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ORIGINAL ARTICLE

Stability of ion-acoustic waves in a pair-ion plasma with a third species of ions: application to cometary plasmas

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Abstract A popular model of a cometary plasma is hydrogen (H^+) with positively charged oxygen (O^+) as a heavier ion component. However, the discovery of negatively charged oxygen (O^-) ions enables one to model a cometary plasma as a pair-ion plasma (of O^+ and O^-) with hydrogen as a third ion constituent.

We have, therefore, studied the stability of the ion-acoustic wave in such a pair-ion plasma with hydrogen and electrons streaming with velocities $V_{d\mathrm{H}^+}$ and V_{de}, respectively, relative to the oxygen ions. We find the calculated frequency of the ion-acoustic wave with this model to be in good agreement with the observed frequencies. The ion-acoustic wave can also be driven unstable by the streaming velocity of the hydrogen ions. The growth rate increases with increasing hydrogen density n_{H^+}, and streaming velocities $V_{d\mathrm{H}^+}$ and V_{de}. It, however, decreases with increasing oxygen ion densities n_{O^+} and n_{O^-}.

Keywords Comets · Ion-acoustic wave · Pair-ion plasma · Streaming ions

1 Introduction

The physics of pair plasmas is now an attractive area of research that encompasses both astrophysical and terrestrial plasma environments. Beginning with the surmise that an electron-positron plasma comprised the early universe, such plasmas are now firmly believed to exist in the magnetospheres of pulsars (McClintock 1984), neutron stars (Dubin 2004), active galactic nuclei (Begelman et al. 1984) and also in the laboratory (Surko and Murphy 1990; Greaves et al. 1994). However, it was only with the production of pure pair-ion fullerene ($C_{60}^{\pm}$) plasmas (Oohara and Hatakeyama 2003; Oohara et al. 2005) in the laboratory that this area has attracted wider attention (Vranjes and Poedts 2005; Shukla and Khan 2005; Saleem et al. 2006; Saleem 2006; Saeed and Mushtaq 2009; Vranjes 2011; Arshad et al. 2011).

It is well known that a cometary plasma, in general, contains hydrogen and new born heavier ions with relative densities depending on the distance from the nucleus. Initially, positively charged oxygen ion was considered as an important heavier ion (Ipavich et al. 1986; Coplan et al. 1987; Balsiger et al. 1986). However, the discovery of negatively charged oxygen ions (Chaizy et al. 1991) enables one to model the plasma environment around a comet as a pair-ion plasma (O^+ and O^-) with other ions (both lighter and heavier than oxygen) and electrons constituting the other components of the plasma.

We have, therefore, studied the stability of the ion-acoustic wave in a plasma that is composed of positively and negatively charged oxygen ions. The electrons and hydrogen ions, with streaming velocities relative to the heavier ions, constitute the other components of our plasma and also are a source of free energy that could drive the ion-acoustic wave unstable. Electrostatic wave modes in pair-ion plasmas are especially interesting since it was observed that the ion-acoustic wave (IAW), the ion plasma wave (IPW) and an intermediate frequency wave (IFW) all propagated parallel to the magnetic field in these plasmas (Oohara et al. 2005). Theoretical studies on ion-acoustic waves

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