Study of system 96 Her by Fourier disentangling

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Outline

- 1. Method of Fourier disentangling
- 2. Program KOREL
- 3. 96 Her
- 4. Results
- 5. Summary

Methods of the analysis of the composite spectra

- Measurement of the radial velocity and solution of RV curve
- Cross-corellation
- Method of the broadening function
- Methods of spectra decomposition
  - Direct decomposition
  - Tomographic separation

- Method of simple disentangling
- Fourier disentangling

Disadvantages of the classical methods

- Often is necessary to know RV in advance
- Some methods need knowledge of a template spectrum
- Due to using recurrent procedures random noise cumulates (e.g. direct subtraction)

Simple disentangling

- Simultaneous decomposition of spectra and determination of their RV, or direct solution of orbital parameters (Simon & Sturm, 1994)

$$\begin{pmatrix} M_{\mathbf{A1}} & M_{\mathbf{B1}} \\ \ldots & \ldots \\ M_{\mathbf{AN}} & M_{\mathbf{BN}} \end{pmatrix} \begin{pmatrix} I_A \\ I_B \end{pmatrix} = \begin{pmatrix} I(t_1) \\ \ldots \\ I(t_N) \end{pmatrix}$$

- Set of M x N linear equations, M – number of pixels in a typical exposition, N – number of expositions
- $\mathbf{M}$ are matrices with units shifted off-diagonal for RV in pixels

Fourier disentangling

- Hadrava (1995)
- Calculates with Fourier images of the observed spectra
  - numerically easier
  - allows further generalization

Principle of the Fourier disentangling

- Assuming multiple system of n stars and spectrum of every component $I_j(x)\Big|_{j=1}^{n}$ is constant in time with Doppler shift in radial velocity $v_j(t)$ – star j in time t

- Composite spectrum observed in time t is thus $$I(x,t)=\sum_{j=1}^{n} I_j(x)*\delta(x-v_j(t)).$$

  and its FT is $$\tilde{I}(y,t)=\sum_{j=1}^{n} \tilde{I}_j(y)\exp(iyv_j(t)).$$

Principle of the Fourier disentangling

- Huge set of linear equations in FT splits into many simple sets with a dimension of number of stars in the system

- Generalization $$I(x,t)=\sum_{j=1}^{n} I_j(x)*\Delta_j(x,t,p)$$

where Δ_j are general broadening functions = Doppler shift + line-profile broadening, p are parameters characterizing orbital motion or physical conditions of formation of the spectra

Principle of the Fourier disentangling

- Principle of disentangling lies in minimalization of the sum of integrated squares of deviations between observed and modelled spectra

$$0=\delta\sum_{l=1}^{N}\int\left|I(x,t_l)-\sum_{j=1}^{n}I_j(x)*\Delta_j(x,t_l,p)\right|^2 dx$$

Line strength variability

- Admitting line-strength variability of some components – original motivation – better results for phases with partially or completely eclipsed component

- To the equations we put time-dependent factors of line-strength $s_{jl} = s_j(t_l)$ for every component, then

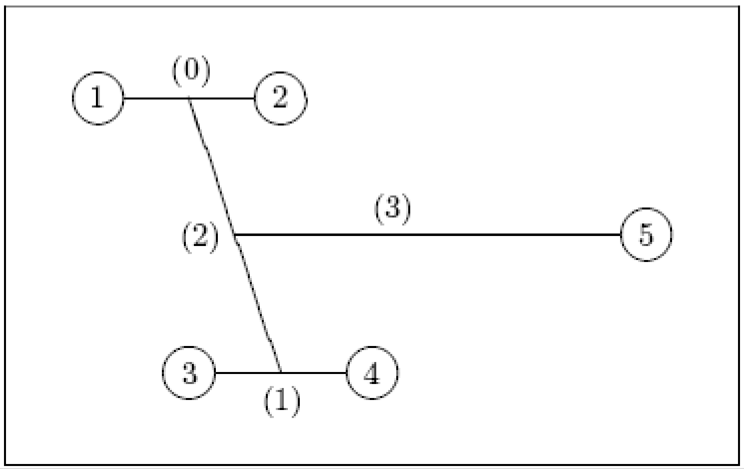
$$\Delta_j(x, t_l, p) = s_{jl}\,\delta(x - v_j(t_l, p))$$

and FT is $\tilde{\Delta}_j(y, t_l, p) = s_{jl} e_{jl}$

KOREL

- Developed by dr. Hadrava (1995, 1997)
- Fourier disentangling
- Decomposition of time series of multiple systems' spectra (max. 5 components)
- From k spectra of n stars ($k>n$) finds individual spectra and corresponding RV by the method of least squares
- It is possible to determine orbital elements of the system – using simplex minimalization method

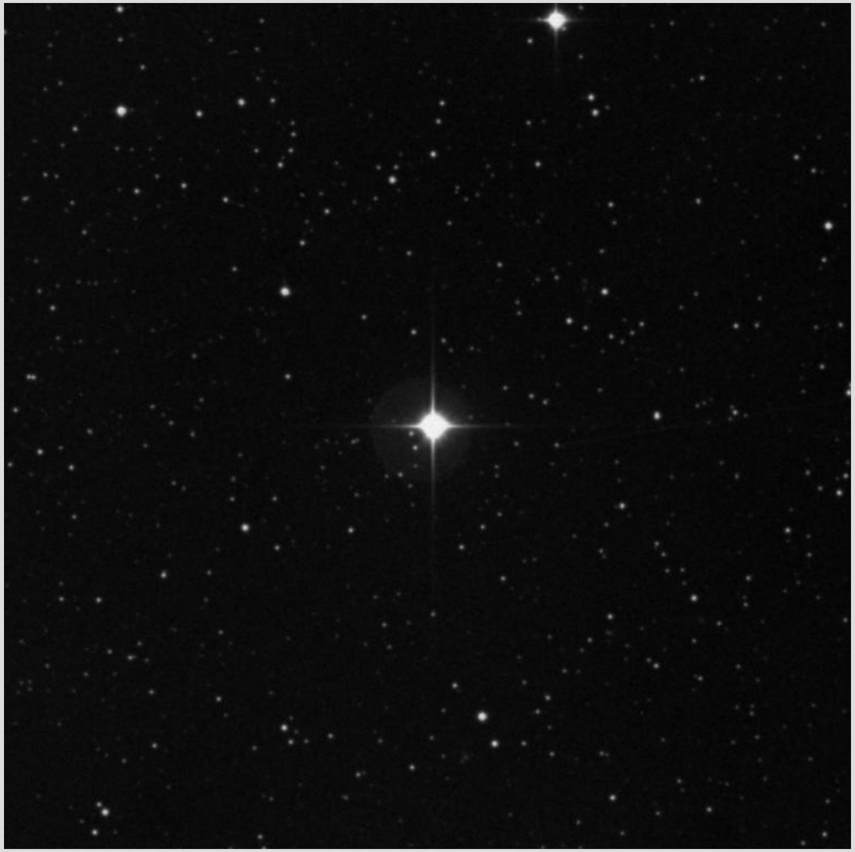
KOREL



- Hierarchic structure of a stellar system

- Input data – program PREKOR – we choose a region of spectra for the solution
- For first iteration is necessary to know an approximate estimation of orbital parameters

