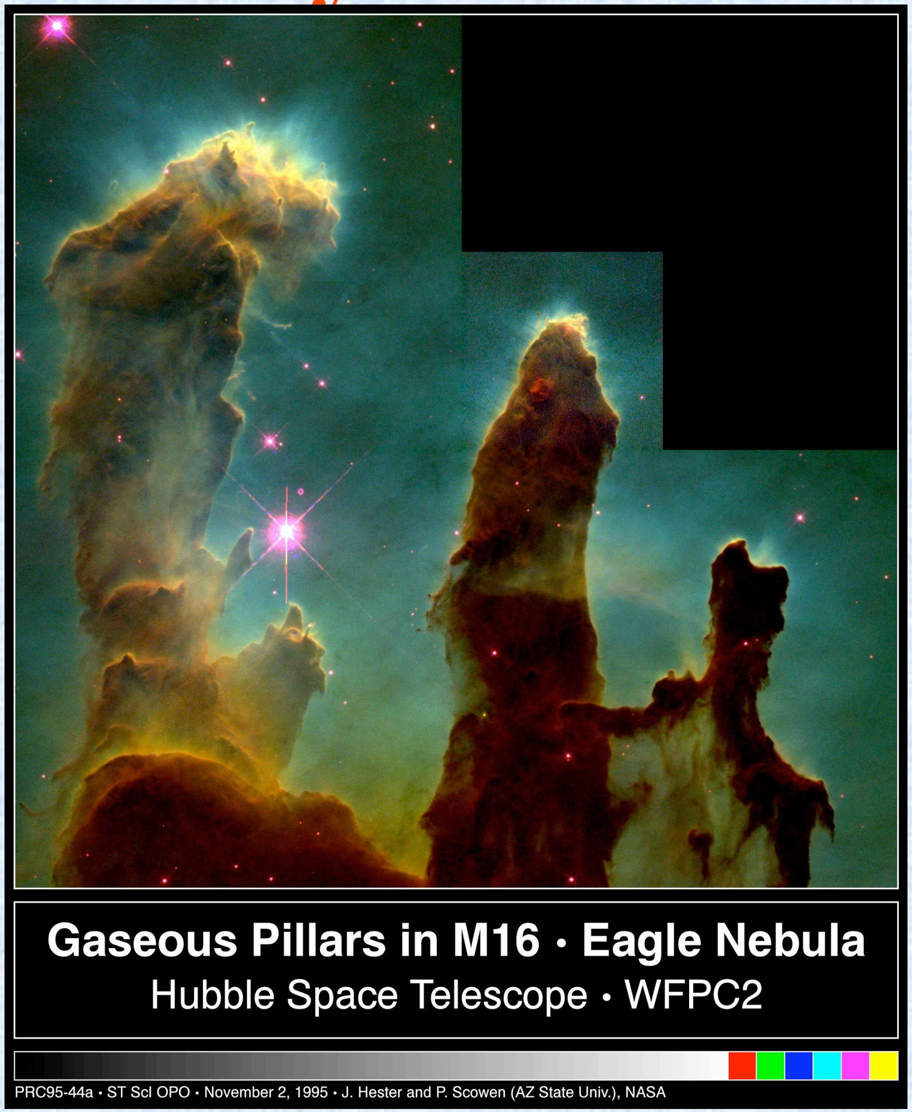
Astronomy 1 – Winter 2011



Lecture 24; March 7 2011

Previously on Astro-1

- Introduction to special relativity
- Introduction to general relativity
- Introduction to black holes, stellar and supermassive

Today.. On Astronomy-1. Introduction to cosmology

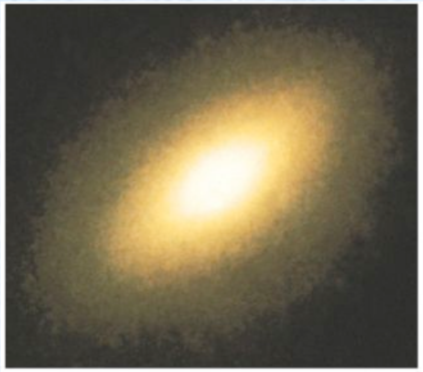
1. Olbers's paradox. The Universe is evolving
2. Hubble's Law. The Universe is expanding
3. Timescales.
4. The age of the Universe and the age of stuff in the Universe. Is there a conflict?

The universe is filled with galaxies

Spiral galaxies and barred spiral galaxies

Lots of interstellar gas

Ongoing star formation in the spiral arms



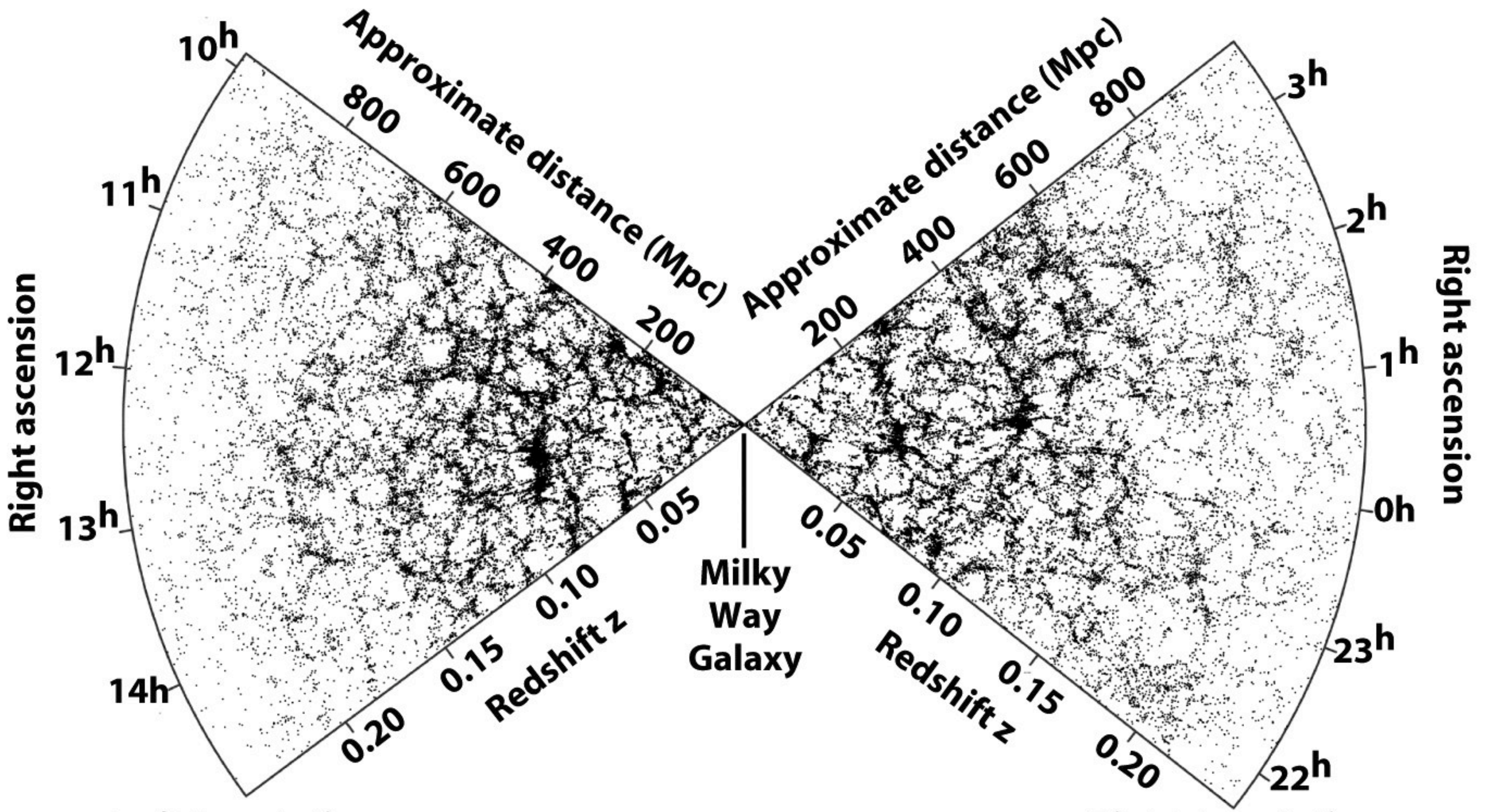
Elliptical galaxies

Little interstellar gas

No ongoing star formation

Irregular galaxies

Lots of interstellar gas Ongoing star formation

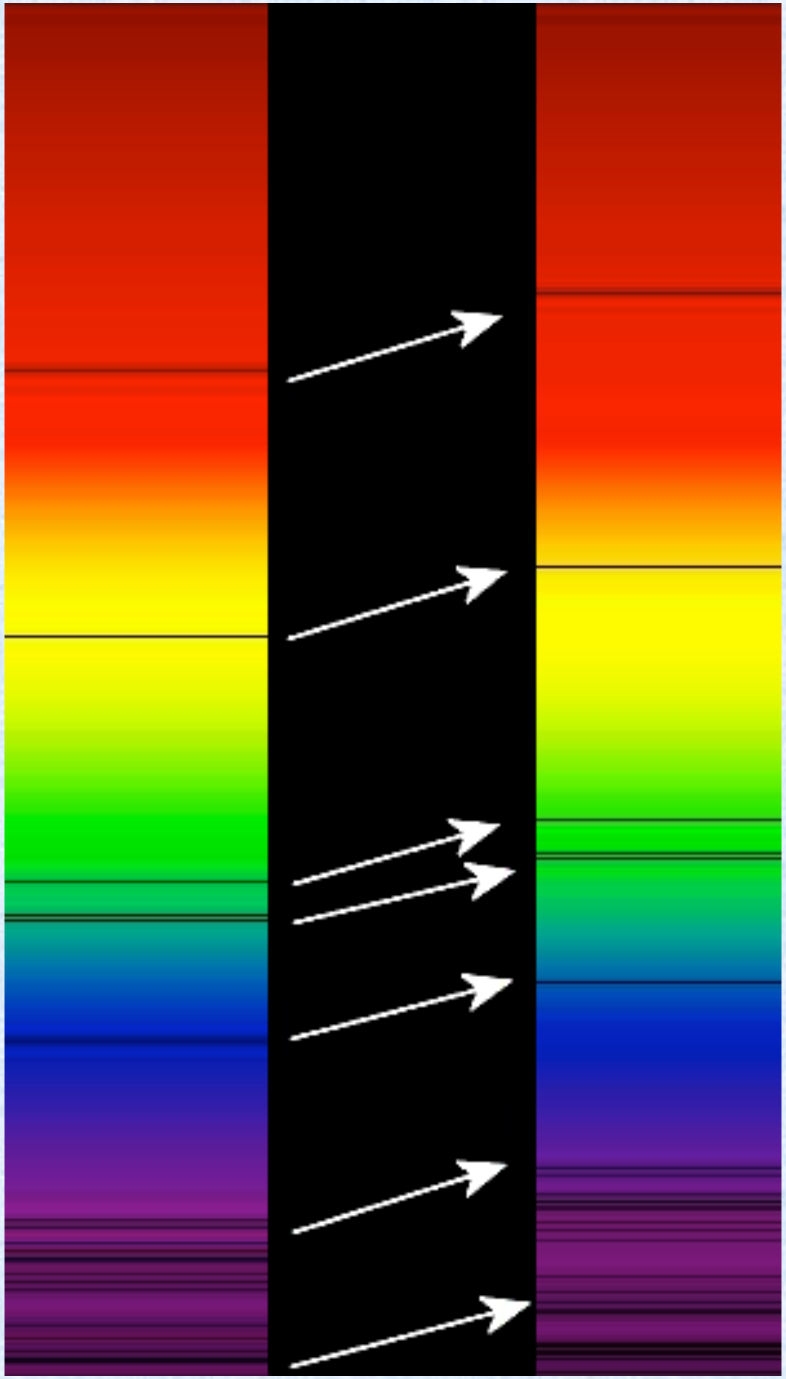


Left-hand slice:
Declinations bracketing 0°

Right-hand slice:
Declinations bracketing –30°

The 2dF galaxy survey

Figure 24-24a
Universe, Eighth Edition



Redshift

Distant galaxies have spectra that are the superposition of millions or billions of stellar spectra. For all but a few of the nearest galaxies, the absorption and emission lines are *redshifted* relative to the solar spectrum.

