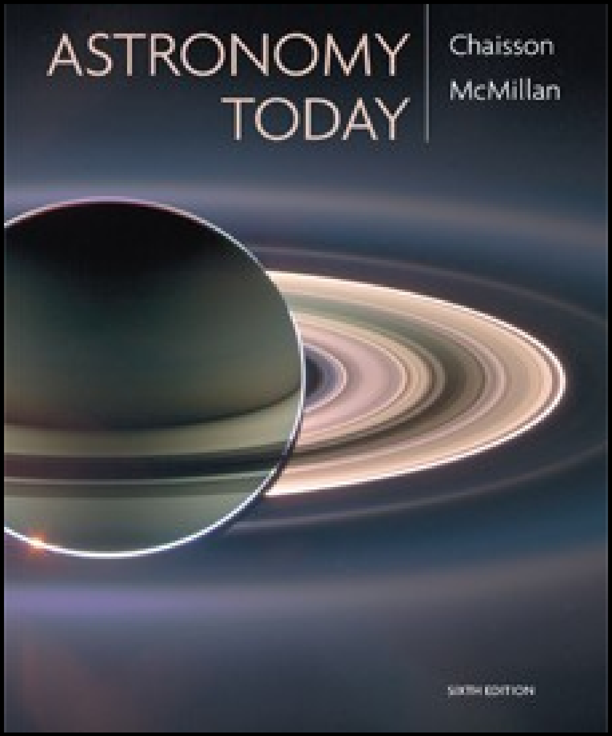


Lecture Outlines

Chapter 26

Astronomy Today,

6th edition

Chaisson

McMillan

Chapter 26
Cosmology

Big Questions of Cosmology

1. When did the Universe begin, if there was a beginning? [Same as "how old ...?" and "Is it infinitely old?".]
2. How did the Universe evolve into its current state?
3. How will the Universe end?
4. How big is the Universe? Does it have an edge, or is it infinite?
5. Are we (humans) the only technologically advanced civilization?
6. Are we special or central in any way?

Others: are there other galaxies like ours? What are black holes and what do they have to do with the big bang? What is the Big Bang? ...

Some quick answers ...

1. When did the Universe begin, if there was a beginning? [Same as “how old ...?” and “Is it infinitely old?”.]

A: 13.82 billion years ago. We call the beginning event the “Big Bang”

2. How did the Universe evolve into its current state?

A: Ch. 27: how particles formed in early Univ.
  Ch. 18-22: how stars formed
  Ch. 15: how solar system(s) formed
  Ch. 25: how galaxies formed
  Ch. 28: how life formed
  See the “Big Bang Theory” TV opener...

Some quick answers ...

3. How will the Universe end?
A: Probably continued expansion, “heat death”, possible “big rip”. (See “The Five Ages of the Universe” - F. Adams.)
4. How big is the Universe? Does it have an edge, or is it infinite?
A: Define the “Observable Universe” = the part of the universe that we can see. If the universe was static, this would be the distance that light can travel in 13.8 billion yrs (~4000 Mpc). Compensating for the time delay of light, and the expansion of space, the current (“proper”) distance to the observable limit is 46 billion LY.

Some quick answers ...

4. How big is the Universe? (continued)

The most distant "stuff" we detect is the Cosmic Microwave Background – the glow of protons and electrons combining into Hydrogen at a redshift of $z \sim 1000$!

Inflation theory suggests that there should be more beyond our "horizon", in fact, that our observable universe is only $1 / 10^{23}$ of the entire universe. Also, the universe is possibly infinite.

Membrane theory allows for there to be a "multiverse" consisting of separate universes from ours, but we don't know how to test this.

Some quick answers ...

5. Are we (humans) the only technologically advanced civilization?

A: The *Drake equation* is an equation used to estimate the number of detectable extraterrestrial civilizations in the Milky Way galaxy.

$$N = R^* f_{planets}\ n_{habit}\ f_{life}\ f_{intel}\ f_{tech.civ}\ L_{survive}$$

Estimates range from N = 0.000065 to 20,000.

N=10 used in 1961 plea.

6. Are we special or central in any way?

A: So far, we are the only planet known to have intelligent, creative life.

We are not centered spatially in any way – but sometimes data gives that illusion. ("finger of God", expansion)

26.1 The Universe on the Largest Scales

The **cosmological principle** includes the assumptions of isotropy and homogeneity. It can be stated as:

> ***Viewed on a sufficiently large scale, the properties of the Universe are the same for all observers.***

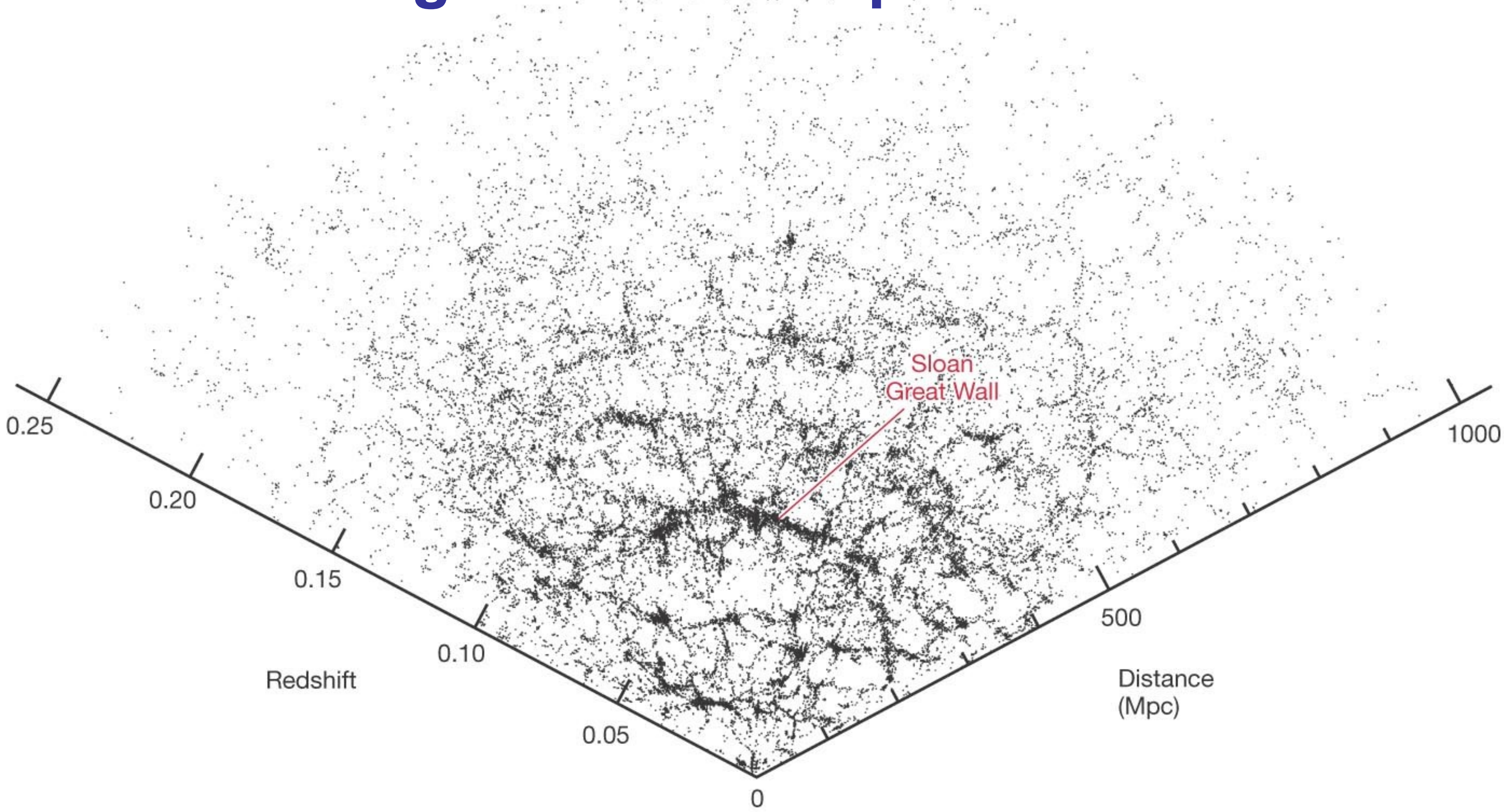
The Universe appears **homogenous** (any 300-Mpc-square block appears much like any other) on scales greater than about 300 Mpc.

The Universe also appears to be **isotropic**—the same in all directions and from every vantage point.

Evidence ...

