The fine effects in the TESS light curves of selected CP stars

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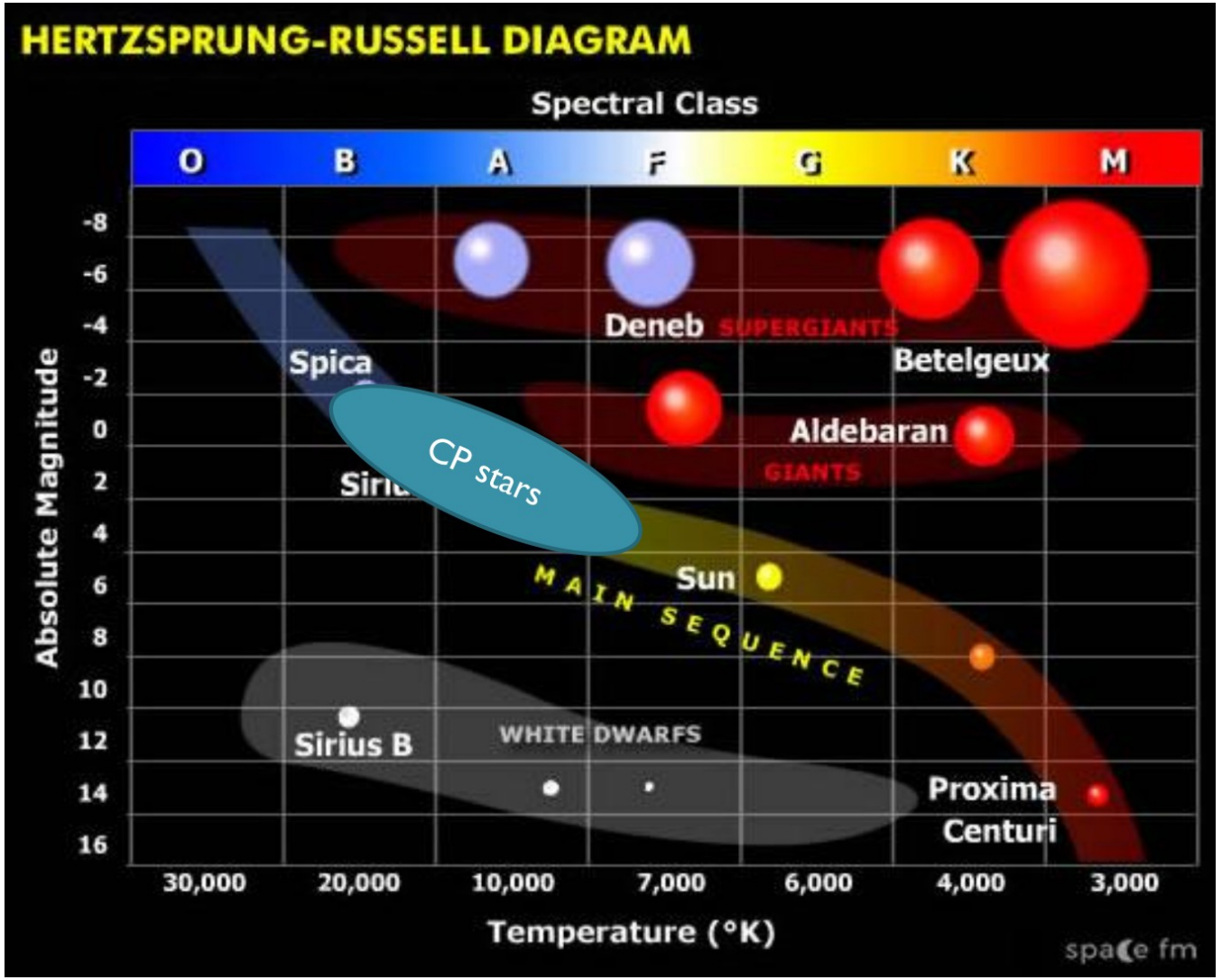
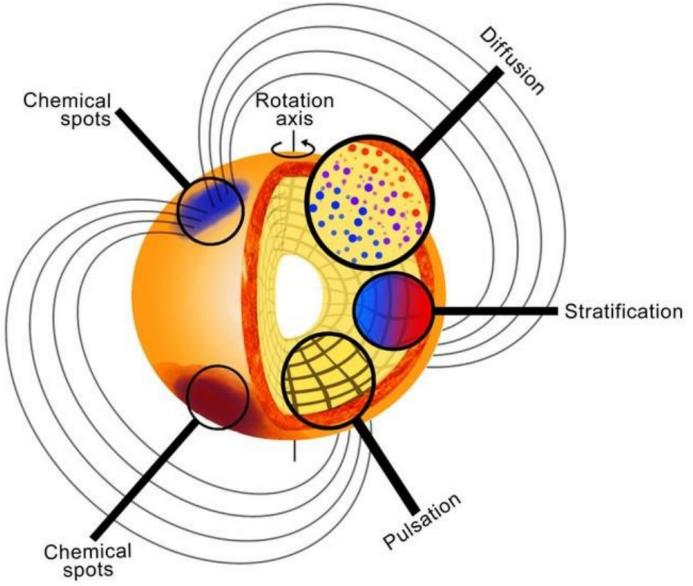
- A diverse group of upper MS stars with an anomalous surface chemical composition



- Overabundance Si, Fe, Cr, Ti, Sr – Eu, Pr, and Hg, Pt, often by several orders
- Anomalies are also in abundace and isotopic composition of helium
- The overabundant elements are distributed unevenly on the surface, creating persistent vast spectroscopic spots

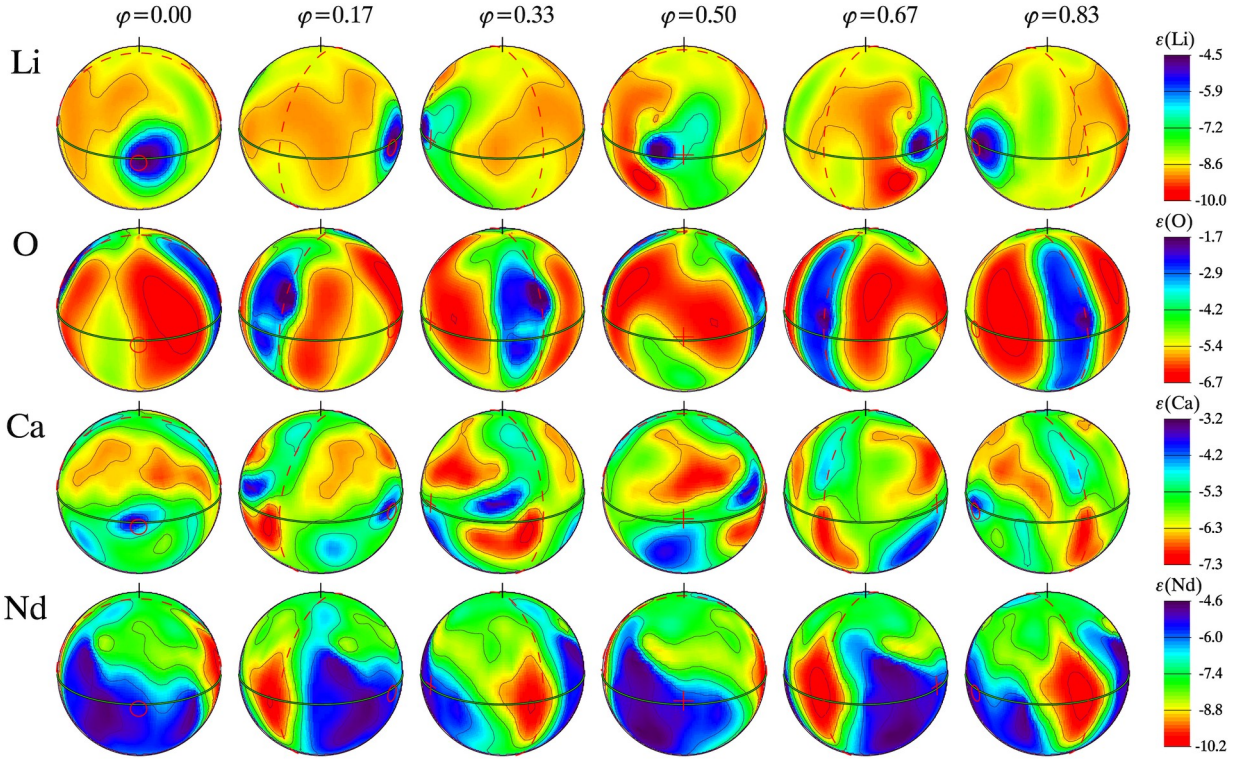
Diffusion
of elements



Credit: Victoria Antoci, DTU Space, Technical University of Denmark

- The chemical peculiarity: result of slow radiatively driven difussion and possible gravitational setling of different ions.
- A generally slow rotation and a strong global magnetic field (mostly dipole) enable the origin and sustaining of the peculiarity.

