The Roles of Transport and Wave-Particle Interactions on Radiation Belt Dynamics

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Outline

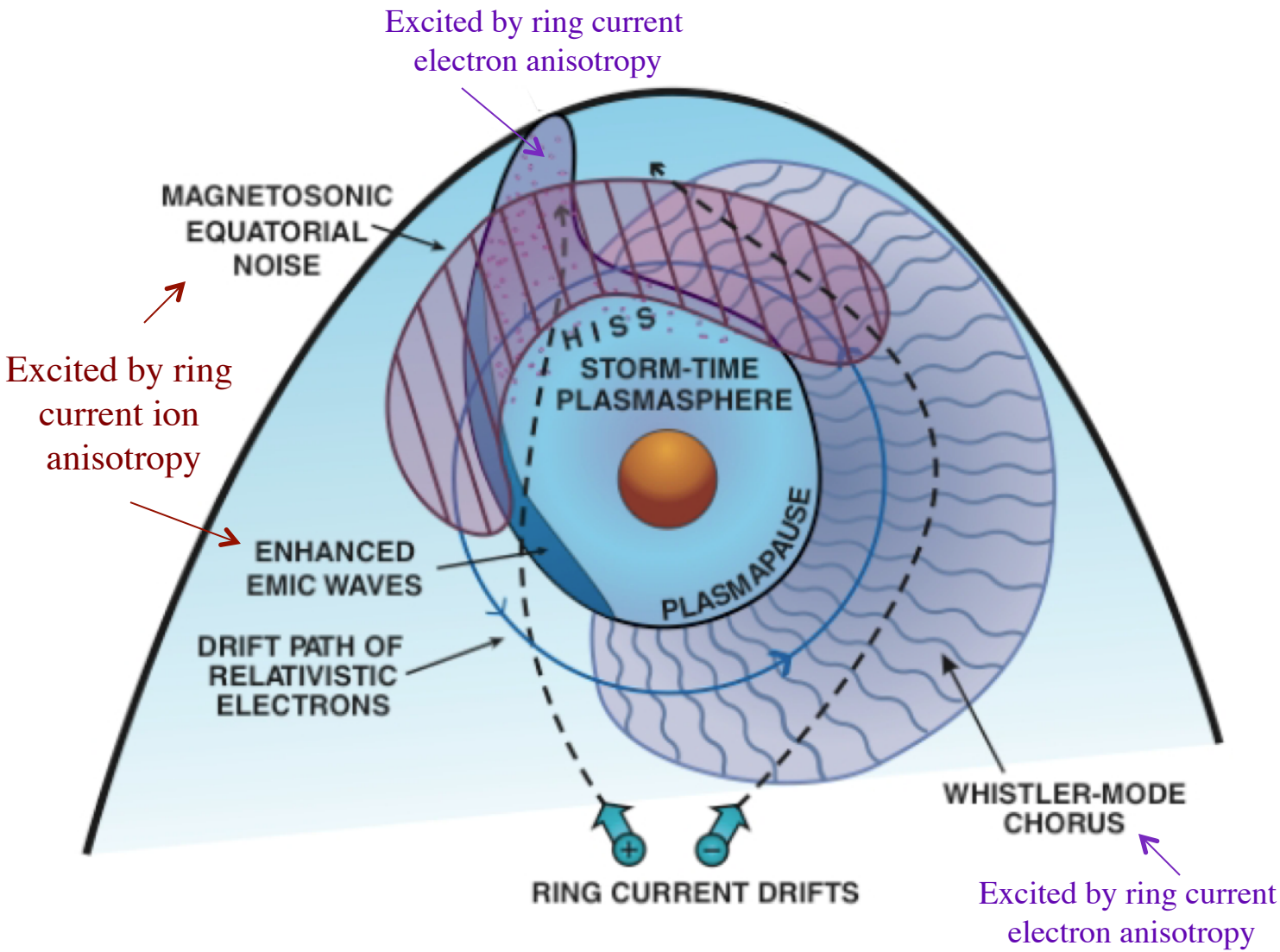
- Processes that control the radiation belt dynamics

- The Radiation Belt Environment (RBE) model
  - Model logic
  - Model formulation
  - Model input/output

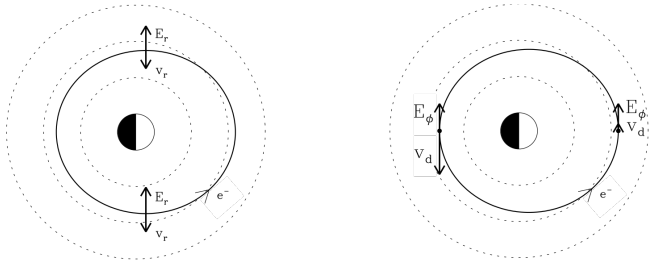
- Model the radiation belt enhancements during storms in October 2002, September 2008 and August 2010

- Roles of transport and wave diffusion processes in controlling electron flux variations

