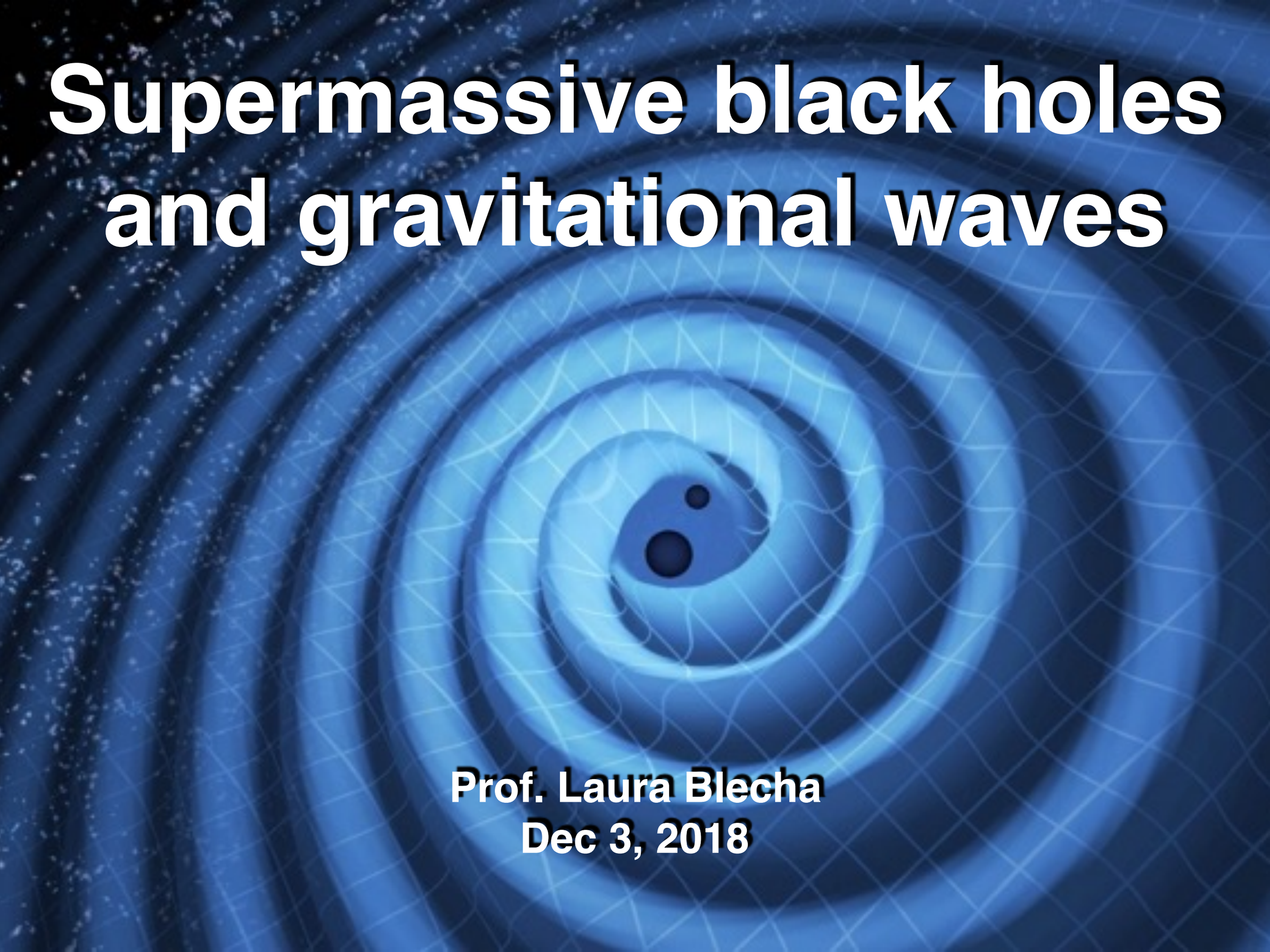
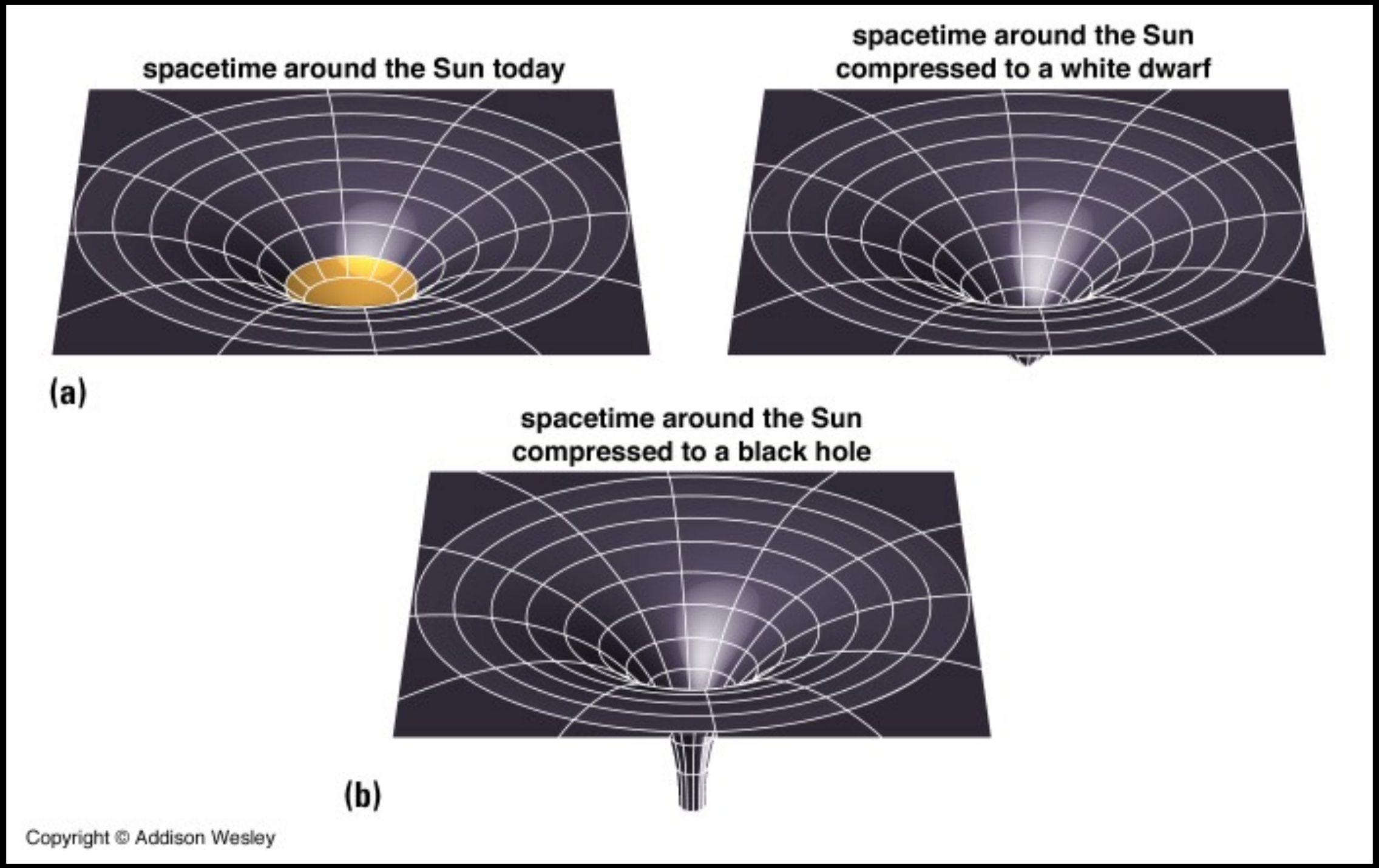
Supermassive black holes and gravitational waves



Prof. Laura Blecha

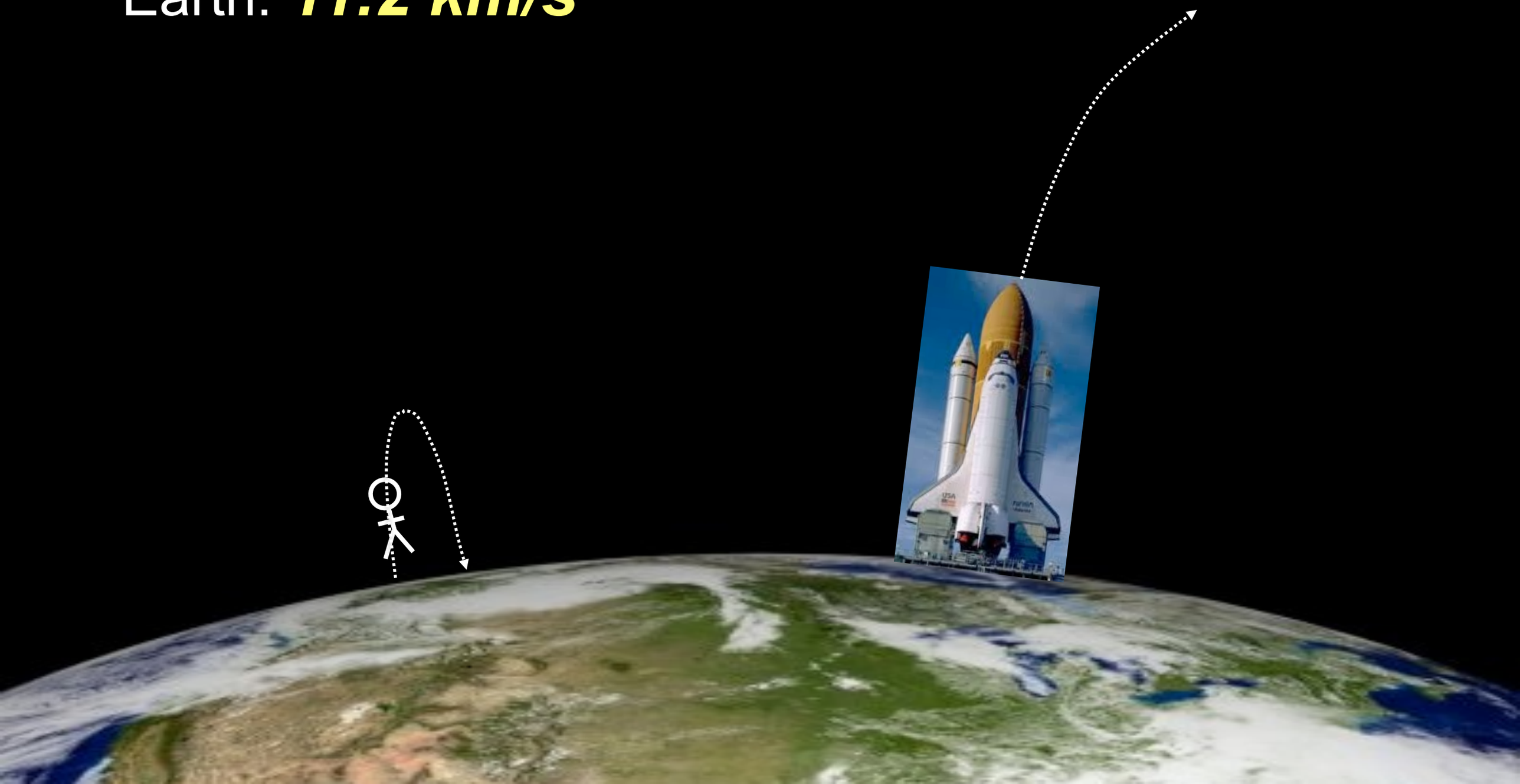
Dec 3, 2018

What is a Black Hole?



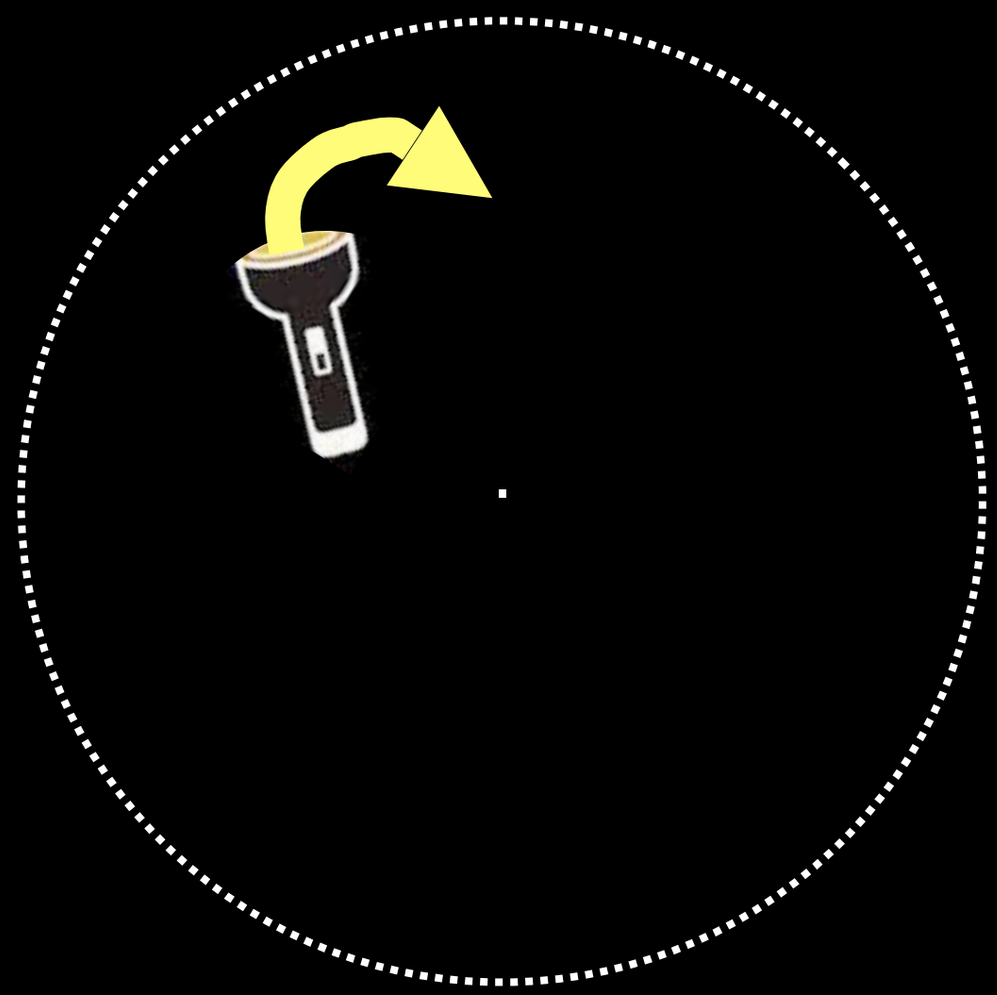
What is a Black Hole?

