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Letter to the Editor

The detection of 3 & 5 min period oscillations in coronal loops

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Abstract. High cadence, 171 Å, TRACE observations show that outward propagating intensity disturbances are a common feature in large, quiescent coronal loops. These oscillations are interpreted as propagating slow magneto-acoustic waves. Using a wavelet analysis, we found periods of the order of 282 ± 93 s. However, a careful study of the location of the footpoints revealed a distinct separation between those loops that support oscillations with periods smaller than 200 s and periods larger than 200 s. It was found that loops that are situated above sunspot regions display intensity oscillations with a period of the order of 172 ± 32 s, whereas oscillations in "non-sunspot" loops show periods of the order of 321 ± 74 s. We conclude that the observed longitudinal oscillations are not flare-driven but are most likely caused by an underlying driver exciting the loop footpoints. This result suggests that the underlying oscillations can propagate through the transition region and into the corona.

Key words. MHD – Sun: oscillations – corona – sunspots

1. Introduction

Due to the high spatial and temporal resolution of present day spacecrafts such as SOHO and TRACE, we have recently seen an increasing amount of observational evidence for both longitudinal and transversal coronal oscillations. Using the White Light Channel of the UVCS instrument (SOHO), Ofman et al. (1997) found signatures of compressional waves in plumes high above the limb. Coherent quasi-periodic compressive waves were detected by DeForest & Gurman (1998) in EIT (SOHO) observations of solar polar plumes and Ofman et al. (1999) interpreted those disturbances as slow magneto-acoustic waves. De Moortel et al. (2000) reported on the detection of similar propagating oscillations observed in a large coronal loop on 23rd March 1999 in the TRACE 171 Å passband, which they also suggest to be propagating slow magneto-acoustic waves. Robbrecht et al. (2001) compare propagating disturbances in coronal loops, observed on 13th May 1998, in the TRACE 171 Å and EIT (SOHO) 195 Å passbands. Transversal, flare-excited oscillations of coronal loops were first discussed by Schrijver et al. (1999), and subsequently by Aschwanden et al. (1999), Nakariakov et al. (1999) and Schrijver & Brown (2000). An extensive overview and analysis of transversal coronal loop oscillations was presented by Schrijver et al. (2002) and Aschwanden et al. (2002). Obviously, detecting oscillations in coronal loops is crucial to improve existing estimates of coronal properties and dissipation coefficients, vital information for both numerical and theoretical coronal heating models.

In this Letter, we report on the relation between the observed periods of longitudinal oscillations in large, quiescent coronal loops and the position of their footpoints above either sunspot or non-sunspot regions. In Sect. 2 we describe the observations and the preparation of the data. An explanation of the analysis and an overview of the results are given in Sect. 3, followed by a discussion in Sect. 4 and summary in Sect. 5.

2. Observations

The analysis in this letter uses high-cadence, 171 Å TRACE data that was taken as part of JOP 83 (23 March 1999 and 04–19 April 2000) and JOP 144 (5–13 June 2001). At the time of observing, the observed active regions were generally quiescent and only a few (small) flares occurred. All data have been corrected for dark current and cosmic ray hits using the standard TRACE procedures. For a detailed analysis, we extracted subcubes of roughly 25–30 min, with a constant cadence of typically 10 s for the JOP 83 data and 30 s for the JOP 144 data. The selected subcubes are the longest sequences with identical exposure times and a roughly constant cadence,