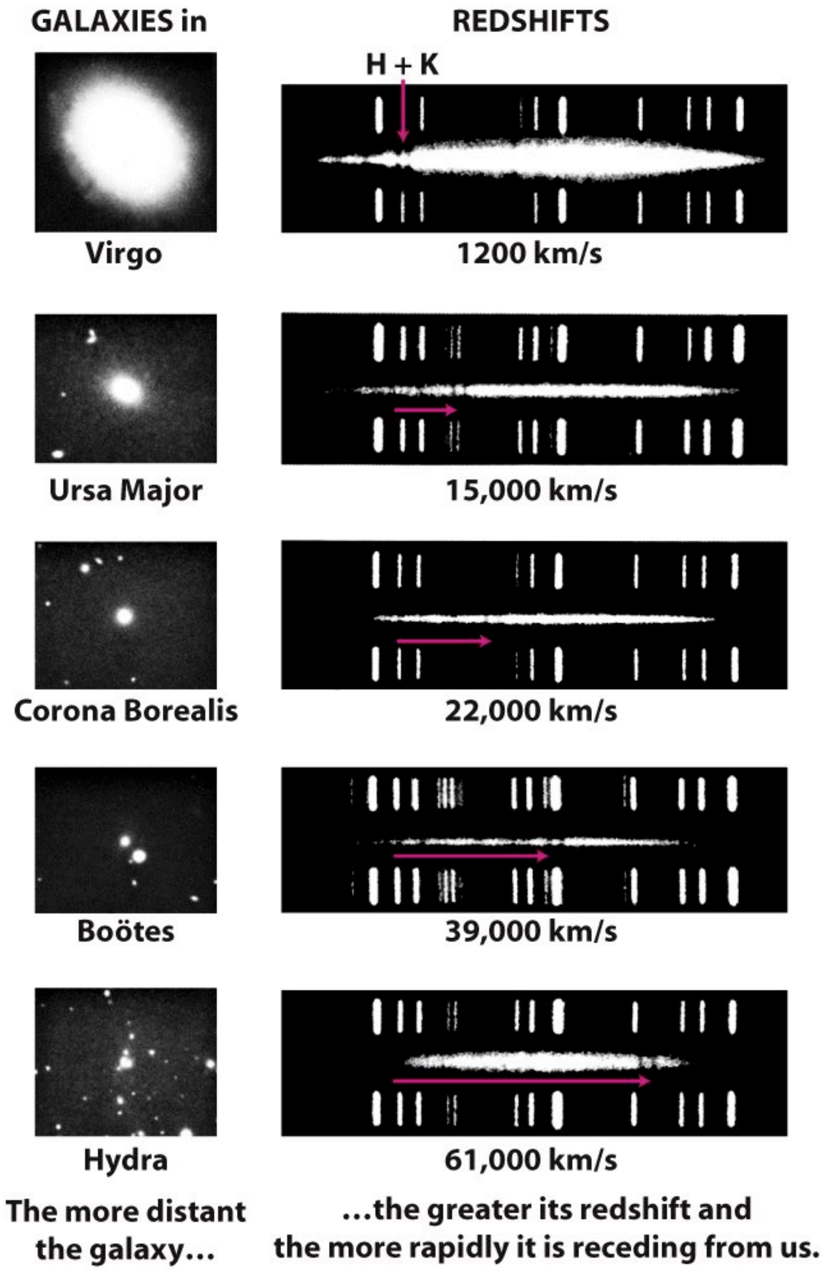
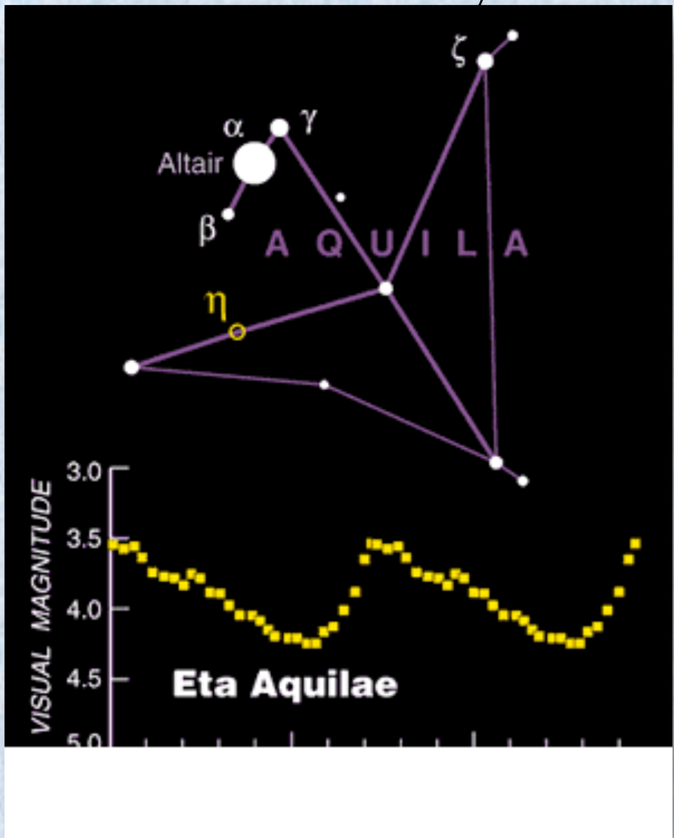


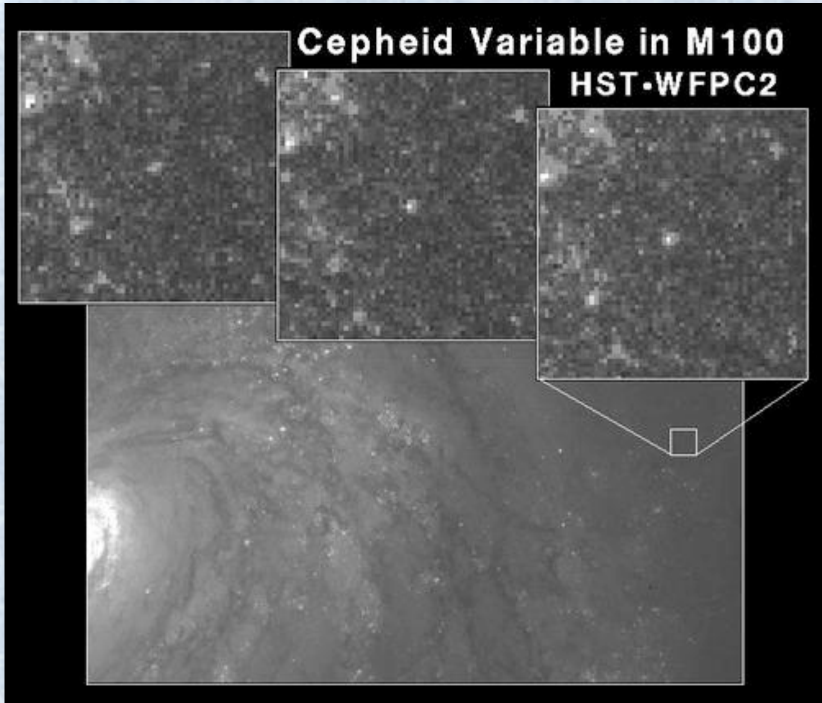
Figure 24-16
Universe, Eighth Edition

As we look out in every direction, we see that almost all galaxies have redshifts – they have velocities moving away from us. Does this mean we are at the center of the universe?

Henrietta Swan Leavitt (1868-1921) discovered that certain pulsating stars (Cepheid Variable stars) take longer to pulsate the brighter they are.



Edwin Hubble: In Mid 1920s used Cepheid Variable stars to determine distances to "Spiral nebulae" – proved they were distant galaxies like the Milky Way



Hubble's law: galaxies are moving away from us!

Velocity-Distance Relation among Extra-Galactic Nebulae.

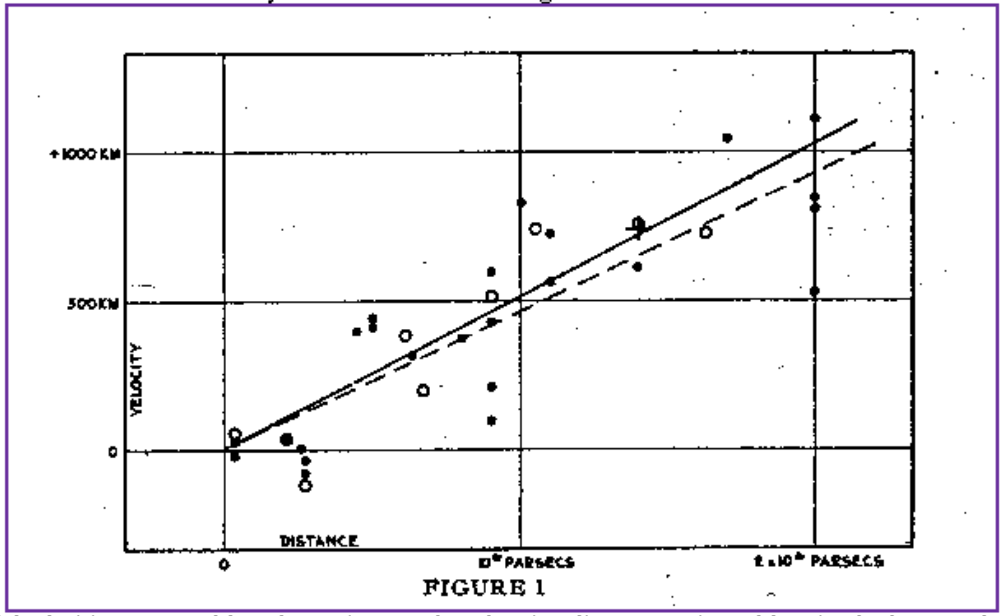


Figure 1: *Radial velocities, corrected for solar motion, are plotted against distances estimated from involved stars and mean luminosities of nebulae in a cluster. The black discs and full line represent the solution for solar motion using the nebulae individually; the circles and broken line represent the solution combining the nebulae into groups; the cross represents the mean velocity corresponding to the mean distance of 22 nebulae whose distances could not be estimated individually.*

- Hubble found that redshift (or velocity) is proportional to distance (Hubble's law): if you measure double speed, you also measure double distance!

