TITLE: Effect of Ion-Parallel Viscosity on the Propagation of Alfven Surface Waves

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Effect of ion-parallel viscosity on the propagation of Alfvén surface waves

Nagendra Kumar and Himanshu Sikka
Department of Mathematics, K.G.K.(P.G.) College, Moradabad-244001 (U.P.) India

The paper analyzes the damping of the Alfvén surface waves via ion parallel viscosity at a single magnetic interface. The dispersion relation is obtained and characteristics curves are drawn for the real and imaginary phase speeds. The modes thus obtained are two damped Alfvén modes propagating in a way such that when one mode dies new mode appears after a certain propagation gap. The results are applicable for the situation in solar wind at AU for values obtained from the spacecraft data.

1. Introduction

Alfvén waves have been widely discussed in space plasma and their ubiquitous presence in the solar wind was demonstrated by [1]. They lose energy as they propagate outward from the Sun. If we consider solar wind as the part of the corona we can undoubtedly say that Alfvén waves lead to coronal heating. The wave damping in solar wind is not well understood. In what follows we study the viscous damping of Alfvén surface waves propagating at the magnetic interface in the solar wind. The Braginskii viscosity ([2], [3], [4] and [5]) is a tensor with terms \( \eta_0 \), \( \eta_1 \), and \( \eta_2 \), describing viscous dissipation and terms proportional to \( \eta_0 \) and \( \eta_1 \) as nondissipative and describe wave dispersion related to the finite ion gyroradius. Since \( \omega_c / \tau_i \) can typically be of the order of \( 10^6 \) in the solar wind, where \( \omega_c \) is the ion cyclotron frequency and \( \tau_i \) is the ion collision time, the term \( \eta_0 \) 'parallel viscosity' becomes far more important than all other terms.

2. Basic equations

We consider an incompressible and viscous magneto-fluid of uniform density under the assumption, when subscripts are understood. In what follows we study the viscous to obtain the second order differential equation for the \( x \)- component of velocity, \( v_x \),

\[
\frac{d^2}{dx^2} v_x - m^2 v_x = 0, \tag{6}
\]

where \( B_0 = B_0 \hat{z} \); \( v \) and \( b \) are the perturbed velocity and magnetic field, and \( p^T \) is the total pressure (plasma and magnetic).

Equations (3)-(5) can be Fourier-analysed, assuming all perturbed quantities \( \alpha g(x) \exp(-i\omega t + ik_z) \) i.e. \( \partial \theta / \partial t = -i\omega, \partial / \partial x \neq 0, \partial / \partial y = 0 \), and \( \partial / \partial z = ik_z \), to obtain the second order differential equation for the \( x \)- component of velocity, \( v_x \),

\[
\frac{\partial b}{\partial t} = B_0 \cdot \nabla v, \quad (4)
\]

\[
\nabla \cdot v = 0, \nabla \cdot b = 0, \quad (5)
\]

where \( B_0 = B_0 \hat{z} \); \( v \) and \( b \) are the perturbed velocity and magnetic field, and \( p^T \) is the total pressure (plasma and magnetic).

Using the boundary conditions, we derive the dispersion relation in normalized form for the surface waves

\[
(x^2 - 1 + 2ixV_0)^2 \sigma^2 m_0^2 = m_x^2 (x^2 - a_A^2 + 2ixV_0), \tag{9}
\]

where

\[
\begin{align*}
\omega &= \frac{\omega_c}{k_z V_A}, \quad V_0 = \frac{\nu_{ion} k_z}{V_A}, \quad V_e = \frac{\nu_{ion} k_z}{v_A}, \\
a_A &= v_A/v_{A0}, \quad \tau = \frac{\rho_0^2}{\rho_e^2},
\end{align*}
\]
and
\[ m_o^2 = k_o^2 \frac{(x^2 - 1)}{x^2 - 1 + 3ixV_o}. \]

and
\[ m_e^2 = k_e^2 \frac{(x^2 - a_{Ac}^2)}{x^2 - a_{Ac}^2 + 3ixV_e}. \]

Here \( \nu_{ion,o} \) and \( \nu_{ion,e} \) are the kinematic viscosity coefficients, and \( v_{Ac} \) and \( v_{Ae} \) are the Alfvén velocities on either side of the interface. In the absence of ion-parallel viscosity, the dispersion relation reduces to
\[ \frac{\omega^2}{k^2} = \frac{\rho_e v_{Ac}^2 + \rho_e v_{Ae}^2}{\rho_o + \rho_e} \]

which is the well known dispersion relation for Alfvén surface waves in an incompressible fluid. In order to know the nature of waves in our case we need to study the equation (9). On setting \( V_e = \alpha V_o \), where \( \alpha = \frac{v_{ion,e}}{v_{ion,o}} \), we solve numerically the dispersion relation (9) for phase speeds as a function of \( V_o \) in the context of a situation in solar wind at 1 AU. The ratio of current plasma densities on either side of the interface, \( \rho_o/\rho_e \) is taken 0.2. The values of real and imaginary phase speeds are obtained from the values of \( x \) in units of \( v_{A0} \). Figs. 1 and 2 show the variations of real and imaginary phase speeds with the parameter \( V_o \) for \( \alpha = 0.04, a_{Ac} = 0.44 \) and \( \alpha = 0.5 \). It is evident from the figures that the Alfvén surface waves propagating along the interface are damped waves. It is also found that there are only two damped modes of Alfvén surface waves which do not propagate simultaneously; the latter mode propagates with slower speed than previous one. It is seen from figure 1 that the speed of Alfvén surface wave decreases as ion-parallel viscosity increases. This wave becomes evanescent at a critical value of \( V_o = 0.55 \). After the disappearance of this mode a new second mode arises from 0.6 whose phase speed decreases with the increase in the value of the parameter \( V_o \). It is also notable that there is a small region from \( V_o = 0.55 \) to 0.6 where there is no propagation of either of the wave. This region is called a non propagation region. Figure 2 depicts the damping rate of the wave with the parameter \( V_o \). Damping of the mode increases as \( V_o \) increases but decreases after the value of 0.9. Thus the modes of surface waves become damped owing to ion-parallel viscosity in an incompressible fluid.

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References

Figure 1: Variation of real phase speeds \( \omega_R/k \) with parameter \( V_0 \). Dark line represents first mode while light line represents second mode of Alfvén surface waves.

Figure 2: Variation of imaginary phase speeds \( \omega_I/k \) with parameter \( V_0 \). Dark line represents first mode while light line represents second mode of Alfvén surface waves.