Seminář Stelárního oddělení Astronomického ústavu AV ČR, Ondřejov,
February 3, 2025, 13:00

Probing the magnetospheres of chemically peculiar stars through the dips in their light curves

Zdeněk Mikulášek, Jiří Krtička, Jan Janík, Oleg Kochukhov,
Mathew Shultz, Miloslav Zejda, Eugene Semenko

Chemically peculiar stars. V901 Orionis

The advent of extensive photometric surveys such as Corot, Kepler, and TESS missions has also enabled unexpected discoveries in the study of **magnetic chemically peculiar stars**.

MCP stars are a diverse group of slowly rotating upper MS stars with a global magnetic field and unevenly distributed chem. elements that create vast spots.

- The stars show rotationally modulated brightness, spectrum, and magnetic field variability. We can create charts of element distribution and magnetic field geometry using so-called Doppler tomography.

Chemically peculiar stars. V901 Orionis

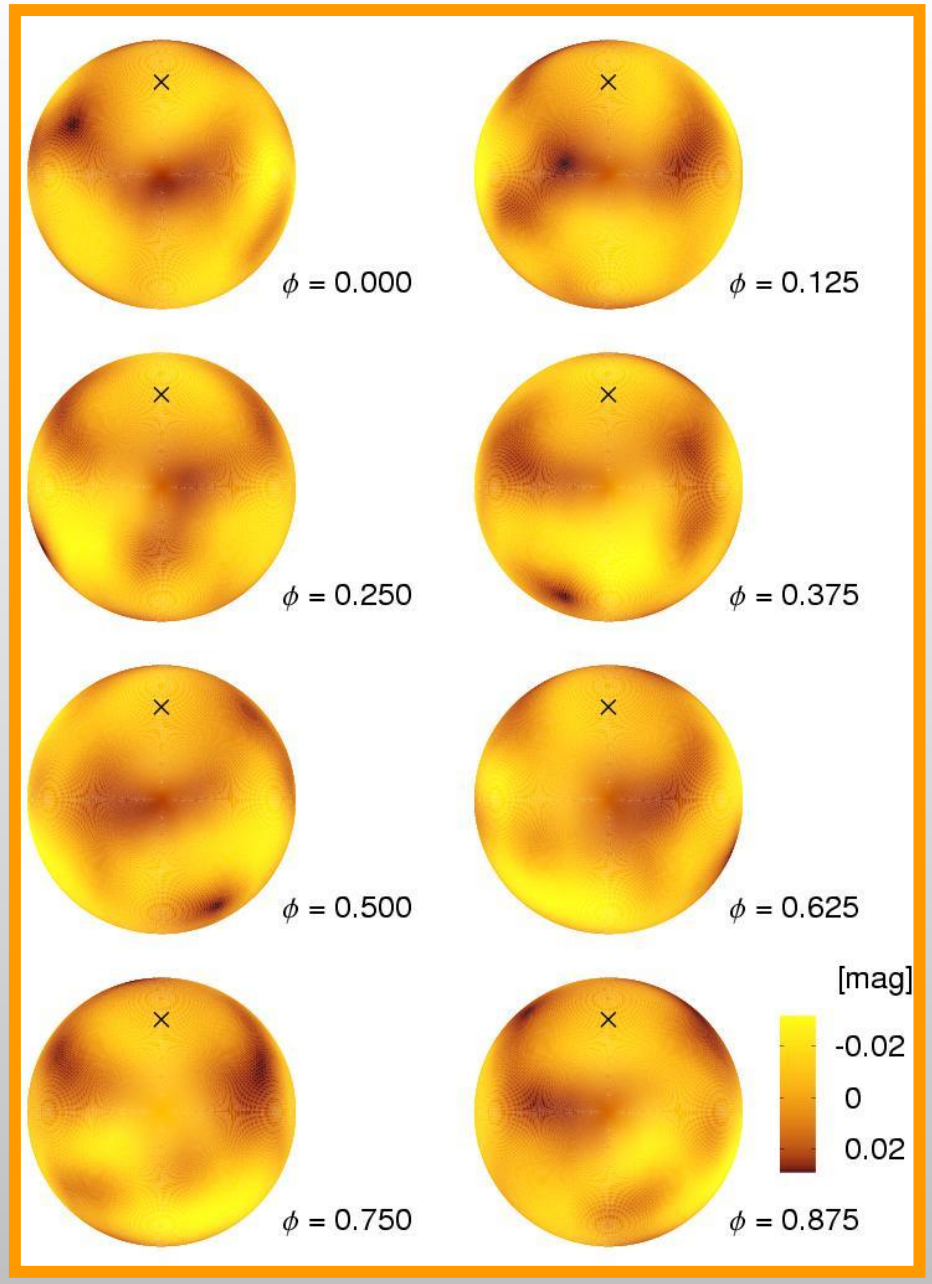
The advent of extensive photometric surveys such as Corot, Kepler, and TESS missions has also enabled unexpected discoveries in the study of **magnetic chemically peculiar stars**.

MCP stars are a diverse group of slowly rotating upper MS stars with a global magnetic field and unevenly distributed chem. elements that create vast spots.

- The stars show rotationally modulated brightness, spectrum, and magnetic field variability. We can create charts of element distribution and magnetic field geometry using so-called Doppler tomography.

Khokhlova et al. (2000) mapped a He-strong mCP star **V901 Ori = HD 37776**, overabundant in helium and silicon, concentrated in different spectroscopic spots.

Krtička, Mikulášek, et al. 2007 showed that observed light variations are due to radiation redistribution from UV to the optical region caused by **Si** and **He**. Despite its complex distribution on the star, the resulting synthetic model light curve is a **smooth** one-wave curve, in agreement with observation at the time.


