Ongoing stellar and exoplanetary projects

M. Vaňko

T. Pribulla, A. Maliuk

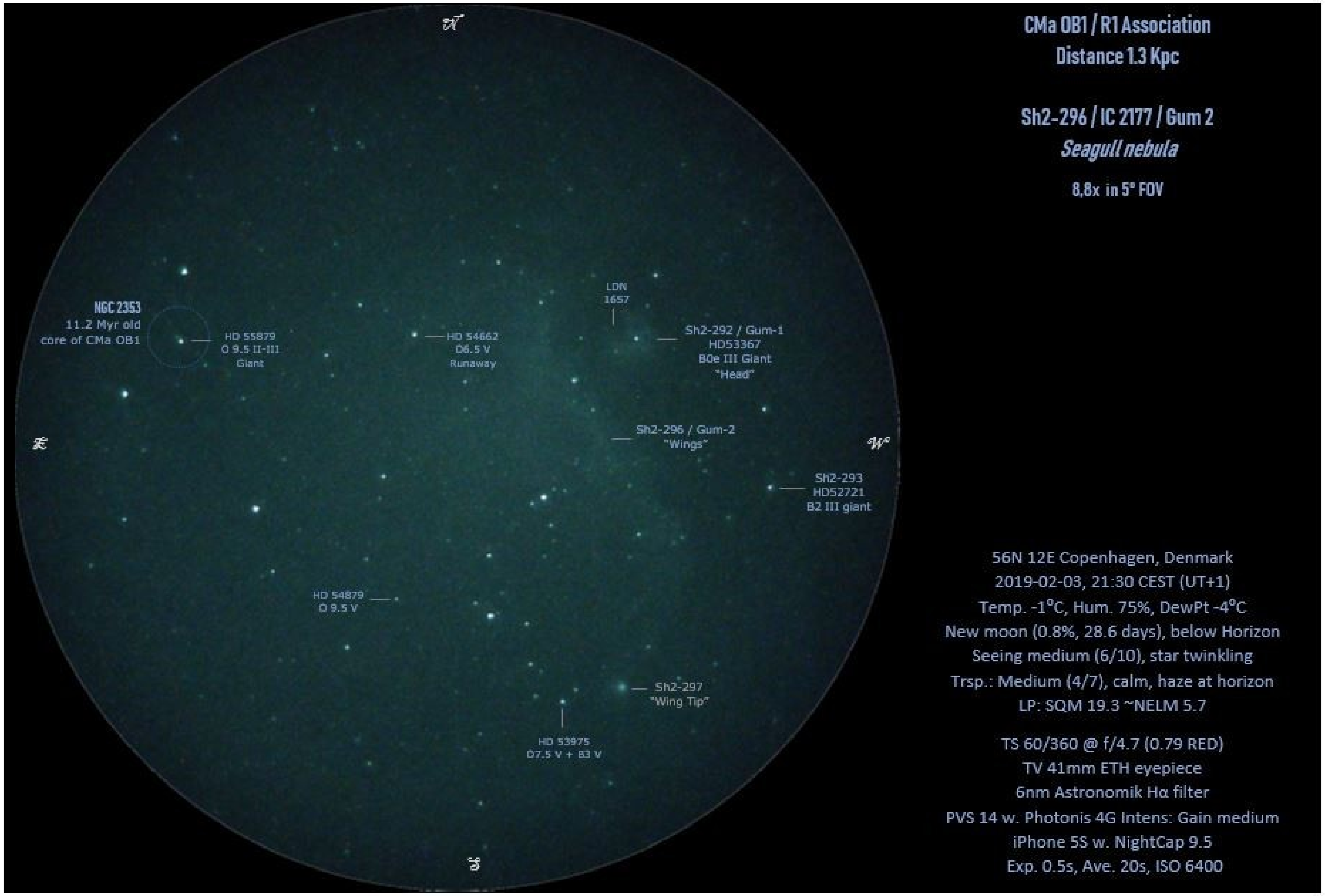
Institute seminar AI SAS, May 15, 2024

Outline

- CMa OB1 Member: FM Canis Majoris
- ζ Pegasi: slowly pulsating B star
- Spectroscopic follow-up of the TESS planetary candidates

FM CMa

- CMa constellation – stellar associations: (i) CMa OB1/R1 (d ~ 1.15 kpc), (ii) CMa OB2 (d ~ 740 pc). The predicted ages are 3 Myr and 100 Myr for CMa OB1/R1 and OB2, respectively (Tunç & Bakış, 2019).
- Study of Eclipsing Binaries and Multiple Systems in OB Associations: CMa OB1 Member FM Canis Majoris

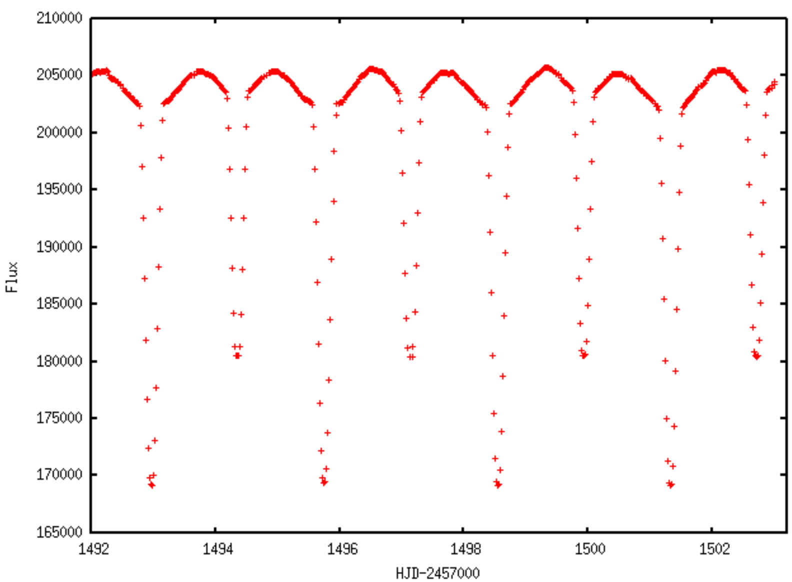


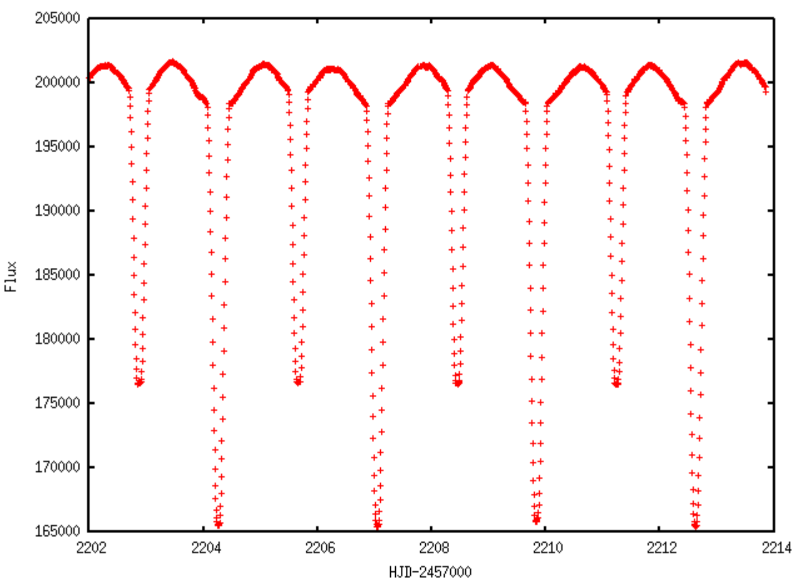
Dystrup, 2017

FM CMa: photometry

- FM CMa (*V* = 8.73): a hot eclipsing binary composed of a B2 primary and a cooler secondary orbiting in *P* = 2.78945 days
- Gaia DR3 spectroscopy: T_{eff} = 17368 [17219, 17640] K, log (g) = 3.618 [3.589, 3.670], [M/H] = 0.646 [0.537, 0.706], *d* = 862 [812, 901] pc.
- The *TESS* photometry: (i) total eclipses, (ii) low-amplitude variability in the out-of-eclipse parts of the light curve, (iii) caused by radial pulsations (componets rotates synchronously) or spots (asynchronous rotation) P ≈ 5.5 cycles/day (4.3 hours).

