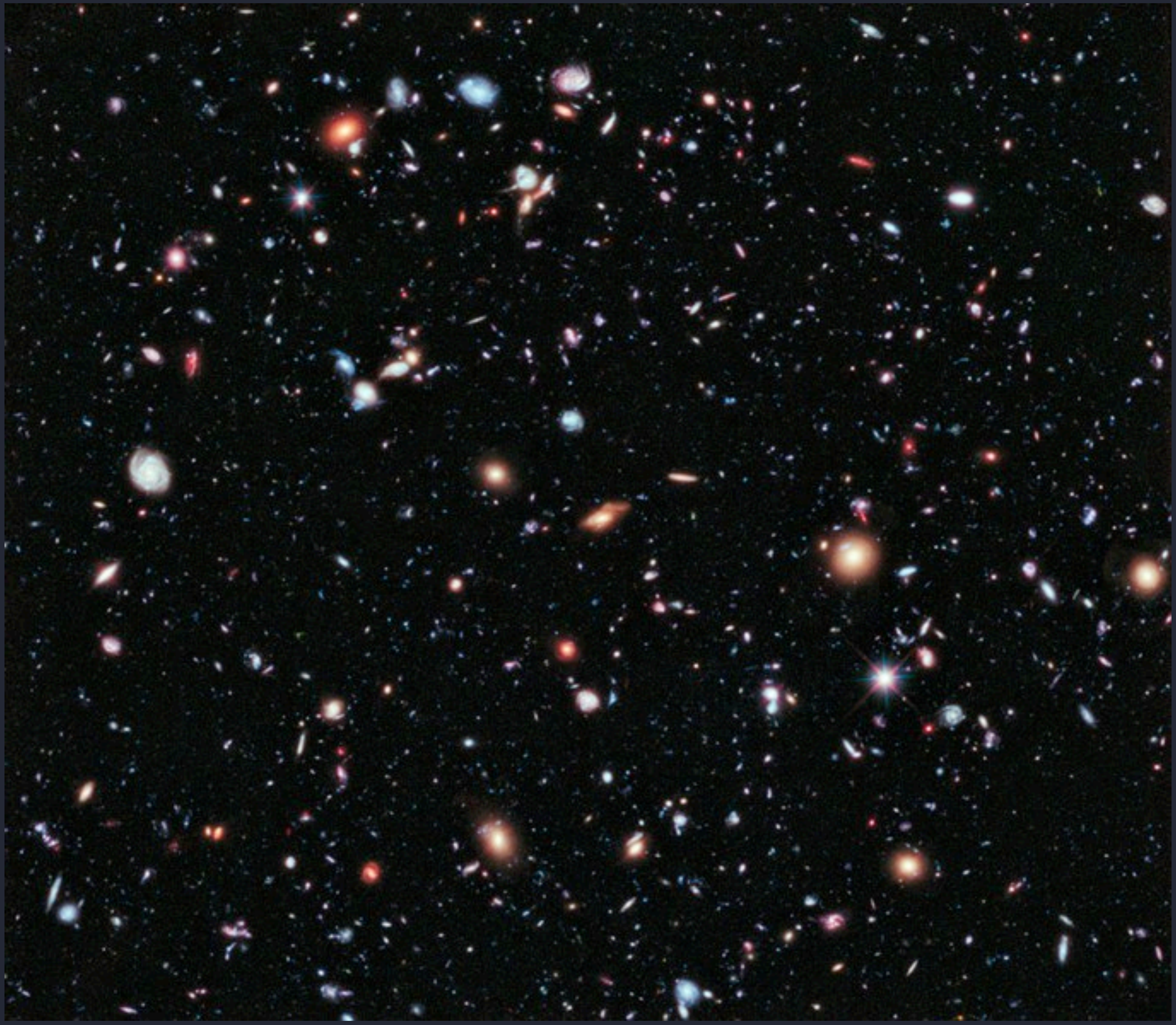
Astro 1: Introductory Astronomy

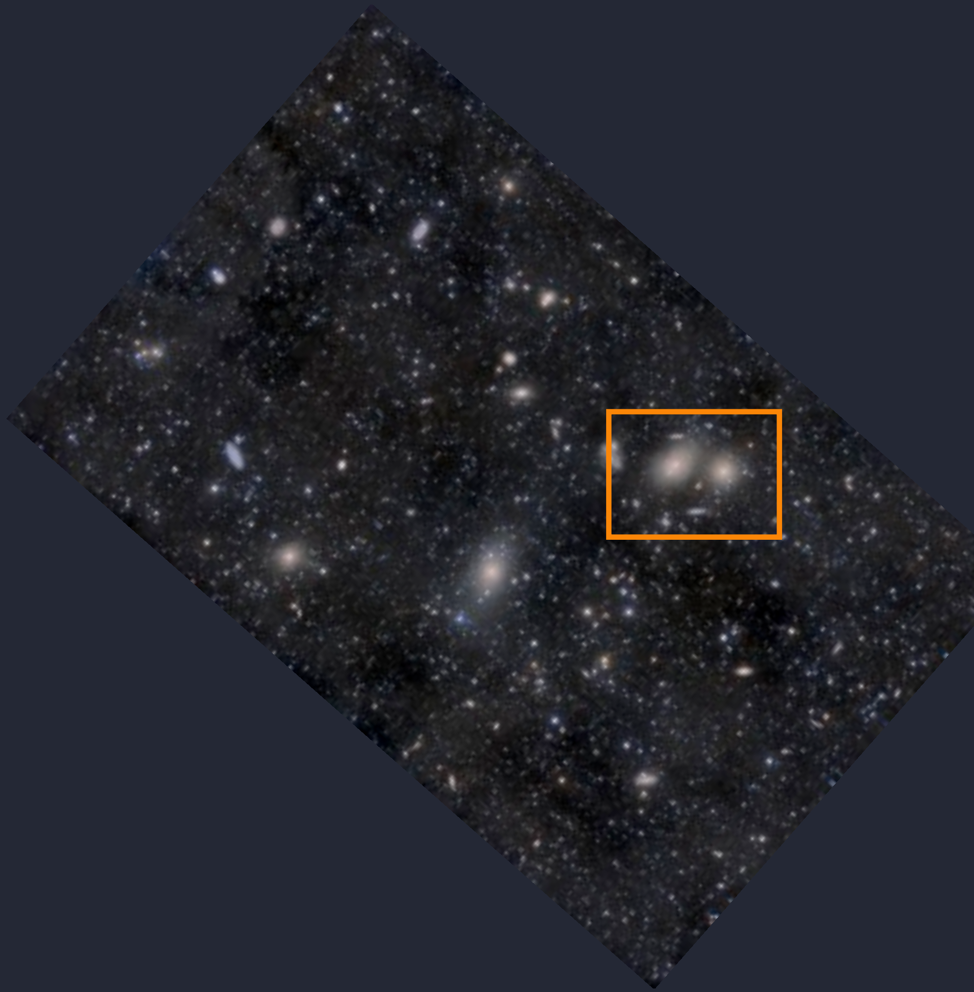


David Cohen

Class 28: Thursday, May 1

Spring 2014

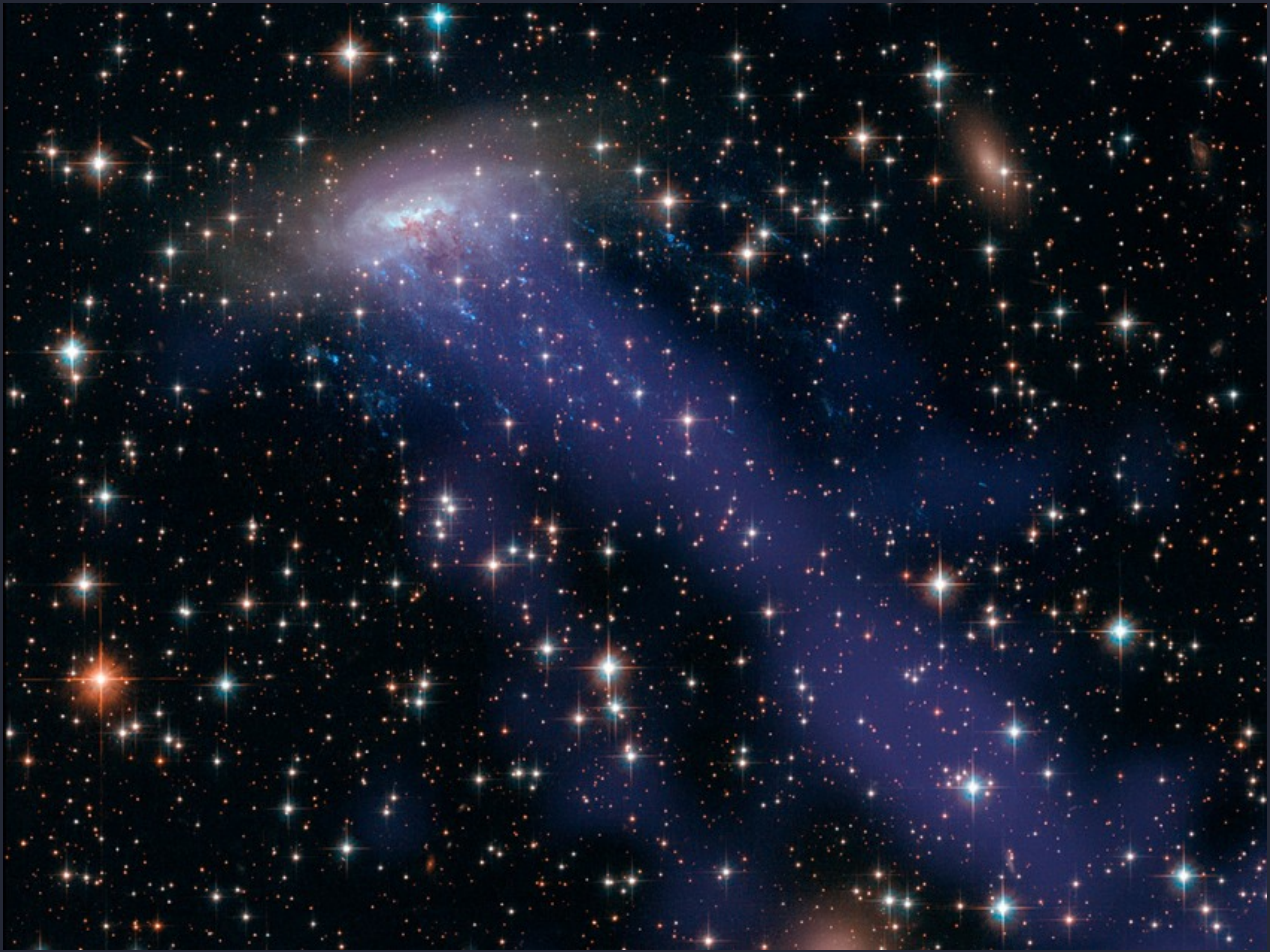
Virgo cluster: nearest big galaxy cluster



