Studying the peculiar and complex line profiles in the spectra of hot emission stars and quasars

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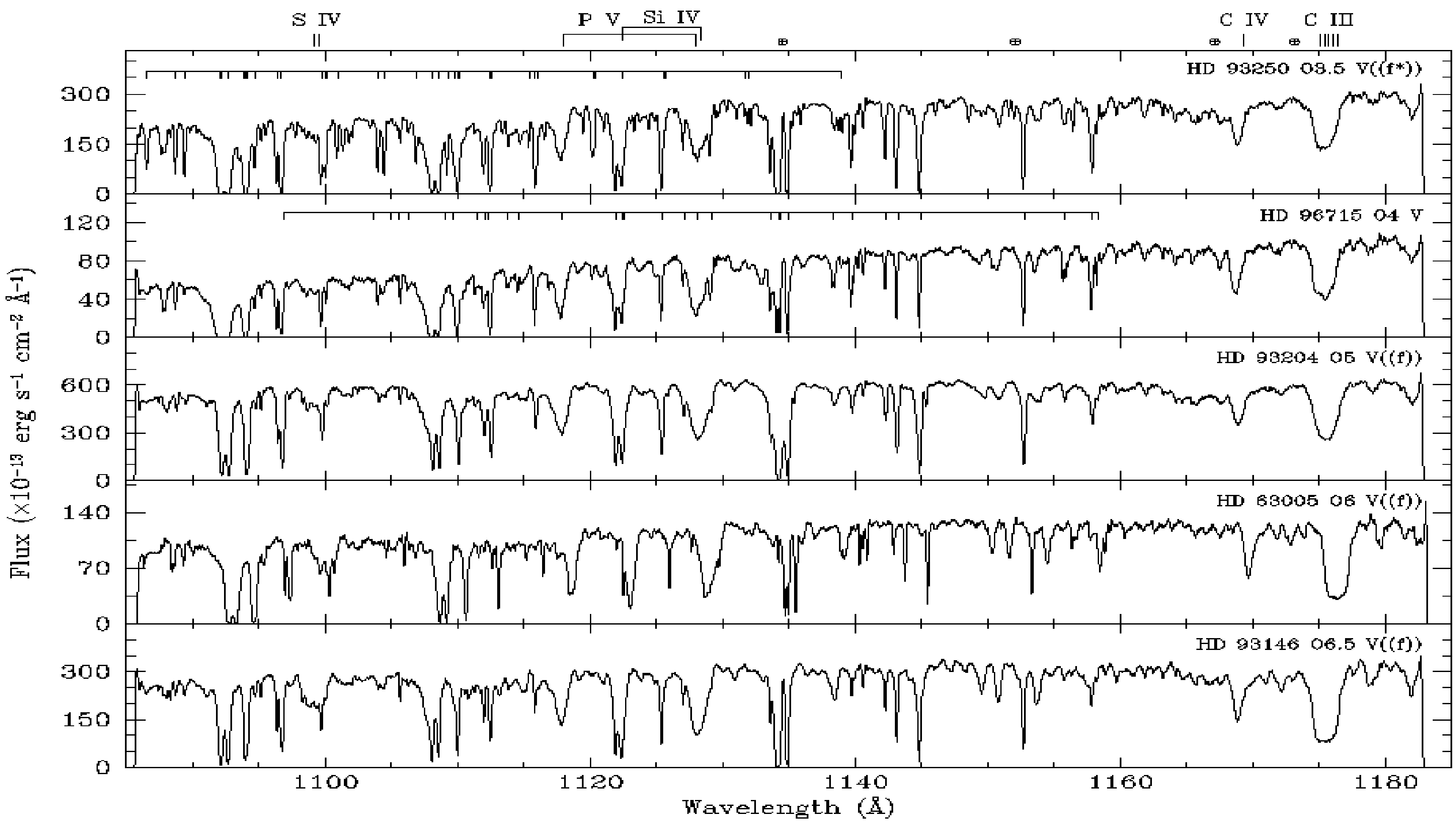
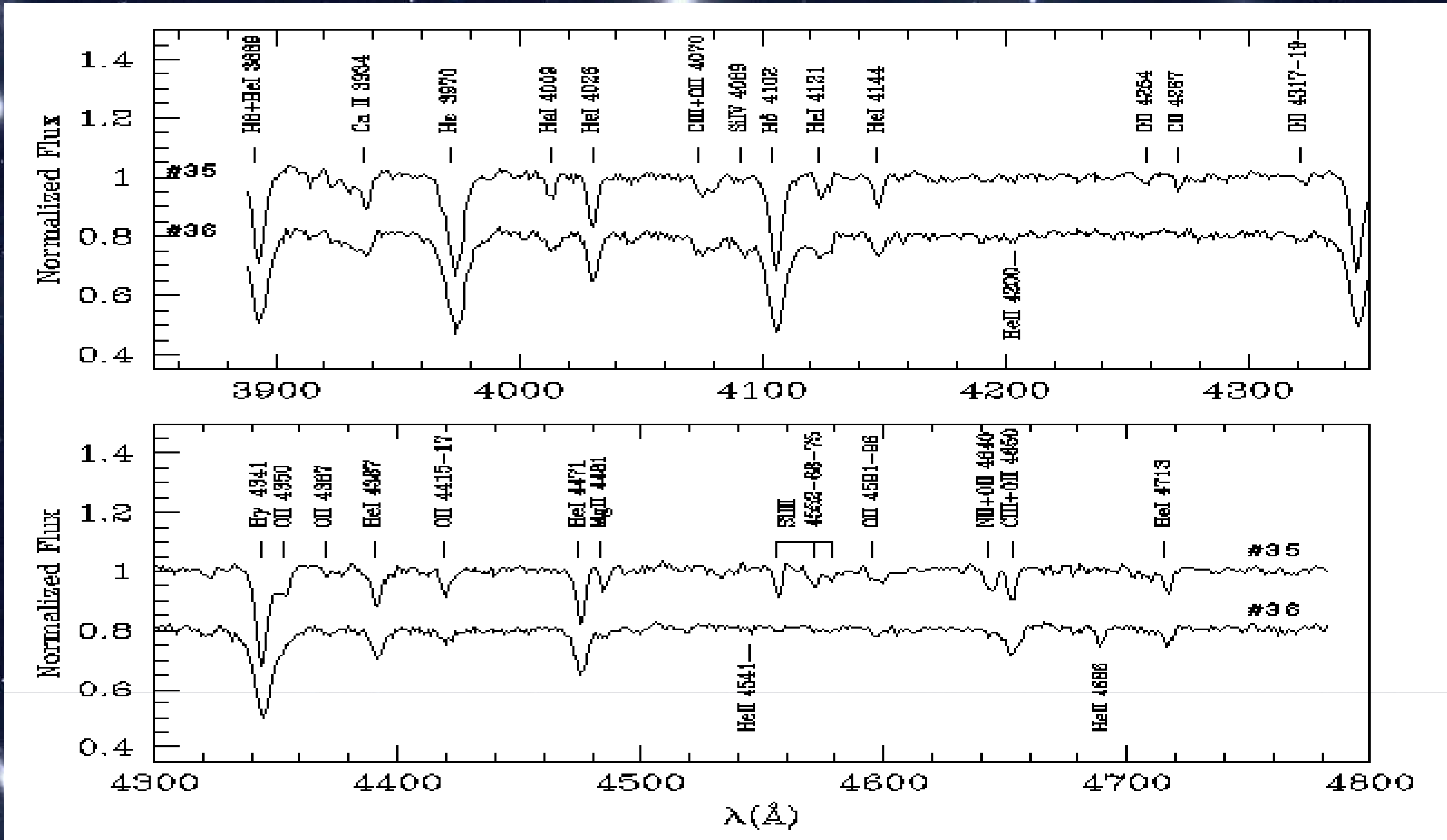
This presentation is only a global view of the problems that we detect in the plasma around some hot emission stars and quasars that present complex and peculiar profiles

