2025 COMMUNITY SPACE WEATHER MODELING AND DATA ASSIMILATION WORKSHOP

Modeling Relativistic Electron Dropout in the Outer Radiation Belt During the 31 December 2016 Storm

Jinbei Huang[1,2], Xingzhi Lyu[1,3], Weichao Tu[1,2], Qianli Ma[4,5], Richard Selesnick[6], Xu Liu[7], Lunjin Chen[7]

[1]Department of Physics and Astronomy, West Virginia University, Morgantown, West Virginia, USA
[2]Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI, USA
[3]Helmholtz Centre Potsdam German Research Centre for Geosciences, GFZ, Potsdam, Germany
[4]Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, CA, USA
[5]Center for Space Physics, Boston University, Boston, MA, USA
[6]Retired from Space Vehicles Directorate, Air Force Research Laboratory, Kirtland AFB, NM, USA
[7]William B. Hanson Center for Space Sciences, University of Texas at Dallas, Richardson, TX, USA

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UNIVERSITY OF MICHIGAN

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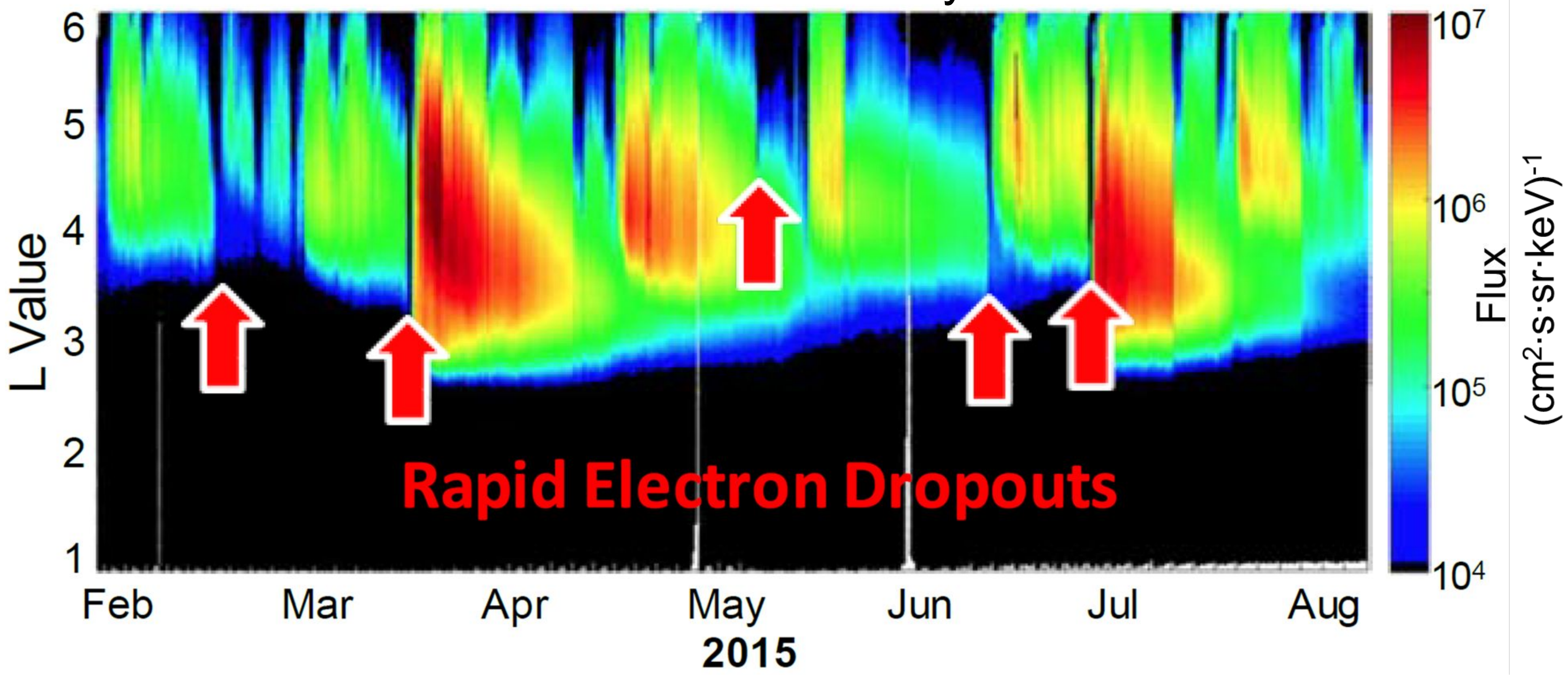
jinbei@umich.edu

Radiation Belt Electrons Loss

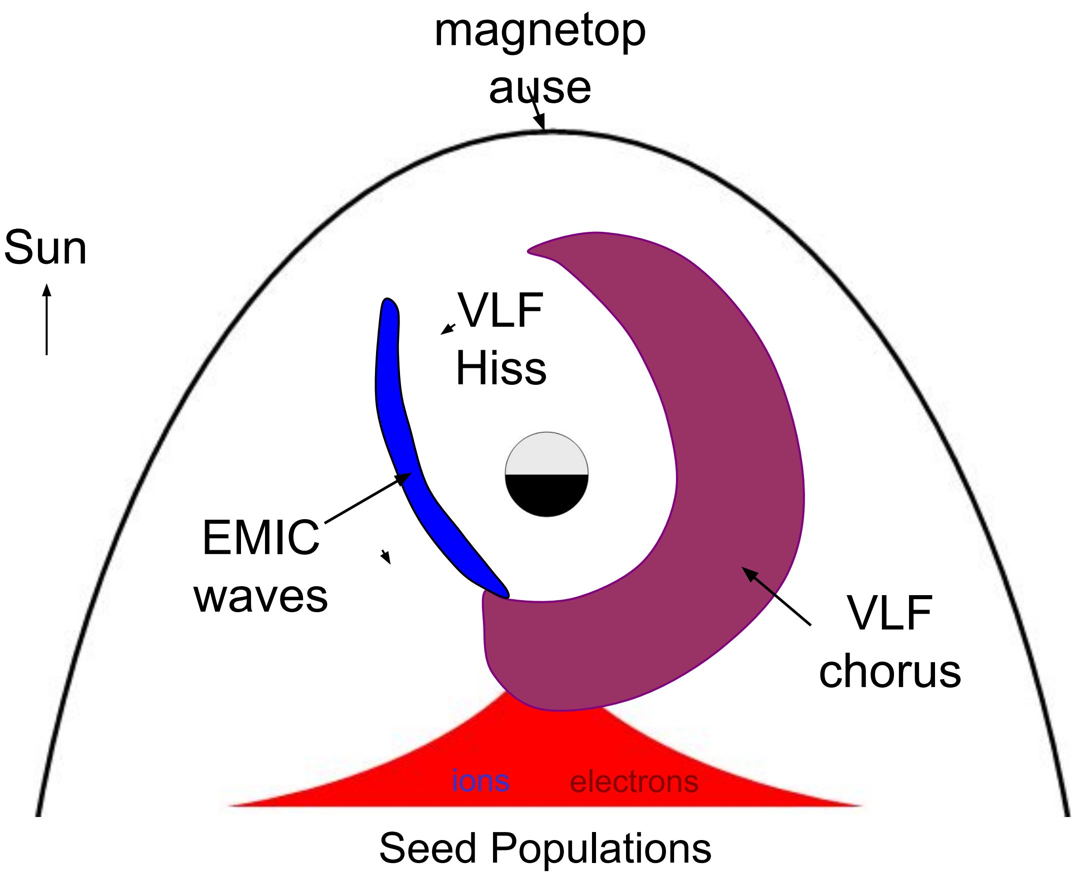
1.8 MeV electron flux observed by Van Allen Probes

