AST 301
Introduction to Astronomy

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Topics for this week

Describe the Milky Way Galaxy

Describe the Standard Candle method of determining distances and how Cepheid variable stars are used as standard candles.

Describe how astronomers measure the distribution of mass in a galaxy and what they find.

Describe the various types of galaxies and how they differ from the Milky Way.

What is Hubble's law? How is it measured, and what does it tell us about the Universe?

1. a) The Sun is in hydrostatic equilibrium. What does this mean? What is the definition of hydrostatic equilibrium as we apply it to the Sun?

Pressure inside the star pushing it apart balances gravity pulling it together.

So it doesn't change its size.

1. a) The Sun is in thermal equilibrium. What does this mean? What is the definition of thermal equilibrium as we apply it to the Sun?

Energy generation by nuclear fusion inside the star balances energy radiated from the surface of the star. So it doesn't change its temperature.

b) Give an example of an equilibrium (not necessarily an astronomical example) different from hydrostatic and thermal equilibrium.

Water flowing into a bucket balances water flowing out through a hole.

When supply and demand are equal the price is stable.

The floor pushes me up to balance gravity pulling me down.

2. If I want to use the Doppler technique to search for a planet orbiting around a star, what measurements or observations do I have to make?

I would measure the Doppler shift in the spectrum of the star caused by the pull of the planet's gravity on the star.

2. If I want to use the transit (or eclipse) technique to search for a planet orbiting around a star, what measurements or observations do I have to make?

I would observe the dimming of the star's light when the planet passes in front of the star.

If I find evidence of a planet this way, describe some information my measurements give me about the planet. (Do I know its mass? size? composition? orbit?) Explain briefly how the observations gave this information.

Doppler technique tells me the orbital period of the planet from the period of variation of the Doppler shift and information about the mass of the planet from the motion of the star caused by the planet's gravity.

The transit technique tells me the size of the planet from the fraction of the star's light it blocks. It also tells me the period of the planet's orbit from the time between transits.

3. The diameter of Polaris (the north star) is 100 times the diameter of the Sun.
a) How does the circumference of Polaris compare to the circumference of the Sun? (Which is larger, and how many times larger?)
Polaris. 100 times larger. (Both diameter and circumference are distances (1-dimensional quantities) so they scale together.)
b) How does the surface area of Polaris compare to the surface area of the Sun?
Polaris is $10{,}000 = 100^2$ times as big in area. (Area is 2-dimensional.)
c) How does the volume of Polaris compare to the volume of the Sun?
Polaris is $1{,}000{,}000 = 100^3$ times as big in volume. (Volume is 3-dimensional.)
d) If the mass of Polaris is 10 solar masses, how does the density of Polaris compare to the density of the Sun?
Density = Mass / Volume, so Polaris is 10 / 1,000,000 = 1 / 100,000 times the Sun.
e) Polaris lies directly above the Sun on the H-R diagram. What does this tell you about Polaris?
Polaris is more luminous. If it is directly above the Sun, it has the same temperature as the Sun.
f) How does the luminosity of Polaris compare to the luminosity of the Sun?
If its temperature is the same as the Sun's, its luminosity scales with its surface area, so it is 10,000 times the Sun's.

4. Each second, $600\text{x}10^9$ kg of hydrogen is converted to $596\text{x}10^9$ kg of helium inside of the Sun. How can I use Einstein's equation $E = m\ c^2$ to calculate the rate of energy generation by the Sun? How is this related to the luminosity of the Sun?
Each second $600\text{x}10^9 - 596\text{x}10^9 = 4\text{x}10^9$ kg of mass is converted into energy.
So the energy generated is $4\text{x}10^9 \text{ x } c^2$ Joules/second. This is the luminosity of the Sun.

5. The luminosity of a 2 solar mass main-sequence star is about 10 solar luminosities.
a) Why is the luminosity of a 2 solar mass star greater than the luminosity of the Sun?
Its greater mass gives it greater gravity, so its interior pressure and density are greater. This makes fusion run faster.
The location on the HR diagram tells us that the 2 solar-mass star has greater luminosity, but it doesn't explain why it does.
The greater size and surface temperature of the 2 solar-mass star are results of the greater rate of energy generation by fusion.
b) How does the main-sequence lifetime of a 2 solar mass star compare to that of the Sun? (Which is greater, and how many times greater is it?)
Like a car, the 2 solar-mass star has twice as much fuel, but it is burning 10 times as much each second, so it only lasts 2/10 = 1/5 times as long.

