Spectral Analysis of the Constellation Stars of Cygnus (The Swan)

Anthony S. Harding Jr.
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Abstract

This paper will elucidate the spectral features of the main stars in the constellation Cygnus. 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 confined to the stars forming the constellation lines.

The stars in the constellation will 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.

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. (Prior attempts with a color camera proved incredibly unreliable, so this camera was obtained specifically for this application.)

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.

Data Processing Details

Most of the spectra obtained for this analysis were obtained on the evening of July 22, 2023. However, upon processing the data it was discovered that the capture performed for Kappa Cygni was not correct; I had managed to capture the wrong star. So, on the evening of August 18, 2023 (EDT) a second capture was made (this time correct). Additional specifics for each capture are included with 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 times, 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 dark or flat frames were used for these captures. 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.

α Cygni

Alpha Cyngi, or Deneb, is classified as an early A-type star[1]. That being the case, we should expect to see prominent hydrogen Balmer lines in the spectrum.

The processed spectrum is as follows:

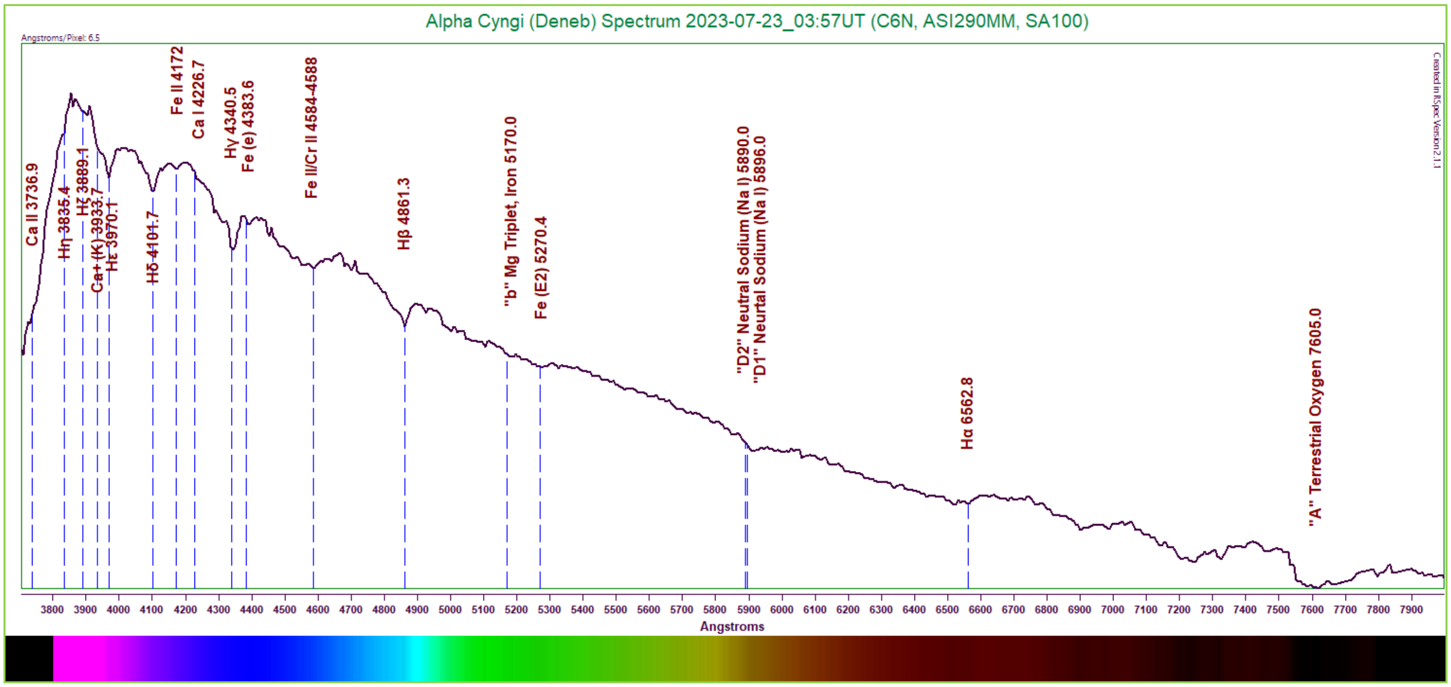

Figure 1: Alpha Lyrae (Deneb) Spectrum (6.5 Angstroms/pixel)
Capture Details 1: Exposure 165ms, Gain 80, 50% of 740 frames stacked

As expected, the hydrogen Balmer lines are evident, though the Hα absorption is quite weak. Even the other hydrogen Balmer lines are weaker than noted for the earliest A-type stars (such as Vega in Lyra). The Ca II line at 3736.9 Angstroms is evident, as are some others. The calcium K line is visible as a bump just below the Hε line. Between the Hδ and Hγ lines are two faint lines—one for ionized iron and one for neutral calcium. The Fe (e) line can be seen above this region, as well as a very broad and relatively deep absorption for ionized iron and chromium. The magnesium triplet is extremely weak, as is the Fe (E2) line, though they are causing a definite but subtle dip in the continuum. A bit stronger is are the sodium D1 and D2 lines at 5890-5896 Angstroms.

Applying Wien's Law, we can establish a very rough estimate of the star's effective temperature. Using a peak energy wavelength of approximately 3854 Angstroms, the temperature comes out to 7518K. (The star's established temperature is approximately 8525K[2].)

β-1 Cygni

Beta Cygni, better known as Albireo, is recognizable for its two component stars' striking contrast of colors. These stars were easily separated, so we will consider each independently.

β-1 Cygni is considered to be an early K-type star, and has a very close late B-type companion of its own[1,2]. Considering this, the spectrum should look quite different from that of Deneb above.

The processed spectrum is as follows:

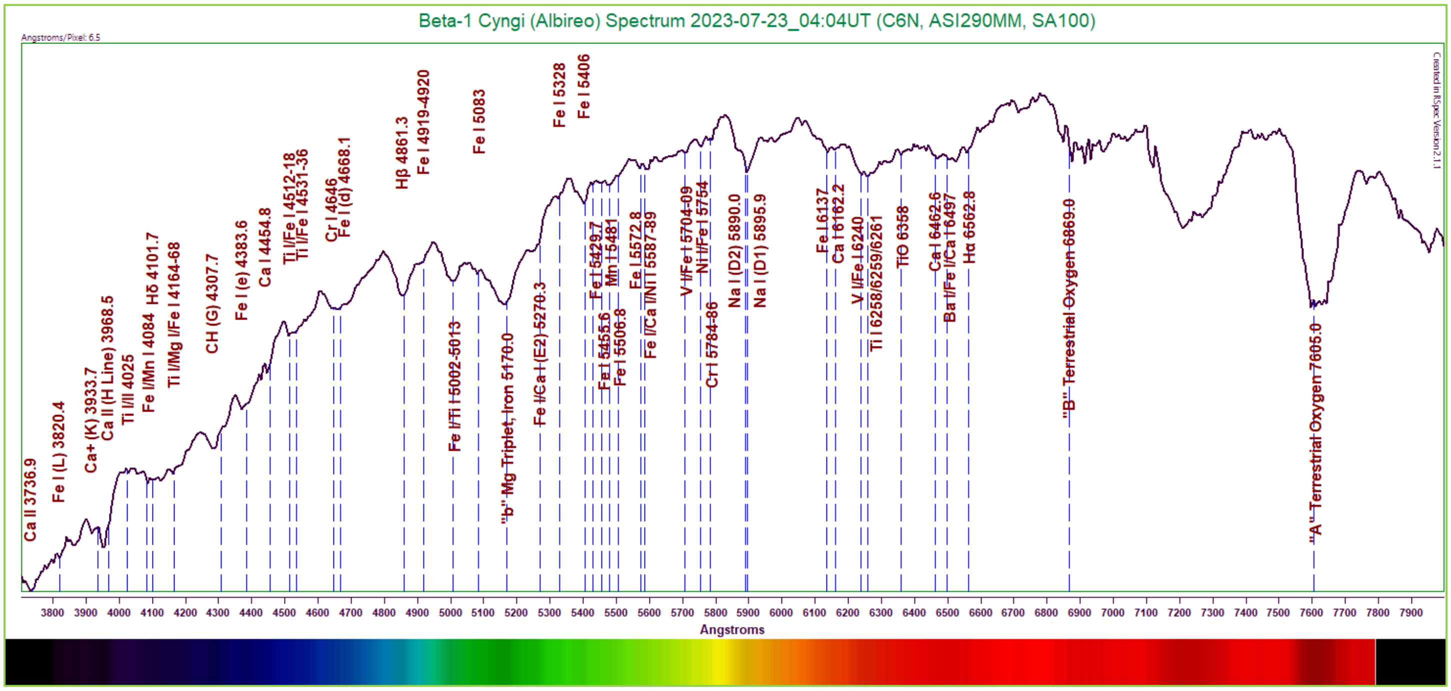

Figure 2: Beta-1 Cygni (Albireo) Spectrum (6.5 Angstroms/pixel)
Capture Details 2: Exposure 554ms, Gain 149, 60% of 225 frames stacked

As expected, this one is quite different. The spectrum is dominated by the K-type properties, showing iron, magnesium, and sodium lines. Some relatively strong hydrogen Balmer lines are still evident, particularly the Hβ line. A fairly strong Ca II absorption is still visible at 3736.9 Angstroms, along with a very weak Fe (L) line above it. The calcium H and K lines are combined to produce a notable absorption in the low wavelength region of the spectrum. The CH (G) band is also quite notable, along with neutral iron at 4383.6 Angstroms and neutral calcium at 4454.8 Angstroms. One TiO line is poking through at 6358 Angstroms. Both the magnesium triplet and the sodium D1 and D2 lines are quite prominent. A few more very weak calcium lines are also labeled.

Using Wien's Law with an estimated peak energy wavelength of 6778 Angstroms yields a very rough approximate effective temperature of 4275K. The currently accepted temperatures of the two components are 4383K and 10,000K[2]. Considering that the K-type primary dominates the spectrum, this is a very close estimate!

β-2 Cygni

Beta-2 Cygni is classified as a late B-type star[1]. That being the case, we might expect to see strong hydrogen Balmer absorptions, and possibly a weak helium line or two.

The processed spectrum is as follows:

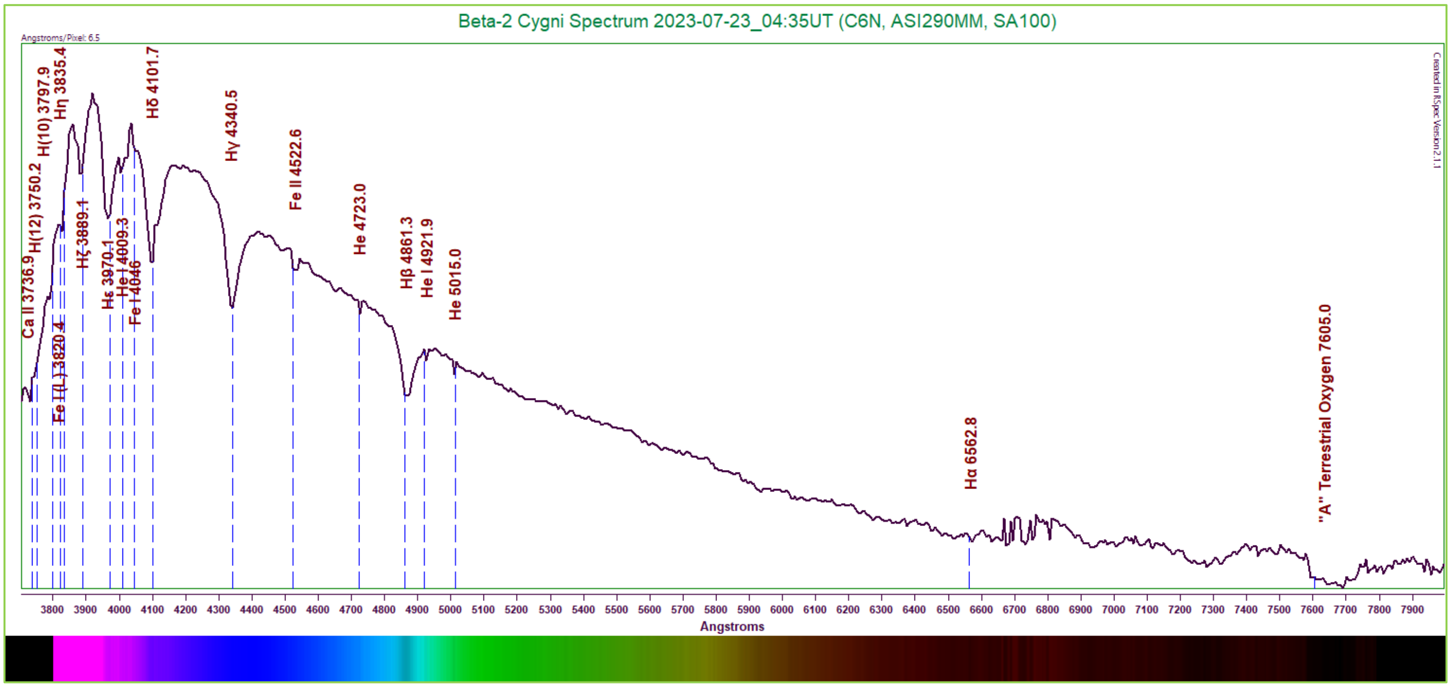

Figure 3: Beta-2 Cygni Spectrum (6.5 Angstroms/pixel)
Capture Details 3: Exposure 753ms, Gain 208, 55% of 167 frames stacked

As expected, β-2 Cygni shows the characteristic hydrogen Balmer lines, but slightly weaker than most of the cooler A-type stars. The Hα line is exceptionally weak. Three weak helium lines are present at 4009.3, 4723.0 and 5015.0 Angstroms. The Fe (L) line is combining with the Hη line to create a larger absorption around 3830 Angstroms. Another iron line can also be seen at 4046 Angstroms, Plus, an early peak indicates a high temperature.

