Spectroscopy of binary and multiple stars

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Spectroscopic binaries

- SB = binaries detected from the radial-velocity changes
- For RVs of the components we have

$$RV_1 = V_0 + K_1[e\cos\omega + \cos(\omega + \nu)]$$

$$RV_2 = V_0 - K_2[e\cos\omega + \cos(\omega + \nu)]$$

- Spectroscopic triples/multiples: perturbations, photodynamical models, dynamically-induced apsidal motion, precession

SB1, SB2

* If only one component visible = SB1, mass function:

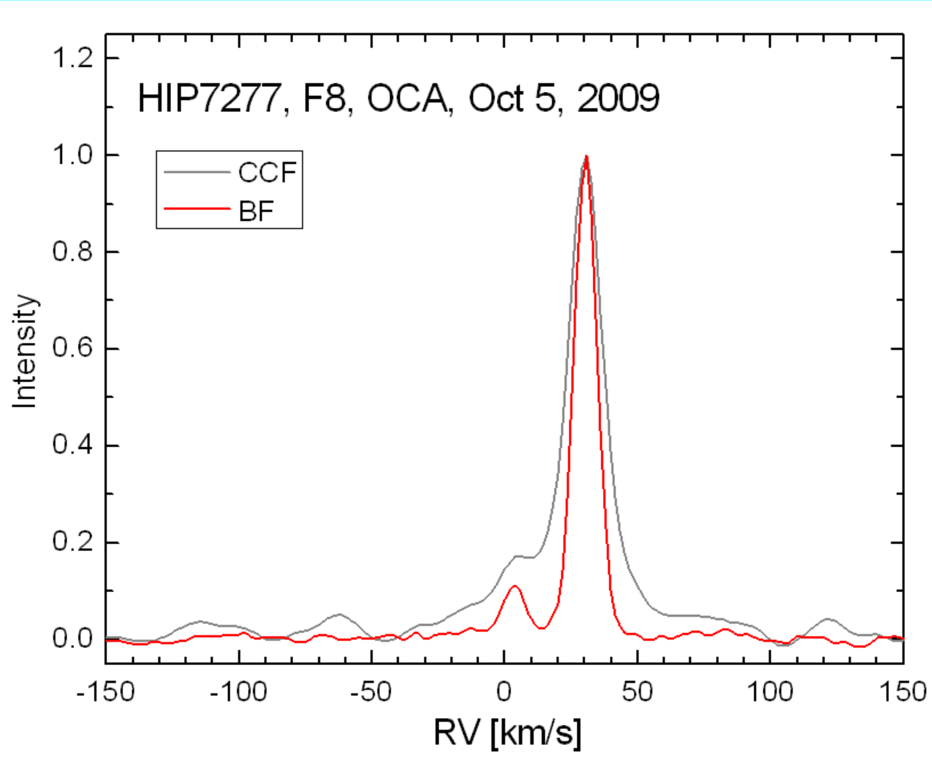
$$f(m) = \frac{m_2^3 \sin^3 i}{(m_1 + m_2)^2} = \frac{PK_1^3}{2\pi G}(1 - e^2)^{3/2}$$

* If both components visible = SB2, minimum masses:

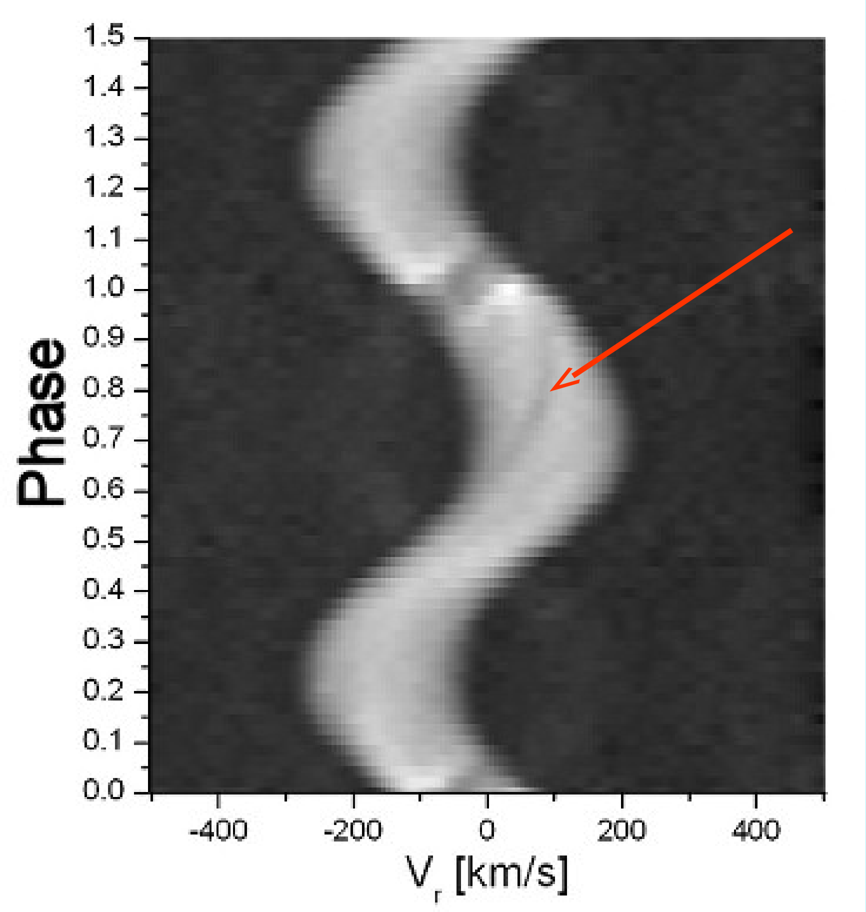
$$m_{1,2} \sin^3 i = \frac{1}{2\pi G}(1 - e^2)^{3/2}(K_1 + K_2)^2 K_{2,1} P$$

RV measurements

* Numerical cross-correlation, CCF (Simkin, 1974)
* BF technique (Rucinski, 1992)
* TODCOR (Zucker & Mazeh, 1994): 2D CCF
* LSD technique – close to BF (Donati+, 1997)
* Model spectra fitting (e.g. Pribulla+, 2023)



