Global Dynamics of the Ring Current, (Plasmasphere) and its Coupling to the Ionosphere

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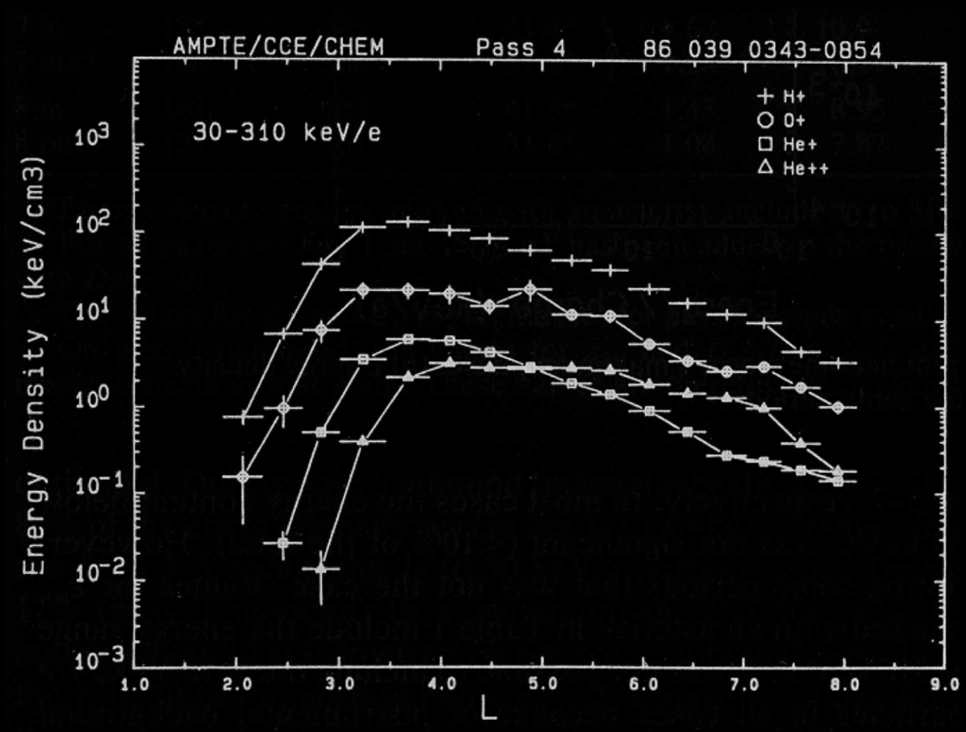
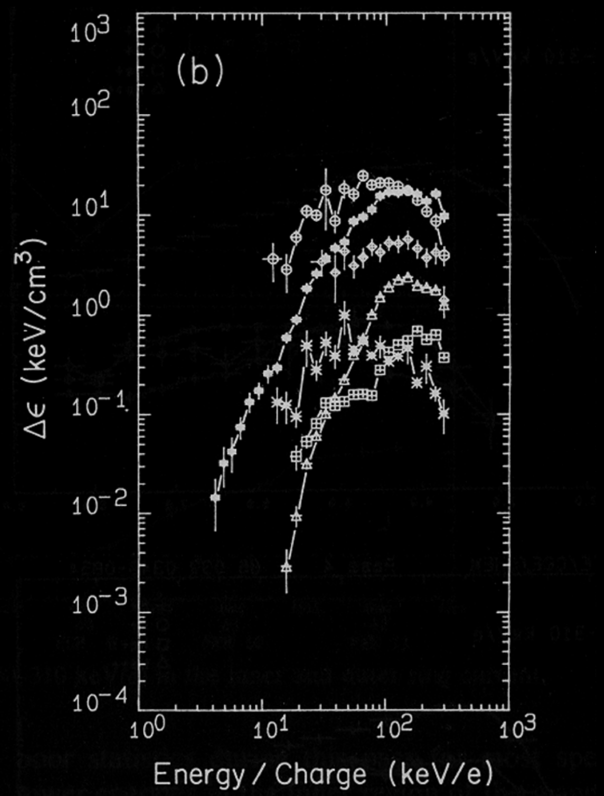
Immediate RBSPICE science investigations:

1. **Radial Profiles of Pressure and Current Density of Protons, Helium, and Oxygen in the Ring Current Region**
2. **Morphology and dynamics of the storm-time ring current ion distribution**
3. **Injection mechanisms and ring current pressures**
4. **Ring current and E- and B-fields**
5. **EMIC waves and ring current ion anisotropies**

1. **Ring current distribution**
2. **Ring current formation**
3. **Ring current drivers**
4. **(Plasmasphere Dynamics)**
5. **Space Weather Impacts**
6. **Summary**

1.1 Radial and energy distribution





The ring current energy density peaks at around L=3 for storms with a peak energy of about 100 keV.