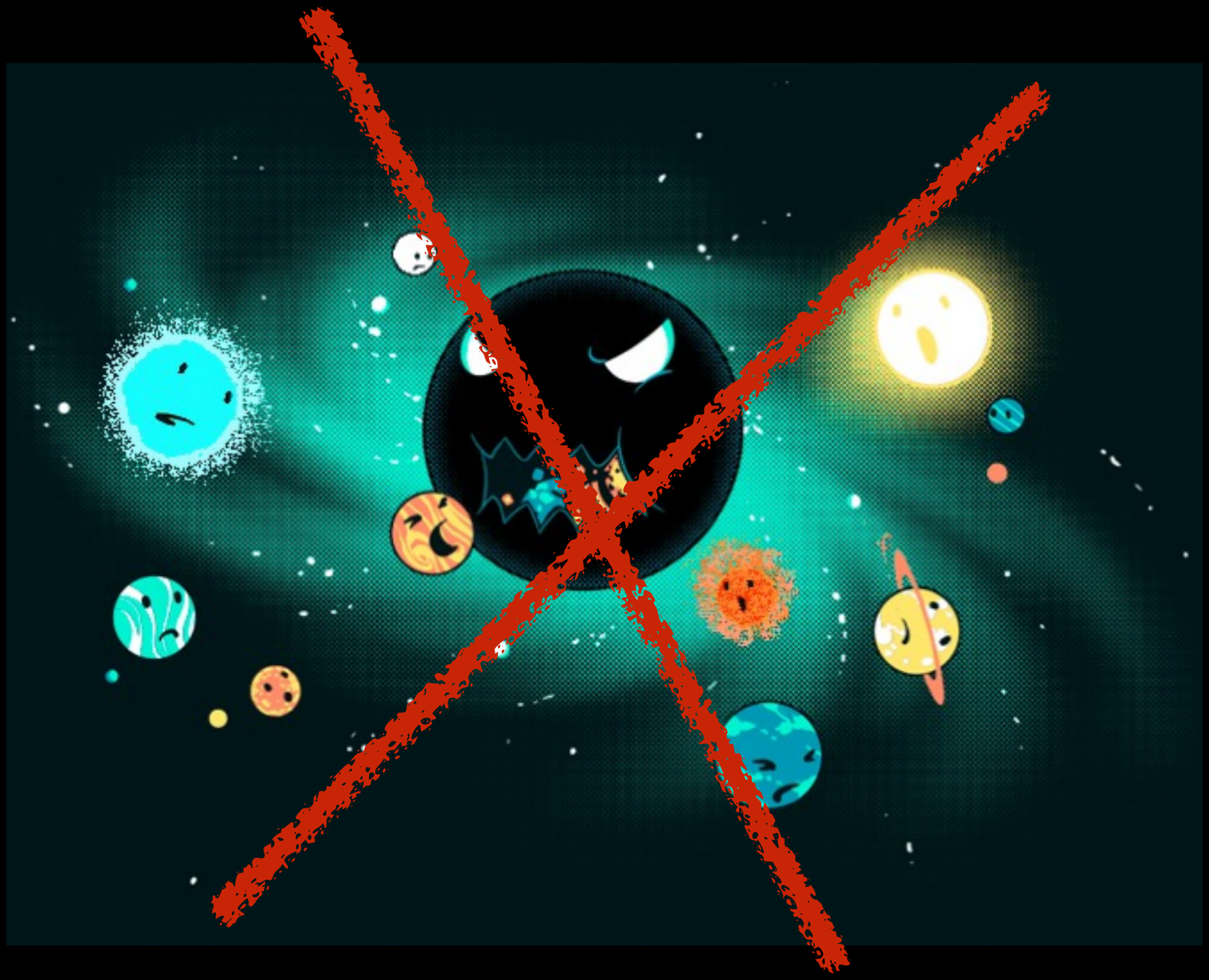
Escape speed from the surface of Earth: ***11.2 km/s***

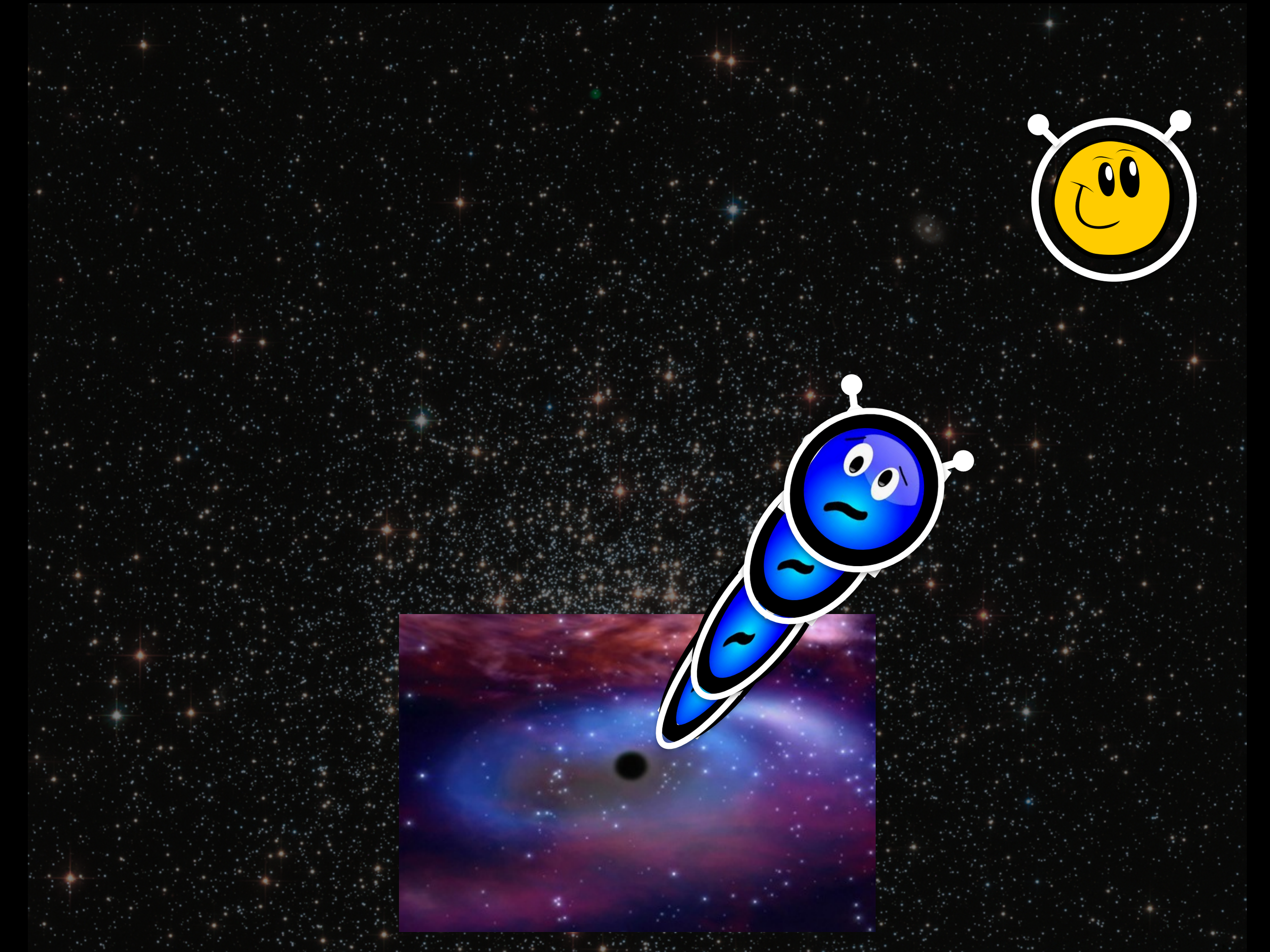


What is a Black Hole?

Escape speed from the "***event horizon***"
of a black hole:
the speed of light! (300,000 km/s)







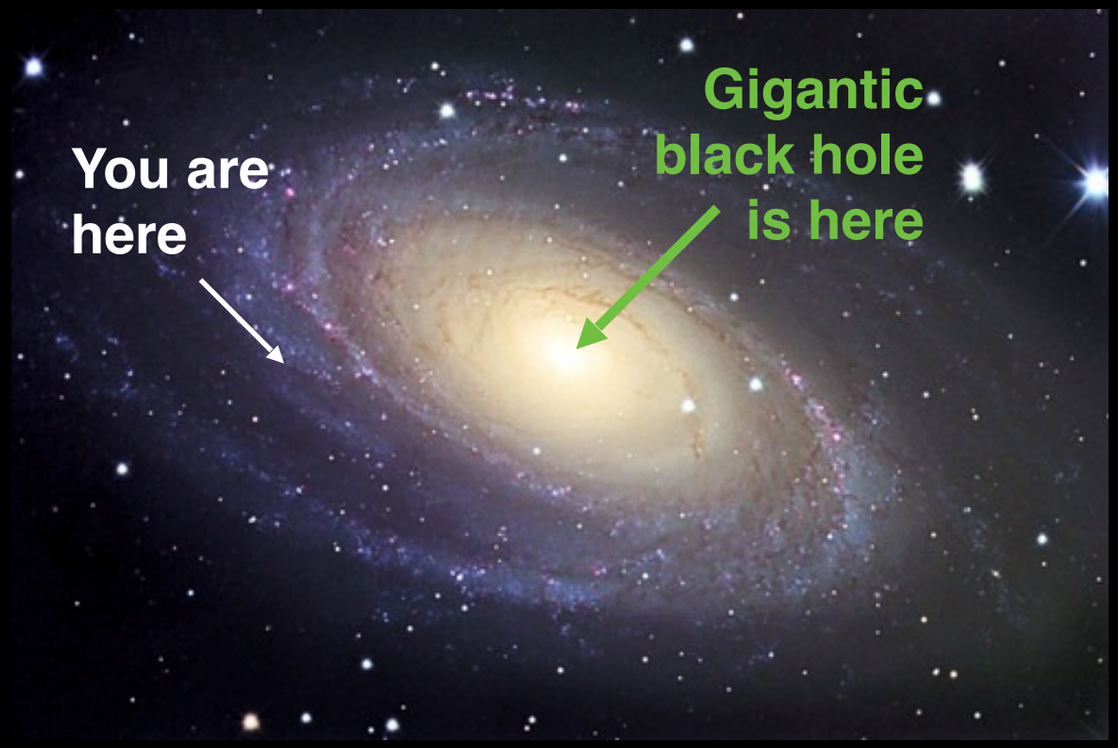
Know your black holes

“Supermassive”:

- Form early in the Universe… somehow
- Live at the centers of galaxies
- ***Millions to billions*** of times the mass of the Sun

