CIMI – Modeling the Inner Magnetosphere

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Outline

- **CIMI: C**omprehensive **I**nner **M**agnetosphere-**I**onosphere Model

    Convection-Diffusion Model of Radiation Belts and Ring Current

    + Ionospheric Potential Solver

- CIMI: Space Weather Applications

    - plasma environment (e-: 1 keV – 5 MeV; ions: 0.1 – 500 keV) at L ~ 2 to 10

    - particle precipitation and currents at ionosphere

    - Dst prediction

    -

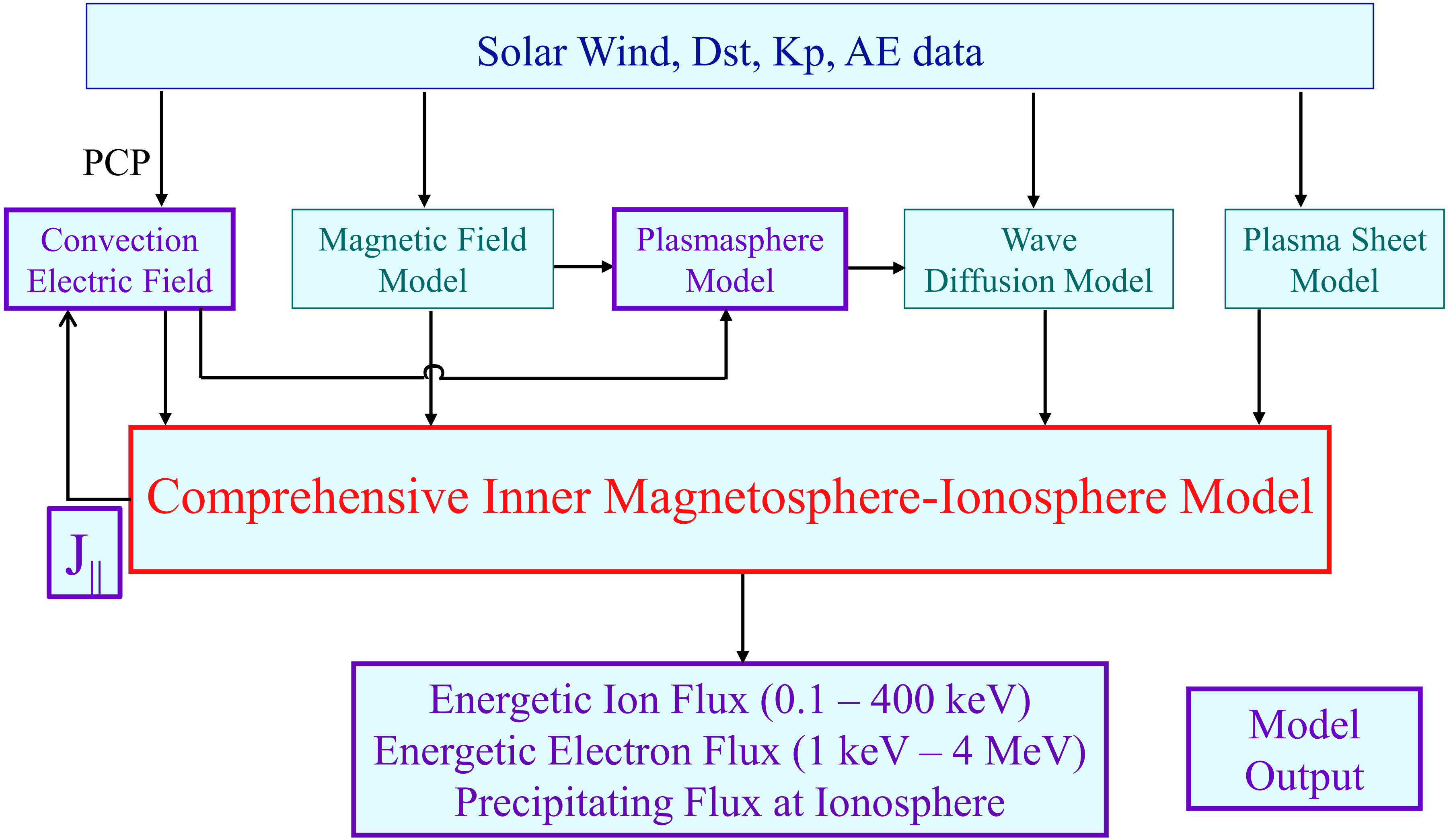
- Advances and Challenges

Modeling Approaches of Radiation Belts/Ring Current

Models	Equations	Pros and Cons	Examples
Test-Particle Model	$\begin{cases} \dfrac{d\mathbf{p}}{dt} = q\mathbf{E} + q\mathbf{v} \times \mathbf{B} \\ \dfrac{d\mathbf{r}}{dt} = \dfrac{\mathbf{p}}{m} \end{cases}$	P: Full particle kinetics *C: Computationally intensive*	Delcourt, Li, Hudson, Elkington, CHIMP
Convection-Diffusion Model	$\frac{\partial f}{\partial t} + \dot{\boldsymbol{\theta}} \cdot \frac{\partial f}{\partial \boldsymbol{\theta}} + \dot{\mathbf{J}} \cdot \frac{\partial f}{\partial \mathbf{J}} = \left(\frac{\delta