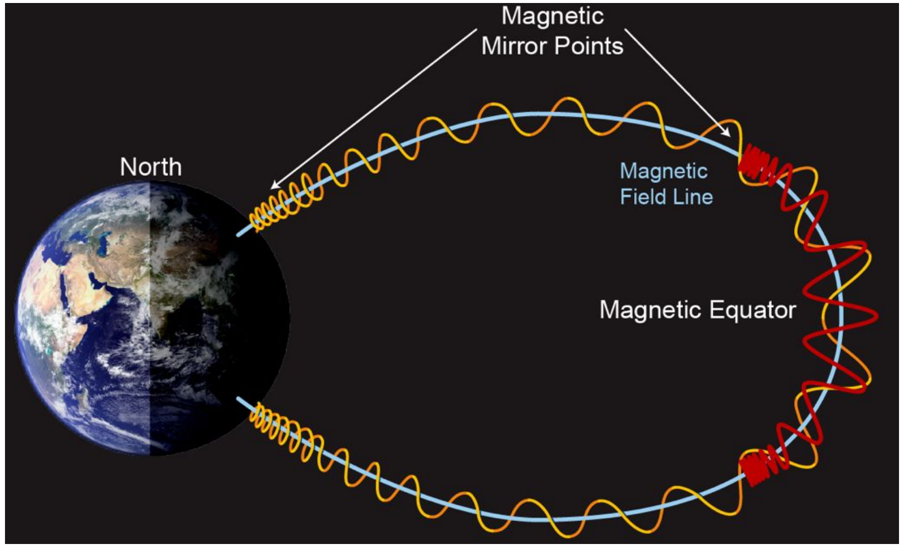


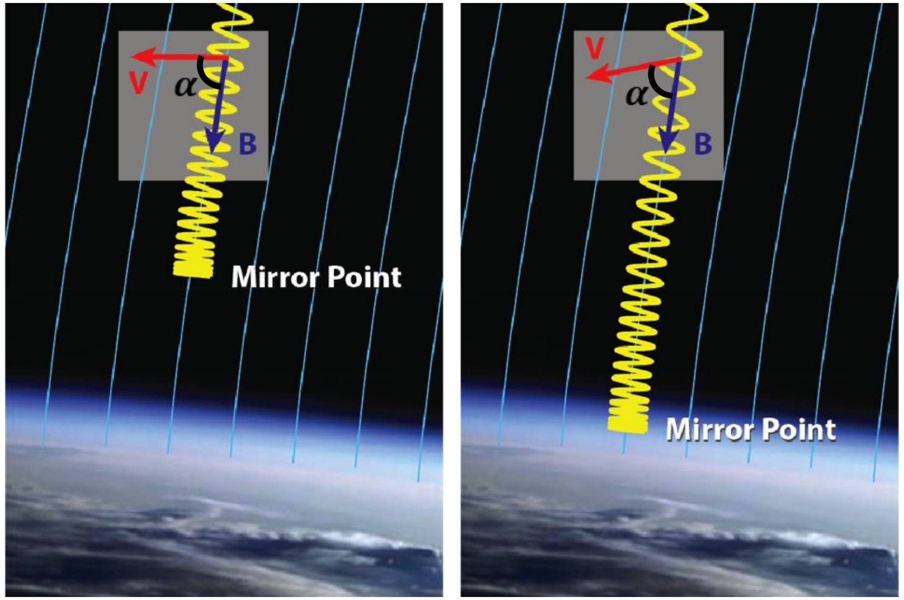
The fast dropout of the relativistic radiation belt electrons is one of the most compelling and outstanding questions in radiation belt studies.

Radiation Belt Electrons Loss Mechanisms

- Precipitation loss: pitch angle scattering by, e.g., VLF, EMIC waves, or field line curvature