6. a) Why does the core of a massive star collapse once fusion has turned the elements in the core into iron?
Fusion of iron absorbs energy instead of generating energy. So it removes energy and pressure from the core of the star, so pressure no longer balances gravity, so the core collapses. If the core mass is less than about 4 solar masses a neutron star is formed.
b) What prevents a white dwarf from collapsing when nuclear fusion stops so energy is no longer being made by nuclear fusion?
Densely packed electrons (degenerate electrons) must move fast even if they are cold. So the pressure doesn't drop when a white dwarf can't generate energy to replace what it loses, so it doesn't collapse.

Different types of galaxies

- Spiral galaxies are like the Milky Way
  - Most of their stars are in thin disks, with spiral arms.
  - There are also clouds of gas and dust in the disks, where new stars are forming.
  - And they have bulges at the centers of their disks and halos of stars around the disks.
  - Some of them have stars concentrated along bars near their centers.
- Elliptical galaxies are like the halos of spiral galaxies, but they might have many more stars that halos do.
  - They do not have much gas and dust, or newly forming stars.
- Irregular galaxies can be small satellites of bigger galaxies, or they can be the result of collisions between galaxies.
  - They may have very active star formation.

Motions of Galaxies

In 1920s Vesto Slipher measured spectra of galaxies.

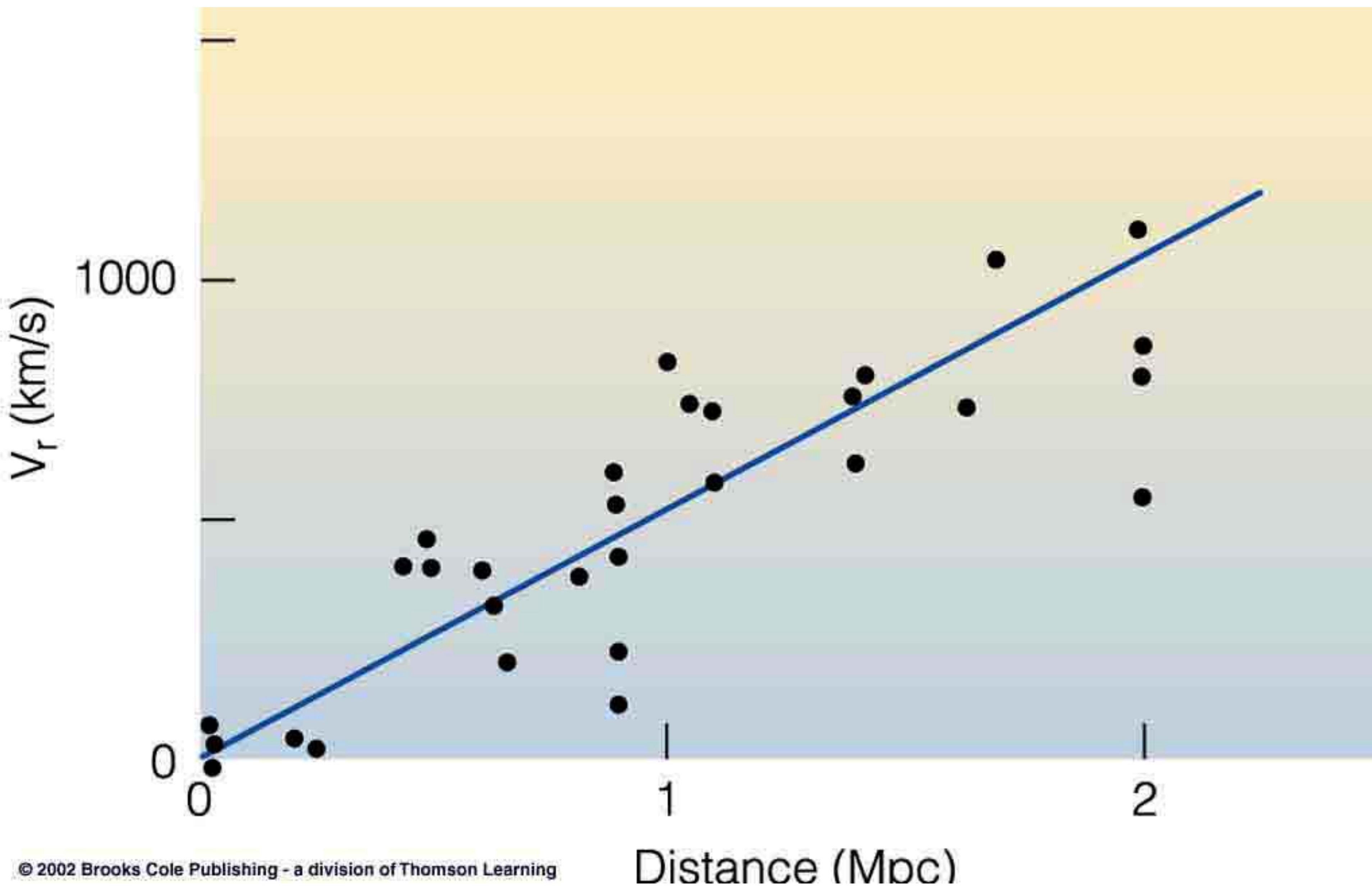
He found that most galaxies are redshifted, that is they are moving away from us.

