# Spectral Analysis of the Constellation Stars of Virgo (The Virgin)

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## Abstract

This paper will elucidate the spectral features of the main stars in the constellation Virgo. 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).

## Data Processing Details

All of the spectra obtained for this analysis were obtained on the evening of April 30, 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.

## **α Virginis**

Alpha Virginis, known by the common name Spica, is a spectroscopic binary classified as an early B-type[1] star. This specimen should demonstrate a curve consistent with a hotter star, with relatively weak hydrogen Balmer lines and several helium absorptions in its spectrum.

The processed spectrum is as follows:

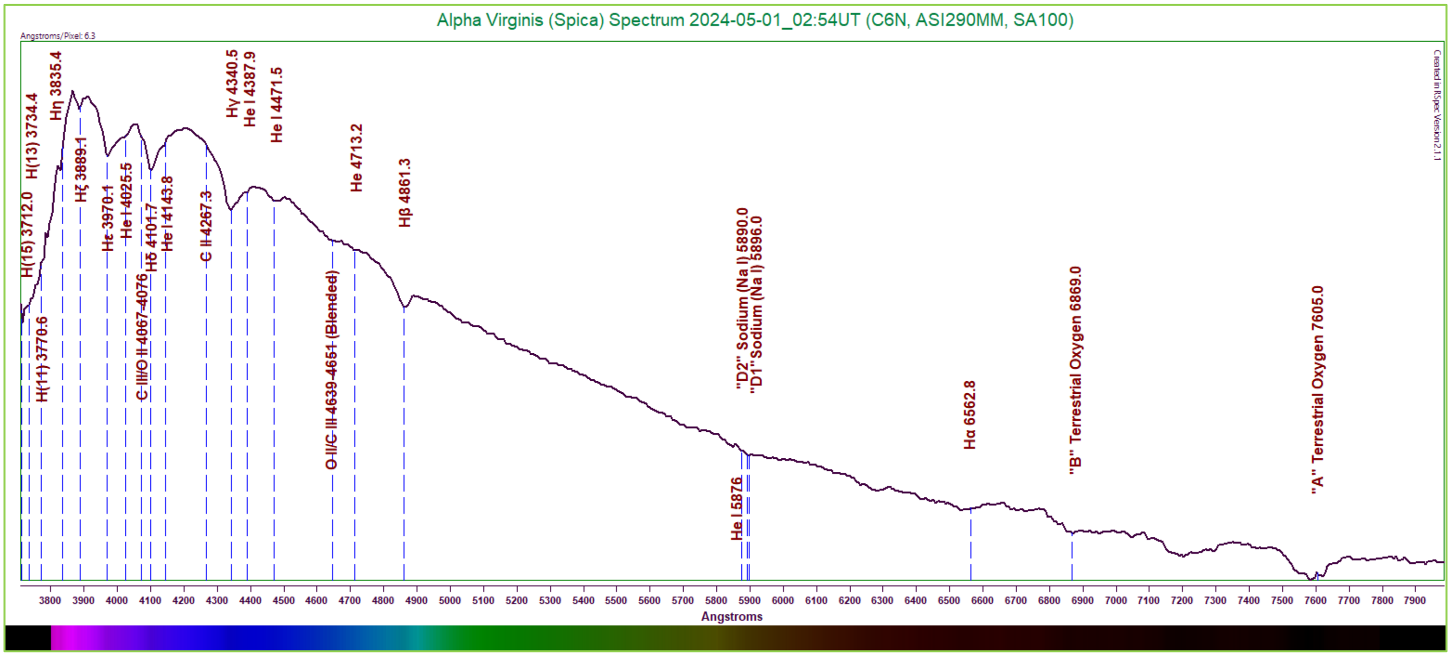


*Figure 1: Alpha Virginis (Spica) Spectrum (6.3 Angstroms/pixel)*
*Capture Details 1: Exposure 194ms, Gain 33, 20% of 1254 frames stacked*

We can see from the shape of the curve that we are definitely dealing with a very hot star. The hydrogen Balmer lines are fairly weak here, as expected. A good number of neutral helium lines can be seen—at 4025.5, 4143.8, 4387.9, 4471.5, 4713.2, and 5876 Angstroms. The sodium doublet at 5890-96 Angstroms is very small, possibly interstellar in nature. Some very faint metals are identifiable as well, including carbon and oxygen.

As an exercise to demonstrate the inaccuracy for this type of star, we will employ Wien's Law to see what kind of temperature estimate it avails. Using an estimated peak energy wavelength of 3866 Angstroms, the estimate comes out at 7496K. The accepted temperature of the star is listed as 20900K[2]. Our estimate is short by nearly a factor of 3.

## γ Virginis

Gamma Virginis, called Porrima, is a binary system of two very similar stars classified as early F-type[1] and/or very early F-type[2]. (Classification seems to vary depending upon the source consulted.) The two stars cannot be currently separated in our instrument, so we will see a combination of the two. Based on their type, we should see a relatively hot spectrum showing clear hydrogen Balmer lines, with some weak metals also present.

The processed spectrum is presented here:

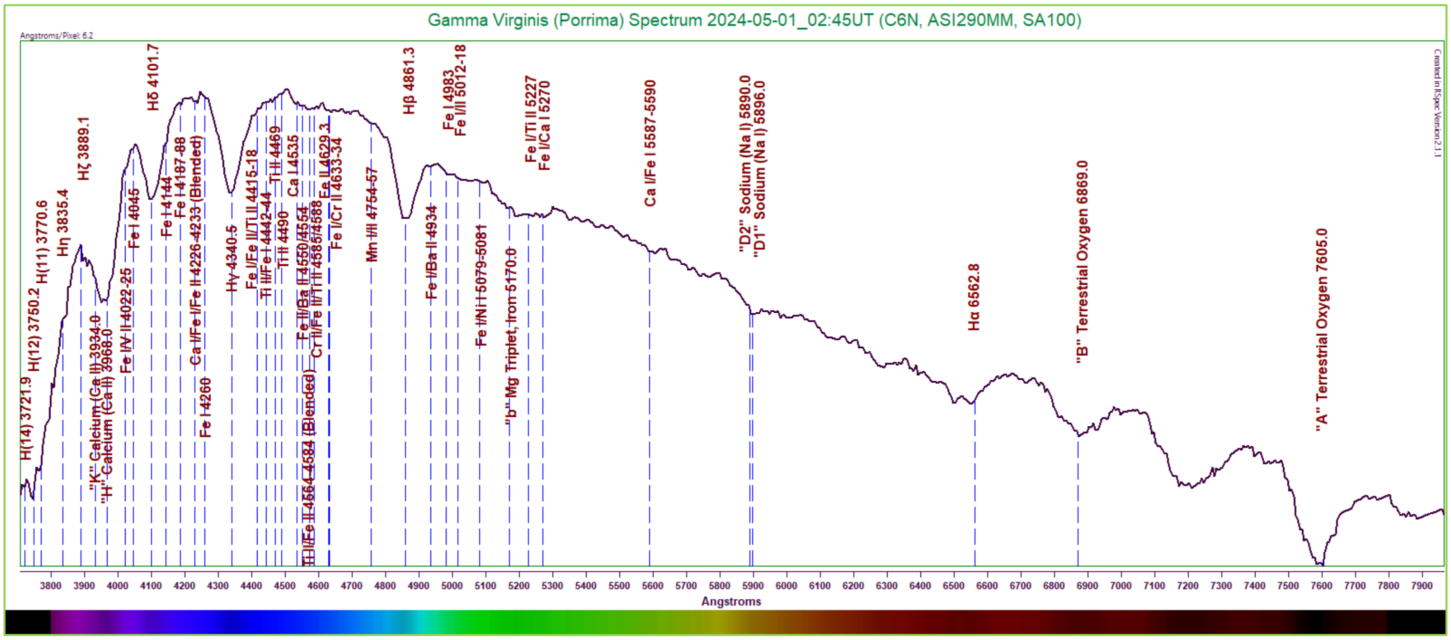


*Figure 2: Gamma Virginis (Porrima) Spectrum (6.2 Angstroms/pixel)*
*Capture Details 2: Exposure 227, Gain 157, 30% of 1067 frames stacked*

The curve does seem to match the general shape expected. Most of the hydrogen Balmer lines are fairly strong. The calcium K and H lines at 3934 and 3968 Angstroms are causing a prominent dip in the continuum. The magnesium triplet at 5170 Angstroms is not terribly deep, but appears broad due to the two iron lines above it. The sodium doublet at 5890-96 Angstroms is also causing a dip, but it is much sharper than the magnesium triplet. We can see a good number of fainter metal lines here, including iron, calcium, titanium, chromium, and manganese.

