

Amplitudes of High-Degree p -Modes in the Quiet and Active Sun

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Motivation.

The global and local analysis of intermediate and high degree modes indicates that the mode amplitudes and solar activity level are anti-correlated (e.g. Chaplin et al., 2000, MNRAS, 313, 32). Further studies (see Rajaguru et al., 2001, ApJ, 563,410; Howe et al., 2004, ApJ, 608, 562) reveal a strong dependence of the amplitude on the local magnetic flux. In this work we investigate the mode amplitude in active and the quiet Sun at both maximum and minimum of the solar activity cycle. We mask active regions of certain magnetic field strength and compare the masked and unmasked acoustic power. This is carried out using two different methods, the ring-diagram technique and the peak profile fitting of the power spectrum.

Data Analysis.

We analyzed the following data sets:

- Two 10h time series of MDI Dopplergrams at solar minimum (May 24, 1996) and at solar maximum (September 9, 2000).
- Twenty two 10h long GONG Dopplergrams around solar minimum (June 02-13, 2007) and solar maximum (December 03-14, 2001).
- MDI full disk magnetograms to identify active regions and create corresponding masks for the analyzed days.

We apply two different methods and analyze $p1$ - $p4$ ridges as a function of the mode degree:

- The standard ring-diagram technique from the GONG pipeline where the patches within 30° from the disk center are averaged.
- The asymmetric peak profile fitting of the power spectrum (l - v diagram). Images are remapped, tracked, filtered with 15 min. running mean, and decomposed into Spherical Harmonic coefficients.

We perform the above analysis without masking of active regions. A mask for each day is created. An example of the mask is shown in *Figure 1*. The velocity images of each day are multiplied with the corresponding mask and the analysis is repeated. The computed acoustic power is normalized for the number of non-zero pixels.

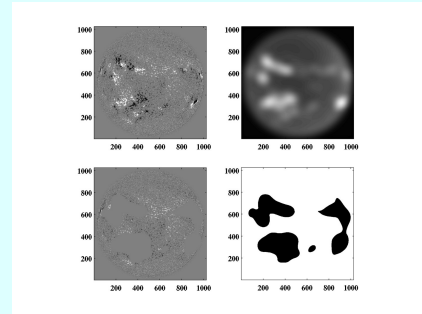


Figure 1. Top left: An MDI magnetogram; Top right: Smoothed unsigned magnetogram averaged over time; Bottom left: Masked magnetogram obtained from the top-right image with a cut-off value of 20 G showing only the quiet regions; Bottom right: Mask of strong field regions.

Results and Discussion.

In this study we address the following questions: How different is the mode amplitude in active and quiet Sun at minimum and maximum of the solar activity cycle? Do the mode parameters of the Quiet Sun vary with solar cycle? Does the Quiet Sun have more acoustic power at solar minimum in comparison with solar maximum or vice versa?

In this context, we have performed a few experiments where we have masked the active regions and compared the masked and unmasked acoustic power. *Figure 2* shows the amplitudes of $p1$ - $p4$ modes as a function of the degree of the mode obtained from 10h of MDI data. The mask used in this analysis is shown in *Figure 1*. We observe that the amplitude at solar minimum is lower than that of the solar maximum up to $l \sim 300 - 400$ and higher at higher degrees. The same trend is seen when we apply the mask, but the amplitudes decrease for all the modes. In an attempt to understand what causes the decrease in the amplitude when the mask is applied, we performed an experiment in the ring-diagram technique and excluded the active regions by masking the pixels above certain threshold level. The results (see *Figure 3*) manifest that the mode amplitudes decrease with removal of flux; the mode amplitudes became smaller and smaller with removal of more and more of the activity. These results are consistent with those obtained from the masking (see *Figure 2*).

