Observations of the Elements Found in the Sun

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Abstract

Through our observations of the suns solar spectra we were able to identify strong absorption lines representing certain elements that exist within the suns atmosphere. Through the determination of the equivalent width of these lines we were able to show the strength of these spectral features and determine their approximate abundances relative to the amount of hydrogen in the Sun.

1 Introduction

The aim of this paper is to describe intermediate-resolution spectra of our sun as found by our observations. With this we then identify the more abundant elements in the photoshpere and estimate approximate ionic abundances relative to hydrogen.

To make these observations we allow light from the sun to enter the spectrograph where the observed spectrum was then recorded into our CCD detector.

After identifying the observed absorption lines in the suns spectrum, we found their appropriate wavelengths and the element corresponding to them. Using the NIST database [4] we determined the degrees of ionization and the ionization potentials for each found element. Once these were found we were able to determine the strength of these absorption line via their equivalent widths.

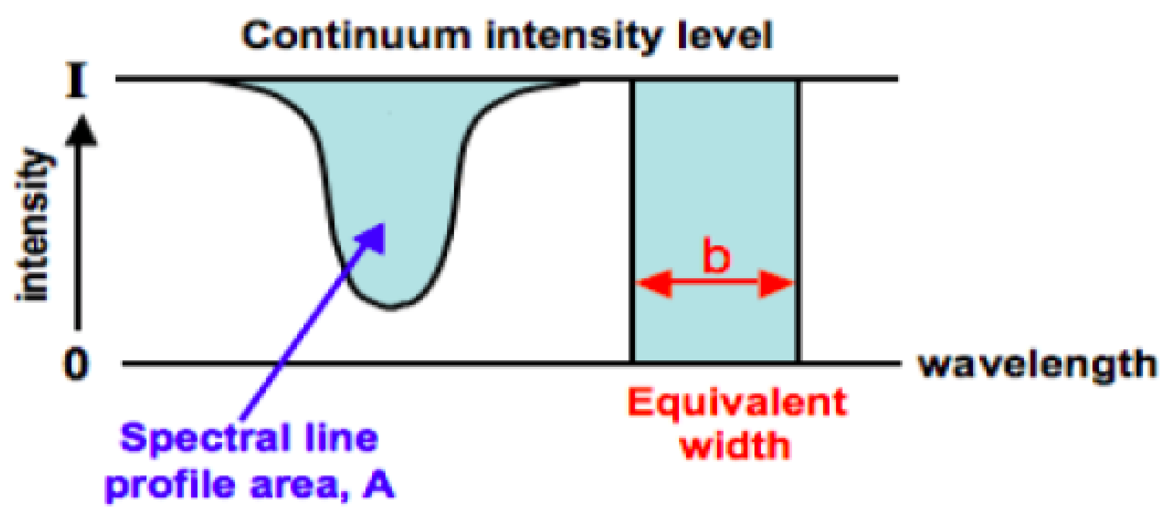

Figure 1: Equivalent width is is the area of the absorption divided by the mean height of the quadrilateral.

Once we found these equivalent widths we were then able to plot them on the typical curve of solar growth (Figure 2) and determine a value of X from Equation 1. X is the product of the relative number of absorbers, the wavelength and the gf value (relative cross section).

This gf value is what we then used to plug into our abundance calculator [1] to help us determine the relative abundances of each specific metal in comparison to hydrogen.

