The structure of Si IV region in Be stars

A study of Si IV spectral lines in 68 Be stars

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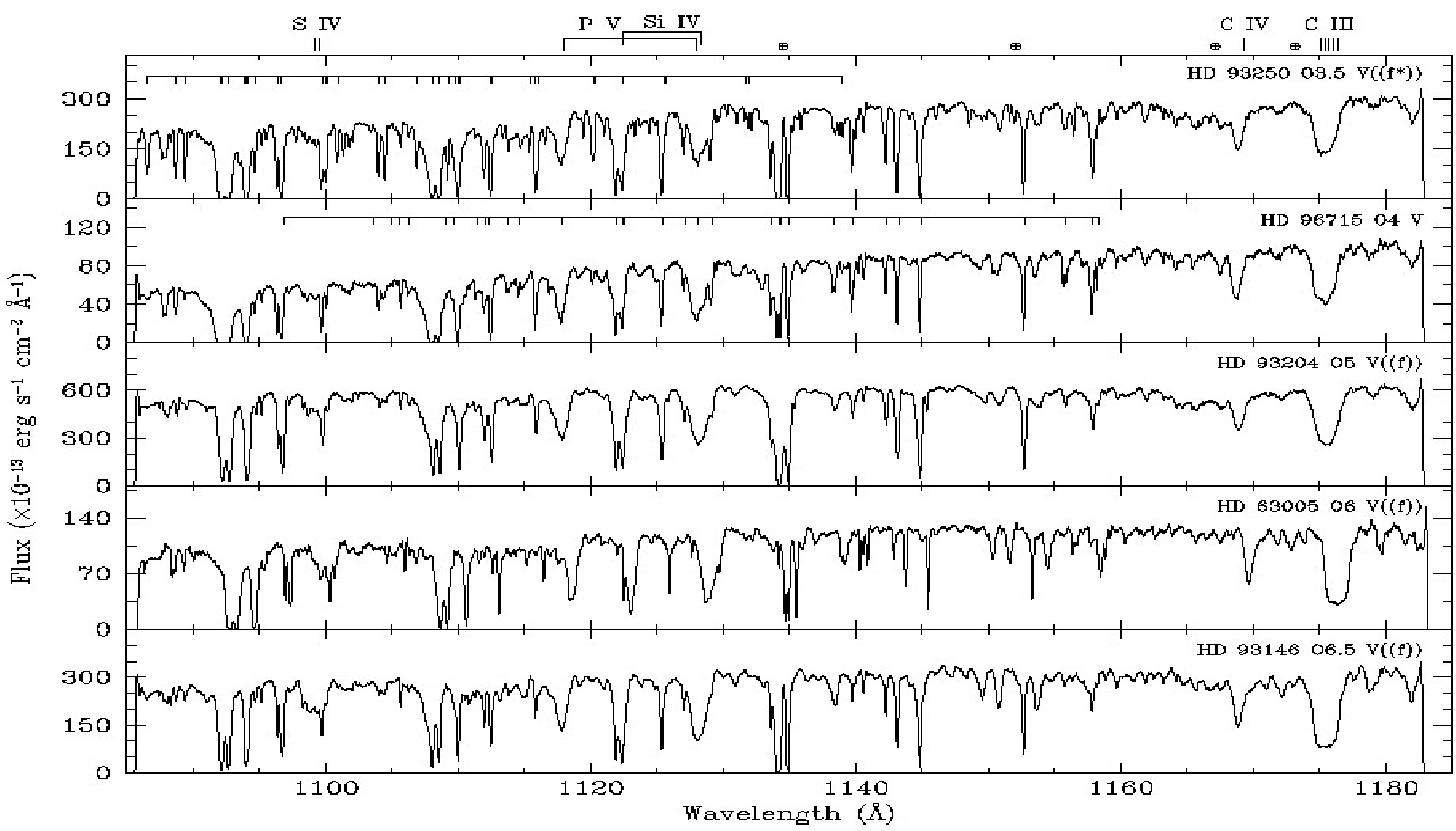
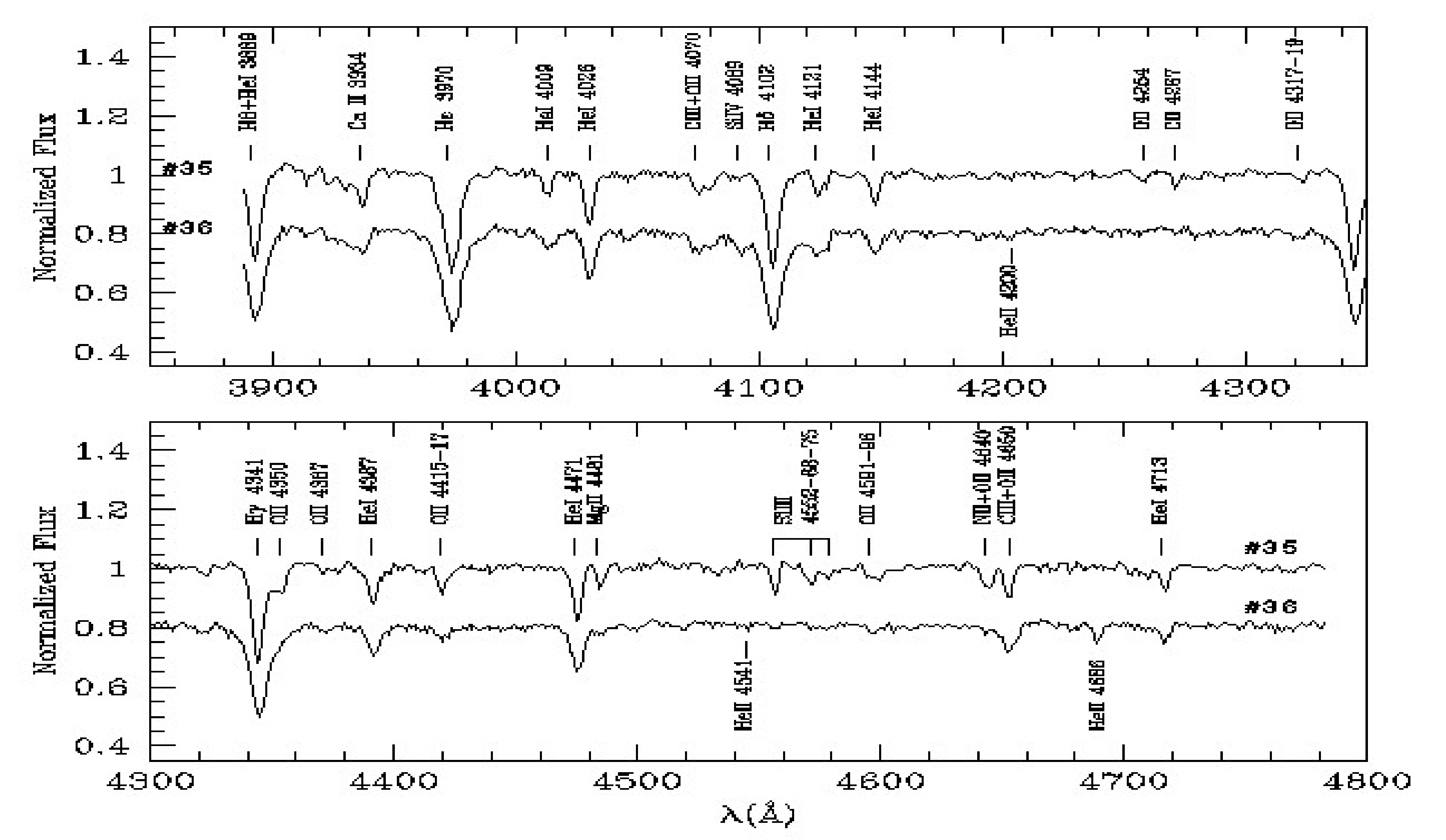
There is a general principle: All the stars of the same spectral type and luminosity class present the same absorption lines in their spectra





Two Be stars of the same luminosity class present the same absorption lines in their spectra

All the Stars…?

