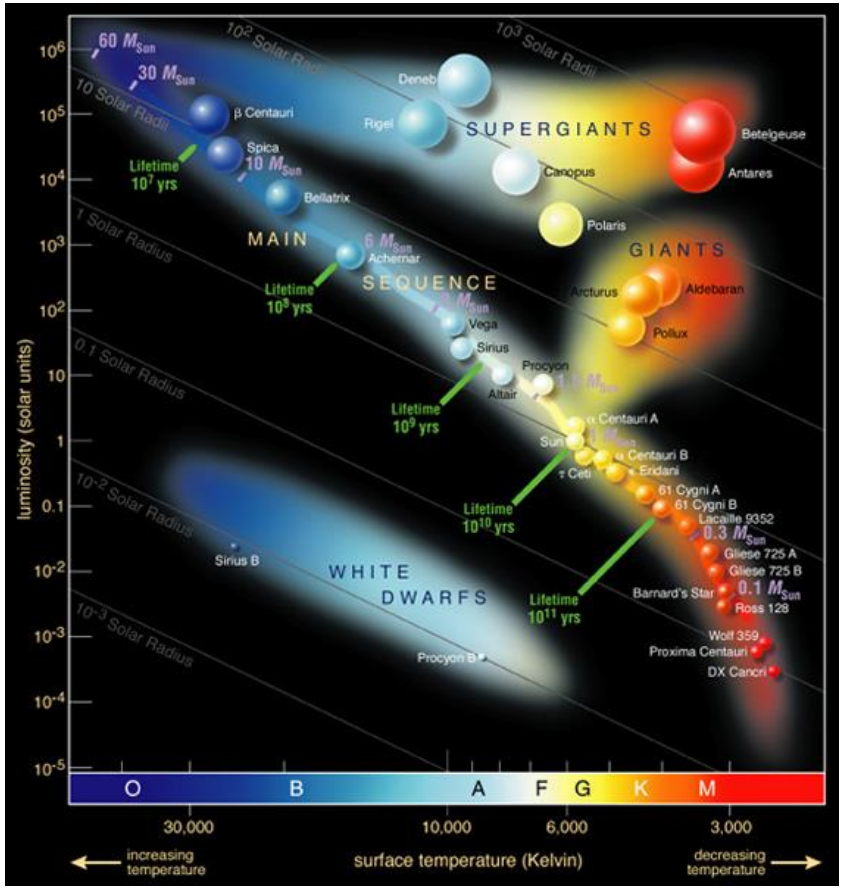
Magnetic fields of cool giant and supergiant stars: models versus observations

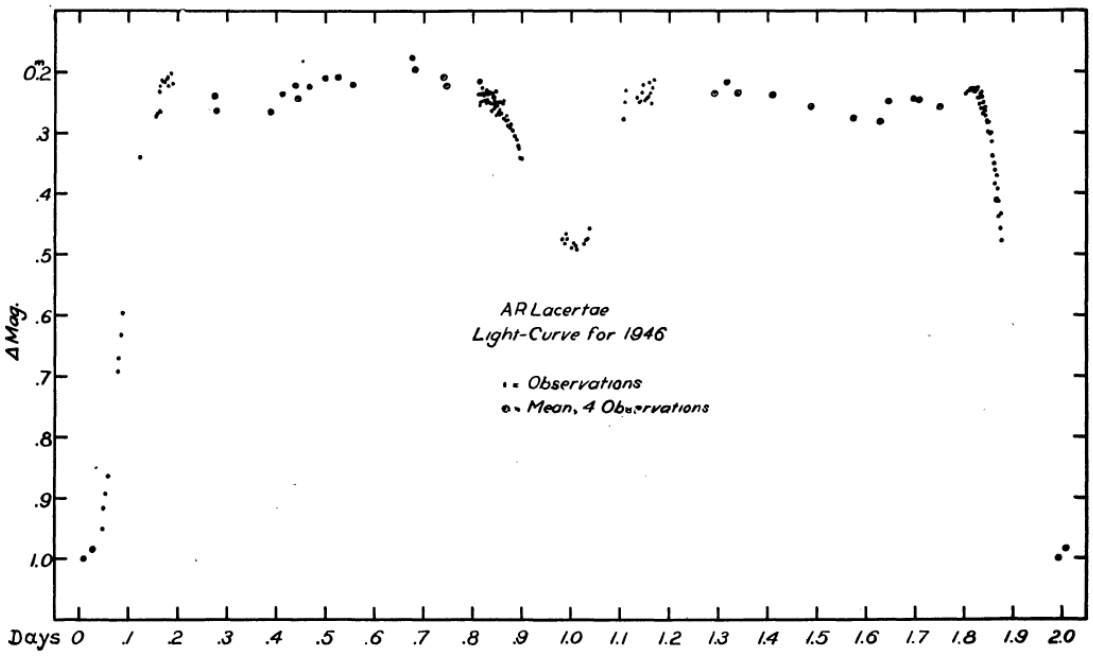
Heidi Korhonen
DARK, Niels Bohr Institute
University of Copenhagen
Denmark

Outline

- Magnetism in ‚active‘ giants
- …and in ‚normal‘ giants
- Magnetism in red supergiants



First detection of starspots in AR Lac



RS CVn binary:

- close detached binaries
- primary G–K III or VI
- secondary G–M V or VI
- typical period from few days to ~20 days

Kron 1947

An examination of all data for AR Lacertae indicates that, without exception, the irregularities repeat themselves with high precision from one revolution of the binary to the next, but that changes in the nature of the irregularities take place within a few weeks to a few months.

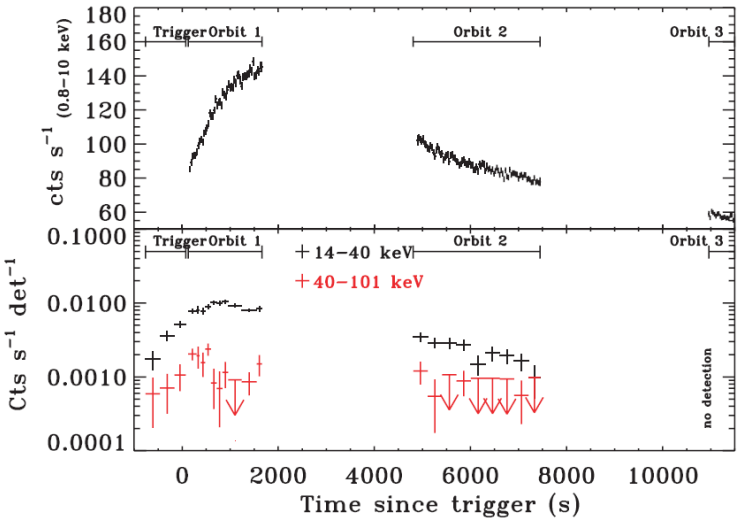
Kron 1947, PASP 59, 261

Title:	The Probable Detecting of Surface Spots on AR Lacertae B
Authors:	Kron, Gerald E.
Publication:	Publications of the Astronomical Society of the Pacific, Vol. 59, No. 350, p.261 (PASP Homepage)
Publication Date:	10/1947
Origin:	ADS

