The Kochukhov-Piskunov recipes for Zeeman Doppler mapping : a critique

Martin J. Stift

formerly Universitätssternwarte Wien

Public, revised version of the invited talk given at the 14th Potsdam Thinkshop, June 2017

What we have been told

(abstract booklet of the 14th Potsdam Thinkshop)

Spectropolarimetric observations are *“revealing remarkable examples of previously unseen complexities of the surface magnetic field distributions ...”*

Abundance mapping demonstrates *“the presence of diverse, large-scale chemical inhomogeneities, largely incompatible with predictions of the currently available theoretical diffusion models.”*

In Potsdam I asked

Are the *"remarkable examples of previously unseen complexities of the surface magnetic field distributions"* compatible with basic physics ?

Have the *"large-scale chemical inhomogeneities, largely incompatible with predictions of the currently available theoretical diffusion models"* been established with algorithms that take into account the physical reality ?

Diffusion theory does not have to explain abundance maps that are manifestly unphysical or based on spurious magnetic maps !

Closed issue : a regularisation based on a totally unphysical assumption

Claim (Kochukhov et al., A&A 2006) **:** *"we have developed and applied the first assumption-free method of reconstruction of the chemical stratification in stellar atmospheres".*

Fact : Kochukhov et al. assume abundances which asymptotically become (or stay) solar !!

Is there any known physical mechanism that would lead to stratified abundances in the atmospheres but keep them solar both in the outermost layers and deep down ?

No !!! Such a regularisation is downright **unphysical**; it can neither be applied to non-magnetic nor to magnetic stars.

Let me quote Rumsfeld (even though I am not his greatest fan) this quote – not his own creation – is useful

As we know, there are **known knowns**; there are things we know we know. We also know there are **known unknowns**; that is to say we know there are some things we do not know. But there are also **unknown unknowns** – the ones we don't know we don't know.

Known unknowns : diffusion and vertical abundance stratifications

Michaud (1970) proposed that selective radiative levitation of certain chemical elements is responsible for over-abundances, gravitational settling of other elements for under-abundances.

Radiative accelerations depend on the stellar temperature, the distribution of the spectral lines over frequency, line strengths and line widths.

Vauclair et al. (1979) investigated the role of magnetic fields which can modify diffusion. **Horizontal fields greatly reduce vertical diffusion velocities of charged ions.**

A simple approach : equilibrium solutions

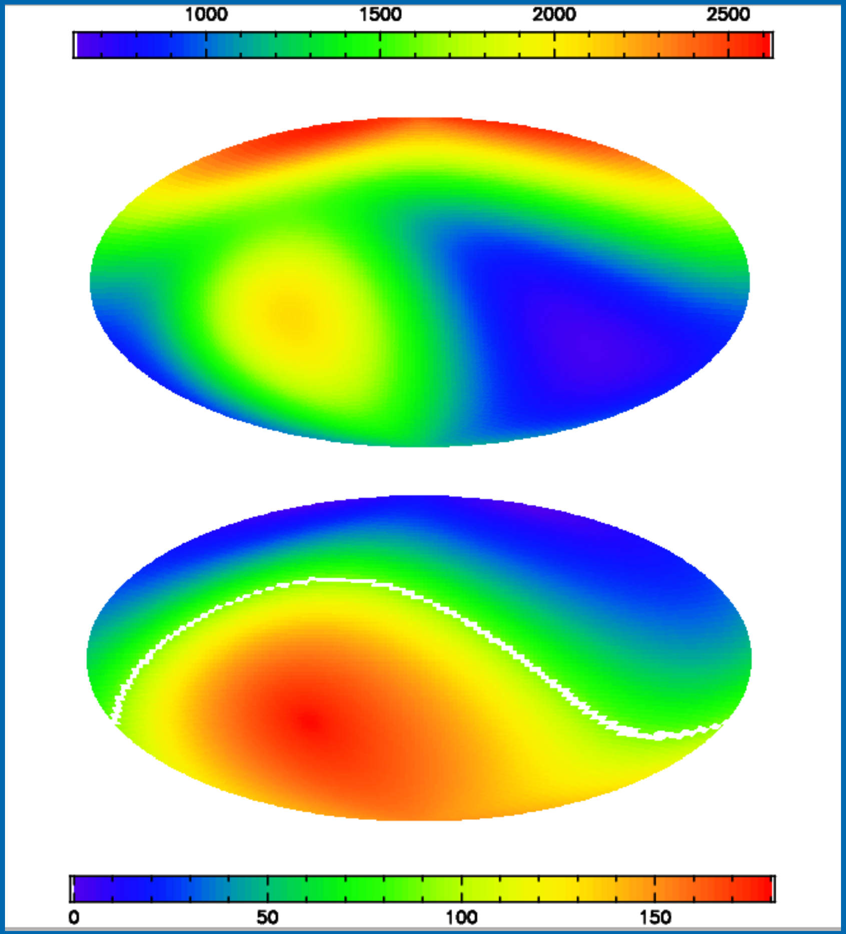
It is supposed that the time-dependent process builds up a stable stratification with

$$\partial z \, [\, N \, V_D \,] = 0$$

This defines a class of stationary solutions (constant element flux throughout the atmosphere). A particular sub-class of solutions corresponds to the case **V_D = 0 everywhere** in the atmosphere, which we call **equilibrium solutions.**

Conservation of mass is not taken into account. The atmosphere is adjusted to the chemical stratification.

Scaled field strength vs. angle for HD154708

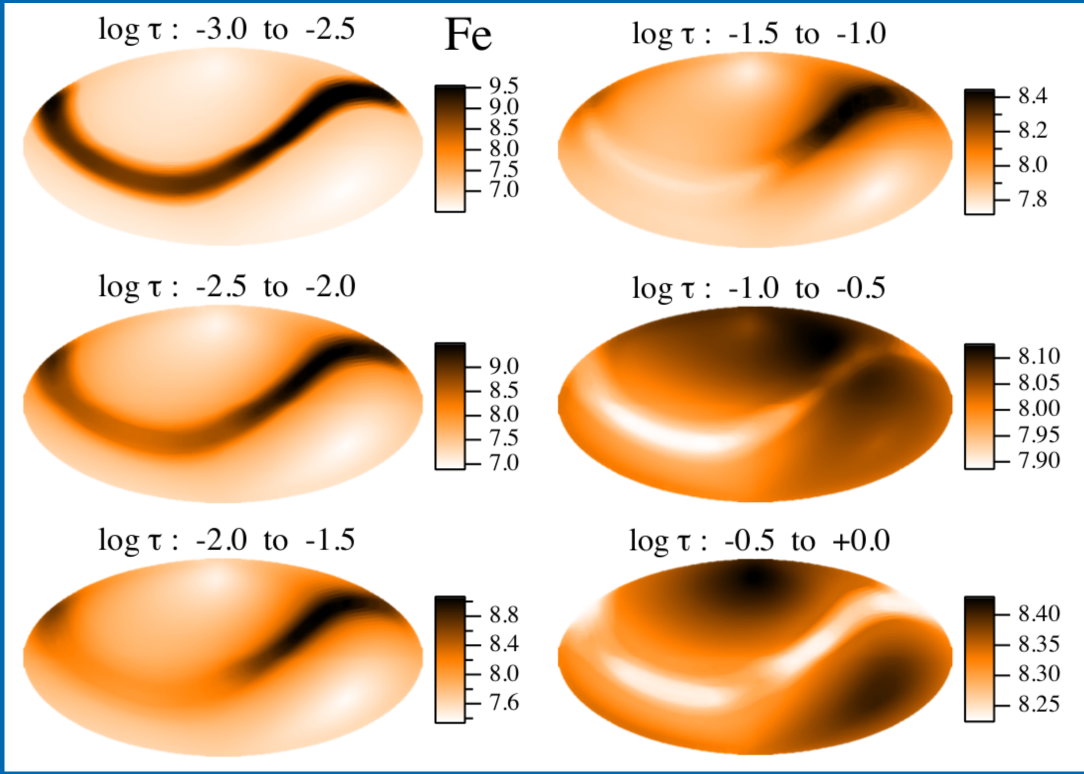


Top : Field strength
Bottom : Field direction

The tilted excentric dipole (Stift, MNRAS 1975) is offset from the centre of the star by 0.15 units of radius. The obliquity is 37°. Axisymmetric models fail completely.

This model fits the H_{eff} and H_s variations at the same time as the Si I 1082.7 nm and 1084.4 nm lines.

Equilibrium stratifications in a star with the field geometry of HD154708 (Alecian & Stift, MNRAS 2017)



Stift's excentric tilted dipole model leads to warped pseudo-rings. The contrast changes with optical depth and with longitude. Field range : 7-17 kG

In other words :

there is no such thing as a globally constant stratification profile in magnetic stars.

This plot dispels the myth of *"razor-sharp overabundance rings predicted by the current diffusion calculations"*.