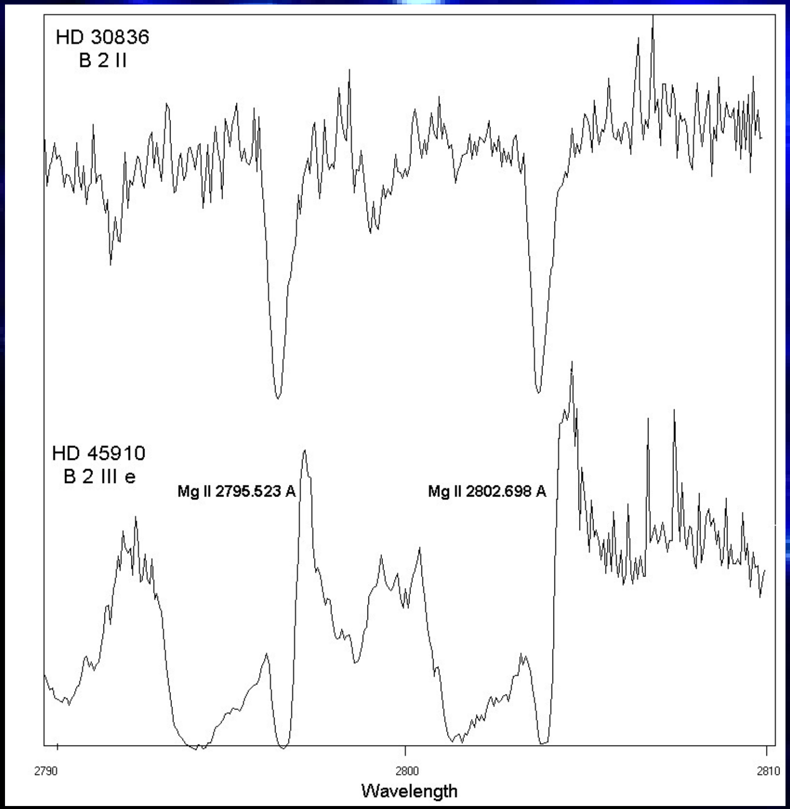
In the UV spectral region, some hot emission stars (Oe and Be stars) present some absorption components that **should not appear** in their spectra, according to the classical physical theory.

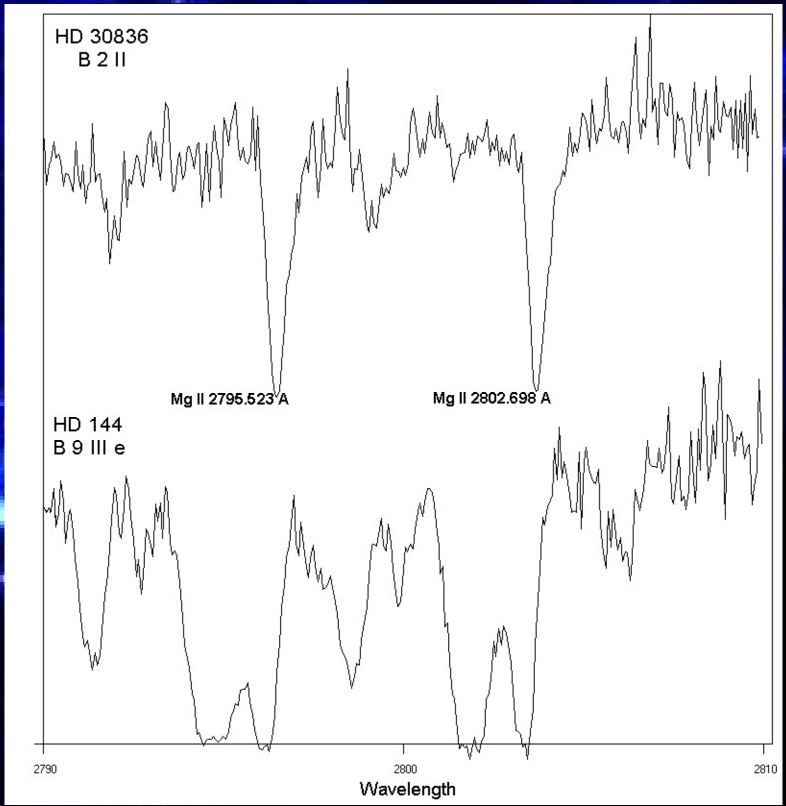
Many researchers[*] have observed the existence of these absorption components shifted to the violet or red side of the main spectral line. These components were named Discrete or Satellite Absorption Components[**]. They probably originate in separate regions that have different rotational and radial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

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

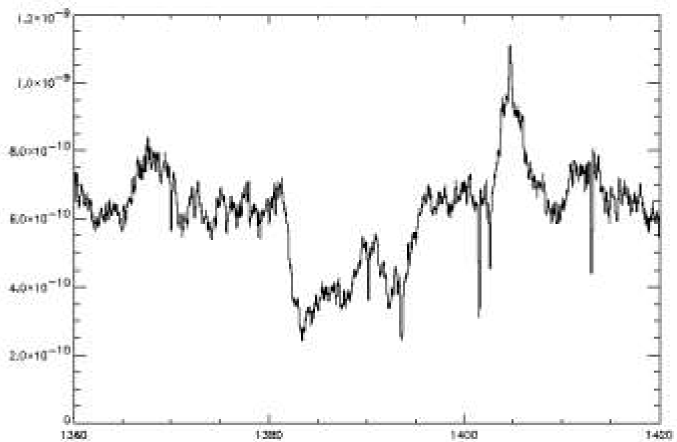
[**]Bates & Halliwell 1986, Danezis et al. 2003; Lyratzi & Danezis 2004

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.



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

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.

Using the G(aussian)R(otation) 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 68 Be stars of different spectral subtypes

1. we calculate the above mentioned parameters
2. we present the variation of them as a function of spectral subtype
3. in some cases we give the relation among some of the calculated parameters. In this case we calculate the Linear Regression and the Linear Correlation Coefficient R^2

