A 3D test particle simulation for the electron injections associated with the 23 March 2007 substorm

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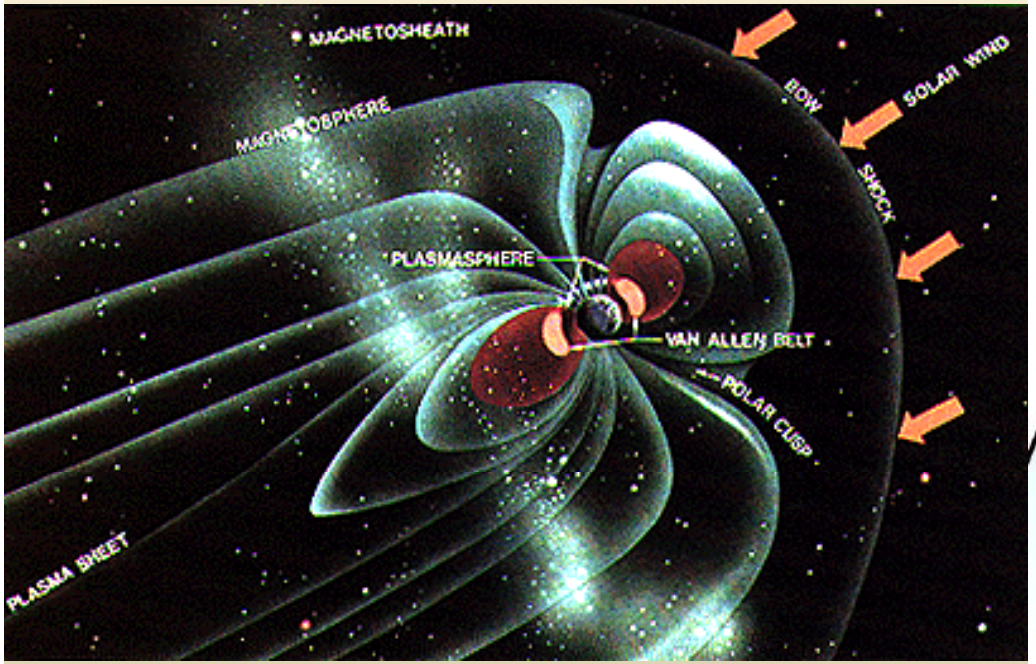
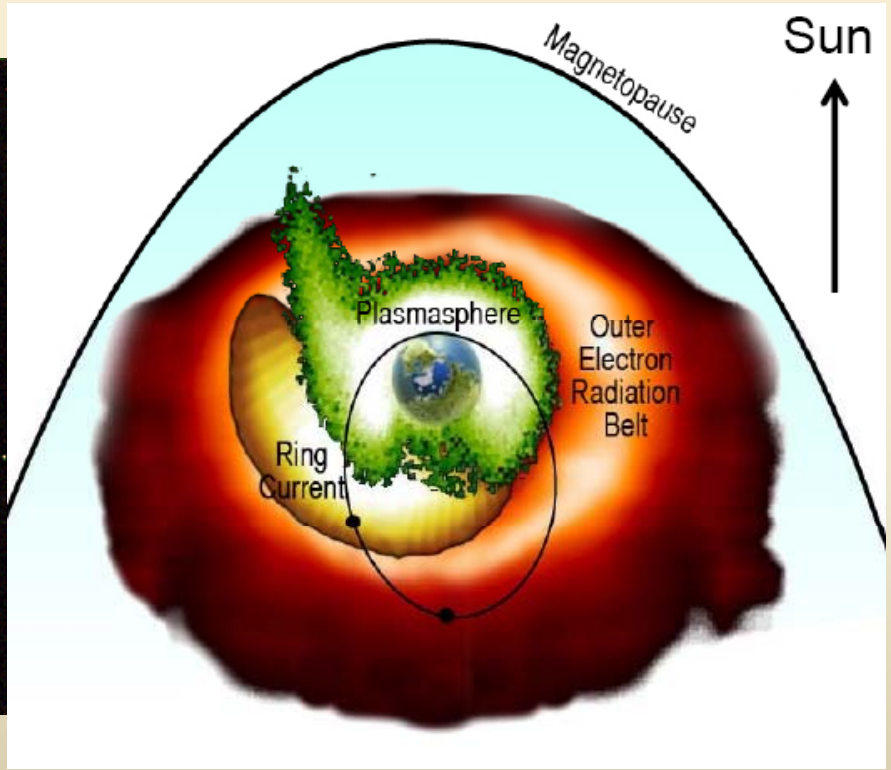
NJIT

