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GUIDED MHD WAVES AS A CORONAL DIAGNOSTIC TOOL

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INTRODUCTION

The coronal atmosphere is observed to be highly inhomogeneous with marked density and temperature variations; coronal loops abound. Magnetic forces dominate the atmosphere providing thermal insulation across field lines and almost rigid wave guides for the propagation of MHD waves. In a homogeneous low beta plasma, the slow magnetoacoustic wave gives one-dimensional propagation of sound whereas the fast magnetoacoustic wave gives isotropic propagation at the Alfvén speed. (See Weitzner (1983) and Roberts (1984, 1985) for recent discussions of the properties of MHD waves.) If, however, the low beta plasma is inhomogeneous in density, as with the corona, then fast magnetoacoustic waves are guided by regions of low Alfvén speed (Habbal, Leer, Leer, and Holzer 1979; Edwin and Roberts 1982, 1983; Roberts, Edwin, and Benz 1983, 1984; see also Newcomb 1957). For a general overview see Edwin and Roberts (1986a). Regions of low Alfvén speed occur in both coronal loops and in open field regions (coronal holes). We note, too, that current sheets (regions of the plasma where field reversal occurs) provide wave guides for fast magnetoacoustic waves (Edwin, Roberts, and Hughes 1986).

An important thing about such wave guides is that they preferentially select certain ranges of frequency and wavenumber for guided propagation. If a fast mode is generated impulsively, such as by a flare, it is guided along a region of low Alfvén speed and will exhibit frequencies of the order of the Alfvén speed divided by the width of the inhomogeneity. For typical coronal conditions, this will give rise to frequencies of about 1 Hz or higher.

The occurrence of preferred frequencies in an impulsively generated fast magnetoacoustic wave raises the interesting possibility that such distinctive signatures could be used as a seismological probe of the coronal atmosphere, allowing us to determine magnetic field strengths and/or spatial extents of density inhomogeneities. We discuss this possibility here (see also Edwin and Roberts 1986b).

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IMPULSIVELY GENERATED FAST WAVES

Consider a field-aligned cylindrical tube of dense gas embedded in a uniform magnetic field. In a low beta atmosphere, impulsively generated fast waves exhibit timescales (periodicities) of the general order (Roberts et al. 1984)

$$\tau = \frac{2.6a}{v_A}\left(1 - \frac{\rho_e}{\rho_o}\right)^{1/2} , \qquad (1)$$

where ρ_o and v_A are the gas density and Alfvén speed within the cylinder of radius a, and ρ_e is the gas density in the environment (where the Alfvén speed is v_{Ae}, with $\rho_o v_A{}^2 = \rho_e v_{Ae}{}^2$). Ducting occurs provided $v_{Ae} > v_A$, which corresponds to $\rho_o > \rho_e$. In a very dense region ($\rho_o >> \rho_e$), equation (1) reduces to

$$\tau = \frac{2.6a}{v_A} . \qquad (2)$$

For example, with $a = 500$ km and $v_A = 10^3 \text{km s}^{-1}$ we obtain, from (2), $\tau = 1.3\text{s}$.

In fact, the timescale τ is the maximum timescale that an impulsive event exhibits. Suppose that the source is located on the axis of the cylinder at $z = 0$, the impulse occurring at time $t = 0$. Then, at an observation point $z = h$ ($>> a$) far down the axis of the cylinder, pressure and magnetic field variations, due to the passage of the impulsively generated fast magnetoacoustic wave (taken to be symmetric, sausage mode, oscillations within the cylindrical inhomogeneity), will exhibit three distinct phases (Roberts et al. 1984), analogous to sound waves in ocean layers (Pekeris, 1948). The first phase--called the periodic phase--begins at time $t = h/v_{Ae}$; in this phase the wave's amplitude is low and its period is given by (1). The second phase commences at a time $t = h/v_A$ when both the amplitude and the frequency of the wave undergo a substantial increase. This is the quasi-periodic phase. It lasts until the time $t = h/c_g{}^{min}$, where $c_g{}^{min}$ is the minimum value of the mode's group velocity, when the amplitude of the wave begins to decline as the wave passes by the observation point $z = h$; this is the decay (or Airy) phase. A sketch of these three phases is given in Roberts et al. (1983, 1984).

DIAGNOSTICS

The distinctive theoretical profile of impulsively generated oscillations within a density enhancement (e.g., coronal loop) suggests that such oscillations might be used as a diagnostic probe of in situ coronal conditions. The periodic phase is of lower amplitude than the quasi-periodic phase. Thus, it is possible that the periodic phase of the motion be obscured by noise and so the fact that it is a precursor to the quasi-periodic phase may pass unnoticed. Considering the quasi-periodic phase, we note that its duration, τ_{dur}, is given by

$$\tau_{dur} = h \left(\frac{1}{c_g^{min}} - \frac{1}{v_A}\right) = \frac{h}{v_{Ae}} \left[\frac{v_{Ae}}{c_g^{min}} - \left(\frac{\rho_o}{\rho_e}\right)^{1/2}\right] . \tag{3}$$

Thus the duration depends both on the distance h between the source and the observation level and also on the magnitude of c_g^{min}, which in turn depends upon the magnitude of the density enhancement. In fact, τ_{dur} is related to the frequency ω^{min} within the quasi-periodic phase (strictly, the frequency at the end of the quasi-periodic phase): for fixed h, a and v_{Ae}, the higher the frequency ω^{min} the shorter the duration time τ_{dur} (Roberts et al. 1984). There is some observational support for this relation in Tapping's (1978) record of meter wavelength pulsating bursts, but further studies are needed. The greater the density enhancement (i.e., the larger the value of ρ_o/ρ_e), the lower the frequency ω^{min} and the lower the group velocity minimum, c_g^{min}, thus suggesting that very dense inhomogeneities have long quasi-periodic phases. By contrast, much smaller density enhancements ($\rho_o \approx \rho_e$) have short quasi-periodic phases but extended decay phases, giving an event with the appearance of a decaying oscillation of extended duration. This may be an explanation of the gradually decaying wave train observed by McLean and Sheridan (1973).

A numerical illustration of equation (3) may be helpful. With $\rho_o = 10\ \rho_e$, inspection of Figure 4 in Roberts et al. (1984) gives $\omega^{min}\ a \approx v_{Ae}$ for which (from their Figure 7) $\tau_{dur} \approx h/v_{Ae}$. Thus, with $v_{Ae} = 2 \times 10^3$ km s^{-1} (so $v_A = 630$ km s^{-1}), a = 10^3 km and h = 5×10^4 km, the quasi-periodic phase has a period of about 3s and a duration of 25s (or some 8 periods). Other choices of ρ_o/ρ_e, h and a will clearly give somewhat different numbers.

In summary, then, we have described how fast magnetoacoustic waves are ducted along regions of low Alfvén velocity (high density) in the corona, exhibiting a distinctive wave signature which may be used as a diagnostic probe of *in situ* coronal conditions (magnetic field strength, density inhomogeneity, etc.) Some observational knowledge of the start time of the impulsive wave source, possibly a flare, the start and end times of the generated wave event, and the frequency of the pulsations in that event permit a seismological deduction of the physical properties of the coronal medium in which the wave propagated. With good observations the theory offers a new means of probing the coronal atmosphere.

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