Leibniz-Institut für
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Spot evolution on the red giant star XX Triangulum

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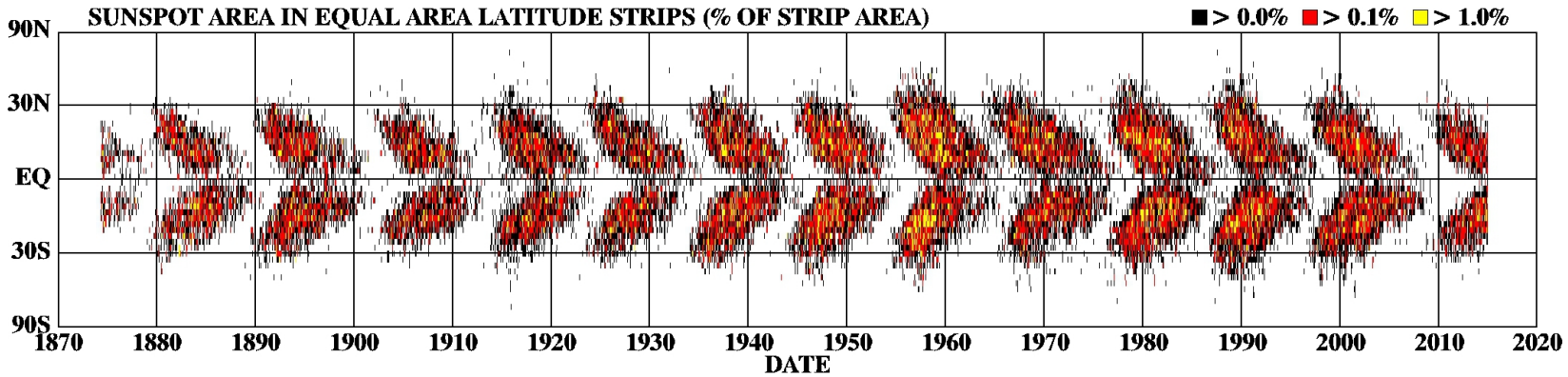
Sunspots & solar activity

Sunspot properties

- Area: up to 0.2% of SH,
  1 SH = 3.05 Gm^2
- Lifetime: up to 4 months
- Decay: quasi-linear,
  $dA/dt = D$, $D \approx$ MSH/day
- Cycle: ≈ 11 years

http://sohowww.nascom.nasa.gov/sunspots/



NASA/Hathaway: http://solarscience.msfc.nasa.gov/SunspotCycle.shtml

Starspots & stellar activity

Observations

- Photometry:
  Lightcurve variations
- Spectroscopy:
  Line profile distortions
  Hα- / Ca II H&K - emission
- Doppler imaging (DI) & ZDI

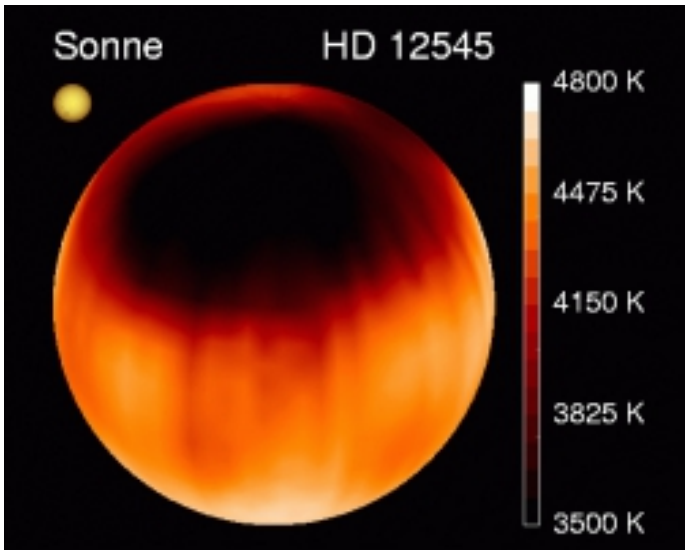
Activity phenomena

- Spots
- Active longitudes
- Flip-flops
- Differential rotation
- Cyclic activity

Starspots

- Area: up to a few tenth
- Position: all latitudes
- Lifetime: up to years/decades
- Decay: *unknown*

XX Tri (= HD 12545) :



Strassmeier 1999, A&A, 347, 225

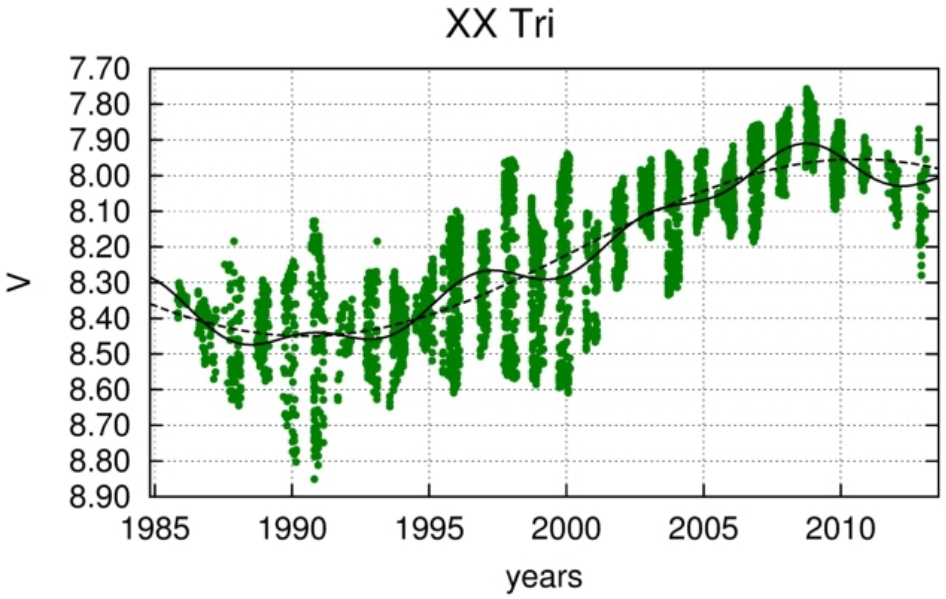
XX Triangulum (1)

Activity signatures

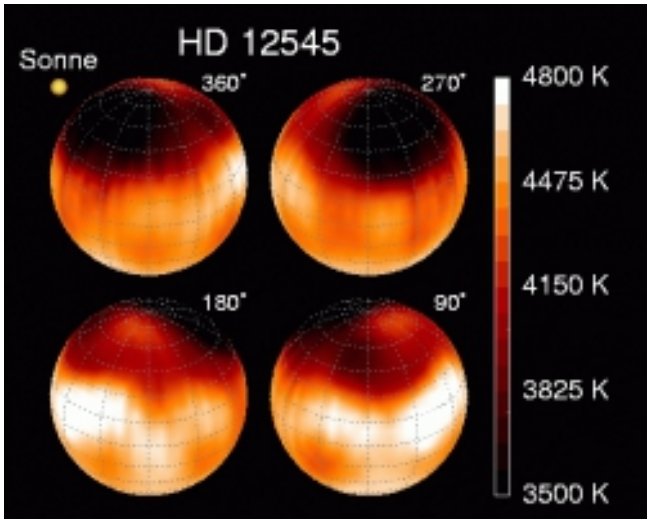
- Large lightcurve variations
  → photospheric activity
- Strong Ca II H&K emission
  → chromospheric activity

Detection of 'superspot'

- Large polar spot
  → 11% of stellar surface
  → 12 x 20 $R_\odot$
- Smaller cool and hot spots



