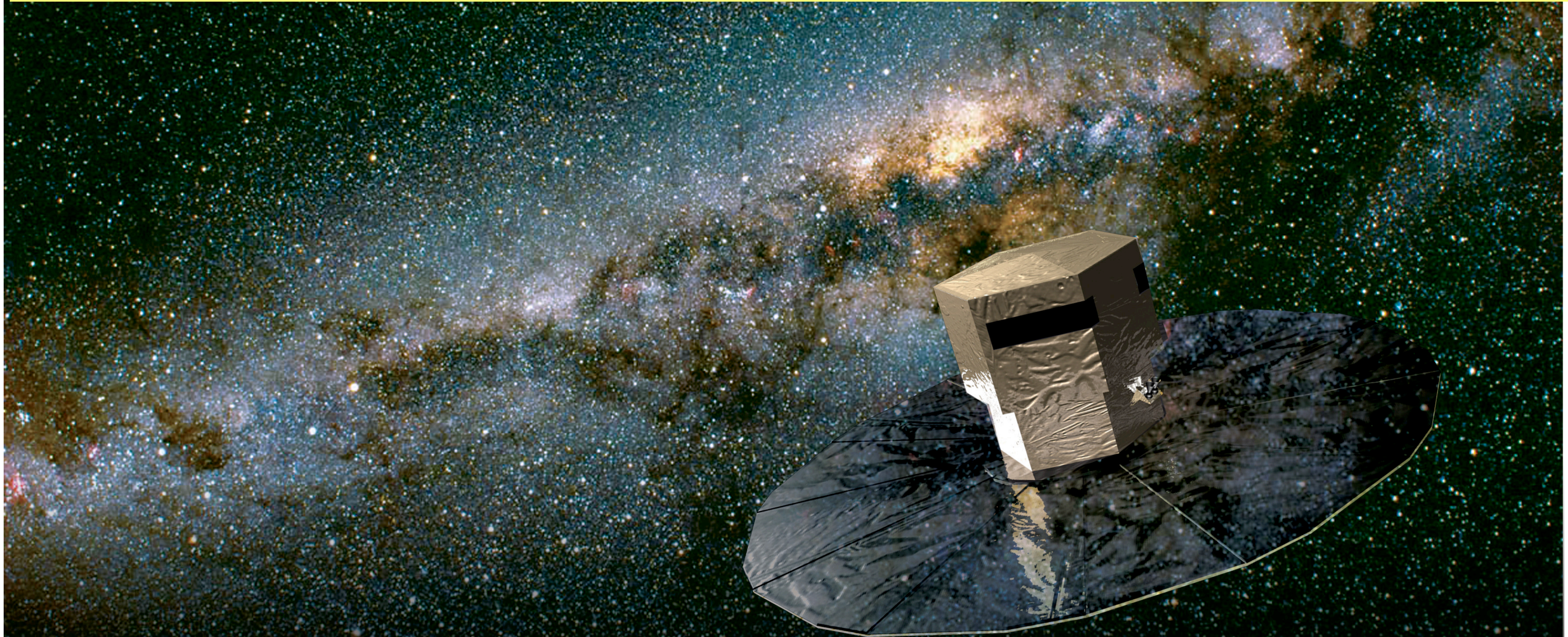
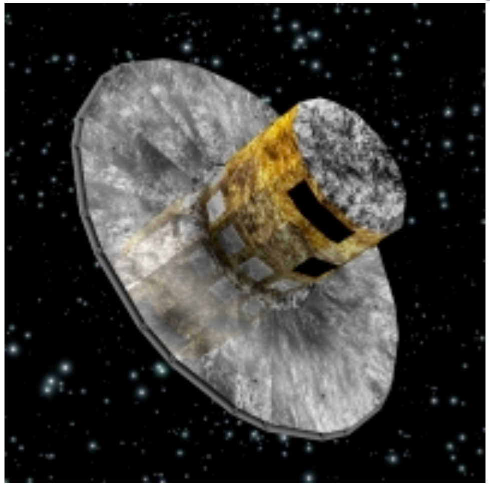
The GAIA satellite: a tool for Emission-Line Stars and Hot Stars



C. Martayan, martayan@oma.be
Y. Frémat, R. Blomme, A. Jonckheere,
M. Borges, B. de Batz, B. Leroy, R. Sordo, J.-C. Bouret,
F. Martins, J. Zorec, C. Neiner, Y. Naze, E. Alécian,
M. Floquet, A.-M. Hubert, D. Briot, A. Miroshnichenko,
I. Kolka, P. Stee, T. Lanz, G. Meynet

The space mission GAIA

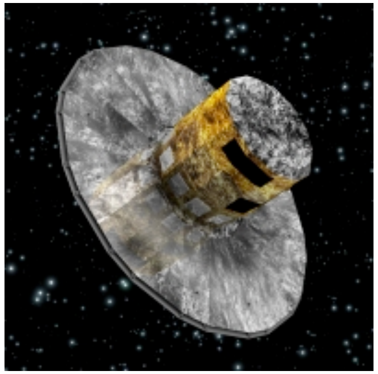
- **Mission:**
  - Launch: Dec-2011/2012
  - Mass: 2030kg
  - Orbit: L2, anti-solar
  - Lifetime: 5 years

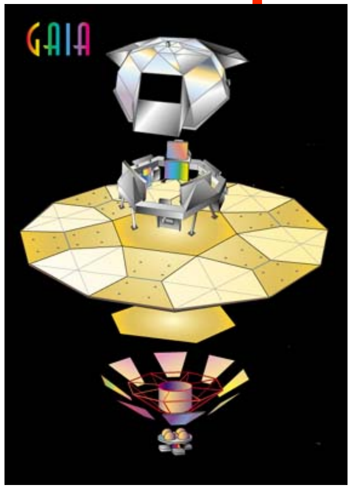


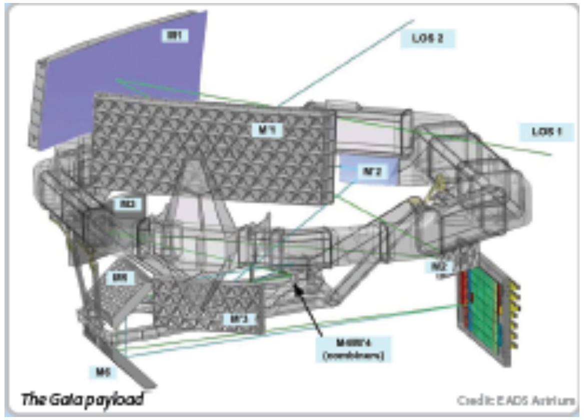
- **Instruments:**
  - **Astrometric measurements (ASTRO)**:
    density up to 3 million stars/deg², accuracy down to 20µas at G~20
    200 times more accurate than Hipparcos
  - **Bp/Rp spectrophotometers** (R~100, 320-660 & 650-1000nm)
  - **Radial Velocity Spectrometer** (RVS, R=5000-11500, 847-874nm, designed for GK stars, V~17, density up to 40000 objects/deg², accuracy of RV: 1km/s)
  - **1 billion of stars**
  - 106 CCDs (1 Gigapixels), **200 TeraBytes of data /year**

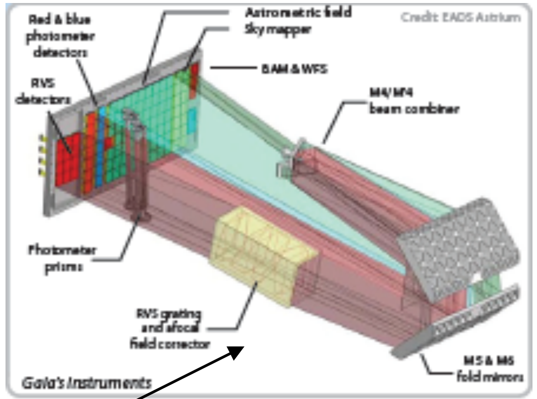
⇒ **Automatic treatments, new softwares, java algorithms**

The space mission GAIA

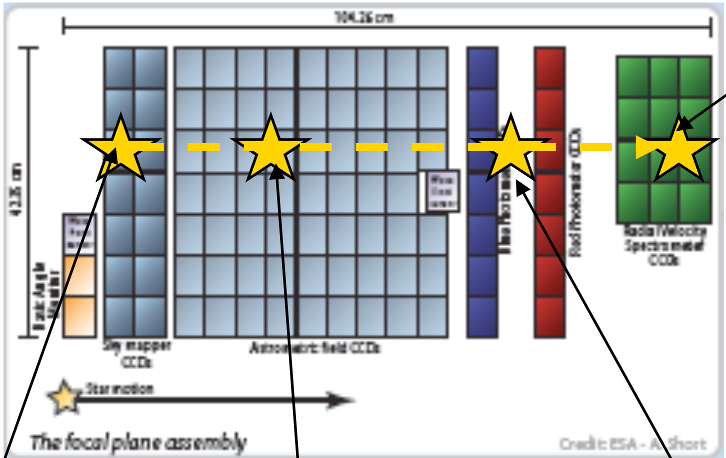


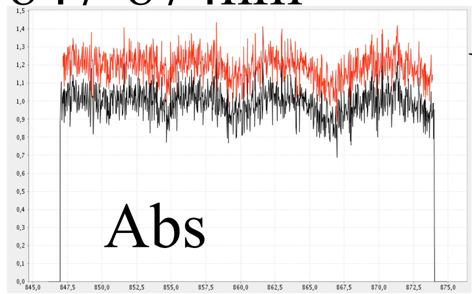




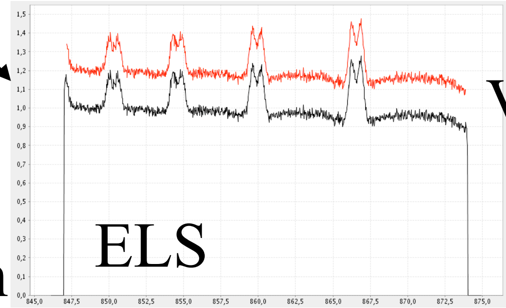


Spectroscopy RVS (G*K*)
R:5000-11500 847-874nm
CaII, Pa lines





V=14



V=6

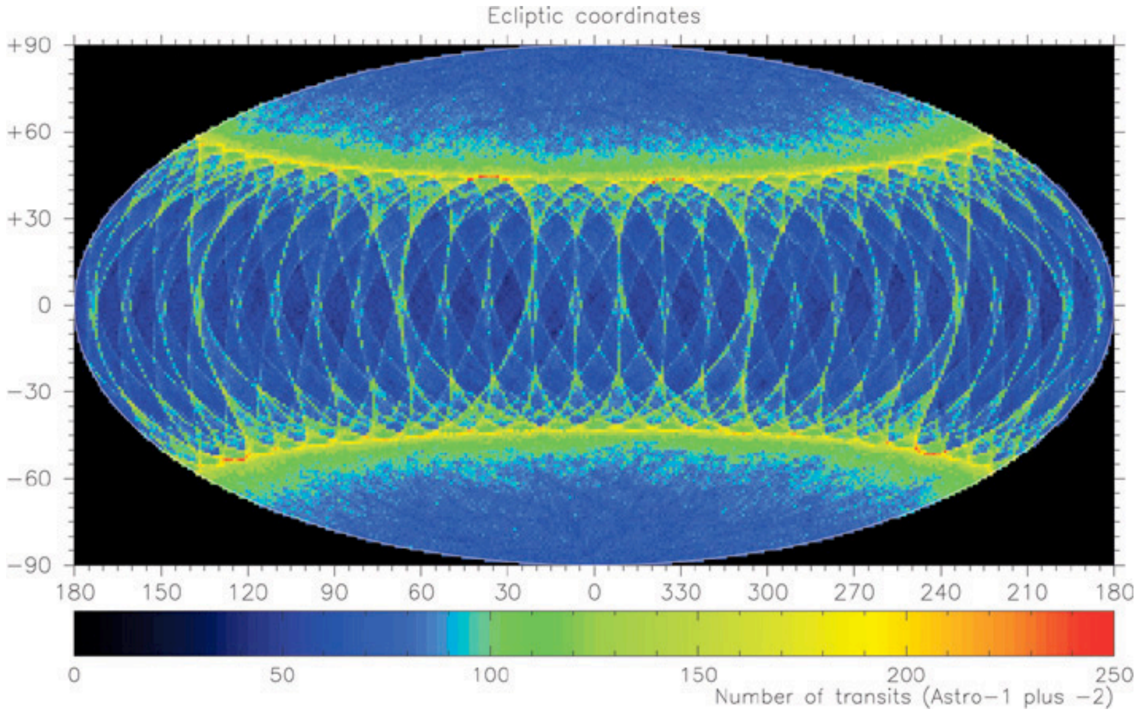
Spectro-photometry Bp/Rp
R~100, 330-660, 650-1000nm

Detection

Astrometry

RVS simulated spectra

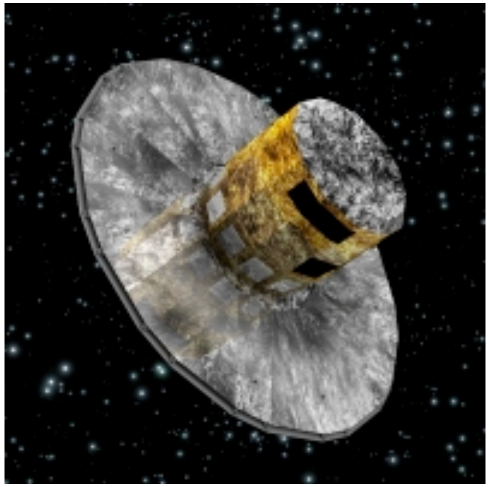
Observations/transits



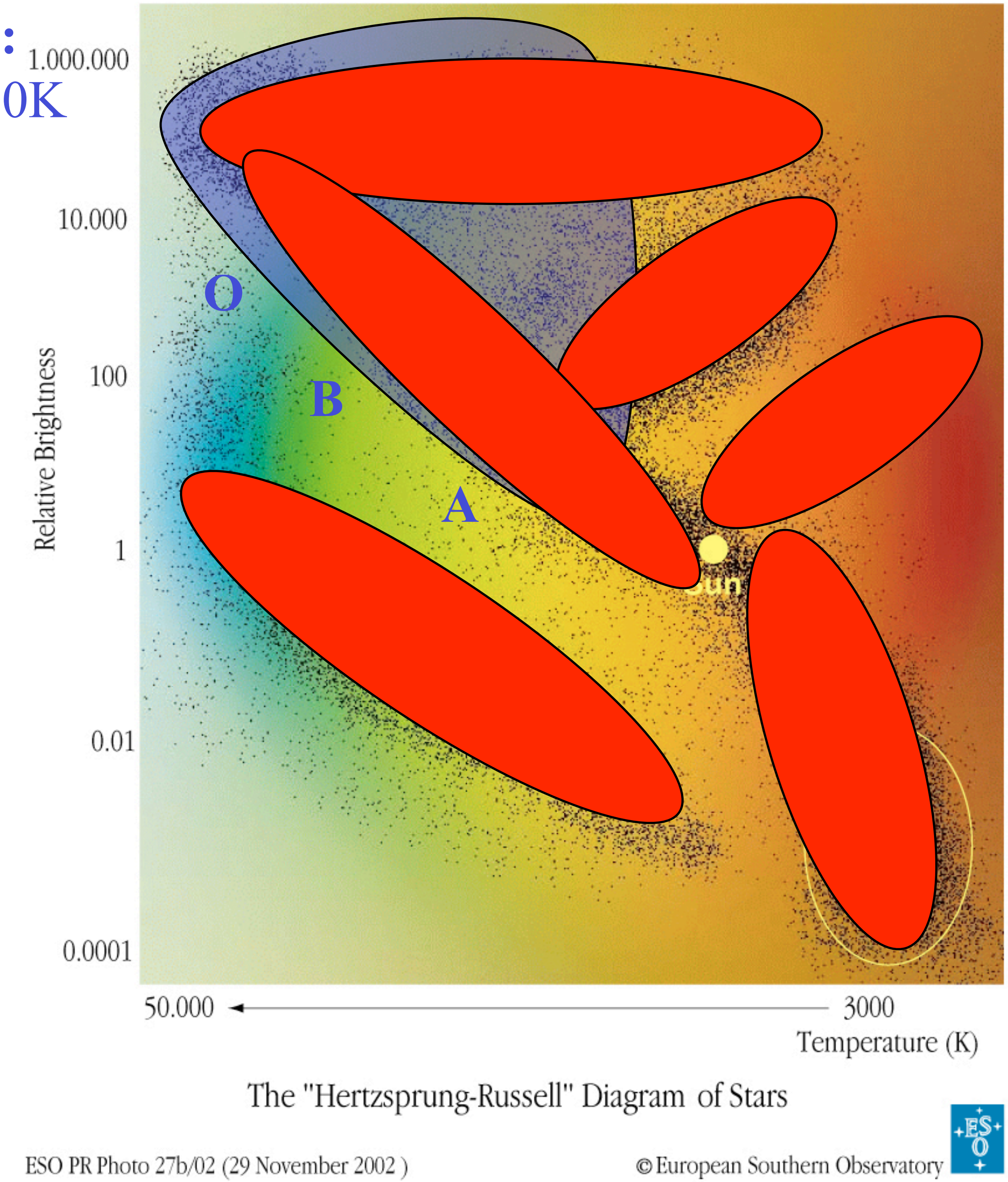
The average number of astrometric observations, (both astrometric fields) equals 83.

