Low-frequency electromagnetic fluctuations and plasma heating in multi-ion-species plasmas

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Fusion and space plasmas usually contain multiple ion species. In such multi-ion-species plasmas, wave propagation and energy transport are quite different from those in a single-ion-species plasma. For example, a nonlinear magnetosonic pulse is damped, even if the plasma is collisionless and the pulse propagation is perpendicular to a magnetic field?[1]. The damping is due to the energy transfer from the pulse to heavy ions. Autocorrelation functions of quasi-modes consisting of electrostatic ion Bernstein waves are also practically damped [3], although each perpendicular sinusoidal wave is undamped.

We here study long-wavelength electromagnetic fluctuations across a magnetic field with attention to the effect of multiple ion species. In the frequency regime lower than the lower hybrid frequency, there exist three types of mode. We call them magnetosonic mode, ion cyclotron modes, and heavy-ion cut-off modes. (A heavy-ion cut-off mode has the ion-ion hybrid cutoff frequency, which exists slightly above the gyrofrequency of each heavy ion.) The power spectra of magnetic fluctuations in a thermal equilibrium state are analytically and numerically obtained. In a single-ion-species plasma, the magnetosonic mode is an overwhelmingly dominant mode. The autocorrelation function is thus given by a cosine function with a constant amplitude. In a multi-ion-species plasma, however, the amplitudes of the heavy-ion cutoff modes can be comparable to that of the magnetosonic mode. Therefore, the autocorrelation function is initially damped owing to the phase mixing of the magnetosonic and heavy-ion cutoff modes, and its recurrence time becomes quite long. This suggests that heavy-ion cutoff modes can play essential roles in energy transport.

Evolution of macroscopic magnetohydrodynamic disturbances is also studied with theory and electromagnetic particle simulations [4]. Analyses are carried out on disturbances where the initial magnetic profiles are sinusoidal. Using a linear kinetic theory based on the Vlasov and Maxwell equations, we show that the amplitude of the disturbance has the same time dependence as the autocorrelation function of thermal magnetic fluctuations. It is then confirmed by simulations that in a single-ion-species plasma, the disturbance is undamped with its energy oscillating between the magnetic field and ion velocity. In a multi-ion-species plasma, however, it is initially damped. Furthermore, long-time simulations demonstrate that the amplitude of the disturbance continues to decrease in a multi-ion-species plasma. This is due to nonlinear mode couplings. The magnetic energy is irreversibly transferred to the ions.

These results indicate that the presence of multiple ion species can enhance the energy transfer from magnetohydrodynamic disturbances to the ions. These processes could be important in the transport in, for instance, the solar corona, where the number of ion species is quite large and each ion species has many different ionic charge states.

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