P-MODES IN AND AWAY FROM A SUNSPOT

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**Abstract.** A time series of GONG Dopplergrams for the period 10-14 May 1997 from Udaipur and Big Bear sites has been used to measure the velocity fluctuations in the sunspot (NOAA active region 8038) and quiet photosphere simultaneously. We observe that the power of pre-dominant p-mode is reduced in the sunspot as compared to quiet photosphere by 39-52% depending on the location of the sunspot region on the solar disk. We also observe a relative peak frequency deviation of p-modes in the sunspot, of the order of 80-310 $\mu$Hz, which shows a linear dependence on the magnetic field gradient in the active region. The maximum frequency deviation of 310 $\mu$Hz on 12 May appears to be an influence of a long duration solar flare that occurred in this active region. We interpret this relative peak frequency deviation as either due to power re-distribution of p-modes in the sunspot or a consequence of frequency modulation of these modes along the magnetic flux tubes due to rapidly varying magnetic field structure.

**Keywords:** Sun: Photosphere – Sun: Sunspot – Sun: Oscillations

1. **Introduction**

The study of intensity and velocity variations in and above an active region is continuously refined with successively improved observational techniques. The intent of such studies is to understand the basic mechanism of the interaction of acoustic waves with the complex magnetic features. These investigations are carried out by measuring and quantifying the scattering properties viz. amplitude, frequency and phase of solar eigen-modes. There are two possible methods to carry out this study. The first method involves the relative study of the properties of solar surface waves travelling towards an active region and the wave that is reflected from it (Tarbell et al. 1988; Braun, Duvall, Jr., and Labonte, 1988; Braun et al. 1992; Bogdan et al. 1993; Keppens, 1994; Cally, 1995). The other way can be a direct observation in and above an active region at photospheric and chromospheric layers respectively, which relates to the possible modulation of these acoustic waves along the magnetic flux tubes (Giovanelli and Slaughter, 1978; Lites, White, and Packman, 1982; Title et al. 1992; Hindman and Brown, 1998;
The investigations by both the methods have revealed a reduction in p-mode amplitude within active regions due to absorption of acoustic waves by magnetic structures. It is well established that the typical sunspots absorb as much as 40-50% of the power of incident acoustic waves (Braun, Duvall, Jr., and LaBonte, 1987). However, Braun and Duvall Jr. (1990) observed power reduction of nearly 70% in a large sunspot group (NOAA active region 5395).

There has been ample evidence towards significant deviations in peak frequency of the Doppler velocity and intensity oscillations in sunspots at upper photospheric and chromospheric layers with the help of a lot of new measurements in different spectral lines and with improved observational techniques (Kentischer and Mattig, 1995 and references therein). On the contrary, the p-mode oscillations in sunspots at photospheric layers have been reported to be of 300s (Beckers and Schultz, 1972; Rice and Gaizauskas, 1973; Soltau, Schröter, and Wohl, 1976; Livingston and Mathew, 1981) and 310 sec (Bhatnagar, Livingston, and Harvey, 1972), which is nearly same as that in the quiet photosphere. However, Nye et al. (1981) showed that the mean power spectrum of the umbral oscillations has several clear peaks, including a group of three peaks clustered around five minute period (260s, 300s and 350s) and a peak at about 200s. Similarly, Horn, Staude, and Landgraf (1997) have shown that the spectra of velocity oscillations in the sunspot show features of strengthened power peaks in the bands of periods around 3 min and weakened in 5 min with respect to the quiet Sun.

In this paper, a time series of GONG Dopplergrams has been analysed to improve our present understanding of the influence of magnetic fields on the oscillation properties of acoustic waves near a sunspot. The GONG instrument provides a spatial resolution of 8 arc-sec/pixel, which may be taken as a reasonable resolution for comparative study of p-mode oscillations in sunspot and quiet regions.

