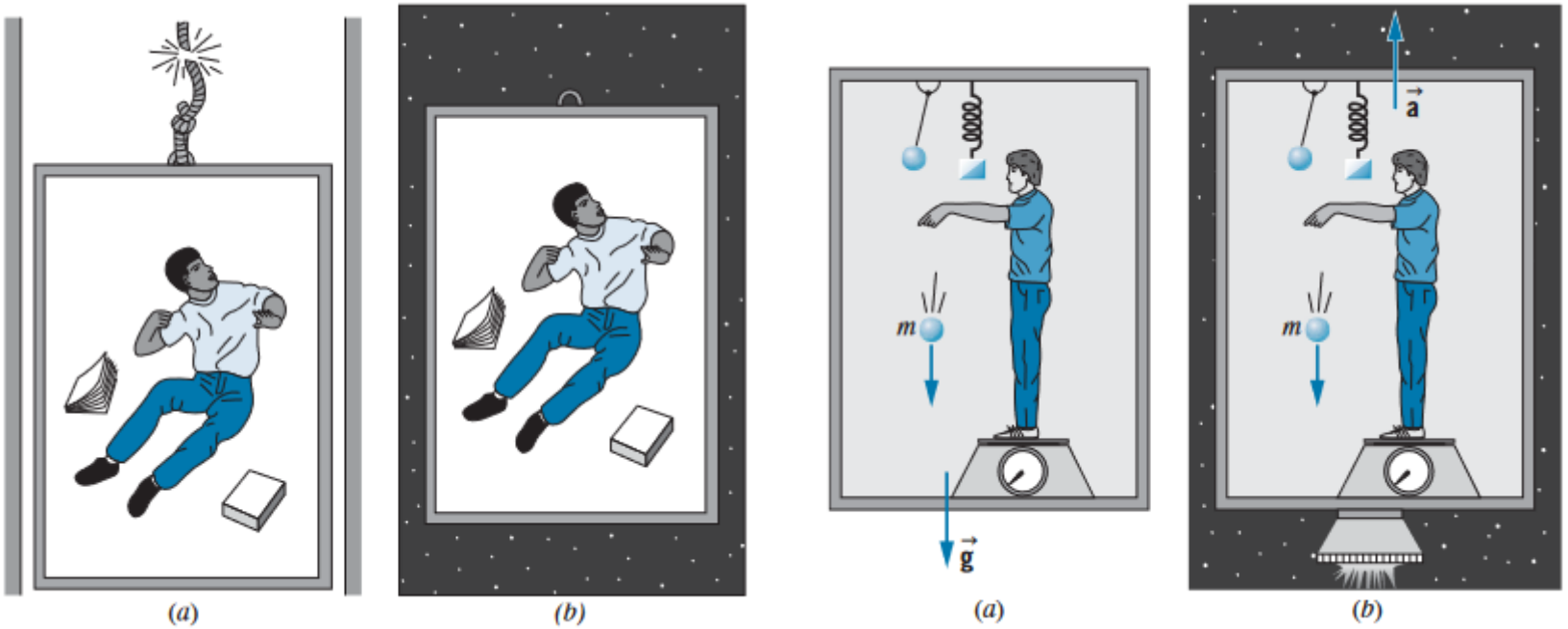
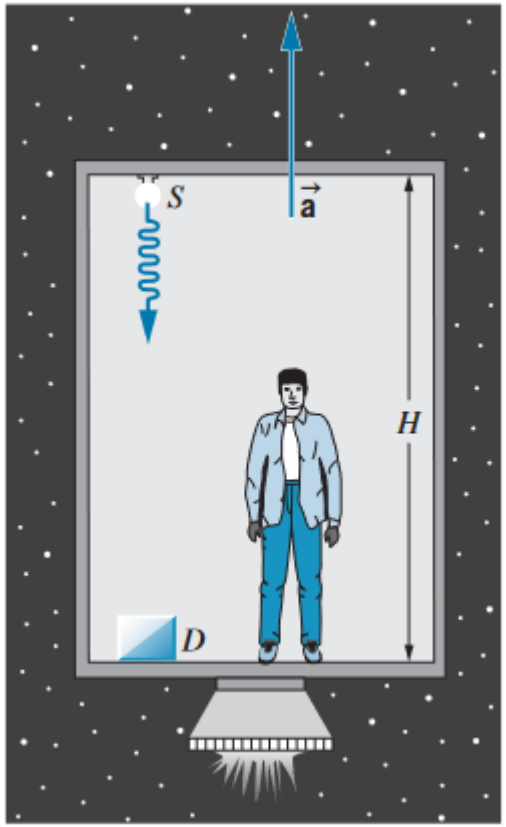
You can't tell whether stationary+gravity or accelerating.



