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09:45-10:00

Study of the nonlinear scattering of energetic electrons into the loss cone by coherent whistler-mode waves

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Whistler mode chorus emissions play important roles in the pitch angle scattering process of energetic electrons. Previous studies revealed high correlation of the wave amplitude of chorus emissions to both auroral luminosity [Nishimura et al, 2010] and the electron flux in the loss cone [Kasahara et al, 2018]. However, detailed processes scattering electrons into the loss cone are still unclear. Conventionally, the pitch angle scattering of energetic electrons has been considered as a diffusion process based on the quasi-linear theory. On the other hand, Kitahara and Katoh (2019) has theoretically and numerically revealed that coherent whistler-mode waves effectively trap small pitch angle electrons and change their pitch angle away from the loss cone. Further investigation for the detailed process of the pitch angle scattering by chorus emissions has been required.
To clarify the physical process of scattering electrons into the loss cone, we have updated the test particle code of Kitahara and Katoh (2019) in order to compute the motion of a large number of electrons by a massively parallelized supercomputer system. By using the developed code, we compute the motion of energetic electrons moving along a field line under the presence of a packet of monochromatic whistler-mode waves generated at the magnetic equator. We assume both the wave amplitude and frequency of whistler-mode waves; the wave frequency 0.3 times of the electron gyrofrequency at the magnetic equator, and wave amplitude 0.01% ~ 0.1% of the background magnetic field intensity at the equator (B_{0eq}). We also assume that the plasma frequency is equal to 4 times of the electron gyrofrequency at the magnetic equator and is uniform along a field line. We calculate the motion of 17,212,500 energetic electrons, whose initial energies and equatorial pitch angles are assumed to be in the ranges of 10 ~90 keV and 5 ~ 89 degree, respectively.
Our simulation results show that electrons not only near the loss cone but also in the large pitch angle range are scattered into the loss cone and contribute to the loss cone flux. We evaluate the ratio of the number of electrons inside/outside the loss cone quantitatively. We obtained the ratio 0.5 for the wave amplitude 0.1% of the background magnetic field. We also analyzed the trajectories of electrons scattered into the loss cone in order to investigate the physical process responsible for the pitch angle scattering. According to Omura et al. (2008), we estimated the size of the trapping region in the velocity phase space, in other words the θ - ζ phase space, where θ is the difference between the parallel component of the electron velocity and the resonance velocity, and ζ is the relative phase angle between gyrophase and wave phase, which is useful to understand the changes of the pitch angle and kinetic energy of resonant electrons.
Based on the results, we categorize 2 types of the nonlinear pitch angle scattering; resonant scattering and non-resonant scattering. Resonant scattering decreases electrons' pitch angle greatly. The range of pitch angle change is almost corresponding to the electromagnetic electron hole size. This feature is consistent with the report by Hikishima (2010) as “non-linear scattering". Non-resonant scattering makes electrons of a few degrees larger than the loss cone fall into the loss cone. Even if electrons do not satisfy the resonance condition, the pitch angle of electrons is perturbed by the wave electromagnetic field and therefore some of electrons are scattered into the loss cone.
For the case of the wave amplitude 0.1% of the background magnetic field, we further analyzed the origin of electrons scattered into the loss cone. The simulation result revealed that half of electrons inside the loss cone had their initial pitch angle near the loss cone (α_{LC}) and that others had a few to twenty degree away from the loss cone (α_{NS}), indicating the role of the resonant nonlinear scattering. We found that α_{NS} is energy dependent; 15 and 10 degree for 20 and 30 keV electrons, respectively. On the other hand, electrons whose pitch angle between α_{LC} and α_{NS} do not contribute the electron flux inside the loss cone, because of the effect of anomalous trapping of low pitch angle electrons [Kitahara and Katoh, 2019]. Focusing on the influence of the wave amplitude, the number of electrons scattered into the loss cone by non-resonant scattering increases as the wave amplitude increases. We also found the increase of the number of electrons scattered into the loss cone from the larger pitch angle range by resonant scattering. Based on the simulation results, we discuss how the waves amplitude affects loss cone flux and roles of nonlinear effect in the pitch angle scattering of energetic electrons.
References
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