AST 301
Introduction to Astronomy

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Topics for this week

What does Hubble's law tell us about the Universe?

What is the Universe made of?

What are dark matter and dark energy?

Is the rate of expansion of the Universe changing?

Will the Universe pull back together some day?

Hubble's Law

Edwin 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?

We conclude that the galaxies are accelerating, but that is to explain deviations from Hubble's law. If Hubble's law is accurate, the galaxies are not accelerating.

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.

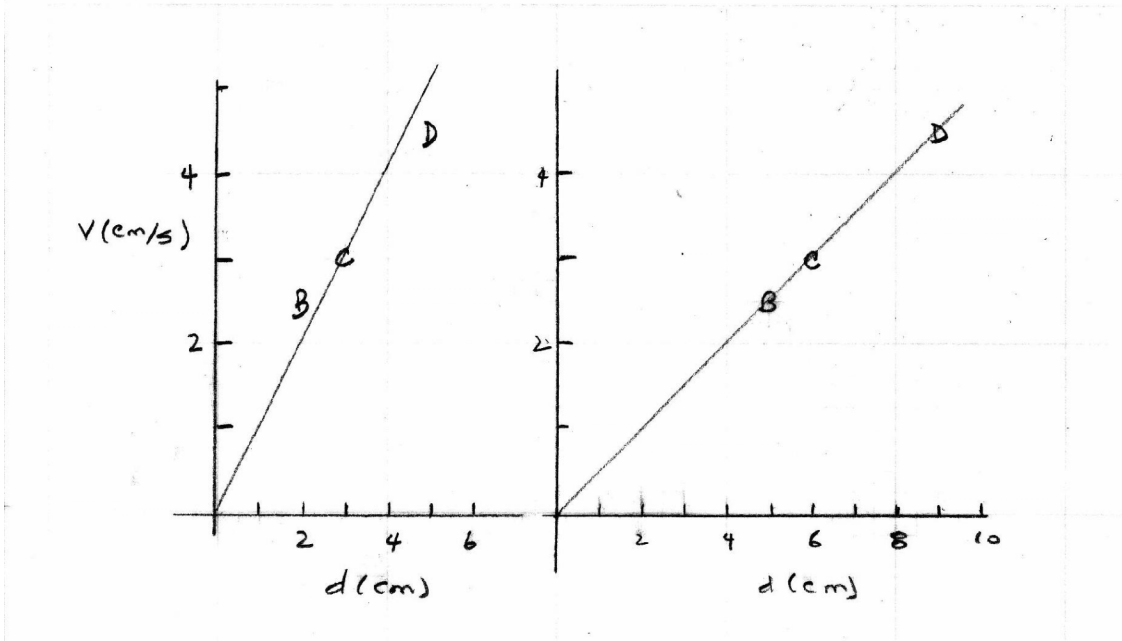
This still sounds like it means that the big bang occurred here, and we are at a special place in the Universe.

That is wrong.

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

Sample table for homework

	A-B	A-C	A-D	average H
3 in. balloon speed/distance	2 cm 1.25 (cm/s)/cm	3 cm 1.00 (cm/s)/cm	5 cm 0.90 (cm/s)/cm	 1.02 (cm/s)/cm
6 in. balloon speed/distance	5 cm 0.50 (cm/s)/cm	6 cm 0.50 (cm/s)/cm	9 cm 0.50 (cm/s)/cm	 0.50 (cm/s)/cm
9 in. balloon speed/distance	7 cm 0.36 (cm/s)/cm	9 cm 0.33 (cm/s)/cm	14 cm 0.32 (cm/s)/cm	 0.33 (cm/s)/cm
average speed	2.5 cm/sec	3 cm/sec	4.5 cm/sec	



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.

What is the Universe made of?

Stars and planets are made of protons, neutrons, and electrons. These particles are called baryonic matter [although strictly speaking only protons and neutrons are baryons (heavy particles); electrons are leptons (light particles)].

But we have reasons to believe that there are other unseen kinds of matter in the Universe.

One is dark matter, which seems to dominate the mass of the Milky Way and other galaxies.

The first evidence for dark matter was the motions of galaxies in clusters, observed by Fritz Zwicky.

