

## Course 12.425. Problem Set 1. Due 20 Sept. 2007

1. **How long would it take for a spacecraft to get from Earth to the nearest star with an exoplanet?** List any assumptions you made and show your calculation.
2. **Properties of known exoplanets.** From the Extrasolar Planets Encyclopaedia at (<http://exoplanet.eu/>), find the interactive catalog for planet candidates detected by radial velocity (<http://exoplanet.eu/catalog-RV.php>). Construct three different diagrams (either histograms or correlation diagrams). You may use any available parameter for the  $x$  and  $y$  axes (e.g., planet mass, radius, semi-major axis, year of discovery, etc.) Identify any trends that are or are not present. The intention of this exercise is both to update the planet property diagrams presented in Lecture 1 and to explore exoplanet properties not discussed in class.
3. **Exoplanet transit light curves for non-central transits.** See Figures 1 and 2.
  - a. Show that the transit duration for a non-central transit is

$$t_T = \frac{PR_*}{\pi a} \sqrt{\left(1 + \frac{R_p}{R_*}\right)^2 - \left(\frac{a \cos i}{R_*}\right)^2}. \quad (1)$$

Here  $t_T$  is the total transit duration,  $R_*$  is the stellar radius,  $R_p$  is the planet radius,  $a$  is the orbital semi-major axis, and  $i$  is the orbital inclination. Here  $i = 90^\circ$  is "edge on."

- b. Show that the duration of the "flat part" of the transit light curve, i.e. the time when the planet is fully superimposed on the stellar disk, is

$$t_F = \frac{PR_*}{\pi a} \sqrt{\left(1 - \frac{R_p}{R_*}\right)^2 - \left(\frac{a \cos i}{R_*}\right)^2}. \quad (2)$$

- c. Describe why the impact parameter  $b$  is

$$b = \frac{a}{R_*} \cos i. \quad (3)$$

The impact parameter  $b$  is defined as the projected distance between the planet and star centers during midtransit in units of  $R_*$ .

4. **Planet radius, star radius and mass, semi-major axis, and orbital inclination for HD 209458.** For this problem you will estimate  $R_p$ ,  $R_*$ ,  $a$ ,  $i$ , and  $M_*$  from a real exoplanet transit data set. You will need the equations shown in problem 3, as well as the following: Kepler's Law

$$P^2 = \frac{4\pi^2 a^3}{GM_*}; \quad (4)$$

the stellar mass-radius relationship

$$\frac{M_*}{M_\odot} = \left(\frac{R_*}{R_\odot}\right)^x, \quad (5)$$

where  $x$  will be defined below; and the planet-star flux ratio

$$\Delta F = \left(\frac{R_p}{R_*}\right)^2. \quad (6)$$

- a. Download the data for the star-planet system HD 209458 from the MIT Server. Plot the transit light curve: relative intensity vs. phase.
  - b. Average the data into larger time bins. This will make the transit light curve more clear. For example, you could average twenty adjacent points. Describe your method for averaging and approximately what duration your time bins are.
  - c. Estimate  $\Delta F$ ,  $t_T$ ,  $t_F$ . Use  $P = 3.52474859$  days .
  - d. Using the equations in problem 3 and 4, part 4c, and  $x = 2.61$ , derive  $R_p$ ,  $R_*$ ,  $a$ ,  $i$ , and  $M_*$ .
  - e. Estimate or compute the scatter in the data. In other words, by how much do the points deviate from an average value? Describe the method you used.
5. **Planet radius, star radius and mass, semi-major axis, and orbital inclination for GJ 436.**
  - a. through d. as in Problem 4. Use  $P = 2.64385$  days and  $x = 1$ .

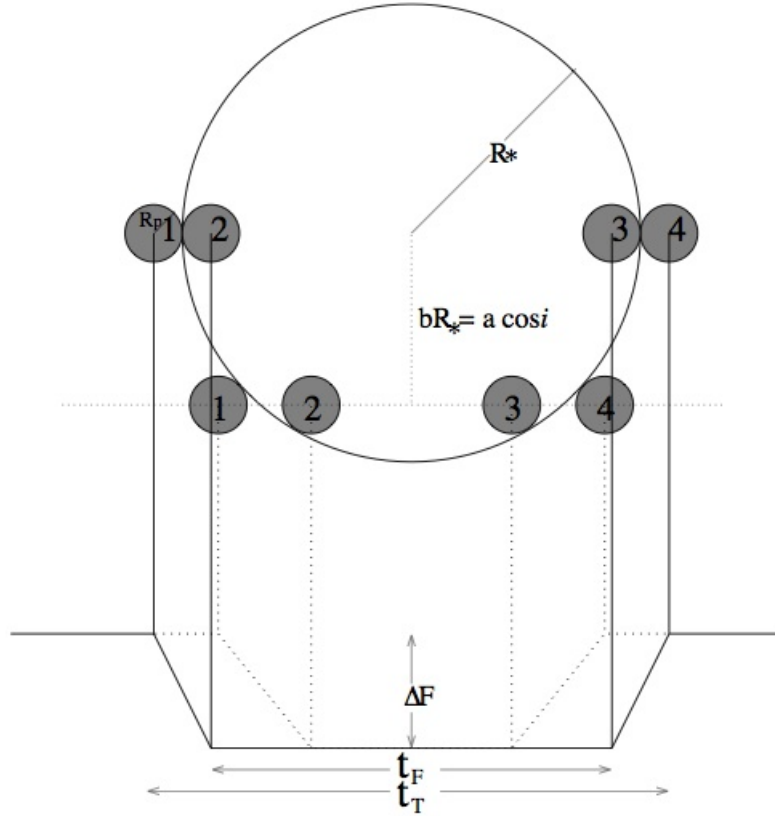


FIG. 1: Definition of transit light-curve observables. Two schematic light curves are shown on the bottom (solid and dotted lines), and the corresponding geometry of the star and planet is shown on the top. Indicated on the solid light curve are the transit depth  $\Delta F$ , the total transit duration  $t_T$ , and the transit duration between ingress and egress  $t_F$  (i.e., the "flat part" of the transit light curve when the planet is fully superimposed on the parent star). First, second, third, and fourth contacts are noted for a planet moving from left to right (not needed for this problem set). Also defined are  $R_*$ ,  $R_p$ , and impact parameter  $b$  corresponding to orbital inclination  $i$ . Different impact parameters  $b$  (or different  $i$ ) will result in different transit shapes, as shown by the transits corresponding to the solid and dotted lines.

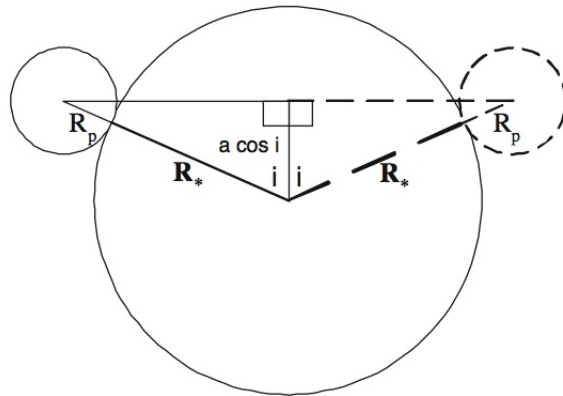


FIG. 2: Transit planet schematic for deriving non-central transit parameters. Note the definition of  $i$  for orbital inclination ( $i = 90^\circ$  corresponds to "edge-on"). Figure from R. Santana.