Plasma Pressure Constraints on Magnetic Field Structure in the Substorm Growth Phase

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Motivation

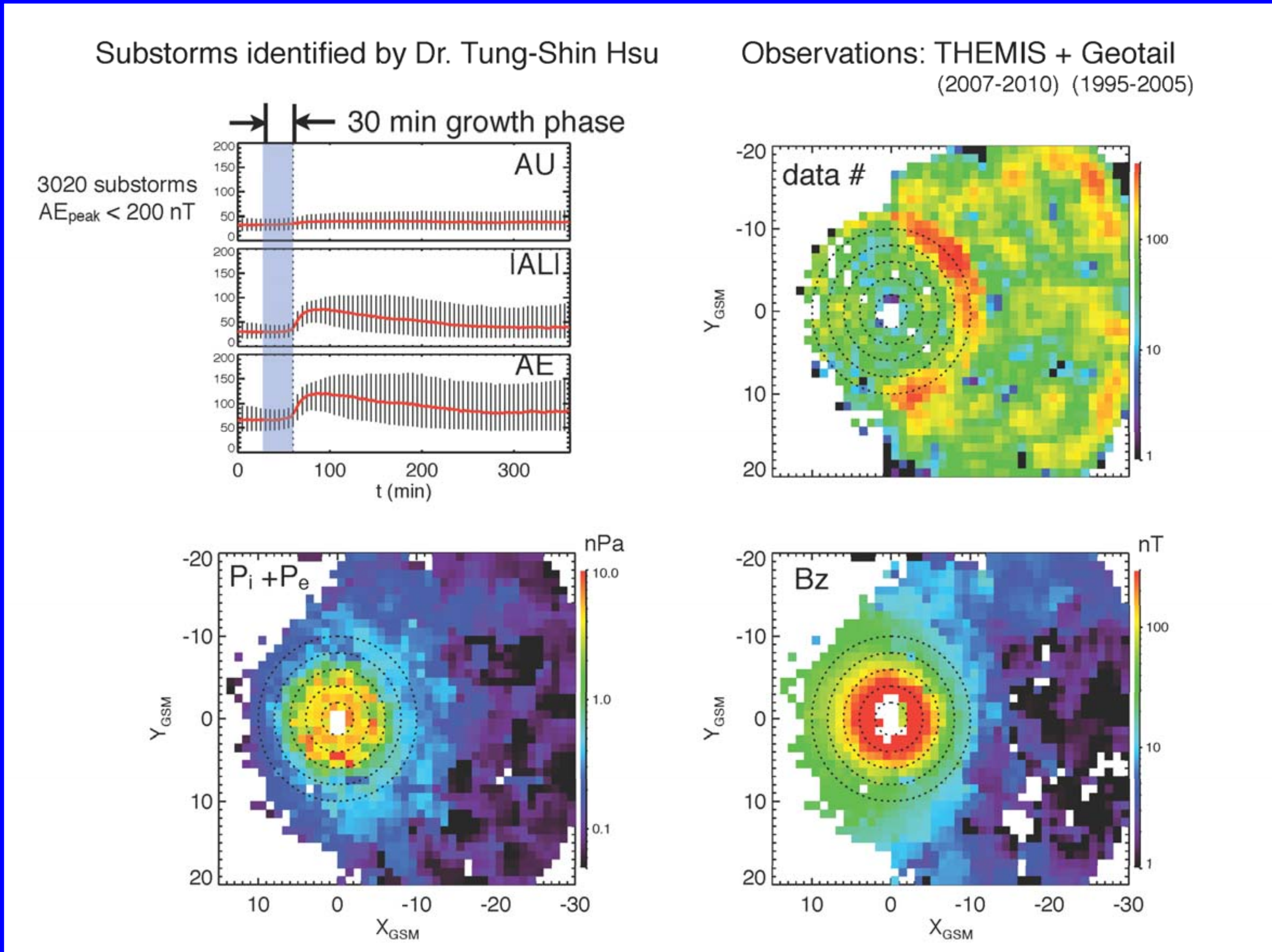
I. **Substorm growth phase**
   - **Gradual energy loading on time scale >> Alfven time scale**
   - **Configuration (magnetic field, electric current) not well described by existing models**

II. **Large plasma beta (ratio of plasma pressure to magnetic pressure; values of 50 and higher *[Saito et al., GRL 2008]*) plasma has strong influence on the field**

