Normal fast rotating A- and B-type stars seen pole-on

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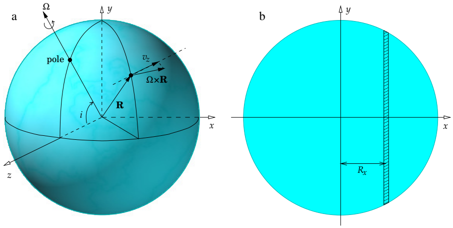
Overview

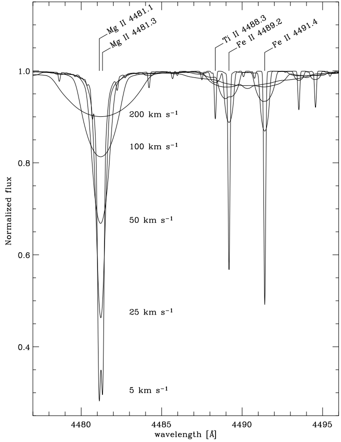
1. Context
2. Observing programme
3. Fast rotation, gravity darkening

Context

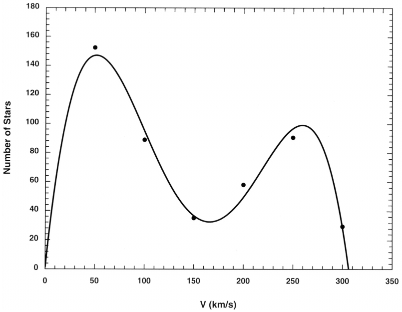
Spectral line broadening: $v \sin i$



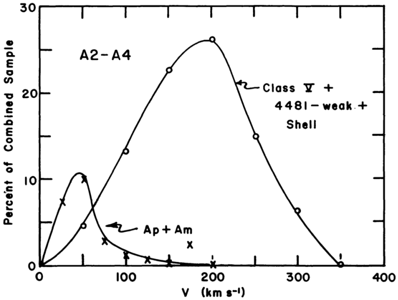
$v \sin i$: projection of the rotational equatorial velocity v on the line of sight

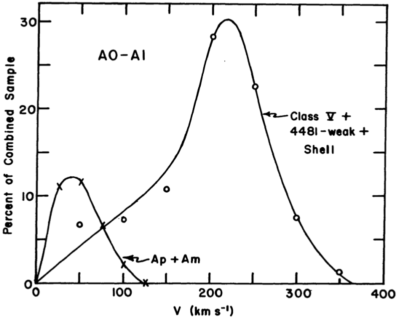


Bimodality of rotational velocity distributions



- Abt et al. (2002): deconvolved v distribution for B8–B9.5 stars
- Abt & Morrell (1995): deconvolved v distributions for A-type stars

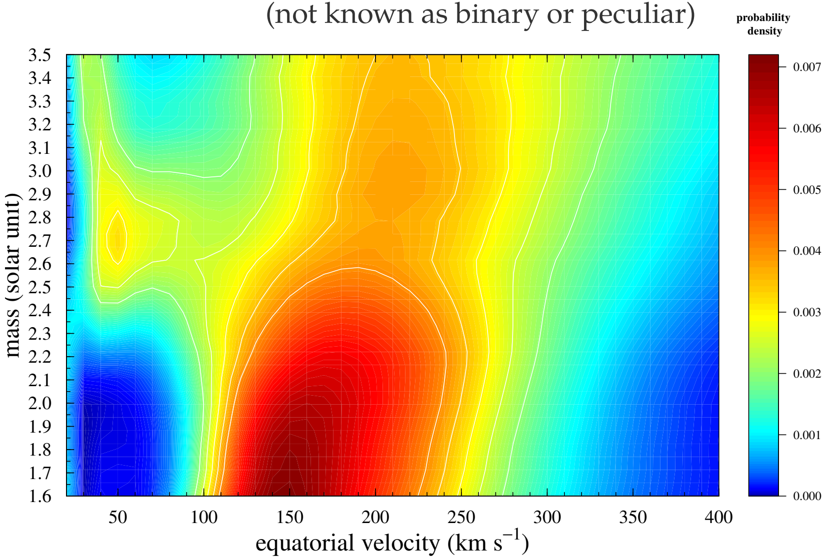




2D rotational velocity distribution of normal stars

~ 1500 B6- to F2-type NORMAL stars (Zorec & Royer 2012)