In order to obtain a temperature estimate, we will employ Wien's Law. The peak energy wavelength in this curve appears to lie between the peaks at 4245.2 and 4507.3 Angstroms. Taking an average value between these two of approximately 4525 Angstroms, Wien's Law provides a temperature of 6404K. The listed temperature for the binary is 6757K[2]. Considering the lack of a clear peak in the curve, our estimate is not too shabby.

# δ Virginis

Delta Virginis, also named Minelauva, is a suspected binary system classified as early M-type[1,2]. This specimen should show a curve representative of a very cool star, with its energy peak near the long wavelength region. The spectrum should show TiO lines and some metals as well.

The finished spectrum can be found below:

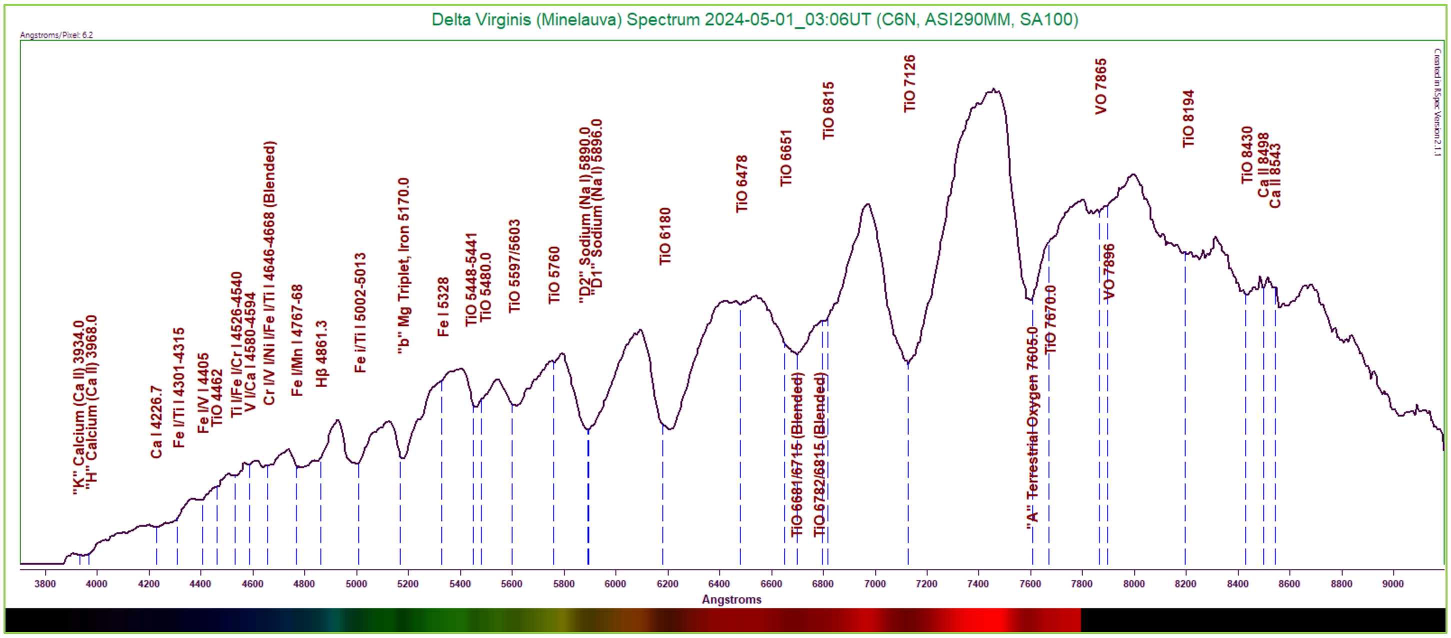


*Figure 3: Delta Virginis (Minelauva) Spectrum (6.2 Angstroms/pixel)*
*Capture Details 3: Exposure 256ms, Gain 187, 40% of 946 frames stackes*

Before diving into this one, observe that the wavelength range has been extended to 9200 Angstroms in order to display some near infrared features. Looking at the results, we can identify only one hydrogen Balmer line, the Hβ line, and it is extremely weak. The calcium K and H lines at 3934 and 3968 Angstroms are very weak, merely causing a gentle blended dip in the continuum. The magnesium triplet at 5170 Angstroms is notable, as is the massive dip caused by the sodium doublet at 5890-96 Angstroms (possibly assisted by TiO absorptions that do not show up discretely). As anticipated, we see a lot of TiO lines here. We can also notice two VO lines at 7865 and 7896 Angstroms. Two ionized calcium lines can also be seen, at 8498 and 8543 Angstroms. A number of additional very faint neutral metals can be seen in the lower third of the wavelength range. These include calcium, iron, titanium, vanadium, and chromium.

Employing Wien's Law, we will calculate an effective temperature for the star. Using the peak energy wavelength of 7459 Angstroms, we obtain a temperature of 3885K. The accepted temperature for the star is 3657K[2]. Our estimate is only a little more than 200K too high. All things considered, not too bad.

## **ε Virginis**

Epsilon Virginis, also known by the unusual name Vindemiatrix, is classified as a late G-type star[1]. Based upon this, we can expect to see a star a bit cooler than our Sun, with lots of metals present in the spectrum, especially iron.

The processed spectrum is below:

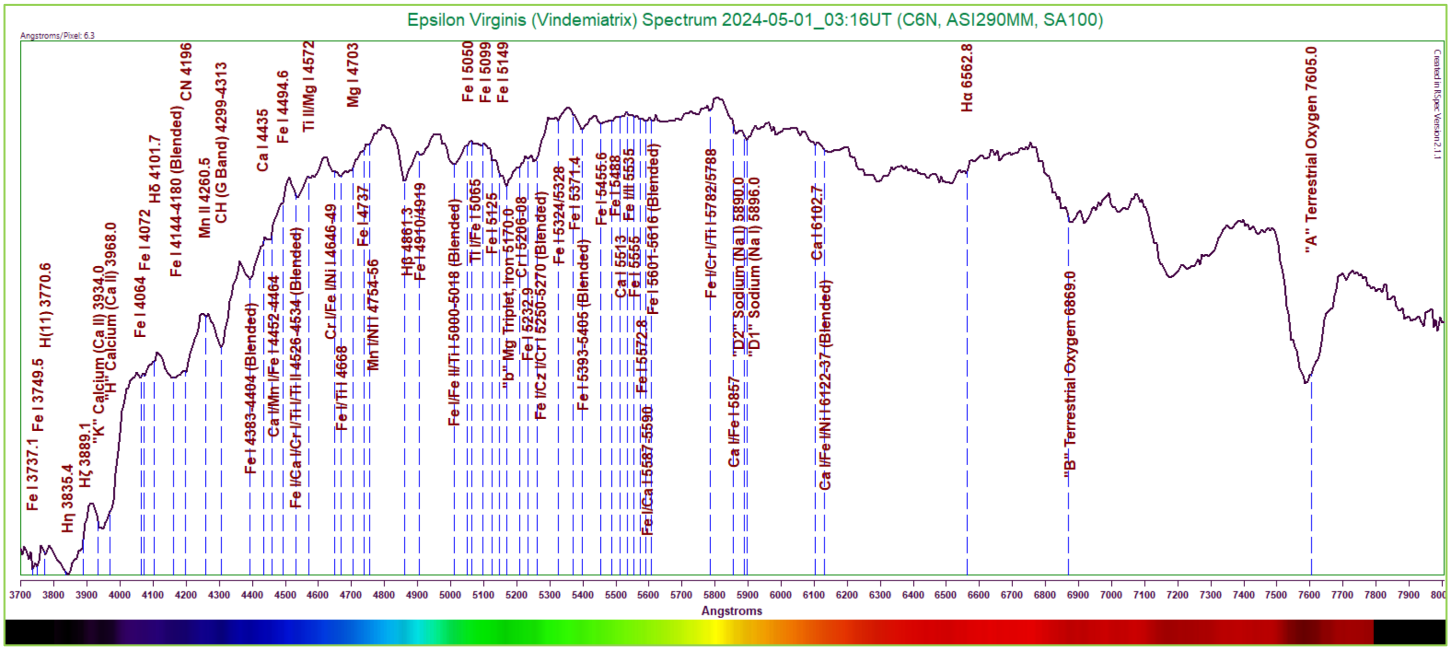


*Figure 4: Epsilon Virginis (Vindemiatrix) Spectrum (6.3 Angstroms/pixel)*
*Capture Details 4: Exposure 285ms, Gain 166, 20% of 1270 frames stacked*

A G-type star's curve is certainly represented here, including the great number of tightly packed iron lines. (Be careful when tracing labels on this one.) The hydrogen Balmer lines that are present appear moderate to weak in strength. The calcium K and H lines at 3934 and 3968 Angstroms are collectively causing a significant groove in the continuum. A very nice blended absorption appears in the 4144-4180 Angstroms range, caused by several iron absorptions. The CH (G) band is very sharp and well defined at 4299-4313 Angstroms. The magnesium triplet at 5170 Angstroms, along with its attendant flanking iron lines, is producing a deep cut also. The sodium doublet at 5890-96 Angstroms is remarkably well-defined as well. The calcium/iron line at 5857 Angstroms below it is also well shown. A number of additional faint metal lines are indicated, including lots of iron, CN, manganese, calcium, titanium, chromium, and magnesium.

We will apply Wien's Law to determine an effective temperature, then compare the result with the professionally derived value. Using a peak energy wavelength of 5808 Angstroms, we obtain a result of approximately 4989K. The listed value for the star is 5086K[2]. Our estimate is pretty close in this case—less than 100K removed from the actual value!

## <u>ζ Virginis</u>

Zeta Virginis, known by the name Heze, is a double star classified as early A-type[1,2]. The companion was only recently discovered, but it is a suspected red dwarf of low luminosity. This being so, we can expect the primary to overwhelm its dimmer companion, and therefore not interfere with our analysis. We can expect very strong hydrogen Balmer lines, along with some very faint metals sprinkled in. The spectrum curve should peak near the lower wavelength range, indicating a high temperature.

The processed spectrum follows:

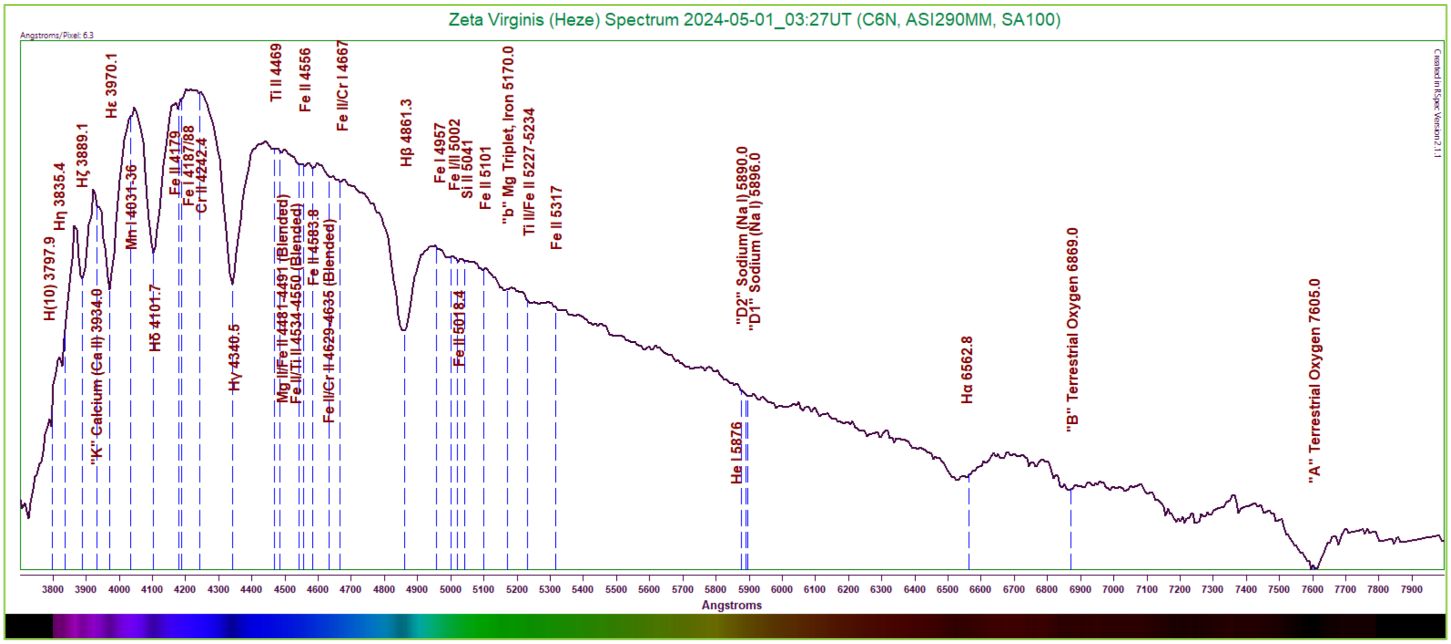


*Figure 5: Zeta Virginis (Heze) Spectrum (6.3 Angstroms/pixel)*
*Capture Details 5: Exposure 260ms, Gain 187, 25% of 930 frames stacked*

The general shape of the spectrum curve seems to match our expectations, with a peak near the lower wavelength region. The hydrogen Balmer lines appear strongly here. At 3934 Angstroms we see the Ca II K line emerging, but only managing to carve out a small bump on the lower wing of the Hε absorption. The magnesium triplet at 5170 Angstroms is very weak. The sodium doublet at 5890-96 Angstroms is even weaker, and is a potentially suspicious identification. However, the tiny absorption from neutral helium on its lower side would seem to confirm it. A number of additional faint to very faint metal lines are indicated, including manganese, neutral and ionized iron, chromium, titanium, magnesium, and even one tiny ionized silicon line at 5041 Angstroms.

