

## DOPPLER OSCILLATIONS IN HOT CORONAL LOOPS

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### ABSTRACT

Recently, a new kind of damped oscillations of hot coronal loops was revealed by the Solar Ultraviolet Measurements of Emitted Radiation (SUMER) spectrometer on SOHO. Such events seem to be a common feature observed in active region loops, seen very often when these lines brighten. The oscillations always have an impulsive trigger and are strongly damped while they cool down. However, in lines formed at coronal temperatures of  $\approx 2$  MK never any signature of these oscillations has been observed. In this study, we present the main properties of Doppler oscillations derived from a statistical study of 17 flare-like events, and a comparison with TRACE transverse loop oscillations. We also discuss the oscillation modes and their damping mechanism.

### INTRODUCTION

Transverse oscillations of active region loops were first discovered with TRACE in EUV bands (Aschwanden et al. 1999), and more cases have been reported in a recent statistical study by Schrijver et al. (2002). These transverse loop oscillations are excited by flares, and show a very quick decay on time scales from 3 to 21 min, with oscillation periods of 2 to 11 min. Aschwanden et al. (1999) and Nakariakov et al. (1999) have interpreted the loop oscillation as a fundamental resonance of the kink mode, and Nakariakov et al. (1999) concluded that the rapid damping is due to anomalously high viscosity, or resistivity in the coronal plasma. Ofman et al. (2002) investigated the scaling of the oscillation damping time for the TRACE loops, and found that the scaling agrees best with phase mixing as the damping mechanism.

Recently, additional evidence of damped oscillating coronal loops was found by SUMER spectral observations (Kliem et al. 2002, Wang et al. 2002a, 2002b, 2002c). They show that Doppler shift oscillations in hot coronal loops ( $T \approx 10^7$  K) have a damping

time range comparable to that of the TRACE loops, but oscillation periods distinctly longer than those observed by TRACE. This difference is confirmed by new observations with a higher cadence reported in this study. We present a representative case and statistical results of the hot loop oscillations analyzed so far.

### OBSERVATIONS

In all cases, the SUMER spectrometer slit was placed at a fixed position in the corona about 100'' above an active region at the limb. The earlier observations during 1999 - 2001 were made in a wide spectral window with a 162 s exposure time. The new observations obtained in April 2002 were made in three lines (Si III / S III, Ca X, and Fe XIX) with a high cadence of 50 s. The selected lines cover a wide temperature range from  $T = 10^4$  to  $10^7$  K.

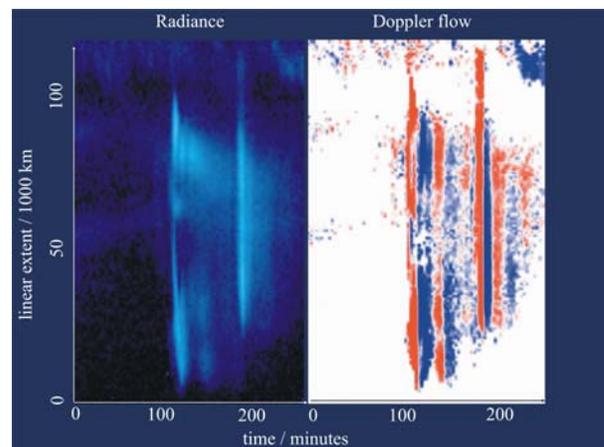


Figure 1: A recurring impulsive flare-like event observed in the Fe XIX  $\lambda$  1118 flare line both in radiance and in Doppler flow. Oscillations occurred at the place where the slit crossed a SXT loop, indicative of hot plasma dynamics. No signatures are seen in the lines at  $T < 2$  MK.

## EXAMPLE

We have selected a text book oscillation event observed on Sep 29, 2000 representative of many more cases for further analysis. The Fe XIX radiance and Doppler flow during this event is shown in Fig. 1. Fitting the average time profiles of the Doppler oscillation by a function

$$v(t) = v_0 + v_m \sin(\omega t + \varphi) e^{-\lambda t} \quad (1)$$

yields oscillations periods of 25 – 30 min, with a decay time of 21 – 29 min. Brightness variations show no fluctuation behaviour with the oscillation period.

Based on an ellipse model applied on SXT images, we derive geometrical parameters of the oscillating loop:

the loop length  $L = 473$  Mm, the loop height (radial distance to solar surface)  $H = 104$  Mm, the azimuth angle to EW of 23 deg, the inclination angle to the vertical plane of 28 deg, the angle between loop baseline and line-of-sight of 34 deg.