(not known as binary or peculiar)



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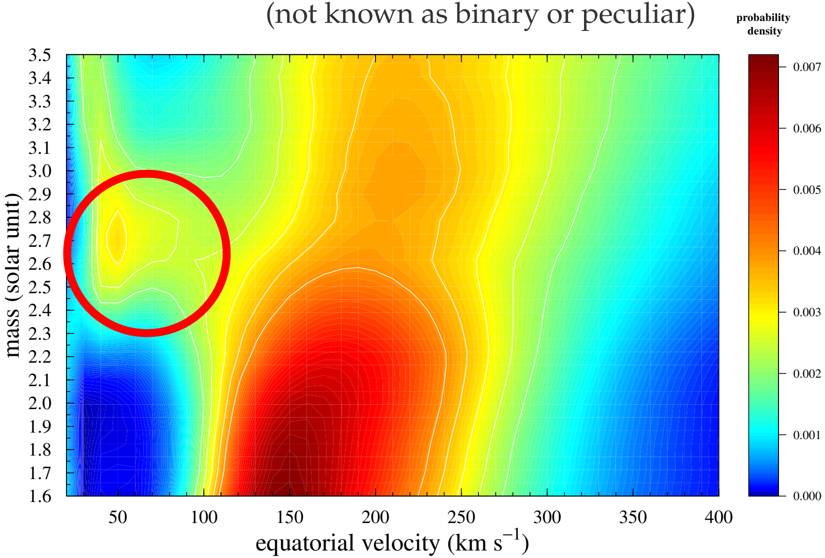
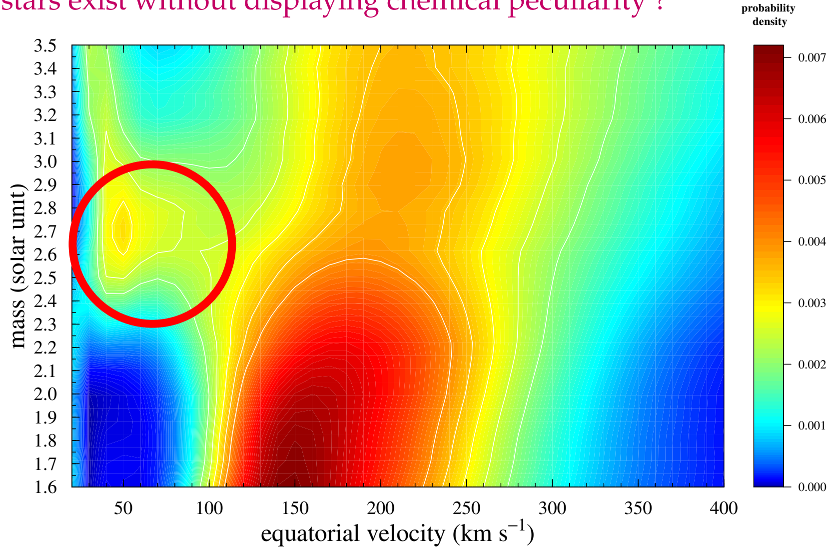


2D rotational velocity distribution of normal stars

Is this overdensity real ? Do slowly rotating early-type stars exist without displaying chemical peculiarity ?



