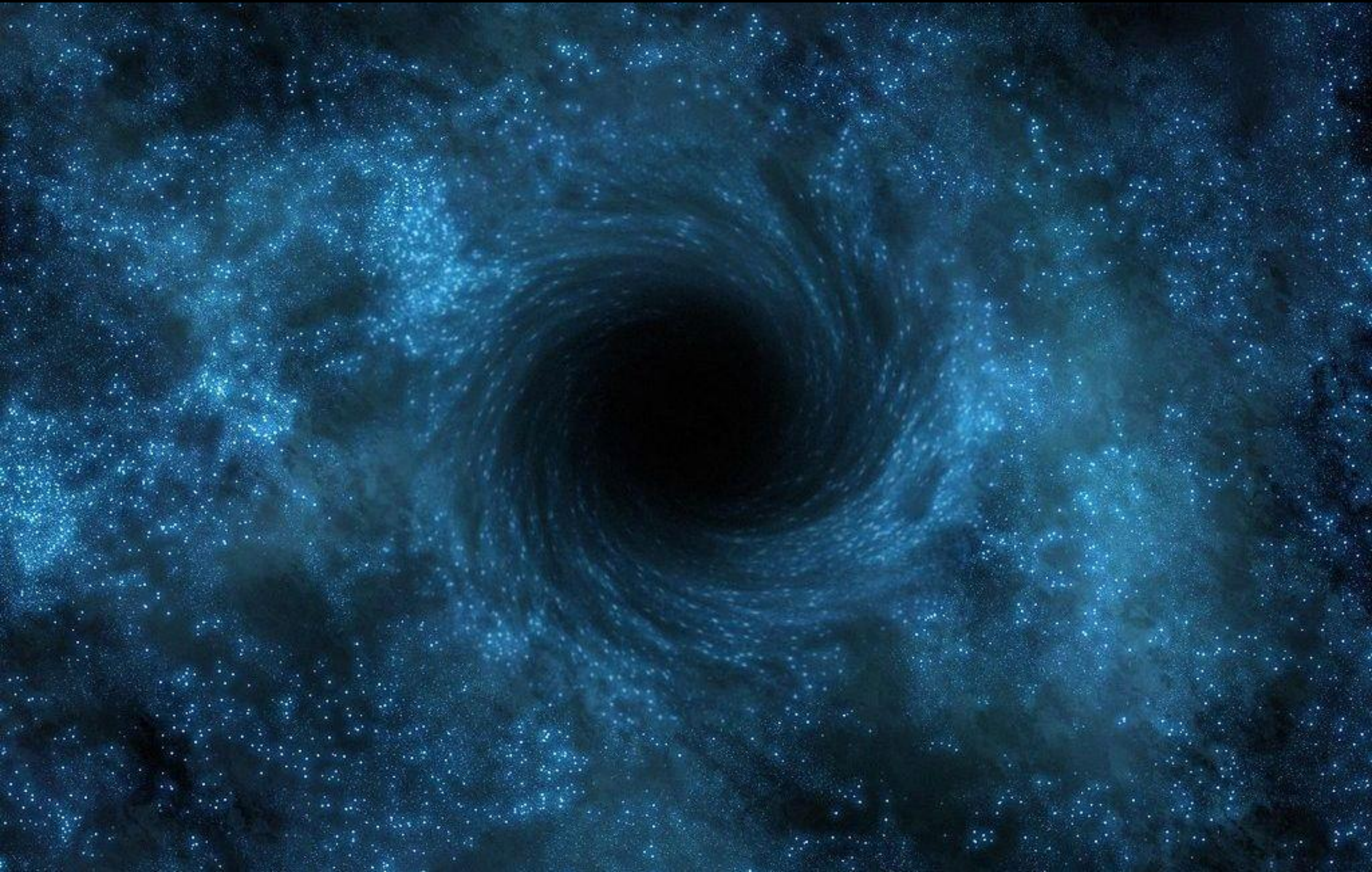
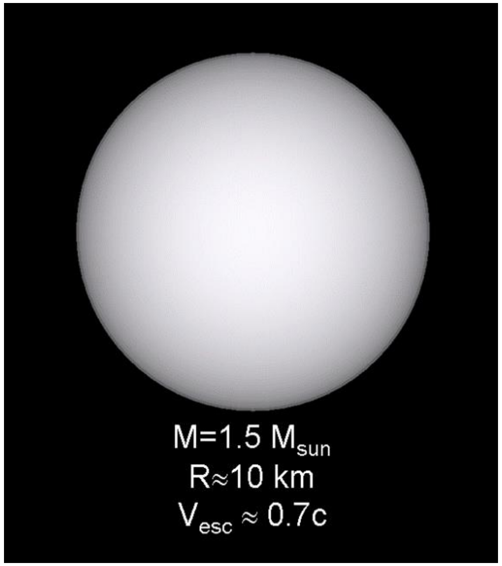
Lecture 20 - Black Holes



Neutron Star Limit



- Neutrons in the same place cannot be in the same state.
- *Neutron* degeneracy pressure can no longer support a neutron star against gravity if its mass exceeds about 3 M_{Sun}.
- *What if it exceeds this limit?*

Think/Pair/Share

What happens to the escape velocity from an object if you shrink it?

