

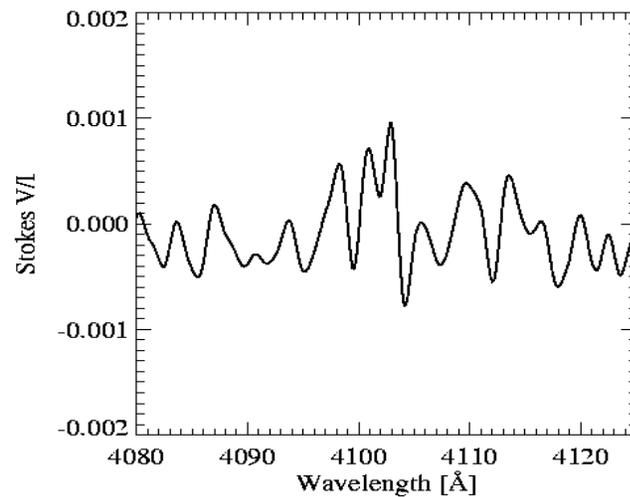
The central role of low-resolution
FORs 1/2 spectropolarimetric
observations for the investigation of
magnetic fields in massive pulsating
stars

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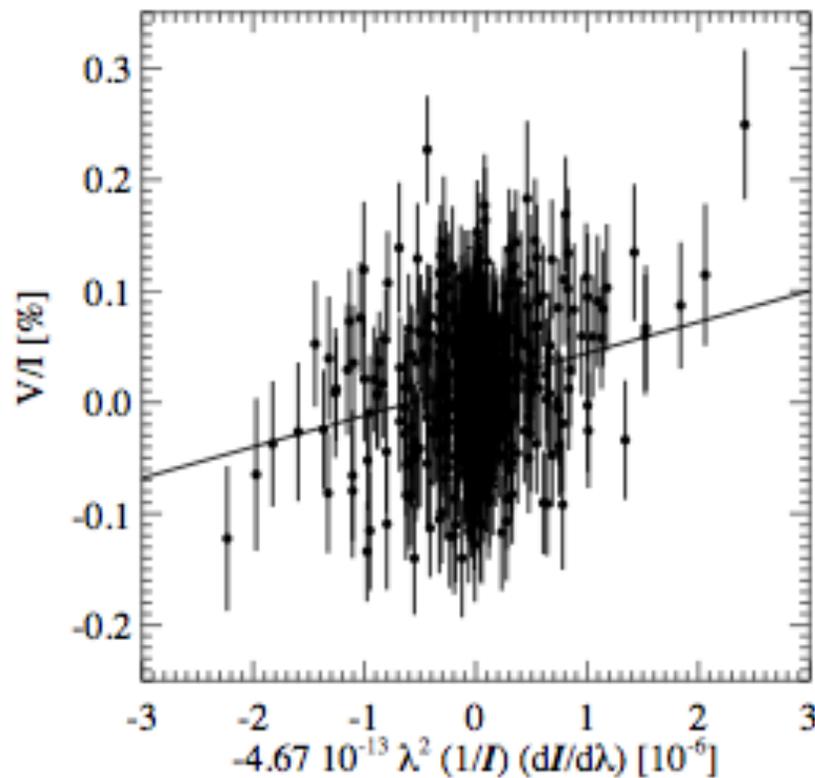
Polarization V spectra observed with FORS1/2

$$\frac{V}{I} = \frac{1}{2} \left\{ \left(\frac{f^o - f^e}{f^o + f^e} \right)_{\alpha=-45^\circ} - \left(\frac{f^o - f^e}{f^o + f^e} \right)_{\alpha=+45^\circ} \right\}$$

α gives the position angle of the retarder waveplate and f^o and f^e are ordinary and extraordinary beams, respectively.