Observing programme

Stellar sample

SELECTION:

- spectral class: B8- to A1
- luminosity class V, IV/V or IV
- **not** known for being binary nor chemically peculiar
- $v \sin i < 65\,\mathrm{km\,s^{-1}}$ (Royer et al. 2007)
- $V \lesssim 6.5\,\mathrm{mag}$
- declination $\delta > -15°$

Spectroscopic observations

Instruments:

- SOPHIE@T193, OHP France [$R \sim 75\,000$],
- ÉLODIE@T193, OHP France [$R \sim 42\,000$],
- HERMES@Mercator, La Palma (Belgian GTO) [$R \sim 85\,000$]

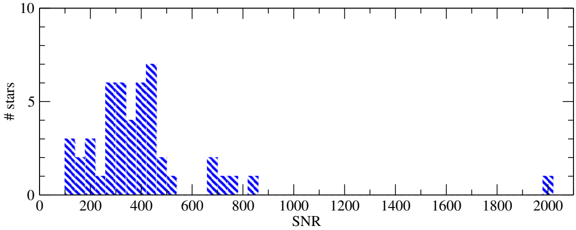
Objectives:

1. identify and confirm normal stars
   - discard spectroscopic binaries
   - perform spectral synthesis, SNR ~ 150–200
2. disentangle v and i for the confirmed normal stars
   - search for gravity darkening signatures, SNR $\gtrsim$ 400

Data

Spectral range: 4000 – 6700 Å

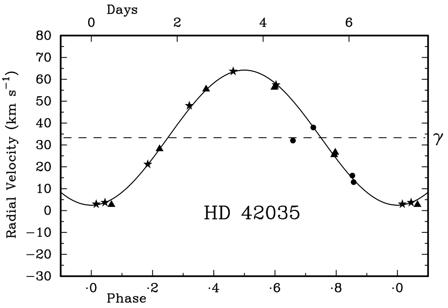
- A0–A1 stars
  - 47 objects
  - $130 \lesssim \mathrm{SNR} \lesssim 800$
- B8–B9.5 stars
  - 49 objects
  - ongoing observations ...



Spectroscopic binaries (SB)

Spectroscopic binaries are detected using:

- radial velocity variability
- shape of cross-correlation function
- consistency check on T_{eff} and $\log g$: comparing luminosities from calibrated stellar radius (Torres et al. 2010) and from Hipparcos parallax



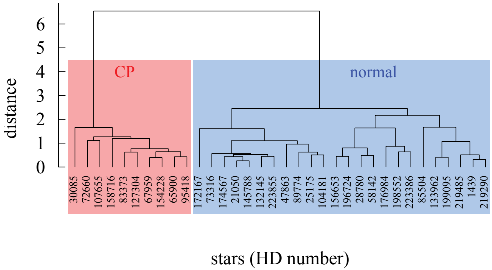
Classification CP vs. normal stars

A0–A1 SUBSAMPLE

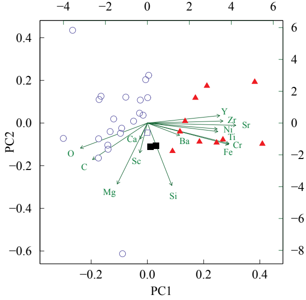
Classification in the 14-dimension abundance space (C, O, Mg, Si, Ca, Sc, Ti, Cr, Fe, Ni, Sr, Y, Zr, and Ba)

Hierarchical classification tree:

- 2 groups

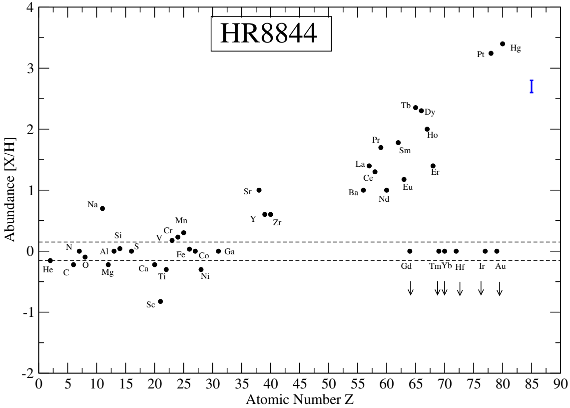


Verification using PCA



Detection of new CP stars

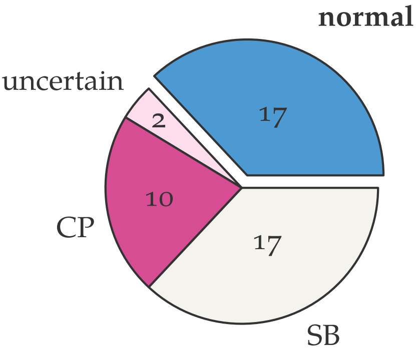
- HD18104, HD30085, HD32867 and HD53588: HgMn stars (Monier et al. 2015)
- HD67044 (Monier et al. 2016)
- ongoing analysis for other objects



