Part I: Extrasolar Planet Systems' Properties of Motion & Doppler Shift

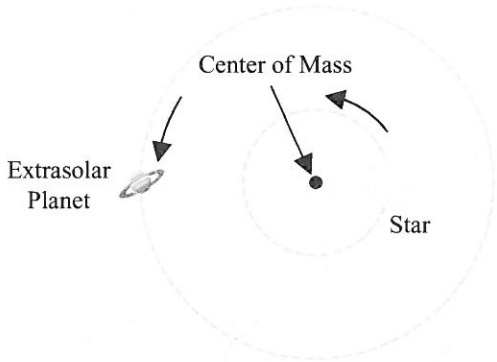

Figure 1. Extrasolar planet and star as seen from above. (not to scale)

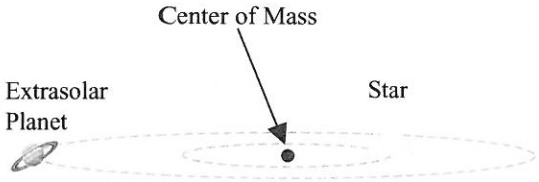

Figure 2. Extrasolar planet and star as seen edge-on or from the side. Note that the extrasolar planet is moving toward you. (not to scale)

Figure 1 and Figure 2 show the orbits of the same extrasolar planet and star from two different points of view.

1) As an extrasolar planet orbits around a star, the gravitational attraction between the two objects causes the star to make a small orbit around the system's center of mass. Which object travels in the largest orbit (*circle one*)?

the extrasolar planet	the star	they both have the same size orbit	you can't determine which has the larger orbit

2) Which object takes a greater amount of time to complete one orbit (*circle one*)?

the extrasolar planet	the star	they both take the same amount of time	you can't determine which takes longer

Explain your reasoning.

3) At the instant shown in Figure 1, which direction is the extrasolar planet moving (*circle one*)?

toward the bottom of the page	toward the top of the page	toward the star

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4) At the instant shown in Figure 1, which direction is the star moving (*circle one*)?

toward the bottom of the page	toward the top of the page	toward the extrasolar planet

5) In general, how does the direction the extrasolar planet is moving compare with the direction the star is moving?

6) Figure 2 shows the extrasolar planet and star from the side or as seen edge-on. At the instant shown, which direction is the planet moving (*circle one*)?

coming out of the page directly toward you	moving into the page directly away from you	toward the central star

7) Two students are having a discussion about the relationship between the movement of the central star and extrasolar planet and the Doppler shift of the light coming from the star.

Student 1: *Since Figure 2 states that the extrasolar planet is moving out of the page, directly toward us, then the light from the star we observe will be blueshifted.*

Student 2: *I disagree, the light from the star will be redshifted because the star is moving in the opposite direction the planet is moving.*

Do you agree or disagree with either or both of the students? Why?

8) Would the light from the star in Figure 1 be blueshifted, redshifted, or not shifted? Explain your reasoning.

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9) Would the light from the star in Figure 2 be blueshifted, redshifted, or not shifted? Explain your reasoning.

10) If you are unable to detect any Doppler shift from a star in an extrasolar planet system, how must this system be oriented with respect to your line of sight? Explain your reasoning and include a drawing to illustrate your answer in the space below.

Continue to next page.

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Part II: Evaluating Extrasolar Planet Systems

The amount that the light from a star in an extrasolar planet system will be Doppler shifted depends on the mass of the star M_{star}, the mass of the planet m_{planet}, and the distance d between the star and the planet. This relationship can be written as:

$$\textit{Amount of Doppler shift in stars's light} \propto \frac{m_{planet}}{\sqrt{M_{star}d}}$$

Figure 3 below shows four different extrasolar planet systems (A–D). Use this figure to answer Questions 11–16.