Oláh et al. 2014, A&A, 572, A94

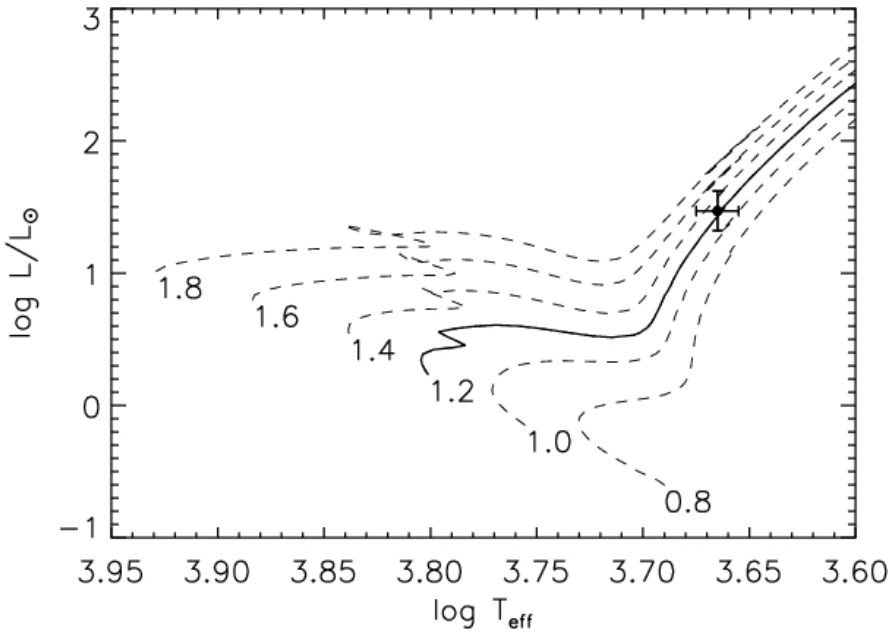


Strassmeier 1999, A&A, 347, 225

XX Triangulum (2)

Stellar and orbital properties

- RS CVn-type binary star (SB1)
- Spectral class K0III
- $P_{orb} \approx P_{rot} \approx 24.0$ days
- $d \approx 160$ pc, $V_{mag} = 7.76$
- $L = 30 \pm 10\ L_{\odot}$
- $T = 4620 \pm 30$ K
- $R = 10.9 \pm 1.2\ R_{\odot}$
- $M = 1.26 \pm 0.15\ M_{\odot}$
- Age = 7.7 ± 3.1 Gyr

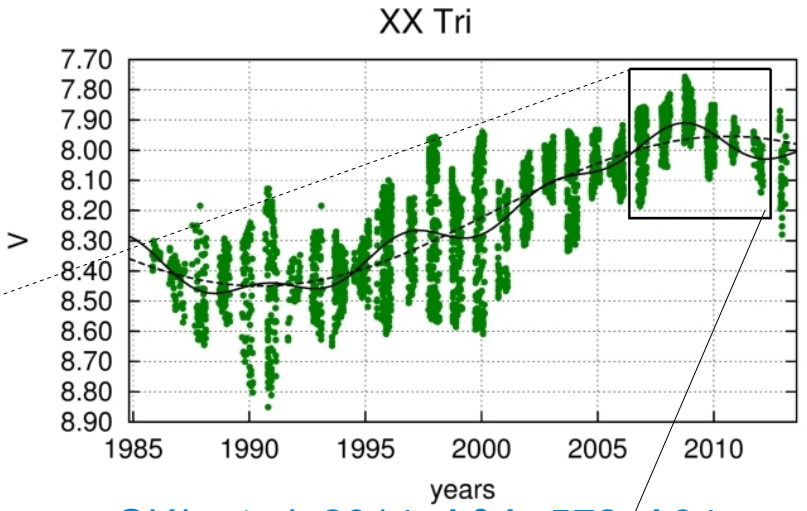


Künstler et al. 2015, A&A, 578, A101

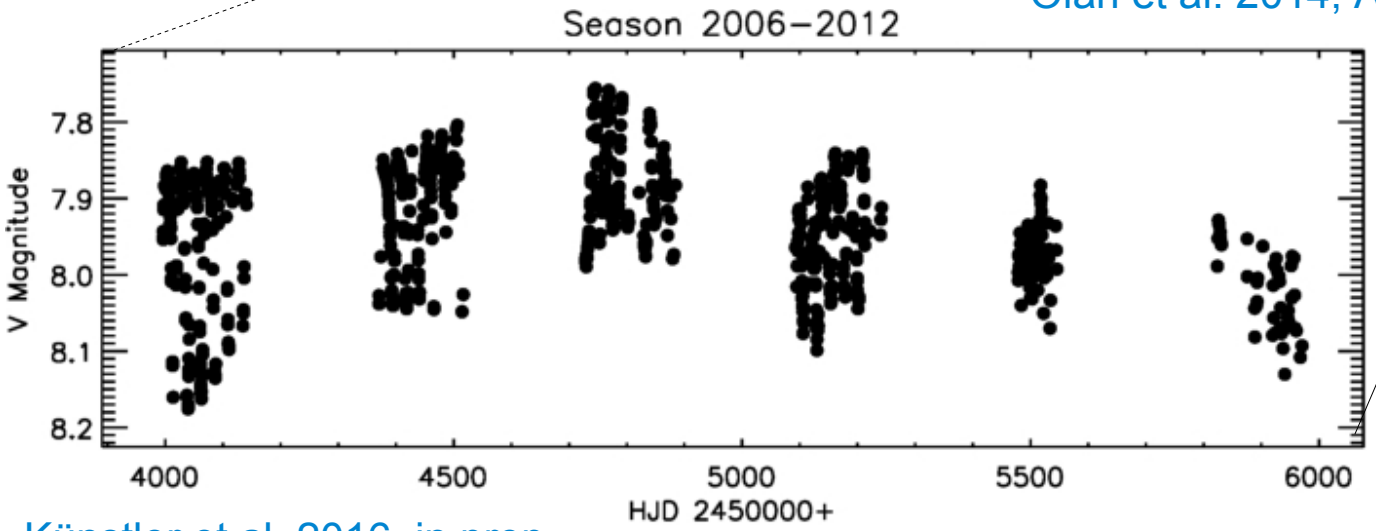
APT photometry

Photometric analysis

- P_{rot} = 23.97 ± 0.03 days
- V_max = 7.76 mag
- Cycles: 6, 12, 28 years (Oláh et al. 2014)



Oláh et al. 2014, A&A, 572, A94



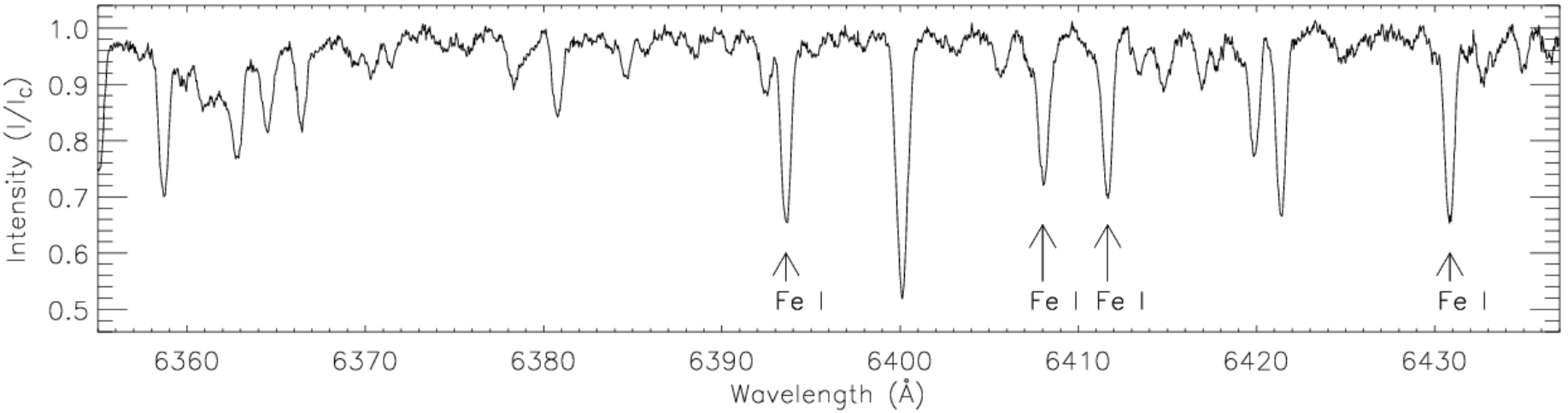
Künstler et al. 2016, in prep.