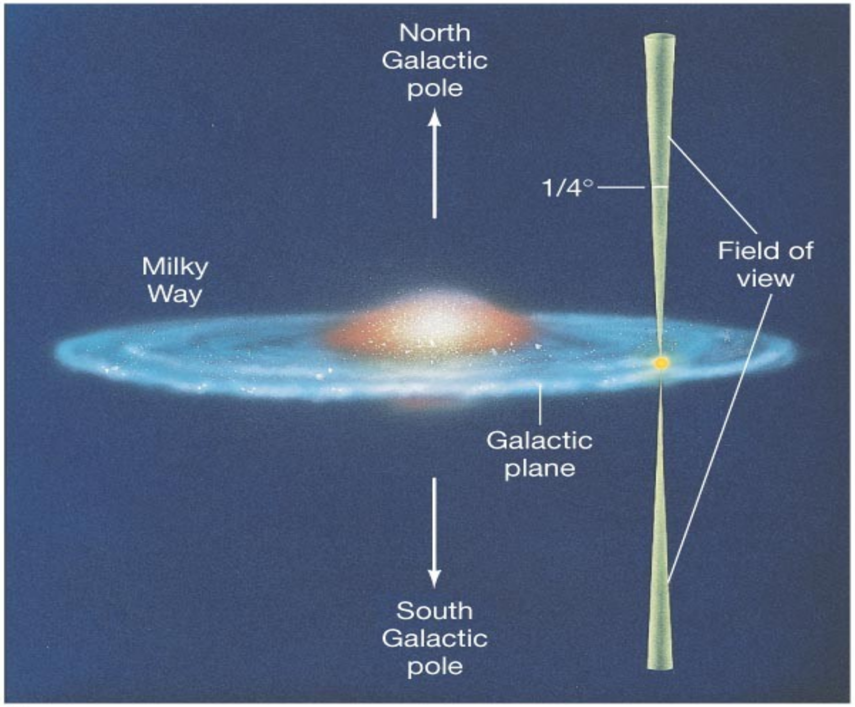
The universe is homogeneous...

This map shows the largest structure known in the Universe, the Sloan Great Wall. No structure larger than 300 Mpc is seen.

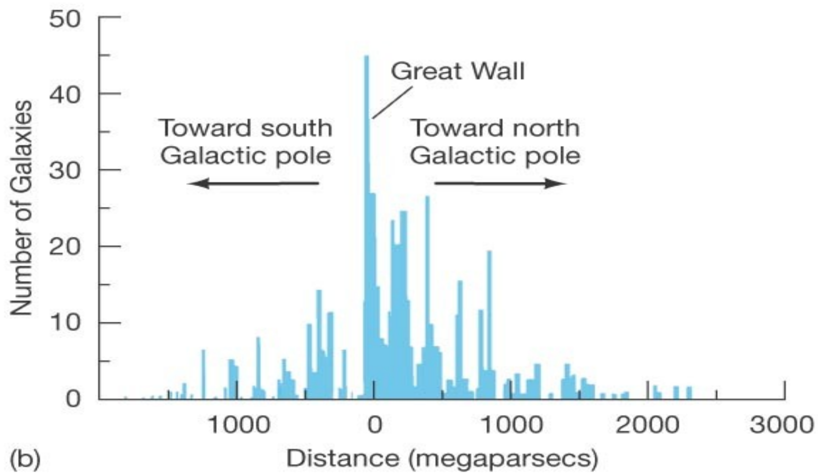


26.1 The Universe on the Largest Scales

This **pencil-beam survey** is another measure of **large-scale structure**. Again, there is structure at about 200–300 Mpc, but nothing larger.



(a)



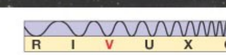
(b)

Discovery 26-1:
A Stunning View of Deep Space

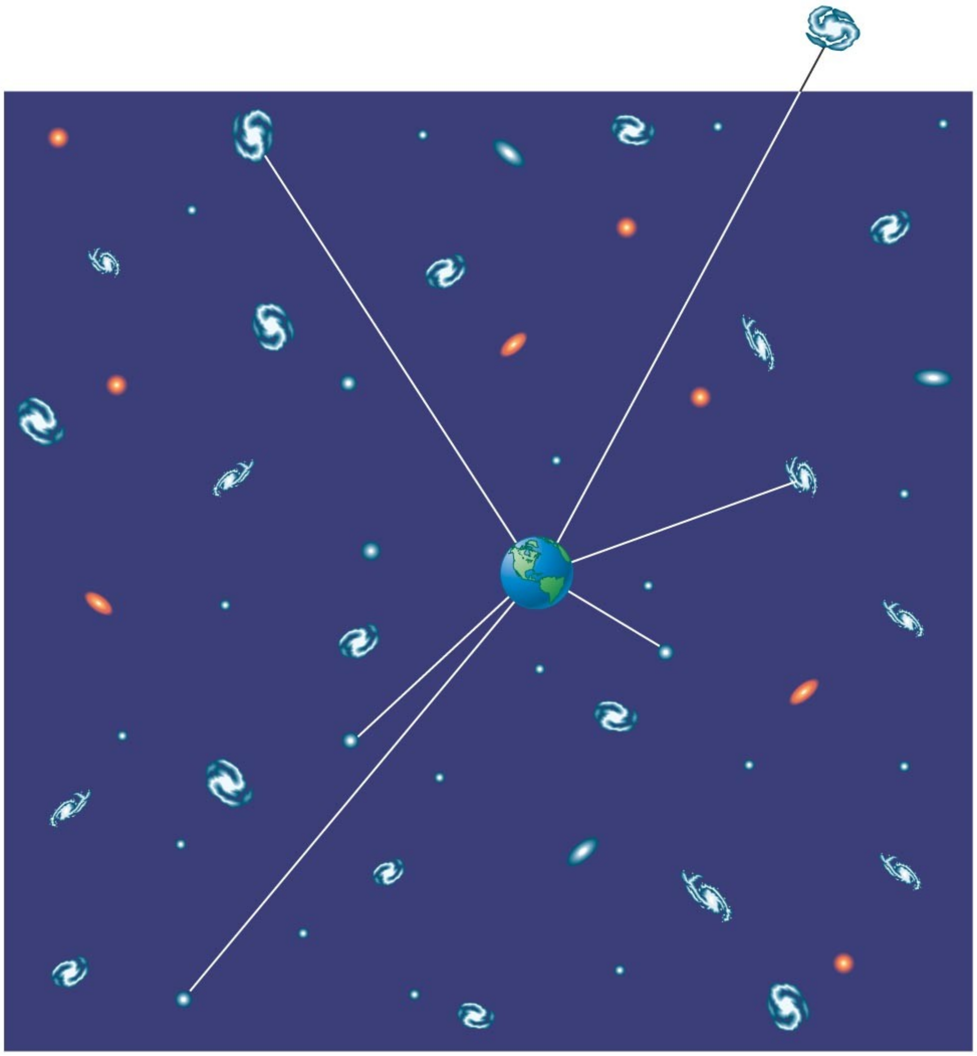
The **Hubble Ultra Deep Field**

Exposure time of 1 million seconds.

It contains about 10,000 galaxies.



What we can learn from observations on large scales.



Olbers's Paradox:

Why is the sky dark at night?

If the universe is **homogeneous**, **isotropic**, **infinite**, and **unchanging**, the entire sky should be as bright as the surface of a star.

What we can learn from observations on large scales.

Olbers's Paradox: will go away if we remove one or more of those 4 assumptions.

We think that the universe appears **homogeneous** and **isotropic**, so we keep those.

That leaves the assumptions that the universe is infinitely large and old. So we can conclude that the (observable) universe is <u>not *both* infinitely large and old.</u>

26.2 The Big Bang

Pillars of evidence:

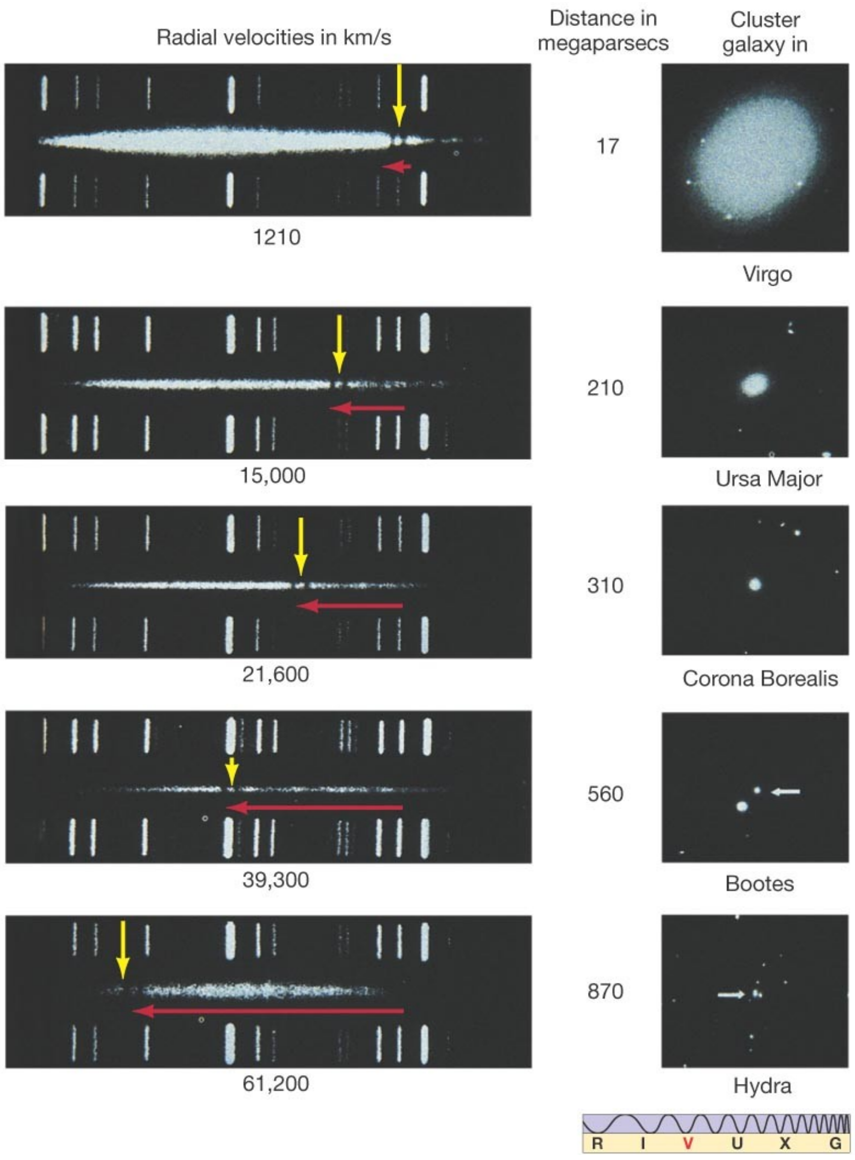
1. Expansion of universe (universal recession)
2. Primordial abundances are consistent with current abundances
3. The cosmic microwave background (CMB or CBR)

