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Cross-scale Wave-particle Interactions: A New Mechanism for Cross-scale Energy Transfer

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Identifying how energy transfer proceeds from macroscales down to microscales in collisionless plasmas is at the forefront of astrophysics and space physics. It provides information on the evolution of involved plasma systems and the generation of high-energy particles in the universe.

Here, we propose that cross-scale wave-particle interaction, namely, charged particles simultaneously interacting with plasma waves of different physical scales, provides a mechanism for cross-scale energy transfer in collisionless space and astrophysical plasmas. To show this, we investigate cross-scale wave-particle interaction events observed by NASA's Magnetospheric Multiscale spacecraft in Earth's magnetosphere in detail. In these events, hot ions simultaneously undergo interactions with macroscale (~10^5 km) ultra-low-frequency waves and microscale (~10^3 km) electromagnetic-ion-cyclotron (EMIC) waves. The cross-scale interactions cause energy to directly transfer from macroscales to microscales, and finally dissipate at microscales via EMIC-wave induced ion energization. The direct measurements of the energy transfer rate in these events confirm the efficiency of this cross-scale transfer process, whose timescale is estimated to be roughly ten EMIC-wave periods (about 1 min). Therefore, these observations experimentally demonstrate that simultaneous macroscale and microscale wave-ion interactions provide an efficient mechanism for cross-scale energy transfer and plasma energization in astrophysical and space plasmas.

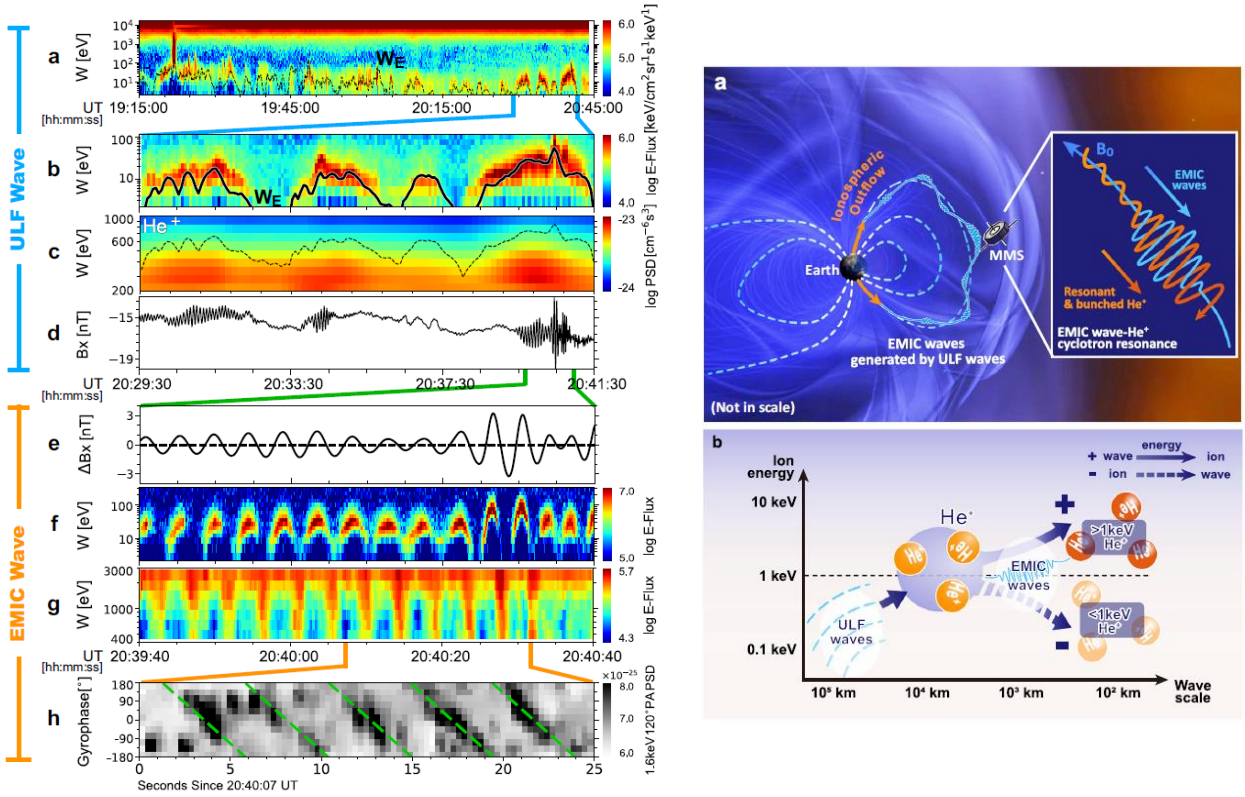

Figure 1. Cross-scale interactions of ULF waves, EMIC waves and He^+ ions in the January 7, 2019, event. (left) MMS observations of the ULF waves and EMIC waves, and the response of low-energy hydrogen ions and hot helium ions to the two wave modes. (right) Schematics of this event.