Galaxies

- Stars come in large groups (20 - 200 billion stars) called Galaxies
- >200 billion observable galaxies. Come in Shapes and Sizes depending on how they were formed

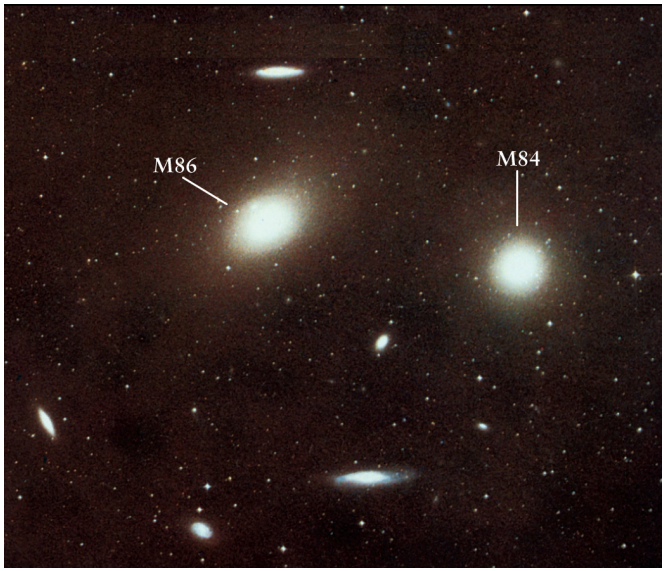
  Elliptical (football shape)
  Spirals (frisbee shape)
  Irregulars (ill-defined shape)

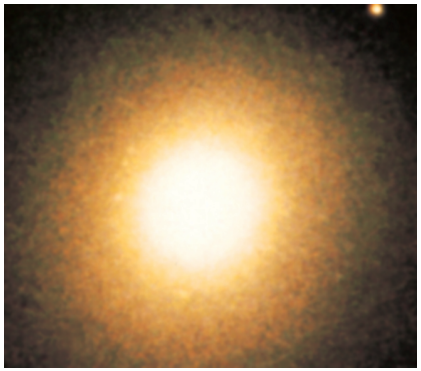
- Look at structure, mass, history of galaxies

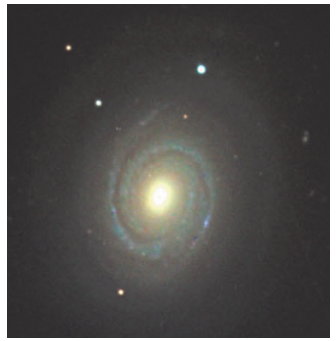
Hubble Deep Space View

The **Hubble Deep Field (HDF) is an image of a small region in the constellation Ursa Major,** constructed from a series of observations by the Hubble Space Telescope. It covers an area of 2.5 arcminutes across, about one 24-millionth of the whole sky, which is equivalent in angular size to a 65 mm tennis ball at a distance of 100 meters.

Galaxy Types



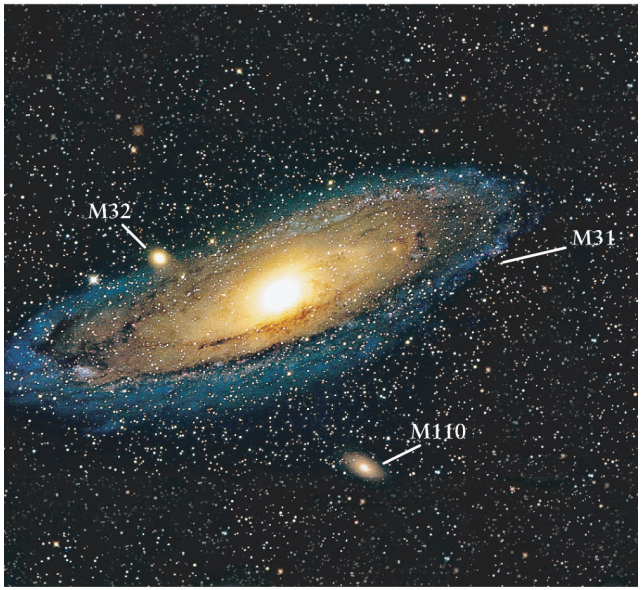


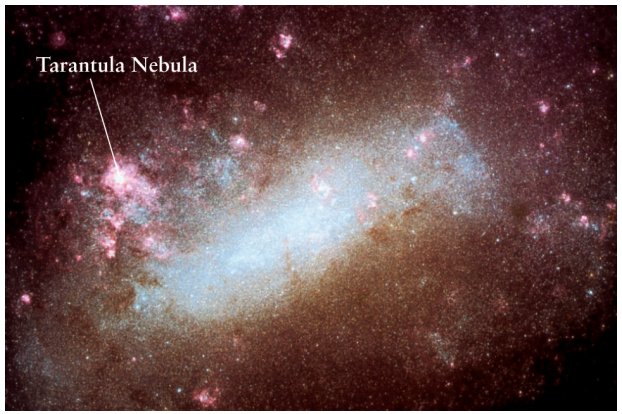


Elliptical ^

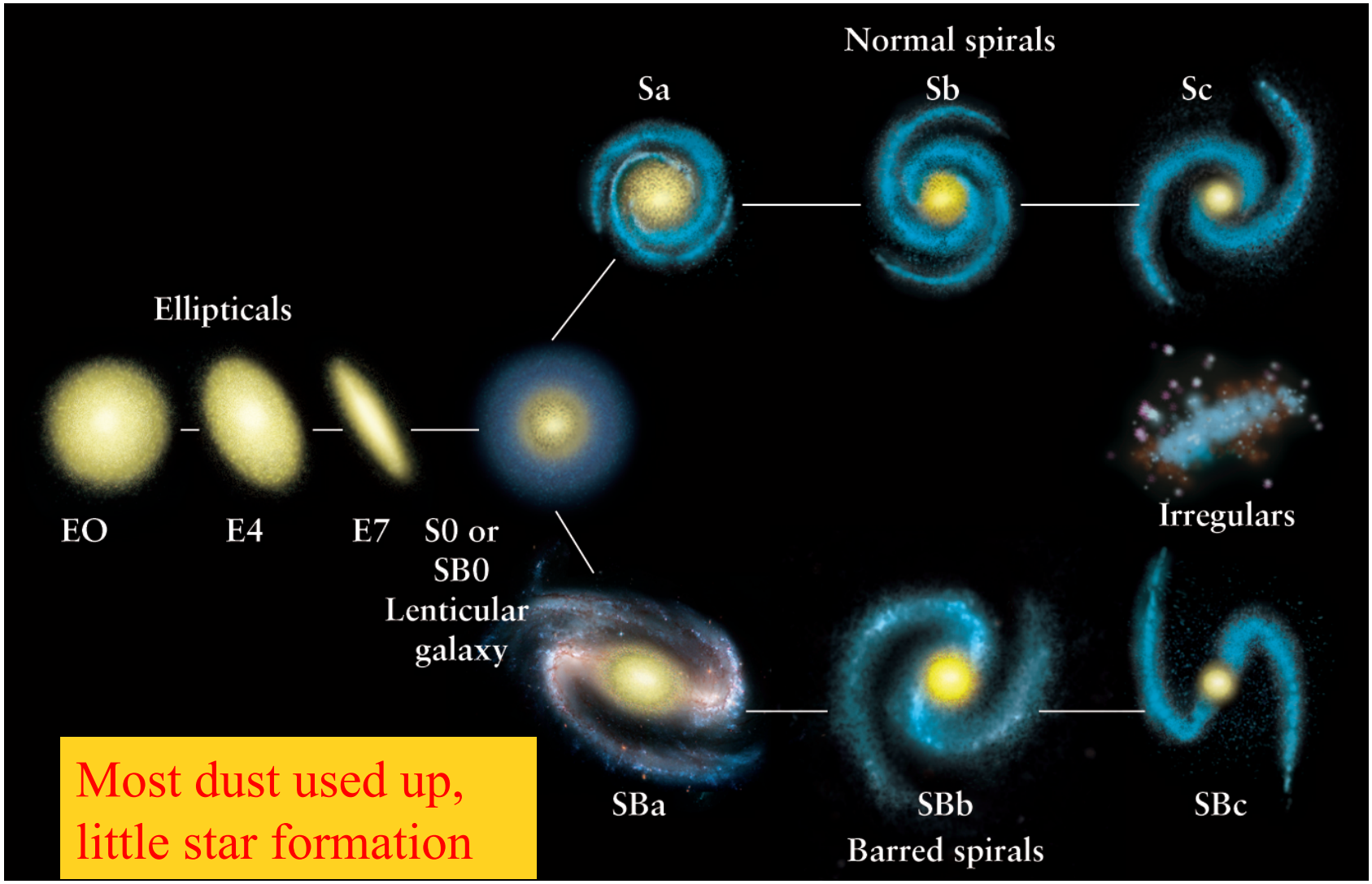
Spiral →

< Irregular v

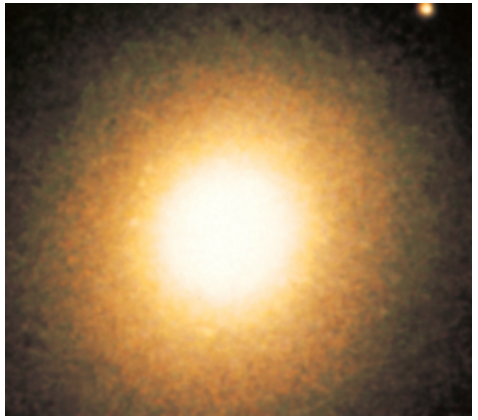




Galaxy Classification (won't test)