24.3 Hubble's Law

Universal recession: all galaxies (with a couple of nearby exceptions) seem to be moving away from us.

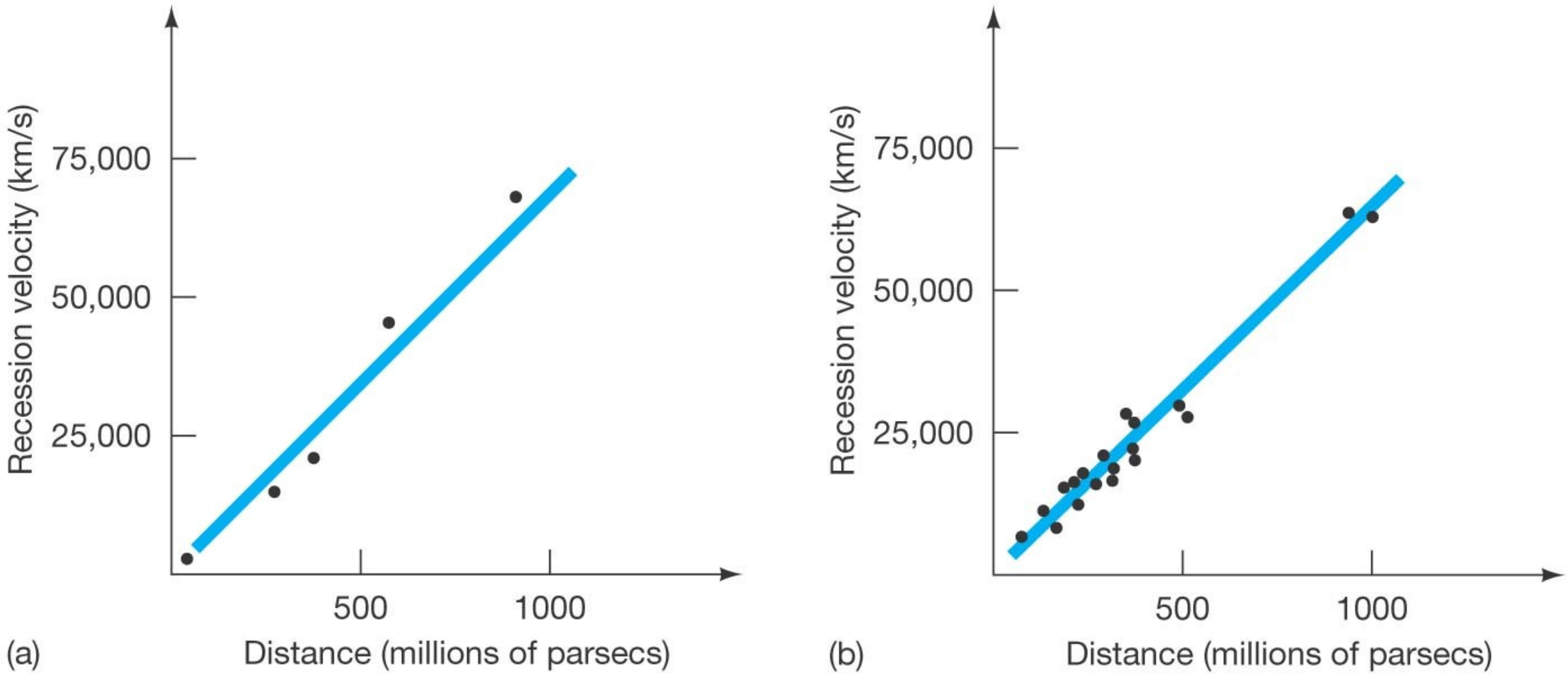
The **redshift**, z, of their spectra correlates with their **distance**.

$$cz = H_0 \times \text{distance}$$



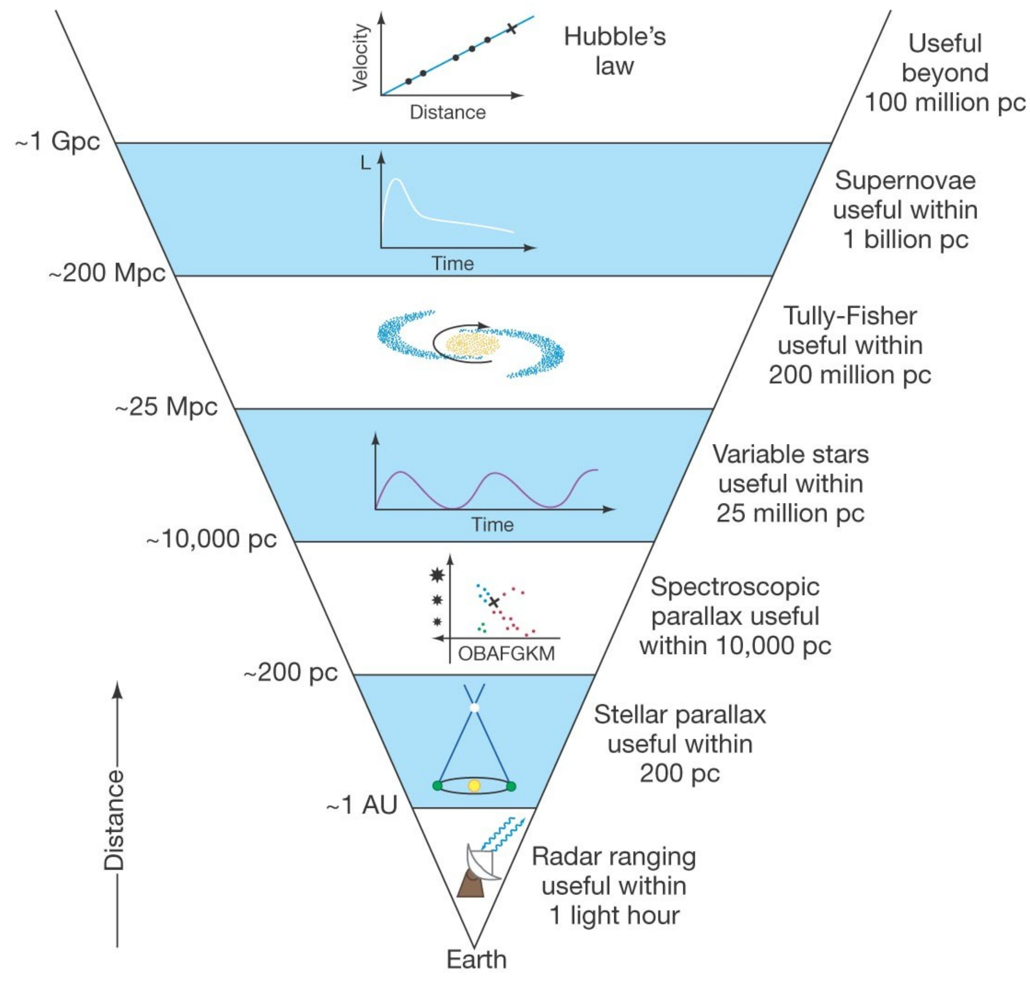
24.3 Hubble's Law

These plots show the relation between distance and recessional velocity for the five galaxies in the previous figure, and then for a larger sample: $V = H_0 D$



24.3 Hubble's Law

This puts the final step on our distance ladder:



26.2 The Expanding Universe

How long has this expansion been going on?

