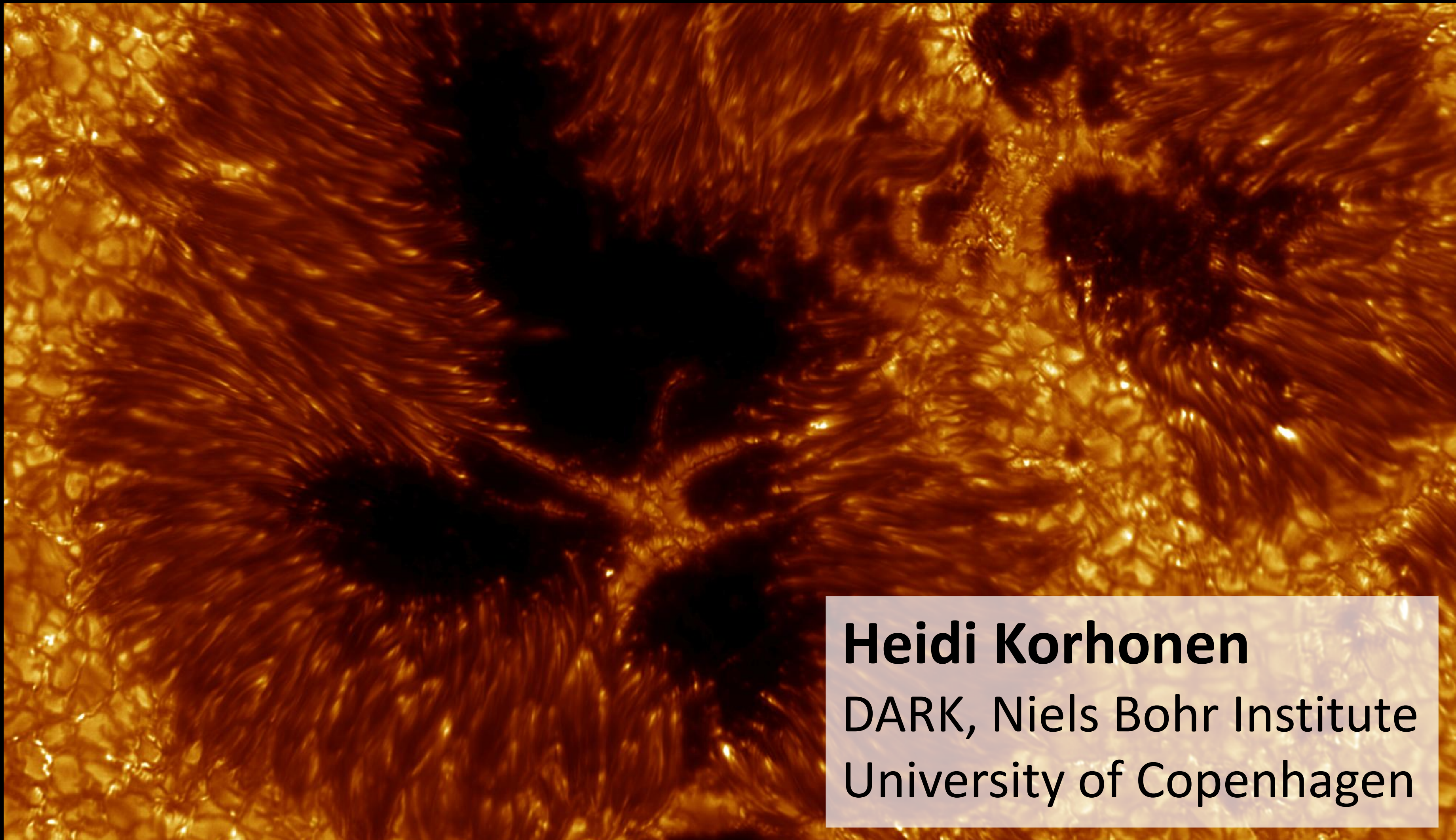
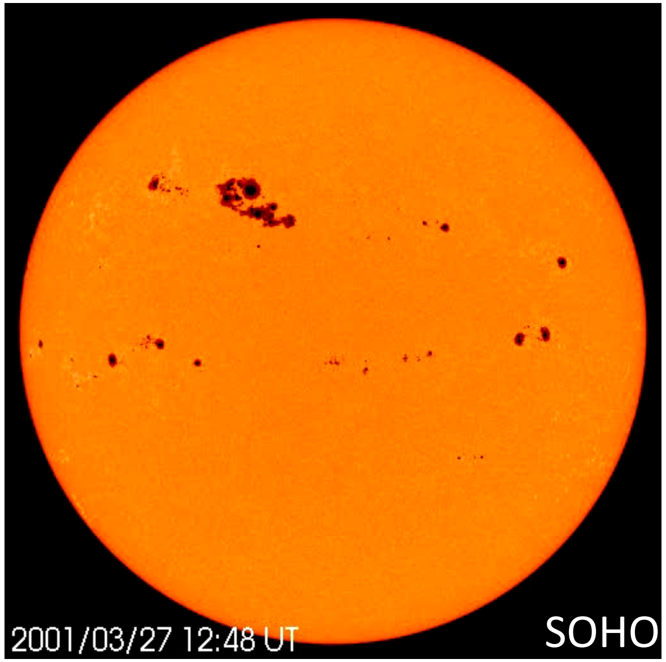
Imaging stellar surfaces: prospects with the SONG



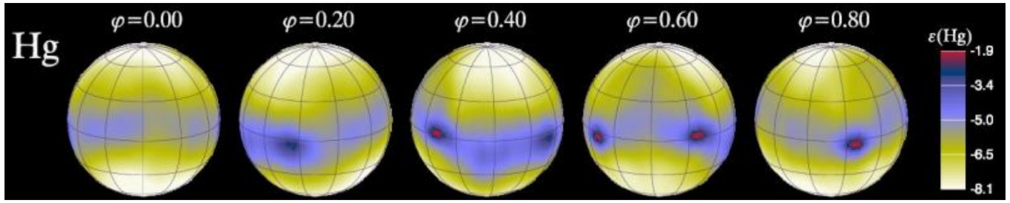
Heidi Korhonen
DARK, Niels Bohr Institute
University of Copenhagen

