ASTRO 1050 - Fall 2012
LAB #12: Distant Galaxies and the Expanding Universe

ABSTRACT

The Universe is expanding. The light we receive from galaxies is redshifted because they are receding from us. You will use the Doppler shift formula to calculate how fast they are receding. You will prove for yourself that the nature of their motion means that the Universe is expanding, and you will even calculate the age of the Universe!

Materials

Textbook, Mind

Excercises

Galaxies form giant groups called "superclusters." The supercluster closest to our own galaxy can be seen (with a telescope) in the direction of the constellation Virgo. We call this supercluster the Local Supercluster or the Virgo cluster; it is approximately 50 million light years (15 million parsecs) away. Many even more distant superclusters have been found in other directions. They all contain some very large elliptical galaxies, and many smaller galaxies.

On the last page are pictures showing what an elliptical galaxy would look like if it were located in different superclusters. The farther away the supercluster is, the smaller the galaxy looks – there is an inverse relation between apparent size and distance. Next to each galaxy, there is a spectrum of a bright star in the galaxy. The dark lines are 'Balmer' hydrogen absorption lines. These lines are not always found at the same wavelength; they are "shifted." The general pattern that the hydrogen lines form in each spectrum always stays the same. That is how we can tell if a certain line is a hydrogen line even though it is not always found at the same wavelength. The "shift" of the pattern is called the *Doppler Effect*, and it is caused by the motion (relative to us, the observers) of the star that is emitting the light.

When the wavelengths of hydrogen lines are measured in a laboratory, using a stationary hydrogen lamp, each line is always found at the same wavelength. We call this wavelength the "rest wavelength" and denote it is by λ_{rest}. The rest wavelengths of the hydrogen lines (from right to left) are:

H_α (H-alpha)	$\lambda_{rest} = 656$ nm	[nm = 10^{-9} meter]
H_β (H-beta)	$\lambda_{rest} = 486$ nm	
H_γ (H-gamma)	$\lambda_{rest} = 434$ nm	
H_δ (H-delta)	$\lambda_{rest} = 410$ nm	

The Doppler effect does not only affect light, but occurs with waves of all kinds. A familiar example is the change in pitch of the sound from a car as it moves towards you passes you and moves away from you. As the car moves towards you, the sound waves that move past you are more closely spaced than normal – their wavelength is shortened. As the car moves away, the sound waves move past you with longer spacing than normal – their wavelength is increased. Since a high-pitched sound has a short wavelength, and a low-pitched sound has a long wavelength, we can actually hear the Doppler effect.

This is analogous to what happens to light from a moving source. If a star is moving towards us, its light will have a higher wavelength – the light is "blue-shifted." If the star is moving away from us, the wavelength of the light is longer – the light is "red-shifted." It is easiest to detect the change in wavelength of the light from the shift of the spectral lines. (The shift of the line is the difference between the observed wavelength and the rest wavelength.)

1. On the last page, label the four 'balmer' hydrogen lines in each spectrum. Also mark the rest wavelength λ_{rest} of these lines on the scale below the spectra.

2. Compare the rest wavelength and the observed wavelength of the hydrogen lines in the previous question. Which wavelength is longer? Are the galaxies moving towards us or away from us?

The shift of the line gets larger the faster the light source is moving relative to us. There is a formula that makes it possible to determine how fast a source is moving by measuring the change in wavelength.

$$\text{Doppler formula:} \qquad \frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}} = \frac{v}{c} \tag{1}$$

