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A statistical study of the UV Si IV resonance lines′ parameters in 20 Be stars

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It is already known that all the stars of the same spectral type and luminosity class present the same absorption lines in their spectra

All the Stars…?

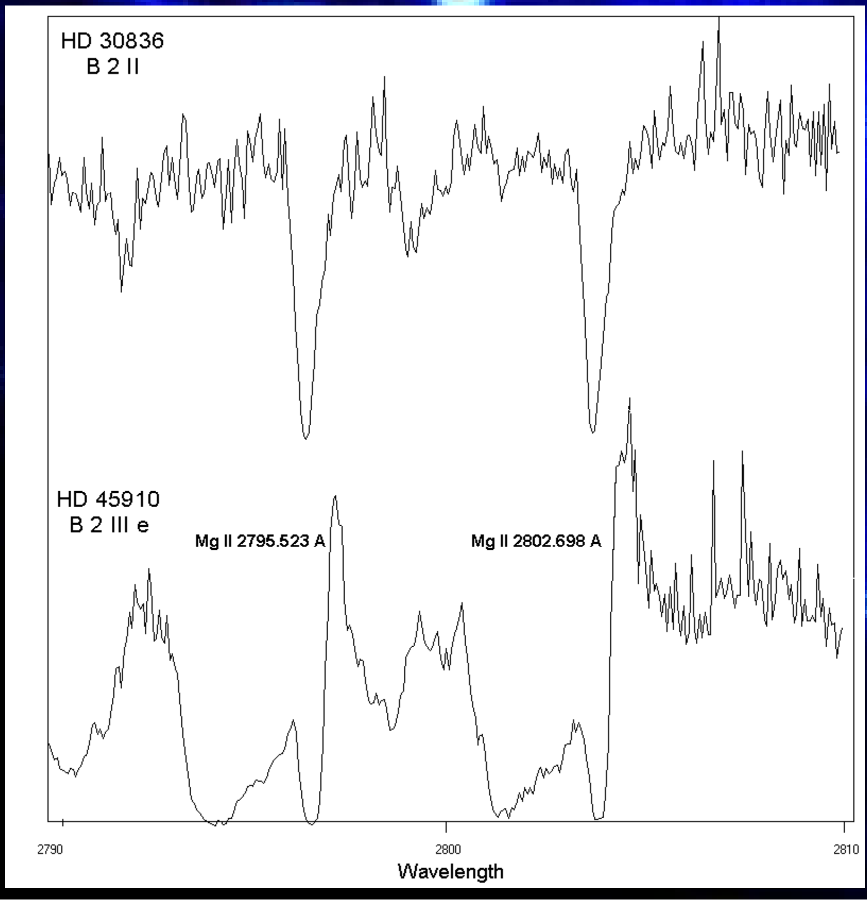
In the UV spectral region, some hot emission stars (Oe and Be stars) present some absorption components that should not appear in their spectra, according to the classical physical theory.

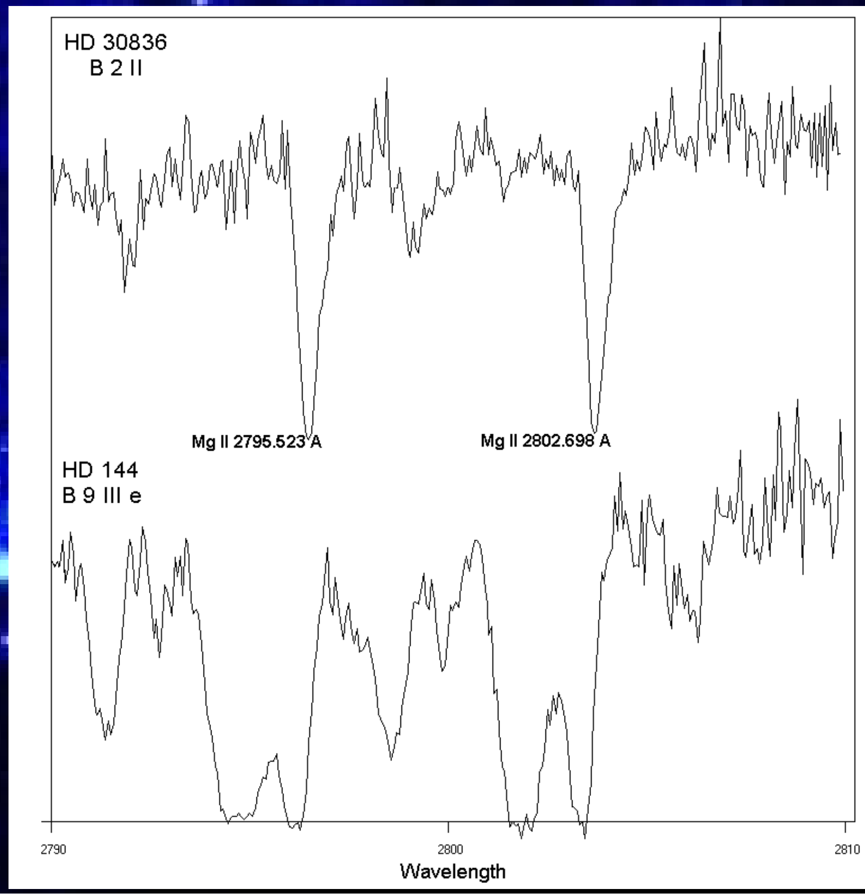
Many researchers* have observed the existence of these absorption components shifted to the violet or red side of the main spectral line. These components were named Discrete or Satellite Absorption Components**. They probably originate in separate regions that have different rotational and radial velocities.

*e.g. Doazan 1982, Danezis et al. 1991, Doazan et al. 1991, Lyratzi et al. 2003, 2007, Danezis et al. 2007

