Problem Set #3

Due Friday, October 6 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).

1. Planet Compositions

In this problem, you will compare the observed masses and radii of exoplanets to theoretical models to investigate the compositional diversity of planets. Begin by downloading the compositional grid developed by Zeng, Sasselov, & Jacobsen (2016). The grid is posted on Li Zeng's website at `https://www.cfa.harvard.edu/~lzeng/tables/mrtable3.txt`. The file has 44 columns. The first column is the mass of a model planet (in $\mathrm{M}_\oplus$) and the remaining columns are corresponding radius (in $\mathrm{R}_\oplus$) assuming that the planet has the composition described in the column title. (You can read more about the grid on the main page of Li's website at `https://www.cfa.harvard.edu/~lzeng/planetmodels.html`)

a. Using the model tracks you downloaded, generate a diagram showing the mass-radius curves for planets with the following compositions: 100% Fe, 50% Fe, 30%Fe, Rock, 25%H_2O, 100%H_2O, and cold H_2/He.

b. Why aren't these curves simply lines of constant density?

c. Add the Solar System planets to your diagram. How well do the Zeng et al. models describe the actual compositions of these planets? (i.e., are the planets closest to the model tracks that best match their compositions?)

d. Consulting the Confirmed Planets table on the NASA Exoplanet Archive (`https://exoplanetarchive.ipac.caltech.edu/cgi-bin/TblView/nph-tblView?app=ExoTbls&config=planets`), make a second version of your planet composition plot showing all of the exoplanets with both mass and radius estimates. Include the mass and radius errors reported in the table.

e. Write a few sentences describing how the measured masses and radii of the exoplanets compare to the expectations from theoretical models. Which planetary compositions best describe planets of different masses? Are any planets in "forbidden" regions? Why might that be?

f. Use the system properties listed in the table to compute the insulation flux received by each planet. (This value is already reported in the table for some planets). How do the compositions of highly-irradiated planets compare to those of cooler planets? Include a figure illustrating your answer.

2. Disks

a. What are debris disks, primordial disks, transition disks, protoplanetary disks, and circumstellar disks?

b. Sketch the spectral energy distribution for each distinct type of disk. What can astronomers learn about disks from SEDs?

c. Modeling the disk as a thin infinite sheet of mass with surface density Σ, use Gauss' theorem to show that the acceleration outside the sheet is constant with distance:

$$g_{\mathrm{z,disk}} = 2\pi G\Sigma \tag{1}$$

d. Equating your answer to Part (c) with the acceleration due to the vertical component of stellar gravity at $z = h$, find the surface density Σ for which the self-gravity of the disk can be neglected when computing the vertical structure.

e. Rewrite your answer to part (d) in terms of the disk mass $M_{\rm disk}(r)$ enclosed at radius r. (i.e., get rid of Σ)

3. **For Experienced Programmers:** ***Mystery Planet Detected!***

Exciting news! You've been conducting a survey for transiting planets and you just spotted a single transit of a planet in the light curve of one of your target stars. The host star is a mid-M dwarf with $M_\star = 0.157\,{\rm M}_\odot$, $R_\star = 0.211\,{\rm R}_\odot$, and $T_{\rm eff} = 3026$ K. The transit lasted about an hour and the star was 1.3% dimmer during transit.

a. How large is the planet? (State your answer in Earth radii.)

b. Based on the reported transit duration, what is your initial guess for the orbital period of the planet? Upon closer inspection, the impact parameter of the planet appears to be about 0.35. You see no evidence for an eccentric orbit.

c. One of your colleagues has access to a radial velocity spectrograph and took a few observations of the star for you. Download your colleague's data from the course website and plot the observed RVs versus time.

d. Phase-fold the RVs to the orbital period that you guessed in part (b). Do you see any evidence of a planet?

e. Assuming that the planet has a circular orbit, fit the RVs to refine your estimate of the orbital period. You can either write your own code or use the `RadVel` Python package developed by B.J. Fulton and Erik Petigura (`http://radvel.readthedocs.io/en/master/`). If you decide to use `RadVel`, run through the "Example Fit" before attempting to fit the mystery data set. Once you've fit the RVs, make a new version of the plot from part (d). Your new plot should include both the best-fit model and your colleague's RVs.

f. What is the mass of the planet?

g. Which of the compositional models from Problem 1 are most consistent with the measured mass and radius?

h. How much insolation flux does the planet receive? Should you write a press release announcing that you found Earth 2.0? Why or why not? If "Habitable Planet Discovered! Pack Up and Move Today!" isn't an appropriate newspaper headline, provide a more suitable alternative.

4. **Programming-Free Alternative to Problem 3:** ***Highlights from the Literature***

Select one paper from each category and summarize the motivation, methodology, results, and conclusions. Include a representative figure from each paper and write a few sentences explaining how the figure connects to the rest of the paper. Your full answer for each paper should be 1–2 paragraphs. You may summarize up to three additional papers (6 papers total) for extra credit.

a. Pick 1: Agol et al. 2005; Carter 2012; Hadden & Lithwick 2017

b. Pick 1: Seager et al. 2007; Owen & Wu 2013; Lopez & Fortney 2014; Rogers 2015

c. Pick 1: Haisch, Lada, & Lada 2001; Oberg et al. 2011; Andrews et al. 2013; Rosenfeld et al. 2013; Montesinos et al. 2016; MacGregor et al. 2017; Powell et al. 2017