Background: Magnetosphere

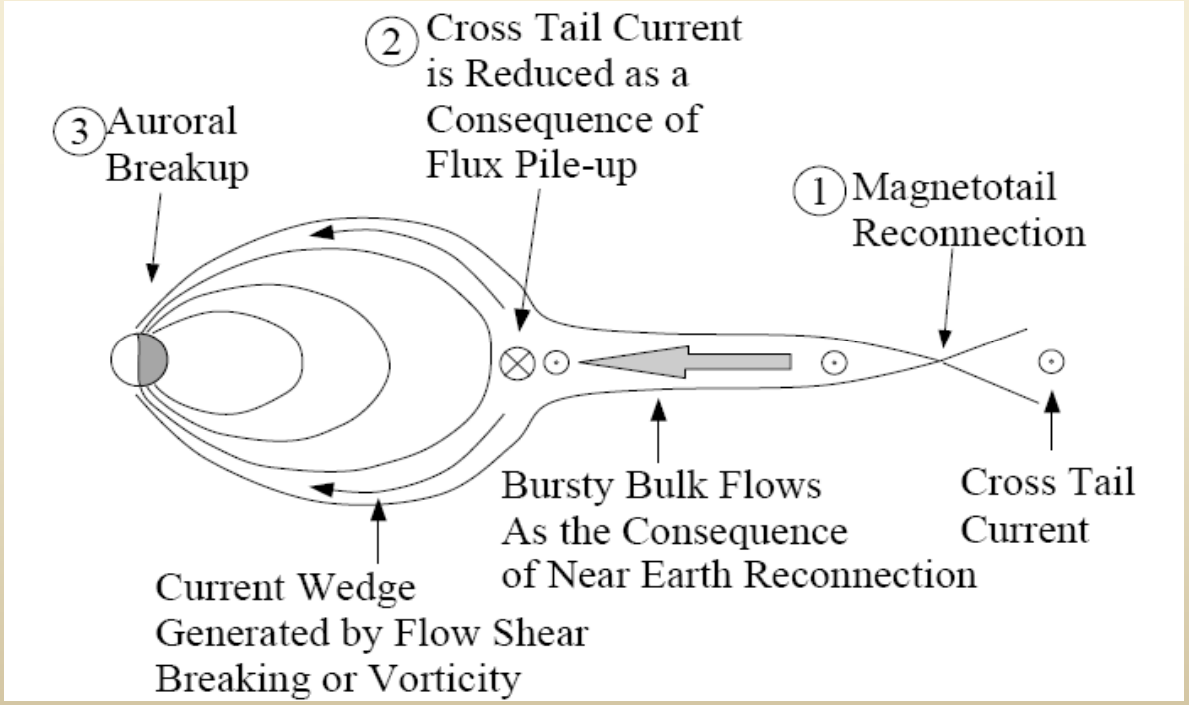




Background: Chorus waves and Substorm

• **Chorus waves: whistle mode waves believed to be generated through the electron cyclotron instability by anisotropic distributions of energetic electrons in the range of 5 to 150 keV [e.g. Thorne, 1977]**

• **Substorm-enhanced Chorus events (SCE): Chorus waves associated with substorm injection**



