Name:
Group Members:

Lab 4

I. The Wobble:

One person here will play the planetary system and the other(s) the observers. Trade off roles at least once so each person in the group has a chance to be an observer.

The planetary system person (PSP) should stand holding a lollipop (representing the planet) at arm's length out to the side with one hand, and holding the paper plate (representing the star) up to their shoulder with the other. Observers should stand 2 or 3 meters away. To model orbital motion, have the PSP turn slowly while the observers answer the following questions:

(A) When the paper plate is moving away from you, is the lollipop moving towards you or away from you?

(A) ____________

(B) When the paper plate is moving towards you, is the lollipop moving towards you or away from you?

(B) ____________

(C) When the lollipop is moving away from you, is the paper plate moving towards you or away from you?

(C) ____________

(D) When the lollipop is moving towards you, is the paper plate moving towards you or away from you?

(D) ____________

(E) In which of the above situations (A-D) would the light from the star be redshifted?

(E) ____________

(F) In which of the above situations (A-D) would the light from the star be blueshifted?

(F) ____________

(G) When viewed from above, both the lollipop and the paper plate are moving in a circle. Which is moving in the larger circle?

(G) ____________

(H) Draw a diagram showing the observers, star, and planet, as well as their paths of motion, as viewed from above. Indicate on the diagram which direction the star and planet are moving.

(I) The observers in your demonstration are said to see the star/planet system "edge-on." Why is that an apt description?

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(J) An observer on the ceiling would see the system "face-on." Why is that description apt?

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(K) Observers viewing a system edge-on will see light from the star alternately redshifted and then blueshifted. Will an observer viewing the system face-on see Doppler shifts? Explain yourself.

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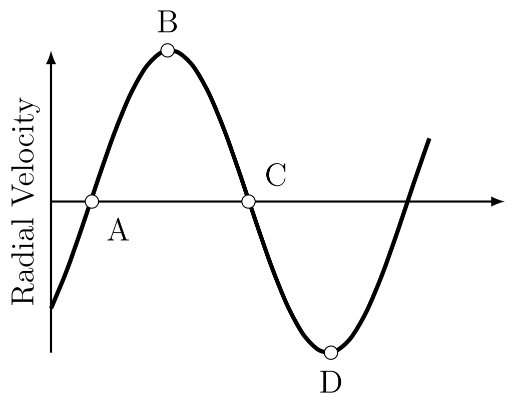
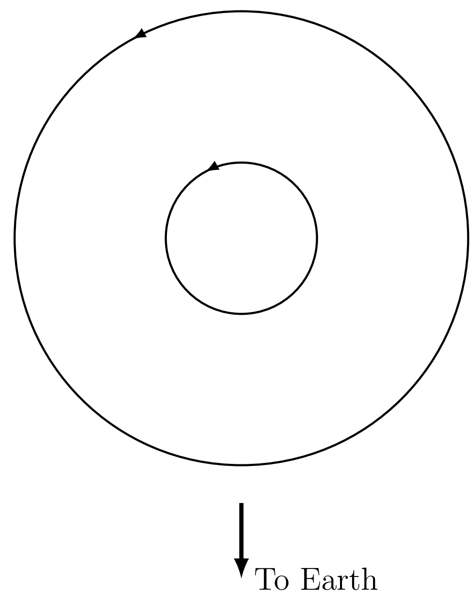
II. **Doppler Shifts and Binary Orbits:**

The image below shows the orbit of a star (inner circle) and a planet (outer circle), as well as the radial velocity curve of the star. A radial velocity curve shows the speed at which the star is moving towards or away from the Earth, with negative velocity corresponding to moving towards the observer and positive velocity to moving away.

The star and the planet orbit counter-clockwise as shown by the arrows, and the observers on Earth are toward the bottom of the diagram.





(A) The four labeled points in the velocity curve correspond to four points on the star's orbit. Draw and label these points on the star's orbit.

(B) On the planet's orbit, label where the planet is at each of these points as well. (Hint: where does the planet need to be if the sun and planet both orbit the center of mass?)

