The Stellar Optical Spectroscopy in Virtual Observatory

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Information from (multi) spectral lines

Position (wavelength):

- Chemical elements
- Excitation / Ionization state (Grid of models)
  - If unknown – SLAP, TSAP (molecules in IR)
- RV (binarity, orbital parameters...)

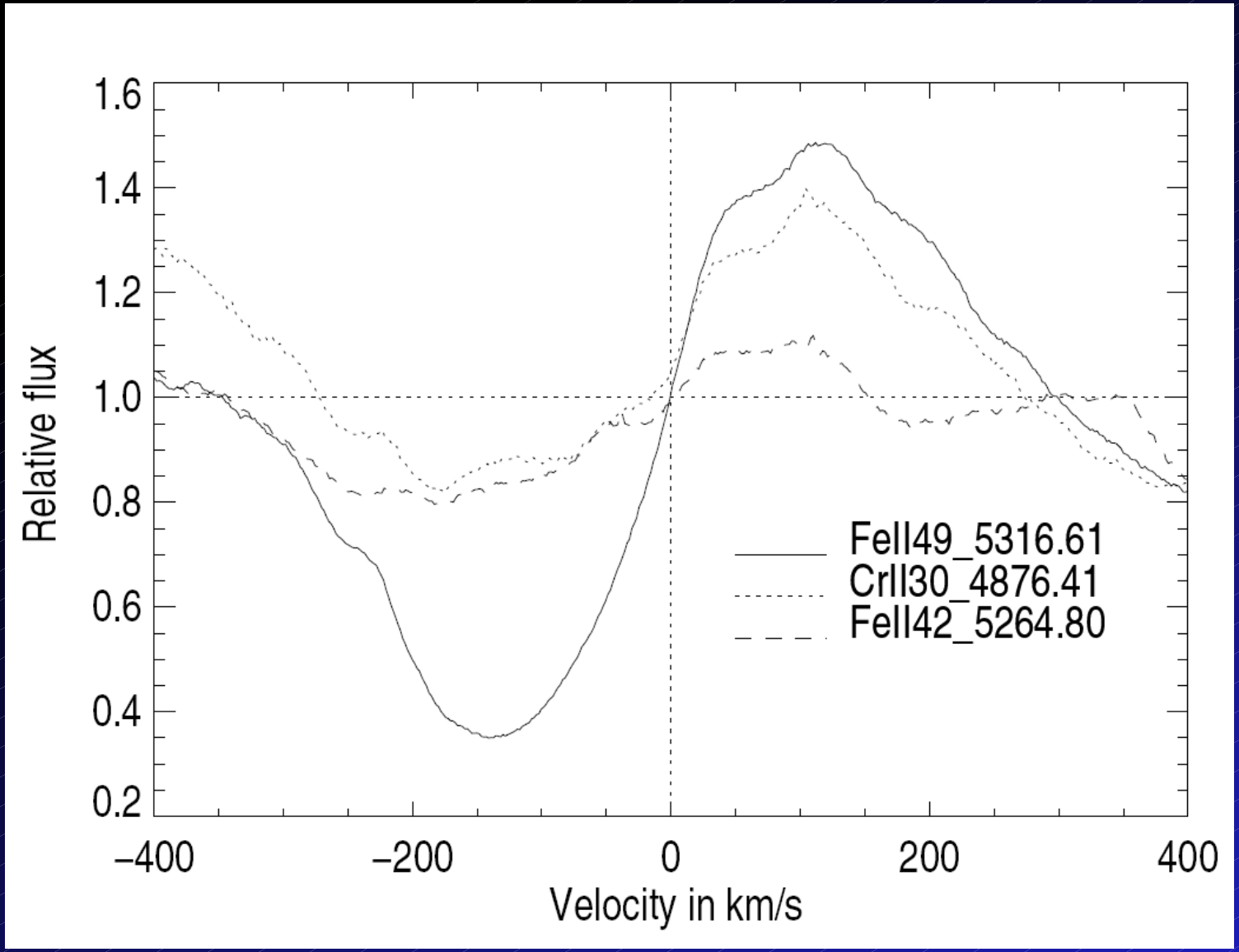
Shape

- Stellar parameters (Teff, log g, rotation)
- Stellar activity (Turbulence, granulation)
- core/wings – diferrent physics – optical depth, limb darkening
- Expansion, shells, winds (P Cyg, Novae)

Time variability (LPV)

- Change of physical state (Be, outburst)
- Spots (Mg field, overabundance – Ap)
- Pulsations (Delta Ceph, RR Lyr, Miras)
- Non radial pulsations (NRP)
- Multiple systems – disentangling of orbital parameters, individual spectra
- Detection of ES planets in spectra (Bisector – small contributions enlarged)

Different Lines overploted in RV



V838 Mon: Kipper et al. 2004

Classification of Stellar Spectra selected (many) lines

Manual – by direct comparison with model grid

Automatic

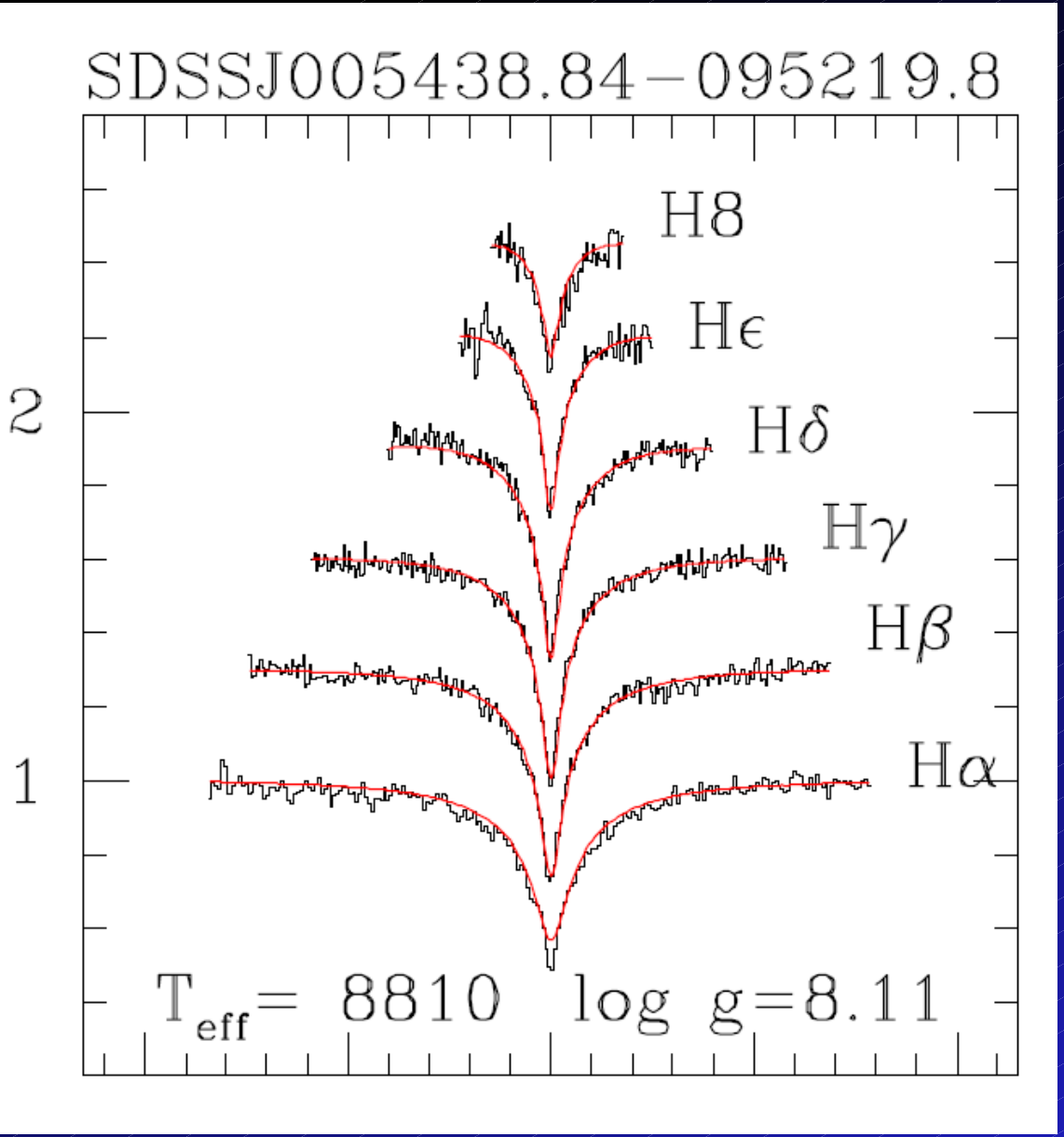
direct chi^2 minimization (SFIT code, line broadening – Jefferey 2001) Simplex AMOEBA or Levenberg-Marquardt)

Genetic Algorithm

Artificial Neural networks

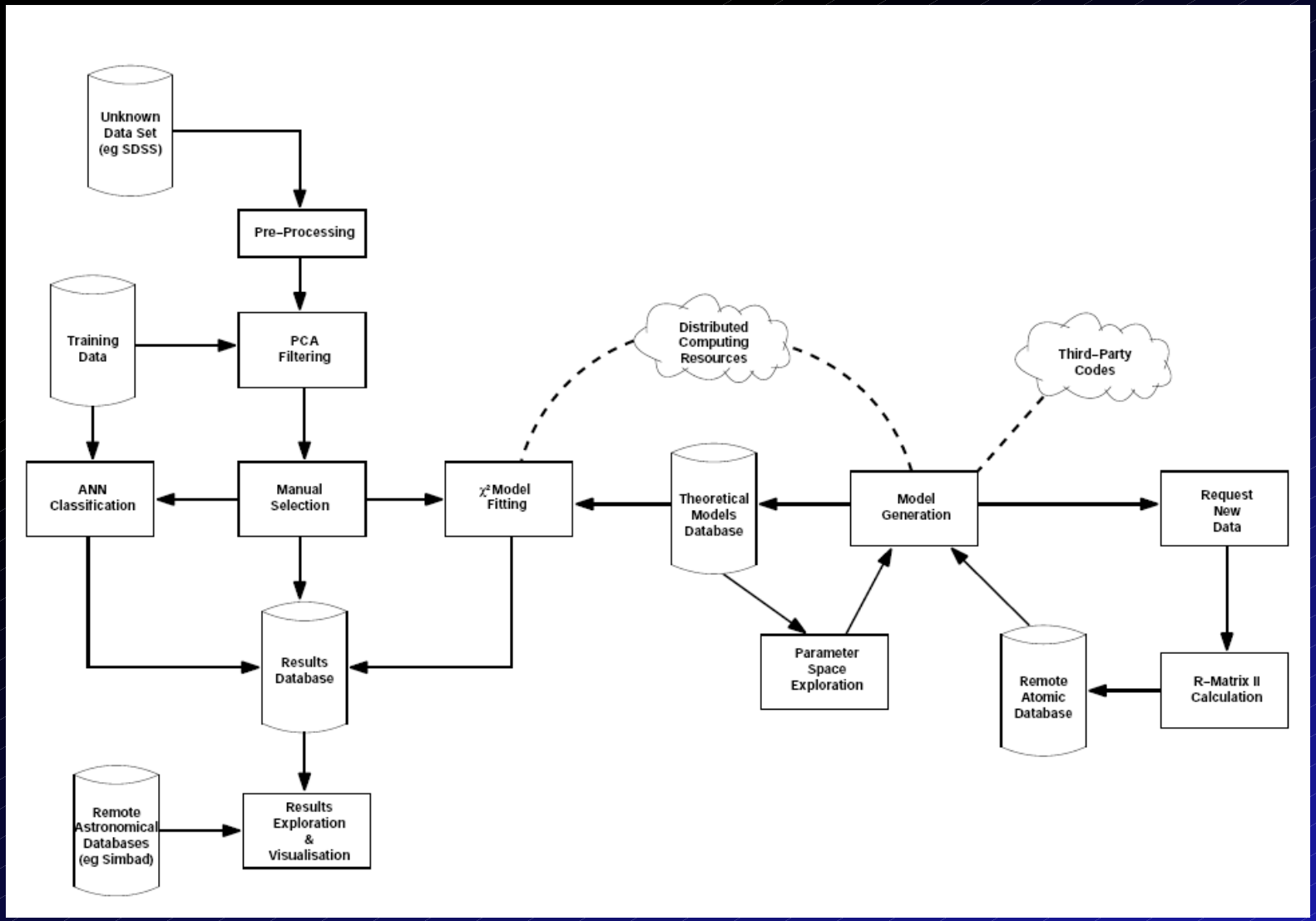
PCA – template spectrum + differences

WD models by manual fitting interpolation by experience



Kawka, Vennes 2005

Automatic classification engine

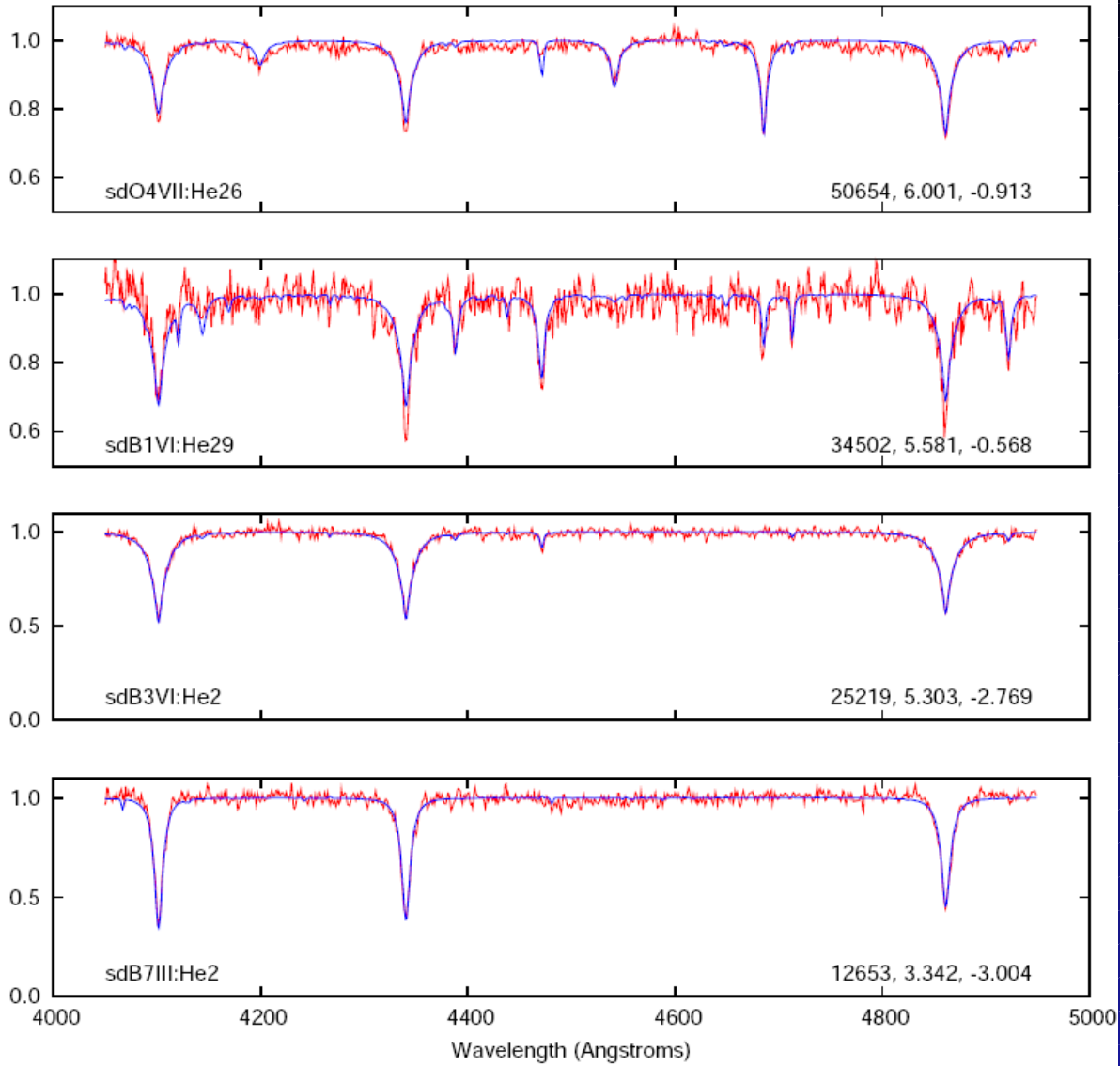


Winter 2006

Workflow

Parallel

Classification od hot subdwarfs



Winter 2006

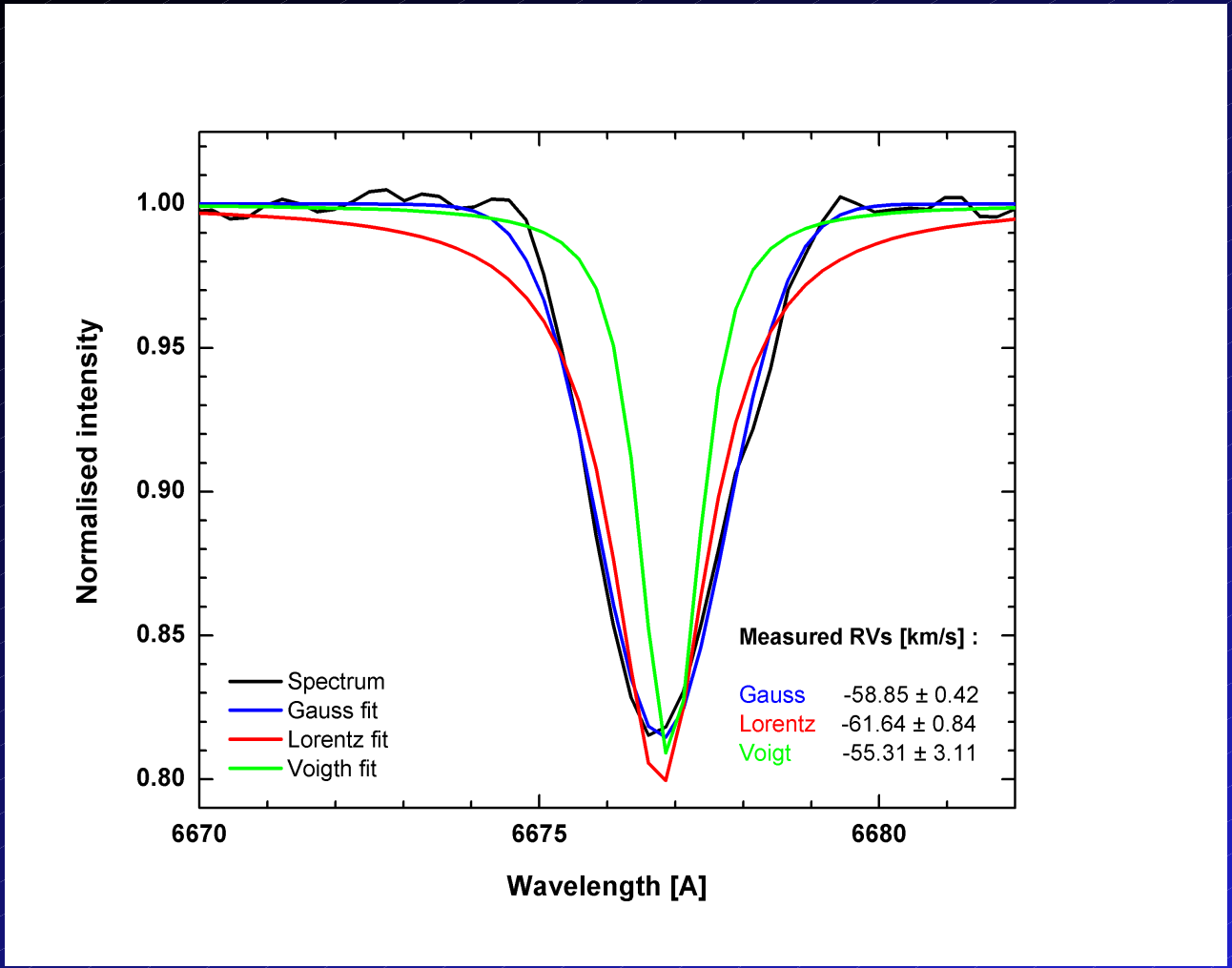
Figure 5.3: Four example fits from the 282 SDSS hot subdwarfs. The classificatio and physical parameters ($T_{\rm eff}$ (K), $\log g$, $\log(n_{\rm He}/n_{\rm H})$) obtained for each star are printe in the lower corners of each plot.