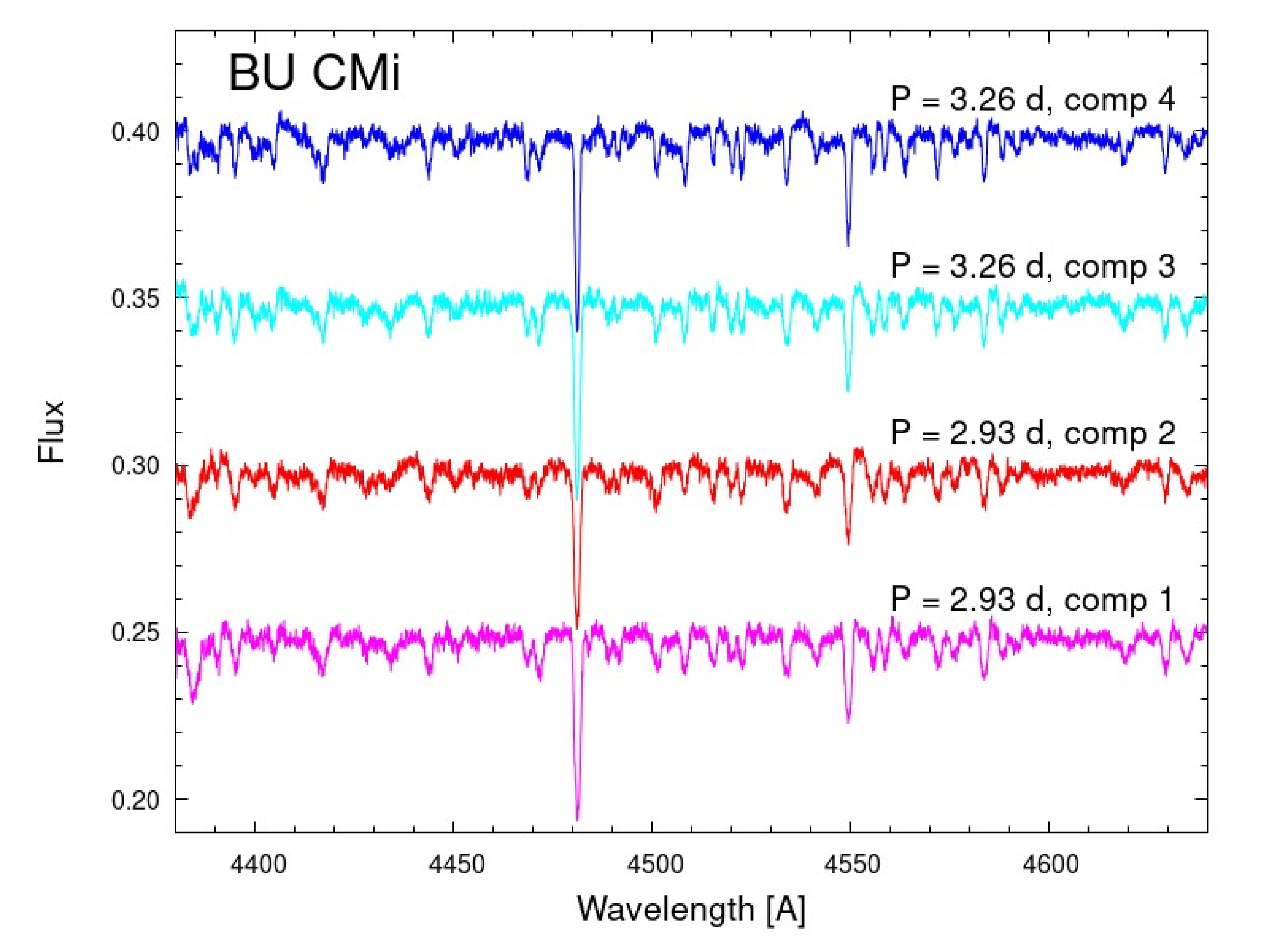
CCF and BF comparison: SB2 composed of two slowly rotating stars: CCF does not have sufficient resolution to analyze this SB2 (Pribulla+, 2014)



Trailed BF of late-type spotted binary XY UMa, Pribulla+, 2007 (DDO XII)

Spectra separation/disentangling

- Sum of component spectra observed
- RV of components changes ==> tomography
- Iterative tomographic disentangling, Bagnuolo & Gies (1991)
- SVD linear decomposition Simon & Sturm (1994)
- Fourier space disentangling (Hadrava 1995)
- Combination of Fourier disentangling and other techniques, Ilijić et al. (2004)



SB4

T_4 = 10040(350) K
log g_4 = 4.18(23)

T_3 = 10820(380) K
log g_3 = 4.63(26)

T_2 = 10180(430) K
log g_2 = 4.11(30)

T_1 = 10760(360) K
log g_1 = 4.23(29)

Tomographic disentangling of spectra assuming model RVs, iterative technique of Bagnuolo & Gies (1991) used, correct disentangling depends on flux ratios (see Pribulla+, 2023)

Motivation and importance

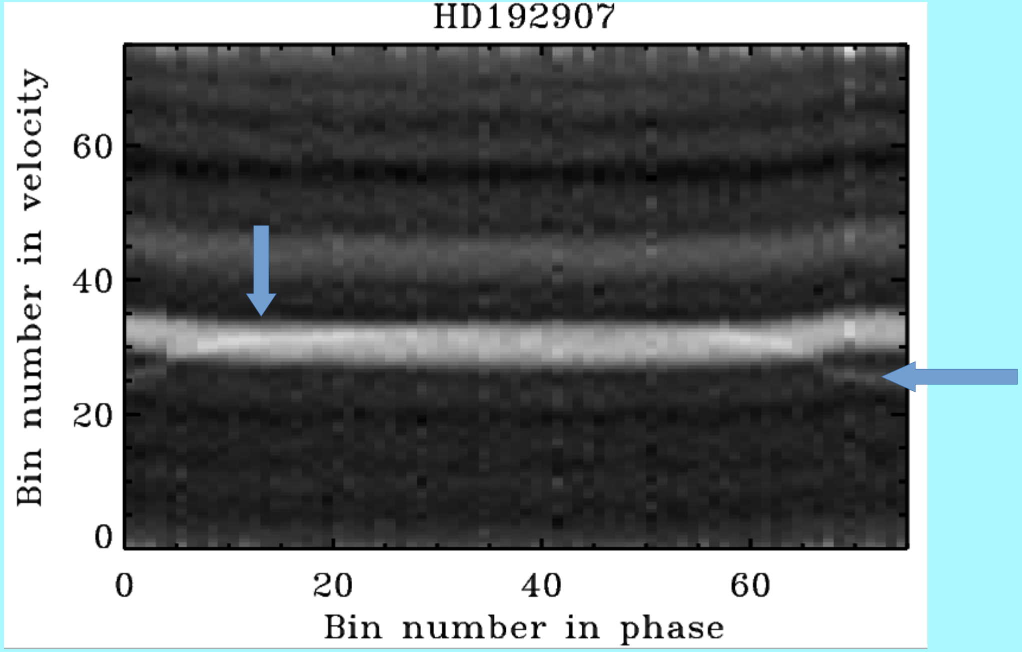
* Constraining models of stellar structure and evolution
* Calibrating cosmic distance ladder (Pribulla+, 2018, V923 Sco)
* Developing and testing codes to model observations
* Common modeling tools with exoplanets
* Precise RV observations: circumbinary planets
* Suitable facilities at SL + SP: testing possibilities

