Misc

1. Final exam is scheduled for ***Monday, March 17, 1:30-3:30PM here in KPTC 106***.

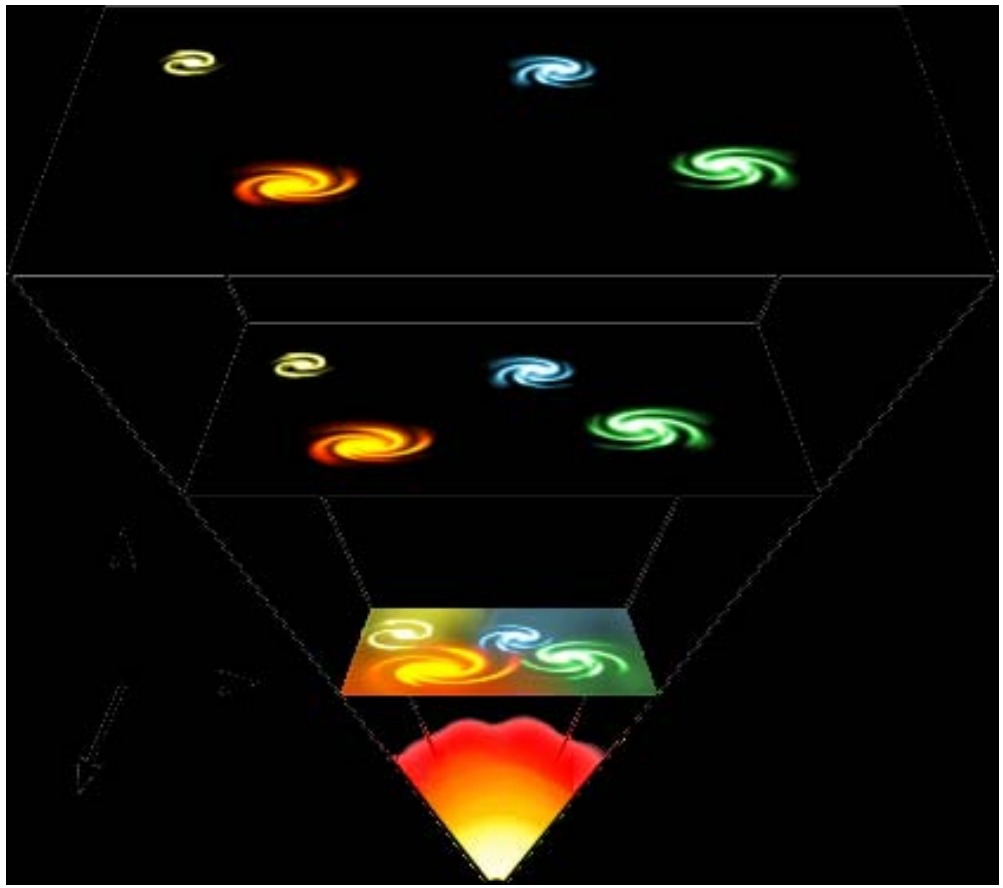
2. Second midterm is next Wednesday, usual class time (will be proctored by Dr. Brant Robertson and TAs).

3. Homework 4 is distributed today, *due Wednesday* in class (also available on the class web site as PDF: http://astro.uchicago.edu/~physci/120/winter-2008/)