96 Her



Courtesy: Aladin database

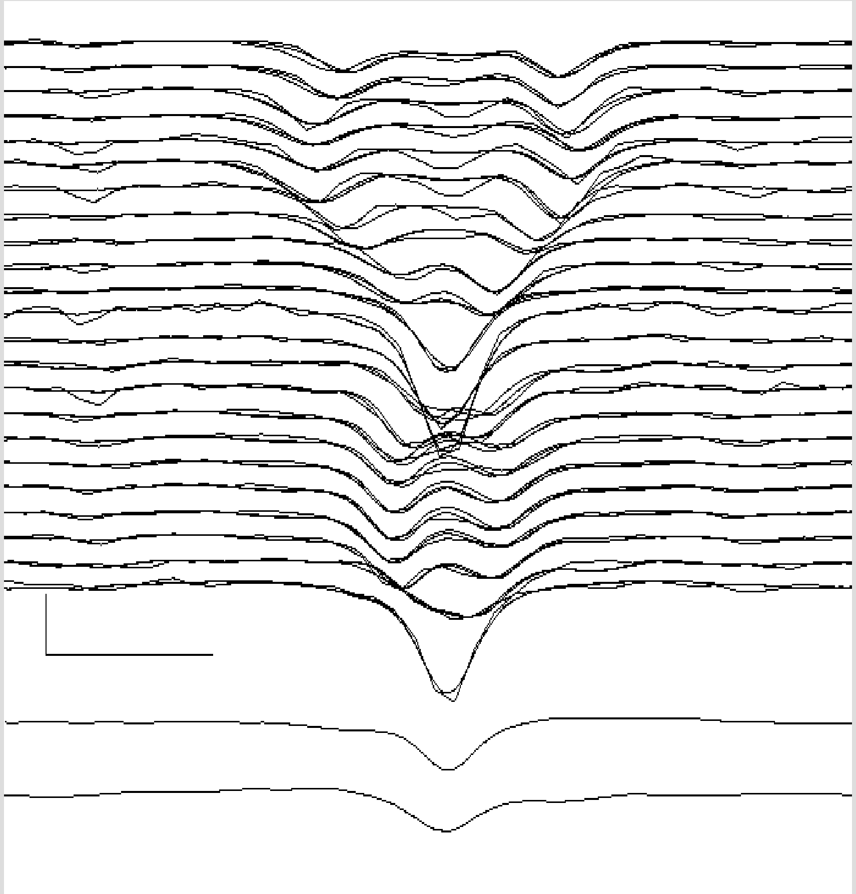
96 Her

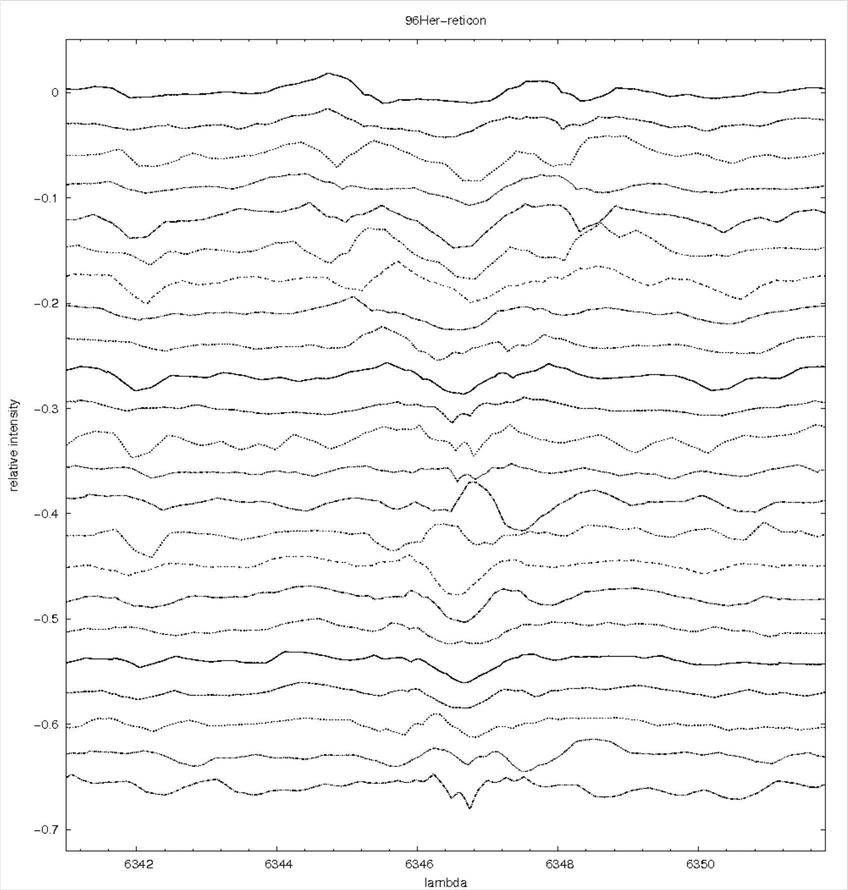
- All components visible in the spectrum are B2-3V
- Variation of RV discovered in 1911 (Mitchell)
- Presence of another component (besides the binary) confirmed by several observations
- Suspicion for apsidal motion, precession of the orbit of the close binary A+B, orbitally bound changes in brightness

96 Her

- Processed spectra – Ondřejov (RETICON: 1993-95, CCD: 2004-2008), Pic du Midi (Musicos: 2003-2004)
- Solution mainly for lines… 1: He I 6678
  2: Si II 6347
  3: Si II 6371
- Convergence of orbital parameters and in several cases also line-strengths

96 Her – 3 components?





96 Her – orbital parameters

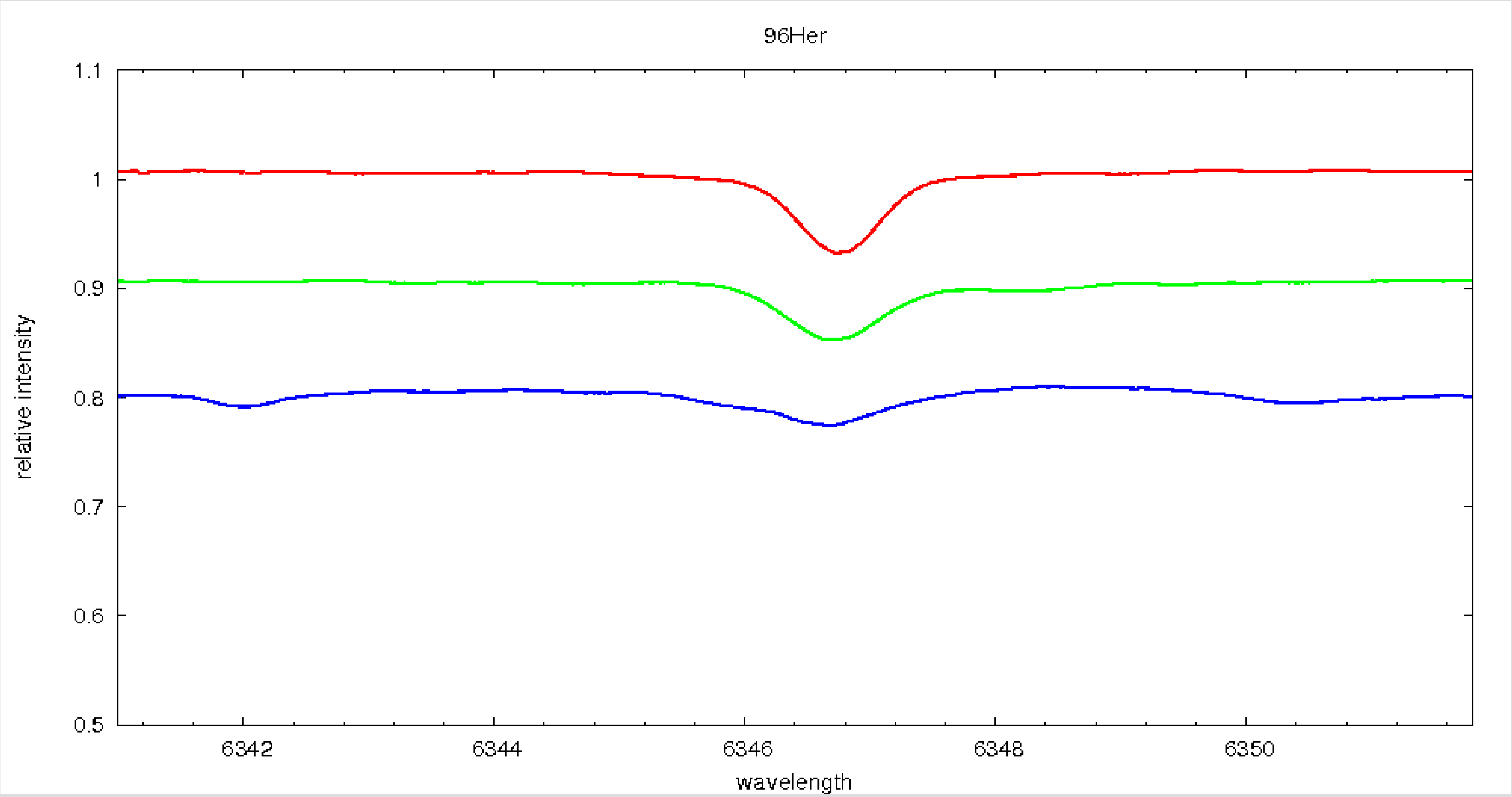
- Close binary

- $P = 12.460326$ d
- $T_0 = 49084.777$ JD
- $e = 0.53$
- $\Omega = 317.15°$
- $K_1 = 55.68$ km/s
- $q = M_2/M_1 = 0.9582$

