Are starspots equivalents to sunspots?

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Outline

- How do the methods influence which starspots we see?
- Spot evolution
- Connection between spots and magnetic fields
- Other models for starspots
- Conclusions

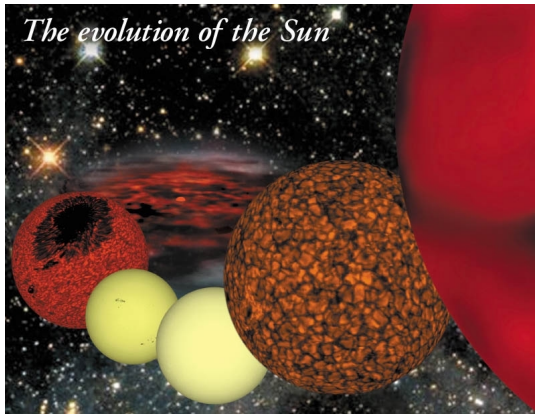
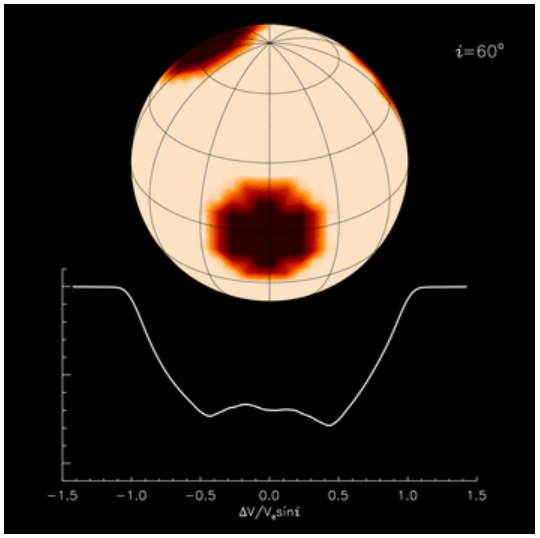


Figure: Schrijver

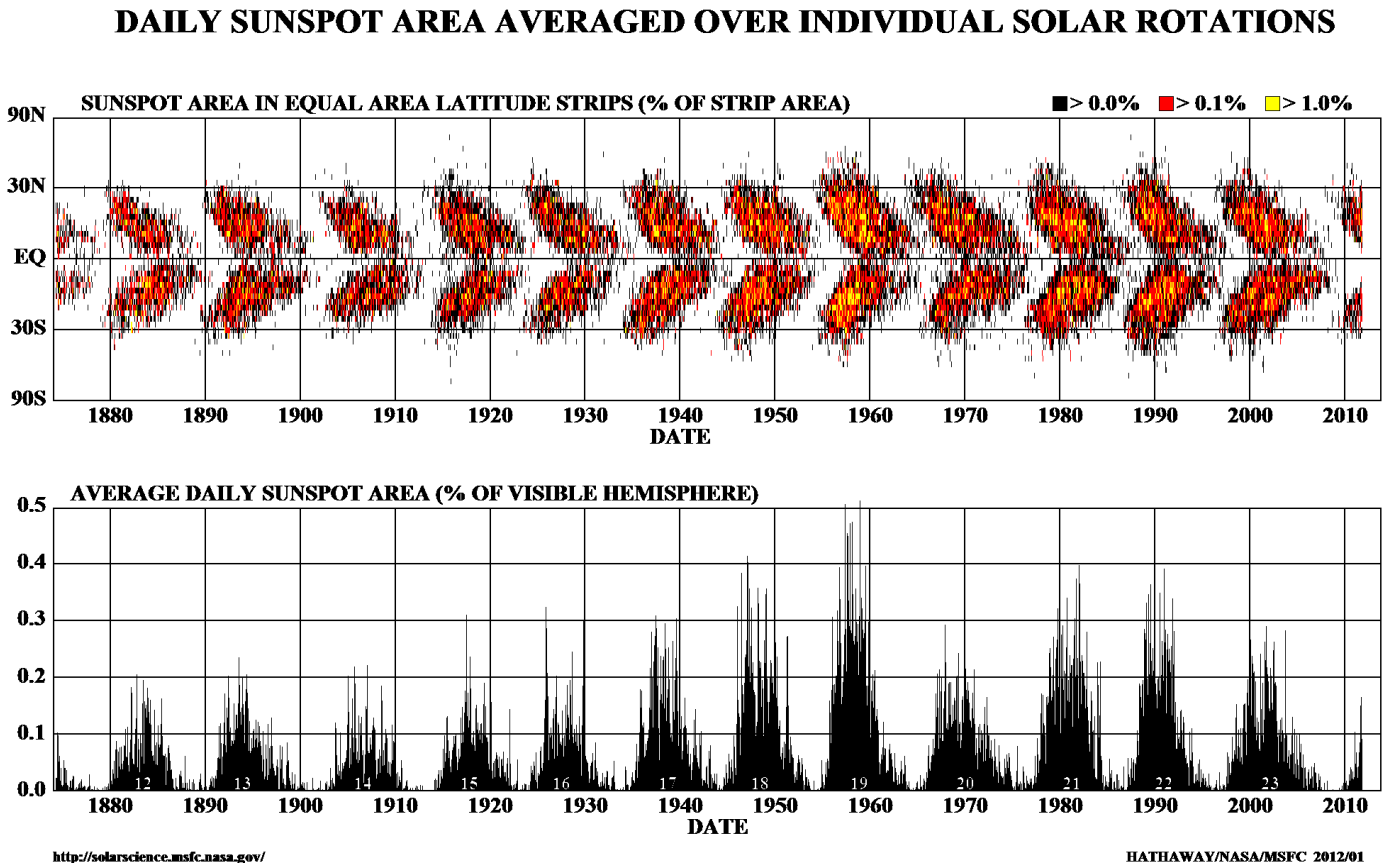
1. Methods of studying starspots

- Most methods strongly favour large spots:
  - Doppler imaging and Zeeman Doppler imaging
  - Analysis of light curves
- E.g. analysis of molecular lines => large number of small spots



