7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

Excitation of ULF waves and transport of plasma through wave-particle interaction in the Earth's magnetosphere

Kazuhiro Yamamoto[1], A.V. Rubtsov[2], D. V. Kostarev[2], P. N. Mager[2], D. Yu. Klimushkin[2], M. Nosé[3], A. Matsuoka[4], K. Asamura[5], Y. Miyoshi[6], S. Yokota[7], S. Kasahara[1], Y. Kasahara[8], A. Kumamoto[9], F. Tsuchiya[9], M. Shoji[6], S. Nakamura[6], and I. Shinohara[5]

[1] Graduate School of Science, The University of Tokyo, [2] Institute of Solar-Terrestrial Physics SB RAS, [3] School of Data Science, Nagoya City University, [4] Graduate School of Science, Kyoto University, [5] Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 6 Institute for Space-Earth Environmental Research, Nagoya University, [7] Graduate School of Science, Osaka University, [8] Graduate School of Natural Science and Technology, Kanazawa University, [9] Graduate School of Science, Tohoku University

e-mail (speaker): yamamoto.kazuhiro@eps.s.u-tokyo.ac.jp

We examined the Arase satellite data on 19th November 2018. Firstly, electromagnetic field oscillations of poloidal Pc 5 (~4.4 mHz) waves were detected from 02:40 to 03:40 UT at R = 5.7-6.0 R_E around the magnetic equator on the duskside, where R is a radial distance from the center of the Earth, R_E is the Earth's radius, and UT is the universal time. From the large amplitude ratio between the radial magnetic field and the azimuthal electric field, these waves are the second harmonic mode of the standing Alfvén wave, because the second harmonic wave has its node of electric field oscillations around the equator. From the finite Larmor radius effect [1], we estimated that the poloidal waves propagate eastward with a high wave number (m ~ 220).

At the same time, earthward penetration of energetic protons was observed at ~3-30 keV. The energy and spatial distributions of energetic ions are formed by the ions transported from the Earth's plasmasheet and are called "nose structure". There were two energy bands of the nose structure at ~5 keV and ~20 keV. In the pitch angle (α) distributions of protons, proton fluxes at 5-25 keV oscillated with the frequency same as the poloidal waves. Proton fluxes of the bouncing population (α ~ 30/150 degrees) were coherently modulated by the waves. Proton fluxes at α > 90 degrees show antiphase oscillations for those at α < 90 degrees. These characteristics imply that strong interaction of protons and the second harmonic poloidal standing Alfvén wave.

The destabilization condition of the drift-bounce resonance is summarized as $df/dW = \partial f/\partial W + (dL/dW)\partial f/\partial L > 0$, where f is the distribution function, W is particle kinetic energy, and L is the L-shell, which represents the radial distance of a field line at the equator. This equation is similar to the destabilization condition of toroidal Alfvén eigenmodes (TAE) in the laboratory plasma. From this equation, we found that waves were excited by a positive radial gradient of the proton distribution function if the waves propagate eastward.

After the poloidal wave excitation, the Arase satellite moved into a region where β reached up to ~1. In this region, compressional Pc 4-5 waves were observed. Proton fluxes at 20-30 keV around α = 90 degrees coherently oscillated, indicating that equatorially bouncing protons are related to the generation of compressional waves. These flux oscillations correspond to the drift resonance with westward propagating waves with azimuthal wave numbers |m| of 120–160, which is in agreement with observational values.

We calculated the anisotropy parameter Γ for the drift mirror mode instability. Γ was lower than −0.5, excluding drift-mirror mode interpretation. Based on the recent theoretical studies [2,3], we calculated the eigenfrequency and pressure perturbations for the drift compressional mode. The calculated values were close to the observed compressional waves, suggesting that the observed compressional wave is the drift compressional mode. The instability condition for the drift resonance was satisfied by a negative radial gradient of the proton phase space density. In addition, an outward proton temperature gradient is sometimes positive. This result suggests that both the drift resonance and the ion temperature gradient instability can provide free energy to the wave. Similar drift waves can be seen in the laboratory plasma and it is considered to cause a radial diffusion of the plasma. In the magnetospheric plasma, a radial diffusion leads to the decay of the ring current, which is one of the global current systems in the magnetosphere and changes the magnetic field strength on the surface of the Earth.

References

[1] Su, S.-Y., Konradi, A., & Fritz, T. A. (1977). On propagation direction of ring current proton ULF waves observed by ATS 6 at 6.6 RE. Journal of Geophysical Research, 82 (13), 1859–1868. doi: 10.1029/JA082i013p01859

[2] Mager, P. N., Klimushkin, D. Yu., & Kostarev, D. V. (2013). Drift-compressional modes generated by inverted plasma distributions in the magnetosphere. Journal of Geophysical Research: Space Physics, 118, 4915–4923. doi: 10.1002/jgra .50471

[3] Takahashi, K., Crabtree, C., Ukhorskiy, A. Y., Boyd, A., Denton, R. E., Turner, D., . . . Spence, H. E. (2022). Van Allen Probes observations of symmetric stormtime compressional ULF waves. Journal of Geophysical Research: Space Physics, 127 (2), e2021JA030115. doi: 10.1029/2021JA030115