The initial red shifts suggest the trigger may be hot plasma flow injected into the loop from one footpoint, seen as a brightening in SXT. With a sound speed of  $C_s \approx 416$  km/s for  $T = 6.3$  MK (Fe XIX), we obtain a period of standing slow waves,  $P \approx 2L/C_s = 38$  min, this is about 1.4 times the observed periods.

With  $B = 10$  G and  $n = 1.0 \times 10^9$  /cm<sup>3</sup>, we obtain  $C_A = 689$  km/s,  $C_k = 930$  km/s, and a period of global kink mode  $P = 2L/C_k = 17$  min, and a plasma  $\beta$  of 0.44 in the coronal loop.

## STATISTICAL RESULTS

So far we have analyzed 35 Doppler oscillation components in 17 flux enhancement events of hot plasma (>6 MK). In each event, we identified several oscillation components along the slit, due to differences in Doppler shift, intensity, or line width. All events show impulsive flux variations typical for flares, but only 3 of the 17 events were associated with GOES flares above detection limit. A comparison of the statistical results from TRACE and SUMER is given in Figure 2, where we show histograms of the oscillation periods, the damping times, the Doppler flows, and the maximum displacements observed by both instruments. In the SUMER case, the displacement amplitude has been derived by integration of equation (1). Although the new observations had a high cadence of 50 s, which

would allow detection of short-period oscillations down to periods of 3 minutes, no oscillations are found with periods shorter than 10 min. We measure oscillation periods ranging from 10.8 to 31.1 min with a mean of  $(18.5 \pm 5.8)$  min, damping times ranging from 5.5 to 28.9 min with a mean of  $(14.6 \pm 6.3)$  min, maximum Doppler velocities ranging from 14 to 315 km s<sup>-1</sup> with a mean of  $(102 \pm 81)$  km s<sup>-1</sup> and derived maximum displacements ranging from 2 to 54 Mm with a mean of  $(18 \pm 15)$  Mm.

If we compare the parameter distributions of the SUMER oscillation events to the TRACE transverse oscillations events triggered by strong flares (Aschwanden et al. 2002), we find that:

- the Doppler oscillation periods found by SUMER are distinctly longer than those observed by TRACE. Standing slow modes roughly match the observed periods.
- the damping time found by SUMER is comparable to the TRACE damping time.
- the maximum velocities and displacement amplitudes found by SUMER are larger than TRACE values.

We also investigated the scaling law between damping time and oscillation periods observed by both instruments, (c.f. Figure 3) and found significant differences.

## MHD SIMULATION: SLOW WAVE DAMPING BY THERMAL CONDUCTION

Using 1D MHD code, Ofman and Wang (2002) model the oscillations and damping of slow magnetosonic waves in a model coronal loop. They find that:

- Due to the high temperature of the loops, the large thermal conduction, which depends on temperature as  $T^{2.5}$ , leads to rapid damping of the slow waves on a time scale comparable to observations.
- The scaling of the dissipation time with period agrees well with the 35 cases observed by SUMER
- The decay time due to compressive viscosity alone is an order of magnitude longer than the observed decay times.