Time-dependent diffusion : an implicit, conservative scheme

The transport of a particular species with number density n is determined by the equation of continuity

$$\frac{\partial n}{\partial t} + \nabla \cdot (n\,\boldsymbol{u}) = 0\,, \qquad (2)$$

Defining the number density at position z_i at the old time level $t^{(k)}$ by $n_i^{(k)}$ and at the new time level $t^{(k+1)}$ by $n_i^{(k+1)}$ we end up with the discrete version of the continuity equation (3)

$$\Delta z_i \left(n_i^{(k+1)} - n_i^{(k)} \right) = \delta t \left(\tilde{n}_{i+1}^{(k+1)}\, u_{i+1} - \tilde{n}_i^{(k+1)}\, u_i \right)\,, \qquad (9)$$

including the time step $\delta t = t^{(k+1)} - t^{(k)}$. To complete our discretization scheme we have to specify the particle fluxes at the cell boundaries

$$\tilde{n}_i^{(k+1)} = \begin{cases} n_{i-1}^{(k+1)}, & \text{if} \quad u_i \geq 0 \\ n_i^{(k+1)}, & \text{otherwise} \end{cases}\,. \qquad (10)$$

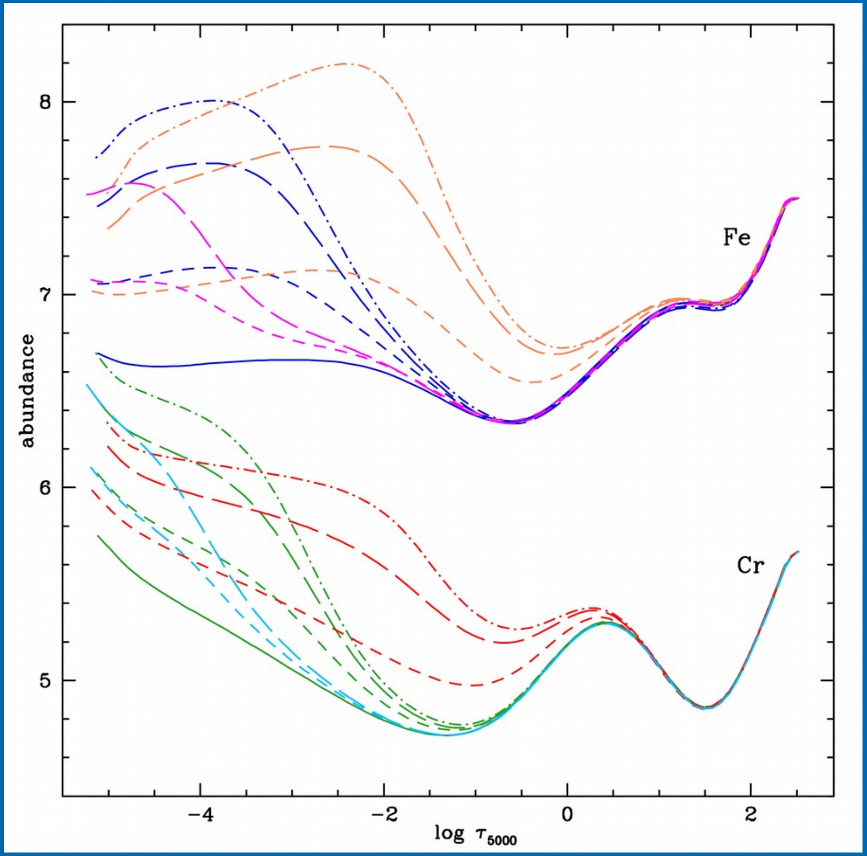
1st order upwind ("donor cell") method

avoids the Courant-Friedrichs-Lewy condition which severely limits the time-step

ensures mass conservation

dissipative

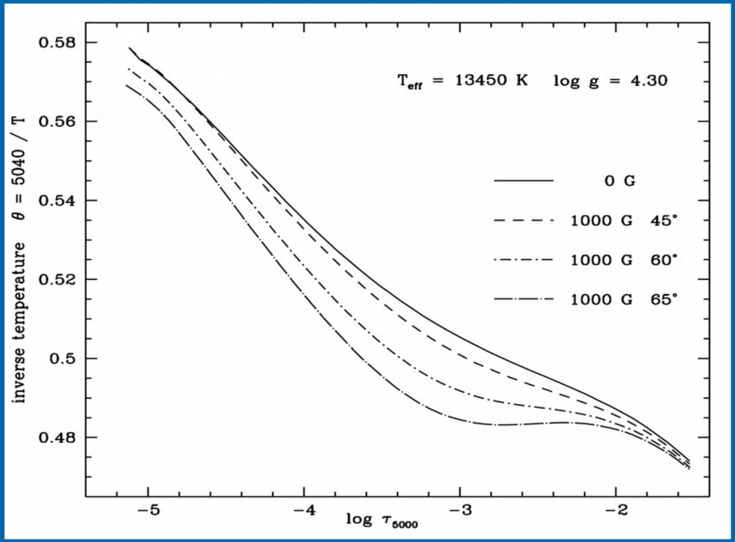
Stratifications : non-magnetic and magnetic

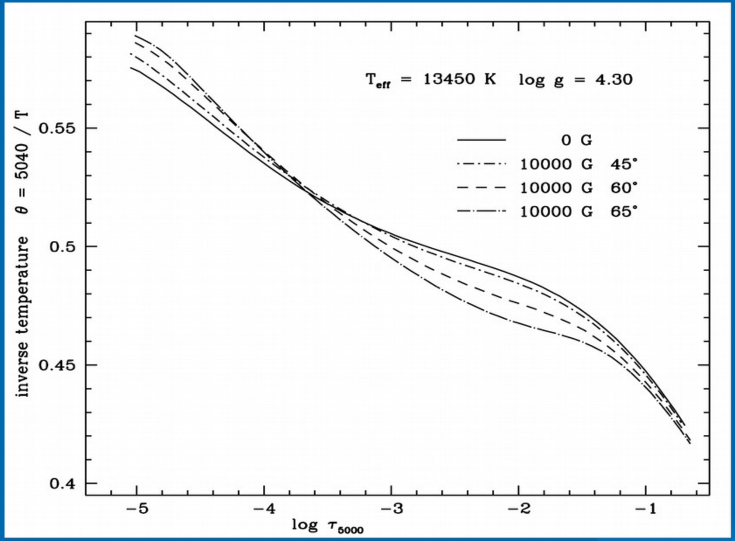


Time-dependent results
for a star with T_{eff} = 13450 K

The effect of the magnetic field strongly increases with the angle relative to the surface normal (45°, 60° ,65°)
Full lines : non-magnetic
From right to left :
10000 G, 1000 G, 200 G

Note : In this scheme, abundances are kept constant at the bottom .





Stratified atmospheres

Temperature structure of a star with T_{eff} = 13450 K as a function of magnetic field strength and direction.

Weak fields affect the highest layers; temperature increases with field angle. **Temperature inversions can develop.**

Strong fields lead to changes over a larger interval in log τ_{5000} . These changes are more in line with the picket fence model.

Open issue : 3D stratifications and a missing paper

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.

I **Rusomarov, N.**, Kochukhov, O., Piskunov, N., Jeffers, S. V., Johns-Krull, C. M., Keller, C. U., Makaganiuk, V., Rodenhuis, M., Snik, F., Stempels, H. C., and Valenti, J. A. *Three-dimensional magnetic and abundance mapping of the cool Ap star HD 24712 I. Spectropolarimetric observations in all four Stokes parameters*, A&A, 558, A8, 2013.

II **Rusomarov, N.**, Kochukhov, O., Ryabchikova, T., and Piskunov, N. *Three-dimensional magnetic and abundance mapping of the cool Ap star HD 24712 II. Two-dimensional magnetic Doppler imaging in all four Stokes parameters*, A&A, 573, A123, 2015.

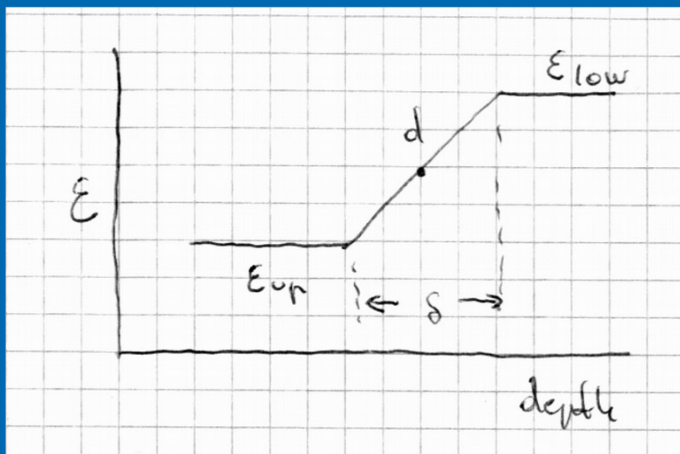
III **Rusomarov, N.**, Kochukhov, O., and Ryabchikova, T. *Three-dimensional magnetic and abundance mapping of the cool Ap star HD 24712 III. Three-dimensional abundance distribution of iron and calcium*, to be submitted to A&A

IV **Rusomarov, N.**, Kochukhov, O., Ryabchikova, T., and Ilyin, I. *Magnetic Doppler imaging of the magnetic chemically peculiar star HD 125248*, A&A, in press, 2016.

A potentially interesting PhD thesis refers to its central paper that has never been published in a refereed journal !!

It is nevertheless possible to reconstruct the method and to assess whether it is compatible with our known knowns.

Closed issue : an unphysical regularisation function



From the Rusomarov thesis:
The stratification profile depends on 4 parameters, i.e. ε(up) high in the atmosphere, ε(low) deep in the atmosphere, position d and width δ of the transition region.

The penalty function minimises the difference between ε(up) and ε(low) for each point on the stellar surface.

$$
\begin{aligned}
\mathcal{R} = {} & \Lambda_{up} \sum \|\nabla \varepsilon_i^{up}\|^2 + \Lambda_{low} \sum \|\nabla \varepsilon_i^{low}\|^2 + \\
& \Lambda_{\delta} \sum \|\nabla \delta_i\|^2 + \Lambda_{up,low} \sum \left(\varepsilon_i^{up} - \varepsilon_i^{low}\right)^2 + \\
& \Lambda_{d} \cdot \sum \|\nabla d_i\|^2
\end{aligned}
$$

Unphysical empirical 3D stratifications and correlations

From the Rusomarov PhD thesis :

„… we developed the first 3D Doppler imaging method that can recover the full 3D abundance distribution of a chemical element in the atmospheres of Ap stars."

„We discovered a strong correlation between the surface abundance derived with 2D magnetic Doppler imaging and vertical stratification of Fe: higher surface abundance corresponds to a transition region that occurs higher in the atmosphere and vice versa."

Since the regularisation function is absolutely unphysical, the alleged correlation is devoid of any meaning.

HD3980 : one of the strangest star in the universe ?

Nesvacil, Lüftinger, Shulyak ... Weiss, Drake … Ryabchikova, Kochukhov, Piskunov … (2012) have mapped Li, O, Mn, Pr, Nd, Si, La, Ce, Eu, Gd, Ca, Cr, Fe, neglecting a magnetic field of 7 kG estimated polar field strength. According to a flawed analysis (for a detailed critique see Stift & Leone 2017), Mn and O were found to be as abundant as helium in several spots - throughout the atmosphere ! - **Si as abundant as hydrogen.**

A mean atmosphere was used over the whole star despite the huge differences in local abundances and corresponding pressure scale heights. The Mn, O and Si spots were thus modelled with O assumed underabundant by -0.5 dex, Si overabundant by +1 dex and Mn by +2 dex !!