Determination of the magnetic field



The mean longitudinal magnetic field is the average over the stellar hemisphere visible at the time of observation of the component of the magnetic field parallel to the line of sight. It is diagnosed from the slope of the linear regression:

$$\frac{V}{I} = -\frac{g_{\text{eff}} e \lambda^2}{4\pi m_e c^2} \frac{1}{I} \frac{dI}{d\lambda} \langle \mathcal{B}_z \rangle$$

Surveys of magnetic fields in pulsating B-type stars with FORS1

Prior to our survey:

2 magnetic β Cephei stars and 1 magnetic SPB star

Magnetic field survey of pulsating B-type stars with FORS1:

34 stars (2003-2005) + 53 stars (2009)

The β Cephei star ξ^1 CMa, with a longitudinal magnetic field of the order of 300–350G, was then the largest among the known magnetic β Cep stars (see poster A1 on HD 96446)

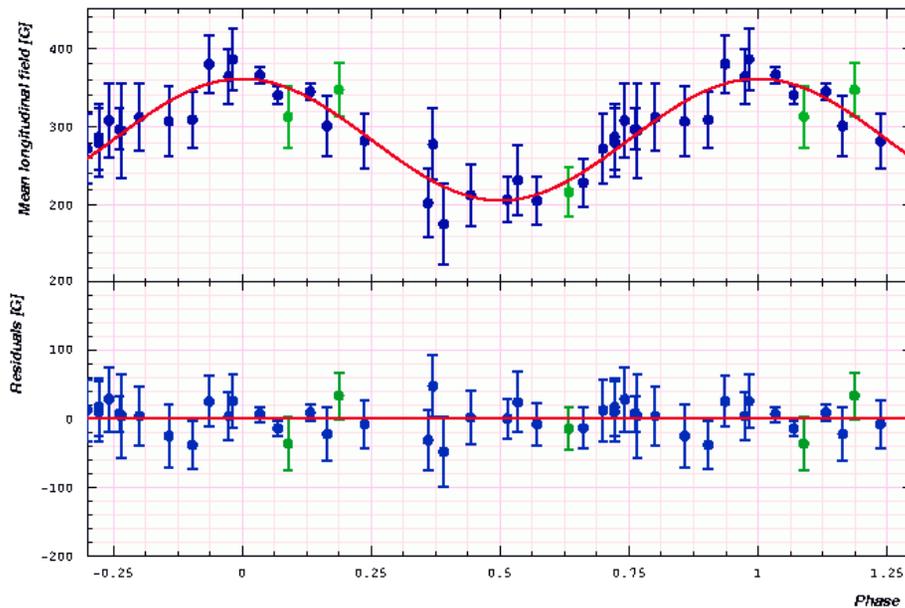
Hubrig et al. (2006)

Surveys of magnetic fields in pulsating B-type stars with FORS1

For the target selection we used the following criteria:

- a) nitrogen-rich
- b) radial pulsations or multiperiodic pulsations dominated by a radial mode (β Cephei stars), although a few stars pulsate non-linearly
- c) Geneva photometric observations available
- d) slow rotation
- e) identified pulsation modes
- f) no SB2 systems

The rotation period of ξ^1 CMa (FORS1/2)