ϕ = 0.000
ϕ = 0.125
ϕ = 0.250
ϕ = 0.375
ϕ = 0.500
ϕ = 0.625
ϕ = 0.750
ϕ = 0.875
[mag]
-0.02
0
0.02

Chemically peculiar stars. V901 Orionis

The advent of extensive photometric surveys such as Corot, Kepler, and TESS missions has also enabled unexpected discoveries in the study of **magnetic chemically peculiar stars**.

MCP stars are a diverse group of slowly rotating upper MS stars with a global magnetic field and unevenly distributed chem. elements that create vast spots.

- The stars show rotationally modulated brightness, spectrum, and magnetic field variability. We can create charts of element distribution and magnetic field geometry using so-called Doppler tomography.

Khokhlova et al. (2000) mapped a He-strong mCP star **V901 Ori = HD 37776**, overabundant in helium and silicon, concentrated in different spectroscopic spots.

Krtička, Mikulášek, et al. 2007 showed that observed light variations are due to radiation redistribution from UV to the optical region caused by **Si** and **He**. Despite its complex distribution on the star, the resulting synthetic model light curve is a **smooth** one-wave curve, in agreement with observation at the time.

- The model of the mCP light variability has been then generally accepted.

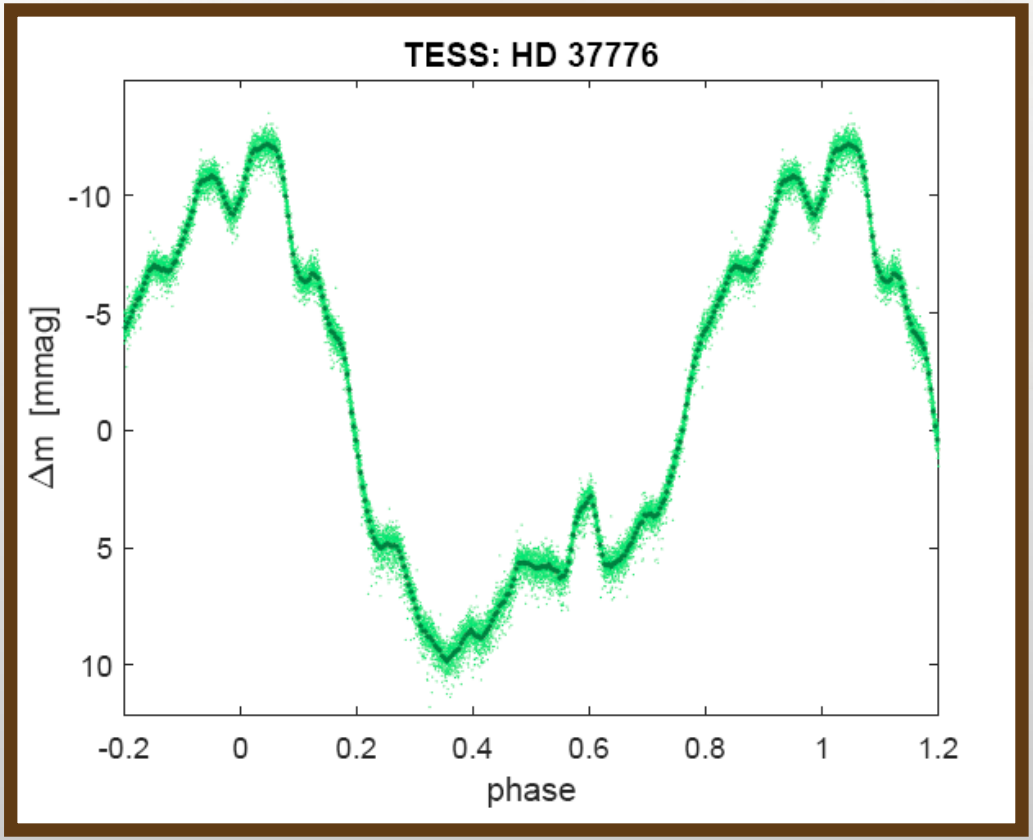
Nevertheless, TESS observations of V901 Ori from Dec. 2018 brought another look.

