From stellar spots to surface flows

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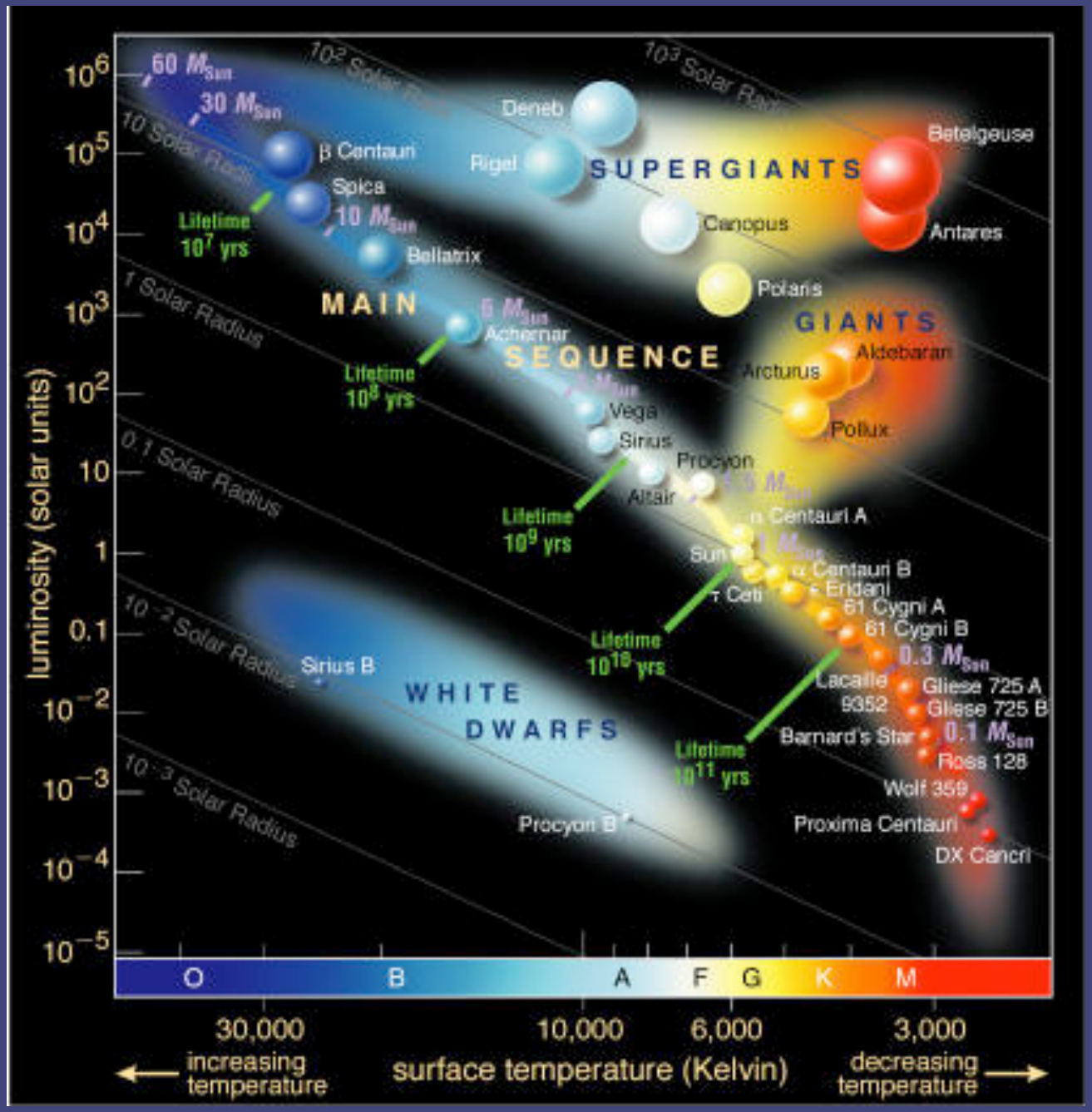
observing the dynamo

ZSOLT KŐVÁRI
Konkoly Observatory
Budapest, Hungary

Starspots in the HRD: G-K-M



Why useful to observe starspots?

- Understanding the nature of magnetic activity (magnetic dynamo)
- "Solar paradigm"
  - testing solar models (e.g., Sun-in-time)
  - constraints for stellar dynamo theory
- Short-term changes (~P_{rot})
  - spot evolution, differential rotation
- Long-term changes (~10^2-10^4 days)
  - cycles, differential rotation

Dynamo observables

- long-term cycles
  - photometry, UV, X-ray, radio
- multiple periods
  - cf. solar 11/60-70/200-300yr
- differential rotation
  - from photometry ($\Delta P/P$)
  - from spatially resolved surface images
- meridional circulation
  - from spatially resolved surface images

How to observe starspots?

Stars are point sources → no direct spatial information

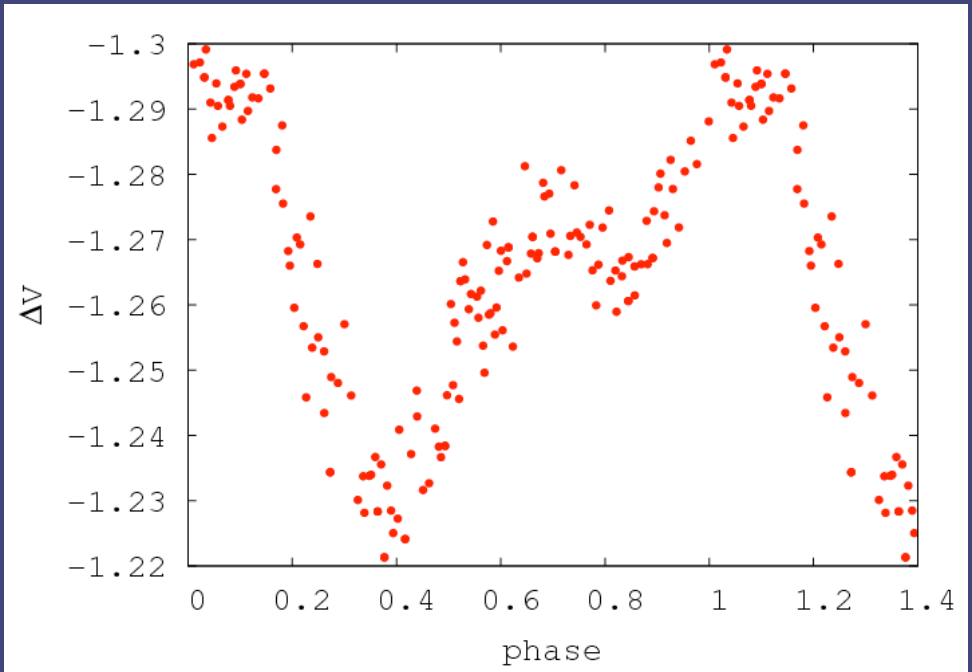
Indirect means are needed:

→ Photometric imaging

→ Doppler imaging

Photometric spot modelling

As the star rotates, its brightness is modulated by spots on the surface.



Vida et al. 2010

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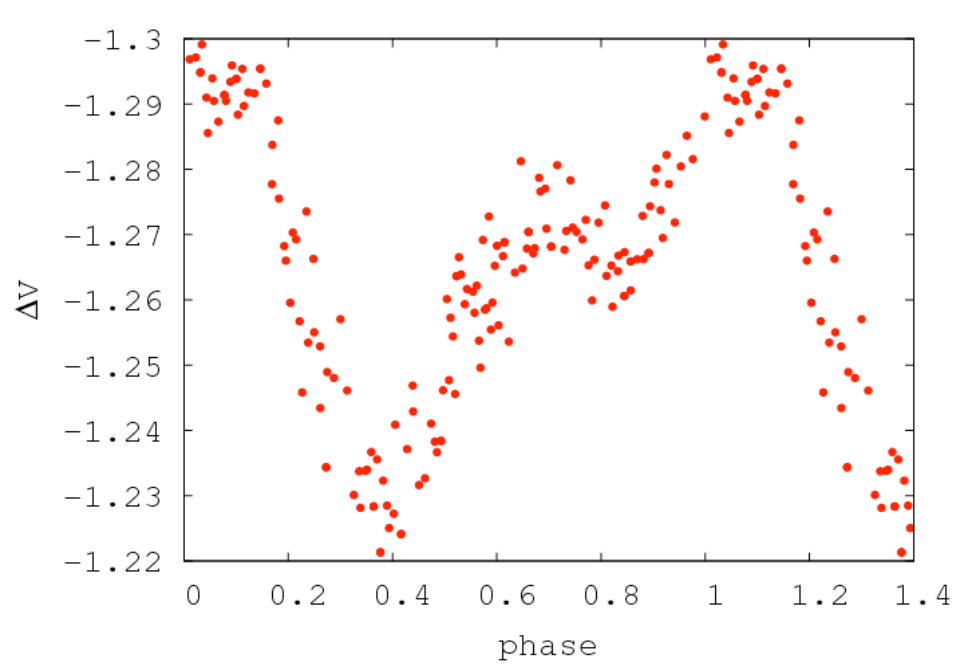
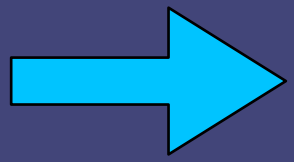
EY Dra light curve



Vida et al. 2010

+ many assumptions



model

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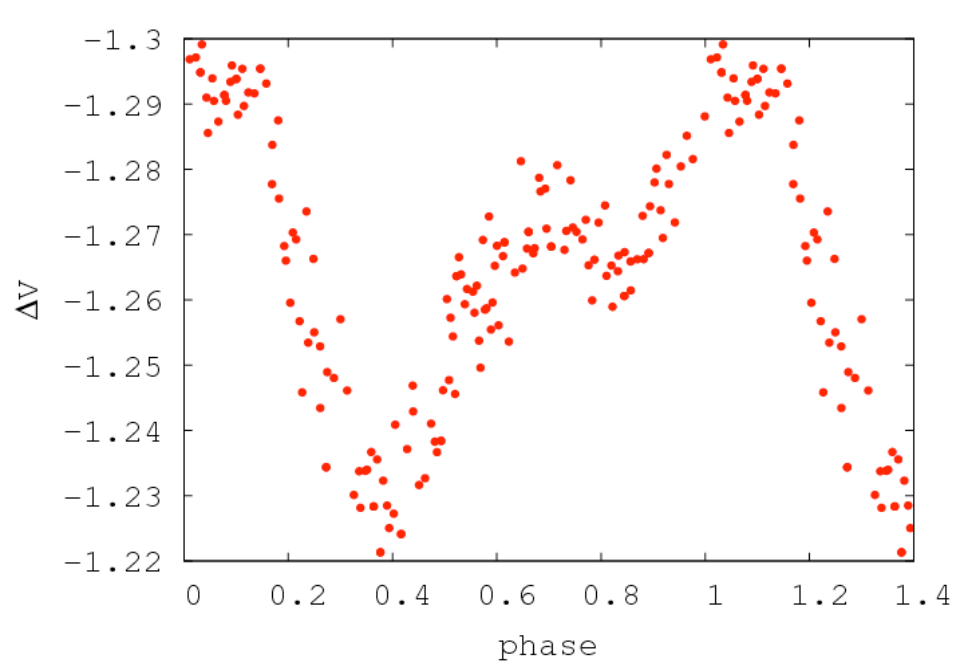

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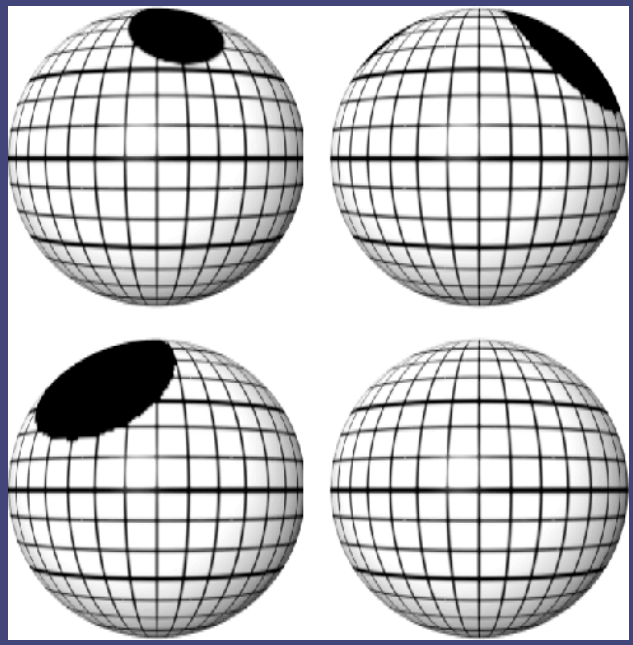