III. **Use growth phase observations to construct empirical pressure model**

IV. **Use pressure model as input to 3D force balanced magnetospheric model**

THEMIS/Geotail Plasma Pressure



Preliminary Results: Using THEMIS/Geotail Plasma Pressure

- Geotail + THEMIS growth phase data/binned by AE
- Smooth profile while capturing major features
- Nonlinear least square fit with constraints
  - $P > P_{min}$
  - Bound constraints for coefficients a

$$P(R,\phi) = \exp(a_1 R)\left(a_2 + a_3 \sin\phi + a_4 \sin^2\phi\right) + R^{b_1}\left(b_2 + b_3 \sin\phi + b_4 \sin^2\phi\right)$$

- Global vs. Local Optimization; solution uniqueness
- Cf. *Tsyganenko and Mukai, [2003]*
  (no dawn/dusk asymmetry from Geotail data – LEP)

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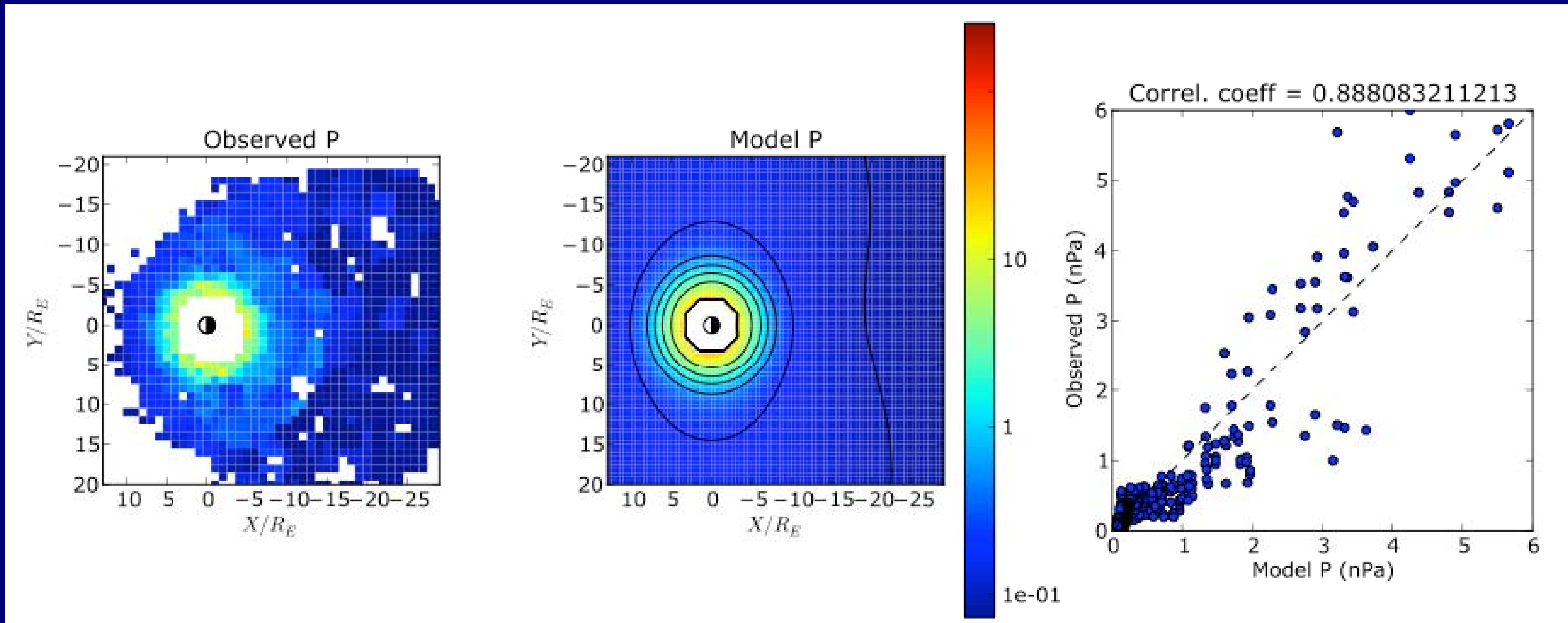
THEMIS/Geotail P Fitting



- High correlation coefficient (cf. *Tsyganenko and Mukai, [2003]*)
- Dawn-dusk asymmetry in near-Earth region

