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Damping of Fast Magnetohydrodynamic Oscillations in Quiescent Filament Threads

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Abstract. High-resolution observations provide evidence of the existence of small-amplitude transverse oscillations in solar filament fine structures. These oscillations are believed to represent fast magnetohydrodynamic (MHD) waves and the disturbances are seen to be damped in short timescales of the order of 1 to 4 periods. We propose that, due to the highly inhomogeneous nature of the filament plasma at the fine-structure spatial scale, the phenomenon of resonant absorption is likely to operate in the temporal attenuation of fast MHD oscillations. By considering transverse inhomogeneity in a straight flux tube model we find that, for density inhomogeneities typical of filament threads, the decay times are of a few oscillatory periods only.

1. Introduction

Early quiescent filament observations (Engvold 1998) as well as recent high-resolution Hα observations have revealed that their fine structure is composed by many horizontal and thin dark threads that seem to be partially filled with cold plasma (Lin et al. 2005), typically two orders of magnitude denser than that of the corona. Small amplitude oscillations have been observed in filaments. Two-dimensional observations of filaments by Yi & Engvold (1991) and Yi et al. (1991) revealed that individual threads or groups of threads may oscillate independently with their own periods, which range between 3 and 20 minutes. More recently, Lin (2004) reports that spatially coherent oscillations are found over slices of a polar crown filament, and that among other, a significant periodicity at 26 minutes, strongly damped after 4 periods, appears. Furthermore, Lin et al. (2007) have shown evidence about travelling waves along a number of filament threads with oscillatory periods of the individual threads that vary from 3 to 9 minutes. The observed periodic signals are obtained from Doppler velocity measurements and can therefore be associated to the transverse displacement of the fine structures. They have been interpreted in terms of MHD waves (Oliver & Ballester 2002) and theoretical models have been developed (see Ballester 2005).

The time damping of prominence oscillations has been unambiguously determined in some observations by Molowny-Horas et al. (1999) and Terradas et al. (2002), in prominences, and by Lin (2004), in filaments. The values thus obtained are usually between 1 and 4 times the corresponding period. Linear non-adiabatic MHD waves (Carbonell et al. 2004; Terradas et al. 2001, 2005;

Soler et al. 2007, 2008) are able to explain slow wave damping, but fast waves remain almost undamped. Ion-neutral collisions provide a possible mechanism to damp fast waves, as well as Alfvén waves, in particular for a quasi-neutral gas (Forteza et al. 2007). Apart from the mentioned non-ideal damping mechanisms, the phenomenon of resonant wave damping (Goossens et al. 2006) provides an alternative mechanism. Here, we address this mechanism in the context of filament thread oscillations and assess its relevance in explaining the observed attenuation time scales.

2. Non-Uniform Filament Thread Model

Given the relatively simple structure of filament threads, when compared to the full prominence/filament structure, the magnetic and plasma configuration of an individual and isolated thread can be theoretically approximated using a rather simplified model. We consider a gravity-free, straight, cylindrically symmetric flux tube of mean radius a. In a system of cylindrical coordinates (r, φ, z) with the z-axis coinciding with the axis of the tube, the magnetic field is pointing in the z-direction, $\mathbf{B} = B\hat{\mathbf{e}}_{\rm z}$. We neglect gas pressure, which allows us to concentrate on the oscillatory properties of fast and Alfvén MHD waves and their mutual interaction. In our straight field configuration this zero-β approximation implies that the field strength is uniform and that the density profile can be chosen arbitrarily. The inhomogeneous filament thread is then modelled as a density enhancement with a one-dimensional non-uniform distribution of density, $\rho(r)$, across the structure. The internal filament plasma, with uniform density, ρ_f, occupies the full length of the tube and is connected to the coronal medium, with uniform density, ρ_c, by means of a non-uniform transitional layer of thickness l. The ratio l/a provides us with a measure of the transverse inhomogeneity length-scale, that can vary in between $l/a = 0$ (homogeneous tube) and $l/a = 2$ (fully non-uniform tube).

3. Damping of Linear Fast Kink Waves

In the zero-β approximation slow waves are absent. The properties of the remaining small amplitude fast and Alfvén waves can readily be described by considering the linear MHD wave equations for adiabatic changes of state for perturbations of the form $f(r)\exp[\imath(\omega t + m\varphi - k_z z)]$. Here m and k_z are the azimuthal and longitudinal wave-numbers and ω the oscillatory frequency. We further concentrate on perturbations with $m = 1$, which represent fast kink waves that produce the transverse displacement of the tube. In the long wavelength ($k_z a \ll 1$) and thin boundary ($l/a \ll 1$) approximations the period and damping time of the $m = 1$ fast kink wave are given by (see Edwin & Roberts 1983; Goossens et al. 1992)

$$P = \frac{\sqrt{2}}{2}\frac{\lambda}{V_{Af}}\left(\frac{1+c}{c}\right)^{1/2}; \quad \frac{\tau_d}{P} = \frac{2}{\pi}\;\frac{a}{l}\;\frac{c+1}{c-1}, \tag{1}$$

with $c = \rho_f/\rho_c$ the density contrast and $\lambda = 2\pi/k_z$ the wave-length.