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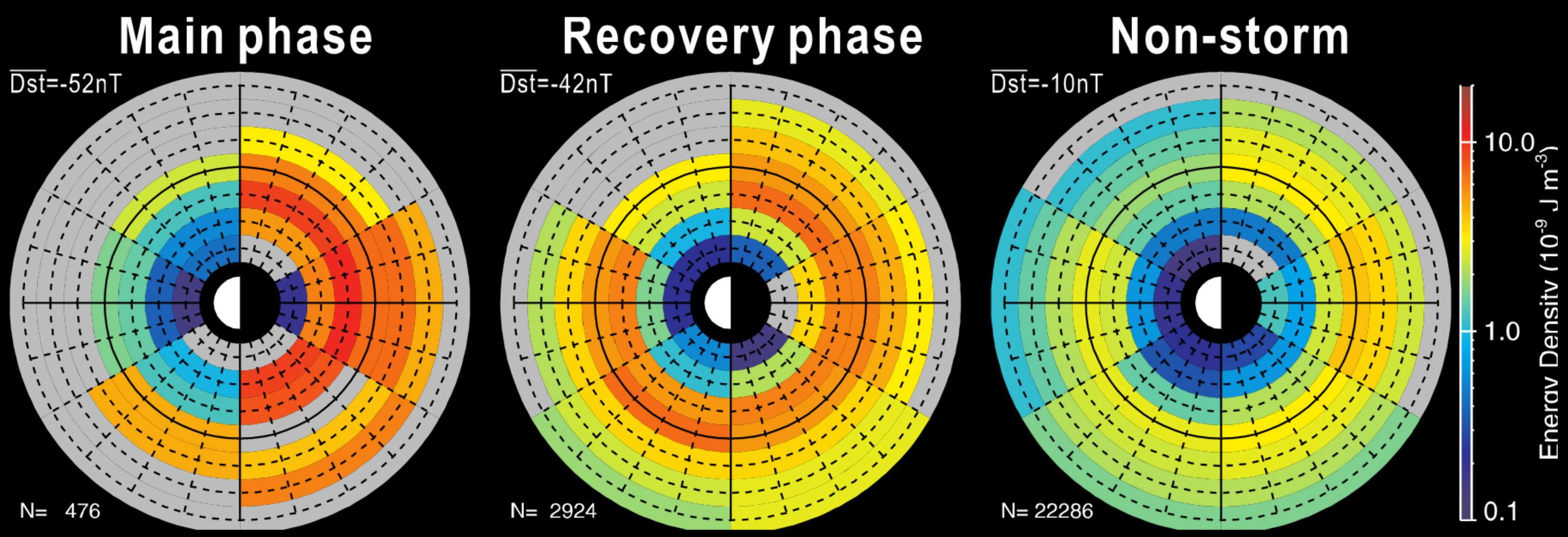
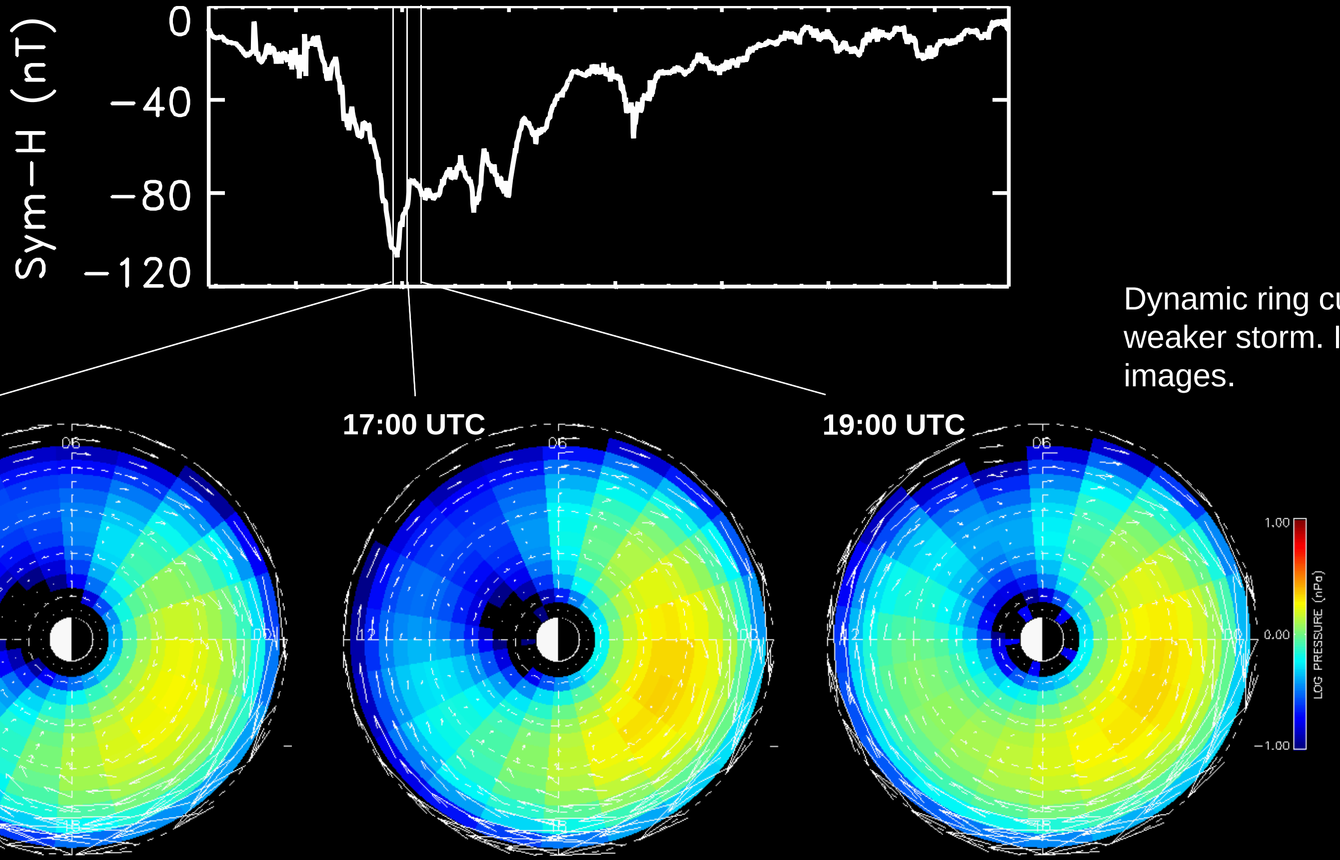
1.2 Highly asymmetric during storms



Statistical proton pressure distributions in the 1-200 keV range derived from in-situ POLAR/MICS measurements. Ring current is highly asymmetric in the main phase of storms and becomes more symmetric in the recovery phase. Plot taken from *Ebihara et al. [2002]*.