Measurement of RV, z

Normalization

Fits of Gauss, Maxwell, Voigt

Asymmetry ??

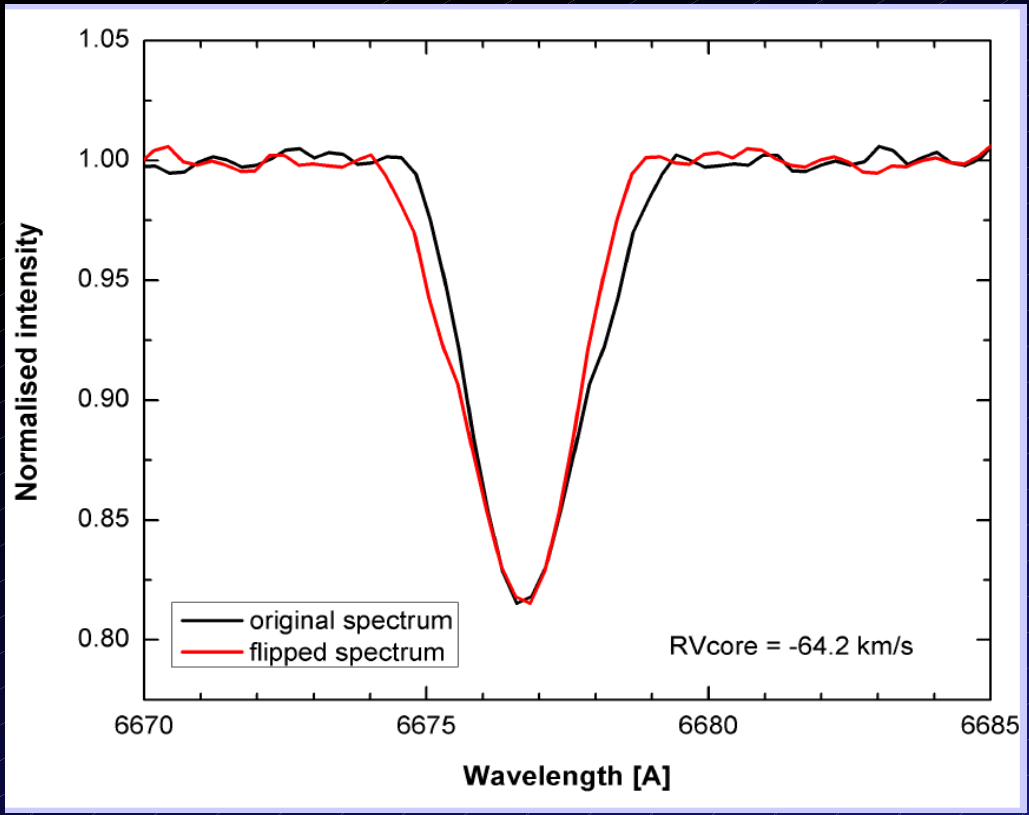


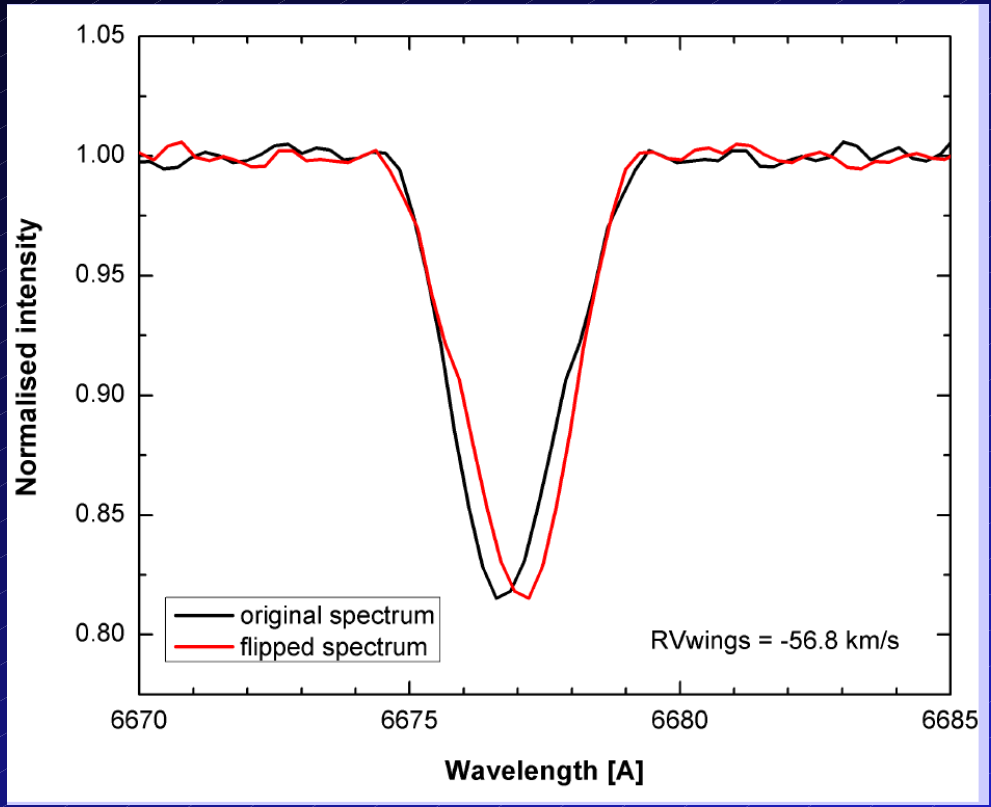
Mirorring Method

Separate match of core from match of wings – where in depth ?

Different physics (shells, shears, winds)

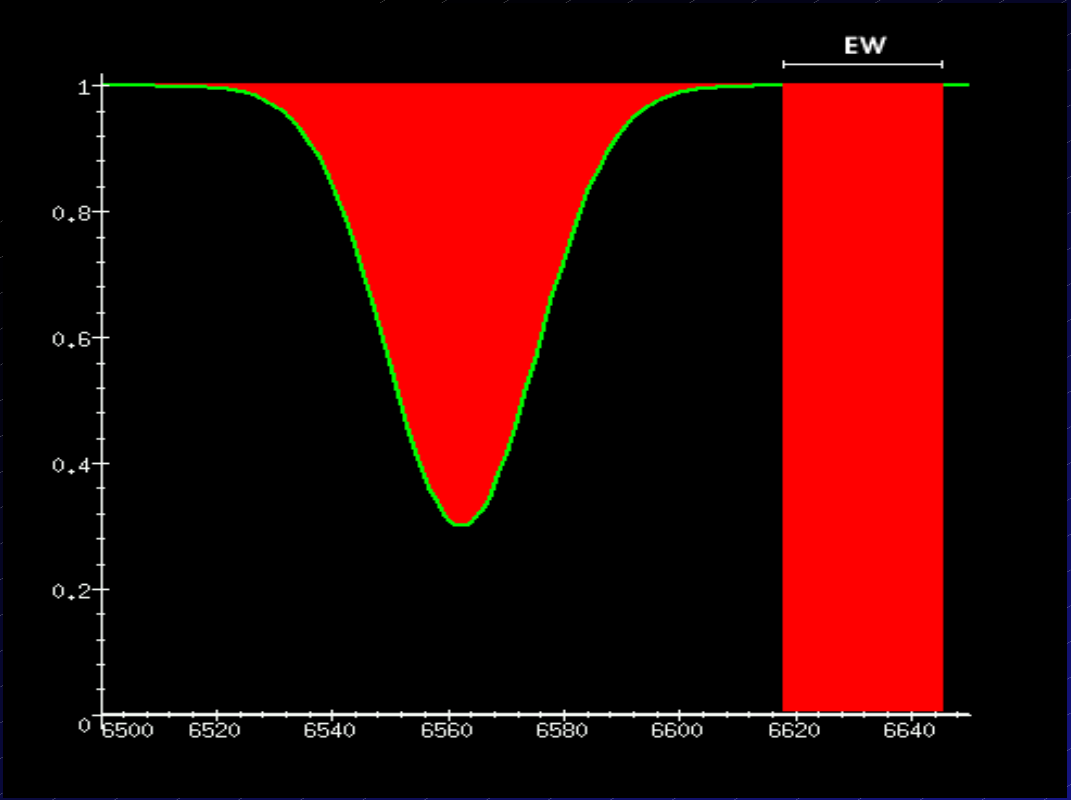
Asymmetry – how to handle ?



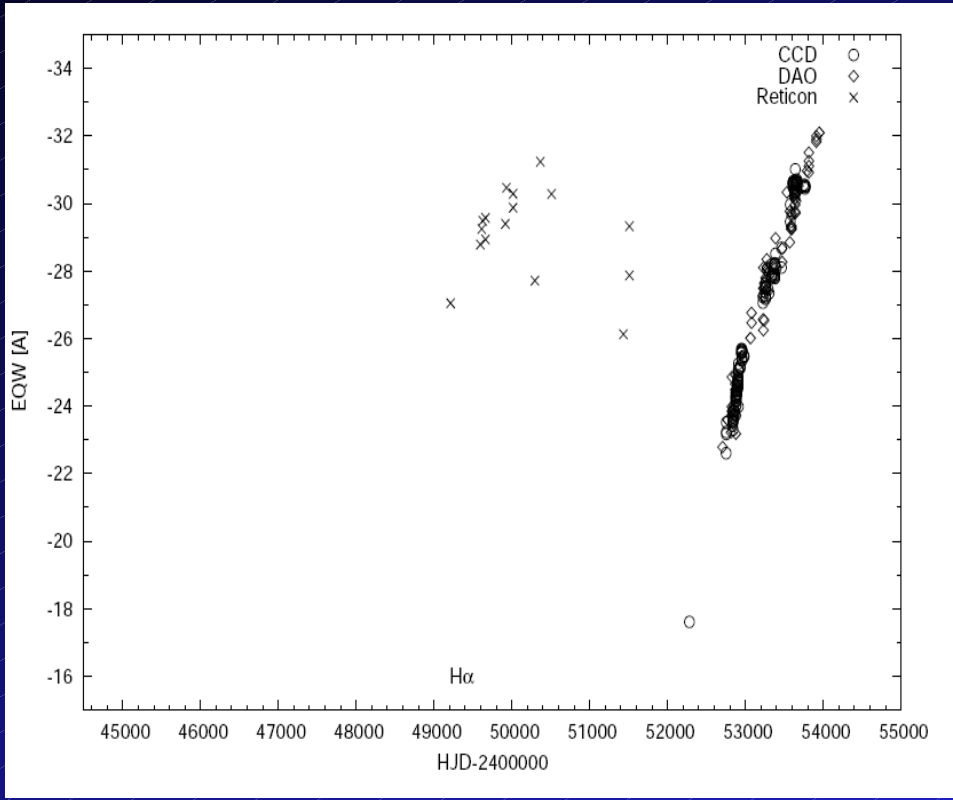


Equivalent Width (EW)