f}{\delta t}\right)_{\text{coll}}$ $\frac{\partial f_b}{\partial t} + \langle \dot{\theta}_3 \rangle \frac{\partial f_b}{\partial \theta_3} + \langle \dot{J}_3 \rangle \frac{\partial f_b}{\partial J_3} = \sum_{ij=1}^{2} \frac{\partial}{\partial J_i} D_{ij} \frac{\partial f_b}{\partial J_j} + \left(\frac{\delta f_b}{\delta t}\right)_{\text{coll}}$	P: Drift-phase dependent, valid for wide range of energy (RC to RB) *C: Solving advection for RB particles is challenging*	RAM-SCB, CIMI, VERB-4D
Diffusion Model	$\frac{\partial f_d}{\partial t} = \sum_{ij=1}^{2} \frac{\partial}{\partial J_i} D_{ij} \frac{\partial f_d}{\partial J_j} + \frac{\partial}{\partial J_3} D_{33} \frac{\partial f_d}{\partial J_3} + \left(\frac{\delta f_d}{\delta t}\right)_{\text{coll}}$	P: Efficient, good for long-term simulation *C: No drift-phase dependence*	Salammbo, Dilbert, VERB-3D, BAS-RBM, DREAM

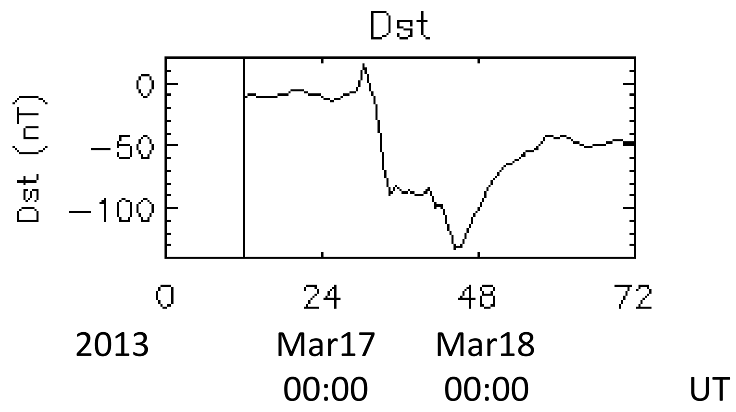
f_b: Bounce-averaged phase space density
f_d: Drift-averaged phase space density
RB: Radiation Belts
RC: Ring Current

CIMI: Model Logic

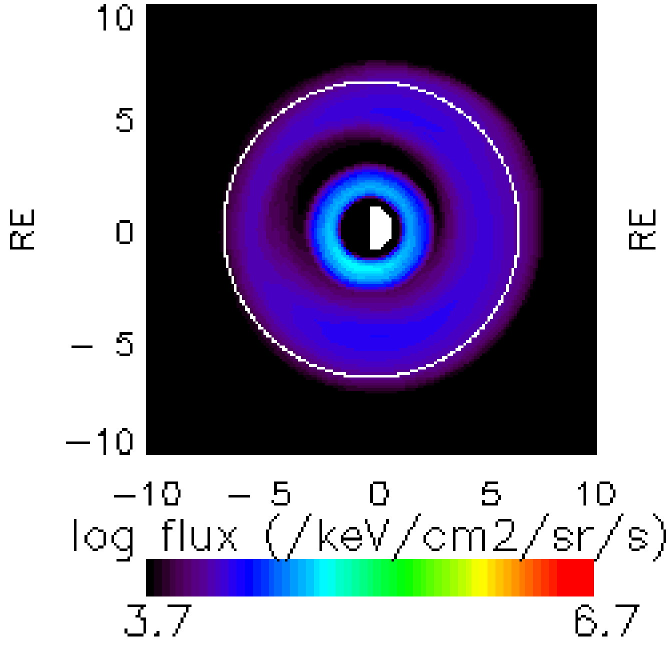


[Mei-Ching Fok et al., 2014]