$$X_i = (gf)\lambda N_{i,e} \tag{1}$$

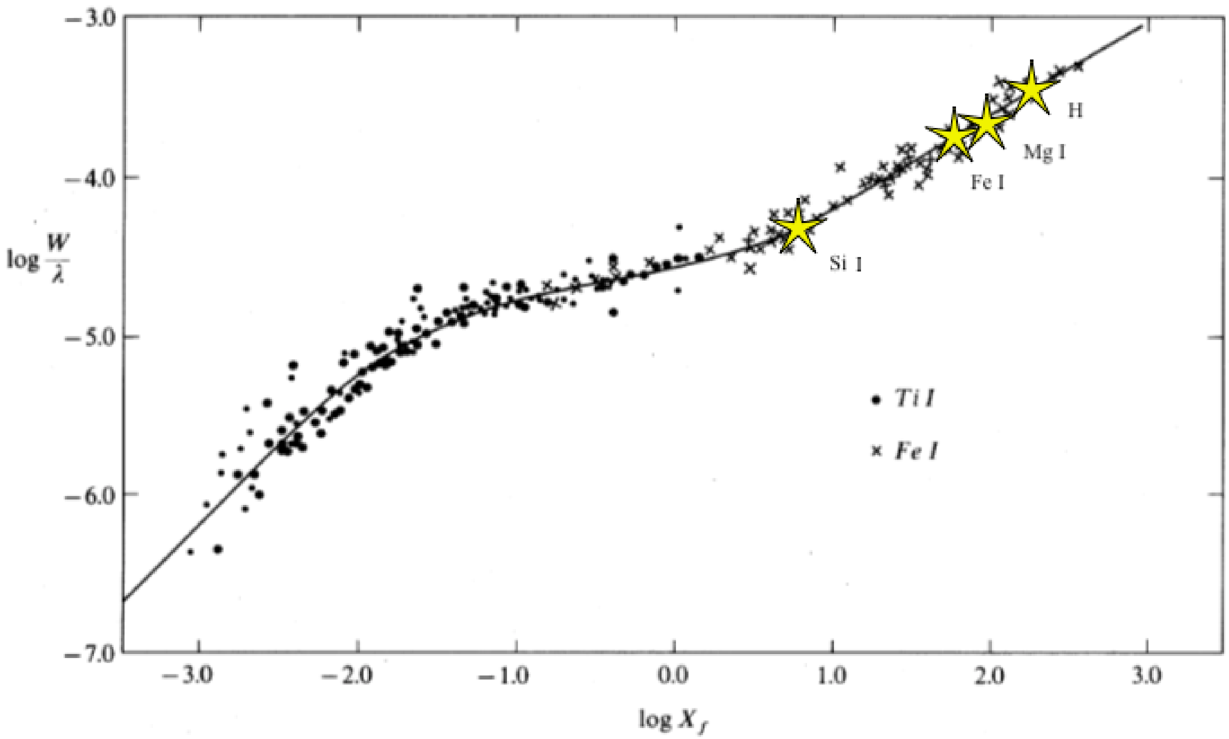

Figure 2: Solar curve of growth with our three selected absorption lines plotted. X if the product of the relative cross section, relative number of absorbers and the wavelength λ.

2 Procedure

For these observation we required a spectrograph, a CCD camera, a laptop computer and wavelength calibration lamps. Our measurements were taken for 7 different micrometer readings (found in Table 1) where we observed the spectra of the sun, an Ne lamp and a Hg/Ar lamp (found in Table 1. These measurements were taken in in order of least to greatest micrometer reading. The reason for dissension was to eliminate backlash. With the lights off, we made measurements of each spectra in one minute intervals.

For each lamp of each grating we extracted the observed wavelengths using the CCDOps program. We then took these wavelengths and applied them to excel [2]. This excel template added the observed wavelengths and automatically calculated the pixel numbers, wavelength averages, and the "peaks" (referring to where the wavelengths average spikes in number, indicating where a emission line may be found in the spectrum). On top of this, the excel sheet also calculated four separate plots:

- A residuals from fit plot: wavelength versus the difference in wavelength.

- A Provisional calibrations plot: Pixel versus wavelength.

- And the two spectrum plots: One of wavelength versus counts and another of pixels versus counts.

After putting the data into excel we used the guess calibration settings, also supplied to us by Gaskell [2]. This tool took in the grating measurements (in microns) and gave back the dispersion (Angstroms/Pixel), the pixel zero wavelength (Angstroms) and also gave us the starting wavelength.

The dispersion and the pixel zero wavelength were then input into the excel calibration sheet as a jumping off point for our calibration. When input into our calibration excel sheet, these numbers then adjusted the spectrum to better aligning our observational spectral data with the accepted values. This was just a rough estimate and so further fine tuning was needed.

observing the plot of wavelength versus counts, we then compared that and its peak values of accepted spectra within similar wavelength ranges. Once we identified accepted wavelengths that aligned with our data, we input these values into our excel sheet which then in turn calculated the “residuals”. The residuals represent the difference between our data and the accepted wavelength. If the residual number was over $\pm.5$, then further adjustments needed to be made to the data calibration.