In the above analysis we found day-to-day variations and to remove these systematic variations, we carried out an analysis averaging the data over a period of 11 days. In *Figure 4*, the amplitudes of $p1$ - $p4$ modes as a function of the degree of the mode obtained from 10h of GONG data, averaged over 11 days each in 2001 and 2007 are presented. The results confirm that the amplitude at solar minimum is higher than at solar maximum for all analyzed l -range. After masking the active regions, we again observe that the amplitude at solar maximum has the same tendency as the analysis involving one day, while at the solar minimum the amplitude decreases along l -range.

In order to comprehend the changes in amplitude, we performed a numerical simulation where we applied a circular artificial mask of three different radius to one day (Nov. 12, 2006) of MDI data. From the results obtained with the power spectrum analysis, shown in *Figure 5*, it appears that the variation in the amplitude seen above could be due to the effect of the mask or center-to-limb variations of the velocity. We plan to extend this study with artificial mask of different size and location on the solar disk and to carry out center-to-limb correction of the velocity to understand its effect on the mode amplitudes.

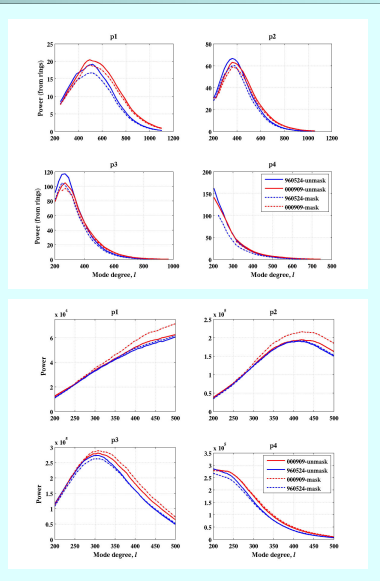


Figure 2. Amplitudes of $p1$ - $p4$ modes as a function of the mode degree obtained from 10h of MDI data. Solid red and blue lines correspond to unmasked active regions at solar maximum and minimum, respectively. Dot-dashed lines are for the masked active regions. Top and bottom panels show results from the ring and the power spectrum analysis, respectively.

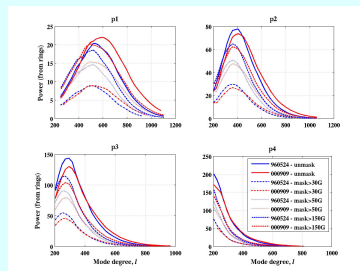


Figure 3. Amplitudes of $p1$ - $p4$ modes as a function of the mode degree obtained from 10h of MDI data by masking the pixels with unsigned magnetic field above certain threshold values. Solid red and blue lines correspond to unmasked active regions at solar maximum and minimum, respectively; dot-dashed are for a threshold of 30 G, dotted are for 50 G and dashed are for 150 G.

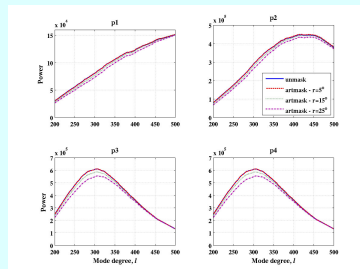


Figure 5. Amplitudes of $p1$ - $p4$ modes as a function of the mode degree obtained from the power spectrum analysis of MDI data Nov. 12, 2006. Here we construct circular artificial masks of different radius. The blue solid line shows the unmasked amplitudes. The red dashed, green dotted and magenta dot-dashed lines are for the results from 5° , 15° and 25° radius masks.

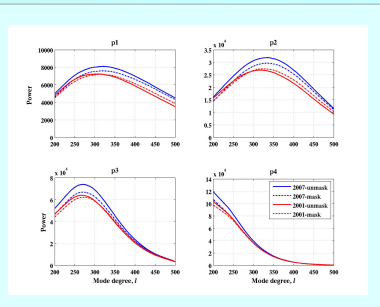


Figure 4. Amplitudes of $p1$ - $p4$ modes as a function of the mode degree obtained from the power spectrum analysis of 10h of GONG data, averaged over 11 days each in 2001 and 2007. The colors and the line styles have the same meaning as in *Figure 2*.

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