Magnetic Activity in Close Binary Systems

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STellar Activity Research @ Konkoly (STARK)

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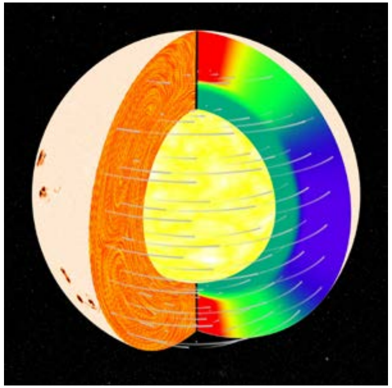
Why to study magnetic activity in CBs?

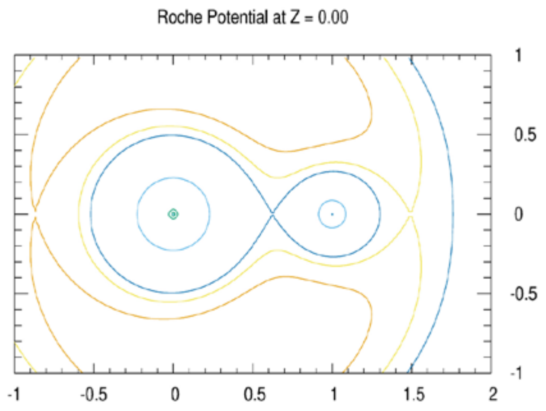
- Understanding the overall role of magnetism in CBs
- To answer
  - What are the similarities and differences between dynamos in single stars and binary systems?
  - How a close companion (star or planet) affects dynamo operation?
  - How magnetism affects the evolution and dynamics in CBs?
- Disentanglement of activity phenomena from other effects
  - e.g., starspots vs. a faint eclipsing companion

The solar dynamo:



Plasma dynamics
+
Magnetic field
=
Dynamo mechanism
– global/cyclic

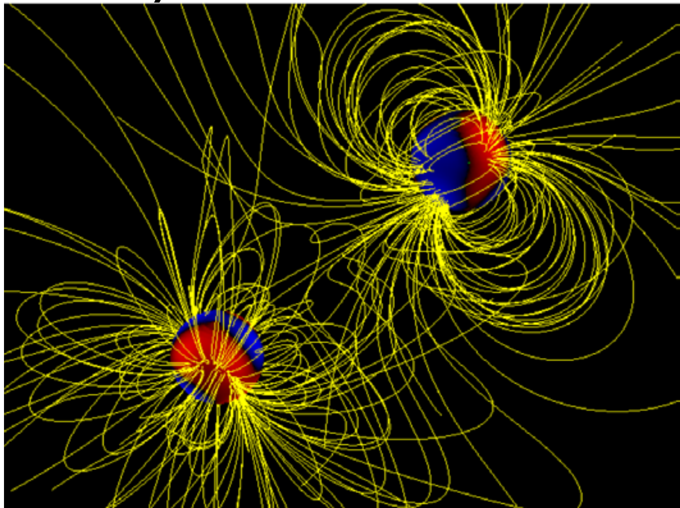
The multifaceted role of tidal interaction



- Synchronization
- Circularization
- Distortion of the shape (non-axisymmetry)
- Angular momentum transfer, mass loss, ...
- Stellar evolution
- ...

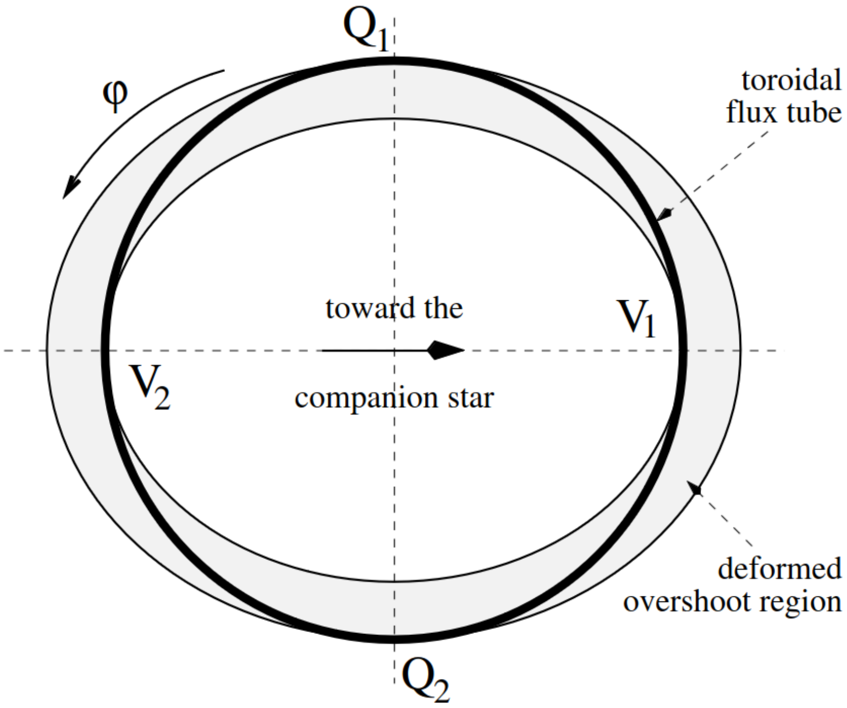
The role of binarity in terms of magnetic activity

- Maintaining rapid rotation (→ enhanced dynamo action)
- Confinement/induction of differential rotation
- Tidal interactions may induce helical flows
- Activity centers bound to the orbit (active longitudes)
- Induced flare/CME activity due to interacting magnetospheres



V4046 Sgr
Gregory et al. 2018

Dynamics of toroidal magnetic flux tubes under tidal influences

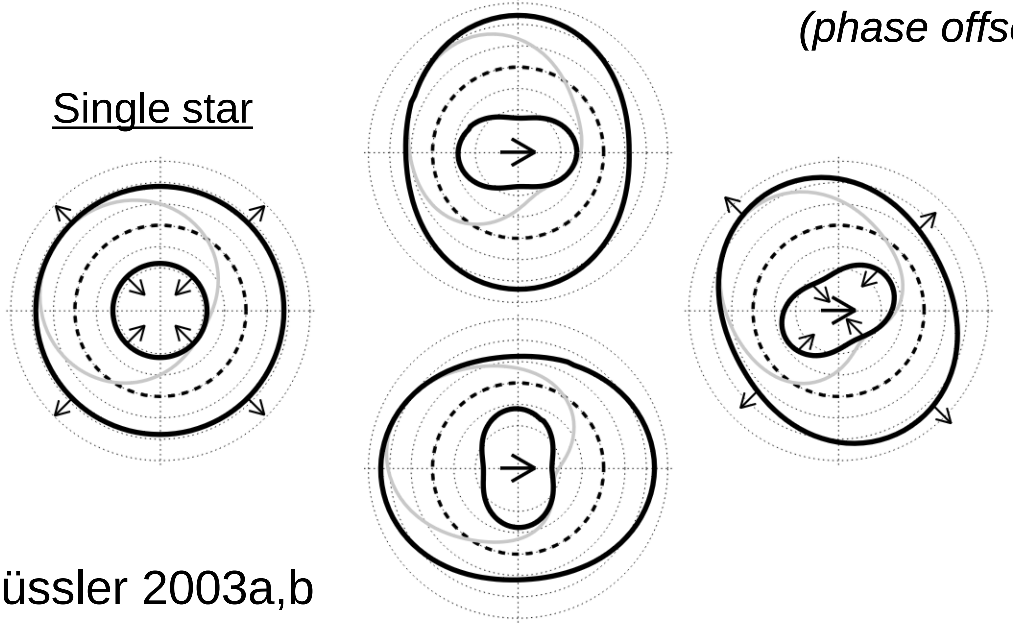


Active star in a CB

Single star

stable modes

unstable mode (phase offset)



Holzwarth & Schüssler 2003a,b

but not only

Activity observables in CBs

- Starspots, plages
- Active longitudes
- Activity cycles
- Flares, CMEs
- Extra emission from radio to UV to X-rays
- etc.

Indirect means I.

Photometric spot modeling

802 Zs. Kővári & J. Bartus: Testing th

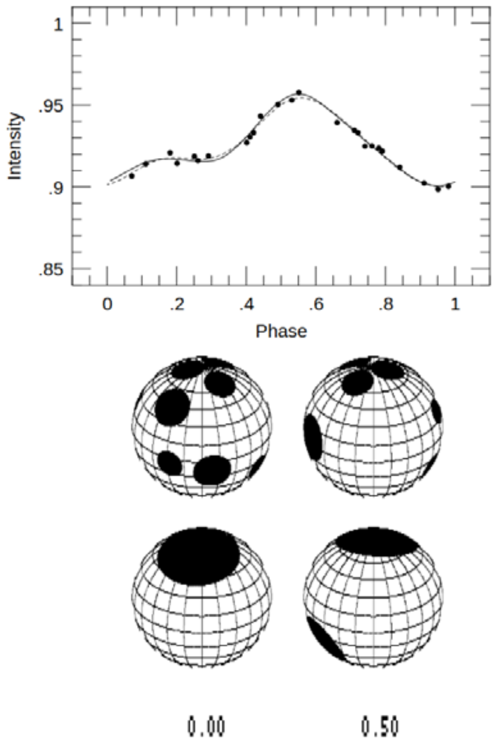


Fig. 1. An example of fitting a ten-spot curve with two spots.

The Astronomical Journal, 162:123 (18pp), 2021 September Luger et al.

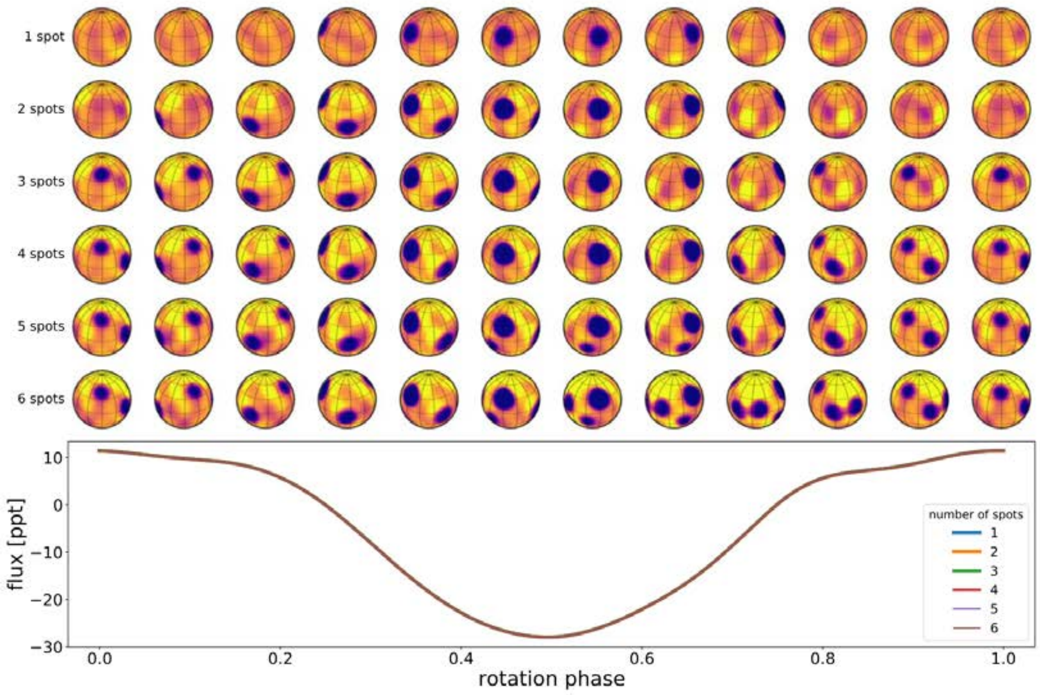
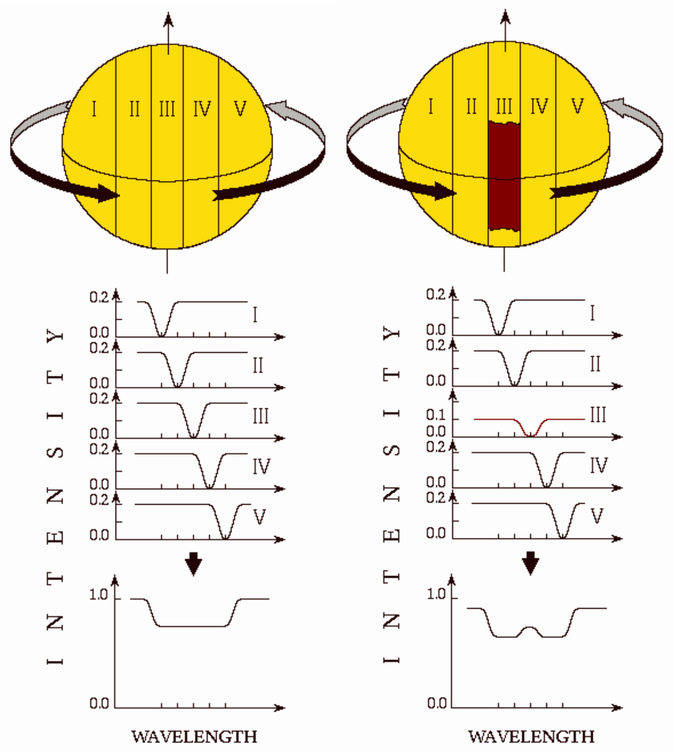
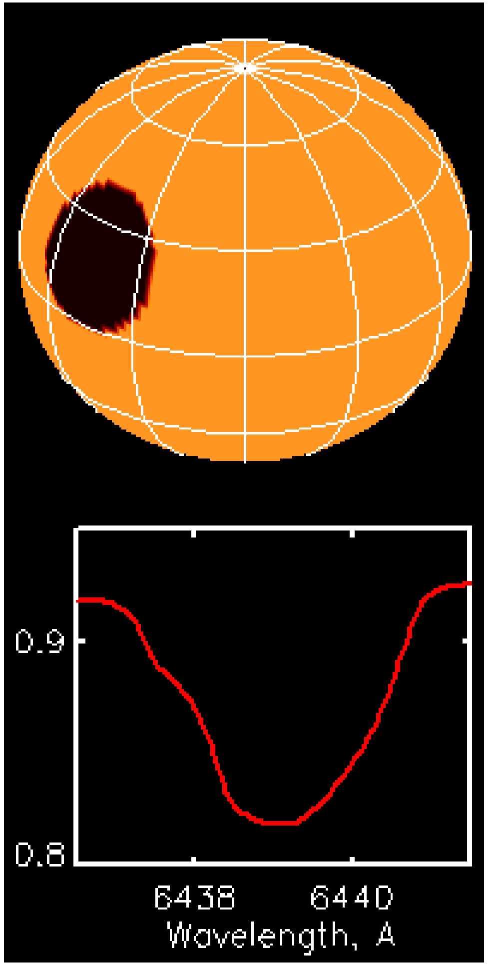


Figure 1. Fundamental limitations of the mapping problem. Each row corresponds to a stellar surface with a different number of dark spots seen at various phases at an inclination $I = 60°$; all images are shown on the same color scale. The bottom panel shows the light curves of each of these stars. All six light curves are indistinguishable from each other, even at an infinite S/N. See text for details.