That's the *age of the observable universe*! If we assume that the expansion has been constant (H is constant with time), then ...

time = distance / velocity

= distance / (H_0 x distance)

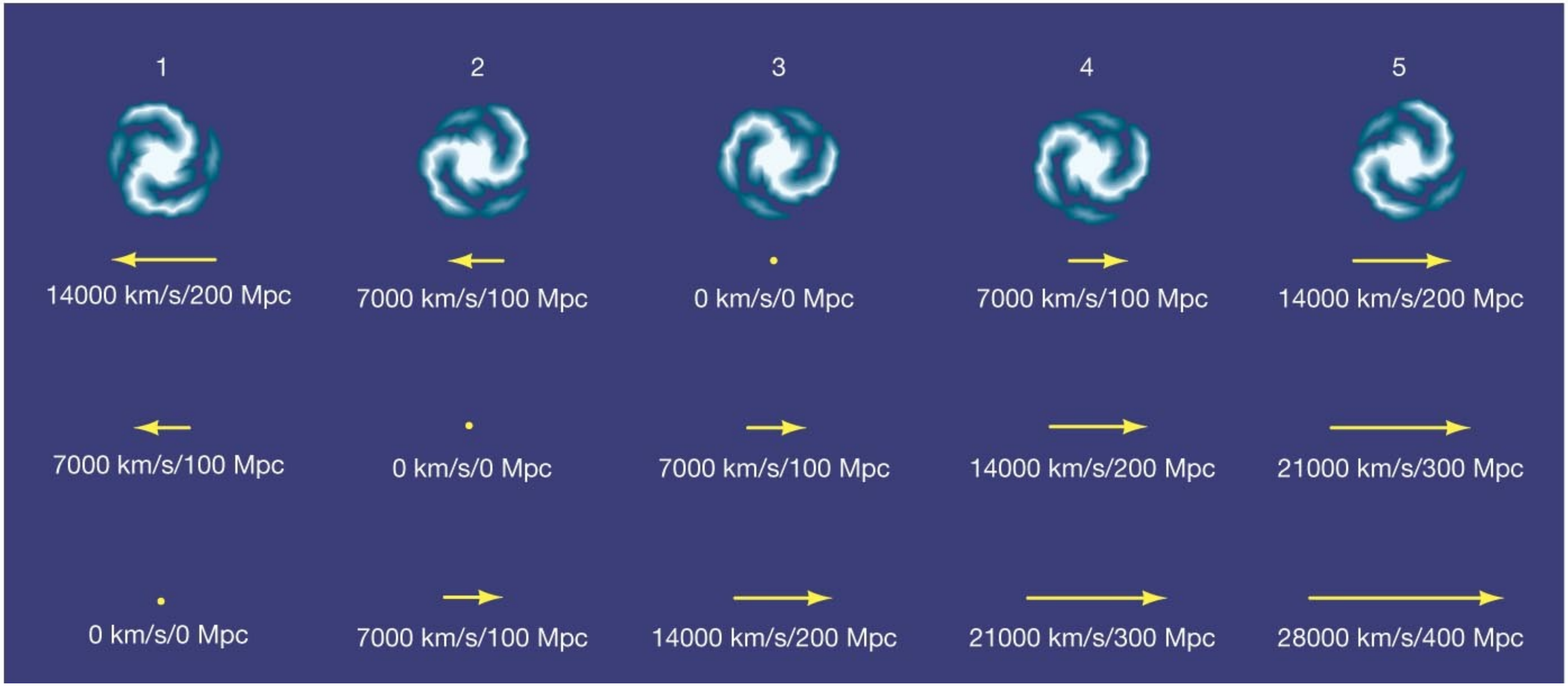
= $1/H_0$

Using H_0 = 70 km/s/Mpc, we find that time is about 14 billion years. (Now H_0 = 67.3)

Accepted age of universe = 13.8+-0.1 Gyrs

26.2 The Expanding Universe

Note that Hubble's law is the same no matter who is making the measurements.



7000km/s / 100 Mpc = 70 km/s/Mpc = H_0

26.2 The Expanding Universe

If this expansion is extrapolated backwards in time, all galaxies originate from a single point in an event called the Big Bang.

So, where was the Big Bang?

It was everywhere! No center!

The same relation between recessional velocity and distance is observed by all galaxies.

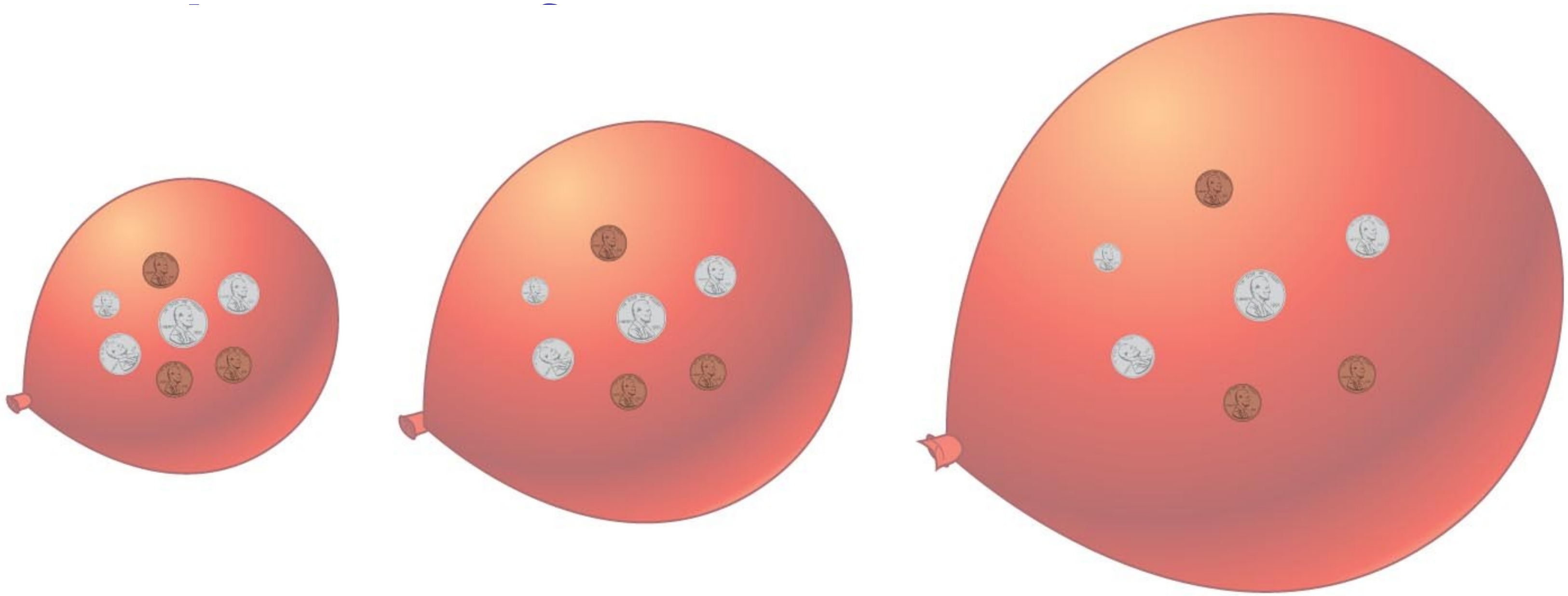
26.2 The Expanding Universe

Analogies to expanding universe:

1) raisin bread.   raisins=galaxies, bread=space

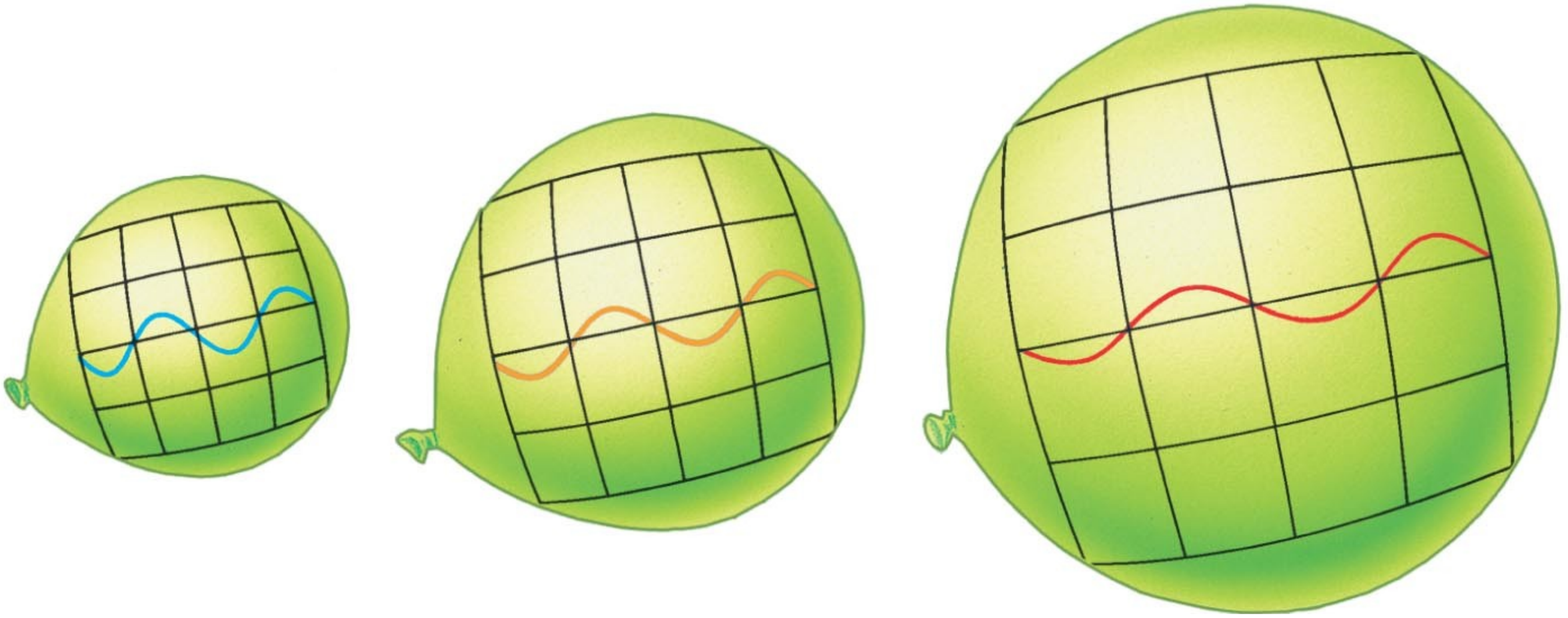
2) inflating balloon

The surface of the balloon represents all of space-time, the coins galaxies. No “center” of ex