A. It increases.
B. It decreases.
C. It stays the same.

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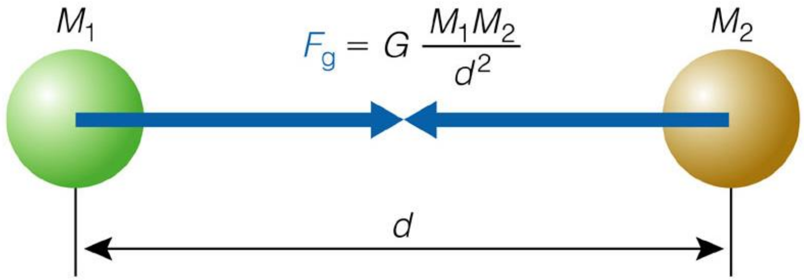


Relationship Between
Escape Velocity and Radius

What Is a Black Hole?

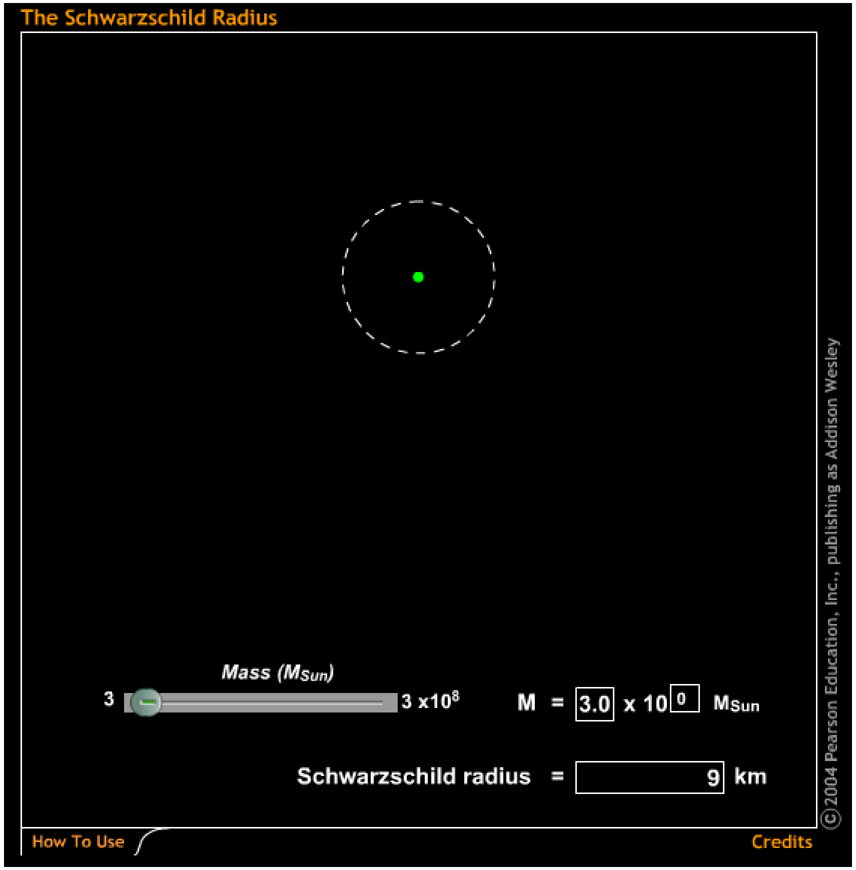
- A ***black hole*** is an object whose gravity is so powerful that not even light can escape it.

- Within a certain radius,
  the escape velocity > speed of light!

“Surface” of a Black Hole

- The “size” of a black hole is the *radius* at which escape velocity equals the speed of light.
- This mathematical boundary is known as the ***event horizon.***
- A typical $3M_{\text{Sun}}$ black hole has a radius of only a few miles!

