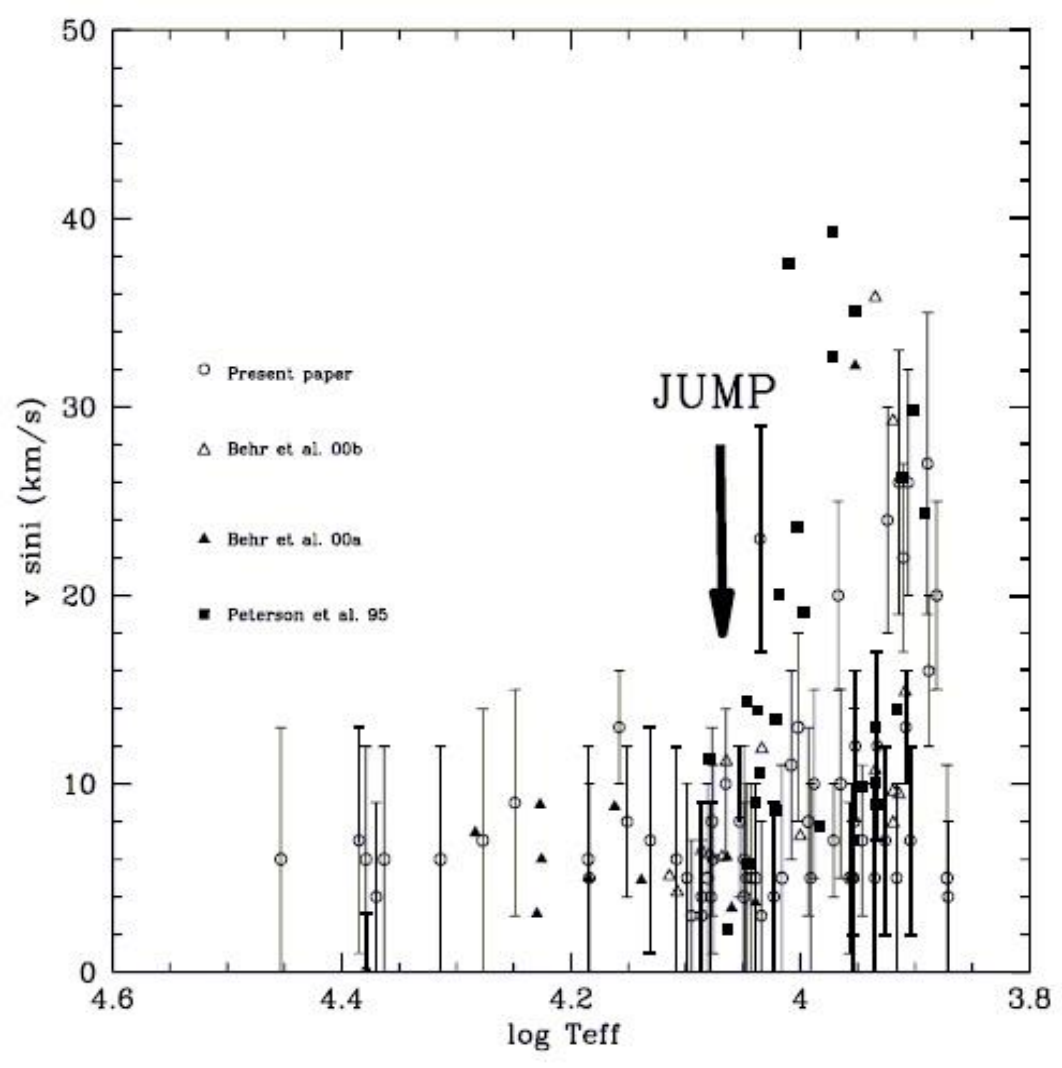
Project VeSElkA.
Search for Vertical Stratification of Element Abundances in CP stars

Viktor Khalack

Blue Horizontal Branch stars



Projected rotational velocities as a function of temperature for BHB stars at M13 and M15 globular clusters (Recio-Blanko et al. 2004).

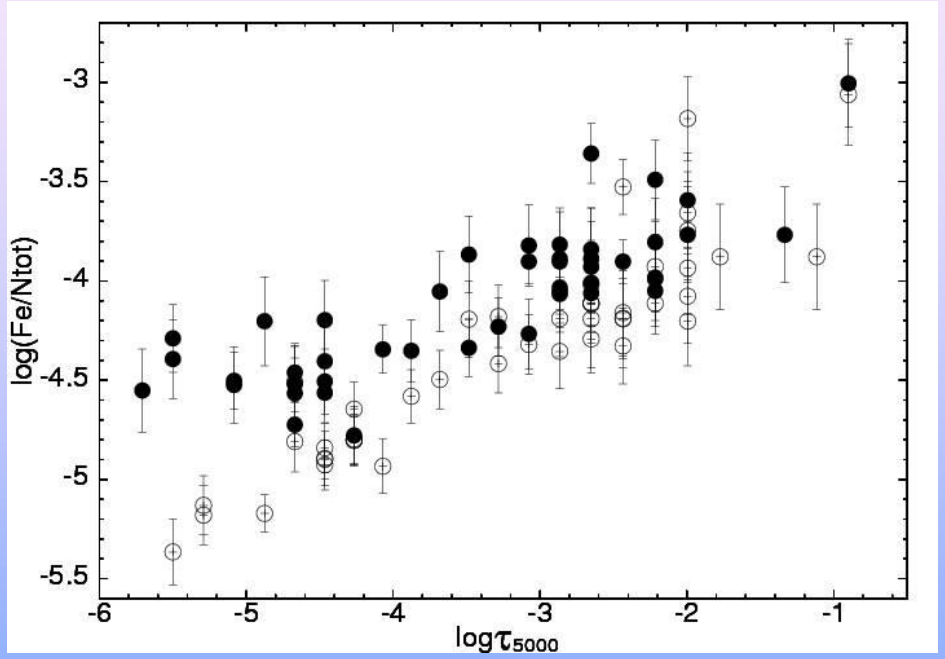
BHB stars with T_{eff}>11500K

- show iron enrichment and strong helium depletion
- photometric jump
- have lower gravity and
- essentially lower rotational velocities

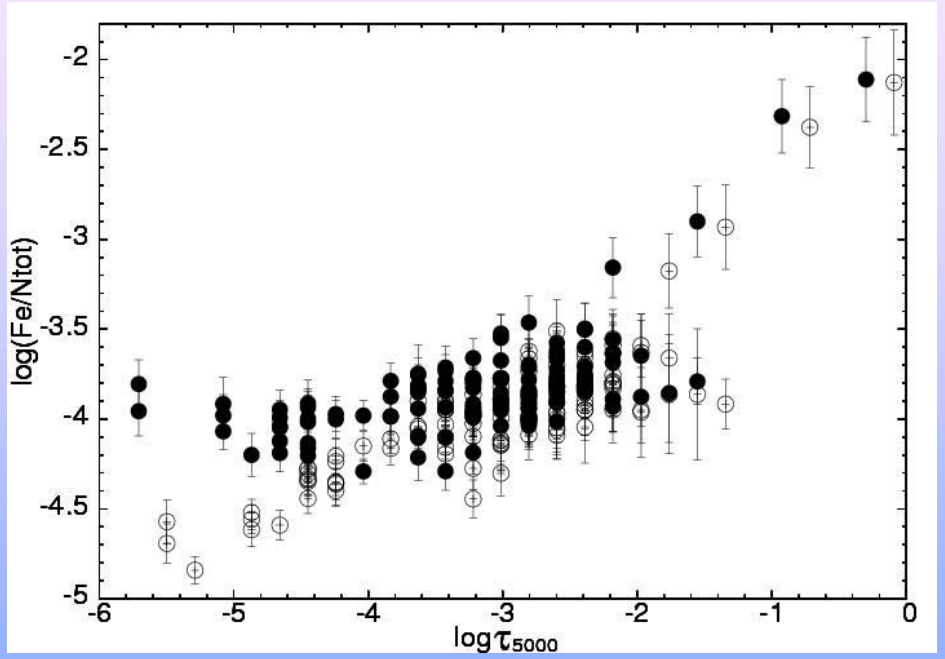
Atomic diffusion (Michaud 1970) can explain qualitati-vely these observational features.