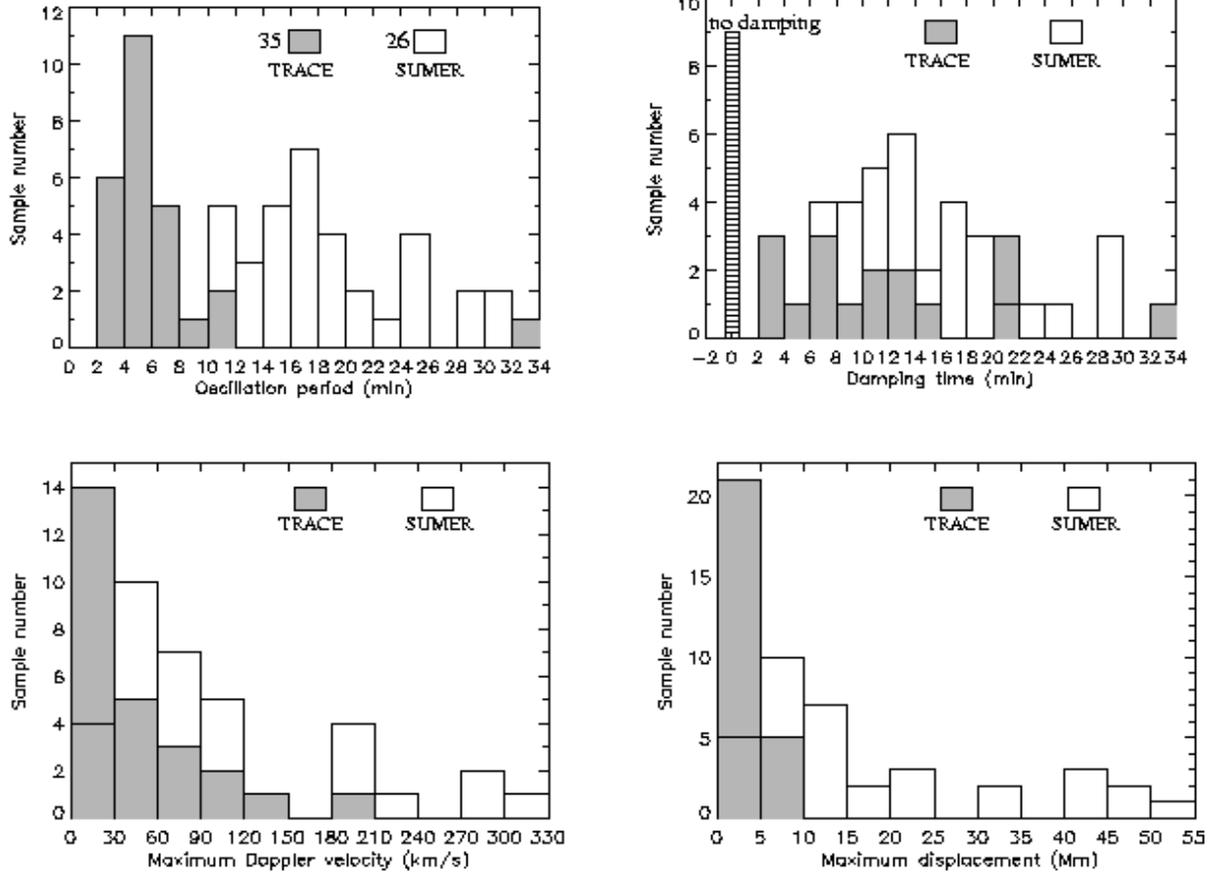


Figure 2: Comparison of the oscillation periods, the damping constants, the Doppler flows, and the maximum displacements observed by SUMER and TRACE (TRACE parameters from Aschwanden et al. 2002).

We have used the following parameter set for our 1D - MHD simulations:

loop length:  $L = 0.57 R_{\text{sun}} = 400 \text{ Mm}$ ,  
density:  $n_0 = 5 \times 10^8 / \text{cm}^3$ ,  
temperature:  $T = 6.3 \text{ or } 8 \text{ MK}$   
the corresponding sound speeds are

$c_s = 416 \text{ or } 469 \text{ km/s}$

and the initial disturbance velocity profile is

$$v(x) = v_0 \sin(2\pi x / L) \quad \text{with} \quad v_0/c_s = 0.18$$

Our results are shown in Figure 4.

## CONCLUSION

SUMER spectral observations have revealed a new kind of coronal plasma oscillations, that were only detected in hot flare lines of  $T > 6 \text{ MK}$ . The coordina-

ted SXT observations indicate that they are hot loop oscillations.

A statistic study on 35 oscillations in 17 flare-like events shows that these Doppler oscillations have periods of 11 to 31 min, with decay times of 6 to 29 min, and show an initial large shift pulse with peak velocities up to 200 km/s. Unlike TRACE loop transverse oscillations that were mostly triggered by strong flares, the SUMER oscillation events happened mostly without associated GOES flares, suggesting a different trigger mechanism.

Doppler oscillations have a distinctly longer period than those observed by TRACE. We find that slow standing waves roughly match the observed periods, while to produce similar periods by a global kink mode would imply an unusual environment  $\beta \geq 1$  in hot coronal loops. Moreover, a nonlinear, dissipative MHD model also strongly suggests that the observed Doppler oscillations are signatures of damped slow magnetosonic waves.

