Presentation for 2020 EGU meeting

Title: Chorus acceleration of relativistic electrons in extremely low L-shell during geomagnetic storm

Zhenxia Zhang[1], Lunjin Chen[2], Si Liu[3], Ying Xiong[4], Xinqiao Li[5] , Yongfu Wang[4] , Wei Chu[1] , Zhima Zeren[1] , Xuhui Shen[1]

1The Institute of Crustal Dynamics, China Earthquake Administration, Beijing, China. 2Department of Physics, University of Texas at Dallas, Richardson, Texas, USA 3School of Physics and Electronic Sciences, Changsha University of Science and Technology, Changsha, China, 4 Institute of Space Physics and Applied Technology, Peking University, Beijing, China 5 Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China.

Correspondence to: Z. X. Zhang, The Institute of Crustal Dynamics, China Earthquake Administration, Beijing, China. (zxzhang2018@163.com)

Abstract

Based on data from the Van Allen Probes and ZH-1 satellites, relativistic electron enhancements in extremely low L-shell regions (reaching L~3) were observed during August 2018 major geomagnetic storm (minimum Dst~ -190 nT). Contrary to what occurs in the outer belt, such an intense and deep electron penetration event is rare and more interesting. Strong whistler-mode (chorus and hiss) waves, with amplitudes 81-126 pT, were also observed in the extremely low L-shell simultaneously (reaching L~2.5) where the plasmapause was suppressed. The bounce-averaged diffusion coefficient calculations support that the chorus waves can play a significantly important role in diffusing and accelerating the 1-3 MeV electrons even in such low L-shells during storms. This is the first time that the electron acceleration induced by chorus waves in the extremely low L-shell region is reported. This new finding will help to deeply understand the electron acceleration process in radiation belt physics.

1. Observation

A major geomagnetic storm occurred during the period of 25 August to 1 September in 2018, as shown in Figure 1. The Dst started to drop at 12:00 UT on 25 August, reached the minimum -190 nT at 06:00 UT on 26 August, recovered rapidly to a moderate level of -100 nT at 12:00 UT on 26 August, and then continuously and slowly recovered for several days, shown in Figure 1. Figures 1f and 1g present the variations in fluxes of radiation belt relativistic(1.8 and 2.6 MeV) electrons measured by the REPT instrument onboard the Van Allen Probes. Here the striking feature is that the MeV electrons penetrated deeply into the low L-shell (L~3); this feature is mainly focused on in this paper. Figures 1h and 1i show the strong chorus waves on 26 and 27 August, near the appearance of the minimum Dst index, measured by the WFR receiver of the EMFISIS instrument. This demonstrated that the MeV electron flux enhancement was associated with the strong chorus waves, which will be proved later in this paper.

Figures 2d, 2e and 2i, 2j display the magnetic field spectral density and the polarization of waves calculated by wave propagation analysis, respectively for observations from Van Allen Probes A and B. The polarization values are both close to 1, suggesting that the waves are indeed chorus waves with the right-hand polarization mode.

