

Read the paper “Direct Imaging and Astrometric Discovery of a Superjovian Planet Orbiting an Accelerating Star.” The Supplemental materials are not needed to answer these questions, so while you’ll see them referred to in the main text, they aren’t included in the text of the cume.

- At the end of your exam time, upload your answers to the canvas page.
- There are 59 total points available. A total of 41 points is expected to be a passing grade.
- Use a new page for each question. This makes it much easier to award partial credit for incorrect answers.
- Be careful with your time management. Do not allow yourself to get stuck on any one question. If you find yourself spending a long time at one question without success, move on and come back to it later. In particular I suggest you try to get through all questions inside the first ~90 minutes and then use the remaining ~30 minutes to go back and complete any parts you have skipped.
- Calculators are only to be used for calculations. You may not store equations.
- You may not use your cell phone at any time. You may not use the internet. You may not consult any notes from classes.
- Show all work for full points. Attempt all parts of all questions.
- Some questions require a value obtained from a previous question. If you don’t know how to compute the answer from the previous question, start the new question by assuming a reasonable value for that answer.

Some useful constants:

$$M_{Sun} = 1.99 \times 10^{33} g$$

$$M_{Jup} = 1.89 \times 10^{30} g$$

$$1 AU = 1.50 \times 10^{13} cm$$

$$1 pc = 3.09 \times 10^{18} cm$$

$$R_{Sun} = 6.96 \times 10^{10} cm$$

1) [10 pts total] This paper describes the discovery and characterization of the exoplanet HIP 99770 b

a) [5 pts] In 3-5 sentences, describe how this exoplanet was discovered. What observational techniques were used, and how did analyzing the data confirm this was a planet?

b) [5 pts] The canonical boundary between giant planets and brown dwarfs is 13 Jupiter masses, but this paper claims that the 16 Jupiter mass HIP 99770 b is a planet, not a brown dwarf. In 3-5 sentences explain what criterion for exoplanets this paper advocates for instead, and why HIP 99770 b is a planet under their definition.

hint: for the following problems, you'll find the values in Table 1 helpful. For each numerical problem below you can take the value in the table for your calculations, and ignore error bars. For example, while the distance is given to be 40.74 +/- 0.15 pc, you can take the distance to be 40.74 pc in your calculations.

2) [4 pts] What is the expected orbital period (in years) of HIP 99770 b?

3) [13 pts total] Astrometry plays a big part in this paper, so let's figure out what size signals we're talking about.

3a) [6 pts] What is the semi-major axis of the star HIP 99770's orbit around its common center of mass with the exoplanet, in AU? In milli-arcseconds?

3b) [3 pts] The mass of the primary star HIP 99770 in Table 1 came from stellar models. If it turns out that modeling work was incorrect, and the star is really twice as massive as the authors thought, would that change their mass estimate for the planet? If so, would the derived planet mass get larger or smaller? Why?

3c) [4 pts] HIP 99770 has a planet orbiting it. Describe qualitatively how this fact can be useful to directly measure the mass of the star HIP 99770 at some point in the future. Write down the equation you would use for this calculation.

4) [12 pts total] Transits

4a) [5 pts] What is the radius of the star HIP 99770, in solar radii? (hint: the radius is not given in Table 1, but you can calculate it from values in Table 1)

4b) [5 pts] If HIP 99770 b transited its star, HIP 99770, how long would a transit last, in hours? (You can assume the orbit is circular for this problem)

4c) [2 pts] Given the values in Table 1, do we expect HIP 99770 b to transit its star? Why or why not?

5) [5 pts total] The paper works hard to find the age of the primary star, and makes this statement: "Masses inferred from luminosity evolution are consistent with the planet's dynamical mass if the system is ~80–200 Myr old" (paragraph 6, Analysis)

5a) [3 pts] Why is the age of the star so important when directly imaging planets from the ground?

5b) [2 pts] There have been cases where initial age estimates of stars have been very wrong, and a star that was assumed to be young turns out to be 5 Gyr. That won't be the case here for HIP 99770, which is definitely not as old as 5 Gyr. Why not?

6) [8 pts total] Spectra

6a) [4 pts] CHARIS is an integral field spectrograph, and while the paper describes it as “low-resolution,” it does not quote a spectral resolution, (also called “resolving power” or R). From Figure 4, what is the unitless spectral resolution of CHARIS (to the precision to which you can read values off a plot)?

6b) [4 pts] The top panel of Figure 4 shows the spectrum of the exoplanet HIP 99770 b, and identifies water absorption features. If this same exoplanet were to be observed with a spectrograph with a much higher spectral resolution than CHARIS, how (qualitatively) would the spectrum appear different, and why? Specifically, what’s happening at the quantum mechanics level to cause these features?

7) [7 pts total] Luminosity

7a) [2 pts] What is the ratio of the planet’s luminosity to the star’s luminosity?

7b) [5 pts] Table 1 gives the predicted contrast ratio (brightness difference between star and planet) at 575, 660, and 730 nm. Are those values similar to what you found in 7a? Why or why not?