Stellar surface structures

temperature **vs** **chemical spots**

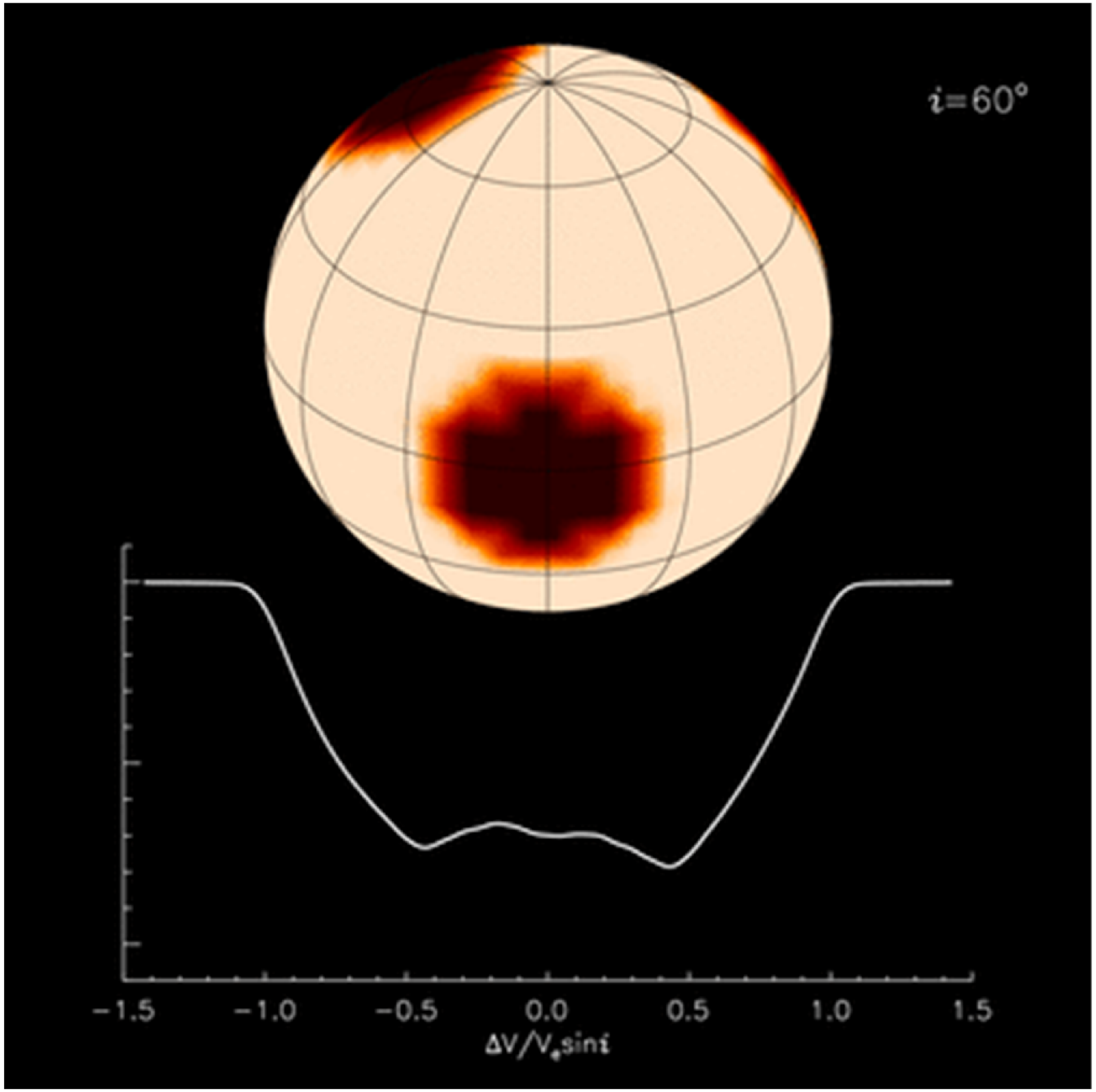


- Cool stars with outer convective envelopes
- Caused by dynamo created magnetic fields



Kochukhov et al. 2007

- Hot stars with radiative outer layers and stable atmospheres
- Chemical stratification due to gravitational settling and radiative levitation
- Magnetic fields collect some elements as surface spots



From Oleg Kochukhov

Mapping starspots with Doppler imaging

Spectra:
Temperature spots
Chemical spots

Spectropolarimetry:
Magnetic fields

Limitations of Doppler imaging

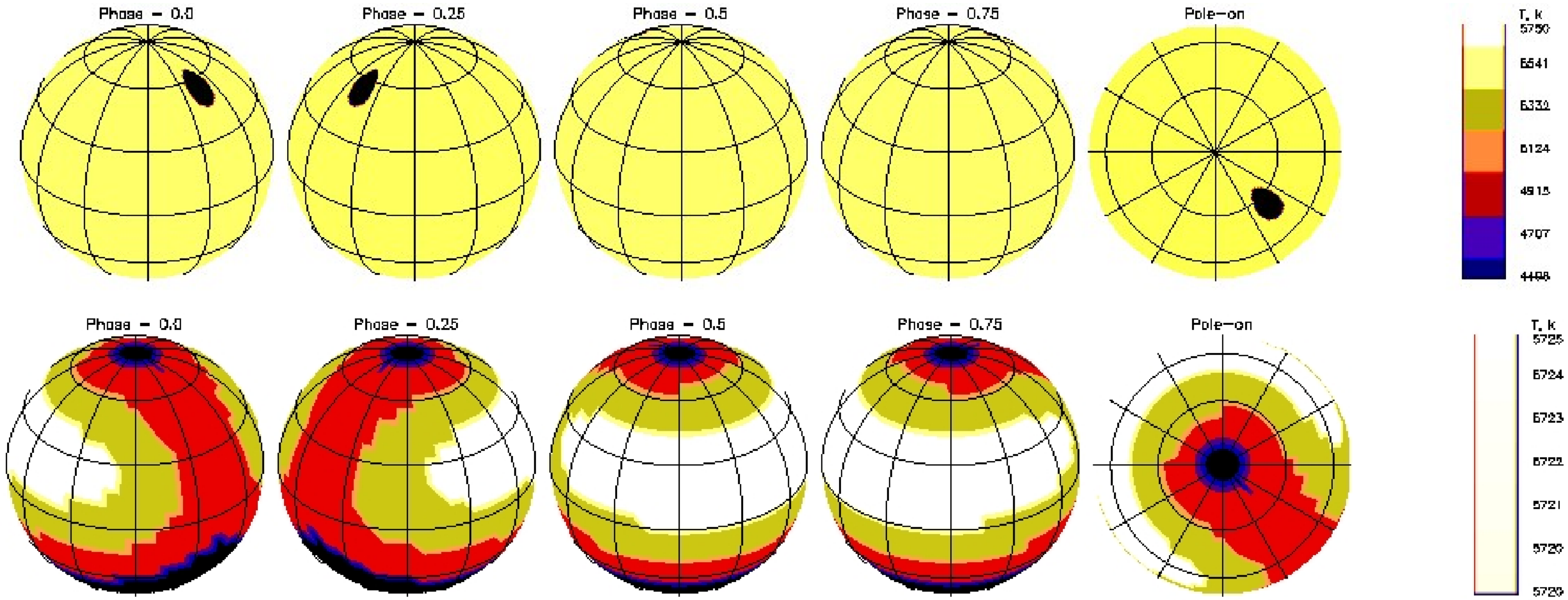
Instrumentation

- High spectral resolution
- High signal-to-noise ratio
- Ability to get good phase coverage

Object

- Good phase coverage (=convenient rotation period)
- Rapid rotation (vsini > ~15km/s)
- Not too long exposure time (bright)
- Something to map!

