Notes for Teachers
Discovery of Extrasolar Planets

This lab assumes that students (1) know about the Doppler shift and Kepler’s third law, (2) know how to find limits and make an X-Y scatter plot on graph paper, and (3) know how to change units. This lab will be challenging for the lower half of the “typical” astronomy 101 population: make sure the students work in small groups.

Answers to Questions

Question 1: (What do you expect to see?) This question is very important and the students should be encouraged to answer at length. “I expect a smooth up-and-down velocity curve that repeats after one orbit” is a good minimum reply. Each sketch should be checked before the students go on.

Graph 1: 51 Peg velocity vs. date.

Graph 2: same, vs. phased date.

Q2: Discuss graph 1. Students may try to force a sine wave through this data anyway (if so, remind them of the “uncertainty” column in the data table), but most will realize that the data isn’t “right” somehow.

Q3: \( a^3 = (4.2\text{days}/365\text{days/yr})^2 \) leads to \( a = 0.051 \text{ A.U.} = 7.6\times10^9 \text{ m} \). The velocity of the planet \( v_{\text{planet}} = \frac{2\pi a}{P} = (2.0\times3.14\times7.6\times10^9 \text{ m})/(4.2 \text{ d} \cdot 86400 \text{ s/d}) = 1.3\times10^5 \text{ m/s} \). The mass of the planet \( m_{\text{planet}} = m_{\text{star}} \cdot v_{\text{star}}/v_{\text{planet}} = (1.99\times10^{30} \text{ kg} \cdot 55 \text{ m/s})/1.3\times10^5 \text{ m/s} = 8.4\times10^{26} \text{ kg} \) where the 55 m/s is up to the student to measure from his or her graph. In Jupiter masses \( m_{\text{planet}} = 0.44 \text{ M}_J \), and in Earth masses, \( m_{\text{planet}} = 141 \text{ M}_E \).

Q4 is a discussion question. The two biggest omissions from this lab are the inclination of the orbit (we really have measured \( m\sin i \)) and the consideration of eccentric orbits.
**Q5**: This data set is slightly incomplete near velocity extremes, so the students will have some variance in their measurements of velocity amplitude and period, around 105 m/s and 1050 days, respectively. For 109 Psc, \( a^3 = (1050 \text{days}/365 \text{days/yr})^2 \) leads to \( a = 2.0 \) A.U. = \( 3.0 \times 10^{11} \) m. The velocity of the planet \( v_{\text{planet}} = 2\pi a/P = (2.0 \times 3.14 \times 3.0 \times 10^{11} \text{m})/(1050 \text{d} \cdot 86400 \text{s/d}) = 2.1 \times 10^4 \) m/s. The mass of the planet \( m_{\text{planet}} = m_{\text{star}} v_{\text{star}}/v_{\text{planet}} = (1.99 \times 10^{30} \text{kg} \cdot 105 \text{m/s})/2.1 \times 10^4 \text{m/s} = 1.0 \times 10^{28} \) kg. In Jupiter masses \( m_{\text{planet}} = 5 \text{M}_J \). (Vogt et al. derive \( m_{\sin i} = 6.35 \) because of the more massive primary, an orbital eccentricity of \( e = 0.12 \), and period of 1072 days.) The discussion part of this question encourages students to compare the two planets they have discovered: 51 Peg’s half-Jupiter-mass planet at \( 1/8^{\text{th}} \) the distance of Mercury versus 109 Psc’s 6-Jupiter-mass planet at 2 A.U.

**Simplifications**: If this lab is too long, the instructor can fill in the phased date column for the 51 Peg data. One can also write a table of \( a \) and \( P \) for Kepler’s third law on the blackboard so that students will not have to find a cube-root. It is important to keep the 109 Psc section as it is: the students learn how it all works from 51 Peg and then apply it to 109 Psc.

**References**:  

**Updates**: The 2001 version of this lab is a “test version” that will be modified according to feedback from users in 2002. Send comments to gworthey@wsu.edu. This and updated versions are or will be available at http://astro.wsu.edu/labs/.