- Chemical anomaly is the subject of a thin skin of CPs only – the structure and life of inner part of stars is quite normal and corresponds to their masses and age.
- CPs show rotationally modulated variability in brightness, spectrum, and magnetic field. Thanks to this, the stability of their characteristics can be tested precisely



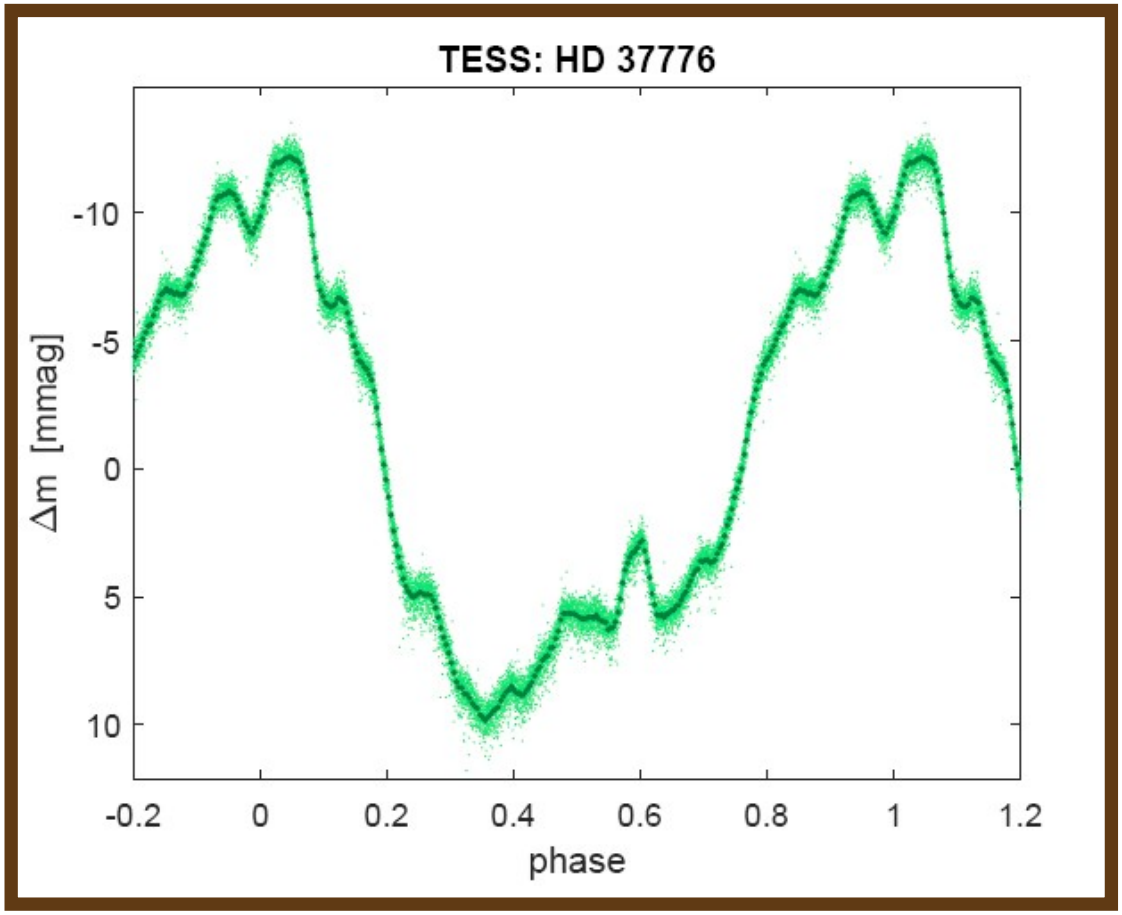
Kochukhov 2025

Light curves from satellite missions

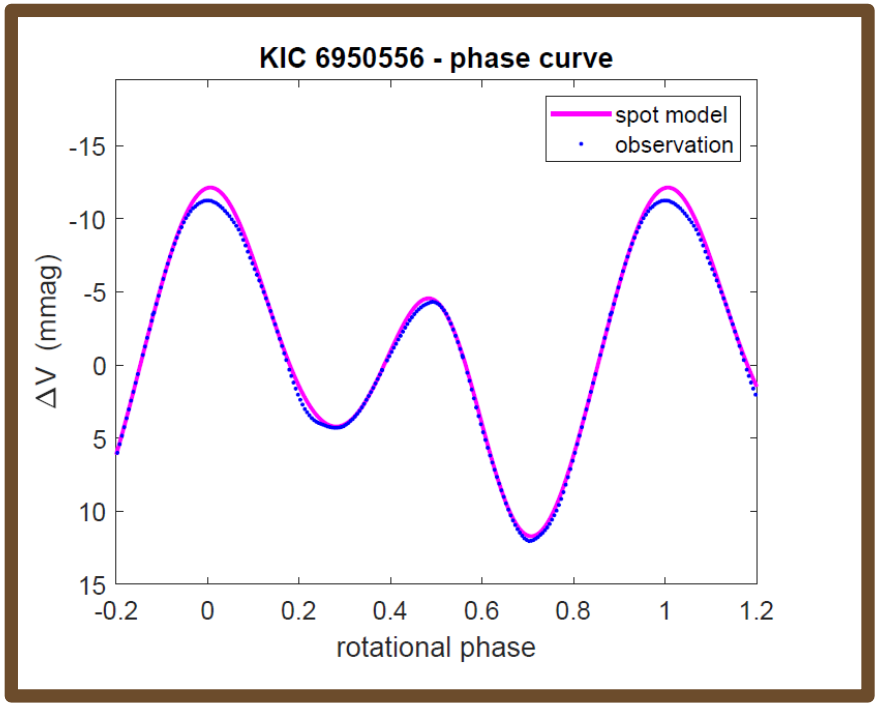
- CP stars typically show periodic variability due to surface spots that in most cases can be modeled by low-order harmonic expansion.
- High-precision satellite photometry reveals tiny complex features in the light curves of some of these stars that are difficult to explain as caused by a surface phenomenon under reasonable assumptions.
- Sudden and narrow decreases in brightness, later called "dips" (the instrumental effects were excluded) located at completely fixed points of the light curve.
- The first observation from December 2018 obtained by TESS satellite was announced at the John Landstreet 80th birthday conference in London, Canada, July 2019 (Mikulášek et al., 2020).
- Later, they found a similar course, in many others mCP stars.

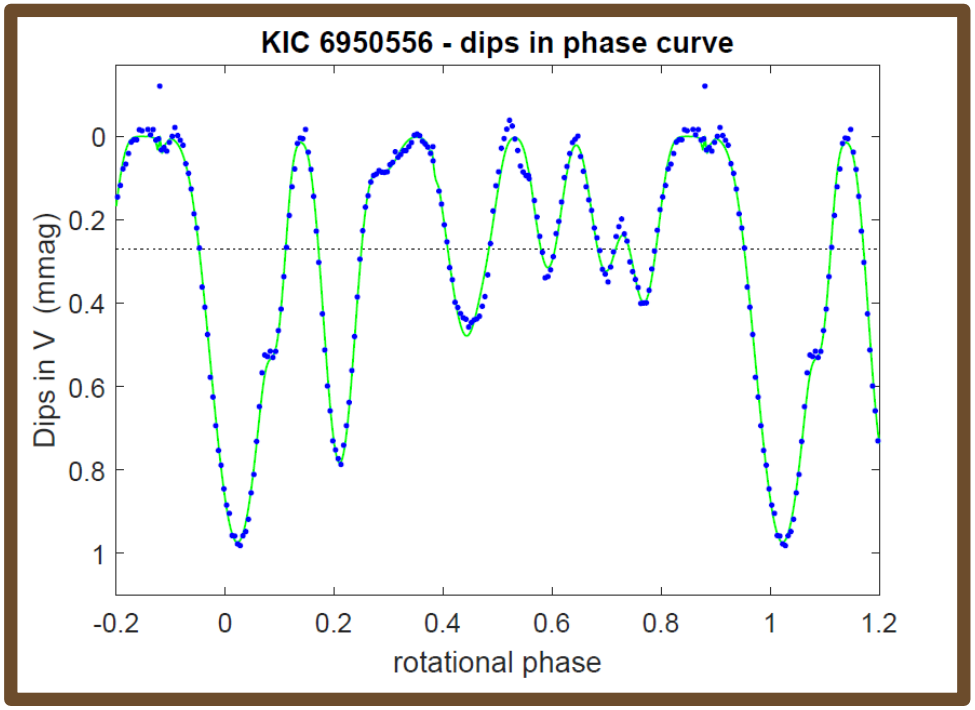
Light curves in TESS

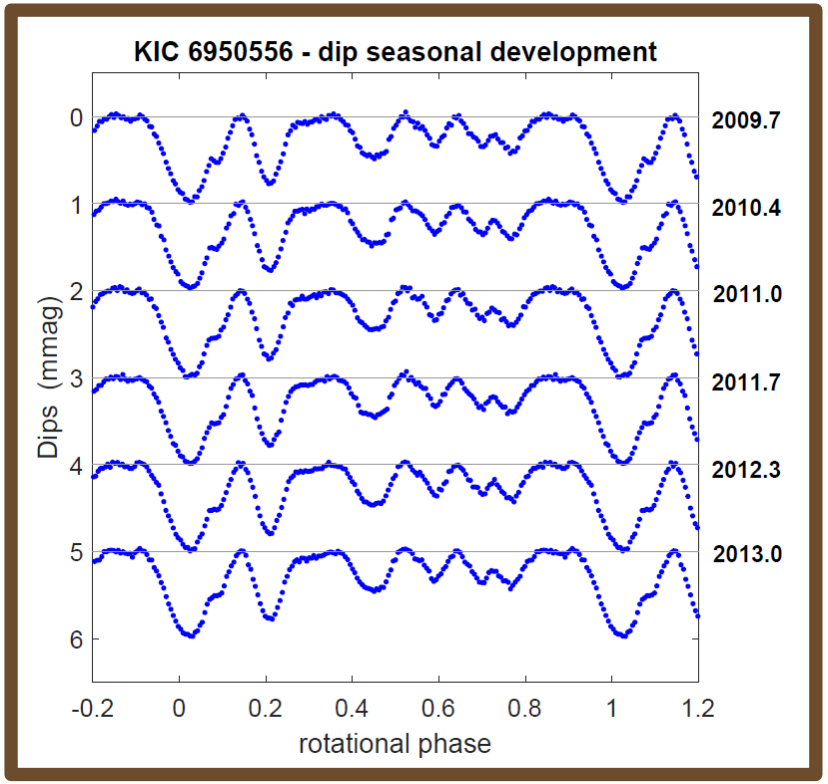
- HD 37776 (V901 Ori)



