Measuring Stellar Elemental Abundances

Authors: D. Zurawski, J. Kamen, V. Karkour

Motivation

The motivation for this paper is to investigate and evaluate elemental abundances in stars. This can help us draw conclusions about the elemental abundances of those star's exoplanets and further our understanding of the universe. We will use formulas such as the Saha equation as well as the curve growth method to help us evaluate these stellar abundances, exploring how things are done in the real world. We will analyze and present our findings in the terminology of both astronomers and physicists, to give us a good idea of how these ideas are communicated in a real working environment. Overall, we hope to finish this project with a general better understanding of not only stellar composition, but also scientific communication in the real world.

Methods

To begin, we had to import our raw solar spectrum that was provided into python. It contained columns describing the wavelength of light and flux of the observations. Then, we needed to normalize the raw solar spectrum, both for the purpose of easier visualization and to make analyzing the sodium lines simpler. Limits were now set on the plot to section off the sodium doublet lines in question. Now, mathematically, it becomes very apparent how to solve for the equivalent width of these sodium lines.

We used a variety of coding techniques to pursue the next set of questions. To find the number density of sodium atoms in the ground state, it was necessary to use a growth curve plot (shown to the right) and specific internal imported packages such

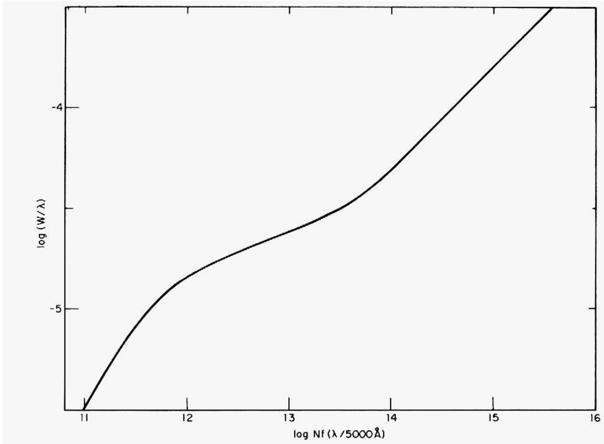
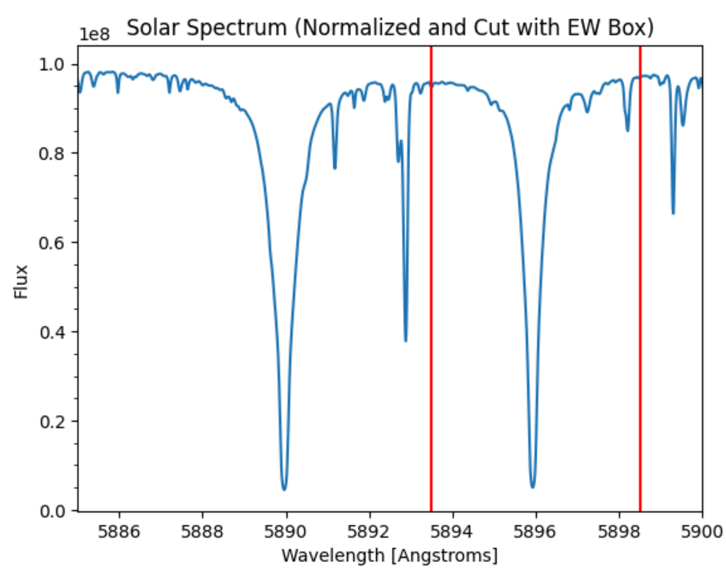


Figure 9.22 A general curve of growth for the Sun. (Figure from Aller, *Atoms, Stars, and Nebulae*, Revised Edition, Harvard University Press, Cambridge, MA, 1971.)

as numpy. Continuing, we estimated the ratio of sodium atoms in the ground state to sodium atoms in the excited state. To do this, we had to use the relationship developed from the Boltzmann equation, helping to provide this ratio of ground state to excited state atoms. This equation, similar to above, called for complex mathematical expressions like exponentials, one's that python packaged tools could handle. To now solve for the ratio of neutral sodium atoms to ionized sodium atoms, we used the Saha equation. The equation itself is a well known physics expression which relates the ionization of a gas in thermal equilibrium to its temperature and pressure. Using the number density derived previously, along with the known energies of different excited states, this approach proved very useful for answering our questions. With all these number densities now derived, we used a formula to calculate the total column density for all the sodium atoms in the Sun's photosphere. Finally, we could use logarithmic equations and ratios provided to compare our values with values known by astronomers and physicists.

