

Search for pulsations in HgMn stars with CoRoT

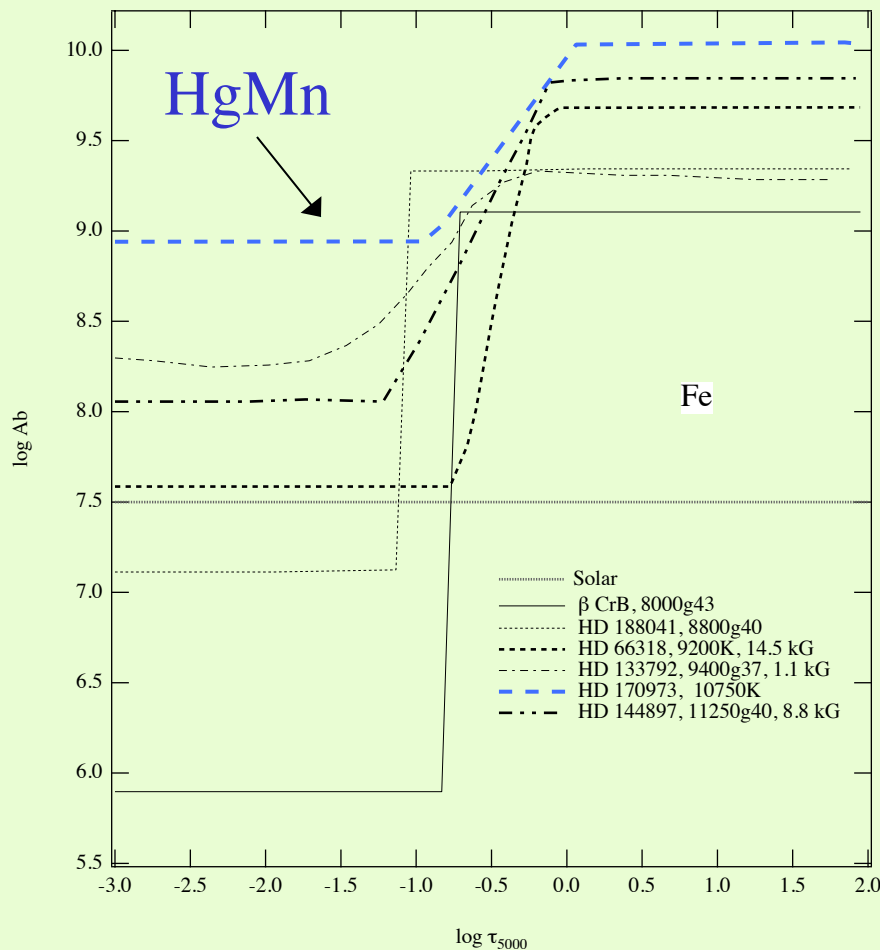
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HgMn stars main properties

- **Main sequence stars (late B-type) chemically peculiar stars (CP)**
- **Supposed to be rather quiet stars:**
 - Very slow rotation
 - Sharp lines
 - No superficial convection zone
 - No detection of magnetic field (**very weak field?**)
 - Not classified among variable stars
 - More often binaries than “normal” stars.
- **Abundance stratifications due to **atomic diffusion****

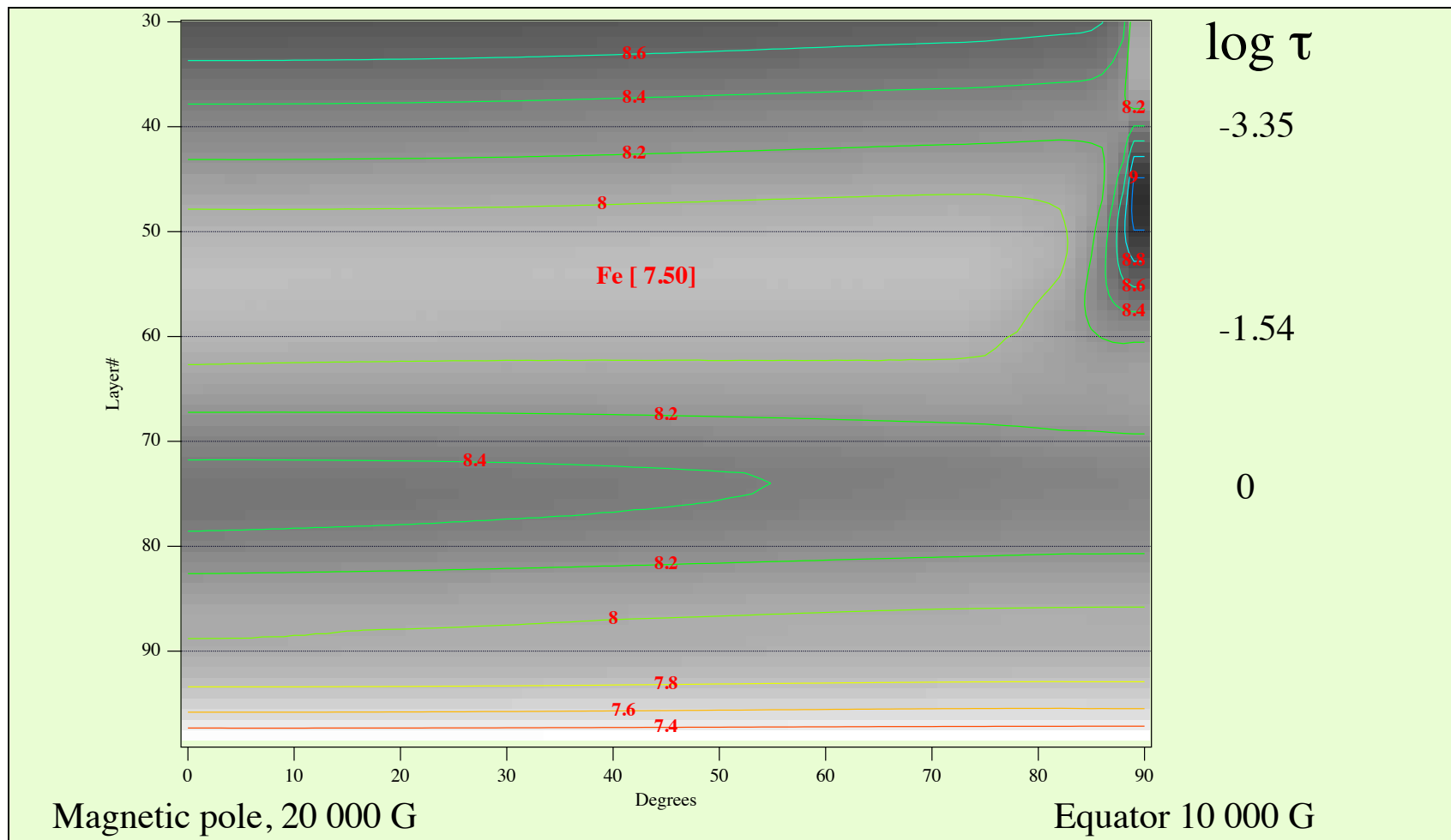
Stratifications of elements in atmospheres