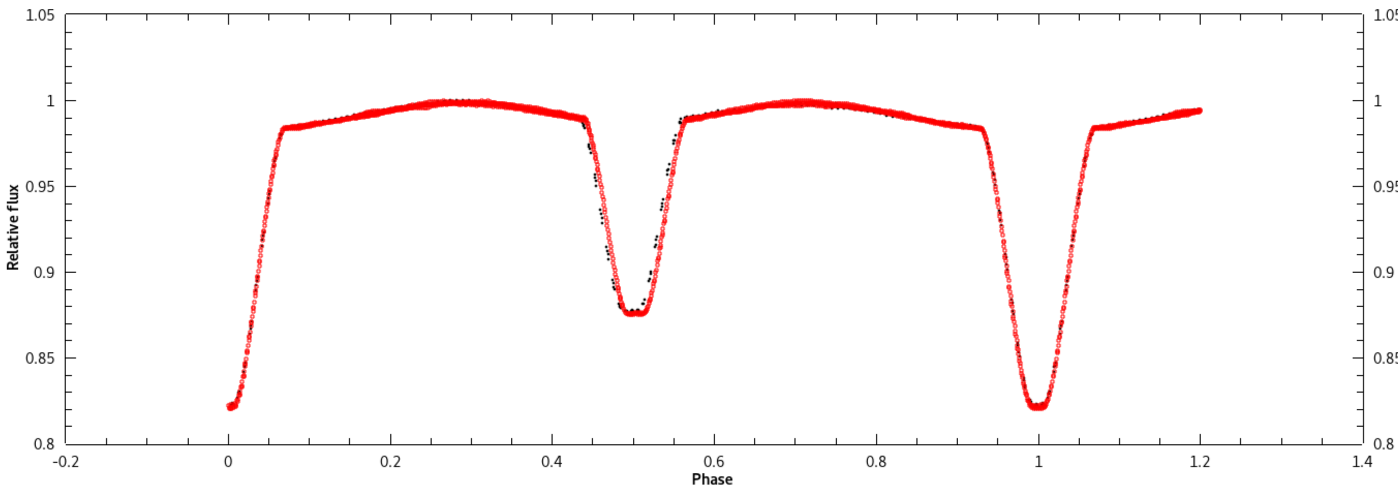
- A comparison of the data from the two sectors (almost two years apart). Apsidal motion cycle about *U* = 92 years long. (*the secular precession of the major axis of the binary orbit*)





FM CMa: photometry

- FM CMa (V … orbiting in
  P = 2.78945 …
- Gaia DR3 s…
  [M/H] = 0.64…
- The *TESS* ph… ts of the light
  curve, (iii) ca… ous rotation)
  P ≈ 5.5 cycle…



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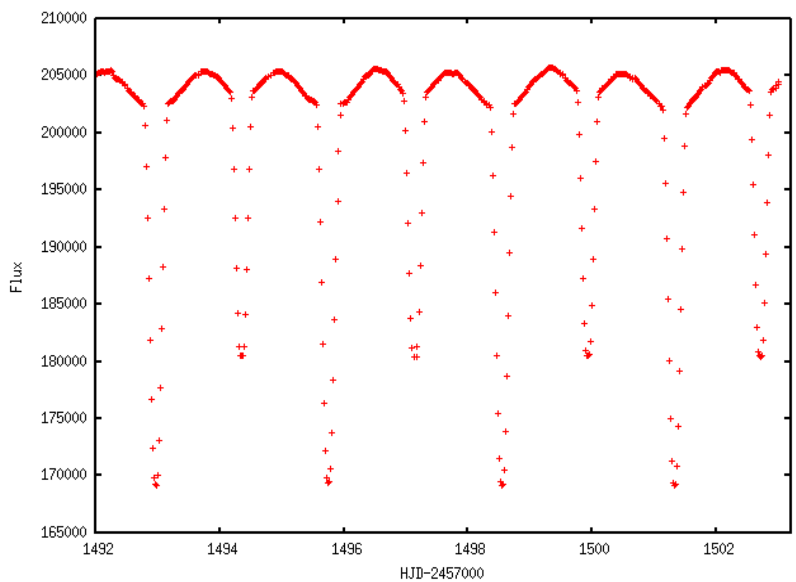
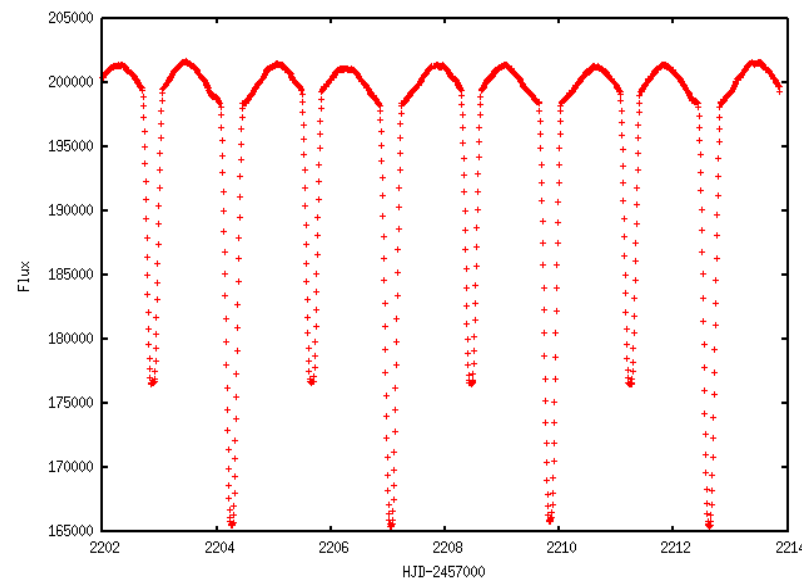
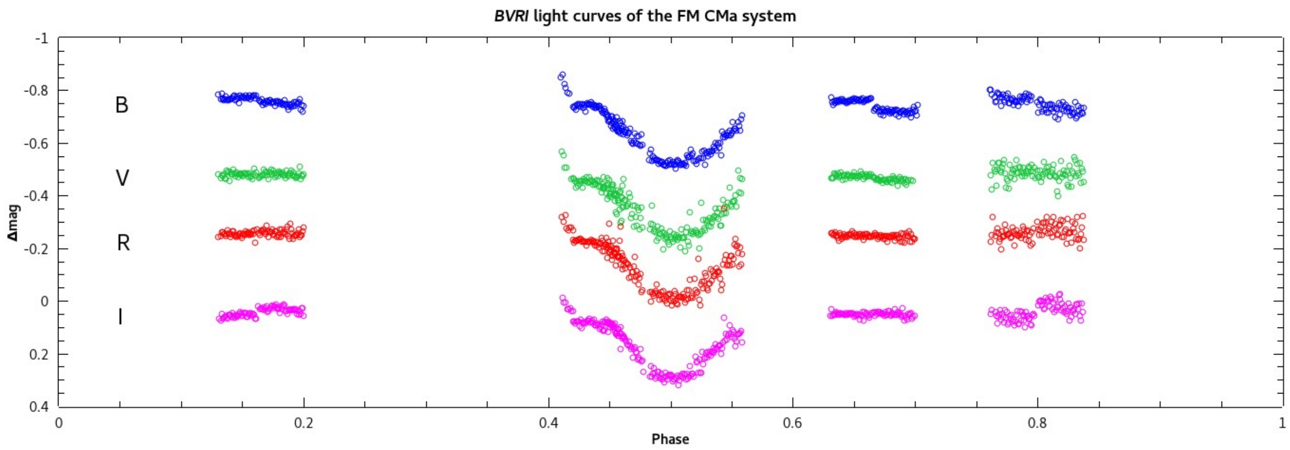
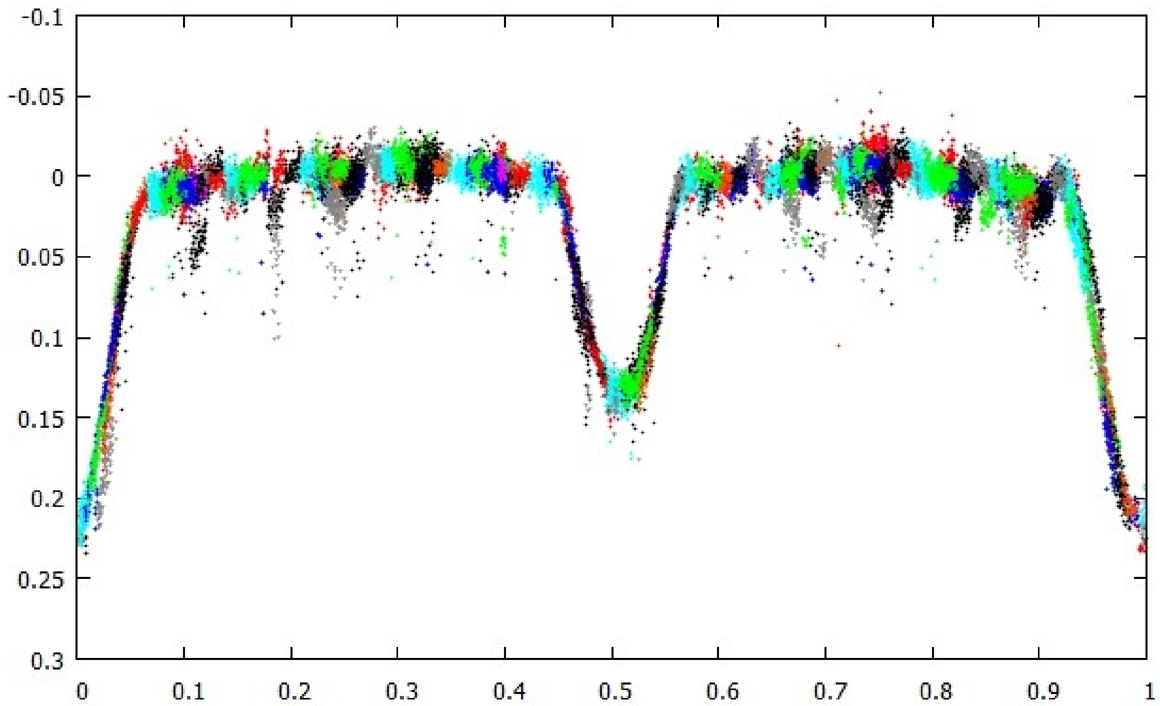