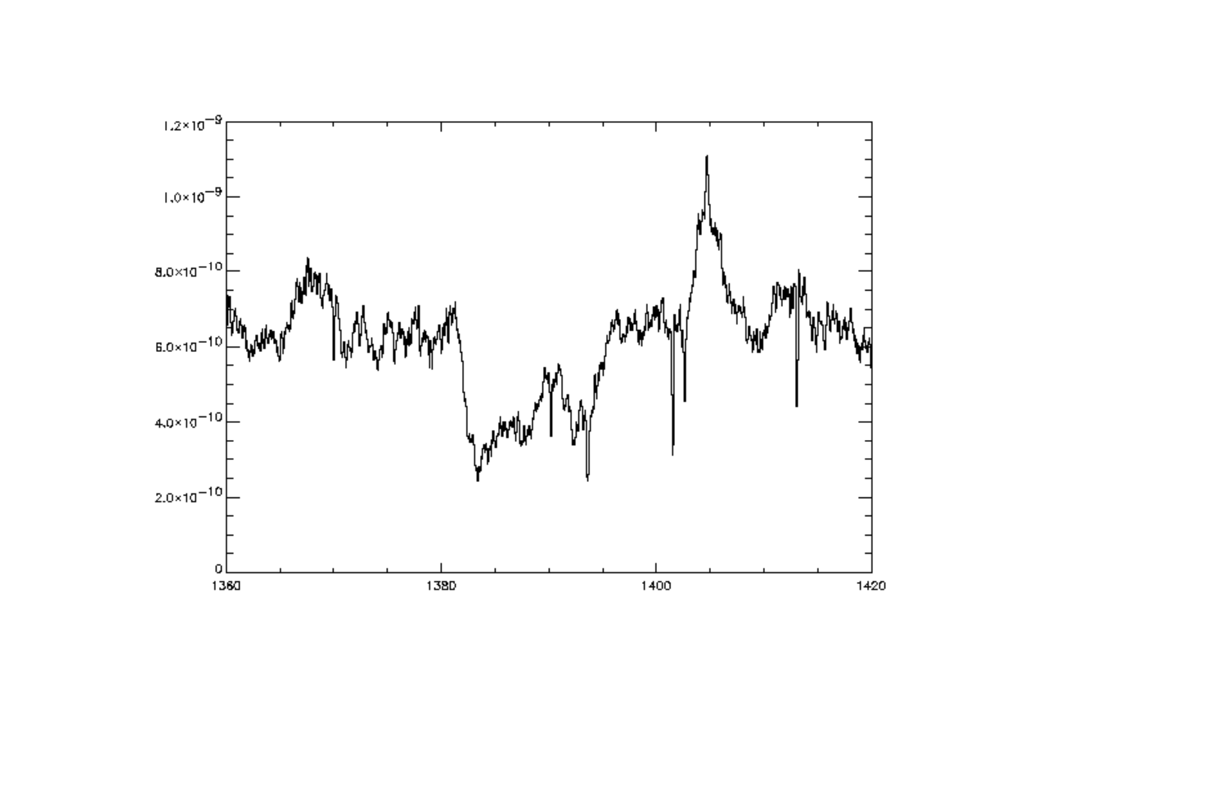
**Bates & Halliwell 1986; Danezis et al. 2003; Lyratzi & Danezis 2004

In these figures we can see the comparison of Mg II resonance lines between the spectrum of a normal B star and the spectra of two active Be stars that present complex and peculiar spectral lines. In the first figure we observe a combination of an emission and some absorption components (P Cygni).





The Si IV resonance lines have also a peculiar profile in the Be stellar spectra, which indicates a multicomponent nature of their origin region.



The whole observed feature of the Si IV resonance lines is not the result of a uniform atmospherical region, but it is constructed by a number of components, which are created in different regions that rotate and move radially with different velocities.

In this figure we see the Si IV $\lambda\lambda$ 1393.755, 1402.778 Å resonance lines of the star HD 203064

Using the G(aussian)R(rotation) model

Danezis, E., Nikolaidis, D. , Lyratzi, E., Antoniou, A. Popovic, L.C., Dimitrijevic, M.,
PASJ, 2007

We can calculate some important parameters of the density regions that construct the Discrete or Satellite Absorption Components like:

As direct calculations

- Apparent rotational velocities of absorbing or emitting density layers (V_{rot})
- Apparent radial velocities of absorbing or emitting density layers (V_{rad})
- The Gaussian standard deviation of the ion random motions (σ)
- The optical depth in the center of the absorption or emission components (ξ_i)

As indirect calculations

- The random velocities of the ions (V_{random})
- The FWHM
- The absorbed or emitted energy (Ea, Ee)
- The column density (CD)

Our research

In this application we study the **UV Si IV λλ 1393.755, 1402.778 Å resonance lines** in the spectra of 20 Be stars of different spectral subtypes and

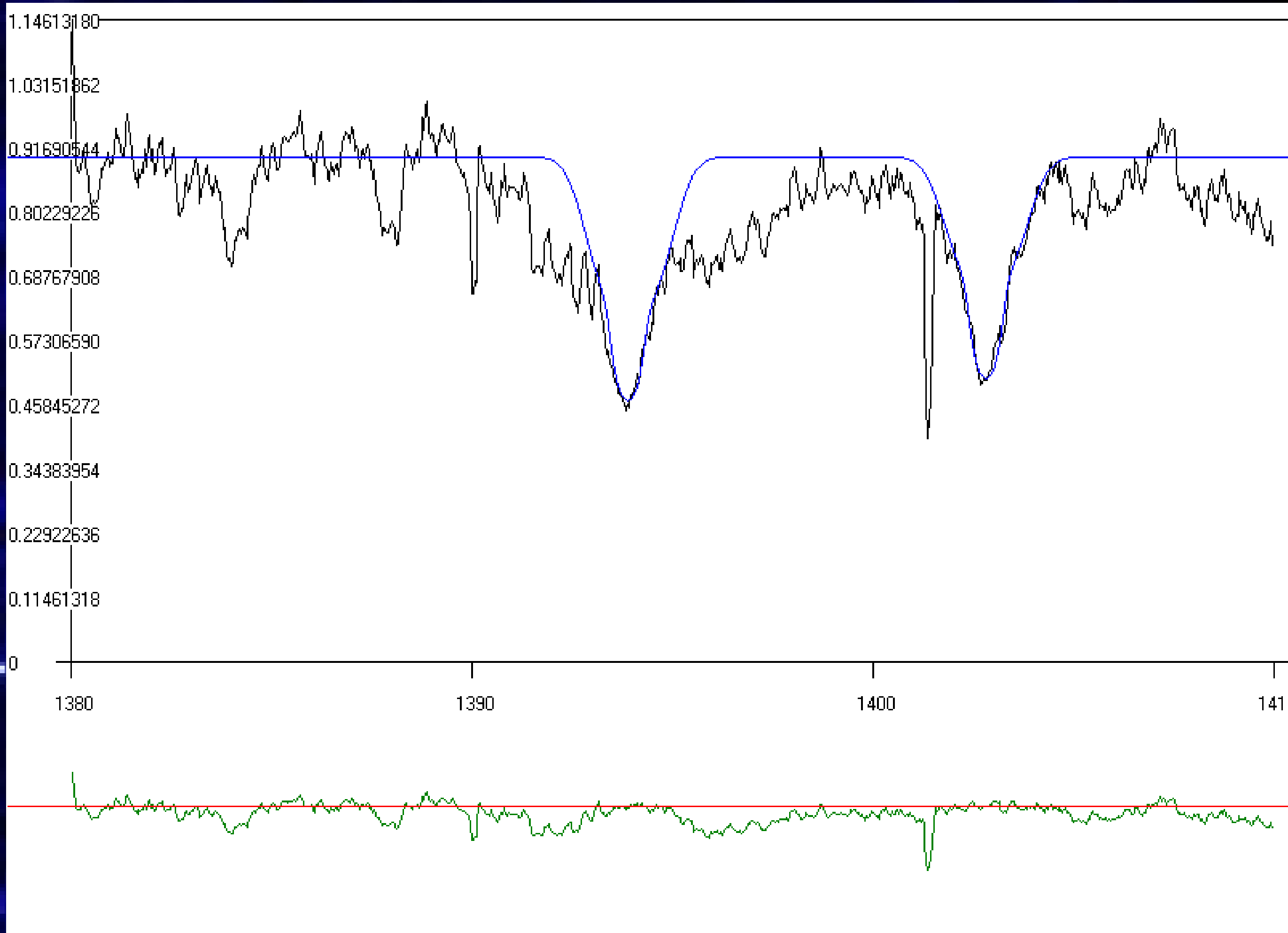
1. we calculate the above mentioned parameters
2. we present the variation of them as a function of the stars' effective temperatures

