Spectral Analysis of the Constellation Stars of Sagitta (The Arrow)

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Abstract

This paper will elucidate the spectral features of the main stars in the constellation Sagitta. The selection of stars was chosen to coincide with those typically used to trace the constellation lines that form the geometric shape of the constellation itself[1]. Though other stars within the boundary of the constellation (as determined by the IAU) may be objects of interest, the analysis is generally confined to the stars forming the constellation lines.

The stars in the constellation will generally be presented in order of their accepted Bayer designations, using Greek letters to rank them roughly in order of decreasing brightness. Alpha (or α) is usually the brightest star in a constellation. Afterward, Beta (β), Gamma (γ), and so on indicate decreasing apparent magnitude. It is usually the brightest stars that define the constellation lines. Of course, there are deviations from this rule that have been retained for historical consistency.

Equipment Used

All spectra used in this analysis were captured using the following equipment and resources:

Telescope: Celestron Advanced C6-N Newtonian Telescope, with an aperture of 6 inches, and a focal length of 750mm. This makes the focal ratio f/5.

Mount: Meade LX85 German Equatorial Go-To Mount. The mount was aligned using the three-star method.

Camera: ZWO ASI290MM monochrome camera.

Transmission Grating: The SA100 grating was employed to produce the spectra used in this analysis. The grating has 100 lines per millimeter.

Capture Software: The ASI Studio suite of programs was used in the capture process. Following capture, the same suite was used to stack images and export them as TIF files for evaluation and analysis.

Analysis Software: Rspec v2.1.1 by Field Tested Systems, LLC.

Reference Material Used in Analysis: The *Spectral Atlas for Amateur Astronomers* by Richard Walker and *Spectroscopy for Amateur Astronomers* by Marc F. Trypsteen and Richard Walker were both used to assist in identifying specific facets of the resulting spectra, and proved invaluable in this process. Wikipedia and Stellarium were also instrumental in obtaining information regarding the various stars. An additional resource was used in identifying infrared features in M-type stars: the SAO/NASA ADS database. Specifically, the paper entitled *The Infrared Spectral Classification of M-Type Stars* by Stewart Sharpless (U.S. Naval Observatory, 1956). Finally, due to an invalid listing on Wikipedia for one of the stars, the website www.universeguide.com was consulted.

Data Processing Details

All of the spectra obtained for this analysis were obtained on the evenings of July 26, 2024 (EDT) and August 22, 2024 (EDT). Additional specifics for each capture are included for each star's spectrum in the pages that follow. The times presented there are given in UT, as is desirable for any astronomical work. Also included are the exposure lengths, number of frames captured, and the percentage of those frames which were applied to the stacking process. The determination of this percentage was subjectively chosen based on the quality of the footage captured—the accuracy of the tracking, the steadiness of the atmosphere at the time, etc.

The tracking of the Meade LX85 mount used in the capture process has limitations regarding its accuracy. Therefore, some gain was applied during the captures in order to shorten the exposure times. This was kept to a minimum, as excessive use of it does compromise the quality of the exposures. No bias, dark, or flat frames were used for these captures, nor were reference stars captured for individual sessions. The captures must therefore be considered "Quick and Dirty," and so are unsuitable for professional or purely scientific applications. However, this author believes that they are adequate for general demonstration purposes. Refinements to these results are certainly possible if extra steps were taken to account for camera read noise, image defects in the optical train, and specific atmospheric influences that differ from those encountered when generating the initial response curve (Alpha Lyrae on July 18, 2023). Also, no sharpening or other image modifications were made to the stacked images. Most of the spectra therefore show telluric absorption bands; some of these are labeled, where others are not.

This is another constellation that proved more difficult than it should have been last year. I am hopeful that this run (like the one for Vulpecula) will assist in eliminating this incomplete constellation from my list.

α Sagittae

Alpha Sagittae, also known as Sham, is classified as an early G-type star[1]. Based on this, we can expect to see a star with lots of neutral iron lines, with a temperature not entirely dissimilar from that of our own Sun.