Reminder : a known known since 1935

archaic

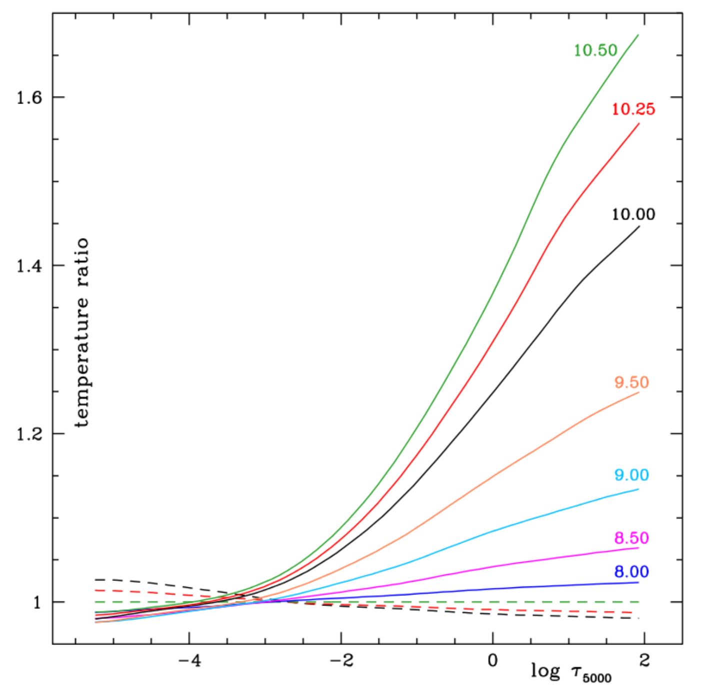


Figure 1. Variations, as a function of iron abundance, in the run of temperature with $\log \tau_{5000}$ in an Atlas12 model atmosphere with $T_{\rm eff} = 12000$ K, $\log g = 4.0$ (all other elements have solar abundances). The curves pertain to iron abundances ranging from $A(\mathrm{Fe}) = 6.50$ to 10.50 and are plotted relative to the temperature profile of the $A(\mathrm{Fe}) = 7.50$ model.

Chandrasekhar (1935) shewed that stellar atmospheric structure changes with metallicity.

Higher abundances lead to a larger temperature gradient and to a different height of the atmosphere.

In general you cannot carry out an inversion using a globally constant mean atmosphere. (Stift, Leone & Cowley 2012).

The HD3980 Mn, Si and O „spots“ : what a leading expert in the field of stellar atmospheres has to say

Dear Martin,

*… **the present case**, where the abundance of Si and other species go to 1 relative to hydrogen, **seems to be absurd.** …. if one constructs a model atmosphere for the ambient atmosphere and for the patch, the latter would have 10 or more time less geometrical height corresponding to the given column mass. **I cannot imagine how such a structure would survive.***

No longer an unknown unknown

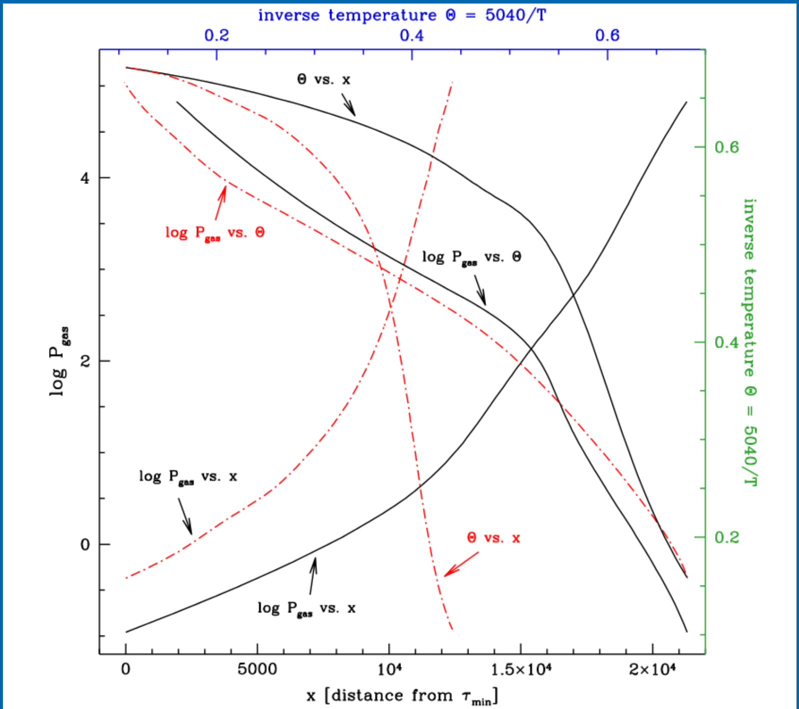


Figure 9. Structure of two stellar atmospheres with identical $T_{\rm eff}$ = 12000 K and log g = 4.0, but different Fe abundances. The black full lines show the results for [Fe] = 7.50, the dash-dotted red lines for [Fe] = 10.50. The abundances of all other 91 elements are assumed to be solar.

The mean molecular weights in two “cylinders” (with solar Fe abundance and 3 dex vertically constant overabundance) on a spotted star differ by a factor of ~2.5.

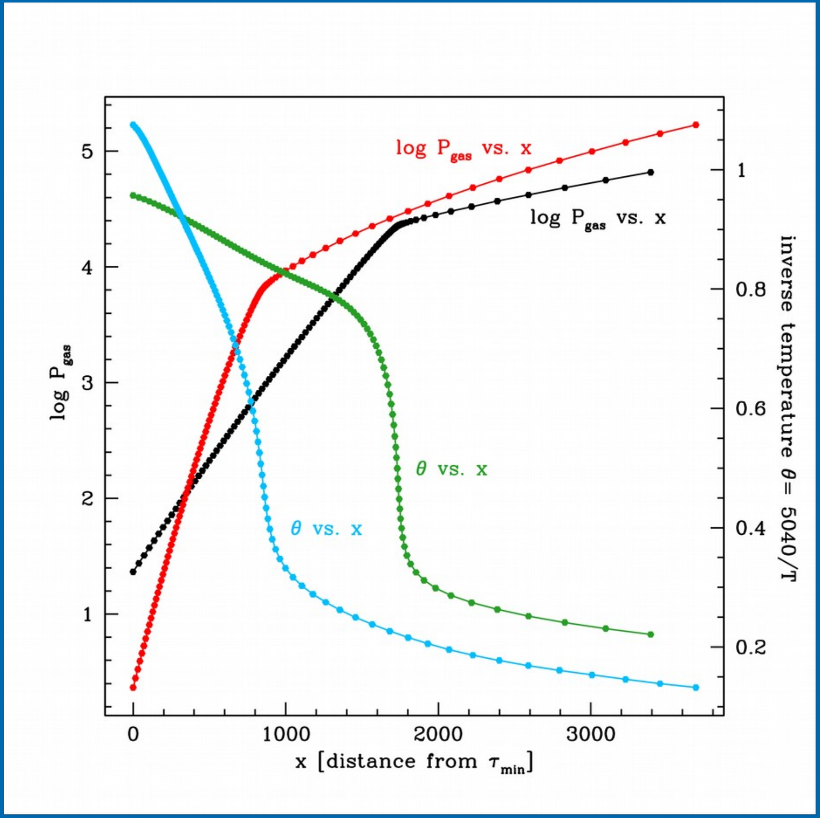
The corresponding pressure scale heights imply horizontal pressure differences between the “cylinders” reaching several orders of magnitude.

Simple (astro)physics : pressure scale heights and the opinion of a leading expert

I wrote : For this purpose I have taken two Atlas12 atmospheres with 12000K, log g = 4.0, one with Fe = 7.50 (where H = 12.00) and the other with Fe = 10.50. The mean molecular weight in the first case is 1.26, in the second case 2.81 (remember that in the spots claimed by Nesvacil et al. 2012 it would be ~15). The plot shows
a) log P_{gas} vs. z b) log P_{gas} vs. theta c) theta vs. z

Dear Martin,
I must say I agree with virtually everything you say. Your plot nicely demonstrates what I tried to express verbally

Open issue : HR3831
less extreme but large pressure differences



The maximum difference in mean molecular weight in two “cylinders” is rather modest in HR3831, but the effects are still quite noticeable.

The corresponding pressure scale heights imply horizontal pressure differences between the “cylinders”, reaching up to 1 dex.

A very open issue : kappa Psc

T_{eff} = 9250K, log g = 3.75, ***i = 35^0****, P = 1.418 d*

The Cr abundance varies between -6.08 and -3.42 according to Ryabchikova et al. (1996)

T_{eff} = 9250K, log g = 4.50, ***i = 70^0 (!?)****, P = 1.409582 d*

The Cr abundance varies between -6.09 and +0.27 according to Piskunov et al. (1998)

The pressure scale height in the Cr "spot" claimed by Piskunov would be at least **30 times smaller** than in the rest of the atmosphere ! How could such a configuration ever be stabilised by the weak magnetic field ?

The spots from a terrestrial perspective

The pressure scale height on earth is ~8 km, the height of Chomolungma, earth’s highest mountain.

Relating the O, Si, and Mn “spots” claimed for HD3980 to an atmosphere with solar abundances, the pressure on top of Mt. Errigal (Donegal, 751m) would equal the pressure on top of Chomolungma.

Taking Piskunov’s Cr “spot” in kappa Psc, the pressure on top of Heaval (Barra, Outer Hebrides, 383m) would be even lie below the pressure on top of Chomolungma.

Just try to imagine these mountains standing near each other, maintaining huge pressure differences for thousands of years !!

Drawing a few conclusions

Theory predicts that chemical stratifications in Cp stars with moderate to strong magnetic fields depend on magnetic field angle and strength:

a) There is no such thing as a global stratification profile.

b) ZDM inversions based on abundances that vary horizontally but are constant with depth are doomed.

Horizontal pressure equilibrium between chemical spots and their surroundings is a 3D problem that cannot be solved at present. Empirical unstratified abundances certainly do not ensure pressure equilibrium.

Not a single regularisation function formulated so far reflects this complex physical reality.

Magnetic pressure and equilibrium in 53 Cam
should we worry ?

At phase 0.60 (Piskunov, Phys.Scr. 2008, Fig. 3), field strengths over the visible hemisphere differ by a factor of ≥ 5. This translates to a factor of ≥ 25 in magnetic pressure.

A patch with field < 7 kG and another patch in its immediate vicinity with ~19 kG are found along the magnetic equator (horizontal field lines) ==>
~ 7-fold difference between (high) magnetic pressures within a distance of only ~30^0.