In the following presentations we will analyze and discuss many interesting points of these problems

All the stars of the same spectral type and luminosity class present the same absorption lines in their spectra

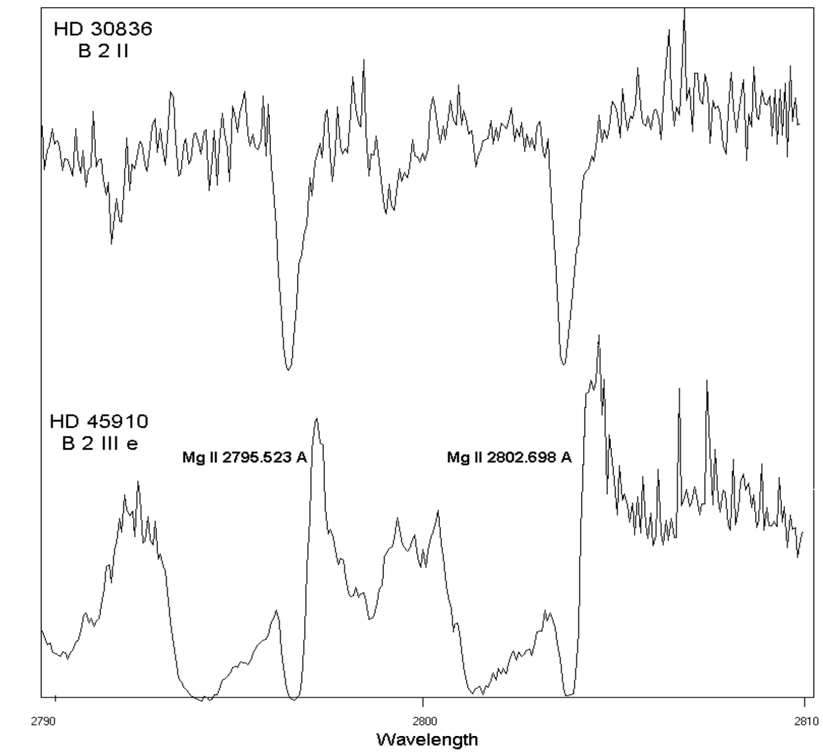


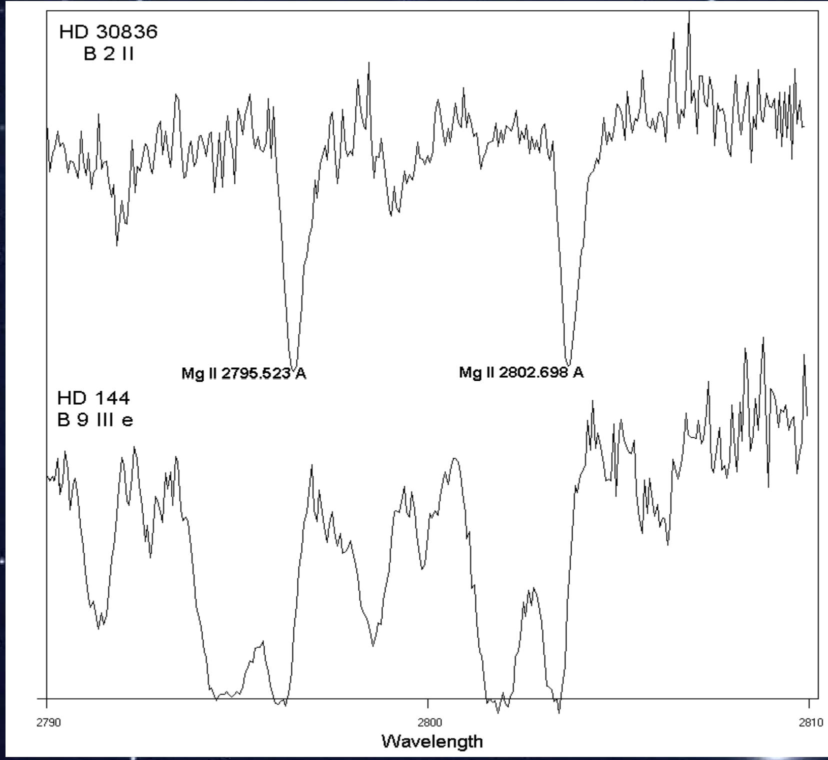


Two Be stars of the same luminosity class present the same absorption lines in their spectra

All the Stars…?

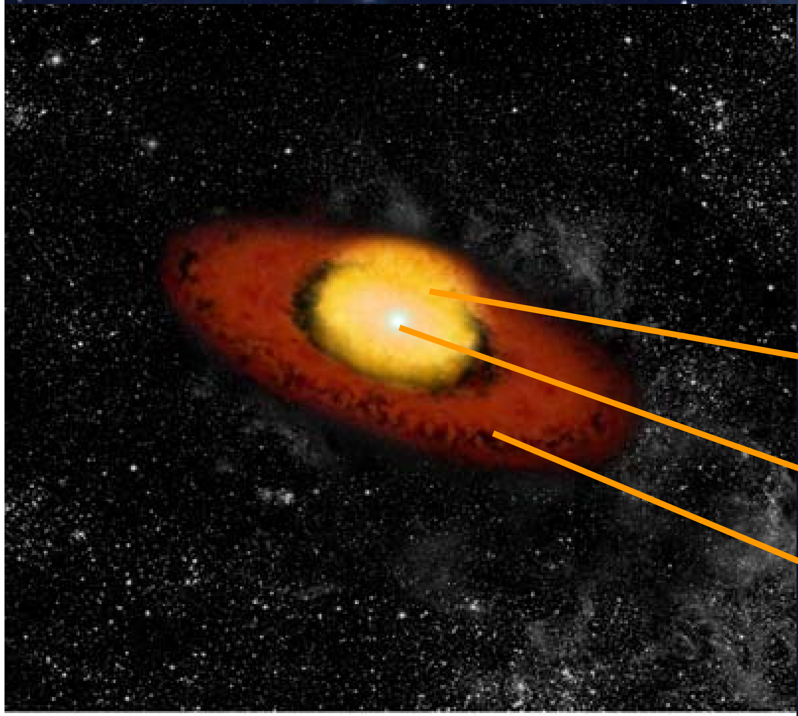
In the UV spectral region, some hot emission stars (Oe and Be stars) present some absorption components that **should not appear** in their spectra, according to the classical physical theory.





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. As we can observe the Be stars present some absorption components that do not appear in the spectrum of the classical B star.