Using Wien's Law with an estimated peak energy wavelength of 3919 Angstroms yields a very rough effective temperature of 7394K. The current accepted temperature is 13200K[2]. This is much higher than the estimate, which seems to consistently be the case when estimating temperatures for early type stars.

<u>γ Cygni</u>

Gamma Cygni, or Sadr, is classified as a late F-type star[1]. We should expect to see some very interesting features on this one.

The final spectrum follows:

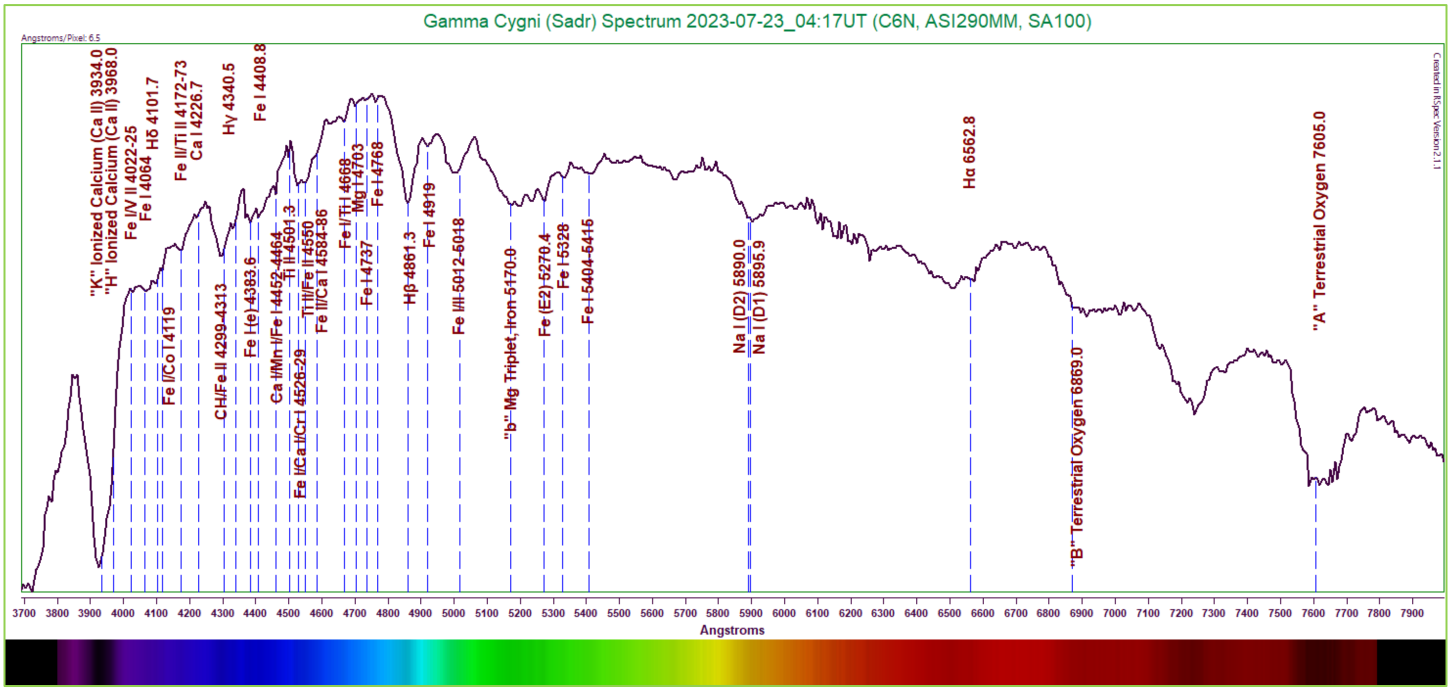

Figure 4: Gamma Cygni (Sadr) Spectrum (6.5 Angstroms/pixel)
Capture Details 4: Exposure 499ms, Gain 98, 65% of 248 frames stacked

The most immediately obvious feature is the extremely deep calcium H and K lines! Wow. Above this incredible absorption, we can see numerous iron and calcium lines. The Hγ line is very weak, showing up as only a bump at 4340.5 Angstroms. The iron and titanium absorptions at 4526-4550 Angstroms is impressively deep. The magnesium triplet can be seen, as well as the iron E2 line above it. The sodium D1 and D2 also show up very well. Also, a somewhat lower temperature is expected from the curve of the continuum.

Again we can employ Wien's Law to obtain a very rough estimate of the effective temperature of the star. Using an approximate peak wavelength of 4751 Angstroms results in a temperature of 6099K. The accepted temperature of the star is approximately 5790K[2]. In this case, our estimate is a bit too high.

δ Cygni

Delta Cygni, or Fawaris II, is a close double star. The primary is a very late B-type star, while its close companion is an early F-type star[2]. The double star is often listed as a combined very early A-type star[1,2].

The processed spectrum is as follows:

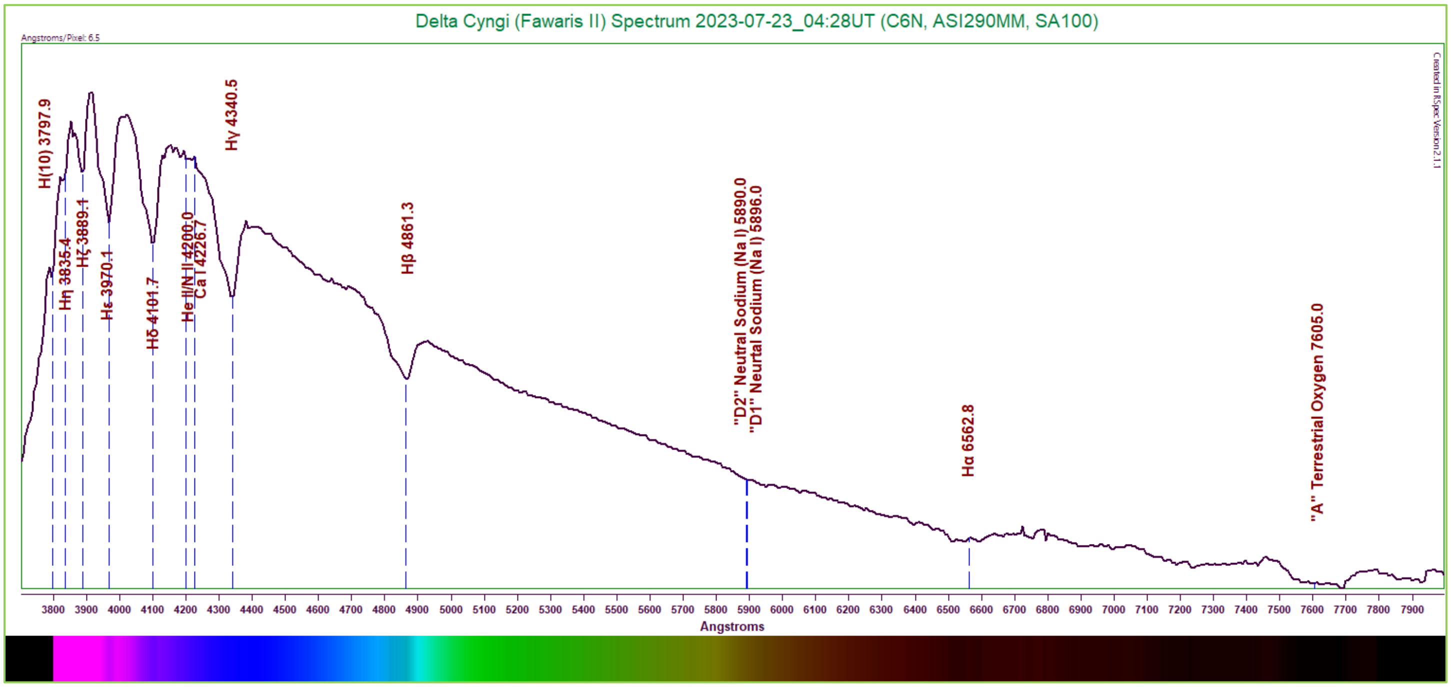

Figure 5: Delta Cygni (Fawaris II) Spectrum (6.5 Angstroms/pixel)
Capture Details 5: Exposure 742ms, Gain 77, 80% of 168 frames stacked

We can definitely see characteristics consistent with a very late B-type or very early A-type star. The hydrogen Balmer absorptions are clear, though perhaps slightly muted. The He II/N II absorption is evident, though weak. The adjacent calcium absorption at 4226.7 Angstroms is similar. The sodium D1 and D2 lines are only causing a subtle dip in the continuum, but this is visible.

Applying Wien's Law to the pair, we can obtain a temperature estimate of the stars. From the curve, we can probably expect this to be similar to an early A-type star, which the data suggests. Using an approximate peak energy wavelength of 3911 Angstroms, the effective temperature works out to 7409K. The established *combined* temperature of the two stars is 10150K[2]. Again, our estimate is too low.

ε Cygni

Epsilon Cygni, also known as Aljanah, is a multiple star system. Our equipment did not split these components, as they are much too close together, so our spectrum will be a composite of the stars involved. Taken collectively, the stars are regarded as a very early K-type star[1]. We should see some interesting features in this one.

The processed spectrum is as follows:

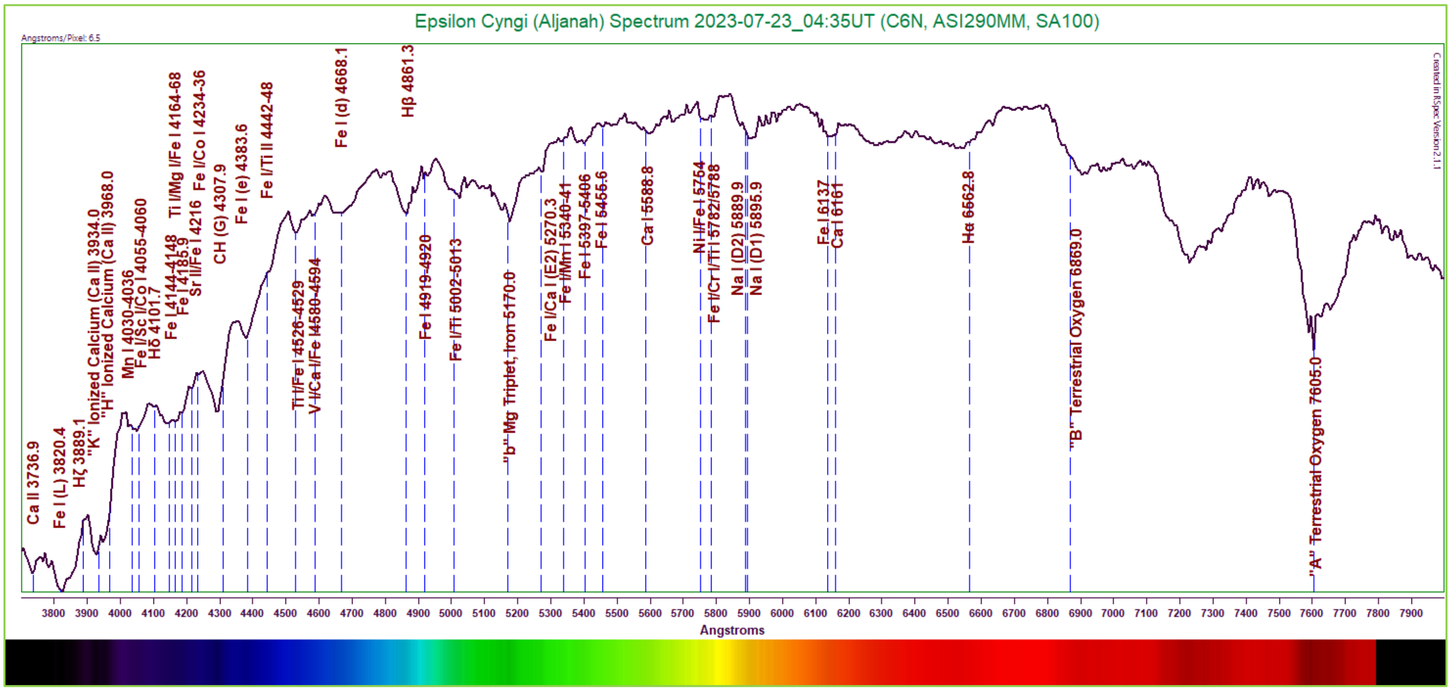

Figure 6: Epsilon Cygni (Aljanah) Spectrum (6.5 Angstroms/pixel)
Capture Details 6: Exposure 742, Gain 77, 80% of 166 frames stacked

As anticipated, we see many features of a cooler star, as the continuum curve seems to indicate. The hydrogen Balmer lines are subdued, but several can still be pulled out. An incredible number of metal lines are evident, particularly the various iron lines. The calcium H and K lines are causing a deep absorption in the lower wavelength region. In addition to iron, we can also see some manganese, titanium, strontium, vanadium, nickel, and calcium throughout. The CH (G) band is also quite conspicuous. The magnesium triplet is clear, as is the combined absorption for the sodium D1 and D2 lines. All-in-all, this is a very busy spectrum!