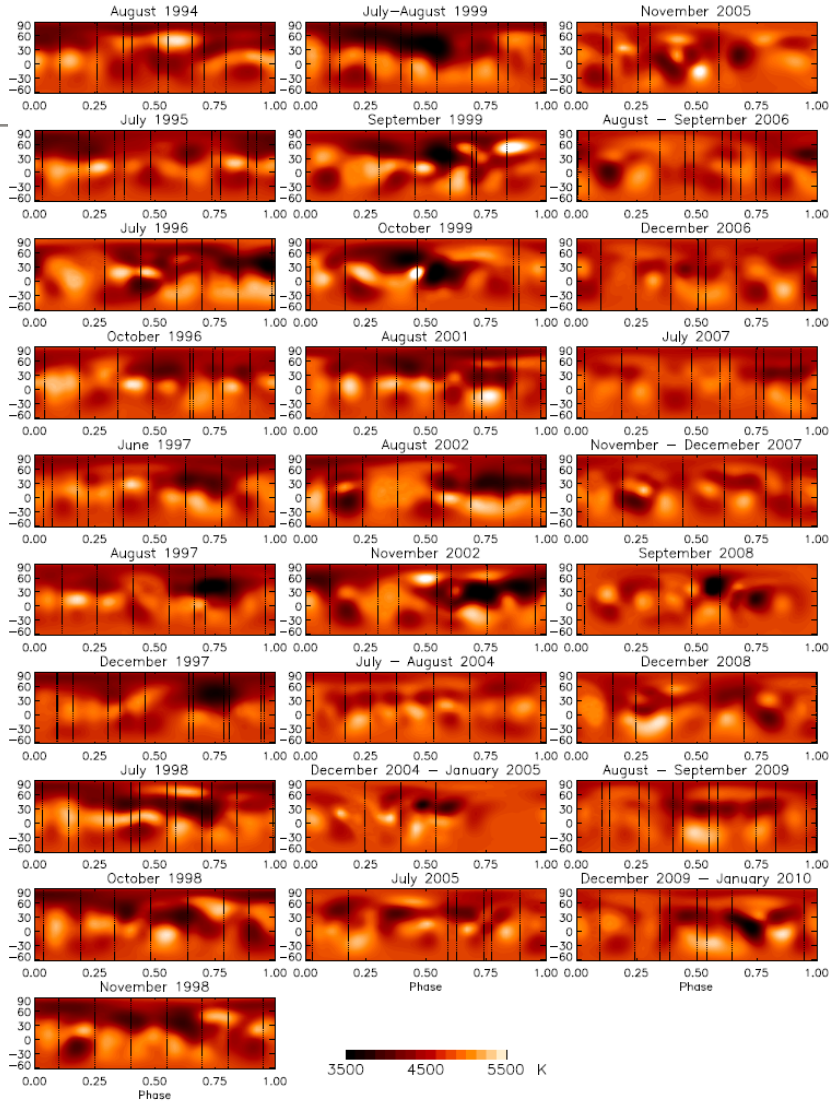
Influence of cool spots on a photospheric spectral line. Animation by O. Kochukhov.

2.1 Evolution of sunspots

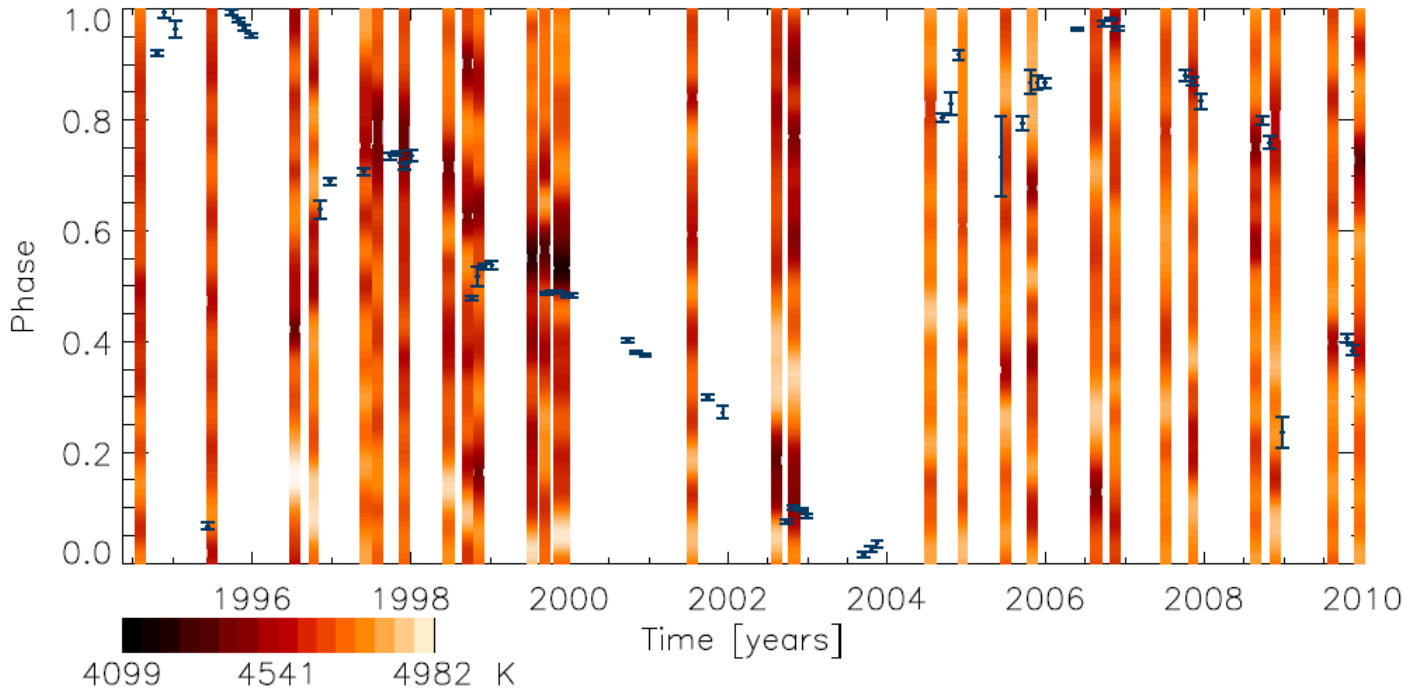


2.2 Evolution of starspots: II Peg

- 28 Doppler images from 1994-2010 (Hackman et al. 2011 & 2012):
  - No solar like butterfly diagram …
  - … but possibly azimuthal dynamo wave

