The DACs and SACs effects from stars to Quasars. Some first general notices

E. Danezis

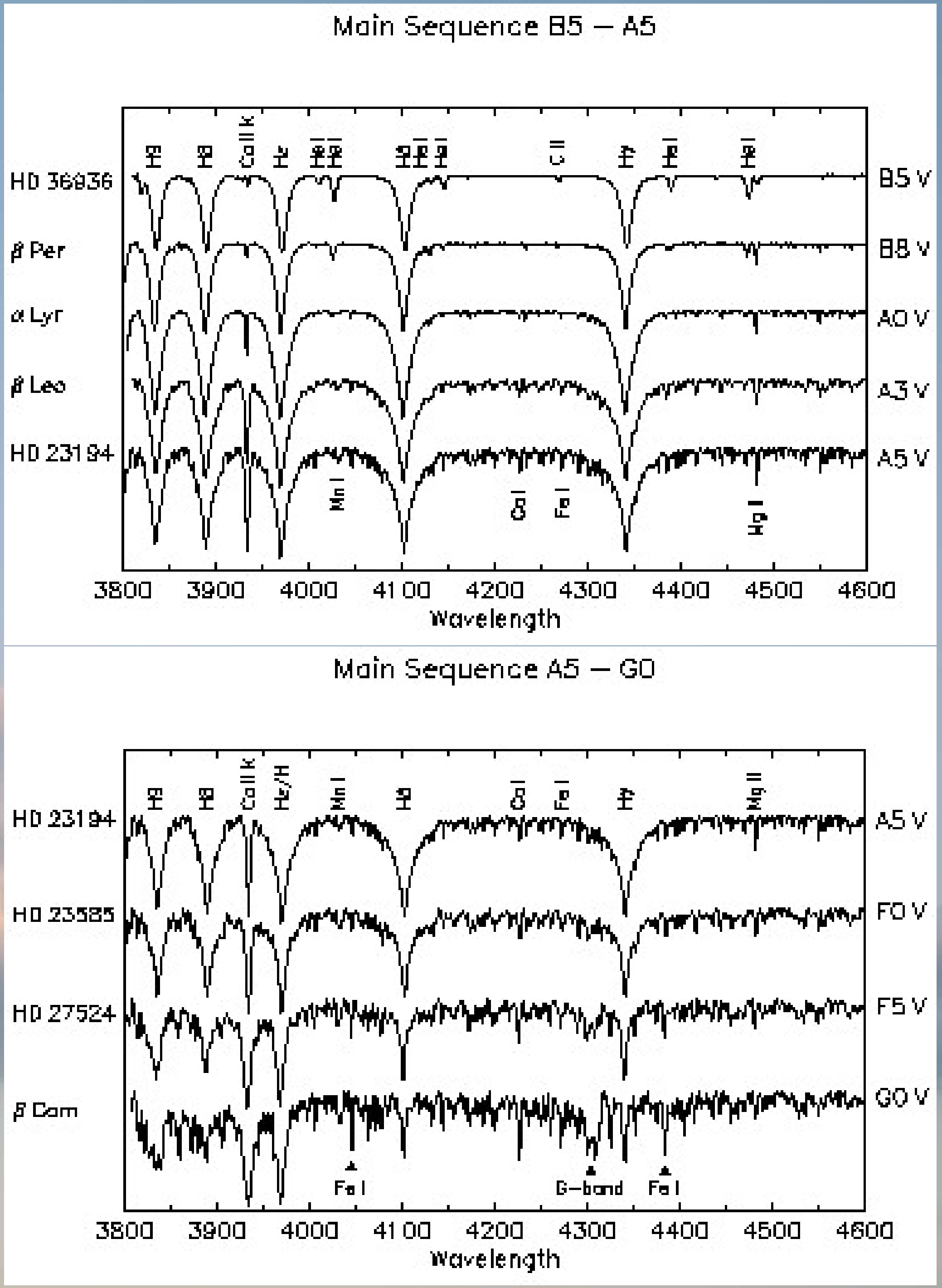
University of Athens, Faculty of Physics,
Department of Astrophysics, Astronomy and Mechanics

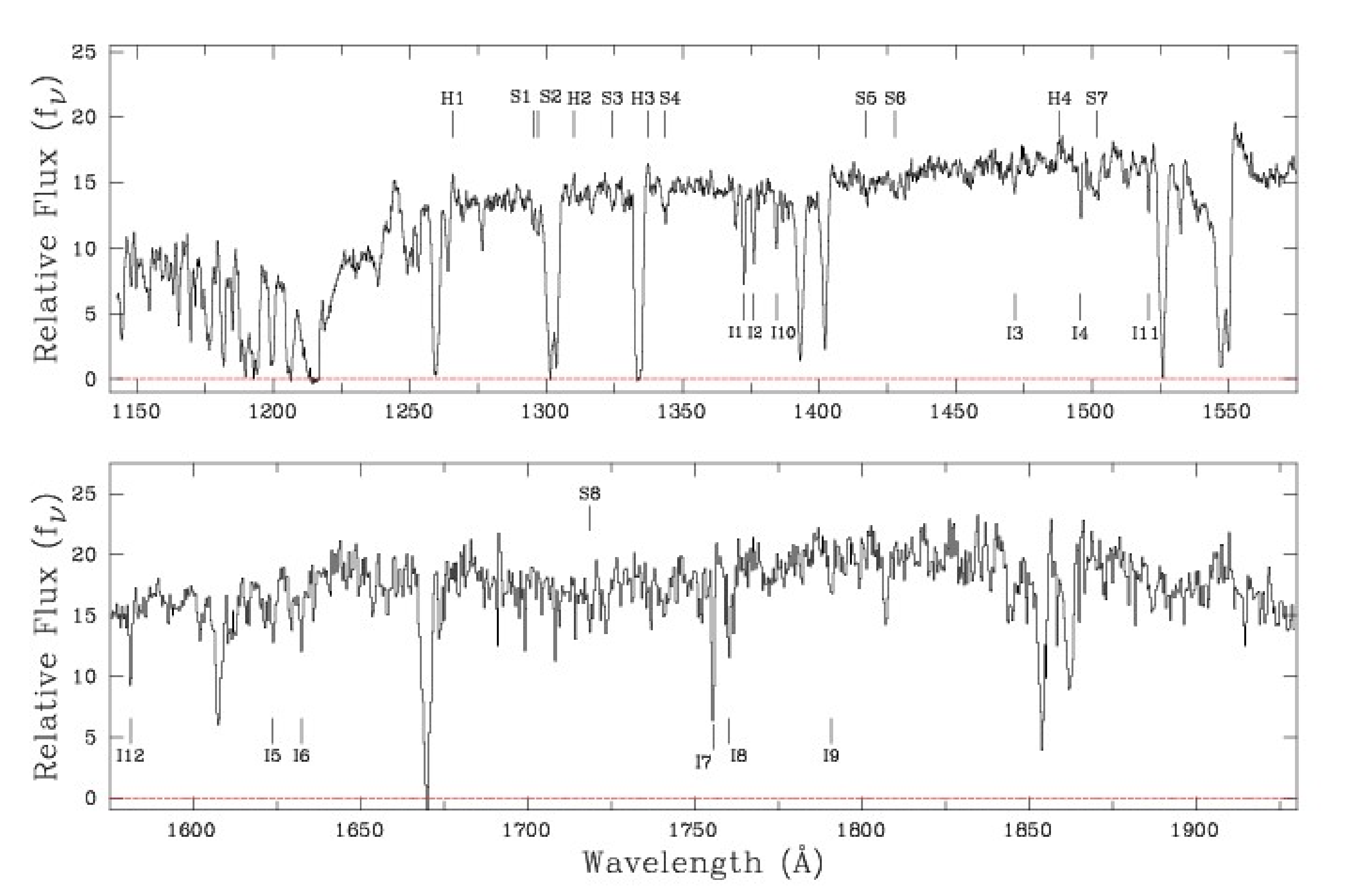
In collaboration with
A. Antoniou (University of Athens)
E. Lyratzi (University of Athens)
L. Č. Popović (Astronomical Observatory of Belgrade)
M. S. Dimitrijević (Astronomical Observatory of Belgrade)

The spectral lines in astrophysical objects

It is well known that the absorption spectral lines that we can detect in the spectra of normal stars or normal galaxies, are an important factor to study many physical parameters of plasma surrounding these objects.

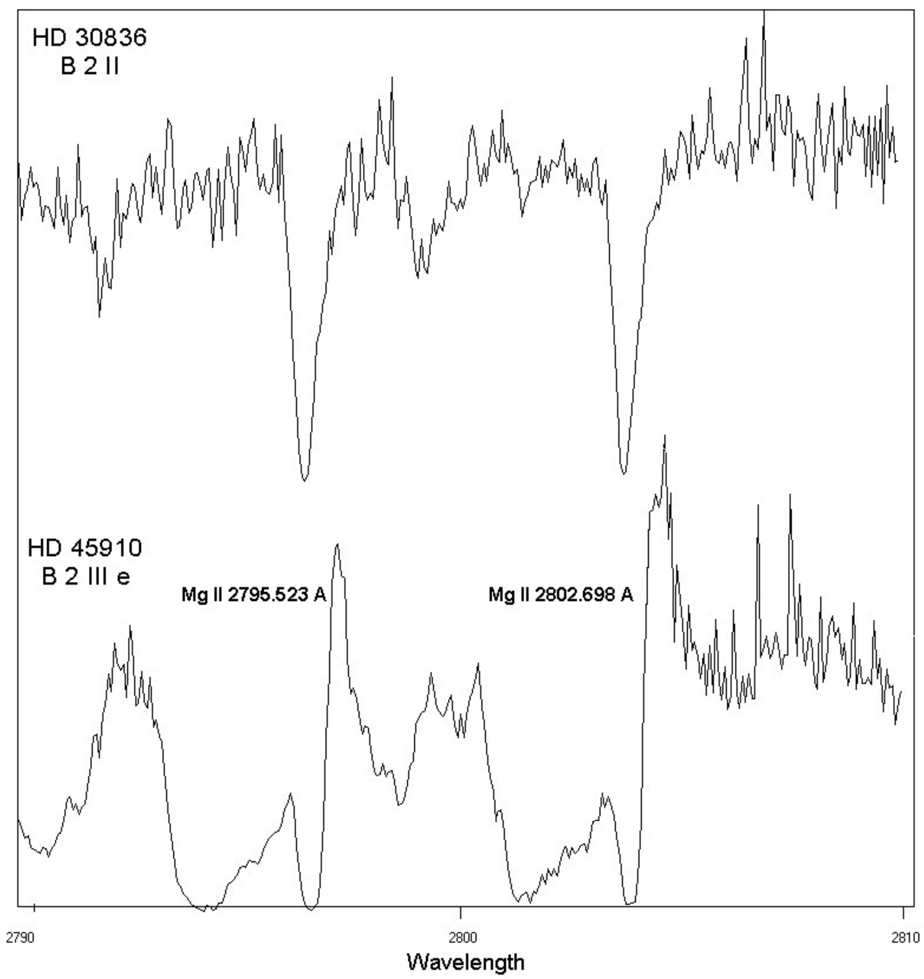
In these figures we can see two groups of classical stellar spectra of different spectral subtypes that present normal spectral absorption lines.

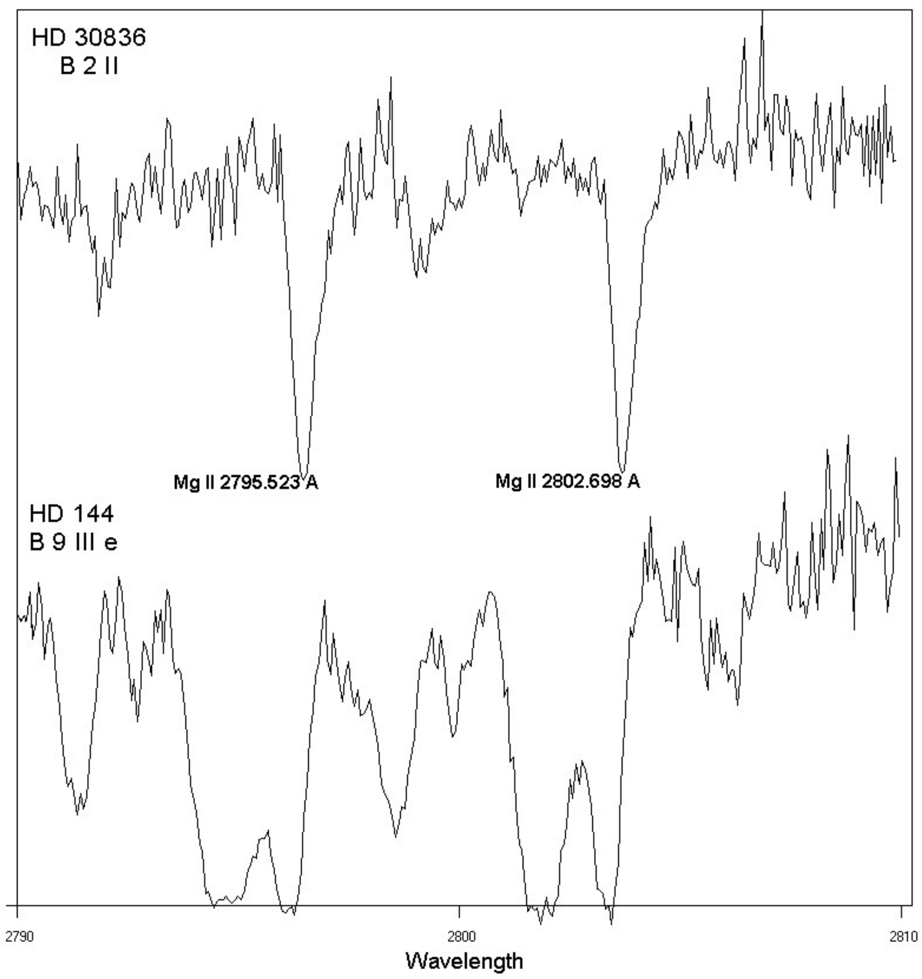




Two typical spectra of normal Galaxies that present only absorption spectral lines.

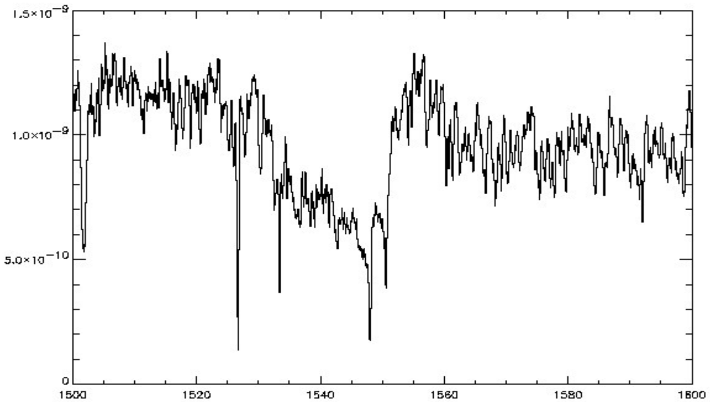
However Hot Emission Stars (Oe and Be stars) present peculiar line profiles





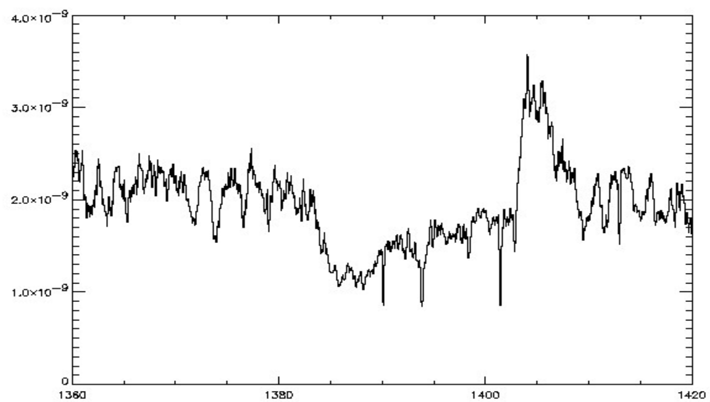
Here we can see the comparison of Mg II resonance lines between the spectrum of a normal B star and the spectra of two active Be stars that present complex and peculiar spectral lines. In the first figure we observe a combination of an emission and some absorption components (P Cygni).

HD 37022, SWP07481



C IV λλ 1548.155, 1550.774 Ǻ

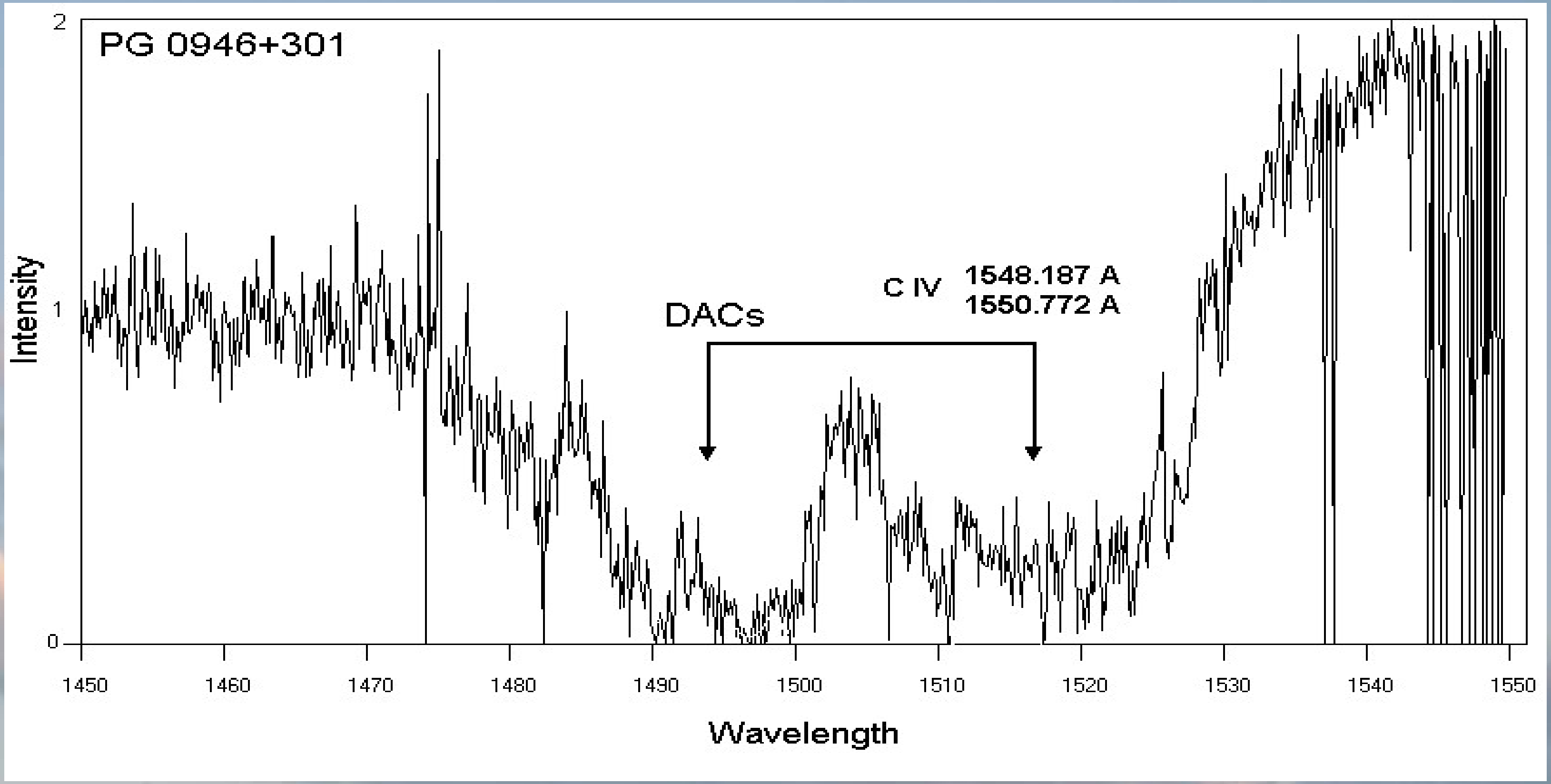
HD 57061, SWP18949



Si IV λλ 1393.755, 1402.770 Ǻ

In this figures we can see the complex structure of the C IV and Si IV UV resonance lines in the spectra of two Oe stars

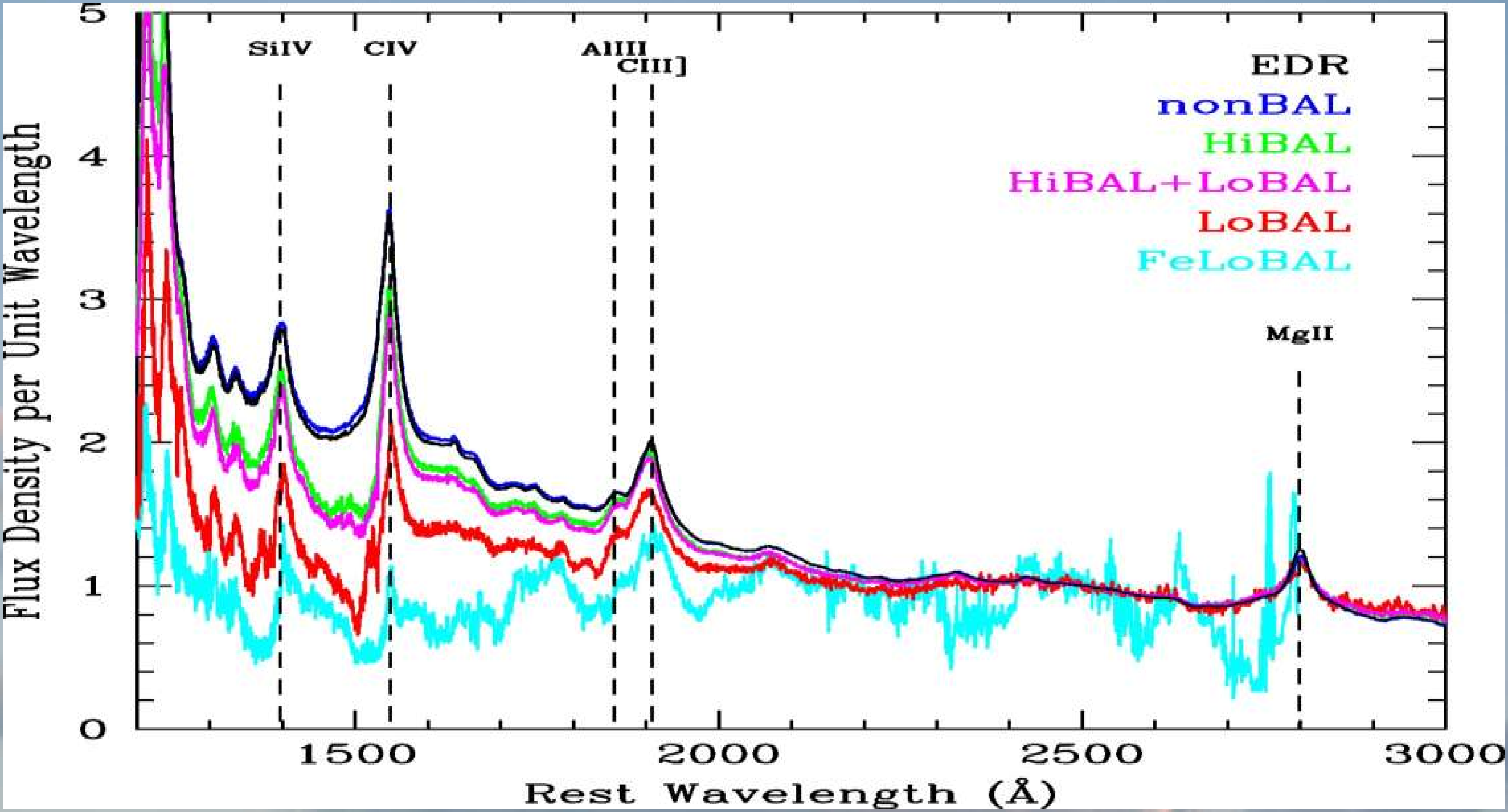
Some times we can detect peculiar spectral lines in AGNs spectra



Here we present the peculiar profile of C IV doublet in the UV spectrum of AGN PG 0946+301.

The two observed features do not present the two resonance lines

Peculiarity in AGN spectra



In this figure we present typical spectra of many types of AGNs in the UV spectral range (Reichard et al. 2003, AJ, 126, 2594). The combination of emission and, in some cases, absorption components produce peculiar profiles (P Cygni profiles).

In order to explain the peculiarity of the line profiles in the spectra of hot emission stars, our team proposes and uses the DACs (Bates & Halliwell, 1986) and SACs (Danezis et al. 2005) theory.

The DACs phenomenon

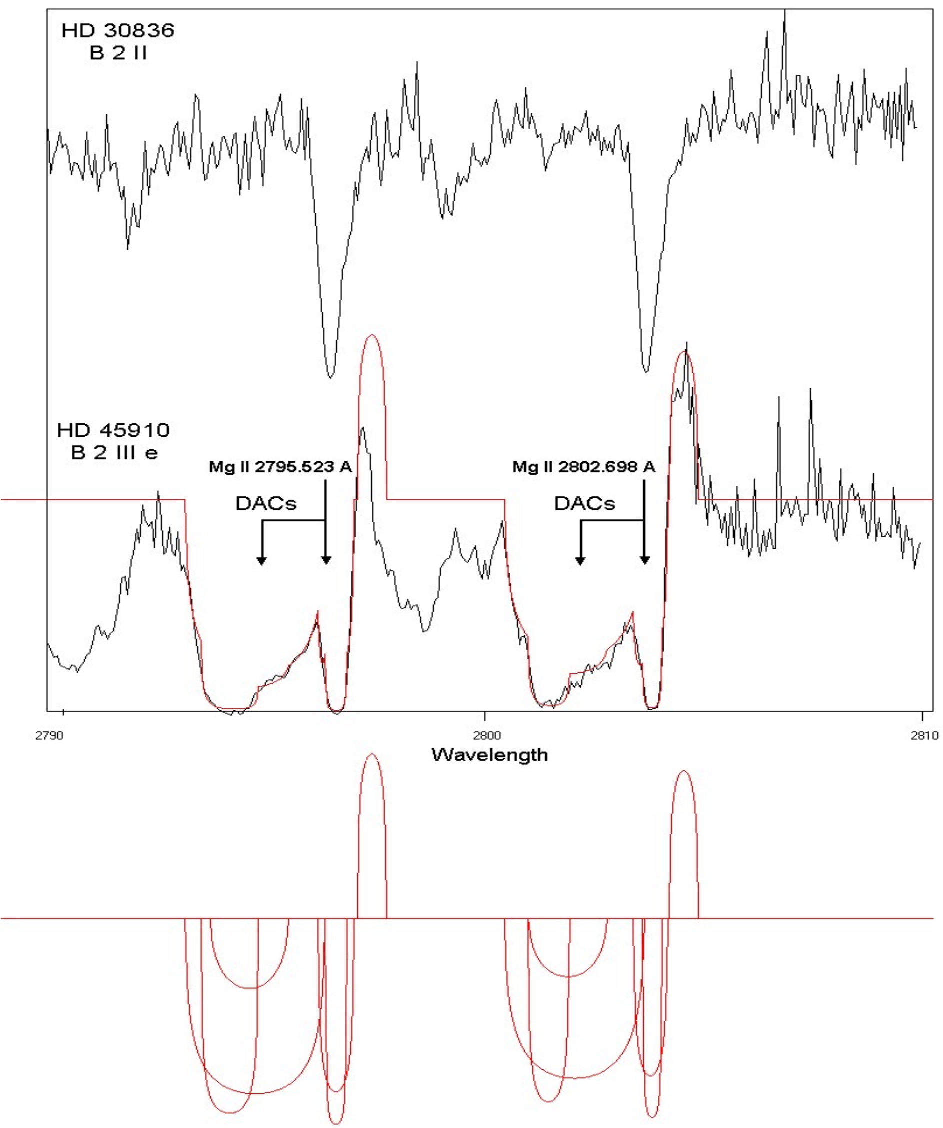
In a stellar atmosphere, or disc, that we can detect around hot emission stars, an absorption line can be produced in several density regions that present the same temperature. From each one of these regions an absorption line arises.

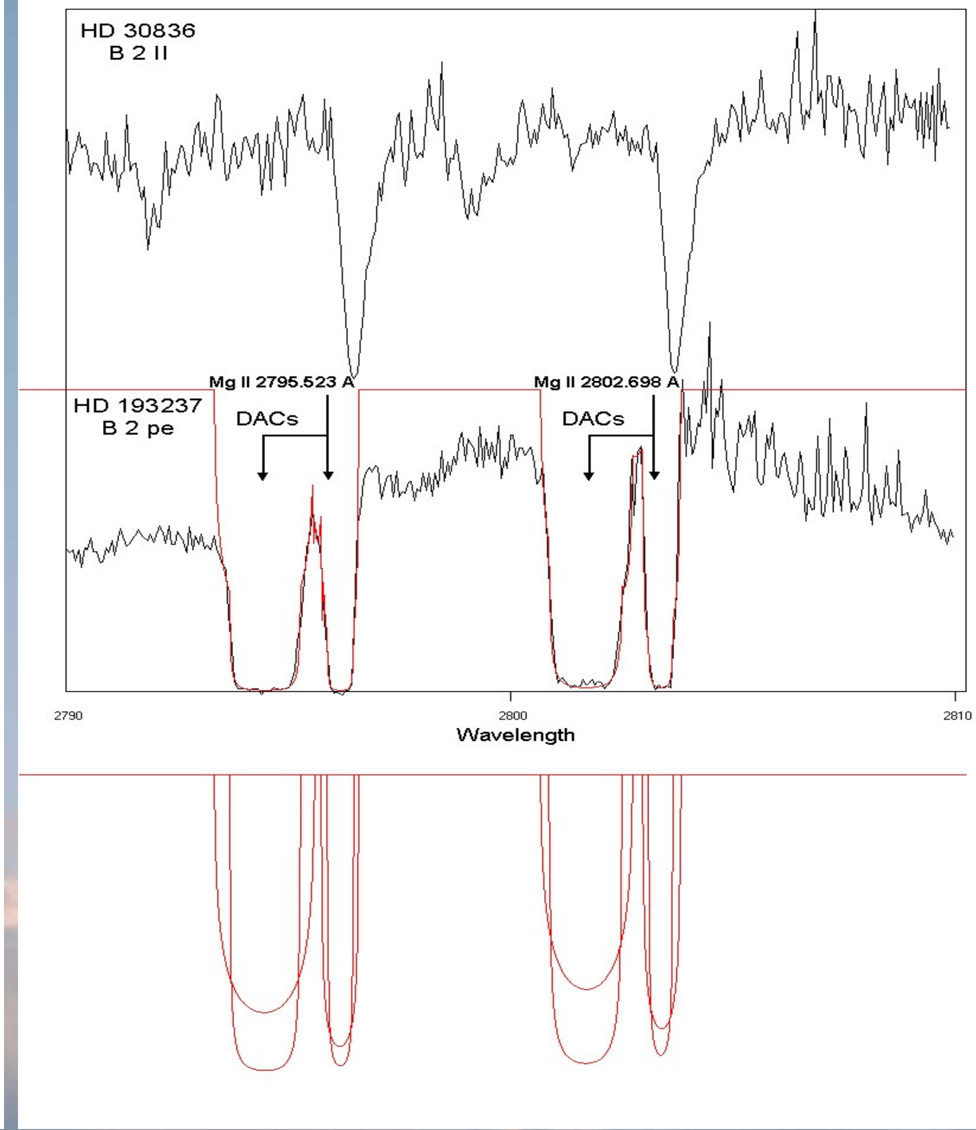
The line profile distribution of each one of these absorption components is a function of a group of physical parameters, as the radial, the rotational, the random velocities and the optical depth of the region that produces the specific components of the spectral line.

