Coronal loop dynamics as seen from combined Imaging & Spectroscopic observations

By
S. Krishna Prasad

Supervisors:
Prof. Jagdev Singh
Prof. Dipankar Banerjee

Indian Institute of Astrophysics, Bengaluru.
Overview

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  • TRACE & CDS
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Introduction

- Berghmans et al. 1999, first observed the quasi-periodic propagating intensity disturbances in fan like loop structures using EIT/SoHO in 195 A channel.
- These were later confirmed using TRACE 171 A data. (De Moortel et al. 2000) and were interpreted as slow magneto-acoustic modes (Nakariakov et al. 2000).
- These waves were thought to be important for understanding the energy balance and coronal seismology (Nakariakov et al. 2005).
- There were many observations of 3 min and 5 min oscillations propagating supporting their origin in photospheric p-mode wave leakage (De Pontieu et al. 2005).
- Slightly longer periods (10-15 min) were also observed by some of the authors, using EIT, TRACE & EUVI/STEREO but their origin is not clear. (Berghmans et al. 1999; McIntosh et al. 2008; Marsh et al. 2009)
- There were some attempts to study these oscillations using spectroscopy. (for e.g., Marsh et al. 2006; Wang et al. 2009)
Table 1  Statistical overview of the averages and ranges of the physical properties of the 63 oscillations in coronal loop footpoints analysed by De Moortel et al. (2002a) and McEwan and De Moortel (2006). Note that the uncertainty in the parameters is taken to be the standard error in the mean, $\sigma_M$. (Taken from McEwan and De Moortel 2006)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oscillation Period, $P$</td>
<td>$284.0 \pm 10.4 \text{ s}$</td>
<td>$145$–$550 \text{ s}$</td>
</tr>
<tr>
<td>Propagation Speed, $v$</td>
<td>$99.7 \pm 3.9 \text{ km s}^{-1}$</td>
<td>$O(45)$–$O(205) \text{ km s}^{-1}$</td>
</tr>
<tr>
<td>Relative Amplitude, $A$</td>
<td>$3.7% \pm 0.2%$</td>
<td>$0.7$–$14.6%$</td>
</tr>
<tr>
<td>Detection Length, $L_d$</td>
<td>$8.3 \pm 0.6 \text{ Mm}$</td>
<td>$2.9$–$23.2 \text{ Mm}$</td>
</tr>
<tr>
<td>Energy Flux, $F$</td>
<td>$313 \pm 26 \text{ erg cm}^{-2} \text{ s}^{-1}$</td>
<td>$68$–$1560 \text{ erg cm}^{-2} \text{ s}^{-1}$</td>
</tr>
</tbody>
</table>

Table 2  Overview of the propagation speeds of propagating slow MHD waves detected in coronal loop (adapted from De Moortel 2006)

<table>
<thead>
<tr>
<th>Source</th>
<th>Speed (km/s)</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nightingale et al. (1999)</td>
<td>130–190</td>
<td>171 &amp; 195</td>
</tr>
<tr>
<td>Schrijver et al. (1999)</td>
<td>70–100</td>
<td>195</td>
</tr>
<tr>
<td>Berghmans and Clette (1999)</td>
<td>75–200</td>
<td>195</td>
</tr>
<tr>
<td>De Moortel et al. (2000)</td>
<td>70–165</td>
<td>171</td>
</tr>
<tr>
<td>Robbrecht et al. (2001)</td>
<td>65–150</td>
<td>171 &amp; 195</td>
</tr>
<tr>
<td>Berghmans et al. (2001)</td>
<td>$\sim 300$</td>
<td>SXT</td>
</tr>
<tr>
<td>De Moortel et al. (2002a)</td>
<td>$122 \pm 43$</td>
<td>171</td>
</tr>
<tr>
<td>King et al. (2003)</td>
<td>25–40</td>
<td>171 &amp; 195</td>
</tr>
<tr>
<td>McEwan and De Moortel (2006)</td>
<td>$98 \pm 6$</td>
<td>171</td>
</tr>
</tbody>
</table>
**Observations I : TRACE & CDS**

Details of the 11th September 2003 JOP165 data.