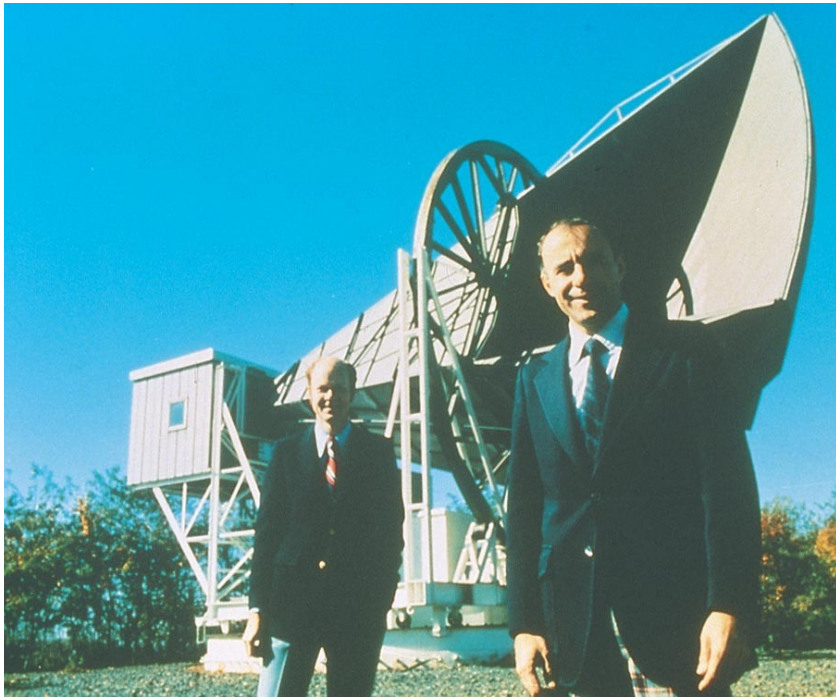
26.2 The Expanding Universe

The same analogy can be used to explain the **cosmological redshift**:



26.7 Cosmic Microwave Background

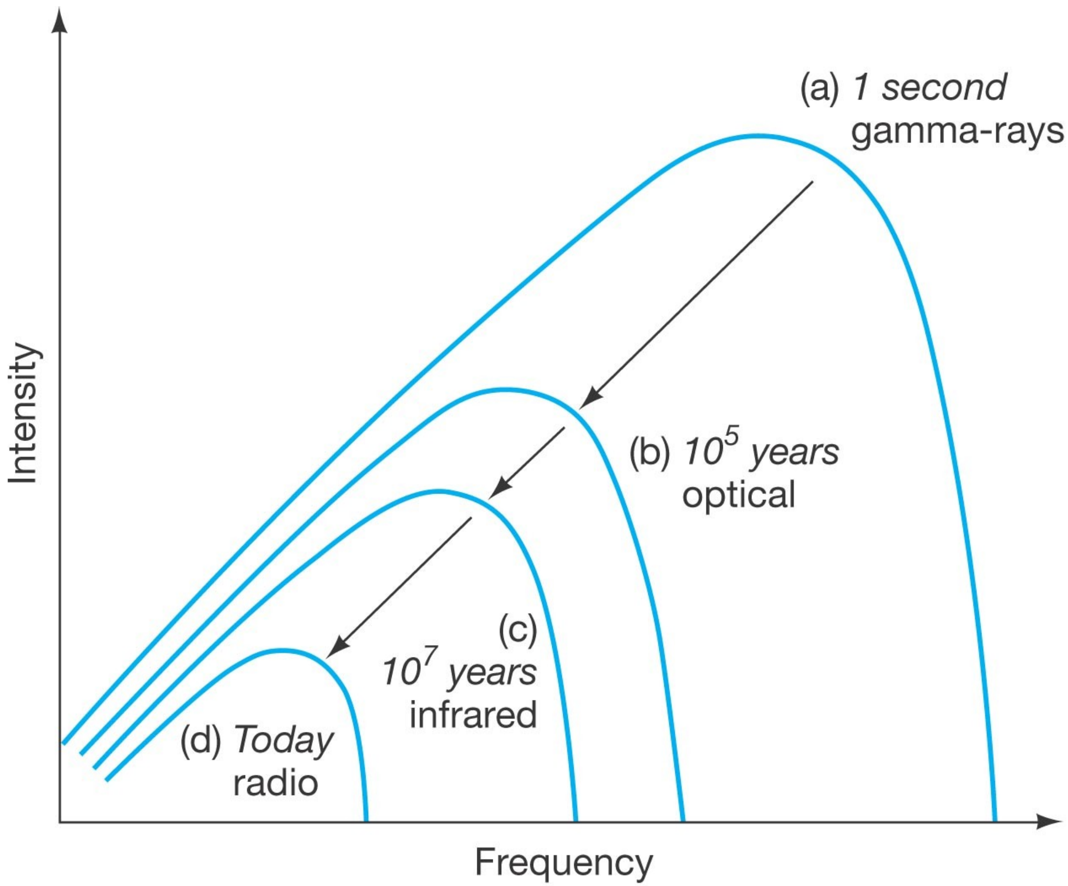
The **cosmic microwave background** was discovered fortuitously in 1964, as Penzias and Wilson tried to get rid of the last bit of “noise” in their radio antenna.



Instead, they found that the “noise” came from all directions and at all times, and was always the same. They were detecting light left over from the **Big Bang**.

26.7 Cosmic Microwave Background

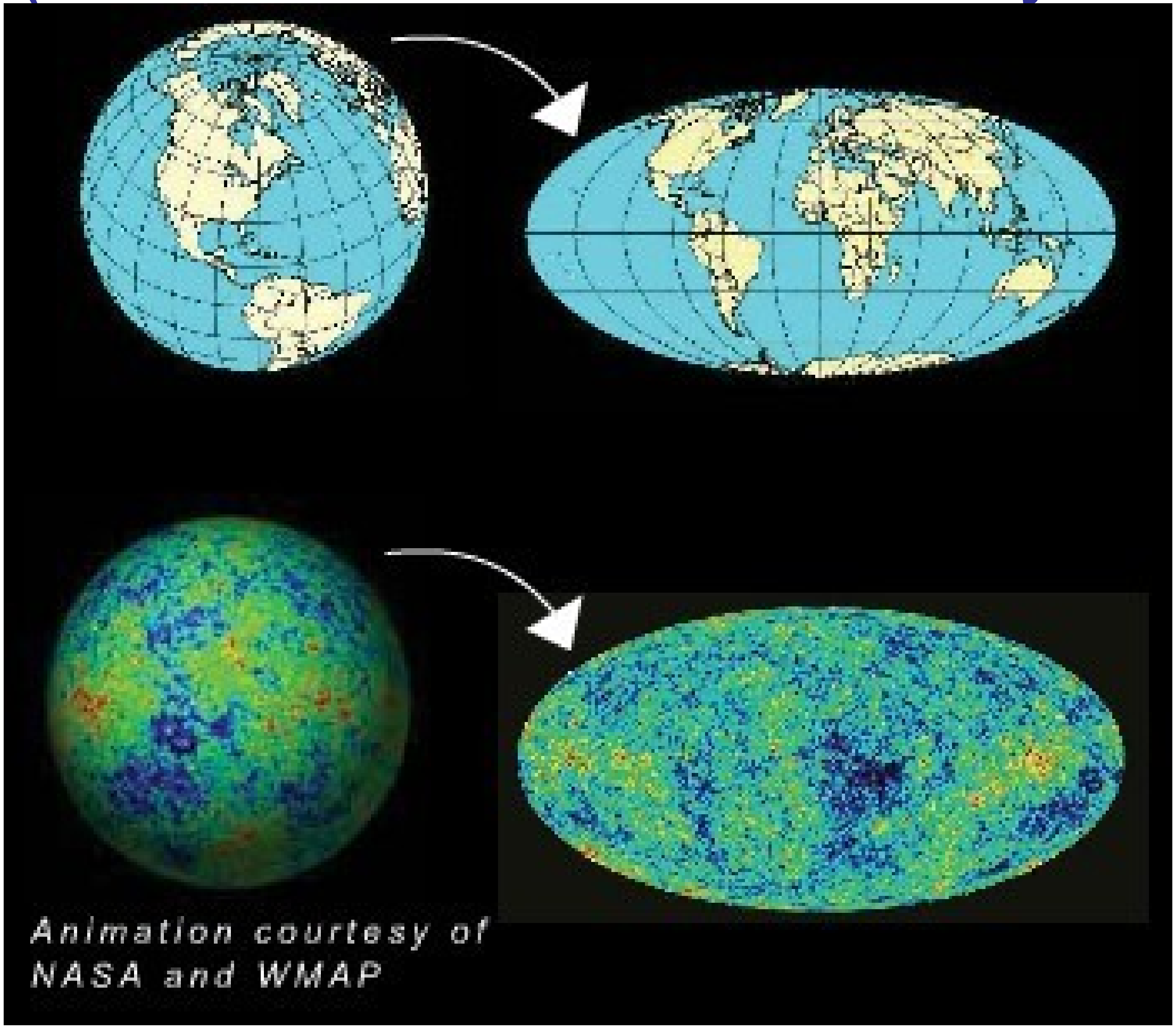
When the universe was about $3x10^5$ yrs old, the radiation had a blackbody spectrum with a peak in the visible part of the EM spectrum. That's when the universe became transparent. Subsequently,