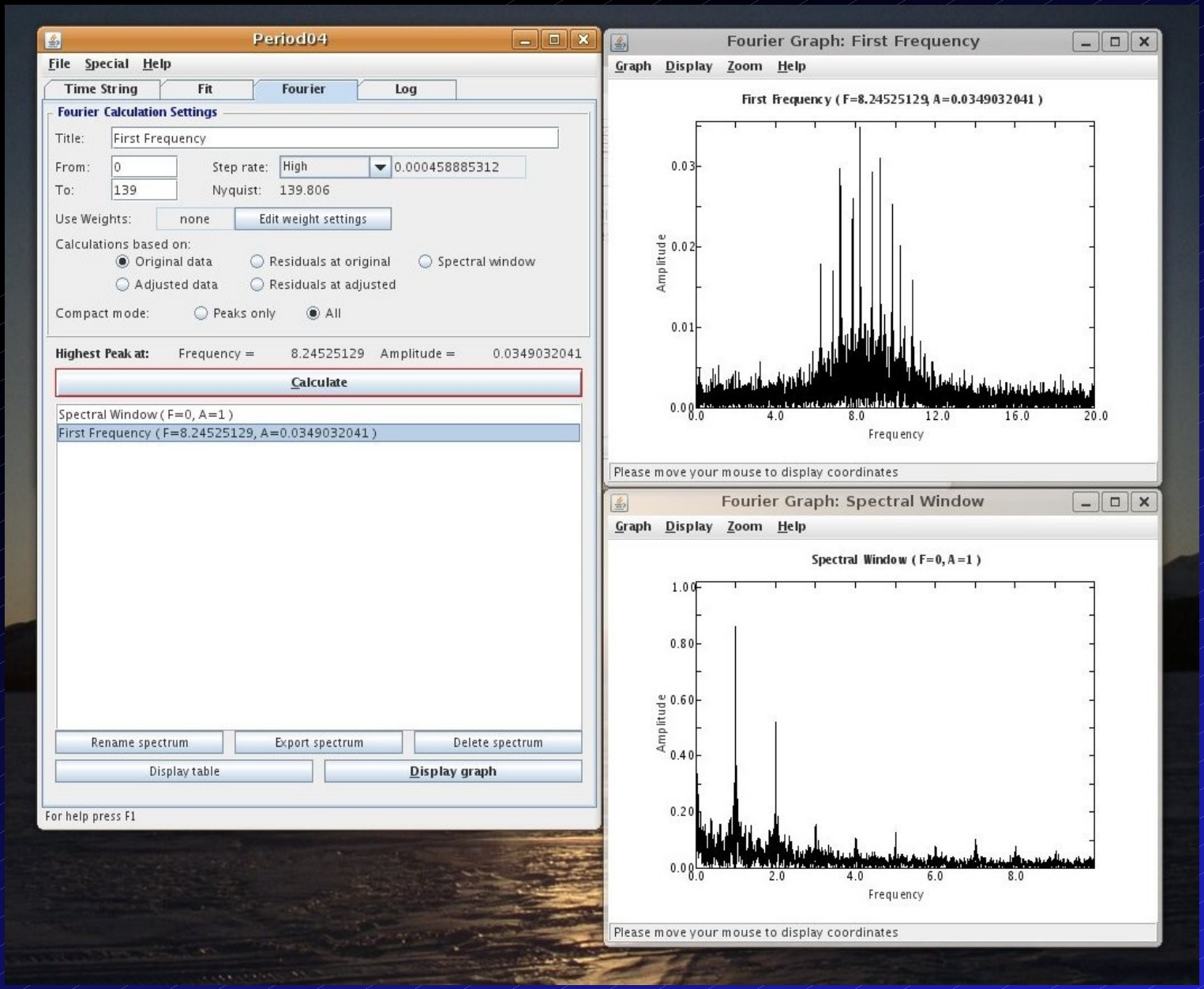
Definition by area under LP



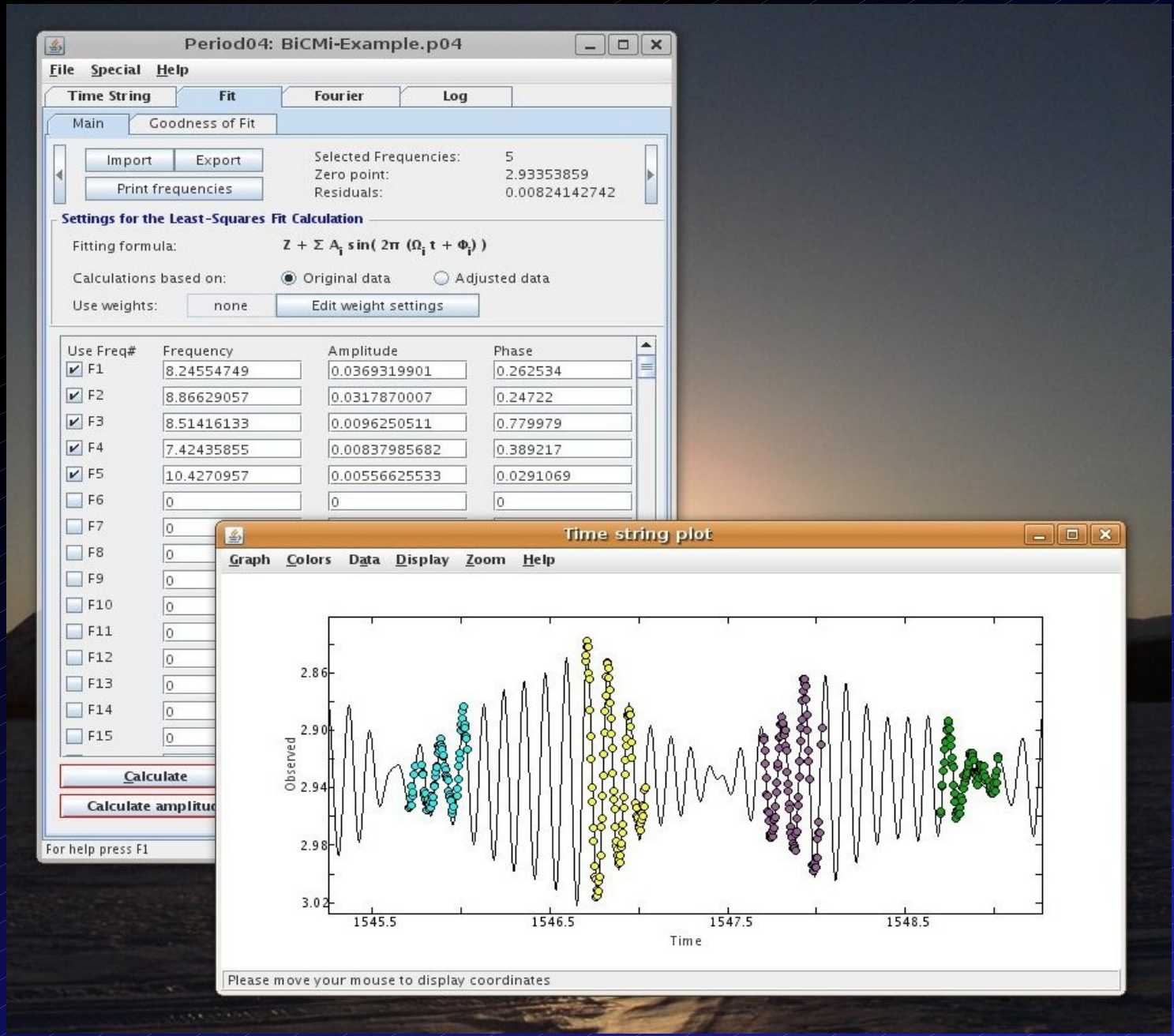
EW changes – shell evolution



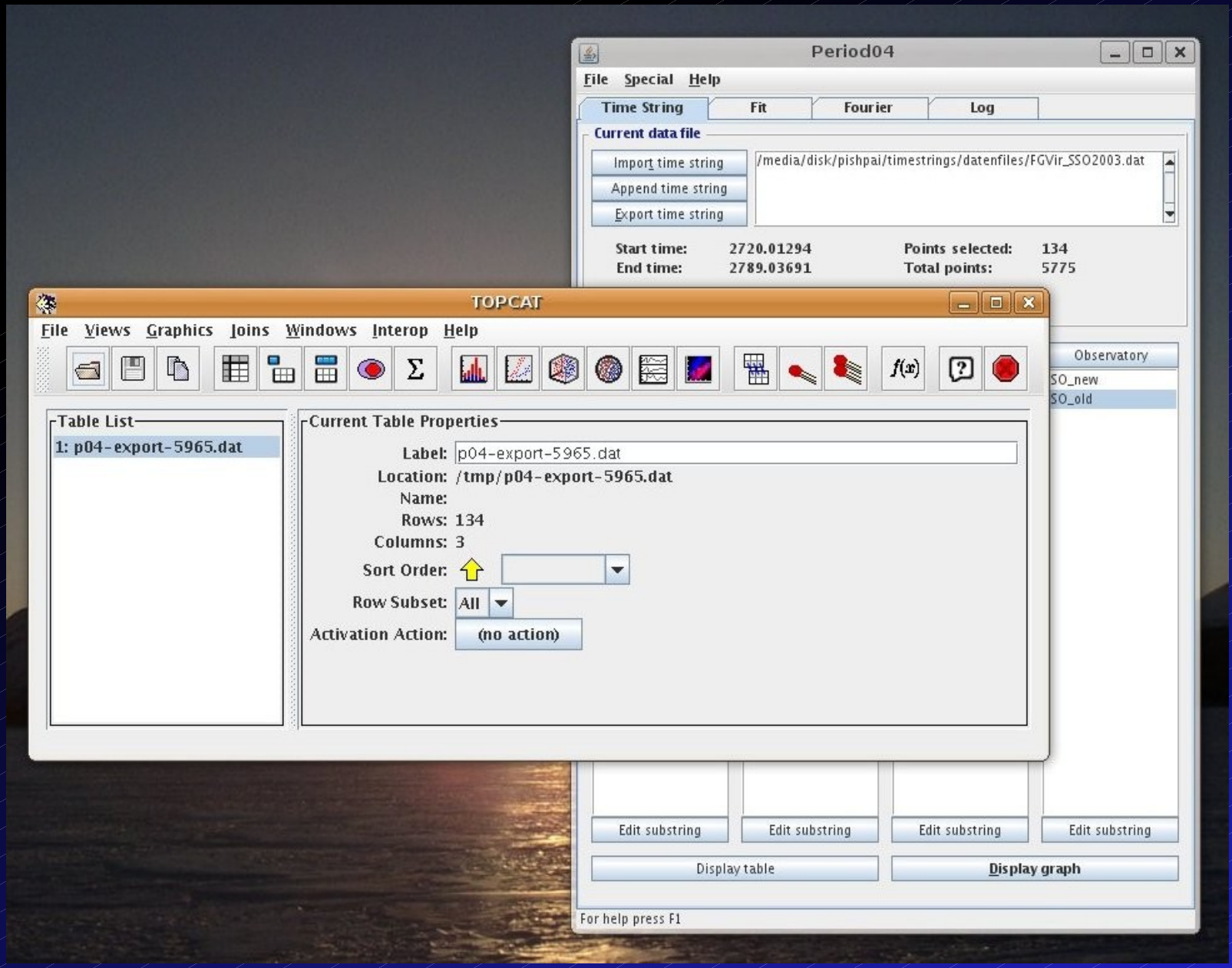
Period04 – Power Spectrum Window Function



Period04 – Fit with found periods



VOTABLE sending to TOPCAT



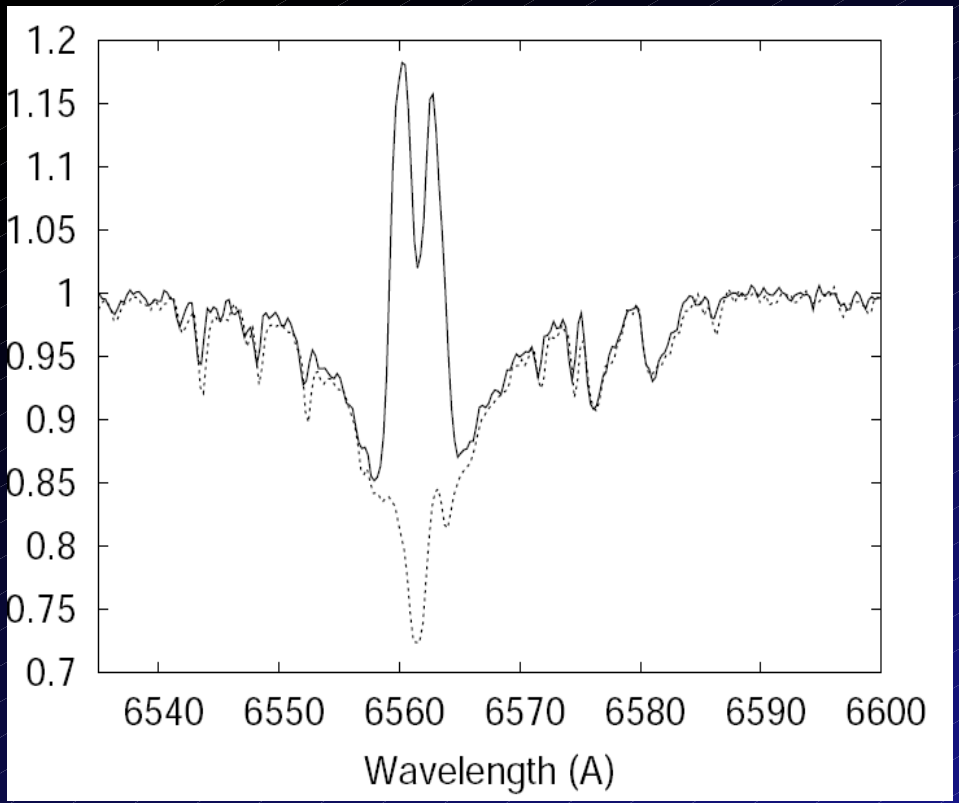
Changes of Line Profiles in Time

Blind comparison of different exposures

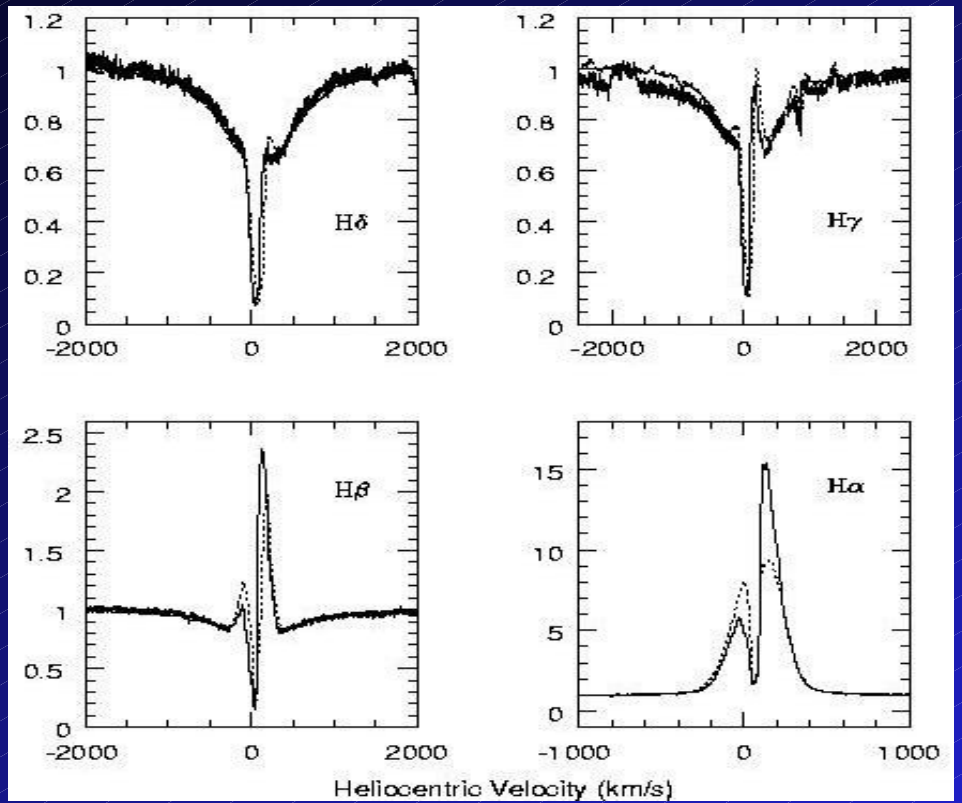
Emission/absorption, shell phases

Time evolution of object – mass transfer,

V/R variations

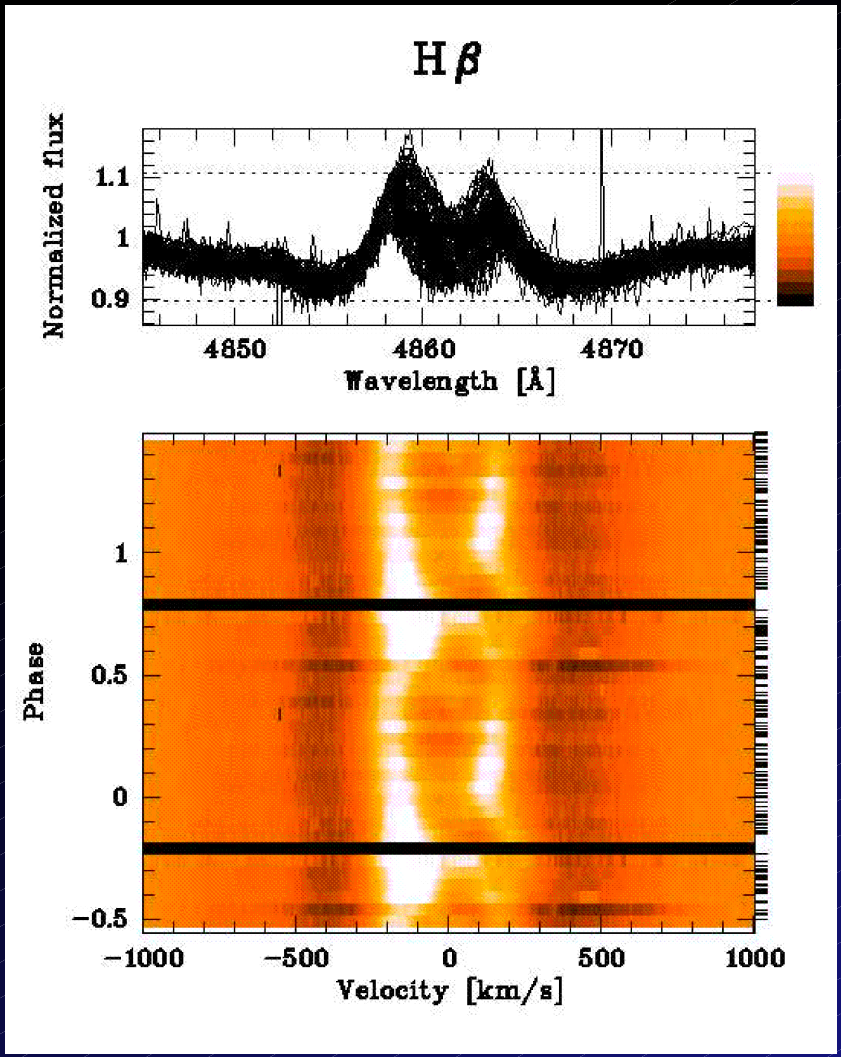


HD6226 : Slechta and Skoda 2004



Borges et al. 2008

Dynamic Spectra



Quotient, Difference template (average)

For study of LPV (asteroseismology, winds)

Requires

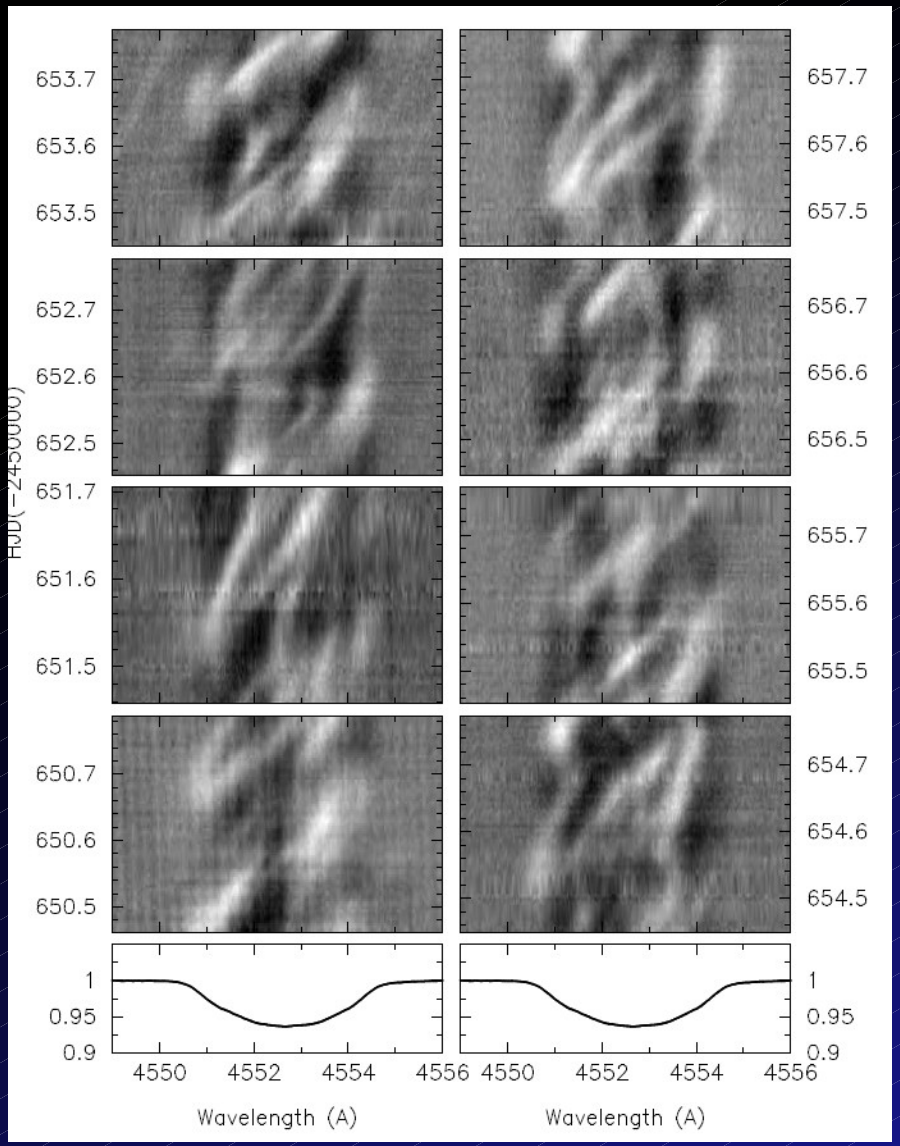
time (JD) - winds

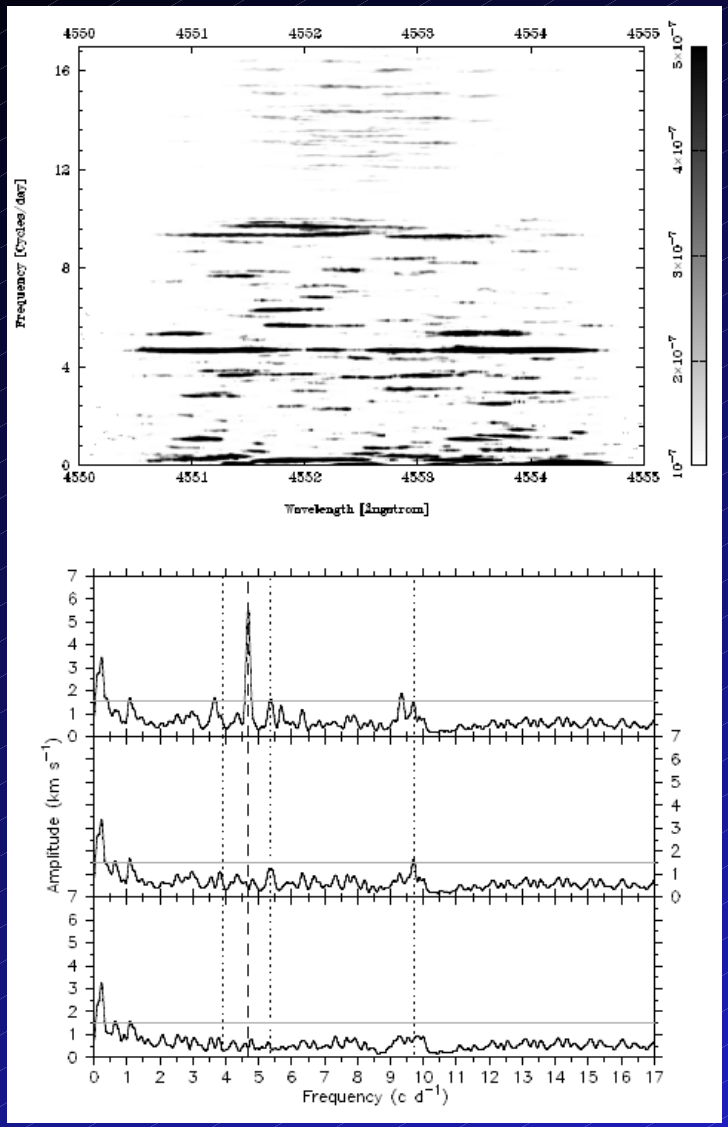
period (see Period analysis) - phase (LPV)

change of template (average, median)

removing bad data (interactive overplotting)

Periodogram of Line Profile NRP





Lambda Sco: Uytterhoeven 2004

Spectral Disentangling

For blended spectra of binary (multiple) stars

Very powerful

Requires good orbital coverage, estimate of orbital parameters (SIMBAD)