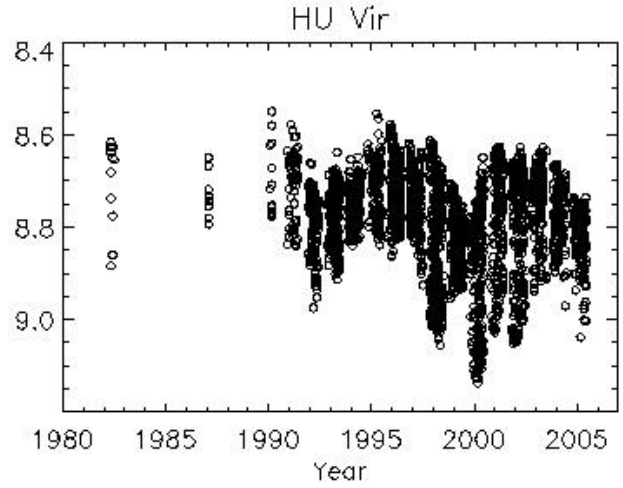
THE PROBABLE DETECTION OF PATCHES OF VARYING BRIGHTNESS ON AR LACERTAE B

GERALD E. KRON
Lick Observatory

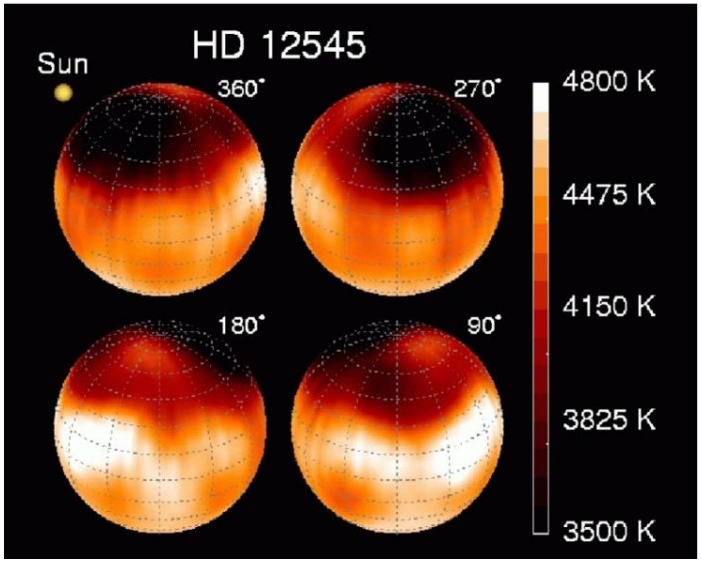
Magnetism on RS CVn binaries



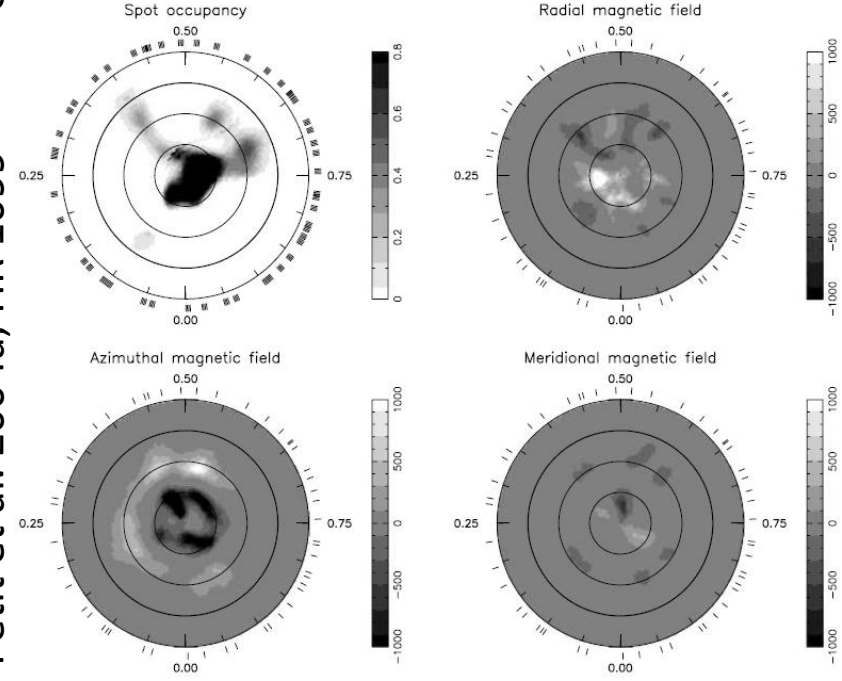
Osten et al. 2007, II Peg



Oláh et al. 2009



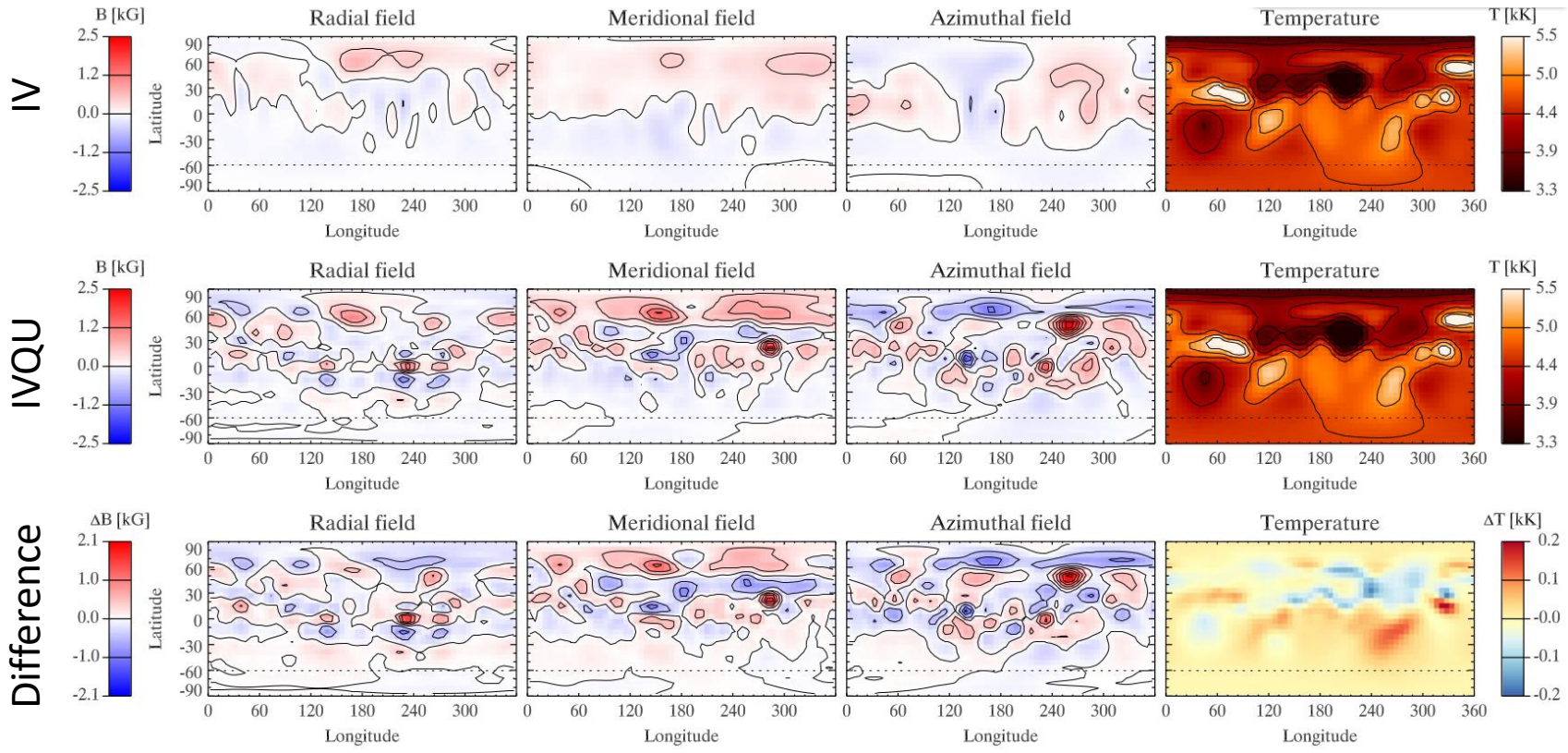
Strassmeier 1999



Petit et al. 2004a, HR 1099

Magnetic field maps from all four Stokes parameters

RS CVn binary II Peg in 2012

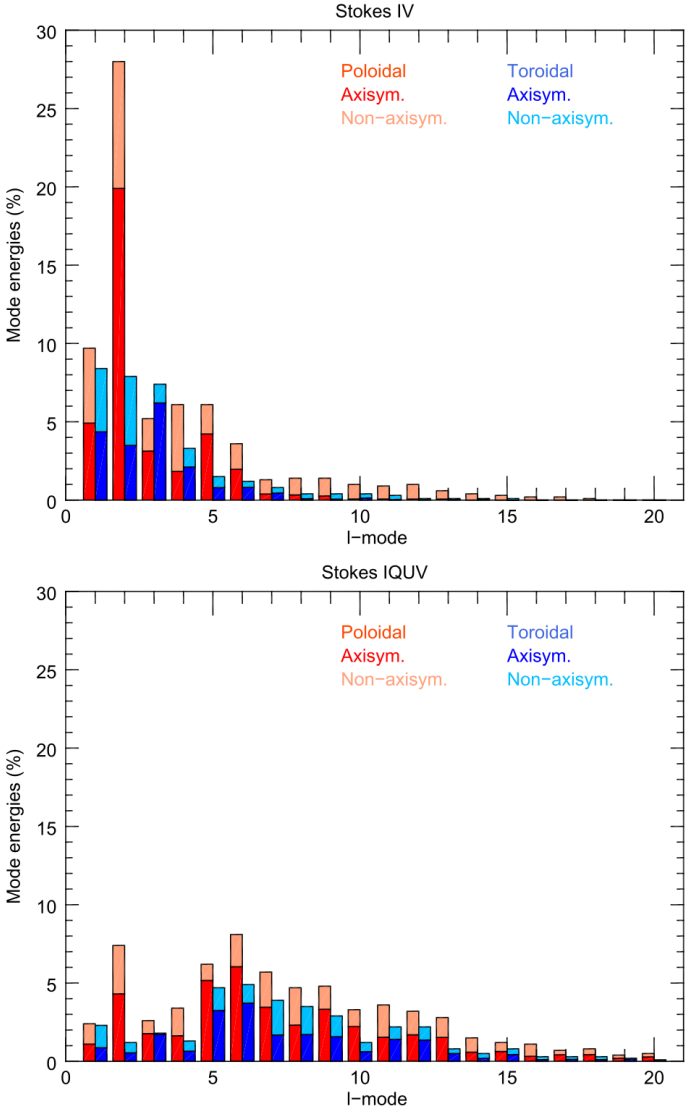


Rosén et al. 2015

Magnetic field maps from all four Stokes parameters

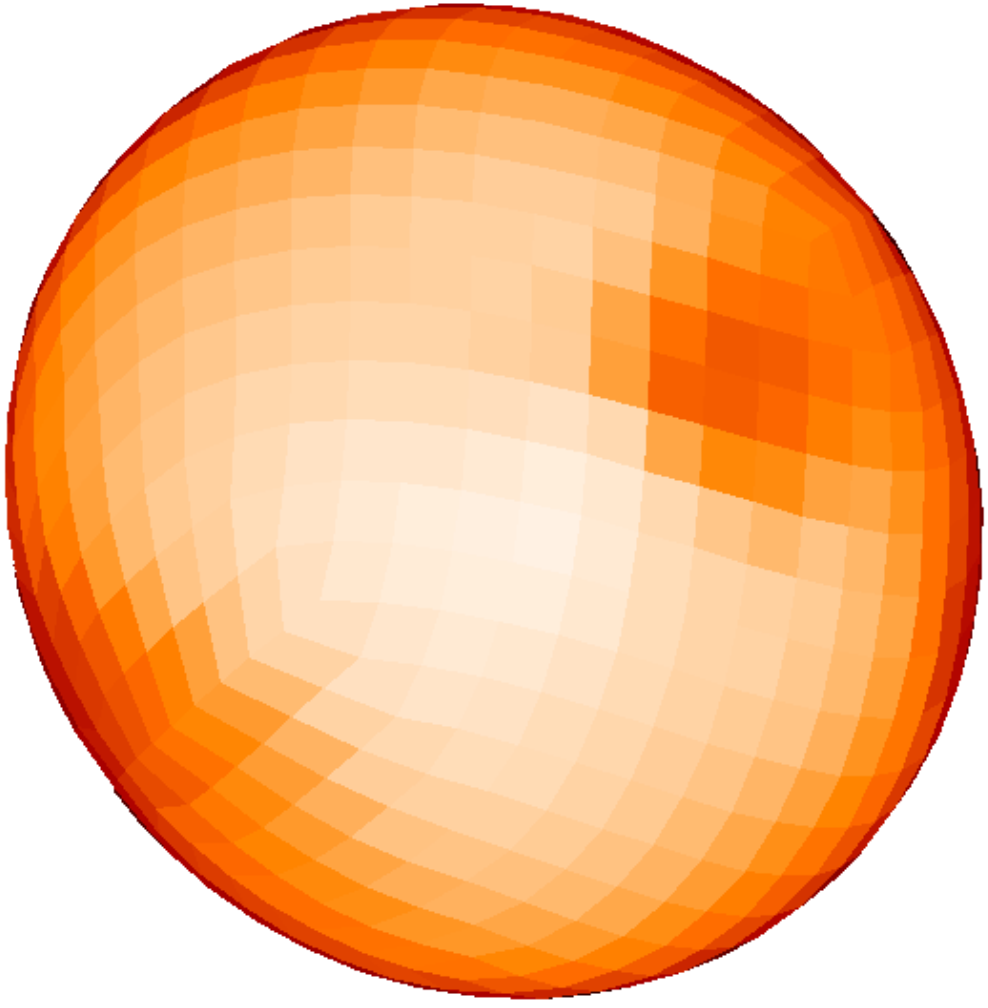
Differences between the IV and IVQU maps:

- The strength of some surface features is doubled or even quadrupled when linear polarization is taken into account.
- The total magnetic energy of the reconstructed field becomes about 2.1 - 3.5 times higher.
- The overall complexity is increased as the field energy is shifted toward higher harmonic modes when four Stokes parameters are used.