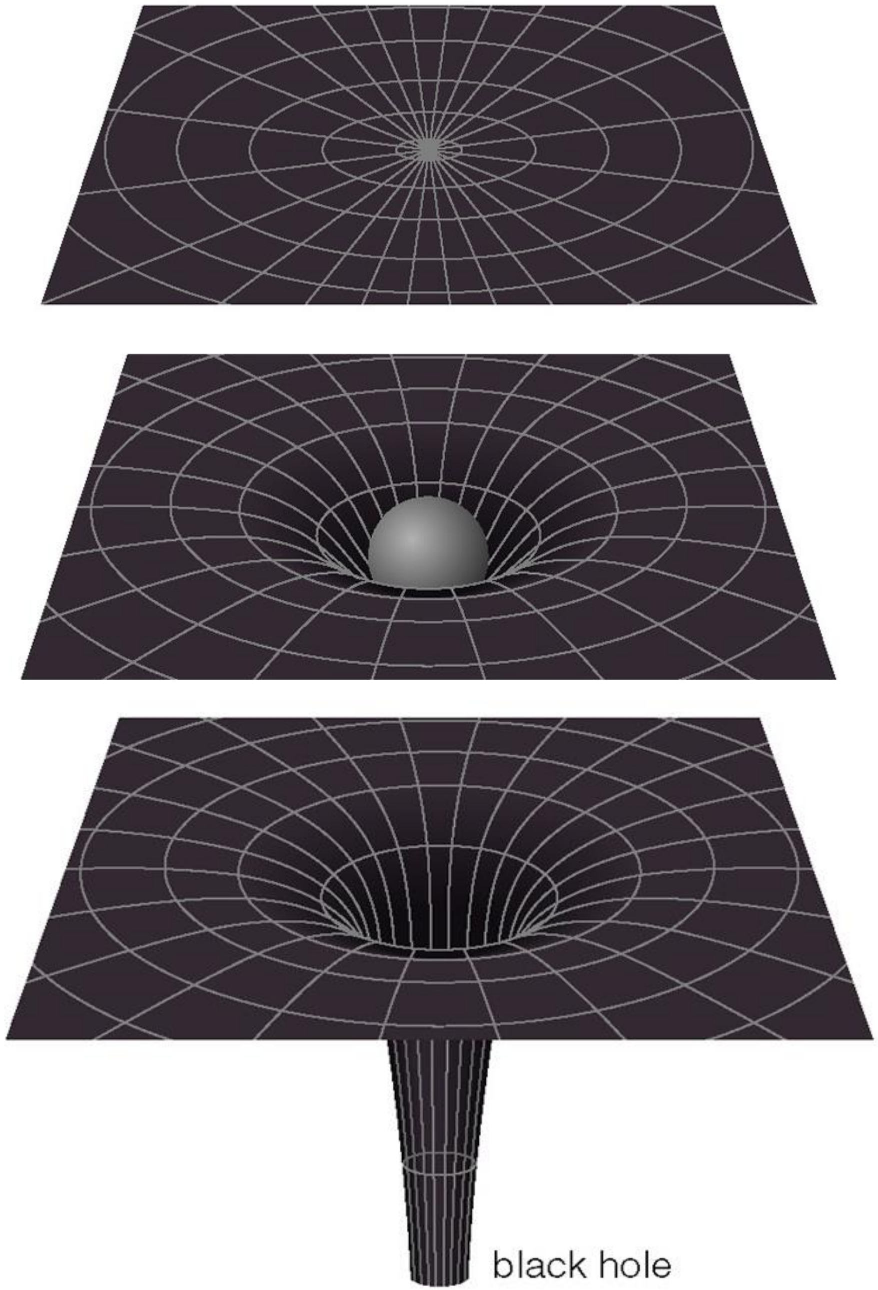
Schwarzchild radius



The Schwarzschild Radius

- The radius of the event horizon is known as the ***Schwarzschild radius.***
- This radius is larger for black holes of larger mass

$$R_S = 2GM / c^2$$

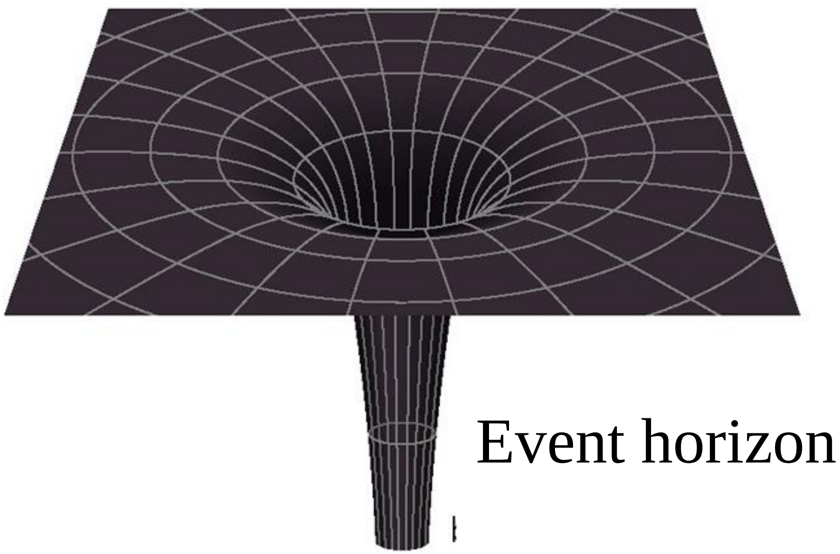


Event horizon

• A black hole's mass strongly warps space and time near the event horizon.

• Near the event horizon, *time slows down* and tidal forces are very strong.

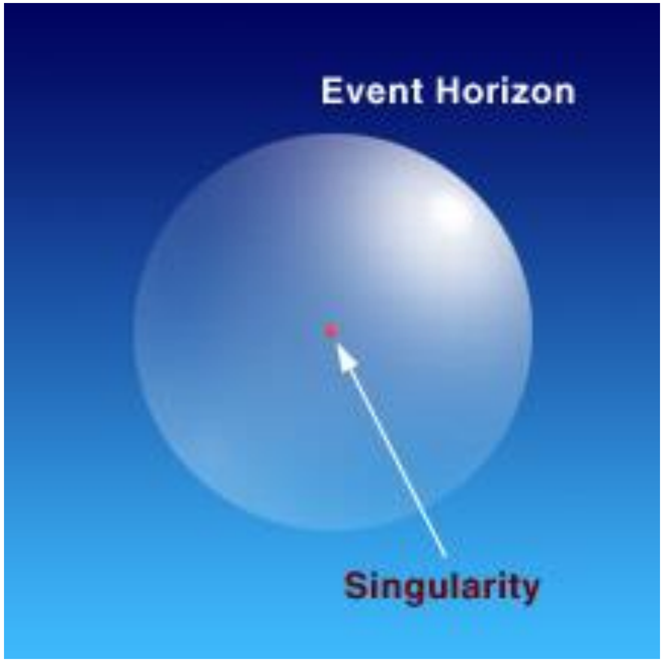
No Escape



- Nothing can escape within the event horizon because nothing can go faster than light.
- No escape means there is no more contact with something that falls in.
- In falling matter increases the hole’s mass, but otherwise loses its identity.
- Only mass, electric charge, and angular momentum are preserved.