10°deg radius spot

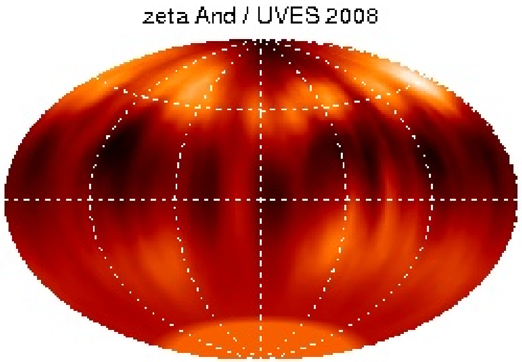


Simulation by Silva Järvinen

Cannot be used for studying solar-type spot groups

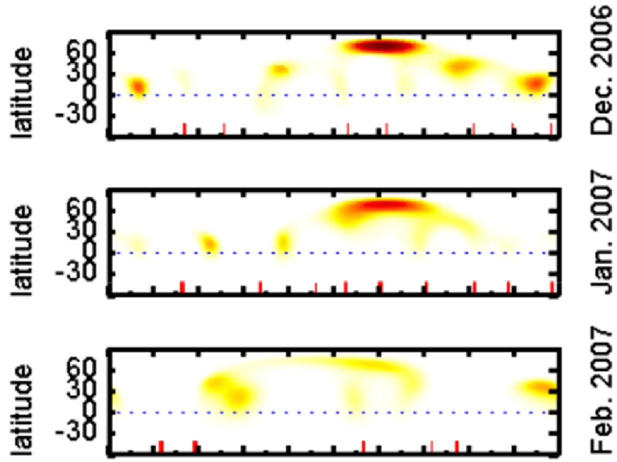
Examples of DI results

Ellipsoidal primary of RSC vn binary zeta And



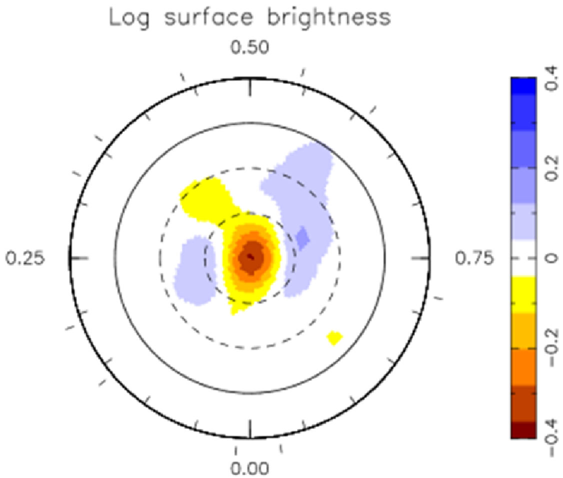
Korhonen et al. 2010

70Myr 'Sun' EK Dra



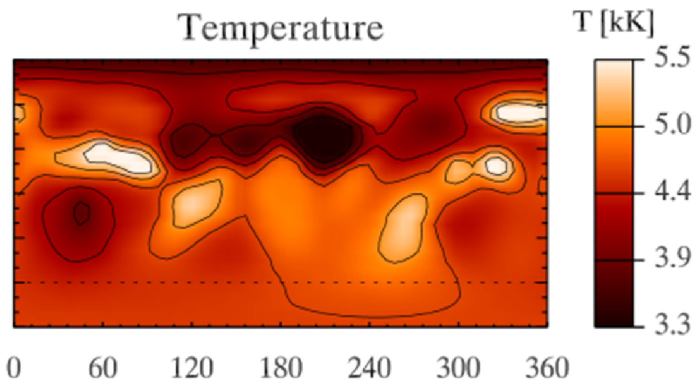
Waite et al. 2017

T Tauri star of Par 1379



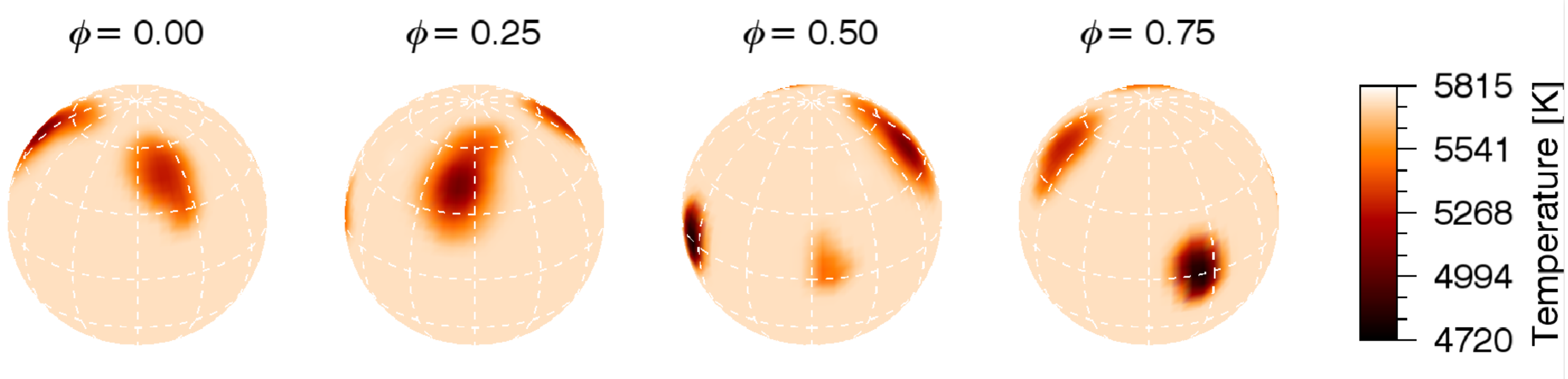
Hill et al. 2017

RSCVn binary II Peg



Rosén et al. 2015

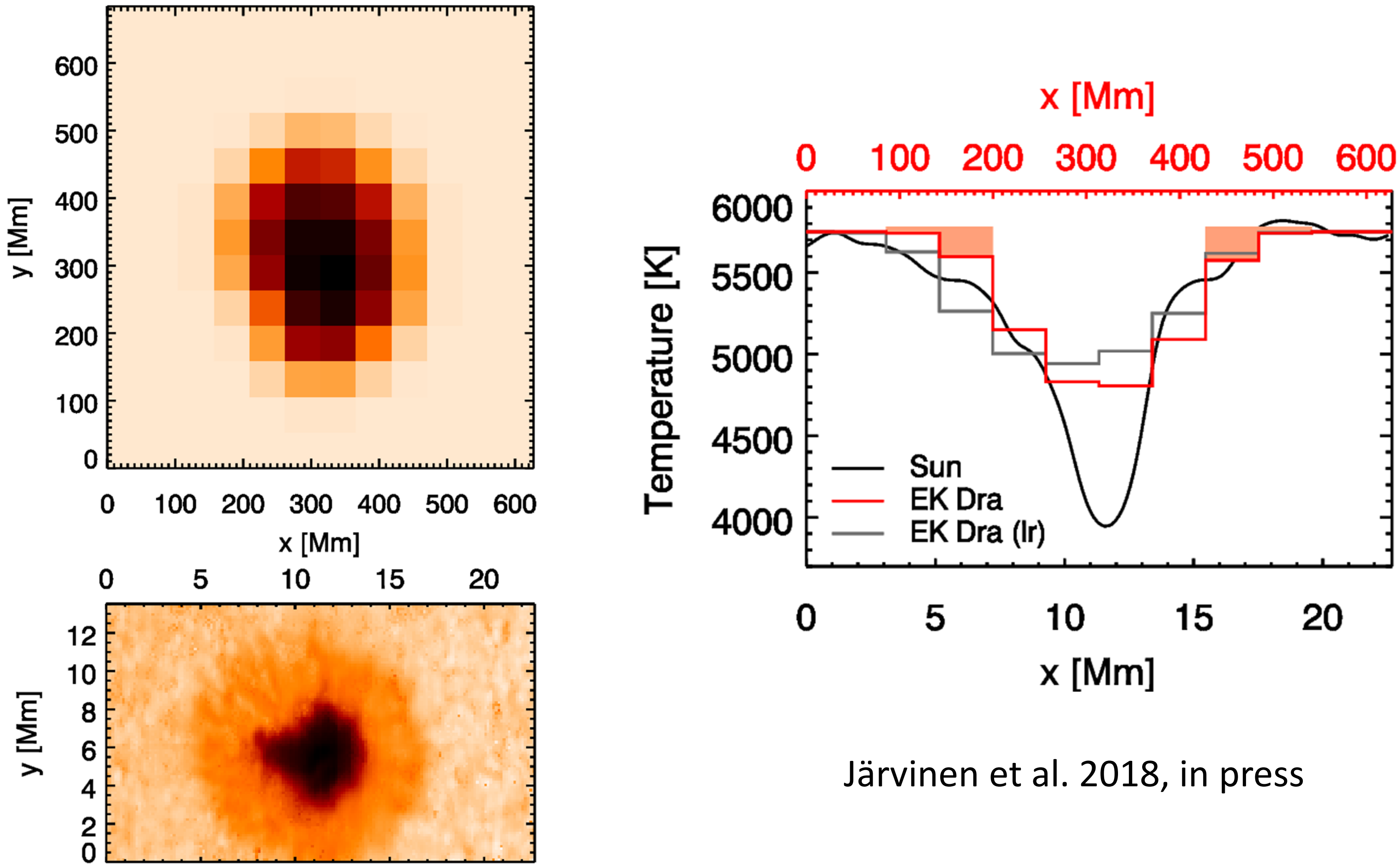
EK Dra with very high resolution



Järvinen et al. 2018, in press

- EK Dra:
  - Young Sun: G1.5V, ~70Myrs
  - Rapid rotator: P=2.6d, vsini=17km/s
- Observed with PEPSI high resolution mode R=250,000

