Physics Factsheet
www.curriculum-press.co.uk Number 280

Exoplanets and Their Stars

Exoplanets are planets belonging to a different solar system. They orbit a star other than our Sun.

Direct Observation of Exoplanets

The direct observation of exoplanets is difficult because:

a) Exoplanets are very small and distant, so the angle subtended by the exoplanet will be very small compared to the resolution of the telescope.

b) The light reflected from the surface of the exoplanet will be very much less than the light given out by the star.

The Habitable Zone of a Star

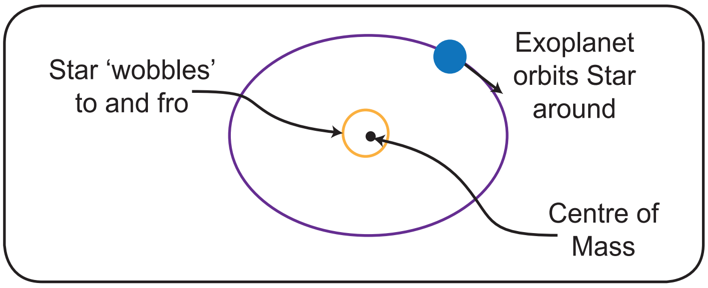
The habitable zone of a star is the region where all water on a planet orbiting the star would not be permanently frozen and not have evaporated. It would be possible for life such as that on Earth to exist there (assuming the other conditions for life were fulfilled).

The Radial Velocity Method of Exoplanet Detection

This method of exoplanet detection works by detecting a Doppler shift in the spectrum of light from a star.

The planet and star orbit about a common centre of mass which will be between the star and the exoplanet. The star is much larger than the exoplanet and so the centre of mass will be very near where the centre of mass of the star alone would be. If an exoplanet is orbiting it, the star's orbit undergoes 'small wobbles' moving towards and away from the Earth. The gravitational pull of the exoplanet causes the star to move in a small circle or ellipse. This gives rise to the Doppler shift in the light spectrum from the star. The star moving towards the observer will cause the light to appear bluer, whereas moving away will cause a red shift in the light. The resulting regular alternate red and blue shifts in the spectrum from the star can be detected by very sensitive spectrographs.

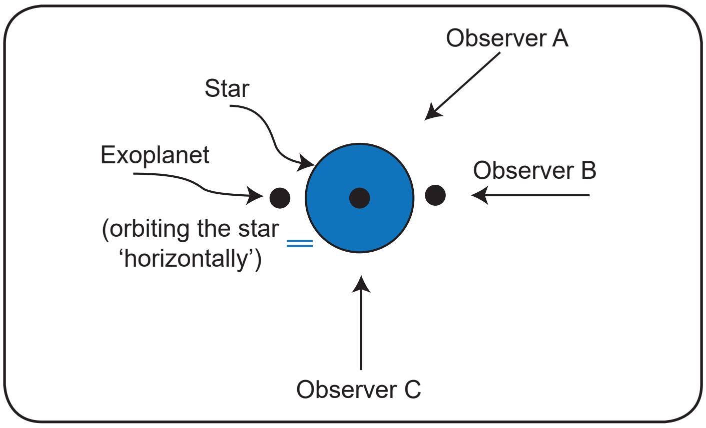
Figure 1



Determining the Mass of the Planet from Radial Velocity Measurements

The method will only detect the amount by which the exoplanet causes the star to shift away or towards the Earth. However, in general, the change in star movement in the direction of Earth will only be a component of the movement of the star. The total movement of the star due to the exoplanet will actually be greater.

Figure 2



The observers cannot see the exoplanet directly as it is too small. They use the Doppler shift in the light from the star to estimate the exoplanet's mass.

The star's movement is used to estimate the mass of the exoplanet and so from this calculation a minimum mass is derived.