Indirect means II.
Doppler imaging

- Line profiles are 1D fingerprints of the apparent surface
- The surface can be reconstructed from a set of spectra <u>covering the full rotational phase</u> (→ time average images)

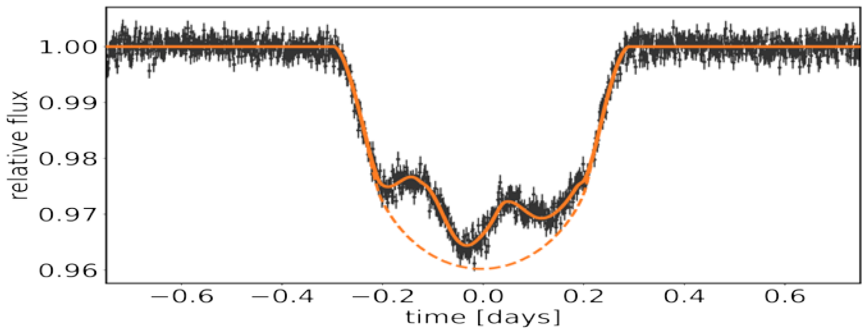


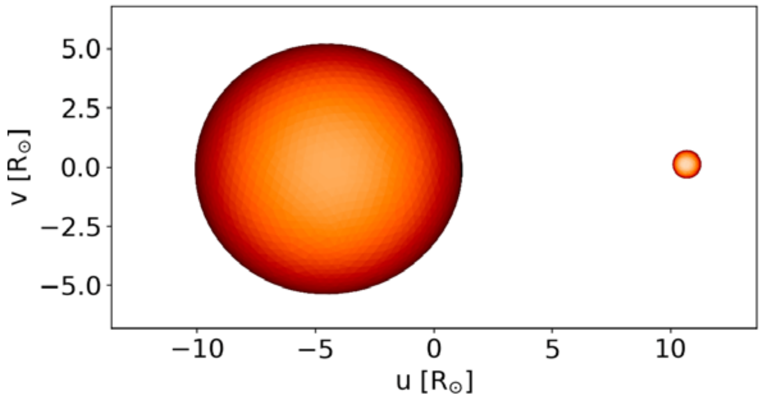


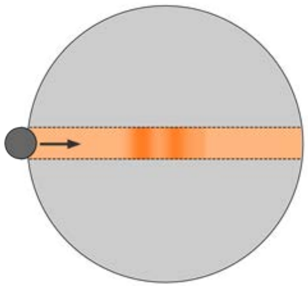
- Vogt & Penrod 1983

Indirect means III.
Eclipse/transit mapping

- A complementary method to detect starpots
- The precision of space photometry is necessary





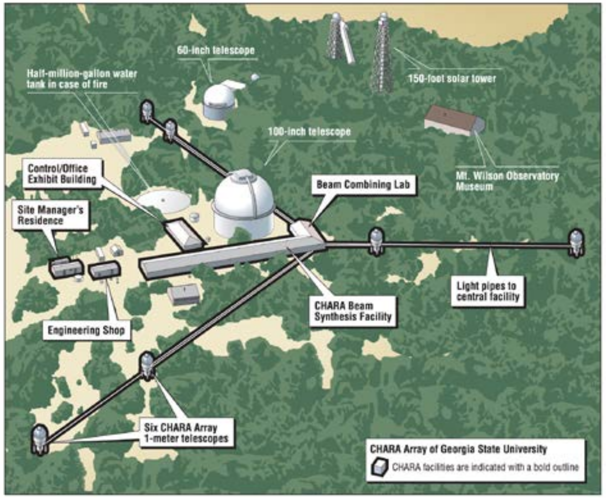


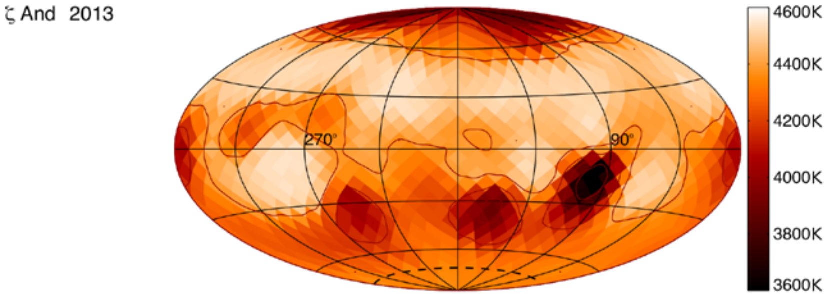
(PHOEBE, A. Prsa)

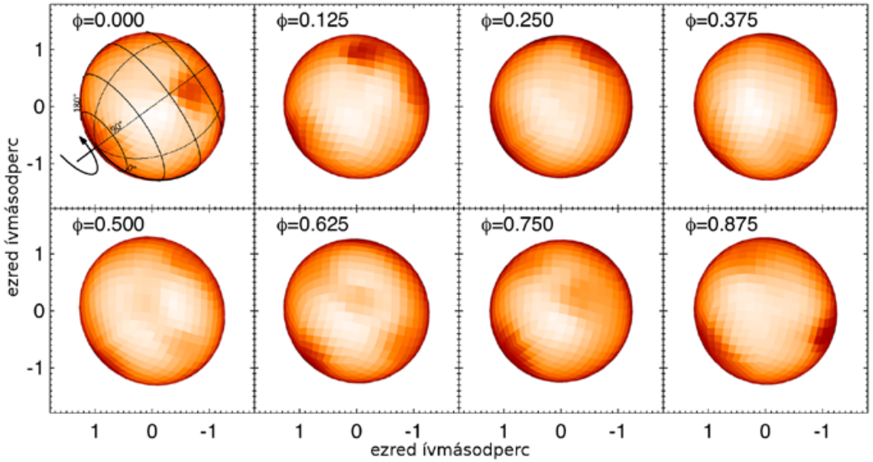
Direct imaging of starspots

- Long-baseline optical/NIR interferometry
- ‘Snapshot’ imaging
- Strong constraints (bright object, large enough angular diameter)

CHARA / MIRC



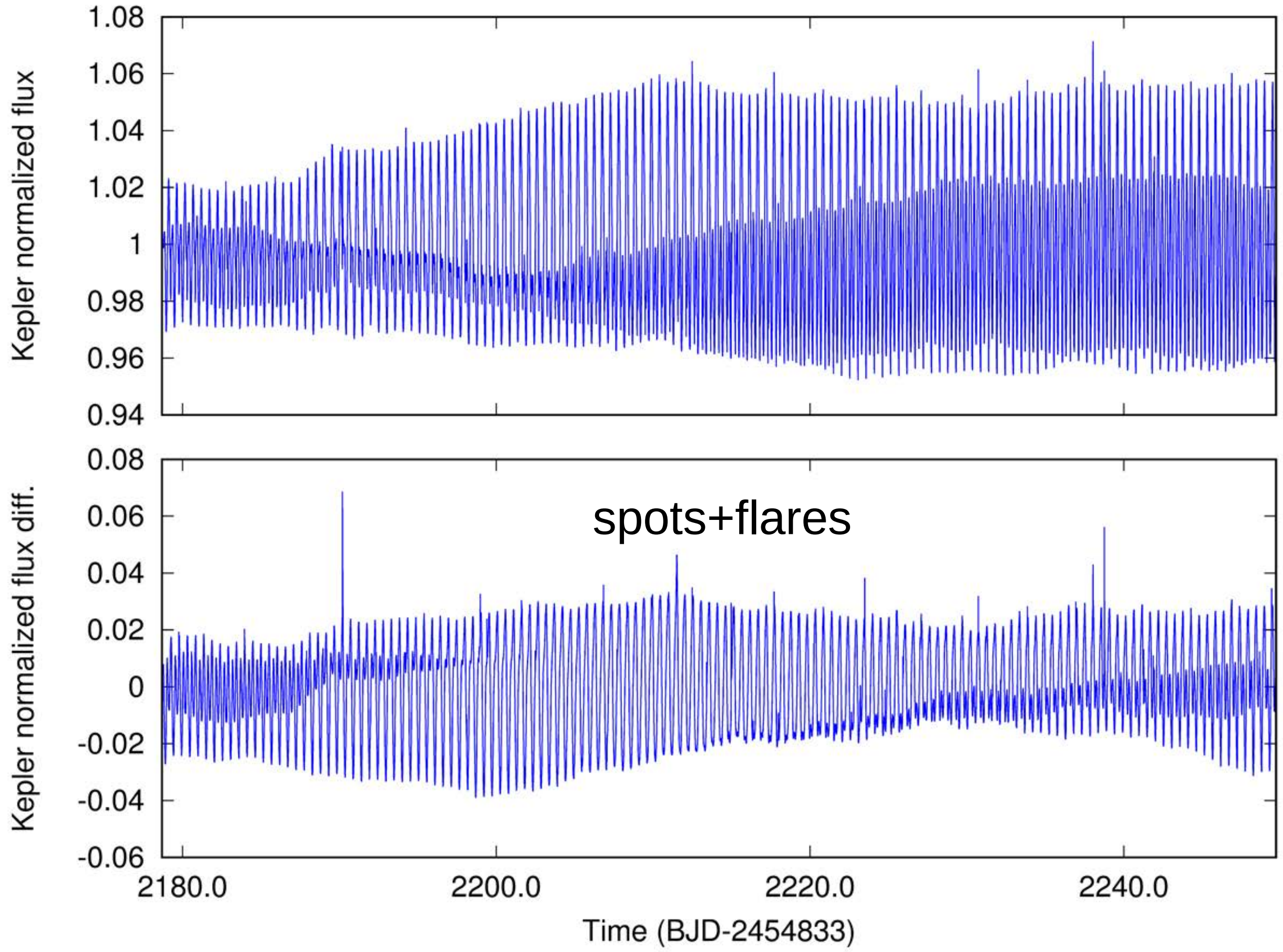




Roettenbacher et al. 2016

V471 Tau

Eclipsing binary system of K2V+WD (Kővári et al. 2021)



K2 light curve

$P_{rot} \sim P_{orb} = 0.52$d

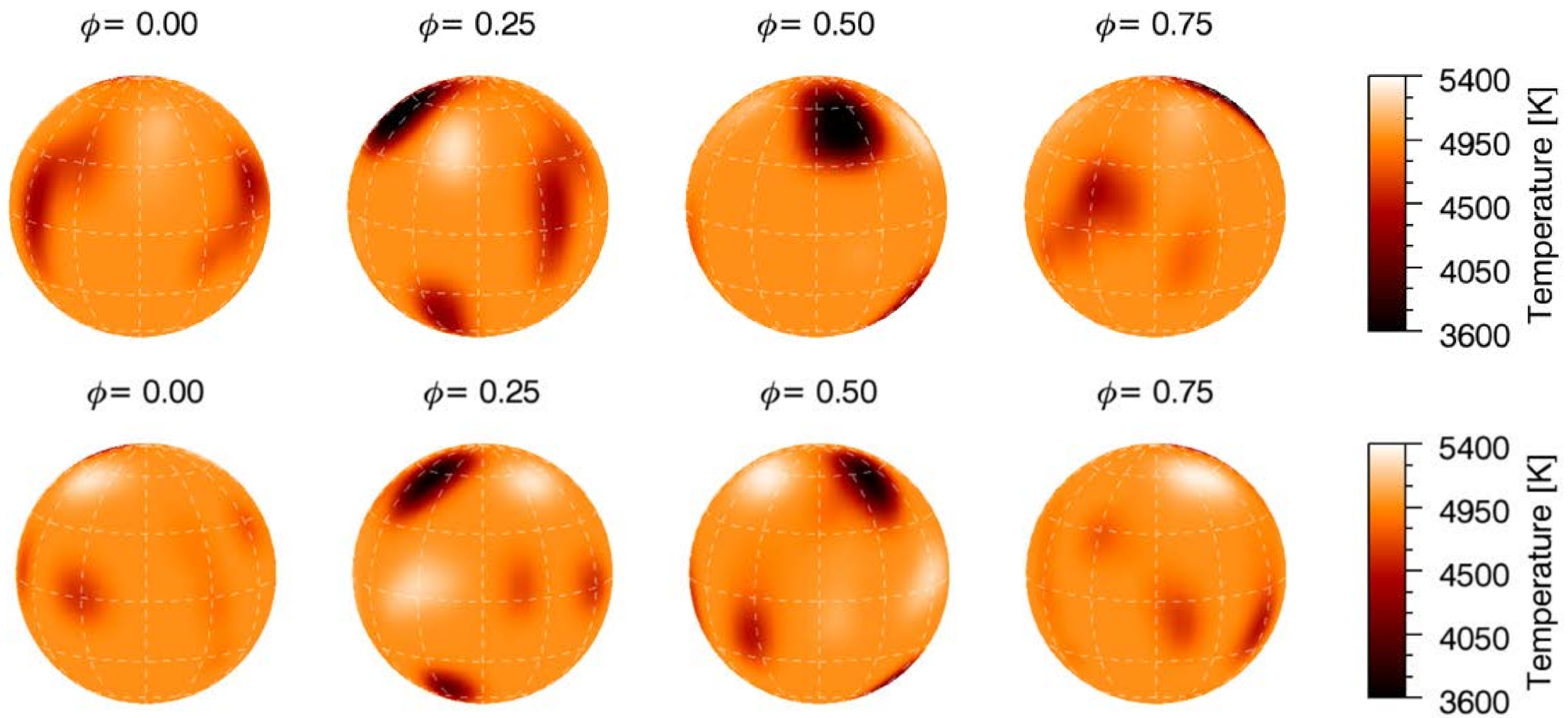
K2 light curve after EB model extracted

V471 Tau

Stable spot configuration, active longitude facing the WD

200
5

2014-2015



Kővári et al. 2021

Measuring surface differential rotation from spot tracking

AB Dor
Image #1

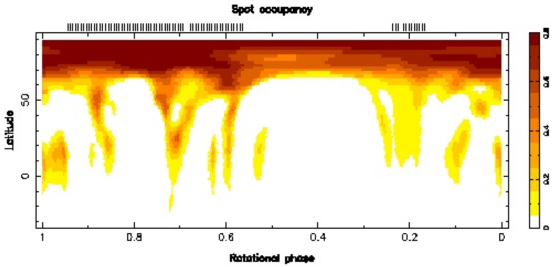
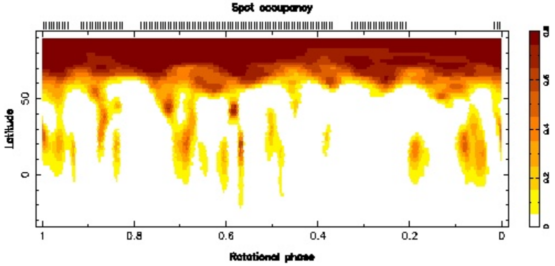
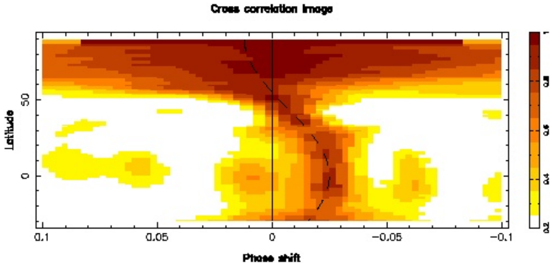