Once enough lines were identified we then looked to the plot of provisional calibration and the plot of the residuals from fit. Starting with the Provisional calibration plot, we used the equation of the line it produced to better adjust the spectrum's fit to actual accepted values. This equation of the line took the form of $y = mx + b$. where m represented the dispersion and b represented the pixel zero wavelength.

The adjustments mentioned were done in tandem between the Ne and Ar/Hg lamp data, allowing for any gaps in one spectrum of a lamp to be filled and calibrated better by the other.

If we found that the residual were under $\pm.5$, and the mean as well as median of these residuals were under $\pm.5$, we were then considered done with our calibration. If this were not the case it was possible that either more fine tuning of the residuals must take place, or that we had identified our data incorrectly when comparing it to the accepted wavelengths and spectra.

Once we appropriately calibrated the wavelengths for each grating, the corresponding dispersion and pixel zero wavelength were then entered into the suns spectrum. Next we set out to identify absorption lines of the suns spectrum. To do so we used the plot of wavelength versus counts that our data produced and compared it with the solar spectral atlas [5]. We focused on the peak wavelengths produced in our plot and matched these wavelengths to those in the spectral atlas. once we found the appropriate wavelengths and their related element, we then used the NIST database [4] to determine the degrees of ionization and the ionization potentials for each found element.

For the last step, we chose one of the identified hydrogen lines and three other separate metal lines. The purpose of this was to measure their absorption line strengths, which we did through an excel sheet provided to us by Gaskell [3]. Once we found the equivalent widths we were then able to plot them on typical curve of solar growth (Figure 2) and determine a value of X (Equation 1). X is the product of the relative number of absorbers and the wavelength, otherwise the gf value (relative cross section). This gf value is what we then used to determine the relative abundance of each specific metal in comparison to hydrogen.

3 Results

For each grating we calibrated our data to the appropriate wavelength. The wavelengths and their corresponding micrometer grating can be seen in Table 1.

Table 1: Starting wavelengths for each micrometer reading.

Micrometer Reading	4140	5430	6000	6720	7370	8010	8660
Starting wavelength	3802.6	5082	5641.4	6342.9	6971.2	7585.2	8204.2

All solar spectra were taken and can be found in the Appendix as Figures 3 through 9. We present some of the stronger absorption lines (also labeled in Figures 3 through 9) found at each grating in Table 2.

Table 2: Representation of some of the strongest absorption wavelengths found for each grating and the elements in which they coincide. These absorption wavelengths found in the solar spectrum of the sun represent the elements found within its atmosphere. The depths of these strong absorption lines tell us a lot about the temperature. The wavelength shifts of these lines also help us understand how the elements are moving within the sun.

Grating	4.14	5.43	6	6.72	7.37	8.01	8.66
Element	Mn I	Mg I	Na I(D1)	Si I	Si I	ATM O2	Ca II
Wavelength	4033.07	5183.79	5895.3	7004.52	7275.72	7645.59	8497.39
eV	-0.617 eV	2.72 eV	.108 eV	5.98 eV	6.10 eV		1.69 eV

Lastly, after having determined the equivalent widths and wavelengths of three separate absorption lines plus that of hydrogen, we determined the log(X) value and calculated the value of gf using the NIST data base. These found values and the corresponding abundances are represented in Table 3.

Table 3: Table representing final data. The value of T 5600 K and an assumed Boltzmann distribution was used to convert relative level populations (RLP) of the different ions to relative ionic abundances (RIA).

Ion name	λ	EW	$log(\frac{w}{\lambda})$	$log(x)$	eV	$log(gf)$	log l	$log(N)$	$log(RLP)$	$e^{-\frac{E}{KT}}$	$log(e^{-\frac{E}{KT}})$	$log(RIA)$
Hydrogen	4340.47	1.32	-3.517	2.200	10.199	-0.45	3.638	-0.988	0	1	0	0
Fe I	4045.81	0.54	-3.875	1.4	1.48	0.28	3.607	-2.487	-1.499	0	-7.574	-9.073
Si I	7005.88	0.29	-4.383	0.9	5.98	-0.6	3.845	-2.345	-1.358	0	-3.665	-5.023
Mg I	5183.604	0.76	-3.834	1.35	2.72	-0.167	3.715	-2.198	-1.21	0	-6.497	-7.707

4 Discussion

Besides systematic errors, the error in our calculation of the equivalent width could be attributed to the quality/signal-to-noise ratio of the data itself. Another cause for error could be Doppler broadening or saturation of the line, both of which could cause the equivalent width to increase rendering it less accurate.