Using Wien's Law we will calculate an effective temperature. Once again, though, we are dealing with a hotter star and must be prepared for an answer that falls far short of the actual temperature. Using a peak energy wavelength of 4202 Angstroms, we arrive at an estimate of 6896K. The listed temperature for the star is 8247K[2]. Indeed, our estimate is too low, as expected.

# η Virginis

Eta Virginis, also called Zaniah, is a very close triple star system classified as early A-type[1,2]. The companions are much too close to be separable in telescopes. From the overall type, we can expect a similar result to that obtained for Heze above—very strong hydrogen Balmer lines, some faint metals, and a high temperature.

The finished spectrum is presented here:

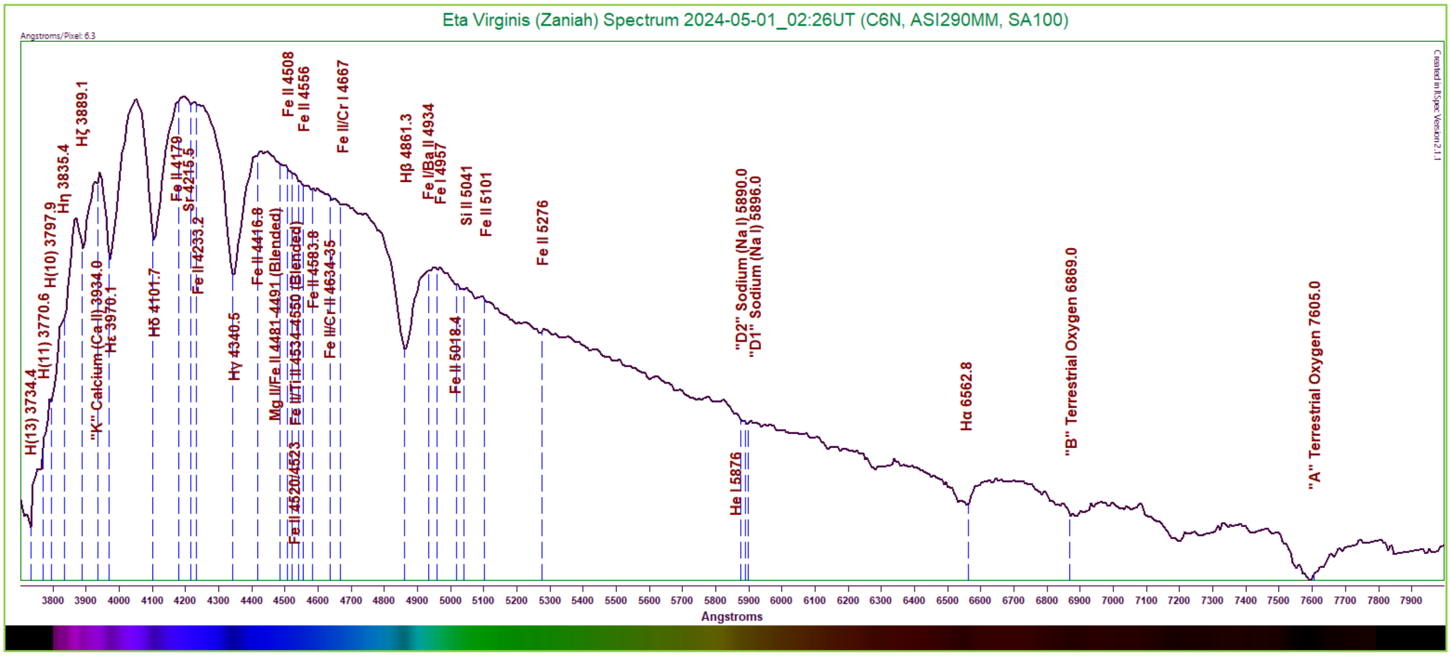


*Figure 6: Eta Virginis (Zaniah) Spectrum (6.3 Angstroms/pixel)*
*Capture Details 6: Exposure 383ms, Gain 169, 40% of 646 frames stacked*

Doesn't this look familiar? The result is indeed very similar to that obtained for Heze. Many of the same lines appear here, but with a few differences. The hydrogen Balmer lines are very strong again, as expected. One peculiarity in the spectrum can be seen at the Ca II K line at 3934 Angstroms. In our result, it actually appears to lie slightly outside the wings of the Hε line. Very curious. The magnesium triplet is missing, but the sodium doublet at 5890-96 Angstroms looks almost identical to the dip in Heze, complete with the tiny helium line below it. Other very faint metals marked include iron, strontium, magnesium, and the very faint silicon line at 5041 Angstroms.

Again we will employ Wien's Law to obtain a temperature estimate, but we expect to receive a result that is once more significantly low. The peak energy wavelength for this spectrum appears to lie within the bounds of the Hδ absorption, between the peaks at 4053.8 and 4197.8 Angstroms. Taking an average of these two gives us a value of approximately 4126 Angstroms. Using this value, Wien's Law returns a temperature estimate of 7023K. The listed temperature for this star system is 9333K[2]. We again come in below the mark, but slightly higher than for Heze above, which is consistent with this star having an actual temperature that is also higher.

## ι Virginis

Iota Virginis, also known by the name Syrma, is another binary system, whose primary is classified as a late F-type star[1,2]. The two cannot be separated by telescope, but the secondary is much less massive and less luminous than the primary, so its presence should pose no problems. This spectrum should be much different from the last two, with a lower temperature, less-pronounced hydrogen Balmer lines, and more metals present.

The spectrum can be found below:

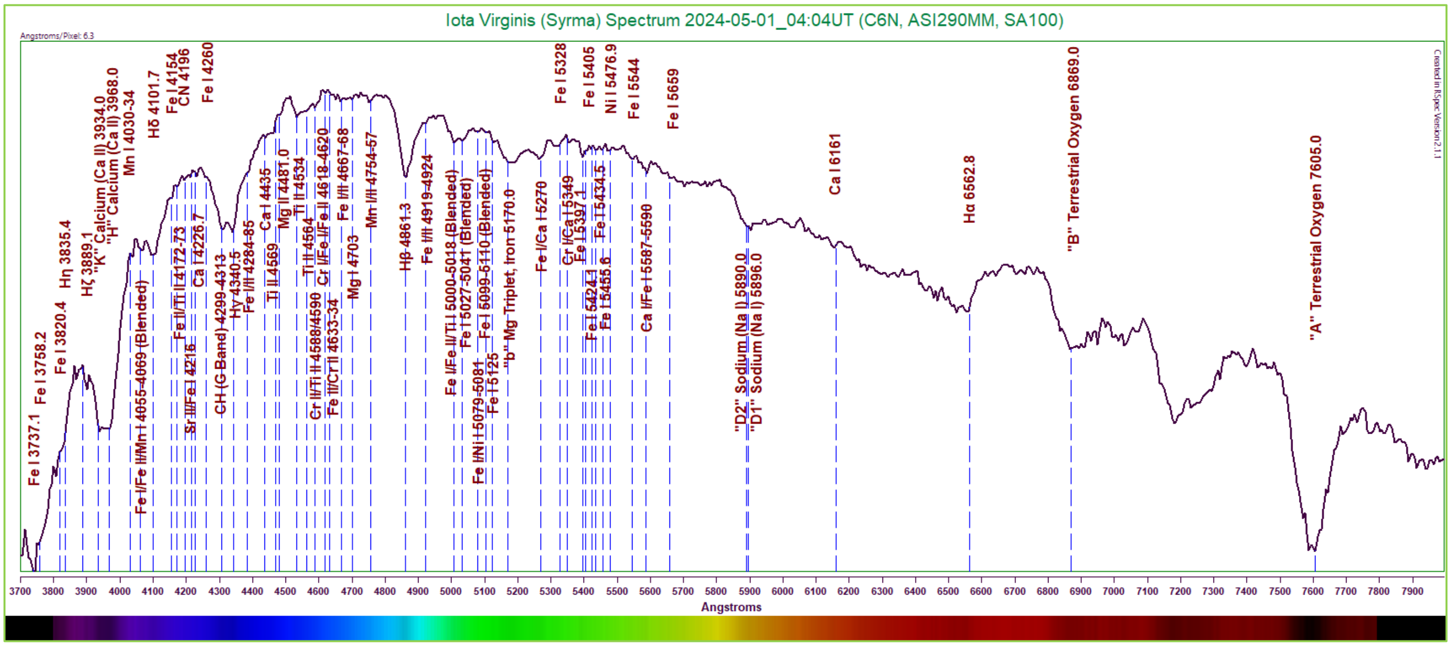


*Figure 7: Iota Virginis (Syrma) Spectrum (6.3 Angstroms/pixel)*
*Capture Details 7: Exposure 648ms, Gain 199, 20% of 473 frames stacked*

Ah, now this one indeed looks different. The peak of the curve is shifted a bit toward longer wavelengths, and we see a lot more metals present. Most of the hydrogen Balmer lines are present, but not overly strong. The calcium K and H lines at 3934 and 3968 Angstroms appear nearly identical, combining to produce a deep, flat-bottomed absorption. The CH (G) band and Hγ absorptions are doing nearly the same thing, but the lines appear distinct. The magnesium triplet at 5170 Angstroms is present, but only moderately so. The sodium doublet at 5890-96 Angstroms appears perhaps a tiny bit deeper, but not much. A great number of fainter metal lines are labeled, including lots of iron, manganese, CN, strontium, calcium, titanium, chromium, magnesium, and nickel. (Some of the lines are very close together, so use great care when tracing labels.

Utilizing Wien's Law, we will calculate an approximate temperature for the star. Using a peak energy wavelength of 4627 Angstroms, we obtain a result of 6263K. The listed temperature for the star is 6282K[2]. Wow, our rough estimate is off by only 19K!

## **κ Virginis**

Kappa Virginis is also called by the name Kang. (Probably not named after the Star Trek character…) The star is classified as an early K-type star[1]. Based on this classification, we can expect a cooler star, with the peak of its energy curve tending toward the longer wavelength region. We should see a great number of metals, with a few molecular bands apparent as well.

The processed spectrum is presented here:

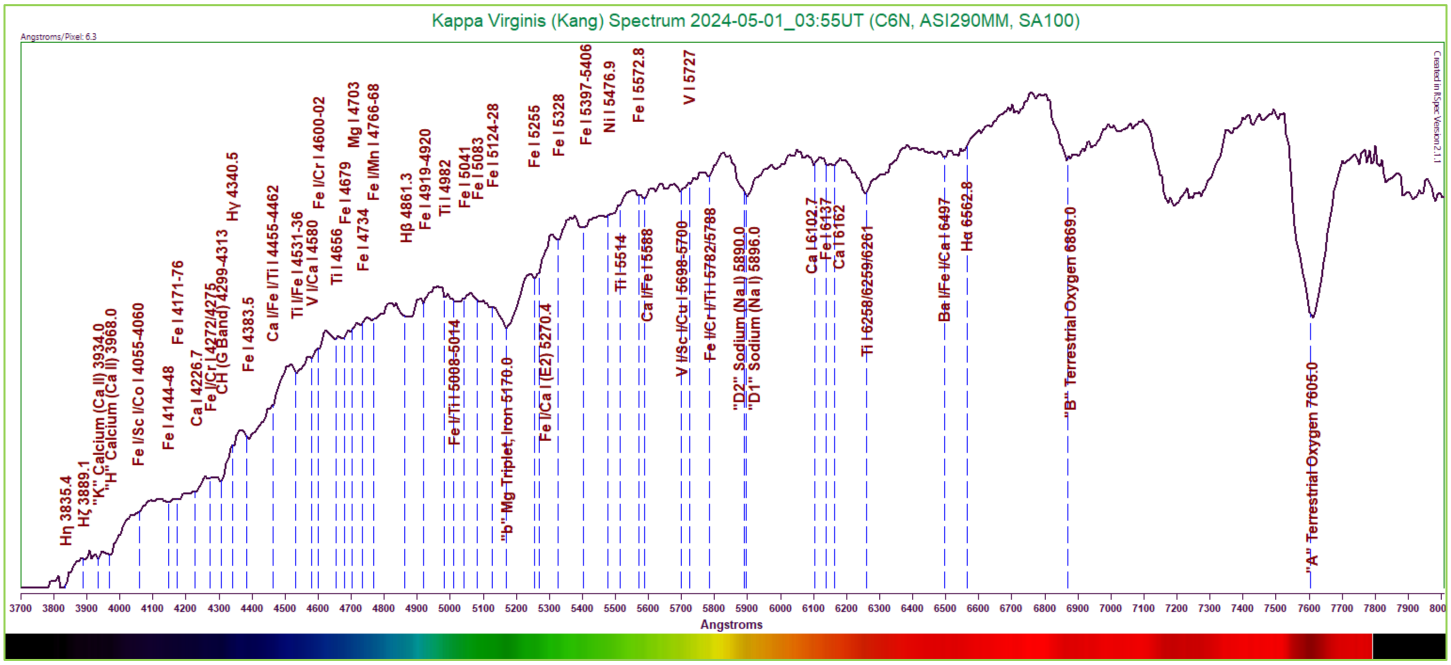


*Figure 8: Kappa Virginis (Kang) Spectrum (6.3 Angstroms/pixel)*
*Capture Details 8: Exposure 575ms, Gain 199, 40% of 480 frames stacked*

Indeed we are looking at a cooler star. Most of the hydrogen Balmer lines are either extremely weak or altogether absent. The Ca II K and H lines at 3934 and 3968 Angstroms are present, but also extremely weak. The CH (G) molecular band is a bit deeper, but still appears muted. The magnesium triplet at 5170 Angstroms by contrast stands as the most prominent absorption. The sodium doublet at 5890-96 Angstroms is well-defined, but not nearly as strong. A number of additional fainter metal lines are spread throughout, including iron, calcium, titanium, vanadium, magnesium, nickel, and barium. (The general weakness of all the lines is likely due to the star being a giant.)

Using Wien's Law, we will calculate a temperature estimate. Using a peak energy wavelength of 6759 Angstroms, we obtain a temperature of 4287K. The accepted temperature of the star is listed as 4235K[2]. Another outstanding estimate, coming within 52K of the accepted value!

## μ Virginis

Mu Virginis, also called Rijl al Awwa, is an early F-type star[1]. From this we can expect to see fairly strong hydrogen Balmer lines in a moderately hot star. Some metals will be present as well, though many of them will likely be very weak.

