Spectral Analysis of the Constellation Stars of Boötes (The Herdsman)

Anthony S. Harding Jr.

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Abstract

This paper will elucidate the spectral features of the main stars in the constellation Boötes. 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 mostly 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.

Data Processing Details

All of the spectra obtained for this analysis were obtained on the evening of April 5, 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 set of acquisitions was done on the same night as the data collection for the stars of Leo. The combined session was long (about 5 hours), but very productive.

α Boötis

Alpha Boötis, known more commonly by the name Arcturus, is classified as an early K-type star[1]. This specimen should demonstrate a curve consistent with a cooler star, showing lots of metals spread throughout.

The processed spectrum is as follows:

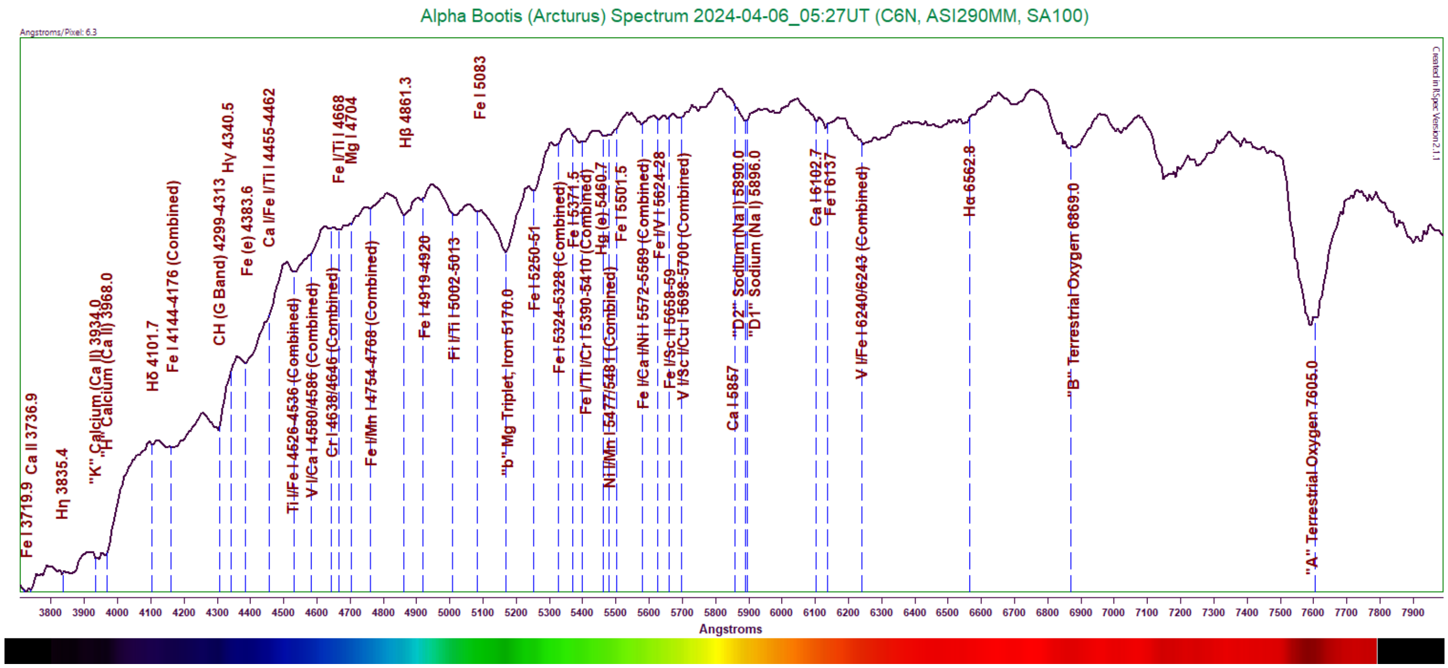

Figure 1: Alpha Boötis (Arcturus) Spectrum (6.3 Angstroms/pixel)
Capture Details 1: Exposure 180ms, Gain 0, 65% of 1012 frames stacked

The spectrum curve is consistent with a cooler star, with the highest points of the curve tending toward the higher wavelength end. One other aspect that is worth mention is the unusually high number of blended/combined lines in this spectrum. Several of the hydrogen Balmer lines are still visible, but weak to very weak in appearance. There is a significant dip at the extreme lower end of the spectrum at 3719-3734 Angstroms due to neutral iron and ionized calcium. The calcium H and K lines are strong, causing a strong trough in the continuum. The CH (G) band is also prominent at 4299-4313 Angstroms. The magnesium triplet is extraordinarily prominent, as is usual for stars of this type. The sodium doublet is also visible, though not as strongly. A number of additional, fainter metals are present here, including numerous neutral iron lines, calcium, titanium, vanadium, chromium, magnesium, mercury, and nickel.

Employing Wien's Law, we can obtain as estimate of the star's effective temperature. The peak energy wavelength is difficult to determine here, appearing to lie somewhere between the peaks at 5816.8 and 6752.6 Angstroms. Averaging these, we will adopt a value of approximately 6285 Angstroms. Wien's Law then provides a result of approximately 4611K. The actual temperature of the star is listed as 4286K[2]. Considering the lack of certainty in our peak energy wavelength estimate, our result, though too high, isn't terribly bad.

β Boötis

Beta Boötis, also known by the name Nekkar, is classified as a late G-type star[1]. We should expect to see a star somewhat cooler than our Sun, but warmer than Arcturus above, with lots of metal lines present, particularly iron.

The processed spectrum is as follows:

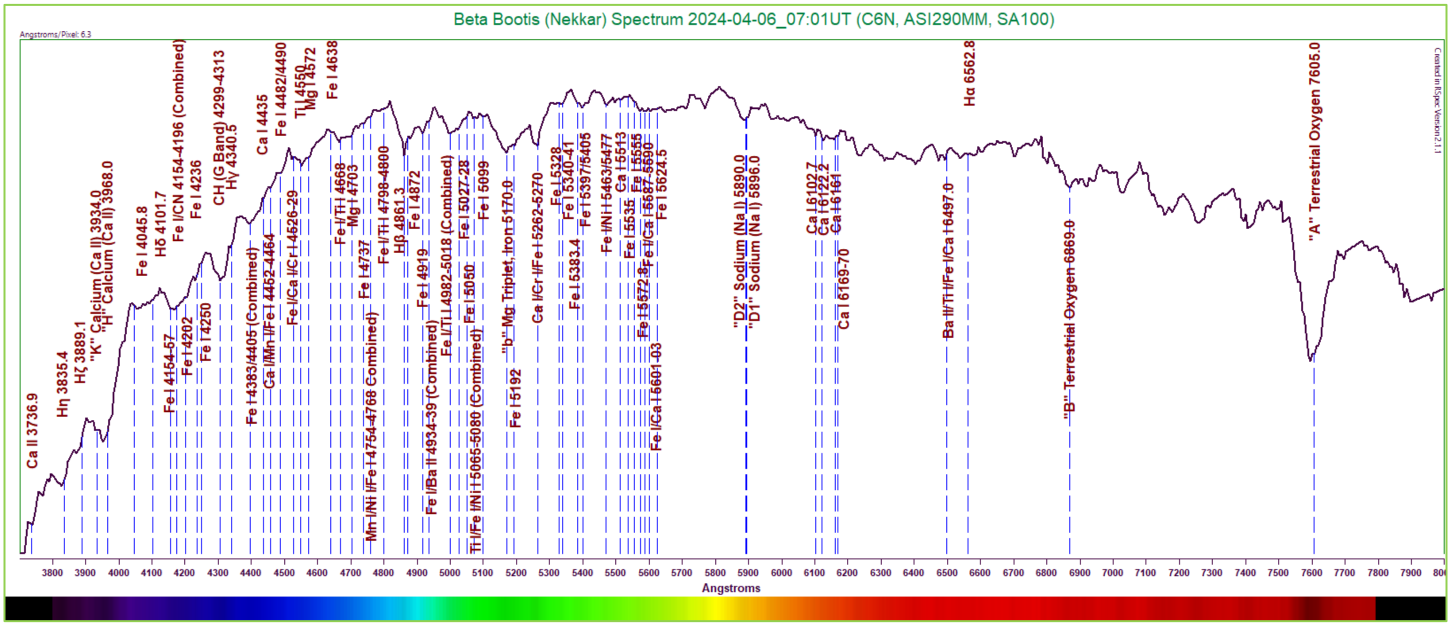

Figure 2: Beta Boötis (Nekkar) Spectrum (6.3 Angstroms/pixel)
Capture Details 2: Exposure 463ms, Gain 107, 65% of 525 frames stacked

As anticipated, we have a spectrum with tightly packed metal lines. (Be cautious when tracing them, as distinguishing them can be difficult!) Some of the hydrogen Balmer lines are present here, but definitely leaning to the weak side. The calcium K and H lines at 3934 and 3968 Angstroms are carving out a nice section of the continuum curve. The iron/CN blended line at 4154-4196 Angstroms is also carving a nice scoop out of the curve, along with its flanking iron lines. The CH (G) band is sharper at 4299-4313 Angstroms, with the Hγ line displayed very faintly above it. Another notable, but smaller, valley is seen at 4526-4572 Angstroms, caused by iron, titanium, and magnesium. The magnesium triplet at 5170 Angstroms is also notable. The calcium/chromium/iron absorption at 5262-5270 Angstroms is almost as deep. The sodium doublet at 5890-96 Angstroms is easily spotted, and appears a bit broadened at the bottom. A large number of smaller features can be seen along the spectrum including calcium, a lot of iron, magnesium, manganese, titanium, and barium.

Using Wien's Law, we will attempt to estimate the star's temperature. Visually inspecting the curve, the peak would appear to lie in the vicinity of 5812 Angstroms. Using this value, we arrive at temperature of 4986K. The listed value for the temperature is 4932K[2]. In this case, our estimate comes out pretty close! It also falls in the range we were hoping for, between that of our Sun and Arcturus.

γ Boötis

Gamma Boötis, also known as Seginus, is a double star classified as a late A-type[1]. In this case, the companion is too dim to register with our equipment, and will therefore not interfere with interpreting the spectrum of the primary. With this in mind, we should expect to find fairly prominent hydrogen Balmer lines, along with some faint metals sprinkled in. The curve of the spectrum should represent a fairly hot star.

The processed spectrum is found here:

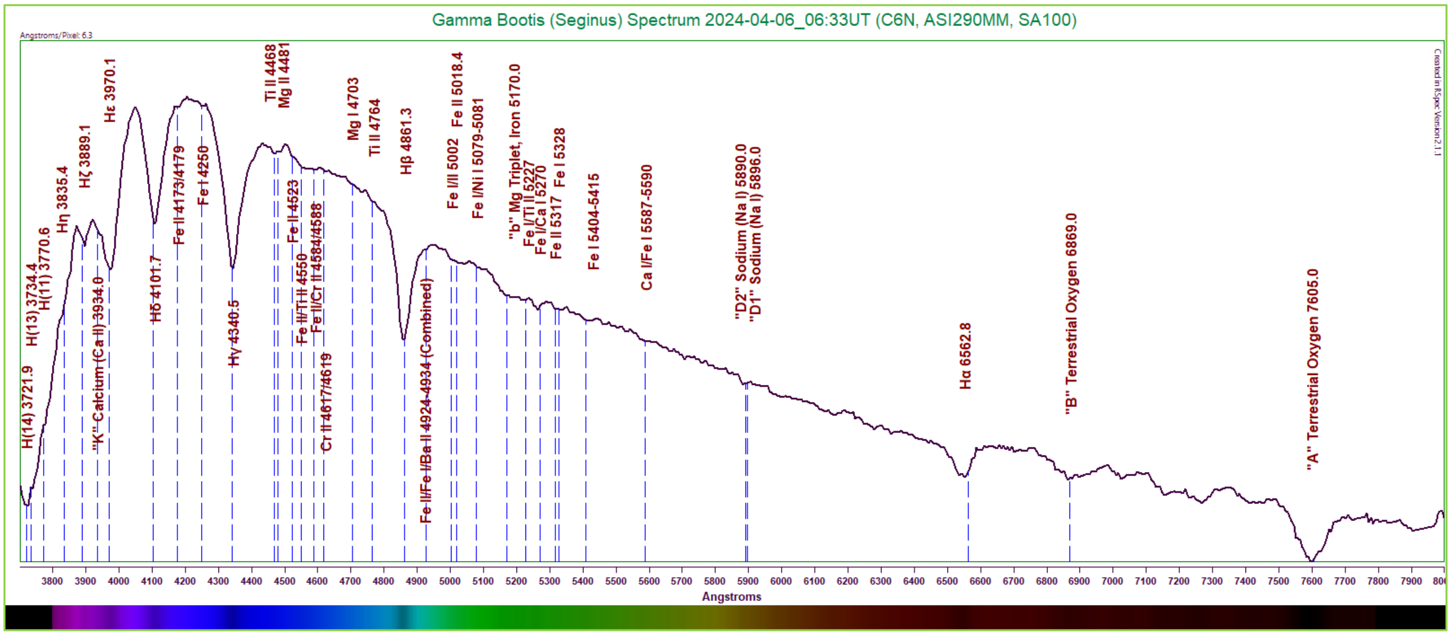

Figure 3: Gamma Boötis (Seginus) Spectrum (6.3 Angstroms/pixel)
Capture Details 3: Exposure 506ms, Gain 116, 65% of 479 frames stacked