Sample

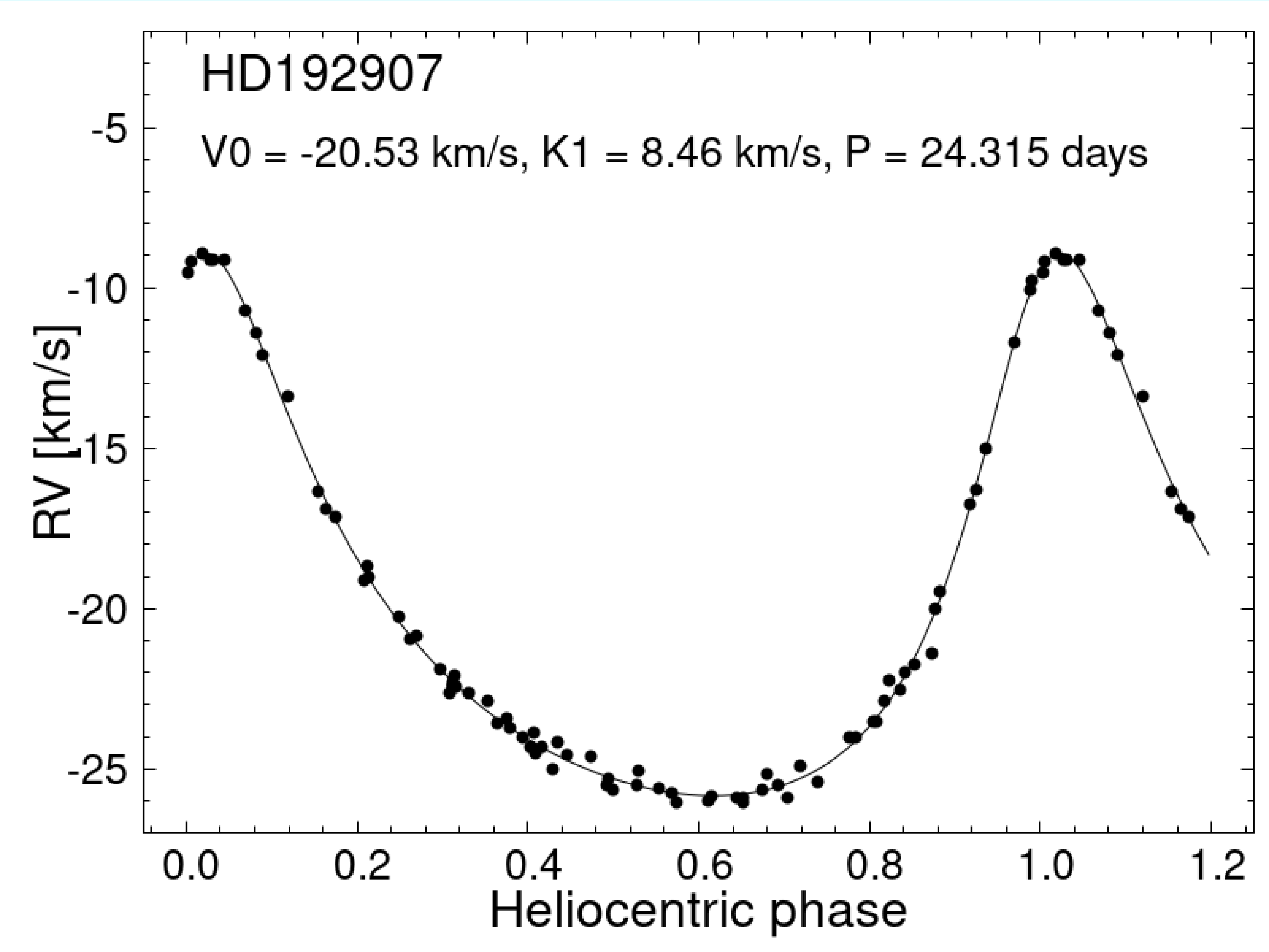
- Focus on eclipsing systems: inclination angle
- Contact binaries without reliable spectroscopic elements
- Detached or semi-detached active systems
- Multiple stellar systems
- High-contrast binaries/multiples

HD192907: SB1 “standard”

- HD192907, *V* = 4.39, BIII9, used as a spectrophotometric standard at G1 and SP, a slow rotator with *v* sin *i* = 25 km/s
- Adelman (1996): RV of HD192907 varies: SB1, parameters not determined
- Gaia DR3: single object, RV= -22.5 ±1.3 km/s, T^{eff}=10344 K, log *g* = 3.617
- Hot object with H and He lines dominant: CCF technique to measure RVs
- BF extracted with HD185144 (K0V) ==> faint secondary detected



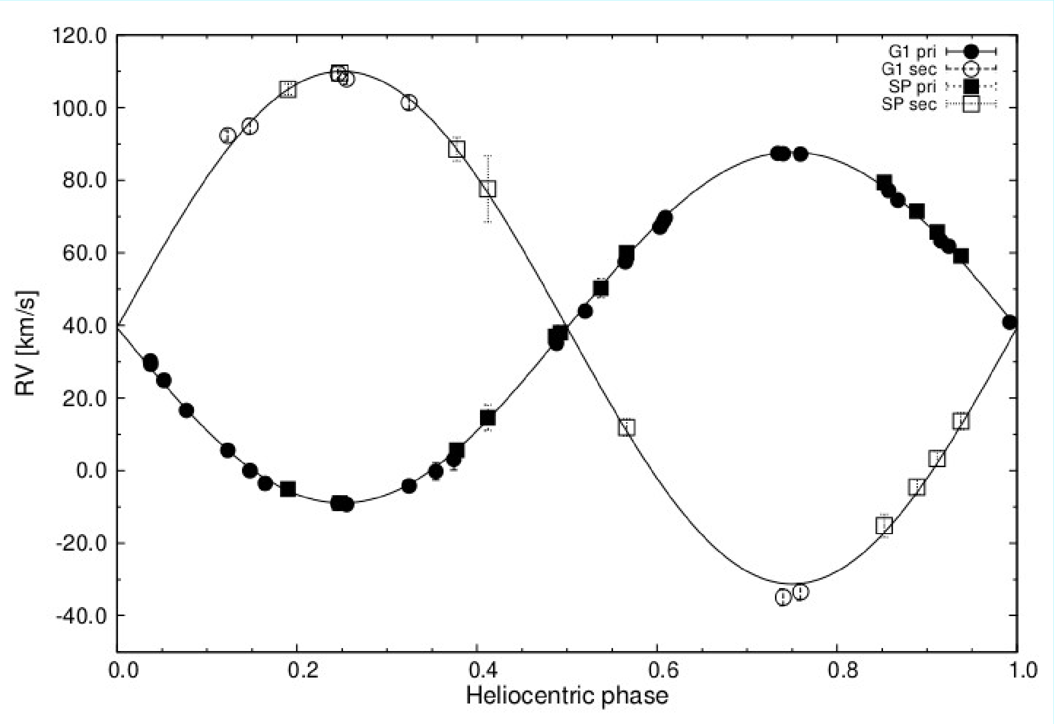
Secondary component !