Experimental test to better than 1 part in 10 trillion.

S. Schlamminger et al, Phys. Rev. Lett. **100**, 041101 (2008).
https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.100.041101

The frequency of light changes as travels from top to bottom of accelerating frame.



For this situation, is the frequency measured at D higher or lower than the frequency emitted.

What if S was on the floor and D on the ceiling?

What if box not accelerating but in a gravitational field??

Question #1

Relative to clocks on the surface of Earth, the clocks in the GPS satellites run

(a) fast.

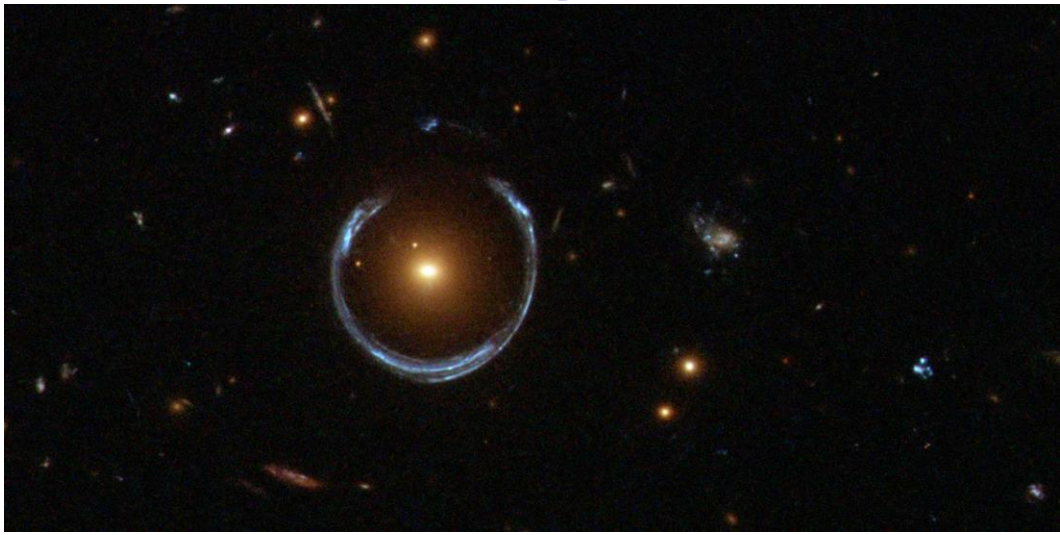
(b) slow.

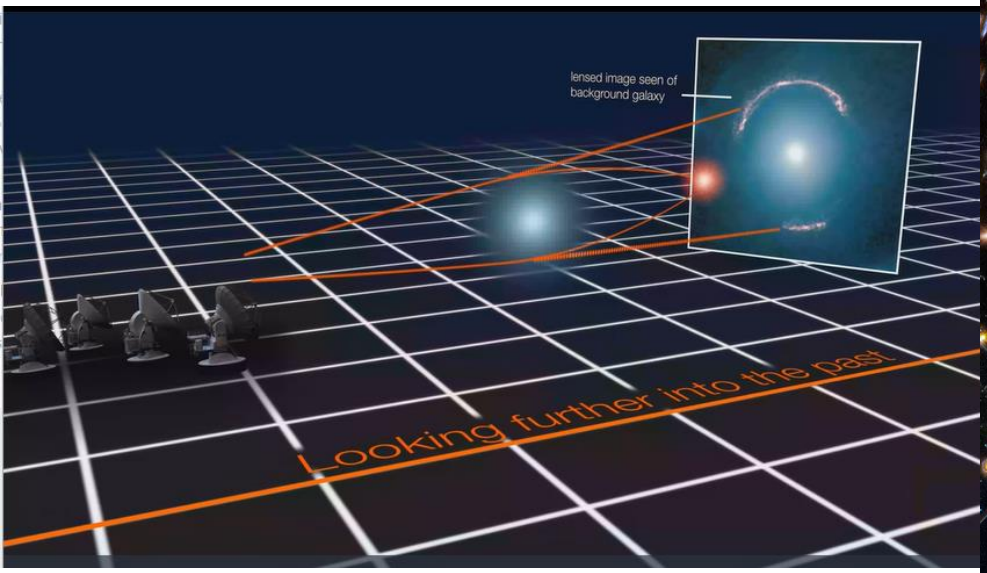
(c) the same.

