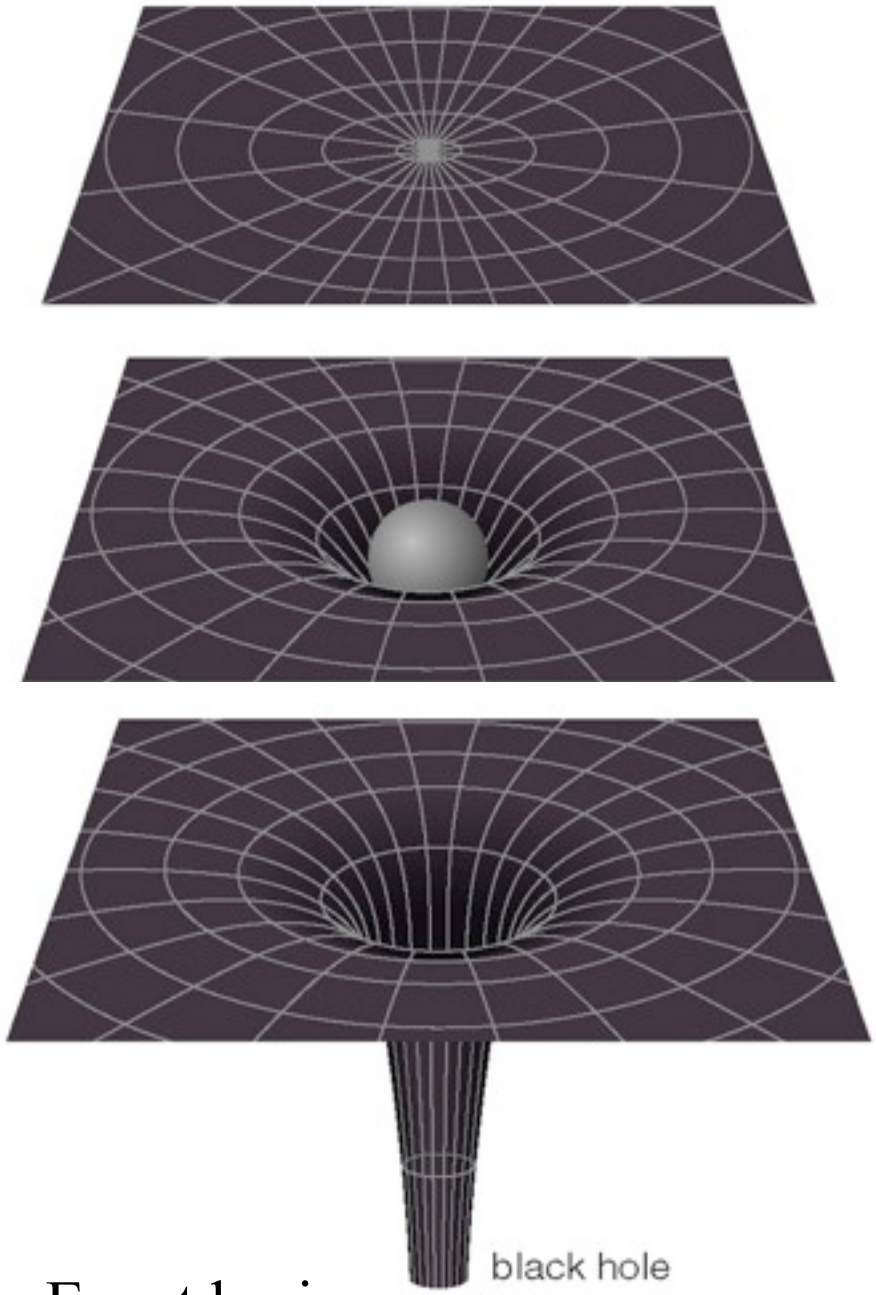
The "Event Horizon" is the radius of no return, from which even light cannot escape.

$$R_{EH} = \frac{2GM}{c^2}$$

$$R_{EH} = 3\,\mathrm{km} \text{ for } M = 1\,\mathrm{M}_\odot$$

“Surface” of a Black Hole

- The “surface” of a black hole is the radius at which the escape velocity equals the speed of light. This is not a physical surface, just the point in space where gravity prevents the escape of light.
- This spherical surface is known as the ***event horizon.***
- The radius of the event horizon is known as the ***Schwarzschild radius.***



A black hole's mass strongly warps space and time in the vicinity of the event horizon.

Gravity is warped space: the effective force felt by trying to mover in a straight line through a curved space-time.

No Escape

- Nothing can escape from within the event horizon because nothing can go faster than light.
- No escape means there is no more contact with something that falls in. It increases the hole's mass, changes its spin or charge, but otherwise loses its identity.

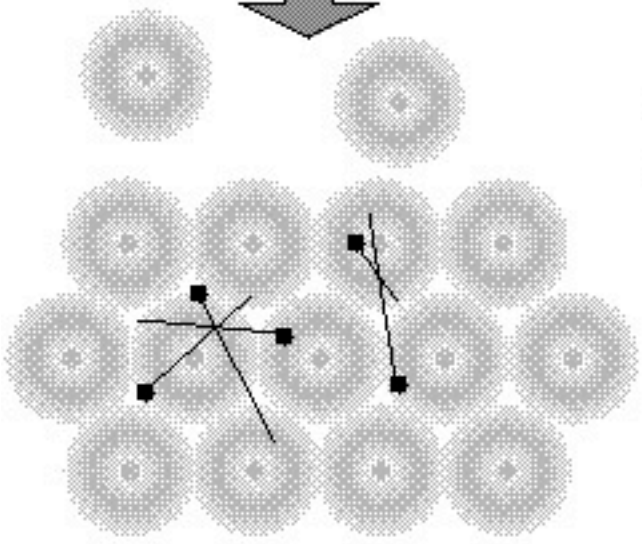
Singularity

- Beyond the neutron star limit, no known force can resist the crush of gravity.

- As far as we know, gravity crushes all the matter into a single point known as a ***singularity.***

Mass < 1.4 solar masses

GRAVITY



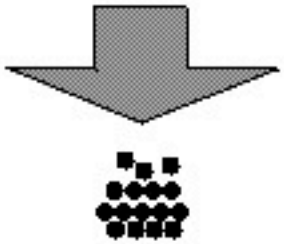
White Dwarf

Electrons run out of room to move around. Electrons prevent further collapse. Protons & neutrons still free to move around.

Stronger gravity => more compact.

Mass > 1.4 solar masses
but mass < 3 solar masses

GRAVITY



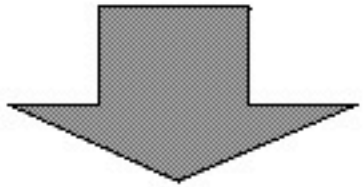
Neutron Star

Electrons + protons combine to form neutrons. Neutrons run out of room to move around. Neutrons prevent further collapse. Much smaller!