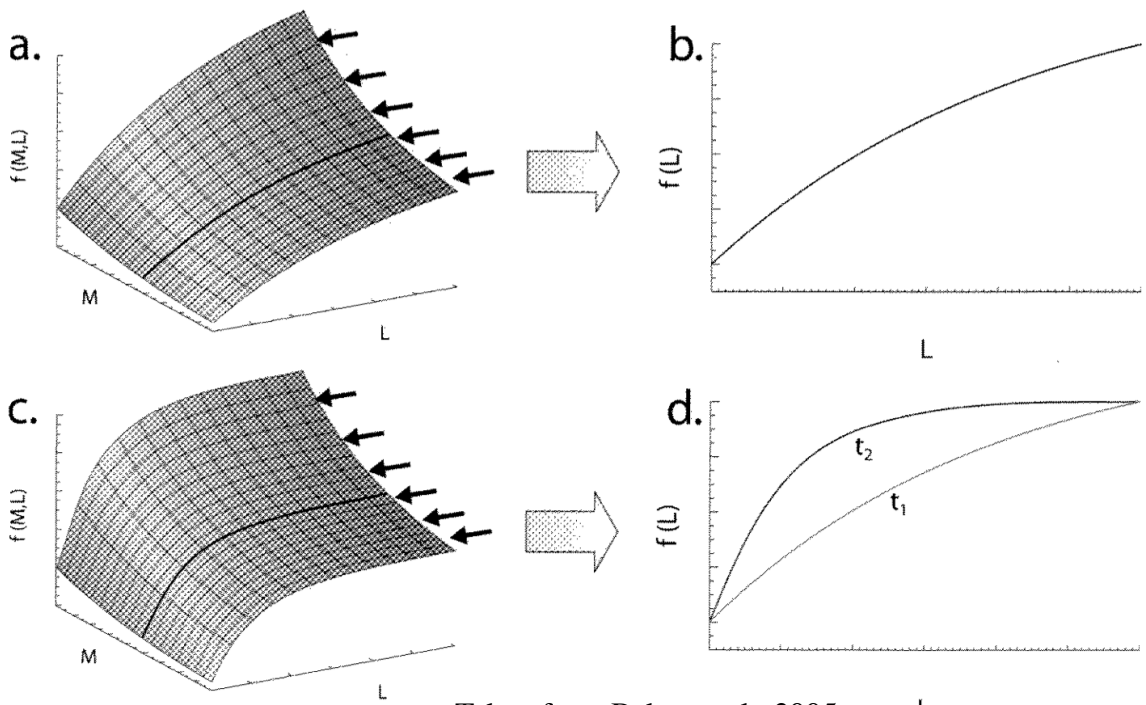
RB Process: Wave-Particle Interactions



RB Process: Radial Diffusion

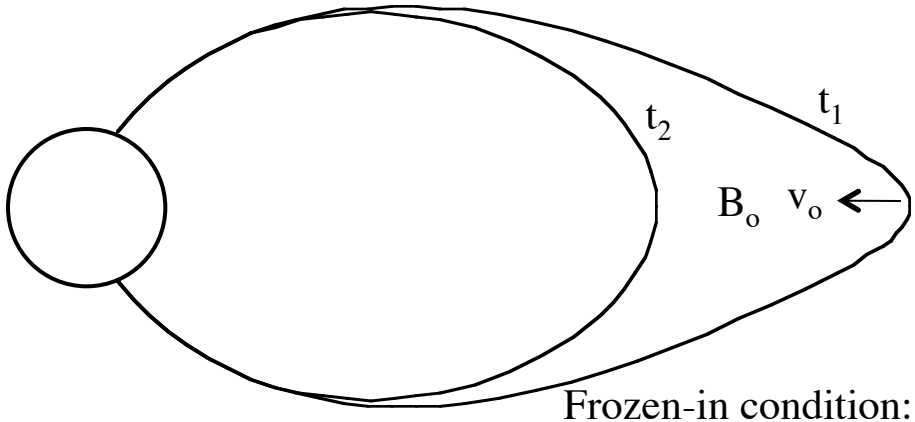


Taken from Elkington et al., 2003



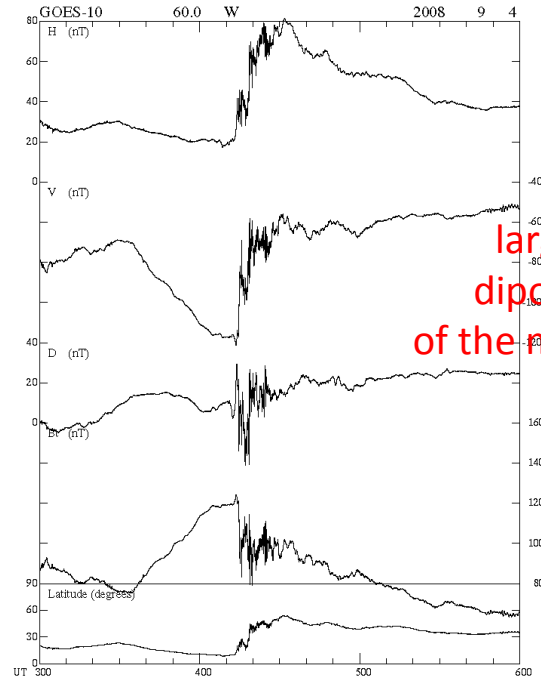
Taken from Baker et al., 2005

RB Process: (De) Energized by Inductive Fields

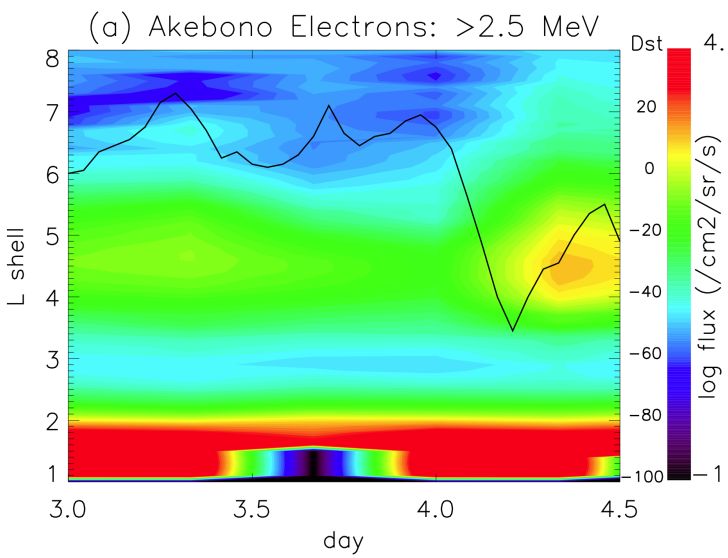


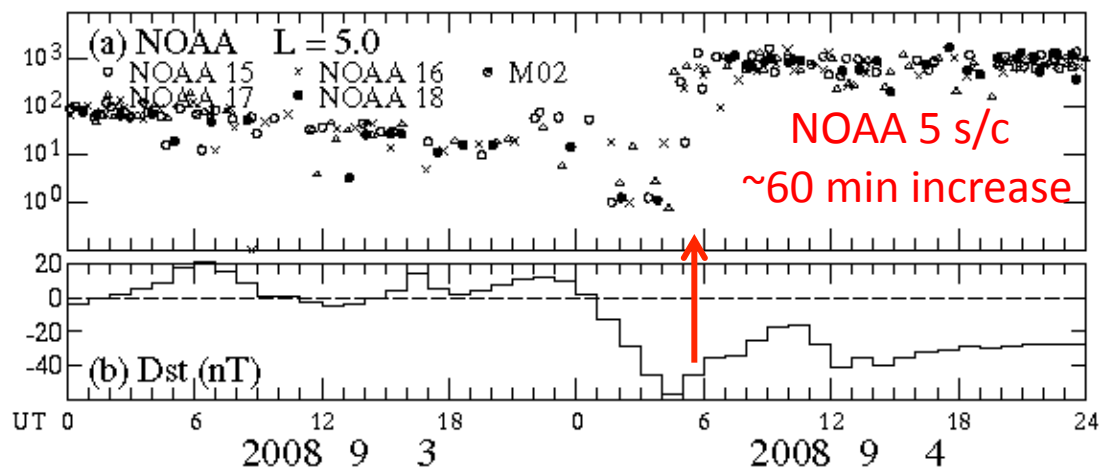
Frozen-in condition:

$$\mathbf{E}_{ind} = -\mathbf{v}_o \times \mathbf{B}_o$$



large-scale dipolarization of the magnetic field

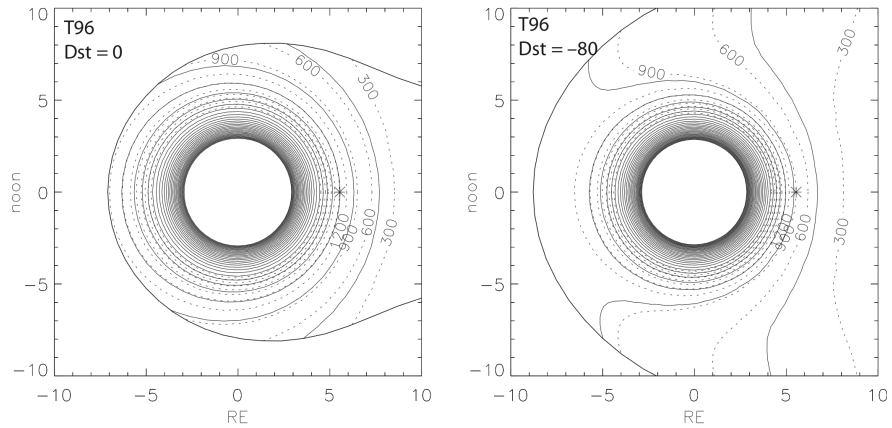


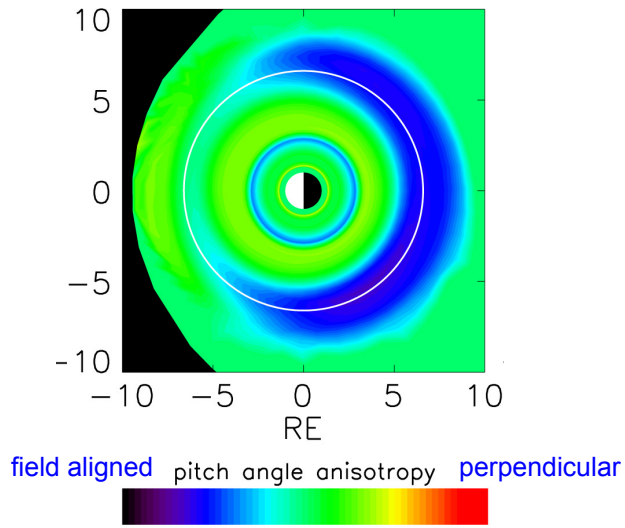


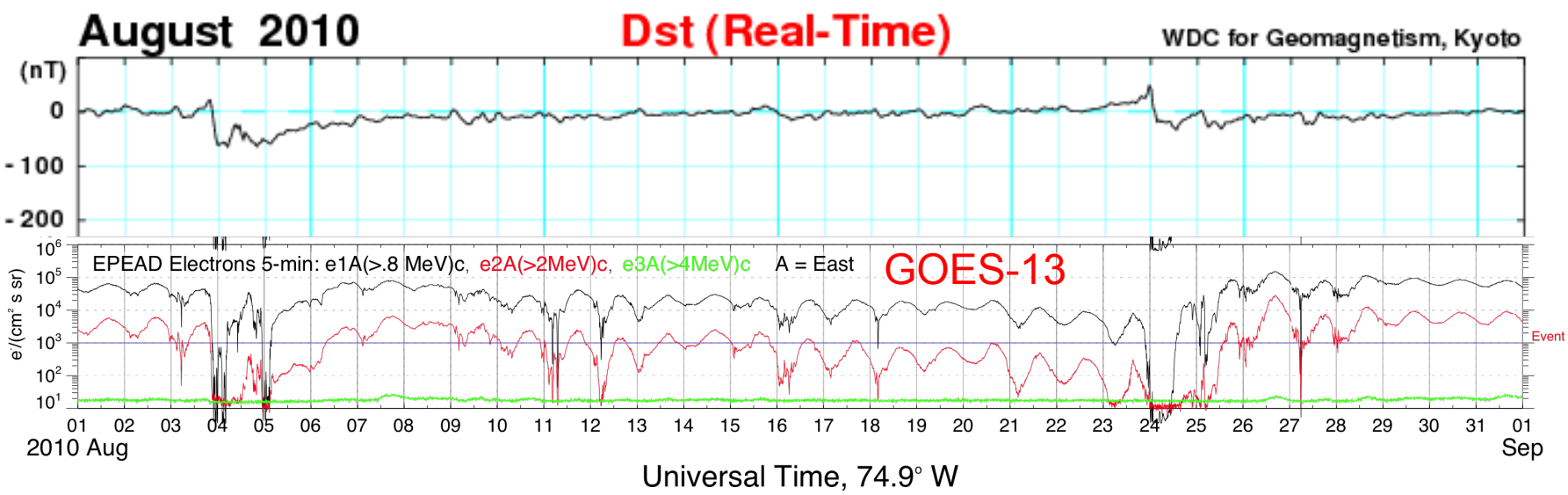
NOAA 5 s/c

~60 min increase

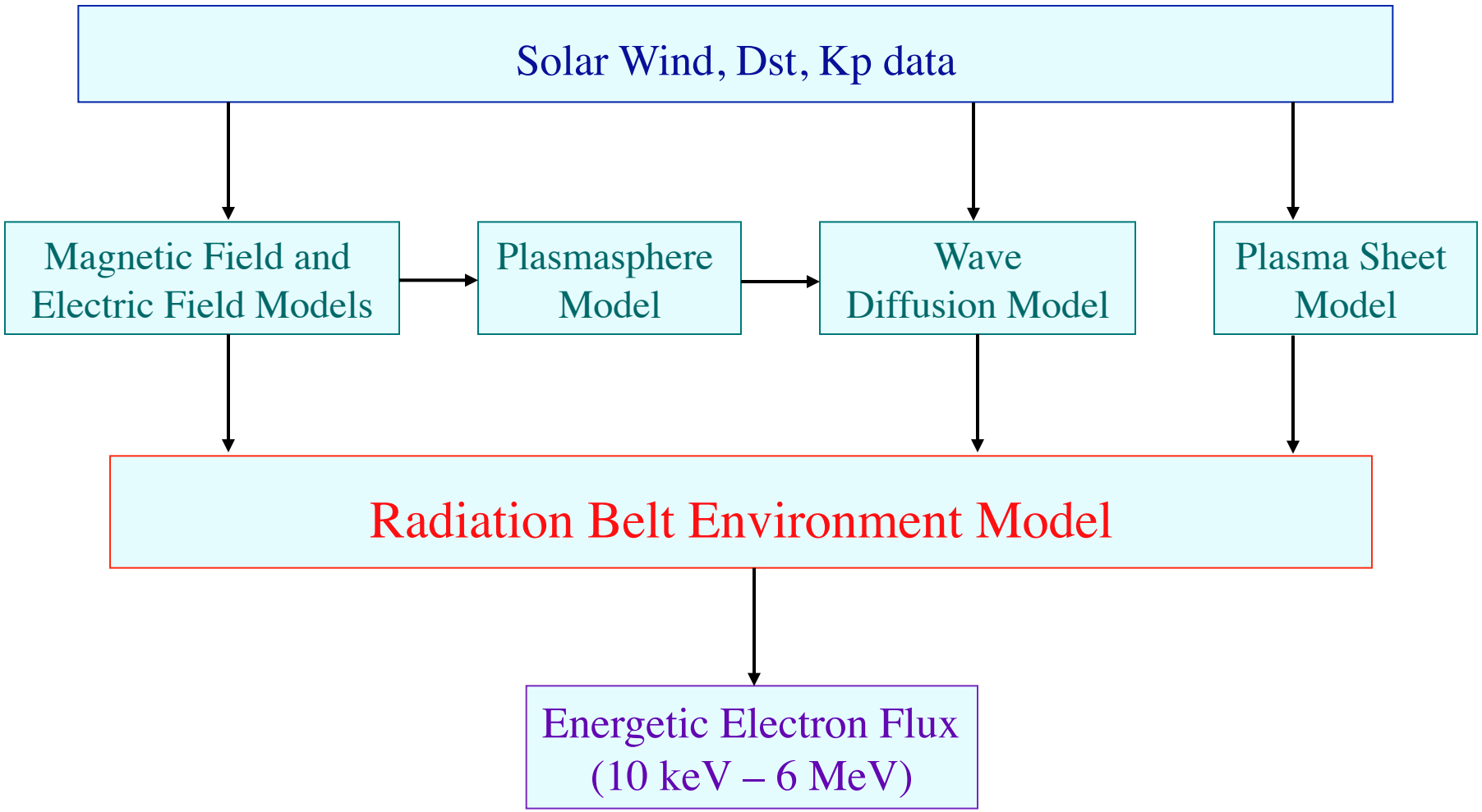
RB Process: Magnetopause Shadowing







The Radiation Belt Environment (RBE) Model



Radiation Belt Environment Model: The Equation

$$\frac{\partial f_s}{\partial t} + \langle \dot{\lambda}_i \rangle \frac{\partial f_s}{\partial \lambda_i} + \langle \dot{\phi}_i \rangle \frac{\partial f_s}{\partial \phi_i} = \frac{1}{G}\frac{\partial}{\partial \alpha_o}\left[G\left(D_{\alpha_o \alpha_o}\frac{\partial f_s}{\partial \alpha_o} + D_{\alpha_o E}\frac{\partial f_s}{\partial E}\right)\right] + \frac{1}{G}\frac{\partial}{\partial E}\left[G\left(D_{EE}\frac{\partial f_s}{\partial E} + D_{E\alpha_o}\frac{\partial f_s}{\partial \alpha_o}\right)\right] - \left(\frac{f_s}{0.5\tau_b}\right)_{\substack{\text{loss}\\ \text{cone}}}$$

$f_s = f_s(t, \lambda_i, \phi_i, M, K)$: phase space density of electrons

λ_i : magnetic latitude at the ionosphere

ϕ_i : magnetic local time at the ionosphere

M : magnetic moment

K : longitudinal invariant

$\langle \dot{\lambda}_i \rangle, \langle \dot{\phi}_i \rangle$: drift velocities (convection + magnetic drift + corotation)

$G = T(\alpha_o)\sin 2\alpha_o (E + E_o)\sqrt{E(E + 2E_o)}$, E_o = rest mass energy, and $T(\alpha_o) = \frac{1}{2R_o}\int_{s_m}^{s_m^*} \frac{ds}{\cos\alpha}$

τ_b: bounce period

Inductive effect and radial diffusion is included implicitly in the time-varying B and E fields.

Radiation Belt Environment Model: The Input

- Dst, Kp: Kyoto University Geomagnetic Data Service
- Shifted solar wind data: ACE or WIND satellite
- Magnetic field model: T04 model or MHD model
- Electric field model: Weimer model or MHD model
- Distribution at the outer boundary (10 RE): kappa distribution
  Nps(t) = [(0.02 Nsw(t-2hr) + 0.316)] sqrt(amu) cm^-3
  Eo(t) = 0.016 Vsw(t-2hr) - 2.4 keV
- Diffusion coefficients: Jay Albert's diffusion code
- Chorus and hiss powers: Gaussian fits based on CRRES data