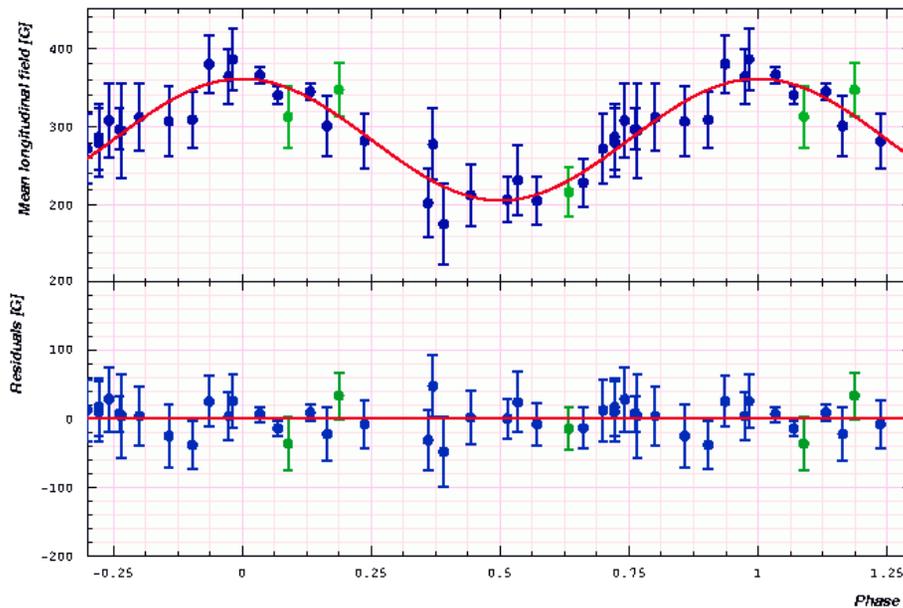


$P = 2.1795$ d
(Hubrig et al. 2006, 2011):
 $B_d \sim 5.3$ kG

FORS1/2 (exposure times of 0.25s; $V = 4.3$)

Peak-to-peak RV amplitudes reach 33 km/s

The rotation period of ξ^1 CMa (FORS1/2)



$P = 2.1795$ d
(Hubrig et al. 2006, 2011)

Fourtune-Ravard et al. 2011:
 $P \sim 4.2680$ d (ESPaDOs,
long exposures corresponding
to a significant fraction of the
pulsation period)

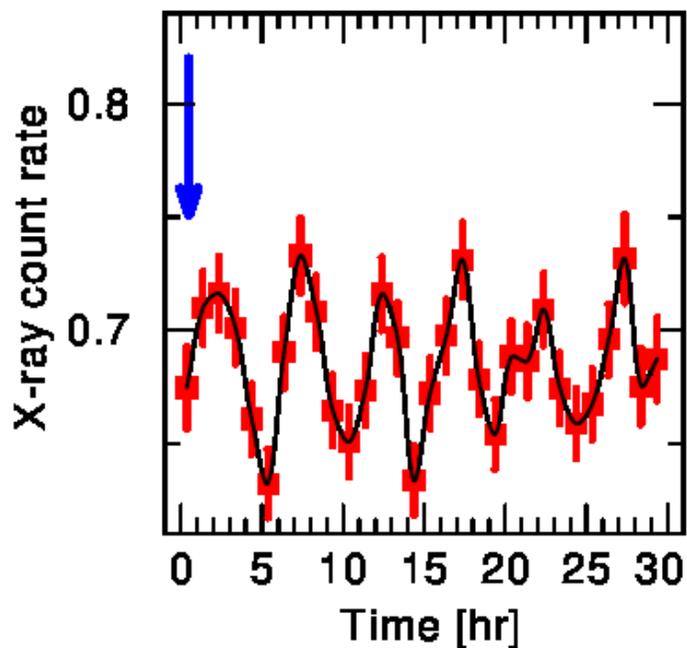
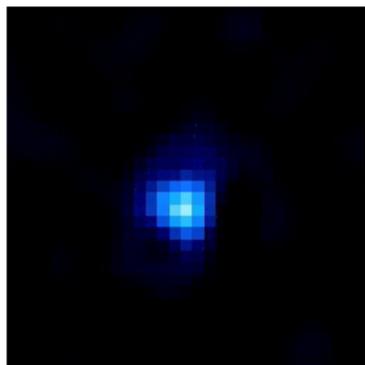
ESPaDOs +
two old obs. with
MuSiCoS
 $\rightarrow P_{\text{rot}} \sim 60$ yrs
(Shultz et al. 2015)

The target is not in a favourable position
to be observed
from Pic du Midi (elevation $\sim 20^\circ$).