These spectral lines are named ***Discrete Absorption Components (DACs)*** *when they are discrete (Bates, B. & Halliwell, D. R.: 1986, MNRAS, 223, 673).*

DACs *are discrete but not unknown absorption spectral lines. They are spectral lines of the same ion and the same wavelength as a main spectral line, shifted at different $\Delta\lambda$, as they are created in different density regions which rotate and move radially with different velocities (Danezis et al. 2003).*

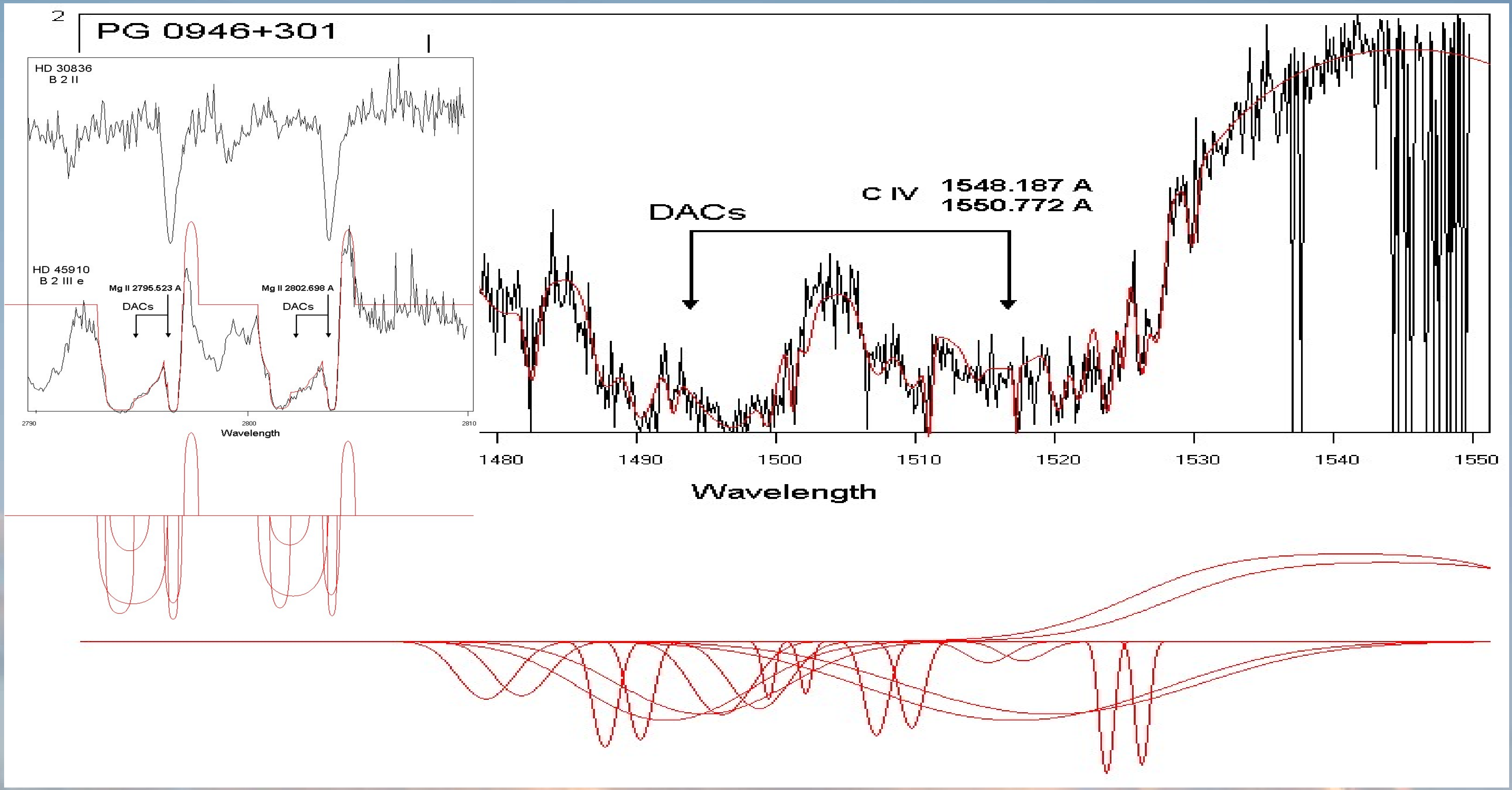
DACs *are lines, easily observed, in the spectra of some Be stars, because the regions that give rise to such lines, rotate with low velocities and move radially with high velocities (Danezis et al. 2005).*





In these figures we can see the Mg II spectral lines of two Be stars that present DACs, in comparison with the Mg II lines of a classical B star. In these line profiles we can see the main spectral lines and at the left of each one of them a group of DACs.

It is very important to point out that we can detect the same phenomenon in the spectra of some AGNs

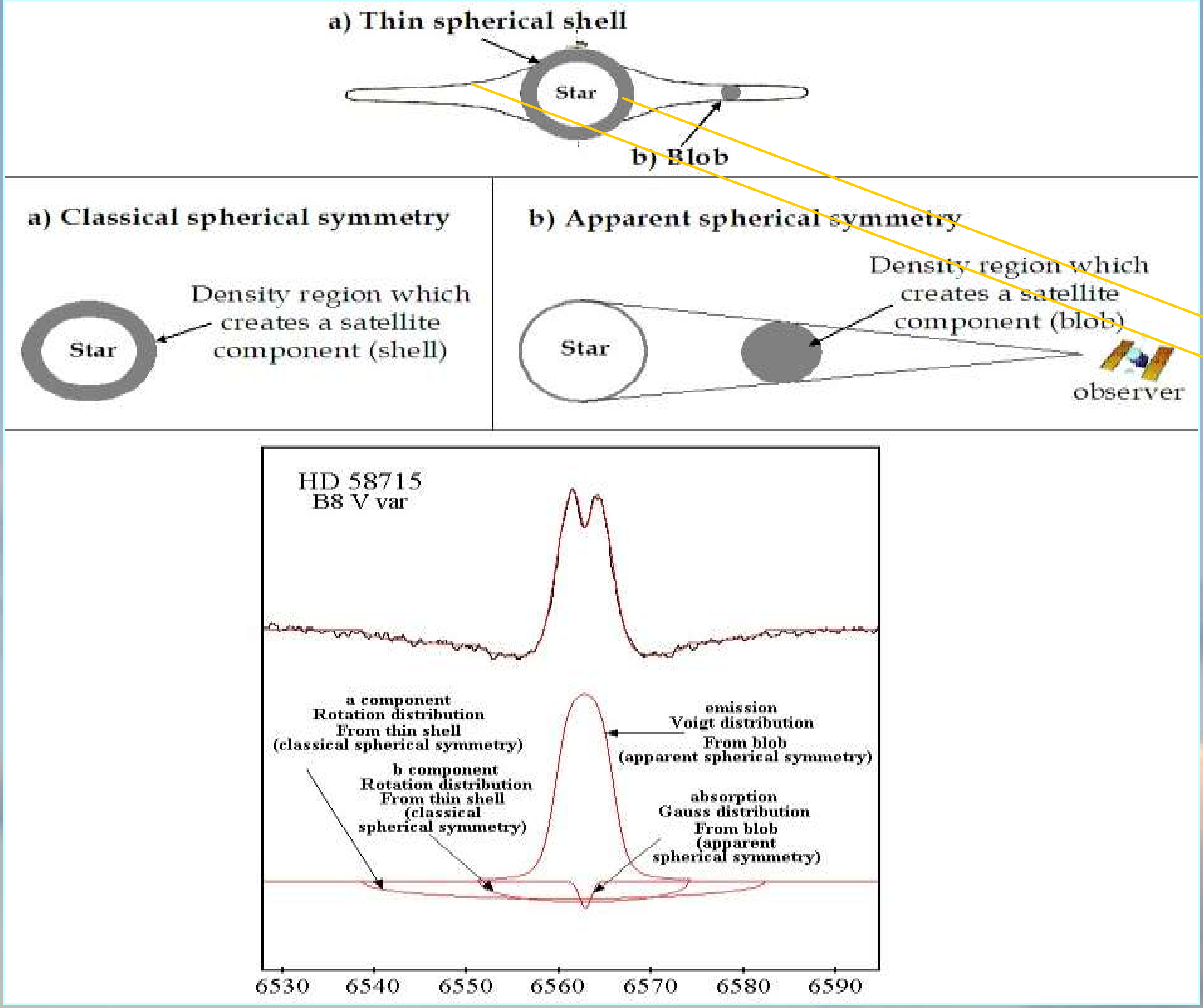


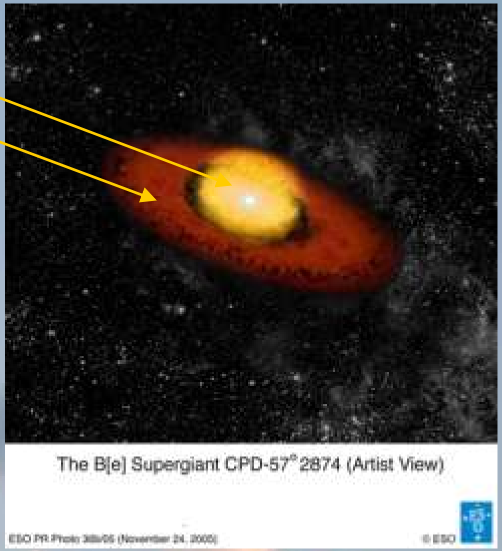
In this figure we can see the C IV UV doublet of an AGN (PG 0946+301).

From the values of radial displacements and the ratio of the line intensities we can detect that the two observed C IV shapes indicate the presence of a DACs phenomenon similar with the DACs phenomenon that we can detect in the spectra of hot emission stars.

What is the origin of DACs phenomenon

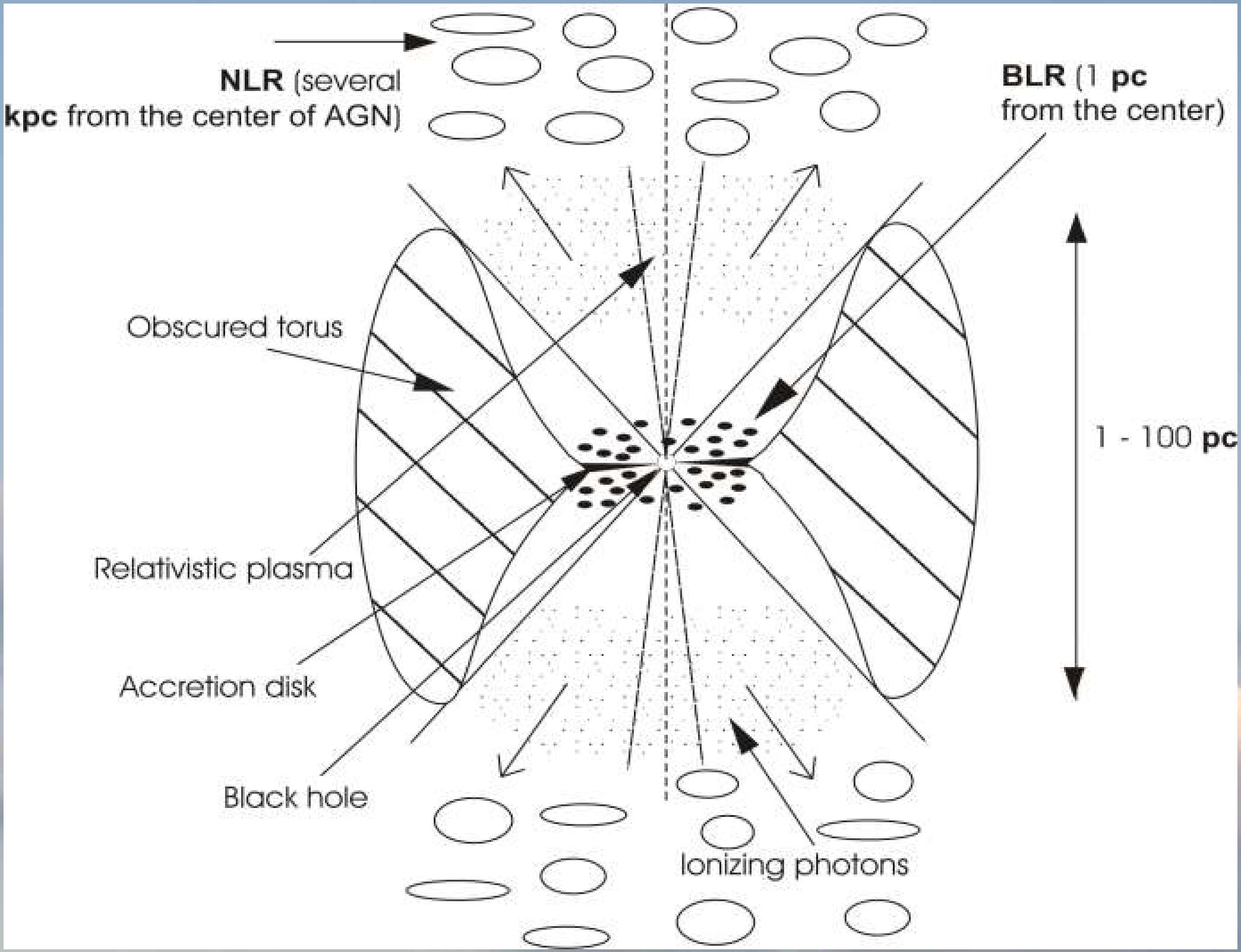
In the stellar atmospheres or disc





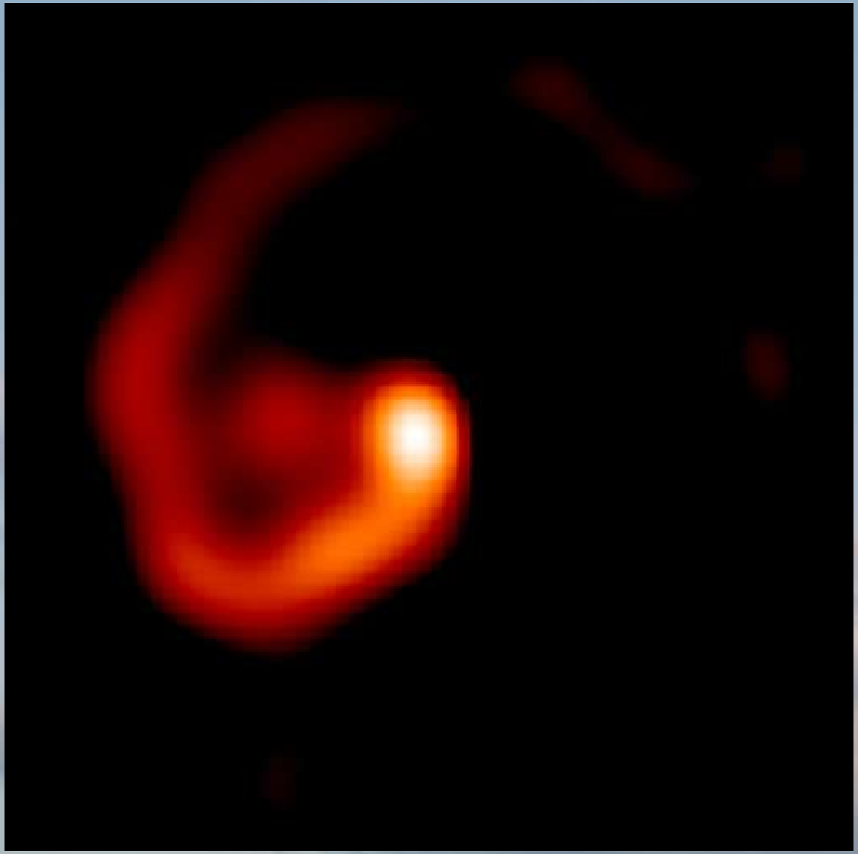
The DACs arise from spherical density regions around the star, or from density regions far away from the star that present spherical (or apparent spherical) symmetry around their own center.

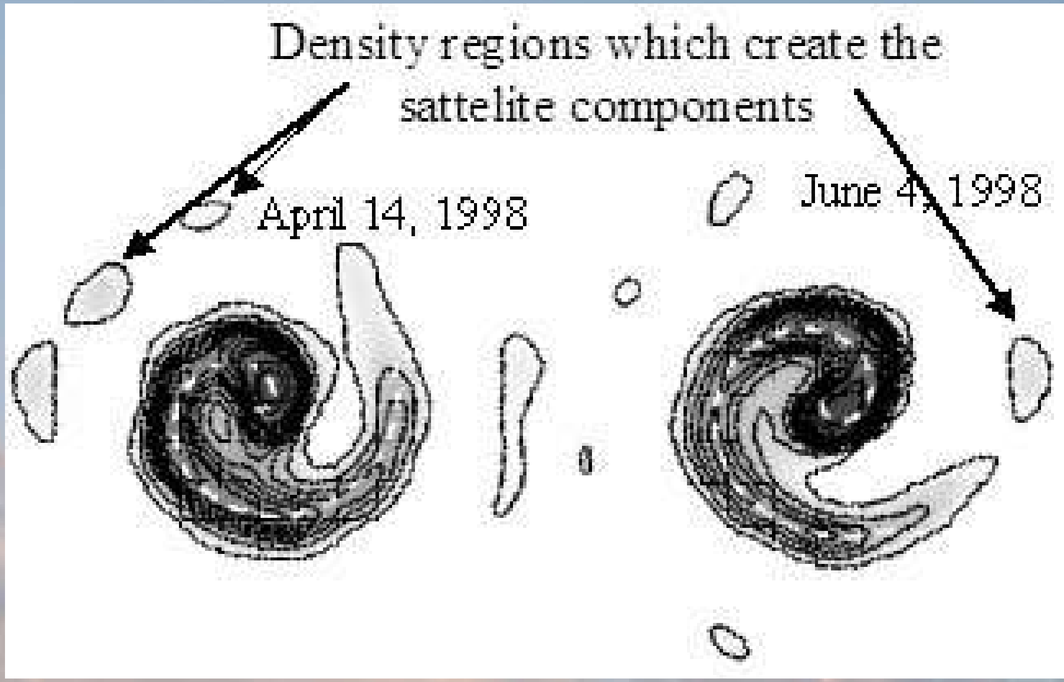
In the case of AGNs Spectra



In the case of AGNs, accretion, wind (jets, ejection of matter etc.), BLR (Broad Line Regions) and NLR (Narrow Line Regions) are, perhaps, the density regions that construct peculiar profiles of the spectral lines.

Similar phenomena can be detected as an effect of the ejected plasma around peculiar stars.





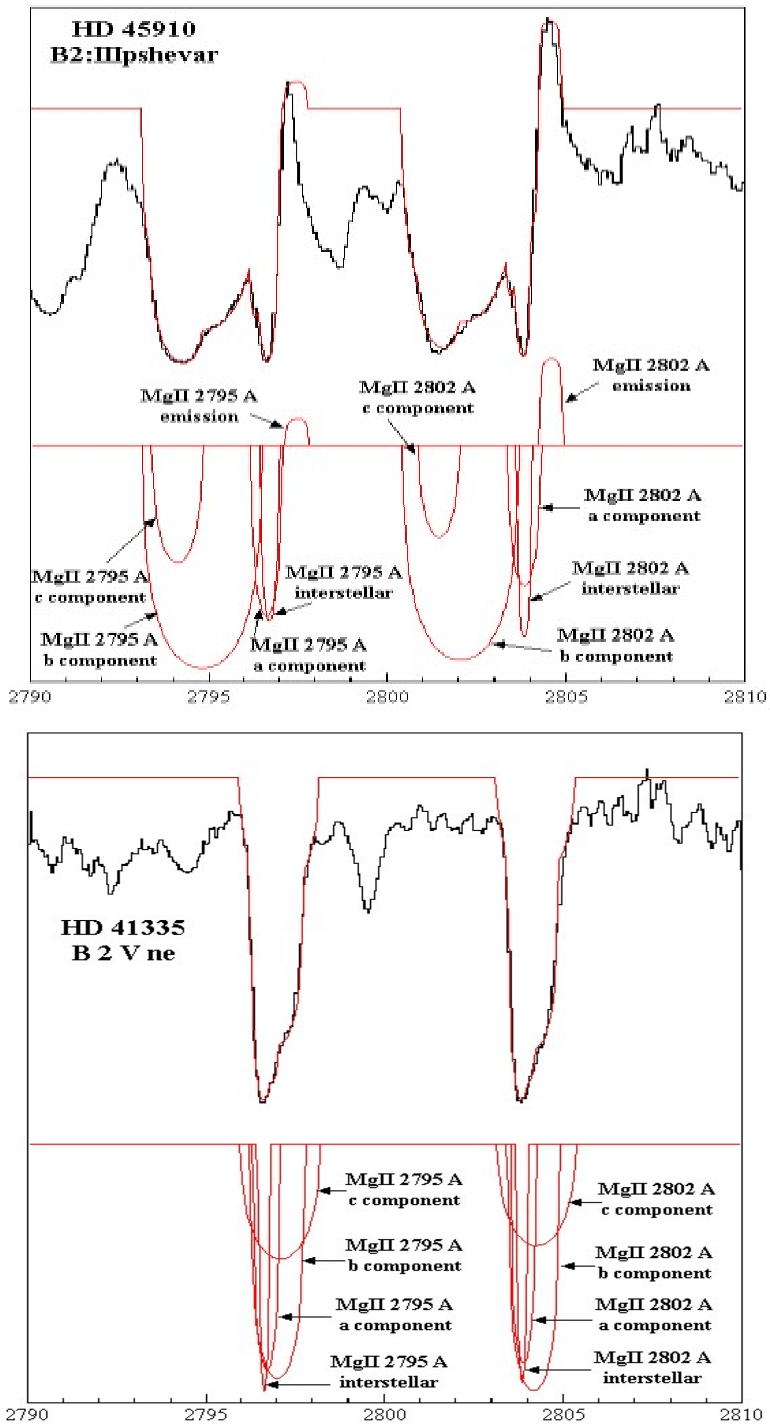
Around a Wolf-Rayet star (WR 104) we can detect density regions of matter quite away from the stellar object, able to produce peculiar profiles.

(This figure is taken by Tuthill, Monnier & Danchi (1999) with Keck Telescope.)

The SACs phenomenon

If the regions that give rise to the DACs, rotate with large velocities and move radially with small velocities, the produced lines have large widths and small shifts.

As a result they are blended among themselves as well as with the main spectral line and thus they are not discrete. In such a case the name Discrete Absorption Components is inappropriate and we use only the name Satellite Absorption Components (SACs) (Danezis et al. 2005).

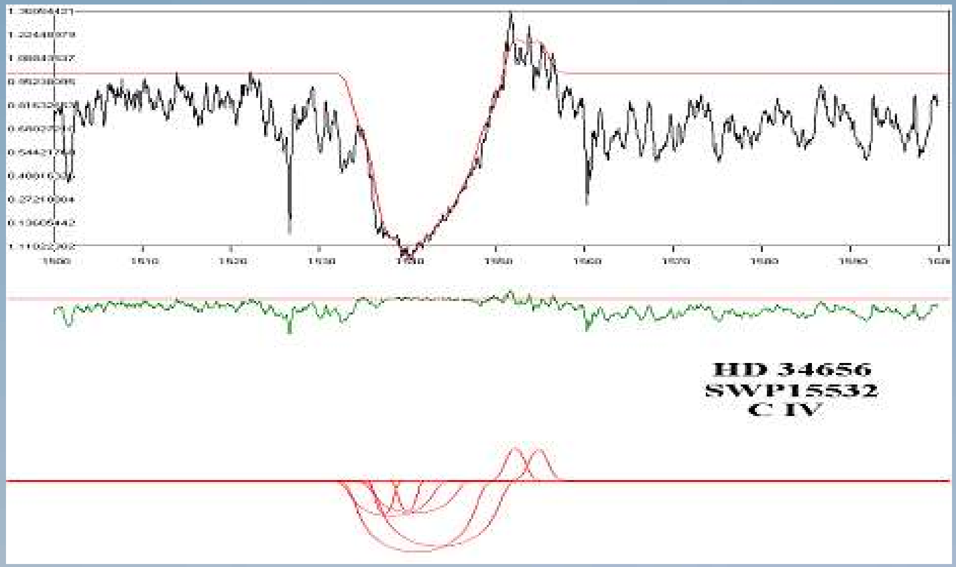


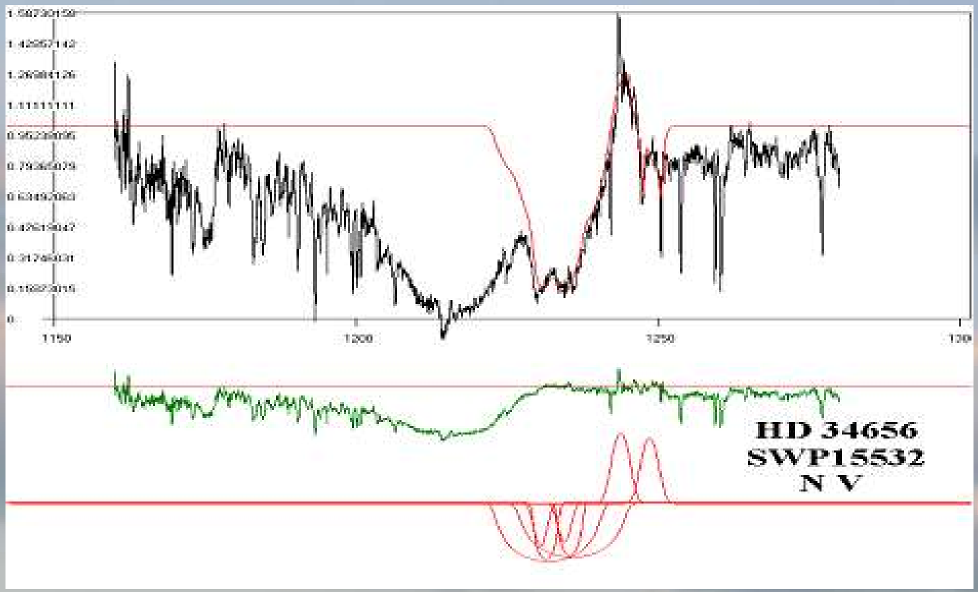
In this figure it is clear that the Mg II line profiles of the star AX Mon (HD 45910), which presents DACs and the star HD 41335, which presents SACs are produced in the same way.

The only difference between them is that the components of HD 41335 are much less shifted and thus they are blended among themselves.

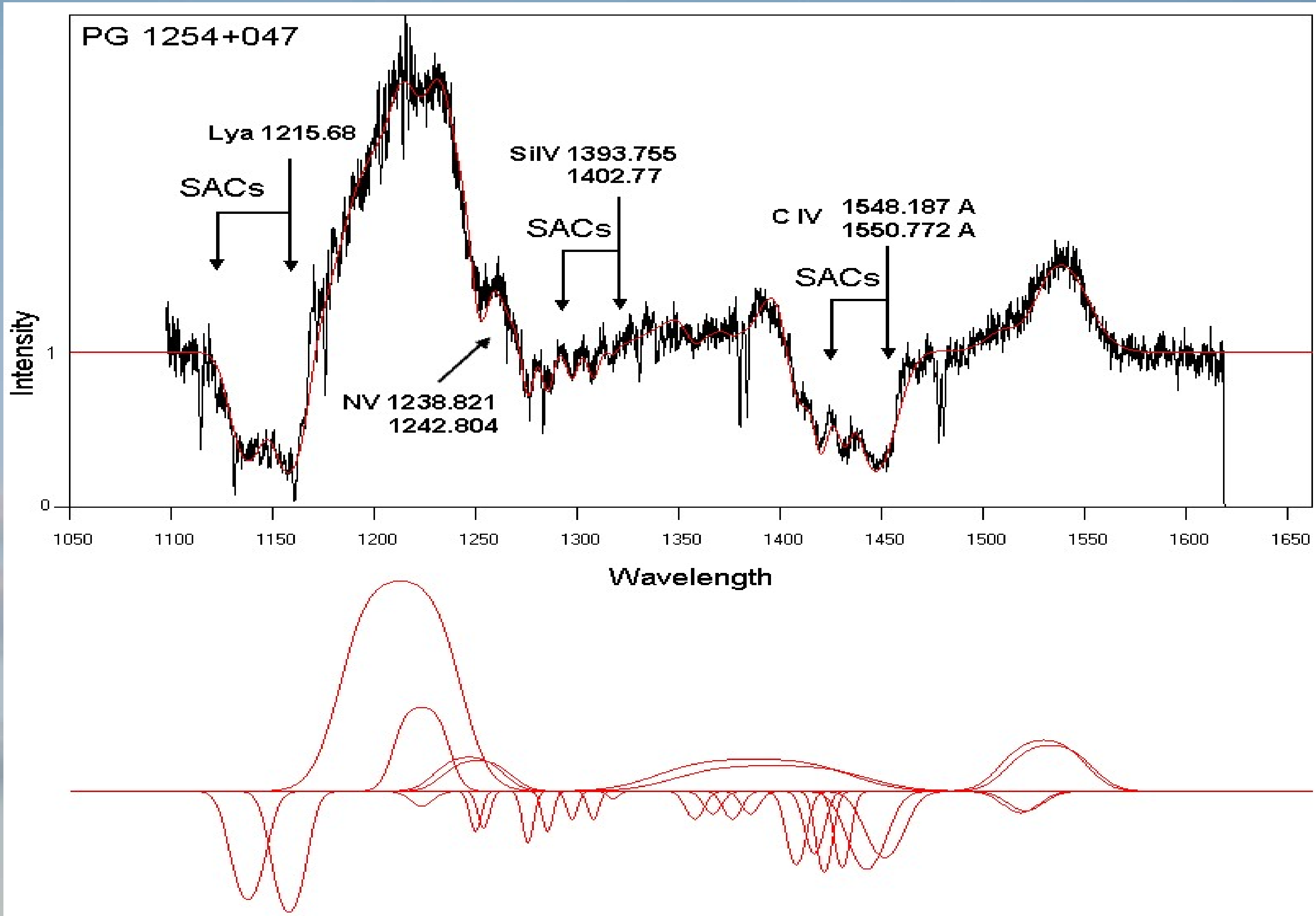
The black line presents the observed spectral line's profile and the red one the model's fit.