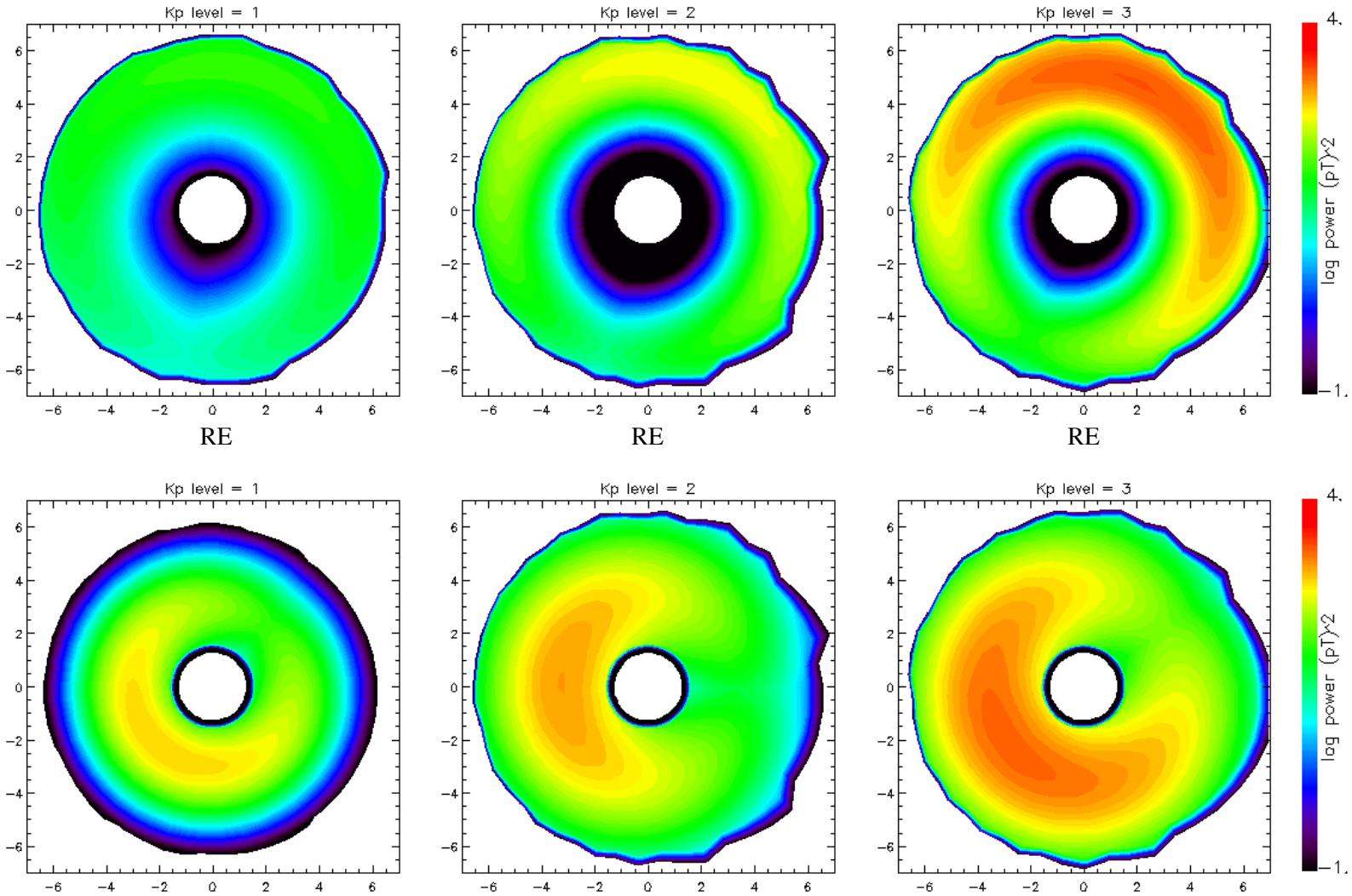
Model of Wave Power

Kp < 2 | 2 < Kp < 4 | Kp < 4

Chorus

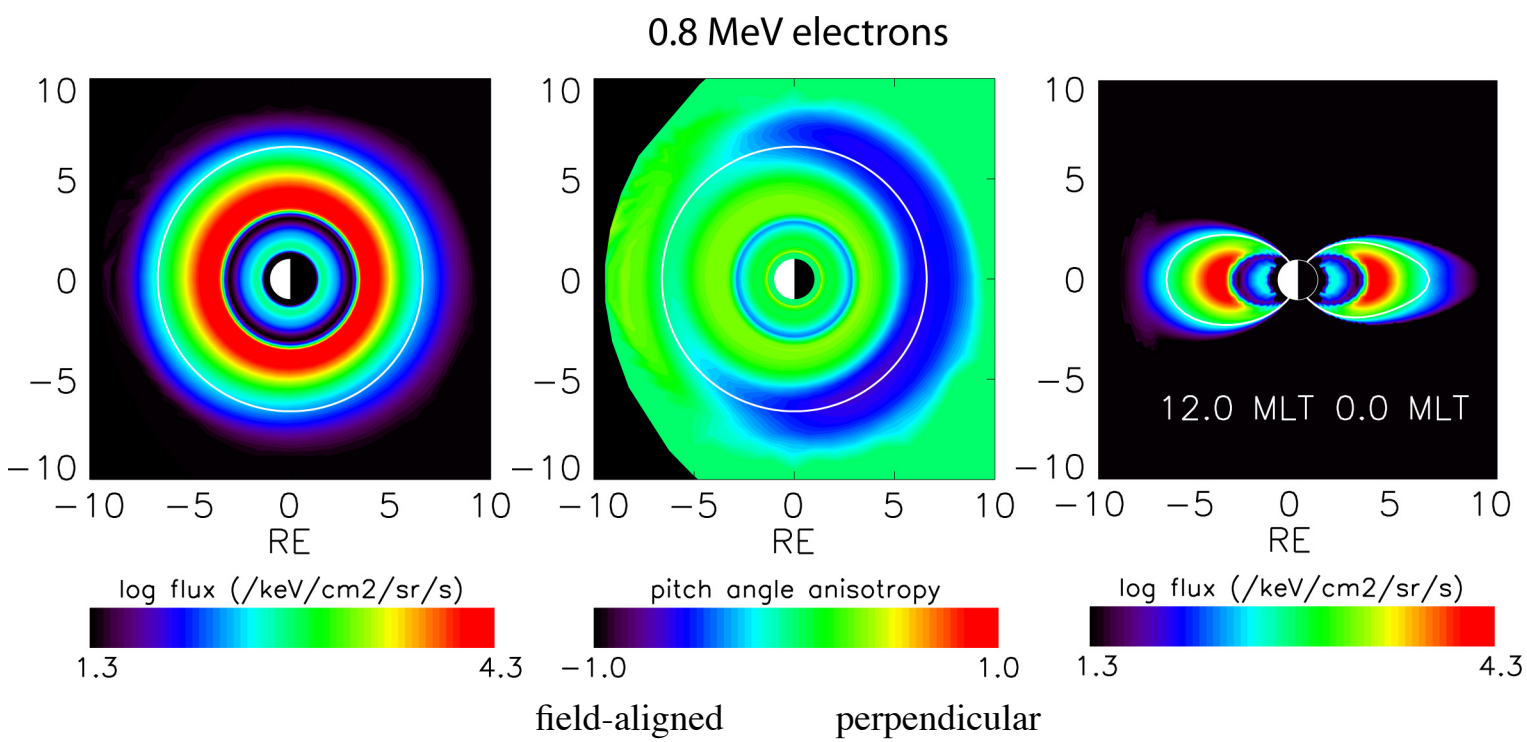
← Sun

Hiss



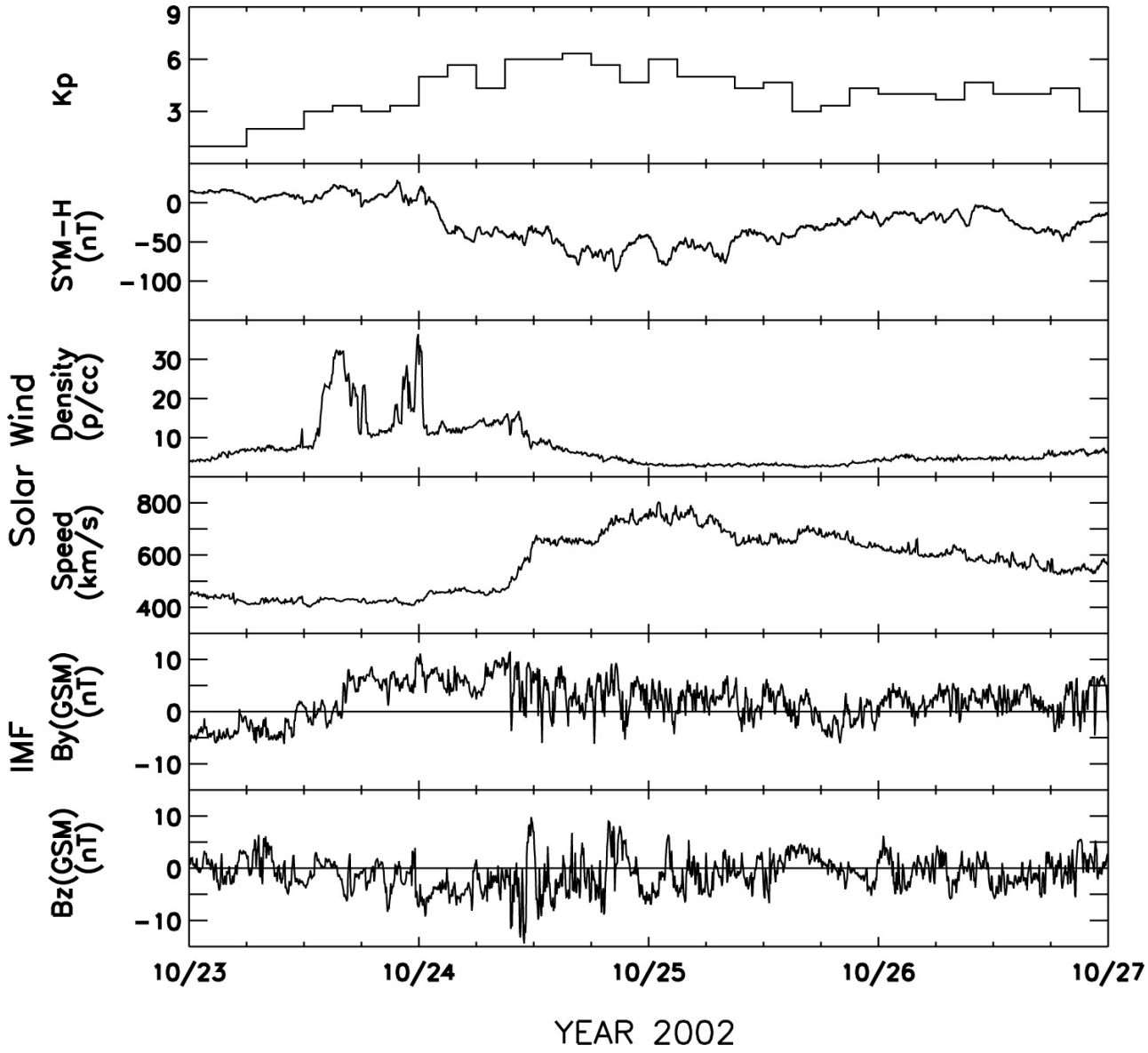
Radiation Belt Environment Model: The Output