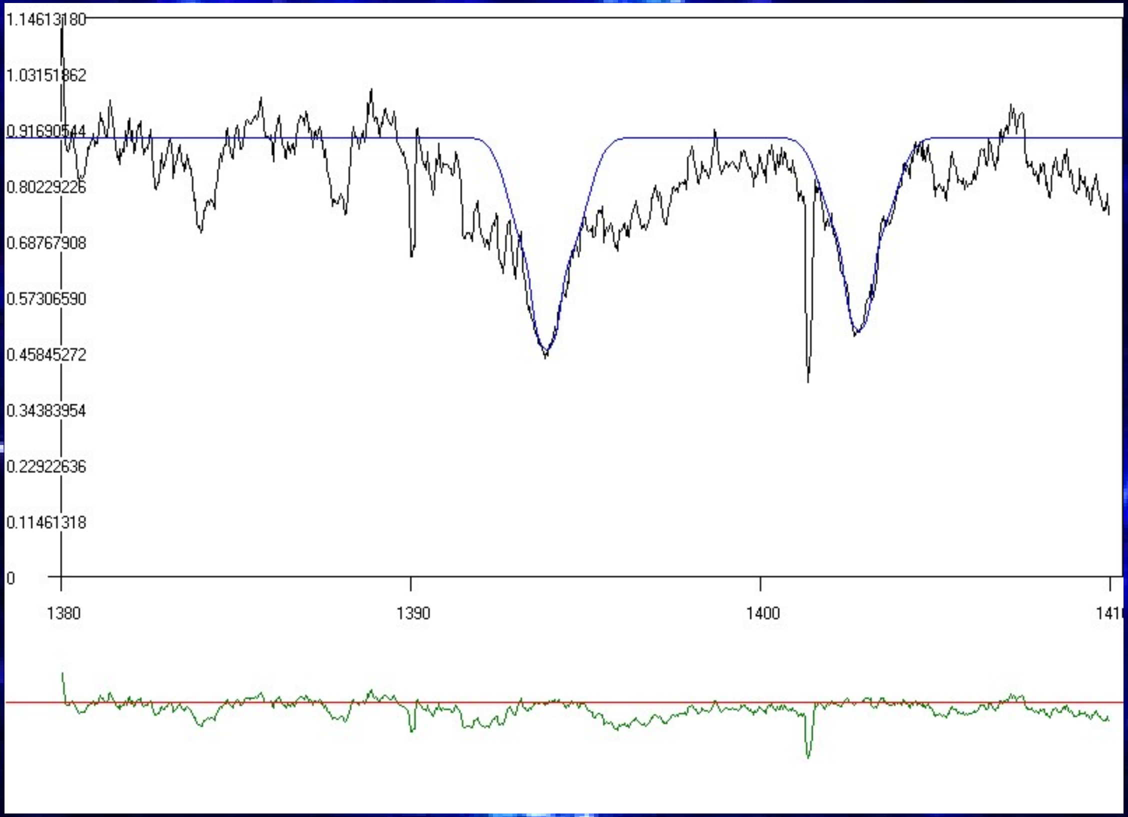
The Data

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)

Table with the stars

The best fit has been obtained using

1 absorption component in 11 stars
2 absorption components in 28 stars
3 absoption components in 29 stars



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 spectral subtype as well as the relation among some of them. In this 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

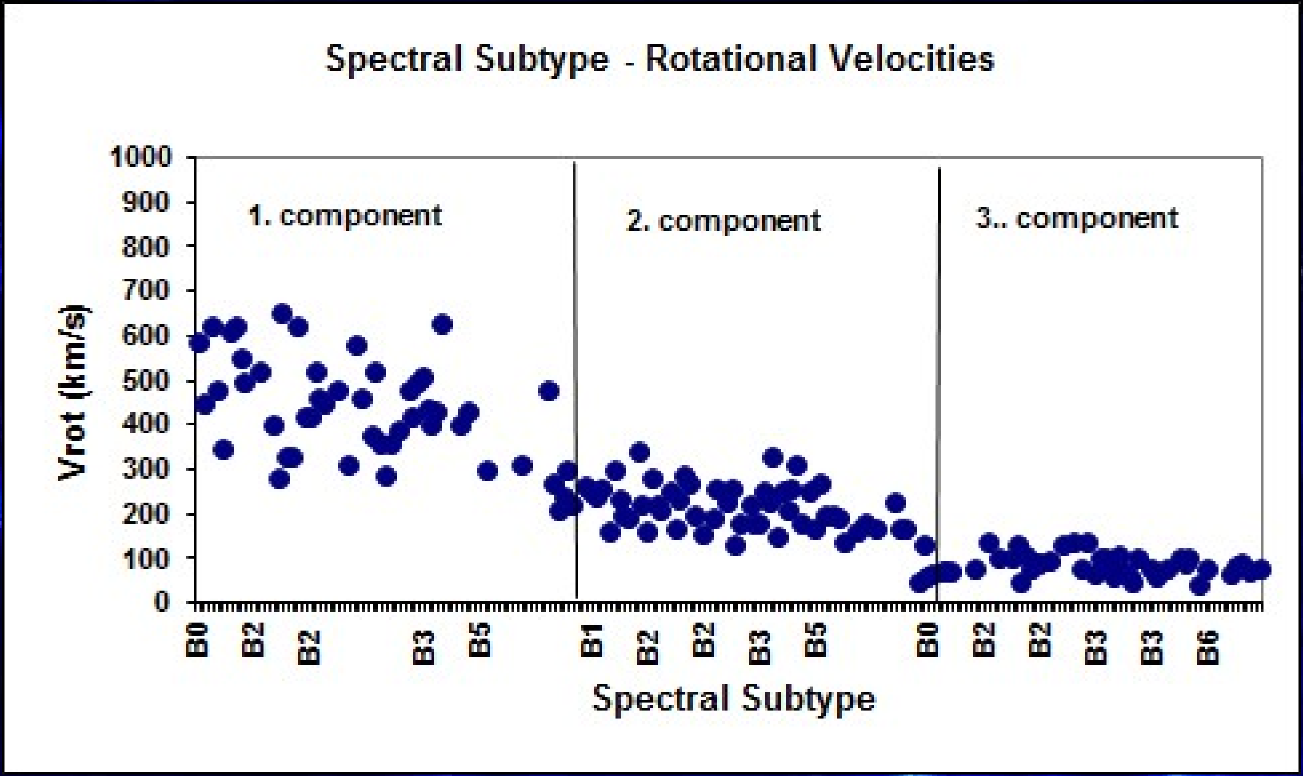
$$R = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2} \sqrt{\sum (y_i - \bar{y})^2}}$$

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”.**

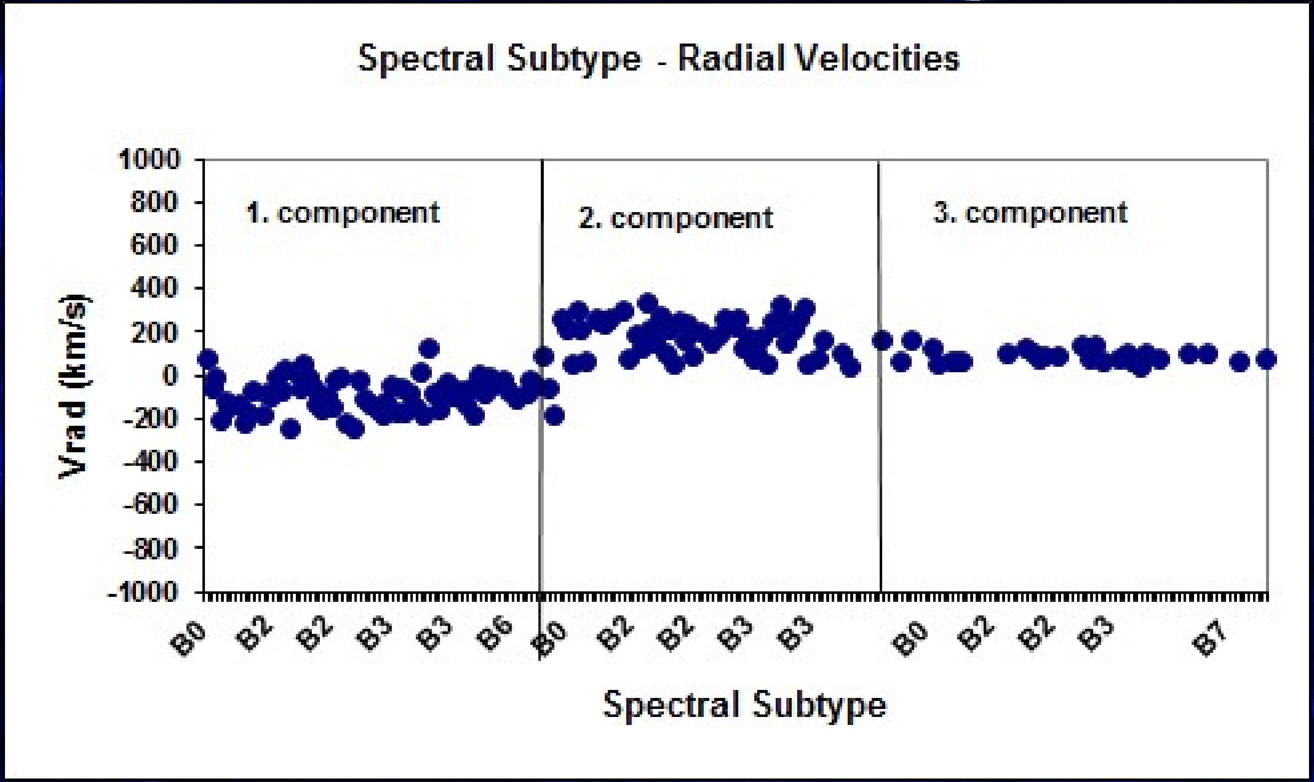
otherwise there is no linear correlation