The Hubble law:

(recessional velocity v) = H_0(distance d)

H_0 = Hubble constant

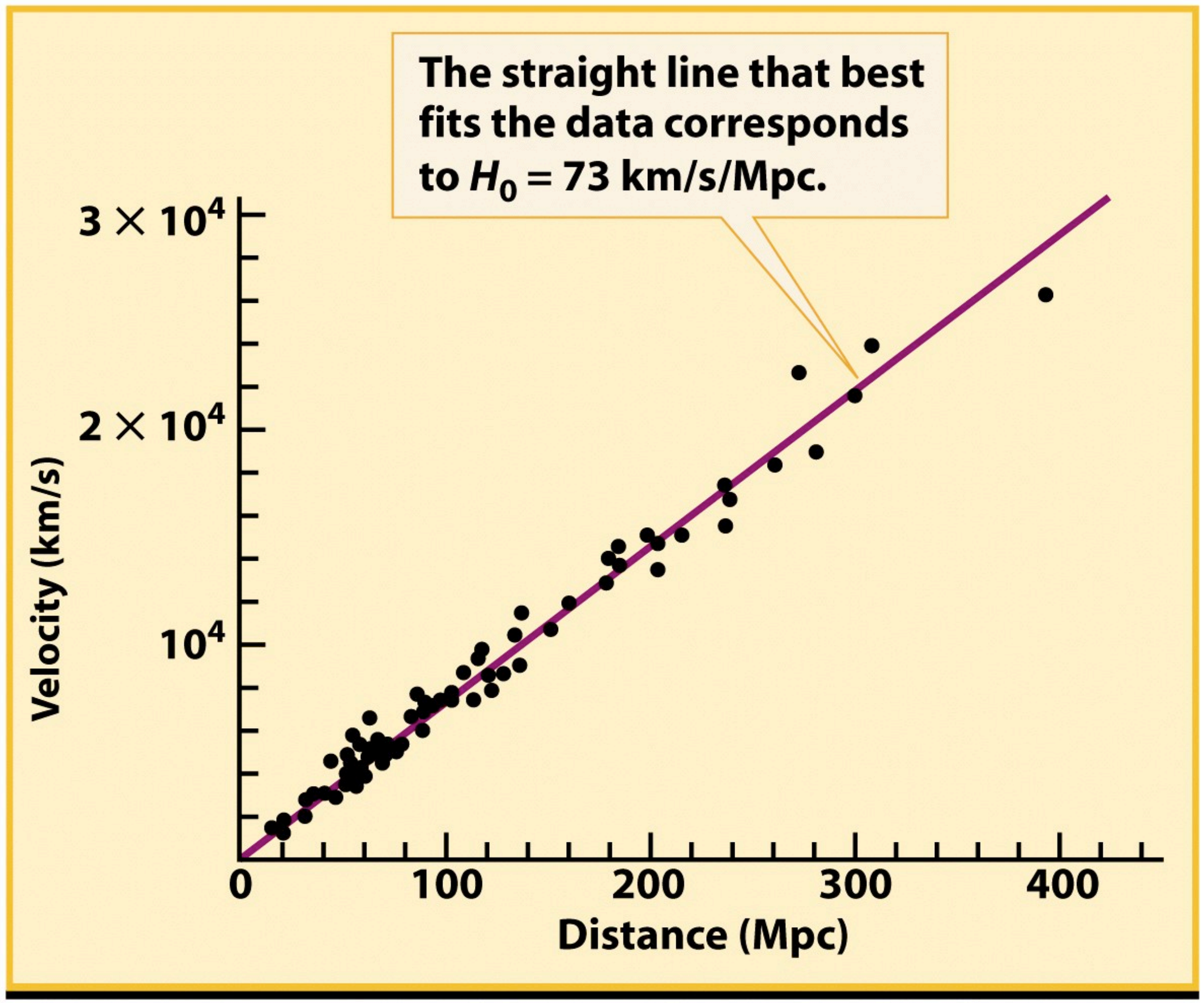


Figure 24-17

Universe, Eighth Edition

Interpretation of Hubble's Law

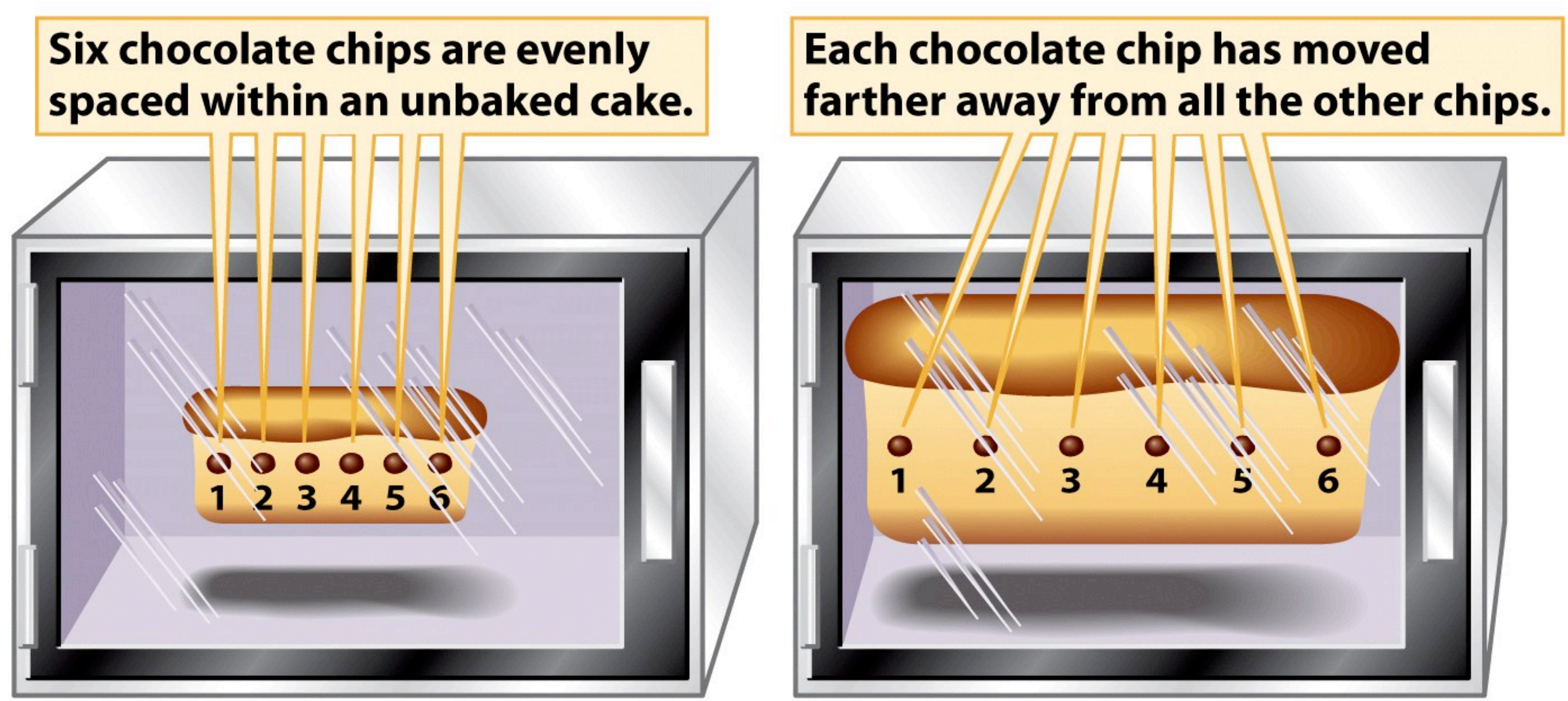
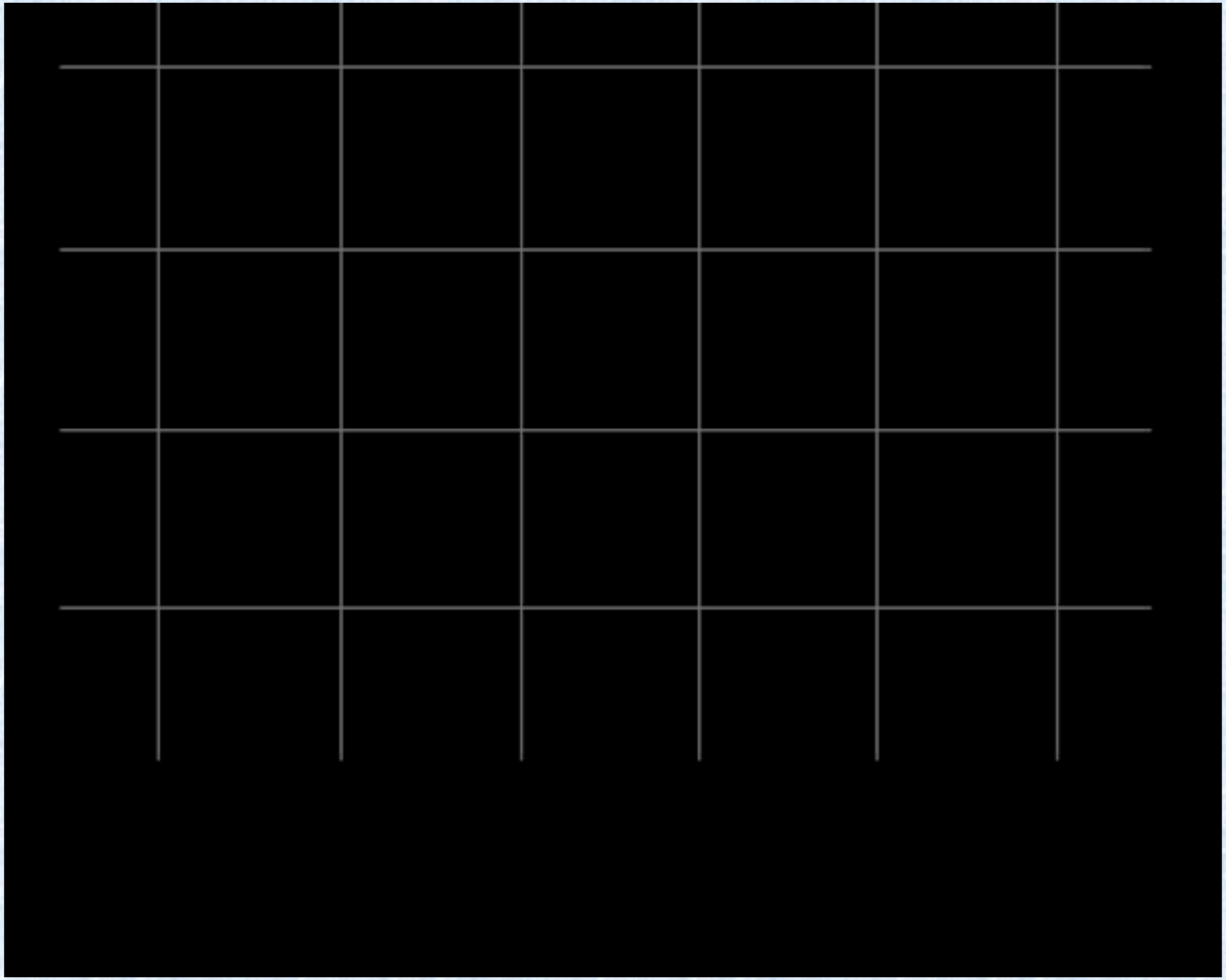
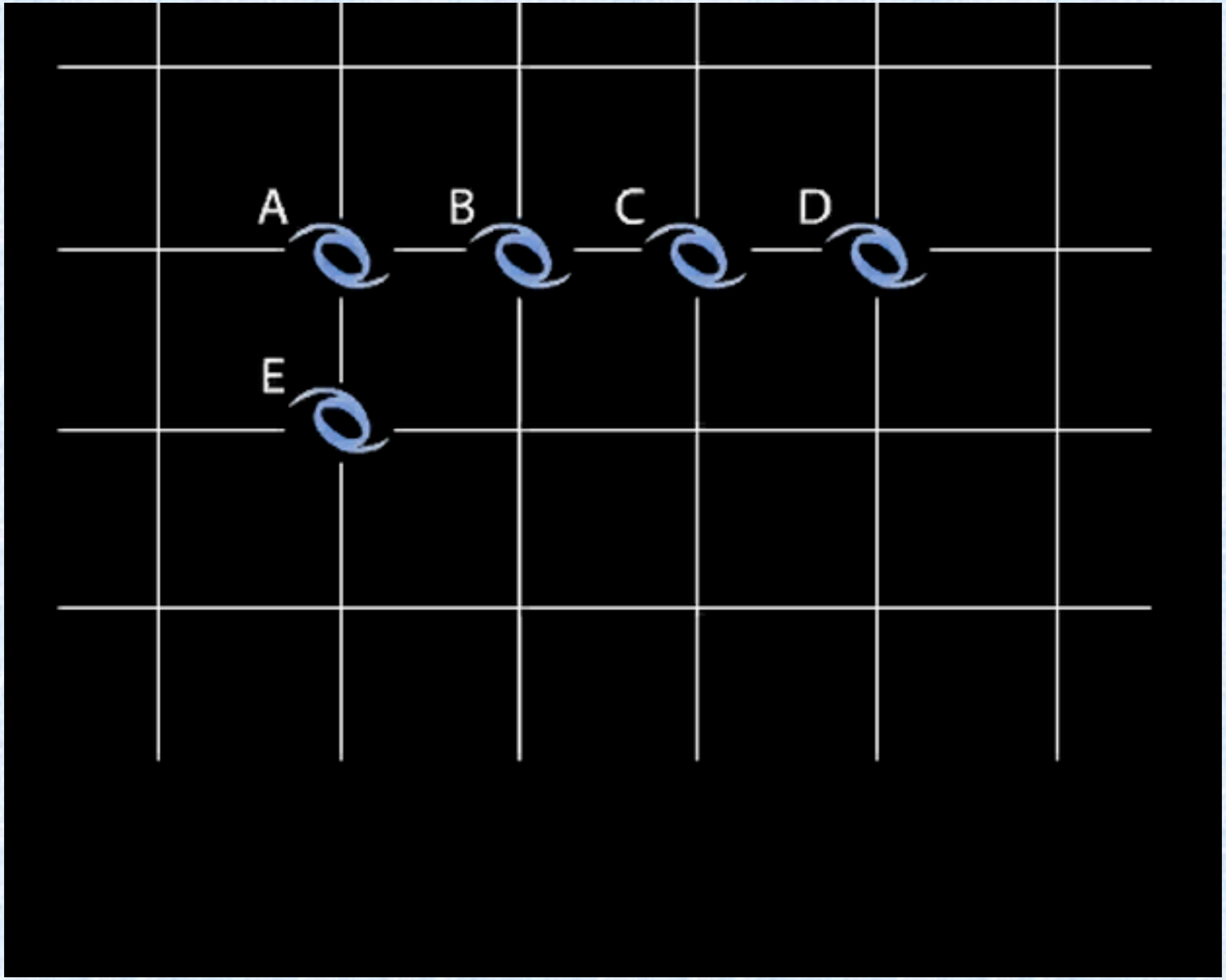


