The Radial Velocity Method

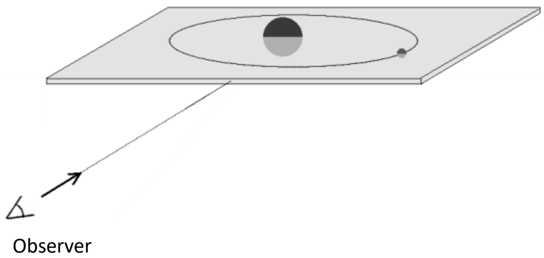


Fig. 1. Source: M. Borchardt

If the orbit of an exoplanet is oriented in such a way that we look from Earth at the edge or somewhat obliquely at the surface of the orbital plane, the planet sometimes moves towards us and sometimes away from us. However, we cannot observe this directly because we cannot see the planet due to the huge distance. However, the movement of the planet produces a reflex movement of the star. Then, as the planet moves away from us, the star comes towards us a little, and as the planet moves towards us, the star moves away. Both bodies revolve around their common centre of gravity.

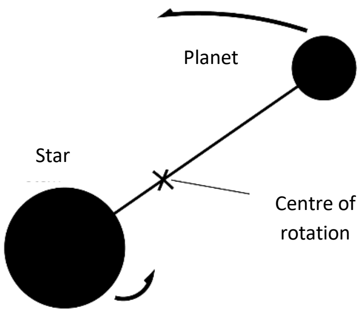


Fig. 2. Source: M. Borchardt

In order to understand this, it helps if you imagine a dumbbell bar with two balls of unequal weight: Throw them in the air and the system will rotate around the centre of gravity of the two balls. The speed at which the star is moving towards us and away from us (radial velocity) can be determined by spectrally splitting the starlight (for example, by sending it through a prism or an optical grating) and looking closely at the position of certain colours (spectral lines). The "Doppler effect" produces a shift in the colours – depending on the speed of the star. It is thus possible that we can perceive the presence of the planet <u>indirectly</u> without seeing it ourselves.

Task 1:
Research on the internet what the **Doppler effect** does with sound and with light, and summarise the essential aspects in your own words.

It was already mentioned that the speed of the star is sometimes oriented towards us (negative) and sometimes away from us (positive). But how it develops more precisely during an orbit around the centre of gravity in the course of time is to be worked out with the help of the following task.

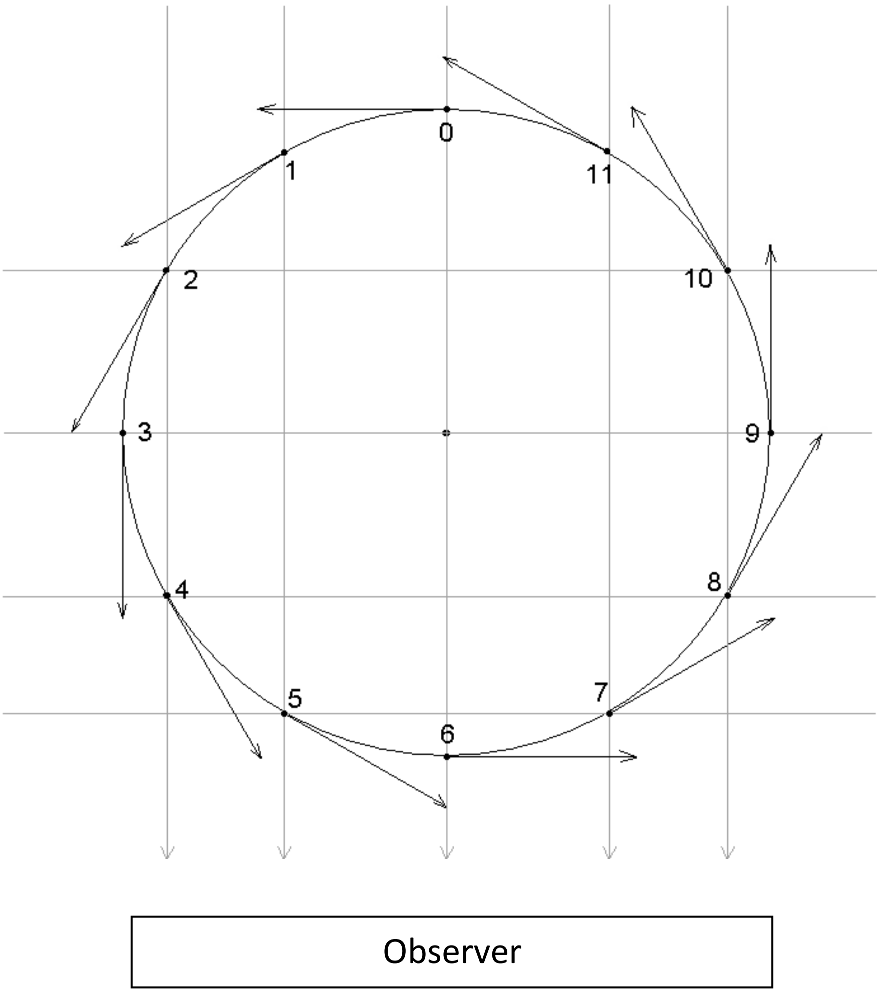
Task 2:

Look at the illustration on the following page. We assume that the star moves in a perfect circular orbit around its own centre of gravity. In doing so, it has the same orbital velocity at every point. In the drawing, this is represented by arrows of equal length. We are interested in the component of each of these arrows in the direction of the observer. To do this, decompose each arrow into two components – one in the direction towards the observer and a second perpendicular to it. Measure the length of the first component with a set square, transfer the value to the table, and enter the table values in the diagram below. Draw a curve (not a straight line) through the points by eye. This gives you a typical curve of the **radial velocities of** the star.

Task 3:

Valuable information about the (invisible) exoplanet can be derived from the radial velocity curve of the star. For example, it is easy to determine the orbital period of the planet. The shape of the planet's orbit (circular or elliptical) and the position of the ellipse in relation to the observer can also be determined. Unfortunately, the mass of the planet cannot be derived directly from the curve because the amplitude of the curve depends not only on the masses of the star and planet but also on the inclination of the orbital plane to the observer.
With the help of the small computer programme "Radialgeschwindigkeit.exe"[1], you can easily understand this. Open the programme, and let the exoplanet orbit around you. The simulation draws the curve of the radial velocity. Try out the effects of different mass ratios on the amplitude of the curve. If you now change the inclination of the orbital plane, you should see that the amplitude also changes. For this reason, only a lower limit for the mass can usually be given. This would be the result if you looked at the edge of the orbital plane (i.e. sideways at the rotating system). For all other inclinations of the orbital plane, you must assume a larger mass.
By the way: If you choose an elliptical path instead of a circular path, you will notice that, depending on the eccentricity and position of the ellipse, the curve of the radial velocity changes significantly. In reality, such curves provide important information about the shape and orientation of the elliptical path.

[1] http://www.mabo-physik.de/radialgeschwindigkeitsmethode.html



Time	Radial velocity (length of the arrow component to the observer)
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11