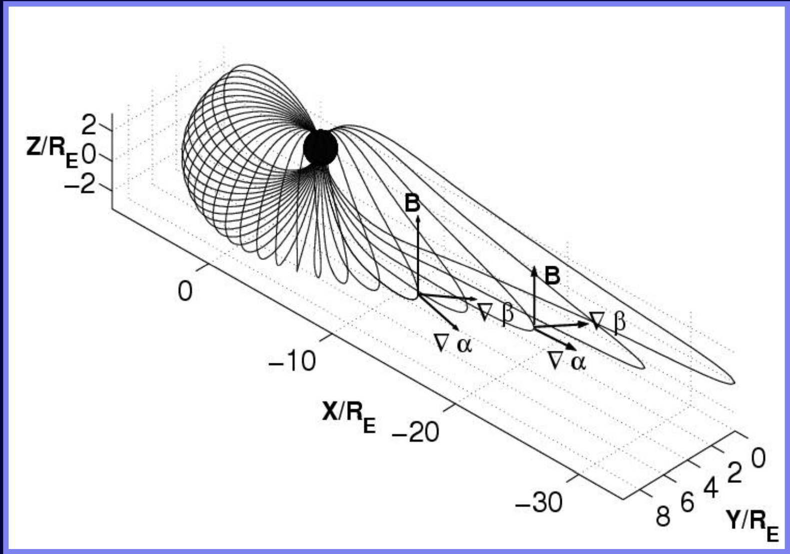
3D Equilibrium - Euler Potential Form

$$\mathbf{J} \times \mathbf{B} = \nabla P$$

- With isotropic pressure: $P = P(\alpha, \beta)$
- De-composition along $\mathbf{B} \times \nabla\alpha$ and $\mathbf{B} \times \nabla\beta$:

$$\mathbf{J} \cdot \nabla\alpha = \frac{1}{\mu_0} \nabla \cdot \left[(\nabla\alpha)^2 \nabla\beta - (\nabla\alpha \cdot \nabla\beta)\nabla\alpha \right] = -\frac{\partial P}{\partial \beta} \qquad (1)$$

$$\mathbf{J} \cdot \nabla\beta = \frac{1}{\mu_0} \nabla \cdot \left[(\nabla\alpha \cdot \nabla\beta)\nabla\beta - (\nabla\beta)^2 \nabla\alpha \right] = \frac{\partial P}{\partial \alpha} \qquad (2)$$



$$\mathbf{B} = \nabla\alpha \times \nabla\beta$$

- (1), (2) coupled Grad-Shafranov-like “quasi-2D” equations on const. **α and β** surfaces; needed: pressure profile + magnetic boundary conditions
- Solution - in inverse form; magnetic field lines are explicit output (no need for integration etc.)