Soon after that Edwin Hubble measured the distances to galaxies.

He found that in general more distant galaxies are moving away from us faster than closer galaxies are.

This is Hubble's law: $v = H\,d$ or $v \propto d$

The Hubble diagram is like the H-R diagram, but each dot is a galaxy (instead of a star) and the axes are distance and speed (instead of temperature and luminosity).



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How are distance and speed measured?

Speed is measured with the Doppler shift – the faster a galaxy moves away from us, the more the spectrum is shifted to longer wavelengths.

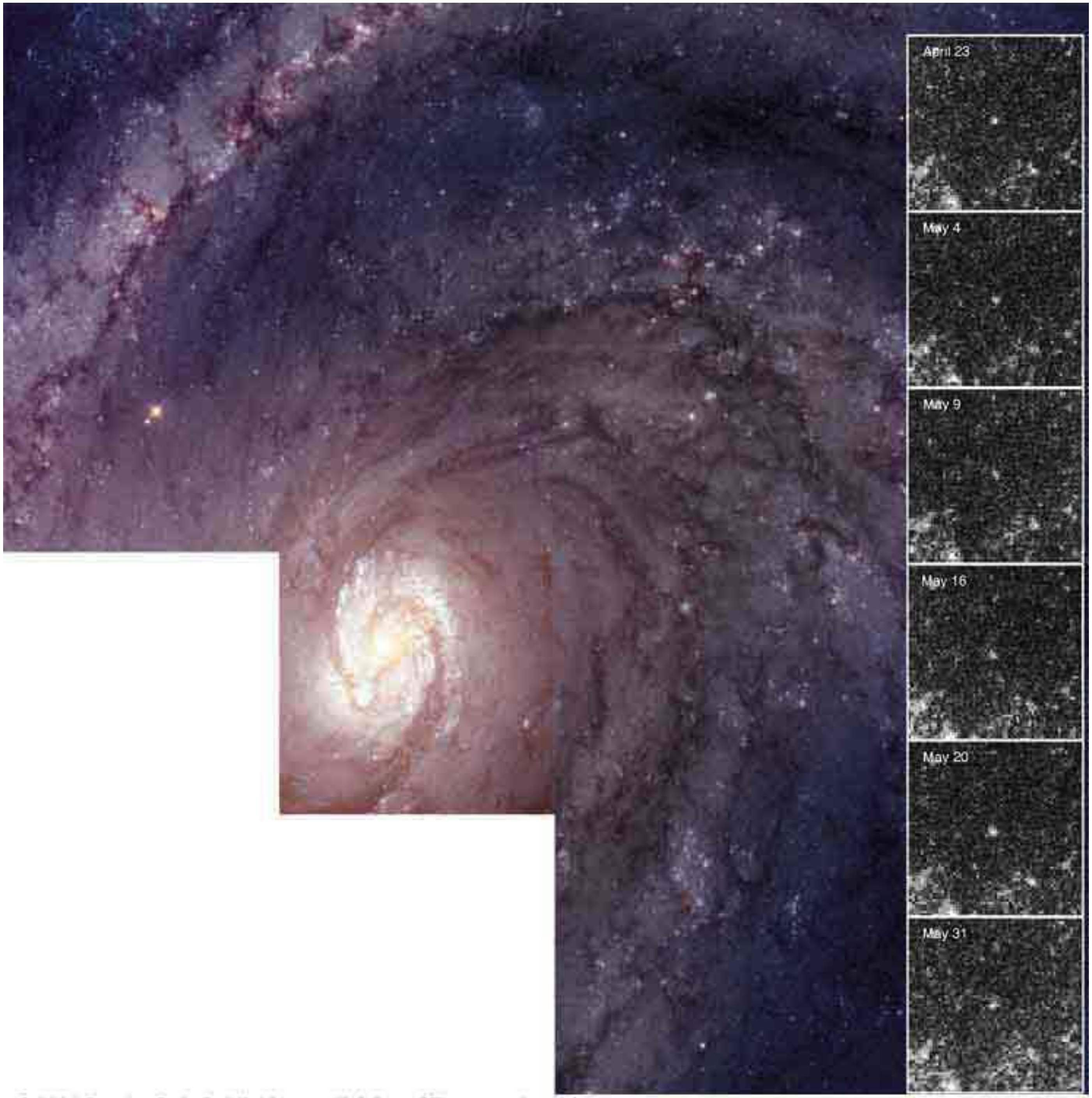
Distance is more difficult.