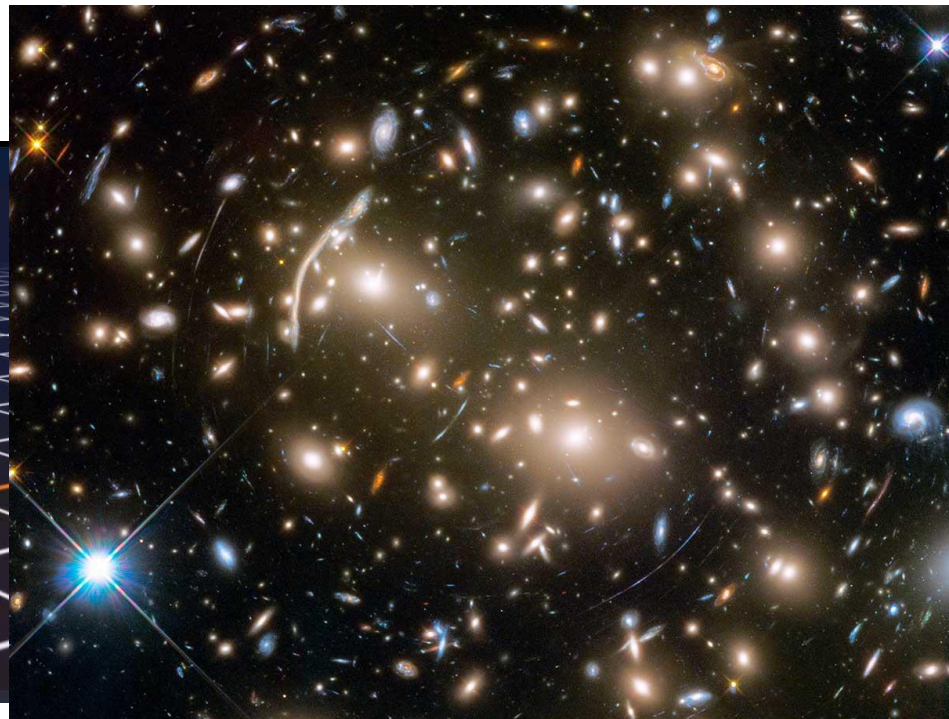
Gravitational Lensing!

The mass in some galaxies is large enough to focus the light on the other side giving the blue arcs