(Levels of overabundances are possibly overestimated. Stift et al 2010)

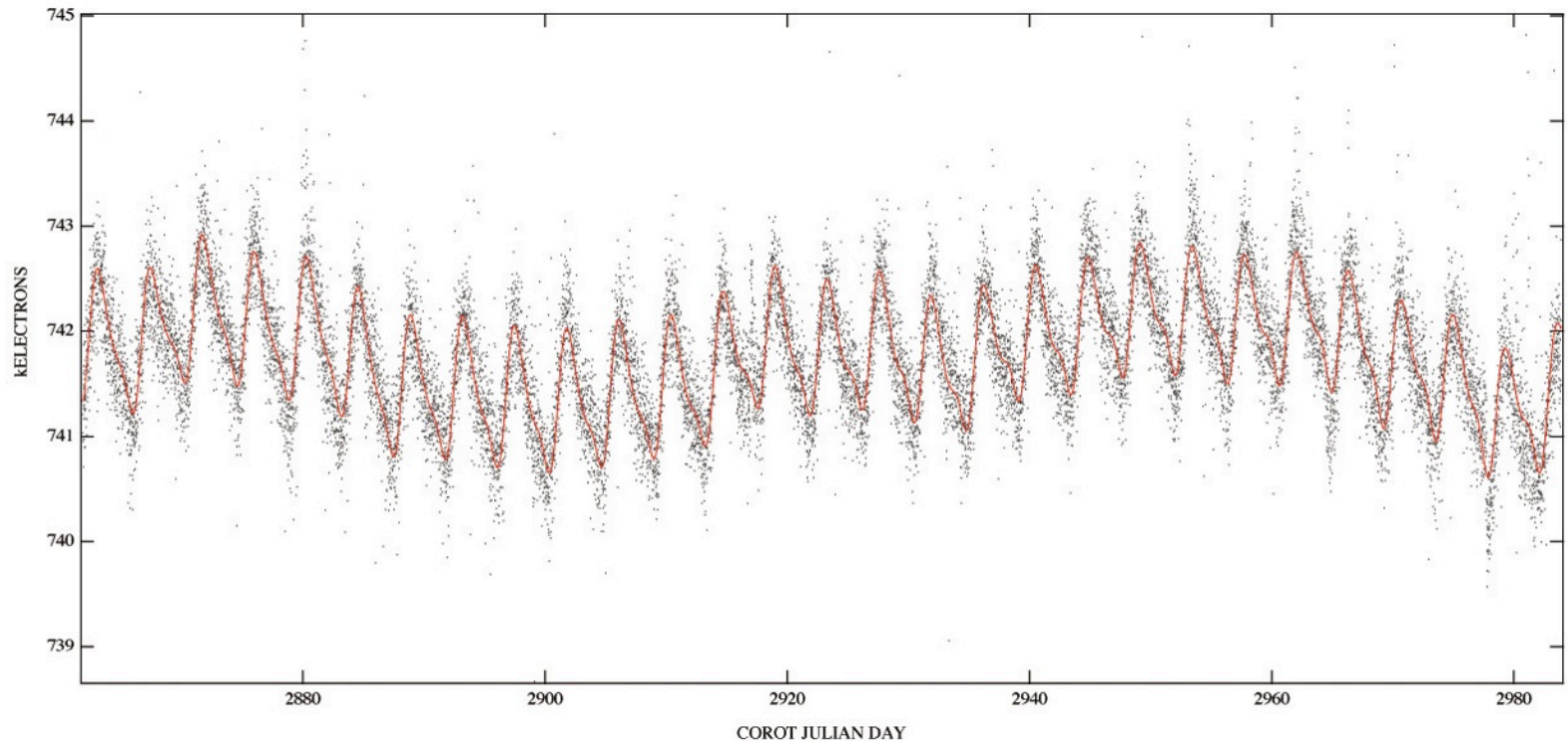
Compilation of Fe stratifications determined from the spectra of six CP stars (compilation by Ryabchikova 2008)

Bi-dimensional stratification of Fe (calculated, equilibrium) in magnetic Ap stars. Dipolar field. (Alecian & Stift 2010)



A CoRoT signal !