Using Wien's Law with an approximate peak energy wavelength of 6796 Angstroms, we obtain a very rough estimate of the effective temperature: 4264K. The established temperature is 4710K[2]. Not a terribly bad estimate.

ζ Cygni

Zeta Cygni, Fawaris III, is a binary system. The primary is a late G-type star, while the secondary is a white dwarf[1,2]. The smaller companion should not contribute anything to the spectrum. We should expect to see a spectrum not much different from that of Aljanah above.

The final, processed spectrum follows:

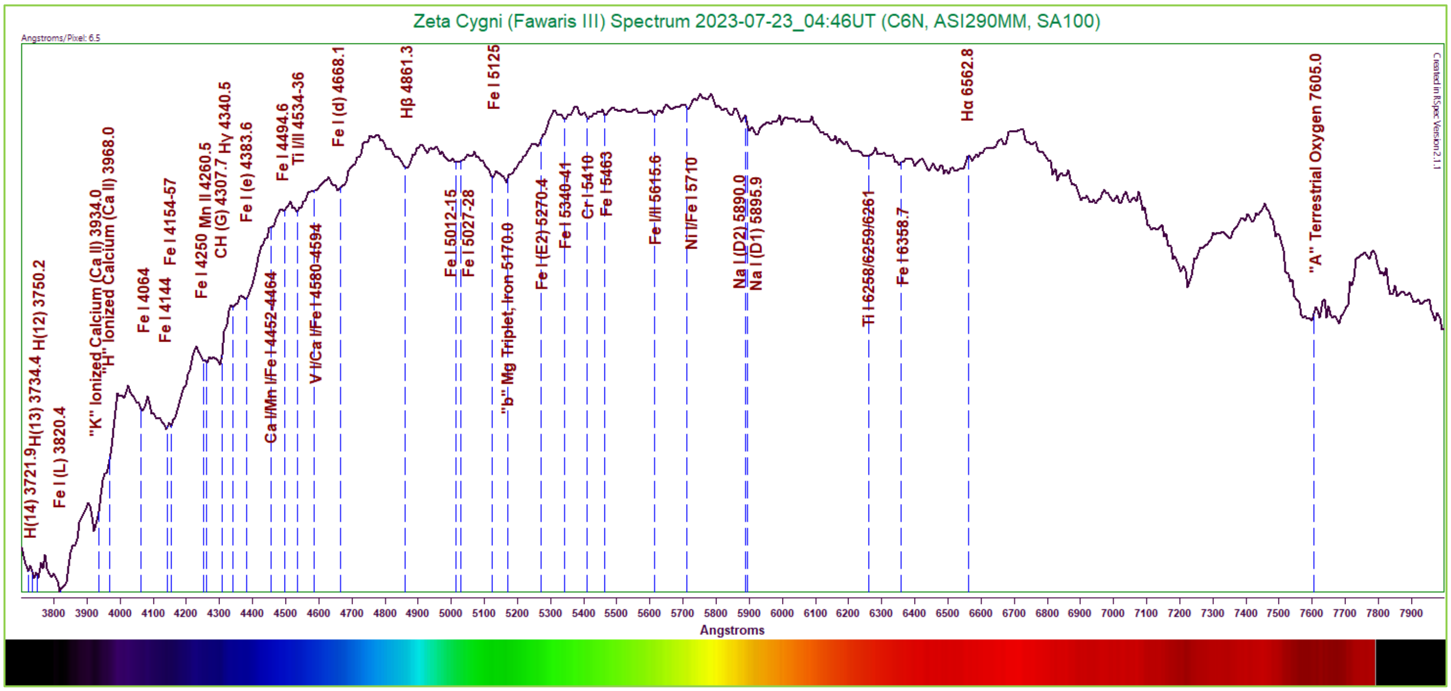

Figure 7: Zeta Cygni (Fawaris III) Spectrum (6.5 Angstroms/pixel)
Capture Details 7: Exposure 884ms, Gain 80, 100% of 44 frames stacked

This spectrum does resemble that of Aljanah, but there is less detail (probably due to the target's dimmer apparent magnitude). The iron line at 3820.4 Angstroms appears quite strong. The calcium H and K lines are also evident, though they are less intense. Several more iron lines, as well as the CH (G) band, appear as we climb up the wavelength scale. The only notable hydrogen Balmer line is the Hβ line; most of the others are hidden or subsumed by other lines. The magnesium triplet absorption is deep, and the iron E2 line can also be seen. The sodium D1 and D2 lines are also visible, though less pronounced.

We again use Wien's Law to obtain a very rough estimate of the effective temperature. Using an estimated peak energy wavelength of 5786 Angstroms, the temperature works out to 5008K. The accepted temperature is 4910K[2]—very close! This also matches our expectations, as the star should be a bit cooler than the Sun.

η Cygni

Eta Cygni is a visual multiple star composed of five components, though only one is physically bound to the primary. The separation of the components is too fine for my survey telescope to split, so the spectrum will be an amalgamation of them. The combined spectral type is regarded as a very early K-type[1].

The recorded spectrum is as follows:

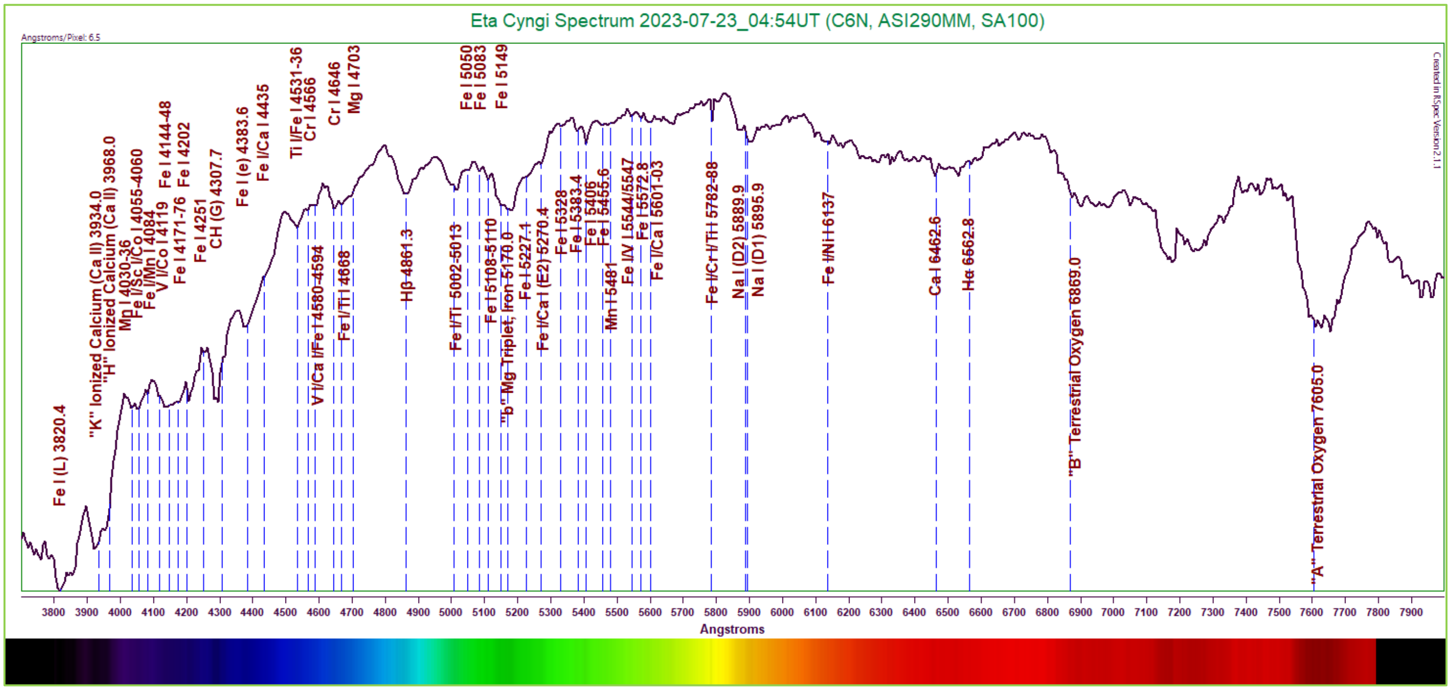

Figure 8: Eta Cygni Spectrum (6.5 Angstroms/pixel)
Capture Details 8: Exposure 800ms, Gain 149, 70% of 156 frames stacked

From the spectrum, it is easy to see that the K-type primary dominates here. A lot of metals are present in the spectrum. Again, the Fe I (L) line is pretty strong. The calcium H and K lines are fairly strong also. Some weak manganese and iron lines can be seen, along with another fairly strong CH (G) band absorption. Some more prominent iron, titanium, and chromium lines are visible, and a weakened Hβ absorption can also be seen. The magnesium triplet and the sodium D1 and D2 lines are evident. A calcium line at 6462.6 Angstroms stand out from the continuum level.

Accepting an estimated peak energy wavelength of 5827 Angstroms, Wien's Law provides a rough effective temperature of 4973K. The accepted value is 4783K[2]—our estimate is not too shabby!

ι Cygni

Iota Cygni, often called Iota-2 Cygni to avoid confusion with another, dimmer star in Cygnus which bears the same Bayer designation, is classified as a middle A-type star[1]. We can probably expect to see notable hydrogen Balmer features, though not as prominent as in earlier stars of the same type.

The processed spectrum follows:

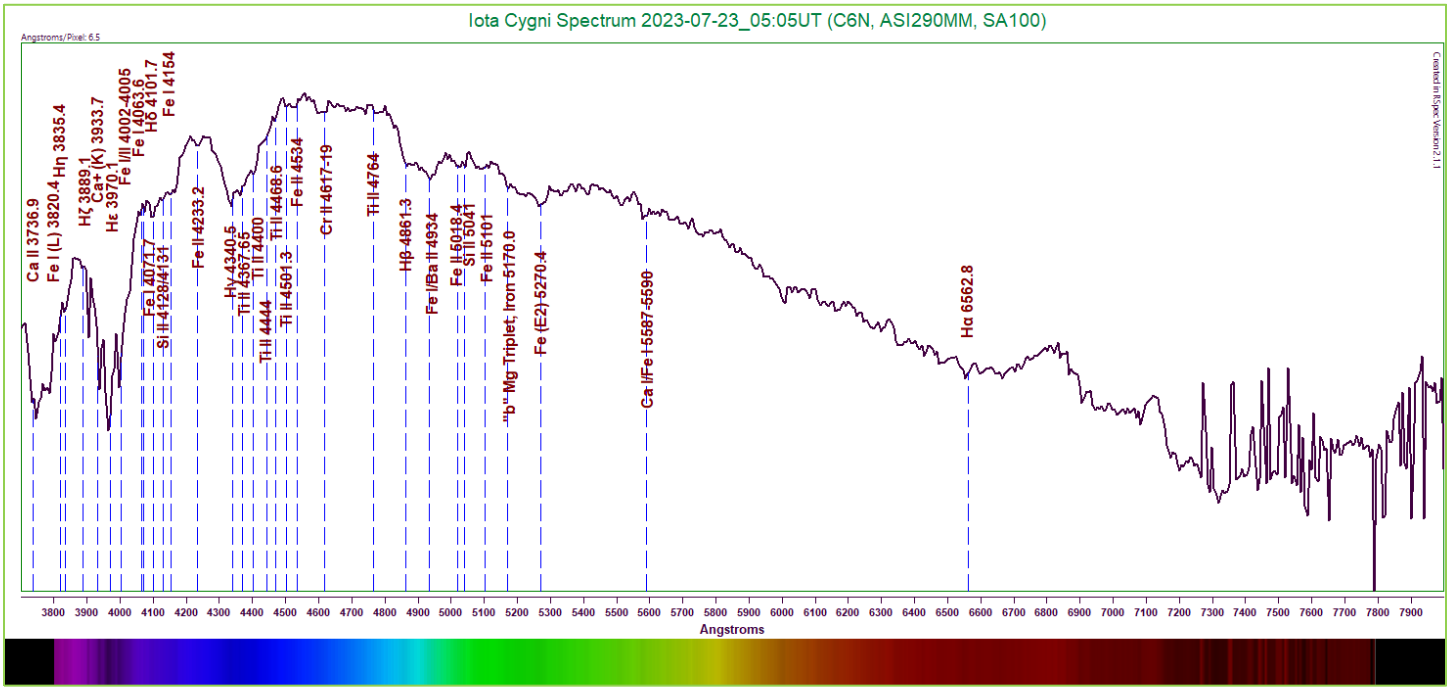

Figure 9: Iota Cygni Spectrum (6.5 Angstroms/pixel)
Capture Details 9: Exposure 3s, Gain 178, 85% of 59 frames stacked

This capture turned out very noisy, but some features can still be identified. The hydrogen Balmer lines can be seen here, though they are somewhat weakened. The calcium II line at 3736.9 Angstroms is strongly visible at the extreme low wavelength range. The Fe I (L) line and Hη line are separated and distinct, though weak. The Ca K line can be seen alongside the Hε line. A conspicuous iron line at 4002-4005 Angstroms is also visible. Additional metals—iron, silicon, titanium, chromium, and calcium can be seen throughout, though most appear very weak.

Wien's Law can be employed to obtain a very rough estimate of the star's effective temperature. Using an estimated peak energy wavelength of 4558 Angstroms, the temperature comes out to 6358K. The established temperature for the star is 8216K[2].