RBE Output: 3-dimensional Electron Flux
from 10 keV to 6 MeV at all pitch angles

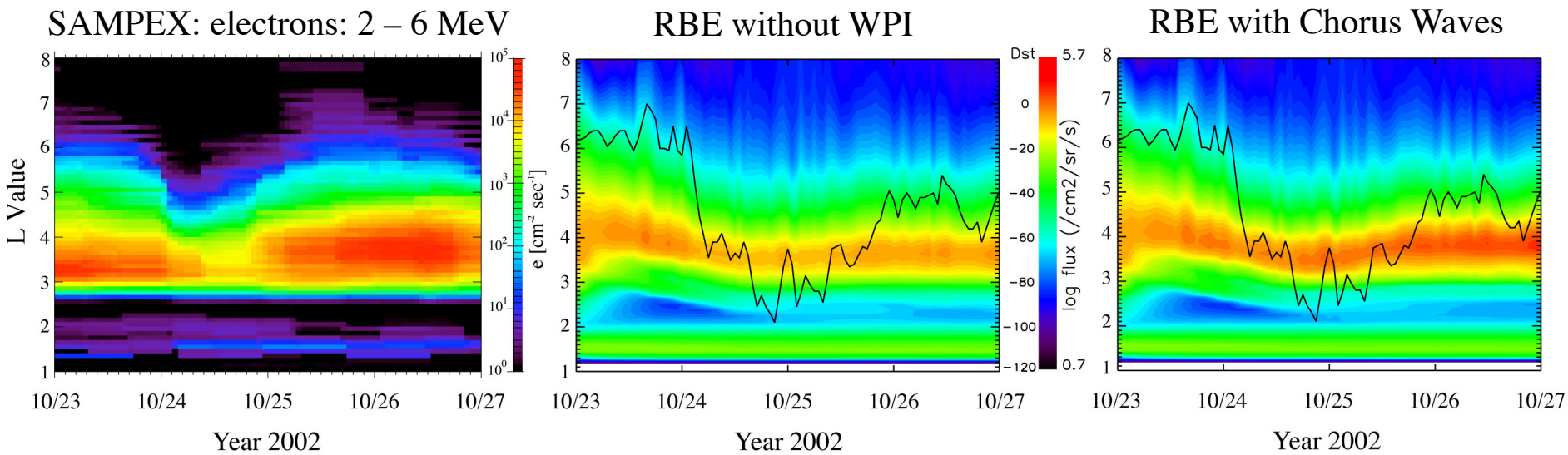


Equatorial Flux | Pitch-angle distribution | Meridian Flux

Magnetic Storm on 23 - 27 October 2002



Flux Enhancement by Wave-Particle Interactions: 23-27 Oct 2002 Storm

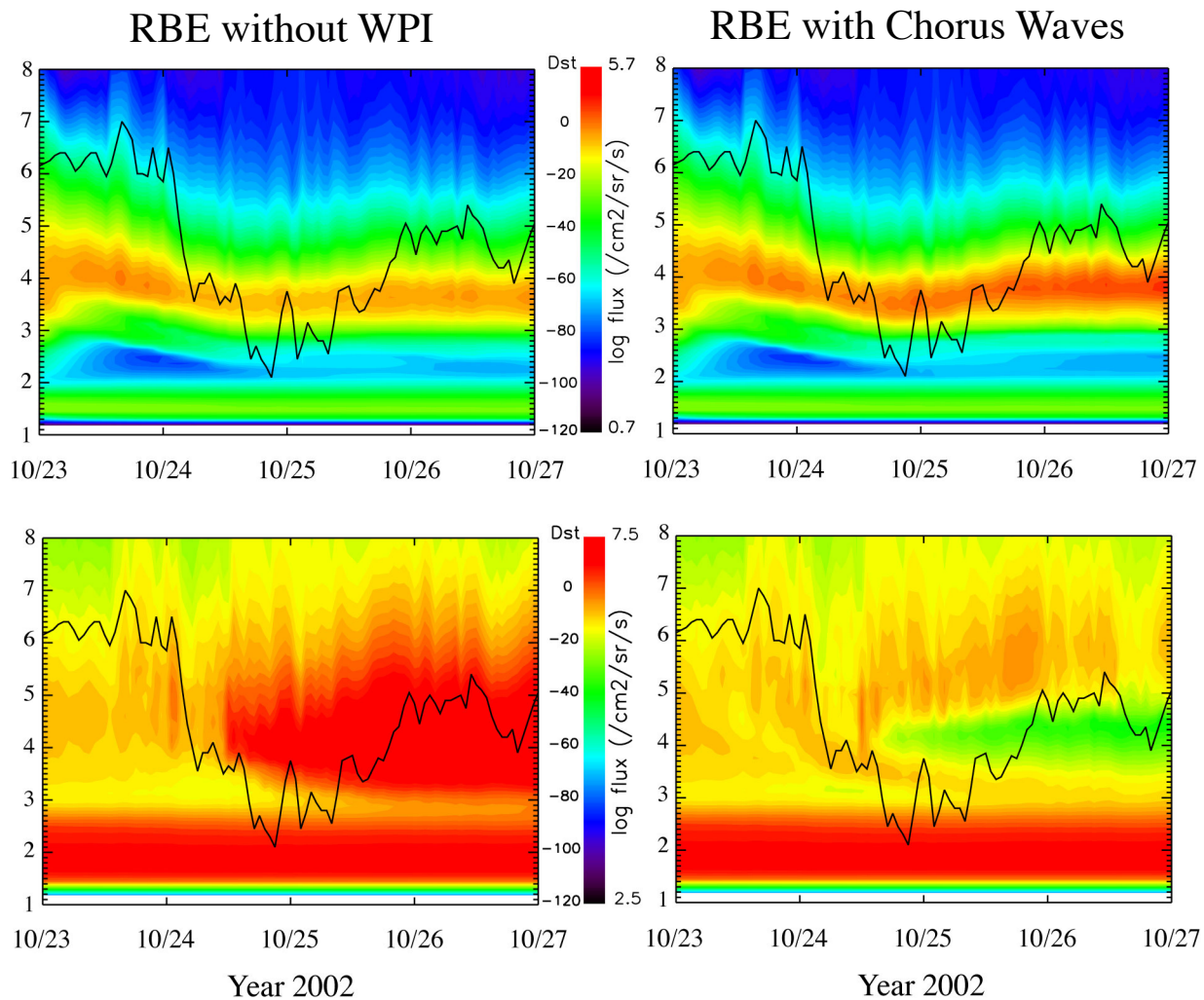


- RBE produces less dropout during storm main phase than observed.
- Enhancement during storm recovery cannot be explained without wave-particle interactions (WPI).

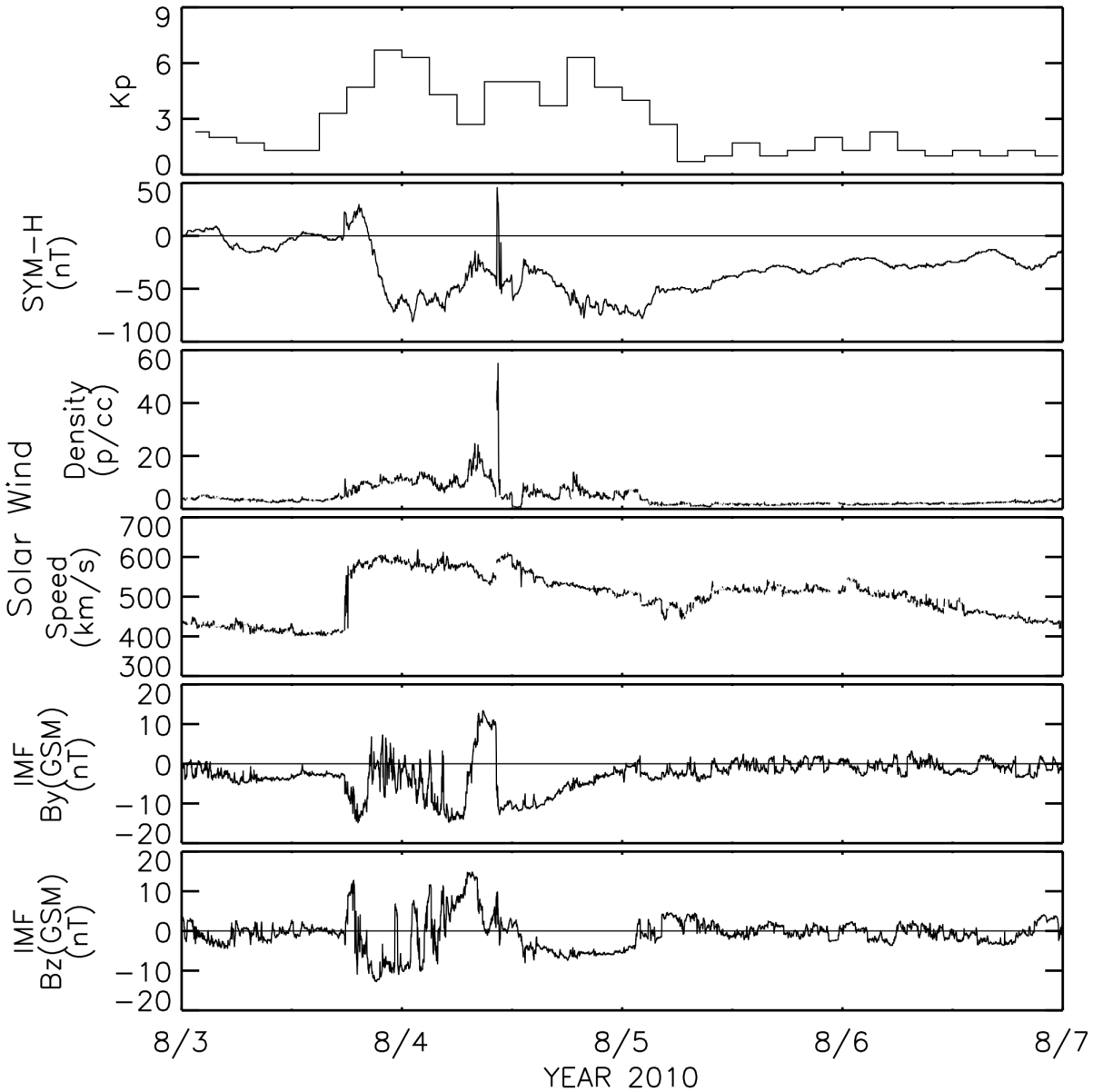
Ring Current Electron Loss by Chorus Wave Diffusion