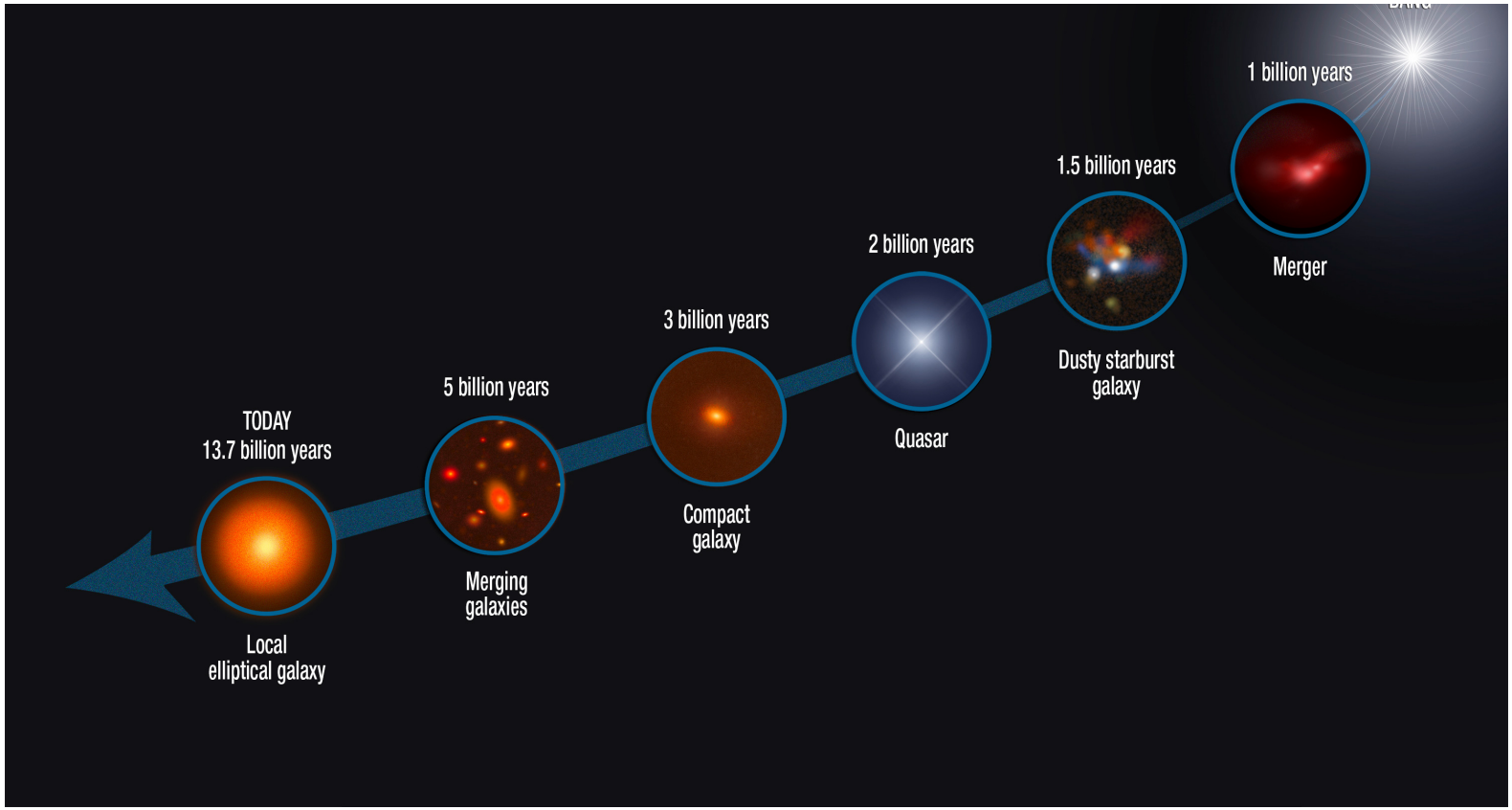


Elliptical Galaxies



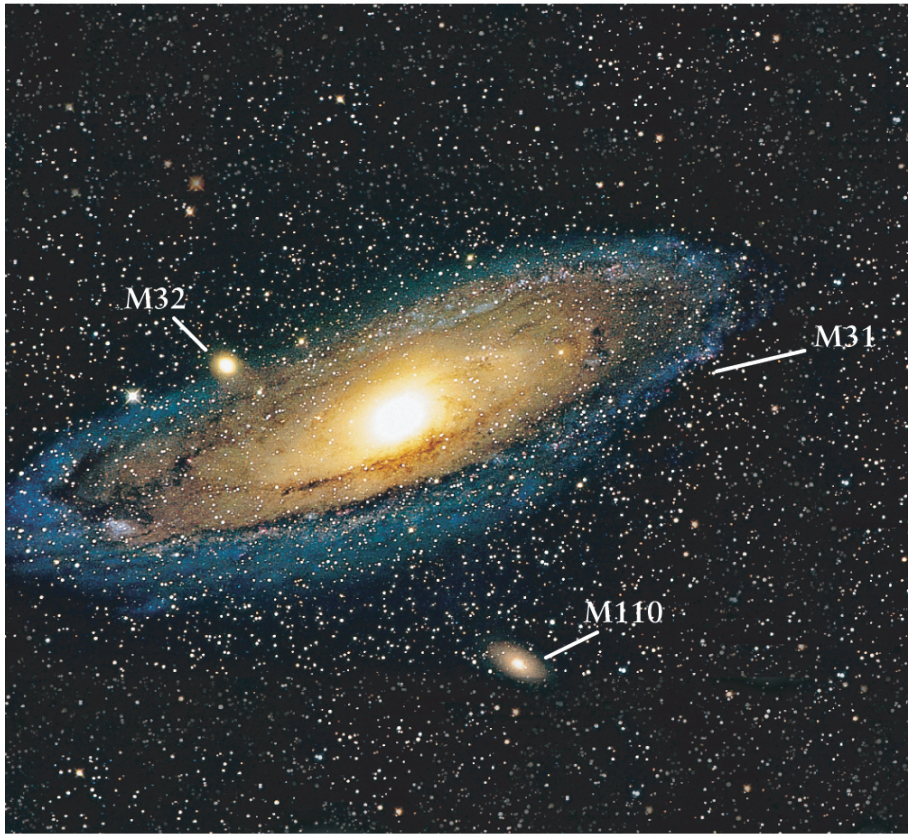
- Usually old Type II stars (little heavy elements)
- Limited new star formation (lack of gas)
- Range in size from 10^7 to 10^{13} times the mass of the Sun

Elliptical Galaxies



Thought to have been created by merging (colliding) galaxies common in the early universe…

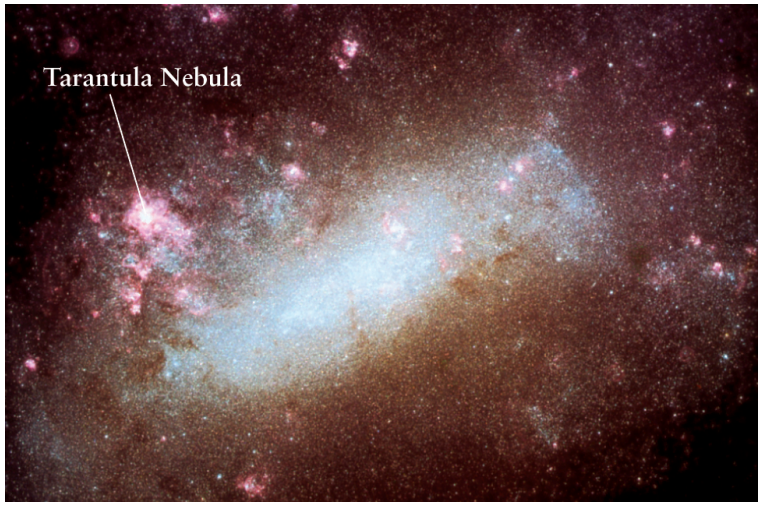
Spiral Galaxies



- Both young Type I (with heavy elements) and old Type II stars (little heavy elements)
- Active new star formation
- Range in size from 10^9 to 10^{12} times the mass of the Sun
- Most common type of galaxy

Andromeda M31

visible by eye 2.2 MLY away



Irregular Galaxies

- Mostly young Type I (with heavy elements)
- Active new star formation
- Range in size from 10^8 to 10^{10} times the mass of the Sun
- Mostly near larger galaxies whose gravity impacts shape

Large and Small Magellanic Clouds

visible by eye 170,000 LY away (angular size of LMC ~ 44 times larger than Moon)