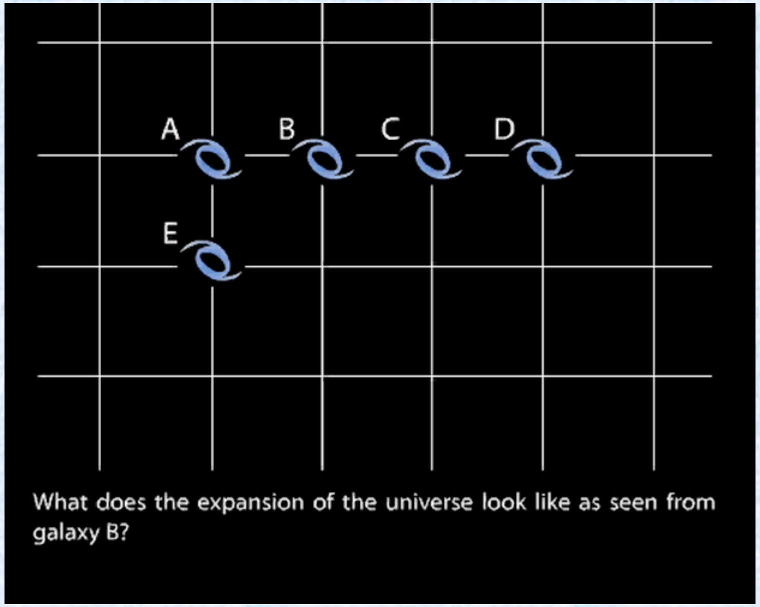
Figure 26-2
Universe, Eighth Edition



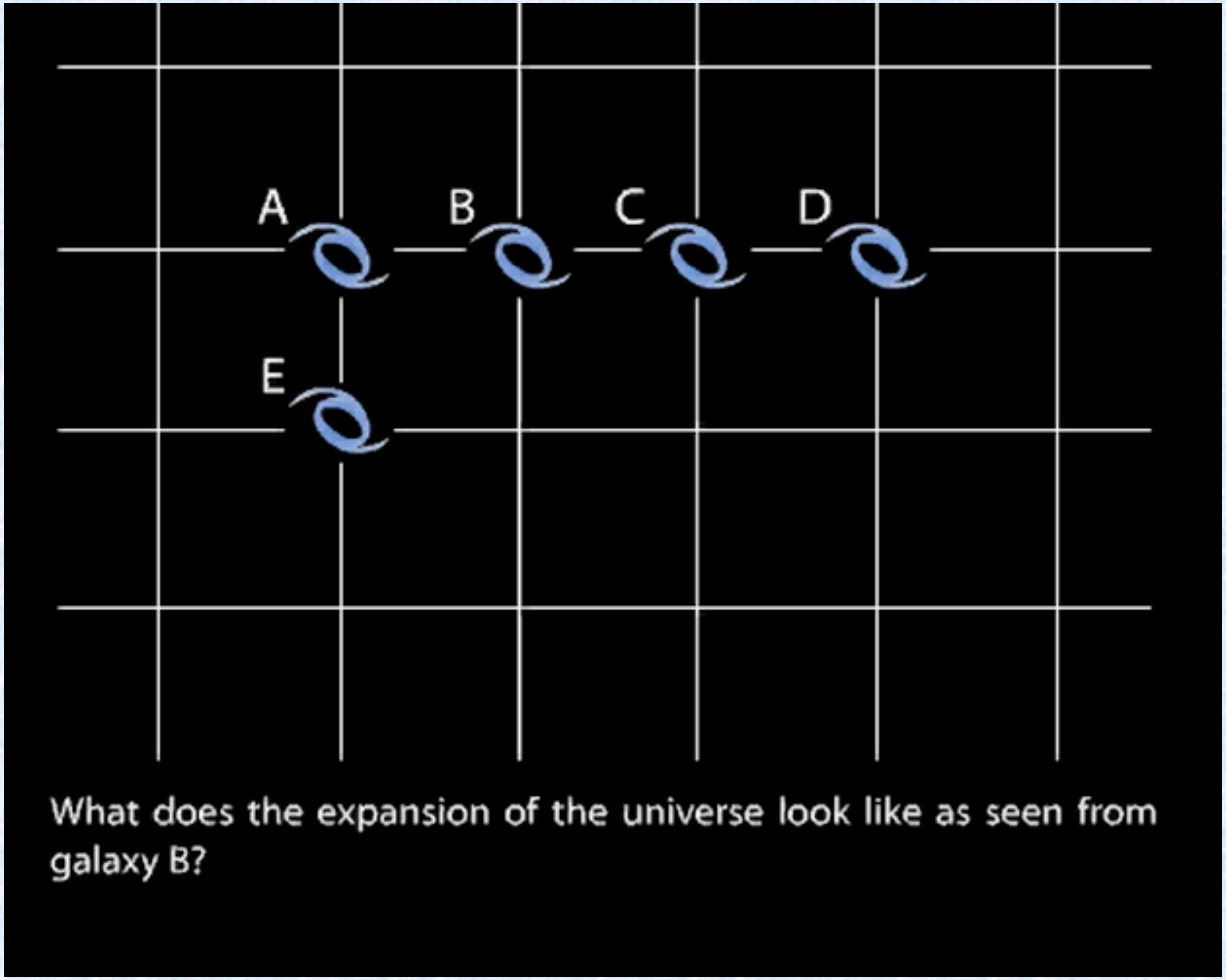

A
B
C
D
E

What does the expansion of the universe look like from galaxy B?

A)All the other galaxies have the same recession velocity.
B)Galaxies A and C have the same recession velocity, but galaxy D has a higher recession velocity.
C)Galaxies A and C have the same recession velocity, but Galaxy D has a lower recession velocity
D)All the galaxies have different recession velocities.