Where is the stabilising force for horizontal equilibrium ?

One is struck by contradictions between maps of field direction and of field strength

Largely dipolar field directions do not conform with zero-field patches and small, high-contrast magnetic “spots”. They are incompatible with an expansion in spherical harmonics.

Quote (Kochukhov et al., A&A 2004**) :**
“This is a very large flux imbalance (44% of the total possible flux). **It appears that the MDI map of 53 Cam does not satisfy Eq. (15).**”

A similar situation is encountered in many other magnetic maps of Ap stars.

Conjecture : many or most magnetic maps are spurious with div B ≠ 0

Maps (co)published by Kochukhov exhibit field contrasts of up to 80 and higher, in conjunction however with largely dipolar field directions !!

53 Cam (2007) 1.5 – 25.2 kG
α^2CVn (2014) 0.1 – 4.9 kG
HD32633 (2015) 0.0 – 17.0 kG
HD125248 (2016) 0.14 – 11.16 kG

Quote : Kochukhov et al. 2012 (attacking Stift et al. 2012)
“The unspecified “eccentric dipole” with an unusually high contrast (field strength variation by a factor of 3.7 instead of a factor of 2 expected for a centred dipole) seems to have been hand-picked to maximise profile differences.”

Magnetic maps of α^2CVn : changes occur on very short notice

0.3 – 4.3 kG   “Magnetic Stars”, 2004

1.0 – 4.3 kG   IAUS 224, 2004

0.0 – 4.4 kG   Skalnate Pleso, Vol. 35, 2005

0.6 – 3.1 kG Solar Polarization 4, ASP Conf. Series 358, 2006

0.1 – 4.9 kG   IAUS 302, 2013

Same star (53 Cam)
same element, same data set, same code
different spots, different overall contrast

Spots with extreme abundances change position

Kochukhov et al. (2004) and http://www.astro.uu.se/~oleg/ :

$\Delta\varepsilon$(Si) = 3.4 dex $\Delta\varepsilon$(Fe) = 4.0 dex

Two southern spots (-30 and -45°), no south polar spot

Piskunov (Phys.Scr. 2008) :

$\Delta\varepsilon$(Si) = 4.3 dex $\Delta\varepsilon$(Fe) = 5.0 dex

Extreme south polar spot (-1.4) !!

Compare spectral resolution to rotational Doppler shift and admire spatial resolution of abundance structures :

R = 35000 → 140 mÅ

vsini = 12.5 $\mathrm{kms^{-1}}$ → +/- 208 mÅ

Redefining the meaning of the word “confirm“ in the context of the mapping of HD24712

Lüftinger et al. (A&A 2010) $\Delta\varepsilon(Nd) = 1.1$ dex

Rusomarov et al. (A&A 2015) $\Delta\varepsilon(Nd) = 2.6$ dex

Nd III : not only does a 1.1 dex contrast increase to 2.6 dex
the spot even changes position !!

Quote Rusomarov (A&A 2015) **:** *“The new maps confirm the previous findings, and also show some details not present in the previous study.”*

New data → new maps forever ?

Looking at the analyses of α^2CVn in 2002, 2010 and 2014, we note huge changes in abundance contrasts.

Ap stars are known to be very stable, so it is not the star but the data (and the method) that are responsible for widely differing results. Watch the abundance ranges !

The following Fe contrasts have been claimed :

- **2.3 dex** Kochukhov et al. (2002)
- **4.9 dex** Kochukhov & Wade (2010)
- **3.5 dex** Silvester et al. (2014)

Doppler abundance mapping is not at all difficult to program

As long as you adhere to the usual assumptions concerning atmospheric structure and the absence of abundance stratifications, you can transform a spectral line synthesis code like Cossam to a working DM code in just a few days.

These usual (unprovable) assumptions are:

a) The stellar atmosphere is the same everywhere, regardless of the actual elemental abundances,

b) abundances are vertically constant throughout the atmosphere, varying only with position on the stellar disk,

c) the regularisation function ensures a unique solution, but compatibility with the physics of the problem is not required

CossamDoppler is written in a language more popular than Fortran (according to Tiobe.com : 2017-03, 2017-06, 2018-01)

Quote (Kochukhov et al. 2012) **:**
"This experience shows that currently available computing resources and standard scientific programming techniques based on well-established FORTRAN codes enable a fully realistic treatment of the lateral variation of stellar atmosphere, without a recourse to the next generation computers or exotic programming languages advocated by S12."

Ada 26th position
Fortran 27th position

Ada 26th position
Fortran 29th position

Ada 29th position
Fortran 33rd position

Have Doppler mapping codes been tested extensively and realistically ?

1or 3 large, well-distributed “monolithic” abundance spots were employed in tests by Kochukhov & Piskunov (2002).

Quote : *”The abundance distribution adopted in the MDI simulations consisted either of three spots of enhanced Fe abundance located at different latitudes or a larger single spot centred on the negative magnetic pole. We used an iron abundance $\varepsilon(\mathrm{Fe}) \equiv \log(N_{\mathrm{Fe}}/N_{\mathrm{total}}) = -4.0$ outside spots and $\varepsilon(\mathrm{Fe}) = -2.5$ inside iron concentrations.”*

Quote : ***”We believe*** *that the code can be successfully applied to the imaging of global stellar magnetic fields and abundance distributions of an* ***arbitrary complexity”.***

„Arbitrary complexity“ : umbra + penumbra ?

Quote (Kochukhov, A&A 2017) **:** *“DI reconstruction is equally successful for a complex element distribution comprised of multiple circular element overabundance spots …”*

The idealised map adopted by Kochukhov :
“4 circular overabundance spots, with log N(Fe) / N_tot = −2.5 in the spot centres and log N(Fe) / N_tot = −4.0 in the background. The spots were placed at the latitudes of −30, 0, 30, and 60^{o} and spaced equidistantly in longitude. We adopted the inner spot radius of r_in = 15^{o} and the outer radius of r_out = 30^{o}. The element abundance was linearly interpolated between r_in and r_out, resulting in smooth spot edges.”

Note : The effects of abundance variations on the model atmosphere are ignored. **Errors are large (up to 50%) in relation to the initial contrast.**

Is a test with 4 identical umbra-penumbra spots, equidistantly placed in longitude and latitude, relevant for example to HR3831 ?

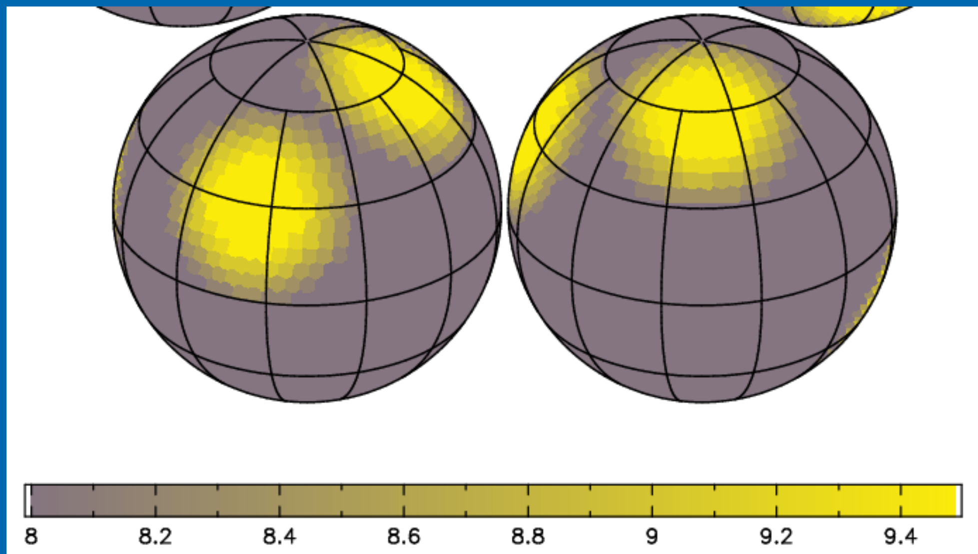
Kochukhov et al. (2004) neglected an estimated 2.5 kG field

Quote:
*”The distribution of this element … reveals a **stunning complexity** of the horizontal abundance pattern and no obvious correlation with the magnetic field geometry.”*

Note :
The magnetic field geometry of HR3831 is essentially undetermined (longitudinal field measurements only available, Kochukhov assuming a centred dipole).

http://www.ada2012.eu/HR3831.html

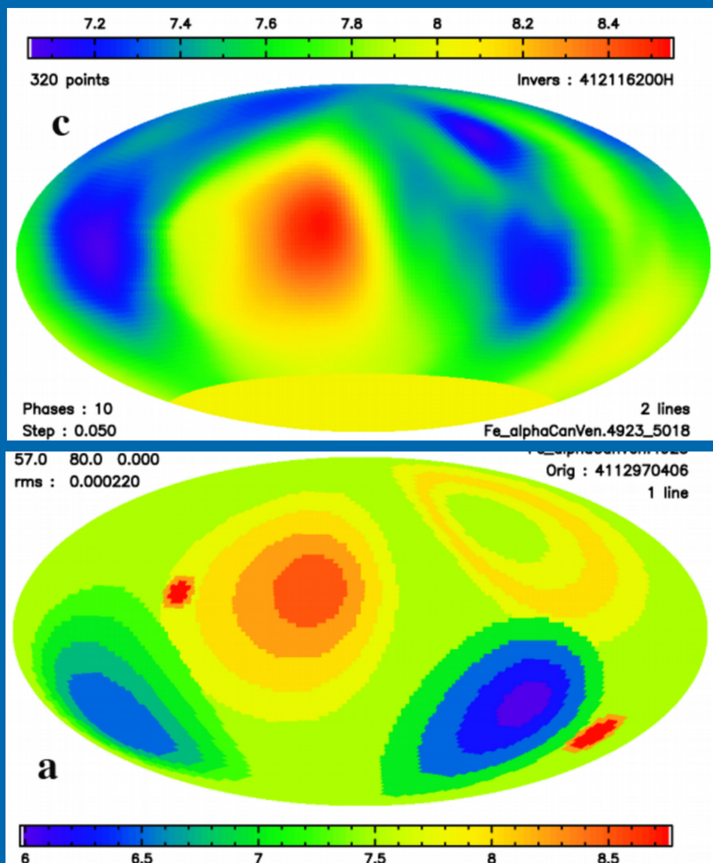
40 latitude belts (Stift) vs. 38 belts (Kochukhov)



see
http://www.ada2012.eu/super.html

Compare the coarse pixels resulting from resolution involving 40 latitude belts to the **smoothed images** in Kochukhov (2017) which do not show the raw results of the ZDM inversion. Such smoothing makes a realistic assessment of the inversion errors impossible and would never be applicable to stars like HR3831.