$M > 3\ M_{\odot}$

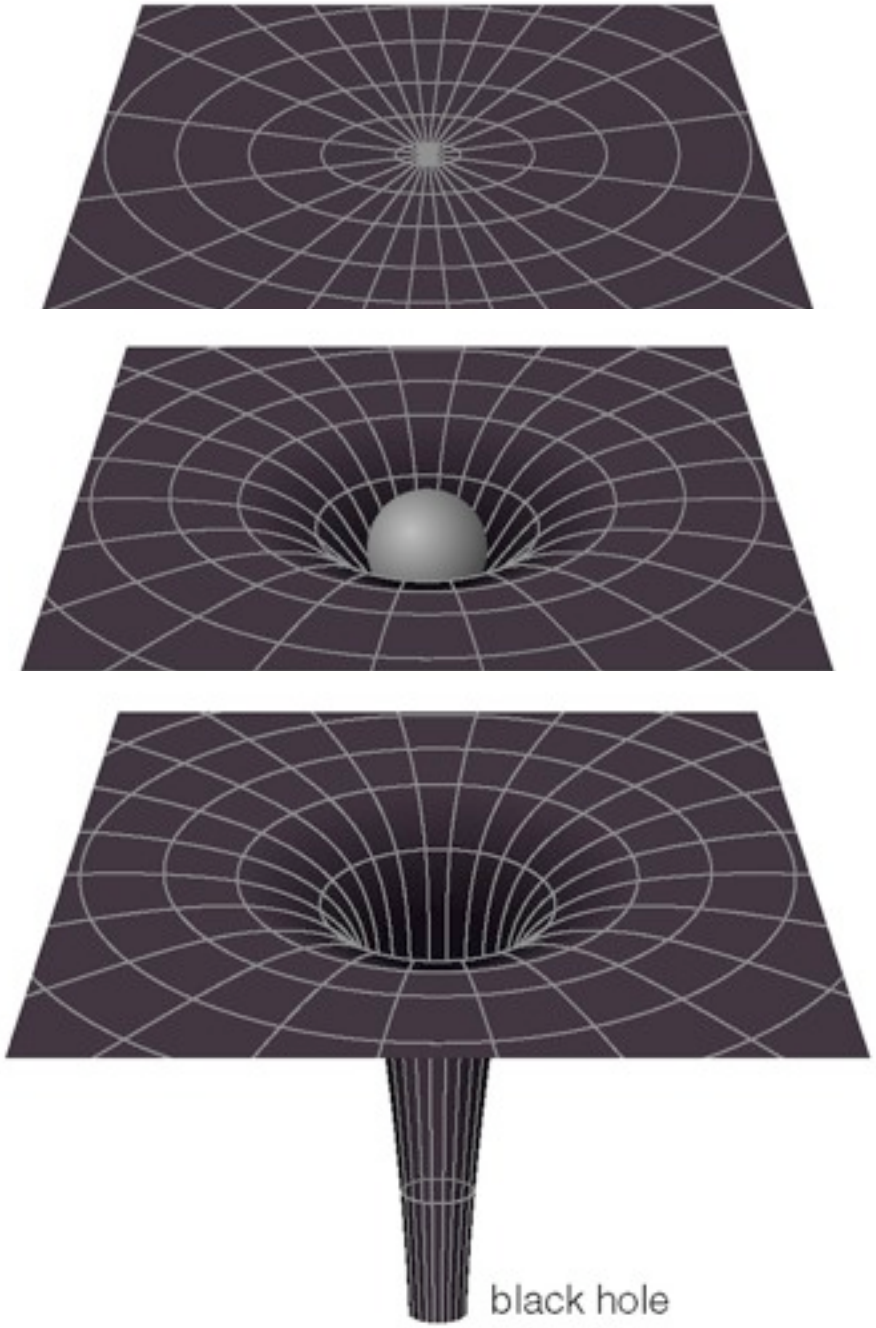
Mass > 3 solar masses

GRAVITY



Black Hole

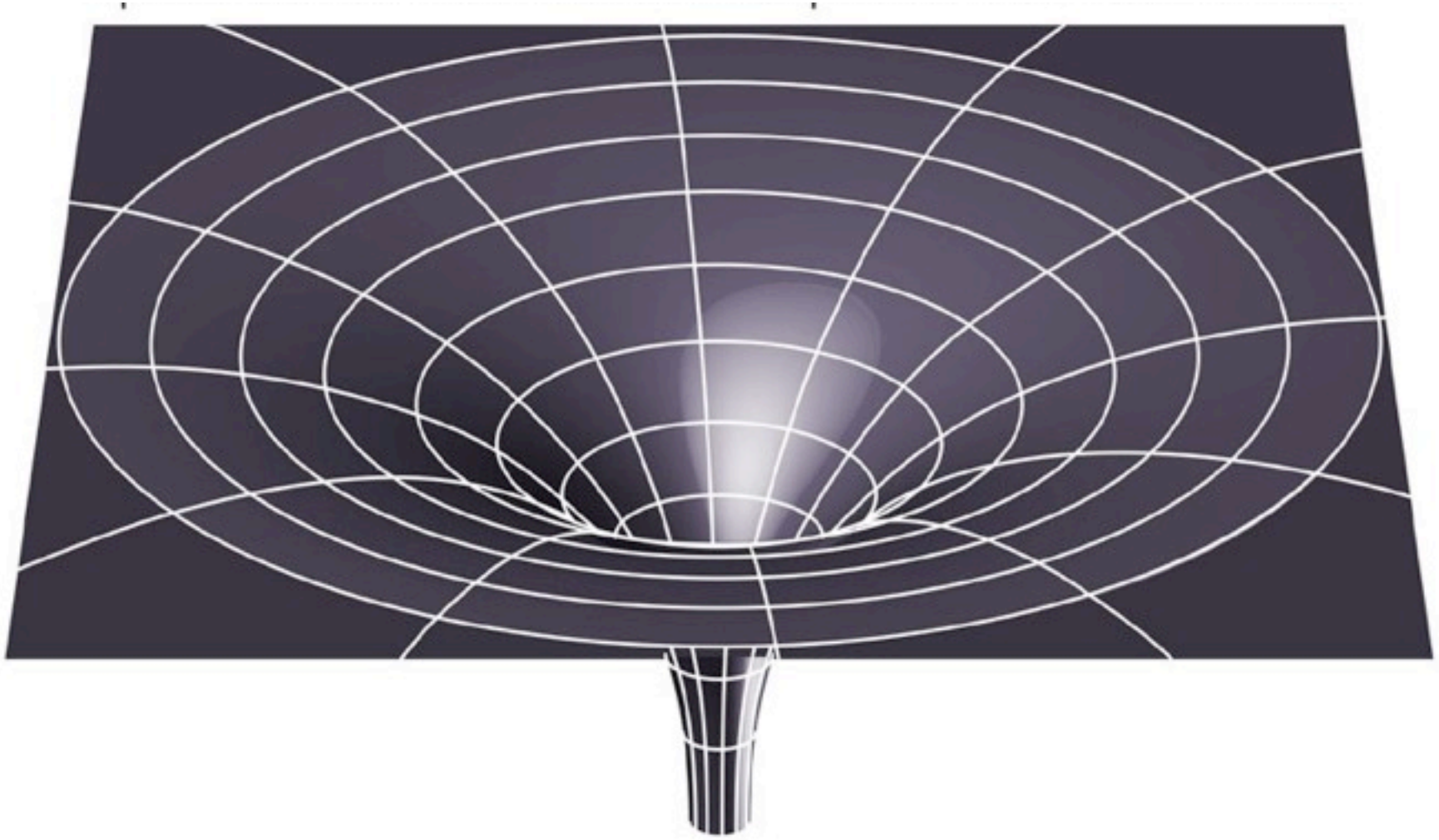
Gravity wins! Nothing prevents collapse.