Quick Questions:

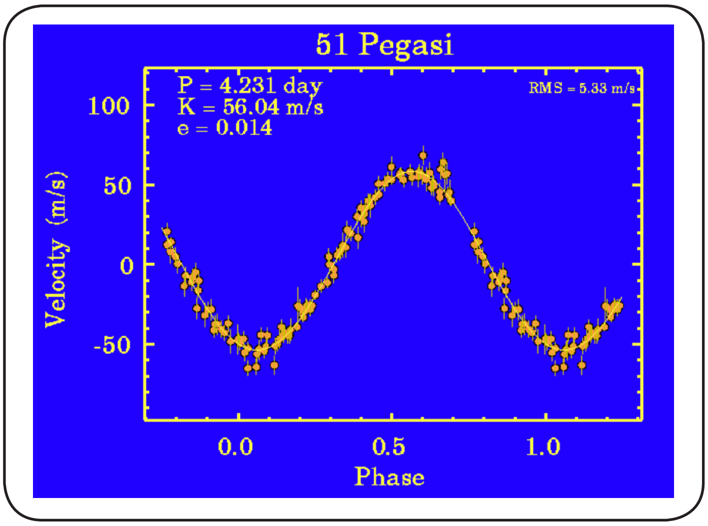
1) *Which of the observers will calculate the largest mass for the exoplanet? Explain your answer.*
2) *Which of the observers would not be able to detect the exoplanet by this method? Explain your answer.*
3) *Observer B calculates a mass for the exoplanet. How will this mass compare with the actual mass of the exoplanet?*
4) *Why can the radial velocity method only calculate a minimum mass for the planet?*

The planets most likely to be detected by the radial velocity method are the 'hot Jupiters'. These are planets that are large and relatively close to the star they are orbiting. Because they are close to the star, this results in them having short orbital periods. These cause the biggest 'stellar wobbles'. However, a 'hot Jupiter' is unlikely to provide a home for any of the life forms which are of interest to us. There is also little likelihood of Earth-like planets which might have life forms of interest to us being able to survive in the proximity of a 'hot Jupiter'.

A sinusoidal radial velocity graph is typical of a star responding to the pull of an exoplanet.

For example, 51 Pegasi was the first exoplanet discovered. It was discovered because its star rocked to and fro displaying the sinusoidal radial velocity graph shown on the next page:

Figure 3



Source: *Bruce Murray Space Image Library of the Planetary Society*

The Transit Method of Exoplanet Detection

This method of exoplanet detection makes use of the change in apparent magnitude which occurs if the orbit of the exoplanet results in the exoplanet moving in front of the star (viewed by the observer on Earth).

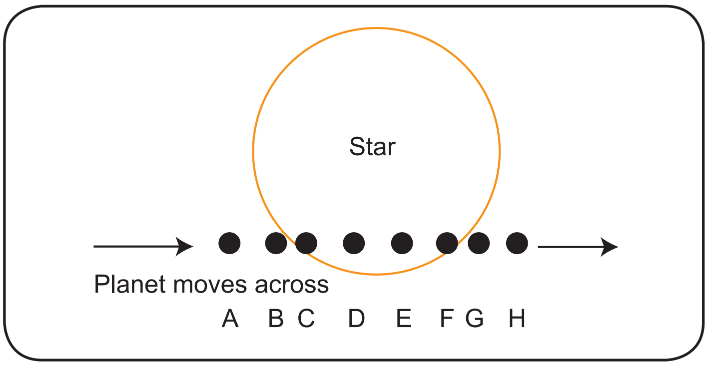
The apparent magnitude is the measure of the amount of light reaching Earth from the star.

As it transits across the star, the exoplanet will block out some of the light from the star, reducing the apparent magnitude.

Transit of a Star by an Exoplanet

As the planet's orbit begins to move across the star, and first begins to obscure light from the star, the light received by the observer will begin to fall. This fall in light will increase as more and more of the planet comes in front of the star, until the planet is completely in front of the star.