The hydrogen Balmer lines in this spectrum are very strong! At 3934 Angstroms we can see the slight bump due to the calcium K absorption sitting on the lower side of the Hε line. A nice double absorption can be seen at 4468 and 4481 Angstroms, due to adjacent ionized titanium and ionized magnesium. Above that, a notable scoop can be seen taken out of the continuum due to a combination of ionized iron lines at 4523, 4550, and 4584/88 Angstroms. Above the Hβ absorption, another significant dip can be seen—again caused by ionized iron. This one covers the 5002-5018 Angstroms range. The magnesium triplet at 5170 Angstroms is visible, along with several adjacent iron lines. The sodium doublet carves out a distinct but small cut at 5890-96 Angstroms. Other, fainter metals noted include iron, chromium, magnesium, titanium, and calcium.

Wien's Law will now be applied to obtain a temperature estimate. However, since this is an A-type star, we must accept that our estimate will be too low. Using a visually estimated peak energy wavelength of 4206 Angstroms, the result comes out to approximately 6890K. The accepted temperature of Seginus is listed as 7800K[2]. As expected, the estimate falls significantly short.

δ Boötis

Delta Boötis, also known by the name Thiba, is a suspected double star[2]. The primary is classified as a late G-type star[1]. The secondary component is very dim, and should not interfere with our analysis. Considering the type of the primary, we can expect to see a star a little cooler than our Sun, with a lot of metal lines.

The spectrum is presented below:

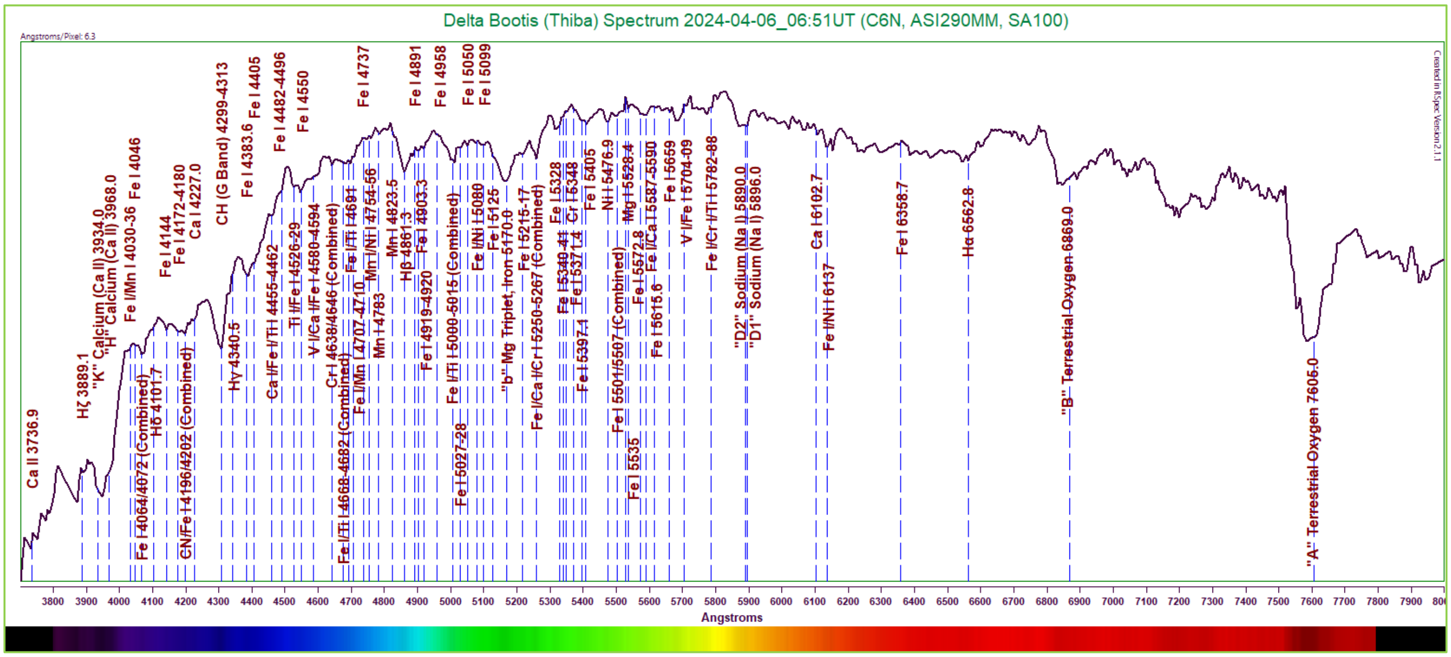

Figure 4: Delta Boötis (Thiba) Spectrum (6.3 Angstroms/pixel)
Capture Details 4: Exposure 528ms, Gain 92, 65% of 354 frames stacked

Wow, this one indeed shows a lot of faint metal lines! Many of the hydrogen Balmer lines can be identified, but they do tend to be weak. The calcium K and H lines at 3934 and 3968 Angstroms are quite strong, carving a deep gouge out of the continuum. The CH (G) band is sharp and well defined at 4299-4313 Angstroms. The magnesium triplet at 5170 Angstroms appears obviously, also showing a sharp cut in the continuum curve. The sodium doublet at 5890-96 Angstroms is also easily identifiable. The absorption appears to be broadened by an adjacent line just below it, but attempts to identify this failed. Many additional faint metal lines are labeled, including calcium, copious amounts of iron, CN, calcium, vanadium, chromium, manganese, nickel, and magnesium. With the identified lines being packed so closely together, take great care when tracing labels!

Using Wien's Law, we will ascertain the effective temperature of the star. Using a visually estimated peak energy wavelength of 5831 Angstroms, we arrive at a temperature of approximately 4970K. The listed temperature for the star is 4847K[2]. Our estimate is only off by 123K!