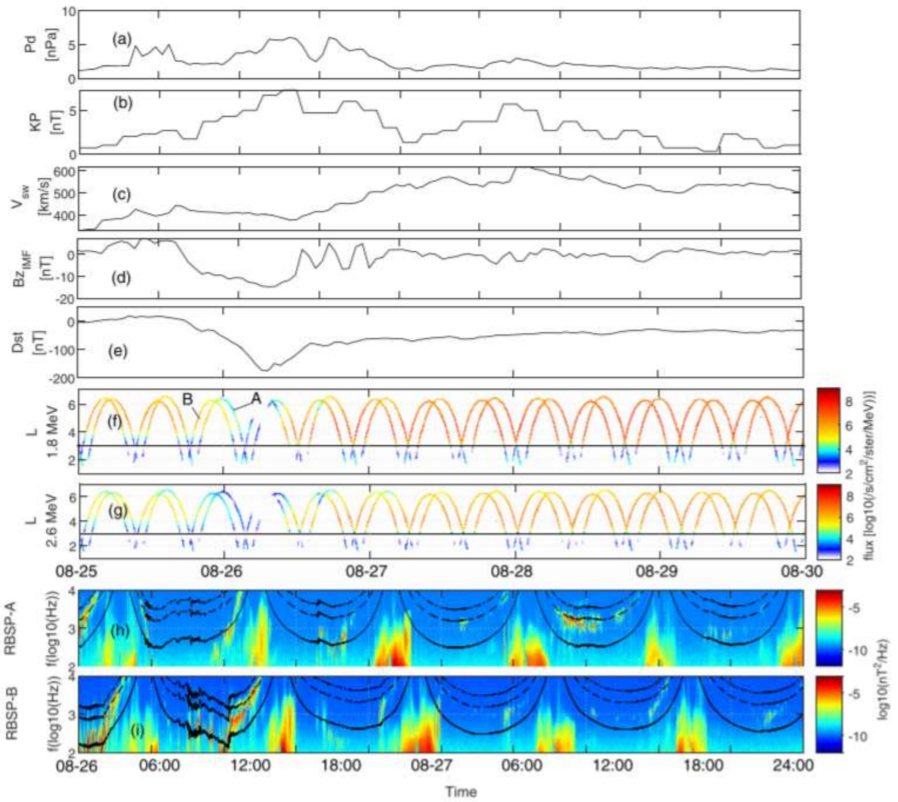

Figure 1. Overview of the electron evolution during storm of August 2018 observed by Van Allen Probes. (a) Solar wind pressure, (b) Kp index, (c) solar wind speed, (d) IMF Bz, and (e) geomagnetic storm index Dst. (f and g) The electron evolution in L-shell for the energy range of 1.8 and 2.6 MeV, respectively. (h and i) The electromagnetic signals exited during storms. The solid black line in panels (f) and (g) denote $L = 3$. The black lines in panels (h) and (i) denote $0.1f_{ce}$(solid), $0.5f_{ce}$(dashed), and f_{ce}(dotted).

The sun-synchronous orbit ZH-1 satellite was launched successfully in February 2018 and monitors space electromagnetic fields, ionospheric plasma, and high-energy charged particles. The satellite flies at an altitude of 507 km and has an orbit inclination of 97°. Figures 3b, 3c, and 3d show the dynamical evolution of radiation belt relativistic (0.1-3 MeV) electrons observed by HEPP-L detectors (including descending and ascending orbits). Most interestingly, we can find that the 1-3 MeV electron fluxes increased only in the 2.8<L<5 range by a factor of 2-3 orders (Figure 3d).

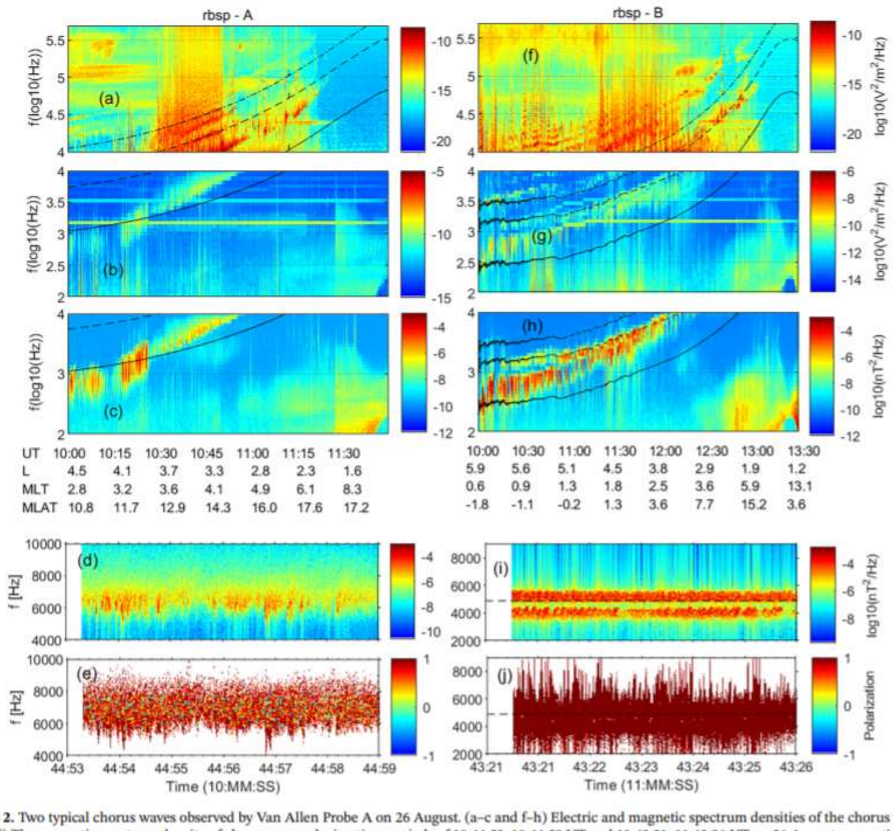

Figure 2. Two typical chorus waves observed by Van Allen Probe A on 26 August. (a–c and f–h) Electric and magnetic spectrum densities of the chorus waves. (d and i) The magnetic spectrum density of chorus waves during time periods of 10:44:53–10:44:59 UT and 11:43:21–11:43:26 UT on 26 August, respectively. (e and j) The polarization values calculated by wave propagation analysis. The black lines denote $0.1 f_{ce}$(solid), $0.5 f_{ce}$(dashed), and f_{ce}(dotted).

