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Impact of magnetic fields on the structure of convective atmospheres of red giant stars

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Abstract. We use 3D magnetohydrodynamic `CO5BOLD` model atmospheres to study the interplay between magnetic fields and convection in the atmospheres of red giant stars. We find that vortex-like structures occur prominently in stars with stronger magnetic fields and lead to alterations of their thermal structures.

Key words: stars: atmospheres – convection – hydrodynamics – magnetohydrodynamics (MHD) – stars: late-type

1. Introduction

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 experience a noticeable influence from the magnetic fields resulting, for example, in the formation of 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 atmospheric structure of red giant stars.

In this study we used 3D hydrodynamical $\texttt{CO}^5\texttt{BOLD}$ model atmospheres (Freytag et al., 2012). 3D hydrodynamical $\texttt{CO}^5\texttt{BOLD}$ model atmospheres from the CIFIST grid (Ludwig et al., 2009) were used as starting models for the MHD simulations. The CIFIST models were extended both vertically and horizontally to avoid expanding shockwaves colliding with themselves in the outer chromosphere due to periodic horizontal boundary conditions. To construct the 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 the Rosseland optical depth $\log \tau_{\mathrm{Ross}} \approx -10$.

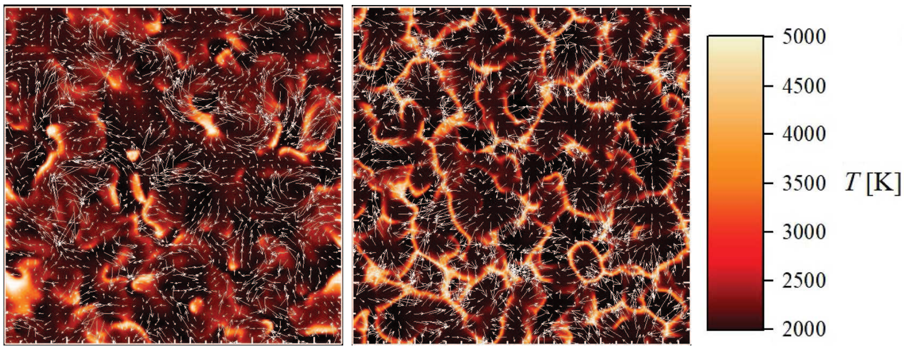

Figure 1. Horizontal cuts through the model atmosphere of a red giant ($T_{\rm eff}$ = 4500 K, $\log g$ = 2.5, [M/H] = –2.0). The color maps show the thermal structure in the outer atmosphere ($\langle \log \tau_{\rm Ross} \rangle \approx -8$), white vectors delineate the horizontal velocity field. *Left*: MHD model atmosphere with the inital mean magnetic field strength $\langle |B| \rangle \approx 50$ G. *Right*: purely hydrodynamic model atmosphere ($\langle |B| \rangle = 0$).

2. Influence of magnetic fields on the atmospheric structure

At solar metallicity, the presence of a magnetic field typically results in the increase of atmospheric velocities and higher temperatures in the chromosphere, whereas in the red giant model at [M/H] = –2.0 the velocity field is noticeably dampened. In both cases the mean temperature profiles are only weakly affected by the magnetic field, whereas stronger initial magnetic field of 50 G results in the decrease of RMS temperature.

Horizontal cuts through the model atmosphere at the Rosseland optical depth $\langle \log \tau_{\rm Ross} \rangle = -8$ show that whereas the non-magnetic model atmosphere exhibits usual filamentary structure in the outer layers, this pattern is replaced with an apparently more uniform temperature distribution in the magnetic model atmosphere where vortex structures are clearly prominent (Fig. 1).

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