Characterisation of the sample

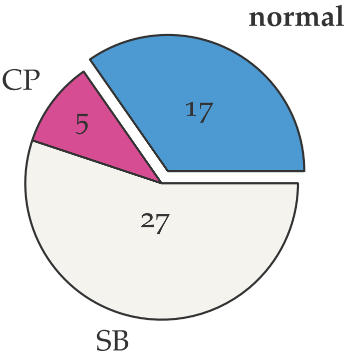
A0–A1 SUBSAMPLE

(Royer et al. 2014)



B8–B9.5 SUBSAMPLE

(preliminary)



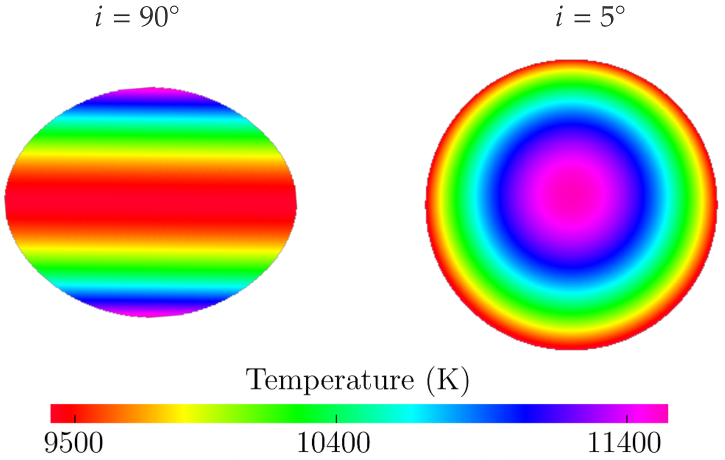
Fast rotation, gravity darkening

Gravity darkening (GD)

MODEL: $3\,M_\odot$ star – $\Omega/\Omega_c = 90\%$

○ geometrical deformation, centrifugal acceleration

⇒ non-uniform surface gravity and temperature



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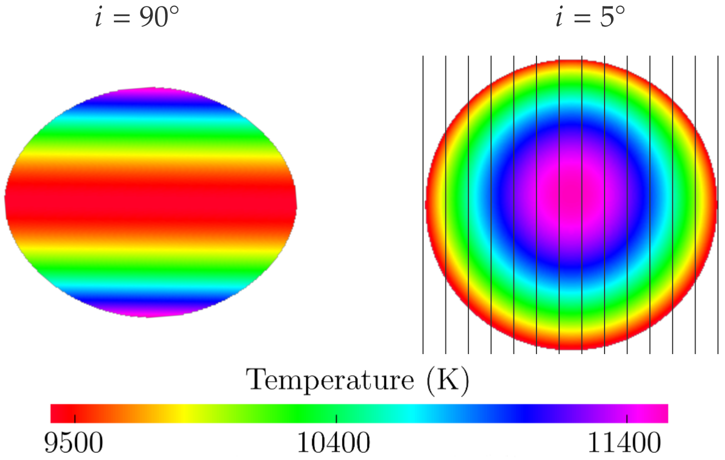