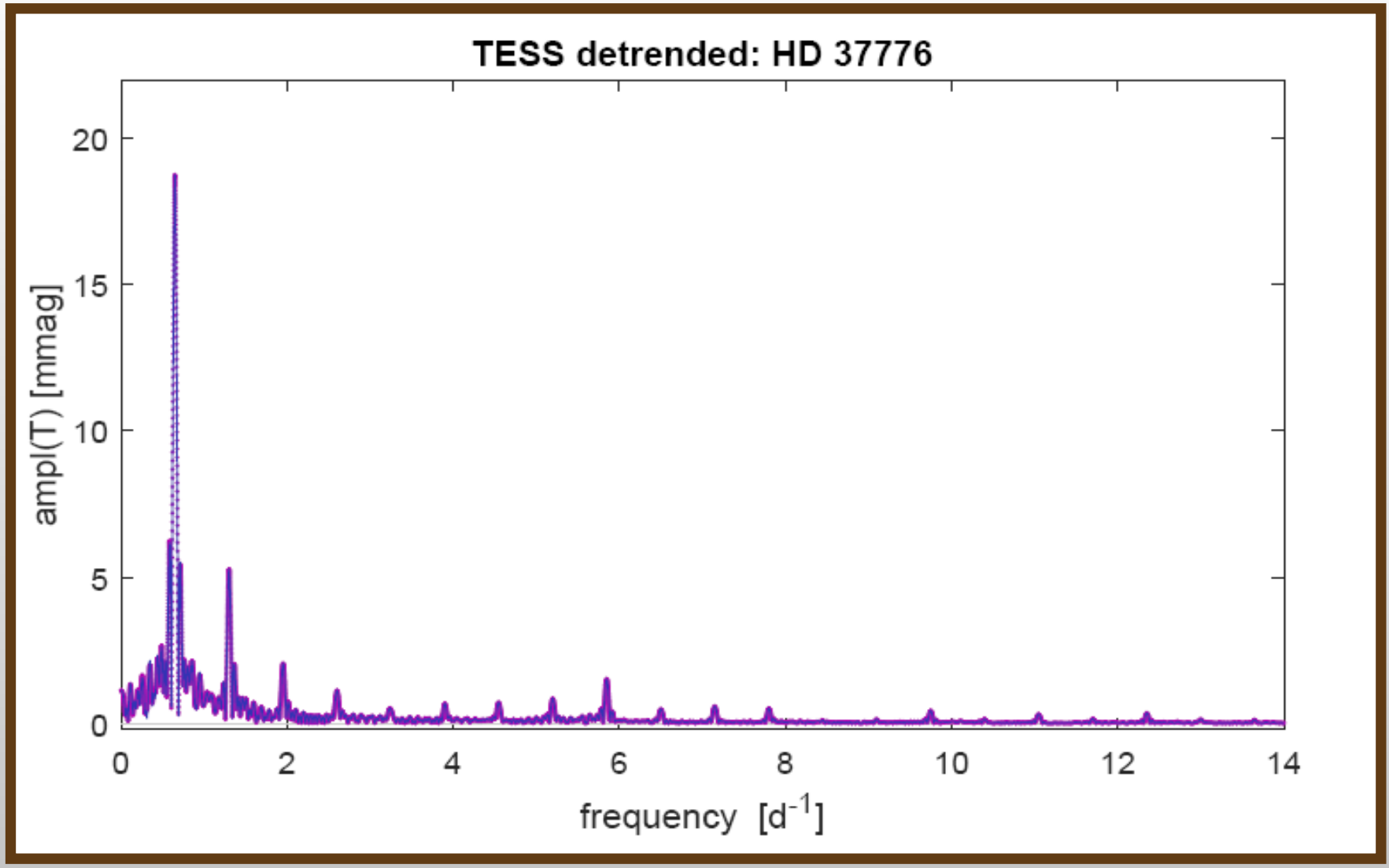
Shocking details

High precision TESS photometry, Sect. 6 (n = 14871, s = 0.43 mmag) shows unexpected details in the light curve, which we thought was smooth.

Sudden and narrow decreases in brightness, later called "dips," were located at completely fixed points of the light curve.

We can also identify the dips in the archival photometry.




TESS detrended: HD 37776
ampl(T) [mmag]
0
5
10
15
20
0
2
4
6
8
10
12
14
frequency [d^{-1}]

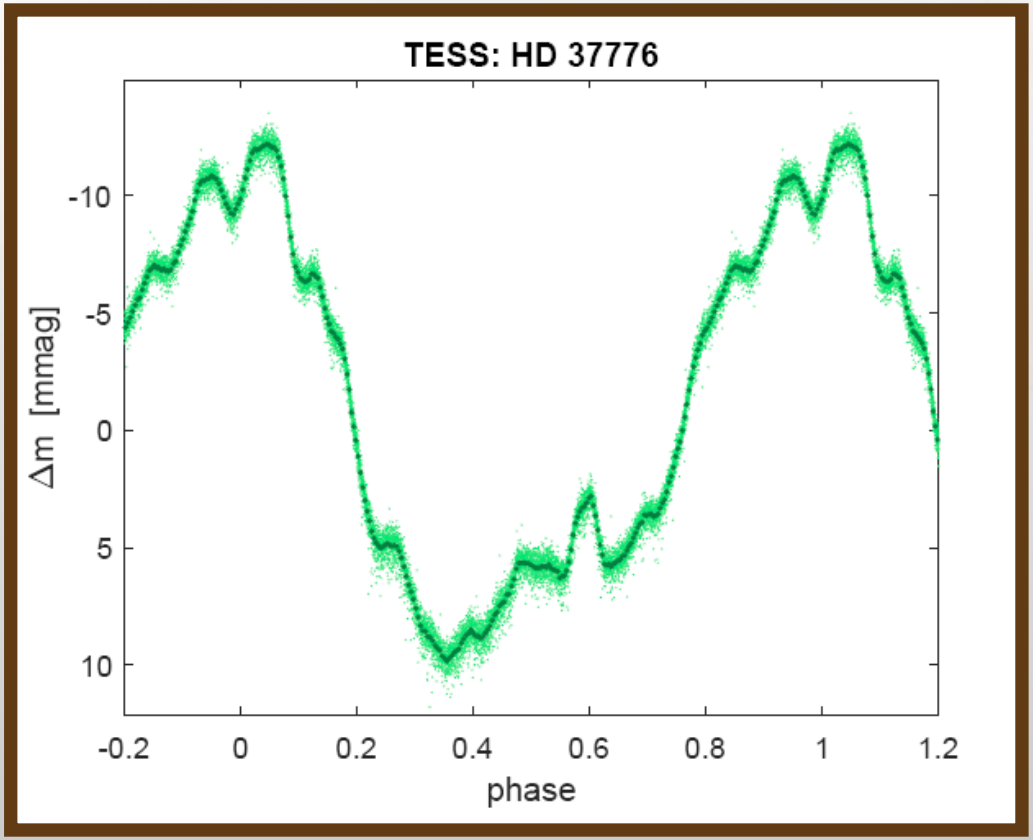
Shocking details

High precision TESS photometry, Sect. 6 (n = 14871, s = 0.43 mmag) shows unexpected details in the light curve, which we thought was smooth.

