Measuring the Stellar Abundance of Sodium

Astron 5205 SP22

Shannon McKinney, Bailee Wolfe, Madison Englerth, Payton Cassel, Richard Kane

1. Motivations

- Measuring the width of a solar Sodium doublet line
- Finding the number density of Sodium atoms in the ground state
- Estimating the ratio of Sodium atoms in the ground state to those in excited states
- Estimating the ratio of neutral Sodium atoms to ionized sodium atoms
- Calculating the total column density of Sodium atoms in the sun’s photosphere
- Stellar abundance suggests planet composition

2. Methods

- Used the solar spectrum from BASS2000 to find the equivalent width of the Sodium doublet line at 5890 Angstrom
- Found the number density of Sodium atoms based on a specific growth plot
- Used the Boltzmann equation to estimate ratio between ground and excited states
- Used Saha equation to estimate ratio between neutral and ionized atoms
- Used both ratios to compute column density in photosphere
- Found Sodium abundance relative to Hydrogen

Equivalent Width

- Essentially the area of the absorption line
- 5890 Angstrom
- Width of the absorption line and height of the continuum emission

Curve of Growth Plot

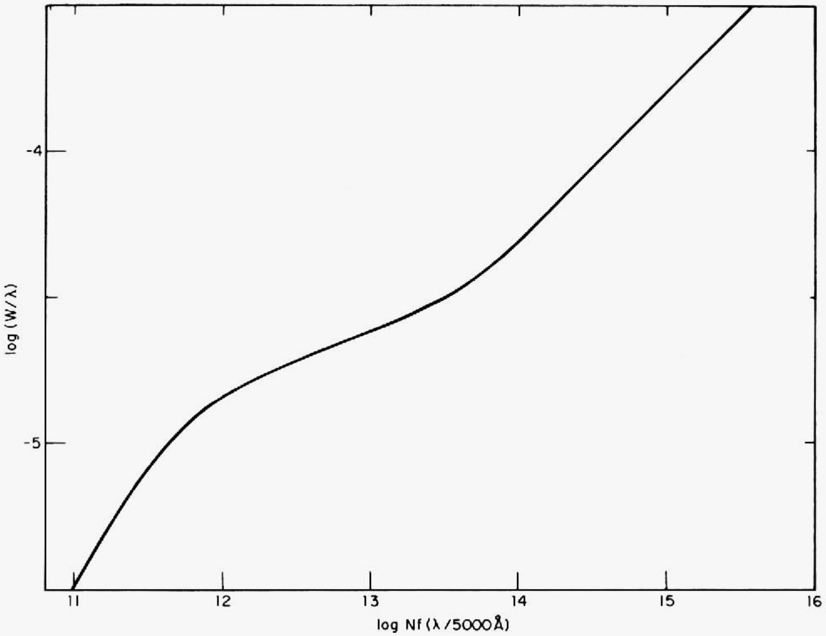

Figure 9.22 A general curve of growth for the Sun. (Figure from Aller, *Atoms, Stars, and Nebulae*, Revised Edition, Harvard University Press, Cambridge, MA, 1971.)

Ground State to Excited State

- Used the following Boltzmann equation to estimate the ratio of Sodium atoms in the ground state to the Sodium atoms in excited states

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

- Where the subscripts 1 and 2 refer to the 3s and 3p states, N is the number density, g is the number of separate states degenerate in energy, E is the energy, k is the Boltzmann constant, and T is the temperature

Neutral to Ionized

- Used following Saha equation to estimate the ratio of neutral Sodium atoms to ionized Sodium atoms

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

- Where m_e is the electron mass, Z_I and Z_II are partition functions equaling 2.4 and 1.0 respectively, P_e is electron pressure, and χ is the ionization energy equaling 5.1 eV

Total Column Density in Sun's Photosphere

- Assuming that the total number of Sodium atoms equals to

$$N_1 \times \frac{N_2}{N_1} \times \frac{Na_{II}}{Na_I}$$

- N_1 is measured from growth curve the ratios are the previously calculated ratios

Sodium to Hydrogen

- The column density of Hydrogen is about 6.6×10^{23}
- Relative log abundance for Hydrogen is set to 12
- The abundances of all other elements are expressed as

$$12 + log_{10}(N_{element}/N_H)$$

- Where N is number density

3. Results

- Equivalent width: 0.8347 Angstrom
- N_2/N_1: 200 ionized for each neutral
- N_aII/N_aI: 0.05

Na/H

- Astronomer’s: about 0.6 ([Na/H] ratio calculated/sun ratio)
- Physicist’s: 3.3 x 10^-7 (Mole ratio to Hydrogen)

4. Conclusions

- Stellar abundance -> planet composition
- Sodium in gas giant planets
- WASP-39b and 96b (direct detection of sodium)

5. Citations

- *Curve example image- spiff.rit.edu*. (n.d.). Retrieved March 30, 2022, from http://spiff.rit.edu/classes/phys440/lectures/curve/curve_example.pdf
- Schulze et al. 2020
- Wang et al. 2019
- Nikolov et al. 2018