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Velocity oscillation amplitude in bipolar active regions through SDO observations

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Abstract. Since their discovery, velocity oscillations in the lower solar atmosphere have been observed to interact with magnetic fields. The nature of this interaction, and the mechanisms that channel the energy to the upper layers, represent a crucial issue for the corona heating. In this work, we use SDO dopplergrams and magnetograms of 12 bipolar active regions (βARs) to study the relation between velocity oscillation amplitude and magnetic field. We find that the velocity oscillation amplitude depends not only on the magnetic field strength, but also on its polarity.

Key words. Sun:activity – Sun: oscillations

1. Introduction

The interaction between acoustic waves and magnetic fields generates MHD modes, which are able to channel and carry energy to the upper atmosphere. For this reason, this interaction may play an important role for solar corona heating.

The first evidence of velocity oscillation dependence on the magnetic field was provided by the works of Leighton et al. (1962); Woods & Cram (1981); Lites et al. (1982). They reported an amplitude reduction in the five-minute band by a factor 2 – 3 within ARs. Such a behavior was also found in smaller magnetic field concentrations (e.g. Roberts & Webb 1978; Spruit 1981).

Several mechanisms may explain the observations (Hindman et al. 1997): the intrinsic power inhibition due to local convection suppression; partial p-mode absorption (Braun et al. 1987; Bogdan et al. 1993; Cally 1995); opacity effects; and the alteration of the p-mode eigenfunctions at the hands of the magnetic field (Jain et al. 1996; Hindman et al. 1997).

From an observational point of view, it is natural to find a more evident amplitude reduction within ARs, where the strongest and largest scale magnetic fields are found. Among them, bipolar active regions (βARs) show peculiar morphological and physical asymmetries (e.g. Balthasar & Woehl 1980; Ternullo, M. et al. 1981; Zwaan 1985; van Driel-Gesztelyi & Petrovay 1991; Fan et al. 1993).

In this work we investigate the velocity oscillation amplitude reduction by the magnetic field. We conclude that such a reduction does

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Table 1. Details of SDO-HMI data used.

βAR number	Observation Date	Location
AR11166	2011.03.08 UT11:00-14:00	N11 W01
AR11283	2011.09.05 UT17:00-20:00	N13 W01
AR11302	2011.09.28 UT17:30-20:30	N13 W06
AR11319	2011.10.15 UT07:00-10:00	N09 E02
AR11316	2011.10.15 UT07:00-10:00	S12 E01
AR11330	2011.10.27 UT18:30-21:30	N09 E04
AR11338	2011.11.06 UT20:00-23:00	S14 W00
AR11341	2011.11.11 UT07:00-10:00	N08 W00
AR11362	2011.12.03 UT20:00-23:00	N08 W06
AR11367	2011.12.07 UT20:00-23:00	S18 W05
AR11375	2011.12.13 UT19:00-22:00	N08 W03
AR11389	2012.01.03 UT16:00-19:00	S22 W05

not depend only on the magnetic field strength, but also on the polarity of the field.

2. Data and analysis

Our data set consists of 12 HMI/SDO magnetogram and dopplergram series (Scherrer et al. 2012), with 1 arcsec spatial resolution and time cadence of 45 seconds (upper frequency cut-off).

Observations are 3 hour long (lower frequency cut-off $\sim 10^{-4}\mathrm{s}^{-1}$) and cover the interval from 2011 March 8 to 2012 January 3 (see Table1). The targets, chosen as close as possible to the disk center, correspond to 12 βARs, 8 in the N hemisphere and 4 in the S hemisphere.

In figure 1 we show the mean magnetogram of a selected βAR, namely AR 11166.

The observations for each selected βAR have been co-registered by FFT techniques. By visual inspection, we verified that the strong magnetic structures, i.e. those not vanishing

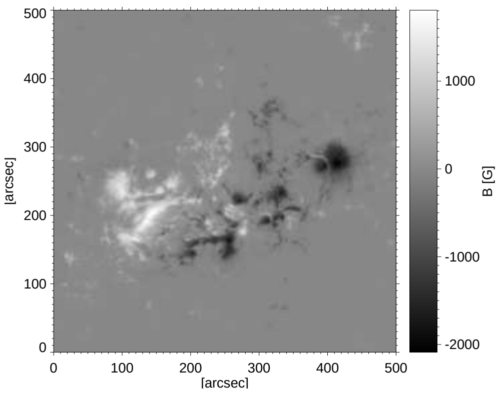

Fig. 1. SDO-HMI mean magnetograms of AR 11166.

on average, remain at the same location during the acquisition. Velocity oscillation amplitude was estimated pixel-by-pixel as follows. We selected a spectral window $\Delta\nu = 1$mHz around $\nu_0 = 3.3$ mHz (five-minute band). Then we integrated the FFT amplitude spectrum A_ν in that frequency range

$$A_{xy} = \int_{\Delta\nu} A_\nu d\nu$$

The field of view was divided into magnetic field bins, each 25 G wide, and the amplitude of velocity oscillations was averaged in each bin, thus obtaining $A_B =< A_{xy} >_B$. Only pixels with $|\mathbf{B}| > 25$ G were considered.