Photometric spot modelling

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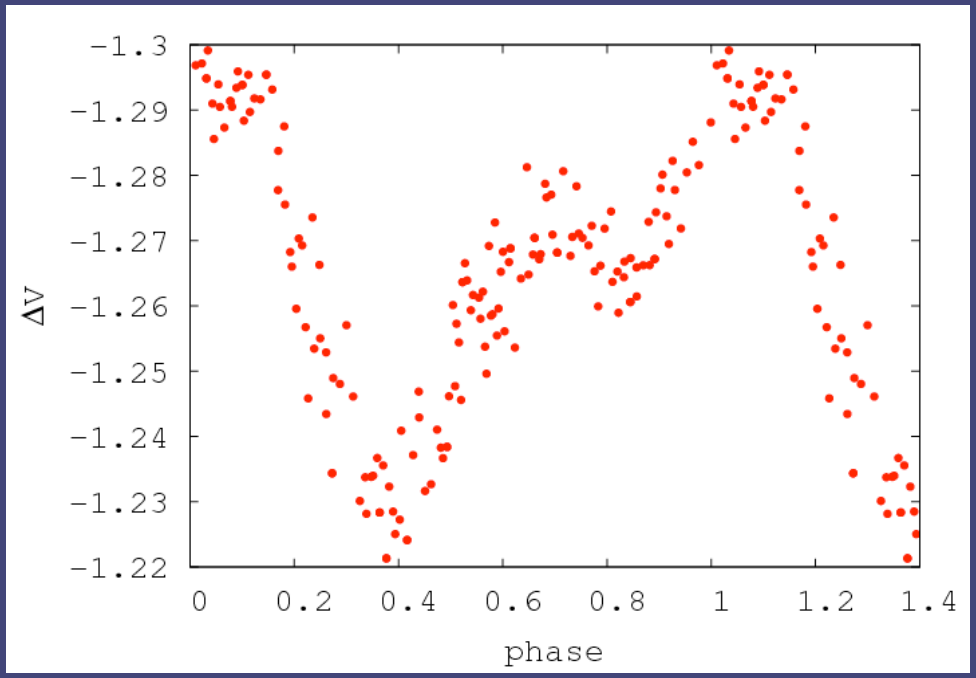
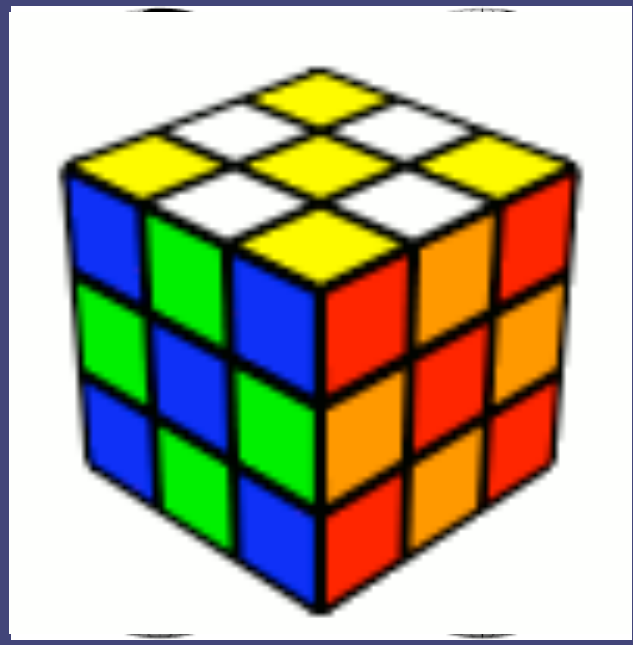


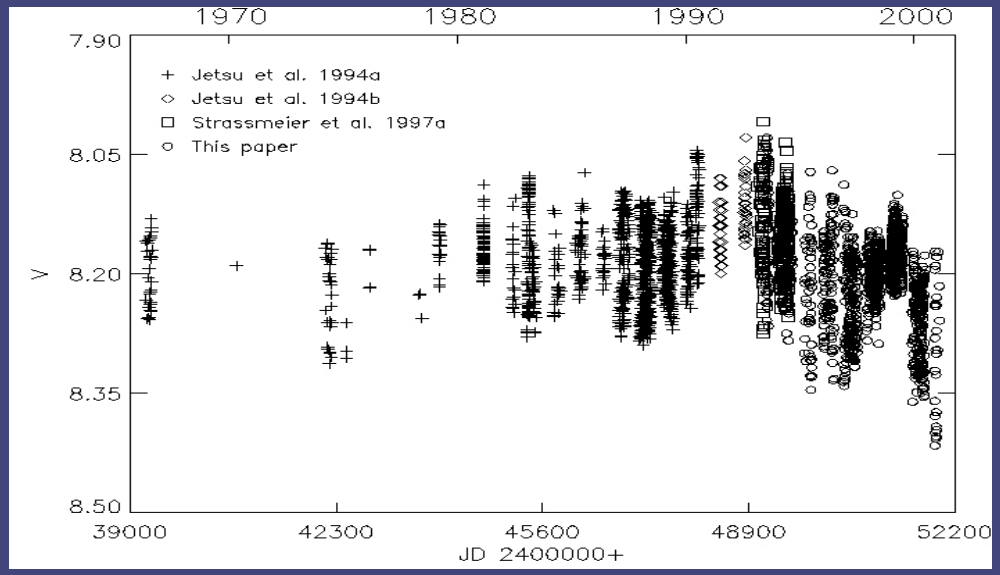
Vida et al. 2010

+ many assumptions

model

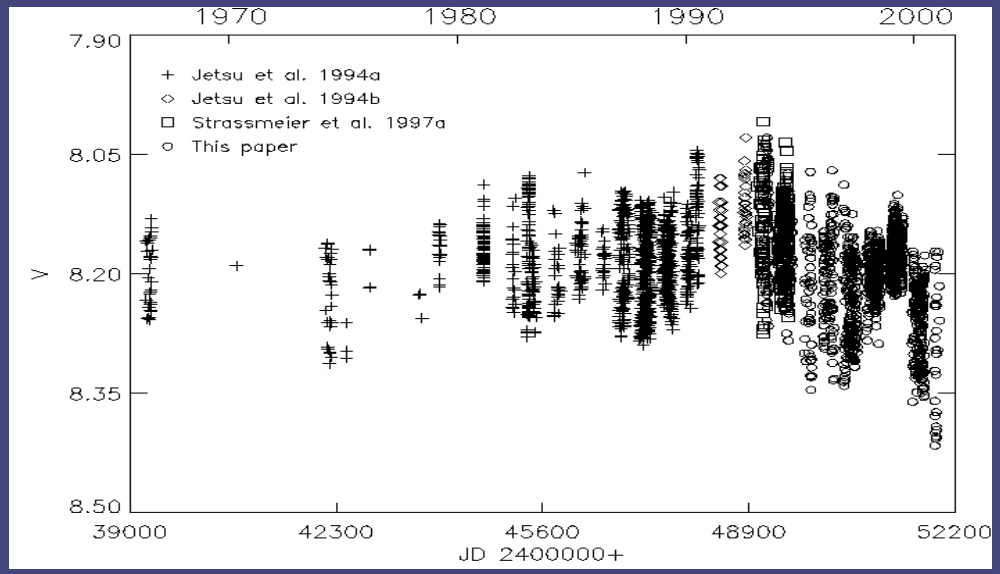


Starspot mapping from long-term photometry



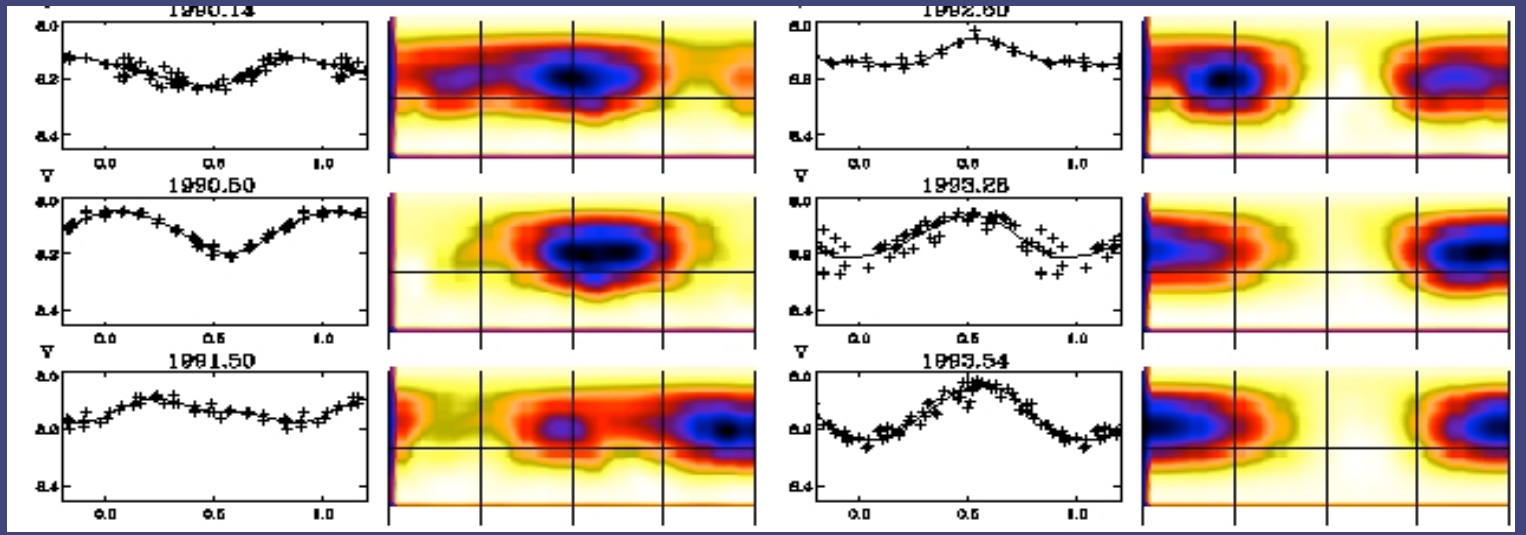
Long-term V band of FK Com (Korhonen et al. 2001)

Starspot mapping from long-term photometry



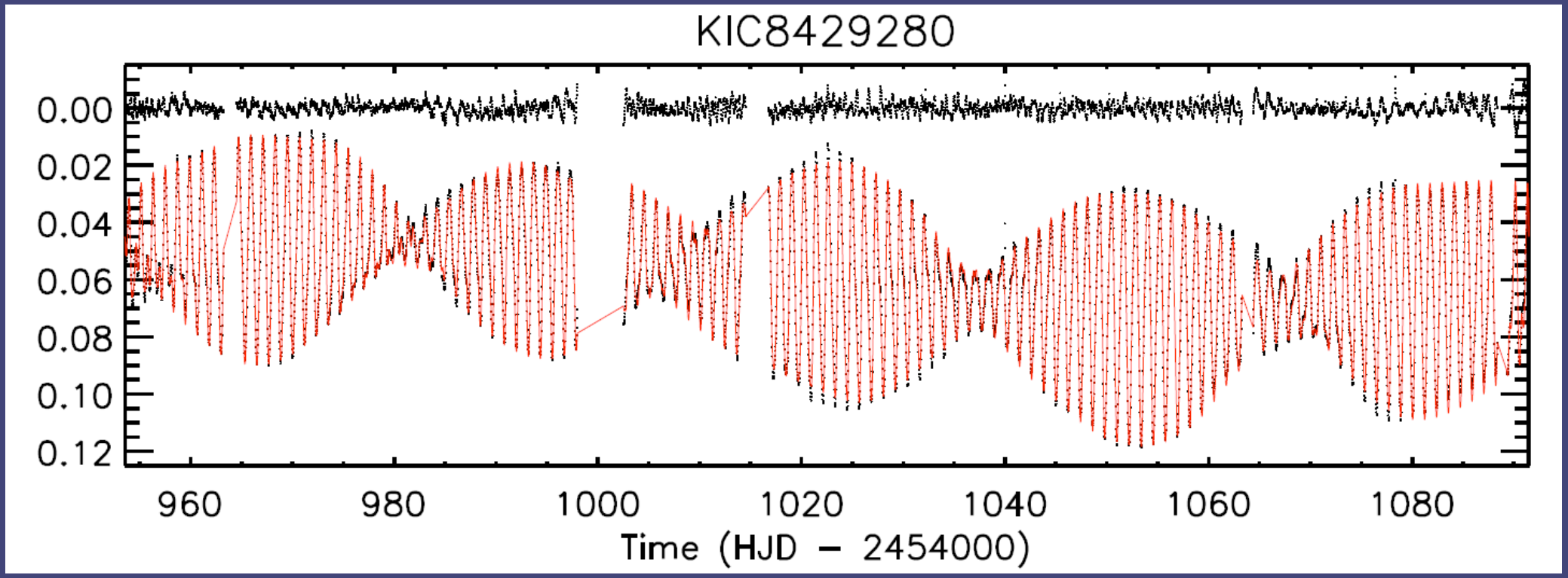
Long-term V band of FK Com
(Korhonen et al. 2001)