FM CMa: photometry

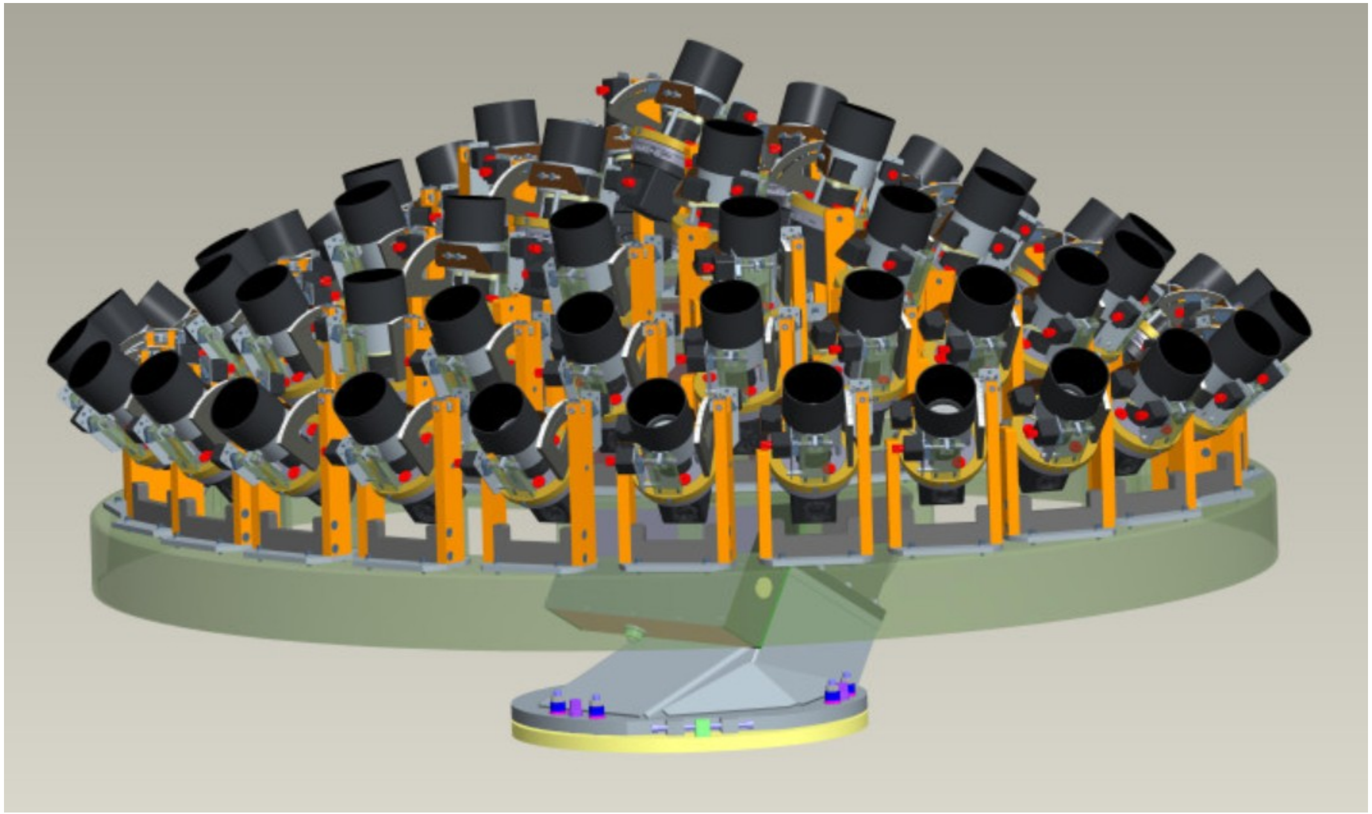


Ground-based *BVRI* photometry obtained at the Kolonica Saddle Observatory in 2022



Phase-folded light curve of FM CMa obtained by
HAT-Pi (Hungarian Automated Telescope) instrument (Bakos et al. 2004)

FM CMa with HAT-PI



https://wbhatti.org/research/hatpi.html

- HAT-PI uses 64 CCDs, each with a 13 x 13 degree field, to observe the sky above 30 degrees.
- It has no declination axis, only tracks in Right Ascension.
- High cadence (every 30 seconds) photometry, resolution (23 arcseconds per pixel), and high photometric precision (1 mmag, at 30 second cadence)
- Saturation limit - $V \sim 8$ mag
- Standard Cousins *I* filter as primary band, complemented by a Johnson *V* filter

FM CMa: spectroscopy

- Four sources of spectroscopic observations

(i) November 2009:
Coudé-Échelle Spectrograph (CES) attached to the 1.5-m RTT150 telescope, TÜBİTAK National Observatory (TUG), Antalya, Turkey

(ii) August/September 2017:
FEROS spectrograph at 2.2-m MPG/ESO telescope at La Silla, Chile

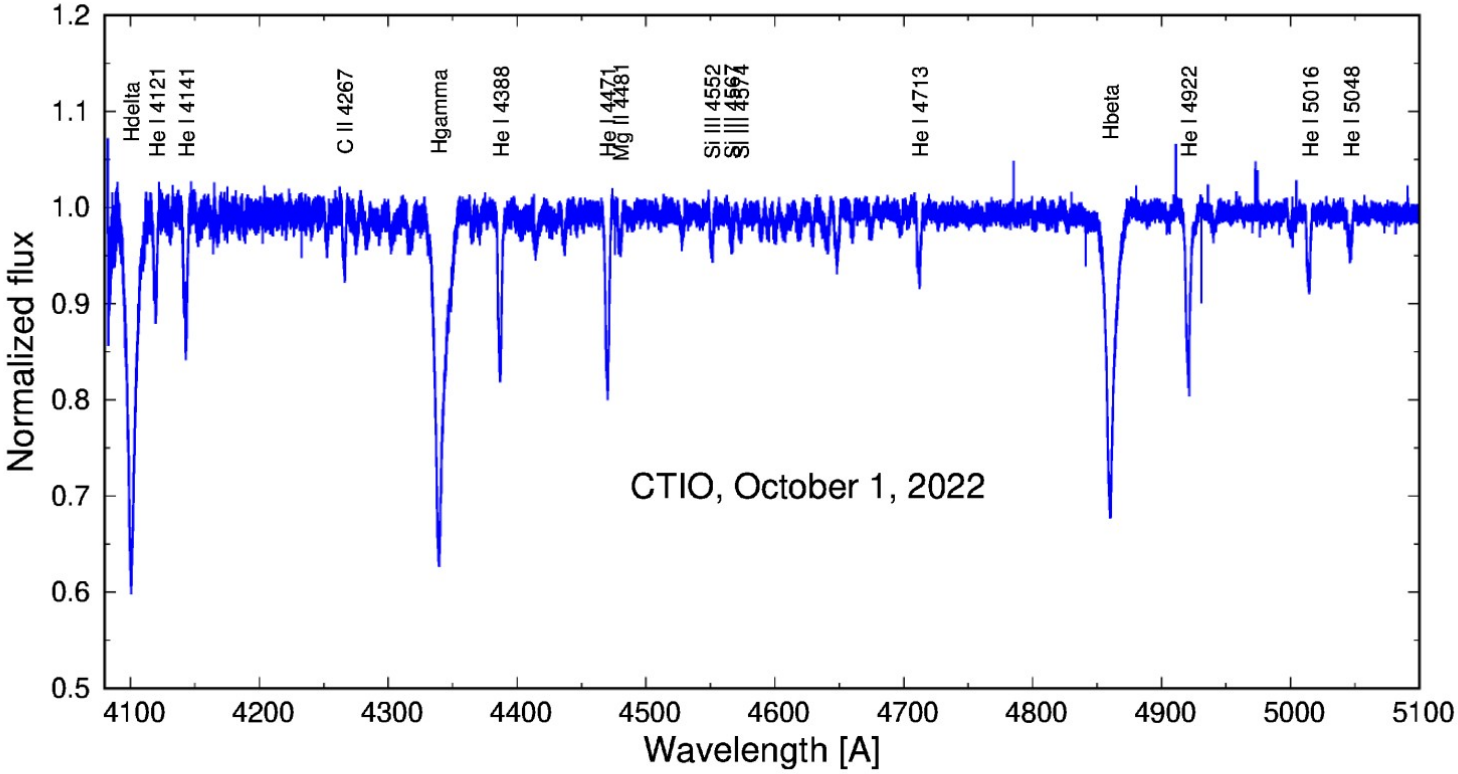
(iii) October/December 2022:
SMARTS CHIRON spectrograph at 1.5-m telescope, The Cerro Tololo Inter-American Observatory, (CTIO), Chile