ε Boötis

Epsilon Boötis, also called Izar, is a double star whose primary is regarded as a very early K-type star[2]. Though our equipment is not capable of separating the two components, the primary is much more luminous and should therefore dominate the spectrum. We should expect a curve representative of a cooler star, with many metals present.

The finished spectrum follows:

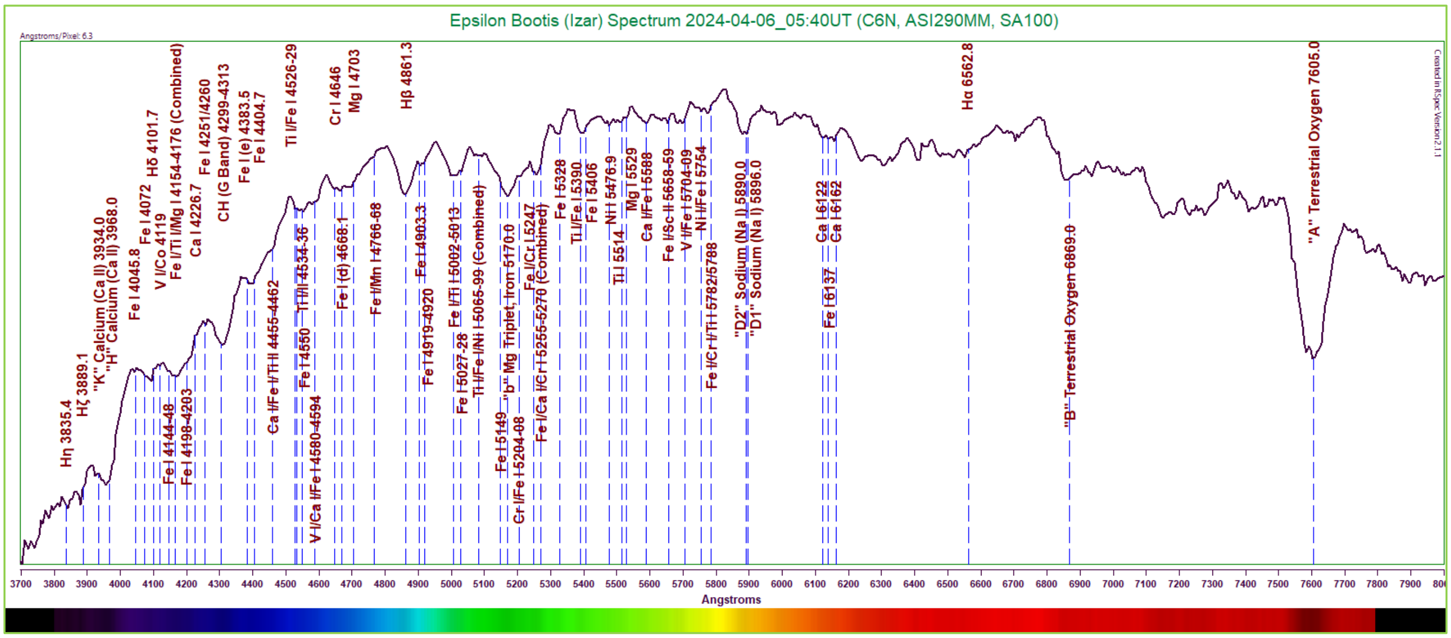

Figure 5: Epsilon Boötis (Izar) Spectrum (6.3 Angstroms/pixel)
Capture Details 5: Exposure 303.226ms, Gain 95, 65% of 602 frames stacked

This spectrum strongly resembles the one obtained for Thiba above. The hydrogen Balmer lines are similar in appearance. The calcium K and H lines at 3934 and 3968 Angstroms are again strong. The CH (G) band at 4299-4313 Angstroms is very distinct. The magnesium triplet is pronounced, appearing here with flanking iron and chromium lines. The sodium doublet at 5890-96 Angstroms appears very similarly here, too. Other fainter identified metals include lots of iron, vanadium, calcium, chromium, magnesium, titanium, and nickel. Some of the absorptions are very close together, so be careful when tracing the labels.

Employing Wien's Law once more, we will estimate the star's temperature. With this target's spectrum so similar to that of Thiba, we should expect a similar result. Using a visually estimated peak energy wavelength of 5824 Angstroms, we arrive at an estimate of 4976K. The listed temperature for the star is 4550K[2]. In this case, our estimate came in a bit too high.

ζ Boötis

Zeta Boötis is a very close double star. However, both stars are of the same early A-type[2], so their combined light should pose no abnormalities. We should expect to see strong hydrogen Balmer lines in this spectrum, with a few metal lines peeking through the continuum. The curve should be consistent with a hotter star.

The processed spectrum is presented below:

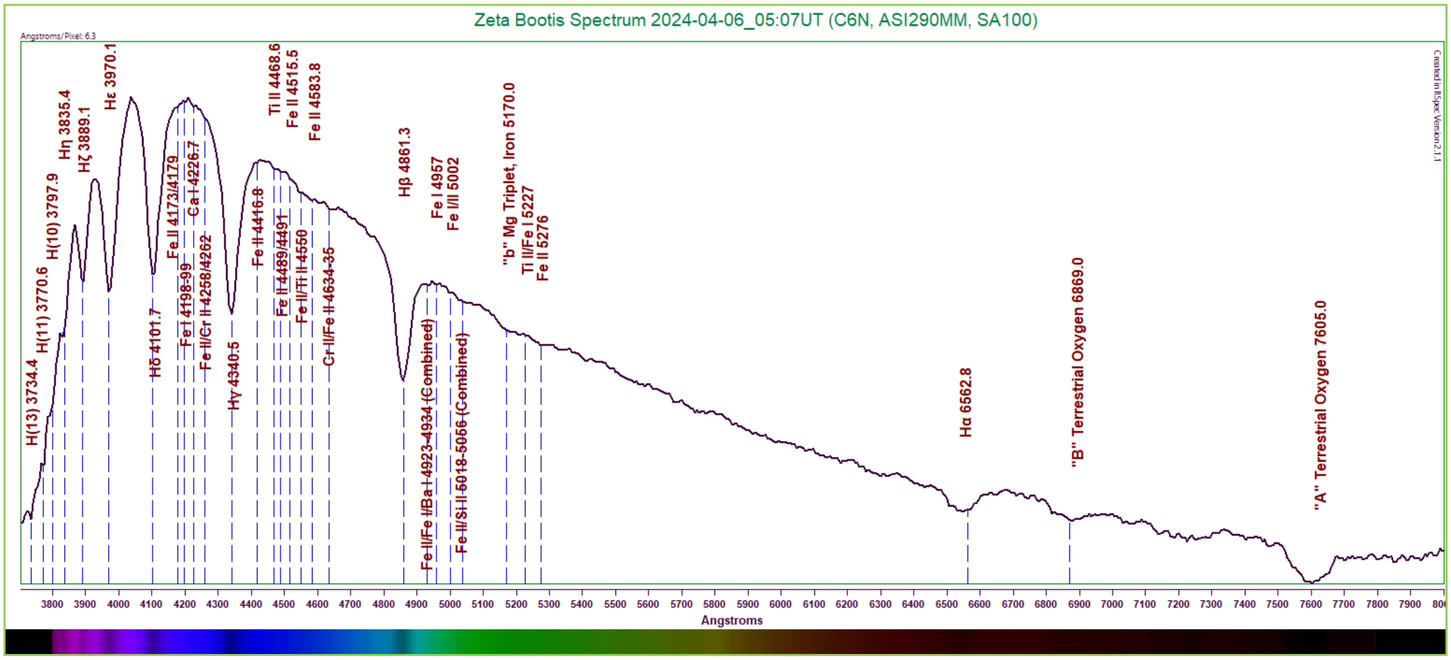

Figure 6: Zeta Boötis Spectrum (6.3 Angstroms/pixel)
Capture Details 6: Exposure 416ms, Gain 187, 65% of 442 frames stacked

Here we see a classic early A-type spectrum. The hydrogen Balmer lines are extremely strong and sharp. The “step” at the Hη absorption is very clear. The magnesium triplet is showing, though it is quite weak. Several fainter metal lines are marked, including ionized and neutral iron, calcium, titanium, and chromium. Very nice.

We will employ Wien’s Law to obtain a temperature estimate, but our results will be too low due to this being a hotter star. The peak energy wavelength appears to lie in the vicinity of the Hδ absorption at 4101.7 Angstroms. Dropping the fraction, we arrive at an estimate of 7066K. No actual temperature was readily available, but values around 9000K would be appropriate[2].

η Boötis

Eta Boötis, more commonly referred to by the name Muphrid, is a suspected spectroscopic double star of the very early G-type[1,2]. We should see a star slightly warmer than our Sun, with plenty of metal lines spread throughout (particularly iron).

The spectrum follows:

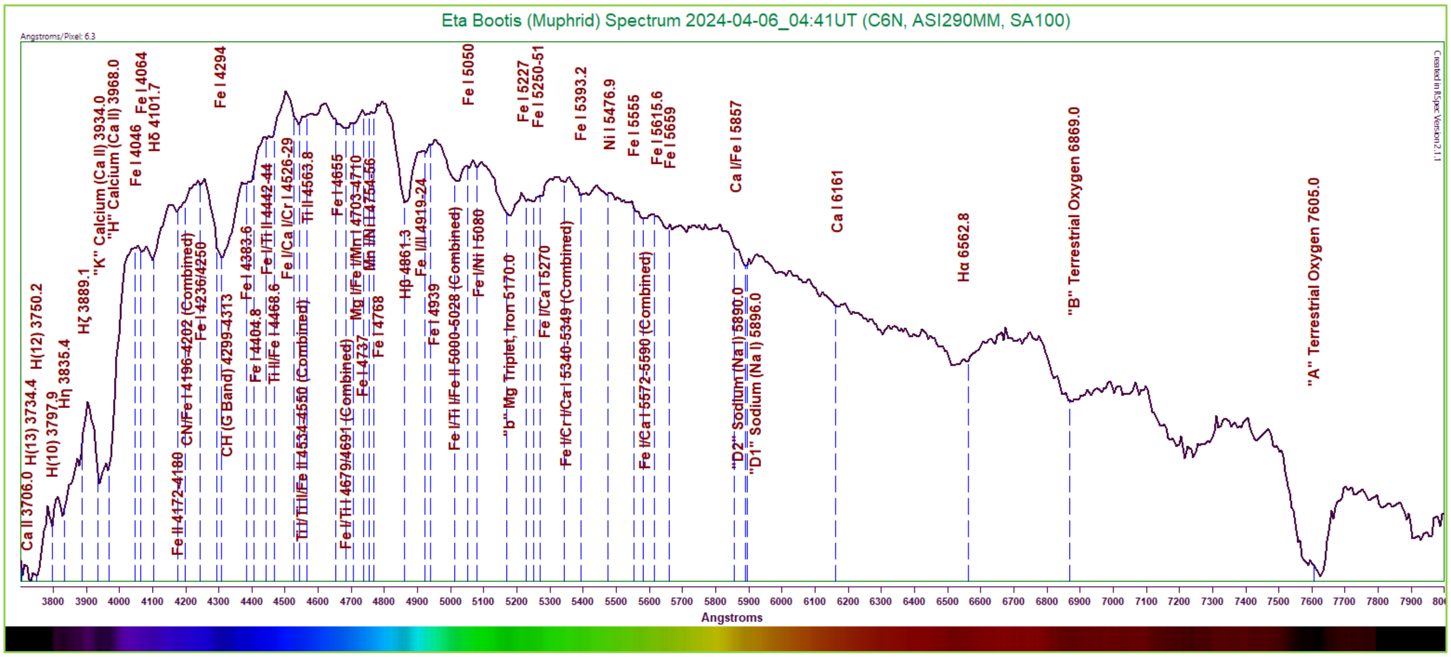

Figure 7: Eta Boötis (Muphrid) Spectrum (63 Angstroms/pixel)
Capture Details 7: Exposure 383ms, Gain 119, 50% of 638 frames stacked

Per our expectations, we can see a lot of metal lines present, many of them blends. Most of the hydrogen Balmer lines are present and still quite strong. The calcium K and H lines at 3934 and 39638 Angstroms are carving a tremendous cut out of the continuum. The CH (G) band at 4299-4313 Angstroms is very prominent here, joined by a single iron line just below it at 4294 Angstroms. The magnesium triplet at 5170 Angstroms also carves out a respectable gouge. The sodium doublet at 5890-96 Angstroms marks a smaller but quite sharp cut as well. We can even see the calcium line at 5857 Angstroms on its lower side.

