PROPAGATING WAVES IN OFF-LIMB POLAR REGIONS

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ABSTRACT

We examine long spectral time series taken in off-limb polar locations with the Coronal Diagnostic Spectrometer (CDS) on board SOHO. From a study of the transition region O v 624 Å line and the coronal lines of Mg x 609, 624 Å and Si xii 520 Å, we report on the presence of oscillations found in these regions. Using calculations of phase delays between cooler and hotter lines, we present evidence both for wave propagation and for the presence of particular wave modes.

Key words: Oscillations; Waves; Transition Region; Corona.

1. INTRODUCTION

Evidence for waves in the outer atmosphere of the Sun comes from measurements of radiance and Doppler velocity oscillations in a range of frequencies, including visible, ultraviolet, X-ray and radio, given off by different solar structures at chromospheric, transition region and coronal temperatures. A number of studies (Ofman et al. 1997, DeForest & Gurman 1998, Banerjee et al. 2000, Banerjee et al. 2001a, Banerjee et al. 2001b) have measured oscillations in plumes, interplumes and coronal holes in the polar regions of the Sun. All of these studies point to the presence of compressional waves, thought to be slow magnetoacoustic waves as found by DeForest & Gurman (1998). In this work we look for further evidence of propagating slow magnetoacoustic waves in polar regions of the Sun.

2. OBSERVATIONS

The seven CDS temporal series datasets (26348, 26363, 26406, 26438, 26447, 26478, 26542) used in this study were taken in a Northern polar region between the 29th November and the 27th December 2002. The seven
Figure 2. Typical wavelet results for the four lines, as labeled. These oscillations were taken from a height of 989'' in dataset 26363. In the top panel is shown the relative (background trend removed) intensity, in the central panels the colour inverted wavelet power spectrum, in the bottom panel the variation of the probability estimate associated with the maximum power at each time in the wavelet power spectrum (marked with the dotted white lines), and in the right middle panel the global (averaged over time) wavelet power spectrum. Above the global wavelet are printed the frequencies measured from the first and second maxima in the global wavelet spectrum, together with estimates of probability (errors in brackets) that these oscillation are not due to noise. The cross-hatched regions in the wavelet spectrum are locations where estimates of the oscillation frequency become unreliable. As a result of the COI the minimum measurable frequency is 0.27 mHz (dashed line in the global spectrum plots).
Figure 3. (a) (left panel) Simulated data showing the presence of a fixed 250s time delay between two time series (solid and dotted lines). (right panel) Calculated phase delay results for the simulated data (square symbols) overplotted with the expected phase delays for a fixed time delay of 250s (solid line). (b) The same results for a fixed time delay of 500s.

datasets each contain 150 time frames obtained with an exposure time of 60s. The data were binned by 2 along the 143” slit to produce 70 pixels in Y, in order to improve the signal-to-noise (S/N). Data were obtained for 11 transition region and coronal lines but here we shall only discuss four of these; the transition region O II 629.73 Å line (≈2.5×10^3K) and the coronal lines of Mg x 609.79, 624.94 Å (≈1.25×10^6K) and Si xi 520.67 Å (≈2.5×10^6K). We shall henceforth refer to the lines without the following decimal places, e.g., 629 in place of 629.73, etc.

3. ANALYSIS AND RESULTS

In Fig. 1 we show the location of the CDS slit (for four representative datasets) in the Northern polar region, overplotted on an EIT 171 image taken at ≈1.3×10^6K and an EIT 284 image at ≈2×10^6K. In Fig. 2 we show, using wavelet plots, some typical oscillations measured in our data. Note that at all temperatures similar frequencies of oscillations are present, suggesting the presence of waves travelling from cooler (O II) to hotter (Mg x, Si xi) temperatures. We show these oscillations in the form of wavelet plots solely as a visual example. To actually measure if there are any phase delays between these oscillations we will use instead the techniques of Fourier time series analysis.

Since the expected phase differences are given by the equation, Δφ=2πfT, where F is the frequency and T the time delay in seconds, the phase difference will vary linearly with f, and will change by 360° over frequency intervals of Δf=1/T. An example of this is given in Fig. 3 for simulated data, where Δf=1/250s=4 mHz and Δf=1/500s=2 mHz.

So, measuring the phase differences (or delays) at all frequencies allows us a technique for measuring the time delays between different temperature lines. A result of such a measurement with our data is shown in Fig. 4.

Note that the measured phase delays lie along roughly straight sloping lines as expected from the simulated data in Fig. 3. However, these ‘straight’ lines are at intervals of less than Δf. Shifting the phase delay values to the horizontal allows us to produce histograms of the phase distribution lying along the sloping data points in Fig. 4 (c.f. Fig 5). To achieve this a straight line fit was first made to the sloping set of data points that run through the zero point (0°) of the phase delays in Fig. 4. Then, a rough fit was made to determine the approximate slope of these scattered points and this was then further refined by iteration and by only choosing datapoints that lie within σ/2 of the fitted line on each iteration. Using this sloping fitted line, and shifting it to the horizontal (i.e., so that it lies along Y=0° at all frequencies) by adding (or subtracting) the relevant phase difference at each frequency, we were then able to shift all our measured points by the equivalent phase amounts at each frequency.

These shifted phase delays were used to produce the histograms of phase distribution shown in Fig. 5. From Fig. 5 we see that the phases are at intervals of f/4 (90°) and 3f/16 (67.5°), for Mg x 609–Si xi 520 only, suggesting that Δφ=2π(f + nΔf)T, where n=0,1,2,etc. and Δf=f/4 or 3f/16. Straight lines, in blue, at these intervals are plotted over the data in Fig. 4.

4. DISCUSSION

From straight line fits to the slopes of the lines in Fig. 4, we measure fixed time delays of 58±7s for O I 629–Mg x 624, 106±14s for O I 629–Si xi 520, 65±5s for Mg x 609–Si xi 520 and 71±6s for Mg x 624–Si xi 520. From measurements of limb brightening the formation heights between the different lines were measured allowing us to measure propagation speeds of 154±18 km/s for O I 629–Mg x 624, 218±28 km/s for O I 629–Si xi 520, 236±19 km/s for Mg x 609–Si xi 520 and 201±17 km/s for Mg x 624–Si xi 520. These speeds are close to those expected for sound-like waves propagating at these temperatures.

5. CONCLUSIONS

We conclude from this work that the oscillations we see in off-limb polar regions are due to upwardly propagating
Figure 4. Phase delays measured between the oscillations in the different line pairs, as labeled, e.g., between O V and Mg X 624 (left panel). Radiance oscillations are shown as the black circles while (Line-Of-Sight) L.O.S. velocity oscillations are shown as the grey circles. Phase delays were measured at the 95% and 99% significance levels. Phase delays at the 99% significance level are indicated by the slightly larger symbols. Average uncertainties in the 95% and 99% phase delay estimates are shown by the representative error bars in each plot. Over-plotted on this plot are lines corresponding to fixed time delays of 90° and 67.5° (for Mg X 609–Si XII 520).

waves with speeds close to those of sound. The waves are likely to be slow magnetoacoustic waves. The presence of phase delays at fixed intervals of 90° and 67.5° suggests the influence of resonant cavities on the waves; the waves are either produced in these cavities or are passing though them.

REFERENCES


Figure 5. Histograms showing the number of occurrences of phase delay measurements as a function of their value. Dotted lines refer to fixed phases at 90° intervals, whole dashed lines refer to fixed phases at 67.5° intervals.