$$X(\alpha,\beta,\chi),\ \ Y(\alpha,\beta,\chi),\ \ Z(\alpha,\beta,\chi)$$

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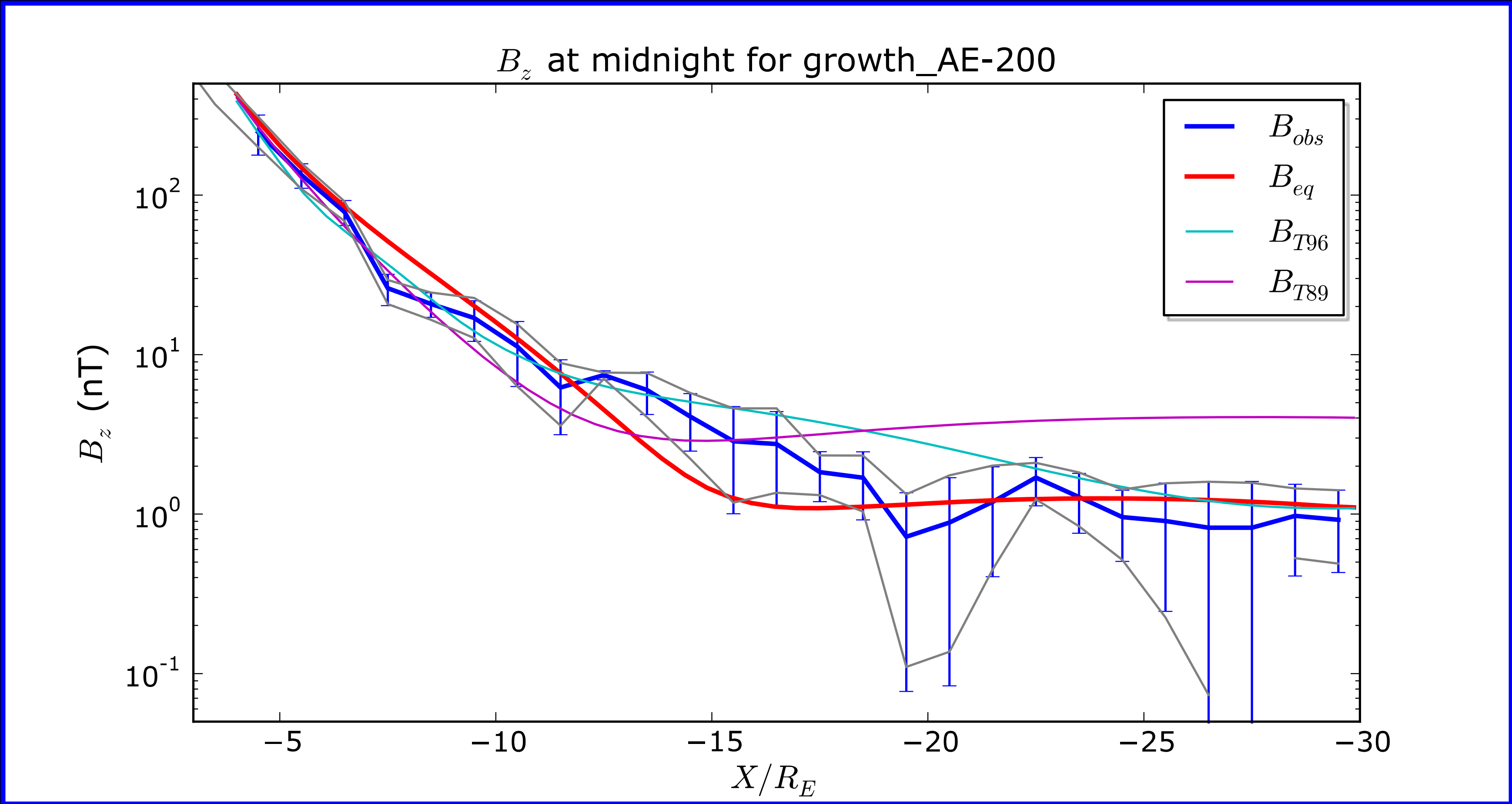
Equatorial B-Field

Observed

Calculated

B-Field on Midnight Meridian



- Observations not exactly at Z=0; no realistic tilt in model
- T89, T96 fields too large at |X| > 15 R_E (not enough stretching)

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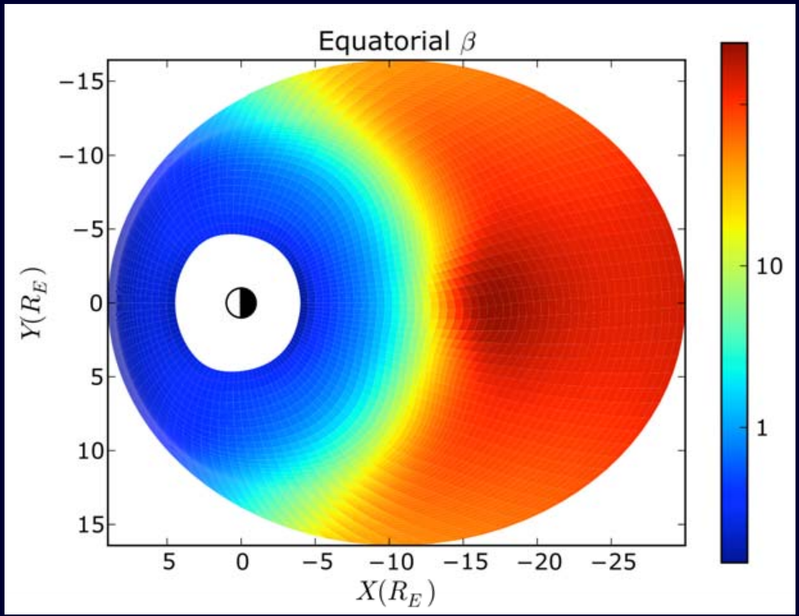
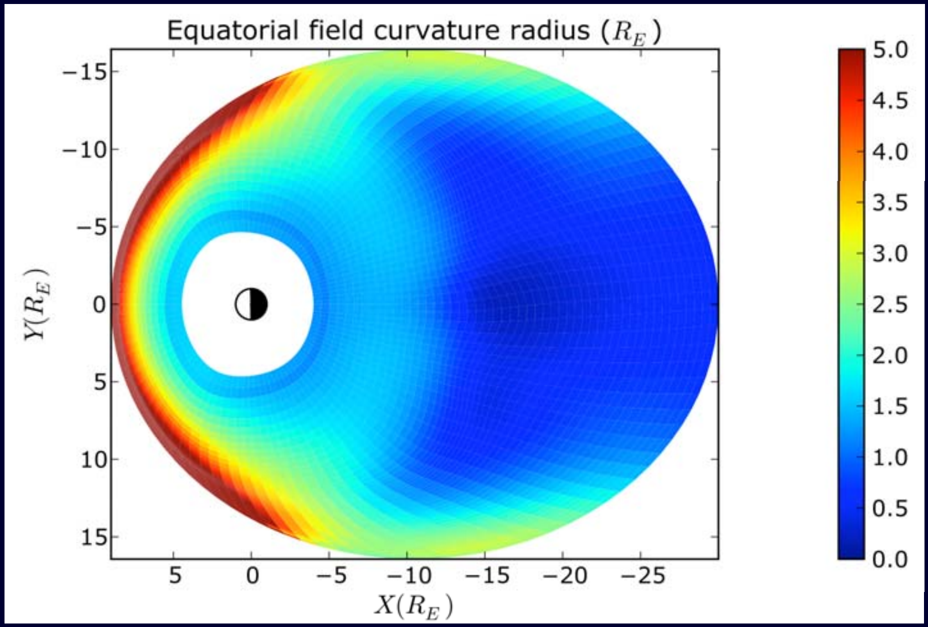
Plasma Beta and Field Curvature