The completed spectrum is presented below:

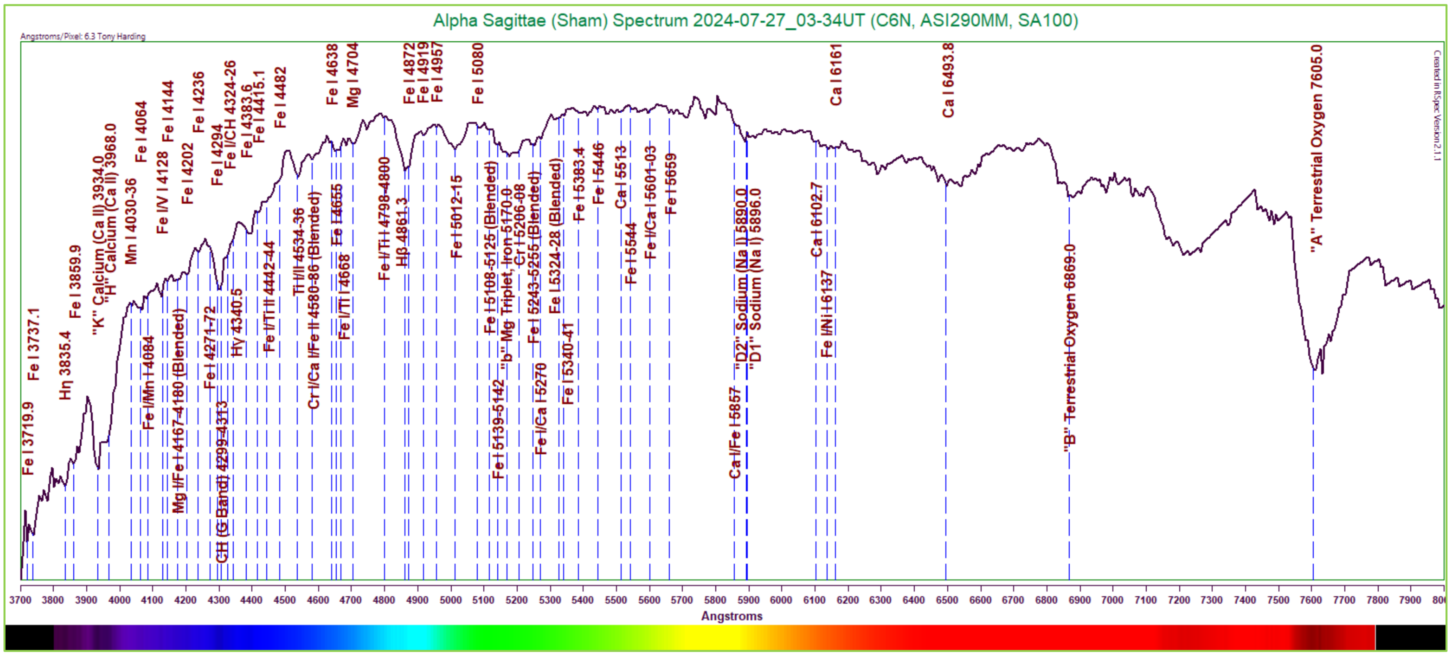

Figure 1: Alpha Sagittae (Sham) Spectrum (6.3 Angstroms/pixel)
Capture Details 1: Exposure 496ms, Gain 178, 29% of 734 frames stacked, Integration Time 105s

We can definitely see a familiar overall shape here, one representative of G-type stars. Only three of the hydrogen Balmer lines are visible—Hη, Hγ, and Hβ. These are all significantly weakened when compared to earlier-type stars. (The star is also a giant, which serves to reduce the magnitude of all absorption lines.) The calcium K and H lines at 3934 and 3968 Angstroms are evident, and quite deep. The CH (G Band) molecular absorption at 4299-4313 Angstroms is notable as well. The magnesium triplet at 5170 Angstroms appears somewhat shallow, but broad, with its attendant iron lines assisting. The sodium doublet at 5890-96 Angstroms is sharp, but not terribly deep. The calcium/iron line at 5857 Angstroms just below it is also visible. Fainter absorptions labeled include iron, manganese, magnesium, titanium, chromium, and calcium.