Conclusion: The universe is expanding

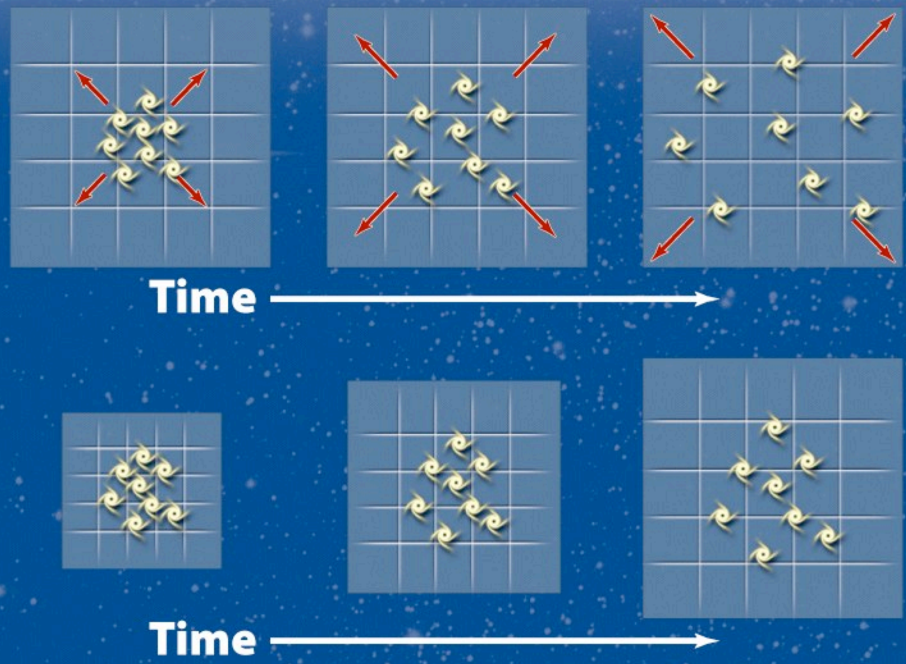


Urban Legend #1:

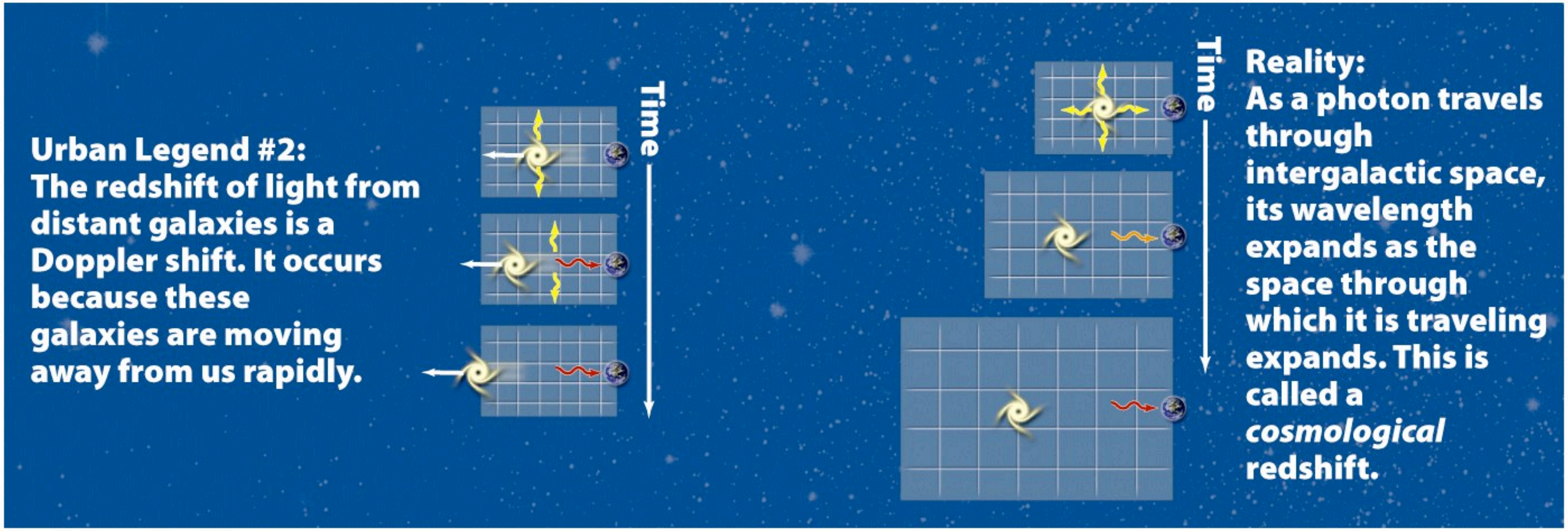
The expansion of the universe means that as time goes by, galaxies move away from each other through empty space. In this picture, space is simply a background upon which the galaxies act out their parts .

Reality:

The expansion of the universe means that as time goes by, *space itself* expands. As it expands, it carries the galaxies along with it.



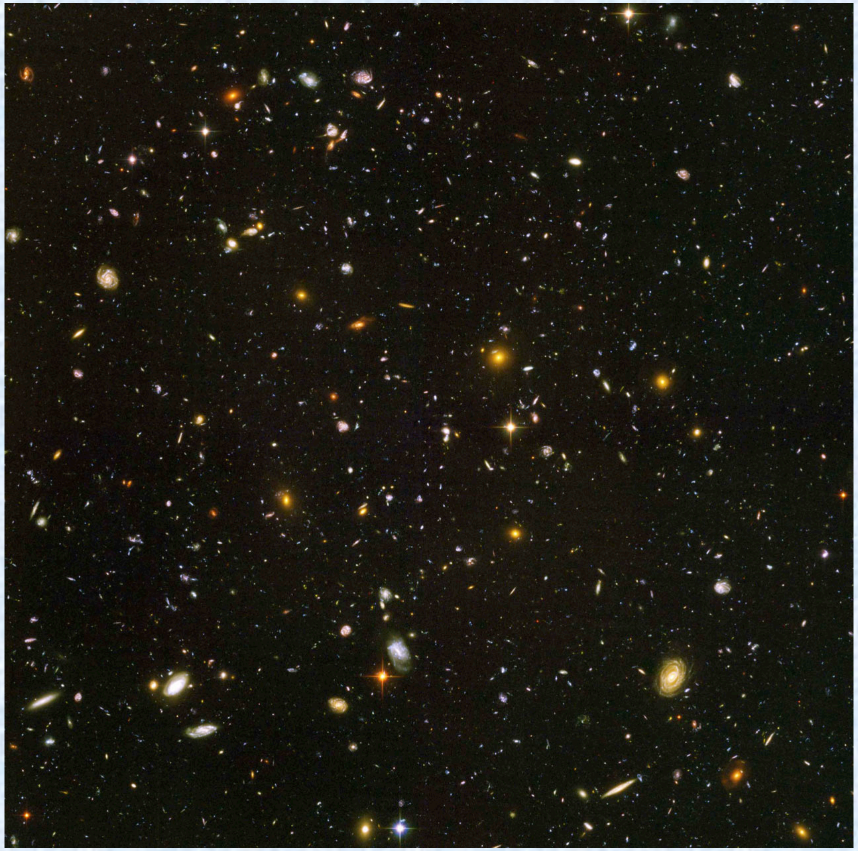
Cosmic Connections 26a
Universe, Eighth Edition



Cosmic Connections 26b
Universe, Eighth Edition

Olbers's paradox. The night sky

- What strikes you of the night sky?
- It is dark!!
- This apparently superficial statement (formulated by Heinrich Olbers in the early 1800s) has very profound consequences and is one of strongest pieces of evidence in favor of the big bang

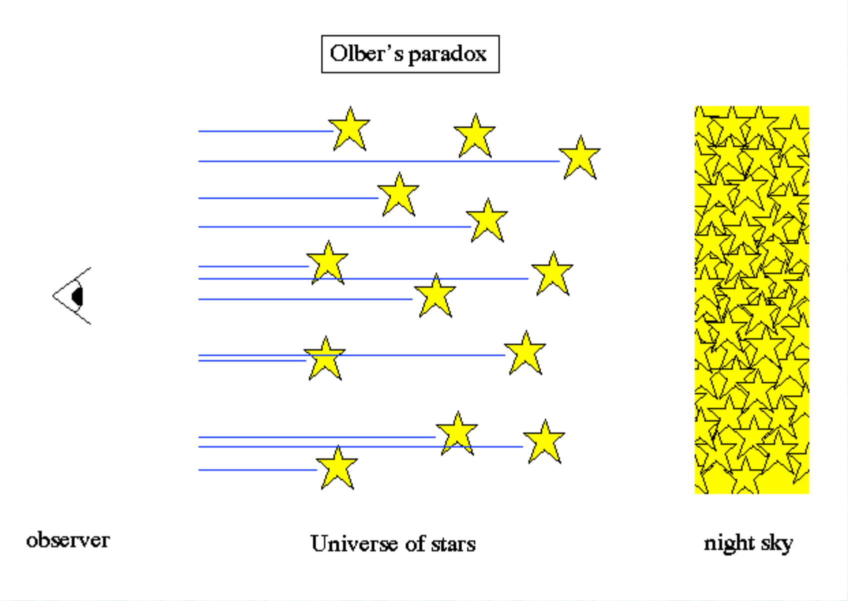


Olbers's paradox. A step back..

- Newton's model of the universe was:
- Eternal
- Infinite (otherwise it would collapse gravitationally)
- Flat Space
- Time independent of space

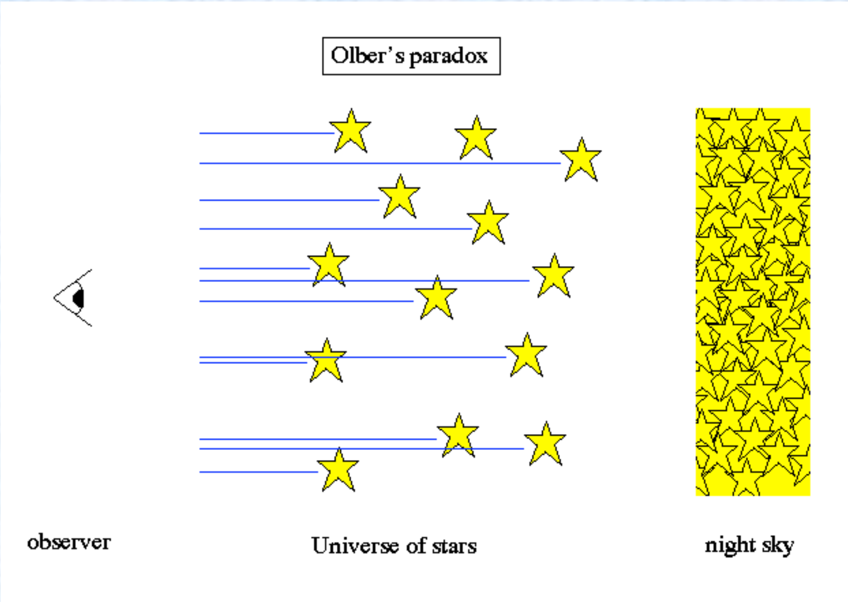
Olbers's paradox. What does the sky look like in Newton's model?

- For every line of sight sooner or later you find a star
- Surface brightness is independent of distance for a Euclidean flat space (draw on the blackboard)
- This would mean that the sky should have the same surface brightness of the sun, your average Joe star.



Olbers's paradox. What does the sky look like in Newton's model?

