Chapter 9: Wobbling Stars: Detecting Extra-Solar Planets Using the Doppler Shift

Student Worksheet

Objective:

Use NASA data to plot the wobbles of stars, indicating a planet or system of planets in orbit.

Engage:

Table 1 below shows a system of exoplanets found orbiting a star very much like our Sun. Study the chart to imagine what this system of planets might be like in comparison to our solar system. Write your thoughts in the space below.

Table 1

	Planetary Characteristics							Planetary Orbit			
Name	KOI#	Mass		Radius		Density	Temp*	Transit Duration	Period	Semi-Major axis	Eccen-tricity
		Jupiter masses	*Earth masses*	*Jupiter radii*	*Earth radii*	*grams/cc*	*Kelvin*	*hours*	*days*	*AU*	
Kepler-11b	157	0.014	4.3	0.175	1.97	3.1	900	4.02	10.30375	0.091	(0)
Kepler-11c	157	0.042	13.5	0.28	3.15	2.3	833	4.62	13.02502	0.106	(0)
Kepler-11d	157	0.019	6.1	0.305	3.43	0.9	692	5.58	22.68719	0.159	(0)
Kepler-11e	157	0.026	8.4	0.402	4.52	0.5	617	4.33	31.99590	0.194	(0)
Kepler-11f	157	0.007	2.3	0.232	2.61	0.7	544	6.54	46.68876	0.25	(0)
Kepler-11g	157	<0.94	<300	0.326	3.66	?	400	9.60	118.37774	0.462	(0)

* The value for the mass of the planet is a lower limit if determined from radial velocity measurements, in cases where no actual transit was observed and inclination is unknown.

Information from NASA/Kepler Discoveries

Introduction:

Not long ago, planetary systems were thought to be rare occurrences around stars. Today, there are NASA missions like Kepler dedicated to looking for planets around other stars. Missions like Kepler are teaching us that most stars have planets. The possibility for life on these planets is a very exciting are of study. Kepler has discovered thousands of candidate planets, and hundreds have been confirmed.

There are a couple of methods of looking for extra solar planets. One method involves looking for the *dimming* of a star when a planet passes in front of it. Another method involves looking for a *wobbling* star, which indicates the star is being pulled back and forth by the planets in orbit around it–that is, the planets and the star are orbiting a common center of mass. The star is by far the most massive thing in a star system so the center of mass of the star system is usually inside or very close to the star itself. Figure 1 below shows the Sun and Jupiter orbiting a common center of mass.

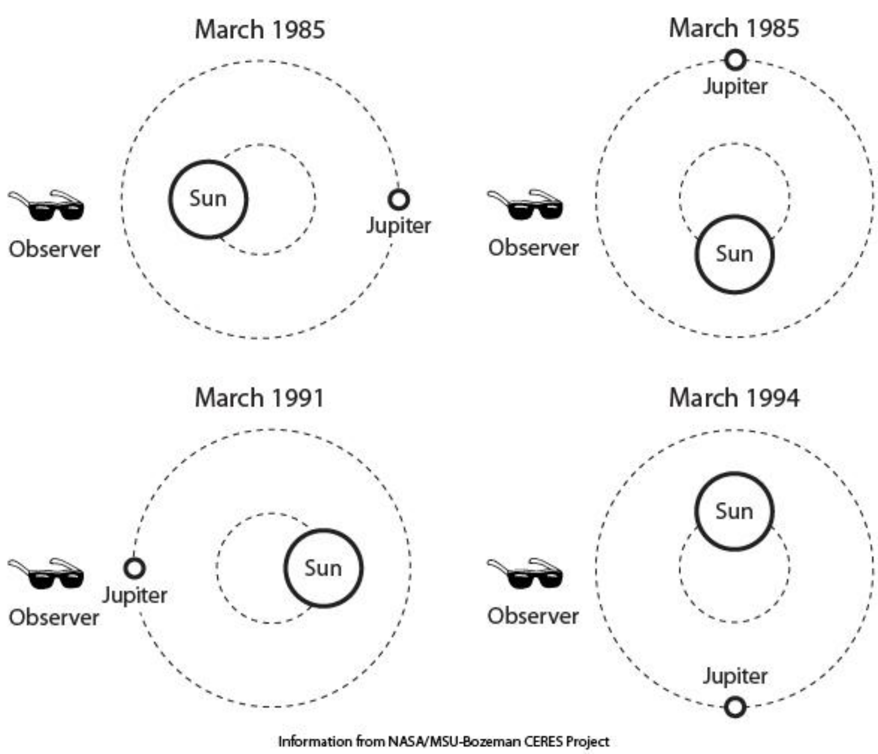


Figure 1

If you imagine an observer looking from a vantage point located along the bottom edge of Figure 1, you can see how sometimes the Sun would exhibit side-to-side, or tangential, motion while at other times the Sun would exhibit forward and backward, or radial, motion. Either motion is considered a wobble, but astronomers can use the forward and backward motion to determine whether a star has a planetary system around it.