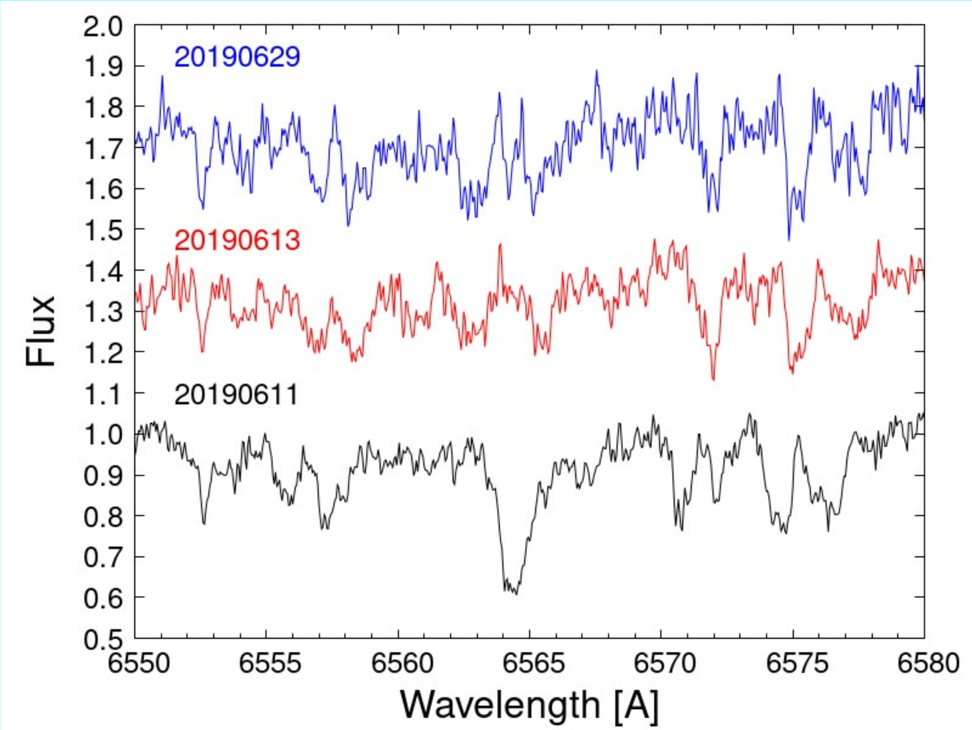
HD192907: low-amplitude SB1/SB2, P = 24.315 days, e = 0.398, K_1 = 8.46 km/s, σ = 260 m/s, V_0 = -20.53 km/s, $f(m)$ = 0.00118 $M_{\odot}$ ==> very low inclination

IN Vir: an active non-eclipsing binary

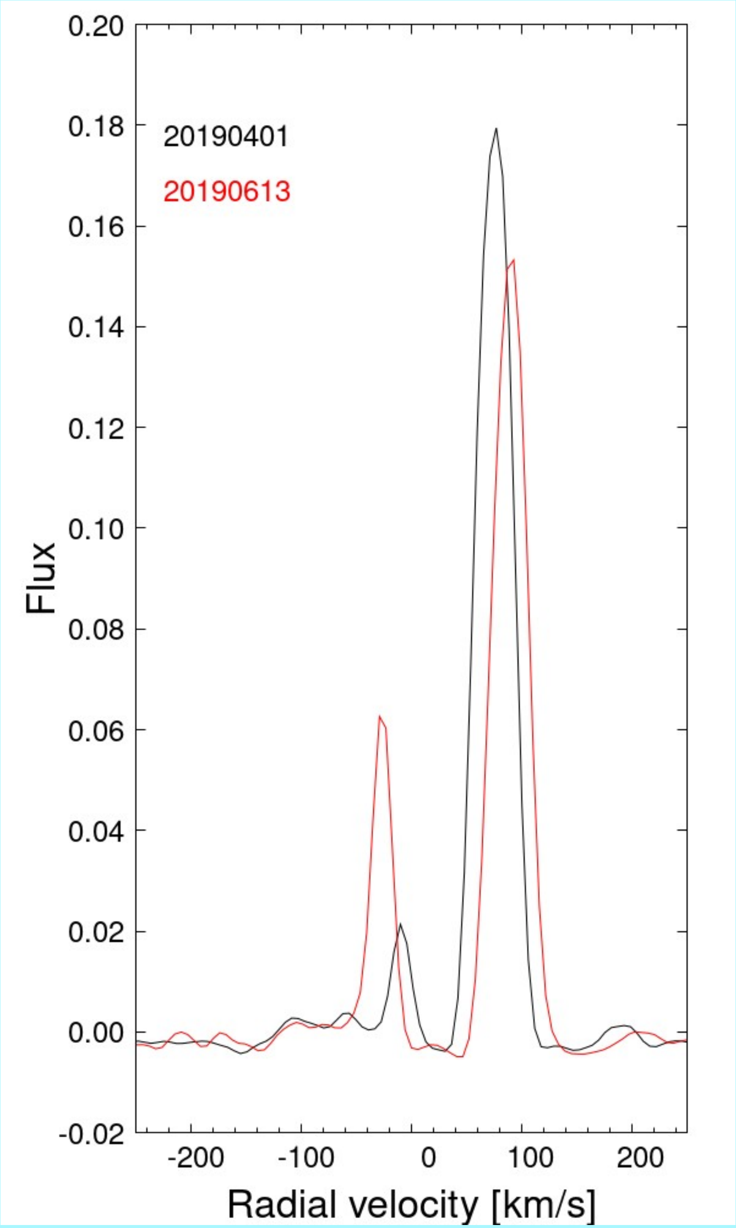
- ✶ RS CVn-like system, V = 9.13, K4 IV + G8 V, X-ray source
- ✶ SB1 (Strassmeier, 1997), Doppler imaging
- ✶ Clear detection of the secondary in BFs



IN Vir: SB2, P = 8.18977 days, e = 0, K_1 = 48.35 km/s, K_2 = 70.6 km/s, V_0 = +39.38 km/s, $m_1 \sin^3 i = 0.848\ M_\odot$, $m_2 \sin^3 i = 0.581\ M_\odot$