Blue Horizontal Branch stars

M15/B267



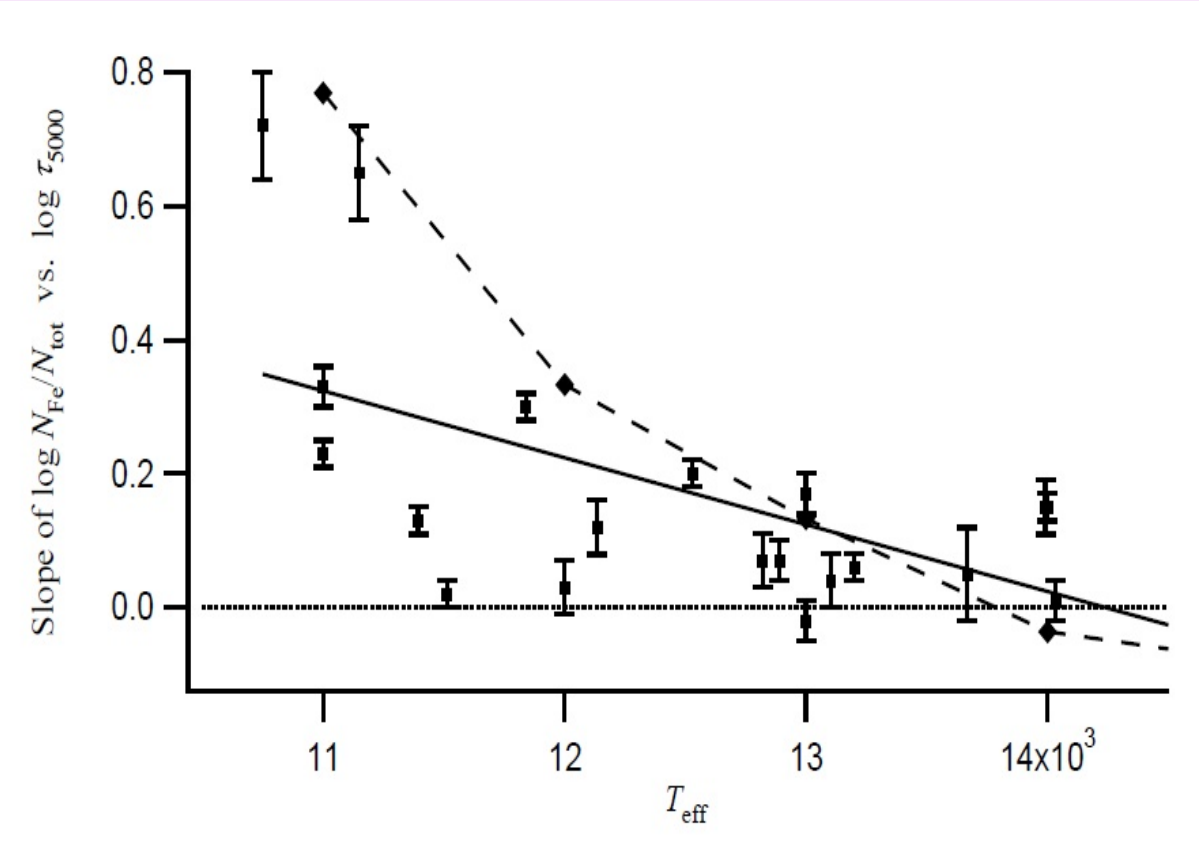
M13/WF4-3085



Abundance estimates from the analysis of FeII lines in the spectra of M15/B267 (left) and M13/WF4-3085 (right) as a function of optical depth of line (core) formation, assuming zero microturbulence (filled circles) and 2 km/s (open circles).

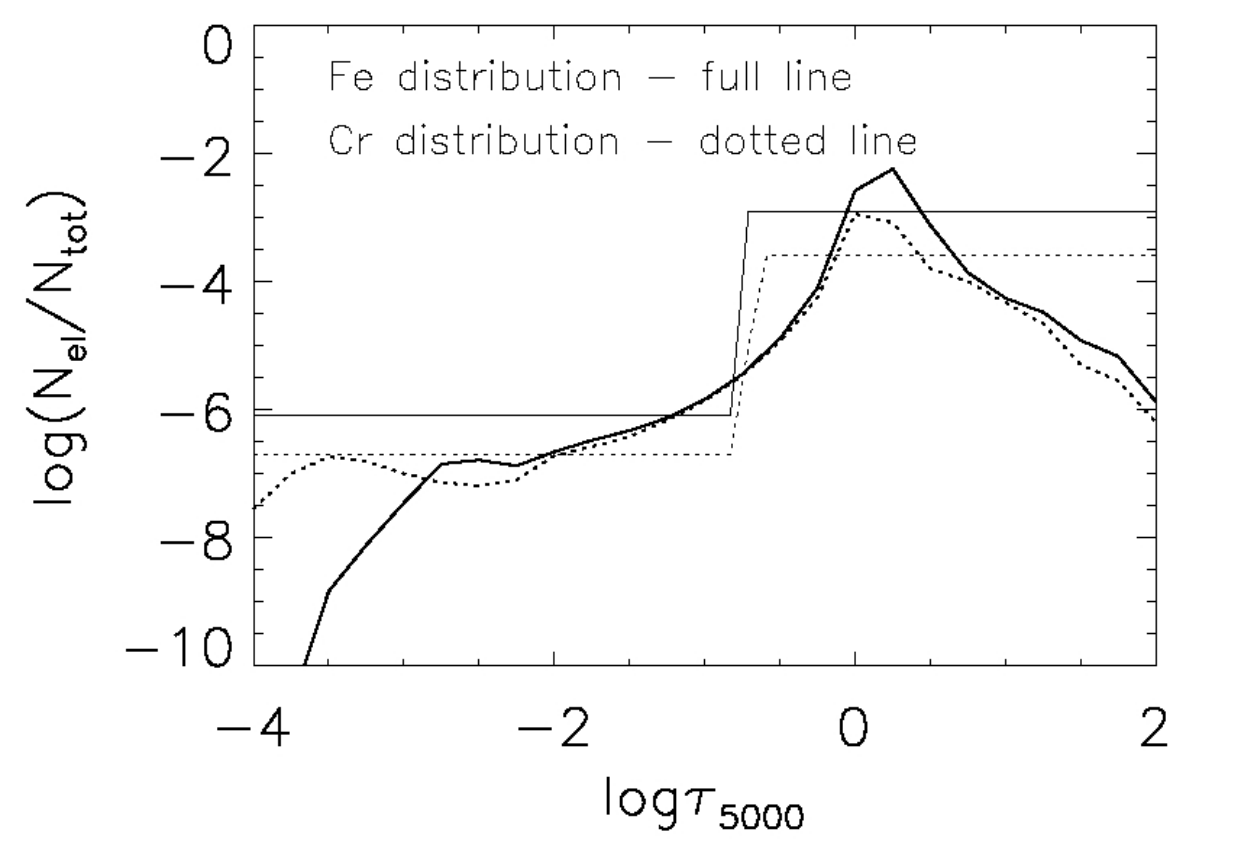
Vertical stratification of iron abundance

Blue Horizontal Branch stars



The slope of vertical stratification of iron abundance decreases with T_{eff} and becomes negligible for the BHB stars hotter than 14000K (LeBlanc, Hui-Bon-Hoa and Khalack 2010).

Phenomenon of the main sequence CP stars



Some chemical elements also show vertical abundance stratification (Ryabchikova et al. 2002)

Atomic diffusion (Michaud 1970) can explain qualitatively these features.

Comparison of the empirical data for vertical stratification of Fe and Cr (fine lines) with the results of numerical modeling of abundance stratification taking into account the effect of atomic diffusion (thick lines) for β CrB.

Project VeSElkA

VeSElkA stands for: Vertical Stratification of Elements Abundance in CP stars (on main sequence)

It aims to search for and study the signatures of abundance stratification of chemical species with optical depth in the atmospheres of slowly rotating (Vsini < 40 km/s) main sequence CP stars

The slow rotation is an indicator of the hydrodynamically stable atmosphere, where diffusion process may result in vertical stratification of chemical abundances.