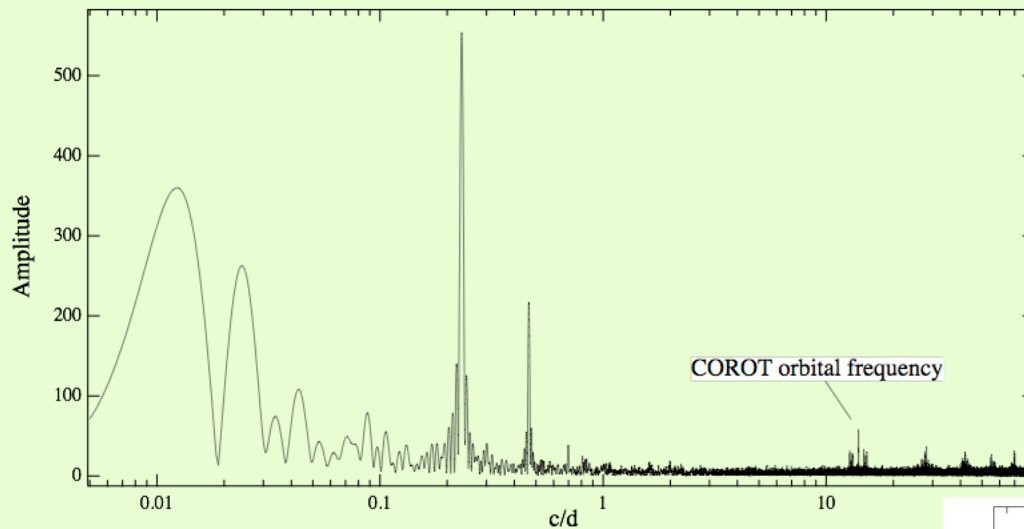
(Alecian, Gebran, Auvergne, Richard, Samadi, Weiss, Baglin, A&A 2009)



Lightcurve from the “exofield”

Amplitude ≈ 1.6 mmag

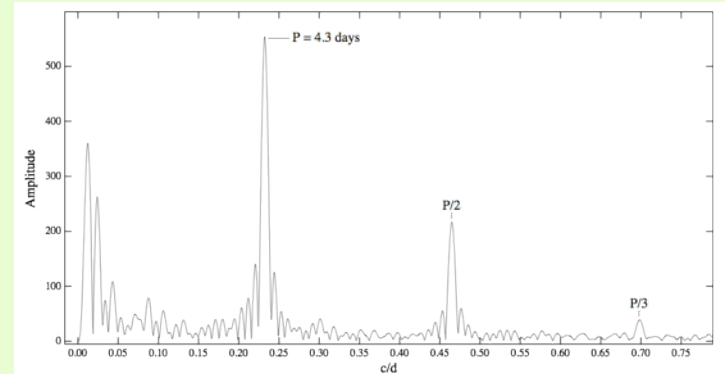
Frequencies from the CoRoT lightcurve



USNO-A2: 0825-03036752
 $T_{\text{eff}} \approx 13500\text{K}$, $\log g \approx 4$
 (HgMn)

Rotational modulation
 cannot be excluded !

N	c/d	μHz	Ampl.	Phase	Period (days)
1	0.0114	0.132	413.9	0.7943	88.007
2	0.0146	0.169	106.3	0.8962	68.412
3	0.0251	0.290	174.6	0.0849	39.880
4	0.0436	0.505	74.1	0.7371	22.913
5	0.0877	1.015	73.5	0.4033	11.401
6 (P)	0.2324	2.689	552.9	0.9211	4.304
7 (P/2)	0.4648	5.379	212.7	0.6286	2.152
8 (P/3)	0.6982	8.081	37.1	0.5796	1.432



New results for HD 45975 (HgMn)

See the poster:

A search for pulsations in HgMn stars with CoRoT observations of HD 45975
(Morel et al. 2013)

$$f = 0.7572 \text{ c/d} \\ (1.321 \text{ d})$$

$$T_{\text{eff}} \approx 12500\text{K}$$

A search for pulsations in HgMn stars with CoRoT observations of HD 45975

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Background
The existence of pulsations in HgMn stars is still debated. Excitation through the α mechanism is predicted by models to lead to easily detectable photometric variations (Lecache & Richard 2005; Aleccian et al. 2009). However, variations of much smaller amplitude have only been recently detected using CoRoT (Bastien et al. 2009 and Kijak & Hellwig et al. 2011). Moreover, it is still unclear whether they can be attributed to pulsations or instead to rotational modulation of spots at the surface.

Objectives
To provide the first unambiguous observational detection of pulsations in HgMn stars, we monitored the bright star HD 45975 for nearly two months with CoRoT in October-November 2011. A multi-line ground-based spectroscopic campaign overlapping the CoRoT observations was also carried out to identify the origin of the variations (pulsations vs rotational modulation).

The target
HD 45975 (BV V; $F = 7.46$ mag, $v_{\text{rad}} \sim 62 \text{ km s}^{-1}$) was identified as a new HgMn star by Niemczura et al. (2009). Our new abundance analysis confirms this result. It is overabundant with respect to solar by >2 dex, Hg by ~ 5.5 dex, Ga and Y by ~ 3.0 - 3.5 dex. The target is situated in the instability strip for SPB-like oscillations (Fig.1).

A HgMn star in a binary system
Our ground-based observations reveal that this star is part of a long-period binary system (Fig.2).

Processing of CoRoT data: "imagingette"
HD 45975 was observed during the run SR044. Shortly after the beginning of the acquisition, it appeared that the data may be affected by a faint contaminating star (see Fig.3, at the right of the main target). To quantify this contamination, we considered a series of 210 one-second "imagingette" (0.8×0.8 pixels) corresponding to 13 days of observation, with a 512 binning. We measured the electronic counts in these imagingettes, using two masks, one around the main target (mask 1) and the other one around the contaminating source (mask 2). The light curves obtained through these masks are shown in Fig.4. Note that these light curves are obtained from raw data (before the corrections applied for ND data). The photometric variation is clearly absent from the light curve of the contaminating source.

Fig.1 - Position of HD 45975 for instability strips for SPB stars (Maglio et al. 2007).

Fig.2 - Variations of the radial velocities as a function of observation date. The dates of the CoRoT observations are indicated.

Fig.3 - CoRoT "imagingette" of HD 45975. The darkest area around the target is the mask used for the light curve derived in ND data shown in Fig.4.

Fig.4 - Upper grey line: light curve using mask 1 (around HD 45975, points to the left). Bottom green line: light curve using mask 2 (around the contaminating star, points to the right). Bottom inset: CoRoT Cadence days.