For RVS: 40 transits
For Bp/Rp: 70 transits

Introduction: main questions

 + ★ = ?

Hot stars:
Teff >7500K



Emission line stars:

Evolved or young

Cool or hot:

WR, LBV, Oe, Of, Be, Sge, PNe, HBe/Ae, B[e], HB[e], Mira e, TTauri, UV Ceti, Flare stars…

Introduction

- **ASTRO:** proper motion, distances (parallaxes) determinations
- **RVS spectroscopy:** radial velocity determination, spectroscopic fundamental parameters determination, detection of emission line stars (ELS), stellar classification
- **Bp/Rp spectrophotometry:** ELS detection, stellar classification, photometric fundamental parameters
- **How long?** N measurements/5years ⇒ objects variability
- **Where?** Objects in the Milky Way + bright objects in close local group galaxies (LMC, SMC, SDG).
- **How much?** 1 billion of stars

  Several million of hot stars, several 100000s of ELS

  (maxi: 68 million HS, 6 million ELS, estimated from IMF *Kroupa 2001*)

Introduction: main answers

- **Distances, proper motions, radial velocity:**
  - 3D static map
  - 3D dynamic map
  - (site of origin, site of formation, open cluster membership, ⇒ characteristics of stars: metallicity of origin, etc).
- **Distance:** statistical link between Mv and spectral types. If deviation ⇒ enlightening of « abnormal behaviour ». *Lamers et al. 1997*, calibration based on Hipparcos parallaxes, OB stars out of statistics: link with fast rotation?
- **Interstellar reddening map** (needs a lot of stars) ⇒ for each star reddening corrected ⇒ corrected magnitudes ⇒ reddening due to the disk (Be, HBe/Ae, etc).
- **Detection of new** Be, WR, other ELS ⇔ (40 to 70 transits)

Introduction

- **Be stars:** evolutionary status from absolute dereddened magnitudes and from spectroscopy (comparison)
- WR: indice of deviation from expected behaviour
- **Stars [e]**, >50% bad or not classified: SgB[e], PN[e], HB[e] because unknown distance
- **Binarity:** detection of companions (RVs, EBs):
  - Proportion of binaries among Be stars?
    75% *McSwain & Gies 2005* or 30% *Porter & Rivinius 2003*?
  - Proportion of binaries among hot stars?
    60% *O: *Sana 2007*, 30% *B: *Porter & Rivinius 2003*

⇔ Detection of new ELS (Be, embedded WR, etc)

⇔ Identification and classification of HS and ELS

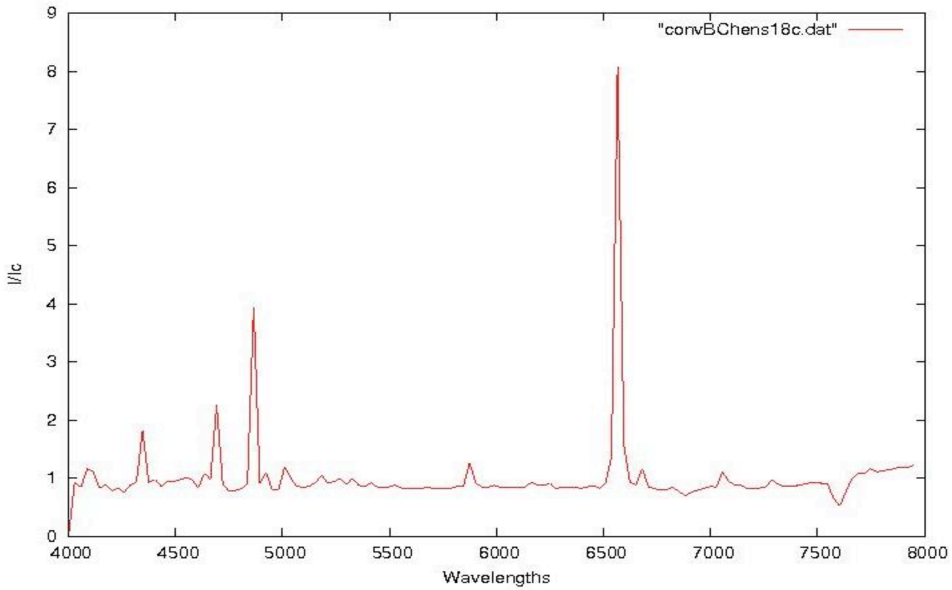
⇔ Astrophysical parameters of hot stars and ELS

Goals

CU6: Coarse Characterization of Sources (C. Martayan)
CU8: Extended Stellar Parametrizer (Y. Frémat)
CU8: Emission Line Stars (C. Martayan)
CU8: Hot Stars (R. Blomme)

- **Detection/identification** of new and known ELS, HS
- Flags about the presence of emission, lists of lines, variability
- **Spectral parameters** (EWs, I) of lines, statistics between Hα and Pa, CaII, between Pa themselves, etc
- **Fundamental parameters** of hot stars and/or **parameters of circumstellar disks**
- **Stellar classification**
- With 1 transit(=1 spectrum) or/and with combined spectra
- **Statistical studies** (3D distributions of stars, Ocl, metallicity, disks properties, etc.)

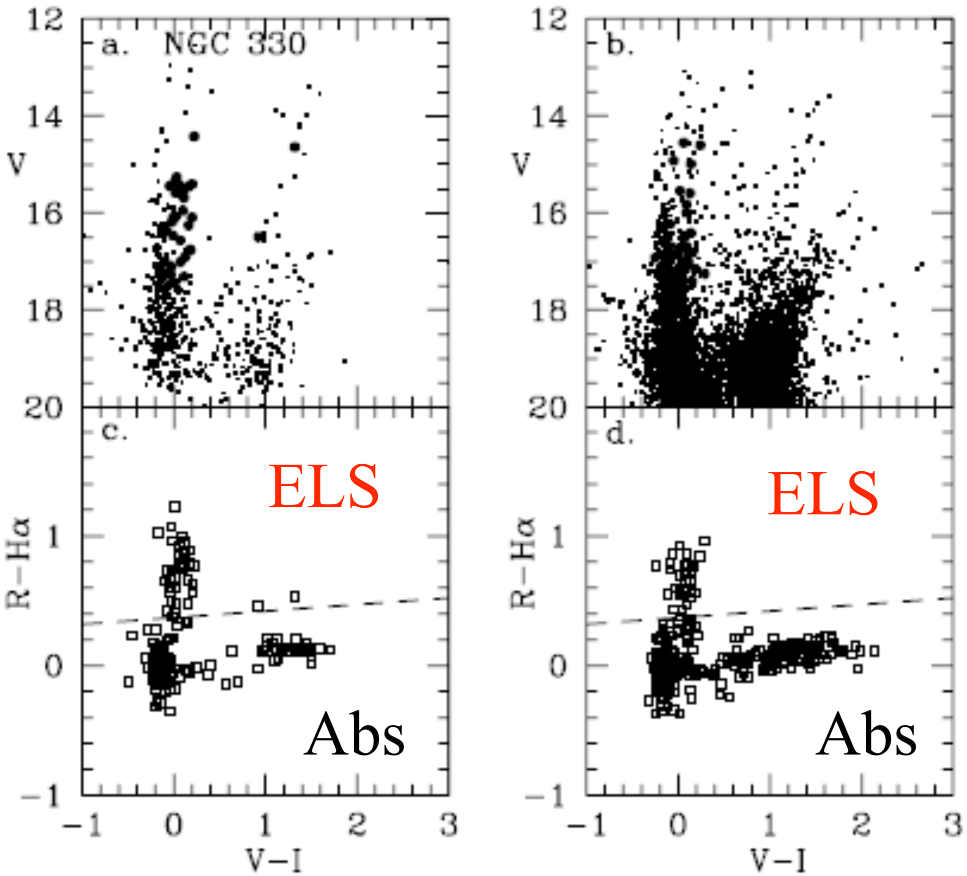
With Bp/Rp spectrophotometry



Bp/Rp Photometry & detection of ELS

possible Johnson filters : U, B, V, R, I

possible Geneva filters: U, B1, B, B2, V1, V, g



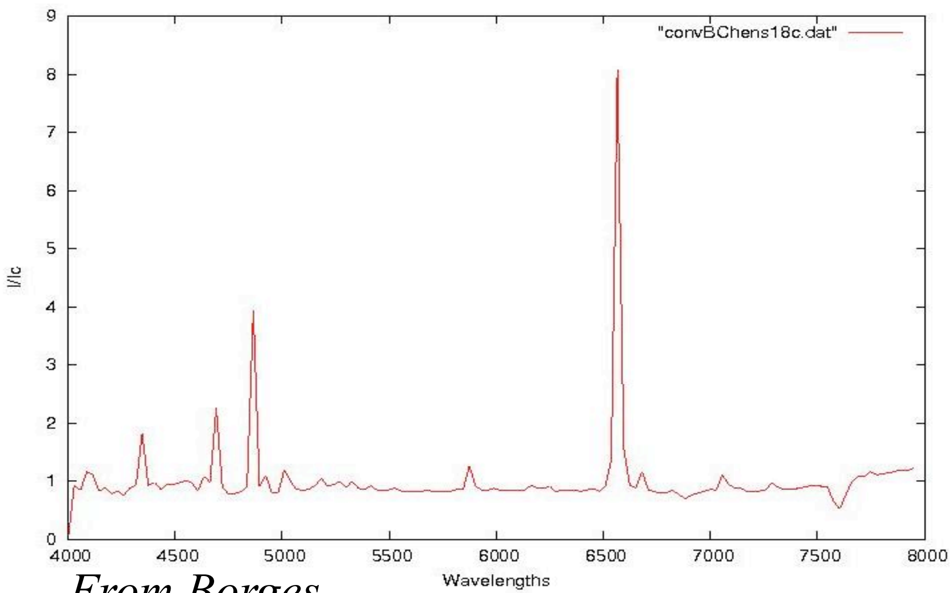
Use of this type of diagramme to detect the ELS in Hα from Bp/ Rp.

Pb: needs to know and correct the instrumental response (not yet done)

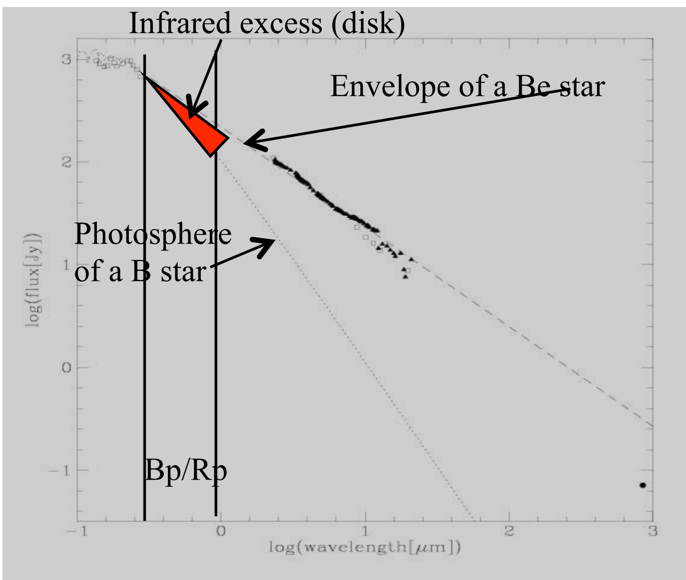
Keller et al. 1999

From Bp/Rp spectrophotometry

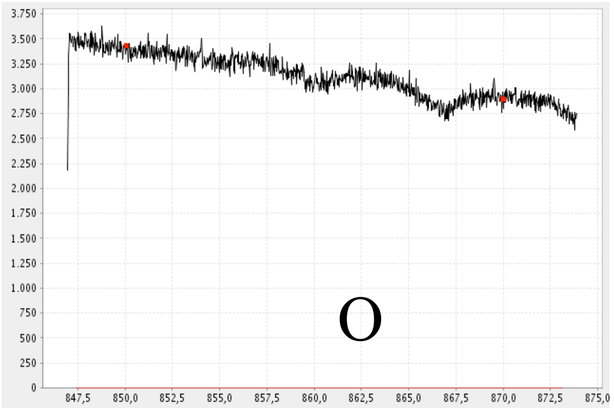
- Stars till mag. G~20
- Fundamental parameters from photometry
- ELS with Hα emission (in Bp/Rp) without emission in the RVS
- R~100, only strong lines can be seen (for emission: mainly Hα)
- SEDs, detection of disks, fits of them

