32nd URSI GASS, Montreal, 19-26 August 2017

Non-Resonant Interactions of Electromagnetic Ion Cyclotron Waves with Relativistic Electrons

Lunjin Chen*(1), Richard M. Thorne (2), Jacob Bortnik(2), and Xiao-Jia Zhang (2,3)
(1) Department of Physics, William B. Hanson Center for Space Sciences, University of Texas at Dallas, Richardson, Texas, USA
(2) Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, USA
(3) Department of Earth, Planetary, and Space Sciences and Institute of Geophysics and Space Physics, University of California, Los Angeles, USA.

1. Extended Abstract

Electromagnetic ion cyclotron (EMIC) waves are naturally-occurring emissions in the Earth's magnetosphere, observed at frequencies below the proton gyro-frequency with predominantly left-handed polarization. The EMIC wave frequency spectrum is separated into multiple bands due to the presence of the heavier He+ and O+ ions [e.g., *Gomberoff et al.,* 1983]. He+ band waves just below Ω_{He+} attain large wave numbers in the cold plasma limit, thus acting as a potential candidate for producing resonant scattering loss of relativistic electrons (~MeV) [*Thorne et al.,* 1971]. The observational evidence of relativistic electron precipitation induced by EMIC waves is also reported [e.g., *Rodger et al.,* 2008, *Usanova et al.,* 2014]. However, recent studies [e.g., *Chen et al.,* 2011] indicate that thermal He+ effect can not be ignored, since EMIC waves with wave frequencies close to Ω_{He+} are suppressed due to cyclotron resonant damping of He+ ions. Consequently, the generation of EMIC waves that are able to resonate with MeV electrons or lower requires a fairly restricted set of plasma conditions [*Chen et al.,* 2011], e.g., outer plasmasphere and plume. The energies of electrons that are able to resonate with unstable EMIC waves, and thus be subjected to resonant pitch angle scattering loss, are generally above 2 MeV in most regions of magnetosphere. *Clilverd et al.,* 2015 reported that the observed lower cutoff energy of electron precipitation induce by EMIC waves can be as low as ~ 300 keV, which is unexpectedly lower than typical minimum resonant energy of magnetospheric EMIC waves. Other experimental studies also support that EMIC waves can cause precipitation of electrons with energies as low as a few 100s keV [*Hendry et al.,* 2014].

The quasi-linear resonant diffusion theory of EMIC waves producing relativistic electron loss has been tested against test particle simulations, which reveals a variety of nonlinear resonant interactions. For instance, the phase bunching effect tends to produce advection toward larger pitch angle, rather than stochastic scattering [*Albert and Bortnik* 2009]. Such advection prevents losses into the lower atmosphere, in contrast to the predictions of quasi-linear theory. A few studies [e.g., *Omura et al.*, 2012] also demonstrate nonlinear phase trapping effects, which could lead to loss of relativistic electrons over a wide range of pitch angles. However, all these nonlinear effects require a resonant interaction between EMIC waves and relativistic electrons, thus limiting the affected energies to ~ 2 MeV and above.

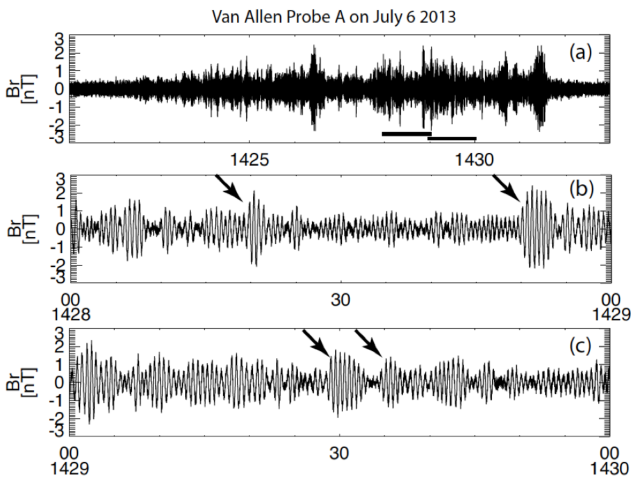

Figure 1. (a) Detrended magnetic field component in the meridian plane and perpendicular to 1-sec averaged background magnetic field for an EMIC wave event observed by Van Allen Probe A on July 6, 2013. Expanded view of panel (a) over two one-minute intervals (represented by horizontal bars) in panel (b) and in panel (c), respectively. The arrows indicate a sharp wave edge of ~nT amplitude variation over several wave cycles.

In the present study, the dynamics of relativistic electrons traveling through a parallel-propagating, monochromatic electromagnetic ion cyclotron (EMIC) wave in the Earth's dipole field are investigated via test particle simulations. Both resonant and nonresonant responses in electron pitch angle are considered and the differences between the two are highlighted. Nonresonant electrons, with energies below the minimum resonant energy down to 100s keV, are scattered stochastically in pitch angle and can be scattered into the atmospheric loss cone. The nonresonant interaction is dominated by diffusion in pitch angle rather than advection. The nonresonant effect is attributed to the spatial edge associated with EMIC wave packets (Figure 1). A condition for effective nonresonant response is also provided. This effect is excluded from current quasi-linear theory, can be a potentially important loss mechanism of relativistic and subrelativistic electrons in the radiation belts.

2. References

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