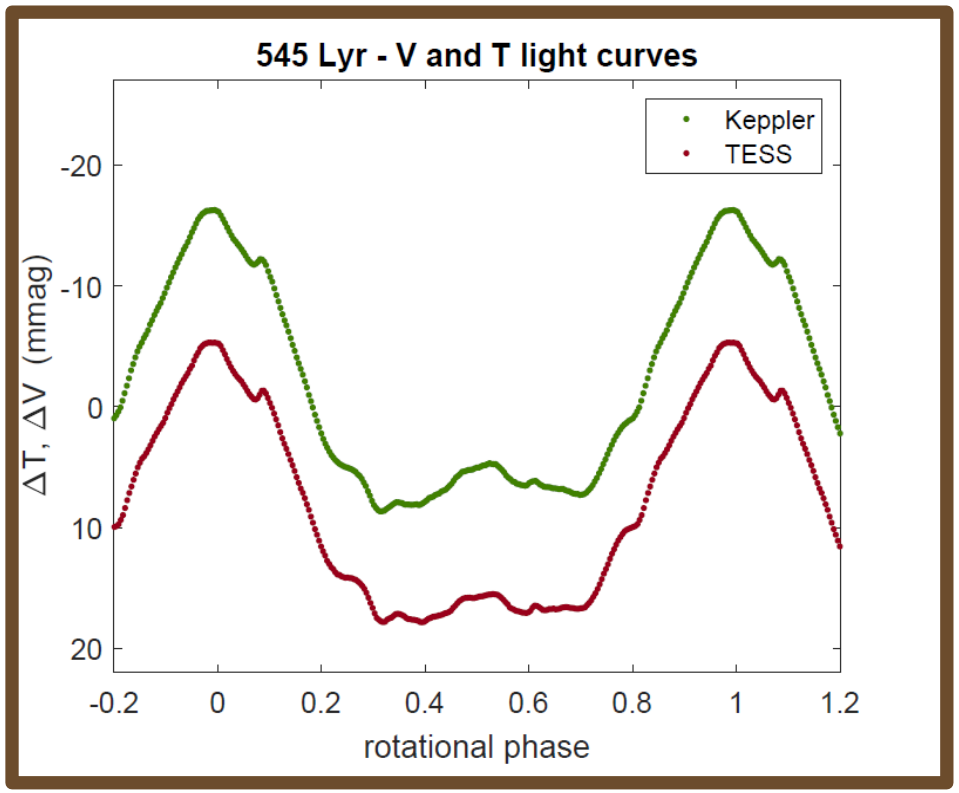
Mikulášek et al. 2020

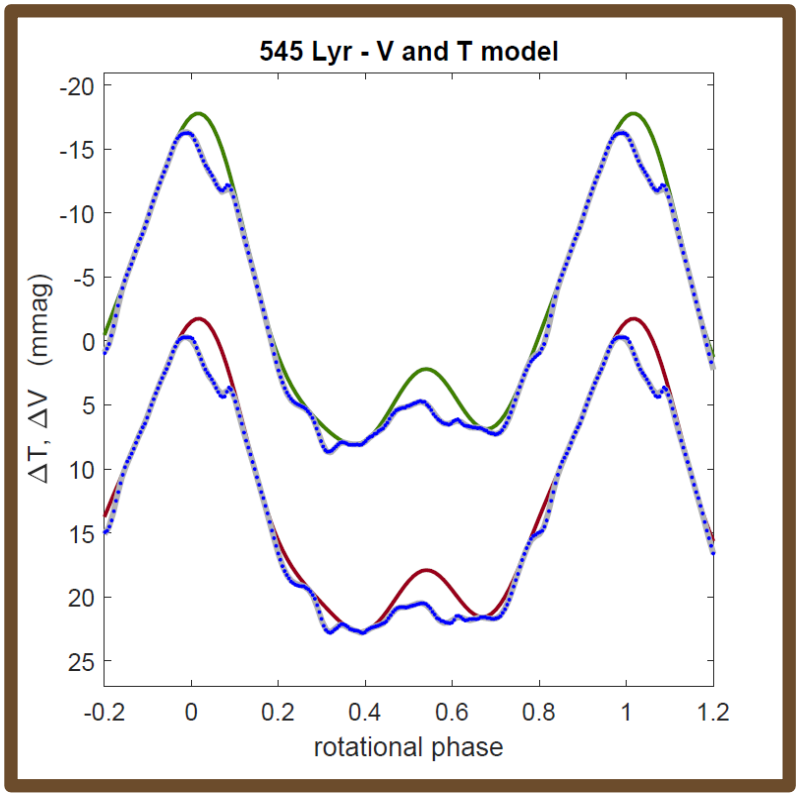


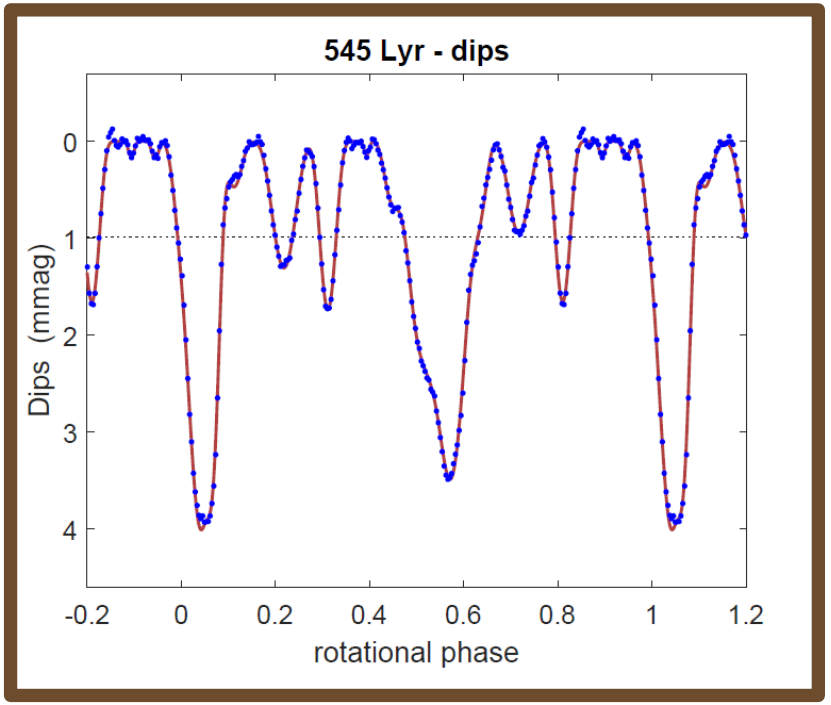




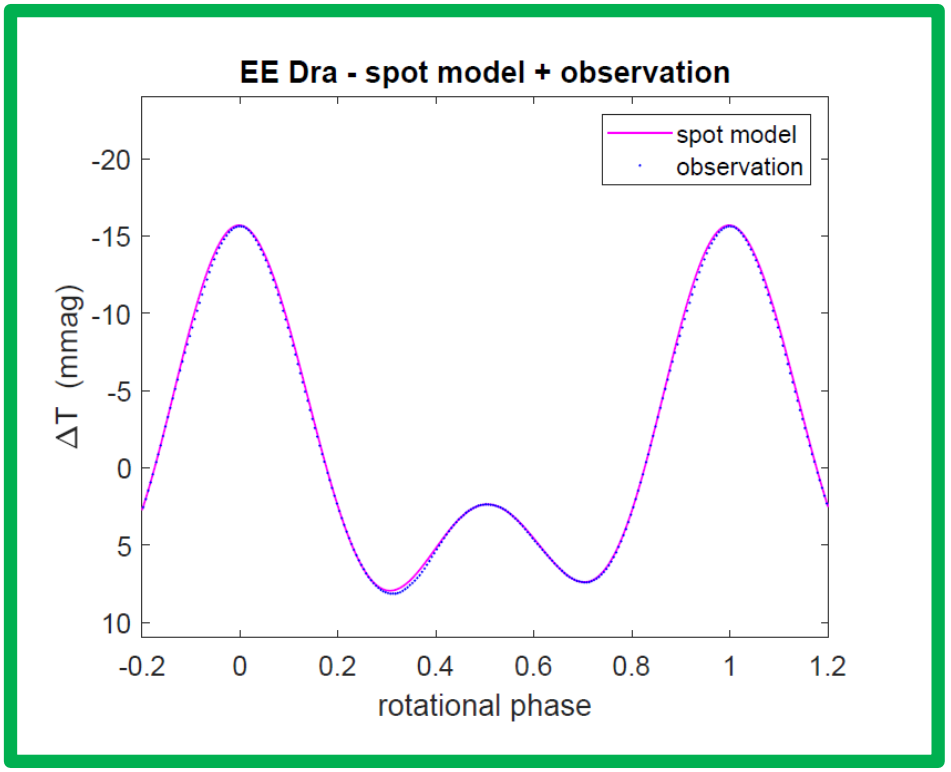
Mikulášek 2024

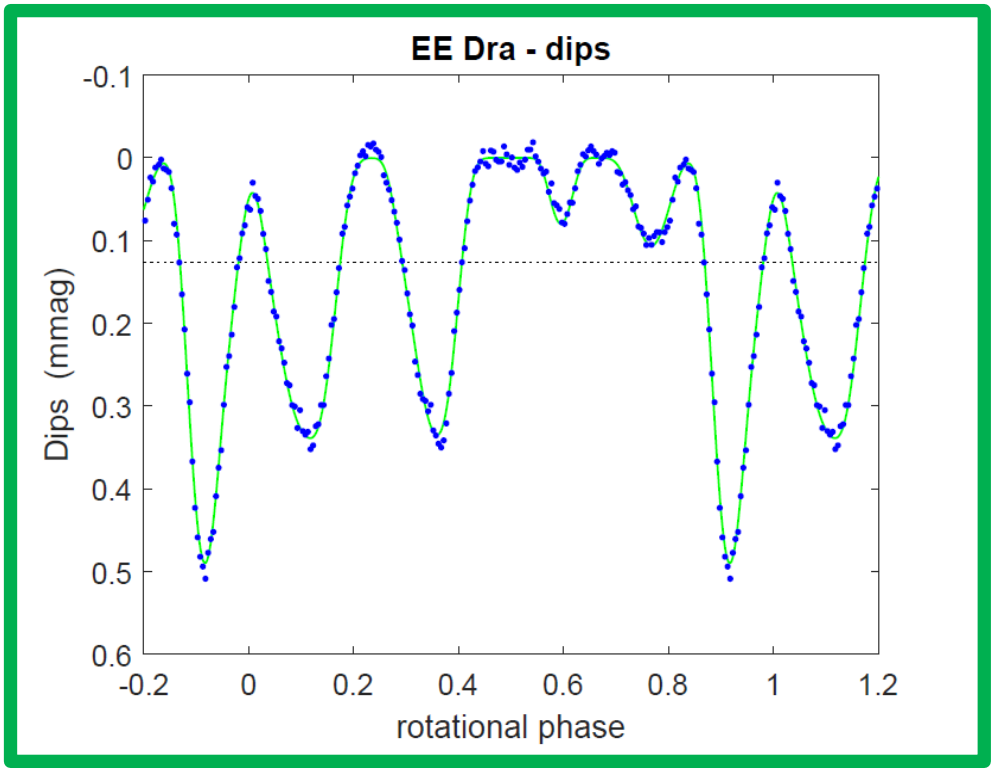


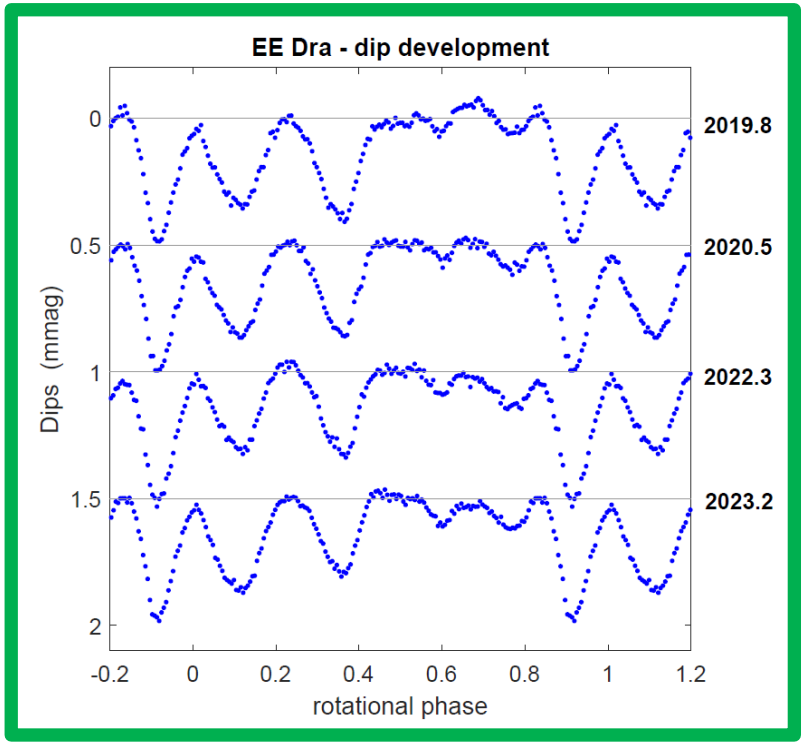




Mikulášek 2024







Mikulášek 2024

Dips in the light curves of mCPs
Several questions...

Are dips in the light curve transient or permanent?

- More or less permanent in the time scale of decades.

- How does the depth of the dips correlate with wavelength?

- Very few, if any.

Can we use the model of a rotating star with small spots to explain them?

- It was guaranteed not. This is not possible even if we use a large number of very contrasting small spots. It is necessary to place the cause of dips outside the star's surface in its corotating magnetosphere.

Dips in the light curves of mCPs

- Possible explanation: In corotating magnetospheres with the multipole magnetic field (Krtička et al. 2022), traps for more or less permeable plasma may exist. Dips in LC occur as the plasma cloud transits through the stellar disk. The rate of passage of the obstacle through the disk will depend on the cloud's distance from the rotation axis.

- Although we do not know the physics of the whole phenomenon very well, we can phenomenologically model the dips in the light curve (Mikulášek 2015).

