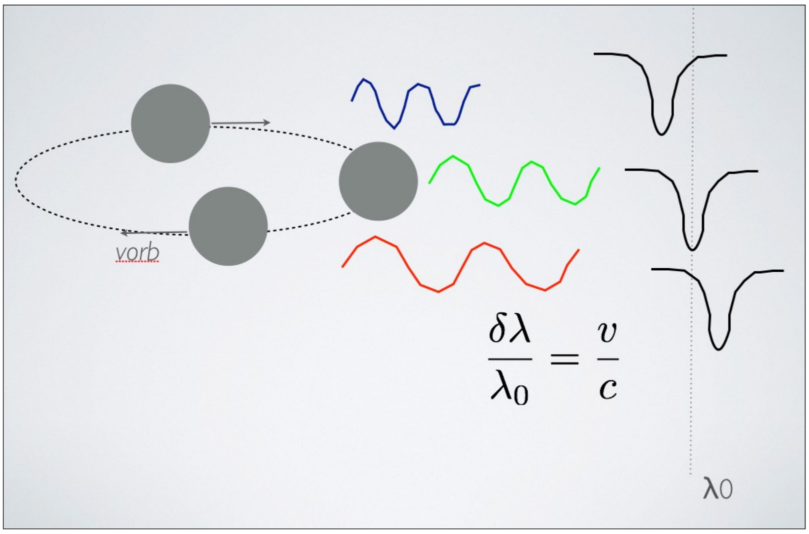
DOPPLER SHIFT



Objective

To demonstrate how the Doppler shift can be used to measure the motion of a planet orbiting a star, calculating the speed and period of the orbit.

Introduction

When a light source, such as a planet, star or galaxy, moves towards or away from an observer, the light waves will be scrunched up or stretched out so that they appear bluer or redder. This is the Doppler effect, and corresponds to a change in wavelength of the light. The wavelength change is proportional to relative motion along the line of sight. To measure it, we need to know the wavelength of both the emitted light and the received light. Light is absorbed and emitted by atoms at precise wavelengths, corresponding to lines seen in the spectrum. By measuring the wavelength of a known line, we can calculate the red shift. The relative shift in the wavelength is then equal to the radial velocity, relative to the speed of light.

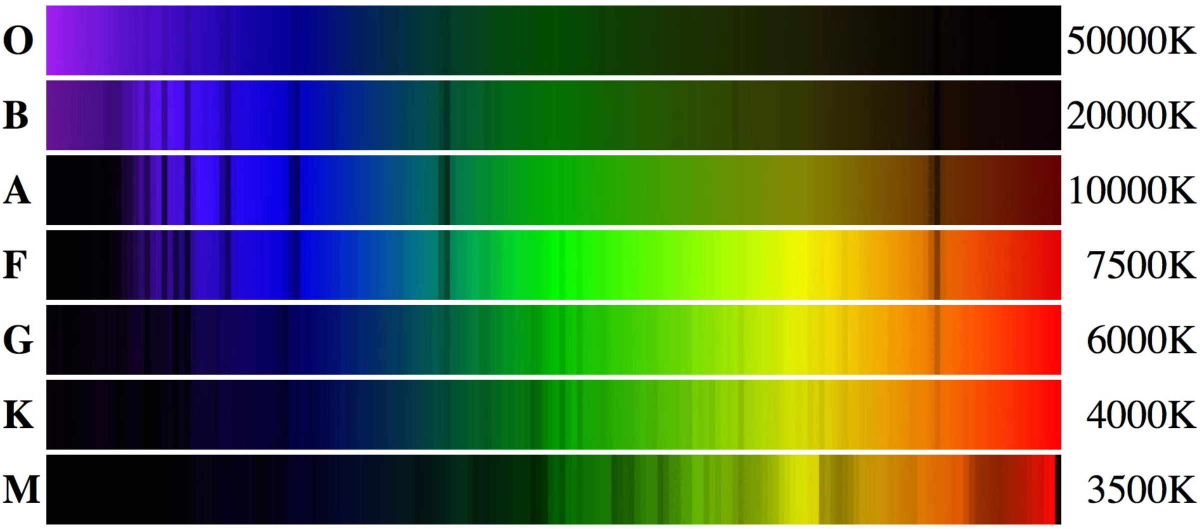


Figure 1. The visible light emitted by different types of star as viewed through a spectrometer. Wavelength runs from left (blue) to right (red). The spectral type of each star is shown on the left, and the star's surface temperature is shown on the right. The Sun is a G star. The hottest stars show a blue colour and strong dark lines due to atomic hydrogen. F and G stars are yellow, and show a veil of faint atomic lines. Cool stars are red and show bands due to molecules. Credit: Michael Lemke.