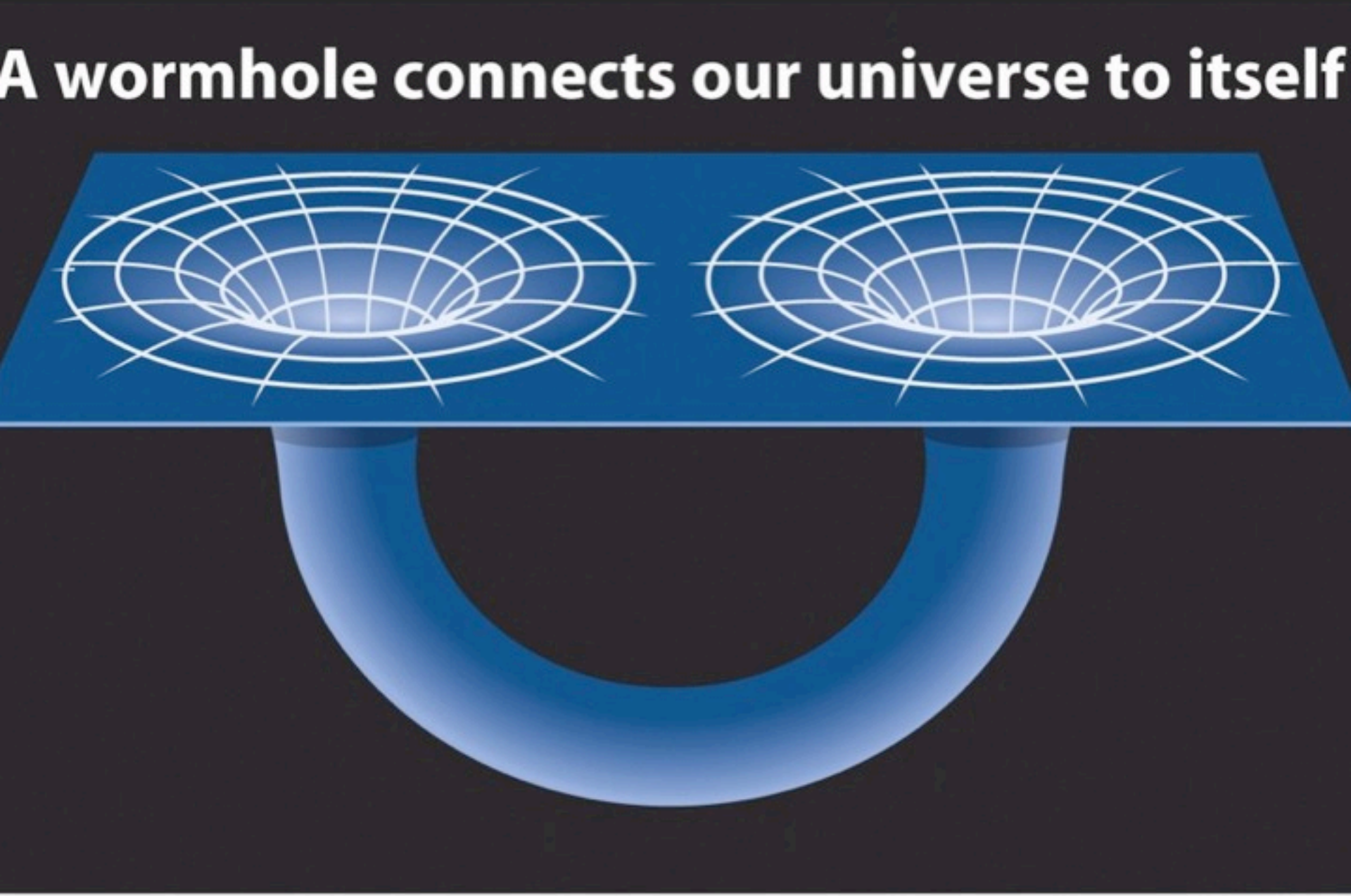
If the Sun shrank into a black hole, its gravity would be different only near the event horizon.

Far away, the gravity of a mass looks like it comes from a point, no matter the real shape.