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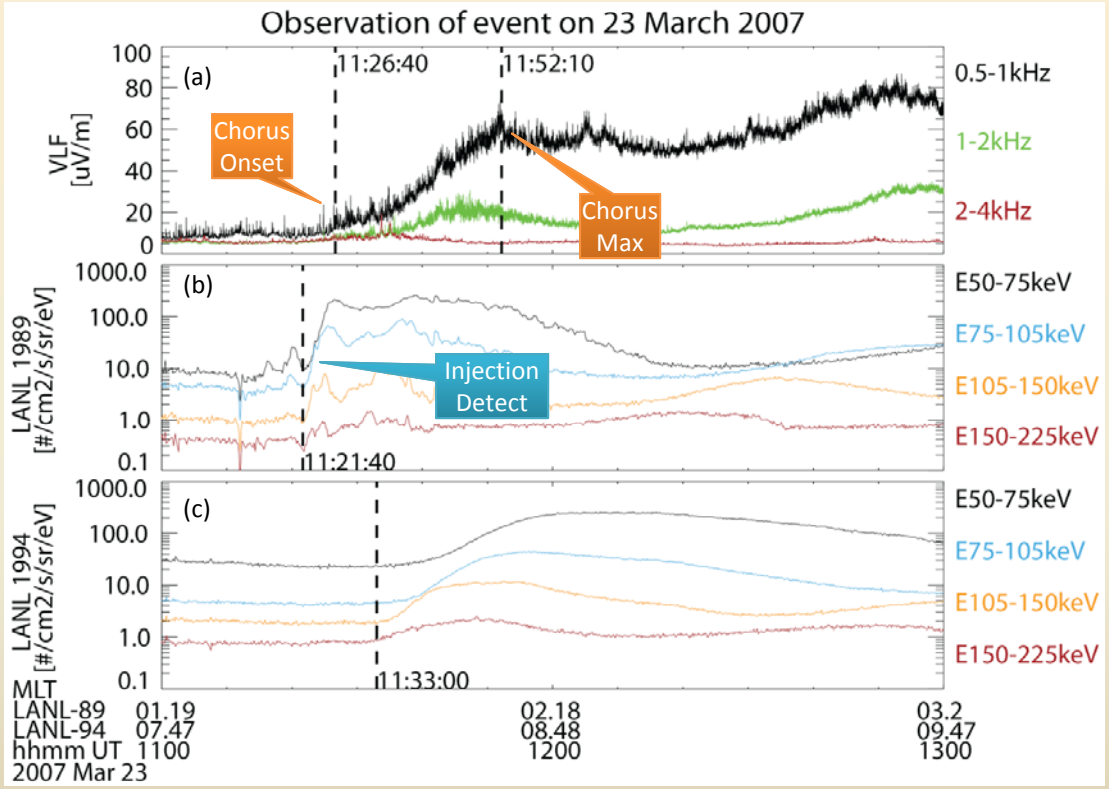
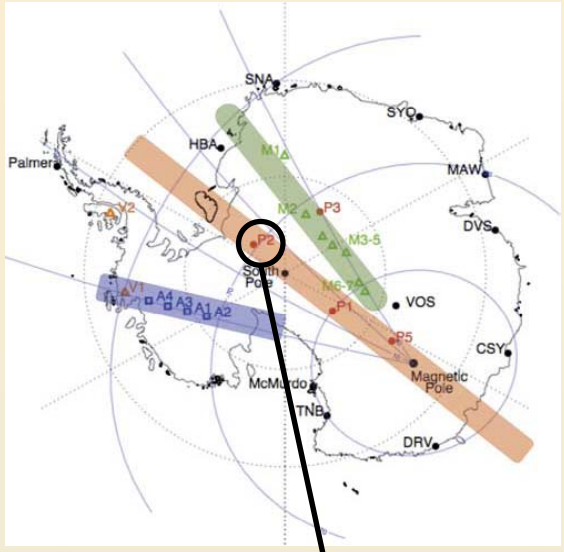
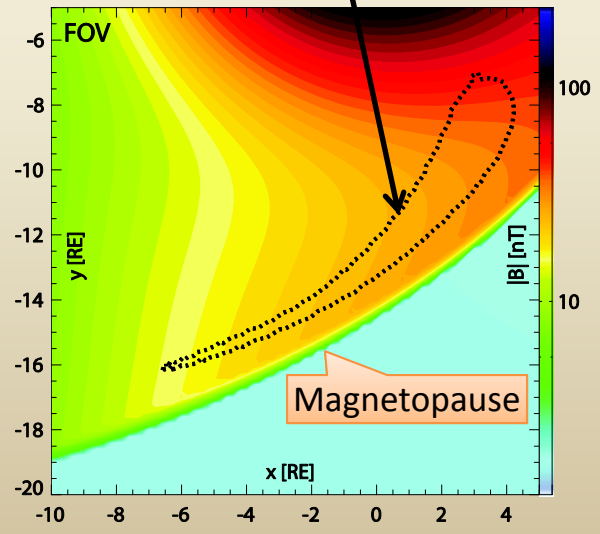
Observations of Chorus Waves during 23 March Substorm