We give also the Linear Regression and the Linear Correlation Coefficient R^2

The Data

Star	Spectral Subtype
HD 53367	B0 IV e
HD 44458	B1 V pe
HD 58343	B2 N ne
HD 45910	B2 III e
HD 41335	B2 V ne
HD 52721	B2 V ne
HD 37202	B2 IV p
HD 32991	B2 V e
HD 58050	B2 V e
HD 37490	B3 III e
HD 25940	B3 V e
HD 183362	B3 V e
HD 217050	B4 III pe
HD 67888	B4 III pe
HD 89884	B5 III
HD 23480	B6 IV e
HD 192044	B7 V e
HD 29866	B8 IV ne
HD 199218	B8 IV nne
HD 50138	B9

The spectrograms of the stars have been taken with IUE satellite, with the Long Wavelength range Prime and Redundant cameras (LWP, LWR) at high resolution (0.1 to 0.3 Å)



In this figure, we see the Si IV doublet of the B2 Ve star HD 58050 and its best fit. The best fit has been obtained using two absorption components. The graph below the profile indicates the difference between the fit and the real spectral line.

In the following figures we'll see the variation of the physical parameters of the Si IV regions of the studied stars, as a function of the stars' effective temperature (Teff).

In each case we give the Linear Regression and the respective Linear Correlation Coefficient R^2.

We remind that the Linear Regression is given by

$$\hat{y} = \hat{\alpha} + \hat{\beta}x \qquad \hat{\beta} = \frac{n\sum x_i\, y_i - (\sum x_i)(\sum y_i)}{n\sum x_i^2 - (\sum x_i)^2} \qquad \hat{\alpha} = \bar{y} - \hat{\beta}x$$

and the Linear Correlation Coefficient

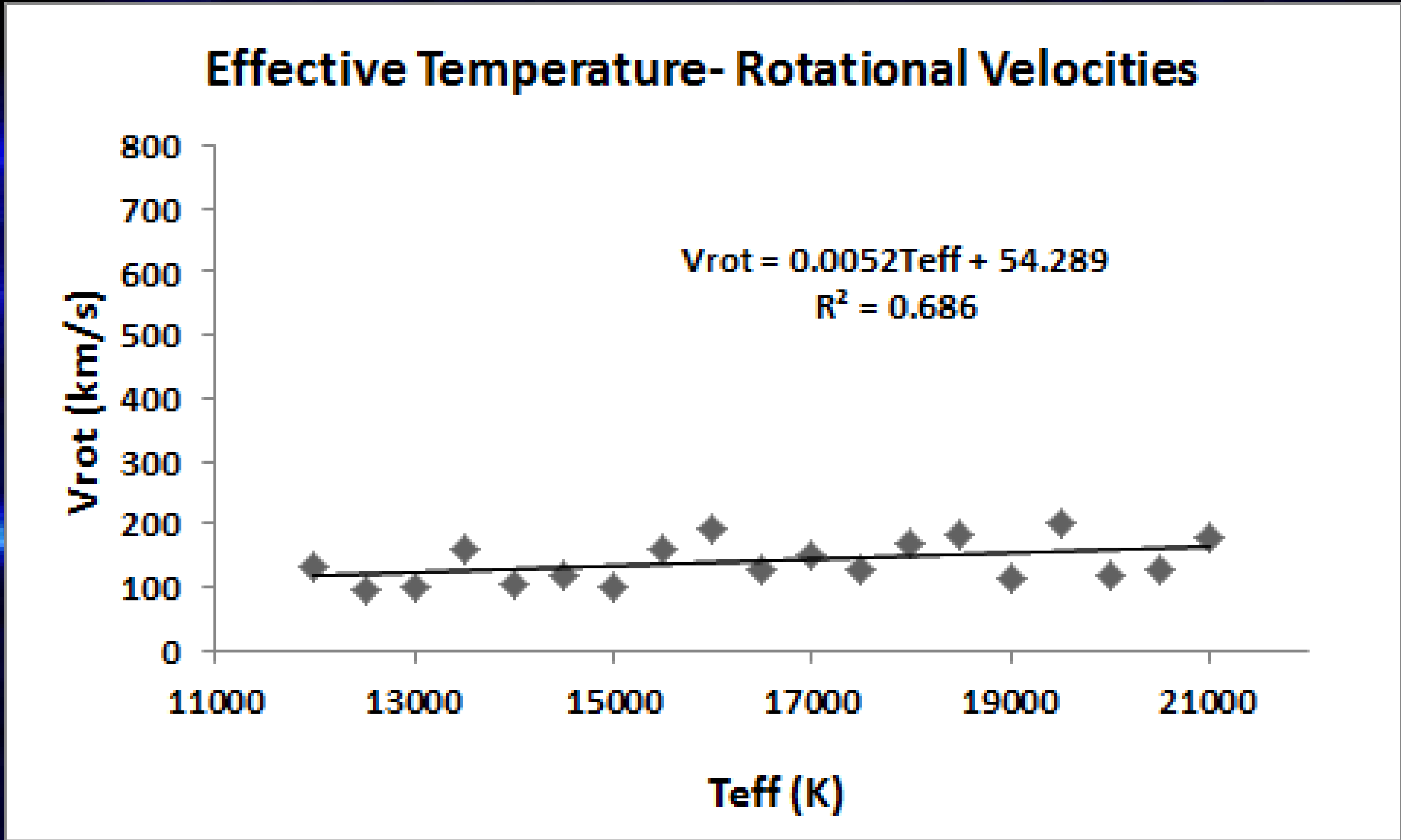
$$R = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2}\,\sqrt{\sum(y_i - \bar{y})^2}}$$

With regard to the Linear Correlation Coefficient (R^2)