Image #2



$\Delta t \sim P_{rot}$

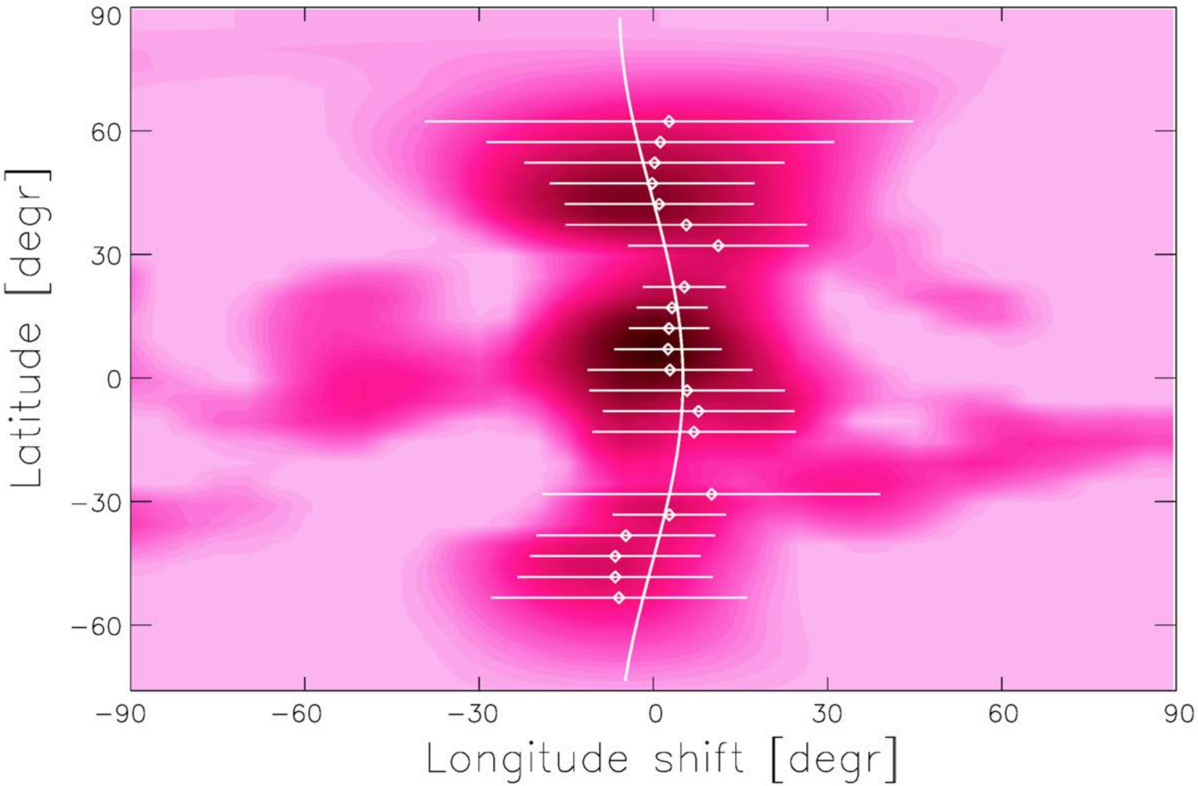
Longitudinal
cross-correlation
function map



Donati & Collier Cameron
1997

V471 Tau

Average cross-correlation function map indicating weak solar-type DR

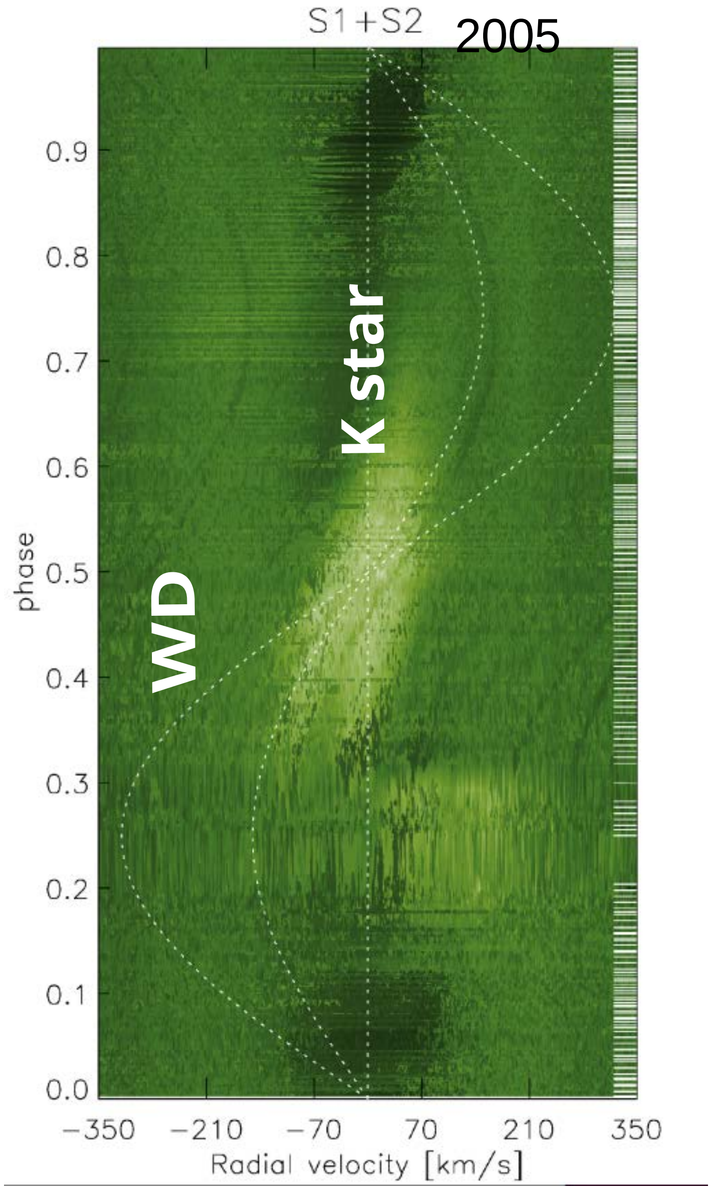


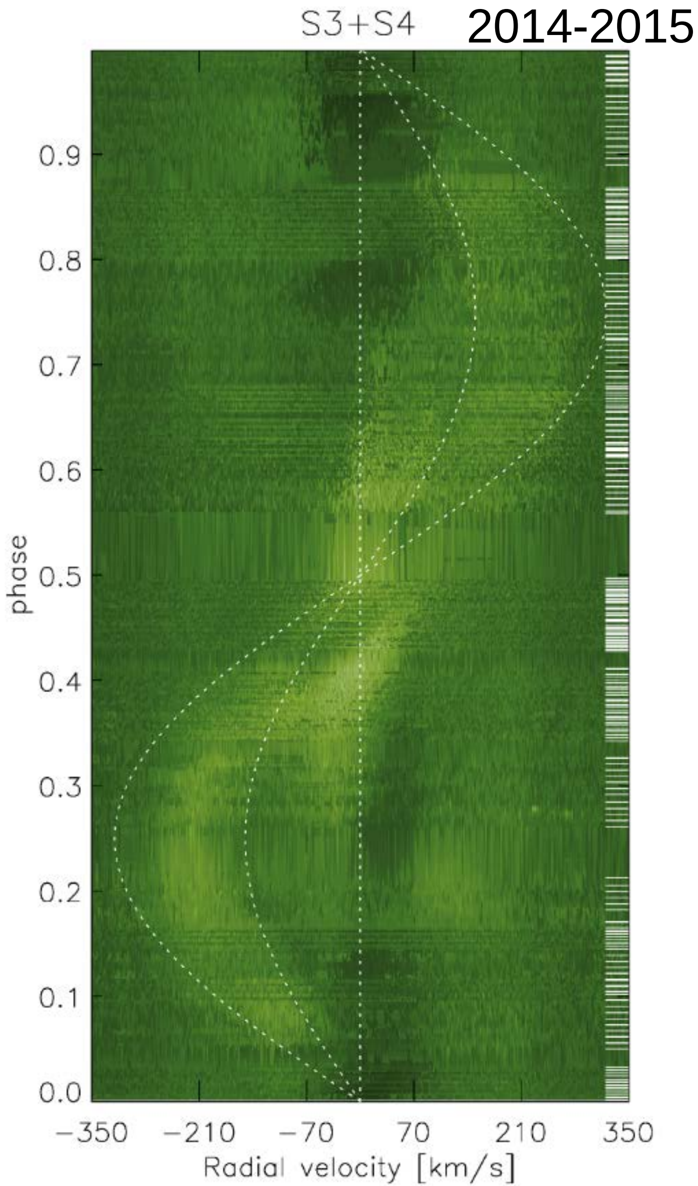
V471 Tau

Dynamic Hα spectra

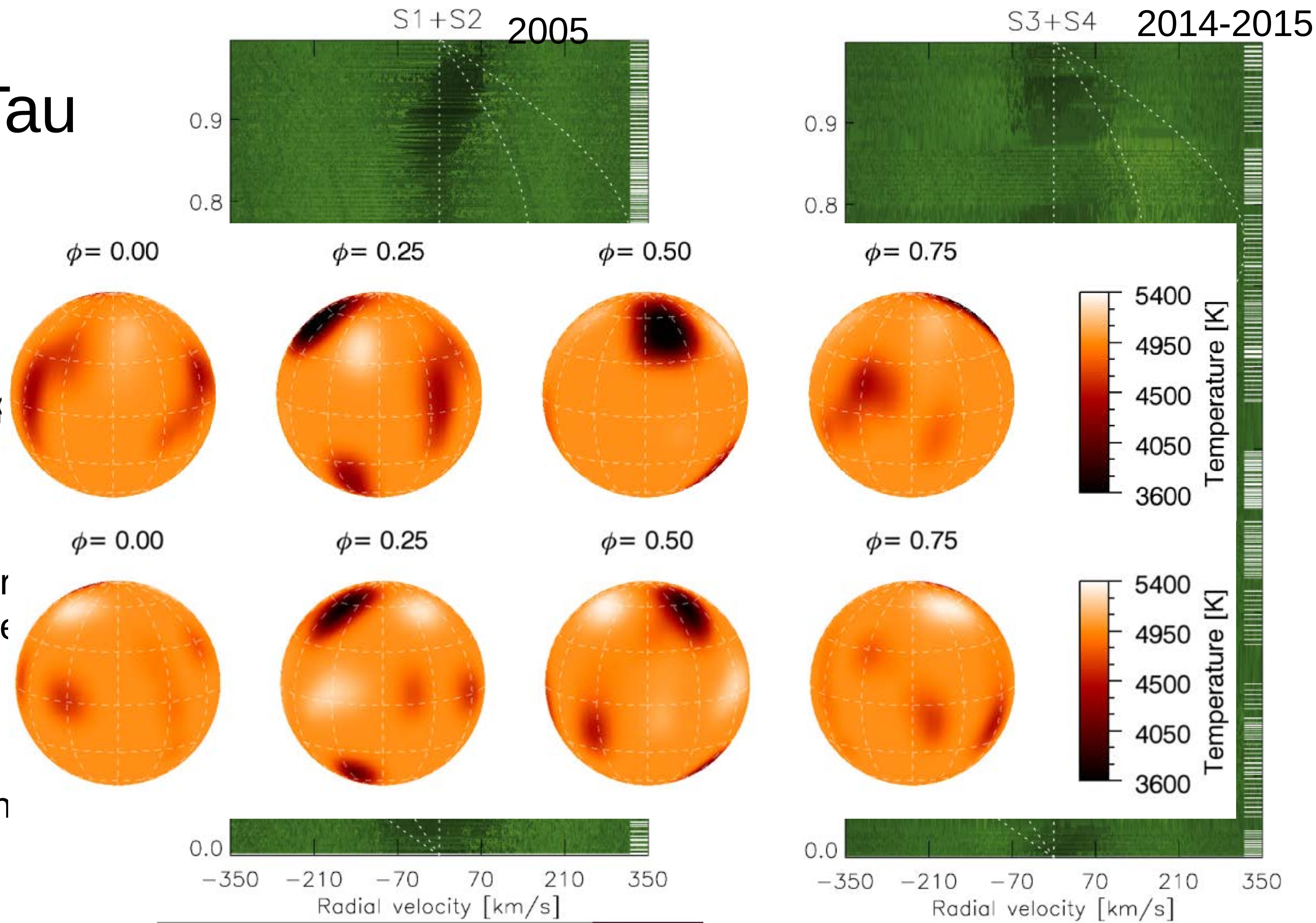
+emission
→ plages, interacting magnetospheres, activity cycle?

+absoption
→ dark filaments





V471 Tau



Dynamic Hα sp

+emission
→ plages, inter
magnetosphere
activity cycle?