Spectroscopy (1)

STELLA SES data

- July 2006 – April 2012
- 667 usable spectra
- Optical range: 390 – 880 nm
- R = 55,000
- S/N ≈ 150

Credit: M. Weber (AIP)



Künstler et al. 2015, A&A, 578, A101

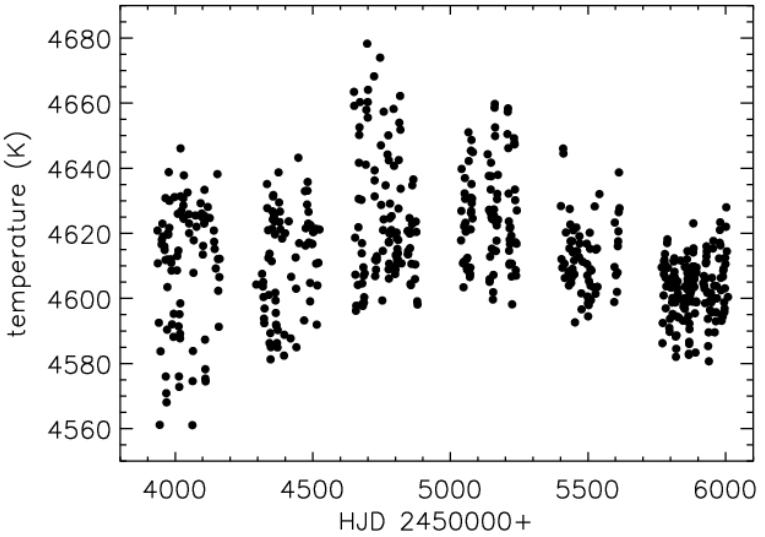
Spectroscopy (2)

PARSES analysis

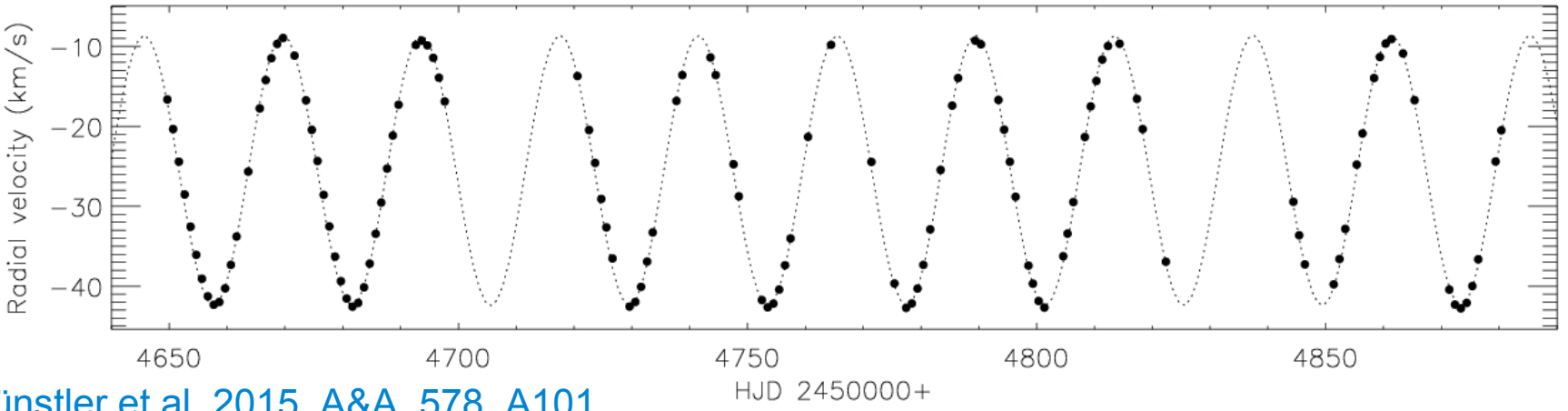
- T = 4620 ± 30 K
- Log g = 2.82 ± 0.04
- V sin i = 19.9 ± 0.7 km/s
- [Fe/H] = - 0.13 ± 0.04 dex

