9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Violation of the Impenetrable Barrier: MSS-1 and Arase Observations of MeV Electrons in the Inner Radiation Belt During the May 2024 Geomagnetic Storm

Yi-Xin Sun[1], Ying Liu[2], Qiu-Gang Zong[1,2], Yu-Guang Ye[2], Hong Zou[1,2], Yoshizumi Miyoshi[3], Li Li[4], Yoshiharo Omura[5,2], Zi-Kang Xie[1], Zi-He Zhao[1], Zi-Yang Wang[1], Yi-Xin Hao[6], Xing-Ran Chen[2] , Yong-Fu Wang[1], Dedong Wang[7,3], Zhao-Guo He[2], Chao Yue[1], Xu-Zhi Zhou[1], Shan Wang[1], Keika Kunihiro[8], Nana Higashio[9], Takefumi Mitani[9], Takeshi Takashima[9], Iku shinohara[9], Kitamura Naritoshi[3]

[1] Institute of Space Physics and Applied Technology, Peking University, China

[2] State Key Laboratory of Lunar and Planetary Science, Macau University of Science and Technology, China

[3] Institute for Space-Earth Environmental Research, Nagoya University, Japan

[4] School of Geophysics and Information Technology, China University of Geosciences (Beijing), China

[5] Research Institute for Sustainable Humanosphere, Kyoto University, Japan

[6] Max Planck Institute for Solar System Research, Germany

[7] GFZ Helmhotz Center for Geosciences, Germany

[8] Graduate School of Science, The University of Tokyo, Japan

[8] Japan Aerospace Exploration Agency, Japan

e-mail (speaker): sunyixin@pku.edu.cn

During the Mother's Day Storm, the most intense storm of the last 20 years, with a peak Dst of less than -400 nT, the Macau Science Satellite-1 observed the penetration of relativistic electrons of an energy greater than 1 MeV into the inner radiation belt at low Earth orbit. The arrival of the MeV electrons was observed to occur instantaneously following the Dst minimum, with their continuous enhancement in the South Atlantic Anomaly over seven days in the recovery phase reaching L$=$1.5. The so-called impenetrable barrier, previously estimated to be located at L$=$2.8 during the Van Allen Probes' era, has been significantly violated. A combined analysis of observations with Arase data at mid-latitude reveals the evolution of electron spectrum and pitch angle distribution for the first time, including zebra stripe patterns, an increase in electron flux near the loss cone, and a decrease in electron flux at larger pitch angles. These new results suggest that MeV electrons might undergo several steps to reach the inner radiation belt at LEO during this storm, which includes radial transport, radial diffusion and pitch angle scattering.

The following features are found.

1. Within 1 day after the Dst minimum of the May storm, MeV electrons could reach Lm $=$ 2. The outer edge of the inner radiation belt gets populated with zebra stripe electrons. Electrons at all the pitch angles increase simultaneously.

2. MeV electrons are diffused or transported both to the lower Lshell region and to a smaller pitch angle regime in the next several days, which causes relatively slow but continuous enhancement of MeV electrons at low earth orbit for around one week. Pitch angle distributions are more butterfly-like, and the phase space density radial gradient is positive during this time.

3. After the storm, MeV electrons at the outer edge of the inner radiation belt gradually lost, and the slot region of MeV electrons reoccurred in about one month, while MeV electrons in the inner radiation belt remain for several months.

Combining observations from MSS-1 and Arase, the present study provides evolutions of pitch angle distributions and spectra of MeV electrons in the inner radiation belt during the extreme geomagnetic activity. Compared to the absence of such phenomena during the Hallowe'en storm, the new information obtained thus provides a more robust foundation upon which to discuss the mechanisms responsible for the acceleration of MeV electrons in the inner radiation belt.