The CoRoT light curve
The CoRoT data exhibit nearly sinusoidal variations with a peak-to-peak amplitude of ~ 2800 ppm. After detrending, there is only evidence for one frequency, $f = 0.7572 \text{ c/d}$ (of period of 1.321 d), and its harmonics in the light curve (Fig.5). There is no evidence for additional signals down to an amplitude of ~ 50 ppm. A model fit reproduces satisfactorily the photometric variations (Fig.6).

Fig.5 - Raw Fourier spectrum (upper panel) and after prewhitening with f_1 (middle panel) and with f_1 and $2f_1$ (lower panel). No signals of physical origin remains after this operation. No signs of physical origin remains after this operation. The 1- σ dispersion of the residuals is ~ 50 ppm.

Fig.6 - CoRoT light curve with the theoretical model fit (red line). The upper panel shows the full light curve, while the bottom one only shows two cycles and the residuals (observations minus model). The 1- σ dispersion of the residuals is ~ 50 ppm.

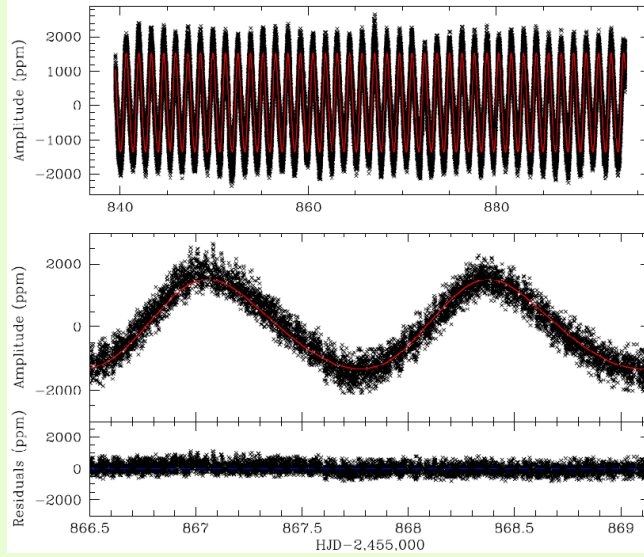
Line-profile variations
Large line-profile variations are often observed in HgMn stars and attributed to the rotational modulation of spots at the surface (e.g. Brigueot et al. 2010). Detecting f_1 in the lines of some elements but not in others would clearly favour an interpretation in terms of spots. For the photometric variations the period found is compatible with the rotational one according to our vrad and radius estimates. The HERMES spectra reveal at best marginal evidence for variability (Fig.7). No periodic signals are found, either at the line moment or at the pixel-located variations. However, data of higher quality remain to be analyzed (UYES, HARPS).

Fig.7 - Superposition of the individual HERMES spectra for a set of subselected lines (mean profile overlaid in red). The bottom panels show the temporal variance spectrum (TVS; Fallouts et al. 1998), which provides a quantitative assessment of the level of variability taking into account the data quality. The blue line shows the threshold for a variability significant at the 99% confidence level. Note how the level of variability is comparable across the line profiles and in neighbouring continuum regions.

Conclusions
The CoRoT data show evidence for mono-periodic variations with $f_1 = 0.7572 \text{ c/d}$ and an amplitude (peak-to-peak) of ~ 2800 ppm comparable to that previously reported in other HgMn stars from space observations. The line profiles show little variability, if any. A deeper analysis of the spectra will be used to identify pulsations or rotational modulation as the cause of the variations seen in the CoRoT data. Our observations already place tight upper limits on the amplitude of any variations arising from pulsations. If the changes are eventually attributed to rotational modulation, the existence of pulsations producing photometric variations above the ~ 50 ppm level could be ruled out. This would provide strong constraints on the excitation/damping of pulsation modes in HgMn stars.

References
Aleccian, Gebreau, Auvergne, et al. 2009 A&A, 506, 69
Bastien, Pigulski, De Cat, et al. 2011 MNRAS, 413, 2403
Brigueot, Kerkhofs, Gontcharov, et al. 2010 A&A, 511, 471
Fallouts, Gies, & Bolino 1998, A&S, 103, 475
Maglio, Manduca, & Dugger 2007 MNRAS, 375, 1121
Niemczura, Morel, & Aerts 2009 A&A, 506, 213
Turicotte & Richard 2003, ApJSS, 174, 225

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Not all the HgMn stars!

The case of HD 175640

bright B9-V type star with 6.21 apparent magnitude. It was well identified as belonging to the HgMn group and studied in detail through high resolution UVES-VLT spectra by Castelli & Hubrig (2004).

It was observed by CoRoT astero channel during SRc02 (2008). **No significant signal** above the noise level (*Ghazaryan et al 2013, submitted*)

Pulsations ?

Model of Turcotte & Richard 2003:

Oscillations could be driven by κ -mechanism, as for SPB stars.

But, it is not clear whether HgMn stars are really inside the SPB instability strip, because of abundance stratifications deep inside the star (which change with the age due to atomic diffusion). This numerical model has to be improved.

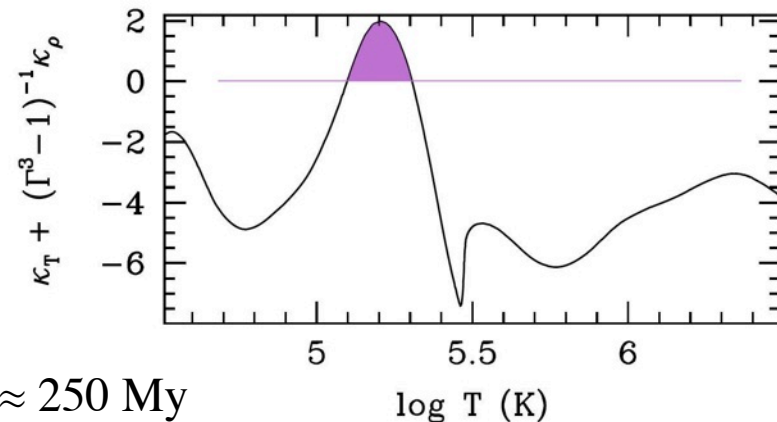
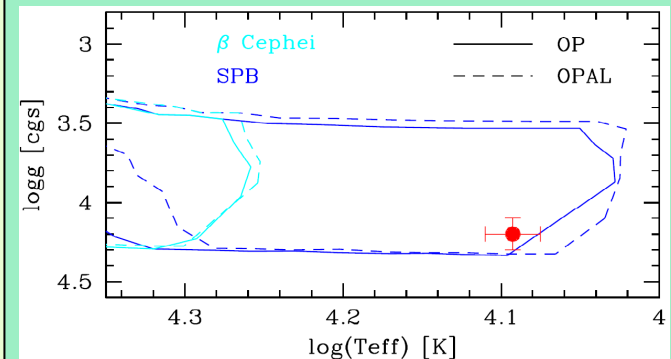