2. Data Analysis and Results

The data used in this study consists of Udaipur and Big Bear GONG Dopplergrams taken during 10-14 May 1997. The GONG instrument (Harvey et al. 1996) uses Ni I 6768 Angstrom spectral line to measure the global intensity and velocity variations in the solar photosphere. This instrument acquires full disk images of the Sun on a 256x256 pixel CCD camera implying a spatial resolution of 8 arc-sec/pixel. In spite of this low spatial resolution and a constant parasitic stray light problem in the sunspot, the GONG data can be reasonably used to
Table I. Data Description

| Station name | Date (1997) | Observing Time (UT) | Average sunspot location (Heliographic Coordinates) |
|--------------|-------------|---------------------|-----------------------------------------------------|
| Udaipur      | 10 May      | 03:30-11:00         | N20E17                                               |
|              | 11 May      | 02:16-12:36         | N21E04                                               |
|              | 12 May      | 02:30-11:30         | N21W10                                               |
|              | 13 May      | 03:00-11:30         | N21W22                                               |
|              | 14 May      | 03:00-11:20         | N21W35                                               |
| Big Bear     | 12 May      | 15:00-20:20         | N21W16                                               |
|              | 14 May      | 15:00-23:20         | N21W41                                               |

investigate the influence of magnetic field on the propagation of p-modes by carrying out a comparative study in quiet and sunspot region. We have used once a minute GONG Dopplergrams of the observing interval on each day during 10-14 May to measure the velocity fluctuations in the sunspot (NOAA active region 8038) and quiet photosphere simultaneously on the solar disk. The observing interval along with the position of the sunspot in Heliographic coordinates is given in Table 1. We have carried out this analysis for five continuous days, and also included data from two different stations, to enhance the statistical confidence.

The intensity and velocity images of the solar disk for 12 May taken at 05:13 UT from Udaipur site are shown in Figures 1 and 2 respectively. Since a sunspot is not visible on the Dopplergram, the corresponding intensity filtergrams have been used to locate the position of the sunspot on the solar disk. It is well known that Dopplergrams in addition to p-modes also exhibit variety of features such as supergranulation pattern, meridional flows and solar rotation gradients. A two point backward difference filter (GRASP/IRAF software package),

\[
\text{FilteredImage}(t) = \text{Image}(t) - \text{Image}(t - 1)
\]

is applied to the Dopplergrams to enhance the p-mode oscillations above other features.

The size of the sunspot under study is about 20 arc-sec, which is three times higher than the spatial resolution of GONG instrument. The size of the sunspot remains nearly the same for the period under study, and hence it remains confined within a pixel matrix of 3x3 during its passage on the solar disk during 10-14 May. Thus we chose a grid of 3x3 pixels for measuring the velocity fluctuations inside the sunspot.
in the time series of each individual day. On the other hand, three quiet photospheric regions (q1, q2 and q3) of equal grid size have been chosen at approximately the same limb distance to account for the effect of limb darkening, foreshortening and various other known effects. The selection of three quiet regions, instead of a single region on the opposite longitude, is carried out in view of (i) to increase the statistical confidence for a comparative study and (ii) to quantify the variation in the properties of acoustic modes in different locations of the quiet photosphere.

The velocity fluctuations are measured for each pixel inside the grid as a function of time. In Figure 3, we illustrate these fluctuations for 12 May 1997, Udaipur station. This time series of each pixel is subjected to Fourier Transform to obtain the power spectrum. The power spectra from 9 pixels in the grid are then averaged to improve the signal to noise ratio as suggested earlier by Kentischer and Mattig (1995). In this way, we obtain four average power spectra for each day as shown by dashed lines in Figures 4-10. It may be noticed that the power in sunspot is appreciably reduced as compared to all the quiet regions while the power and frequency of p-modes in quiet regions do not vary with statistical significance.