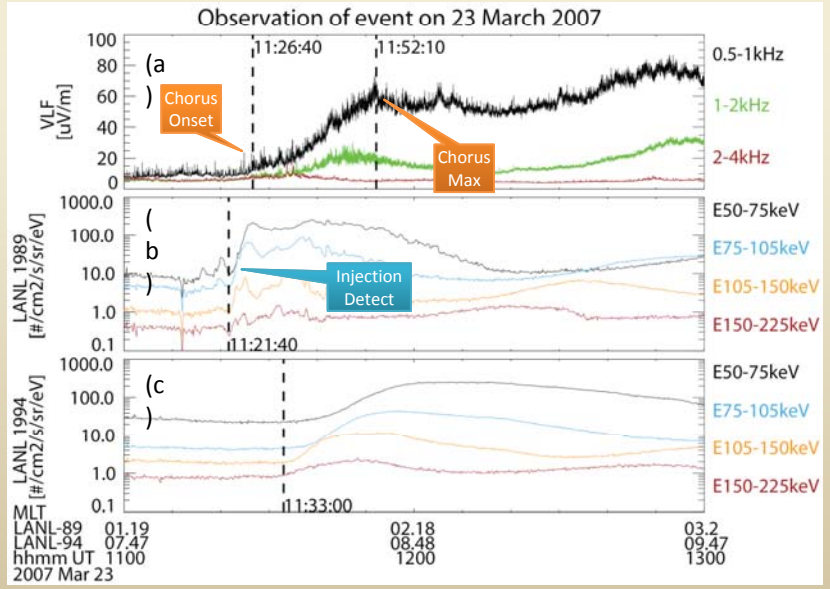


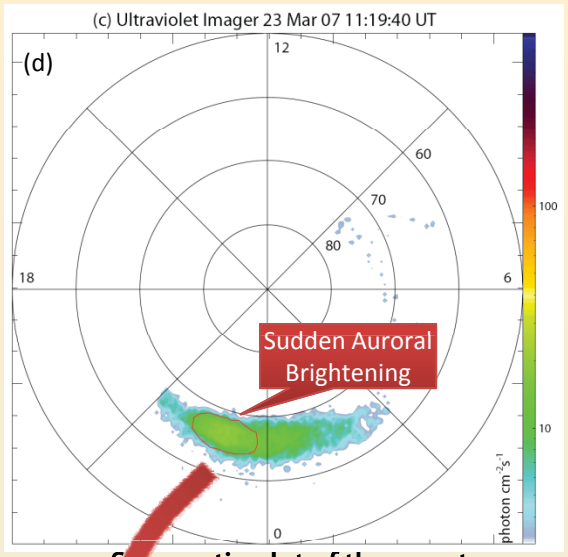




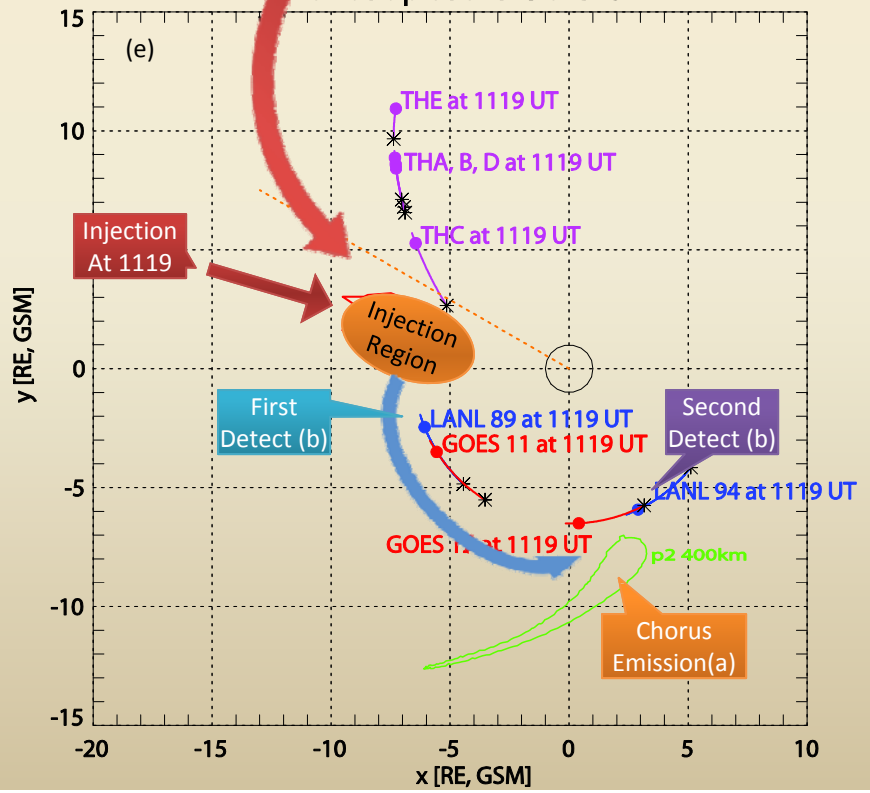
Qualitative Interpretation of the Event

1. Substorm onset (1119 UT, THEMIS)
2. Electron precipitation (1119 UT, POLAR)
3. Electron flux increase (1121 UT, LANL89)
4. Electron drift toward stations' FOV ?
5. Chorus emission (1126 UT, AGO)
6. Energy-dispersed electron flux increase (1133 UT, LANL 1994)
7. Magnetic field change (GOES11 not GOES12)





Schematic plot of the event



Goal:

investigate the relationship between the substorm-injected electrons (near midnight) and the chorus wave generation (near MP)

Challenges:

- Chorus emissions near the MP have not been much studied.
- Particles at all pitch angles should be traced.
- 3D motion in a realistic geomagnetic field is required.

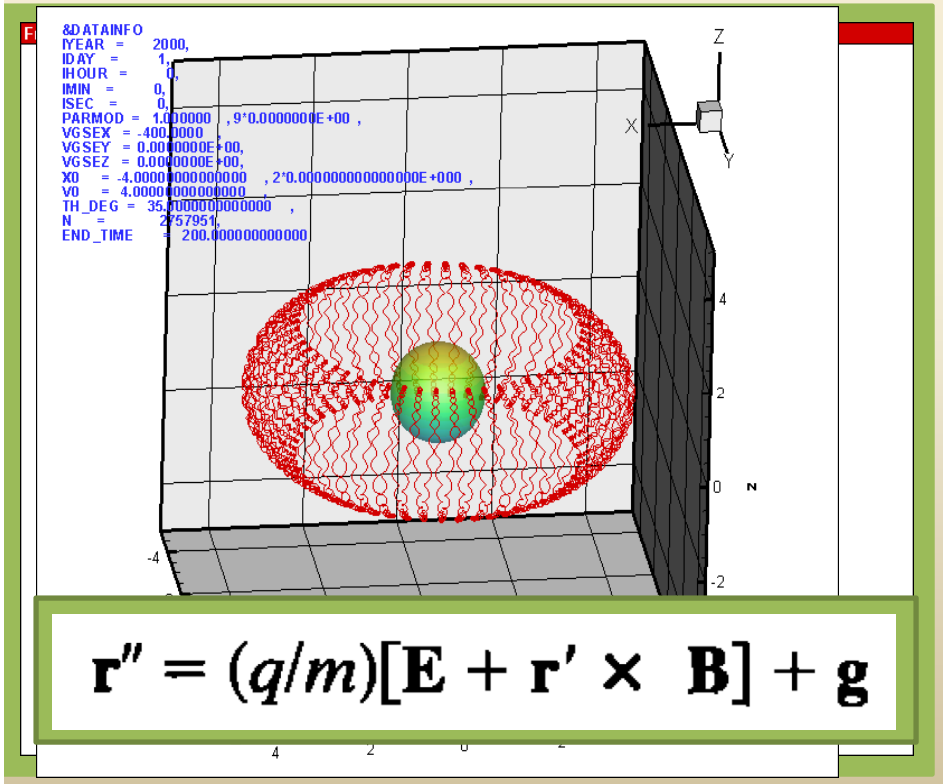
Our approach:

- Test particle simulation of substorm-injected electrons
- Initial condition: LANL 1989 observation and auroral images
- Sample time-dependent pitch angle distribution of electrons at P2 FOV
- Calculate the anisotropy factor as a proxy of the wave growth rate
- Compare this with the VLF signal in the rising phase (~1 hr from the substorm injection onset).

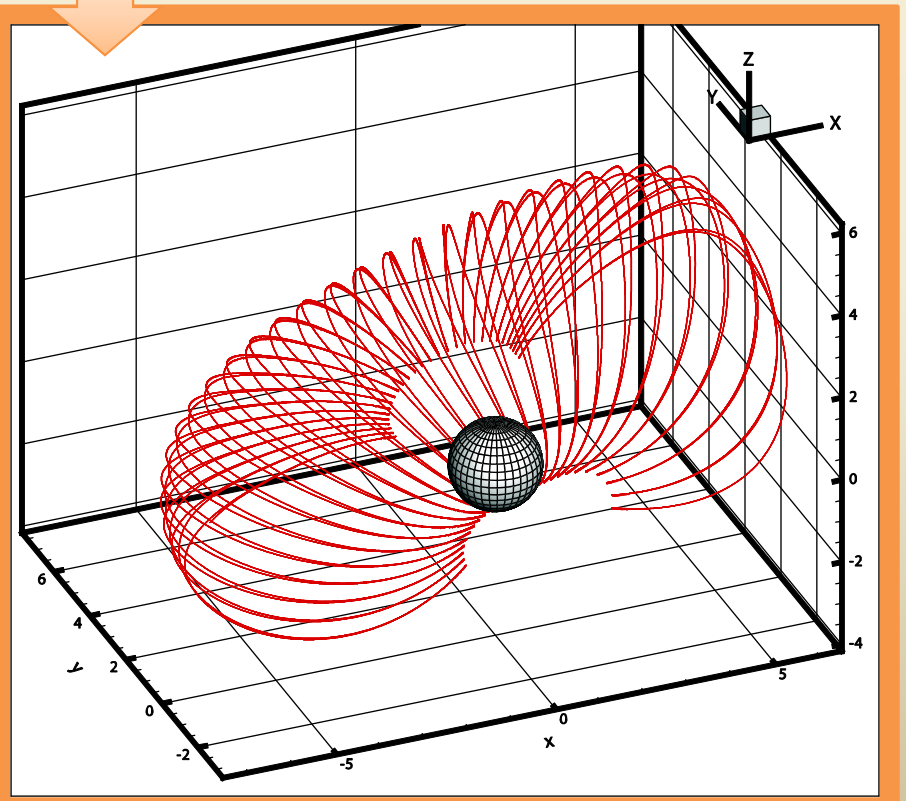
Equation of Motion under the Relativistic Guiding Center Approximation (Brizard & Chan 1999)

$$\mathbf{v_d} = \frac{p_\parallel}{m_0\gamma}\frac{\mathbf{B}^*}{B_\parallel^*} + \frac{c}{q\gamma B_\parallel^*}\hat{\mathbf{b}}\times M\nabla B + \frac{c}{B_\parallel^*}\mathbf{E}\times\hat{\mathbf{b}}, \qquad \frac{dp_\parallel}{dt} = \frac{\mathbf{B}^*}{B_\parallel^*}\cdot\left(q\mathbf{E} - \frac{M}{\gamma}\nabla B\right),$$