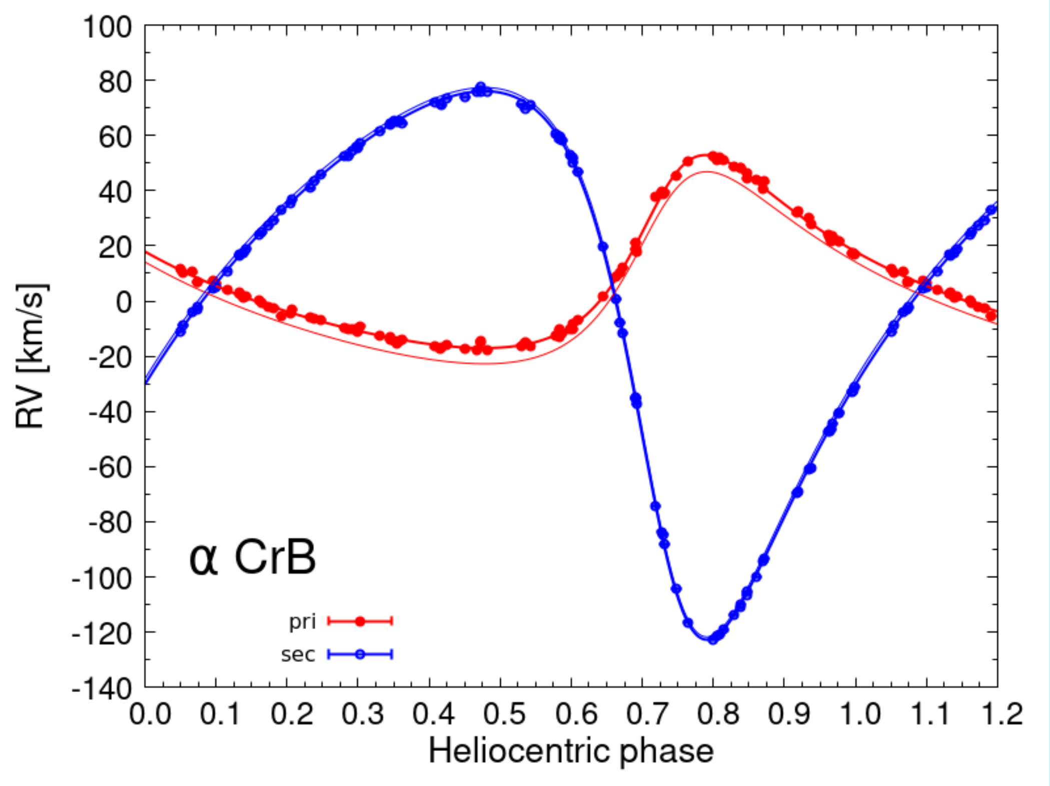
Strong flare on the secondary component seen in the Hα line on June 13 and 29, 2019

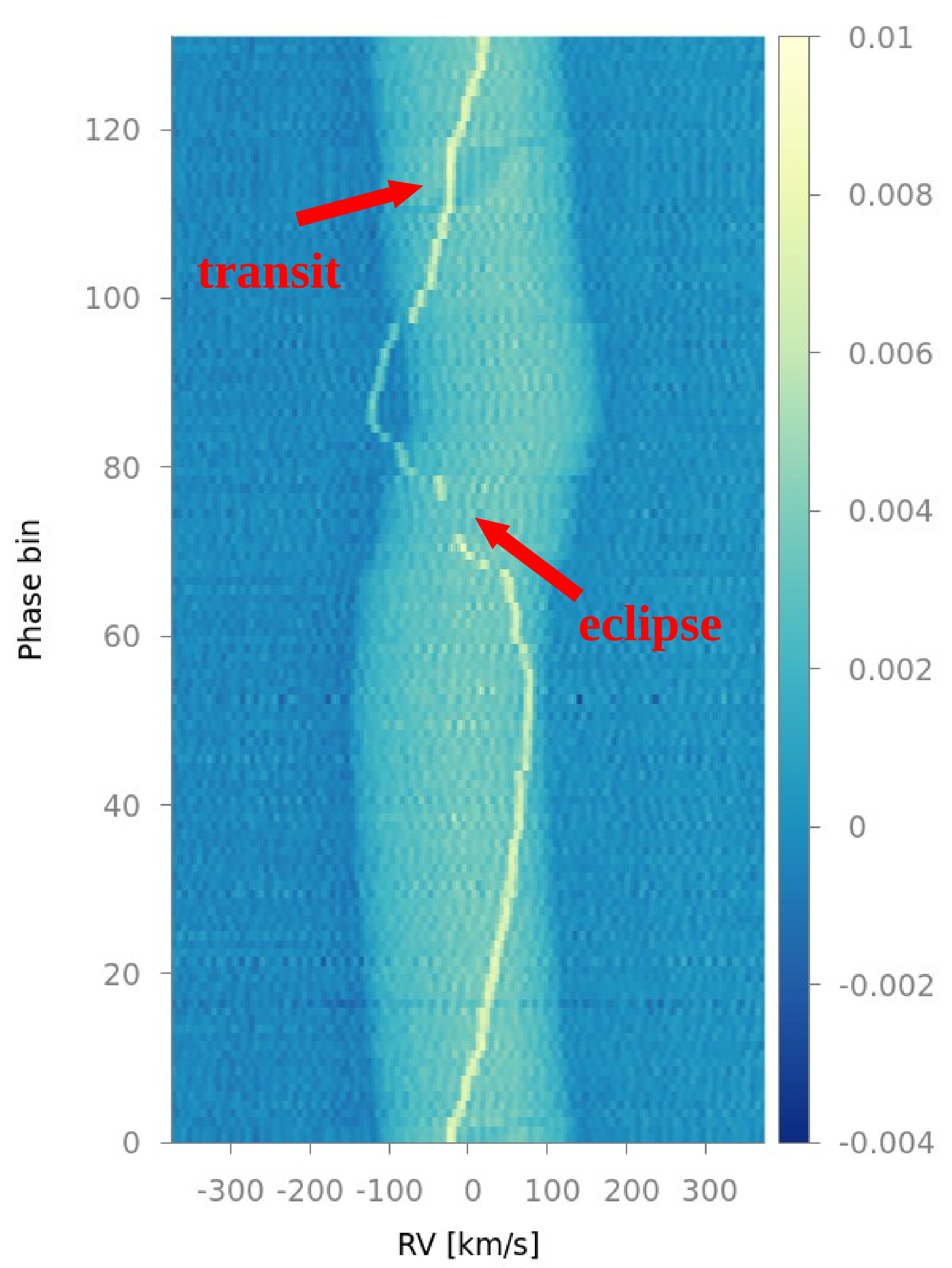


BFs extracted from metallic lines during a flare (20190613) and in a quiescence phase (20190401)

α CrB: bright, high-contrast system

- α CrB, $V = 2.24$, A1IV+, eclipsing binary (P=17.36 days) with big contrast of components, too bright for Gaia: no astrometry
- Well-characterized by Schmitt+ (2016, 2023)
- Hot fast rotating primary + cold slowly rotating secondary: easy case





α CrB, SB2 but:
primary orbit:
P = 17.3596 days, e = 0.404,
K_1 = 34.97 km/s, V_0 = +7.99 km/s