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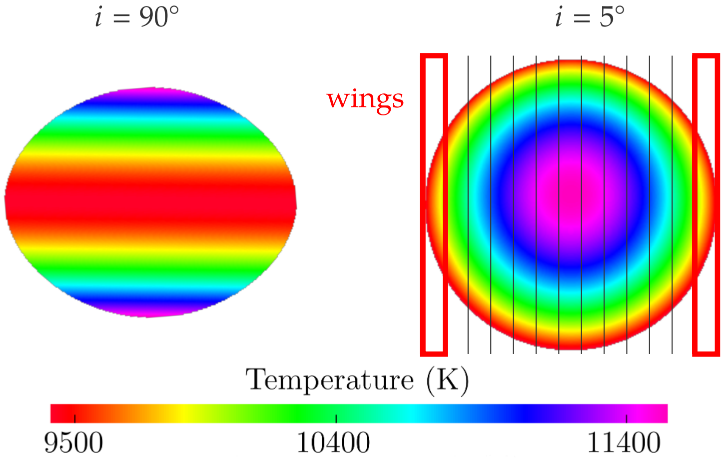

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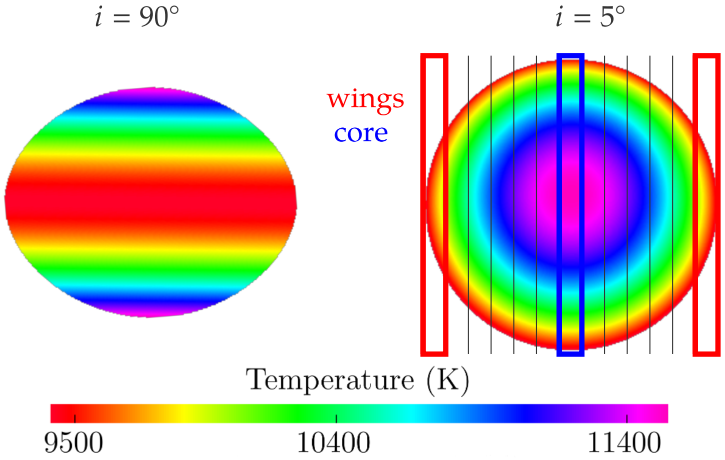
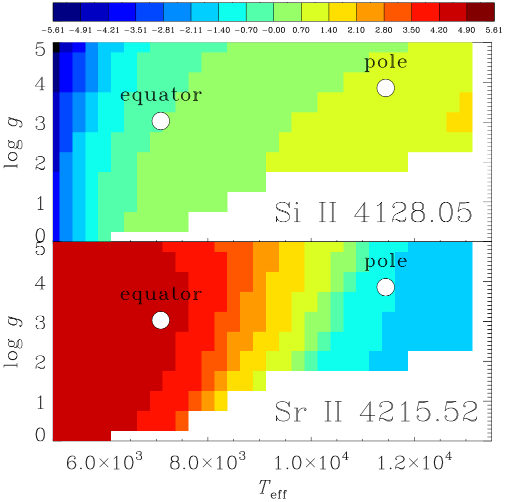


Distortion of the line profiles

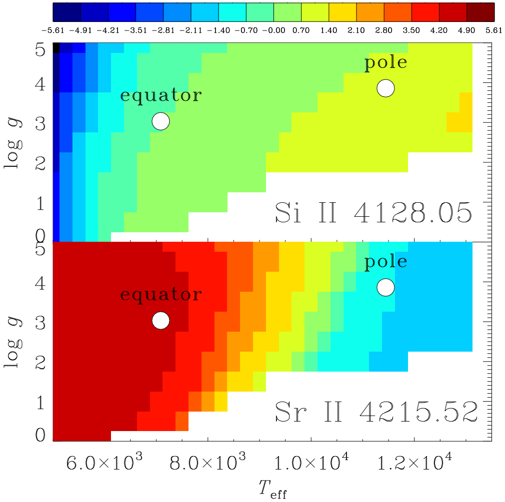
Intensity maps vs T_{eff} and log g

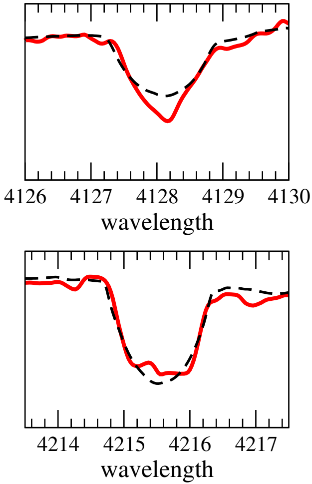


- ∨ Si II 4128.05 Å
  positive slope with T_{eff}
  POINTY SHAPE
- ⊔ Sr II 4215.52 Å
  negative slope with T_{eff}
  FLAT-BOTTOMED SHAPE