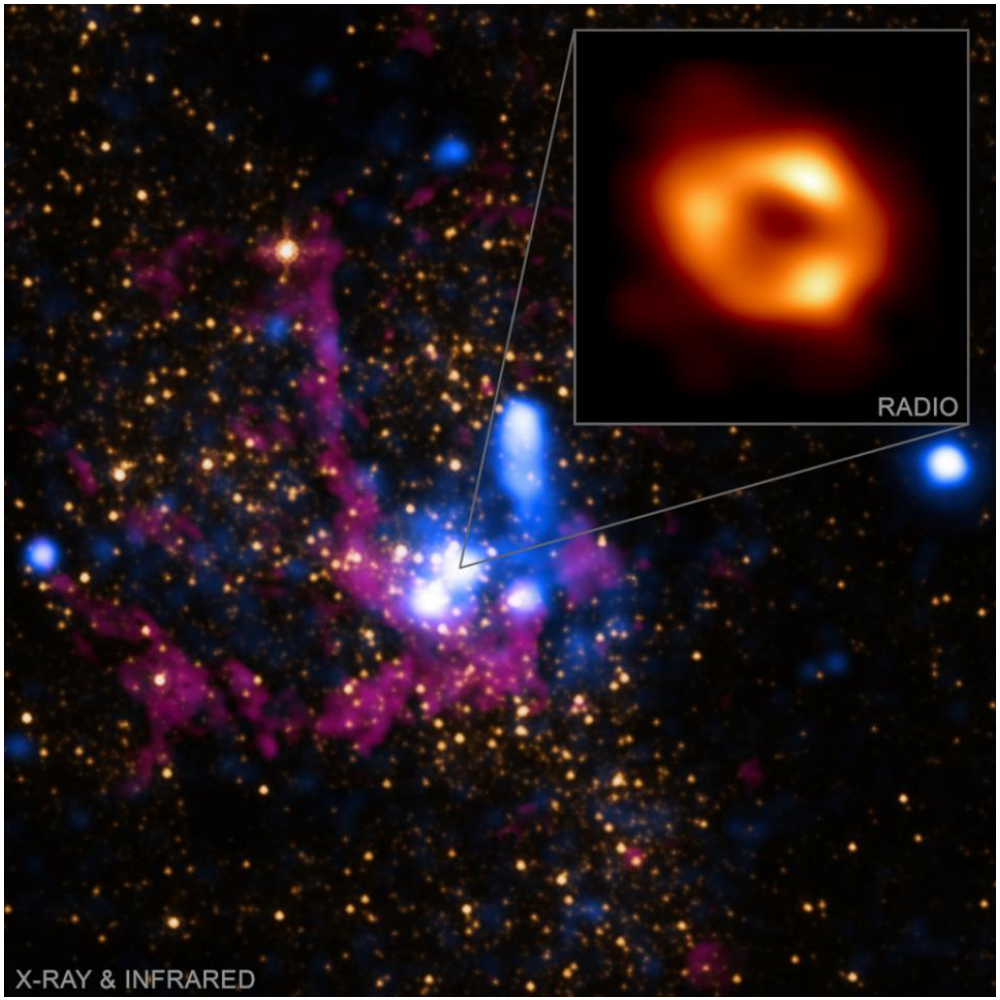
Images from: https://en.wikipedia.org/wiki/Gravitational_lens







Black Hole – not even light can escape



Telescopes have imaged the motion of stars in the neighborhood of our black hole

https://www.youtube.com/watch?v=B0QRpid5_QU

https://www.nobelprize.org/prizes/physics/2020/summary/

NASA image

https://www.nasa.gov/image-article/sagittarius-nasa-telescopes-support-event-horizon-telescope-studying-milky-ways-black-hole/

Question #2

Accelerating objects in air emit sound waves. Accelerating charges emit light waves. Accelerating mass in space emit:

(a) light waves

(b) sound waves

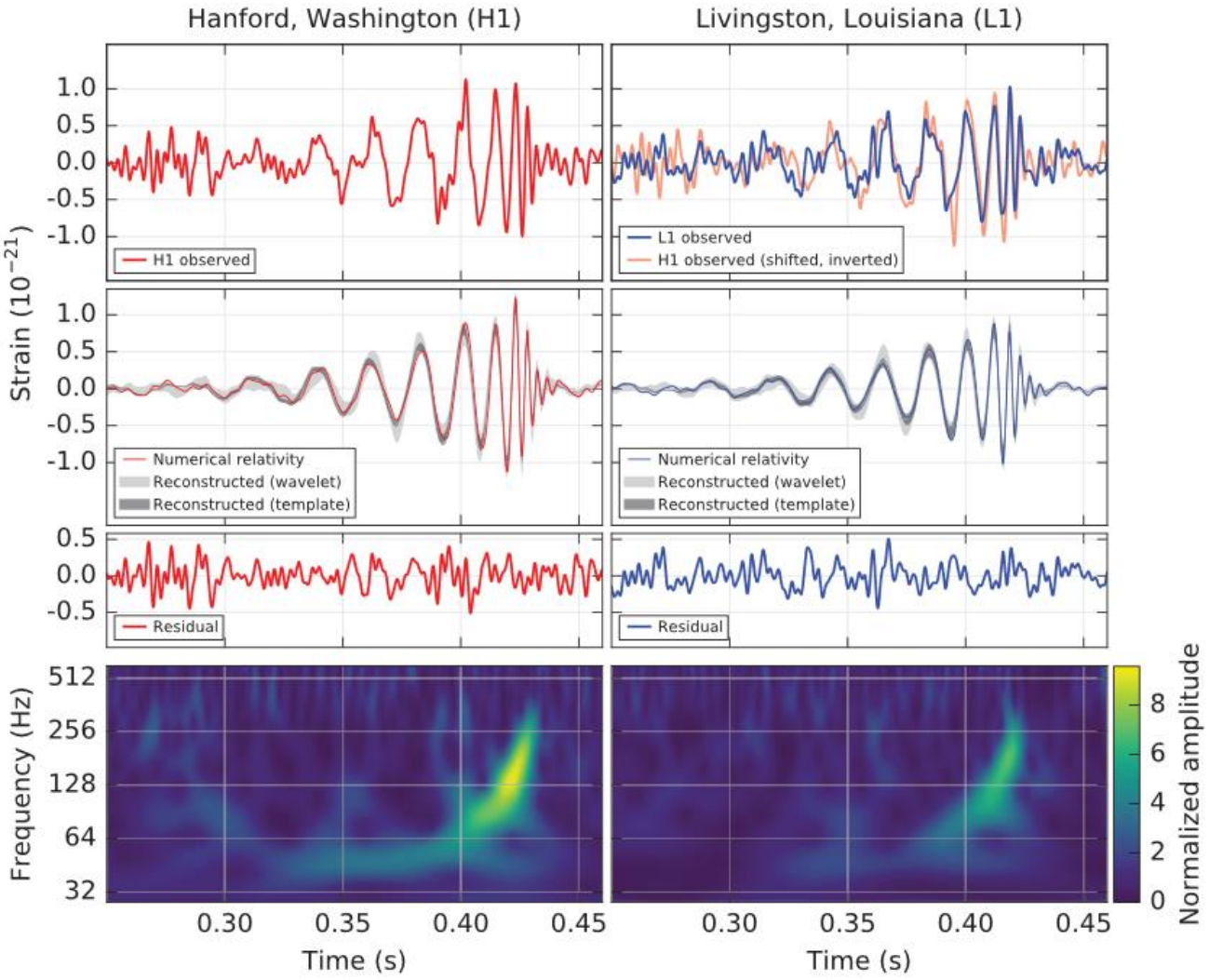
(c) gravitational waves

(d) nothing

Laser Interferometer Gravitational-Wave Observatory
https://www.ligo.caltech.edu/page/gravitational-waves

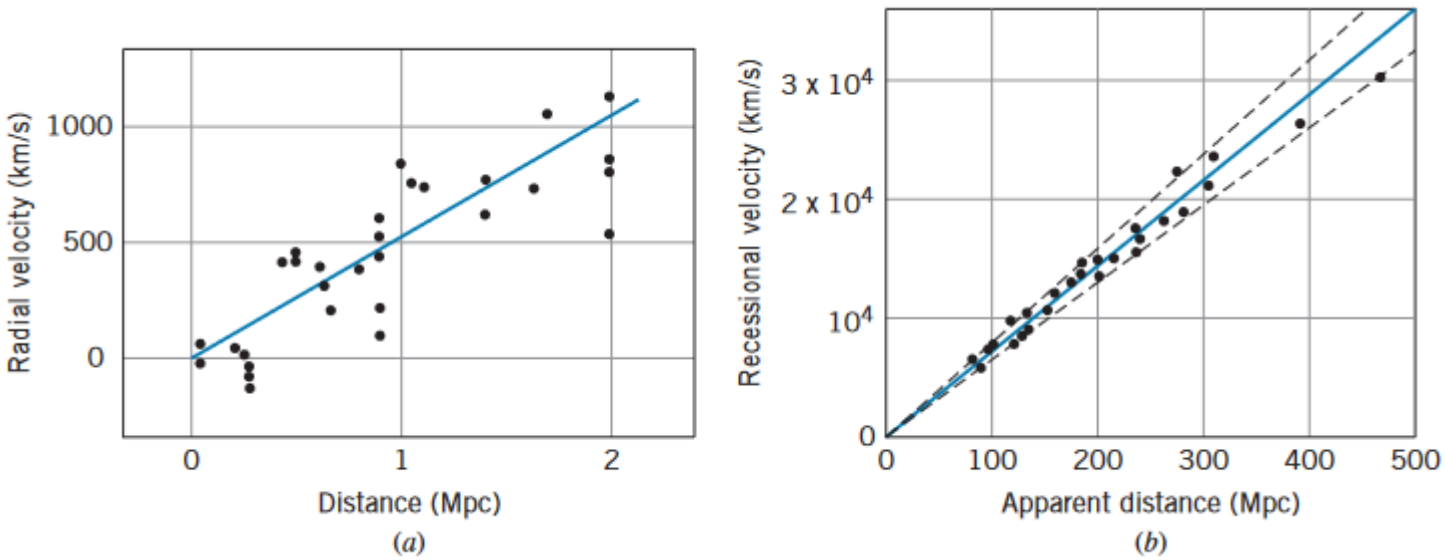
B.P. Abbott et al, Phys. Rev. Lett. 116, 061102 (2016)