(iv) 2017/2023:
MUSICOS spectrograph at 1.3-m telescope, Skalnaté Pleso Observatory, Slovakia

FM CMa: spectroscopy

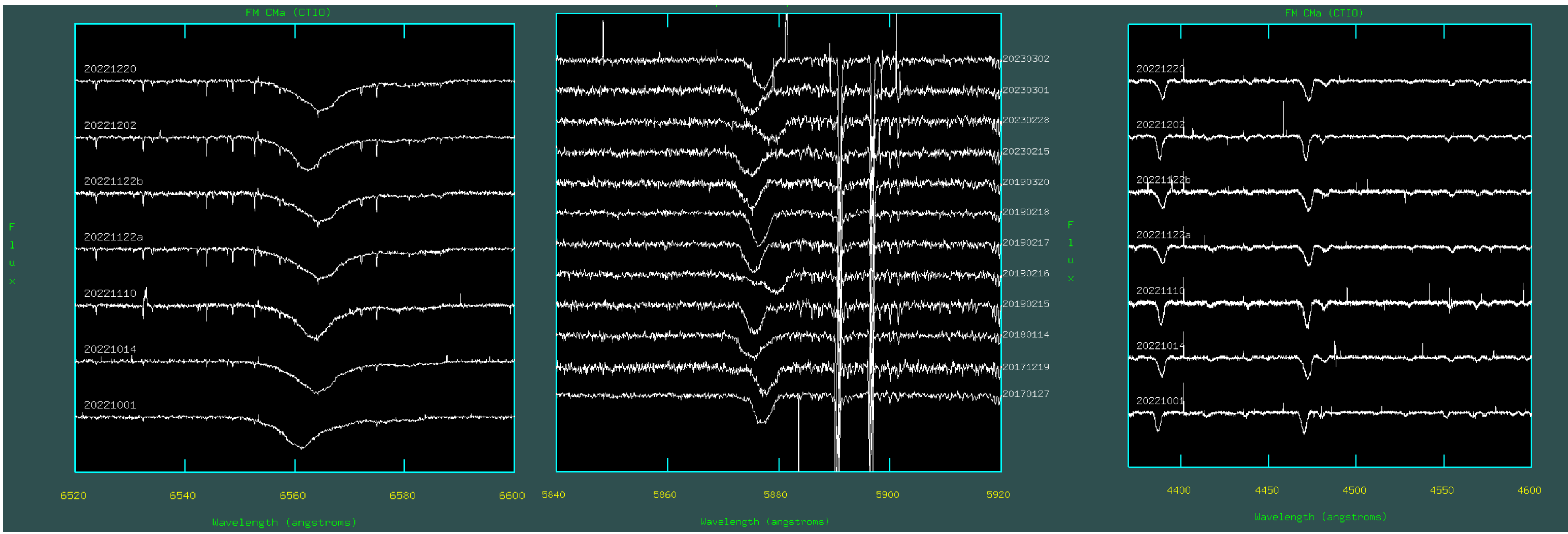
- The spectra confirm the early B spectral type manifested by the dominant hydrogen Balmer and neutral helium lines. Only the strongest metallic lines are visible (e.g., Mg II 4481, C II 4267, and the silicon triplet).

- The lack of metallic lines complicates the determination of the radial velocity and spectra disentangling.



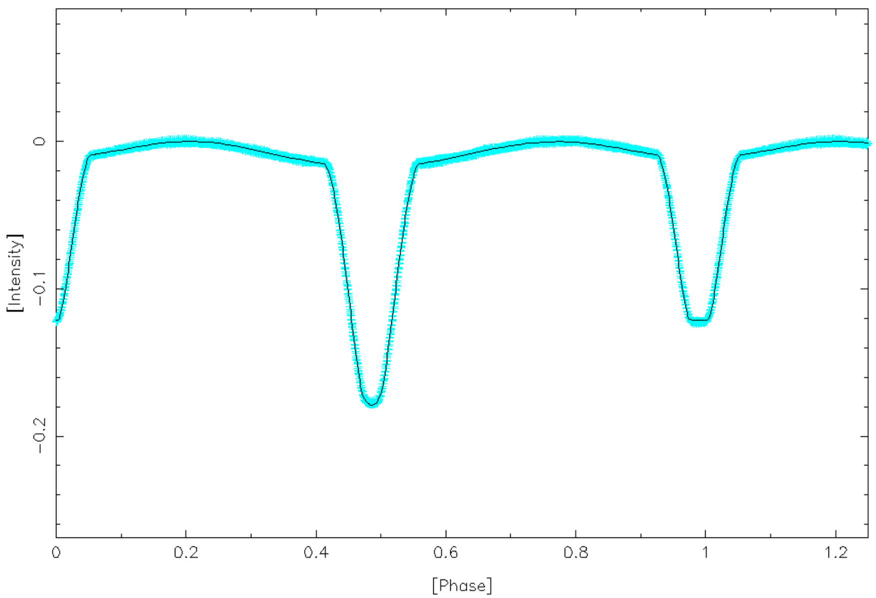
FM CMa: spectroscopy

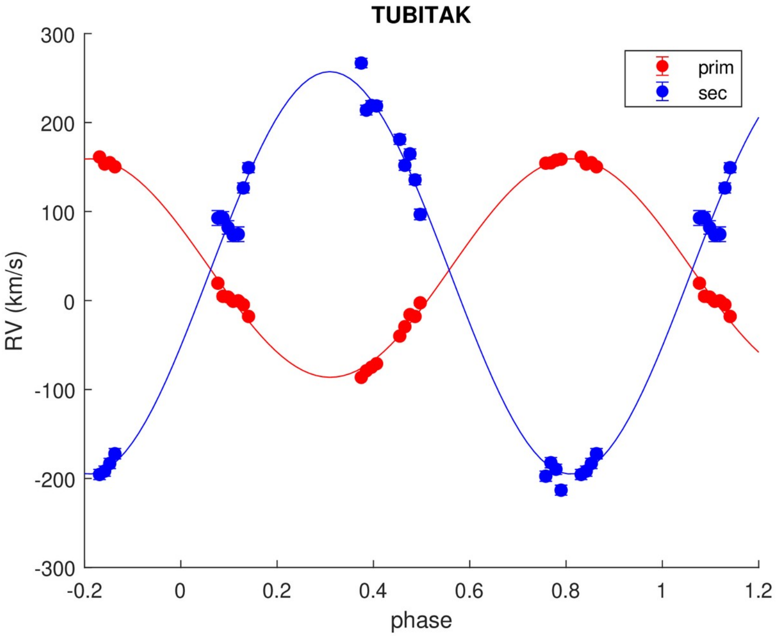
Hα line | He 5875 Å line | Mg 4481 Å line



- The variable asymmetric shapes of the absorption lines: complex and non-uniform wind flows from the two components in the orbital plane.
- A similar system (*P* = 1.8 days) with two massive B-type components AH Cep was detected in X-rays by Chandra observatory (Ignace et al., 2017). Its X-ray luminosity can originate from the wind collision between the two stars, supporting the complexity of the circum-stellar matter distribution in such systems.

FM CMa: preliminary solution





Parameter	Value	σ
P [d]	2.78928	0.00012
T_0 BJD [TDB]	2459202.9041	0.0034
i [deg]	86.7	0.6
$r_{\rm pri}$	0.2640	0.0025
$r_{\rm sec}/r_{\rm pri}$	0.596	0.009
e	0.067	0.005
ω [deg]	274.4	0.4
l_3	0.95	0.15
$T_{\rm pri}$ [K]	17368	–
$T_{\rm sec}$ [K]	14700	450

K_1 = 129.4(2.1) km/s
K_2 = 228.3(3.0) km/s
V_γ = 40.9(1.4) km/s
q = 0.57(2)

M. Vaňko, T. Pribulla, N. Shagatova, R. Komžík, P. Dubovský: 2024, I*n Conference Proceeding,*
CAOSP **54**, no. 2, p. 171-174.