We notice that the power spectrum of acoustic modes in the quiet region follows an asymptotic Lorentzian distribution as observed earlier by Anderson et al. (1990). On the other hand, a significant departure from such a Lorentzian profile can be seen in the sunspot power spectrum. The power spectrum of p-mode oscillations in sunspot shows distinctly several peaks around 5 min period in agreement to earlier investigations (Nye et al. 1981; Horn, Staude, and Landgraf, 1997) which have been obtained using high resolution observations. Based on the approach for modelling the solar oscillation spectra for global p-modes, Anderson et al. (1990) suggested that Lorentzian fitting could be a suitable peak finding algorithm. However, in view of our sunspot results, the Lorentzian fitting may not be the best peak finding technique. Also with the aim of comparing the properties of p-mode oscillations between sunspot and quiet region, we need to apply the same peak finding algorithm to both the regions. Thus, to determine the genuine peak power and corresponding frequency of the power envelope, we applied a low pass digital filter, namely a Savitzky-Golay filter (Press et al. 1992), to the average power spectrum for both quiet and sunspot regions separately. This filter basically smooths the data by a window function of a predefined number of data points and a polynomial order with a proper weighting. After several experimental values of data points and polynomial orders, the optimal statistical fit is observed with a window of 32 data points and a polynomial of order 6. We have
Table II. Power and frequency estimate from S-G filter for quiet regions (q1, q2 & q3) and sunspot

| Date       | $P_{q_1}$ (1E5) | $\nu_{q_1}$ (mHz) | $P_{q_2}$ (1E5) | $\nu_{q_2}$ (mHz) | $P_{q_3}$ (1E5) | $\nu_{q_3}$ (mHz) | $P_s$ (1E4) | $\nu_s$ (mHz) |
|------------|-----------------|-------------------|-----------------|-------------------|-----------------|-----------------|-------------|---------------|
| Udaipur data: |
| 10 May     | 1.63 (1E5)      | 3.26 (mHz)        | 1.65 (1E5)      | 3.26 (mHz)        | 1.67 (1E5)      | 3.30 (mHz)      | 8.79 (1E4) | 3.19 (mHz)   |
| 11 May     | 1.86 (1E5)      | 3.26 (mHz)        | 1.90 (1E5)      | 3.29 (mHz)        | 1.89 (1E5)      | 3.26 (mHz)      | 11.27 (1E4) | 3.18 (mHz)   |
| 12 May     | 1.74 (1E5)      | 3.26 (mHz)        | 1.77 (1E5)      | 3.29 (mHz)        | 1.76 (1E5)      | 3.26 (mHz)      | 9.95 (1E4)  | 2.96 (mHz)   |
| 13 May     | 1.63 (1E5)      | 3.25 (mHz)        | 1.68 (1E5)      | 3.28 (mHz)        | 1.65 (1E5)      | 3.28 (mHz)      | 9.28 (1E4)  | 3.09 (mHz)   |
| 14 May     | 1.57 (1E5)      | 3.25 (mHz)        | 1.58 (1E5)      | 3.28 (mHz)        | 1.59 (1E5)      | 3.25 (mHz)      | 7.58 (1E4)  | 3.14 (mHz)   |
| Big Bear data: |
| 12 May     | 1.03 (1E5)      | 3.26 (mHz)        | 1.04 (1E5)      | 3.32 (mHz)        | 1.05 (1E5)      | 3.26 (mHz)      | 6.39 (1E4)  | 3.07 (mHz)   |
| 14 May     | 1.24 (1E5)      | 3.26 (mHz)        | 1.27 (1E5)      | 3.26 (mHz)        | 1.27 (1E5)      | 3.29 (mHz)      | 6.28 (1E4)  | 3.15 (mHz)   |

Table III. Estimation of relative power reduction and frequency deviation in the sunspot