Sudden and narrow decreases in brightness, later called "dips," were located at completely fixed points of the light curve.

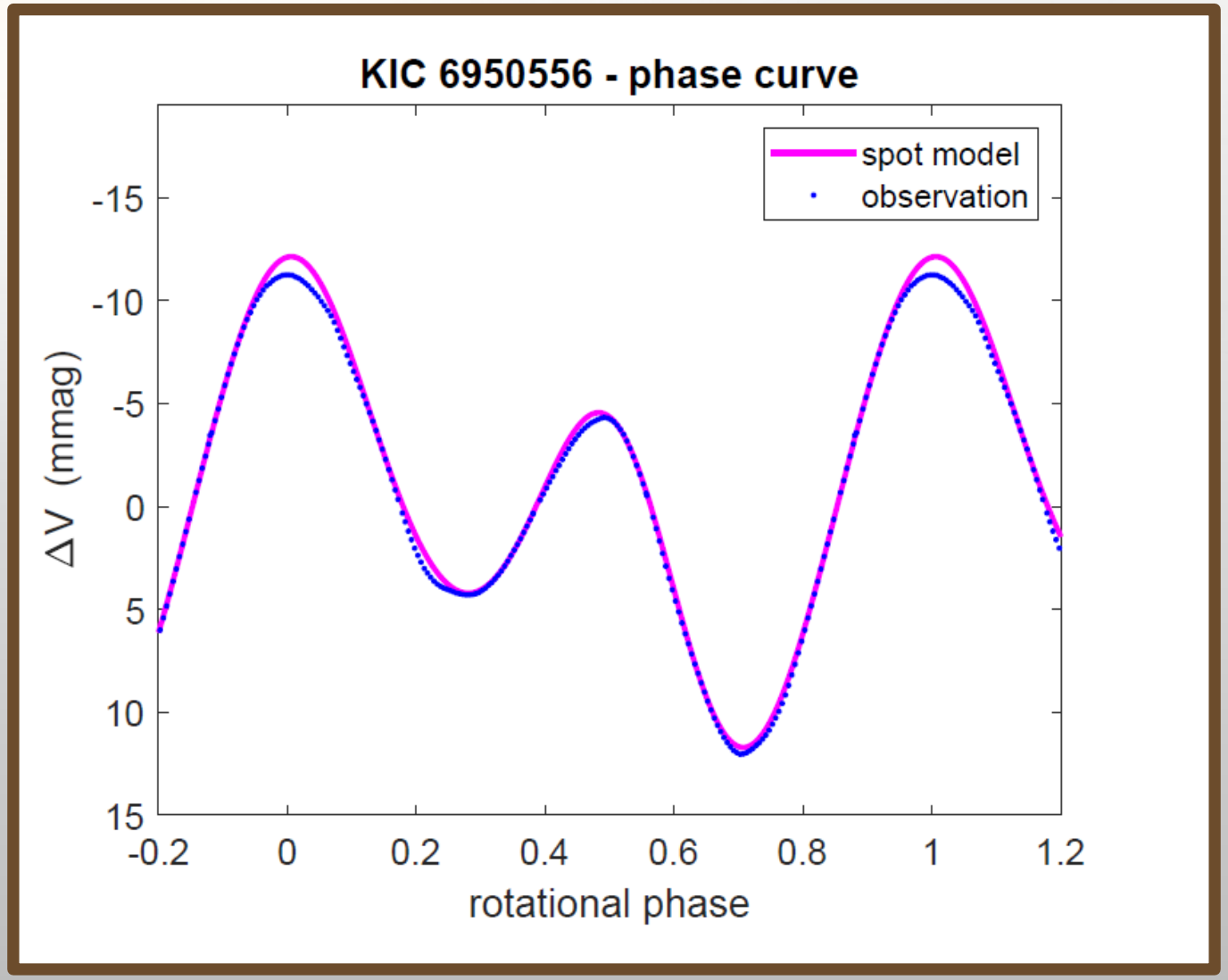
We can also identify the dips in archival photometry.

- In the periodogram, we see well-defined harmonics up to the 30-th order.