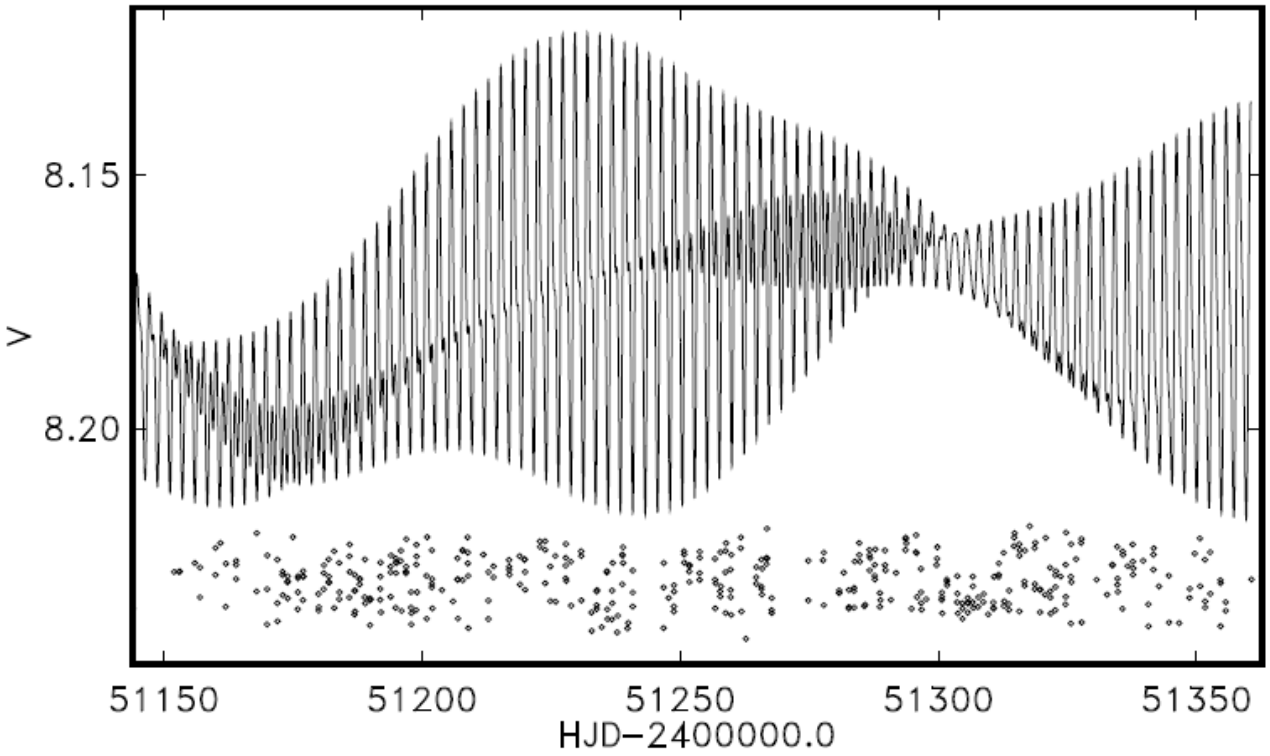


2.3 Longitudinal distribution of spots of II Peg: Azimuthal dynamo wave?



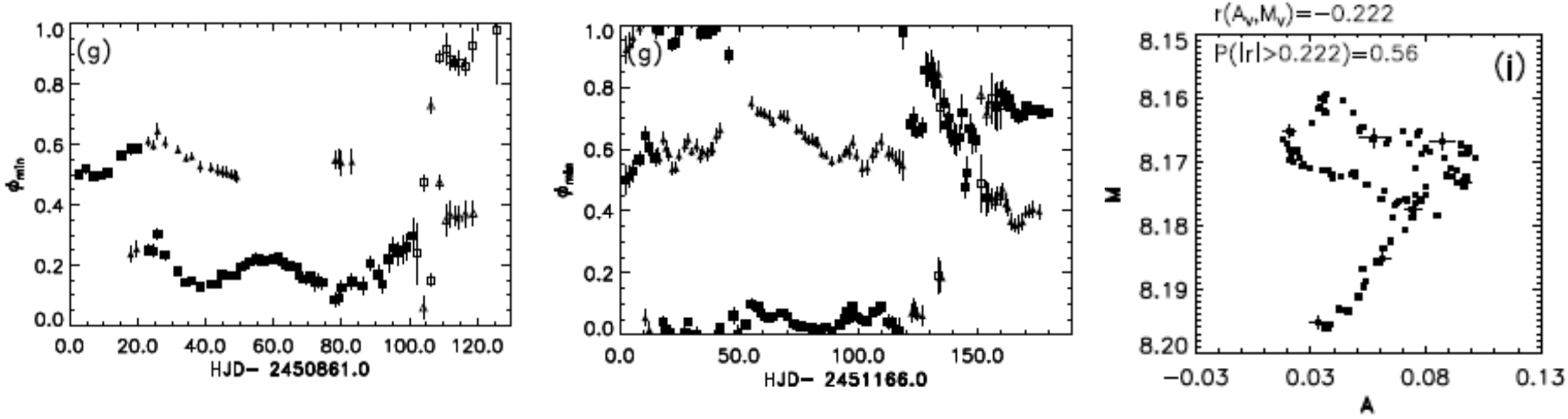
Temperature averaged over latitude and phases for photometric minimum in the orbital rotation frame P=6.^{d}724333 (Hackman et al. 2011).

2.4 Light curve evolution of FK Com



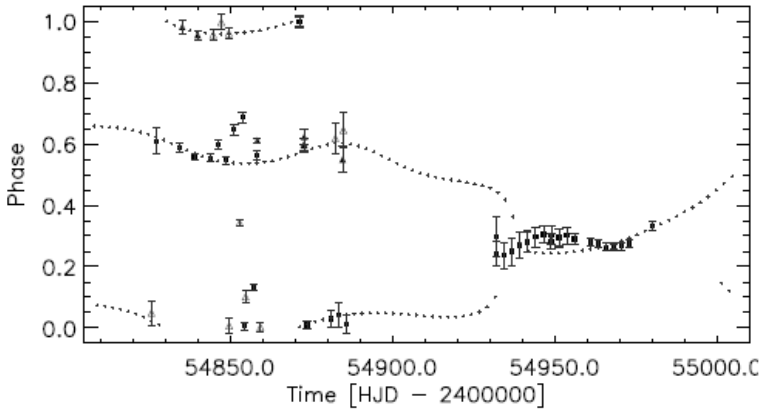
CF- model for V-photometry: Differential rotation + spot evolution on scales of days (Hackman et al. 2013).

