BiteScis

Student Handout

# Momentum of Exoplanets

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## Introduction

Okay—so we're interested in planets outside of our solar system (aka **exoplanets**), right? If you follow the news, you probably know we've discovered a lot of them recently, but that's all thanks to recent technological advances. It wasn't until 1995 that we found the first exoplanet! We didn't do that by looking directly for planets, but by observing stars (turns out space is big and planets are not even needles in the haystack, but like, atoms in a haystack). As planets orbit a star, they cause the star to "wobble" as the planet pulls the star towards it as shown in **Figure 1**. From Earth, we can monitor the star's wobble (noting how it moves toward us or away from us) and infer from that the presence of a planet orbiting the star. Neat, right? Well, in this lesson you'll explore how conservation of momentum can be used to help scientists learn about the mass and velocity of exoplanets.

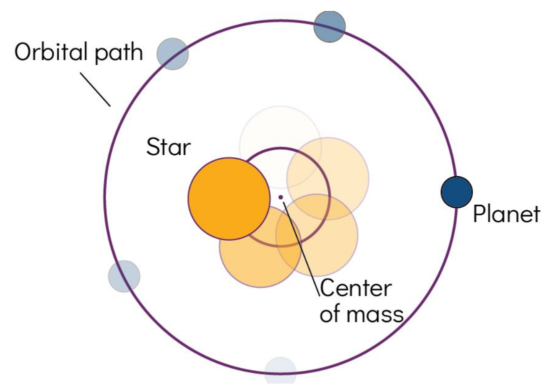



**Figure 1. A Planet Causing a Star to Wobble**. As a planet orbits a star, the force of gravity from the planet causes the star to wobble in a circular pattern around the system's center of mass. *Not to scale.*

## What To Do

Answer the analysis questions below, reading the Bite when instructed.

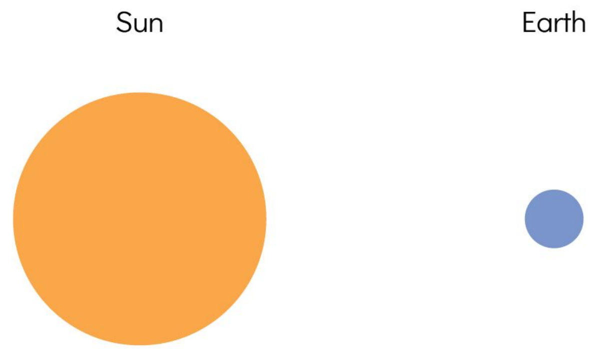
## Analysis Questions

1. Earth causes the sun to wobble, but only a very small amount. To explain this phenomenon, a student writes, "The sun exerts a gravitational force on the Earth and the Earth exerts a gravitational force on the sun, but since the sun is much more massive than Earth, the force from the sun on the Earth is much larger than the force from the Earth on the sun."

   Do you agree or disagree with the student? Explain your answer.

2. Draw the force of the sun on the Earth and the force of the Earth on the sun on the diagram

below (not to scale). Be sure to correctly represent the relative magnitudes and directions of the forces.




**3.** The orbital velocity of the Earth around the sun is about 30,000 m/s. The sun is about 300,000 times more massive than the Earth. Neglecting the presence of other planets or masses, the conservation of momentum guarantees that the sun and Earth will have equal and opposite momentum at any given time as the total momentum of this system is 0 kg • m/s.

**a.** Calculate the orbital velocity of the sun as induced by the gravitational pull of the Earth. Show your work and include units in your answer.

**b.** The planet Jupiter is about 300 times the mass of the Earth. If Jupiter were to suddenly replace the Earth in its orbit, how much higher or lower would the magnitude of the orbital velocity that Jupiter induces on the sun be compared to what Earth induces on the sun?

**4.** The first exoplanet scientists discovered was orbiting a star called 51 Peg. 51 Peg has a mass of $2.208 \times 10^{30}$ kg, while the planet orbiting it has a mass of $8.7336 \times 10^{26}$ kg. Assuming the system consists only of the planet and 51 Peg, if the planet induced a maximum wobble of 50 m/s on 51 Peg, what is the approximate velocity of the planet around 51 Peg?

STOP & read Science Bite:

**Using Wobbly Stars to Discover New Planets**

**5.** Imagine a star system that contains just one star and one planet. At any given instant, is the velocity of the planet in the same direction or opposite direction of the velocity of the star? *Hint: Consider the conversation of momentum—just like the sun and Earth, the total momentum of the system must be 0 kg • m/s.*

**6.** The star discussed in the Bite, HD 3167, has a mass of $1.71 \times 10^{30}$ kg. Scientists were able to determine the masses of the planets orbiting HD 3167 using the methods discussed in the Bite. **Table 1** provides the mass and velocity of two of the planets orbiting HD 3167. Mass and velocity data for the third planet are not available.

| Planet | Mass (kg) | Velocity (m/s) |
|---|---|---|
| HD 3167 b | $5.84 \times 10^{25}$ | 65,400 |
| HD 3167 c | $2.99 \times 10^{25}$ | 206,000 |

**Table 1. The Mass and Velocity of Two Planets Orbiting HD 3167.**

**a.** What is the momentum of HD 3167 b?

**b.** When scientists were measuring the wobble of HD 3167 caused by HD 3167 b, what is the maximum velocity of the wobble that they could expect to measure? *Hint: Simplify your system to just HD 3167 and HD 3167 b and consider conservation of momentum.*

**c.** When scientists were measuring the wobble of HD 3167 caused by HD 3167 c, what is the maximum velocity of the wobble that they could expect to measure?

A student says, “The planet HD 3167 b travels at 65,400 m/s around the star HD 3167. If we consider only HD 3167 b and HD 3167 in our system, the total momentum must be conserved, therefore the star must also have a velocity of 65,400 m/s, but in the opposite direction of the planet.”

**d.** Based on your calculations is the student correct?

**e.** What misconception does the student have?

**7.** **Connect to the Big Question**. In order to develop a better understanding of exoplanets, scientists need to use multiple observations. What types of observations were discussed in the Bite that help us get a more complete picture of an exoplanet? How do you use multiple observations of one object in your everyday life to get a better understanding of the object? Compare how scientists use multiple observations to how we use multiple senses.