The finished spectrum follows:

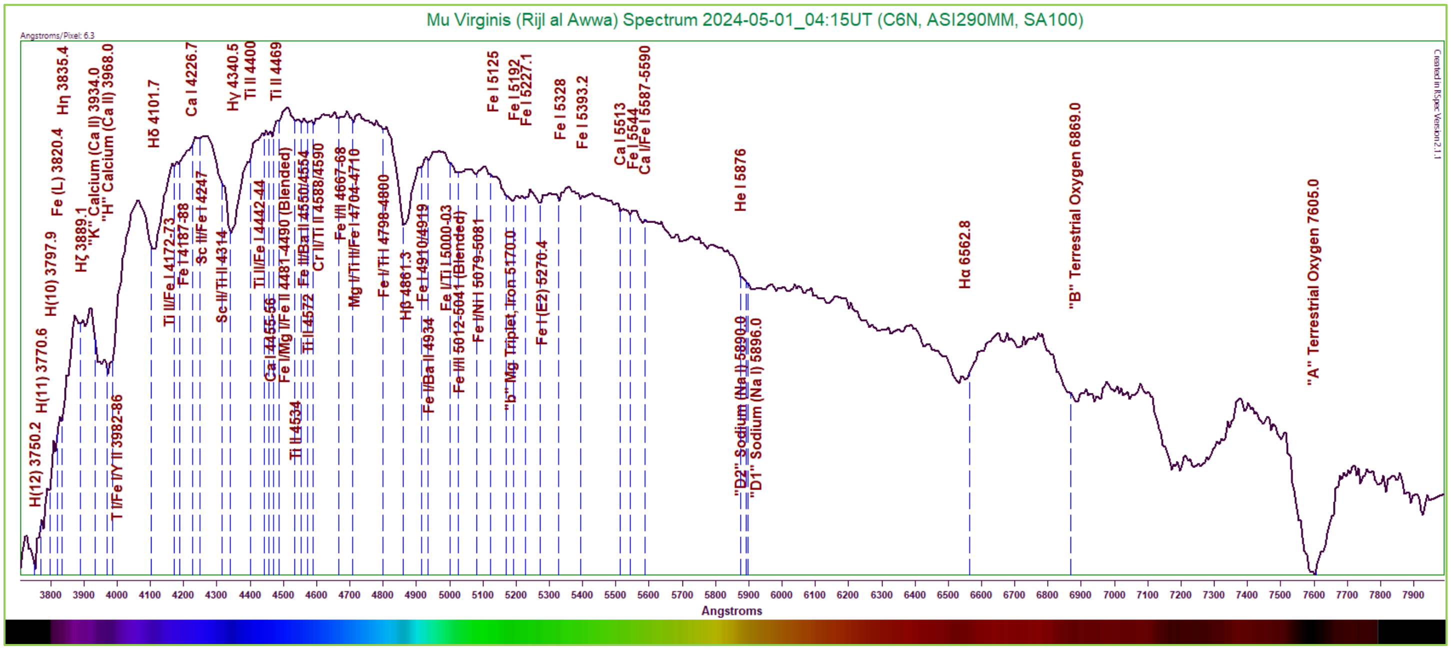


*Figure 9: Mu Virginis (Rijl al Awwa) Spectrum (6.3 Angstroms/pixel)*
*Capture Details 9: Exposure 474ms, Gain 193, 25% of 639 frames stacked*

Though a bit noisier than preferred, the spectrum does correspond with an F-type star. The hydrogen Balmer lines are fairly string, excepting the Hε line which has been overpowered by the Ca II K line. The Fe (L) line at 3820.4 Angstroms appears distinctly near the extreme lower wavelength range. The calcium K and H lines are strong, causing a deep cut in the continuum at 3934 and 3968 Angstroms. A third line just above these at 3982-86 Angstroms contributes to the absorption (due to titanium). The magnesium triplet at 5170 Angstroms is not terribly strong, but definitely identifiable. The sodium doublet at 5890-96 Angstroms may be a tiny bit stronger, with the accompanying helium line at 5876 Angstroms visible. Numerous additional faint metal lines are indicated, including iron, titanium, calcium, scandium, chromium, and magnesium.

Employing Wien's Law, we will calculate an effective temperature and compare this to the actual value. Using a peak energy wavelength of 4511 Angstroms, we arrive at a temperature of 6424K. The listed temperature for the star is 6751K[2]. Our estimate in this case falls short, but it is in the right neighborhood.

## μ Virginis

Nu Virginis is classified as an early M-type star[1]. We should expect to see a very cool star with several TiO lines visible. Some metal absorptions will certainly be clinging on in the lower wavelength range.

The processed spectrum is presented here:

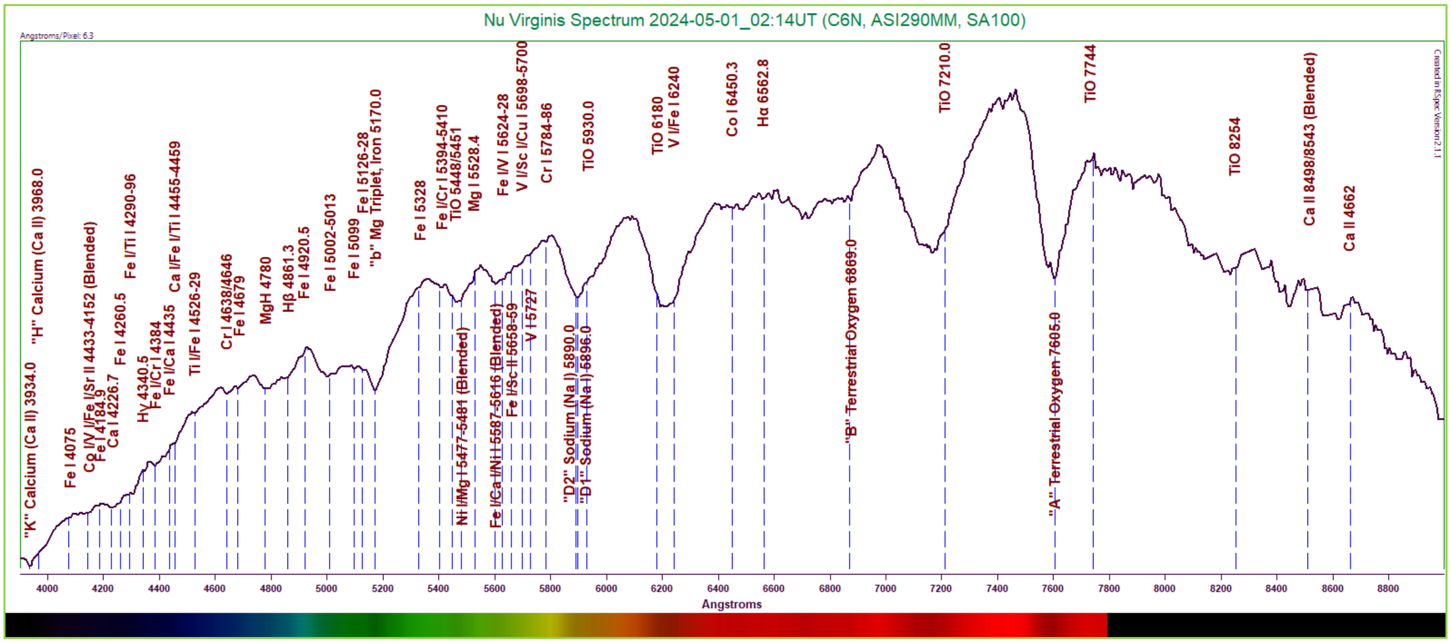


*Figure 10: Nu Virginis Spectrum (6.3 Angstroms/pixel*
*Capture Details 10: Exposure 361.29ms, Gain 175, 35% of 841 frames stacked*

The first thing to note about this spectrum is that the wavelength range has been altered to include a bit more of the near infrared. The few hydrogen Balmer lines that can be seen are very weak. The calcium K line at 3934 Angstroms is visible as a small dip in the continuum at the extreme low wavelength range. Though the line is not distinct, the location of the calcium H line at 3968 Angstroms is also indicated. The Ca I line at 4226.7 Angstroms is faint, but notable. The magnesium triplet at 5170 Angstroms is very pronounced, causing a nice deep cut in the spectrum. In the 5448-5616 Angstroms range we can see a nice gouge caused by a combination of things, including TiO, nickel, and magnesium. The sodium doublet at 5890-96 Angstroms is also quite strong, no doubt aided by the TiO line just above it. Another notable dip is seen at 6180-6240 Angstroms, caused by TiIO, vanadium, and iron. A number of additional very faint metals are indicated, including iron, cobalt, calcium, titanium, chromium, MgH, magnesium, and vanadium. In the infrared region, an additional TiO line is marked at 7744 Angstroms, as well as two features due to ionized calcium.

