# VARIATION OF WIDTH, ASYMMETRY, AMPLITUDE AND FREQUENCY OF SOLAR *p*-MODES DURING THE SUN'S MAGNETIC ACTIVITY CYCLE

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## ABSTRACT

The mechanism of the sun's magnetic activity cycle is one of the major questions that has persisted in solar astronomy for the past three decades.  It is believed that by studying structural properties of the sun such as its activity cycle, we will be able to make important advances in understanding the solar interior and solar evolution that can then be applied to other more distant stars.  In this project, the author has used a global helioseismic approach to examine temporal shifts in the width, asymmetry, amplitude and frequency parameters of the high degree and high frequency pressure modes within the sun.  These shifts are then compared to corresponding changes in the level of solar activity during part of the year 2001.  The data used consisted of sets of power spectra that were computed from three-day observing runs obtained by the Global Oscillation Network Group.  These spectra were generated prior to this study at the University of Southern California.  The power spectra were then renormalized, averaged with respect to the azimuthal order *m*, and fit to both symmetric and asymmetric theoretical profiles.  Temporal differences in the frequency, width, and asymmetry parameters were compared to 10 different sets of solar activity changes using a linear regression model.  The fitted parameter differences were binned as a function of frequency and the linear regression model was applied for each of the 25 resulting frequency bins.  The linear regression analyses showed systematic signatures for the frequency dependence of the shifts in the frequencies, amplitudes, widths and asymmetries. An improved understanding of the causes of these temporal shifts will be of paramount importance to furthering our knowledge of the solar cycle, and of stellar evolution and structure in general, just as earlier examinations of the pressure modes have lead to discoveries regarding internal solar structure that are now known as the hallmarks of Helioseismology.

## 1.0 INTRODUCTION

### 1.1 HISTORY

Astronomy has been a topic of scientific interest for centuries, and the star nearest to us (our sun) has always been of particular interest.  In the mid-20th century, as observational technology continued to improve, scientists and astronomers began to notice specific features of the sun as well as some of its major surface dynamics.  Among these early observations of the

solar surface were those performed by Leighton, Noyes and Simon (1962), who claimed that the entire photosphere was oscillating with a period of five minutes. The study we now call helioseismology is a relatively new science that began its development in 1970 when Roger K. Ulrich first suggested that these five-minute oscillations extend much deeper into the sun. He suggested that this cyclic pattern of the entire solar surface is actually an integrated result of many smaller waves or "modes" that extend much deeper into the sun. Furthermore, he suggested the waves were caused by pressure gradients in the upper convective zone of the solar interior. These pressure modes, or "p-modes" that are like ordinary spherical sound waves in nature, vibrate in various resonance cavities within the sun. This phenomenon has lead helioseismologists to make the popular comparison of the sun to a ringing bell. It is this discovery that has allowed us to study the structure of the solar interior by studying the behavior of the p-modes.

Since these fundamental discoveries were made, helioseismologists have acquired a wealth of data characterizing these modes that can be analyzed and inverted in various ways to study properties of the solar interior. In addition to allowing us to examine the specific properties of the sun, we may also study physical properties of conditions that cannot be reproduced in any lab on Earth. Some major areas of interest in terms of solar interior exploration have included various thermodynamic properties, the depth of the convective zone, radial angular velocity variation, and general composition (i.e. Helium abundance). The work that I will be doing will be concerned primarily with an observational result that appeared in the mid-1990's, specifically dealing with temporal shifts in mode parameters as they are related to the sun's magnetic activity cycle (also known as "the solar cycle").

1.2 STATEMENT OF PURPOSE

The purpose of this project is to examine various parameters of high degree and high frequency pressure modes and how they change over the solar cycle. These parameters will include, in addition to an analysis of the frequencies that were previously examined for this particular data set, mode widths, amplitudes, and asymmetries. I will be using m-averaged three-day power spectra computed from observing runs performed by the Global Oscillation Network Group. The observing run occurred at the maximum of the most recent completed solar cycle (during 2001) and is a period during which average solar activity is increasing. After the peaks in the power spectra are fit with both symmetric and asymmetric theoretical profiles, the data will be analyzed using a subtraction method in order to obtain the temporal changes in the mode width, amplitude and asymmetry that can then be compared to changes in the level of solar activity using a linear regression model. This will be the first study to specifically look at the changes in these parameters of p-modes of degrees from 0 to 1000 at high frequencies (from about 1000 to above 7000μHz). Finally, this study will offer minimal speculation as to the still open question of exactly how changes in various mode parameters come about and rather offer high quality observational results that may be used to further explore the mechanism that is causing the various mode parameter shifts.

1.3 RESEARCH QUESTIONS

How do different parameters of solar pressure modes (specifically mode widths, frequencies, amplitudes, and asymmetries) change with the varying levels of magnetic activity characteristic of the progression of the solar cycle, and what can these shifts tell us about the mechanism of the solar cycle? Also, does the theory that increased magnetic activity has a

damping effect on p-modes within the sun hold when compared to shifts and correlations that will comprise the results of this study?