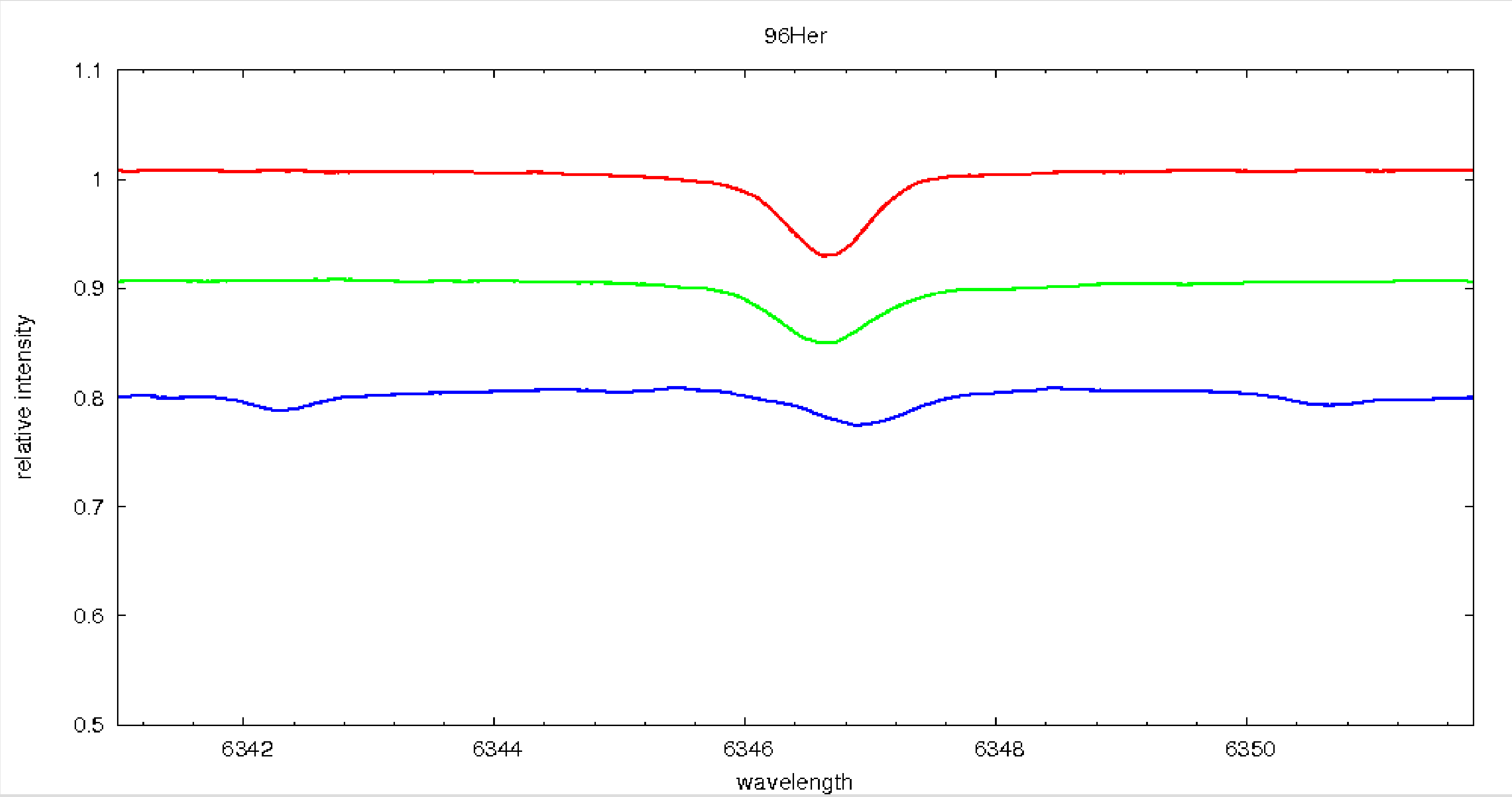
- Third component

- **$P = 7680.04$ d**
- $T_0 = 46228.573$ JD
- $e = 0.176$
- $\Omega = 34.49°$
- $K_1 = 6.23$ km/s
- $q = 1.048$

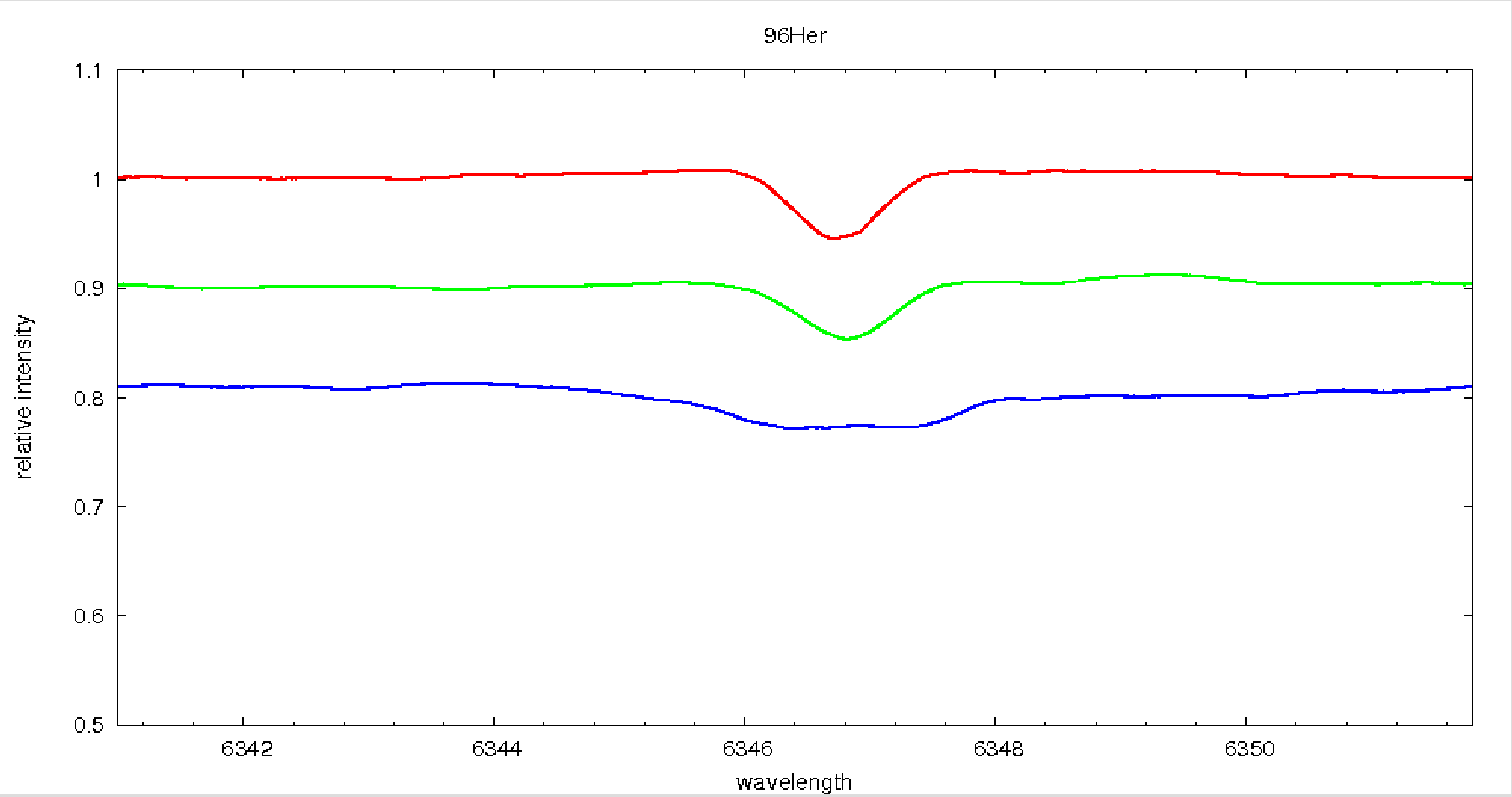
RETICON – 3 components



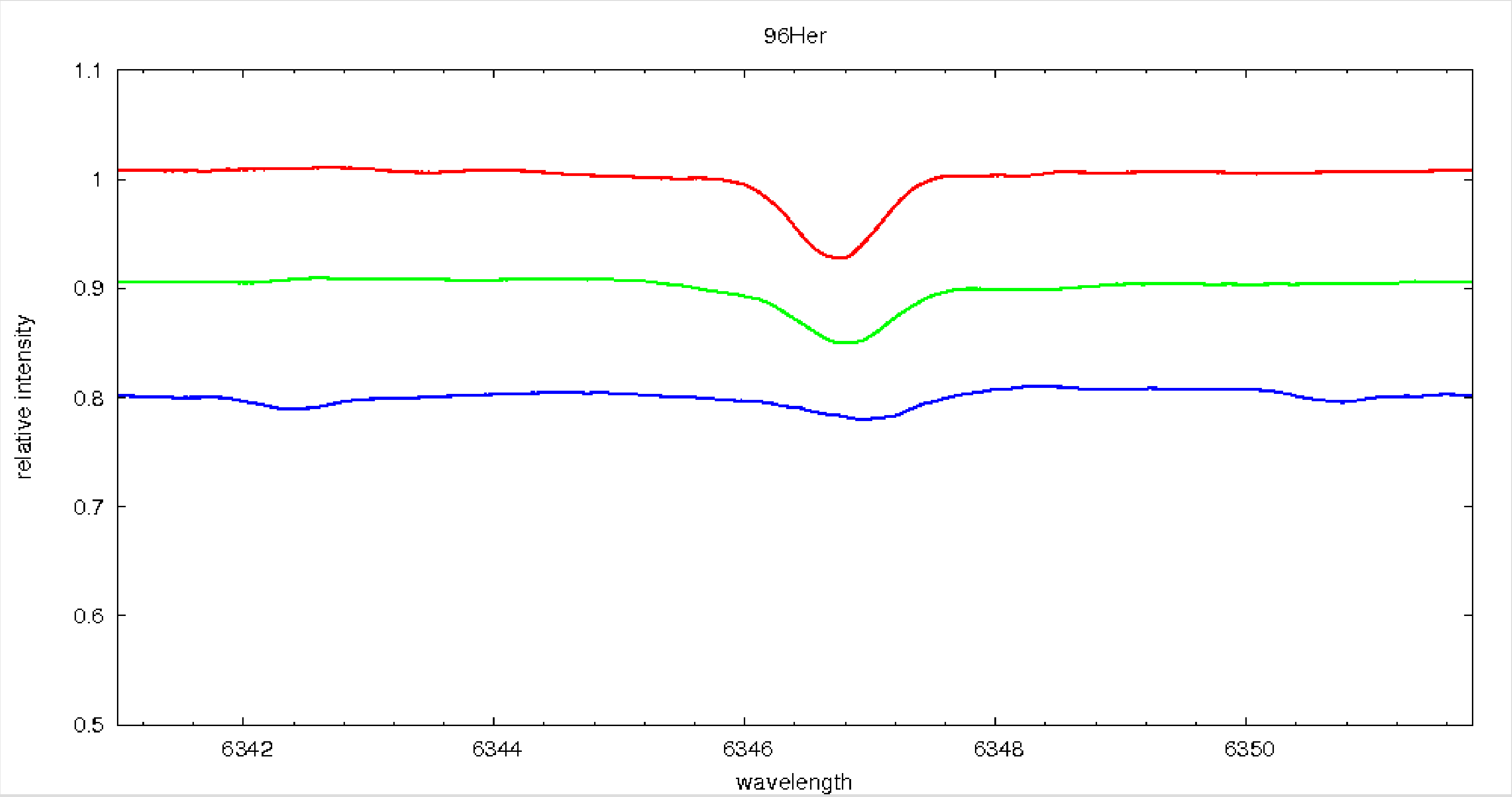
RETICON – 2 stellar components + 1 telluric