Distortion of the line profiles

Intensity maps vs T_{eff} and $\log g$



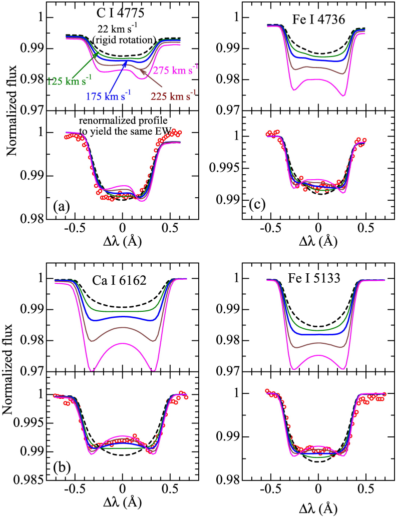


Previous studies on Vega

Analysis of 196 weak lines

- 87 neutral lines, sensitive to GD
- 109 ionized lines, insensitive to GD

Takeda et al. (2008)



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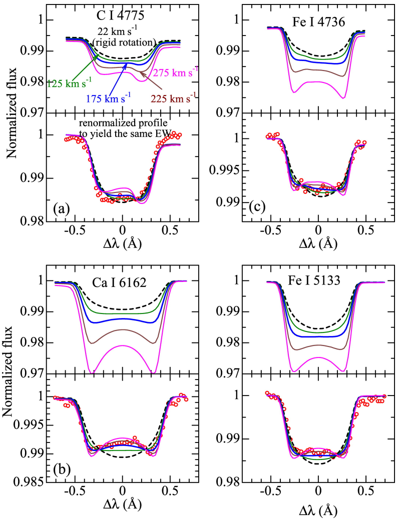

HIGH QUALITY REQUIRED !

- Gulliver et al. (1994) : $R \sim 110\,000$, SNR~ 3300, [4487–4553Å]
- Takeda et al. (2008): $R \sim 100\,000$, SNR~ 1000–3000, [3900–8800Å]

FASTROT

FASTROT computer code developed by Frémat et al. (2005):

- stellar photosphere = mesh of plane-parallel model atmospheres, each depending on the local temperature and surface gravity
- surface equipotentials = Roche approximation
- von Zeipel (1924) relation: $T_{\mathrm{eff}}^4 \propto g^\beta$ ($\beta = 1$ for $T_{\mathrm{eff}} > 7000\,\mathrm{K}$)

Methodology

Spectrum fitting
SNR $\gtrsim$ 700

- linelist (Takeda et al. 2008) + Hβ
- line-by-line fitting
- optimization of ($T_{\rm eff}$, log g, Ω/Ω_c, i) using FASTROT and *gradient method* (`iminuit`)
- chemical abundances derived in a second step

