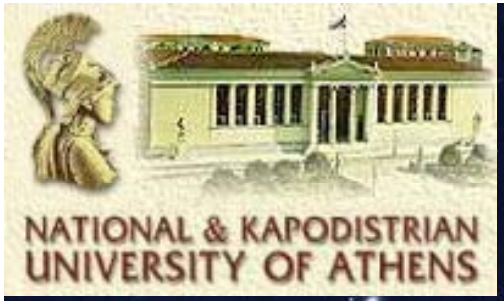



# Using the GR model
# Some important remarks

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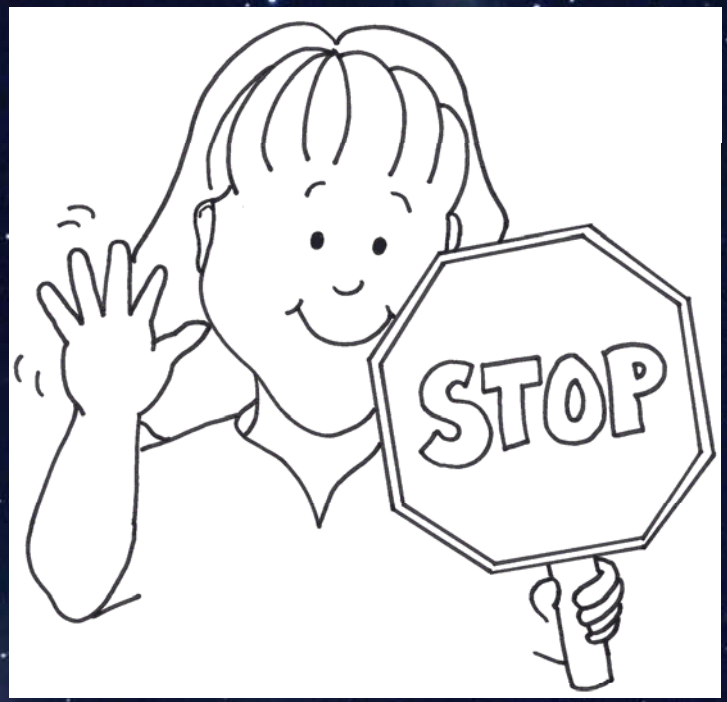
# A first important remark

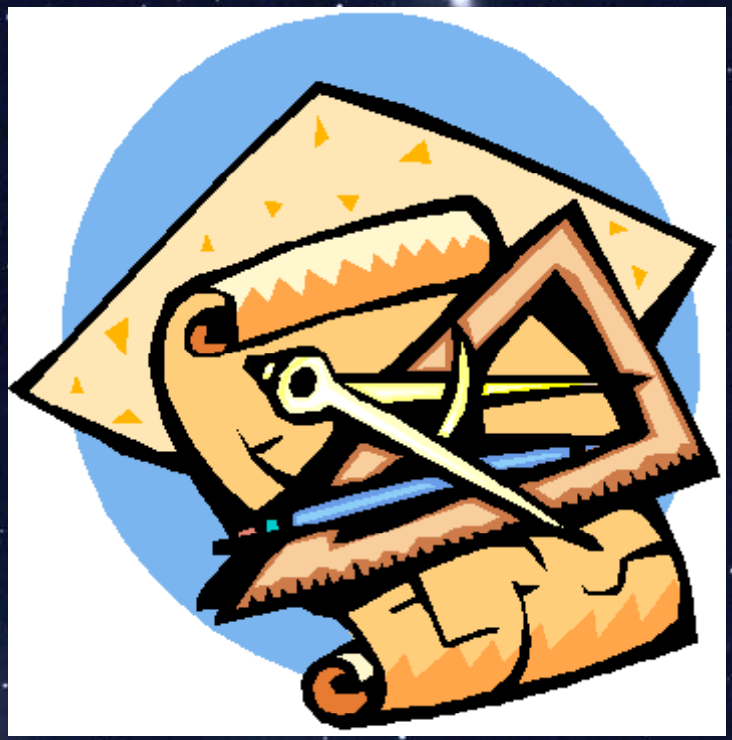


*We point out that with the proposed model we can study and reproduce specific spectral lines.*

*This means that we can study specific density regions in the plasma surrounding the studied object.*

*In order to construct a general model we need to study with the proposed model many density regions that produce spectral lines of different ionization potential, meaning different temperature and thus different distance from the studied object.*

# The Geometry of the model



## Geometry

As we can see the line function of the GR model has the form:

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

We have already seen that the calculation of the function $I_\lambda$ **does not depend on the geometry** of the absorbing or emitting independent density regions of matter.

**The decision on the geometry is essential for the calculation of the distribution functions $L_i$.**

**By deciding on a different geometry we conclude to a different analytical form of $L_i$, and thus to a different shape of the profile of the spectral line, which presents SACs.**

## Geometry

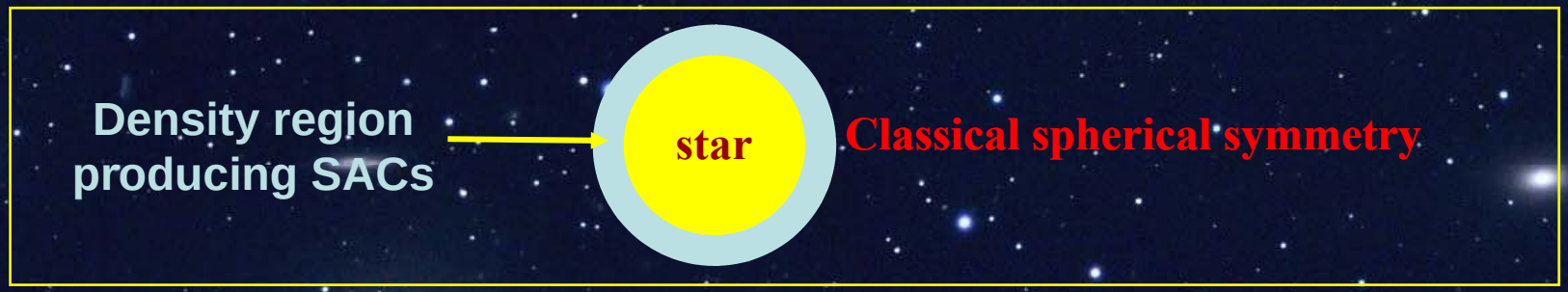
In order to decide on the appropriate geometry we took into consideration the following important facts:

The spectral line profile is reproduced in the best way when we consider **spherical symmetry** for the independent density regions.
Such symmetry has been proposed by many researchers (Lamers et al. 1982, Bates & Gilheany 1990, Gilheany et al. 1990, Waldron et al. 1992, Rivinius et al. 1997, Cidale 1998, Markova 2000).

However, **the independent layers of matter**, where a spectral line and its SACs are born, **could lie either around the star**, in which case spherical symmetry is justified, **or at a greater distance from the star,** where the spherical symmetry can not be justified.

1. Independent density regions of matter that lie **around the star:**

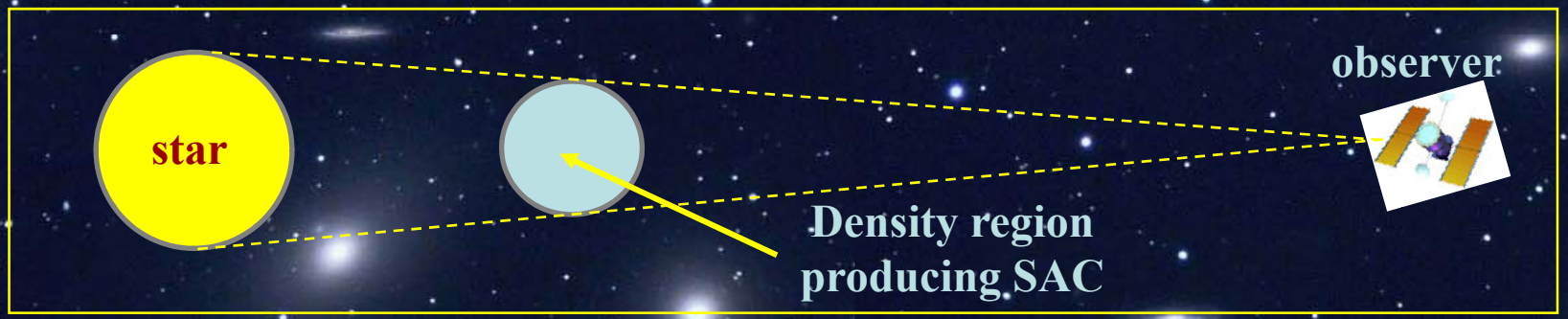
We consider the existence of a **classical spherical symmetry**



