Detecting exoplanets by spectroscopy

Example of 51 Pegasus b

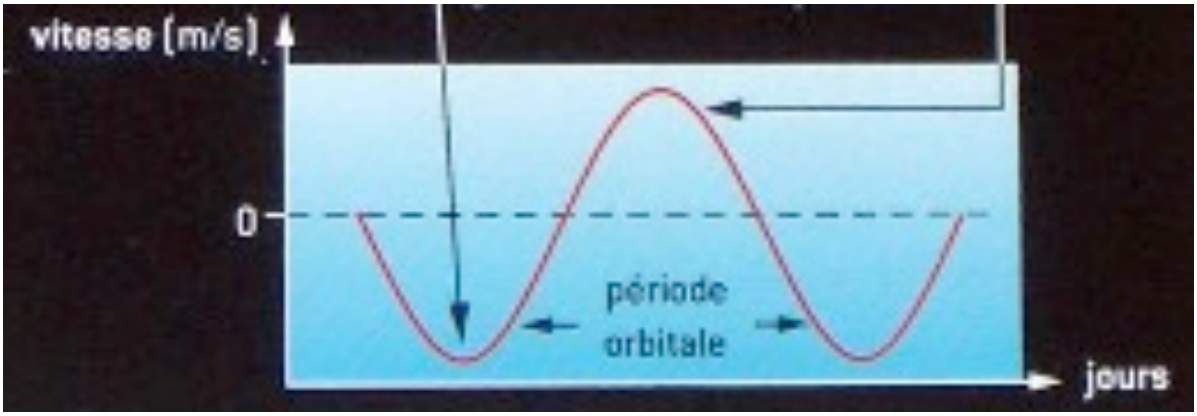
Solutions

1 The star-planet system

Here are the positions on the graph where:

- The star is closest from the Earth: C
- The star is furthest from the Earth: F
- The star in in an intermediate position: I

F I C I F I C



Explanation: the radial velocity is nil when the star is either closest or furthest from the Earth.

2 Analysis of the spectroscopic data that led to the detection of 51 Peg b

Time period T of the sinusoid: 4.2 days

Amplitude K of the sinusoid: 56 m/s

3 The exoplanet's parameters

Using Kepler's 3rd law we retrieve the star-planet distance:

$$a^3 = T^2 \times \frac{\mathcal{G} M_{star}}{4\pi^2} \quad \Rightarrow \quad a = 0.05\ AU$$

Using the barycentre properties, we retrieve the mass ratio of the planet and the star:

$$M_{star} \times r_{star} = m_{planet} \times r_{planet}$$

Assuming a circular orbit, the star's velocity is:

$$V = \frac{2\pi r_{star}}{T} = \frac{2\pi}{T} \frac{r_{planet} \times m_{planet}}{M_{star}} \sim \frac{2\pi}{T} \frac{a \times m_{planet}}{M_{star}}$$

Applying the definition of K:

$$K = V \sin i \quad \Rightarrow \quad m_{planet} \sin i = \frac{K \times T \times M_{star}}{2\pi a} = 9.2 \times 10^{26} kg = 0.46 M_J$$

4 Limitations of this method

- The speed of the Sun perturbed by Jupiter oscillates with a maximum amplitude of 13 m/s over a period of 12 years.

- The speed of the Sun perturbed by the Earth oscillates with a maximum amplitude of 9 cm/s over a period of one year.

- With the HARPS spectrograph, star speeds of one metre per second are detectable, but do not yet allow the detection of planets like the Earth.

- Detection of Saturn: Radial velocity detection requires observations over the period of a planet, i.e. 30 years for Saturn. With observations starting in 1995, Saturn will not be detectable before 2025.

- This method has a bias: the speed detected is the radial speed, which is zero for planets whose orbit is in the plane of the sky. Planets whose orbital plane is perpendicular to the line of sight are therefore undetectable using this method.