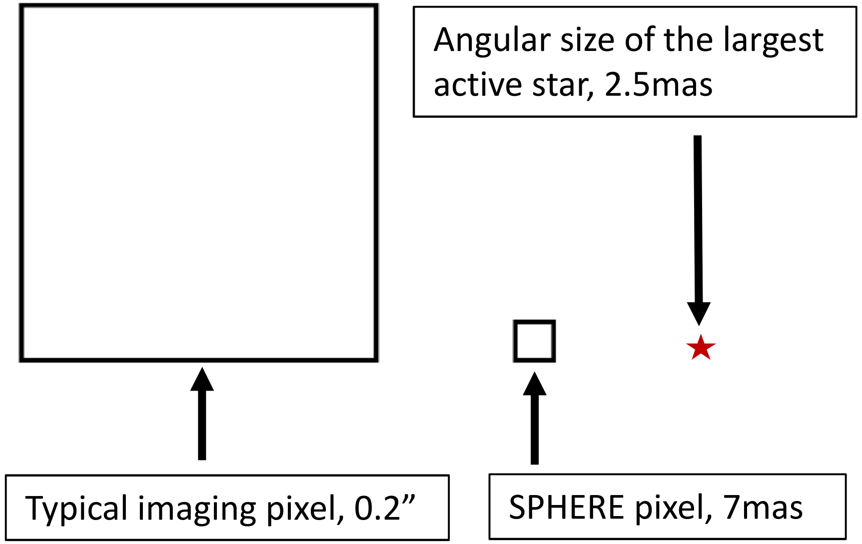
EK Dra spots vs sunspots

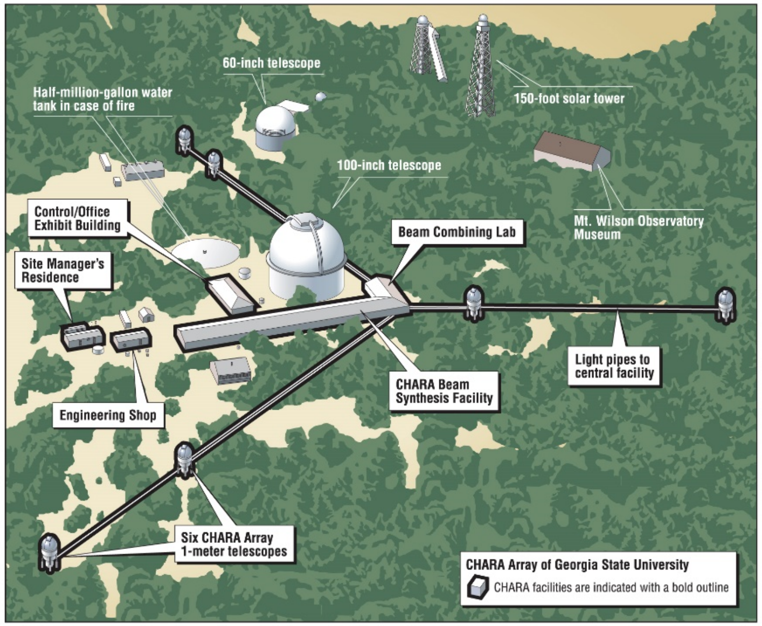


Järvinen et al. 2018, in press

Is it possible to directly image starspots?

- Unfortunately most active stars are apparently small, and spots naturally even much smaller
- But one can try to use near-infrared interferometry

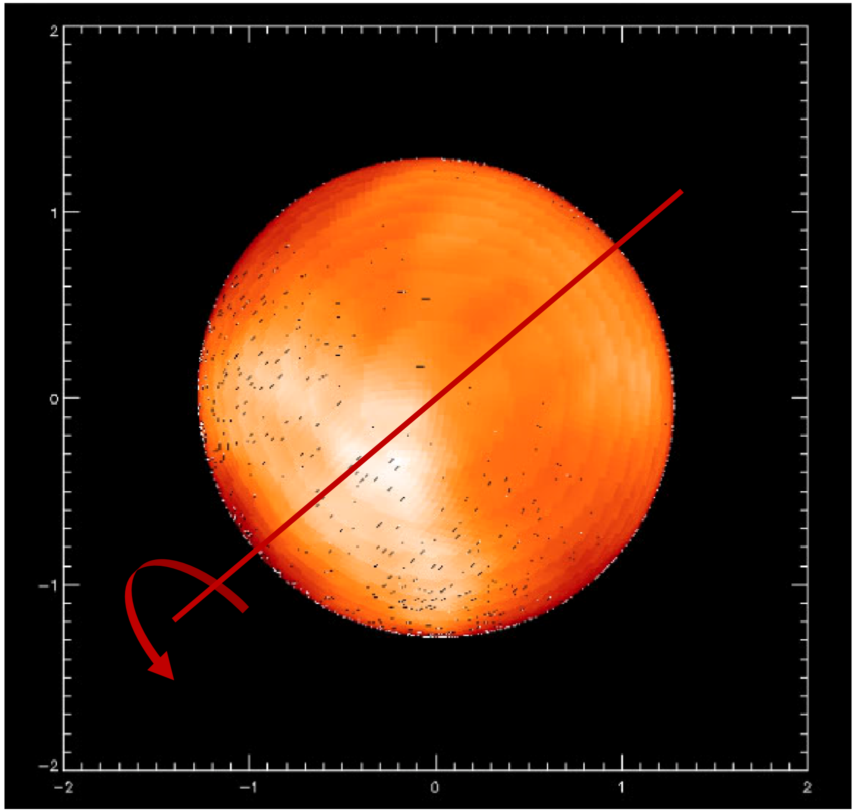




ESO VLTI: resolution ~3mas
CHARA array: resolution ~0.5mas

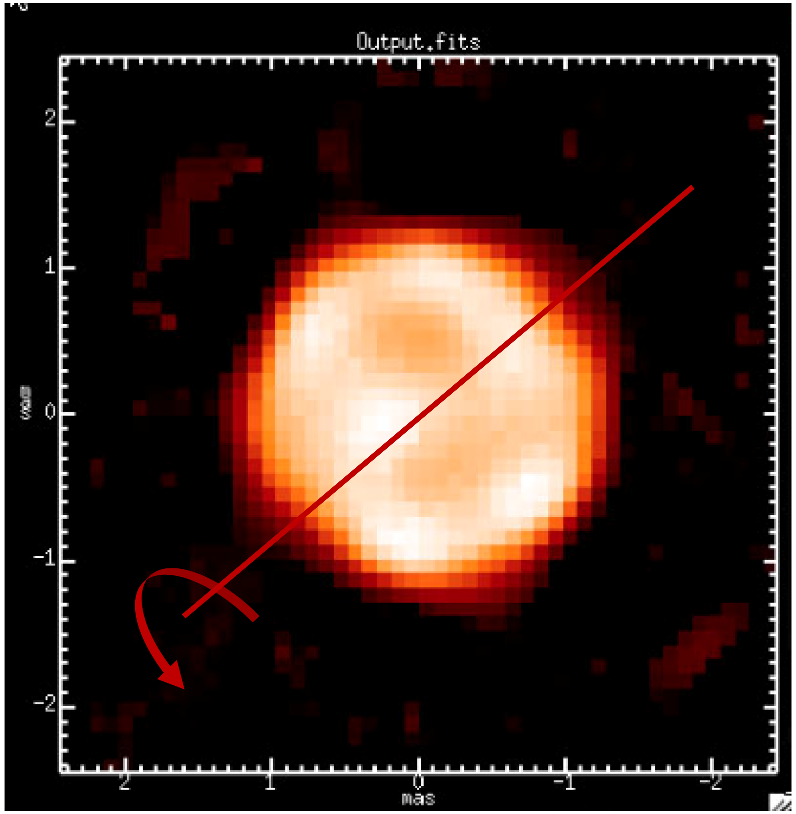
Centre for High Angular Resolution Astronomy