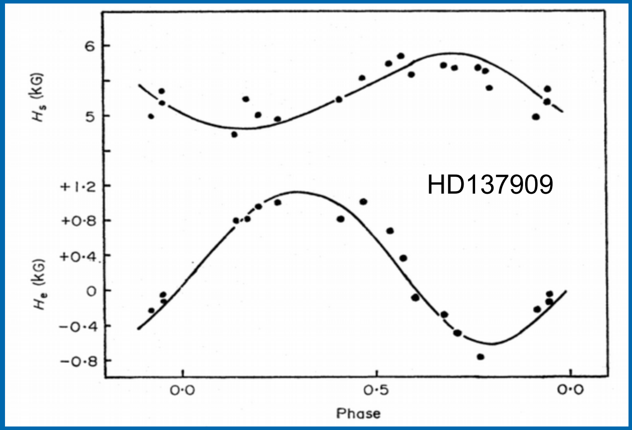
Open issue : complex abundance distributions appallingly poor recovery of abundance structure

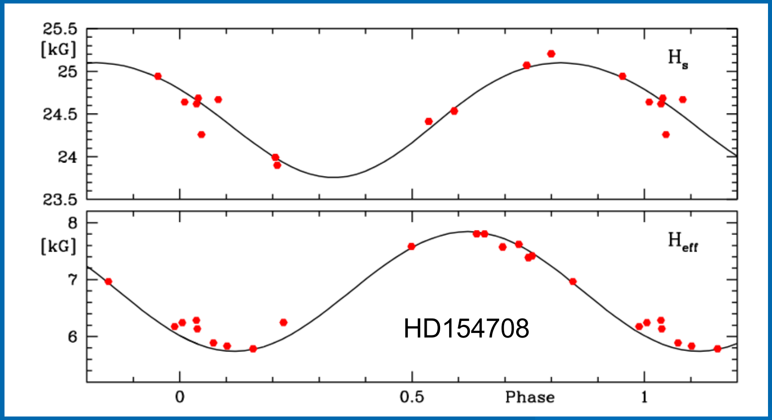


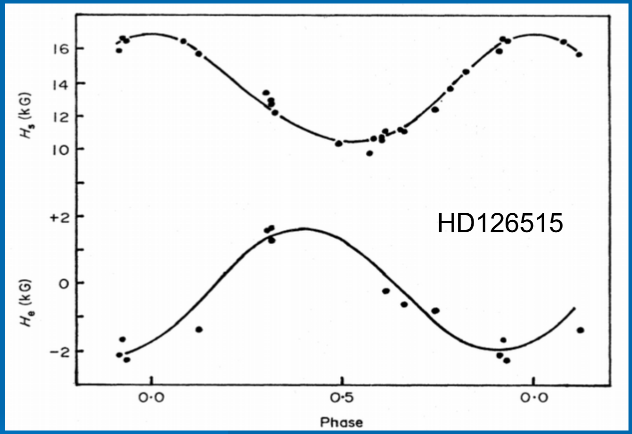
Abundance map consisting of 5 spots and 1 ring-like structure. Using 2 lines in all 4 Stokes parameters as in Kochukhov & Piskunov (2002) we have 1280 profile points to fit. Despite the magnetic field, the inclination, the atmospheric model and the atomic parameters all being exactly known, we are not able to recover more than 1 of the 6 abundance structures in the input model !!

Fields need not be (rarely are ?) axisymmetric

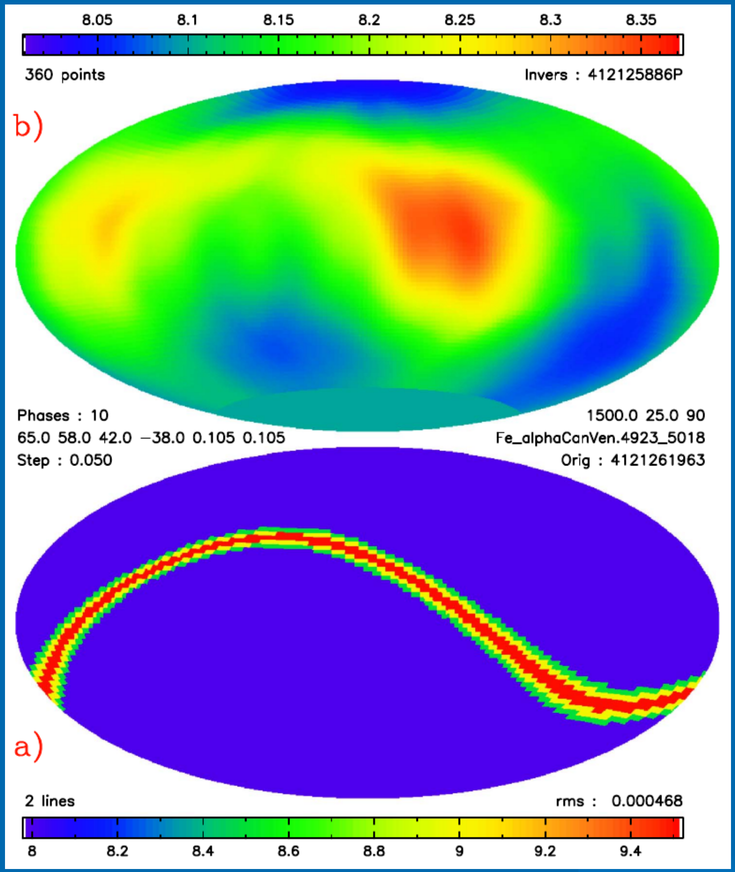
Phase-shifts are found between the variations in the field modulus and those in the longitudinal field. They have successfully been modelled with the non-axisymmetric, tilted excentric oblique rotator model of Stift (MNRAS 1975).







Open issue : complex abundance distributions in non-axisymmetric magnetic geometries



Quote Kochukhov (A&A 2017) **:**
"A reduction of the line list to 1–2 spectral features, including blended one, leads to only a marginal increase of the average inversion errors to about 0.1 dex and ***maximum errors to ~0.15 dex****. Therefore, apart from counteracting random observational noise, abundance DI inversions do not gain significantly from modelling a large number of spectral lines."*

Here the max. errors exceed 1 dex

Open issue : „canonical“ inversion of field-dependent stratifications

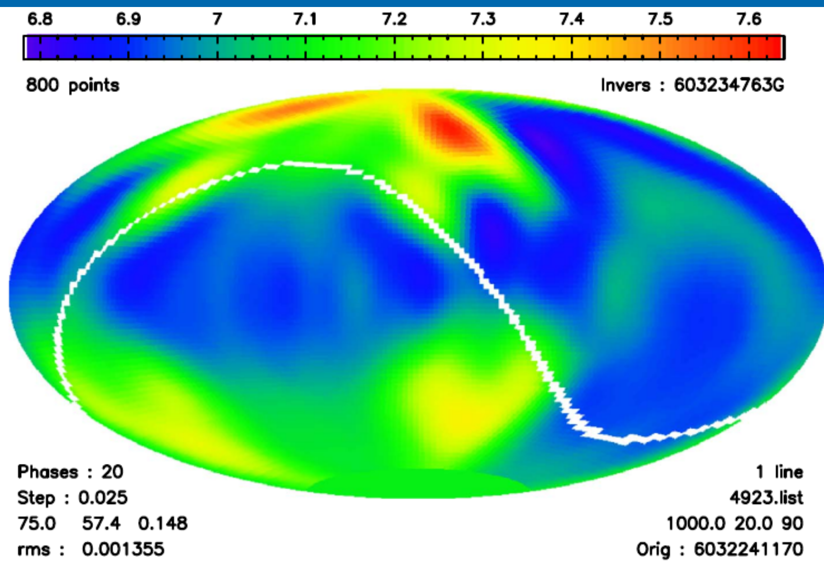


Figure 8. Doppler map obtained from the inversion of the Fe II λ 4923.93 line, adopting a mean atmosphere with $T_{\rm eff} = 10{,}000$ K, $\log g = 4.0$, and [Fe] = 8.0. The input spectrum has been calculated with field-dependent stratification profiles as shown in Stift & Alecian (2016); overabundances decrease with distance from the magnetic equator (indicated as a white warped ring). The non-axisymmetric oblique rotator model is characterized by inclination $i = 75°$, obliquity $\beta = 57\overset{\circ}{.}4$, and dipole offset 0.148 (in units of stellar radius). Field strengths range from 660 to 2375 G.

Inversion of spectra calculated with field-dependent stratifications and corresponding local atmospheres.

Adopting a mean atmosphere and vertically constant abundances results in totally spurious results.

What happens in general when one neglects magnetic fields in the inversion process ?

Many of the stars for which abundance maps have been derived harbour magnetic fields of several kG strength.

Magnetic intensification will play an important role; its repercussions on non-magnetic abundance maps are almost impossible to predict without detailed simulations.

On the other hand, a forward spectral line synthesis based on the published maps will immediately reveal the effect of the magnetic field: simply compare the non-magnetic spectra to the magnetic spectra (see the HD3980 example published by Stift & Leone, MNRAS 2017).

