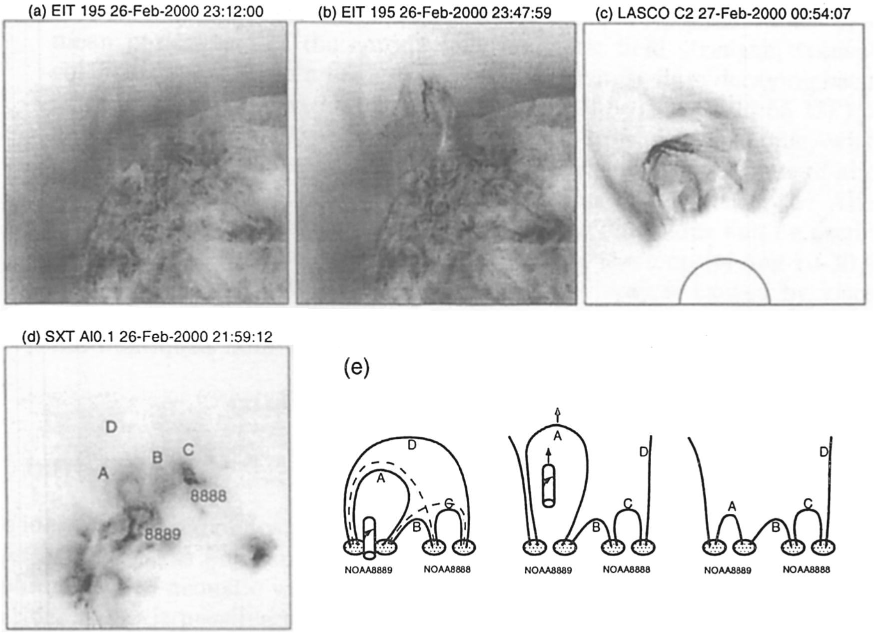
Session IV

Structure and Dynamics of the Transiton Region and Corona


(a) EIT 195 26-Feb-2000 23:12:00

(b) EIT 195 26-Feb-2000 23:47:59

(c) LASCO C2 27-Feb-2000 00:54:07

(d) SXT Al0.1 26-Feb-2000 21:59:12

(e)

CME and filament eruption observed with (a-b) the EIT and (c) the LASCO of SOHO. (d) The coronal loop structure observed with the SXT of Yohkoh just before the eruption. All images are shown in negatives. (e) Schematic drawing of the filament and the coronal loops in the CME source region before, during, and after the eruption (adapted from Hanaoka, p. 393).

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MHD Seismology of the Solar Corona with SOHO and TRACE

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Abstract. Recent discoveries of MHD wave motions in the solar corona done with EUV imaging telescopes onboard SOHO and TRACE provide an observational basis for the MHD seismology of the corona. Measuring the properties of MHD waves and oscillations (periods, wavelengths, amplitudes, temporal and spatial signatures), combined with theoretical modeling of the wave phenomena, allow us to determine values of the mean parameters of the corona (the magnetic field strength, transport coefficients, etc.). As an example, we consider post-flare decaying oscillations of loops, observed with TRACE (14th July 1998 at 12:55 UT). An analysis of the oscillations shows that they are quasi-harmonic, with a period of about 265 s, and quickly decaying with the decay time of about 14.5 min. The period of oscillations allows us to determine the Alfvén speed in the oscillating loop about 770 km/s. This value can be used for deduction of the value of the magnetic field in the loop (giving 10-30 G). The decay time, in the assumption that the decay is caused by viscous (or resistive) dissipation, gives us the Reynolds number of $10^{5.3-6.1}$ (or the Lundquist number of $10^{5.0-5.8}$).

1. Introduction

The idea of remote diagnostics of the Sun with observationally determined properties of waves, has been successfully realized in helioseismology. Measurement of parameters of acoustic waves propagating through various layers of the solar interior, makes it possible to reconstruct the physical conditions in these parts of the Sun, non-observable by usual methods.

In contrast with the solar interior, the corona of the Sun is well-seen in a wide spectrum of the electromagnetic emission, from radiowaves up to hard X-rays. However, the coronal physical conditions, namely rare, weakly collisional and almost ionized plasma highly structured by the magnetic field, complicate the observational investigation of the corona dramatically. For example, some parameters which are of crucial importance for our understanding of physical mechanisms acting in the corona, such as the magnetic field strength and transport coefficients, remain not revealed.