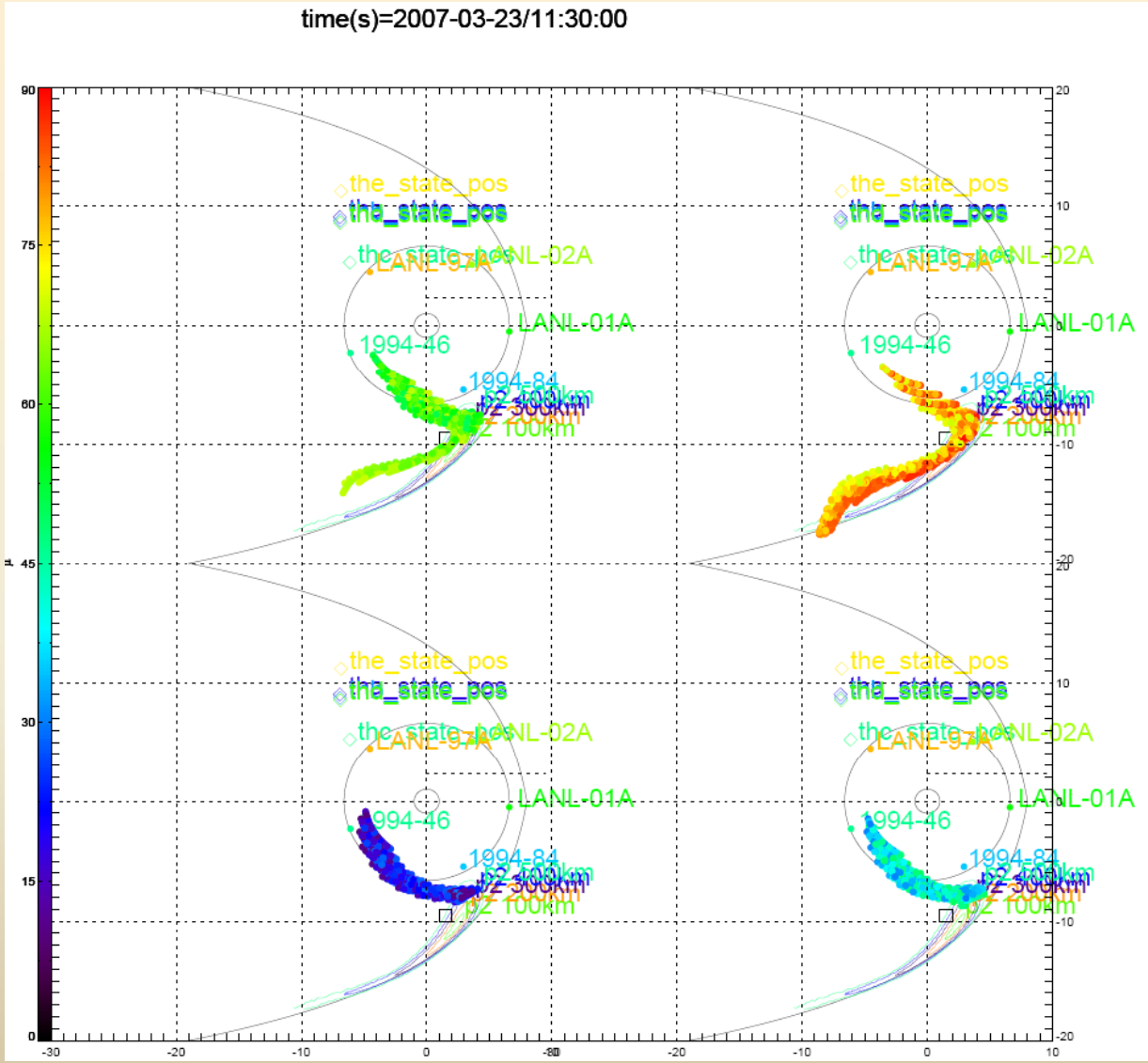
$$\mathbf{B}^* = \mathbf{B} + \frac{cp_\parallel}{q}\nabla\times\hat{\mathbf{b}}, \qquad B_\parallel^* = \hat{\mathbf{b}}\cdot\mathbf{B}^* = B\left(1 + \frac{cp_\parallel}{qB}\hat{\mathbf{b}}\cdot\nabla\times\hat{\mathbf{b}}\right).$$



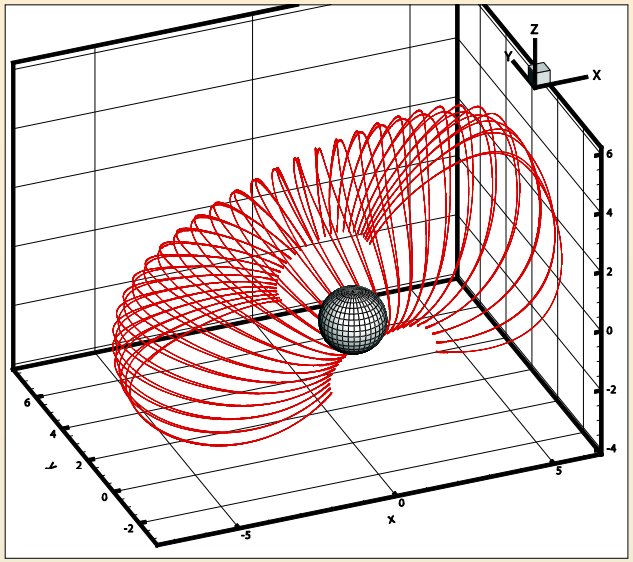
$$\mathbf{r}'' = (q/m)[\mathbf{E} + \mathbf{r}' \times \mathbf{B}] + \mathbf{g}$$