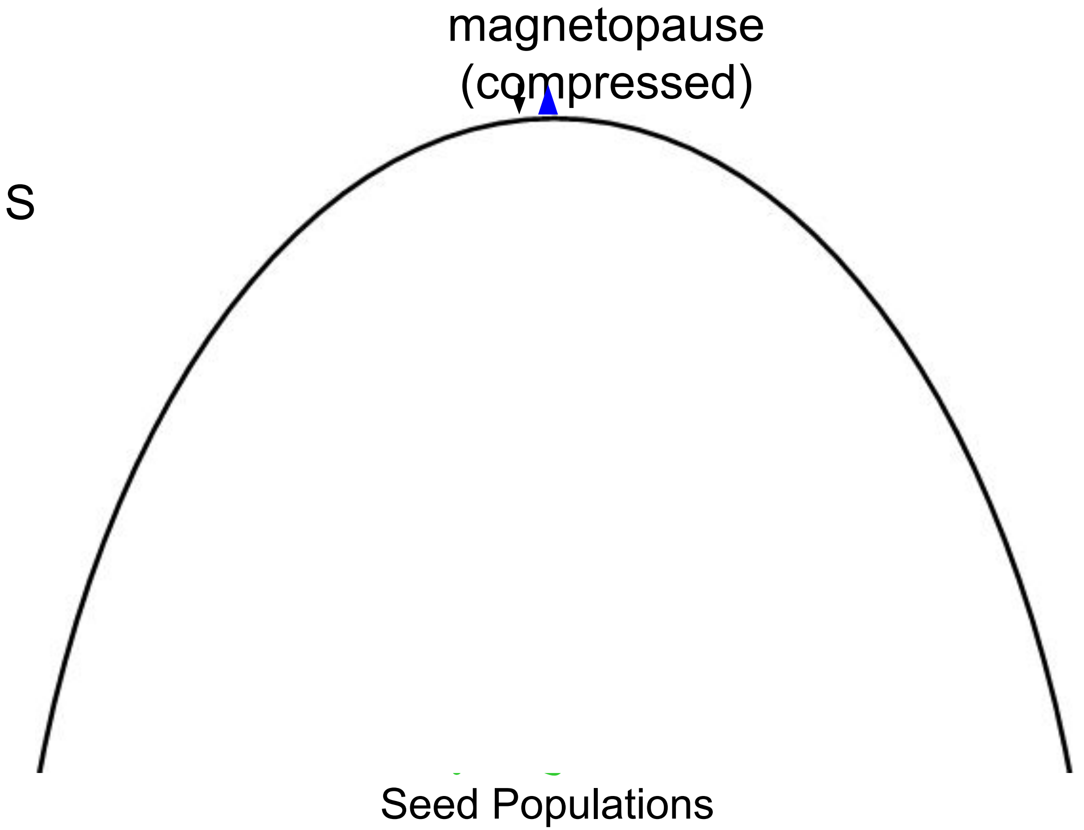


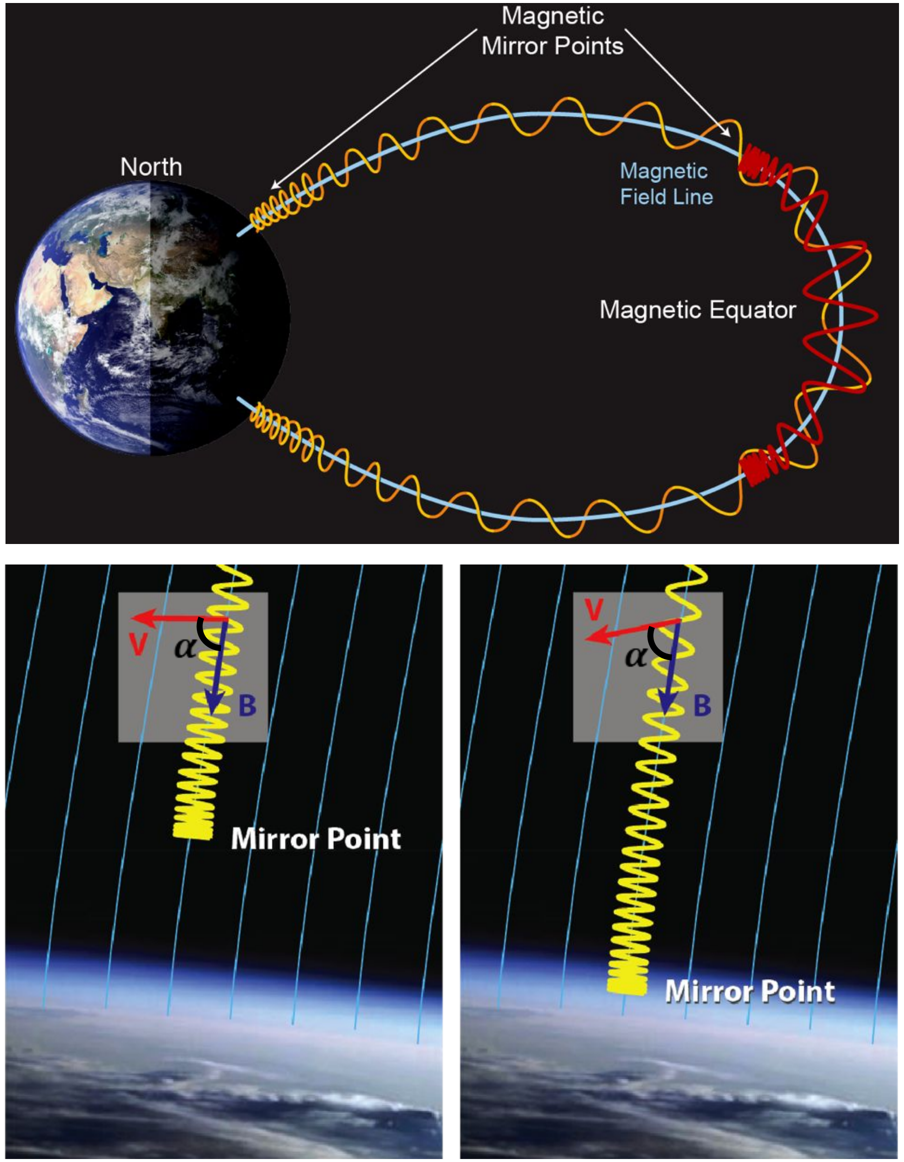




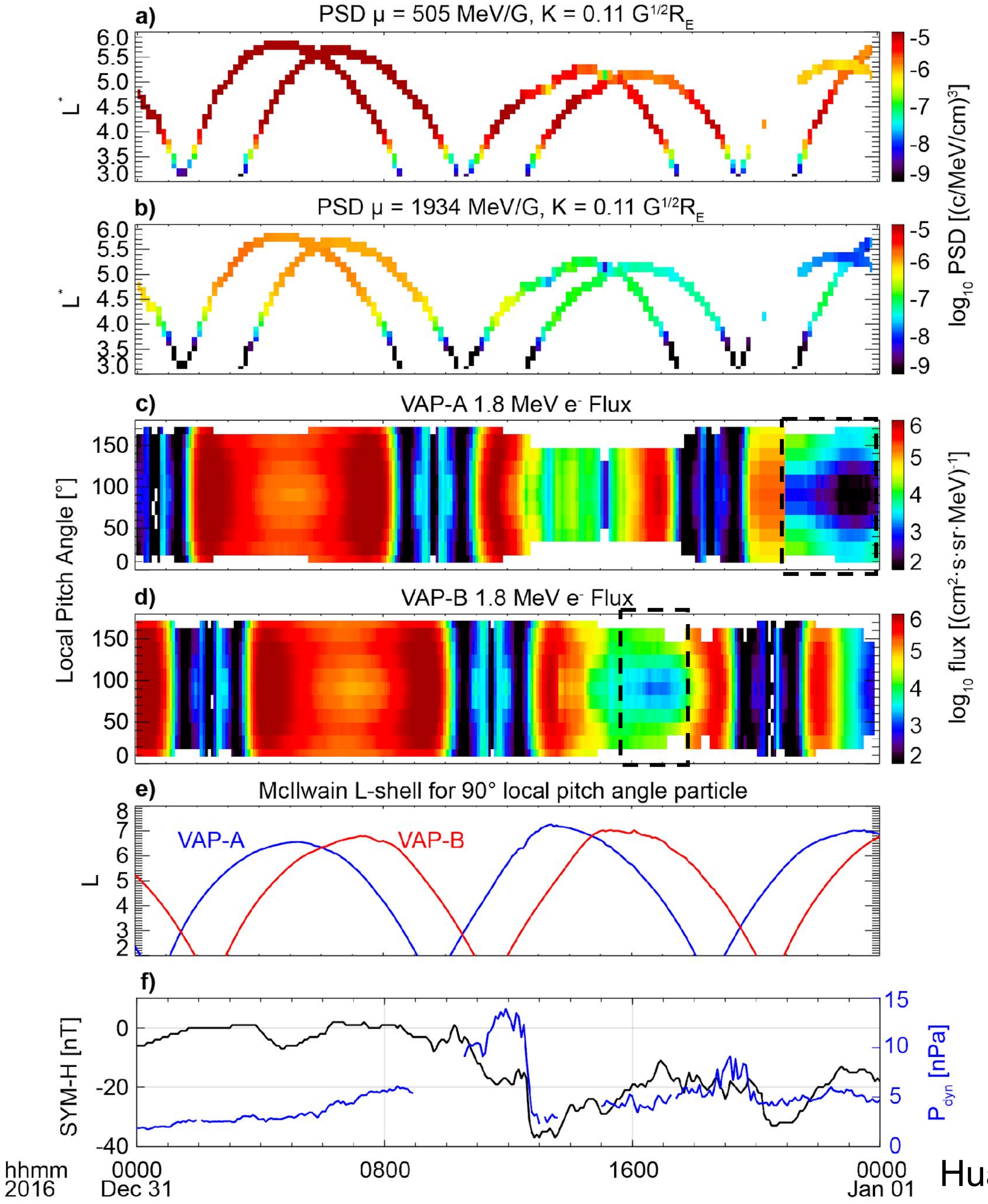
Radiation Belt Electrons Loss Mechanisms

- Precipitation loss: pitch angle scattering by, e.g., VLF, EMIC waves, or field line curvature
- Magnetopause shadowing: combined with outward radial transport by ULF waves

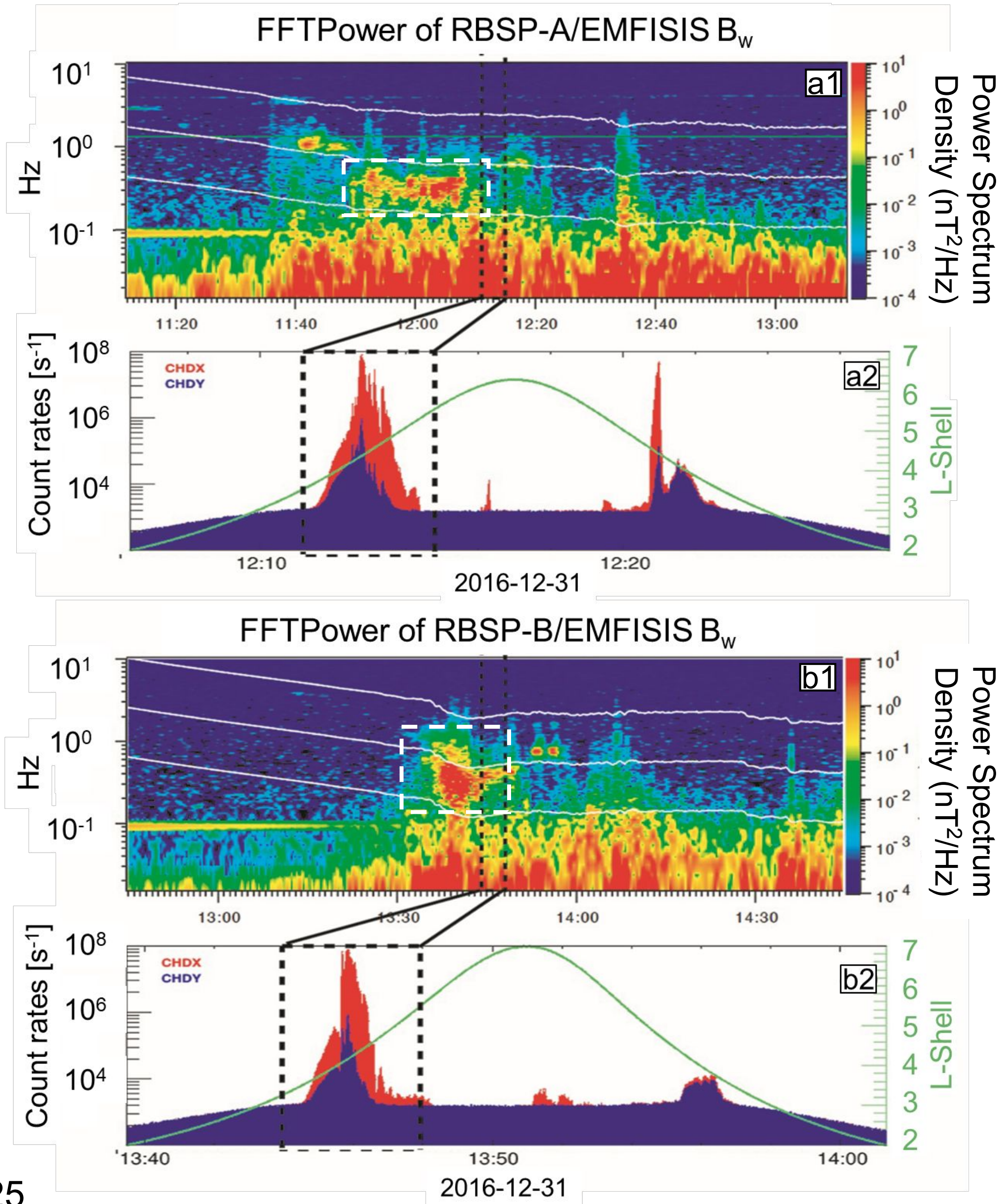




Event Overview



Huang et al., 2025



Bruno et al., 2022

Model Description

- 2D diffusion model (radial and pitch angle)

