PIC simulations of a three component plasma described by Kappa distribution functions as observed in Saturn's magnetosphere

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Introduction

The Kappa Velocity Distribution Function (Kappa-VDF) is characterized by an energetic tail and it is represented by the following equation:

$$f_\kappa(v) = \frac{1}{(\pi\kappa\theta^2)^{3/2}} \frac{\Gamma(\kappa+1)}{\Gamma(\kappa-1/2)} \left(1+\frac{v^2}{\kappa\theta^2}\right)^{-(\kappa+1)}$$

where $\theta^2=(2\kappa-3)v_{th}^2/\kappa$ and $3/2<\kappa\leqslant\infty$. Kappa-VDF represents plasma out of thermal equilibrium and the kappa index represents how far the plasma is from the Maxwellian distribution (distribution on equilibrium). Kappa-VDF tends to the Maxwellian when $\kappa\rightarrow\infty$.

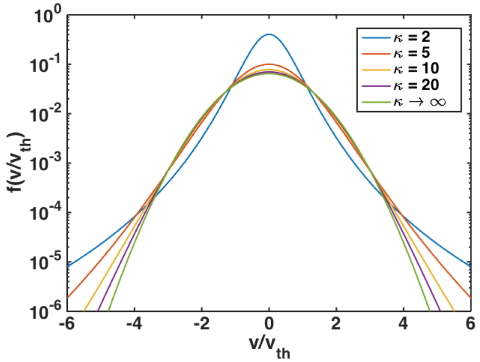

Figure 1: Kappa distribution for different values of kappa index.

This distribution is usually found in plasmas in our solar system such as in the Sun, the solar wind, the Earth's magnetosphere and in the magnetosphere of other planets (Jupiter, Saturn, Uranus, Neptune).

We developed a numerical procedure to generate a set of velocities that follows the Kappa-VDF to use in the PIC simulation.

Electron velocity distribution in the saturnian magnetosphere

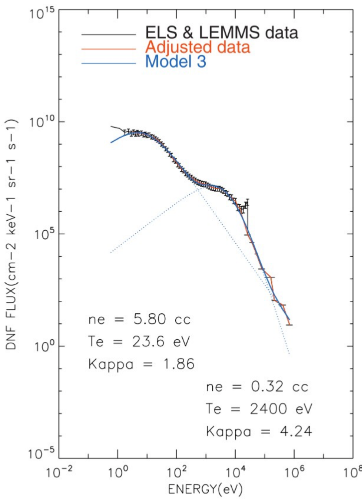

Figure 2: Electron population in Saturn at 9 Saturn radii.

Using data from the Cassini mission, Schippers et. al. (2008) characterized the electron population found in the magnetosphere of Saturn for a region between 6 and 18 Saturn radii. They obtained a distribution that is a combination of two electron population both described by Kappa-VDF with different temperatures, densities and kappa indexes.

A background plasma composed by two electron populations allows the existence of the electron-acoustic mode parallel to the ambient magnetic field. In the perpendicular direction the Bernstein modes are modified by this distribution.

Results: Bernstein Modes

Bernstein modes propagate perpendicularly to the ambient magnetic field in the harmonic of the electron cyclotron frequency. Below the Upper Hybrid Frequency ($\omega_{UH}=5.099\,\omega_{ce}$ in the simulation) the modes occupy all the band between $n\omega_{ce}$ and $(n-1)\omega_{ce}$,while above there are regions without wave propagation. The simulation was done with KEMPO1, which is a 1D electromagnetic particle code, developed by Omura and Matsumoto (1993), modified to introduce, as the initial condition, electrons following a Kappa-VDF. For the simulation, the parameters for the hot and cold electron are: $n_h=n_c=0.5\,n_e$ and $T_h/T_c=101.659$. The results show that the dispersion relation for the Bernstein modes are strongly dependent of the kappa index of the cold electrons, and are in good agreement with previous theoretical results, as shown in the figure below.

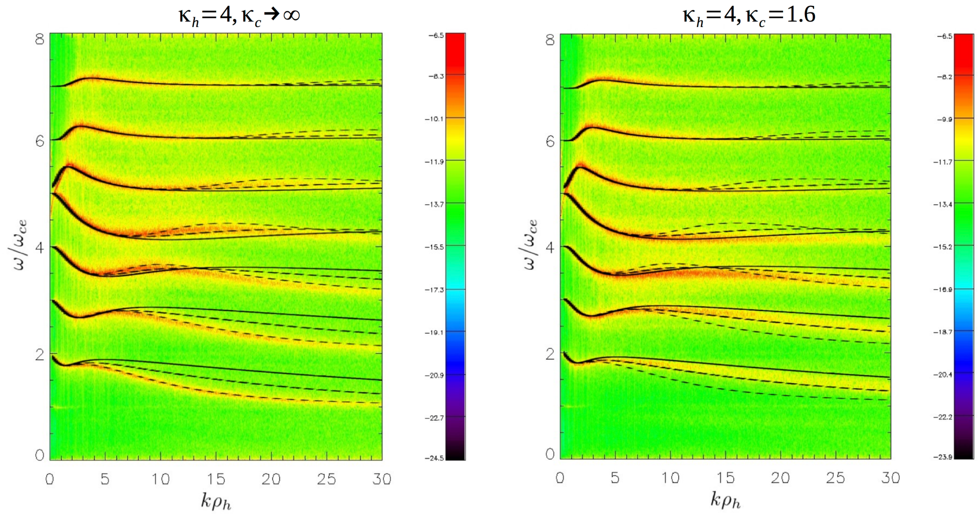

Figure 3: Dispersion diagram for the component E_x. The lines are the theoretical results of Henning et. al. (2011); the hot electrons have $\kappa_h=4$ and the cold electrons have $\kappa_c\rightarrow\infty$ (solid line), $\kappa_c=2$ (thick dashed) and $\kappa_c=1.6$ (thin dashed).

Conclusions

The results obtained here are in good agreement with Henning et. al. (2011) who solved the dispersion relation for the electrostatic Bernstein modes. In contrast with their results, PIC simulations presents the electromagnetic modes X and Z, since simulations include electromagnetic effects. The method developed to create the initial distribution can be used to study different problems in the future.

- Omura, Y.; Matsumoto, H. Kempo1: Technical guide to onedimensional electromagnetic particle code. Computer Space Plasma Physics, p. 21–65, 1993.
- Schippers, P., et al. (2008), Multi-instrument analysis of electron populations in Saturn's magnetosphere, J. Geophys. Res., 113
- Henning, F. D., R. L. Mace, and S. R. Pillay (2011), Electrostatic Bernstein waves in plasmas whose electrons have a dual kappa distribution: Applications to the Saturnian magnetosphere, J. Geophys. Res., 116.

Acknowledgement

CAPES

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