# RADIAL VELOCITIES OF A BINARY SYSTEM: COMPUTER MODEL

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Reference: Carroll, Bradley W. & Ostlie, Dale A. (2007), *An Introduction to Modern Astrophysics*, 2nd Edition; Pearson Education - Chapter 7, Problem 7.15.

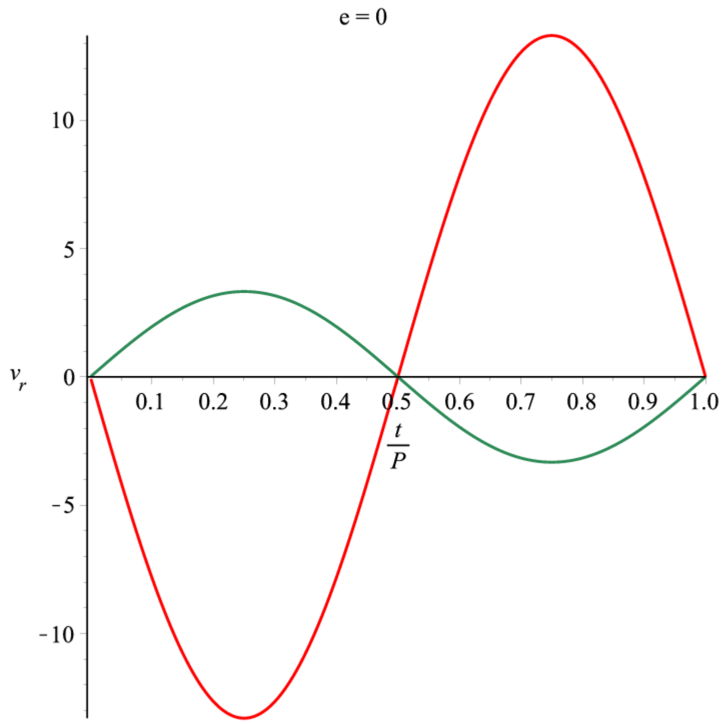
In their Appendix K, Carroll & Ostlie describe a computer program called *TwoStars*, which computes radial velocities and magnitudes for an eclipsing binary system. We won't repeat the description here; rather we'll just summarize how it works.

The required input to the program is the mass, radius and temperature of each of the two stars, the orbital period, the eccentricity and inclination of the orbit, the angle of periastron (the angle between the minor axis and line of sight) and the velocity of the centre of mass. The program then uses these data along with Kepler's laws to calculate the orbits of the two stars as a function of time, using numerical simulation. At each time interval, a check is made to see if one star eclipses the other and, if so, the change in received flux from the system is calculated by subtracting the flux from the obscured portion of the eclipsed star, thus generating a light curve.

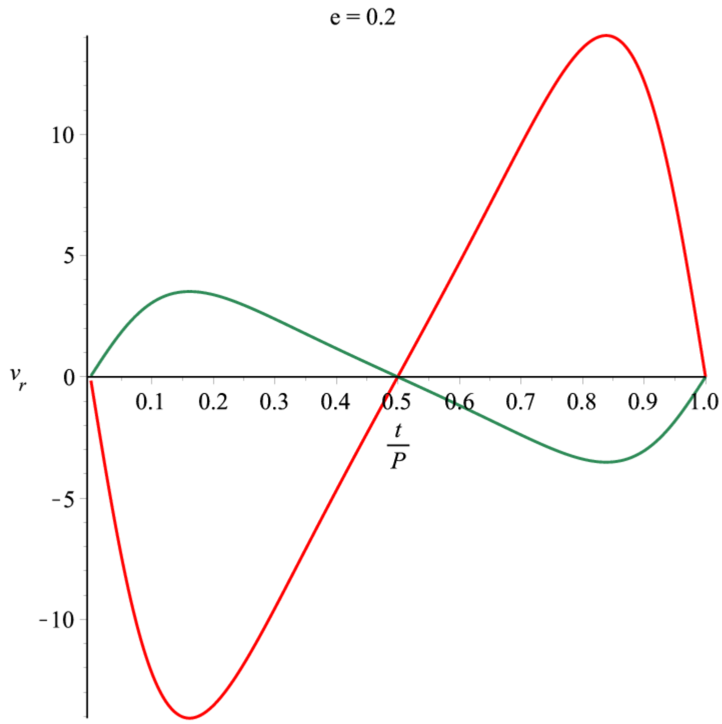
They provide their source code in Fortran and C++, but in order to facilitate the generation of plots, I translated the code into Maple. The code is too long to reproduce here (and it's also kind of ugly), but if you're interested, you can download the Maple code for this problem from here.