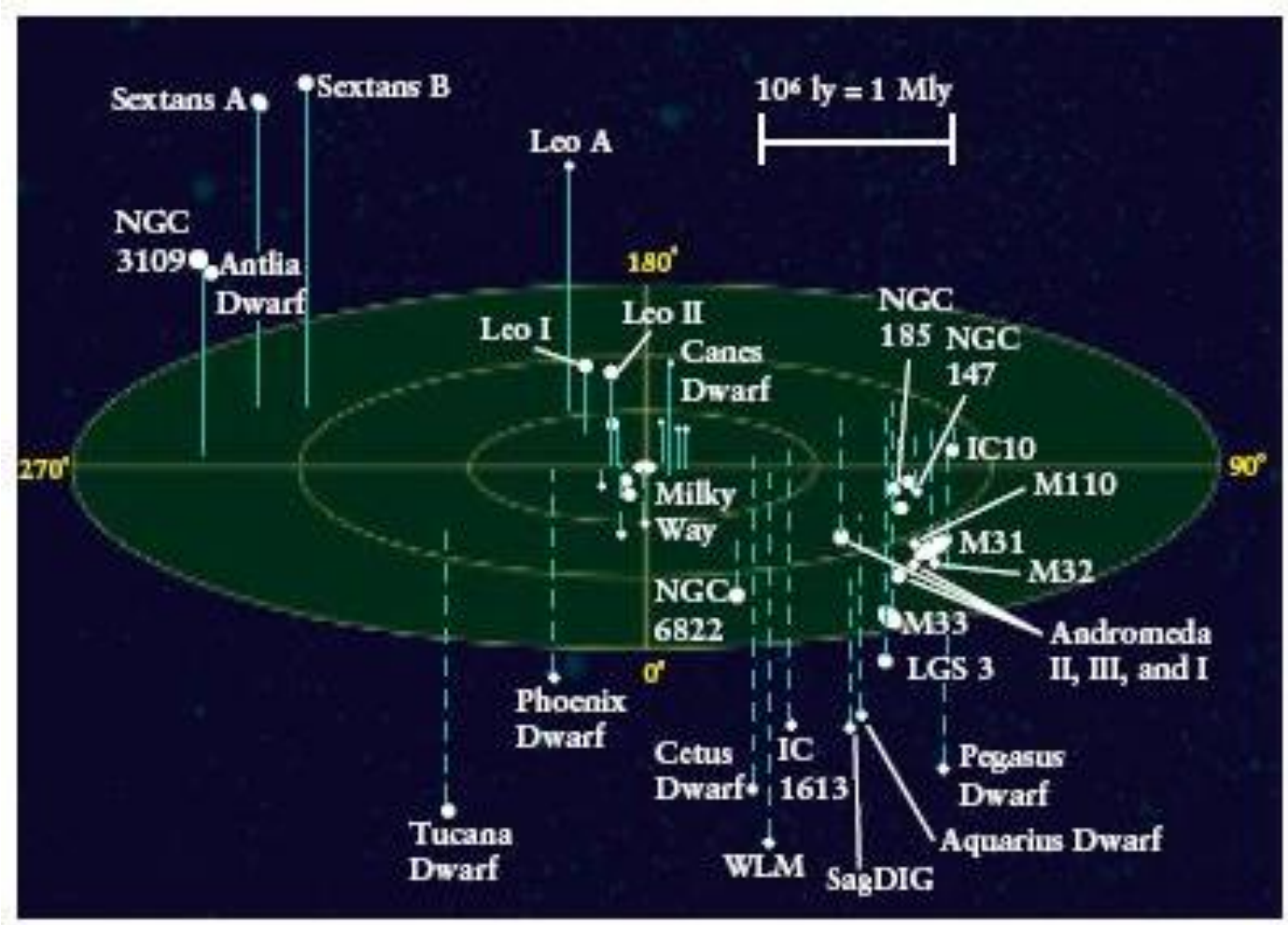
Galaxy Clusters and Superclusters

- Galaxies come in clusters of 10-1000 galaxies: gravitationally bound, impacts formation
- Clusters usually part of superclusters which reflect distribution of matter in early Universe

Formax Cluster

60 MLY from us

Local Cluster = "Local Group"

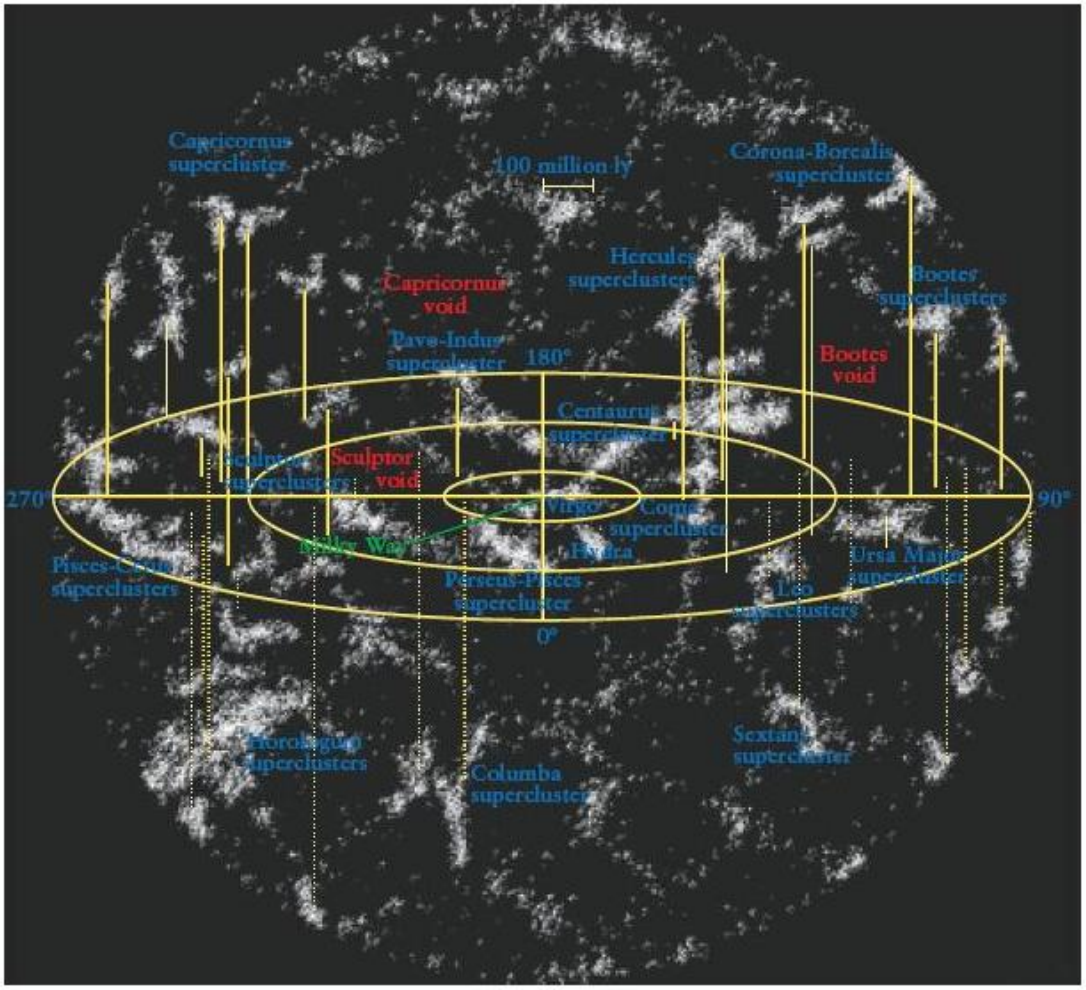


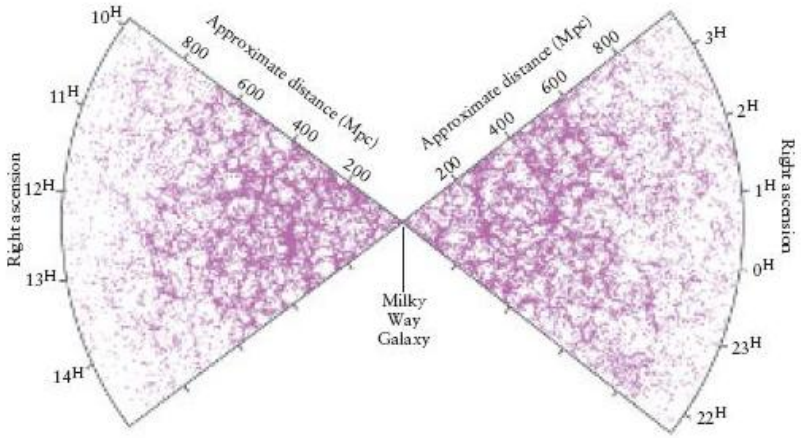
Spiral: MW, Andromeda (M31), M33

Elliptical: NGC205, M32, NGC185, NGC147

Irregular: LMC, SMC, NGC 6822, IC 1613

Superclusters of Galaxies

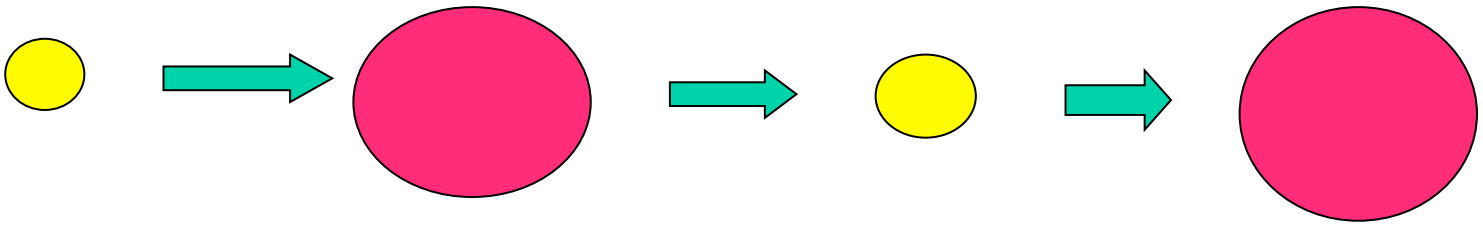




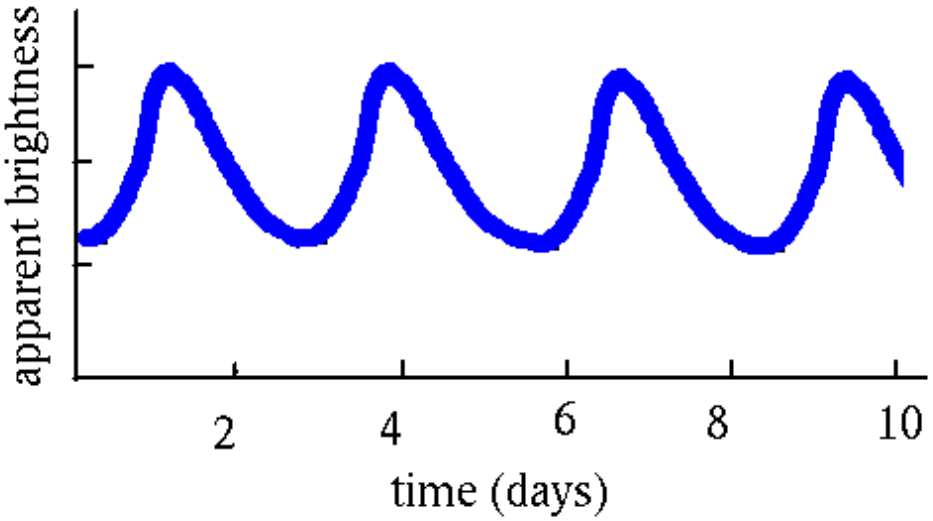
The 2dF Galaxy Survey

Measuring Distances

- Directly using parallax (triangulation) - good within few 100 LY
- "Spectroscopic parallax" - compare spectrum of distant star to similar close star. Large uncertainty.
- Variable Stars, especially Cepheids, give small error during certain stages of star's evolution it is non-stable. Luminosity varies with time