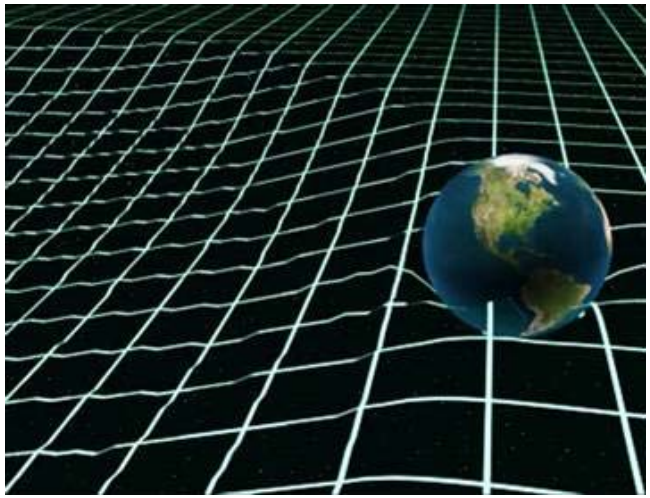
4. Homework 3 is due today in class

5. Today, we are covering material of S 26-2, 26-3, 26-5

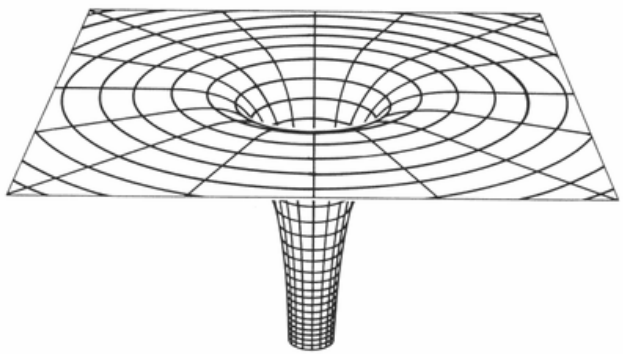
Lecture 13

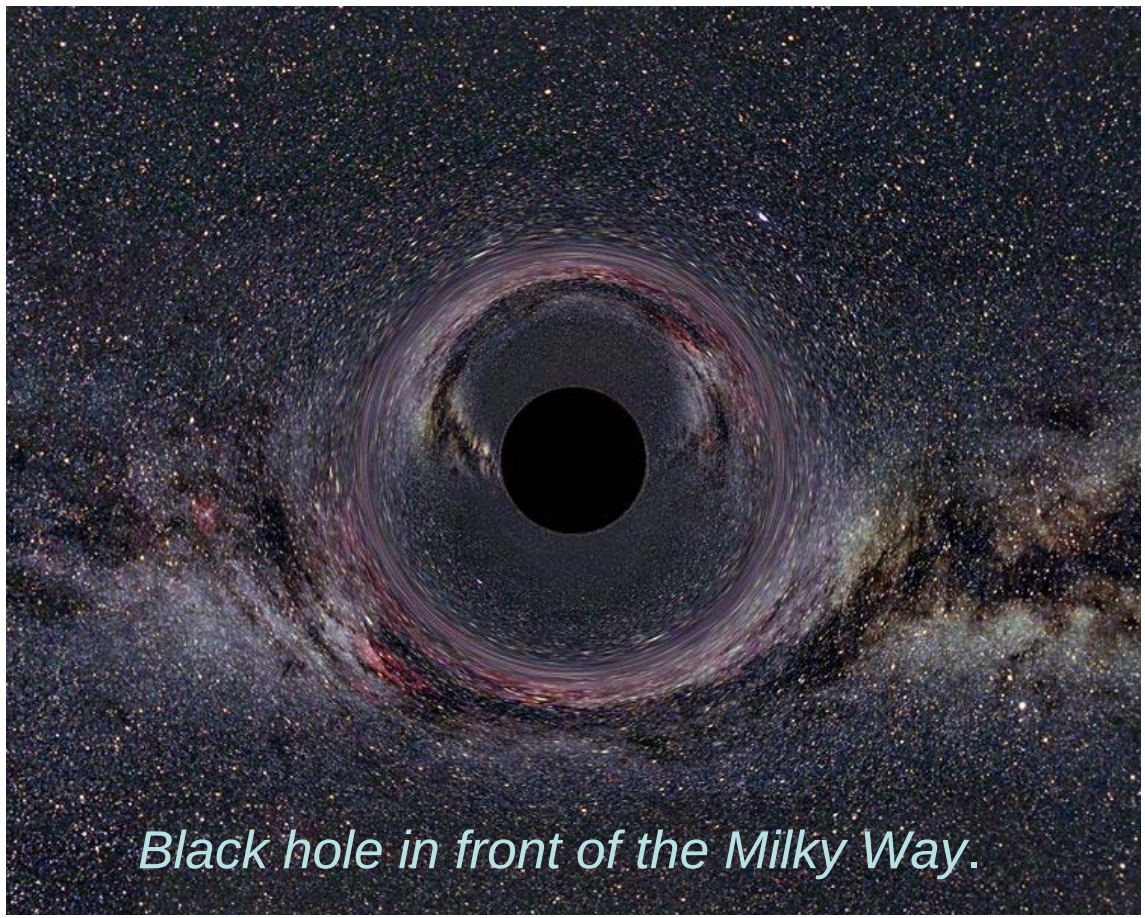


Expansion of the Universe. Cosmological redshift.
The age of the Universe and the Big Bang.



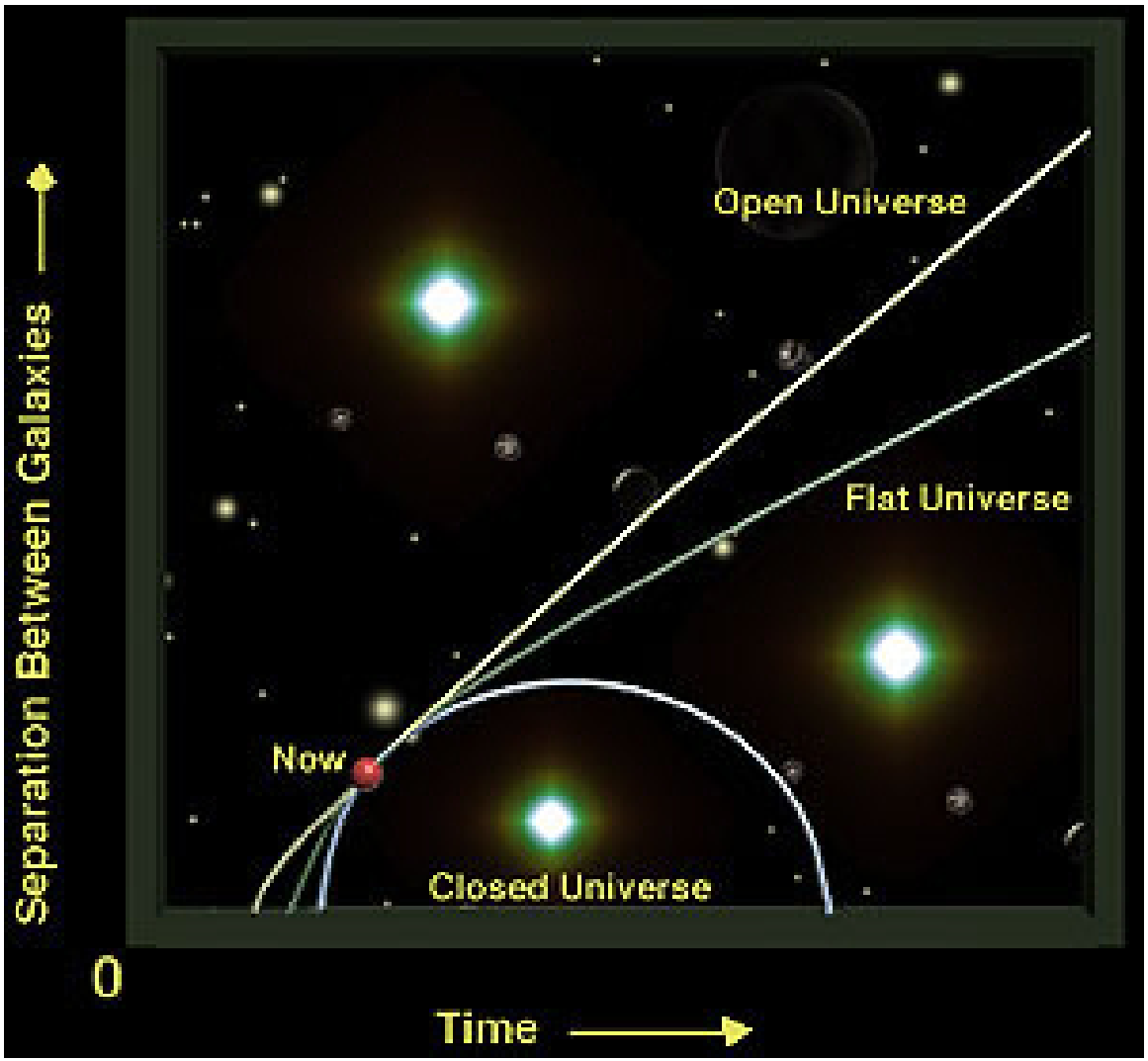
Theory of general relativity states that mass and energy (related by $E=mc^2$) can stretch and curve the space-time.

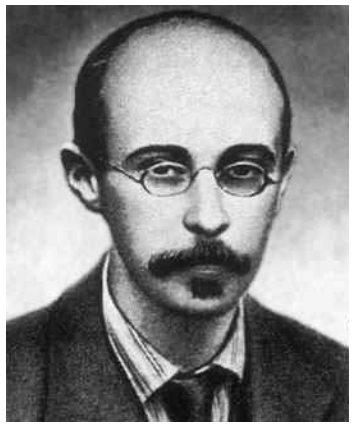




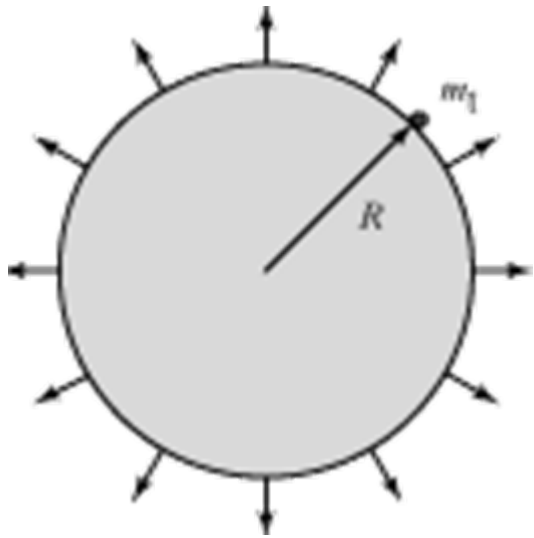
Black hole in front of the Milky Way.