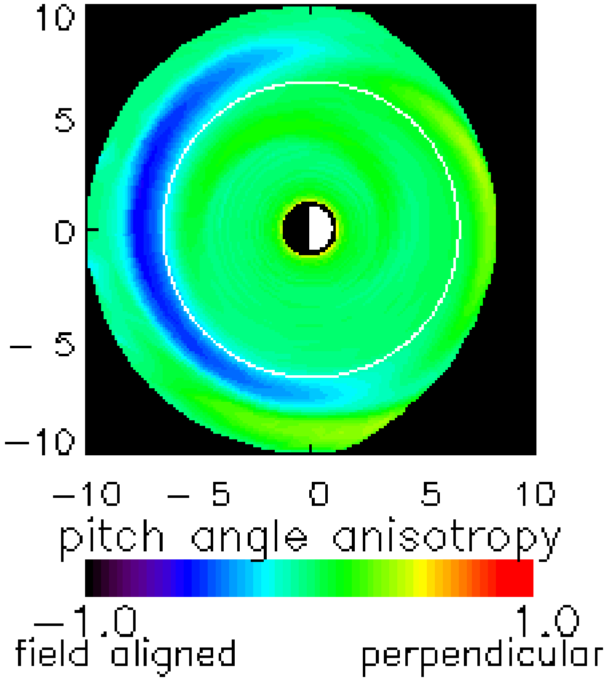
CIMI Prediction of Plasma Environment (100 keV e-)