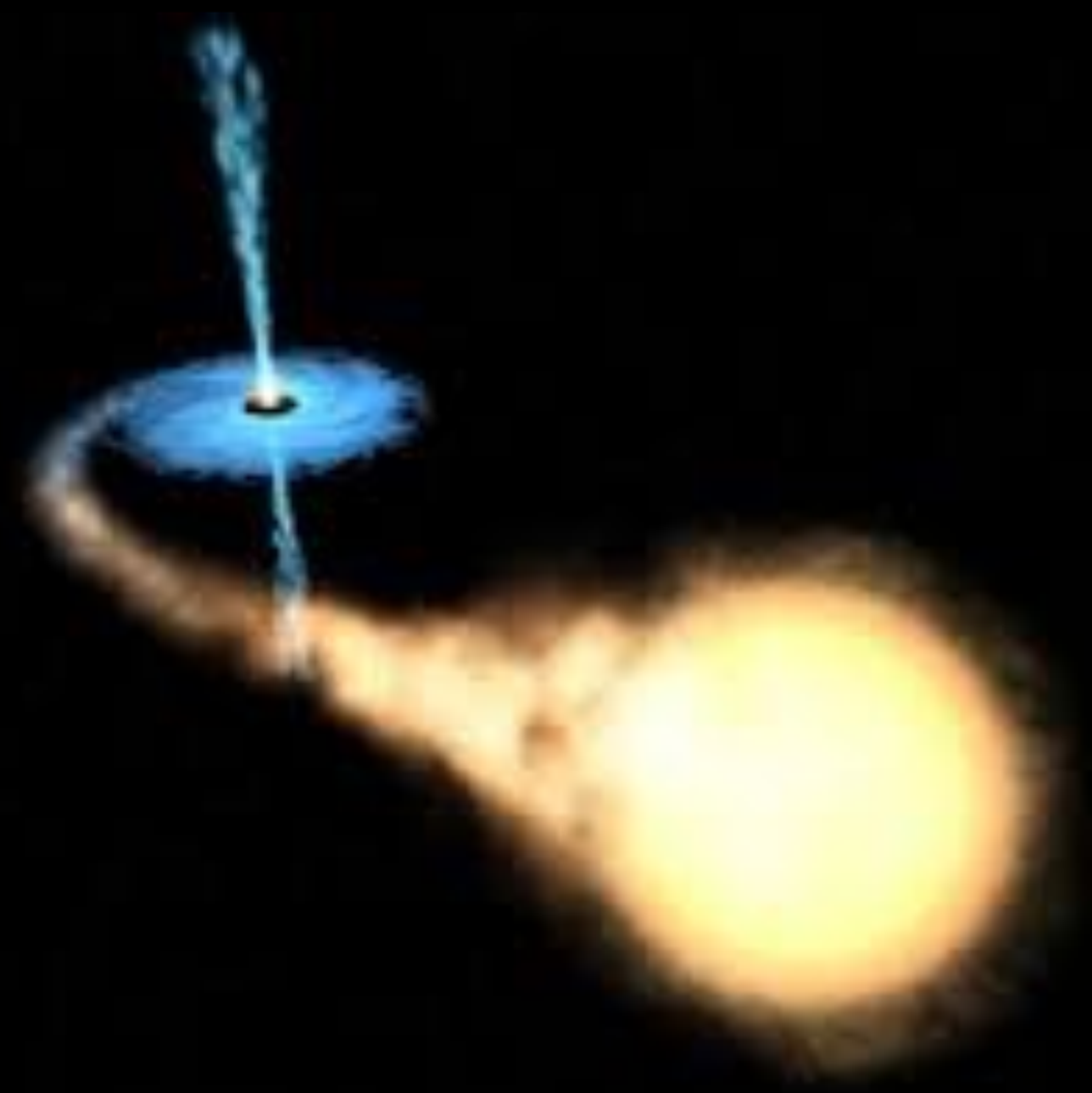
“Stellar mass”:

- Form after massive stars explode
- About 10x the mass of the Sun



How do we know black holes exist?

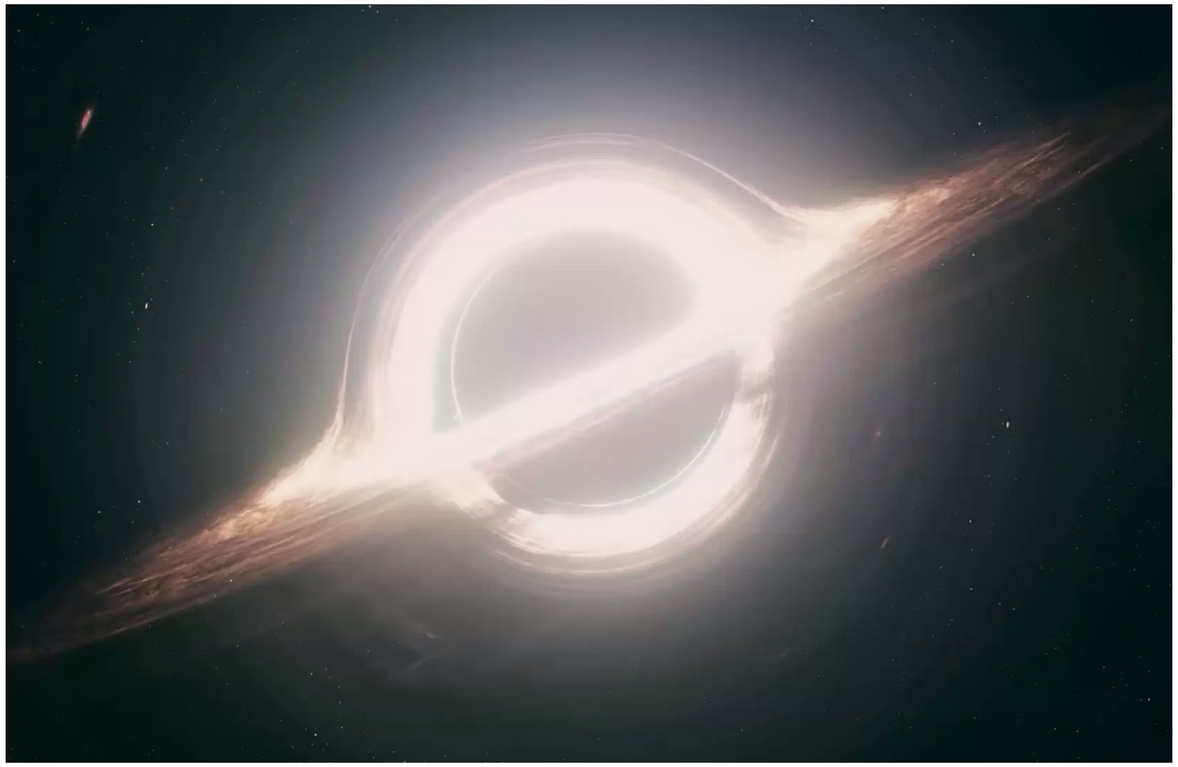
How do we know black holes exist? (part 1)



Stellar mass black hole in a ***binary*** with a companion star

How do we know black holes exist? (part 1)

- Event horizon of a supermassive BH is ***10 billion times smaller*** than the galaxy's size
- Infalling gas streams ***never manage a "direct hit"*** – causes a disk of gas to form around the BH
- Friction heats up the gas; ***huge amounts of energy released*** cause the gas to shine brightly
- Rapidly-accreting BHs ("quasars") can be ***as luminous as an entire galaxy***

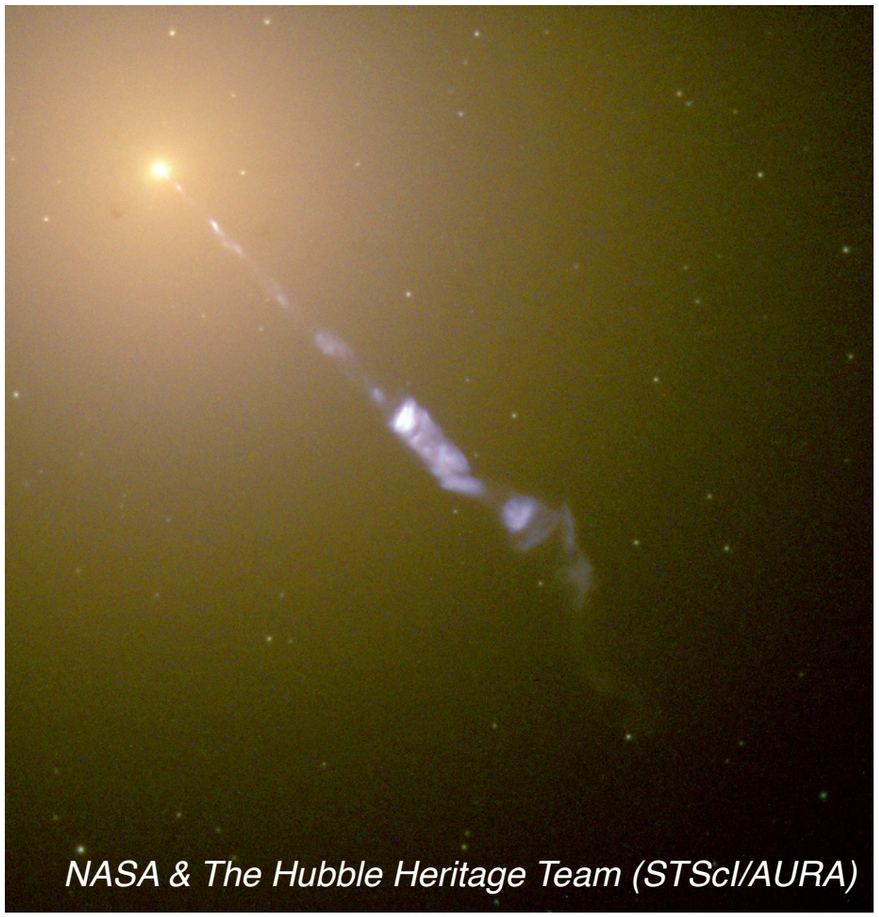


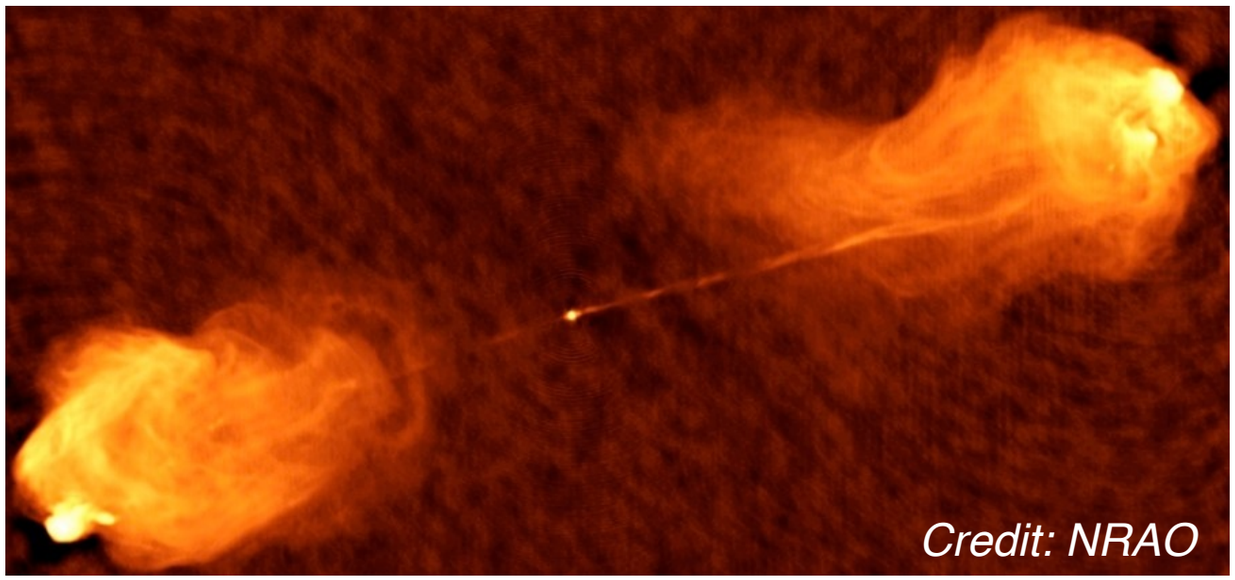
Radiative Power of Black Holes

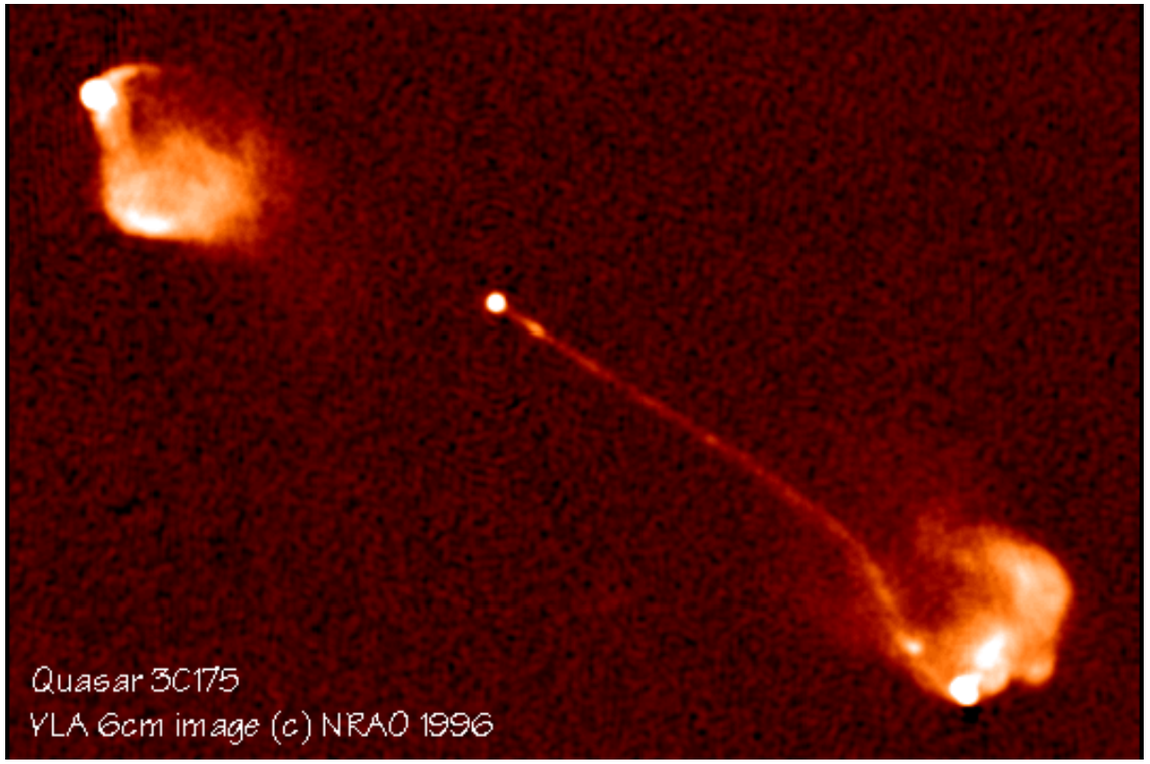
- **100 Watts:** Light bulb
- **10^9 Watts:** Largest power station
- **1.21 GigaWatts:** Flux Capacitor
- **10^{15} Watts:** Most powerful laser
- **10^{24} Watts:** Tsar Bomba (50 Megatons)
- **10^{26} Watts:** Sun (10^{17} hits Earth)
- **10^{32} Watts:** **Stellar-mass BH Binaries**
- **10^{37} Watts:** All stars in a galaxy **OR 1 active supermassive black hole**
- **10^{45} Watts:** Supernova

Active Black Holes: What We See

- Usually, just points of light like stars, but with different spectra
- Sometimes we see powerful jets


NASA & The Hubble Heritage Team (STScI/AURA)


Credit: NRAO



The supermassive black hole in our Milky Way galaxy

(or, how do we know black holes exist? part 2)

Credit: ESO

What is a Galaxy?