Radial velocity fit

- P_{orb} = 23.9674 ± 0.0005 days



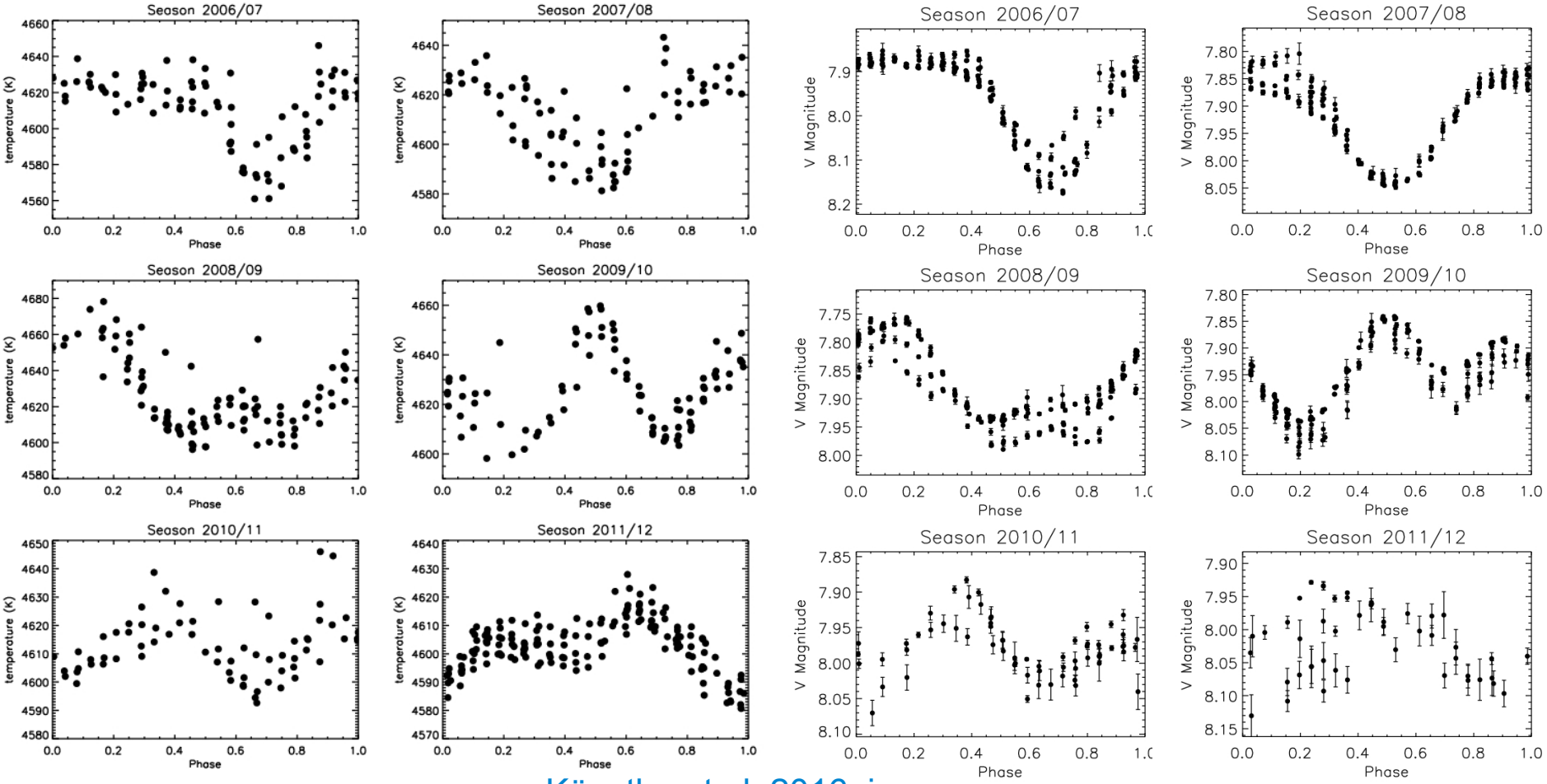
Künstler et al. 2015, A&A, 578, A101



Künstler et al. 2015, A&A, 578, A101

Rotational spot modulation (1)

Spectroscopy vs. Photometry

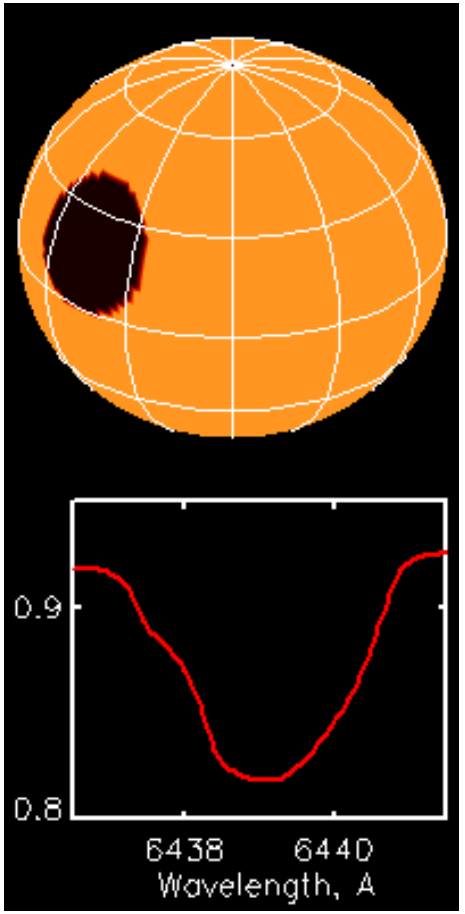


Künstler et al. 2016, in prep.

Doppler imaging

Methodology

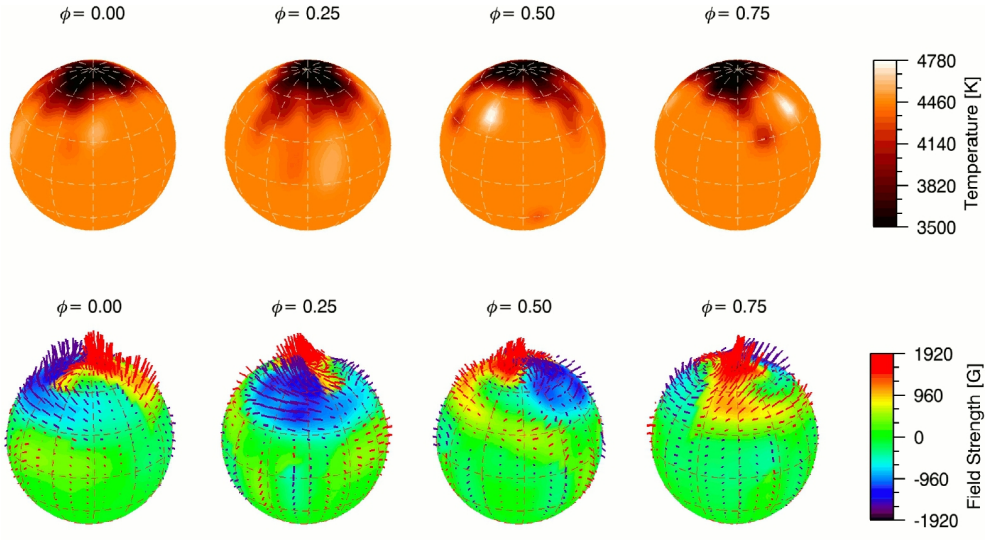
- Stellar surface mapping
- Rotational broadened line profiles
- Doppler effect
- Spots cause local distortions
- Fully covered rotation constrains the location of spots
- Inversion of a time series of line profiles results in a temperature map



Berdyugina: http://www3.kis.uni-freiburg.de/~sveta/Starspots/starspots.html

Inversion code *iMap*

- DI (& ZDI) code (Carroll et al. 2012)
- Multi-line inversion
- Full radiative transfer (LTE)
- Kurucz model atmospheres
- Input parameters: T_{eff}, log g, metallicity, inclination, v sin i, microturb, macroturb