Hot emission stars environment



The B[e] Supergiant CPD-57°2874 (Artist View)

ESO PR Photo 36b/05 (November 24, 2005) © ESO

spherical envelope around hot emission stars

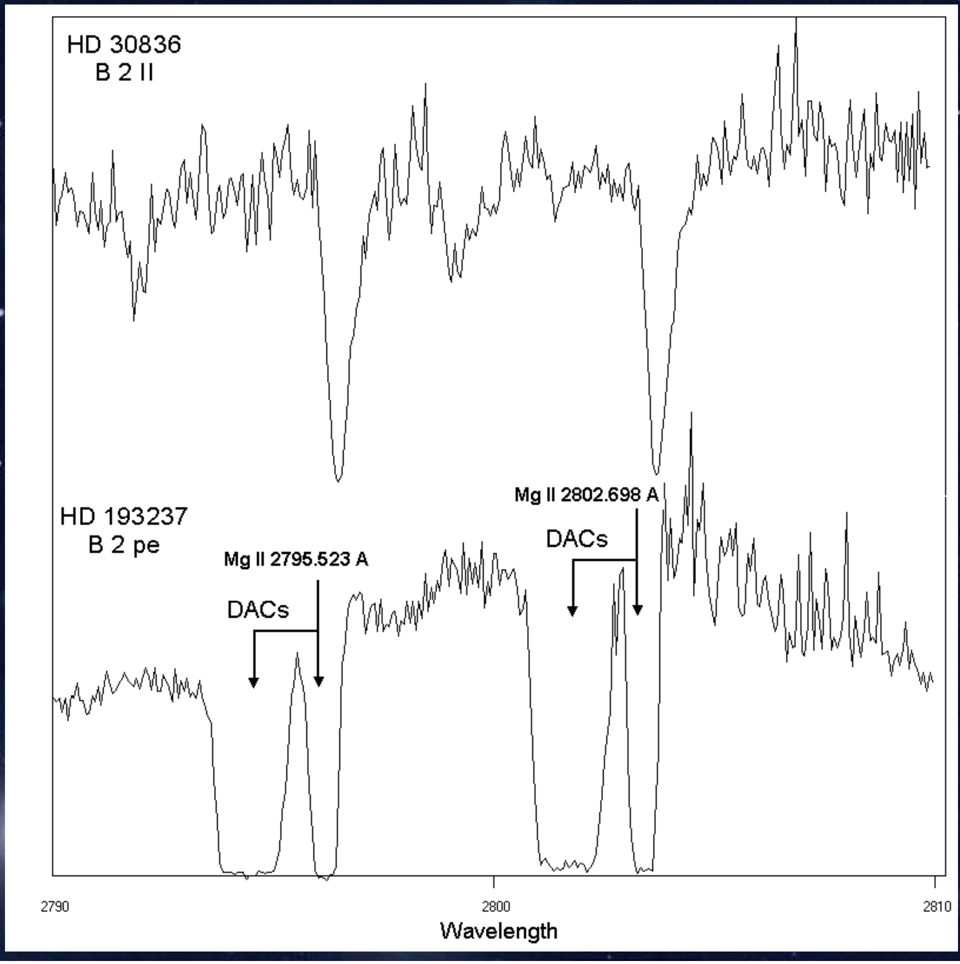
the hot emission star

the disc around the stars

In the case of hot emission stars we call the absorption spectral lines that do not correspond to any known absorption line of the same spectral type stars **DACs**

(Discrete Absorption Components)

(Bates & Halliwell 1986 MNRAS)

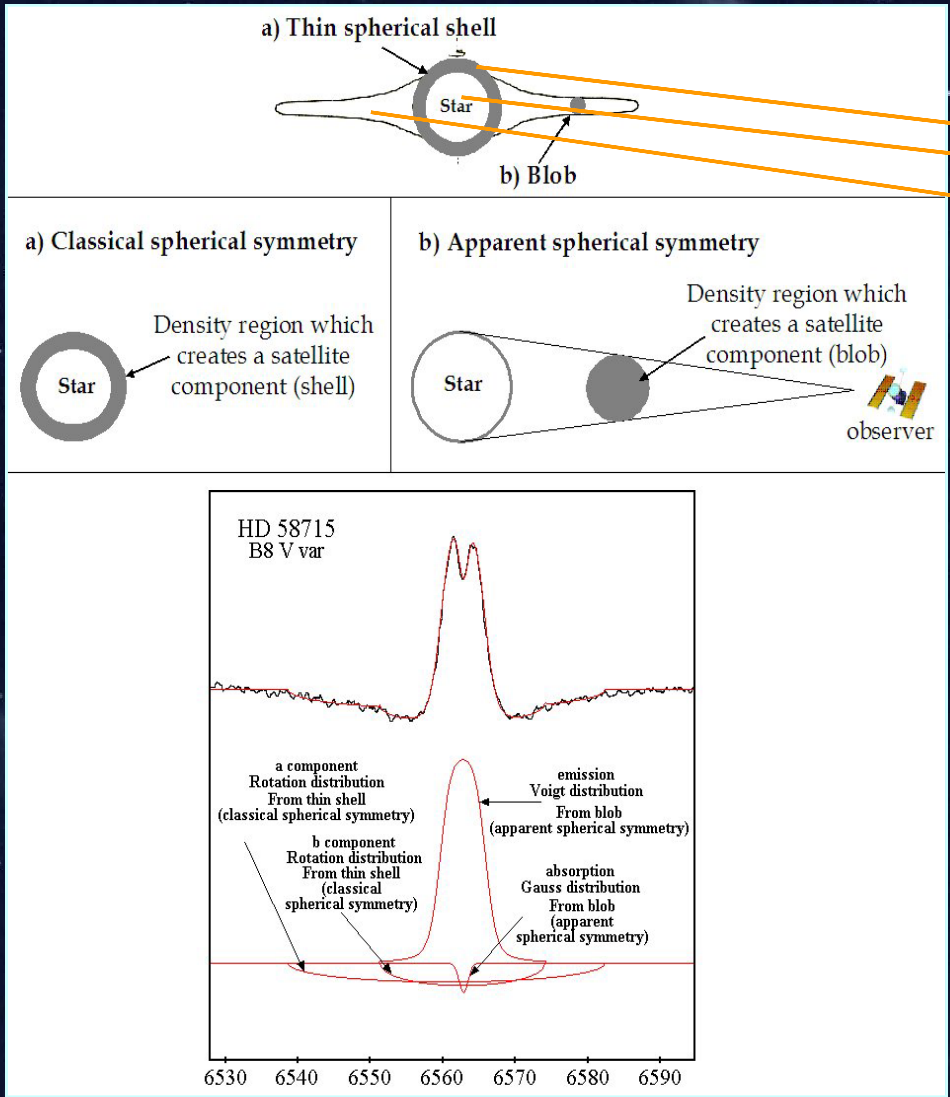


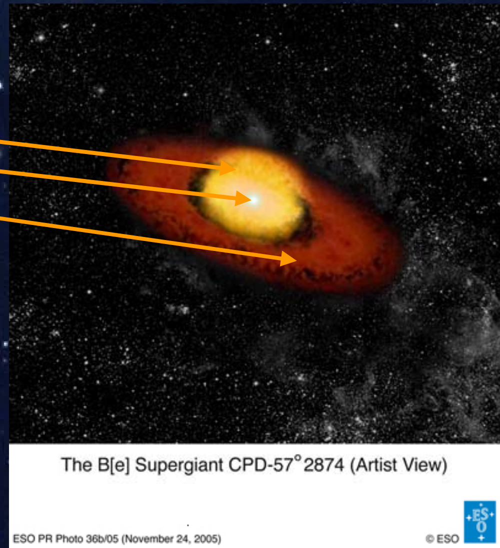
DACs are not unknown absorption spectral lines, but spectral lines (Satellite Absorption Components) of the same ion and the same wavelength as a main spectral line, shifted at different $\Delta\lambda$, as they are created in different density regions which rotate and move radially with different velocities.