Figure 4

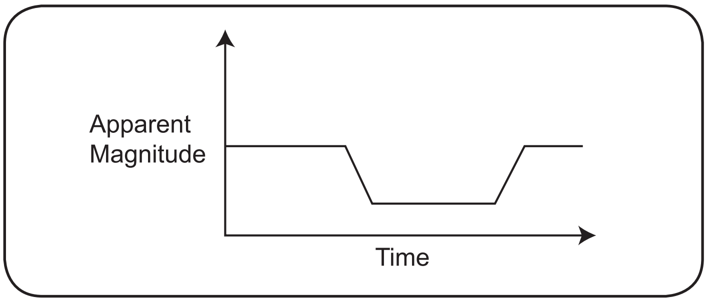


Quick Question:

5) *Give the letter(s) for the following positions:*
   i) *Where the light from the star begins to be obscured*
   ii) *Where the light from the star is obscured by the greatest amount.*
   iii) *Where the light from the star is not obscured.*
   iv) *Where the light from the star will have increased to be very nearly its maximum.*

The Typical Light Curve of a Star showing the Transit of an Exoplanet

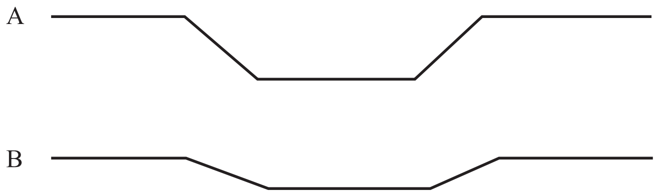
Figure 5



During the transit of the planet across the star, the amount of light obscured will initially be increasing (apparent magnitude falls) and then be constant until it reaches the other edge of the star and the amount of light obscured decreases again (apparent magnitude increases).

Exam Questions:

1) Give two reasons why it is difficult to make a direct observation of a planet orbiting a star. (2 marks)
2) The movement of a star is modified by a planet which is orbiting it. Describe and explain the change in movement of the star. (1 mark) Give the two conditions relating to the exoplanet which will make this change in movement larger. (1 mark) Give the name for this technique of detecting exoplanets. (1 mark)
3) Cross through one word of each alternative to make the sentences correct: the faster a star moves away from you the higher/lower the red/blue shift of the light will be. The frequency of the light you receive is lower/greater. (3 marks)
4) The following light curves show the transit of exoplanets across the **centre** of stars of similar size and light output.



   Which curve relates to the smaller exoplanet? Give a reason for your answer. (1 mark)
5) A large proportion of exoplanets detected and imaged are 'hot Jupiters'. Give two reasons for this. (2 marks)

Answers to Exam Questions:

1) The planet subtends a very small angle in comparison to the resolution of the telescope. (1 mark) The light reflected from the planet is very much less than the light from the star, the star is much brighter. (1 mark)
2) The star will move in a circle or ellipse towards and away from the Earth, due the gravitational pull of the exoplanet. (1 mark) The larger the exoplanet and the closer it is to the star the greater the change in movement of the star. (1 mark) Doppler (shift). (1 mark)

3) Higher, red, lower. (3 marks)
4) Curve B because the exoplanet obscures less light and so would be smaller. (1 mark)
5) These planets are large and so the optics can resolve them more easily. (1 mark) They also radiate in the infra-red due to their temperature. Therefore, imaging does not rely on reflected light. The infra-red radiation they emit can be differentiated from the visible light of the star. (1 mark)

Answers to Quick Questions:

1) Observer C because there is no component of the movement of the star caused towards or away from observer C and so the spectrum of the light received by C would not change systematically. The 'wobble' of the star is perpendicular to the observer's line of vision.
2) Observer B because the maximum movement in the star caused by the exoplanet is towards and away from Observer B and so the Doppler shift in the wavelength of the light will be greatest.
3) The mass Observer B calculates will be too small.
4) In general, observers will be observing a Doppler Shift which is less than the maximum and so their calculated mass will always be below the real mass, unless it corresponds to the position of Observer B (the observer will not, in general, be in a position to observe light from the full movement of the Star due to the exoplanet).
5) i) B
   ii) C, D, E and F
   iii) A and H
   iv) G

Acknowledgements: *This* ***Physics Factsheet*** *was researched and written by* ***Cristine Collier*** *and published in* ***April 2018*** *by* ***Curriculum Press****.*

ISSN 1351-5136