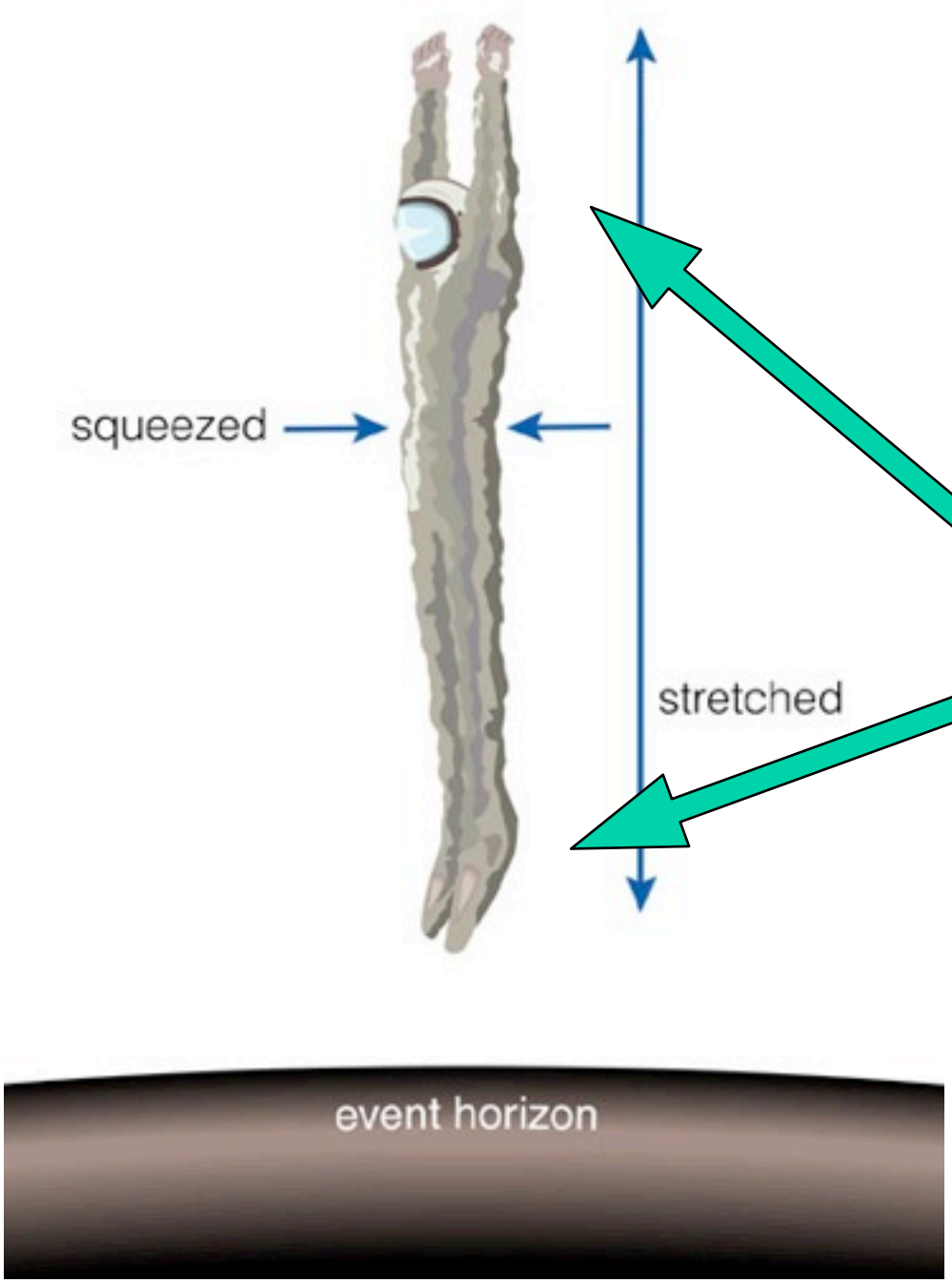
Black holes don't suck!



Light waves lose energy climbing out of a deep hole in spacetime leading to a ***gravitational redshift.***



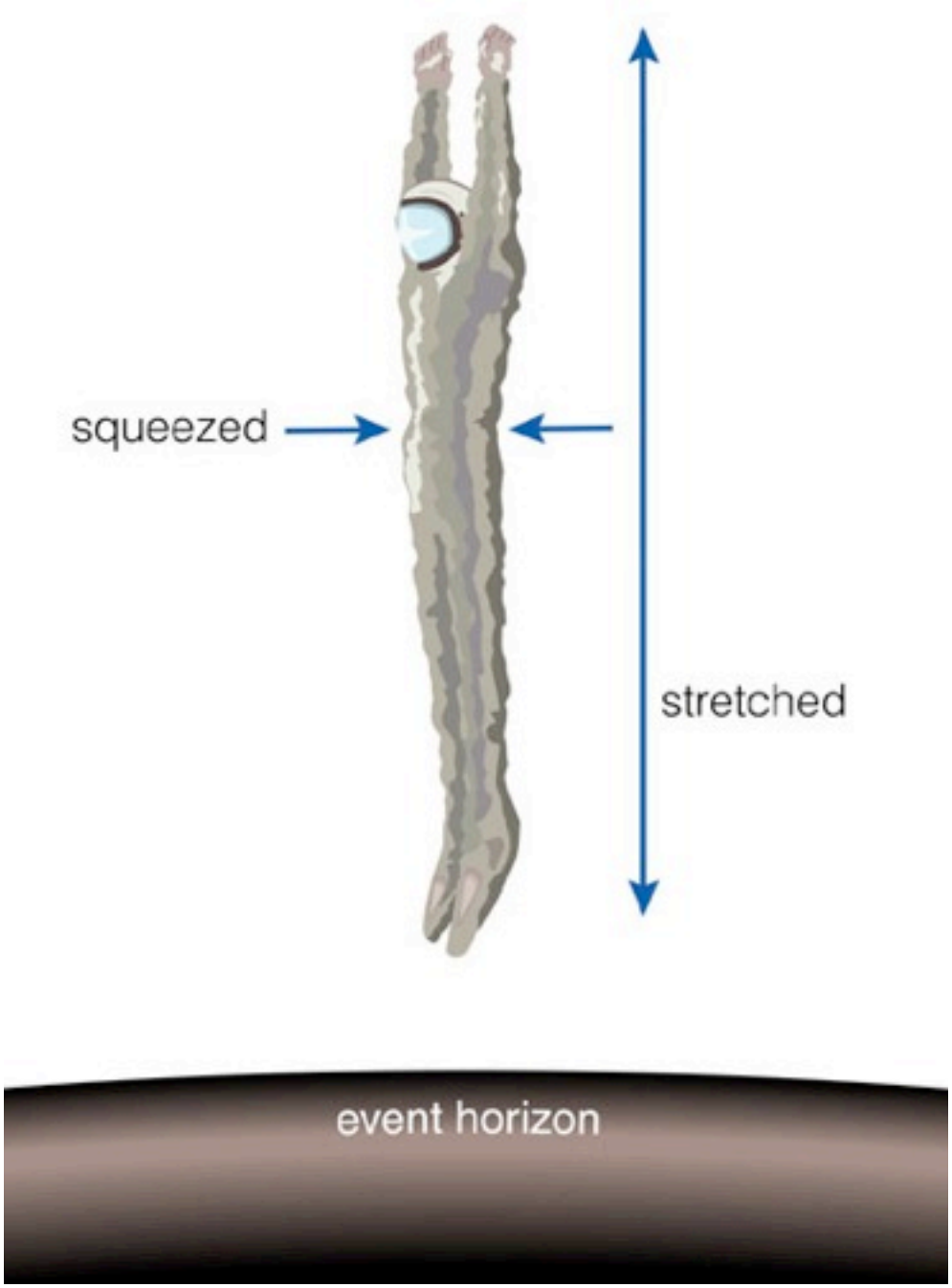
Two black hole entrances grafted together.