Rosén et al. 2015

Starspots have even been interferometrically imaged on RS CVn binaries



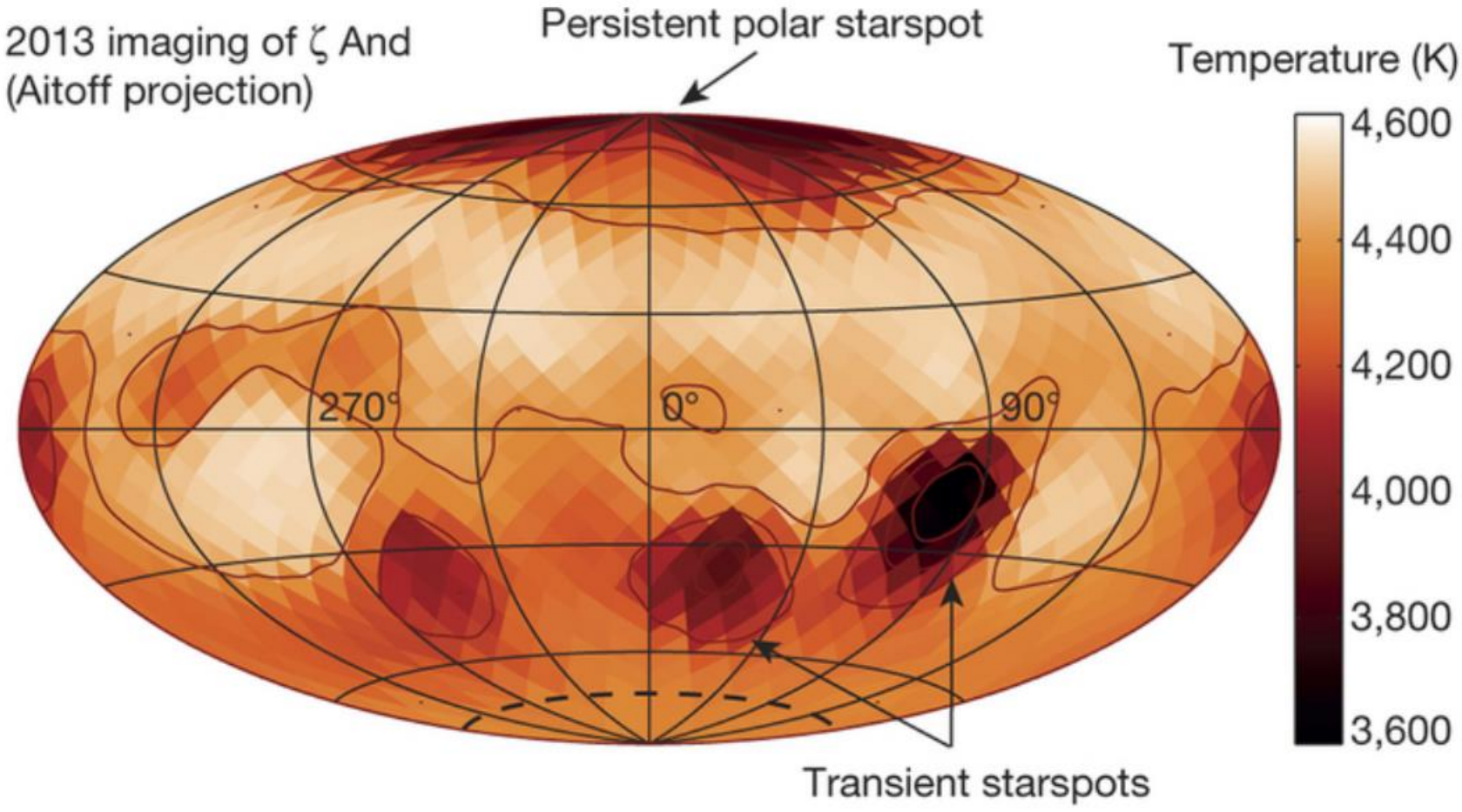
Roettenbacher et al. 2016, Nature

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

The same as a temperature map

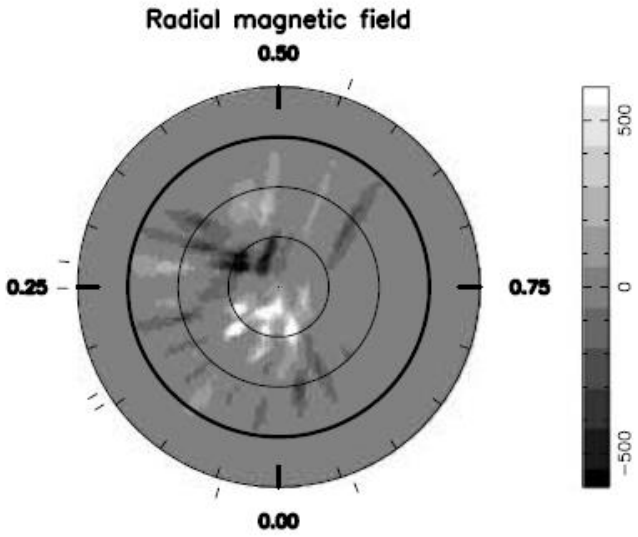


Roettenbacher et al. 2016, Nature

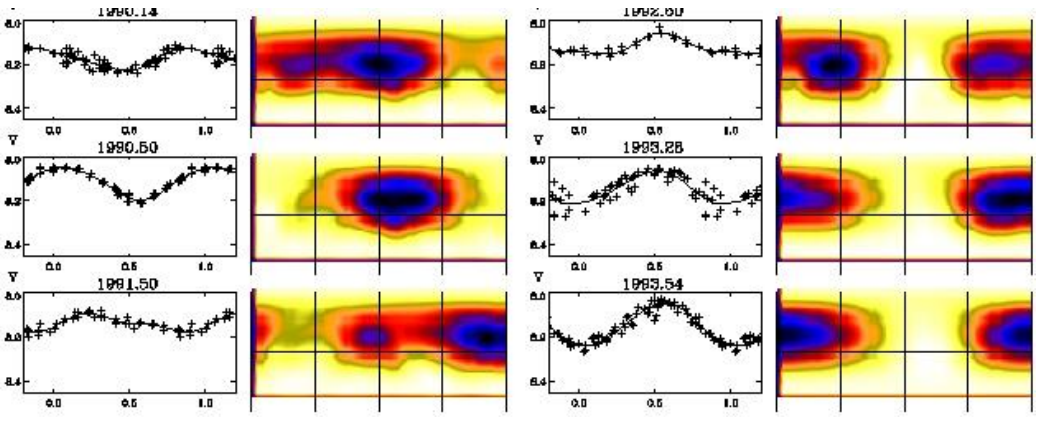
Magnetism on FK Com-type stars

FK Comae stars:

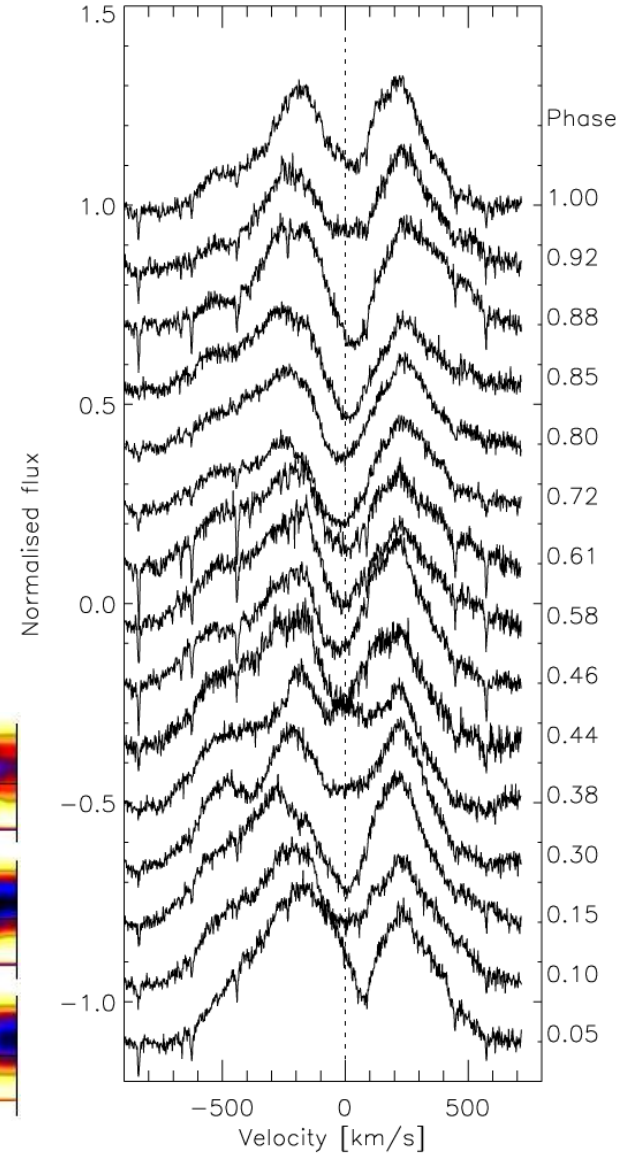
- single
- G III or IV
- typical period a few days
- Coalesced WUMa systems?