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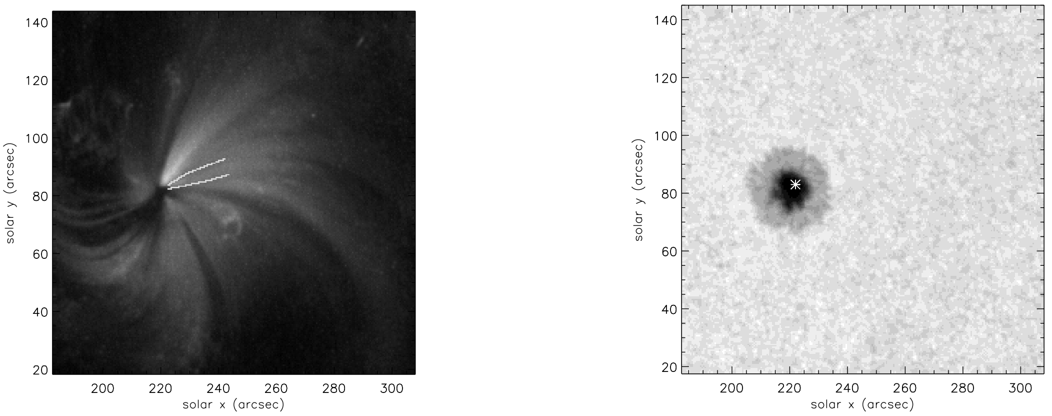

Fig. 1. Typical example (TRACE 171 Å – 13 June 2001, 0646 UT) of a large coronal loop footpoint supporting an oscillatory signal (left) and underlying TRACE White Light image.

which are uninterrupted by the South Atlantic Anomaly (SAA) and radiation belt transits. To increase the signal-to-noise in the JOP 83 data, we summed over consecutive images, thus reducing the cadence to about 20 s. All JOP 83 data and the JOP 144 data taken on 5 June 2001 have a pixel size of 1″, whereas the remaining JOP 144 data have a pixel size of 0.5″.

3. Analysis and results

The data analysis is based upon the method described by De Moortel et al. (2000); a running difference is used to identify propagating disturbances and an oscillation timescale is subsequently determined from a wavelet analysis, with a 99.0% confidence level. We divide the lower part of the loop that displays an intensity oscillation (see Fig. 1, left) into cross-sections and add all the unique data counts along 2 or 4 cross-sections, for 1″ and 0.5″ pixel sizes respectively. After this procedure, a cross-section corresponds to roughly 2″. To obtain a uniform normalisation, we finally divide by the number of pixels present in each cross-section. To extract and enhance the time-variable behaviour of the loop, a running difference was created by subtracting an earlier timestep from each frame and an example of such a running difference is shown in Fig. 2. The clear, diagonal bright and dark bands in the running difference indicate the presence of propagating disturbances with respectively higher and lower intensities. The horizontal feature that can be seen in the running difference between $t = 650$ s and $t = 750$ s is caused by a data anomaly that occurred 638 s after the start of the time series.

We examined a total of 51 TRACE 171 Å subcubes and we here present the 38 best examples of coronal loop footpoints that display intensity oscillations. We note that, in this context, the term *footpoint* does not refer to the actual photospheric/magnetic footpoint of the loops, but to what appears to be the lower coronal part of the loops. In Table 1, we give an overview of the distribution of some characteristics of the loops and the observed oscillations.

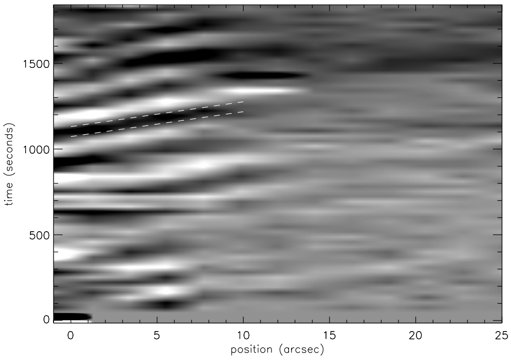

Fig. 2. A plot of the running difference between the average time series for each position along the structure.

Table 1 gives the range of observed periods $P_{\rm min} \rightarrow P_{\rm max}$ that were obtained using a wavelet analysis, giving values from 145 to 525 s. In all cases, the maximum period $P_{\rm max}$ was still well within the cone of influence of the wavelet analysis. However, as we want to concentrate here on propagating disturbances, we only take into account those periods $P_{\rm prop}$ that are consistent in a significant number of consecutive positions along the loop. We found values for these dominant oscillatory periods with a mean and standard deviation of $P = 282 \pm 93$ s, ranging from 145 s to 525 s. All periods are well above the acoustic cutoff (Ofman et al. 1999) and hence the waves can propagate into the corona. The obtained periods have also been confirmed by a fast Fourier transform. Subsequently, we used TRACE White Light data to determine whether the analysed loop footpoints where situated above a sunspot. As an example, Fig. 1 (right) shows the TRACE WL image that underlies the coronal region and the asterisk indicates the position of the start of the coronal loop that is marked in Fig. 1 (left). Unfortunately there were a few examples (marked with ? in Table 1) where the available data did not allow us to make a definite conclusion. We found 10 loops that are situated above sunspots, 25 loops