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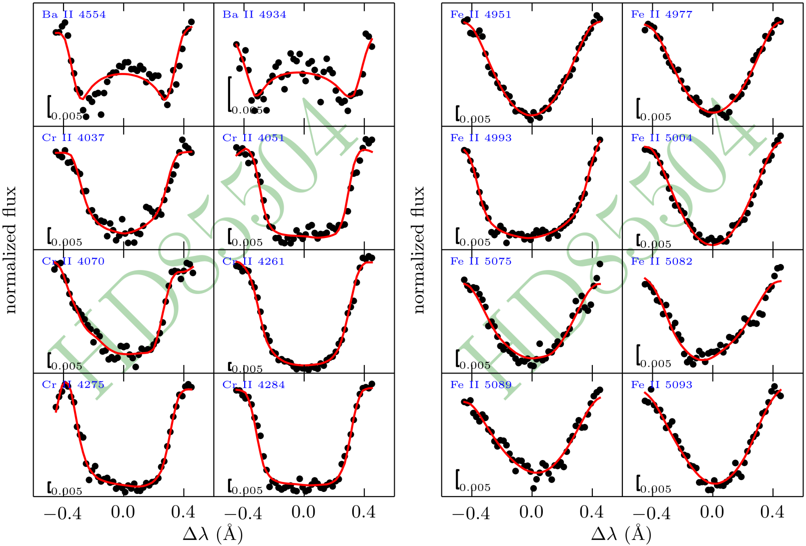
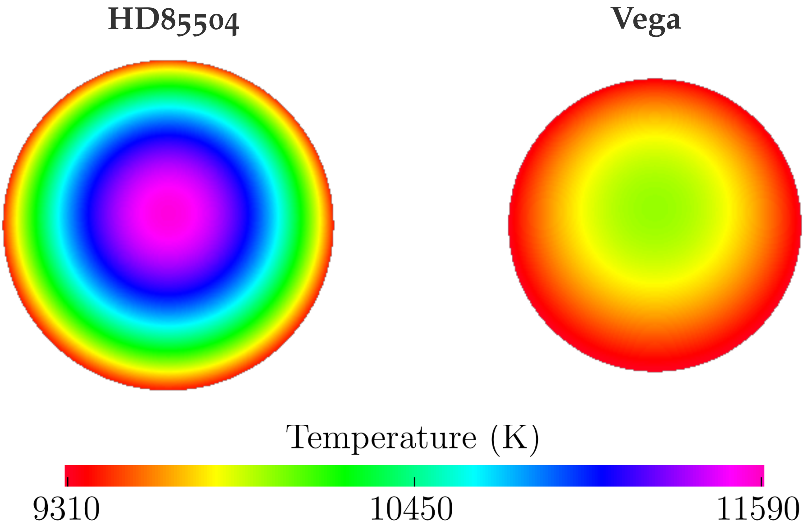
Mean profile fitting
SNR $\gtrsim$ 400

- selection of sensitive lines
- mean line profile from simple line addition
- grid of FASTROT models ($T_{\rm eff}$, log g, $\Omega/\Omega_{\rm c}$, i)
- selection of models in a range of $T_{\rm eff}$ and $v \sin i$
- scaling of model mean line profile
- best fitting model from χ^2