## Geometry

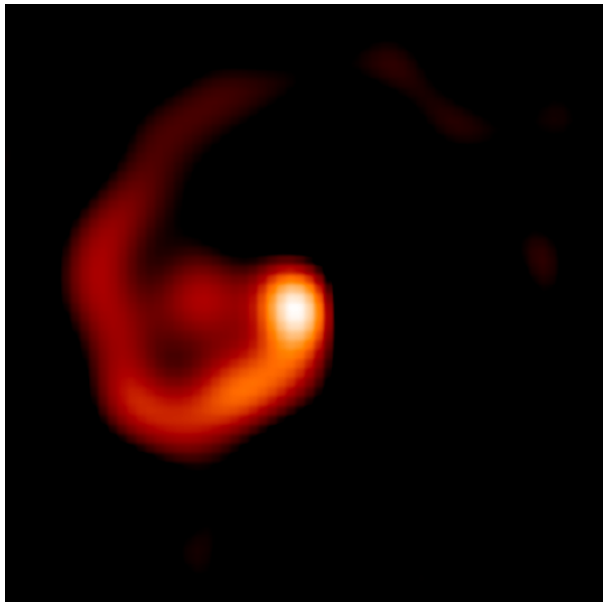
2. Independent density regions of matter that lie **at a greater distance from the photosphere:** We consider the existence of independent density regions such as **blobs**, which cover all or a substantial fraction of the stellar disk. These regions, do not present spherical symmetry around the star, but they may present **local spherical symmetry around themselves** and they form spectral line profiles which are identical with those deriving from a spherically symmetric structure. So, even if **the density regions** are not spherically symmetric, through their effects on the line profiles, they **appear as spherically symmetric structures to the observer.**

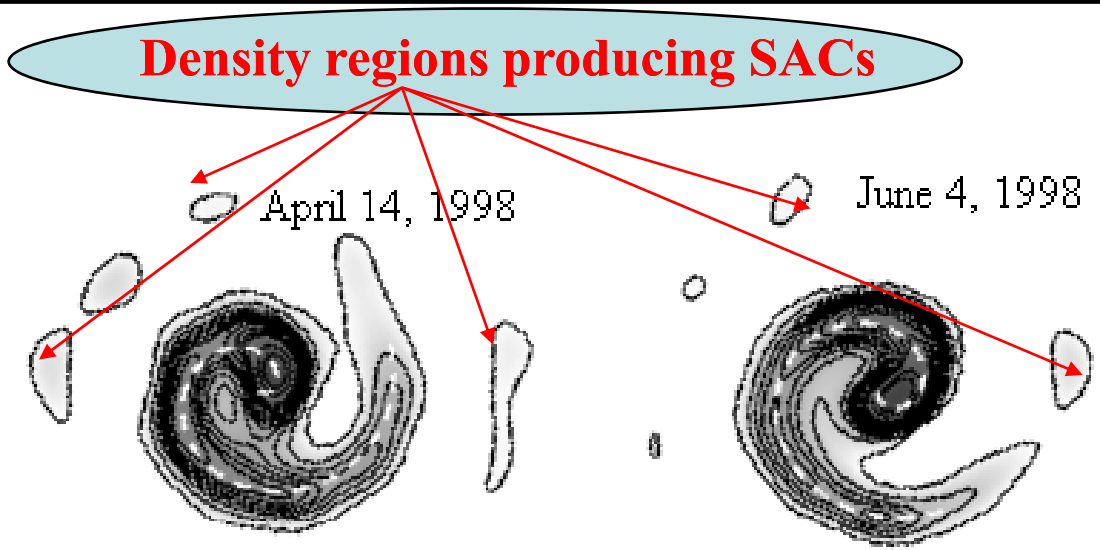
**Apparent or local spherical symmetry**



## Geometry

2. The star ejects mass with a specific radial velocity. The stream of matter is twisted, forming density regions such as corrotating interaction regions (CIRs), structures due to magnetic fields or spiral streams as a result of the stellar rotation (Underhill & Fahey 1984, Mullan 1984a,b 1986, Prinja & Howarth 1988, Cranmer & Owocki 1996, Fullerton et al. 1997, Kaper et al. 1996, 1997, 1999, Cranmer et al. 2000)). This means that hydrodynamic and magnetic forces take effect as centripetal forces, resulting to the outward moving matter twisting and moving around the star. Some parts of these streams cut off and form the observed high density regions (shells, blobs, puffs, spiral streams).






Tuthill, P., Monnier, J. & Danchi, W. (1999)

# An important notice

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

**The proposed line function ($I_\lambda$) can be used for any number of absorbing or emitting regions.** This means that it can also be used in the simple case that *i*=1 and j=0 or i=0 and *j*=1, meaning when we deal with simple, classical absorption or emission spectral lines, respectively. This means that **we can calculate all the important physical parameters**, such as the rotational, the radial and the random velocities, the optical depth, the column density and the absorbed or emitted energy, **for all the simple and classical spectral lines in all the spectral ranges.**

# The case of many absorption or emission components.

**In the GR line function**

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

**the final profile that is produced by a group of absorption lines is given by the product of the line functions of each SAC.**

**On the other hand, the final profile that is produced by a group of emission lines is given by the addition of the line functions of each SAC.**

The addition of a group of functions is completely different than the multiplication of functions.
The spectral line profile that results from the addition of a group of functions is exactly the same with the profile that results from a composition of the same functions.

On the contrary, the product of a group of functions is completely different from the composition of the same functions.

As a result, we can use the composition of functions for the emission lines, but not for a group of absorption components. This means that in such a case we can not refer to the low of reversion of the spectral lines.

The function $I_{\lambda i} = e^{-L_i \xi_i}$ reproduces the spectral line profile formed by the i density region (profile of one component).

**In the case of the GR distribution function, $L_i$ is given by:**

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

$$\lambda_0 = \lambda_{lab} \pm \Delta\lambda_{rad}$$

$V_{rad}$

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

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

So, for each quadruplet of the parameters $V_{rot\,i}$, $V_{rad\,i}$, $V_{rand\,i}$ and $\xi_i$, we have a different profile.

This results to the existence of only one quadruplet able to give the best fit of the i component.

# Fitting Criteria

**In order to accept as best fit of the observed spectral line, what is given by the quadruplet ($V_{rot\ i}$, $V_{rad\ i}$, $V_{rand\ i}$, $\xi_i$) of all the calculated SACs, we must adhere to all the physical criteria and techniques.**

## As a first step

**It is necessary to have the superposition of the spectral region that we study with the same region of a classical star of the same spectral type and luminosity class, in order to identify the existence of spectral lines that blend with the studied ones and the existence of SACs .**

## The resonance spectral lines

The resonance lines, as well as those that form in regions that are close to each other (small difference in ionization potential), must have **the same number of SACs and the same values for $V_{rad}$, $V_{rand}$ and $V_{rot}$.** Besides, in the cases of resonance lines and of lines of the same ion and the same multiplet, **the ratio of the values of $\xi$ must be the same as the ratio of the respective intensities.**

## The final criterion

The final criterion to accept or reject a best fit is that **the calculated values of the physical parameters should not go against the classical physical theory.**

# The method to fit a spectral line

In order to conclude to the group of the parameters which give us the best fit, we use the model by the following two methods:

1. **In the first method** we consider that the main reason of the line broadening of the main line and the satellite components is the rotation of the region which creates the components of the observed feature and a secondary reason is the thermal Doppler broadening. This means that we start fitting the line using the maximum $V_{rot}$. Then we include Doppler broadening, in order to accomplish the best fit (Rotation case).

2. **In the second method, we consider the opposite. This means that in this case the main reason of the line broadening of the main line and the satellite components is supposed to be the thermal Doppler broadening and the secondary reason is the rotation of the region which creates the components of the observed feature. This means that we start fitting the line using the maximum Doppler broadening. Then we include $V_{rot}$, in order to accomplish the best fit (Doppler case).**

**In both of the above cases (Rotation case and Doppler case):**

**We check the correct number of satellite components that construct the whole line profile.**

**At first**

**We try to fit with one component. We add another one only when we see that we cannot fit with only one component. We keep adding components until we accomplish the best fit.**

**Finally, we fit using the number of the components that give the best difference graph between the fit and the real spectral line (step by step, component by component).**

**Then we fit using one component less than in the previous fit.**

**The F-test between them allows us to take the correct number of satellite components that construct in the best way the whole line profile.**

The F-Test between these two cases indicates the best way to fit the spectral lines.

When the F-Test cannot give definite conclusion on which case we should use,

we still could obtain information about the limits of $V_{rot}$ and $\sigma$.

If the F-Test gives similar values, then the Rotation Case defines the maximal $V_{rot}$ and the minimal σ and the Doppler Case defines the minimal $V_{rot}$ and the maximal σ.

The profiles of every main spectral line and its SACs are fitted by the $e^{-L_i \xi_i}$ function, in the case of an absorption component or $S_{\lambda ej}\left(1-e^{-\tau_{ej}}\right)$, in the case of an emission component.

