

Cume #474
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Welcome to your Thanksgiving appetizer cume! You will have received the corresponding paper, [Das et al. \(2023\)](#) prior to receiving this exam. Herein, you will find questions on that paper and related topics.

There are 13 questions/subquestions with 43 points possible. A score of 30 points or more will warrant an automatic pass.

In reading the paper, I do not suggest that you read it linearly from front to back. First, focus most on the main text and not the Appendices. For this particular paper, I might suggest reading the Abstract; peruse the figures and read the captions, keeping an eye out for which figures might include key results highlighted in the Abstract; read Section 1; read Section 4; skim Section 2 without getting too bogged down in the equations; and then focus on Section 3.

As a reminder, references beyond this paper, notes, or communication (other than with me) are NOT permitted during this exam. **Online resources, including AI-driven tools such as ChatGPT, are strictly forbidden.** You are permitted to use the basic functions of a calculator, i.e., not graphing or information stored prior to the exam. If you need a calculator that is not on your phone, please ask to borrow one; we have them available and phones should be turned off and put away during the exam.

Please make sure your writing is legible. As a general rule, I try to assign partial credit for good efforts, but I *cannot if the writing is illegible*. Also, please show all the work and attempt each problem, showing your thought process even if you can't solve it completely. Note that most questions have multiple parts, so make sure you answer the entire problem.

If anything needs clarification, please drop by my office in AY 205 or email me (jnb@nmsu.edu).

Possibly relevant information:

$$k_B = 8.6 \times 10^{-5} \text{ eV/K} = 1.38 \times 10^{-16} \text{ erg / K}$$

$$m_p = 1.673 \times 10^{-24} \text{ g}$$

$$M_\odot = 1.988 \times 10^{30} \text{ kg}$$

$$G = 6.674 \times 10^{-11} \text{ m}^3 / (\text{kg s}^2)$$

$$1 \text{ pc} = 3.08 \times 10^{16} \text{ m}$$

1) This paper attempts to measure the thermal Sunyaev-Zel'dovich effect. In 1-2 sentences *plus* a drawing, describe what is meant by thermal Sunyaev-Zel'dovich effect *without* using the phrase 'inverse Compton scattering'. (4 pts)

2. The measurements herein employ stacking techniques to measure the Compton y parameter.

2a) In what situations is it useful to 'stack' data (in 1-2 sentences)? (2 pts)

2b) Describe, in 1-2 sentences, one method of stacking either used in this paper or in another work you are familiar with. (2 pts)

2c) Das et al. use a sample of galaxies with photometric redshifts for their stacking experiment. What is a typical error on z_{phot} and how (qualitatively) do errors in z_{phot} impact the stacking experiment results? (Hint: What happens if z_{phot} is an overestimate? What about an underestimate?) (5 pts)

2d) The angular diameter distance may be approximated as follows:

$$d_A \approx \frac{c}{H_0} z \left(1 - \frac{3 + q_0}{2} z \right)$$

Where $q_0 = \Omega_{r,0} + \frac{1}{2}\Omega_{m,0} - \Omega_{\Lambda,0}$.

Given your typical error quoted for part (c) above, what would be the corresponding error in angular diameter distance at the median redshift (see Figure 3) of their galaxy sample? You may use either concordant cosmological parameters or those adopted and provided in the paper. (5 pts)

2e) How might the results shown in Figure 5 be affected by such errors? Hint: one approach might be to calculate the angular diameter distance and then the fractional error. (3 pts)

3a) Referring to the authors' main conclusions in Section 4, in which panel of which figure can we see the corresponding data leading to their Conclusion 2 (deviation from self-similarity)? Describe specifically what we should look for to see the result described, such as points at particular values and the data included on the plot for comparison. (3 pts)

3b) Referring to the authors' main conclusions in Section 4, in which panel of which figure can we see the corresponding data leading to their Conclusion 3? Describe specifically what we should look for to see the result described, such as points at particular values and data included on the plot for comparison. Note that two results are described here: 1) the baryon-sufficiency of certain galaxies and 2) a nonmonotonic trend. (3 pts)

4) Focusing now on Figure 7, the authors report a 'nonmonotonic behavior' of baryon fraction as function of stellar mass. What is your assessment of the robustness of this claim? (3 pts)

5a) If you were trying to build upon this study, what different observational datasets would you desire to improve upon its results, e.g., the parameter space covered or the significance of certain measurements? Note, you don't have to name particular surveys, just the salient desired features

of the datasets and, importantly, how they translate to better measurements of the tSZ effect (i.e., looking for a bit more precise language here than occurs in the last paragraph of the paper). (4 pts)

5b) The authors mention angular resolution of the SZ map as an important attribute of the mm-wave data. What angular resolution (in arcsec) would be desired to have multiple (say 3) sampling bins within R_{200} of a galaxy in the lowest mass bin from the Das et al. study? Note that Table 1 lists the R_{200} for each mass bin, and you can use your angular diameter distance from Question 2e. (4 pts)

6. The concept of ‘baryon sufficiency’ is somewhat subjective, and researchers from different communities have come to different conclusions about what baryon content might be deemed ‘sufficient’.

6a) What is meant by ‘baryon sufficiency’ in the context of this Das et al. 2023 study? Please include both what components ‘baryons’ comprises here and what makes them ‘sufficient’. (2 pts)

6b) What is the virial temperature (see Equation 10b) corresponding to the mass bin with the peak baryon fraction in Figure 7? Assume values for the physical constants as given above and mean molecular mass $\mu = 1.3$ for ionized, metal-enriched gas. (3 pts)

6c) Observational studies using ultraviolet spectra of background quasars have reported detections of Mg II and H I around equally massive galaxies. What are the implications of these observations? What potential tensions would arise with the results and conclusions presented by Das et al. 2023? (4 pts)