

UNIT 22 - VISUAL BINARY STARS

Introduction

In order to calculate the mass of our Sun, we measure the distance of any planet in the Solar System from the Sun, and the time it takes the planet to complete one orbit. Then, using Newton's Universal Law of Gravity we can calculate the mass of the Sun. In principle, for distant stars we should be able to apply the same logic if we could directly observe planets orbiting the star. Since this is not yet the case, the masses of these stars cannot be determined using this method.

However, many of the stars in the sky are partners in binary systems - two stars orbiting around each other. Using the mechanics of the stars' motions, it is possible to deduce the masses of both stars once we have measured their separation and the time in which they orbit around one another.

Providing the stars can be resolved as separate objects in the field of view of a telescope, their separation distance can be determined from their angular separation and their distance from us. The distance can be deduced using one of a variety of techniques; including stellar parallax, spectroscopic parallax, etc. The time to orbit one another is also an easy measurement for these stars, except that it might be impractically long, perhaps many years. An alternative method would be to measure the orbital speeds of the stars using the Doppler Effect. Combining the orbital speeds and separation data of the stars also allows us to calculate the two masses.

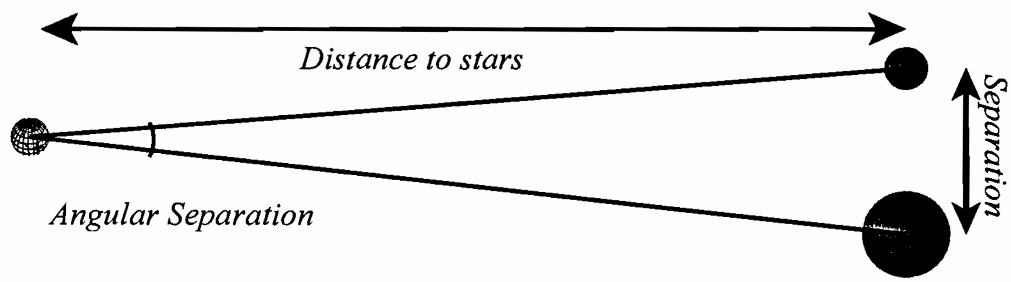

Figure-1

Calculating Speeds from the Doppler Effect

As the stars orbit around each other, each one alternately moves towards us, when it is on one side of the orbit, and away from us, when it is on the other[9]. Because of this motion, the light that it emits is detected by us with a slightly different wavelength, a phenomenon known as the Doppler Effect. When the star is moving towards us the light has a slightly shorter wavelength (blue shifted), and when the star is moving away from us the light has a slightly longer wavelength (red shifted).

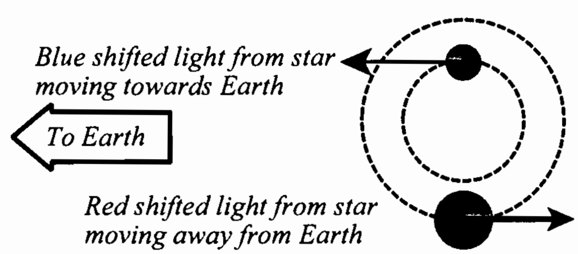

Figure-2

[9] For the purposes of this exercise we will assume that the star system as a whole is stationary relative to us.

- *Grid* menu - you can turn a reference grid on and off. When the grid is displayed, each division corresponds to an angular width of 1 arc-second.

OBTAINING THE SPECTRUM

If you click on either of the stars, that star's hydrogen spectrum will be displayed. The spectrum is divided into two halves. The top half is the true hydrogen spectrum as measured in a laboratory (see Table-1), and is used for a reference. The lower half is the spectrum from the star, which is Doppler shifted due to the star's orbital motion.

Since the speed of light is so large, the change in wavelength is too small to be seen on this scale. However, if you click on any one of the four spectral lines you will see a greatly expanded view of that portion of the spectrum, in which the wavelength change is easily noticeable.

The hydrogen spectrum	
Line	Wavelength
Violet	410 nm
Indigo	434 nm
Green	486 nm
Red	656 nm

Table-1

The expanded view contains information indicating which star is being analyzed, and the true wavelength of the light. A grid appears along with the spectrum, each square on the grid corresponds to a wavelength change of 0.005 nanometers (nm).

Measurements

You will need to make the following measurements:

1. *The separation between the stars.*
   Turn on the reference grid by selecting *Grid* from the overhead menu. Using the reference grid, measure the separation between the stars (measured center-to-center). Each division on the grid represents an angle of 1 arc-second. Once you have measured this angle, then you can get the separation distance between the stars once you know their distance from Earth. This distance is given to you when you open the window to enter your results.

2. *The speed of the stars in their orbits around each other.*
   Measure the Doppler shift of at least one of the four hydrogen lines given off by the star, and from that measurement calculate the orbital speed of the star (use equation-1). You will need to do this for both stars, since their speeds are usually different. In making this measurement, there are some points to note. First of all, the Doppler Effect only measures that portion of the velocity which is directed either towards or away from you. This is the orbital speed of the star only if the measurement is made when the star is at either the extreme left or extreme right of its orbit. You might want to examine the Doppler shift when the star is at different points in its orbit, in which case you will see that the Doppler shift varies. Secondly, if the speed is high, and since the spectrum scale only goes up to 0.025 nm on either side of the true wavelength, then it is possible that the Doppler shift is so large that the spectral line from the star is beyond the limit of the scale. This is most likely to occur when making measurements with the red spectral line. If you experience this condition, then switch to using the green spectral line instead.

Select *Check Your Answers* from the overhead menu. In the window which opens, the distance between the Earth and the binary pair is given to you. Calculate the separation distance between the

By measuring this change in wavelength, we can deduce the speed with which the star is moving away from or towards us in its orbit:

$$\frac{\textit{change in wavelength}}{\textit{true wavelength}} = \frac{\textit{speed of star}}{\textit{speed of light}} \qquad \textbf{(1)}$$

in which the speed of light equals 3.00 x 10^8 meters/sec, or 186,000 miles per hour. Since this number is much larger than the orbital speed of the stars, the wavelength change is very small and precise measurements are necessary[10].

Calculating the Masses of the Stars
The full derivation of the formulae for calculating the masses of the two stars is given in the appendix to this unit. We will simply state the results here. Let R denote the distance between the stars, and v_1 and v_2 the orbital speeds of the two stars, then the masses are given by:

$$m_1 = \frac{(v_1 + v_2)\, v_2\, R}{G}$$
$$m_2 = \frac{(v_1 + v_2)\, v_1\, R}{G} \qquad \textbf{(2)}$$

where G is the gravitational constant.[11]

Instructions
Select *Visual Binary Stars* from the *Start Lab* menu. The field of view shows two stars orbiting each other as a binary system. You can adjust the view using the following controls:

- *Animation* menu - choose between fast, medium, and slow simulation speeds. You can also start and stop the animation in order to take data. Note: none of these controls affect the data, they are provided only for convenience.

- *Viewing Angle* menu - you can select to view the binary system using one of two perspectives:
  a. *Axial* (the default setting) - A face-on view which shows the circular motion of the stars. In this window, the Earth is in the plane of the screen, but well below the screen.
  b. *Planar* - an edge-on view as you would see the stars from Earth.
  Note: the view you select does not affect the data.

---

[10] For the same reason, we can ignore corrections to the Doppler formula due to the effects of relativity.

[11] With distance measured in meters, mass in kilograms, and time in seconds, the value of G is 6.67×10^{-11}. If you use AU as units for distance, years for time, and solar masses for mass, then G is 39.2.