Recent discoveries of wave activity in the corona, in particular longitudinal compressive waves in polar plumes (Deforest & Gurman 1998; Ofman, Nakariakov, & Deforest 1999) and coronal loops (Berghmans & Clette 1999; De Moortel, Ireland, & Walsh 2000; Nakariakov et al. 2000) and flare-generated decaying oscillations of coronal loops (Aschwanden et al. 1999, Nakariakov et al. 1999, Schrijver & Brown 2000) provide us with the new tool for determination of the coronal parameters – MHD coronal seismology. Measuring the properties of coronal MHD waves and oscillations (periods, wavelengths, amplitudes, temporal and spatial signatures, scenaria of the wave evolution), combined with theoretical modeling of the wave phenomena, we can determine values of the mean parameters of the corona.

Here, we restrict our attention to the discussion of possible methods of determination of the coronal magnetic field strength and transport coefficients.

2. Determination of the Magnetic Field Strength

Analyzing observational examples of flare-generated coronal loop oscillations on 14th July 1998 (Aschwanden et al. 1999, Nakariakov et al. 1999) and on 4th of July, 1999 (Schrijver & Brown 2000) registered by the EUV imaging telescope onboard the Transition Region and Coronal Explorer (TRACE) in both 171Å and 195Å bandpasses, we obtain that the displacement of the loop in time can be approximated by a harmonic function, $\sim \sin(t/P)$, where P is the period of the oscillations. These phenomena have been interpreted as standing kink fast magnetoacoustic modes (see Nakariakov et al. 1999 for details).

The loop footpoints prescribe the nodes of the mode. Consequently, the loop plays a role of the resonator for the mode. The length of the loop L determines the resonant period P of the standing modes. Neglecting the effects of the corona stratification and loop curvature, and assuming that the loop cross-section is circular, the period of the global mode is given by the equation

$$P \approx 2L/C_k, \quad \text{where} \quad C_k = \left(\frac{2}{1+\rho_e/\rho_0}\right)^{1/2} C_{A0} \tag{1}$$

is a so-called *kink* speed, C_{A0} is the Alfvén speed inside the loop and ρ_e and ρ_0 are plasma densities outside and inside the loop, respectively. Measuring the periods of the loop oscillations and the loop lengths, one can determine the kink speed. The kink speed is proportional to the Alfvén speed C_{A0} with the factor about $\sqrt{2}$, because normally ρ_e/ρ_0 is small. Thus, we can estimate the Alfvén speed in the corona. For $P \approx 265$ s and $L \approx 130$ Mm (14th July 1998' event), the kink speed C_k is 1020 ± 132 km/s, which gives us the Alfvén speed in the loop $C_{A0} = 777 \pm 100$ km/s.

A similar estimation can be obtained for the event on 4th of July, 1999. For the period of oscillations 360 s and the loop length 186 Mm, we obtain $C_k = 1030 \pm 410$ km/s and the Alfvén speed about 780 km/s.

The estimations for the Alfvén speed in the loop allow us to determine the magnetic field strength, as

$$B_0 = (4\pi\rho_0)^{1/2} C_{A0} = \frac{\sqrt{2}\,\pi^{3/2} L}{P}\sqrt{\rho_0(1+\rho_e/\rho_0)}, \tag{2}$$

This requires the value of plasma density in the loop, which is not currently available for the analyzed events. But, the *weak* dependence of the Alfvén speed upon the density (as the square root) minimizes this uncertainty. Indeed, for the wide range of plasma number densities, from 1.0×10^{15} to 1.0×10^{16} m^{-3}, the value of the magnetic field is between 10 and 30 G.

3. Determination of the Reynolds number

The decay time of the flare-generated coronal loop oscillations can be connected with several possible mechanisms: leakage through the footpoints, leakage through the loop boundaries, mode conversion and dissipation. Estimations show that those mechanisms have different characteristic times. In particular, the footpoint leakage time is greater than 90 min, and this option has to be excluded. Also, the perpendicular leakage must not be efficient because the loop is a region with enhanced plasma density, and, consequently, a waveguide for MHD waves. The sharp gradients in the density on the loop boundary lead to efficient confinement of the energy of oscillations to the loop in the perpendicular plane. It is difficult to distinguish between the last two options, because they act together through, e.g. the mechanism of resonant absorption. Applying the numerically determined scaling laws (e.g. Ofman, Davila, & Steinolfson 1994, Nakariakov et al. 1999), which connect the oscillation decay time and the Reynolds $\mathcal{R}$ and Lundquist $\mathcal{L}$ numbers, we can estimate $\mathcal{R} = 10^{5.3-6.1}$ and $\mathcal{L} = 10^{5.0-5.8}$. These figures are much smaller than commonly quoted $\mathcal{R} = 10^{14}$ and $\mathcal{L} = 10^{13}$.

4. Conclusion

We conclude that the method of MHD coronal seismology, based on high resolution observations of the coronal wave activity, can become a powerful tool for determination of physical parameters in the corona.

References

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