- How much is that?
- The sun angular diameter is ½ a degree.. i.e. the solid angle covered is $\pi(1/4)^2 = 0.2$ sq degrees.
- The whole sky is 41,253 sq degrees…
- And the answer is?
- Does this make sense to you?

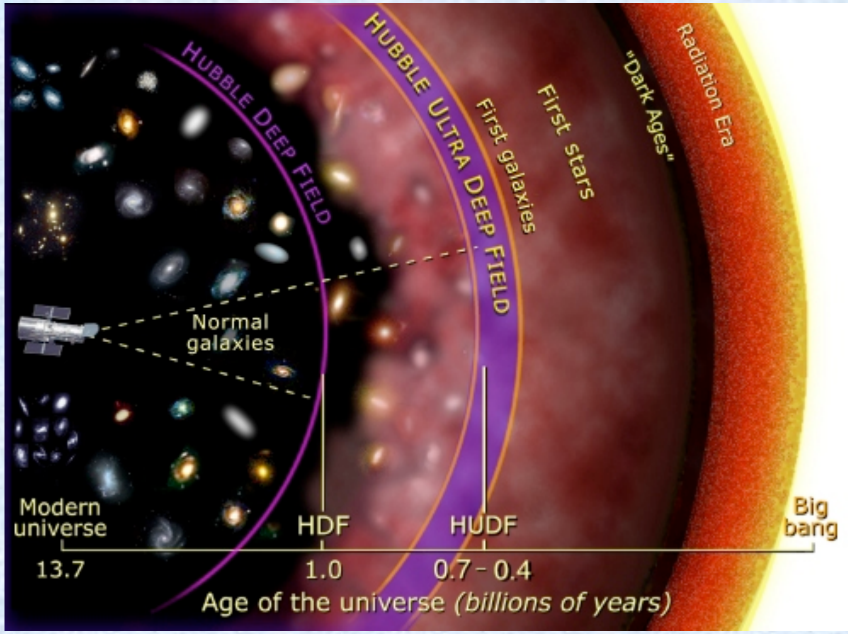


Olbers's paradox. Olbers's solution.

- Olbers postulated that the Universe was filled with an absorbing medium, like fog
- However, if light is absorbed it will also re-radiate, producing light albeit at different wavelengths, so this doesn't work!

Olbers's paradox.
The Big-Bang's solution

- In the Big Bang model the Universe is finite in TIME (13.7 billion years)
- This means that we can only see as far away as light has had time to travel
- Furthermore stars were not always shining (the sun for example is 4.5 Gyrs old).



Olbers's paradox. Summary

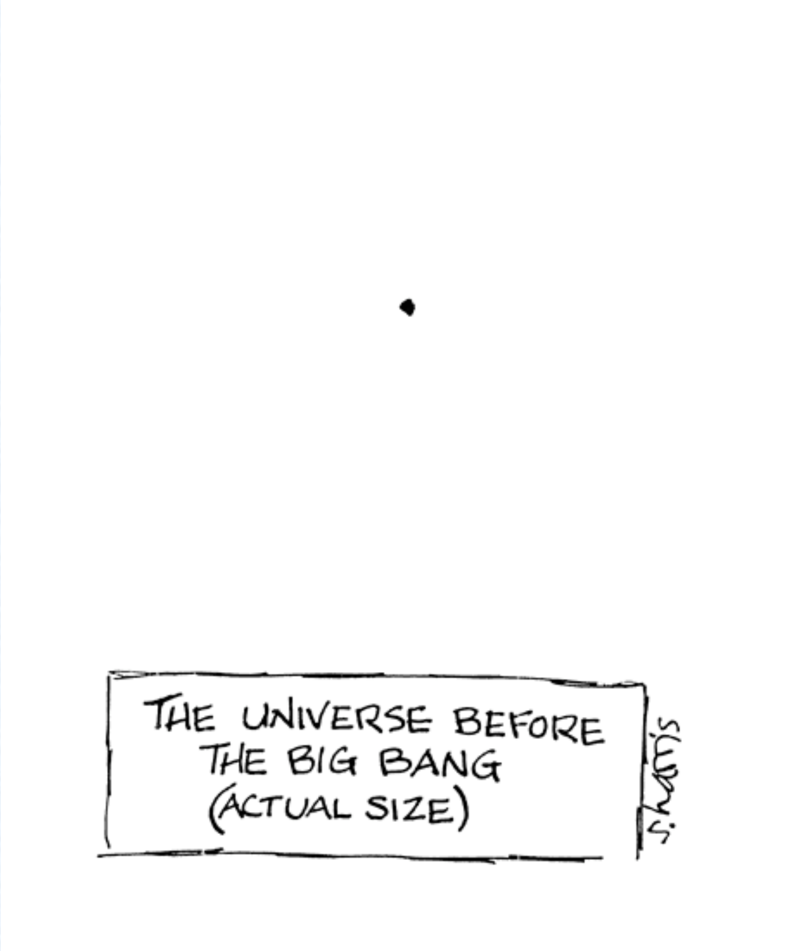
- The night sky is dark
- This implies that the emission of starlight in the universe must be finite, in space, time or both.
- This is fundamental test for any cosmological model
- The Big-bang explains Olbers's paradox with the finiteness of the lifetime of the Universe and hence of its stars:
- The universe is NOT eternal in the past! The universe evolves!

Frequently asked questions…just checking…

- What is the universe expanding into?
- Nothing, the universe is all there is, spacetime is expanding itself
- Where is the center of the expansion?
- Nowhere, there is no center, the universe is homogenous and isotropic
- Do we expand as well?
- No, because we are bound by electromagnetic forces
- Do galaxies expand?
- No because they are bound by gravity and they detach from the Hubble Flow

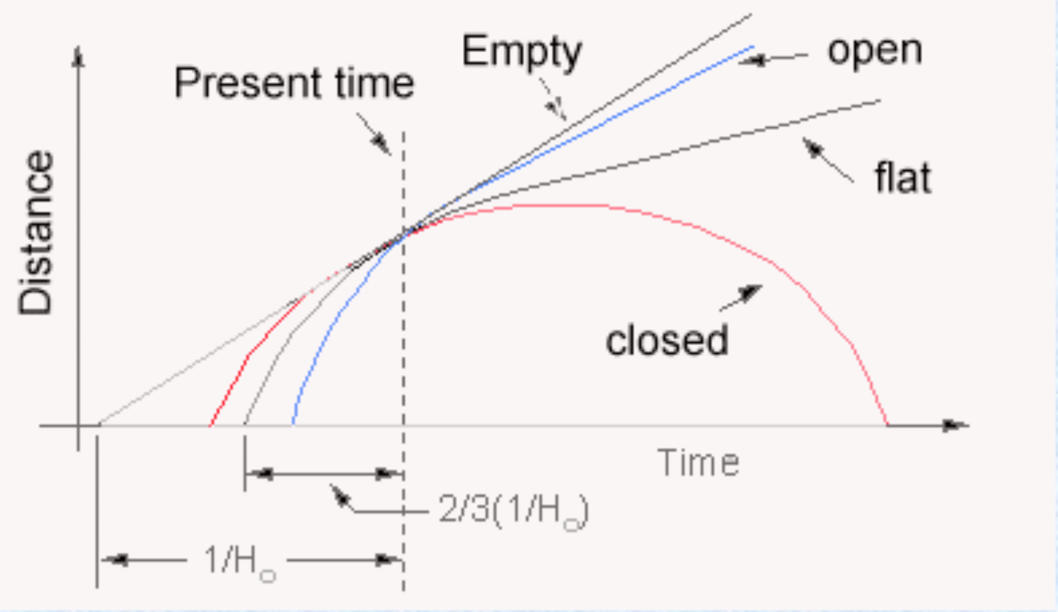
The expansion of the Universe in the Big-Bang model

- In the Big Bang model if you extrapolate back in time the size of the universe (or the average distance between galaxies) you find that it goes to zero in a finite amount of time (the age of the Universe).
- If you pick any arbitrary distance as small as you like (e.g. two inches), a finite amount of time ago any two points in the universe was closer to each other than that distance.



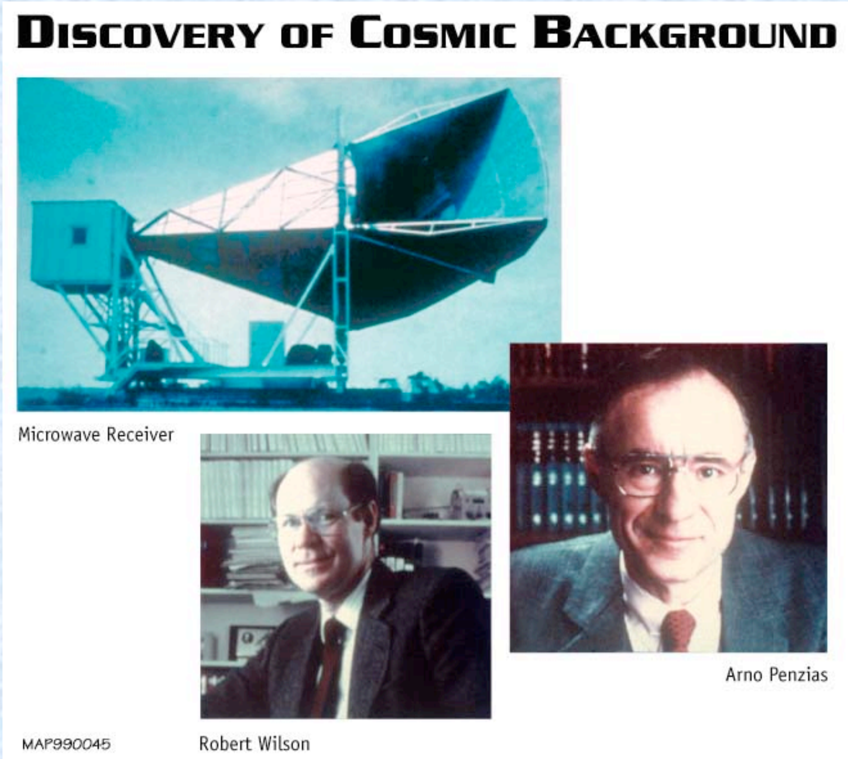
The expansion of the Universe in the Big-Bang model

- In the Big Bang model the dynamics of the universe depends on of its geometry and content
- The simplest order of magnitude estimate of the age is a straight line:
  - That means that the age of the universe now is $1/H_0$



