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Sodium Abundance Within Solar Photosphere

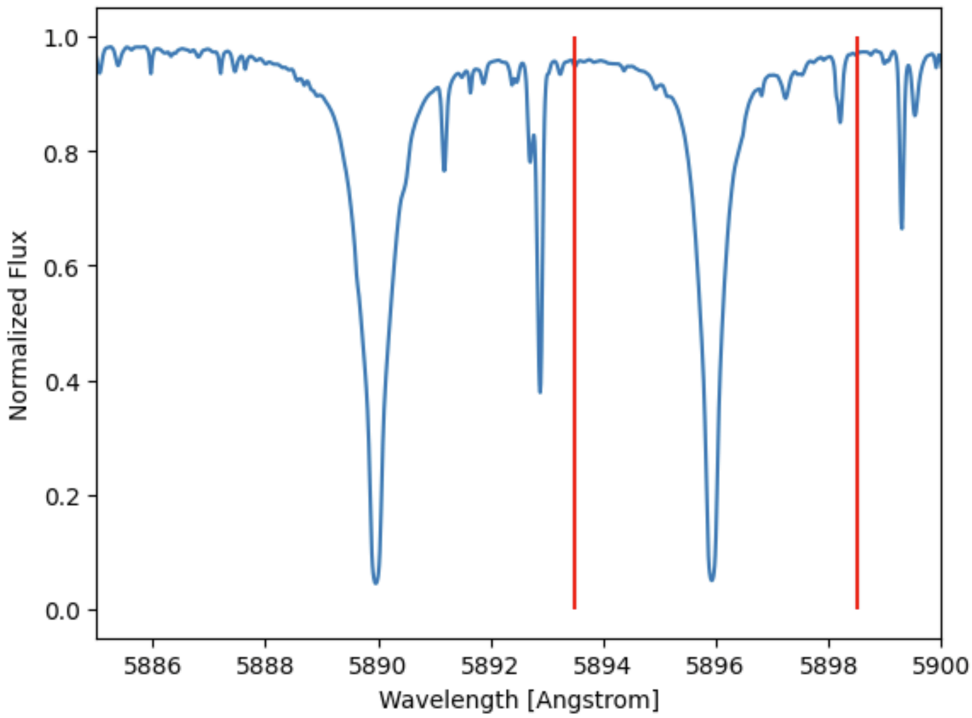
Motivations

Measuring chemical abundances in stellar spectra can reveal information about the planets around them since planets and their host stars form from the same dust cloud. A star with a lot of sodium will have planets that also have a lot of sodium, which impacts the structure of the planet. Stellar composition also impacts activity, which can determine the size of the planet. Fulton et al. (2017) showed that there are few planets with a radius of $1.8R_E$, which can be attributed to photoevaporation. Stellar activity is likely to play a role in this process.

We will measure the abundance of sodium in the stellar atmosphere because it has strong absorption lines at visible wavelengths, meaning we can easily measure the equivalent width of these absorption lines.

Methods

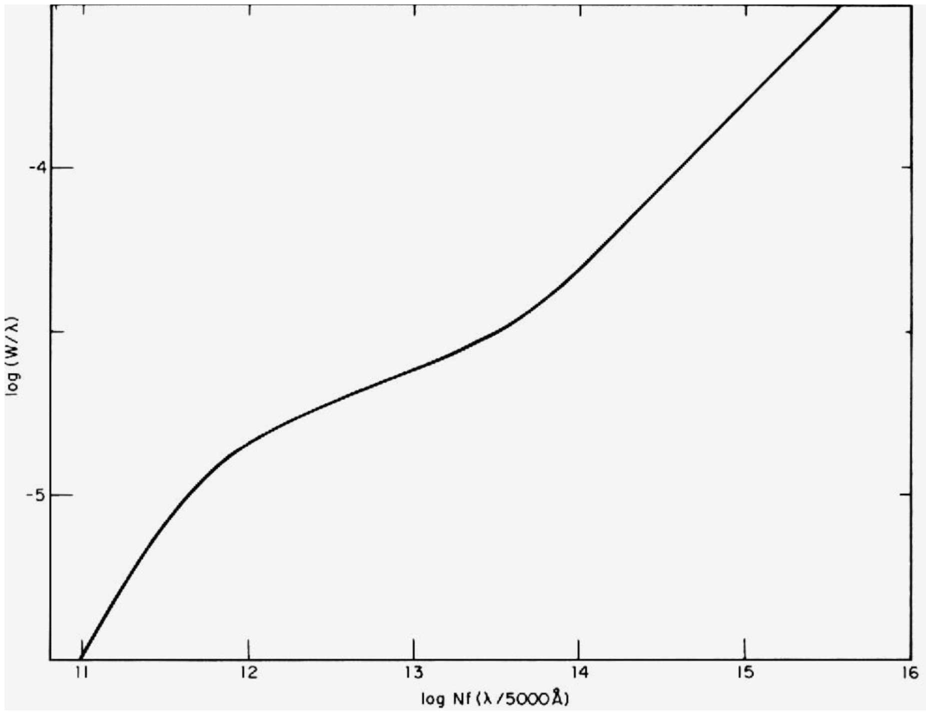
We obtained a solar spectrum from class files and normalized it to the continuum by



dividing fluxes by 10000.