$$\nabla\left(P+\frac{B^2}{2\mu_0}\right)=\frac{(\mathbf{B}\cdot\nabla)\mathbf{B}}{\mu_\mathbf{0}}=\kappa B^2$$

P= Plasma pressure

$B^2/2\mu_0$= "Magnetic pressure"

$\beta = 2\mu_0 P / B^2$

$R_c = \frac{1}{\kappa}$ Radius of curvature

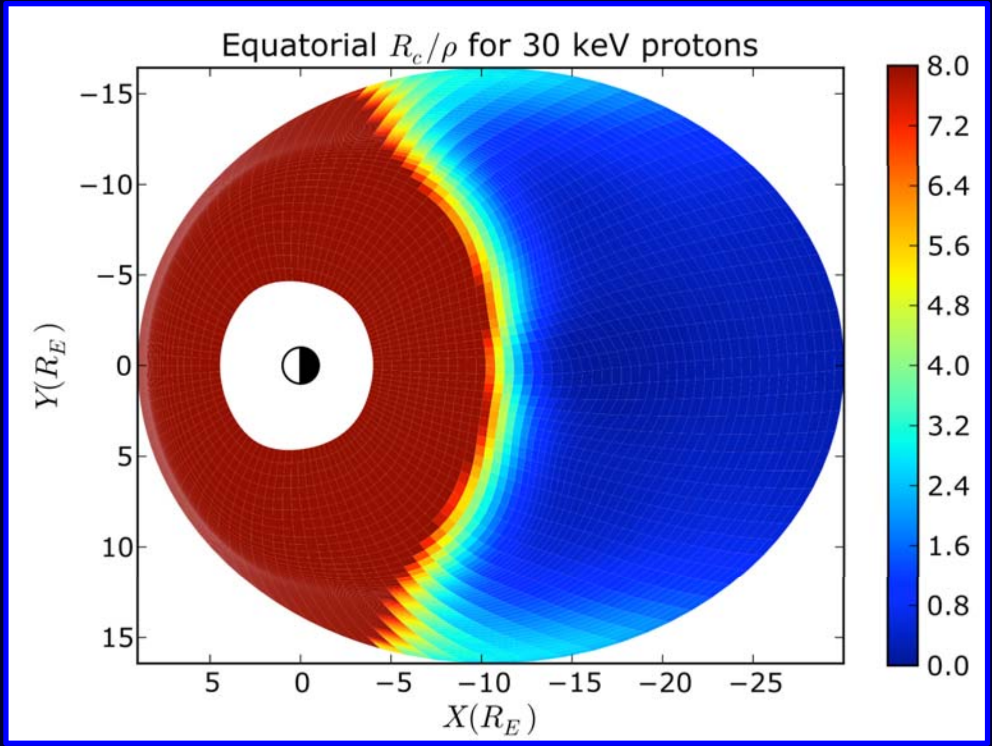
Isotropy Boundary

Isotropy boundary – separating poleward region of energetic (> 30keV) particle isotropic precipitation from equatorward region of weak precipitation/loss-cone filling

Threshold condition $R_c / \rho < 8$ [Sergeev, 1993]

Remote sensing tool – proxy for field curvature

Future work: combine with low-altitude observations (DMSP, FAST)



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