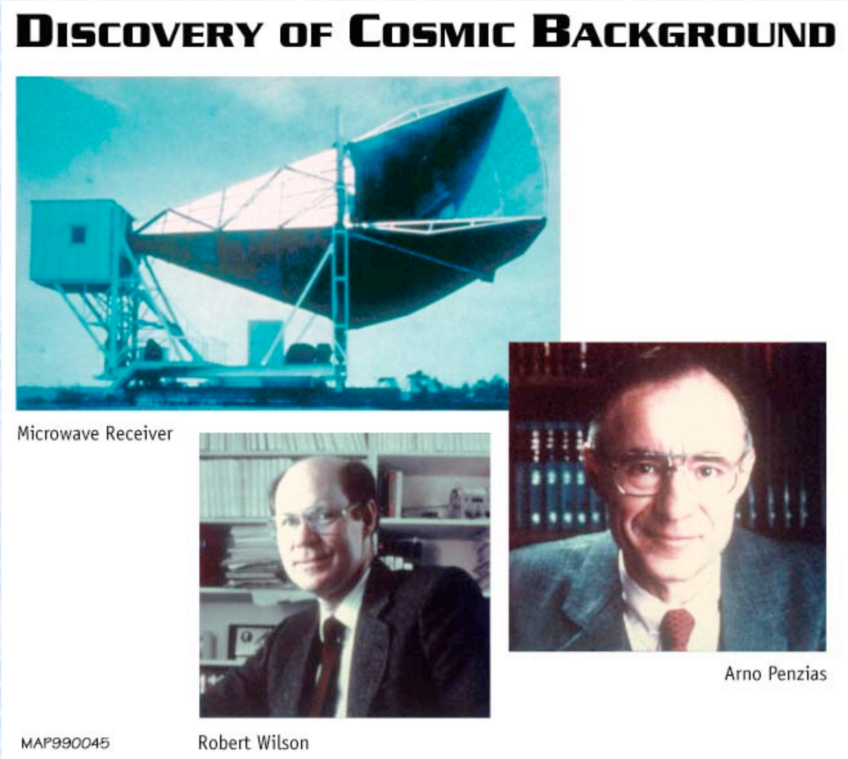
Cosmic Microwave Background

- The cosmic microwave background was discovered as a background "noise" a real problem for telecommunication satellites
- Wherever Penzias and Wilson pointed their antenna they would detect a microwave signal, very uniform across the sky
- This signal is now called the cosmic microwave background…



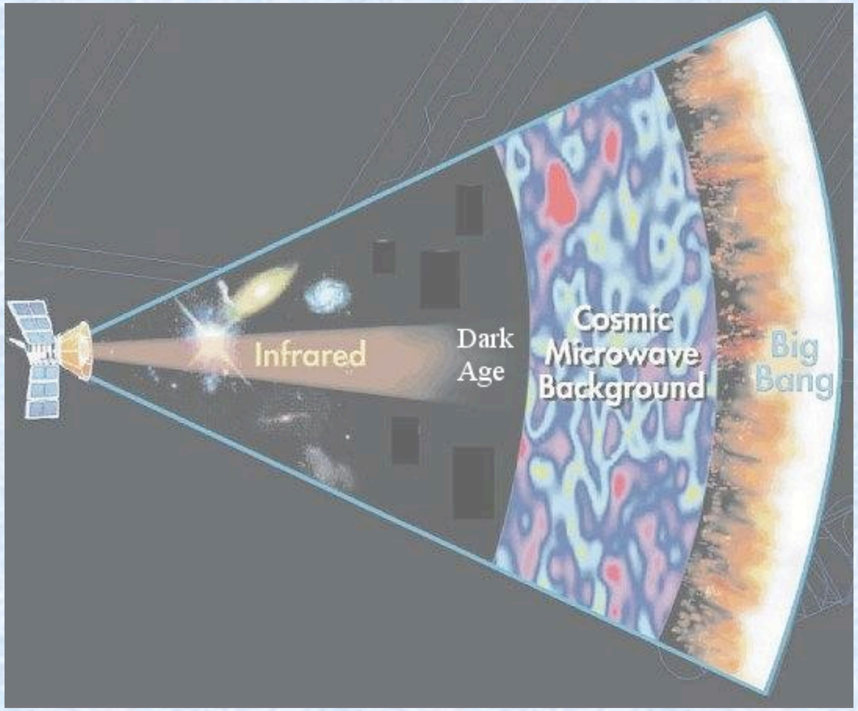
Cosmic Microwave Background

- The CMB was already visible in the data taken by Dunham and Adams of the properties of CN in the interstellar medium …back in 1937
- The saw that CN was excited as if it was immersed in a thermal bath of radiation of temperature T~3K…
- But nobody realized it.. So the Nobel Prize went to Penzias & Wilson… and not to Dunham and Adams.. Such is life..



Cosmic Microwave Background

- A group of physicist (initially Alpher and Hermann and then Dicke and his group at Princeton) had predicted such radiation, from the so-called big bang nucleosynthesis theory (later in the class..)
- The CMB was predicted to be:
  - Thermal
  - At a temperature of about 5K
  - Isotropic



Cosmic Microwave Background. Thermal “Blackbody” Radiation

- We know Penzias and Wilson detected isotropic radiation, so that was consistent with the Big Bang model and the copernican principle
- The theory predicted it to be thermal, i.e. a blackbody.
- But what is a blackbody?
- A blackbody is a very specific spectral energy distribution

Plank’s Equation

$$B_\lambda = \frac{2hc^2}{\lambda^5} \frac{1}{\exp\frac{hc}{\lambda k T} - 1}$$

Where:

B_λ = *Magnitude of Radiation per Wavelength.*

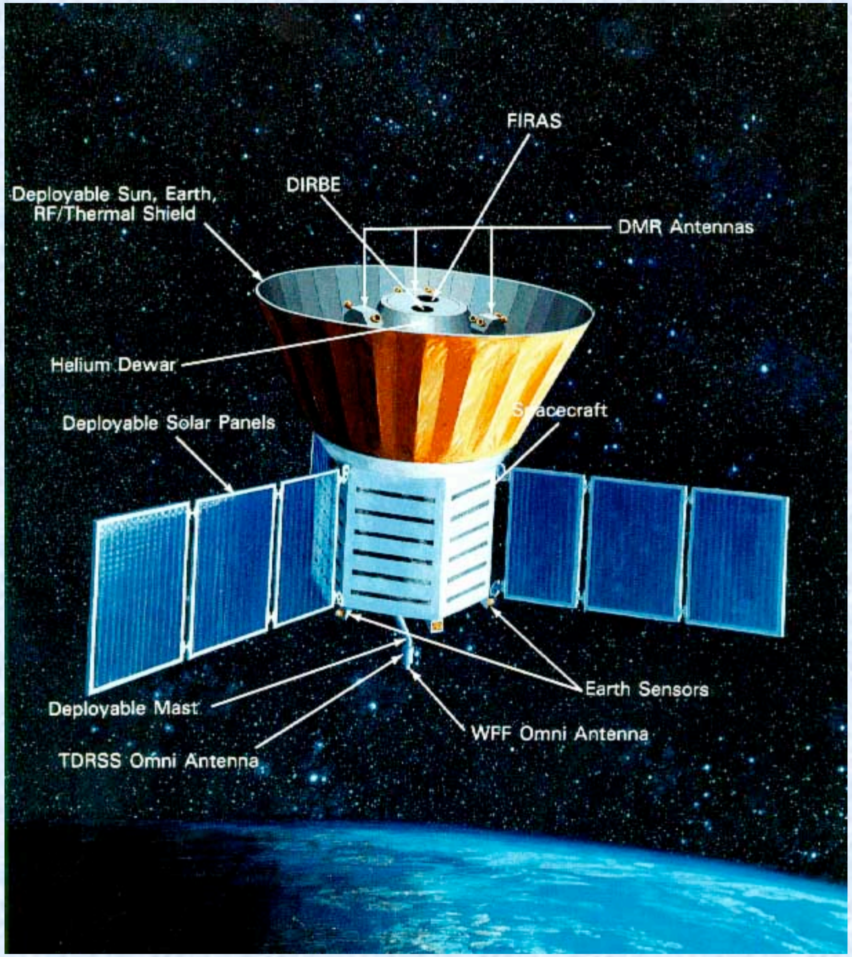
λ = *Wavelength.*

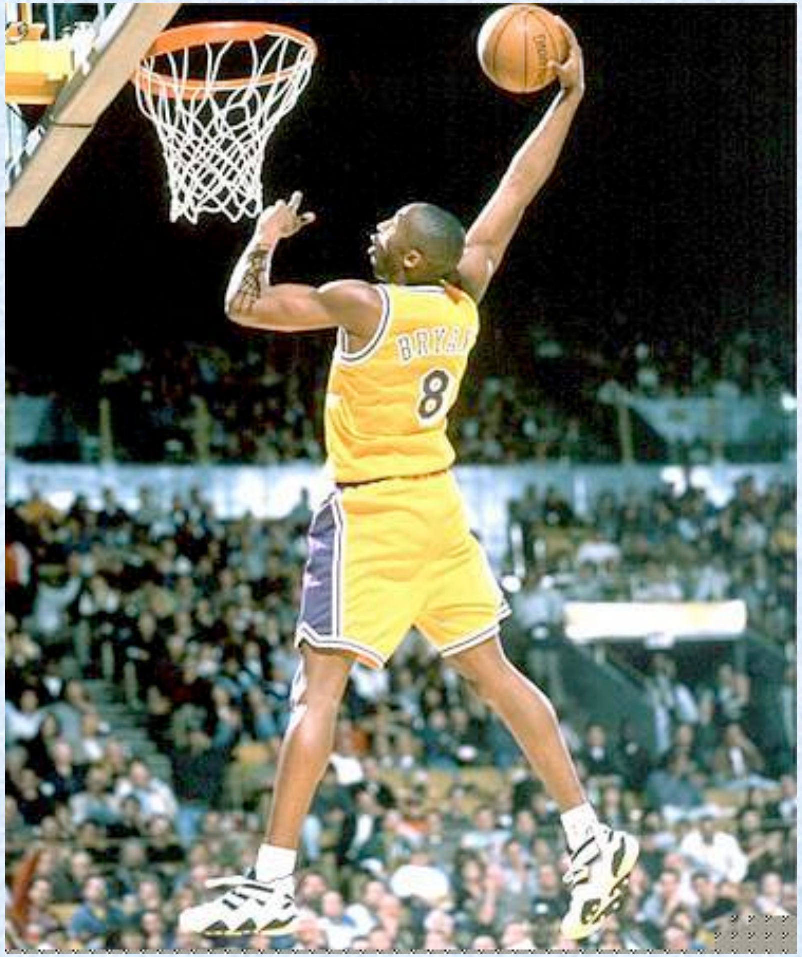
h = *Plank's Constant* (6.6238 * 10^{-34} *Js*).

c = *Speed of Light* (3.0 * 10^{8} *m/s*).

k = *Boltzmann Constant* (1.3807 * 10^{-23} *J/K*).