Made up of ***dark matter, stars, gas, dust (& a central supermassive BH)***

Our galaxy is the ***Milky Way***

How many stars?

In the Milky Way, ***about 60 billion***

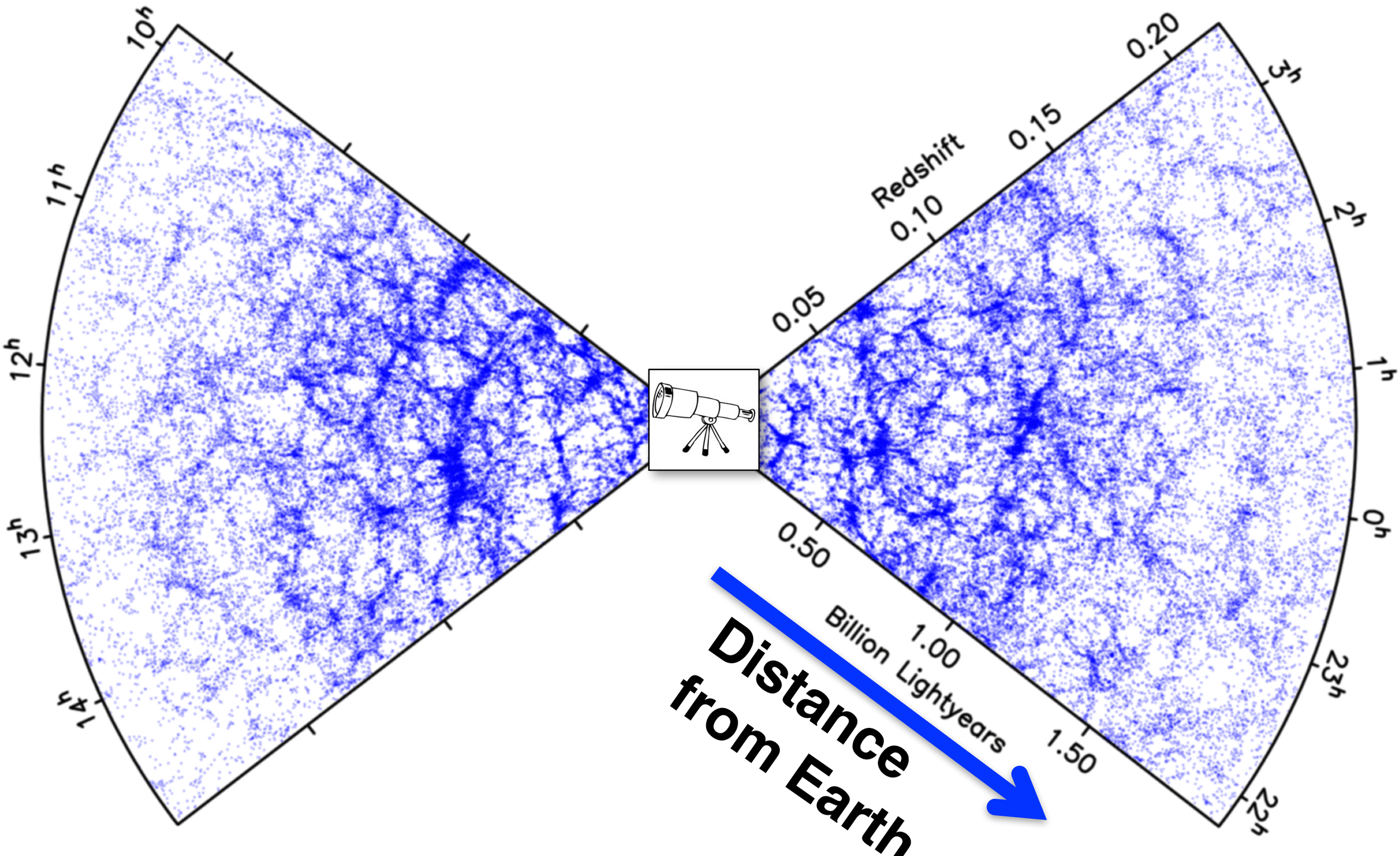
Distance from Sun to supermassive BH at Galaxy center: ***24,000 light years***

NGC 3521; Credit: ESO

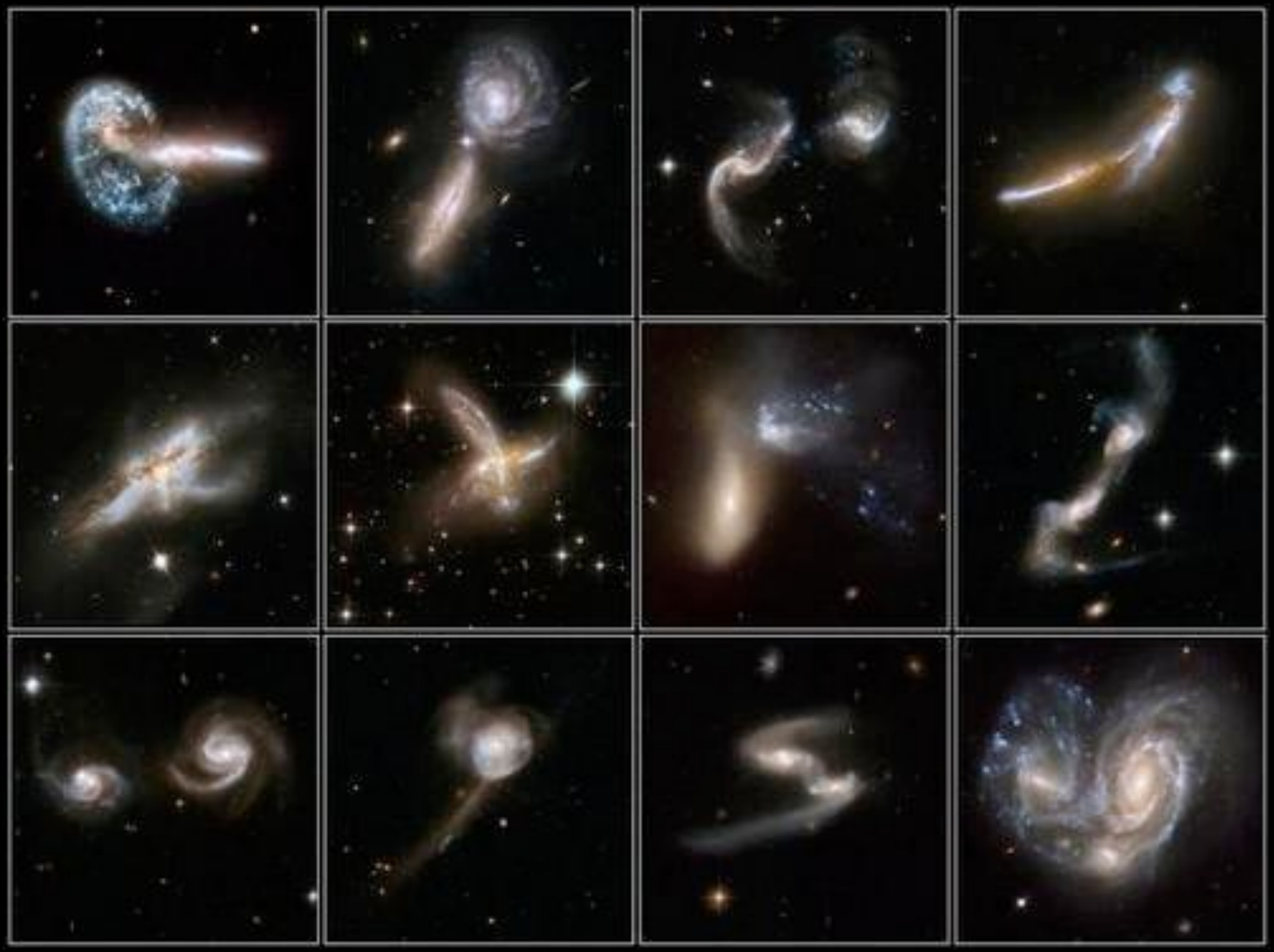
Click here to see a simulation of dark matter evolution in the Millennium II simulation:
https://wwwmpa.mpa-garching.mpg.de/galform/millennium-II/Movies/msII_hires_fast.mp4

Click here to see a simulation of dark matter and gas evolution in the Illustris Simulation:
http://www.illustris-project.org/movies/illustris_movie_cube_sub_frame.mp4

Large-scale structure in the Universe

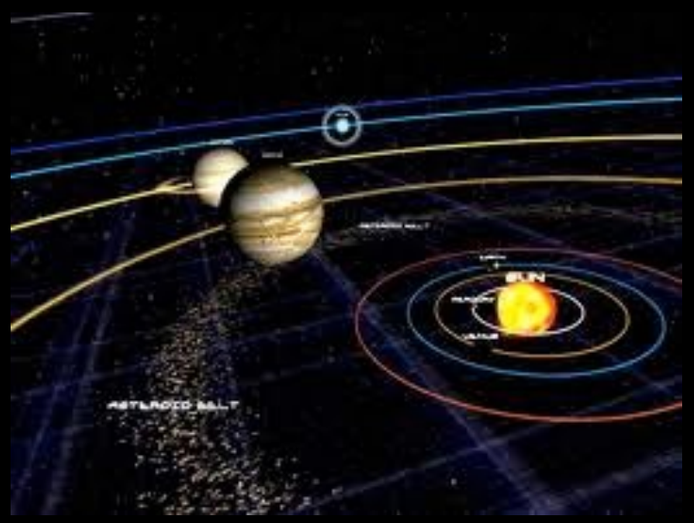


Sometimes, galaxies collide!



The Fate of the Milky Way

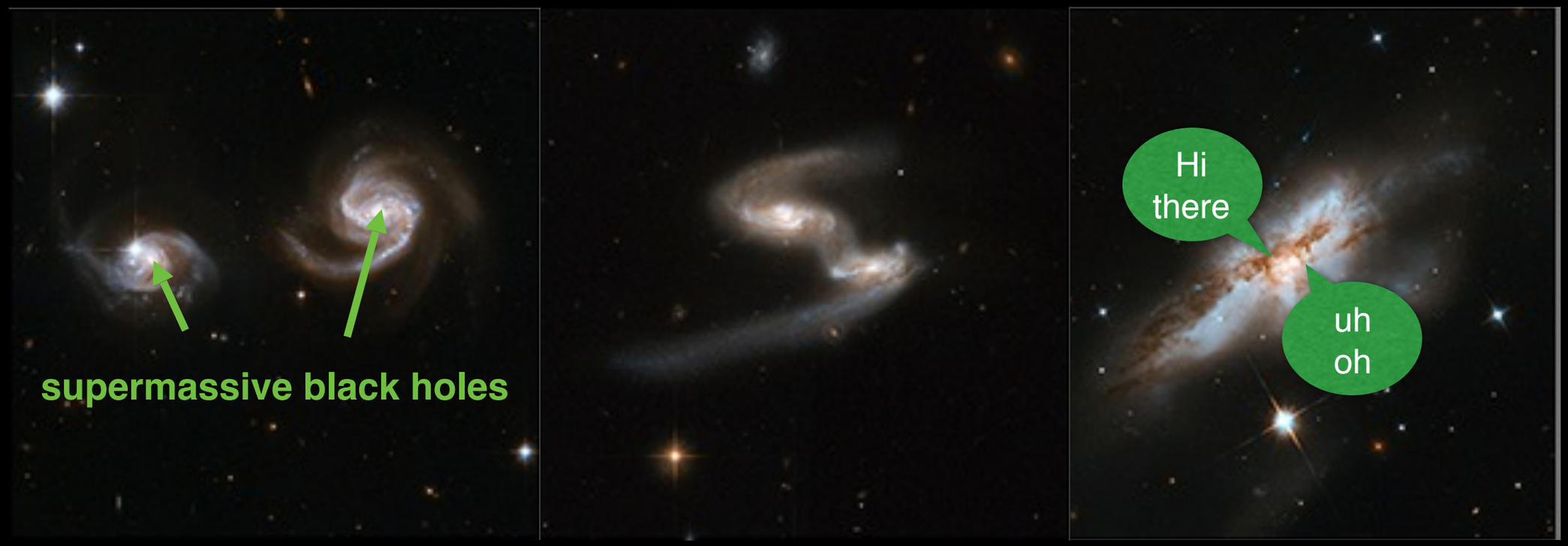
- ***The bad news***: the Milky Way will begin to **merge** with Andromeda in about 3 billion years
- ***The good news***: stars virtually ***never*** collide during galaxy mergers, so our solar system won't be destroyed
- ***The other bad news***: the Sun is getting brighter as it ages, so Earth will be uninhabitable by then (in 1-2 billion years)