<table>
<thead>
<tr>
<th>Data</th>
<th>Start &amp; End time</th>
<th>Total duration (approx.)</th>
<th>Cadence</th>
<th>Exp. time</th>
<th>Spatial resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRACE Images</td>
<td>13:00:17.000 - 20:59:32.000</td>
<td>8 Hours</td>
<td>1 min.</td>
<td>46.34 sec.</td>
<td>0.5&quot; x 0.5&quot;</td>
</tr>
<tr>
<td>CDS Raster</td>
<td>13:45:34.712 - 14:07:15.715</td>
<td>22 min.</td>
<td>21 sec</td>
<td>15 sec</td>
<td>4&quot; x 3.3&quot;</td>
</tr>
<tr>
<td>CDS Slits [Sit &amp; Stare]</td>
<td>14:07:51.199 - 19:37:26.081</td>
<td>5 ½ Hours</td>
<td>21 sec.</td>
<td>15 sec.</td>
<td>4&quot; x 3.3&quot;</td>
</tr>
<tr>
<td>(Total 11 slits 0-10, each of duration 30min.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDS Raster</td>
<td>19:38:10.087 - 19:59:49.583</td>
<td>22 min.</td>
<td>21 sec</td>
<td>15 sec</td>
<td>4&quot; x 3.3&quot;</td>
</tr>
</tbody>
</table>
Field of view

NOAA no.: AR 10457
TRACE FOV: 512” X 512”
CDS FOV: 240” X 231”
MDI magnetogram over plotted on TRACE

Location of fan loops chosen from TRACE
Results and discussion

At Pos 11: Running difference image and wavelet diagram.

Projected propagation speed: 74.46 km/s
Periodicity: 5.8 min.

Wavelet at pixel 30 from the foot point

Global Period at max. power (< 8.8 min.)
= 5.8 min.
Prob. level: 99–100%
Image showing the locations where significant oscillation is found. Different images represent different time slots.

11-Sep-2003 13:33:12.000 UT

11-Sep-2003 15:54:19.000 UT

11-Sep-2003 17:39:48.000 UT

11-Sep-2003 19:02:16.000 UT
Image showing CDS slit locations in the time slots chosen

No overlaps!!
We studied CDS independently. Following plot shows the locations on CDS where significant oscillations are identified.
<table>
<thead>
<tr>
<th>Location (sol_x, sol_y)</th>
<th>Slit No.</th>
<th>Spectral line</th>
<th>Int. Oscill. period Primary (secondary) (in min.)</th>
<th>Prob. Level (%)</th>
<th>Vel. Oscill. period Primary (secondary) (in min.)</th>
<th>Prob. Level (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 (47, -384)</td>
<td>5</td>
<td>O_V</td>
<td>4.5 (6.9)</td>
<td>99-100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>He_I</td>
<td>6.3 (4.9)</td>
<td>99-100</td>
<td>4.9 (~10)</td>
<td>97.5</td>
</tr>
<tr>
<td>P2 (73, -393)</td>
<td>0</td>
<td>O_V</td>
<td>5.3 (~10)</td>
<td>99-100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P3 (77, -249)</td>
<td>6</td>
<td>O_V</td>
<td>8.2 (4.1)</td>
<td>99-100</td>
<td>8.2 (2.9)</td>
<td>99-100</td>
</tr>
<tr>
<td>P4 (77, -296)</td>
<td>6</td>
<td>O_V</td>
<td>5.8 (~10)</td>
<td>99-100</td>
<td>5.3 (~11)</td>
<td>99</td>
</tr>
<tr>
<td>P5 (147, -207)</td>
<td>10</td>
<td>O_V</td>
<td>9.0 (4.9)</td>
<td>99-100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P6 (194, -294)</td>
<td>2</td>
<td>O_V</td>
<td>5.8 (9.0)</td>
<td>99-100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P7 (215, -343)</td>
<td>4</td>
<td>O_V</td>
<td>6.3 (9.8)</td>
<td>99-100</td>
<td>8.2 (5.3)</td>
<td>99-100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>He_I</td>
<td>6.9 (6.9)</td>
<td>99-100</td>
<td>5.3 (~11)</td>
<td>99-100</td>
</tr>
<tr>
<td>P8 (255, -271)</td>
<td>3</td>
<td>O_V</td>
<td>9.8 (4.9)</td>
<td>99-100</td>
<td>6.9 (6.9)</td>
<td>99-100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>He_I</td>
<td>9.0 (2.1)</td>
<td>99-100</td>
<td>9.0 (9.0)</td>
<td>99-100</td>
</tr>
</tbody>
</table>
Conclusions: part I

- We find around ~5 min oscillations from TRACE, exhibiting the properties like damping and filamentary nature.