These functions produce symmetrical line profiles. However, we know that most of the spectral lines that we have to reproduce are asymmetric.

This fact is interpreted as a systematical variation of the apparent radial velocities of the density regions where the main spectral line and its SACs are created.

**In order to approximate those asymmetric profiles we have chosen a classical method.**

**This is the separation of the region, which produces the asymmetric profiles of the spectral line, in a small number of sub-regions, each of which is treated as an independent absorbing shell.**

**In this way we can study the variation of the density, the radial shift and the apparent rotation as a function of the depth in every region which produces a spectral line with an asymmetric profile.**

**All the above must be taken into account during the evaluation of our results and one should not consider that the evaluated parameters of those sub-regions correspond to independent regions of matter, which form the main spectral line or its SACs.**

In this case we could use **asymmetric distributions** (e.g. Maxwell). This means that we could fit the observed profile with an asymmetric mathematical distribution.

However, until now we do not have an expression of the distribution function L that would correspond to a Maxwell distribution and which would include physical parameters.

As a result, even if we could fit the observed profile with a mathematical asymmetric distribution, we would not be able to calculate any physical parameter.

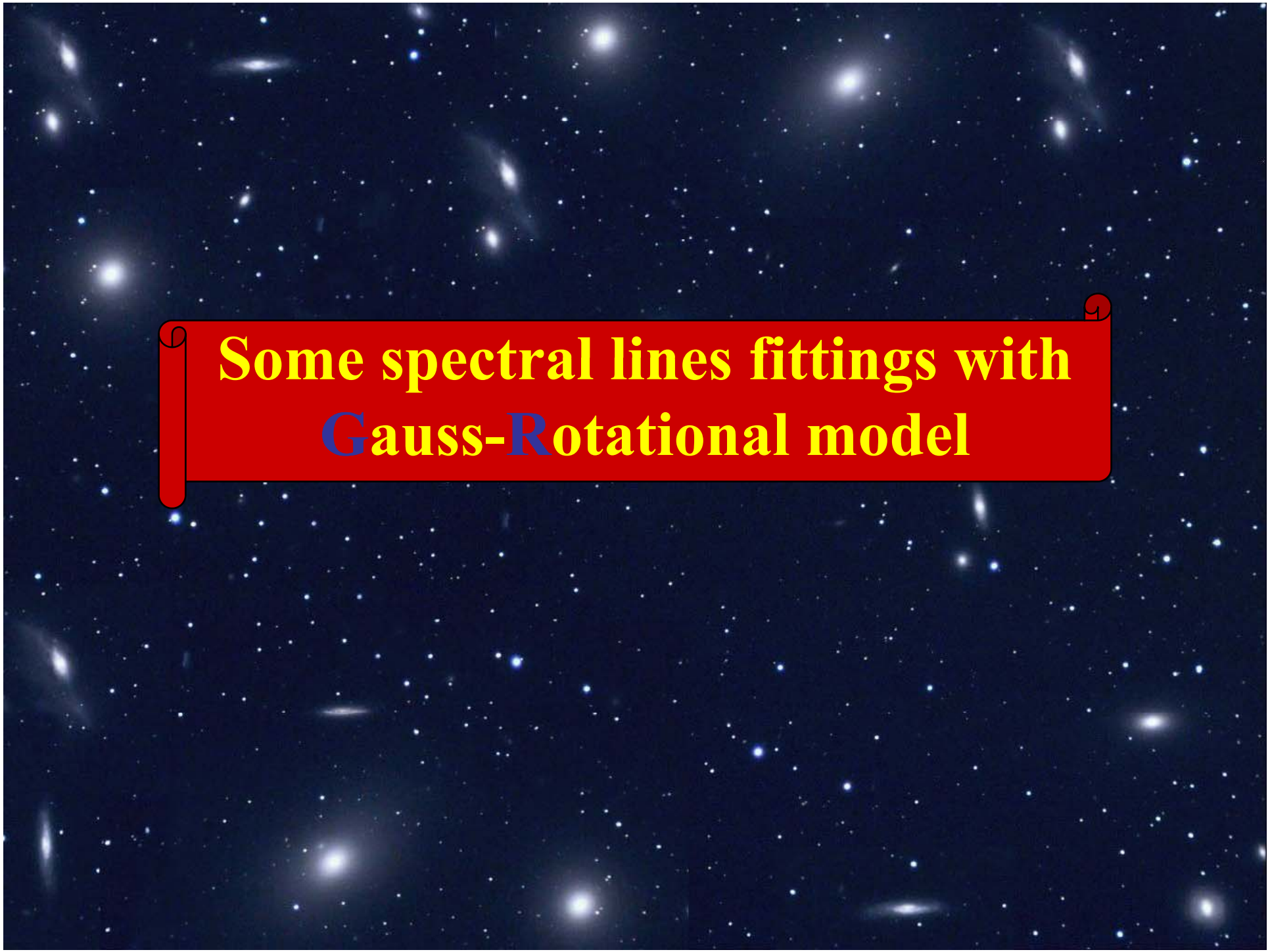
In order to be able to calculate some physical parameters, we use the above mentioned way.

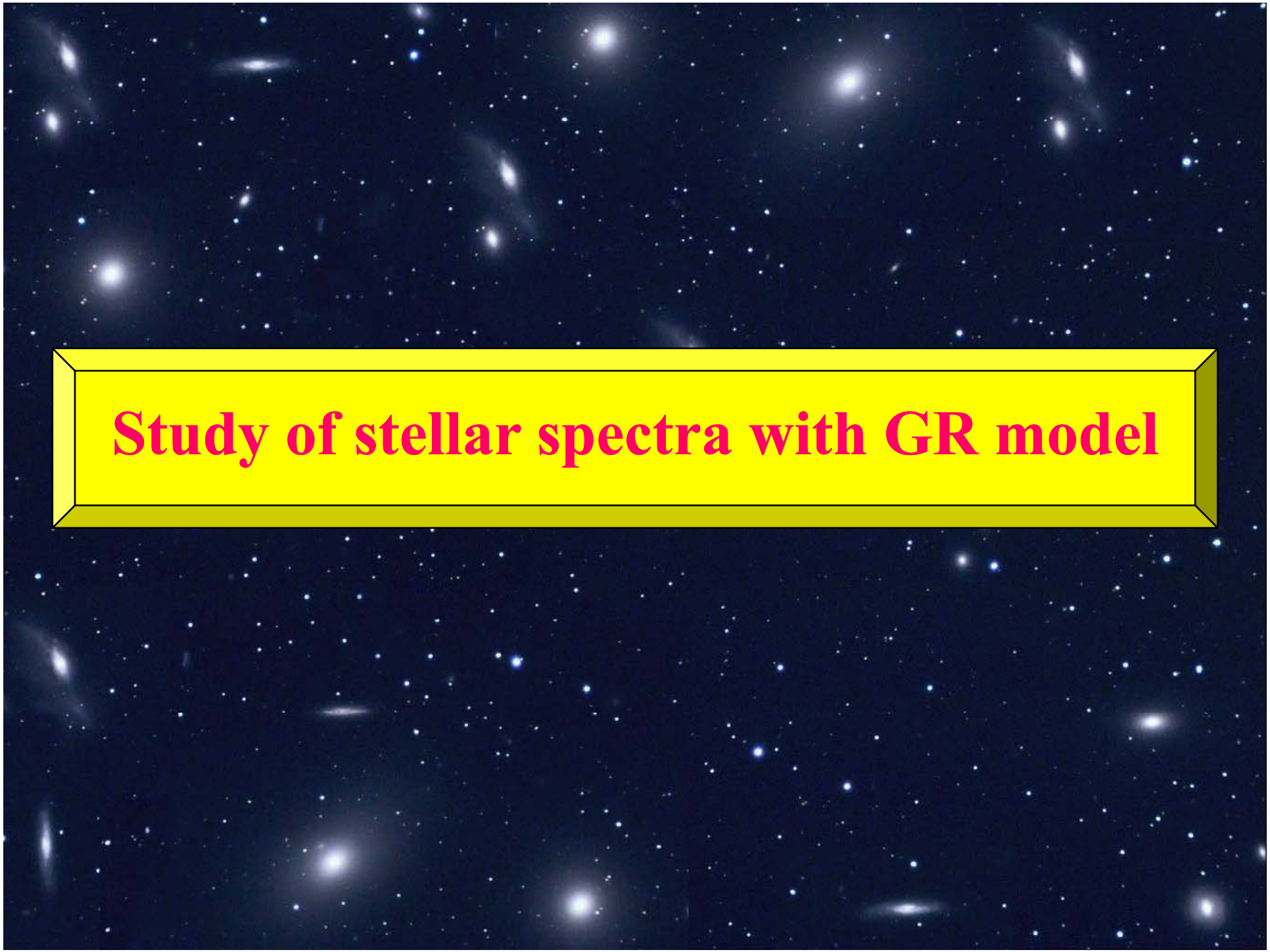
# The spectral line width

**We suggest that the width of the blue wing is the result of the merging of the profiles of the main spectral line and its SACs.**