+absoption
→ dark filamen

V471 Tau

Dynamic Hα spectra

+emission
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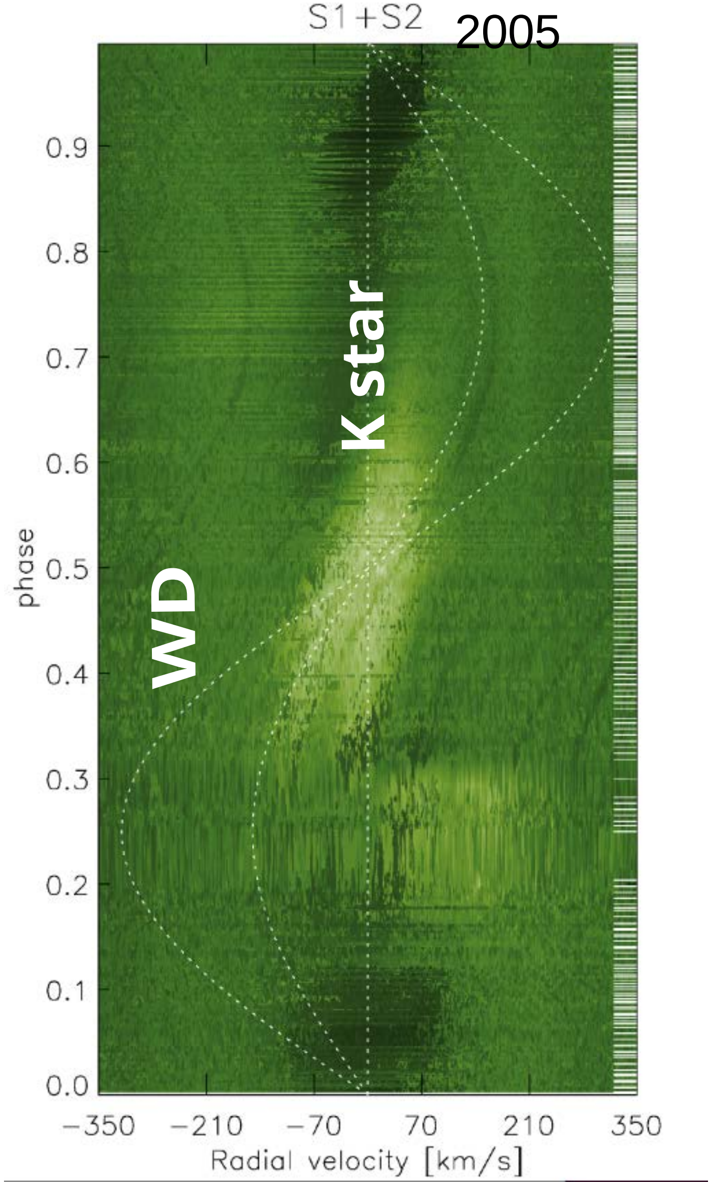
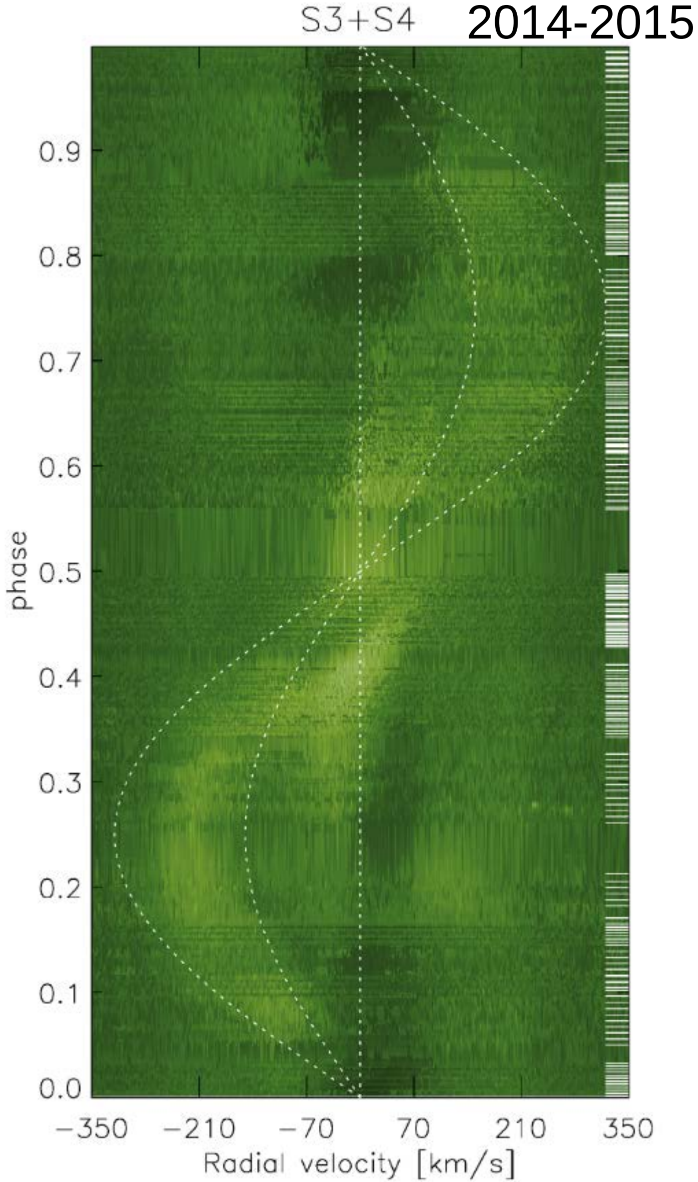
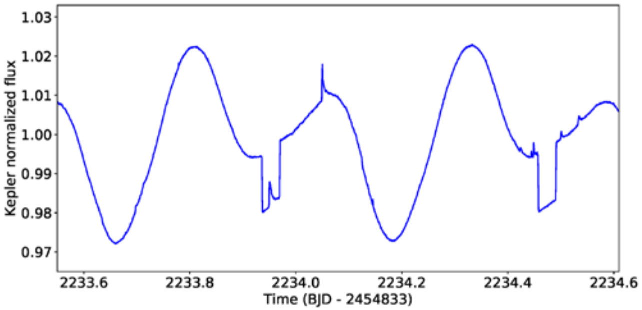
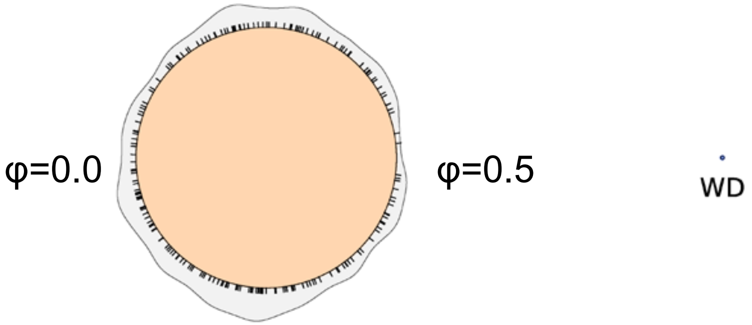




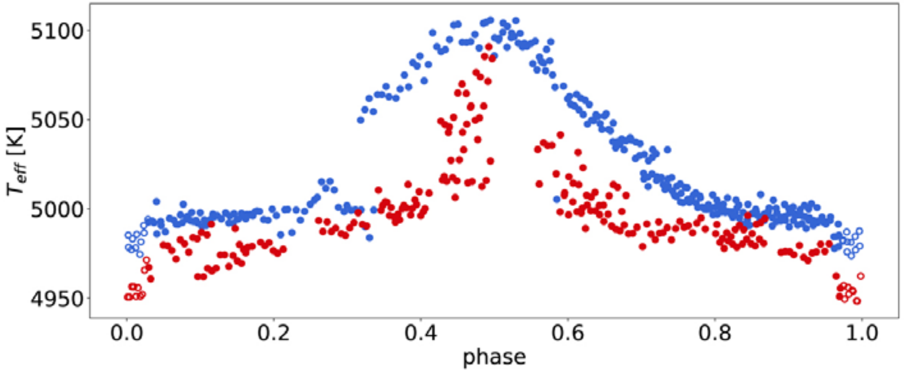
V471 Tau

No phase dependency in flare occurence

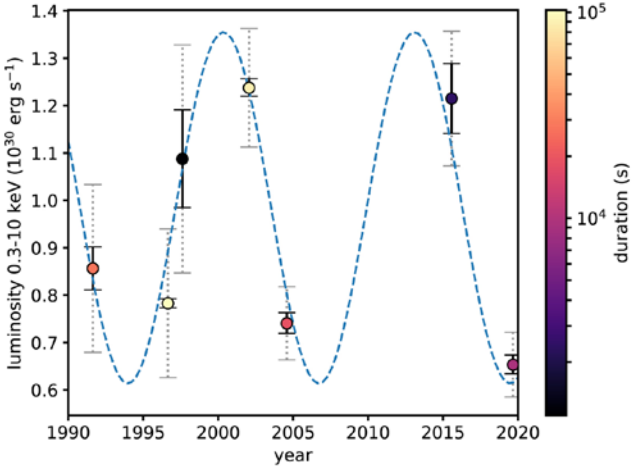




Irradiation by the WD



12.7-yr activity cycle in X-ray

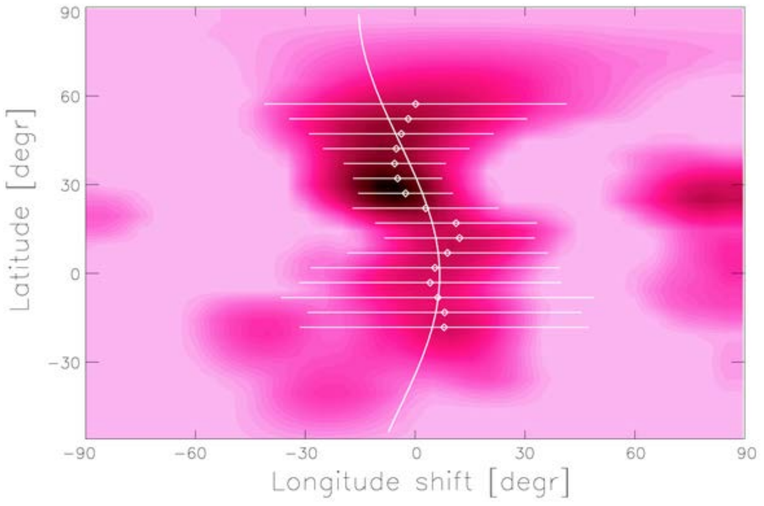


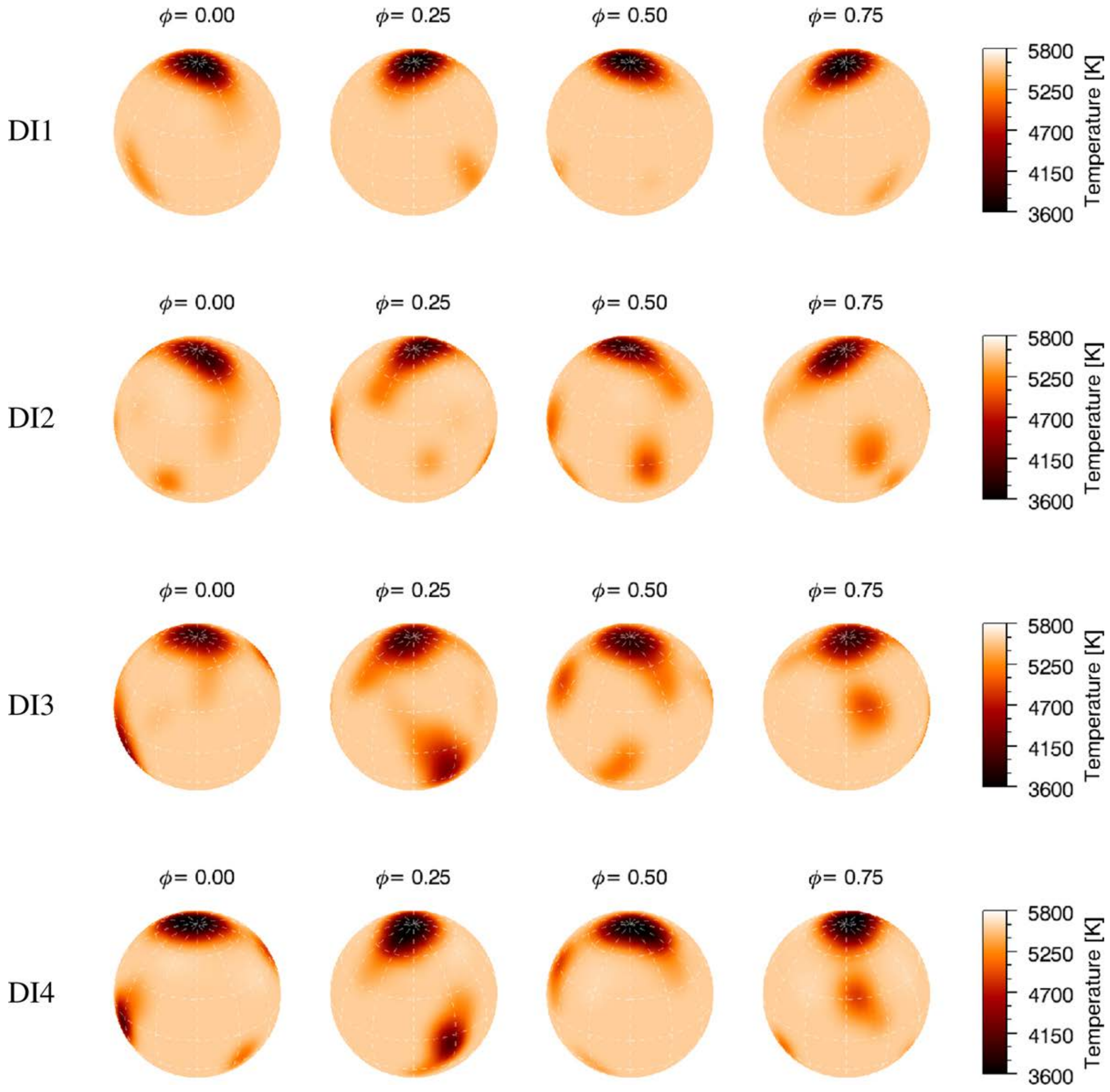
EI Eri

a CB of G5IV+unseen M?V
(Kriskovics et al. 2023)

$P_{rot} \sim P_{orb} = 2d$

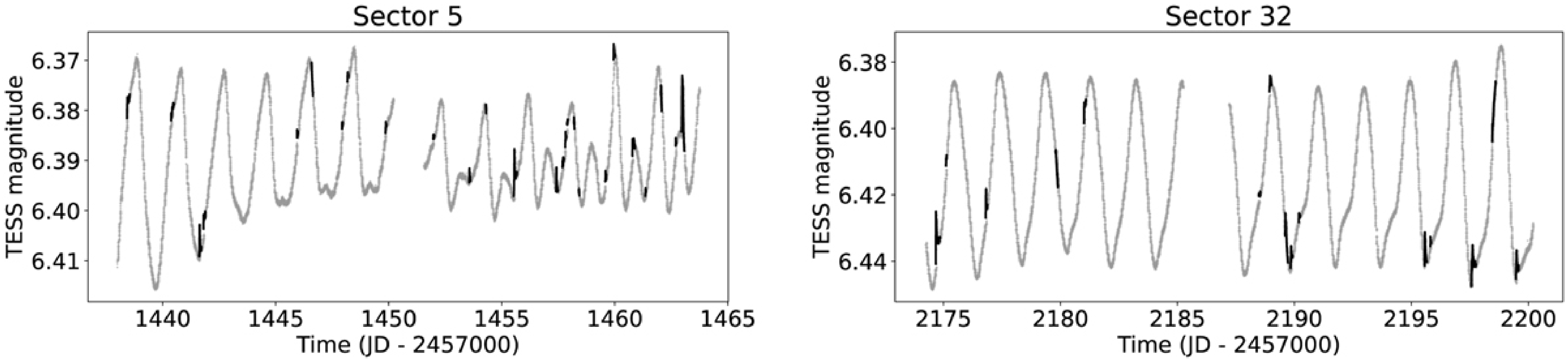
Weak solar-type DR from the cross-correlation function map