The Hydra cluster

http://apod.nasa.gov/apod/ap120512.html

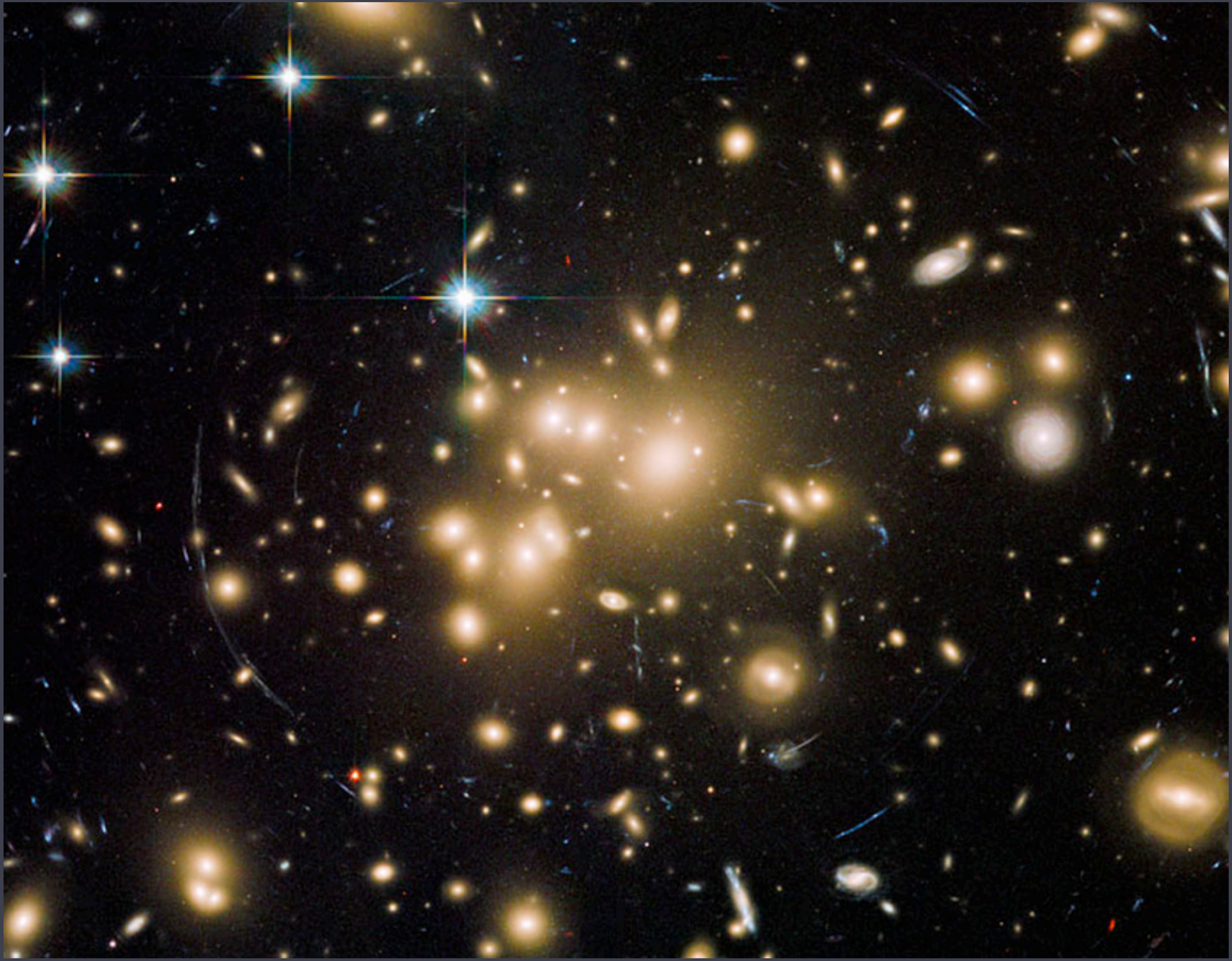
a galaxy is stripped of its gas as it orbits around its cluster
blue is X-ray emitting hot gas

