Spatial variation of periods of ion and neutral waves in a solar magnetic arcade

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Motivations & Aims

Although the numerical simulations with use of magnetohydrodynamic (MHD) equations have contributed to many important scientific discoveries, the natural path of progress is to develop more complex models of the solar atmosphere. We use innovative JOANNA code for the partially ionized solar atmosphere described by 2-fluid (ions+electrons and neutrals) equations.

Our goal is to:

1. study two-fluid waves propagating in a magnetic arcade embedded in the partially-ionized,lower solar atmosphere,
2. investigate the impact of the background magnetic field configuration on the observed wave-periods.

Two-fluid equations

For neutrals:

$$\frac{\partial \varrho_n}{\partial t} + \nabla\cdot(\varrho_n \mathbf{V}_n) = 0\,, \qquad (1)$$

$$\frac{\partial(\varrho_n \mathbf{V}_n)}{\partial t} + \nabla\cdot(\varrho_n \mathbf{V}_n \mathbf{V}_n + p_n \mathbf{I}) = \alpha_{in}(\mathbf{V}_i - \mathbf{V}_n) + \varrho_n \mathbf{g}, \qquad (2)$$

$$\frac{\partial E_n}{\partial t} + \nabla\cdot[(E_n + p_n)\mathbf{V}_n] = \alpha_{in}\mathbf{V}_n\cdot(\mathbf{V}_i - \mathbf{V}_n) + Q_n^{in} + \varrho_n \mathbf{g}\cdot\mathbf{V}_n, \qquad (3)$$

where the heat production and exchange term for neutrals is given by

$$Q_n^{in} = \alpha_{in}\left[\frac{1}{2}|\mathbf{V}_i - \mathbf{V}_n|^2 + \frac{3k_B}{m_H(\mu_i + \mu_n)}(T_i - T_n)\right], \qquad (4)$$

and for ions+electrons:

$$\frac{\partial \varrho_i}{\partial t} + \nabla\cdot(\varrho_i \mathbf{V}_i) = 0, \qquad (5)$$

$$\frac{\partial(\varrho_i \mathbf{V}_i)}{\partial t} + \nabla\cdot(\varrho_i \mathbf{V}_i \mathbf{V}_i + p_{ie}\mathbf{I}) = \frac{1}{\mu_0}(\nabla\times\mathbf{B})\times\mathbf{B} + \alpha_{in}(\mathbf{V}_n - \mathbf{V}_i) + \varrho_i \mathbf{g}, \qquad (6)$$

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla\times(\mathbf{V}_i\times\mathbf{B}), \quad \nabla\cdot\mathbf{B} = 0, \qquad (7)$$

$$\frac{\partial E_i}{\partial t} + \nabla\cdot\left[\left(E_i + p_{ie} + \frac{|\mathbf{B}|^2}{2\mu_0}\right)\mathbf{V}_i - \frac{1}{\mu_0}\mathbf{B}(\mathbf{V}_i\cdot\mathbf{B})\right] = \alpha_{in}\mathbf{V}_i\cdot(\mathbf{V}_n - \mathbf{V}_i) + Q_i^{in} + \varrho_i \mathbf{g}\cdot\mathbf{V}_i + L_r, \qquad (8)$$

with a similar heat exchange and production term for ions given by

$$Q_i^{in} = \alpha_{in}\left[\frac{1}{2}|\mathbf{V}_i - \mathbf{V}_n|^2 + \frac{3k_B}{m_H(\mu_i + \mu_n)}(T_n - T_i)\right]. \qquad (9)$$