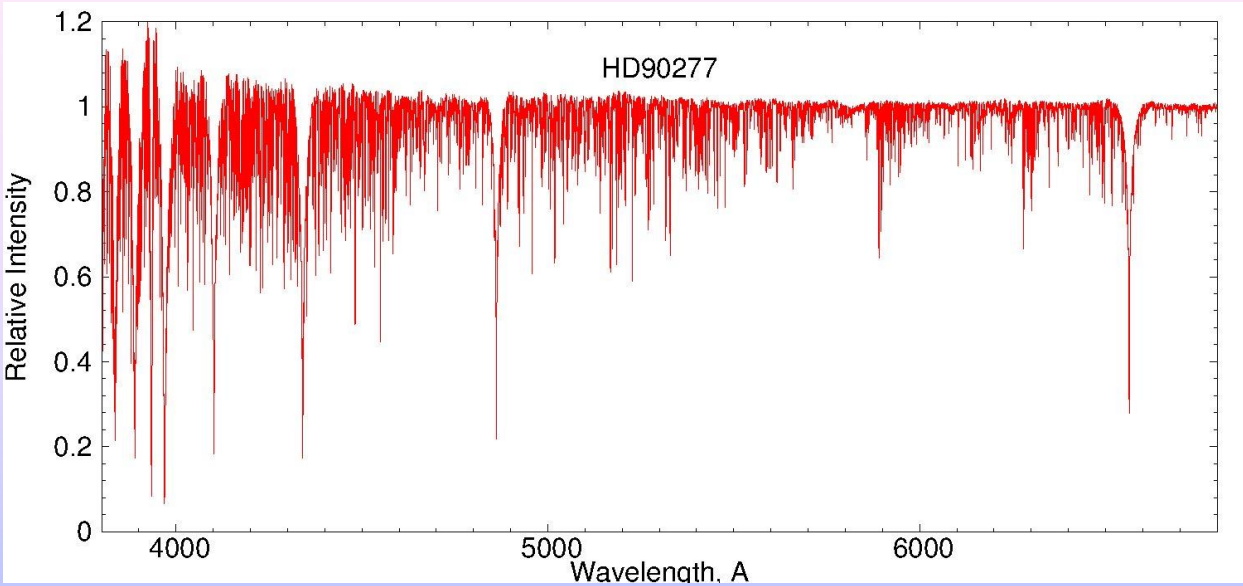
A list of suitable candidates has been compiled based on the catalog of Ap, HgMn and Am stars of Renson & Manfroid (2009).

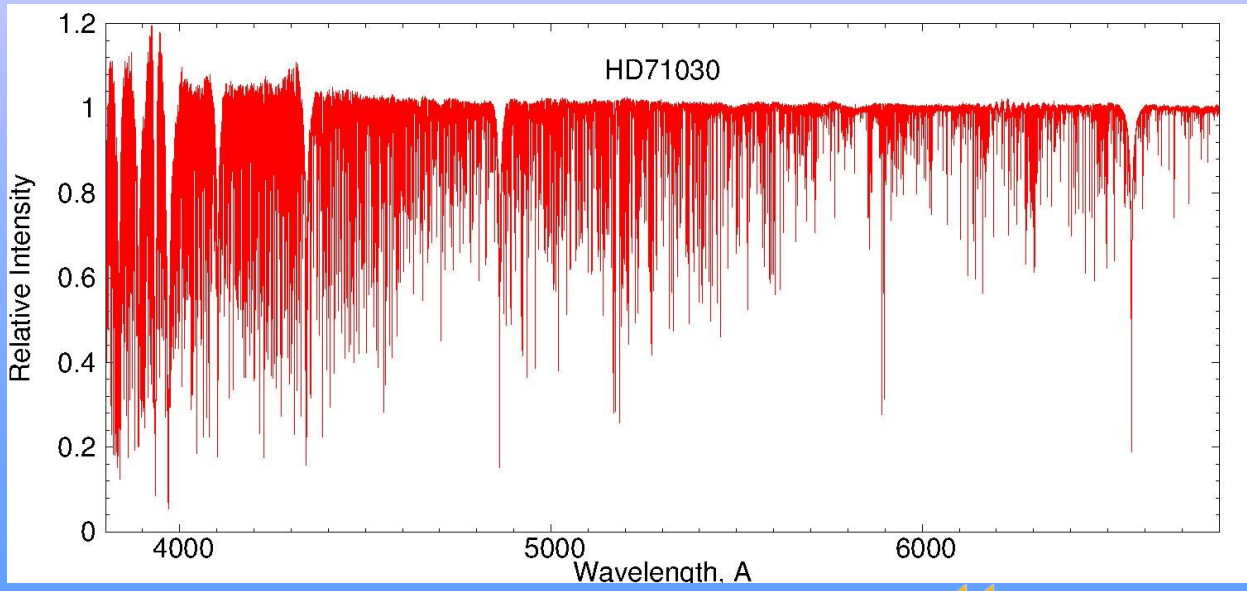
Observations of these stars have been carried out with the spectropolarimeter ESPaDOnS at the Canada-Franse-Hawaii telescope.

Project VeSElkA: Observations of CP stars

ESPaDOnS spectra:
Semester 2013A

Name	Vsin(i)
HD53929	25 km/s
HD68351	33 km/s
HD71030	9 km/s
HD83373	28 km/s
HD90277	34 km/s
HD95608	21 km/s
HD97633	23 km/s
HD110380	23 km/s
HD116235	26 km/s
HD159082	22 km/s
HD164584	12 km/s





Project VeSElkA: Observations of CP stars

ESPaDOnS spectra:

Semester 2013A

Name	Vsin(i)
HD53929	25 km/s
HD68351*	33 km/s
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HD95608	21 km/s
HD97633	23 km/s
HD110380	23 km/s
HD116235	26 km/s
HD159082*	22 km/s
HD164584	12 km/s

Semester 2013B

Name	Vsin(i)
HD6397	10 km/s
HD12869*	18 km/s
HD15385	29 km/s
HD22920	39 km/s
HD23878	24 km/s
HD24712	22 km/s
HD25267	28 km/s
HD166473	20 km/s
HD170973	18 km/s
HD209459	14 km/s
HD223640	28 km/s
HD224103	28 km/s

Semester 2014A

Name	Vsin(i)
HD2628	21 km/s
HD40394	18 km/s
HD148330	18 km/s
HD157087	15 km/s
HD158261*	17 km/s
HD174933	20 km/s
HD176232	18 km/s
HD186568	15 km/s
HD190229*	8 km/s
HD196821	22 km/s
HD207840	15 km/s
HD214994	14 km/s

*Spectroscopic Binaries

Project VeSElkA: Planned observations of CP stars

ESPaDOnS spectra
Semester 2016A :