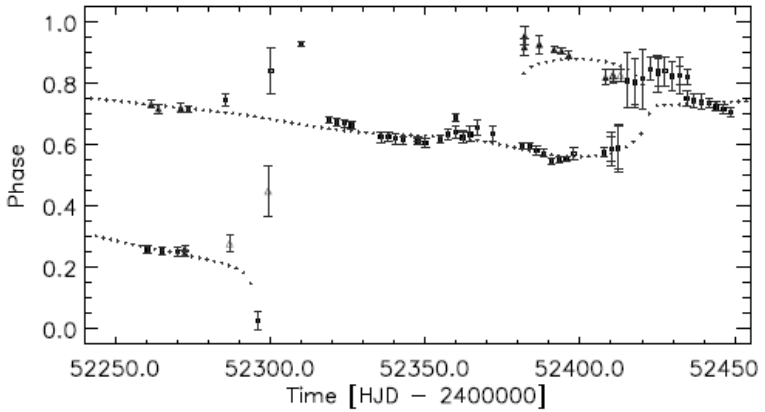
2.5 Flip-flops of FK Comae



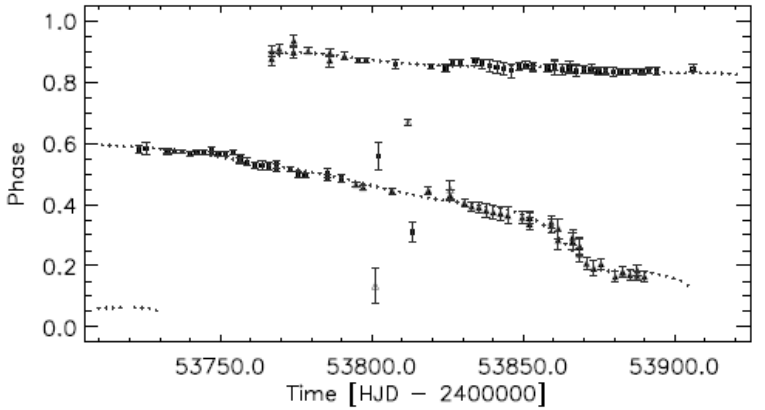
”Normal” flip-flop, ”apparent” flip-flop (due to differential rotation) and complex relation between light curve amplitude (A) and mean (M) (Hackman et al. 2013).

2.5 Flip-flops of FK Com

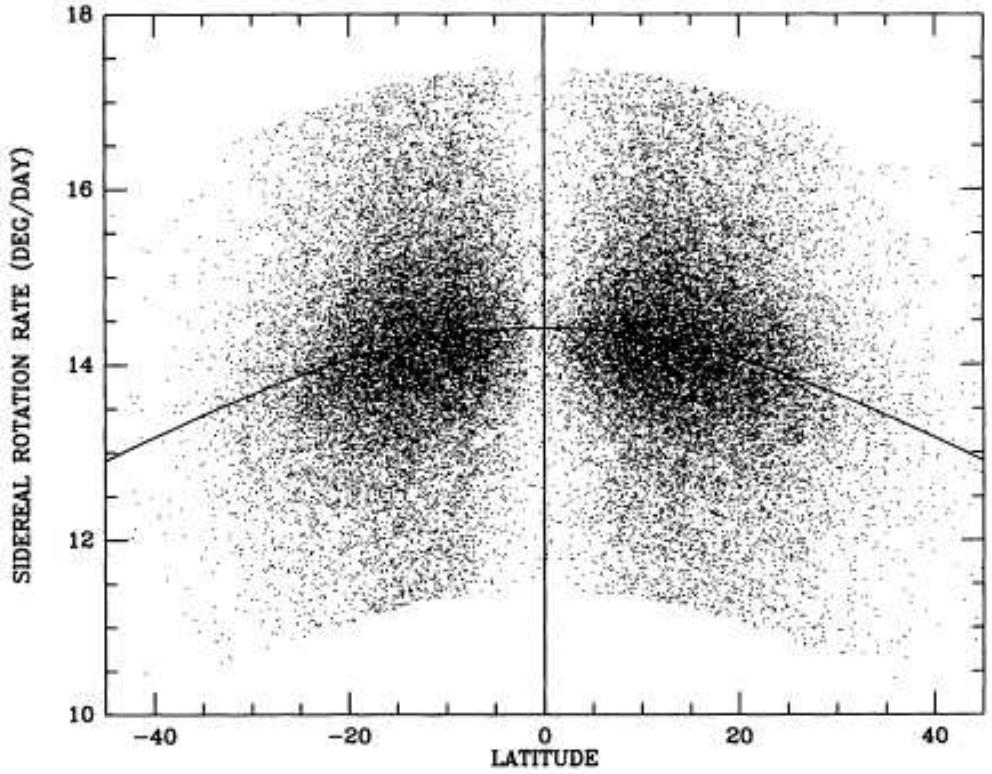




Spot mergers and drifts studied by HJD vs. photometric minimum phases retrieved by the CPS and CF-methods (Hackman et al. 2013).