Numerical results

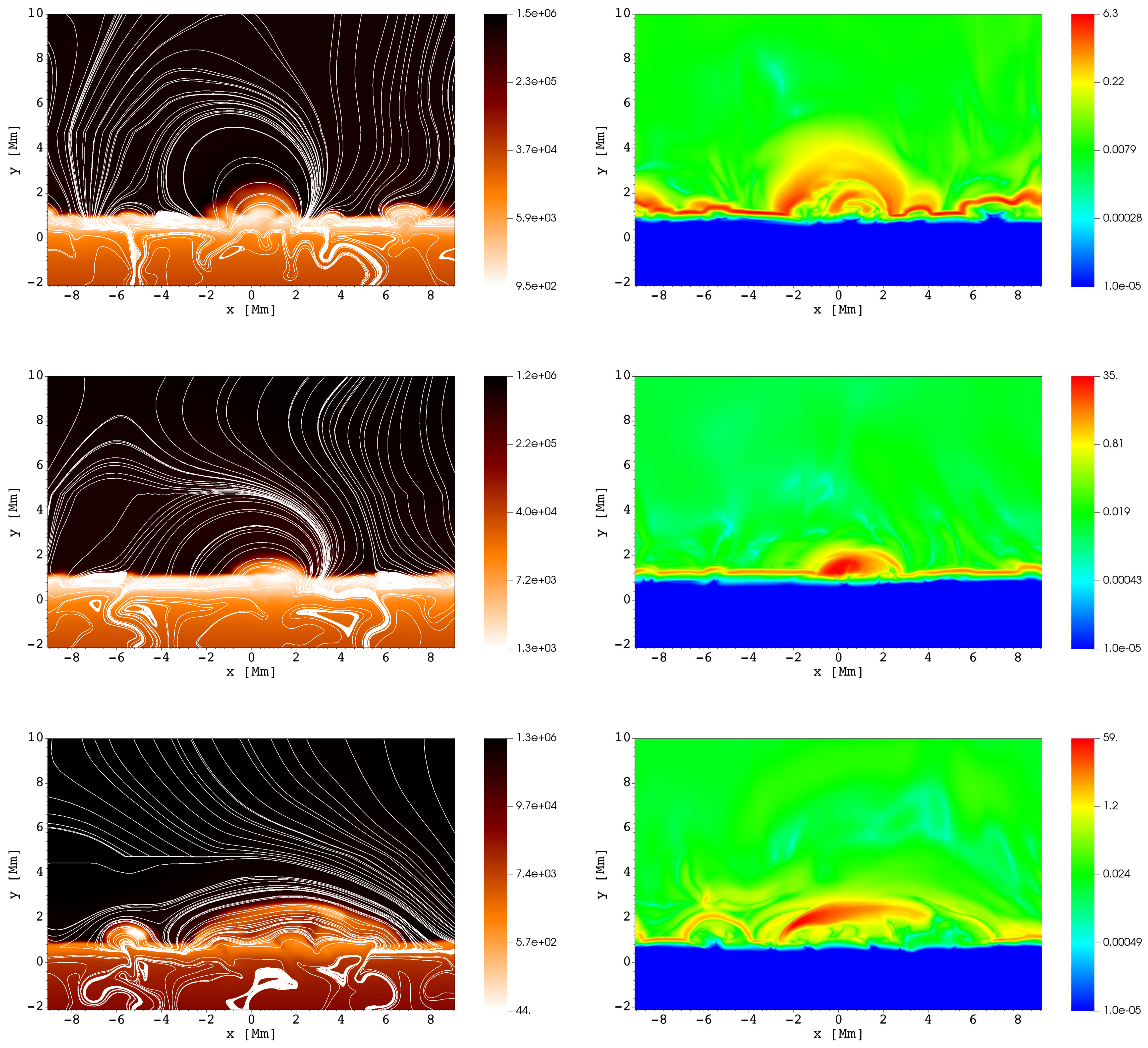

Fig. 1 Spatial profiles of logarithm of the ion temperature, T_i, expressed in K, overlayed by the magnetic field lines (left) and the corresponding ion-neutral drift, $|V_i - V_n|$, expressed in m s^{-1} (right) at $t = 3800$ s, $t = 4000$ s, and $t = 4200$ s (from top to bottom).

Conclusions

In the photospheric regions of highly turbulent and strongly coupled plasma the main period of excited waves is close to 300 s, while in the chromosphere, where both fluids decouple, situation differs between regions outside and inside of the solar magnetic arcade. It is shown, that in such magnetic structures a strong ion-neutral drift is present, while outside of these structures, ions and neutrals remain essentially coupled. In addition, refraction and subsequent reflection of magneto-acoustic waves around the regions of $\beta = 1$ significantly alters the wave propagation in this model.

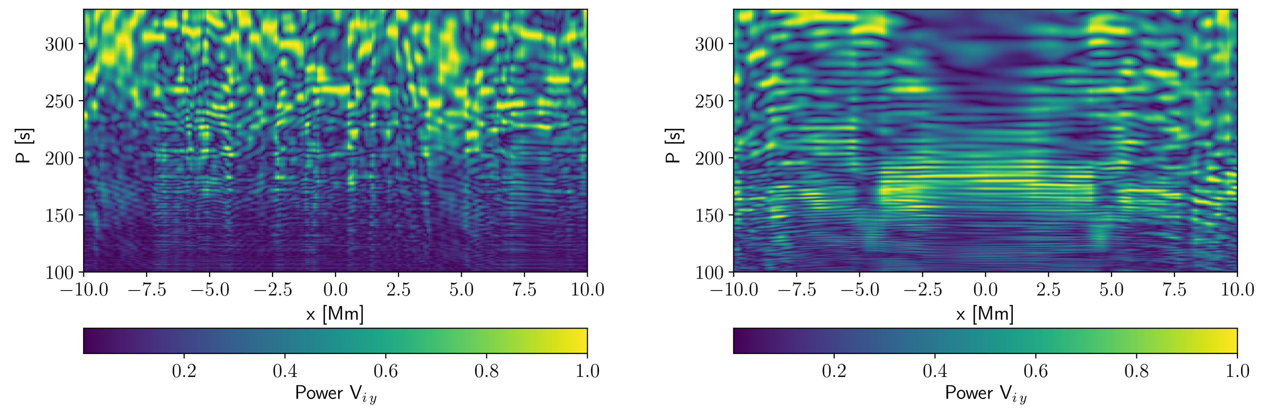

Fig. 2 Fourier power spectrum of P (in arbitrary units) associated with ion vertical component of velocity, evaluated at $y = 0.25$ Mm (left) and $y = 3.5$ Mm (right), vs horizontal distance x in the solar atmosphere.

Above the foot-points of the considered arcade, the plasma is dominated by a vertical magnetic field along which ion slow magnetoacoustic-gravity waves are guided. These waves exhibit a broad range of periods with the most prominent periods of 180 s, 220 s, and 300 s. Above the main loop of the solar arcade, where mostly horizontal magnetic field lines guide ion magnetoacoustic waves, the main spectral power reduces to the period of about 180 s and longer wave-periods do not exist.

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