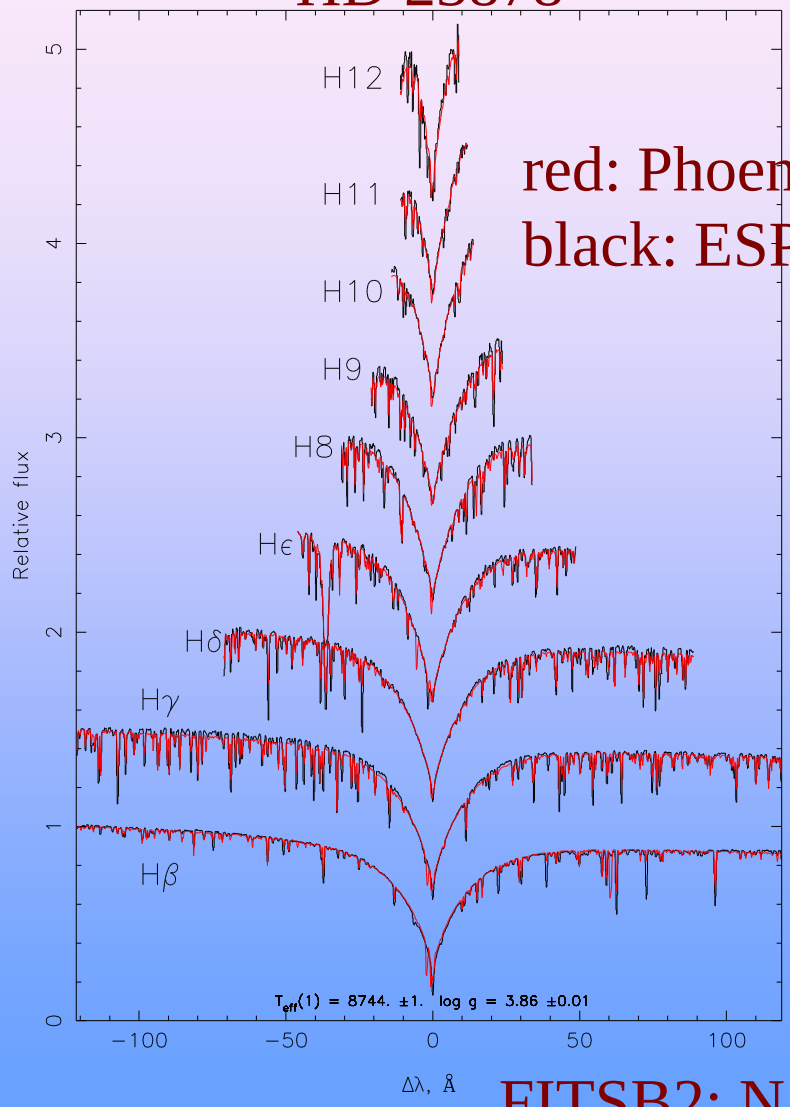
Name	Vsin(i)	Name	Vsin(i)
HD25823	25 km/s	HD74521	18 km/s
HD26571	30 km/s	HD85504	27 km/s
HD26553	18 km/s	HD89822	18 km/s
HD32188	23 km/s	HD90569	18 km/s
HD38104	29 km/s	HD92728	22 km/s
HD40626	18 km/s	HD108662	18 km/s
HD41076	14 km/s	HD110066	29 km/s
HD43819	20 km/s	HD111133	18 km/s
HD49606	15 km/s	HD127304	14 km/s
HD72660	8 km/s	HD153882	30 km/s

GRACES spectra:
Semester 2016A

Name	Sp
HD93700	A0
HD107000	A2p
HD122024	B9
HD146971	A0
HIP52123	B4p

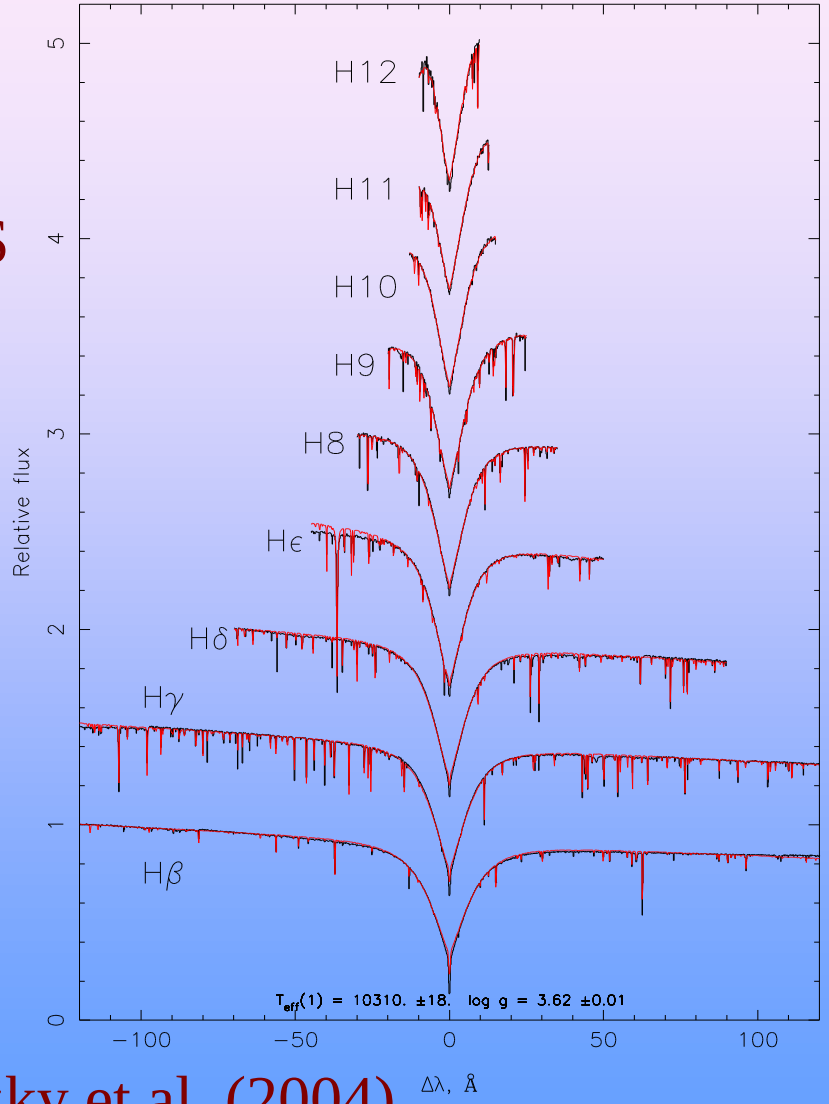
Project VeSElkA: Estimates of T_{eff} and log(g)

HD 23878



red: Phoenix15
black: ESPaDOnS

HD 209459



FITSB2: Napiwotzky et al. (2004)

Project VeSElkA: Estimates of T_{eff} and log(g)

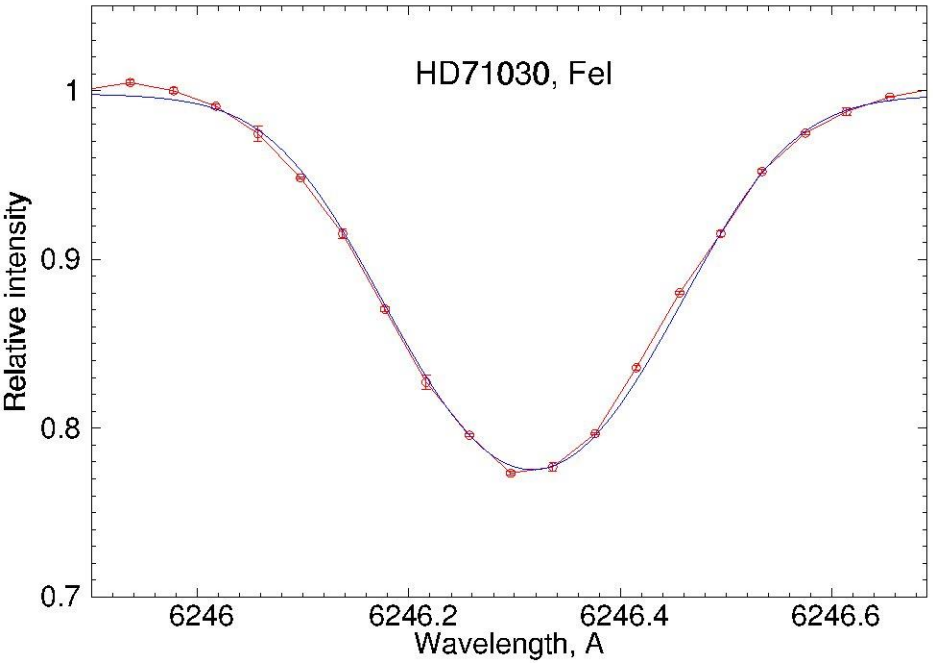
Determined values of the effective temperature and the surface gravity for the programm CP stars.

