The impact of magnetic fields on the structure of convective stellar atmospheres across the H-R diagram

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Abstract

It is well-known that magnetic fields are present in stellar atmospheres even in the regions which can be regarded as magnetically-quiet. In the Sun, such regions can nevertheless experience a noticeable influence from the magnetic fields resulting, for example, in the formation of the vortex-like structures and thereby affecting the overall structure of the solar atmosphere. As such effects are still largely unexplored in other types of stars, we investigate the interaction of convection and magnetic field and their combined impact on the structure of stellar atmospheres in different types of stars. For this work, we use 3D magnetohydrodynamic CO5BOLD model atmospheres. We find that the vortex-like structures do indeed become increasingly prominent in the atmospheres of stars with stronger magnetic fields which leads to alterations of their atmospheric structures.

Setup of the model atmospheres

For this study we used CO5BOLD 3D hydrodynamical model atmospheres (Freytag et al. 2012), which were computed in a „box-in-a-star" setup on a Cartesian grid. Chemical composition was solar-scaled with [α/Fe]=+0.4 enhancement for the metal-poor model atmospheres. Radiative transfer was computed in LTE, using MARCS monochromatic opacities (Gustaffson et al. 2008) grouped into 5-6 opacity bins (for the binning procedure see, e.g., Vögler et al. 2004).

To take into account chromospheric activity, CIFIST model atmospheres that were used as starting models in this study (Ludwig et al. 2009) were extended both vertically and horizontally to avoid expanding shockwaves colliding with each other in the outer chromosphere. No time-dependent ionization was included in the modeling at this point. To construct model atmospheres of appropriate size, we have extended CIFIST model atmospheres by 1.5-2 times horizontally and ≈1.5 times vertically. In the vertical direction, the goal was to include layers up to Rosseland optical depth log τ_{Ross} ≈ --10.

Horizontally-averaged structures

In Fig. 1 we show several horizontally-averaged quantities in the model atmosphere characterized by T_{eff} = 4500 K, log g = 2.5, [M/H] = --2.0 (clockwise, from top left): average temperature, RMS of temperature $T_{RMS} = \sqrt{\frac{1}{n}\sum_i (T_i - \langle T \rangle)^2}$, where n is the total number of columns in a model atmosphere, i is the index of the individual column, <T> is temperature horizontally-averaged on the surface of equal optical depth), and absolute velocity, all plotted as functions of Rosseland optical depth (different line styles denote models with the different initial average magnetic field strengths, B_z). At solar metallicity, the presence of magnetic field typically results in the increase of atmospheric velocities in the chromosphere, whereas at [M/H] = --2 the movement of matter is noticeably dampened. In both cases the temperature profiles are only weakly affected by the magnetic field, whereas a stronger magnetic field of 50 G results in the decrease of temperature RMS.

