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Excitation of magneto-acoustic waves in network magnetic elements

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Abstract. From radiation magnetohydrodynamic (RMHD) simulations we track the temporal evolution of a vertical magnetic flux sheet embedded in a two-dimensional non-stationary atmosphere that reaches all the way from the upper convection zone to the low chromosphere. Examining its temporal behavior near the interface between the convection zone and the photosphere, we describe the excitation of propagating longitudinal waves within the magnetic element as a result of convective motion in its surroundings.

Keywords. Sun: photosphere, sun: chromosphere, sun: oscillations, Suun: magnetic fields, MHD

1. Introduction

Filtergrams or spectroheliograms in Ca II H and K reveal two main sources of Ca II emission: plages, which spatially coincide with the active regions, and the chromospheric network, which outlines the boundaries of the supergranular velocity field (Simon & Leighton 1964). Both are also the location of small magnetic flux concentrations in the photosphere. The close relationship between Ca II emission and magnetic flux (Skumanich *et al.* 1975; Schrijver *et al.* 1989) suggests that the magnetic field plays a key role for the chromospheric emission. The chromospheric heating must be greatly enhanced in areas where the magnetic flux density is large. The heating source and the dissipation mechanism has remained elusive, but likely candidates are the dissipation of magnetohydrodynamic waves or the direct dissipation of electric currents. With regard to chromospheric heating by MHD-waves, numerous studies have been carried out based on the approximation of slender flux tubes (Herbold *et al.* 1985; Huang *et al.* 1995; Fawzy *et al.* 1998 and Hasan & Ulmschneider 2004 and references therein). They have greatly expanded our understanding of the physics of tube modes, mode coupling, dependency on the excitation mechanism and the tube geometry, shock formation, etc.

Some of these models consider the generation of longitudinal and transverse waves in a flux tube by turbulent motions in the convection zone, where an analytical treatment of turbulence based on the Lighthill-Stein theory of sound generation is used (e.g., Musielak

& Ulmschneider (2001) and references therein). Others take a driving motivated by observations of the motion of photospheric magnetic flux concentrations, suggesting that transverse waves can be generated through the impulse transmitted by granules to magnetic flux tubes, as, e.g., in Choudhuri *et al.* (1993a,b); Hasan *et al.* (2000), and Cranmer & van Ballegooijen (2005).

All the above mentioned simulations impose a given driving, which is either monochromatic or impulsive or derived from a theoretical spectrum of turbulence. The focus of this investigation is the self-consistent excitation of a thick magnetic flux concentration through the ambient convective motion.

2. Numerical method

The simulations were carried out with the CO^{5}BOLD-code (Freytag *et al.* 2002). The code solves the coupled system of the equations of compressible magnetohydrodynamics in an external gravity field and non-local, frequency-dependent radiative transfer in one, two, or three spatial dimensions. The two-dimensional computational domain extends over a height range of 3160 km of which 780 km reach above the mean surface of optical depth unity and the rest below it. The horizontal extension is 11200 km.

The simulation starts with a homogeneous, vertical, unipolar magnetic field of a flux density of 80 G superposed on a previously computed, relaxed model of thermal convection. The magnetic field is constrained to have vanishing horizontal components at the top and bottom boundary but lines of force can freely move in the horizontal direction. The magnetic field quickly starts to concentrate in the intergranular downdrafts by the convective motion. Subsequently, individual flux concentration start to merge. After approximately 100 min, the magnetic field concentrates in a single magnetic 'flux sheet' with a strength of approximately 2000 G near optical depth unity within the flux concentration. It then remains in this state for the following 86 min simulation time. This state, however, is not a static or stationary one—as a consequence of the interaction with the surrounding convective motion, the flux concentration moves laterally, gets distorted, and exhibits internal plasma flow in the course of time. Here we describe the excitation of longitudinal slow modes within the flux sheet.

3. Excitation of magneto-acoustic waves

The top and bottom panels in Fig. 1 show part of the computational domain with the magnetic flux concentration (gray magnetic field lines) in the middle, the temperature field (gray scale), the velocity field (arrows), continuum optical depth unity (black horizontally running contour), and the plasma-beta unity (a black dashed curve) for an arbitrary time instant. They show the full width of the computational domain but only a section of the full height range, which reaches 2300 km below and 830 km above mean optical depth unity. Note that the temperature scale stops at 10 000 K so that the temperature field saturates below $\tau_c = 1$. The snapshot shows warm granular upwellings framed by narrow cool intergranular downflows in the convection zone. It also shows two narrow downflow channels in the close vicinity on both sides but outside of the magnetic flux concentration below the surface of optical depth unity. These 'downflow jets', which were in detailed described by Steiner *et al.* (1998), are a consequence of a baroclinic flow impinging on the magnetic flux concentration from the lateral directions, driven by the radiative cooling at the 'hot walls' of the flux concentration.