(Danezis 1984, 1986, Danezis et al. 1991, 2003 and Lyratzi & Danezis 2004)

How are DACs created?

The density regions which create the observed DACs in the stellar spectra are:





The B[e] Supergiant CPD-57°2874 (Artist View)

DACs arise from:

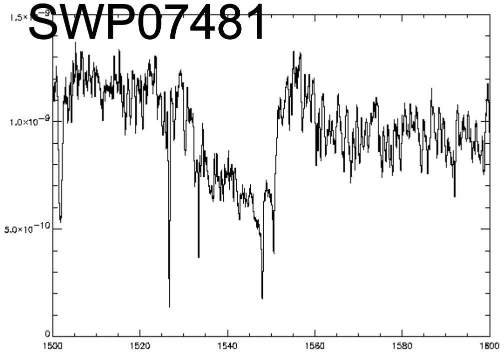
a) Thin spherical envelope around hot emission stars

or

b) (Apparent) spherical density regions in the disc around the stars

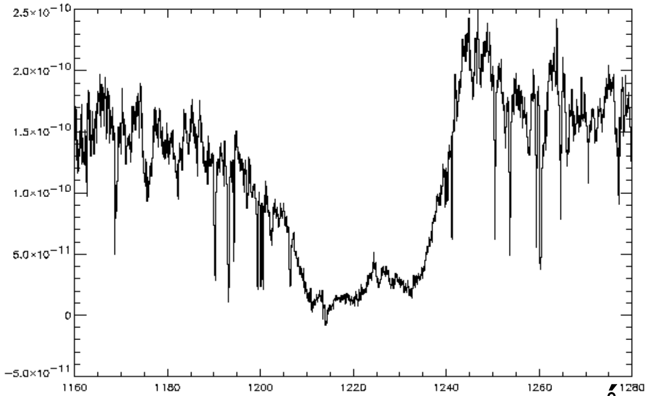
Another problem of this group of hot emission stars is:

HD 37022,
SWP07481



C IV λλ 1548.155, 1550.774 Å

HD 164794,
SWP02202



N V λλ 1238.821, 1242.804 Å

The presence of very complex profile of the spectral lines that we can't produce theoretically.

This means that

we could not know the physical conditions that exist in the high density regions that construct these spectral lines

The origin of the complex profiles

In order to explain this complex line profile our scientific group proposed the SACs phenomenon (Satellite Absorption Components).

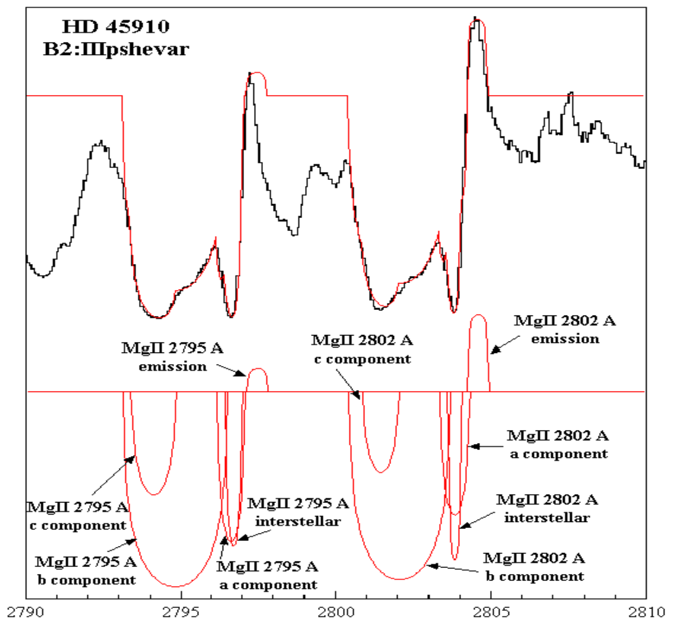
If the regions that construct the DACs rotate with large velocities and move radially with small velocities, the produced lines have large widths and small shifts.

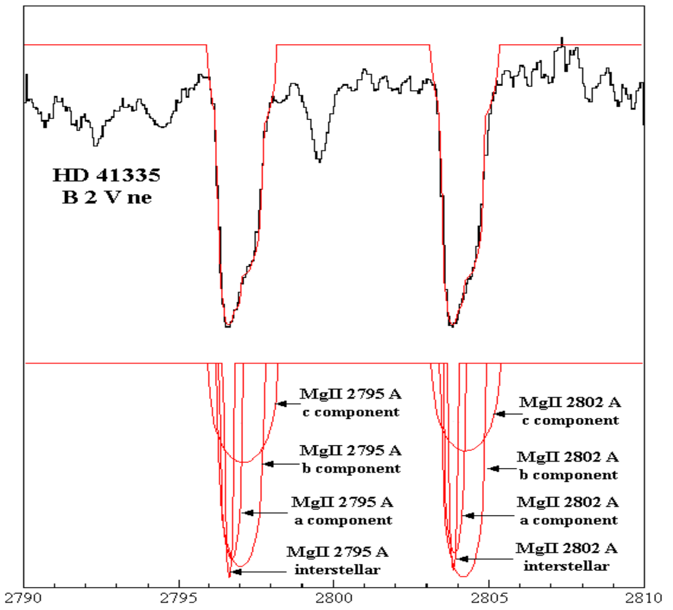
As a result, they are blended among themselves as well as with the main spectral line and thus they are not discrete. In such a case the name Discrete Absorption Components is inappropriate and we use only the name:

Satellite Absorption Components (SACs)

(Sahade et al. 1984, 1985, Danezis 1984, 1987, Lyratzi & Danezis 2004, Danezis et al. 2006)

DACs / SACs, a Similar phenomenon





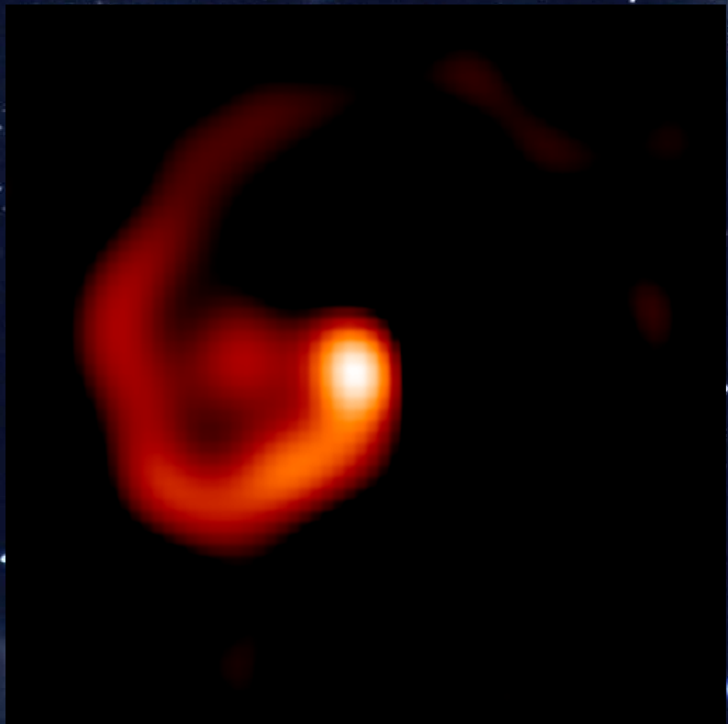
In this figure it is clear that the Mg II line profiles of the star AX Mon (HD 45910), which presents DACs and the star HD 41335, which presents SACs are produced in the same way. The only difference between them is that the components of HD 41335 are much less shifted and thus they are blended among themselves.