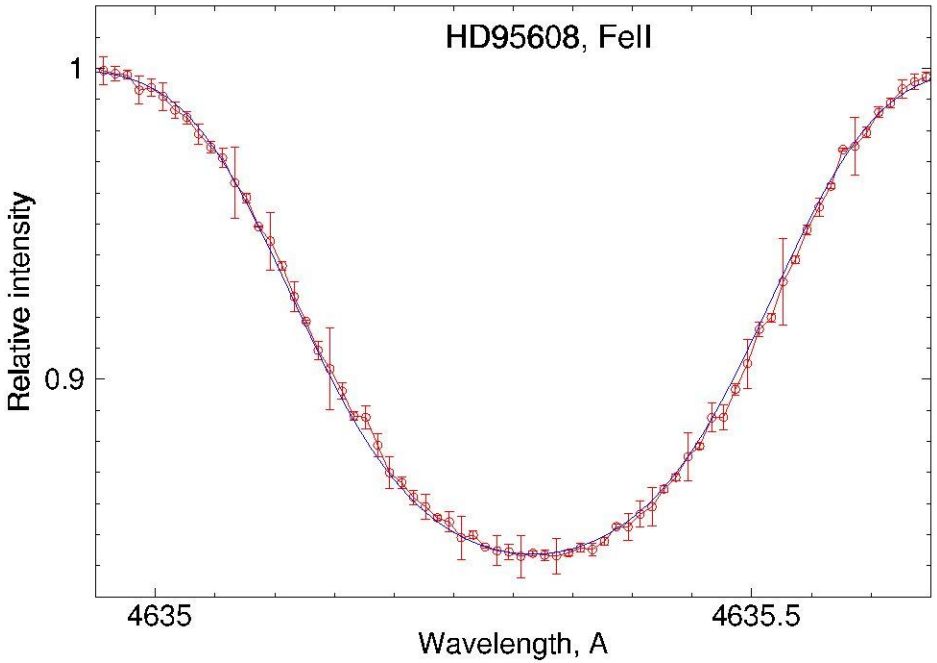
Star	Balmer lines					Previous publications		
	T_{eff} (K)	log g	V_r (km s^{-1})	[M/H]	χ^2/ν	T_{eff} (K)	log g	$V \sin i$ (km s^{-1})
HD 15385	8230±200	4.00±0.2	22.0±1.0	0.0	0.65	8154[a]	4.12[a]	21[a], 29[b]
HD 22920	13640±200	3.74±0.2	20.0±2.0	-0.5	5.67	13700[c]	3.72[c]	30[d], 39[b]
HD 23878	8740±200	3.86±0.2	29.5±1.0	0.0	0.62			24[b]
HD 53929	13950±200	3.90±0.2	15.0±1.0	-1.0	3.20	14050±250[e]	3.60±0.25[e]	25[b], 30[e]
HD 68351	10080±200	3.22±0.2	18.1±1.0	0.0	1.17	10290±340[f]		33[b]
HD 71030	6780±200	4.04±0.2	38.1±1.0[h]	0.0	0.28	6541±47[g]	4.03±0.05[g]	9±2[h]
HD 83373	9800±200	3.81±0.2	26.5±1.0	0.0	0.92			28[b]
HD 90277	7250±200	3.62±0.2	14.5±1.0	0.0	1.29	7440[i]	3.46[i]	34[b]
HD 95608	9200±200	4.25±0.2	-10.4±1.0[h]	+0.5	0.59			21[b],17±2[h]
HD 97633	8750±200	3.45±0.2	8.2±1.0	0.0	0.61	8790±351[j]	3.59±0.89[j]	23[b]
HD 110380	6980±200	4.19±0.2	-17.6±1.0	0.0	0.31	6720[k]	4.20[k]	23[b]
HD 116235	8900±200	4.33±0.2	-10.3±1.0[h]	+0.5	0.49	8570[l]	4.23[l]	20±2[h]
HD 164584	6800±200	3.54±0.2	-11.2±1.0	0.0	1.16			
HD 186568	11070±200	3.44±0.2	-9.5±1.0	-0.5	1.81	11596±120[m]	3.39±0.15[m]	18[m]
HD 209459	10310±200	3.62±0.2	-0.3±1.0	0.0	0.97	10455±400[m]	3.52±0.15[m]	14[b]
HD 223640	12500±200	4.08±0.2	17.0±2.0	+1.0	1.65	12429±435[g]	3.93±0.23[g]	28[b]

Notes: [a]Künzli & North (1998), [b]Royer et al. (2002), [c]Catanzaro et al. (1999), [d]Leone & Manfrè (1996), [e]Smith & Dworetsky (1993), [f]Aurière et al. (2007), [g]Prugniel et al. (2011), [h]Khalack et al. (2013), [i]Berthet (1990), [j]Koleva & Vazdekis (2012), [k]Boesgaard & Trypicco (1986), [l]Erspamer & North (2003), [m]Hubrig & Castelli (2001)

Khalack & LeBlanc (2015)

Project VeSElkA: Abundance analysis





From the analysis of observed line profiles while using the modified ZEEMAN2 code we can determine the following data :

radial velocity, $V \sin(i)$ and

abundance of the analyzed element: $\log(N_E/N_{tot})$

Project VeSElkA: Abundance analysis

Average abundance

Element	HD 71030		HD 95608		HD 116235		HD 186568	
	N	[X/H]	N	[X/H]	N	[X/H]	N	[X/H]
He I	0	-	0	-	0	-	6	0.46±0.19
C I	2	-0.384±0.002	0	-	4	-0.43±0.37	2	-0.34±0.12
N I	2	-0.50±0.18	2	-1.14±0.29	0	-	10	0.12±0.16
O I	2	0.45±0.36	1	0.72	2	-0.12±0.37	5	0.16±1.64
Na I	2	0.58±0.58	3	0.54±0.18	2	1.08±0.65	0	-
Mg I	9	-0.05±0.22	0	-	4	0.03±0.18	0	-
Mg II	2	-0.32±0.04	1	0.34	0	-	8	-0.15±0.28
Al I	0	-	2	1.42±0.95	0	-	0	-
Al II	0	-	1	0.54	0	-	0	-
Al III	0	-	0	-	1	0.43	0	-
Si I	14	-0.20±0.51	2	0.37±0.02	3	0.60±0.45	0	-
Si II	0	-	5	0.30±0.20	0	-	15	0.16±0.19
S I	2	-0.20±0.51	2	0.38±0.08	3	0.83±0.50	0	-
S II	0	-	0	-	0	-	10	0.28±0.16
Ca I	8	0.51±0.63	4	-0.33±0.41	7	-0.17±0.14	0	-
Ca II	1	-0.25	1	-0.36	0	-	0	-
Ti I	15	0.16±0.49	4	2.11±0.74	2	1.63±1.15	0	-
Ti II	2	-0.23±0.05	15	0.00±0.34	6	0.90±0.83	9	-0.67±0.12
Cr I	10	0.29±0.45	12	1.84±1.19	3	1.34±0.89	0	-
Cr II	3	0.13±0.09	14	1.14±0.59	15	2.26±0.61	11	-0.19±0.14
Mn I	3	1.23±1.16	0	-	0	-	0	-
Fe I	142	0.19±0.33	139	0.59±0.35	126	0.68±0.39	6	-0.23±0.42
Fe II	23	0.11±0.34	31	0.72±0.33	18	1.43±0.60	77	-0.03±0.13
Co I	0	-	1	0.56	0	-	0	-
Co II	0	-	2	0.96±0.97	0	-	0	-
Ni I	35	0.05±0.17	11	2.19±0.39	9	0.80±0.16	0	-

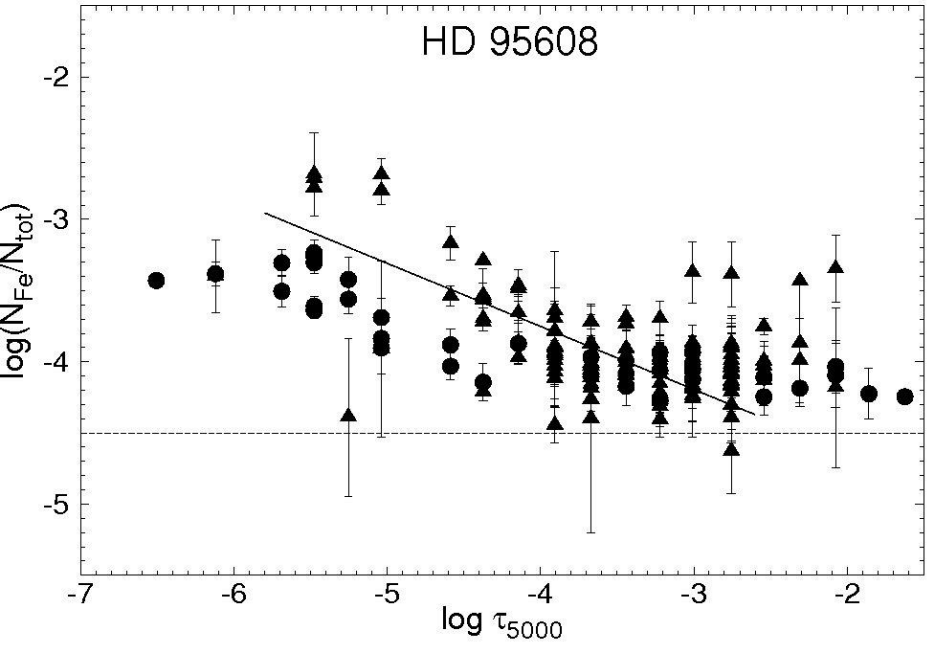
$$[X/H] = \log(N_X/N_H)_* - \log(N_X/N_H)_\odot$$

