Holistic magnetohydrodynamic simulation from the convection zone to the chromosphere

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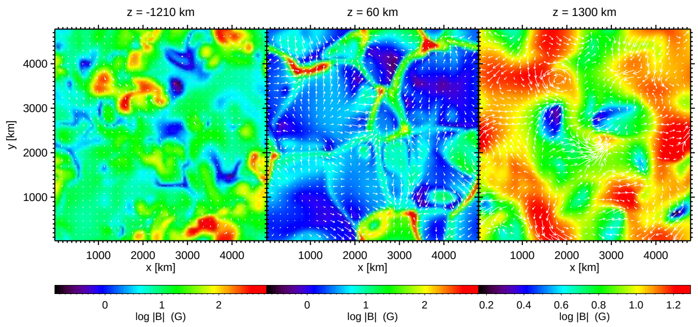
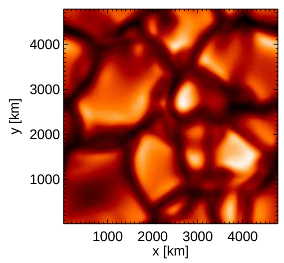
A *three-dimensional magnetohydrodynamic simulation* of the integral layers from the convection zone to the chromosphere was carried out. It starts with a homogeneous, vertical, unipolar magnetic field of 10 G superposed on a previously computed relaxed model of thermal convection. With this flux density the simulation ought to mimic magnetoconvection in a *network-cell interior*. The three-dimensional computational domain extends from 1400 km below the surface of optical depth unity to 1400 km above it and it has a horizontal dimension of 4800 × 4800 km.

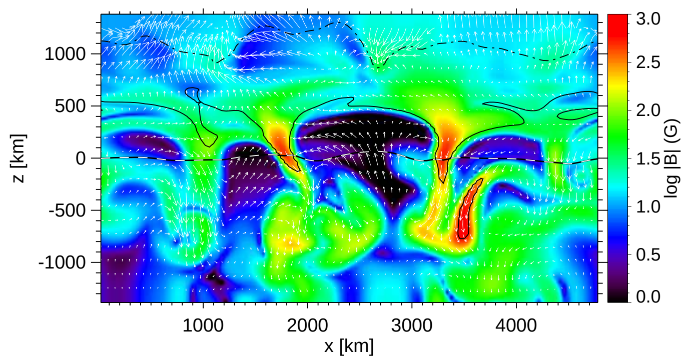


Three *horizontal sections* through the three-dimensional computational domain. The color coding displays the logarithm of the absolute magnetic field strength, with the individual scalings indicated in the color bars. **Left:** Bottom layer at a depth of 1210 km. **Middle:** Layer 60 km above optical depth $\tau_c = 1$. **Right:** Top, chromospheric layer in a height of 1300 km. The white arrows indicate the horizontal component of the velocity field on a common scaling for all three panels. The longest arrows in the panels from left to right correspond to 4.5, 8.8, and 25.2 km/s.

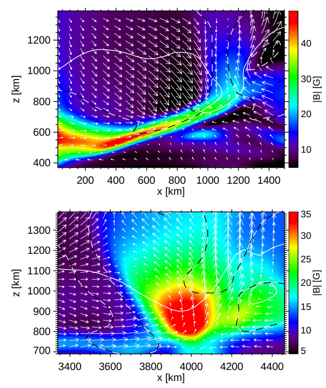


Emergent Rosseland mean *intensity*.

The magnetic field concentrates in narrow sheets and small knots near the surface of optical depth unity with field strengths up to approximately 1 kG. Below the surface the field disperses again but partially remains concentrated in flux tubes with a strength of a few hundred Gauss. The *chromospheric magnetic field is marked by strong dynamics* with a continuous reshuffling of magnetic flux on a time scale of less than 1 min, much shorter than in the photosphere or in the convection zone. There, the field has a strength between 1 and 20 G in this snapshot. Different from the surface magnetic field, it is more homogeneous and practically fills the entire region so that the magnetic filling factor in the top layers is close to unity.



Snapshot of a *vertical section* showing the logarithm of the absolute field strength (color coded) and velocity vectors projected on the vertical plane (white arrows). The b/w dashed curve shows optical depth unity for vertical lines of sight and the dot-dashed and solid black contours correspond to $\beta = 1$ and 100, respectively.



Two close-ups of *shock induced magnetic field compression* in the chrompsphere. Absolute magnetic flux density (colors) with velocity field (arrows), Mach = 1-contour (dashed) and $\beta = 1$-contour (white solid).

Highly dynamic, transient filaments of stronger than average magnetic field form in the chromosphere in the compression zone downstream and along propagating shock fronts. These magnetic filaments that have a flux density rarely exceeding 20 Gauss, rapidly move with the shock waves and quickly dissolve or form with them. The *surface of $\beta = 1$* separates the region of highly dynamic magnetic fields from the more slowly evolving field below it and seems to act as a mode conversion zone. This surface is located at about 1000 km above optical depth unity.

The magnetic field gets almost entirely expelled from the photospheric layers of granule interiors, leading to a horizontally directed but continuously changing small-scale *"canopy field"* that overlays regions void of magnetic field. Overall, the picture of flux concentrations that expand through the photosphere into a more homogeneous chromospheric field remains valid.

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