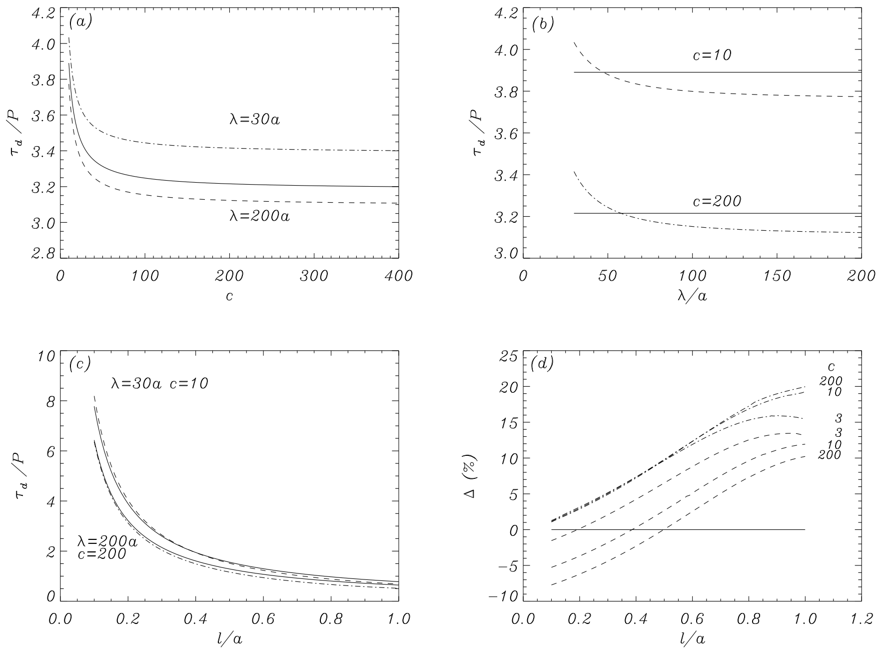

Figure 1. *(a)–(c):* Damping time over period for fast kink waves in threads with $a = 100$ km. In all plots solid lines correspond to analytical solutions. *(a):* As a function of density contrast, with $l/a = 0.2$ and for two wavelengths. *(b)*: As a function of wavelength, with $l/a = 0.2$, and for two density contrasts. *(c)*: As a function of transverse inhomogeneity length-scale, for two combinations of wavelength and density contrast. *(d)* Percentage difference, Δ, with respect to analytical formula for different combinations of wavelength, $\lambda = 30a$ (dashed lines); $\lambda = 200a$ (dash-dotted lines), and contrast.

Figure 1 shows that τ_d/P rapidly decreases for increasing thread density, but stops being dependent on this parameter in the large contrast regime, typical of filament threads. The damping time over period is independent of the wavelength of perturbations, but rapidly decreases with increasing inhomogeneity length-scale. These results suggest that resonant absorption is a very efficient mechanism for the attenuation of fast waves in filament threads. We have next computed numerical approximations to the solutions by solving the full set of linear, resistive, small amplitude MHD wave equations for the $m = 1$ transverse kink oscillations. Analytical and numerical solutions display the same qualitative behaviour with density contrast and transverse inhomogeneity length-scale. Now the damping time over period slightly depends on the wavelength of perturbations, but the differences with respect to analytical results are small.

4. Conclusion

Due to the highly inhomogeneous nature of filaments at their transverse scales the process of resonant absorption is an efficient damping mechanism for fast

MHD oscillations propagating in these structures. For the typical large filament to coronal density contrast the mechanism produces rapid damping in timescales of the order of a few oscillatory periods only. The damping rates are only slightly dependent on the wavelength and they become independent of density contrast for large values of this parameter. This has two seismological consequences. First, the observational determination of density contrast is less critical than in the low contrast regime. Second, according to seismic inversion results that combine theoretical and observed periods and damping times (Arregui et al. 2007; Goossens et al. 2008), high density threads would be compatible with relatively short transverse inhomogeneity length-scales. Analytical estimates of $l/a \sim 0.15$ can even be calculated using equation (1) for a given observed $\tau_d/P = 4$, taking the limit $c \rightarrow \infty$.

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