Fig. 14. Logarithmic opacity derivatives vs temperature for the $4.0 M_{\odot}$ model at the same age as in Fig. 13.

$$\kappa_T = (\partial \ln \kappa / \partial \ln T)_{\rho} \text{ and } \kappa_{\rho} = (\partial \ln \kappa / \partial \ln \rho)_T$$

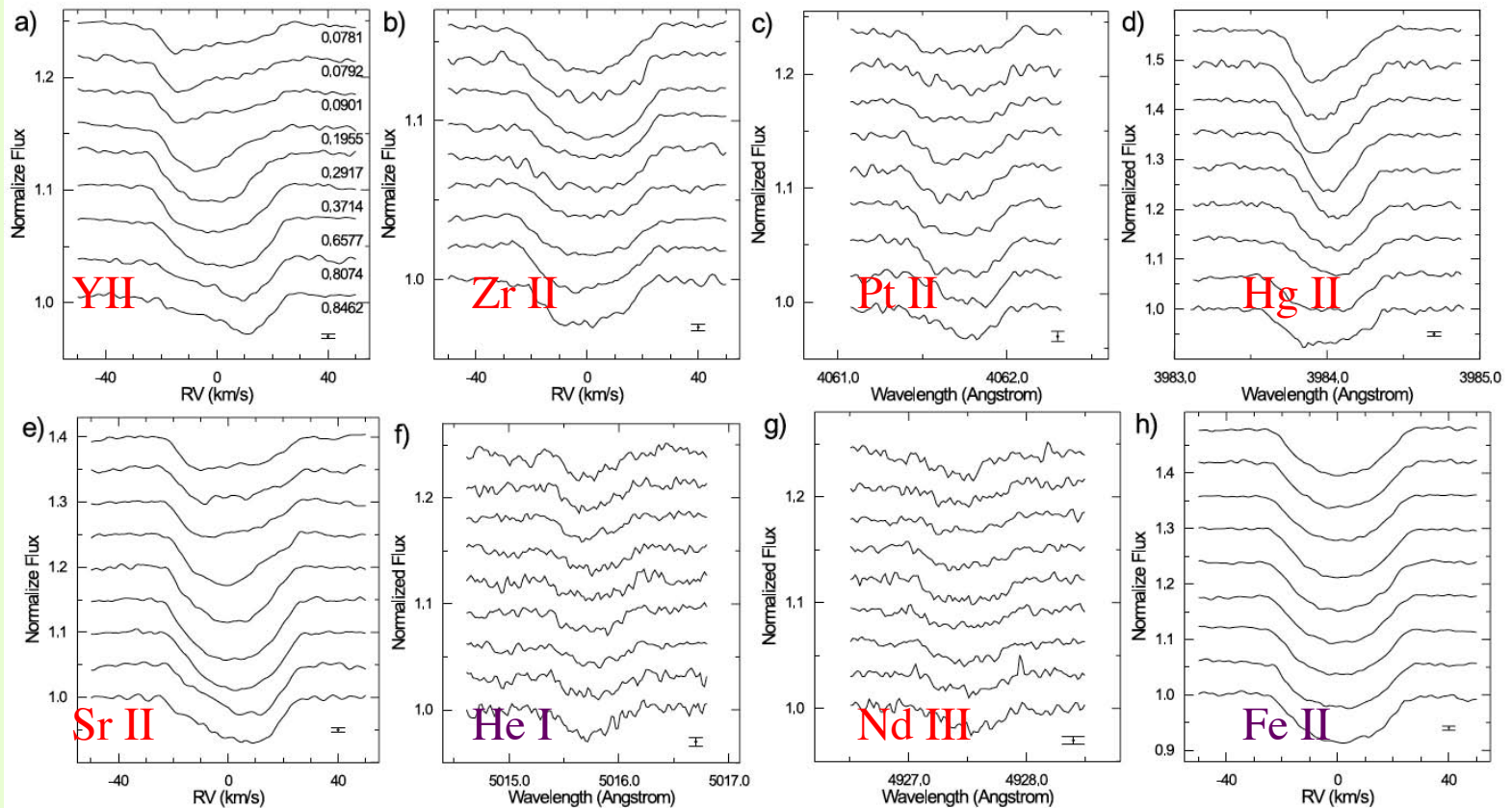
Other theoretical models are carried out for homogeneous Z ! (*Miglio et al. 2007*)

Fig. from Morel et al. 2013 (poster)



Spots ?

Hubrig et al. 2006 (eclipsing binary AR Aur, primary:HgMn)



Another case of a HgMn star with spots

HD 11753 : *Briquet et al. 2010*

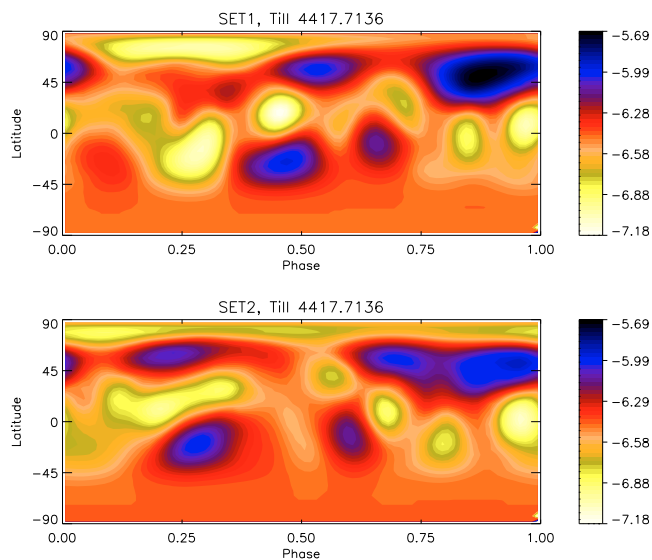


Fig. 4. Ti abundance map of HD 11753 obtained from Ti II line 4417.7136 Å for set1 and set2. The colour indicates the abundance with respect to the total number density of atoms and ions.