Closed issue : a known known since 1996

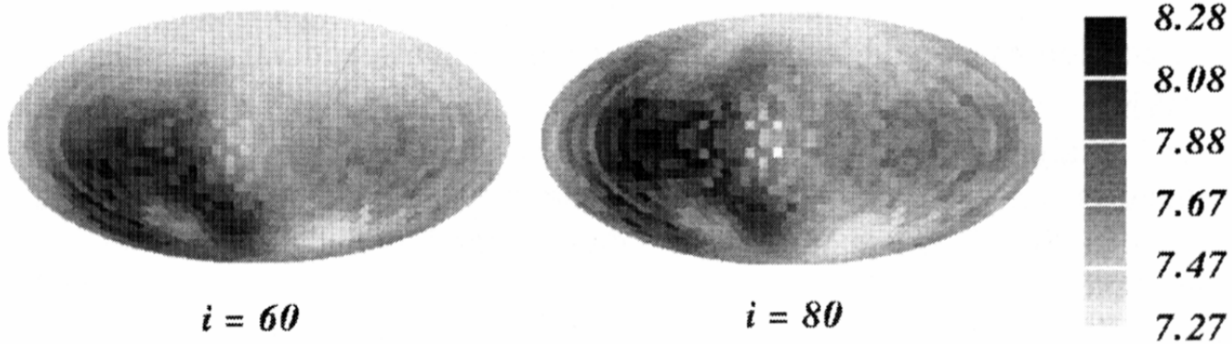
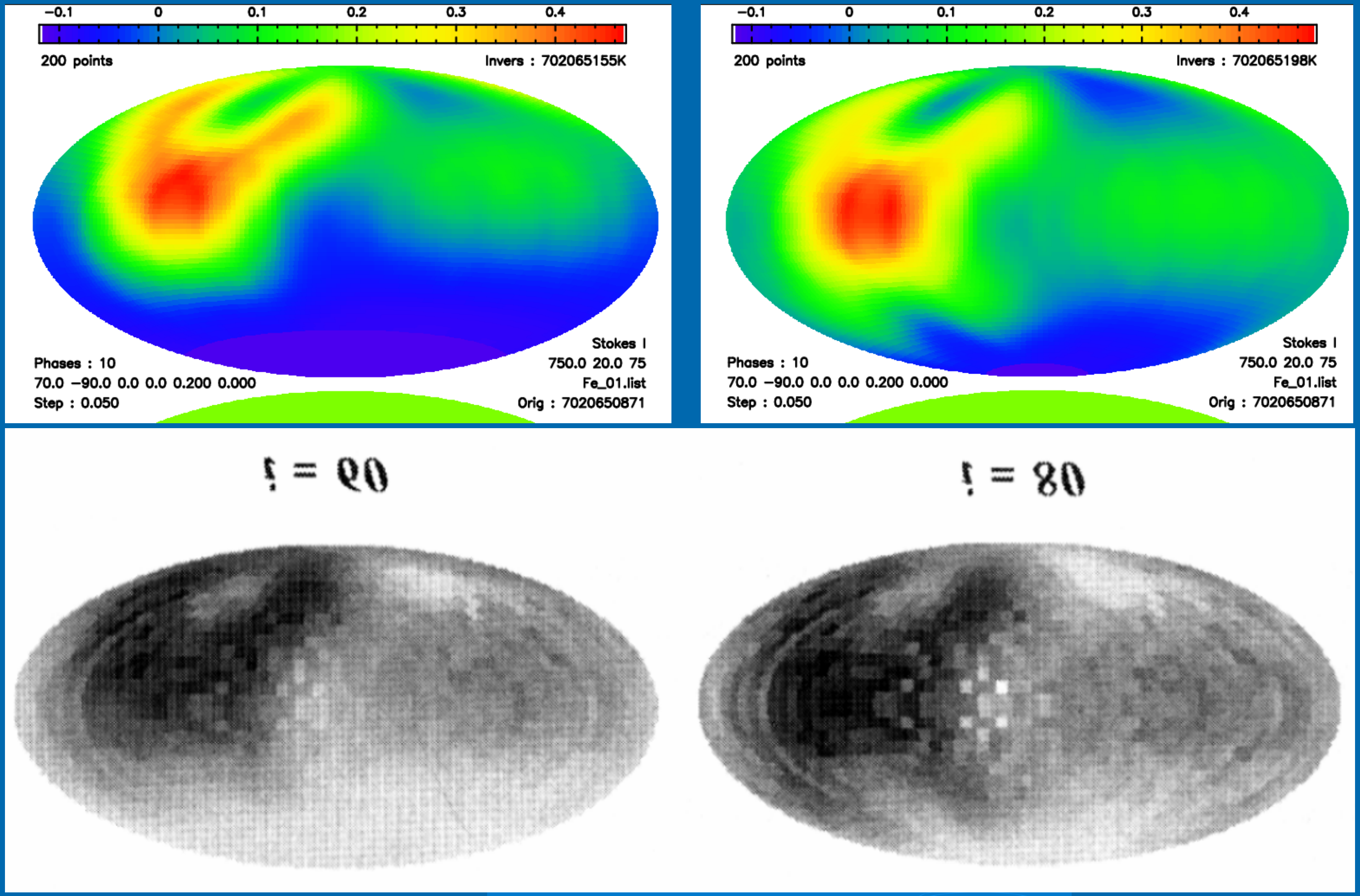


Figure 2. Spurious abundance maps (in dex) obtained from the zero field inversion of Stokes I profiles synthesised for an ORM with uniform abundance $\epsilon = 7.4$ and $i = 70°$, $\alpha = -90°$, $\beta = 0°$, $\gamma = 0°$, $x_2 = 0.20$, $x_3 = 0.00$ with $\mathbf{m} = 0.075$ Tesla and $v \sin i = 20$ km/s. The inclinations adopted for the inversion are given below the respective Hammer equal area projections, $v \sin i$ is the same as for the synthesised profiles.

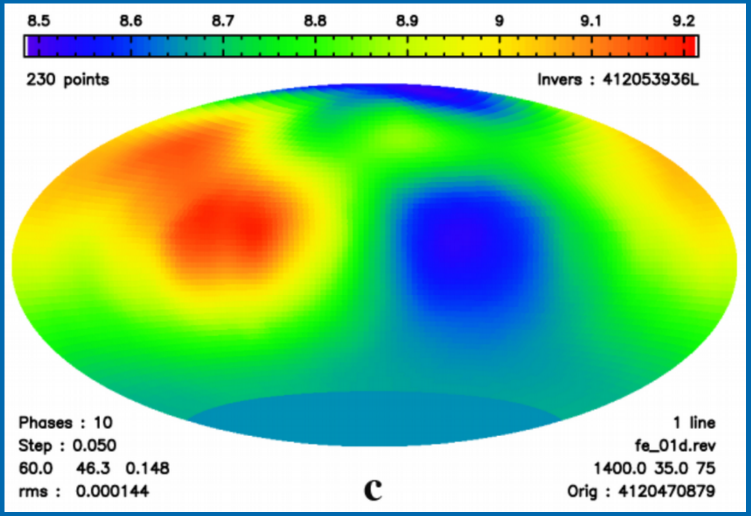
again archaic

Back in 1996 Stift shewed that zero field DM inversions will yield spurious abundance maps, even when magnetic field strengths are fairly moderate.

20 years later : better resolution, identical maps



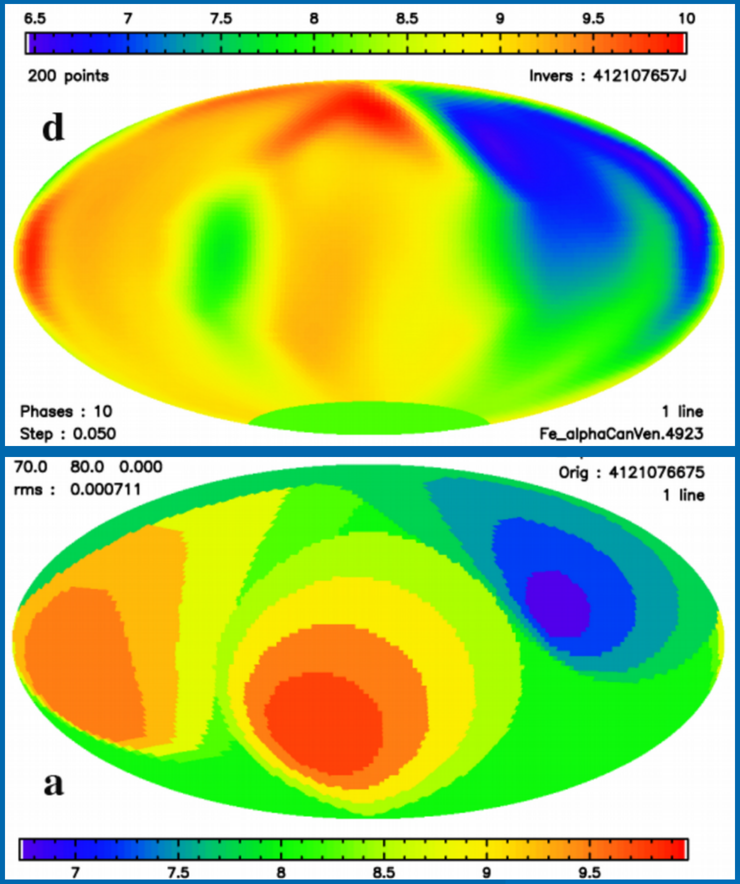
Zero-field inversion of a spotless magnetic star : spurious components



Quote Kochukhov (A&A 2017) **:**
*"Ignoring a moderately strong, 2.5 kG dipolar magnetic field in abundance DI introduces a mean offset of about 0.3 dex in the recovered chemical maps. The average relative reconstruction errors increase to ~0.2 dex while the maximum relative errors reach ~0.3 dex. These errors correspond to distortions of real surface abundance inhomogeneities. **The spurious component** of abundance maps (i.e. Zeeman broadening and intensification misinterpreted as abundance variations) **does not exceed ~0.15 dex on average.**"*

Here the spurious component reaches 1.2 dex !!