Singularity

- Beyond the neutron star limit (neutron degeneracy), **no known force** can resist the crush of gravity.
- Gravity crushes all the matter into a single mathematical point known as a ***singularity.***
- Density = infinite, size = 0



Think/Pair/Share

How can we study black holes if we can't see them? Select the *incorrect* answer.

A. We can't – they are only theoretical constructs.
B. We might observe their gravitational influence on other objects.
C. Black holes might have accretion disks that give off light of various wavelengths.
D. We might observe effects of their gravity in other ways.

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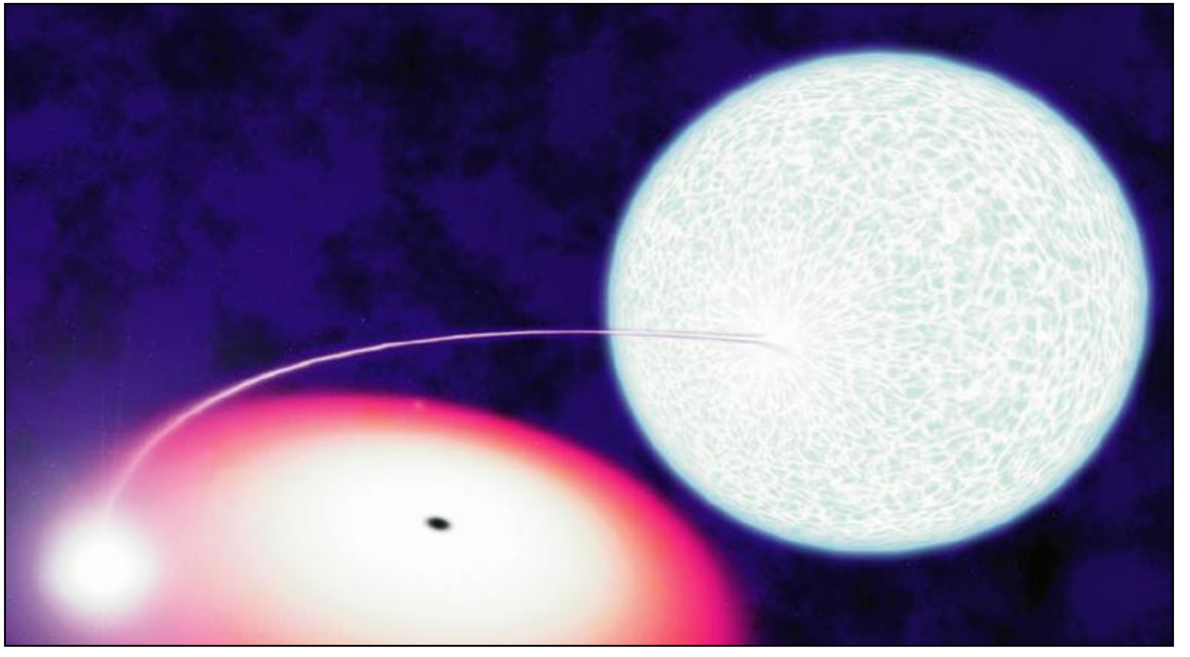
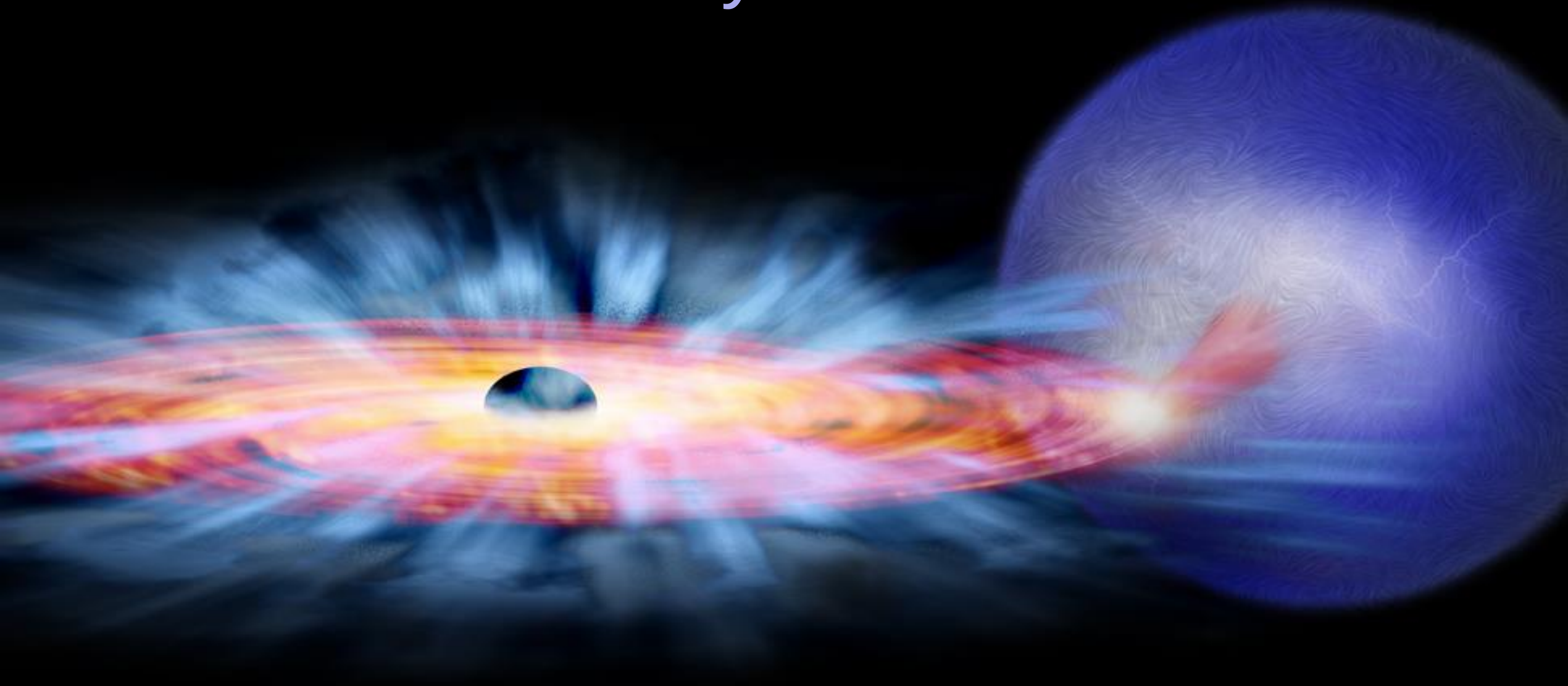
Do Black Holes exist?