- **if $R^2=1$ the linear correlation is ideal**
- **if $0.5<R^2<1$ the linear correlation is considered as "good"**
- **if $0.3< R^2<0.5$ the linear correlation is considered as "weak".**

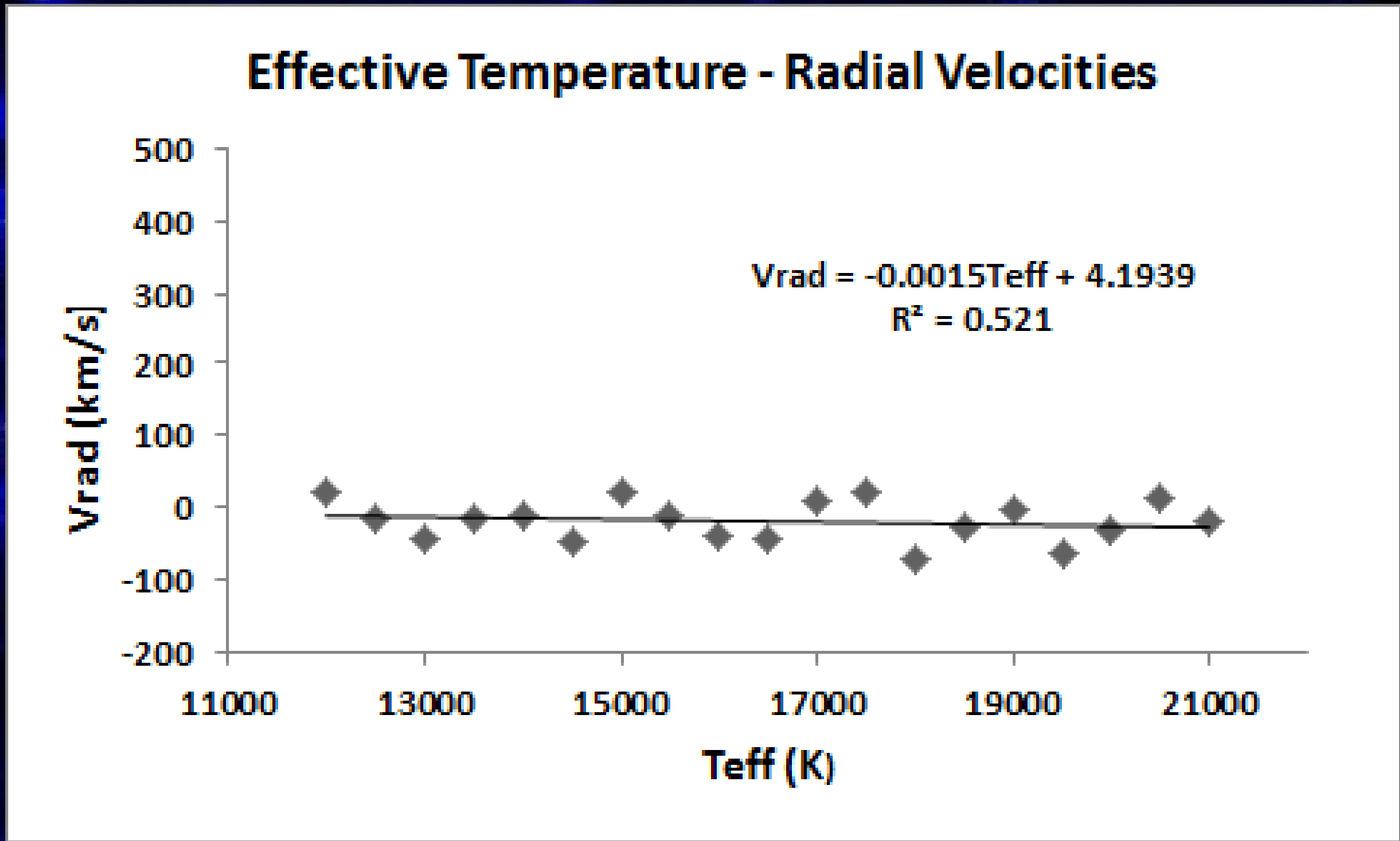
otherwise there is no linear correlation

Rotational Velocities (Vrot)



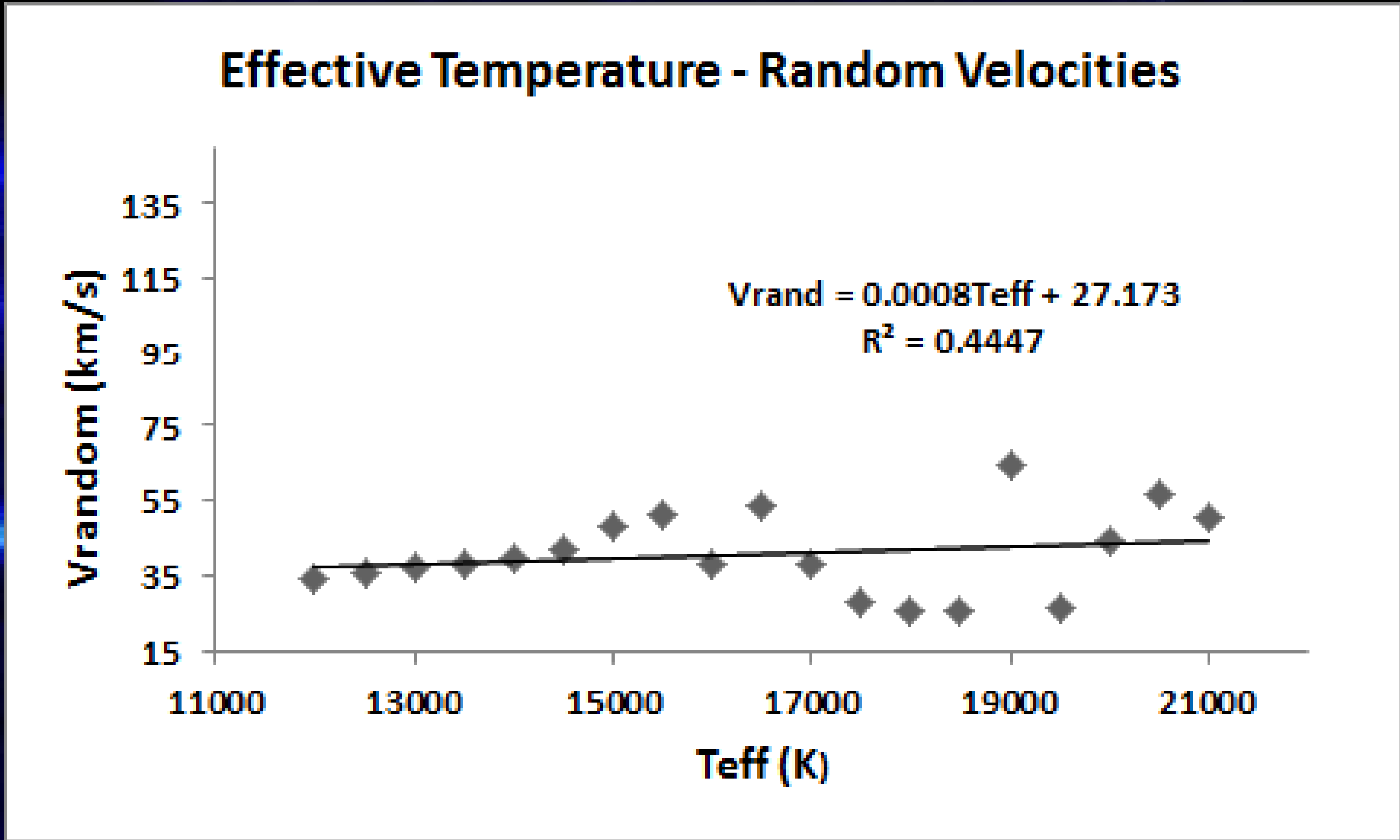
Variation of the rotational velocities of the Si IV resonance lines ($\lambda\lambda$ 1393.755, 1402.778 Å) for the independent density regions of matter which create the absorption components, as a function of the effective temperature. We see a slightly increasing linear trend of the rotational velocities and a “good” linear correlation (R^2=0.686)