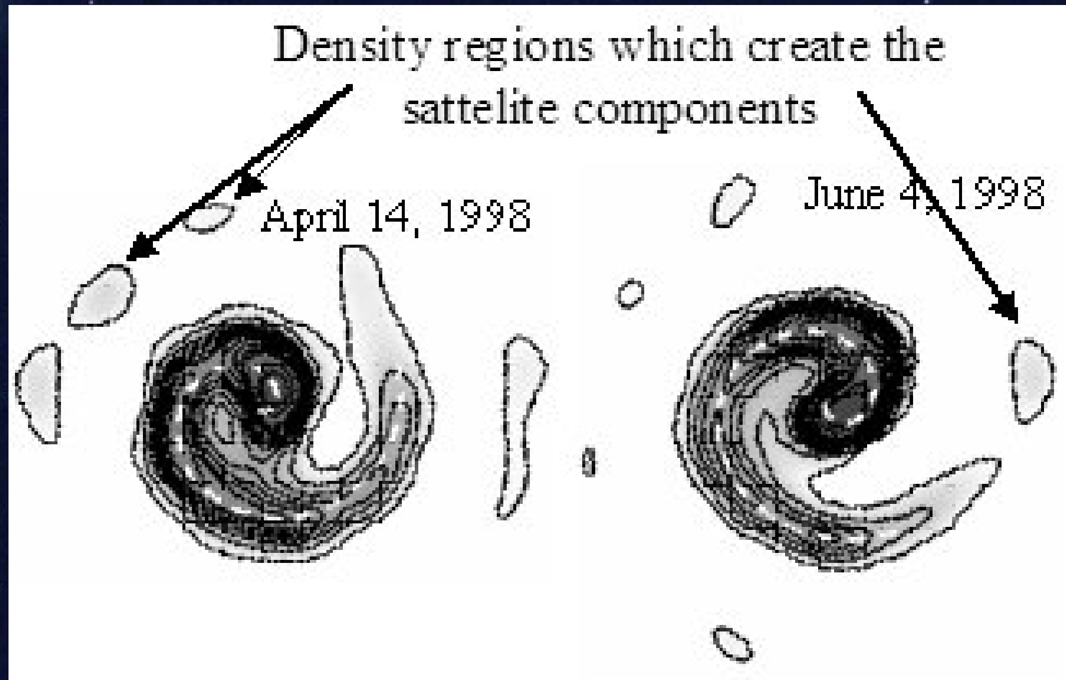
The black line presents the observed spectral line's profile and the red one the model's fit.

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

(Danezis et al. 2006)

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

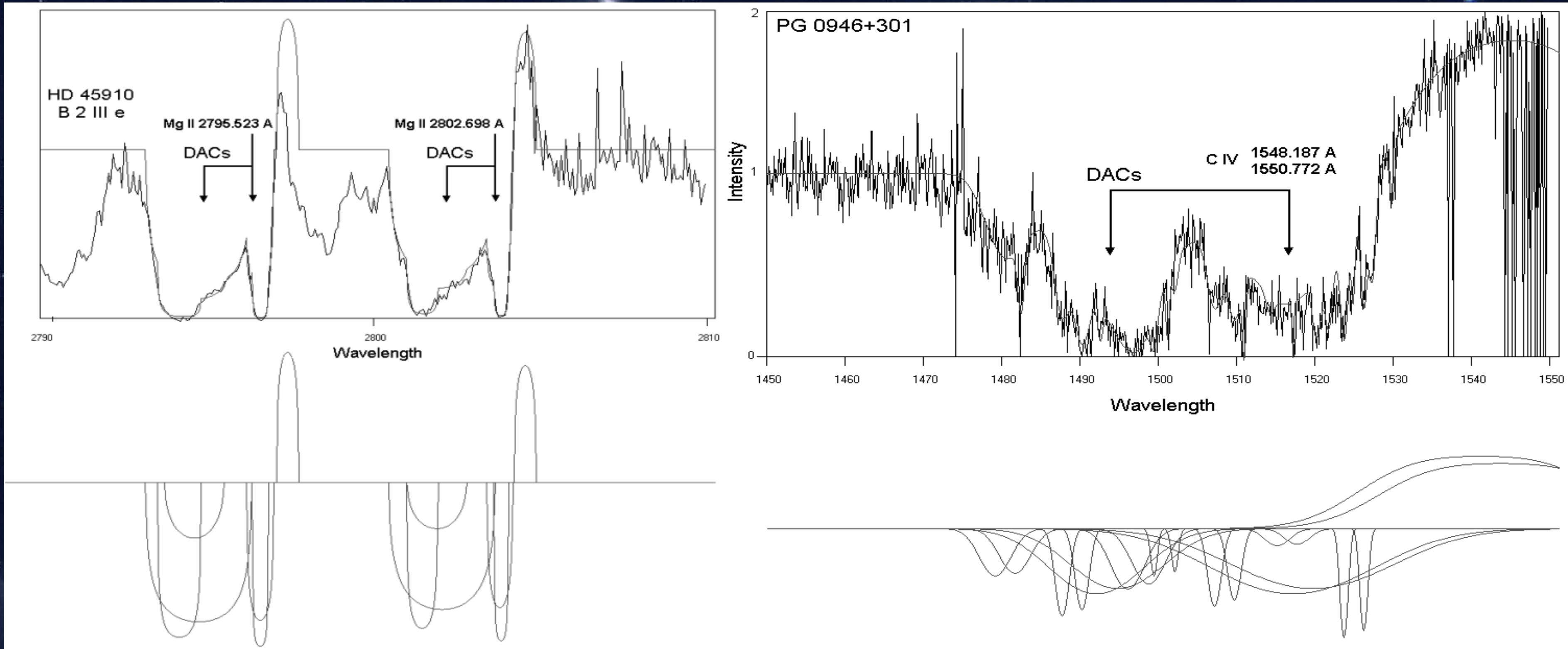




Around a Wolf-Rayet star (WR 104) we can detect density regions of matter, quite away from the stellar object, able to produce peculiar profiles. (This figure is taken by Tuthill, Monnier & Danchi (1999) with Keck Telescope.)