Example of spectrum fitting



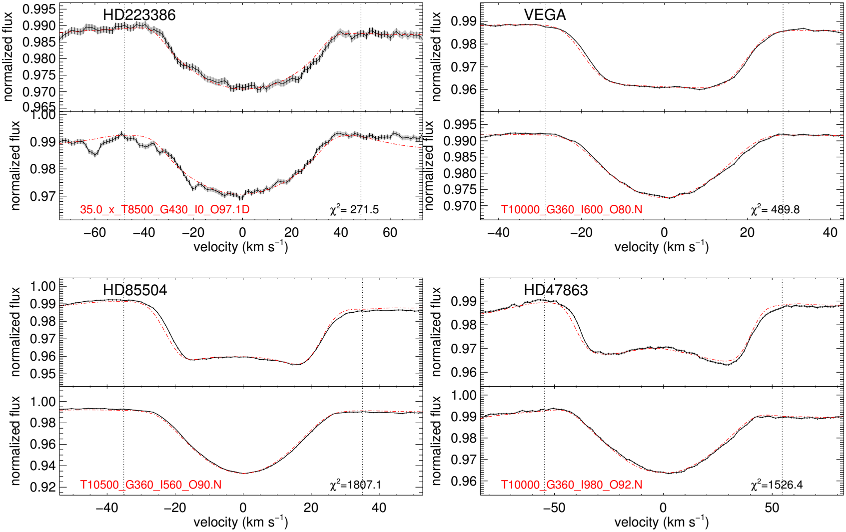
Temperature maps



Examples of mean profile fitting

Upper panels: mean of 23 lines $\sqcup$

Lower panels: mean of 28 lines $\vee$



Preliminary results for HD85504

Parameter	Spectrum fitting	Mean profile fitting
$T_{\mathrm{eff}}^{\mathrm{nrcp}}$	10450 K	10500 K
$\log g^{\mathrm{nrcp}}$	3.77	3.80
v/v_{c}	0.75	0.80
i	5.3°	5.0°
v	$257\,\mathrm{km\,s^{-1}}$	$278\,\mathrm{km\,s^{-1}}$
$v \sin i_{\mathrm{true}}$	$23.8\,\mathrm{km\,s^{-1}}$	$24.3\,\mathrm{km\,s^{-1}}$
$T_{\mathrm{eff}}^{\mathrm{equa}}$	8455 K	8111 K
$T_{\mathrm{eff}}^{\mathrm{pole}}$	11176 K	11350 K
$\log g^{\mathrm{equa}}$	3.33	3.27
$\log g^{\mathrm{pole}}$	3.82	3.86
$\Omega/\Omega_{\mathrm{c}}$	0.867	0.900

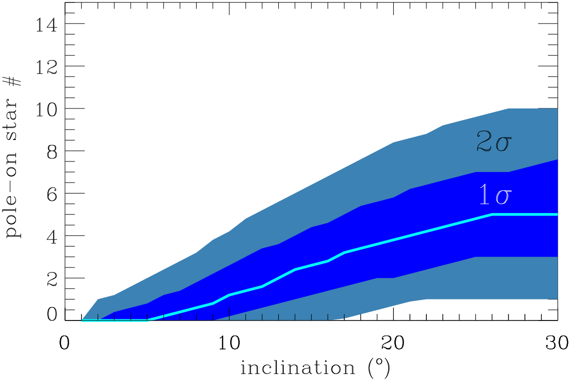
Preliminary table of results

Star	$v \sin i$	v	i
HD21050	26.6	×	×
HD25175	54.9	×	×
HD28780	32.1	142.9	13.0°
HD47863	44.2	259.4	9.8°
HD58142	18.3	×	×
HD73316	32.3	155.5	12.0°
HD85504	24.7	253.4	5.6°
HD89774	63.5	144.7	26.0°
HD104181	51.2	185.6	16.0°
HD132145	12.5	179.0	4.0°
HD133962	51.2	185.6	16.0°
Vega	21.8	208.8	6.0°
HD198552	52.5	×	×
HD219485	26.0	149.8	10.0°
HD223386	35.0	×	×
HD223855	64.2	349.1	10.6°

Distribution of inclination angles

Simulated sample:

- 121 stars – 1000 simulations
- v generated from Royer et al. (2014)
- i: random orientation



Cumulative distribution:

$$\begin{cases} v \sin i < 65\,\mathrm{km\,s^{-1}} \\ v > 120\,\mathrm{km\,s^{-1}} \end{cases}$$

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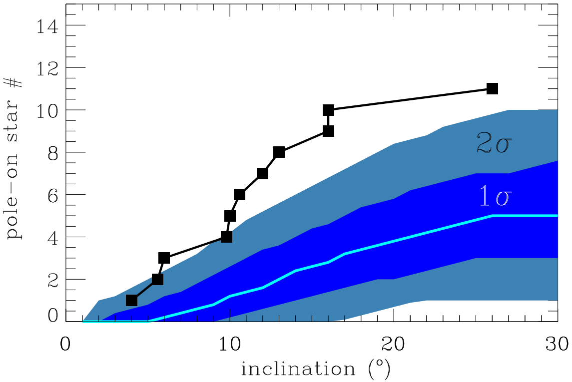

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■ measured i

Summary

- Detection of clear GD signatures
- Among the normal A0–A1 stars with $v \sin i < 65\,\mathrm{km\,s^{-1}}$
  - 69% have $v > 140\,\mathrm{km\,s^{-1}}$ and low i
  - 31% have no detectable sign of GD
- Higher occurence of low i than predicted by random orientation

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- Analyse the B8–B9.5 sample to increase statistics of i
- Check/monitor the *intrinsic* slow rotators
- Study the very fast pole-on rotators (HD85504, HD47863, HD223855, ...).