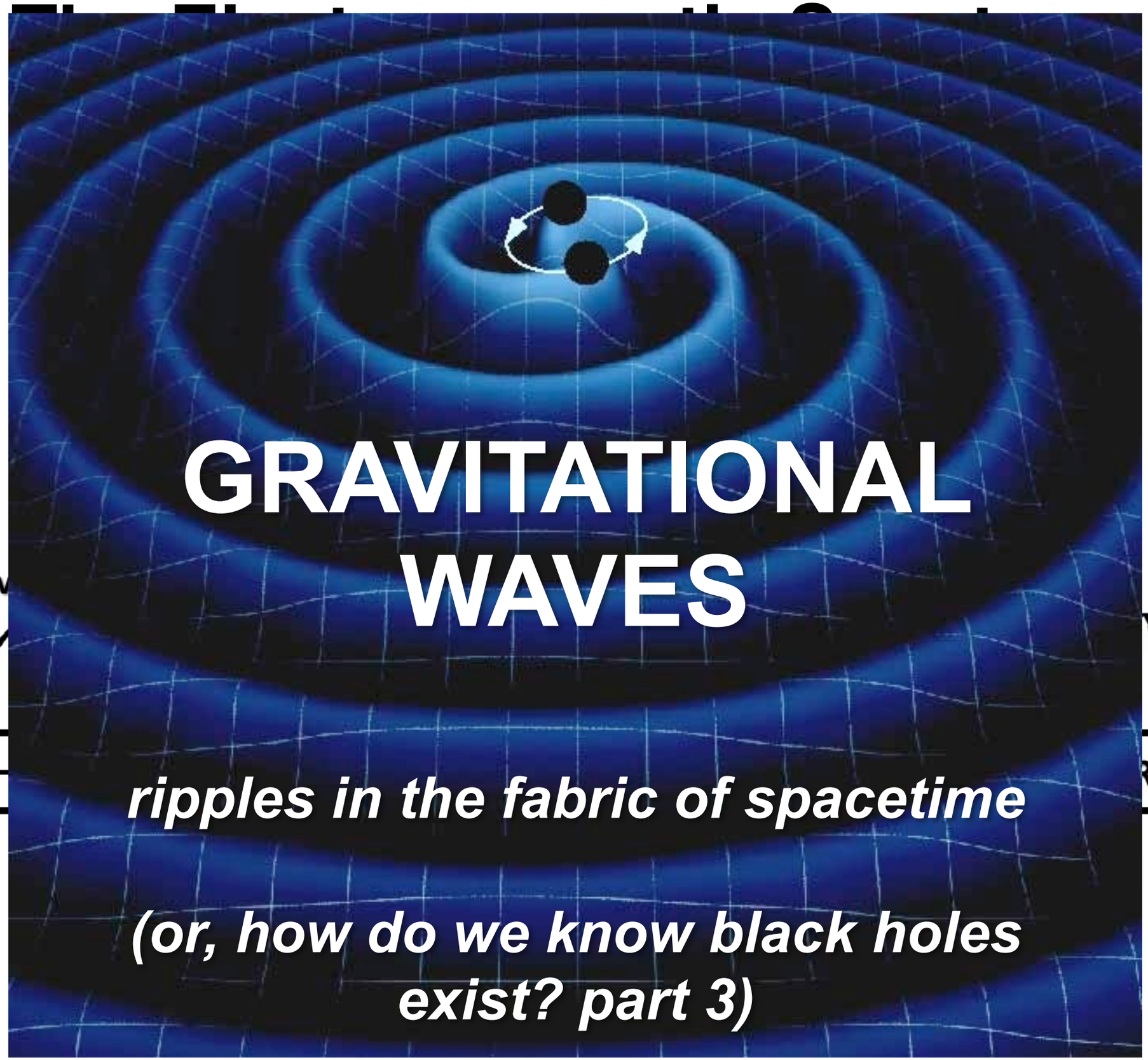


Black Hole Collisions

Many stars are “fraternal twins” ***(binaries)***

Galaxy mergers cause ***supermassive*** black hole collisions

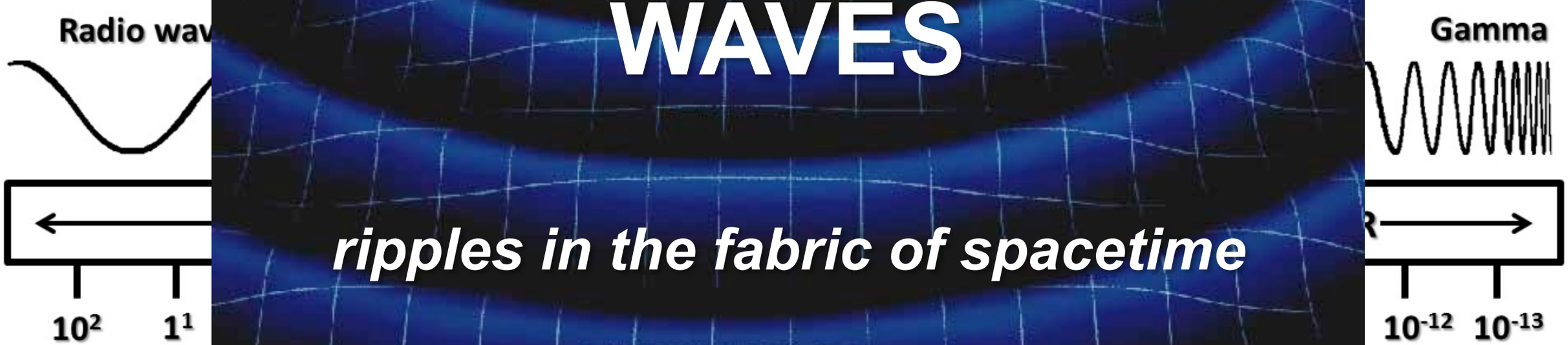




GRAVITATIONAL WAVES

ripples in the fabric of spacetime

(or, how do we know black holes exist? part 3)

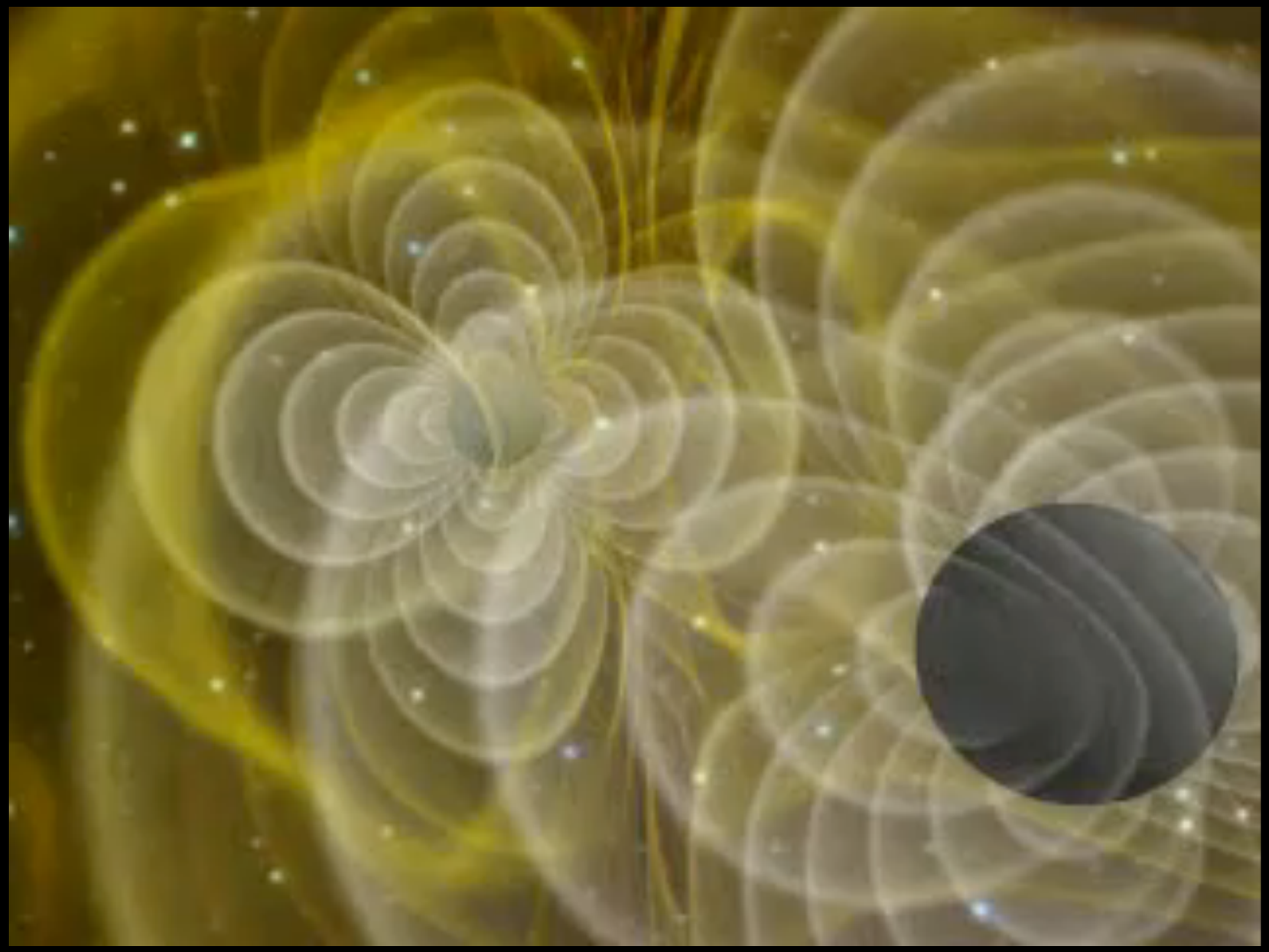


Gravitational Waves

% deformation of
Einstein's face: ≈ 50 %
(sorry, Einstein)

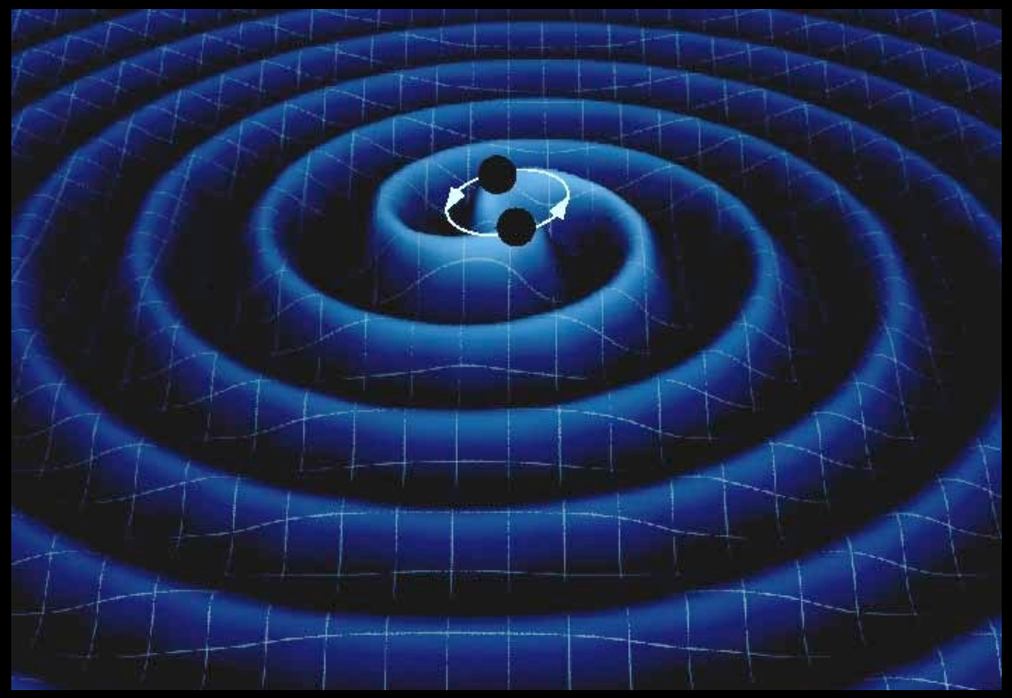
% deformation on Earth by
gravitational waves from black
hole merger:
≈ 0.0000000000000000001 %