We also present all the components which contribute to the observed features, separately.





In these figures we can see the SACs phenomenon in the spectra of three Oe stars



In this figures we can see the SACs phenomenon in the spectrum of an AGN

The proposed model

In the case of DACs or SACs phenomenon we need to calculate the line function of the complex line profile. Recently, our group proposed a model in order to explain the complex structure of the density regions of hot emission stars and some AGNs, where the spectral lines that present SACs or DACs are created (Danezis et al. 2003, 2005).

The main hypothesis of this model is that the stellar envelope is composed of a number of successive independent absorbing density layers of matter and a number of emission regions.

The line function

$$F(\lambda)_{final} = \left[F_0(\lambda) \prod_i \exp\left\{-L_i \xi_i\right\} + \sum_j S_{\lambda ej} \left(1 - \exp\left\{-L_{ej} \xi_{ej}\right\}\right) \right] \exp\left\{-L_g \xi_g\right\}$$

absorption — emission — General absorption

where:

$I_{\lambda 0}$: is the initial radiation intensity,

L_i, L_{ej}, L_g: are the distribution functions of the absorption coefficients $k_{\lambda i}$, $k_{\lambda ej}$, $k_{\lambda g}$,

ξ: is the optical depth in the centre of the spectral line,

$S_{\lambda ej}$: is the source function, that is constant during the specific observation.

$$L_{final}(\lambda) = \frac{\sqrt{\pi}}{2\lambda_0 z} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \left[erf\left(\frac{\lambda - \lambda_0}{\sigma\sqrt{2}} + \frac{\lambda_0 z}{\sigma\sqrt{2}} \cos\theta \right) - erf\left(\frac{\lambda - \lambda_0}{\sigma\sqrt{2}} - \frac{\lambda_0 z}{\sigma\sqrt{2}} \cos\theta \right) \right] \cos\theta d\theta$$

$$\lambda_0 = \lambda_{lab} \pm \Delta\lambda_{rad}$$ → V_{radial}

$$z = \frac{V_{rot}}{c}$$ → $V_{rotation}$

σ → $$V_{random} = \frac{\sigma c \sqrt{2 \ln 2}}{\lambda_0}$$

Gaussian standard deviation

Danezis, E., Lyratzi, E., Nikolaidis, D., Antoniou, A., Popović, L. Č. & Dimitrijević, M. S., 2007 PASJ (accepted) and SPIG 2006, Kopaonik, Serbia.

The calculation of the parameters

- **Directly from the model**
- **The apparent radial velocities (Vrad) of the absorbing or emitting density regions**
- **The Gaussian standard deviation (σ) of the random motions distribution**
- **The apparent rotational velocities (Vrad) of the absorbing or emitting density region.**
- **The optical depth (ξ) in the center of the spectral line**
- **From the above parameters we can calculate**

1. The percentage contribution (G%) of the random velocities to the broadening of the spectral line

2. The FWHM

3. The random velocities of the ions (Vrandom) that produce the spectral lines

4. The absorbed or emitted energy (Ea, Ee)

5. The column density (CD)

We point out that with the proposed model we can study and reproduce specific spectral lines. This means that we can study specific density regions in the plasma surrounding the studied object.

Some first general results

As we know, in order to find the mechanism that is responsible for the structure of DACs or SACs density regions we need to calculate the values of a group of parameters, such as the rotational, the random and the radial velocities, the FWHM, the optical depth, the absorbed or emitted Energy, the Column Density, and the Gaussian Standard Deviation, as well as the relation among them.

Another interesting point is to study the time scale variation of all the above parameters.

This is the reason why we present the following applications.

A statistical study of C IV, N IV and N V regions in the spectra of 20 Oe stars

In this application we study the C IV, N IV and N V regions in the spectra of 20 Oe stars and we calculate the values of the above parameters of these regions. We also study the relation among them.
At the end of this session Dr Lyratzi will present some general conclusions about the structure of Si IV, Mg II and Ha density regions in Be stars

The studied Stars

Stars	Spectral types
HD24534	O9.5 III
HD24912	O7.5 III ((f))
HD34656	O7 II (f)
HD36486	O9.5 II
HD37022	O6 Vp
HD47129	O7.5 III
HD47839	O7 III
HD48099	O6.5 V
HD49798	O6p
HD57060	O8.5If

Stars	Spectral types
HD57061	O9.0I
HD60848	O8.0Vpe
HD91824	O7V((f))
HD93521	O9.5II
HD112244	O8.5Iab
HD149757	O9V(e)
HD164794	O4V((f))
HD203064	O8V
HD209975	O9.5I
HD210839	O6.0I

In this table we present the studied stars. As we know it is not possible to find stars between O0 and O3 spectral subtypes.

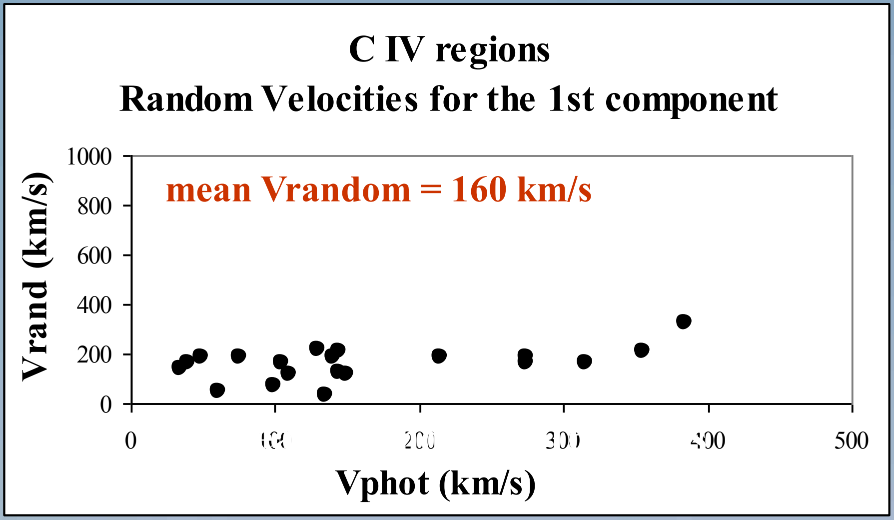
With our model we calculated the random velocities of the layers that produce the C IV, NIV and NV satellite components in the spectra of 20 Oe stars, with different photospheric rotational velocities.

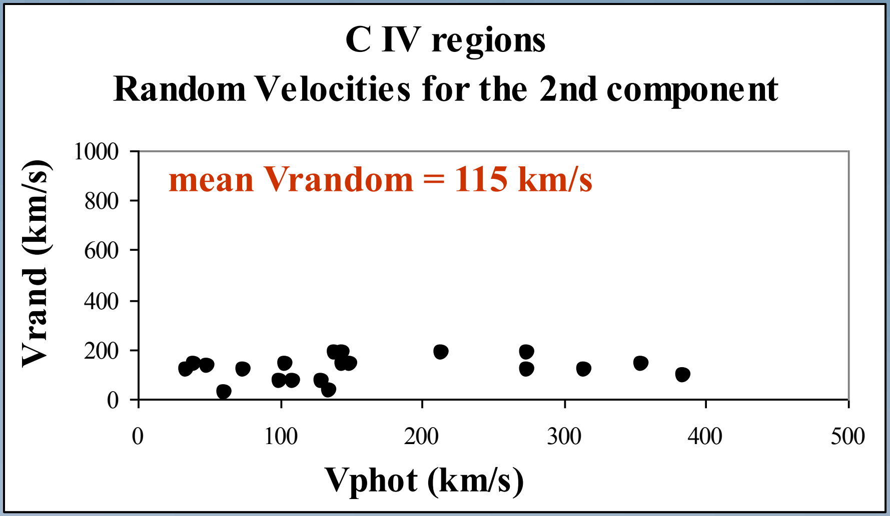
The ionization potential of each studied ion, for all the studied stars, is the same, so the respective random velocities will be the same.

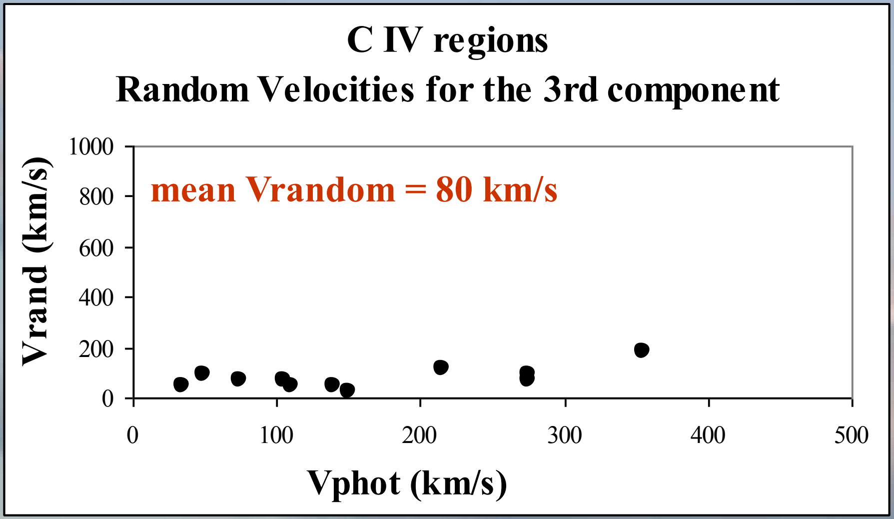
As the values of the random velocities do not depend on the inclination of the rotational axis, we expect similar average values of the random velocities for each component for all the studied stars.

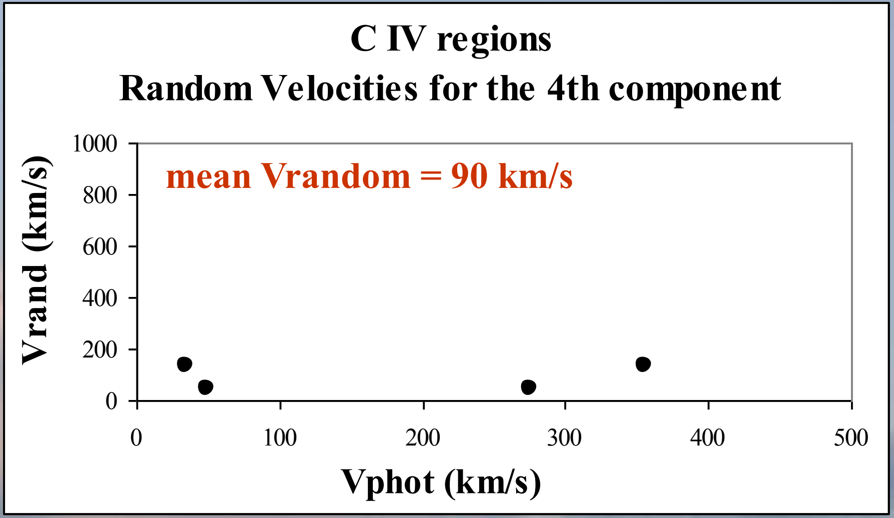
In the following figures we present the relation between the random velocities of the ions that create the C IV, N IV and N V lines in the spectra of 20 stars as a function of the photospheric rotational velocities of the studied stars

The C IV region of 20 Oe stars



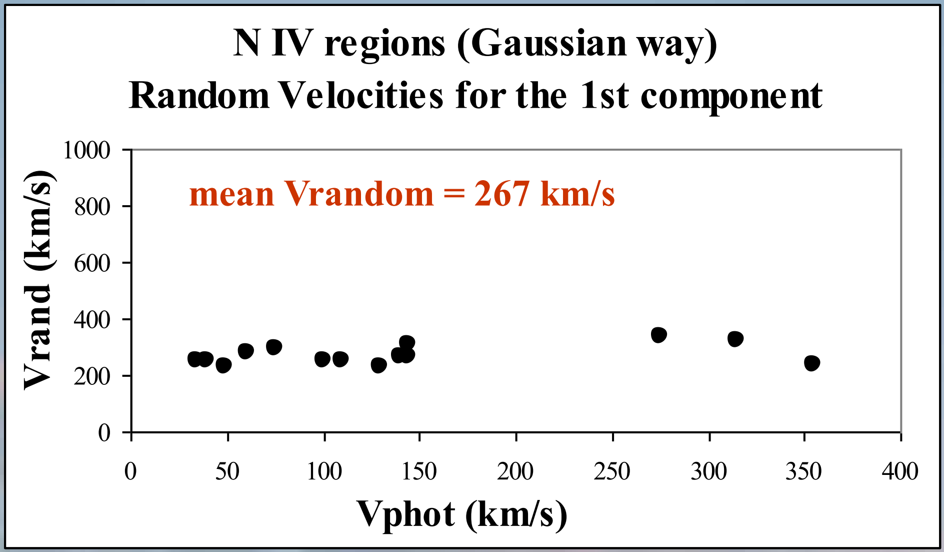


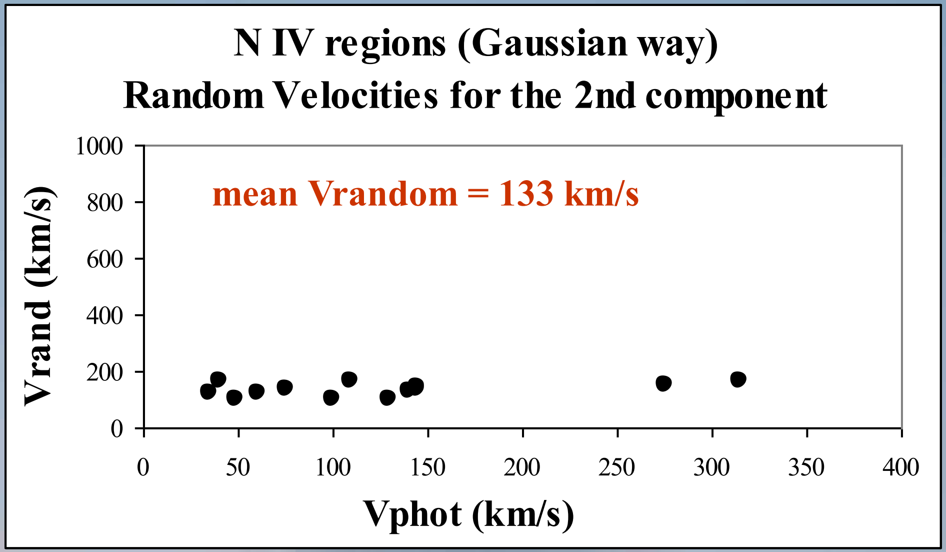




In this figures we present the random velocities (Vrand) of the ions in the C IV regions that produce the satellite components as a function of the apparent photospheric rotational velocities (Vphot). We detect similar average values of the random velocities for each component for all the studied stars

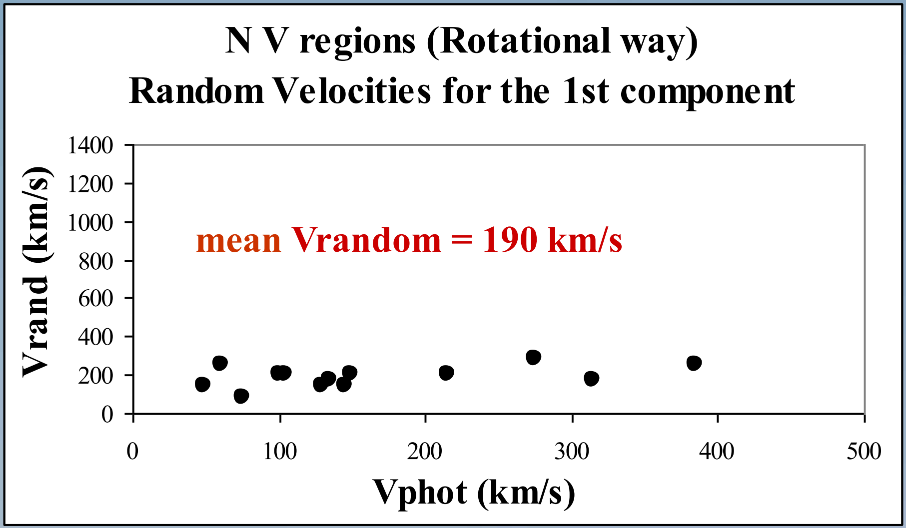
The N IV regions of 20 Oe stars

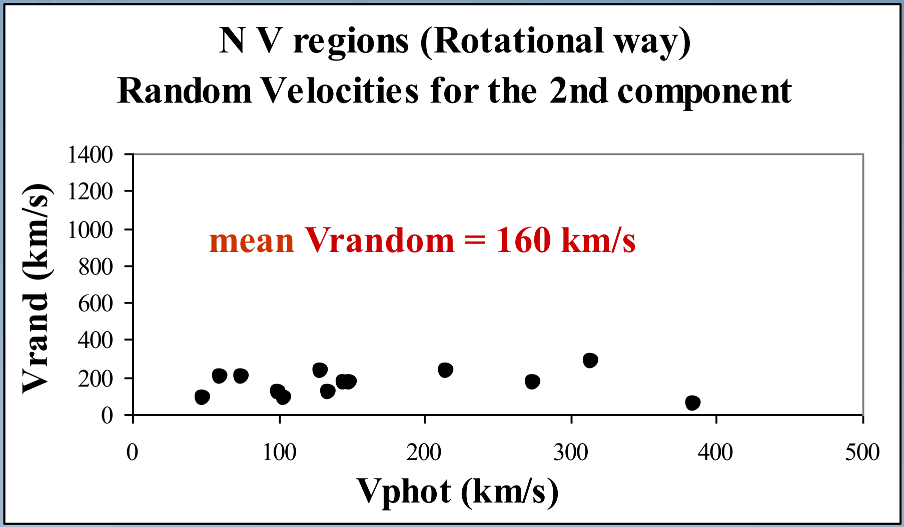


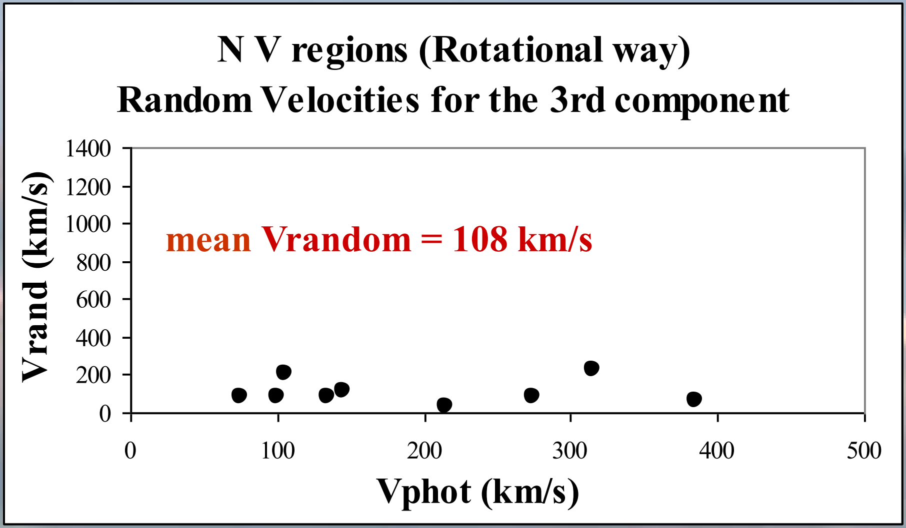


In this figures we present the random velocities (Vrandom) of the N IV regions that produce the satellite components as a function of the apparent photospheric rotational velocities (Vphot). We detect similar average values of the random velocities for each component for all the studied stars

The N V region of 20 Oe stars







In this figures we present the random velocities (Vrand) of the N V regions that produce the satellite components as a function of the apparent photospheric rotational velocities (Vphot). We detect similar average values of the random velocities for each component for all the studied stars

Important remark

As we see, we detect similar average values of the random velocities for each component, for the C IV, N IV and N V regions, for all the studied stars. The above results, taken with our model agree with the theory.

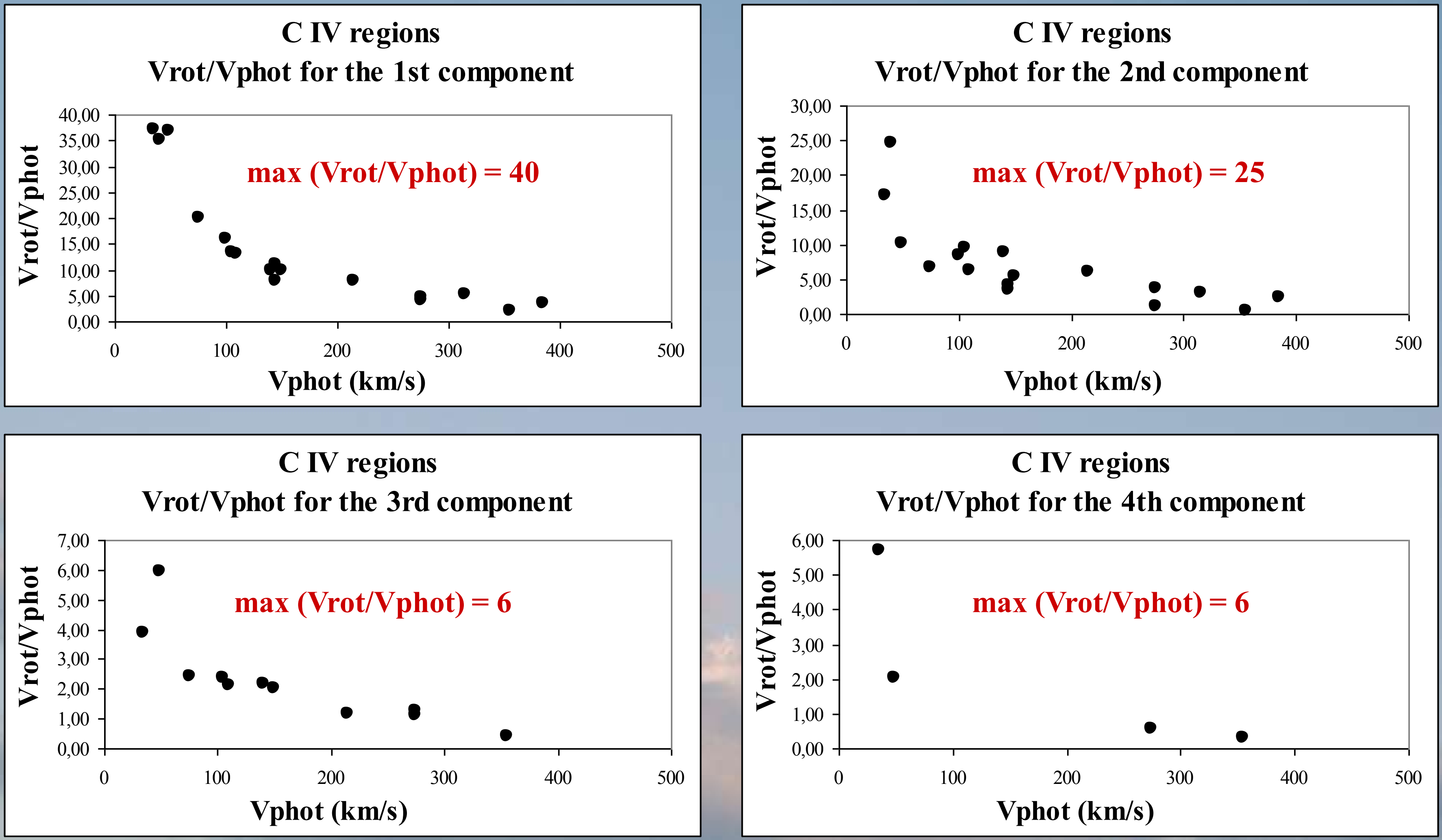
This agreement between theory and calculations is a favourable test for our model.

Studding the Rotational Velocities of the density layers of matter

2. In the following figures we present the ratio Vrot/Vphot of the C IV, N IV and N V components as a function of the photospheric rotational velocity (Vphot).

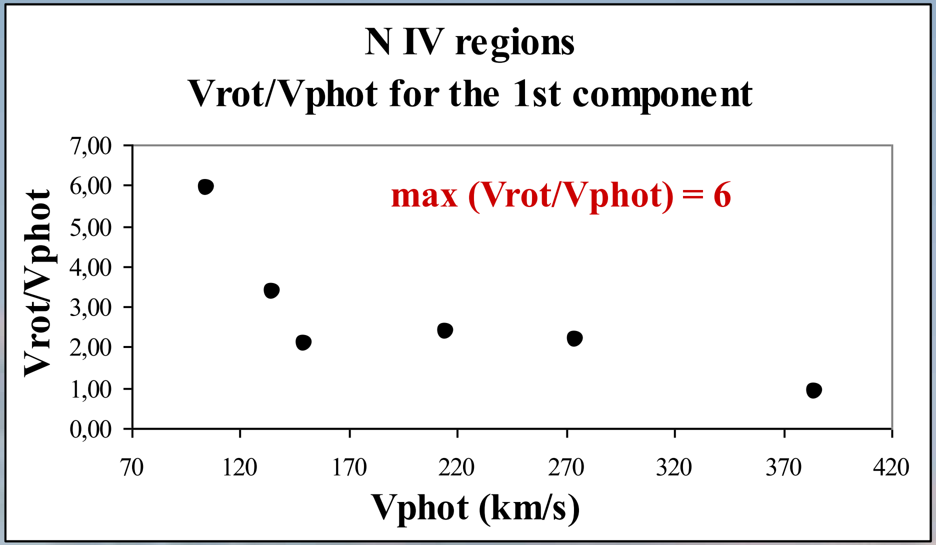
This ratio indicates how much the rotational velocity of the specific layer that construct the specific component is higher than the apparent rotational velocity of the star

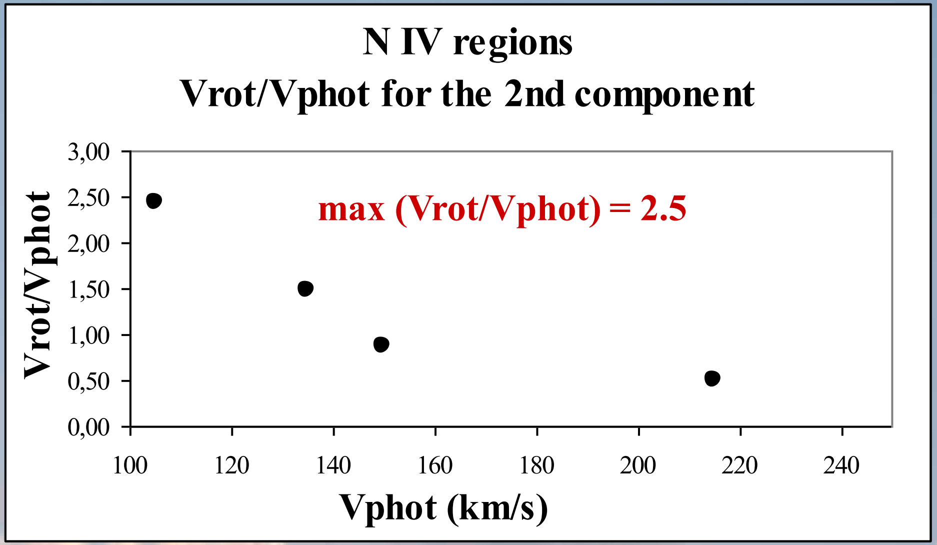
Vrot=Rotational Velocity of the studied density region
Vphot=Apparent Photospheric Rotational Velocity



In these figures we present the ratio Vrot/Vphot of the four detected components of C IV as a function of the photospheric rotational velocity (Vphot).