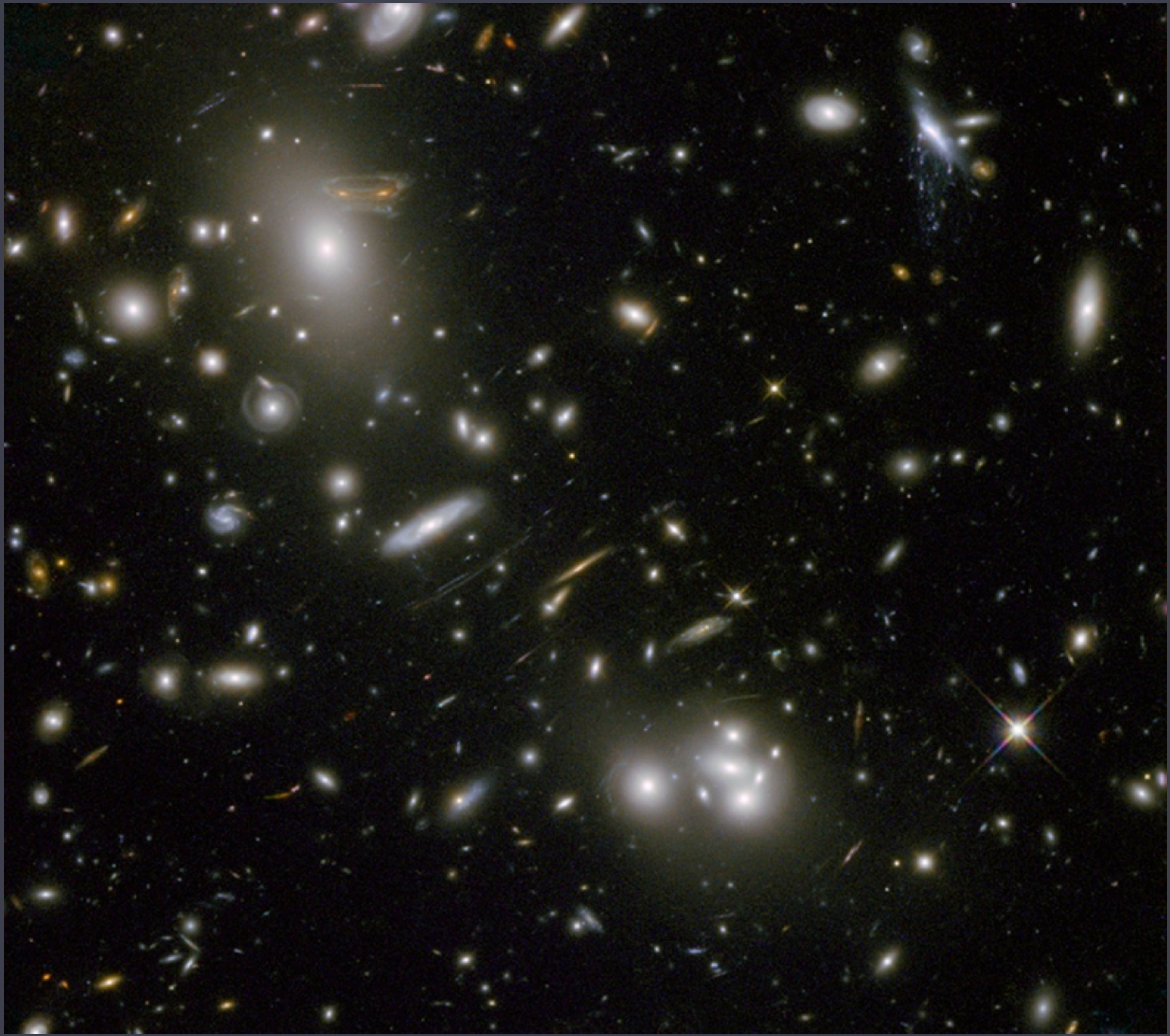


http://apod.nasa.gov/apod/ap140328.html

Abell 2744: huge galaxy cluster, filled with X-ray emitting gas

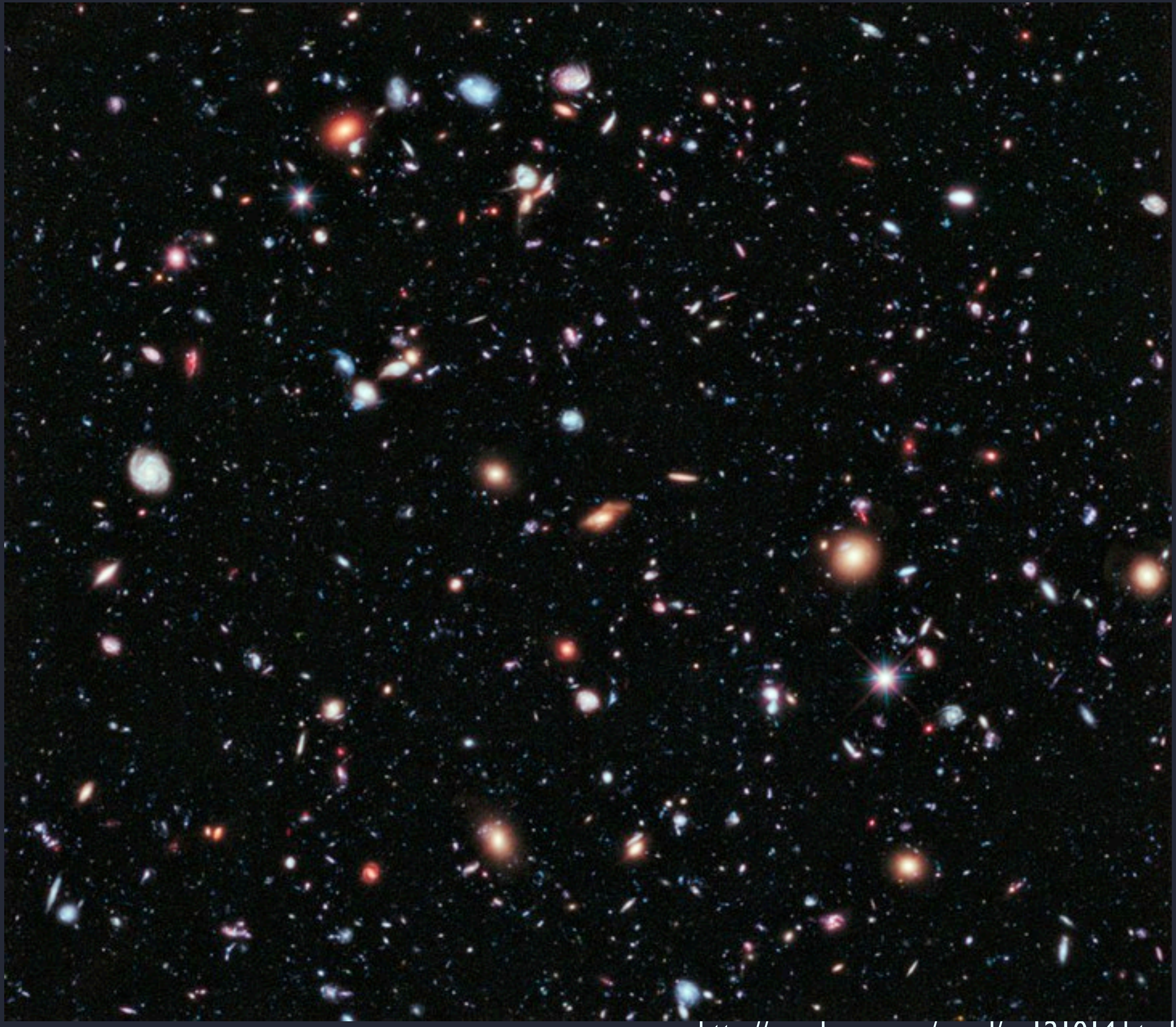
http://apod.nasa.gov/apod/ap110629.html





http://apod.nasa.gov/apod/ap130308.html

The Hubble Deep Field (multi-week exposure: 1000s of galaxies)

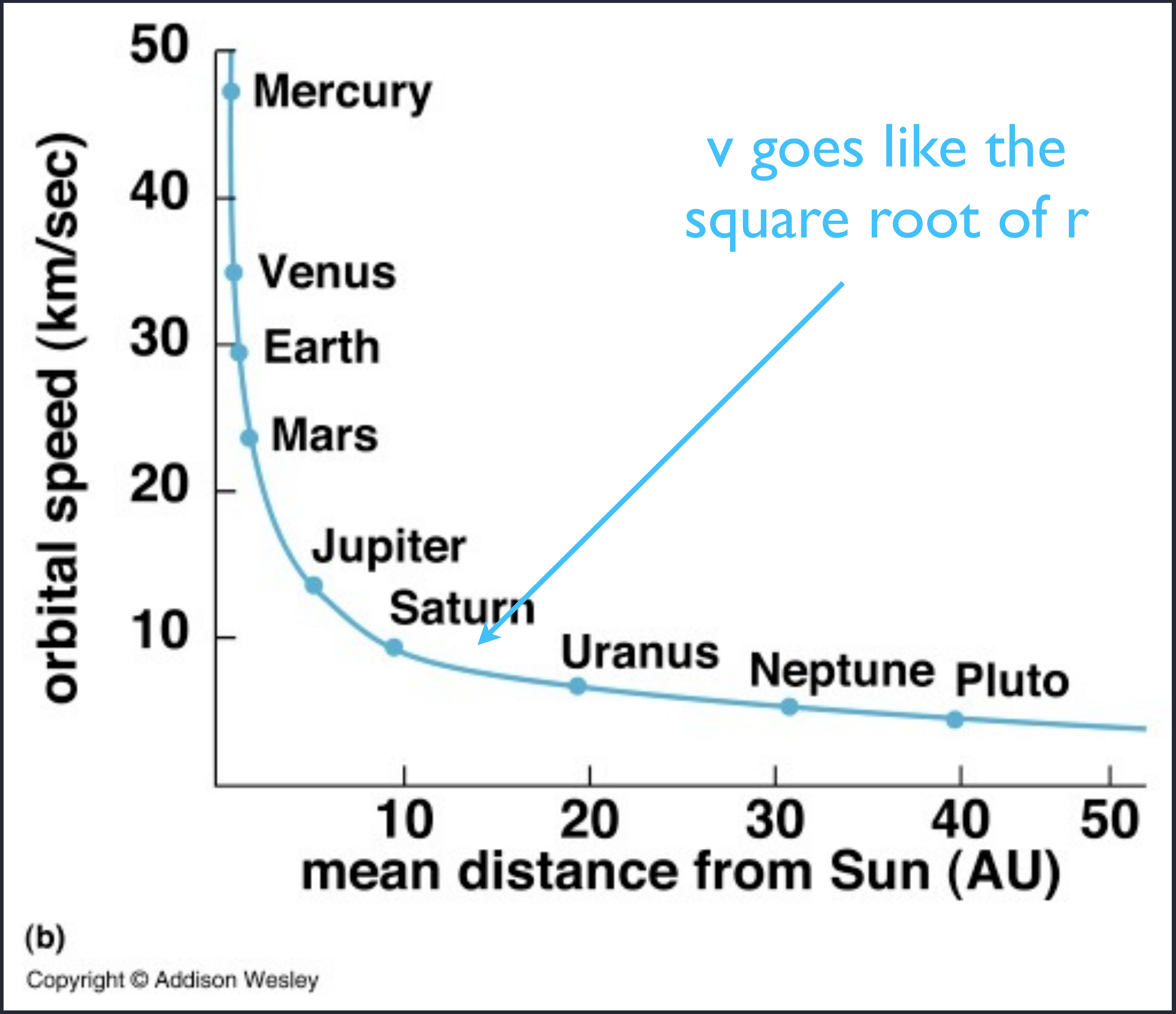


http://apod.nasa.gov/apod/ap121014.html

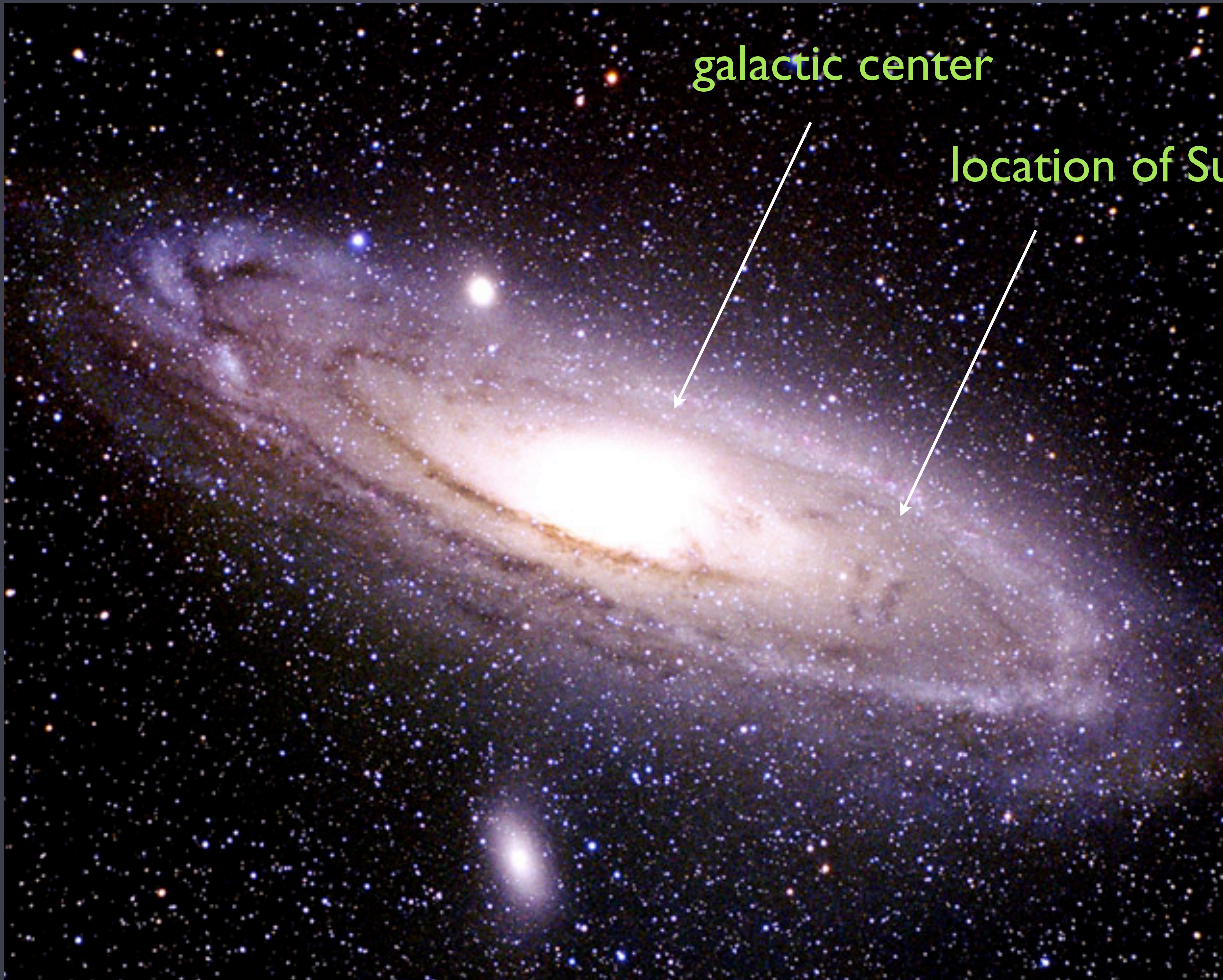
We can use a version of Kepler's third law ($M = rv^2/G$) to weigh these galaxy clusters; and when we do we find that there's a lot more mass there than what we'd assume from just the galaxies and the X-ray emitting gas

We term this unseen additional mass, that has gravity but doesn't emit or absorb light, *Dark Matter*