Petit et al. 2004b, HD199178

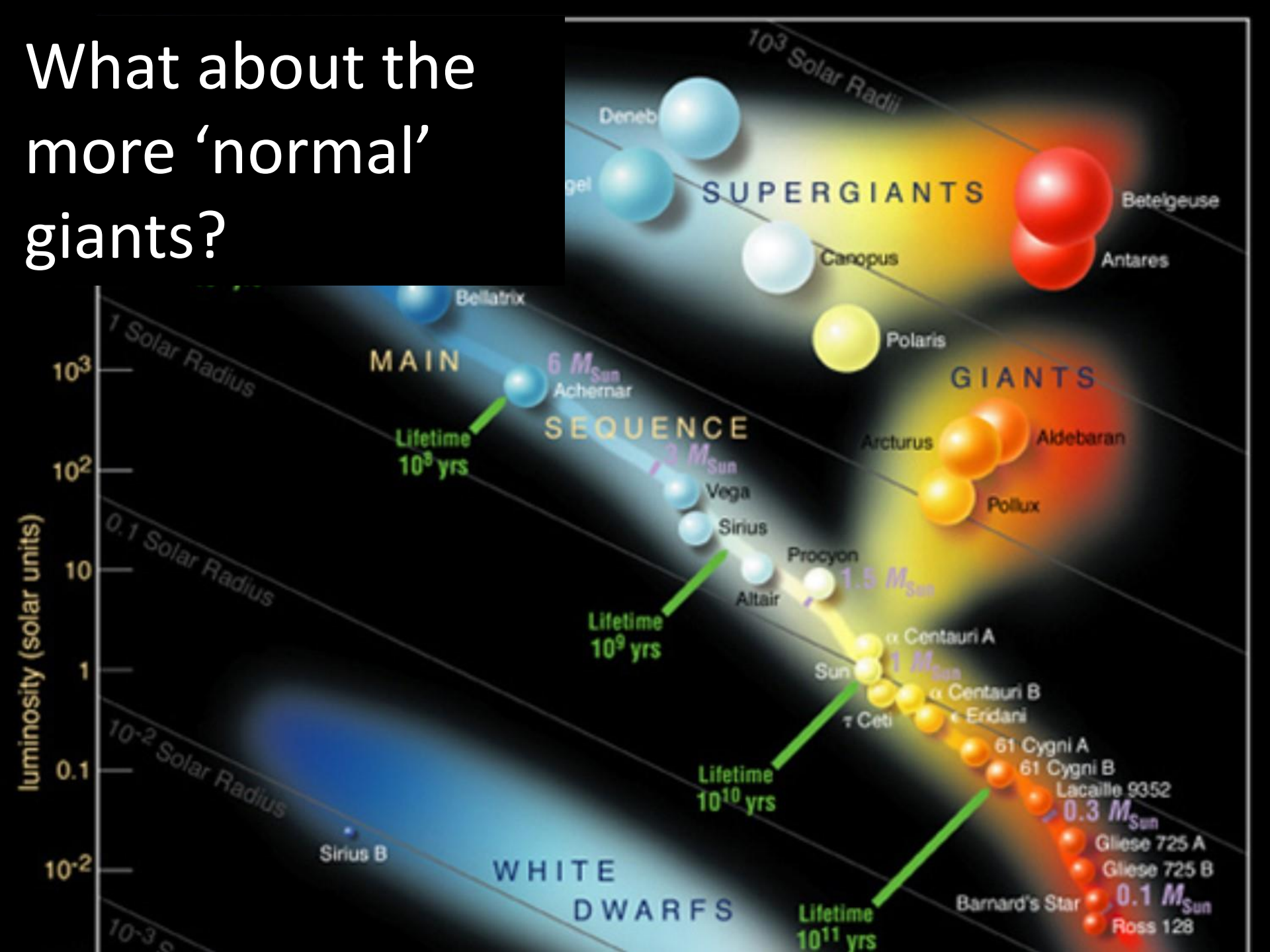


Korhonen et al. 2002, FK Com

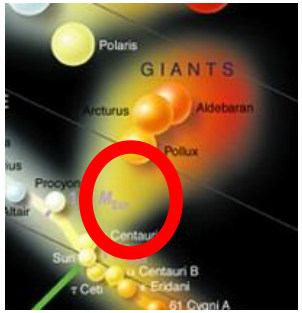


Korhonen et al. 2009, FK Com

What about the more 'normal' giants?

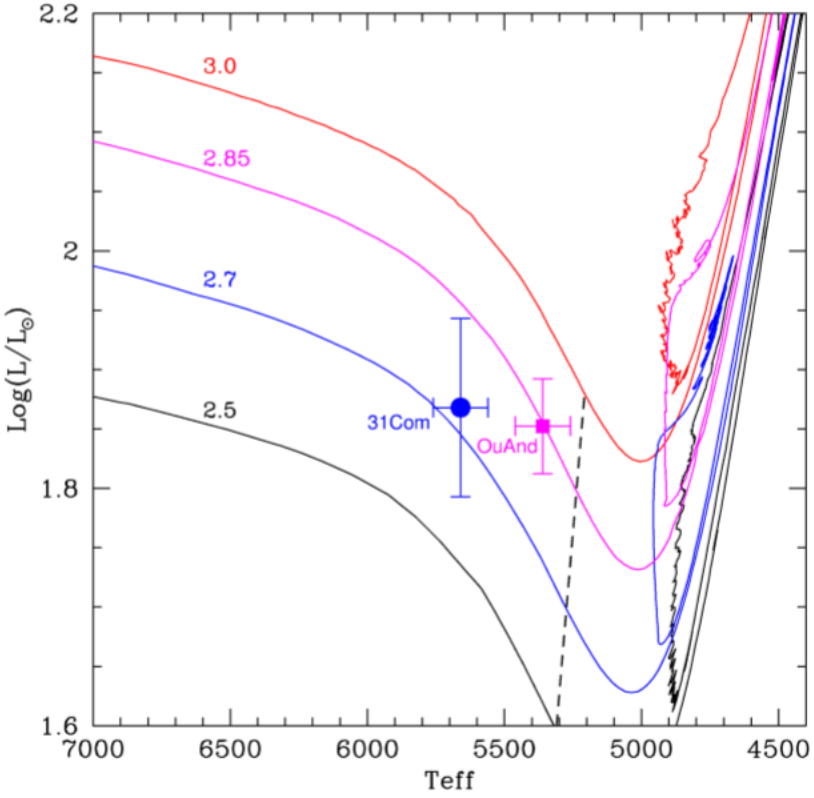


Hertzsprung gap



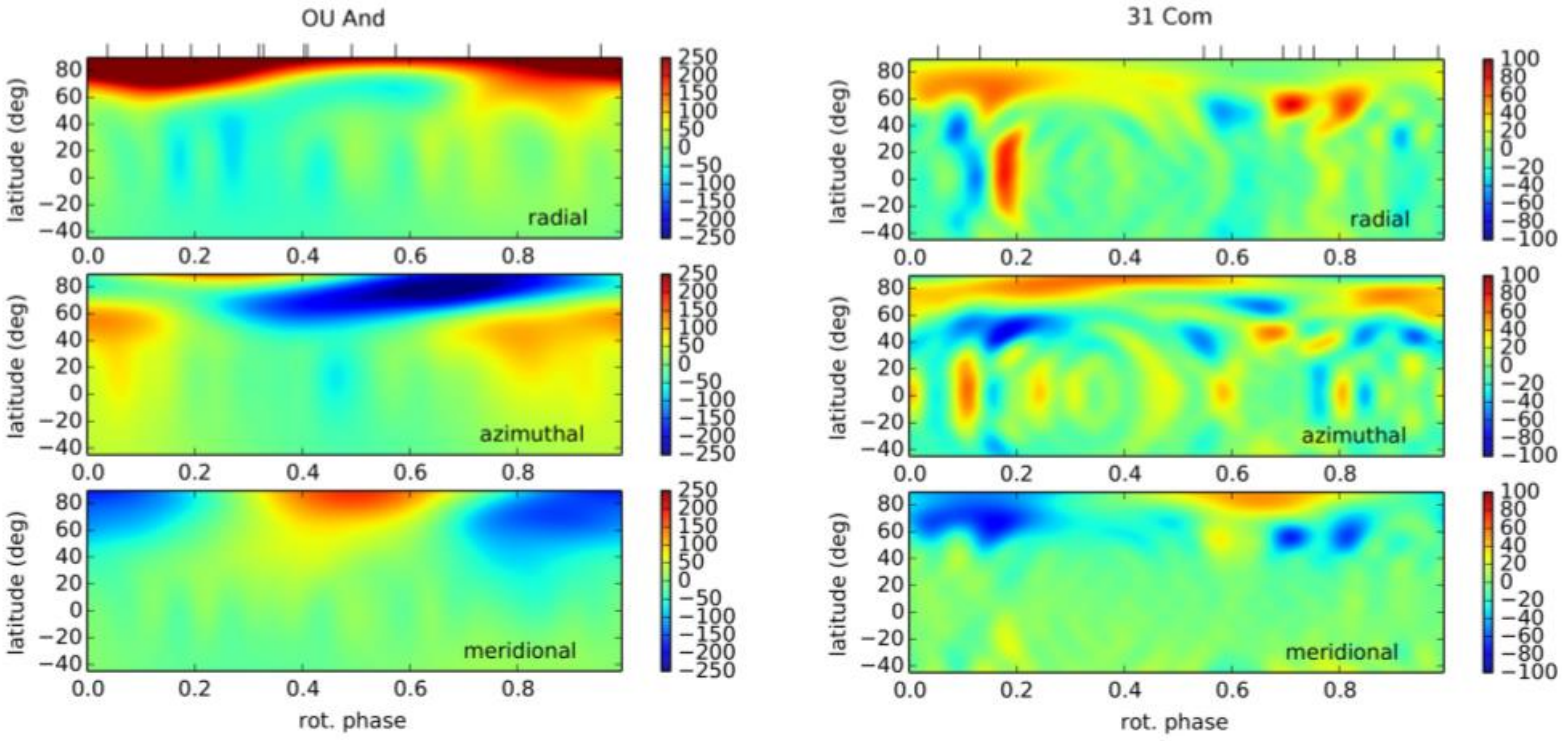
- Comparison of two stars in the Hertzsprung gap (Borisova et a. 2016)
- OU And
  - Prot=24.2 d
  - 2.7 Msolar
- 31 Com
  - Prot=6.8 d
  - 2.85 Msolar