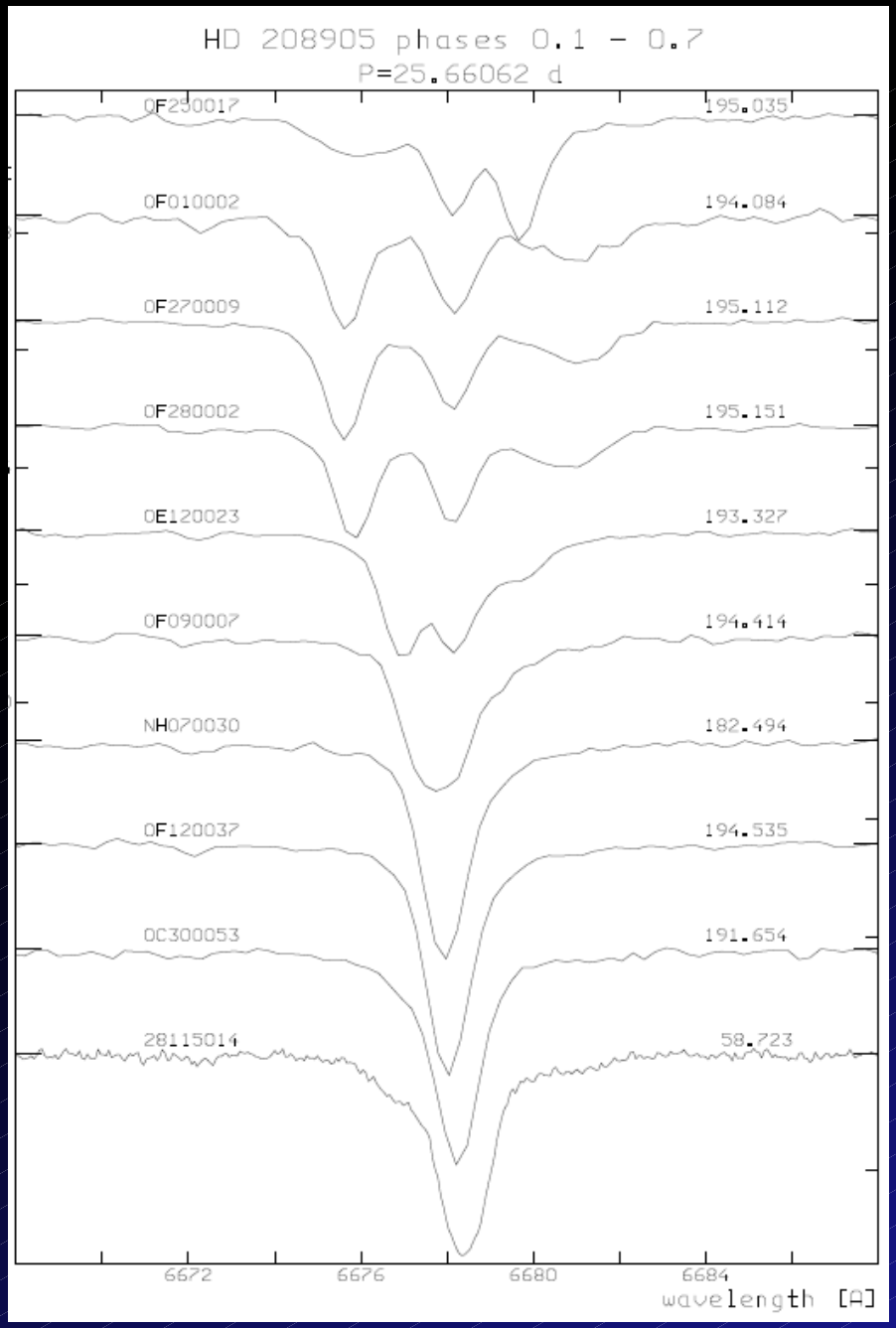
Wavelength space disentangling - computing power, space (Simon&Sturm)

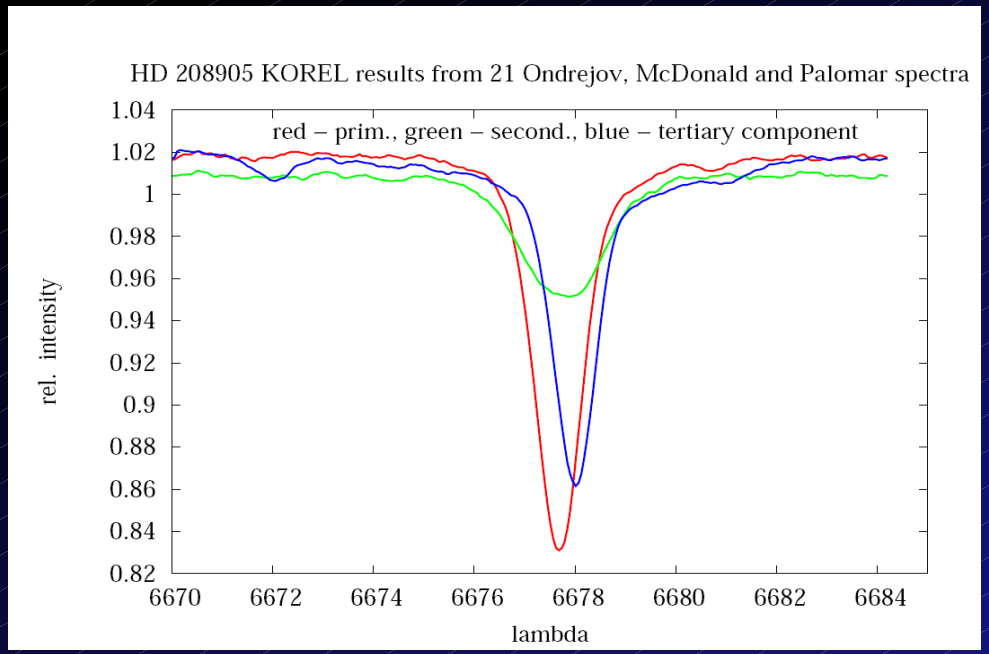
Fourier disentangling - perfect continuum, cut regions, log lambda (Hadrava)

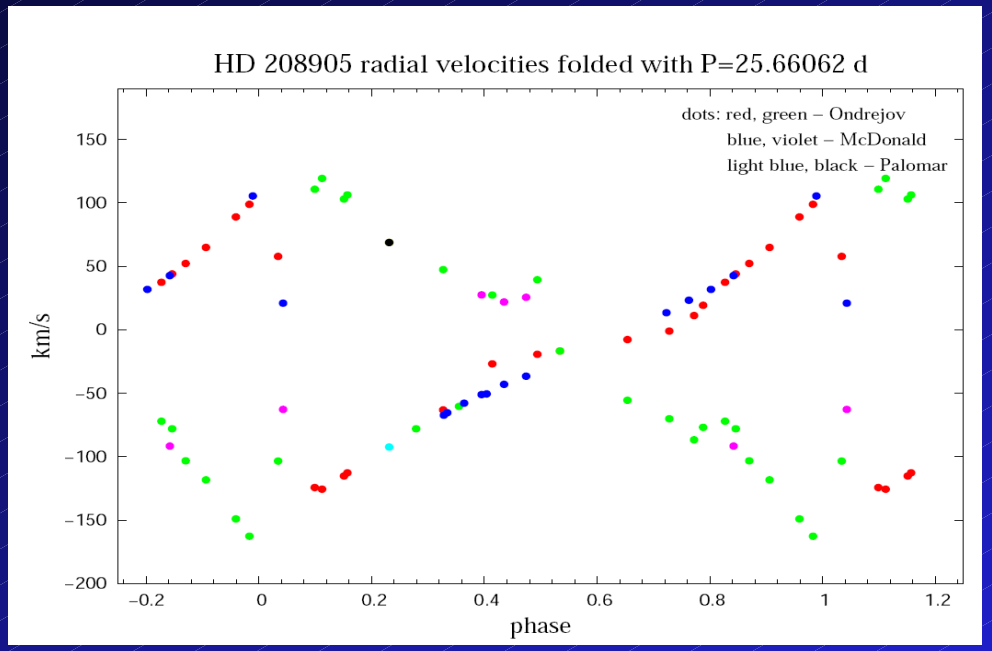
PREKOR – spectra list to ASCII file

KOREL – engine (backend)

Spectra Disentangling in Fourier Space - KOREL

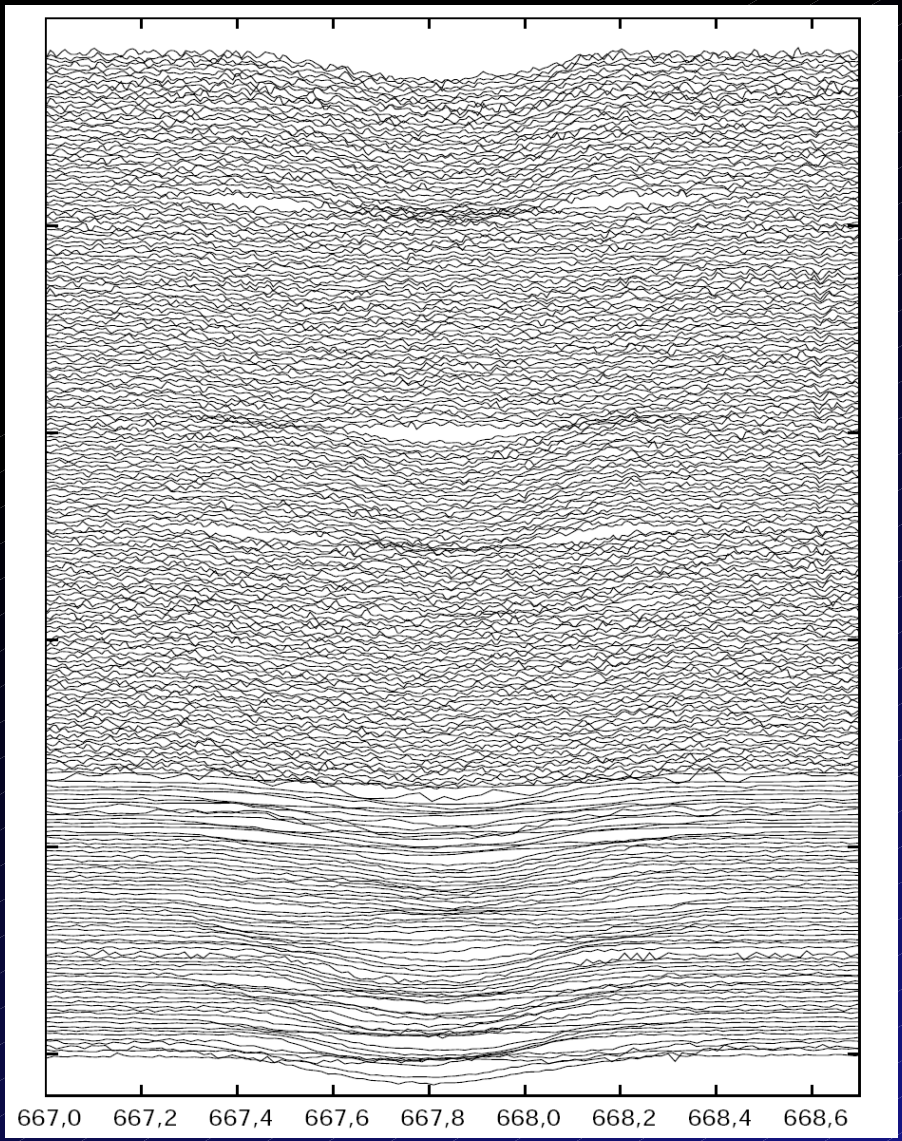


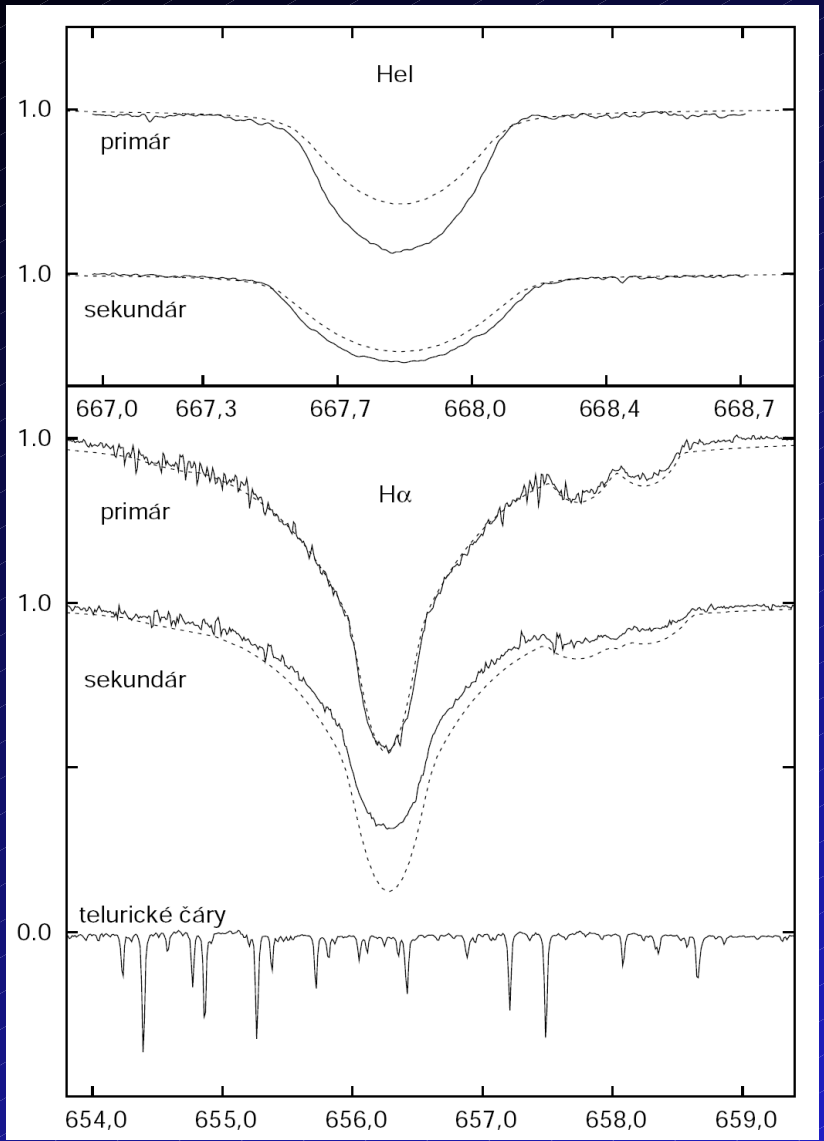




HD208905: Koubsky et al. 2006

Many spectra overploted to find cuts





V436 Per Janík 2003

KOREL as VO service

- VO will replace PREKOR
- Using VO for getting data, convert, display (user interaction) – spektra from servers, elements from catalogues
- Spectra postprocessing (rebin, rectif, convolve)
- list of spectra sent between applications (SAMP)
- Integration with other services (Period04 , TSAP)
- Run on GRID (as Astrogrid workflows, Montage)
- Now web based service for computing and display
- (http://stelweb.asu.cas.cz/vo-korel)

Bisector Analysis

Quantitative study of LPV

Searching exoplanets

High resolution - echelle

Rectified (normalized) spectra

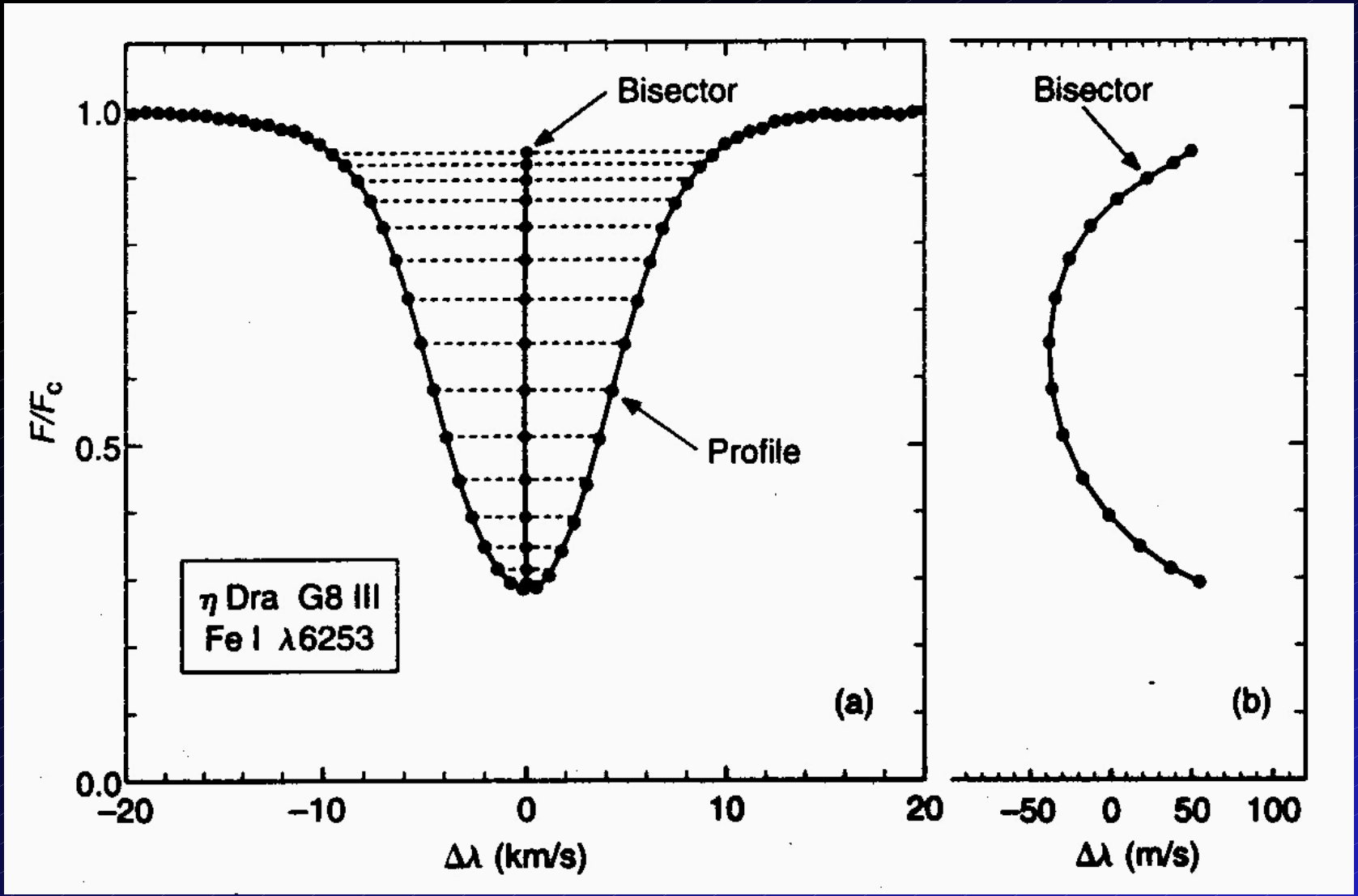
Various smoothing

Cuts in relative depth of line - half of span

Zoom of bisectors position

Results in 3D cube (time, line, depth)