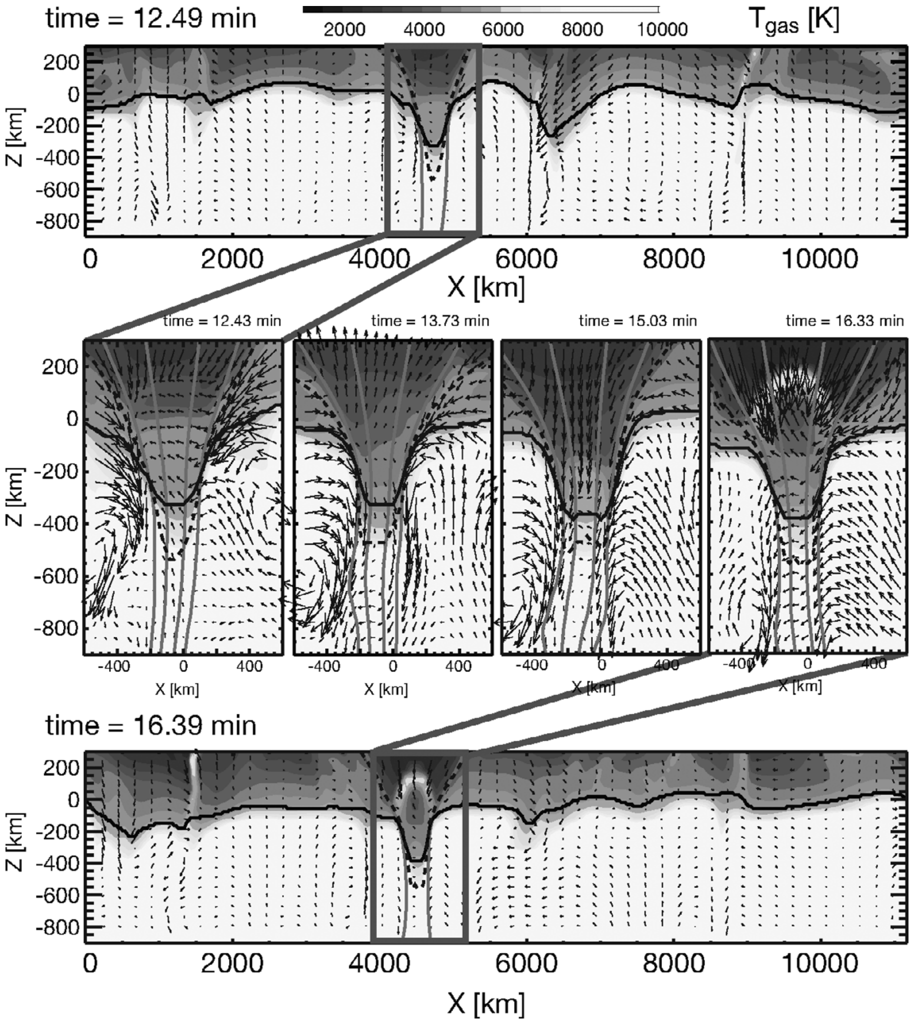

Figure 1. Top and bottom panels: snapshots of a magnetic element showing the full width of the computational domain. The gray-scale indicates the temperature. Gray solid contours indicate magnetic field lines. Black solid curves indicate the optical surface ($\tau = 1$) and black dashed curves indicate the surface of plasma-$\beta = 1$ above which plasma-$\beta < 1$. Arrows indicate the velocity vectors. Middle panels: close-up views of the magnetic element.

In the present simulation we observe that these downflows are far from stationary. They tend to be present most of the time but get transiently enhanced, weakened, or interrupted. Sometimes, the lateral inflow carries a preexisting regular intergranular downflow with it. It then merges with the downflow channel of the flux concentration, which results in a particular strong 'downflow jet'. We identify such transients to be an important source for magneto-acoustic waves within the magnetic flux concentration, in particular a source for longitudinal slow modes. The middle row of Fig. 1 shows a time series of close-ups of such a transient event. The flows in the close surroundings of the magnetic flux concentration generate flows within the magnetic funnel, which leads to an upwardly propagating longitudinal wave and finally to the "bow-shaped" shock front, visible in the last panel of the series.

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4. Summary

We have carried out a radiation magnetohydrodynamic simulation of a magnetic flux concentration embedded in the solar atmosphere as representative of network magnetic elements. The analysis of the simulation results focusses on the excitation of magneto-acoustic waves within the magnetic flux concentration. It is shown that convective down-flow events in the close surroundings of the magnetic funnel are responsible for the excitation of propagating longitudinal waves within the magnetic funnel. They steepen to shock waves in the upper photosphere. Presently, we further analyze the simulation data and plan to further elucidate the newly found mechanism in a subsequent paper.

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References

Choudhuri, A. R., Auffret, H., & Priest, E. R. 1993a, *Solar Phys.*, 143, 49
Choudhuri, A. R., Dikpati, M., & Banerjee, D. 1993b, *Astrophys. J.*, 413, 811
Cranmer, S. R. & van Ballegooijen, A. A. 2005, *Astrophys. J. Suppl.*, 156, 265
Fawzy, D. E., Ulmschneider, P., & Cuntz, M. 1998, *Astron. Astrophys*, 336, 1029
Freytag, B., Steffen, M., & Dorch, B. 2002, *Astron. Nachr.*, 323, 213
Hasan, S. S., Kalkofen, W., & van Ballegooijen, A. A. 2000, *Astrophys. J.*, 535, L67
Hasan, S. S. & Ulmschneider, P. 2004, *Astron. Astrophys*, 422, 1085
Herbold, G., Ulmschneider, P., Spruit, H. C., & Rosner, R. 1985, *Astron. Astrophys*, 145, 157
Huang, P., Musielak, Z. E., & Ulmschneider, P. 1995, *Astron. Astrophys*, 297, 579
Musielak, Z. E. & Ulmschneider, P. 2001, *Astron. Astrophys*, 370, 541
Schrijver, C. J., Cote, J., Zwaan, C., & Saar, S. H. 1989, *Astrophys. J.*, 337, 964
Simon, G. W. & Leighton, R. B. 1964, *Astrophys. J.*, 140, 1120
Skumanich, A., Smythe, C., & Frazier, E. N. 1975, *Astrophys. J.*, 200, 747
Steiner, O., Grossmann-Doerth, U., Knölker, M., & Schüssler, M. 1998, *Astrophys. J.*, 495, 468