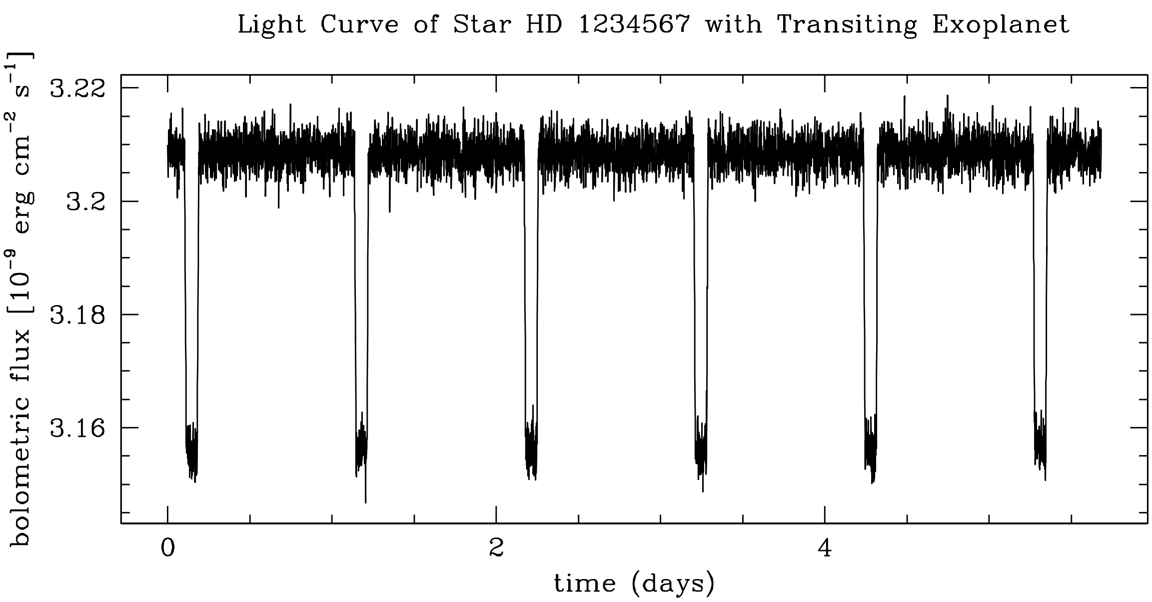
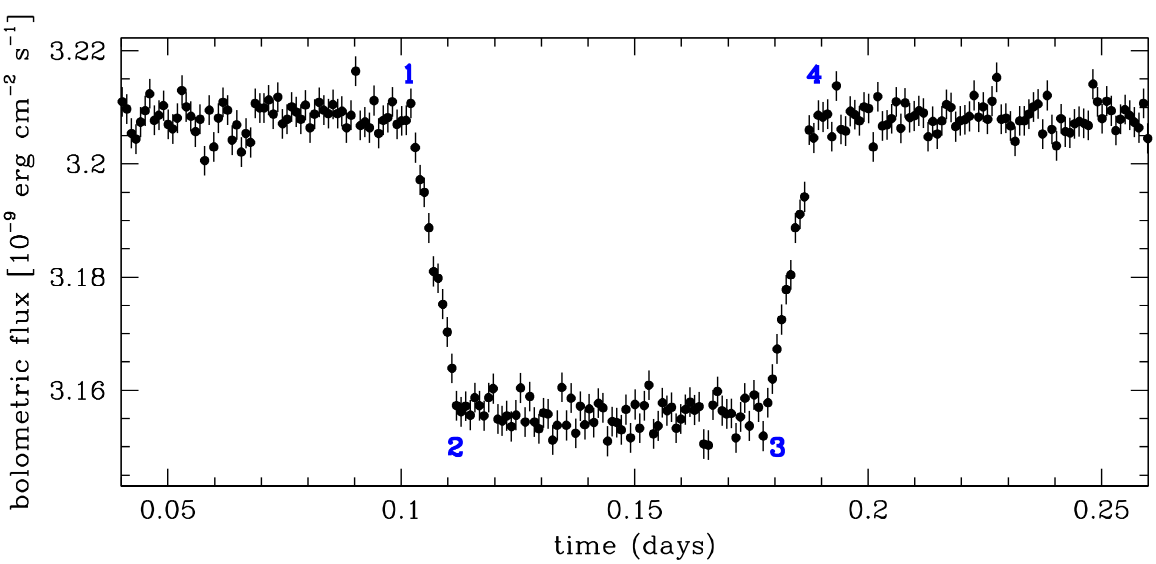
Name: ____________________

ASTR 414 - Astrophysics Laboratory
Transiting Extrasolar Planet

Write all your answers to the questions posed below *neatly* on separate paper. Staple these extra pages to the assignment to hand in.