- The occurrence of dips becomes an independent diagnostic tool for the magnetospheres of all magnetic stars, i.e., even those for which we do not find emissions in Hα. At the same time, photometric analysis is straightforward, fast, and reliable (Mikulášek et al. 2020, Semenko et al. 2024, Mikulášek 2024).

An analysis of the dips: 53 Aur, 45 Leo and HR 2461

53 Aur

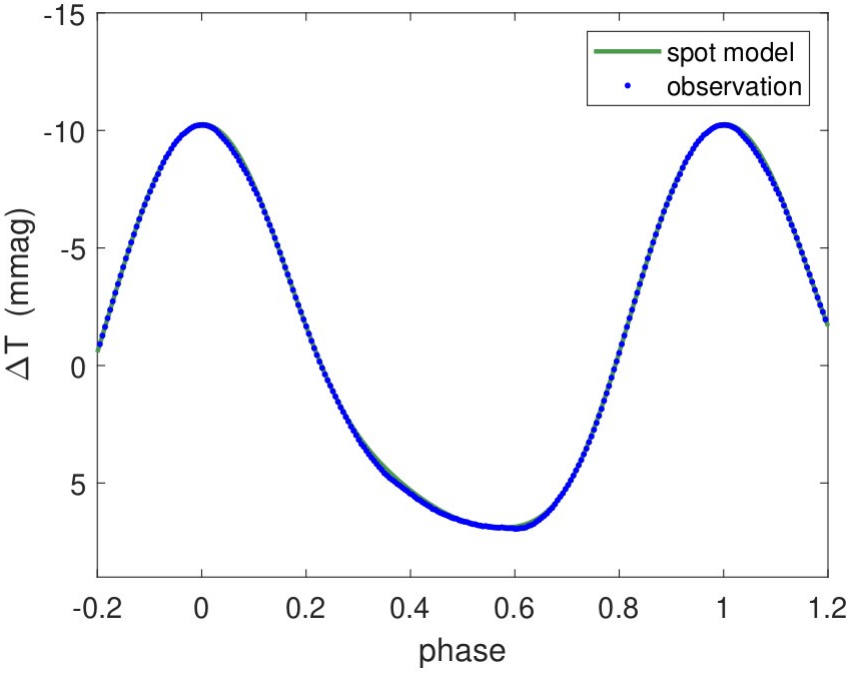
- 53 Aur (HD47152, B9Mn+F0m, V = 5.7), we have used 77,025 measurements from the sectors: 43, 44, 45, 71, and 72 with a typical accuracy of 0.22 mmag. The light changes are strictly periodic and are caused by the star's rotation with a period P = 2.711 116 2(5) d.

An analysis of the dips: 53 Aur, 45 Leo and HR 2461

53 Aur

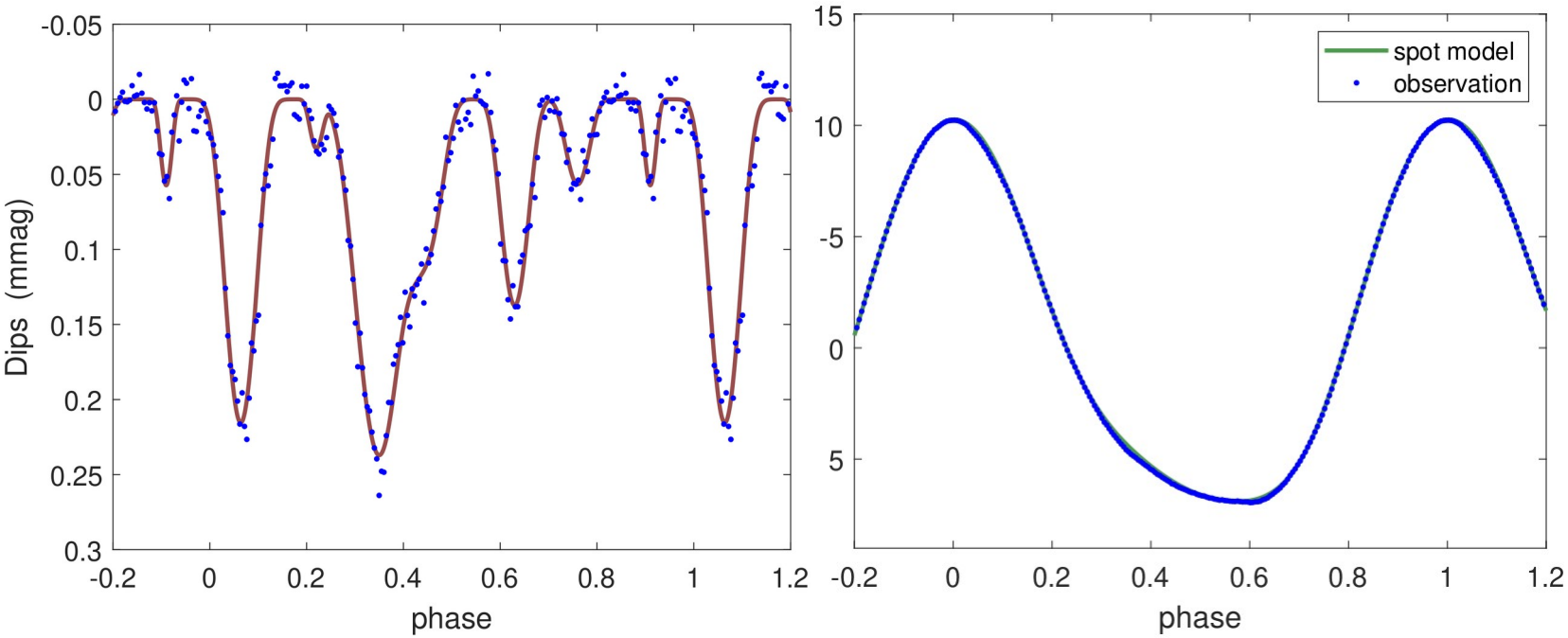
- 53 Aur (HD47152, B9Mn+F0m, V = 5.7), we have use
  43, 44, 45, 71, and 72 with a typical accuracy of 0.
  periodic and are caused by the star's rotation with a peri

- The light curve is single-wave, slightly asymmetric, with an effective amplitude of 17.4 mmag.



An analysis of the dips: 53 Aur, 45 Leo and HR 2461

53 Aur



- 53 Aur (HD47
43, 44, 45, 7
periodic and a

- The light curv
asymmetric, w
of 17.4 mmag

- Six narrow depressions (dips) with depths of 0.03 to 0.24 mmag have been conclusively identified in the light curve, indicating the presence of clouds of charged particles trapped in pockets of the star's extensive magnetosphere.

- This indirectly confirms that 53 Aur contains a magnetic field, and it is a chemically peculiar star.

