New Perspectives on Solar Prominences, IAU Colloquium 167
ASP Conference Series, Vol. 150, 1998
David Webb, David Rust, and Brigitte Schmieder (eds.)

The Prominence-Corona Transition Region and the Problem of Prominence Oscillations

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Abstract. Recent theoretical investigations of prominence oscillations indicate that the prominence-corona transition region (PCTR) may have a great influence on the magnetohydrodynamic modes of the whole system. We here consider an isothermal prominence embedded in an isothermal corona with a thin PCTR providing a smooth temperature transition between prominence and corona. The effect of the PCTR on the oscillations of the prominence body are investigated.

1. Introduction

Many of prominences' physical features still remain enigmatic – questions regarding the formation, long-term equilibrium, dynamic evolution and eventual eruption of quiescent prominences are yet to be answered. *Prominence seismology*, i.e., the constructive interaction between the modelling of prominence equilibrium, the theoretical study of the vibrations of their structure (normal modes) and direct observation (e.g., Molowny-Horas et al. 1998, these proceedings), is a way of improving our knowledge of these objects.

Most models used to investigate the magnetohydrodynamic (MHD) modes of a prominence-corona structure rely on a *discontinuous* temperature profile, with the isothermal prominence embedded in the isothermal corona (e.g., Joarder and Roberts 1992, Oliver et al. 1993). This approximation allows a simplified treatment of the equilibrium model and the wave problem.

On the other hand, Oliver and Ballester (1995) studied the propagation of MHD waves in the Low and Wu (1981) configuration, in which a very thin prominence is linked to the corona by an extended PCTR with a smooth temperature variation. They concluded that the nature of modes undergoes radical changes, and proposed the smooth variation of the temperature in the PCTR to be the reason for those changes.

Prompted by the last result, we consider a thin, non-isothermal PCTR between the isothermal prominence and corona and address the question "Are the modes of oscillation of a two-temperature system with a sharp temperature increase at the interface between the prominence and the corona different from the modes of a system with a smooth temperature variation from the isothermal prominence to the isothermal corona?" This, of course, may have important implications on the models that should be used in future investigations of this kind.

https://doi.org/10.1017/S0252921100047473 Published online by Cambridge University Press

2. The Poland-Anzer Equilibrium Solution

The 1-D model put forward by Poland and Anzer (1971) is chosen to represent the equilibrium state of the system (Figure 1). This is a solution of the Kippenhahn and Schlüter (1957) type that incorporates temperature gradients across the prominence sheet. The temperature profile can be freely imposed, without the need of solving the rather complicated energy equation coupled to the mechanical equilibrium equation.

An analytical expression for $T/\tilde{\mu}$ (with T the temperature and $\tilde{\mu}$ the mean atomic weight) is chosen as follows (Figure 2),

$$\frac{T}{\tilde{\mu}}(x) = \frac{1}{2}\left(\frac{T_c}{\tilde{\mu}_c} + \frac{T_p}{\tilde{\mu}_p}\right) + \frac{1}{2}\left(\frac{T_c}{\tilde{\mu}_c} - \frac{T_p}{\tilde{\mu}_p}\right) \tanh\left(\frac{x - x_{PCTR}}{\Delta}\right), \tag{1}$$

for $x \geq 0$ and a symmetric function for $x \leq 0$. Subscripts 'p' and 'c' correspond to prominence and corona. Moreover, the quantities $\Delta_{PCTR} \simeq 6\Delta$ and x_{PCTR} are the PCTR width and position of PCTR centre.

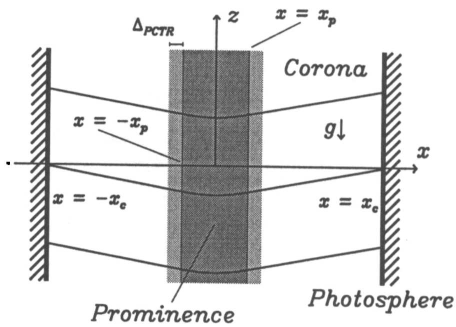

Figure 1. Sketch of the Poland-Anzer prominence solution for a prominence of width $2x_p$ (dark-grey region) surrounded by a thin PCTR of width Δ_{PCTR} (light-grey region), embedded in the solar corona. Support against gravity is achieved by the curvature of magnetic field lines (shown as solid lines) inside the prominence. The length of field lines is of the order of the system width, $2x_c$.