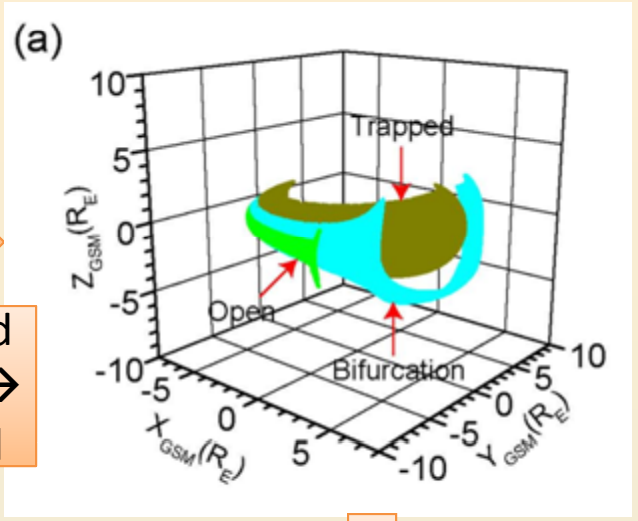
Result 1: electron drift motion depends on pitch angle (Drift Shell Splitting)



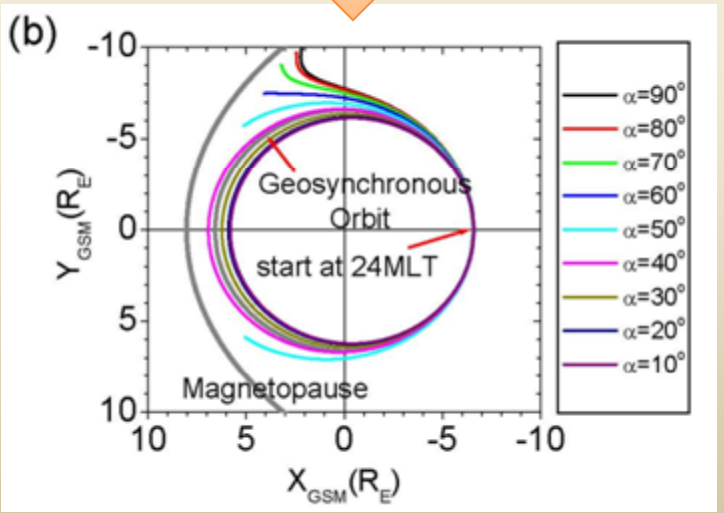
Drift Shell Splitting



Connected drift path→ Drift Shell



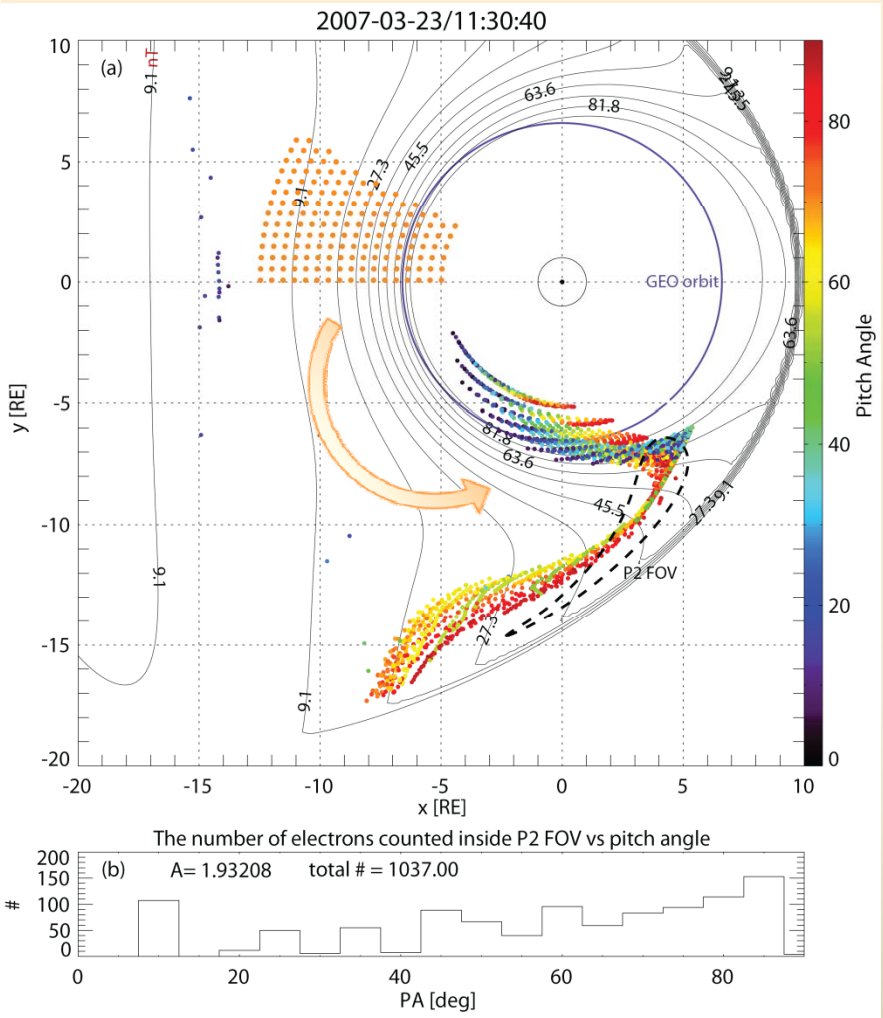
X-Y cut of (a)