An analysis of the dips: 45 Leo and HR 2461

45 Leo

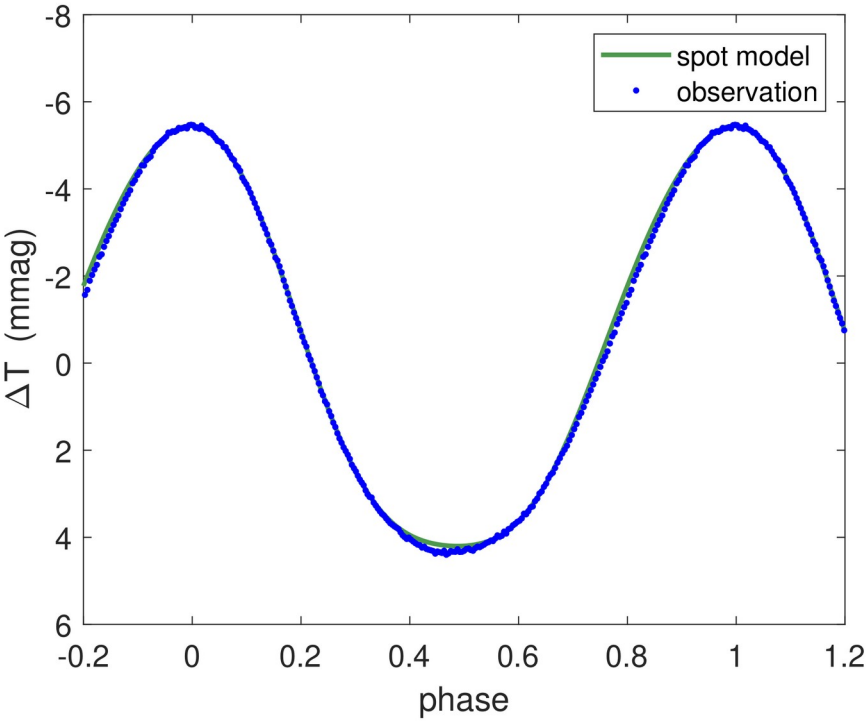
- 45 Leo (HD90596, B9.5IV, V = 6.04), we have used the 33,015 measurements from the sectors 45, 46, and 72, with a typical accuracy of 0.24 mmag were used. The light changes are strictly periodic, caused by the star's rotation with a period of 3.223 271(2) d.

An analysis of the dips: 45 Leo and HR 2461

45 Leo

- 45 Leo (HD90596, B9.5IV, V = 6.04), we have used tl
  45, 46, and 72, with a typical accuracy of 0.24 mmag
  periodic, caused by the star's rotation with a period of 3

- The light curve is single-wave, slightly asymmetric,
  with an effective amplitude of 9.8 mmag.



An analysis of the dips: 45 Leo and HR 2461

45 Leo

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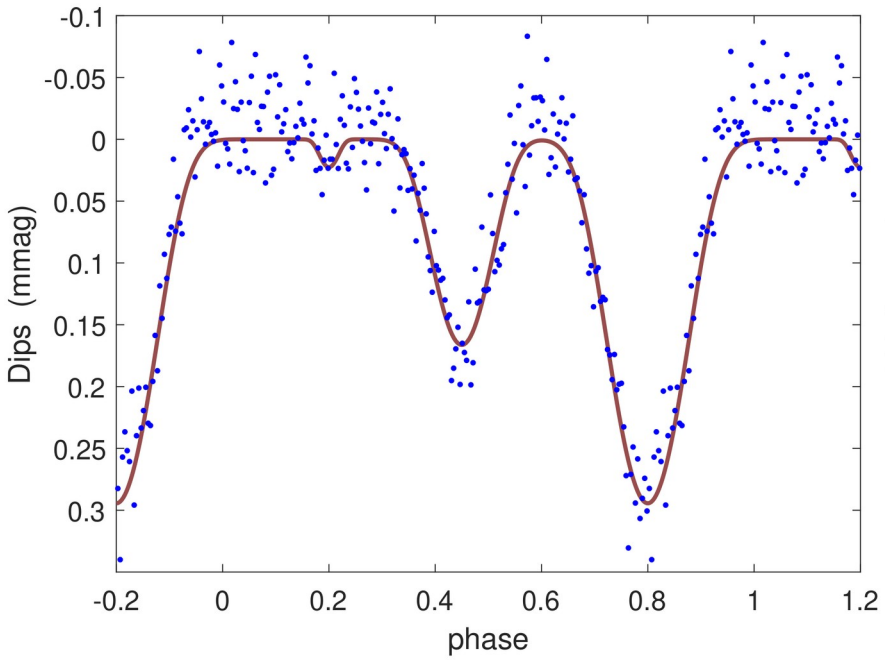
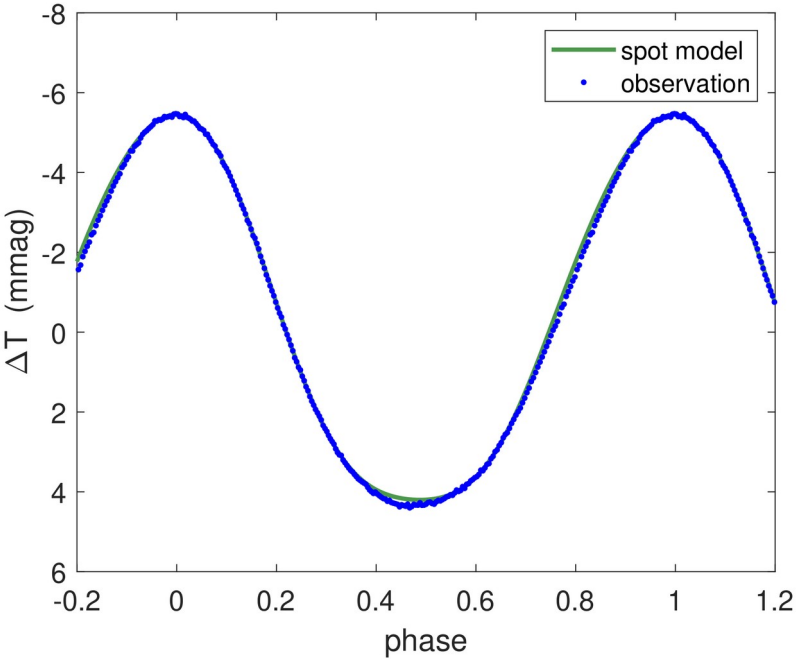




- Three dips with depths of 0.02 to 0.35 mmag have been conclusively identified, indicating a presence of clouds of charged particles trapped in pockets of the star's extensive magnetosphere.

- This indirectly confirms that the object 45 Leo contains a magnetic, chemically peculiar star.

An analysis of the dips: HR 2461

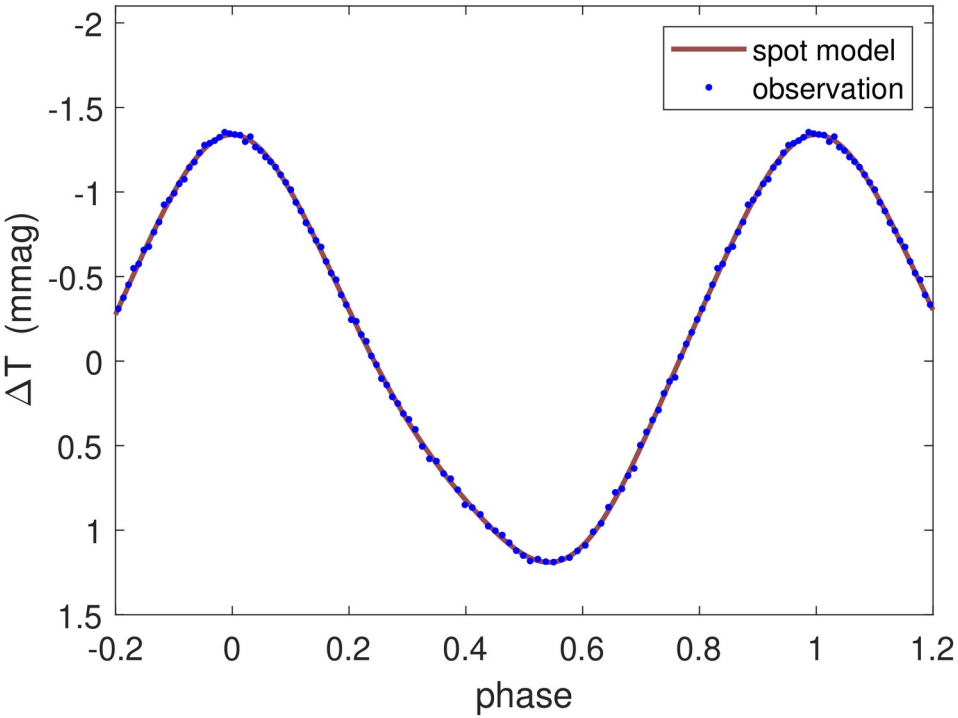
HR 2461

- HR 2461 (HD 47964, B8III, V = 5.7), we have used 31,823 measurements in sectors 6 and 33, with a typical accuracy of 0.28 mmag. The light changes are caused by the uniform rotation of the star with a period P = 4.669 13(2) d.

An analysis of the dips: HR 2461

HR 2461

- HR 2461 (HD 47964, B8III, V = 5.7), we have with a typical accuracy of 0.28 mmag. The lig the star with a period P = 4.669 13(2) d.