Friedmann's solution of Einstein's equations: expansion history of the Universe depends on the matter and energy content of the Universe

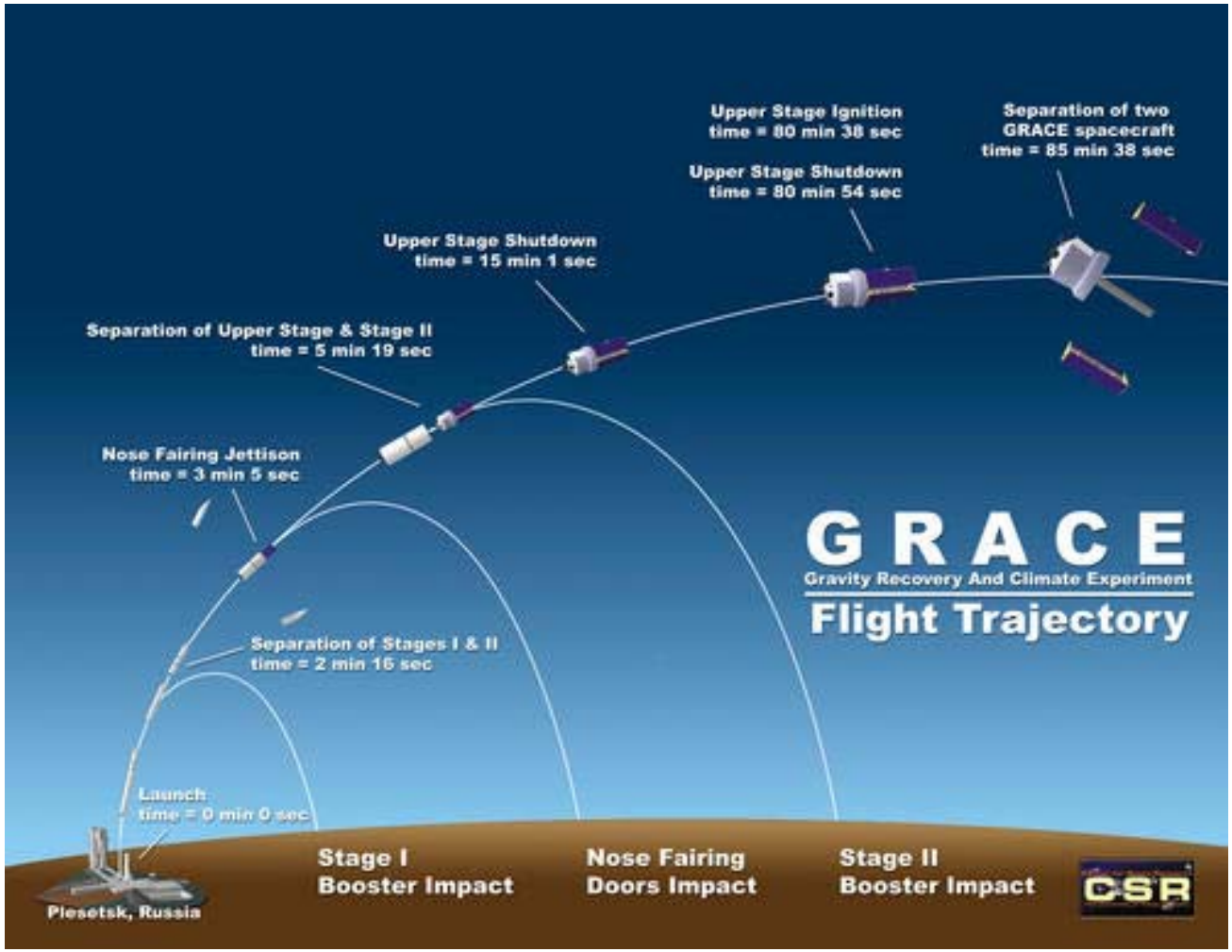




Alexander Friedmann



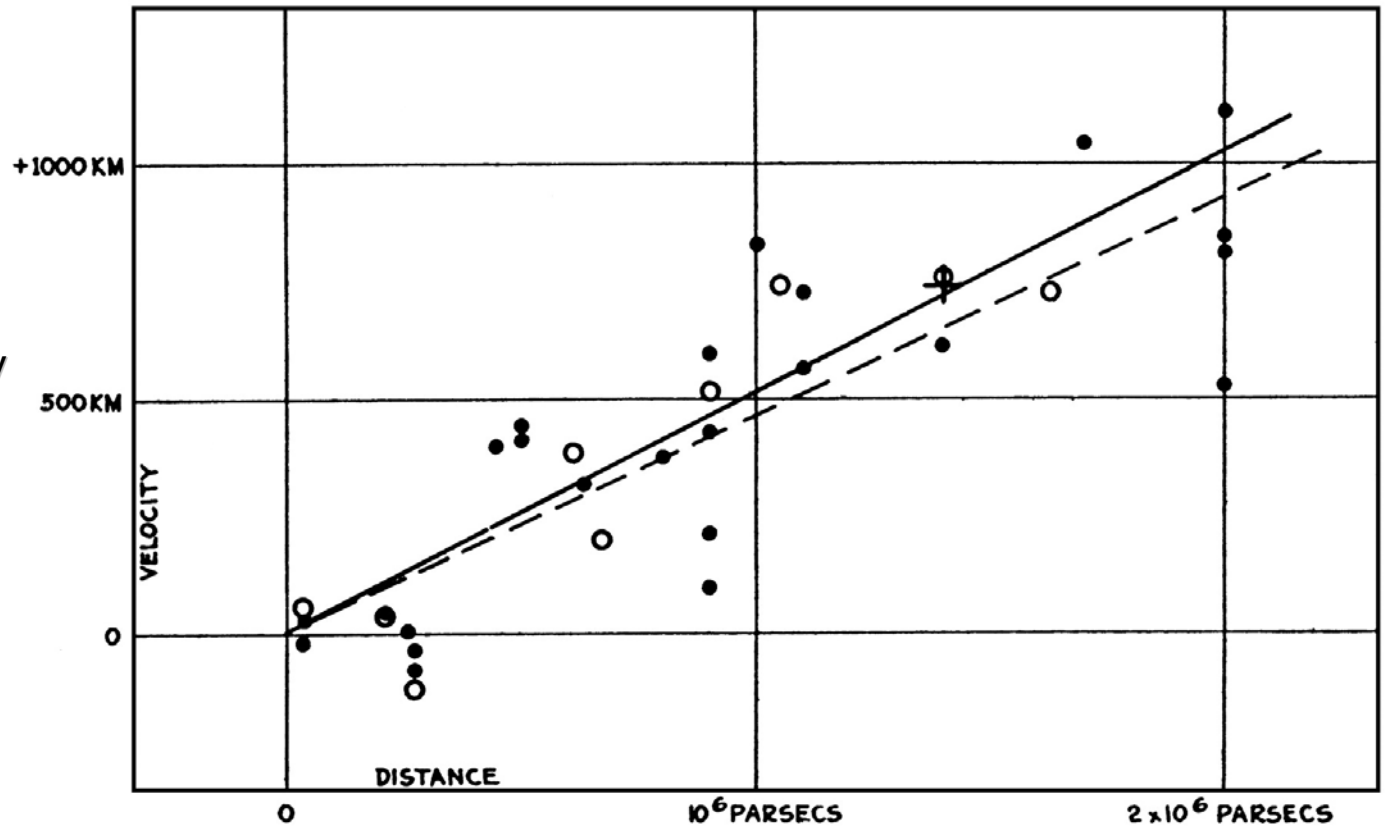
An analogy:


Upper Stage Ignition
time = 80 min 38 sec
Upper Stage Shutdown
time = 80 min 54 sec
Separation of two
GRACE spacecraft
time = 85 min 38 sec
Upper Stage Shutdown
time = 15 min 1 sec
Separation of Upper Stage & Stage II
time = 5 min 19 sec
Nose Fairing Jettison
time = 3 min 5 sec
Separation of Stages I & II
time = 2 min 16 sec
Launch
time = 0 min 0 sec
Plesetsk, Russia
Stage I
Booster Impact
Nose Fairing
Doors Impact
Stage II
Booster Impact
GRACE
Gravity Recovery And Climate Experiment
Flight Trajectory
CSR

Hubble's law implies that the space is expanding

Hubble law: *velocity* = *H* times *distance*
where *H* is a constant now called the *Hubble constant*

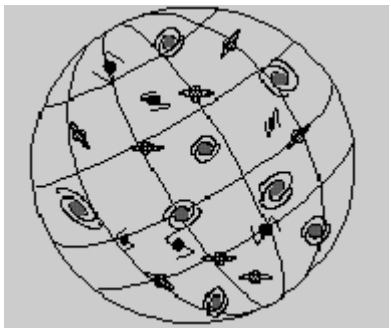
Velocity inferred from galaxy spectrum in km/s

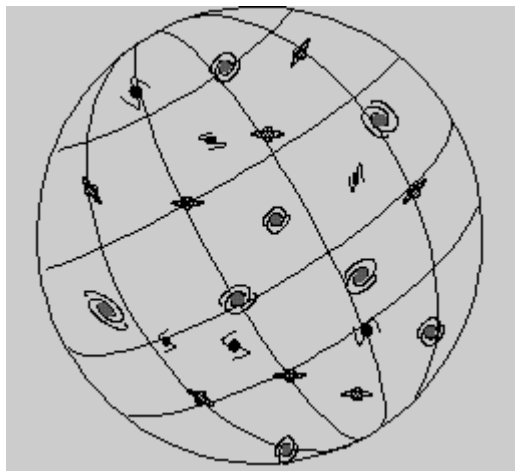


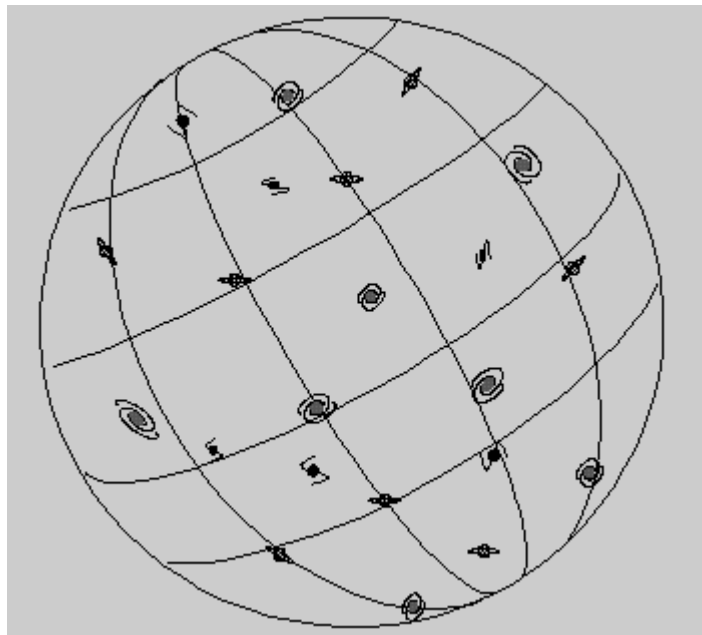
Distance in parsecs (1 parsec = 3.26 light years, 1 million parsecs = Megaparsec or Mpc)

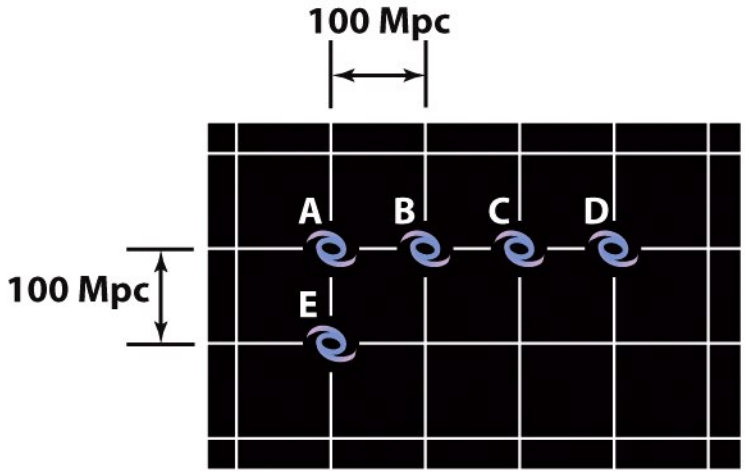
Two dimensional analogy.

Note that observer in each galaxy would see all other galaxies moving away from her!

