Astronomy C249: Planets
Problem Set #1 (Fall 2017)
Due Friday, September 8 at 5pm

Please indicate the time spent on the assignment and list any collaborators. You can submit the assignment by emailing a single PDF to dressing@berkeley.edu or by placing a hard copy in my mailbox or under my door (Campbell 605E).

Intro to Exoplanets

1. The NASA Exoplanet Archive is a fantastic repository of exoplanet discoveries. Go to the website (https://exoplanetarchive.ipac.caltech.edu/) and perform the following tasks:
    a. Using the "Confirmed Planets" table and sorting by "Year of Discovery", report the number of confirmed planets known today. How does that number compare to the number of confirmed planets known in 2010 when our main textbook was written? Produce a plot of the number of confirmed planets versus time and comment on any noticeable features of the distribution.
    b. Either by using the "Confirmed Planets Plotting Tool" in the tools section of the Nasa Exoplanet Archive or by downloading the "Confirmed Planets" data and writing your own code, produce a plot of planet mass versus planet orbital period. Add the solar system planets for reference. How do the properties of known exoplanets compare to those of the planets in our solar system? How are the planets distributed across mass-period space? Which regions of parameter space are most affected by survey incompleteness? If you were to assign labels to different types of planets, where would you draw boundaries? (Actually draw the boundaries on the plot and assign labels to different types of planets. Be creative.)
    c. Repeat exercise (b) using a plot of planet radius versus orbital period.

2. ***Planetary Systems***
    a. Using the program of your choice, plot the planetary orbits in the following systems. Make one set of plots using the same scale for all systems and another set of zoomed-in plots highlighting the properties of each system.
        i. The Solar System
        ii. 51 Peg
        iii. HD 114762
        iv. HD 209458
        v. HR 8799
        vi. Kepler-36
        vii. PSR 1257+12
        viii. Prox Cen
        ix. ups And
        x. TRAPPIST-1
    b. How do the systems compare?

c. Referring to Section 4 of "Introduction to Exoplanets," which detection methods would be best for finding the planets in each system?
d. Order the systems by host star mass and by visual magnitude. Omit the Solar System. Do you notice any correlations between planetary orbital properties and host star properties? Why might these correlations appear?
e. What do those exoplanetary systems have in common?

Orbits *(problem adapted from Planetary Sciences by de Pater & Lissauer)*

3. Named for Walter Hohmann (1880-1945), a Hohmann transfer orbit is an elliptical orbit that is used to switch from one circular orbit to another circular orbit. The periapse of the Hohmann transfer orbit is tangent to the smaller circular orbit and the apoapse of the Hohmann transfter orbit is tangent to the larger circular orbit.
    a. Calculate the velocity (relative to Earth) at the Earth's orbit of the Hohmann transfer orbit that is tangent to both Earth's orbit and Mars's orbit.
    b. Ignoring the Earth's rotation, calculate the minimum velocity required to launch a spacecraft from the surface of the Earth to Mars.
    c. Assuming that the spacecraft will launch from the Earth's equator, update your answer from (b) to include the Earth's rotation. Ignore the Earth's obliquity.
    d. Calculate the time required for a spacecraft moving along a Hohmann transfer orbit to travel from Earth to Mars.
    e. Repeat these calculations for a spacecraft sent from Earth to Saturn on a Hohmann transfer orbit.
    f. Your friend Mark has been stranded on Mars and asked for baked potato toppings. Would you send the grocery delivery rocket along a Hohmann transfer orbit? Why or why not?
    g. Would your answer change if Mark were stranded on Titan instead of Mars?
    h. How did Mars Reconnaissance Orbiter and Cassini reach their respective destinations? Why were those flight paths selected?

4. Astrometric detection

a. Beginning with Kepler's Laws, derive equation (1) in the "Astrometric Detection and Characterization of Exoplanets" chapter of *Exoplanets*. Include a sketch of the system and label the relevant angles and distances.
b. Using Equation (1), estimate the astrometric signal induced by each of the planets of the Solar System. Which planet is most amenable to astrometric detection? How do the amplitudes of the signals compare to the expected final precision of the *Gaia* mission?
c. Using the parameters in Table 15 of McArthur et al. (2010, ApJ, 715, 1203), produce your own versions of their Figures 9 and 10. On your version of Figure 10, mark the astrometric reflex motion of ups And in 2002, 2003, 2004, 2005, and 2006. (You do not need to add the data points and you may neglect the influence of planet b.)

5. **Direct Imaging**
    a. A colleague has just obtained an image of a star with a possible nearby companion. What tests would you perform to make sure that the putative companion is a substellar object and not a speckle? Assuming that the companion really is a substellar object bound to the target star, how would you determine the physical separation, mass, and age of the companion?
    b. Assuming that Venus, Earth, Jupiter, and Saturn all reflect as Lambert spheres, plot the visible contrast ratios of the Venus/Sun, Earth/Sun, Jupiter/Sun, and Saturn/Sun systems as a function of phase angle.
    c. Treating the Sun and all of the planets as blackbodies, how do the visible contrast ratios you found in part (b) compare to the infrared contrast ratios?
    d. An astronomer on a planet 20 pc away has designed an instrument that can achieve contrasts of 10^{-10} in the optical and 5×10^{-8} in the infrared. The instrument has an inner working angle of $2\lambda/d$ and an outer working angle of $10\lambda/d$. Ignoring the zodiacal light, how large of a telescope would the astronomer need to detect each planet? Would the astronomer need to make any modifications to the instrument to observe all four planets at once at both optical and visible wavelengths?