Radial Velocities (Vrad)



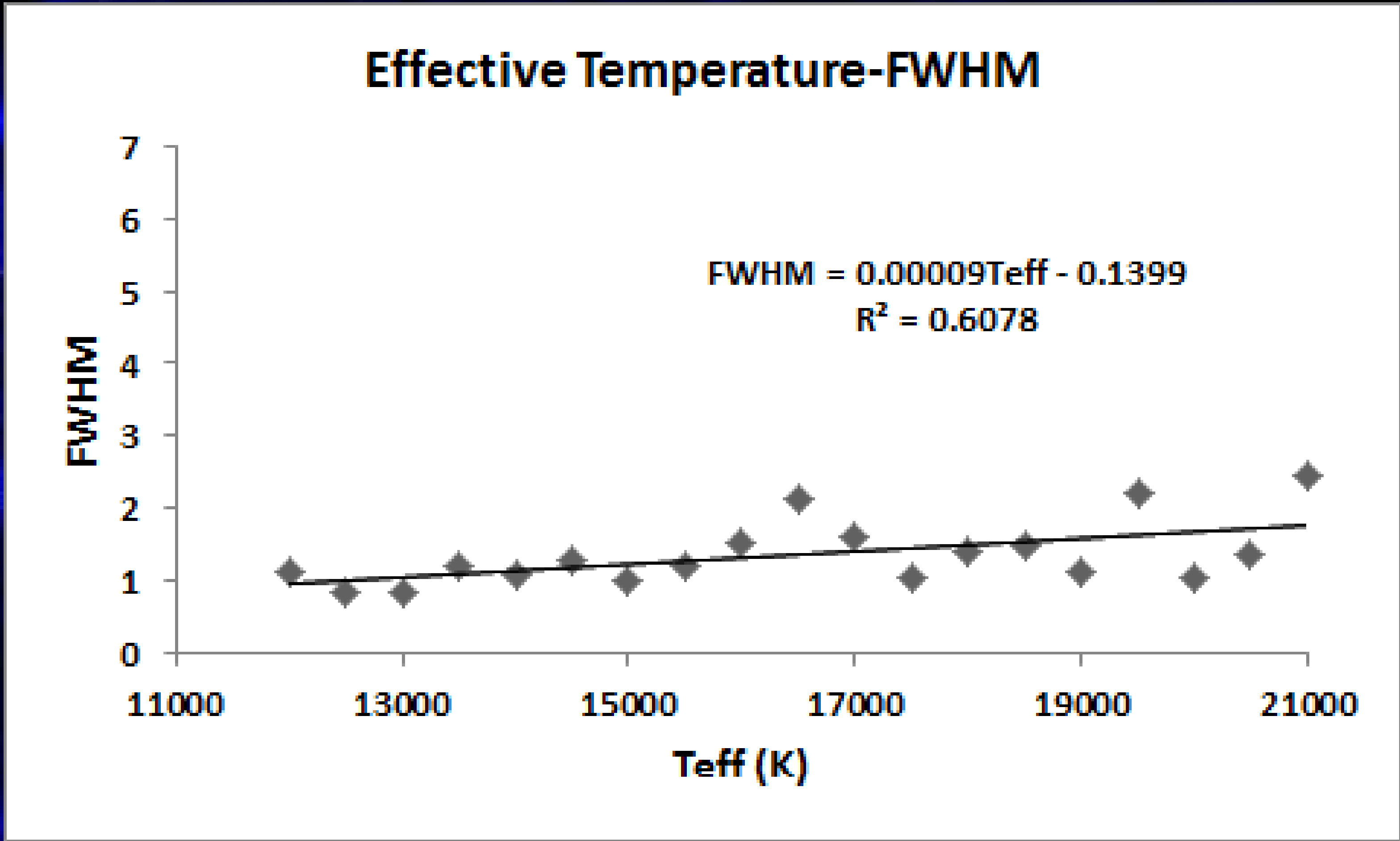
Variation of the radial velocities of the Si IV resonance lines (λλ 1393.755, 1402.778 Å) for the independent density regions of matter which create the absorption components, as a function of the effective temperature. We have also found a very slightly negative slope and a “good” linear correlation (R^2=0.521)

Random Velocities (Vrand)



