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Identification of Linear Slow Sausage Waves in Magnetic Pores

I. Dorotovič[1], **R. Erdélyi**[2] **and V. Karlovský**[3]

[1]Slovak Central Observatory, P. O. Box 42, SK-94701 Hurbanovo, Slovak Republic;
Grupo de Astrofísica da Universidade de Coimbra, Coimbra, Portugal
email: dorotovic@suh.sk

[2]Solar Physics & Space Plasma Research Centre (SP^{2}RC), Dept. of Applied Mathematics,
University of Sheffield, Hicks Building, Hounsfield Road, Sheffield, S3 7RH (England) UK
email: robertus@sheffield.ac.uk

[3]Hlohovec Observatory and Planetarium, Sládkovičova 41, SK-92001 Hlohovec, Slovak
Republic, email: astrokar@hl.cora.sk

Abstract. The analysis of an 11-hour series of high resolution white light observations of a large pore in the sunspot group NOAA 7519, observed on 5 June 1993 with the Swedish Vacuum Solar Telescope at La Palma on Canary Islands, has been recently described by Dorotovič et al. (2002). Special attention was paid to the evolution of a filamentary region attached to the pore, to horizontal motions around the pore, and to small-scale morphological changes. One of the results, relevant to out work here, was the determination of temporal area evolution of the studied pore where the area itself showed a linear trend of decrease with time at an average rate of -0.23 Mm^{2}h^{-1} during the entire observing period. Analysing the time series of the are of the pore, there is strong evidence that coupling between the solar interior and magnetic atmosphere can occur at various scales and that the referred decrease of the area may be connected with a decrease of the magnetic field strength according to the magnetic field-to-size relation. Periods of global acoustic, e.g. *p*-mode, driven waves are usually in the range of 5−10 minutes, and are favourite candidates for the coupling of interior oscillations with atmospheric dynamics. However, by assuming that magneto-acoustic gravity waves may be there too, and may act as drivers, the observed periodicities (frequencies) are expected to be much longer (smaller), falling well within the mMHz domain. In this work we determine typical periods of such range in the area evolution of the pore using wavelet analysis. The resulted periods are in the range of 20−70 minutes, suggesting that periodic elements of the temporal evolution of the area of this studied pore could be linked to, and considered as, observational evidence of linear low-frequency slow sausage (magneto-acoustic gravity) waves in magnetic pores. This would give us further evidence on the coupling of global solar oscillations to the overlaying magnetic atmosphere.

Keywords. magnetic fields — MHD — Sun: photosphere

1. Introduction

There is evidence that magnetic coupling through MHD waves and oscillations at the solar interior - lower and upper atmosphere plays an important role in the processes observed in the solar magnetized atmosphere (see e.g. the reviews by Banerjee et al. (2007), Erdélyi (2006)). McAteer et al. (2003) reported on coupling of upward-traveling kink mode waves with periods of $P = 8-12$ minutes with sausage-mode waves of periods $P = 4-6$ minutes. Rutten & Krijger (2003) detected gravity waves in the chromosphere. De Pontieu et al. (2003a) presented observational study of the interaction of the chromosphere with the upper transition region (TR). Intensity oscillations in the upper TR above active region has been studied by De Pontieu et al. (2003b) where the authors assumed periodic plasma flows causing these oscillations. Bloomfield et al. (2004a) and

Bloomfield et al. (2004b) applied wavelet analysis to study wave packets and identify magnetohydrodynamic (MHD) waves in the quiet-Sun network. Bharti et al. (2006) performed both wavelet analysis and Fourier analysis to examine oscillations (wave packets of traveling MHD waves) in isolated bright points co-spatial and co-temporal in the photosphere and the chromosphere. Coordinated EUV and radio observations have provided powerful diagnostics of the plasma and magnetic field in active regions, e.g. by Brosius & White (2004). They suggested that sunspot plume may be defined as an EUV-emitting source and found, based on the brightness temperature depression observed in radio observations, that the radio emission from the sunspot umbra originated in a volume of cool plasma, associated with a sunspot.

All the above examples identified -or perhaps better to say interpreted observations as-wave motion where the actual observation of the full waveguide itself was not explored. Imagers on satellites or ground-based imaging data, however, would allow a different approach: 2-dimensional imaging will allow us to study the *spatial* variations of oscillatory waveguides. One example of this new approach could be the analysis of the observed amplitude-dependence *along* the waveguide (see the paper by Verth & Erdélyi in this proceedings or Verth et al. (2007)). Another possibility could be the analysis and cross-sectional study of a waveguide, i.e. studying the temporal evolution of the cross-cut or area of e.g. a thin flux tube.

In this work we have focused on the investigation of evolution of the pore area during an 11-hour observing period. Our aim is to identify linear MHD waves in a magnetic pore and to provide further observational evidence for the existence of a magneto-acoustic sausage waves existing in vertical thin flux tubes.

2. Data and Method of Analysis

The sunspot group NOAA 7519 (see Fig. 1 in Sobotka et al. (1997)) was observed at heliographic position N05, E15 on 5 June 1993 with the Swedish Vacuum Solar Telescope (SVST, cf. Scharmer et al. (1985)) at La Palma, Canary Islands. An exceptionally long (11 hours) observing run, of persistently high quality seeing, was acquired with 22 s cadence between $8^{\mathrm{h}}\,07^{\mathrm{m}}$ and $19^{\mathrm{h}}\,07^{\mathrm{m}}$ UT. This sunspot group reached its maximum area on the date of the observation. Description of the observations and data reduction can be found in Sobotka et al. (1997). Recently, Dorotovič et al. (2002) performed an analysis of this 11-hour series of high resolution white light observations with special attention to the evolution of a filamentary region attached to a larger pore in the sunspot group NOAA 7519, to horizontal motions around the pore, and to small-scale morphological changes. The area of the large pore showed permanent decrease with time at an average rate of $-0.23\mathrm{Mm}^2\mathrm{h}^{-1}$ during the whole observing period. Data about the evolution of the area were exactly the main input for our identification of possible wave packets in the observed magnetic pore. Time series of the area has been de-trended by normalisation of each value to its mean value over the whole 11-hour period.

