ASTR 5490 Homework #1

Due Sep. 4th

Learning goals: practice using python to read in data and make quality scientific plots with labels and legends and informative symbols. Become familiar with properties of known exoplanets. Understand and model orbits for 2-body systems, including velocity curves and transit limitations.

Whenever plots and codes are requested in this class, please turn in paper copies of your plots and code with code neatly and abundantly commented to explain your coding. In my box or under my door is fine. In some cases you will find that plotting log(quantity) is more useful than plotting linear quantities. [Careful to not confuse $\log_{10}$ (commonly used by astronomers) in your coding from natural logs (less commonly used...typically only for things like radioactive decays that e-folding properties).] In particular, try to use sensible variable names in calculations where formulas are needed rather than having formulae that appear as a jumble of numbers. This makes your code easier to read and debug!

I do want you to share expertise and help each other while still ensuring that each person can do all of the work that is preparing you to be a practicing scientist.

Please also note the link on the class webpage that contains a useful table of stellar data.

1. Use the **NASA Exoplanet Archive** to download a data table on confirmed exoplanets. Use python read in the table and

- A. Make a plot of planet mass versus semi-major axis. Where the mass is really a lower limit indicated by an Msin(i) measurement, use arrows to indicate lower limits on mass. Color code (or symbol code) the data points by discovery method and include a legend. Write a paragraph interpreting this plot, commenting on apparent clusterings of points or absence of points in certain parts of the diagram.
- B. Make a plot of eccentricity versus semi-major axis. Color code (or symbol code) the data points by discovery method. Comment on trends or features of this plot, providing an interpretation of why the data show these features.
- C. Make a plot of planet mass versus stellar host effective temperature. Again color code by discovery method. Interpret clusterings or features in this plot.
- D. Make a plot of planet mass versus planet radius. Draw lines of constant density on this plot with labels indicating densities of common substances like water or rocks that make up the bulk of the Earth's crust. Use color or symbol size to denote semi-major axis. Comment on the distribution of densities and what it might be telling us about the distribution of planet properties.
- E. Make a histogram of the stellar metallicity of planet hosts. Are planets more or less common around metal-rich or metal-poor stars? Comment on possible biases or reliable conclusions that might be drawn.
- F. Make an additional plot of your choosing from the data that satisfies your curiosity about some other planet properties. Include a discussion of what we learn from your plot.

2. Make a plot of the period of a planet versus planet mass for the data. Using Keplerian physics, overplot lines of constant stellar reflex velocity for the host star. Assume i=90°, a 1 solar mass star, and a circular orbit. Pick v=0.1 m/s and that specifies a certain semi-major axis, and thereby, a certain P for each planet mass in your array. Plot that line. Then do v=1, 10, and 100 m/s. Shade the region of the graph where modern radial-velocity spectrographs could detect a planet and comment how this informs possible biases in detecting planets revealed in #1 above.

3. Transits can only be observed when the inclination of the orbit is sufficiently large. Make a plot of orbital inclination versus semi-major axis. Using geometrical considerations, plot lines that correspond to a minimally detectable grazing transit for a range of planet sizes from Earth-sized to Jupiter-sized. Make one plot for an M0 dwarf (V) host star and one plot for a K0 III (giant) host star. Shade the approximate habitable zone (assume liquid water surface temps) for each star discuss the probability of detecting transits from habitable zone planets. Comment how these geometrical considerations may

bias detection of a planets in plots like those above. Overplot actual planet data, where available, to see if there is evidence of such a bias.

4. Make a plot of a planet's radiative equilibrium temperature versus semi-major axis. Plot a line for a G0V star, an M5V star, an F0V star, and an A0V star. Shade the liquid water habitable zone. Overplot the planets from our solar system to see where they fall, using their actual measured surface temperature values, and comment how close they come to the G2V line.

5. Astrometric motion: Make a plot of the angular shift (i.e., astrometric motion) of a stellar host versus planet mass. Assume the system is observed at $i=0°$ (face-on; or is this assumption not necessary? Argue accordingly). Assume a 1 solar mass host seen at a distance of 100 pc. Draw lines for four selected plant orbital semi-major axes. Shade a region covering the angle that current astrometric missions such as Gaia or ground-based optical interferometers (such as Chara) can resolve.

6. You observe a 1 solar mass host star to have a reflex motion with an amplitude of 100 m/s with a period of 3.0 d. What is the minimum mass of the planet? Solve the quintic equation both analytically by looking up the form of the solution, and solve it numerically by iteration.

7. Create a python program that reproduces the generalized binary orbits of the one shown in class. You need not make a fancy gui (unless you are ambitious and want to develop these skills). Three simple plots will suffice, showing your velocity curve and astrometric orbit alongside the web-based one. Show three combinations of M, a, e, and i that demonstrate your code works as expected. This work will involve solving the Kepler erquation, which you can do by iteration.