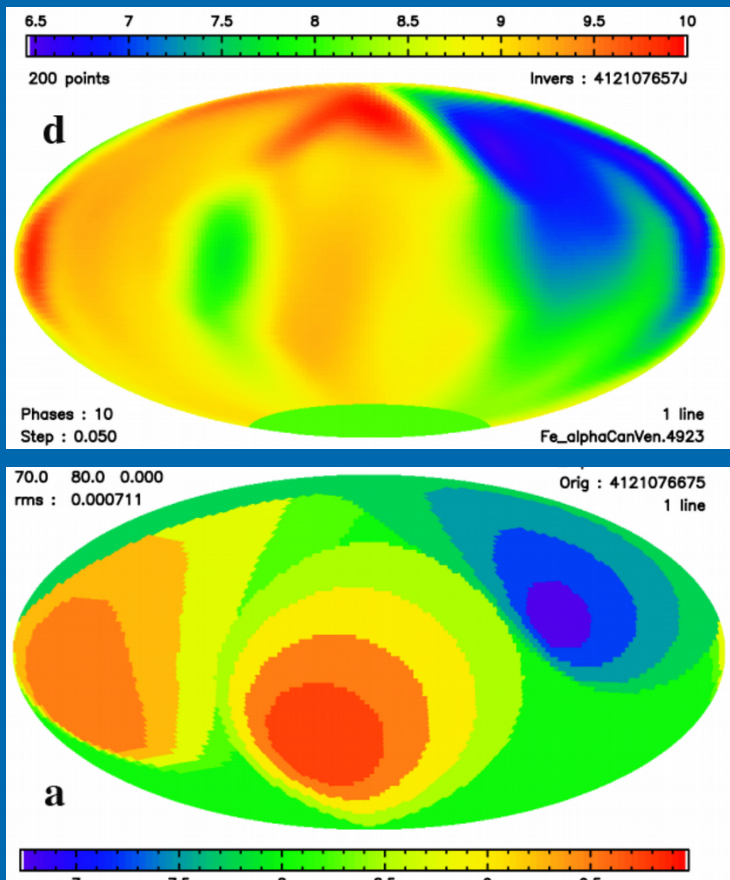
Open issue : using a mean atmosphere and allowing under-abundance “spots”



We assume a star with 3 structured large spots well distributed in longitude and latitude, featuring over- and under-abundances. “True” local atmospheres are used.

When a mean atmosphere is taken for the inversion, 1 spot is not recovered at all, the under-abundances are under-estimated, and a spurious structure appears near the north pole.

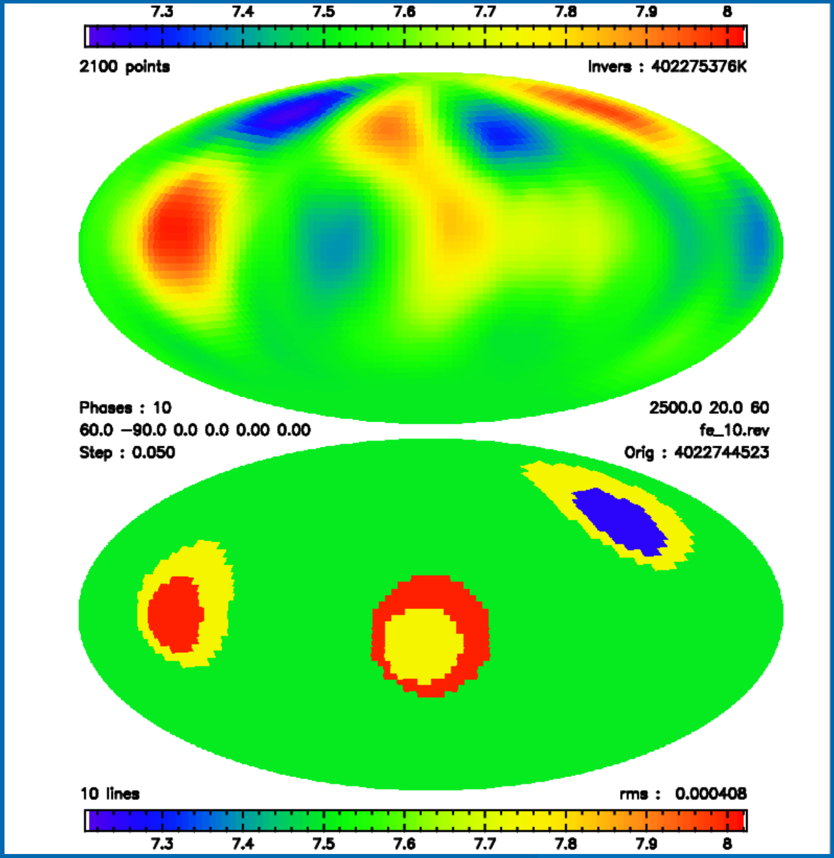
Open issue : no spurious spots produced ?



Quote (Kochukhov, A&A 2017) **:**
„Ignoring local atmospheric structure variations leads to average reconstruction errors of ~0.2 dex and maximum errors of ~0.3 dex. These numbers correspond to the effect of overabundance spots of the element (iron) providing the most important contribution to the atmospheric opacity … no spurious spots are produced."

What about the extreme polar spot ?

The effects of an error of a mere 20% in field strength and of just 10° in inclination

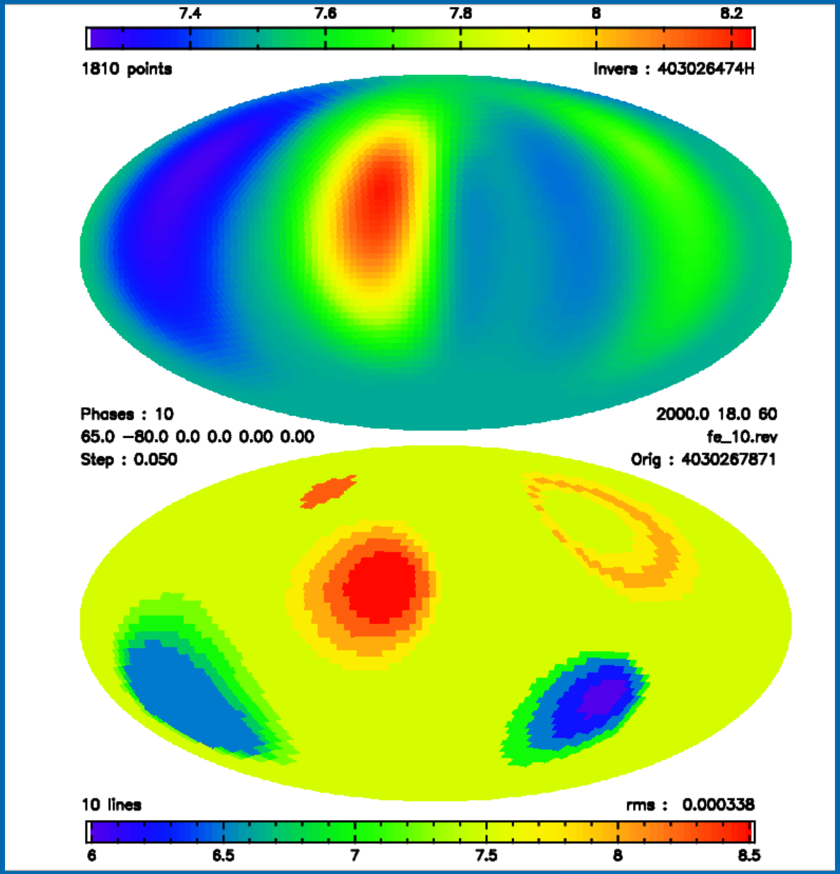


10 lines are taken instead of just 1 or 2. There are 2100 points of the noise-free Stokes I spectrum to fit.

The rms discrepancy between input and recovered profiles is much better than 0.001.

Beware of LSD, the main culprit !!!!

Problems with LSD based ZDM : no longer an unknown unknown

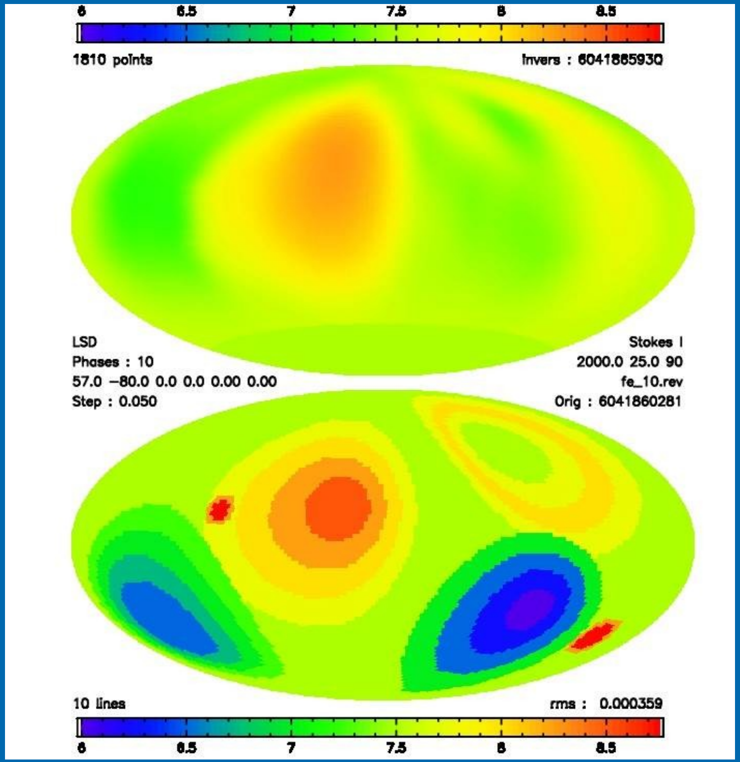


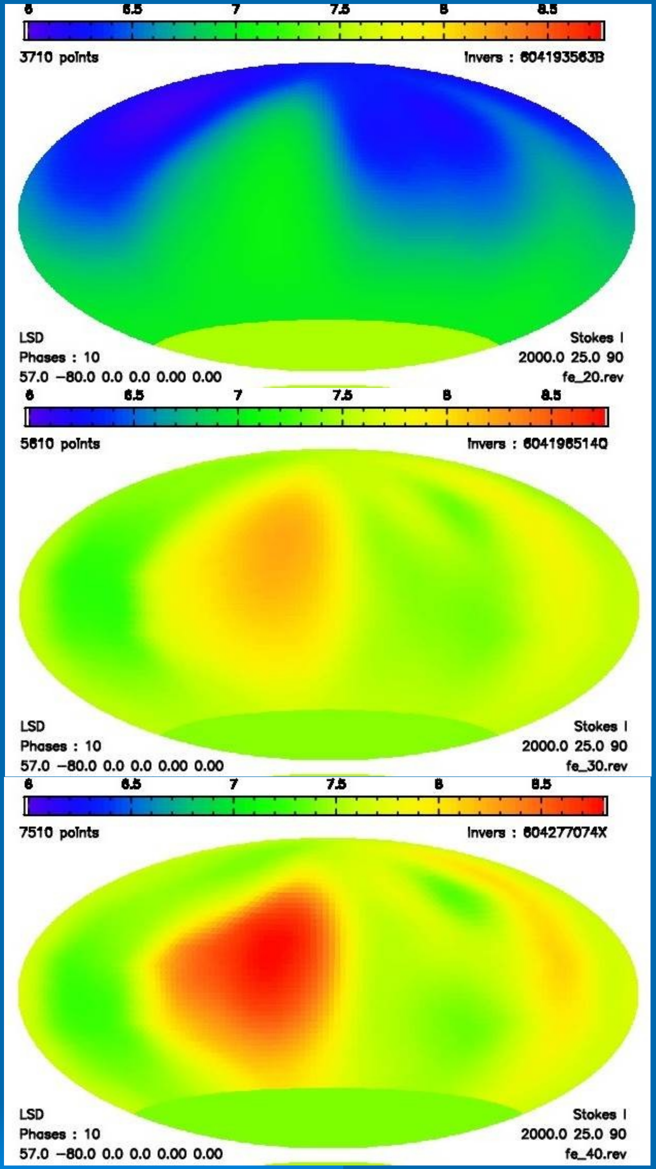
Least-squares deconvolution (LSD, Donati et al. 1997) was devised to detect magnetic signals in noisy spectra.