The N IV region of 20 Oe stars

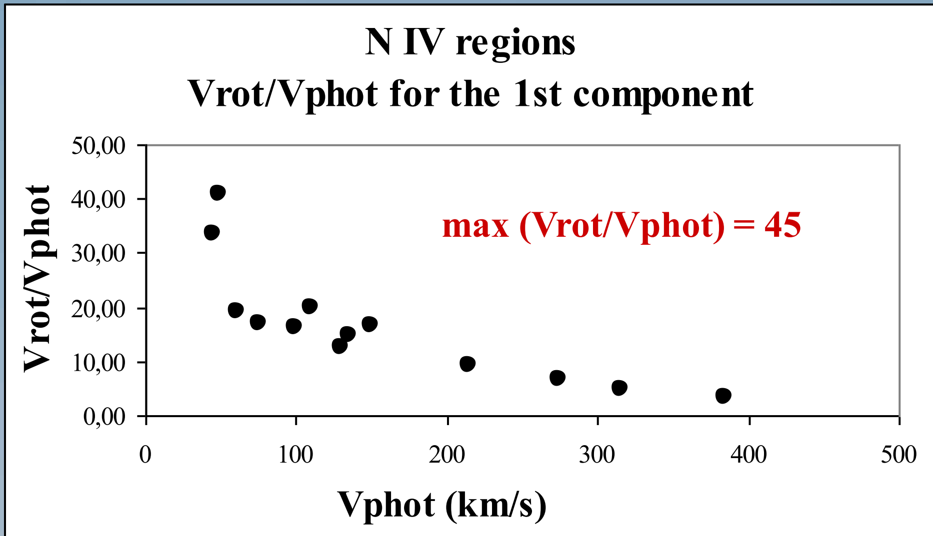


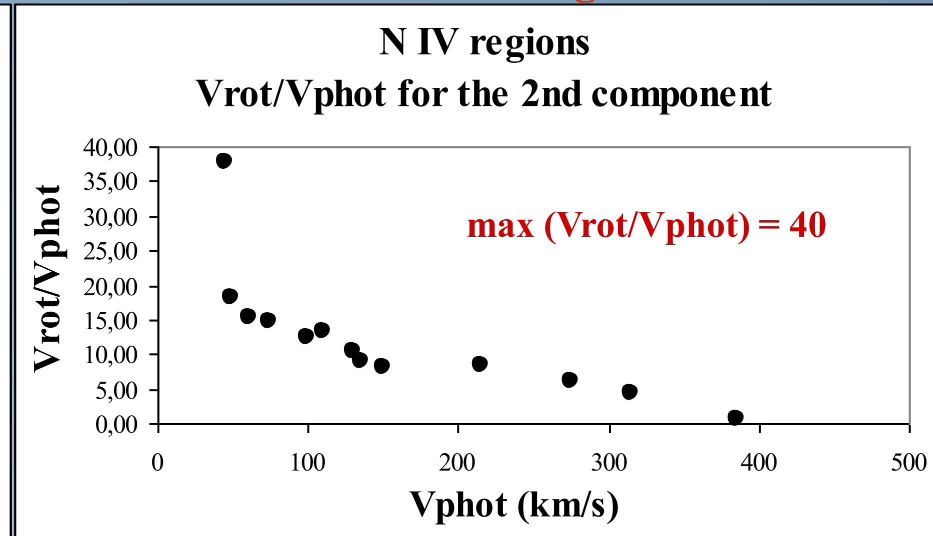


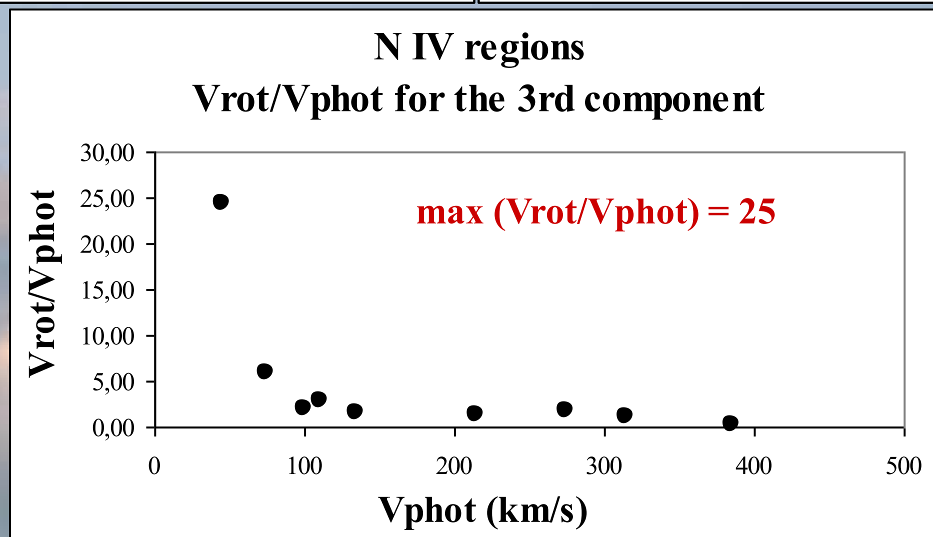
Vrot/Vphot = f(Vphot)

The ratio Vrot/Vphot indicates how much the rotational velocity of the specific N IV layer is higher than the apparent rotational velocity of the star

The N V region of 20 Oe stars







Vrot/Vphot = f(Vphot)

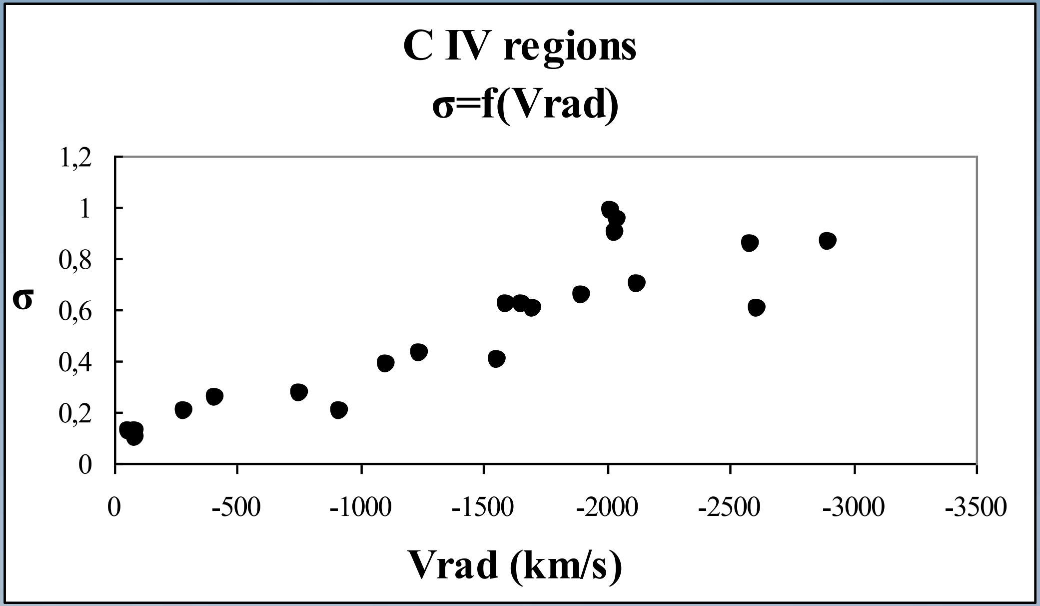
The ratio Vrot/Vphot indicates how much the rotational velocity of the specific N V layer is higher than the apparent rotational velocity of the star

A statistical study of the parameters of the C IV, N IV and N V regions

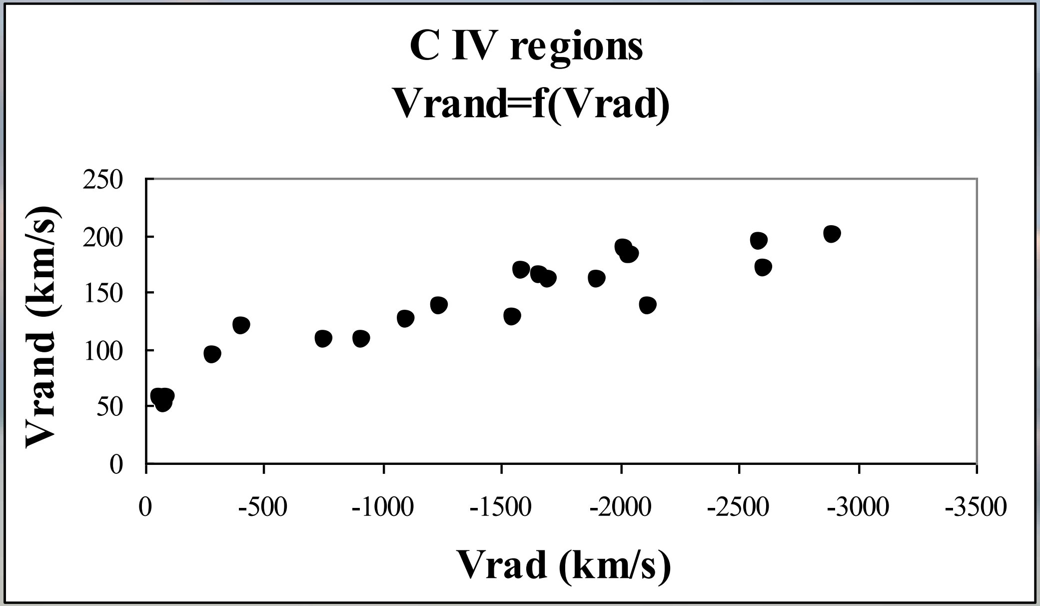
In this application we present (in the following figures) the values of some parameters that we can calculate studding the C IV, N IV and N V density regions of 20 Oe stars and the relations among them.

Also in three poster papers you can see the relation between all the studded parameters of C IV, N IV and N V regions and the spectral subtypes.

C IV region

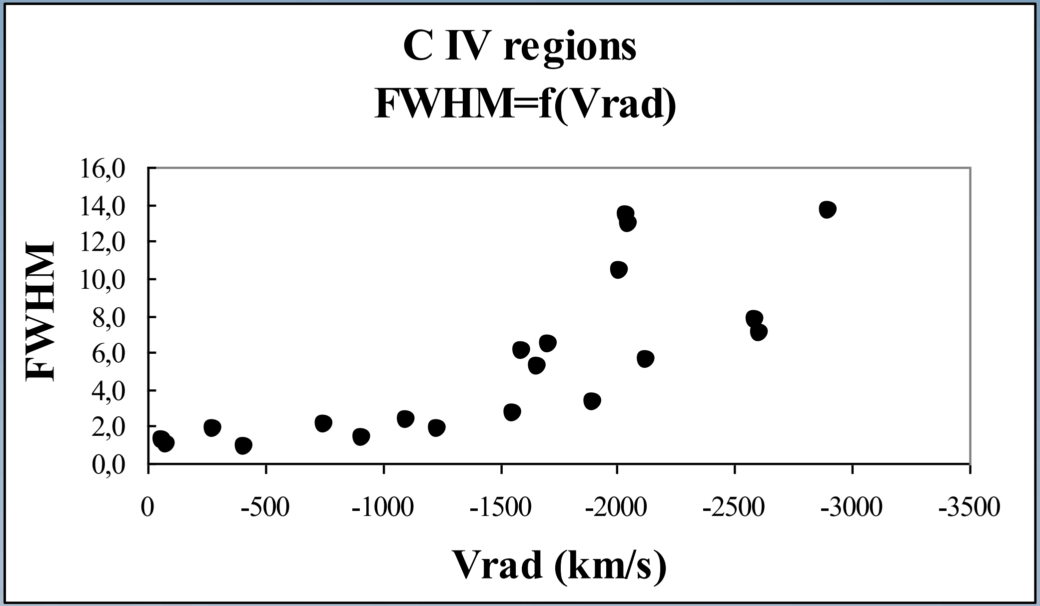


Relation between radial velocities and Gaussian Standard Deviation

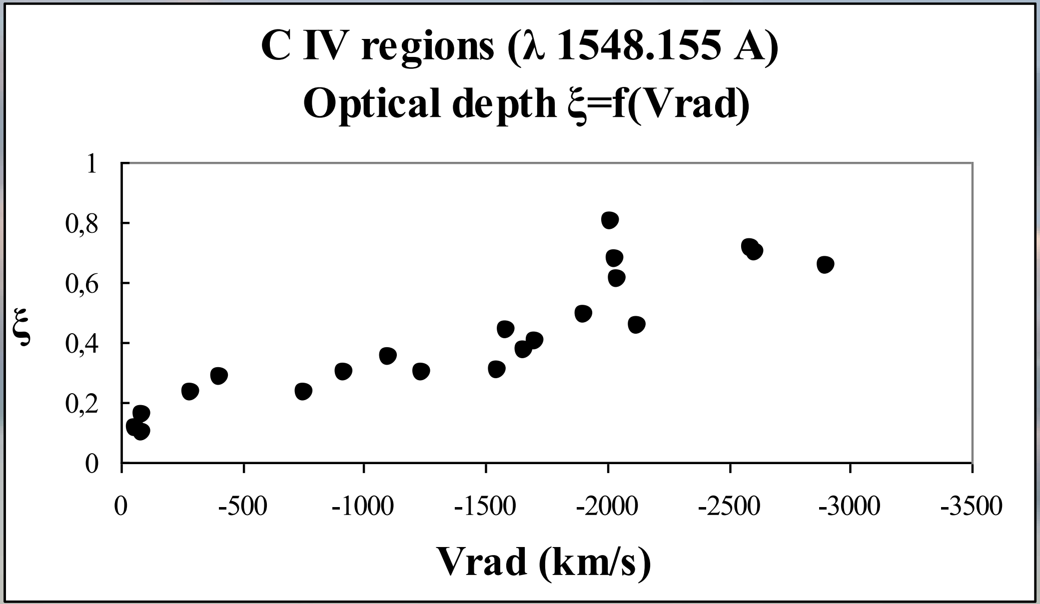


Relation between radial and random velocities

C IV region

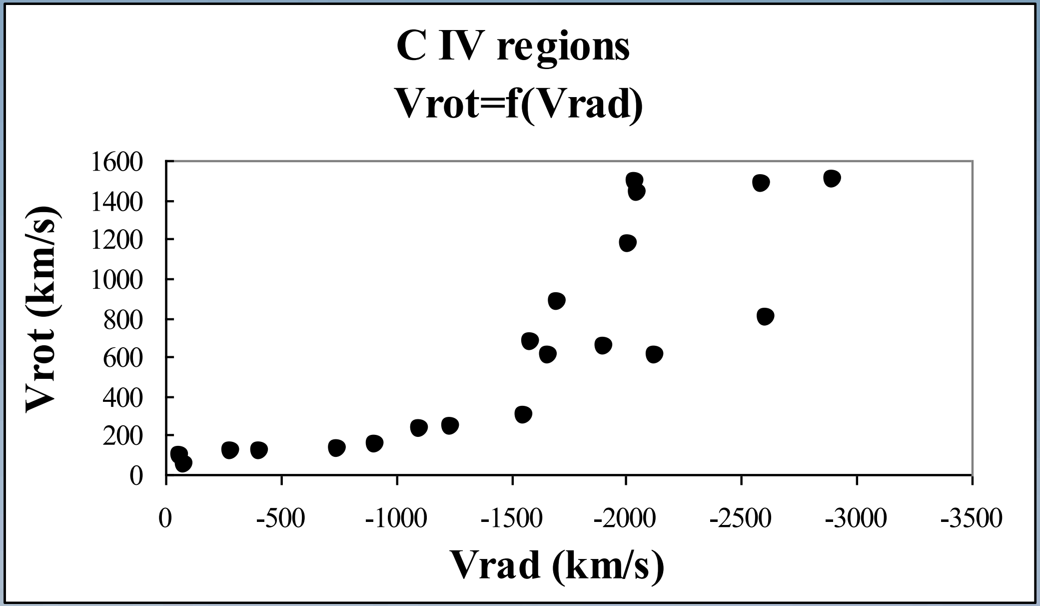


Relation between radial velocities and FWHM

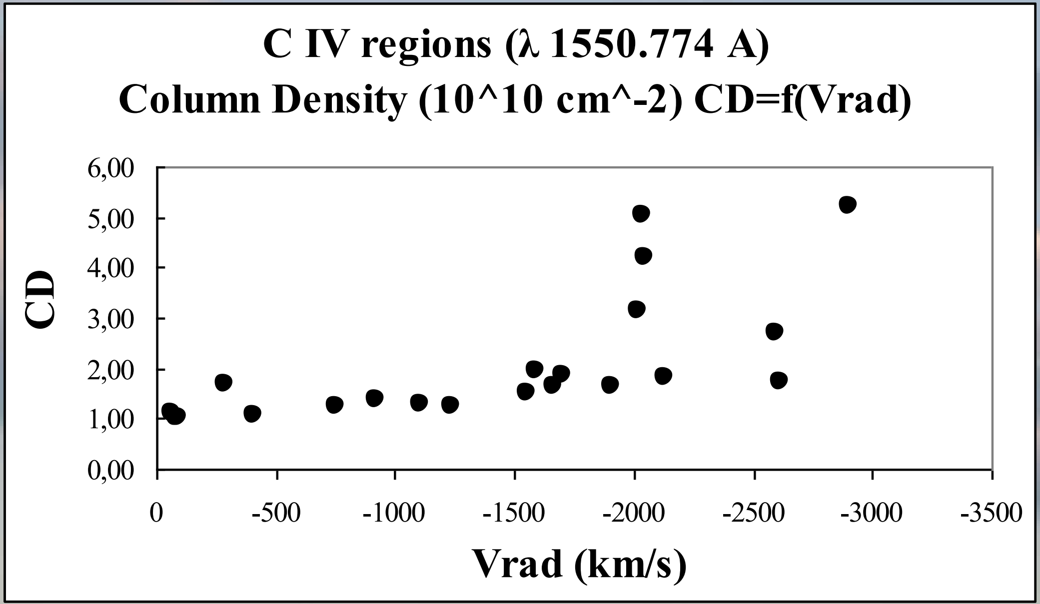


Relation between radial velocities and Optical Depth

C IV region



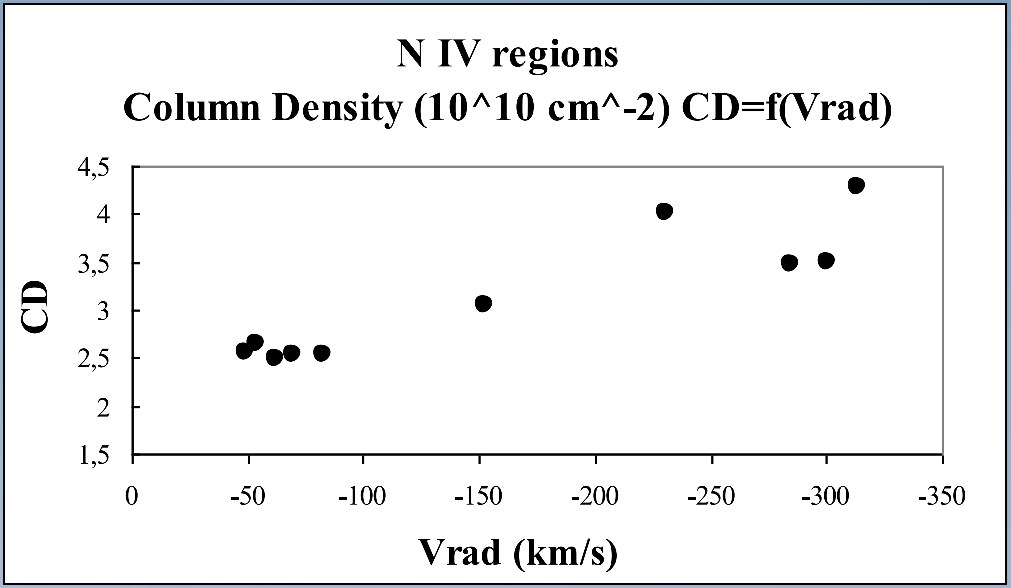
Relation between radial and rotational velocities



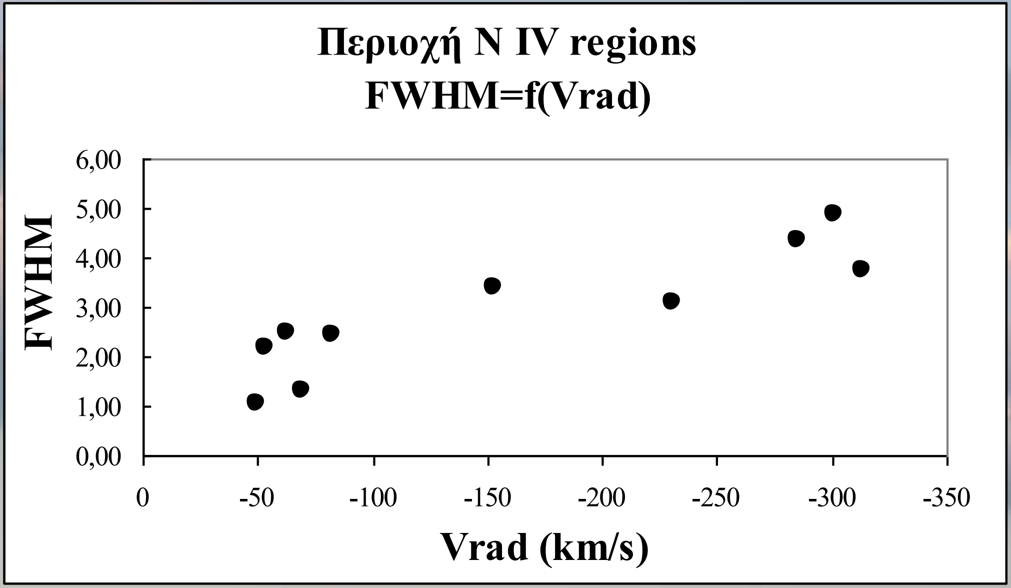
Relation between radial velocities and Column Densities

A statistical study of the parameters of the N IV regions

N IV region

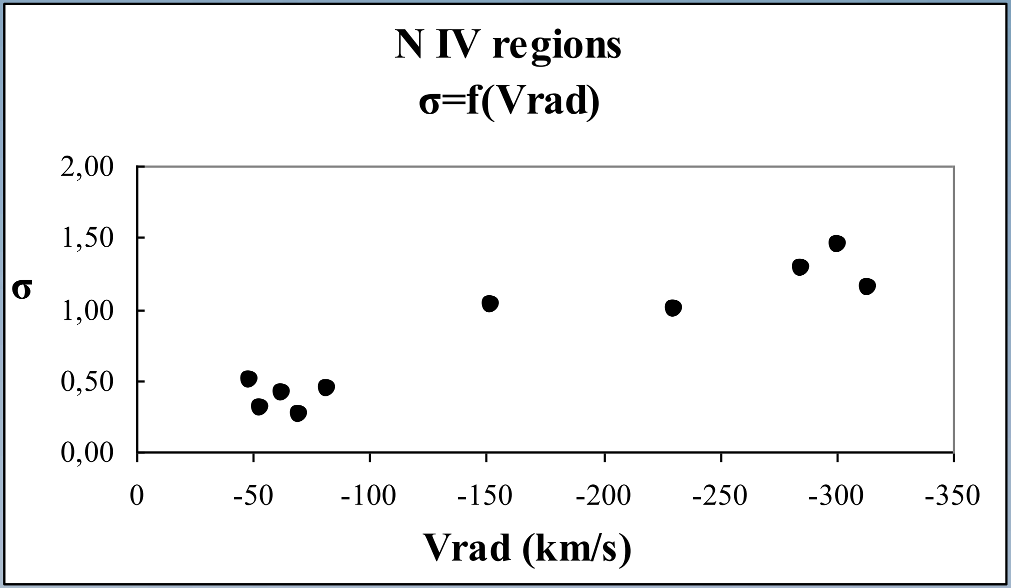


Relation between radial velocities and Column Densities

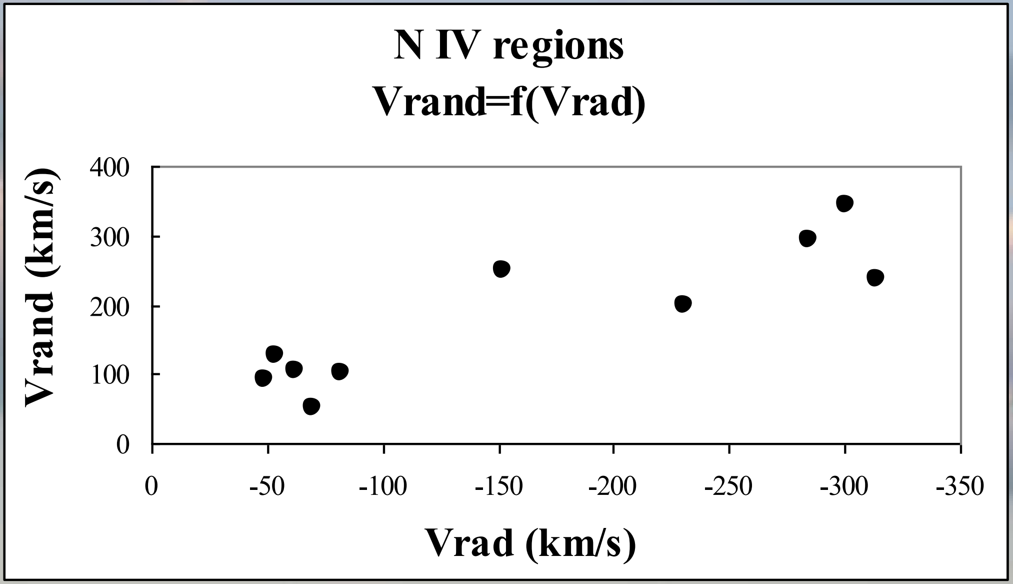


Relation between radial velocities and FWHM

N IV region



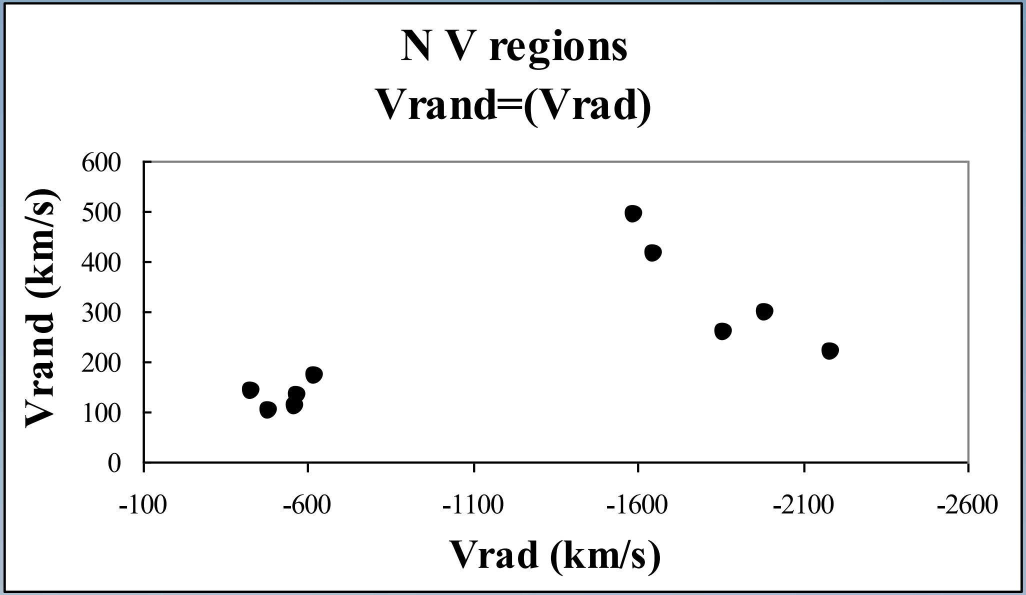
Relation between radial velocities and Gaussian Standard Deviation



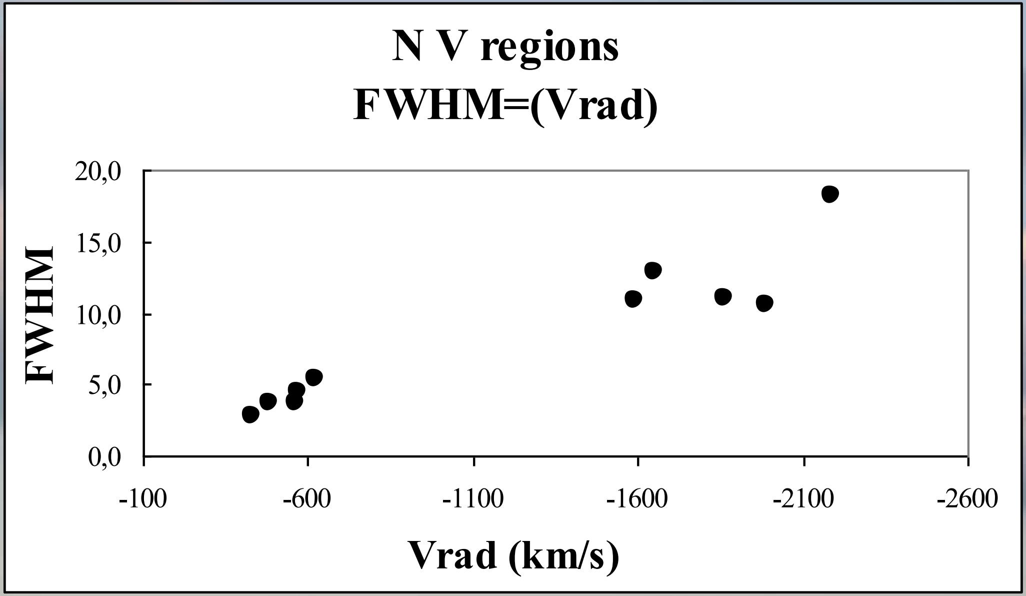
Relation between radial and random velocities