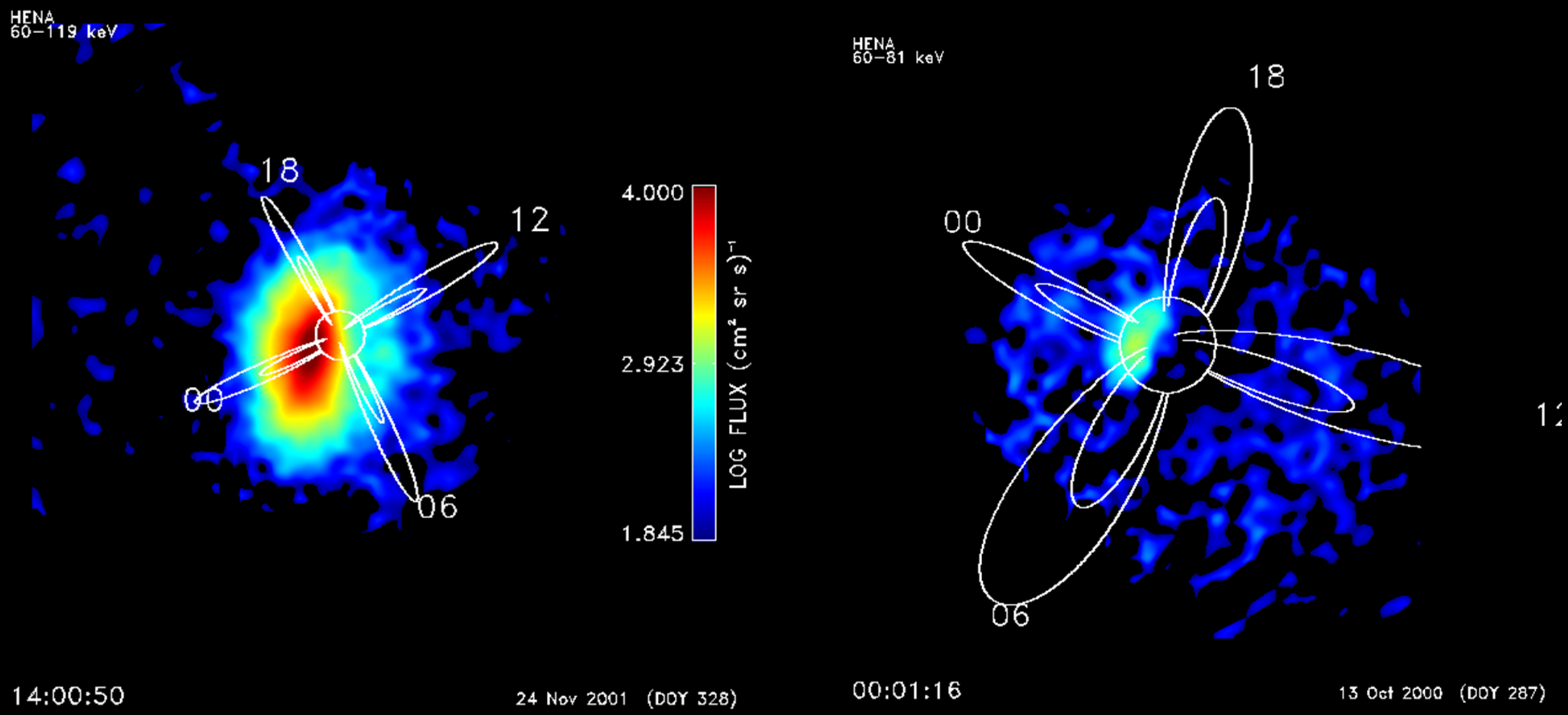
1.3 Global changes in less than one hour



Dynamic ring current during weaker storm. IMAGE/HENA images.

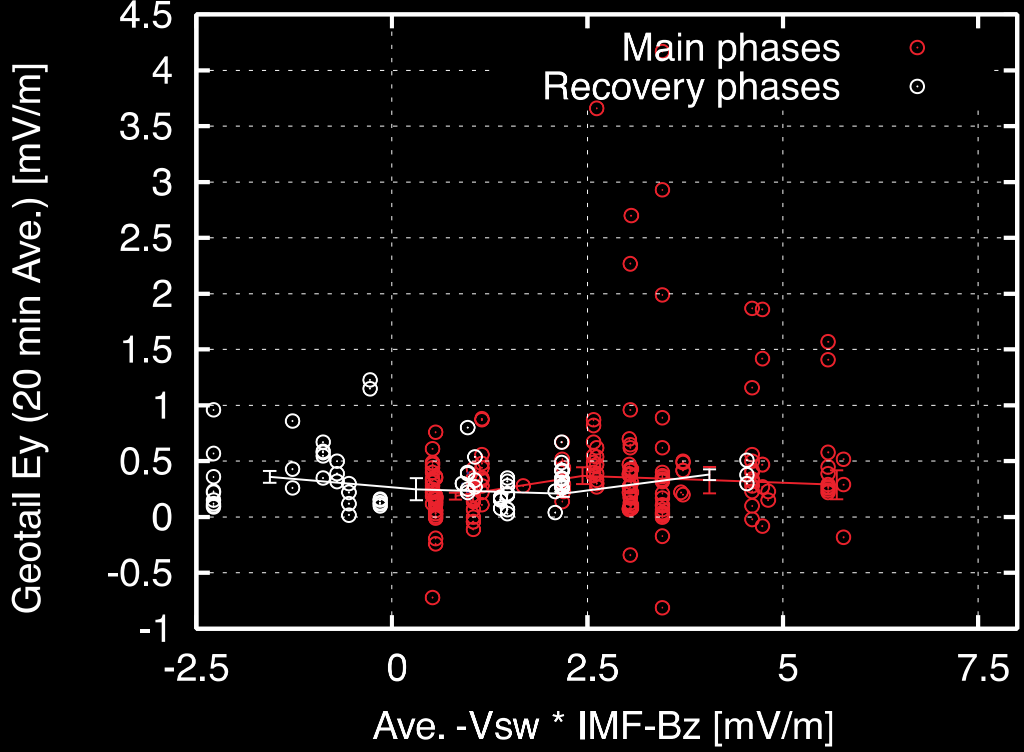
Global ENA images show that the ring current changes from highly asymmetric to symmetric in a several hours only. The plasma proton pressure derived from images in the 60-119 keV range shown. The ring current can also be highly symmetric in the storm recovery phase depending on IMF.

1.4 Global changes in less than one hour



Two movies of the proton ring current taken in ENAs by IMAGE/HENA showing dramatic and global changes of the ring current occurring on time scales much less than one hour.