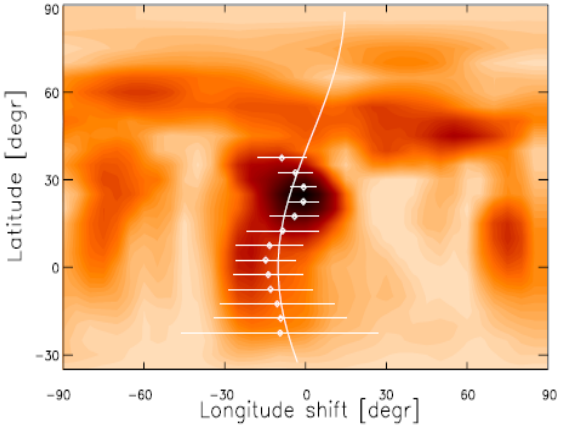
3.1 Sunspots as tracers of differential rotation



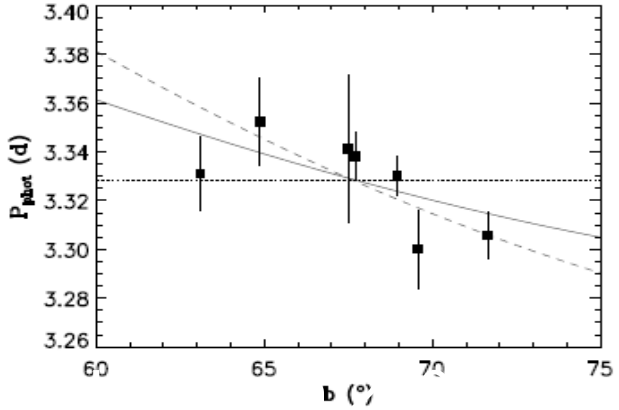
Observations of 36708 sunspot groups (Howard 1994)

3.2 Starspots as tracers of differential rotation

- Sometimes strange results: E.g. antisolar differential rotation for rapidly rotating stars
- Do the spots follow the surface or are they anchored deeper in the convection zone?
- Other problems: Limited latitude range and errors in latitude

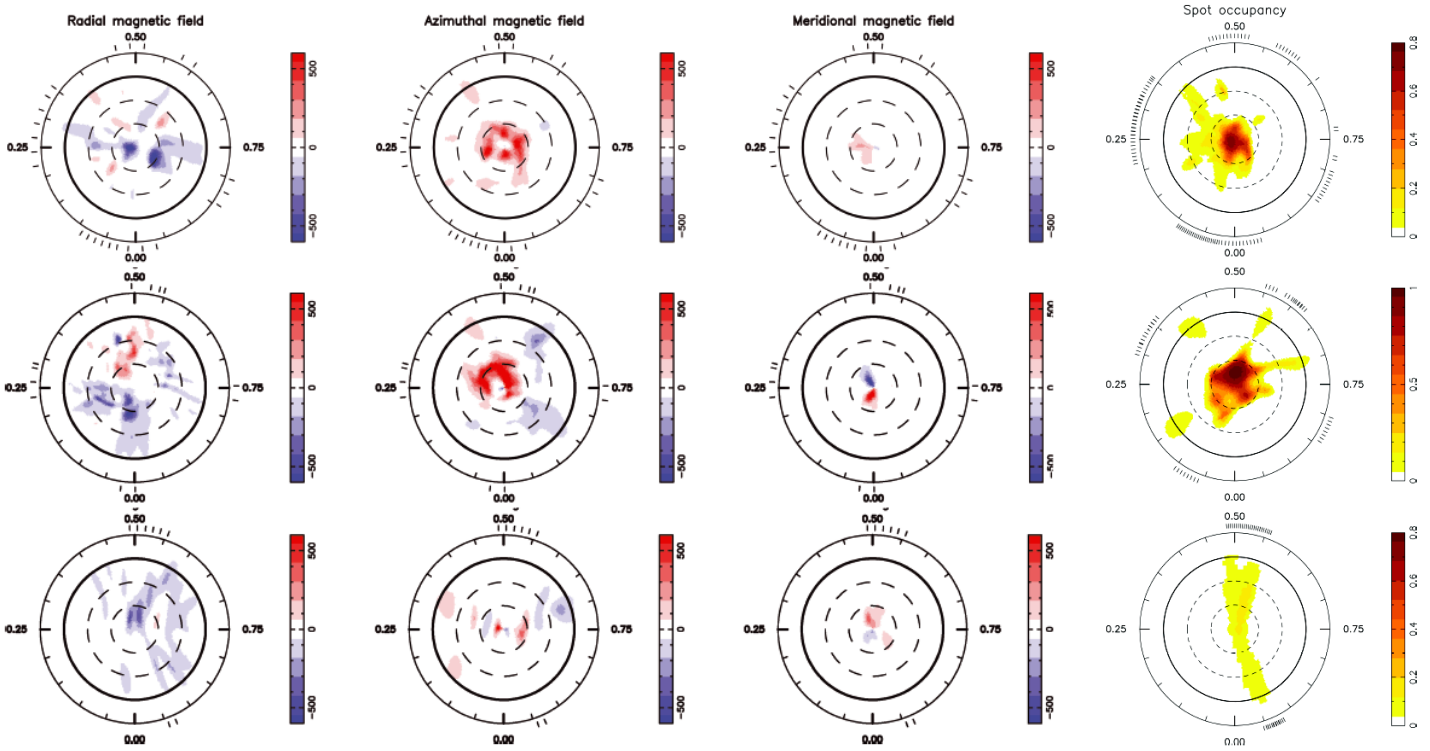


Cross-correlation map for DP Cvn indicating anti-solar rotation (Kovari et al. 2013).