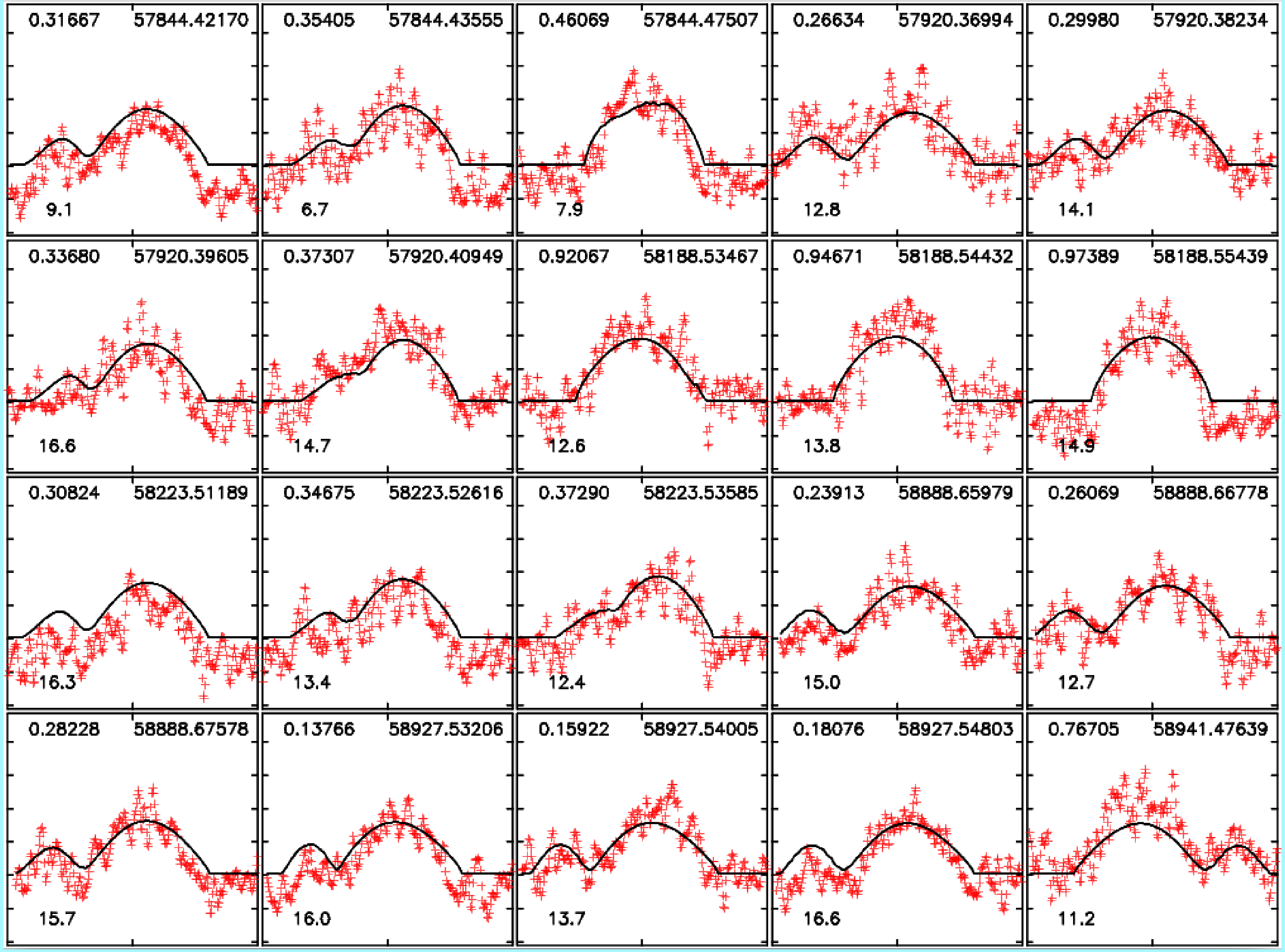
secondary orbit:
P = 17.3599 days, e = 0.382,
K_2 = 99.39 km/s, V_0 = +1.49 km/s

- Big shift in V_0, different orbit shape…
- Slow apsidal motion
- Spin-orbit misalignment ?

Trailing BFs
MUSICOS spectroscopy (SP)

XY Boo: a hard nut to crack

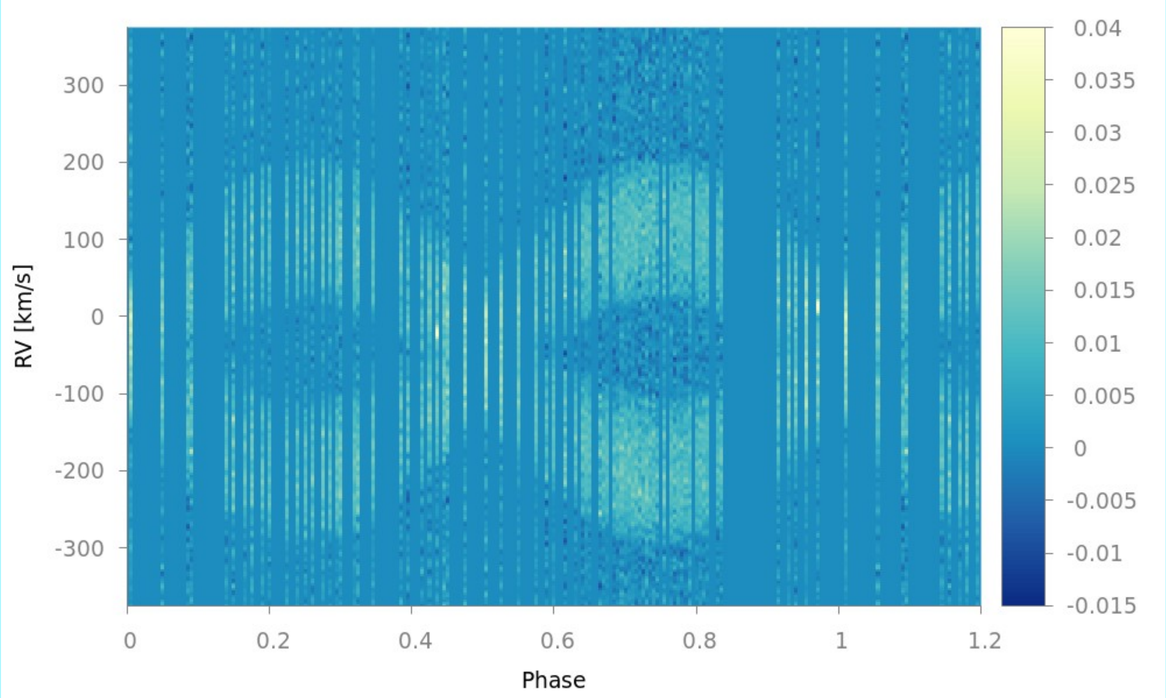
- XY Boo, V = 10.54, F5V, short-period contact binary with P = 0.3705702 days
- Lot of photometry, no spectroscopic orbit
- Relatively shallow lines + phase smearing
- 600 sec exposures at SP ==> poor SNR: only spectra with SNR > 10 used
- Individual BFs extremely noisy…