Wien's Law will be used to ascertain an effective temperature for the star. A visual inspection of the curve, however, does not immediately provide a good estimate of where the peak energy wavelength lies. The line veiling in the central part of the spectrum is masking this, but it appears to lie somewhere between 4785 and 5736 Angstroms. Taking the median point and using 5260 Angstroms, Wien's Law returns an estimate of 5509K. The listed temperature for the star is 5333K[2]. Our estimate comes in too high this time, being off by 176K. Considering the guesswork involved, ours actually isn't a terribly inaccurate estimate.

β Sagittae

Beta Sagittae is classified as a late G-type star[1]. That being the case, we can expect to find a star somewhat cooler than our Sun, with lots of metal lines (particularly iron).

The processed spectrum is found here:

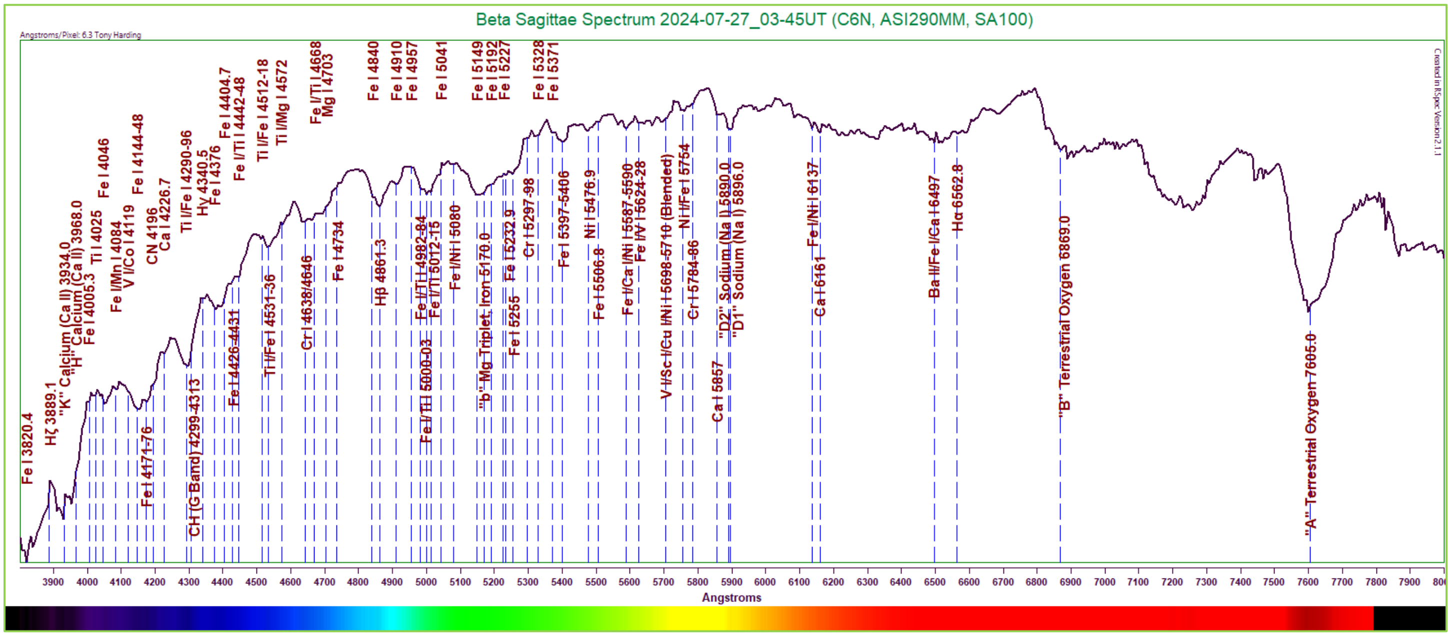

Figure 2: Beta Sagittae Spectrum (6.3 Angstroms/pixel)
Capture Details 2: Exposure 496ms, Gain 184, 29% of 732 frames stacked, Integration Time 105s