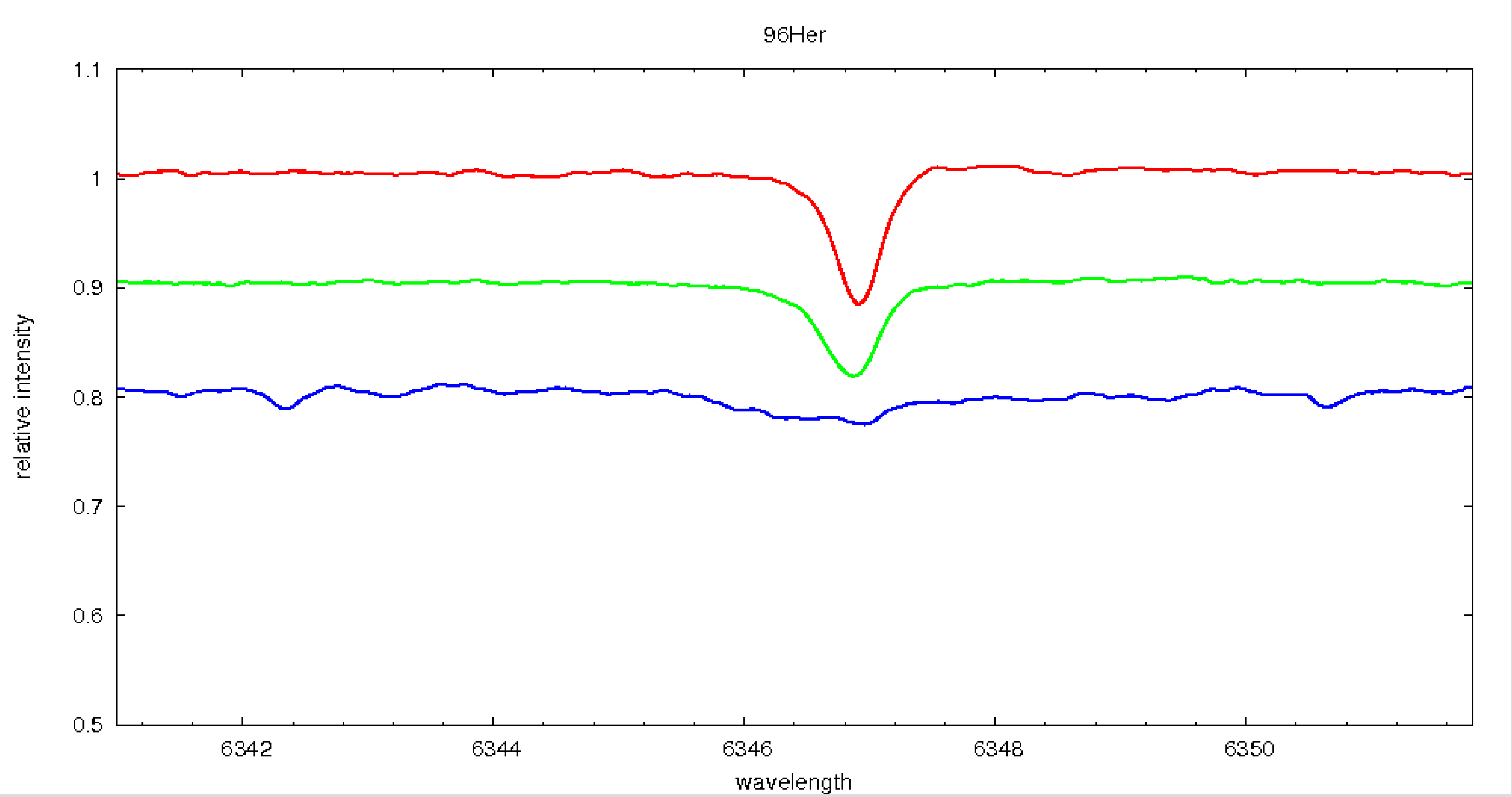
CCD – 3 components



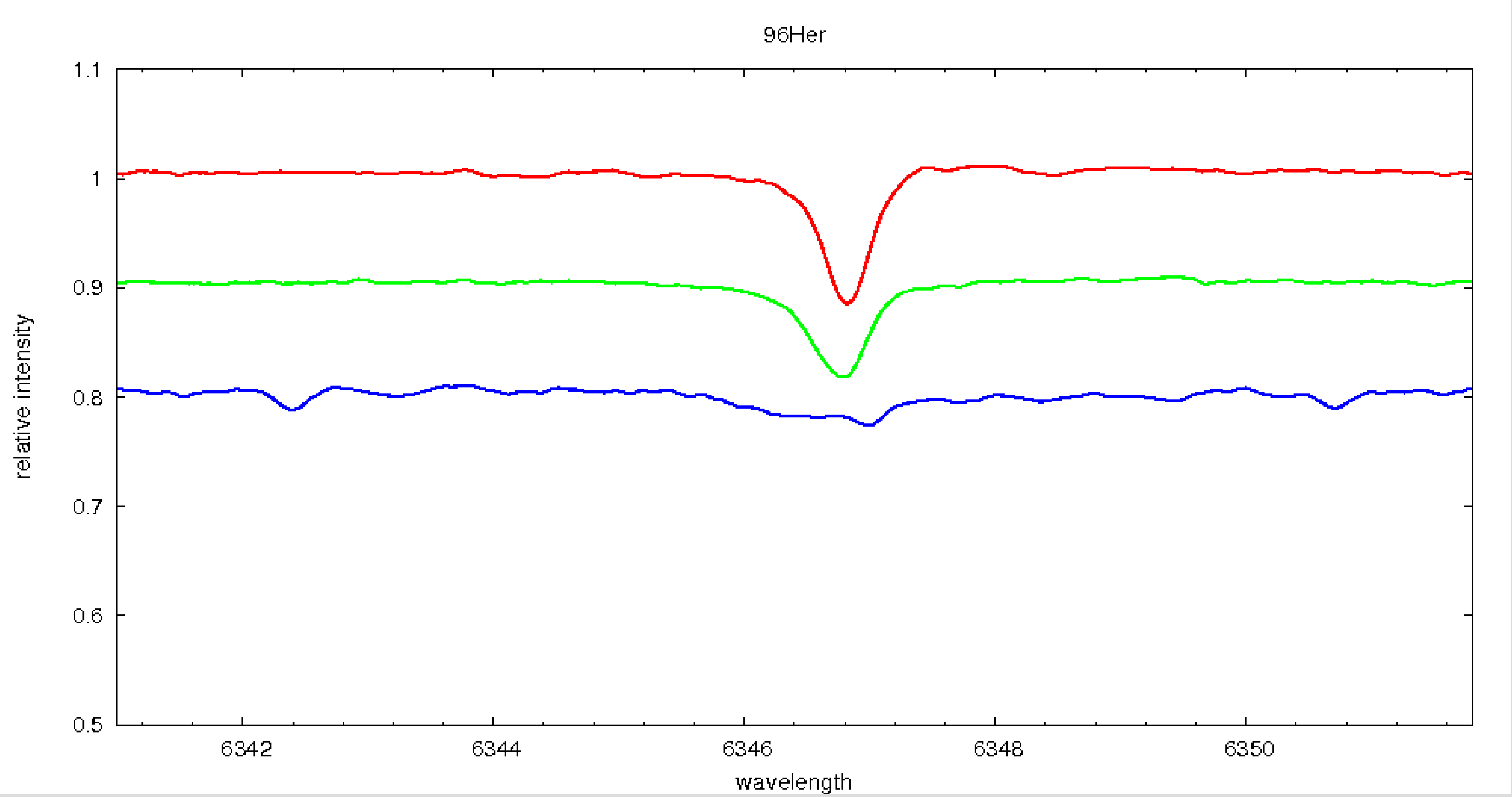
CCD – 2 stellar components + 1 telluric