No galaxy is close enough for us to measure its parallax.

The measurement used to require a difficult chain of measurements, but with the Hubble Space Telescope we can see Cepheid variable stars in many galaxies.

From the periods of their variation we know the luminosities of these stars, and then by measuring their apparent brightnesses (fluxes) we can calculate their distances.

We have also used supernovae as standard candles.



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Hubble's Law

Hubble found that a galaxy's speed away from us is proportional to its distance from us.

$$v = H\,d$$

What does this mean?

If galaxies are objects like the Milky Way, why would they all be moving away from the Milky Way?

And are they accelerating, so they move faster as they move away? What would cause this?

The wrong explanation

We could explain Hubble's law if galaxies accelerated as they went away from us.

Then they would be going faster when they are farther from us.

But then our galaxy (the Milky Way) would have to be special, since all other galaxies would be accelerating away from it.

Besides, what force could cause the galaxies to accelerate away from us?

We don't think this is the right explanation for Hubble's law.

Big Bang explanation for Hubble's law

The galaxies don't have to accelerate as they move away from us to explain the Hubble law.

If different galaxies started out moving away from us faster than others did, and they all started at the same time, the ones moving away faster would have gotten farther by now.

The explosion that started everything is called the Big Bang.

This still sounds like it means that the big bang occurred here, and we are at a special place in the Universe.

That is wrong.

No matter where the explosion occurred, an observer on any galaxy would see other galaxies moving away from him.

ABCD Quiz

Hubble’s law state that:

A. The Milky Way is expanding.

B. The Universe is expanding.

C. The redshifts of distant galaxies are proportional to their distances from us.

D. The redshifts of distant galaxies are proportional to their distances from the center of the Universe.

Another ABCD Quiz

For the redshifts of distant galaxies to be proportional to their distances from us, it must be that

A. Galaxies increase their speeds as they move away from us.

B. Galaxies keep their speeds constant as they move away from us.

C. We are at the center of the expansion of the Universe.

D. We are not at the center of the expansion of the Universe.

The age of the Universe

We can calculate when the big bang occurred by asking how long it would have taken distant galaxies to get to where they are.

If different galaxies started out moving away from us faster than others did, and they all started at the same time, the ones moving away faster would have gotten farther by now.

If the galaxies' speeds have not changed we can calculate how long ago they started moving.

The time to travel a distance d at speed v is given by

time = distance / speed

If we use Hubble's law that speed = H x distance, we get

time = distance / (H x distance) = 1 / H

Using our best number for H, we get the time since the big bang = 13-14 billion years.