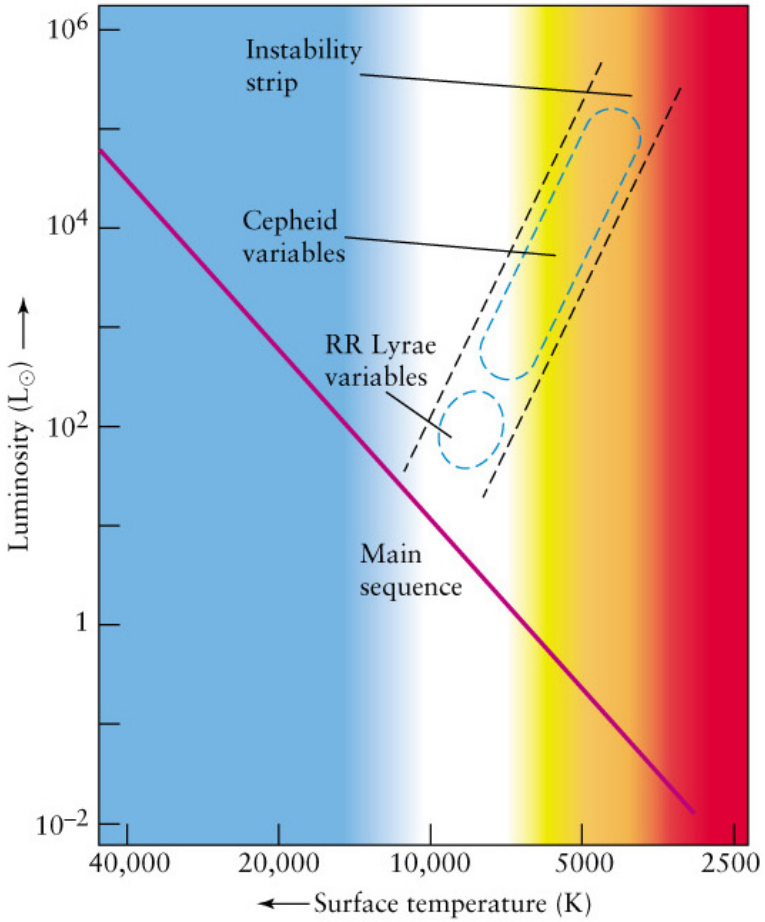


Variable Stars



Find that the brightness of some stars change with time.

Period → absolute luminosity



Variable Stars: Period vs Luminosity

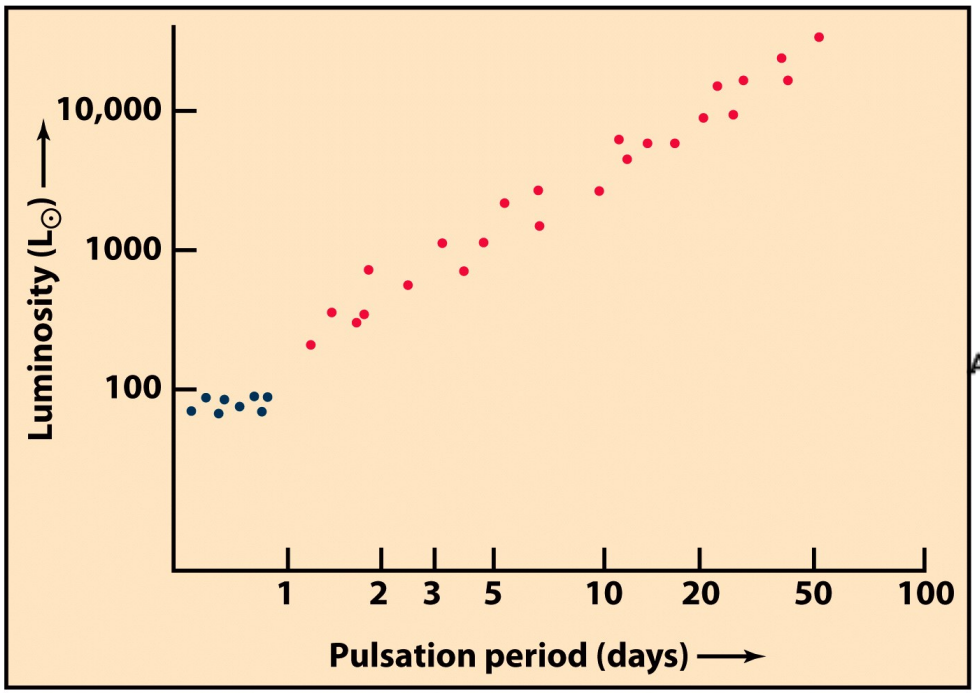
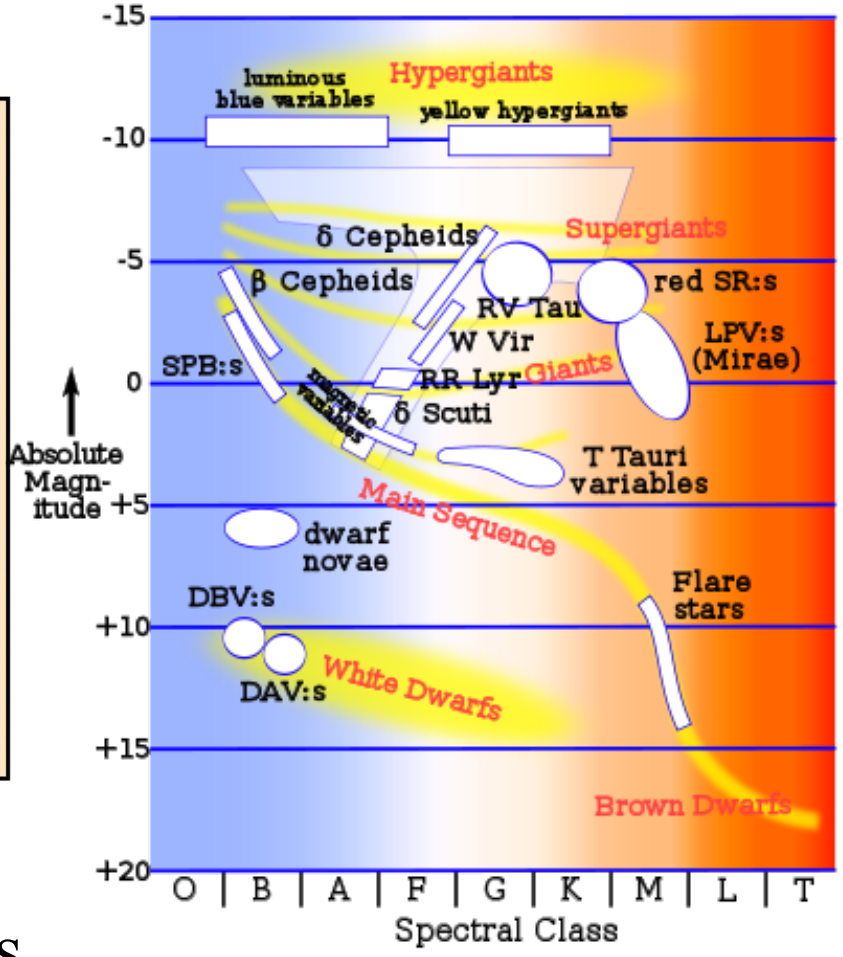


Figure 11-4
Discovering the Essential Universe, Fourth Edition

Cepheid and RR Lyrae Variables



Intrinsic variable types in the Hertzsprung–Russell diagram

Variable Stars

- Because "easy" to measure period of variable star, "easy" to know its absolute luminosity: a "standard candle"
- Finding just a few variable stars gives accurate distance measurement as measure apparent luminosity → distance

(absolute brightness plus apparent brightness gives distance)

- Early 20th Cent. studies of variable stars in Magellanic Clouds gave new tool – Henrietta Leavitt 1908-1912
- Led to understanding intergalactic (> 1 MLY) distances - Edwin Hubble 1920s

Variable Star => Galactic Distances

- Cepheid Variables: common (Polaris is one). Bright, 100,000 L(Sun). First discovered in 1784. 1908: Henrietta Leavitt studies thousands in Large Magellanic Cloud (she was a "computer" working at Harvard; usually females who studied photographic plates in US)