FM CMa: future work

- Disentangling spectra of the system: CHIRON and MUSICOS
- Radial velocities determination, analysis RV curve from all spectroscopic datasets, possible additional component characterisation
- Interpretation of variability in the out-of-eclipse parts in the LC
- Evolutionary status of the system, position in the HR diagram, population type, kinematical analysis, membership in CMa OB1/R1 association

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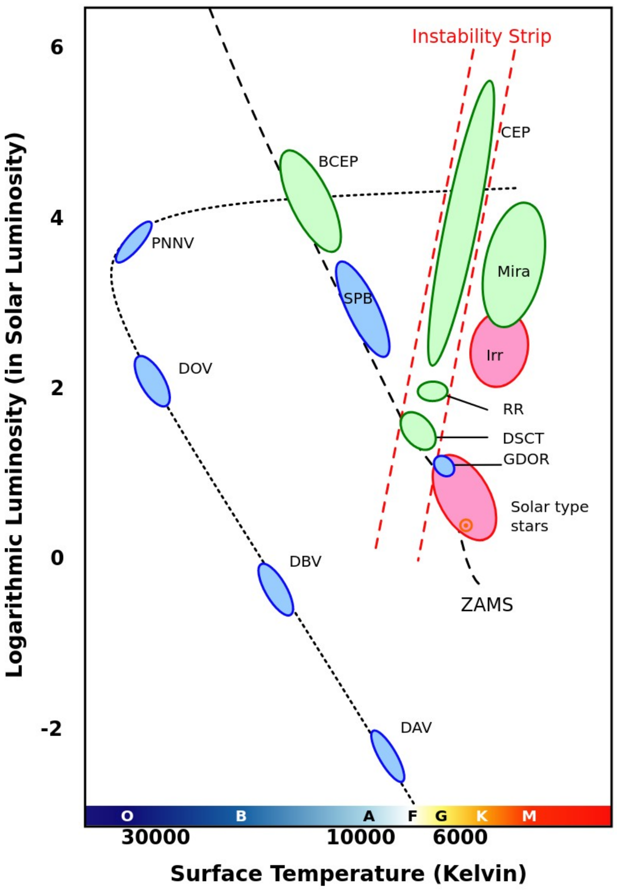
ζ Pegasi

- Belongs to the group of slowly pulsating B stars (SPB stars):
  - objects consisting of mid to late B-type stars that show photometric variability on the order of a few days.
  - The pulsations show multi-periodic, non-radial gravity modes with periods in the range of 0.4-5 days and V-band amplitudes lower than 0.03 mag (e.g. Pedersen 2022; Aerts & Mathis 2023).

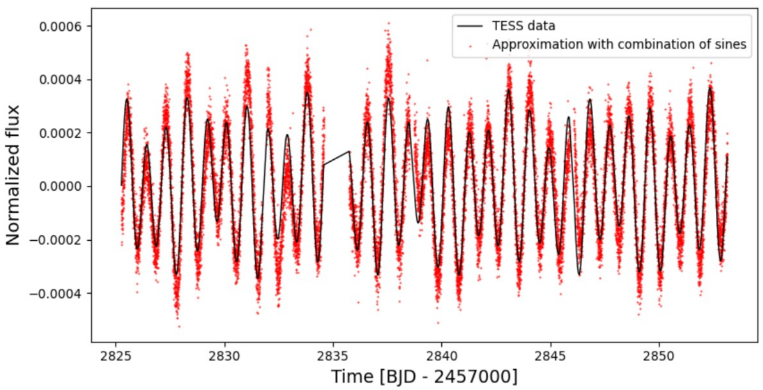


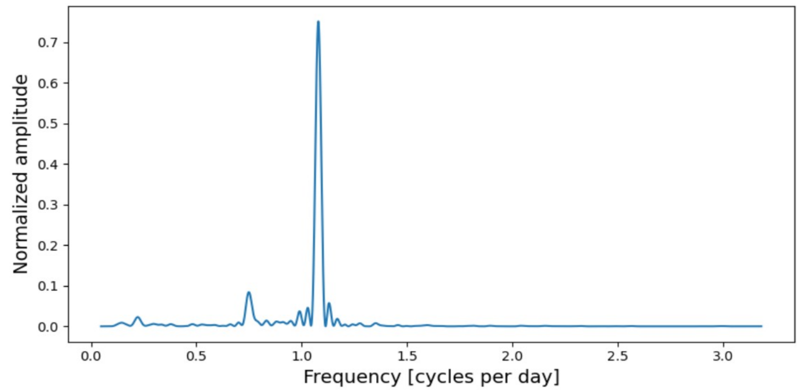
- Broadband photometry of ζ Peg, obtained by guide star telescope of Gravity Probe B (GP-B) mission.
  - Goebel (2007) found that the star is an SPB variable with a period of 22.952 ± 0.804 hours (1.04566 cycles day^{-1}), and an GP−B amplitude of 488 μm.
  - This period was identified as a *g*-mode oscillation.

- T_{eff} are in the range of 11060-12000 K, and values of log (g) are between 3.25 and 4.0 (e.g. Mégessier 1971; Castelli 1991; Leone et al. 1997; Malagnini & Morossi 1997; Fitzpatrick & Massa 2005; Huang & Gies 2008; Wu et al. 2011; Zverko et al. 2016; Takeda et al. 2017)

- Fast rotating star with $v \sin i \approx 130$ km s^{-1}.

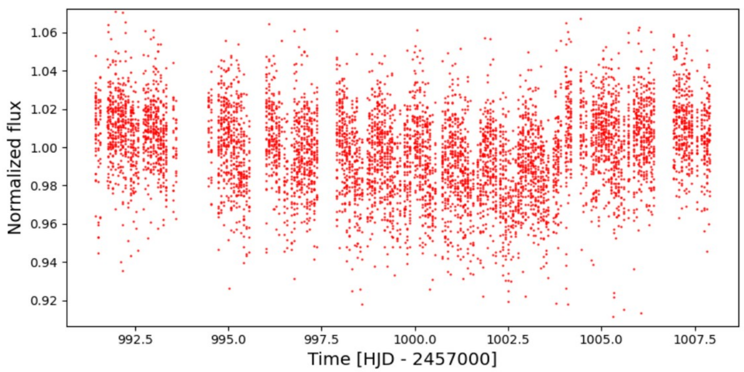
ζ Pegasi: photometry

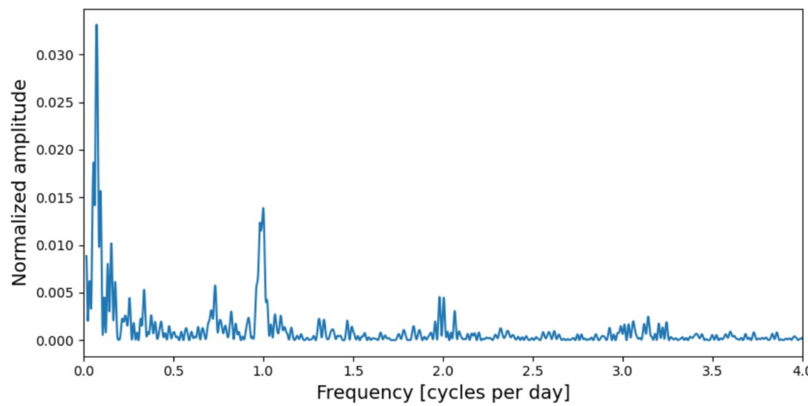




TESS photometry

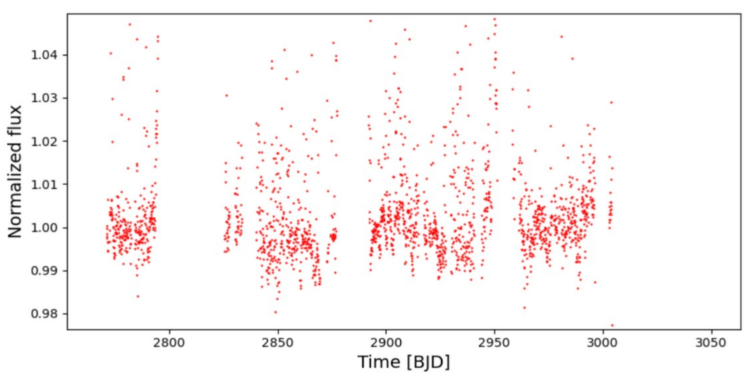
1.0799 cycles day^{-1}
$P \approx 22.224 \pm 0.913$ h