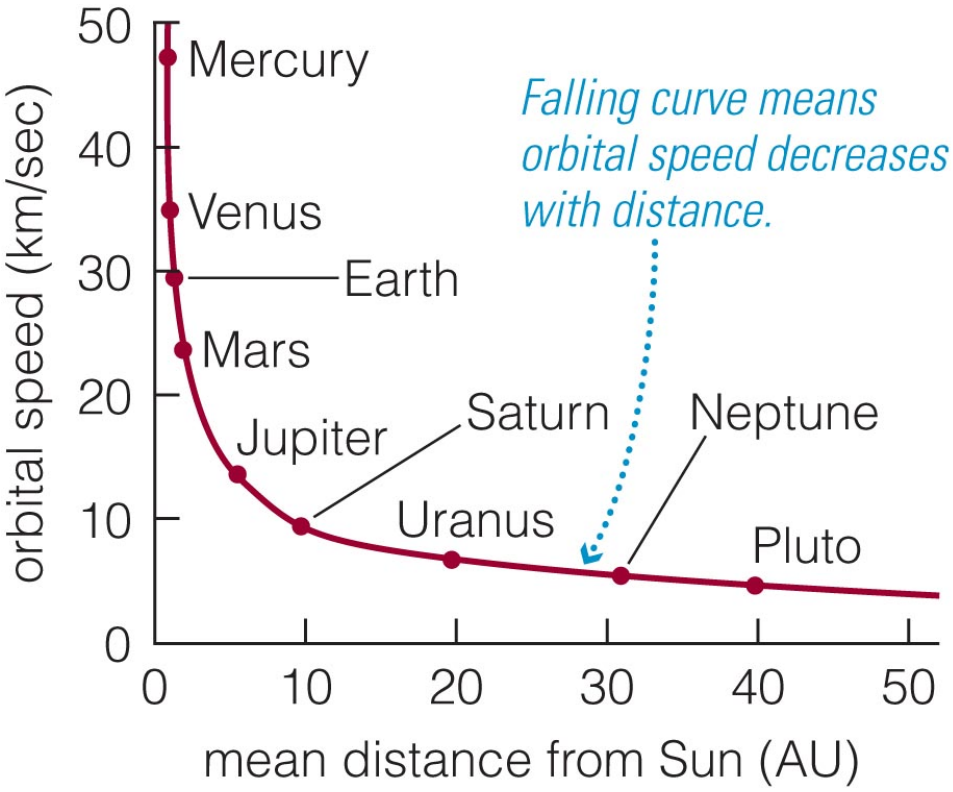
Although galaxies don't move on circular orbits, we can us a form of Kepler's 3rd law to calculate the mass that they orbit around, and it appears to be larger than the mass of the stars we can see in the galaxies.

Dark Matter in galaxies

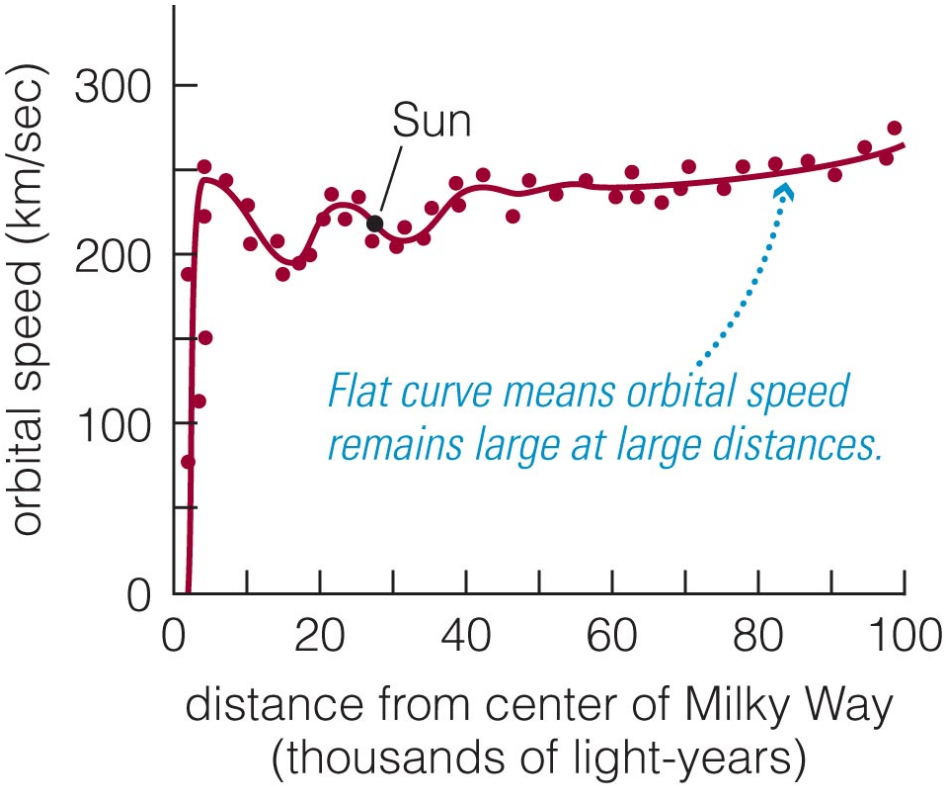
More convincing evidence of dark matter was found by Vera Rubin, who measured masses of galaxies from the orbital speed of stars in spiral galaxies.

She found that as much as 90% of the masses of galaxies is in something other than the stars we see.