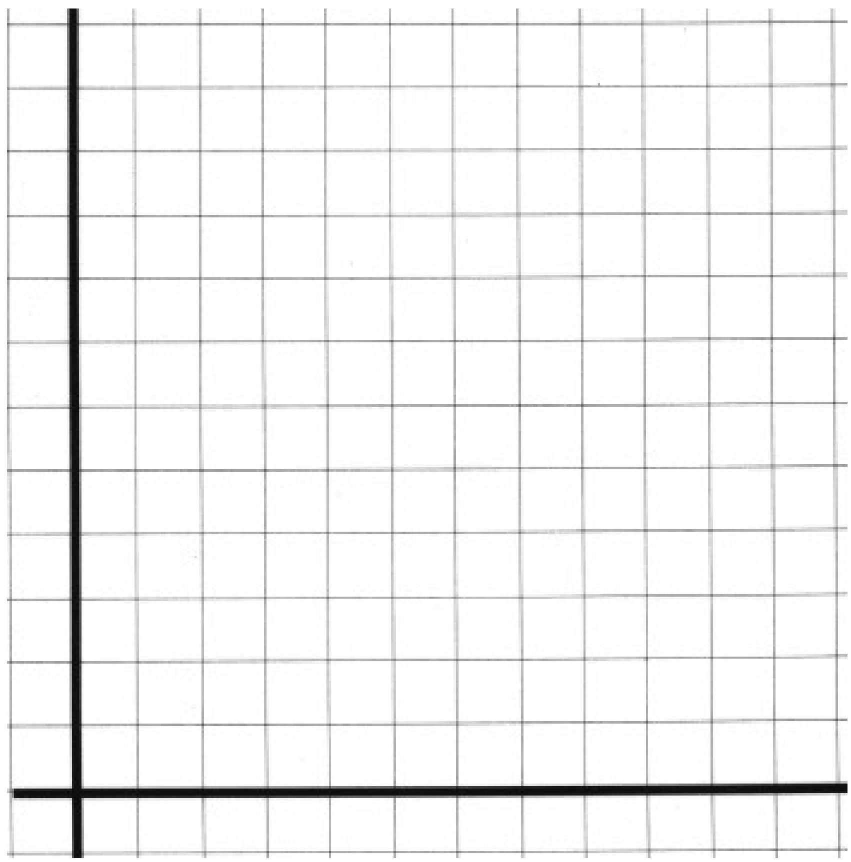
where

λ_{obs}	is the wavelength we observe,
λ_{rest}	is the wavelength from an object which is at rest (lab),
v	is the speed of the object relative to us,
c	is the speed that the wave travels at,

This is a general formula; it can be used both for sound and light, and for any other kind of wave phenomenon. If the speed of the object is zero, the shift in wavelength will also be zero. For an object which is moving at high speed, v will be large, and the shift in wavelength will also be large.

3. Use the Doppler formula to determine the speeds of the galaxies. (Write your answer below each spectrum on the last page.)

4. Compare the distances to the galaxies and the speeds with which the galaxies are moving away from us, and describe their relationship. For each galaxy, plot the recession velocity verses the given distance.



5. Draw a line which best fits the four data points you have plotted. What is the slope of this 'best-fit' line?

You have just done the same calculations that the astronomer Edwin Hubble did in the late 1920's. The relation you described in (4) between the distances and speeds of galaxies is called Hubble's Law, and the slope of the line in question (4) is known as the Hubble Constant.

What does Hubble's Law tell us about the Universe? At first it may seem as if we (in the Milky Way) are in a "privileged position" in the Universe, since all other galaxies are moving away from us. Are we at the center of the Universe?? We will perform a "thought experiment" to find the answer.

Imagine that A, B, C, D, and E are galaxies. The arrows represent the speeds of the galaxies as seen from A (longer arrow = higher speed). This diagram represents what Hubble's Law states.

A	B	C	D	E
You				
ꝏ	ꝏ – >	ꝏ – – >	ꝏ – – – >	ꝏ – – – – >

6. What would an observer sitting in galaxy C see when s/he looked at the other galaxies? Draw arrows to represent the speeds that this observer would measure.

A	B	C	D	E
		You		
ꝏ	ꝏ	ꝏ	ꝏ	ꝏ

7. Change your perspective again and do the same for an observer sitting in E.

A	B	C	D	E
				You
ꝏ	ꝏ	ꝏ	ꝏ	ꝏ

8. Look at the diagrams in questions (5) and (6). What relation will observers in galaxies C and E find between speeds and distances of galaxies? Is the Hubble Law the same for observers in all galaxies?

What you have seen in this thought experiment is precisely the explanation of why the proportionality between galaxy distances and speeds leads to the deduction that the Universe is expanding. All galaxies are getting farther and farther apart all the time!

