9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Direct observations of cross-scale wave-particle energy transfer in space plasmas

Jing-Huan Li[1,2,3], Xu-Zhi Zhou[1*], Zhi-Yang Liu[4], Shan Wang[1], Yoshiharu Omura[2,5], Li Li[1], Chao Yue[1], Qiu-Gang Zong[1,2], Guan Le[6], Christopher T. Russell[7], James L. Burch[8]

[1] School of Earth and Space Sciences, Peking University

[2] State Key Laboratory of Lunar and Planetary Sciences, Macau University of Science and Technology

[3] Swedish Institute of Space Physics

[4] Institut de Recherche en Astrophysique et Planétologie, CNES-CNRS, Universite Toulouse III

[5] Research Institute for Sustainable Humanosphere, Kyoto University

[6] NASA Goddard Space Flight Center

[7] Institute of Geophysics and Planetary Physics, University of California

[8] Southwest Research Institute

e-mail (speaker): lijinghuan1997@gmail.com

The collisionless plasmas in space and astrophysical environments are intrinsically multiscale in nature, behaving as conducting fluids at macroscales and kinetically at microscales comparable to ion and/or electron gyroradii. A fundamental question in understanding the plasma dynamics is how energy is transported and dissipated across scales. Here, we present spacecraft measurements in the terrestrial foreshock, a region upstream of the bow shock where the solar wind population coexists with the reflected ions. In this region, the fluid-scale, ultralow-frequency waves resonate with the reflected ions to modify the velocity distributions, which in turn cause the growth of the ion-scale, magnetosonic-whistler waves. The latter waves then resonate with the electrons, and the accelerated electrons contribute to the excitation of electron-scale, high-frequency whistler waves. These observations demonstrate that the chain of wave-particle resonances is an efficient mechanism for cross-scale energy transfer, which could redistribute the kinetic energy and accelerate the particles upstream of the shocks.

Figure 1

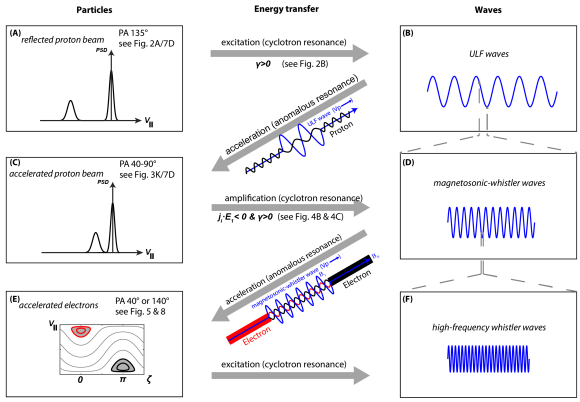
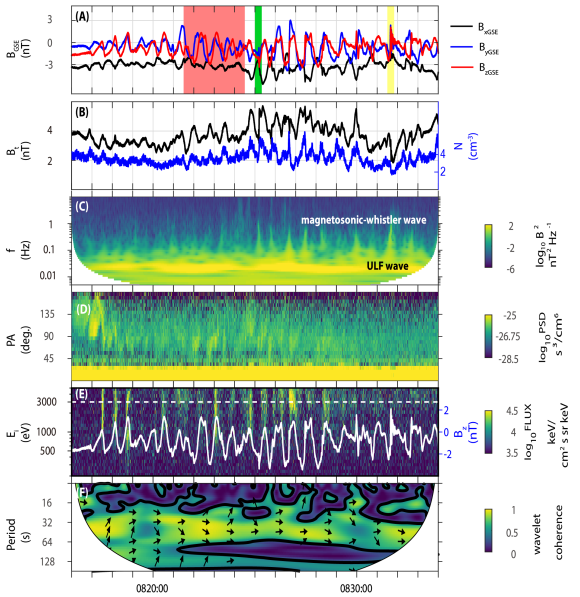


Figure 2



References

[1] Li, Jing-Huan, et al. "Direct observations of cross-scale wave-particle energy transfer in space plasmas." Science Advances 11.6 (2025): eadr8227.

[2] Li, Jing-Huan, et al. "Anomalous resonance between low-energy particles and electromagnetic plasma waves." Communications Physics 5.1 (2022): 300.

[3] Li, Jing-Huan, et al. "Identification of coupled landau and anomalous resonances in space plasmas." Physical Review Letters 133.3 (2024): 035201.

[4] Liu, Z-Y., et al. "Simultaneous macroscale and microscale wave–ion interaction in near-earth space plasmas." Nature Communications 13.1 (2022): 5593.

[5] Chen, Rui, et al. "Cross-scale energy transfer from ion-scale to electron-scale waves in the Earth's foreshock region." Journal of Geophysical Research: Space Physics 129.7 (2024): e2024JA032567.