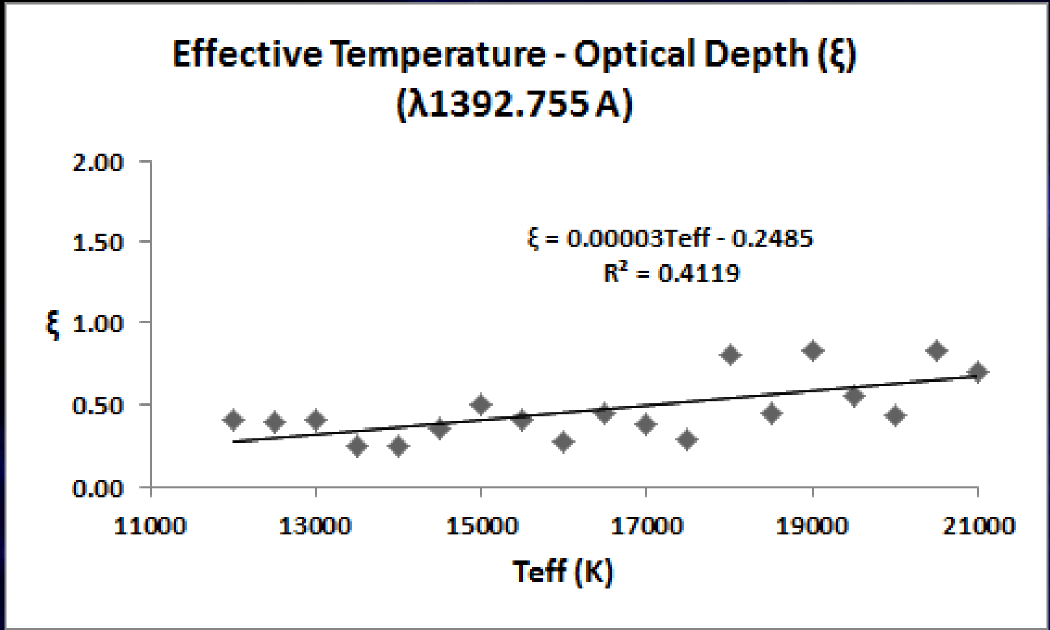
Variation of the random velocities of the ions of the Si IV resonance lines ($\lambda\lambda$ 1393.755, 1402.778 Å) for the independent density regions of matter which create the absorption components, as a function of the effective temperature. We detected almost the same increasing trend of the random velocities as in the case of rotational velocities and a “weak” linear correlation (R^2=0.4447)

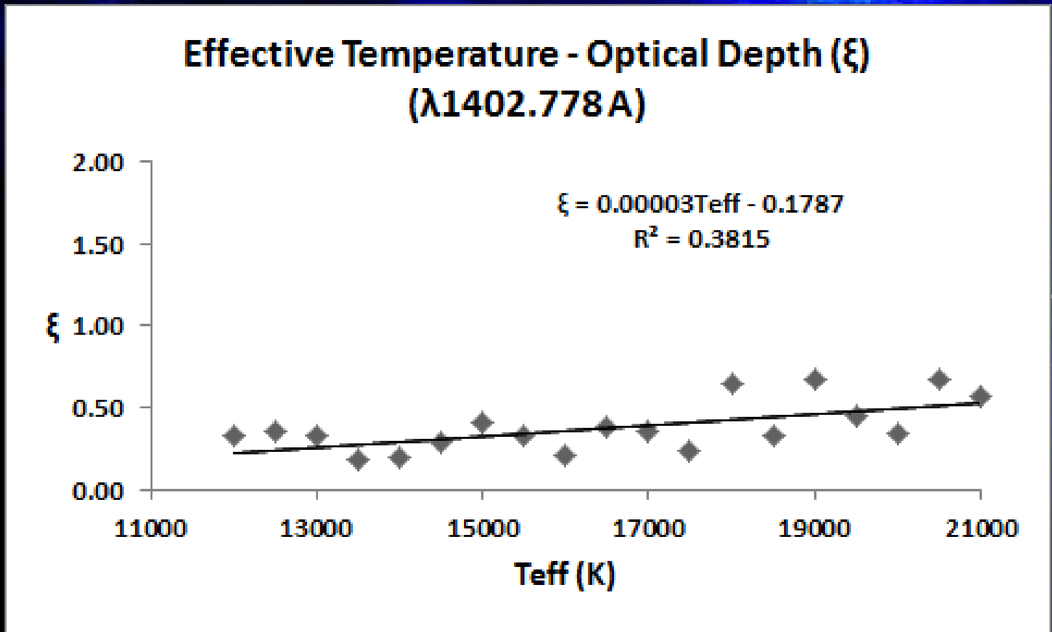
Full Width at Half Maximum (FWHM)



The variation of the FWHM is the same as the variation of the rotational and random velocities. This is expected because the FWHM is a parameter which indicates the line broadening and the rotational and random velocities are parameters which contribute to this situation. The linear correlation is "good" (R^2=0.6078).

Optical Depth (ξ)

