Cume #467

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Welcome to the second cume of 2023! You will have received the corresponding paper, Masterson et al. (2023) prior to the receiving this exam. Herein, you will find questions on that paper and related topics.

There are 15 questions with 42 points possible. A score of 29 points or more will warrant an automatic pass.

As a reminder, references beyond this paper, notes, or communication (other than with me) are NOT permitted during this exam. You are permitted to use the basic functions of a calculator, i.e., not graphing or information stored prior to 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 work and do 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 email me (jnb@nmsu.edu).

Possibly relevant information:

$M_{sun} = 1.988 \times 10^{30}$ kg
$G = 6.674 \times 10^{-11}$ m^3 / (kg s^2)
1 pc = 3.08×10^{16} m
$k_B = 8.6 \times 10^{-5}$ eV/K

1. The title of this paper begins 'Evidence for AGN-Regulated Cooling…'. What, ultimately, is being regulated by the AGN? (2 pts)

2. Observations in three distinct wavelength regimes are employed in this study and, combined, yield the author's claimed evidence.

2a. What are the three wavelength regimes? (3 pts)

2b. In each regime, what facilities provide the observations? (2 pts)

2c. What phenomenon is studied in each wavelength regime? (3 pts)

3. Fun fact: Cool-core clusters were once commonly known as 'cooling flow clusters' before the now-preferred 'cool-core' label.

3a. What are the main characteristics of a cool-core cluster? (2 pts)

3b. Why might 'cooling flow' not be the best name for clusters with cool-core characteristics? (2 pts)

4. A major strength of *Chandra* over, say, *XMM-Newton* is its spatial resolution. Referring to the left panel of Figure 1, why might this strength of *Chandra* be important for this study. Notice the red 'dots' throughout the image. (2 pts)

5. The star formation rate of the brightest cluster galaxy in this analysis is measured from the [O II] line doublet flux (rest-frame wavelength ~3727.6 Angstrom).

5a. The authors quote two potential redshifts for the SPT-CL J0607-4448 cluster as z = 1.401 and z ~ 1.48. At what observed wavelengths would the [O II] doublet fall at each of these redshifts? (2 pts)

5b. The top panel of Figure 5 shows a portion of the BCG's optical spectrum taken with Magellan. Try to ignore the fitted curves in red and blue/green for a bit; focus on the points labeled 'data'. Make your own sketch of the spectrum including *just the data*. In other words, imagine you were 'connecting the dots' from data point to data point. Be sure to label the axes. (3 pts)

5c. Mark the two observed wavelengths you calculated above. (2 pts)

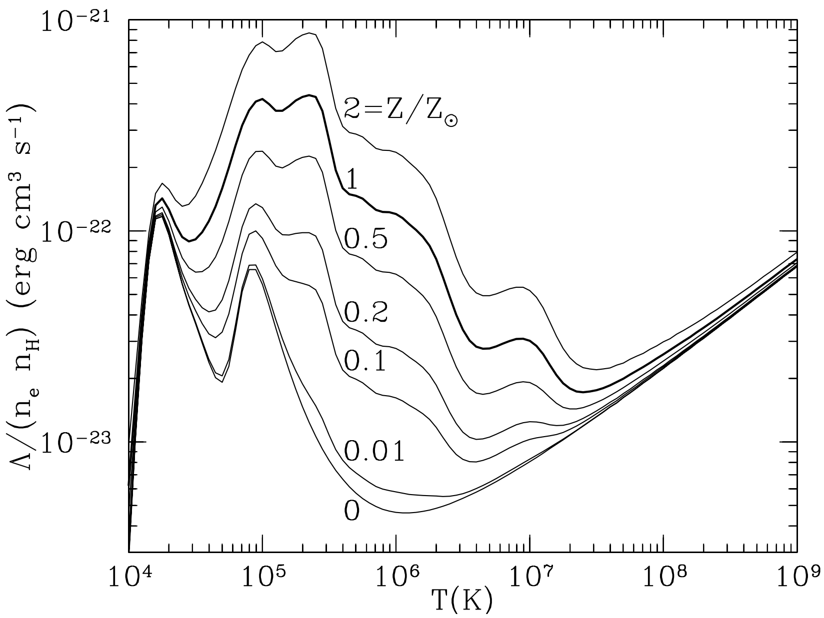
5d. Trying again to ignore where the authors fitted the emission, if you were trying to identify the [O II] emission feature in the spectrum by eye, where would you place it? Does your placement agree with the identification shown by the red curves in Figure 5? In 1-2 sentences, please summarize how your independent analysis either agrees or doesn't agree with the authors'. (4 pts)

5e. If the feature identified as [O II] by the authors were incorrect, how much might this affect the inferred star formation rate of the BCG? Would this impact the main conclusion of the paper? Why or why not? (3 pts)

6. Table 2 summarizes the key observed properties of the BCG and intra-cluster medium (note that the first column's heading incorrectly states that these are just BCG properties) that together lead to the main conclusions of this study. Quoting these measurements, summarize the paper's conclusions in 2-3 sentences. Your summary should address the AGN's activity, what's happening in the ICM, and what's happening in the BCG. (4 pts)

7. Equation 7 shows an expression for the cooling time that includes $\Lambda(\mathrm{T, Z})$, the cooling function. The figure below shows cooling functions for a range of metallicities from primordial (Z = 0) to Z = 2 $Z_{\odot}$. The authors cannot get a reliable metallicity measurement for this cluster, so they assume a metallicity Z = 0.3 $Z_{\odot}$, which is a typical metallicity for more nearby clusters. It is reasonable to posit that at higher redshift, the ICM would be less metal enriched than at z~0.

Equation 7: $$t_{cool} = \frac{3\,(n_e + n_H)\,k_B\,T}{2\,n_e\,n_H\,\Lambda(\mathrm{T,Z})}$$



Cooling functions for gas in collisional ionization equilibrium.
Adapted from "Physics of the Interstellar and Intergalactic Medium" by Bruce T. Draine.

7a. Let's assume that Z = 0.3 $Z_\odot$ is a gross overestimate and that the correct metallicity is closer to Z = 0.01 $Z_\odot$, by how much would the cooling time change? Does this endanger the main conclusions of the paper? Why or why not? (5 pts)

7b. How would you summarize this study's sensitivity to metallicity? What cooling processes are responsible (e.g., metal lines, free-free emission, synchrotron radiation, Compton cooling, convection, etc.)? (3 pts)