

Transverse Coronal Loop Oscillations Seen in Unprecedented Detail by SDO/AIA



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Abstract

We present an observational study of transverse oscillations of several coronal loops observed in three separate events using data from the Solar Dynamics Observatory (SDO) which provides unprecedented temporal and spatial resolution of the solar corona. We study oscillatory events using the Atmospheric Imaging Assembly (AIA) instrument on board SDO, primarily in the 171Å bandpass to obtain information on loop lengths, periods and damping times. Where possible, data from SDO/AIA has been complimented with data from STEREO in order to obtain an estimation of loop inclination angles. Transverse oscillations in solar coronal structures have important applications for coronal seismology where the diagnostic power of the transverse waves can provide information on coronal magnetic and density structuring. Also oscillating loops are often observed to be at or near the site of flares and so can provide information about the physical conditions in the vicinity of these events.

Transverse Loop Oscillations (TLO's)

- Coronal loops are magnetic flux tubes filled with heated chromospheric plasma.
- Transverse oscillations are characterised by the displacement of the loop axis and are interpreted as fast MHD kink modes. [Aschwanden et al., 1999; Nakariakov et al., 1999]
- Oscillations are excited by dynamic phenomena such as flares and CME's. [Van Doorselaere et al., 2007; Verwichte et al., 2009]
- TLO's are often observed to damp on very short timescales. Possible damping mechanisms include phase mixing and resonant absorption. [Ruderman & Roberts, 2002; Goossens et al 2002; Aschwanden & Ofman 2002]
- Parameters such as the period and length of the loop can be used to derive coronal properties such as the magnetic field strength using the technique of coronal seismology. [Nakariakov & Ofman, 2001; Verwichte et al., 2004, 2010]

SDO/AIA

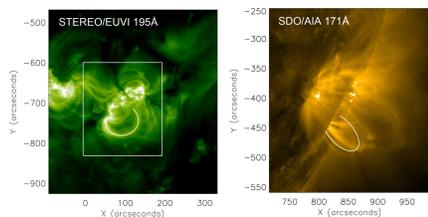
AIA was designed to study the magnetically dominated coronal plasma
Observes the corona in seven EUV bandpasses ranging from 94Å to 335Å
Spatial resolution of 1.5", pixel size of 0.6" and field of view of 41' x 41'
All three events were observed with a 12 second cadence

Inclination Angles Using SDO/AIA and STEREO/EUVI

Where possible inclination angles have been estimated by comparing AIA data with EUVI data from the STEREO spacecraft.

A loop path is chosen on the EUVI image (both 171Å and 195Å were used) and the coordinates are projected onto the AIA image. The reverse process can also be done.

The path is matched to a loop by changing the inclination angle until a good fit is observed. This technique also allows loop length estimates to be made.



Left: EUVI image from STEREO A of event 1 (active region NOAA 11079) with a chosen loop path plotted. Right: The path coordinates chosen on the EUVI image are projected onto the AIA image. The loop is assumed to be planar.

Time Series Analysis

Slices in time of the data are obtained by choosing a path on an image and cutting this path out of all images for that event.

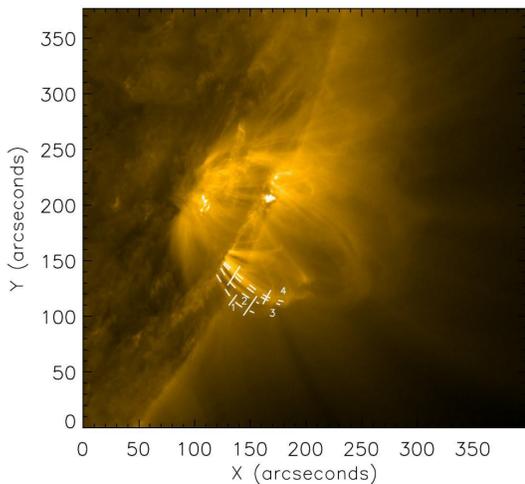
The time series for the observed oscillation is either estimated interactively by eye or by fitting a Gaussian function to each of the time slices.

