Cume #472

80 Points Possible

60 Points is Guaranteed Pass, but passes with lower scores are possible

Administered September 29, 2023

THE SURPRISINGLY CONSTANT STRENGTH OF O VI ABSORBERS OVER COSMIC TIME

Andrew A. Fox 2011, ApJ, 730, 58 (12 pages)

Be sure your solutions in your uploaded document presents in portrait mode. For Canvas uploads, submit a single document with your answers in exact problem order with the start (problem number) and end/solution of each problem clearly marked.

YOU MAY USE A CALCULATOR, BUT NO OTHER RESOURCES. NO COMPUTERS, BOOKS OR NOTES. CELL PHONES OFF OR IN AIRPLANE MODE.

Before answering any problems, be sure to familiarize yourself with the full exam so that you can obtain some insight on how to partition your time management between problems. For any hand drawn diagrams, be sure to provide axes scales and labels very clearly. Please be sure your plots are also in portrait mode. At your discretion, where you think it will help guide my eye while grading, please box answers.

1. **[20 pts]** Let's consider the ion on which this paper is focused.

   (a) [8 pts] The O VI notation refers to an ion of oxygen. (i) Which ion is this? In other words, how many electrons have been removed (ionized) from the neutral oxygen atom? (ii) Write out the electron configuration of the O VI ion. (iii) What is meant when we say that O VI is a lithium-like ion.

   (b) [4 pts] O VI $\lambda\lambda 1031, 1037$ absorption is a fine-structure doublet. (i) What is a fine-structure doublet? (ii) What atomic physics is responsible for the split energy levels of fine-structure doublets?

   (c) [8 pts] Draw the Grotrian energy diagram showing the O VI $\lambda\lambda 1031, 1037$ absorption energy structure. Use Russel-Sanders notation ($^{2S+1}L^o_J$) to label the ion states on the axes of the diagram and label the individual energy states that the active electron transitions between with their quantum numbers n, l, j.

2. **[14 pts]** In Section 2, the author reviews ionization physics of O VI.

   (a) [4 pts] Given the energy required to ionize the O VI ion (which is stated in the paper), and knowing that hydrogen ionizing photons have $\lambda < 912$ Å, what is the wavelength range of photons that are capable of ionizing O VI ions?

   (b) [2 pts] What are the two main mechanisms of ionization for the creation and destruction of O VI? Just name them here.

   (c) [4 pts] Provide a brief description of the first mechanism you wrote down in (b). Under what astrophysical environments/conditions is this mechanism expected to dominate? Are there environments/conditions where it is believed it is not operating?

   (d) [4 pts] Provide a brief description of the second mechanism you wrote down in (b). Under what astrophysical environments/conditions is this mechanism expected to dominate? Are there environments/conditions where it is believed it is not operating?

3. **[15 pts]** The abundance of oxygen relative to hydrogen is written $\alpha_{\rm O} = n_{\rm O}/n_{\rm H}$, where $n_{\rm O}$ is the oxygen number density and $n_{\rm H}$ is that of hydrogen. The ionization fraction of O VI is written $f_{\rm OVI} = n_{\rm OVI}/n_{\rm O}$, where $n_{\rm OVI}$ is the number density of O VI ions. The column density of O VI, which is a measured quantity form its absorption lines, is written $N_{\rm OVI}$. The column density is the product of density of O VI and the size of a gas cloud, L, giving $N_{\rm OVI} = n_{\rm OVI} L$.

(a) [6 pts] Derive an expression for the size of a gas cloud in terms of the measured $N_{\rm OVI}$, and the quantities $f_{\rm OVI}$, $\alpha_{\rm O}$, and $n_{\rm H}$.

(b) [4 pts] (i) What is the size of a cloud (in kiloparsecs) if the O VI column density is 10^{13} cm^{-2}, if the oxygen abundance is 10^{-4}, if 10% of the oxygen is in the form of O VI, and if the hydrogen density of the cloud is 0.1 cm^{-3}? There are approximately 3×10^{18} cm in a parsec. Show your work. (ii) Approximately, what fraction of the Galactic *radius* is this cloud?

(c) [5 pts] (i) Given this column density in (b), if this cloud is measured in Galactic absorption (see Figure 1 in the paper), in which kind of Galactic environment would you assess it arises? (ii) Do you think your size estimate from (b) is reasonable for this kind of Galactic component? Provide your astrophysical reason(s).

4. **[16 pts]** Let's consider the main plots in the paper.

   (a) [8 pts] Figures 3 and 4. (i) What are these figures illustrating to the reader? (ii) What are the astrophysical interpretations/implications of these findings, as discussed by the author?

   (b) [8 pts] Figure 5. (i) What is this figure illustrating to the reader? (ii) What are the astrophysical interpretations/implications of these findings, as discussed by the author?

5. **[15 pts]** Finally, let's consider the overall roadmap and general experiment conducted for this paper, including the motivations, the observations, the analysis, and the results. Please read all the questions before answering any of the parts. Note, each of these components is being asked about separately; in addition to evaluating your explanation of the components of this paper, to a large degree, part of the grading of this question is to assess how well you can properly partition the work into its component parts.

   (a) [3 pts] In one sentence (yes one!), state what this paper is about.

   (b) [3 pts] In no more than three sentences, describe the astronomical context (big picture) motivating this work.

   (c) [3 pts] In no more than three sentences, describe the observational data employed and their suitability to the experiment.

   (d) [3 pts] In no more than three sentences, describe the experiment and the scientific analysis performed (do not describe results or findings here).

   (e) [3 pts] In no more than three sentences, describe the *new* most important conclusion(s), i.e., central to the larger picture addressed by the paper, i.e., your "walk away" result(s).