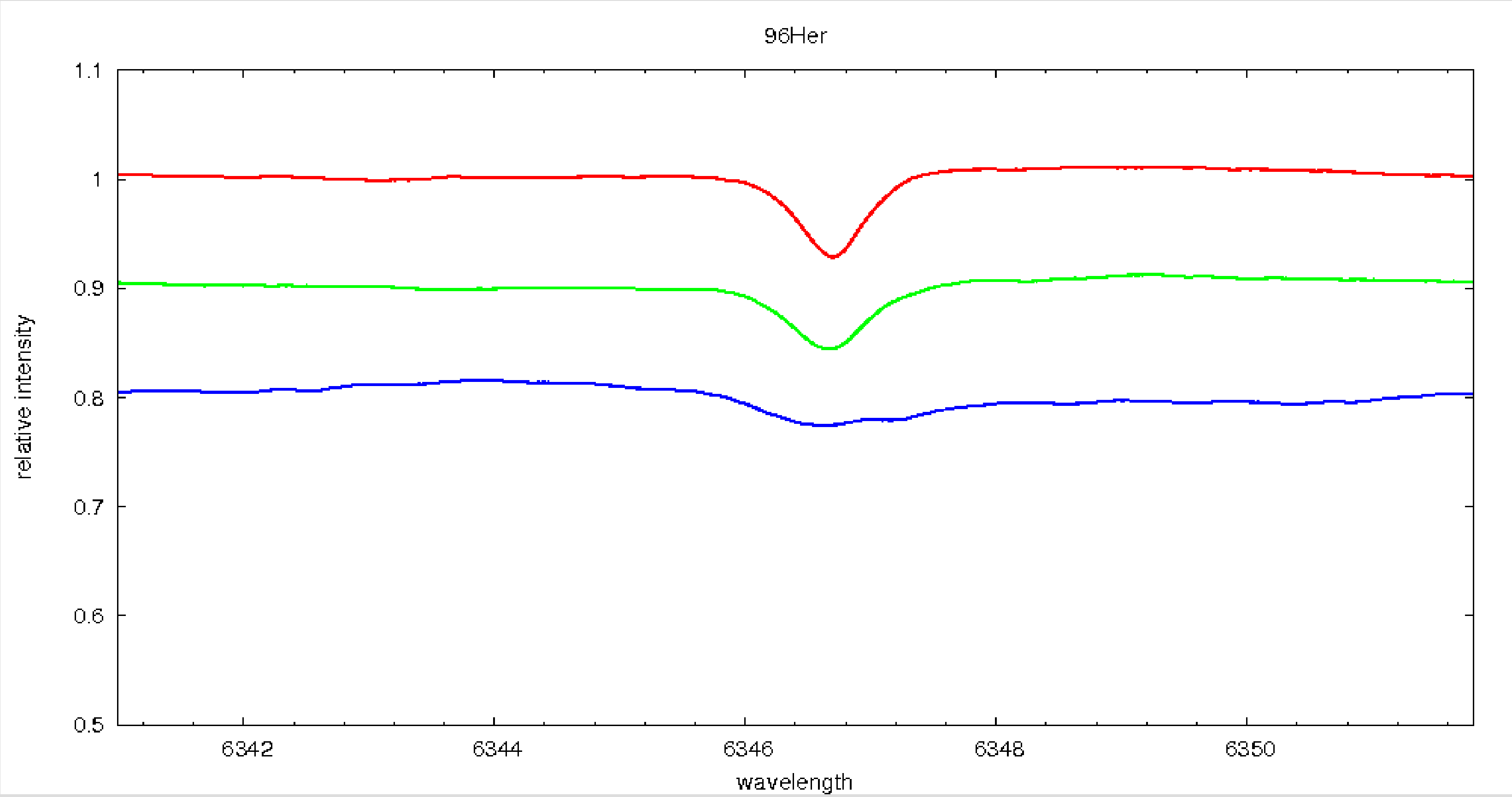
MUSICOS – 3 components



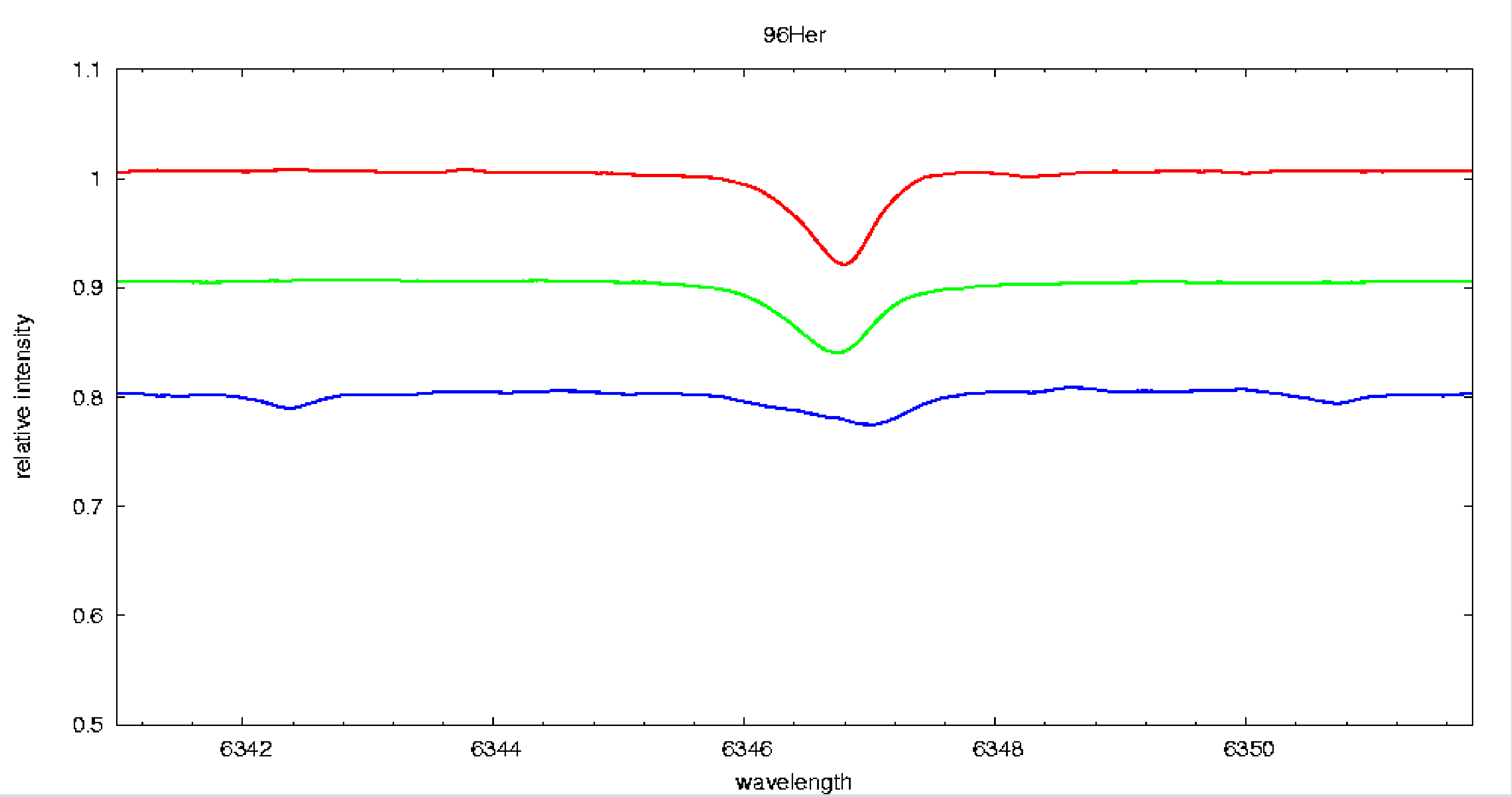
MUSICOS – 2 stellar components + 1 telluric