V410 Tauri: Carroll et al. 2012, A&A, 548, A95

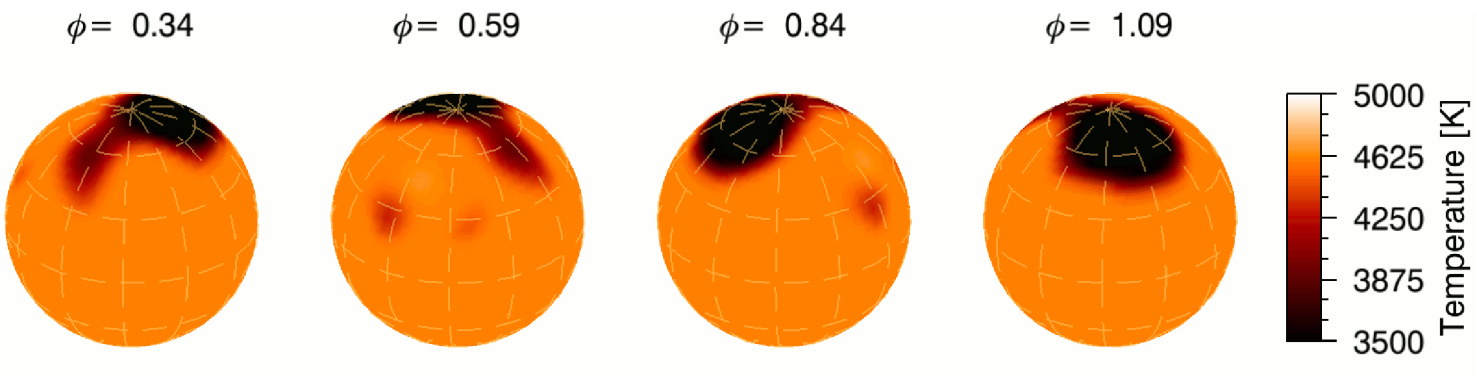
Time-series of Doppler maps

Time-series

- 36 maps in total
- 5 to 7 maps per season
- Covering 86 rotations

Spot appearance

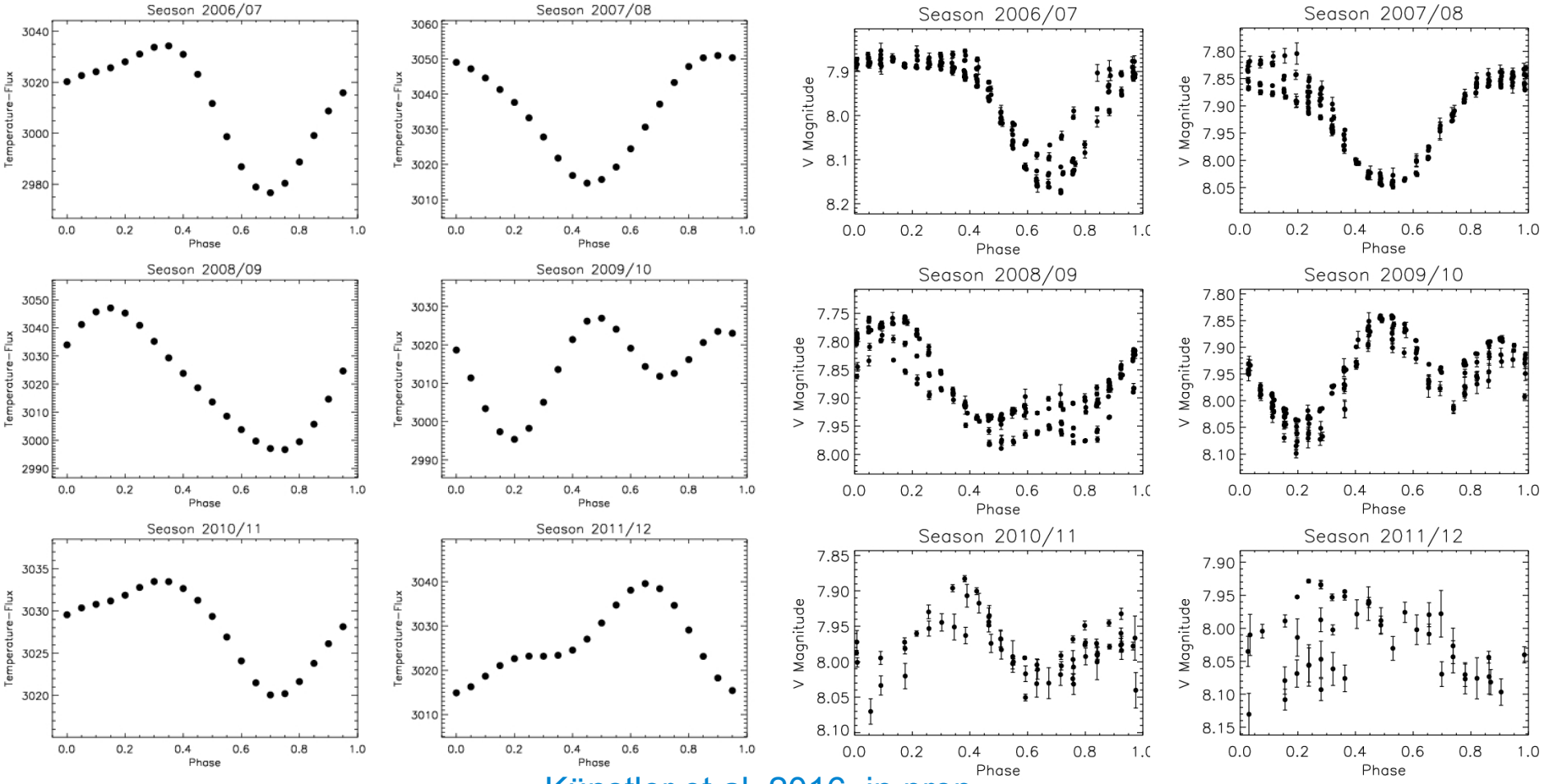
- Large high-latitude/polar spots
- Small equatorial spots
- Spot merging/fragmentation
- Spot decay/formation



Künstler et al. 2015, A&A, 578, A101

Rotational spot modulation (2)

Doppler maps vs. Photometry

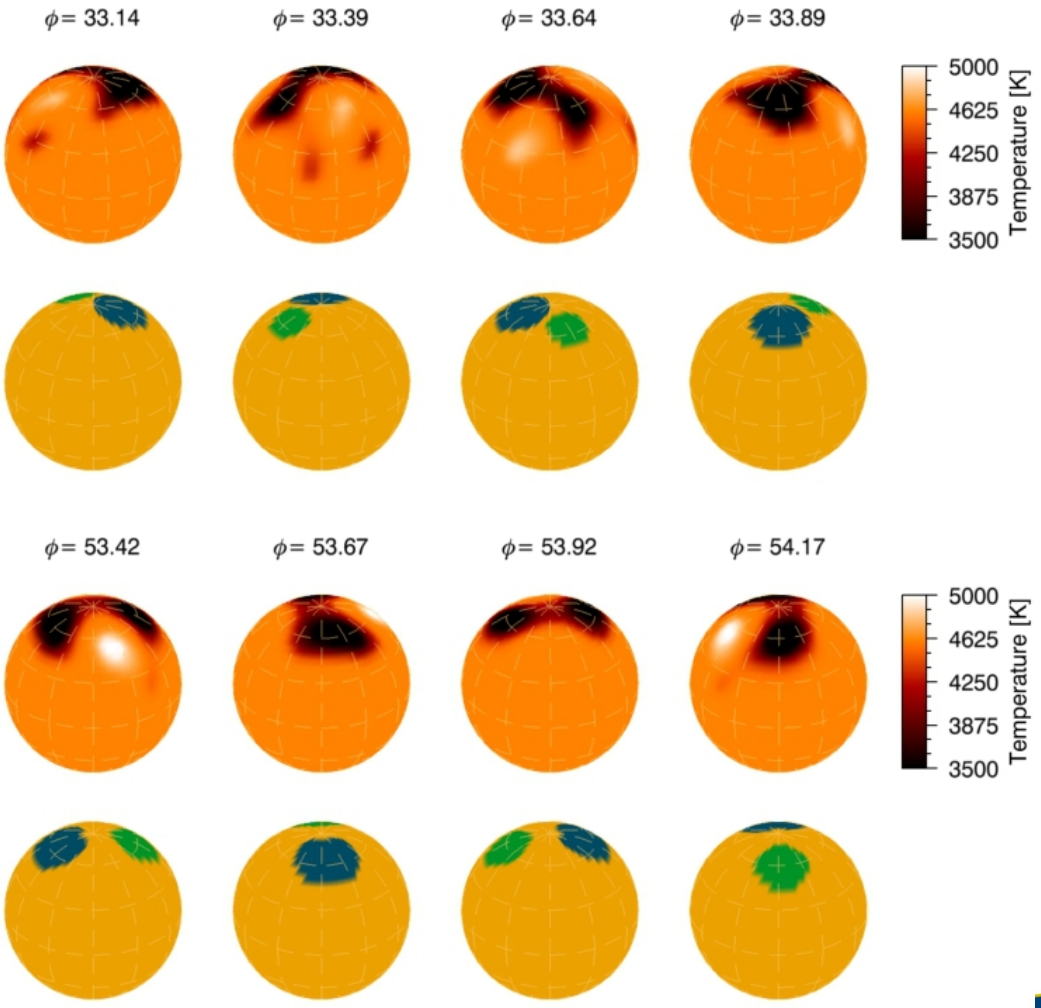


Künstler et al. 2016, in prep.

