Magnetospheric ULF waves: Excitation mechanisms and interaction with charged particles

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The terrestrial magnetosphere is filled with ULF waves at frequencies from 1 to 1000 mHz. Although the basic properties of the waves are well described using the magnetohydrodynamics (MHD) theory, which predicts presence of compressional (magnetosonic) and shear (Alfvén) waves, the waves are still actively studied because the magnetosphere is a valuable laboratory for studying wave propagation in structured plasma and also because the waves play important roles in geomagnetic phenomena such as magnetic storms and substorms.

This presentation reviews studies that used data from the Van Allen Probes (RBSP) -A and -B spacecraft, which made observations in the inner magnetosphere from 2012 to 2019 at radial distances smaller than 6 Earth radii. The comprehensive experiments and the unique orbits of the spacecraft allowed us to significantly advance our understanding of ULF waves.

A class of ULF wave are excited by sources external to the magnetosphere. RBSP detected multiharmonic compressional oscillations immediately following the arrival of an interplanetary shock. The spacecraft were radially separated but observed nearly identically waveforms. A numerical simulation confirmed that cavity mode oscillations were excited (Takahashi et al., 2018). In another occasion, RBSP detected compressional waves originating from ULF waves excited in the ion foreshock by an ion beam instability (Takahashi et al., 2021).

Impulsive excitation of cavity mode oscillations is possible when the magnetotail undergoes a sudden configurational changes known as substorms. A substorm generates bursty flows of plasma which excite cavity mode oscillations in the inner magnetosphere. A substorm event was studied in detail using data from several spacecraft including RBSP, which were ideally positioned to capture the magnetotail disturbances at different distances. Cavity mode oscillations were detected only by spacecraft close the Earth (Takahashi et al., 2018b).

Standing Alfvén waves with a short azimuthal wavelength are excited through resonant interaction of the waves with energetic ions (1-300 keV) in the ring current region. In most cases, the excited waves have a second harmonic standing structure along the background magnetic field. These wave are excited by the drift-bounce resonance of ions, with the free energy coming from either a bump-on-tail ion energy distribution or a radial gradient of the ion phase space density (Takahashi et al., 2018c). In rare occasions, a fundamental wave is excited by drift resonance instability in the presence of an inward gradient of the ion phase space density (Takahashi et al, 2018d).

The presentation concludes with an outlook on analysis of the archived RBSP data and related simulation studies.

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