$$\text{Ti} [\odot N(\text{Ti})/N_{\text{tot}} = -7.02]$$

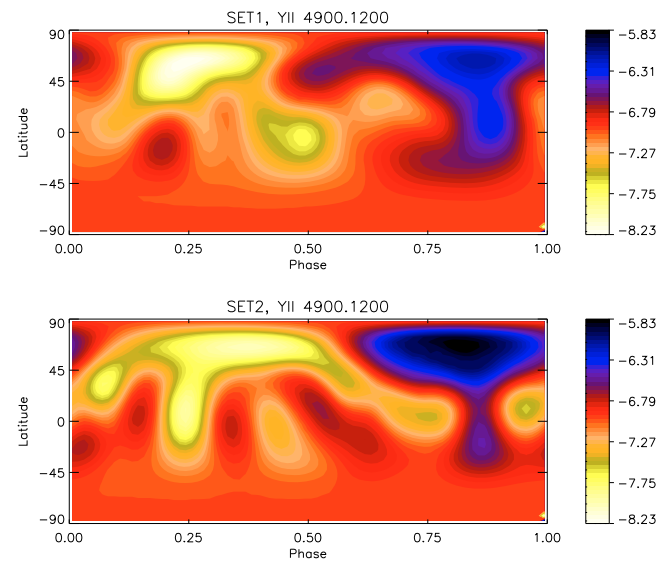
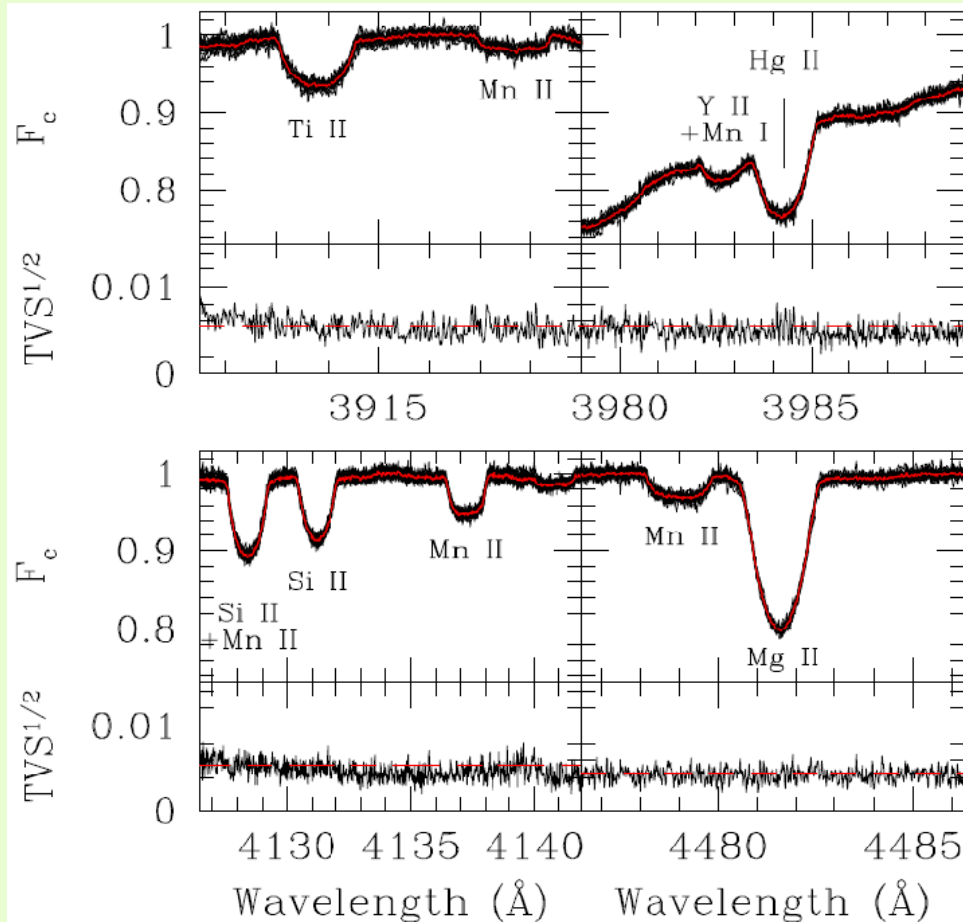


Fig. 5. As in Fig. 4, but now using the Y II line 4900.1200 Å.

$$\text{Y} [\odot N(\text{Y})/N_{\text{tot}} = -9.8]$$

HD 45975 (*Morel et al. 2013, the poster*)