- Additionally Tsevtkova et al. (2017) looked at 37 Com, another Hertzsprung gap star (mass 6.5 Msolar)



Borisova et al. 2016

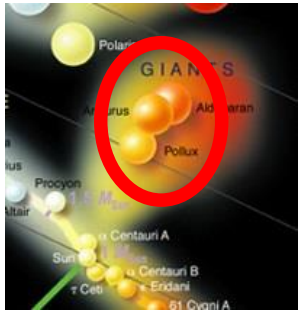
Hertzsprung gap



Borisova et al. 2016

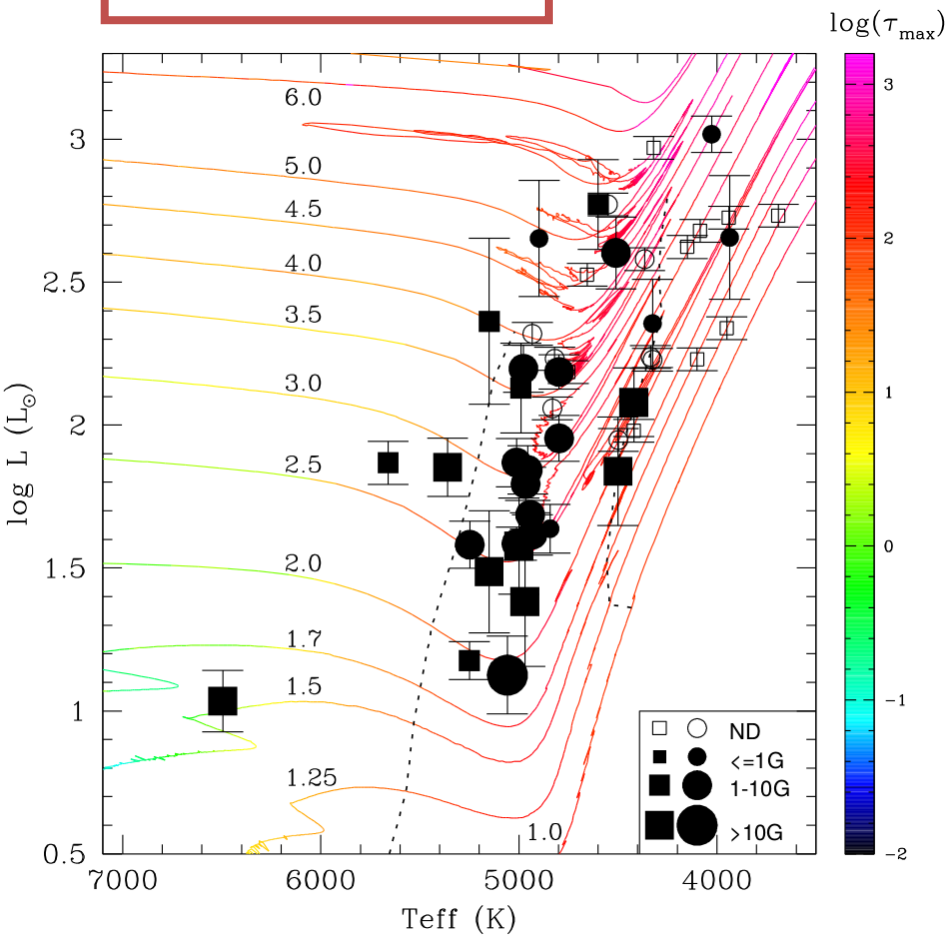
- Field detections in both stars:
  - OU And: strong, largely dipolar field
  - 31 Com: weaker field with complex topology
- OU And probable descendant of a magnetic Ap star,
- 31 Com descendant of a relatively fast rotator

Red giants



- Sample of 48 evolved cool stars Definite detection of magnetic field in 29 targets.
- Zeeman signatures are found in all but one of the 24 active red giants
- And in 6 out of 17 bright giant stars.

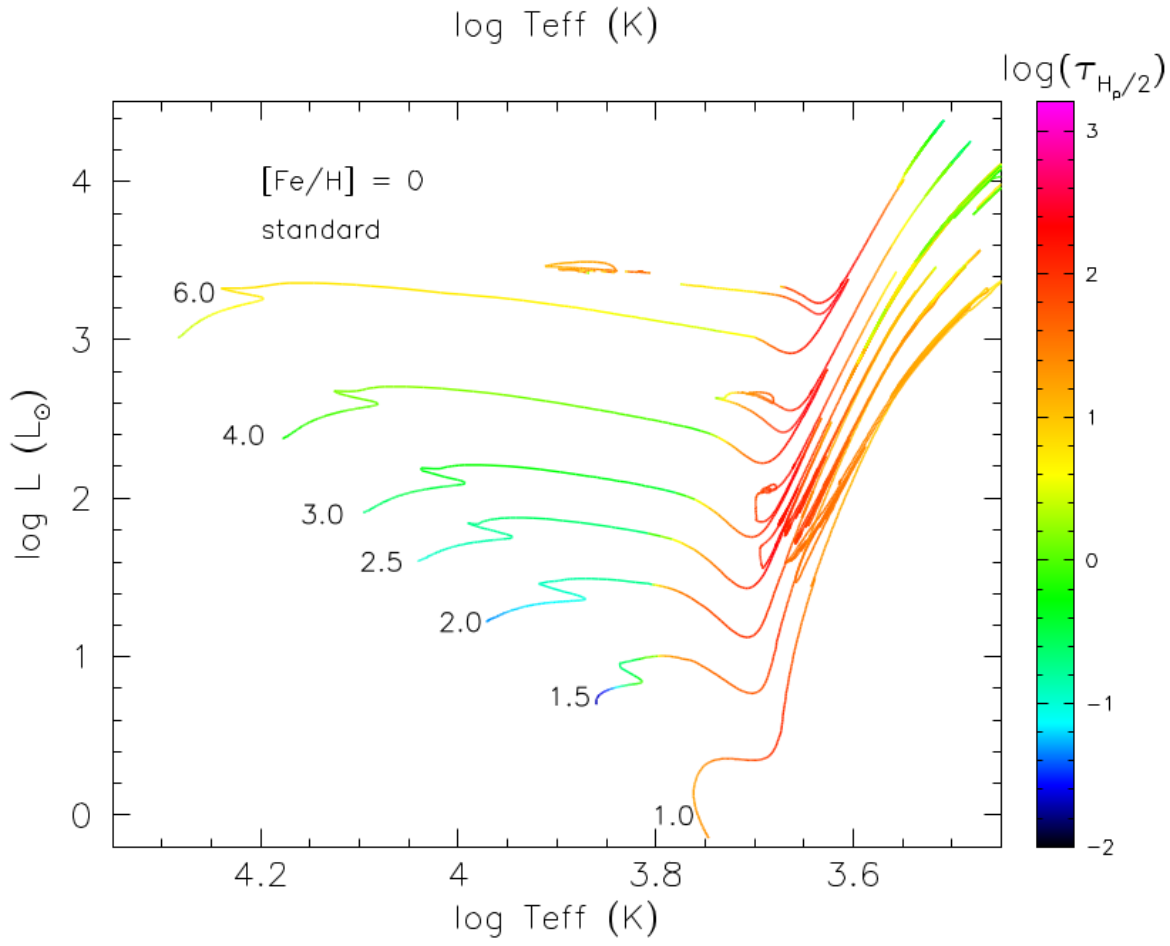
Aurière et al. 2015



Magnetic strips of evolved stars

Dynamo processes might be favoured in the stellar convective envelope at two specific moments along the evolution tracks:

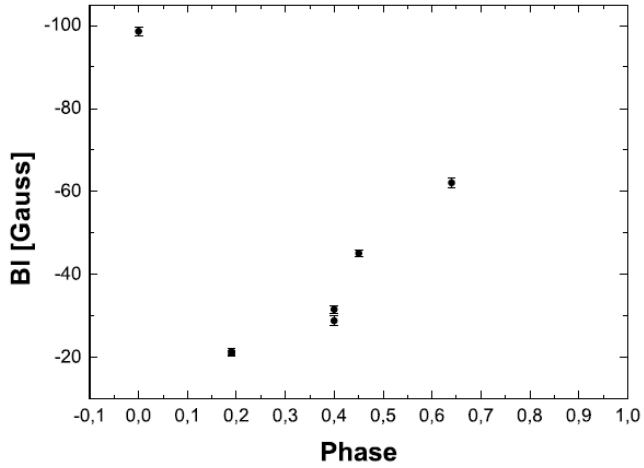
- During the first dredge-up
- During central helium burning in the helium-burning phase and early-AGB.