Rotational Velocities (Vrot)



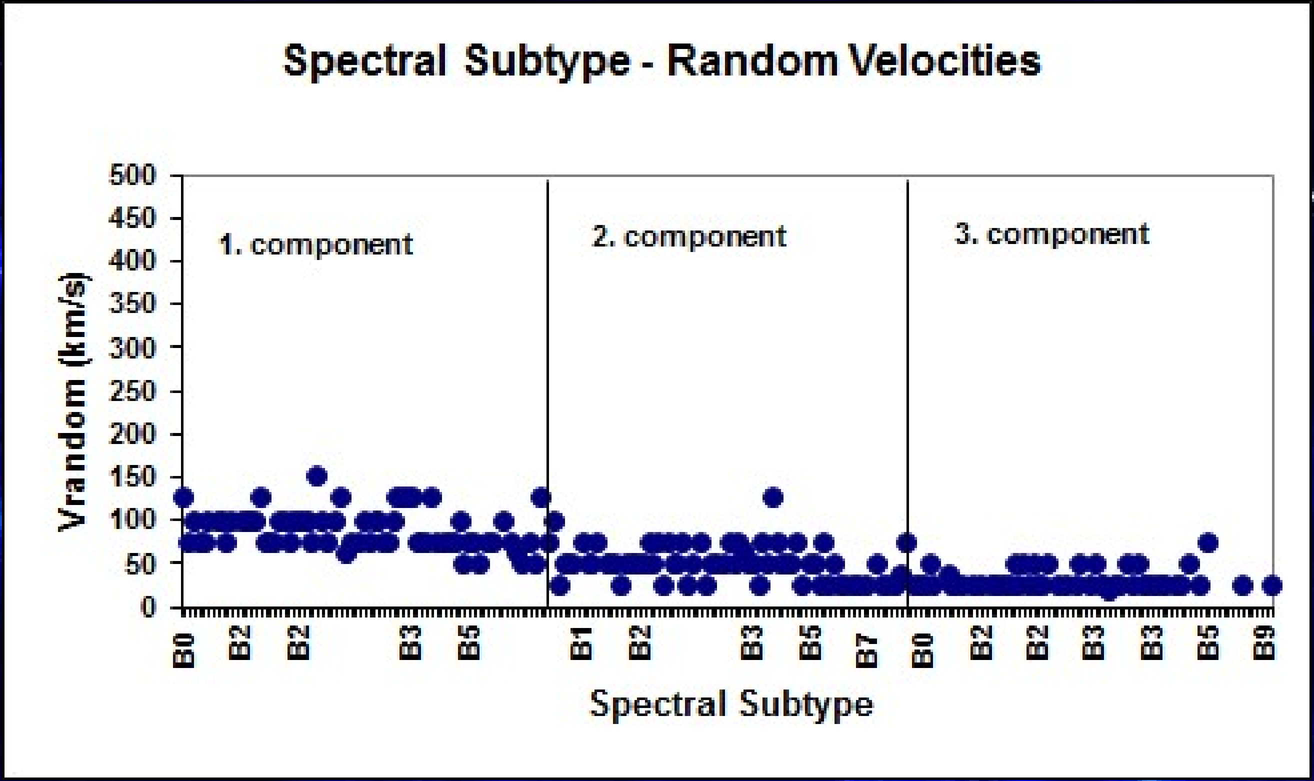
In this figure we present the variation of the rotational velocities of the Si IV resonance lines ($\lambda\lambda$ 1393.755, 1402.778 Å) for the independent density regions of matter which create the absorption components, as a function of spectral subtype. As we see the cinematically independent regions rotate with different mean velocities, with values about 455±102 km/s, 221±49 km/s, 85±25 km/s respectively. The rotational velocities of the found independent regions present a uniform fluctuation with the spectral subtype.

Radial Velocities (Vrad)



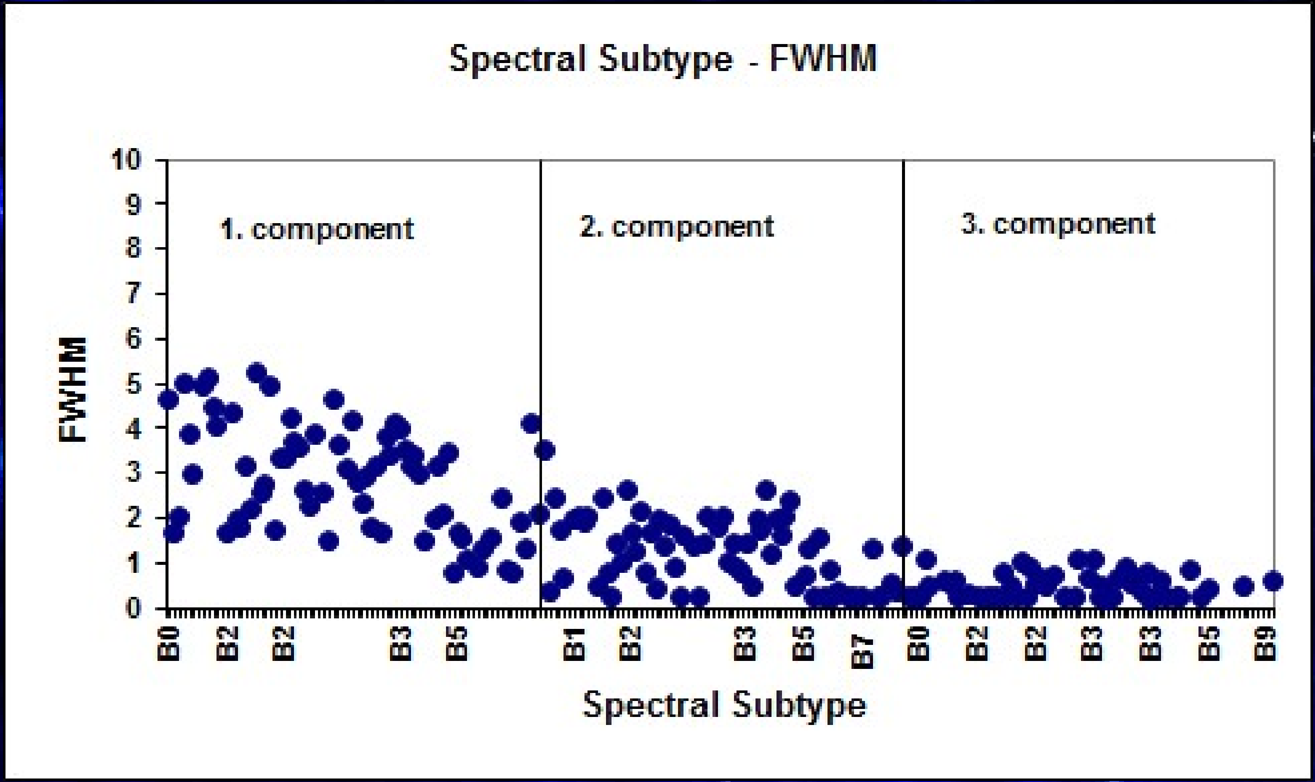
Here one can see the variation of the radial velocities of the Si IV resonance lines ($\lambda\lambda$ 1393.755, 1402.778 Å) for the independent density regions of matter which create the absorption components, as a function of the spectral subtype. We found values -83±81 km/s for the first component, 185±82 km/s for the second one and 89±25 km/s for the third one.