| Date       | $P_q$ (1E5) | $\nu_q$ (mHz) | $P_s$ (1E4) | $\nu_s$ (mHz) | $\delta \nu$ (µHz) | $\Delta P$ (%) | $\Delta \nu$ (µHz) | $\Delta \nu$ ($\sigma$) |
|------------|-------------|---------------|-------------|---------------|-------------------|----------------|-----------------|-------------------|
| Udaipur data: |
| 10 May     | 1.65 (1E5) | 3.27 (mHz)    | 8.79 (1E4) | 3.19 (mHz)    | 34.72 (µHz)       | 46.66 (%)      | 80 (2$\sigma$) | $>$2$\sigma$ |
| 11 May     | 1.88 (1E5) | 3.27 (mHz)    | 11.27 (1E4) | 3.18 (mHz)    | 26.88 (µHz)       | 40.15 (%)      | 90 (3$\sigma$) | $>$3$\sigma$ |
| 12 May     | 1.76 (1E5) | 3.27 (mHz)    | 9.95 (1E4)  | 2.96 (mHz)    | 30.80 (µHz)       | 43.39 (%)      | 310 (10$\sigma$) | $>$10$\sigma$ |
| 13 May     | 1.66 (1E5) | 3.27 (mHz)    | 9.28 (1E4)  | 3.09 (mHz)    | 32.68 (µHz)       | 43.97 (%)      | 180 (5$\sigma$) | $>$5$\sigma$ |
| 14 May     | 1.58 (1E5) | 3.26 (mHz)    | 7.58 (1E4)  | 3.14 (mHz)    | 33.33 (µHz)       | 52.01 (%)      | 120 (3$\sigma$) | $>$3$\sigma$ |
| Big Bear data: |
| 12 May     | 1.04 (1E5) | 3.28 (mHz)    | 6.39 (1E4)  | 3.07 (mHz)    | 52.00 (µHz)       | 38.52 (%)      | 210 (4$\sigma$) | $>$4$\sigma$ |
| 14 May     | 1.26 (1E5) | 3.27 (mHz)    | 6.28 (1E4)  | 3.15 (mHz)    | 33.33 (µHz)       | 50.13 (%)      | 120 (3$\sigma$) | $>$3$\sigma$ |

then applied it to the average power spectrum for each day during 10-14 May to obtain the proper fitted power envelope as shown in Figures 4 to 10 by solid lines.

The estimated peak power and the corresponding frequency in the quiet regions (q1, q2 & q3) and sunspot are shown in Table 2 for each individual day. Based on the results listed in Table 2, we have calculated the variation in peak power and the corresponding frequency of the power envelopes for the three quiet regions. It is observed that the
variation in power among q1, q2 and q3 is within 5%, whereas the variation in frequency remains within the frequency resolution limit ($\delta \nu$) of the power spectra. This implies that the variation in power and frequency of the power envelope in the different quiet regions is within the limits of one standard deviation. Thus we conclude that the properties of p-modes do not vary significantly from one quiet region to other within the error limits. Therefore, we have averaged the peak power and corresponding frequency of all the quiet regions, which is then compared with that of the sunspot. The peak power ($P_s$) and the corresponding frequency ($\nu_s$) in the sunspot with the average peak power ($P_q$) and frequency ($\nu_q$) in the quiet regions are given in Table 3. It is observed that the sunspot peak power is reduced ($\Delta P$) by 39-52% as compared to quiet region during its passage on the solar disk. It is interesting to note that the corresponding frequency of the power envelope in the sunspot deviates ($\Delta \nu$) in the range of 80-310 $\mu$Hz relative to the quiet region. The comparison of the power envelopes estimated by S-G filter for quiet and sunspot regions for Udaipur station on 12 May is shown in Figure 11. The relative power reduction in the sunspot is clearly seen. A relative frequency shift of the power envelope in the sunspot is also noted.