Phased light-curves and
light-curve inversions
(spot filling factor maps)



The beat phenomenon: fingerprint of DR

K2 V ZAMS star (1.2d) from the Kepler-field



$\alpha = \Delta\Omega/\Omega = 0.23$

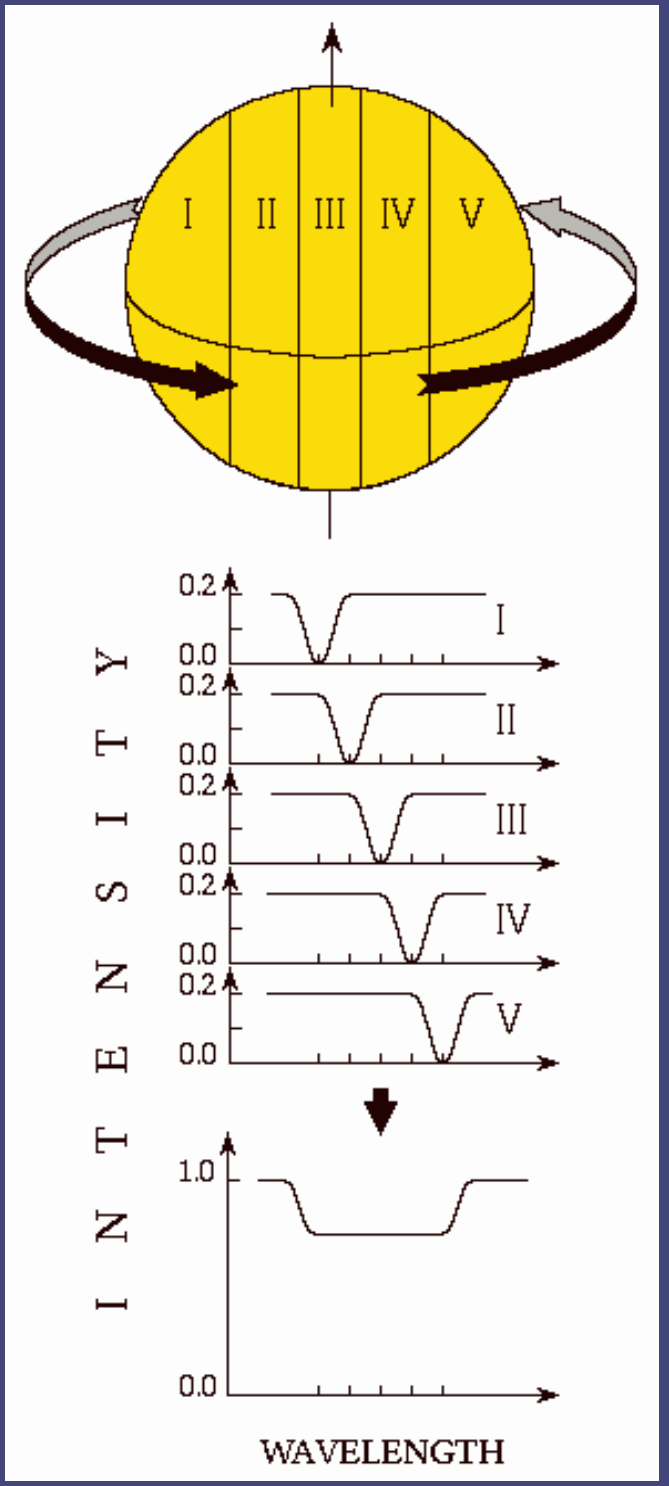
Frasca et al. 2011

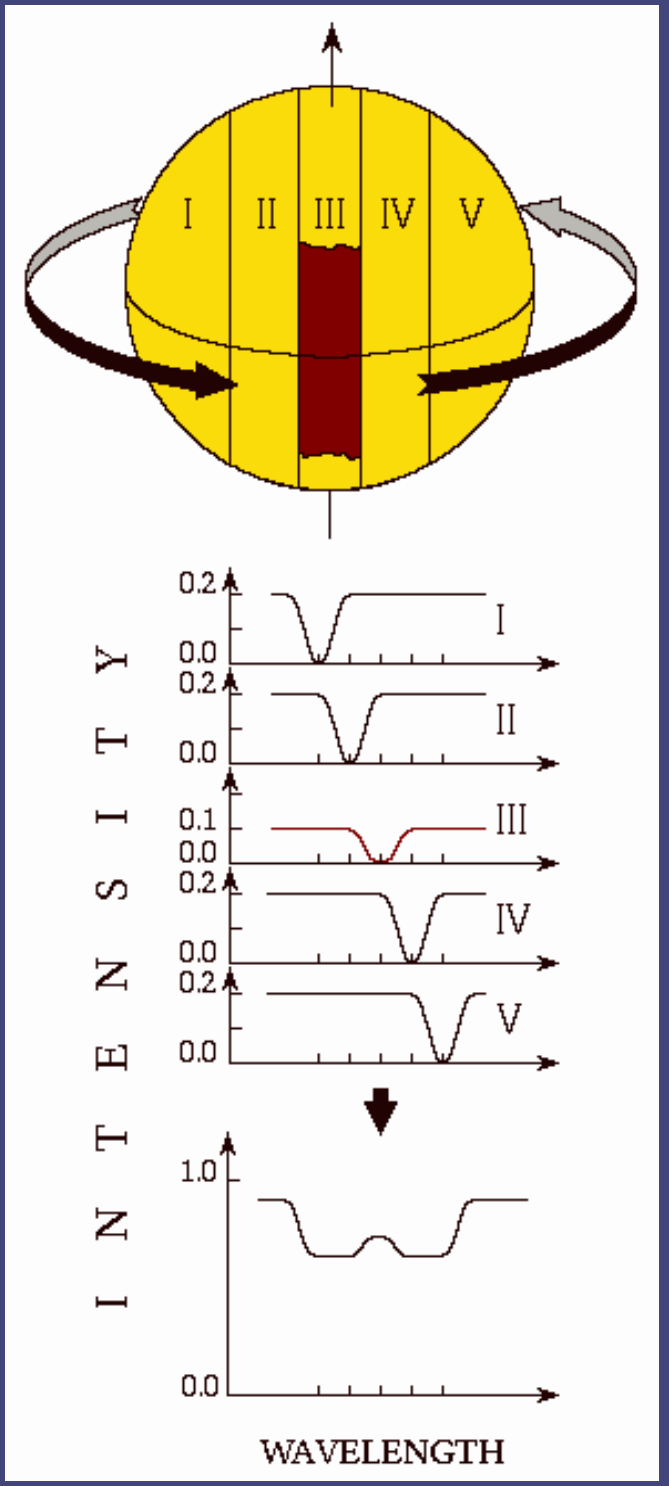
What can we derive from photometric spot modelling?

- long-term (multiple) cycles
- overall spotted area
- spot temperatures
- differential rotation
- preferred (“active”) longitudes
- ...
- but: no latitudinal information

Doppler imaging of stellar surface

Vogt & Penrod (1983)