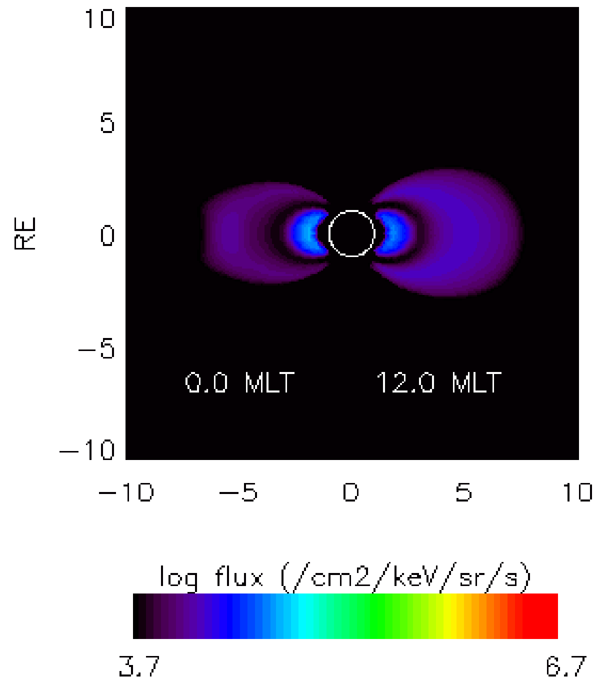
Equatorial Flux



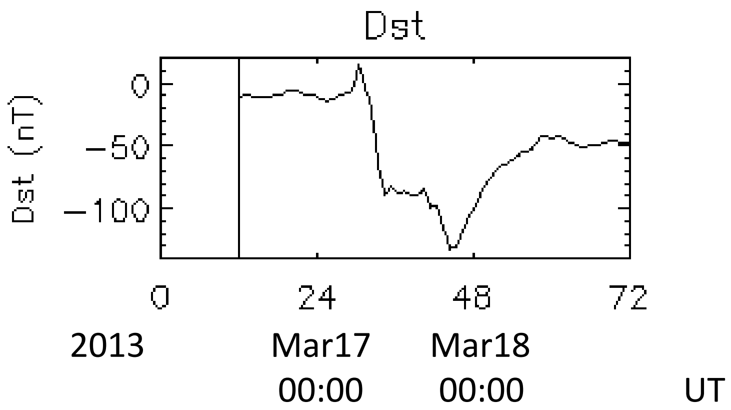
Pitch-Angle Anisotropy



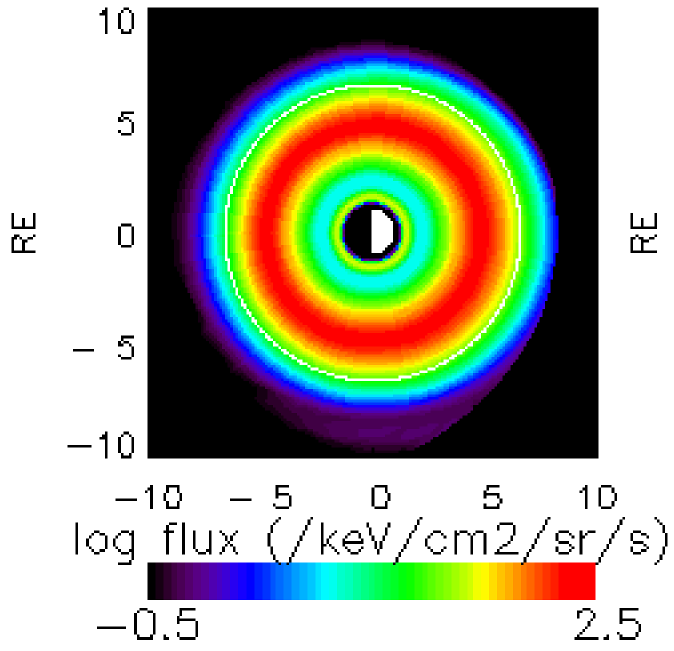
Midnight-Noon Meridian



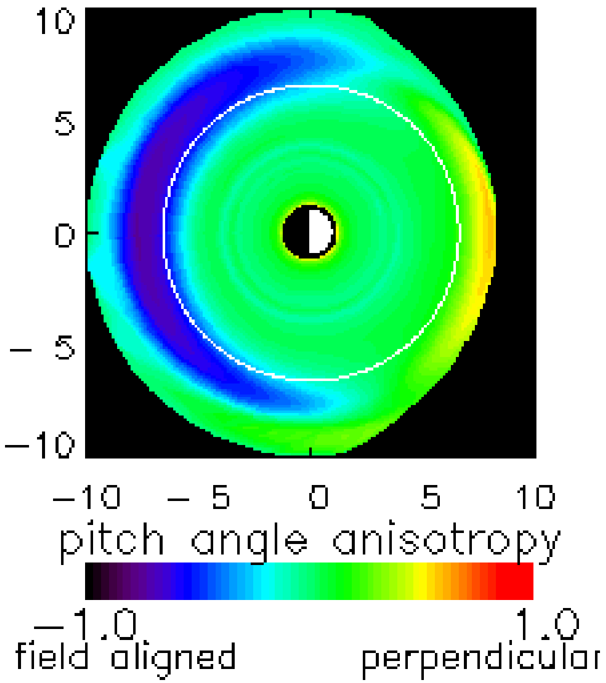
CIMI Prediction of Plasma Environment (1 MeV e-)