We can see here a spectrum curve not entirely unlike that obtained for Sham previously. The peak energy wavelength appears shifted toward somewhat longer wavelengths, though. The visible hydrogen Balmer lines are further weakened here. The Hα absorption is labeled, but the identification is somewhat suspect due to the noise in that region of the spectrum. The Fraunhofer K and H ionized calcium lines at 3934 and 3968 Angstroms are easily recognized, but they are somewhat weaker than for Sham. An obvious gouge in the continuum can be seen at 4119-4196 Angstroms due to a combination of vanadium, iron, and molecular CN. The CH (G Band) absorption at 4299-4313 Angstroms is also prominent, aided by the titanium/iron line just below it at 4290-96 Angstroms. The magnesium triplet at 5170 Angstroms is fairly deep and quite broad. The flanking iron lines help contribute to the overall absorption. The sodium doublet at 5890-96 Angstroms is not as strong, but is still notable. The neutral calcium line below it at 5857 Angstroms is distinctly visible as well. Other fainter metal lines labeled lots of iron, titanium, calcium, chromium, magnesium, vanadium, and barium. (Some of the lines are packed tightly together, so use caution when tracing the labels.)

We will once more use Wien's Law to obtain a rough temperature estimate. Like with Sham previously, the peak energy wavelength appears clouded by line veiling, but it appears to lie between the local peaks at 5825 and 6795 Angstroms. Using the median value of 6310 Angstroms, Wien's Law provides an estimate of 4592K. The established temperature for the star is listed as 4850K[2]. This puts our estimate off by approximately 260K.

γ Sagittae

Gamma Sagittae is classified as a very early M-type star[1]. We can expect to see results very different from the last two stars. The TiO lines so prominent in later M-type stars should be emerging. The low temperature should also be reflected in the peak energy wavelength being nearer the infrared region.

The completed spectrum follows:

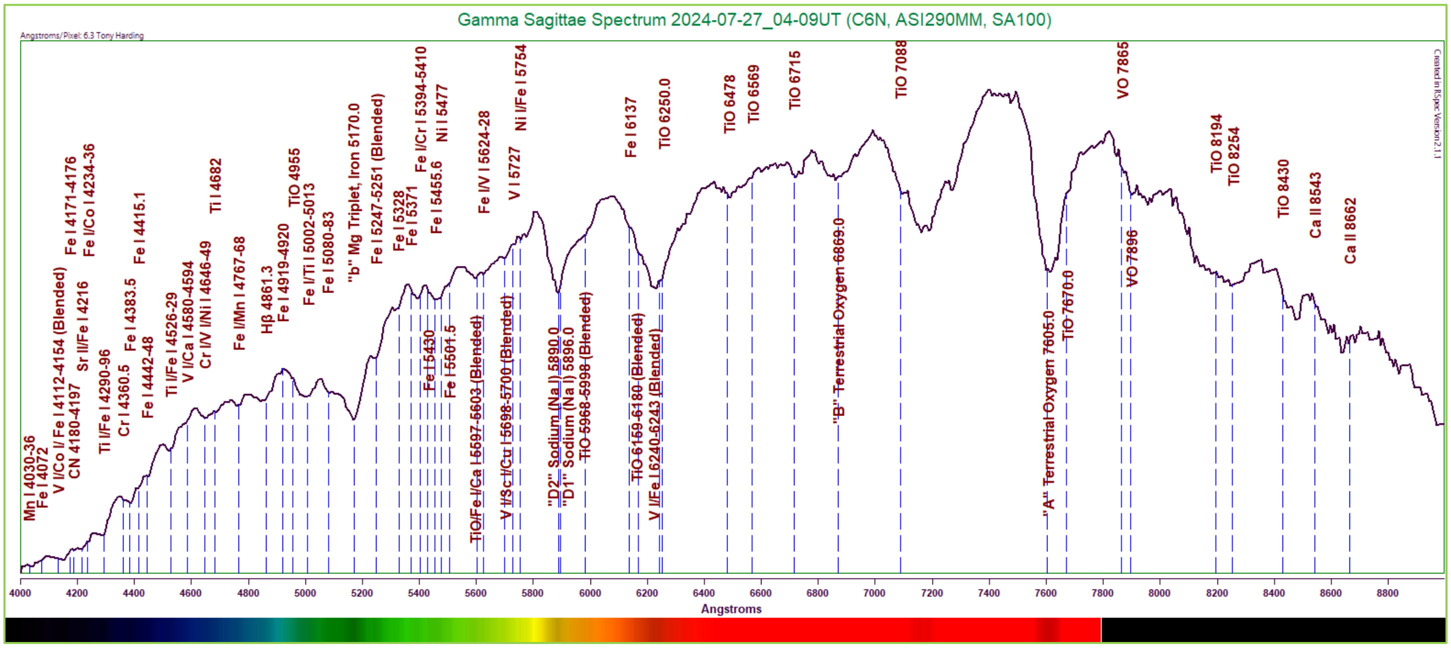

Figure 3: Gamma Sagittae Spectrum (6.3 Angstroms/pixel)
Capture Details 3: Exposure 365ms, Gain 140, 35% of 832 frames stacked, Integration Time 106s