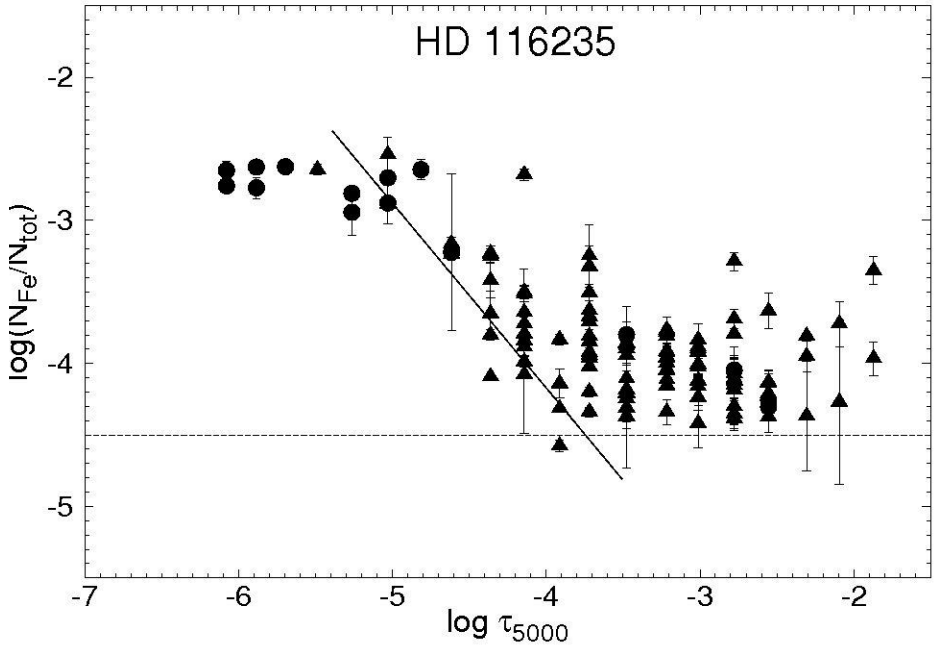
Khalack et al. (2014)

LeBlanc et al. (2015)

Project VeSElkA: Abundance analysis

Vertical stratification of iron abundance





Slope with a = -0.44 ± 0.10

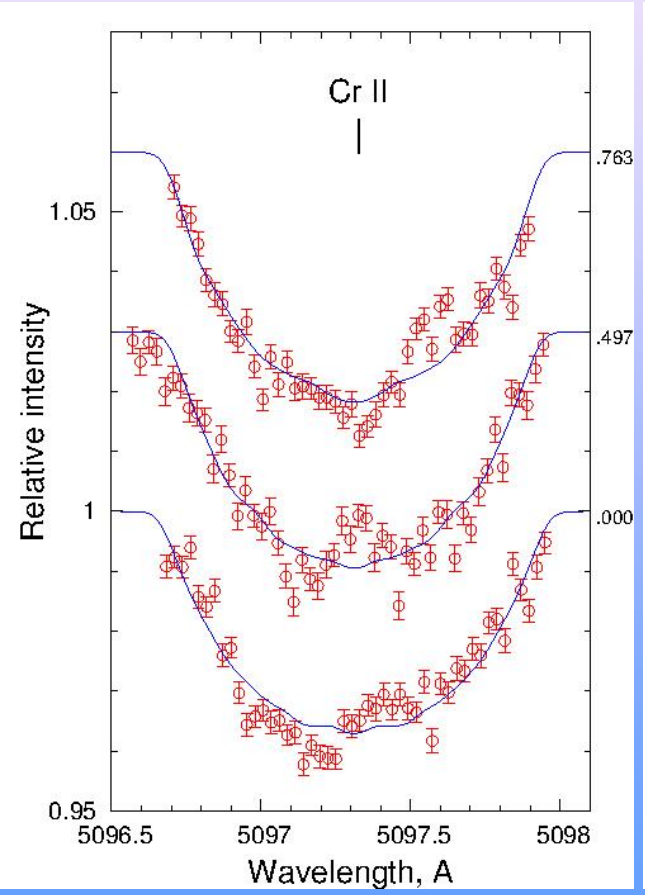
Slope with a = -1.29 ± 0.13

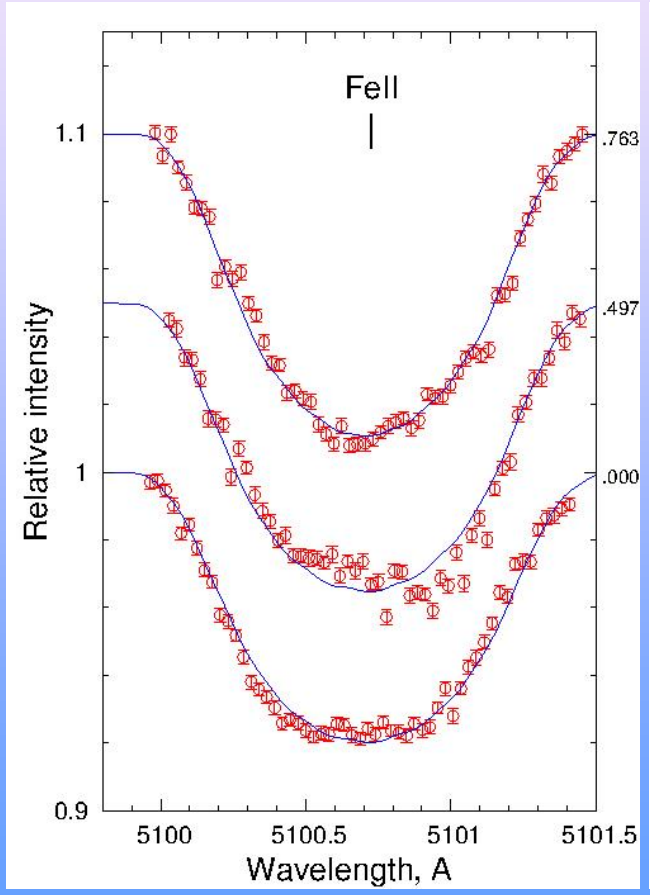
We have also found similar signatures of vertical stratification of chromium abundance in HD95608 and HD116235.

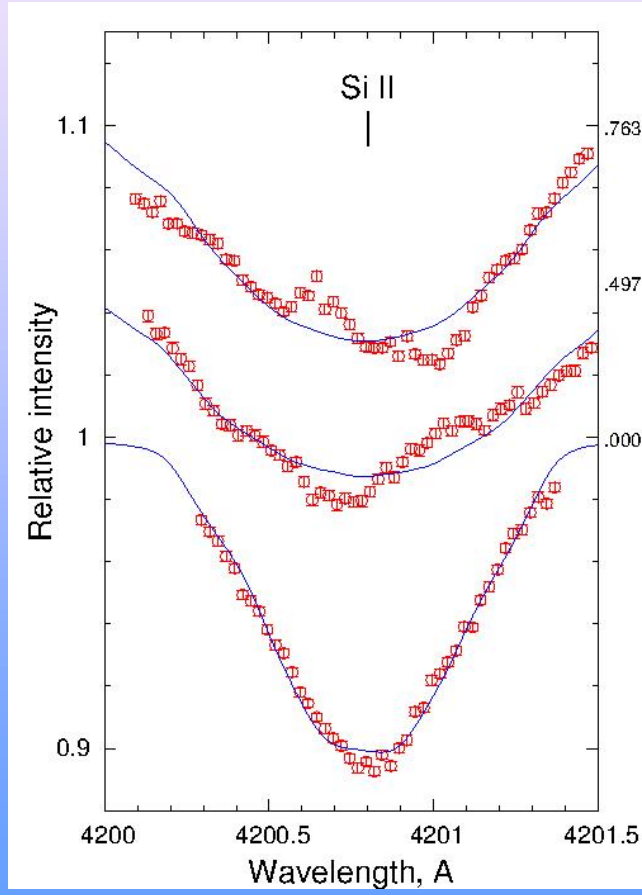
Project VeSElkA: Magnetic star HD 22920

Weak photometric variability with a period $P=3^{d}.95$ (Bartholdy 1988)