Spot area determination

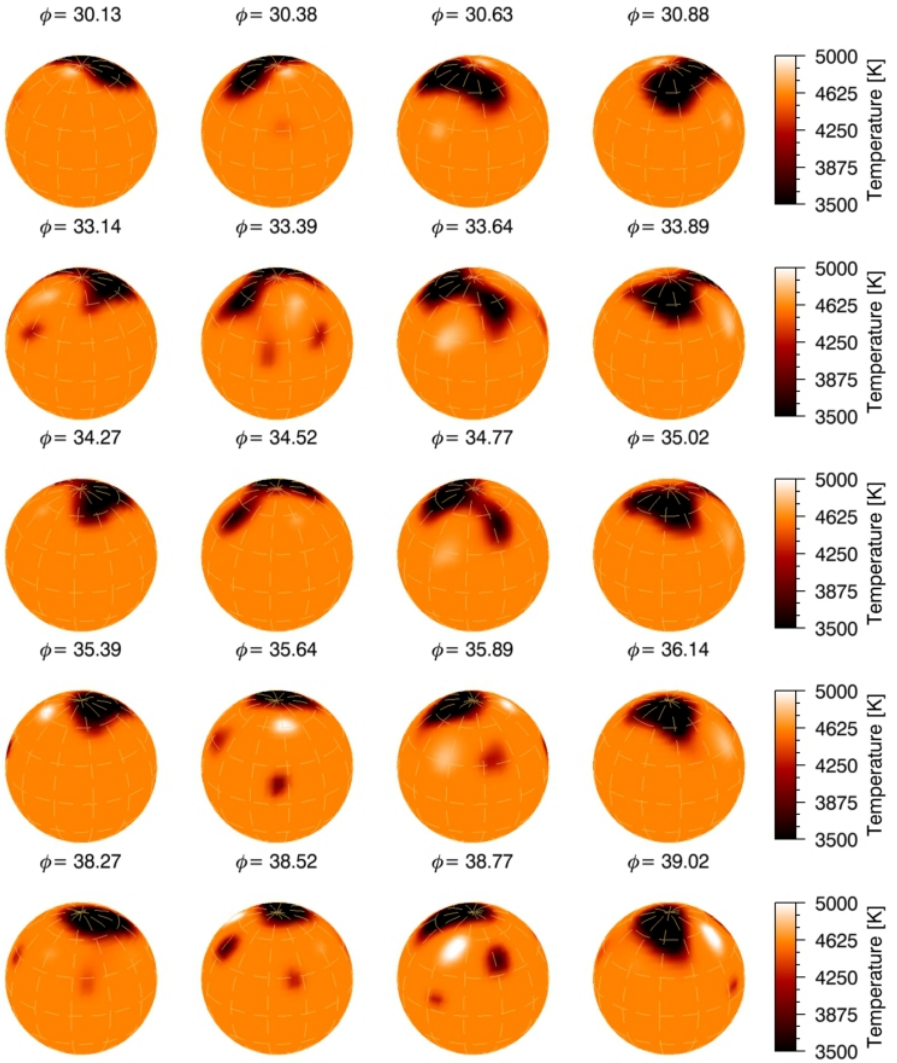
N-spot modeling

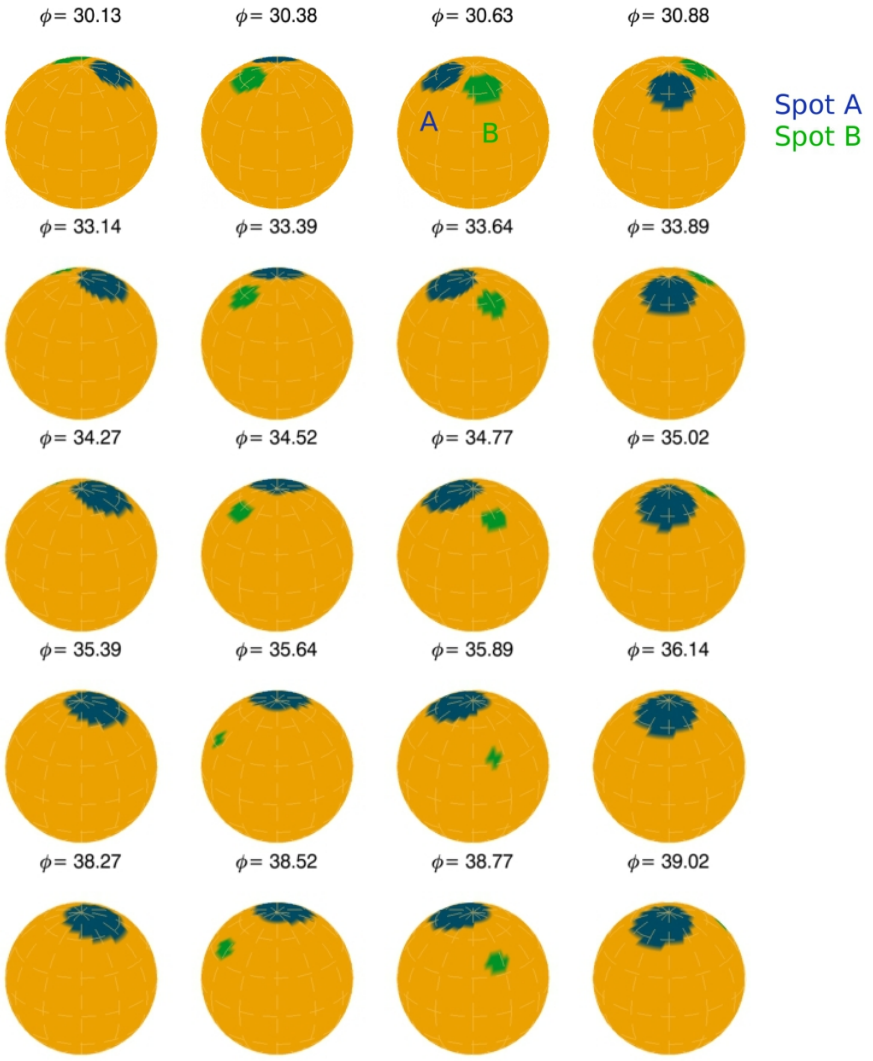
- Simple spot-models with circular shape and const T
- Cross-correlation between spot-model map and DI
- Monte-Carlo approach
- 10,000 randomly distributed spot configurations
- Free parameters: latitude, longitude, radius