ζ And first attempts



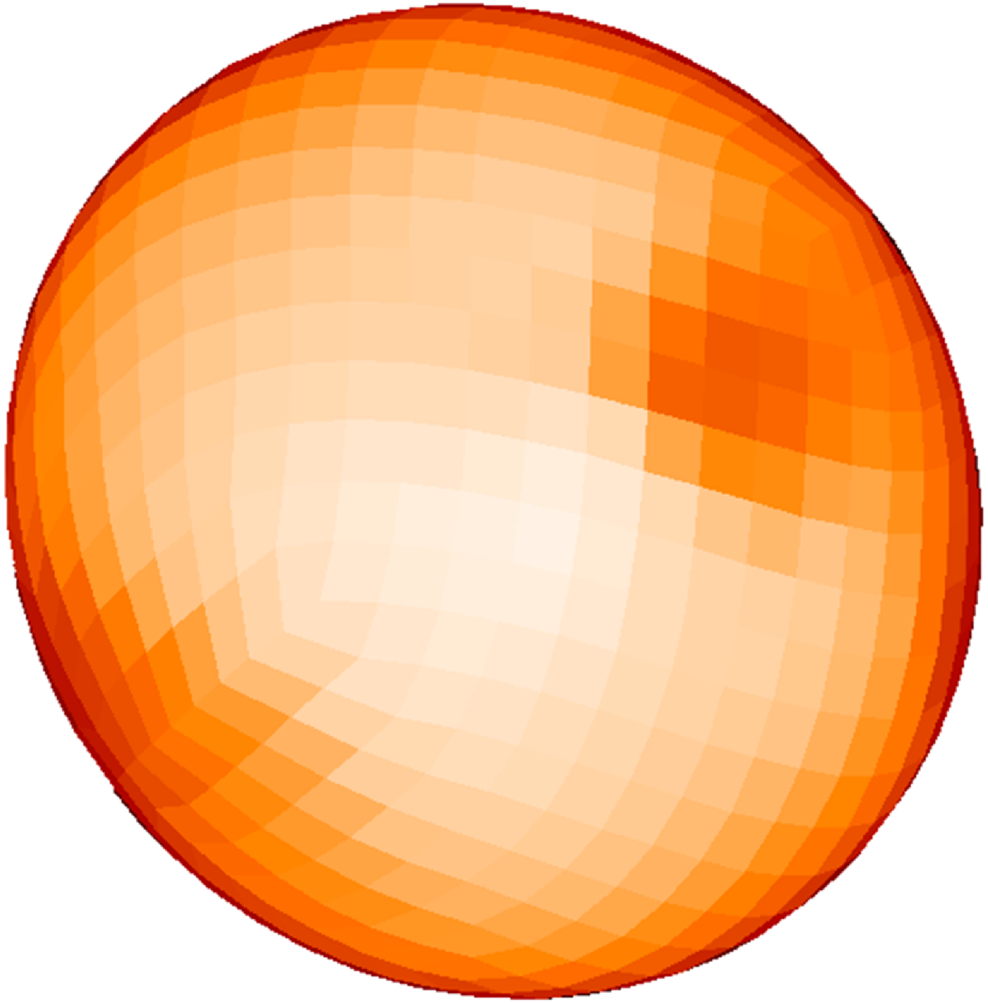
Doppler imaging: Kővári & Korhonen

19 July 2011 (6T)



Interferometry: Roettenbacher & Monnier

ζ And attempt number N



Roettenbacher, Monnier, Korhonen et al. 2016, Nature

ζ Andromedae:

- K giant
- 4600 K, R=15Rsolar
- RS CVn binary
- Starting to fill Roche lobe

Intensity image at H band using MIRC and all 6 CHARA telescopes

Spot hemispheres

- Persistent polar spot

  ➡

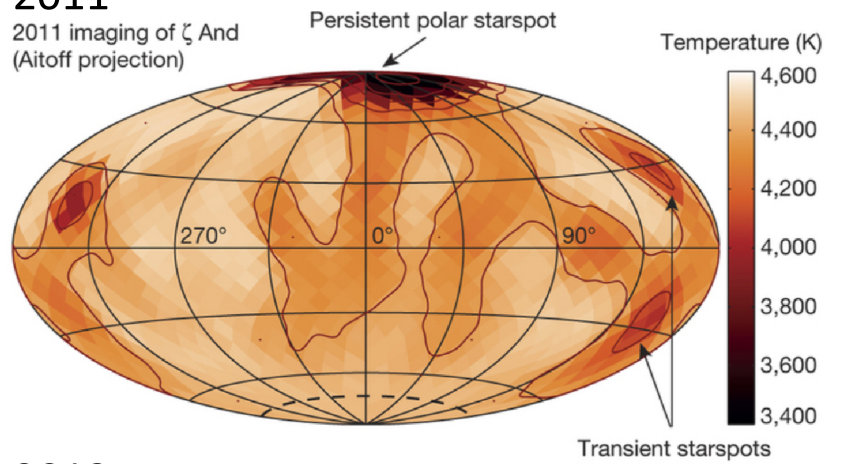
  Polar spots are real

- The transient spots in 2011 are concentrated to the ‘northern’ hemisphere and in 2013 to the ‘southern’ hemisphere