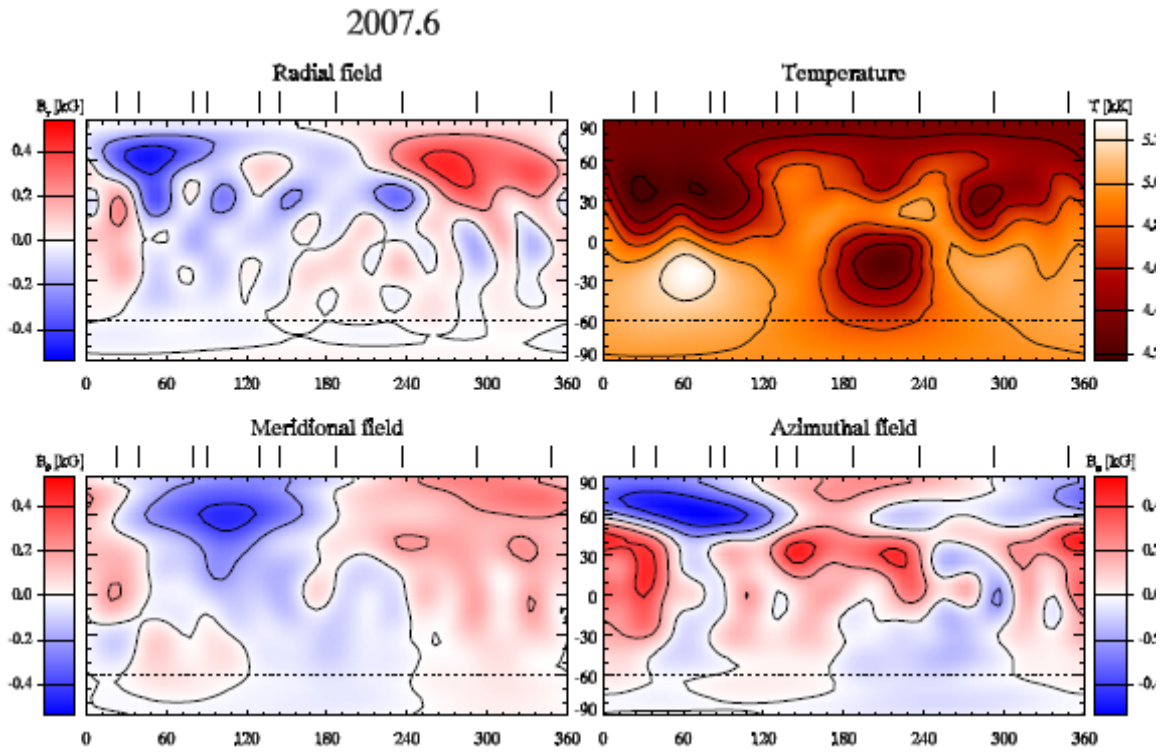
Latitude of main spot vs. photometric rotation period for HD199178 indicating anti-solar differential rotation (Hackman 2004).

4.1 Connection between spots and magnetic fields: HD171488



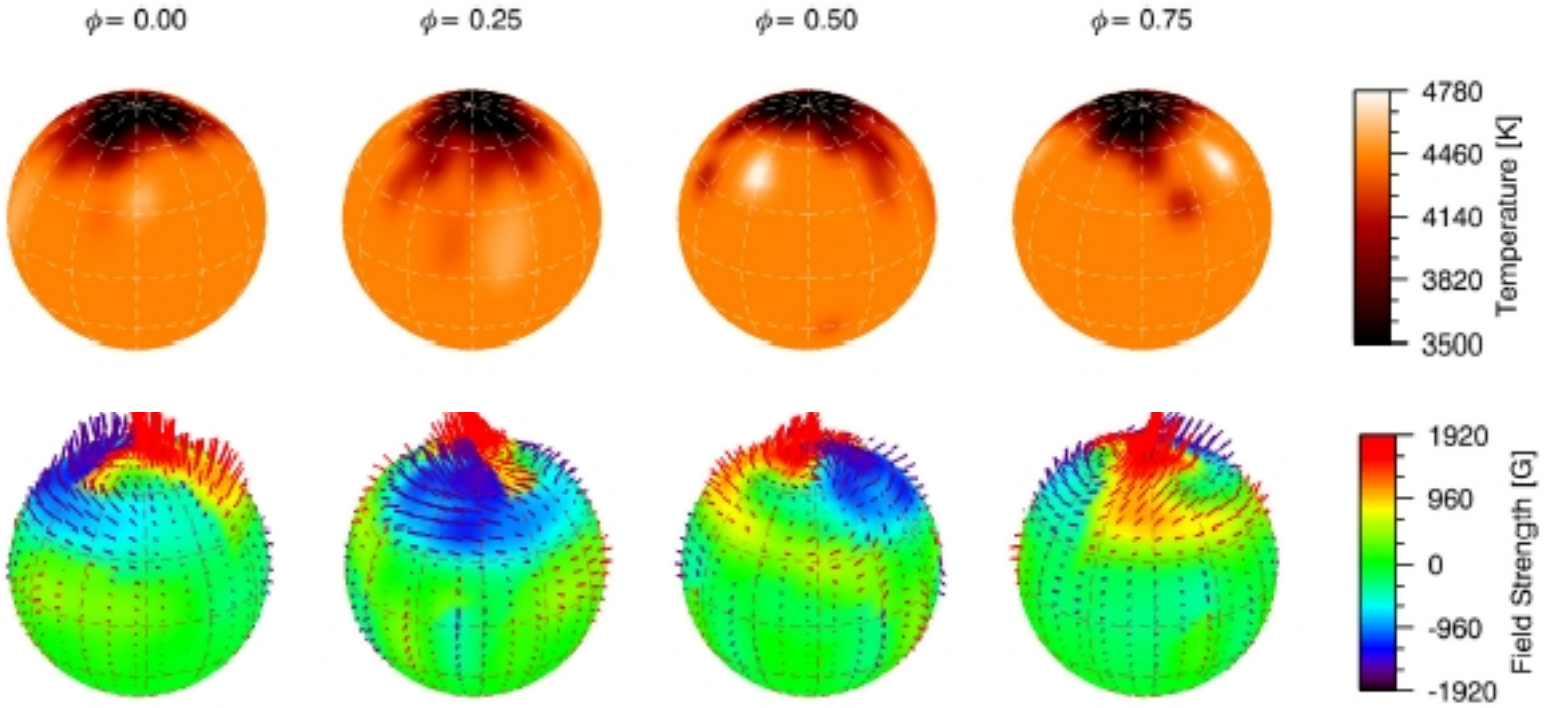
Surface magnetic field (radial, azimuthal, meridional) and spot occupancy of HD171488 do not coincide (Jeffers et al. 2010).