Random Velocities (Vrand)



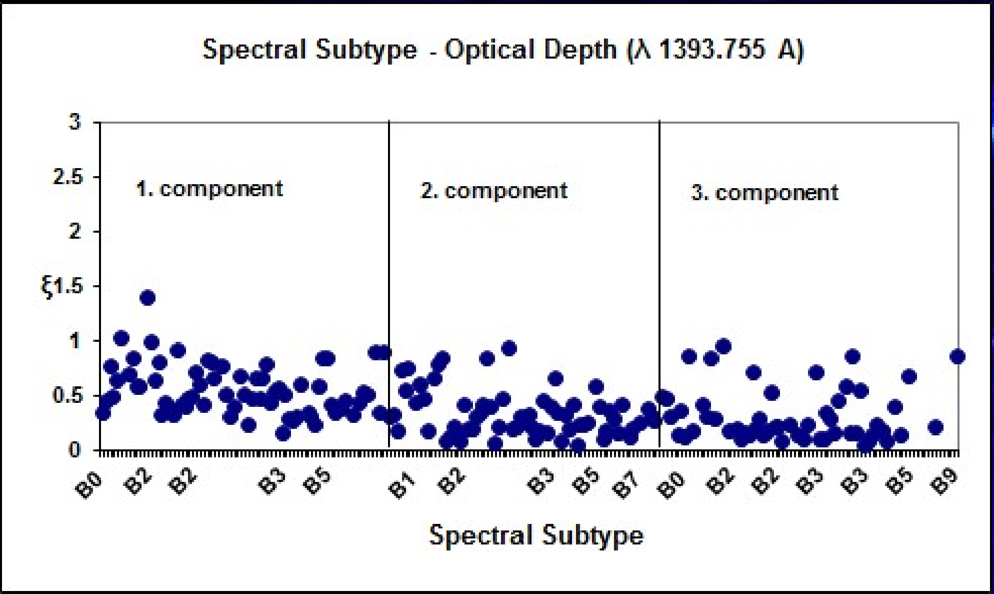
Variation of the random velocities of the ions of the Si IV resonance lines ($\lambda\lambda$ 1393.755, 1402.778 Å) for the independent density regions of matter which create the absorption components, as a function of spectral subtype. We detected an almost constant trend of the random velocities for each component. We found values 90±22 km/s for the first component, 51±21 km/s for the second one and 31±12 km/s for the third one.

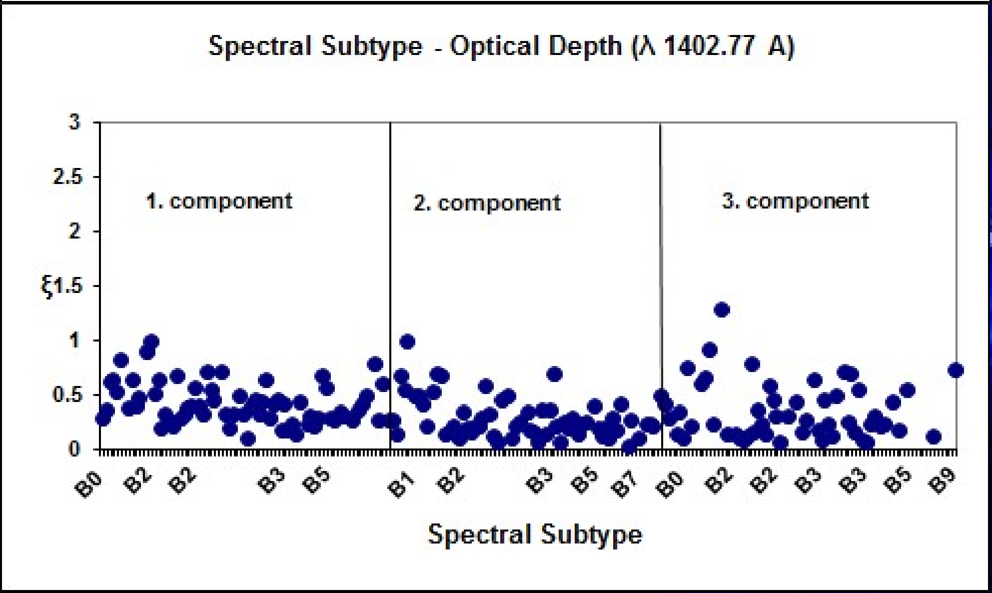
Full Width at Half Maximum (FWHM)



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

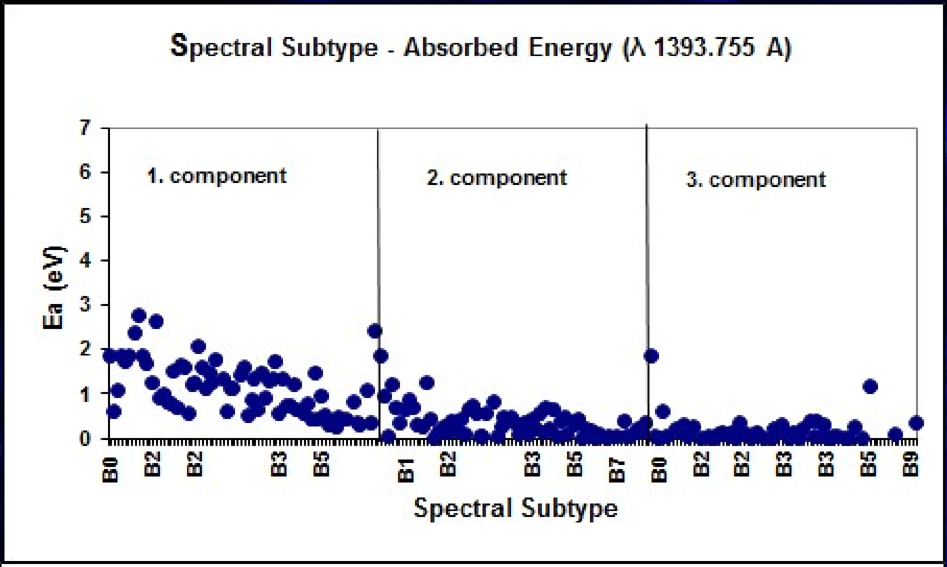
Optical Depth (ξ)

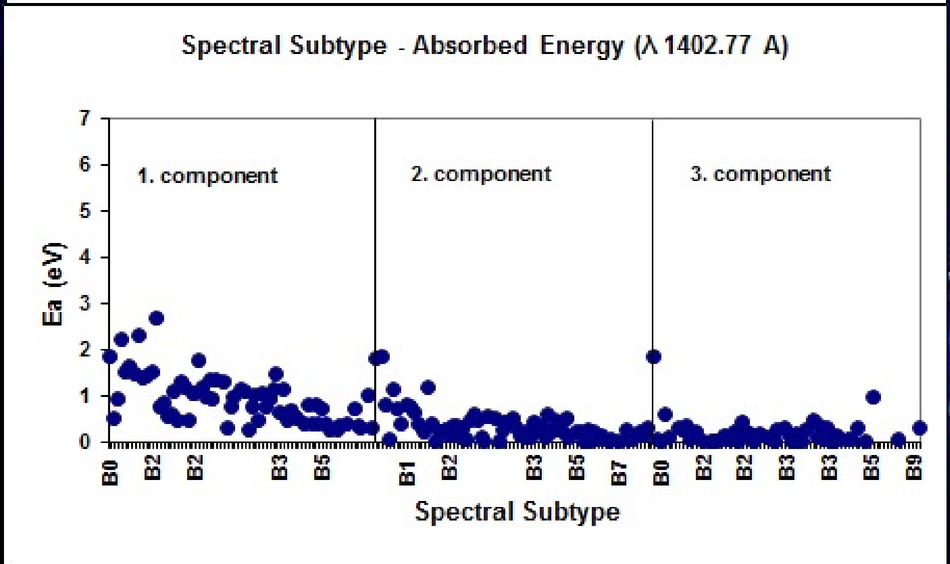




The variation of the optical depth (ξ) is the same in both of the Si IV resonance lines. The optical depth's values in the Si IV λ 1402.772 Å spectral line are 0.8 of the optical depth's values in the Si IV λ 1392.755 Å. This is in agreement with the atomic theory.