We performed wavelet analysis according to the computing algorithm of Torrence & Compo (1998) to study effects of MHD waves on the evolution of the area of the observed pore. The standard Morlet wavelet, a plane sine wave with an amplitude modulated by a Gaussian function, has been used here.

3. Results and Discussion

The wavelet spectrum plot is depicted in the form of a time-period map in Figs. 1 and 2. The crosshatched area marks the coin of incidence (COI) where edge effects affect

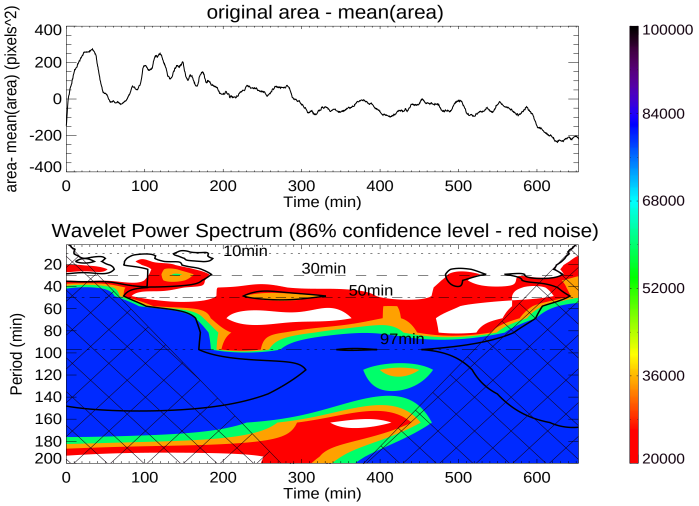

Figure 1. Evolution of the area of the pore (*upper panel*) and the wavelet power spectrum for red noise (*lower panel*). COI is marked as a crosshatched area.

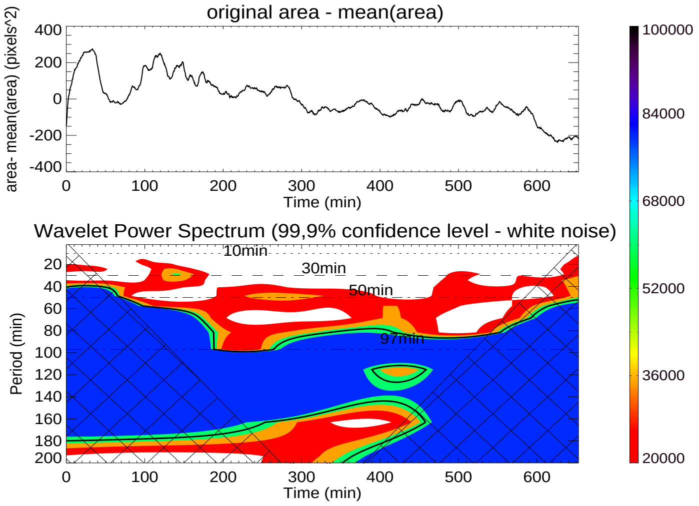

Figure 2. Evolution of the area of the pore (*upper panel*) and the Wavelet power spectrum for white noise (*lower panel*). COI is marked as a crosshatched area.

the WT results, contours show the confidence level (86 % for red noise and 99.9 % for white noise, respectively). The same analysis was done also for GWS noise, where the confidence level was set to 86 %.

Checking the WT power spectra we identified the following periods: 12, 17, 29, 48, 97 minutes. Periods of 17 and 49 minutes correspond well with results of Gelfreikh et al. (2004) who found radio oscillations at the wavelength of 1.76 cm above small sunspots with periods of 20, 30, and 40 minutes, respectively. Periods from our work, i.e. 29, 48, and 97 minutes, correspond well with values of periods of 30, 50, and 90 minutes found by Gelfreikh et al. (2004) for large sunspots. Increase of periodicities with time from 17 to 29, 48, and 97 minutes indicates energy dissipation of oscillations. This is manifested in the area decrease of the pore. Most probably oscillations in lower atmospheric layers can initiate oscillations of coronal loops which are sources of radio emission.

4. Conclusions

Based on the evolution of the studied pore area we naturally interpreted the observed periodic changes in the area cross-section of a thin flux tube, manifested as pore, as proof of existence of linear slow (magneto-acoustic) sausage waves. Increase of periods with time indicates energy dissipation of oscillations whereas energy dissipation refers to transfer of acoustic waves to chromosphere, TR, and corona. Characteristics of layers upwards from the photosphere are strongly varying. The behaviour of acoustic waves in such nonlinear environment is that energy flux is constant along their beam (Whitham 1974). Since density decreases rapidly with height, energy has to be spread to lower and lower number of particles and this leads to a heating process. Absorption in such environment depends both on the frequency and the thermal conduction (the latter being about 10 W/m.K in the sunspot photosphere). Acoustic waves have evidently wide range of frequencies where higher frequencies (shorter periods) are absorbed more than lower frequencies (longer periods), and then periods are gradually increasing. After inspecting Figure 1, one concludes that at time of approximately 500 mins there appears again new 30 minute period as if a new dose of acoustic waves leading to decrease of the area of the observed pore (energy dissipation).

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