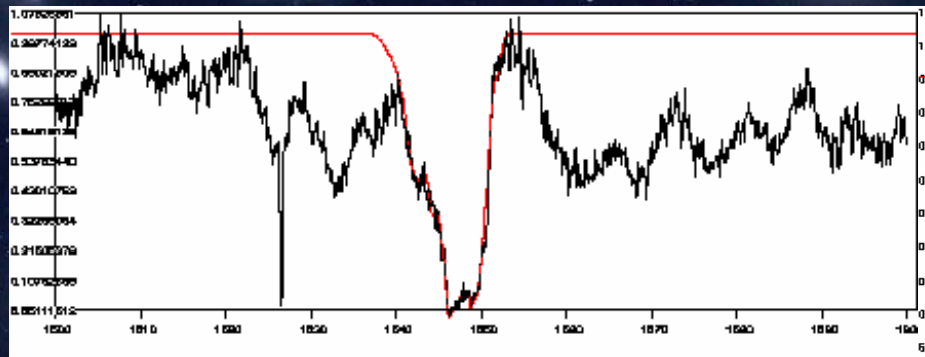
**Thus, the blue wing of each SAC gives the apparent rotational velocity of the density shell, in which it forms.**

**This means that, in order to have measurements with physical meaning, we should not calculate the width of the blue wing of the observed spectral feature but the width of the blue wing of each SAC.**

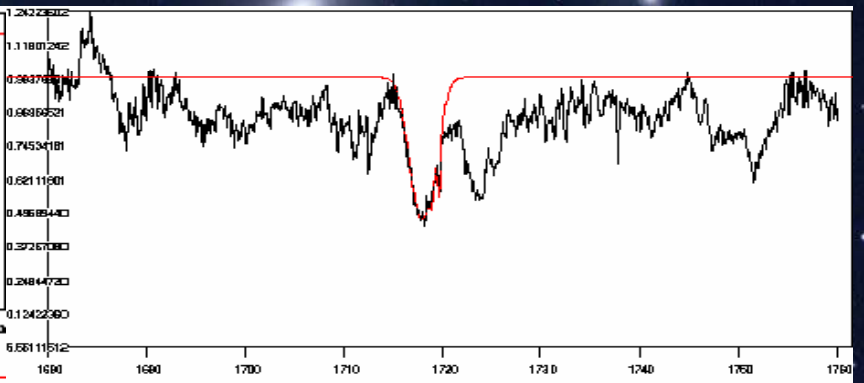

Some spectral lines fittings with
Gauss-Rotational model


Study of stellar spectra with GR model

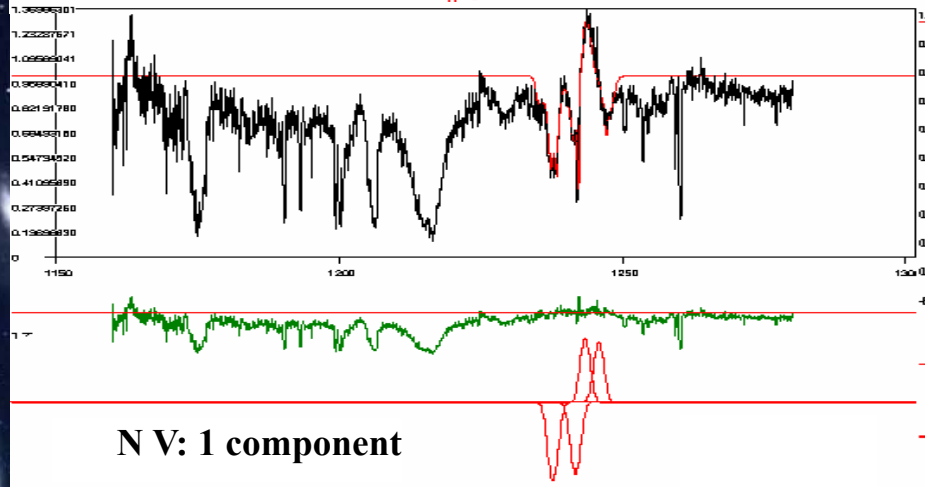
# A study of HD 93521 UV spectrum (Antoniou et al. 2006)