3. Discussion and Conclusions

Our results distinctly show the power reduction in the sunspot relative to a quiet region on each day in agreement to earlier investigations. However, the amount of relative reduction in power in the sunspot ($\Delta P$) is found to be dependent on the location of the sunspot. During the period 10-13 May, when the sunspot is found within $\pm 25$ deg to the central meridian (Table 1), $\Delta P$ varies around 43%. On the other hand, on 14 May, when the sunspot moves further apart from the central meridian, $\Delta P$ is found to be significantly higher; of the order of 52% as illustrated in Table 3. Our study also shows an apparent frequency deviation of the power envelope of acoustic modes in the sunspot as compared to quiet regions. This frequency deviation ($\Delta \nu$), as shown in Table 3, is also varying during 10-14 May, the lowest being on 10 May and the highest on 12 May. It may be noted from Table 3 that the observed frequency deviation varies from 2-10$\sigma$, where $1\sigma$ is taken equivalent to the frequency resolution ($\delta \nu$) of the power spectrum. The frequency deviation of the power envelope ($\Delta \nu$) is considered to be of statistical significance when $\Delta \nu \geq 3\sigma$. Following this, we find that only the deviation between 11-14 May is significant. As observed from the Udaipur data, $\Delta \nu$ increases from 2$\sigma$ on 10 May to 10$\sigma$ on 12 May and
then drops to $5\sigma$ and $3\sigma$ on 13 May and 14 May respectively. Recently, Jain et al. (1999), based on the study of evolution of a sunspot region using SOHO magnetograms, have shown that the magnetic structure in this active region was rapidly varying. This conclusion was inferred from the growth and decay of emerging flux of both polarities close to the sunspot. As a ready reference, we show a sequence of few high resolution magnetograms of this active region taken from Jain et al. (1999) in Figure 12. It is observed that two major opposite polarities were approaching towards each other since 10 May, resulting in the growth of the magnetic field gradient, so as to collide around 04:42 UT on 12 May leading to a long duration solar flare event (04:42-06:20 UT) of 1B importance and an associated CME. We have calculated the daily variation in magnetic field gradient of this active region between 10-14 May and plotted it with the daily variation in peak frequency deviation in the sunspot (see Figure 13). This plot shows a strong linear dependence of the frequency deviation on the magnetic field gradient and hence magnetic structure of the active region. This indicates the role of the magnetic field gradient on the frequency deviation of the peak power in the power envelope of the acoustic modes of the sunspot relative a quiet region. The extraordinary increase in $\Delta \nu$, of the order of $310 \mu$Hz, on 12 May for Udaipur station may be interpreted as the influence of the long duration solar flare in the course of observing sequence as detected earlier by Jain and Tripathy (1998) while investigating the chromospheric modes in solar flare using high resolution H$\alpha$ filtergrams. However, we obtain a frequency shift of $210 \mu$Hz on 12 May from the Big Bear data comprising of a post flare time slot (15:00-20:00 UT), which can be understood by the simplification of the magnetic field structure as explained by Jain et al. (1999). The frequency deviation obtained from Big Bear data on 14 May is consistent with that obtained from Udaipur site on this day.

We conclude that in addition to the magnetic field gradient, the high energy build-up processes in the solar flares influence the properties of p-modes in the sunspot as compared to the quiet region. We conjecture that the deviation of the peak frequency of power envelope of p-modes in the sunspot as compared to quiet region is either due to a power re-distribution so as to peak at nearby frequency, or it could be the frequency modulation of these acoustic modes along the magnetic flux tube underneath the sunspot.
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References

Anderson, E.R., Duvall, Jr., T.L. and Jeffries, S.M.: 1990, Astrophys. J., 364, 699
Beckers, J.M. and Schultz, R.B.: 1972, Solar Phys., 27, 61
Bhatnagar, A., Livingston, W.C. and Harvey, J.W.: 1972, Solar Phys., 27, 80
Bogdan, T.J., Brown, T.M., Lites, B.W. and Thomas, J.H.: 1993, Astrophys. J., 406, 723
Braun, D.C., Duvall, Jr., T.L. and LaBonte, B.J.: 1987, Astrophys. J., 319, L27
Braun, D.C., Duvall, Jr., T.L. and LaBonte, B.J.: 1988, Astrophys. J., 335, 1015
Braun, D.C. and Duvall, Jr., T.L.: 1990, Solar Phys., 129, 83
Braun, D.C., Duvall, Jr., T.L., LaBonte, B.J., Jeffries, S.M., Harvey, J.W., and Pomerantz, M.A.: 1992, Astrophys. J., 391, L113
Balthasar, H., Martinez Pillet, V., Schleicher, H. and Wohl, H.: 1998, Solar Phys., 182, 65
Cally, P.S.: 1995, Astrophys. J., 451, 372
Giovanelli, R.G. and Slaughter, C.: 1978, Solar Phys., 57, 255
Harvey, J. et al.: 1996, Science, 272, 1284
Hindman, B.W. and Brown, T.M.: 1998, Astrophys. J., 504, 1029
Horn, T., Staude, J. and Landgraf, V.: 1997, Solar Phys., 172, 69
Jain, R., and Tripathy, S.C.: 1998 Solar Phys., 181, 113
Jain, R. et al.: 1999, ApJ (submitted)
Kentischer, T.J. and Mattig, W.: 1995, Astron. Astrophys. 300, 539
Keppens, R.: 1994, in GONG '94: Helio- and Asteroseismology from the Earth and Space, ed. Roger. K. Ulrich, Edward J. Rhodes, Jr., and Werner Dappen (A.S.P. Conference Series), p. 250
Lites, B.W., White O.R. and Packman, D.: 1982, Astrophys. J., 253, 386
Livingston, W.C. and Mahaffey, C.: 1981, in The Physics of Sunspots, ed. Lawrence E. Cram and John H. Thomas (Sac Peak Observatory conference proceedings 14-17 July, 1981), p. 312
Nye, A.H., Cram, L.E., Thomas, J.H. and Beckers, J.M.: 1981, in The Physics of Sunspots, ed. Lawrence E. Cram and John H. Thomas (Sac Peak Observatory conference proceedings 14-17 July, 1981), p. 313
Press, W.H., Teukolsky, S.A., Vellerling, W.T. and Flannery, B.P.: 1992, *Numerical Recipes in FORTRAN*, Cambridge Univ. Press, p. 644
Rice, J.B. and Gaizauskas, V.: 1973, *Solar Phys.*, 32, 421
Soltau, D., Schroter, E.H. and Wohl, H.: 1976, *Astron. Astrophys.* 50, 367
Tarbell, T.D., Peri, M., Frank, Z., Shine, R. and Title, A.: 1988, in *Seismology of the Sun and Sun-like Stars*, ed. V. Domingo and E.J. Rolfe (SP-286; Noordwijk: ESA), p. 315
Title, A.M., Topaka, K.P., Tarbell, T.D., Schmidt, W., Balke, C. and Scharmer, G.: 1992, *Astrophys. J.*, 393, 782
Figure 1. Calibrated GONG intensity filtergram (IZI) of the solar disk acquired at Udaipur site on 12 May 1997 at 05:13 UT. The image has been corrected for camera offset, camera rotation and camera pixel aspect ratio. The location of the sunspot is marked.