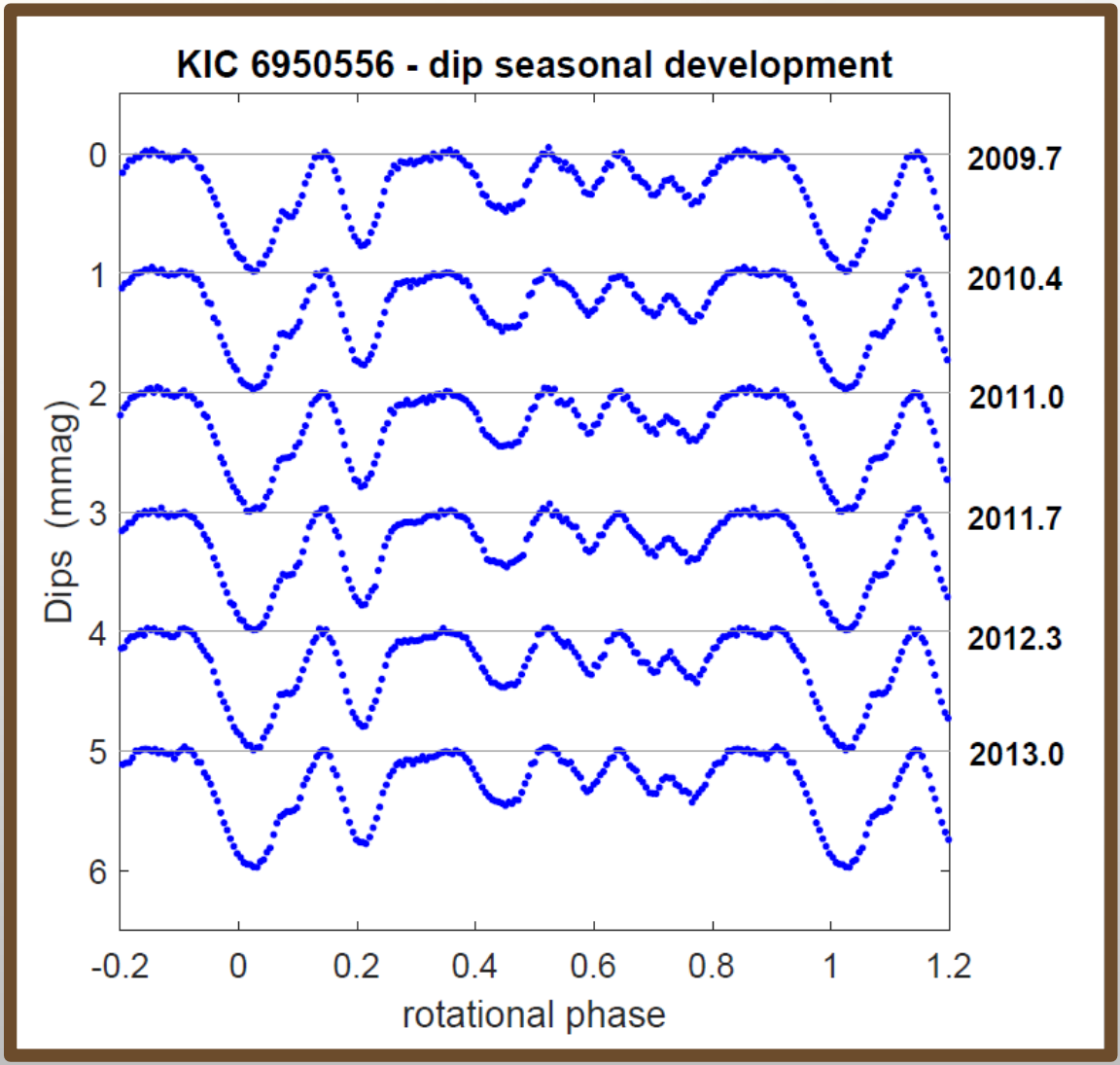


Since the announcement of the dip revealing (Mikulášek et al., 2020), we analyzed LCs of more than a hundred mCP stars. We conclude that the dips are present in most mCPs of all types, even though they used to be not so pronounced.