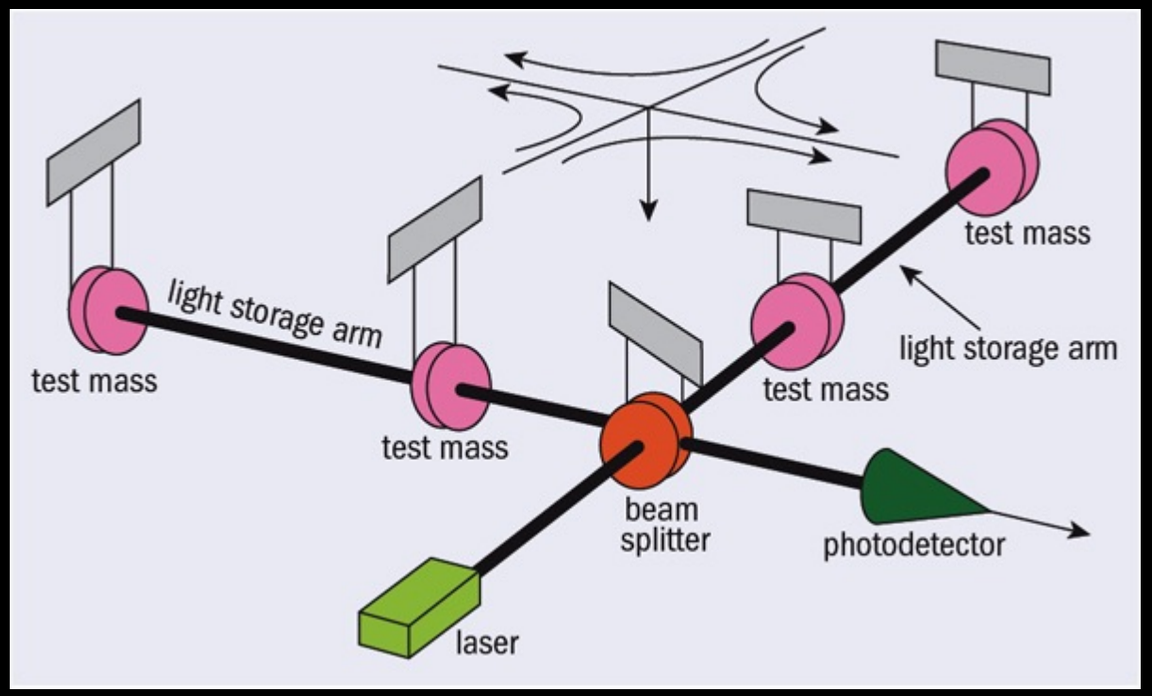
Gravitational waves from a black hole merger

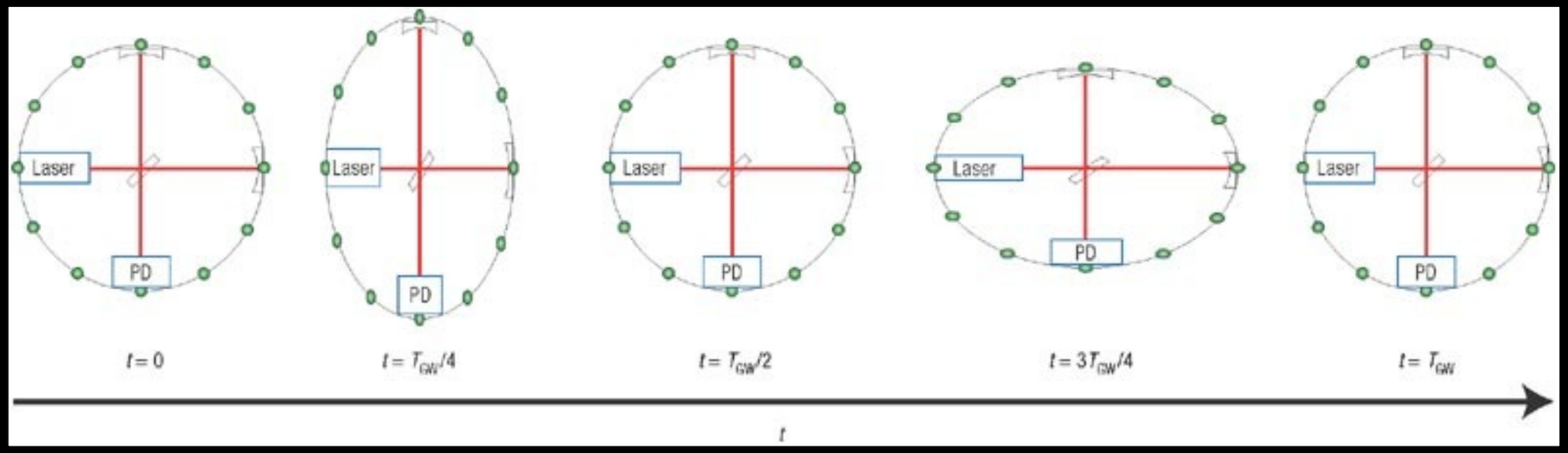


Animation credit: Eric Henze
http://www.nasa.gov/vision/universe/starsgalaxies/gwave.html

Detecting gravitational waves from black hole collisions





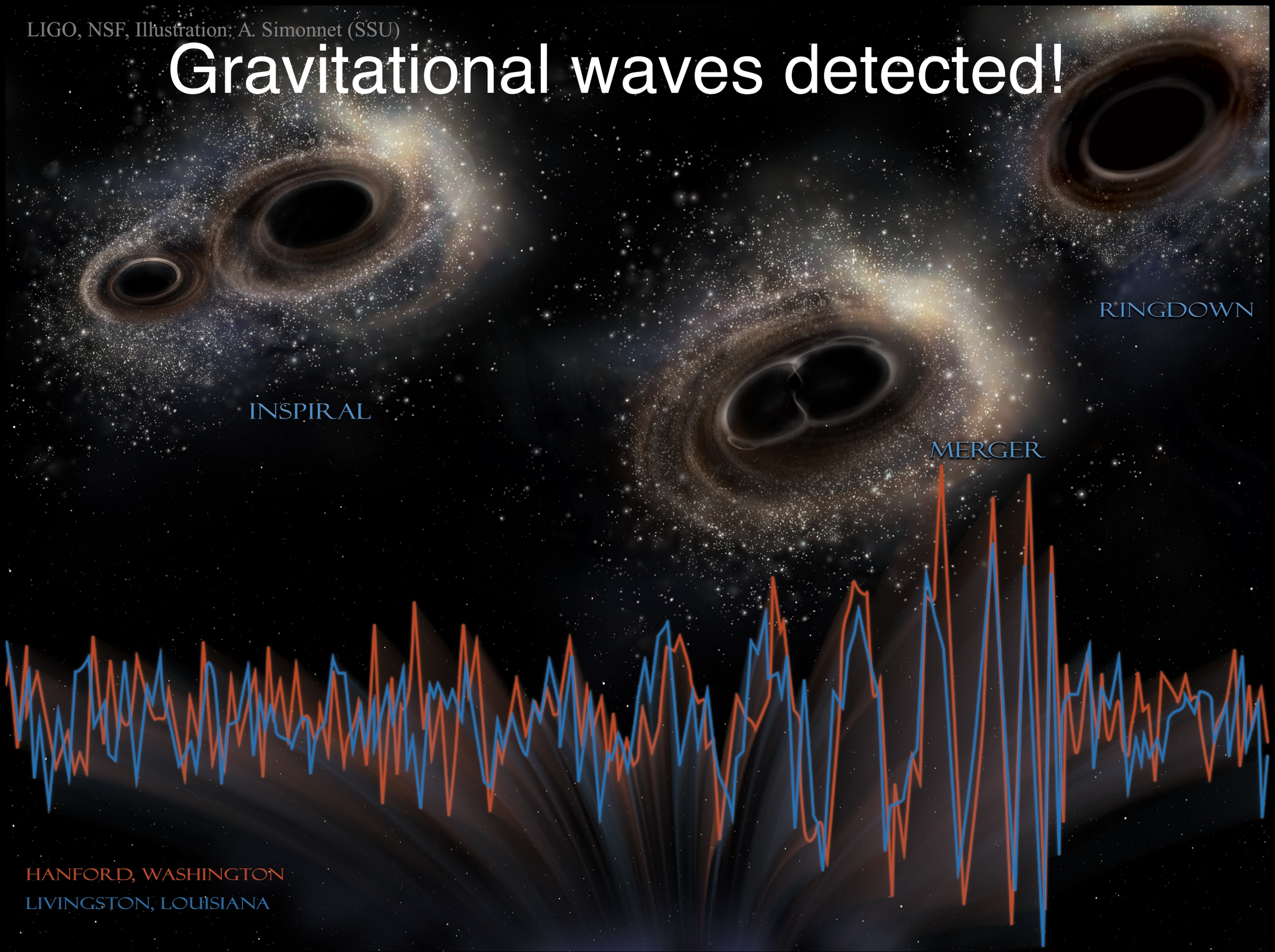


Detecting gravitational waves from black hole collisions

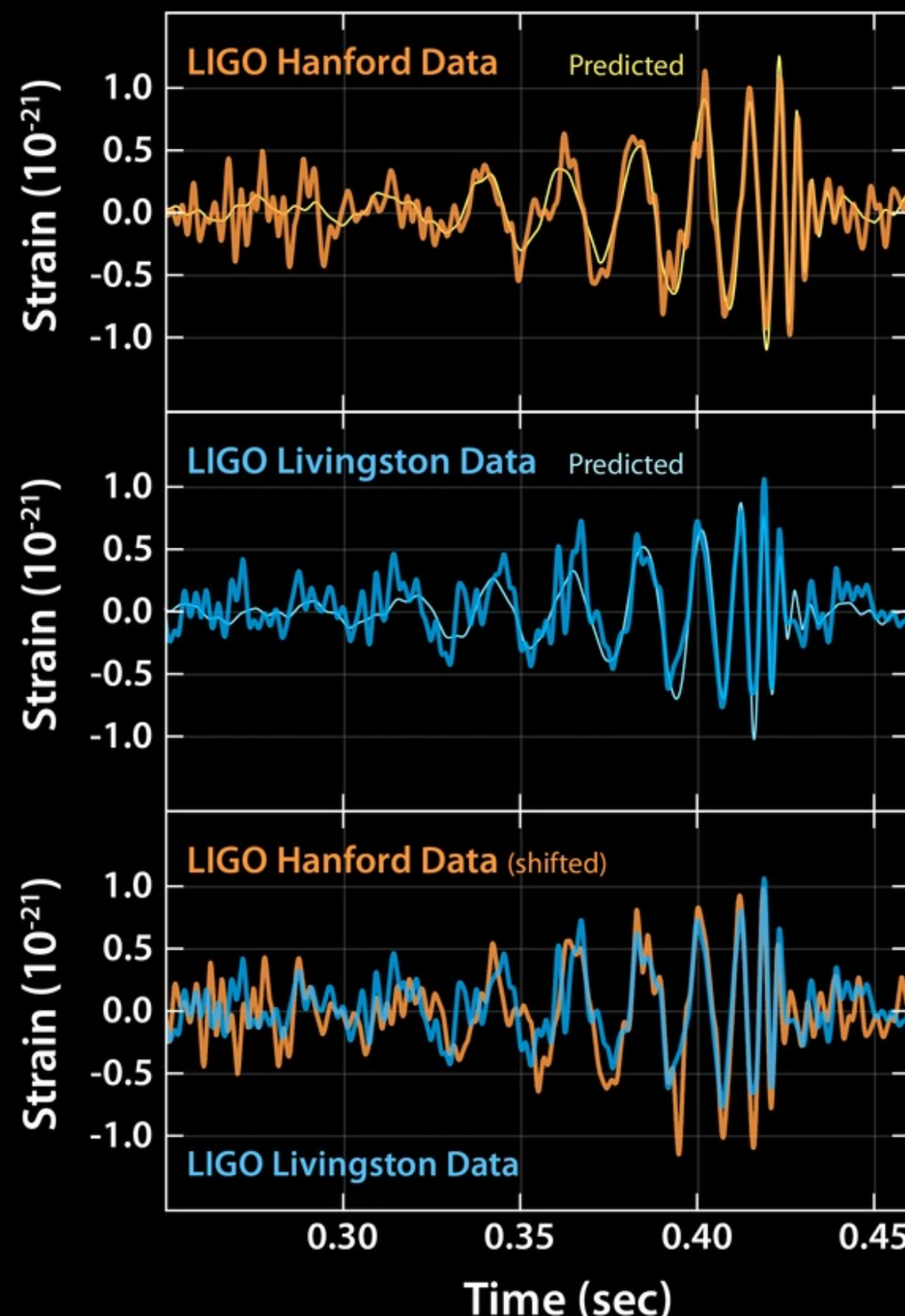
LIGO:

Laser Interferometer Gravitational-wave Observatory

Gravitational waves detected!



Gravitational waves detected!