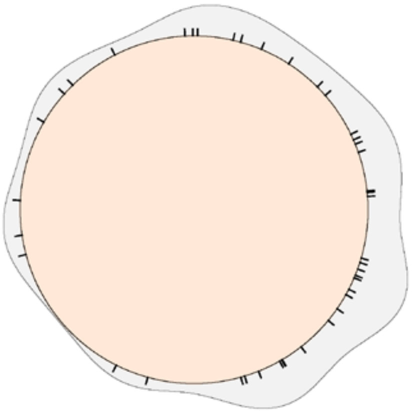




EI Eri

TESS light curves with spots and flares





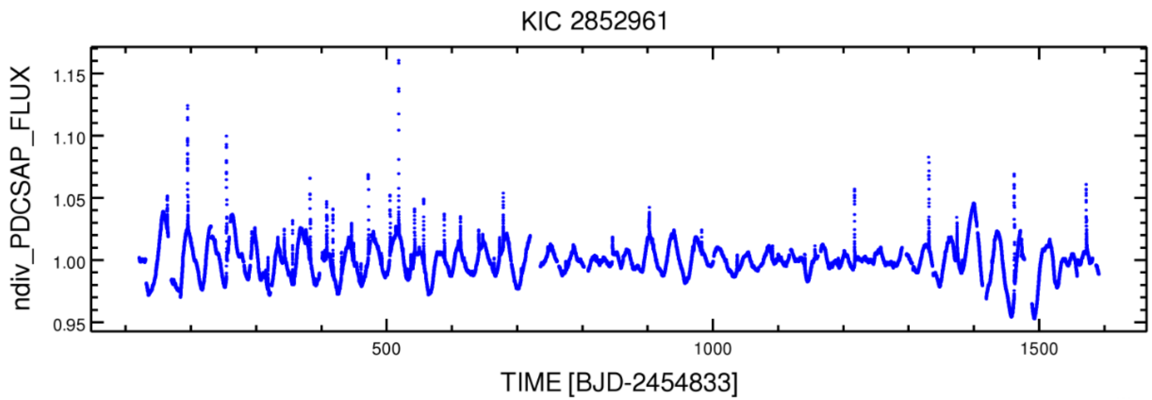
Phase dependency in flare occurence

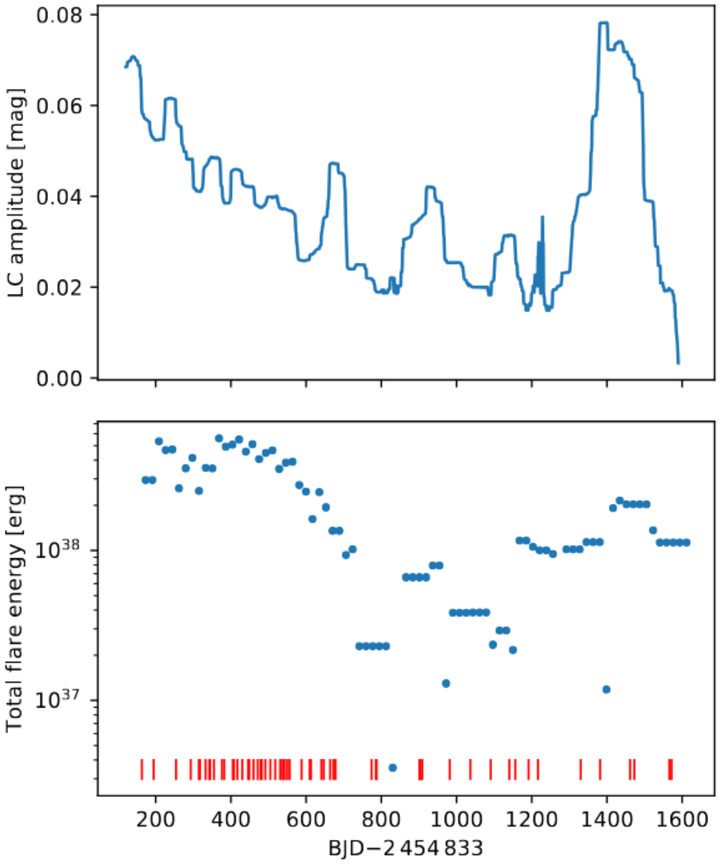
(Kriskovics et al. 2023)

KIC 2852961

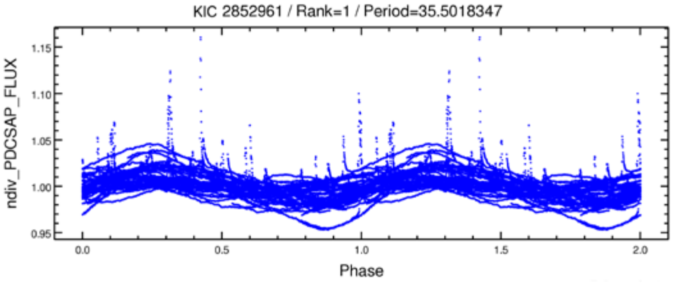
K0 III primary of an RS CVn binary (SB1)
P_{rot}=35.5d
P_{orb}=? (probably synchronized)

Kepler Q4 light curve





- 59 flare events
- Δt = 5h–38h
- Most of them are extremely energetic

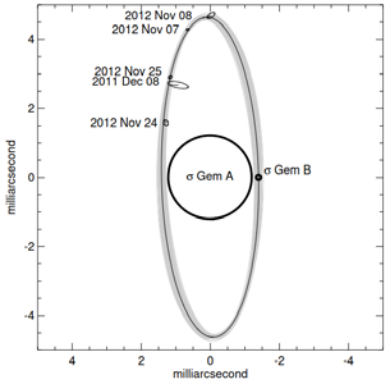


(Kővári et al.

σ Gem

An RS Cvn type close binary system (SB1) with a K1III primary

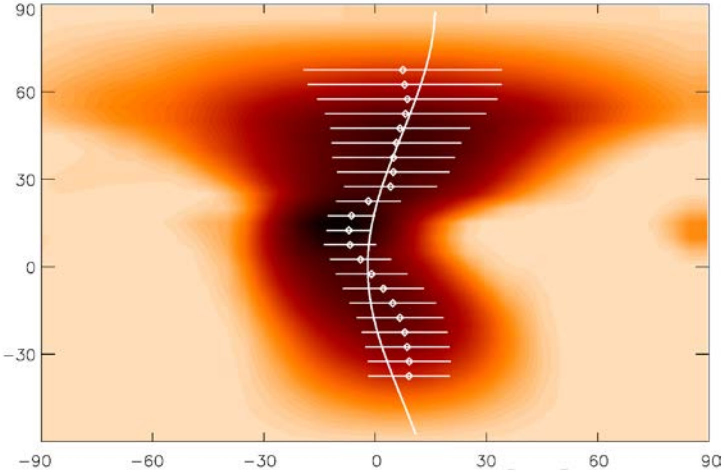
Roettenbacher et al. 2015



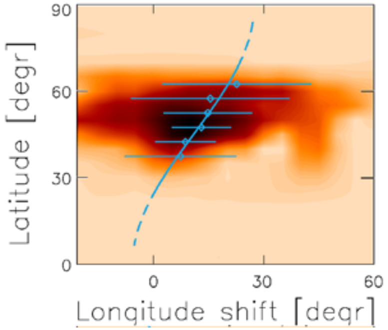
Anti-solar DR and surface flows:

Average <u>longitudinal</u> cross-correlation function maps

NSO data from 1996/1997



STELLA data from 2006/2007

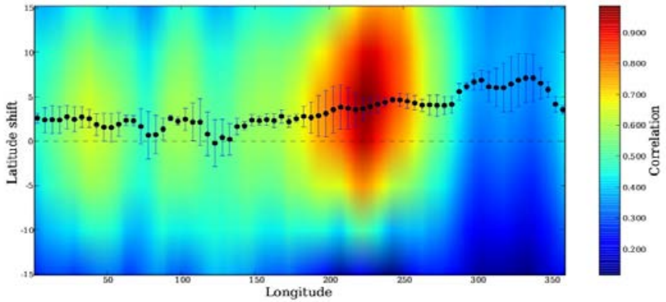


$$\Omega(\beta) = \Omega_{eq}(1 - \alpha \sin^2 \beta)$$

$$\alpha = (\Omega_{eq} - \Omega_{pol}) / \Omega_{eq}$$

$$\alpha = -0.04 \pm 0.01$$

Average <u>latitudinal</u> cross-correlation function map



Common poleward motion of ~310 ms^{-1}
cf. Kitchatinov & Rüdiger 2004:

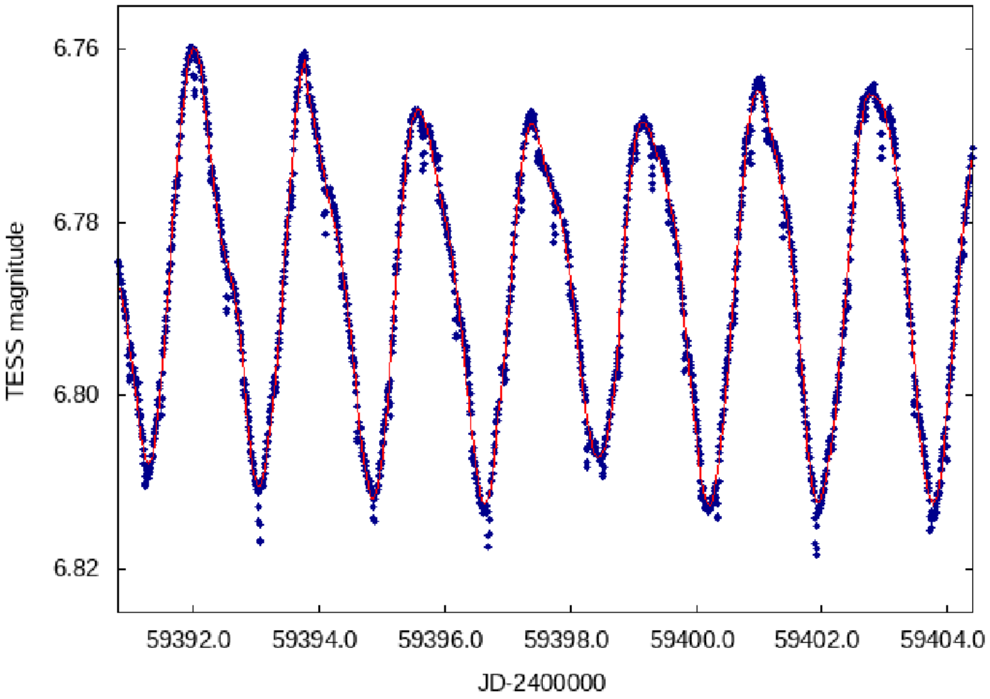
$$u_{min} = l^2 / (\tau R) \sim 0.3 km/s$$

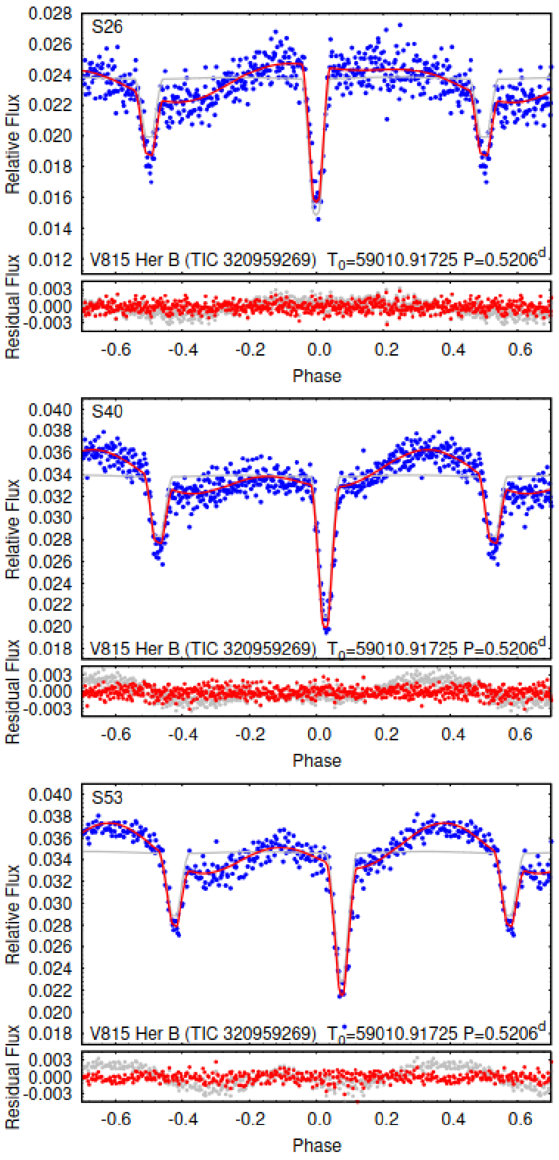
flow required to maintain anti-solar DR

Kővári et al. 2007, 2015

V815 Her, a compact 2+2 hierarchical system

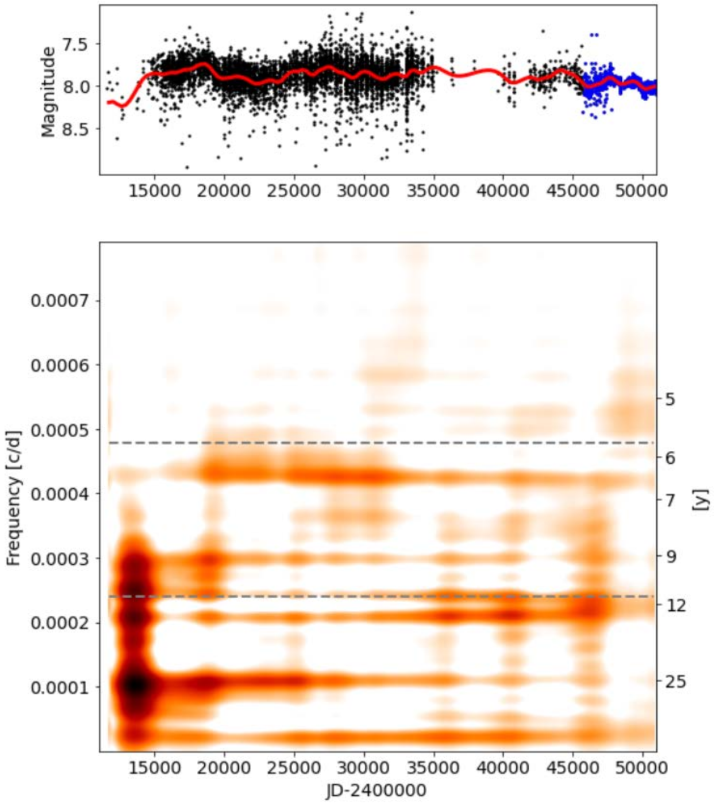
V815 Her A: G6V+ 0.3M_{Sun} (unseen)	P_{rot} ~ P_{orb} = 1.8d	a_A ≈ 2 R_{Sun}
V815 Her B: (EB) 0.44M_{Sun}+ 0.19M_{Sun}	P_{orb} = 0.52d	a_B ≈ 2.35 R_{Sun}
V815 Her AB:	P_{orb} = 2092d	a_{AB} ≈ 1.6 AU