expansion has redshifted the peak into the radio. We see a blackbody curve corresponding to about 2.7 K.

26.7 Cosmic Microwave Background

A special (Aitoff) projection is used to show the microwave sky (here with Earth's motion and Galaxy subtracted).



26.3 The Fate of the Cosmos

There are two main possibilities for the Universe in the far future:

- It could keep **expanding** forever.
- It could **collapse**.

Gravity counteracts expansion.

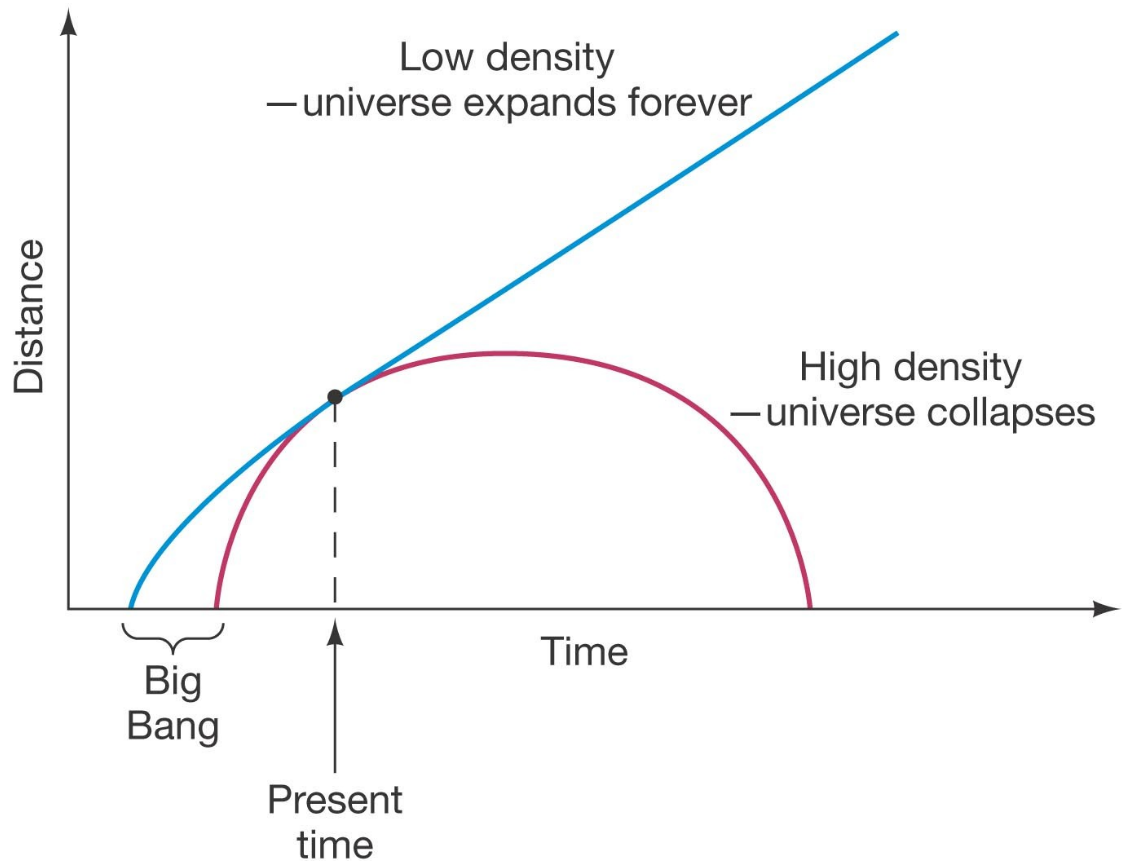
More mass $\rightarrow$ more gravity.

Higher density $\rightarrow$ more gravity.

Thus, destiny is determined by **density!**

26.3 The Fate of the Cosmos

If the density is **low**, the universe will **expand** forever. If it is **high**, the universe will ultimately **collapse**.



26.3 The Fate of the Cosmos

There is a **critical density** between collapse and expansion (assuming no dark energy).

Given the present value of the Hubble constant, that **critical density** is:

$$9 \times 10^{-27}\ \mathrm{kg/m^3}$$

This is about five hydrogen atoms per cubic meter.

26.3 The Fate of the Cosmos

The fate of the universe is actually related to the curvature of space-time.

- **Closed**—this is the geometry that leads to ultimate collapse. Positive curvature.
- **Flat**—this corresponds to the critical density. Zero curvature.
- **Open**—expands forever. Negative curvature.

26.4 The Geometry of Space

These three possibilities can be described by comparing the **actual density**, ρ, of the Universe to the **critical density**, ρ_c .

Astronomers refer to the ratio of these densities, ρ / ρ_c as the density parameter Ω_0.

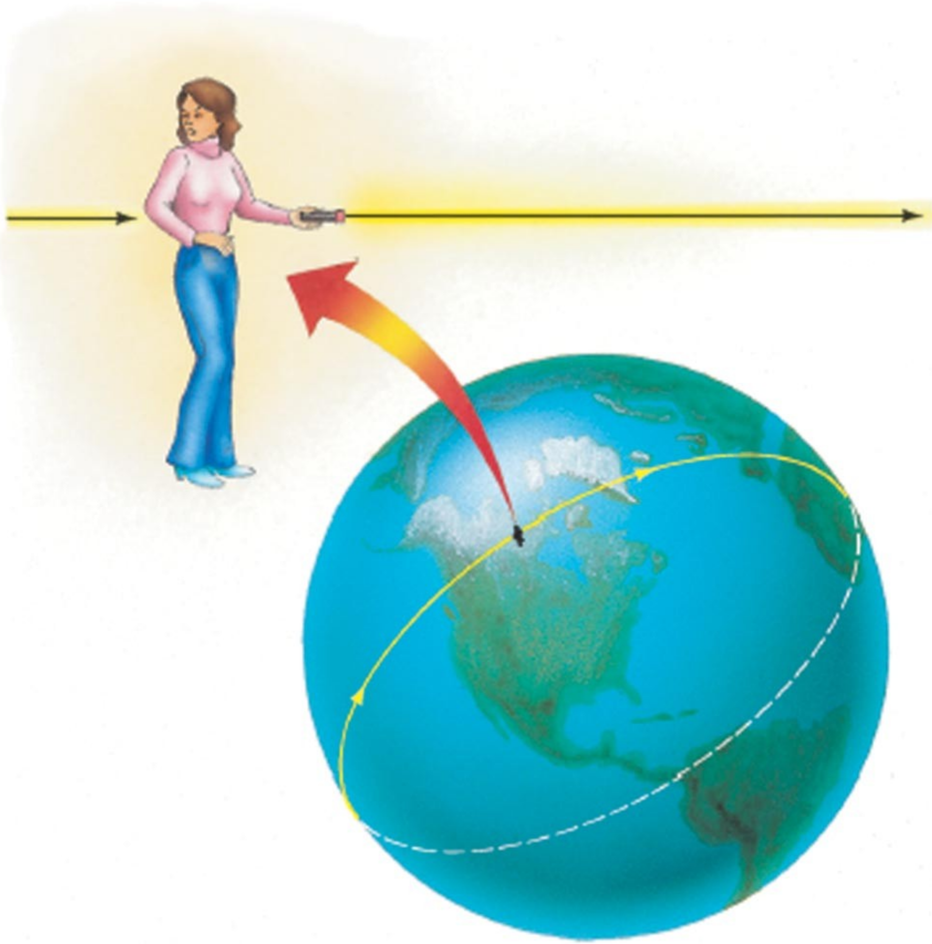
Then we can describe the three possibilities as:

$\Omega_0 < 1$ **Open** geometry

$\Omega_0 = 1$ **Flat** geometry

$\Omega_0 > 1$ **Closed** geometry

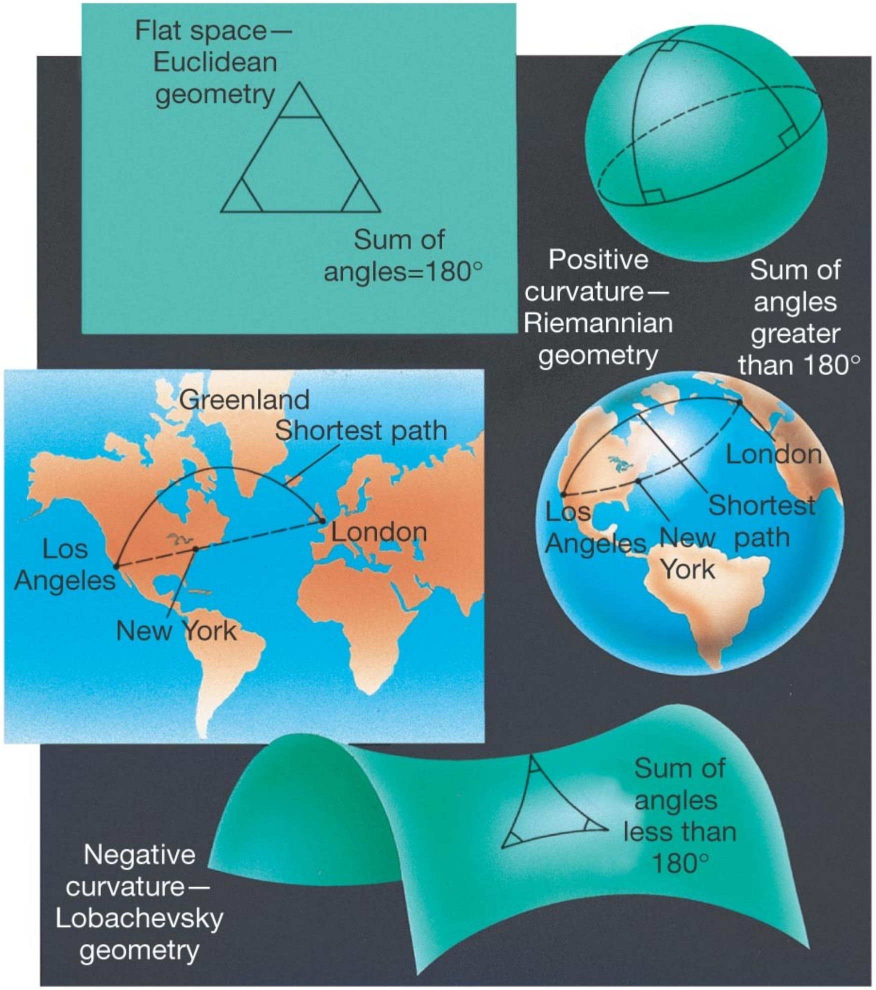
26.4 The Geometry of Space



In a **closed** universe, you can travel in a straight line and end up back where you started (in the absence of time and budget constraints, of course!).

More Precisely 26-1: Curved Space

The three possibilities for the overall geometry of space are illustrated here: The **closed** geometry is like the surface of a **sphere**; the **flat** one is **flat**; and the **open** geometry is like a **saddle**.



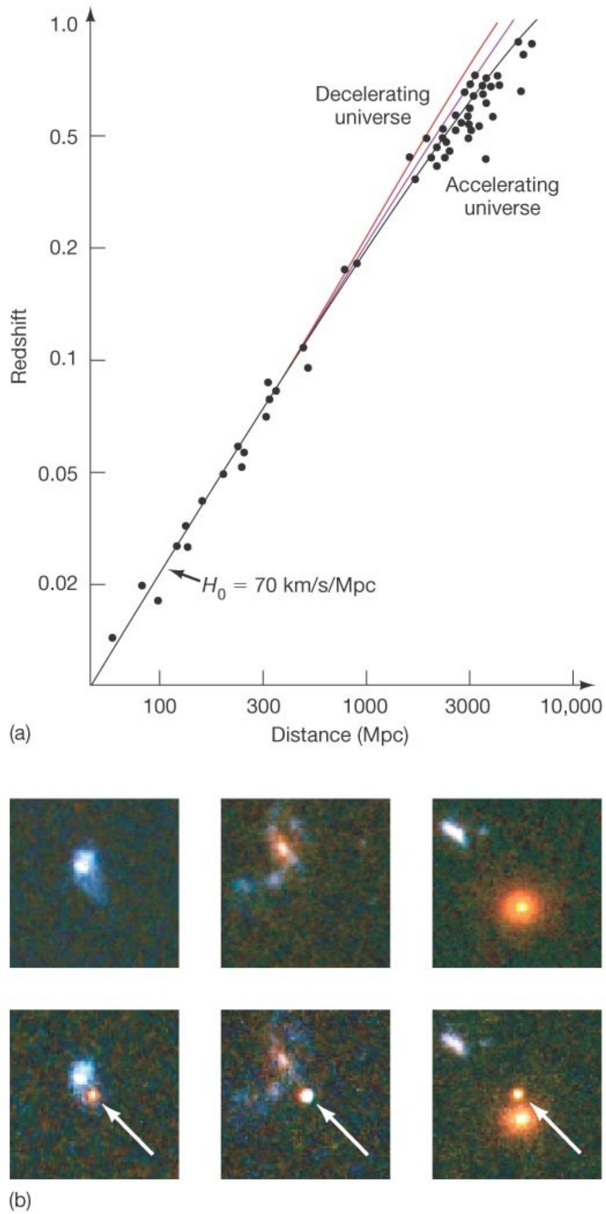
26.5 Will the Universe Expand Forever?

Instead, study expansion of universe to see whether accelerating or decelerating.

Type I supernovae can be used to measure the expansion rate at large redshifts.

If the expansion of the Universe is decelerating, as it would if gravity were the only force acting, the farthest galaxies had a more rapid recessional speed in the past, and will appear as though they were receding faster than Hubble’s law would predict.

26.5 Will the Universe Expand Forever?



Observations of Type Ia supernovae indicate that we are in an accelerating one!

The various hypotheses that attempt to explain the acceleration almost all invoke some kind of Dark Energy.