The background is subtracted by fitting a 3rd order polynomial function to the series and a damped cosine function is fitted to the result:

$$f(t) = A \exp\left(\frac{-t}{\tau}\right) \cos\left(\frac{2\pi t}{P} - \phi\right)$$

Event 1

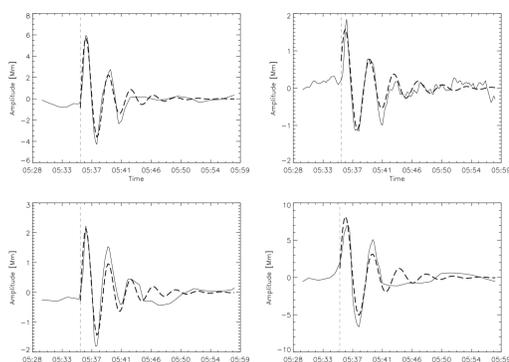
Observed on June 13th 2010 at 05:20:11 - 06:19:59 UT
Active region NOAA 11079



171Å AIA image of event 1 at 5:20:11 UT. The analysed loops are labelled 1 to 4 and the solid lines mark the regions within which the oscillations were investigated.

Loop	Length (Mm)	Inclination Angle (°)	Period (s)	Damping time (s)	Phase	Amplitude (Mm)
1	121 ± 2	38 ± 3	195 ± 2	205 ± 13	93.7 ± 2.1	7.32 ± 0.38
2	111 ± 6	26 ± 5	213 ± 1	294 ± 12	67.4 ± 1.1	4.60 ± 0.36
3	132	-	213 ± 2	251 ± 17	80.2 ± 2.5	3.20 ± 0.24
4	113 ± 4	12 ± 3	216 ± 2	230 ± 20	90.1 ± 3.0	10.07 ± 0.71

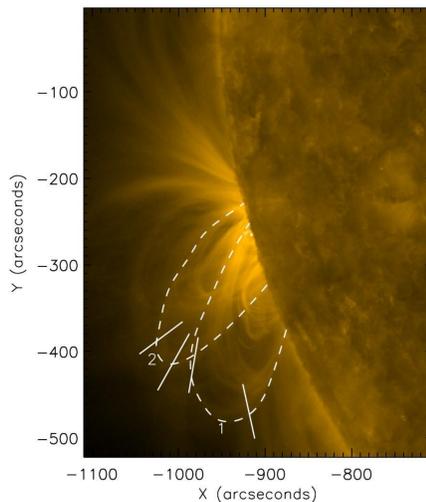
Loop lengths and inclination angles determined by comparing AIA and EUVI images. Loop 3 could not be reliably identified in the EUVI image so the length has been estimated assuming that the loop is semicircular and the height of the loop is equal to the radius. Periods, damping times, phases and amplitudes were obtained from the time series analysis. The amplitudes reported are the maximum amplitudes obtained for each loop.



Example time series plots for loops 1 (top left), 2 (top right), 3 (bottom left) and 4 (bottom right) that have been fitted with a damped cosine function (thick dashed line). The vertical dashed line marks the start of the oscillation at 05:35:59 UT. The time series for loop 2 was found automatically from a Gaussian fit of the time series. The other time series were determined interactively by eye.

Event 2

Observed on August 8th 2010 at 04:15:12 - 05:29:48 UT
Active region NOAA 11095

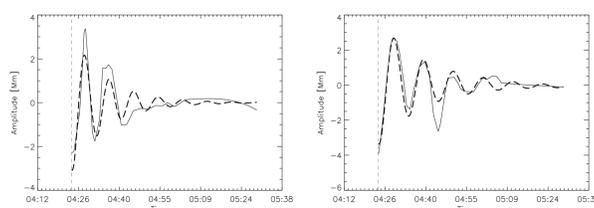


171Å AIA image of event 2 at 04:15:12 UT. The solid lines show the locations of the cuts made to analyse the loop oscillations.

Inclination angles and loop lengths were not determined using EUVI data because of the low contrast between the loops and the background on the EUVI images.