Radial diffusion by ULF waves (Murphy et al., 2023)

$$log_{10}(D_{L^*L^*}) = c + a_1 L^* + a_2 SymH + a_3 B_z + a_4 V + a_5 P_{dyn}$$

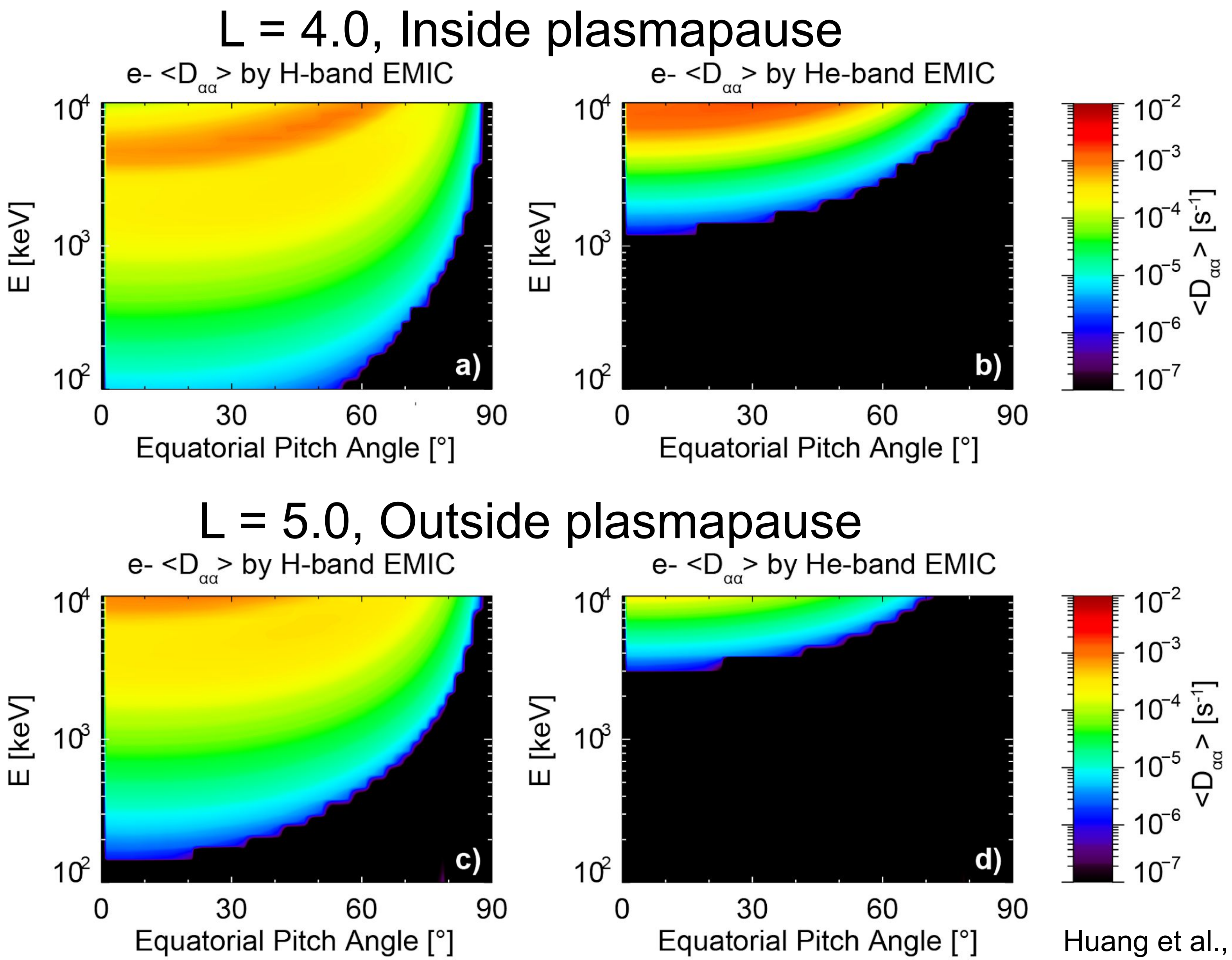
$$\frac{\partial f}{\partial t} = {L^*}^2 \frac{\partial}{\partial L^*}\left(\frac{D_{L^*L^*}}{{L^*}^2}\frac{\partial f}{\partial L^*}\right) + \frac{1}{G}\frac{\partial}{\partial \alpha}\left(G\langle D_{\alpha\alpha}\rangle \frac{\partial f}{\partial \alpha}\right) - \frac{f}{\tau}$$

$$G = T(\alpha)sin(2\alpha), T(\alpha) = 1.38 - 0.32\left(\sin(\alpha) + \sqrt{sin(\alpha)}\right)$$

Pitch angle diffusion by EMIC waves (based on Zhang et al., 2016), or by field line curvature (FLC) scattering (Young et al., 2008)

Electron lifetimes: on the order of electron drift periods outside the last closed drift shell (LCDS) (Huang et al., 2023) or inside the drift loss cone

