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Electromagnetic ion cyclotron wave propagation from the geosynchronous orbit: A Full-wave simulation study

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This presentation examines electromagnetic ion cyclotron (EMIC) wave propagation in the magnetosphere numerically using the full-wave simulation tool, Petra-M. Recent full-wave simulation capability has been significantly extended to 3D space. The Petra-M code [1] is a state-of-the-art generic electromagnetic simulation tool for modeling RF wave propagation based on MFEM [http://mfem.org]. This code successfully examined RF wave properties in the various laboratory plasmas using realistic antenna geometry in tokamaks [2].

Here, we examine EMIC wave properties by adopting Earth's dipole magnetic field geometry with an empirical density profile. EMIC waves in the Pc 1-2 frequency range (0.2–5.0 Hz) are broadly detected at Earth's magnetosphere. Numerous wave observations comparing wave activity in the equatorial magnetosphere with ground-based magnetometers provide evidence that EMIC waves excited in the equatorial magnetosphere can propagate into the ionosphere. However, understanding how Pc 1-2 waves are detected at the ground is a significant scientific issue because previous theoretical and numerical studies showed that left-handed polarized EMIC waves were reflected at the Buchsbaum resonance location and could not reach ionospheric altitudes.

This presentation mainly shows how the wave normal angle (WNA) affects wave propagation in multi-ion magnetospheric plasmas. Although it is well known that EMIC waves have various WNA up to 60 degrees, how the WNA is related to EMIC wave propagation to the ground remains largely unexplored. Previous full-wave simulations showed polarization reversal and mode conversion of "obliquely" propagating waves at the crossover frequency is critical; therefore, it was suggested that WNA could be an important parameter to control EMIC wave propagation to the ground [3]. However, these studies were based on a 1D full-wave code or provided a limited simulation domain near the heavy-ion cyclotron frequency location.

Figure 1 shows full-wave simulations using the Petra-M simulation tool covering the entire space from the equatorial source to the Earth. For this simulation, we launched He+ mode EMIC waves of 0.8Hz at L=6.8 in 5% He+ plasma with various WNA (Θ) at the source region, i.e., the magnetic equator. Consistent with the previous full-wave simulations, the results show that inclusion of heavy ions could prevent EMIC wave propagation to the ground when waves propagate quasi-parallel to the magnetic field. Figures 1(a)-(c) demonstrate that when waves propagate to the higher magnetic latitude, wave polarization rapidly changes from the left-handed (LHP) to linear, and waves reflect at the Buchsbaum resonance location.

When waves propagate obliquely, polarization reversal and mode conversion between LHP and RHP waves can occur at the crossover frequency. Incoming guided propagating LHP waves are mode-converted into the unguided LHP waves. Their polarization also changes to RH, and these waves below the Buchsbaum resonance are unguided. For higher WNA cases ($\Theta = 45°, 60°$), RHP waves are also launched at the magnetic equator. In these cases, mode conversion at the crossover is visible. The mode-converted, unguided LHP waves propagate to the outer magnetosphere, while mode-converted RHP waves propagate to the lower L-shell and reach the ionosphere.

For the highest WNA case ($\Theta = 60°$), we found an interesting wave mode at smaller L-shell. These waves appear to be generated from the RHP waves that reach lower altitude, propagating with linear polarization. These waves propagate without any interruption with a shorter wavelength across field lines. Indeed, all these characteristics are similar to field line resonance.

References

[1] Shiraiwa S. et al., EPJ Web of Conferences 157, 03048 (2017)

[2] Kim, E.-H. et al, AIP Conf. Proceeding 2254, 050010 (2020); Bertelli, N. et al., AIP Conf. Proceeding 2254, 030001 (2020)

[3] Johnson and Cheng, Geophys. Res. Lett. 26, 671 (1999); Kim and Johnson, Geophys. Res. Lett. 43, 13-21, doi:10.1002/2015GL06697 (2016)

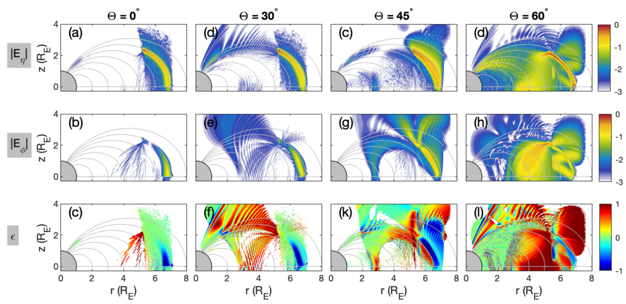

Figure 1. Electric field amplitude of (upper) E_η, across the field line, and (middle) E_ϕ, azimuthal direction, and (bottom) wave ellipticity for WNA (Θ) is (a-c) 0°, (d-f) 30°, (g-i) and (j-l) 60°, respectively.