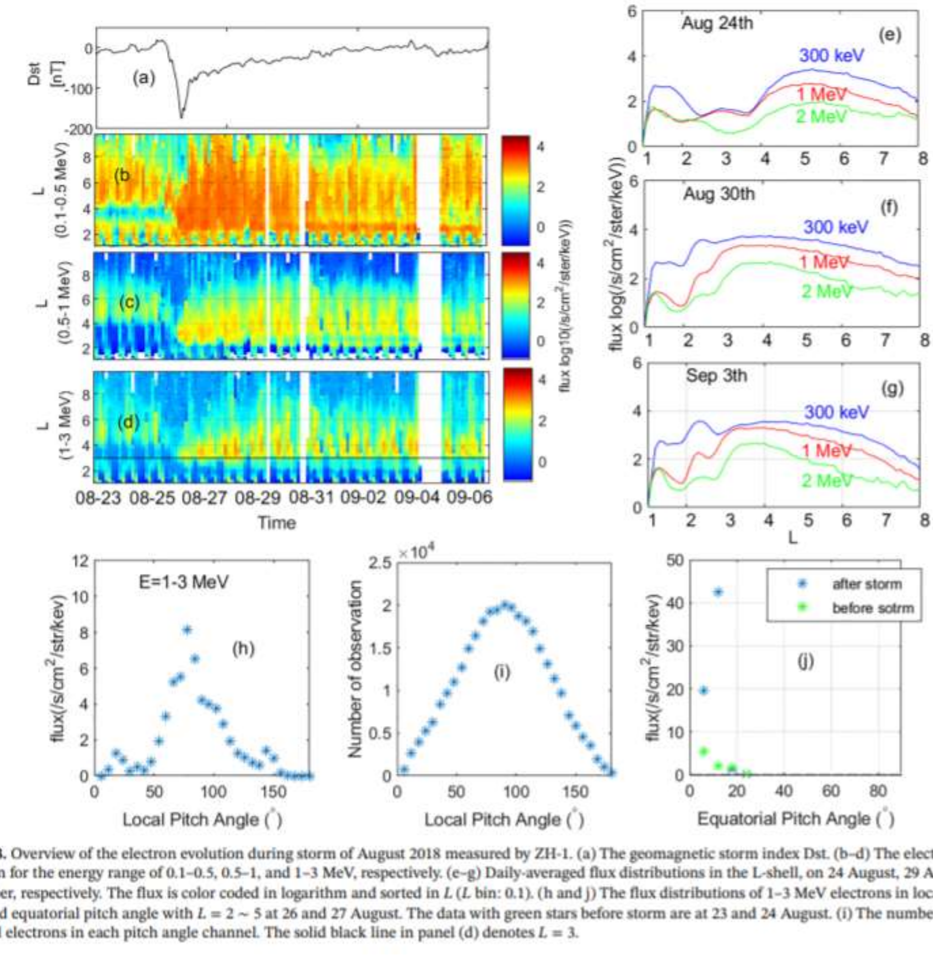

Figure 3. Overview of the electron evolution during storm of August 2018 measured by ZH-1. (a) The geomagnetic storm index Dst. (b–d) The electron evolution for the energy range of 0.1–0.5, 0.5–1, and 1–3 MeV, respectively. (e–g) Daily-averaged flux distributions in the L-shell, on 24 August, 29 August, and 3 September, respectively. The flux is color coded in logarithm and sorted in L (L bin: 0.1). (h and j) The flux distributions of 1–3 MeV electrons in local pitch angle and equatorial pitch angle with $L = 2 \sim 5$ at 26 and 27 August. The data with green stars before storm are at 23 and 24 August. (i) The number of observed electrons in each pitch angle channel. The solid black line in panel (d) denotes $L = 3$.

2. Verification by Quasi-linear Diffusion Coefficients Calculation

As mentioned above, the observed chorus is likely to accelerate the seed population through energy diffusion and produce a relativistic electron source at extremely low L$-$shells. We use bounce-averaged quasi-linear diffusion coefficients to evaluate this physical process and explain the nonadiabatic acceleration mechanism.