$\langle D_{\alpha\alpha} \rangle$ by EMIC

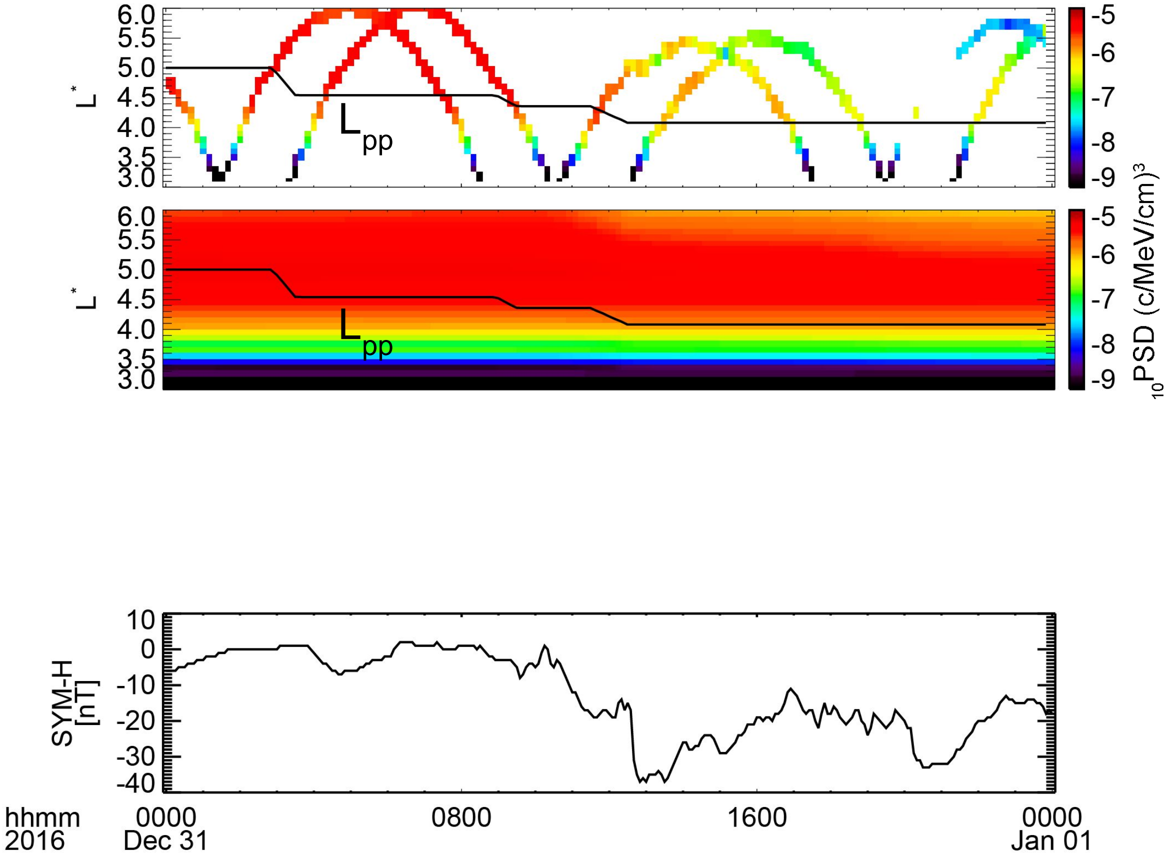


Huang et al., 2025

Simulation Results

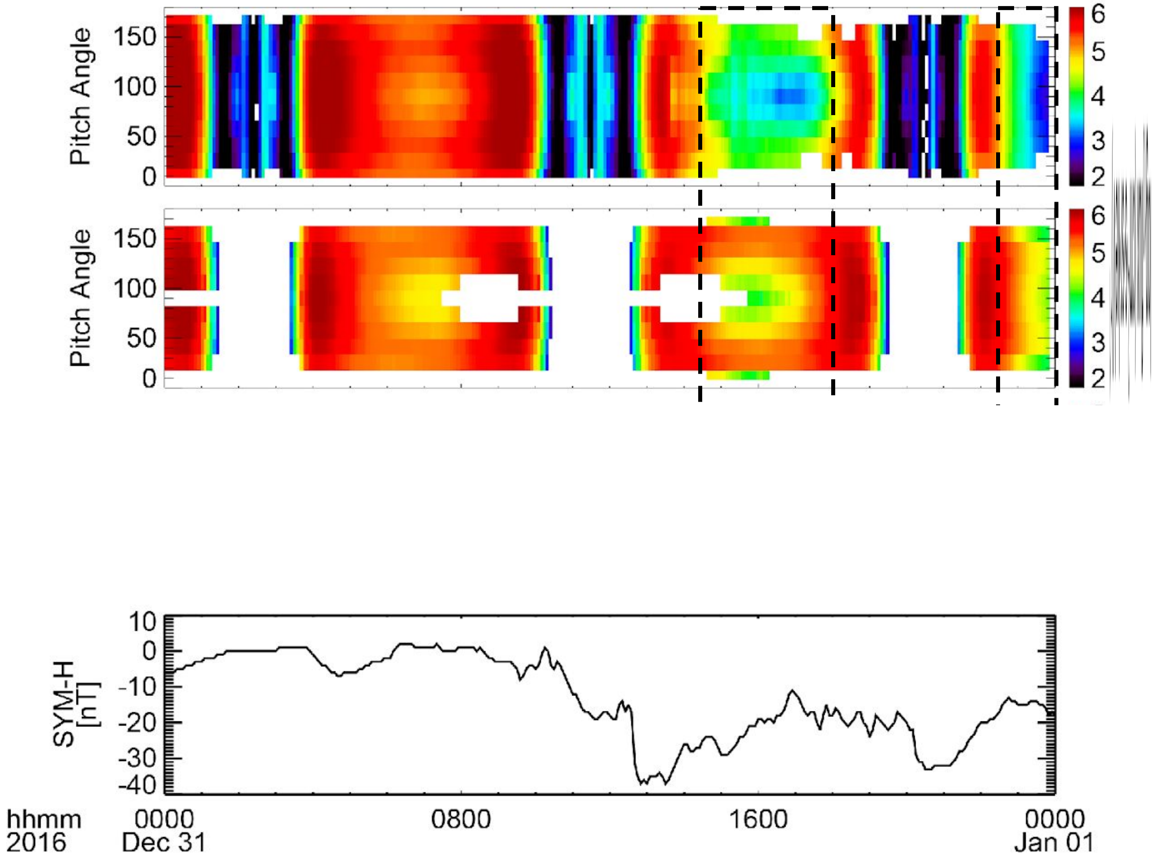
e- PSD: μ = 1934 MeV/G, K = 0.03 $R_E G^{1/2}$