Radiation Belt Electrons
(2 – 6 MeV)

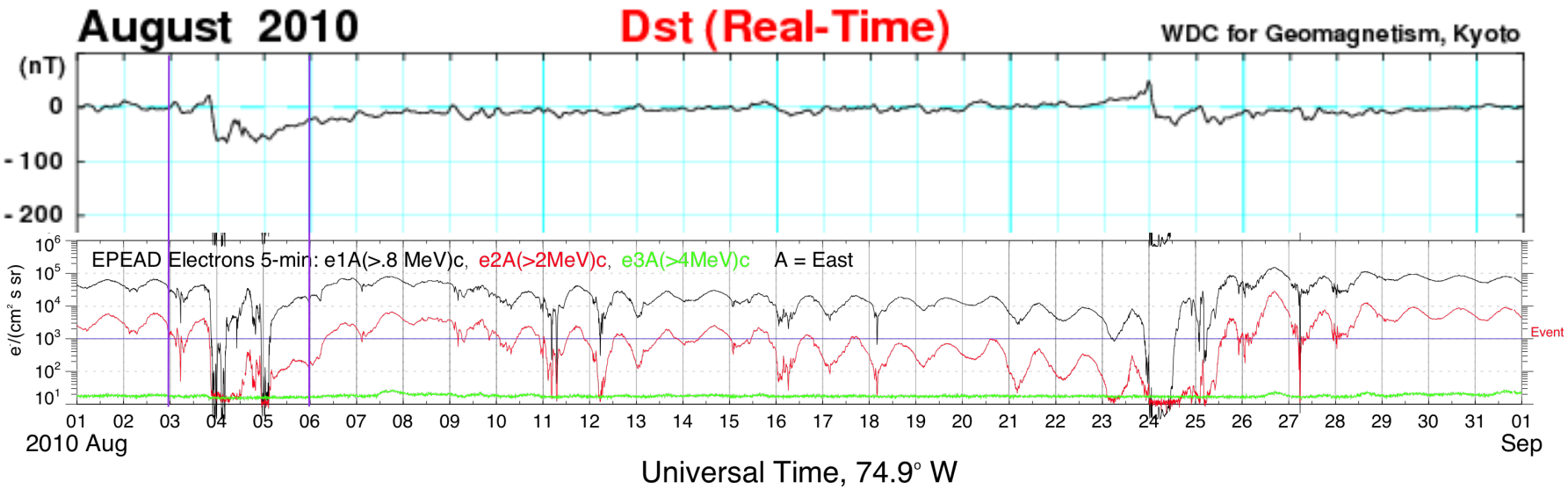
Ring Current Electrons
(40 – 200 keV)



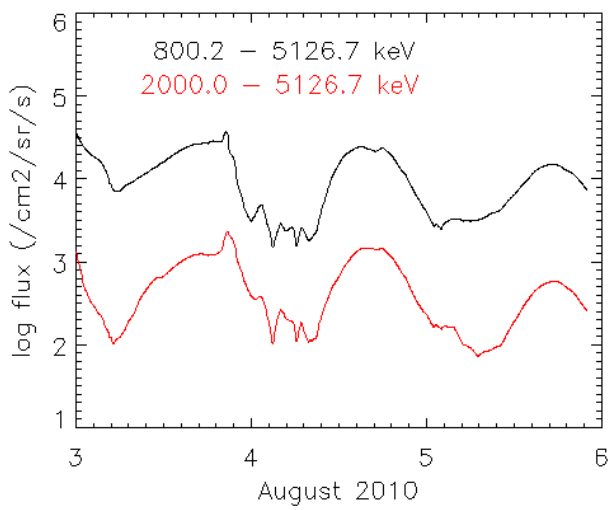
Magnetic Storm on 3 - 7 August 2010



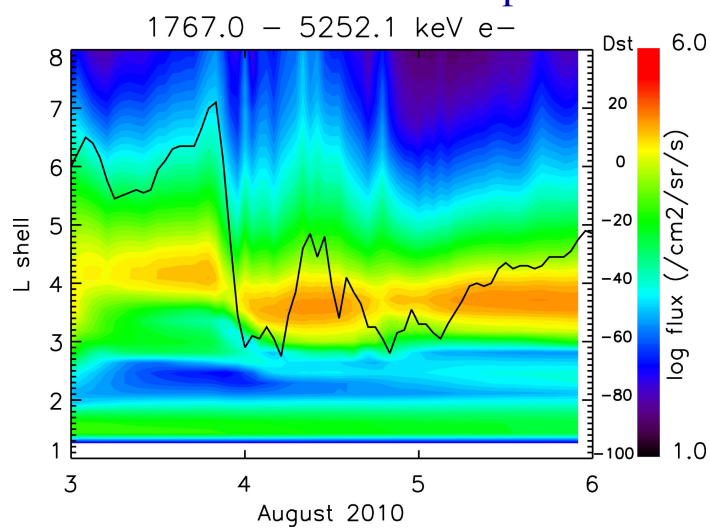
Deep Flux Dropout during the Storm on 3-6 August 2010