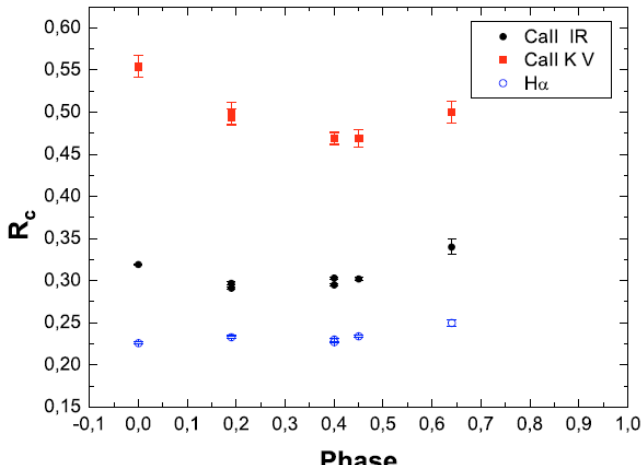


Charbonnel et al. 2017

Red giants – EK Eri

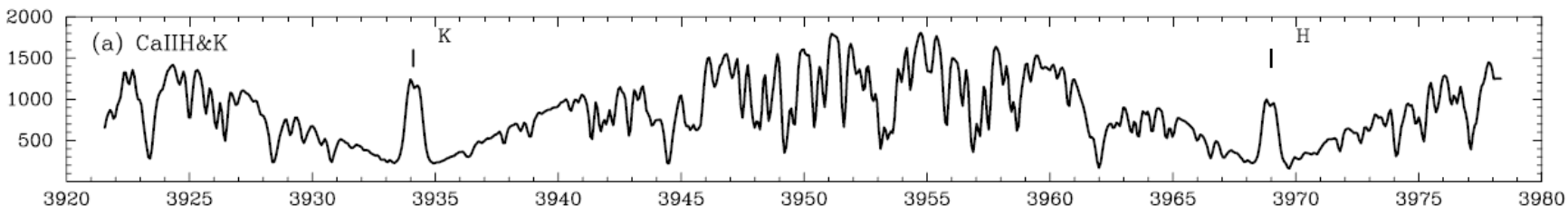
Aurière et al. 2008





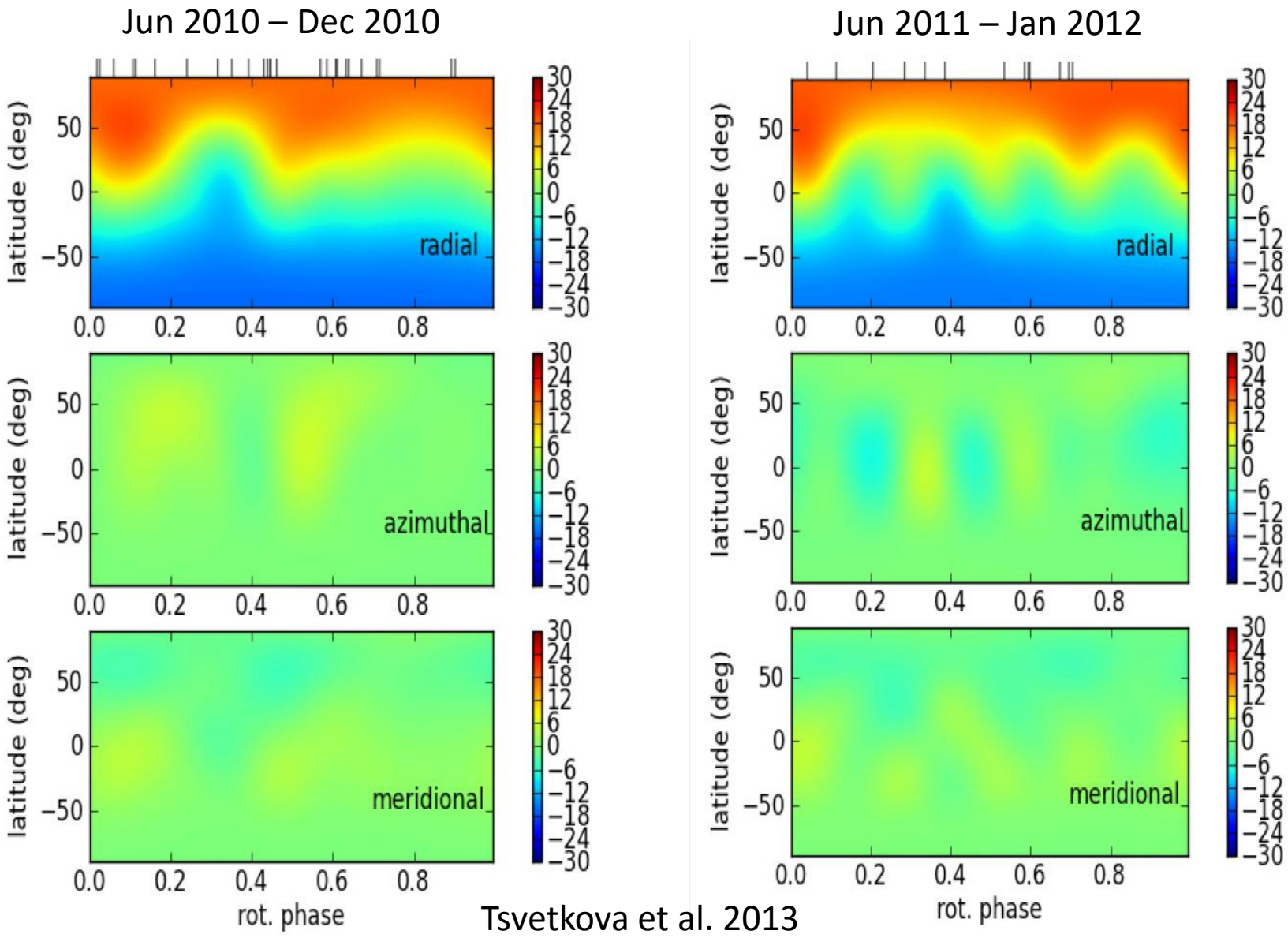
- Highest measured longitudinal magnetic field in EK Eri is ~100G
- But the rotation period is ~300 days…
- Most likely descendant of a strongly magnetic Ap star.

Strassmeier et al. 1999



Another descendant from Ap stars?

Red giants – β Cet

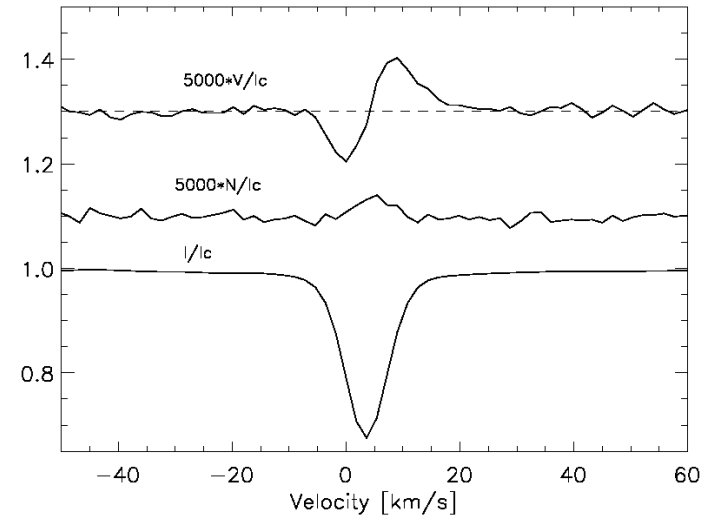


Tsvetkova et al. 2013

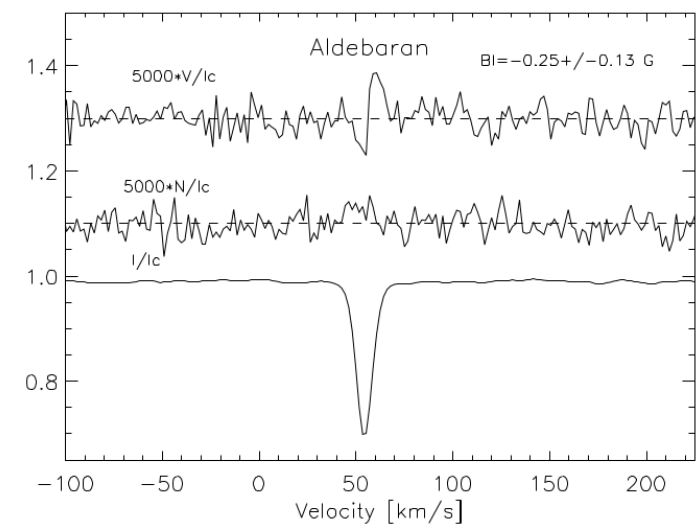
Red giants – slowly rotating stars

- Pollux K0 III, period ~100-500d
  - weakly-active (e.g., Strassmeier et al. 1990)
  - longitudinal magnetic field −0.46 ± 0.04 G (Aurière et al. 2009)
- Another similar case, Arcturus , has a field of 0.65 ± 0.26 G (Sennhauser & Berdyugina 2011)
- Aurière et al. 2015 detect weak fields also on Aldebaran, Alphard, and η Psc
- possibly a solar-like αΩ-dynamo driven by convection and differential rotation