Discovery of X-ray pulsations in ξ^1 CMa

(Oskinova et al. 2014)

X-ray Image



Sequence of X-ray images clearly shows intensity of emission changing with time

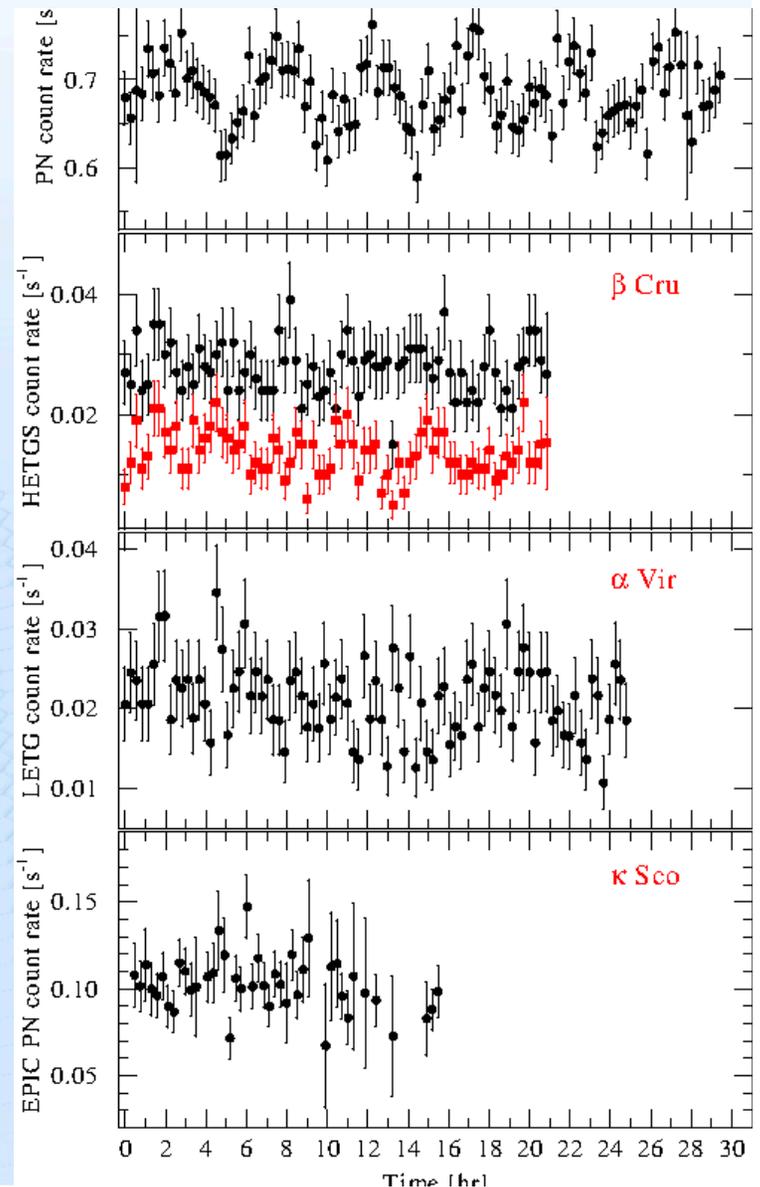
Evident in the light curve: count rate measured by the EPIC PN camera vs. time after the start of observation

Earlier X-ray pulsation detections?

X-ray light curves (0.2-10.0 keV) of β Cephei variables.

The red colour shows the hard band (1.0-10.0 keV).