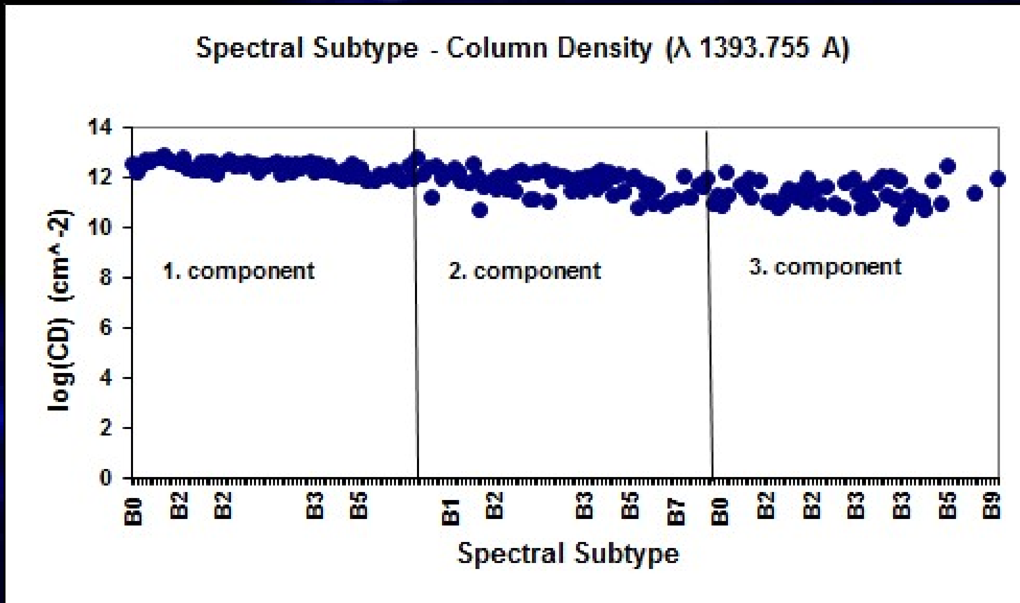
Absorbed Energy (Ea)

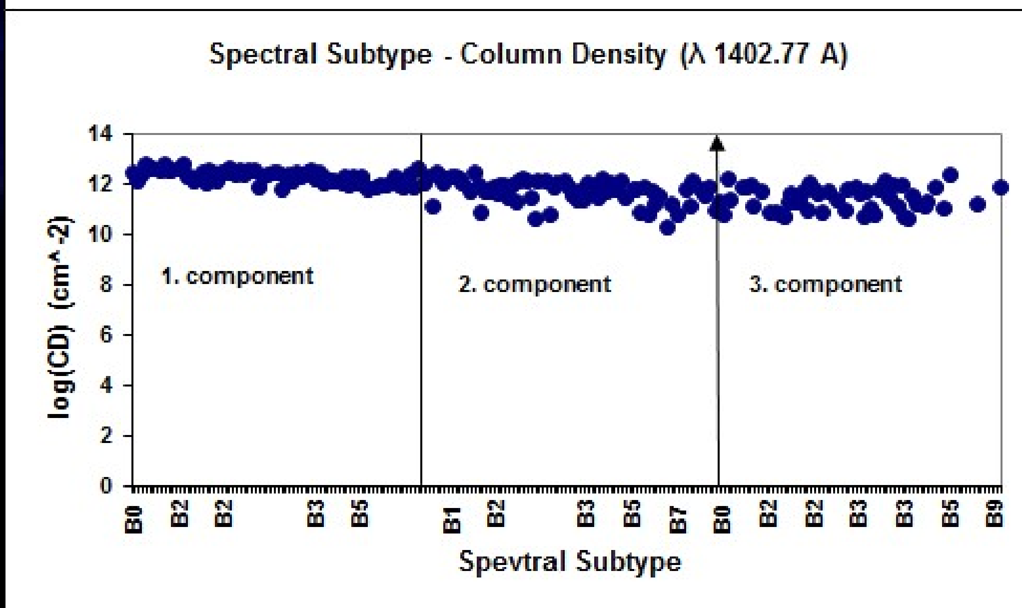




As in the case of the optical depth, the variation of the absorbed energy (Ea) is the same in both of the Si IV resonance lines and the absorbed energy's values in the Si IV λ 1402.772 Å spectral line are 0.8 of the absorbed energy's values in the Si IV λ 1392.755 Å. This is also in agreement with the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

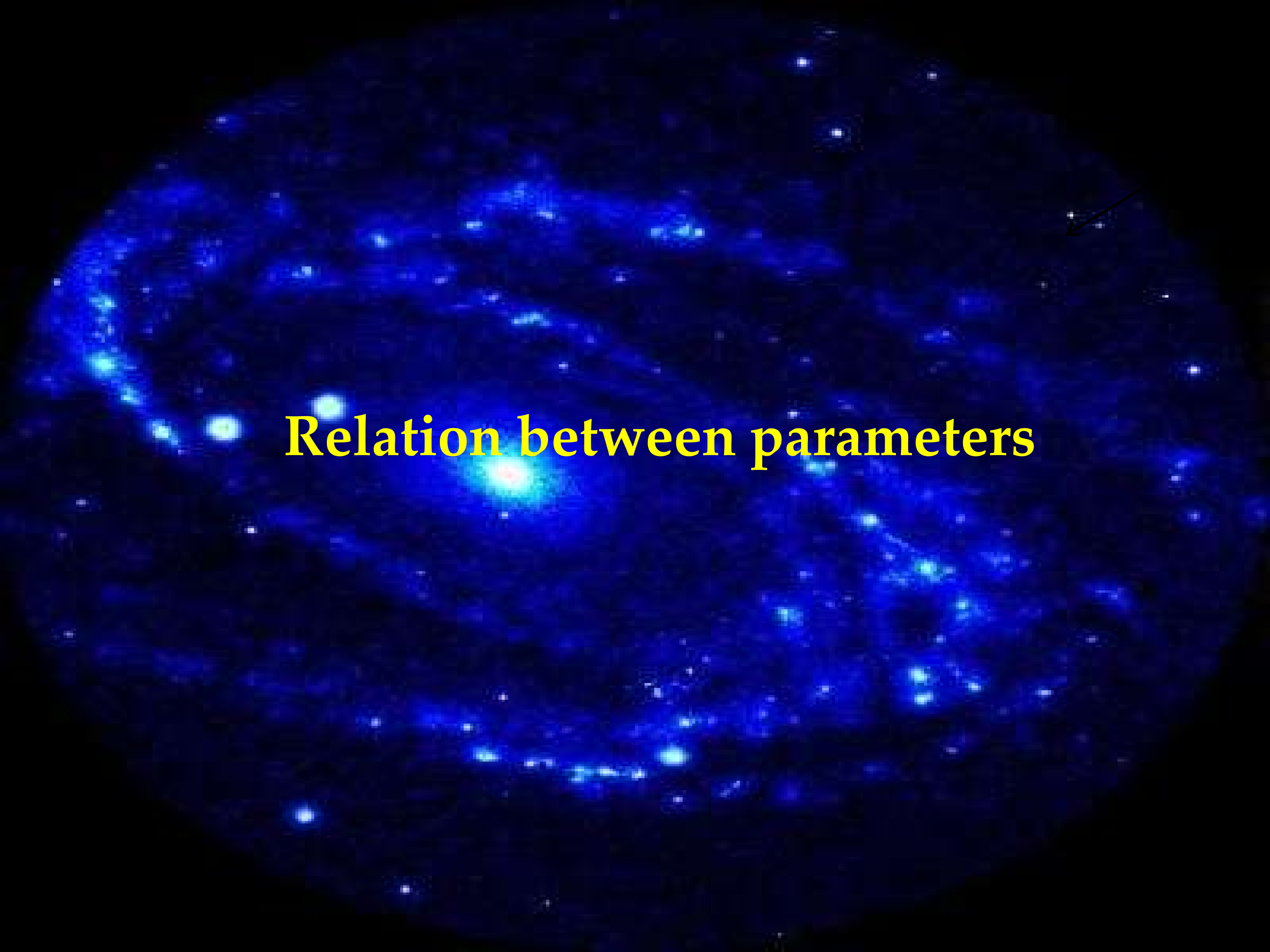
Column Density (CD)