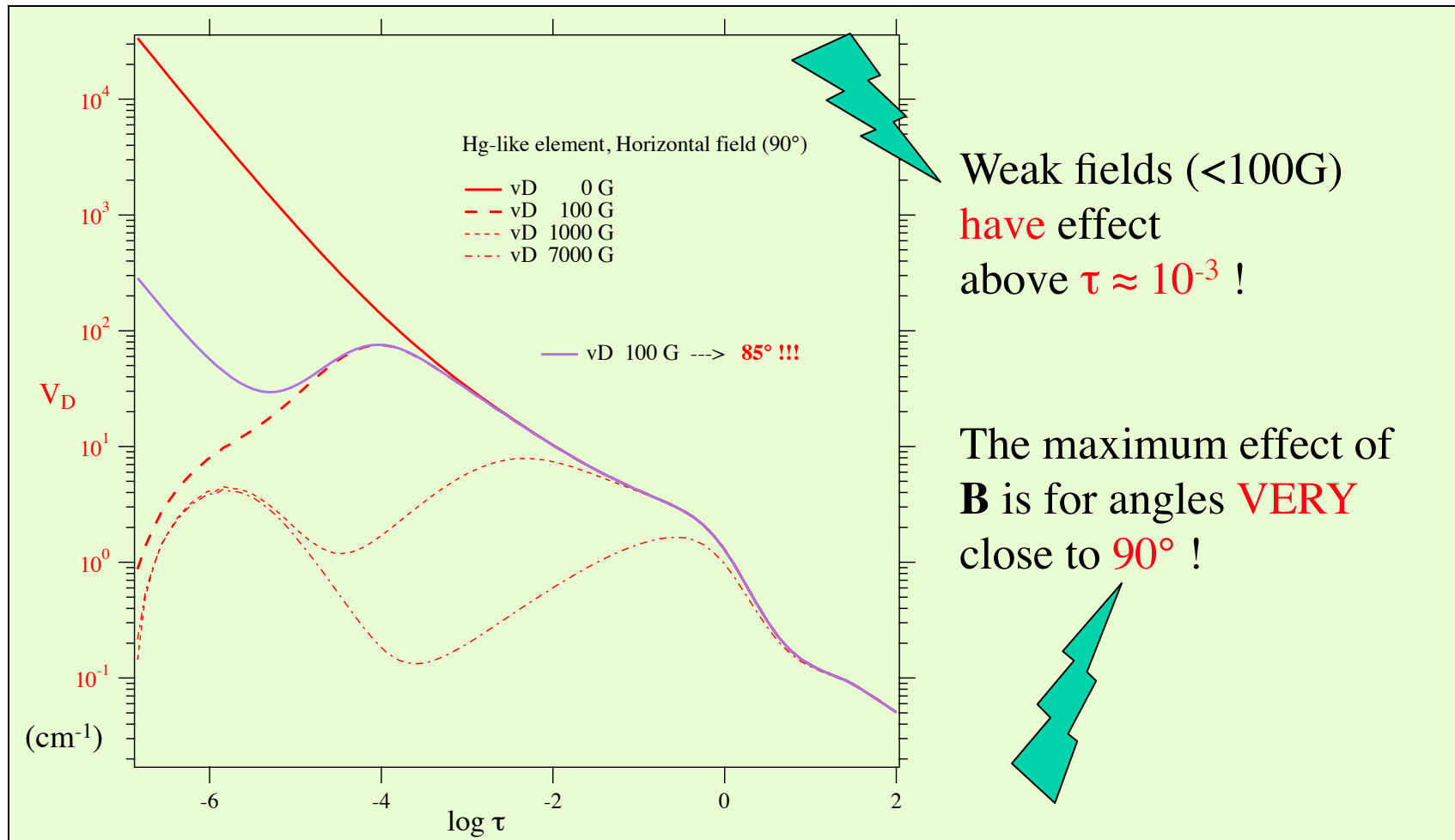
UVES spectra
No variation
inside these lines

Spots seem to exist, but...

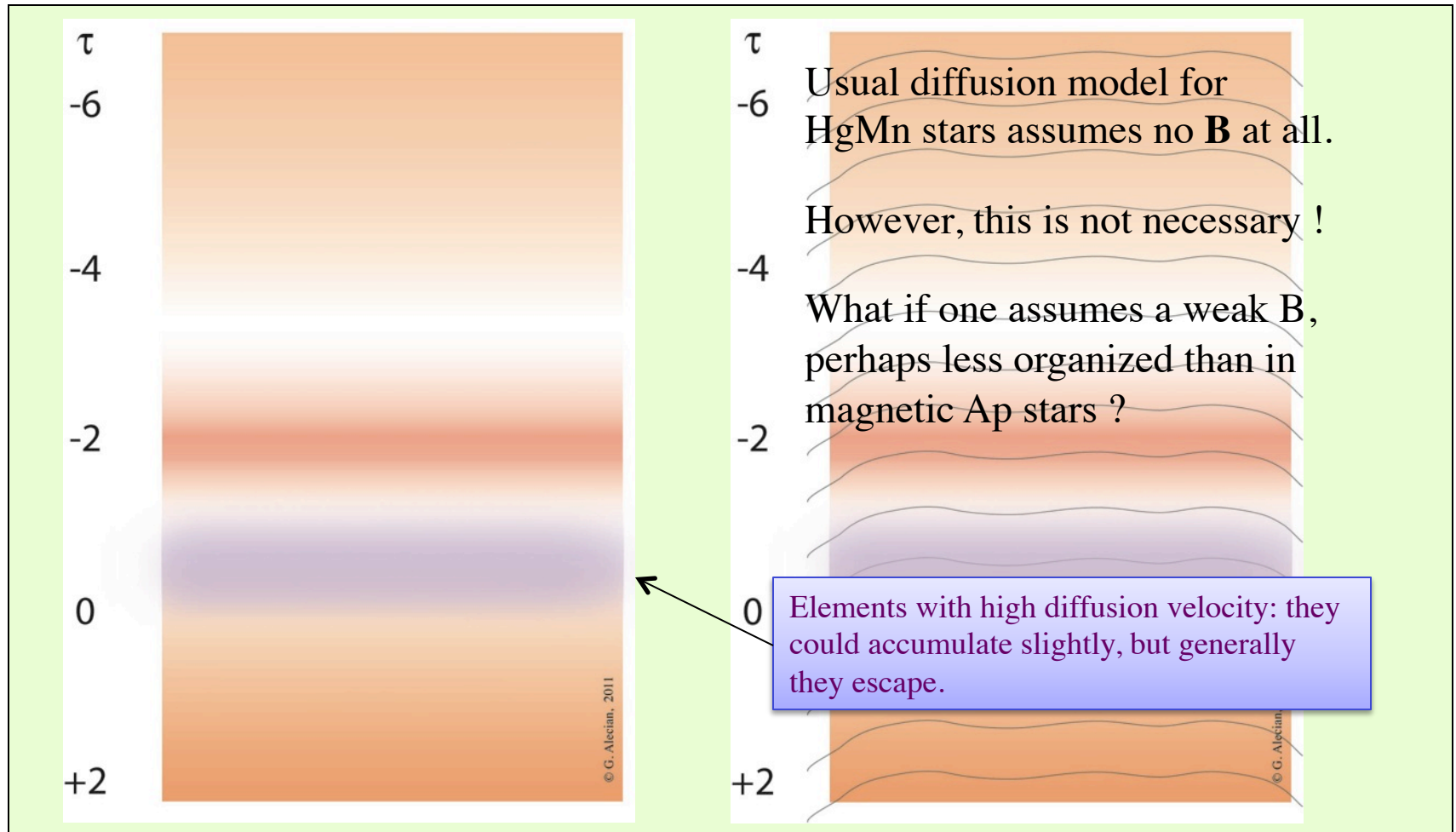
Spots exist in **upper layers** of some stars HgMn, but :

