Waves & Oscillations in the Solar Atmosphere:
Heating and Magneto-Seismology
Proceedings IAU Symposium No. 247, 2007
R. Erdélyi & C. A. Mendoza-Briceño, eds.

doi:10.1017/S1743921308014683

P-mode leakage and Lyman-α intensity

W. Finsterle[1], M. Haberreiter[1], S. Kosovichev[2] and W. Schmutz[1]
[1]PMOD/WRC, Dorfstr. 33, CH-7260 Davos Dorf, Switzerland
[2]HEPL, Standford University, Stanford CA, U.S.A.
email: `wolfgang@pmodwrc.ch`

Abstract. We present an observational test of the hypothesis that leaking p modes heat the solar chromosphere. The amplitude of the leaking p modes in magneto-acoustic portals is determined using MOTH and MDI data. We simulate the propagation of these modes into the chromosphere to determine the height where the wave energy is dissipated by shock waves. A statistical approach is then used to check if this heating process could account for the observed variability of the intensity in the Lyman-α emission.

Keywords. waves, Sun: atmosphere, Sun: photosphere, Sun: chromosphere, Sun: oscillations, Sun: magnetic fields, Sun: UV radiation

1. Introduction

In magnetized areas p modes can escape the internal acoustic cavity of the Sun and propagate upwards into the solar chromosphere (De Pontieu et al. 2003ab, Jefferies et al. 2006, Marsh & Walsh 2006). The underlying mechanism is thought to be wave conversion from sound waves into predominantely magnetic waves. A comprehensive review of the involved mechanisms can be found in Campos (1987) or De Pontieu & Erdélyi (2006). As the pressure and density of the plasma decreases with height the pressure fluctuations of the wave can no longer be considered infinitesimal and hence the wave crest is significantly accelerated due to the temperature increase induced by the wave itself. This eventually leads to the formation of a shock front, i.e. a quasi non-linear increase of pressure and temperature. The shock front continues to travel upwards while dissipating its energy and thus heating the plasma. In this paper we simulate this heating process and we can show that the induced temperature fluctuations in the chromosphere qualitatively agree with the oscillation pattern of the Lyman-α intensity observed with TRACE.

2. Numerical Simulation of Leaking P Modes

We simulate the propagation of acoustic waves in a modified VAL atmosphere structure for quiet Sun (Vernazza et al. 1981). The simulation is based on a 1-d code by Kosovichev & Popov (1981). The wave-induced temperature fluctuations are shown in Figure 1, where a 2-4 mHz frequency-filtered wave train measured by MDI (Scherrer et al. 1995) in a plage pixel on January 20, 2003 was used to drive the simulation. The pixel was chosen from an area where the concurrent observations of the MOTH instrument (Finsterle et al. 2004) reveal upward traveling waves in the p-mode frequency range (Haberreiter & Finsterle 2007). Figure 1 shows that the temperature in above ~700 km is strongly affected by the shock fronts in a typical, quasi-periodic manner. Lyman-α intensity observed by TRACE (Handy et al. 1999) in plage regions shows a very similar periodicity (see Section 3), hence suggesting that the leaking p modes modulate the solar Lyman-α emission. On average, the chromospheric temperature is *hotter* than if no shocks were present. However, in the wake of strong shocks occasional *cooling* down to ~3500 K also occurs perdominantely