Experiment

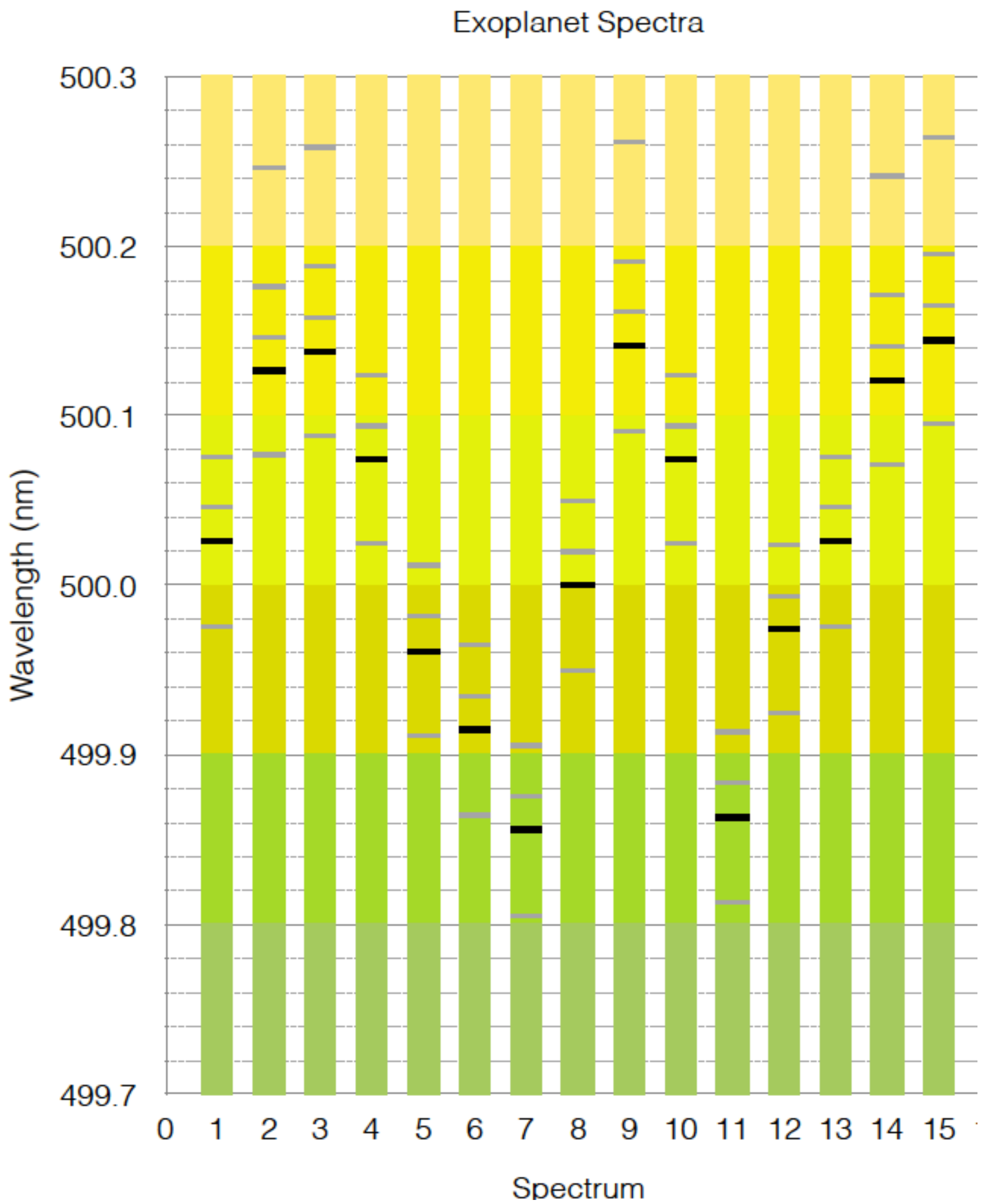
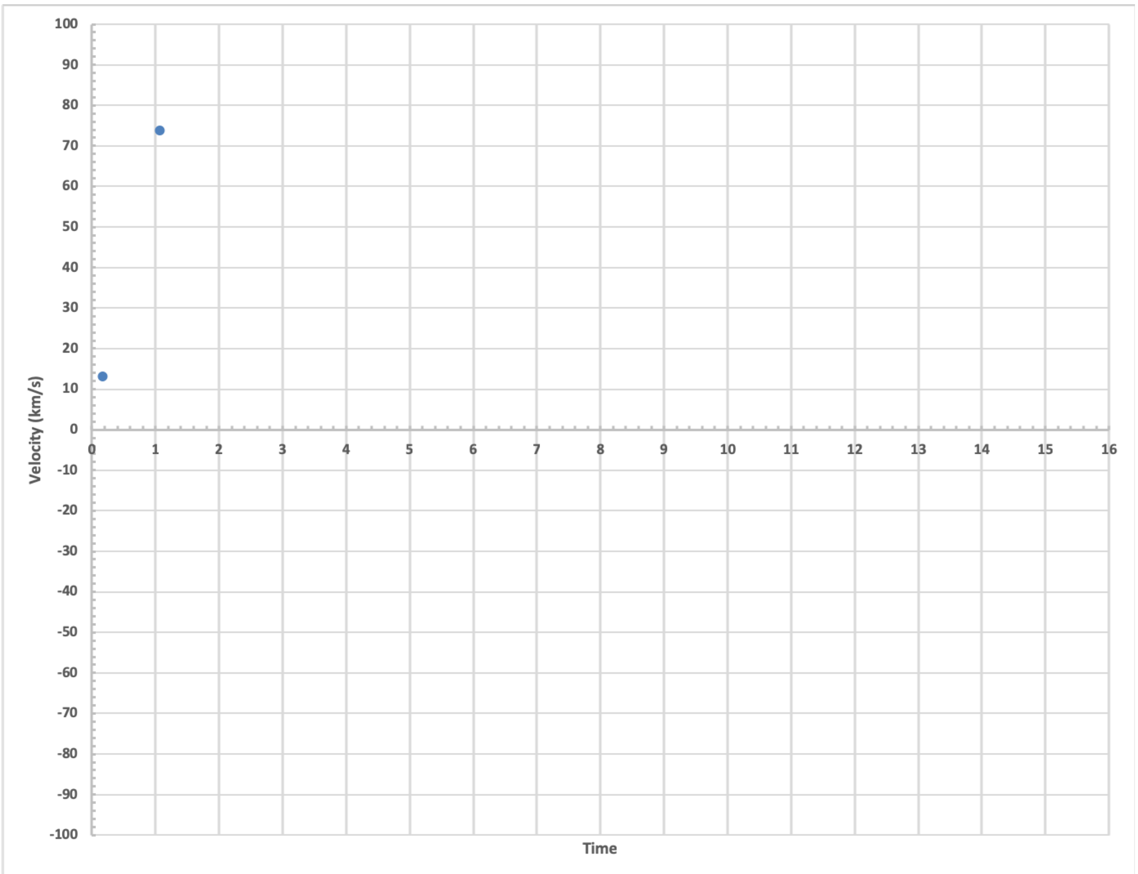