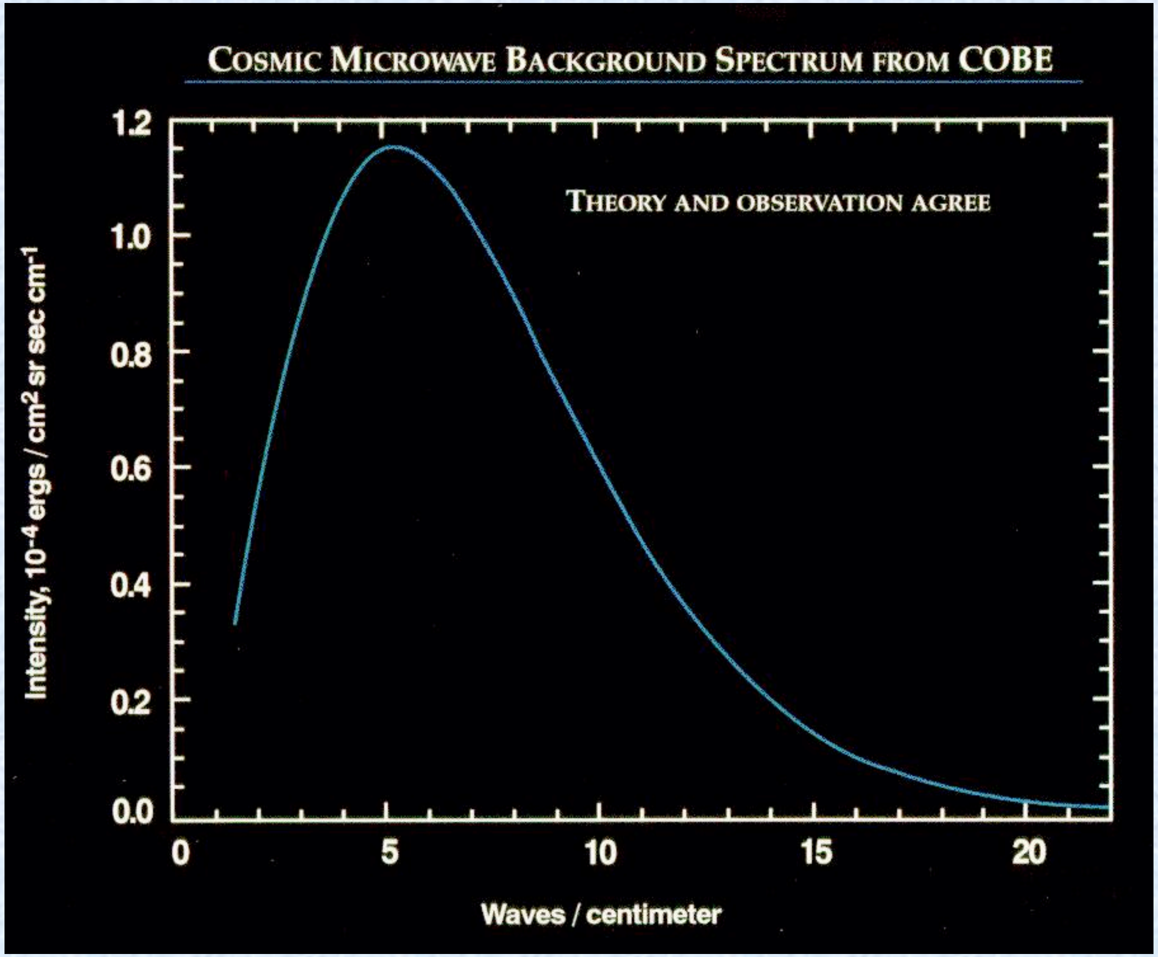
Is the CMB a Blackbody? COBE got the answer





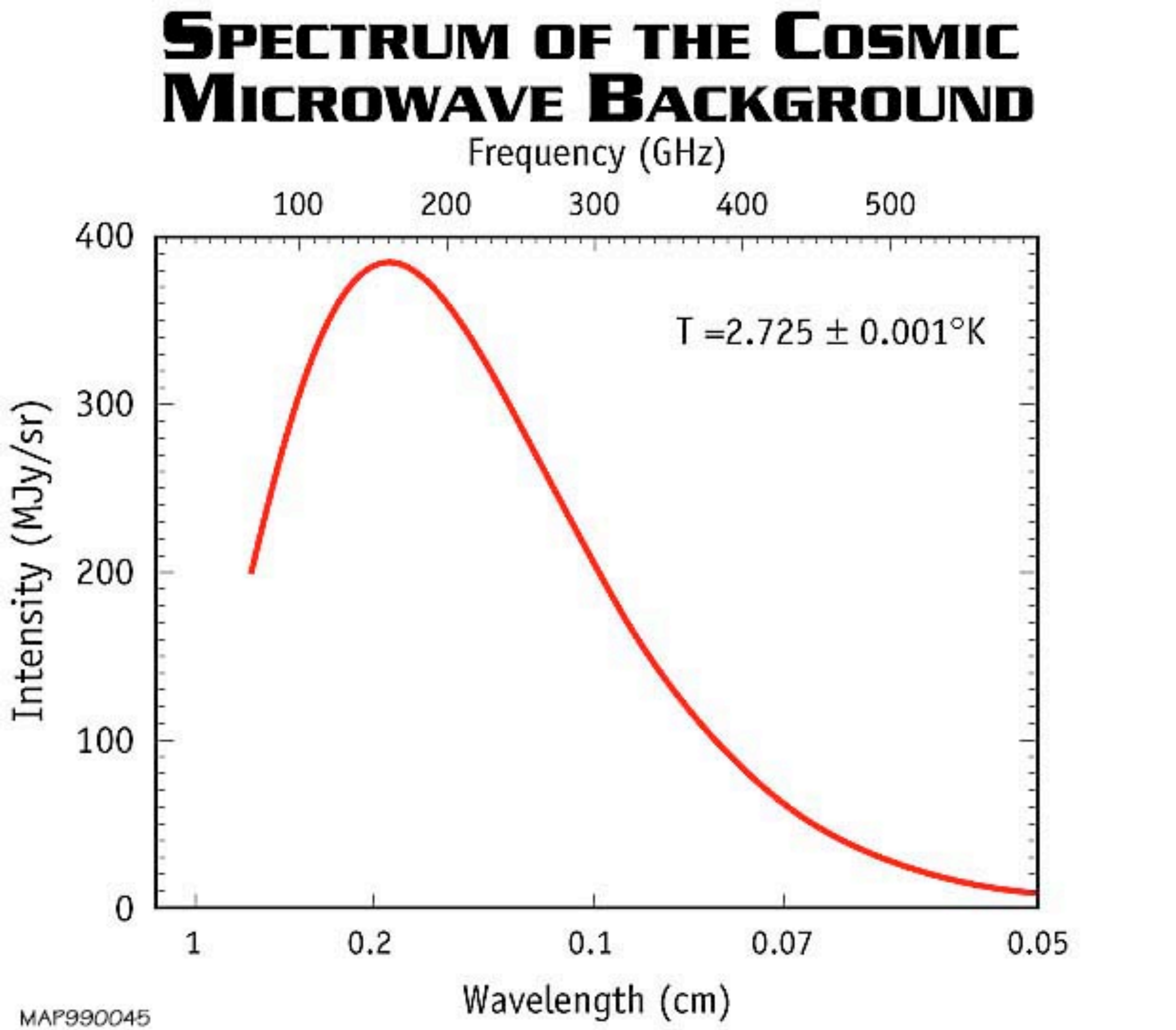
COBE……………………………NOT KOBE!

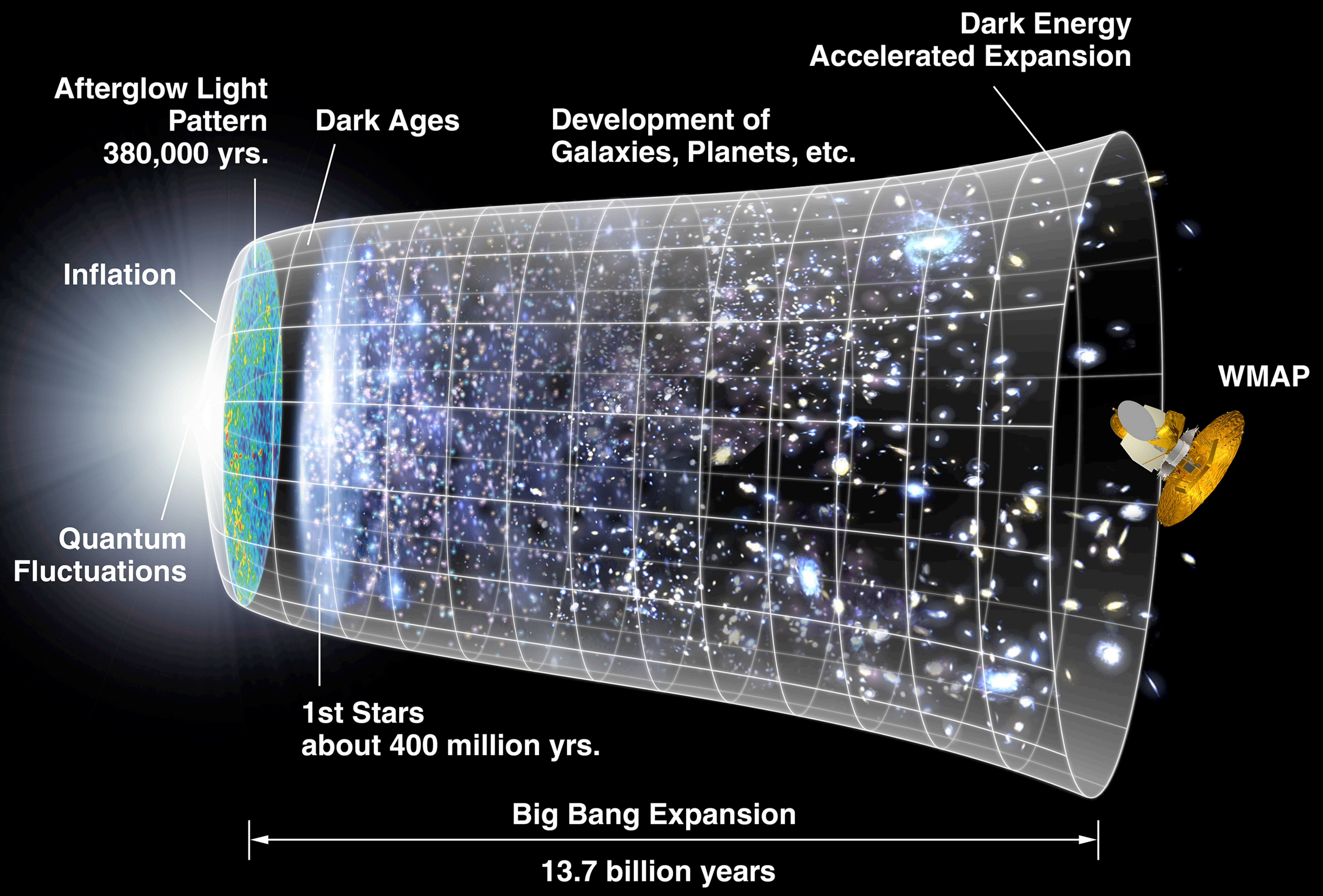
Cosmic Microwave Background.
The CMB is a “perfect” Blackbody



COBE FIRAS 1989

Cosmic Microwave Background.
The temperature is 2.725 K..




Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
380,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

The End

See you on Wednesday!