Using mean LSD profiles for ZDM (following Kochukhov et al., A&A 2014) however may invite trouble.

Here all stellar parameters are exactly known. The fit to the mean profile is brilliant.

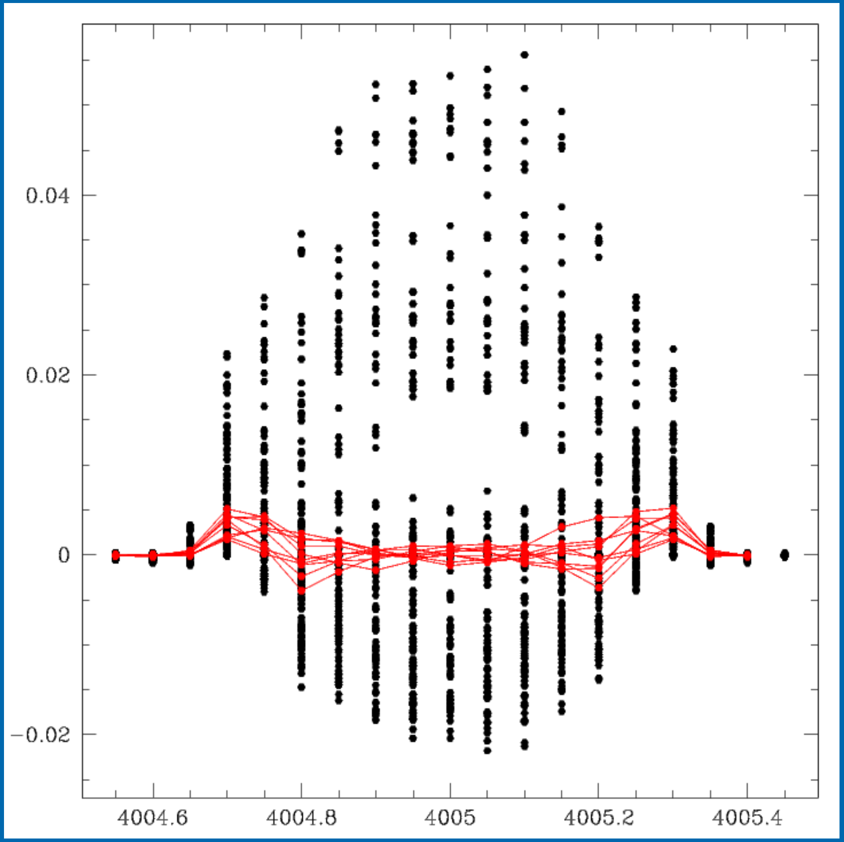
Open issue : LSD and ZDM





5 spots and 1 ring-like structure, inverted with 10, 20, 30, 40 lines

Open issue : what actually happens in LSD based ZDM inversions

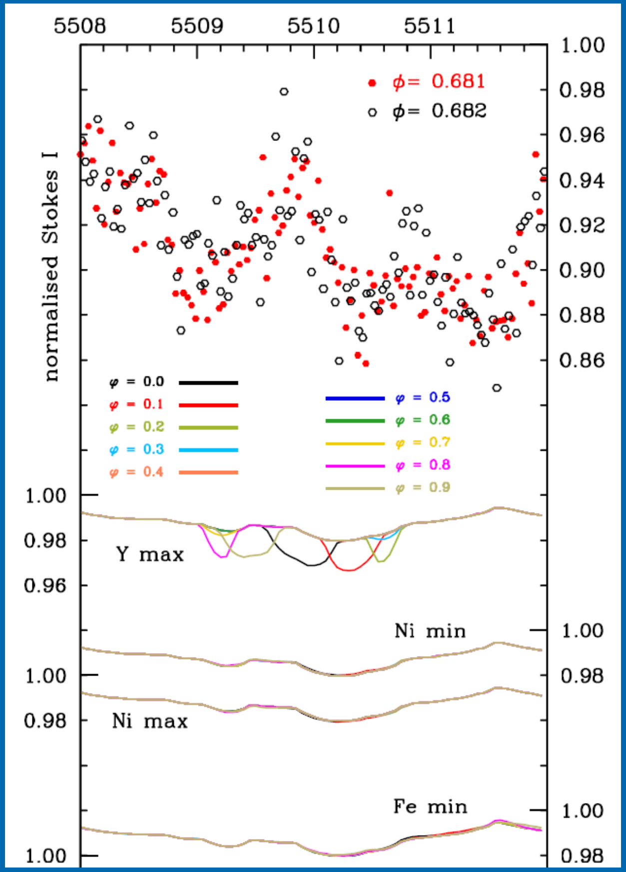


In the approach of Kochukhov et al. (A&A 2014) the fit is made to a mean profile determined from many individually synthesised lines. There is no fit to a fictitious single line profile!

The traditional problem of the single mean line is now traded against an even less tractable problem: **the code achieves an almost perfect fit to the mean observed profile by summing up over individual profiles which may all be incorrect**.

see http://www.ada2012.eu/lsd.html

Deconstructing the low-contrast Ni spot on HD50773



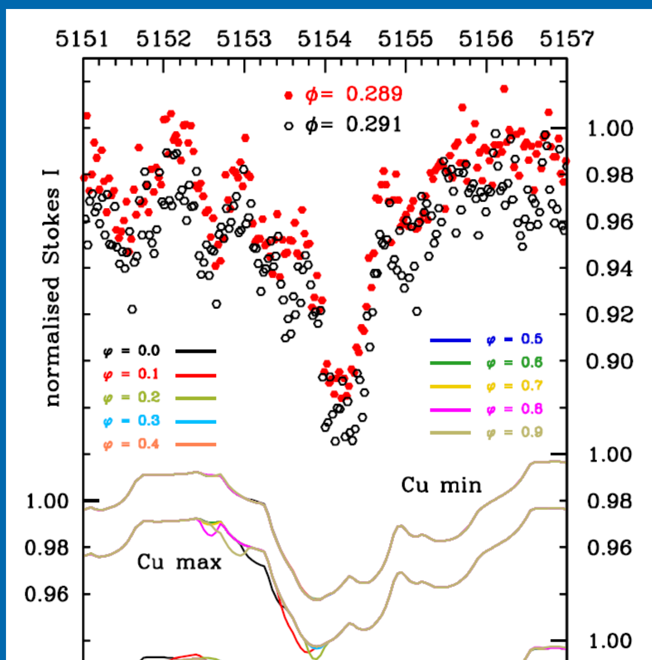
The signals of spots with minimum abundances of Y, Ni, Fe and Cr do not exhibit variations with phase.

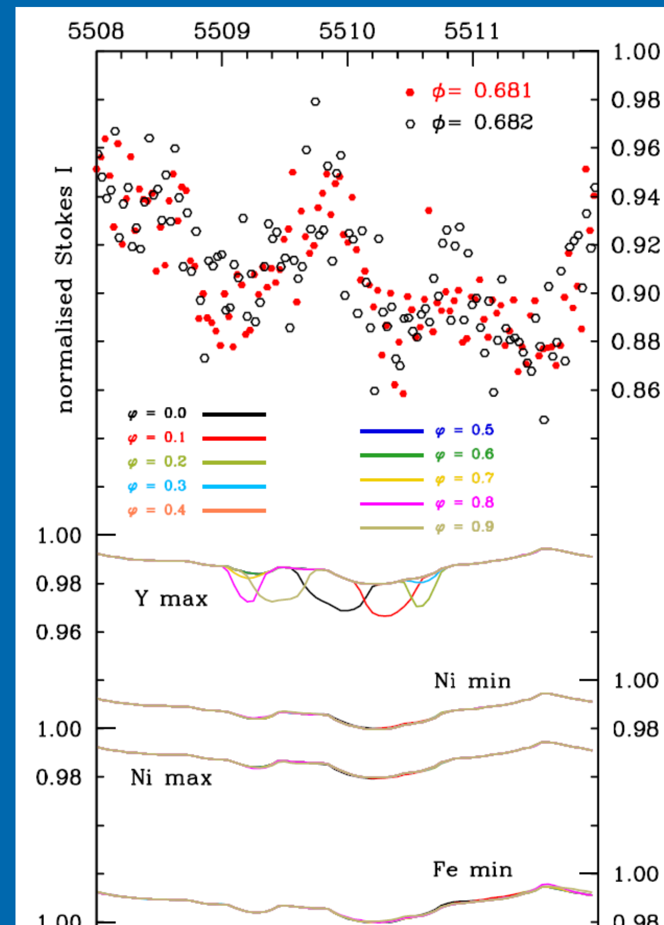
The Ni signal is undetectable altogether but Lüftinger et al. (2010) managed to publish a Ni map in A&A.

Keep in mind that the Ni line is heavily blended with Cr, Fe, Y !!

S/N ~ 120 R = 65000

Closed issue : „spots” that leave no signal in the spectrum are not spurious but simply imaginary





Now you can judge these claims for yourself

Quote : (Kochukhov et al. 2004) HR3831
"Our study represents the most thorough examination of the surface chemical structure in a magnetic Ap star and provides important observational constraints for modelling radiative diffusion in magnetic stars."

Quote : (Nesvacil, Lüftinger, Shulyak et al. 2012) HD3980
"No obvious correlation between theoretical predictions of diffusion in CP stars and the abundance patterns could be found. This is likely attributed to a lack of up-to-date theoretical models."

Quote : (Silvester et al. 2014) α^2CVn
"We also find a lack of agreement with theoretical predictions. This suggests that there is a gap in our theoretical understanding … "