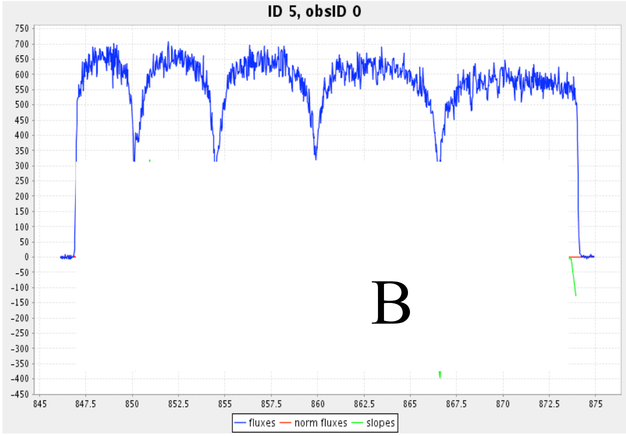


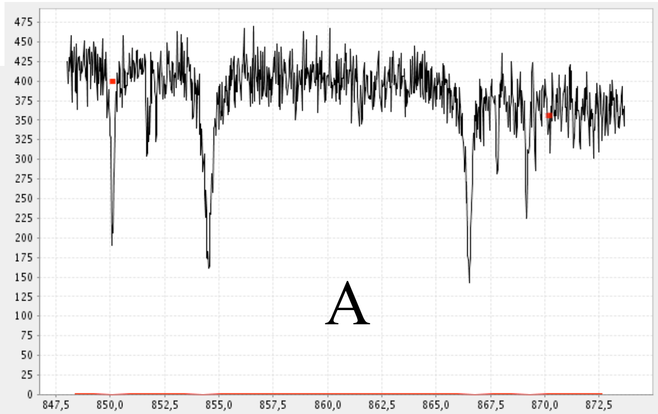
From Borges



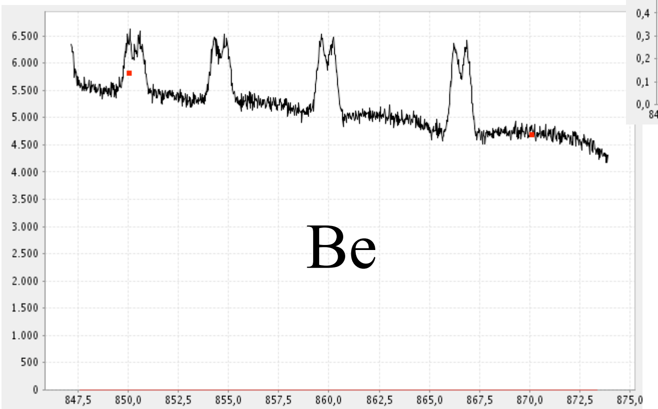
From Neiner

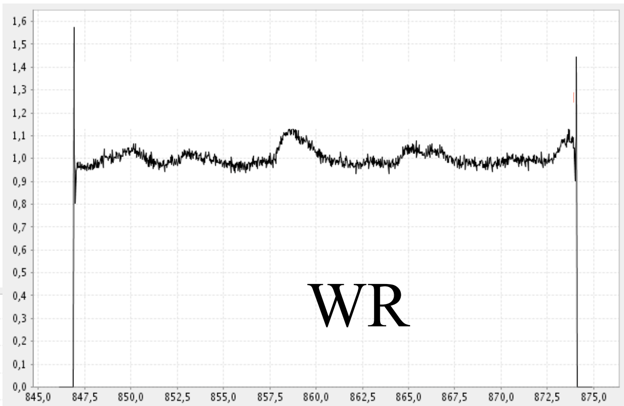


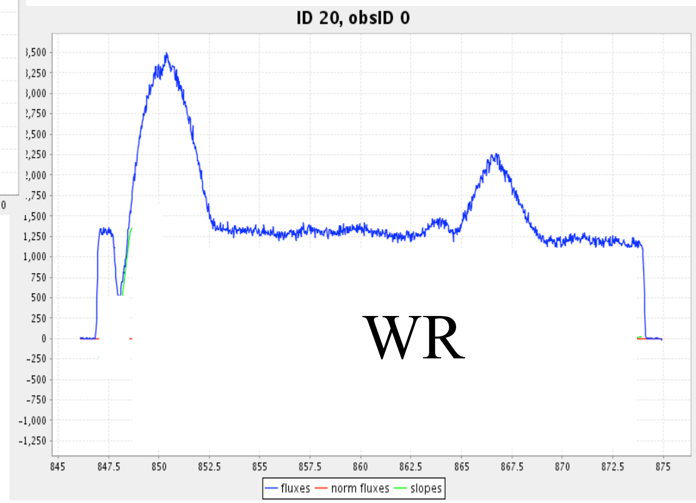




With RVS spectroscopy



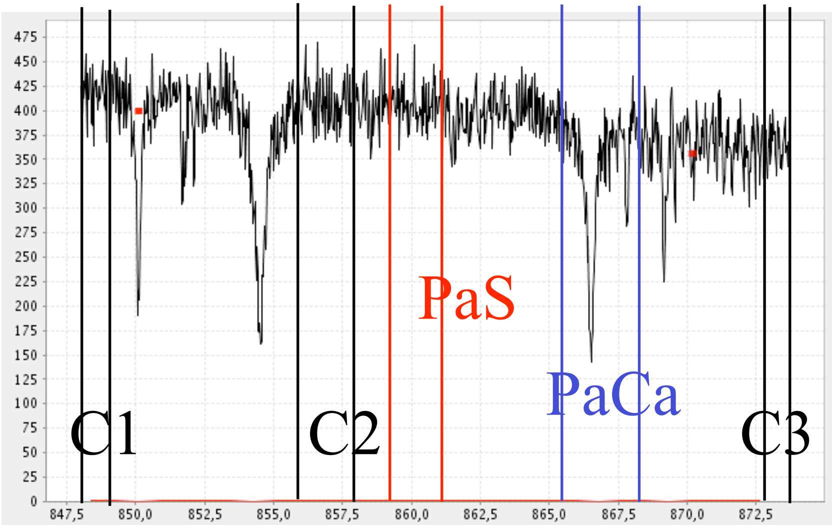


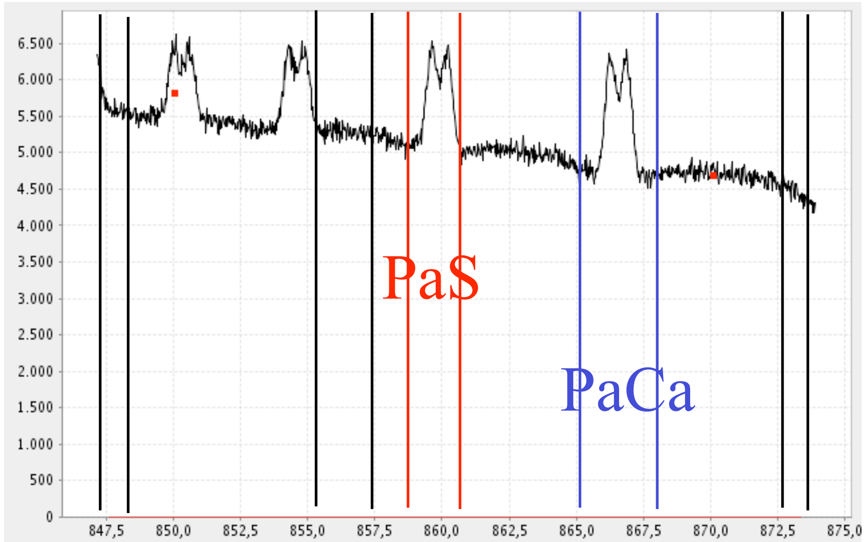


Simulated spectra from CU2

Photometry & detection of ELS with the RVS

- To provide a first robust clue on the presence of emission lines
- Compute magnitudes filters in the RVS
- Normalize the magnitudes to the size of the filters
- Compute theoretical magnitudes
- Compute colour indices
- Colour/colour diagrams for ELS and ABS stars.





Filters: C1, C2, C3, PaS, PaCa

Theoretical mag at PaS and PaCa by linear interpolation between C2 and C3

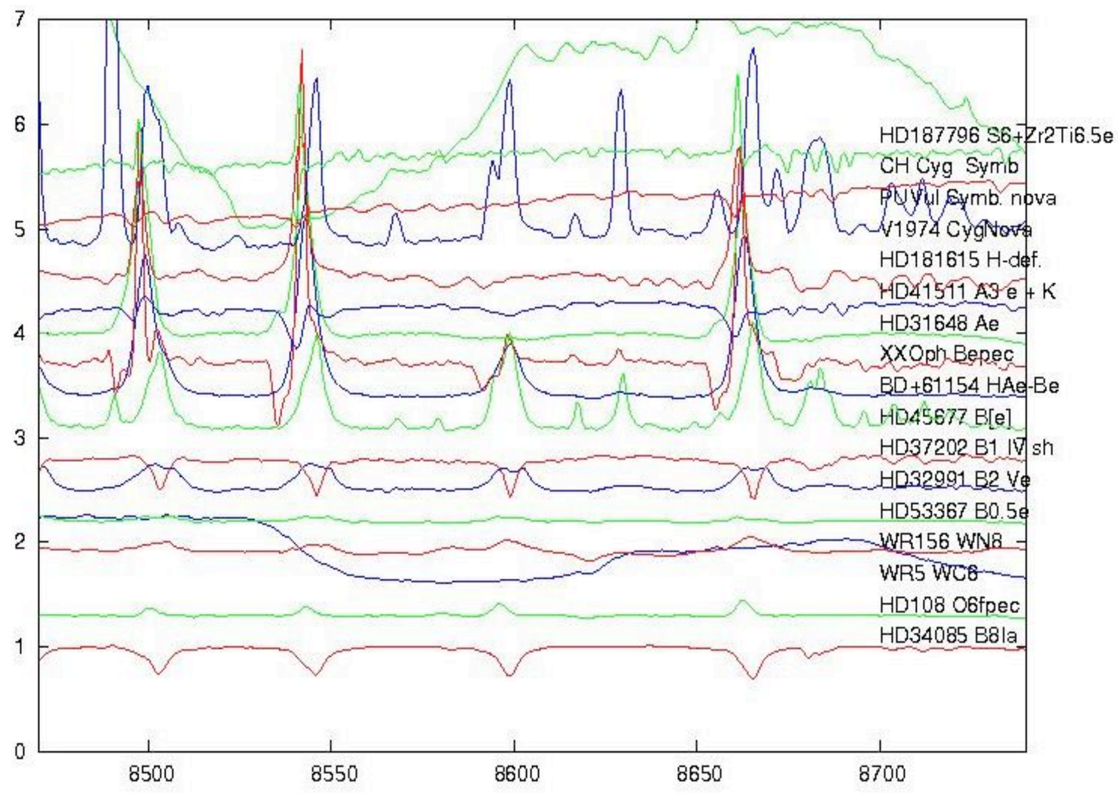
IC: C1-C3, MagTh_PaCa – PaCa, MagTh_PaS – PaS

⇒ Flag: presence of emission

- Tests on HR simulated spectra for normal stars (Teff:4000, 5500, 7500, 10000, 20000, 30000, 39000 K)
- Tests on simulated spectra for ELS: Be and WR
- Tests on observed spectra from *Andrillat et al. (1995)* from different kinds of ELS(∇) and normal stars (spectra normalized to the continuum)
- Total **~500000 spectra**

Known **ELS in Hα** but **without emission** in the **RVS** domain.

Emission in the RVS: from CaII or from Pa or Ca and Pa together or other lines (He, C, N)

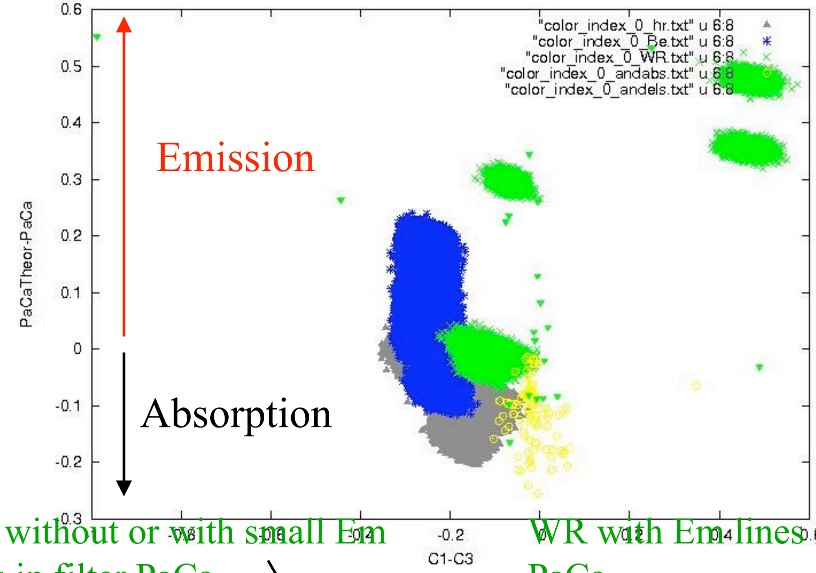


Blue: simulated Be, green: simulated WR, grey: simulated Absorption*

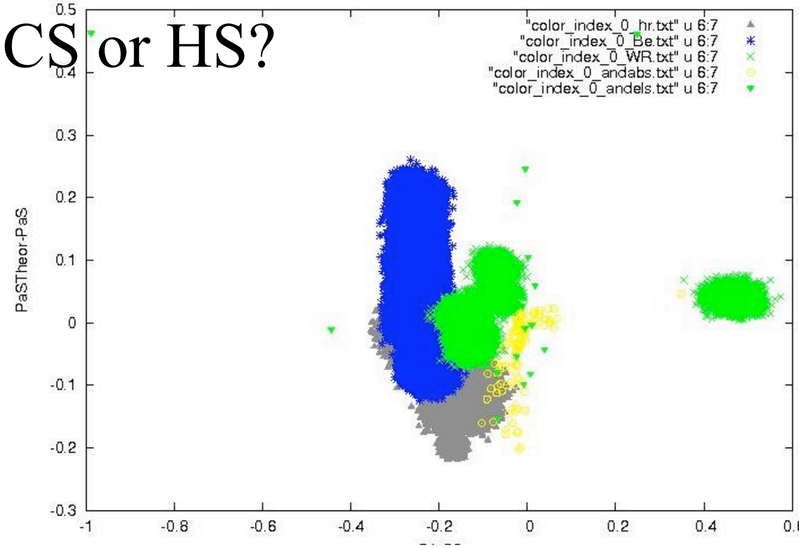
Yellow: observed absorption, green ∇: observed ELS (Hα or/and RVS)

~500000 spectra

Filter PaCa: detection of emission



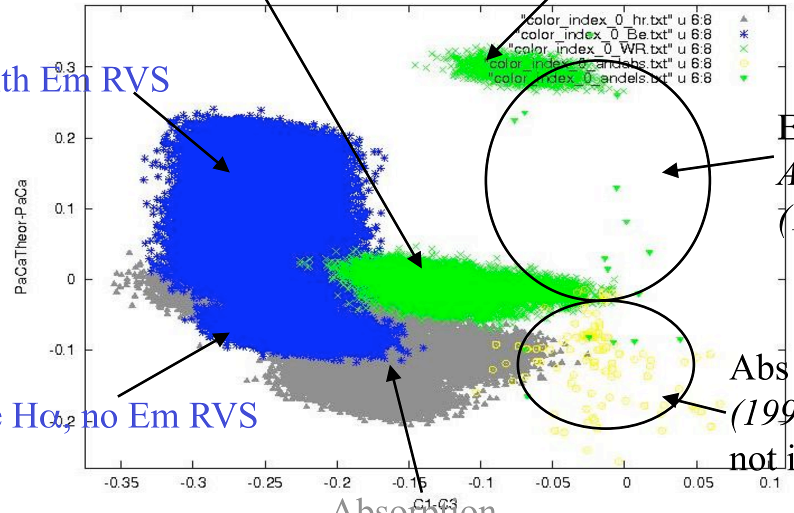
Filter PaS: if emission: Pa or not? CS or HS?