A statistical study of the parameters of the N V regions

N V region

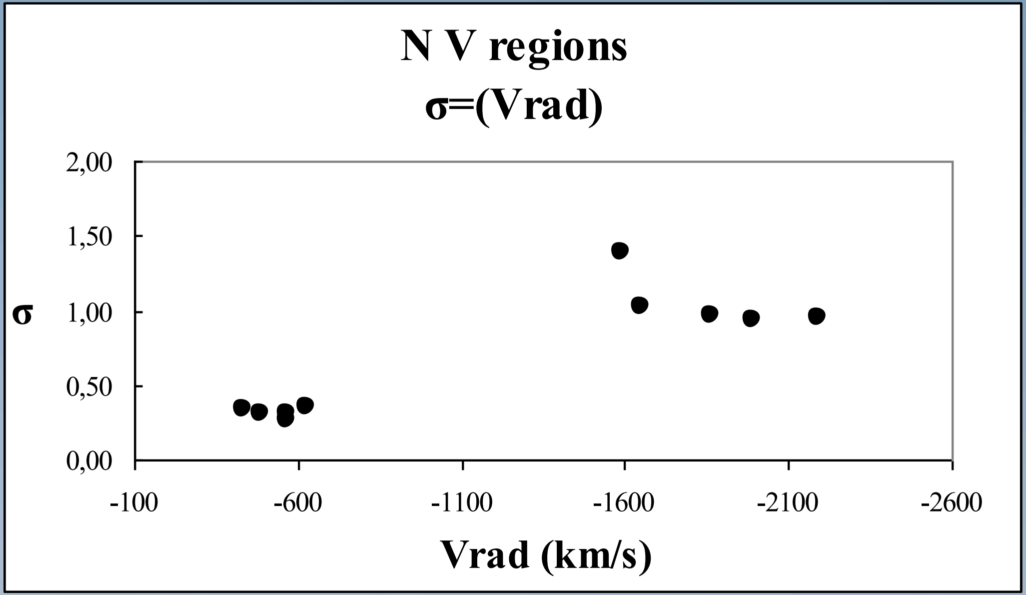


Relation between radial and random velocities

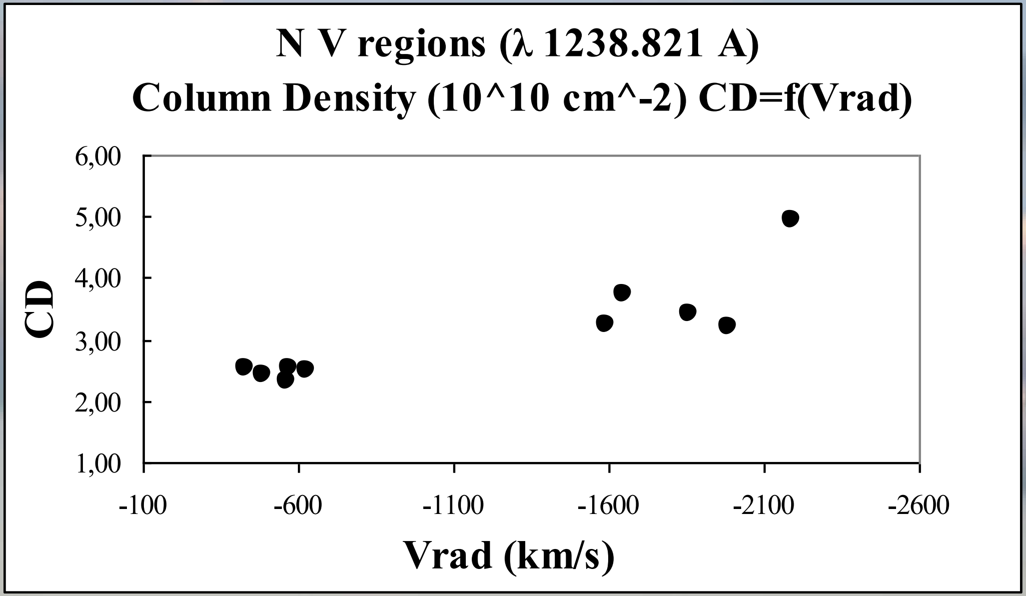


Relation between radial velocities and FWHM

N V region

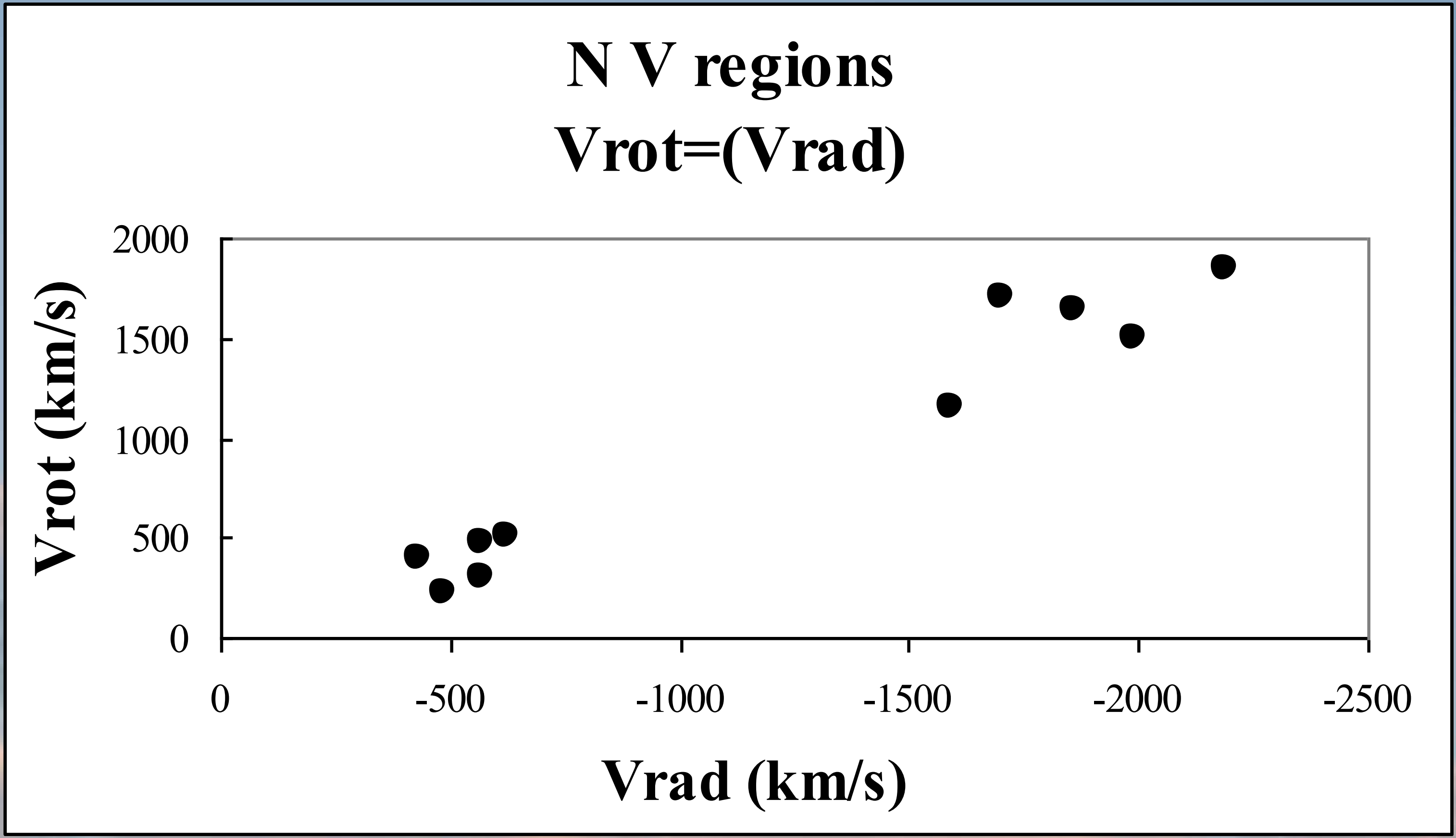


Relation between radial velocities and Gaussian Standard Deviation



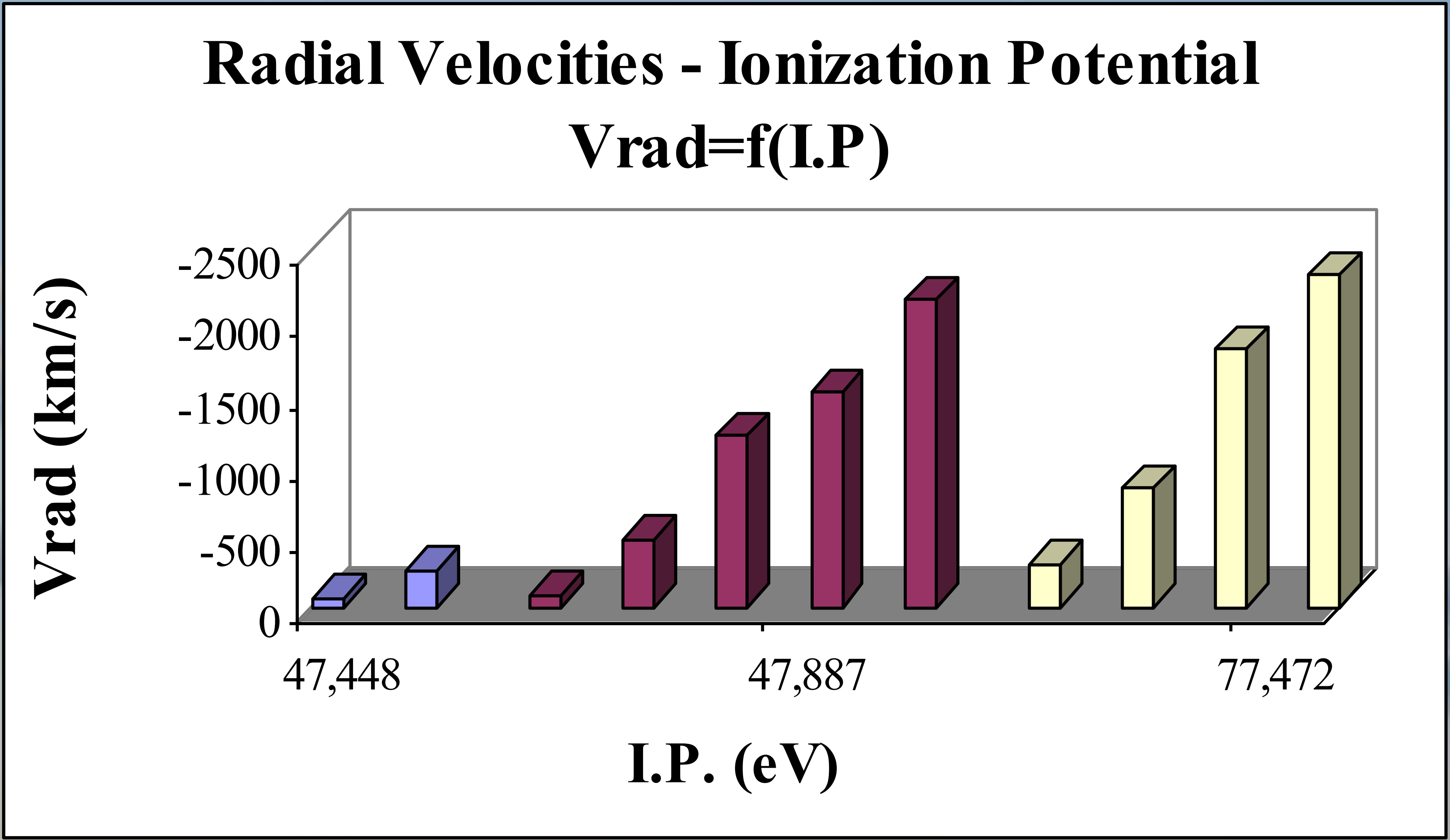
Relation between radial velocities and Column Densities

N V region



Relation between the radial velocities and the Rotational Velocities

As Franco et al. (1982) and Kapper et al. (1996) indicate, the radial velocities increase from the high to the low ionization potential. Our results verify this proposition.



Time scale variations of the C IV, Si IV, N IV and N V density regions in the HD 93521 stellar atmosphere

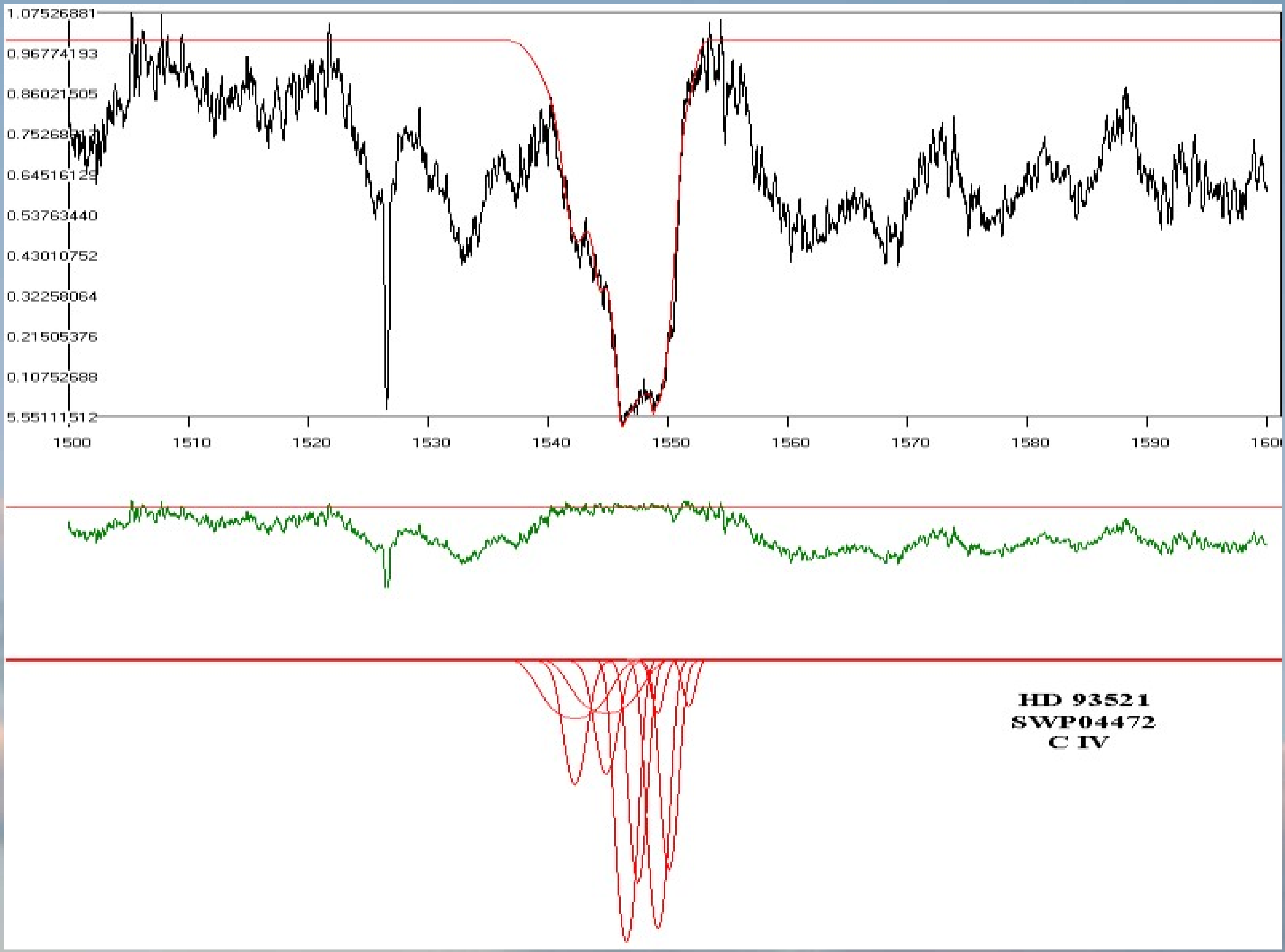
In this application we present the time scale variations of the C IV, N IV, Si IV and N V regions parameters.

This is an important study to examine in a future work the mechanism that is able to construct the DACs or SACs Phenomenon

Antoniou, A., Danezis, E., Lyratzi, E., Nikolaidis, D., Popović, L. Č., Dimitrijević, M. S., & Theodosiou, E., XXVIth IAU General Assembly, Prague, August, 2006.

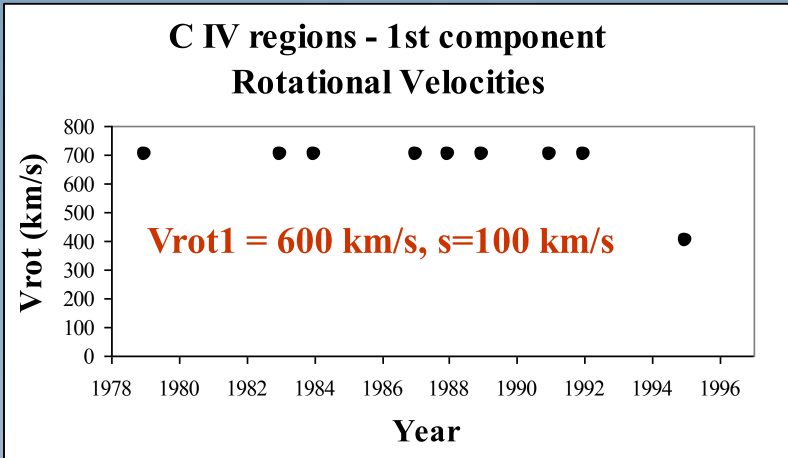
A study of the density regions that construct the C IV resonance lines λλ 1548.155, 1550.774 Å in the HD 93521 (Oe) UV spectrum

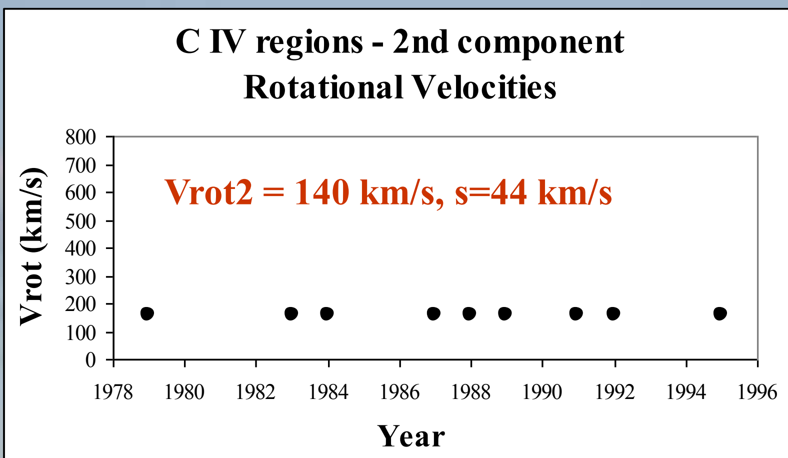
The Oe star HD 93521. The C IV region

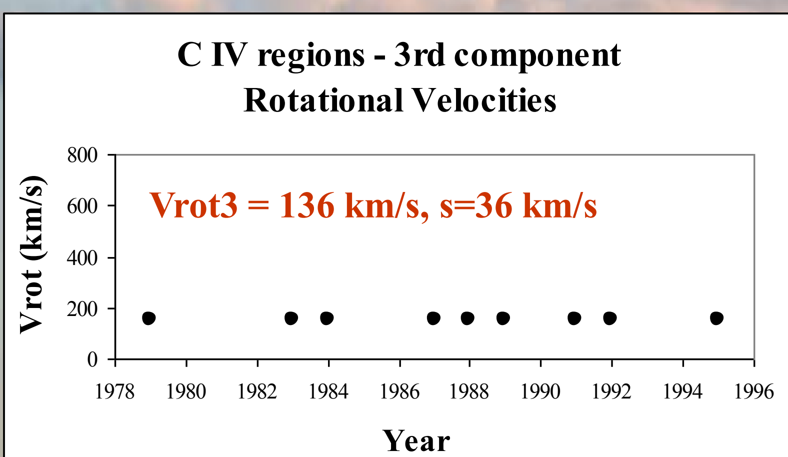


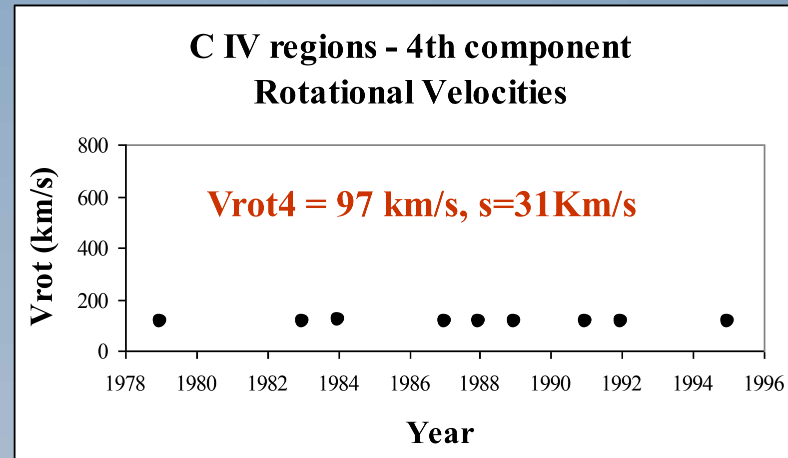
In this figure we can see the complex structure of C IV UV resonance lines. Each one of them consists in five components

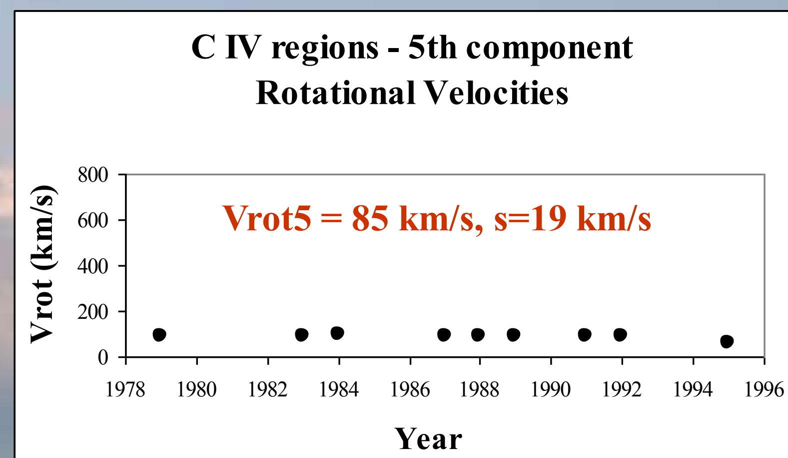
The Oe star HD 93521. The C IV region







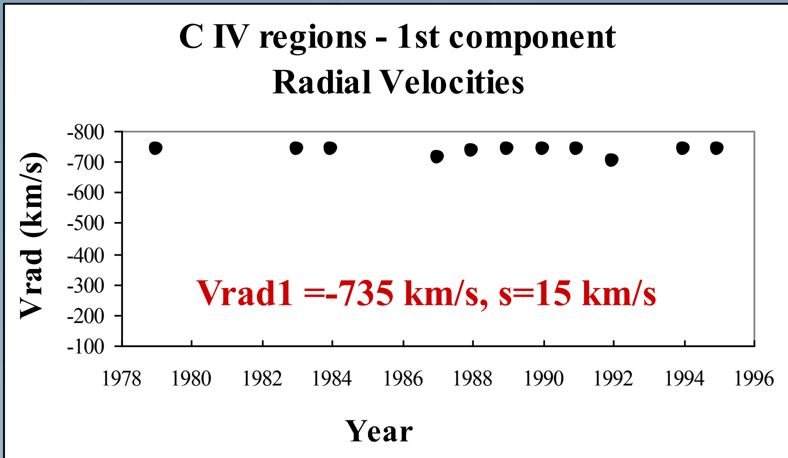


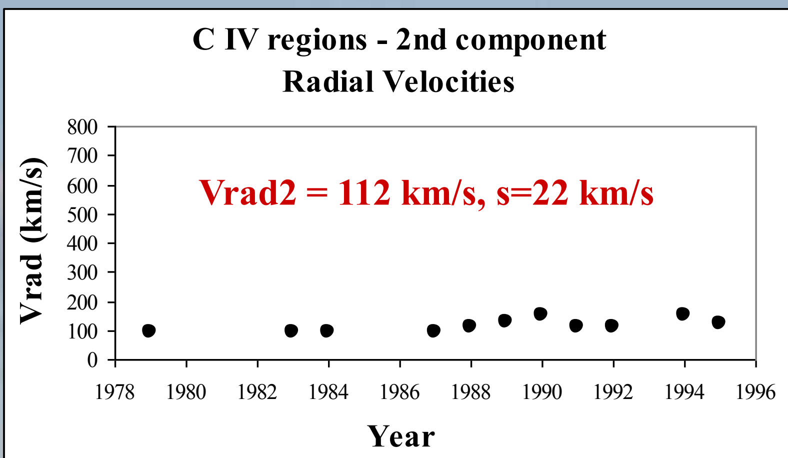


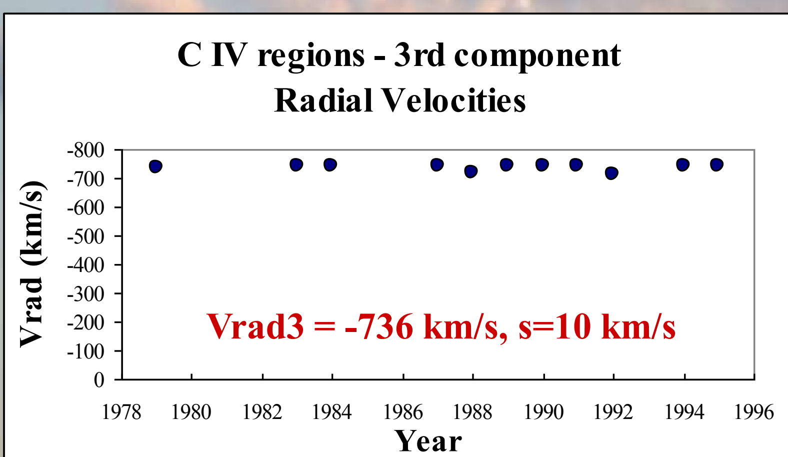
Time scale variation of Rotational Velocities (Vrot) for the five components

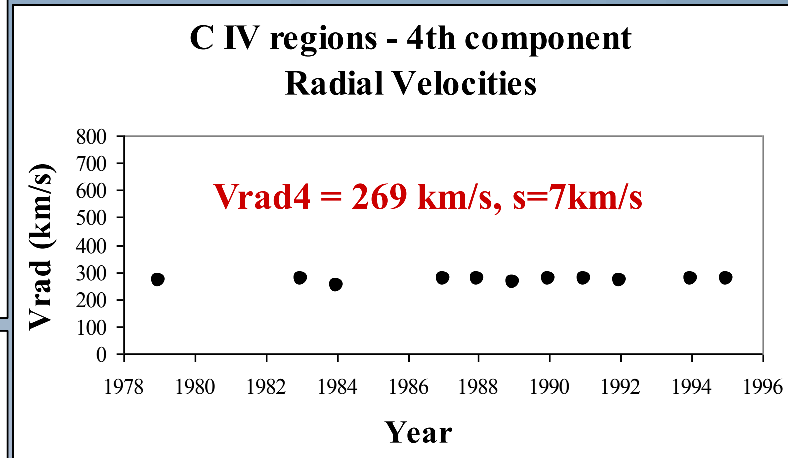
The Oe star HD 93521. The C IV region

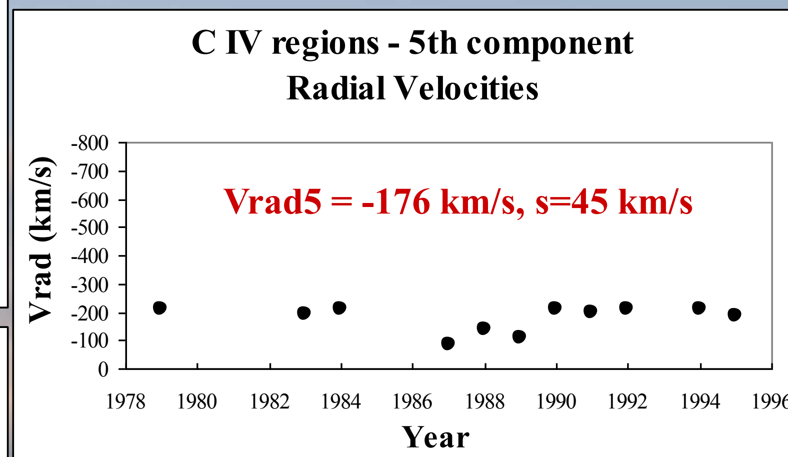
Time scale variation of Radial Velocities (Vrad) for the five components





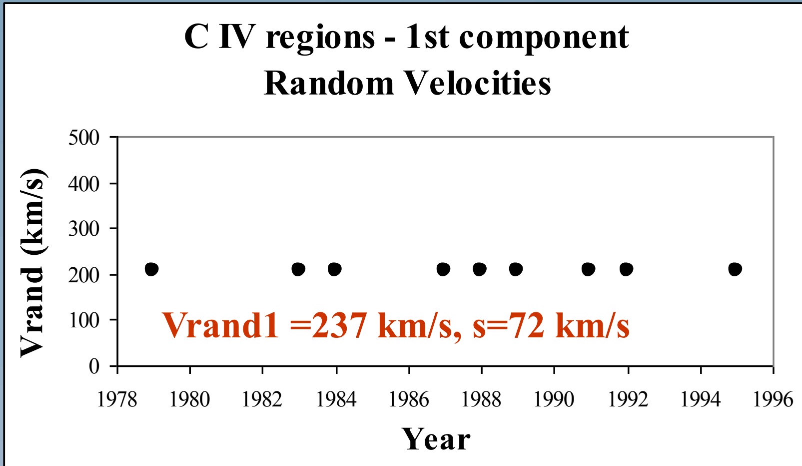


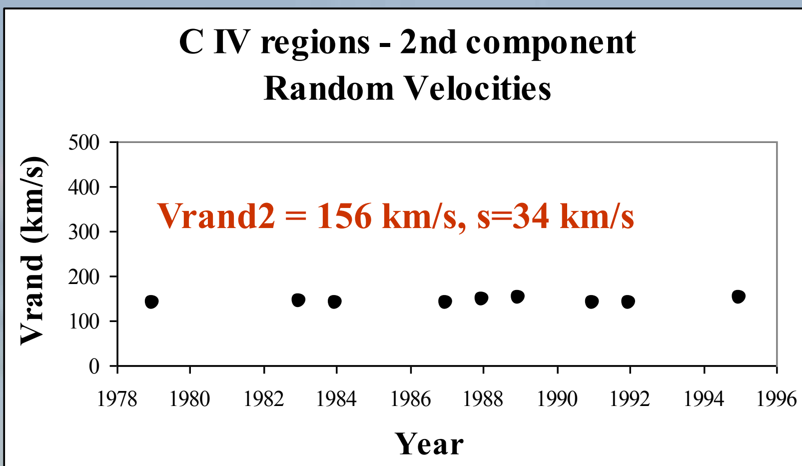


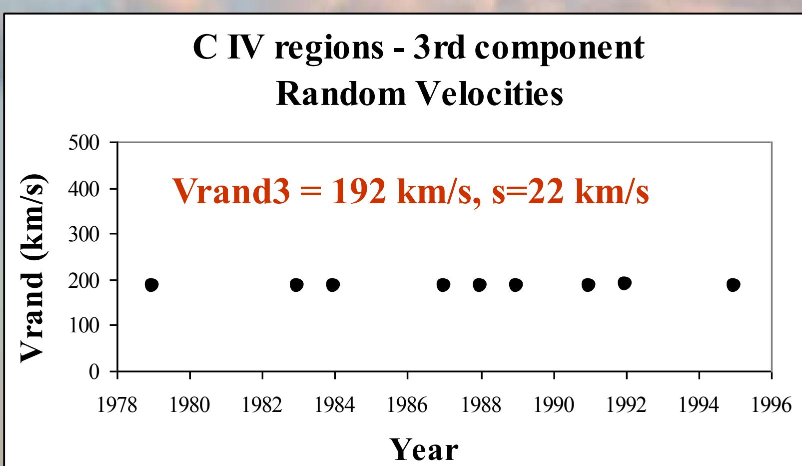


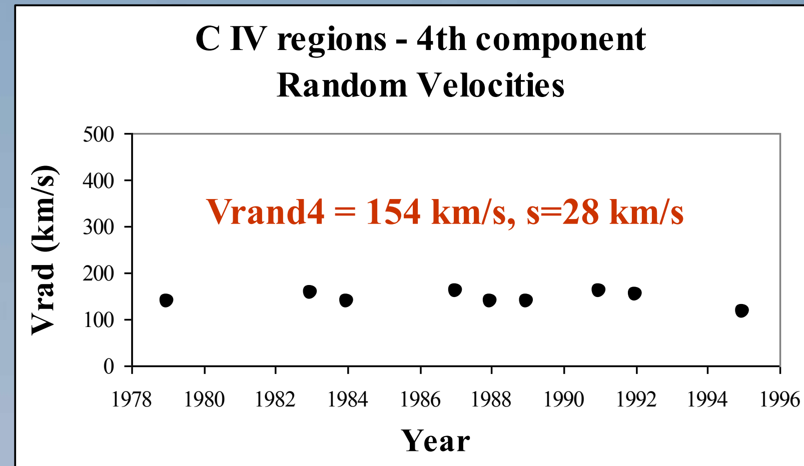
Here and in all the following figures, s (standard deviation) does non depend only on the statistical error but, mainly, it indicates the time scale variation of the studied values.

