Physics/ Dr. Lankar Name: ______________ section: ______grade% _______

LAB: EXPANDING UNIVERSE – HUBBLE LAW – AGE OF THE UNIVERSE

PART1 :INTRODUCTION:

Hubble discovered that galaxies are systems of stars and that they are all moving away from us and all moving away from each other at a constant rate. In other words, he discovered that the universe was expanding, or rather the space between the cluster of galaxies was expanding like A rubber sheet. He theorized that anything in the universe was at the same location before the Big Bang and that since then it was expanding. Using this new theory and his measurements of the recession speeds of galaxies, he computed an estimation of the age of the Universe.
In the 20s, (1929) it was a breakthrough. At the time, scientists thought that gravity , that binds all the objects of the universe together, could also cause the universe to collapse in a " big crunch ".

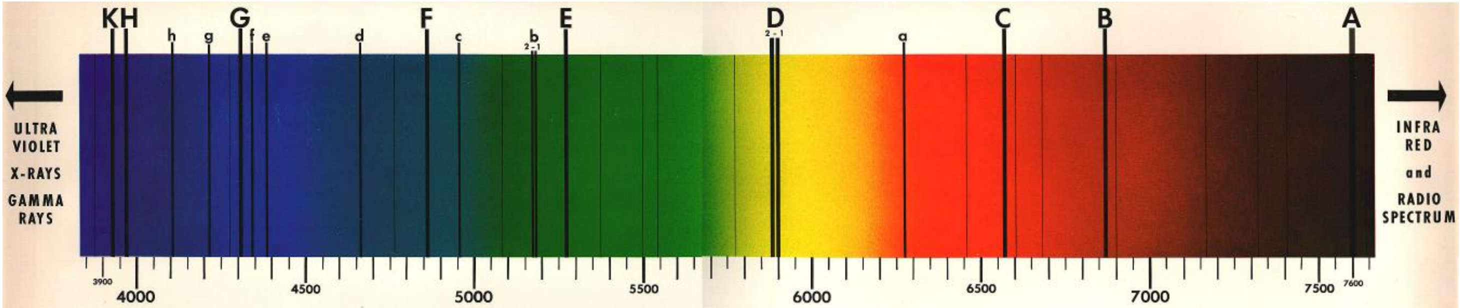
In this lab, using quantitative math and the same method than Hubble, you will estimate the age of the universe.
First take a guess. The universe is _______________ old.

Hubble based his discovery by studying the spectra of given galaxies he was observing in his laboratory. He found out that the farther away the galaxy was from us , greater was it relative speed. (relative to us). He used the concept of the Doppler effect to compute these recession speeds.

PART2: DOPPLER EFFECT – HOW TO COMPUTE THE RECESSION SPEED OF GALAXIES

You might know that a given type star (or galaxy) produces a given spectrum. It is like fingerprint (I call it ID). (FIGURE1).
The spectrum is produced by looking at the light emitted by the luminous object through a prism. (Decomposing the light into colors or wavelengths)

FIGURE 1 : spectral lines of the Sun. (called the The Fraunhofer lines) . All the stars, similar to our sun (same age, mass, gas ..) will produce the same spectrum. Note that wavelengths are noted below in nanometers (10^{-9} m). To the right, the wavelengths increases toward the radio waves . To the left , the wavelengths decreases to the X-rays. A given wavelength = given color. Gamma rays, x rays, visible light, radio waves are all part of the electromagnetic spectrum.