• Some binaries containing compact objects of mass > 3 M_{Sun} are likely black holes.
• Gamma ray bursts may be caused by massive supernovae forming black holes.

X-ray bursts



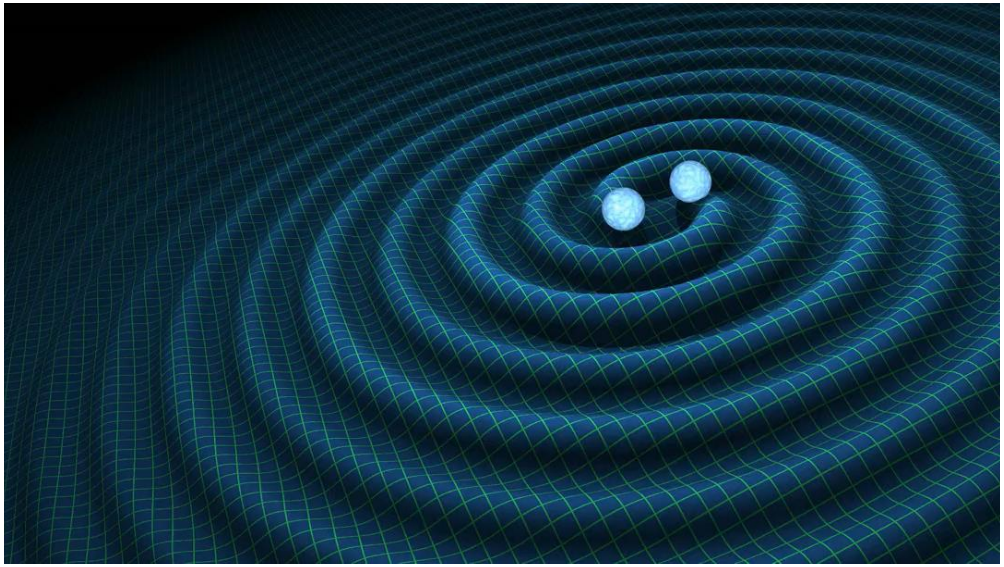
- **“X-ray binaries”** emit strong X-rays; how explained?
- The enormous gravity of a black hole heats infalling matter tremendously in an “accretion disk” which emits x-rays bursts.

1. Indirect evidence

- *Need to measure mass* of an object
  - Use orbital properties of companion.
  - Measure period and distance of orbiting companion star or gas.
- It's a black hole if it's not a star and its mass exceeds the neutron star limit (~3 M_{Sun}).

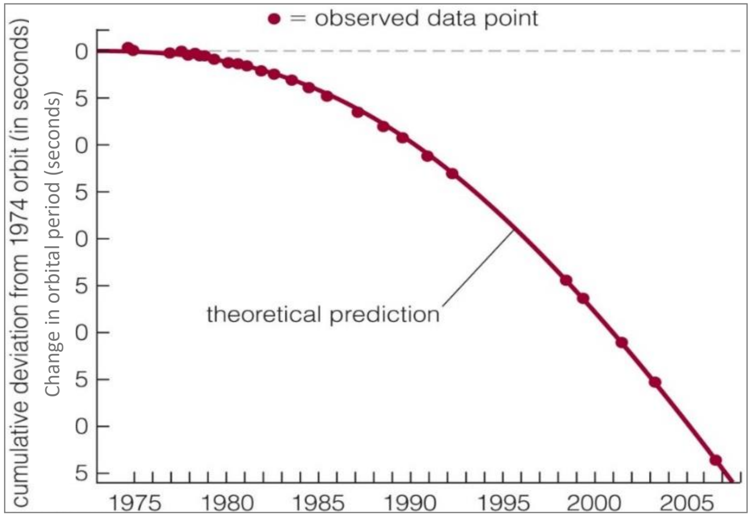
2. Gravitational Waves

Motion of massive objects generates *waves of gravity!*



Courtesy: CalTech / MIT / LIGO

- As massive objects orbit, they lose energy as gravity waves.
- Energy lost causes them to spiral closer together, shortening orbital period:



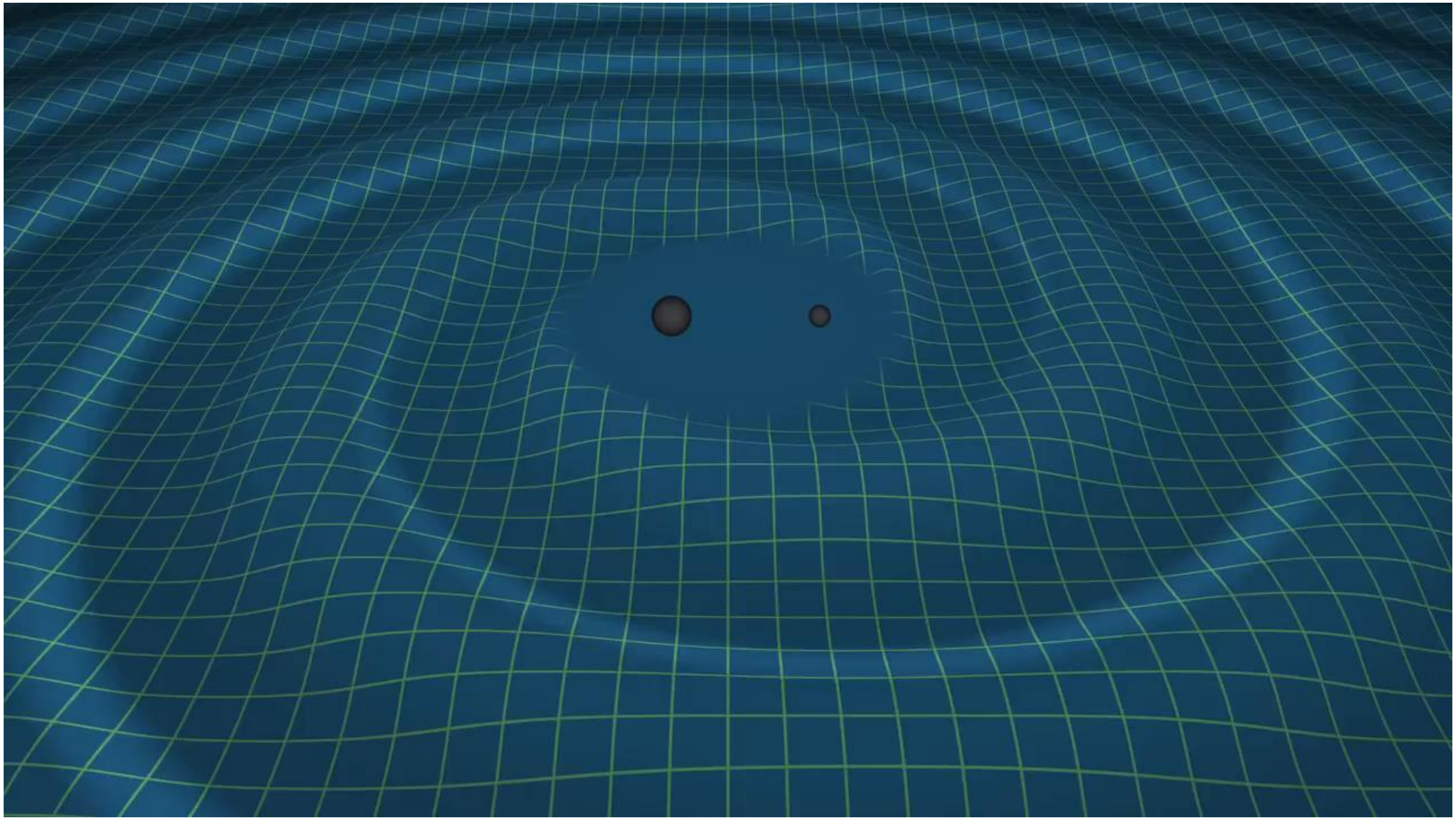
- *At merger, there's a burst of gravity waves.*
- How can we detect these?

LIGO detects gravity waves

- Gravitational waves are now detected by the **Laser Interferometer Gravitational-wave Observatory (LIGO)** detectors.
- In a fraction of a second, two black holes merge into one, converting mass to energy which is emitted as gravitational waves.