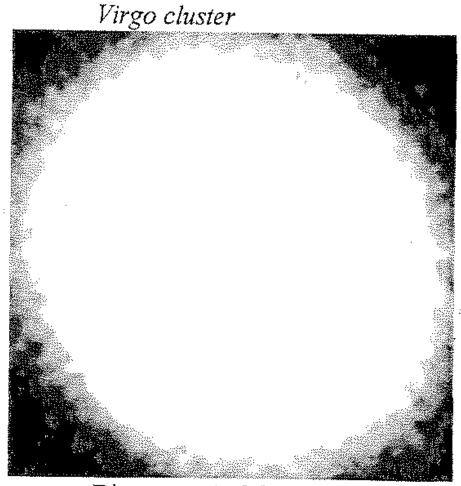
It is also possible to decide how long the expansion has been going on; this is the time which astronomers take as the age of the Universe, or the time since the Universe was born in the Big Bang and began to expand.

(There are 3×10^7 seconds in a year.)

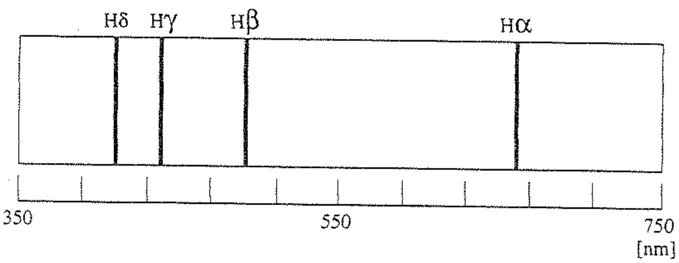
9. For any galaxy except the one in the Virgo cluster, take the distance and speed you have calculated. By imagining backwards in time, calculate how many years this galaxy has been moving away from the Milky Way. That is how long the Universe has been expanding; your answer is the age of the Universe! Explain how your answer is achieved.

Elliptical galaxy in...

Virgo cluster

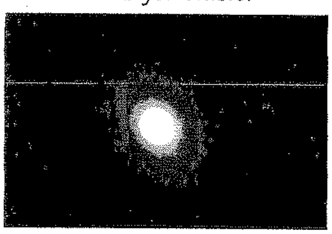


Distance: *15 Mpc*

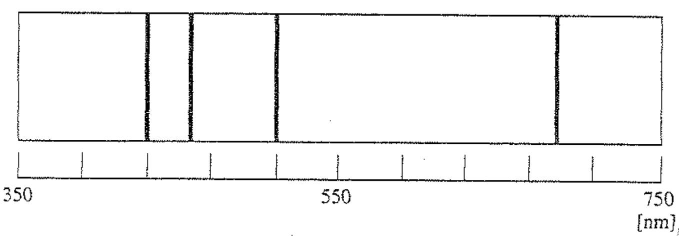


Speed:____________________

Ursa Major cluster

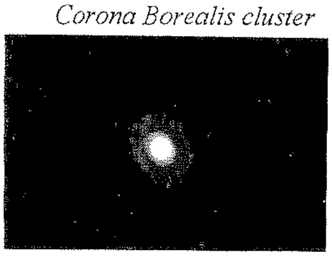


Distance: *190 Mpc*

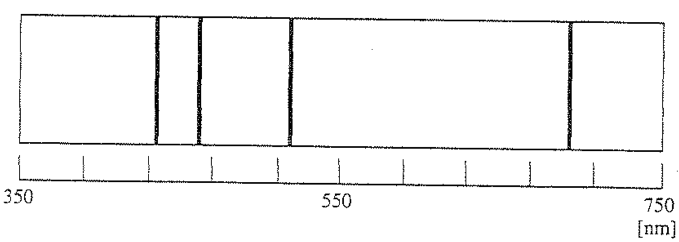


Speed:____________________

Corona Borealis cluster

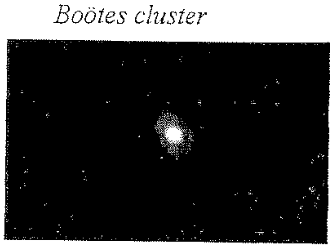


Distance: *270 Mpc*

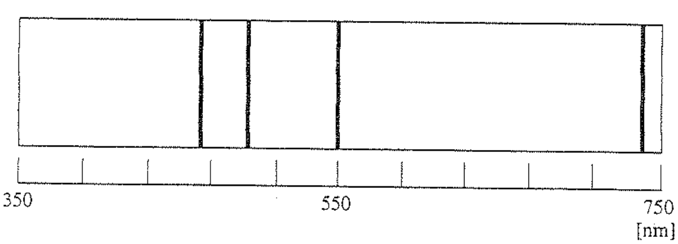


Speed:____________________

Boötes cluster



Distance: *490 Mpc*



Speed:____________________