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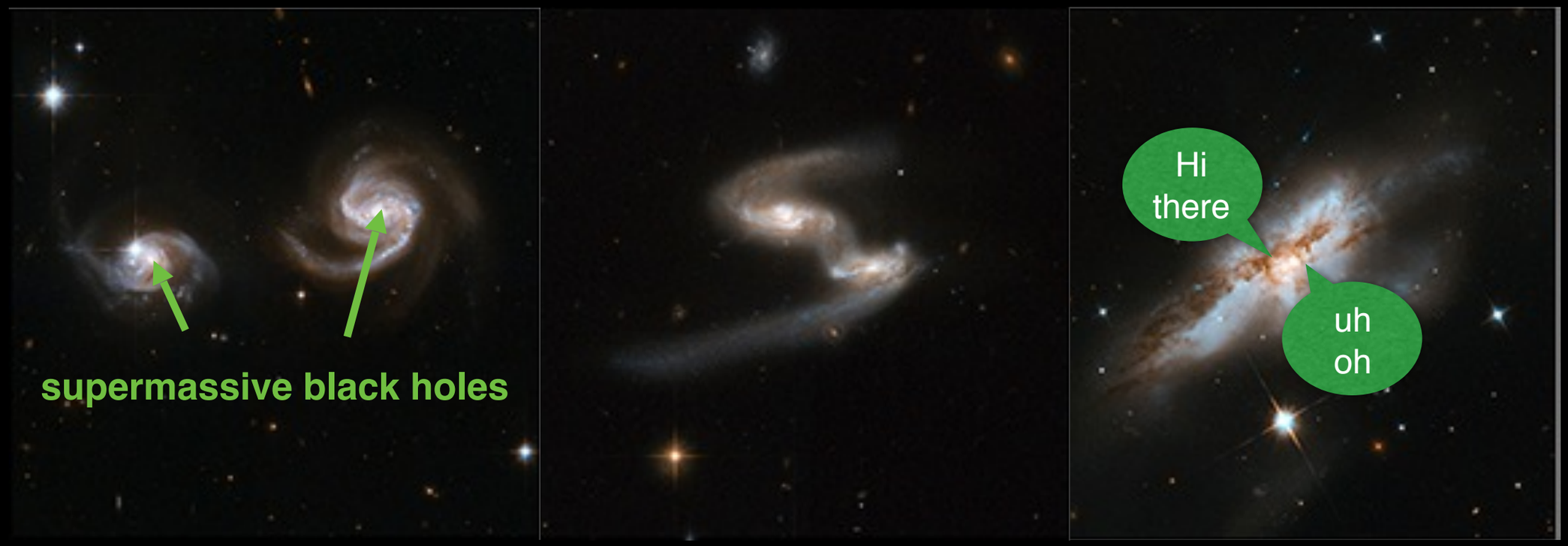
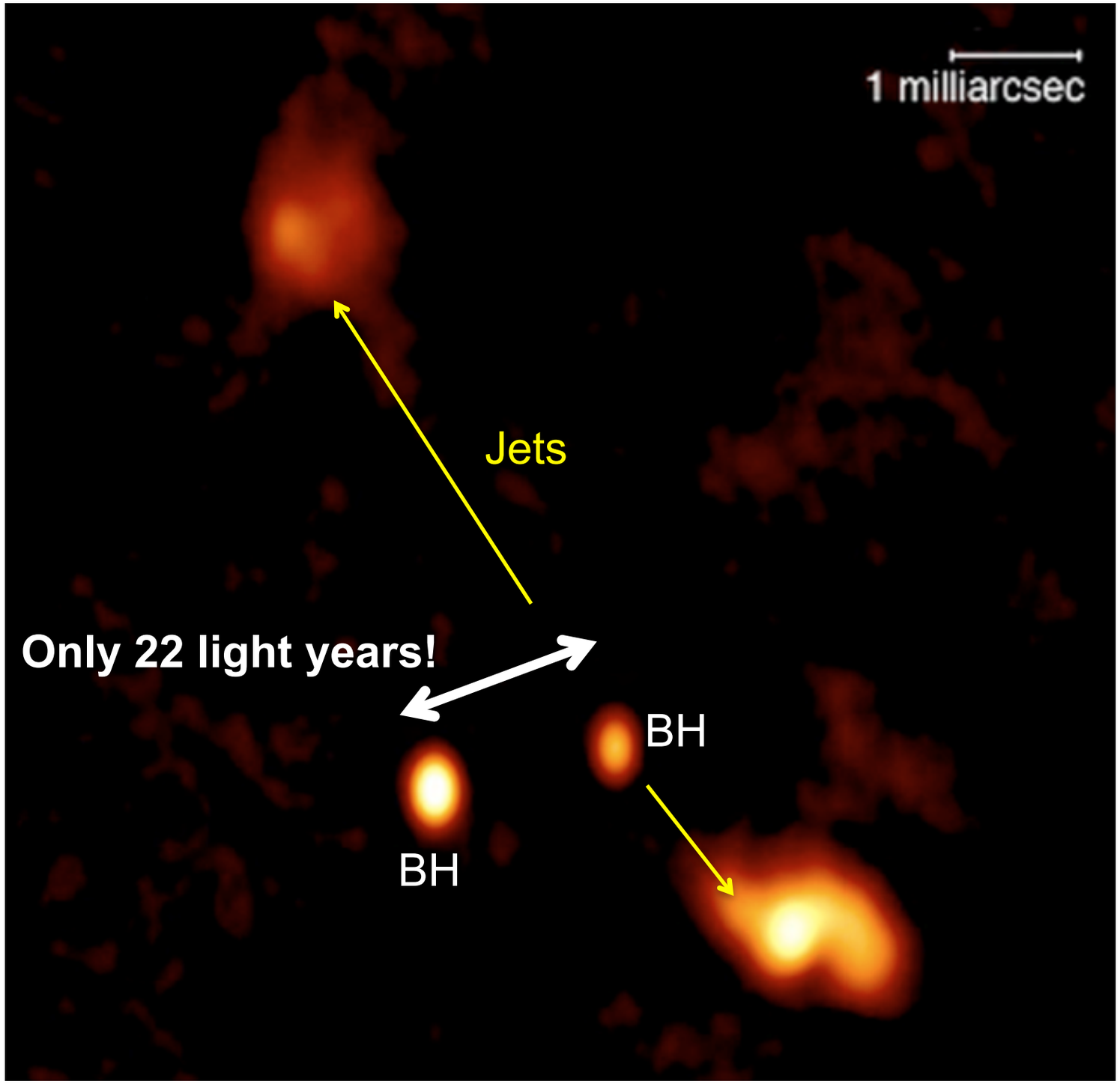


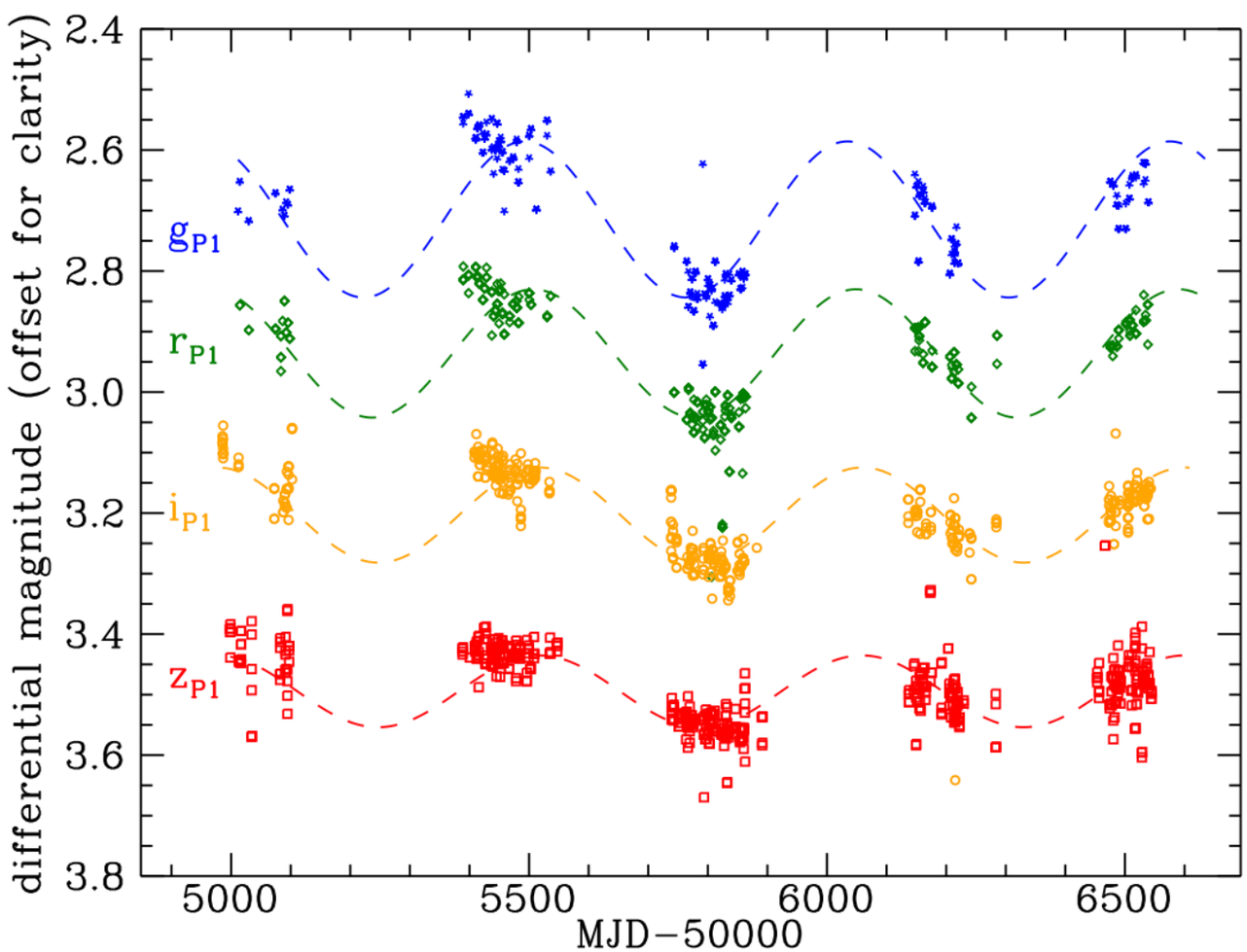
A future supermassive black hole collision!



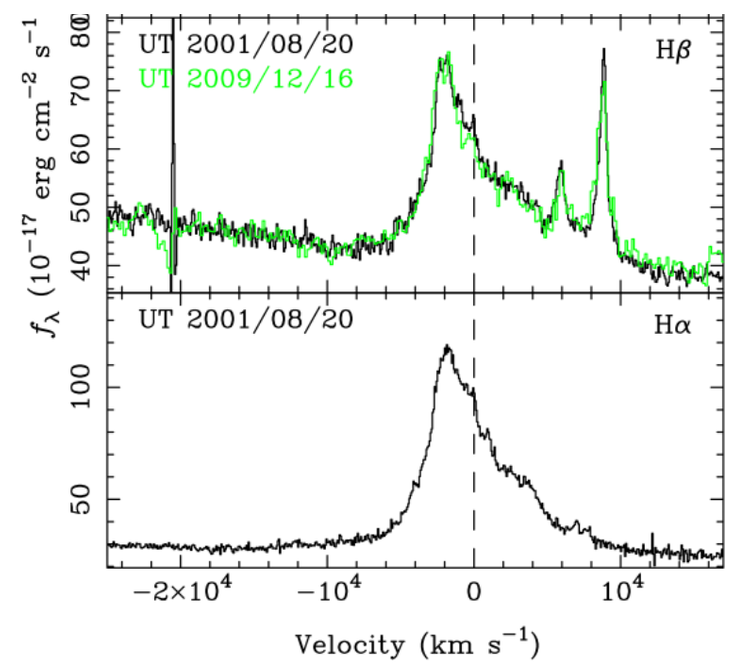
Other supermassive black hole binary candidates