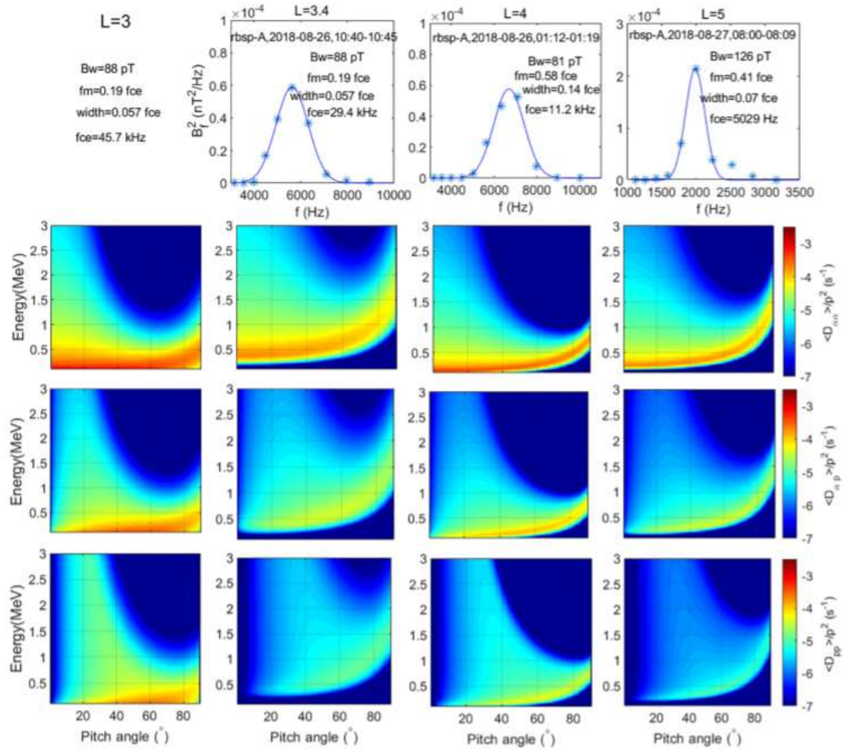

Figure 4. Quasi-linear diffusion coefficients including pitch angle diffusion coefficient, momentum coefficient, and the cross term. The Gaussian fits of spectrum density are shown in the top three panels corresponding to the three typical chorus waves at different times, with the fitted wave parameters written on each plot.

3. Discussion and conclusion

The PSD level increased from $L^{*}=2.9$ and formed a peak in L*=2.9~4 (corresponding to L=3.1~5) shown with red and purple lines at around UT8:00-13:00. And the appearance time of the PSD profile growing peaks are consistent with the time of chorus wave observations in Figure 2. This provides a solid evidence for the existence of nonadiabatic process. Considering that we indeed observed persistent chorus waves and obtained consistent theoretical calculation, the chorus acceleration tends to play a dominant role in the relativistic electron enhancements in low L - shell (at least low to L~3).

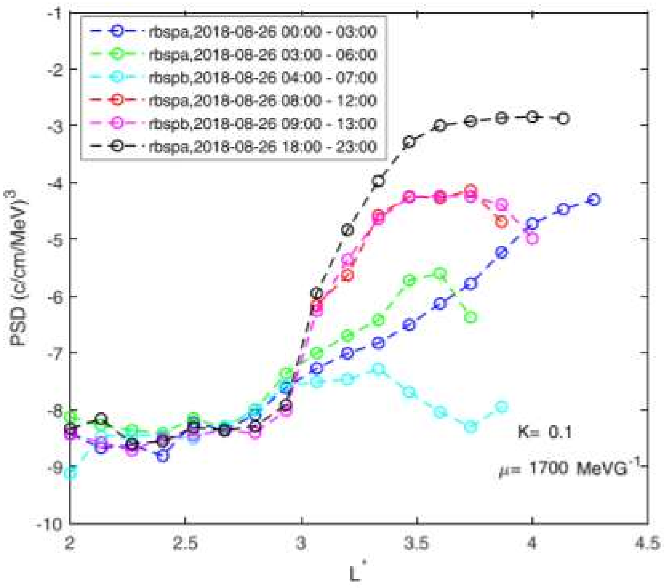

Figure 5. The electron PSD at $\mu = 1{,}700$ MeV/G, $K = 0.1R_E G^{1/2}$ (R_E is Earth's radius).

The man content comes from the paper:

Zhang, Z., Chen, L., Liu, S., Xiong, Y., Li, X., Wang, Y., et al. (2020). Chorus acceleration of relativistic electrons in extremely low L-shell during geomagnetic storm of August 2018. Geophysical Research Letters, 47, e2019GL086226. https://doi.org/10. 1029/2019GL086226