## 1.4 HYPOTHESES

As is consistent with the idea that increased solar activity has a damping affect on pressure modes within the sun, we expect to find that mode widths become larger with increased solar activity. That is to say, we expect to find that the widths are positively correlated with solar activity. Also consistent with the damping effect, we expect to find that the amplitudes decrease with increasing solar activity, and so are anti-correlated. In terms of the asymmetries, a small body of previous work with low degree modes has suggested that systematic temporal variations may become apparent in our study.

## 1.5 RECENT WORK ON SOLAR CYCLE-RELATED PARAMETER SHIFTS

The first ever sign of the correlations between changes in frequency and the changes in solar activity was discovered by Martin Woodard and Robert Noyes when they compared the changes in solar irradiance as measured by the ACRIM instrument to changes in low degree mode frequencies and discovered a definitive trend. The data they compared were from the years 1980 and 1984, close to solar maximum and minimum respectively. This allowed them to see a fluctuation in the average frequencies of about 0.42µHz. Later, it would be confirmed that low degree mode frequencies are in fact positively correlated with changes in solar activity, as they had demonstrated.

In 1990, Libbrecht & Woodard found that the frequencies of intermediate degree p-modes also change over time in relation to the solar cycle, and that the magnitude of these shifts

depended strongly on the frequency.  In this pioneering study, the authors also began to hypothesize about what exactly it is about the change in solar activity that causes these frequency shifts.  They believed it to be a periodic change in the structure of the sun and, because the magnitude of the frequency shifts depended on the mode frequency, they inferred that whatever relevant structural change was causing the shifts was occurring near the surface.  Libbrecht & Woodard also examined even frequency splitting coefficients for the modes and found similar frequency dependence, further exposing the character of what they referred to as near-surface "perturbations."  Since then, a parallel result has been discovered for low and high degree p-modes, although less work has been done with the latter.  It is the general result of Libbrecht and Woodard's findings, these apparent temporal shifts of mode parameters, which we will attempt to expand on in our study.

In the last 20 years, various studies have been done to explore the effects of the solar cycle not only on acoustic mode frequencies, but also on other structural properties such as wave propagation speed and radially varying solar rotation.  It is the hope that studying the details of these p-mode shifts along with the other changes that distinguish the solar cycle (such as the periodically fluctuating number of sunspots and changes in the magnetic field strength) will give us a way to refine current theories regarding the workings of the solar cycle mechanism.  One such study was done by Golreich *et al.* (1991) and examined the changes in magnetic field and entropy of the sun in order to discern the cause of temporal p-mode frequency shifts.  Another study by Antia *et al.* (2001) examined solar cycle related changes in sound speed by looking at frequency splitting coefficients that have previously been used to look at radially varying angular velocities within the sun.

More recent studies in this very specific area of solar cycle-related p-mode shifts, have focused on using increasingly accurate data sets and various analysis techniques (often essentially related to the analysis that was used in this study) to discover new features of the frequency shifts and more rarely, the shifts of other mode parameters.  By virtue of being newer studies, they feature newly produced data that has not yet been analyzed in this way.  Two such papers were written by Elsworth *et al.* (1994) and Bhatnagar *et al.* (1999).  Elsworth uses similar methods of analysis on data from the BISON network, while Bhatnagar analyzed data from the GONG network.  Both of these are ground-based networks of telescopes equipped with specialized instruments positioned around the world.  These types of papers provide continually interesting results as some of the newest and most accurate instrumental additions to the arsenal of solar observation tools, including the Solar and Heliospheric Observatory satellite, have barely been in operation for more than one solar cycle.

Naturally, the recent works that are most closely related to mine are those done by Dr. Edward Rhodes.  In the last ten or so years, Rhodes has shifted his focus to the specific area of helioseismology concerning the variation of p-mode frequencies with solar cycle.  Even more specifically, he now focuses on high degree and high frequency modes and the effect of anti-correlation at higher frequencies (above $5000\mu Hz$).  This is especially exciting as it has only been within the last 12 or so years (just more than a solar cycle) that high degree oscillations have been accurately distinguishable.  In a recent conference proceeding, Rhodes emphasizes the importance of analyzing data gathered for high degree modes in addition to low and intermediate degree modes in order to obtain a more complete understanding of various solar phenomena and internal structure, including sound speed and even the equation of state.  The result of his 2003 study that is most pertinent to my work is included in the section that addresses temporal

frequency shifts with the progression of the solar cycle. His main findings in this area were that shorter observation periods yield more visible changes and allow increased sensitivity to short term changes with solar cycle, rather than observing changes occurring over long periods of time. He was also able to show that not only were the frequency shifts of higher degree modes ($l > 5000$) anti-correlated with changes in solar activity, but they were also more sensitive to these changes (Rhodes, *et al.* 2003).