We then measured the equivalent width of the sodium line at approximately 5896 angstroms by summing the data points from 5893.5 to 5898.5 angstroms, which were estimated to be the bounds of the absorption line, specified on the graph above by the red lines.

We calculated the log of the equivalent width and its location on the growth curve from Aller (1971). This plot shows log*(EW/λ)* as a function of log*Nf(λ/5000Å)*, so we solved for N.



With this information, we obtained the ratio of the number of sodium atoms in the ground state to excited state using the Boltzmann equation:

$$\frac{N_2}{N_1} = \frac{g_2}{g_1} exp\left(-\frac{E_2 - E_1}{kT}\right)$$

E_2 - E_1 is the energy difference between the ground and first excited state (in this case 3.37×10^{-19}J), g_2/g_1 is the ratio of degenerate states for each energy, *k* is the Boltzmann constant, and we assumed *T* = *5800* K since we are observing the photosphere.

We then calculated the ratio of neutral to ionized sodium atoms with the Saha equation:

$$\frac{Na_{II}}{Na_I} = \frac{2kT}{P_e} \cdot \frac{Z_{II}}{Z_I} \left(\frac{2\Pi m_e kT}{h^2}\right)^{\frac{3}{2}} exp\left(-\frac{\chi}{kT}\right)$$

In this equation, Z_I and Z_{II} (the partition functions) are 2.4 and 1.0, χ = 5.1 ev , P_e = *1.0 N/m*^{2}*,* and *T* = *5800* K. We obtained these values from class notes. P_e is the electron pressure calculated from the ideal gas law ($P_e = n_e kT$), while χ is the ionization energy of sodium and h is Planck's constant. Calculating these ratios helps astronomers model the environment of the sun's photosphere, which has a large impact on orbiting planets.

We then measured the column density of sodium atoms in the photosphere. It is important to account for neutral, excited and ionized sodium in the calculation, so we used this equation from the assignment notebook:

$$N_{Na} = N_1\left(1 + \frac{N_1}{N_2}\right)\left(1 + \frac{Na_{II}}{Na_I}\right)$$

To put the column density of sodium in the sun's photosphere in perspective, we calculated the mass ratio of sodium to hydrogen using the column density of hydrogen in the sun's photosphere, $N_H = 6.6 \times 10^{23}$. We express this ratio in two ways, one being as a simple ratio in physicist's terms, and the other being on a logarithmic scale in astronomer's terms as follows:

$$12 + log_{10}\left(\frac{N_{Na}}{N_H}\right)$$

Results

We find the equivalent width of the sodium line at 5896 angstroms is 0.70 angstroms, which is approximately equal to the 0.83 angstroms measured in the example notebook. Differences between these values likely arise from the selection of boundaries for the measurement and another emission line that appears in the 5890 line but not the 5896 line.

Using our equivalent width value, we visually estimated that $\log N(\lambda/5000Å) = 14.7$, meaning that $N = 6.54 \times 10^{14}$, which is within an order of magnitude of the example calculation ($N = 8.2 \times 10^{14}$).

We found $N_2/N_1 = 0.04$ and $Na_{II}/Na_I = 2643.5$, which are similar to the 0.03 and 2518.0 given in the other example notebook. While the N_2/N_1 value was not calculated in the notebook, the fact that our value is similar to the one given shows that our value is reasonable.

The column density of sodium in the photosphere is 1.81×10^{18}. In physicist's terms, this means that the relative abundance of sodium is 2.74×10^{-6}, while in astronomer's terms the abundance is 6.44. These values are similar to the abundance in astronomer's terms of 6.3

given in class, but our value does fall outside the uncertainty of 0.03. This discrepancy is likely because the accepted value uses more sophisticated techniques.

Conclusions

We measured the relative abundance of sodium in the sun's photosphere from the equivalent width of the 5896 angstrom absorption line. Our values were roughly equal to the accepted value, showing that our technique works and can be used for other elements. This is promising for better understanding planetary systems in other stars - particularly rocky exoplanets, since they're notoriously difficult to observe. Their stars, however, can offer us insight into their chemical composition, since they're much easier to gather information from. Considering exoplanets are a relatively new field of astronomy, this relationship will be very valuable in its expansion.

References

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