Wien’s Law will now be used to calculate an effective temperature for the star. The peak energy wavelength in this case is a bit difficult to estimate, but it appears to lie in the vicinity of 4621 Angstroms. Adopting this value, we arrive at an estimated temperature of 6271K. The accepted temperature of the star is approximately 6100K[2]. Our estimate is a touch too high in this case, but not altogether bad for a visual peak wavelength estimate.

ρ Boötis

Rho Boötis is classified as an early K-type star[1]. From this, we can expect to see a cooler star showing lots of metal lines.

The processed spectrum appears below:

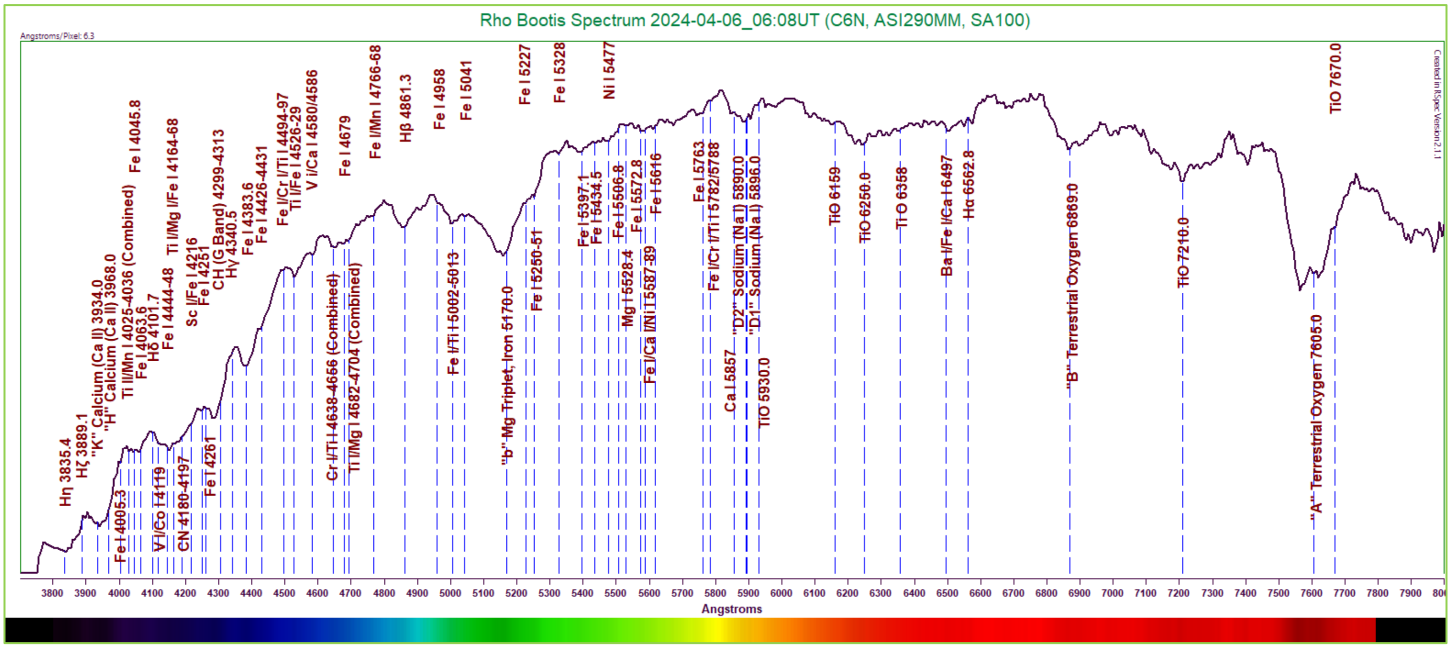

Figure 8: Rho Boötis Spectrum (6.3 Angstroms/pixel)
Capture Details 8: Exposure 441ms, Gain 149, 65% of 207 frames stacked

We can definitely see that this spectrum represents a cooler star. The hydrogen Balmer lines range from weak to extremely weak. The calcium K and H lines at 3934 and 3968 Angstroms are visible here, but also fairly weak. A nice blended absorption can be seen between 4119 and 4197 Angstroms due to a combination of vanadium, iron, titanium, and CN. The CH (G) band at 4299-4313 Angstroms is also notable, though it appears somewhat muted. The Fe (d) line at 4383.6 Angstroms appears fairly strong here. The magnesium triplet, however, cuts a magnificent canyon out of the continuum. The sodium doublet is also visible at 5890-96 Angstroms. A surprising number of TiO lines are just beginning to emerge in the spectrum. None of these absorptions are very strong, and some are even questionable, but others are quite plain.

We will once again employ Wien's Law to ascertain a temperature estimate. The peak energy wavelength appears to fall in the vicinity of the TiO line at 6250 Angstroms. Adopting this number, we arrive at a temperature estimate of approximately 4637K. The listed temperature for the star is 4298K[2]. Our crude temperature estimate is a bit too high here, but not egregiously so.

υ Boötis

Upsilon Boötis is classified as a middle K-type star[1]. Based on this, we should see a star a bit cooler than Rho above. Some of the TiO lines should be visible again on this one, along with a good number of metal lines.

The finished spectrum is presented here:

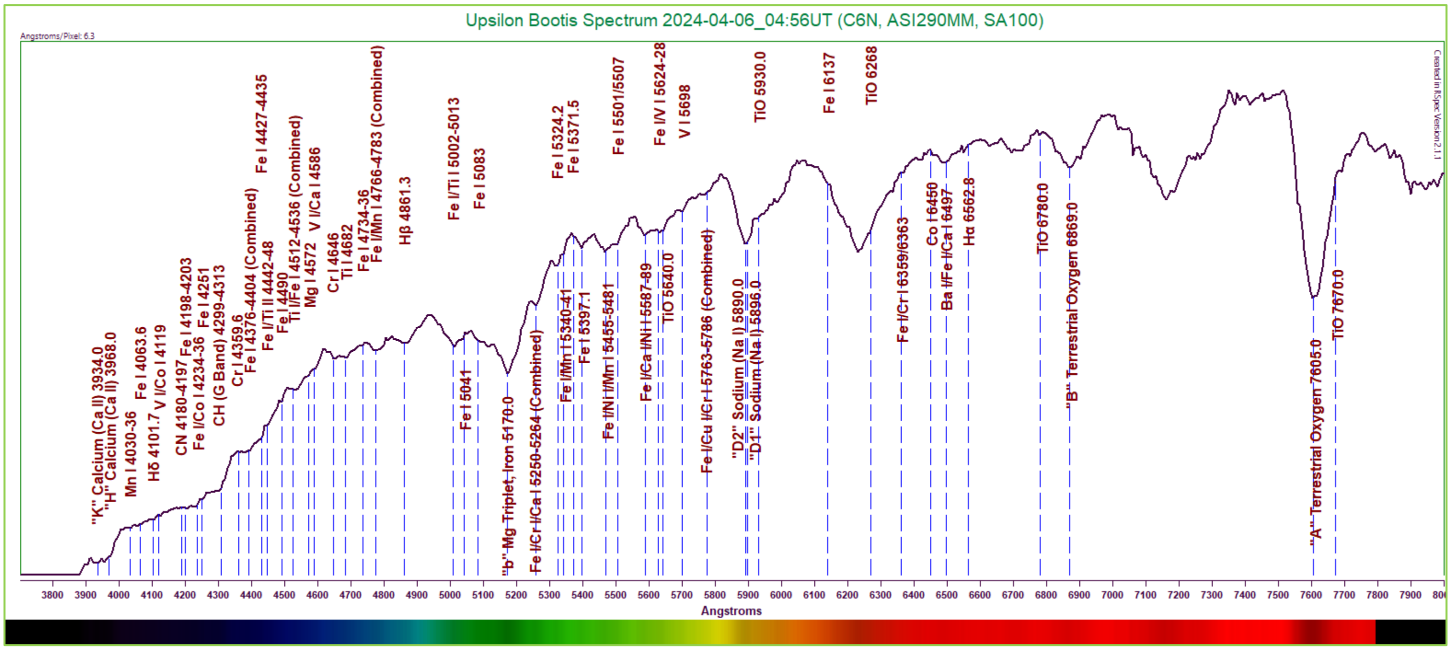

Figure 9: Upsilon Boötis Spectrum (6.3 Angstroms/pixel)
Capture Details 9: Exposure 459ms, Gain 175, 60% of 531 frames stacked

This spectrum definitely represents a cool star. The hydrogen Balmer lines that are visible are all weak. The calcium K and H absorption at 3934-3968 Angstroms are easily identified, but also quite weak. The CH (G) band at 4299-4313 Angstroms is visible, but appears somewhat muted. The magnesium absorption at 5170 Angstroms by contrast cuts a deep, sharp groove in the continuum. The sodium doublet at 5890-96 Angstroms is also deep and sharp. Several TiO absorptions are noted, though most of them are faint. These include lines at 5640, 5930, 6268 (which is contributing to the large cut in the continuum), 6780, and 7670 Angstroms. The last would appear to be slightly off, probably due to image defects in the data acquisition.

We will make use of Wien's Law to ascertain a temperature estimate for the star. Using a visually estimated peak energy wavelength of 7350 Angstroms, we arrive at a temperature of 3942K. The established temperature of the star is 3920K[2]. Our estimate is only off by 20K!

HD 129153

While capturing data for Zeta Bootis, this star peered tantalizingly nearby. A short detour was made to capture its spectrum.

This star is classified as a very early F-type star[1]. We can expect to see a spectrum reflective of a relatively hot star. We should see prominent hydrogen Balmer lines, with a few metal absorptions peeking through.

The processed spectrum is found here:

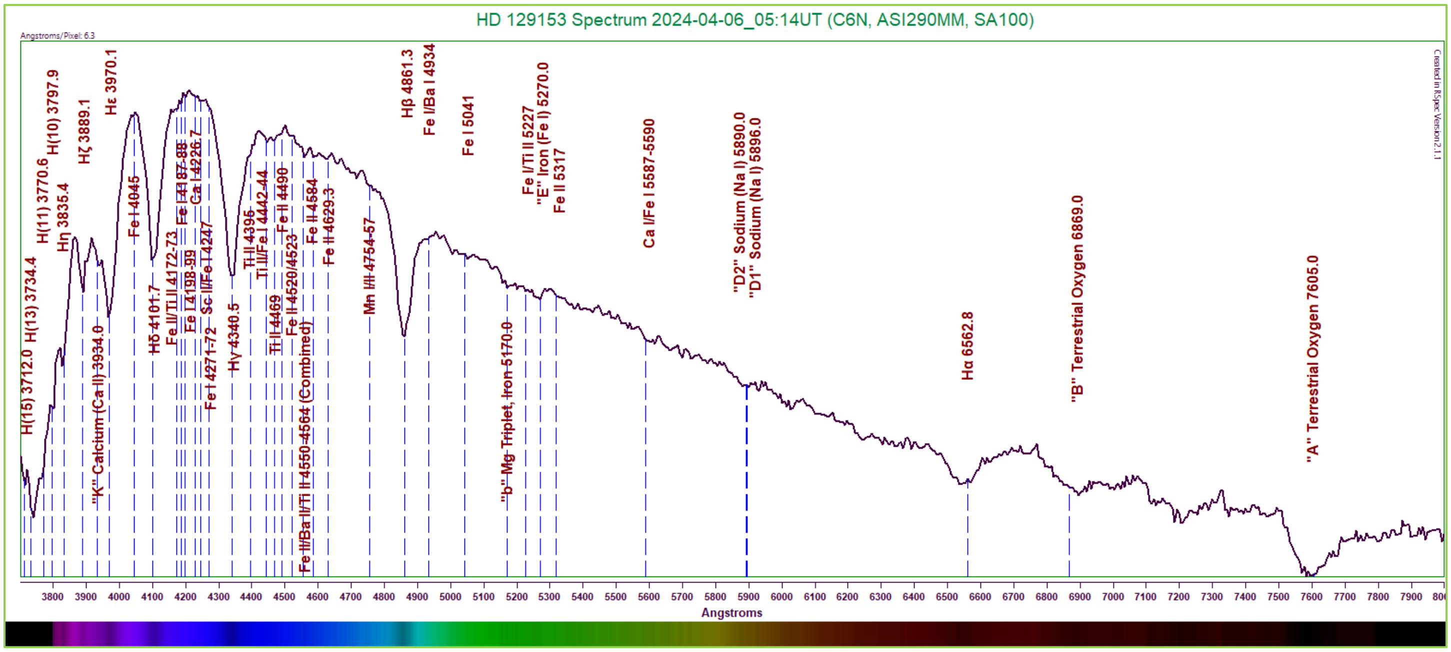

Figure 10: HJD 129153 Spectrum 6.3 Angstroms.pixel)
Capture Details 10: Exposure 2s, Gain 178, 60% of 120 frames stacked

The spectrum curve above does resemble a late A- or early F-type star. One thing to note before diving in is that this target was quite dim, and required longer exposures to capture. Therefore, fewer frames were grabbed, and the results turned out noisier than the others in this run. The hydrogen Balmer absorptions are strong, even extending down into the shorter wavelength range. Just below the Hε line, we can see the calcium K line at 3934 Angstroms beginning to assert itself. Above Hδ, a lot of very faint metal lines can be seen. (These are often crowded closely together, so be careful when tracing labels.) The magnesium triplet at 5170 Angstroms is visible, and appears broadened by the two iron lines above it. The sodium doublet at 5890-96 Angstroms is also weakly visible. Among the fainter metals that are labeled are iron, calcium, scandium, titanium, and manganese.