The main similarity between the work presented in this paper and Rhodes' work described above is the use of three-day time series power spectra of modes ranging in degree from 0 to 1000 and ranging in frequency from 1000 to above 7000μHz. However, because this study does not only look at frequency shifts, we must also mention other studies that have looked at mode width and power in order to help provide a basis for our work. One of the earliest studies that looked at how mode line widths changed with differing levels of solar activity was a study done by Jeffries *et al.* (1991), which used South Pole Ca K intensity data. In terms of temporal shifts affected by solar cycle, Jeffries *et al.* (1991) found that for modes with degrees between 80 and 100 and with central frequencies of about 3000μHz, mode widths were larger when there was increased activity on the sun and smaller when there was less activity (examining data for 1981 and 1987, respectively). The study further hypothesized that mode power would also decrease systematically as the level of solar activity increased.

Another study, performed by Elsworth *et al.* (1993), used data collected by the Birmingham Solar Oscillation Network to look at low-degree p-modes and how their power varied with changing levels of solar activity during the solar cycle that occurred between 1981 and 1992. To do this they used a measurement of the area under the Lorentzian peak, which is defined as the product of the mode height, width and π/2. They found that, for all *l* values

measured, there was a 35±5 percent decrease in mode power from solar minimum to solar maximum. However they claimed not to find significant variation in the widths, and so attributed this extreme power difference to a corresponding decrease in the amplitudes. As a result they concluded that higher levels of activity may affect the strength of p-mode excitation, or else the increased occurrence of various magnetic phenomena causes increased absorption and damping that decreases the observed mode power.

A study performed by Komm, Howe, and Hill (2000) used measurements of mode width and amplitude derived from three-month time series produced by the Global Oscillation Network Group. They found significant changes in the width, amplitude and area of the pressure modes during times of differing levels of solar activity. Similar to Elsworth *et al.* (1993), they found that changes in these various measurements were not dependent on the degree *l*. Komm, Howe, and Hill (2000) found an average of a 3% increase in the width, a 7% decrease in the amplitude, and a 6% decrease in the mode area when examining the time frame of the solar minimum in 1996 to October 1998. These findings are consistent with the trend that seems to suggest that various magnetic phenomena occurring in the photosphere and upper convective zone absorb p-mode energy and therefore enhance an apparent damping effect.

The asymmetry of the spectral peaks we are examining is thought to be caused by the interference of modes that have different phases and are moving in different directions within a certain resonant cavity. The model for this type of wave behavior, which is also related to the damping of p-modes, is a Fabry-Perot interferometer with a source that is close to the cavity. As it is put by Duvall *et al.* (1993), "A phase difference between an outward direct wave and a corresponding inward wave that passes through the cavity gives rise to the asymmetry." This study further suggests that to ignore the asymmetries is to introduce a significantly large

systematic error.  It has not been until very recently that researchers have begun looking at how the asymmetry parameter changes over time.  One very recent study performed by Jimenez, *et al*. (2007) used contemporaneous data from five different ground and space-based data sources to examine asymmetry shifts for low degree ($l \leq 3$) modes.  The study, completed only two years ago, was the first to show the existence of temporal changes of the asymmetry parameter.  We aim to extend these results by examining temporal asymmetry shifts within our own data set, thereby extending the results to higher degree and high frequency modes.

## 2.0 METHODS

2.1 DATA

Currently, there are many different sources that research groups performing helioseismic research may utilize to obtain their data.  Many of these sources are ground-based telescopes or networks of multiple identical telescopes that are equipped with instruments fashioned especially for collecting solar oscillation data.  The data that we will analyze consists of power spectra produced from three-day time series observing runs that are generated by the Global Oscillation Network Group.  The "GONG" network is a project of the National Solar Observatory, an organization devoted to advancing solar research and knowledge.  This group also collaborates with a larger network of scientists, including Dr. Edward Rhodes' research group at the University of Southern California, in order to process and analyze the data that is obtained.

The time series data are composed of full disc Dopplergrams that are decomposed into hundreds of thousands of various individual modes.  Dopplergrams are created by taking two

images of the full solar disc at a set time interval and then subtracting the earlier image from the later one in order to see what parts of the image have shifted towards us and what parts have shifted away as time progresses. Of course, we must initially account for the shifts that will be apparent due to the solar rotation. This rotation will cause the image to have the appearance of fading from dark to light in a general trend across the solar disk. When we correct for this effect, we are able to see the minute details of how the solar surface is fluctuating, with light and dark points speckled across the solar surface. From these Dopplergrams, researchers may use existing software to consolidate the granulated images into useful images that contain information pertaining to individual waves, specifically into something called power spectra.

The creation of power spectra from raw time series data is equivalent to forming pictures of the numerous distinct modes that are manifested on the surface of the sun. This process was completed by another research group at University of Southern California, after which we obtained these raw power spectra and began to analyze them. In the power spectra, we are able to see energy concentrated into ridges at certain frequencies for various wave degrees and radial orders. Contained inside each of these ridges is pertinent information about the frequency, linear width, asymmetry and amplitude of each mode. Particularly we will use these data to, beyond just mapping the properties of modes, look at how these properties change over time. These shifts will then be compared with changes in the level of solar activity, as measured by an array of solar activity indicators.