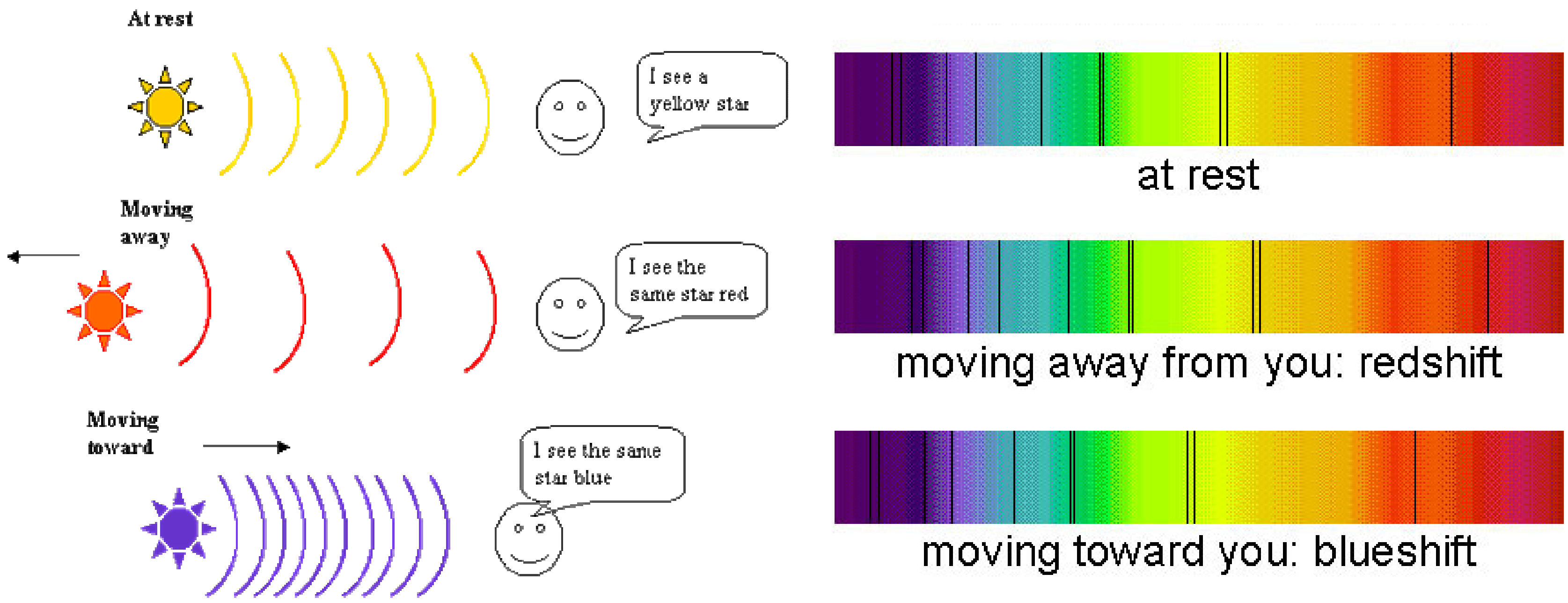
The spectrum of a given star or galaxy look like a *code bar* superposed to the visible spectrum (the spectrum you get when looking at white light from a light through a prism). These bars are called absorption lines or spectral lines and the pattern is identical for a given type of star.
(The lines mark the wavelength at which, gases like hydrogen, in a given type of star, have absorbed light

If a star moves away from us this *code bar* or absorption lines will move toward the red part of the spectrum. We say The pattern is redshifted.
(if the star moves toward us, the lines are shifted toward the blue part of the spectrum or blue shifted)

This phenomenon is very much like the Doppler effect. (*) see below

Likewise, if a star moves away from you, its *bar code* moves toward the low frequencies (or large wavelengths), that is toward the red.
Likewise, If the star moves toward you, its *bar code* moves toward the high frequencies (or short wavelengths) , that is toward blue part of the spectrum.
See FIGURE 3.

FIGURE 3: redshift and blueshift for a star. The yellow star is at rest.



Hubble observed that distant galaxies were redshifted and came to the conclusion that all the galaxies in the universe were receding from us and away from Each other. He measured the redshifts of distant galaxies and computed their recession speed.

Here is the formula to use: (let's call V the recession speed)
(Redshited wavelength) / (rest wavelength) = $\sqrt{}$ **((1+b) / (1- b))** **b** is the ratio between speed of light **c** ($3\ 10^{8}$m/s) and **V**

b = c /V . Let's call the redshifted wavelength **L** and the rest wavelength **Lo**. **L / Lo** = $\sqrt{}$ **((1+b) / (1-b))**
If **L** and **Lo** are known, you can solve for **b**. (by squaring each side).
Say the line of hydrogen (bluegreen and **Lo = 486 nm**) of a galaxy you are observing is shifted to the red at 700 nm. (1 nm = 10^{-9} m)
Find the recession speed of the galaxy as a fraction of the speed of light **c**. You don' t need to convert nm to m.

That is solve for b = _______ (no unit, it is a ratio. Keep 3 decimals). So V = b c = __________ c. That is, V is _________ % of the speed of light.
Show your work.

Why you didn't need to conver nm to m ?

The ratio **z = (L – Lo) / Lo** is called the redshift by astrophysicists. Compute the redshift **z** in the example above. z = _____.
Find the recession speed if z = 0.4. Hint: (L-Lo) / Lo = L/Lo – 1
Use the formula given below to solve for b. b = _________. So V = ______ c . c = 300,000 km/s so V = _________ km/s
You will need this speed later in the lab.