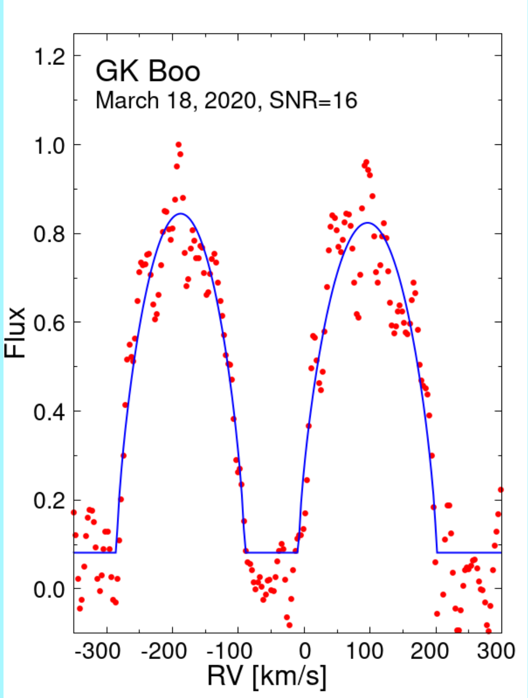


Global fit to 39 BFs using Roche code (Pribulla, 2004): impossible to determine RVs
$m_2/m_1=q=0.17$, K_1+K_2 =348 km/s, V_0=-1.46 km/s, inclination angle fixed to 86 deg

GK Boo: easy case

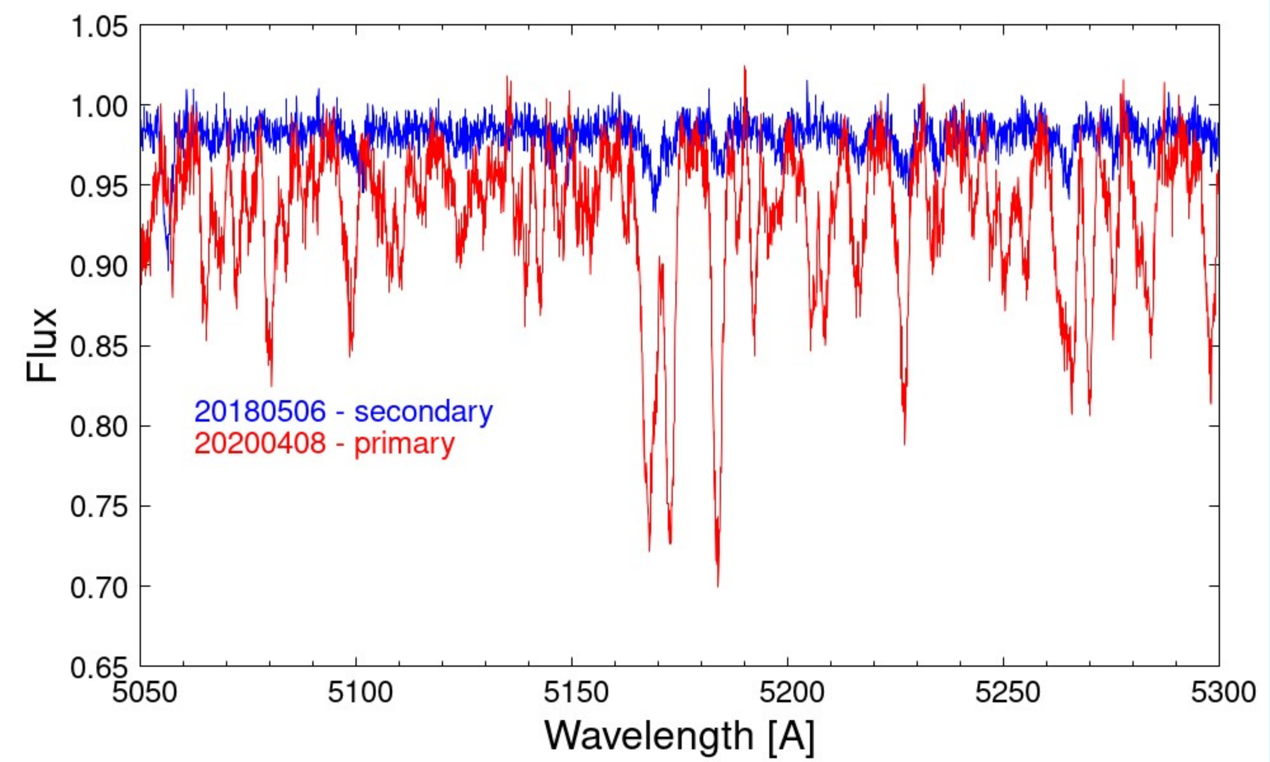
- ✶ GK Boo, V_{max} = 10.93, K0V, short-period close binary with P = 0.477771 days, chromosherically active
- ✶ Lot of photometry, no spectroscopic orbit available
- ✶ SNR only 10-17 but late sp. type, deep lines ==> easy target