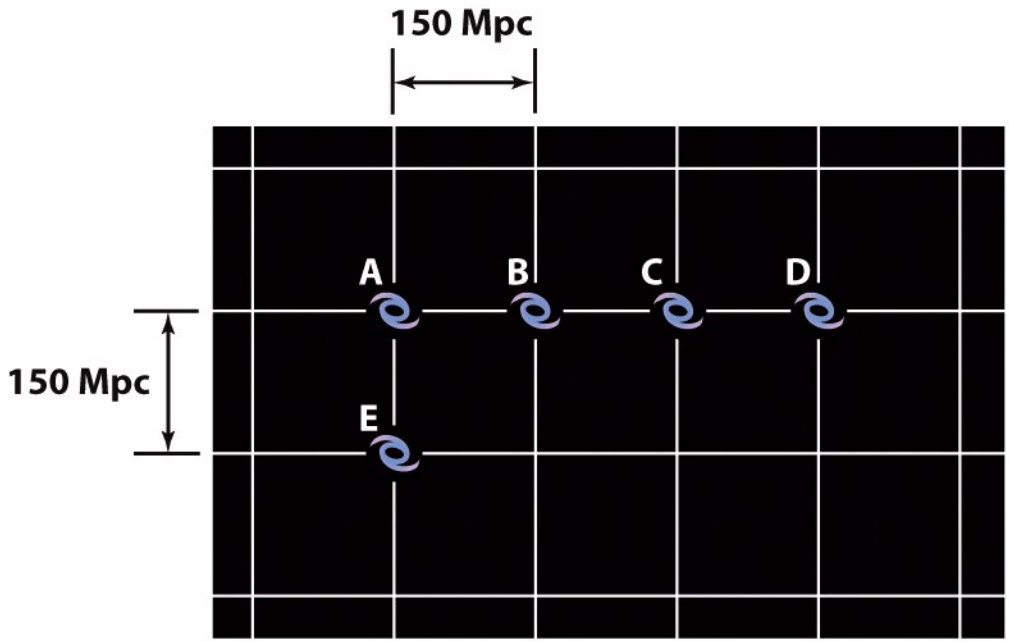








(a) Five galaxies spaced 100 Mpc apart

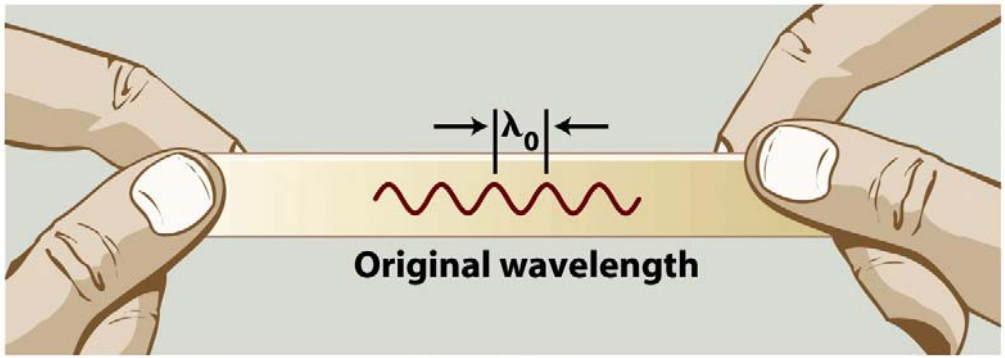


(b) The expansion of the universe spreads the galaxies apart

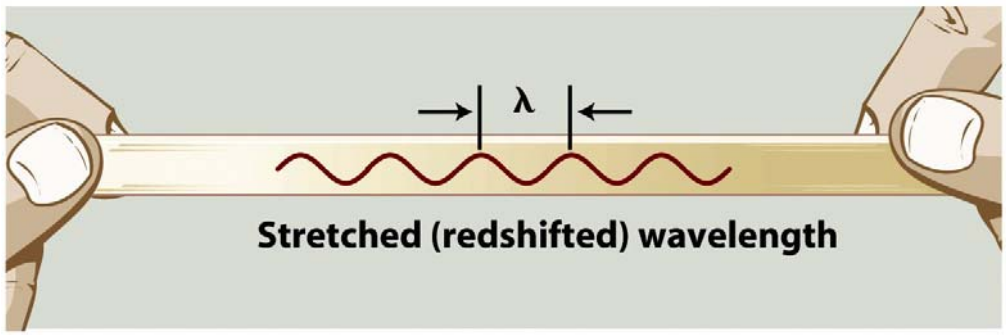
Figure 26-3
Universe, Eighth Edition

Two sources of spectral line shifts

1) The usual Doppler spectral red- or blue-shift is due to physical motion of objects away or towards observer



(a) A wave drawn on a rubber band ...



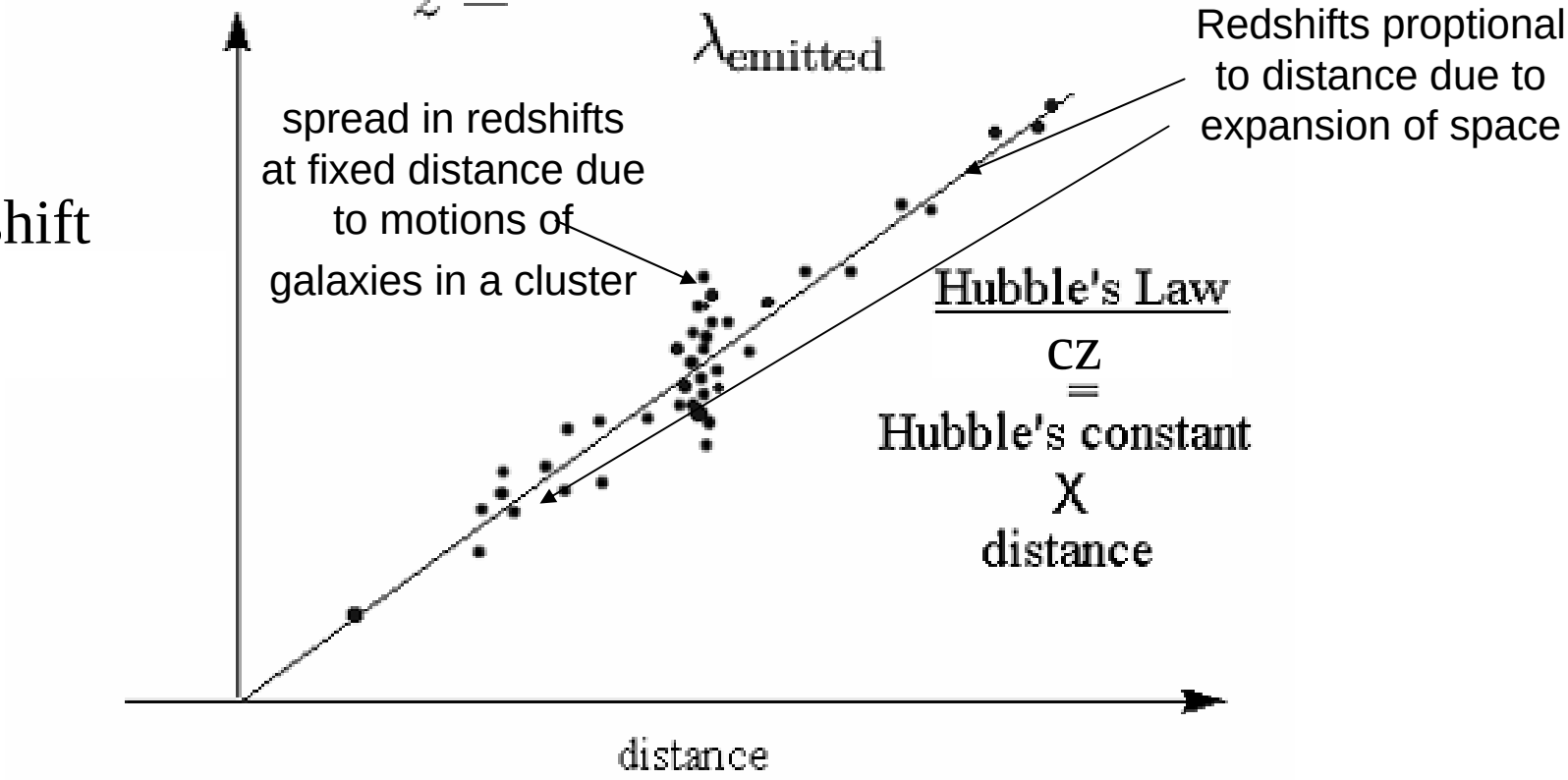
(b) ... increases in wavelength as the rubber band is stretched.