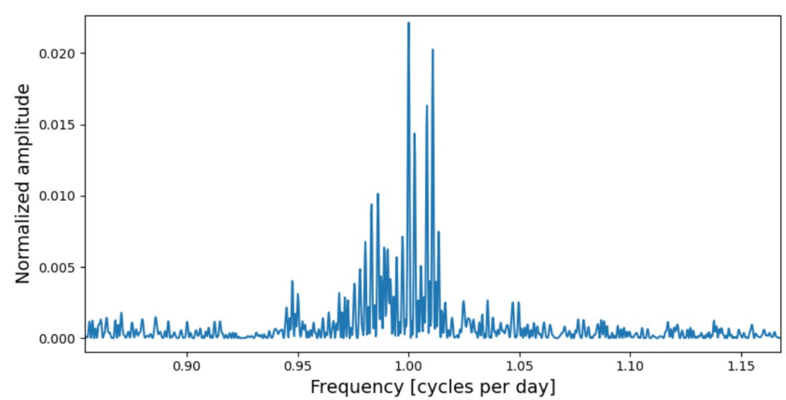




BRITE photometry

BRIght Target Explorer



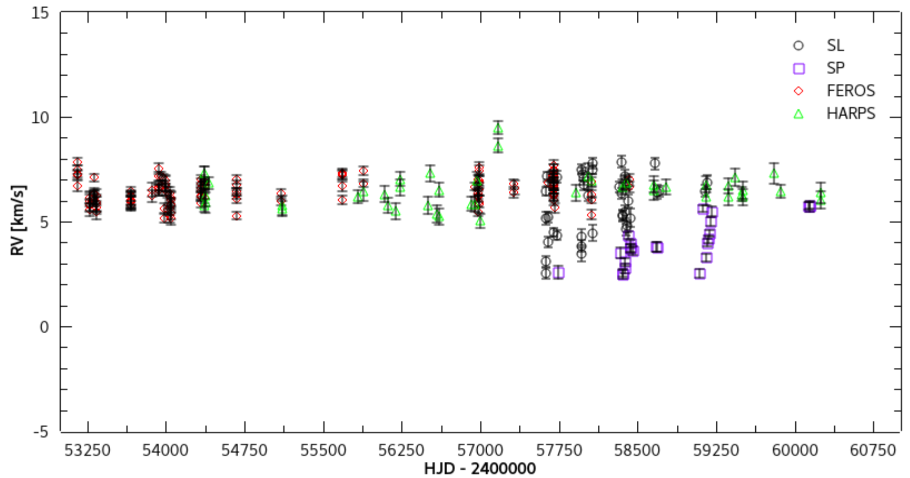


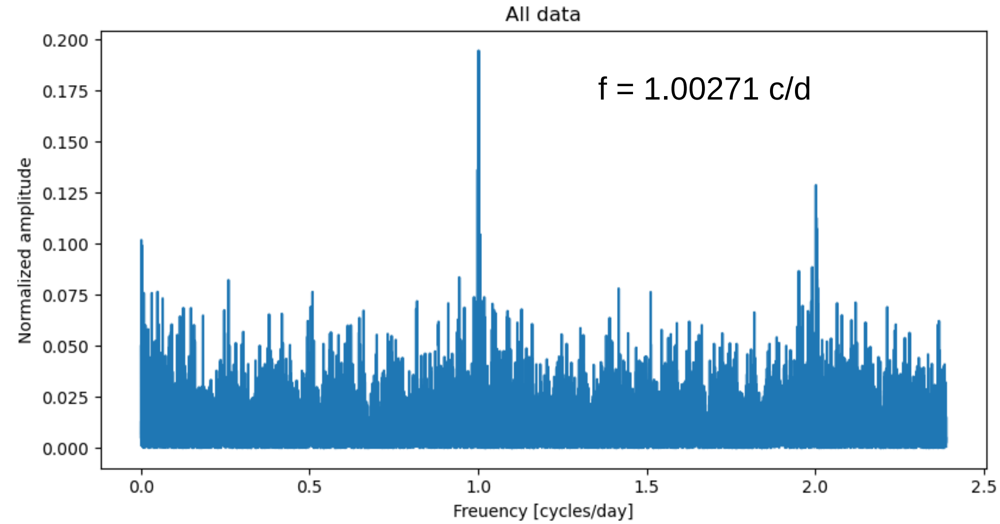
SMEI photometry

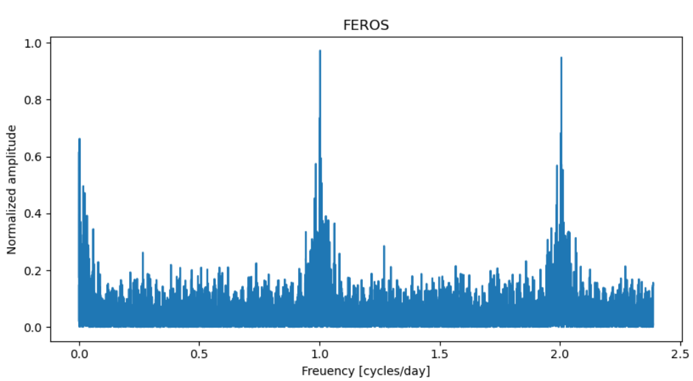
Solar Mass Ejection Imager

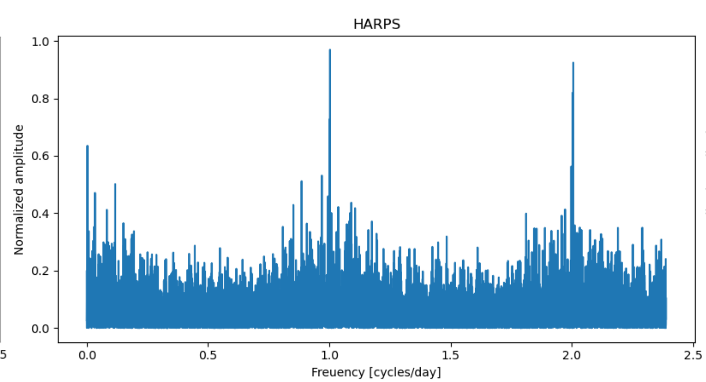
ζ Pegasi: spectroscopy

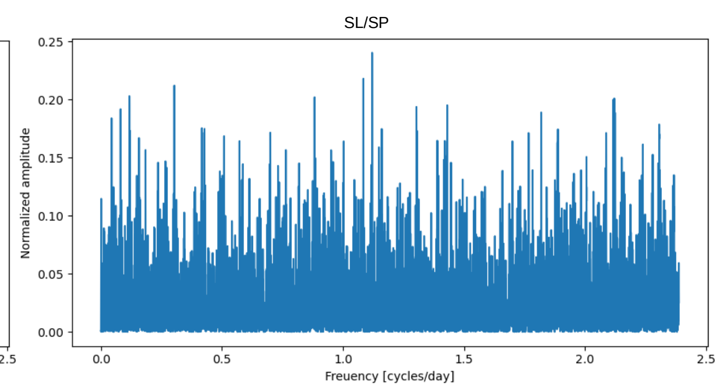
- Spectroscopic observations: Stará Lesná (eShel), Skalnaté Pleso (MUSICOS), 2016-2023, (67)
  La Silla (FEROS), 2003-2018, (163), La Silla (HARPS), 2004-2023, (60)











ζ Pegasi: Asteroseismology

- The main goal: Asteroseismology of studied target, providing invaluable insights into a star's internal structure, composition, and overall evolution.
- Key information about a star's mass, age, and chemical composition by analysing the frequency, amplitude, and duration of pulsations.

- FAMIAS (Frequency Analysis and Mode Identification for Asteroseismology): analysis of photometric and spectroscopic time-series data (e.g. Zima 2008, Wright et al. 2011, Schmid et al. 2014).

(i) *Spectroscopic Mode Identification*: the degree *l*, the azimuthal order *m*, and the velocity amplitude of the pulsation modes as well as parameters such as *v sin i* and the inclination angle.

(ii) *Photometric Mode Identification:* Teff and log(g) for different *l*-values inside a given range.