VAPB 1.8 MeV e- Flux PAD



Data

MPS



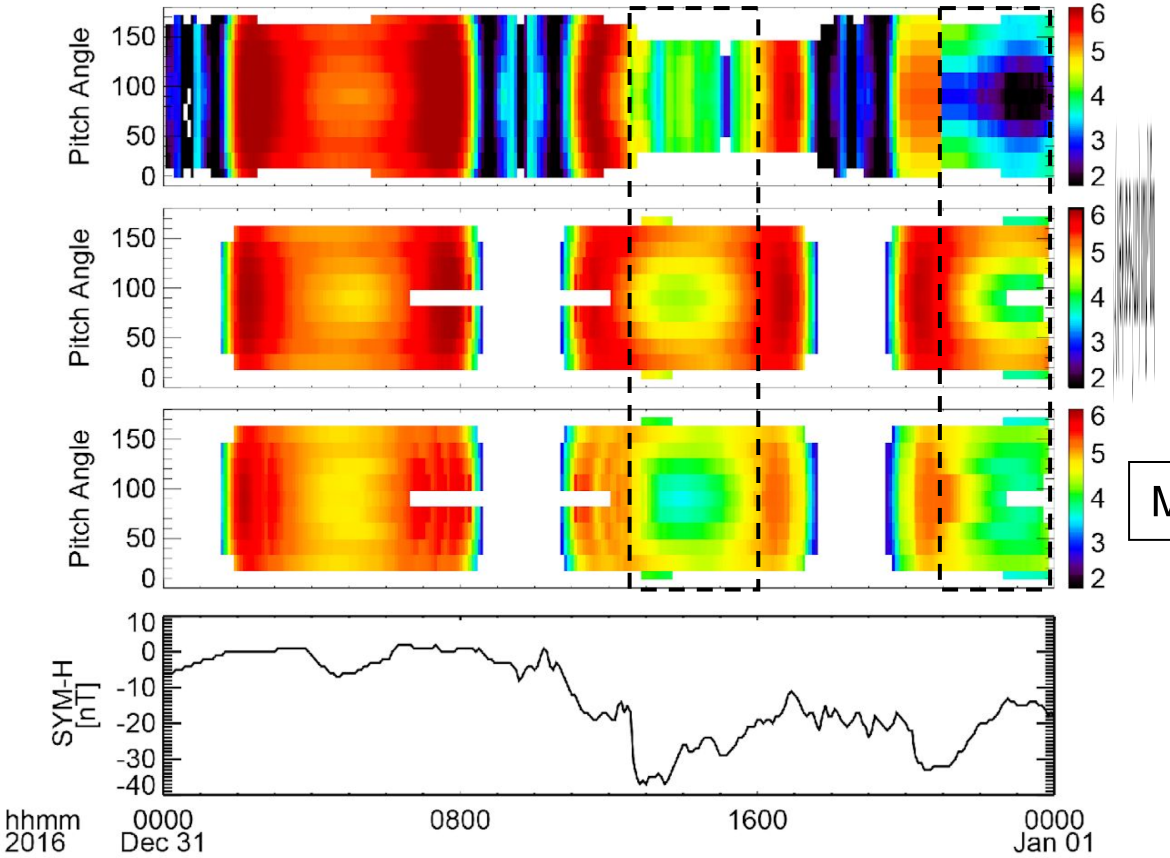
$$L_{pp} = 5.6 - 0.46Kp_{max}$$

Carpenter and Anderson, 1992

Huang et al., 2025

Simulation Results

VAPA 1.8 MeV e- Flux PAD

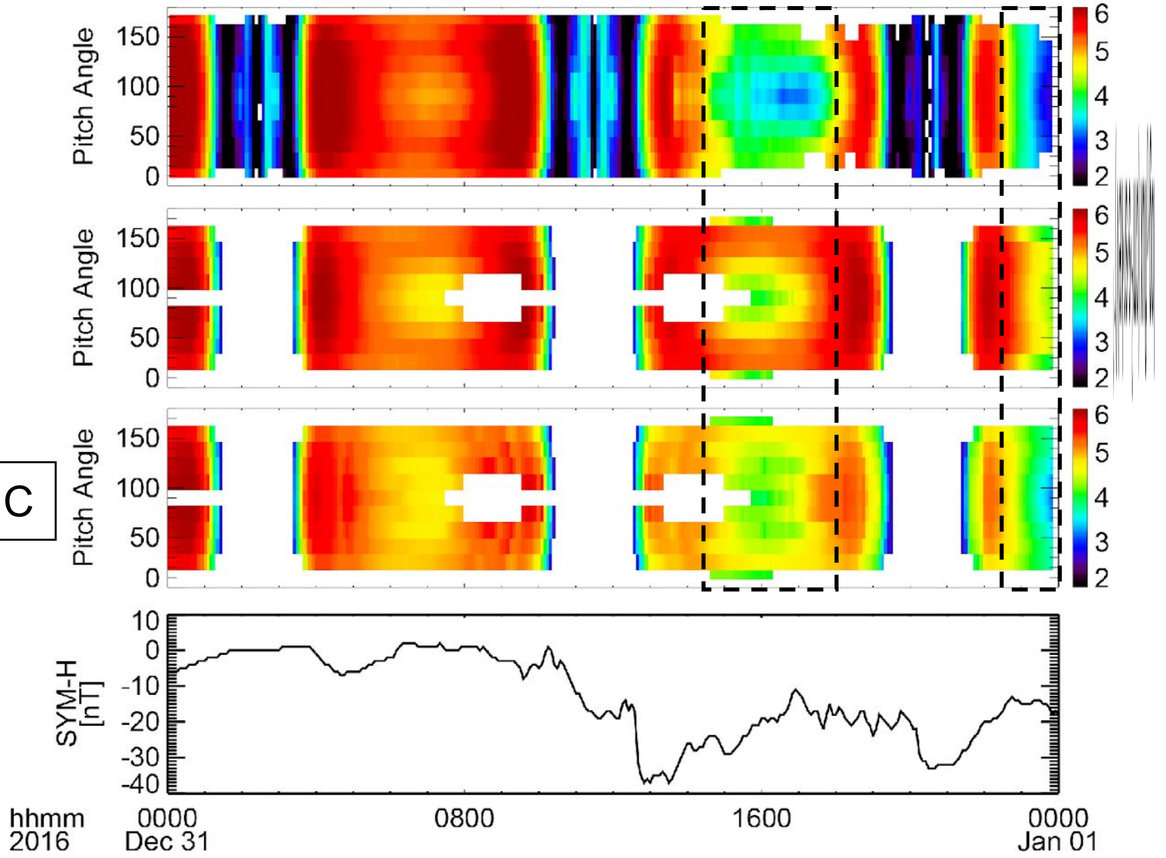


Data

MPS

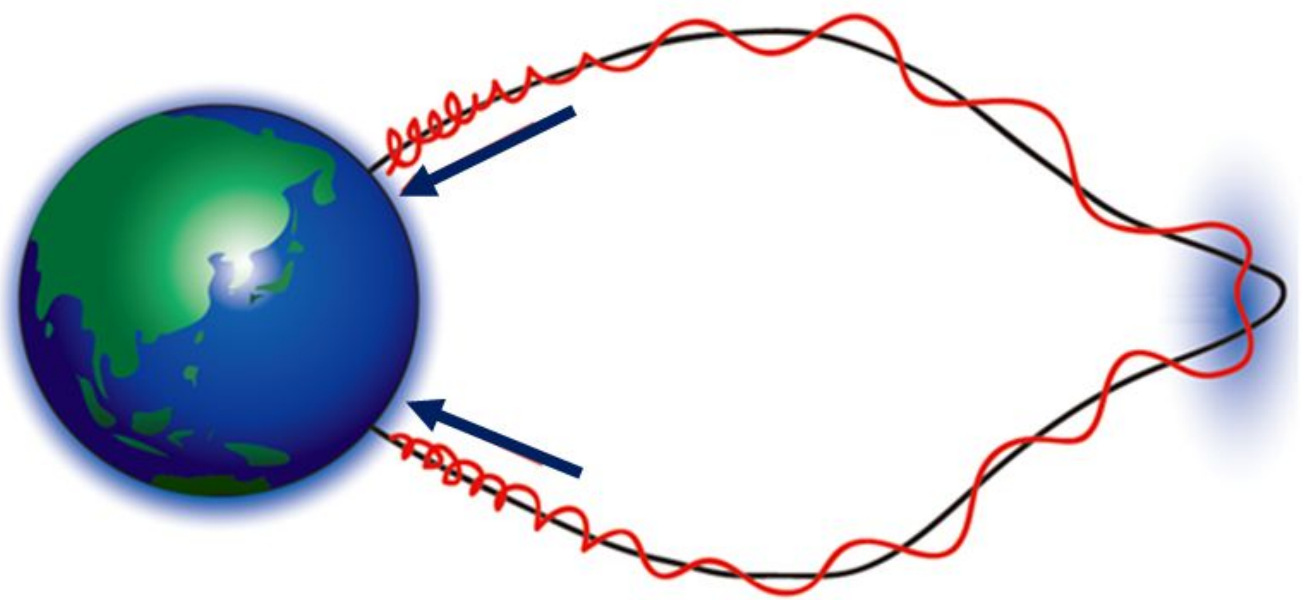
MPS+EMIC

VAPB 1.8 MeV e- Flux PAD



Huang et al., 2025

$\langle D_{\alpha\alpha} \rangle$ by FLC

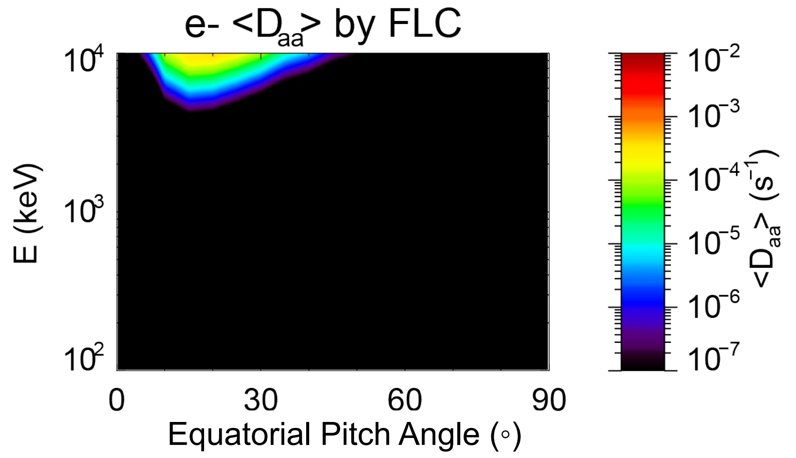


Field line curvature scattering: $\epsilon = R_g/R_c > 0.1$

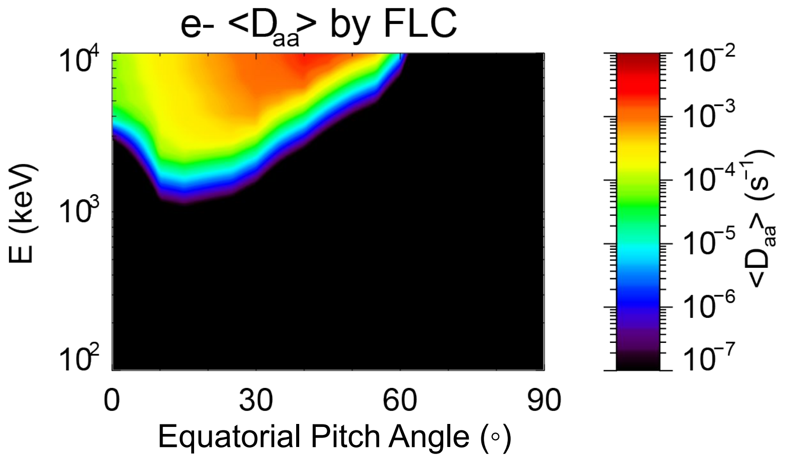
For $\epsilon < 0.584$:
$D_{\alpha\alpha}(\epsilon, \tau_B, \alpha_{eq}$, field geometry) (Young et al., 2008)

For $\epsilon \geq 0.584$:
Strong diffusion: $D_{SD} = 2\alpha_{BLC}^2/\tau_B$ (Kennel, 1969)