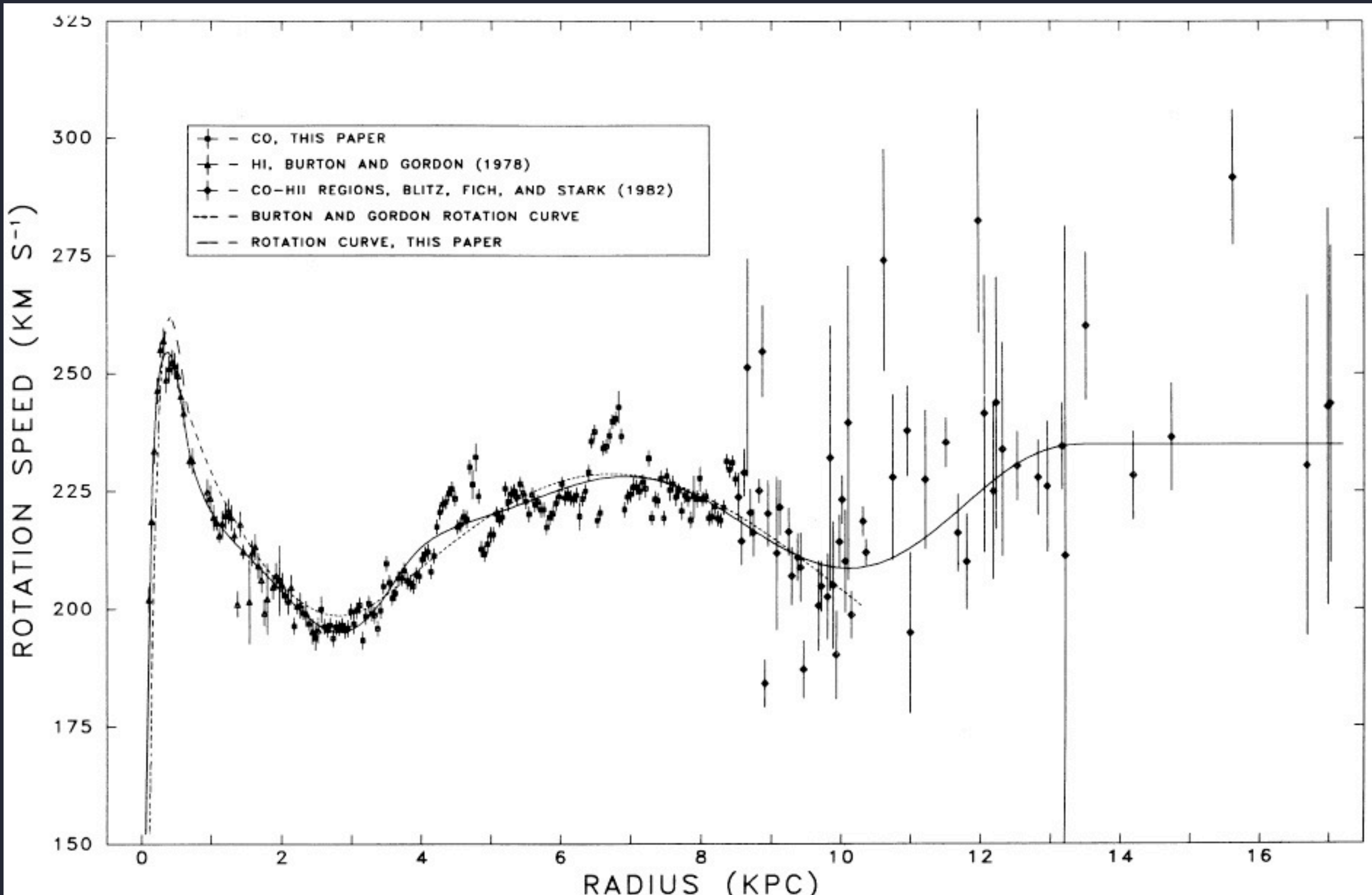
Orbital speed as a function of distance from the Sun