2.2 DATA ANALYSIS

Various methods have been employed in the studies mentioned above, however we have employed what we believe to be the most up-to-date methods that exist for this kind of

work. In our case, another group at the University of Southern California has already put the data we receive into the form of power spectra (of three-day time intervals). After obtaining the power spectra data, we rename it to fit our naming conventions and average the data with respect to the azimuthal order $m$, which corresponds to the characteristic number of longitudinal nodes of each spherical harmonic wave. The M-averaging is done for all modes of degree $l$=0 to $l$=1000 and all relevant values of the radial order, $n$, in order to improve frequency resolution and reduce noise in measurements at the higher frequencies that we are interested in. M-averaging is a process that is familiar to helioseismologists who are examining the details of global oscillations as we are (Gough, D.O. 1996).

Next, the spectra are renormalized in order to account for any downtime that the observing instrument has had (i.e. gaps in otherwise continuous time data) and reduce error that is introduced by this downtime. This is done to adjust the values of the amplitudes by a factor that is directly related to the duty cycle values (number of minutes for which there is data divided by total number of minutes in a given run) as missing data can have the effect of decreasing the magnitude of the amplitude measurement.

We then fit the m-averaged, renormalized spectra to both symmetric and asymmetric theoretical profiles as described in Rhodes et. al. (2003). The fitting method we have employed is known as the "Windowed, Multi-Peak, Averaged-Spectrum" Method or WMLTP. This method is designed to include as many as nine line profiles and its accuracy is increased when the theoretical profile is convolved with the actual temporal window function of each observing run. This method can be employed using a symmetric or asymmetric profile, the asymmetric profile being the more accurate of the two as it better corresponds to the asymmetric forms that

more realistically characterize p-mode spectral peaks.  This process serves the purpose of fitting the individual peaks contained within the ridges of the power spectra in order to obtain measurements of various properties of the individual modes.  These properties include the frequency, width, asymmetry and amplitude of each mode.  At this point, we may begin to look at the temporal width, asymmetry and amplitude differences by using a simple subtraction script that extracts the specified parameter and its error from both files, and subtracts earlier values from later ones.  This allows us to see how the mode parameters change over time.

Subtraction is performed for all of the 27 three-day date ranges (and one two-day run) in the 83 day dynamics run that occurred from March to October of 2001.  These differences are then binned, a process that takes the numerous data points produced by the subtraction and compacts them to 25 or so binned points at distinct frequencies that more readily convey temporal trends when graphed.  The activity differences for the three-day averages of the dynamics run are also calculated separately.  Activity differences are calculated for 10 solar activity indicators. These include the International Sunspot Number, American Sunspot Number, 10.7cm Radio Flux, Magnetic Plage Strength Index, Mount Wilson Spot Index, |B| corr, Magnesium II core to wing ratio, Equivalent Width absorption line, and two Solar Extreme Ultraviolet Monitor channels. Two that will examine more closely in the results section of this paper are the International Sunspot Number and the |B|corr., which refers to the magnitude of the of the sun's magnetic field, averaged over the entire solar disc.  These two have been chosen because not only do they correlate well with the various parameters we are examining, but they are also representative of the other eight solar activity indicators.  After the average activity differences are calculated, the two sets of differences (those of the specified mode parameter and activity indicator) for each binned frequency may be compared.  These two sets are compared

using a linear regression model that produces slopes, slope errors, intercepts, intercept errors and correlation coefficients for the data sets. We then examined the results in order to draw conclusions.

### 3.0 RESULTS

After having performed the linear regression, we were able to examine the slopes, correlation coefficients and intercepts produced by the program. The slopes and correlation coefficients allow us to see the comparison between the changes in the level of solar activity and the changes the particular parameter that we are looking at, be it the width, asymmetry, frequency or amplitude. This regression is at the heart of our analyses. From it, we were able to examine trends and phenomena that became apparent in the graphs of the various regression results in order to add depth to our analysis and thus, our understanding. The discussion of these results will require us to look at trends in the results of the regression analysis, as plotted against frequency. For the purpose of this initial discussion, we will confer the results that came of our regression of the symmetric case including 351 data points, keeping in mind that the asymmetric fit results produced very similar results in terms of general curve behavior.
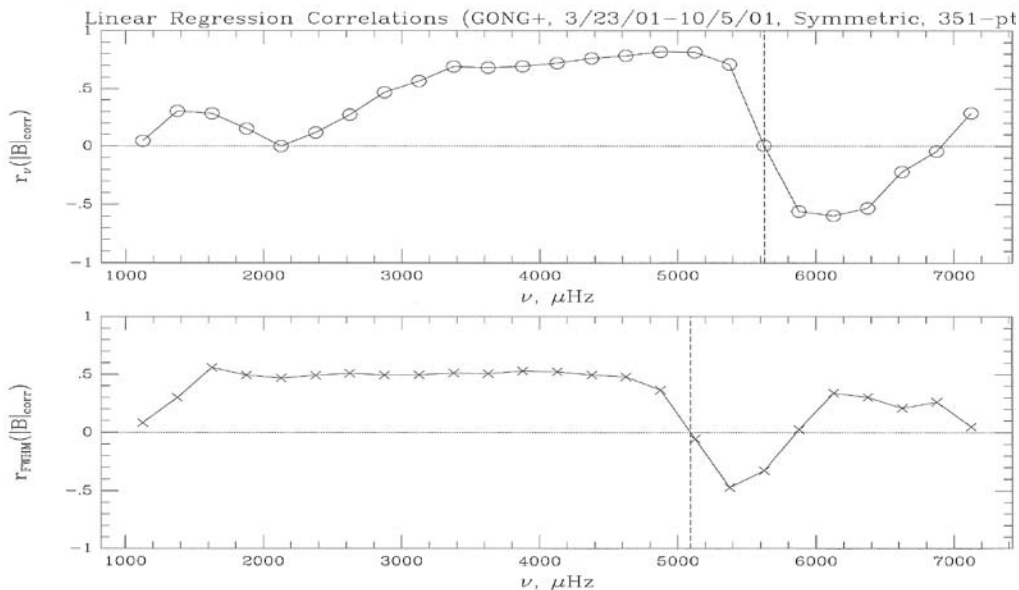