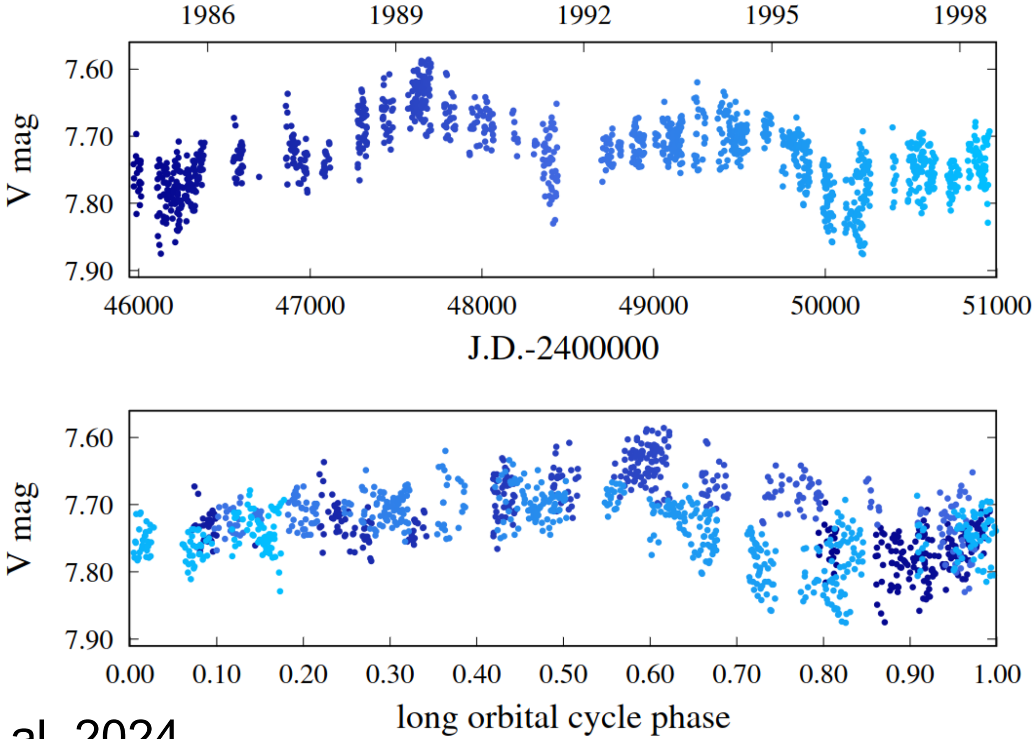


Kővári et al. 2024

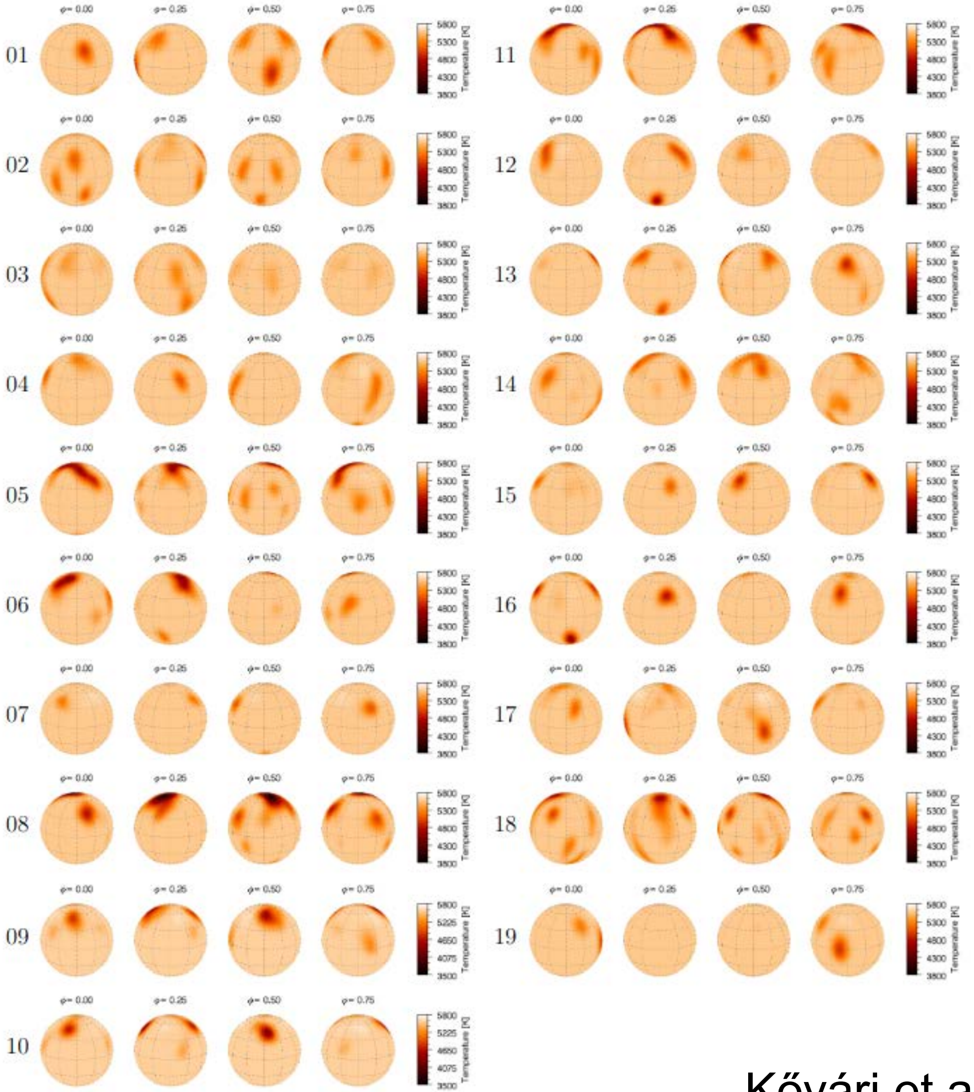
V815 Her long-term photometry



V815 Her AB: P_{orb} = 2092d (5.73yr)



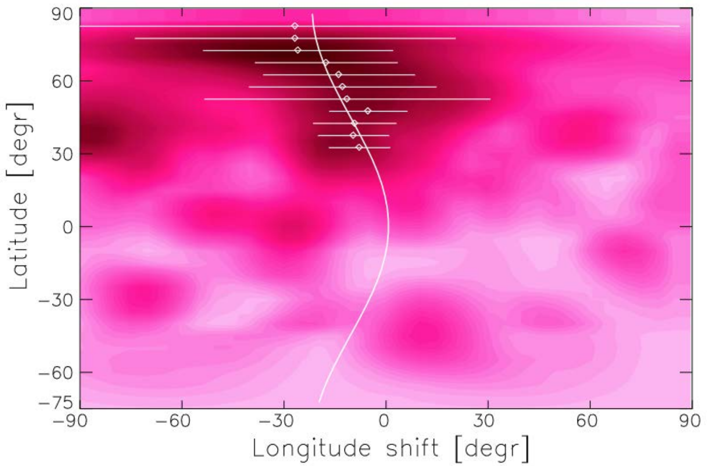
Kővári et al. 2024



V815 Her Doppler imaging

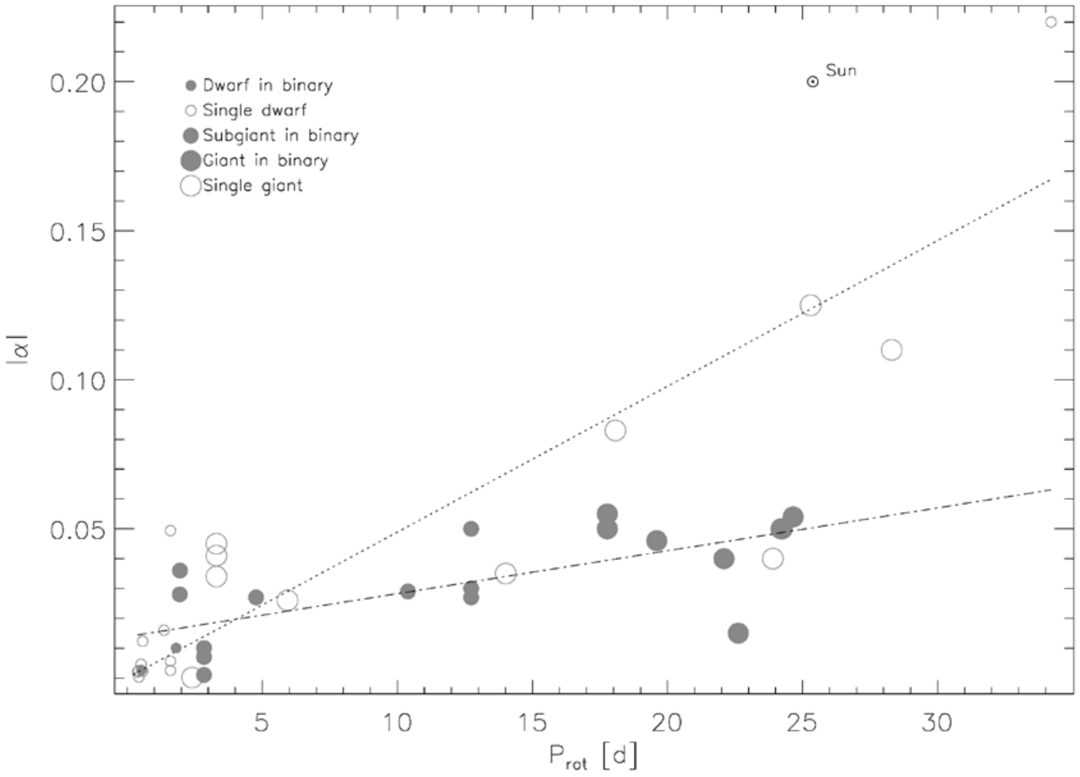
(Mar-Oct 2018)

Average surface shear:



Kővári et al. 2024

Confined DR for members in CBs



Kővári et al. 2017 (updated)

$$\Omega(\beta) = \Omega_{eq}(1 - \alpha \sin^2\beta)$$

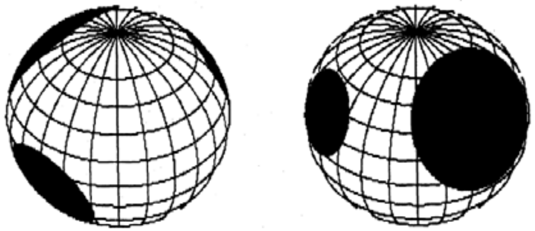
$$\alpha = (\Omega_{eq} - \Omega_{pol}) / \Omega_{eq}$$

- P_{rot}–dependence of the shear parameter (“relative DR”)
- Bimodal relationship:
  - Members in close binary systems show confined DR

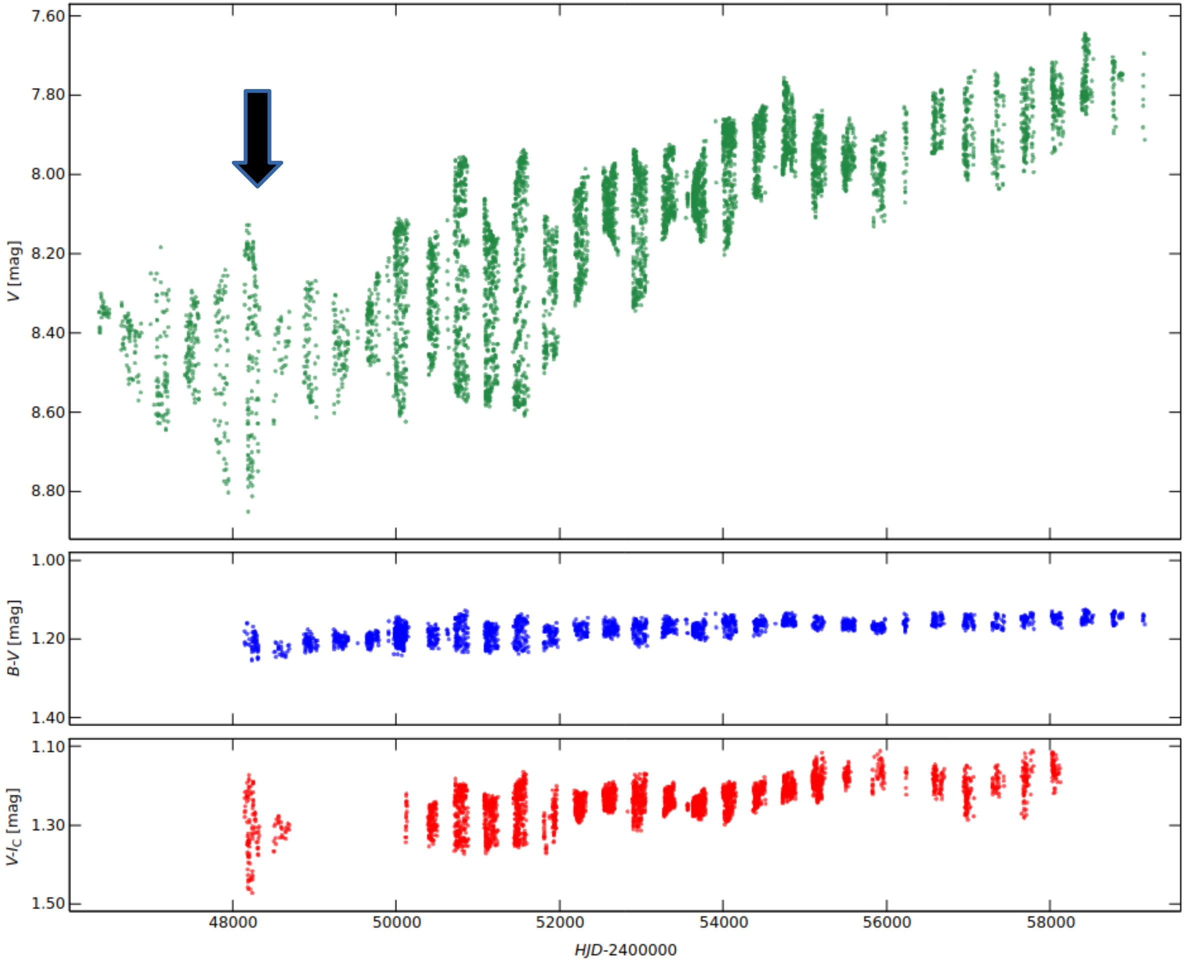
See also Lurie et al. 2017

“The most spotted star in the sky”

- XX Tri
- K0III+M3-5V(unseen)
- $P_{rot} \sim P_{orb} = 24$d



Strassmeier & Oláh 1992



16-yr spot evolution of XX Tri

- Exceptional dataset from STELLA (2006-2022):
  - ~2000 HiRes spectra (R~55000) over 16 years
  - → 99 Doppler images
  - → movie