Bisector Method



Line Profile- Bisectors

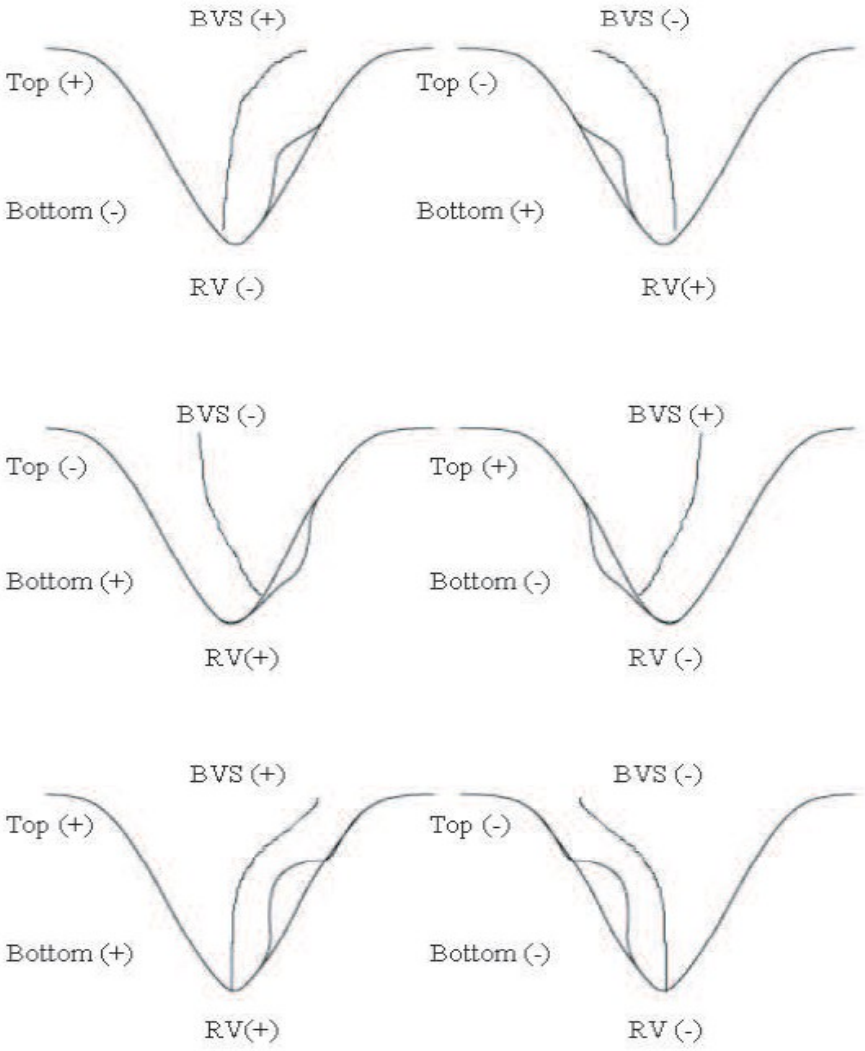
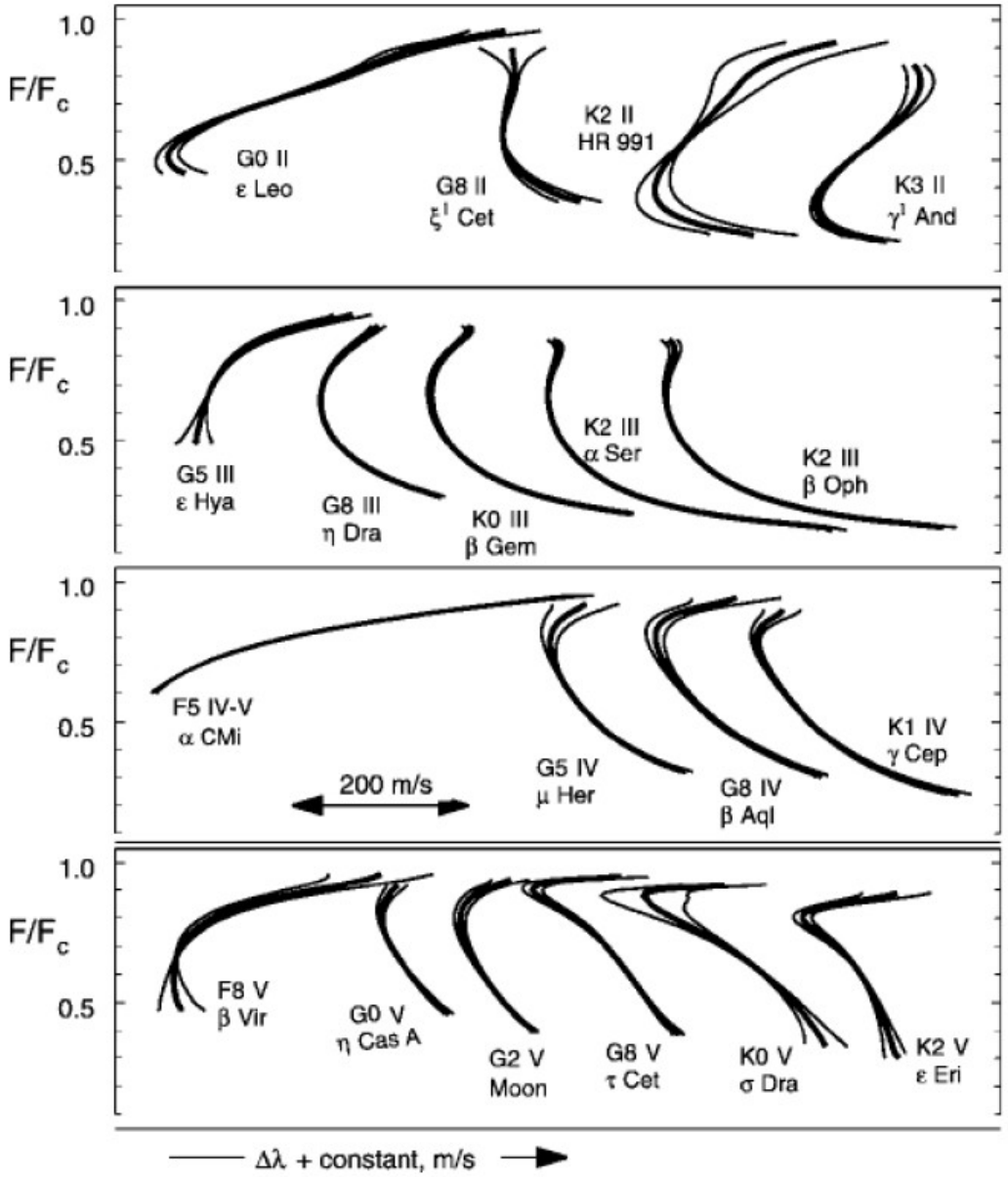


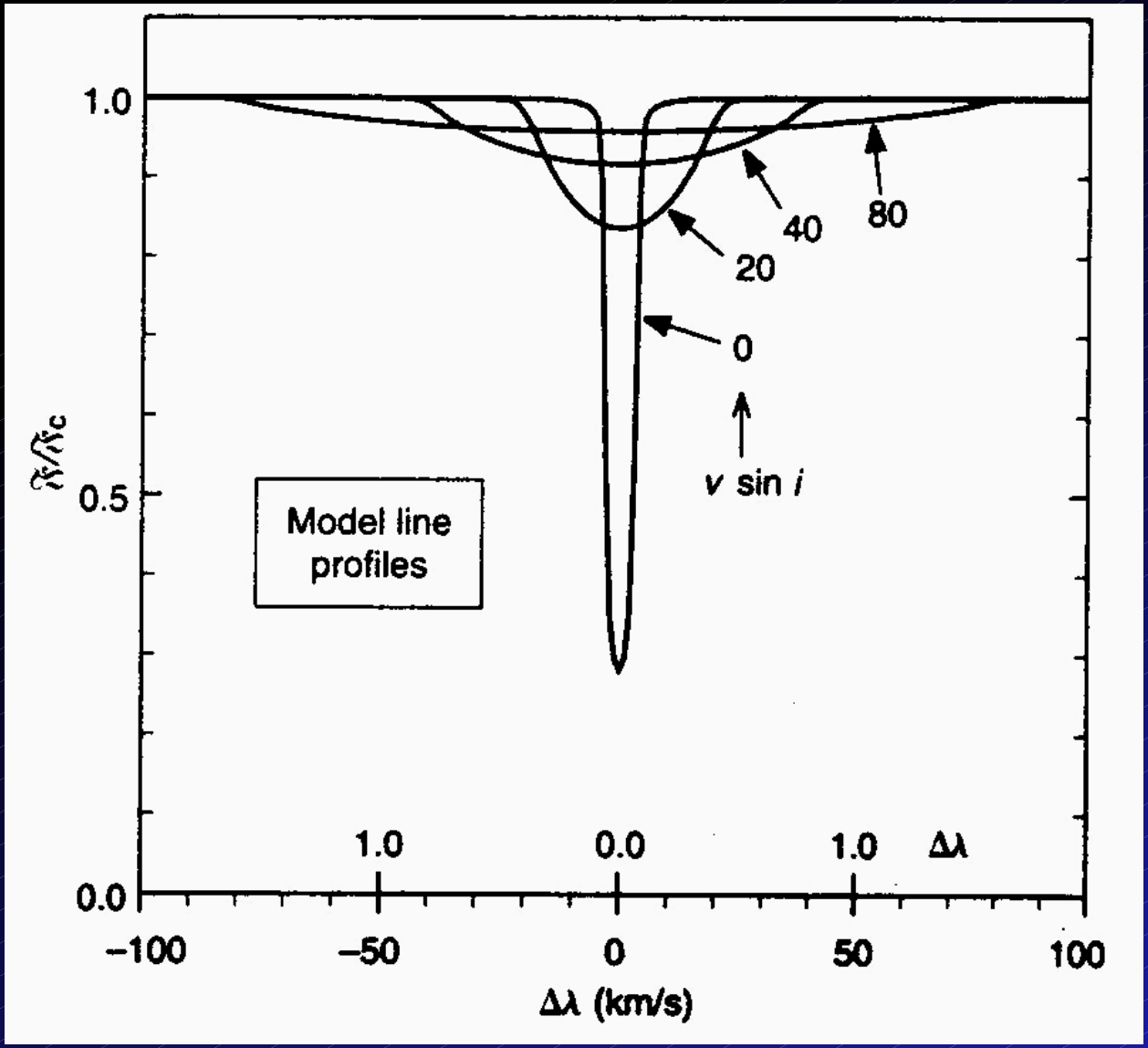
Figure 8.1: Schematic representation of different absorption profiles and their line bisectors, see text. Up: asymmetric absorptions due to spots (upward dip). Middle: asymmetric absorptions due to feculae (downward dip). Low: asymmetric absorptions due to light from a nearby object contaminating the spectrum os the star being observed (upward dip).