*Figure 1. a. (top) Correlation coefficients of the frequency and |B|corr. activity indicator, plotted vs. mode frequency. b. (bottom) Correlation coefficients of the widths and |B|corr. activity indicator, plotted vs. mode frequency.*

The pattern of the curves representing the correlation coefficients for the widths (labeled as FWHM for full width at half maximum) vs. frequency is particularly striking. When compared to the frequency shifts as shown in Figure 1a, we are able to see that the width shifts shown in Figure 1b. are even better correlated with solar activity (as indicated by the |B|corr. in this case) than frequency at frequencies below about 2500µHz. More importantly, the width correlation exhibits a curve very similar to that of the frequency curve, whose behavior, or "signature," that is well established by previous work. Both remain positively correlated until they reach a frequency of about 5000 to 6000µHz, where they become anti-correlated. One noticeable difference in this behavior is that the width curve seems to stay level before going negative, while the frequency curve demonstrates a more complicated behavior, increasing to a point and decreasing only slightly before dropping off.

This "zero-crossing frequency" also seems to be on average about 600µHz higher for the frequency correlation curve than it is for the width correlation curve. Also, depending on the independent variable (the activity indicator), the frequency correlation may or may not show a second definite zero-crossing from negative to positive. However, the width correlation coefficients show this result quite plainly. The fact that the change in the widths is positively correlated (up to about 5000µHz) with solar activity tells us that widths do in fact become larger as the level of solar activity increases. This is consistent with the notion that the increased magnetic activity that is characteristic of the increased solar activity has a significant damping effect on the pressure modes that we are studying. The anti-correlation effect that we see for the width shifts at higher frequencies is consistent with the one we see for the frequencies shifts (although it occurs at a consistently lower frequency). This may suggest that the width and the

frequency shifts are closely related, and that whatever phenomenon that is causing the anti-correlation at high frequencies is affecting both of these parameters.
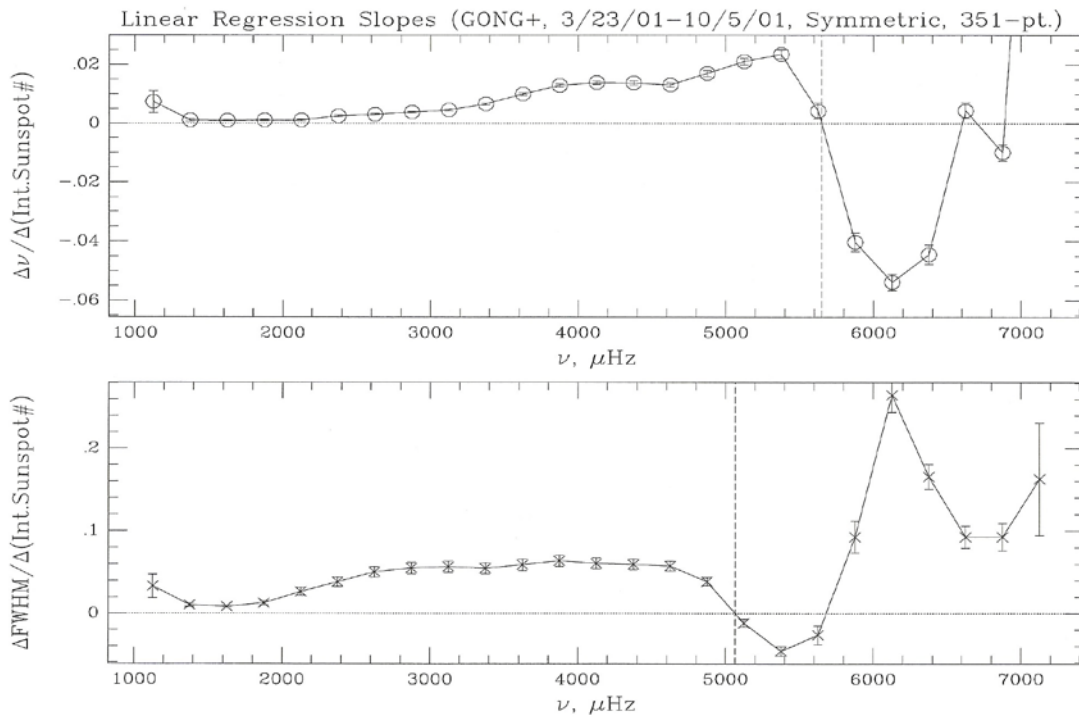