We note that the absolute squared value of the velocity oscillation amplitude corresponds to the power spectrum.

3. Results

In figure 2 we show the power spectrum retrieved by considering AR11166, as an example. Similar results are obtained for each βAR analyzed in this work, but not reported for the sake of brevity. The power spectra have been computed for each pixel, and then averaged in each magnetic bin $|\mathbf{B}| = 25 - 200$ G (black), $200 - 500$ G (red), $500 - 1000$ G (blue) and $1000 - 1500$ G (green). In our analysis we considered separately both polarities (in figure 2 continuous lines correspond to positive polarity and dashed lines to negative polarity).

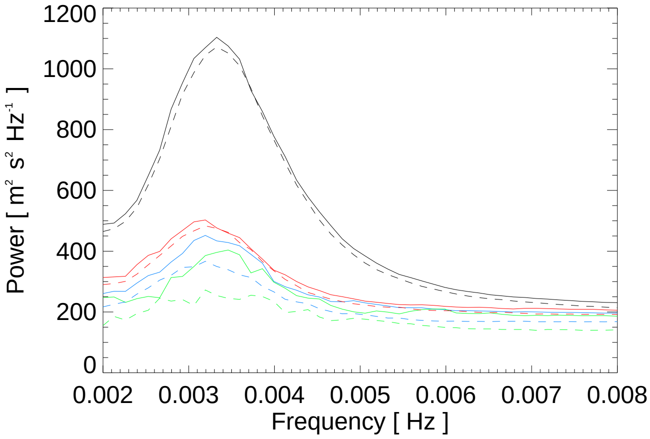

Fig. 2. Averaged power spectrum of AR 11166 in the bins $|\mathbf{B}| = 25 - 200$ G (black), $200 - 500$ G (red), $500 - 1000$ G (blue) and $1000 - 1500$ G (green). Continuous line corresponds to the positive polarity, dashed line to the negative polarity of the βAR.

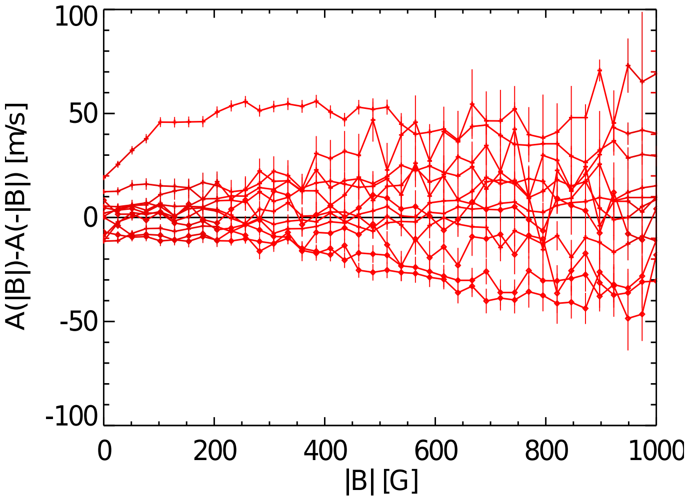

Fig. 3. Difference between oscillation amplitude for both polarities at fixed magnetic field strength VS the magnetic strength itself. Bars represent errors.

The peak in the spectra corresponds to the 3.3 mHz acoustic frequency (i.e. five-minute).

Two main outcomes emerge from this analysis. First, as expected, oscillation power decreases by increasing the magnetic field strength. Second, the reduction in power also depends on the magnetic field polarity. In fact, it is evident that even if the field strength is the same, different polarities correspond to different power reductions. In the case of AR11166, the negative polarity turns out to be more affected by the power suppression than the negative polarity. Moreover, the difference in power between the polarities increases by increasing the magnetic field strength.

The dependence of the oscillation amplitude on the polarity may be also shown fixing a value $|\mathbf{B}|$ for the magnetic strength, and computing the difference between the respective averaged amplitudes for both polarities in each βAR, namely $A_{|\mathbf{B}|} - A_{-|\mathbf{B}|}$. In figure 3 we show these differences versus the absolute value of magnetic strength for all βARs of table 1. In the case of a pure magnetic strength dependence, all the plotted lines should be close to 0. This is not the case. In fact, we note that $A_{|\mathbf{B}|} - A_{-|\mathbf{B}|}$ either increases or decreases with the magnetic field strength, depending on the polarity.

As we have choosen βARs as close as possible to the line of sight, any biasing projection effect should be excluded. Moreover, our sample comprises ARs which belong to both the hemispheres.

4. Conclusions

The interaction between acoustic modes and magnetic fields is a fundamental topic to be addressed, because of its relevance in the framework of the solar corona heating.
By means of SDO observations of 12 βARs in both hemispheres, we proved the dependence of the velocity oscillation amplitude not only on the magnetic field strength, but also on the magnetic polarity.

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