Rotation curves for solar system and Milky Way

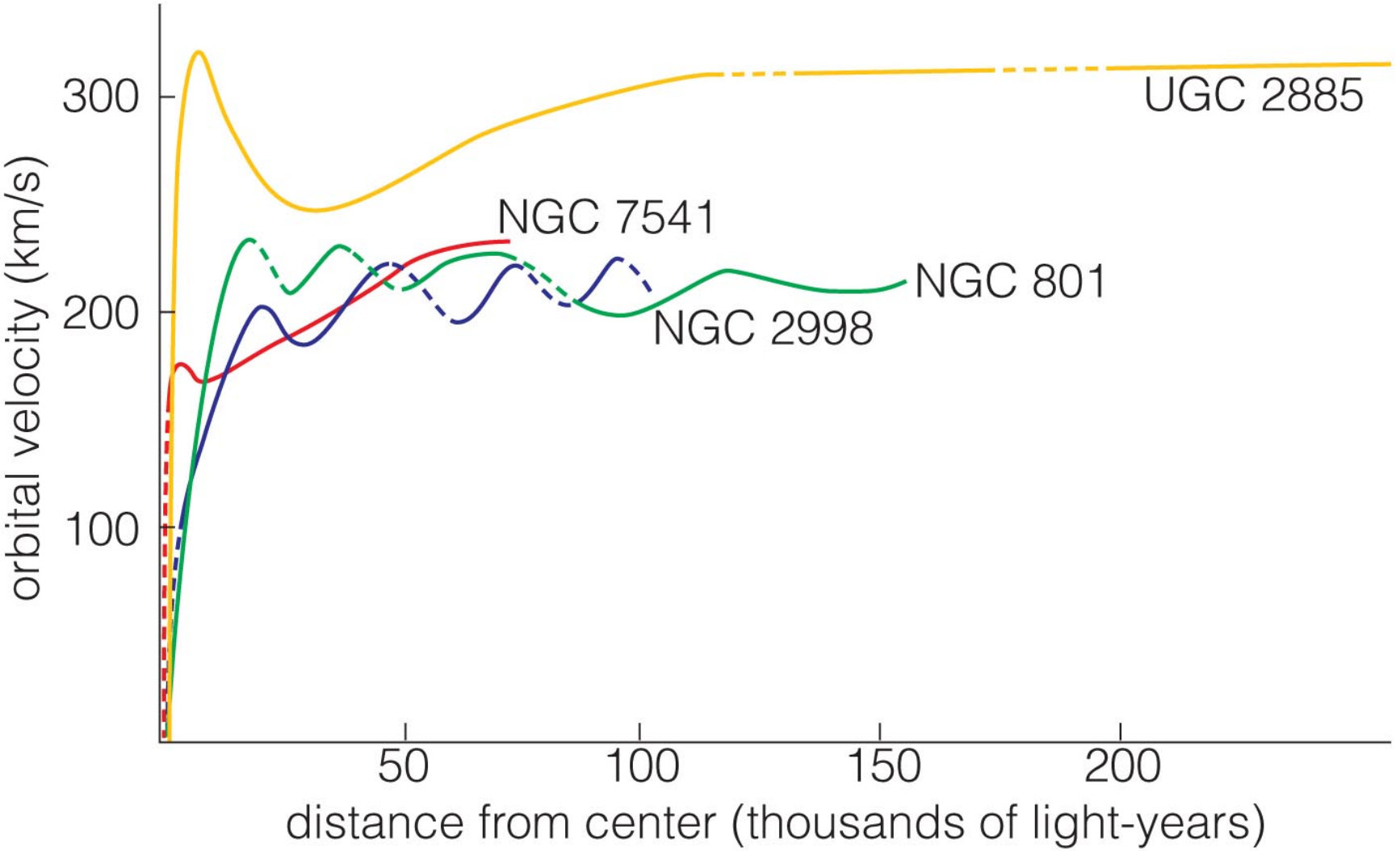


b The rotation curve for the planets in our solar system.



c The rotation curve for the Milky Way Galaxy. Dots represent stars or gas clouds whose rotational speeds have been measured.

Rotation curves for other galaxies



Meaning of flat rotation curves

The fact that rotation curves are flat means that stars orbit around galaxies at about the same speed at all distances from the center.

Kepler's 3rd law says that this means that there is as much mass in a 1000 pc wide ring at the outer edge of a galaxy as within 1000 pc of the center, even though there are many fewer stars near the outer edge.

Especially in the outskirts of galaxies, most of the mass in galaxies must be in something other than stars.

Fritz Zwicky's measurements indicate that even more dark matter is found in clusters of galaxies, in between the galaxies.

Dark Matter in galaxies and galaxy clusters

The dark matter could be in many small black holes, or conceivably even in rocks in space, but we now think it is in some unknown form of matter which doesn't respond to either the electromagnetic force or the strong force.

Neutrinos fit this description, but we don't think they have enough mass to be the dark matter.

Maybe there is some kind of a particle like the neutrino, but with much more mass.

These hypothesized particles are often called WIMPs, or weakly interacting massive particles.