Using Wien's Law, we will calculate an effective temperature for the star and compare the results to the accepted value. Using a peak energy wavelength of 7464 Angstroms, we arrive at an estimate of 3882K. The accepted temperature is listed at 4009K[2]. Considering the crudeness inherent in the work, our estimate is not too bad.

## τ Virginis

Tau Virginis is classified as an early A-type star[1]. Based on this, the hydrogen Balmer lines should appear very strongly. The spectrum curve should peak in the lower part of the visible wavelength region. We can also expect a small number faint metal lines to be present.

The finished spectrum appears here:

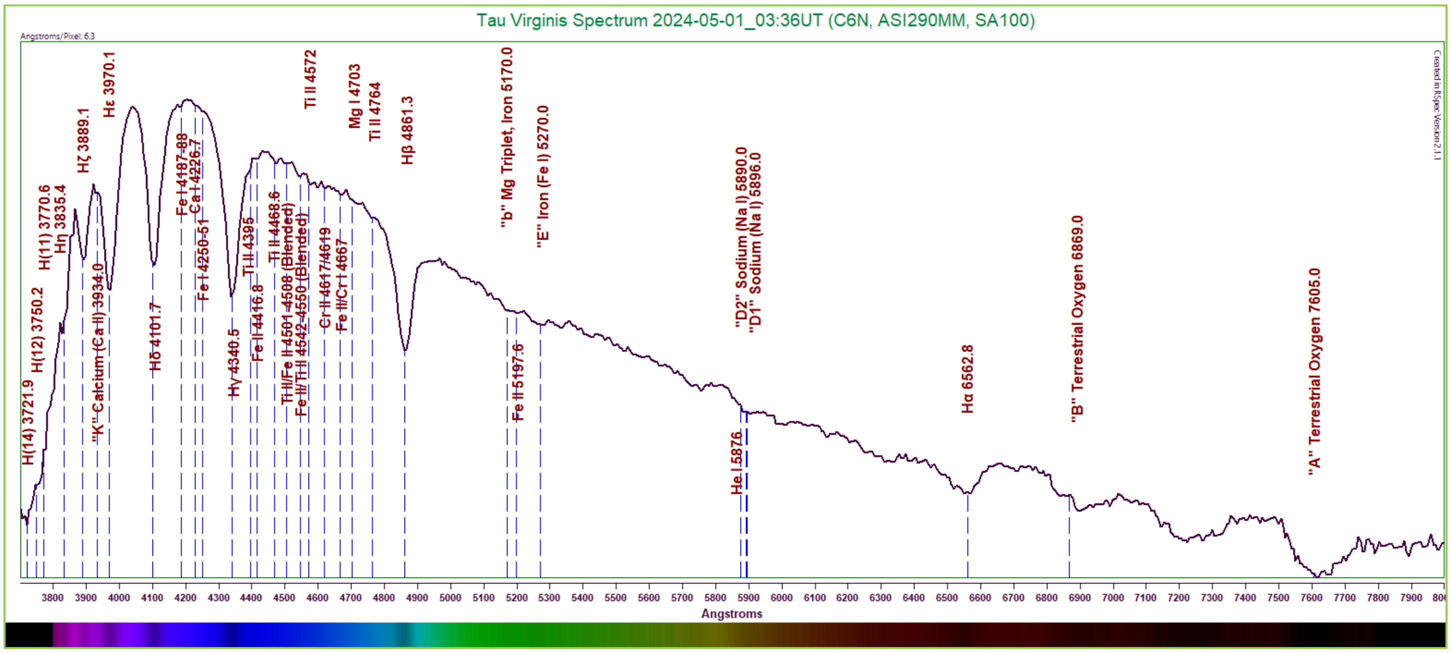


*Figure 11: Tau Virginis Spectrum (6.3 Angstroms/pixel)*
*Capture Details 11: Exposure 608ms, Gain 202, 60% of 312 frames stacked*

The general shape of the spectrum is indicative of an early A-type star. The hydrogen Balmer lines are very strong throughout. The Hη line at 3835.4 Angstroms is revealed by a small but distinct cut in the continuum. The magnesium triplet at 5170 Angstroms is present, but only weakly. Along with the ionized iron line above it at 5197.6 Angstroms, a blended scoop is taken out of the spectrum. The sodium D lines at 5890-96 Angstroms actually appear slightly stronger. The neutral helium line at 5876 Angstroms appears to be present just below, contributing to the breadth of the absorption. As expected, a number of faint to very faint metal lines are present, including iron, calcium, titanium, chromium, and magnesium.

Using Wien's Law, we will calculate an effective temperature for the star. Again, since we are dealing with an early A-type star, our estimate will fall short. The peak energy wavelength appears to lie in the region of the Hδ absorption and is therefore overtaken. Taking the average of the peaks on either side, we obtain 4121 Angstroms as an approximate continuum peak. Using this value, Wien's Law gives us a result of approximately 7032K. The actual listed temperature of the star is 8413K[2]. Indeed, our estimate falls far short, as expected.

## 109 Virginis

109 Virginis is classified as a very early A-type star[1]. The results obtained for this star should be very similar to those for Tau Virginis above. We should see strong hydrogen Balmer lines, with some weak metals spread throughout. The peak of the curve should resemble that of Tau Virginis, but we should obtain a resulting temperature that is slightly higher.

The processed spectrum follows:

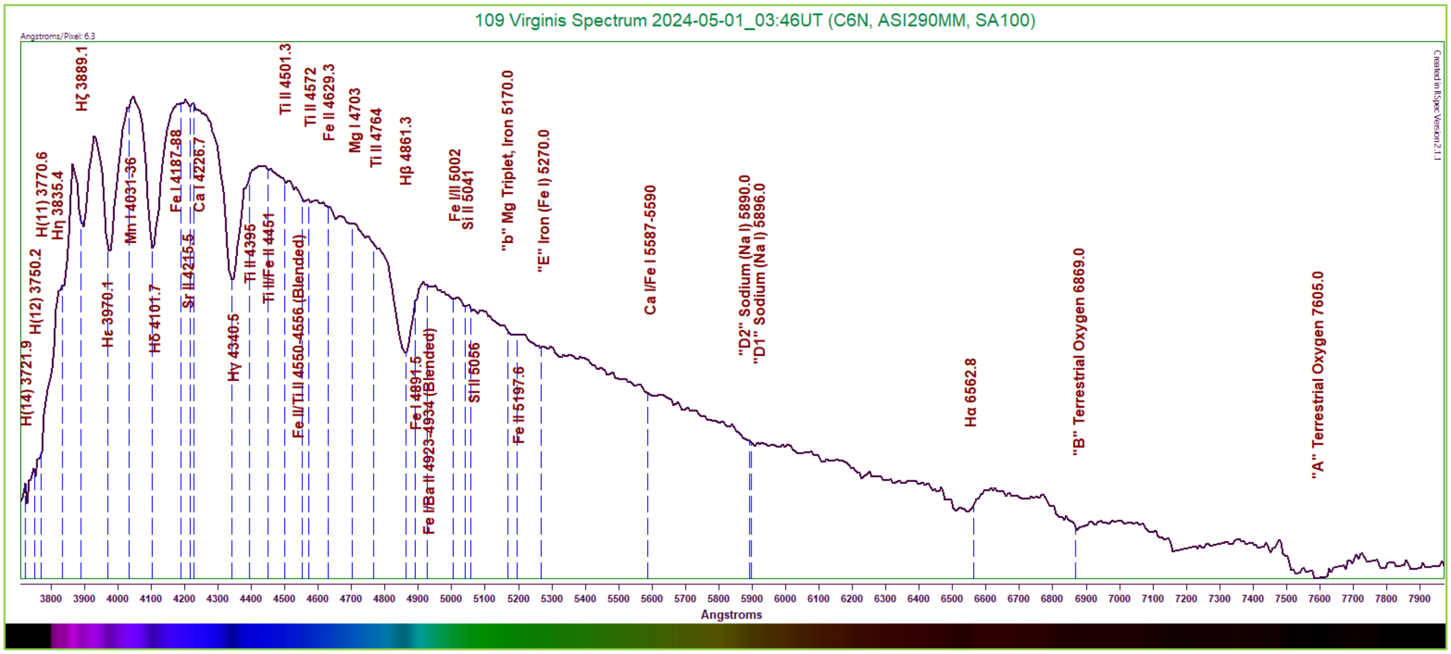


*Figure 12: 109 Virginis Spectrum (6.3 Angstroms/pixel)*
*Capture Details 12: Exposure 365ms, Gain 199, 45% of 500 frames stacked*

Again we see a curve representative of an early-type star. The hydrogen Balmer lines are deep and clear. Unlike Tau Virginis, we can see no trace of the Ca II K line. The magnesium triplet at 5170 Angstroms is very weak, but the sodium doublet at 5890-96 Angstroms is a bit more pronounced. A number of other very weak metal lines are indicated, including manganese, iron, strontium, calcium, titanium, magnesium, and silicon. All of these appear very weakly.

Once again we will apply Wien's Law to determine the effective temperature of the star and compare this to the professional estimate. Of course, we expect our estimate to fall far short due to the type of star involved. Using an estimated peak energy wavelength of 4047 Angstroms, we arrive at an estimate of approximately 7160K. The accepted temperature for the star is listed as 9683K[2]. Our estimate came out a touch higher than that for Tau Virginis, but it misses the target temperature by quite a bit more, as expected.

## β Virginis

At the beginning of the session, a brief stop at this star was made to capture its spectrum since there are no others of this type in this Library.

Beta Virginis, also known as Zavijava, is classified as a very late F-type star[1]. We can expect to see a curve representing a star that is slightly hotter than our Sun, with lots of metal lines present.

The finished spectrum is presented below:

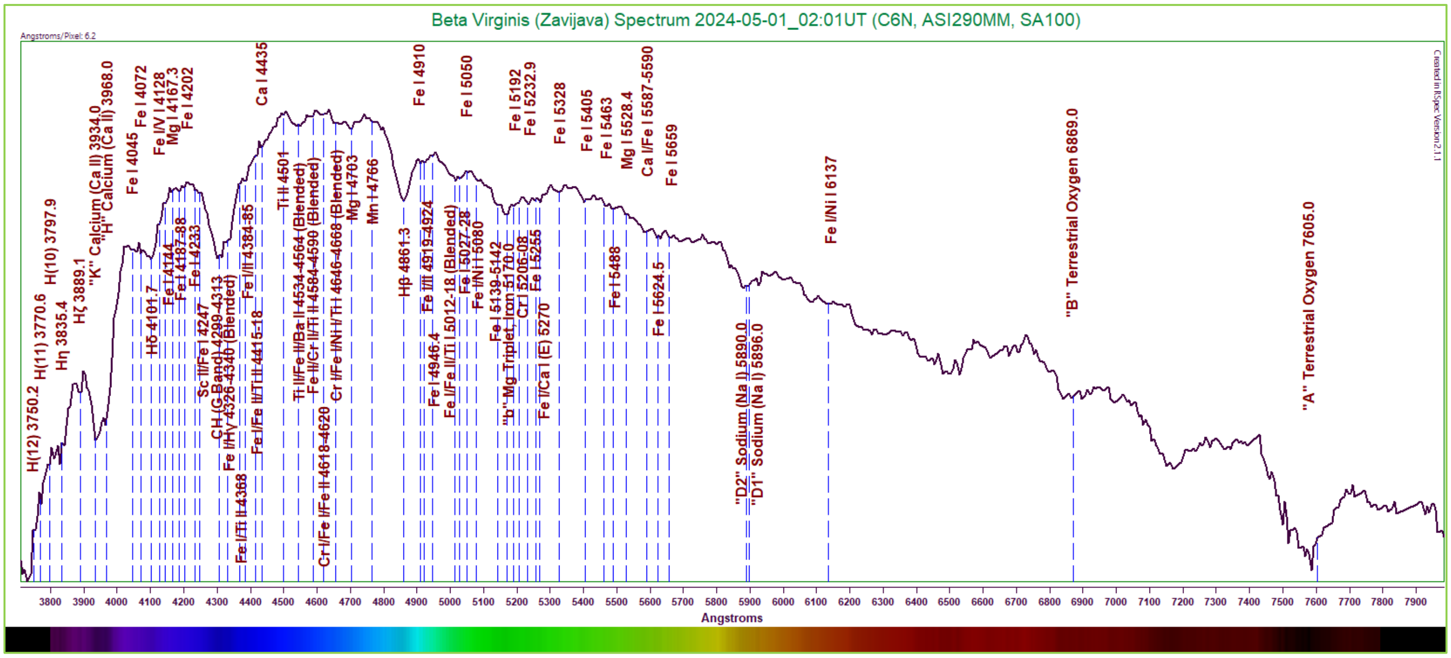


*Figure 13: Beta Virginis (Zavijava) Spectrum (6.2 Angstroms/pixel)*
*Capture Details 13: Exposure 281, Gain 181, 30% of 1045 frames stacked*

The very late F-type spectrum is recognizable here. Most of the hydrogen Balmer lines are present, though only moderately. The Hα line in this specimen is subsumed in continuum noise. The calcium K and H lines at 3934 and 3968 Angstroms are extremely strong by contrast. The next notable feature is the CH (G) molecular band, which is also carving a deep cut out of the continuum. The Hγ line is actually blended with an iron line just above it to produce a small plateau in the groove. The magnesium triplet at 5170 Angstroms is a bit weak here, but it is aided by flanking iron and chromium lines. The sodium D lines at 5890-96 Angstroms are approximately the same strength as the magnesium triplet, and are carving their own distinct gouge out of the spectrum. We can see a large number of additional faint to very faint metal lines—lots of iron, magnesium, scandium, calcium, titanium, chromium, and manganese. Some of these lines are packed closely together, so be careful when tracing labels.

We will employ Wien's Law once again to obtain an effective temperature estimate. Since this star is of a later type than the last few, our estimate should come out much closer to the actual temperature. Using a peak energy wavelength of 4634 Angstroms, we calculate an effective temperature of 6253K. The accepted temperature of the star is listed as 6132K[2]. Our estimate is a little too high, but not terribly far off.

## Conclusion

Virgo is mostly composed of somewhat dimmer stars, so care had to be taken with capturing them. A few required higher gain settings than I normally prefer to use, but the results were still acceptable.

## 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)