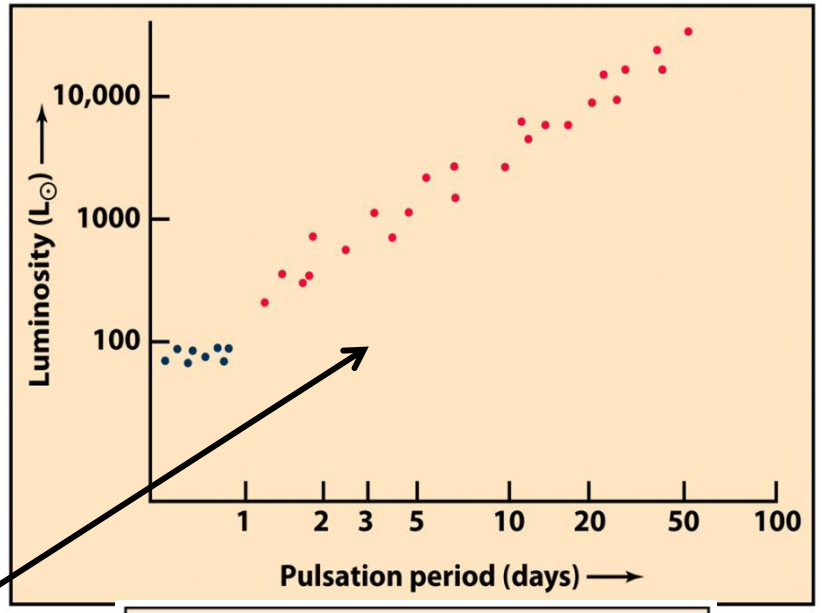


Figure 11-4
Discovering the Essenti
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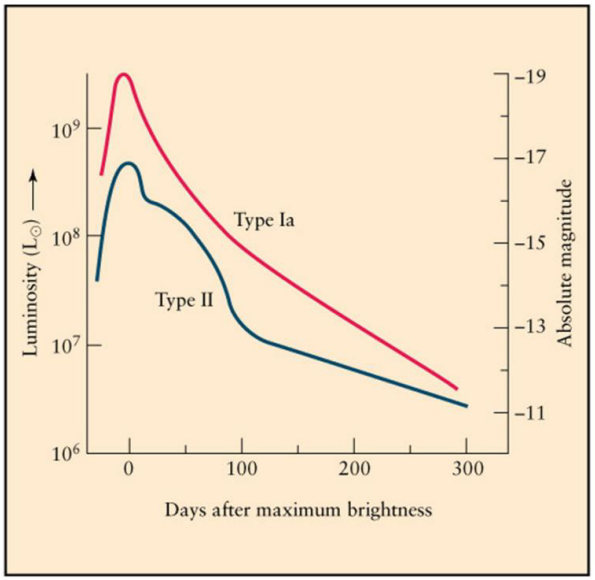
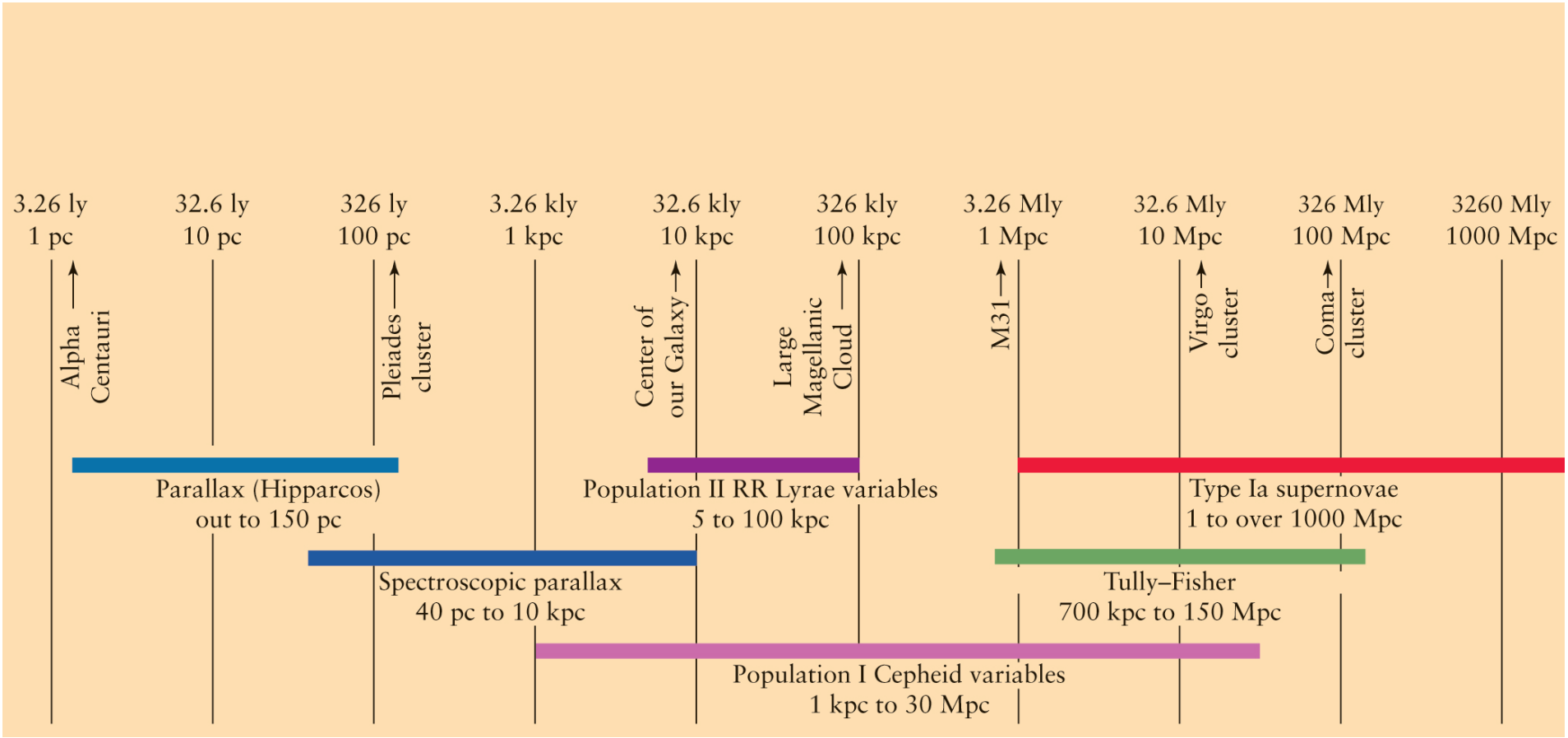
- Type Ia supernovas (white dwarf collapse): Rare but very bright. 10 billion times L(Sun)



The Astronomical "Distance Ladder"



Hubble Law

- Measure velocities of galaxies
  - almost all are moving away
  - larger velocity if further away
- Observe $V = H \times D$ Hubble Law

  V = recessional velocity

  D = distance

  H = Hubble "constant"

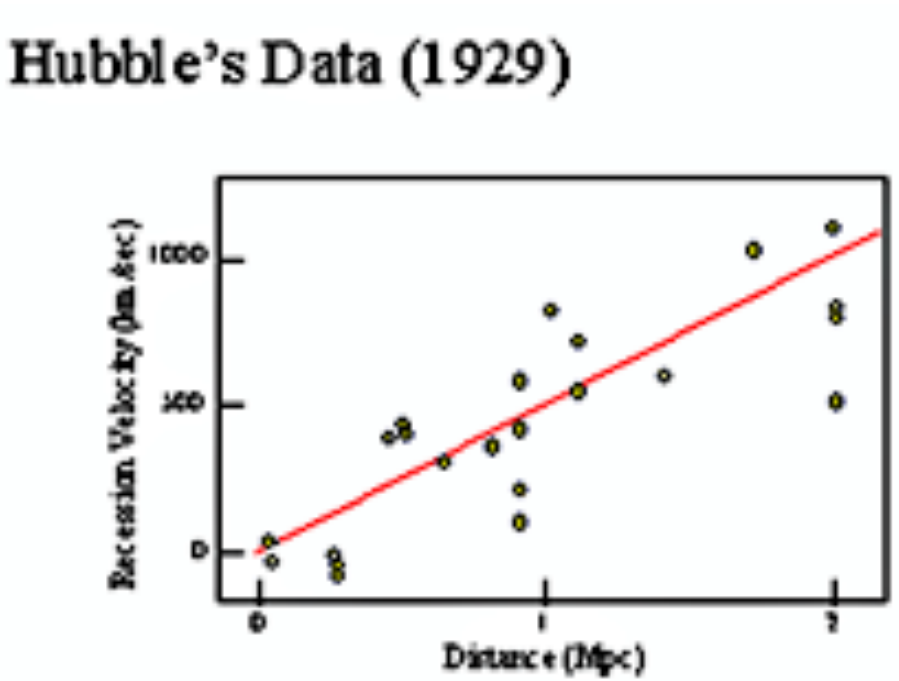
Edwin Hubble 1889-1953

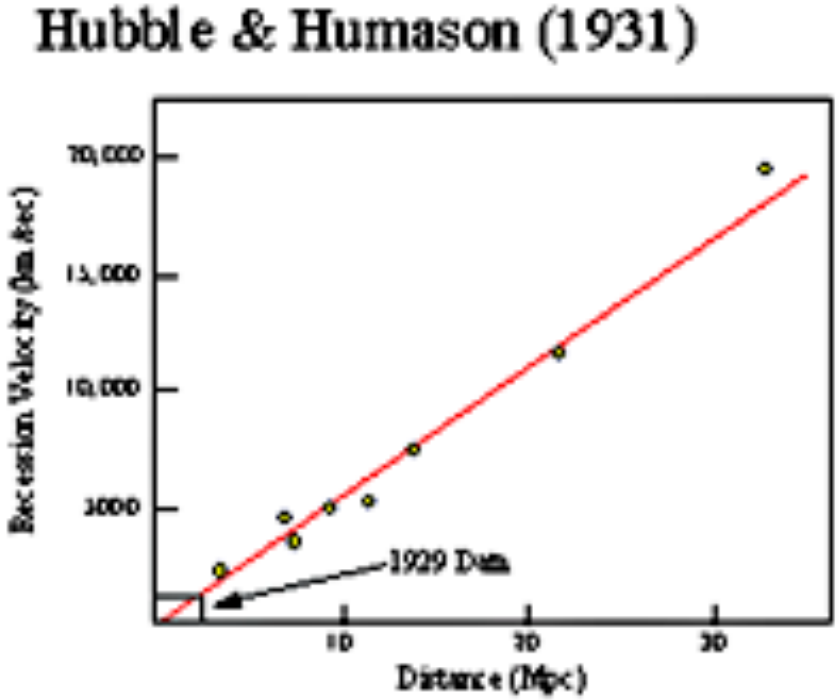
- Grew up in Wheaton, IL, college at U. of Chicago
- Used Mt. Wilson Observatory in Pasadena, CA
- 1922-23. Observed Cepheid variable stars in a number of spiral "nebula" demonstrating they were far away and so galaxies
- 1927-29 combined his distance measurements with redshift measurements of Slipher and Humason giving a measurement of the "Hubble Law"