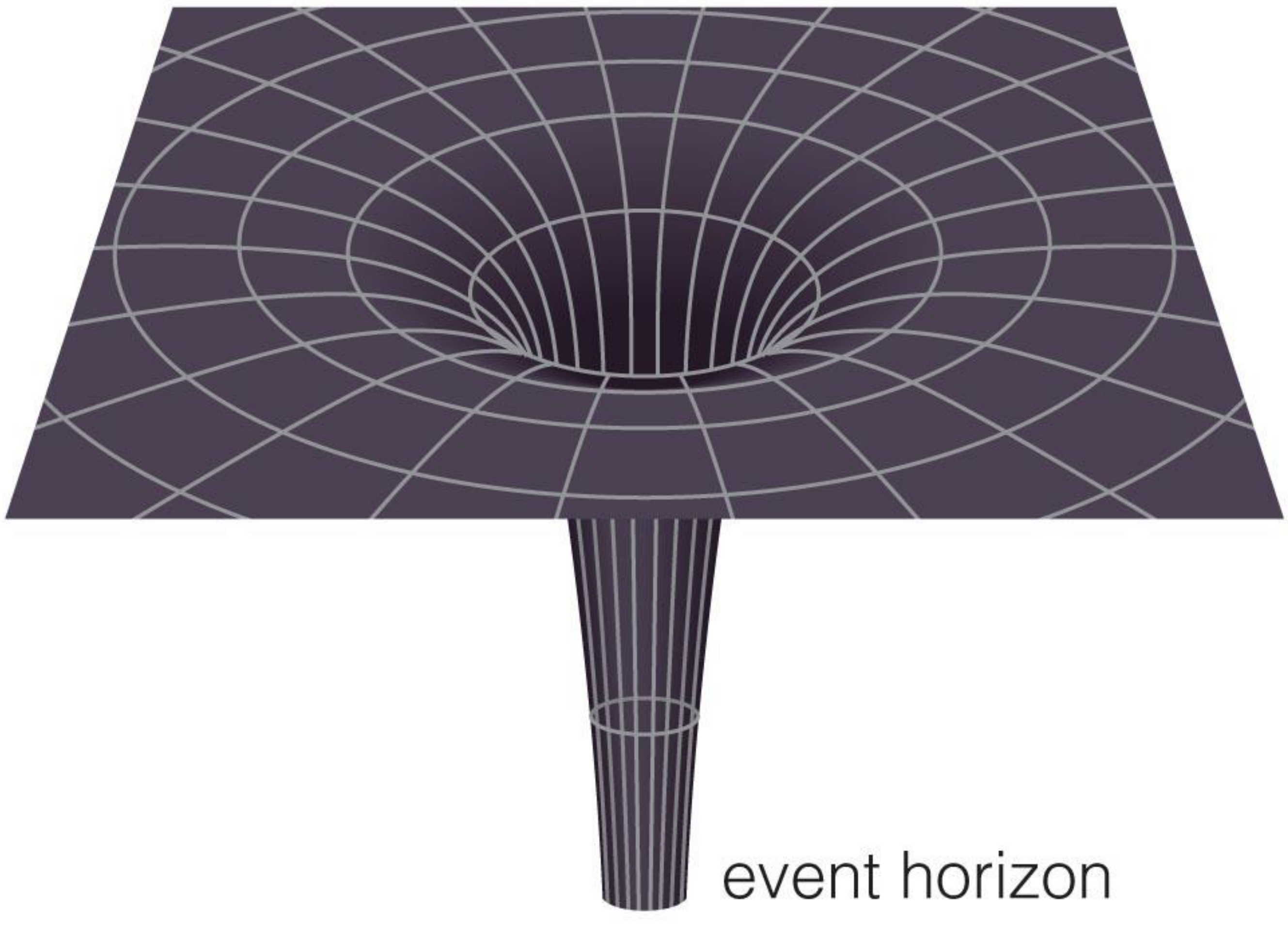
Video

Black hole merger



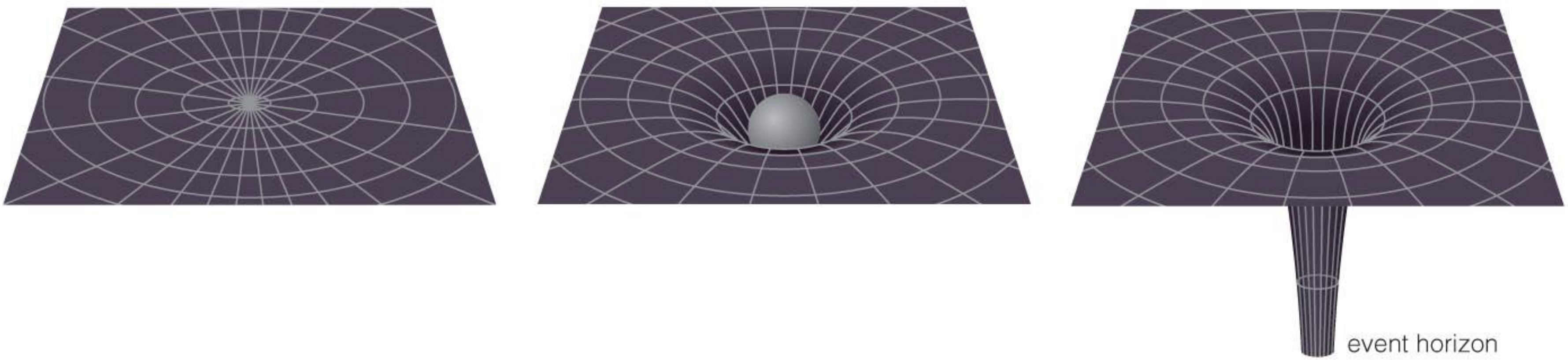
Courtesy: CalTech / MIT / LIGO

What would it be like to visit a black hole?