Tidal forces near the event horizon of a 3 M_{Sun} black hole would be lethal.

$$F = \frac{GMm}{r^2}$$

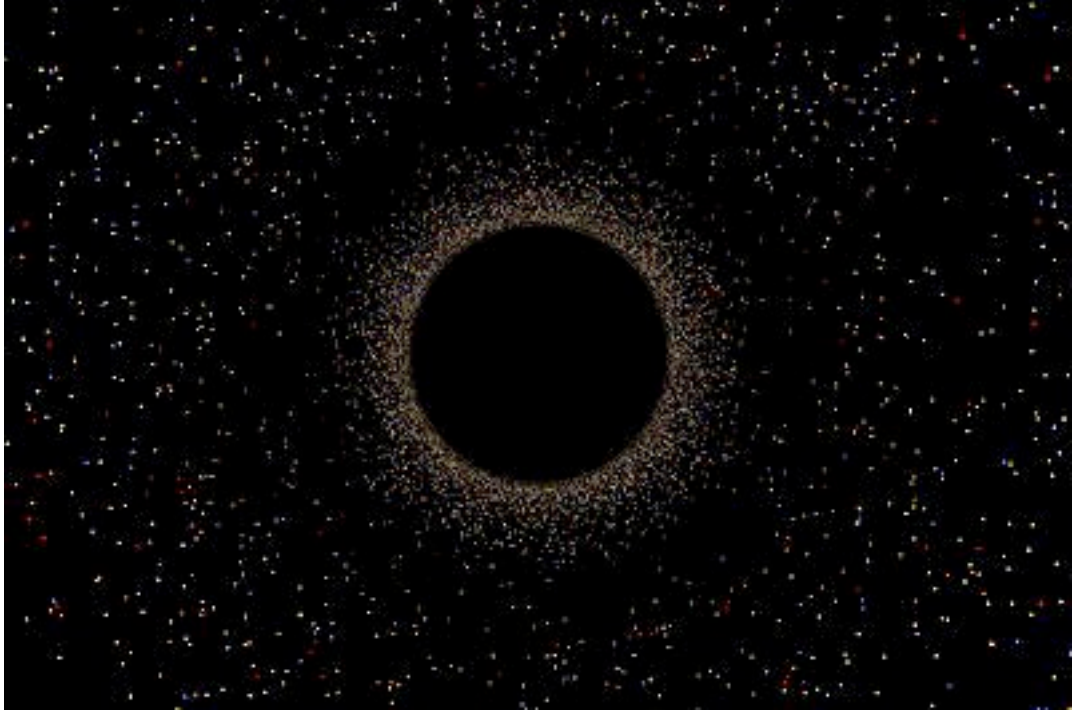
F much stronger on the feet than on the head just because of the small difference in r.



Tidal forces near the event horizon of a 3 M_{Sun} black hole would be lethal.

Tidal forces would be gentler near a supermassive black hole because its radius is much bigger.

"Spaghettification"



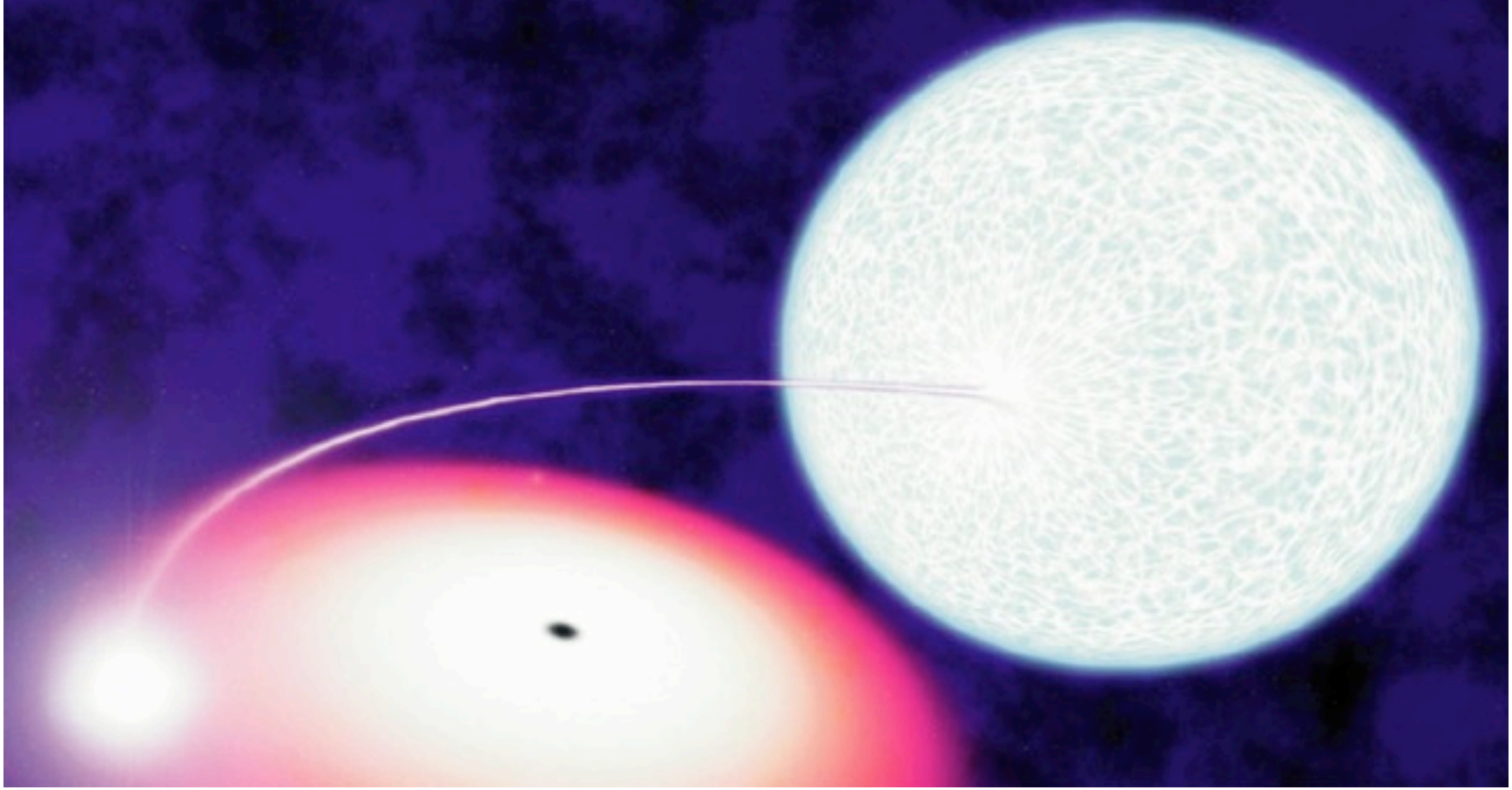
Black holes also bend light around them: *gravitational lensing*.

Black holes not directly observable - no light escapes from the event horizon. But they can be detected by their effects on their surroundings.