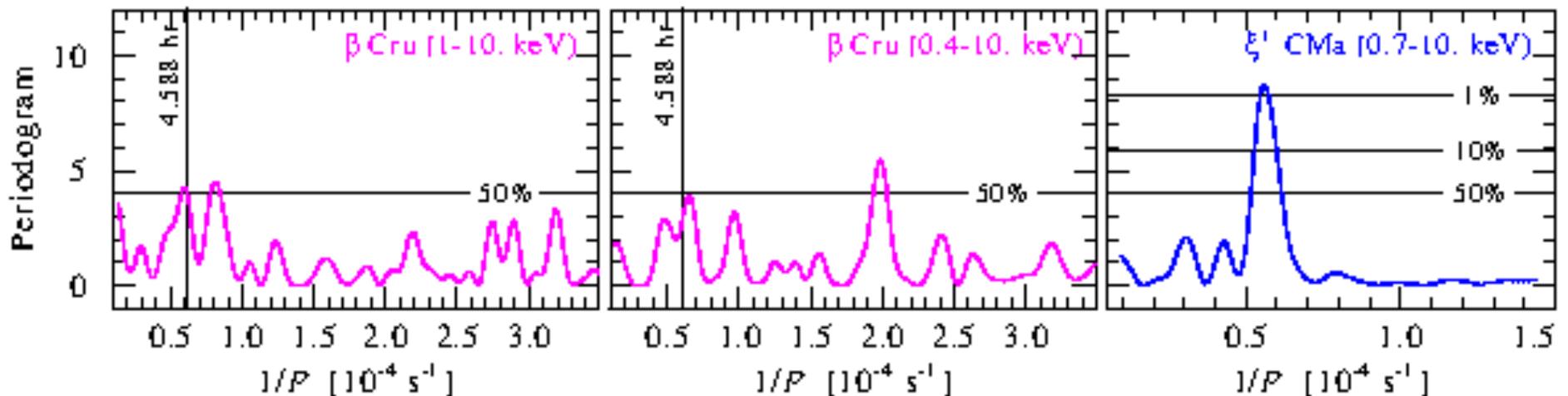
The detection for β Cru was reported by Cohen et al. (2008).



Earlier X-ray pulsation detections?

Power density spectra based on the Fourier transform.
Various false alarm probability levels are marked.

For two stars the detected periods are spurious at a probability of 50% and more (Oskinova et al. 2015).



The A0 supergiant HD 92207

- Hubrig et al. (2012) announced a longitudinal magnetic field of $\langle B_z \rangle = -384 \pm 42$ G in this star
- Bagnulo et al. (2013) claimed that this was a spurious detection, blaming mainly instrument flexures
- Hubrig et al. (2014) looked again at the data and concluded that there are spectral variations intrinsic to HD 92207
- Hubrig et al. (2015) reobserved HD 92207 and could confirm the presence of a weak magnetic field

Issue: “flexures”

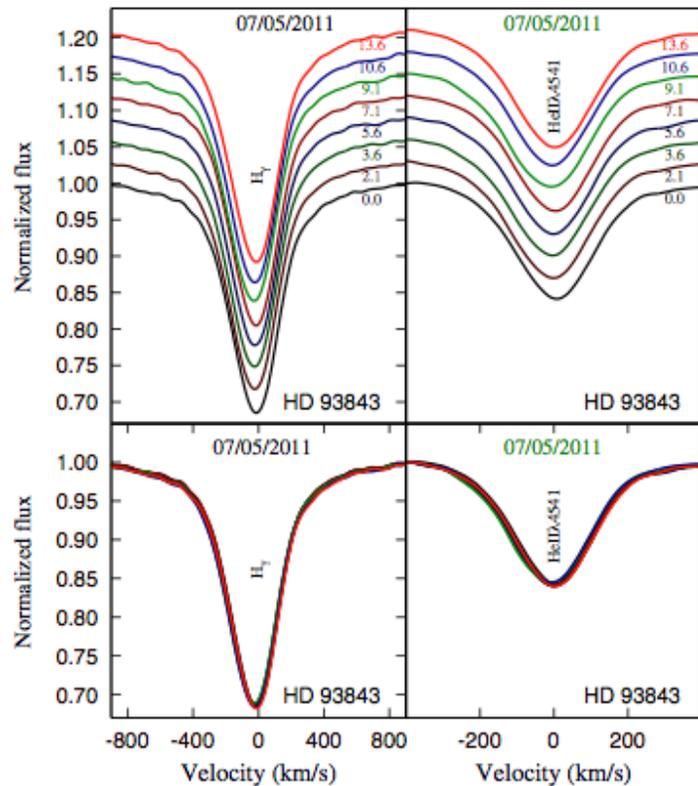


Figure 6. The behaviour of the H γ and He II λ 4541 lines in the FORS 2 spectra of HD 93843 in each subexposure, obtained immediately after the HD 92207 observations in the first epoch.