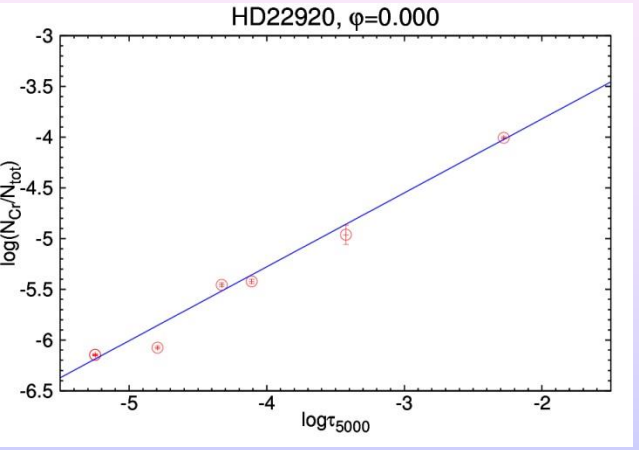
Horizontal stratification of Cr and Si abundance (Khalack & Poitras 2014)

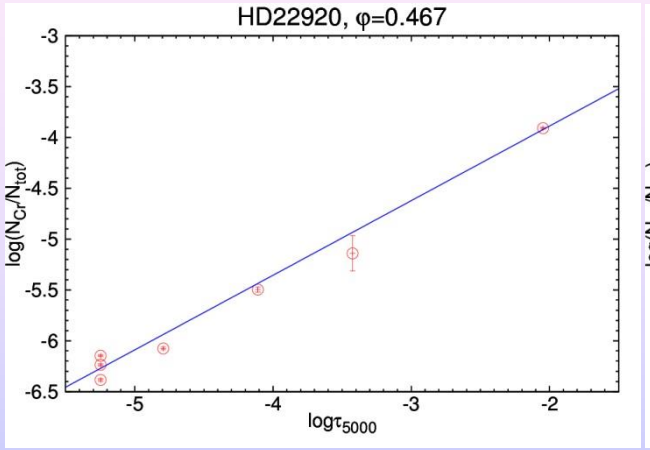


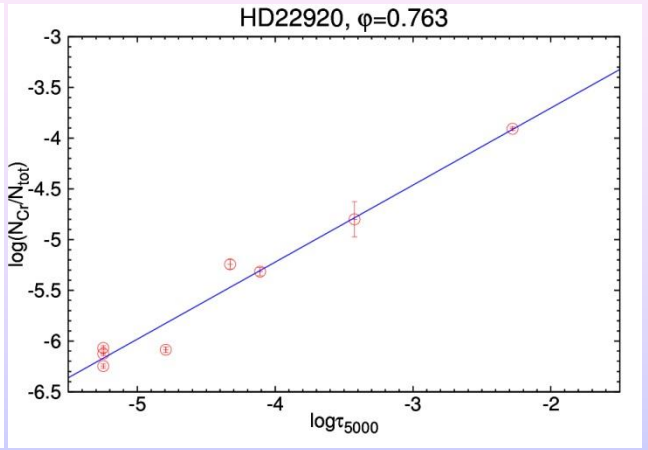


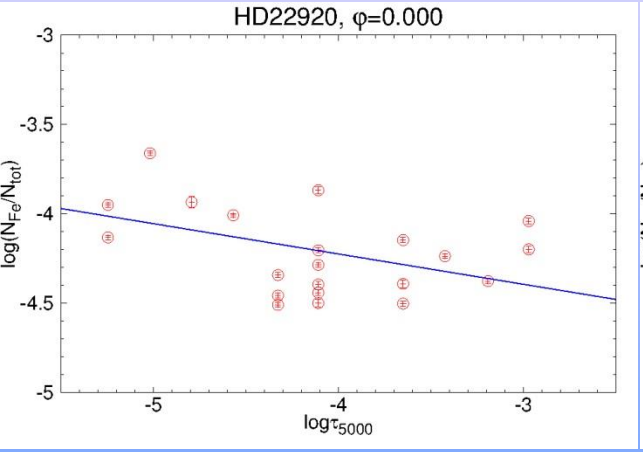


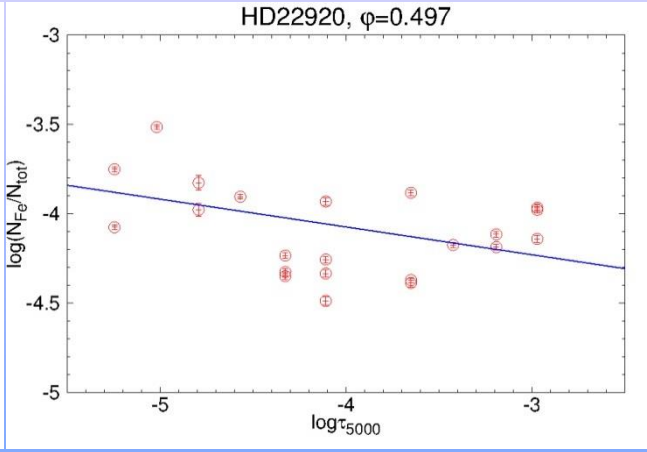
Project VeSElkA: Magnetic star HD 22920

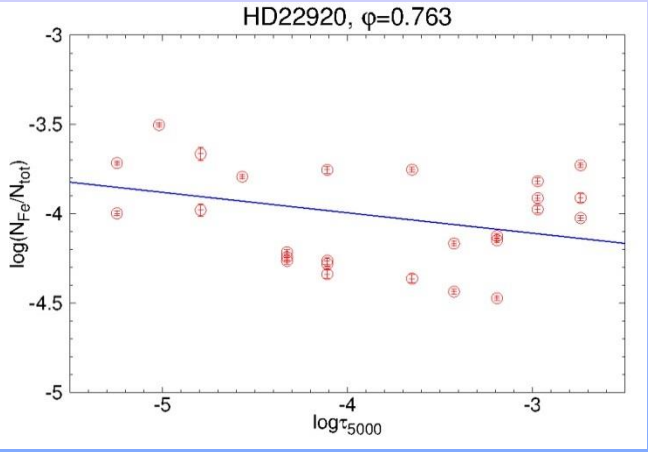










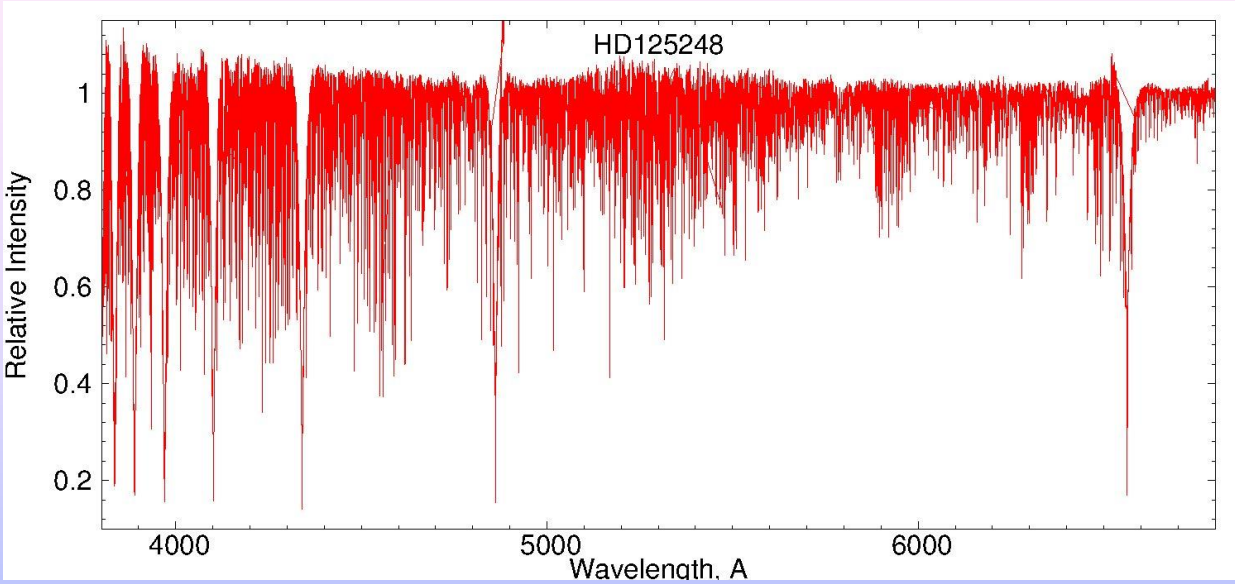


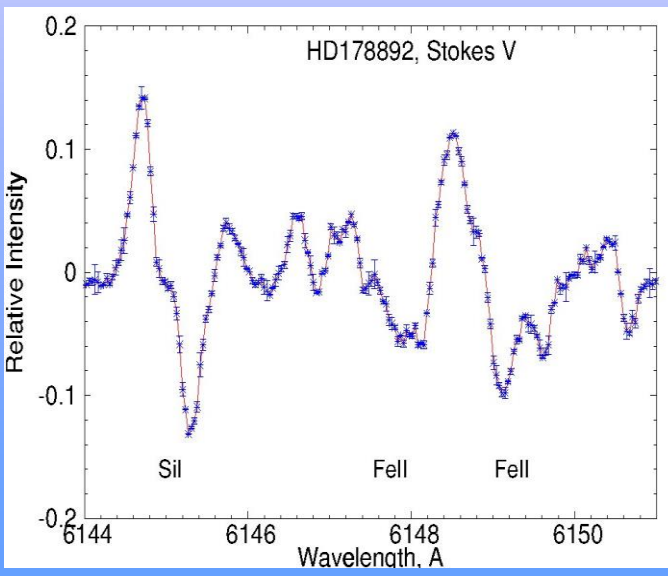
Cr and Si abundances seem to be stratified vertically (Khalack & Poitras 2014)

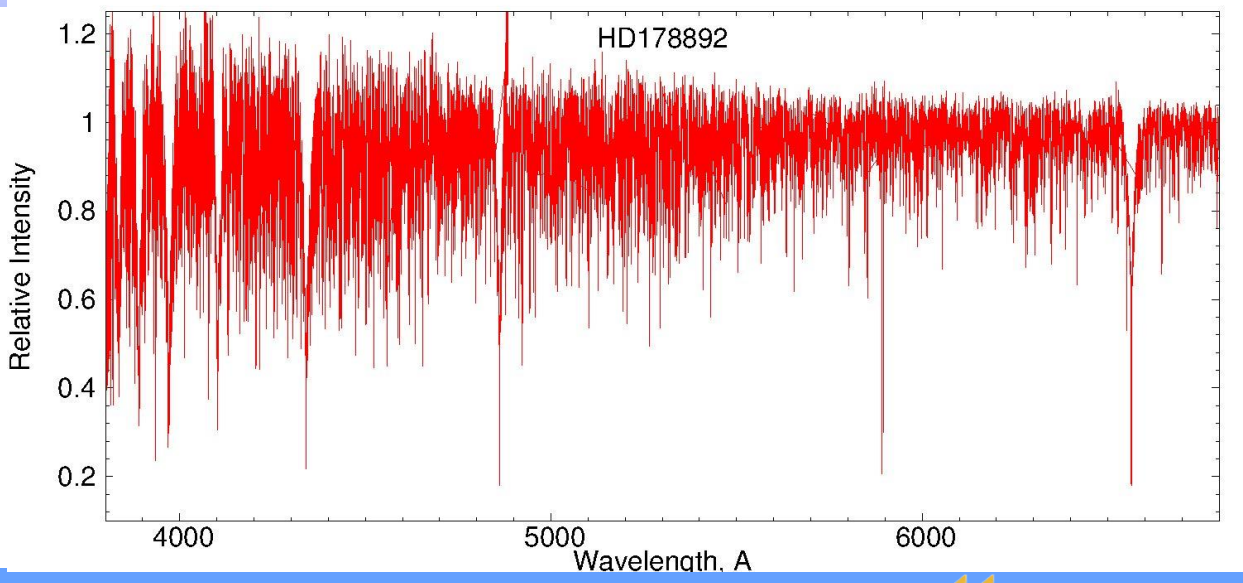
Project VeSElkA: Study of magnetic CP stars

Semester 2013A
ESPaDOnS spectra:

Name	Vsin(i)
HD125248	12 km/s
HD178892	10 km/s
BD+00 4535	--