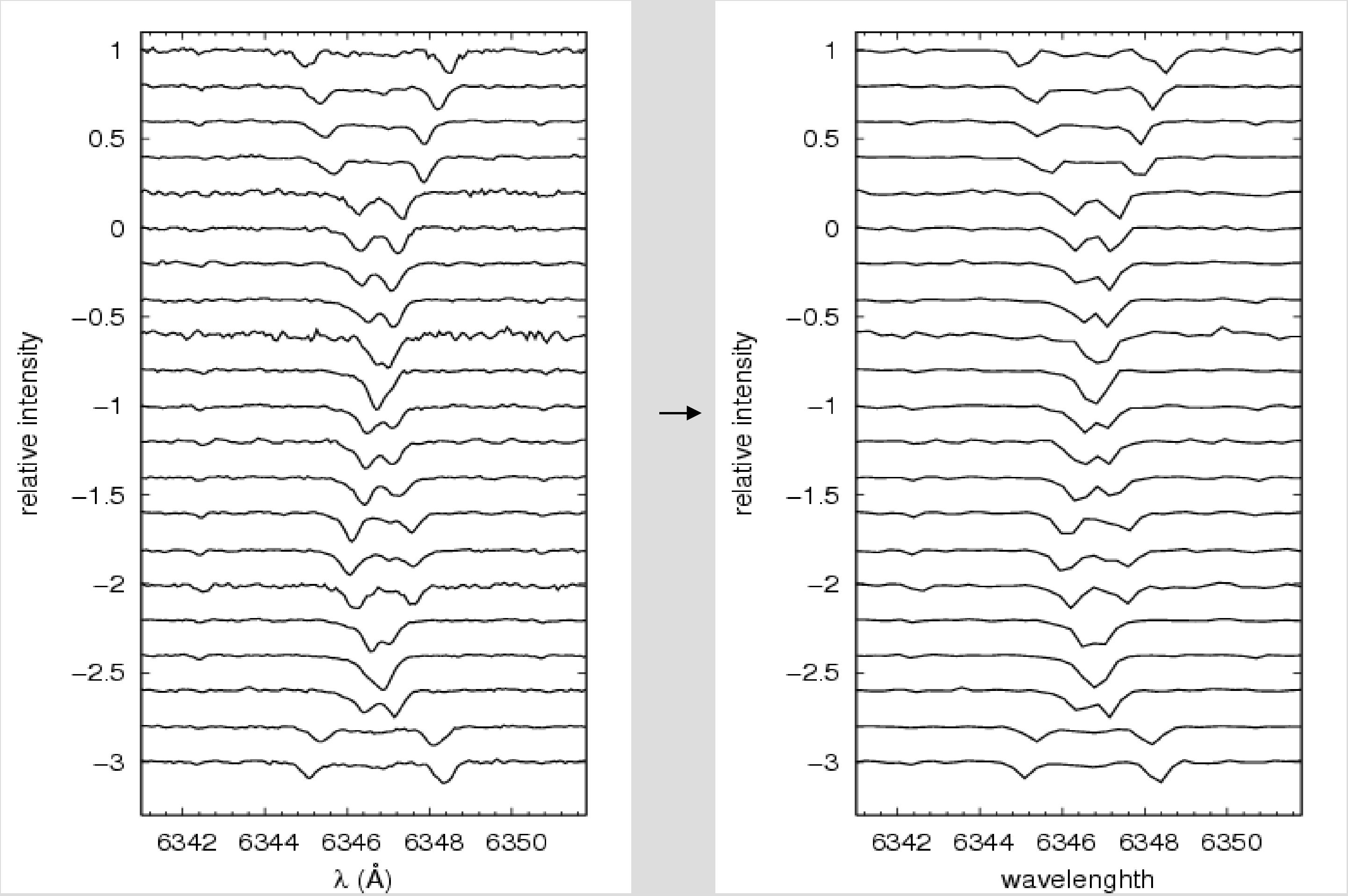
All spectra – 3 components



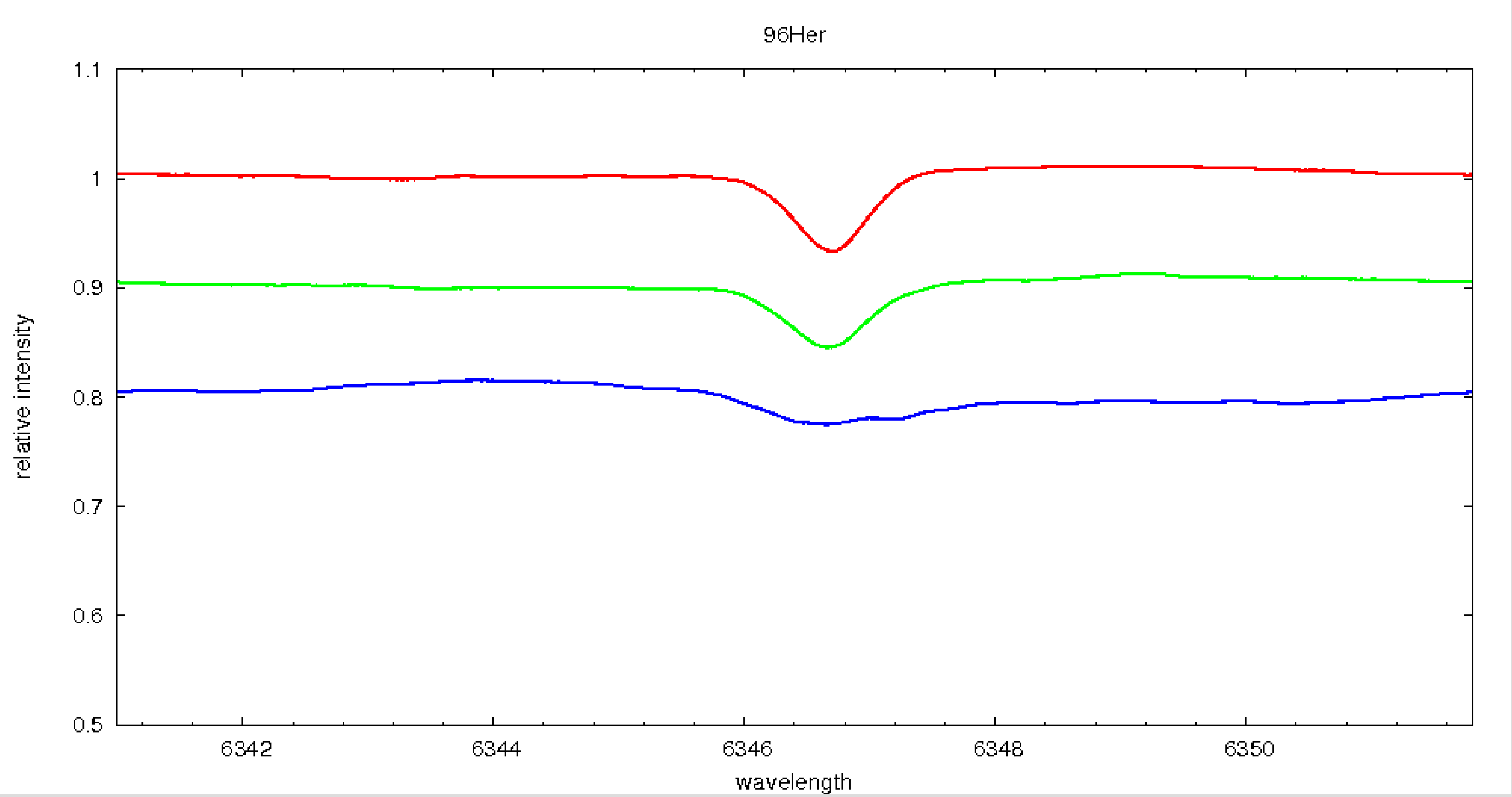
All spectra – 2 stellar components + 1 telluric