Param.	Allende et al. (1999)	Zorec et al. (2009)	Gordon et al. (2019)	This work
T_{eff} [K]	11000±450	10950±250	11400±600	11680±150
log (g)	3.75±0.07	3.80±0.10	3.89±0.09	3.68±0.05

ζ Pegasi: future work

- Disentangling high-dispersion spectra: FEROS and HARPS ➞ confirmation (yes/no) of additional faint component announced by Zverko et al. (2016).
- Including RVs from literature and other archives.
- Asteroseismology - Spectroscopic Mode Identification.
- Position of ζ Pegasi within sample of other known SPB stars – HR diagram

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TOI: TESS Objects of Interest

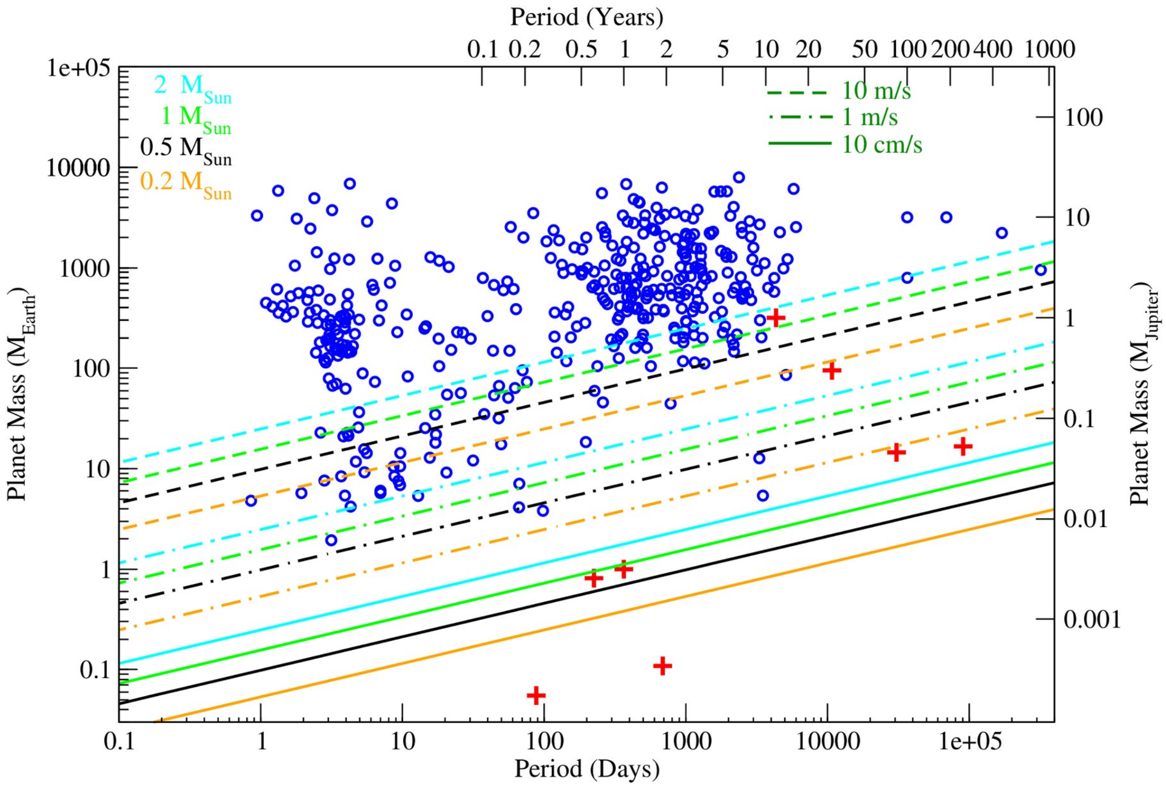
- The spectroscopic follow-up of TESS planetary candidates
- Planetary candidates are selected based on their detectability with meter-class telescopes. Most frequent targets are Hot and Warm Jupiter candidates.
  Furthermore, an important goal is also an initial screening of properties of exoplanet stellar hosts.

- 1.5-m CTIO SMARTS CHIRON spectrograph (Chille)
- 2-m Perek Telescope OES spectrograph (Ondřejov)
- 2-m Alfred-Jensch Telescope, TLS spectrograph (Tautenburg, Germany)
- 1.5-m ESO Telescope, PlatoSpec spectrograph (Chille)
- 1.3m Telescope, MUSICOS spectrograph (SP, Slovakia)

TOI: TESS Objects of Interest

- RV precision depends on (i) signal-to-noise ratio SNR (ii) projected rotational velocity *v* sin *i*, (iii) spectral resolution R, (iv) wavelength coverage B, (v) line density *f* as (Hatzes et al. 2010):

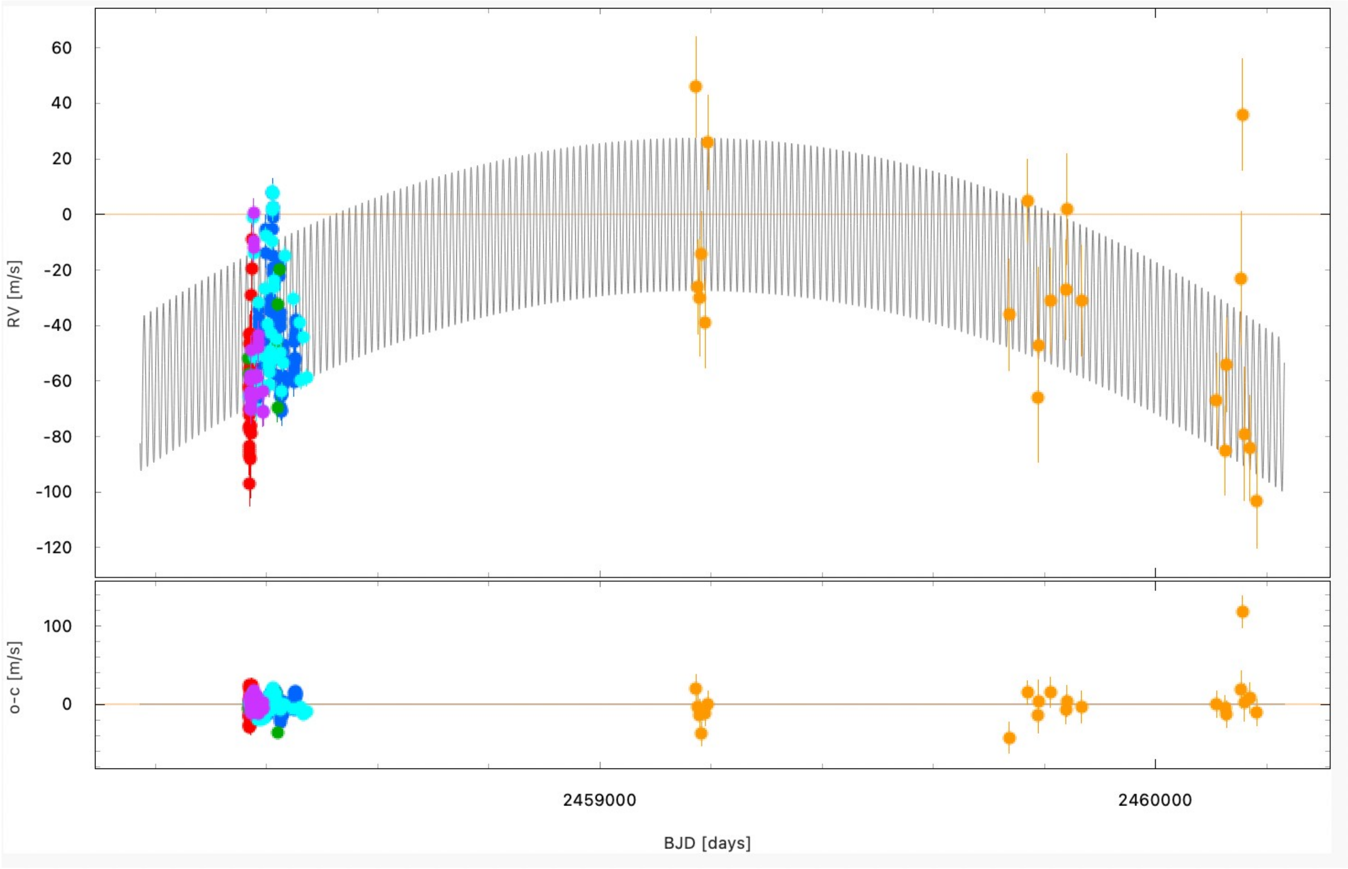
$$\sigma_{\rm RV} = \frac{C1\, v \sin i}{\mathrm{SNR}\sqrt{R^3 B f}}$$