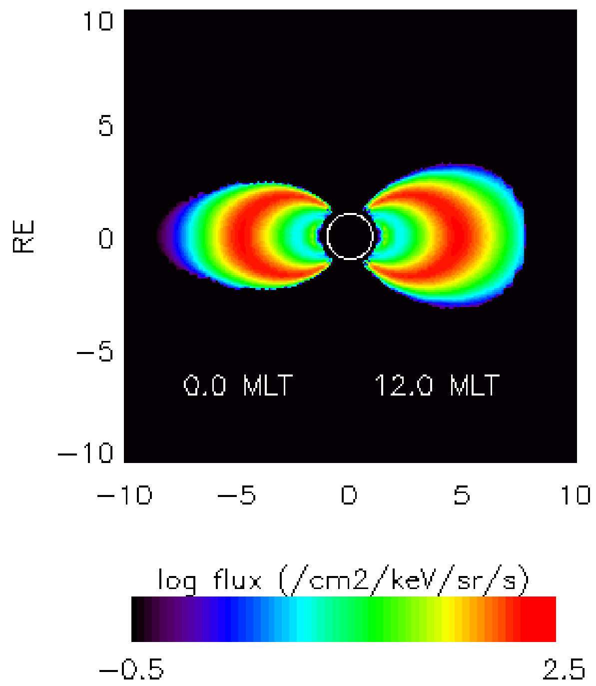
Equatorial Flux



Pitch-Angle Anisotropy

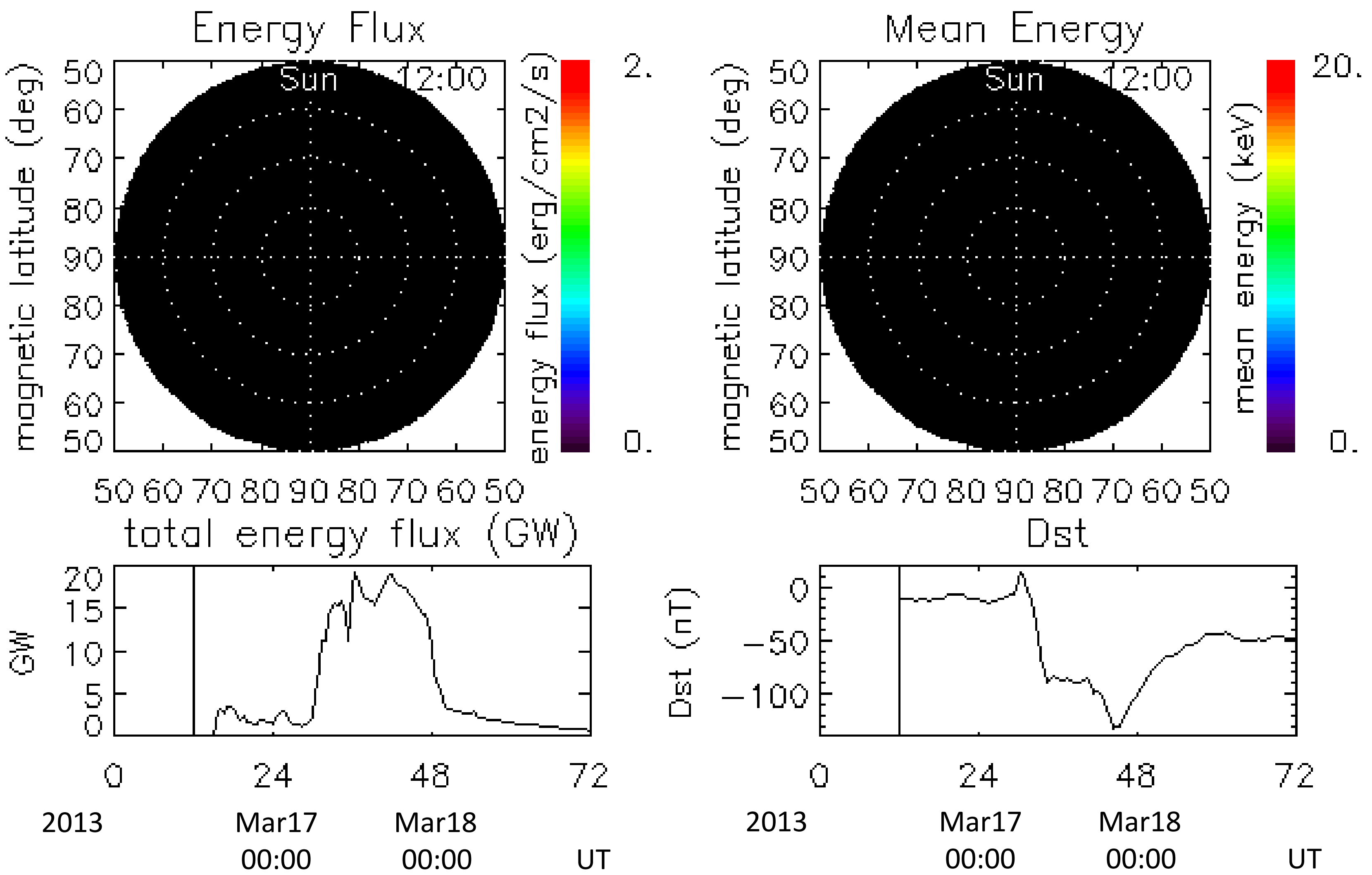


Midnight-Noon Meridian

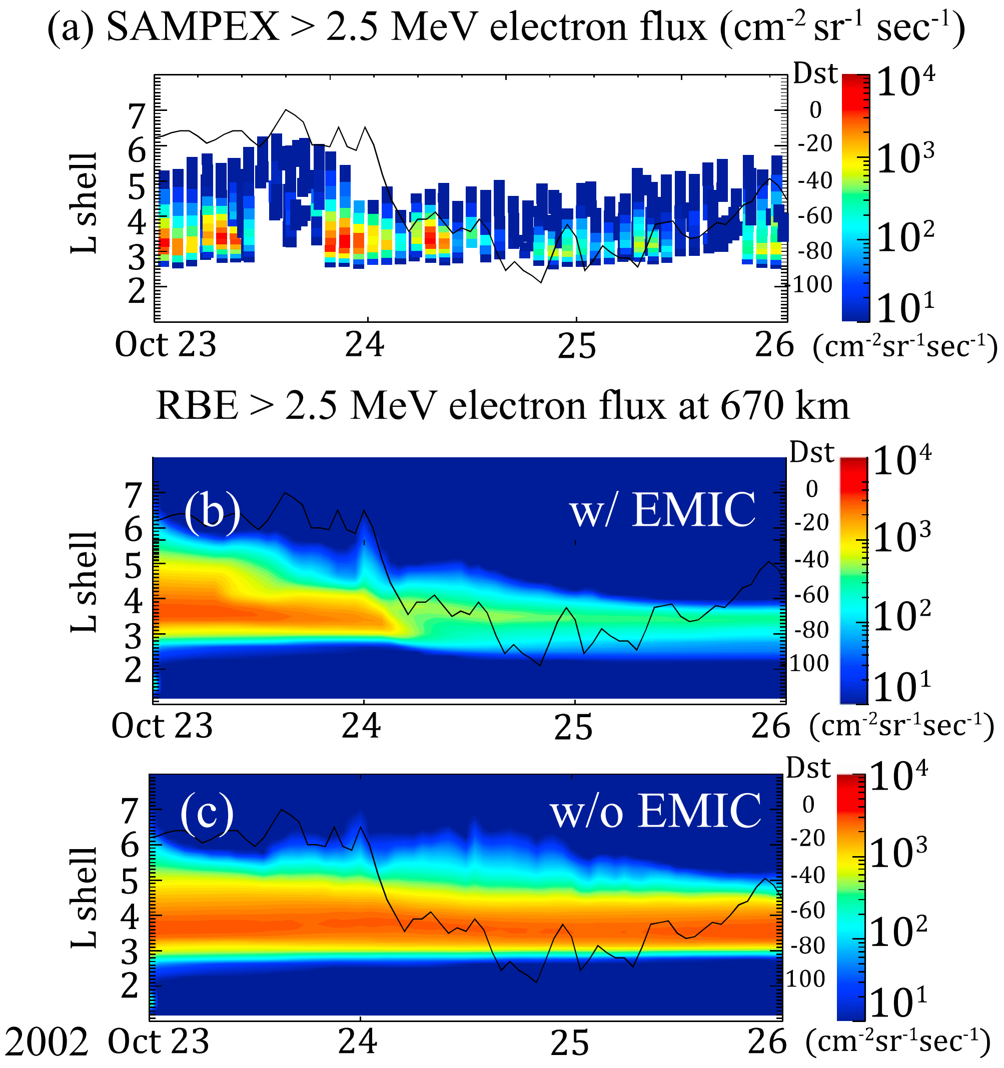