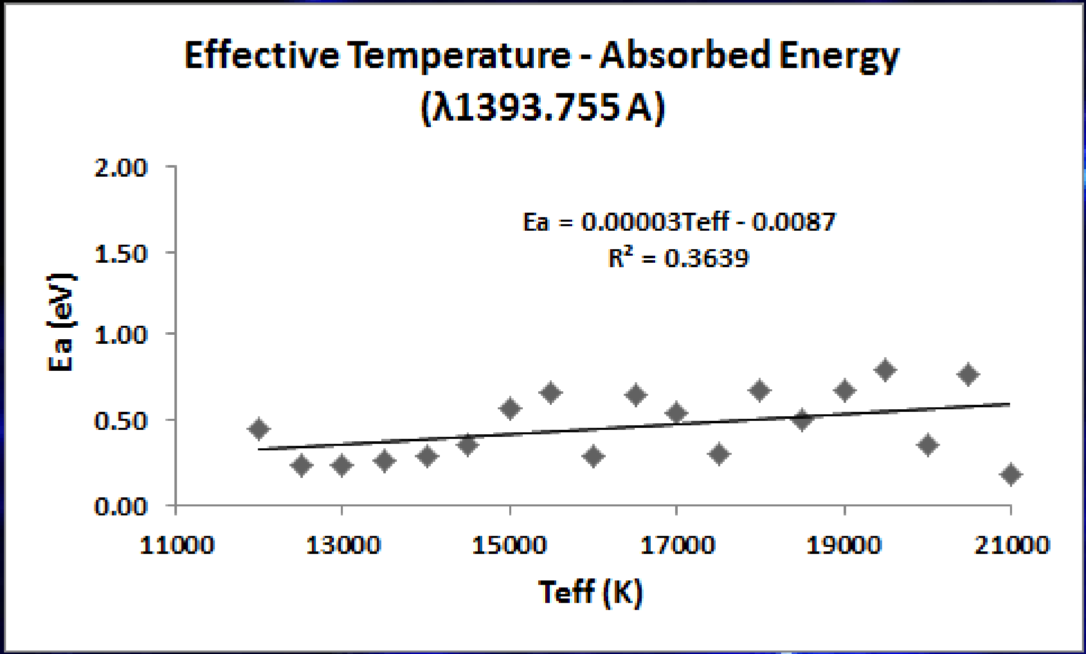


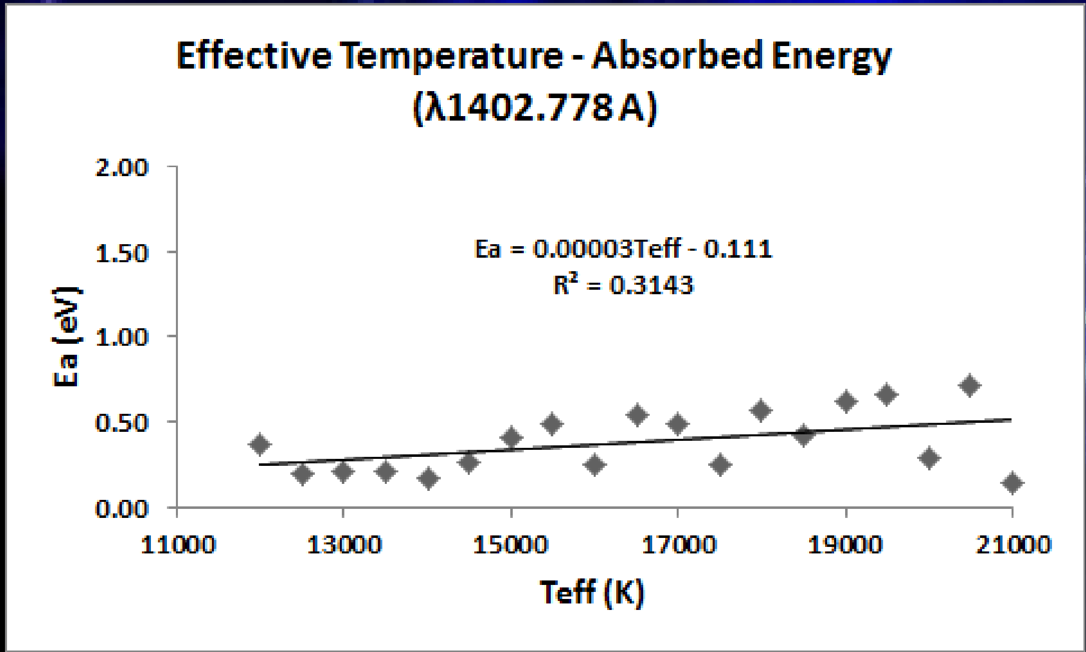


The variation of the optical depth (ξ) is the same in both of the Si IV resonance lines. The optical depth's values in the Si IV λ 1402.772 Å spectral line are 0.8 of the optical depth's values in the Si IV λ 1392.755 Å. This is in agreement with the atomic theory.

The linear correlation in both cases is "weak" (R^2=0.4119 and R^2=0.3815 respectively)

Absorbed Energy (Ea)

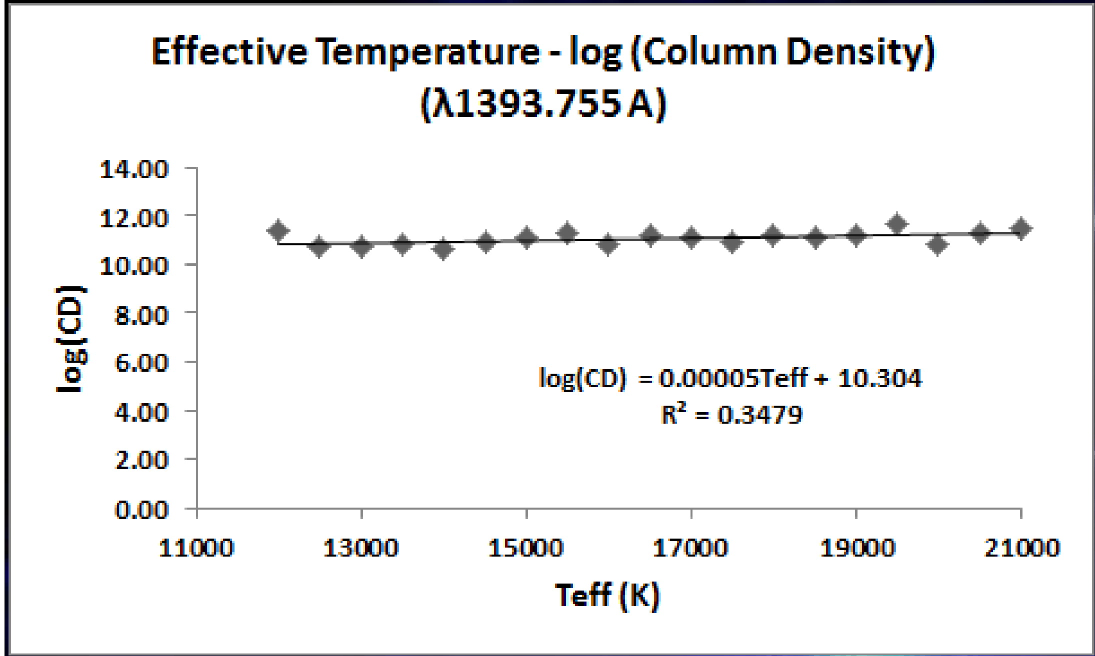


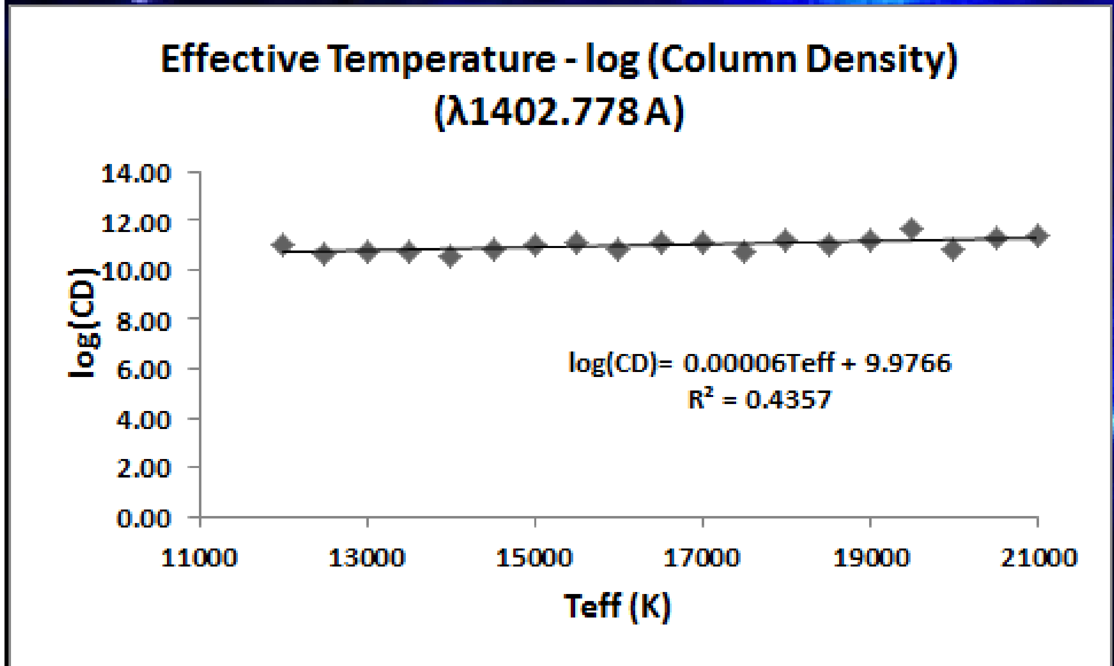


As in the case of the optical depth, the variation of the absorbed energy (Ea) is the same in both of the Si IV resonance lines and the absorbed energy's values in the Si IV λ 1402.772 Å spectral line are 0.8 of the absorbed energy's values in the Si IV λ 1392.755 Å. This is in agreement with the atomic theory.