Results

A great many questions have been answered by implementing the methodology built above. The first major question answered is the equivalent width of the sodium doublet lines from our data. This graph to the right shows our solar spectrum of data normalized, with the limits applied on the graph to section off one of the doublets. This data was used to calculate the width of the sodium lines, which was essential to all of the calculations we do after



this in the project. The value derived for the equivalent width of this sodium line at 5896Å was 0.6987Å. From this, we wanted to ask the number density of sodium atoms in the sodium line. We began by looking at the growth curve plot for the spectrum. This will also help us to approximate our column density later. The equations used here in the code are very self-explanatory, needing little work to get the needed results. Then, the numerical results were placed in a number density equation, giving us a number density of sodium atoms in the sodium line of 1.18 * 10^15 atoms per square centimeter.

Once we had this value, we could begin comparing the number of atoms in the ground state to the number of atoms in the excited state. Using the Boltzmann equation, as described in the methods section, we plugged in our derived number density of sodium atoms. We also had to get the number of separate individual states that are degenerate in energy, denoted by g, for these equations as well as the energy in the excited and ground states. The value we ended up getting for the ratio between the excited state and the ground state was 0.044. This tells us that the excited energy sodium atoms make up an unbelievably small portion of the total sodium.

Next, we want to estimate the ratio of neutral sodium atoms to ionized sodium atoms. This can be done by applying the Saha equation, which is related to the original Boltzmann equation. This is helpful because it means there is nothing new that we have to derive, we simply have to apply our known derivations to the equation along with a range of fundamental constants and known quantities to get this ratio. Through this process, we get a number density ratio between neutral and ionized sodium atoms of 2522. This indicates that neutral sodium way overweighs the population of sodium compared to the ionized form.

Computing the total column density of sodium atoms in the sun's photosphere is the next big task. To solve, we can take our two derived ratios above, of the ground state compared to the excited state and the number density of ionized atoms to neutral atoms. Applying these two found ratios into the equation gives us a total column density of sodium atoms in the sun's photosphere of 3.108 * 10^18 atoms per square centimeter. All of this information above, from the number density of sodium atoms to the ratios with excited state and ionized atoms to the total column density have been derived simply from the initial two columns of flux against wavelength in our initial dataset. It shows the power of observation to gain knowledge about the stellar objects in the universe.

Beyond the simple value calculations, we want to compare our results with the notation used by astronomers and physicists. The terminology that is often used varies from field to field and understanding the importance of each and the conversion between each holds value. For physicist, column density is often compared to the column density of hydrogen, which has a value of 6.6 * 10^23 atoms per square centimeter. Simply comparing these column densities gives us the description physicists use. Our derived ratio of sodium to hydrogen is an abundance ratio of 4.7 * 10^-6. This indicates an overwhelming majority of hydrogen, to a scale of a round 5 sodium atoms per 1 million hydrogen atoms. Next we look at astronomers' descriptions. They use a different ratio, using 12 plus the log of the number density ratio of an element to hydrogen. Here, the abundance of sodium relative to hydrogen is given as 6.67. The final way the abundance is described is by comparing it to the sun. You'd take the ratio of an element to hydrogen and compare it to the ratio of that element to hydrogen in the sun, done by dividing the two. Since the abundance in the top would also be the sun's for this situation, the ratio should produce a value of 1, with the log of that value being 0. That is what we too have gotten.

Conclusion

Overall, this project went over some extremely interesting and important topics involving elemental abundances in stars and professional communication in the fields of astronomy and physics. Over the course of the last 2 weeks working on this project, our team learned a lot about coding, impact of elemental abundance, and real world examples of how data is presented. Our motivation for this project was to explore element types in stars and their abundance. Our motivation was a definite success. Our experience with this project as a whole was mostly positive, and we look forward to the final project in this class.