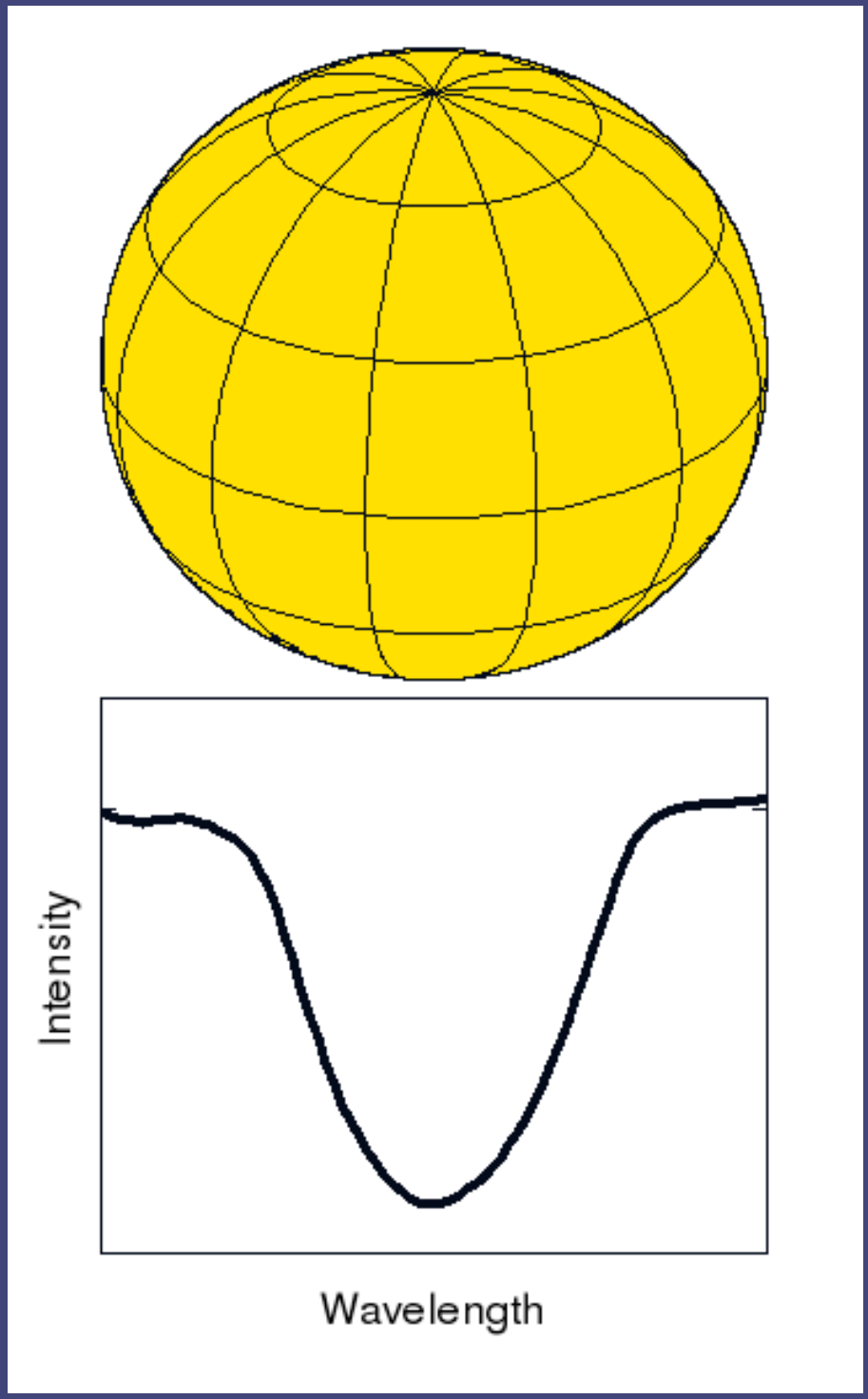


Spot waltz

The line profile is a 1D imprint of the 2D surface

⬇

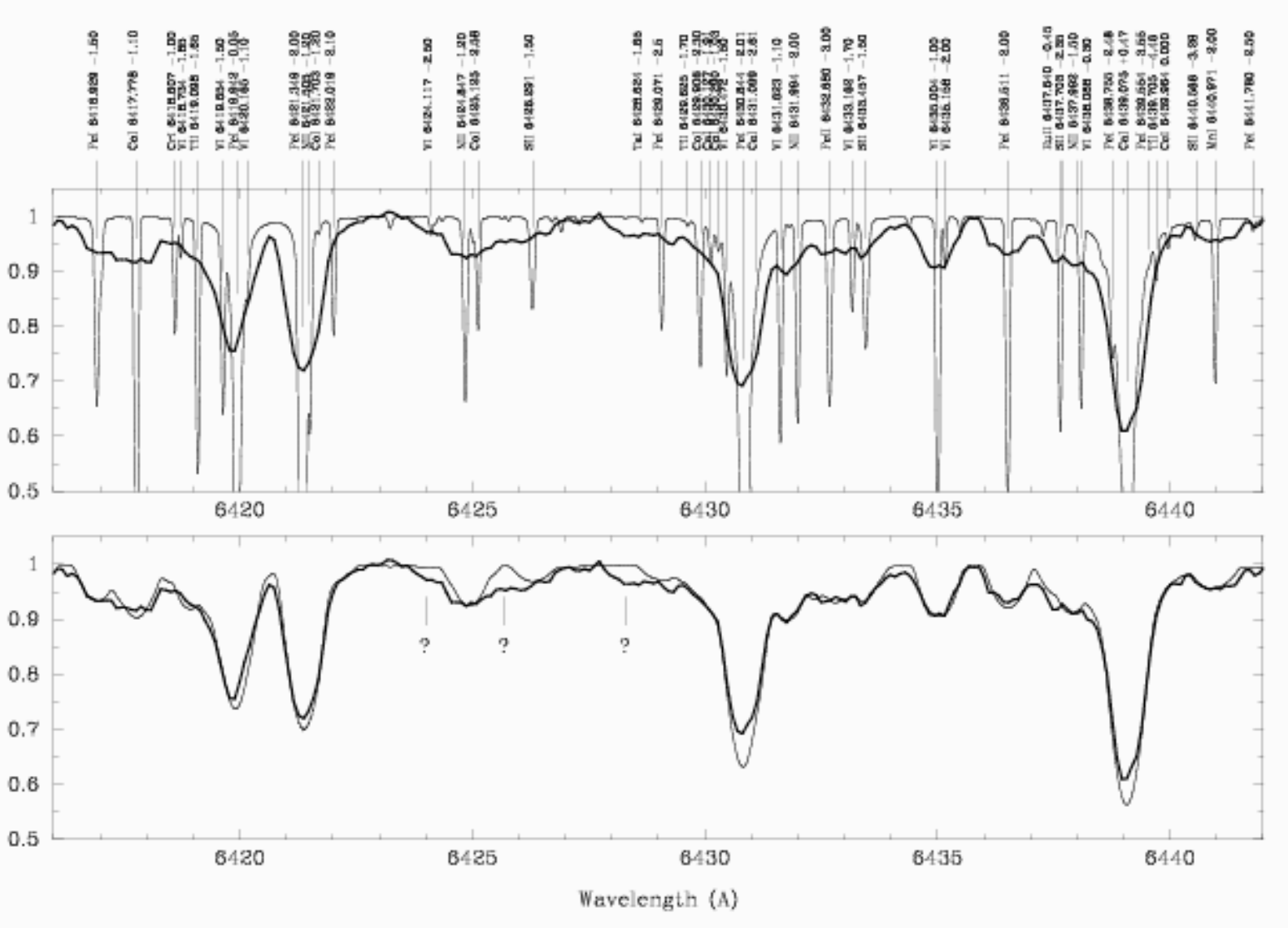
The whole surface could be recovered from a series of spectra covering the full rotational phase



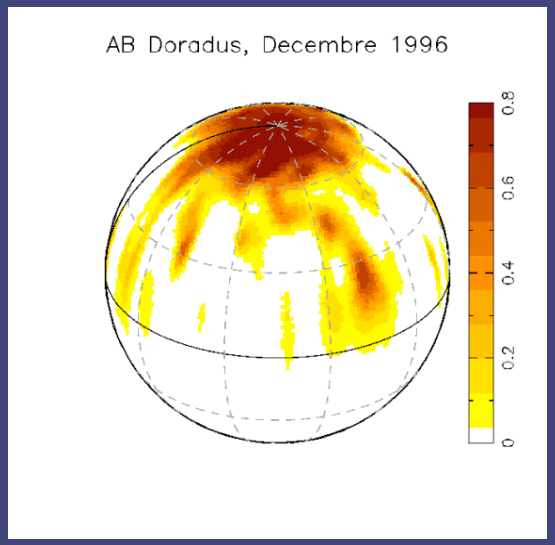
Requirements

- Accurate model parameters
- High spectral resolution
  - minimum of ~25,000, optimally >40,000
- High signal-to-noise ratio
  - > 150-200
  - growing integration
    - (but: phase smearing, saturation, ...)
- Good phase coverage (convenient period)
- Rapid rotation (~25km/s < $v \sin i$)
- etc...

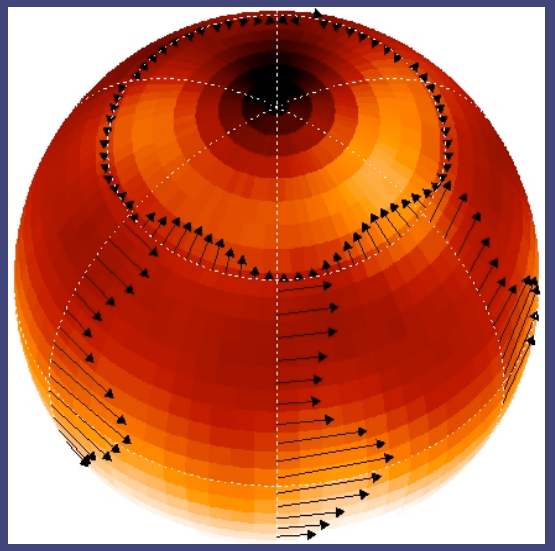
Mapping lines



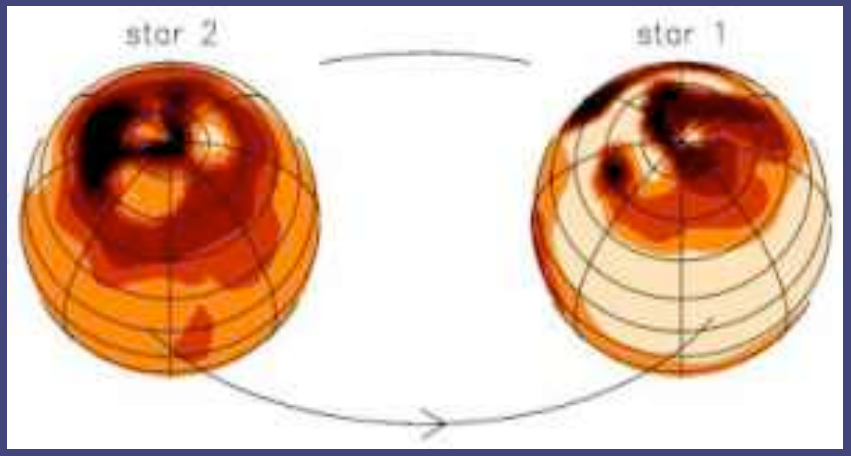
Results



AB Dor
Donati & Collier Cameron 1997



KU Peg
Weber & Strassmeier 2001



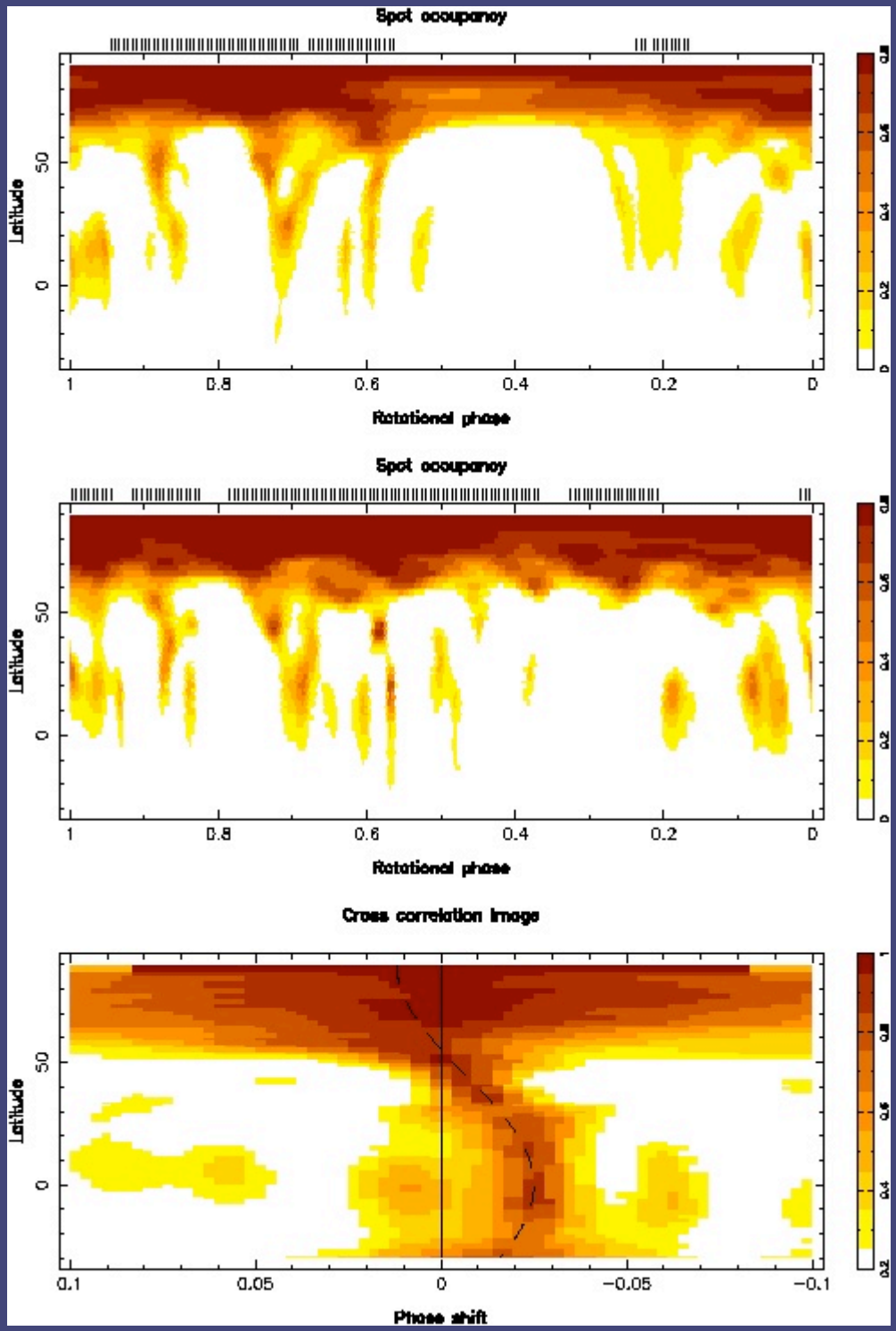
σ^2 CrB
Strassmeier & Rice 2003

Measuring differential rotation from Doppler images

Requirements:

- Two images (from independent data)
- $\Delta t = t_2 - t_1$ < ⟨spot lifetime⟩
- Strong SDR pattern

Differential rotation by cross-correlation of consecutive Doppler images



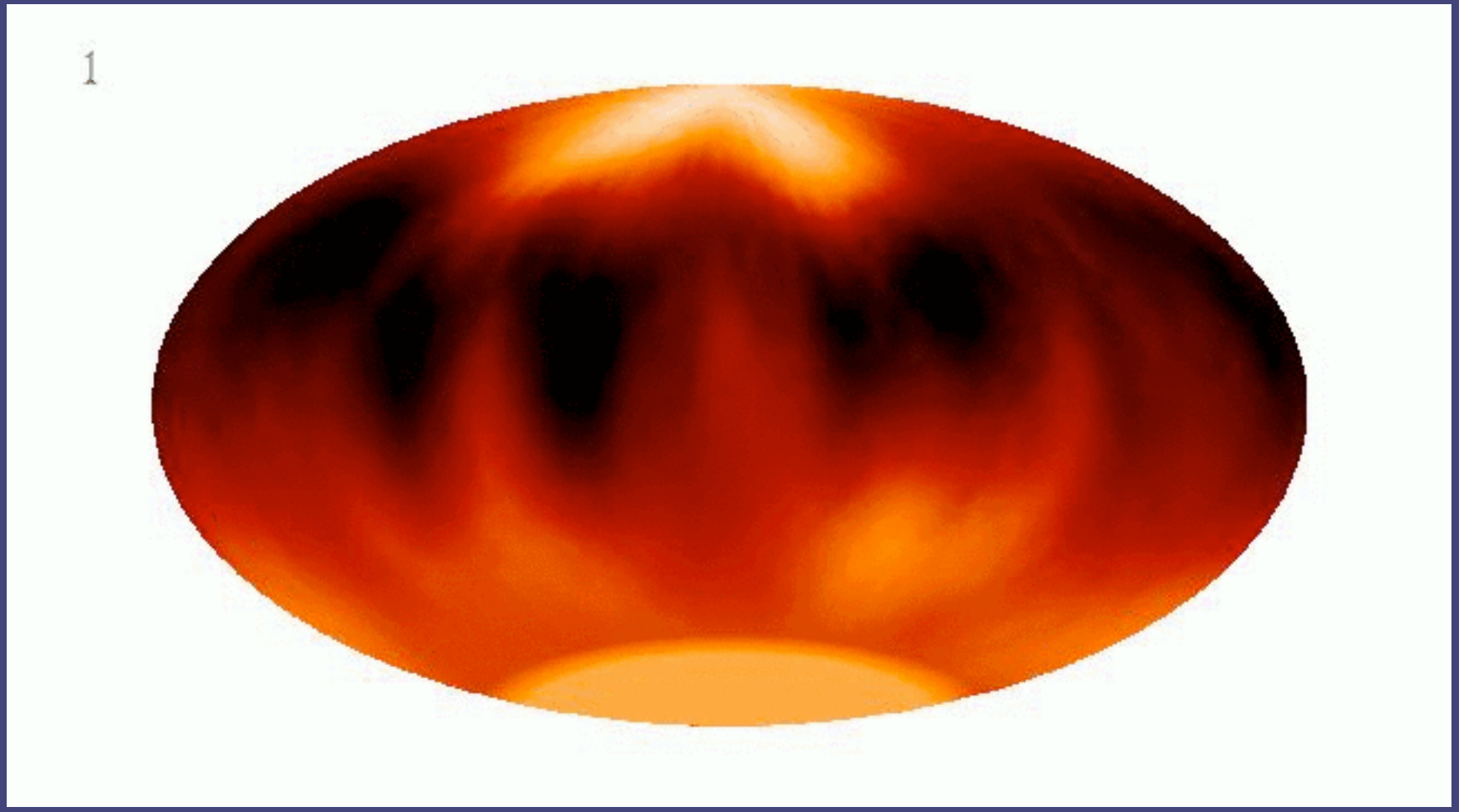
AB Dor
Donati et al. 1997

Time-series Doppler imaging

- Long observing series: ~3xP_{rot}
- Suitable target
- Evenly sampled homogeneous spectra