WR without or with small Em lines in filter PaCa

WR with Em lines in filter PaCa

Be with Em RVS

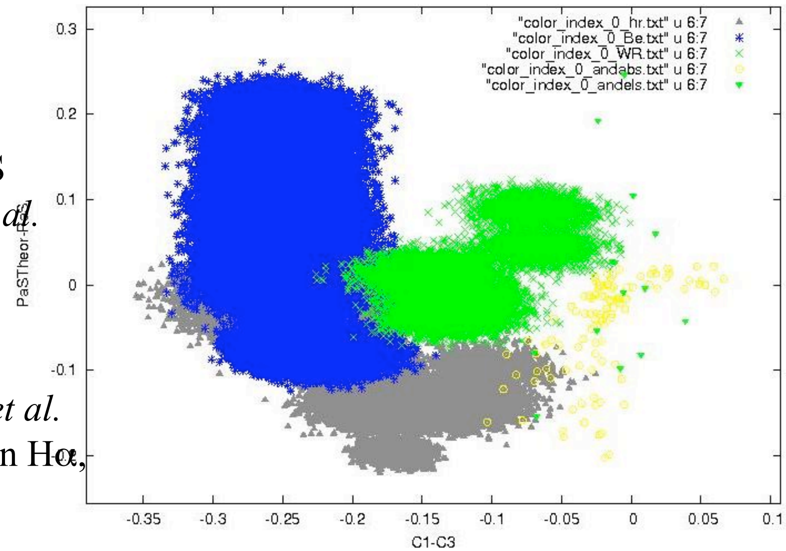


ELS in RVS *Andrillat et al. (1995)*

Abs *Andrillat et al. (1995)* + ELS in Hα, not in RVS

Be Hα, no Em RVS

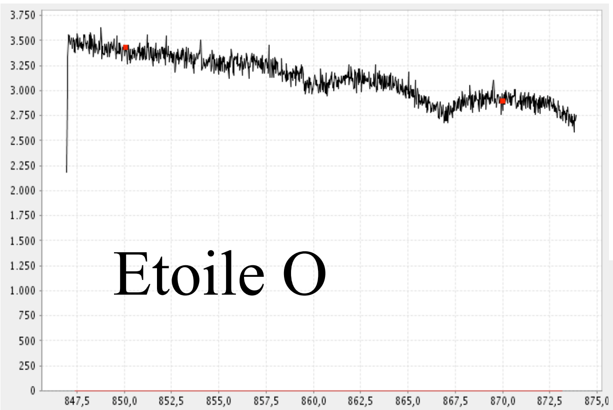
Absorption

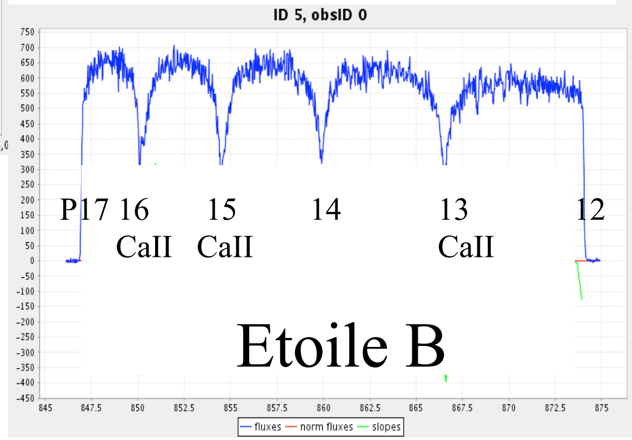


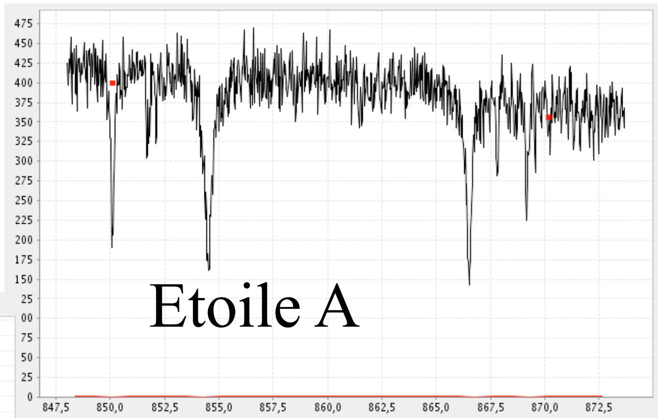

Hot Stars

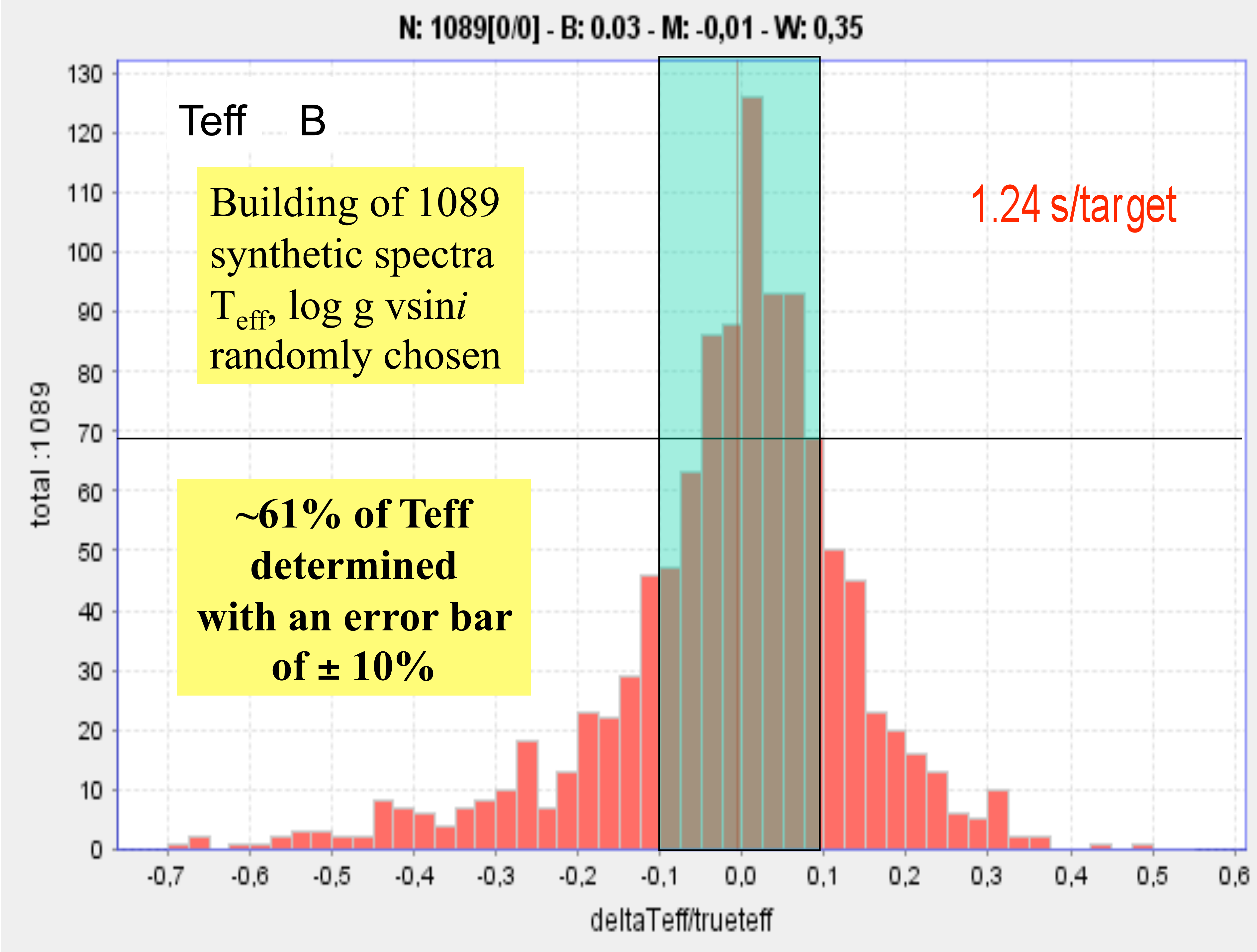
Hot Stars

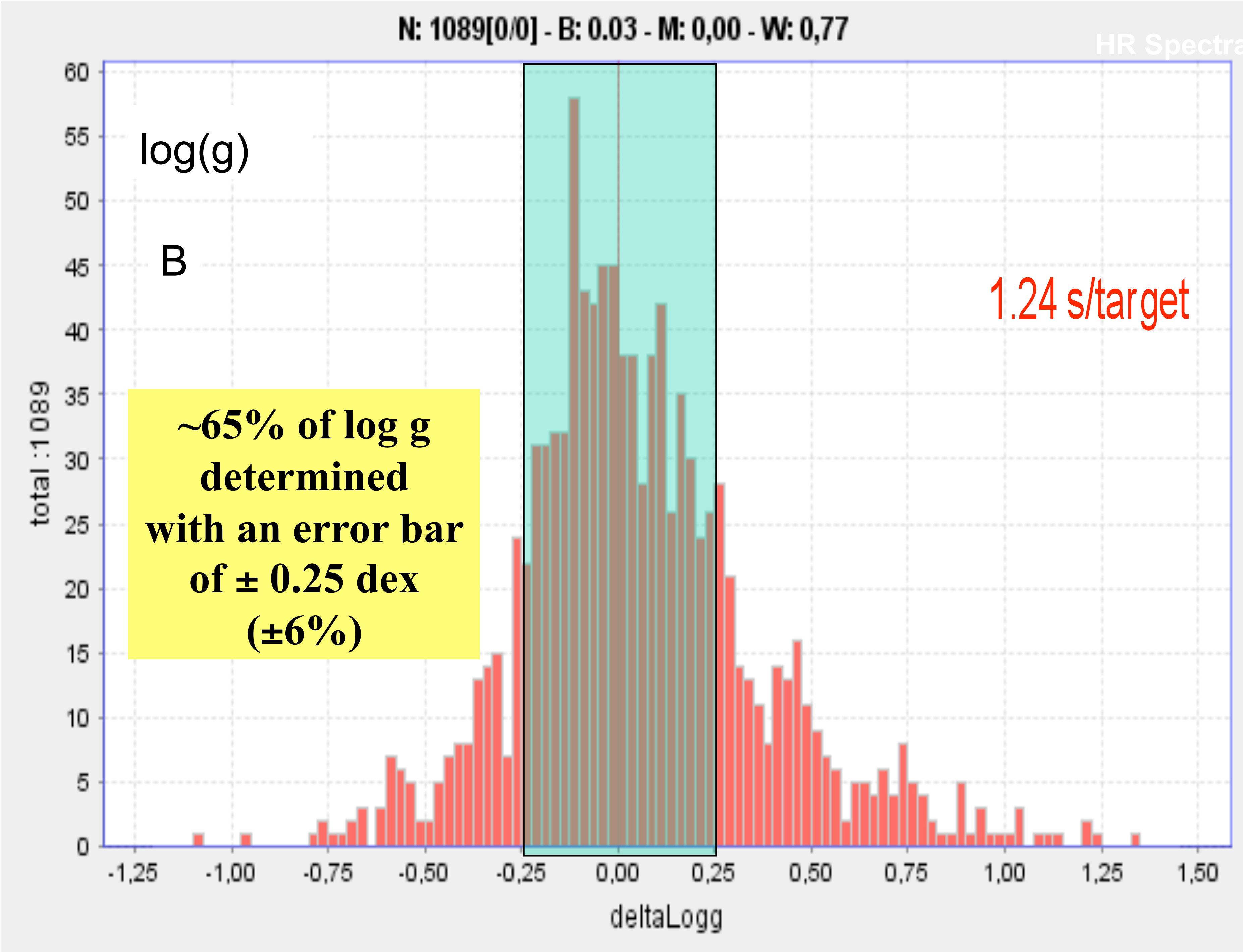
- Determination of fundamental parameters by fitting observed spectra with models NLTE+ winds (Sg, O).
- Ratios of lines (EWs or I)
- Classification by diagrammes in EWs or calibration in Teff-logg plane
- Rotation: determination of Vsini



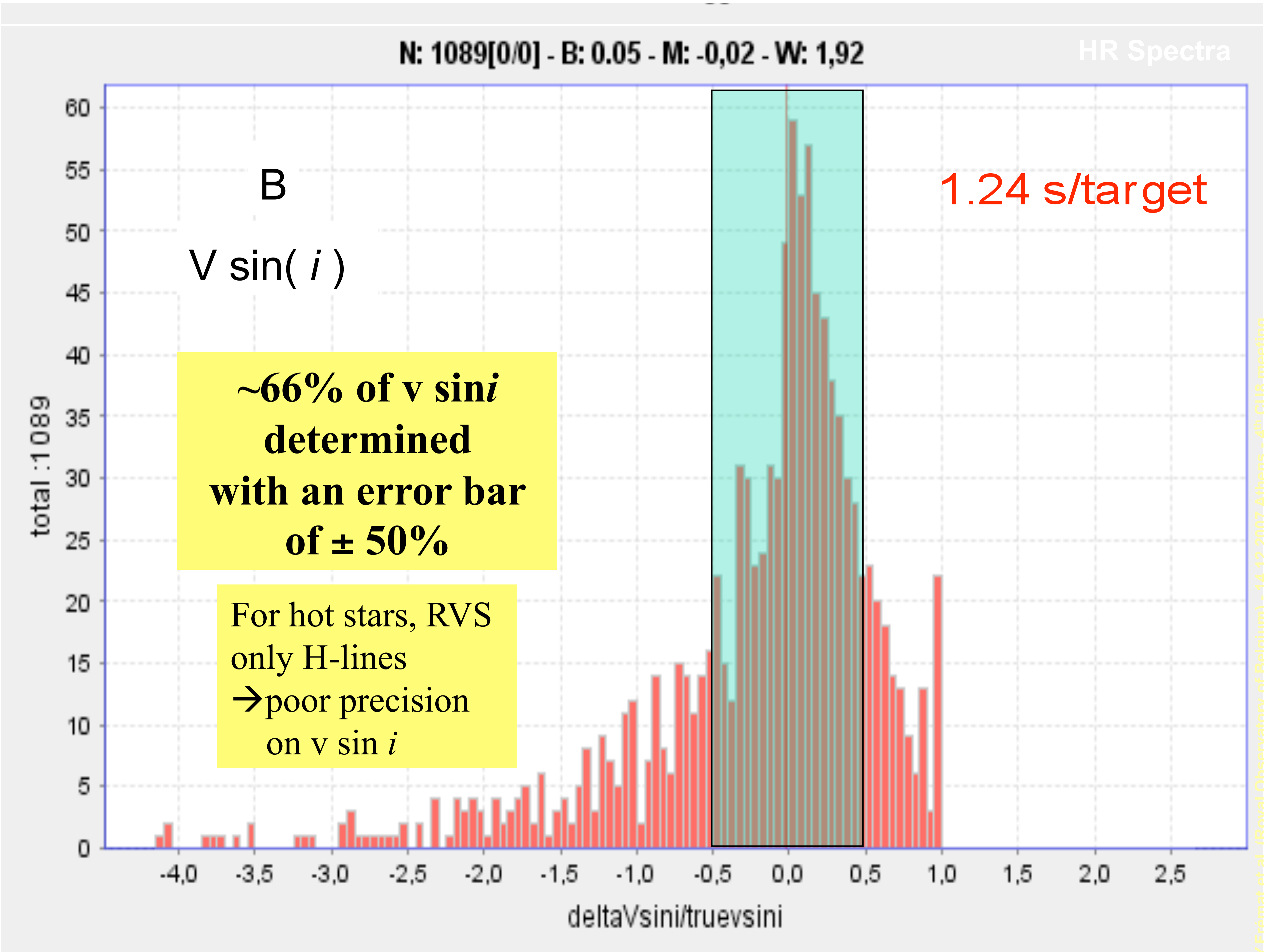




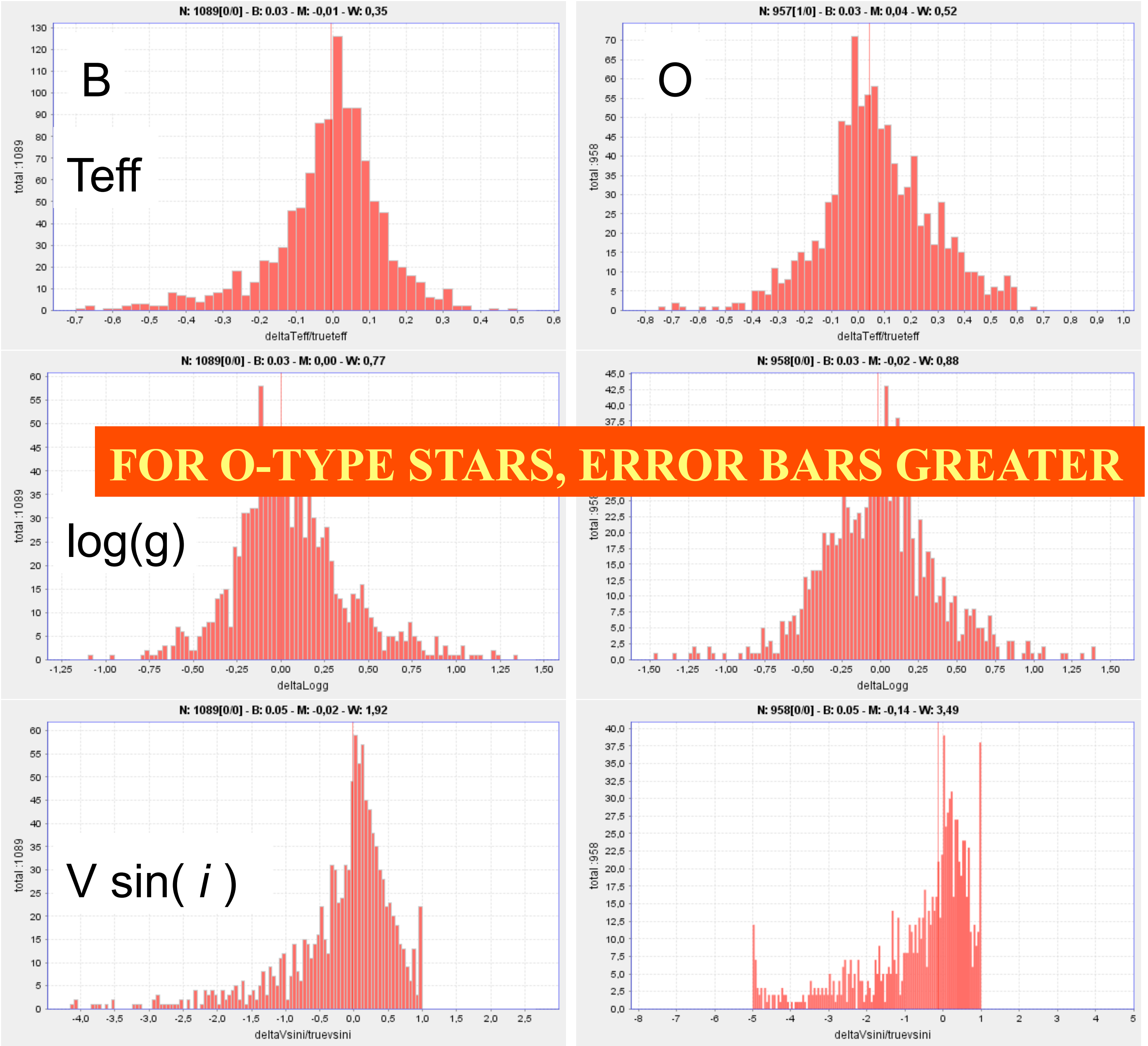

N: 1089[0/0] - B: 0.03 - M: -0,01 - W: 0,35
Teff B
Building of 1089 synthetic spectra T_{eff}, log g vsin*i* randomly chosen
1.24 s/target
~61% of Teff determined with an error bar of ± 10%
total :1089
deltaTeff/trueteff
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-0,7
-0,6
-0,5
-0,4
-0,3
-0,2
-0,1
0,0
0,1
0,2
0,3
0,4
0,5
0,6



N: 1089[0/0] - B: 0.03 - M: 0,00 - W: 0,77
HR Spectra
log(g)
B
1.24 s/target
~65% of log g determined with an error bar of ± 0.25 dex (±6%)
total :1089
deltaLogg
60
55
50
45
40
35
30
25
20
15
10
5
0
-1,25
-1,00
-0,75
-0,50
-0,25
0,00
0,25
0,50
0,75
1,00
1,25
1,50



N: 1089[0/0] - B: 0.05 - M: -0,02 - W: 1,92
HR Spectra
B
V sin(i)
1.24 s/target
~66% of v sini determined with an error bar of ± 50%
For hot stars, RVS only H-lines
→poor precision on v sin i
total :1089
deltaVsini/truevsini
0
5
10
15
20
25
30
35
40
45
50
55
60
-4,0
-3,5
-3,0
-2,5
-2,0
-1,5
-1,0
-0,5
0,0
0,5
1,0
1,5
2,0
2,5