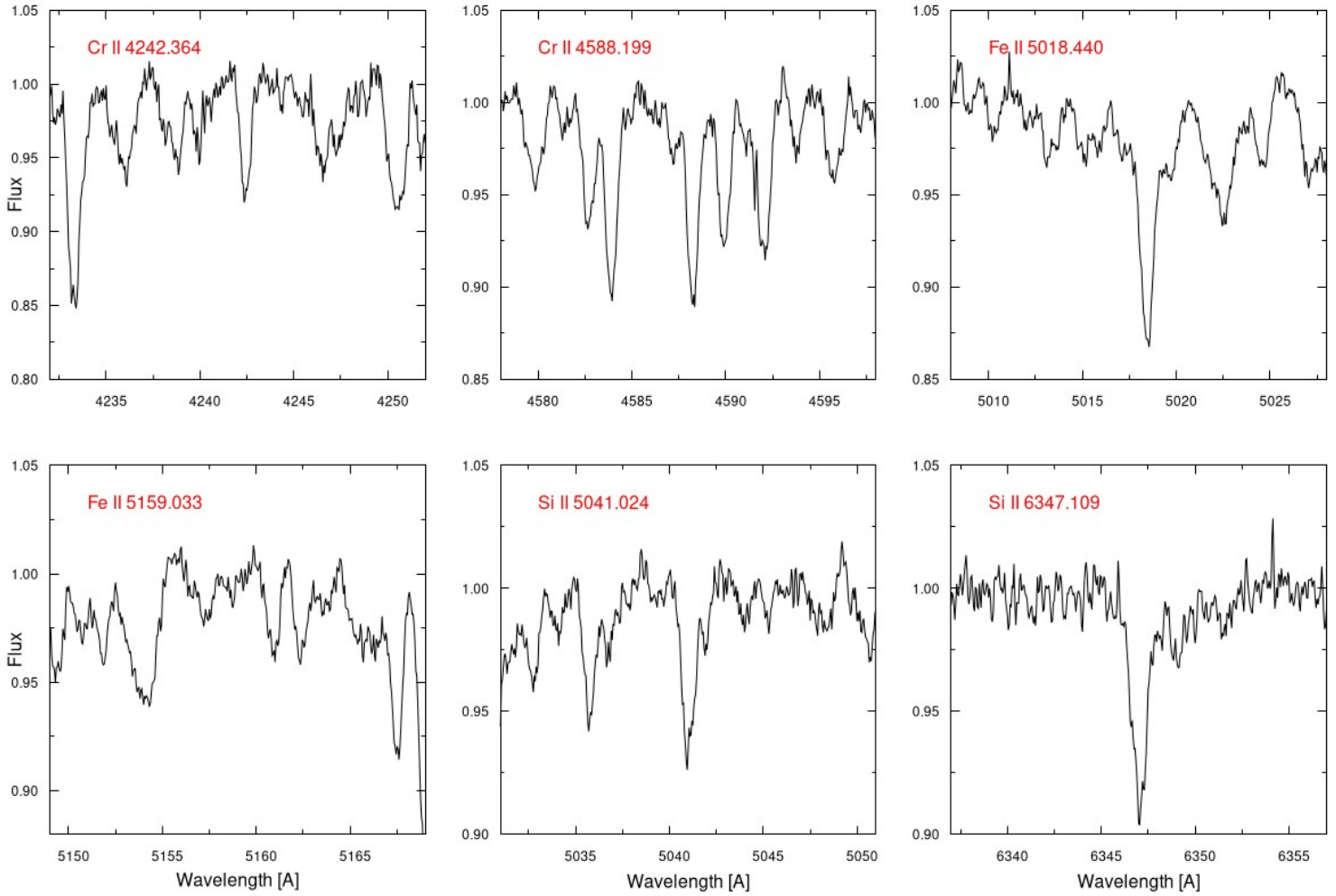
- The light curve is single-wave, slightly asymmetric, with a small effective amplitude of 2.44 mmag. This can be reduced by light from a possible second component.

- No signs of dips were found in the curve, however, the light curve agrees with the curves of the mCP stars.

Spectroscopy

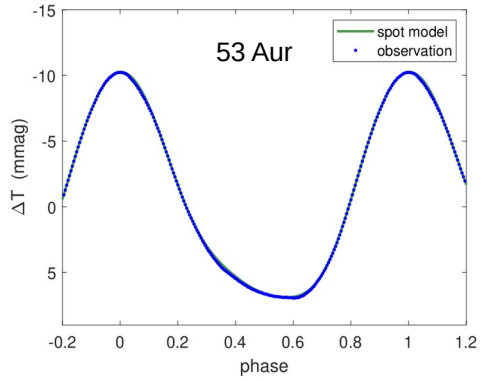
- Spectrographs eShel@SL (2015-2020) and MUSICOS@SP (2016-2024)
- The data from both instruments used for RVs determination for all studied objects
- For the next analysis we have used spectra from MUSICOS only – R ~ 38,000
- **53 Aur:** 44 spectroscopic observations in the range of 2016-2024 (SNR: 93-237)
- **45 Leo:** 37 spectroscopic observations in the range of 2017-2021 (SNR: 87-238)
- **HR 2461:** 23 spectroscopic observations in the range of 2017-2021 (SNR: 70-211)

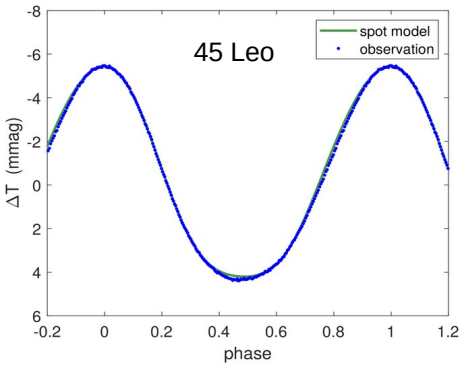
Sp



- Spec
- The
- For t
- **53 A**
- **45 L**
- **HR**

- Equivalent widths, measured by a Gaussian fit of the following spectral lines:
CrII λ4242.364 Å, CrII λ4588.199 Å, FeII λ5018.440 Å, FeII λ5159.033 Å, SiII λ5041.024 Å, SiII λ6347.109 Å


53 Aur
spot model
observation
ΔT (mmag)
phase


45 Leo
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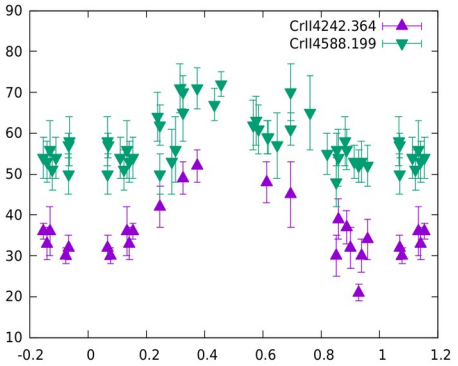
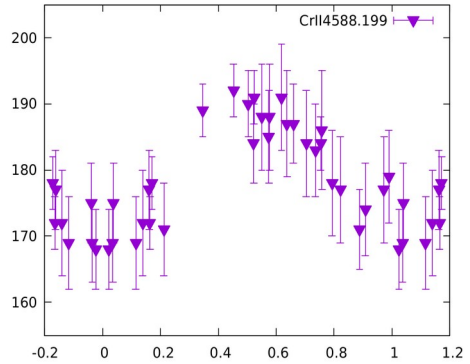
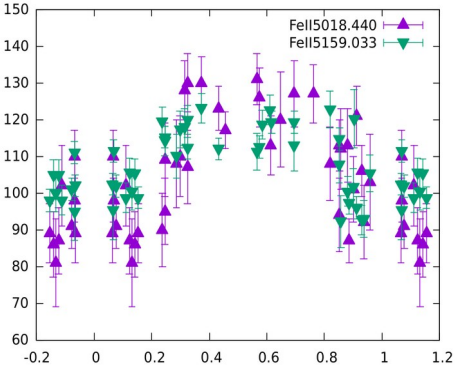
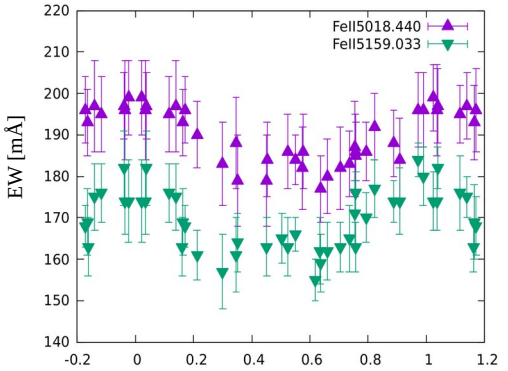

CrII4242.364
CrII4588.199


CrII4588.199


FeII5018.440
FeII5159.033
EW [mÅ]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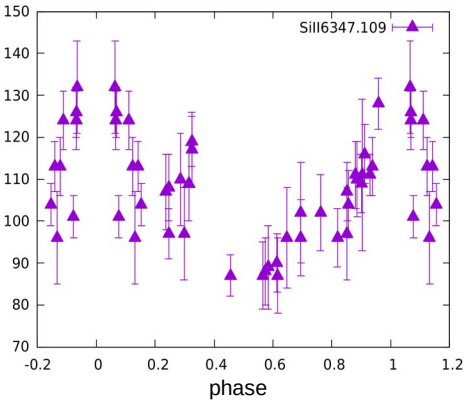
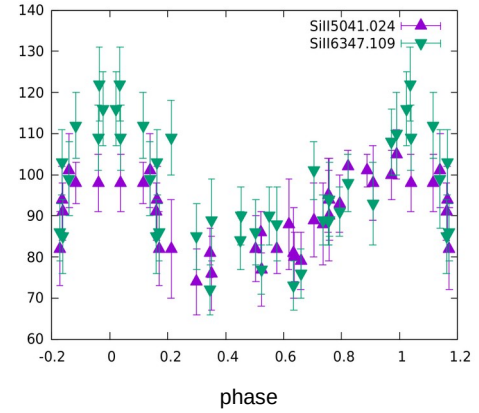

SiII6347.109
phase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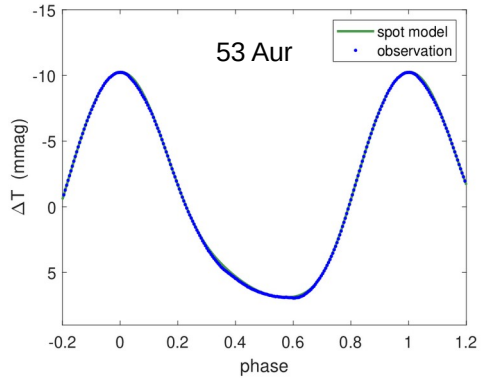
SiII6347.109
phase