LQ Hya: the movie star

K2V, P_{rot}=1.6d, 35sp @NSO 1996

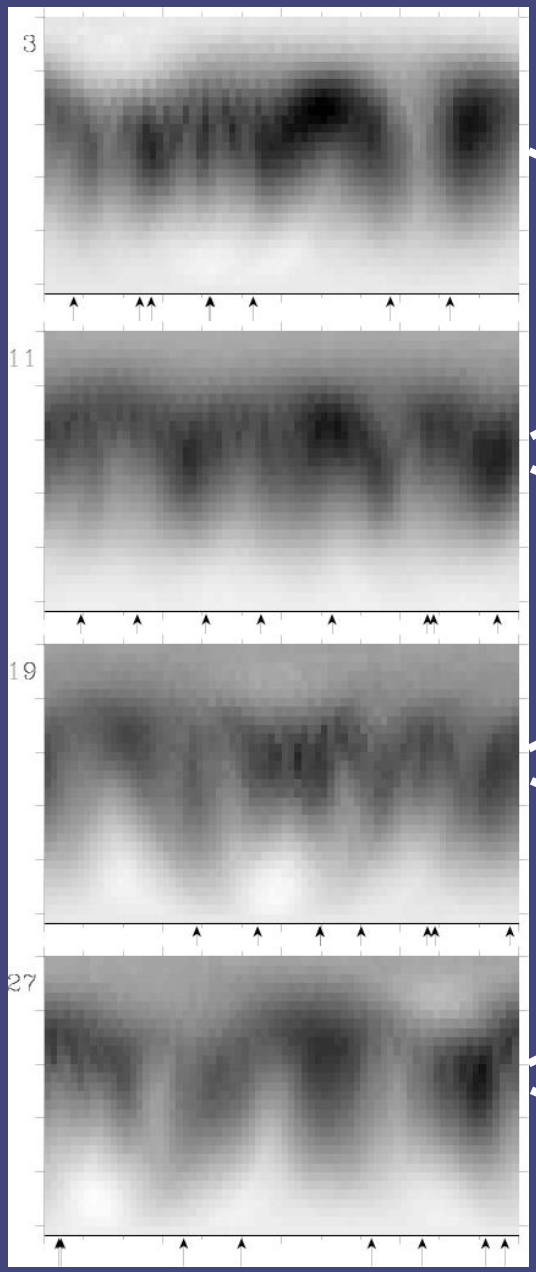


Kővári et al. 2004

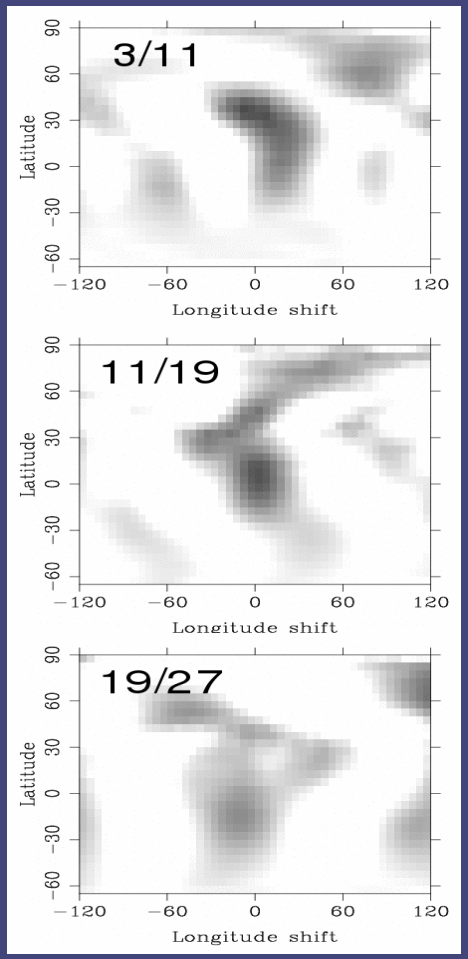
Average Cross-CORrelation of time-series Doppler images

- Averaging more ccf-maps will...
  - emphasize common features
  - diminish differences
- Some cosmetics needed before
  - linear normalisation: $\Delta t_i \sim \Delta \lambda_i$
  - weighting (geometric effects, visibility)

ACCORD



time



...