As before, the linear correlation in both cases is "weak" (R^2=0.3639 and R^2=0.3143 respectively)

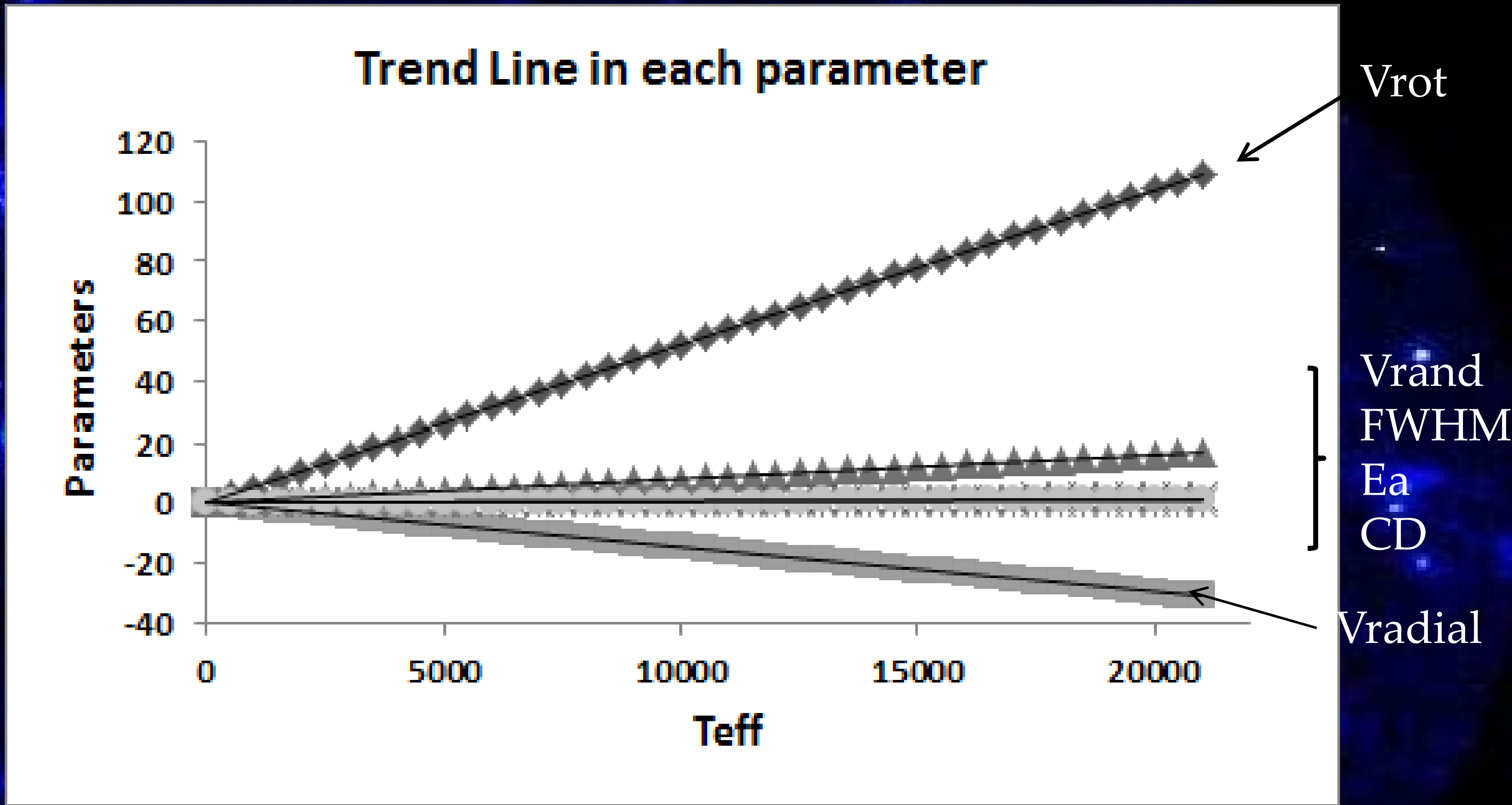
Column Density (CD)





The variation of the column density of the Si IV resonance lines (λλ 1393.755, 1402.778 Å) remains almost constant between 10^{11} and 10^{12} cm^{-2}. The linear correlation is "weak" (R^2=0.3479 and R^2=0.4357 respectively)

Linear Regression in all of the parameters



Finally, in this figure, we see the linear regressions of all of the parameters in the same diagram. The parameters Vrand, FWHM, Ea, CD present a very slight slope.

Conclusions

- **The values of all of the calculated parameters are in agreement with the physical theory**

- **The best fit has been obtained with one component in two of the twenty studied stars, with two components in twelve of them and with three components in six of them.**

Conclusions

- ***Rotational velocities:***

We have detected a slightly increasing linear trend of the rotational velocities. This means that higher effective temperature of the star could have as consequence slightly higher rotational velocities of the matter, which produces the Si IV spectral lines. The detected linear correlation is "good" (R^2=0.686)

Conclusions

➢*Radial velocities:*

The radial velocities are the unique parameter in which we have found a very slight negative slope. So, we can consider that the radial velocities of the layers of matter which create the Si IV spectral lines remain constant in relation to the stars' effective temperature. The detected linear correlation is "good" (R^2=0.521).

Conclusions

➢ ***Random velocities:***

We detected almost the same increasing trend of the random velocities as in the case of rotational velocities. We can say that the thermal motions of the Si IV ions become higher in relation to the star's effective temperature.

➢ ***Full Width at Half Maximum (FWHM)***

The variation of the FWHM is the same as the variation of the rotational and random velocities. This is expected because the FWHM is a parameter which indicates the line broadening and the rotational and random velocities are parameters which contribute to this situation.

Conclusions

➢ ***Optical Depth, Absorbed Energy***

These parameters have the same slope and the same behavior. This is in agreement with the atomic theory.

➢ ***Column Density***

The variation of the column density of the Si IV resonance lines ($\lambda\lambda$ 1393.755, 1402.778 Å) remains almost constant between 10^{11} and 10^{12} cm^{-2}.

Conclusions

- In most of the calculated parameters the linear correlation is stronger in the stars with lower effective temperature. This means that in Be stars with low effective temperatures, if we know the star's effective temperature, we could estimate the above mentioned parameters.

- This must be confirmed by a greater sample of Be stars and it is a part of our future work.


Thank you very much for your attention