Astr 118, Physics of Planetary Systems
Discussion Week 5: Demographics
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1. Open the Google Colab notebook I emailed out. You'll see a cell that loads in data from the NASA Exoplanet Archive (via a version I prepared on my website, so you don't have to throw out bad data points) into a pandas dataframe. If you haven't used pandas before, you can extract each column as a numpy array and work with those – just make sure you keep the order of your arrays consistent!
   We care about three physical variables in this dataset: period, mass, radius. Some of these planets don't have known masses or radii, but all of them have known periods. It'll probably be useful to log-scale all your scatter plots.
   a. How many planets have been found by each method in total?
   b. Make a plot showing the number of planet detections per year, either as a histogram or the cumulative number over time.
   c. Make the same plot, but restricting to just detections via radial velocity, transits, imaging, and microlensing (each as their own histogram or curve, overplotted). What do you notice?
   d. Which facility (ground- or space-based observatory) has detected the most planets?
   e. Make a scatter plot with period in days on the x-axis and planet radius in Earth radii on the y-axis, with colors or different markers indicating whether the planet was detected by transits, radial velocity, imaging, or microlensing. Add points for Earth and Jupiter (period 11.86 years, radius 11.2 Earth radii).
   f. Repeat with mass in Earth masses on the y-axis. Is there anything substantially different between these two plots?
   g. Make a scatter plot of mass (x) against radius (y), without splitting up by detection type (it's almost all transits). What kinds of planets are we seeing in each region of the graph?
   h. (Bonus) There's a lot of columns in the Exoplanet Archive dataset that I left out. Go onto the Planetary Systems table and identify one parameter you recognize and one you don't. Try and think of a science question you could answer with this dataset (for example, how are detected planets distributed on the sky?) This could be a useful jumping-off point for your project!

2. Imaging planets is challenging because the light from the star is overwhelmingly brighter than the light from the planet. Young planets might glow due to their own thermal emission, but are still about a million times fainter than their star; older planets that don't give off appreciable thermal emission will only be visible due to the reflected light from their star, and they can be more than a billion times fainter. As a result, direct imaging missions usually employ *coronagraphs*: devices to block out the light from stars and only observe planets. One way of describing a coronagraph's efficacy is its *inner working angle* (IWA), the smallest star-planet angular separation at which we can effectively block the starlight. We usually report IWAs in multiples of λ/D, which describes the angular resolution of a telescope with diameter D observing at a wavelength λ.
    a. NIRCam on JWST (in one setting) has an IWA of 6λ/D at a wavelength of 2.1 microns. JWST's diameter is 6.5m. What is its IWA in arcseconds?
    b. If we're observing a planet-star system that's 25 pc away (very close), what is the separation in au of the planet closest to the star we can directly image?
    c. If the star is Sun-like, what is the period of this planet? How close would we have to be to the system to observe an Earth-like planet?

3. The material in disks around stars does not undergo gravitational freefall because of the centrifugal force. Suppose a test particle on a wide (circular) orbit moved radially inwards while maintaining a constant angular momentum. How does the centrifugal force vary with r? Find the critical radius at which the two forces balance.