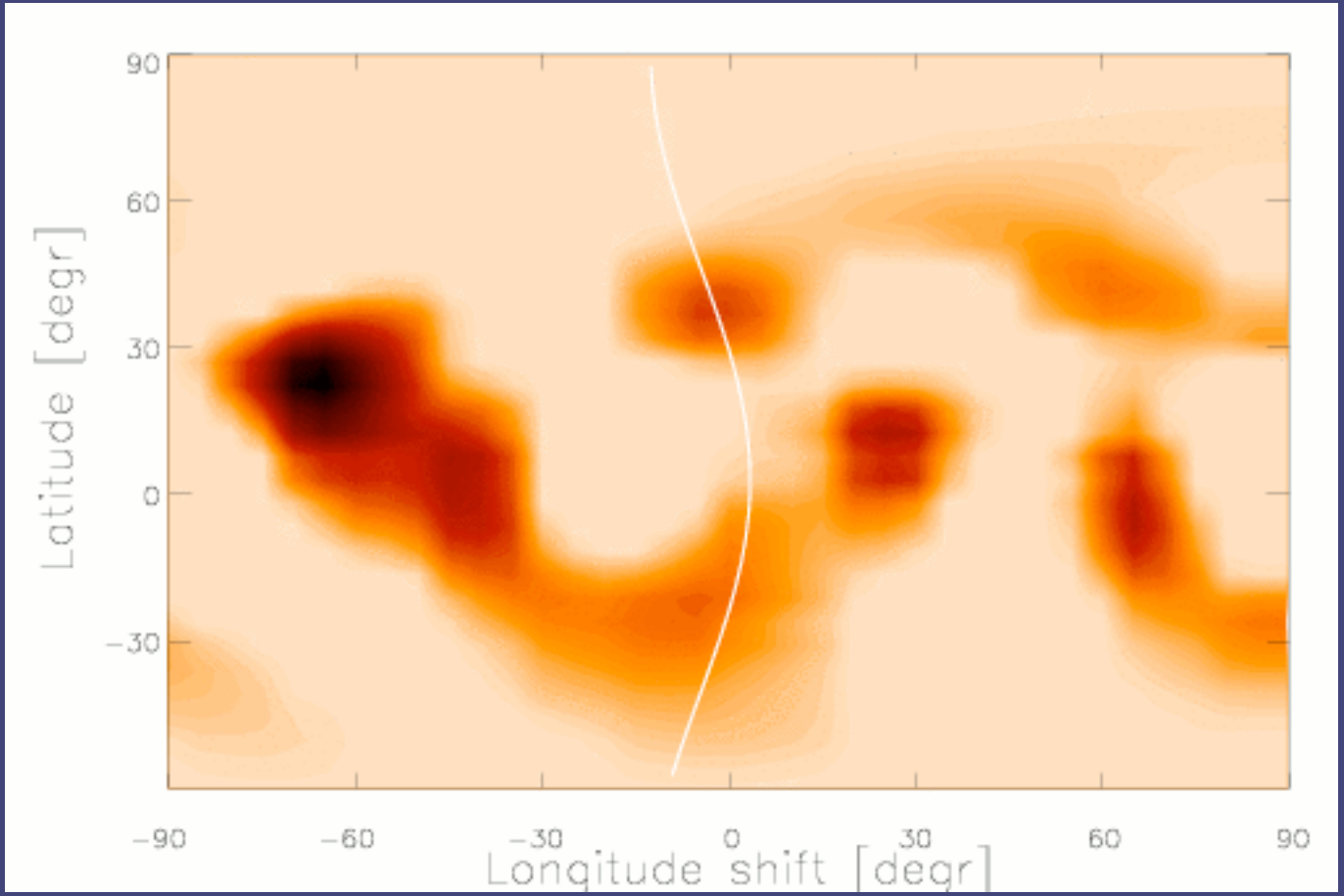
average ccf-map

Solar-type DR law for LQ Hya

$$\Omega(\theta) = \Omega_{eq} (1 - \alpha \sin^2 \beta), \quad \alpha = 0.006$$

Kővári et al. 2004

Solar-type DR law for LQ Hya

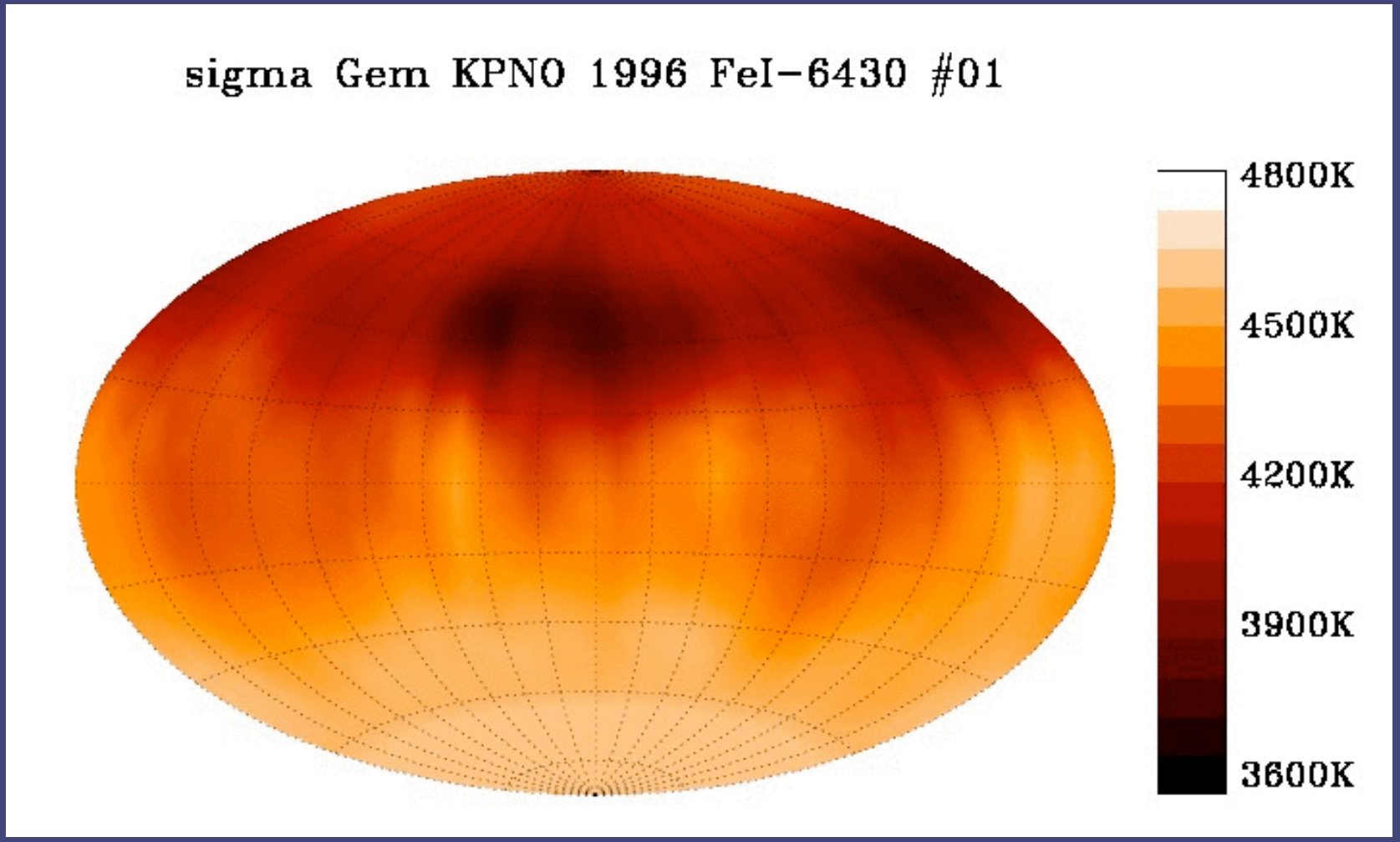


$$\Omega(\theta) = \Omega_{eq}\,(1 - \alpha \sin^2\beta), \quad \alpha = 0.006$$

Kővári et al. 2004

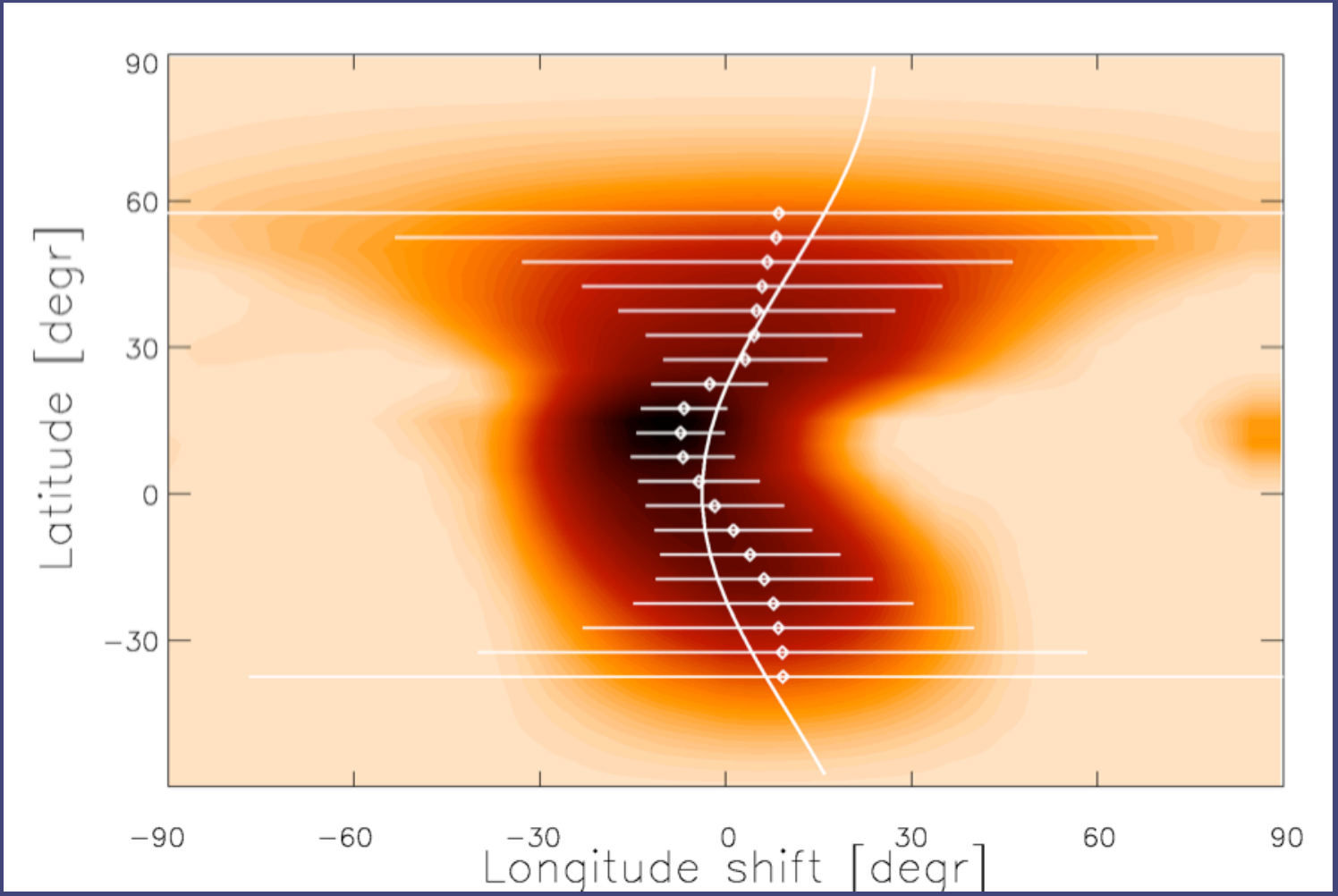
Motion picture of σ Gem

K1 III, P=19.6 days, 52 spectra (in 70 days)



Kővári et al. 2001, 2007a, 2007b, 2010

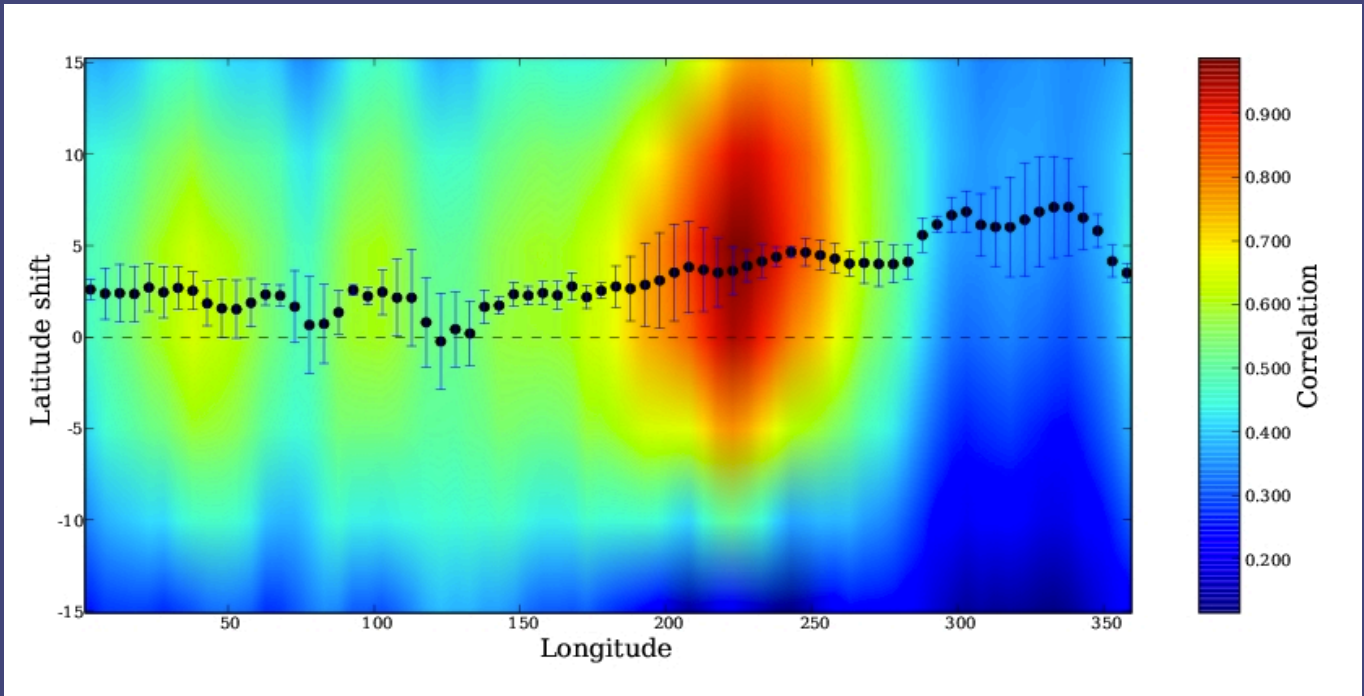
Anti-solar DR law for σ Gem



$\alpha = -0.10 \pm 0.03$

Meridional flow on σ Gem

Coherent poleward migration



predicted by theory:

$u > 300$ m/s

Kitchatinov & Rüdiger 2004

obtained from observations:

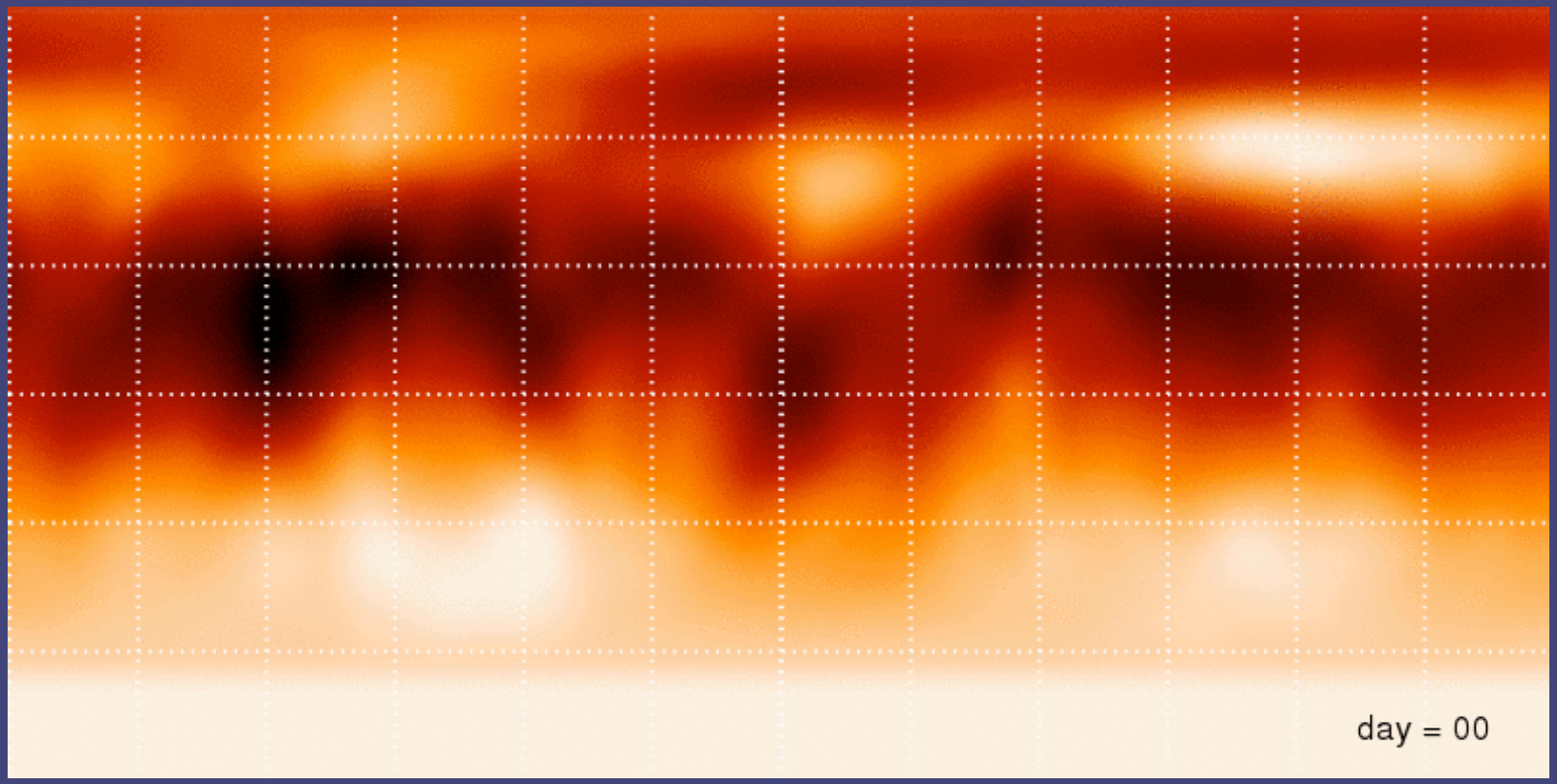
$\langle u \rangle = 350$ m/s

Kővári et al. 2007a, 2007b

Time-series DI of ζ And

K1III, P=17.8 days

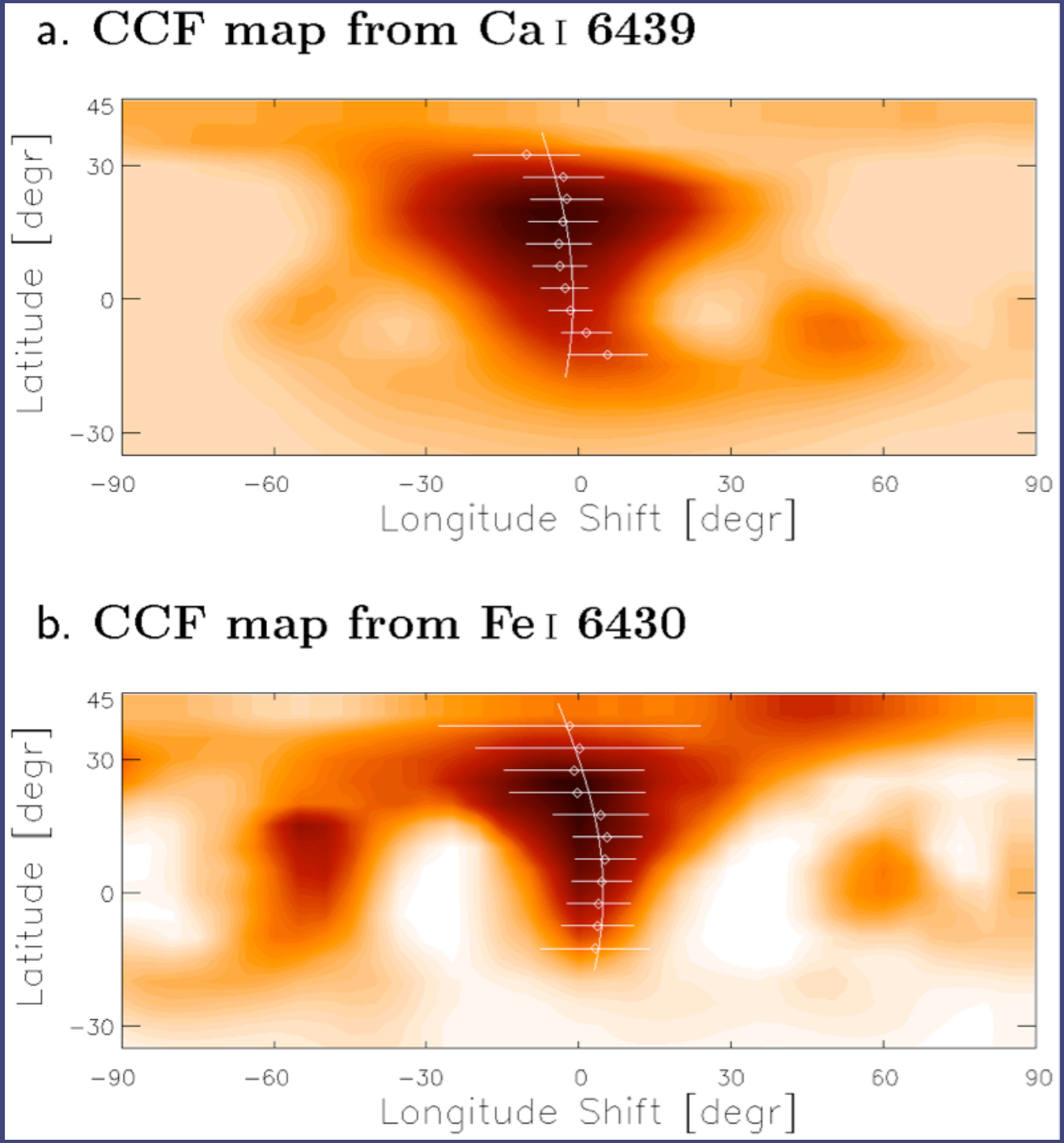
36 time-series DIs from 1996/97 @NSO



Kővári et al. 2007c

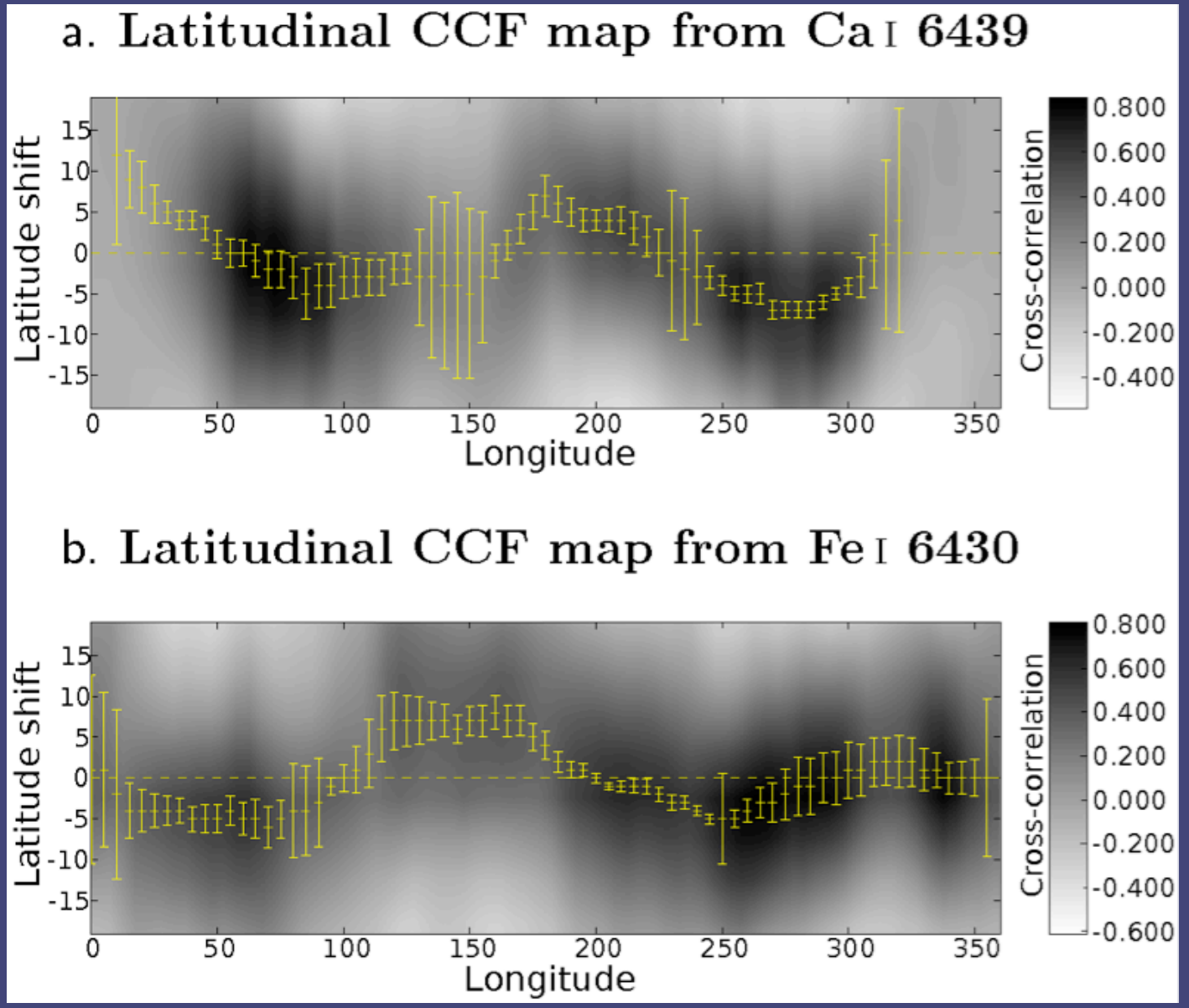
Solar-type DR law for ζ And

$\alpha = 0.049$



Kővári et al. 2007c

No sign of coherent meridional motion for ζ And



Kővári et al. 2007c

Confirming SDR of ζ And

#1 NARVAL@BLT

13 Aug - 31 Aug 2008

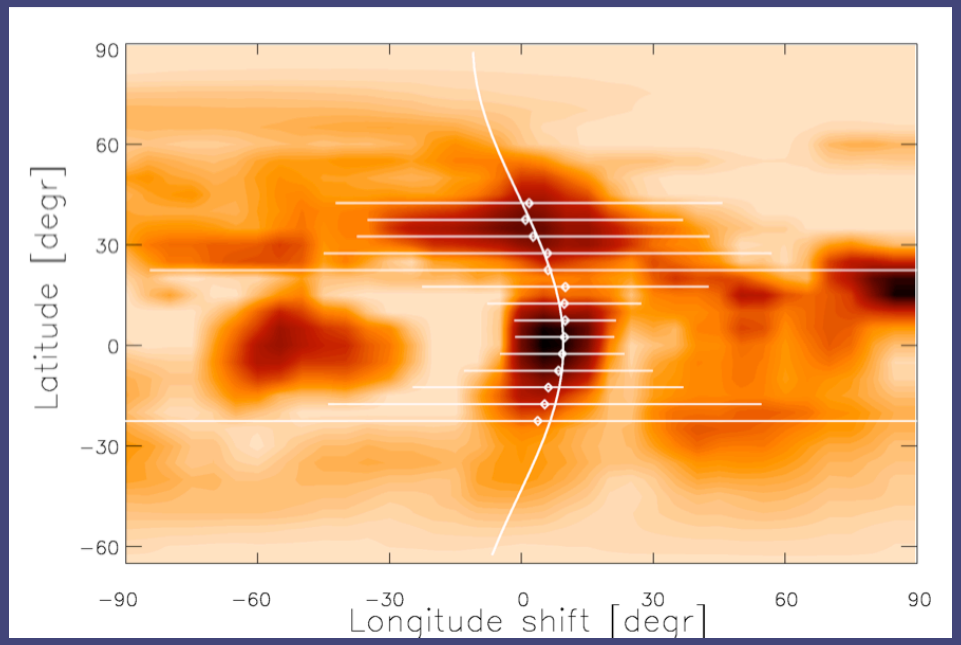
#2 SOPHIE@H-P

30 Aug - 15 Sep 2008

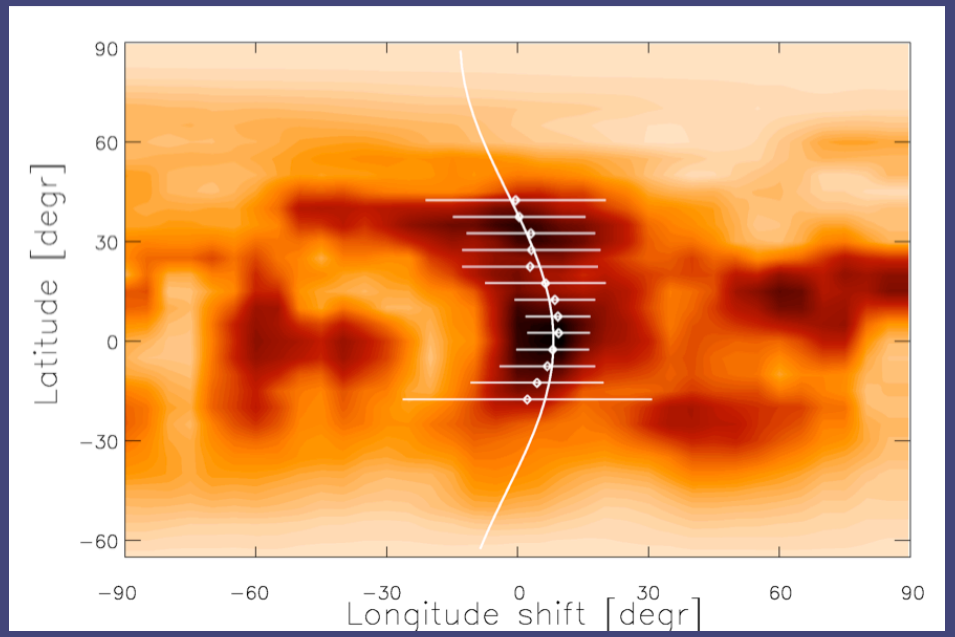
#3 UVES@VLT

13 Sep - 01 Oct 2008

from combined DIs



from individual DIs



$\alpha = 0.053$

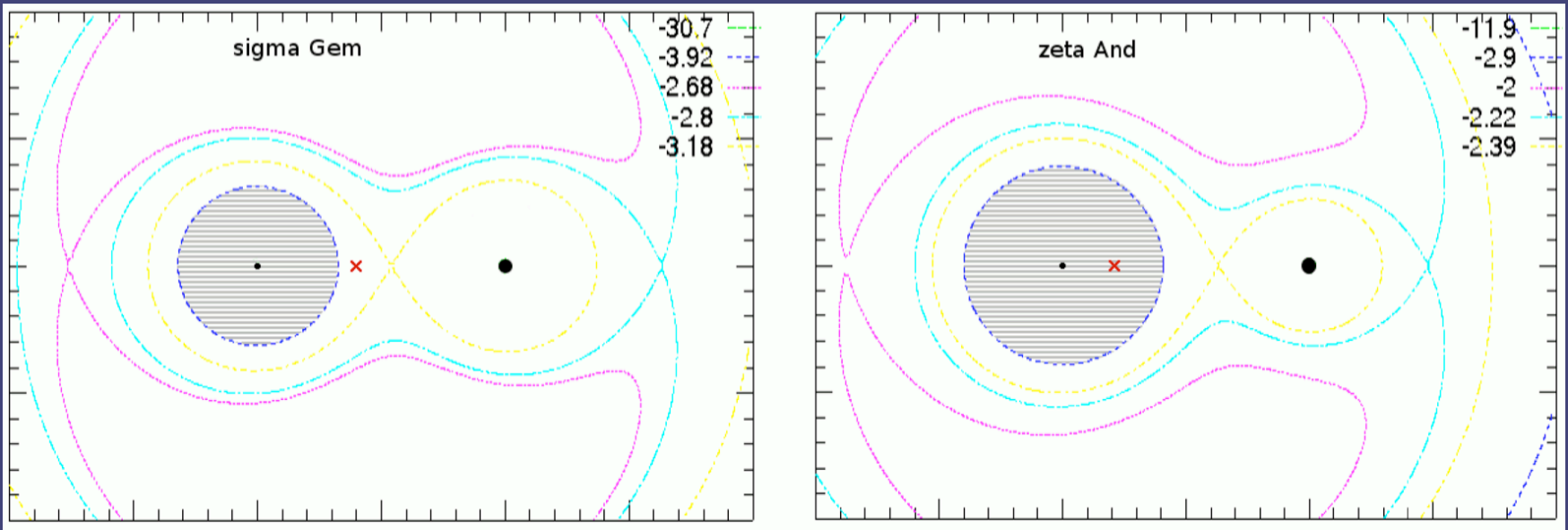
$\alpha = 0.055$

(from NSO96 data: $\alpha = 0.049$)