Figure 26-4
Universe, Eighth Edition

2) Cosmological redshift is due to expansion of space itself

Galaxy redshifts can be due to both their physical motion with respect to us and due to cosmological redshift

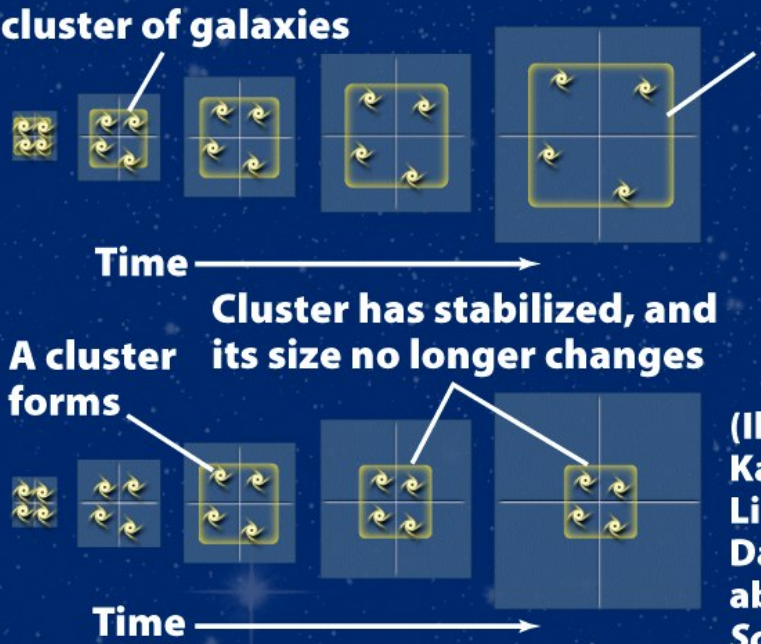
$$z = \frac{\lambda_{\text{observed}} - \lambda_{\text{emitted}}}{\lambda_{\text{emitted}}}$$



Gravitationally bound objects are held together by their own gravity and do not expand with the Universe

Urban Legend #3:
As the universe expands, so do objects within the universe. Hence galaxies within a cluster are now more spread out than they were billions of years ago.

Reality:
At first the expansion of the universe tends to pull the galaxies of a cluster away from each other. But the force of gravitational attraction binds the members of the clusters together, so the cluster stabilizes at a certain size.



(Illustrations by Alfred T. Kamajian, from C. H. Lineweaver and T. M. Davis, "Misconceptions about the Big Bang," *Scientific American*, March 2005)

Cosmological redshift due to expansion of space

$$z = \frac{\lambda_{\text{observed}} - \lambda_{\text{emitted}}}{\lambda_{\text{emitted}}} \longrightarrow 1 + z = \frac{\lambda_{\text{observed}}}{\lambda_{\text{emitted}}}$$

1+z = Rnow/Rthen = 1/Rthen

Where *z* corresponds to a shift of wavelength and frequency of light as the Universe expands from the epoch when scale factor is *Rthen* to the current epoch corresponding to *Rnow*.

For example, *z=1* corresponds to the epoch when the Universe was twice “smaller” than now.

The last paragraph of the Hubble's 1929 paper

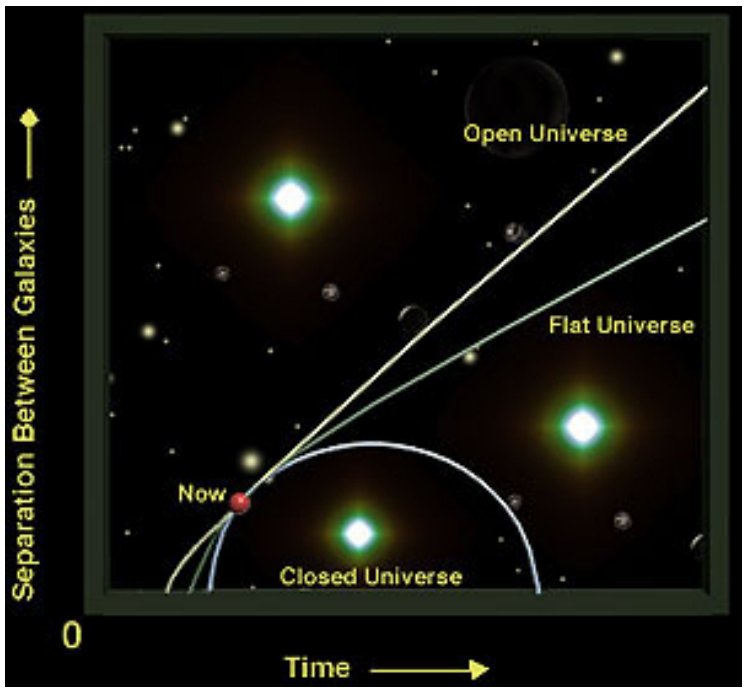
The outstanding feature, however, is the possibility that the velocity-distance relation may represent the de Sitter effect, and hence that numerical data may be introduced into discussions of the general curvature of space. In the de Sitter cosmology, displacements of the spectra arise from two sources, an apparent slowing down of atomic vibrations and a general tendency of material particles to scatter. The latter involves an acceleration and hence introduces the element of time. The relative importance of these two effects should determine the form of the relation between distances and observed velocities; and in this connection it may be emphasized that the linear relation found in the present discussion is a first approximation representing a restricted range in distance.

[1] *Mt. Wilson Contr.*, No. 324; *Astroph. J., Chicago, Ill.*, **64,** 1926 (321).
[2] *Harvard Coll. Obs. Circ.*, 294, 1926.
[3] *Mon. Not. R. Astr. Soc.*, **85,** 1925 (865–894).
[4] These PROCEEDINGS, **15,** 1929 (167).