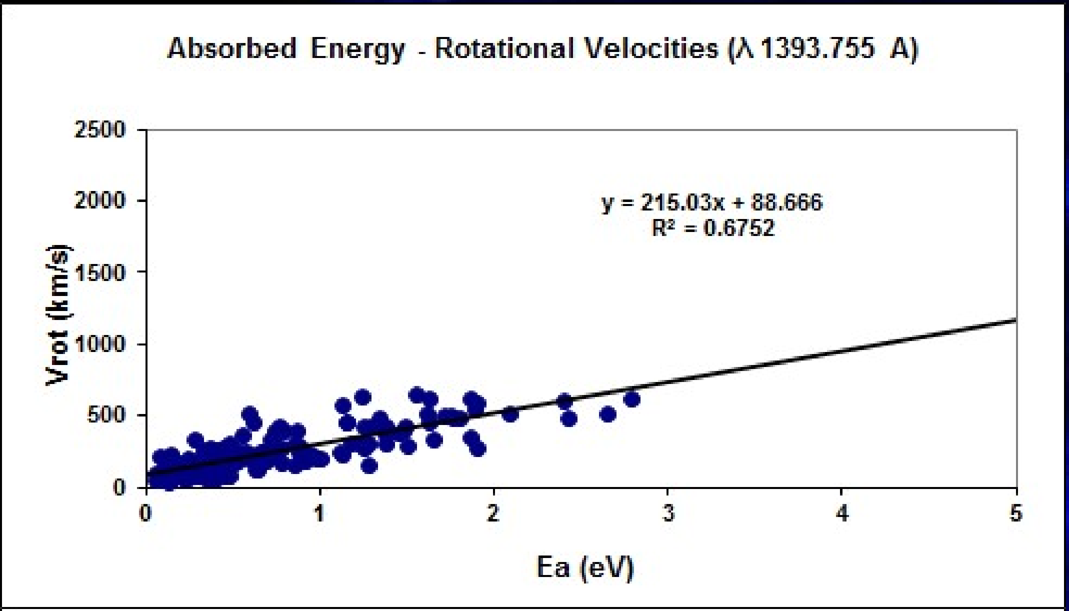


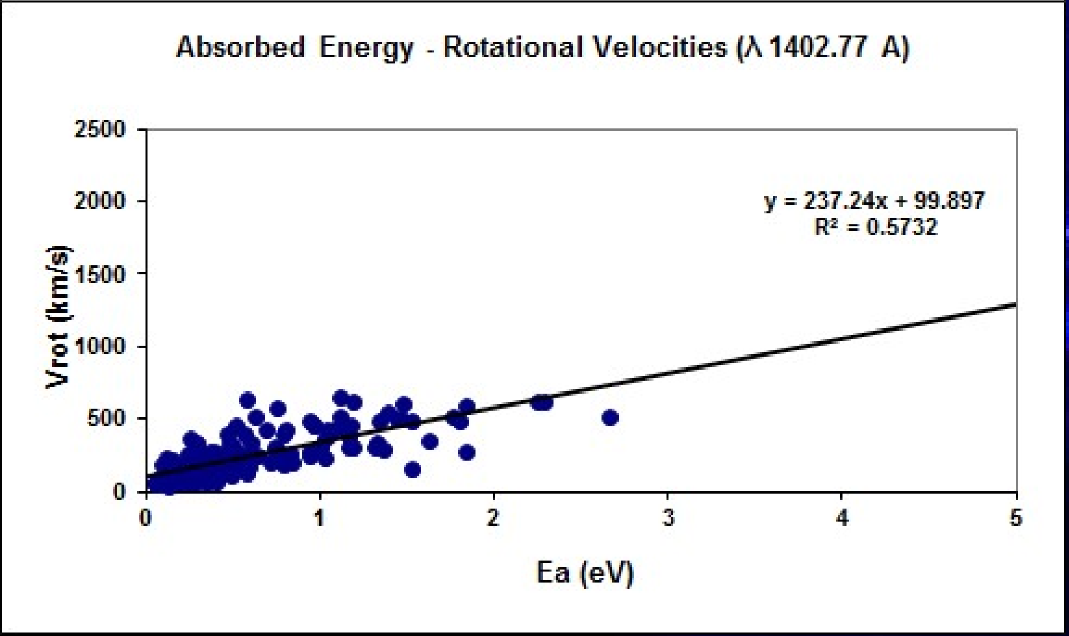
The variation of the column density of the Si IV resonance lines ($\lambda\lambda$ 1393.755, 1402.778 Å) remains almost constant between 10^{12} and 10^{13} cm^{-2}.

Relation between parameters



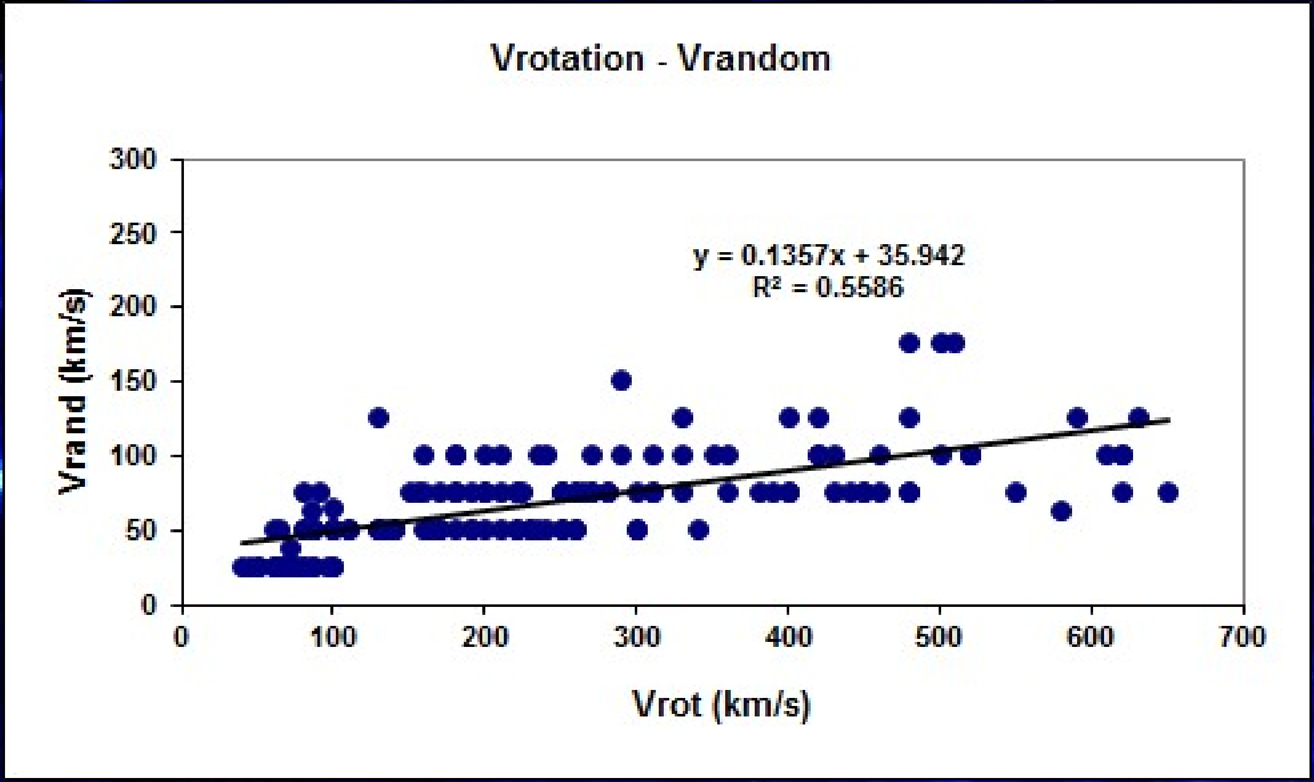
Relation between absorbed energy and rotational velocities