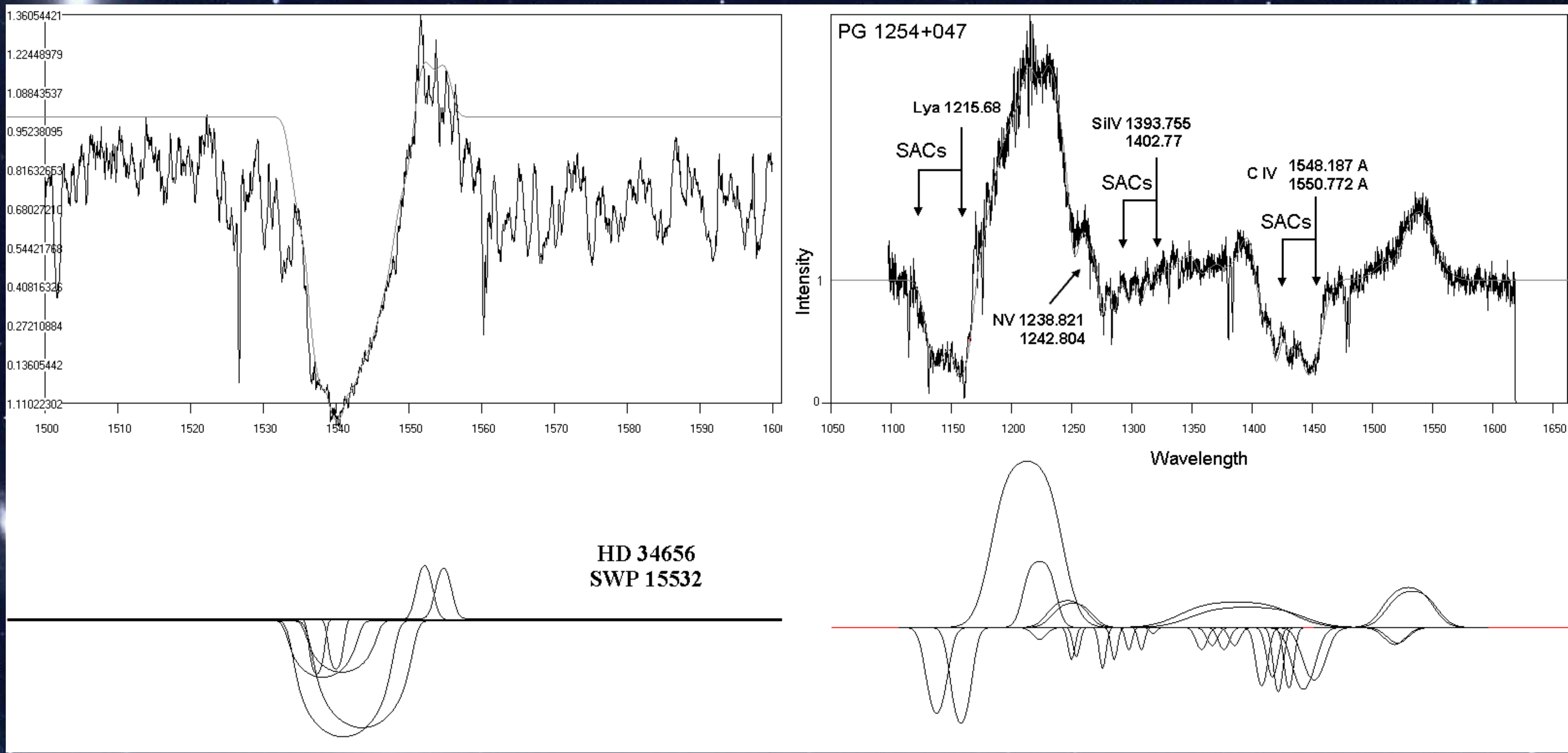
DACs and SACs phenomena in AGNs spectra

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



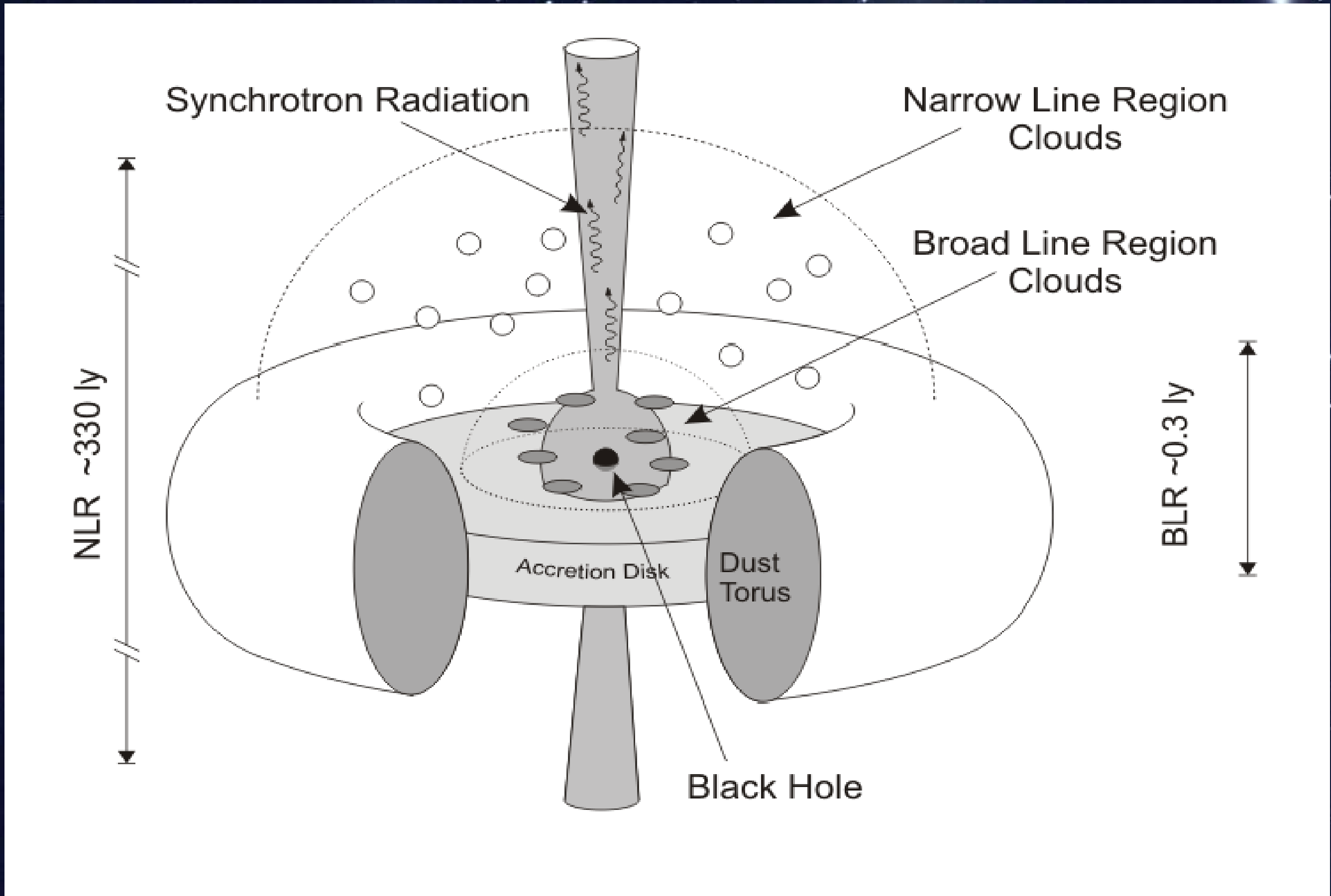
In this figure (right) we can see the C IV UV doublet of an AGN (PG 0946+301). From the values of radial displacements and the ratio of the line intensities we can detect that the two observed C IV shapes indicate the presence of a DACs phenomenon similar with the DACs phenomenon that we can detect in the spectra of hot emission stars (HD 45910)

Since the DACs phenomenon is present in AGNs spectra, we also expect the presence of SACs phenomenon which is able to explain the observed absorption lines complex profiles.