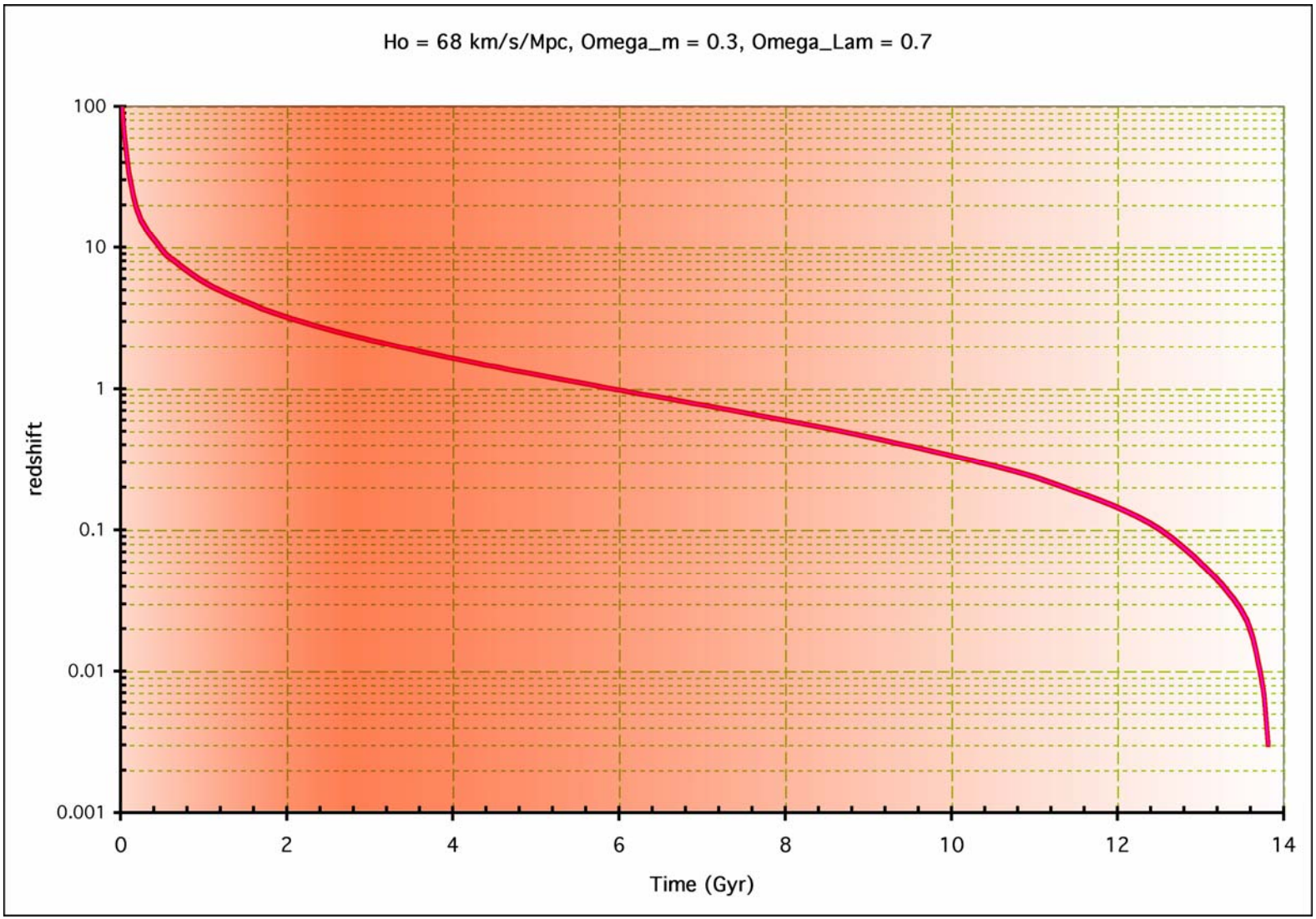
Hubble constant: and the age of the Universe

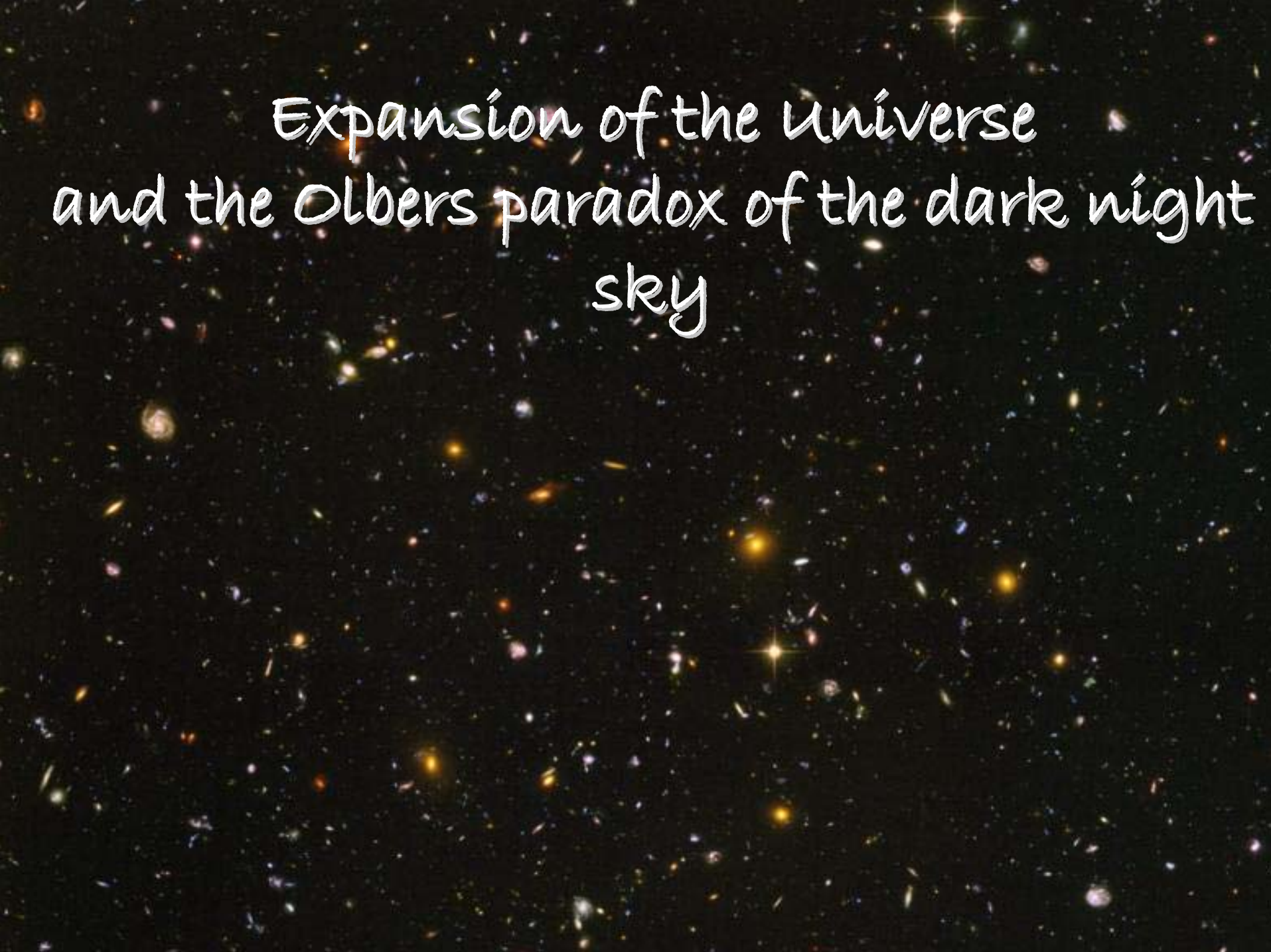
Inverse of the Hubble constant has units of time and corresponds to the *age of the Universe*

If we use *H* to be ~500 km/s/Mpc, as estimated by Hubble, the age will be ~2 billion years.