- The propagation speeds, periodicities, and intensity amplitudes fall in the range given by De Moortel et. Al (2009)

- Although, we could not get the simultaneous spectroscopic information, independent analysis from CDS indicate that these are more likely to be slow magneto-acoustic waves.
Fig. 1. a) The TRACE $\lambda 195$ bandpass image. b) The intensity map in the Fe XII $\lambda 195.12$ line from EIS. The raster observation was taken from 00:12 to 01:22 UT on 2007 February 1. c) The Doppler velocity measurements. The red color represents the redshift and the blue color the blueshift with a scale range from $-20$ km s$^{-1}$ to $+20$ km s$^{-1}$. The vertical line in each plot shows the position of the EIS 1" slit for the sit-and-stare observation. The short horizontal lines on the slit mark the positions where the oscillations are analyzed.

Wang et. al (2009)
Periodicities observed: 12 & 25 min; Propagation speeds: 100 - 120 km/s; Temperature: 0.7 +/- 0.3 MK; Magnetic field inclination: 59 +/- 8 degrees.
De Pontieu & McIntosh (2010) repeated Wang's analysis using their R-B asymmetry technique. They find significant blue shifts 75 km/s to 125 km/s in the line profiles.

They also found line width oscillations in addition to the observed intensity and velocity oscillations and showed from simulations that this can be possible by quasi-periodic high speed upflows.

McIntosh et al (2010) using STEREO observations in polar plumes, suggested that these could be more likely quasi-periodic high speed upflows rather than waves.

Verwichte et al (2010) showed theoretically that the slow modes can produce the line asymmetries when the emission line is averaged over an oscillation period.
Data

HOP 156 observations:

EIS raster for context
EIS slot of cadence: ~6s
EIS slit of cadence: ~6s
Spatial pixel: 1 arcsec
Total duration of observation: 1hr (11:00 - 12:00 UT)
Observed periodicity from the map: ~8 min

Projected propagation Speed: 72 km/s
Fe_{IX} Light curve – Original

Counts

Time (minutes)

Fe_{IX} Light curve – After trend subtraction

Rel. int.

Time (minutes)

Global Period at max. power (< 65.6 min.)
P1 = 7.9 min.
Second highest Peak
P2 = 4.3 min.

Fe_{IX} Wavelet

Global Wavelet

Period (min)

Time (minutes)

Power

0.0000

0.0005

0.0010
### Comparison of results from 171 A and 193 channels

<table>
<thead>
<tr>
<th></th>
<th>171 A channel</th>
<th>193 A channel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observed periodicities (min)</strong></td>
<td>37.4  20.4  12.1  <strong>7.9</strong>  4.3</td>
<td>31.4  18.7  12.1  <strong>8.6</strong>  4.3</td>
</tr>
<tr>
<td><strong>Projected propagation speeds (km/s)</strong></td>
<td>72</td>
<td>65</td>
</tr>
<tr>
<td><strong>Theoretical acoustic speeds (km/s)</strong></td>
<td>136</td>
<td>170</td>
</tr>
</tbody>
</table>

Theoretical speeds are calculated from $C_s = 152 \ T^{(1/2)}$ m/s . T (K)

Ref: Priest (1984)

Peak temperatures: 171 channel - 0.8 MK  
193 channel - 1.25 MK
Results from EIS - Intensity oscillations

Fe_{XII} Light curve – Original

Counts

Fe_{XII} Light curve – After trend subtraction

Rel. int.

Global Period at max. power (< 9.5 min.)
P1 = 8.5 min.
Second highest Peak
P2 = 1.8 min.

Fe_{XII} Wavelet

Global Wavelet

Time (minutes)

Period (min)

Power
Velocity oscillations

Fe XII Light curve — Original

Fe XII Light curve — After trend subtraction

Global Period at max. power (< 9.5 min.)
P1 = 3.3 min.
Second highest Peak
P2 = 1.1 min.
Conclusions : part II

- Multiple periodicities observed ranging from 4 min to 38 min. in both 171 A and 193 A – Periodicities comparable to that observed in polar regions?

- Projected propagation speeds are almost same in both the channels of AIA. Flows?

- The dominant ~8 min periodicity is observed with confidence only from EIS intensity oscillations.

- This could be probably due to the low signal to noise of EIS observations.

- The exact nature of these oscillations cannot be predicted from the current analysis.

Thank you for your attention!
Fig. 3  Running Difference in TRACE 171 Å (top) and 195 Å (bottom), adapted from King et al. (2003)