Below is plotted the measured brightness of a star observed from Earth as an extrasolar planet transits in front of it repeatedly and blocks part of its light. This is a popular method of finding exoplanets (e.g., *Kepler*). You will analyze this system. The top graph shows the entire data set, while the bottom graph shows a magnified view of one transit event. In this magnified view, the 1-σ uncertainties of the flux measurements are shown with error bars, and four key steps during the transit event are indicated with numbers.





1. Make a sketch showing the star, planet, and direction toward Earth, and second sketch showing how the star and planet would appear as seen from Earth if the system could be imaged. On both sketches, indicate clearly where the planet should be in its orbit at each of the four steps indicated on the graph, and why.

2. Measure the time between the start of the first transit event and the start of the second transit event in the first plot. Do the same for other pairs of consecutive events. Take the average of all these times, and the standard deviation of this mean, and report these as the orbit period and its uncertainty in units of days.

3. Measure the duration of the first transit event in the second plot, from time 1 (ingress) to time 4 (egress).

4. Measure the time interval between times 1 and 2 in the second plot. Also measure the time interval between times 3 and 4. Compute the mean of these two time intervals. Describe what is being measured.

5. The star's spectral type is G2V, i.e., a G2-type dwarf on the main sequence. Using a reference book or online resource, estimate the star's radius and bolometric luminosity.

6. Using the measured stellar flux when the planet is *not* transiting and the relation $L = 4\pi d^2 f$, find the distance to the star (ignore Earth atmospheric absorption and interstellar dust extinction). Report this distance in parsecs (1 pc $= 3.0857 \times 10^{16}$ m).

7. What trigonometric parallax in arc seconds would the star have for this distance? Is this easy to measure from the Earth's surface? Explain your answer.

8. Assuming the planetary orbit is (a) circular, (b) significantly larger than the stellar photosphere, and (c) in a plane that includes the line of sight, use the stellar radius and your time measurements to calculate the orbital speed in km/s. Be careful about the exact meaning of the times on the graph!

9. Using the orbital speed and timing data, calculate the planet radius in km. Also express this in units of Earth or Jupiter radii, whichever seems more useful.

10. Using the orbital speed and period, calculate the planetary orbit radius in Astronomical Units (1 AU $= 1.4960 \times 10^8$ km).

11. Use the planetary orbit data to calculate the star's mass. Recall that for a circular orbit, $v = \sqrt{GM/R}$. Check this mass against the mass tabulated for this type of star.

12. Assuming the stellar disk is uniformly bright and the planet does not reflect (or gravitationally lens) any light, use the observed flux during transits vs. the flux outside of transit events to determine what fraction of the stellar disk is blocked by the planet. Calculate the blockage fraction predicted by your earlier estimates of the stellar and planetary sizes, and compare the two results.

13. Use the definition of optical magnitudes ($\Delta m = m_2 - m_1 = -2.5 \log_{10} [f_2/f_1]$) to calculate how much the star's observed magnitude changes during the transit event. How observable do you expect such a change to be with modern telescopes?

14. Using the relation $L = 4\pi d^2 \sigma_{SB} T^4$, where $\sigma_{SB} = 5.671 \times 10^{-5}$ erg s^{-1} cm^{-2} K^{-4}, calculate the thermal equilibrium surface temperature of a perfectly absorbing body facing the star at the planet's orbital radius. Then perform the same calculation assuming half the luminosity to crudely account for planetary rotation. Do either of these results allow for liquid water on the planetary surface (the "Goldilocks condition" for sustaining life)?

15. Terrestrial (rocky) worlds have mean densities of $\langle\rho\rangle \sim 3 - 5$ g cm^{-3}, while ice worlds and gas giants have $\langle\rho\rangle \sim 1 - 2$ g cm^{-3}. Assuming a spherical planet, use this range of densities with the formula for the mean density of a sphere ($\rho = 3M/[4\pi R^3]$) and the radius you found earlier to estimate the likely range of planetary masses consistent with the data. Based on your knowledge of solar system body masses, which type of planet is this one likely to be?

16. Describe how the observed light curve would change if the planet was farther from the star, but all other system parameters were the same. (There are at least two changes.)

17. Describe how the observed light curve would change if the planet was smaller, but all other system parameters were the same. (There are at least two changes.)

18. Do you think this sort of observation is biased toward detecting a certain kind of planetary system? Explain your answer.

19. Describe one simplifying assumption we have made about the transiting planetary system in this analysis, and explain how the the analysis would change if the assumption was not allowed.