The method of looking for planets around a star due to radial velocity is called the *Doppler shift method.* The Doppler effect dictates how the light from a star moving toward or away from a viewer *red-shifts* and *blue-shifts.* The amount of red or blue shifting of the star's light gives astronomers information about the planetary system around the star. When the star is red-shifting, or moving away from you, the radial velocity is negative. When the star is blue-shifting, or moving toward you, the radial velocity is positive. As a planet orbits, a viewer would see a periodic relationship between the radial velocity and time.

In this activity you will look at how data from a wobbling star can indicate a planet, or a system of planets, in orbit.

Procedure:

1. According to Figure 1 above, in which years would Jupiter's radial velocity appear to be positive? Negative?

2. Table 2 and Table 3 on the next page show the *radial velocity* versus *time* data for two stars, A and B. Look at the data tables to see if you can detect any patterns. Write your thoughts in the space below Tables 2 and 3.

Table 2

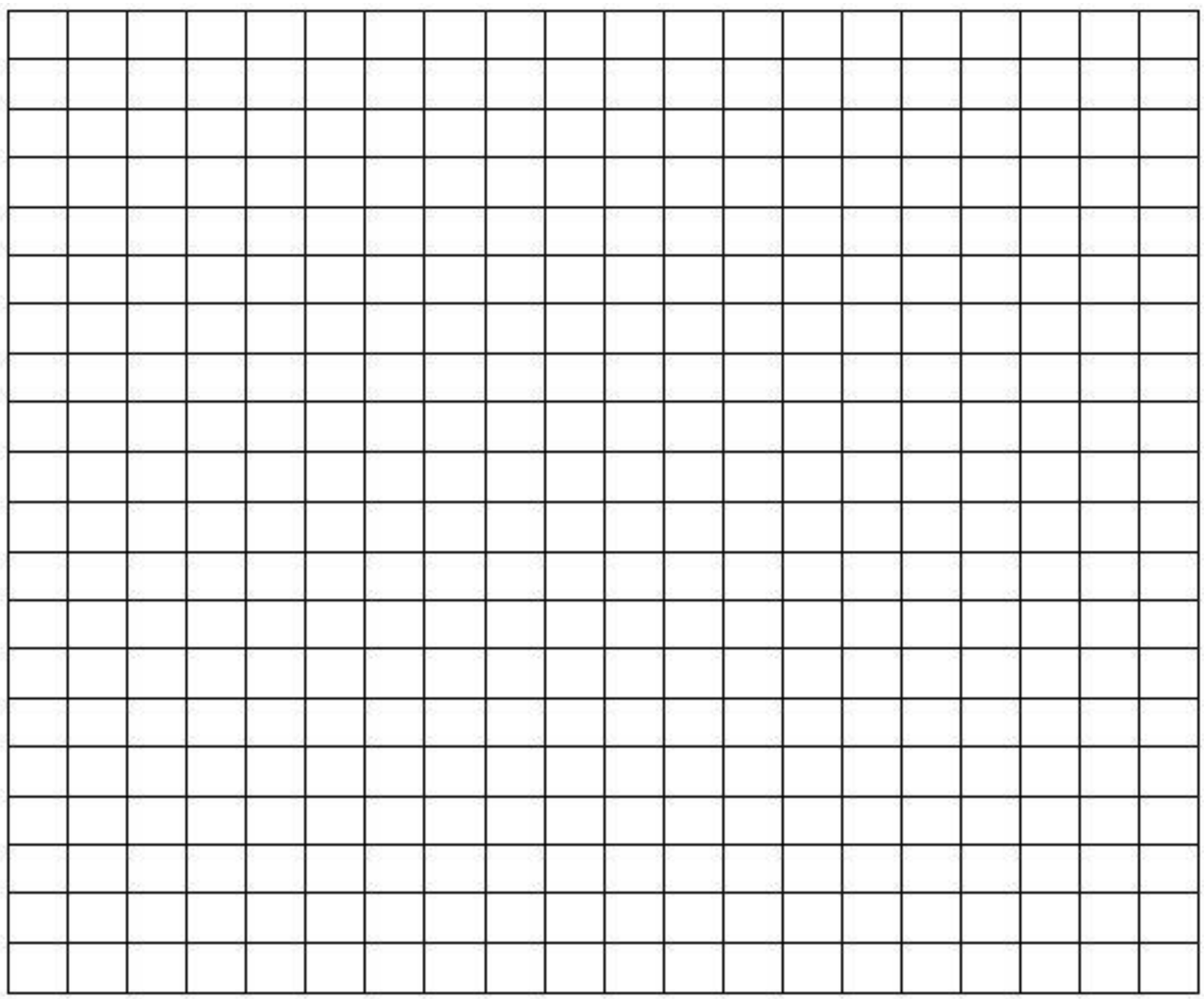
Star A	
Time (Days)	Radial Velocity (m/s)
1	44
2	-41
3	-41
4	41
5	60
6	-30
7	-51
8	10
9	43
10	37
11	-56
12	0
13	60
14	15
15	-29
16	-30
17	60