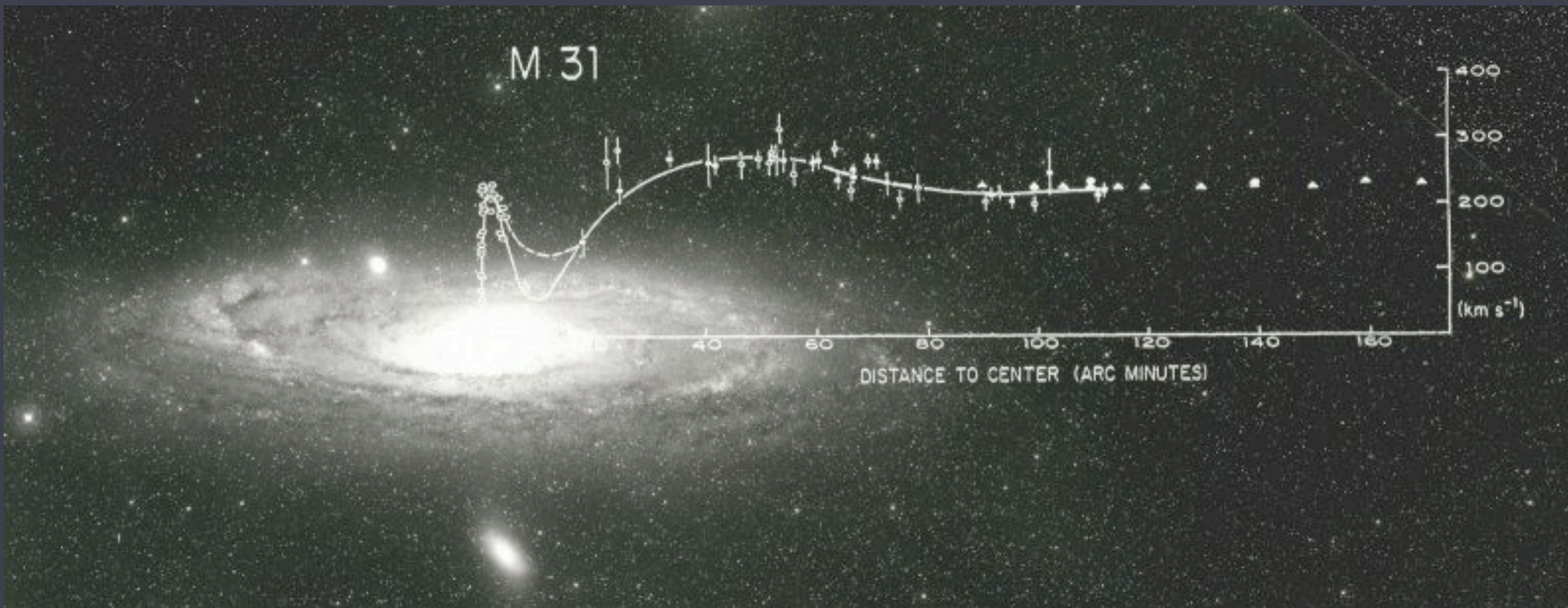
Andromeda



Milky Way's "rotation curve" : rotation speed vs. distance from the center



Andromeda has a flat rotation curve and dark matter, too

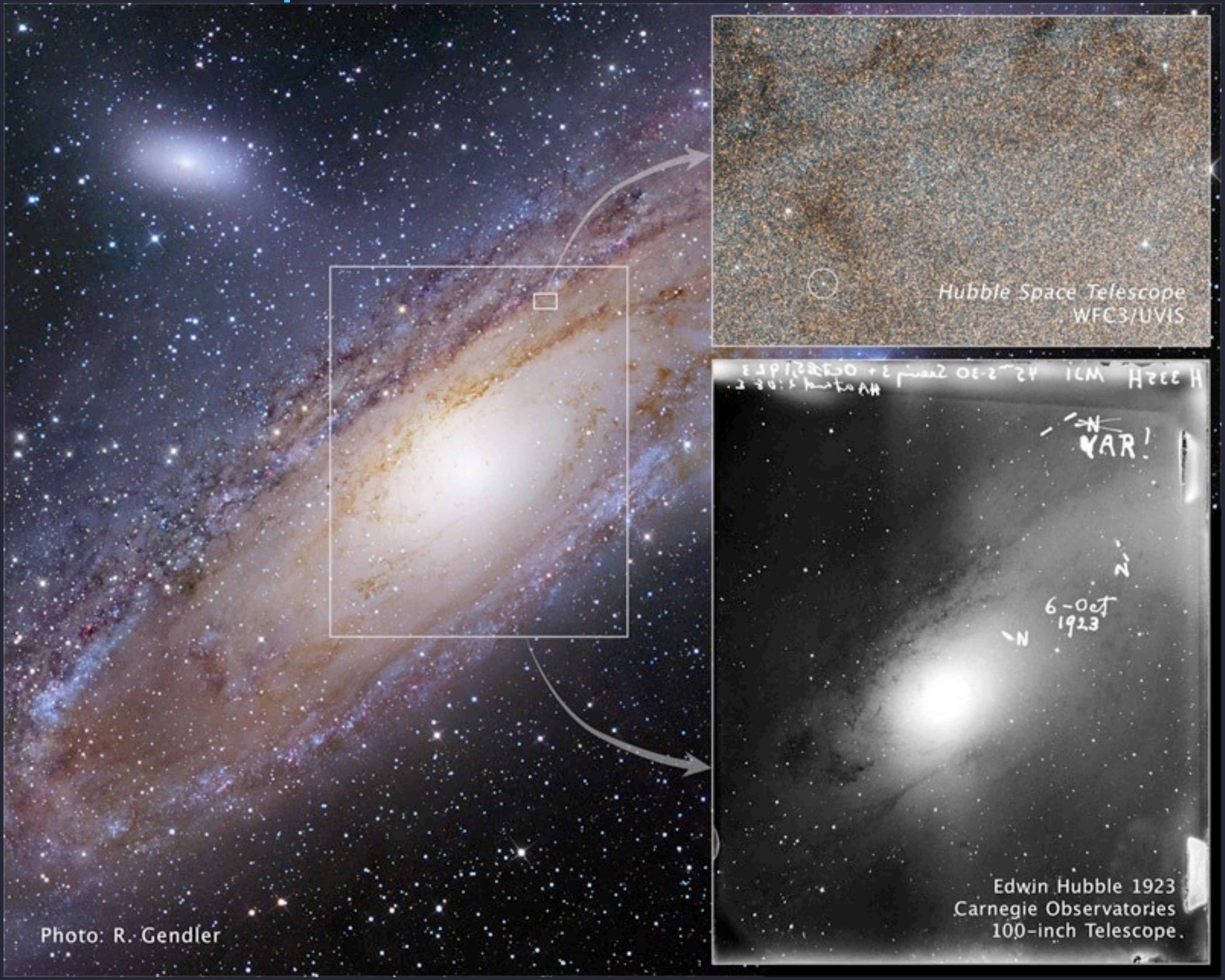


courtesy: Vera Rubin

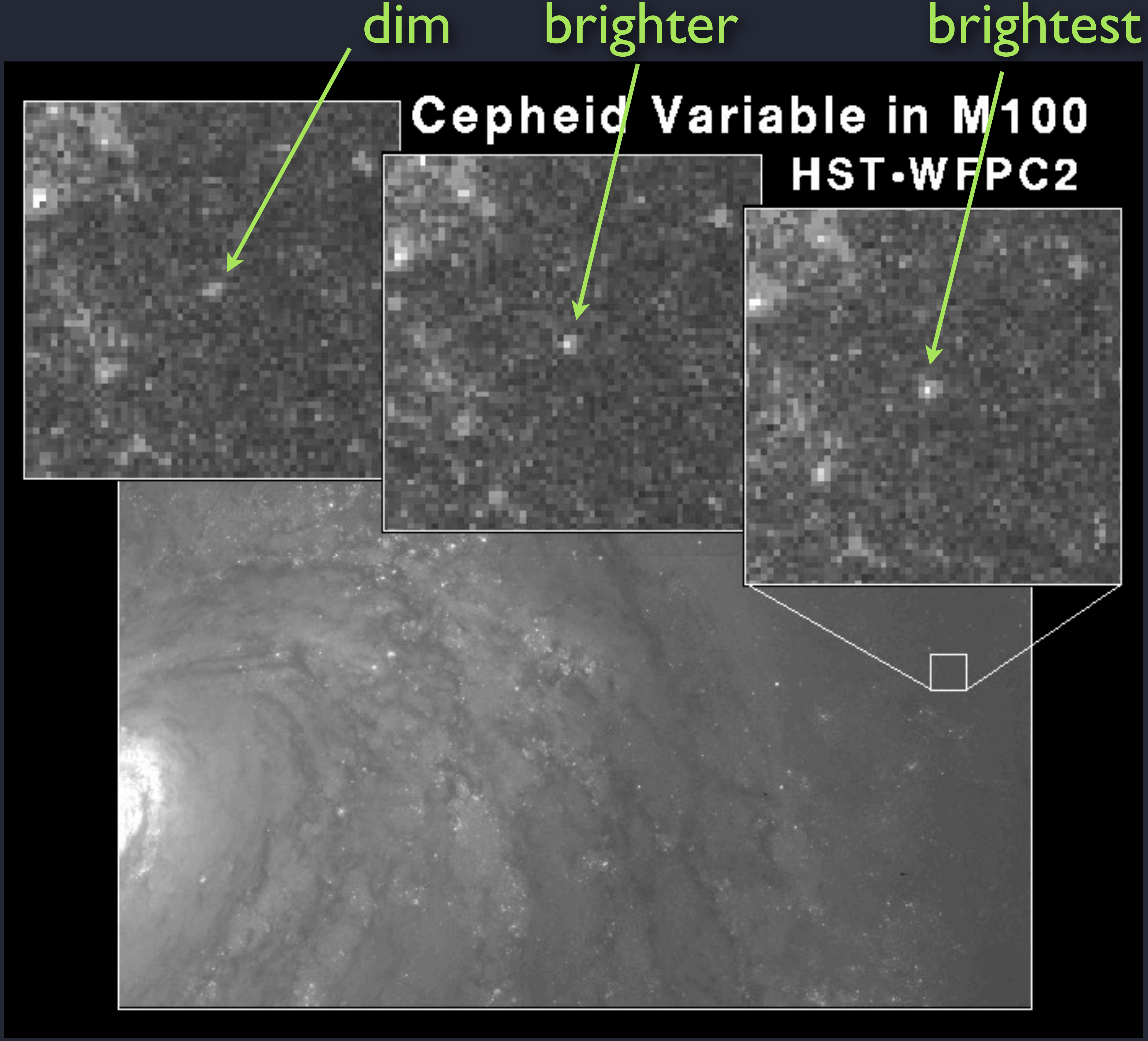
($M = rv^2/G$) implies for a constant v that M, the mass enclosed, increases linearly with radius. There is a lot of mass near the edges of spiral galaxies than we'd expect just from the modest amount of starlight we see.

Dark Matter exists inside spiral galaxies, too, and it's distributed much more evenly than the stars.