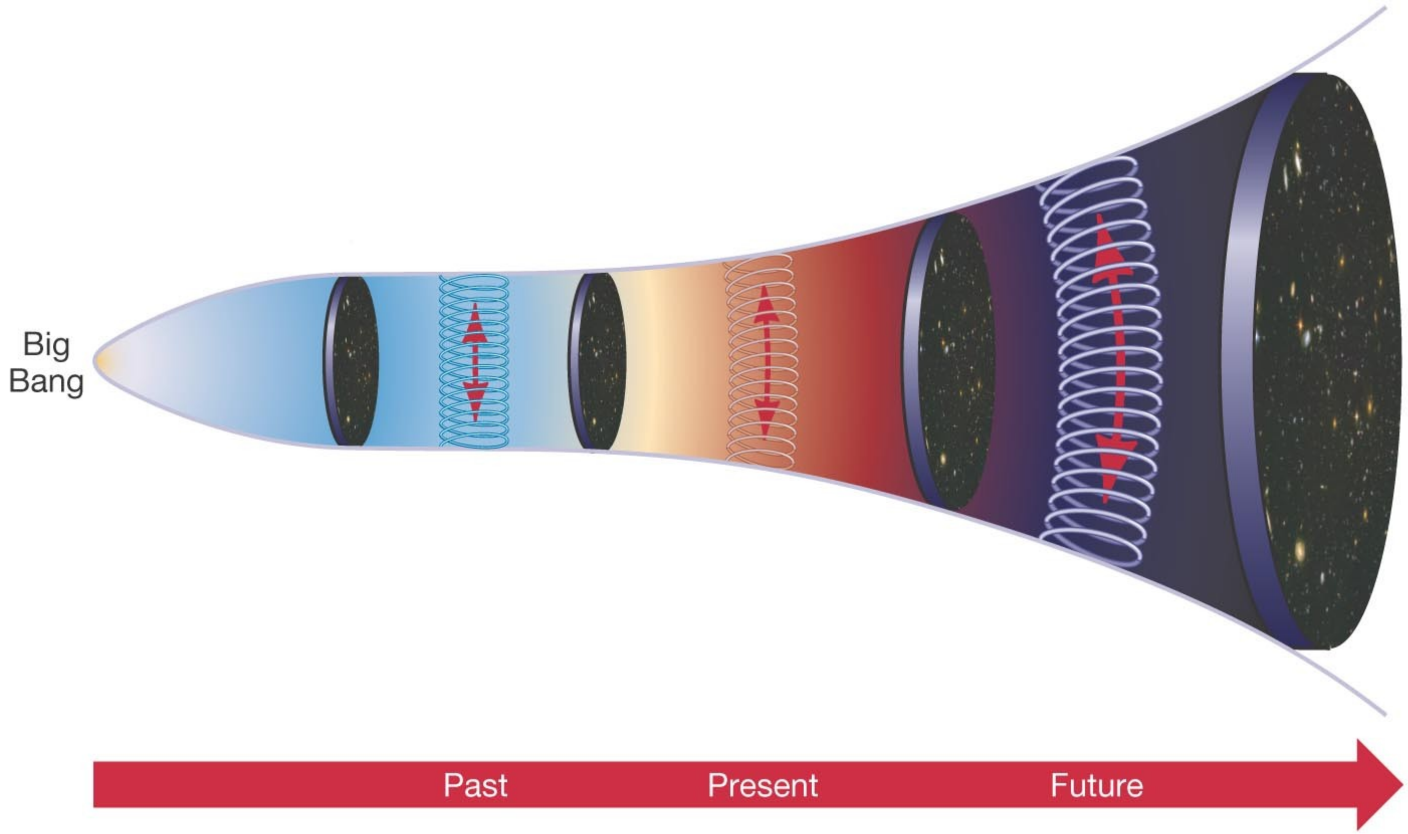
Cosmological constant

Vacuum energy

quintessense

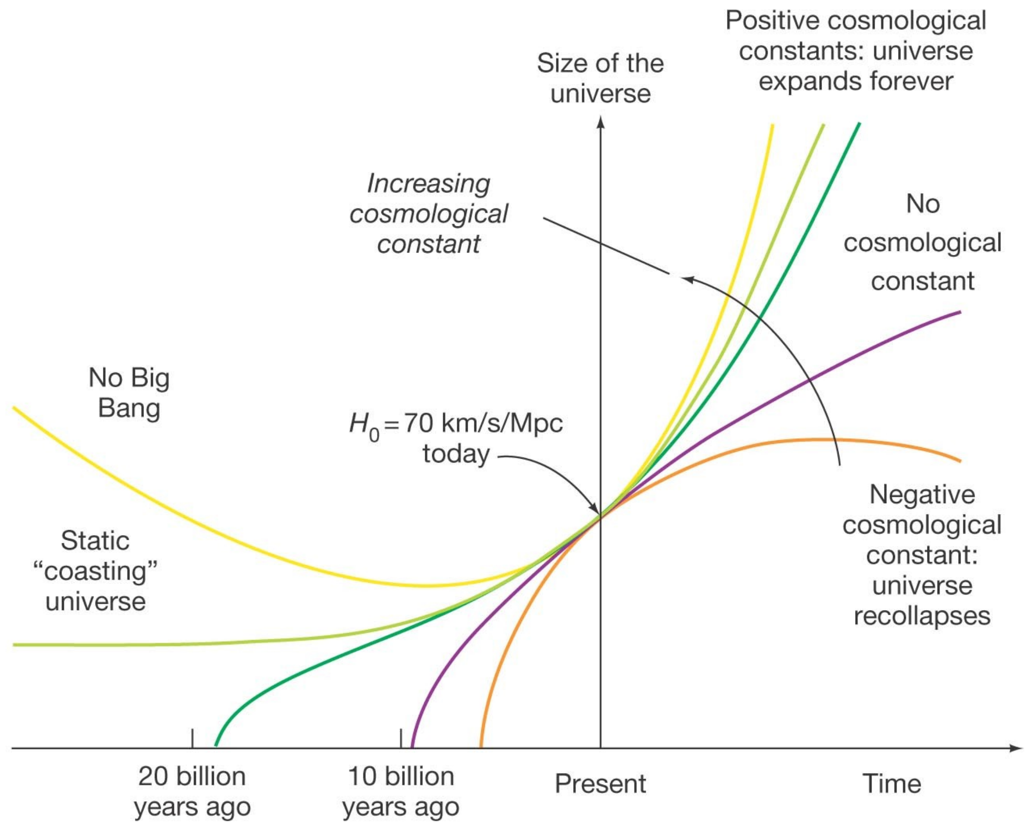
26.5 Will the Universe Expand Forever?

The repulsive effect of the dark energy increases as the Universe expands.



Discovery 26-2:
Einstein and the Cosmological Constant

Now, it seems as though something like a cosmological constant may be necessary to explain the accelerating universe—theoretical work is still at a very early stage, though!



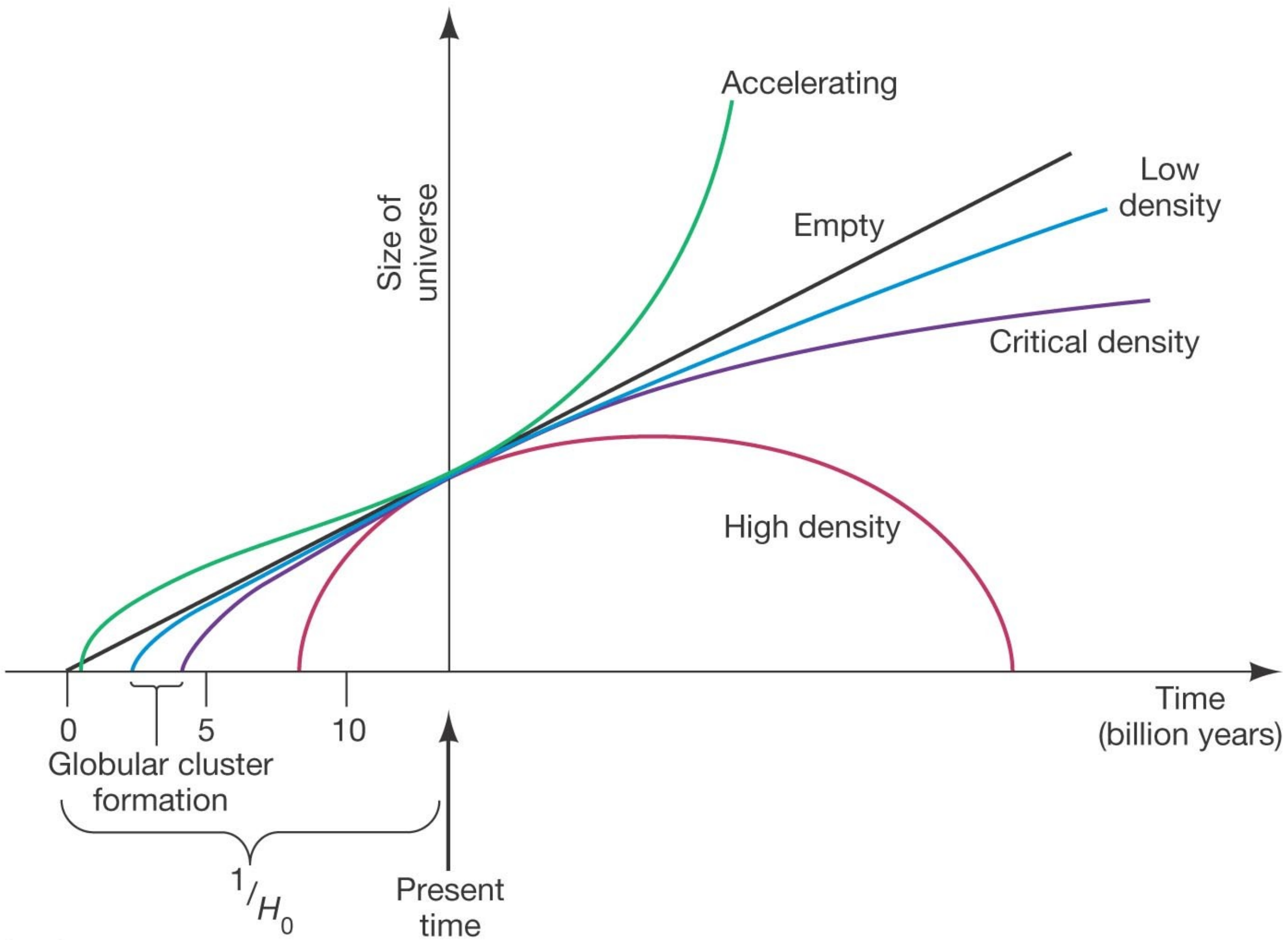
26.6 Dark Energy and Cosmology

What else supports the "dark energy" theory?

- In the very early life of the Universe, the geometry must be flat.
- The assumption of a constant expansion rate predicts the Universe to be younger than we observe.

26.6 Dark Energy and Cosmology

This graph now includes the accelerating universe. Given what we now know, the age of the universe works out to be **13.8** billion years.



26.6 Dark Energy and Cosmology

This is consistent with other observations, particularly of the age of globular clusters, and yields the following timeline:

13.8 billion years ago: Big Bang

13.6 billion years ago: First stars form

13-10 billion years ago: Quasars forming

10 billion years ago: First stars in Milky Way form

Summary of Chapter 26

- On scales larger than a few hundred megaparsecs, the Universe is homogeneous and isotropic.
- The Universe began about 14 million years ago, in a Big Bang.
- Future of the Universe: either expand forever, or collapse
- Density between expansion and collapse is critical density.

Summary of Chapter 26 (cont.)

- A high-density universe has a closed geometry; a critical universe is flat; and a low-density universe is open.
- Luminous mass and dark matter make up at most 30% of the critical density.
- Acceleration of the universe appears to be speeding up, due to some form of dark energy.
- The Universe is about 14 billion years old.
- Cosmic microwave background is photons left over from Big Bang.