https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.116.061102



Two facilities measure the same signal at nearly the same time. The inspiraling of 2 black holes (approx. 36 and 29 solar masses). Note faster rotation (chirp!) as time ~0.43 sec.

The universe appears to be expanding!



Hubble measured velocity of nearby galaxies vs the distance to them (left). More recent and better measurements (right) out to much farther distances.

The further away a galaxy, the faster it moves away from us!

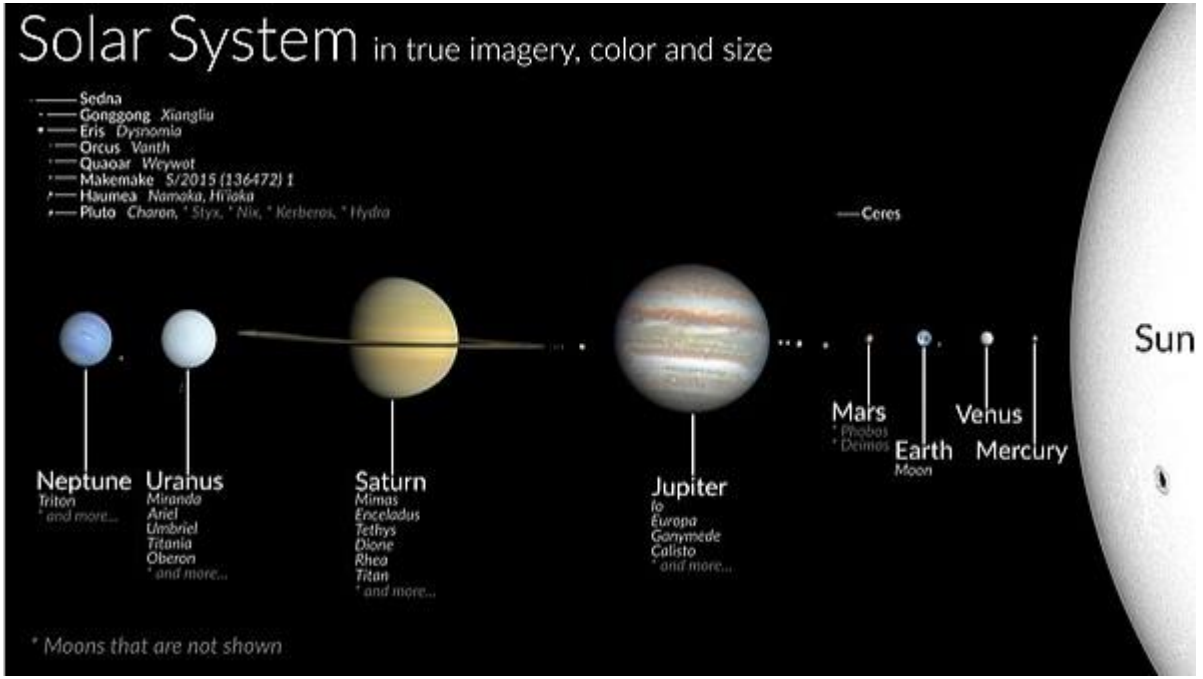
Question #3

Which planet has the longest year?