(C) At what point on the curve (A,B,C,D) is the light from the star going to have the greatest redshift?

(C) ____________

(D) At what point on the curve is the light from the star going to have the greatest blueshift?

(D) ____________

(E) How does the orbital period of the planet compare to the time it takes the star to complete one orbit?

(E) ____________

(F) Since you have (or can measure, bust out a ruler!) the radii of both planet and star here, you can do a quick estimate of the planet's mass in terms of the star's mass using the center of mass. (*To be clear, you are measuring the circles on the previous page, where you sketched in the locations of the star and planet.*)If we say the center of mass is at the center, or 0, then:

$$\begin{aligned} x_{cm} &= \frac{M_s R_s - M_p R_p}{M_s + M_p} \leftarrow \text{ def'n of center of mass} \\ 0 &= \frac{M_s R_s - M_p R_p}{M_s + M_p} \\ 0 &= M_s R_s - M_p R_p \leftarrow \text{ use this equation} \end{aligned}$$

Measuring the above orbits, what fraction of the stars mass is the planet? (What is $\frac{M_p}{M_s}$?)

(F) ____________

III. **Radial Velocity Curves:**
Open the Exoplanet Radial Velocity Simulator at `http://astro.unl.edu/naap/esp/animations/radialVelocitySimulator.html`. In the *Presets* box on the right-hand side, select "'Option A" and click *Set*. This shows a system with a 1 solar mass star and a Jupiter mass planet a distance of 1 AU from the star.

(A) What is the orbital period of the system?

(A) ____________

(B) If the star is 1000 times the mass of the planet and the planet is 1 AU from the star, use the same calculation you did in (F) above to find the radius of the star's "wobble." Report your answer in both AU and meters.

____________ AU ____________ m

(C) If you know the distance the star travels in one orbit (Hint: the circumference of a circle is $2\pi r$) and the time it takes to travel that distance, you can figure out its speed. How fast is the star moving in meters per second? Let the units guide you if you are having trouble remembering what to divide by what.

(C) ____________

(D) Move your cursor along the blue radial velocity curve on the graph. What is the peak speed you find along the curve?

(D) ____________

(E) Do your answers from parts (C) and (D) agree? Should they? Explain yourself.

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(F) If the star had an absorption line with a rest wavelength of 600 nm, what is the observed wavelength of the line for an observer on Earth when the star is moving away from the Earth? You are not going to want to round anything here (keep all your decimals)! Recall that:

$$\frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}} = \frac{V}{c}$$

(F) ____________

(G) Now select "'Option D" from the preset box and click set. What is the peak radial velocity you measure now?

(G) ____________

(H) Will the doppler shift in wavelength be more or less than what you calculated in (F) above?

(H) ____________

(I) Why has the doppler method of finding exoplanets mainly been successful in finding large planets orbiting very near their parent star?

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IV. **Planetary Transits:**

Navigate your way to http://astro.unl.edu/naap/esp/animations/transitSimulator.html so that we can now have a look at planetary transits. Select "OGLE-TR-10 b" in the presets box and click *Set*.

(A) What is the mass of this planet?

(A) ____________

(B) What distance is the planet from the star here?

(B) ____________

(C) The plot to the right of the screen shows the normalized flux of light seen from the star. This is 1.0 when all the light from the star is seen and decreases when something blocks it. What fraction of the star's light does the planet *block* when it moves in front of the star?

(C) ____________

(D) The fraction of light blocked by the planet corresponds to the ratio of the planet's area to the star's area. Assuming the star's radius is approximately 1.2 times the radius as the Sun ($R_{Sun} \approx 700\,000\,\text{km}$), what is the radius of your planet in kilometers?

(D) ____________

(E) What planet in the Solar System is nearest to this planets size?

(E) ____________

(F) Is this planet more dense or less dense than Jupiter?

(F) ____________

(G) If an Earth-sized planet with radius of 0.089 times that of Jupiter passed in front of this star, what fraction of light would the planet block?

(G) ____________