Our error on X can be related to that of the equivalent width error via the linear slopes of the lines on the solar curve of growth chart (Figure 2). Calculating the slope in three separate intervals; log(X) = -3.5 to -1.8, log(X) = -1.8 to .5 and log(X) = .5 to 3, we find the slopes to be .67, 4.59 and 1.66 respectively. These slopes are the ratio of equivalent width and the abundance X. For example, if we find an error of Equivalent width for the values between log(X) = -3.5 and log(x) = -1.8, we know that the error on X will vary by approximately .67.

5 Conclusion

In conclusion, through our observations we were able to successfully determine the equivalent widths and therefore abundances of the elements within the suns atmosphere.

References

[1] Martin Gaskell. *Abundance Calculator*. 2018.

[2] Martin Gaskell. *Calibration Template*. 2018.

[3] Martin Gaskell. *Equivalent Width Calculator*. 2018.

[4] Martin Gaskell. *NIST Database*. Data retrieved from National Institute of Standards and Technology, `https://physics.nist.gov/PhysRefData/ASD/lines_form.html`. 2018.

[5] Martin Gaskell. *Solar Spectral Atlas*. 2018.

6 Appendix

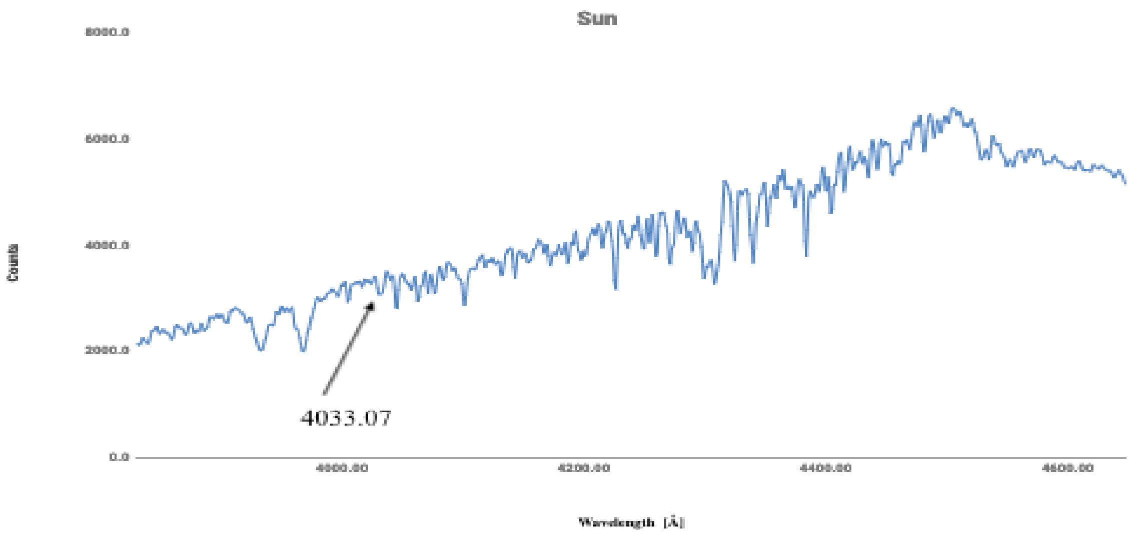

Figure 3: Grating 4.140: Mn I detected at a wavelength of $\lambda = 4055.07$

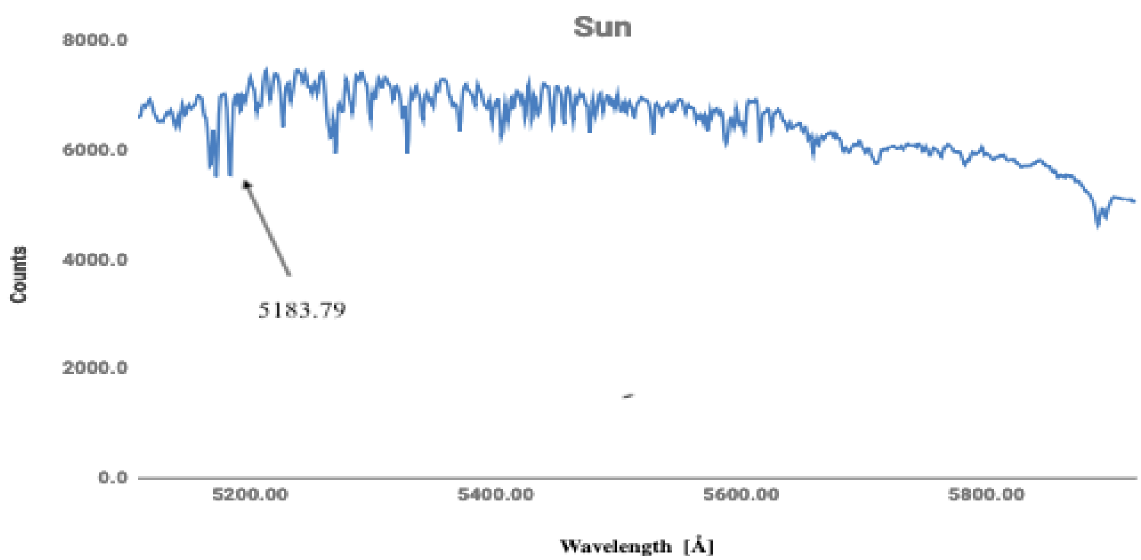

Figure 4: Grating 5.430: Mg I detected at a wavelength of $\lambda = 5183.79$

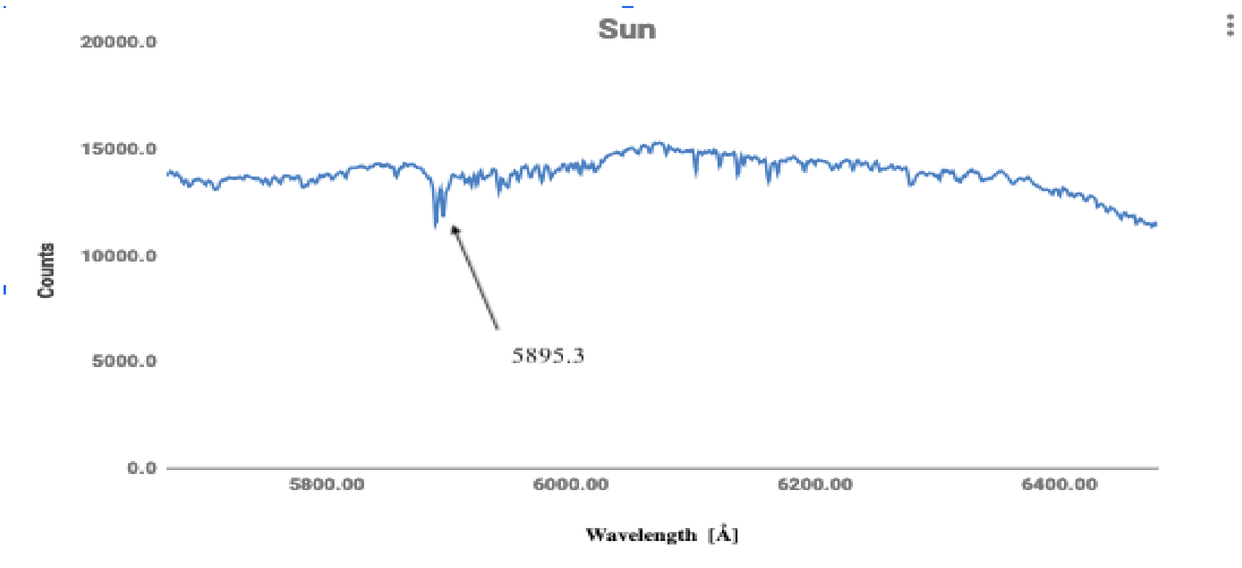

Figure 5: Grating 6.00: Na I detected at a wavelength of $\lambda = 5895.3$