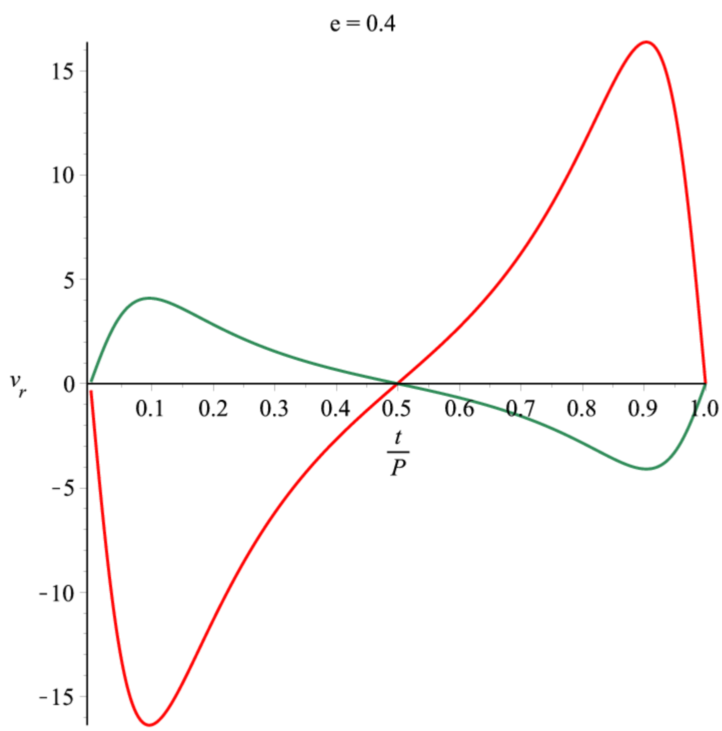
As an example, we'll look at the radial velocities of the components of a binary star with the parameters $M_1 = 0.5M_S$, $R_1 = 1.8R_S$, $T_1 = 8190$ K, $M_2 = 2.0M_S$, $R_2 = 0.63R_S$, $T_2 = 3840$ K, $P = 1.8$ yr, and $i = 30°$. We'll assume that the angle of periastron is $\phi = 0$ and that the velocity of the centre of mass is zero.

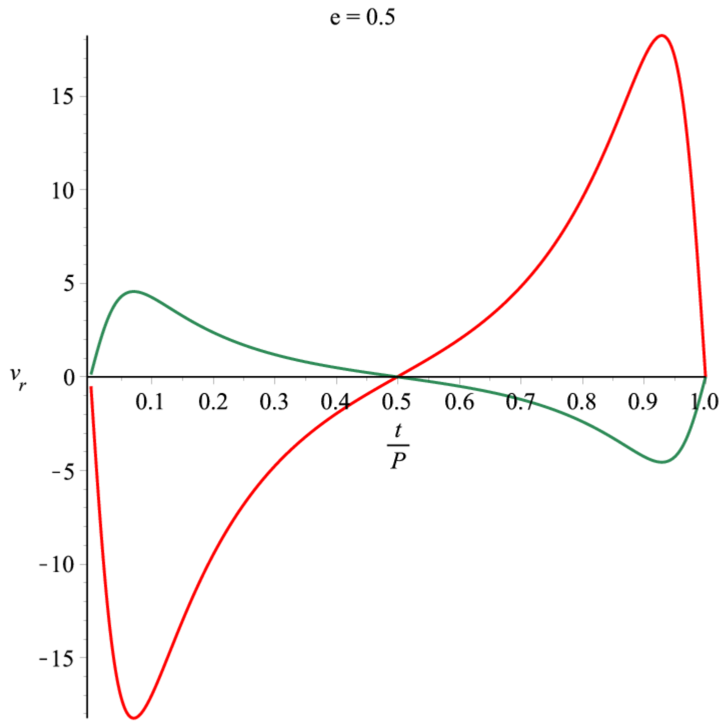
With this inclination, there are no eclipses, so the light curve is constant. We can calculate the radial velocities for several eccentricities of the orbit. For $e = 0$, the orbits are circular, and the velocities follow sine curves:




For higher eccentricities, the curves become more and more lopsided. Here are the graphs for $e = 0.2, 0.4, 0.5$:


e = 0.2
$v_r$
10
5
0
-5
-10
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
$\frac{t}{P}$


e = 0.4
$v_r$
15
10
5
0
-5
-10
-15
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
$\frac{t}{P}$




The eccentricity of a binary system can thus be estimated by comparing the velocity curves with those from a model such as this.

We can check the results for $e=0$ by inverting the process we used to estimate stellar masses to calculate the maximum radial velocities from the parameters given above. We have

$$\frac{v_{2,r}}{v_{1,r}} = \frac{M_1}{M_2} = 0.25 \tag{1}$$

$$v_{1,r}+v_{2,r} = \left(\frac{2\pi G\left(M_1+M_2\right)}{P}\right)^{1/3} \sin i \tag{2}$$

$$= 16.6 \text{ km s}^{-1} \tag{3}$$

$$v_{1,r} = 13.3 \text{ km s}^{-1} \tag{4}$$

$$v_{2.r} = 3.32 \text{ km s}^{-1} \tag{5}$$

These values agree well with the heights of the sine curves in the first plot above.

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