Black Hole Verification

- Need to measure mass
  - — Use orbital properties of companion
  - — Measure velocity and distance of orbiting gas

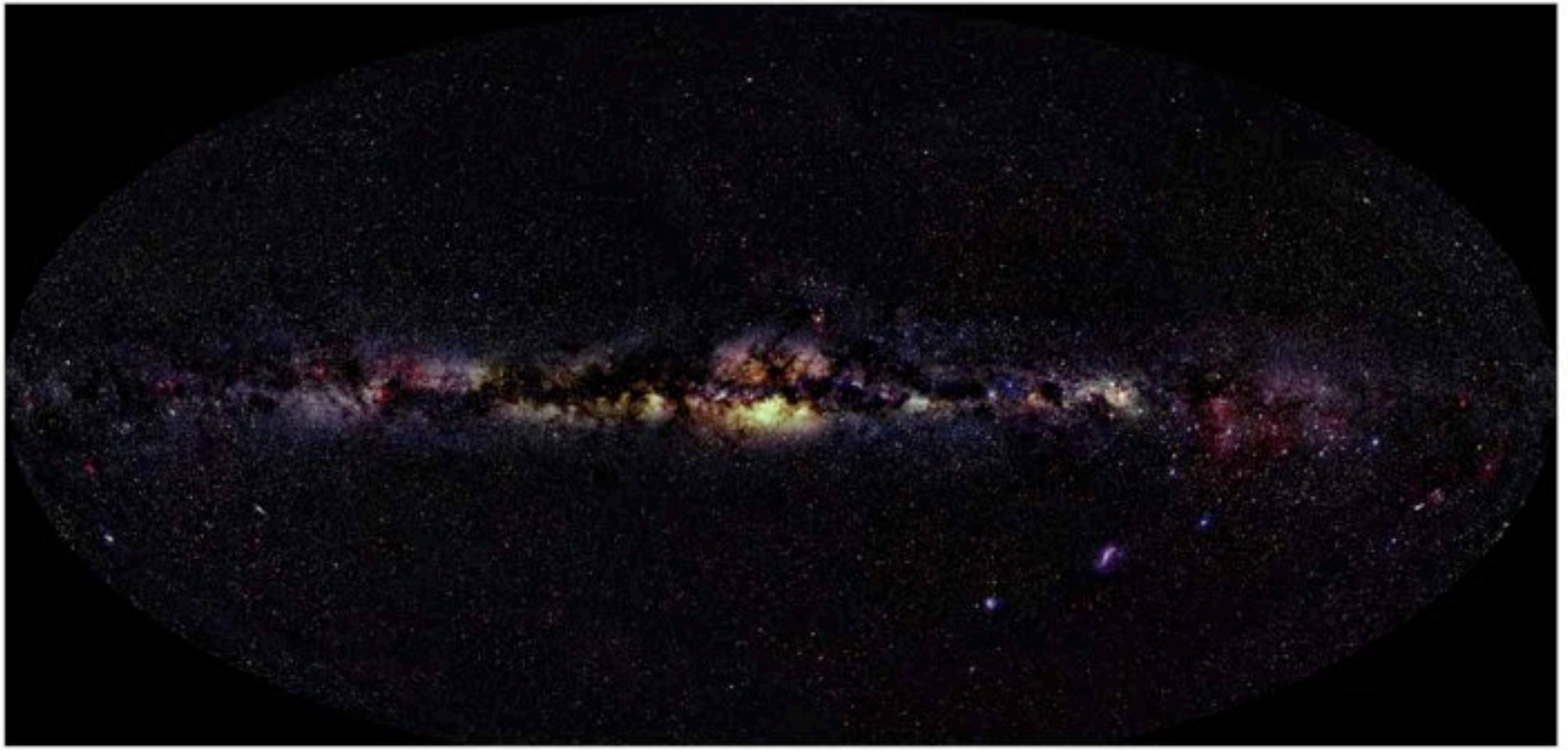
- It's a black hole if it's not a star and its mass exceeds the neutron star limit (~3 M_{Sun}).

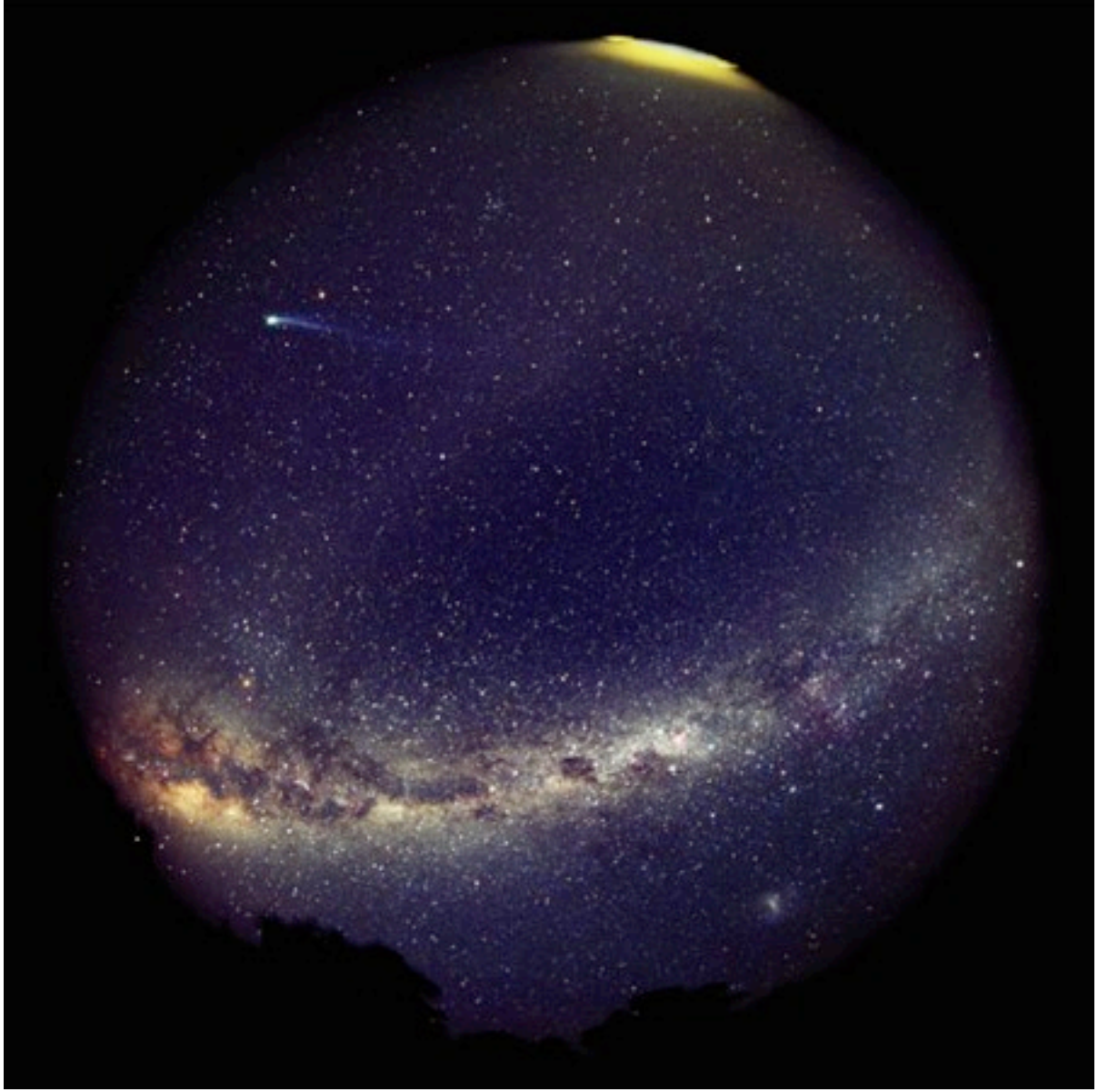


Some X-ray binaries contain compact objects of mass exceeding 3 M_{Sun} which are likely to be black holes.