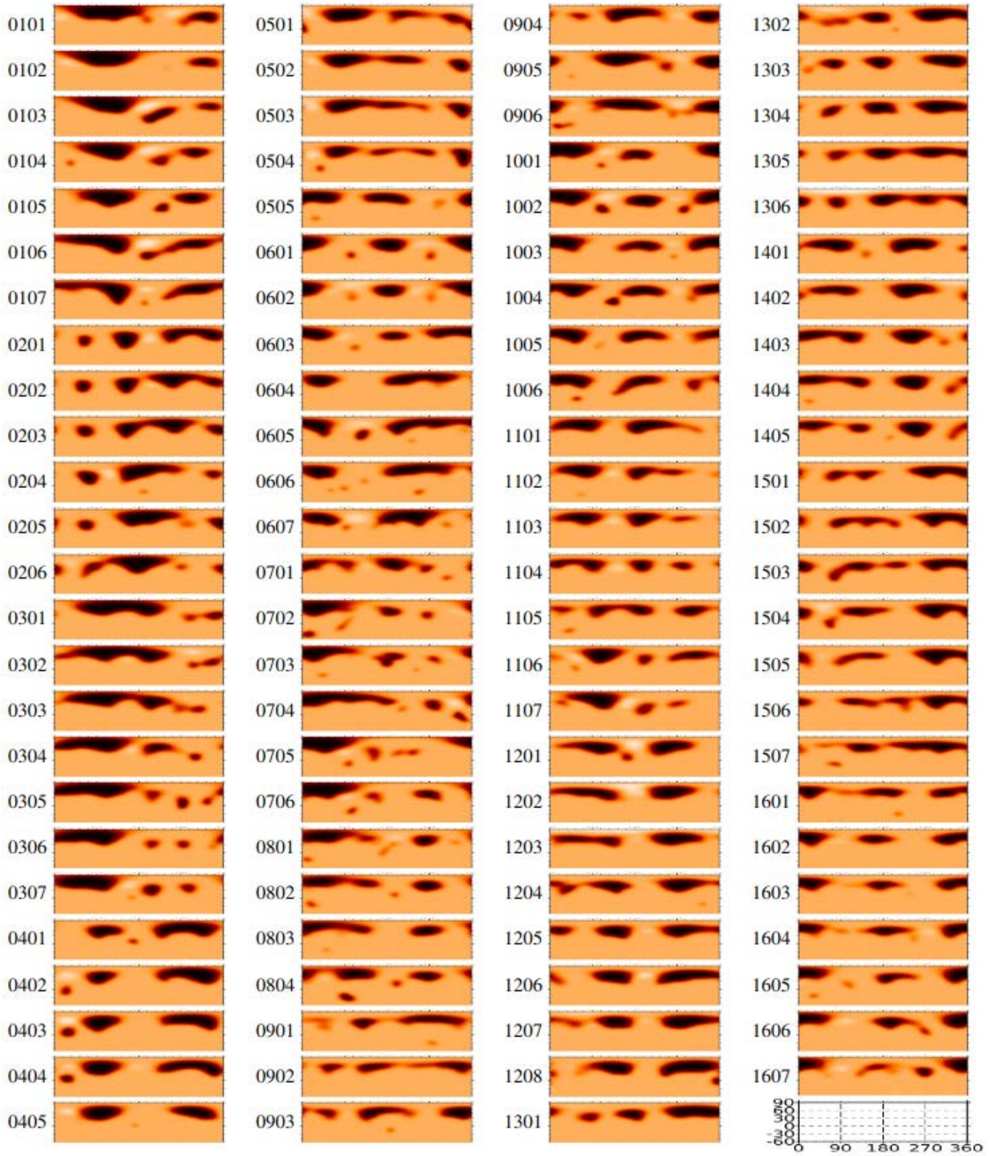
STELLA Robotic Observatory
(AIP+IAC)

Doppler imaging of XX Tri

High-latitude cool spots

- Active longitudes? -Yes
- Bound to orbit? -No

(Strassmeier et al. 2024)

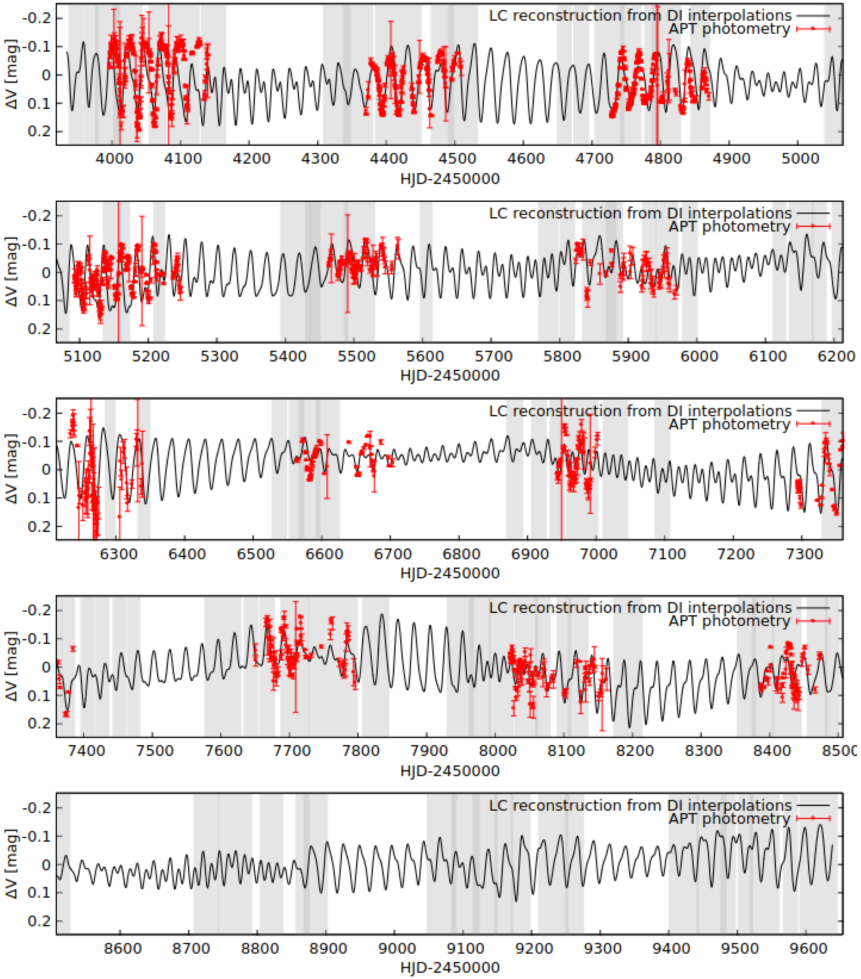


The movie

The real-time coverage is 237 stellar rotations, or 5670 days (Aug. 2006–Feb. 2022, Strassmeier et al. 2024)

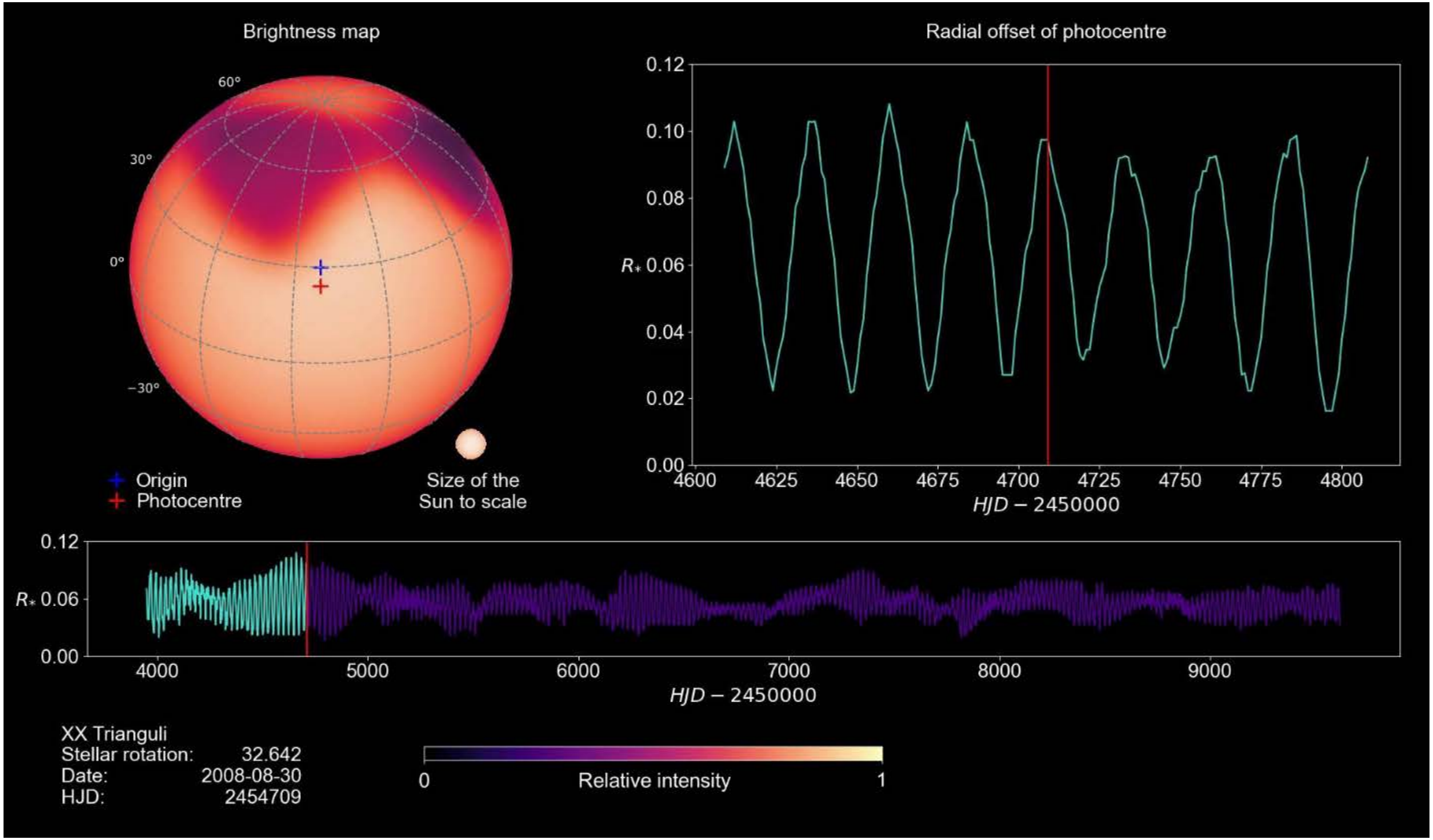
XX Tri: A chaotic non-periodic dynamo

- Huge starspots at high latitudes ~1000 K cooler than the unspotted surface
- Active longitudes unbound to orbit
- Systematic starspot emergences, decays, and also seemingly erratic spot rearrangements over 16 years.
- A more chaotic dynamo than the Sun's
- cf. "No Sun-like dynamo…" in the case of ζ Andromedae, another K-giant in a CB



Strassmeier et al. 2024

A new aspect worthy of attention:



The photocenter of XX Tri

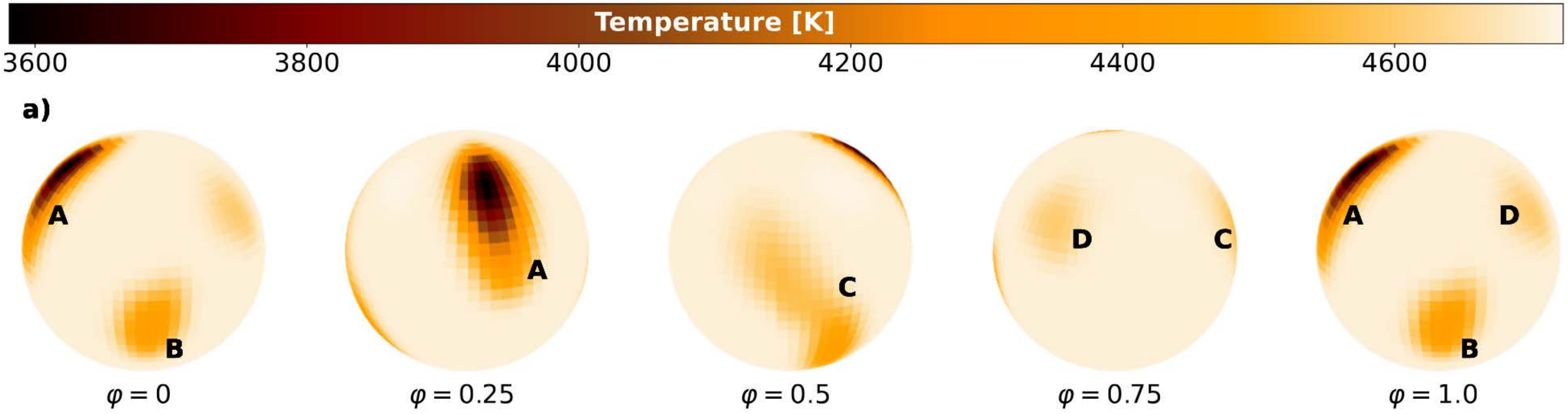
Average photocenter displacement
over 16yr is 6% of the radius (d=640 ly) ~15μas

Maximum photocenter displacement (0.1 R*) ~24μas

Gaia DR3 parallax error ~ 28μas
(Gaia collaboration 2022)

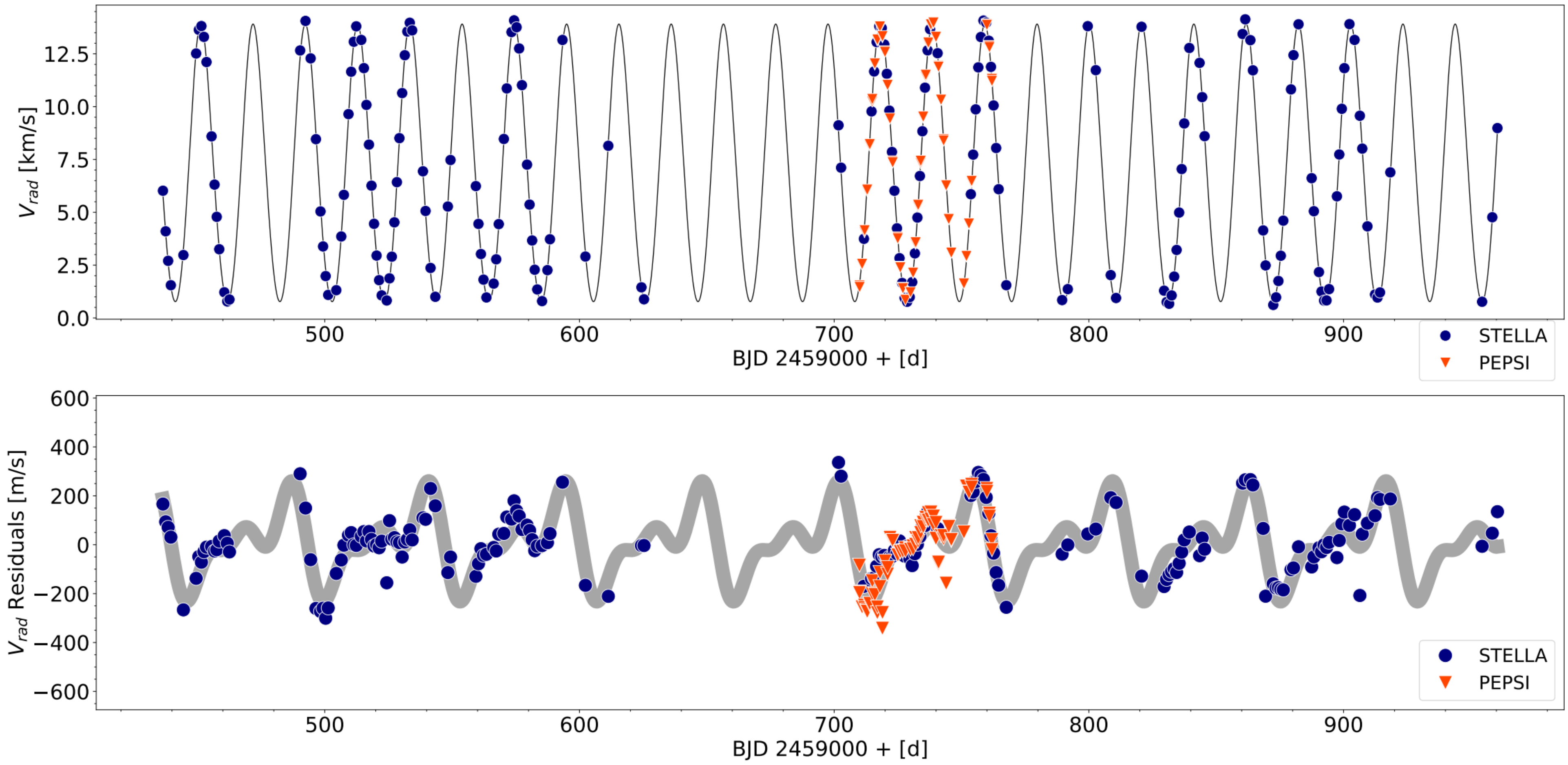
Starspots on the RS CVn binary λ And

- SB1 binary with a G8 III-IV primary, P_{orb} = 20d, e = 0
- **Asynchronous rotation**: P_{rot} = 54.4d ($v \sin i$ = 7km/s ⟶LBT spectra, R= 250,000)
- Doppler imaging ⟶cool spots (spot A reaching ~1000 K contrast)