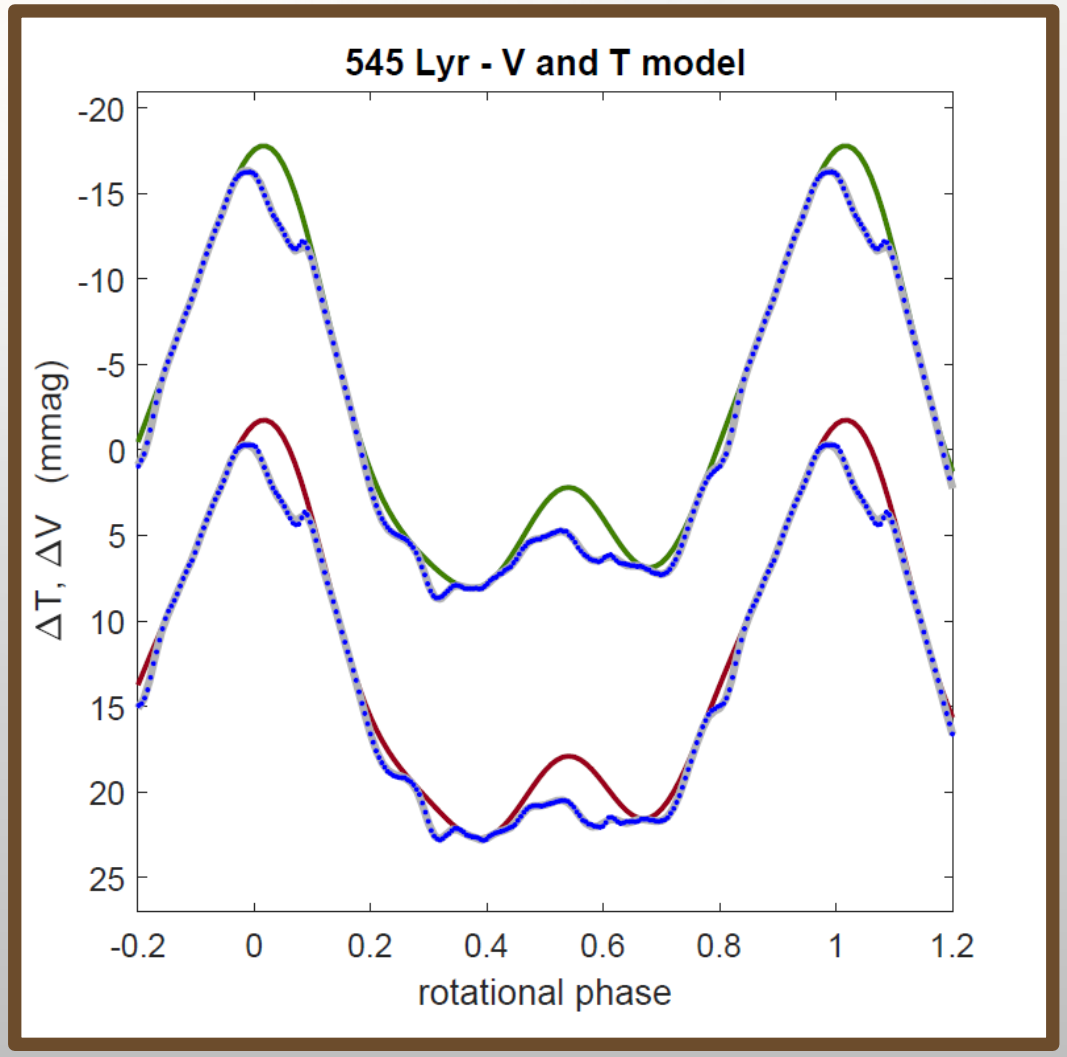
KIC 6950556


KIC 6950556 - phase curve
spot model
observation
ΔV (mmag)
-15
-10
-5
0
5
10
15
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
rotational phase

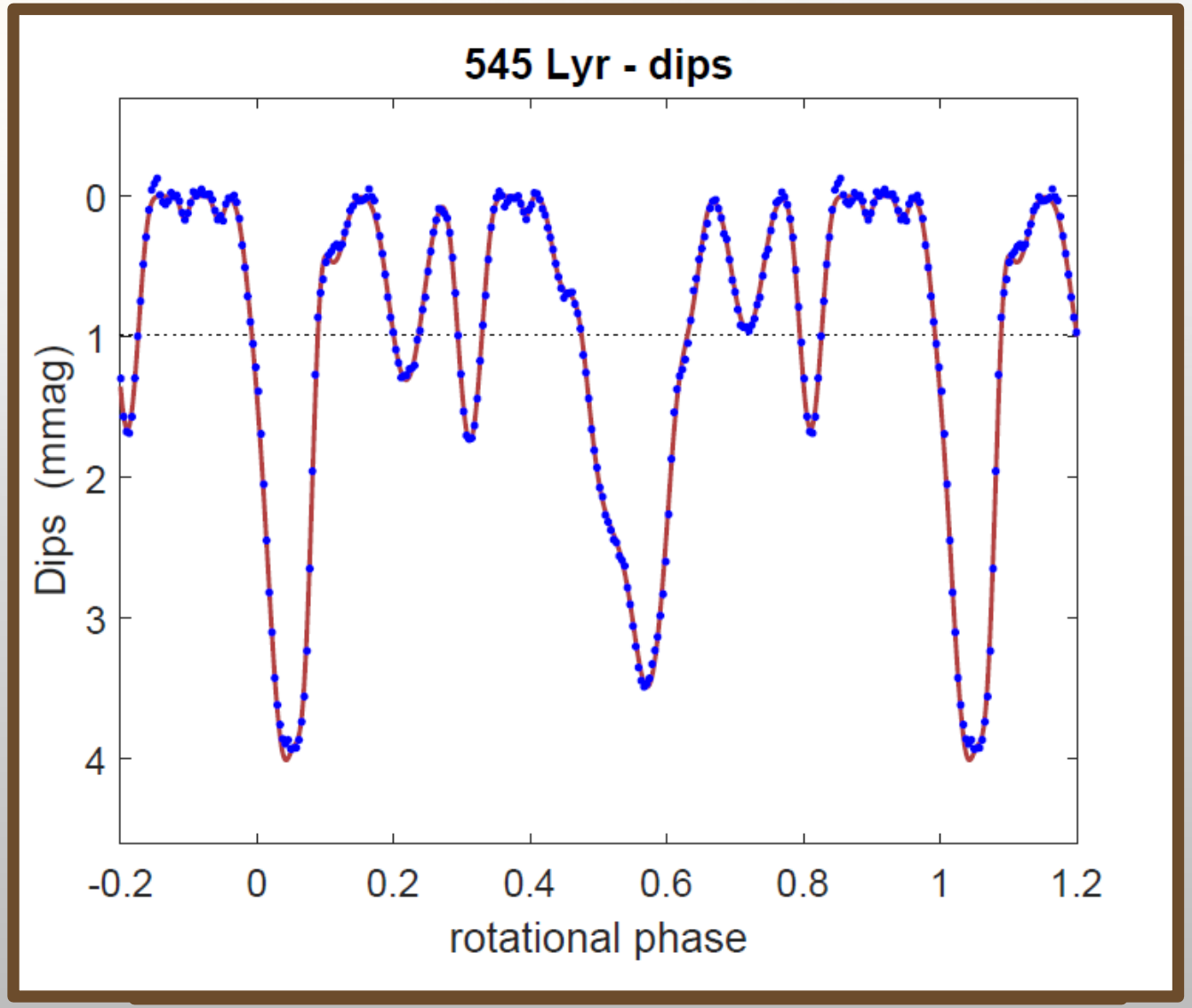
KIC 6950556


KIC 6950556 - dip seasonal development
Dips (mmag)
0
1
2
3
4
5
6
2009.7
2010.4
2011.0
2011.7
2012.3
2013.0
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
rotational phase

V545 Lyrae


545 Lyr - V and T model
ΔT, ΔV (mmag)
-20
-15
-10
-5
0
5
10
15
20
25
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
rotational phase