By way of demonstration, we will apply Wien's Law to obtain a temperature estimate. We will see that the estimate falls short of the accepted value due to the type of star involved. Using a peak energy wavelength of 4212 Angstroms, we arrive at an effective temperature of 6879K. The accepted temperature of the star is listed as 7762K[2]. Indeed, our estimate is too low.

σ Boötis

While capturing data for Rho Boötis earlier, this nearby bright star was easily visible. The decision was made to briefly divert from the constellation line stars to capture its spectrum.

Sigma Boötis is classified as a middle F-type star[1]. We can therefore expect to see the characteristics of a moderately hot star, including fairly strong hydrogen Balmer absorptions and some metals apparent.

The processed spectrum follows:

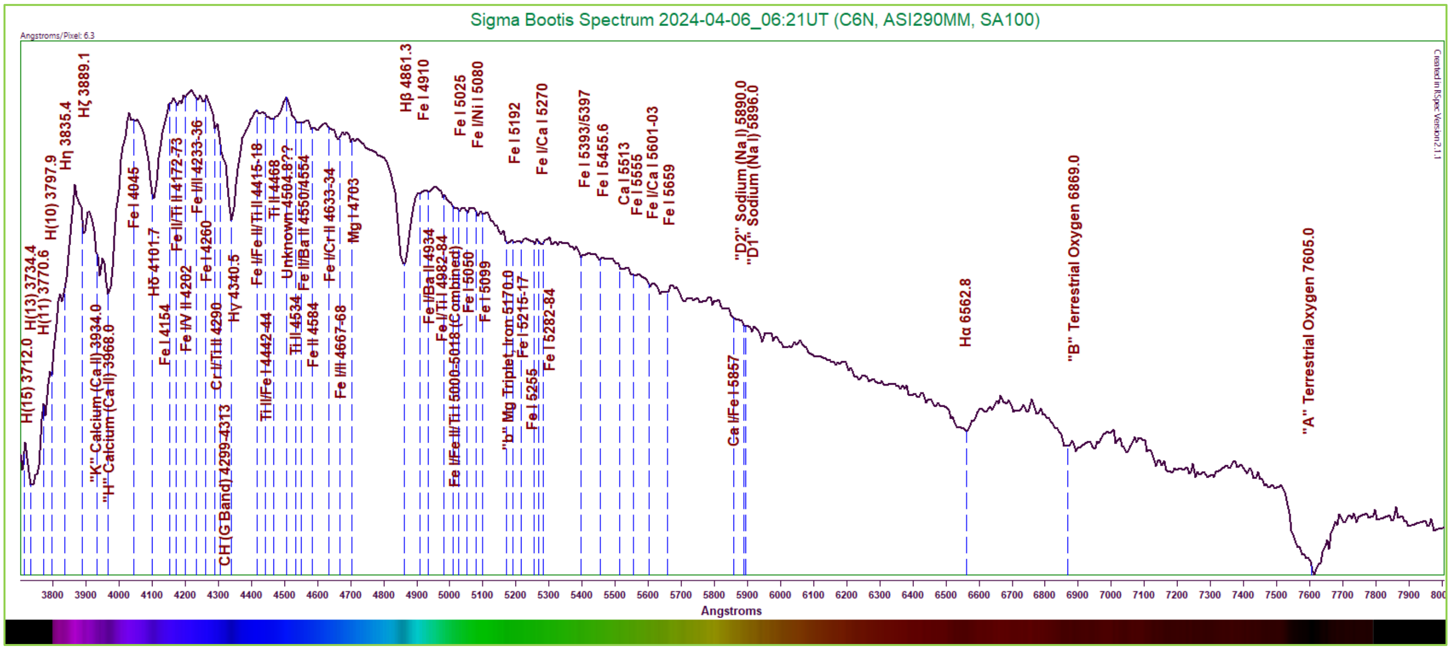

Figure 11: Sigma Boötis Spectrum (6.3 Angstroms/pixel)
Capture Details 11: Exposure 579ms, Gain 193, 65% of 316 frames stacked

The general shape of the curve in this case resembles a late A- or early F-type star, but the presence of so many faint metal lines belies this. Most of the hydrogen Balmer lines are strongly represented, excepting the Hε absorption, which has been overpowered by the calcium H line at 3968 Angstroms. The calcium K line at 3934 Angstroms just below it is less pronounced, but still easily identifiable. The CH (G) band is causing only a small diversion in the curve at 4299-4313 Angstroms, lying just below the Hγ line at 4340.5 Angstroms. A curious spike occurs at 4504.8 Angstroms, for which no identification could be made. This is likely due to a faint foreground start that escaped notice during the capture process. The magnesium triplet at 5170 Angstroms is visible, but not terribly strong. The same can be said for the iron lines immediately above it. The sodium doublet at 5890-96 Angstroms is labeled, but the identification is suspect due to its extreme weakness. However, the calcium/iron absorption just below it at 5857 Angstroms is slightly stronger. A great number of very faint metal lines are indicated along the spectrum, including iron, chromium, titanium, and calcium.

Utilizing Wien's Law, we will calculate an effective temperature for the star. Due to the star's declared type, our estimate should be closer to the mark than for the previous star. Using a peak energy wavelength of 4220 Angstroms, we arrive at an effective temperature of 6867K. The listed temperature for the star is 6594K[2]. Our estimate is still a bit too high, but off by only about 273K.

Conclusion

No unexpected problems were encountered in acquiring the spectra. Processing revealed no misidentifications or other problems, with the exception of the strange spike in the spectrum of Sigma Boötis. Overall, the results turned out well for this run.

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