Indeed, the curve of this spectrum is definitely different! The wavelength range has been altered from our normal range to 4000-9000 Angstroms; this will allow us to see a bit of the near infrared region. The only hydrogen Balmer line visible is the Hβ line. Several emergent TiO bands are visible, at 4955, 5597-5603 (blended with iron and calcium), 6159-6180, 6250, 6478, 6569, 7088, 7670, 8194, and 8254 Angstroms. The magnesium triplet at 5170 Angstroms and the sodium doublet at 5890-96 Angstroms are profoundly strong. Another major absorption is found at 6240-6250 Angstroms, caused by vanadium, iron, and molecular TiO. In the near infrared region, we observe molecular VO and ionized calcium, as well—though, these are weak. Other fainter absorptions labeled include manganese, iron, vanadium, molecular CN, strontium, titanium, chromium, and nickel.

Wien's Law will be used to obtain a rough temperature estimate of the star. A visual inspection of the curve indicates the peak lies near 7398 Angstroms. Using this value, we calculate a temperature estimate of 3917K. The listed temperature for the star is 3862K[2]. In this case, our estimate is very close!

δ Sagittae

Delta Sagittae is a spectroscopic binary, whose primary is classified as an early M-type star[1,2]. The secondary is a very early B-type star[1,2]. The primary is significantly brighter, but the spectrum may show some faint characteristics of the secondary as well if we are lucky.

The processed spectrum is presented below:

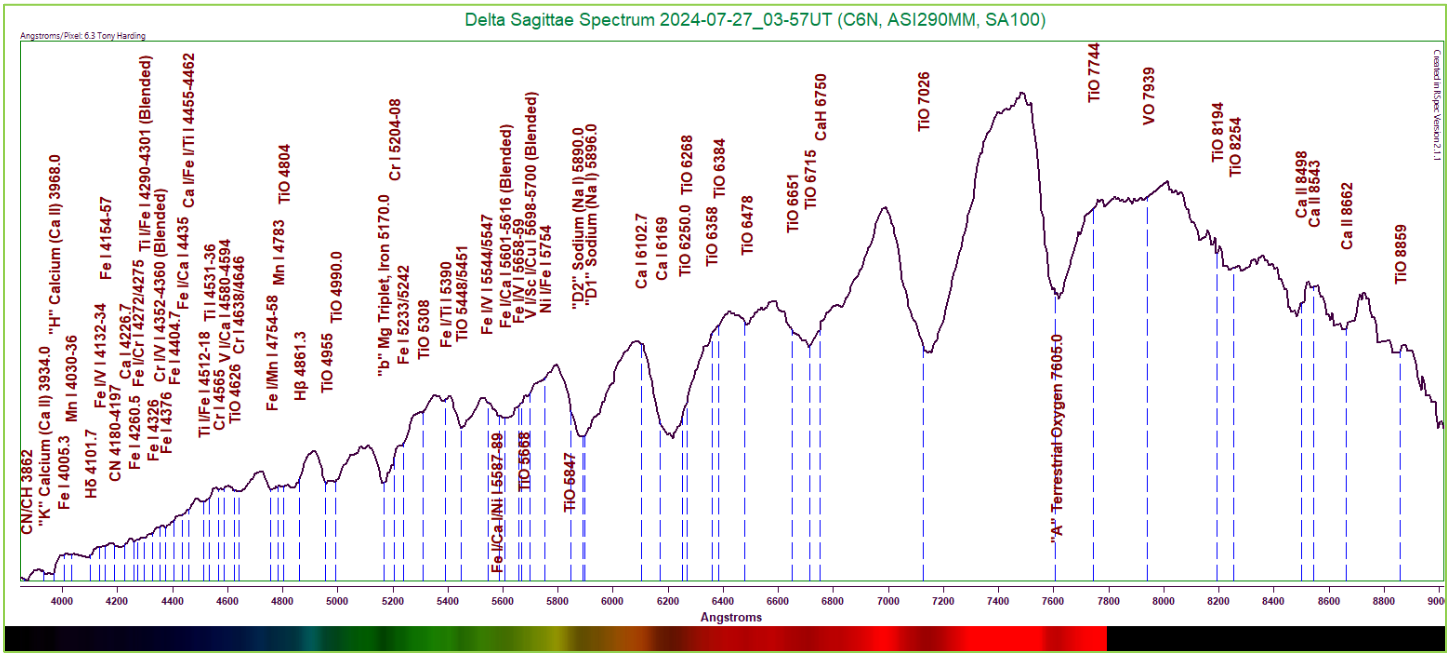

Figure 4: Delta Sagittae Spectrum (6.3 Angstroms/pixel)
Capture Details 4: Exposure 387ms, Gain 131, 35% of 784 frames stacked, Integration Time 106s

Getting a proper calibration and identifying absorptions on this one was unusually difficult. The general shape of this curve indicates an M-type star, certainly. Many of the labeled absorptions, particularly in the lower wavelength region, are extremely weak and therefore subject to uncertainty. For a star of this type, a greater than expected number of faint absorptions are noted, again particularly in the lower wavelength range. Only two of the hydrogen Balmer lines are visible here—Hβ and Hδ. As expected, we see a number of TiO lines—at 4626, 4804, 4955, 5308, 5448/5451, 6250, 6268, 6358, 6384, 6478, 6651, 7026, 7744, 8194, 8254, and (possibly) 8859 Angstroms. These range in strength from extremely weak to obvious. One VO line is labeled at 7939 Angstroms, but the continuum in that region appears muddled. The CN/CH absorption at 3862 Angstroms is visible, but not terribly strong, The CN molecular absorption at 4180-4197 Angstroms is very weak. The CaH molecular line at 6750 is apparent here also. The infrared calcium triplet at 8459, 8543, and 8662 Angstroms is evident, though the individual lines are somewhat weak. Other weak metals present include iron, manganese, calcium, titanium, chromium, vanadium, and nickel. The spectrum appears dominated by the early M-type primary star.

Using Wien's Law, we will obtain an approximate effective temperature. The peak of the energy distribution curve appears to lie at 7480 Angstroms. Using this value, we calculate a temperature of 3874K. The primary star is listed as having a temperature of 3660K[2]. Could the spectroscopic companion be throwing off our temperature estimate?

η Sagittae

Eta Sagittae is a single star classified as early K-type[1]. We can therefore expect to see a star cooler than the Sun, with a lot of metal lines present.

The spectrum is presented here:

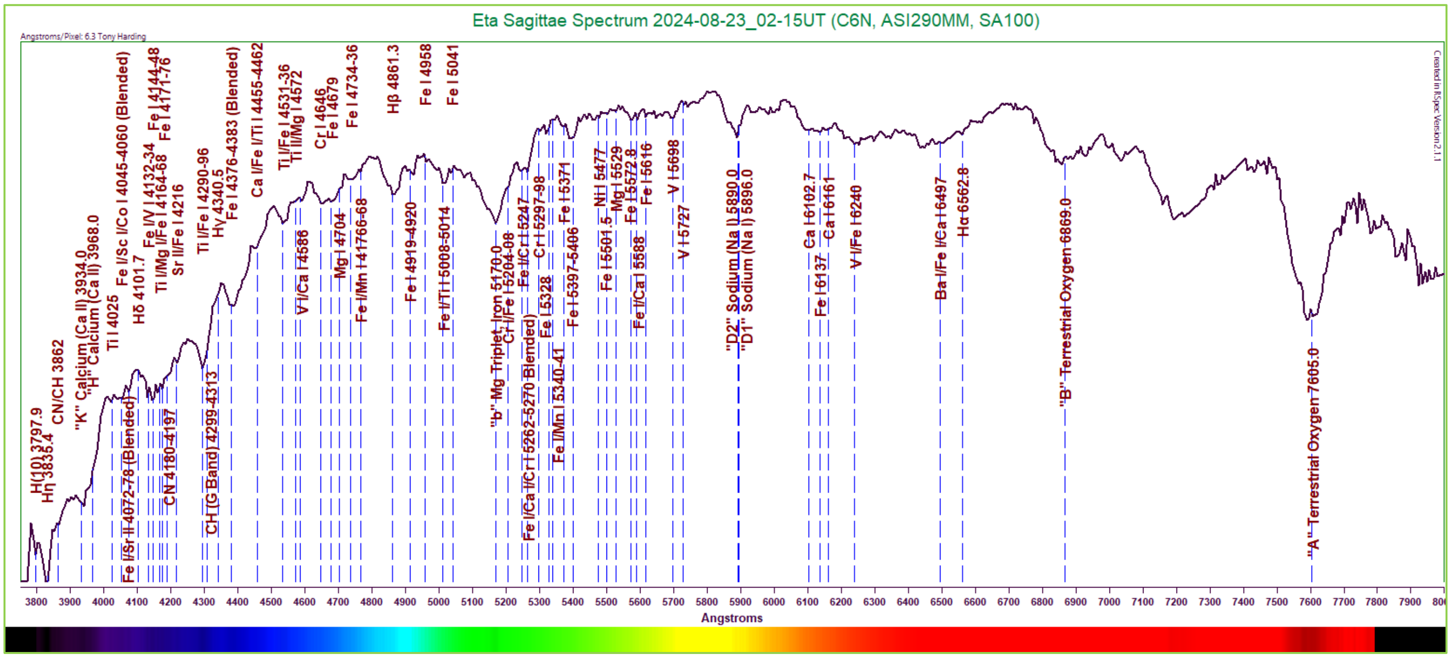

Figure 5: Eta Sagittae Spectrum (6.3 Angstroms/pixel)
Capture Details 5: Exposure 557ms, Gain 205, 30% of 651 frames stacked, Integration Time 108s

The general shape of the spectrum curve shows a specimen lying roughly between a late G-type and an early M-type star, which matches our expectations. Many of the lines are closely spaced here, so use caution when tracing labels. Only a few of the hydrogen Balmer lines are visible. However, the Hα line appears unusually sharp at 6562.8 Angstroms. The ionized calcium K and H lines at 3934 and 3968 Angstroms are present, but not nearly as strong as in the G-type stars. The CH (G Band) absorption at 4299-4313 Angstroms is quite strong, and is aided by a titanium/iron absorption just below it at 4290-96 Angstroms. The magnesium triplet is easily the strongest absorption present, carving a deep, sharp cut into the continuum. The sodium doublet at 5890-96 Angstroms is also quite strong. Other metals and molecules present include CN, CH, titanium, iron, strontium, calcium, vanadium, magnesium, chromium, nickel, and barium.

To employ Wien's Law, we must ascertain an approximate peak energy wavelength. For this spectrum, some significant line veiling appears to be concealing that region of the spectrum in which we would expect to find the peak. Making a very rough visual estimate, the peak appears to lie somewhere in the vicinity of 6033 Angstroms. With this value, we calculate an effective temperature of 4803K. The listed temperature for the star is 4784K[2]. Our estimate of off by only 19K!

Conclusion

I did miscapture one star during the initial run: Eta Sagittae. I had captured the star last year, but the quality of the capture was lacking, so I waited for the weather to clear to reacquire data for it. After this, the processing of the data produced no unexpected difficulties. It is very gratifying to finally get this constellation successfully completed!

Contact

Any comments, questions, criticisms, etc. can be directed to anthonyspectro@gmail.com.

References

[1]: As determined using Stellarium v1.1. (Of course, not all sources agree as to the exact stars used in forming the shapes of the constellations. Alternate designations are also applied to most stars.)
[2]: As indicated by Wikipedia.
[3]: *Spectral Atlas for Amateur Astronomers* by Richard Walker
[4]: *Spectroscopy for Amateur Astronomers* by Marc F. Trypsteen and Richard Walker
[5]: SAO/NASA ADS Database, *The Infrared Spectral Classification of M-Type Stars* by Stewart Sharpless (U.S. Naval Observatory, 1956)
[6]: As found on www.universeguide.com