Table 1. Overview of the oscillations found in the JOP 83 & JOP 144 TRACE data in the 171 Å bandpass; Date gives the date of the observation, t_0 is the start time of the analysed data subcube, AR gives the number of the active region, (x, y) the solar x and y coordinates in arcsec of the loop footpoint, the column under "Sunspot" indicates whether the footpoint is situated above a sunspot or not, $P_{\rm prop}$ is the dominant, propagating period in seconds and $P_{\rm min} \rightarrow P_{\rm max}$ the range of observed oscillation periods in seconds.

Loop	**Date**	t_0	**AR**	(x, y)	**Sunspot**	$P_{\rm prop}$	$P_{\rm min} - P_{\rm max}$
1a	230399	0653	8496	(770, −230)	N	290	180−420
2a	040400	0928	8939	(−112, 364)	N	400	210−430
3a	050400	0230	8939	(60, 361)	N	240	230−470
4a	070400	1328	8939	(548, 344)	N	300	190−420
4b	’	1151	’	(530, 340)	N	210	210−340
4c	’	1242	’	(580, 317)	N	275	255−290
4d	’	1328	’	(433, 295)	N	360	300−410
5a	**080400**	**1204**	**8939**	**(668, 424)**	**Y**	**165**	**160−170**
6a	**090400**	**1354**	**8939**	**(786, 411)**	**Y**	**175**	**170−185**
7a	*110400*	*1514*	*8948*	*(335, −153)*	*?*	*290*	*280−370*
7b	’	*1514*	’	*(345, −166)*	*?*	*330*	*220−370*
7c	’	1514	’	(480, −154)	N	400	345−440
8a	130400	1405	8948	(750, −158)	N	275	250−370
9a	170400	1325	8954	(216, 392)	N	260	210−480
10a	**180400**	**2330**	**8955**	**(219, −266)**	**Y**	**255**	**255−390**
11a	190400	1535	8955	(324, −291)	N	260	170−360
12a	**050601**	**0637**	**9484**	**(237, −93)**	**Y**	**160**	**155−165**
13a	060601	0650	9484	(283, −88)	N	300	260−340
13b	’	0650	’	(280, −95)	N	250	220−365
13c	’	0650	’	(285, −94)	N	330	285−360
13d	’	0650	’	(280, −110)	N	285	265−285
13e	**’**	**0650**	**’**	**(446, −102)**	**Y**	**145**	**130−155**
13f	’	1006	’	(328, −84)	N	270	210−600
13g	**’**	**1006**	**’**	**(481, −101)**	**Y**	**155**	**150−155**
14a	070601	0836	9484	(511, −94)	N	350	250−400
14b	’	0836	’	(505, −111)	N	375	240−400
14c	’	1314	’	(530, −83)	N	525	210−570
14d	’	1314	’	(522, −84)	N	260	220−400
14e	**’**	**1314**	**’**	**(677, −109)**	**Y**	**145**	**145−185**
14f	**’**	**1314**	**’**	**(676, −111)**	**Y**	**160**	**155−170**
15a	*090601*	*0828*	*9487*	*(−145, 330)*	*?*	*350*	*350−450*
16a	120601	0725	9493	(−115, 99)	N	450	400−470
16b	’	0725	’	(−130, 93)	N	325	200−370
17a	130601	0138	9493	(273, 197)	N	440	295−475
17b	’	0646	’	(90, 83)	N	360	350−375
17c	**’**	**0646**	**’**	**(222, 82)**	**Y**	**180**	**170−185**
17d	**’**	**0646**	**’**	**(222, 54)**	**Y**	**180**	**170−400**
17e	’	1300	’	(149, 81)	N	225	225−450

above non-sunspot regions and 3 cases where no conclusion was possible. It is clear from Table 1 that the periods of the oscillations in loops above sunspots are substantially smaller than the periods found in loops that are not situated above sunspots. Only taking into account loops above sunspots, we find periods (marked in bold) of the order of 172 ± 32 s, whereas the "non-sunspot" periods are of the order of 321 ± 74 s.