Turning Hubble's law around

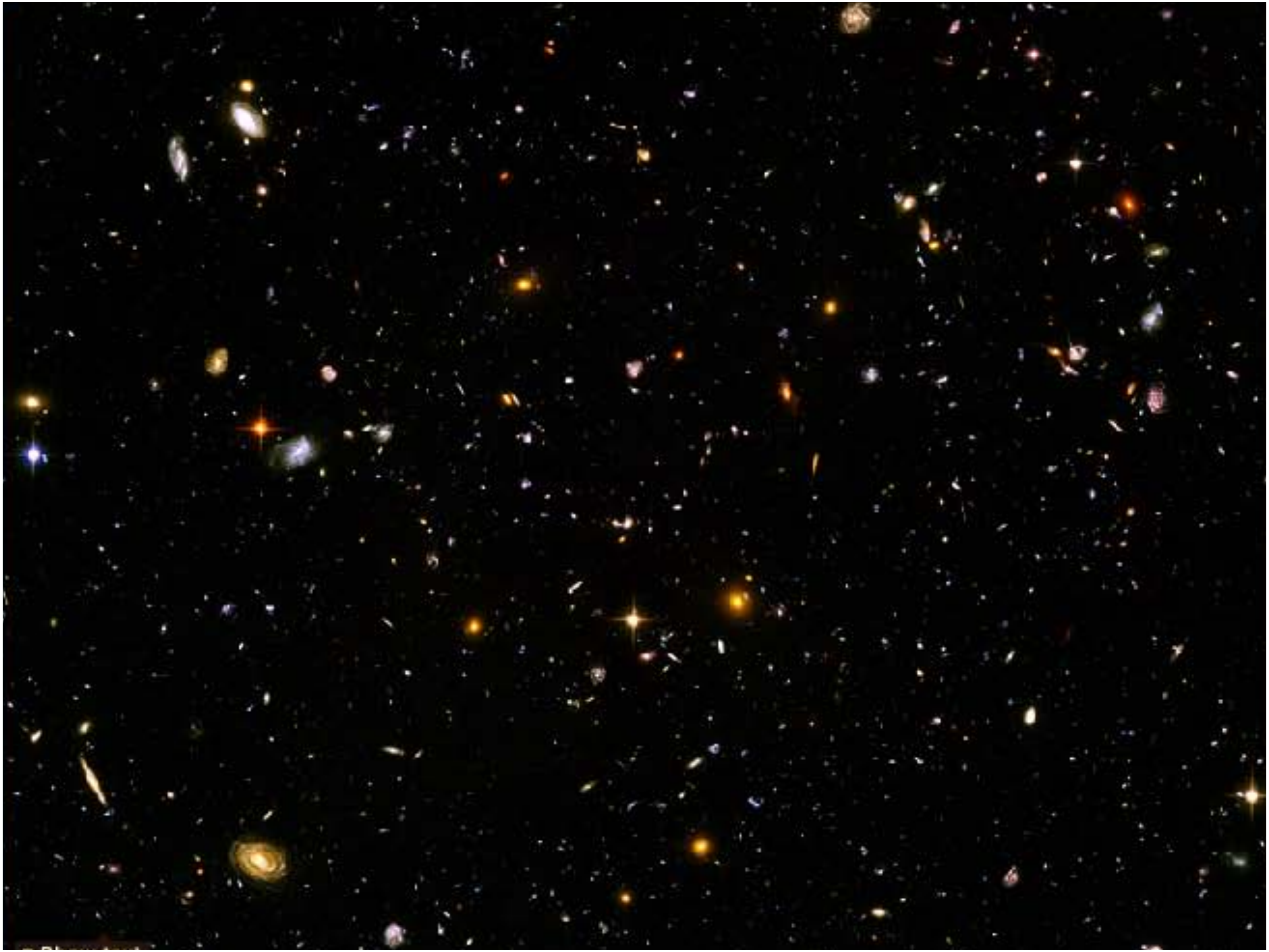
Once we know that more distant galaxies have greater redshifts, we can use a galaxy's redshift to estimate its distance.

speed = Hubble's constant x distance, so

distance = speed / Hubble's constant

From their redshifts, we know that most of the galaxies in the Hubble (Space Telescope) "Deep Field" picture are very distant.

Since light took a long time to get to us, we are seeing them as they were long ago.



Expanding space

Even if Hubble's law would look the same from all places, is there actually some galaxy that we're all moving away from?

Does the Universe have a center or edges?

What is the Universe expanding into?

This isn't a problem if the Universe is infinite.

It would have no edges then.

But the Universe might be finite. We don't know.

Even then it would not have a center or edges.

Like the surface of a sphere has no center or edges.

The best way to look at the expansion of the Universe is to say that space is expanding.

Stretching photons

Saying that space is expanding does not mean that galaxies are expanding or the solar system is expanding.

Gravity keeps the stars orbiting in a galaxy and the planets orbiting in the solar system. The sizes of their orbits don't change.

But the expansion of space does affect photons as they travel to us across space from distant galaxies.

As they travel through expanding space, the wavelength of the light in a photon is stretched.

If space stretches by a factor of 2 while a photon is traveling, the wavelength of the light also stretches by a factor of 2.

This is another way of looking at the redshifts of distant galaxies.