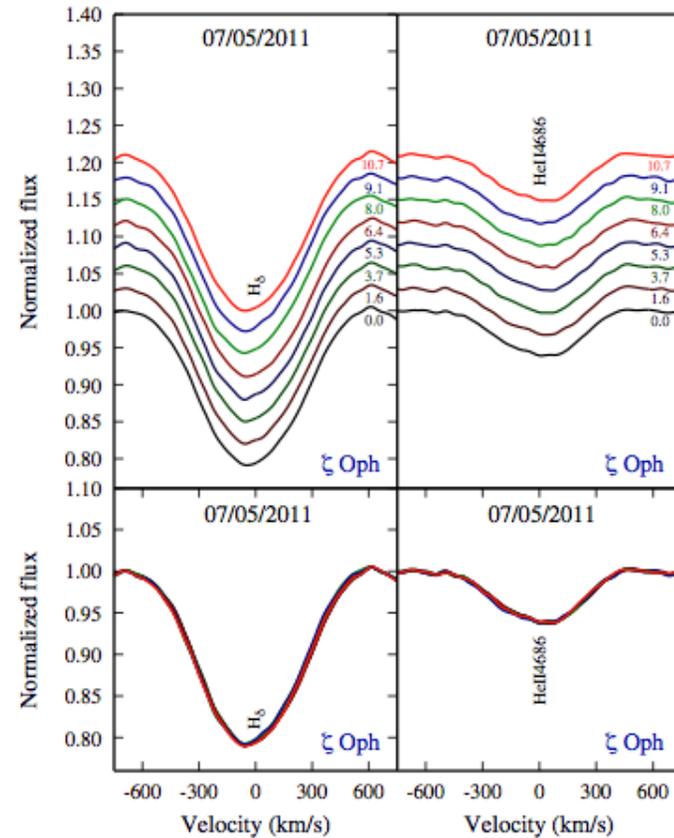


Figure 7. The behaviour of the H δ and He II λ 4686 lines in the FORS 2 spectra of ζ Oph in each subexposure, obtained 1.5 h after the HD 92207 observations in the first epoch.

No variability detected for other targets observed in the same night in similar conditions: same airmass, similar exposure times

The A0 supergiant HD 92207

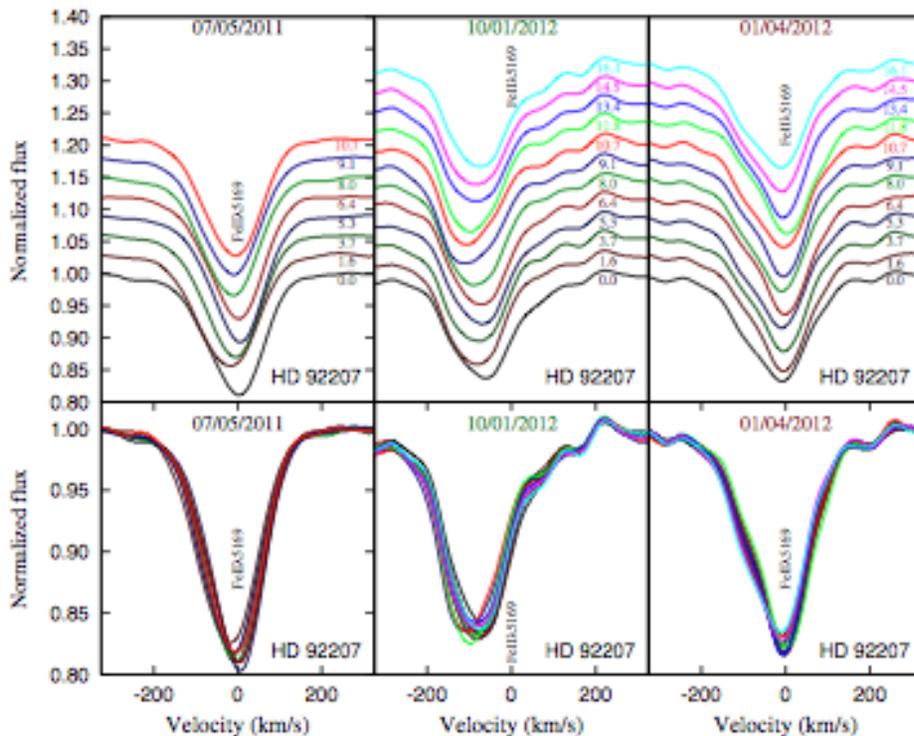


Figure 3. The behaviour of the Fe II $\lambda 5169$ line in the FORS 2 spectra of HD 92207 in each individual subexposure belonging to observations on three different epochs.