Loop	Length (Mm)	Period (s)	Damping time (s)	Phase	Amplitude (Mm)
1	396	520 ± 5	735 ± 53	193.5 ± 3.3	3.14 ± 0.15
2	374	596 ± 2	771 ± 18	170.3 ± 1.1	3.56 ± 0.13

Periods, damping times, phases and amplitudes obtained from the time series for loops 1 and 2. The amplitude reported for loop 2 was obtained from the middle path shown on the figure of the event above.



Time series plots determined interactively for loop 1 (left) and loop 2 (right). The time series for loop 2 corresponds to the middle path on the event figure above. A damped cosine function (thick dashed line) has been fitted to the time series. The vertical dashed line marks the start of the oscillation at 04:24:12 UT

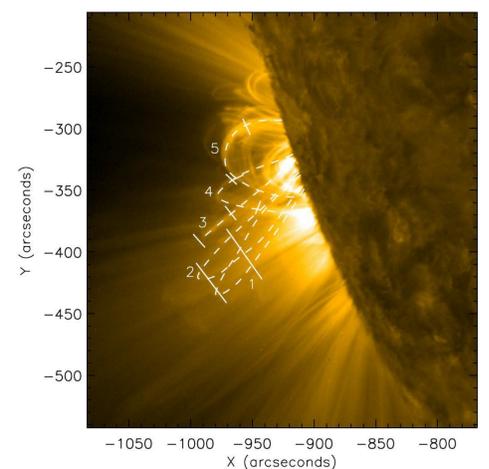
What's Next?

Apply the technique of coronal seismology to determine phase speeds, Alfvén speeds and magnetic field strengths.

Investigate the excitation mechanism and selectivity of the kink modes.

Event 3

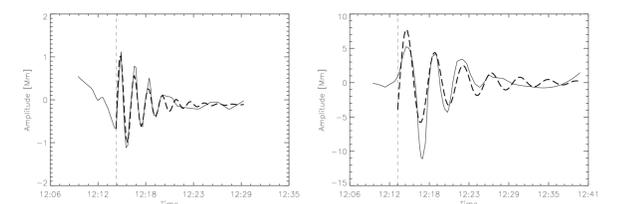
Observed on November 3rd 2010 at 12:10:00 - 13:09:48 UT
Active region NOAA 11121



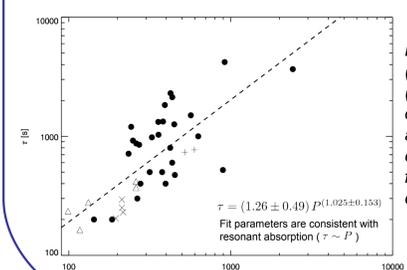
171Å AIA image of event 3 at 12:10:00 UT. The analysed loops are labelled 1 to 5 and the solid lines mark the regions within which the oscillations were investigated.

Loop	Length (Mm)	Inclination Angle (°)	Period (s)	Damping time (s)	Phase	Amplitude (Mm)
1	279 ± 3	26.6 ± 1.43	260 ± 3	370 ± 39	114.0 ± 3.5	9.27 ± 0.85
2	240 ± 4	29.1 ± 1.2	260 ± 1	417 ± 15	94.3 ± 1.5	12.93 ± 0.84
3	241	-	132 ± 1	278 ± 28	87.3 ± 4.0	4.30 ± 0.48
4	159 ± 6	-17.2 ± 0.9	117 ± 2	164 ± 21	287.5 ± 3.9	4.04 ± 0.58
5	132	-	99 ± 1	235 ± 12	88.5 ± 2.8	3.35 ± 0.58

Loop lengths and inclination angles for loops 1, 2 and 4 were determined by comparing the AIA and EUVI images. Periods, damping times, phases and amplitudes were determined from the time series analysis. The amplitudes reported are the maximum amplitudes obtained for each loop.



Example time series plots determined interactively for loop 5 (left) beginning at 12:14:36 UT and loop 1 (right) beginning at 12:13:36 UT. A damped cosine function (thick dashed line) has been fitted to the time series.



Event 1 (crosses), event 2 (plus signs) and event 3 (triangles) show transverse oscillation damping times and periods that are consistent with those found previously (filled circles) [Harris et al., 2011].