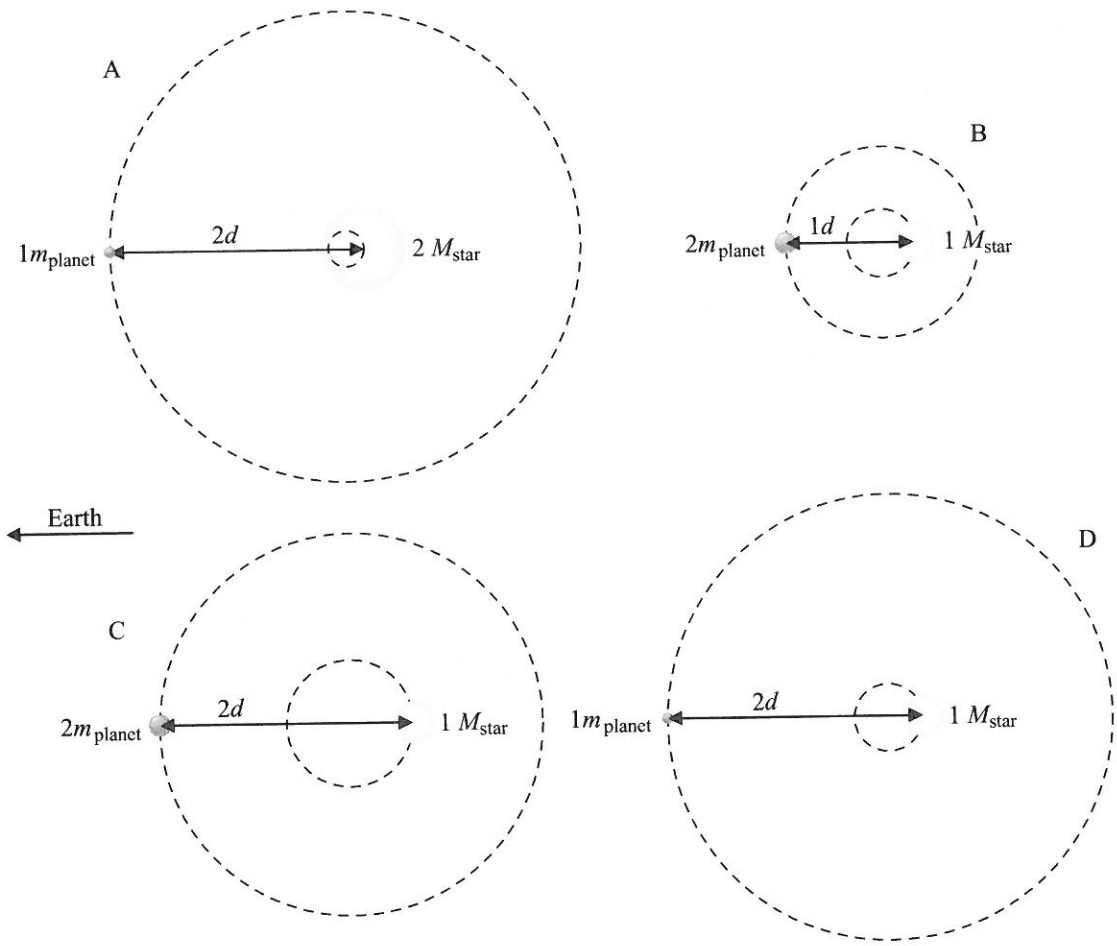

Figure 3

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11) Which extrasolar planet system(s) (A–D) has the lowest mass star?

12) Which extrasolar planet system(s) (A–D) has the highest mass planet?

13) In which extrasolar planet system(s) (A–D) is the planet closest to the star?

14) In which extrasolar planet system(s) (A–D) would we receive light from the star with the largest Doppler shift? Explain your reasoning.

15) Which system (A–D) has the extrasolar planet that is easiest to detect from Earth? Explain your reasoning.

16) Two students are discussing their answers to Questions 14 and 15.

Student 1: *I think Extrasolar Planet System C shows the star with the largest Doppler shift. This is because the star in System C has the largest orbit. This means that this extrasolar planet will be the easiest to detect.*

Student 2: *I don't think that Doppler shift is caused by the size of the star's orbit. To cause a large Doppler shift, you want a low-mass star that is close to a large-mass planet, and that is Extrasolar Planet System B.*

Do you agree or disagree with either or both of the students? Explain your reasoning.

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Figure 4 below shows the graph of four radial velocity curves (E–H) for the four stars in Figure 3. Use these graphs to answer Questions 17 and 18.