Plavchan et al. 2013

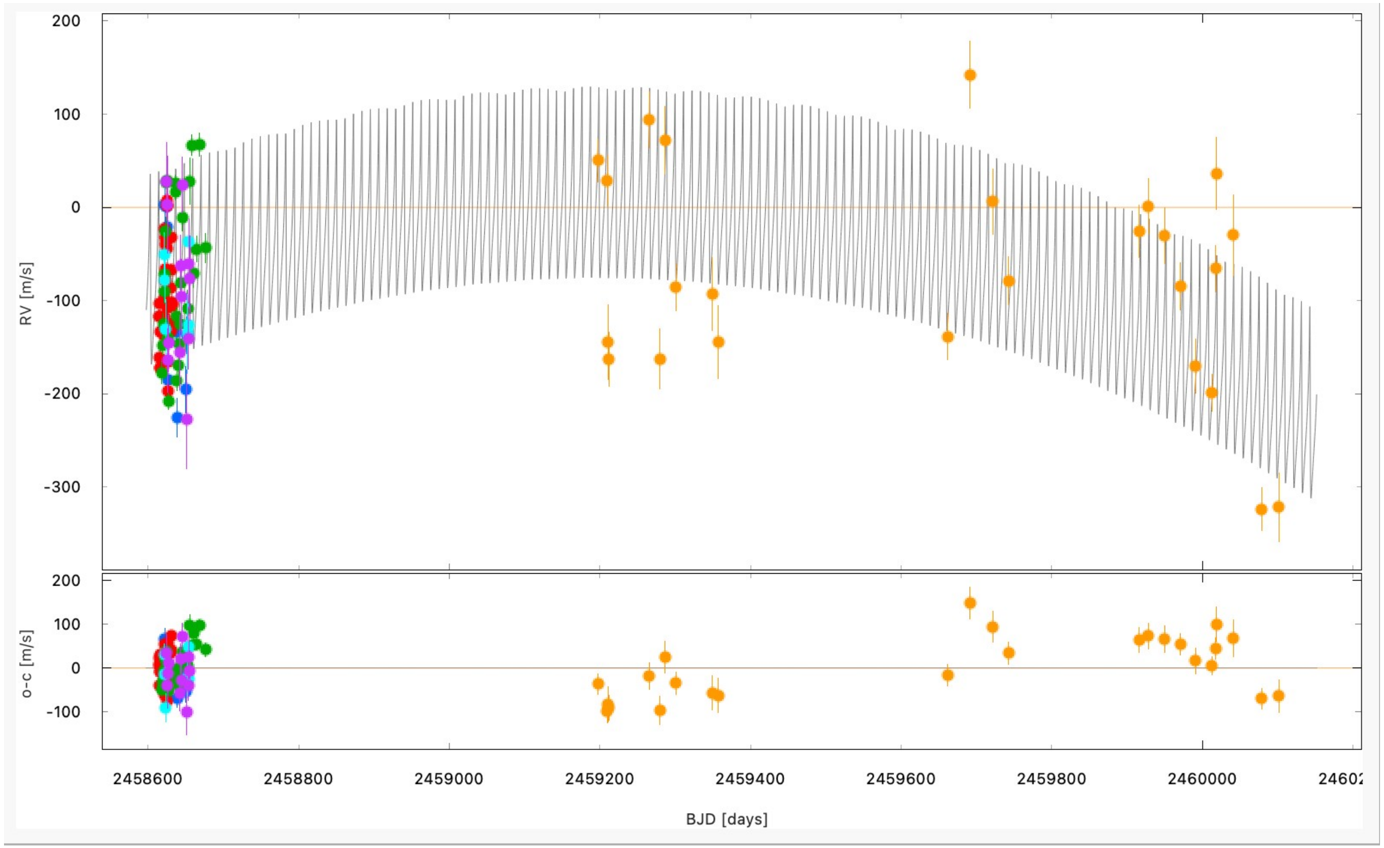
TOI: TESS Objects of Interest

- **TOI-120b**: a giant planet in an 11.54-day eccentric orbit around a bright (*V* = 7.9) G-type subgiant. Mass of 0.415 ± 0.020 M_J and a radius of 1.026 ± 0.026 R_J.
  (Nielsen et al. 2019)

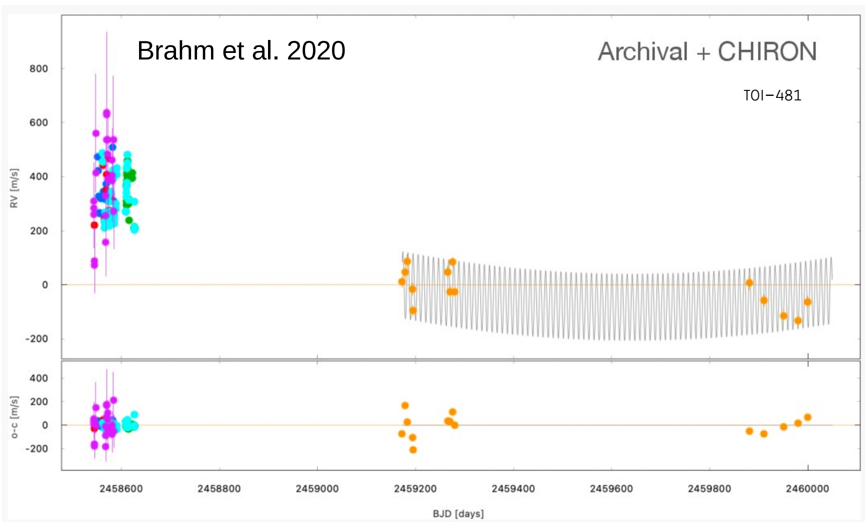


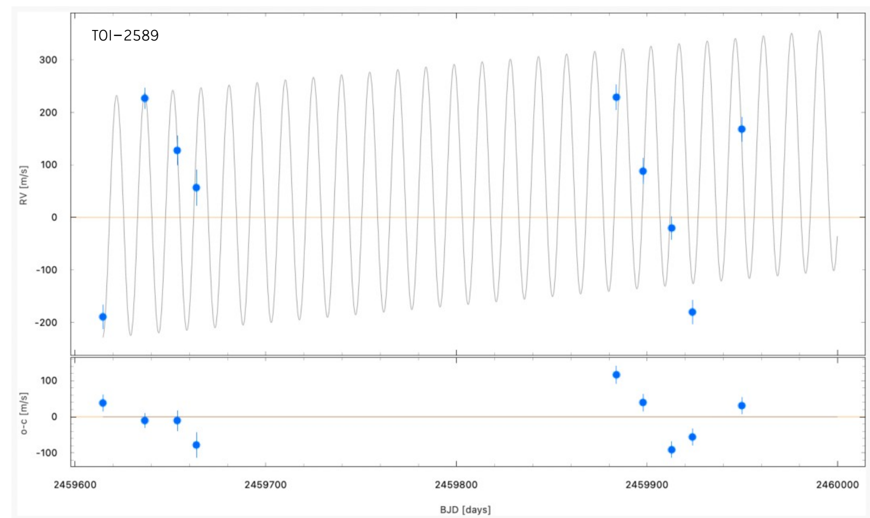
TOI: TESS Objects of Interest

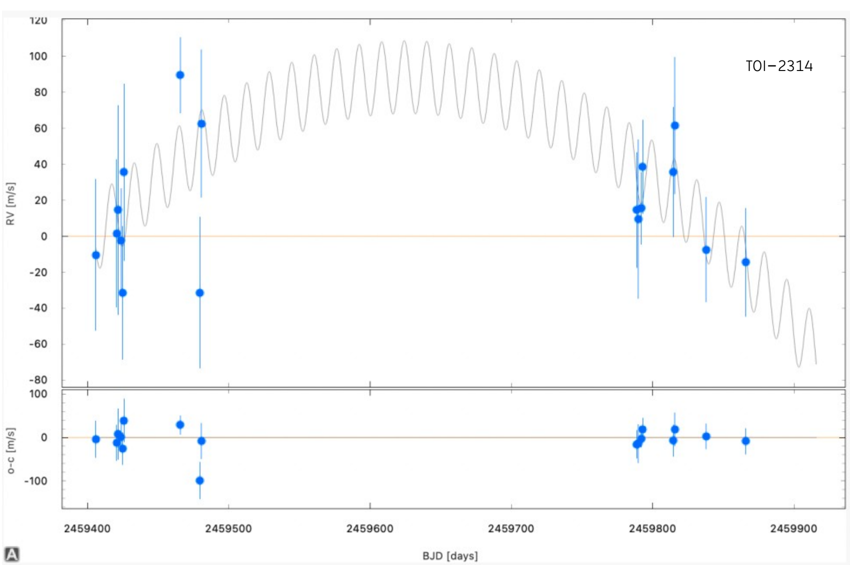
- **TOI-677b**: has a mass of 1.236 ± 0.068 M_J, a radius of 1.170 ± 0.030 R_J, and orbits its bright host star (*V* = 9.8 mag) with an orbital period of 11.2366 d, on an eccentric orbit *e* = 0.435 ± 0.024 (Jordan et al. 2019).



TOI	R_P [$R_\oplus$]	P_{orb} [d]	R_P/R_*	T_{eff} [K]	V_{mag}
481	11.794	10.33	0.0614	5735	9.97
2314	11.92	15.937	0.059	6140	12.29
2589	11.739	61.627	0.0942	5580	11.41







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Thank you for your attention