Künstler et al. 2015, A&A, 578, A101

Doppler maps & spot models



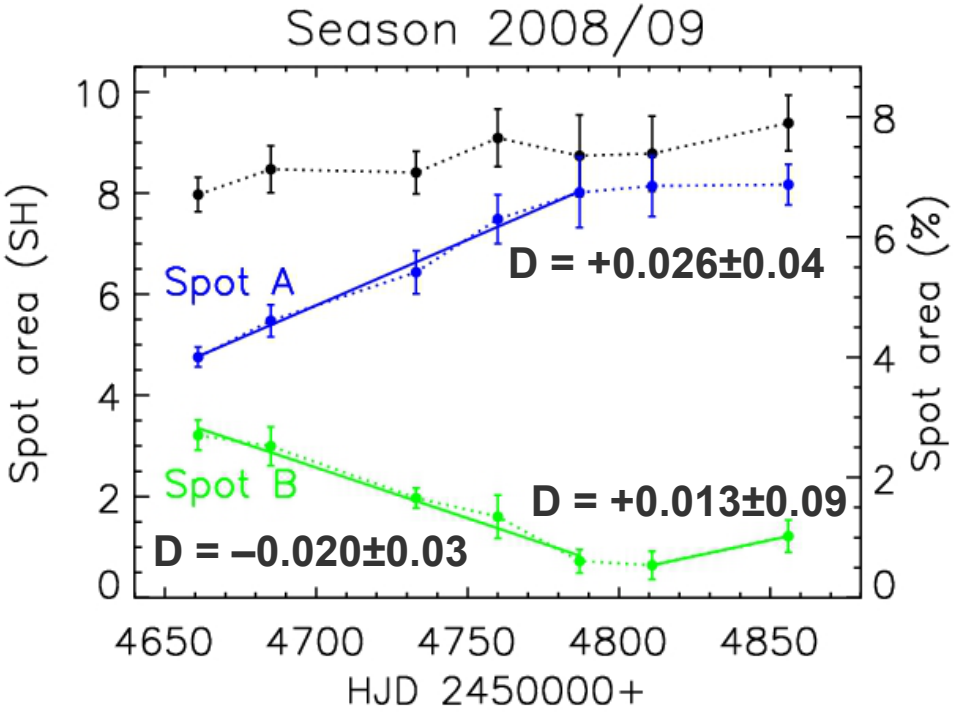


Künstler et al. 2015, A&A, 578, A101

Spot decay/formation

Linear decay law

- dA/dt = D ; [D] = SH/day, where 1 SH = 3.05 Gm^2
- Mean decay rate: –0.022 ± 0.002 SH/day
- Mean formation rate: +0.021 ± 0.002 SH/day
- 10,000 times larger than for sunspots (D ≈ MSH/day)

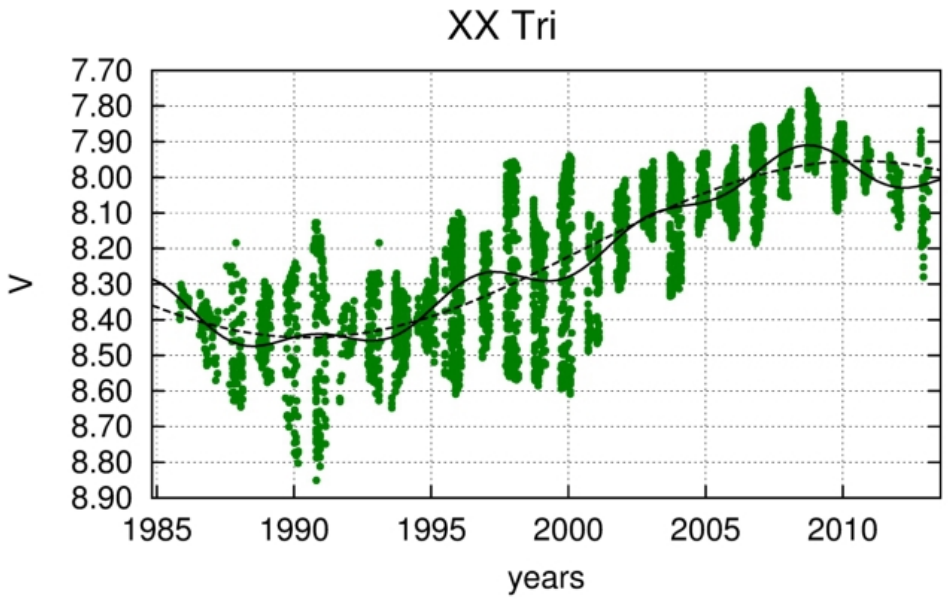


Künstler et al. 2015, A&A, 578, A101

Stellar activity cycle

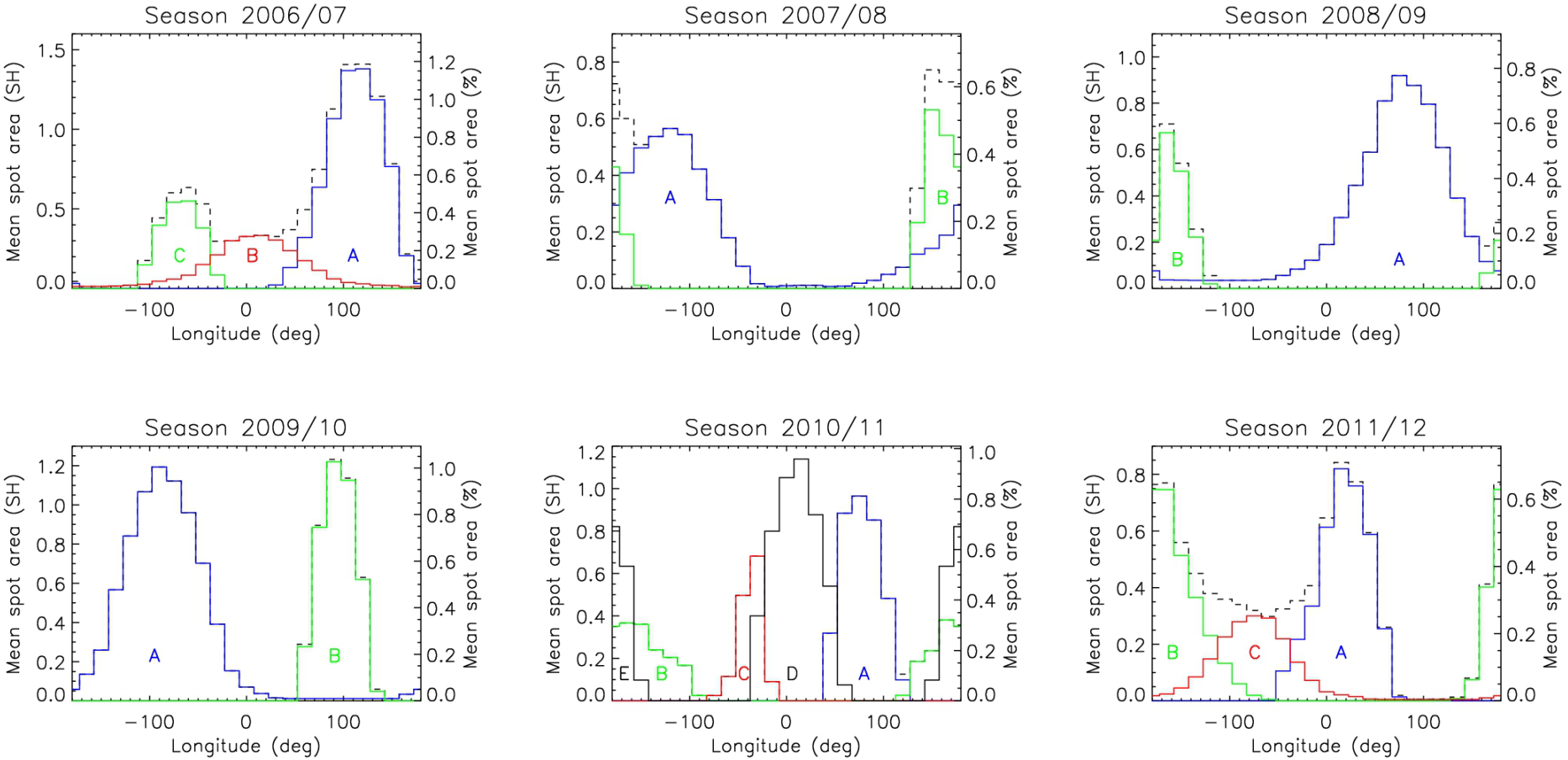
Magnetic diffusivity

- $dA/dt = D = -4\pi\eta_t$
- $\eta_t = (6.3 \pm 0.5) \times 10^{14}$ cm^2/s
- 10 to 10,000 times larger than for the Sun
- Diffusion timescale: $\tau = L^2/\eta_t = 26 \pm 6$ years, where $L^2 = 0.94\ R_{star}$
- Comparison: Photometric long-term trend of ≈ 28 yrs (Oláh et al. 2014)



