Multi-instrument observations of a failed flare-eruption associated with MHD waves in a loop bundle

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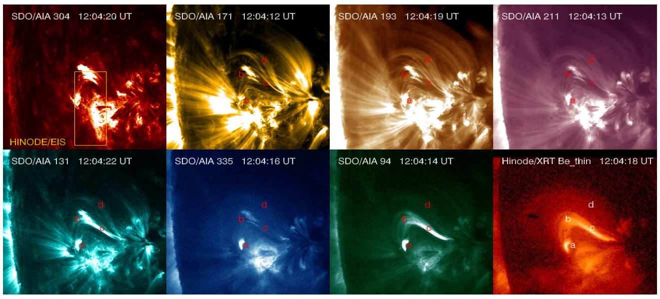
Introduction

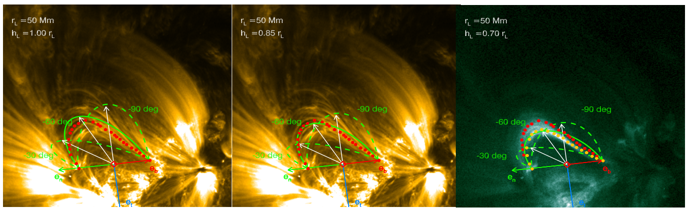
We present observations of a B7.9-class flare occurred on the 24th January, 2015, using the Atmospheric Imaging Assembly (AIA) of the Solar Dynamics Observatory (SDO), the EUV Imaging Spectrometer (EIS) and the X-Ray Telescope of Hinode. The flare triggers the eruption of a dense cool plasma blob, which remains confined within the local bundle of loops exhibiting transverse oscillations. At the same time, a larger diffuse loop observed in the hot EUV/X-ray wavebands shows periodic intensity oscillations, which are interpreted as a longitudinal slow MHD wave [1].



Motivation

- Investigation of the dependence between the observed MHD wave properties (e.g. period, phase speed) and the local plasma parameters (e.g. density, temperature).
- Determination of the plasma-β and adiabatic index γ [2,3].

Determination of the loop length (SDO/AIA 171 and 94 observations)



SDO/AIA 171

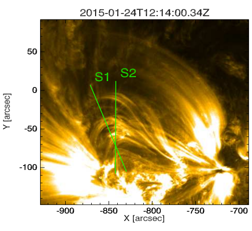
Half footpoint distance: ~ 50 Mm - Best inclination angle : ~ -60 deg

Best loop height: ~ 0.85 r_L - Loop length: ~ 144 Mm

SDO/AIA 94

Best loop height: ~ 0.7 r_L - Loop length: ~ 124 Mm

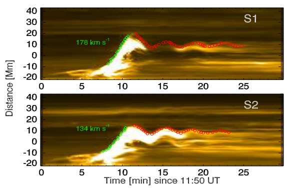
Analysis of the kink oscillations (SDO/AIA 171)

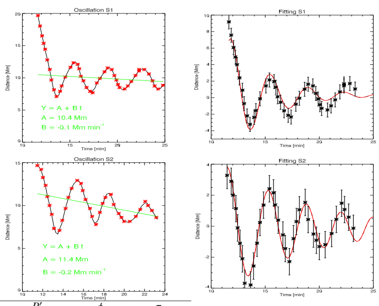


$$C_k = \frac{2L}{P_k} \qquad C_K \approx \left(\frac{2}{1+\rho_e/\rho_0}\right)^{1/2} C_A$$

Fitting function

$$y(t) = y_0 + A\cos\left(\frac{2\pi(t-t_0)}{P_0 + P'(t-t_0)} + \phi\right)\exp\left(-\frac{t-t_0}{\tau}\right)$$



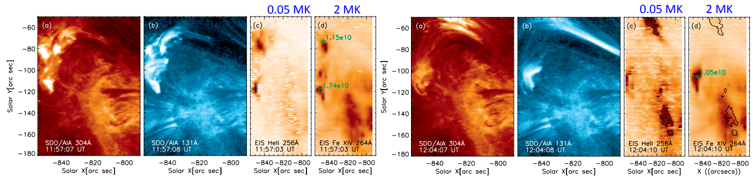


Oscillation	t_0 [min]	y_0 [Mm]	A [Mm]	P [min]	P' [min min^{-1}]	ϕ [deg]	τ [min]
S1	11.6	0.3±0.1	7.3±0.5	3.7±0.2	-0.02±0.03	-24±8	3.7±0.5
S2	11.5	-0.1±0.2	4.0±0.5	4.0±0.3	-0.05±0.03	-2±11	7.9±2.0

References

[1] G. Nisticò, V. Polito, V. M. Nakariakov, and G. Del Zanna, 2017, *A&A*, 600, A37.
[2] T. Van Doorsselaere, N. Wardle, G. Del Zanna, et al. 2011, *ApJ*, 727, L32.
[3] Y. Zhang, J. Zhang, J. Wang, and V. M. Nakariakov, 2015, *A&A*, 581, A78

Density estimates (Hinode/EIS)



