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51 Pegasi: Discovery of a New Planet

In this lab you will discover a planet orbiting another star and compares the results of the discovery with planets in our solar system. In just the past few years, astronomers have announced discoveries of at least 30 planets orbiting nearby stars. These discoveries seem to finally answer the question of whether or not our solar system is unique. We should note, however, that when astronomers state that they have discovered a new planet, what they are really saying is that their data can best be interpreted as a planet orbiting a star. One cannot "prove" that these other planets exist (short of actually going there to explore!); one can only state that, until the hypothesis is disproved, a planet orbiting the star best explains the observations. We cannot see these planets. We can only measure indirectly the influence each one has on its parent star as the star and planet orbit their common center of mass. The planet makes the star "wobble."

We enter this realm of discovery by working with actual data from observations of the star 51 Pegasi (51 Peg) made at the Lick Observatory in California. These data are the measurements of the Doppler shift of the wavelengths of the absorption lines seen in the spectra of 51 Peg. Table 1 lists the measured radial velocities (RV) as a function of time (recorded in days). As you can see, the radial velocities are sometimes positive and sometimes negative indicating that sometimes the star is receding from (the light is redshifted) and sometimes approaching (the light is blueshifted) our frame of reference. This wobble of the star was the first indication that the star 51 Peg had an invisible companion.

Procedure:
Plot the 32 data points on graph paper, setting up your scale and labels. Use the observed radial velocities (in m/s) versus the day of the observation.
Draw a smooth curve (do not simply connect-the-dots) through the data. The curve is a *sine* curve (ask if you don't know what a sine curve is) and thus will always reach the same maximum and minimum values and have the same "number of days" between each "peak" and "valley". You should interpolate between data where points are missing.
Thought question: Why are there data missing? Why are there sizable gaps in the data? (Hint, some gaps are a little over 1/2 day long and these are observations from the ground.)

Table 1 lists the observed radial velocities. These were obtained by measuring the Doppler shift for the absorption lines using the formula:

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

OBSERVATIONS:

TABLE 1: 51 Pegasi Radial Velocity Data

Day	v (m/s)	Day	v (m/s)	Day	v (m/s)	Day	v (m/s)
0.6	-20.2	4.7	-27.5	7.8	-31.7	10.7	56.9
0.7	-8.1	4.8	-22.7	8.6	-44.1	10.8	51
0.8	5.6	5.6	45.3	8.7	-37.1	11.7	-2.5
1.6	56.4	5.7	47.6	8.8	-35.3	11.8	-4.6
1.7	66.8	5.8	56.2	9.6	25.1	12.6	-38.5
3.6	-35.1	6.6	65.3	9.7	35.7	12.7	-48.7
3.7	-42.6	6.7	62.5	9.8	41.2	13.6	2.7
4.6	-33.5	7.7	-22.6	10.6	61.3	13.7	17.6

- A *period* is defined as one complete cycle; that is, where the radial velocities return to the same position on the curve (but at a later time). How many cycles did the star go through during the 14 days of observations?

Number of cycles = _____

- What is the period, P, in days?

Period = _____ days

- What is P in years?

P = _____ years

- What is the uncertainty in your determination of the period? That is, by how many days or fractions of a day could your value be wrong?

Uncertainty = _____ days

- What is the amplitude, *K*? (Take 1/2 of the value of the full range of the velocities.)

$$K = \underline{\hspace{2cm}} \ m/s$$

- How accurate is your determination of this value?

$$Uncertainty = \underline{\hspace{2cm}} \ m/s$$

We will make some simplifying assumptions for this new planetary system:
- the orbit of the planet is circular (*eccentricity = 0*)
- the mass of the star is 1 solar mass
- the mass of the planet is much, much less that of the star
- we are viewing the system nearly edge on
- we express everything in terms of the mass and period of Jupiter

We make these assumptions to simplify the equations we have to use for determining the mass of the planet. The equation we must use is:

$$M_{Planet} = \left(\frac{P}{12}\right)^{1/3} \frac{K}{13} M_{Jupiter}$$

- *P* should be expressed in years (or fraction of a year), and *K* in *m/s*. Twelve years is the approximate orbital period for Jupiter and 13 m/s is the magnitude of the "wobble" of the Sun due to Jupiter's gravitational pull. Not all calculators will take the cube root of a number. Get help if yours does not. Put in your values for *P* and *K* and calculate the mass of this new planet in terms of the mass of Jupiter. That is, your calculations will give the mass of the planet as some factor times the mass of Jupiter (for example: $M_{planet} = 4 \ M_{Jupiter}$). **Show all work**.

- Assume that the parent star is 1 solar mass, and that the planet is much less massive than the star. We can then calculate the distance this planet is away from its star, in astronomical units (AU's) by using Kepler's third law:

$$\frac{a^3}{P^2} = 1$$

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Again, *P* is expressed in years (or fraction of a year), and *a* represents the semi-major axis in AU's. Solve for *a*:

$$a = \left(P^2\right)^{1/3}$$

a = _____ *AU*

Compare this planet to those in our solar system. For example, Mercury is 0.4 AU from the Sun; Venus, 0.7 AU; Earth, 1.0 AU; Mars, 1.5 AU; Jupiter, 5.2 AU. Jupiter is more massive than all the rest of the matter in the solar system combined, excluding the Sun.

• What is unusual about this new planet?

• Science is based upon the ability to predict outcomes. However, nothing prepared astronomers for the characteristics of this "new" solar system. Why was it such a surprise?

• If this actually is a planet, is it possibly hospitable to life? Explain.

• Name your new planet -- a privilege you would have if you really did discover a new planet!

Don't forget to turn in your graph with the lab.