In this figure we can see the similarity of SACs phenomenon in Oe star’s HD 34656 spectrum with AGNs PG 1254+047 spectrum.

The origin of DACs/SACs phenomenon in AGNs



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

The line function

In order to reproduce theoretically the spectral lines that present DACs or SACs we need to calculate the **line function** of the complex line profile.

What is a line function?

It is the function that relates the intensity with the wavelength. This function includes as parameters all the physical conditions that construct the line profile.

By giving values to these parameters we try to find the right ones in order to have the best theoretical fit of the observed line profile.

If we accomplish the best fit, we accept that the theoretical values of the physical parameters are the actual ones that describe the physical conditions in the region that produces the specific spectral line.

The problem

If we could construct a line function able to reproduce theoretically any spectral line of any ion, it should include all the atomic parameters. As a result the line function would be very complex.

Also, if we wanted a time dependent line function , we should include as parameter the time.

The existence of many parameters makes the solution of the radiation transfer equations problematic.

Another problem is to choose the correct values of so many parameters.

Our proposition:

In order to calculate a simple line function we have not included variation with time, as our purpose is to describe the structure of the regions where the SACs are created at the specific moment when a spectrum is taken.

In order to study the time-variation of the calculated physical parameters, we should study many spectra of the same star, taken at different moments.

Additionally

With this model we study a specific spectral line of a specific ion. This means that we do not need to include the atomic parameters in the used model, as in such a case the atomic parameters remain constant.

In this way, we were able to solve the radiation transfer equations and to find the correct group of parameters that give the best fit of the observed spectral line.

The GR line function

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, a number of emission regions and some external absorption region.

By solving the radiation transfer equations through a complex structure, as the one described, **we conclude to a function for the line profile**, able to give the best fit for the main spectral line and its Satellite Components at the same time.

$$I_\lambda = \left[I_{\lambda 0} \prod_i \exp\{-L_i \xi_i\} + \sum_j S_{\lambda ej} \left(1 - \exp\{-L_{ej} \xi_{ej}\}\right) \right] \prod_g \exp\{-L_g \xi_g\}$$

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 one observation.

$$I_\lambda = \left[I_{\lambda 0} \prod_i \exp\{-L_i \xi_i\} + \sum_j S_{\lambda ej} \left(1 - \exp\{-L_{ej} \xi_{ej}\}\right) \right] \prod_g \exp\{-L_g \xi_g\}$$

- **As we can deduce from the above, we can calculate I(λ) by solving the radiation transfer equations.**

- **This means that this form does not depend on the geometry of the absorbing or emitting independent density layers of matter.**

It is the factor L that includes the geometry and all the physical conditions of the region that produces the spectral line.

The decision on the geometry is essential for the calculation of the distribution function that we use for each component.

This means that for a different geometry we have a different shape for the spectral line profile of each SAC.

In the case of rapidly rotating hot emission stars, it is very important to insert in the above line function the rotational, the radial and the random velocities of the regions that produce every one of the satellite components.

In this case we must define the geometry for the corresponding regions.

In the case of the following line function:

$$I_\lambda = \left[I_{\lambda 0} \prod_i \exp\left\{-L_i \xi_i\right\} + \sum_j S_{\lambda ej}\left(1-\exp\left\{-L_{ej}\xi_{ej}\right\}\right)\right] \prod_g \exp\left\{-L_g \xi_g\right\}$$

The $e^{-L_i \xi_i}$ and $S_{\lambda ej}\left(1-e^{-L_{ej}\xi_{ej}}\right)$ are the distribution functions of the absorption and the emission satellite component, respectively.

The factor L must include the geometry and all the physical conditions of the region that produces the spectral line. These physical conditions indicate the exact distribution that we must use.

This means that

if we choose the right physical conditions in the calculations of the factor L, the functions $e^{-L_i \xi_i}$ and $S_{\lambda ej}\left(1-e^{-L_{ej}\xi_{ej}}\right)$ can have the form of a Gauss, Lorentz or Voigt distribution function.

In this case we do not use the pure mathematical distributions that do not include any physical parameter, but the above mentioned physical expression of these distributions.

1. If L_i has the form $L_\lambda = e^{-\alpha(\lambda-\lambda_o)^2}$ $\alpha = \dfrac{1}{2(\Delta\lambda_{width})^2}$

the line function $e^{-L_i \xi_i}$ that defines well an absorption line, has the form of a **GAUSS** distribution.

με

2. If L_i has the form $L_\lambda = \dfrac{1}{1+\beta(\lambda-\lambda_o)^2}$ $\beta = \dfrac{1}{2(\Delta\lambda_{width})^2}$

the line function $e^{-L_i \xi_i}$ that defines well an absorption line, has the form of a. **LORENTZ** distribution.

3. If L_i has the form

$$L_\lambda = \frac{\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} f\left(x, (\lambda - \lambda_o)\sqrt{\alpha}, K\right) dx}{V_0}$$

$$\alpha = \frac{1}{2\left(\Delta\lambda_{width}\right)^2}$$

$$V_0 = \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} f(x, 0, K)\, dx$$

$$0 \le K$$

the line function $e^{-L_i \xi_i}$ **that defines well an absorption line has the form of a VOIGT distribution.**

Similarly

If we put the above expressions of L_i (cases 1, 2, 3)