Fiorenzano PhD 2006

Gray 2005

Rotational Broadening



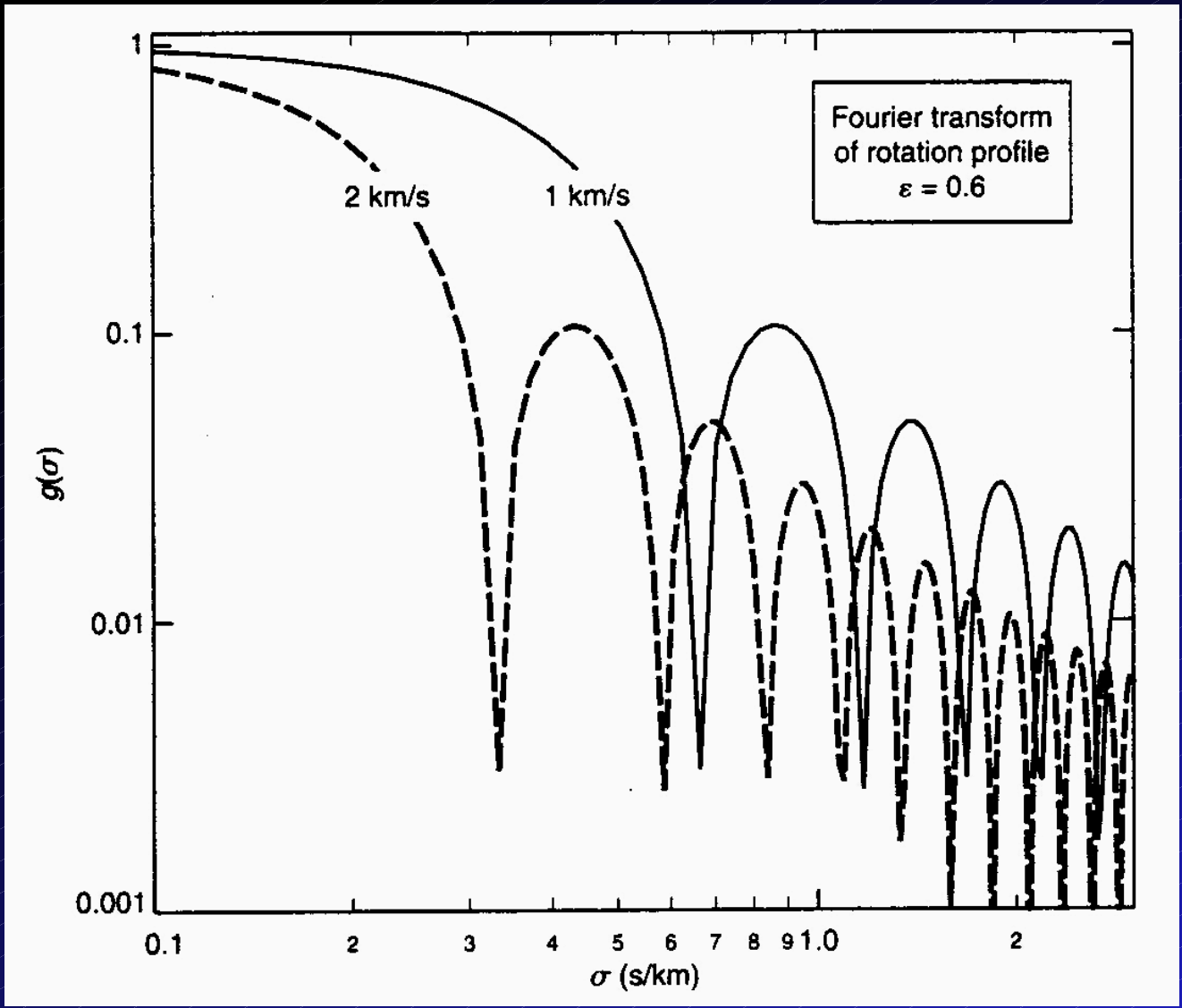
Hot stars

needed to use synthetic spectrum

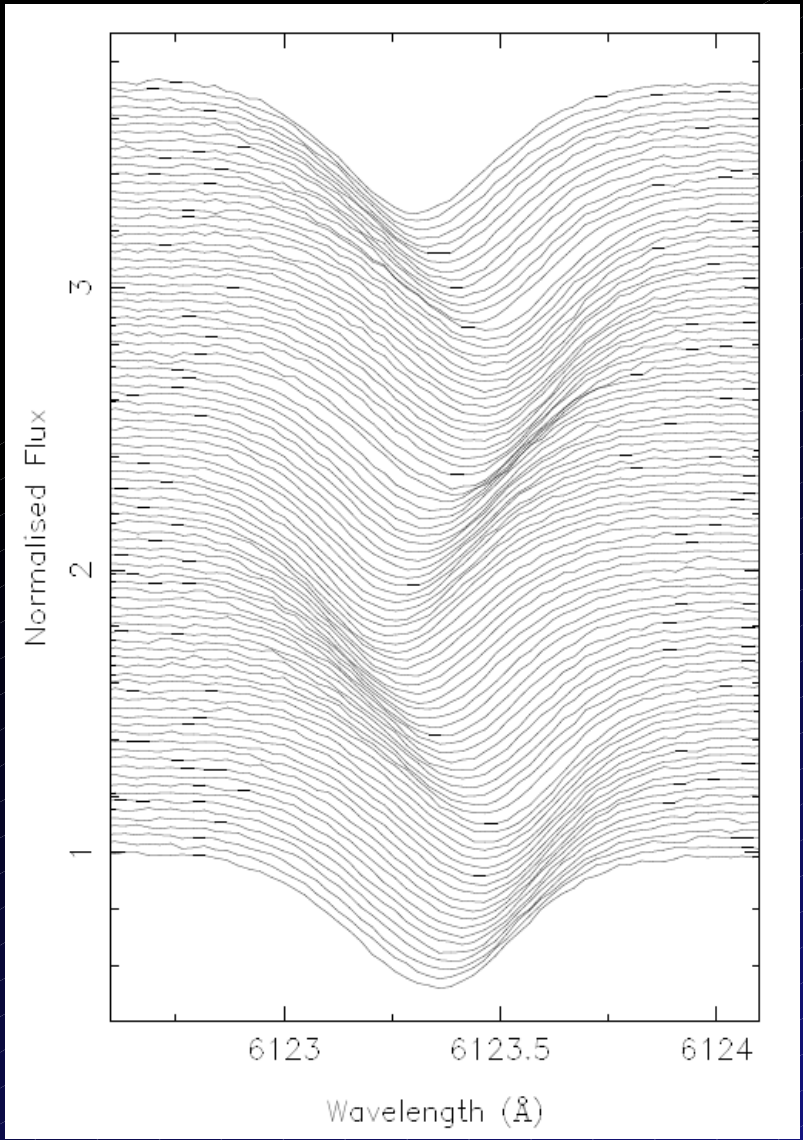
limb darkening problem

estimate of v sin i

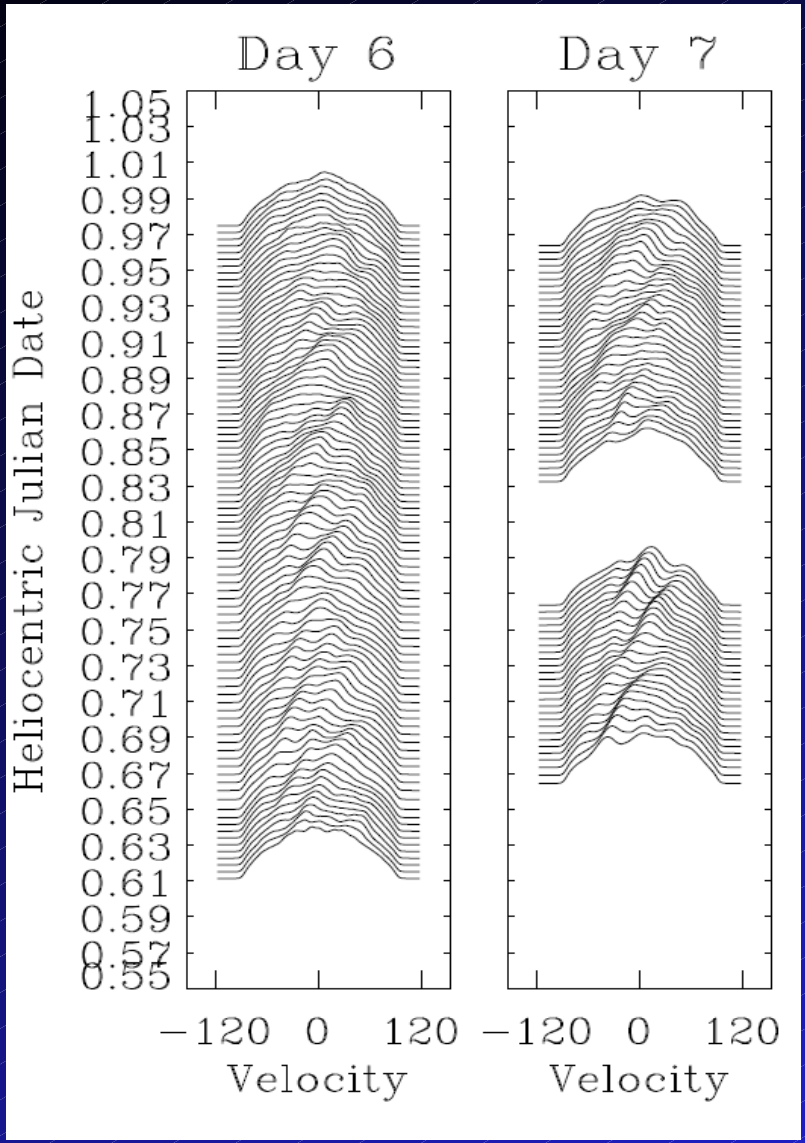
FT of Line Profile



Measured Pulsations

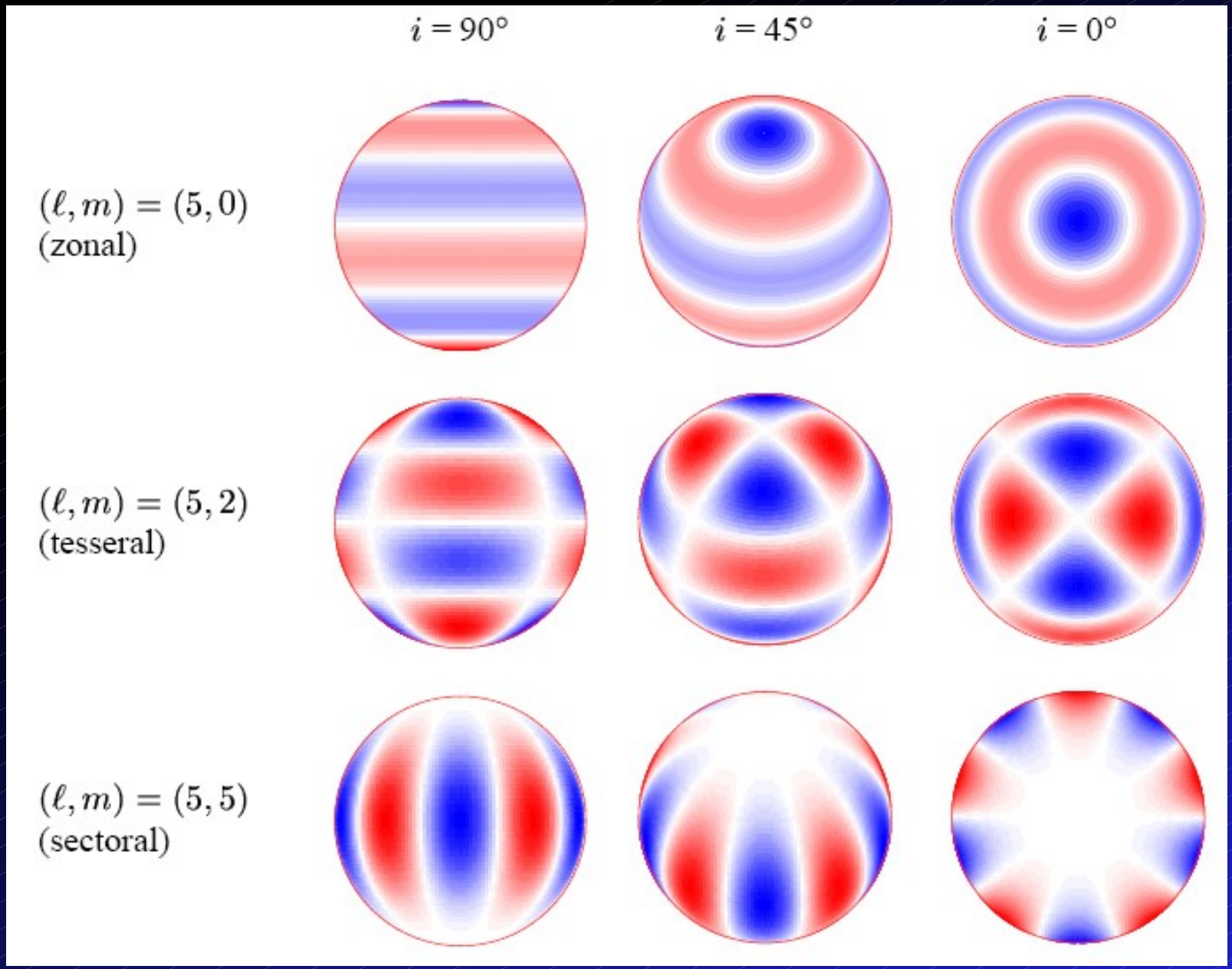


Rho Pup – del Sct type



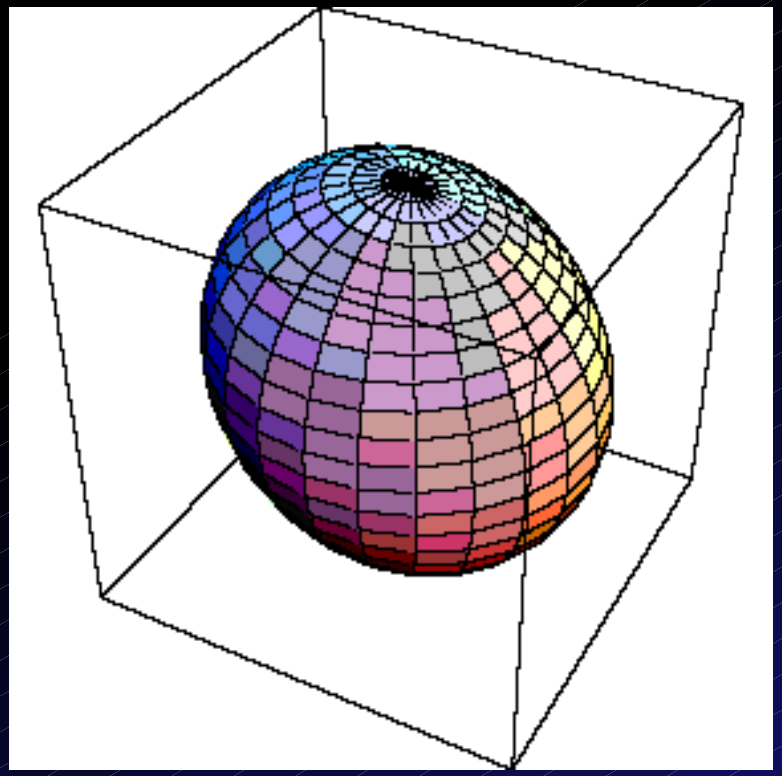
Eps Cep - del Sct type

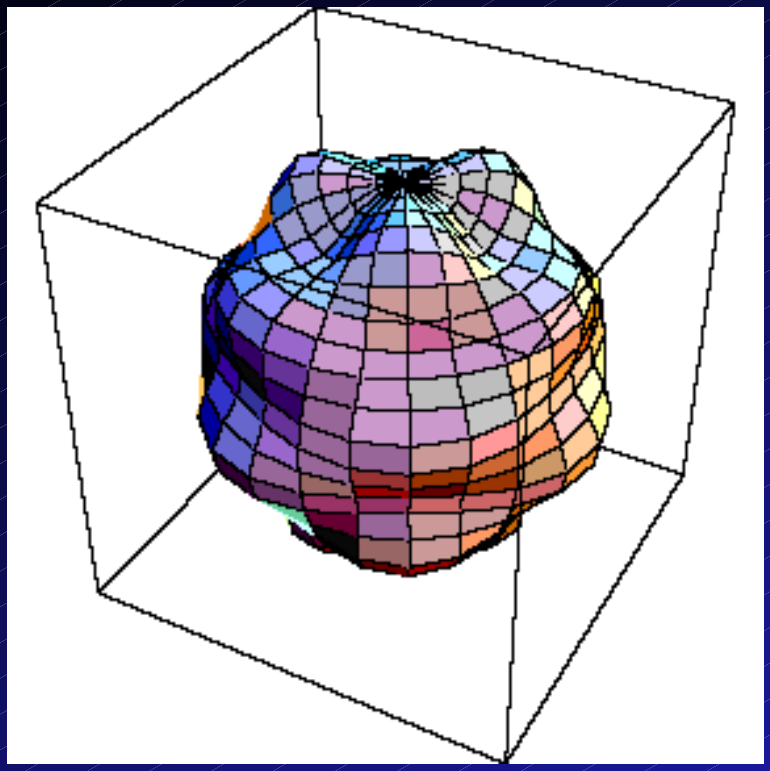
Non Radial Pulsations Modes



C. Schrijvers

Non Radial Pulsation





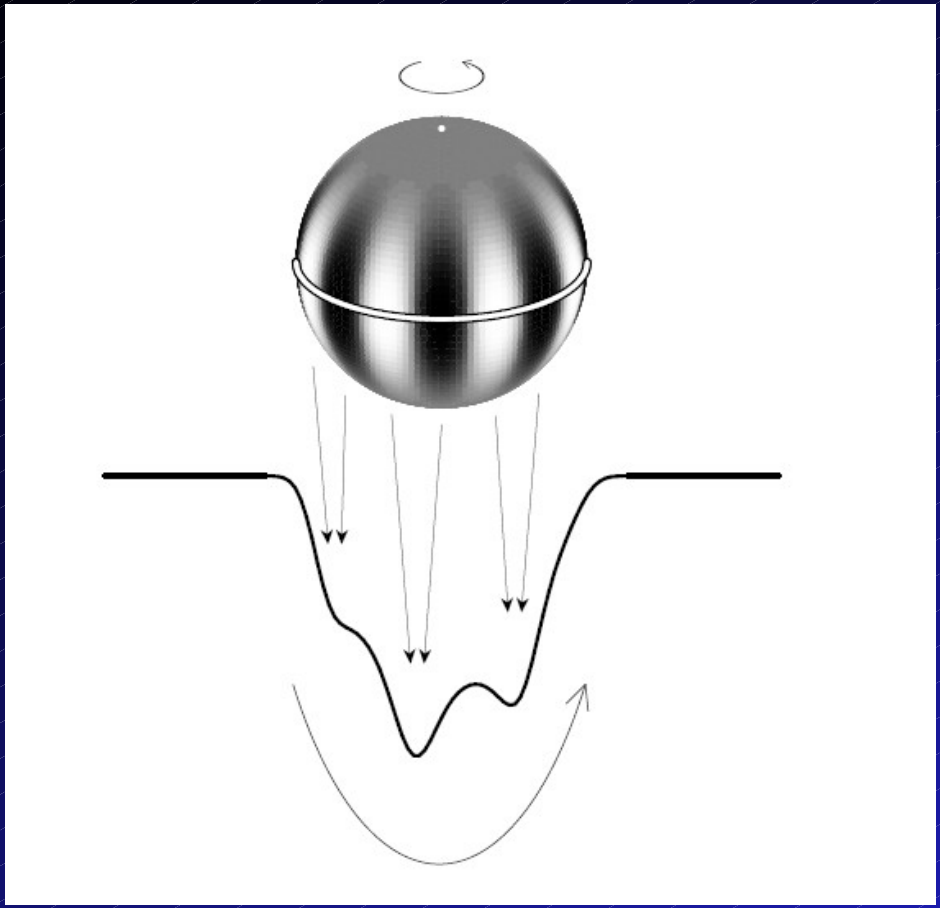
$\ell = 2, m=1$

$\ell = 8, m=3$

Tim Bedding

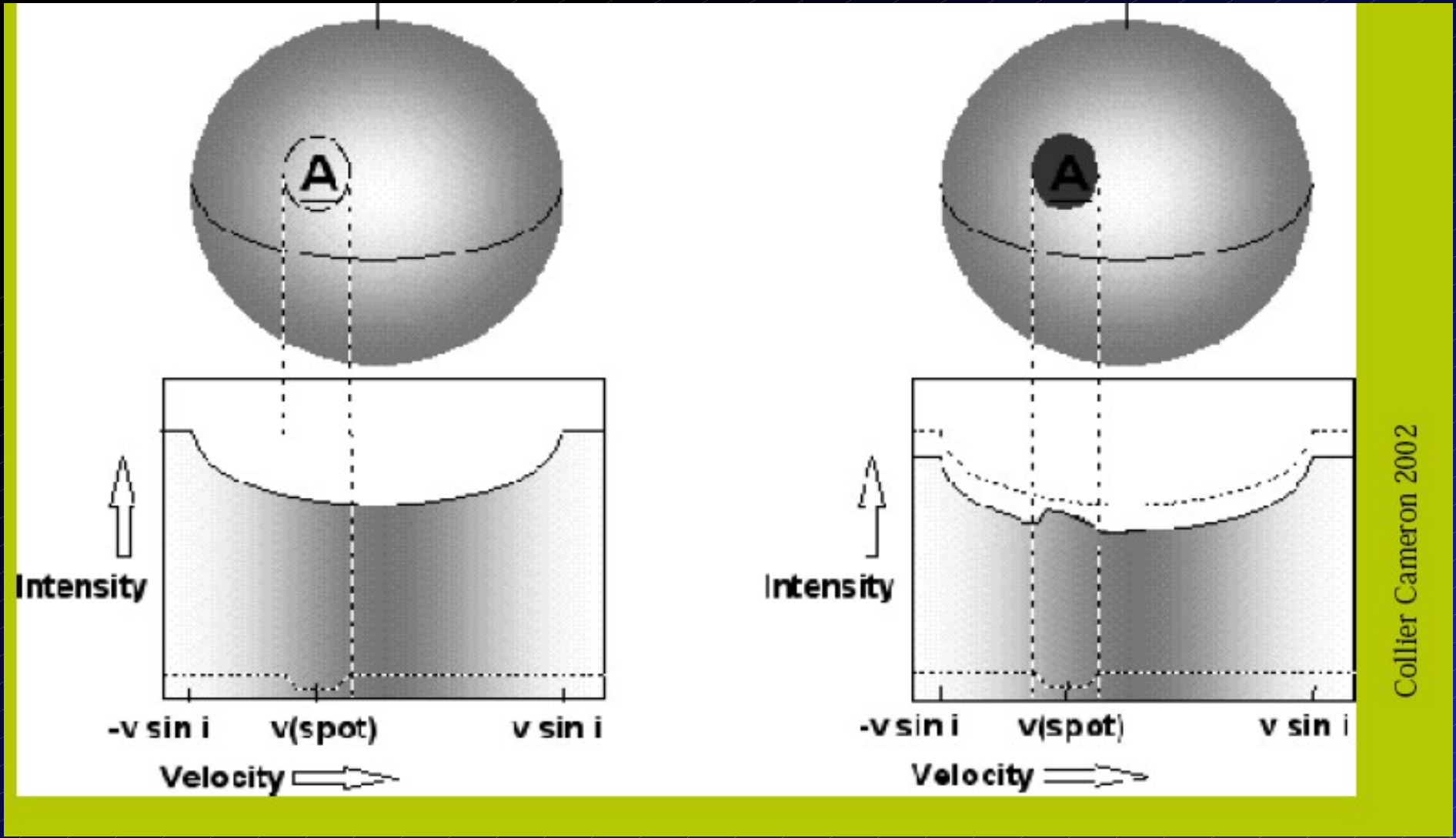
Doppler Imaging - NRP

Vogt & Penrod -80s
Zet Oph

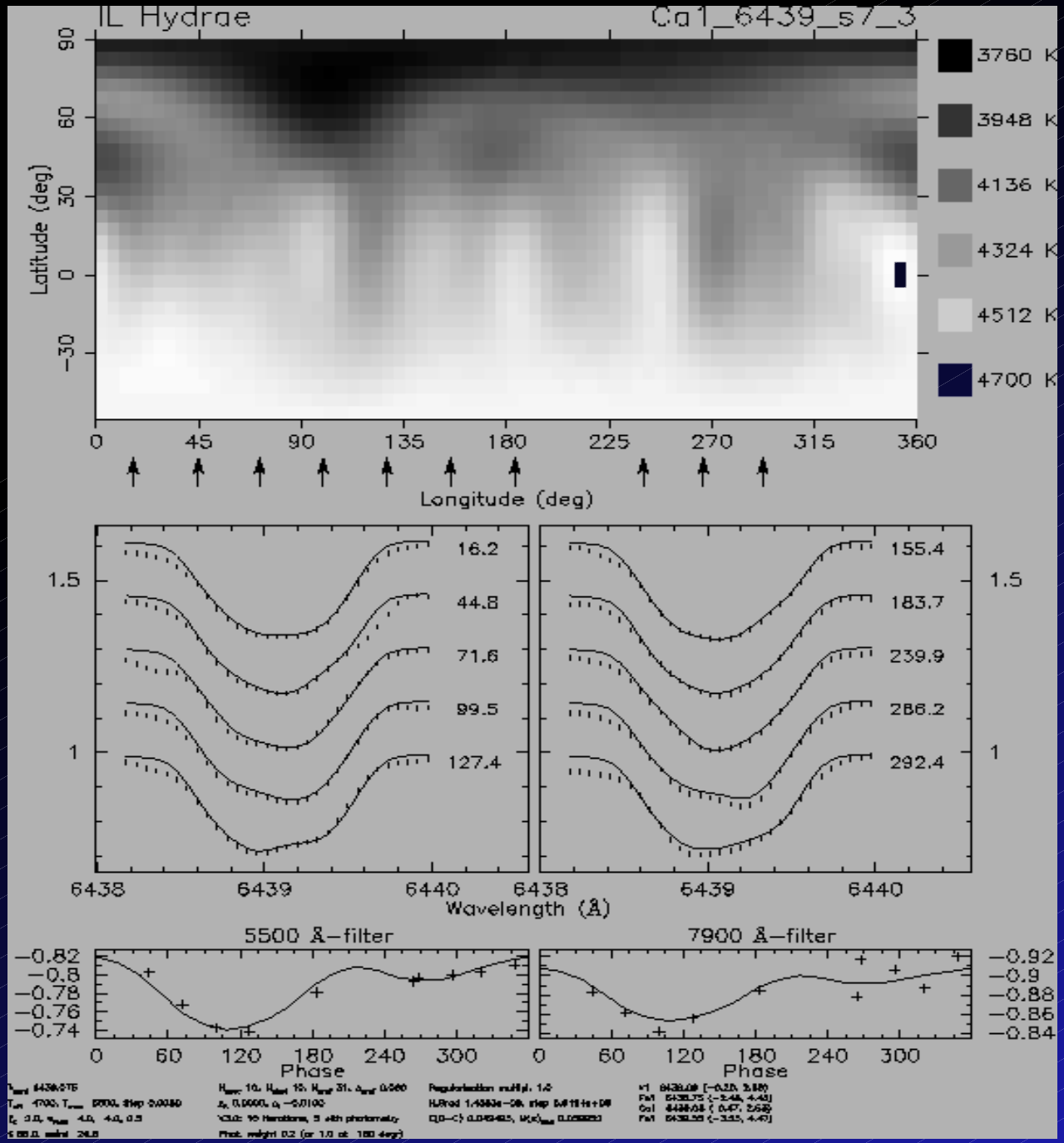


Doppler Imaging

From LPV due to rotation
stellar Spots - darker, brighter – chemical patch



Doppler Imaging



Different elements

temperature distribution

Simulated Magnetic stars - spectra

Kochukhov & Piskunov 2002

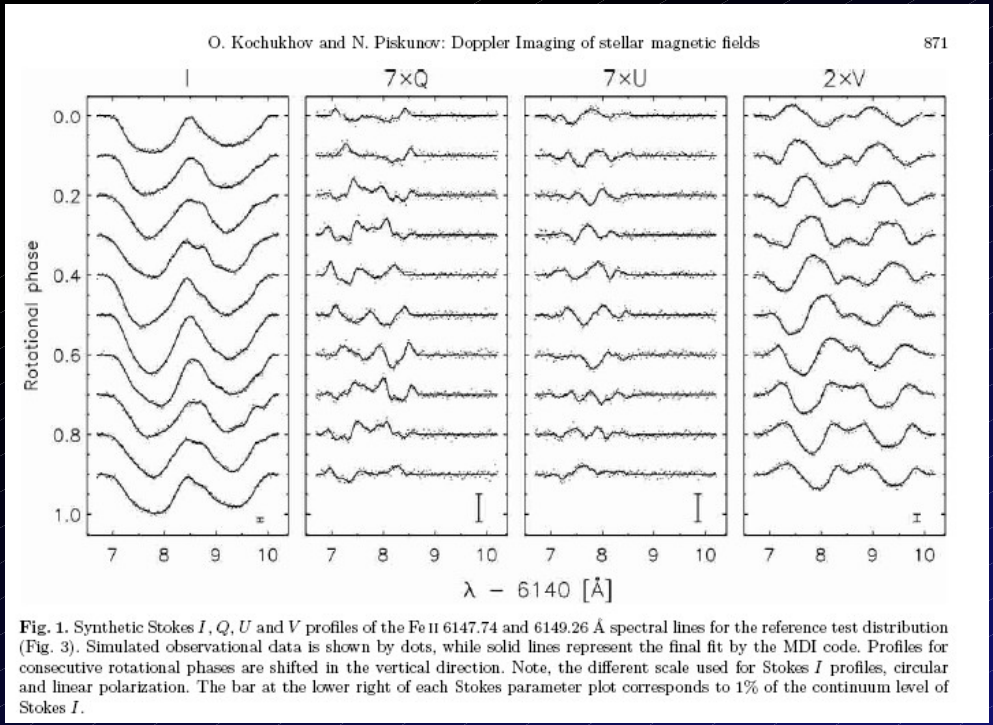


Fig. 1. Synthetic Stokes I, Q, U and V profiles of the Fe II 6147.74 and 6149.26 Å spectral lines for the reference test distribution (Fig. 3). Simulated observational data is shown by dots, while solid lines represent the final fit by the MDI code. Profiles for consecutive rotational phases are shifted in the vertical direction. Note, the different scale used for Stokes I profiles, circular and linear polarization. The bar at the lower right of each Stokes parameter plot corresponds to 1% of the continuum level of Stokes I.