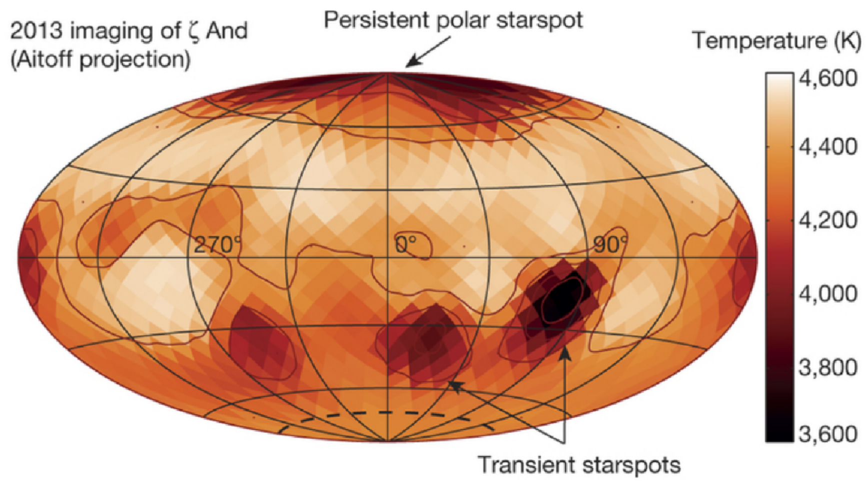
  ➡

  First reliable hemispheres

2011



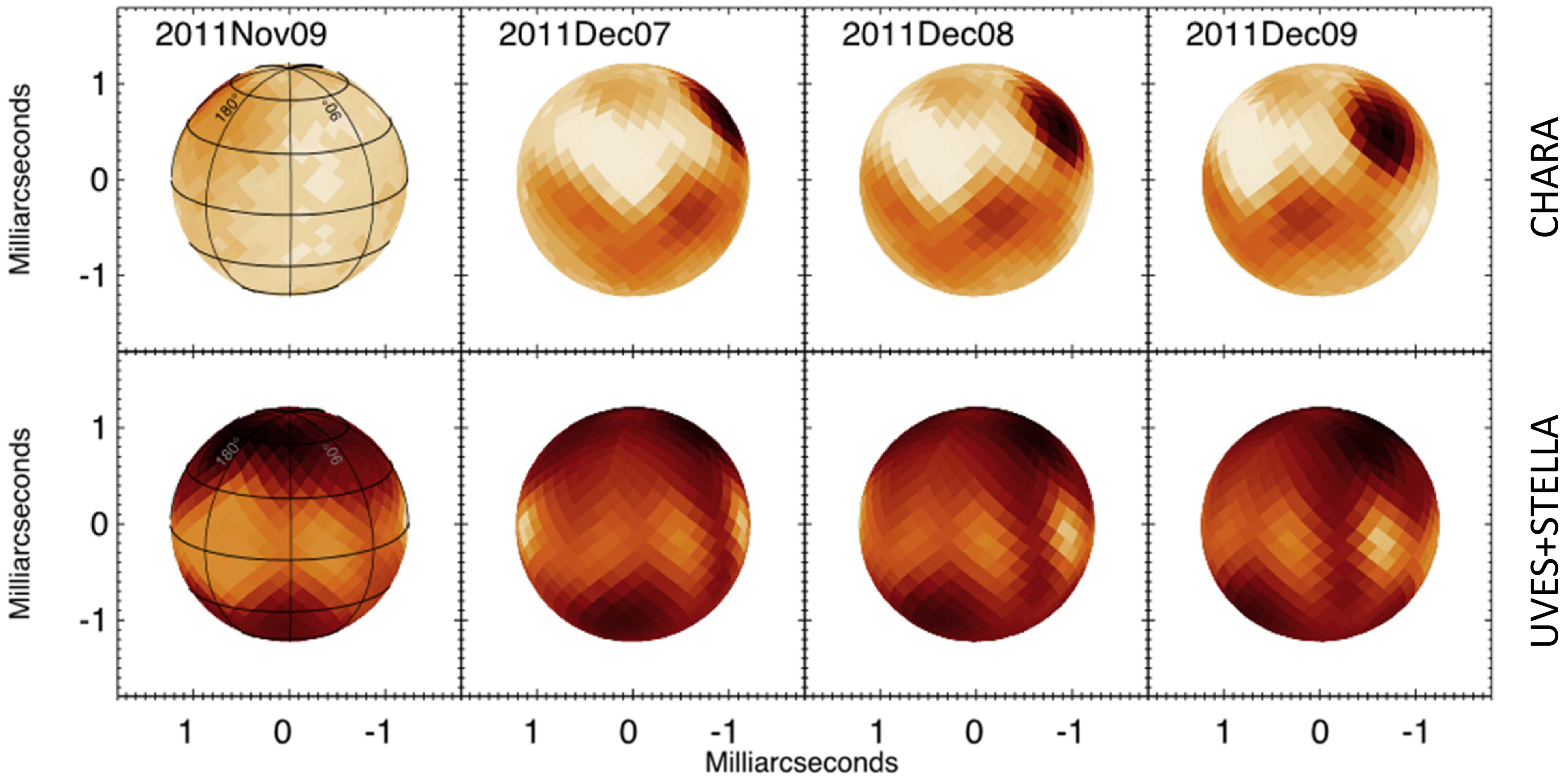
2013



Roettenbacher, Monnier, Korhonen, et al. 2016, Nature

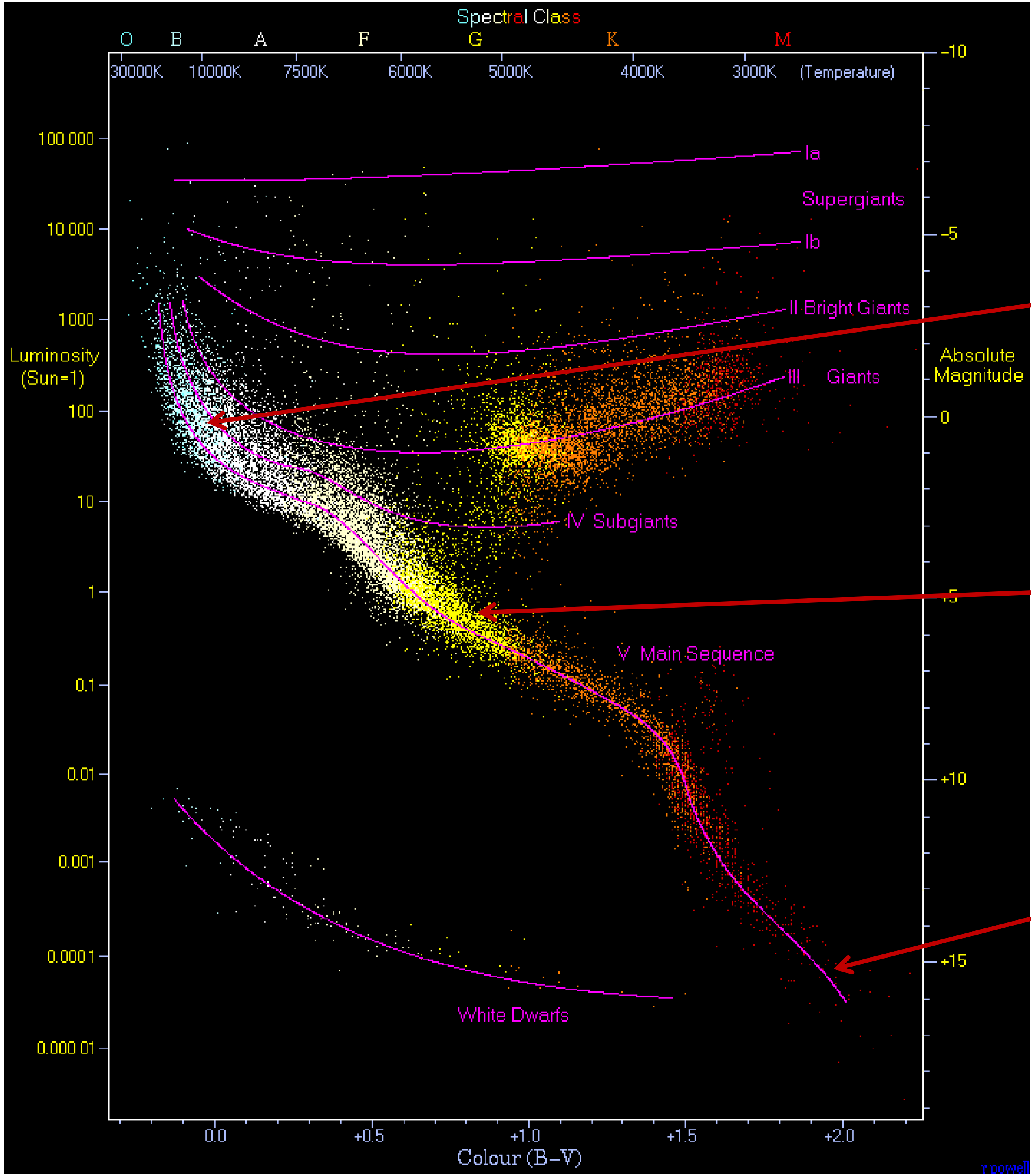
Comparing Doppler and interferometric imaging

