Instructions

A hearty welcome to Cume #455! This exam will address subjects related to extragalactic astronomy, galaxy formation, and cosmology. It makes frequent reference to the paper, "Normal, Dust-Obscured Galaxies in the Epoch of Reionization."

- There are 13 questions and 52 total points are possible. A score of 39 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 paper, then please indicate the number that you obtained 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 cannot obtain an answer to one question that is necessary for a subsequent question, just assume something for the upstream problem and then move on.
- Please let me know if you're hopelessly stuck; I may be able to help.

$$\begin{aligned} G &= 6.672 \times 10^{-8}\,\mathrm{cm^3 g^{-1} s^{-2}} \\ c &= 2.99792458 \times 10^{10}\,\mathrm{cm/s} \\ H &= 100h\,\mathrm{km\ s^{-1} Mpc^{-1}} \\ \mathrm{Mpc} &= 3.0855 \times 10^{24}\mathrm{cm} \\ \pi &= 3.14159265359 \\ M_\odot &= 1.989 \times 10^{33}\mathrm{g} \end{aligned}$$

Schmidt-Kennicutt Law (Kennicutt+1998):

$$\Sigma_{\mathrm{SFR}} = 2.5 \times 10^{-4} (\Sigma_{\mathrm{gas}}/M_\odot \mathrm{pc}^{-2})^{1.4} M_\odot \mathrm{yr}^{-1} \mathrm{kpc}^{-2}$$

1 Cosmology

1. (4 points) Suppose that a monochromatic luminous source is receding from an observer in an inertial reference frame at a speed $v \ll c$. Derive the relationship between the wavelength at which the light is observed λ_{obs} and the intrinsic wavelength λ_0. You should find that the light from the source is observed at a wavelength that is redshifted by the ratio

$$\frac{\lambda_{\mathrm{obs}} - \lambda_0}{\lambda_0} = v/c.$$

2. (4 points) In cosmological applications, one usually quantifies this redshift as

$$z \equiv \frac{\lambda_{\mathrm{obs}}}{\lambda_0} - 1$$

   Using the measured redshift of REBELS-12 from Table 1, what is its recession velocity v? Hint: (Combine the definition of z with the result from Problem 1.)

3. (4 points) You should have found that $v > c$. Explain in 1–2 sentences why this is not a violation of Special Relativity.

4. (4 points) If you were an observer at $z = 1$ studying REBELS-12, what would you measure its redshift to be?

5. (4 points) Review Section F of the Appendix. In 2–3 sentences of your own words, what is the authors' argument that the newly-discovered sources are physically associated with REBELS targets?

6. (3 points) In the second-to-last paragraph of page 4, the authors provide an initial estimate of the cosmic star formation rate density by dividing the total star formation rates from the newly-discovered, dust-obscured galaxies by the total survey volume in the REBELS survey. In 2–3 sentences, what is potentially wrong with this particular estimate?

7. (4 points) The general shape of the star formation density curves in Figure 3 all involve a peak around $z = 2$, when the Universe was only 3 Gyr old. Name and describe in 1–2 sentences each *two* effects that could lead the Universe's star formation rate density to decline at later times.

2 The Schmidt-Kennicutt Law

Let's use the information in Figure 1 along with Appendix E to estimate the star formation rate of REBELS-12-2 using the Schmidt-Kennicutt Law. Remember that, if you can't solve any of the next few problems, you may *assume* an answer and then use that one downstream.

8. (3 points) Compute the object's proper surface area in kpc^2.

9. (4 points) Compute its gas surface density Σ_{gas} in units of **solar masses per square parsec**.

10. (4 points) Use the Schmidt-Kennicutt law (given above) to compute its star formation rate surface density in **solar masses per year per square kiloparsec**.

11. (4 points) Compute the star formation rate of REBELS-12-2. Locate the reported star formation rate given in Table 1 of the paper and comment on whether your estimate agrees with it (spoiler: they won't agree perfectly).

3 Dust

12. (5 points) Name and describe in 2–4 sentences one assumption that must be made in order to relate a galaxy's dust continuum emission to its star formation rate (there are many).

13. (5 points) The authors advocate strongly for an unbiased survey for more dust-obscured galaxies. However, it is also very clear that the observed sample of dust-obscured galaxies is very poorly-understood. Suppose that the authors could *either* apply for further or deeper measurements of the current objects, *or* plan a blind survey. Which approach do you think would be more useful? Please describe at least two separate arguments in support of your preferred approach.