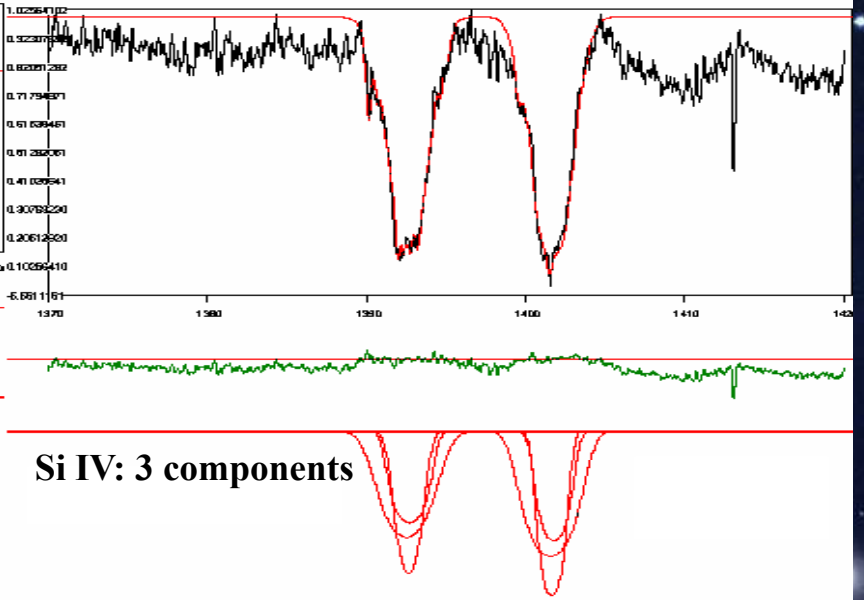
C IV: 5 components



N IV: 1 component

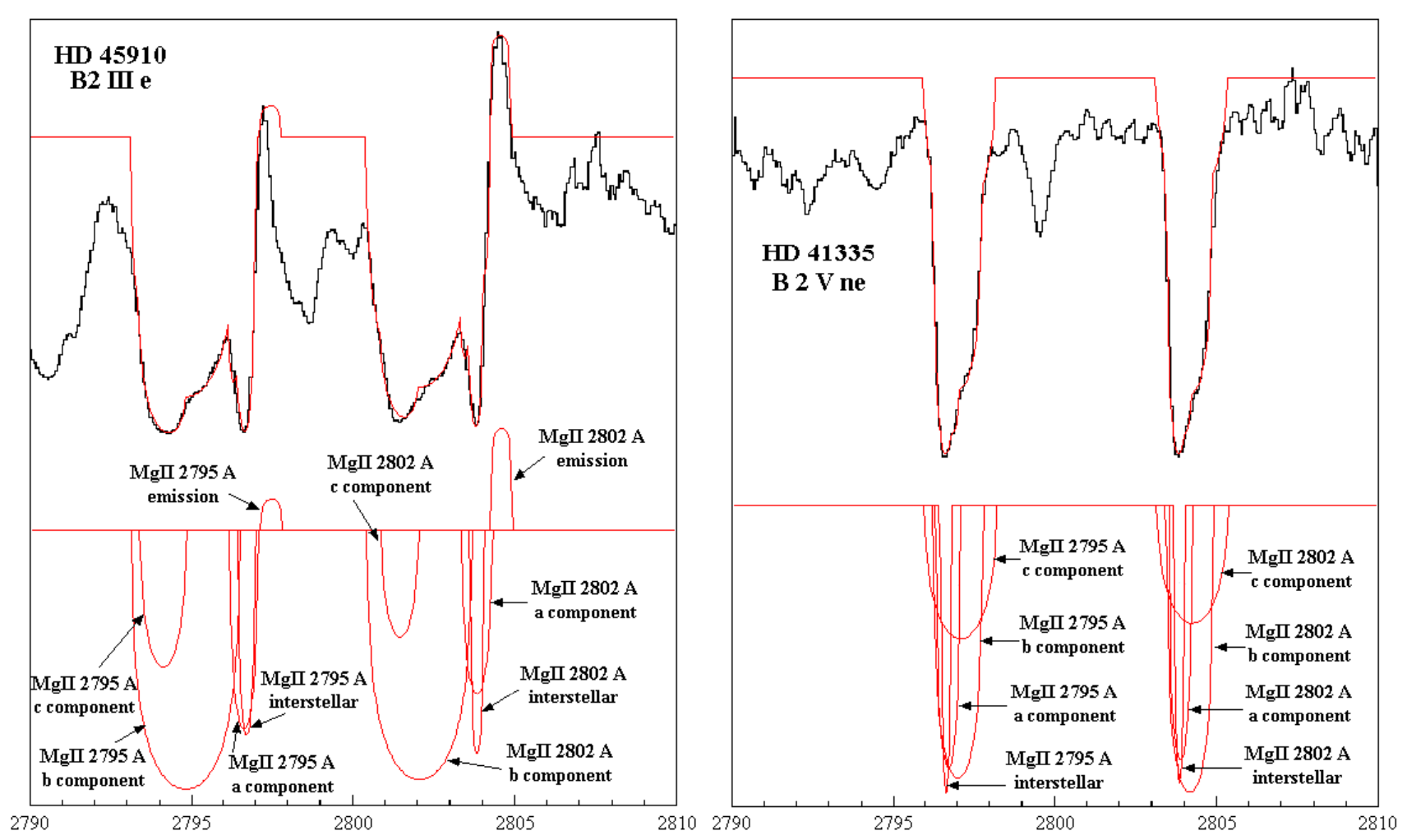


N V: 1 component

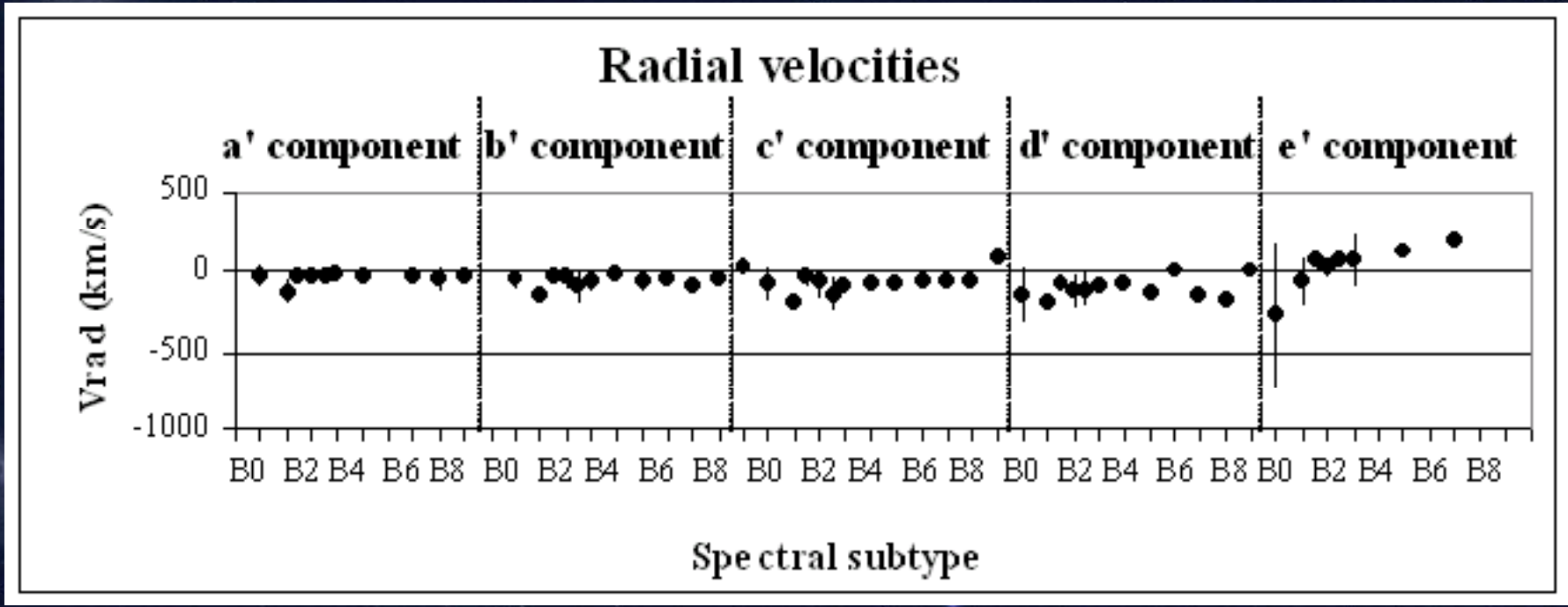


Si IV: 3 components

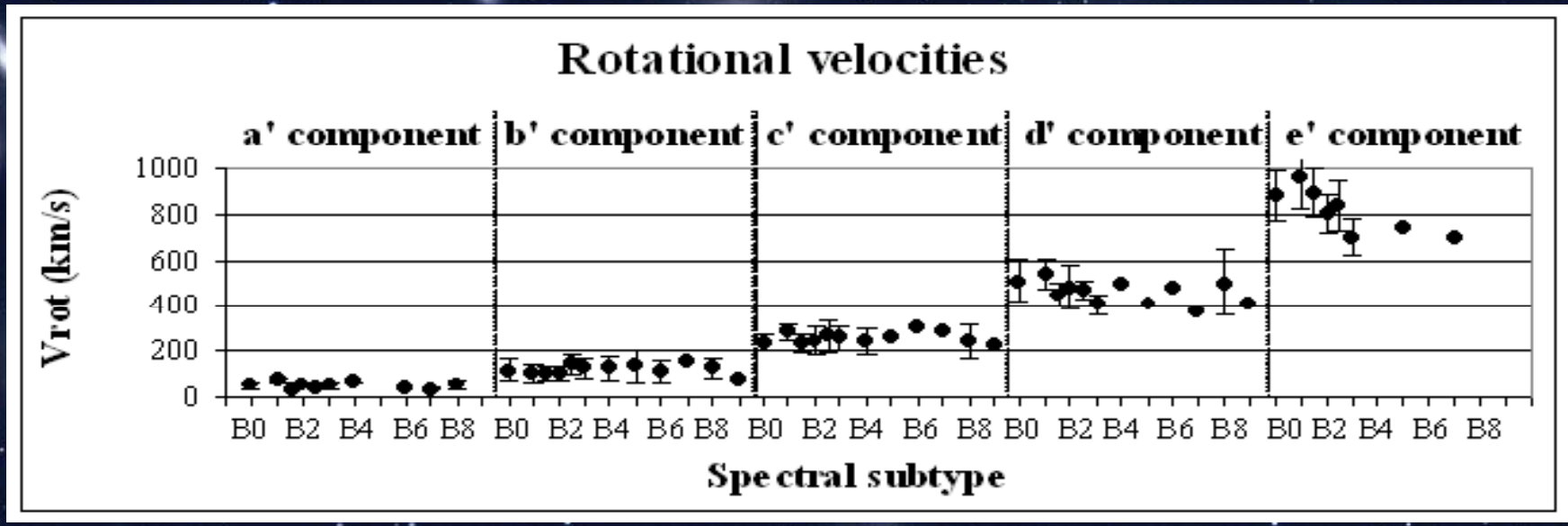
# The UV Mg II resonance lines' fitting (Lyratzi et al. 2007)



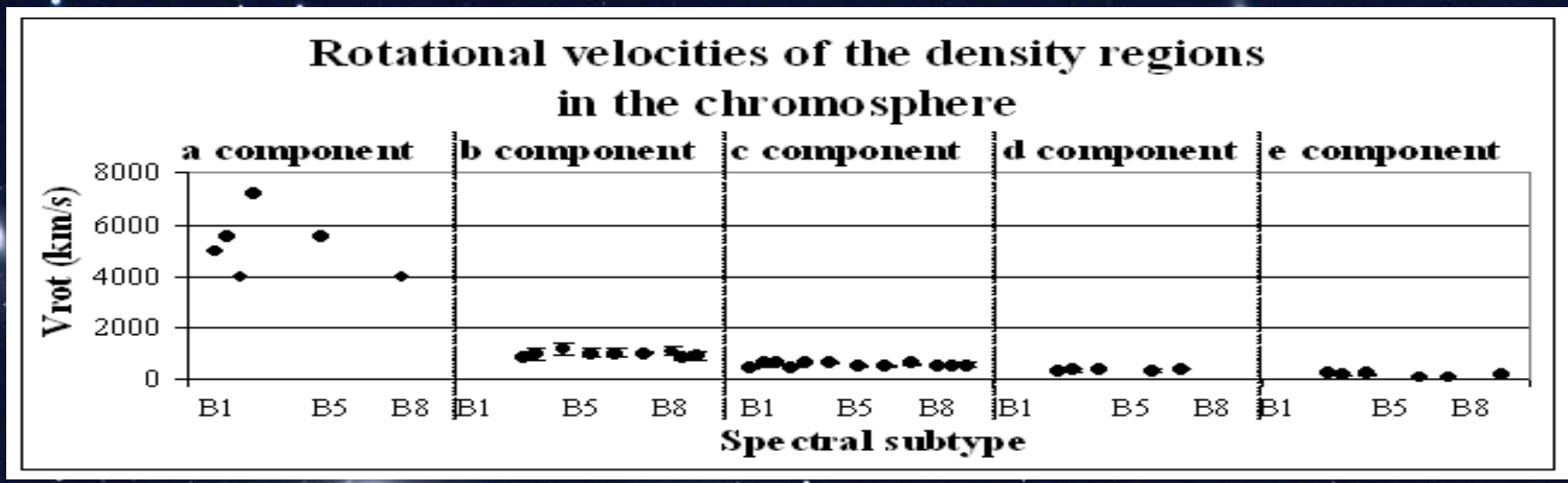
**From the fitting with GR model we calculated the mentioned physical parameters and we took some statistical conclusions.**