2.1 Convection: where is the dawn-dusk E-field?



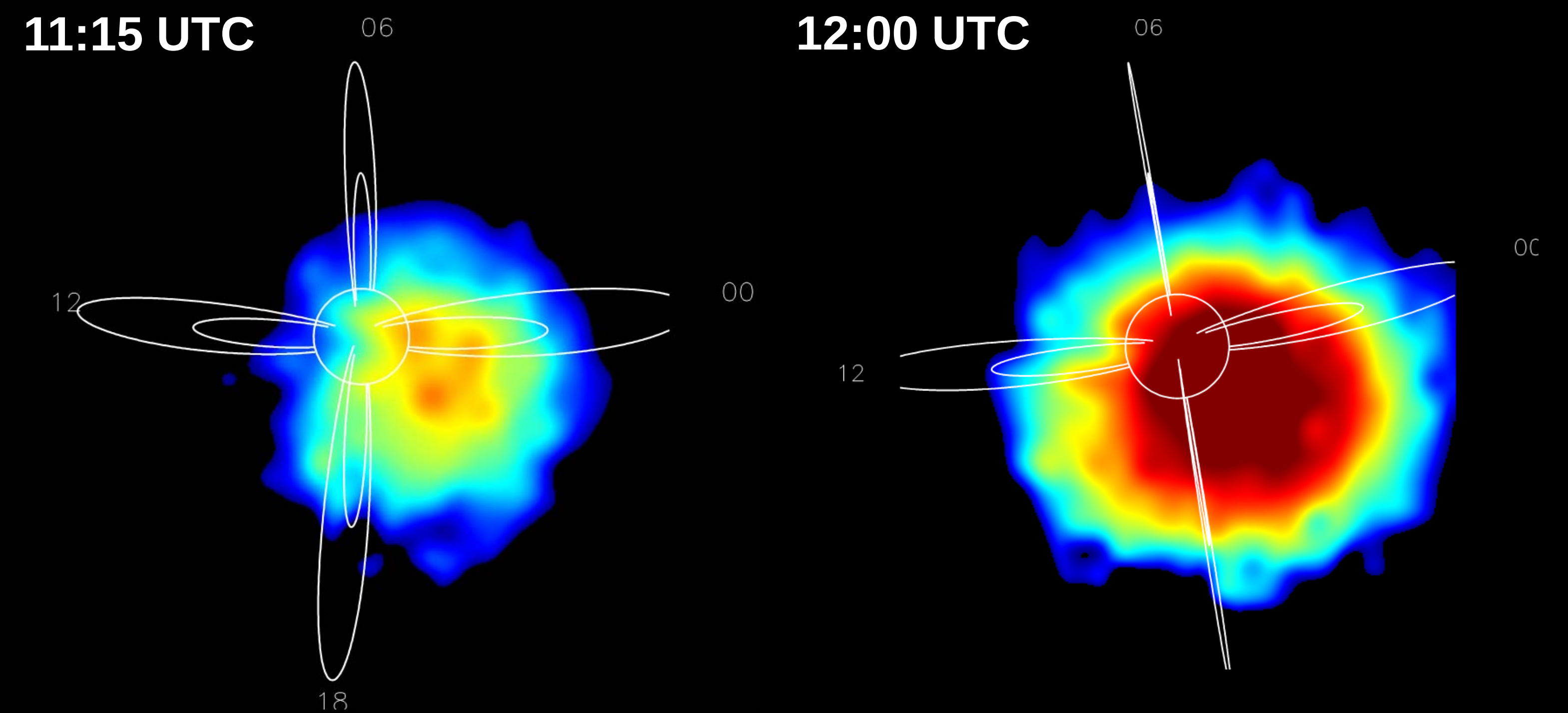
Hori et al. [2005] discovered that there is no steady and large-scale dawn-dusk electric field during storms. Earthward transport during storms consists of bursty bulk flows.

2.2 New modeling shows highly structured flows

Pontus to ask John Lyon if he is willing to share his movie.

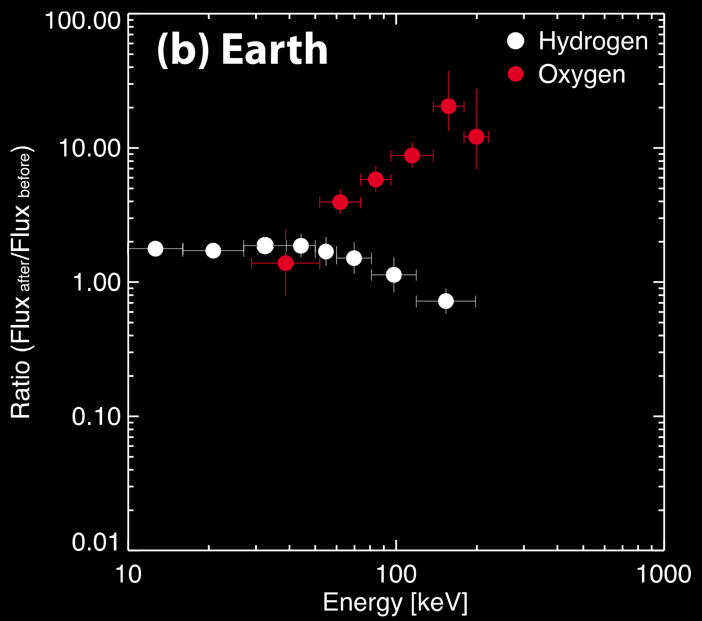
Is this what storm plasma convection looks like? High-resolution MHD model run shows how low-density channels whose electric field “push” plasma in front of them causing plasma heating. Pressure is shown color coded and the run is done during southward IMF. Courtesy of John Lyon. See also *Pembroke et al. [2011].*

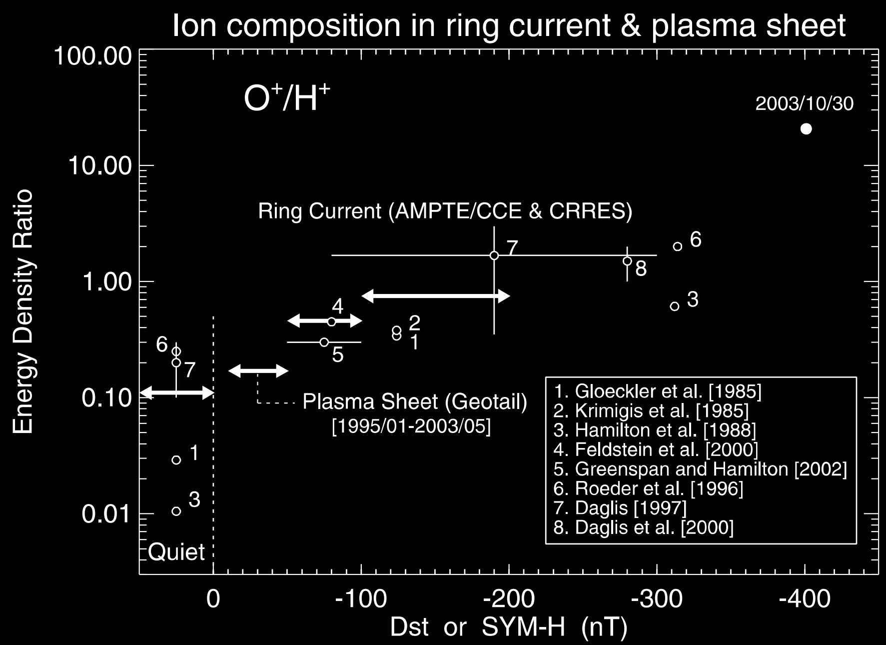
2.3 Substorms: Dramatic ion energization



Global dramatic intensifications of the ring current occur during substorm injections. Sequence shows IMAGE/HENA images of the O^+ ring current in the 96-222 keV range. Intensifications are often more dramatic for O^+ than for protons *[Mitchell et al., 2003]*. 18 April 2002 substorm shown.