Kővári et al. 2012

Dynamos in RS CVn-binaries

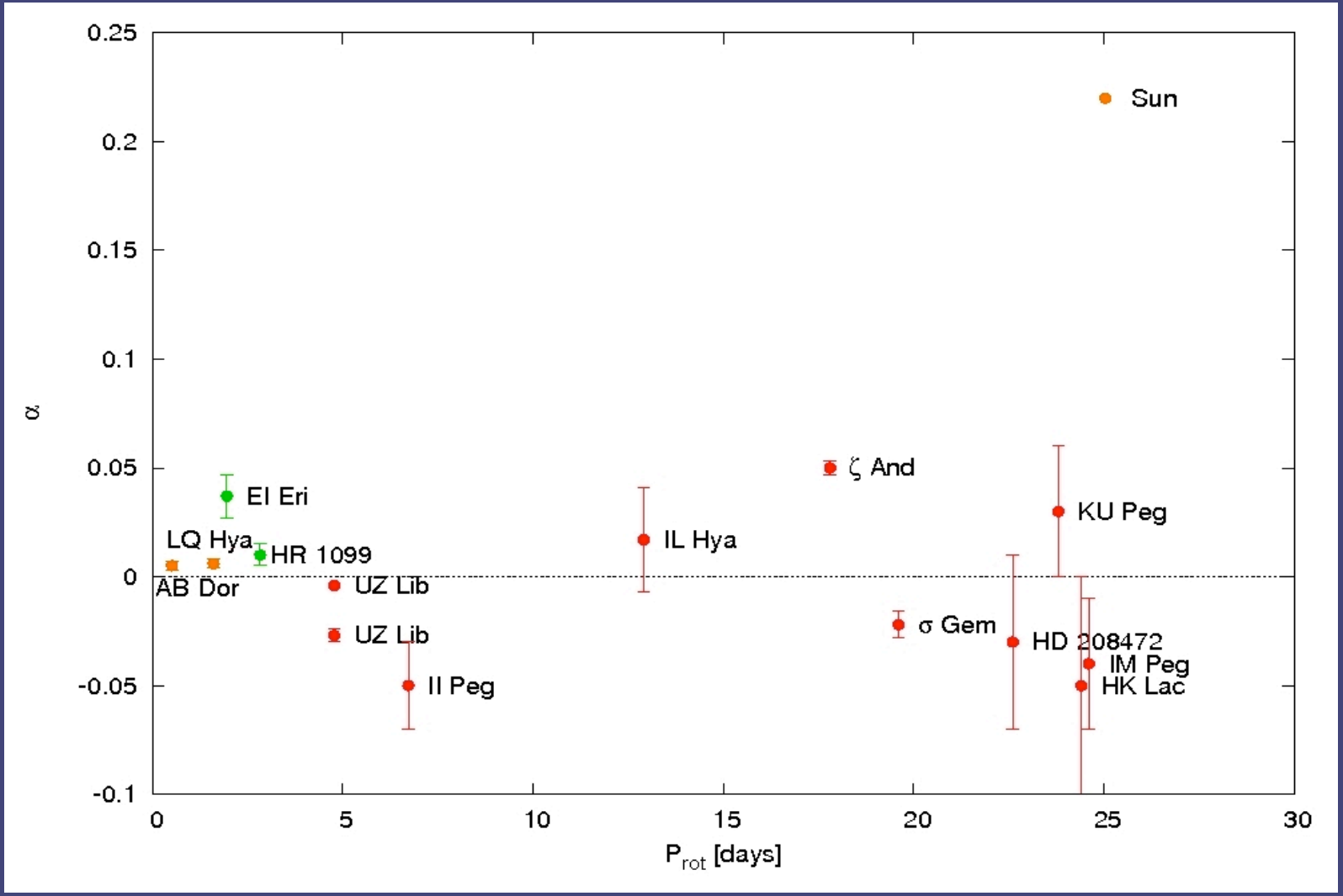
	σ Gem	ζ And
diff. rot.	anti-solar type	solar type
meridional flow	yes (poleward)	no (weak?)
preferred longitudes	no	yes (@quadratures)
distortion	no (small)	yes



Tidal coupling bw diff. rotating envelope and companion is essential!

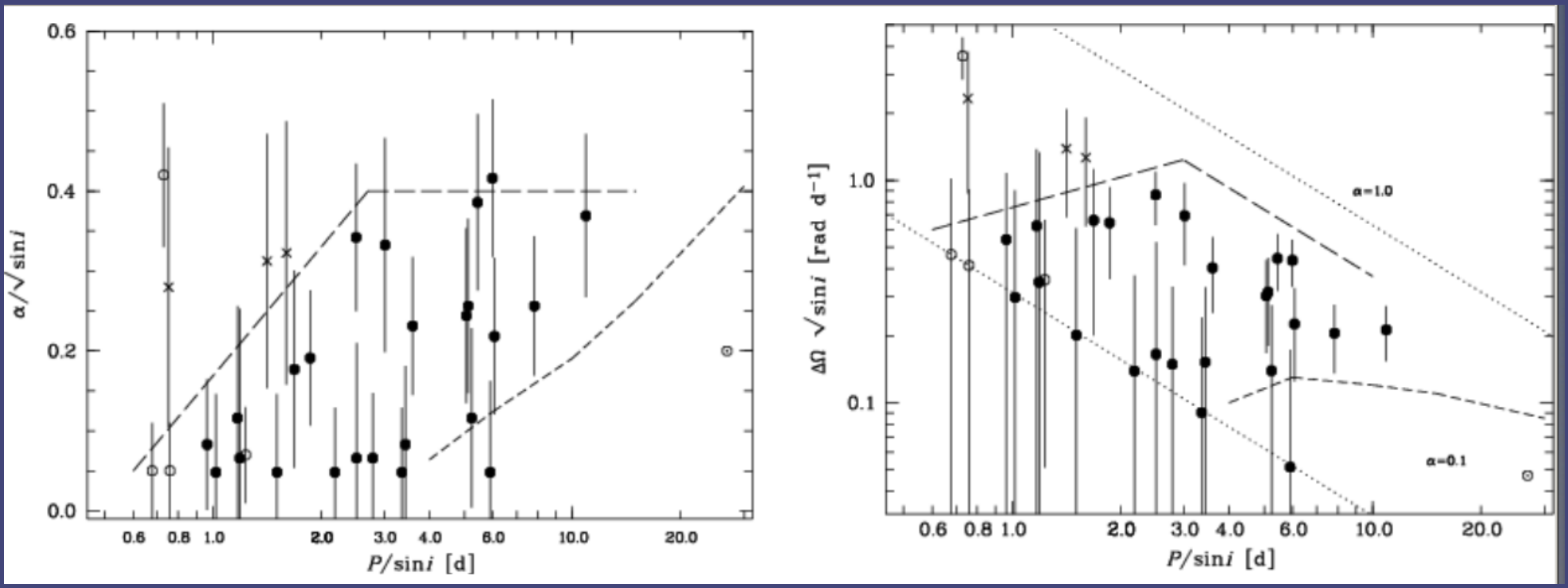
Scharlemann 1981,1982, Schrijver & Zwaan 1991
Holzwarth & Schüssler 2000, 2002

Dependence on rotation?



Weber 2007

Dependence on rotation?

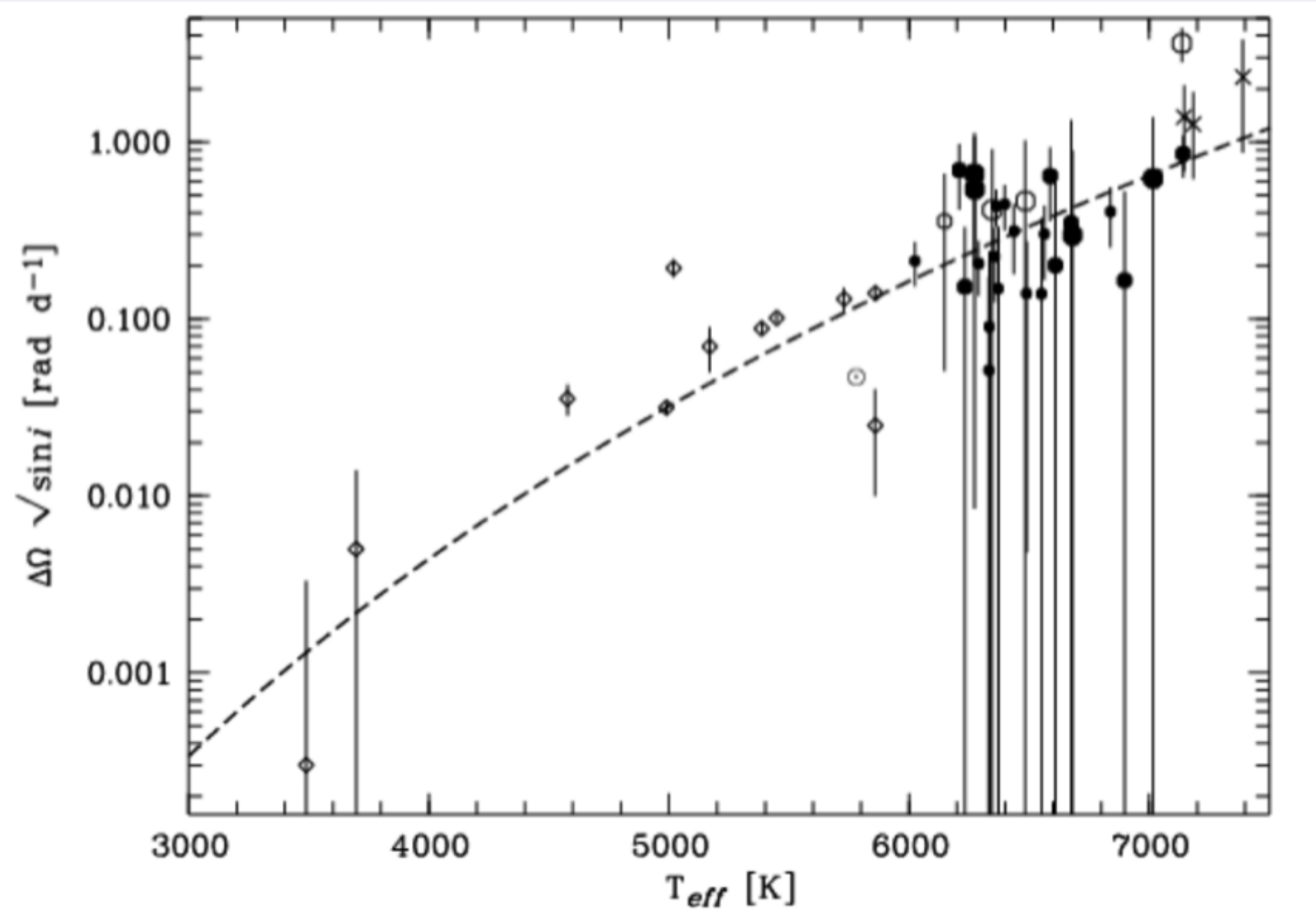


➜ rapid rotators: DR grows with P_{rot}

➜ maximum shear at P_{rot} ~2-3d

Reiners 2006

The color dependency



Barnes et al. 2005, Reiners 2006

Beat a path in the jungle?

- Extending the observations
- Statistically well defined sample
  - spectral type
  - rotation
  - age
  - metallicity
  - single or binary
- Reducing selection effects
- Improving reliability