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The damping of small-amplitude oscillations in quiescent prominences

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Abstract

The presence of small-amplitude oscillations in prominences is well-known from long time ago. These oscillations, whose exciters are still unknown, seem to be of local nature and are interpreted in terms of magnetohydrodynamic (MHD) waves. During last years, observational evidence about the damping of these oscillations has grown and several mechanisms able to damp these oscillations have been the subject of intense theoretical modelling. Among them, the most efficient seem to be radiative cooling and ion-neutral collisions. Radiative cooling is able to damp slow MHD waves efficiently, while ion-neutral collisions, in partially ionised plasmas like those of solar prominences, can also damp fast MHD waves. In this paper, we plan to summarize our current knowledge about the time and spatial damping of small-amplitude oscillations in prominences.

Keywords: Sun: oscillations; Sun: magnetic fields; Sun: corona; Sun: prominences

1. Introduction

Long time ago, observations performed by ground-based telescopes showed that quiescent prominences and filaments display small-amplitude oscillations which are detected, mainly, through the periodic Doppler shift of spectral lines. Further evidence has been provided during last years by ground-based high-resolution observations (Terradas et al., 2002; Lin, 2004) as well as by on-board SoHO instruments (Blanco et al., 1999; Régnier et al., 2001; Pouget et al., 2006). High-resolution observations of solar filaments reveal that they are formed by a myriad of horizontal structures called threads (Lin et al., 2005) and filament oscillations seem to be related with those threads (Yi and Engvold, 1991; Yi et al., 1991). Recent two-dimensional, high-resolution observations (Lin, 2004) have also shown the central part of a filament undergoing damped oscillations while, at the same time, the phase is maintained over the observed region. More extense theoretical and observational information about small amplitude oscillations in prominences and filaments can be found in Engvold (2001; 2004), Wiehr et al. (2004), Oliver and Ballester (2002), Ballester (2006), Banerjee et al. (2007), Engvold (2008), Oliver (2008), Mackay et al. (submitted for publication). Usually, prominence small-amplitude oscillations are interpreted in terms of linear and ideal standing or propagating magnetohydrodynamic (MHD) waves. Furthermore, some observations have also pointed out the damping of oscillations (Molowny-Horas et al., 1999, Fig. 1; Terradas et al., 2002; Lin, 2004) and the time damping of these oscillations has been unambiguously determined from these observations. Reliable values for the damping time, τ_D, have been derived, from different Doppler velocity time series, by Molowny-Horas et al. (1999) and Terradas et al. (2002), in prominences, and by Lin (2004), in filaments. The values of τ_D thus obtained are usually between 1 and 4 times the corresponding period, and large regions of the prominence display similar damping times.

The damping of perturbations is probably a common feature of prominence oscillations, therefore, theoretical damping mechanisms must be explored, and the time scales of damping produced by the different mechanisms should be compared with those obtained from observations. Tentative mechanisms that can provide with an explanation for the observed damping of prominence oscillations could be: radiative damping (Terradas et al., 2001; Terradas et al.,

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2005; Carbonell et al., 2006), wave leakage (Dıaz et al., 2001, 2002), resonant absorption (Ruderman and Roberts, 2002) and ion-neutral collisions (Khodachenko et al., 2004; Forteza et al., 2007). In this paper, we will concentrate in the damping due to non-adiabatic waves and ion-neutral collisions, summarizing our current knowledge.

2. Damping of prominence oscillations

Theoretical studies of small amplitude prominence oscillations make use of the linearised, ideal MHD equations and wave propagation is investigated by assuming perturbations to the equilibrium variables of the form $\exp(i\omega t)$. When a bounded medium is considered, the problem usually reduces to solving a set of ordinary differential equations in which the unknowns are the velocity components. The boundary conditions imposed on the solutions are often the vanishing of the velocity at the edge of the physical domain. However, when an unbounded medium is considered we obtain an algebraic dispersion relation whose roots provide us directly with the frequency of oscillation of the different waves.

In general, theoretical models are divided into two groups which reflect widely different choices of prominence equilibrium configurations: (a) models which consider the prominence as an isothermal plasma slab of finite width; (b) models which are concerned with a single prominence thread assumed to vibrate independently of other threads. Here, we will only consider bounded prominence slabs, bounded prominence/corona slabs, or an unbounded medium with prominence conditions.