(though not the first…)

Hubble Law

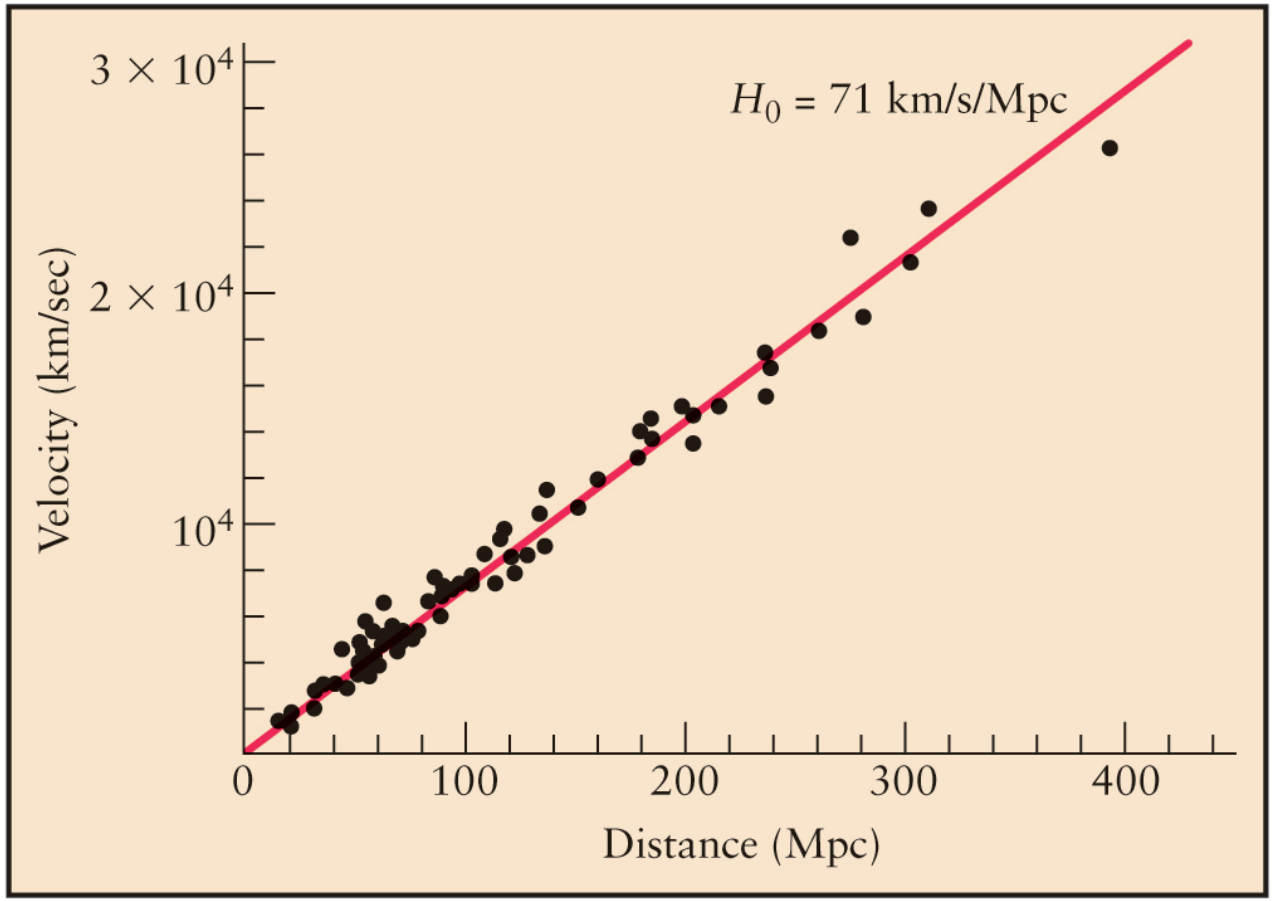
- plotted 46 galaxies in 1929, some indication of straight line relationship in distance vs recessional velocity plane. Later data at greater distances confirmed this (all being done "by hand")