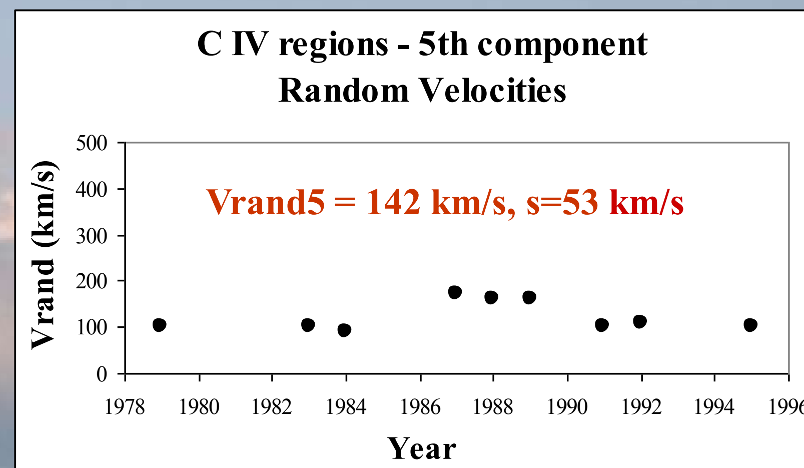
The Oe star HD 93521. The C IV region





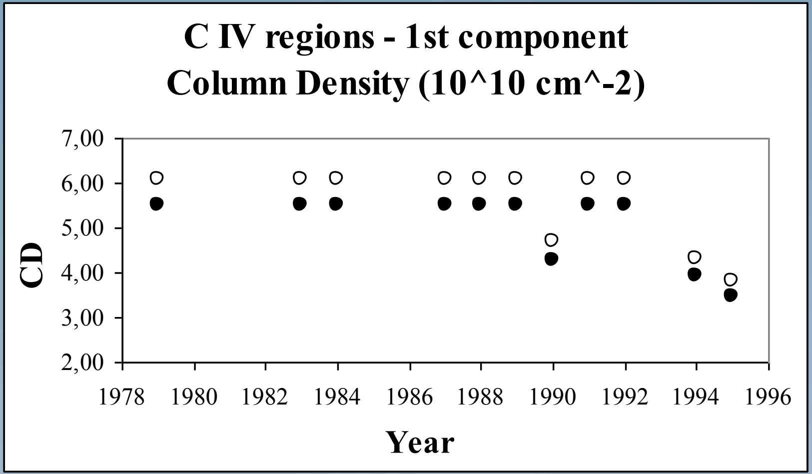


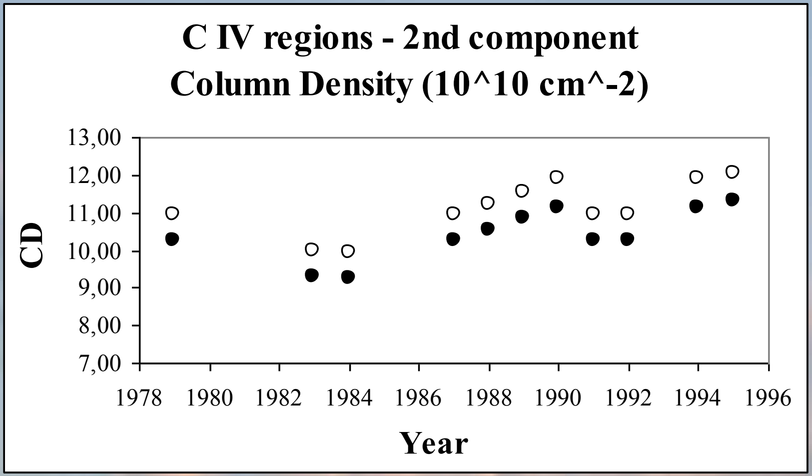


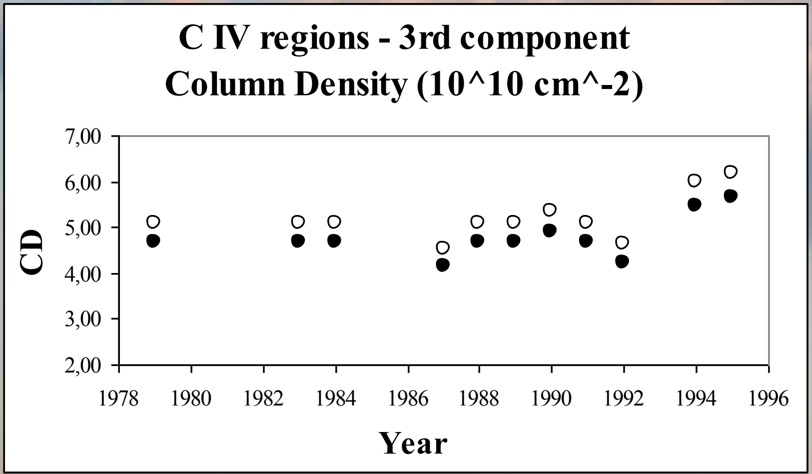


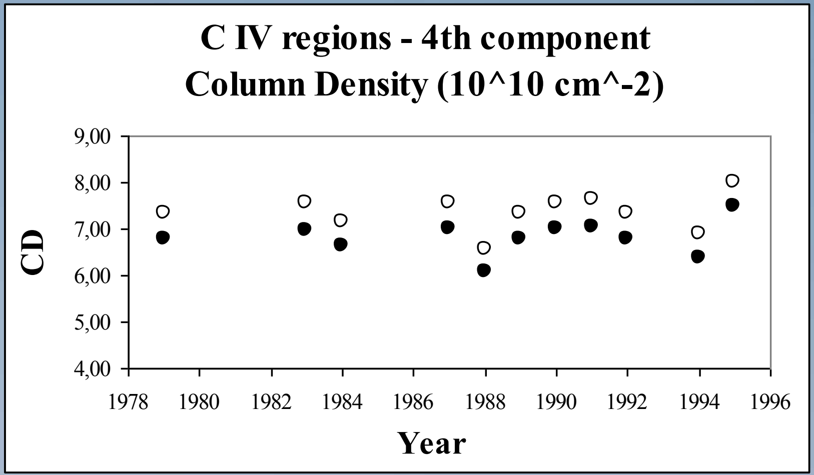
Time scale variations of Random velocities (Vrand) for the five components

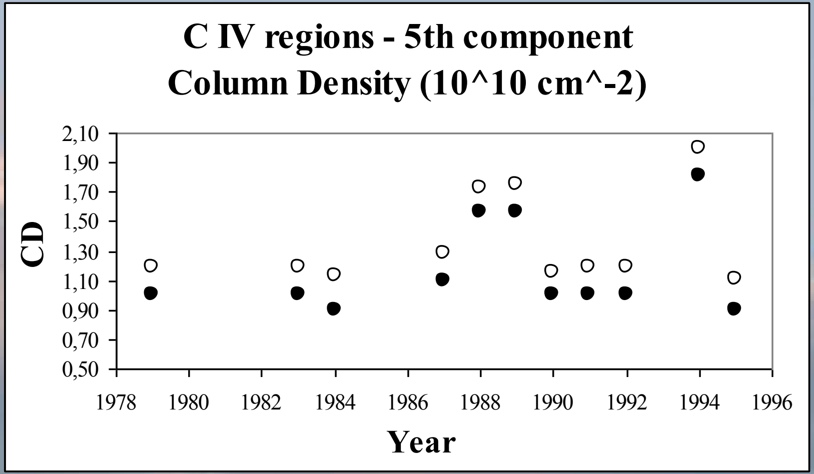
The Oe star HD 93521. The C IV region







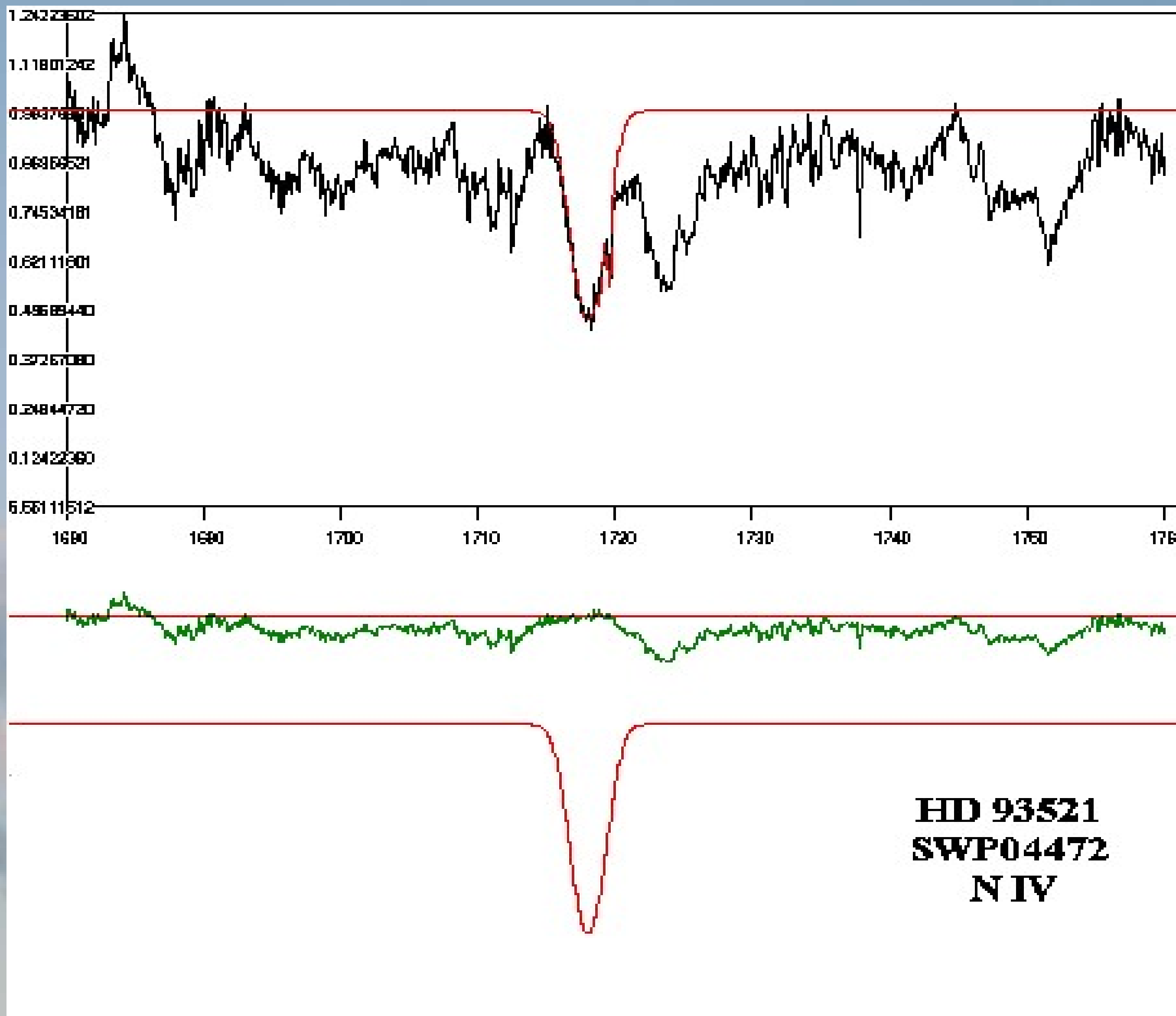




Time scale variation of Column Density for the five components (10^{10} cm^{-2})

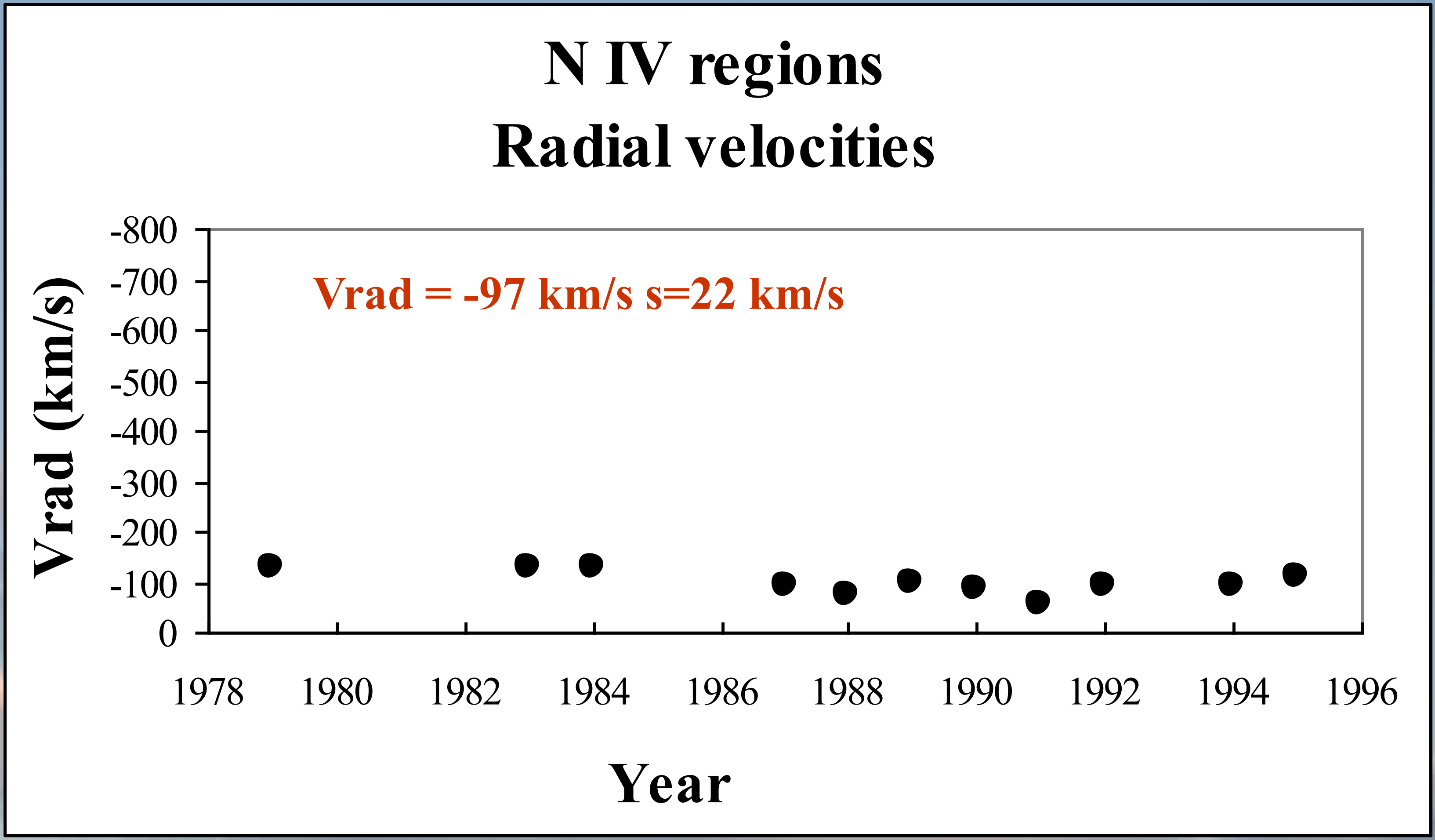
A study of the density regions that construct the N IV spectral line λ 1718.8 Å in the HD 93521 (Oe) UV spectrum

The Oe star HD 93521. The N IV region



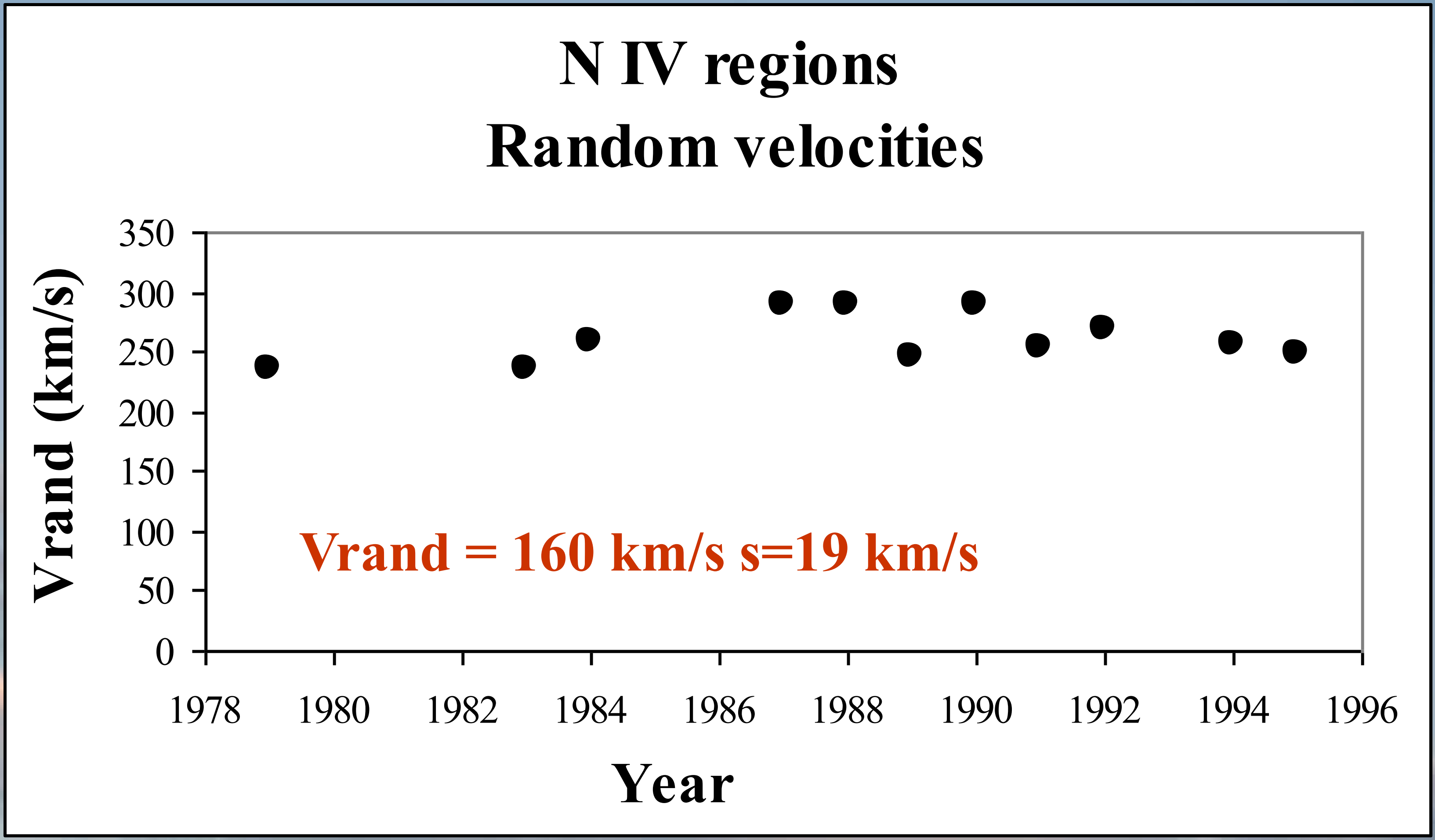
The N IV line is a simple spectral line that we can feet with a Gaussian

The Oe star HD 93521. The N IV region

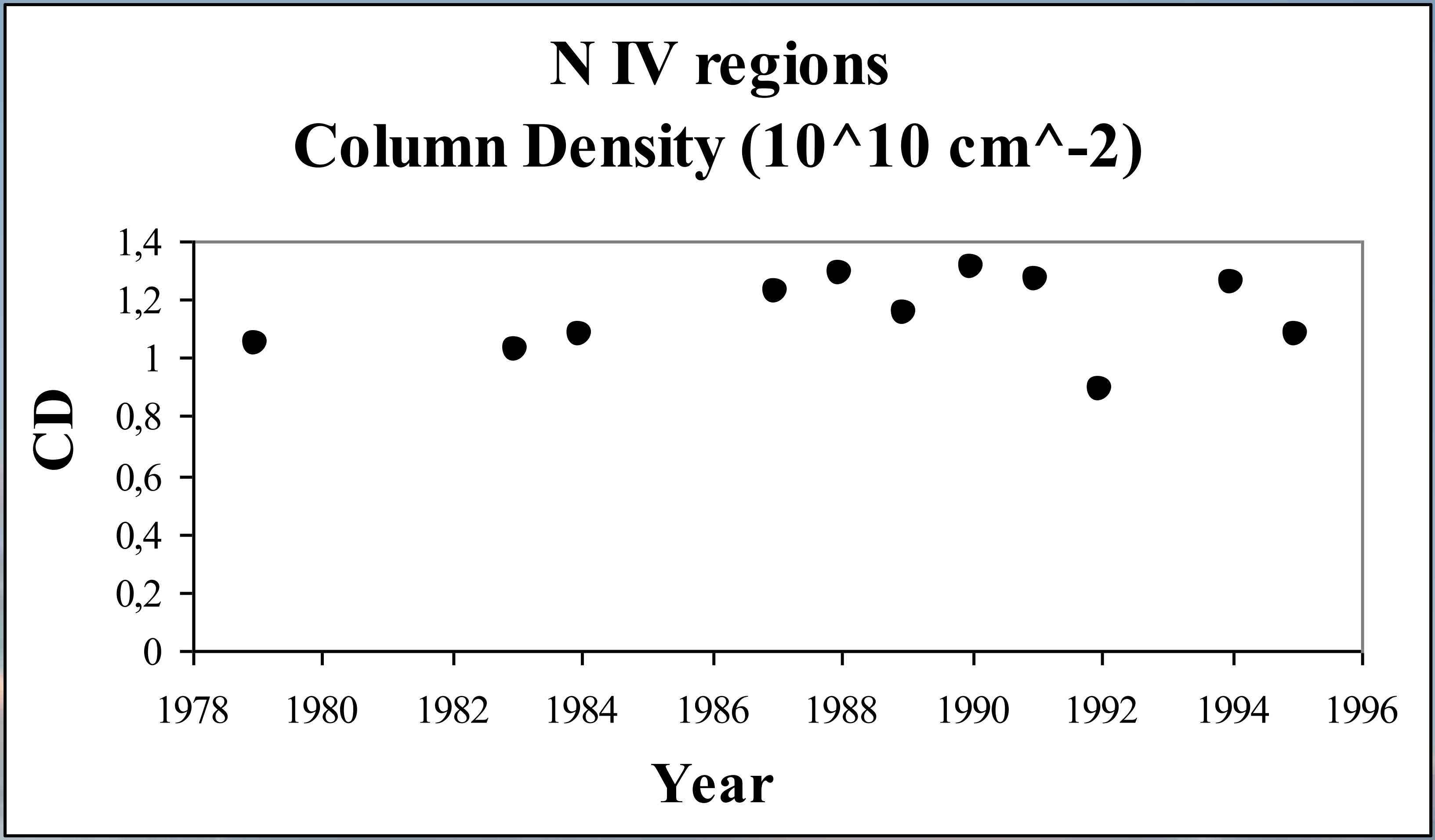


Time scale variation of Radial Velocities <u>(Vrad, km/s)</u>

The Oe star HD 93521. The N IV region



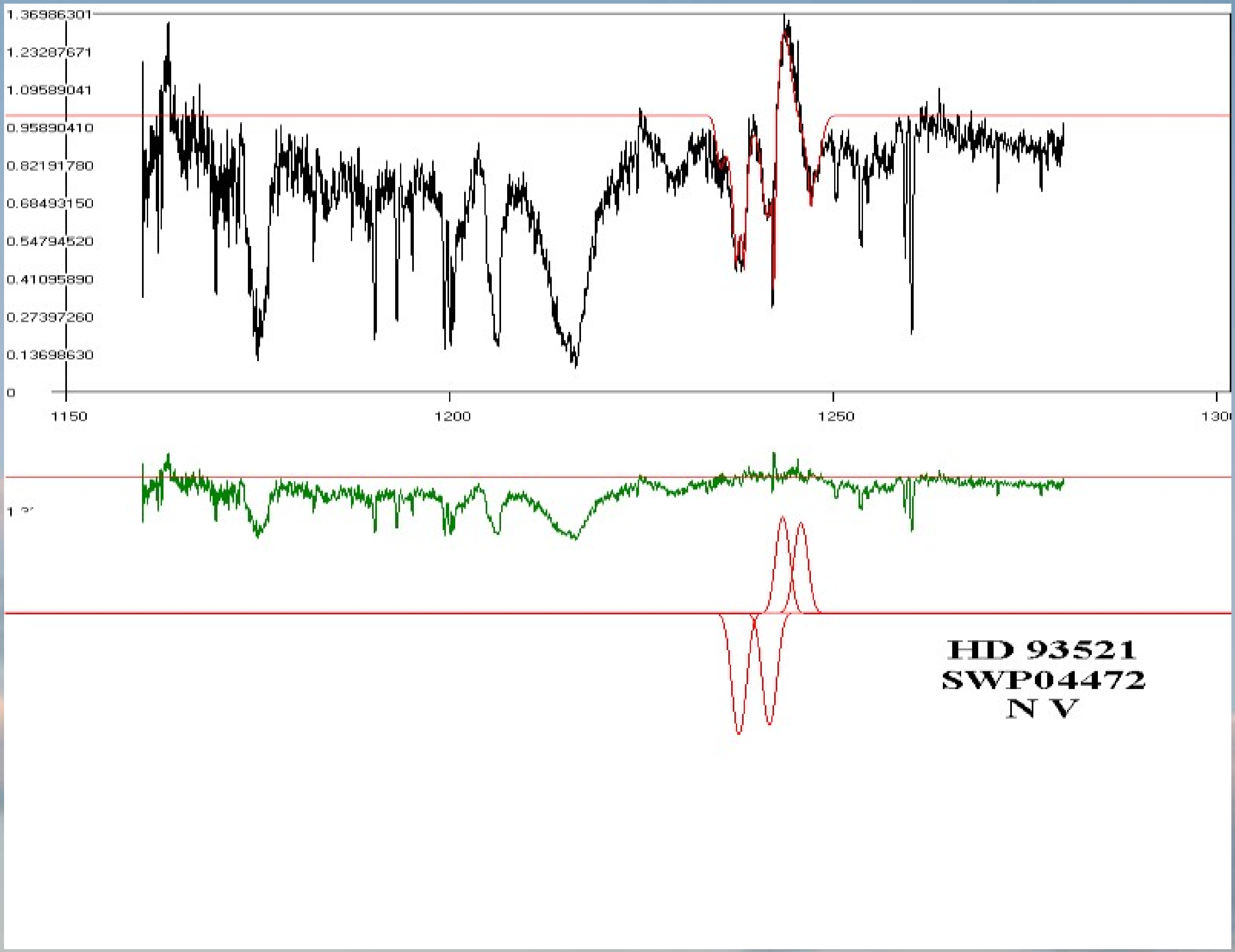
Time scale variation of random velocities <u>(Vrand, km/s)</u>



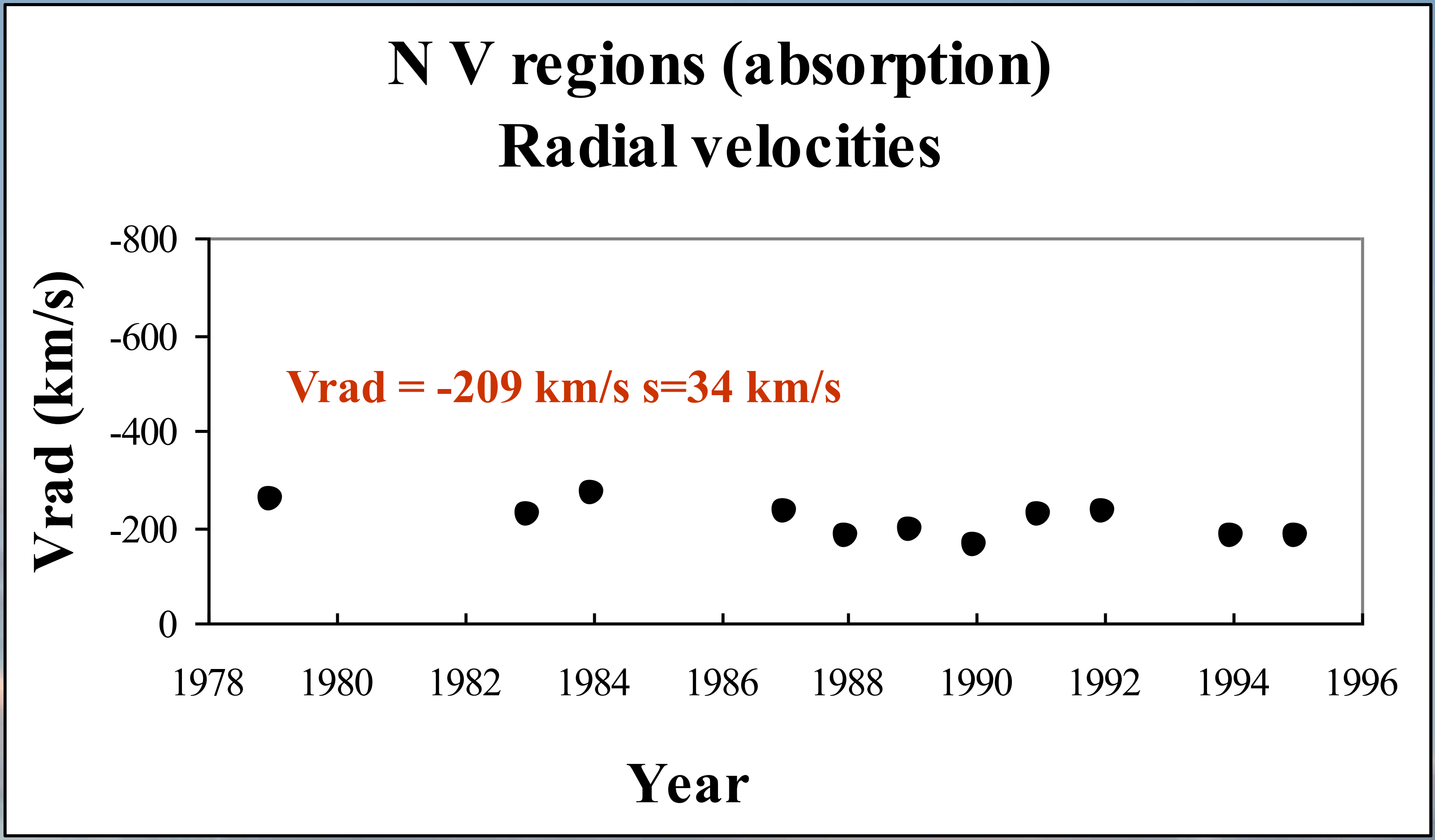
Time scale variation of the Column Density (10^{10} cm^{-2})

The density regions that construct the N V resonance lines λλ 1238.821, 1242.804 Å in the HD 93521 (Oe) UV spectrum