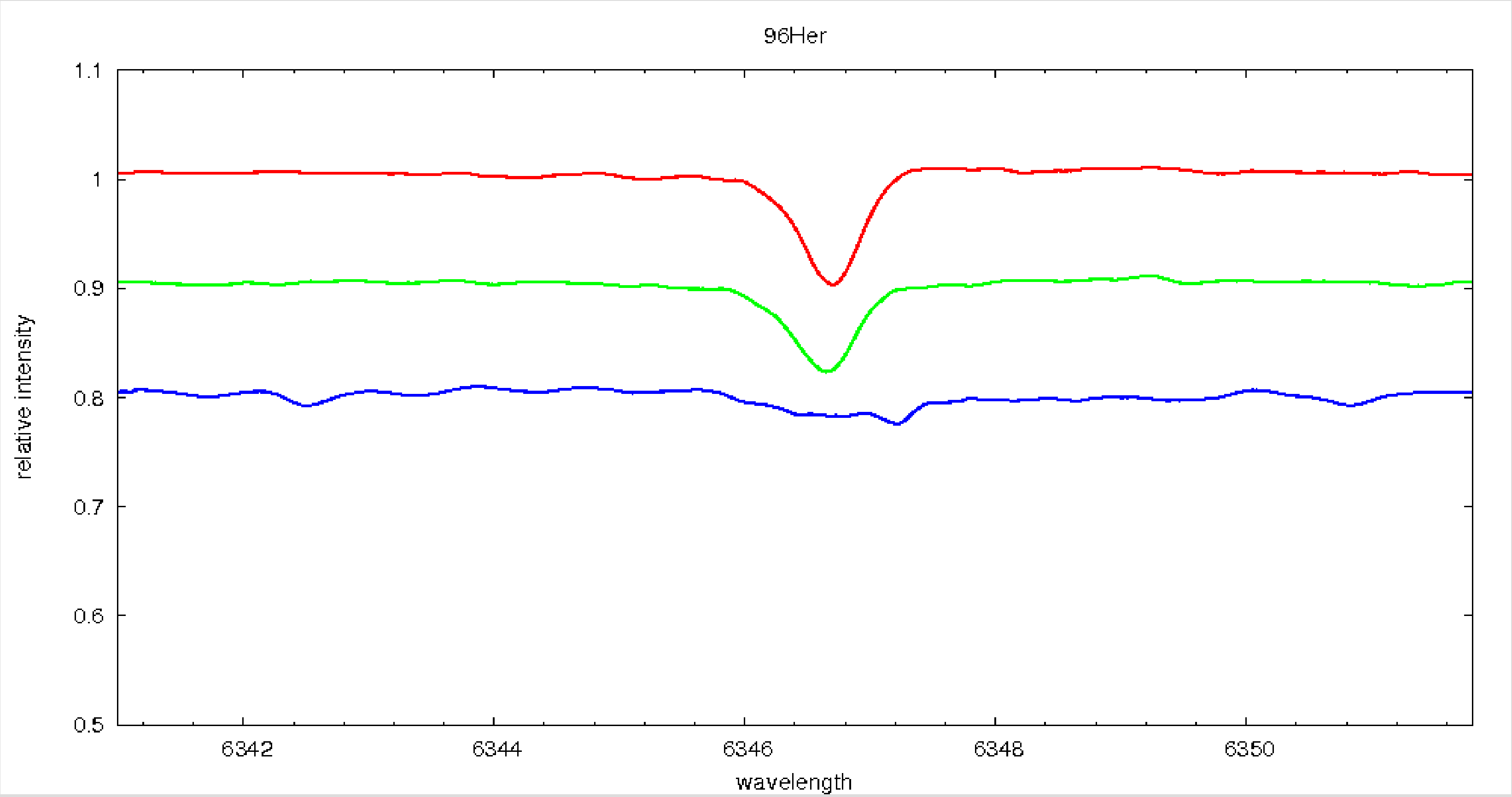
Degrading of MUSICOS data



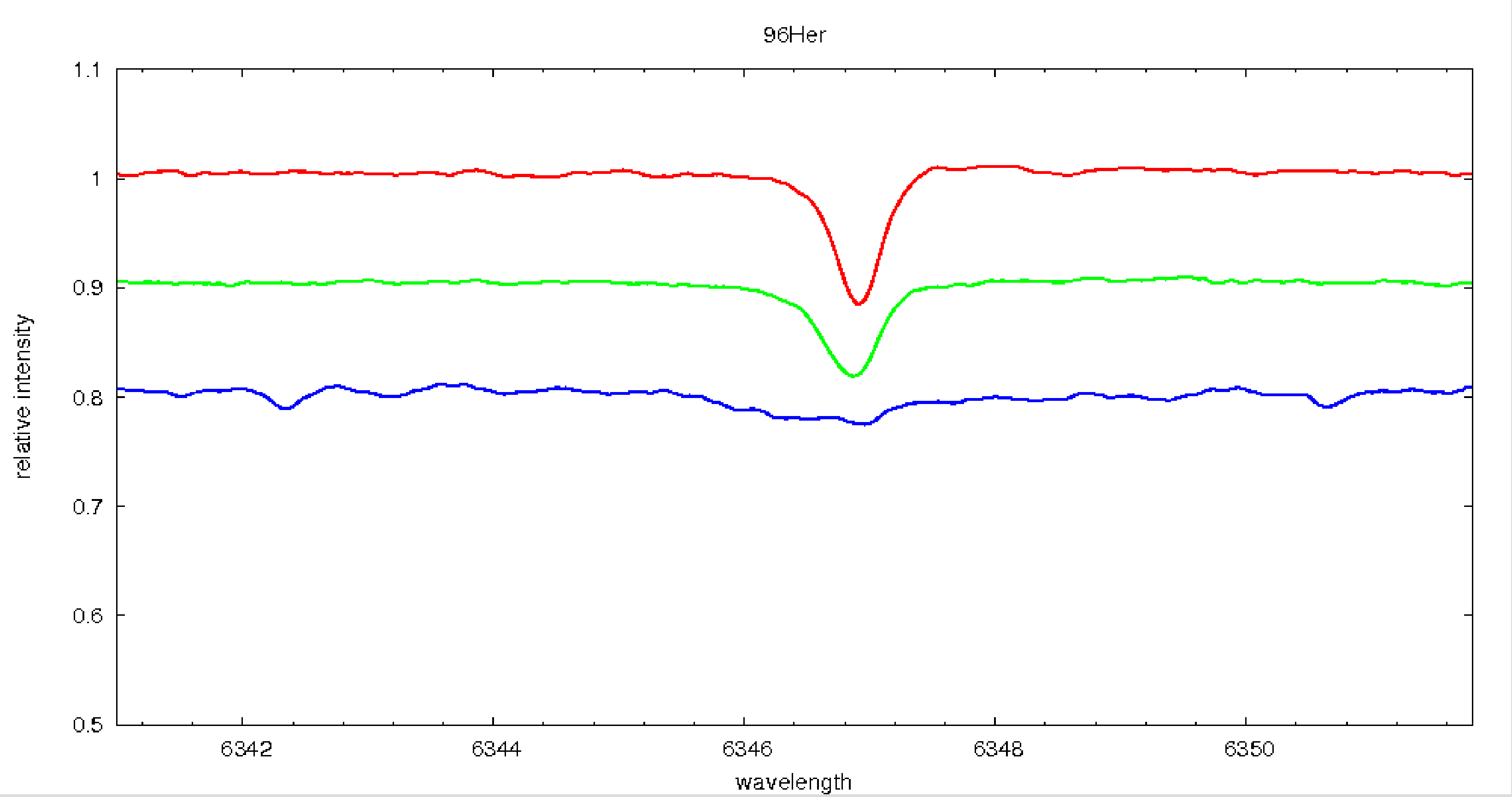
All spectra – resampled data – 3 components