L* = 5.0, TS04, 12/31/2016 13UT

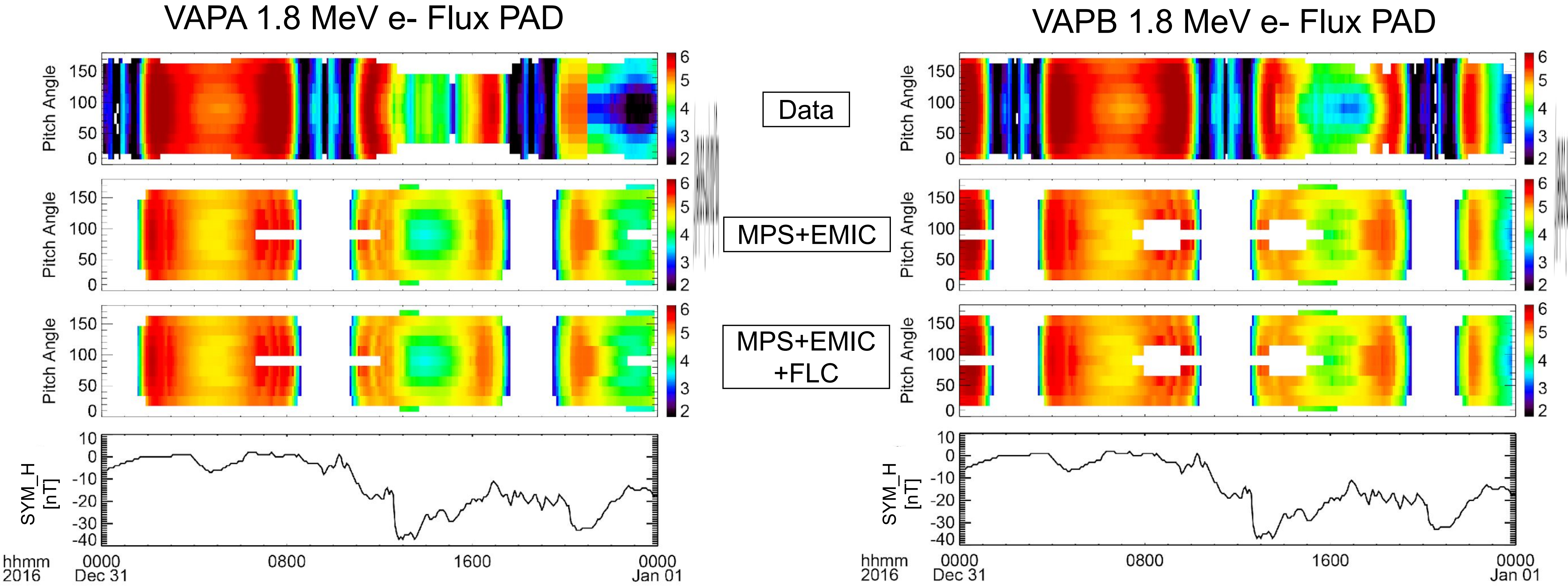


L* = 5.5, TS04, 12/31/2016 13UT



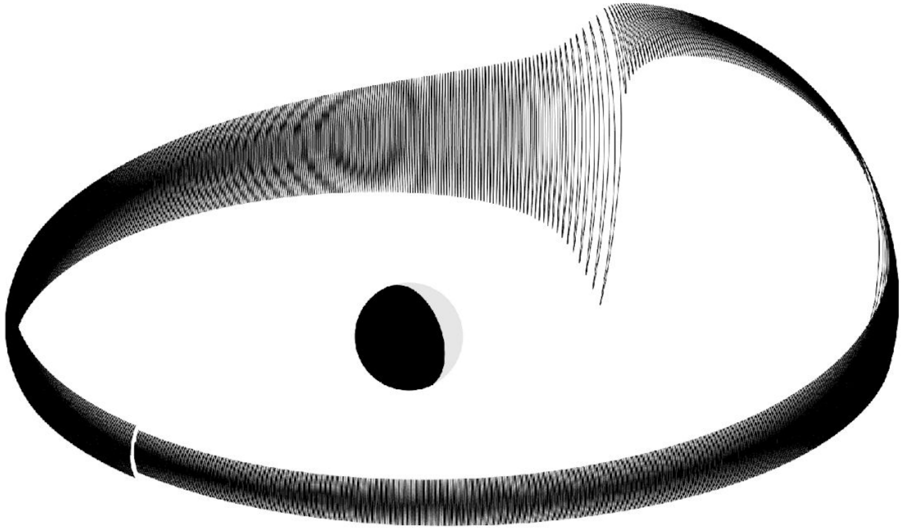
Huang et al., 2025

Simulation Results



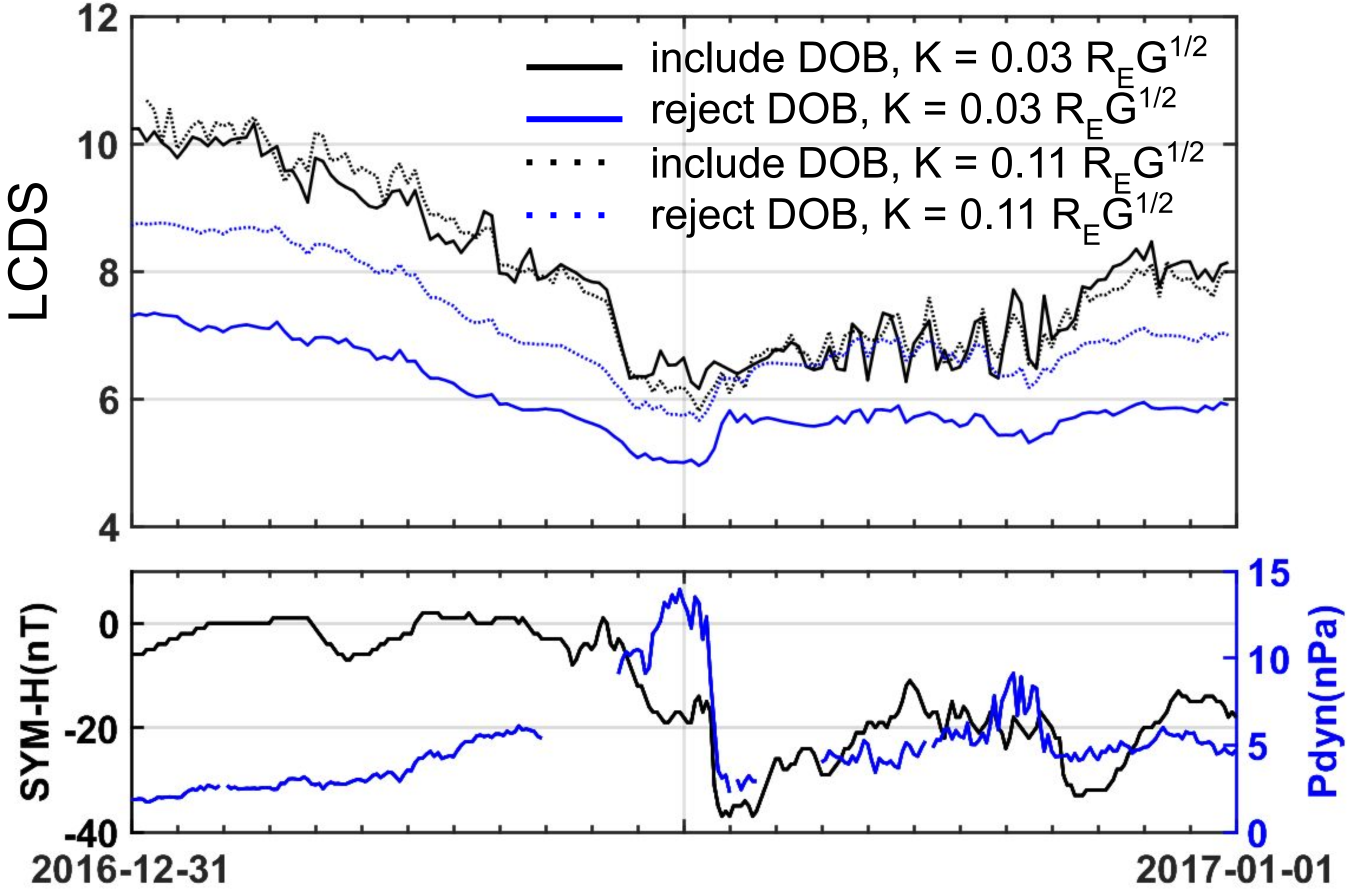
Huang et al., 2025

Uncertainties in LCDS

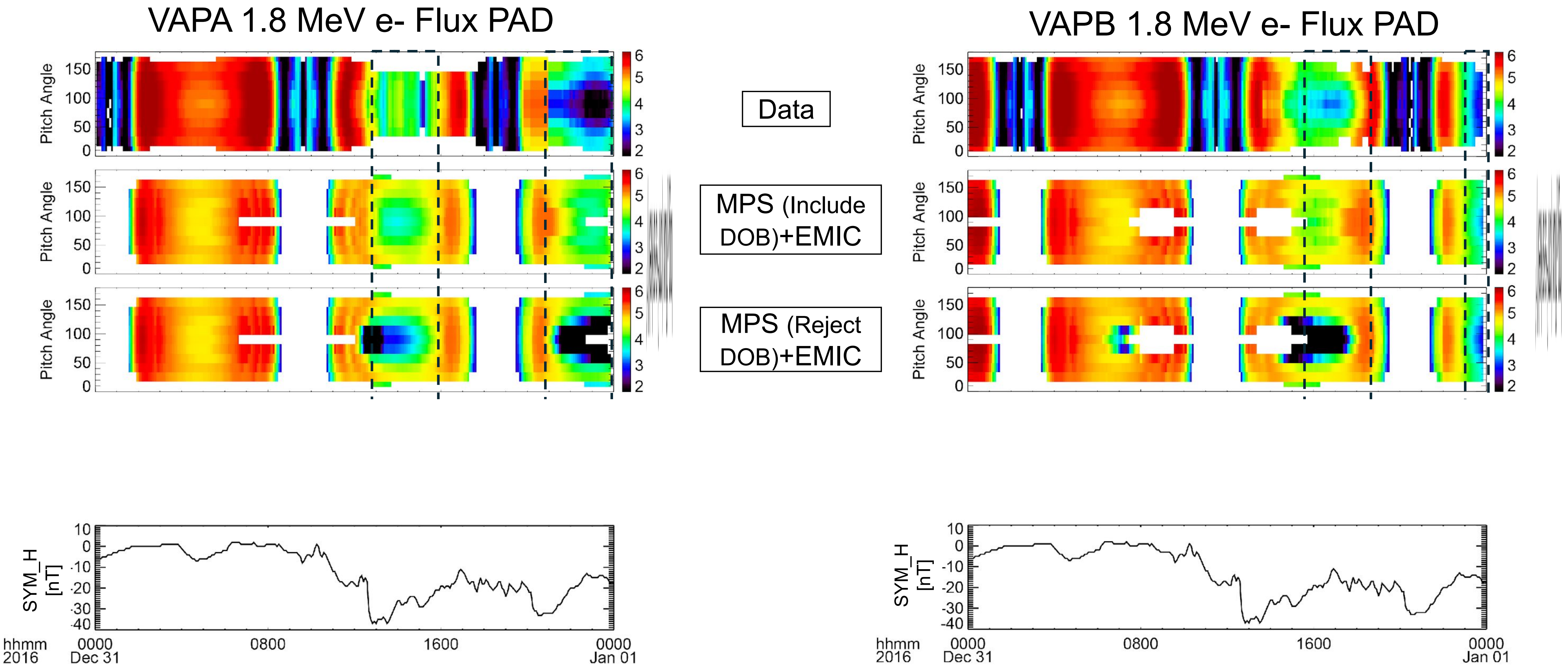


e- Drift Orbit Bifurcation

TS04



Simulation Results



Huang et al., 2025

Conclusions

- 1. The dropout of relativistic outer radiation belt electrons mainly results from the combined effects of MPS and EMIC wave scattering. MPS dominates the dropout at high L and high equatorial pitch angles, while EMIC wave scattering is the primary mechanism at low equatorial pitch angles over a wide L range in the outer radiation belt.
- 2. The FLC effect is negligible in contributing to the observed electron dropout inside the LCDS.
- 3. The diffusion model requires physical quantification of MPS and more realistic and event-specific wave properties for EMIC wave scattering to better reproduce the observed electron dropout.