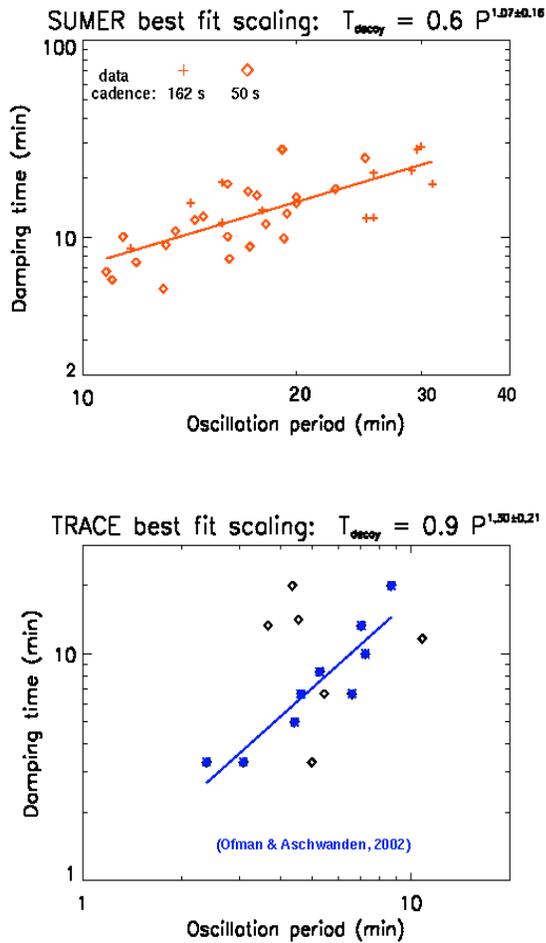


Figure 3: Scaling law between damping time and oscillation period found by TRACE and SUMER.

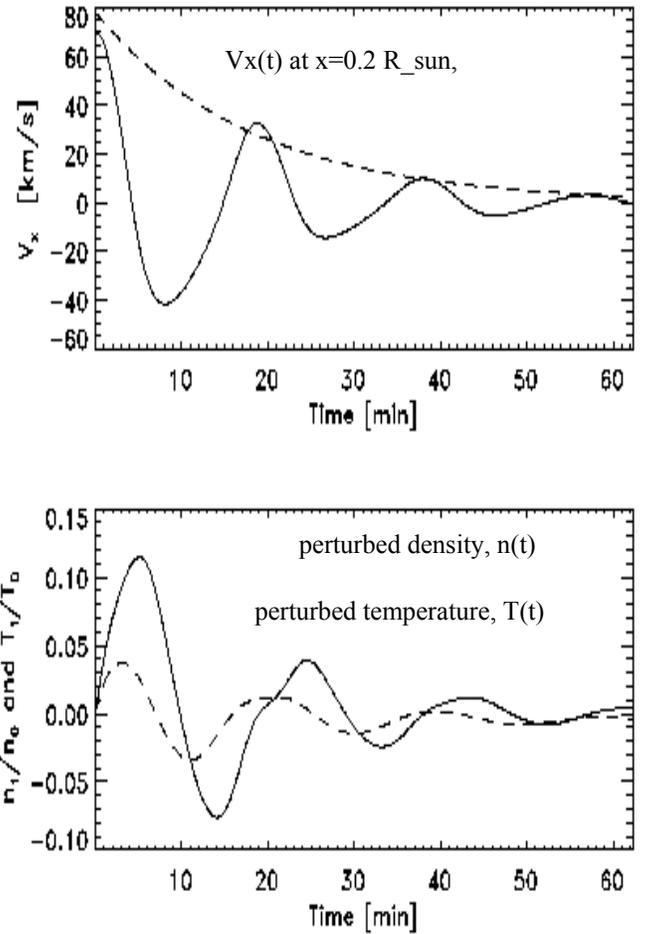


Figure 4: Results from the MHD simulation

## REFERENCES

- Aschwanden, M. J., Fletcher, L., Schrijver, C. J. and Alexander, D. (1999): ApJ, 520, 880
- Aschwanden, M. J., De Pontieu, B., Schrijver, C. J., and Title, A. (2002): Solar Phys., 206, 99
- Kliem, B., Dammasch, I.E., Curdt, W. and Wilhelm, K. (2002): Correlated Dynamics of Hot and Cool Plasmas in the Main Phase of a Solar Flare. ApJ 568, L61
- Nakariakov, V. M., Ofman, L., DeLuca, E. E. et al. (1999): Science, 285, 862
- Ofman, L., and Aschwanden, M. J. (2002): ApJ, L576, 153
- Ofman, L. and Wang, T.J. (2002): ApJL, submitted
- Schrijver, C.J., Aschwanden, M.J. and Title, A.M. (2002): Sol. Phys. 206, 69
- Wang, T.J., Solanki, S.K., Curdt, W., Innes, D.E. and Dammasch, I.E. (2002a): Doppler Shift Oscillations of Hot Solar Coronal Plasma seen by SUMER: A Signature of Loop Oscillations? ApJ 574, L101
- Wang, T. J., Solanki, S. K., Curdt, W., Innes, D. E., and Dammasch, I. E. (2002b) in: Proc. 11<sup>th</sup> SOHO Workshop, Davos, Switzerland, ed. A. Wilson, ESA SP-508, 465
- Wang, T. J., Solanki, S. K., Curdt, W., Innes, D. E., and Dammasch, I. E. (2002c) in: Proc. IAU Colloq. 188 'Magnetic Coupling of the Solar Atmosphere', ed. H. Sawaya-Lacoste, ESA SP-505, in press