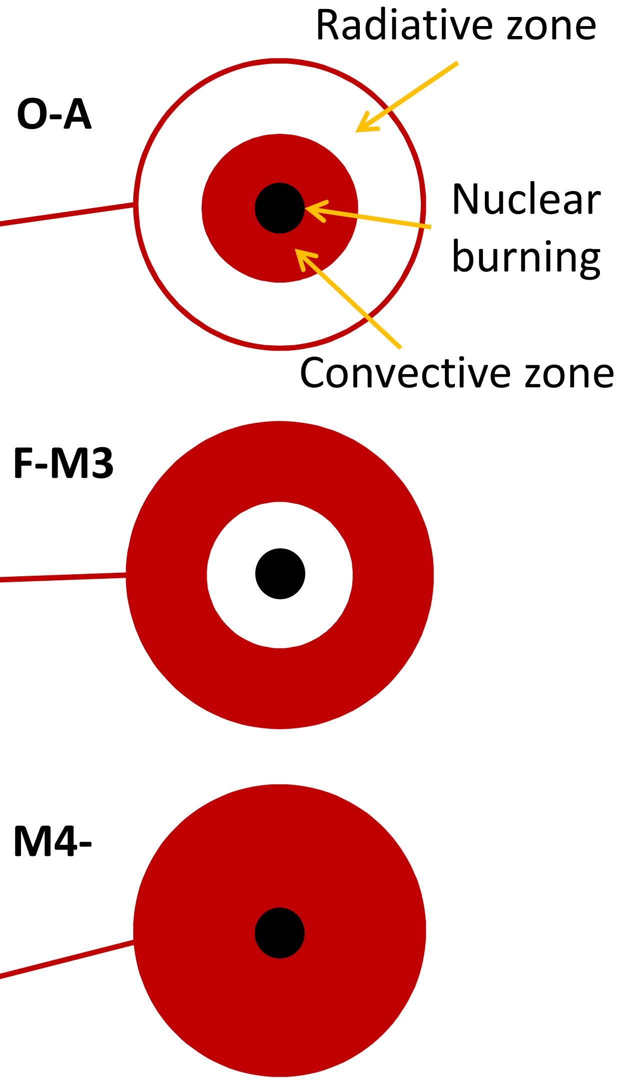
RS CVn binary σ Geminorum



Roettenbacher, Monnier, Korhonen et al. 2017

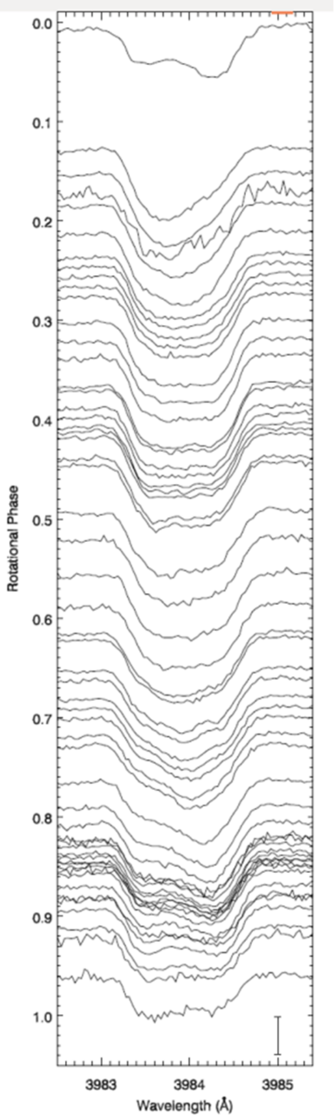
Internal structure





Stars with outer convective envelopes can have dynamos that create magnetic fields

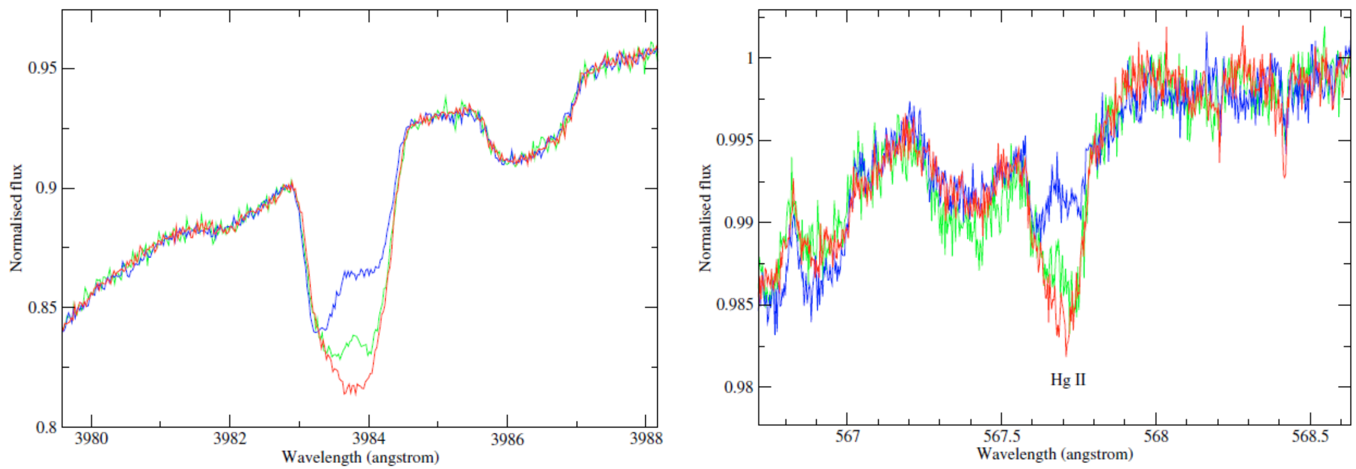
Chemical spots on HgMn star α And



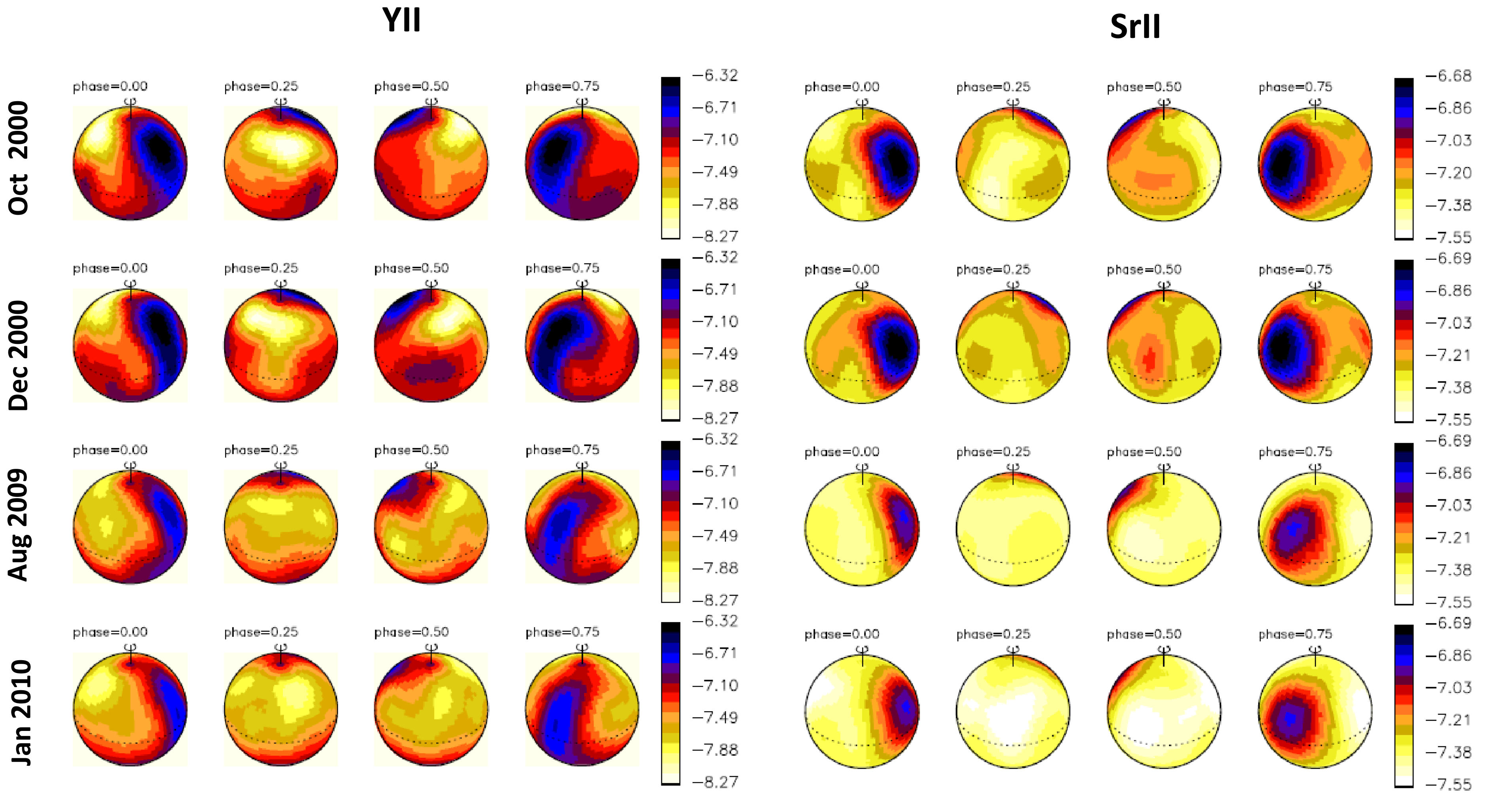
Adelman et al. 2002

„This first definitively identified spectrum variation in any mercury-manganese star is not due to the orbital motion of the companion. Rather, the variation is produced by the combination of the 2.38236 day period of rotation of the primary that we determined and a nonuniform surface distribution of mercury that is concentrated in its equatorial region.“ (Adelman et al. 2002)