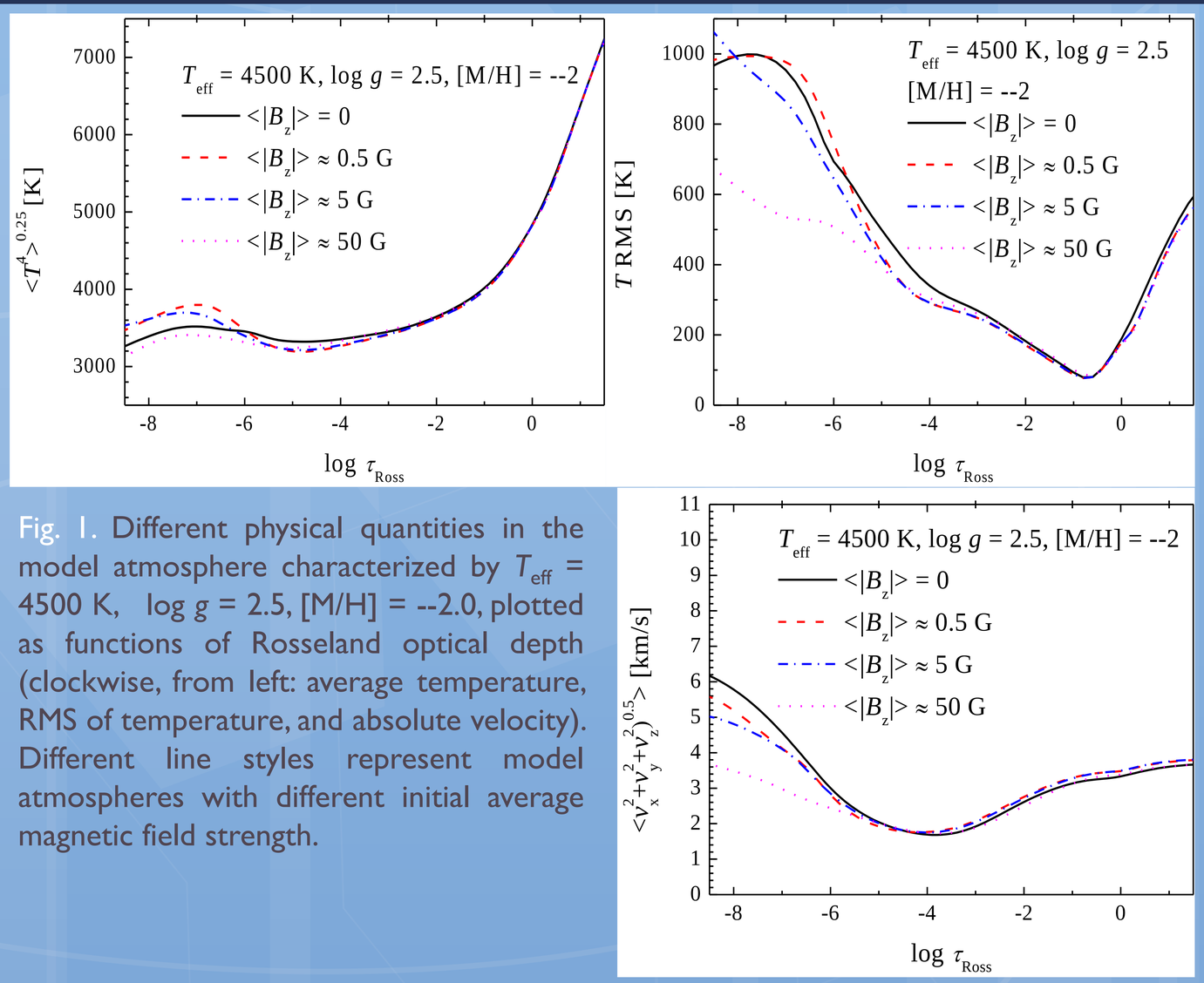

Fig. 1. Different physical quantities in the model atmosphere characterized by T_{eff} = 4500 K, log g = 2.5, [M/H] = --2.0, plotted as functions of Rosseland optical depth (clockwise, from left: average temperature, RMS of temperature, and absolute velocity). Different line styles represent model atmospheres with different initial average magnetic field strength.

Cuts of the model structures

Horizontal cuts of the model atmospheres at the depth corresponding to the Rosseland opacity of log τ_{Ross} = --8 show that whereas non-magnetic model atmospheres exhibit usual filamentary structure in outer atmosphere, these structures are replaced with apparently more uniform temperature distribution for magnetic model atmospheres, with notable vortex structures (Fig. 2).

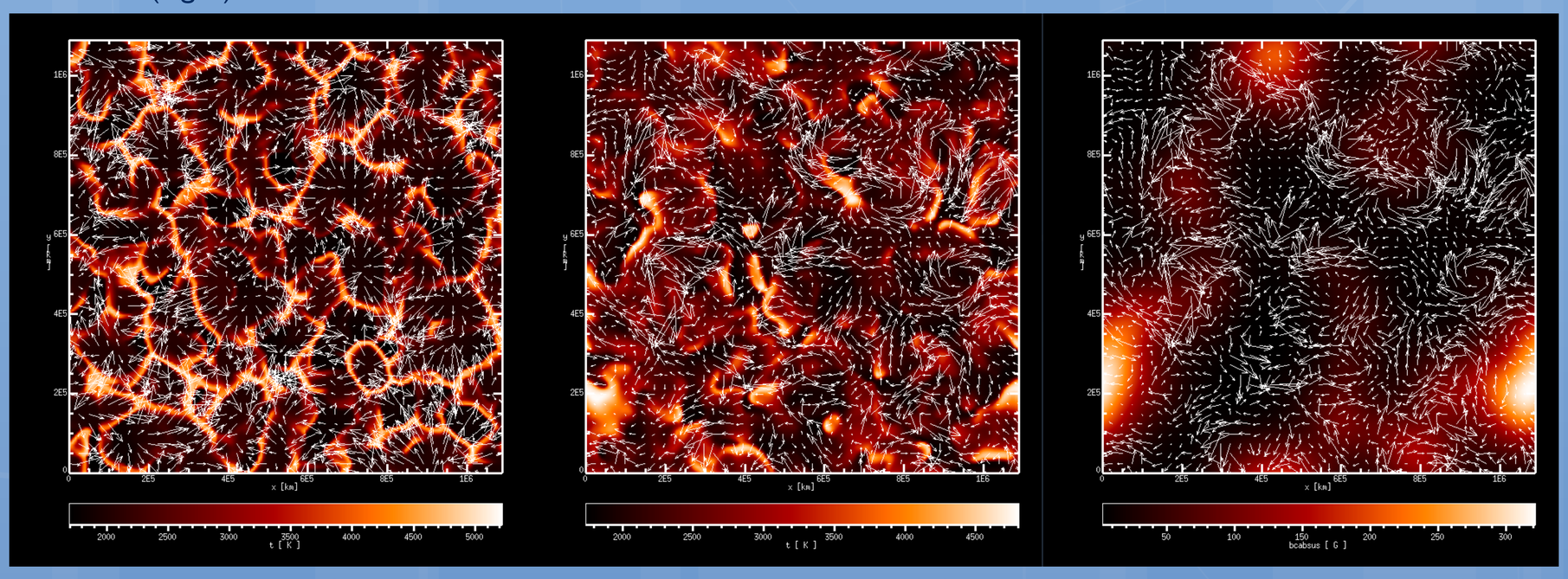

Fig. 2. Horizontal cuts of the model atmospheres at <log τ_{Ross} > ≈ --8 for the model atmospheres with T_{eff} = 4500 K, log g = 2.5, [M/H] = --2.0. **Left**: density plot shows temperature in the non-magnetic model atmosphere (B_z = 0 G). **Middle**: same on as on the left but for the model atmosphere with initial average magnetic field strength of B_z = 50 G. **Right**: density plot shows |B| for the model atmosphere with initial average magnetic field strength of B_z = 50 G. Vectors denote horizontal velocity.

References

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