53 Aur
spot model
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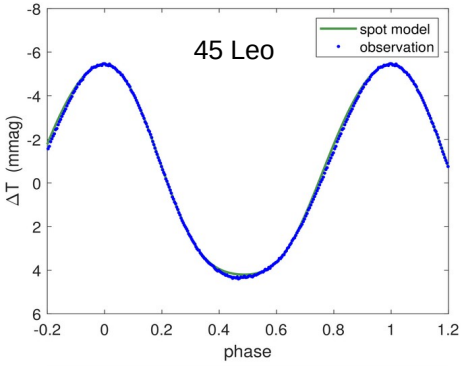
45 Leo
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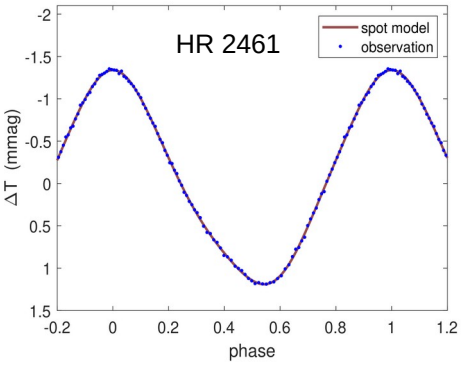
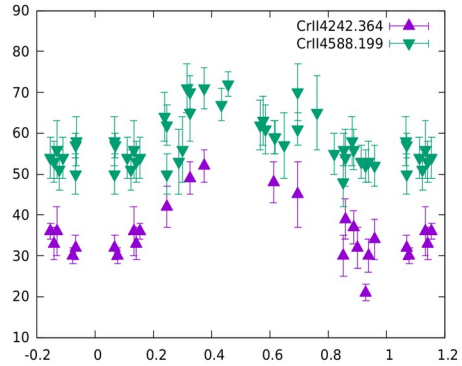
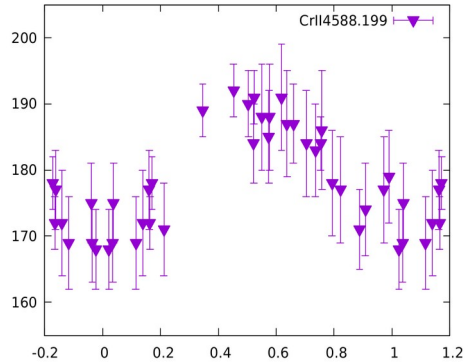
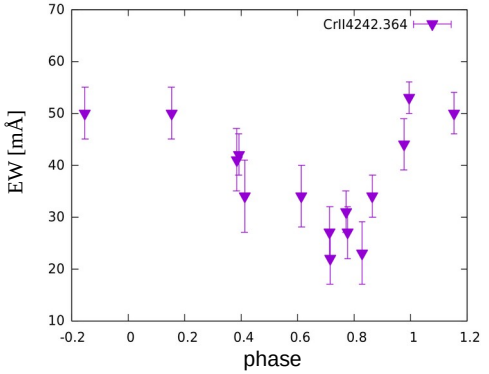

HR 2461
spot model
observation
ΔT (mmag)
phase


CrII4242.364
CrII4588.199


CrII4588.199


CrII4242.364
EW [mÅ]
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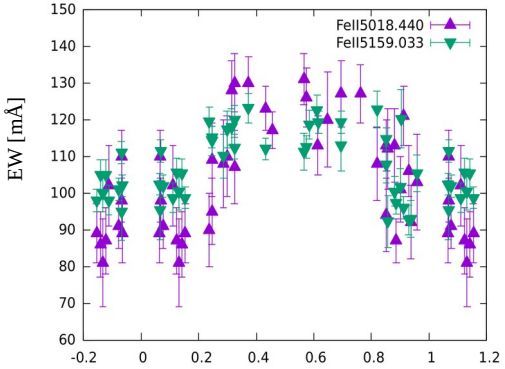
FeII5018.440
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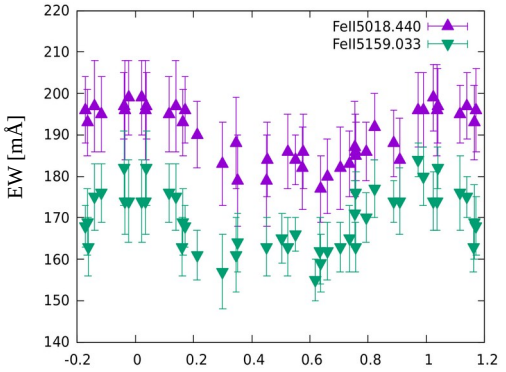
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FeII5159.033
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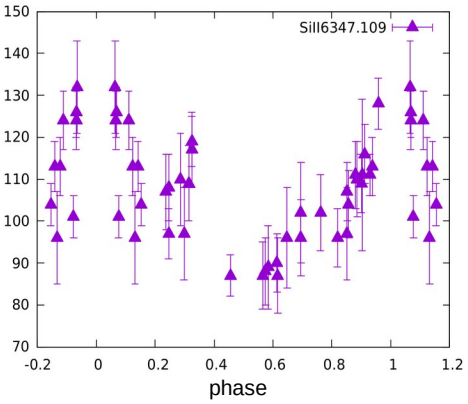
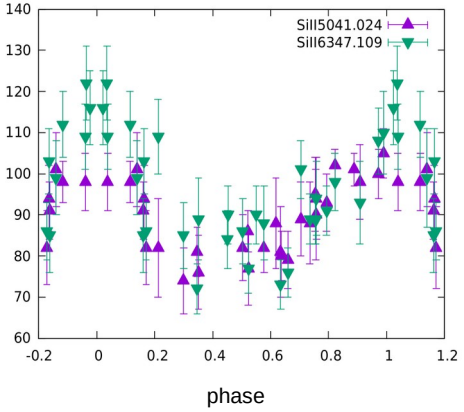
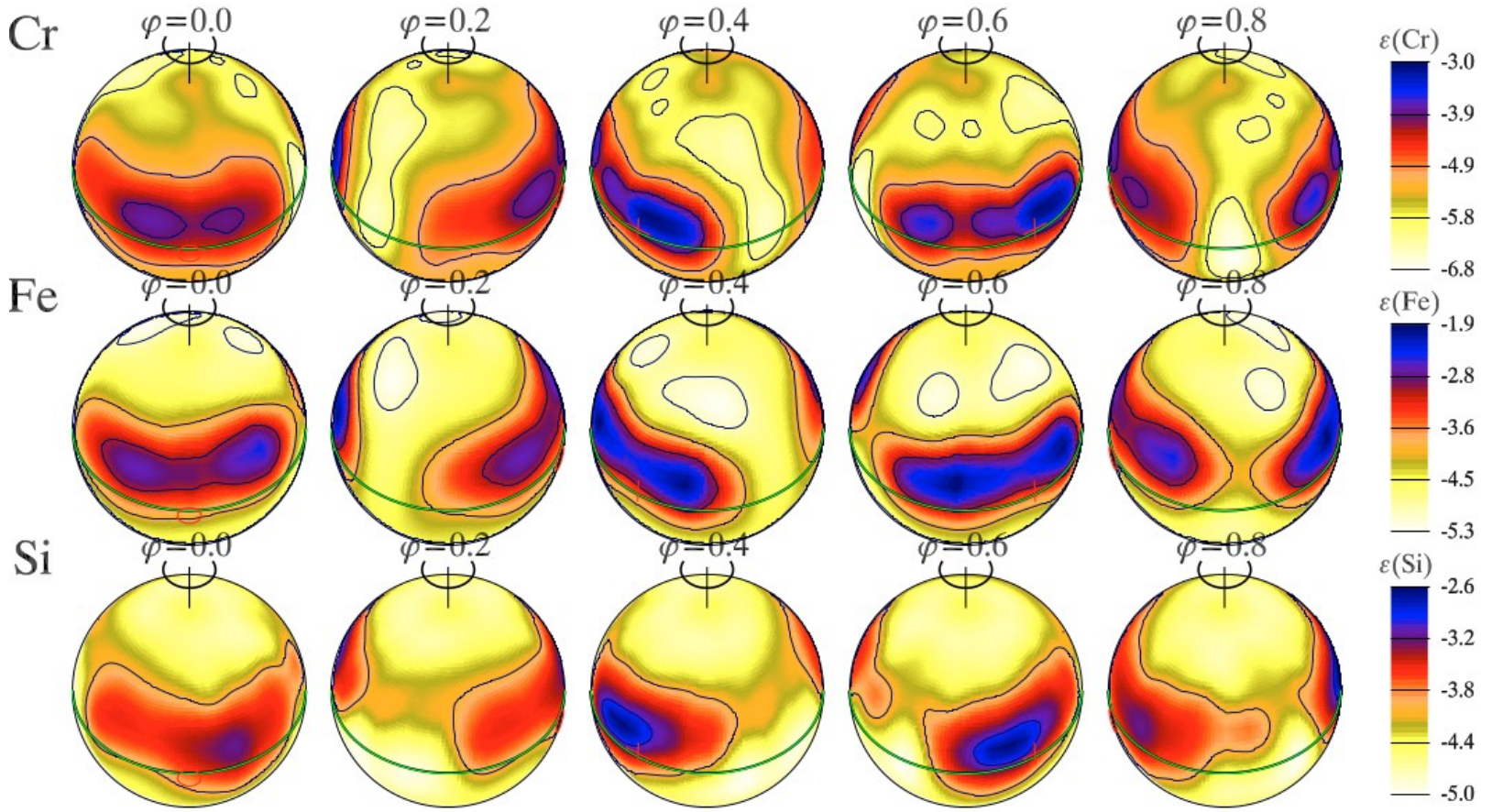