2.4 Oxygen more energized than protons

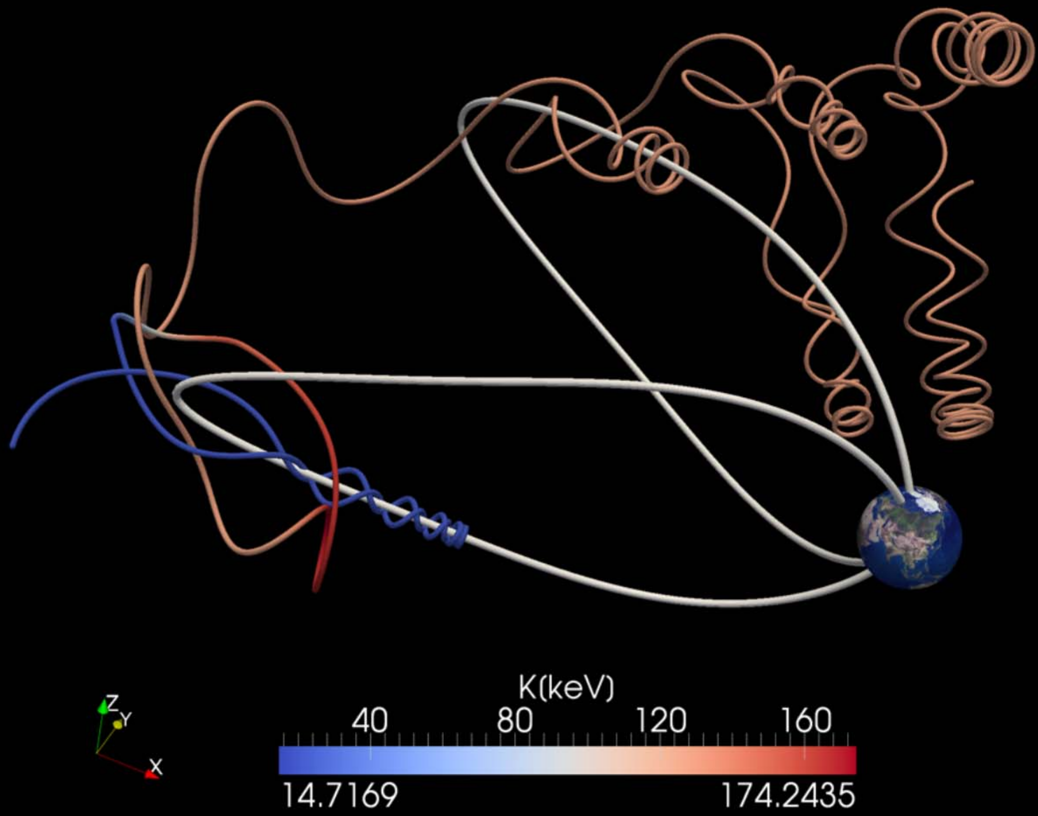




Left: ratio of post- and pre-substorm flux of O and H demonstrating mass dependent acceleration *[Keika et al., 2010]*.

Right: *Nose et al. [2005]* compiled O^+/H^+ ratios to demonstrate that O^+ can dominate the energy density of the ring current for strong storms. It is believed that substorms play a significant role in energizing the O^+.

2.5 Dramatic non-adiabatic ion acceleration



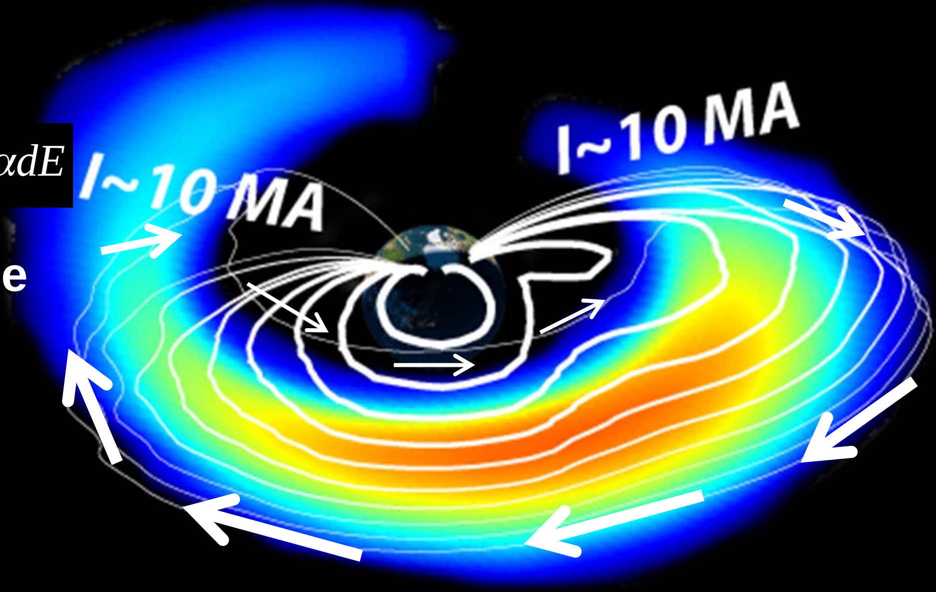
3D particle simulation of an O^+ ion subjected to a dipolarization front. Kinetic energy increases from 15 keV to 175 keV as the O^+ “bounces” against the incoming front. Protons (not shown) are energized too but not as effectively.

3.1 Plasma pressure drives the electrical ring current

Pressure

$$P_\perp = \pi\sqrt{2m}\int\int\sqrt{E}\,j_{ION}(E,\alpha,L)\sin^3\alpha\, d\alpha dE$$

$$P_\parallel = 2\pi\sqrt{2m}\int\int\sqrt{E}\,j_{ION}(E,\alpha,L)\sin\alpha\cos^2\alpha\, d\alpha dE$$