(a) Mercury

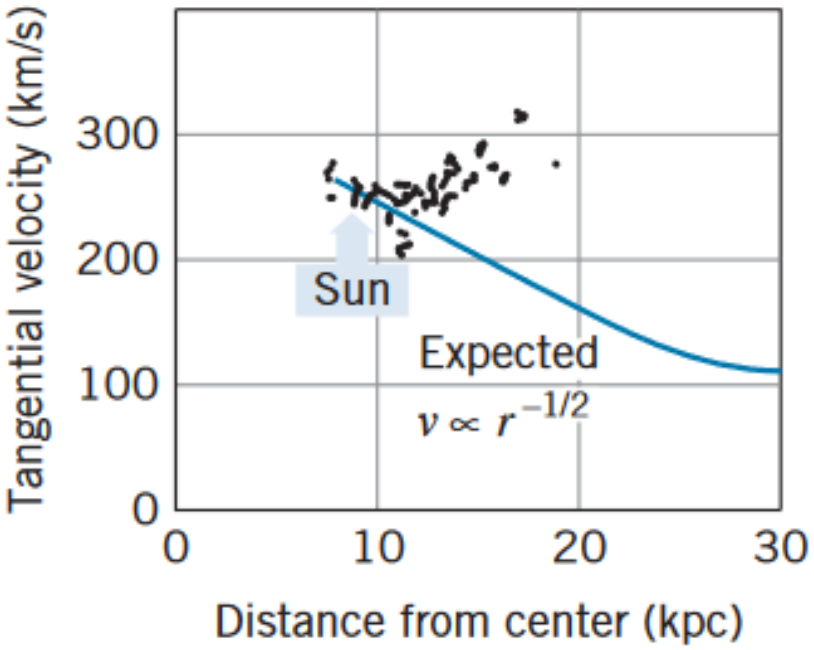
(b) One of the middle ones

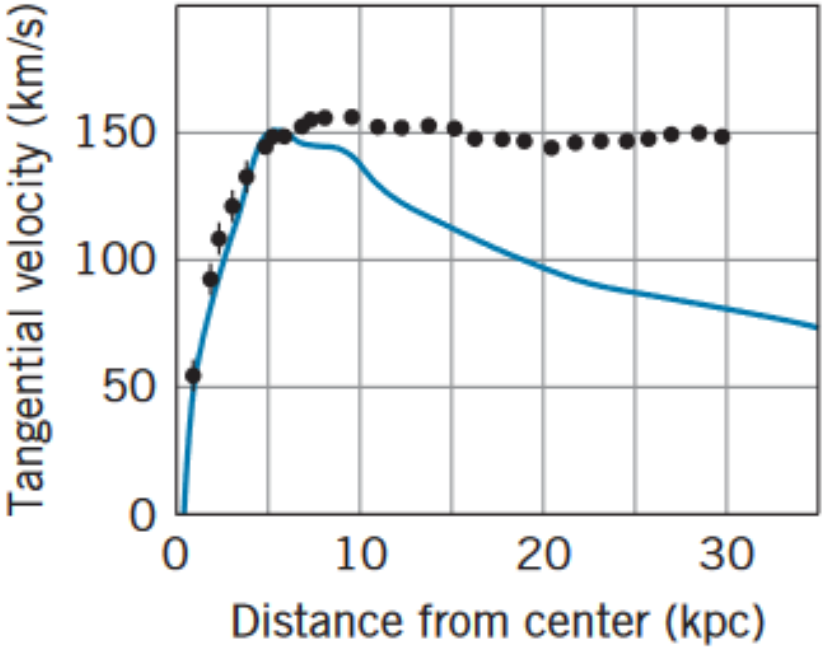
(c) Neptune



https://en.wikipedia.org/wiki/Solar_System

Galaxies are rotating too fast at larger R





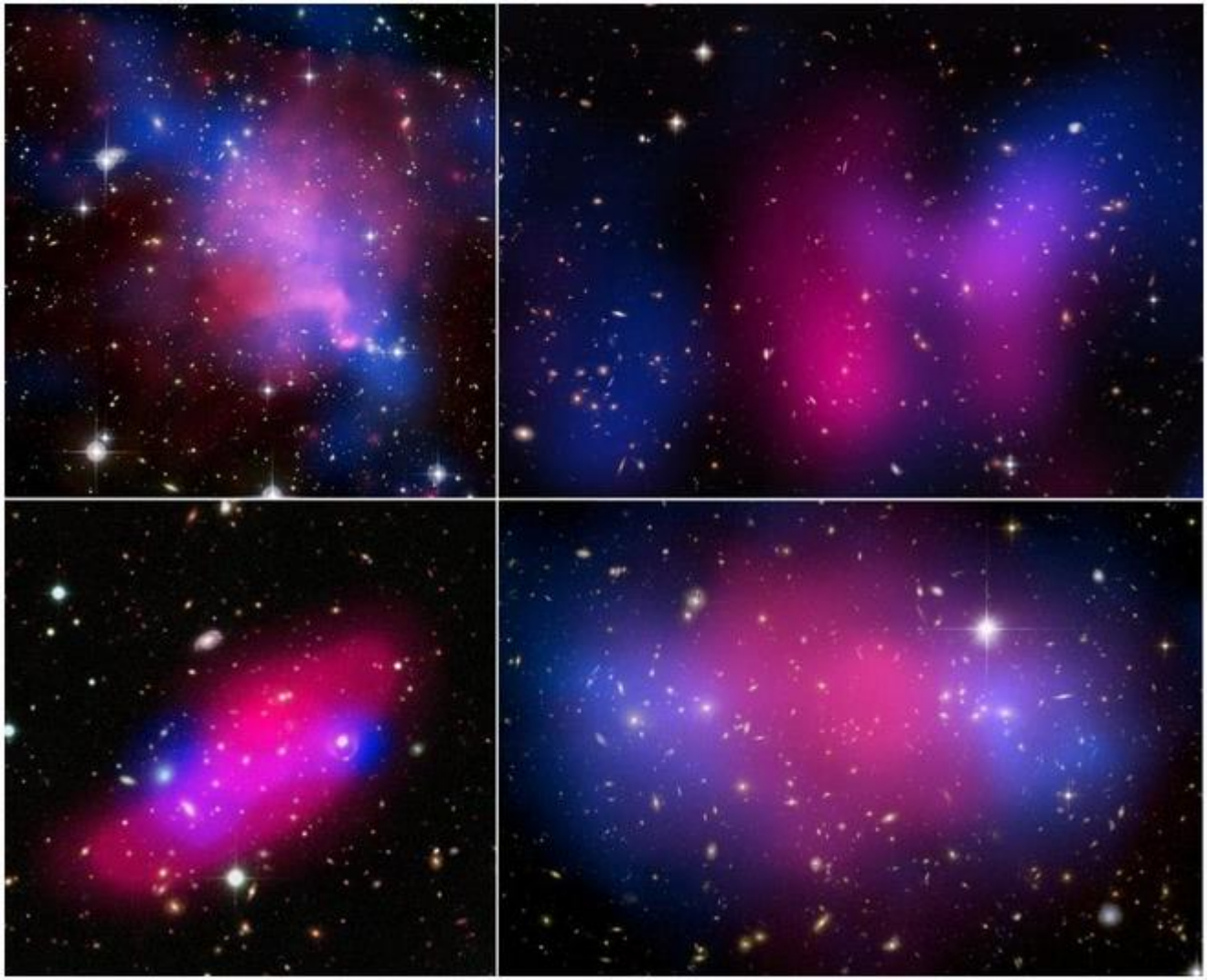
Milky Way

Other "typical" galaxy

Why rotating too fast? Gravitational Law wrong? Mass that isn't emitting light?

Dark Matter!

Colliding galaxies: gravitational lensing not where matter is



4 cases of colliding galaxies: gas from each essentially stop & heat enough to give x-rays. This is where most of the "normal" matter is

Pink (x-rays = visible matter)

Blue (lensing = ?)

Most mass is not visible and "only" interacts through gravity

https://www.forbes.com/sites/startswithabang/2017/11/09/the-bullet-cluster-proves-dark-matter-exists-but-not-for-the-reason-most-physicists-think/?sh=52392c031738