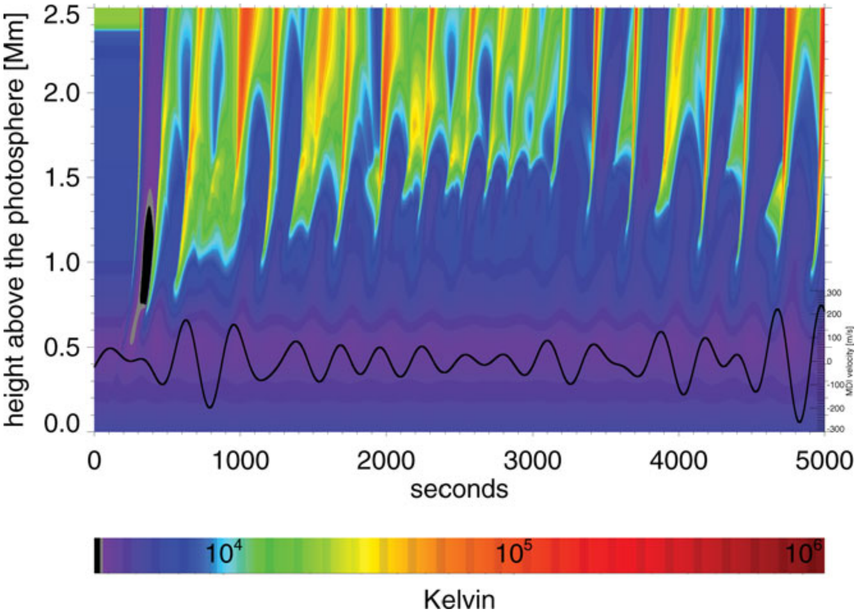

Figure 1. 1-d numerical simulation of the chromospheric temperature structure in a region where p modes escape the internal acoustic cavity of the Sun. The simulation is driven by a piston at the base of the photosphere. The MDI line-of-sight velocity as measured in an area where the MOTH instrument detects leakage of p modes is used for driving the piston.

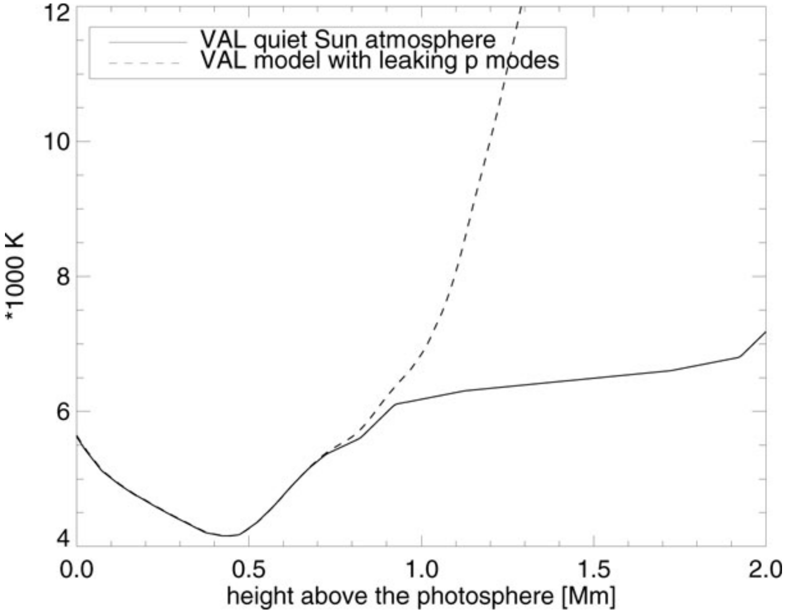

Figure 2. The temperature vs. height for the quiet Sun model atmosphere (solid line). The dashed line shows the temporal average of the temperature when leaking p modes form shocks in the solar chromosphere. Because p-mode leakage is closely related to magnetic fields this mechanism could explain why the chromosphere appears hotter in plage than in quiet Sun areas.

