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Upper-hybrid waves and fluctuations in space plasma

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Quasi electrostatic fluctuations in the upper-hybrid frequency range are commonly detected in the planetary magnetospheric environment. The origin of such phenomena may relate to the instability driven by a loss-cone feature associated with the electrons populating the dipole-like magnetic field. The present paper carries out a one-dimensional electrostatic particle-in-cell simulation accompanied by a reduced quasilinear kinetic theoretical analysis to investigate the dynamics of the upper-hybrid mode instability driven by an initial ring electron distribution function, which is a form of loss-cone distribution. A favorable comparison is found between the two approaches, which shows that the quasilinear theory can be an effective tool in the study of plasma instabilities, especially if it is guided by, and validated against, the more rigorous simulation result.

The type of quasilinear theory employed in the present study assumes that the particle distribution function can be modeled by an analytical time-dependent form. Such a modeling must be done carefully to reflect the actual physics. In the context of solar wind research, the time-dependent bi-Maxwellian distribution has been quite successfully used for various temperature anisotropy-driven instabilities – see, e.g., a recent paper [1]. However, in the present case of an initial ring, or more generally, the loss-cone instability, the time evolution of the electron distribution is not trivial to predict *a priori*. In order to guide the theoretical modeling, we have thus first carried out a one-dimensional electrostatic (1D ES) particle-in-cell (PIC) code simulation. Guided by the results of simulation, we have subsequently modeled the time-dependent hot electron distribution by the same ring form, except that the ring speed and thermal spread are allowed to vary in time. Upon verifying the result of such a reduced quasilinear theory against the PIC simulation, it is found that the quasilinear method quite reasonably reproduces the simulation result.

The present paper is largely motivated by quasi electrostatic fluctuations in the upper-hybrid frequency range pervasively detected in the terrestrial or planetary magnetosphere, which is presumably excited by the loss-cone electrons, ring distribution being a form of loss-cone. However, the occurrence of ring or non gyrotropic ring (also known as the agyrotropic crescent) electron distribution can take place in other physical situations. For instance, such a distribution of electrons have been seen in numerical simulations of magnetic reconnection exhausts [2,3]. Such electron distributions are detected by Magnetospheric Multi-Scale (MMS) spacecraft close to the electron diffusion region, which are accompanied by intense high-frequency upper-hybrid fluctuations [4]. This broadens the relevance of the present to situations beyond the magnetospheric applications.

References

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