- **Doppler effect**

If a car is honking at rest, your ear perceived a given frequency, a given pitch, a given sound.

If the honking car moves away from you, the frequency is now perceived lower. Lower is the pitch (frequency) and larger it the wavelength perceived. This is because the wavelength is inversely proportional to the frequency. If the frequency decreases, the wavelength increases.
If the honking car moves toward you, the frequency is perceived higher. Higher is the pith, smaller is the wavelength perceived.
Here is a nice applet : http://faraday.physics.utoronto.ca/PVB/Harrison/Flash/ClassMechanics/Doppler/DopplerEffect.html

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PART 3: SOME GEOMETRY TO UNDERETAND WHY THE RELATIVE SPEED OF GALAXIES INCREASES WITH DISTANCE

Hubble computed the redshfits of given galaxies and computed their relative speed. Farther the galaxy was, the more redshifted it was, even though if the space is stretching at a constant speed.

Here is how to understand.

Draw a horizontal line . Draw dots every 1 cm. Circle the 2^{nd} dot and call it the Milky Way (MW). Circle the 5^{th} dot and call it galaxy LM. Circle the 10^{th} dot and call it Galaxy VL.

Find the distance between MW and LM . distance d = _____ cm.
Find the distance between MW and VL. distance d = _______ cm

Suppose now that the line is stretching at a constant speed of 1cm/second. It Now all the marks are 2 cm apart. Draw this line with the new scale. Circle again the Milky Way MW (2^{nd}), the LM galaxy (5^{th}) and the VL galaxy (10^{th}).

Find the distance MW - LM now d=____________ cm
Find the distance MW – VL now d = ___________cm

So find the speed LM is moving from the MW. (**change** in distance / time, time = 1 second) speed = _____cm/s
Find the speed VL is moving from the MW. (**change** in distance / time, time = 1 second) speed= ______ cm/s

So relative to us which galaxy is moving the fastest ? _________________ .
And this is despite the fact the line is stretching at a constant rate.

Now if you were to find out for how long the line has been stretching, you would pick on VL at a given time and divide its distance from MW and divide by its relative speed by that time (second step). You find : ________ seconds. This is how Hubble found the age the universe. We will see how below.

- **Doppler effect**

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PART IV – FINDING THE AGE OF THE UNIVERSE

Hubble plotted the relative speeds of the galaxies, he was studying, versus their distance from us.
(He used newly derived distances of these galaxies. For that they used special stars called Cepheid variables or standard candles. There is a simple

relationship between the brightness of these stars and their distance from us.)
Hubble used the relationship between redshifts (speed) and distance to estimate the age of the universe and to introduce the idea of an expanding universe

The table below gives you the recession speed (in km/sec) of some galaxies and their distance from us (in Mpc or Megaparsecs). A parsec is a unit of distance used in astronomy. 1 parsec is about 3 light year or $3\ 10^{13}$ km. 1 Mega parsec is ________ km. (Mega means million)
Note: A light year is a unit of distance. It is the distance covered by the light in ________________.

X= Distance (Mpc)	30	40	50	60	75	80	90	120	130	150	175	230	240	250	350	450
Y=Speed (km/s)	1000	2500	3000	3100	5000	5200	5400	7000	8000	8500	10,500	13,000	14,500	15,000	20,000	29,000

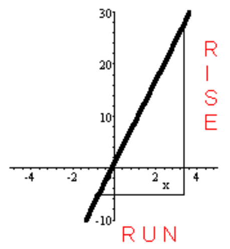
These data are based on real data and are better than the ones used by Hubble. Use a graph paper to plot these points. Don't worry if you can' t find the locations of the points very accurately. You will use a calculator to process the data. !! Don't connect the points!! Don' t forget to label the axis (including the units) and to give a title to your graph. Watch the scales of the axis. You obtain a scatter plot. The trend is ____________.
When the distances increase, the speeds __________. We call it a ________ correlation (negative ? positive ?).
The graph gives the relative _________of some galaxies versus _____________.

Like Hubble in 1929, you come to the conclusion that redshift is proportional to __________________.
Farther is the galaxy, larger is its _______.

Now, with a ruler, trace the best fit line. (try to have as many points above the line than below the line).
!! Since for a distance equal to zero, the relative speed is zero, the line has to go through the __________ !!
That means, you are forcing the y-intercept to be _________.