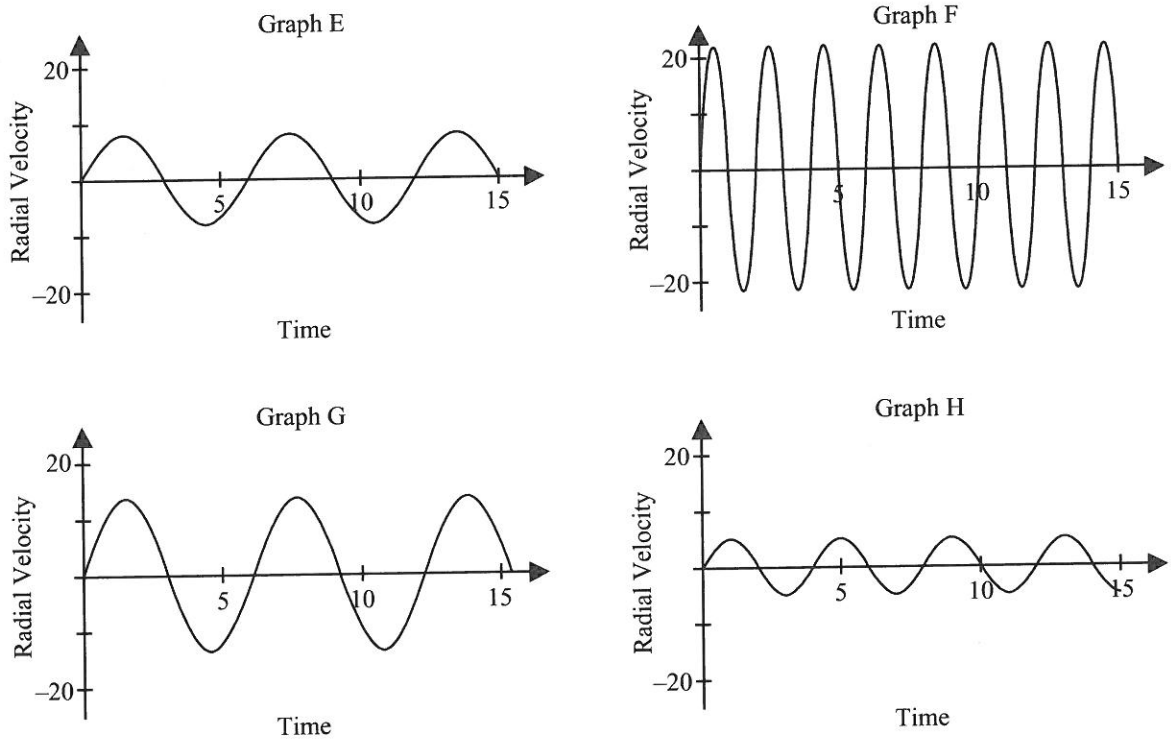

Figure 4

17) Match each graph (E–H) with the extrasolar planet systems (A–D) from Figure 3. Explain your reasoning.

Extrasolar Planet System A:

Extrasolar Planet System B:

Extrasolar Planet System C:

Extrasolar Planet System D:

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18) On the graph (E, F, G, or H) that depicts the largest Doppler shift:

a) draw a circle on the curve at each time that corresponds with the ***star*** moving with its fastest speed toward Earth. Explain your reasoning.

b) draw a triangle on the curve at each time that corresponds with the ***extrasolar planet*** moving with its fastest speed toward Earth. Explain your reasoning.

Use Figure 5 to answer the following question.

19) Given the location marked with the dot on the star's radial velocity curve, at which location (I–L) would you expect the planet to be located at this time? Explain your reasoning.

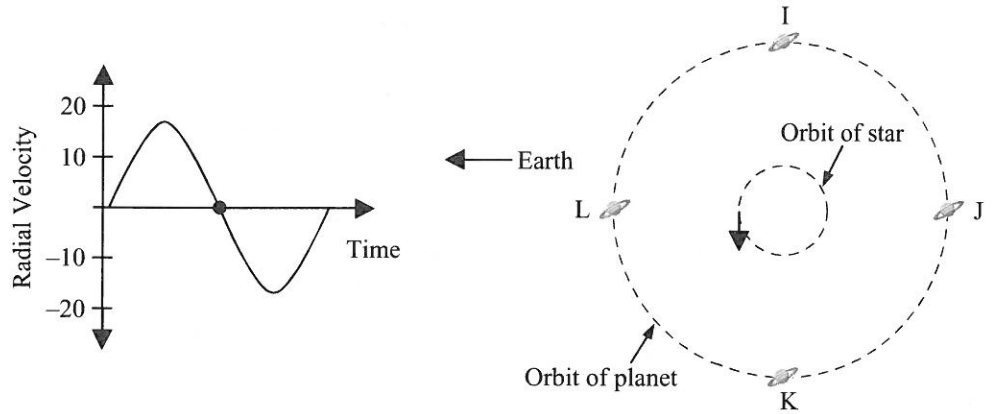

Figure 5

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