4.2 Connection between spots and magnetic field: II Peg



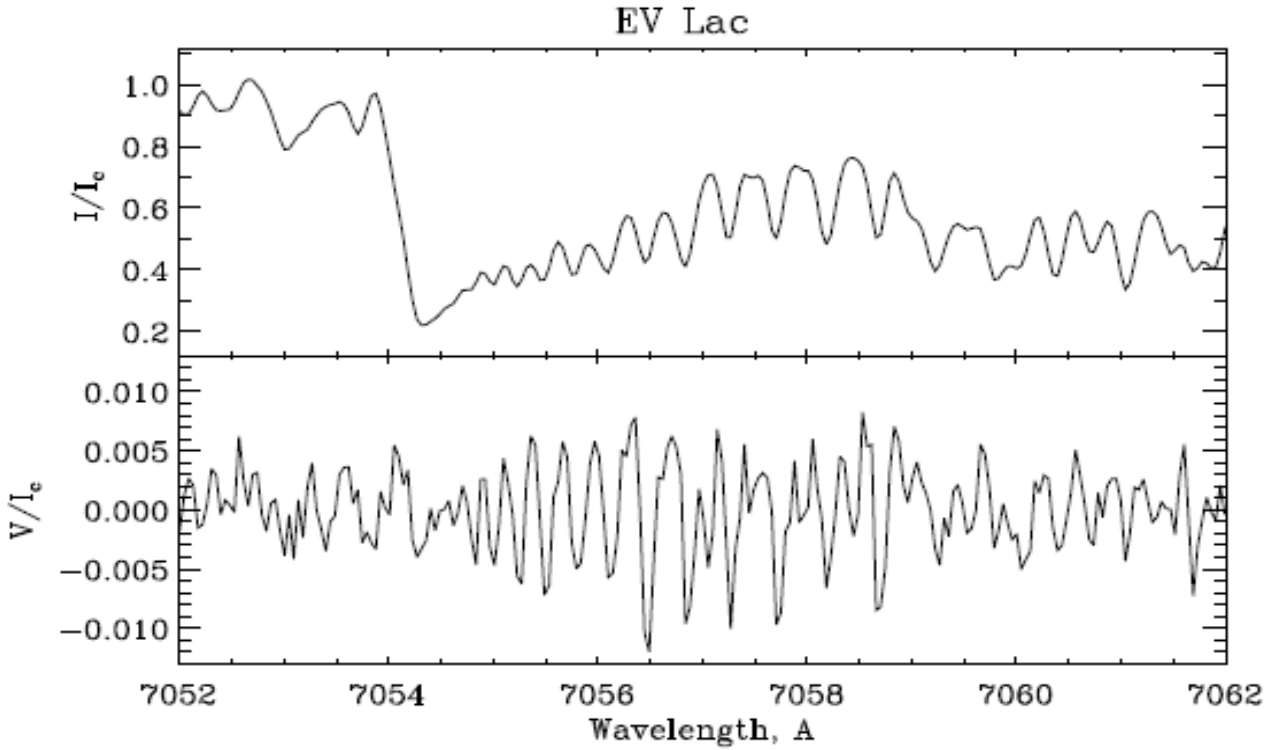
ZD-images from July 2007: No correlation between temperature spots and magnetic fields (Kochukhov et al. 2013).

4.3 Connection between magnetic field and spots: V410 Tau



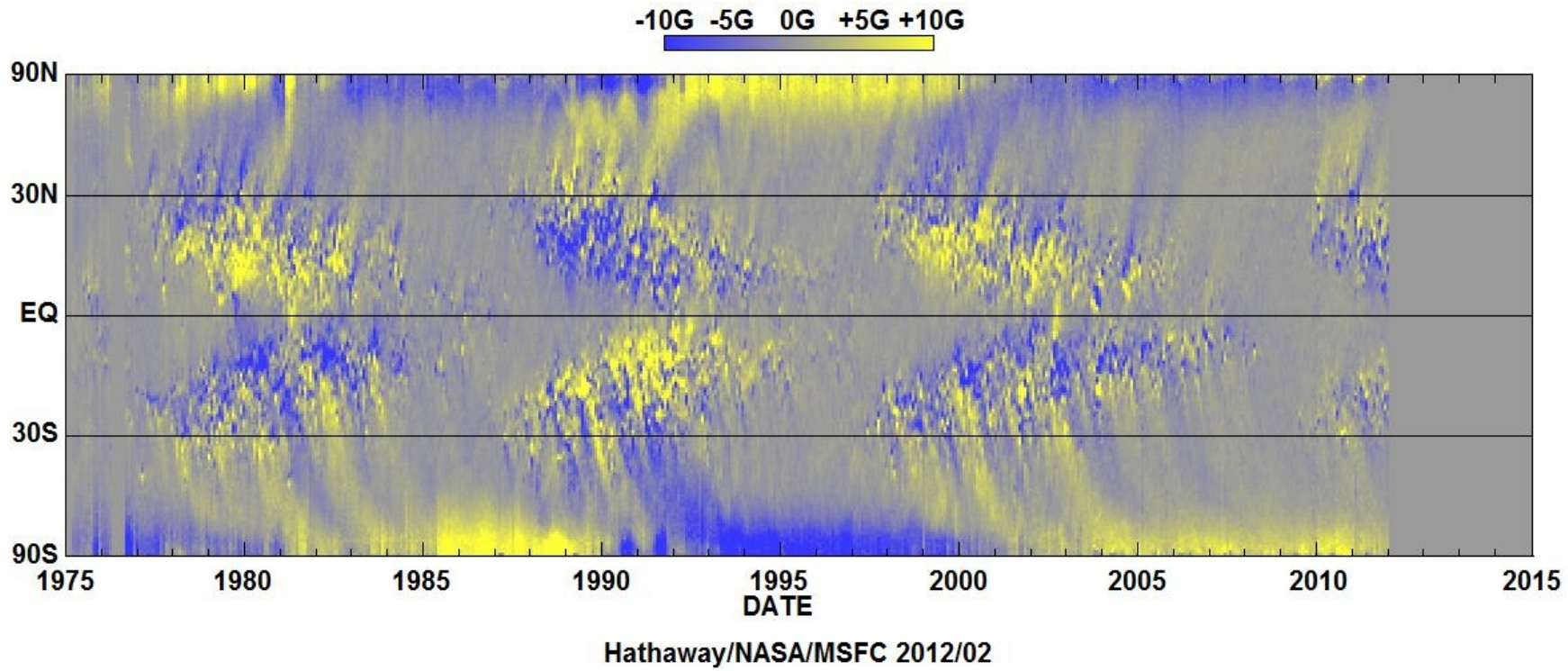
ZDI temperature and magnetic field maps:
Better correlation (Carroll et al. 2012).