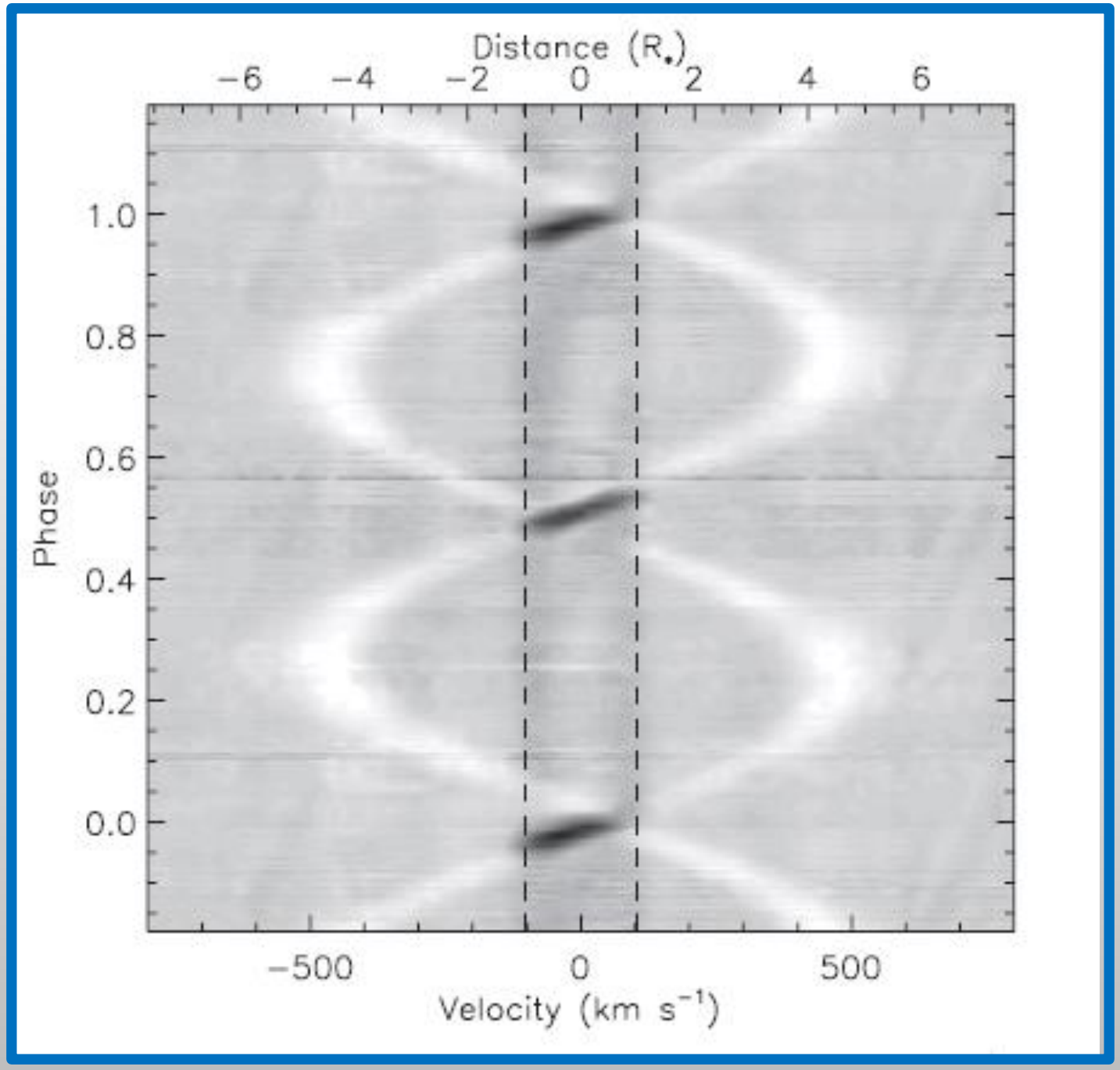
V545 Lyrae


545 Lyr - dips
Dips (mmag)
0
1
2
3
4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
rotational phase

The astrophysical nature of light curve dips

Speculation: In corotating magnetospheres with the multipole magnetic field (Krtička et al., 2022), traps for plasma exist. Dips in LC occur as the plasma cloud transits through the stellar disk. The rate of passage of the obstacle through the stellar disk depends on the cloud's distance from the rotation axis. Although we do not know the physics of the whole phenomenon well, we can phenomenologically model the dips in the light curve.

- Plasma clouds outside the stellar disc should also manifest themselves in radiation, especially in emission lines (if any), namely in Hα. Unequivocal evidence comes from the observation of satellite bright/dark components in the wings of the lines, which should be variable with the period of rotation.
- We can quickly identify the two most prominent clouds in the wings and core of the dynamic spectrogram of Hα of V545 Lyr (Bohlender & Monin, 2011).


Distance (R_*)
−6
−4
−2
0
2
4
6
Phase
1.0
0.8
0.6
0.4
0.2
0.0
−500
0
500
Velocity (km s^{-1})

The astrophysical nature of light curve dips

Speculation: In corotating magnetospheres with multipole magnetic field (Krtička et al., 2022), traps for plasma exist. Dips in LC occur as the plasma cloud transits through the stellar disk. The obstacle's passage rate through the stellar disk depends on the cloud's distance from the rotation axis. Although we do not know the physics of the whole phenomenon well, we can phenomenologically model the dips in the light curve.

- Plasma clouds outside the stellar disc should also manifest themselves in radiation, especially in emission lines (if any), namely in Hα. Unequivocal evidence comes from the observation of satellite bright/dark components in the wings of the lines, which should oscillate in the period of rotation.
- We can quickly identify the two most prominent clouds in the wings and core of the dynamic spectrogram of Hα of V545 Lyr (Bohlender & Monin, 2011).
- The clouds are comparable in size to the star itself. They revolve in circular orbits at a speed of several hundred km/s at distances of several stellar radii.