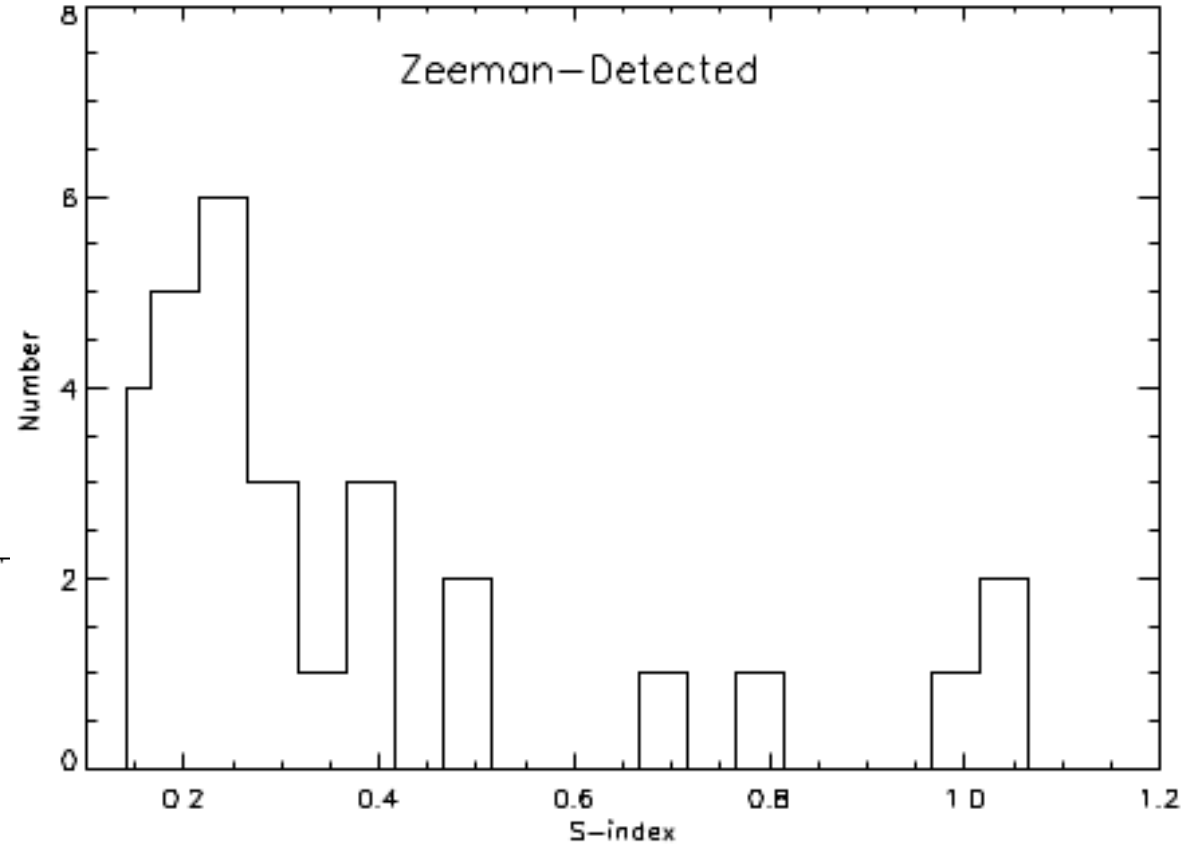
Pollux, Aurière et al. 2009

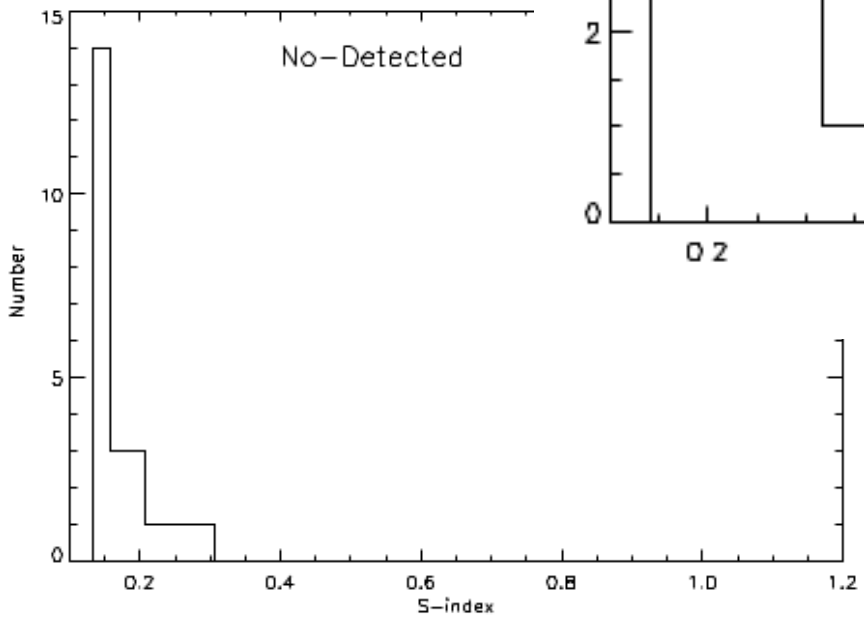


Aldebaran, Aurière et al. 2015



Red giants – activity vs B

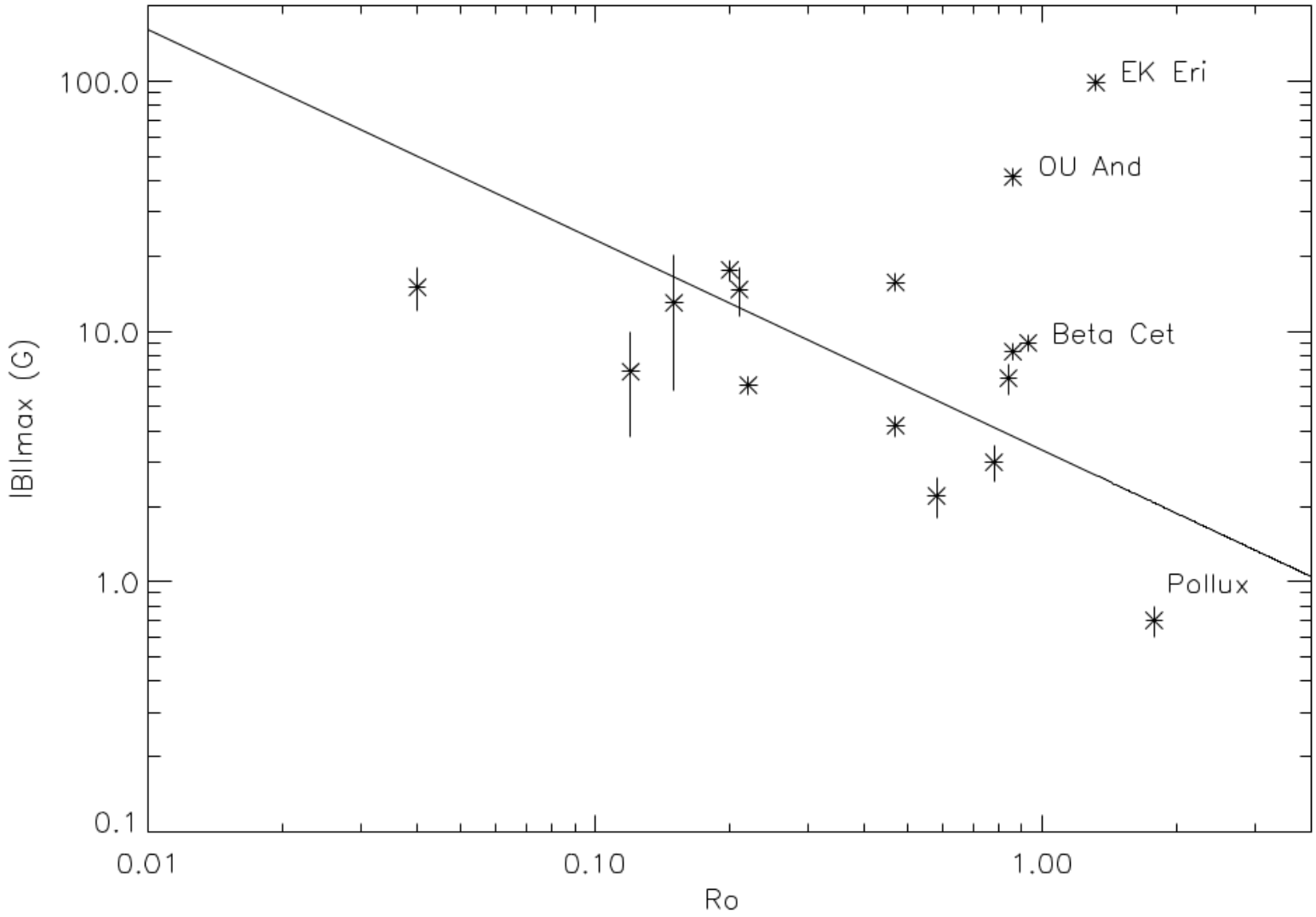




Aurière et al. 2015

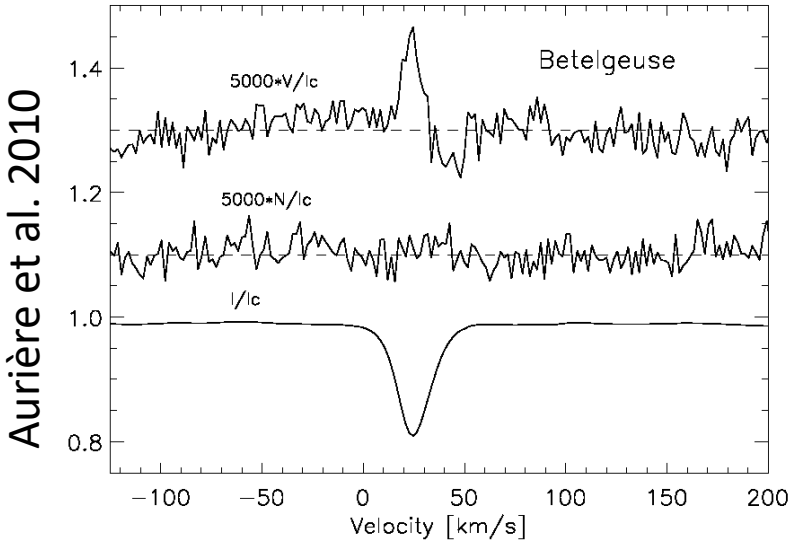
Petit's talk on Tuesday

Red giants – Magnetic field vs rotation

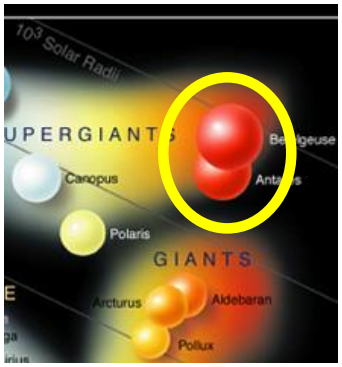


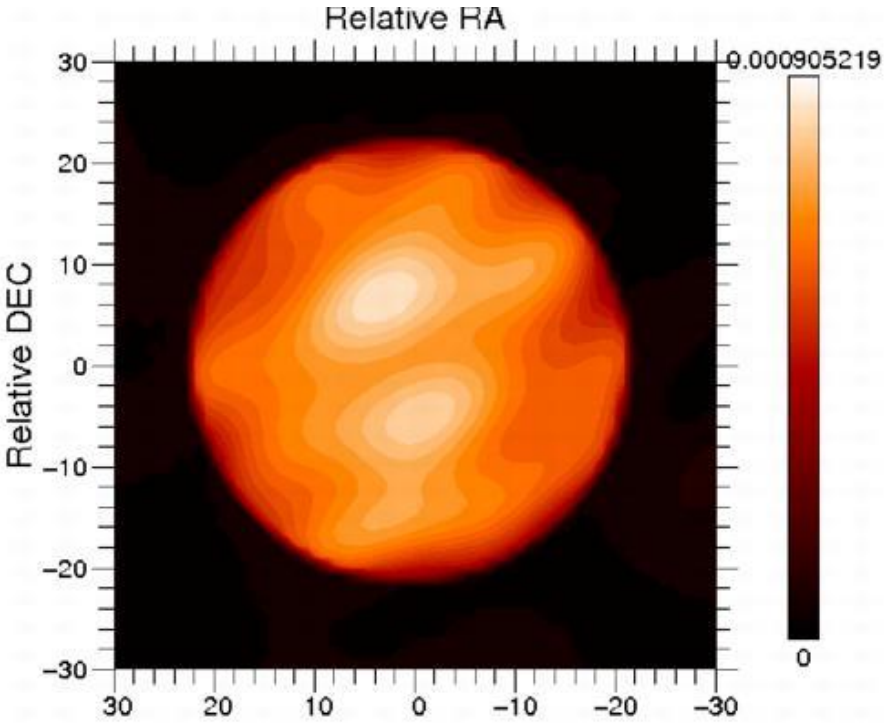
Aurière et al. 2015

Supergiants



Aurière et al. 2010



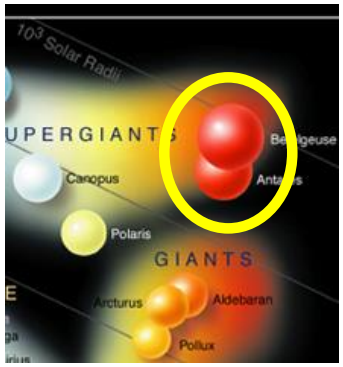


Magnetic field may be associated to the giant convection cells that could enable a “local dynamo”.