4.4 Connection between magnetic fields and cool regions: EV Lac



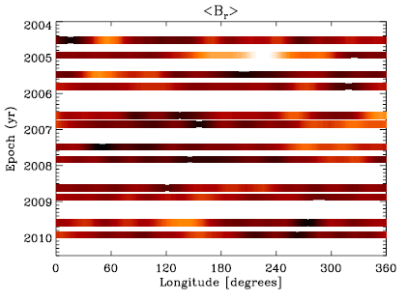
Stokes profiles of TiO bands (Berdyugina et al. 2008):
Strong field in cool surface elements.

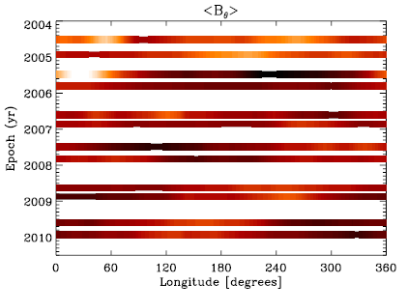
5.1 Magnetic field polarity of the Sun

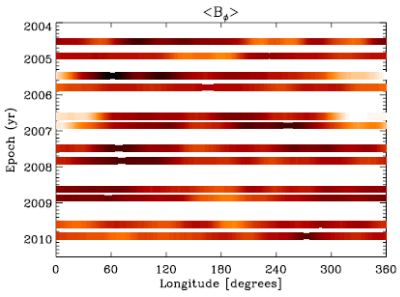


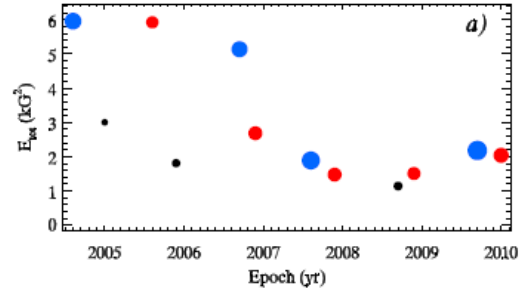
5.2 Surface magnetic field of II Peg

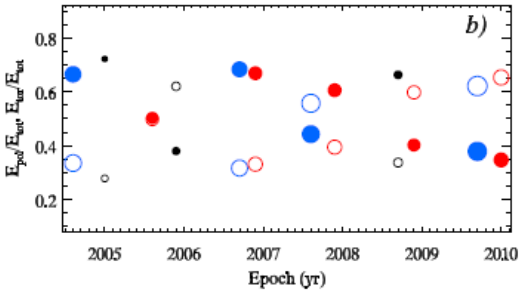
- Evolution of the magnetic field (Kochukhov et al 2013):
  - Field components averaged over latitude
  - Total magnetic energy
  - Toroidal (filled) and poloidal (open) harmonic components
  - Axisymmetric (filled) and non-axisymmetric (open) components

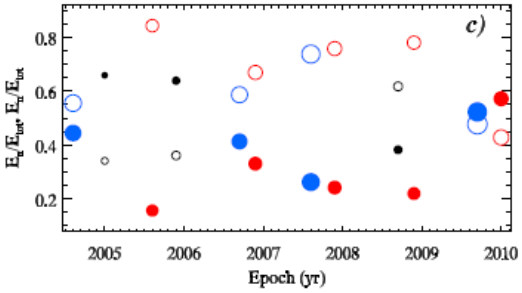






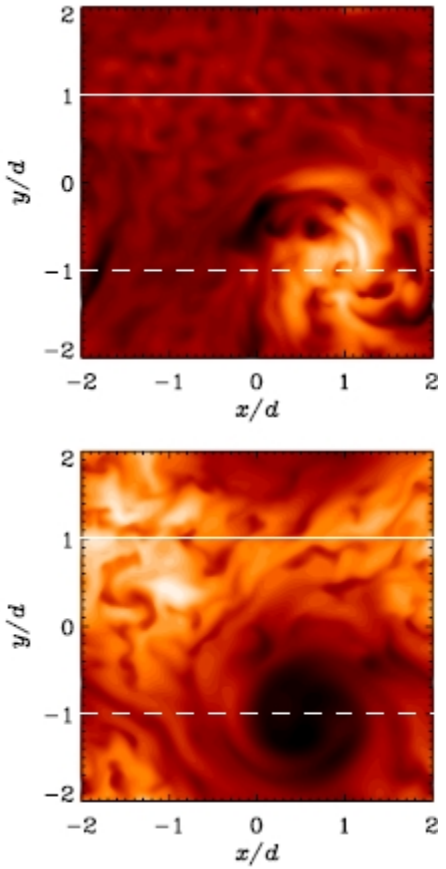






6. Other models for starspots

- Generation of vortices in rotating turbulent convection (Käpylä et al. 2011; Mantere et al. 2011):
  - Spots without magnetic fields



7.1 Conclusions I

Table 1. Sunspot and starspot properties Schrijver 2002

Property	Sun	Stars
Field strength	2-3kG[1]	1-4kG[2]
Umbra to total spot area	0.17	?[3]
Photosphere-spot temperature contrast (K)	600[4]-1800[5]	500-2,000[6]
Spot life time	days-weeks	?
Spot cluster life time	$\lesssim$month	weeks - months; up to $\sim$ 10 yr[7]
Observed "spot" sizes	$\lesssim$ 2 sq. deg.	$\gtrsim$ 15 sq. deg.; $\lesssim$ 66%
Spot-plage correlation	yes	?
Spot-corona anti-correlation	yes	possibly
Time-dependent differential rotation	likely	some reported
Photom. period correlated with cycle phase	yes	likely
Photom. variability correlated with cycle phase	yes	yes
Meridional migration	yes, slow	?[8]

- New results for late-type stars:
  - Magnetic fields 200 – 4000 G
  - Spot life times min. a few days
  - Non-magnetic spots are possible
  - No simple dynamo model can explain the spot evolution

7.2 Conclusions II

- Questions currently beyond observational reach:
  - Penumbra/umbra sizes
  - Are large spots individual spots or spot groups?
  - Anchor depths of spots
- Some future tasks:
  - Combine new methods for determining differential rotation
  - Better definition for a stellar cycle
  - ZDI monitoring over at least two stellar cycles