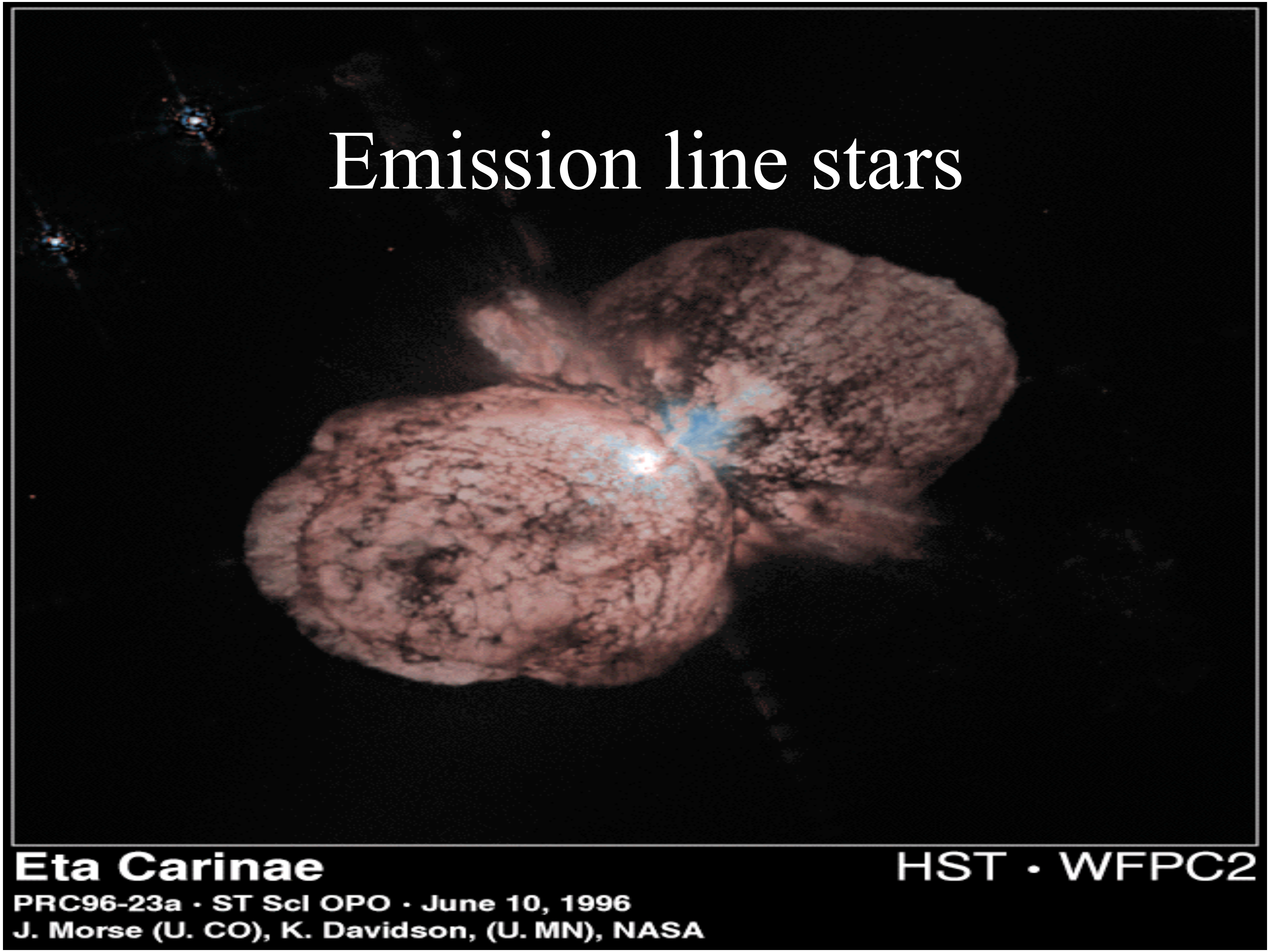


FOR O-TYPE STARS, ERROR BARS GREATER

1.24 s/target

Hot Stars Random testing

Emission line stars



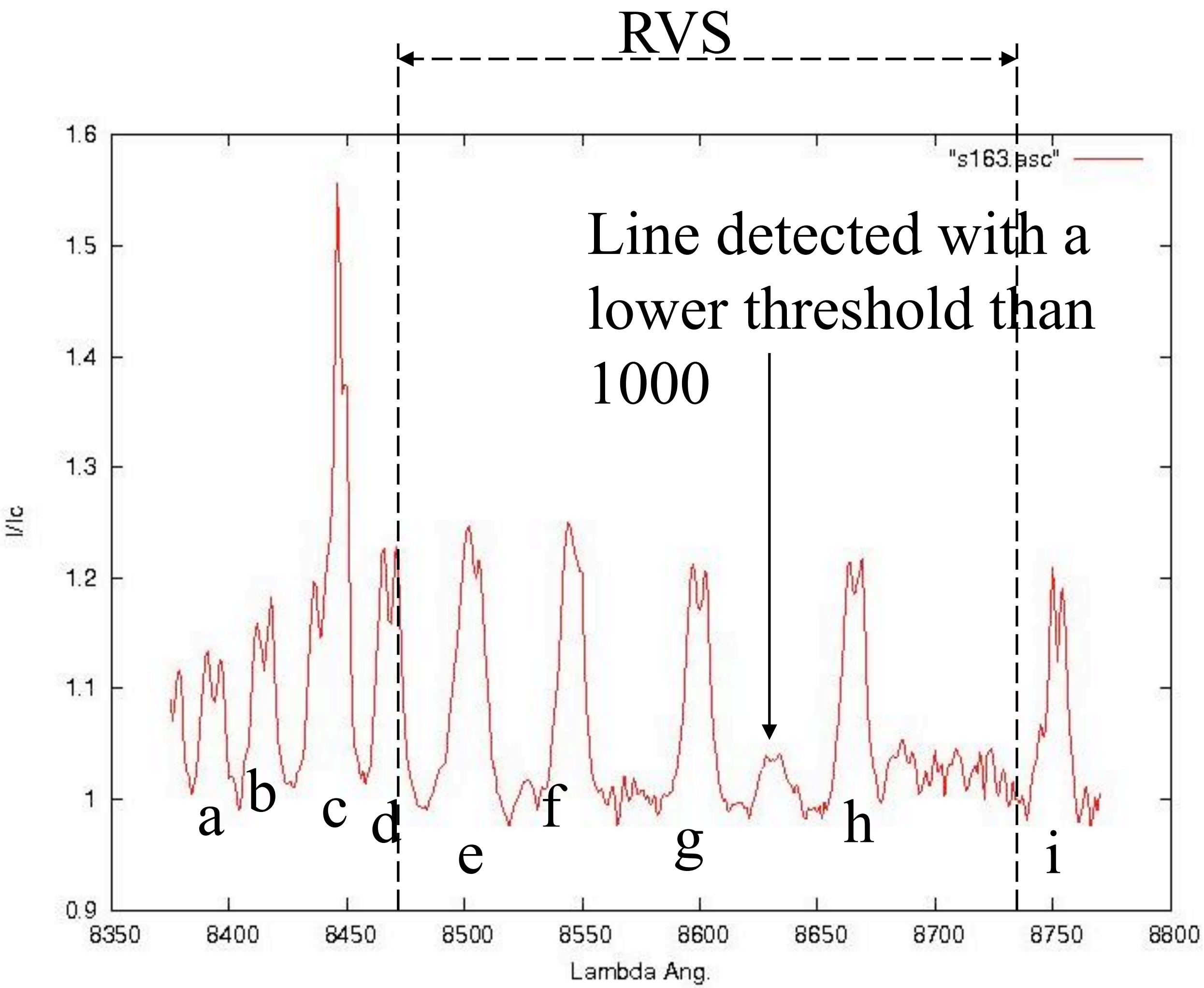
Different algorithms for detecting emission lines (CU6 and CU8)

Based on S/N variations, on local slopes variations, line-fitting:

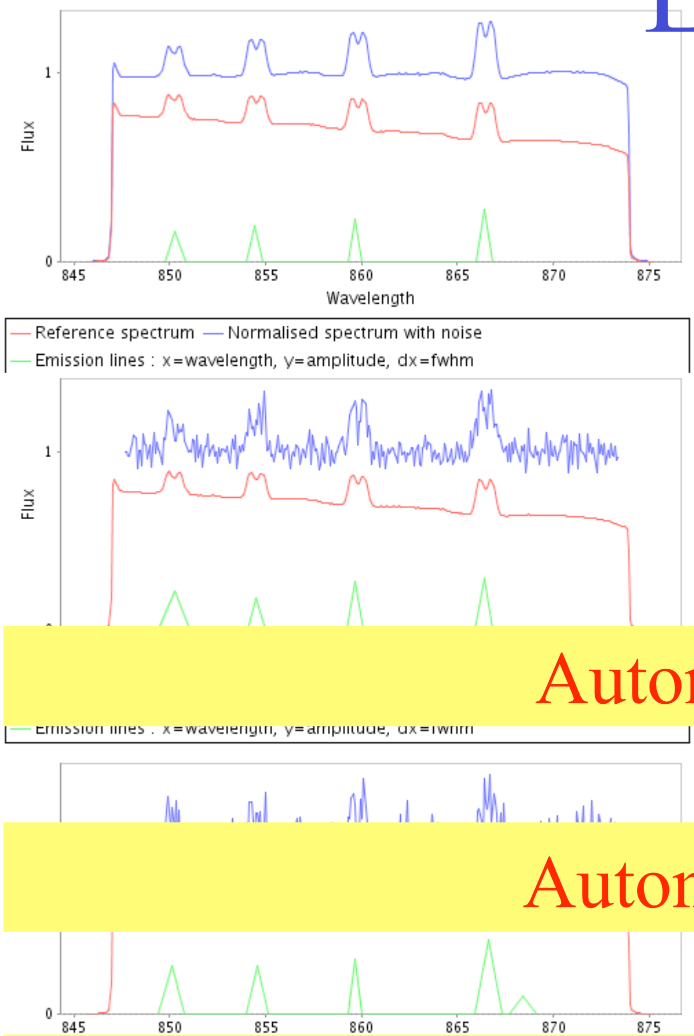
Example:

Emission (Be star from observed spectra)

```
id|obsid|emissionFlag:boolean|centralWavelength:double
163|0|true|838.95 a
163|0|true|841.95 b
163|0|true|844.95 c
163|0|true|847.95 d
163|0|true|850.95 e
163|0|true|853.95 f
163|0|true|859.95 g
163|0|true|865.95 h
163|0|true|874.95 i
```



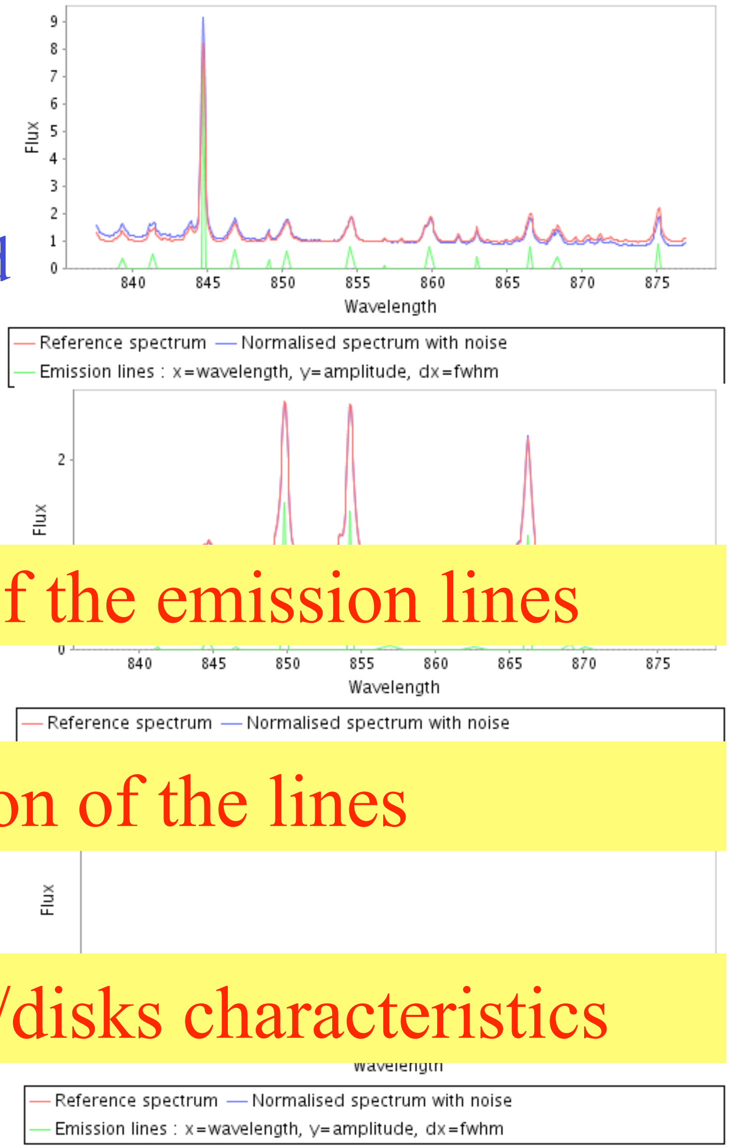
Emission Line Stars



Reference spectrum

Normalized spectrum

Lines detected



Automatic detection of the emission lines

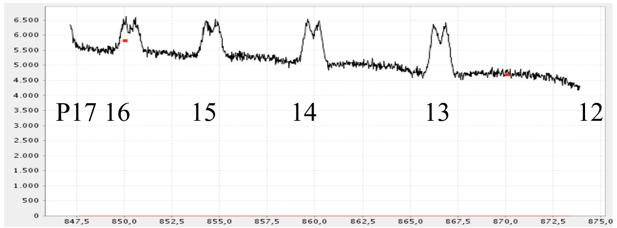
Automatic identification of the lines

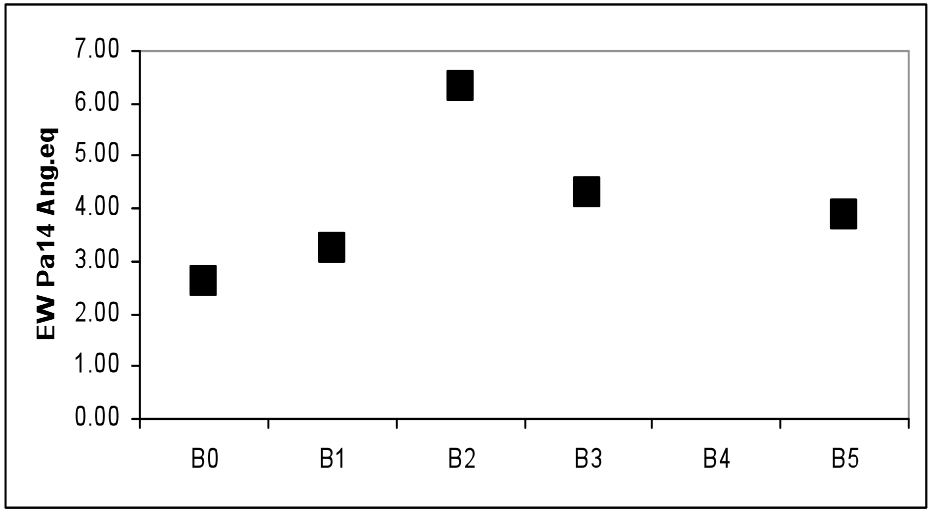
Modelling the emission lines/disks characteristics

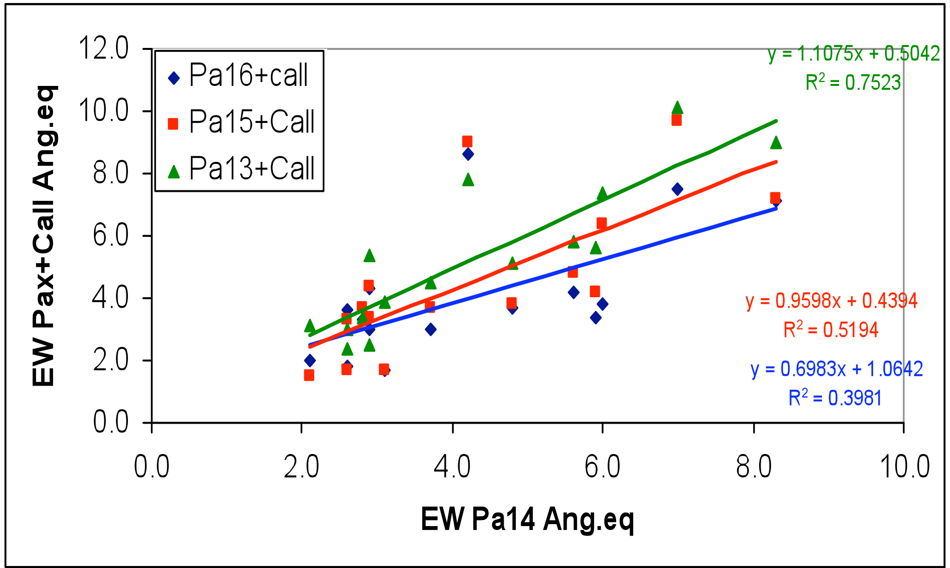
Synthetic simulated spectra for Be stars,
S/N: ∞ , 20, 10
Models for Be and WR stars come from *Frémat & Zorec, Bouret, Lanz & Martins*
Simulations from GAIA CU2 team