Wade et al. 2006

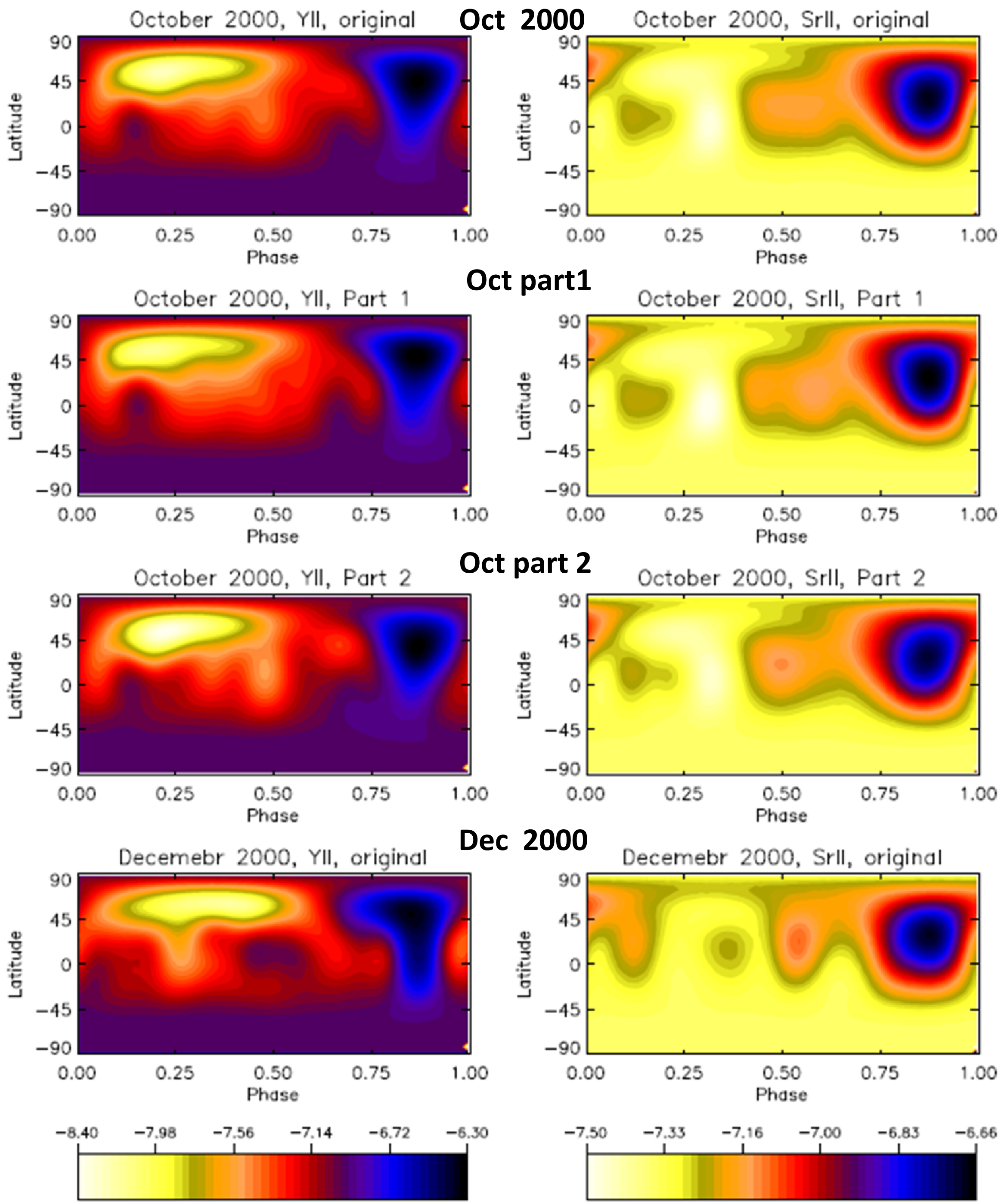


Long-term observations of HgMn star HD11753



All the data from CORALIE spectrograph at La Silla

Korhonen et al. 2013

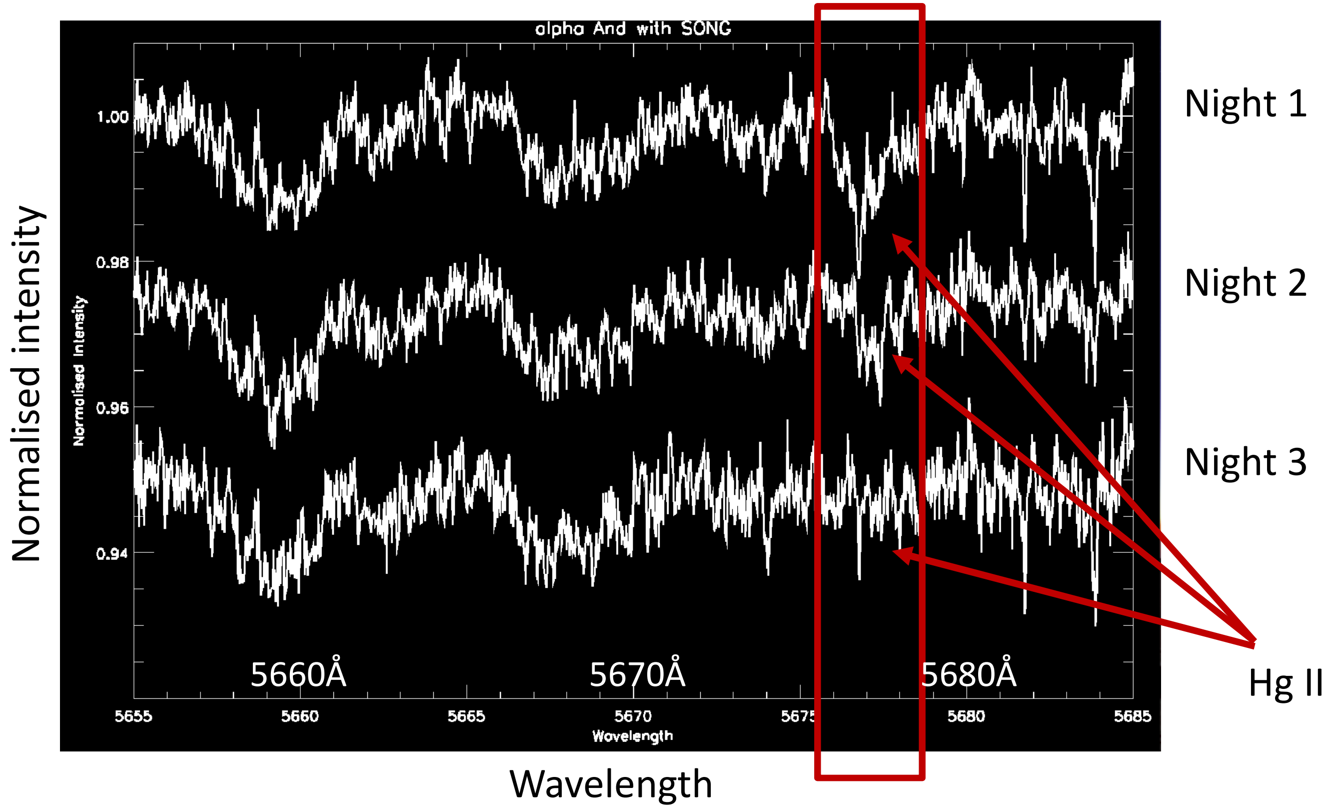


Temporal evolution of spots in HgMn stars

- Slow temporal evolution discovered in α And by Kochukhov et al. (2007)
- Fast evolution discovered in HD 11753 by Briquet et al. (2010)
- Reliability studied in more detail by Korhonen et al. (2013)

Korhonen et al. 2013

α And with SONG



Possible SONG targets for temperature spots:

- zeta And, V=4.1, P=17.8d, vsini=41.4 km/s
- sigma Gem, V=4.3, P=19.6d, vsini=27.5 km/s
- 31 Com, V=4.9, P=6.8d, vsini=67km/s

And for HgMn stars:

- alpha And, V=2.1, P=2.4d
- 66 Eri, V=5.1, P=5.5d
- HD224926, V=5.1, P=3.2d

Outlook with SONG

Strengths of SONG

- Excellent timing of the observations enables mapping spot evolution
  - surface differential rotation and meridional flows in cool stars
  - evolution timescales of spots on HgMn stars
- High spectral resolution enables studying possible starspot penumbra

Contemporaneous observations

- Combined with CHARA for detailed studies of stellar surfaces
- Combined with TESS, e.g., photometric variability of HgMn stars