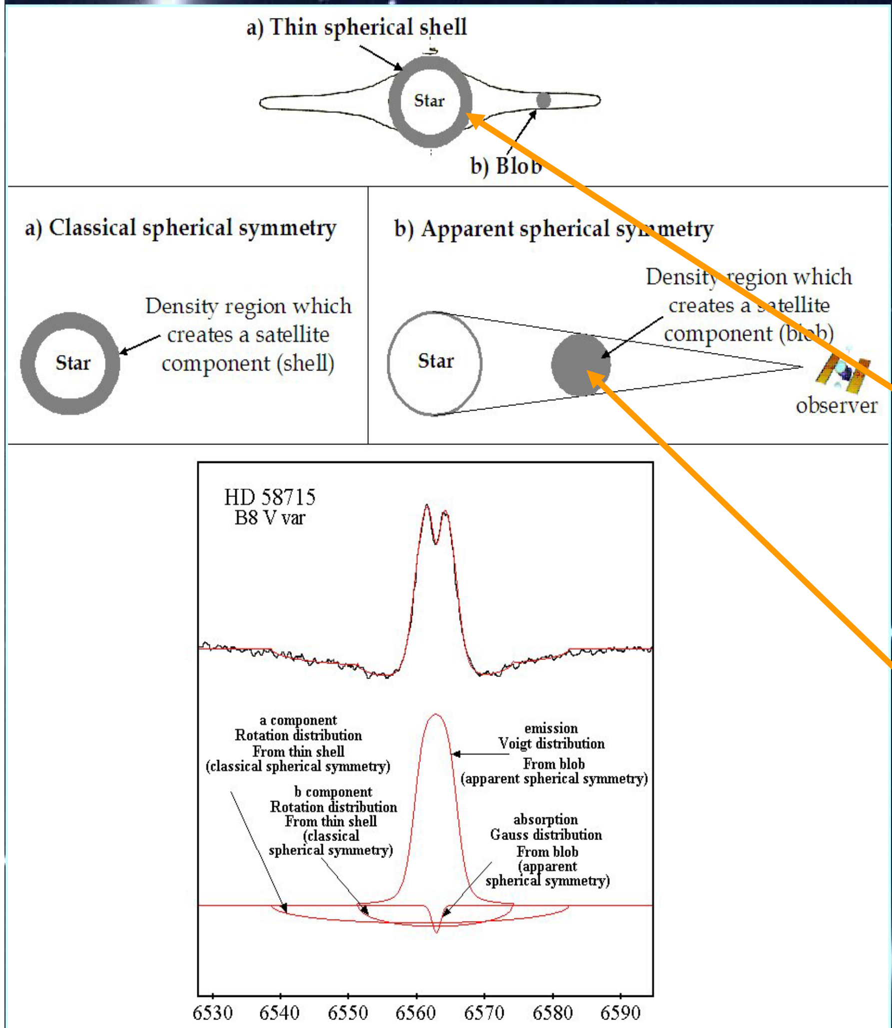
in the emission line function

$$S_{\lambda ej}\left(1-e^{-L_{ej}\xi_{ej}}\right)$$

it will take the form of a

Gauss, Lorentz or Voigt distribution

In our model we choose the spherical geometry. This means that the density layers of matter that produce the specific spectral line present spherical symmetry around their centers.



We remind that the density regions which create the observed DACs in the stellar spectra

arise from:

a) Thin spherical envelope around hot emission stars or

b) (Apparent) spherical density regions in the disc around the stars

As a first step, our scientific group constructed a distribution function L that considers as the only reason of the line broadening the rotation of the regions that produce the spectral lines. We called this distribution:

Rotation distribution

(Astrophysics and Space Science 284, 119-1142, 2003)

But as we know, in a gaseous region we always detect random motions. This means that these motions is a second reason of line broadening. The distribution function that expresses these random motions is the Gaussian.

If we want to have a spectral line that has as broadening factors the rotation of the regions and the random motions of the ions, we should construct a new distribution function L that would include both of these reasons (rotation and random motions).

Our scientific group constructed this distribution function L and named it

Gaussian-Rotation distribution

(GR distribution).

The analytical form of the GR distribution function ($L_{final}(\lambda)$) is:

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

$$erf(x)=\frac{2}{\pi}\int_0^x e^{-u^2}du$$

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

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

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

Danezis et al. 2007 PASJ, Danezis et al. SPIG 2006


Finally

Using the GR model

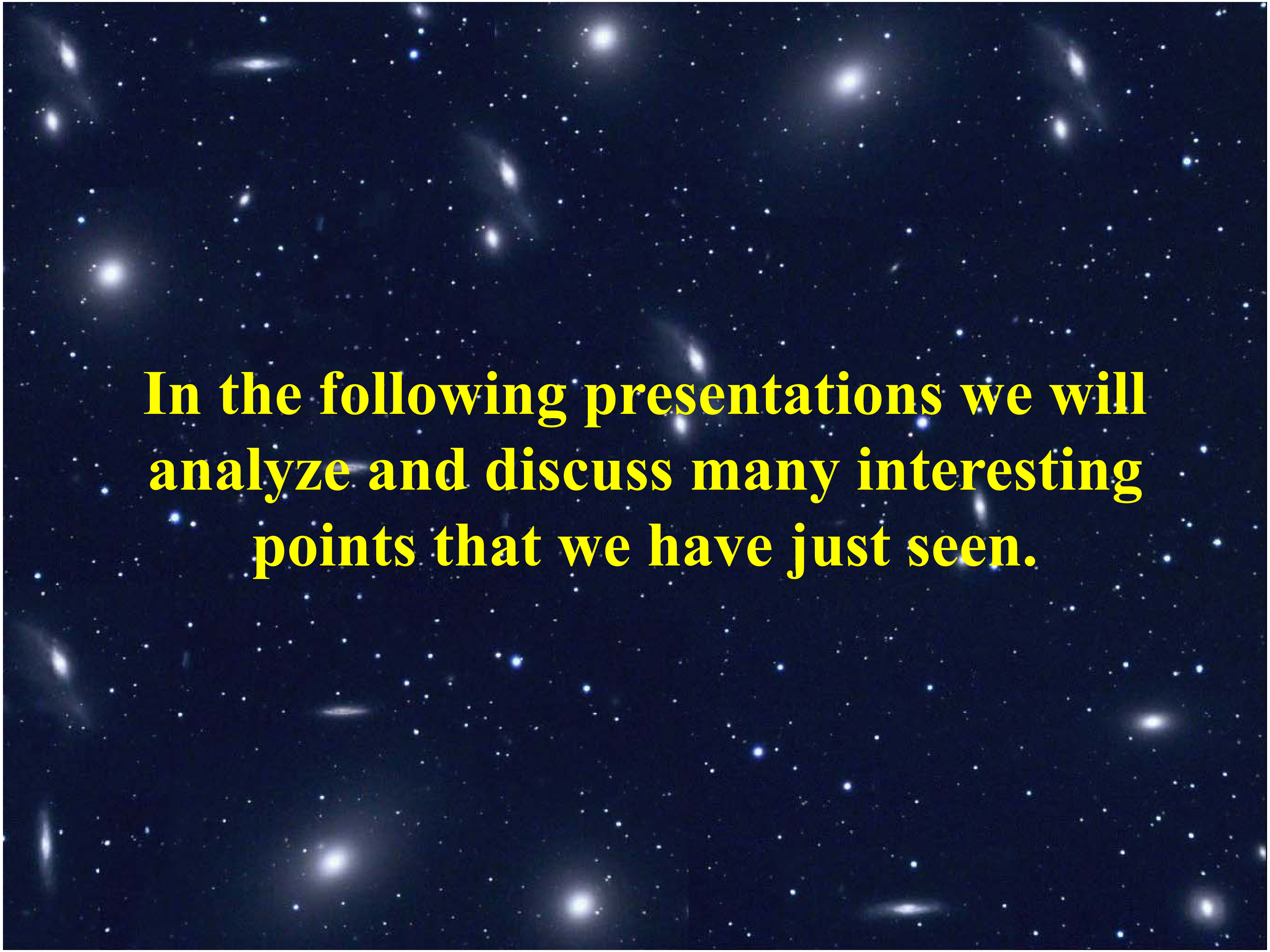
We can calculate some important parameters of the density region that construct the DACs-SACs like:

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 typical deviation of the ion random motions (σ)
- The optical depth in the center of the absorption or emission components (ξ_i)

Indirect calculations

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


In the following presentations we will analyze and discuss many interesting points that we have just seen.

Thank you very much for your attention!!!