Adebali et al. 2024

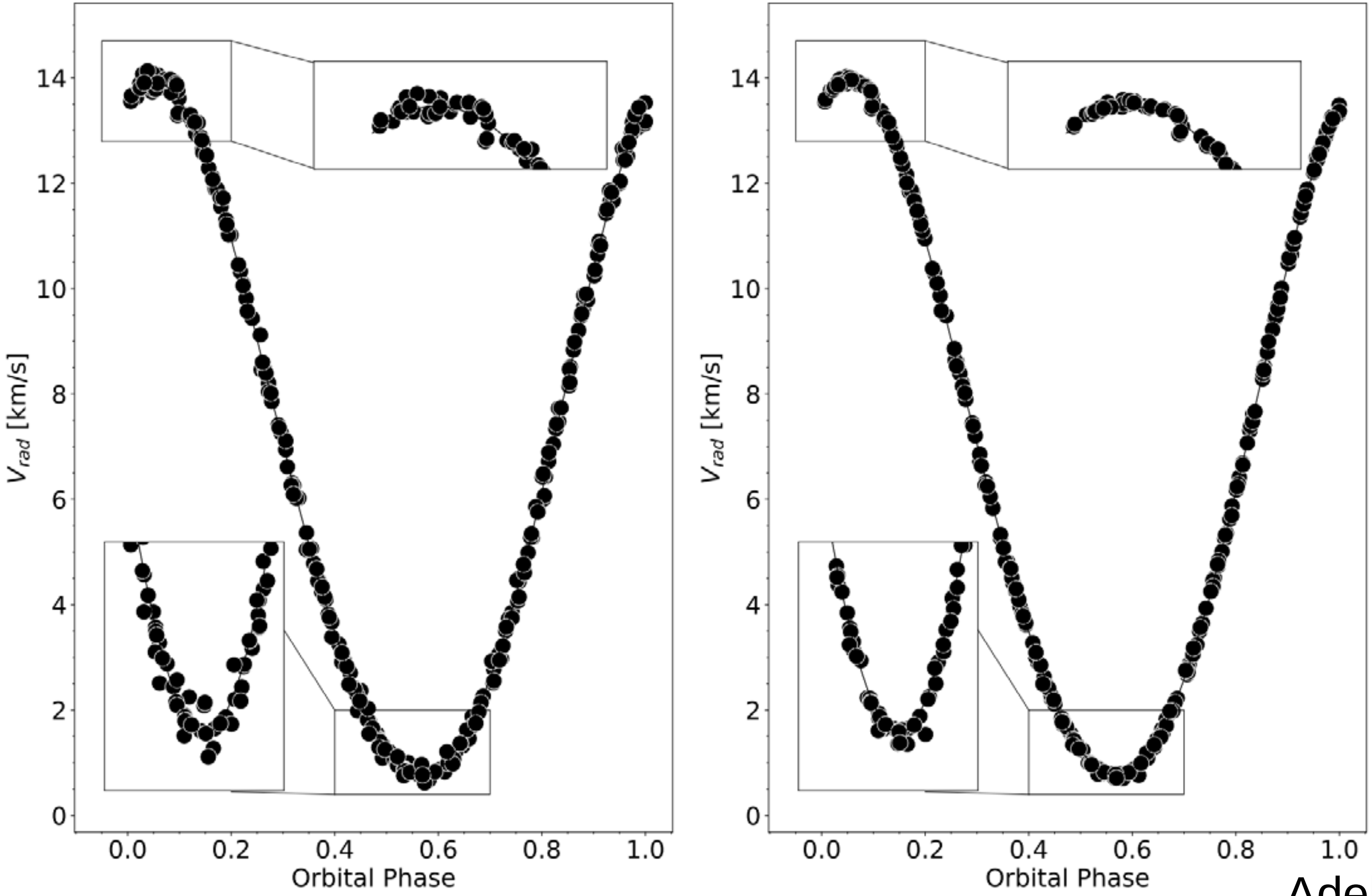
Long-lived spots on λ And



Adebali et al. 2024

Spot-corrected RV curve

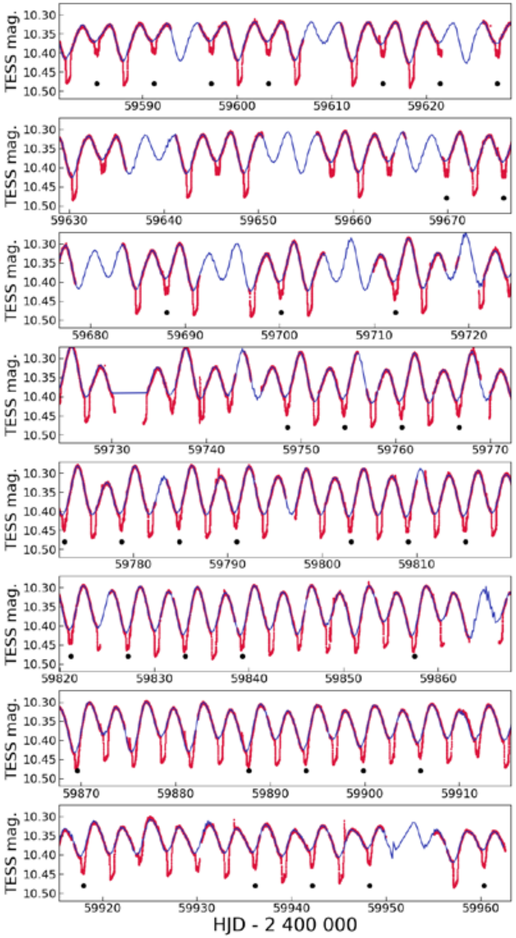
before–after

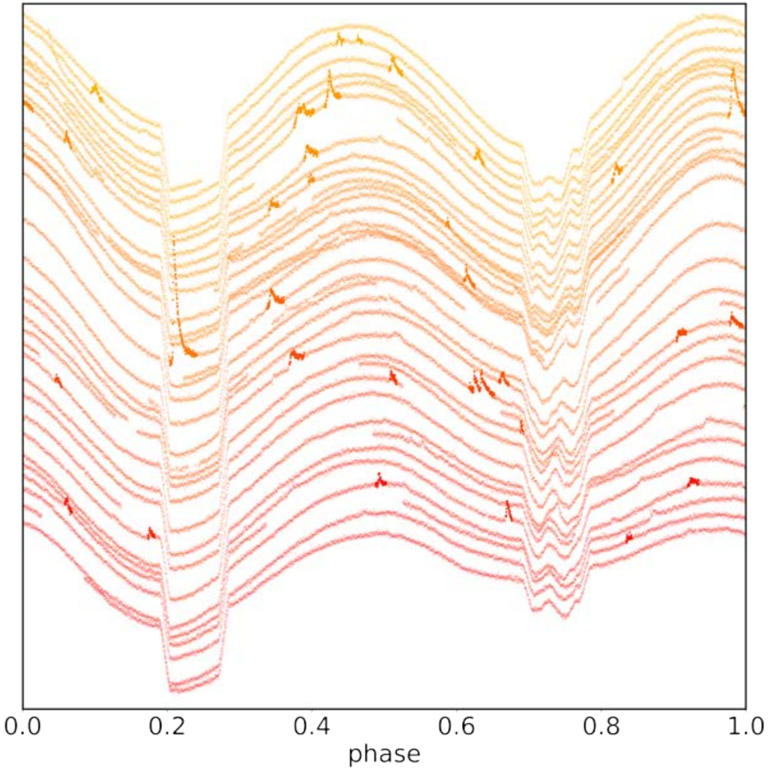


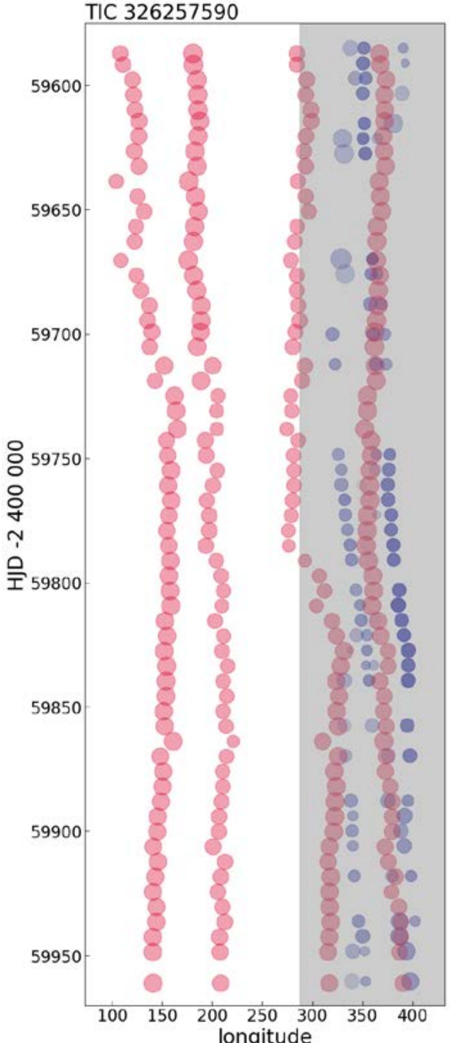
Adebali et al. 2024

Eclipse/transit mapping

TIC 326257590: K0IV+M?V



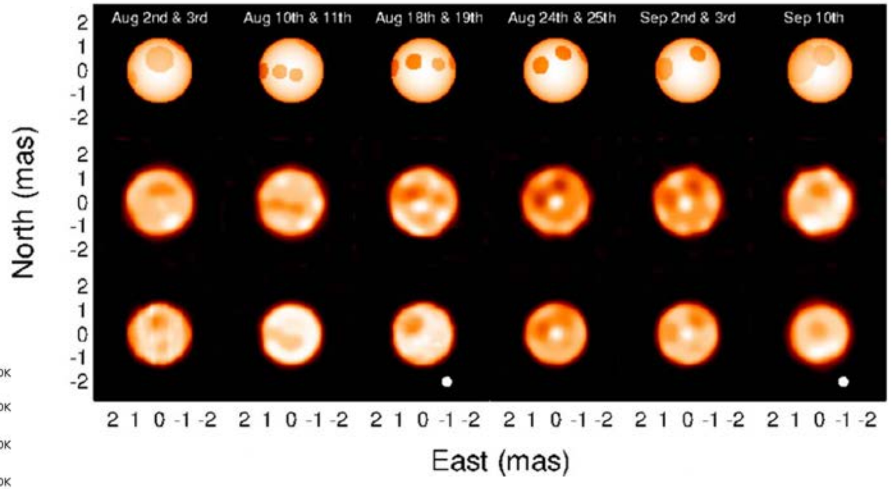




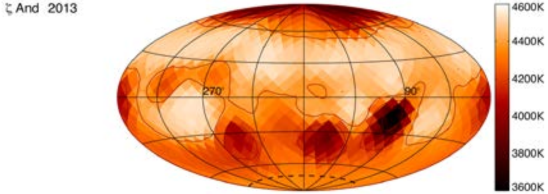
Oláh et al. in prep.

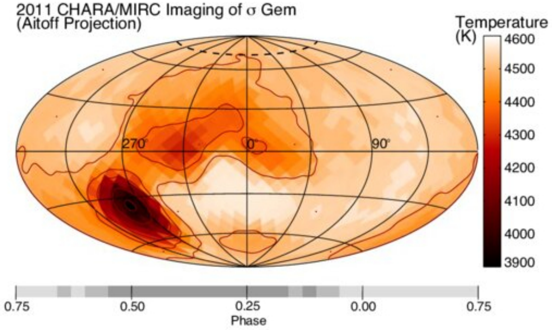
Direct imaging of starspots of giants in RS CVn binaries

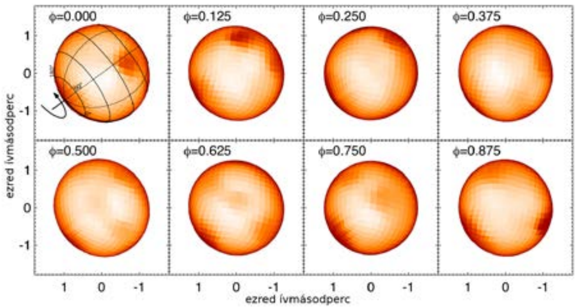
Parks et al.



- ζ And, σ Gem (Roettenbacher et al. 2016, 2017)
- λ And (Parks et al. 2021)
- Polar spots are indeed real!
- Hemispheric differences can be remarkable
- “No Sun-like dynamo…”







Roettenbacher et al. 2016, 2017

Activity phenomena in CBs

Phenomenon	Characteristic
Starspots	Relatively stable spot coverages
Activity cycles	Irregularity, multiplicity, modulation
Active longitudes	Quite common, not necessarily bound to orbit
Surface differential rotation	Usually confined compared to singles
Flare activity	Flares commonly observed, not always coupled to orbit
Interbinary activity	Extended coronal loops, coupled magnetic fields, mass transfer
Magnetic dynamo	Giants: chaotic, non-periodic, not solar like MS: diverse