Using the method indicated by your instructor, find the slope of the best fit line. You could pick 2 points of a line and find the ratio between The rise and the run. That is the ratio between the change in y and the change in x. see FIGURE 4

FIGURE 4



A calculator, like a TI, can do that job for you (see **) or your instructor might want you to use the mathematic formula for the slope of A best fit line (see ***)

slope = _________km/ (sec . Mpc)

The slope is called the Hubble constant H. H = ________

Find the equation of the line: y = ___ x y represent the ________, units in _________ and x the __________, units in __________.

That means if a galaxy is at 1 Mpc from us (about 3 million light years ago), the galaxy is moving at a speed of __________ relative to us.
Just to have a sense of how fast it is, Convert the speed to mph. Speed = _______ mph (1 mile = 1.6km).
If the galaxy is 2Mpc from us, the relative speed is __________ km/s

The equation is linear. If the distance from us to a galaxy is multiplied by 2, the velocity is ___________________.

Remember that speed is distance over time. The slope is a velocity over distance. The reciprocal of the slope is a distance over a velocity.
So the reciprocal of the slope has the dimension of a _________. (speed ? time ? acceleration ? distance? cookies ?)

It is actually the time it took for the galaxies to move away from each other to their today state.
It is the length of time that the Universe has been expanding ! (the same way, you previously find the time the line was stretching, by choosing a given galaxy like DL and dividing the distance from MW by its relative speed at a given time).

You need to find this time in billion years. Find the reciprocal of the slope time = 1/H = __________ (Mpc . sec) / km
The unit of 1/Ho is (Mpc. Sec) / km) . If you convert Mpc to km, then the unit becomes ________. (km cancel out)

1 Mpc = __________km (see above. Use scientific notation). So 1/H = ________seconds (multiply by the previous factor. Use scientific notation).
The unit km cancel out. convert to years. 1/H = time = __________ years (scientific notation)
So age of Universe = _______________ years = __________ billions years. (round to the nearest one)

If you wish to account for the force of gravity which works against the cosmological expansion which is described by Hubble's constant, the age of the universe can be calculated :

Age = 2/ (3*H) = ________________________ billions years. For a long time, that was the accepted valued for the age of the universe.

Using such graphs, scientists can estimate the distance of a galaxy. For example, suppose a galaxy is receding from us at 12,000km/s.
Use the equation to find its distance in Mpc. d= _______ Mpc convert to light years d = _____________ million light years.

Let's say you are observing a galaxy with a redshift of z = 0.4. Find it distance from us. d = _________ Mpc. (use your computation from part2)
Or d= ___________pc. Convert to light years. This is d = _________ billion light years. (1 pc = 3 light years).
So when you are looking at this galaxy, it is a lookback time of _______________.

Recently, the study of the redshifts from supernovae indicate that the slope is about H=71 km/ (sec Mpc). Find the new age for the universe.
Don' t apply the correction. Show your work. Age = _______________ billion years.

Using this new value for the slope (so you get a new equation), find the distance of a galaxy receding from us at 710 km/s.
d= __________ Mpc

New studies of the redshifts of supernovae from distant galaxies indicate that, not only the Universe is expanding, but it is expanding at an accelerated rate. That is, the galaxies are speeding up as they move away from each other.

It seems that there is another, unknown force (or energy) that counterbalances this effect and pull the galaxies apart. This new discovery could be\done Because of the sophisticated telescopes and computers scientists have. This unknown energy is called the ________ ____________.
70% of the universe is made of this ____________- ______________________.
Or it could be that the theory we use to deal with big objects like galaxy (Einstein's general relativity) needs an update.

Dig more: http://cas.sdss.org/dr7/en/proj/advanced/hubble/conclusion.asp

http://abyss.uoregon.edu/~js/ast223/lectures/lec07.html

** with a TI 83 or 84

STAT EDIT enter x-values in L1 and y-values in L2.
2nd MODE to exit.
STAT CALC scroll down to LINREGR(ax+b) ENTER ENTER
The a value is the slope

***** Slope of a best fit line**

The best fit line associated with the n points $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$ has the form

$y = mx + b$ m is the slope and b the y-intercept

where

$$\text{slope} = m = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{n(\Sigma x^2) - (\Sigma x)^2}$$

You don’ t have to worry about b (the y-intercept) because b = 0

Here, Σ means "the sum of." Thus

Σxy = sum of products = $x_1y_1 + x_2y_2 + \ldots + x_ny_n$
Σx = sum of x-values = $x_1 + x_2 + \ldots + x_n$
Σy = sum of y-values = $y_1 + y_2 + \ldots + y_n$
Σx^2 = sum of squares of x-values = $x_1^2 + x_2^2 + \ldots + x_n^2$