*Figure 2  a. (top) Slopes of the frequency and International Sunspot activity indicator, plotted vs. mode frequency.  b. (bottom) Slopes of the widths over International Sunspot Number activity indicator, plotted vs. mode frequency*

We are able to see similar trends for the slopes in Figure 2, which also indicate a correlation but with the International Sunspot Number (up to about 5000µHz for the widths and 5600µHz for the frequencies), and varying anti-correlated behavior thereafter.  As we saw with the correlation coefficients, the anti-correlated behavior of the widths seems to be more consistent than that of the frequencies for our data set.  One parameter for which we were not able to attain a significant result during the time allotted by the research institute was the amplitudes.  As one can see by examining the plot of the amplitude slopes in the third panel of Figure 3, there is one overwhelming result (occurring between about 2000 and 4000µHz) that has effectively erased any interesting behavior that we might have been able to see at other frequencies.  If more time were available, it may have been best to normalize this behavior in

order to better see the finer details of the curve.  Also, Figure 3 allows insight into how similar

the curves for the various solar activity indicators behave when compared to each other by

showing the plots of slopes in 3a and 3b for the |B|corr. indicator, which can be compared to the
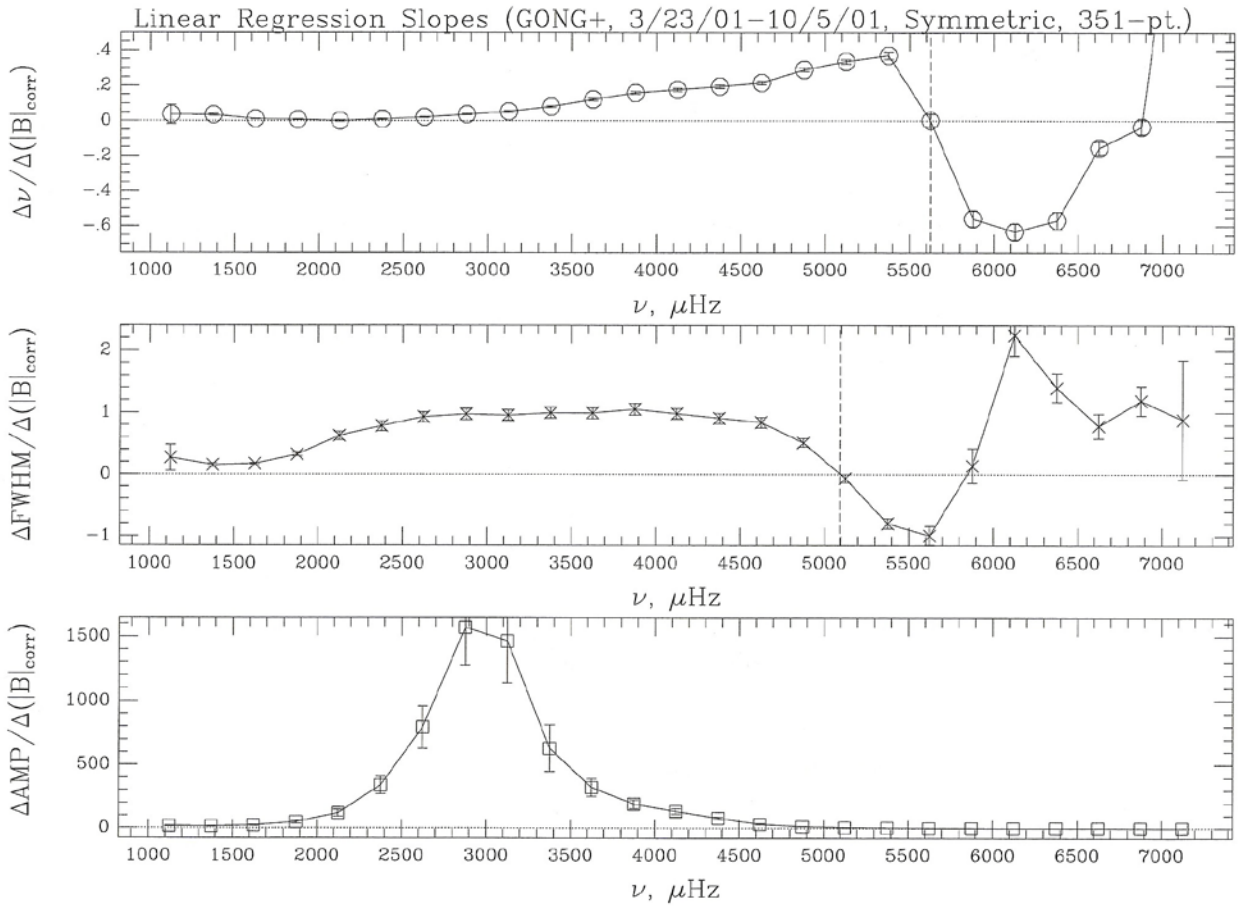
plots in 2a and 2b for the International Sunspot Number case.