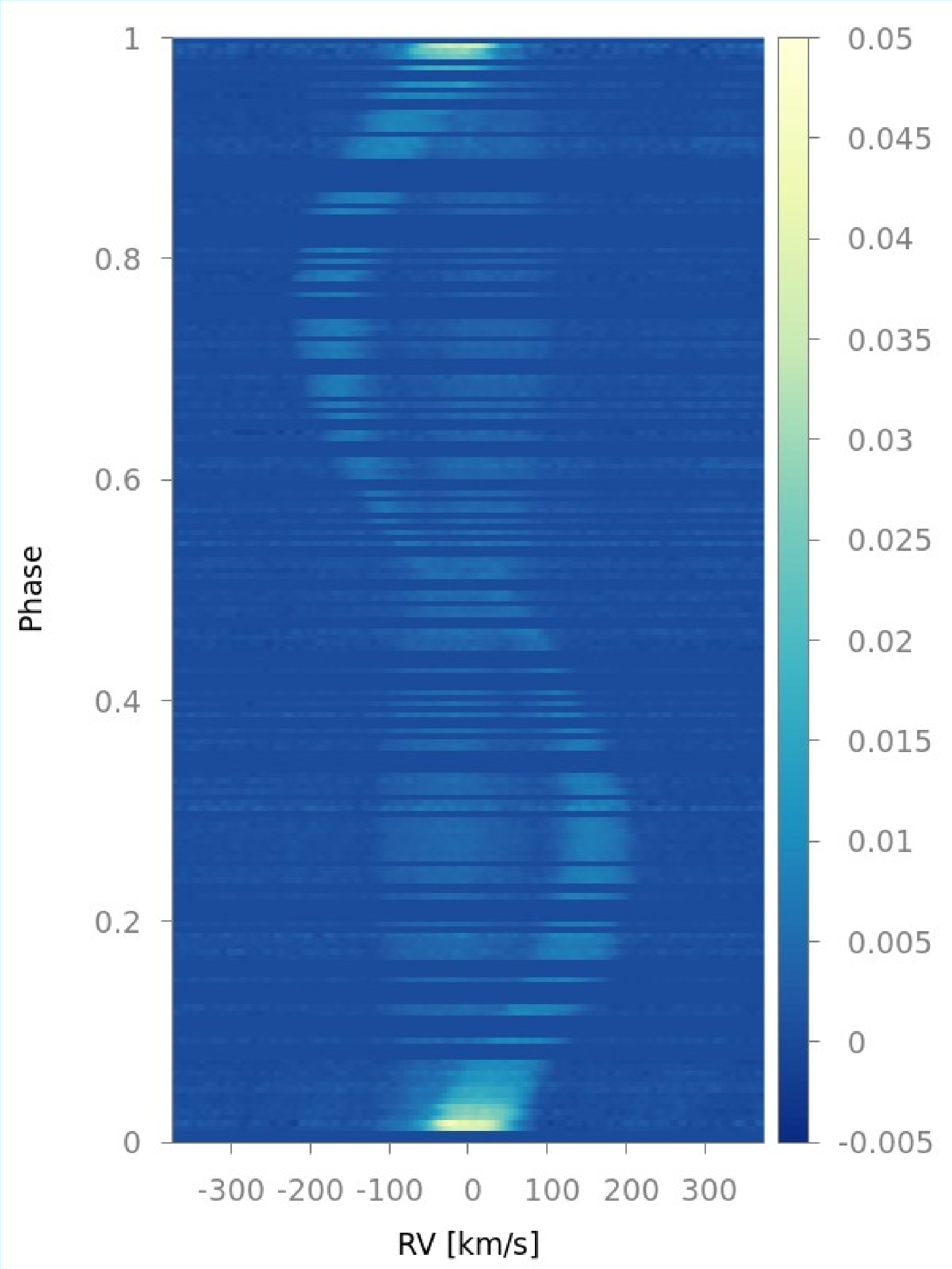




TX UMa: hard case

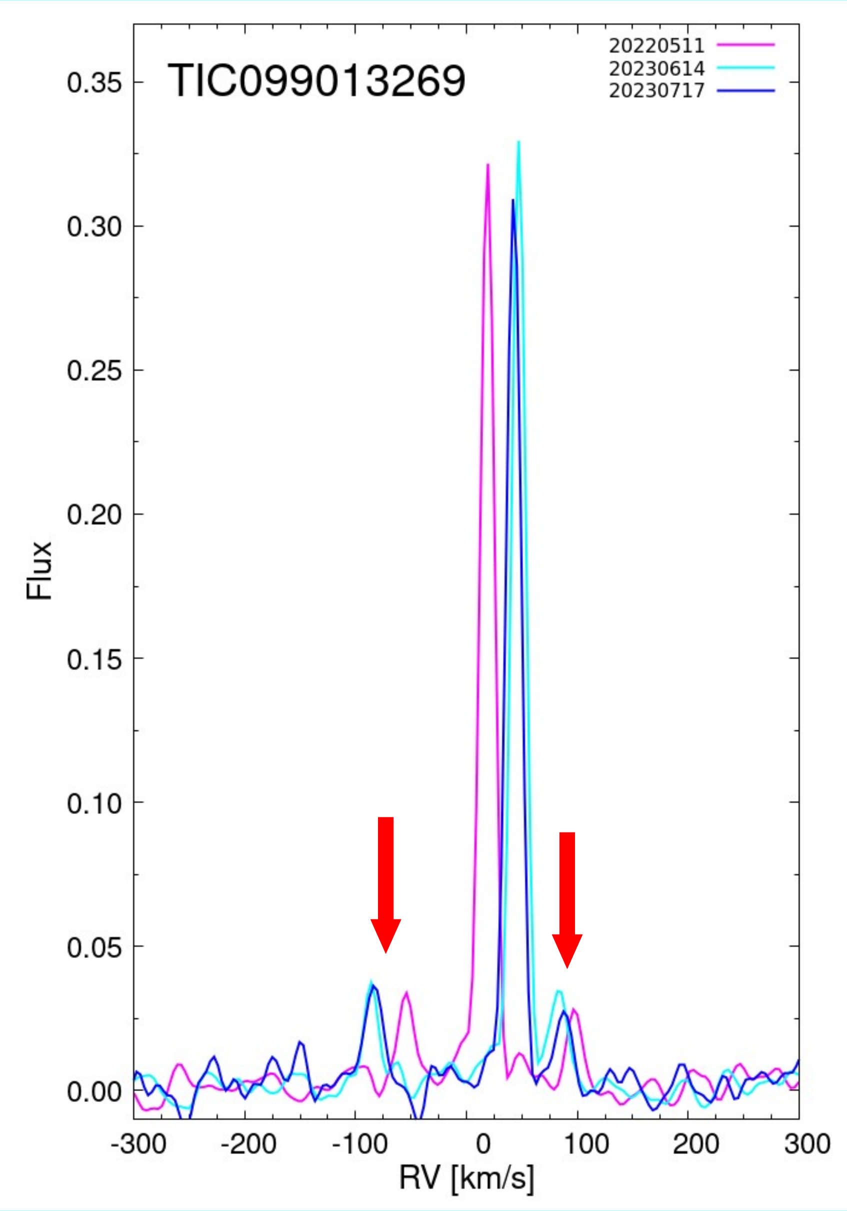
- High-contrast system, P = 3.063 days, B8V + G0III-IV, V_{max}=6.98
- Maxted+ (1995): e ~ 0.0, i ~ 90 deg, $m_1 = 4.76\ M_\odot$, $m_2 = 1.18\ M_\odot$
- Komžík+ (2008): RM-effect: over-synchronous rotation of the primary component, $v \sin i$ = 70.8 km/s, secondary seen only in Min I...





BFs extracted using an F4V star as a template MUSICOS@SP spectra

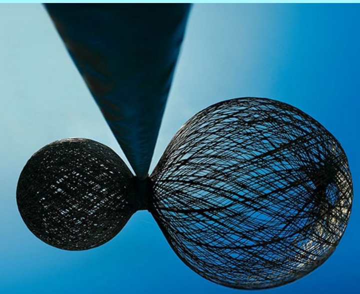
SB3: a recent catch



- TIC099013269: a triply eclipsing triple ($V = 9.92$)
- Rappaport+, 2023 revealed one component: defined outer orbit
- BFs from Skalnaté Pleso spectroscopy: inner binary found !
- Spectroscopic constrains photodynamical model

Conclusions/Perspectives

- Binary stars can be observed spectroscopically with a meter-class telescope
- Magnitude limit depends on the orbital period, spectral type, and rotational velocity
- Improving throughput and RV stability of eShel and MUSICOS
- Further improvement of modeling tools: multi-template BF, full photodynamical modeling, improving reflection effect
- Improving multi-dataset models



Litomyšl

Zámecké návrší
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International Conference

Binary and Multiple Stars in the Era of Big Sky Surveys

Litomyšl, Czech Republic, 8th – 13th September 2024

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