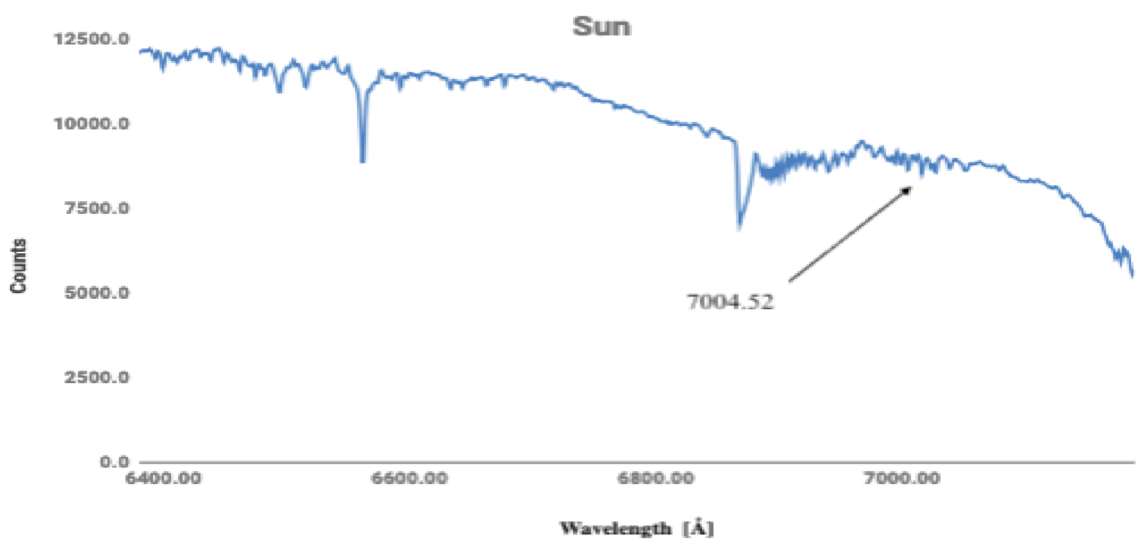

Figure 6: Grating 6.720: Si I detected at a wavelength of $\lambda = 7004.52$

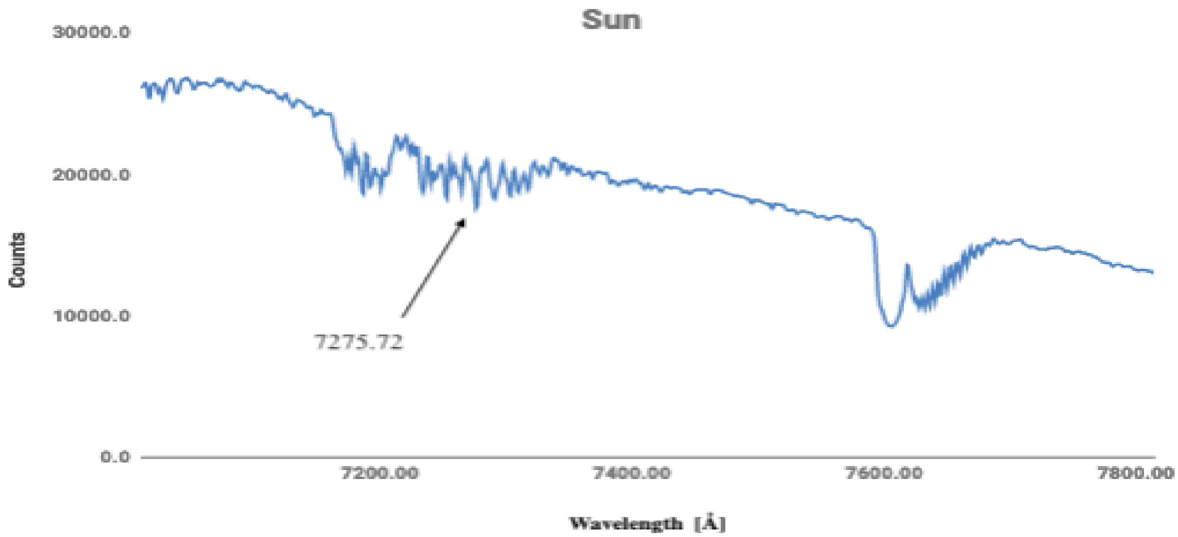

Figure 7: Grating 7.370: Si I detected at a wavelength of $\lambda = 7275.72$

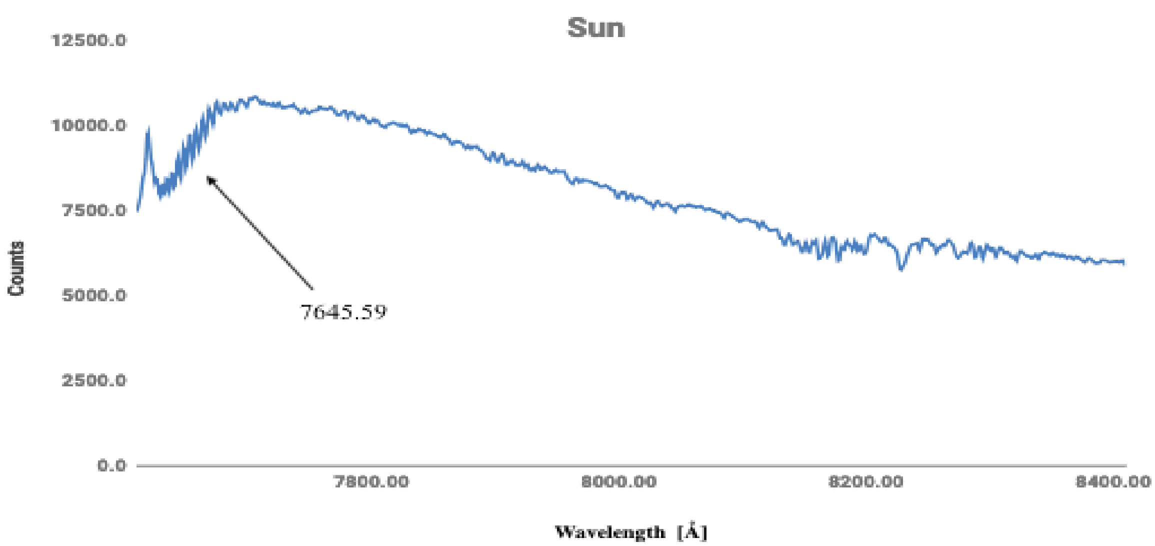

Figure 8: Grating 8.010: ATM O2 detected at a wavelength of $\lambda = 7645.59$

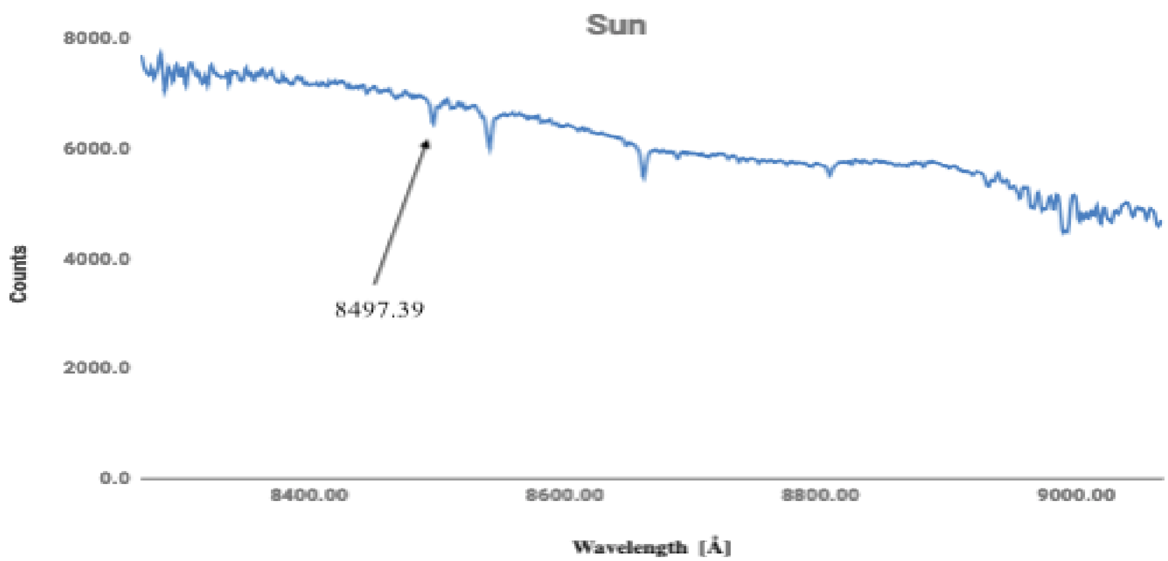

Figure 9: Grating 8.660: CA II detected at a wavelength of $\lambda = 8497.39$