Figure 2. Calibrated GONG Dopplergram (VZI) of the solar disk acquired at Udaipur site on 12 May 1997 at 05:13 UT. The image has been corrected for camera offset, camera rotation and camera pixel aspect ratio and then passed through a two point backward difference filter to enhance the p-mode oscillations above other features.

Figure 3. Time series of velocity oscillations of a single pixel for quiet and sunspot region on 12 May 1997 (02:30-11:30 UT), Udaipur station.

Figure 4. Average power spectra (dashed lines) of p-modes over a grid of 3x3 pixels for quiet regions (q1, q2 & q3) and sunspot on 10 May 1997 for Udaipur station. Shown in solid line is fit estimated by S-G filter after smoothing the data by a window function of 32 points and a polynomial of order 6.

Figure 5. Same as Figure 4 for 11 May 1997, Udaipur station.

Figure 6. Same as Figure 4 for 12 May 1997, Udaipur station.

Figure 7. Same as Figure 4 for 13 May 1997, Udaipur station.

Figure 8. Same as Figure 4 for 14 May 1997, Udaipur station.

Figure 9. Same as Figure 4 for 12 May 1997, Big Bear station.

Figure 10. Same as Figure 4 for 14 May 1997, Big Bear station.

Figure 11. Comparison of the power envelopes estimated by S-G filter for quiet (solid line) and sunspot (dashed line) for Udaipur station on 12 May 1997. The relative power reduction in the sunspot is clearly seen. A relative frequency shift of the power envelope in the sunspot may also be noted.
Figure 12. Sequence of a few high resolution magnetograms of NOAA active region 8038 obtained by MDI/SOHO for the period 11-13 May 1997 (Jain et al. 1999). The relative motion of the regions of opposite polarities can be clearly understood from this sequence of magnetograms of the active region. The ejection of the north polarity flux from the sunspot and growth of new EFRs are observed. The collision of opposite polarities took place at around 04:42 UT on 12 May 1997 and is also visible in the magnetogram at 04:52 UT. This led to a long duration solar flare event (04:42-06:20 UT) of 1B importance.

Figure 13. Plot showing the variation of peak frequency deviation of the power envelope of p-modes in the sunspot with the change in magnetic field gradient of the sunspot active region. The error bars indicate 1σ value.
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