**Statistical study of Si IV resonance lines in the UV spectrum of 70 Be stars (Lyratzi et al. 2004, 17th ICSLS)**

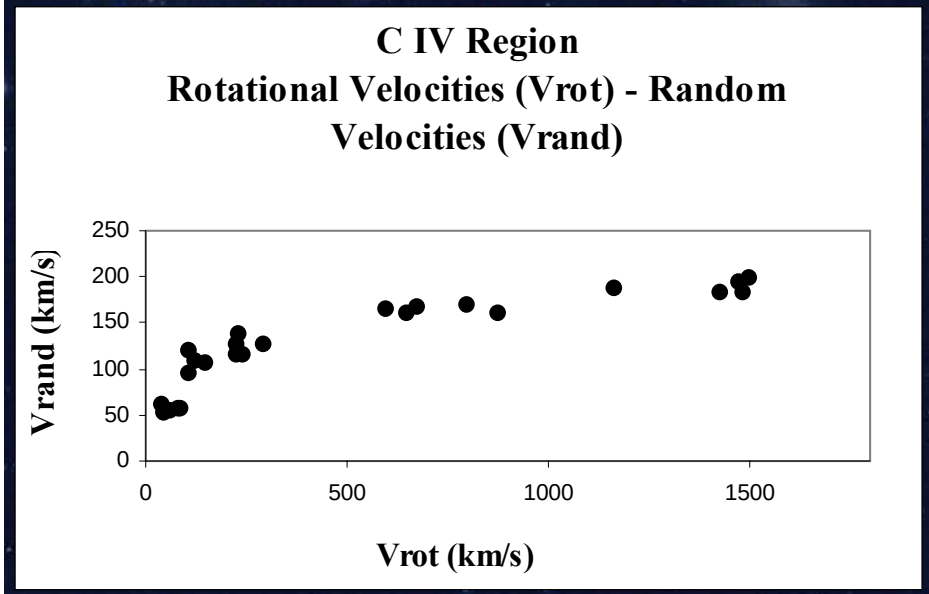


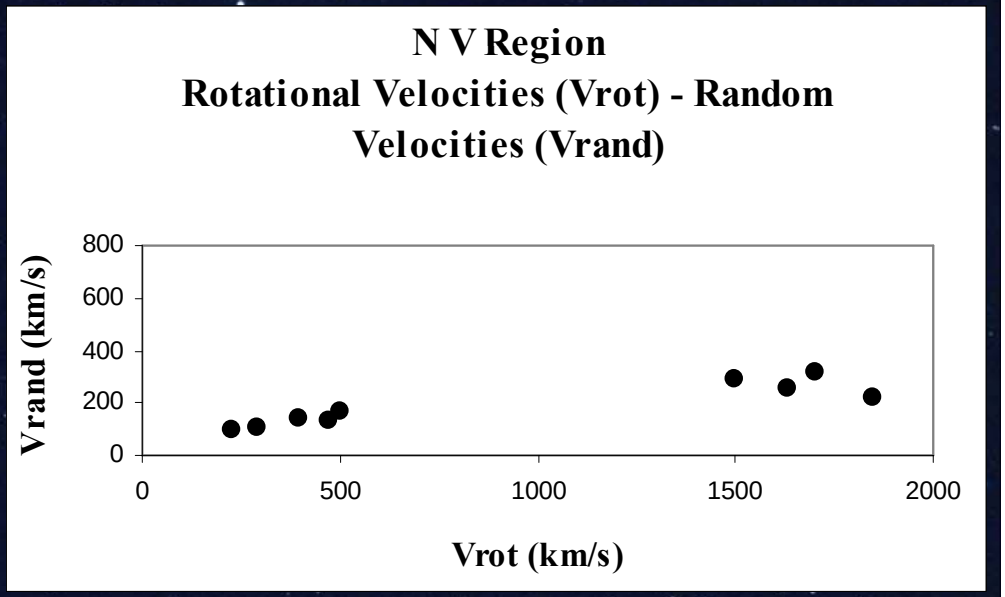

**Statistical study of Mg II resonance lines in the UV spectrum of 64 Be stars (Lyratzi et al. 2007 PASJ)**




**Statistical study of Hα line in the UV spectrum of 120 Be stars (Lyratzi et al. 2005 MSAIS)**

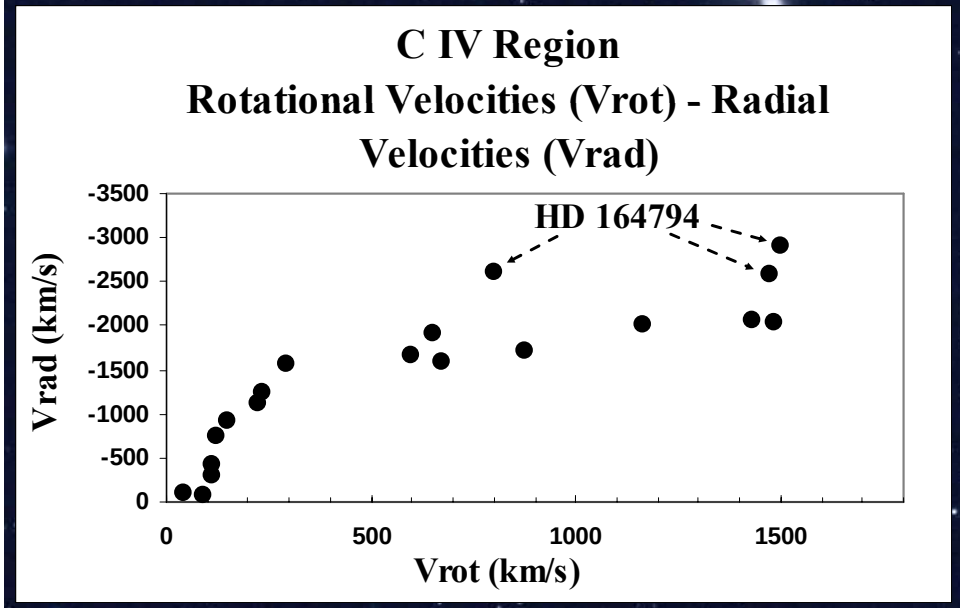
# From the calculation of the above parameters we can study the relations between them

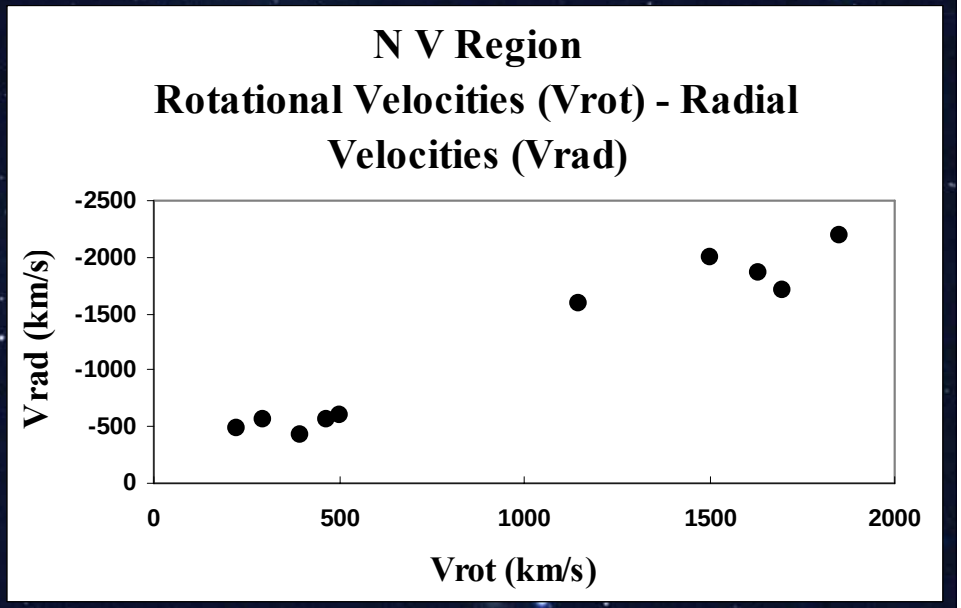



**The random velocities of the CIV and NV density regions, as a function of the apparent rotational velocities, in a sample of 20 Oe stars.**