κ Cygni

This is the star that delayed the publishing of this analysis (due to an error in capturing data for the wrong star the first time through). Kappa Cygni, Fawaris I, is designated as a very late G-type star[1]. We should expect to see spectral features of a star a little cooler than the Sun.

The captured spectrum is as follows:

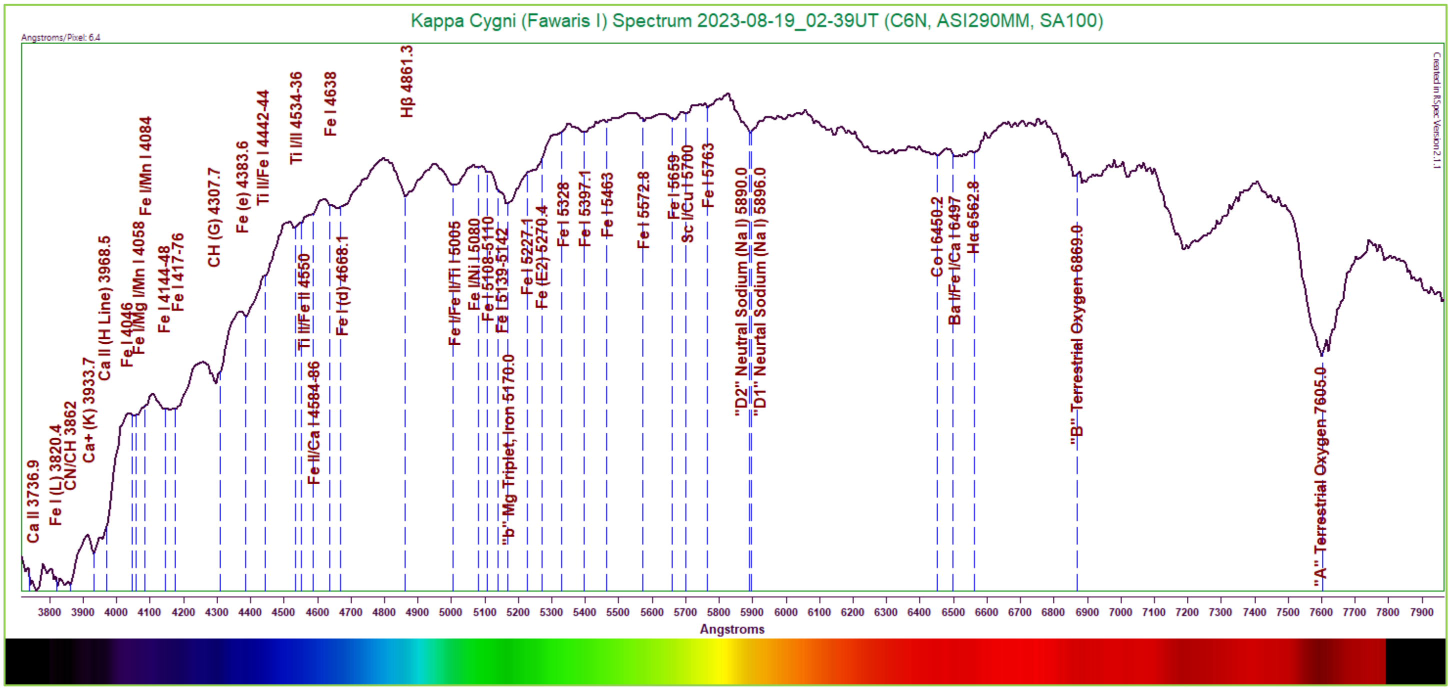

Figure 10: Kappa Cygni (Fawaris I) Spectrum (6.4 Angstroms/pixel)
Capture Details 10: Exposure 496ms, Gain 196, 55% of 369 frames stacked

As anticipated, we see definite features of a slightly cooler star, with a peak energy wavelength shifted to the right. Very small calcium and iron lines can just barely be seen at the extreme low end of the wavelength scale. Just above them, a significant dip from the CN/CH band is obvious. The calcium H and K lines carve a prominent bite out of the continuum. Above these, we see numerous metals indicated by subtle (and not so subtle) absorptions. The Hβ line is fairly strong. The magnesium triplet and sodium D1 and D2 lines are fairly easy to recognize here as well. The Hα absorption appears broad and ill-defined.

Using Wien's Law with an estimated peak energy wavelength of 5828 Angstroms, we obtain a very rough effective temperature estimate of 4972K. The currently accepted temperature is 4920K[2]. Very close!

<u>μ-1 Cygni</u>

Mu Cygni is a binary system, which the survey equipment was able to split. We will therefore consider each component individually.

Mu-1 Cygni is classified as a middle F-type star[1]. We should therefore expect the spectrum to reflect a moderately warm star, one a little hotter than our Sun.

The processed spectrum follows:

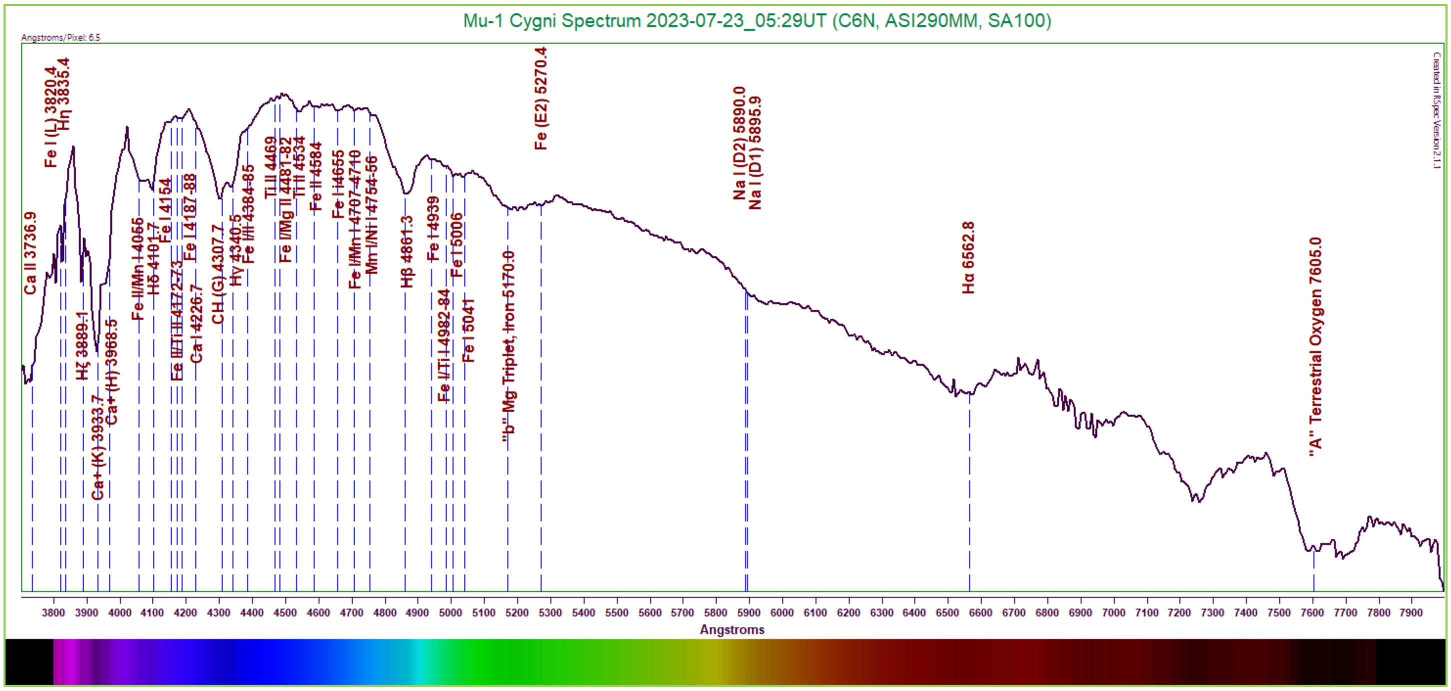

Figure 11: Mu-1 Cygni Spectrum (6.5 Angstroms/pixel)
Capture Details 11: Exposure 3s, Gain 140, 100% of 59 frames stacked

As expected, the spectrum curve does reflect features of the appropriate star type. However, there isn't a lot of detail available, and the results are rather noisy. (This is likely due to the low apparent magnitude of the star). The Ca II line at 3736.9 Angstroms is clear. Above this, the Fe I (L) and Hη lines are rather blurred together. The Hζ line is present, but the deep Ca K line at 3933.7 Angstroms steals the show. The Ca H line shows up as a bump just above the Ca K line, beginning to overpower the Hε line. Additional metal lines, including iron, calcium, titanium, and manganese also appear. The CH (G) line is strong, cutting deep into the continuum. The magnesium triplet and sodium D1 and D2 lines are identifiable, though the magnesium absorption is notably stronger.

Again we use Wien's Law to obtain a very rough effective temperature estimate. Using an estimated peak energy wavelength of 4488 Angstroms, the resulting temperature is 6457K. The established temperature is 6354K[2], fairly close to our estimate!

µ-2 Cygni

Our final star in this survey, Mu-2 Cygni, is classified as an early F-type star[1]. It should display a spectrum curve indicating a temperature a bit hotter than the Sun, and warmer than Mu-1 above.

The processed spectrum for Mu-2 Cygni is as follows:

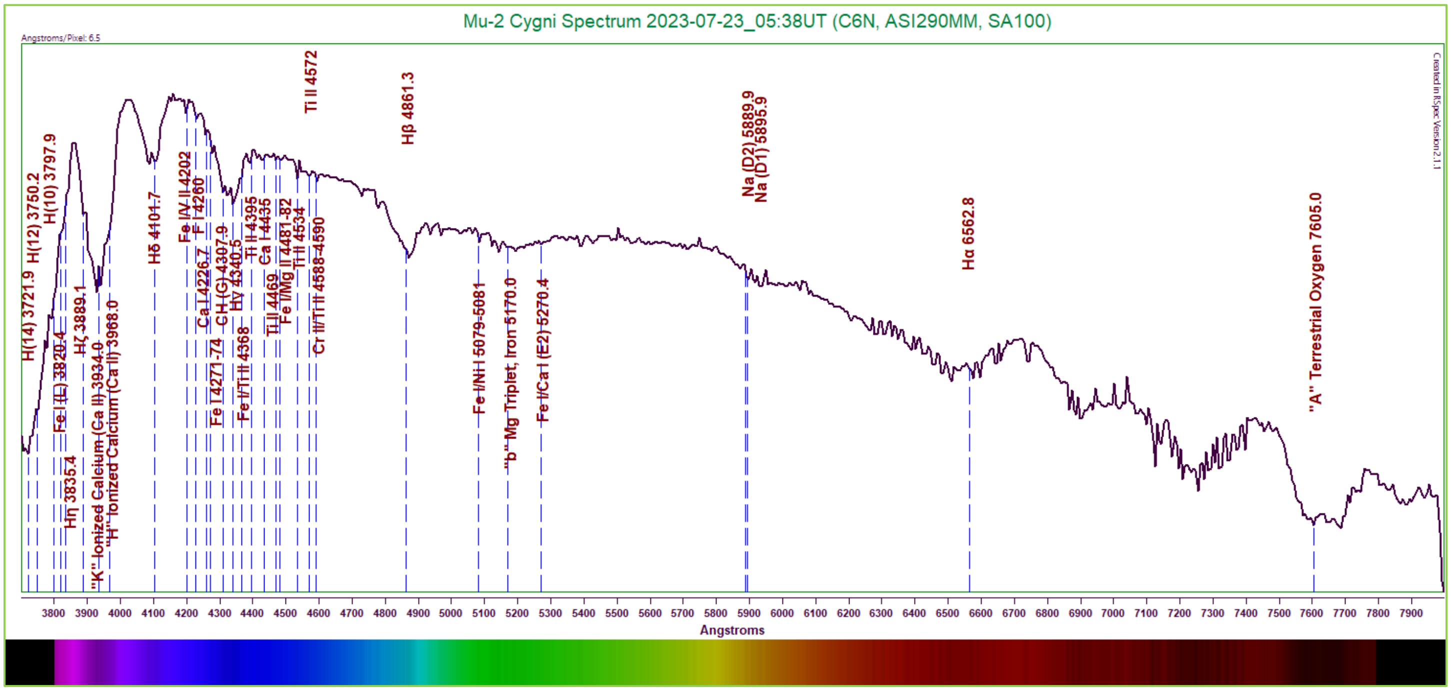

Figure 12: Mu-2 Cygni Spectrum (6.5 Angstroms/pixel)
Capture Details 12: Exposure 5s, Gain 220, 90%of 48 frames stacked

These results are generally in line with expectations. The peak of the curve is a bit more toward the lower wavelength range, indicating a higher temperature. Again, the spectrum appears noisy due to the difficulties of capturing the dimmer target. However, the hydrogen Balmer series is well-represented. The calcium H and K lines cut a deep absorption groove into the continuum here. Iron, calcium, titanium, and chromium appear as faint absorptions in the continuum. The CH (G) band absorption appears as a dip just below the Hγ line. The magnesium triplet appears weak here. The sodium doublet at 5890-96 Angstroms is marked, but is scarcely discernible from the noisy continuum.

Using Wien's Law, we can obtain a very rough estimate of the effective temperature of the star. Using an estimated peak energy wavelength of 4160 Angstroms, the temperature works out to 6966K. The accepted temperature is 5998K[2].

Conclusion

This was the second run through constellation stars for the project. Aside from the snafu of grabbing data for an incorrect star, the process went well. The tasks of identifying features and gauging a star's general type by its curve are definitely becoming easier.

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