Physics 162

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Exercise 1: Hubble's Law[1]

The objective of this exercise is to recreate Hubble's diagram using real data from Type 1a supernova. When Edwin Hubble measured the velocity versus distance to galaxies, he saw that they followed a linear relation where the further a galaxy was from Earth, the faster it was receding. This observation was the first indication that our universe was **expanding**. You will examine the spectra and light curves from seven supernova during the course of this activity. The spectra will be used to measure the recessional velocity of the supernova (and therefor of the host galaxy) while the light curves can be used to obtain an estimate of the distance to the galaxy.

Object List:
sn1994S
sn1994ae
sn1995D
sn1995bd
sn1996X
sn1996bl
sn1996bo

I. Spectra: The spectrum of an object shows the flux at a given wavelength of light. Specifically the spectra in this exercise are absorption spectra. The absorption lines correspond to orbital transitions within different elements that are present in the gas of the supernova. For these supernovae, we will be measuring the Silicon II (Si II] line. If the supernova were not moving with respect to Earth, the Silicon II line would appear at 6150 Angstroms (6150×10^{-10} m). However, the Si II line is redshifted, indicating that the supernova is moving away from Earth. Measure the centroid of the Si II line with either the IRAF software or some other means to calculate the recessional velocity of each supernova.

Procedure:

1. Plot the spectra for each supernova either using IRAF (see the document IRAF.pdf) or some other means.

2. Measure the centroid value for the Si II line.

3. From the centroid value calculate and record the redshift and the recessional velocity.

II. Light curves: When a supernova occurs, it's brightness (magnitude) will change with time. The magnitude we measure is the apparent magnitude (denoted by a lower case m). The apparent magnitude depends on the distance of the supernova from Earth. All Type 1a supernova are created from the same physical mechanism, when a white dwarf exceeds the Chandrasekhar mass limit of $1.4 M_{\odot}$. Since these astronomical events all occur because of the same physical mechanism, they have the same maximum luminosity associated with them. Luminosity is an intrinsic property (i.e. not dependent on the distance to the object) and can be related to something called the absolute magnitude (denoted by a capital M). The

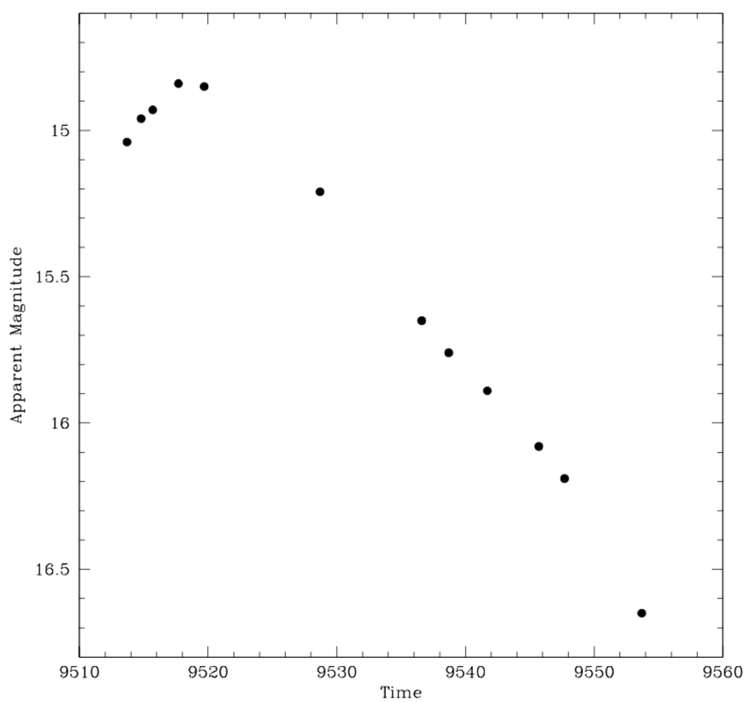
[1] Adapted from *Teacher's Guide to the Universe* by Lindsay M. Clark, MAP Education/Outreach Coordinator: https://www.astro.princeton.edu/ dns/teachersguide/SNLab.html

absolute magnitude for a Type 1a supernova is $M_V = -19.3$.

Download the paper Riess et al. 1998. In this paper you will find data tables that contain the information for how the apparent magnitude (i.e. brightness) changes with time. The data that we will utilize is found starting with Table 6. The magnitude we will use is from the third column, the V-band magnitude. V band describes the wavelength range over which the data was taken. Specifically V band is centered on 551 nm with a bandwidth of 88 nm. The time is given by the first column and is in units of Julian Date. Julian dates (abbreviated JD) are simply a continuous count of days and fractions since noon Universal Time on January 1, 4713 BC (on the Julian calendar).

Procedure:

1. Plot the magnitude (third column 'V') versus time (first column in units of Julian Date) for each of the supernova listed under "objects" above. This plot is called a light curve. *NOTE: magnitude scale is backwards, as in the larger the magnitude number the fainter the object. An example of a light curve plot for sn1994S is shown below. You may use whatever plotting program you would like (e.g., Matlab, Mathematica, Excel,etc...).



2. Fit the light curve to a higher order polynomial and record your fit (please turn in your light curves). Next find when this function is at a maximum. You will most likely need a third order to sixth order polynomial to accurately fit the data. Record the maximum apparent magnitude for all objects. Remember the lower the number, the brighter the supernova is.

3. You can calculate the distance to an object if you measure the apparent brightness (apparent magnitude) and you know what the intrinsic brightness should be (absolute magnitude). Find and record the distance modulus for each supernova, which is defined as $D = m - M$, where m is the observed maximum brightness and M is the absolute brightness for Type 1a supernovae $M_V = -19.3$.

4. Use the distance modulus to find and record the actual distance in parsecs by using the equation: d (distance in pc) = $10^{(D+5)/5}$.

III. Hubble's Law: Create a plot similar to Hubble's original diagram (please turn in your Hubble diagram). Find H_0 from the plot. Compare your value to the known Hubble constant.

Interstellar gas and dust can absorb and scatter light from distant objects. This process is called extinction and will cause objects to look fainter than they actually are. If extinction was not taken into account in this data, describe how it would change your plot and your value of H_0.