Current continuity and force-balance

$$\nabla\cdot\mathbf{J} = \mathbf{0}$$

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

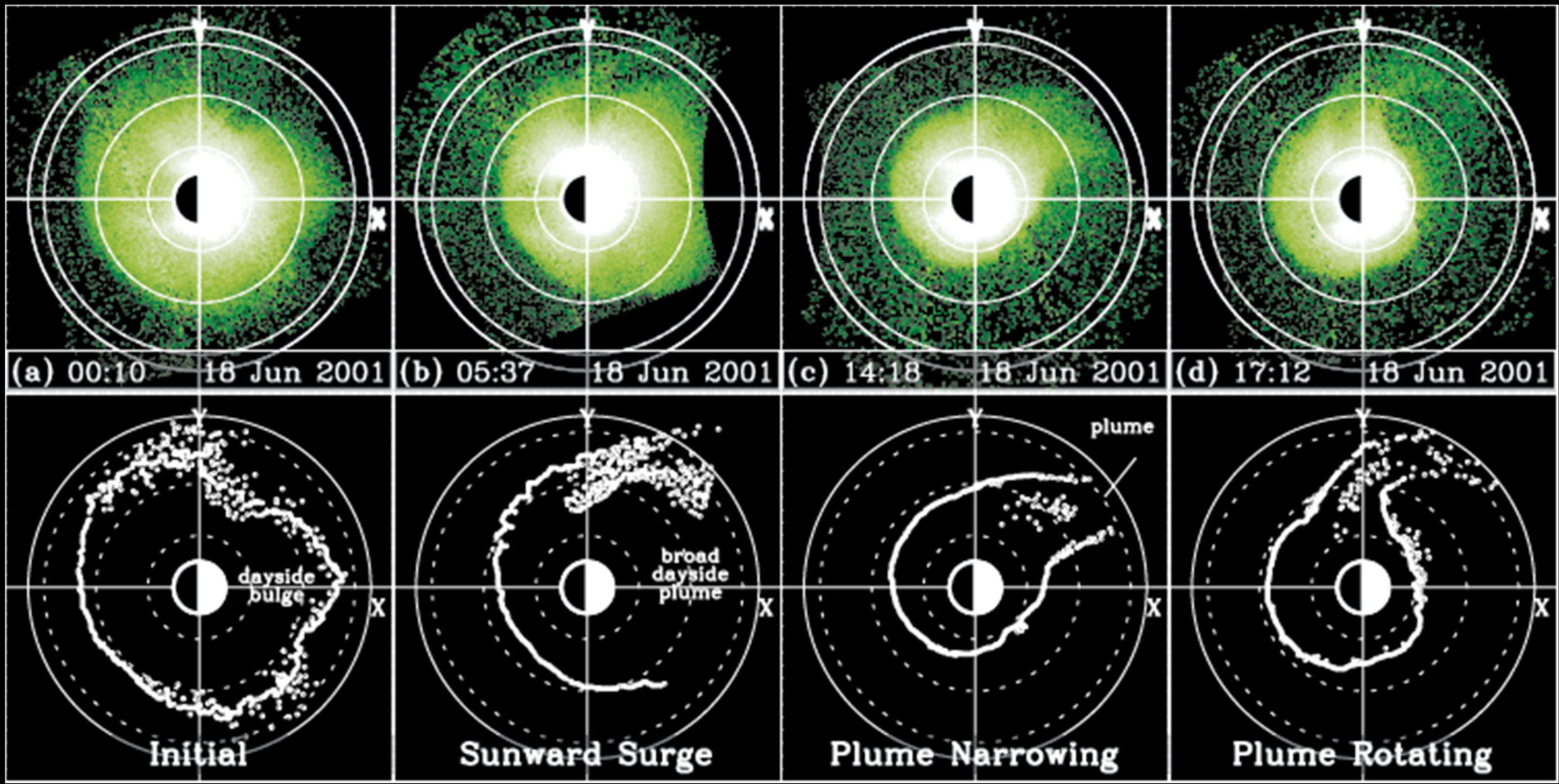
Solution

$$\mathbf{J}_\perp = \frac{\mathbf{B}}{B^2}\times\left[\nabla P_\perp + (P_\parallel - P_\perp)\frac{(\mathbf{B}\cdot\nabla)\mathbf{B}}{B^2}\right]$$

$$B\frac{\partial}{\partial s}\left(\frac{J_\parallel}{B}\right) = -\nabla\cdot\mathbf{J}_\perp$$

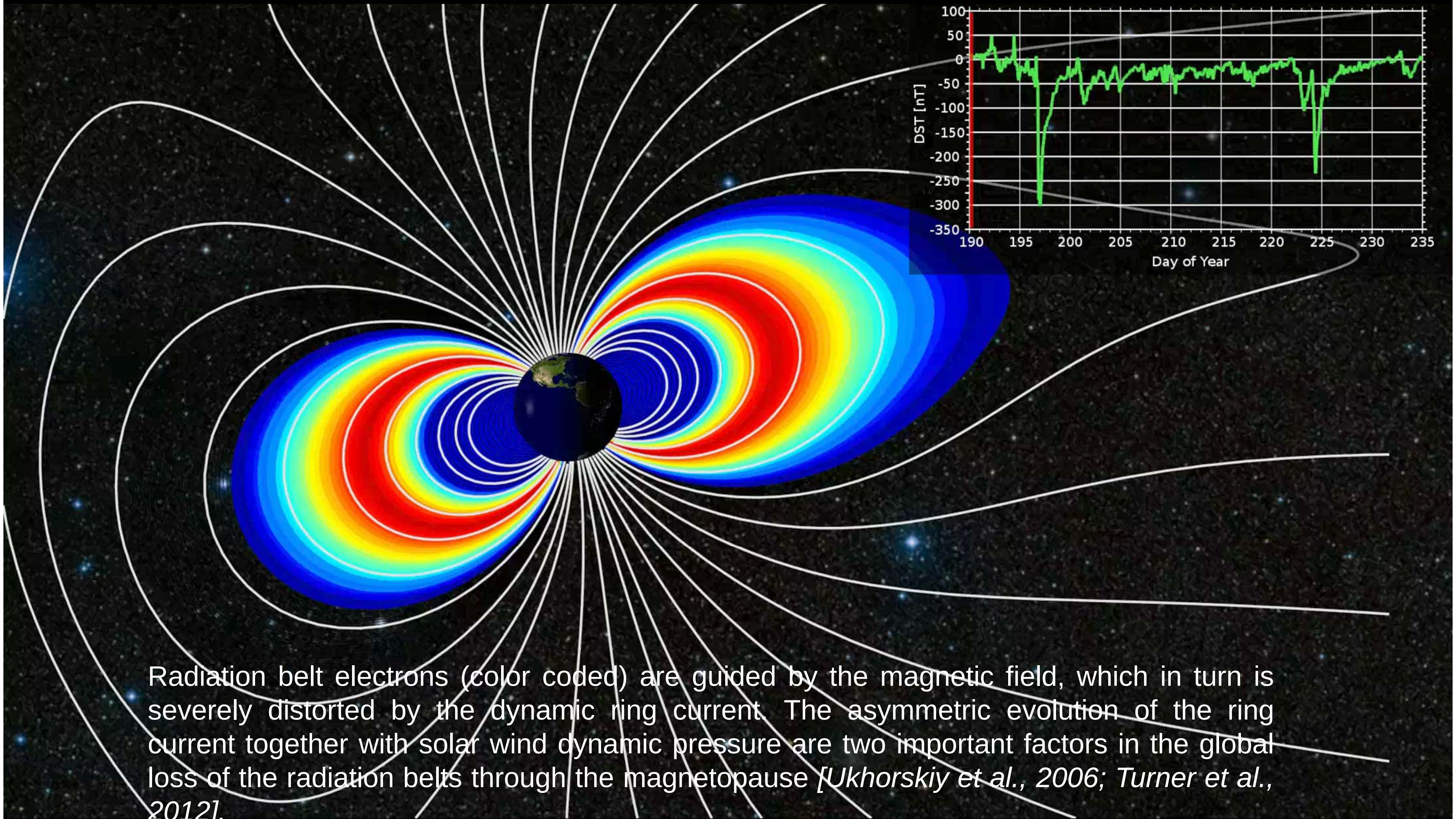
Vasyliunas, 1970; Brandt et al., 2004.