2.1. Non-adiabatic MHD waves in bounded prominence slabs

In order to explain the damped oscillations described in Section 1, Terradas et al. (2001) removed the adiabatic assumption in favour of the so-called Newton's law of cooling with constant relaxation time, which consists of a simple way of taking into account the effect of radiation on waves. In essence, temperature fluctuations are assumed to be radiatively damped on a characteristic time scale τ_R, where the limits $\tau_R \rightarrow \infty$ and $\tau_R = 0$ correspond to adiabatic and isothermal perturbations, respectively. Following this approach, Terradas et al. (2001) investigated the influence of radiative cooling on the fast and slow MHD modes of the Kippenhahn – Schlüter, 1957 and Menzel (1951) prominence models. They found that, in both equilibria, the fast mode frequency is not affected by the cooling mechanism, whereas slow mode frequencies become appreciably smaller when going from the adiabatic to the isothermal limit (Fig. 2(a)). Regarding the damping of disturbances, fast modes are characterised by very large damping times and so other physical effects should be taken into account to explain the damping of these modes. As for slow modes, all of them display strong damping (Fig. 2(b) and (d)) except for the fundamental mode in the Kippenhahn–Schlüter model. Finally, the fundamental slow mode in Menzel's equilibrium attains very large periods for small vertical

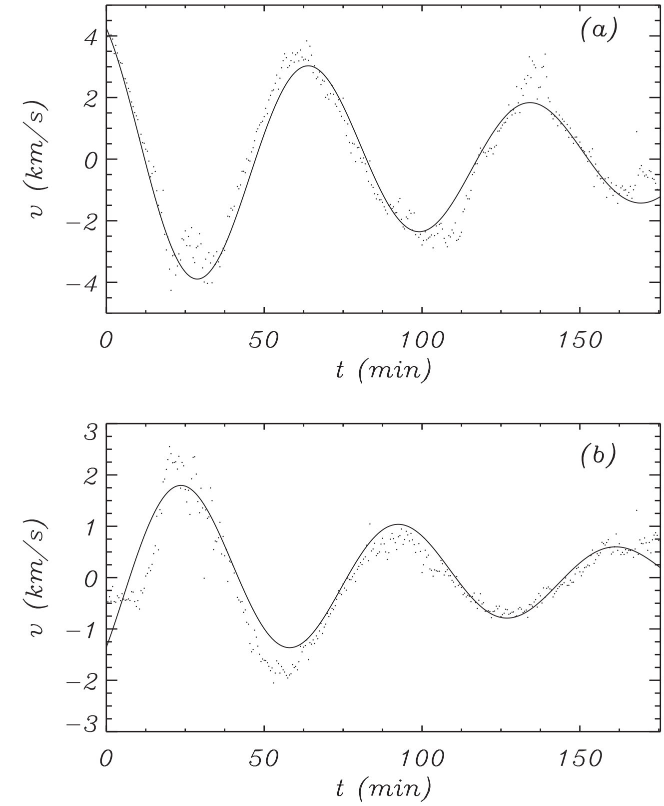

Fig. 1. Observed Doppler velocity (dots) and fitted function (continuous line) vs. time at two different points in a quiescent prominence. The period is $P\left(=\frac{2\pi}{\omega_r}\right) = 70$ min in both points and the damping time is $\tau_D\left(=\frac{1}{\omega_i}\right) = 140$ and 101 min, respectively. The function fitted to the observational data is of the form $v_0 \cos(\omega t + \phi)\exp(-t/\tau_D)$. Adapted from Molowny-Horas et al. (1999).

wavenumbers and certain values of the radiative time τ_R (Fig. 2(c)), this particular behaviour being caused by the destabilising action of gravity. Although rather coarse, this calculation provides with a qualitative explanation, that has not been previously explored, for the Doppler velocity damping observed by Molowny-Horas et al. (1999).

A more complete treatment of the problem was used by Terradas et al. (2005) by considering a bounded slab-like prominence and a full energy equation including optically thin radiation, thermal conduction and heating. The basic MHD equations for the discussion of linear and non-adiabatic MHD waves are:

$$\frac{D\rho}{Dt} + \rho\nabla\cdot\mathbf{v} = \mathbf{0}, \tag{1}$$

$$\rho\frac{D\mathbf{v}}{Dt} = -\nabla p + \frac{1}{\mu}(\nabla\times\mathbf{B})\times\mathbf{B}, \tag{2}$$

$$\frac{Dp}{Dt} - \frac{\gamma p}{\rho}\frac{D\rho}{Dt} + (\gamma-1)[\rho L(\rho,T) - \nabla\cdot(\kappa\cdot\nabla T)] = 0, \tag{3}$$

$$\frac{\partial\mathbf{B}}{\partial t} = \nabla\times(\mathbf{v}\times\mathbf{B}), \tag{4}$$

$$\nabla\cdot\mathbf{B} = 0, \tag{5}$$

$$p = \frac{\rho R T}{\tilde{\mu}}, \tag{6}$$