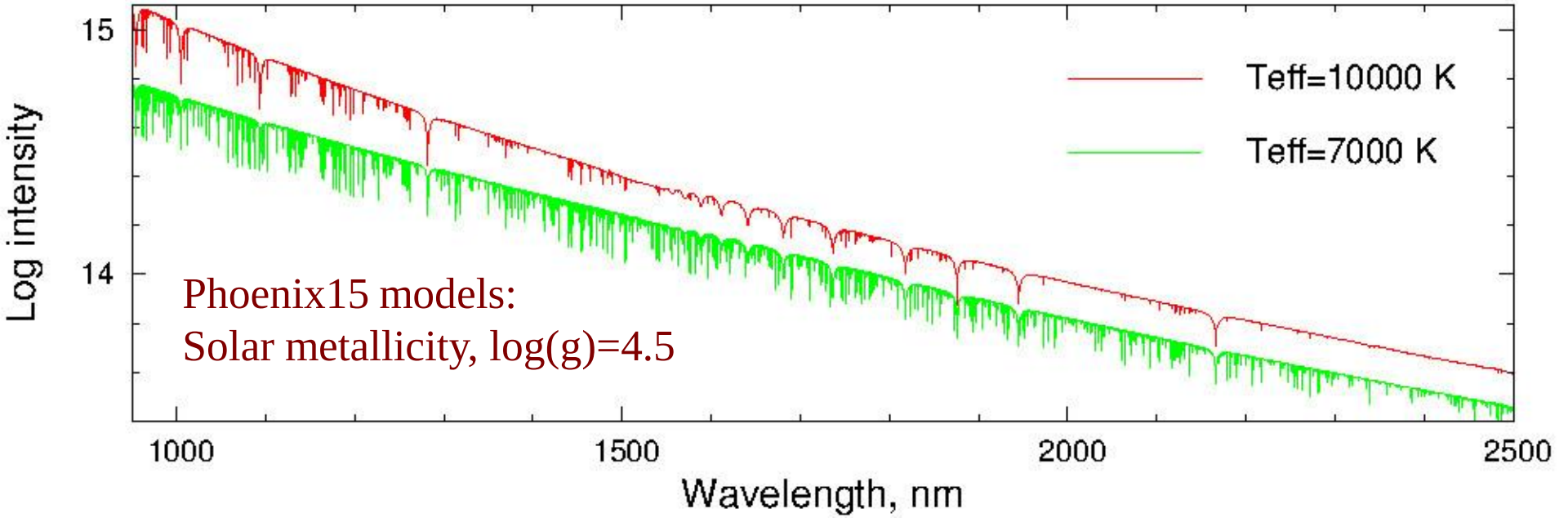


Project VeSElkA: IR observations with SPIRou

SPIRou is a near IR spectropolarimetre/velocimetre proposed for CFHT

The first light at CFHT is planned for 2017 (France-Canada-Brazil collaboration). Canada is planning also to build a copy of SPIRou and to install it in the southern hemisphere (probably with ESO).

Simultaneous spectral range covers 0.98 to 2.5 μm (YJHK bands)
Resolving power R>70K, RV precision < 1 m/s (Delfosse et al. 2013)



I would like to thank to my students that carried out abundance analysis of several CP stars from the project VeSElkA:

Boukari Yaméogo

Patrick Poitras

Christian Thibeault

Isabelle Galant

Thank you very much
for your attention!