Planetary and Space Science 156 (2018) 130–138

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

On the effects of suprathermal populations in dusty plasmas: The case of dust-ion-acoustic waves

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ARTICLE INFO

Keywords:
Space plasmas
Dust
Suprathermal populations
Kappa distribution
Waves

ABSTRACT

Suprathermal populations with energetic distributions deviating from a standard Maxwellian are ubiquitous in dusty plasmas from space environments, as a proof that these systems are out of thermal equilibrium. The excess of free energy may have important implications in the relaxation processes by the plasma waves and fluctuations, as well as in their dissipation. In order to emphasize the effects of suprathermal populations a new realistic interpretation is proposed on the basis of an advanced Kappa modeling in accord with the observations. This article is focused on the kinetic description of dust-modified ion acoustic (DIA) waves in the presence of Kappa-distributed (suprathermal) particles. Our methodology follows closely recent considerations on the structural characteristics of Kappa distributions, contrasting the high-energy tails enhanced by the suprathermal populations with the Maxwellian (thermal) core of the distribution. The effects on DIA waves are found to be highly dependent on the nature of suprathermal particles: both the wave-frequency and Landau damping rate are inhibited by the suprathermal electrons, while the suprathermal ions have an opposite influence.

1. Introduction

Dusty plasmas are ubiquitous in space, where they occur in various environments, e.g., solar wind, planetary magnetospheres, cometary tails, etc., and in a wide range of physical conditions (Horanyi et al., 1988; Goertz, 1989; Horanyi, 1996; Shukla and Mamun, 2002). It is by now established that the presence of charged dust particulates in a plasma may not only affect existing modes, but actually create new ones (Shukla and Mamun, 2002). The dispersion characteristics of the well known ion-acoustic wave, for instance, may be dramatically affected by the presence of the dust. Predicted by Rao et al. (1990), dust ion acoustic (DIA) waves were subsequently observed in experiments (Barkan et al., 1996), which confirmed that the presence of negatively charged dust grains in fact *increases* the phase velocity and reduces the Landau damping rates of these waves (for an extended discussion, see the textbook by Shukla and Mamun (2002)). These are ion-acoustic waves modified by the negative dust grains, which imply a reduction in the density of free electrons, and due to collective effects DIA waves become markedly dependent on the electron and ion properties (see the parameter survey in Baluku and Hellberg (2015).). Usually described in the absence of magnetic fields, DIA waves keep their dispersion properties in the propagation direction parallel to a uniform magnetic field.

Almost 20 years have passed since Tsytovich and de Angelis (Tsytovich and de Angelis, 1999) have formulated the first general kinetic approach for dusty plasmas, and stimulated the interest for understanding their micro-physics, i.e., wave dissipation, instabilities, etc., conditioned by the velocity distributions of plasma particles. Velocity distributions of electrons and ions measured in space plasmas are well described by the Kappa (or κ-) power-laws (Pierrard and Lazar, 2010; Lazar et al., 2012). The kinetic theory of DIA waves, in particular, in the presence of Kappa-distributed electrons and ions is elaborated in Baluku and Hellberg (2015), who extended previous similar investigations, e.g., D'Angelo (1994); Lee (2010), on the basis of the generalized plasma dispersion function introduced in Summers and Thorne (1992); Hellberg and Mace (2002); Mace and Hellberg (2009) for electrostatic waves and arbitrary real κ. (Similar studies have been carried our for electromagnetic modes; see e.g., Gaelzer et al. (2010).) A Kappa distribution for the electron background has been considered in a number of works, with respect to linear and nonlinear DIA solitary waves (Kourakis and Shukla, 2003, 2004; Baluku et al., 2010; Saini and Kourakis, 2010; Kourakis et al., 2012; Verheest et al., 2013). Both the dispersion characteristics of linear DIA waves and the propagation features of solitary waves have

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https://doi.org/10.1016/j.pss.2017.11.011
Received 28 June 2017; Received in revised form 10 November 2017; Accepted 15 November 2017
Available online 21 November 2017
0032-0633/