Short-term spectral variability
on a time scale of minutes in
HD 92207
(Hubrig et al. 2014).

Given the size of the supergiant, the variability cannot be referred to coherent line variations across the entire surface.

Issues: “coherence time”



Table 2. Columns one and three give, respectively, the slit width (in arcseconds) and exposure times (in seconds) adopted for the FORS2 observations of HD 92207, HD 92843, and ζ Oph. Columns two and four give the sky conditions, namely seeing (in arcseconds) and coherence time (in seconds) at the time of the FORS2 observations of HD 92207, HD 92843, and ζ Oph

Star name	Slit width, arcsec	Seeing, arcsec	Exposure time, s	Coherence time, s
HD 92207	0.4	~0.5	3	6
HD 92843	0.4	~0.5	30	6
ζ Oph	0.4	~0.7	0.25	4

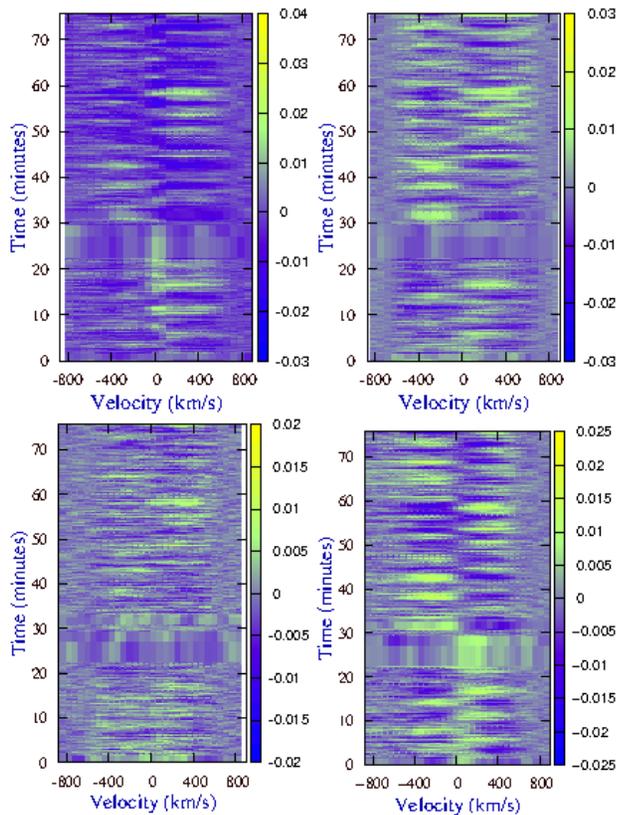
Fossati et al. (2015): seeing variations during the exposure

Yet: coherence time is in milliseconds, NOT in seconds.

Evidence for variations in an O-type giant (Kholtygin et al., in prep.)

