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Parameter study on Kelvin–Helmholtz instability in solar wind type flowing structures

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Abstract. The stability behaviour of the wave modes that propagate in the solar wind plasma is considered in the framework of the Hall-magnetohydrodynamics. The Hall-MHD theory extends the wave frequency limit up to or higher than the ion cyclotron frequency. Due to the different flow velocities of the adjacent media in the solar wind, a Kelvin–Helmholtz instability is naturally expected to arise. The behaviour of the wave modes due to this particular kind of instability is studied under solar wind conditions typical for 1 AU. This is a preliminary study on the stability problem in the solar wind flowing structures and it could be relevant for the interplanetary and space weather research.

Keywords. solar wind, MHD, instabilities

1. Introduction

Stability analysis is performed on the problem of surface waves propagating on solar wind type flowing structures. We follow the procedure discussed in Miteva *et al.* (2004) but for much simpler magnetic structure configuration. Two media (denoted with indexes 1 and 2, correspondingly) are considered in the present study, with parameters of the plasma at 1AU (and given here with standard notation, namely, $v_{\rm A}$, Alfvén velocity, $v_{\rm s}$, sound velocity, V initial flow velocity of the plasma medium, M, Mach number, ρ, plasma density, $n_{\rm e}$. electron number density and B, magnetic field): $v_{{\rm A}_1} = 65\,{\rm km\,s^{-1}}$, $v_{{\rm A}_2} = 100\,{\rm km\,s^{-1}}$, $v_{{\rm s}_1} = 65\,{\rm km\,s^{-1}}$, $v_{{\rm s}_2} = 70\,{\rm km\,s^{-1}}$, $V_1 = 500\,{\rm km\,s^{-1}}$, $M_1 = V_1/v_{{\rm A}_1} = 7.7$, $V_2 = 480\,{\rm km\,s^{-1}}$, $M_2 = V_2/v_{{\rm A}_2} = 4.8$, $\rho_1/\rho_2 = 1.708$, $n_{\rm e} = 3\times10^6\,{\rm m^{-3}}$, $B_1/B_2 = 1.177$, $B_1 = 5\times10^{-9}\,{\rm T}$.

2. Hall-MHD theory

The Hall-magnetohydrodynamic approach accounts for the ion-cyclotron/Hall term in the generalized Ohm's law (reflecting some aspects on kinetic theory) on the dispersion characteristics and the damping of hydromagnetic waves. The Hall-magnetohydrodynamics (Hall-MHD) is defined to be the conventional magnetohydrodynamics together with the Hall term in Faraday's law (i.e. $\nabla\times(\mathbf{j}\times\mathbf{B})/n_{\rm e}e$, Huba (1995), where $\mathbf{j}$ is the current and e is the elementary charge). In this way it is possible to describe waves with frequencies up to the ion-cyclotron frequency ($\omega \approx \omega_{\rm ci}$). Since the model still neglects the electron mass, it is limited to frequencies below the lower hybrid frequency. Generally speaking, the theory of Hall MHD is relevant to plasma dynamics occurring on length scales shorter than an ion inertial length ($L < L_{\rm Hall} = c/\omega_{\rm pi} = v_{\rm A}/\omega_{\rm ci}$), and time scales shorter than an ion cyclotron period ($t < \omega_{\rm ci}^{-1}$). With the so-chosen plasma parameters the Hall length here is $l_{\rm Hall} \approx 140\,{\rm km}$ and the ion cyclotron frequency is $\omega/2\pi = 76\,{\rm mHz}$.

The uniform magnetic fields $B_{1,2}$, the steady flow velocities $V_{1,2}$ and the wave vector k lie in the same direction. The standard system of fluid equations plus the Hall term is considered (see Miteva*et al.* (2004) for a review). Following the already established procedure, we find the dispersion relation for surface waves propagating in semi-infinite plasma media. In its general form the dispersion relation can be written:

$$D(\omega_{\mathrm{complex}},\, k,\, V_{1,2},\, B_{1,2},\, l_{\mathrm{Hall}},\, v_{\mathrm{A}_{1,2}},\, v_{\mathrm{s}_{1,2}},\, \rho_{1,2}) = 0$$

3. Numerical results

The dispersion relation is solved by *Mathematica* package assuming a complex frequency (i.e. $\omega_{\mathrm{complex}} = \omega + i\gamma$). The wave number k is real. From all 6 modes/roots of the dispersion relation, only one has a positive imaginary frequency, γ (indicating to growth rate). Here we present the results for $\gamma(k)$. Two cases are considered: flow structures with different magnetic fields ($B_2/B_1 = 1.177$) and flow structures with equal magnetic fields ($B_2/B_1 = 1.0$)

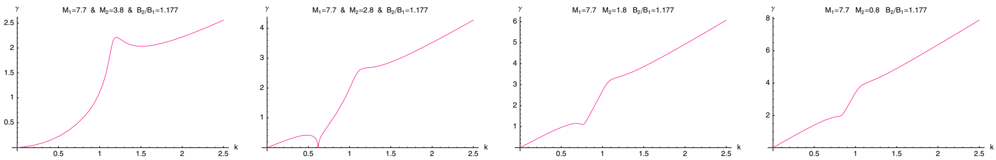

Figure 1. Semi-infinite flowing structures with different magnetic fields.

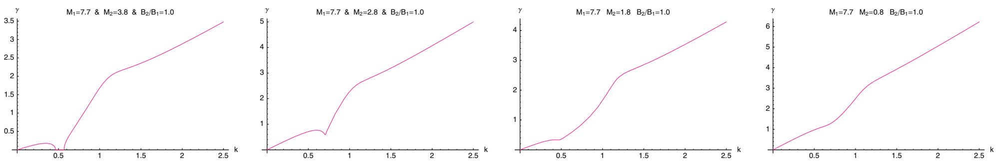

Figure 2. The same magnetic field strength is considered in both media.

The values of the Mach numbers are: $M_1 = 7.7$ ($V_1 = 500.5\,\mathrm{km\,s^{-1}}$) and $M_2 = 3.8;\ 2.8;\ 1.8;\ 0.8$ ($V_2 = 380;\ 280;\ 180;\ 80\,\mathrm{km\,s^{-1}}$) correspondingly. Because the parameters of the solar wind are changing in time, the so-chosen flow velocities could be regarded as time-shots. In any case an instability, of the order of $(0.1 - 10)\omega_{\mathrm{ci}}$, is present for these typical values of the solar wind.

4. Discussions

In general it is expected instability of type Kelvin–Helmholtz to arise on the boundary of two flowing structures with different velocity. Here it is shown that instability is present (a positive imaginary part of the frequency exists) for different magnitudes of the initial flow speeds of the plasma structures. Thus even these preliminary results show that the problem of stability should play important role in discussing the propagation of waves in solar wind plasma. A more detail study is under way.

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