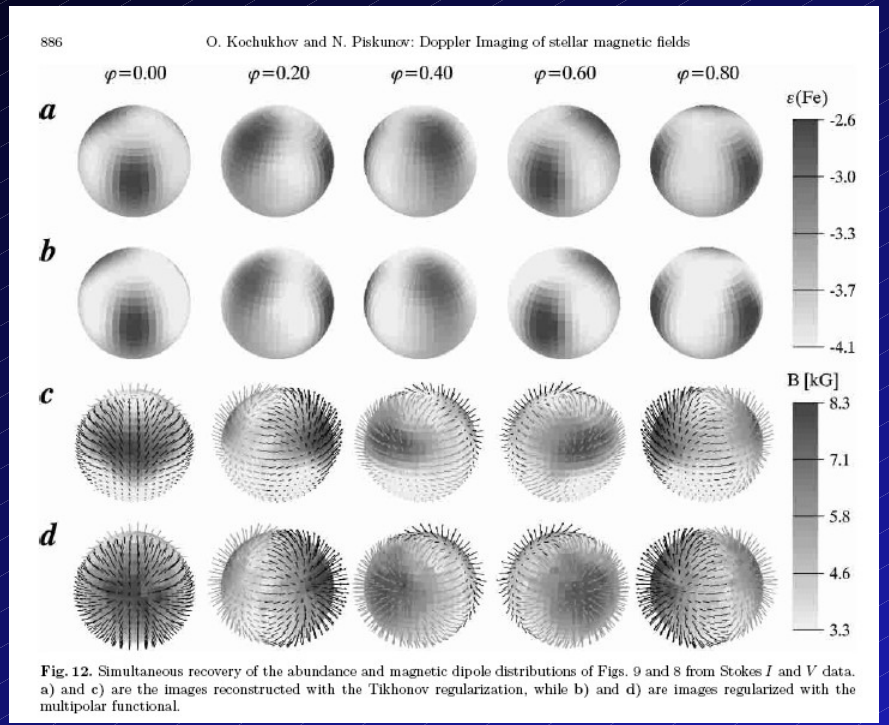
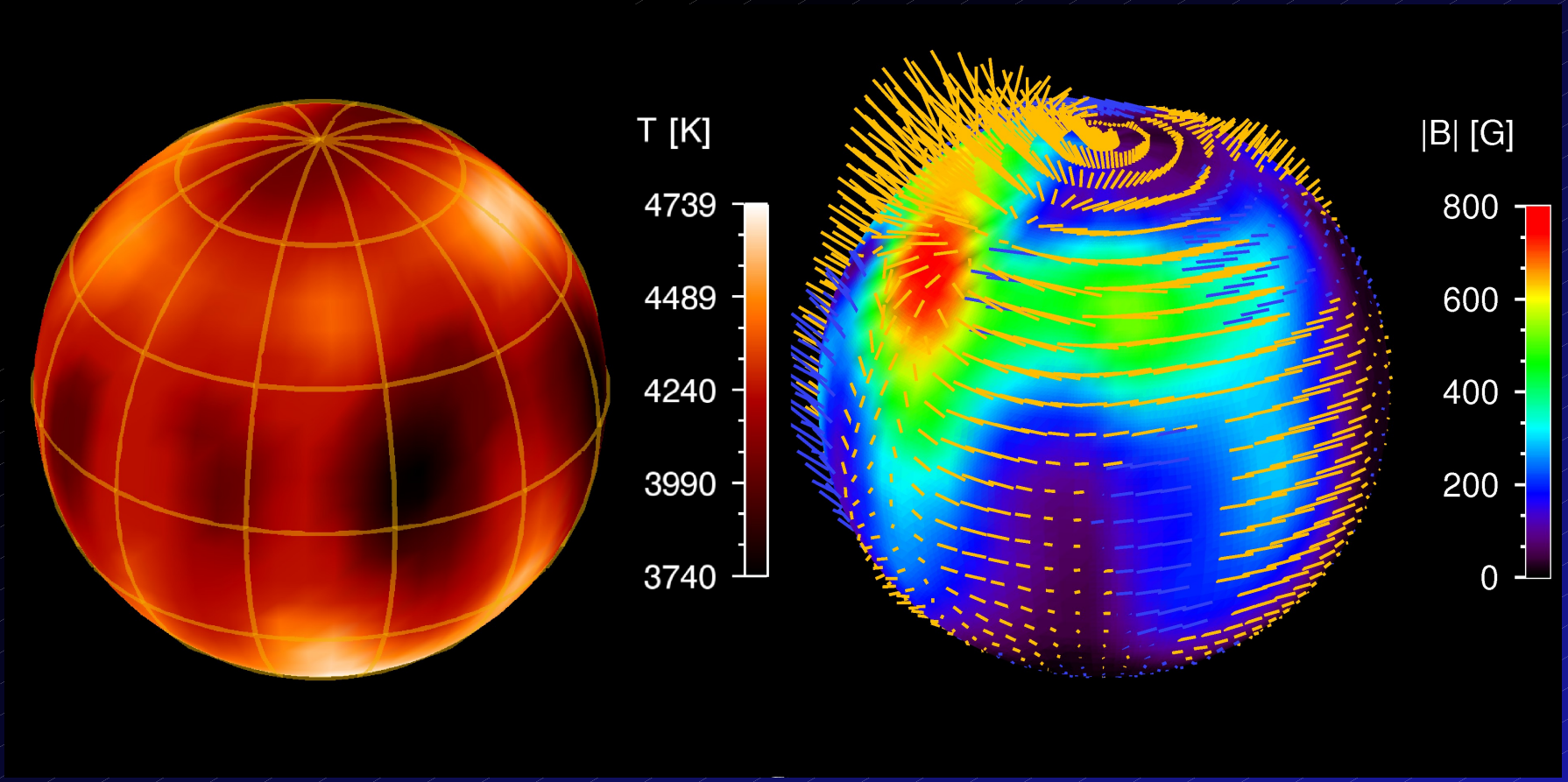


Fig. 12. Simultaneous recovery of the abundance and magnetic dipole distributions of Figs. 9 and 8 from Stokes I and V data. a) and c) are the images reconstructed with the Tikhonov regularization, while b) and d) are images regularized with the multipolar functional.

Stokes parameters spectra

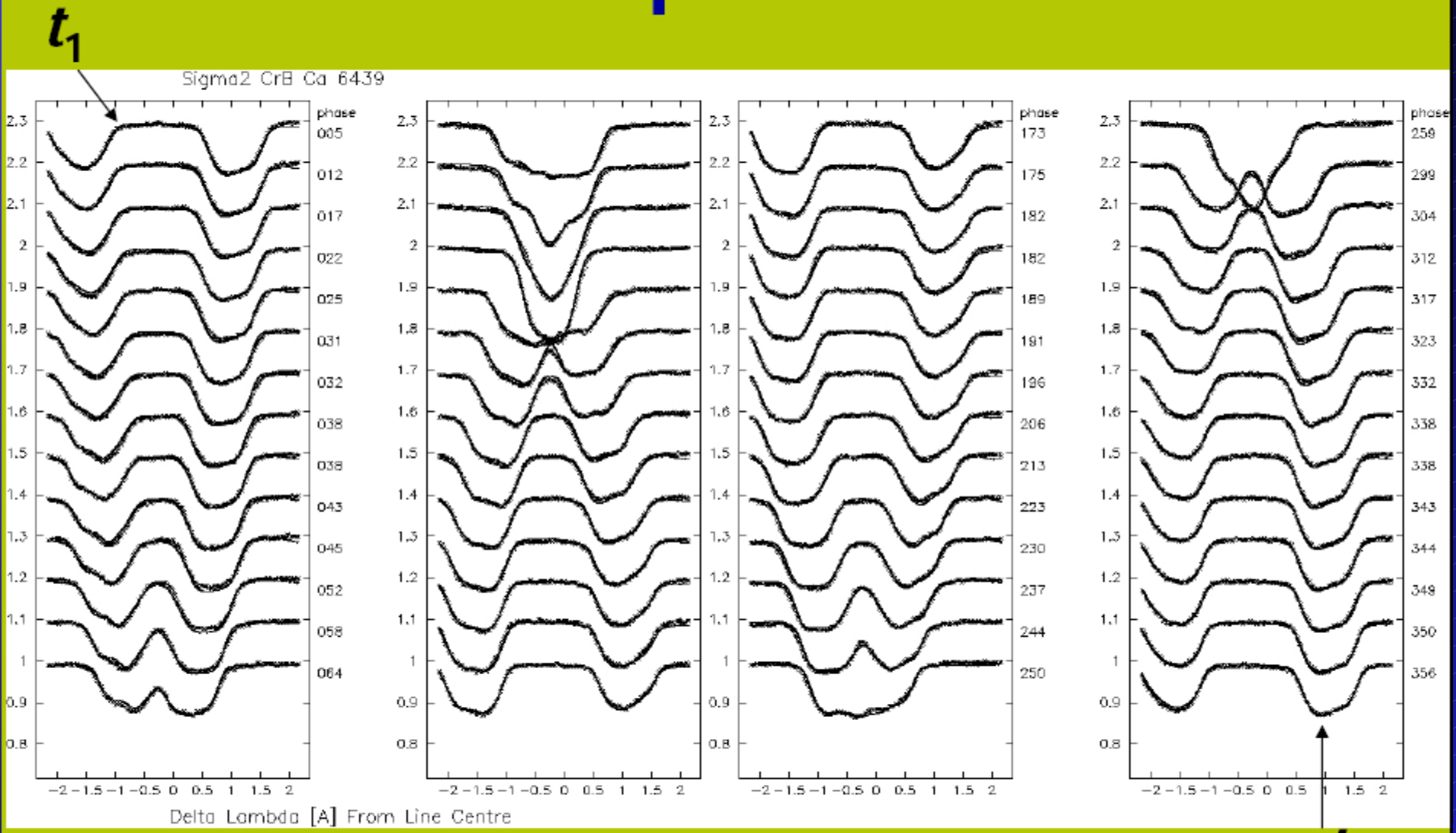
Abundances + Mg field

Zeeman Doppler Imaging



II Peg, Strassmeier 2007

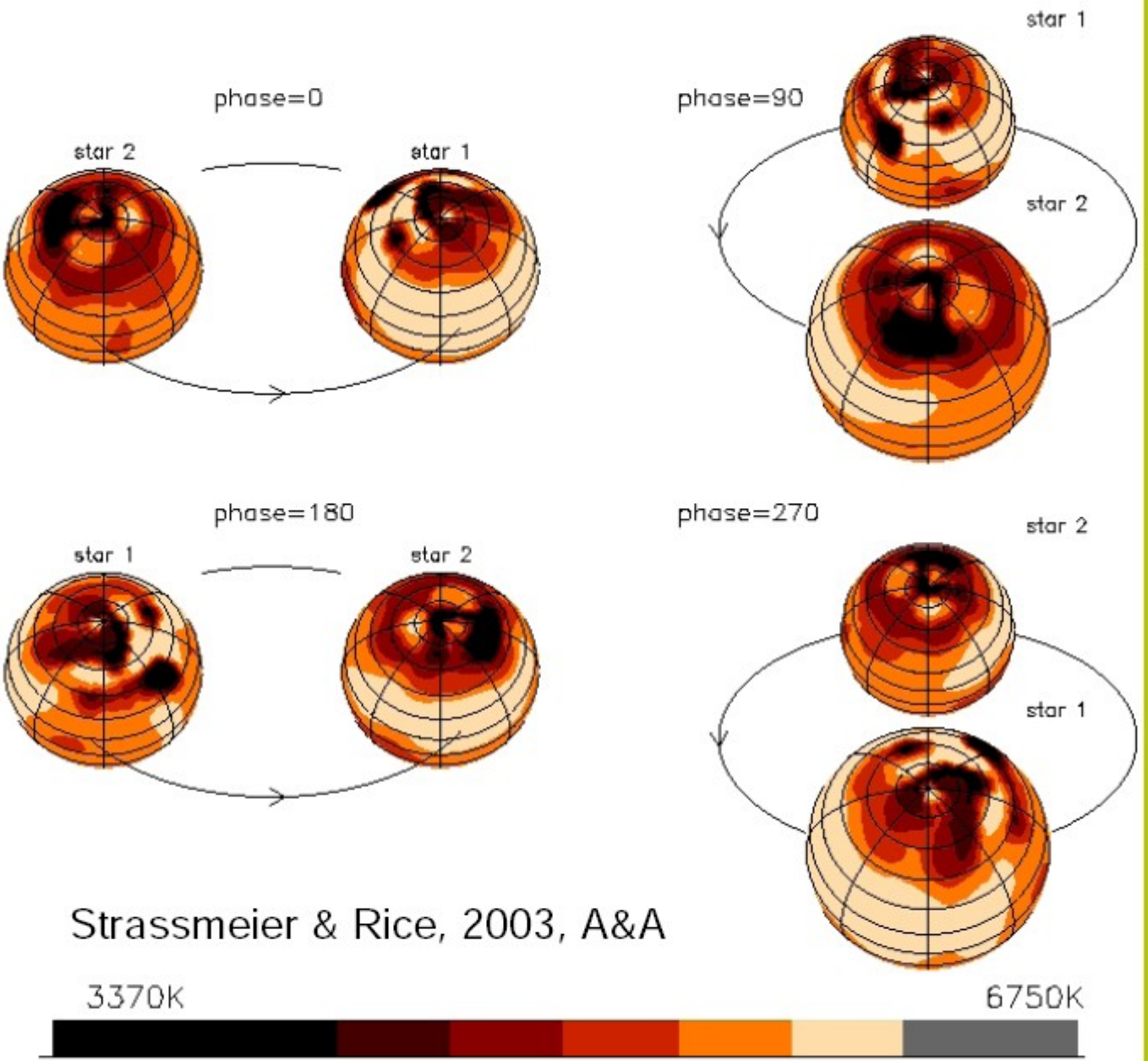
Time series spectra of σ^2 CrB



CFHT, Gecko: $\lambda/\Delta\lambda$=120,000 (2.5 km/s); Δt=23min; S/N=300:1

K. G. Strassmeier
Stellar Coronae, MPIfR, December 2006

Doppler images σ^2 CrB



Strassmeier & Rice, 2003, A&A

NORMALIZED (Rectified) Spectra in VO

Data published in two versions

Raw counts (unrectified, but wavelength calib)

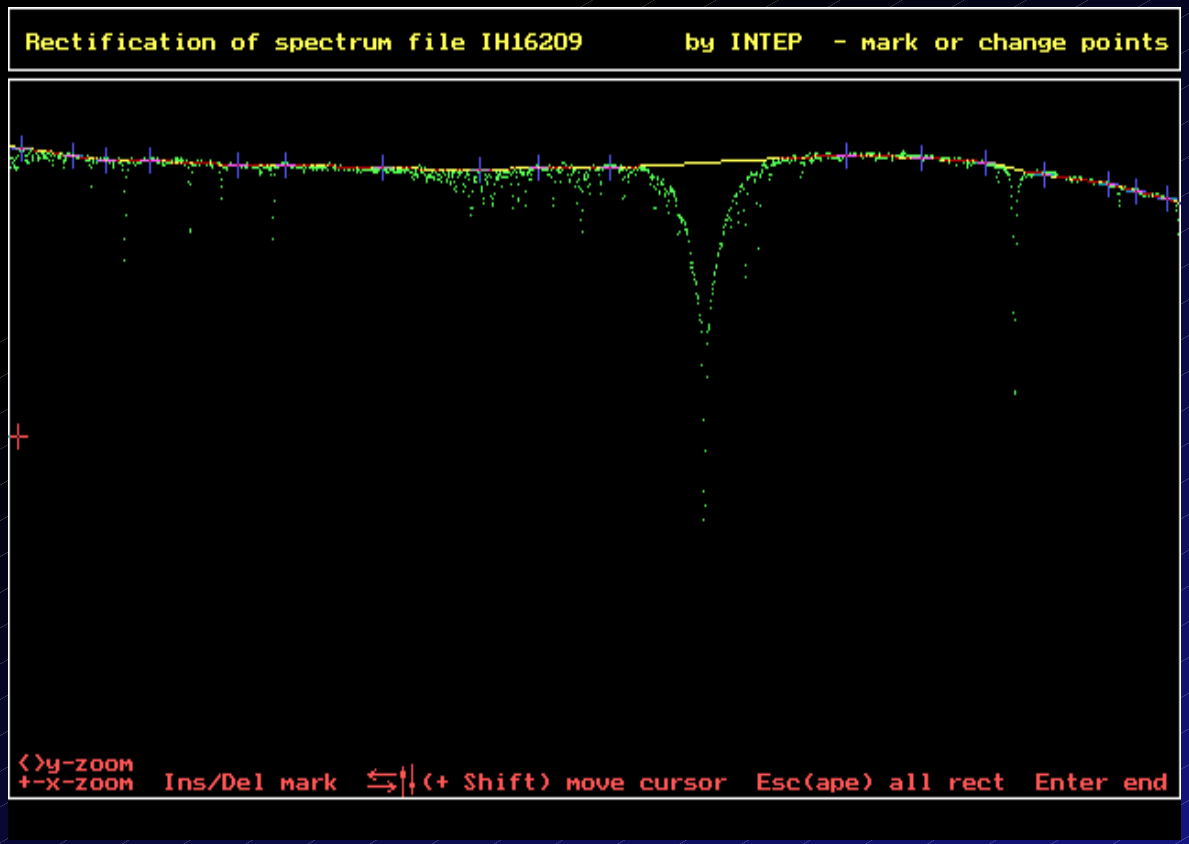
Normalized (1.0) – most of final reports (even artistic continuum – novae , molecular bands)

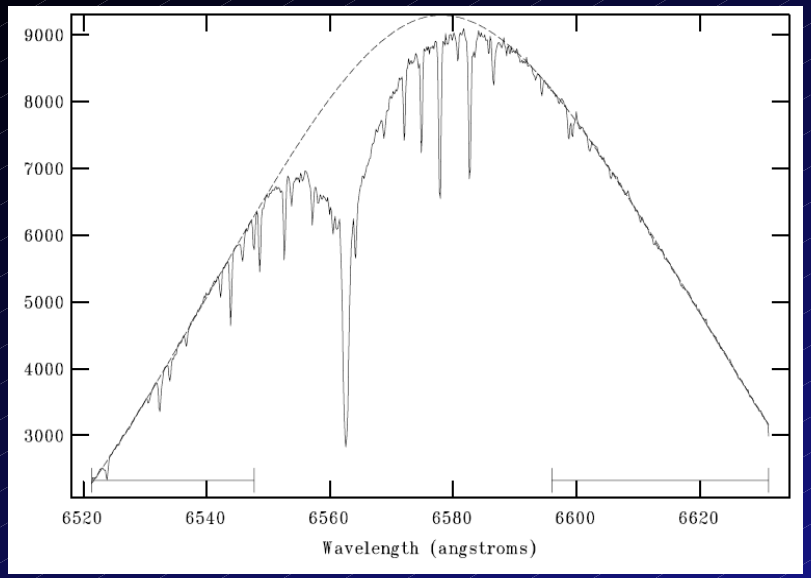
Current tools (very few legacy) do not support both unrectified and rectified in one file (would be nice to switch on and off for check !!!)