age of the Universe at different redshifts




Expansion of the Universe
and the Olbers paradox of the dark night sky

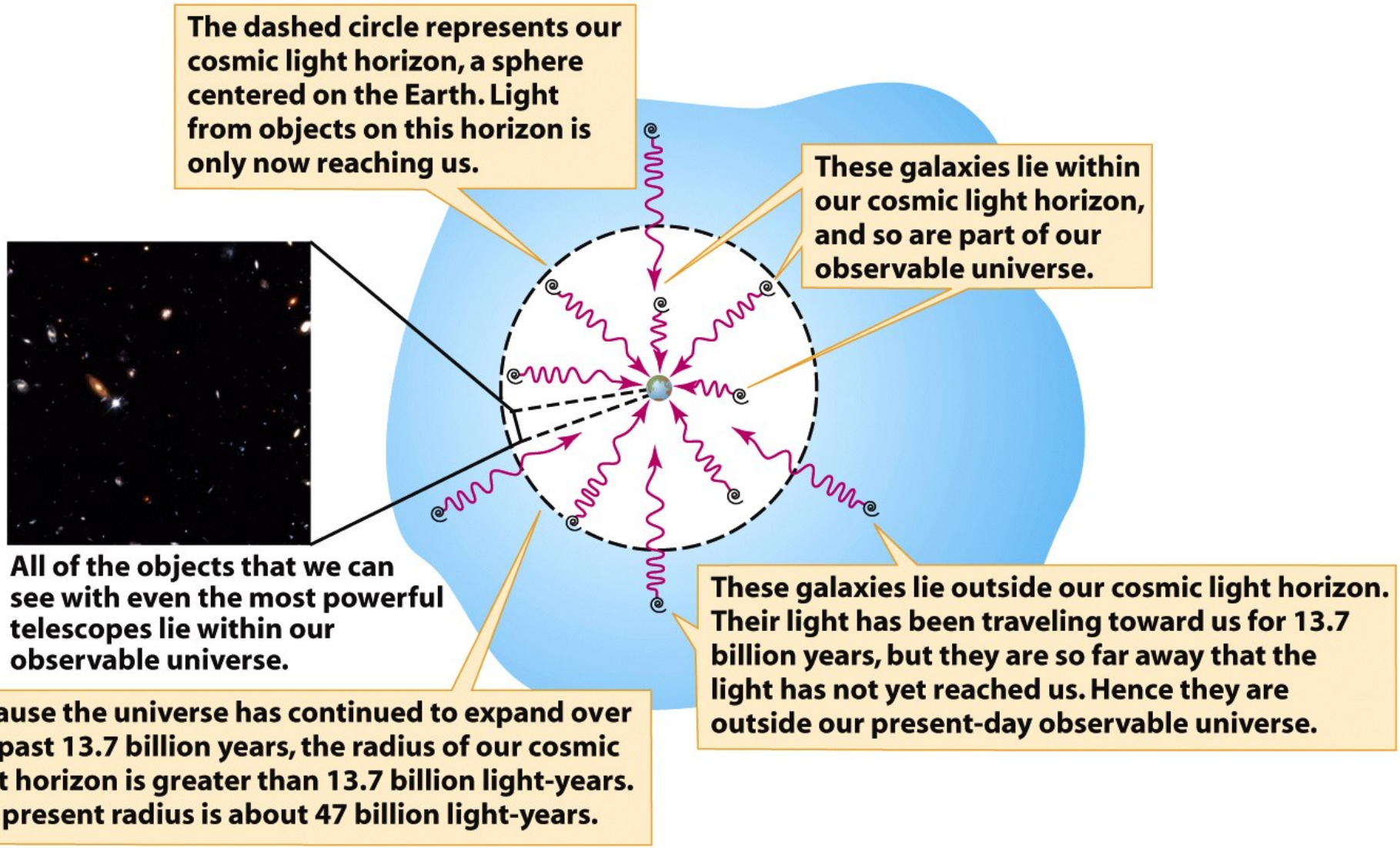
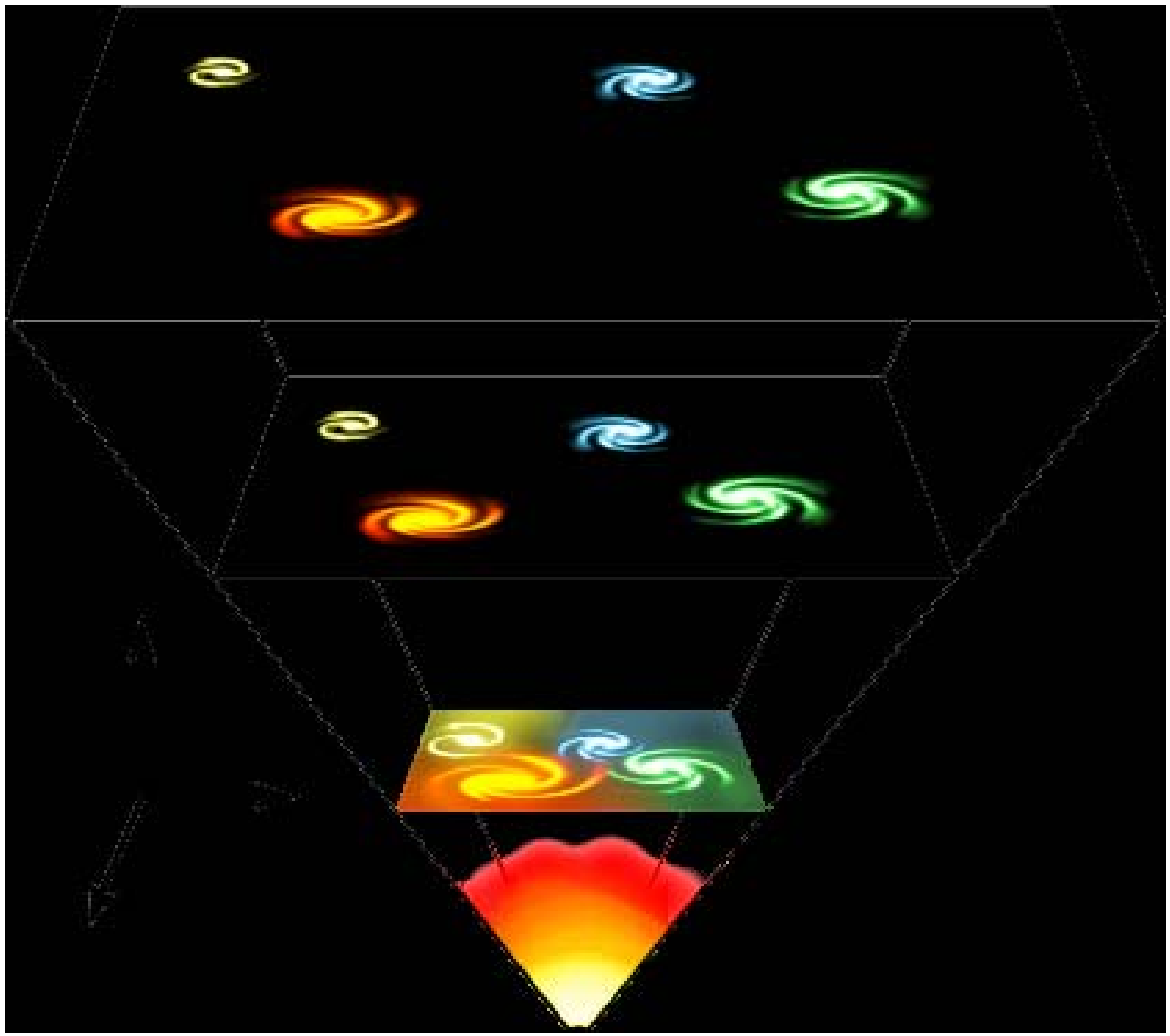


Figure 26-5
Universe, Eighth Edition

The Big Bang in the beginning



time

t=0

(or t=Planck time)

The Big Bang

The Big Bang

Did not have a center!