- No spots detected on HD 45975 (Morel et al. 2013), so spots are not a general property of HgMn stars.
- Such spots of Y or Hg like-elements can they explain the photometric variations observed in the star discussed by Alecian et al. 2009, and in HD 45975 (even if there were spots)? :
 - different phases from line to line,
 - amplitude problem.

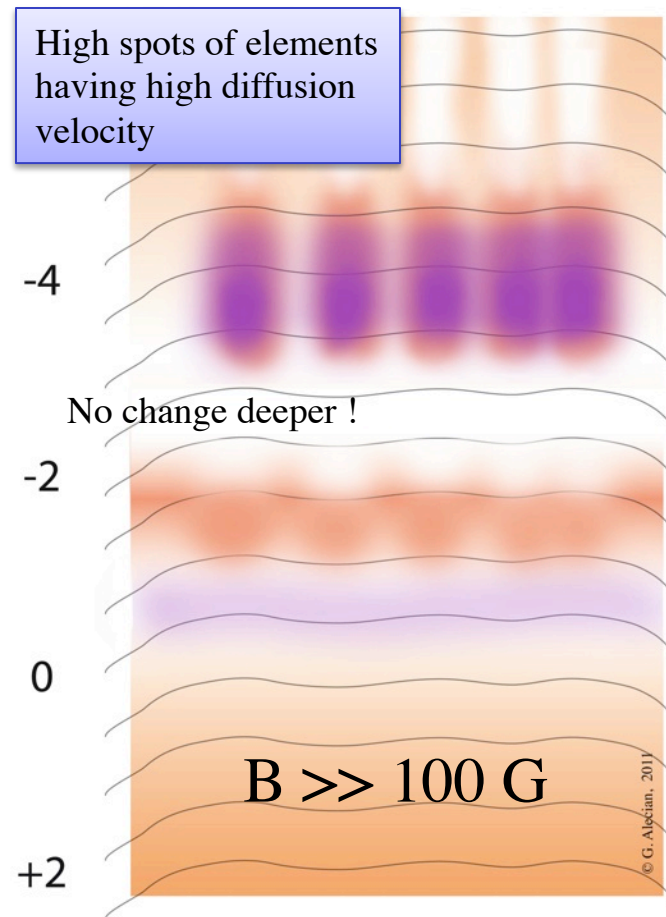
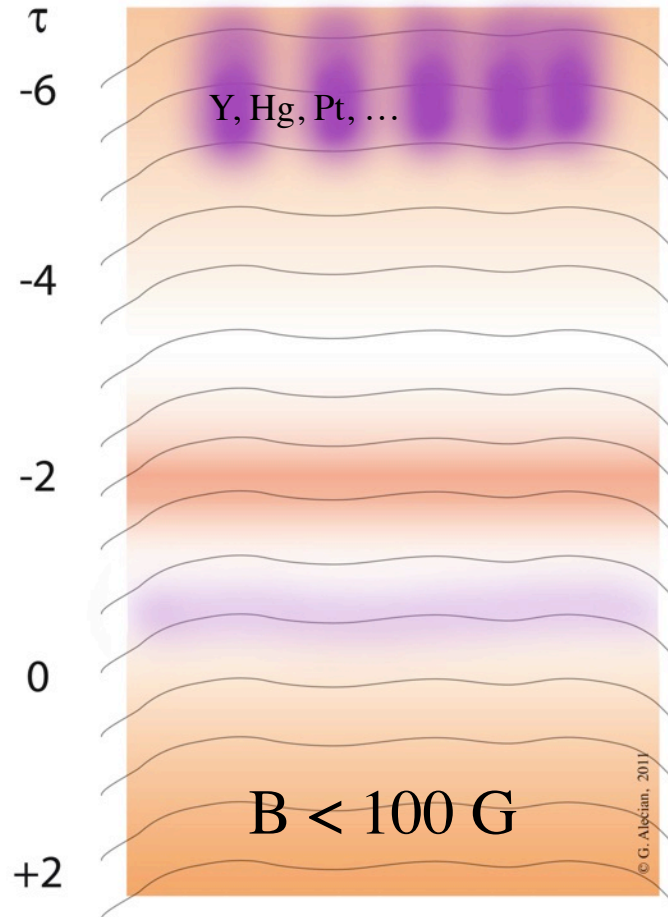
Diffusion velocity, with and without **B**



HgMn star with weak, unorganized \mathbf{B} ?



With magnetic fields



Conclusions

- Photometric variations, $P \approx 1$ to 5 days in some HgMn stars.
- Pulsations (SPB type) or spots (rotational modulation)?
- Smooth stratifications of abundant metals (iron peak) can coexist with high and spotty clouds of heavy elements. But, are such spots able to produce the observed photometric variations ?
 - ✓ my feeling: rather no → pulsations
- Atomic diffusion in weak B, with clouds formation :
 - ✓ explains small variations in the centre of some spectral lines,
 - ✓ high altitude clouds could be unveiled by propagating waves (*Mkrtychian et al. 2008*).

Diffusion timescale in atmospheres

