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Investigation of waves in the very local interstellar medium

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Overview

The Voyager 1 spacecraft now finds itself in the interstellar medium (ISM), an event of enormous historical import as humankind breaks out of its solar neighborhood to make the first ever in situ measurements of the ISM. Models of the ISM typically assume that the plasma and neutral gas is collisionally equilibrated. However, the VLISM is comprised of an admixture of suprathermal protons known as pickup ions (PUIs) and thermal interstellar protons and electrons. We show that the VLISM is not collisionally equilibrated within about 75 – 100 AU of the heliopause. We develop a multi-fluid model of the VLISM based on a kinetic description of the PUIs.

Key Findings

We develop new model equations that provide a plasma physics description of the VLISM. The continuity, momentum, and energy equations for electrons and protons:

$$\frac{\partial n_{e,s}}{\partial t} + \nabla.\left(n_{e,s}u_{e,s}\right) = 0;$$

$$m_{e,s}n_{e,s}\left(\frac{\partial u_{e,s}}{\partial t} + u_{e,s}\,.\nabla u_{e,s}\right) = -\nabla P_{e,s} \mp e n_{e,s}\left(E + u_{e,s} \times B\right);$$

$$\frac{\partial P_{e,s}}{\partial t} + u_{e,s}\,.\nabla P_{e,s} + \gamma_{e,s}P_{e,s}\nabla.u_{e,s} = 0,$$

For pickup ions:

$$\frac{\partial n_p}{\partial t} + \nabla.\left(n_p U_p\right) = 0;$$

$$\frac{\partial}{\partial t}\left(n_p U_p\right) + \nabla.\left[n_p U_p U_p + I P_p\right] = \frac{e}{m_e} n_p\left(E + U_p \times B\right);$$

$$\frac{\partial P_p}{\partial t} + U_p\,.\nabla P_p + \frac{5}{3}P_p\nabla.U_p = \frac{1}{3}\left(\nabla.K.\nabla P_p\right),$$

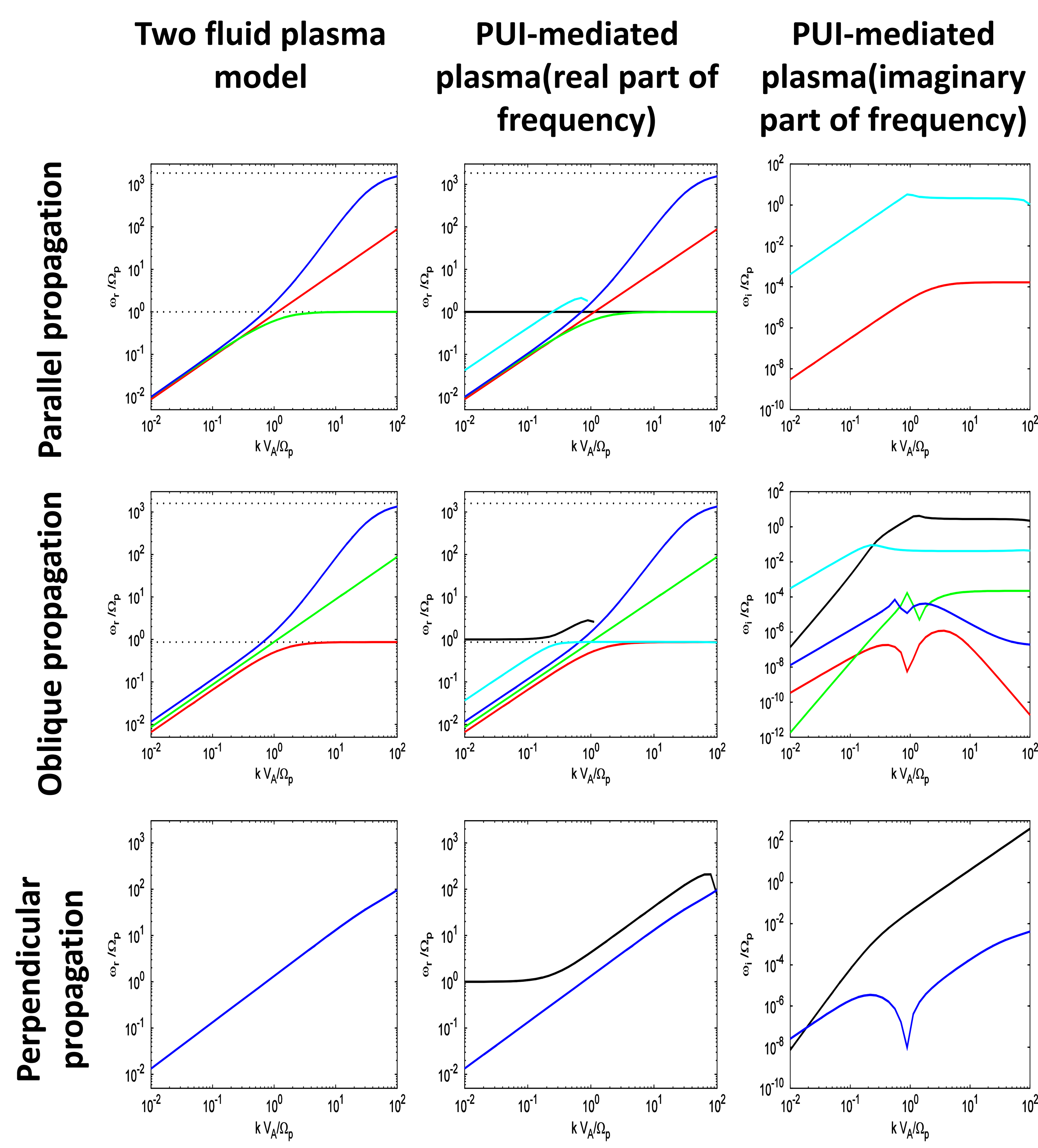
With this model we predict 1) that pickup ions damp all obliquely propagating waves, possibly accounting for the curious Voyager 1 magnetometer observations of a very quiescent ISM; 2) predict the existence of a new class of waves in the VLISM; 3) predict a substantial heat flux associated with pickup ions,

$$q_i(x,t) = -\frac{1}{2}K_{ij}\frac{\partial P_p}{\partial x_j}, \quad K_{ij} \equiv b_i\frac{c^2\tau_s}{3}b_j$$

4) predict a relatively weak coupling of the pickup ions with the thermal interstellar plasma.

Impact

Initial observations of the VLISM by the Voyager 1 magnetometer [Burlaga & Ness (2014)] suggest a surprisingly low level of magnetic field fluctuations. Base on the results presented by Zank et al. (2014), it is possible that PUIs act to damp waves in the VLISM significantly. Investigating waves in the VLISM provides the basis for a detailed understanding of the interstellar medium, which can be tested against the Voyager 1 and 2 observations.



Blue (Fast Magnetosonic wave), **Red** (Slow Magnetosonic wave), **Green** (Alfven wave), **Black** (Fast PUI wave), and **Cyan** (Slow PUI wave). In the three fluid model, two more waves (Fast PUI and Slow PUI waves) exist than the two fluid model.

Explanation

Voyager 1 and soon Voyager 2 represent our only opportunity for humankind to explore the interstellar medium in situ in the next two decades. The value of observations is increased immeasurably by theoretical models. The model here represents the first attempt to develop a detailed plasma physics model of the VLISM.

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