CIMI Prediction of Electron Precipitation

Electron Precipitation (< 40 keV)



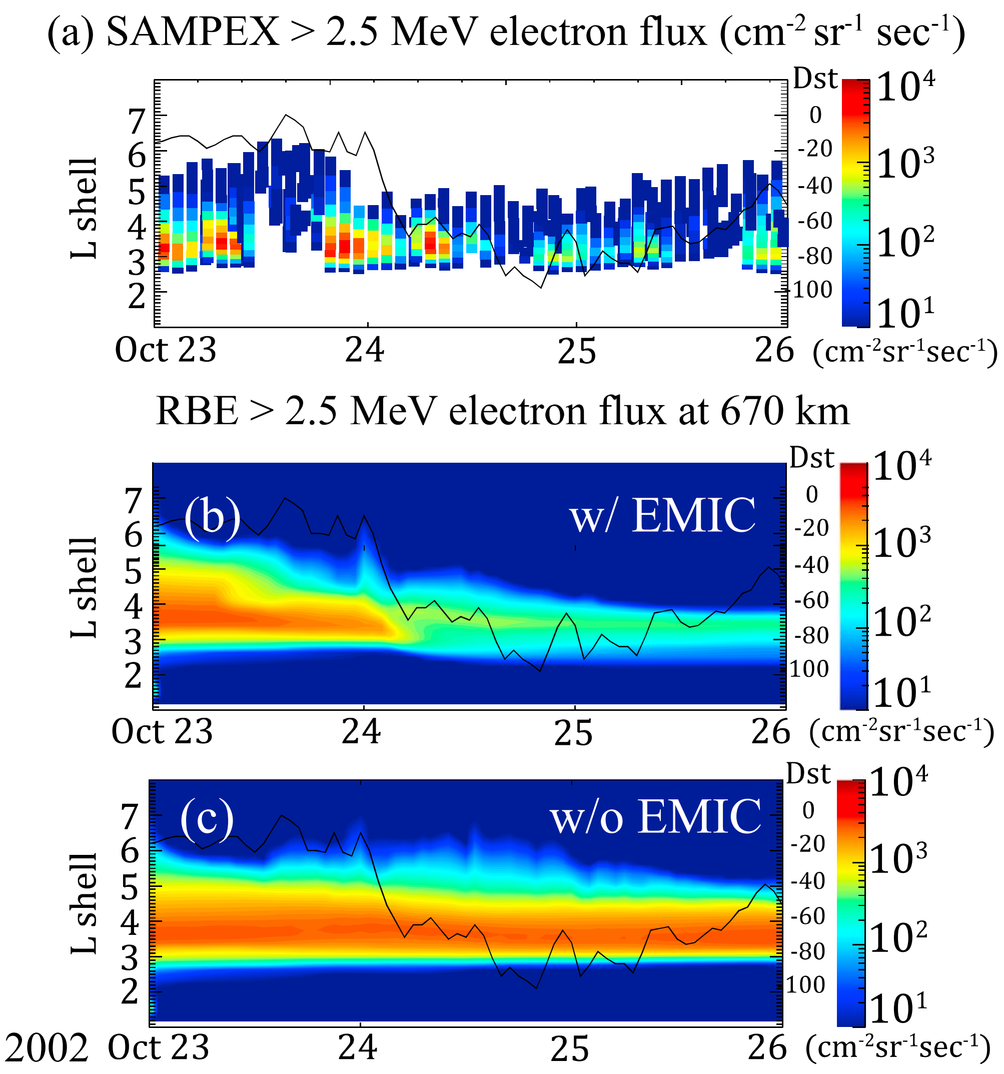
CIMI Predicts RB/RC Flux Along Satellite Paths