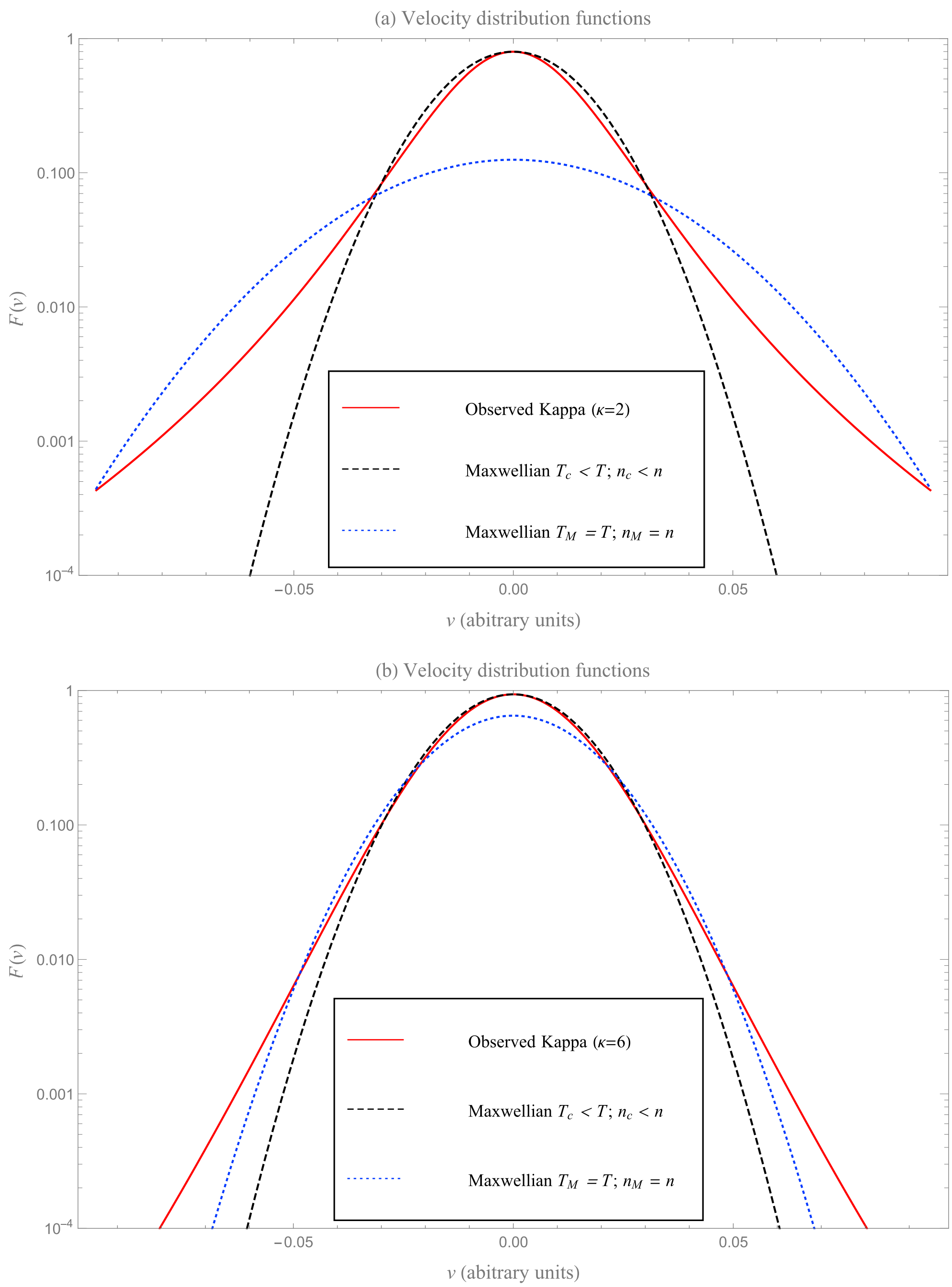

Fig. 1. Kappa distribution (red solid lines), for two values of the power-index $\kappa = 2$ (top panel) and $\kappa = 6$ (bottom panel) is compared with the Maxwellian limits in Eq. (3) (black dashed lines) and Eq. (6) (blue dotted lines). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

been shown to be sensitive to variation of the κ index value (Kourakis et al., 2012), as in fact confirmed by kinetic simulations (Hosseini Jenab et al., 2011; Hosseini Jenab and Kourakis, 2014).

To put things in perspective, as regards earlier works, these have actually mainly focused on the propagation characteristics of linear and nonlinear modes in the presence of charged dust, thus our knowledge in this respect is arguably quite comprehensive at the moment. However, earlier studies have not tackled the actual effects of suprathermal populations on the wave characteristics, as these are manifested, within the kinetic formulation, in the contrast between the distribution with suprathermal tails and the central "core" of the distribution; this is in fact an issue of importance in the interpretation of observational data. This problem is the primary motivation of the work at hand. From a pragmatic viewpoint, the Kappa distribution function is nearly Maxwellian at low-energies, forming the so-called (thermal) core of the distribution, but decreases as a power-law for higher energies exceeding the mean kinetic energy of plasma particles. The high energy tails of the observed distributions are enhanced by the suprathermal populations, especially the suprathermal electrons and ions present in dusty plasmas from space. The abundance of suprathermals is quantified by the low values of κ-index, which are lower for the electrons, usually found in the interval $2 < \kappa < 6$ (Pierrard and Lazar, 2010; Lazar et al., 2012). In the absence of suprathermals the velocity distribution reduces to its Maxwellian core, yet with different parameters, i.e. less populated (number density) and with a lower temperature. The effects of suprathermals thus becomes obvious and can be estimated by a comparative analysis of Kappa-distributed plasma with the Maxwellian core (Lazar, 2017). Such a comparative study is performed in the present paper for DIA waves, and the results are