4. Discussion

Following the arguments of De Moortel et al. (2000), we interpret the observed intensity variations as slow magnetoacoustic waves propagating along the lower part of the coronal loops. We only found positive gradients in the running differences, i.e. we only found outward propagating disturbances and there seems to be no evidence indicating downward propagation. During the analysed data sequences, all loops that displayed coherent, propagating disturbances were found to be quiescent. Their overall, large-scale structure and appearance remained stable and unchanged for long periods of time, indicating that, on large scales, the oscillatory signals have no noticeable effects on the loops. Most loops were situated at the edges of active regions, and no propagating oscillations have been found in actual active region loops. However, it is not clear whether these shorter, more active loops do not support such oscillatory signals, or whether the signals are just obscured by other transient events.

The global 5-min solar oscillations and 3-min sunspot oscillations are well known solar phenomena. When considering the entire set of analysed loops, the range of observed periods (282 ± 93 s) does not allow us to confirm or exclude some form of coupling with the underlying solar oscillations. However, when separating those loops that are situated above sunspots from those that are not, we found a distinct separation in the observed periods. Loops that are anchored in sunspot regions display intensity oscillations with a period that is centred around 3-min (172±32 s), whereas the oscillatory periods in "non-sunspot" loops are centred around 5-min (321 ± 74 s). Previous observations, with a variety of instruments, have found oscillations centred around similar 3-min periods, in both intensity and velocity in sunspot umbrae in the underlying solar atmosphere. For example, Gurman et al. (1982) found evidence for both intensity and line-of-sight velocity oscillations with periods of 129–173 s in sunspots. Transition region umbral oscillations with similar periods are discussed by Brynildsen et al. (1999), Fludra (1999) and, more recently, by Maltby et al. (2001). The first hint that the 3-min umbral oscillations may propagate through the transition region and reach the corona was presented by Maltby et al. (1999). However, the results presented in this paper suggest that not only the 3-min umbral oscillation but also the global 5-min solar oscillations are observed in the corona. Obviously, one would need to make a careful analysis of photospheric and chromospheric data, using CDS onboard SOHO to confirm this result. Although it is impossible to determine how these pulses are excited without a detailed study of the magnetic footpoints of the coronal loops, this result points strongly in the direction of an underlying driver exciting the loop footpoints. As the minor flares that did occur in the observed active regions took place either after or well in advance of the analysed sequences, it is highly unlikely that the observed intensity oscillations are directly, or indirectly, driven by flares.

5. Conclusions

We have analysed a large number of propagating intensity oscillations, using high cadence, 171 Å TRACE data and we interpret the observed intensity variations as slow magneto-acoustic waves, propagating along the lower part of the coronal loops. A careful analysis of the range of observed periods revealed a distinct separation between those loops situated above sunspots and those above non-sunspot regions. In the former, oscillatory periods were concentrated around 3-min, whereas in the later, periods were concentrated around 5-min. As no flares occurred during or just before the analysed sequences, it seems improbable that these longitudinal oscillations are flare-driven. The clear difference in the range of periods on the other hand provides a strong indication for an underlying driver exciting the loop footpoints. In other words, this result suggests that both the 3-min sunspot oscillations and the global 5-min solar oscillations directly or indirectly drive oscillations in coronal loops.

This paper only concentrates on one aspect of the observed intensity disturbances, namely the relation between the period of the oscillations and the position the loop in which they were found. A more comprehensive overview and discussion of the properties of the observed oscillations, and potential relations between them, can be found in De Moortel et al. (2002).

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