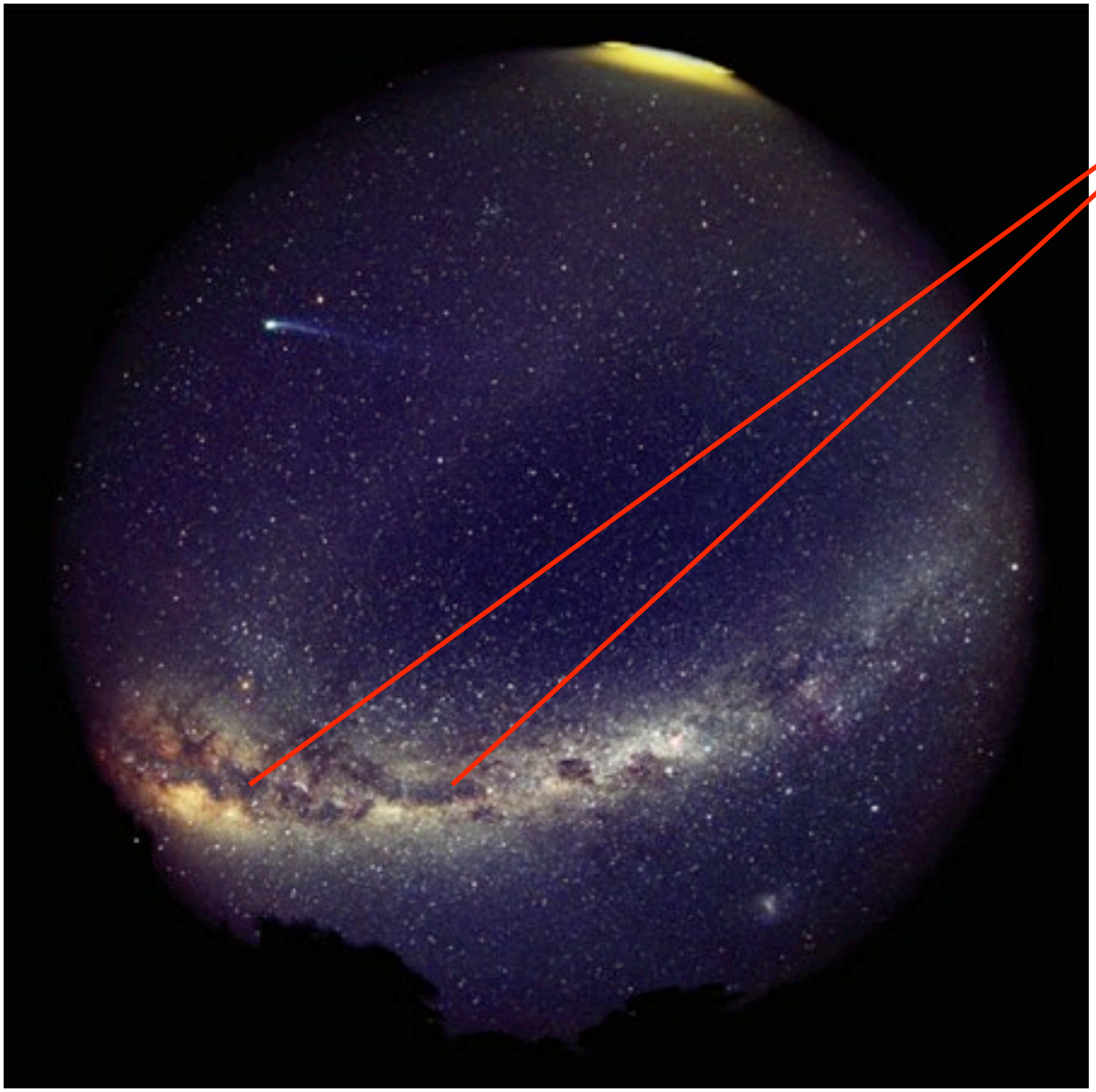
They're real... now there is good evidence for even more massive black holes near the centers of galaxies, like our own Milky Way...

Our Galaxy - the Milky Way





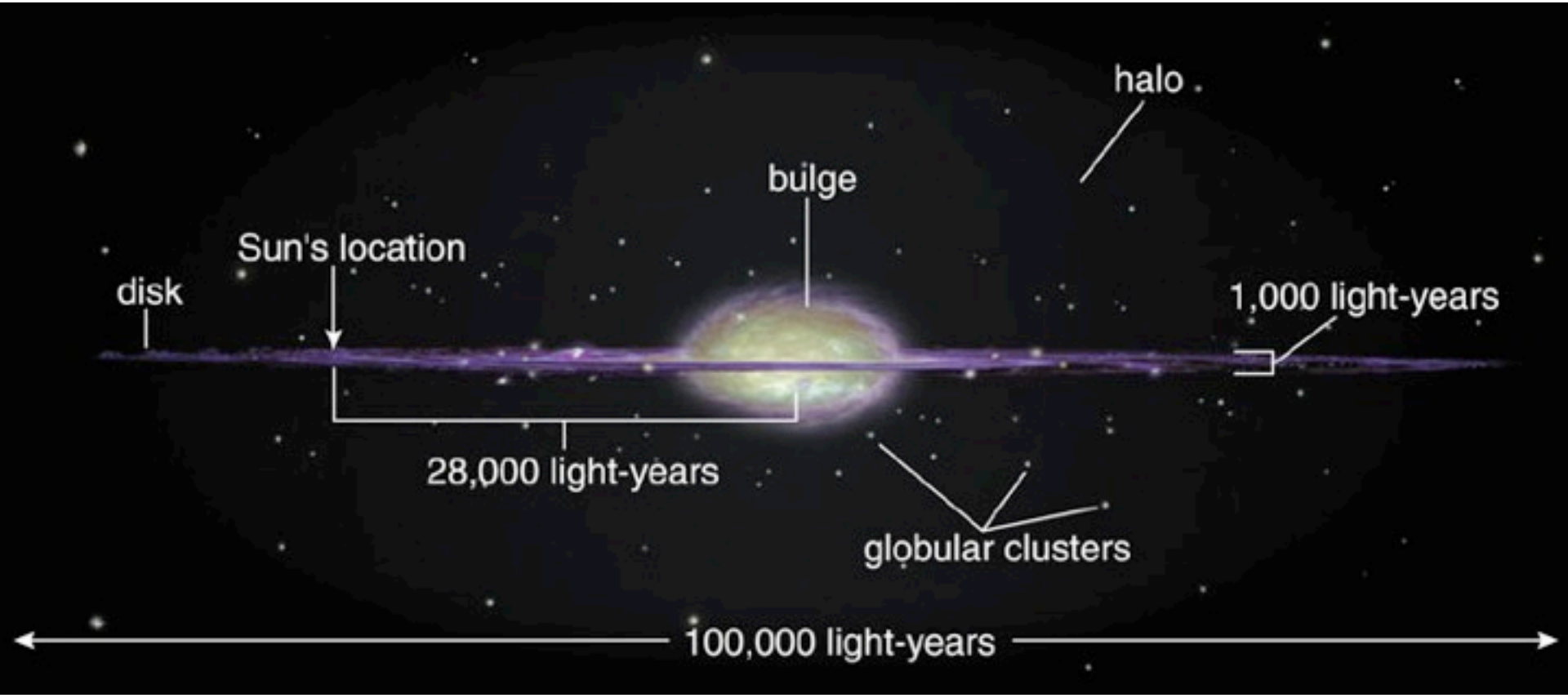
The Milky Way galaxy appears in our sky as a faint band of light - the light from many unresolved stars.