Table 3

Star B	
Time (Days)	Radial Velocity (m/s)
0	-650
0.15	-700
0.50	-550
0.65	-400
1.0	0
1.35	200
1.70	400
2.05	450
2.40	400
2.75	300
3.10	105
3.45	-150
3.80	-650
4.15	-700
4.50	-550

3. Graph the data of Table 2 on the grid below. The x-axis should represent *time*. The y-axis should represent *radial velocity*.

Star A



4. Graph the data of Table 3 on the grid below. The x-axis should represent *time*. The y-axis should represent *radial velocity*.

Star B

5. Describe the similarities and differences in your graphs.

6. Based on the graphs, do these stars have a companion planet? Explain your answer.

7. Estimate the orbital period for the planets if you determined them to have planets.

8. Figure 2 and Figure 3 below show *radial velocity* versus *time* graphs for two other stars.
    a. Do these stars seem to have planets? Why or why not?
    b. If you think the stars have planets, what would be a good estimate of their orbital periods?

Figure 2 Radial Velocity vs. Time: *Star X*

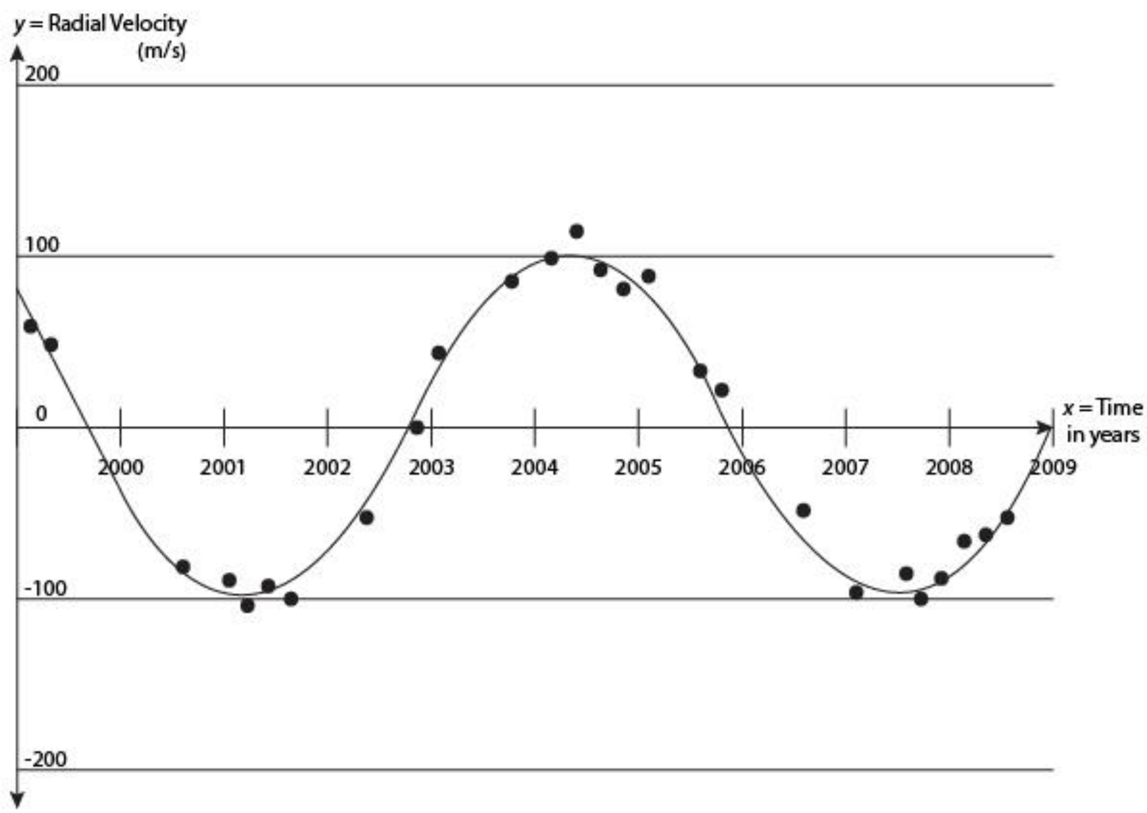
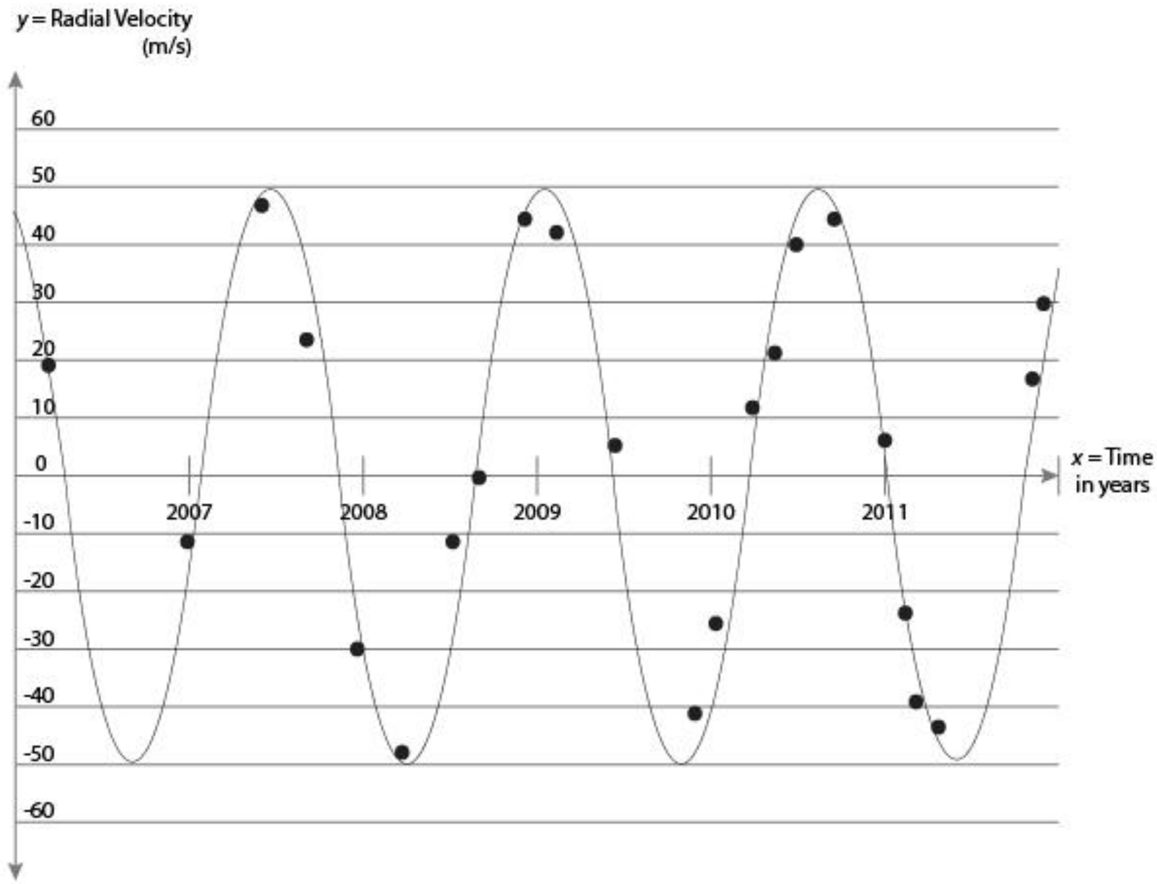


Figure 3 Radial Velocity vs. Time: *Star Y*



Extend:

- Describe two other methods of searching for extra solar planets. What are the pros and cons of each? Which of the methods, including the Doppler shift method, do you think is the most effective? Why?

- Find the Kepler Mission's extrasolar planet discovery table. How many confirmed planets has Kepler found to date? What trends do you see? Describe a few notable discoveries.

- Some of the first exoplanets discovered were those orbiting Tau Bootis and 51 Pegasi. Look into the discoveries. Who found them? When? Often 51 Pegasi is credited as being the first discovered exoplanet, but this is not quite accurate. How would you modify the claim to reflect more accuracy?