Oláh et al. 2014, A&A, 572, A94

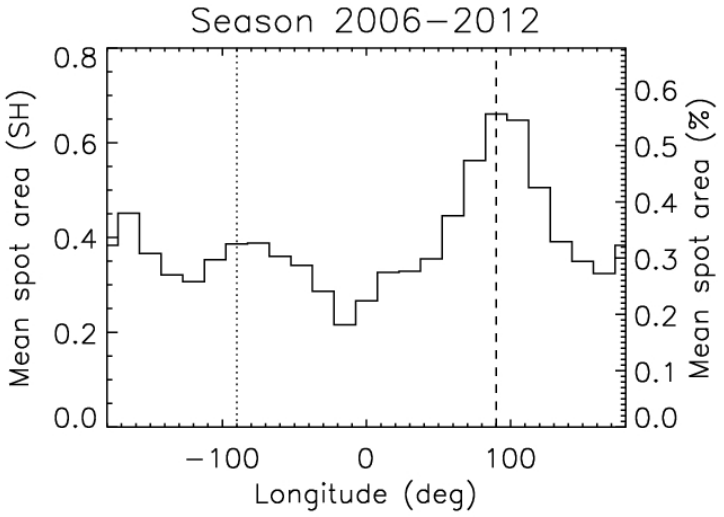
Active longitudes (1)



Künstler et al. 2015, A&A, 578, A101

Active longitudes (2)

- Active longitude towards companion star
- Flip-flop cycle of ≈ 2 years



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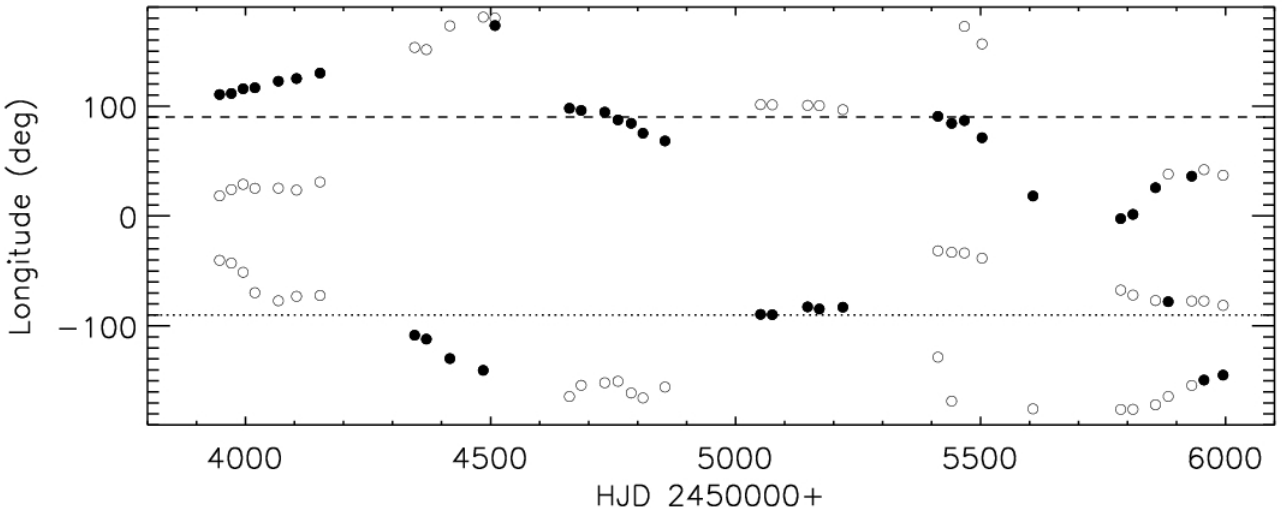
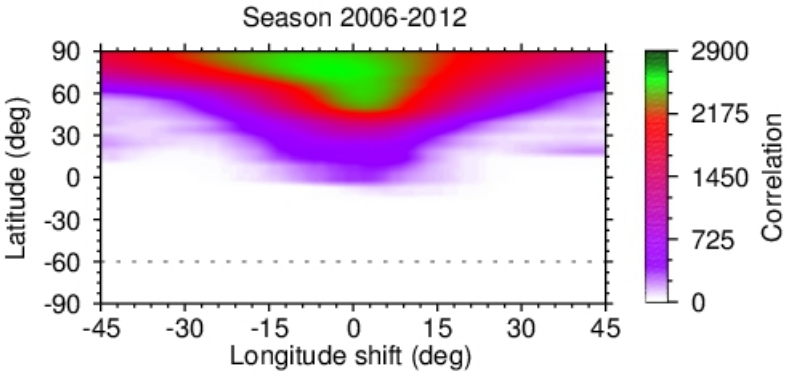


Künstler et al. 2015, A&A, 578, A101

Differential rotation

- Cross-correlation of latitudinal stripes from consecutive maps
- 29 ccf-maps in total
- $\Omega(b) = \Omega_{eq} + \Omega_1 \sin^2(b) + \Omega_2 \sin^4(b)$, where $\Omega_{pol} = (\Omega_{eq} + \Omega_1 + \Omega_2)$
- Rotational shear: $\alpha = (\Omega_{eq} - \Omega_{pol})/\Omega_{eq}$
- Result: Weak solar-like DR with $\alpha = 0.016 \pm 0.005$



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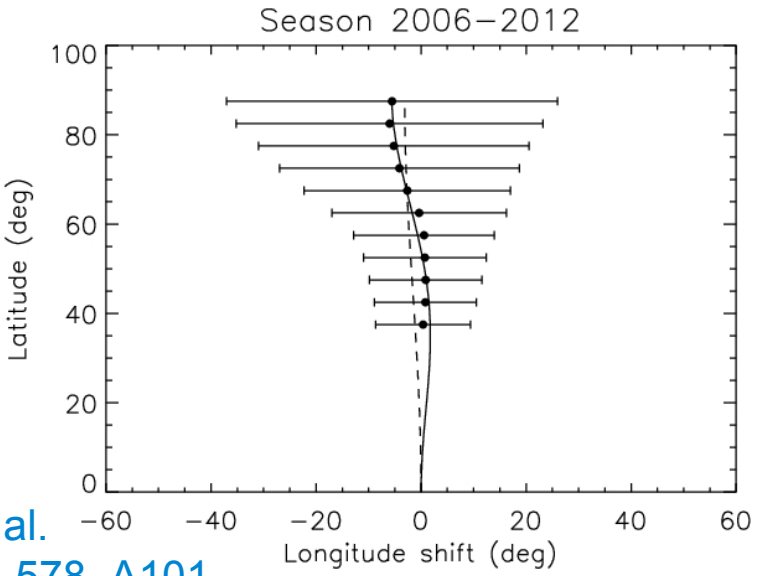

Künstler et al. 2015, A&A, 578, A101

Summary

- **Starspot decay**
  - First-time determination of a starspot decay
- **Stellar activity cycle**
  - First-time prediction of an activity cycle solely based on an observationally constrained value of turbulent diffusivity
- **Active longitudes**
  - Located towards companion star
  - Evidence for a flip-flop cycle of ≈ 2 years
- **Differential rotation**
  - Weak solar-like DR with $\alpha = 0.016 \pm 0.005$