SiII6347.109
phase

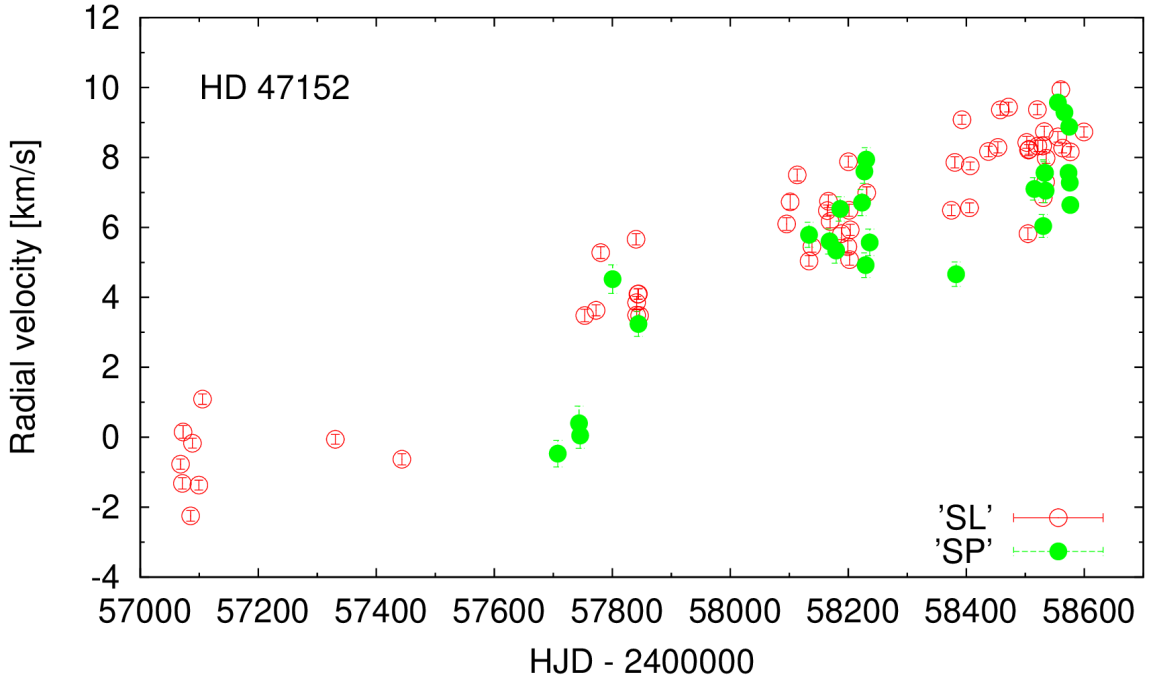

SiII5041.024
SiII6347.109
phase



Lüftinger et al. 2010

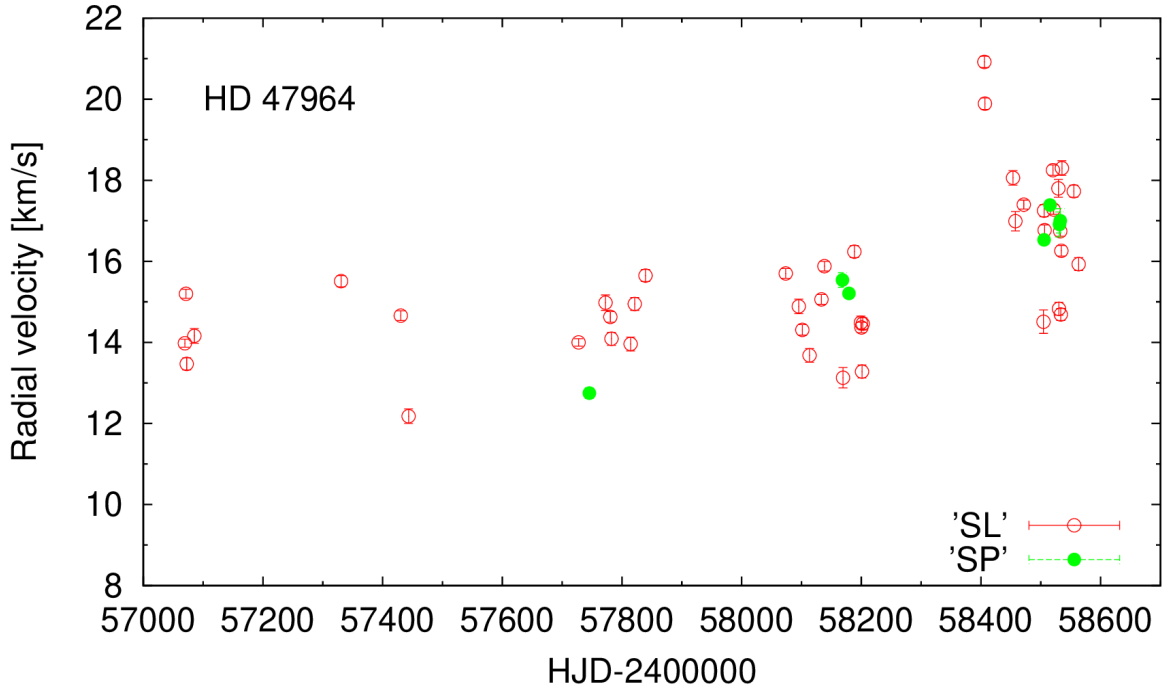
Radial velocities

- (53Aur) A speckle interferometric double with *P*(orb) = 38.9 years, its spectrum was disentangled to two components matching spectral types B9V Mn and F0V m. The two stars contribute to the total luminosity in the ratio 0.9:0.1. The hot component rotates with *v* sin *i* = 25 km/s (Zverko et al. 2008).



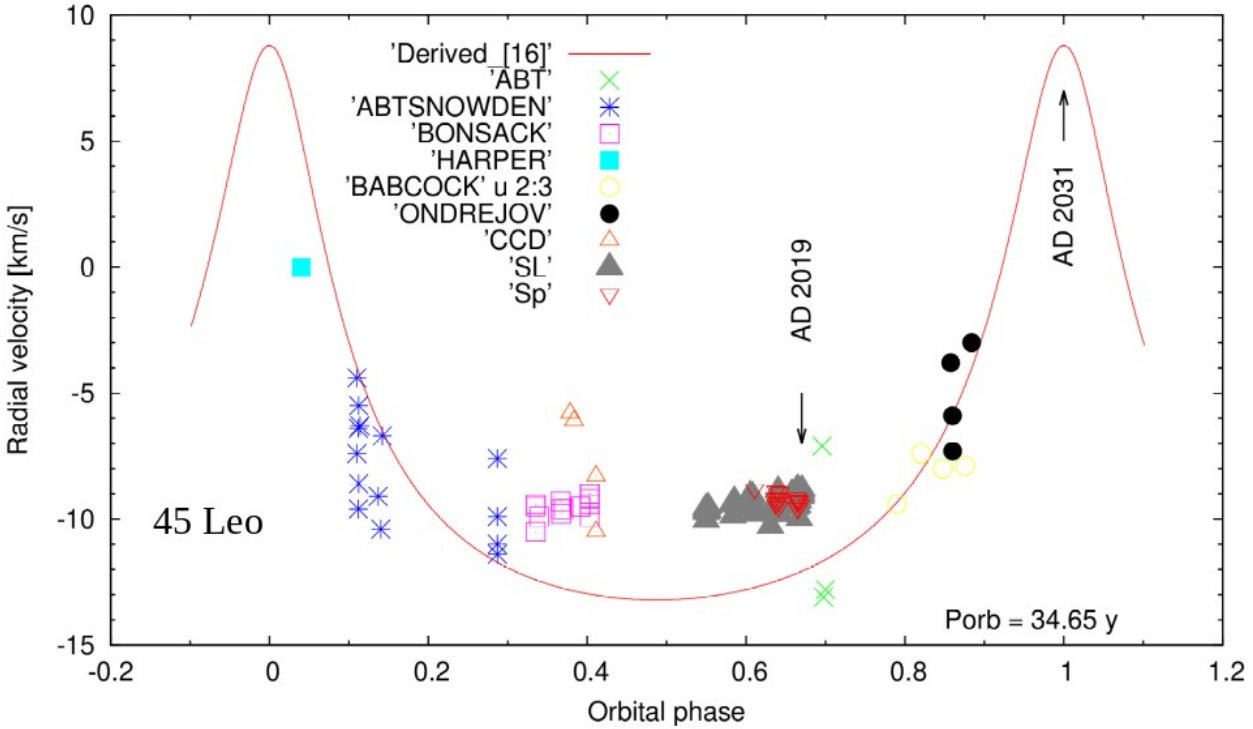
Radial velocities

- (HR2461) was discovered by Hipparcos to be an astrometric binary with the components separated by 0.2 arcsec, which share a common proper motion, and magnitude difference in *V* = 2.8. Radial velocity values vary within 0 and 20 km/s, however, no signs of a secondary spectrum were detected even with a S/N=1100 (Zverko et al. 2013, Vaňko et al. 2020).



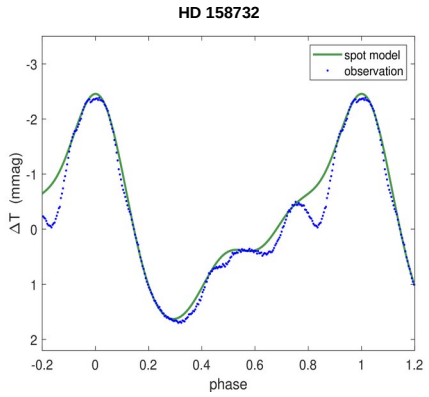
Radial velocities

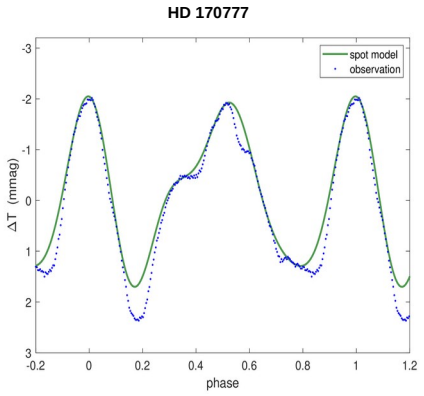
- (45Leo) SB1 binary with a long period P = 34.6 years, showing low velocity variations (Abt & Snowden 1973). Although discovered as an lunar occultation double of two equally bright components, no evidence of a SB2 nature in the spectrum was found in Zverko et al. 2012.

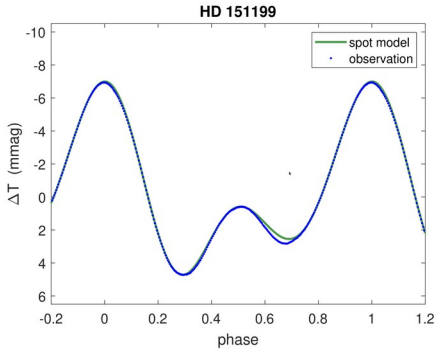


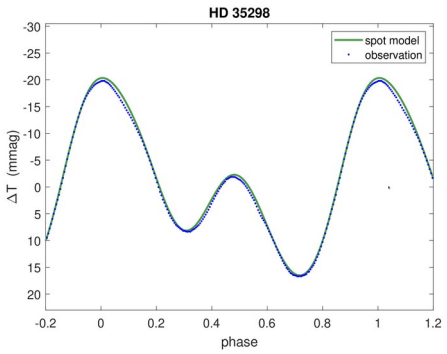
Future work

- Diagnostic of the dips in other mCPs: new candidates
- The spectroscopic observations for new candidates, e.g. LAMOST archive (Large Sky Area Multi-Object Fiber Spectroscopic Telescope), MUSICOS@SP observatory...
- Determination of the spot distribution on the surface of the studied objects.
- Archival/historical RVs for all studied targets.









Thank you for your listening