*Figure 3 a. (top) Slope of the frequency shifts over the changes in |B|corr., plotted vs. frequency.  b.  (middle) Slope of full-width-at-half-maximum shifts over the changes in |B|corr., plotted vs. frequency.  c.  (bottom) Slope of the amplitude shifts over the changes in |B|corr., plotted vs. frequency.*

We have also included the results for the slopes of the asymmetry parameter as compared

to the International Sunspot Number in Figure 5b.  In addition to the slope curve, we have

chosen to include some of the raw values of both the asymmetry and the activity indicator, with

the days between which the observing run that produced our data occurred indicated by two

downward pointing arrows (Figure 4a).  In the graph of the raw asymmetry values we have

included a curve showing the values at high activity, marked by "X" points, and another

indicating the values at low activity, marked by "O" points as shown by the label on the left hand

side.  The two times that we chose to represent widely varying levels of activity are also

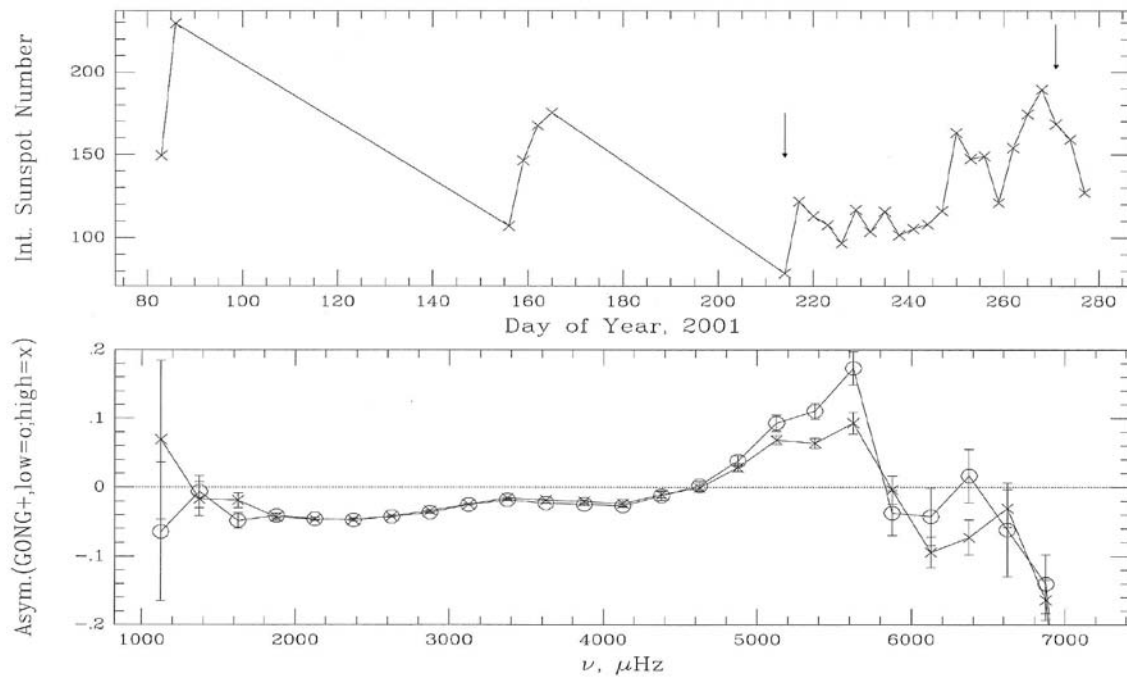indicated by the two arrows on the plot of the International Sunspot Number values.



*Figure 4.  a. (top) Plot of the raw values of the International Sunspot Number during the year 2001.  b. (bottom)  Plot of the values of the asymmetry parameter at high (X points) and low (O points) levels of activity within our data set.  The two points from which these data are taken are indicated by the two downward facing arrows shown in Figure 4a.*

We also include a plot of the changes in the asymmetry vs. the changes in the

International Sunspot Number in order to show the negative trend in the slope (Figure 5a).

Moreover, while the slope curve in Figure 5b of the asymmetries has a shape similar to the slope

curves of both the widths and the frequencies, it appears to have been shifted downward (in the

negative $y$ direction) so that the entire curve is below zero and all of the binned slope values are

negative.  This suggests a varying degree of anti-correlation that also appears to exhibit the steep

decline that we see in the widths and frequencies when they cross zero.  In contrast, the slopes of

the asymmetries seem to stay very close to zero, although below it, until the slopes become more

negative above about 5000μHz. After this dip, the curve begins to climb again in a manner that

is again similar to the behavior of the frequency and width slope curves. This kind of behavior,