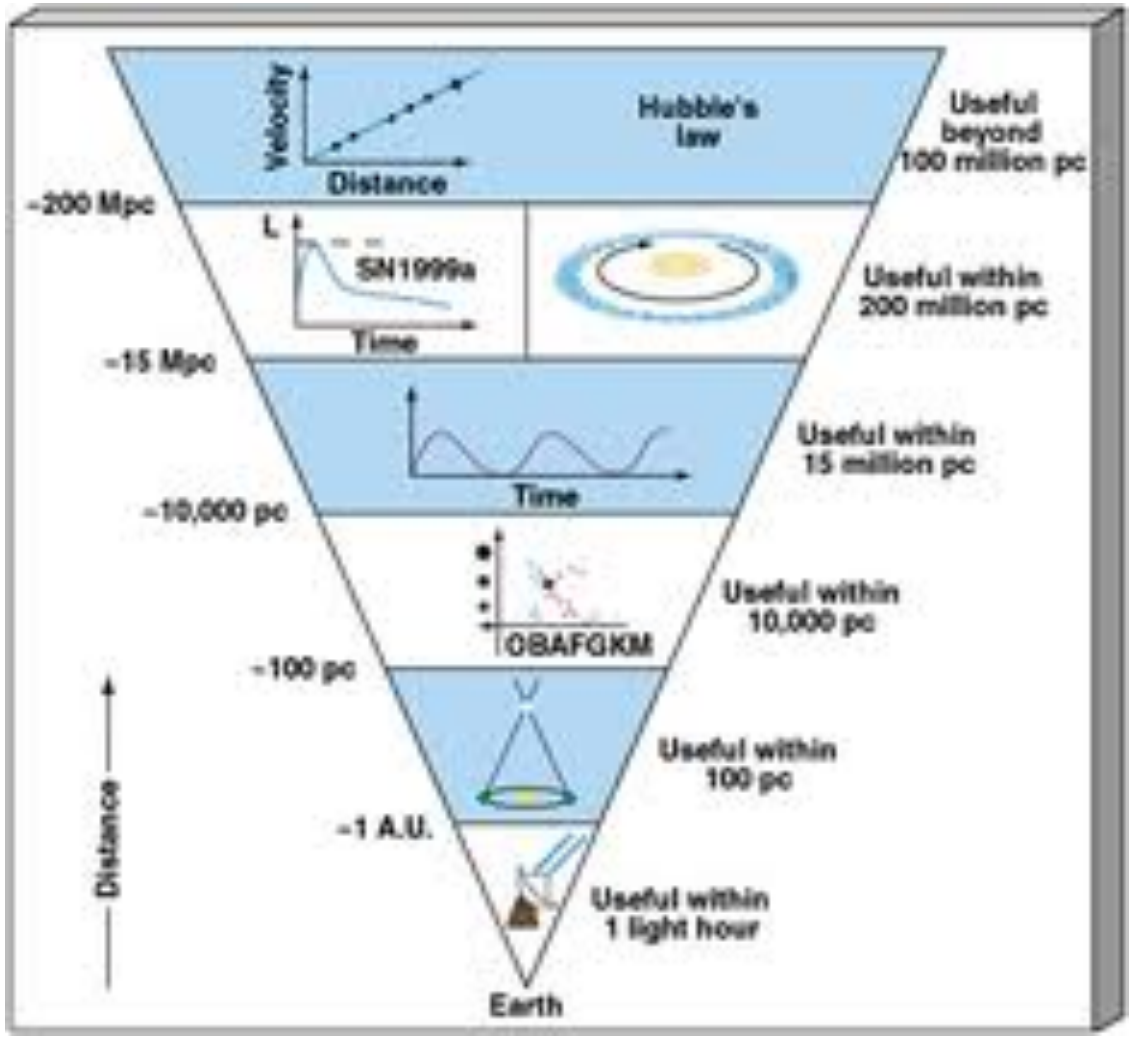


Hubble Law

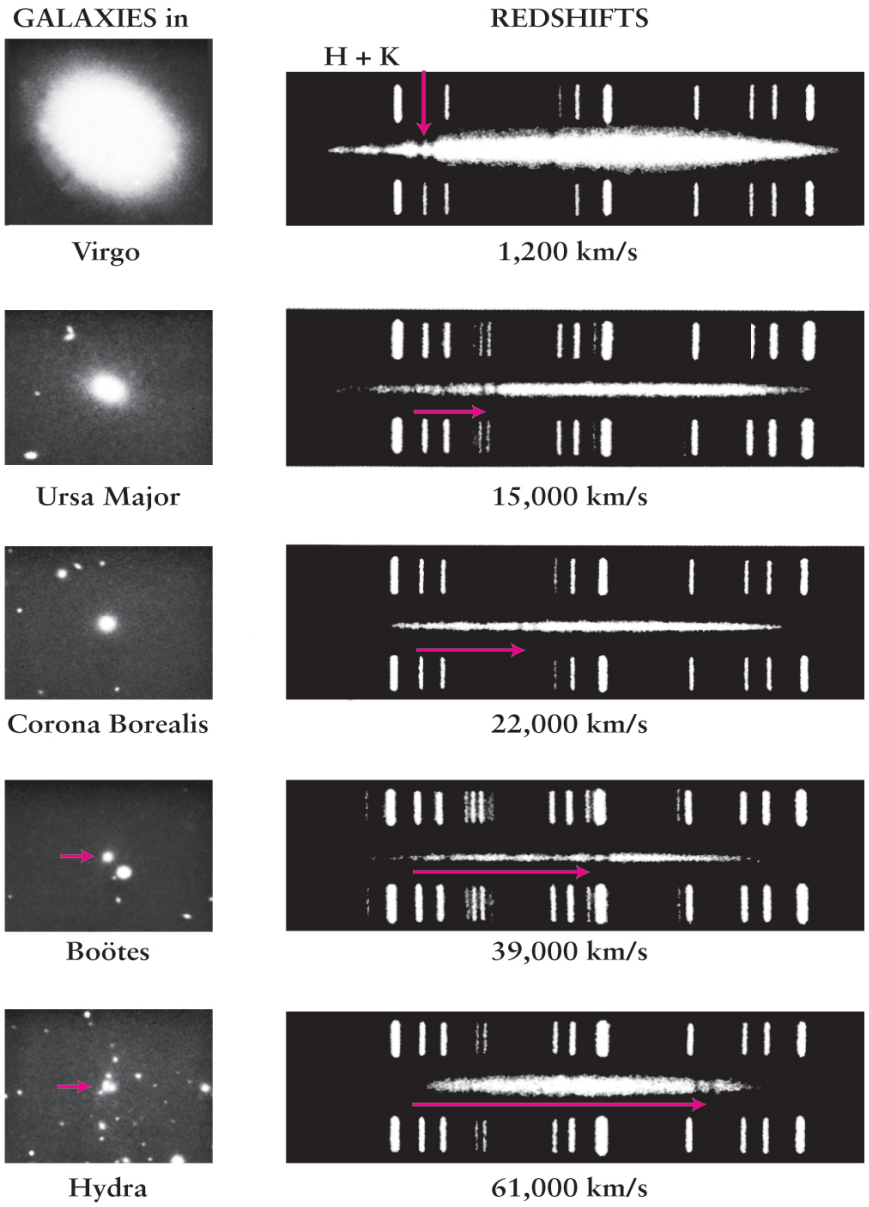
- Measuring recessional velocity vs distance and understanding it is now one of the highest priorities in astrophysics
- Mostly use Supernovas for most distant objects



Hubble Law → Distance



- Once you have measured Hubble Law (using supernovas) then a measurement of the redshift gives you the distance
- Use for determining distance to galaxies formed in early Universe even if they don't have a supernova



Hubble Law → Distance

- Doppler shift larger for more distant galaxies

Meaning of Hubble Law

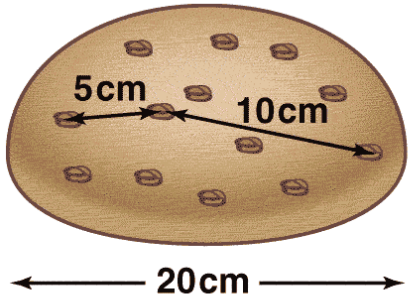
- Distant objects are moving away from us → Universe is expanding
- This was predicted by Einstein's general theory of relativity (~1915) but Einstein thought it was a mistake in the theory prior to results from Hubble and others observations in 1926-1935
- Measurement of Hubble constant gives age of Universe - about 13-14 billion years - depends on how Hubble "constant" is changing with time

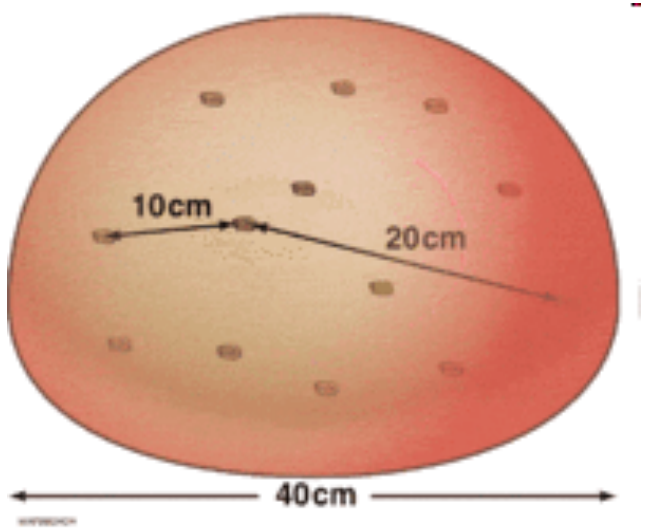
Edwin Hubble, more history…

- We tend to give credit to Hubble for the first observation that the Universe is expanding.
- However Hubble wasn't the first to show the linear relationship between velocity and distance (the Hubble Law) and did not connect this to an expanding Universe
- George Lemaitre did this in 1926 (using same data as Hubble in 1929) plus he derived the "Hubble Law" from Einstein's general theory of relativity

Rubber Band or Balloon or Bread Model

- Mark points on rubber band or balloon or use raisin bread
- Stretch outward at uniform rate
- Velocity away from any point is larger if other point is further away → 5th grad math gives Hubble Law





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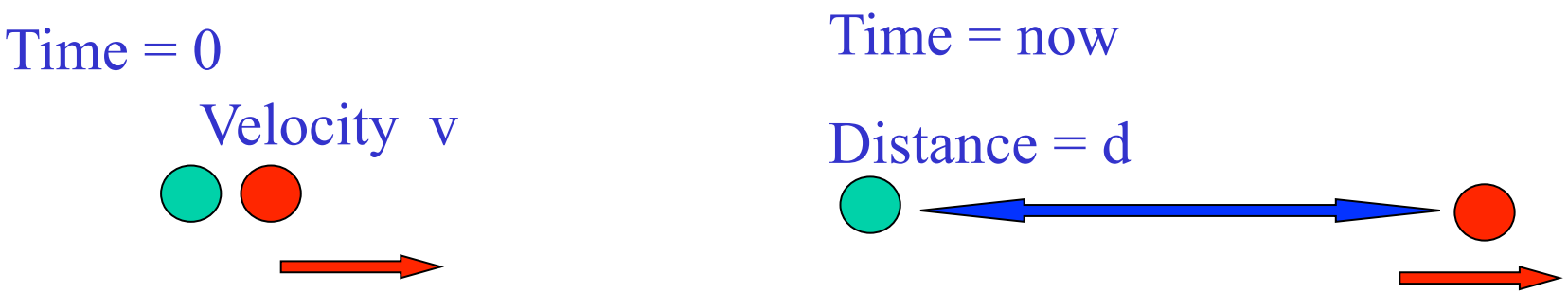
Hubble Law → Age of Universe

- Hubble Law → v = Hd
- Universe is expanding. Work backwards to estimate when time began
- assume constant velocity (not true)

time = distance/velocity = d/v but v = Hd

time = d/Hd = 1/H

so 1/H is about the age of the Universe



Hubble Law → Measure Age of Universe

1/H gives approximate age of Universe (assumes H "constant")

need to convert 71 km/sec/Mpc to inverse years

Remember, parsec = ***par****allax of one* ***arc****second*

$$1\,Mpc \approx 3.3\,MLY$$

$$1LY = 300{,}000\,km/\sec * 1\,year$$

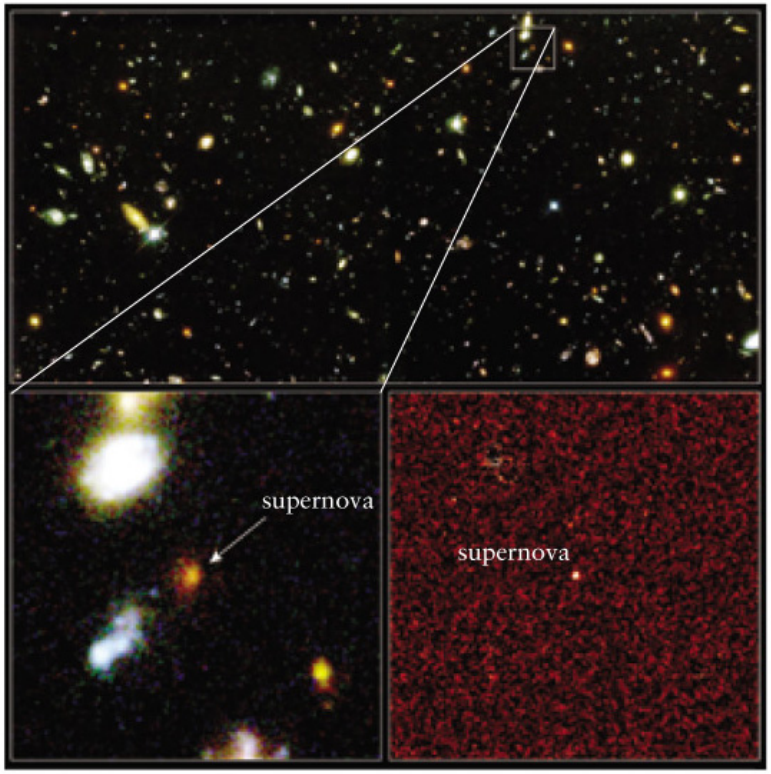
$$\Rightarrow \frac{1}{H} = \frac{Mpc}{71 km/\sec} \approx \frac{3.3\times 10^6 \times 3\times 10^5\, km/\sec * year}{71 km/\sec}$$