Dusty gas clouds obscure our view because they absorb visible light.

This is the ***interstellar medium*** that makes new star systems.

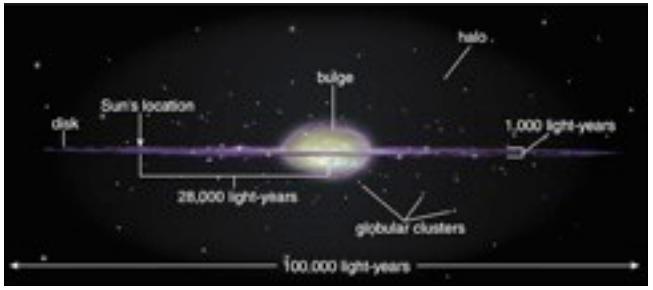
Milky Way schematic, seen edge-on

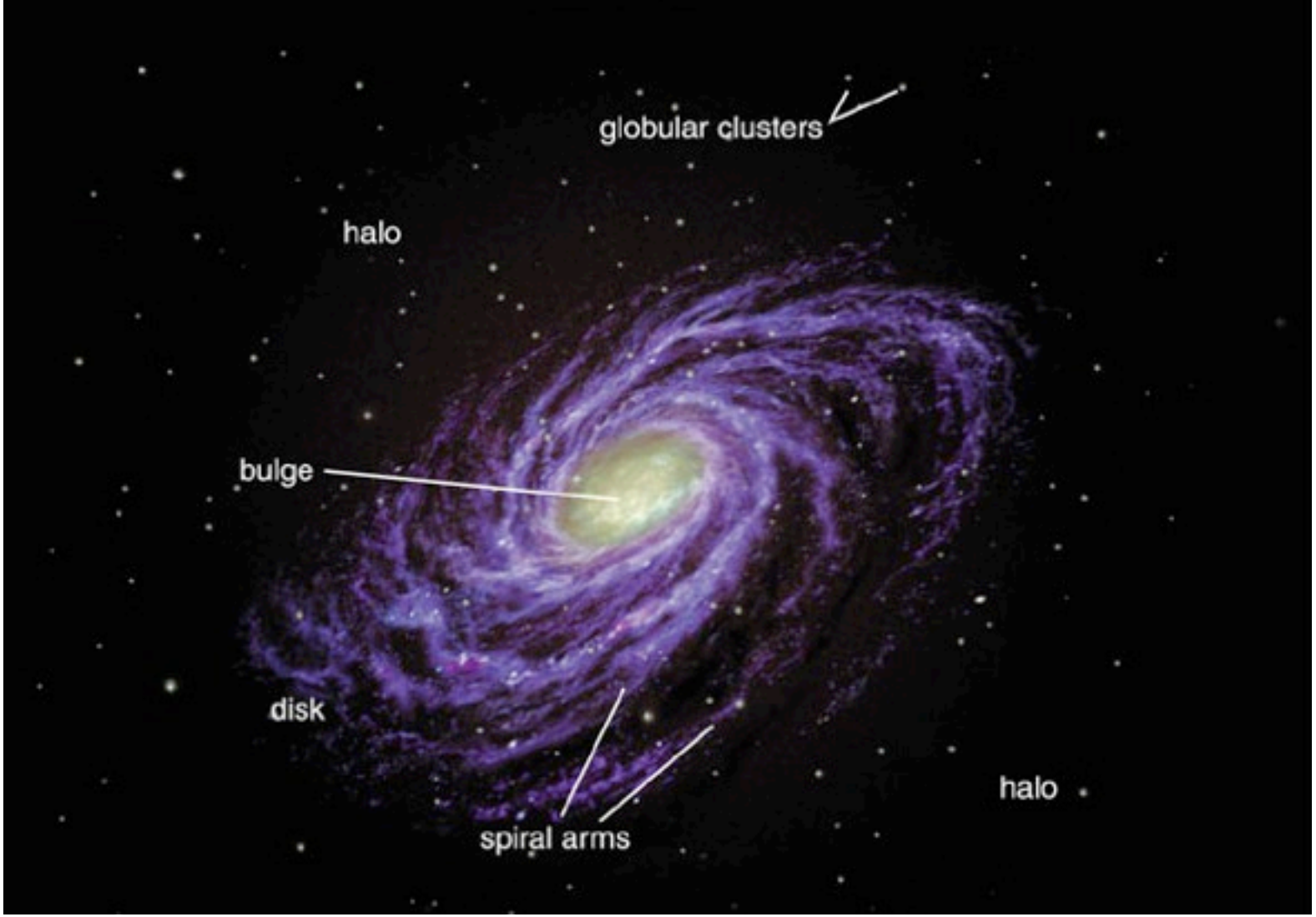


Primary features: disk, bulge, halo.
Globular clusters are part of the halo.
The sun (like most stars) is in the disk.

Galactic Structure

- Stars
  - DISK - individual stars; open clusters
  - BULGE - individual stars; globular clusters
- Gas (mostly in disk)
  - atomic gas ("H I")
  - molecular gas (H_2, CO, many other molecules)
  - hot, ionized gas ("H II")
- Dust (mostly in disk)
  - between stars
  - mostly in spiral arms & molecular clouds





If we could view the Milky Way from above the disk, we would see its spiral arms.