Figure 2. Observations of the spectral lines of an exoplanet in orbit around a star. 15 measurements have been made over a period of 16 days, as indicated in Table 1. The principal line being measured is marked in shown in dark black.

Figure 1 shows how the spectra of various types of star appear when viewed through a spectrometer. A planet in orbit around a star reflects starlight, with a spectrum similar to its parent star. By measuring the red shift of the planet's spectrum, we can find the period and orbital velocity of the planet. Figure 2 shows a series of fifteen 'observations' of an exoplanet, centred on a line with rest wavelength λ_0 = 500 nm and spread over a total of 16 days. The time that each observation was made at is shown in Table 1. Results for the first two measurements have been entered into the Table as a guide.

Table 1

Spectrum Number	Time T	Wavelength λ	Change in Wavelength $\delta\lambda = \lambda - \lambda_0$	Velocity V
	(day)	(nm)	(nm)	(km s^{-1})
	—	[$\lambda_0 = 500.000$]	—	[Col. 4] × c/λ0 = × 600 (km s^{-1} nm^{-1})
1	0.16	500.022	0.022	13.2
2	1.07	500.123	0.123	73.8
3	1.32			
4	2.90			
5	3.80			
6	4.15			
7	4.88			
8	7.00			
9	8.36			
10	9.90			
11	11.80			
12	13.83			
13	14.16			
14	15.03			
15	15.38			



Step 1

For each spectrum in Figure 2, find the darkest line in the spectrum and measure its wavelength in nanometres off the y-axis. Enter these values in Table 1, column 3.

Step 2

Calculate $\delta\lambda = \lambda - \lambda_0$ and enter these values in Table 1, column 4.

Convert these numbers to red shifts using the Doppler formula $v = c \,.\, (\lambda - \lambda_0) / \lambda_0$.

Since $\lambda_0 = 500$ nm and $c = 300{,}000$ km s^{-1}, this means multiplying $\delta\lambda$ by $c / \lambda_0 = 300{,}000 / 500 = 600$ km s^{-1} nm^{-1} in order to find the velocity, *V*, in km s^{-1}. Tabulate these values in column 5.

Take care with minus signs!

Step 3

Plot the velocities against the time of observation on the graph provided (the first two points are shown).

Step 4

Discuss what the plot of velocity against time can tell you. Estimate the period and orbital speed of the planet around its host star from the graph.

Points for Discussion

Which points on the graph correspond to the planet moving towards the observer?

Where on the graph is the planet crossing in front of the star?

How will the spectrum of the planet change in brightness during its orbit?

How easy do you think it would be to make observations like this? Why?

Will these observations help to measure the mass of the planet or the star?

Do you think that the star will also show periodic red shifts?

Will they be larger or smaller than those of the planet?