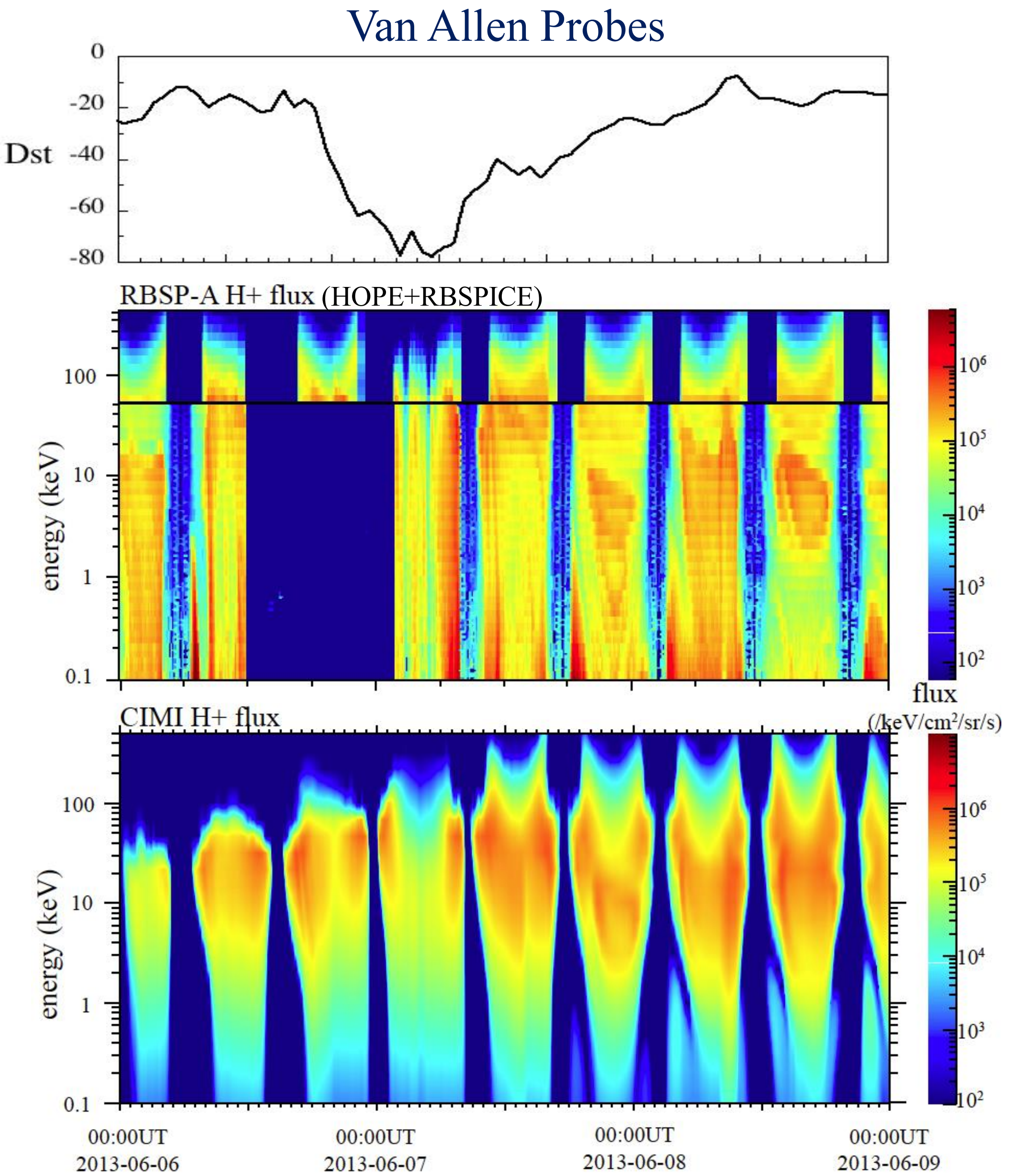


RBE: **R**adiation **B**elt **E**nvironment Model
CIMI = RBE + CRCM

[Kang et al., 2016]

