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Particle-in-cell simulations of magnetosonic waves in the Earth's magnetic field

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Near-equatorial fast magnetosonic waves in Earth's magnetosphere (also known as equatorial noise; MSWs hereinafter) are among the most frequently observed plasma waves and well known for their proton cyclotron harmonic spectrum in frequency. Satellite observations have consistently shown that the occurrence and power distributions of these waves are narrow in magnetic latitude, leading to the general belief that the wave source is also narrow in latitude and the waves excited there propagate toward high latitudes. Recent two-dimensional particle-in-cell (PIC) simulations in the dipole magnetic field concluded that the simulation results are largely consistent with the above interpretation of generation process[1].

However, there still remain several unanswered questions. First, if Liouville's theorem is satisfied—as it is typically assumed in the inner magnetosphere—along the field line for the energetic proton distributions that drive the wave excitation, limiting the wave source at the magnetic equator requires unrealistically large temperature anisotropy. Second, recent MSW propagation analyses suggested that MSWs in the near-equatorial source region preferentially propagate in the azimuthal direction, i.e., in the direction at which the gradient of the background magnetic field vanishes. On the other hand, the recent PIC simulation study[1] (and many of the ray tracing models) adopted a simulation domain on the meridional plane where spatial variations in the azimuthal direction are not permitted.

In this paper, we perform two-dimensional PIC simulations in the dipole field to investigate the generation process of MSWs[2]. Different from the earlier effort, we choose a simulation domain on a constant L-shell surface where azimuthal, instead of radial, propagation is allowed, and assumed an energetic proton distribution with moderate anisotropy. Fig. 1 shows a three-dimensional rendering of the simulated electric field. Despite the assumed extended unstable region in latitude, MSWs do not grow well beyond the equator when they get latitudinally out of resonance, resulting in the wave amplitude maximum near the equator. On the other hand, the scattering of energetic ring-like protons in response to MSW excitation occurs faster than the bounce period of those protons so that they do not necessarily follow Liouville's theorem during MSW excitation, suggesting that the earlier interpretation for MSW generation may still hold. We will present our simulation results and discuss other aspects of the MSW dynamics pertaining to the radiation belts.

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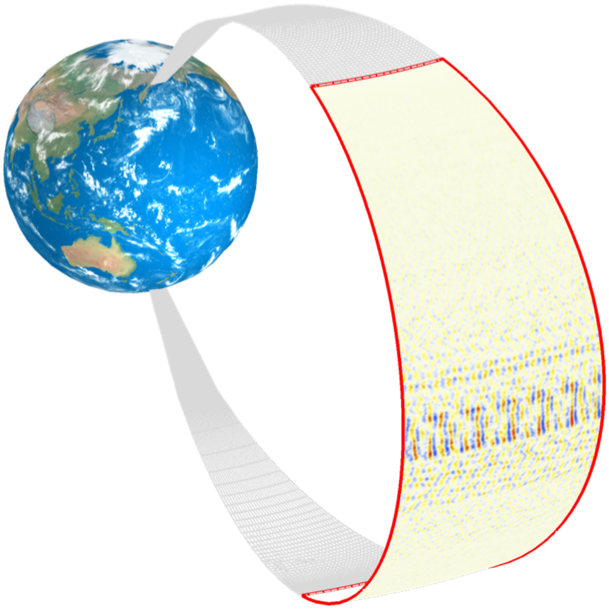

Fig. 1. Three-dimensional rendering of the azimuthal component of the simulated electric field at the time of wave saturation. The gray mesh indicates the constant L-shell surface and the red outline denotes the simulation domain. The domain has been stretched by a factor of ten in the azimuthal direction to properly to display the wave field structure. (Adopted from [2].)

References

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