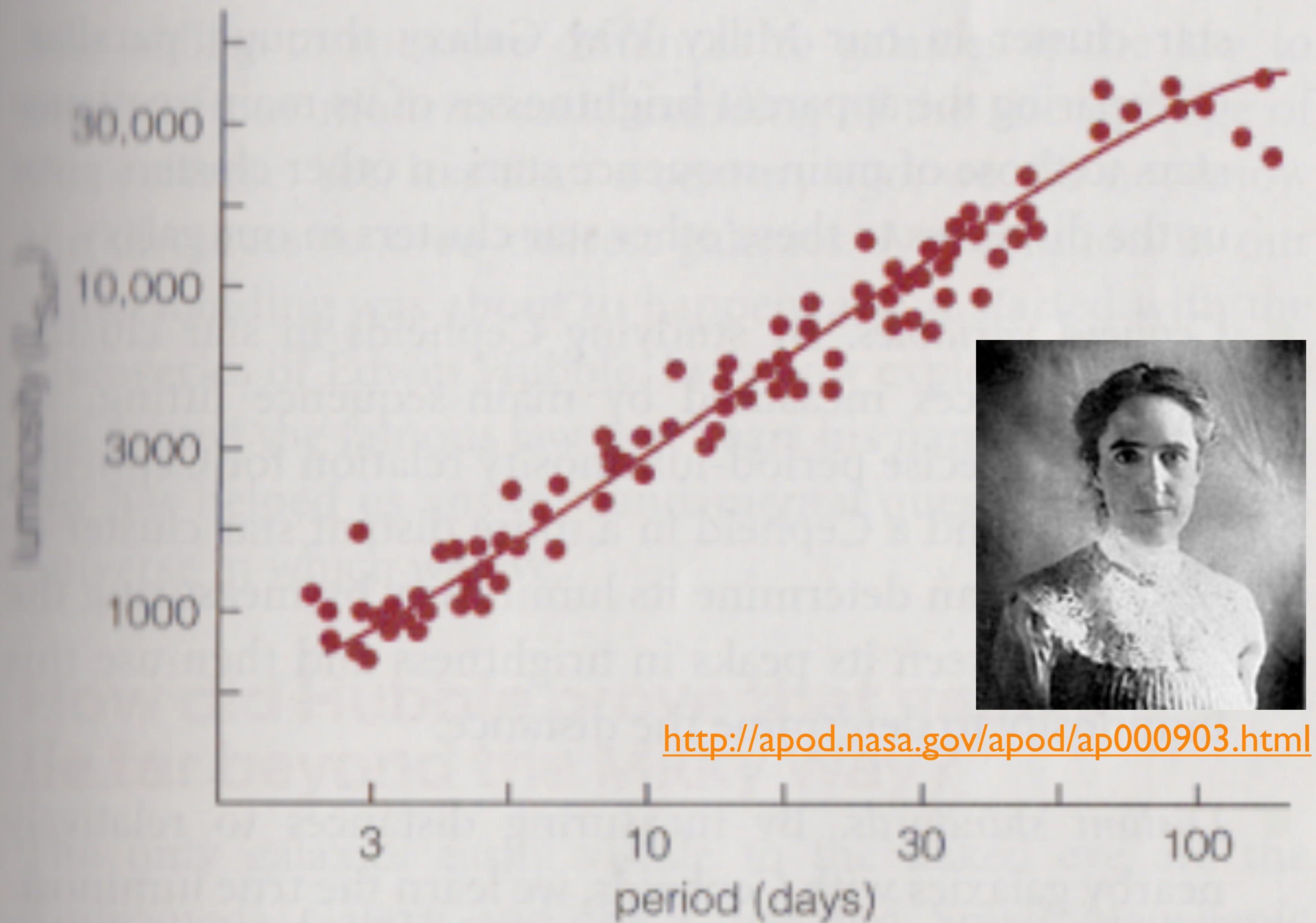
Cepheid variable in Andromeda



http://apod.nasa.gov/apod/ap110701.html


dim
brighter
brightest
Cepheid Variable in M100
HST•WFPC2

Period-luminosity relationship for Cepheid variables

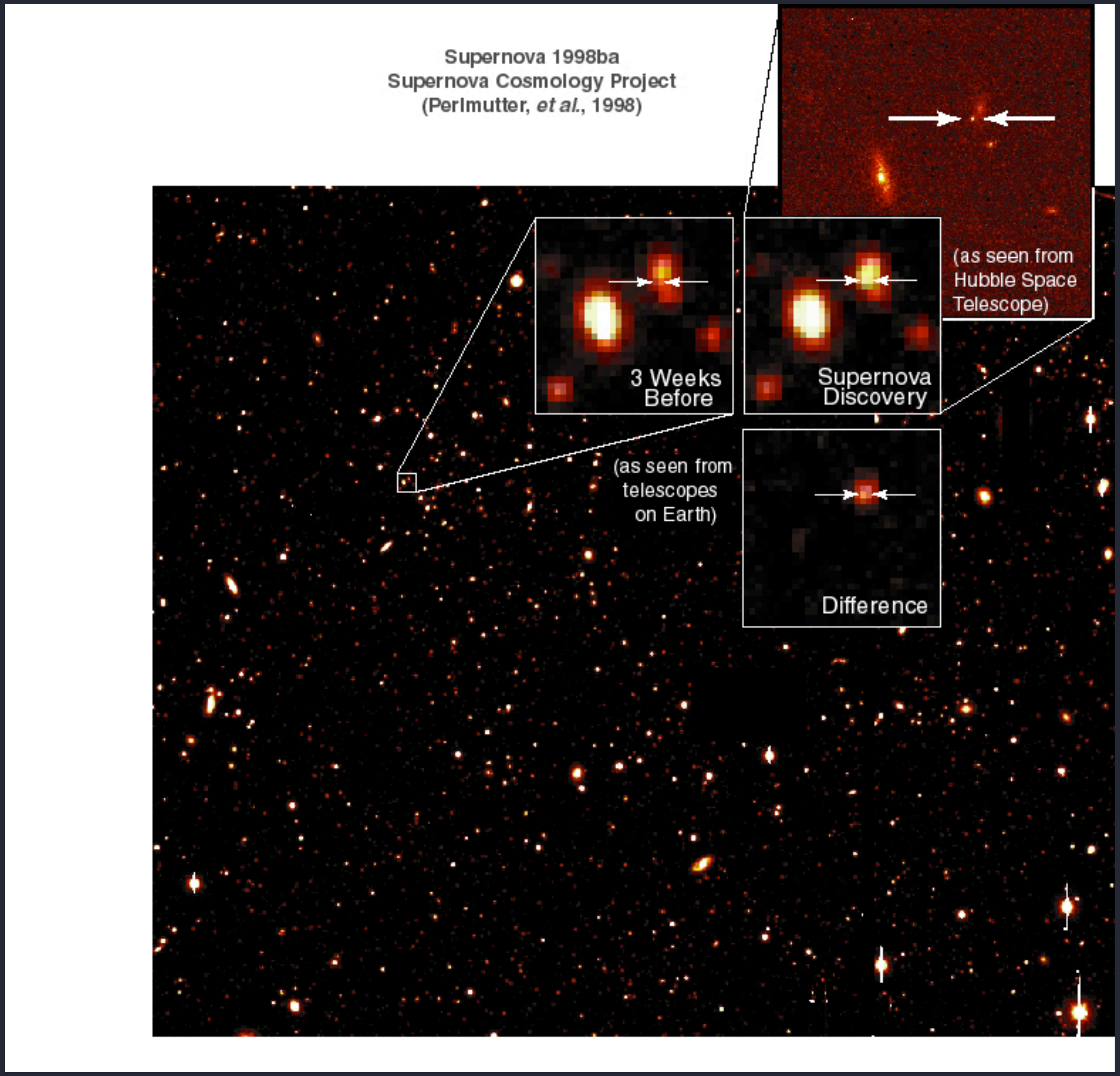


http://apod.nasa.gov/apod/ap000903.html

Henrietta Leavitt
(1920s-30s)

FIGURE 20.12 Cepheid period-luminosity relation. The data show that all Cepheids of a particular period have very nearly the same luminosity. By measuring a Cepheid's period, we can therefore determine its luminosity and hence its distance. (Cepheids actually come in two types with two different period-luminosity relations. The relation here is for Cepheids with heavy-element content similar to that of our Sun, or Type I Cepheids.)

"White Dwarf Supernovae" are the most luminous standard candles



The *Distance Ladder* - overlap of techniques is key

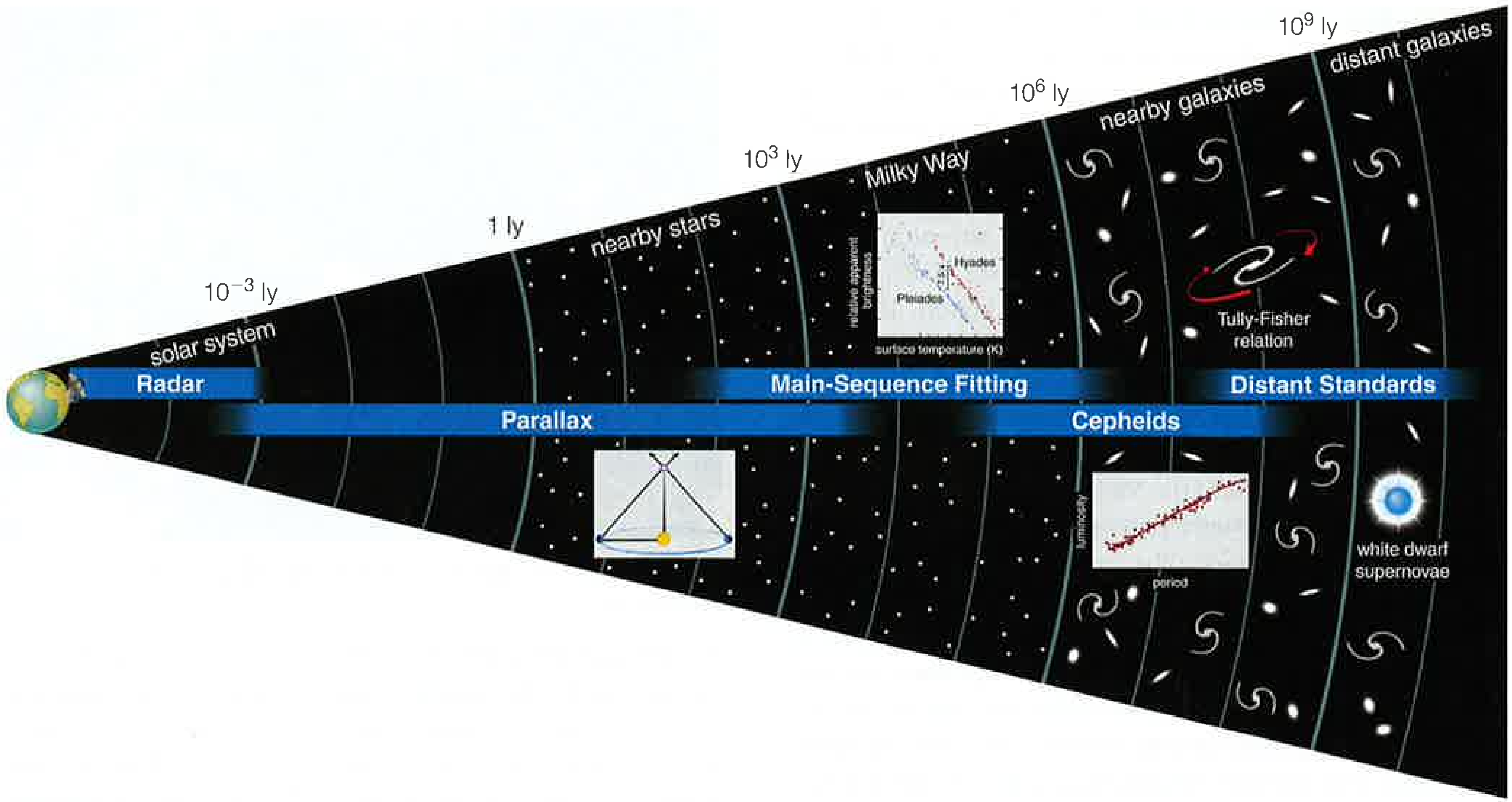
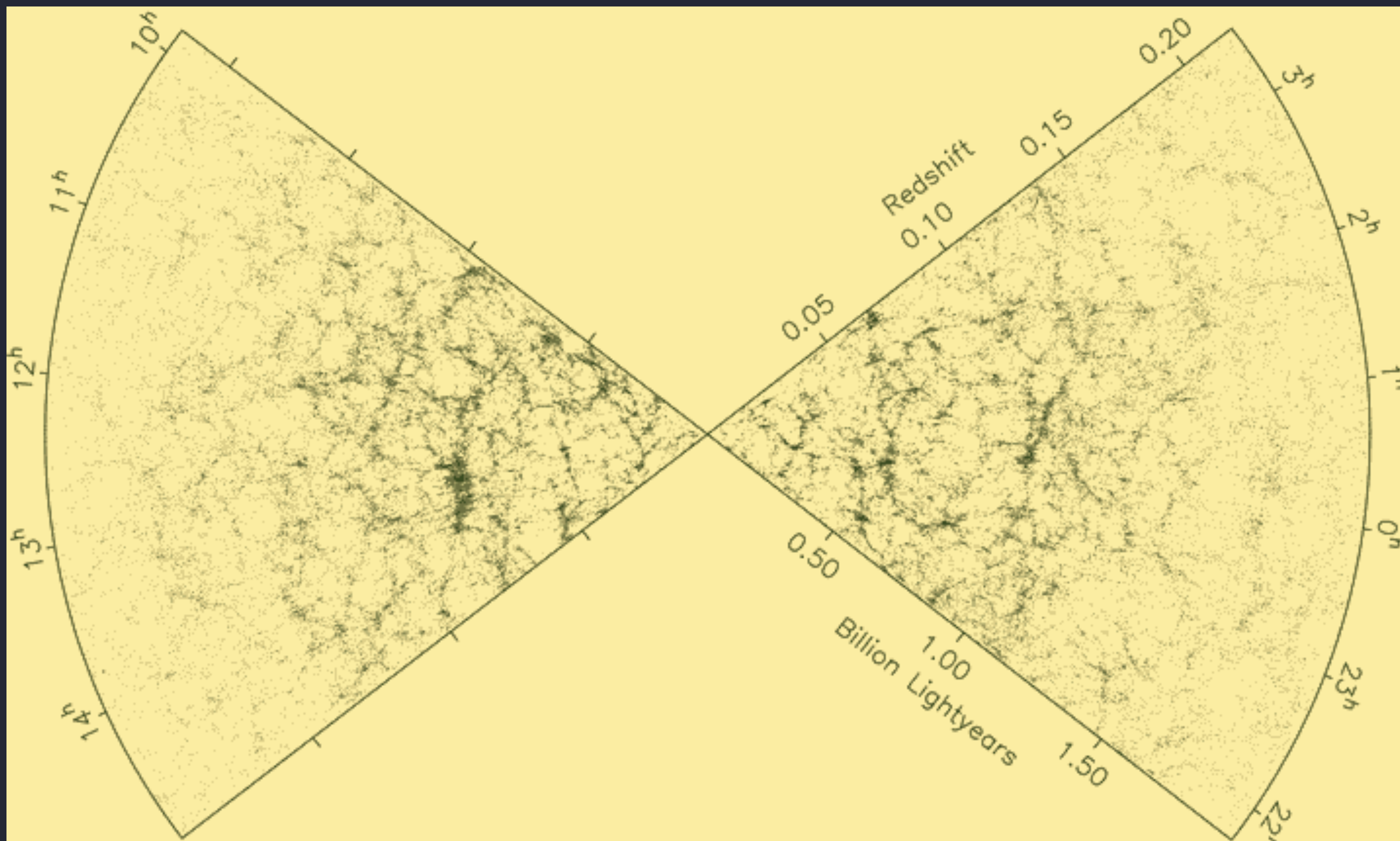


FIGURE 20.16 Interactive Figure Measurement of cosmic distances relies on a chain of interlocking techniques. The chain begins with radar ranging to determine distances within our solar system and proceeds through parallax and standard candle techniques. The use of these techniques allows us to calibrate Hubble's law, which we can then use to estimate distances to galaxies across the observable universe.