What would it be like to visit a black hole?

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

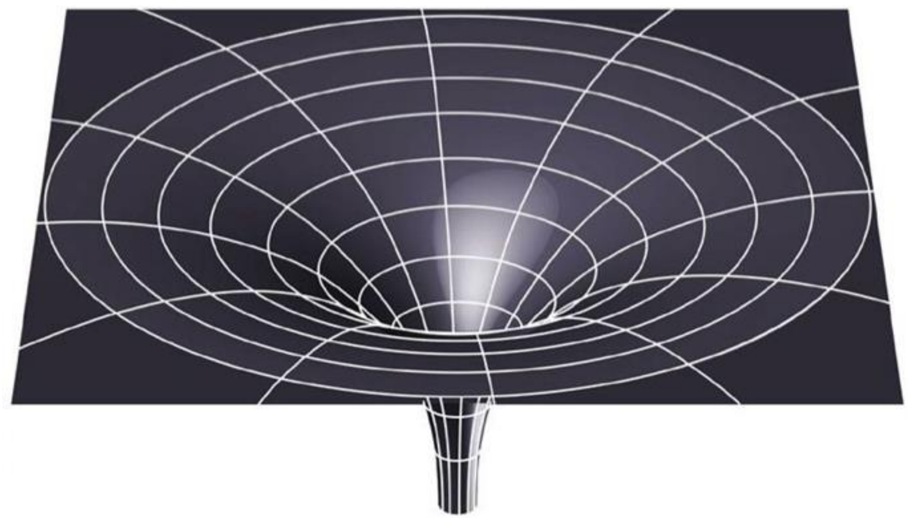


So do black holes suck everything in?

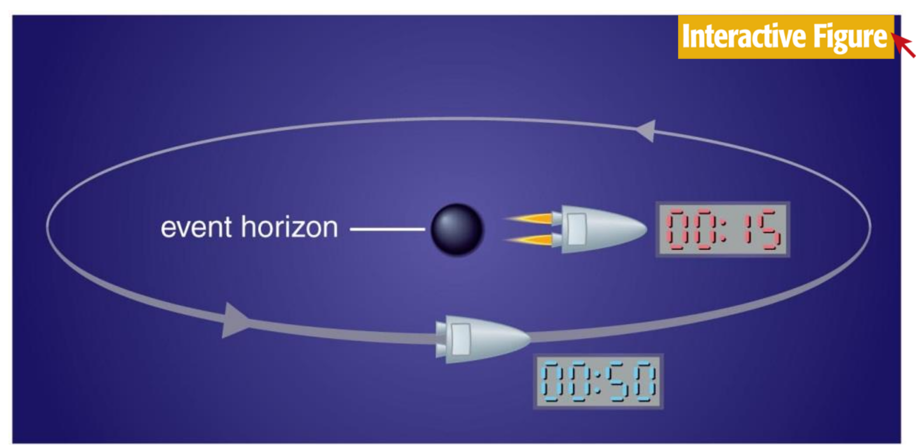
- A stellar mass black hole would be only a few miles across.
- **So, black holes don't suck** (unless you get too close!)

Relativistic effects of very strong gravity

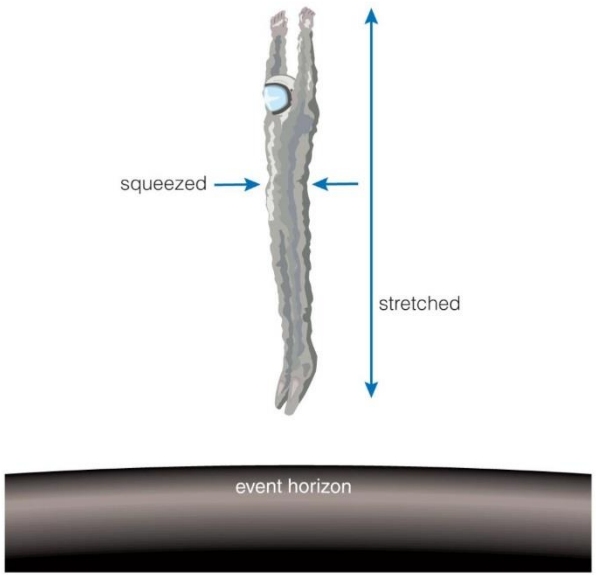
Light waves lose energy to climb out of a black hole causing a ***gravitational redshift.***



Time passes more slowly near the event horizon.



Falling into a black hole



Falling into a black hole

- Tidal forces near the event horizon of a $3M_{\text{Sun}}$ black hole would stretch matter enormously.
- But tidal forces would be gentler near a supermassive black hole because its radius is much bigger.
- The scientific name for this stretching is “spagettification.”

What have we learned?

Begin 3 minute review

What have we learned?

What is a black hole?

A black hole is a massive object whose gravity is so strong that the **escape velocity exceeds the speed of light**.

Do black holes really exist?

Some binaries have x-ray bursts caused by supernovae forming black holes.

We can use NVKTL to find mass, compare to luminosity.

We can now detect gravity waves from black hole mergers.

What would it be like to visit a black hole?

You can orbit a black hole like a star —black holes don’t suck!

Near event horizon, time slows down, emitted light is gravitationally red-shifted, and tidal forces are strong.