Dynamical spectra

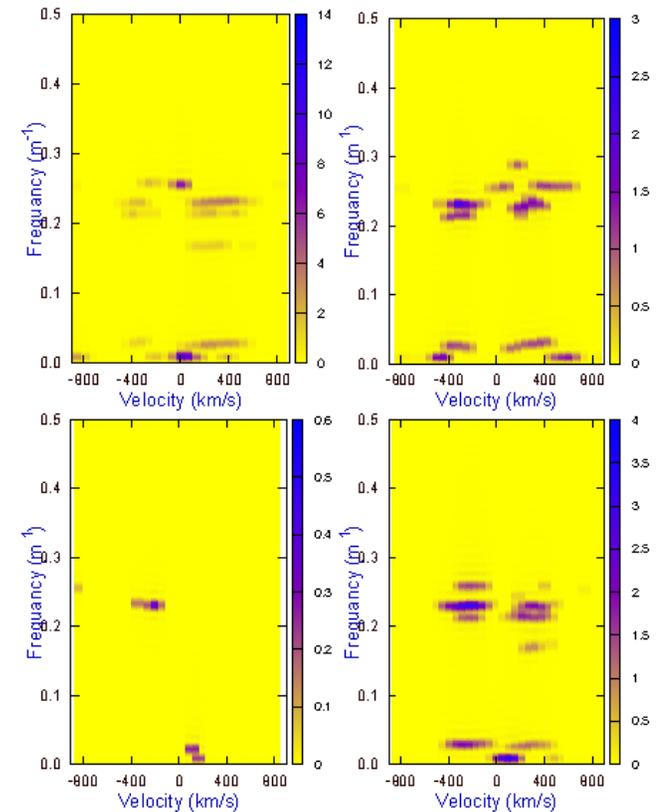
Cleaned Fourier spectra



H δ H γ
He II
4686 H β

P ~ 4-5 min

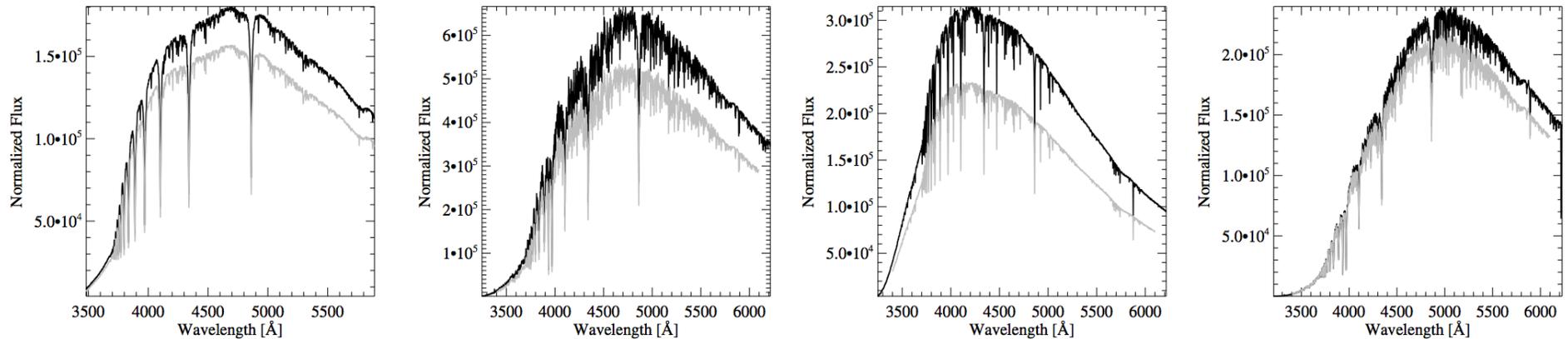
P ~ 24-34 min



Magnetic fields in δ Scuti stars

- Kurtz et al. (2008) were the first to discover a magnetic field in a δ Scuti star (HD 21190): $\langle B_z \rangle = 47 \pm 13$ G
- Neiner & Lampens (2015) claimed that they were the first to detect a magnetic field in a δ Scuti star (HD 188774)
- However, Hubrig & Schöller (2016) reobserved HD 21190 and found $\langle B_z \rangle = -254 \pm 59$ G

Issue: Spectrum extraction



Grey: Fluxes extracted by Bagnulo et al. (2015)

Black: Fluxes extracted by our pipeline

from left to right: the HgMn star α And, the δ Scuti star HD 21190, the nitrogen rich early B-type star HD 52089, and the Herbig Ae star PDS 2.

All these stars were announced in our studies as magnetic.

The most probable reason for the lower flux is a smaller extraction window to overcome reflections in the FORS spectra around H δ .

Summary

- Short exposure times are necessary to adequately sample pulsation periods when looking for magnetic fields
- This can best be achieved with low resolution spectropolarimetry on large telescopes
- (Super)giants are good candidates to find another class of unexpected pulsators – go and observe them