RBE (with T04) flux at GOES13



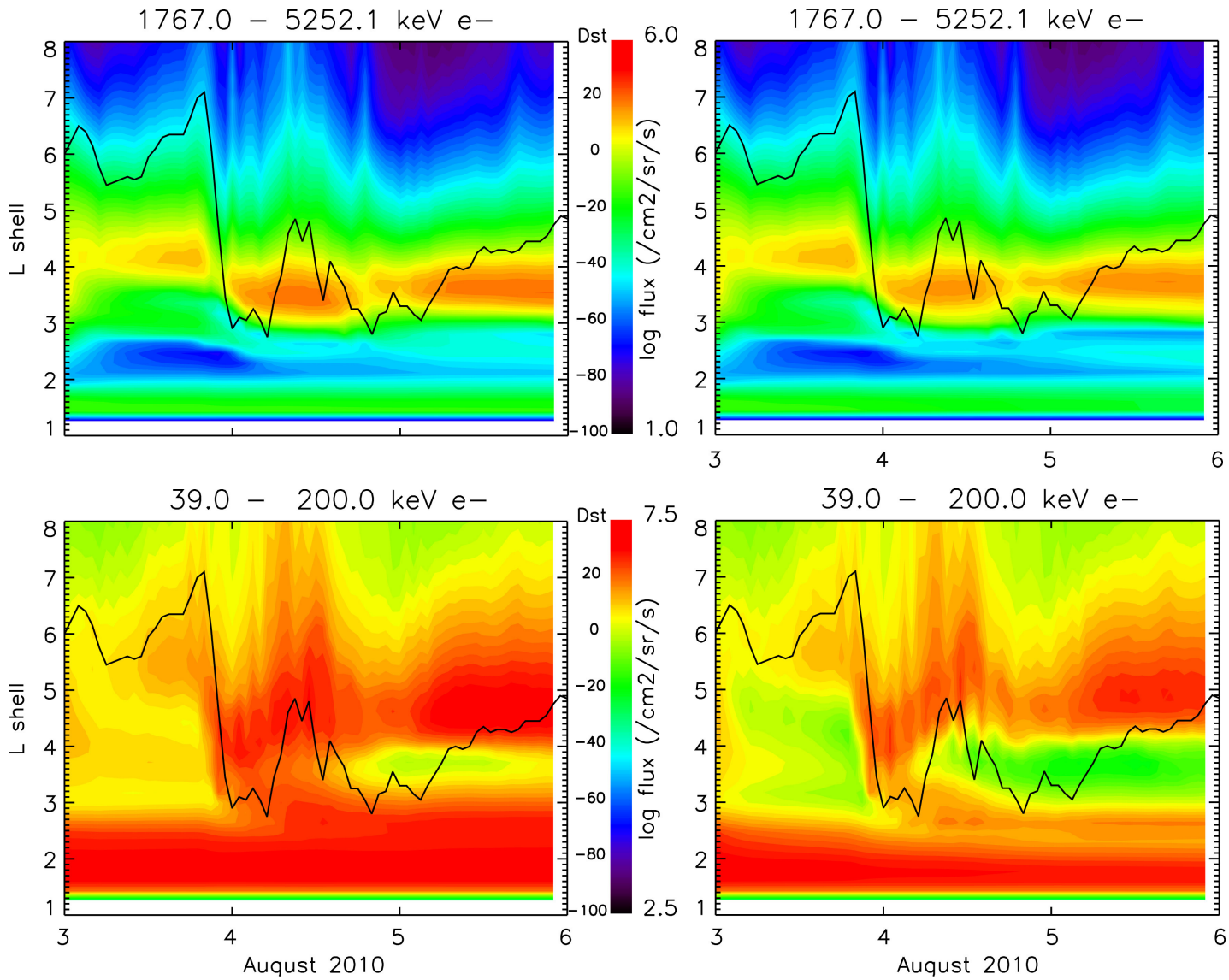
RBE simulated L-Time plot



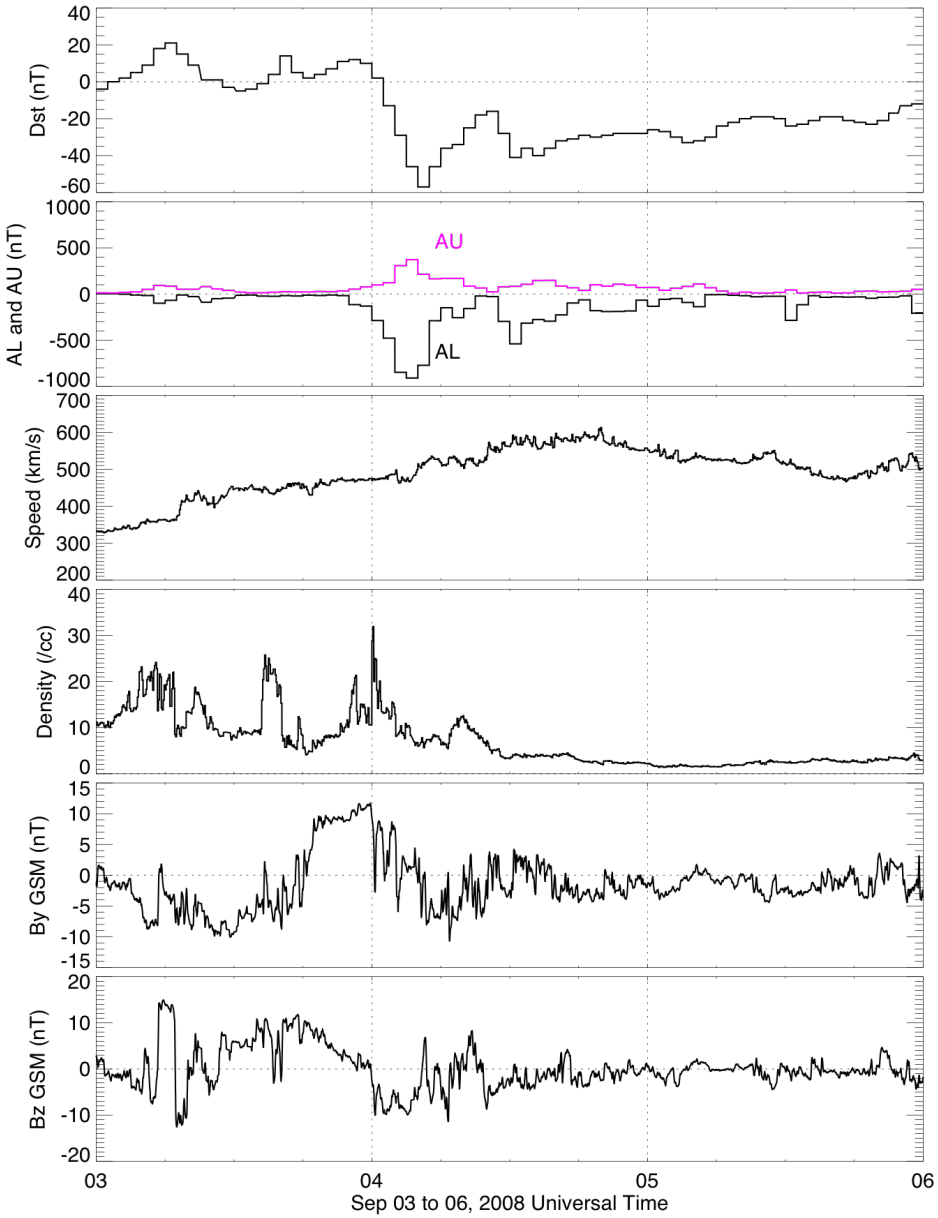
Electron Loss by Plasmaspheric Hiss

RBE Simulation with Chorus

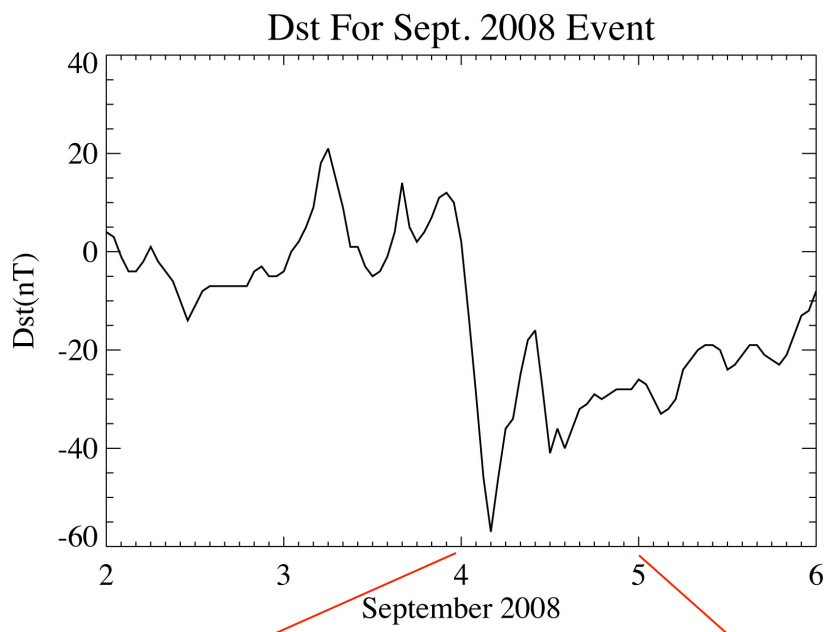
RBE Simulation with Chorus & Hiss

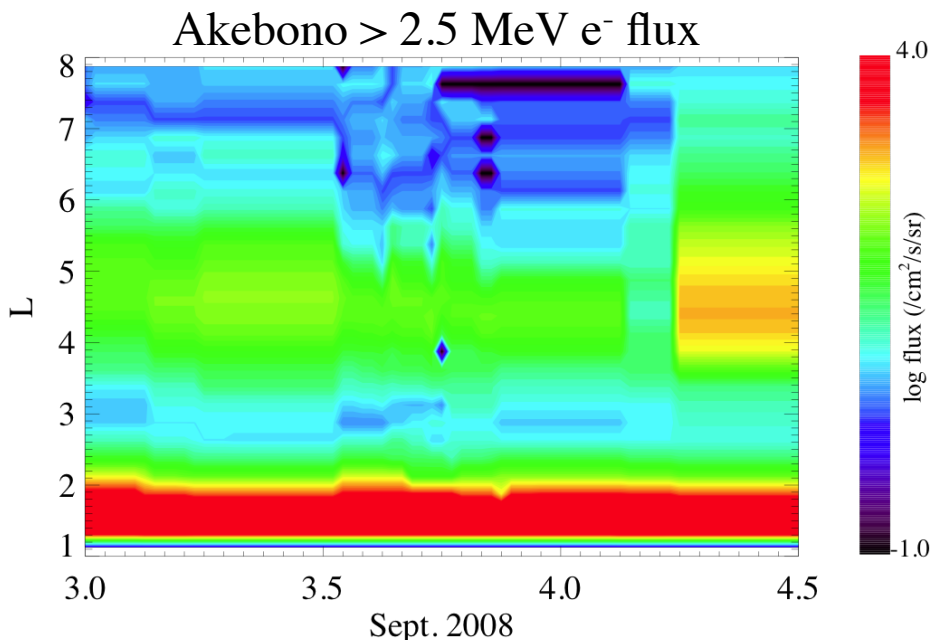


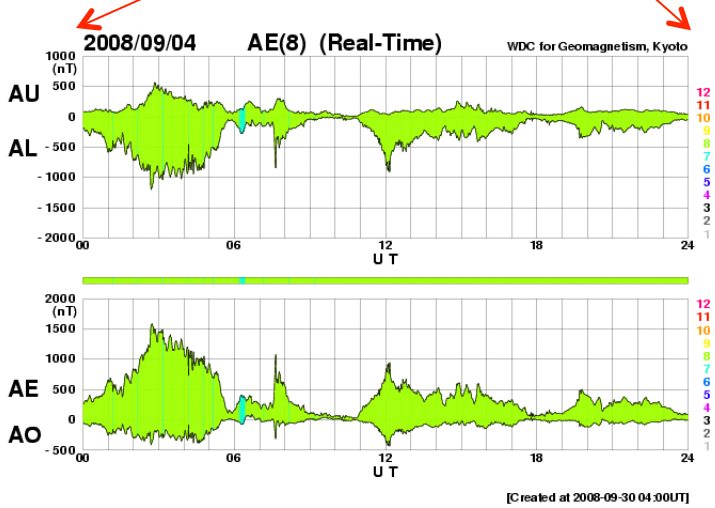
Magnetic Storm on 3 – 6 September 2008

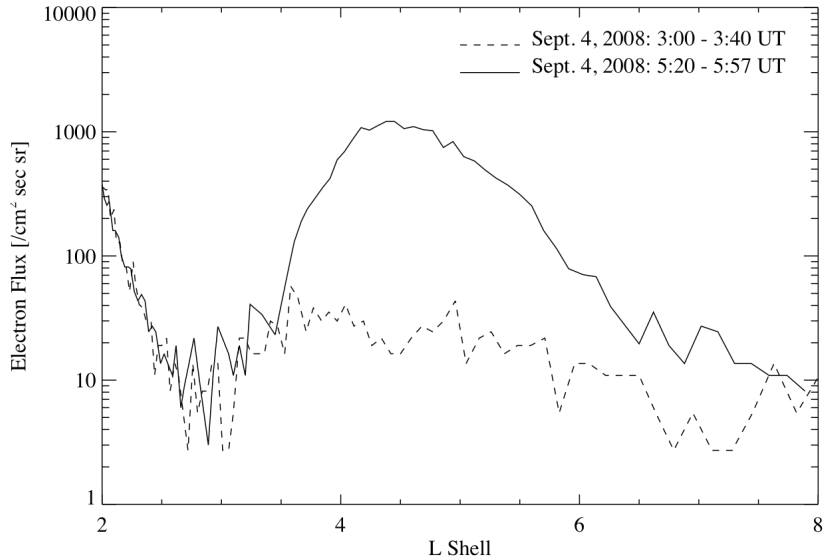


Rapid Rebuilding of Outer Belt Seen by Akebono

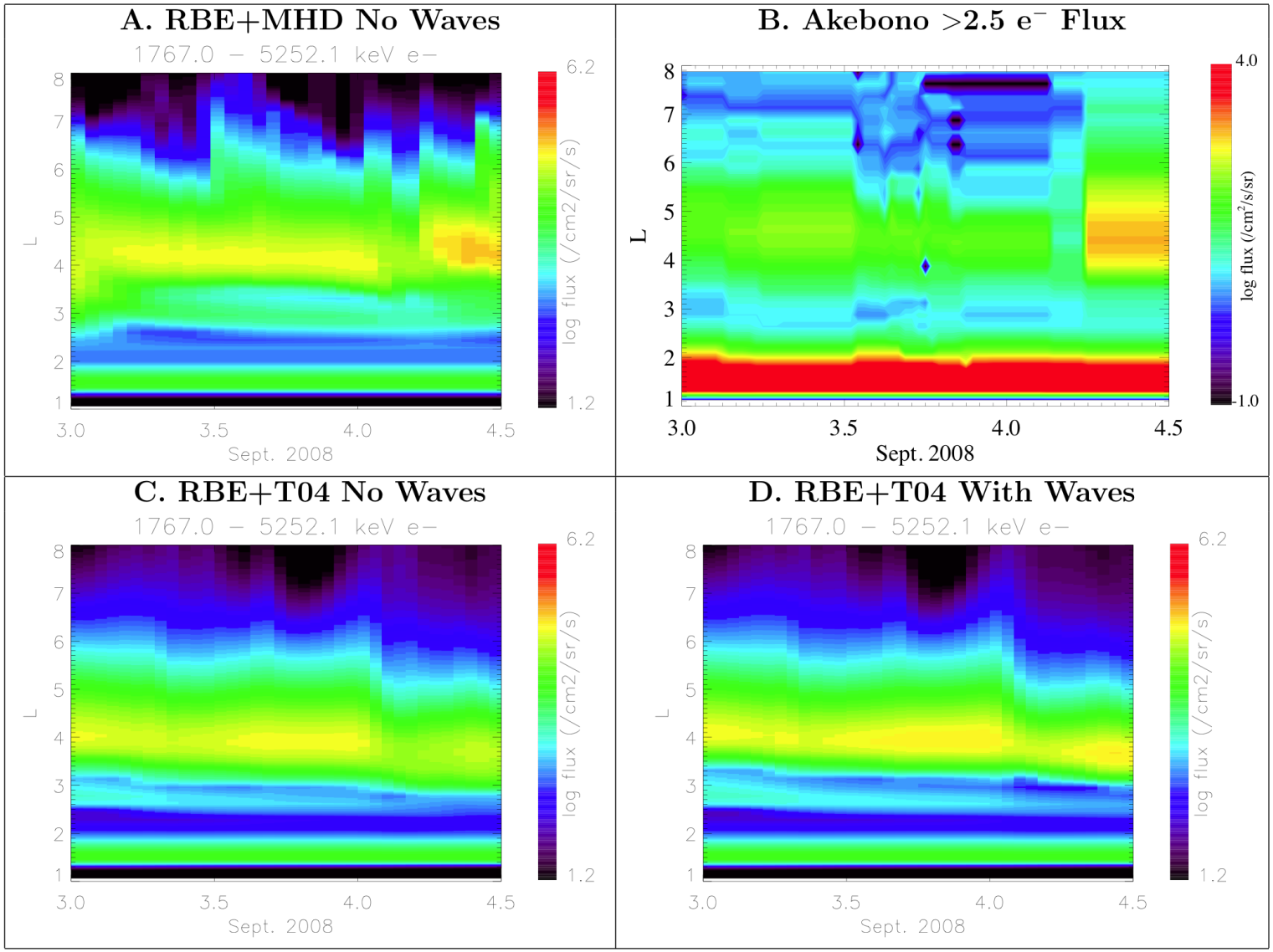




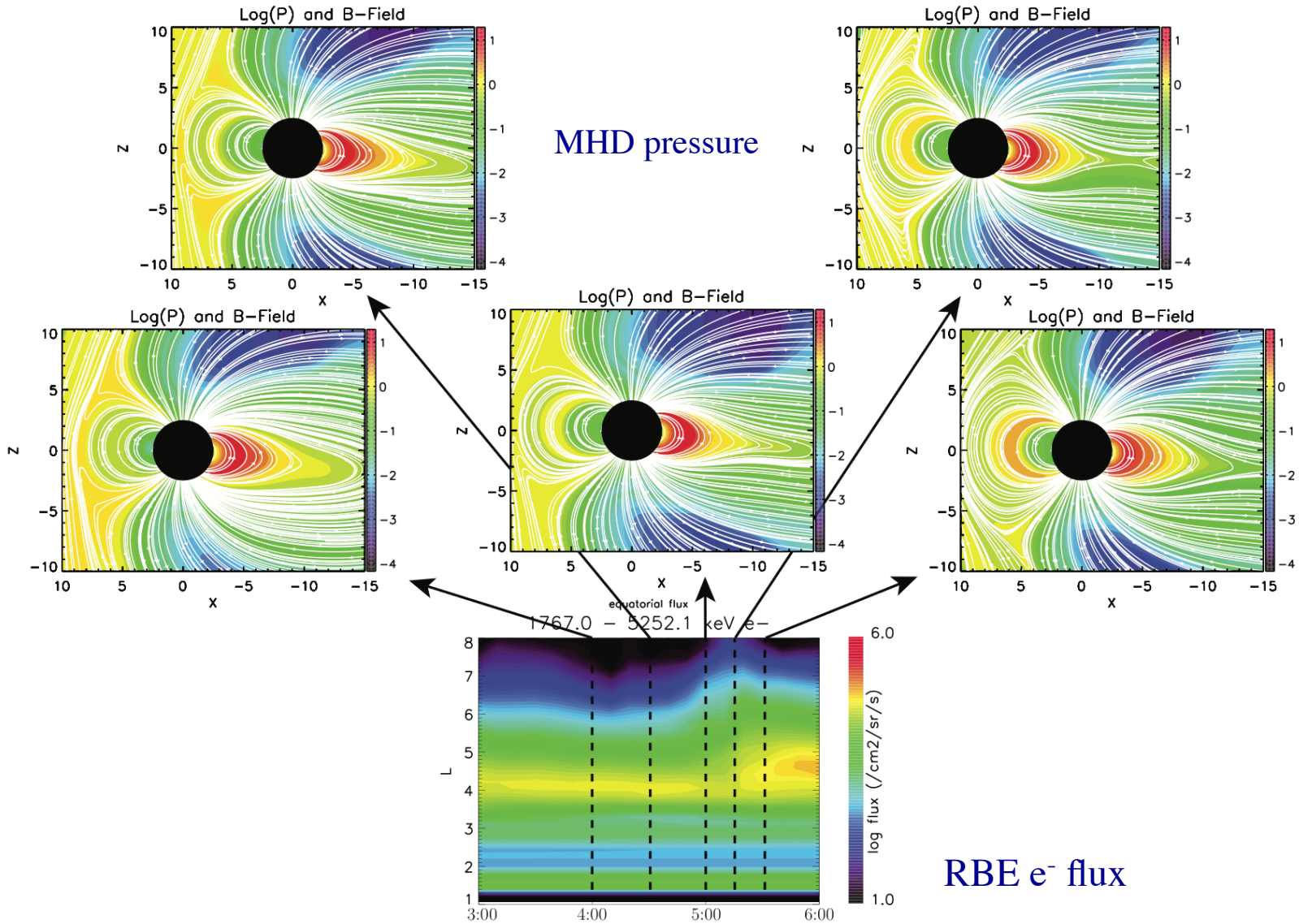




RBE Simulation of the September 2008 Storm



Rapid Rebuilding of Outer Belt during Dipolarization



Summary

- A kinetic model of the radiation belt environment (RBE model) has been developed to understand the roles of wave diffusion and transport in controlling the radiation belt dynamics.

- Storms on October 2002, August 2010, and September 2008 were simulated. We found,

  - Chorus waves play important role in flux increase of RB e^- in storm recovery
  - Chorus waves significantly diffuse ring current (RC) e^- into the loss cone
  - Both RB and RC e^- fluxes are reduced by interacting with plasmaspheric hiss
  - Both magnetopause shadowing and adiabatic deceleration contribute to the flux dropout during main phase
  - Substorm dipolarization is responsible for rapid rebuilding of the outer belt

- Future work:

  - Consider more wave modes, i.e., EMIC, magnetosonic
  - Replace dipole internal field by IGRF in RBE
  - Model-data comparison with measurements from RBSP, ORBITALS, KuaFu, ERG, etc.