4.1 Phases of plasmasphere evolution



The plasmasphere responds clearly to southward IMF by a sunward surge, followed by corotation and the formation of a wrapping plume. EUV images of the resonantly scattered He^+ line obtained by the EUV camera on board IMAGE *[Sandel et al., 2003; Goldstein et al., 2006]*.

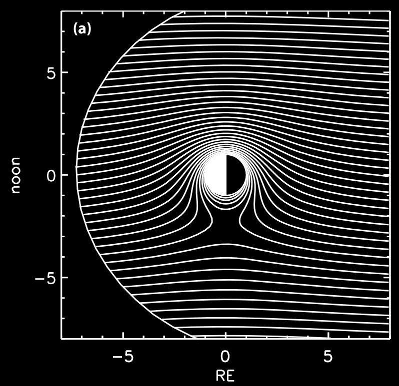
5.1 Ring current strength controls electron drift shells

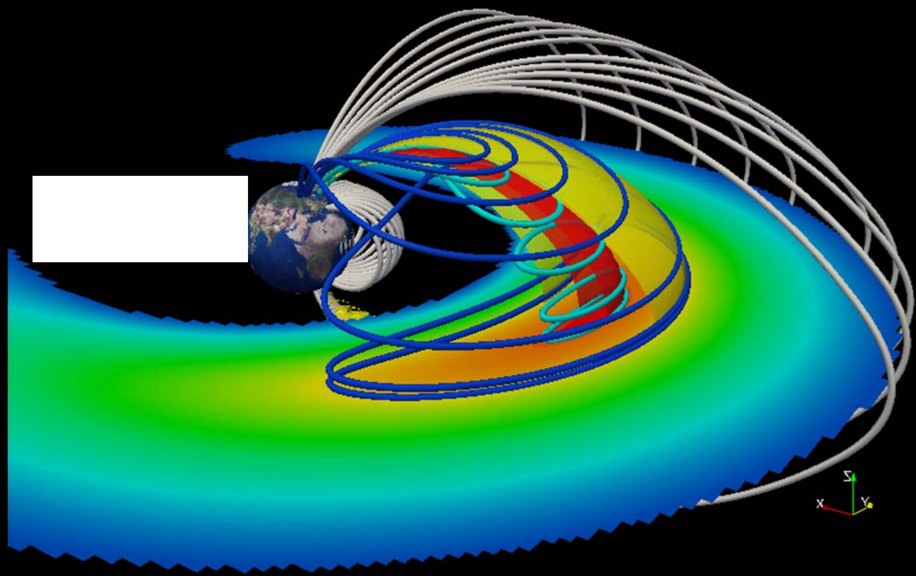


Radiation belt electrons (color coded) are guided by the magnetic field, which in turn is severely distorted by the dynamic ring current. The asymmetric evolution of the ring current together with solar wind dynamic pressure are two important factors in the global loss of the radiation belts through the magnetopause *[Ukhorskiy et al., 2006; Turner et al., 2012].*

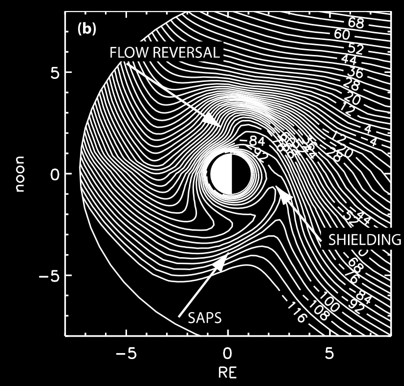
5.2 Closure through the ionosphere distorts global E-field

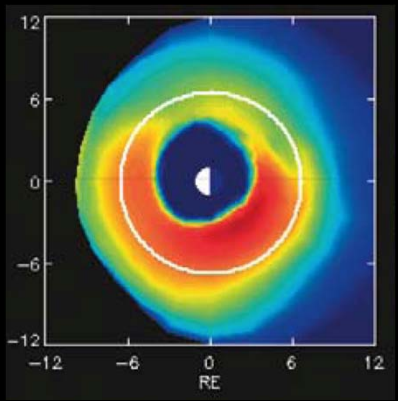
Without closure



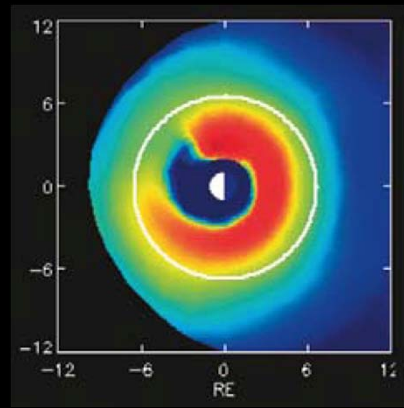


With closure





Left: Magnetospheric E-field and resulting ring current distribution.
Right: By closing the 3D ring current system through the ionosphere, the magnetospheric E-field skews and reproduces the correct ring current distribution *[Brandt et al., 2002; Fok et al., 2003]*.



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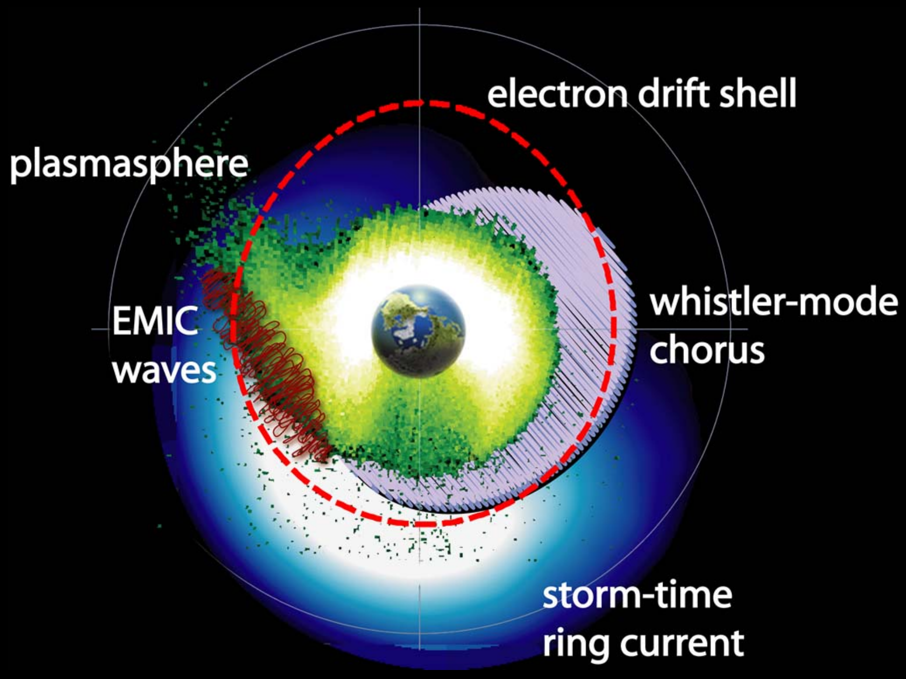
5.3 Ring current and plasmasphere catalyze wave growth