CIMI Predicts RB/RC Flux Along Satellite Paths

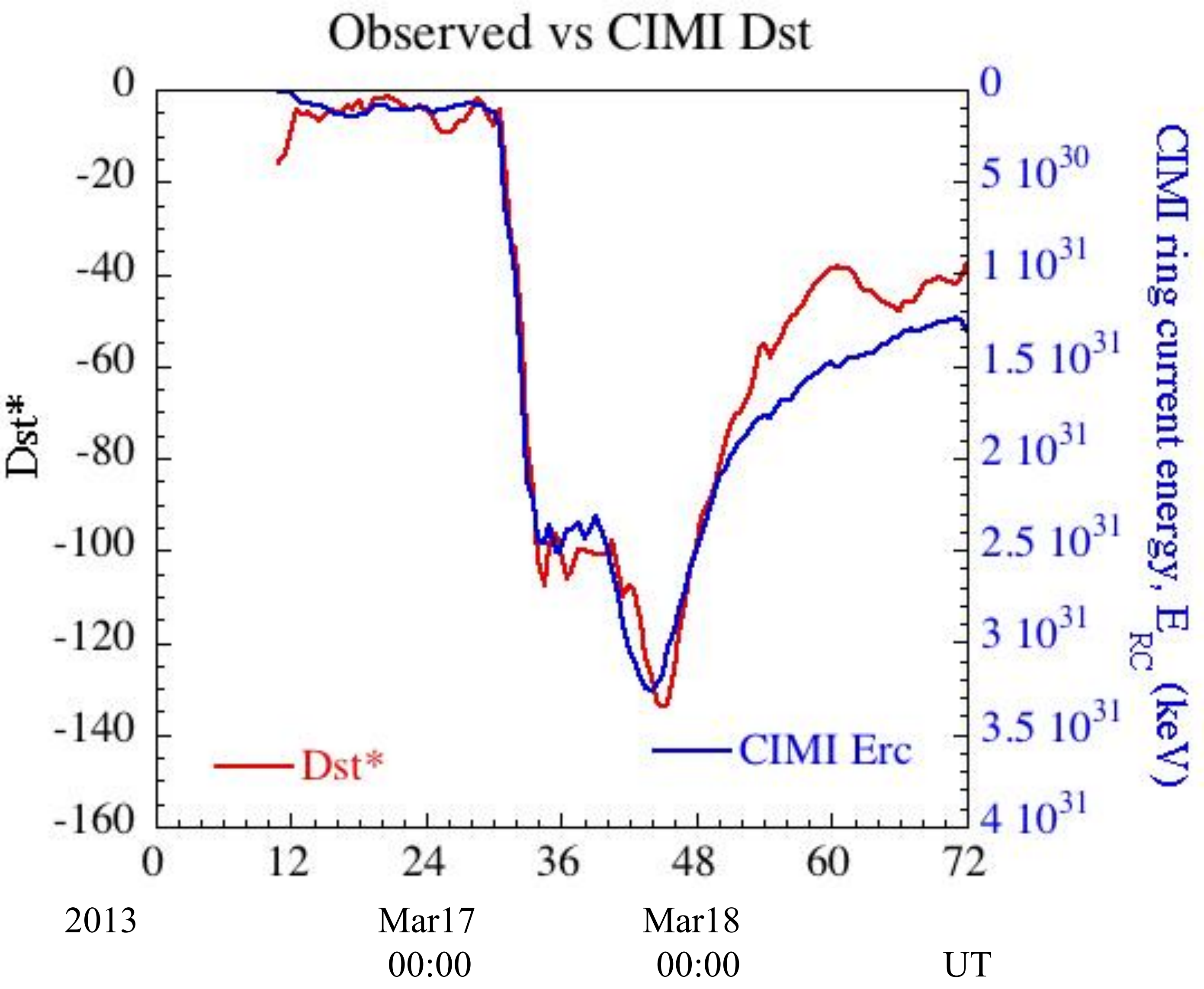




RBE: **R**adiation **B**elt **E**nvironment Model
CIMI = RBE + CRCM

[Kang et al., 2016]

CIMI Prediction of Dst



Advances and Challenges

* Advances:

- transform CIMI transport equation to new coordinates with uniform grid i.e., lnE instead of E
- transform to new coordinates in which cross diffusion vanishes (J. Albert)

* Challenges:

- solving transport of relativistic particles with convection approach is challenging
- need to understand the sources of warm (0.1 – 1 keV) plasma
- reproducing fast initial recovery of Dst is difficult
- getting qualitative agreements with observations but not quantitative