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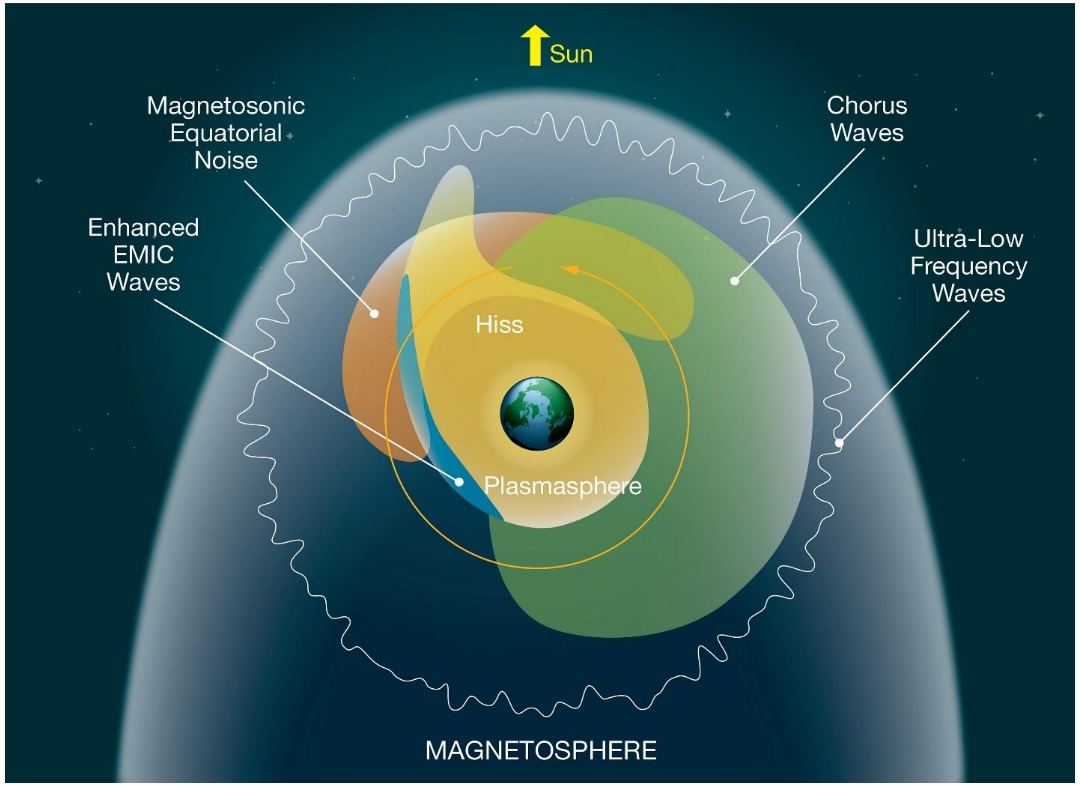
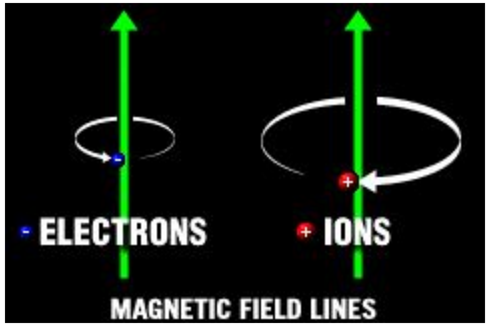
Backup Slides

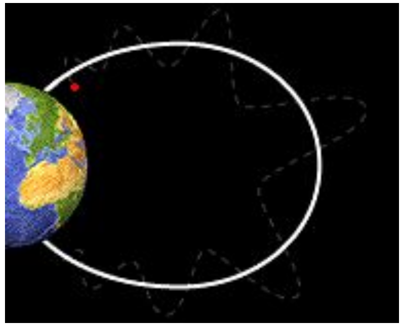
Inner Magnetosphere: Waves

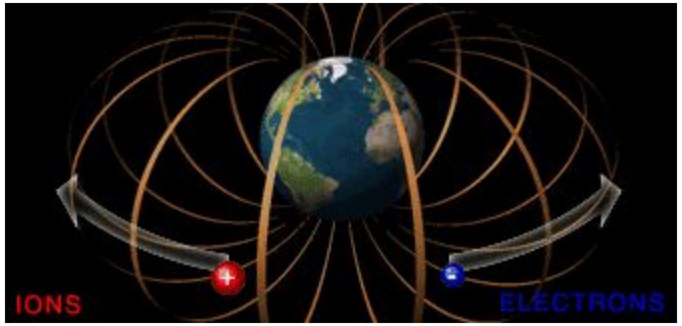
- A variety of electromagnetic waves exist in near-Earth space environment.
  - ULF waves, Chorus, Hiss, EMIC, etc.
- These waves have different frequencies that can resonate with the characteristic motions of charged particles.
  - Drift resonance, bounce resonance, gyro-resonance



Credit: NASA







EMIC wave (Zhang et al., 2016)

% ADOPTED PARAMETERS (EMIC waves):

% B_w=1000.0 pT; MLT=21.0 ;
lambda_min= 0.0 deg, lambda_max=40.0 deg;

% Density Model=C; Ne=
0.1178923E+009m^-3;
fpe/fce= 14.08; N_res = -5 ~ +5;

% omega_lc=   0.25 omega_eq,
omega_uc=   0.99 omega_eq;

% theta_m= 0.0 deg, theta_w= 0.1 deg,
theta_lc= 0.0 deg, theta_uc= 0.2 deg.