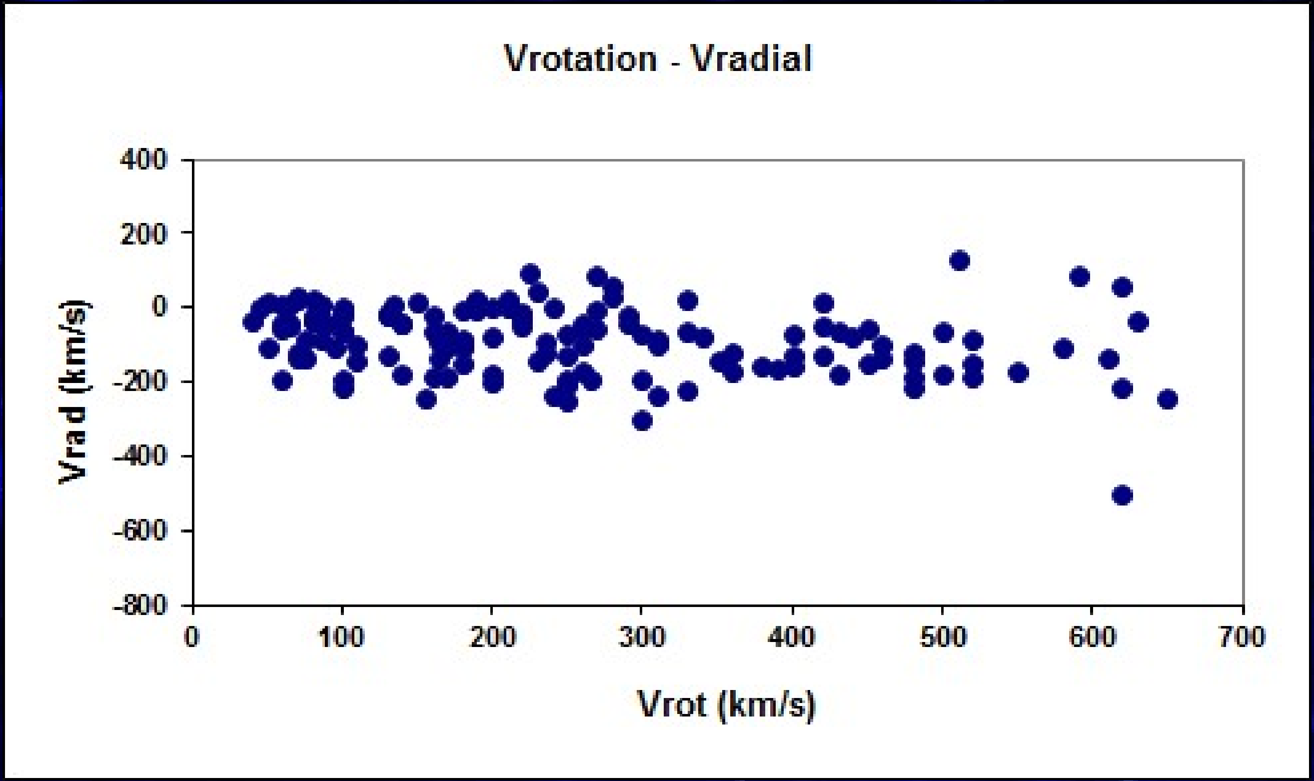
In these figures we present the variation of the rotational velocities of the Si IV resonance lines (*λλ* 1393.755, 1402.778 Å) for the independent density regions of matter which create the absorption components, as a function of the absorbed energy. We see a slightly increasing linear trend of the rotational velocities in the two resonance Si IV spectral lines and a "good" linear correlation (R^2=0.675 and 0.573 respectively).

Relation between rotational and random velocities



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 random velocities. We also see a slightly increasing linear trend of the random velocities and a “good” linear correlation (R^2=0.558).

Relation between rotational and radial velocities



Finally, in this diagram one can see the variation of the radial 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 rotational velocities. We observe a constant behavior of the radial velocities. This means that the radial motion of the density region of matter does not depend on its rotational motion. We haven't detected a linear correlation.

Conclusions

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

- The best fit has been obtained using one absorption component in eleven of the 68 studied stars, with two components in twenty eight of them and with three components in twenty nine of them.
- Using the GR-model (Lyratzi et al. 2006), the best fit has been obtained in most stars with 5 absorption components.

Conclusions

- We calculated a group of parameters as the FWHM, the absorbed energy, the Gaussian Standard Deviation, the random velocities and the column density of the region in which the studied spectral lines are created. These values could not be calculated based on the old GR-model (Lyratzi et al. 2006).

Conclusions

- ***Rotational velocities:***

  The cinematically independent regions rotate with different mean velocities. We calculated values about 455±102 km/s, 221±49 km/s, 85±25 km/s respectively. The found values are not in absolute agreement with the Lyratzi's et al 2006. calculated values, because, as we said, we took into account that the main reason of the spectral line broadening is the rotation of the region which create the specific spectral lines as well as the thermal motion of the ions of the same region. We also note that the rotational velocities of the found independent regions present a uniform fluctuation with the spectral subtype.

Conclusions

➢***Radial velocities:***

We found values -83±81 km/s for the first component, 185±82 km/s for the second one and 89±25 km/s for the third one. These values are partly in agreement with the Lyratzi's et al. found values. Man must take into account that we have obtained the best fit using a maximum of 3 absorption components.

Conclusions

- ***Random velocities:***

We detected an almost constant trend of the random velocities for each component. We found values 90±22 km/s for the first component, 51±21 km/s for the second one and 31±12 km/s for the third one. This is expected because the random motions of the ions depend on the temperature of the region in which the specific spectral lines are created.

- ***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 broadening of the line and the rotational velocities contribute to this situation.

Conclusions

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

These parameters have 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^{12} and 10^{13} cm^{-2}.

Conclusions

➢ ***Absorbed Energy- Rotational Velocities Vrot=f(Ea)***

We detected a slightly increasing linear trend of the rotational velocities in the two resonance Si IV spectral lines and a "good" linear correlation (R^2=0.675 and 0.573 respectively). This means that high values of the absorbed energy indicate high values of rotational velocities.

➢ ***Rotational Velocities – Random Velocities Vrand=f(Vrot)***

We also detected a slightly increasing linear trend of the random velocities as a function of the rotational velocities and a "good" linear correlation (R^2=0.558).

Conclusions

- ***Rotational Velocities – Radial Velocities Vrad=f(Vrot)***

We detected a constant behavior of the radial velocities. This means that the radial motion of the density region of matter does not depend on its rotational motion. We haven't detected a linear correlation.

- In the case of Vrot=f(Ea) and Vrand=f(Vrot) the calculated linear correlation is "good". This means that in Be stars if we know the value of one of them, we could estimate the other one. This thesis must be confirmed by a much greater sample of Be stars and it is part of our future work.

Thank you very much for your attention