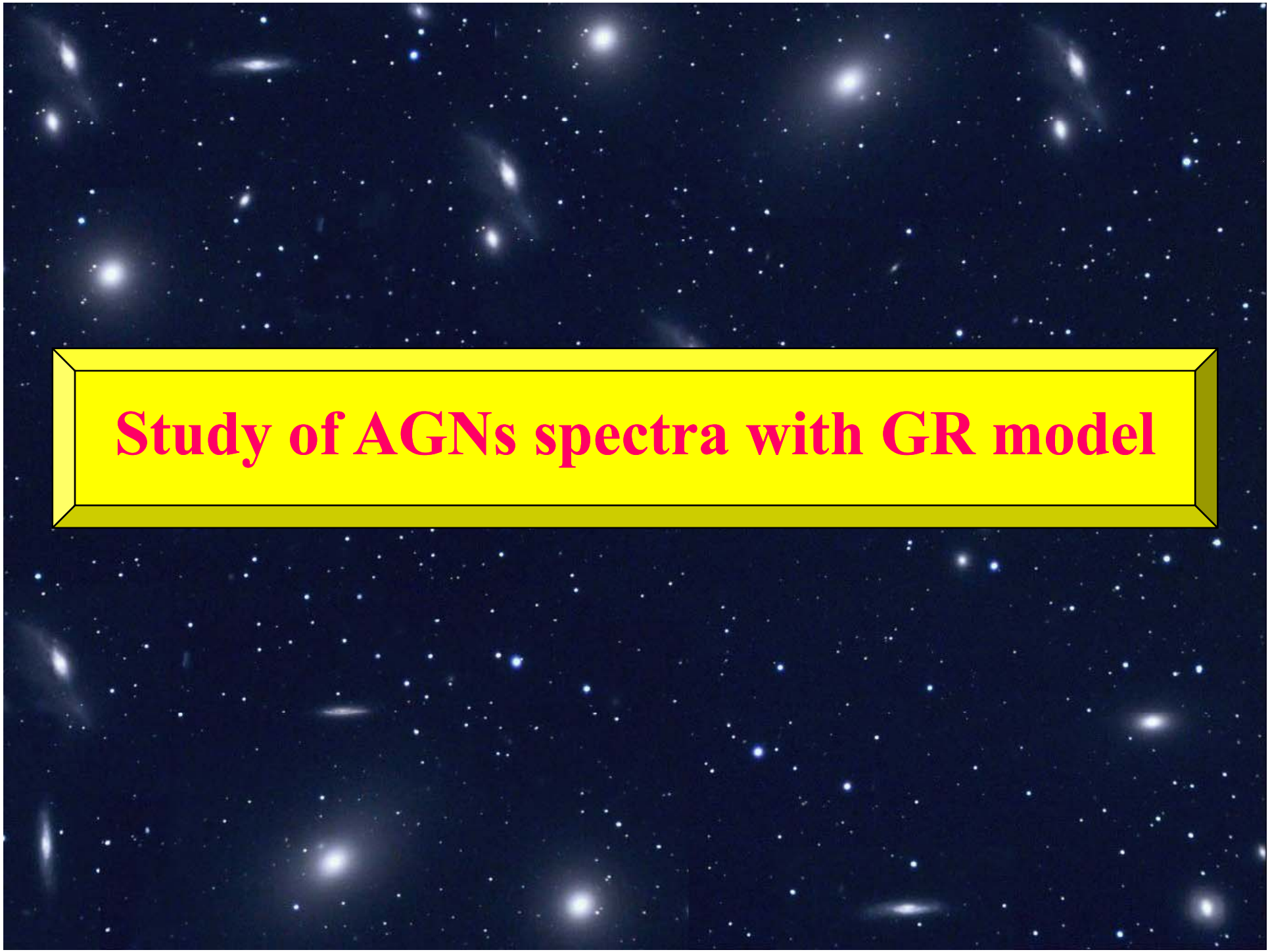
**Danezis et al. 2007 VI SCSLSA**



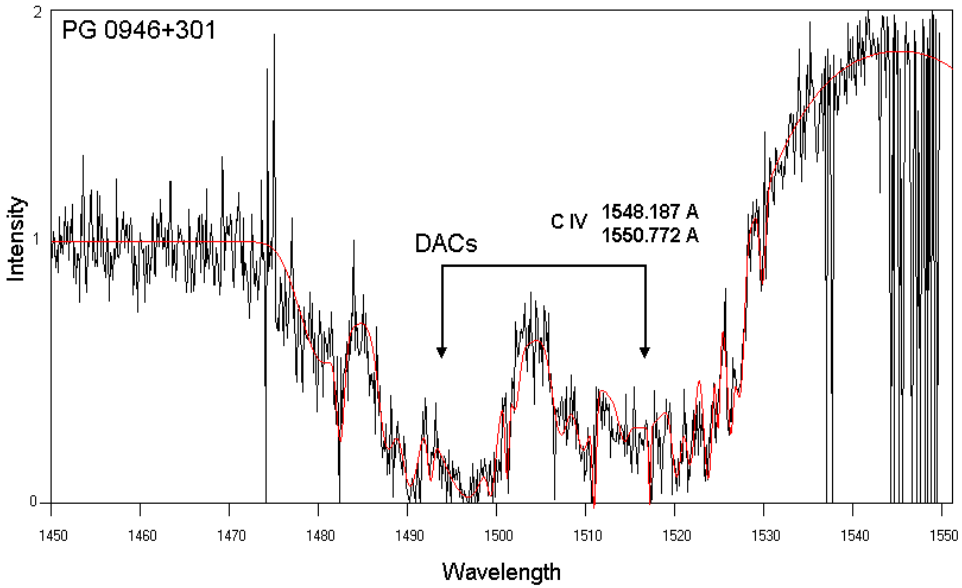

**The radial velocities of the CIV and NV density regions, as a function of apparent rotational velocities, in a sample of 20 Oe stars.**

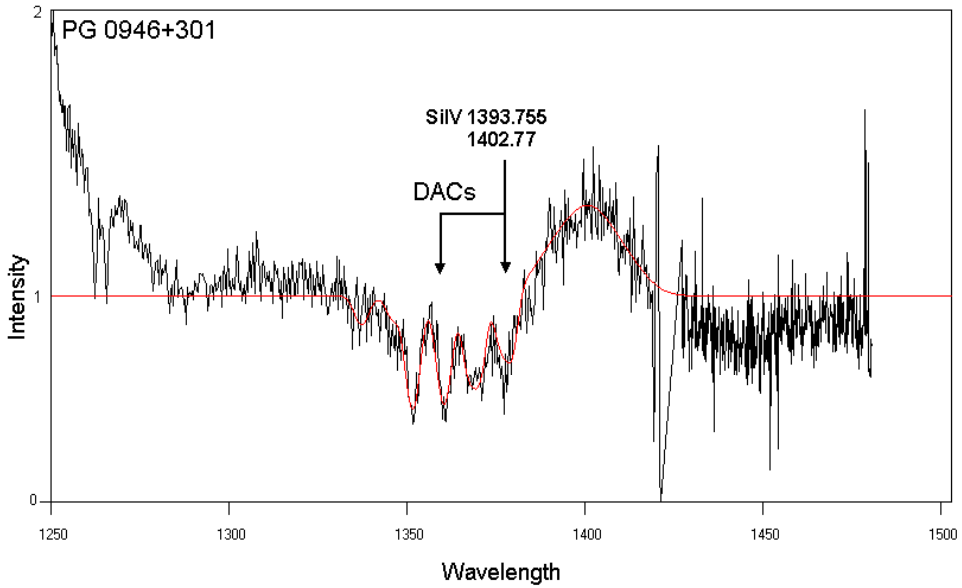
**Danezis et al. 2007 VI SCSLSA**

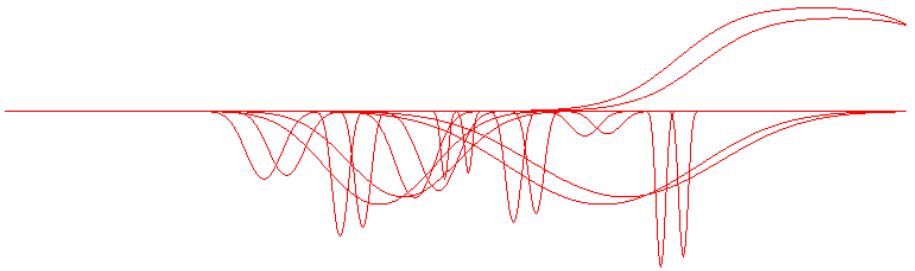

Study of AGNs spectra with GR model

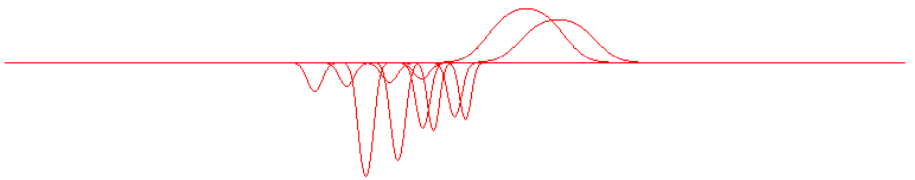
# Study of C IV/Si IV resonance lines in the spectrum of PG 0946+301