as shown in the accompanying figure, is highly similar across different activity indicators.
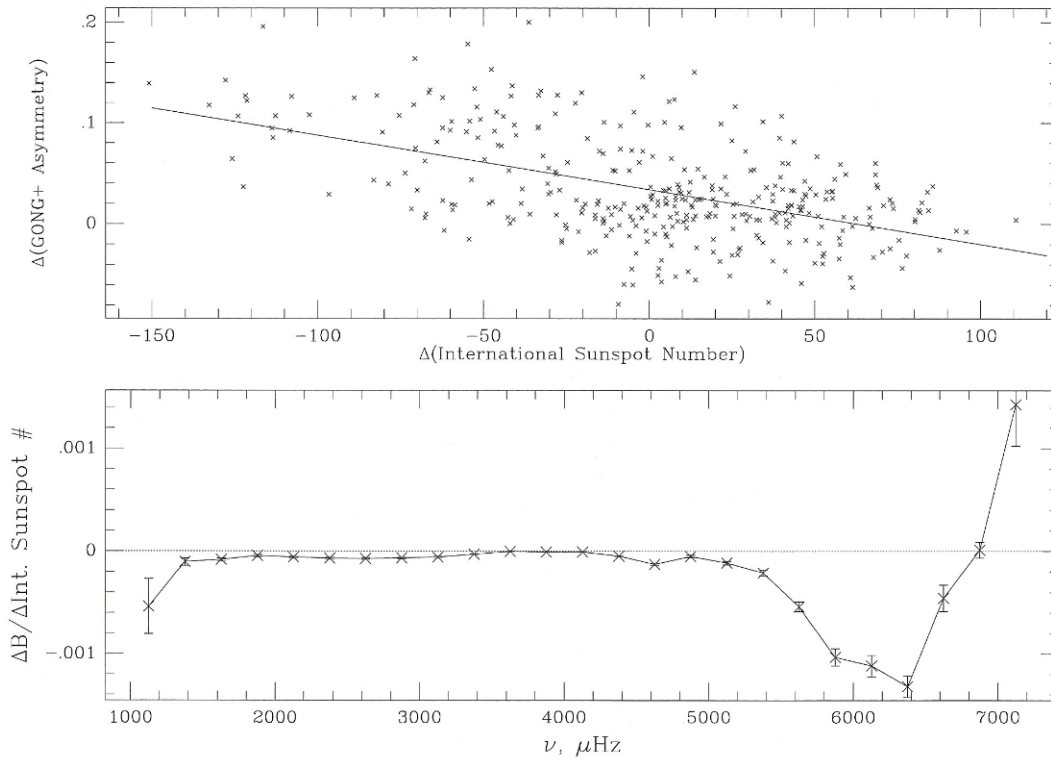


*Figure 5. a. (top) Plot of changes in asymmetry parameter vs. the changes in the International Sunspot Number with the linear regression line drawn over the points. b. (bottom) Slope of the asymmetry parameter shifts over the changes in International Sunspot Number, plotted vs. frequency.*

## 4.0 LIMITATIONS/ ERROR

One of the major limitations inherent in the work presented here is that it only looks at

one 83-day run within one year at solar maximum. Therefore we are not able to compare our

results with years or even time frames that would have exhibited not only different levels of

average activity, but also different degrees of activity changes. Also all of our analyses looked at

regression results as function of frequency while some might argue it is more relevant to look at

those parameters as a function of degree. Other sources of error in our measurements include atmospheric effects (as the telescopes are ground based), any unexpected downtime that we may not have been able to account for that would cause the data to be discontinuous, and human error.

## 5.0  FUTURE AREAS OF STUDY

Because we have not been able to analyze data for other years or time frames in a similar fashion, and because these kinds of results for high degree and high frequency p-modes have not yet been attained elsewhere, it would be in the interest of a future study to explore data from other years using similar methods in order to better frame the results. This would provide a grounding for the results, and allow someone to compare how these measurements change in different years throughout the solar cycle, and permit further insight into what might be causing the various apparent phenomena. Other studies may wish to explore the parameters studied here using different data from other sources, i.e. the Michaelson Doppler Imager aboard the Solar and Heliospheric Observatory satellite. Data from this and future sources will provide even more accurate results as instruments become more advanced and the amount of down time in a given observing run approaches zero. Lastly, it is likely that our group will continue to further explore amplitudes shifts of the modes for this particular data set by normalizing the extreme curvature that we have found in order to better see and understand any trends that may exist.

## 6.0  CONCLUSION

In conclusion, we have demonstrated that there is, in fact, a systematic relationship between the level of solar activity and the widths and asymmetries of pressure modes in our data

set ranging in degree from 0 to 1000 and in frequency from about 1000 to 7000μHz. The affirmation or negation of the existence of any kind of similar systematic trend for the amplitude parameter will require further investigation. We have also shown that the behavior of the width and asymmetry correlation and slope curves show a basic similarity to those of the frequency curves. In the case of the asymmetry curve, these values remain negative but display the same steep drop and subsequent climb that is characteristic of the frequency curves. The width curves appear even more similar as the steep drop they experiences also cross zero, only at a frequency that is consistently about 600μHz lower than that of the frequency parameter zero-crossing frequency. The finding that p-mode widths do increase with increasing solar activity provides evidence of the damping relationship that others have predicted exists regarding increased solar activity and pressure modes within the sun. Thus, this study has opened the door to taking a holistic approach at looking at pressure mode parameter shifts with solar cycle and, if continued, may well produce results that will allow us to better understand the phenomenon that causes these shifts and perhaps the entire solar cycle mechanism.

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