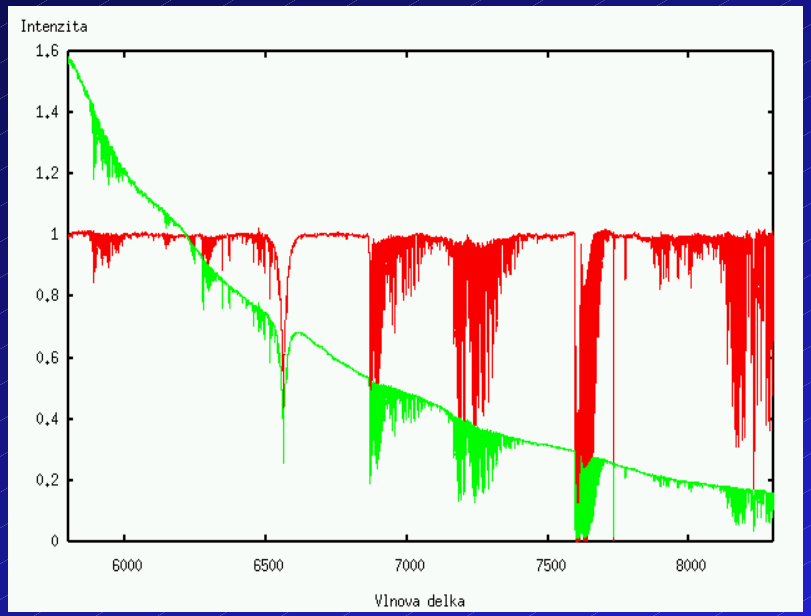
VO could help here (2 images, same metadata, different queries – joined in client)

Curation metadata for description of reduction methods, algorithms, tools, comp arc linelist...

Rectification (Normalization)

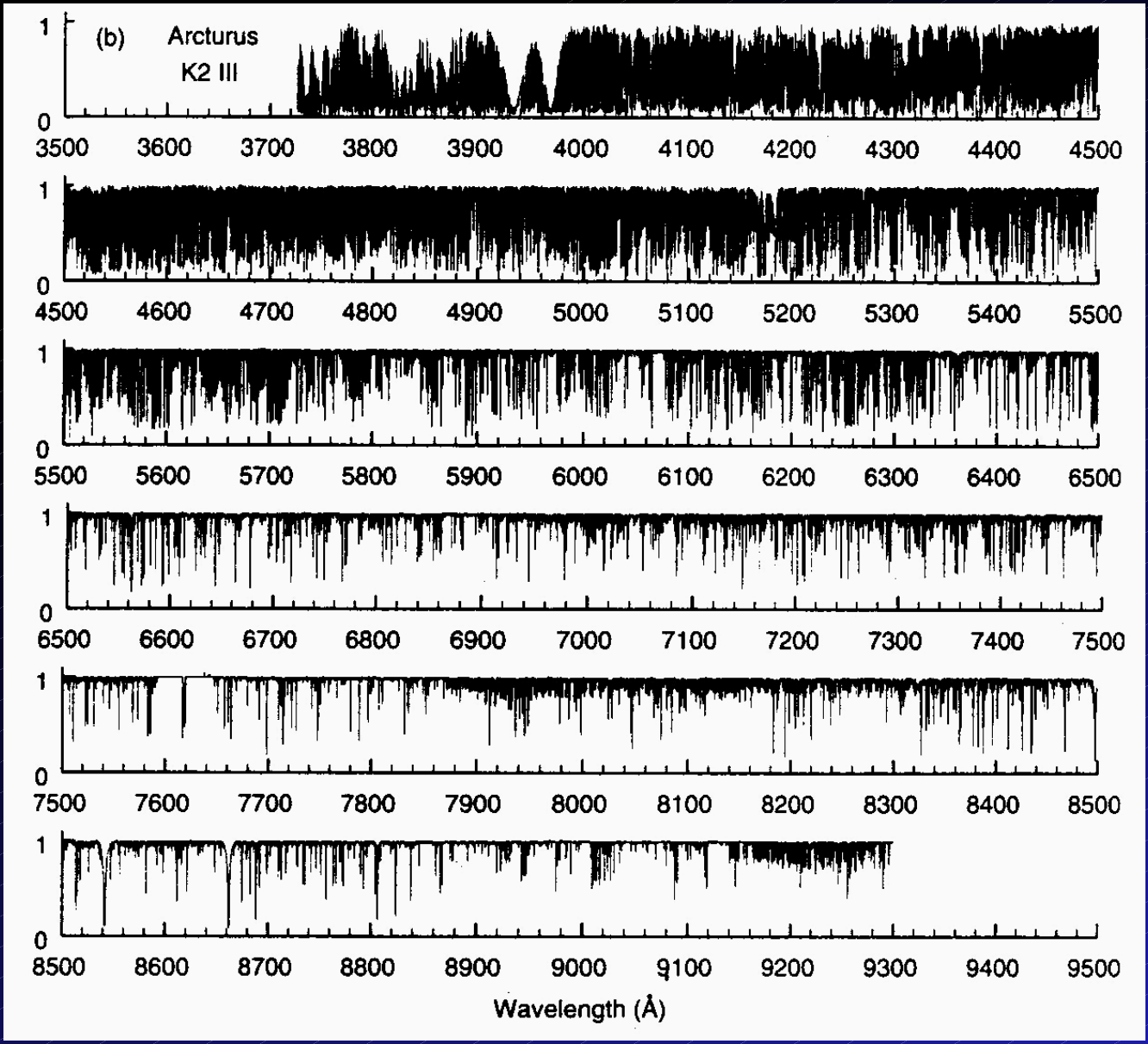






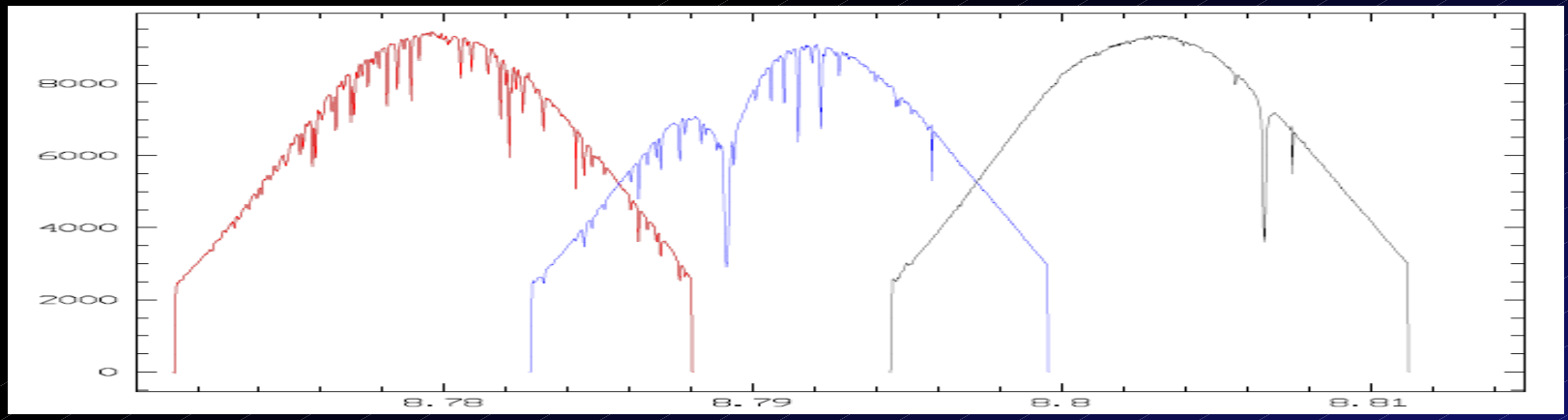
Echelle - tricky

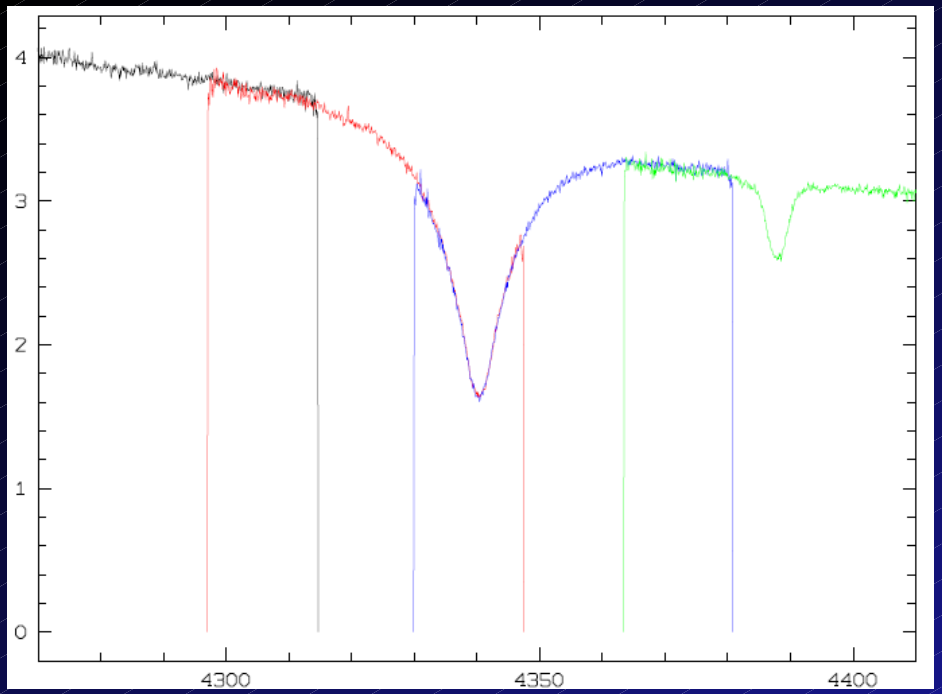
Merged Echelle

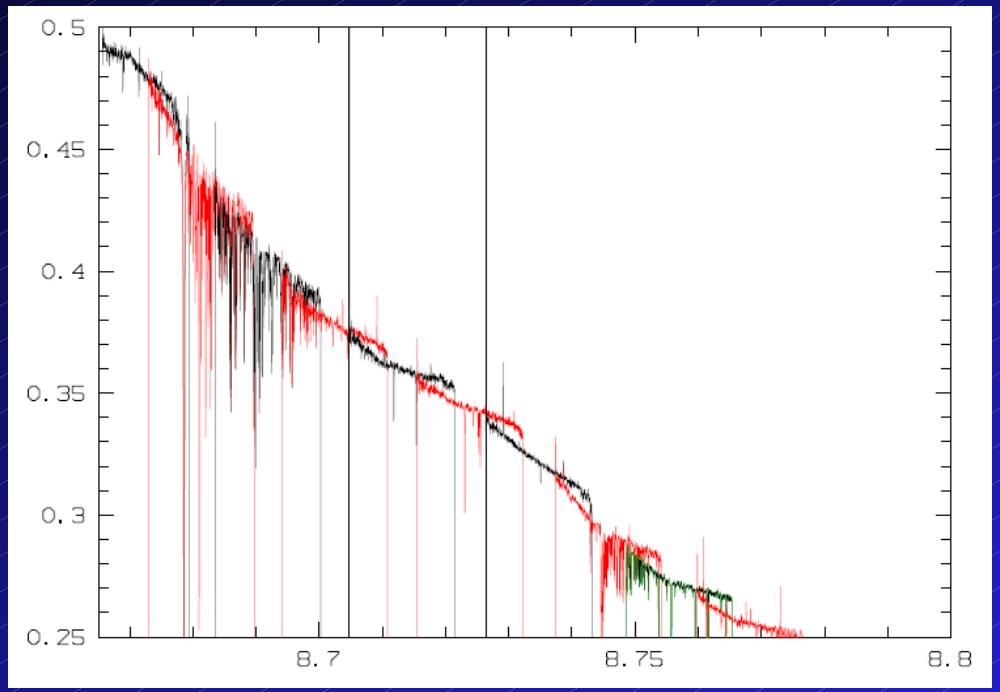


Arcturus: Hinkle et al.

Echelle Spectra Problems

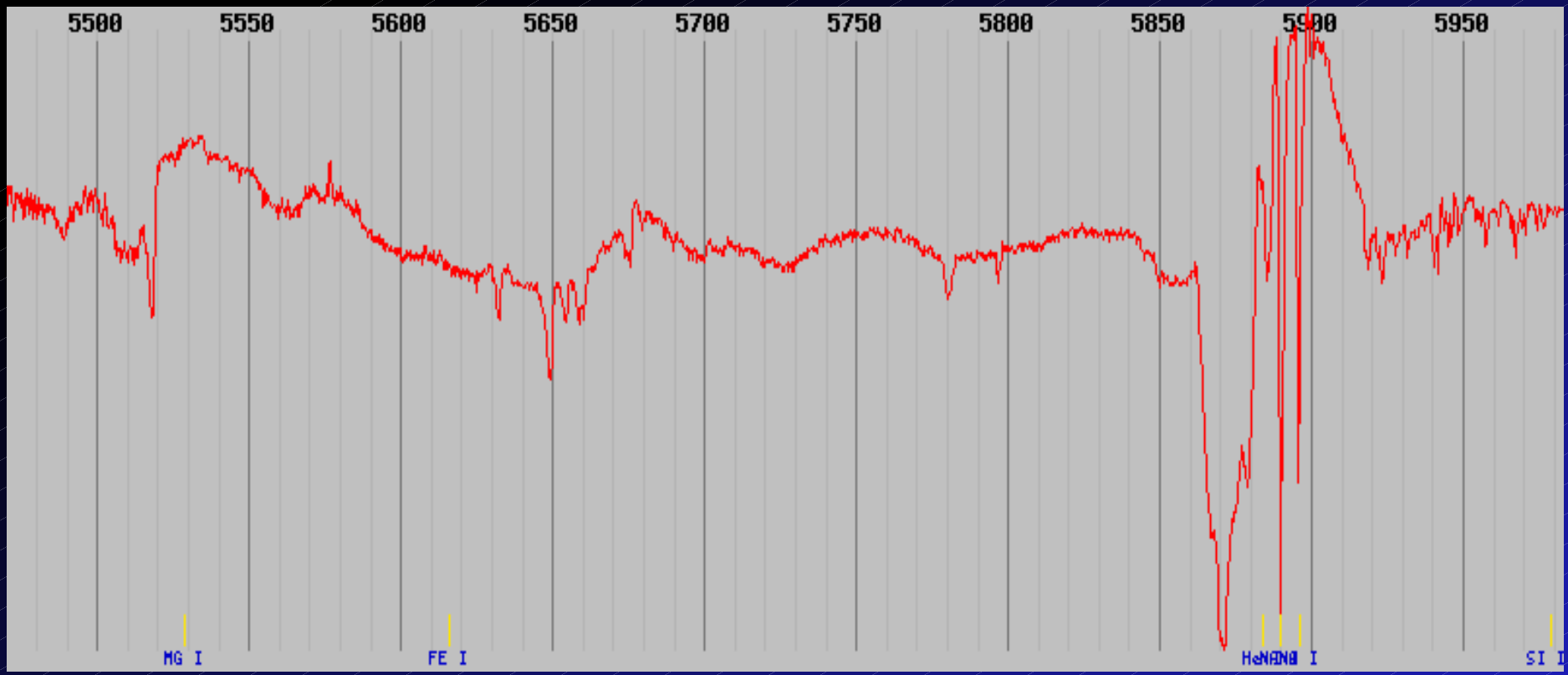






Continuum ???

V 475 Sct – Nova where is the continuum ? P cyg !



Spectra postprocessing

cutout service (ranges in SSAP) CZVO yes

Normalization (Rectification – 1.0) CZVO yes

Rebinning (change od dlambda in echelle)

Instrument profile (de)convolution

Broadening functions (rotation, limb dark)

RV shift

Client or server ?

on client side (memory, size)

Easy, special client + basic SSA servers)

on server side (Pleinpot WWW pipeline)

Aggregation, parallel (GRID processing), workflows

But ALL servers have to support - OR SSA PROXY (problems IP)

(HEROS) Spectra Cutout Service

testbed for SSA features (Skoda+Prugniel)

support of EURO-VO DCA

Implementation:

- In Pleinpot (P. Prugniel, GIRAFFE, ELODIE)
- Clients – best SPLAT
- BAND, (TIME), (FLUXCALIB), (WAVECALIB)
- TARGETNAME ! (double stars)
- Normalized (2 files – different dir/prefix -NORMxxx.fit)
- Pipelines (rebin, RV shift) ready but SSAP params ??

Killer spectral applications for VO

Use VO to find all stars with emission in given line (EW<0) – find the time when it was in em.

Use VO to get 1000s spectra of the given object cut out regions arround given lines, plot the lines, make a gray spectrum folded in time

The same – add period analysis, fold by period

Create Light and RV curve for given period

Fit the grid of models (Teff, log g) to the observed spectrum – for many stars (GAIA – detailed lines 8470-8740A)

Extract lines from echelle archives (unmerged!)

Conclusions

VO can speed up the spectra analysis

Tools are already here or will come soon

Important science with NORMALIZED data

Often SHORT wavelength range sufficient

Multiple regions / Many spectra (objects, time)

Spectra POST-PROCESSING (cutout, rebin)

Server cutout service (speed, echelle orders)

Period analysis in VO – derived products (EW..)

Interoperability of all applications (SAMP)

Practical Issues

SPLAT the BEST !!!! for stellar spectroscopy not only VO visualize but analysis as well

VOSPEC - powerful but not suitable for optical spectroscopy

(but SED nice, automatic unit conversion, mathbox - ???,)

1D FITS not, complicated adding files, mirror to RV?, strict SSA

SpecView – crashes, fitting models (Kurucz, Dusty, HST calib)

SSA not obeyed well in servers – misused in COROT time series

Long spectra – huge memory, long load - no cutout yet

Most of VO spectral stuff is just data discovery and visualisation !

DEMO

SPLAT the BEST !!!!

SSA – HEROS CUTOUT SERVICE – blue and red channel

FLUXCALIB=normalized (NORM{b,r}xnnnn.fit) HOW UNCALIB

POS (name resolver) or TARGETNAME (no space!)

BAND=6550e-10/6570e-10 – cut Halpha line

Using SPLAT stacking – order offset 0.05 ...

other expressions – e.g. Period from epoch

DEMO

Zeta Tau in Halpha

Phi Per

Water lines on Eta Uma

V360 Lac - thick disk – messy profiles

Rho Aur – Binarity

Kap Dra - rising emission

96 Her - double absorption to single

del Sco – profile rising

Catch ! 28 Tau and 27 Tau in POS SIZE=10arcs

With TARGETNAME HR1847B