EE Draconis – instead of conclusion

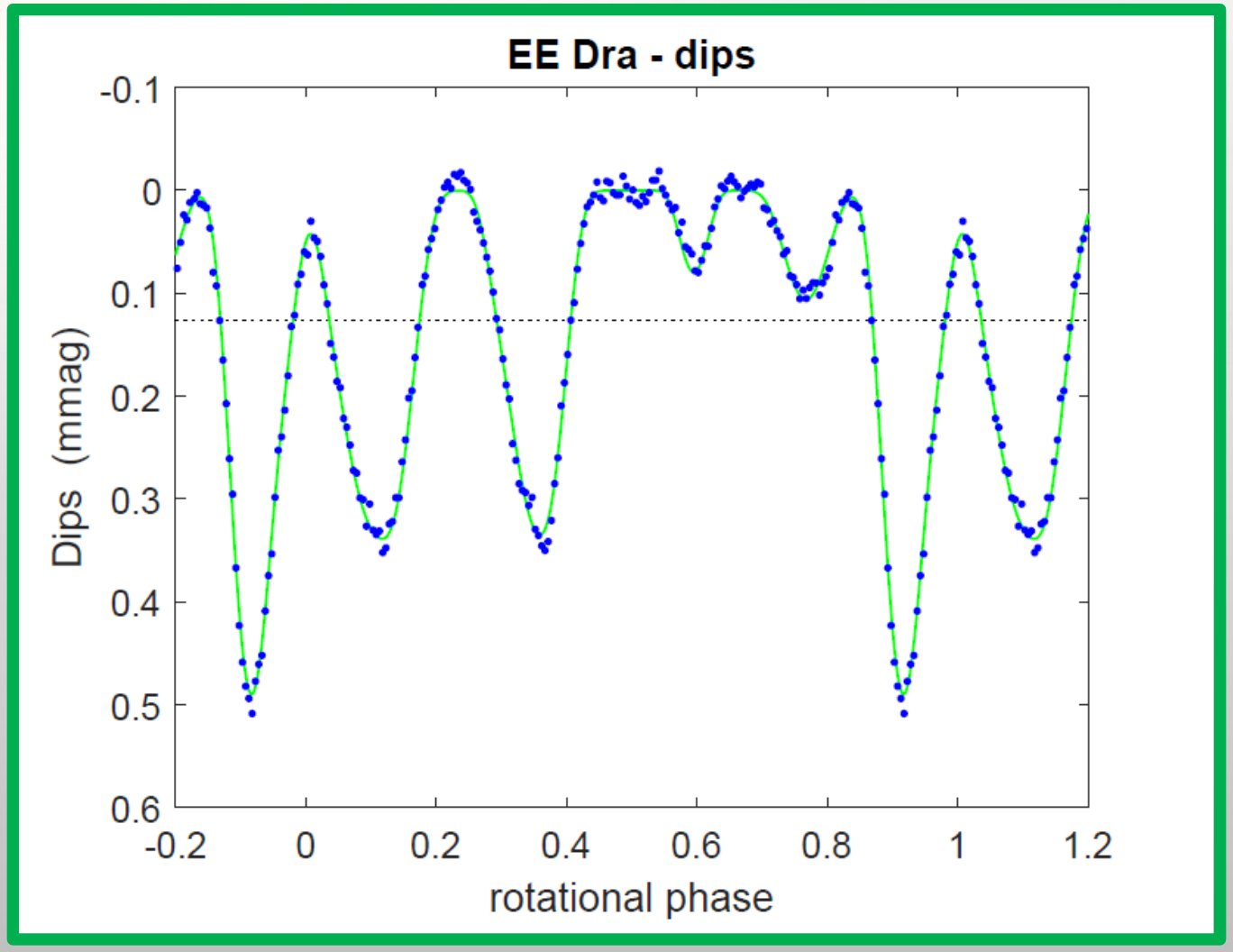
EE Dra = HD 177410 is a CP star that shows all the signs of being a standard magnetic CP star with a large amplitude of variability, with one exception:

- Despite all efforts, we could not spectroscopically confirm its magnetic field (Schultz et al., 2022) up to now.

EE Dra variability is caused by two bright, opposite, unequally contrasting spots overabundant in silicon. A rotational period is 1.123 days.

- EE Dra is currently the best monitored mCP star. It is popular with the TESS satellite, and we have (at the moment) 32 sectors available (461 thousand measurements, s = 0.32 mmag).

EE Draconis – instead of conclusion



EE Draconis – instead of conclusion

EE Dra = HD 177410 is a CP star that shows all the signs of being a standard magnetic CP star with a large amplitude of variability, with one exception:

- Despite all efforts, we could not spectroscopically confirm its magnetic field (Shultz et al., 2022) up to now.

EE Dra variability is caused by two bright, opposite, unequally contrasting spots overabundant in silicon. A rotational period is 1.123 days.

- EE Dra is currently obviously the best monitored mCP star. It is popular with the TESS satellite, and we have (at the moment) 32 sectors available (461 thousand measurements, s = 0.32 mmag).

We have found several well-defined LC dips. The average cloud extinction is 0.127(4) mmag.

- We state extraordinary dip stability over the last few years.

The discovery of dips – proves the existence of persistent transiting clouds in the corotating magnetosphere.

If there is a magnetosphere, there must also be a global magnetic field, however weak.

Thank you for your attention!

Dank für Ihre Aufmerksamkeit!

Merci pour votre attention !

Děkuji/Ďakujem za pozornost/ť!

Дякую за увагу!

HR 2461 – a mCP star without dips