

HAPPY HALLOWEEN! IT'S TIME FOR CUME #446, MWAHAHAHAHA...

You will have received the corresponding paper, Juranova et al. (2020) 30 minutes prior to the receiving this exam. Herein, you will find questions on that paper and related topics.

There are 12 questions/subquestions with 39 points possible. A score of 30 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.

Possibly relevant information:

$$\begin{aligned}m_p &= 1.673 \times 10^{-24} \text{ g} \\k_B &= 1.381 \times 10^{-16} \text{ erg / K} \\M_{\text{sun}} &= 1.988 \times 10^{30} \text{ kg} \\1 \text{ erg} &= 6.241 \times 10^{11} \text{ eV}\end{aligned}$$

Exposition to Juranova et al. (2020):

1. (4 points) (Comprehension) In 2-3 sentences, please describe the most important facets of the experimental setup in this study.
2. (3 points) (Comprehension) In 1-2 sentences, please describe the motivation for the presented study, including the implications of any motivating previous work.

We'll now dive into the gas physics at play here.

3. (3 points) (Synthesis) The assumption of hydrostatic equilibrium is often invoked, as it is here on a couple of occasions, when analyzing atmospheres of various types. In 1-2 sentences, define hydrostatic equilibrium **in the context of a galaxy's 'atmosphere'**.
4. (3 points) (Knowledge) Sketch out a diagram illustrating hydrostatic equilibrium and label the diagram with the appropriate physical quantities.

5. (3 points) (Application) The authors primarily use ‘X-ray friendly’ thermodynamic units and quantities. Let’s orient ourselves with units that might be more familiar. Choose approximate upper and lower bounds of the Juranova et al. (2020) temperature measurements, quote your chosen temperatures in units of keV, and convert those units of K. Be sure and specify where in the paper you found these measurements.
6. (2 point) (Comprehension) As the authors indicate, the literature on hot gas halos typically invoke ‘entropy’ as a key thermodynamic diagnostic. As defined herein, in words, how does entropy depend on other thermodynamic variables? Where does one find this information in the paper?
7. (3 points) (Application) Let’s build some intuition for entropy profiles given some simplifying assumptions, including hydrostatic equilibrium as we discussed above. We need to know how the thermodynamic quantities in the previous question depend on galactocentric radius. The next simplifying assumption we will make is that of an isothermal profile. Which galaxies in the Juranova et al. (2020) sample have (approximately) isothermal profiles? Be specific about the figure(s) or table(s) where you found this information and your reasoning!
8. (2 points) (Application) Assuming an isothermal halo in hydrostatic equilibrium, one often adopts a simple gas density profile, the singular isothermal sphere (SIS):

$$n(r) = \frac{2k_B T}{\mu m_p} \frac{1}{4\pi G r^2} ; \mu = \text{mean molecular mass}$$

First, what is ‘singular’ about this simple model? Is it physically plausible? Why or why not?

9. (6 points) (Synthesis) We don’t have to merely assume some density profile, however. The X-ray data constrain it! The authors fit the X-ray brightness profiles with a β model. Assume that the gas is fully ionized and the X-ray emission goes as the square of the density (as in the case for *bremsstrahlung* emission, but neglect radiative transfer effects). Use this simplifying assumption, the data in Table 4, and appropriate values for the galaxies identified in Question 7, calculate the estimated entropy profile for $r \gg 1$.

On the thermal (in)stability

10. (4 points) (Comprehension) This and many, many other papers use timescale arguments to argue for/against the likelihood of certain phenomena. In 1-2 sentences, please summarize the implications of the timescales measured and discussed by Juranova et al. (2020).

Back to the main conclusions

11. (3 points) (Comprehension) What is the primary piece of evidence presented by Juranova et al. (2020) for the existence of rotating hot gaseous halos around their galaxy sample? What figure and/or table enables one to assess this quantitatively?
12. (3 points) (Evaluation) Would you argue that this piece of evidence is direct or indirect? In either case, please *briefly* justify your conclusion.