MUSICOS – resampled data – 3 components

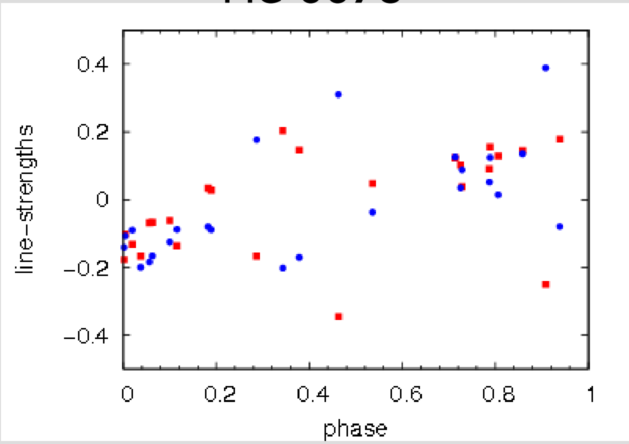


MUSICOS – original data – 3 components

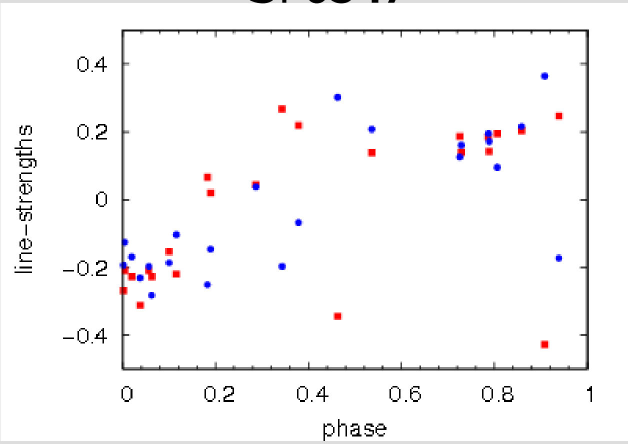


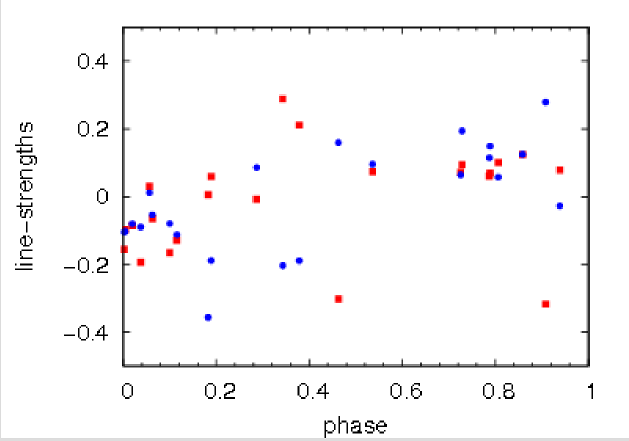
Line-strength vs. phase - RETICON

He **6678**

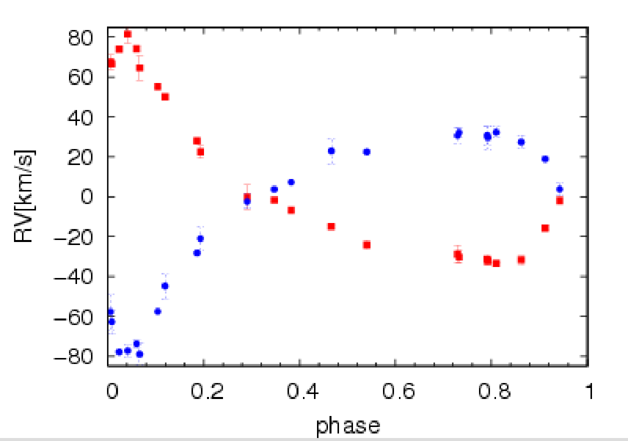


Si **6347**





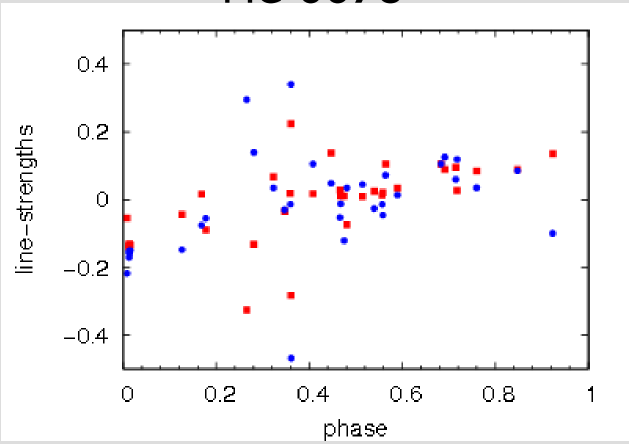
Si **6371**



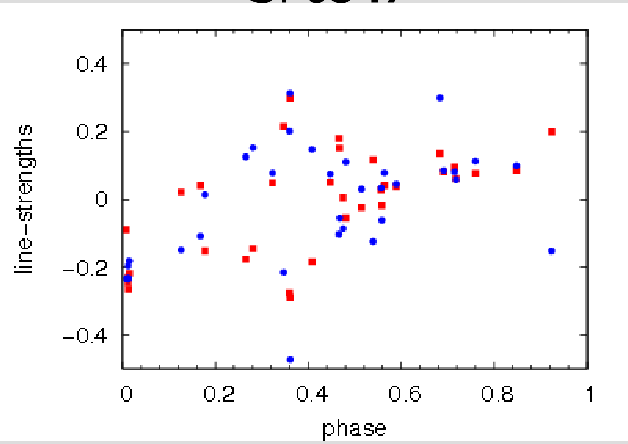
RV curve

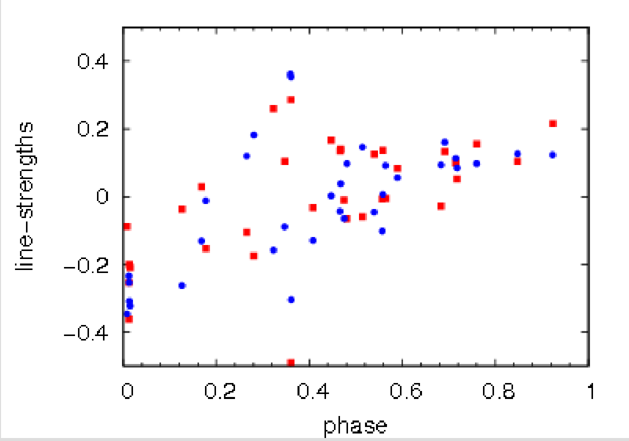
Line-strength vs. phase - CCD

He **6678**

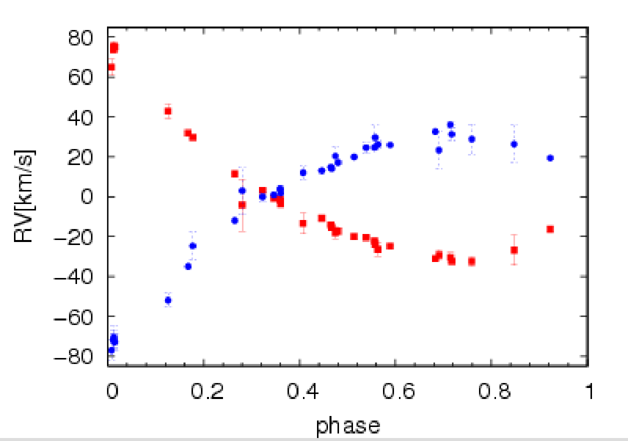


Si **6347**





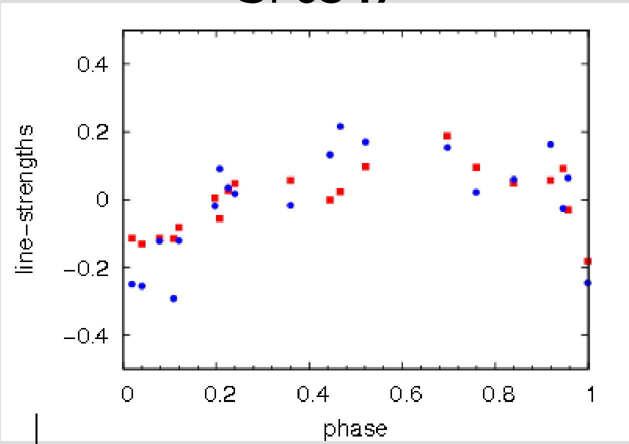
Si **6371**



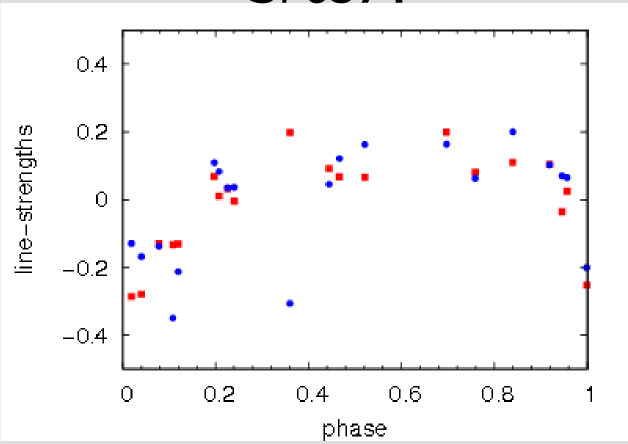
RV curve

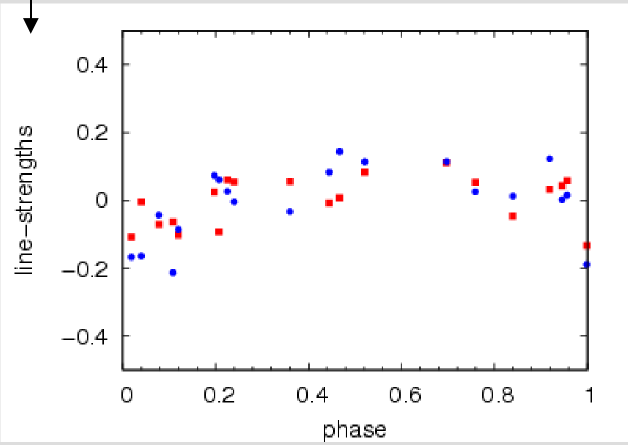
Line-strength vs. phase - MUSICOS

Si **6347**

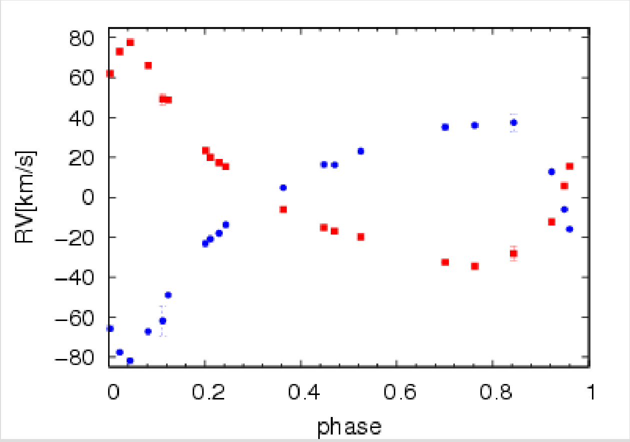


Si **6371**





Si **6347** resampled



RV curve

96 Her – summary

- Cca 70 spectra processed and used for calculations with KOREL
- Third component was separated from the composite spectra – its nature is not definetely distinguished – small sensitivity to longer periods
- Orbital parameters in individual datasets differ

96 Her – problems

- Data from different instruments doesn’t work together smoothly
- Telluric lines found by KOREL do not seem to correspond to known lines of Earth’s atmosphere
- Resampling of Musicos data to the resolution of Ondřejov spectra does not help

Thank you for your attention