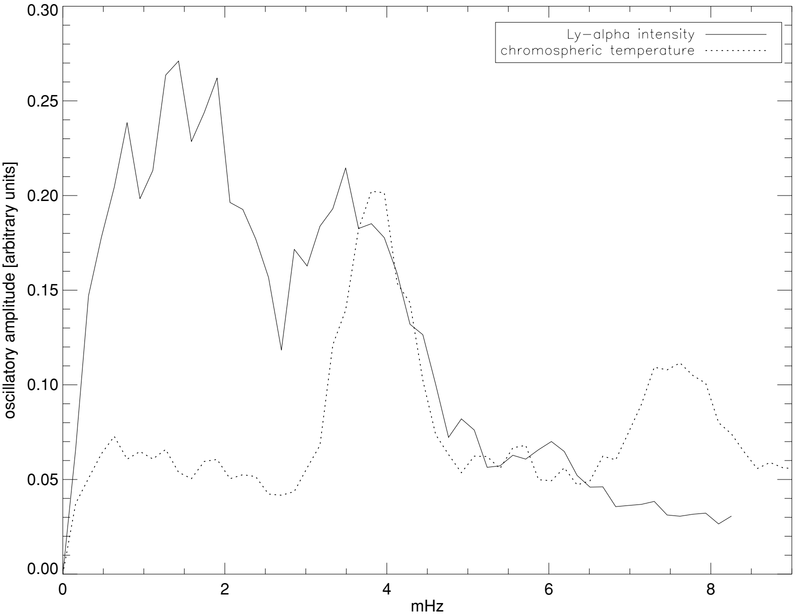

Figure 3. The observed variability of Lyman-α intensity (TRACE, solid line) and the simulated variability of the temperature in the line-forming layer (1.5 2 Mm, dotted line). The temperature in the line-forming layer is directly affecting the intensity of the emission line. The increased power around 3-4 mHz is due to leaking p modes.

around 1 Mm (black and dark blue areas in Figure 1). These could be the regions where solar molecular lines are observed (e.g. Ayres et al. 1986). The temporal average of the shock-induced heating results in a chromospheric temperature structure which resembles the “true” temperature stratification in a magnetized (plage) model atmosphere (Figure 2).

3. Comparison with Observed Lyman-α Variability

The oscillatory spectrum of Lyman-α observations in a plage region by TRACE is shown in Figure 3 (solid line). The TRACE spectrum was derived from a 71-minute run with one minute sampling interval. The dotted line is the oscillatory spectrum of the simulated temperature between 1.5 and 2.0 Mm above the photosphere. Both curves show a prominent peak in the 3-4 mHz area, indicating that the shock-induced temperature fluctuations could indeed be responsible for the observed Lyman-α variability. On larger time scales, the same mechanims could even cause the solar cycle related intensity changes in Lyman-α emission due to the changing surface fraction of magnetized areas on the solar disk.

4. Results and Discussion

P-mode induced shocks modify the temperature stratification of a standard quiet Sun atmosphere to closely resemble that for a plage atmosphere (Figure 2). Since p modes leakage predominantely occurs in magnetic areas the described mechanism could explain why the chromosphere in plage appears hotter than in quiet Sun. We found that Lyman-α intensity oscillations in the p-mode frequency range are comparable to the simulated temperature oscillations of the chromosphere when realistic assumptions for the driving piston are extracted from observations (Figure 3).

Acknowledgements

This work was supported by the Swiss National Science Foundation under SNF grant 200020-109420.

References

Ayres, T.R., Testerman, L., & Brault, J.W. 1986, *ApJ*, 304, 542

Campos, L. M. B. C. 1987, *Rev. Modern Phys.*, 59, 363

De Pontieu, B., Tarbell, T., & Erdélyi, R. 2003, *ApJ*, 590, 502

De Pontieu, B., Erdélyi, R., & de Wijn, A. G. 2003, *ApJ*, 595, L63

De Pontieu, B., & Erdélyi, R. 2006, *Phil. Trans. Roy. Soc. A* 364, 383

Finsterle, W., Jefferies, S. M., Cacciani, A., Rapex, P., Giebink, C., Knox, A., & DiMartino, V. 2004, *Solar Phys.*, 220, 317

Haberreiter, M., & Finsterle, W. (2007), *Solar Phys.*, submitted

Handy, B.N., & the TRACE team 1999, *Solar Phys.*, 187, 229

Jefferies, S.M., McIntosh, S.W., Armstrong, J.D., Bogdan, T.J., Cacciani, A., & Fleck, B. 2006, *ApJ*, 648, L151

Kosovichev, A. G., & Popov, Y. P. 1981, *BULLETIN. CRIMEAN ASTROPHYSICAL OBS*, 63, 15

Marsh, M. S., & Walsh, R. W., 2006, *ApJ*, 643, 540

Scherrer, P., & the MDI team 1995, *Solar Phys.*, 162, 129

Vernazza, J., Avrett, E., Loeser, R. 1981, *ApJS*, 45, 635