2df galaxy survey: each dot is a galaxy, we are at the center



Measuring the redshift of a galaxy (think back to the lab)

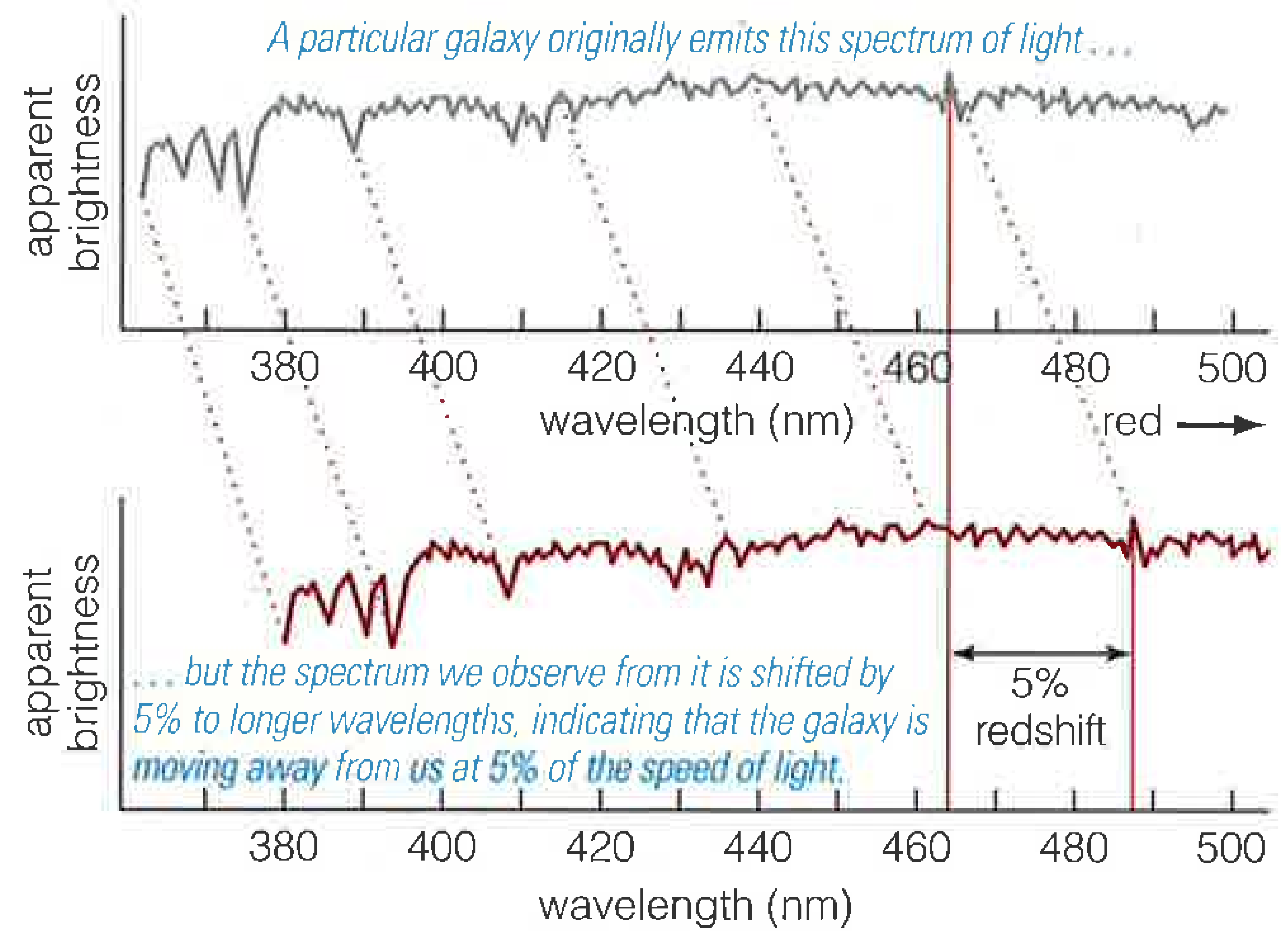
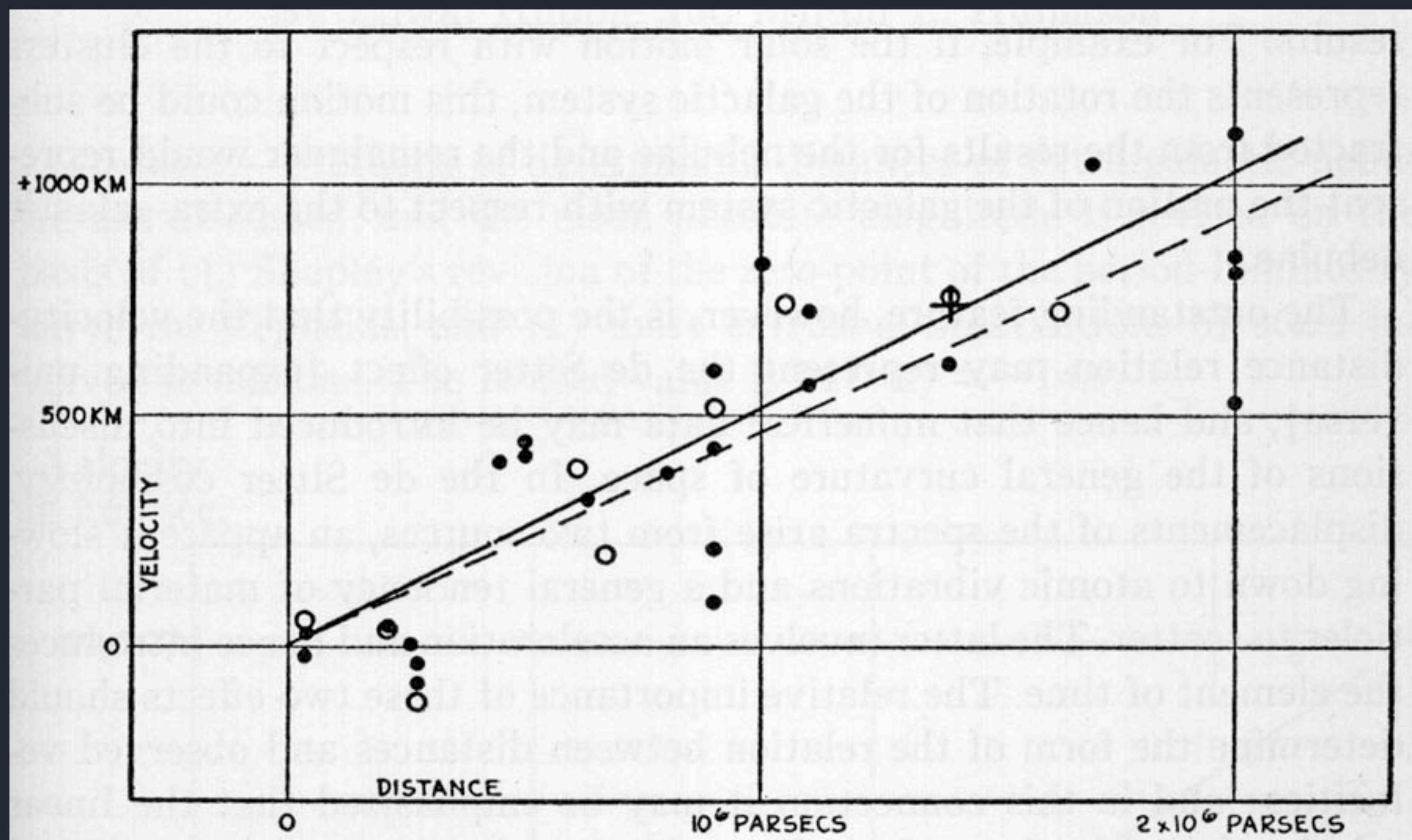
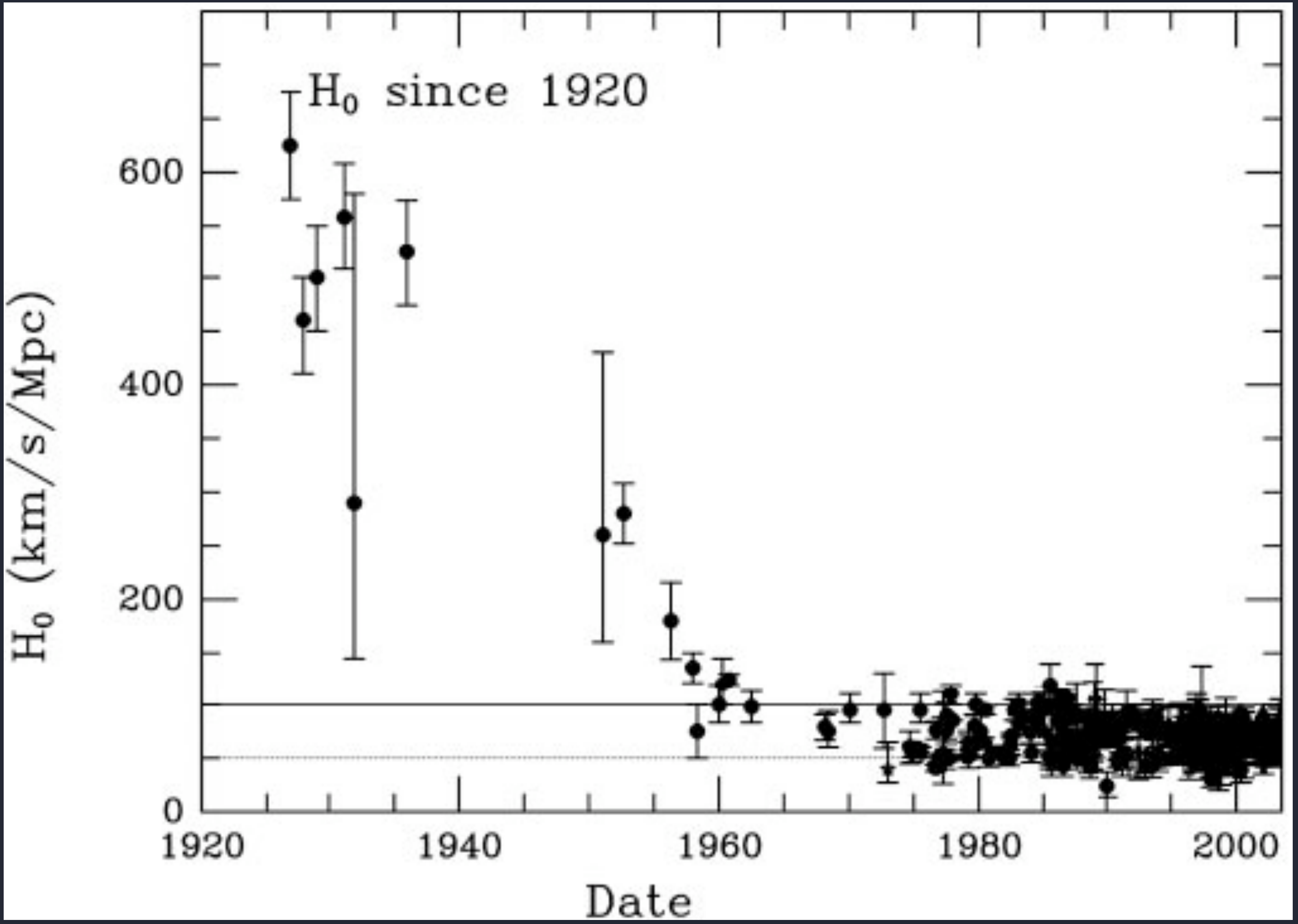


FIGURE 20.19 Redshifted galaxy spectrum.