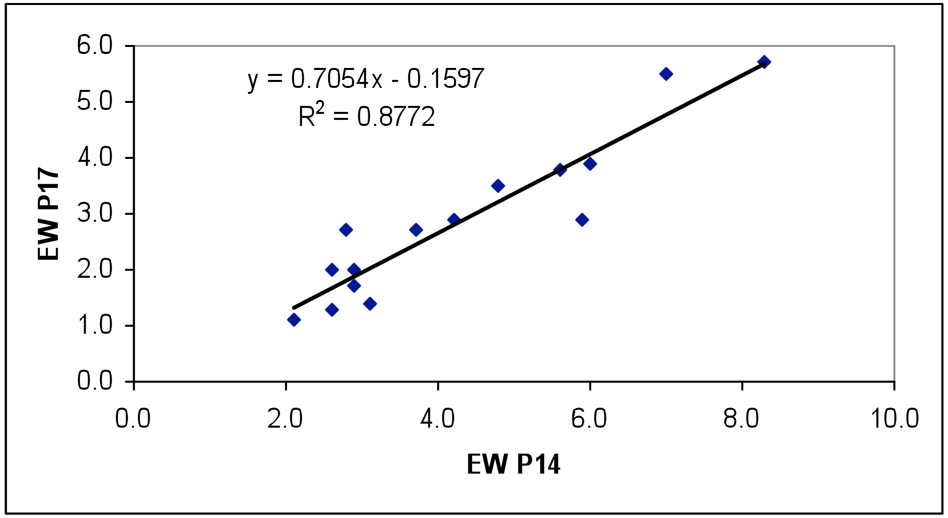
Observed spectra for a B[e], Ae, WR from *Andrillat et al. (1995)*

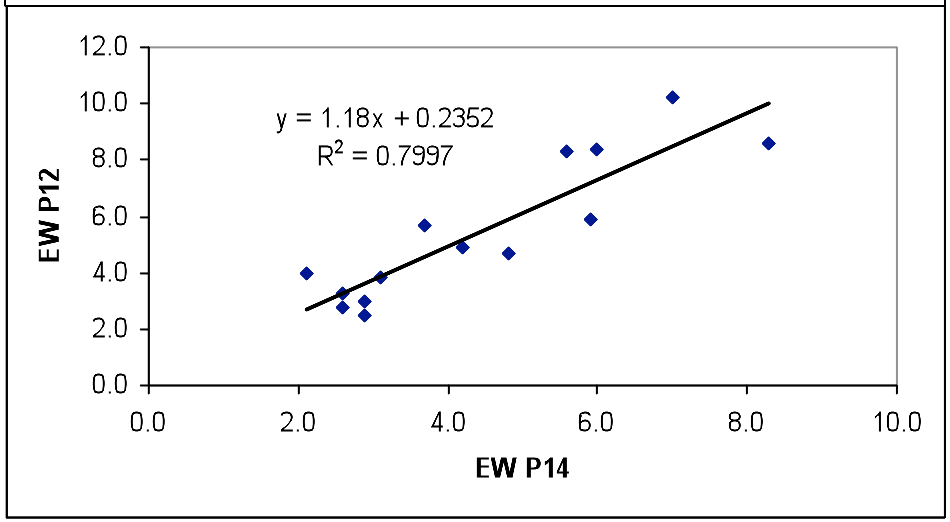
Be stars: empirical links between amounts of emission ⇔characteristics of disks, comparison with numerical models







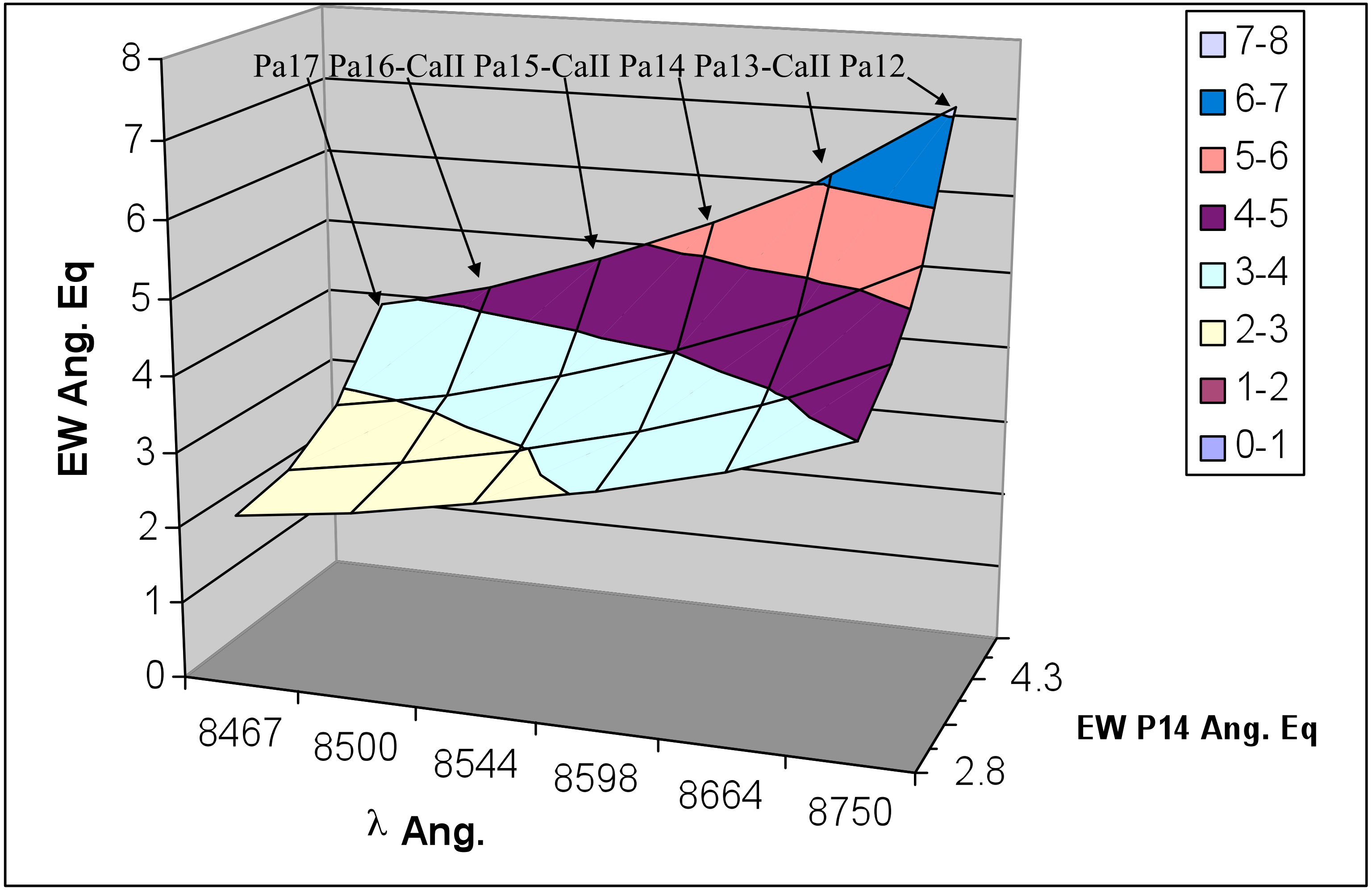




Interpolated distributions from data of *Briot (1981)*, 15 early-Be stars

Distribution of interpolated EWs

Contribution of CaII lines to Pa16, Pa15, Pa13 EWs removed



Interpolation from data of *Briot (1981)*, 15 early-Be stars

- **Needs more observational data** to draw better statistics on **each kind of ELS**
- **Comparison with numerical models** (SIMECA, *Stee 1995* for example) for obtaining Be stars' disks parameters
- Extension of this study to other ELS for obtaining empiral relationships because:
  - no physical models to explain the origin of emission lines
  - or no numerical models to reproduce the emission lines

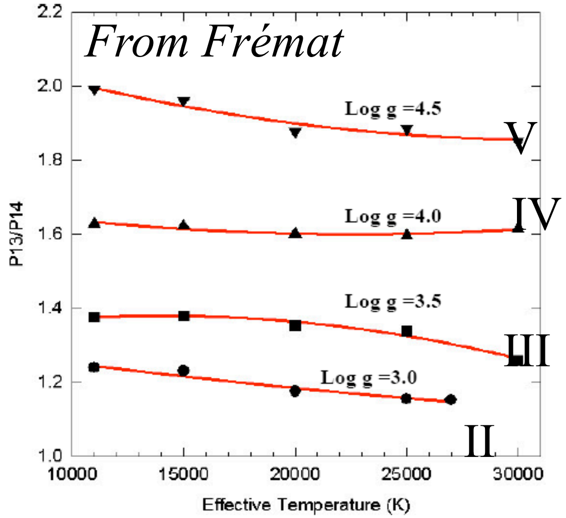
Stellar classification

Stellar classification

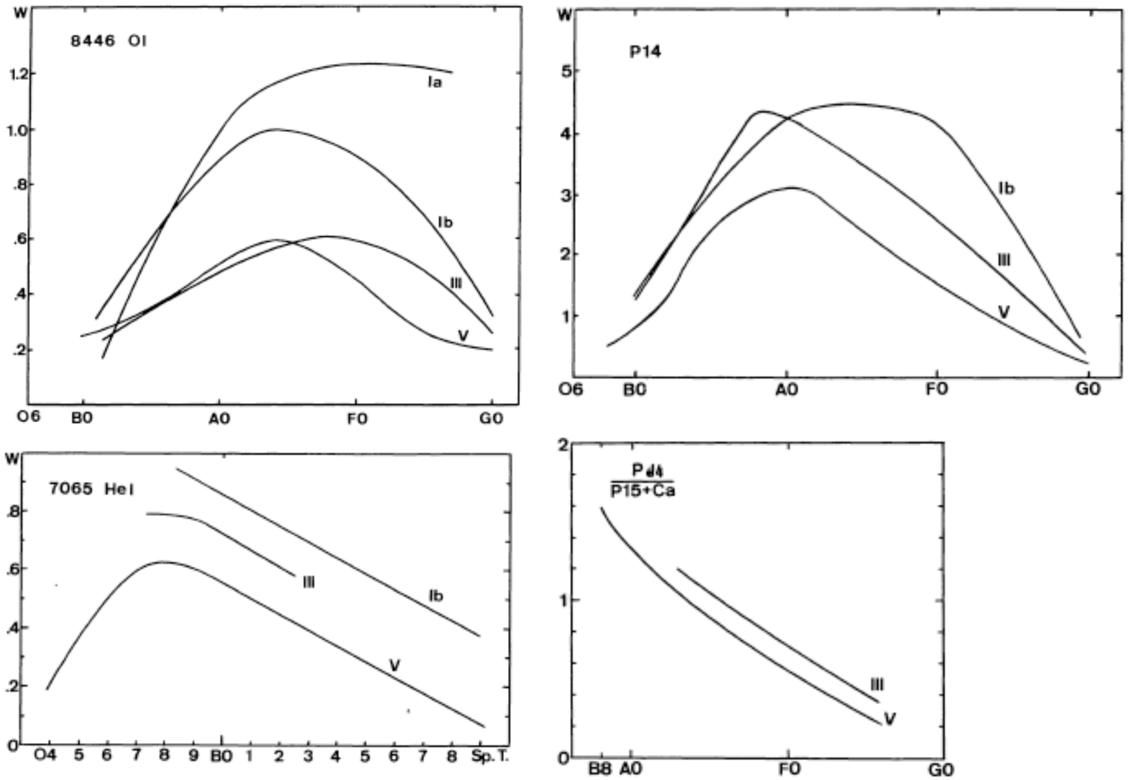
- 2 approaches:
- based on statistics/calibration:
  - Variation of EWs of lines
  - Teff-logg plane
  - Magnitude/colour indices

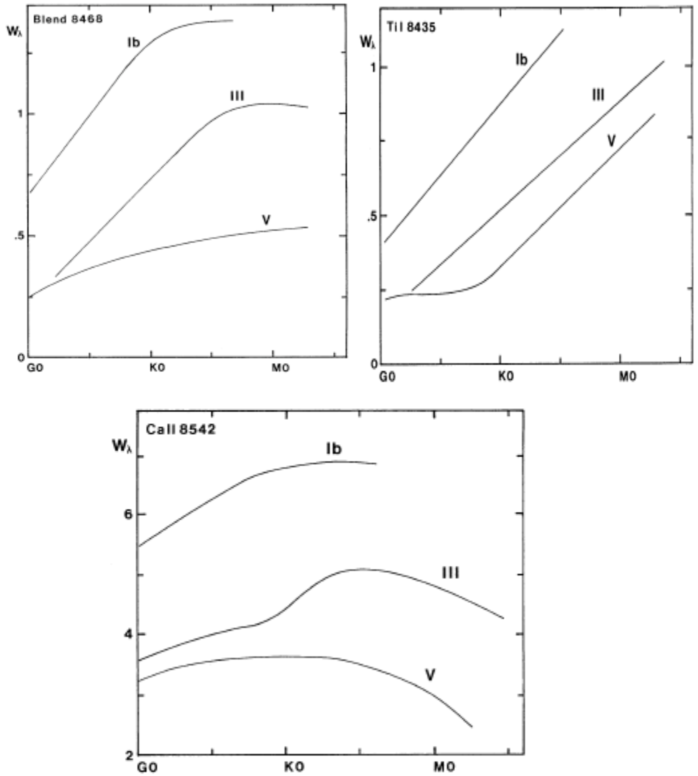
- Based on Neural network:
  - Training with known data
  - Clouds of points with probabilities of memberships

Stellar Classification from EWs variations (Bp/Rp or RVS) for HS & ELS



Andrillat et al., 1995, A&AS, 112, 475

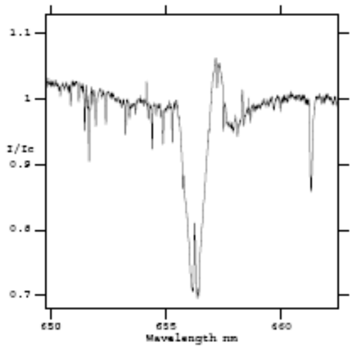


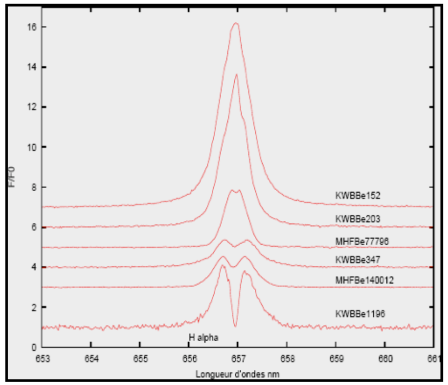


Carquillat et al. 1997, A&AS, 123, 5

For ELS or HS

- Presence of lines: forbidden or not?
  - If yes then [e] star
  - No: other ELS
- Presence of certain permitted lines
- Shapes of lines





- Additional parameters: parallaxes, magnitudes (colour excess, brightness)

Classification with neural networks preliminary results

from B. Leroy, B. de Batz, C. Martayan, A. Jonckheere, Y. Frémat

- First tests with ideal cases:
  - ~1000 synthetic simulated spectra for O, B stars and ELS (Be & WR) with obvious emission in the RVS.
  - No noise
  - Tests on magnitudes or on the whole spectra
- WEKA java library, « pruned tree » (mag+ spec):
  - Correct classification: 96 to 99%
- C++ Fast artificial neural network (10x faster than java WEKA, mag):
  - O stars classified as O stars: 99 to 100%
  - B stars classified as B stars: 98 to 100%

    } Only O, B stars
  - ELS classified as ELS: 95 to 100%
  - O stars classified as O stars: 97 to 100%
  - B stars classified as B stars: 95 to 100%