Periodic variability

Liu et al. 2015

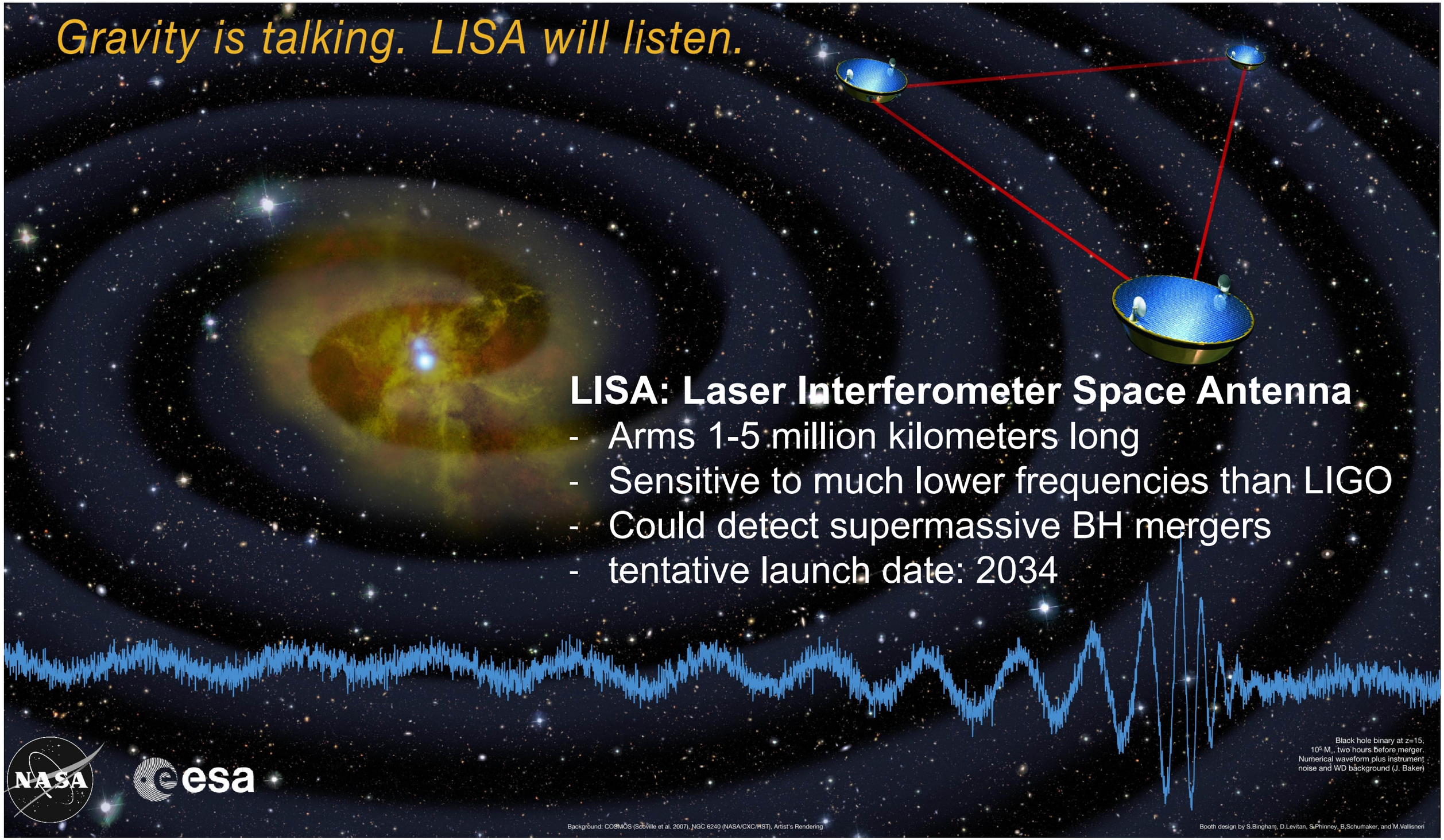


Offset or variable broad emission lines

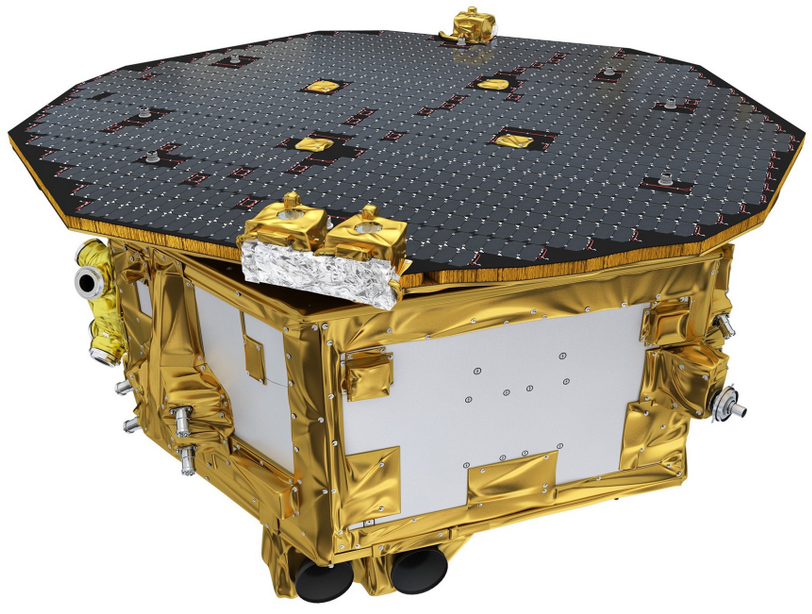


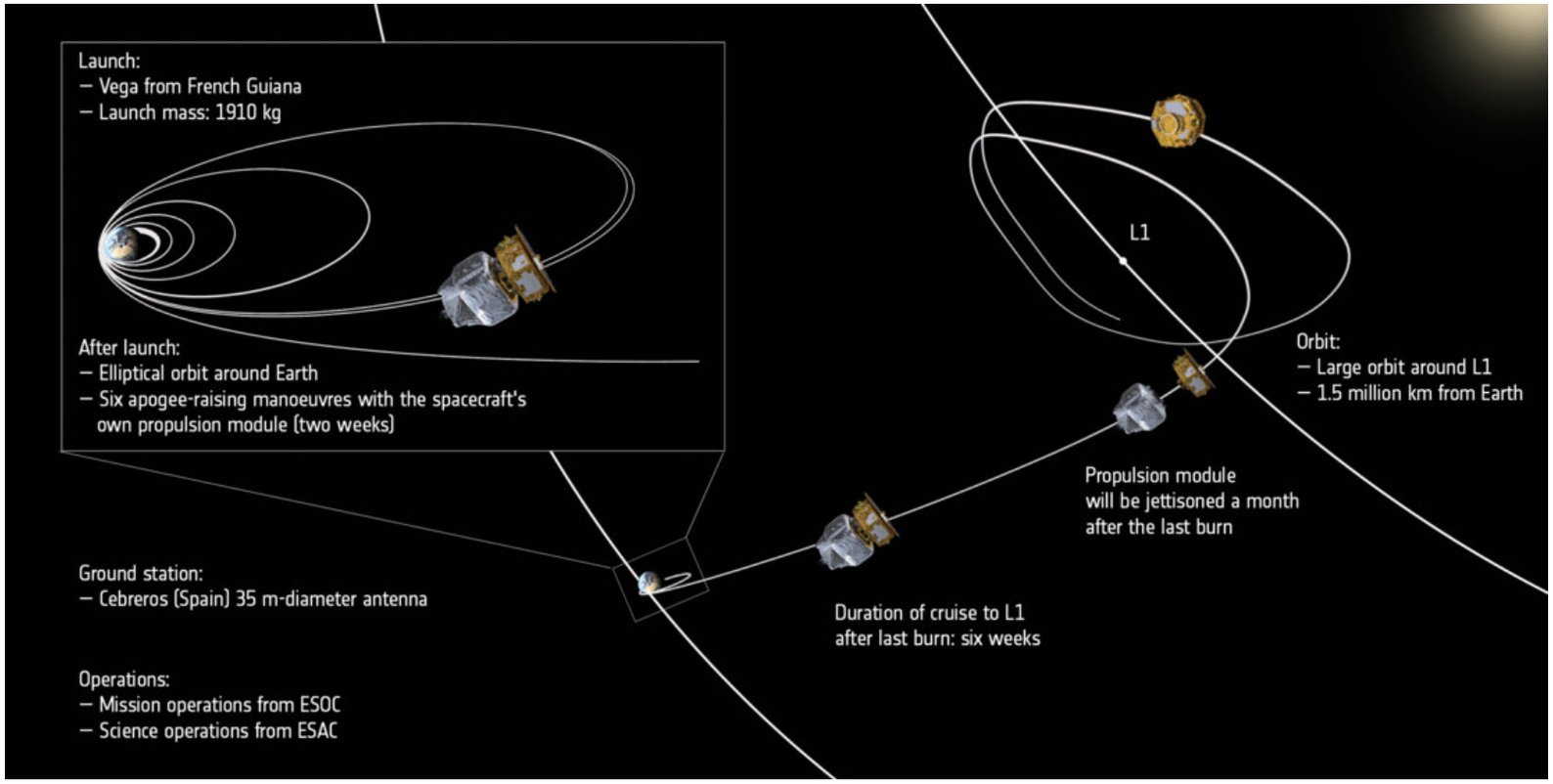
Eracleous et al. 2012

Detecting Gravitational Waves from Supermassive Black Holes: *"LIGO in space"*

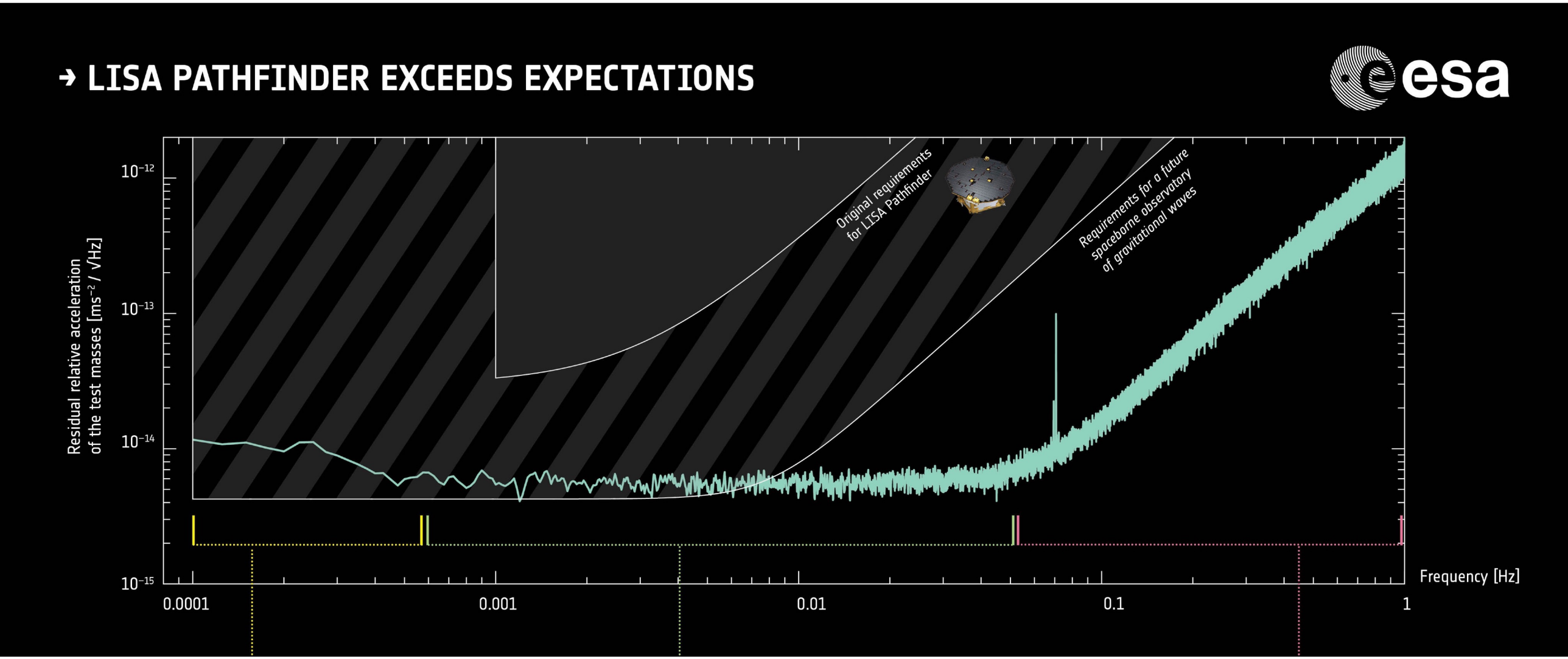


LISA Pathfinder:
Testing technology and Einstein's theories

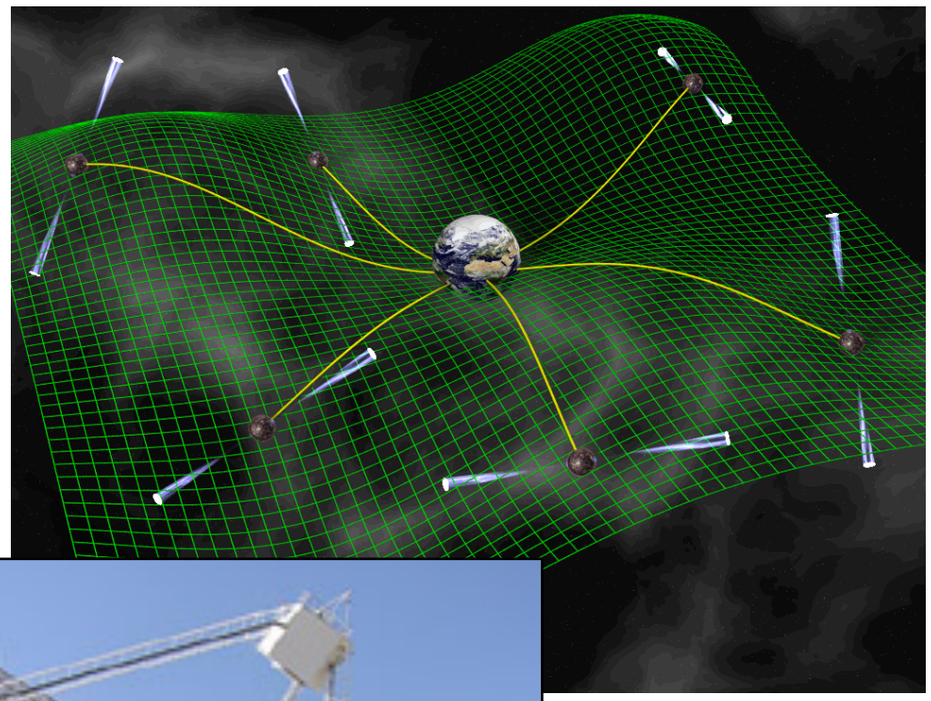




LISA Pathfinder:
A smashing success!!



Detecting Gravitational Waves from Supermassive Black Holes: ***Pulsar Timing Arrays***



Pulsar Timing Arrays:

- Use a network of pulsars (Nature's best clocks!)
- Sensitive to ultra-low frequencies
- Could detect the most massive supermassive BH mergers