

Instructions

A hearty welcome to Cume #451! This exam will address subjects related to extragalactic astronomy and cosmology. It makes frequent reference to the Letter “Lensing From $z \geq 6$ Proximity Zones” (Davies et al. 2020).

- You will need a calculator, but not a fancy one.
- There are twelve questions and 49 total points are possible. A score of 37 points is a guaranteed pass.
- Please show all work and use a nice new piece of paper for each section or problem.
- If the exam asks you to obtain a number from the article, then please indicate the number that you obtain and where you obtained it from.
- Be very explicit. For example, if you need to invoke the concept of a “critical density”, don’t just use that phrase, write down what it actually means.
- If you get stuck on a problem whose answer is important for a subsequent problem, please just introduce a variable or an assumption explicitly and then continue.

Here are some constants. For the most part, you won’t need them.

$$\begin{aligned}\rho_c &= \frac{H_0^2}{(8/3)\pi G} \\ G &= 6.672 \times 10^{-8} \text{ cm}^3 \text{ g}^{-1} \text{ s}^{-2} \\ c &= 2.99792458 \times 10^{10} \text{ cm/s} \\ H &= 100h \text{ km s}^{-1} \text{ Mpc}^{-1} \\ \text{Mpc} &= 3.0855 \times 10^{24} \text{ cm} \\ \pi &= 3.14159265359 \\ M_\odot &= 1.989 \times 10^{33} \text{ g} \\ R_\odot &= 6.96 \times 10^{10} \text{ cm} \\ \text{year} &= 3.156 \times 10^7 \text{ s}\end{aligned}$$

1 Synopsis

1. (4 points) (Comprehension: **what** and **why**) In fewer than three sentences, please describe what question the research in Davies et al. 2020 is *trying* to address *as well as* the scientific motivation for addressing that question. (Note that your answer must have two parts.)
2. (5 points) (Comprehension: **how**) In three to five sentences, please explain their method. Be sure to address what they do at the nuts-and-bolts level as well as how this addresses the question identified above.

2 General Background

3. (4 points) (Knowledge) What is strong lensing? Please accompany your explanation with a sketch.
4. (5 points) (Knowledge) The bottom left panel of Figure 1 indicates distance in units of “proper Mpc.” What is the difference between proper and comoving Mpc? Why is it necessary to distinguish between these two ways of stating a distance? (Note: if you understand the difference but can’t remember which is which, just guess! Partial credit will be awarded for knowing the concept.)
5. (4 points) (Application) Estimate the size of the proximity zone in front of SDSS J0100+2802 in comoving Mpc. Clearly state any numbers that you adopt from the paper.

3 The Impact of Lensing

This paper involves assessing the impact of strong lensing on the apparent luminosities of two high-redshift quasars. Let's think about how strong lensing might impact the shape of the quasar luminosity function. Suppose that the intrinsic number of quasars per luminosity interval per volume is $dN/dL/dV = (L/L_0)^{-\alpha}$ where L_0 is some characteristic luminosity and α is some slope. Suppose further that a fraction f of all quasars are strongly magnified by a factor μ ; that is, the flux that we measure from Earth is μ times larger than it would be if the quasars were not magnified.

6. (2 points) (Application) What is the luminosity function of the just the subset of quasars that are not lensed?
7. (4 points) (Application) What is the luminosity function of the *lensed* quasar population? (*Hint:* The abundance of *strongly lensed* galaxies with apparent luminosity L is f times the abundance of galaxies with *intrinsic luminosity* L/μ .)
8. (4 points) (Application) Sum the two contributions above and simplify to obtain an expression for the total apparent luminosity function.
9. (4 points) (Synthesis) Describe in words how the apparent luminosity function that you derived in the previous problem differs from the intrinsic one. Please address both how the *shape* and the *normalization* of the new luminosity function compare to the intrinsic one. (If you encountered trouble with any of #6–8, you may choose one where you did obtain an answer and compare that one instead.)

4 Proximity Zones

Let's compute the size of a quasar's proximity zone. Suppose that a quasar has a total ionizing luminosity L in units of photons per second and it is embedded in an initially-neutral medium with a (proper) hydrogen number density of n . At $t = 0$ the quasar "turns on."

10. (4 points) (Application) What is the radius R of the ionized region at time t if we neglect recombinations? There is no need to derive a number here; just give an algebraic expression.
11. (5 points) (Analysis + Synthesis) It is not possible to know whether the intergalactic medium surrounding the quasar really was completely neutral before the quasar turned on. It might have been, or it might have been completely ionized, or anywhere in between! Explain how this uncertainty translates into uncertainty in the luminosity as inferred from measurements of the proximity zone. Then, suggest how this uncertainty can be addressed observationally.
12. (4 points) (Comprehension) The paper by Davies *et al.* makes frequent reference to a degeneracy between quasar lifetime and luminosity. What does that mean?