3. Equations of Linear MHD Waves

The equations of ideal MHD are linearised about the equilibrium state for adiabatic perturbations of the form $f(x)\exp(i\omega t - ik_z z)$. The slow and fast magnetoacoustic modes are decoupled from the Alfvén mode. They are described by a pair of equations of the form,

$$\frac{d^2 v_x}{dx^2} = q_1 \frac{dv_x}{dx} + q_2 \frac{dv_z}{dx} + q_3 v_x + q_4 v_z, \tag{2}$$

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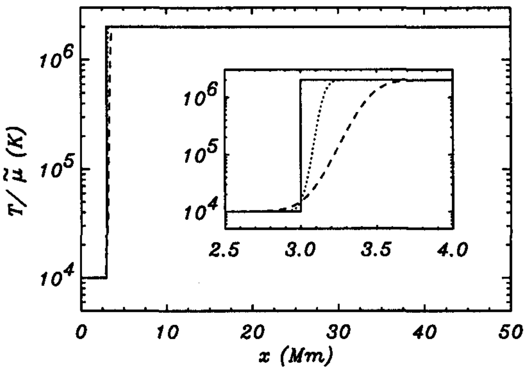

Figure 2. Poland-Anzer temperature profile used in this work ($x > 0$ only). Solid, dotted, dashed lines: $\Delta_{PCTR} = 0$, $\simeq 300$ km, $\simeq 900$ km, respectively.

$$\frac{d^2 v_z}{dx^2} = q_5 \frac{dv_x}{dx} + q_6 \frac{dv_z}{dx} + q_7 v_x + q_8 v_z, \tag{3}$$

where $q_i = q_i(x; \omega, k_z)$ are complex coefficients.

The two magnetoacoustic modes are coupled together and so in this system there are no pure slow or fast MHD modes. However, owing to the small value of the plasma β in prominences, the two waves are effectively independent.

The two ordinary differential equations (2) and (3) constitute an eigenvalue problem that has been solved numerically. Line-tying boundary conditions are imposed on the eigenfunctions: $v_x = 0$ and $v_z = 0$ at the photosphere ($x = \pm x_c$).

4. Results

Previous work used 1-D equilibrium solutions with a temperature discontinuity at the boundary between prominence and corona (e.g., Joarder and Roberts 1992, Oliver et al. 1993). It was found that three different types of MHD modes can propagate in such configurations: internal and external modes have properties determined by the isothermal prominence and corona, respectively, whereas the features of hybrid modes are determined by the two isothermal media. These equilibrium models can be reproduced by setting $\Delta_{PCTR} = 0$ in our temperature profile (see Figure 1). Hence, the question posed above can now be rephrased as, "Are there also internal, external and hybrid modes in a configuration with a PCTR ($\Delta_{PCTR} \neq 0$)?"

A comparison between the dispersion diagrams of the two equilibria (with a sharp temperature discontinuity and with a profile made of two temperature plateaus joined by a smooth transition) reveals that the shape of the magnetoacoustic modes is mostly unchanged, although their frequencies are modified (Figures 3a and b). The frequency change is larger for high harmonics than for low ones, the reason being that low harmonics possess long wavelengths in the x-direction so they do not "feel" the presence of the thin PCTR, while the

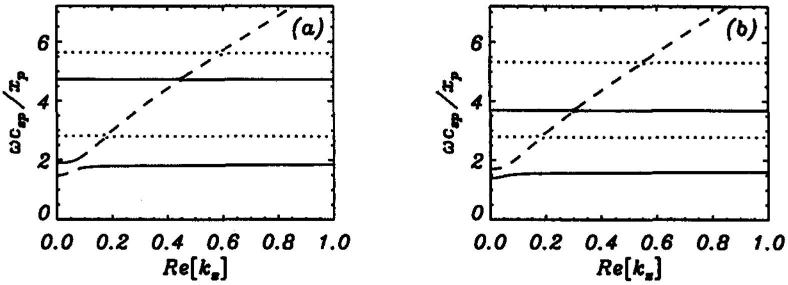

Figure 3. Sausage mode dimensionless frequency ($\omega c_{sp}/x_p$) vs. the real part of the vertical wavenumber. (a) $\Delta_{PCTR} = 0$ and (b) $\Delta_{PCTR} = 9,000$ km. Solid, dotted and dashed lines correspond to internal, external and hibrid modes, respectively.

shorter wavelengths of high harmonics makes them adjust their frequency and eigenfunctions (v_x and v_z) so as to accomodate to the PCTR.

An important feature of internal, external and hybrid modes in a two-temperature system ($\Delta_{PCTR} = 0$) is that their frequencies evolve in a very different manner as the half-width of the system (x_c) is varied. Internal modes are characterized by a constant ω, external modes have $\omega \sim x_c^{-1}$ and hybrid modes have $\omega \sim x_c^{-1/2}$. This is also observed in the present case, even for a relatively thin promienence ($2x_p = 6,000$ km) embedded in a thicker PCTR ($\Delta_{PCTR} = 9,000$ km), so we can conclude that the presence of the PCTR does not eliminate the three types of modes.

So the question now is why there are no internal, external and hybrid modes in the Low–Wu model. The prominence width in this solution is rather small (a few hundred km only); we thus lower x_p in the Poland–Anzer model and look at the modes' features. It turns out that when the prominence region is destroyed (by setting x_p close to 0), the three types of modes disappear and their properties are governed by the dominating coronal medium. Obviously the same happens with the Low–Wu model.

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