Hubble's original (1929) velocity-distance relationship



Hubble constant *determinations* over time



the expansion of the universe is like a uniform stretching

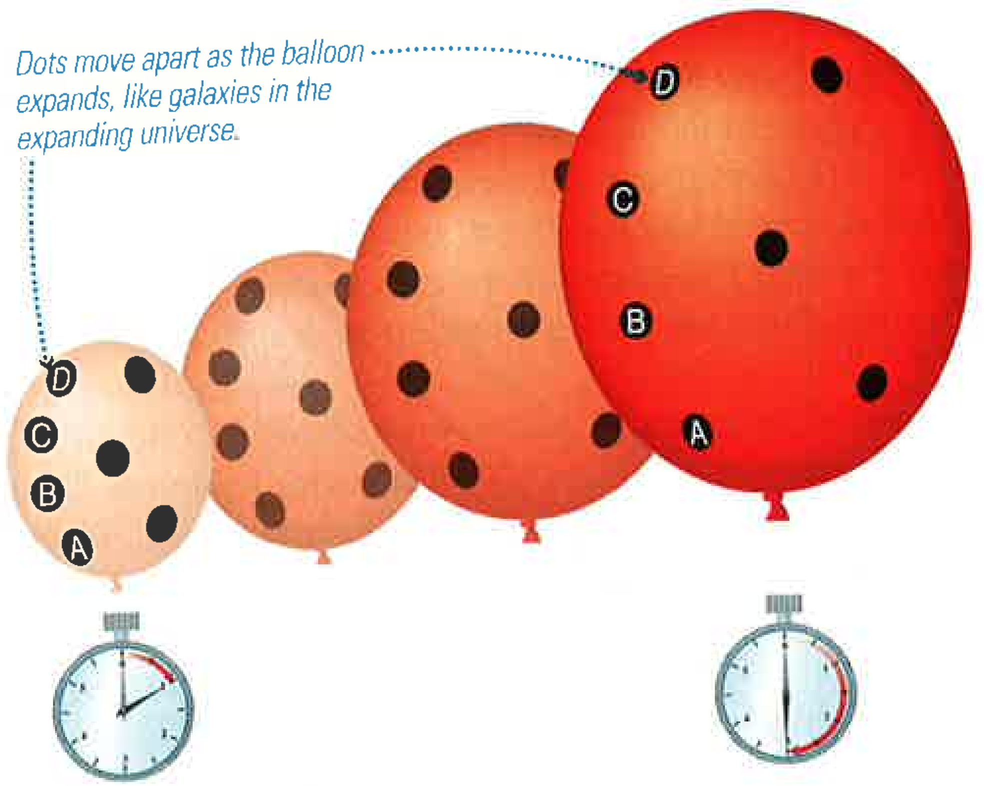


FIGURE 20.22 Interactive Figure As the balloon expands, the dots move apart in the same way that galaxies move apart in our expanding universe.

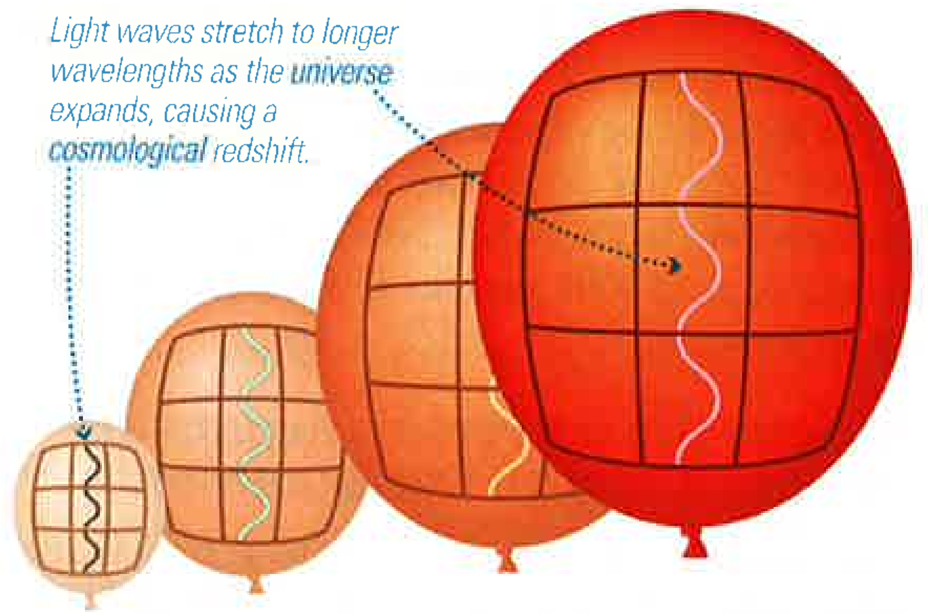


FIGURE 20.24 Interactive Figure As the universe expands, photon wavelengths stretch like the wavy lines on this expanding balloon.

as space expands, the distances between things increases...including the wavelength of light

The Universe is 13.6 billion years old, and it appears that it will expand forever

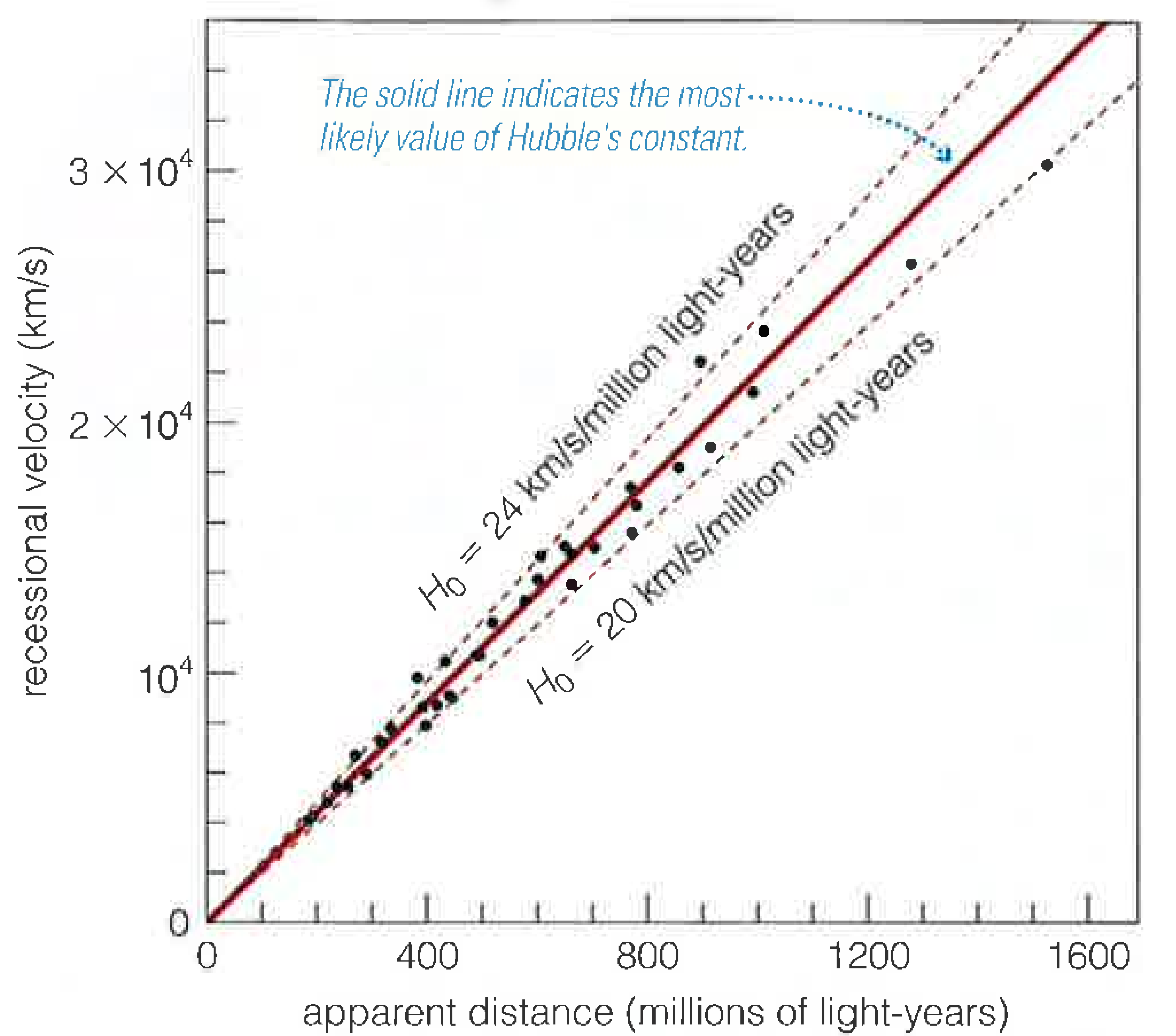


FIGURE 20.21 White dwarf supernovae can be used as standard candles to establish Hubble's law out to very large distances. The points on this figure show the apparent distances of white dwarf supernovae and the recession velocities of the galaxies in which they exploded. The fact that these points all fall close to a straight line demonstrates that these supernovae are good standard candles.