## (Lyratzi et al. 2008 19th ICSLS-poster paper)



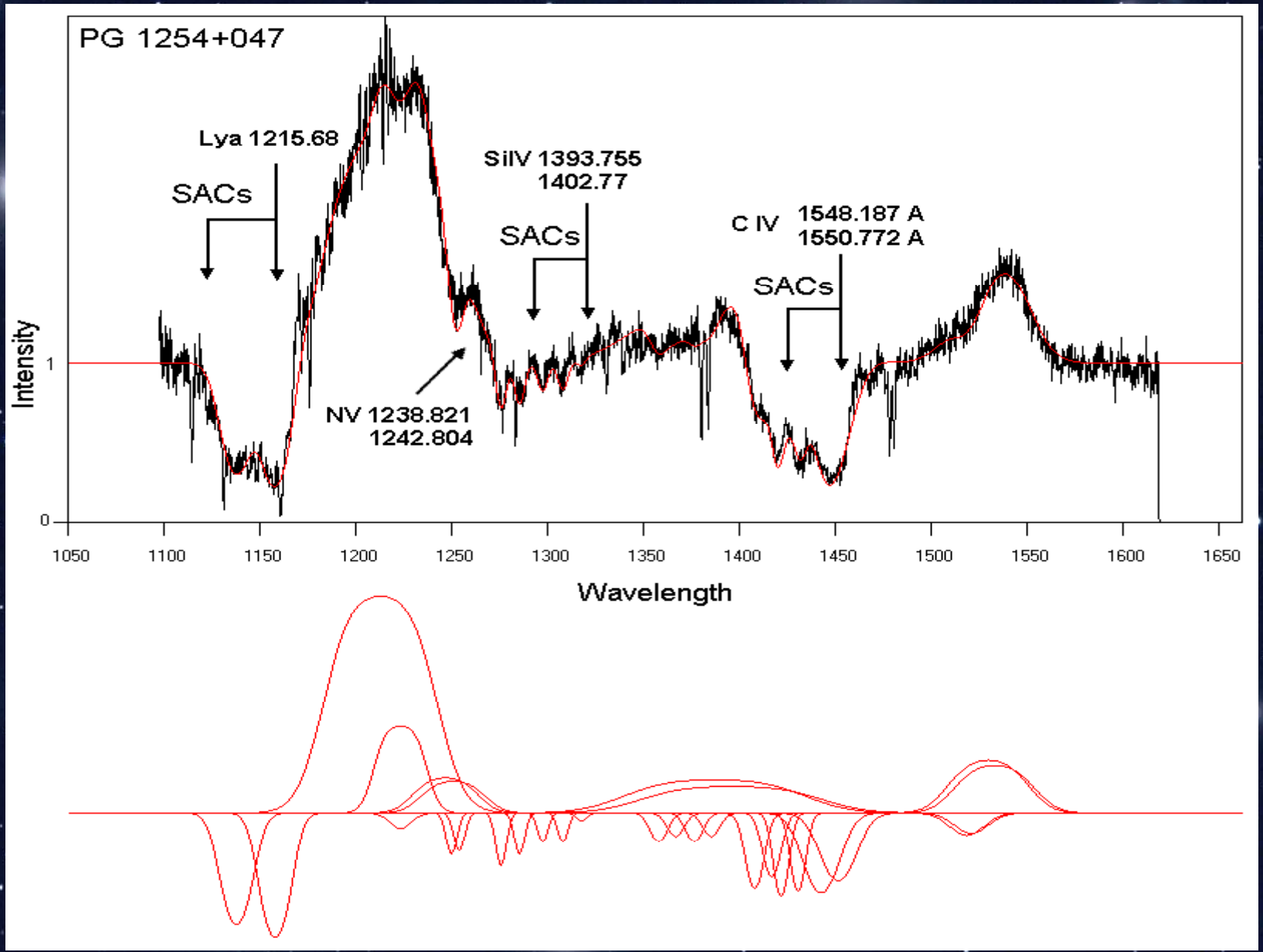



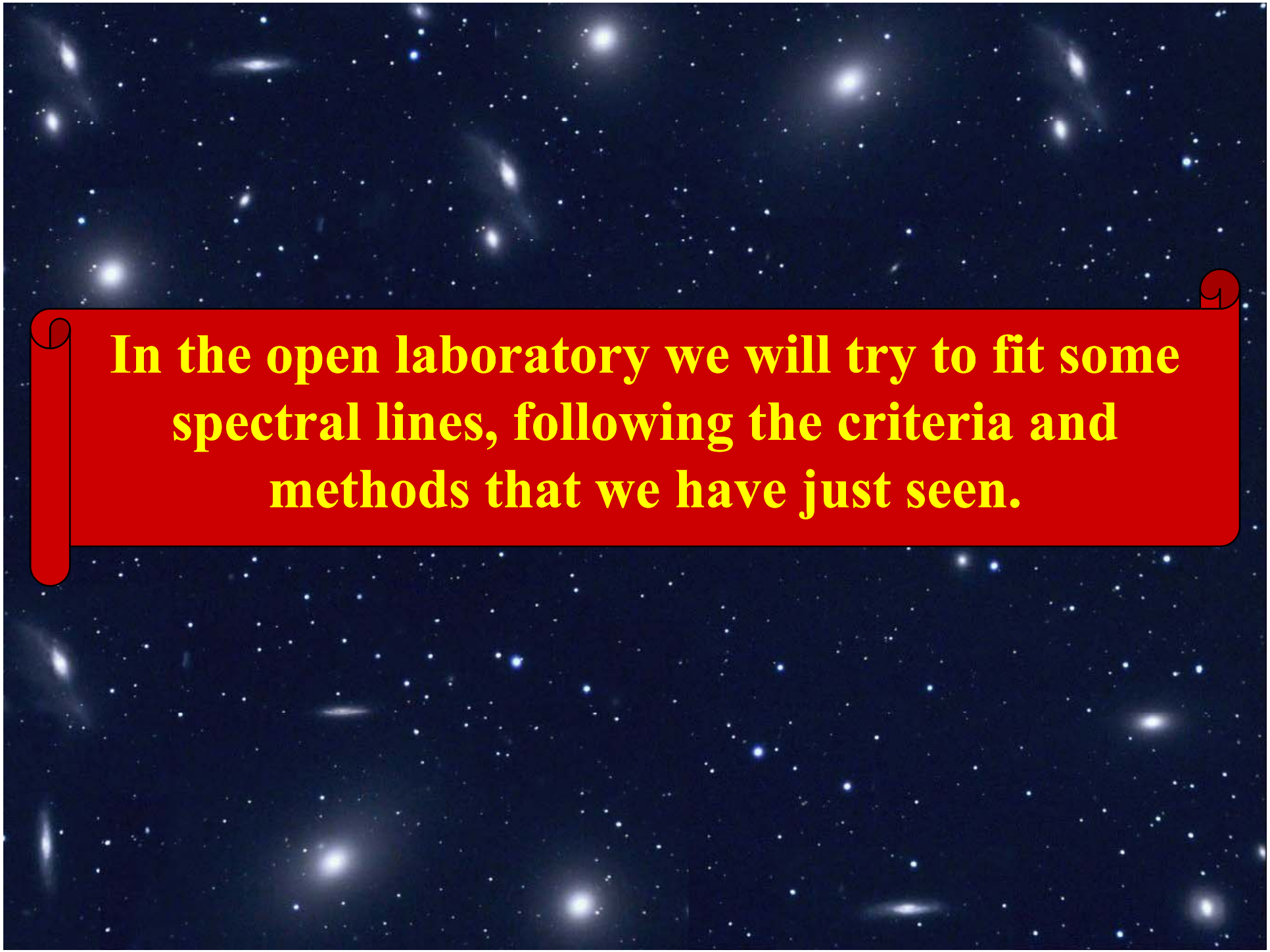





# Study of C IV/Si IV resonance lines in the spectrum of PG 1254+047

## (Lyratzi et al. 2008 19th ICSLS-poster paper)




In the open laboratory we will try to fit some spectral lines, following the criteria and methods that we have just seen.


Thank you very much for your attention