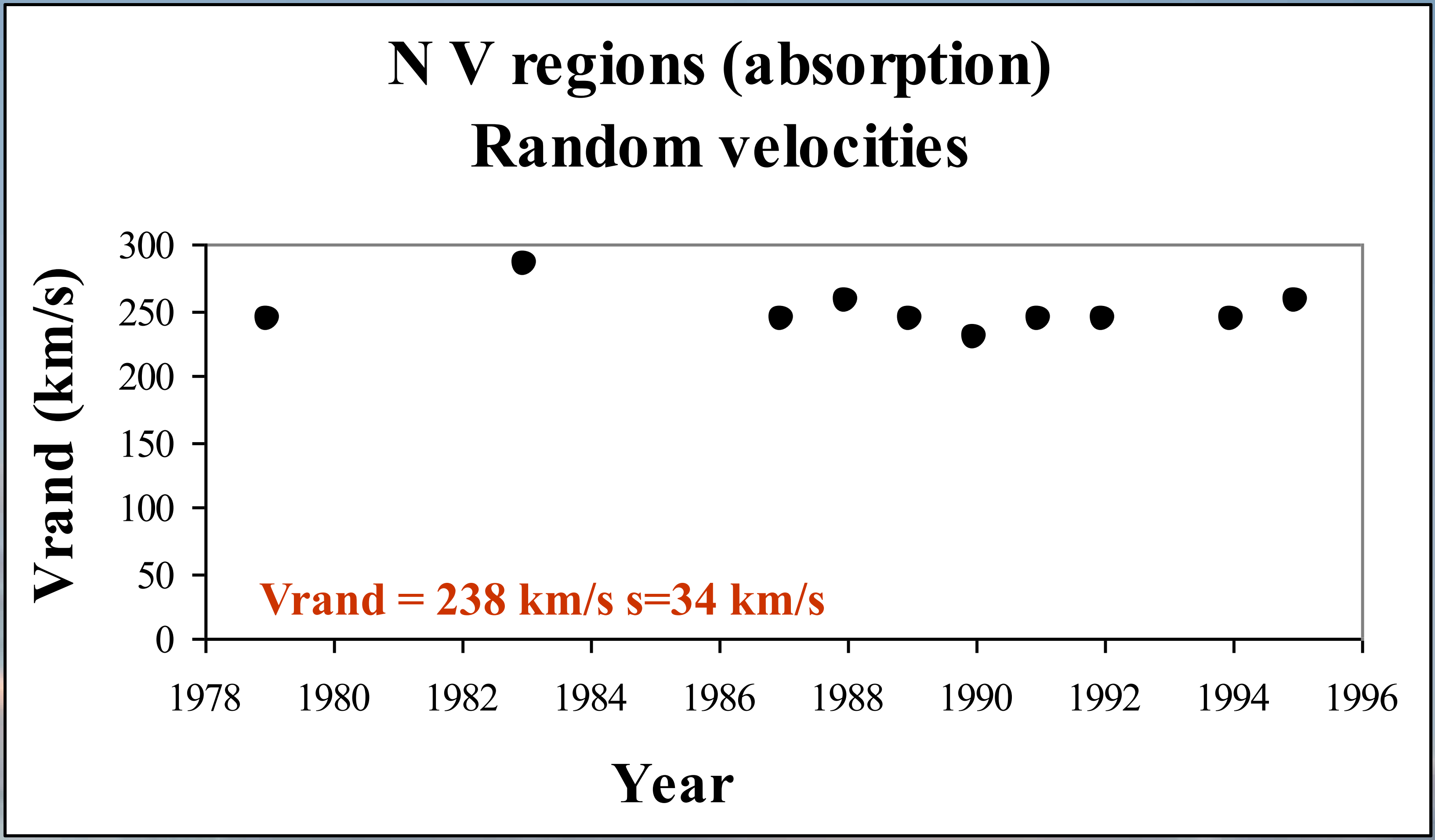
The Oe star HD 93521. The N V region



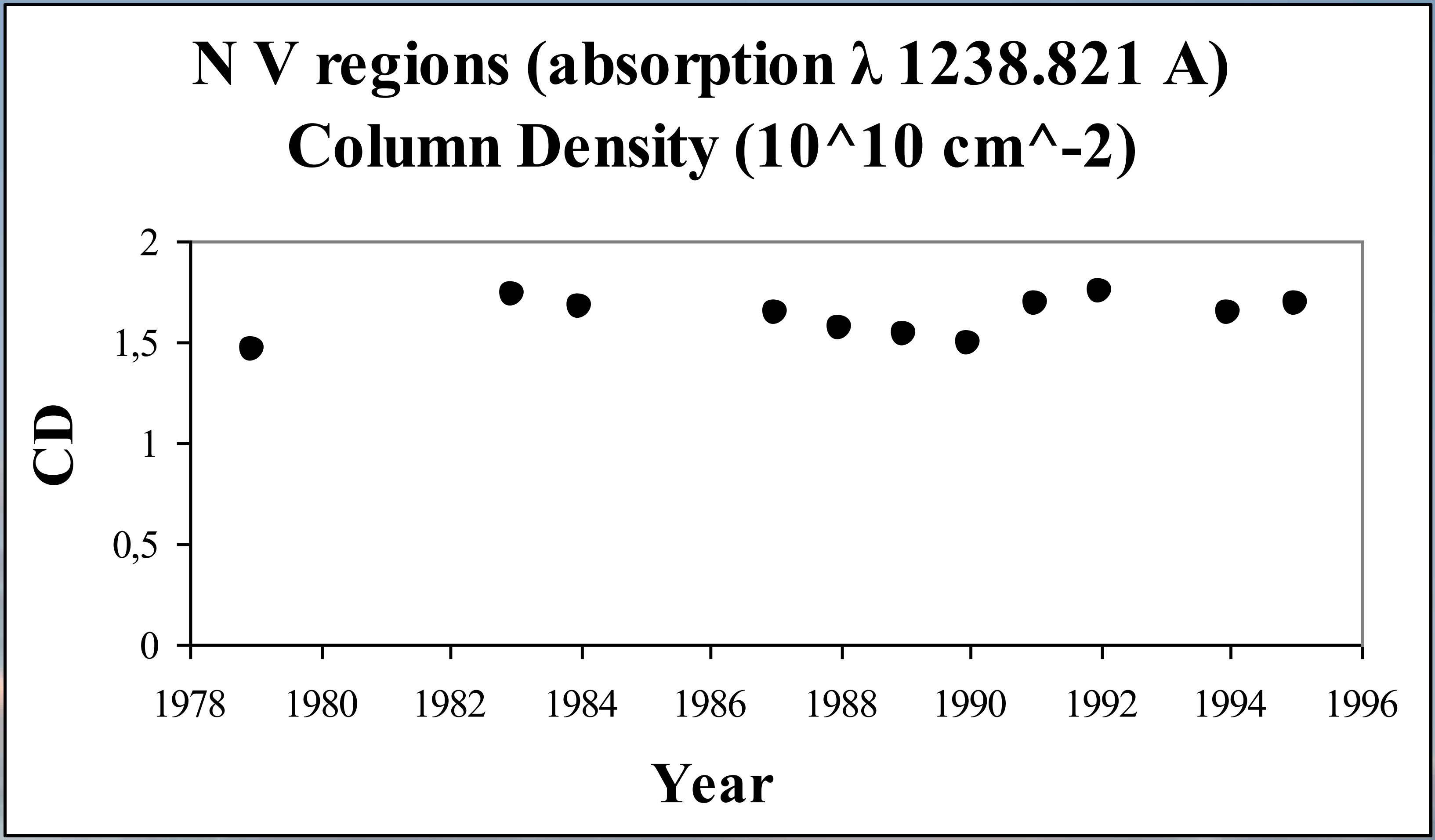
The N V resonance lines consist in an absorption and an emission component. We can feet each one of them with a Gaussian



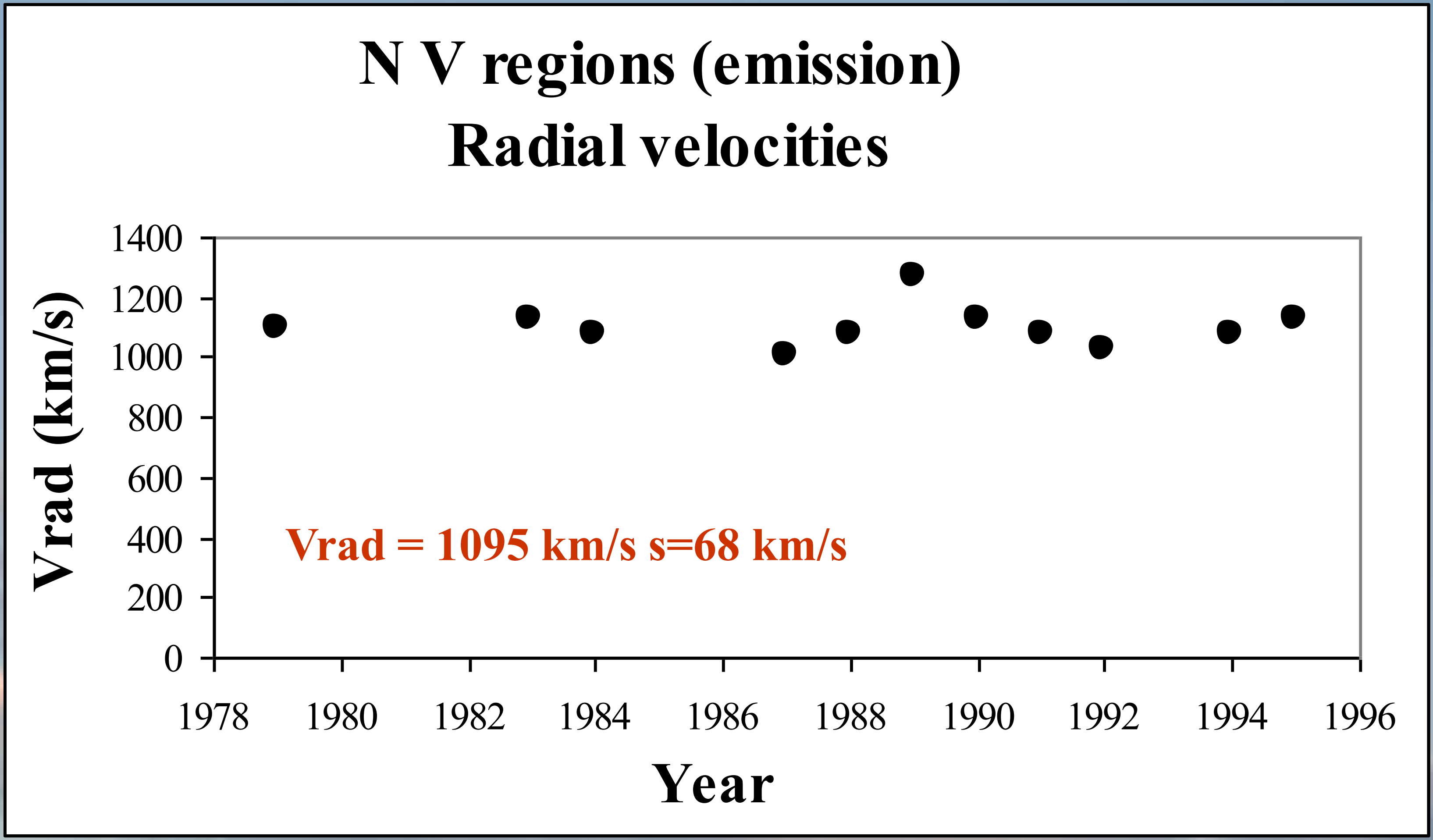
Time scale variation of the absorption component radial velocities (Vrad, km/s)



Time scale variation of the absorption component random velocities (Vrand, km/s)

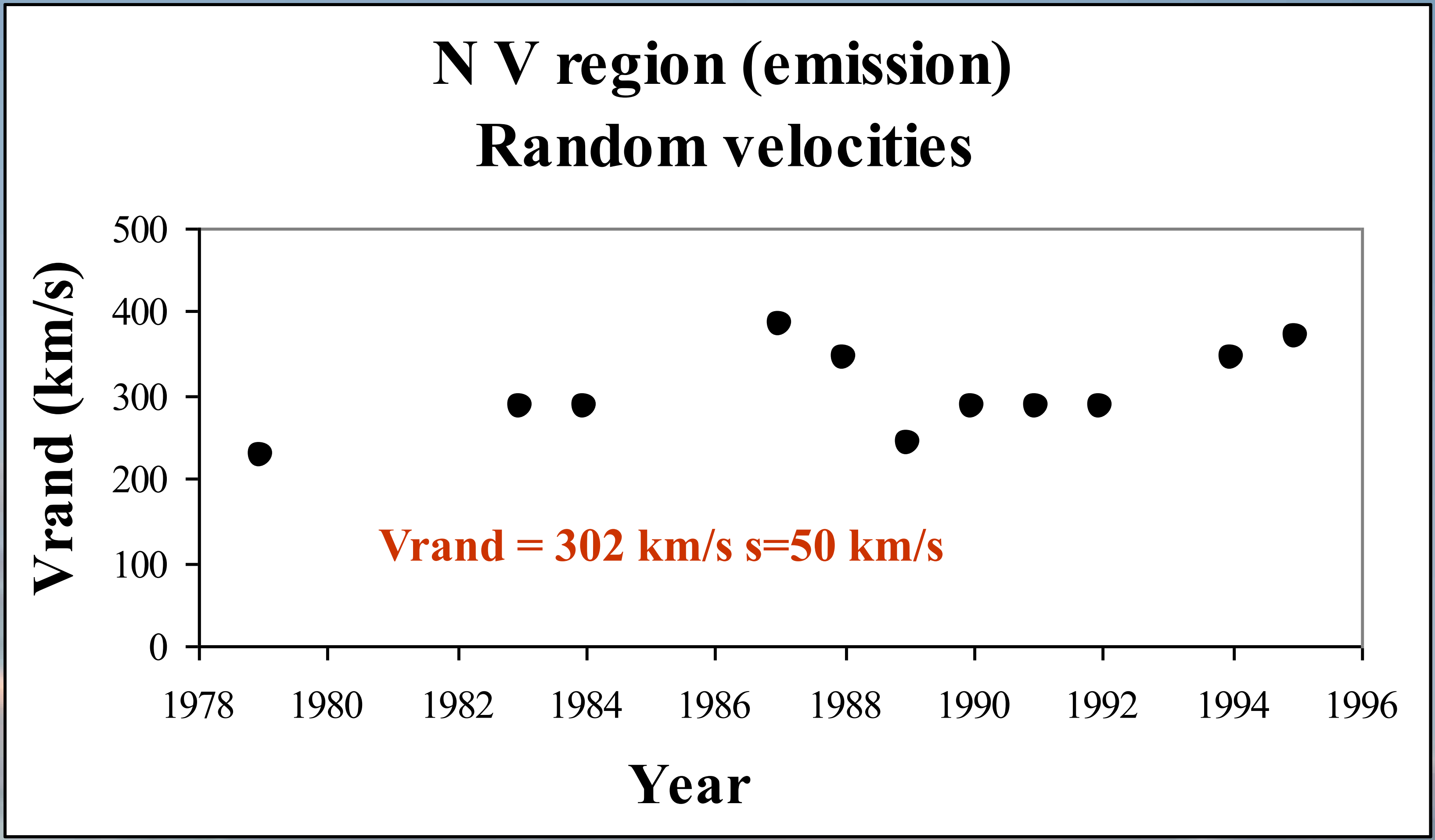


Time scale variation of the absorption component Column Density (10^{10} cm^{-2})

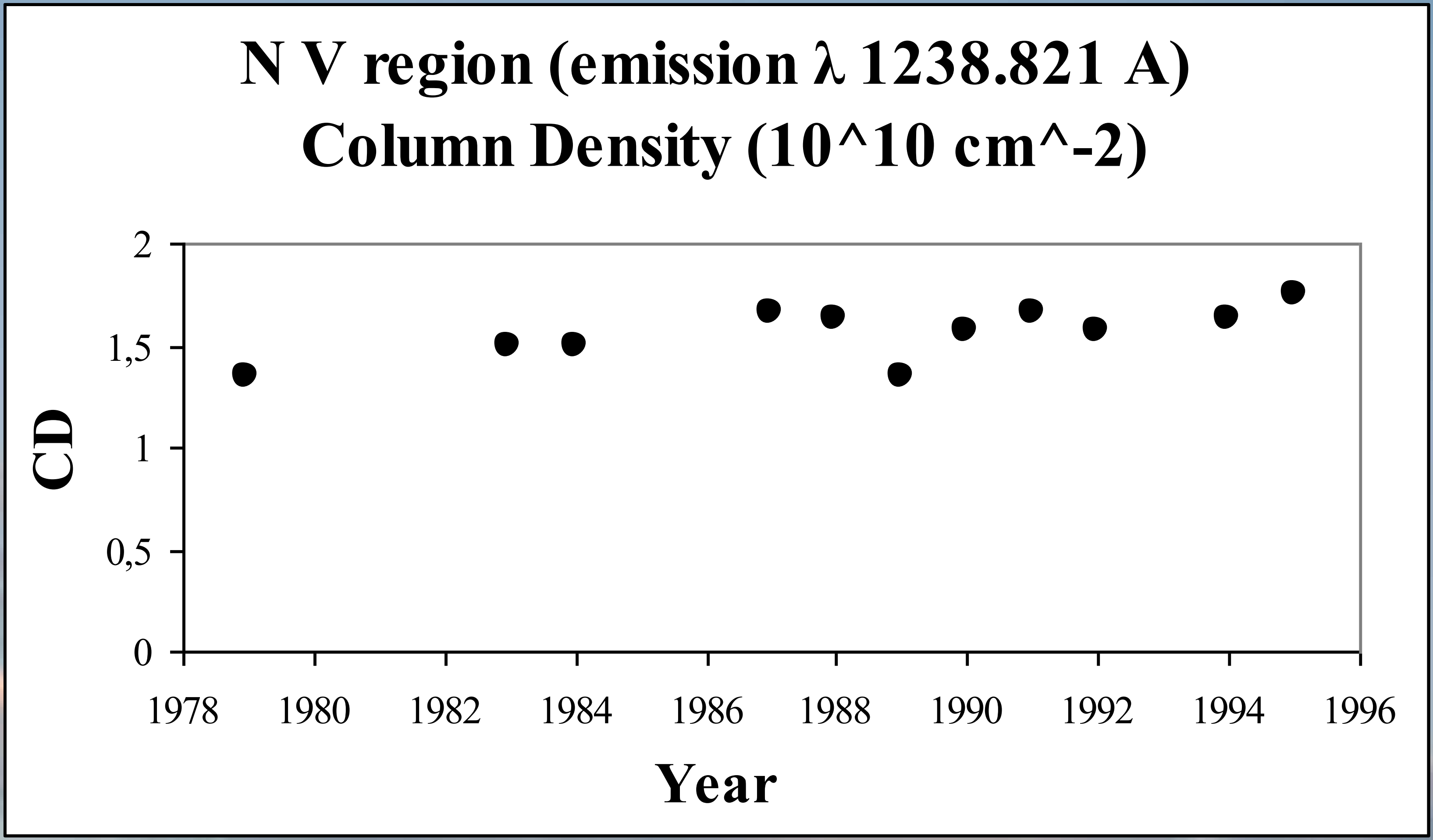


Time scale variation of the emission component radial velocities (Vrad, km/s)

The Oe star HD 93521. The N V region



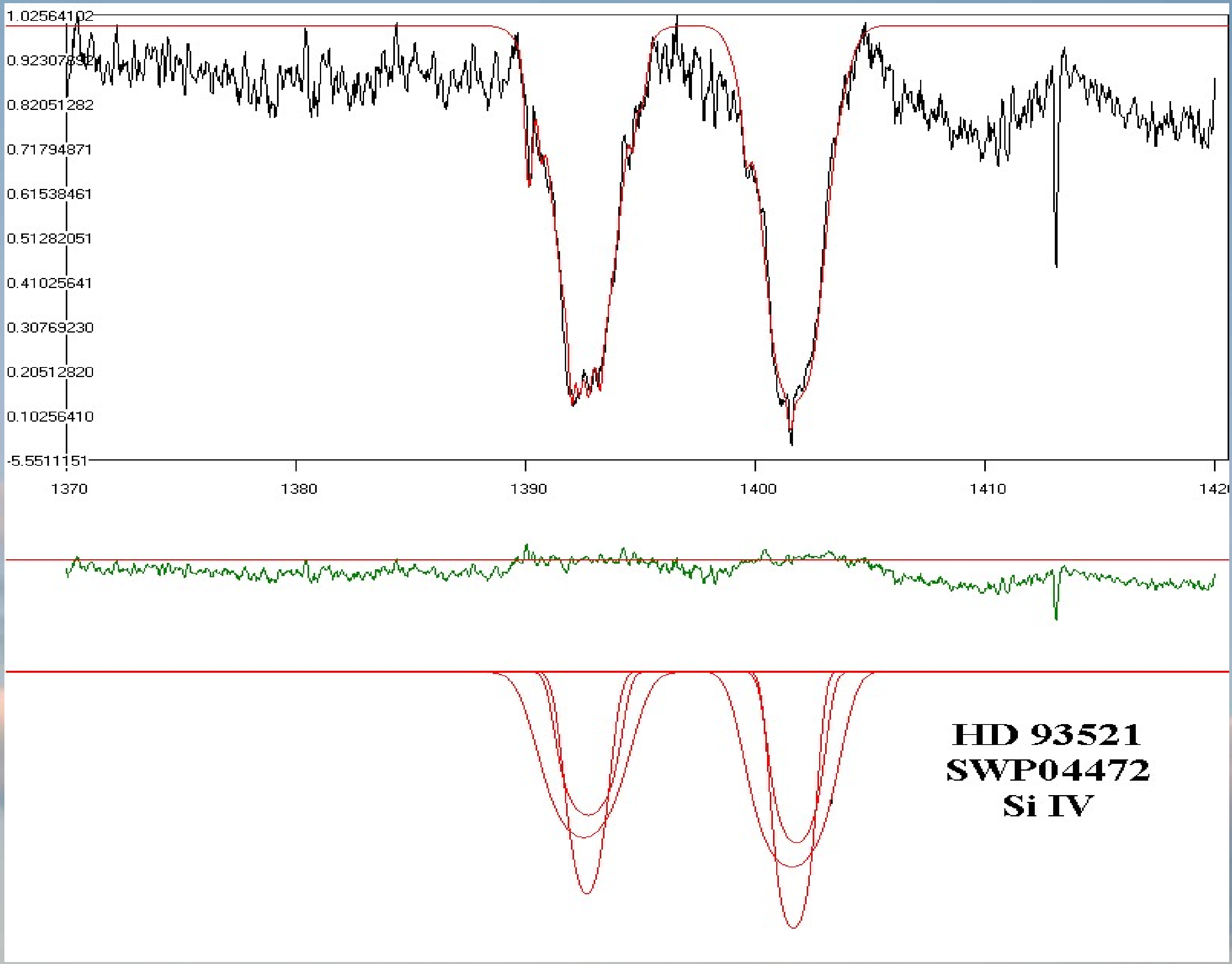
Time scale variation of the emission component random velocities <u>(Vrand, km/s)</u>



Time scale variation of the emission component Column density (10^{10} cm^{-2})

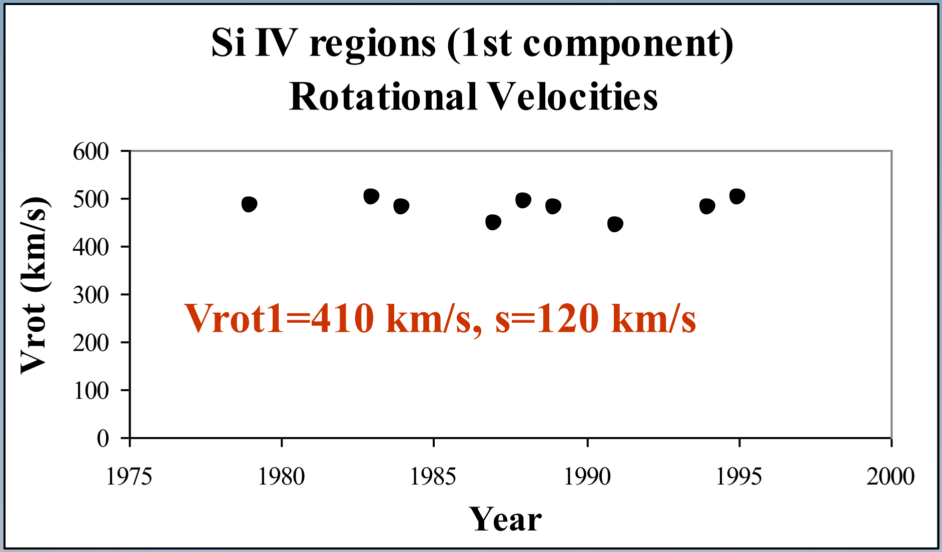
The density regions that construct the UV Si IV resonance lines λλ 1393.755, 1402.770 Å in the HD 93521 (Oe) UV spectrum

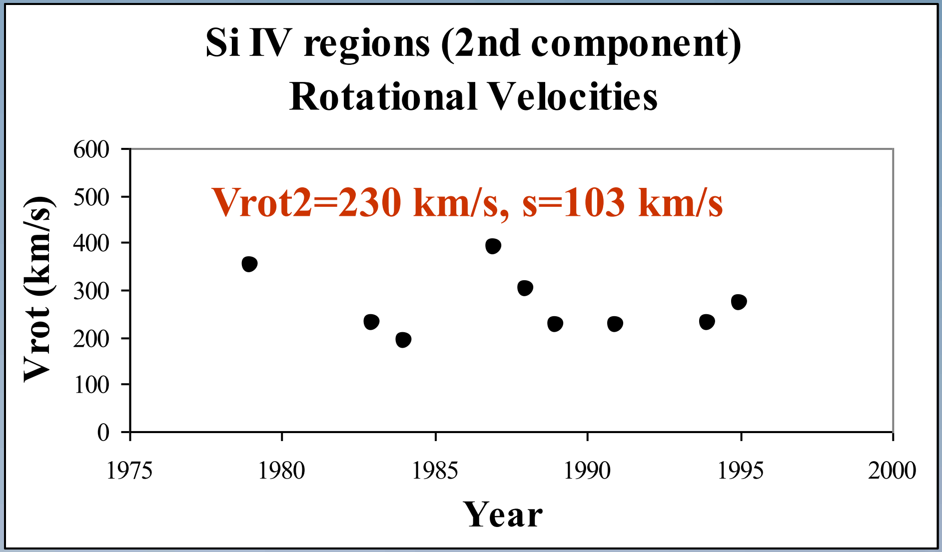
The Oe star HD 93521. The Si IV region

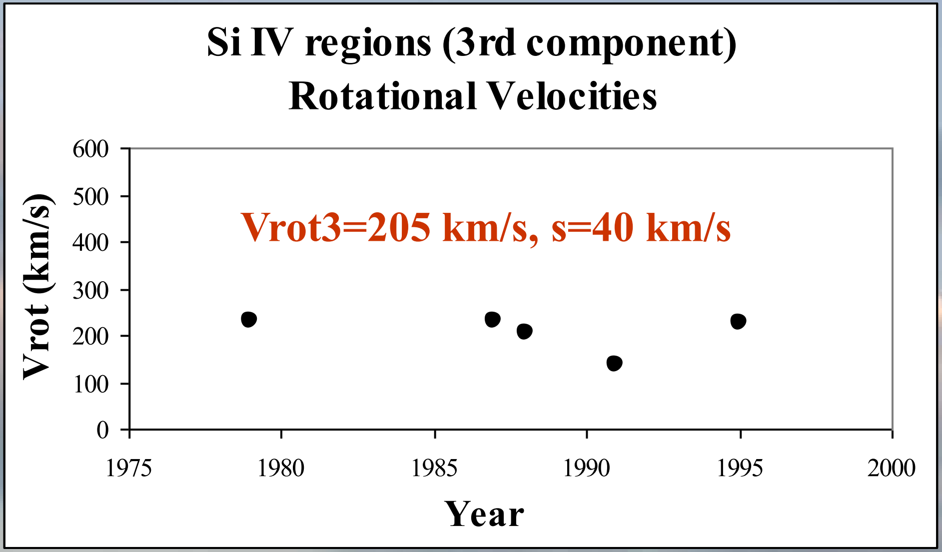


In this figure we can see the complex structure of UV Si IV resonance lines. Each one of them consists in three components