Observed magnetic elements may be concentrated in the sinking components of the convective flows. (Petit et al. 2013)

Interferometric image of Betelgeuse
Haubois et al. 2009

Supergiants – other detections



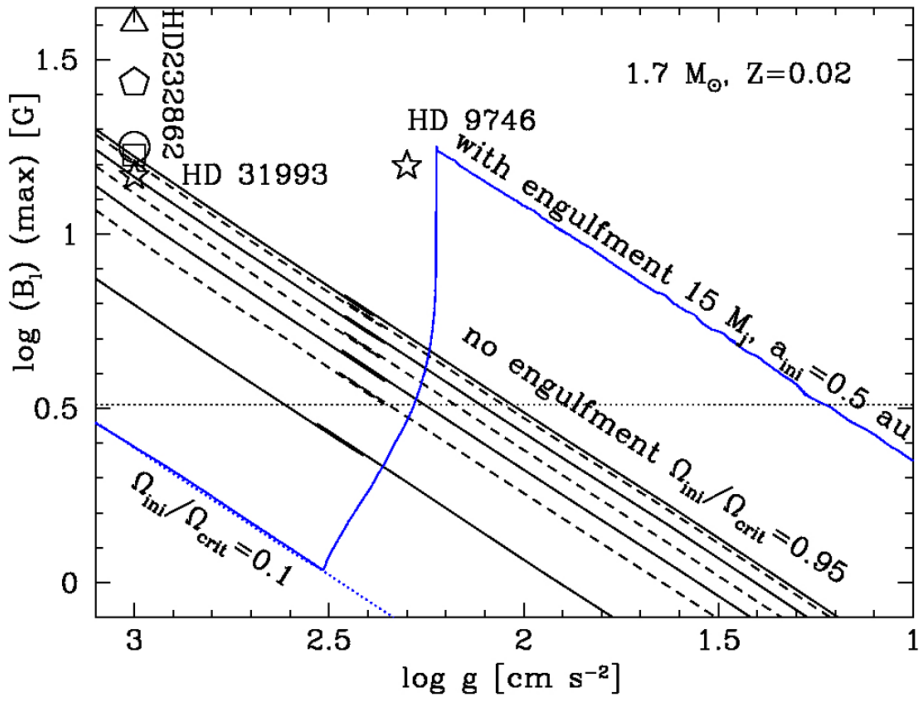
Tessore et al. 2017:
Magnetic field detection in two RSG: CE Tau and μ Cep
Other targets: ρ Cas (post-RSG star), and α Her (most likely AGB)

Target	Obs. date	$\overline{\lambda}$	$\overline{g}$	$\overline{d}$	$B_\ell \pm \sigma$ (G)	Detection (Stokes V)	Detection (*null*)
μ Cep	2015-07-09*	772	1.14	0.66	-	-	DD
	2015-09-01*	772	1.14	0.69	-	-	DD
	2015-10-14*	772	1.14	0.69	-	-	DD
	2015-11-11*	772	1.12	0.69	-	-	DD
	2016-12-18	772	1.24	0.69	1.0 ± 0.3 †	DD†	ND
	2017-01-07	772	1.16	0.69	1.3 ± 0.3 †	DD†	ND
α Her	2015-03-11	772	1.19	0.68	-5.8 ± 0.4	DD	ND
	2015-07-11	772	1.19	0.66	-7.4 ± 0.3	DD	ND
	2015-09-06	772	1.20	0.66	-7.6 ± 0.5	DD	ND
	2016-09-02/03/05/06/07	772	1.27	0.67	-2.7 ± 0.3	DD	ND
CE Tau	2015-03-06	772	1.20	0.69	-1.2 ± 0.3	MD	ND
	2016-09-03/07	772	1.20	0.68	-1.7 ± 0.2	DD	ND
	2016-10-14	772	1.13	0.69	-1.2 ± 0.2	DD	ND
	2016-12-18	772	1.15	0.69	-2.7 ± 0.5	DD	ND
ρ Cas	2015-08-11/28	570	1.30	0.64	-	ND	ND
	2015-09-07/08/10	570	1.30	0.62	-	ND	ND

Tessore et al. 2017

Dynamo enhancement due to engulfment of planets?

- Planet engulfment increases rotation and enhances dynamo operation
- For reasonable magnetic braking laws, the high surface velocity reached after a planet engulfment may be maintained sufficiently long to be observable

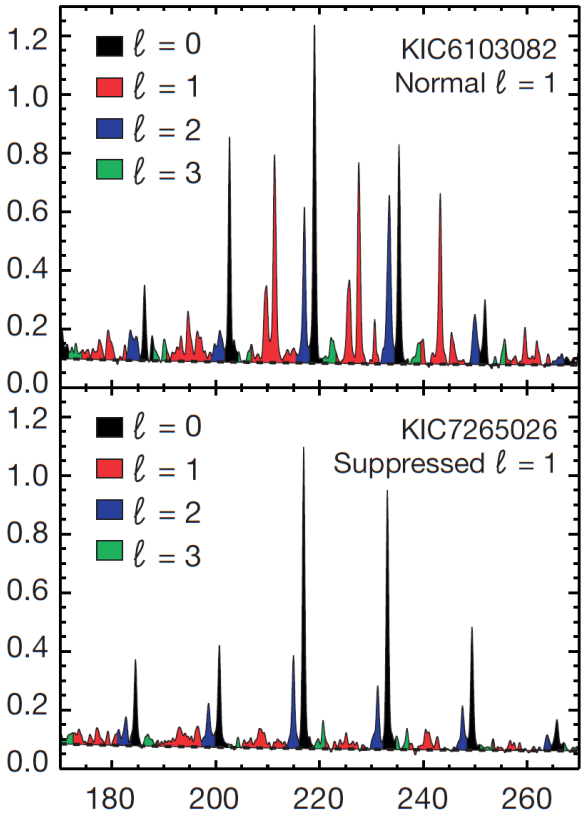


Privitera et al. (2016) show that the engulfment of a 15 MJ planet produces a dynamo triggered magnetic field stronger than 10 G for gravities between 2.5 and 1.9.

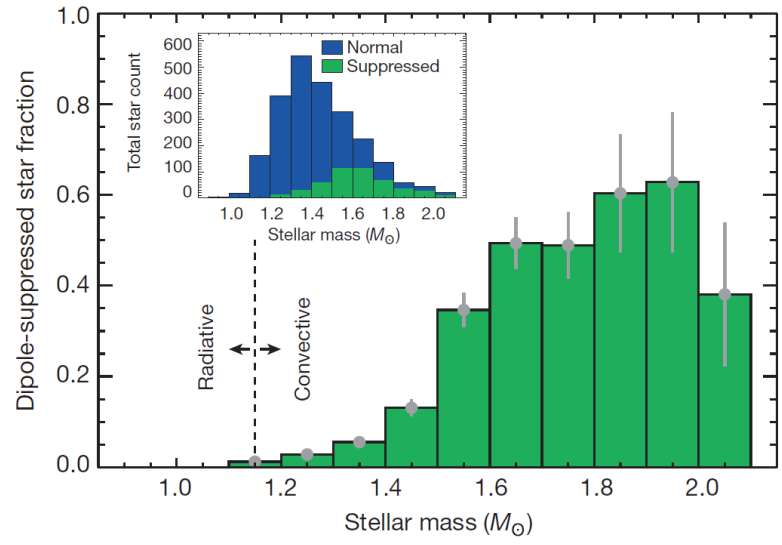
Walczak's talk on Tuesday

The mysterious case of red giant oscillations

- 20% of red giants have supressed l=1 modes.
- Fuller et al. (2015) show that the suppression can be explained if waves entering the stellar core are prevented from returning to the envelope.



Stello et al. 2016



Stello et al. saw no suppression in red giants below 1.1Msolar, and the incidence of magnetic suppression increases with mass, with red giants above 1.6Msolar showing a suppression rate of 50% to 60%.

Some closing remarks

- Rapidly rotating G-K giant stars are among the most magnetically active stars known.
  - They show large starspots, choromospheric and coronal activity, frequent flaring and activity cycles.
- Slowly rotating G-M giants can also have magnetic fields, maybe through weak dynamo action or due to relic fields (descendants of Ap stars)
- Cool supergiants can possibly have a local dynamo operating in the giant convection cells.
- Can the red giant magnetic fields be enhanced due to engulfment of planets?
- Possibly dynamo operating in the convective cores of A and B type stars?

- Some other interesting developments
  - Magnetic fields in the extended stellar environment of AGB stars and red supergiants (e.g., Duthu et al. 2017, Vlemmings et al. 2017)
  - Asymmetries on red giant branch surfaces from CHARA/MIRC optical interferometry (Chiavassa et al. 2017)
  - Vigorous atmospheric motion in the red supergiant star Antares (Ohnaka et al. 2017)
  - Evidence of asymmetries in the Aldebaran photosphere from multiwavelength lunar occultations (Richichi et al. 2016)
  - Strong linear polarisation in the atmosphere of Betelgeuse due to anisotropic radiation induced by brightness spots at the surface and Rayleigh scattering in the atmosphere (Auriere et al. 2016)