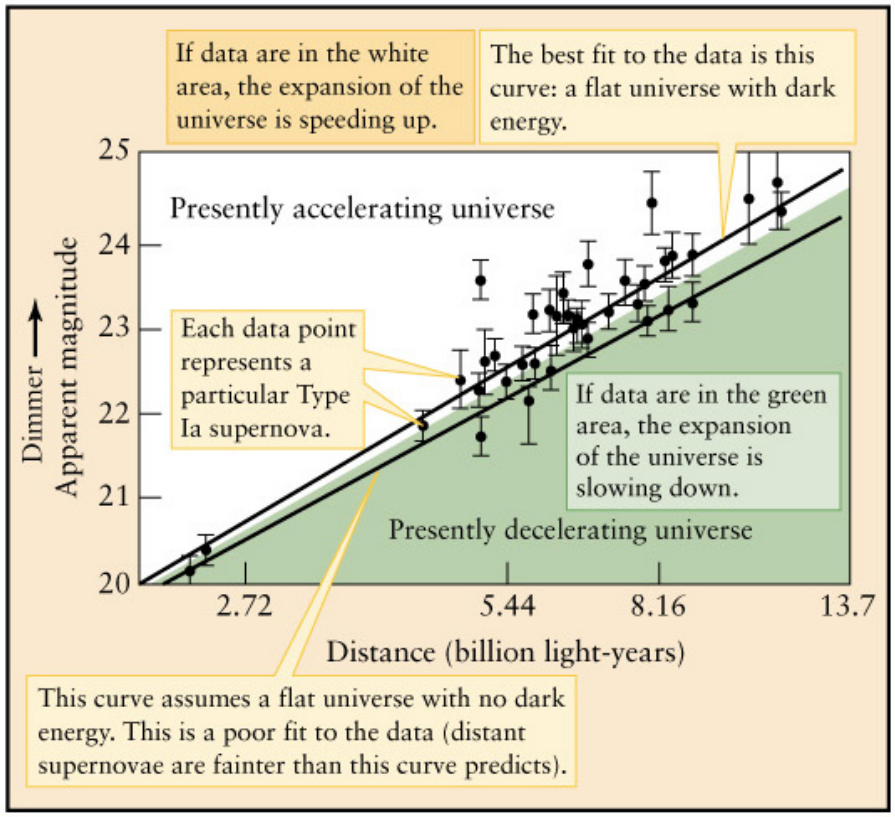
$$\Rightarrow \frac{1}{H} \approx 14\,billion\,years$$

Expanding Universe Facts..

- Hubble constant H changes with time
- Gravity can slow the expansion rate (by pulling "inward")
- Expand forever → Open Universe
- Stop expanding and then contracts → Closed Universe
- How rapidly H changes depends on the amount of matter - we seem to be very close to the Critical Density which separates an Open from a Closed Universe (hint of underlying physics?)
- Recent (perplexing) data indicated Universe is accelerating! Like anti-gravity!

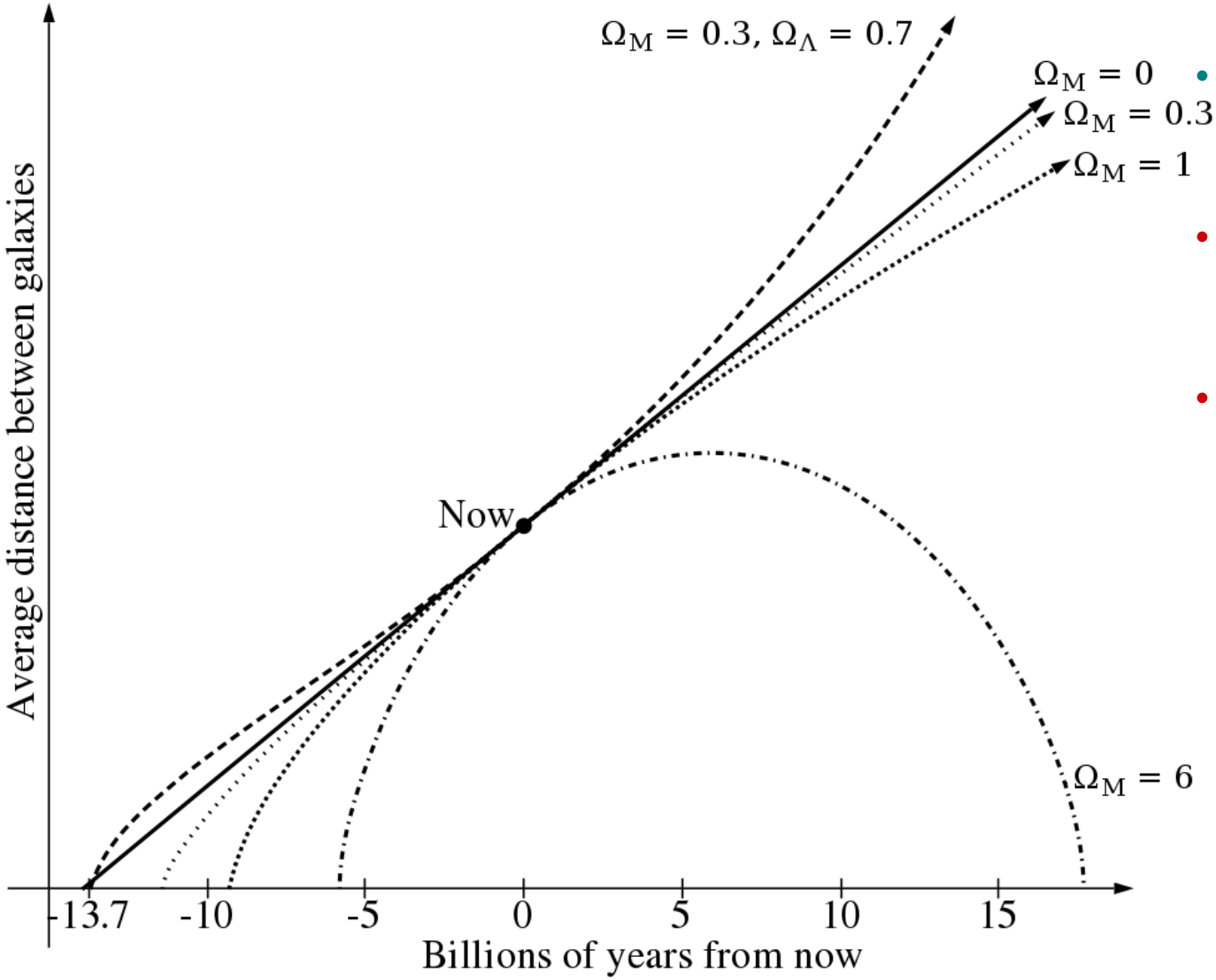
Expanding Universe Facts (con't)





- Most distant supernovas are dimmer then expected (2011 Nobel Prize)
- Shows rate of expansion of Universe is increasing
- "Dark energy" used to explain, though no one quite knows **what** this is

Expanding Universe, (con't)



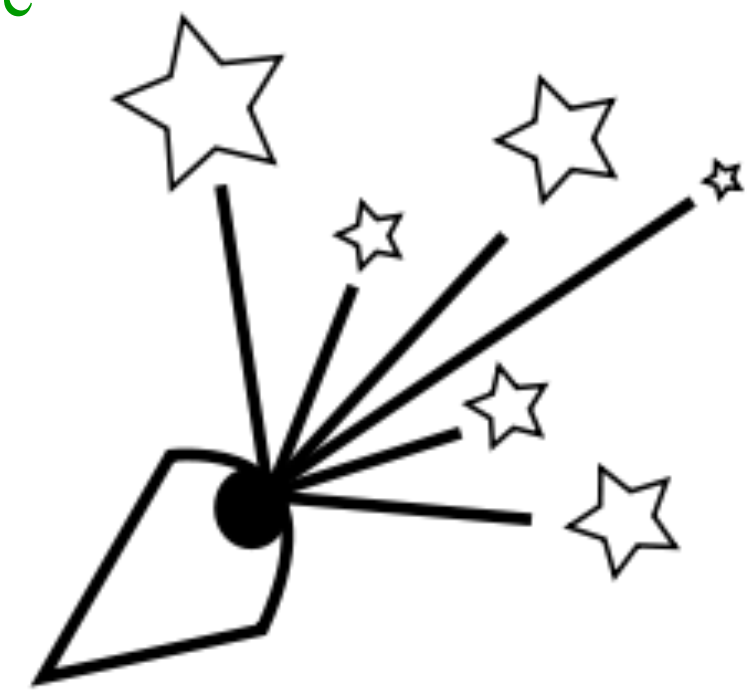
- Hubble constant H changes with time
- expand forever → Open Universe
- stop expanding and then contracts → Closed Universe

Cosmology

- Origin, early history, and fate of the Universe
- Does the Universe have a beginning? An end? What physics processes "caused" the Universe to be what it is? Are other universes possible? Would they look like ours (have the same physics)?
- Cosmological Principle - the Universe appears the same from any location - Isotropic
  - no center
  -no edge
- Indication that the Universe is finite in time, is expanding, and it has been ever since it was created in the Big Bang about 13 billion years ago

Why is the Sky Dark at Night? Olber's Paradox

- If the Universe were infinite, then their would be an infinite number of stars. As dark at night, Universe is finite in time (first suggested as answer by Edgar Allen Poe) and/or distance



Every line of sight ends on a star