Blob: 1.15×10^{10} cm^{-3} - Background: 3×10^{9} cm^{-3}

Coronal seismology with kink waves

$$C_k = \frac{2L}{P_k}$$

$$C_K \approx \left(\frac{2}{1+\rho_e/\rho_0}\right)^{1/2} C_A$$

$$C_A = B/\sqrt{4\pi\rho_0}$$

$$\rho = \mu m_p n_0$$

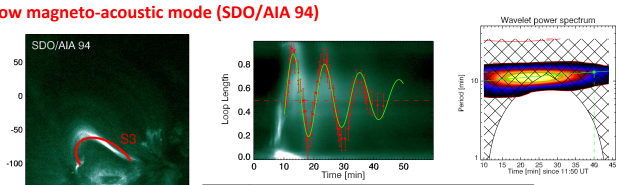
Inputs

- L = 144 +/- 14 Mm
- $n_0 = 1.15 \times 10^{10}$ cm^{-3}
- $n_e = 3 \times 10^{9}$ cm^{-3}
- P = 3.9 +/- 0.3 min

Outputs

- C_k = 1231 +/- 155 km s^{-1}
- C_A = 977 +/- 123 km s^{-1}
- B = 54 +/- 7 Gauss

Slow magneto-acoustic mode (SDO/AIA 94)



$$\frac{\delta P}{P_0} = -\frac{\delta T}{2T_0}$$

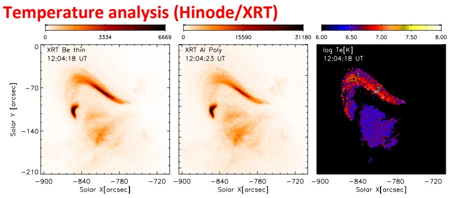
$$\frac{\delta P}{P_0} = 0.30$$

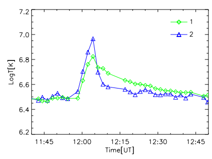
Oscillation	t_0 [min]	y_0 [Mm]	A [Mm]	P [min]	P' [min min^{-1}]	ϕ [deg]	τ [min]
S3	10.1	0.02±0.01	0.4±0.1*	9.7±0.4	0.05±0.02	-110±8	40.3±14.7

P' = 0.1 min min^{-1}

L = 123 +/- 12 Mm $\qquad C_L = \frac{2L}{P_L}$ = 425 +/- 46 km s^{-1}

Temperature analysis (Hinode/XRT)





T_0 ~ 6-10 MK $\qquad T_f$ ~ 3 MK $\qquad -\frac{\delta T}{2T_0}$ =0.29-0.35

Sound speed $\quad C_S = \left(\frac{\gamma p}{\rho}\right)^{1/2} = \left(\frac{2\gamma k_B T}{\mu m_p}\right)^{1/2} \quad$ C_S = 465+/- 34 km s^{-1}

Acoustic or tube speed?

Tube speed $\quad C_T = \frac{C_S C_A}{\sqrt{C_S^2 + C_A^2}}$

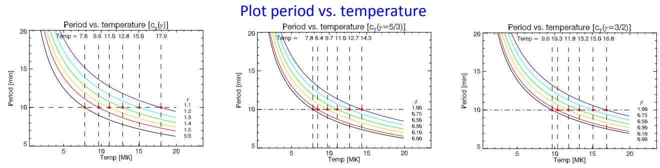
Plasma-beta $\quad \beta = \frac{2}{\gamma}\left(\frac{C_S}{C_A}\right)^2$

$$C_T = \frac{1}{\sqrt{1+\beta\gamma/2}} C_S = \left(\frac{\gamma}{1+\beta\gamma/2}\frac{2k_B}{\mu m_p}T\right)^{1/2}$$

Effettive adiabatic index $\quad \gamma_{\rm eff} = \gamma/(1+\beta\gamma/2) \quad \beta = 2\left(\frac{1}{\gamma_{\rm eff}} - \frac{1}{\gamma}\right)$

[2] estimated an effective adiabatic index equal to 1.1

Plot period vs. temperature



We consider that values γ=5/3 and 0.1<β<0.3 can describe the dynamics of the slow MHD wave in the hot loop.

Conclusion

- We have presented observations of simultaneous fast kink and slow MHD waves in a loop bundle.
- The variations of the wave properties look consistent with those of the plasma parameters.
- We have shown that the adiabatic index estimates can be affected by the low-finite plasma-beta value: it is important to distinguish between sound and tube speeds.

Poster

4. Eruptions in the solar atmosphere

Multi-instrument observations of a failed flare eruption associated with MHD waves in a loop bundle

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We present multi-instrument observations of a B7.9-class flare occurred on January 24th, 2015, using SDO/AIA, Hinode/EIS and XRT. The flare heats the local plasma up to temperatures of $\sim$ 8 MK, and triggers the eruption of a dense blob, which is unable to expands completely, and remains confined within the local bundle of active region loops. During this process, vertically polarised kink oscillations of the loop threads with a period of 3.5–4 min and an amplitude of 5 Mm are driven by the blob, which diffuses and descends along each loop strand causing variations in density. In addition, a co-existing longitudinal slow MHD wave propagates along the hot loop bundle with a period of 10 min, and a phase speed of $\sim$ 430 km s^{-1}. We show that the evolution of these waves are determined by the temporal variations of the local plasma parameters (e.g. density, temperature), caused by the flare heating and the consequent cooling. Furthermore, the correct interpretation of the nature of both the observed fast and slow magneto-acoustic waves is exploited to determine better the plasma-β and the adiabatic index γ of the coronal plasma.