    } O, B stars + ELS

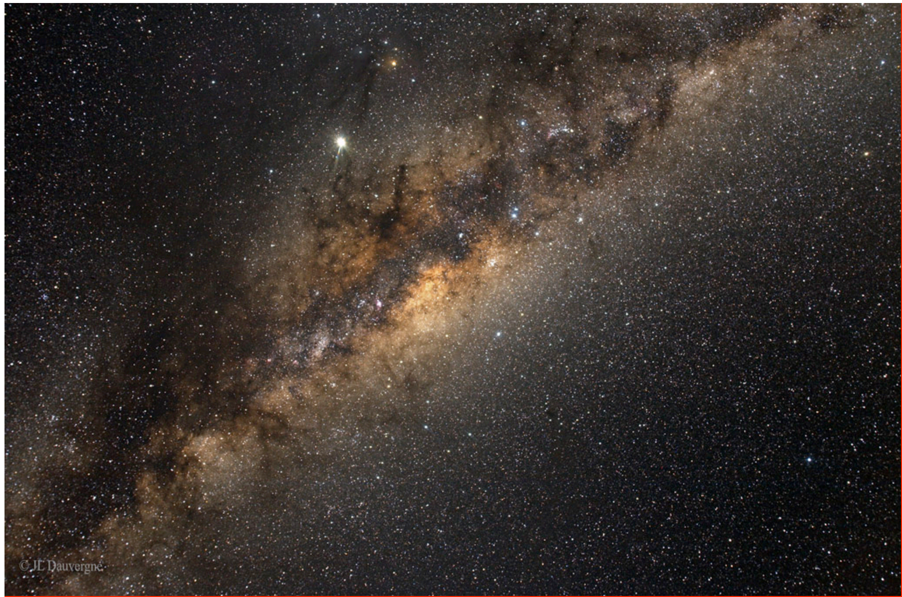
Conclusions

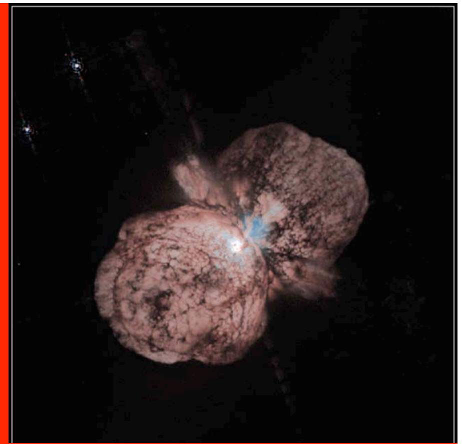
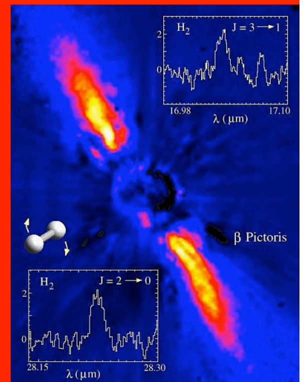
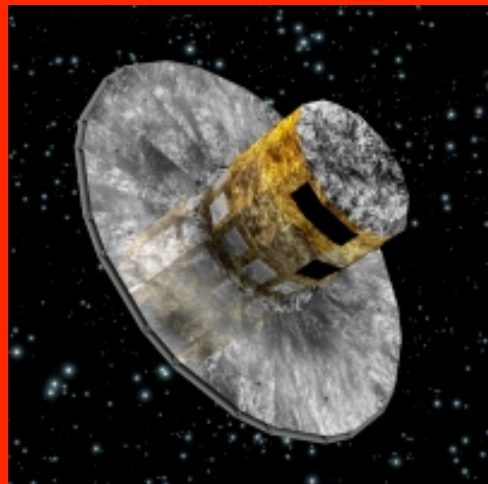
- **Gaia** will provide accurate parallaxes, photometry, spectroscopy **for several million HS & 100000s ELS**
- **Detection of new** HS and ELS
- **3D static and dynamic maps** of stars (Ocl, Z-effect, age-effect, galactic distribution, and in the LMC/SMC, SDG)
- Long and mid-term **variability** of stars

⇔**algorithms development** for:

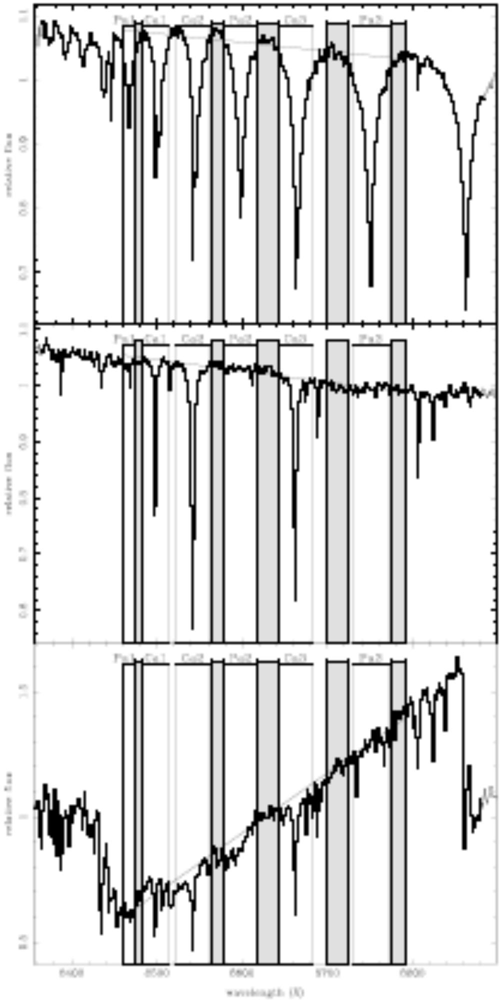
  - detection/identification/classification of hot stars and ELS
  - Obtaining fundamental parameters of stars/disks
  - Needs more observational data to draw preparatory statistics for the algorithms (from GBOG).

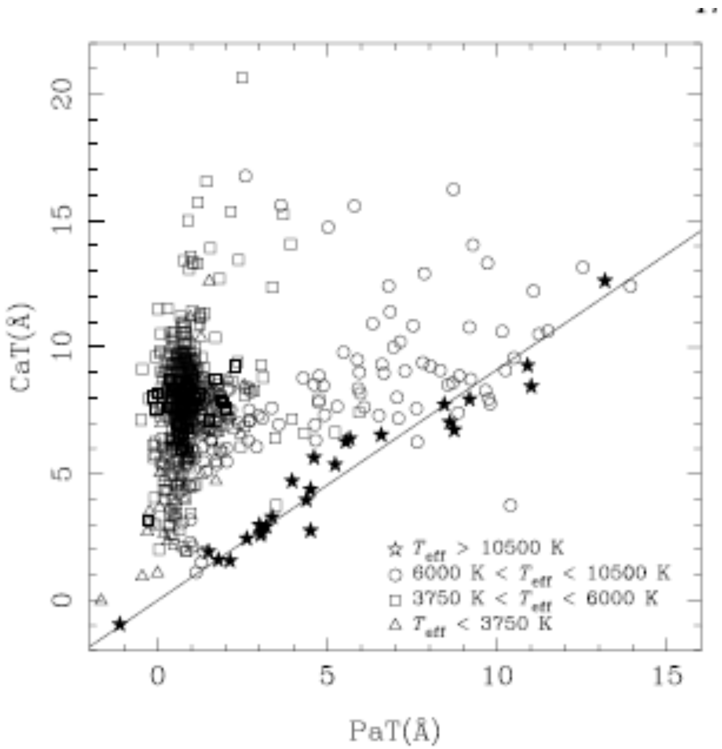
- Improvement of stellar evolution models
- Development/improvement of models for ELS, galaxy


© JL Dauvergne



H$_2$
J = 3 → 1
2
0
16.98
λ (μm)
17.10
β Pictoris
H$_2$
J = 2 → 0
2
0
28.15
λ (μm)
28.30


Stellar classification from EWs filters

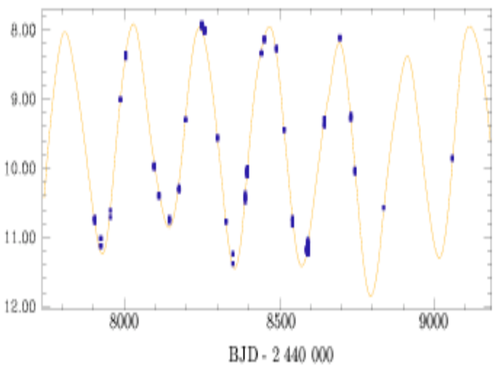




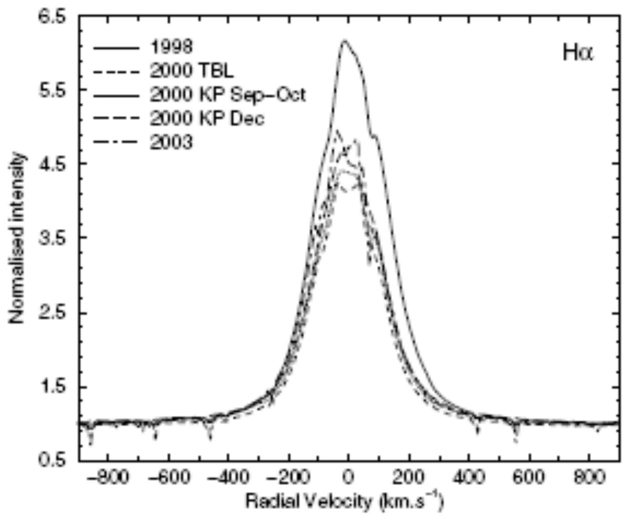
Cenarro et al. 2001, MNRAS, 326, 959

Variability

Photometric & spectroscopic variability from hours to couples of years

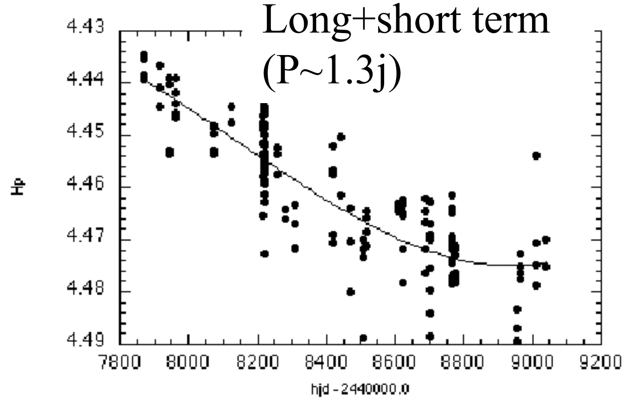


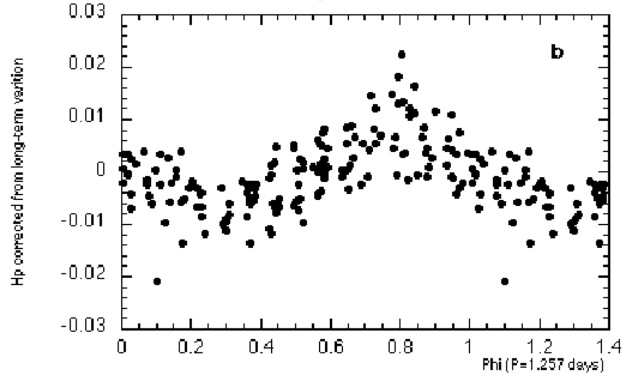
RS Her Mira-type
Period: 218,1 j



Be star Ups Cyg. 5 years Hα variation, Em could disappear

Be star O Cas
Long+short term
(P~1.3j)





Development of models for Em*

TTauri

•Origin of Em line:

unknown but new explanations

•Best model: magnetospheric accretion

•Pbles: Inclination angle, veiling, **2/5 stars OK.**

AJ 1998, 116, 455

J. Bouvier private com.

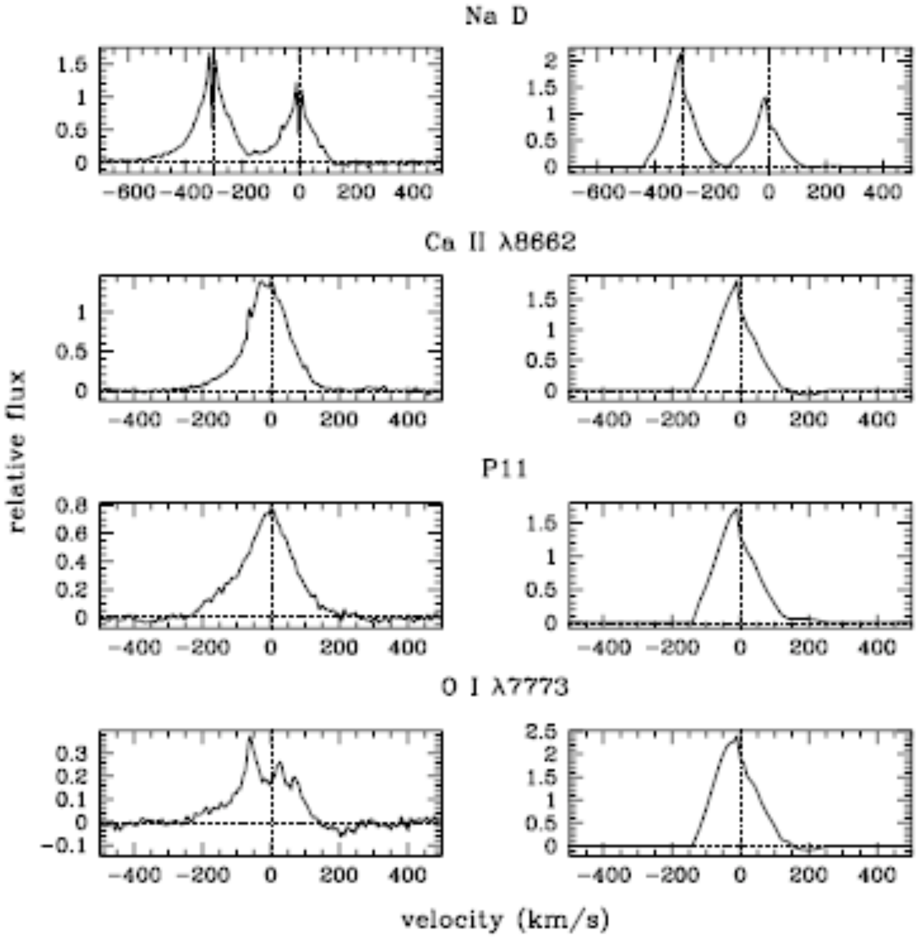
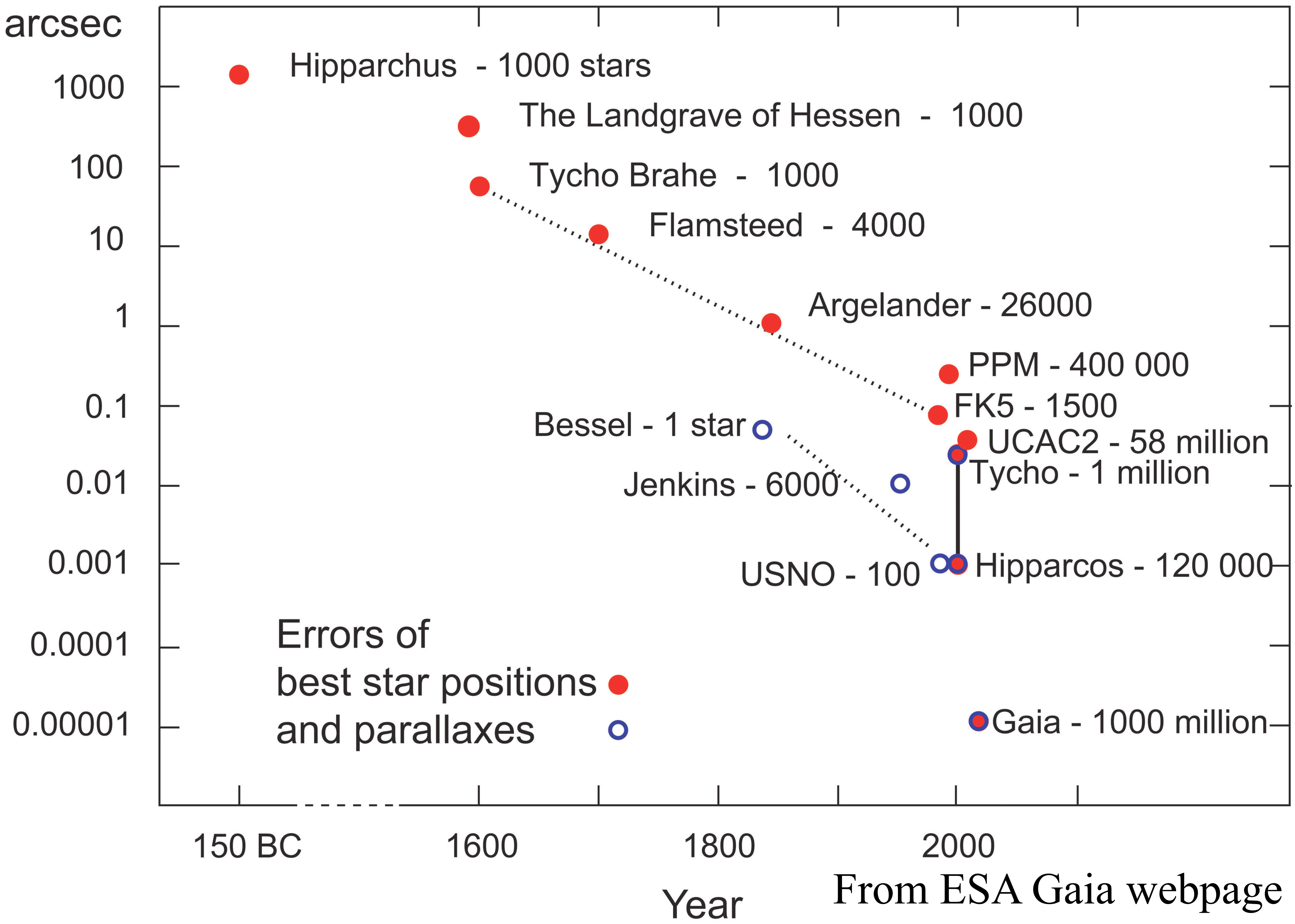