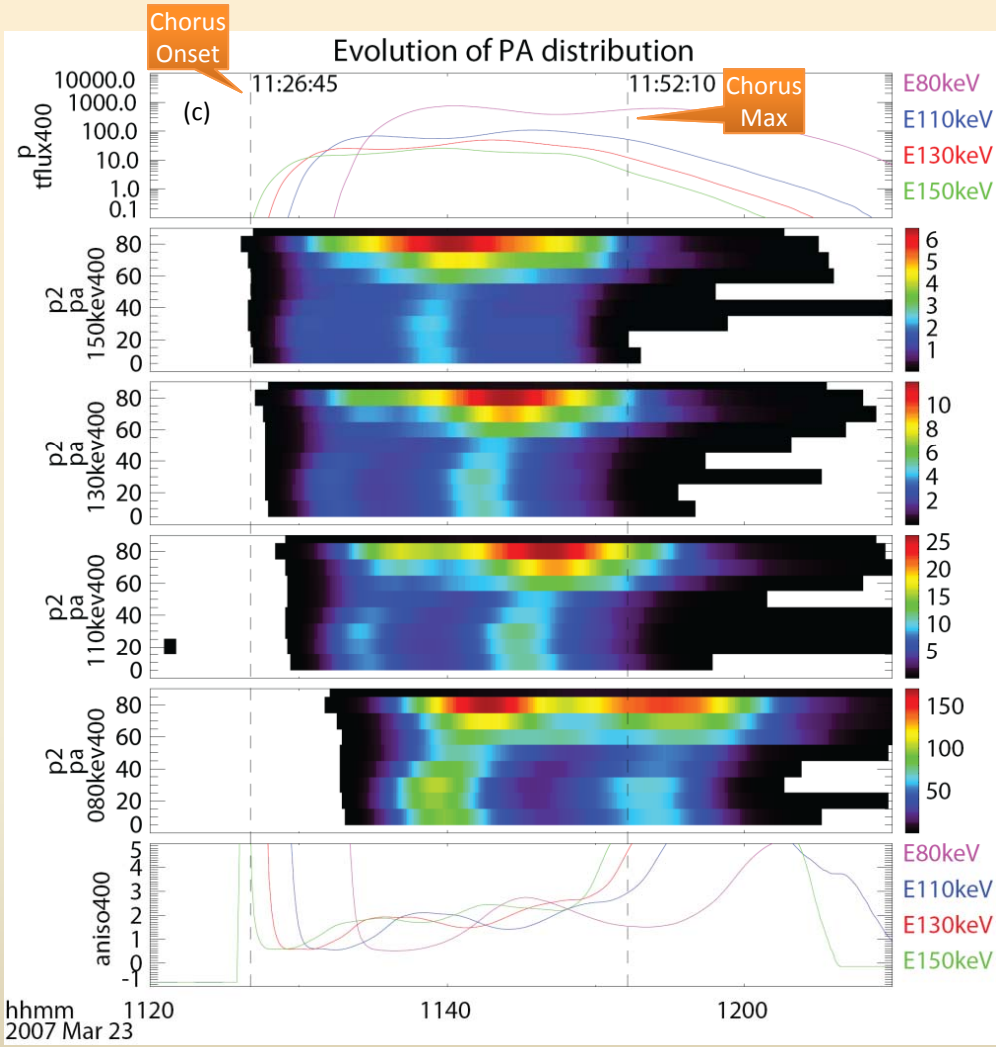


- As the magnetic field becomes asymmetric, drift shell is splitting in a way that

1. high PA electrons drift outward and
2. low PA electrons drift inward.

Result 2: Anisotropic distribution of electrons inside FOV develops and is maintained for the time comparable to the VLF observation





$$A(E) = \frac{\int_0^{\pi/2} f(E,\alpha_0)\sin^3\alpha_0 d\alpha_0}{2\int_0^{\pi/2} f(E,\alpha_0)\cos^2\alpha_0 \sin\alpha_0 d\alpha_0} - 1$$

Conclusions

1. **The result shows the chorus near the MP was due to substorm-injected electrons which developed the pitch angle anisotropy as they drifted toward FOV.**

2. **Drift shell splitting is important for the anisotropy when the magnetic field is far from the dipole field.**

3. **The ground-based observations of chorus waves observed at high-latitude observatories and proper modeling are important to the study of the evolution of the substorm injected electrons.**