SG-I6 AAPPS-DPP2019

3rd Asia-Pacific Conference on Plasma Physics, 4-8,11.2019, Hefei, China

Direct measurements of two-way wave-particle energy transfer in a collisionless space plasma

Naritoshi Kitamura[1], Masahiro Kitahara[2], Masafumi Shoji[3], Yoshizumi Miyoshi[3],
Hiroshi Hasegawa[4], Satoko Nakamura[5], Yuto Katoh[2], Yoshifumi Saito[4], Shoichiro Yokota[6],
Daniel J. Gershman[7], Adolfo F. Vinas[7,8], Barbara L. Giles[7], Thomas E. Moore[7],
William R. Paterson[7], Craig J. Pollock[9], Christopher T. Russell[10], Robert J. Strangeway[10],
Stephen A. Fuselier[11,12], and James L. Burch[11]
[1] Department of Earth and Planetary Science, Graduate School of Science, the University of Tokyo, [2] Department of Geophysics, Graduate School of Science, Tohoku University, [3] Institute for Space-Earth Environmental Research, Nagoya University, [4] Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, [5] Research Institute for Sustainable Humanosphere, Kyoto University, [6] Department of Earth and Space Science, Graduate School of Science, Osaka University, [7] NASA Goddard Space Flight Center, [8] Department of Physics, American University, [9] Denali Scientific, [10] Institute of Geophysics and Planetary Physics, University of California, Los Angeles, [11] Southwest Research Institute, [12] University of Texas at San Antonio, San Antonio
e-mail: kitamura@eps.s.u-tokyo.ac.jp

Wave-particle interactions are thought to play a crucial role in energy transfer in collisionless space plasmas in which the motion of charged particles is controlled by electromagnetic fields. Such wave-particle interactions occur ubiquitously in space. Although the co-existence of waves and accelerated particles (or particle populations that have free energy for wave growth) has been studied for decades in the magnetosphere, such co-existence does not necessarily indicate that energy is transferred between them at the observation site and time. In most situations, moving particles interact gradually with propagating waves in a spatially extended region, and it is not realistic to track a certain particle or wave packet by spacecraft. Thus, detecting local energy transfer between the fields and particles is necessary to quantitatively evaluate the magnitude of any interaction.

The energy transfer rate via cyclotron type interactions between cyclotron waves and ions was calculated as the dot product of the wave electric field ($\mathbf{E}_{\mathrm{wave}}$) and the ion current ($\mathbf{j}_{\mathrm{i}}$) perpendicular to the background magnetic field ($\mathbf{B}_0$). The full-sky field of view of Fast Plasma Investigation Dual Ion Spectrometer (FPI-DIS) on the Magnetospheric Multiscale (MMS) spacecraft enabled fast measurements of instantaneous $\mathbf{j}_{\mathrm{i}}$ and thus of energy transfer rate ($\mathbf{j}_{\mathrm{i}} \cdot \mathbf{E}_{\mathrm{wave}}$).

During an EMIC event in the Earth's dusk side magnetosphere, 15-second averages of $\mathbf{j}_{\mathrm{i}} \cdot \mathbf{E}_{\mathrm{wave}}$ reached -0.3 pW m^{-3} for ions with energies 14–30 keV and pitch angles around the first order cyclotron resonance condition for H^+. This demonstrates that the energy of H^+ was being transferred to the cyclotron wave by the cyclotron resonance. As a quantitative measure of energy transfer, gyro phase averaged energy gain per H^+ ion perpendicular to $\mathbf{B}_0$ was computed for each bin by dividing $\mathbf{j}_{\mathrm{i}} \cdot \mathbf{E}_{\mathrm{wave}}$ by the partial number density. Energy loss rates (negative energy gain) of up to ~80 eV s^{-1} per H^+ ion were identified around the H^+ resonance velocity.

Shortly after the beginning of the wave, He^+ with a peak at ~1.5 keV was detected in ion composition data. This coincides with an ion population observed by FPI-DIS in the corresponding energy range that is concentrated in pitch angle between 90° and 112.5°. These ions were concentrated in less than four 11.25° gyro phase bins and were rotating with the wave, i.e., they were phase bunched. Positive $\mathbf{j}_{\mathrm{i}} \cdot \mathbf{E}_{\mathrm{wave}}$ indicates that the He^+ ions with the highest flux in the event were being accelerated by $\mathbf{E}_{\mathrm{wave}}$. The parallel motion of He^+ opposite to the direction of He^+ resonance velocity, is inconsistent with the cyclotron resonant acceleration, which has been considered as the most plausible candidate for He^+ energization perpendicular to $\mathbf{B}_0$. Thus, the interaction must be of non-resonant type.

Using MMS's high time resolution measurements of ions with a full-sky field of view, together with composition-resolved ion measurements, we have quantitatively demonstrated the simultaneous occurrence of two concurrent energy transfers: one from hot anisotropic H^+ (the free energy source) to the ion cyclotron wave via cyclotron resonance and the other from the wave to He^+ via non-resonant interaction [1]. This provides direct quantitative evidence for collisionless energy transfer between distinct particle populations via wave-particle interactions. Such measurements, including information on the gyro phase of energetic charged particles relative to wave fields, provide the capability to unambiguously identify which types of wave-particle interaction are occurring.

References

1. N. Kitamura, M. Kitahara, M. Shoji, Y. Miyoshi, H. Hasegawa, S. Nakamura, Y. Katoh, Y. Saito, S. Yokota, D. J. Gershman, A. F. Vinas, B. L. Giles, T. E. Moore, W. R. Paterson, C. J. Pollock, C. T. Russell, R. J. Strangeway, S. A. Fuselier, and J. L. Burch (2018), Direct measurements of two-way wave-particle energy transfer in a collisionless space plasma, *Science*, *361*, 1000-1003. DOI: 10.1126/science.aap8730