The Oe star HD 93521. The Si IV region

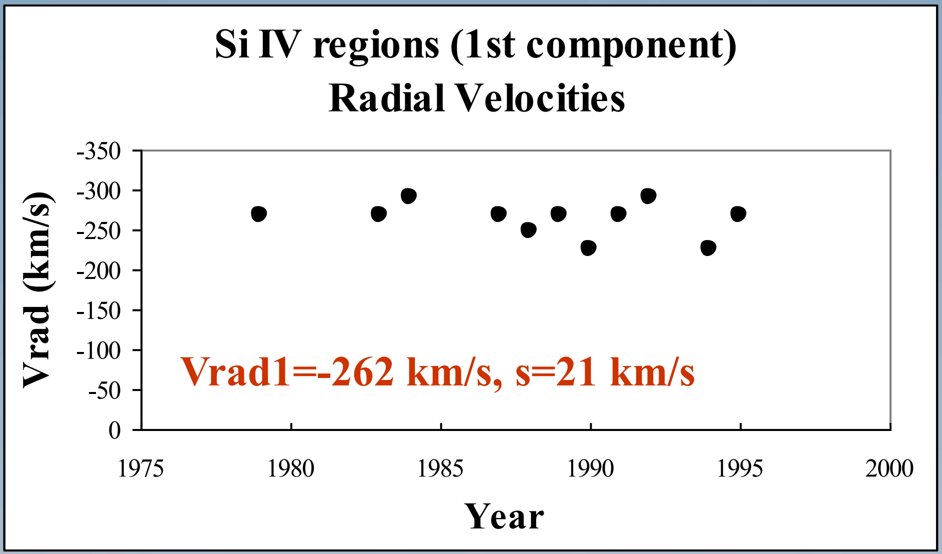


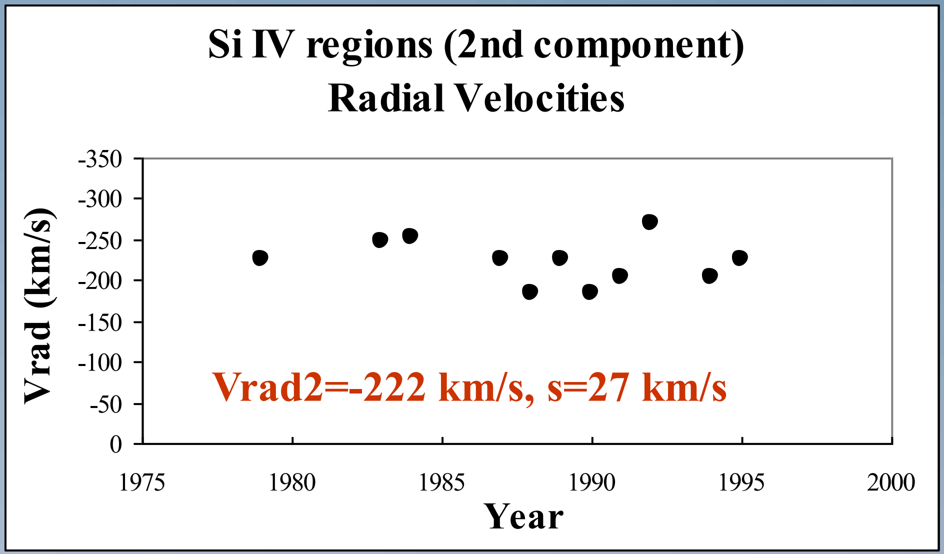


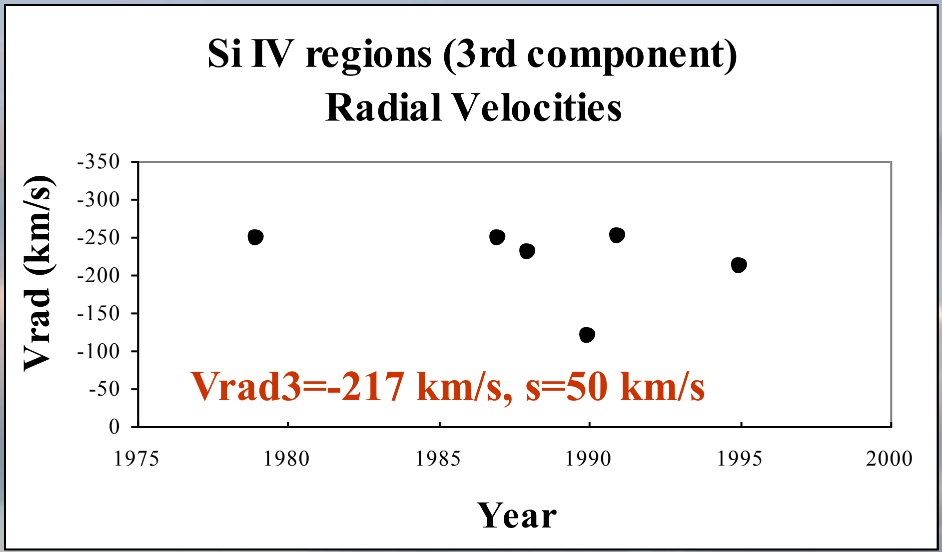


Time scale variations of Rotational Velocities (Vrot) for the three components

The Oe star HD 93521. The Si IV region

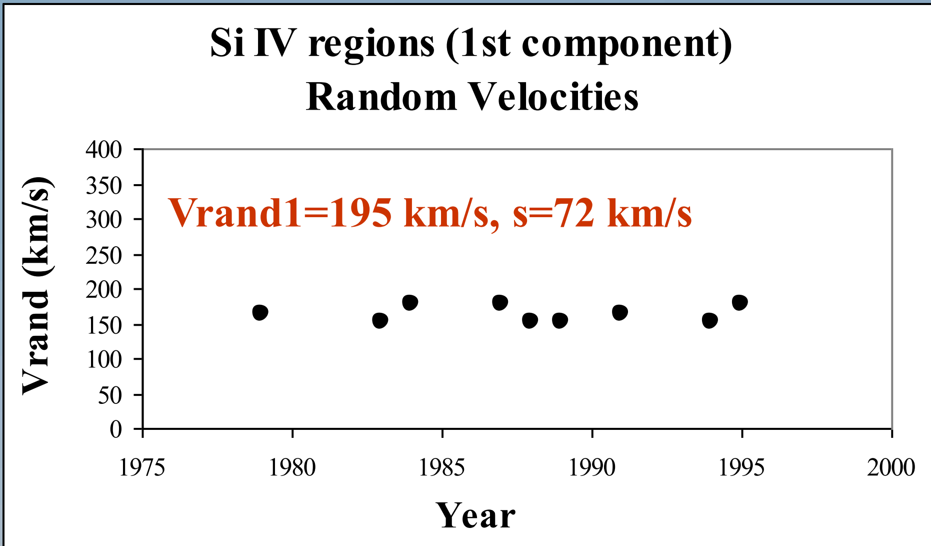


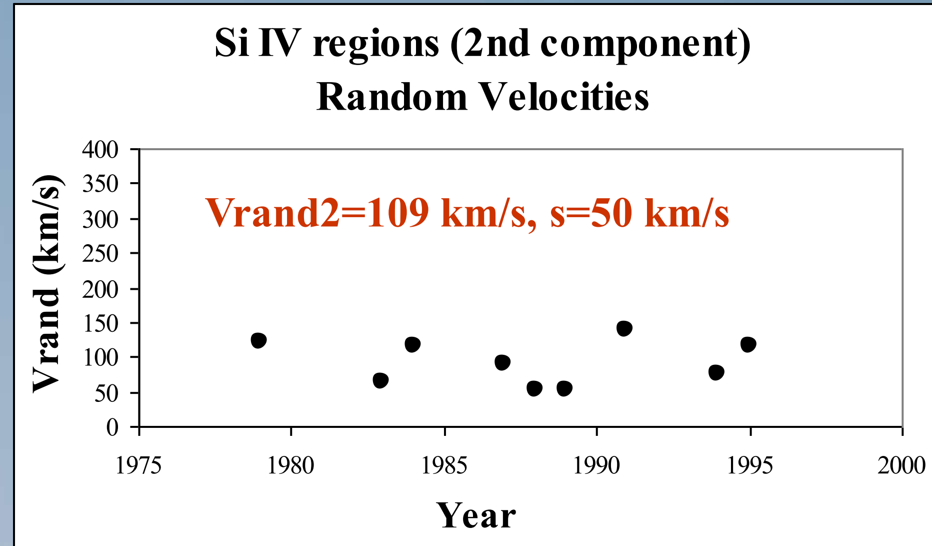


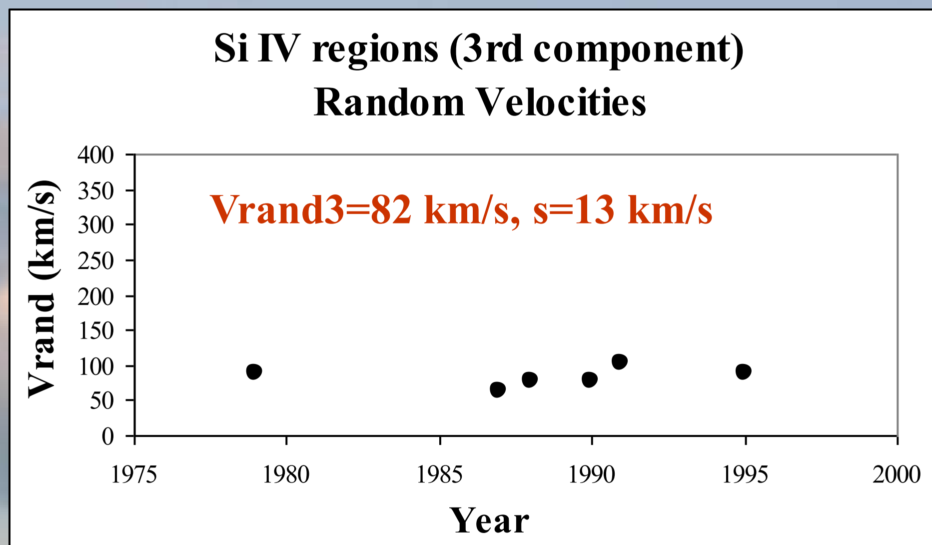


Time scale variations of Radial Velocities (Vrad) for the three components

The Oe star HD 93521. The Si IV region

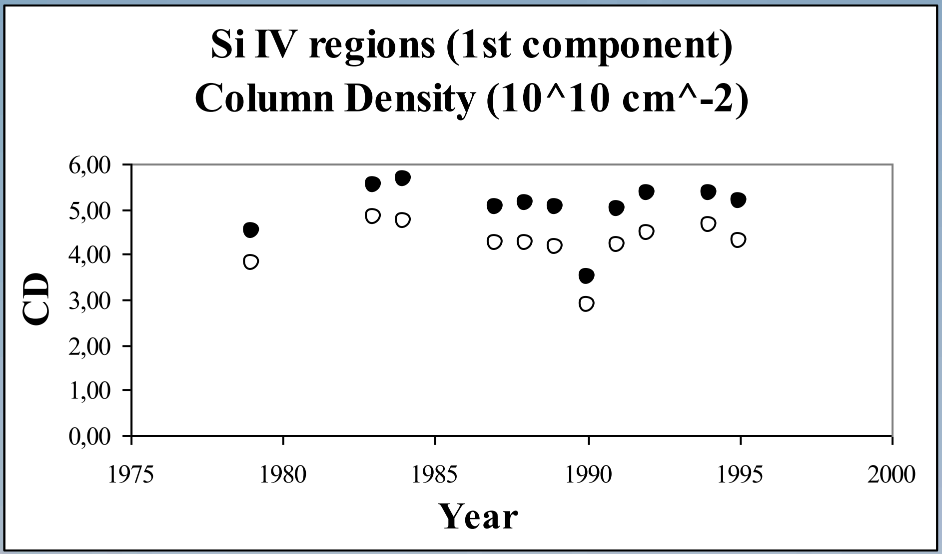


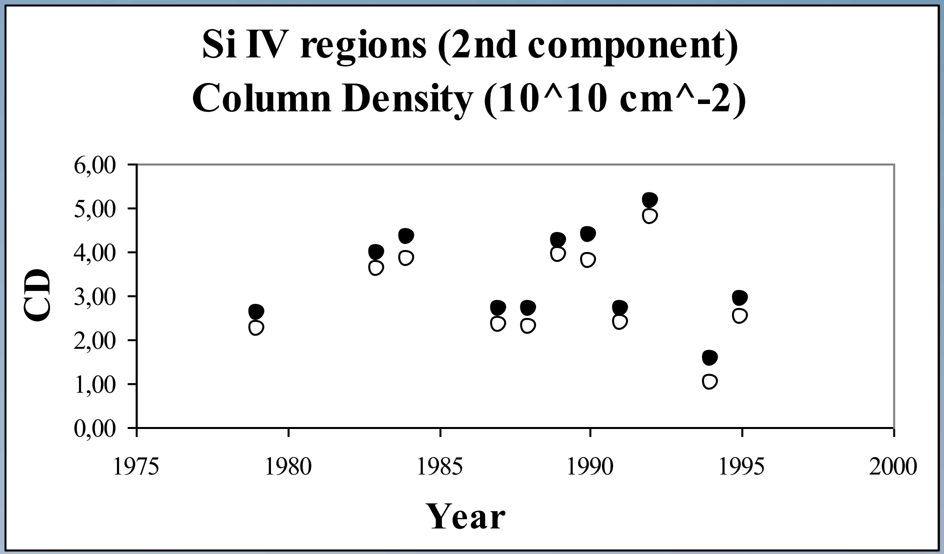


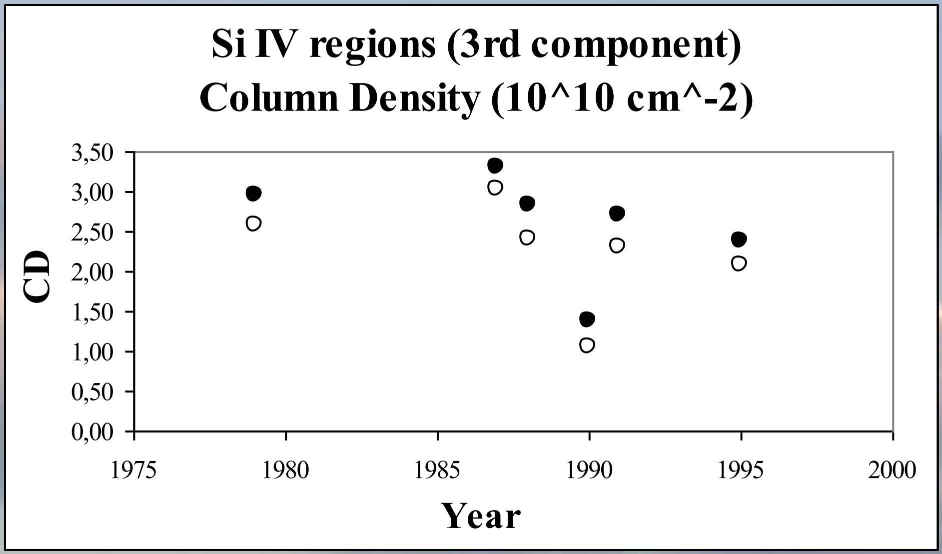


Time scale variations of Randon velocities (Vrand) for the three components

The Oe star HD 93521. The Si IV region







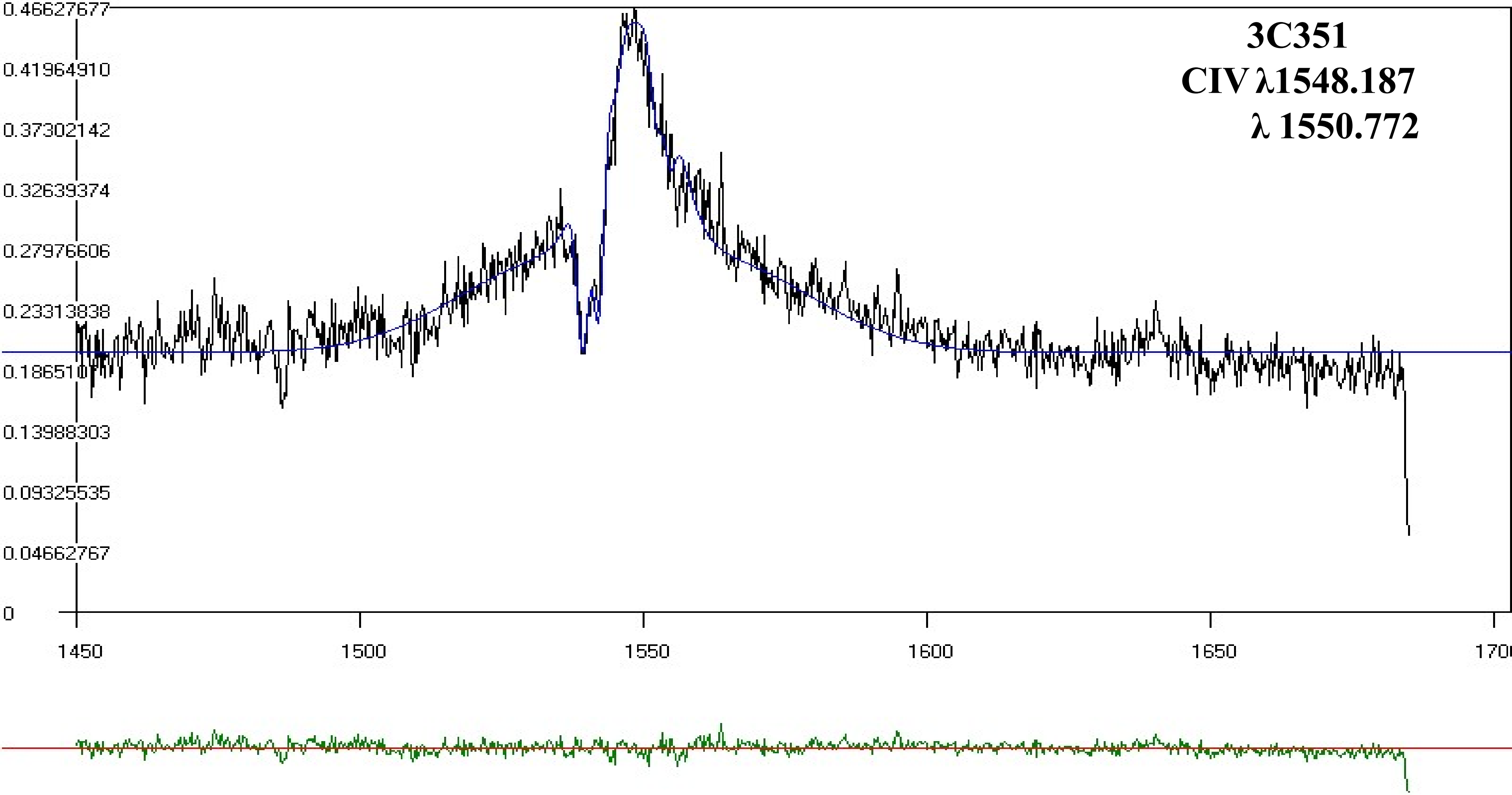
Time scale variations of Column Density for the five components (10^{10} cm^{-2})

Fitting some AGNs spectral lines

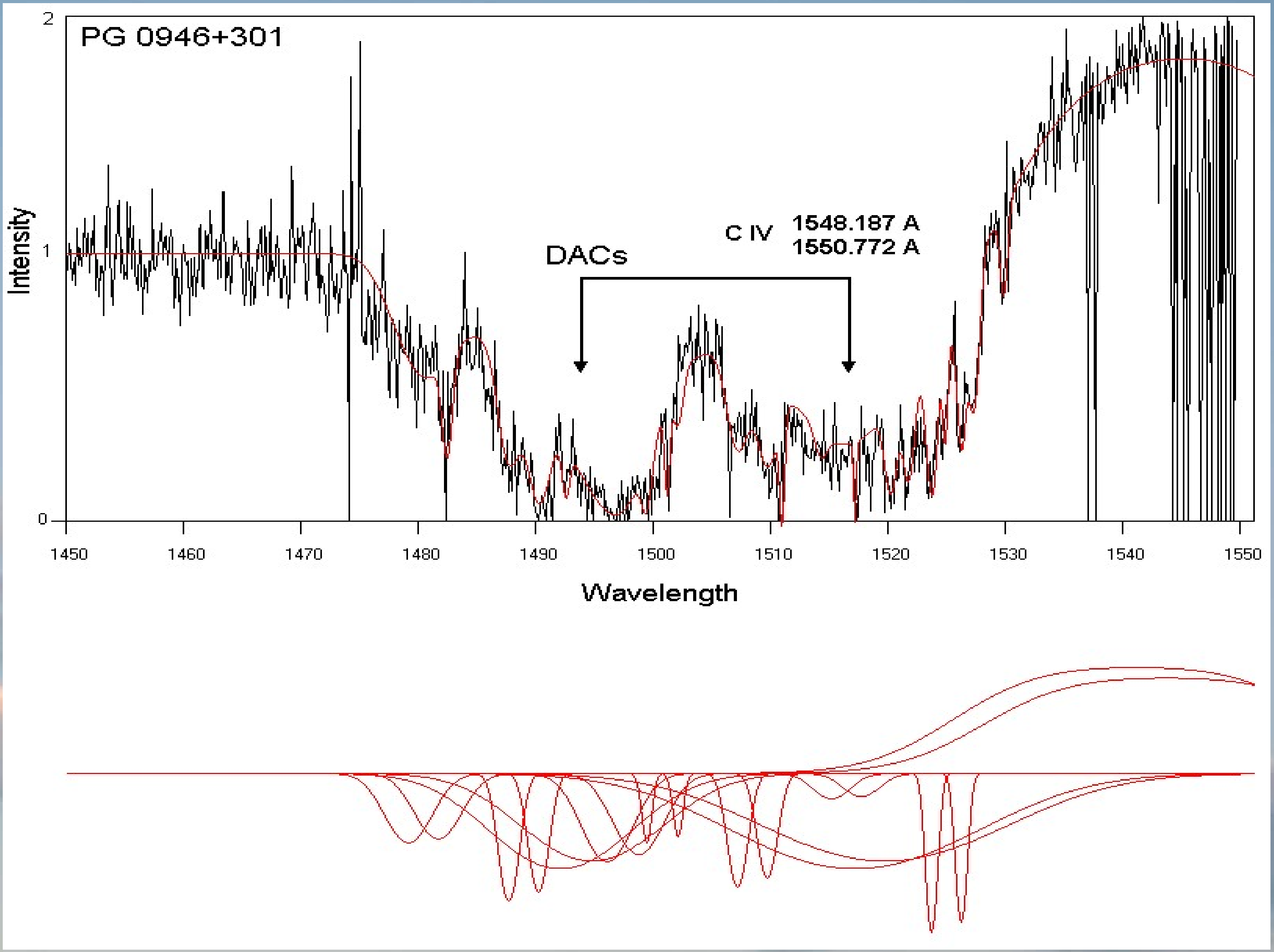
The present work of our scientific group is to study the complex structure of some AGNs spectral lines with the proposed model in order to understand the origin of DACs and SACs phenomena.

Some days before, Dr Chatzichristou presented some first ideas about this problem

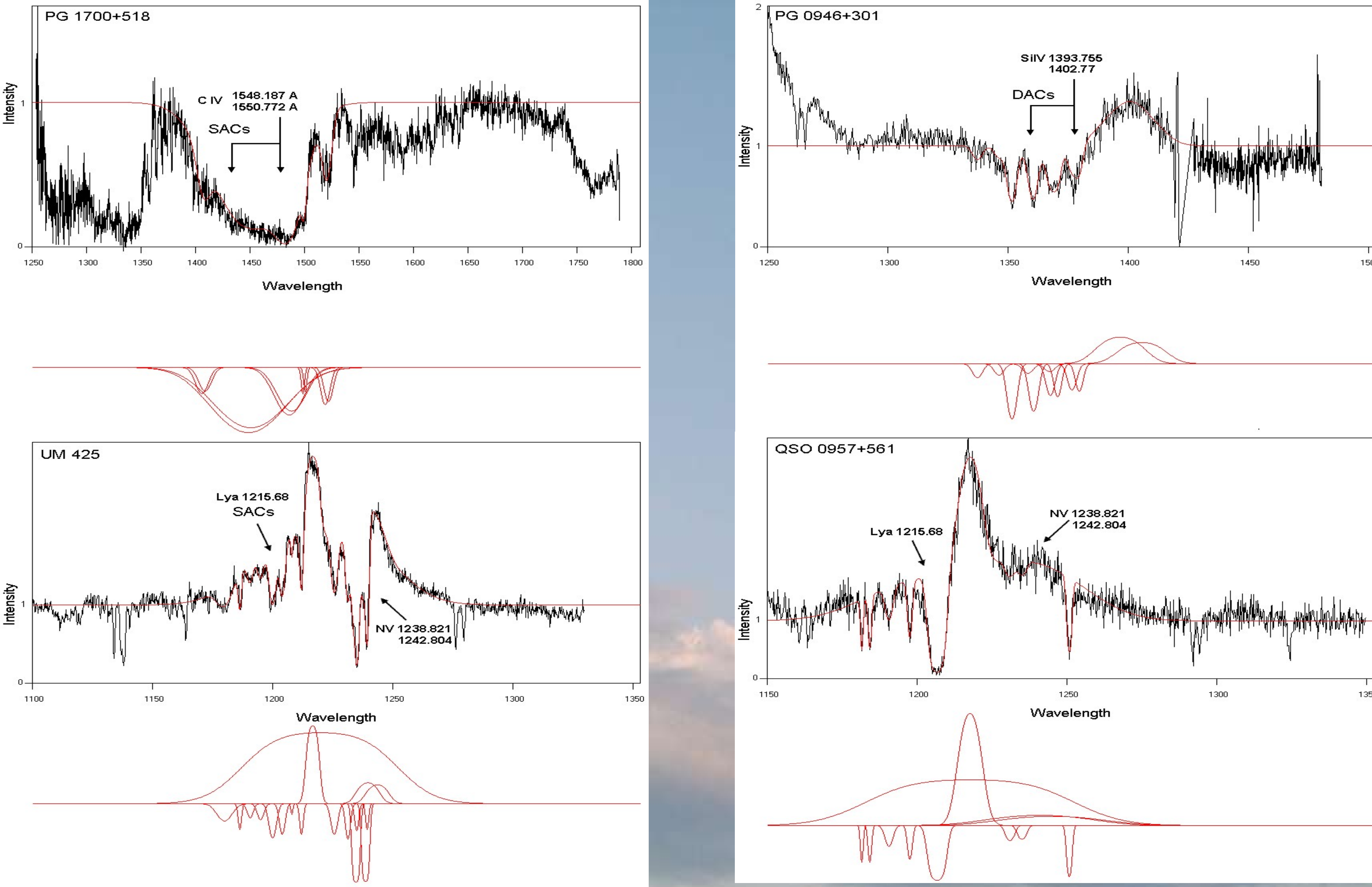
In the following figures we present fits of some AGNs complex spectral lines.



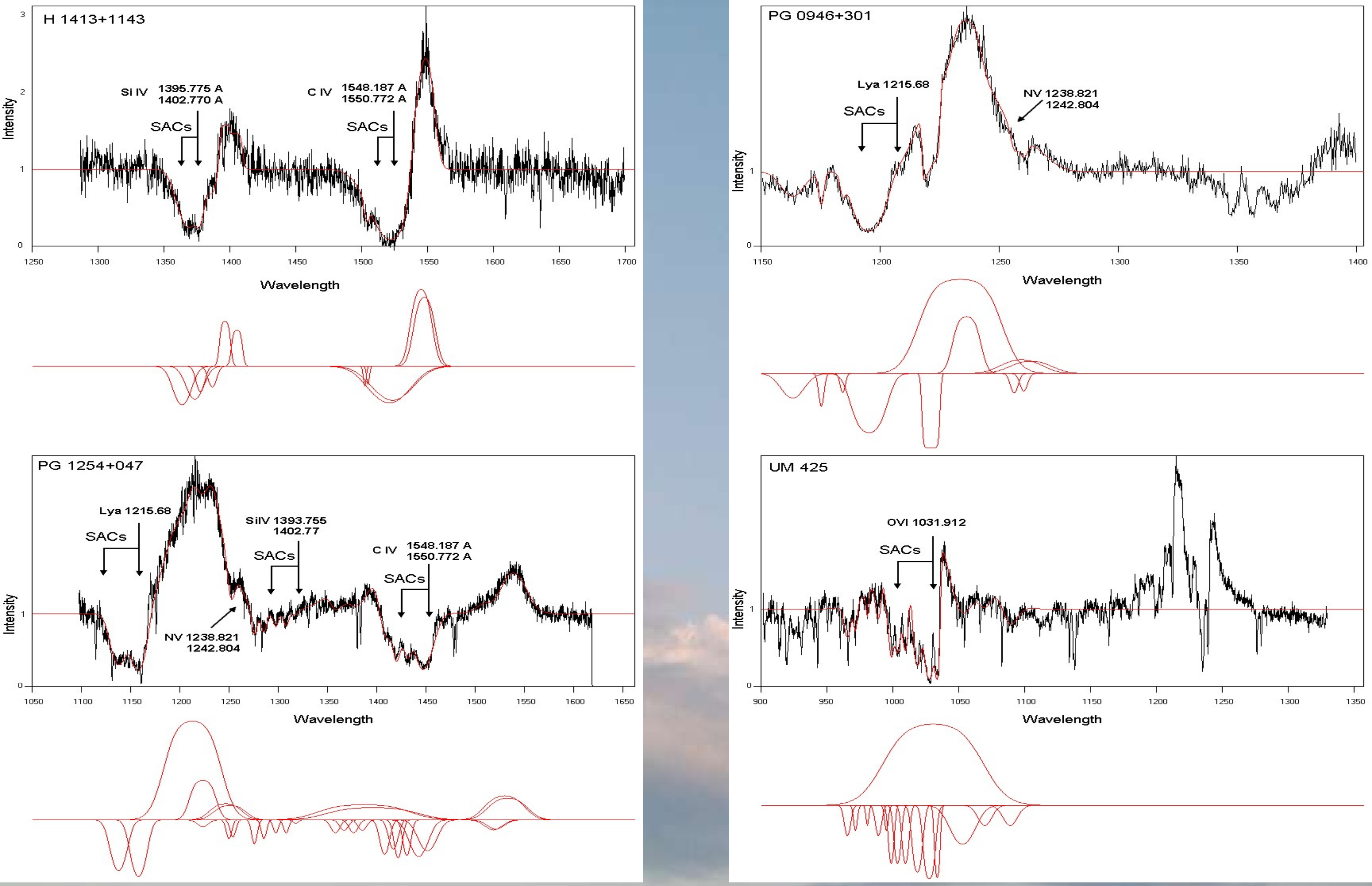
The fit of C IV resonance lines (λλ 1548.187, 1550. 772 Å) with the proposed model. The green line indicates the difference between the observed and the theoretical line profile.



In this figure we can see the fitting of the C IV UV doublet of an AGN (PG 0946+301) that presents DACs, with the proposed model.



In these figures we can see the fitting of some AGN spectral lines that present SACs, with the proposed model.



In these figures we can see the fitting of some AGN spectral lines that present SACs, with the proposed model.

Conclusions

1. Using the proposed model, we can calculate the values of some parameters such as the rotational, the random and the radial velocities, the FWHM, the optical depth, the absorbed or emitted Energy, the Column Density and the Gaussian Standard Deviation, as well as the relation among them. This means that now we can try to understand the mechanism that is responsible for the DACs or SACs phenomenon.

2. The acceptance of SACs and DACs phenomena as the reason of the spectral lines complex structure lead us to accept smaller broadening, FWHM, optical depths, column densities and different rotation, radial and random velocities, because now the idea is that the complex line shape does non present a single spectral line, but a group of satellite components (DACs or SACs). From these new ideas we have taken different values of the parameters that, (perhaps) lead us to a different mechanism for the construction of the density regions that produce the DACs or SACs regions.

3. The detected time scale variation of the parameters values in the C IV, N IV, N V and Si IV density regions in the UV spectrum of the Oe star HD 93521 indicates that the radial, rotational and random velocities, the column densities, and the optical depths present only small variations.

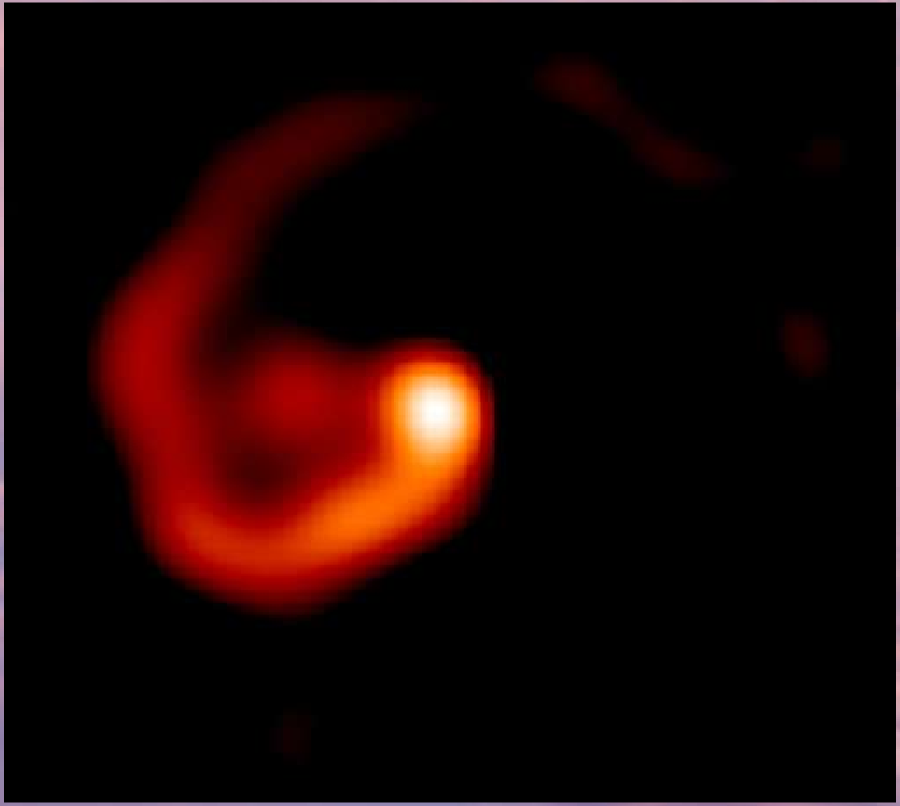
This fact lead us to accept that matter which creates DACs or SACs remains practically stable during the studied period of 18 years.

An other explanation of this phenomenon is that in the area where we can detect high density regions, matter flows, and only the physical properties (conditions) which lead to high density, remain stable (for example magnetic fields or shocks from a companion in the case of a binary system).

But the main questions remain………

1. *What is the origin and the mechanism that permit the periodic ejection of mass from the equator of rapidly rotating Hot Emission Stars?*
2. *What is the origin and the mechanism responsible for the construction and the long time stability of density regions that produce DACs and SACs phenomena and lie in the ejected matter?*

These great questions and many others that arise from the study of hot emission stars and AGNs with the proposed model, wait for future answers.



Thank you very much for your attention