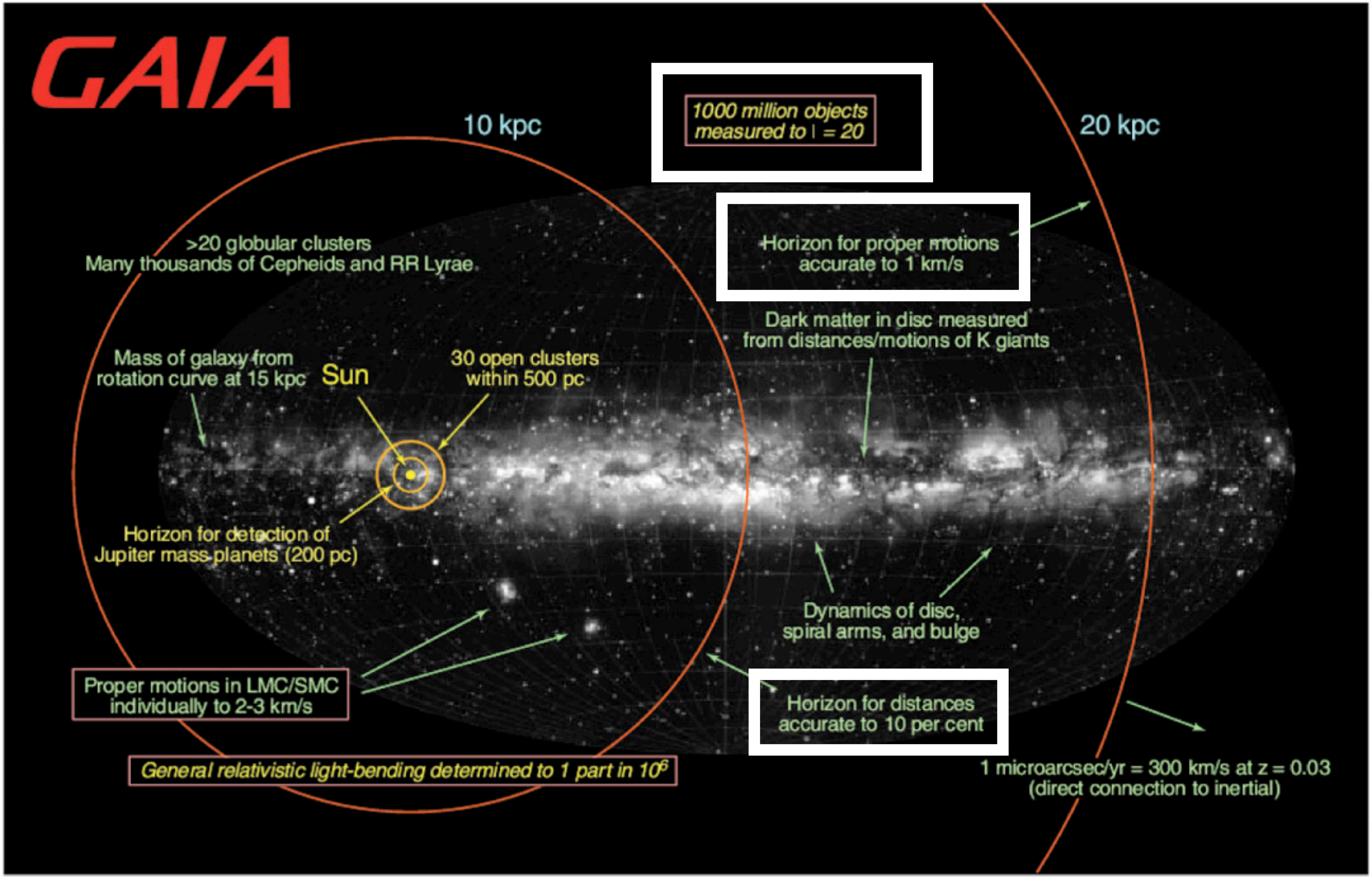
FIG. 7.—Comparison of observed (*left*) and model (*right*) profiles for BP Tau. The model parameters are $T = 10{,}000$ K, $\dot{M} = 3 \times 10^{-8}\ M_{\odot}\ yr^{-1}$, and magnetosphere base radii 2.2–3 R_*. The O I feature is a triplet; only one component is treated in the model calculation.

Muzzerolle, Hartmann

200 times more accurate than Hipparcos (2 millions stars)



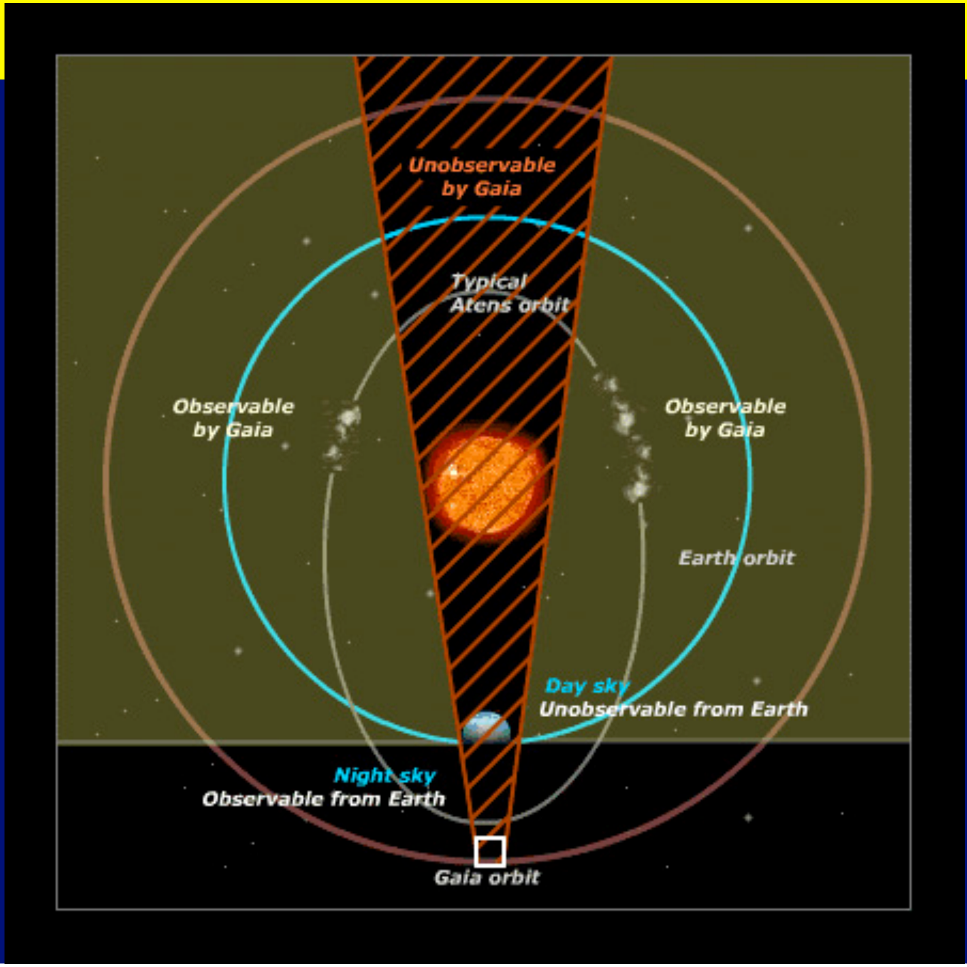
From ESA Gaia webpage

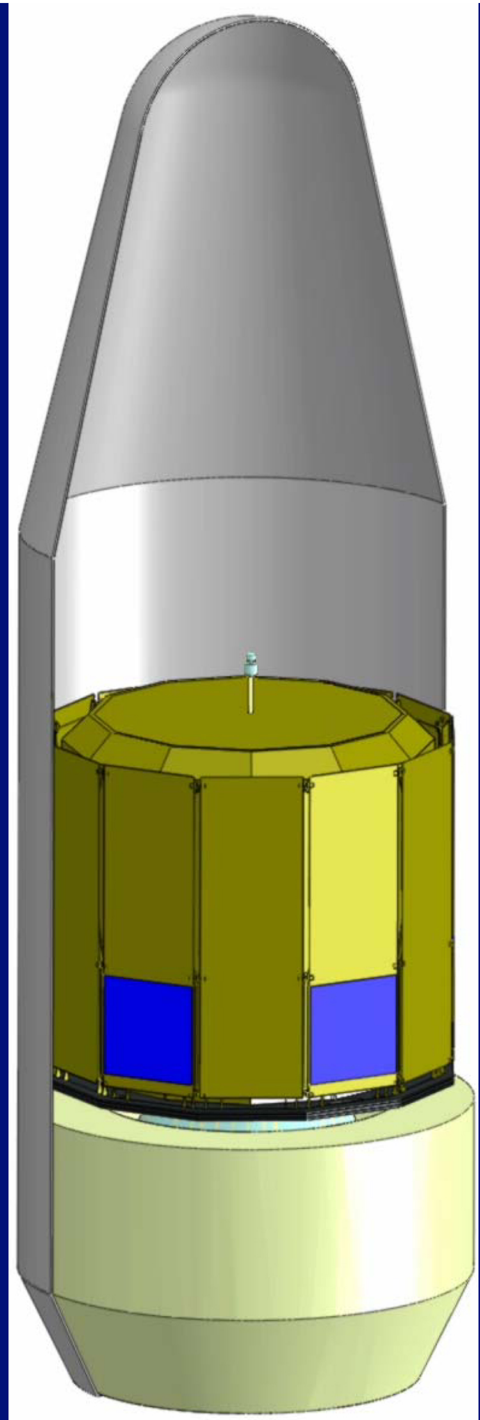


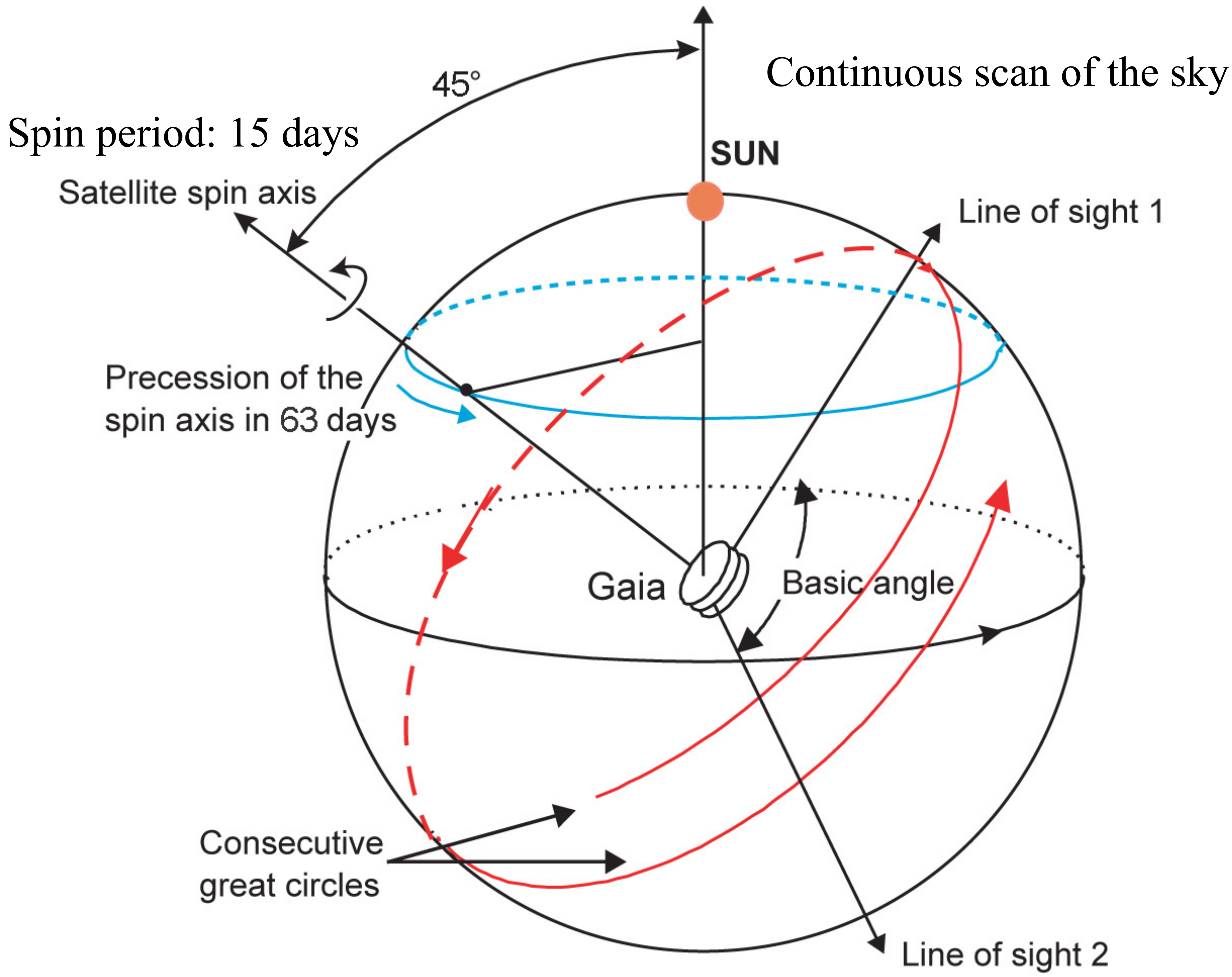
GAIA
10 kpc
1000 million objects
measured to I = 20
20 kpc
Horizon for proper motions
accurate to 1 km/s
>20 globular clusters
Many thousands of Cepheids and RR Lyrae
Dark matter in disc measured
from distances/motions of K giants
Mass of galaxy from
rotation curve at 15 kpc
Sun
30 open clusters
within 500 pc
Horizon for detection of
Jupiter mass planets (200 pc)
Dynamics of disc,
spiral arms, and bulge
Proper motions in LMC/SMC
individually to 2-3 km/s
Horizon for distances
accurate to 10 per cent
General relativistic light-bending determined to 1 part in 10^6
1 microarcsec/yr = 300 km/s at z = 0.03
(direct connection to inertial)

Mission:

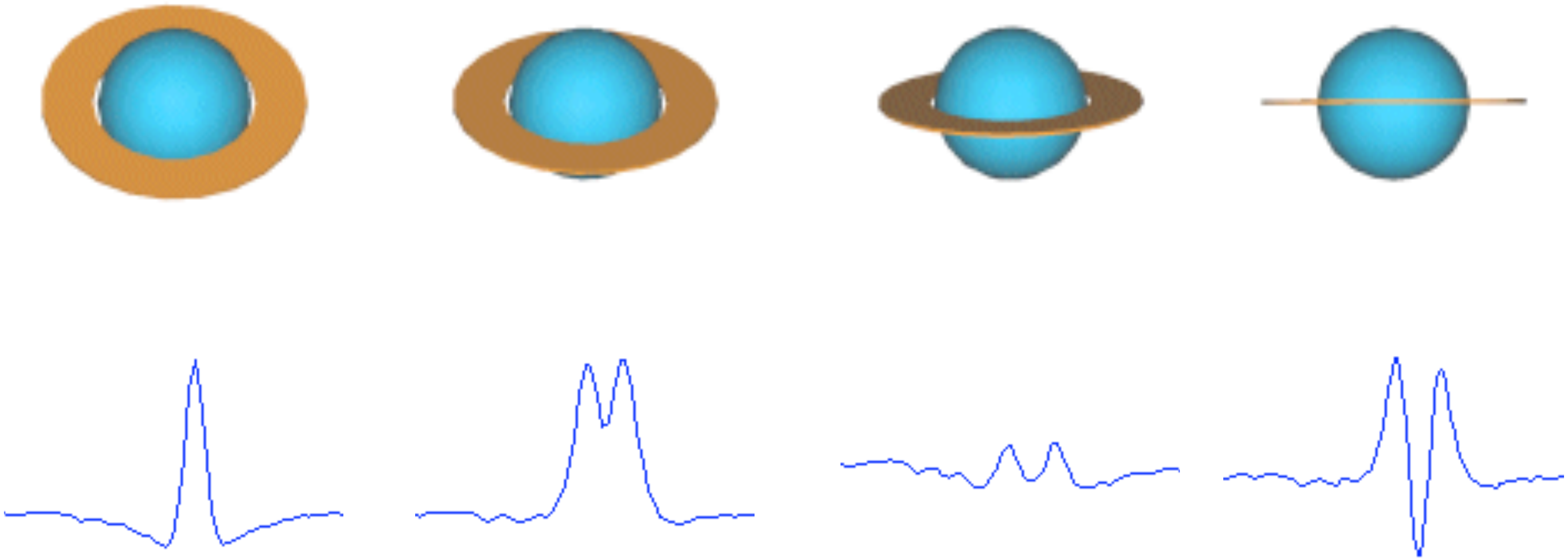
Launch: Dec-2011/2012
Mass: 2030 kg
Orbit: L2, anti-solar
Lifetime: 5 years
Gaia catalog → 3 y. after end of






Continuous scan of the sky
Spin period: 15 days
45°
SUN
Satellite spin axis
Line of sight 1
Precession of the
spin axis in 63 days
Gaia
Basic angle
Consecutive
great circles
Line of sight 2

Differents types de profils de raie



Slettebak 1979