- **Electrons accelerated to relativistic energies through whistler-mode chorus wave interactions near plasmapause *[Horne et al., 1998; Chen et al., Nature, 2007]***
  - *Important to understand ~100 keV injections and pitch-angle anisotropy, and plasmaspheric distribution*
- **Some electron loss due to EMIC wave interactions**
  - *EMIC waves generated by the presence of hot ion (ring current) anisotropies*



The variability of the outer electron radiation belts are due to competing global and local acceleration and loss processes, such as chorus waves and ULF waves versus magnetopause shadowing and EMIC waves.

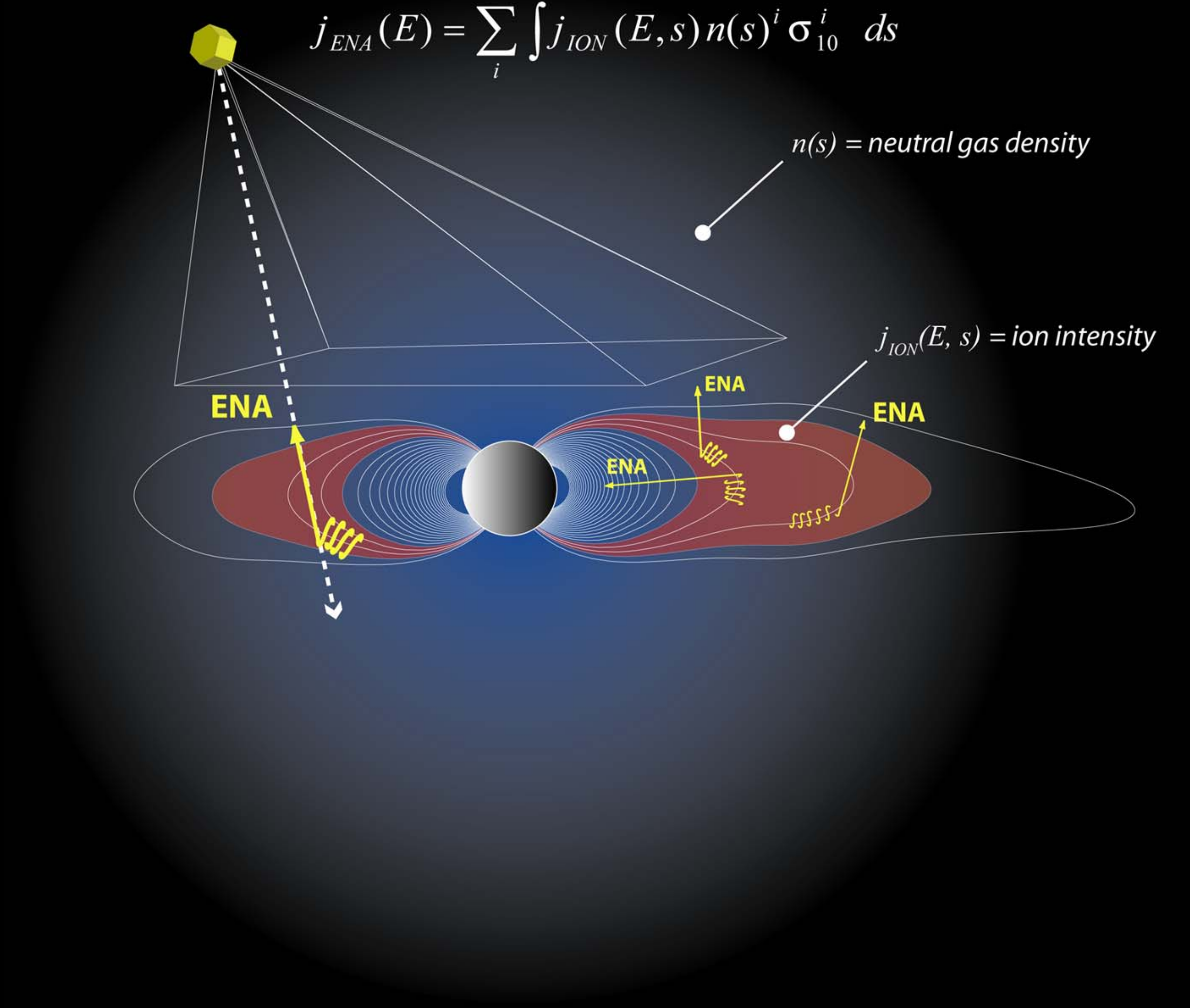
6. Summary

- **Ring Current Distribution**
  - *plasma pressure peaks around L~3 during storms*
  - *Ring current changes its MLT distribution from maximum on the night side to almost symmetric in several hours*
- **Ring Current Pressure build up**
  - *Magnetospheric "convection" is bursty and provides some level of heating and transport*
  - *Substorms cause dramatic, non-adiabatic energization of ions (especially O+)*
- **Ring Current Driver**
  - *The electrical ring current is mainly pressure-driven*
- **Plasmasphere Dynamics**
- **Space weather impacts**
  - *Severe magnetic field distortions that impact the global loss of the electron radiation belts*
  - *Current closure through the ionosphere modify the large-scale electric fields that impact the large scale configuration of the ring current and plasma sphere*
  - *Plasmasphere, electron and ion anisotropies of injections critical for wave growth*

- **New NSF/GEM Focus Group "Tail-Inner Magnetosphere Interactions (TIMI)"**
  - *GEM 17-22 June, Snowmass, CO, USA.*
- **NASA/LWS Focused Science Topic: "Plasmasphere Behavior and Impact"**
  - *Teams doing first principles modeling, empirical modeling, data analysis and assimilation*
  - *Email pontus.brandt@jhuapl.edu to join*

Extra Slides

ENA imaging


$j_{ENA}(E) = \sum_i \int j_{ION}(E,s)\, n(s)^i \sigma_{10}^i \; ds$
$n(s)$ = neutral gas density
$j_{ION}(E, s)$ = ion intensity
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