Ion distributions upstream of earthward propagating dipolarization fronts

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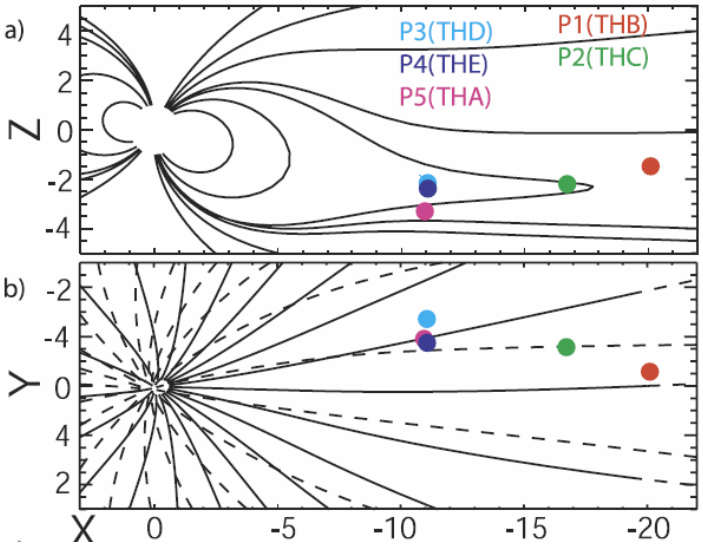
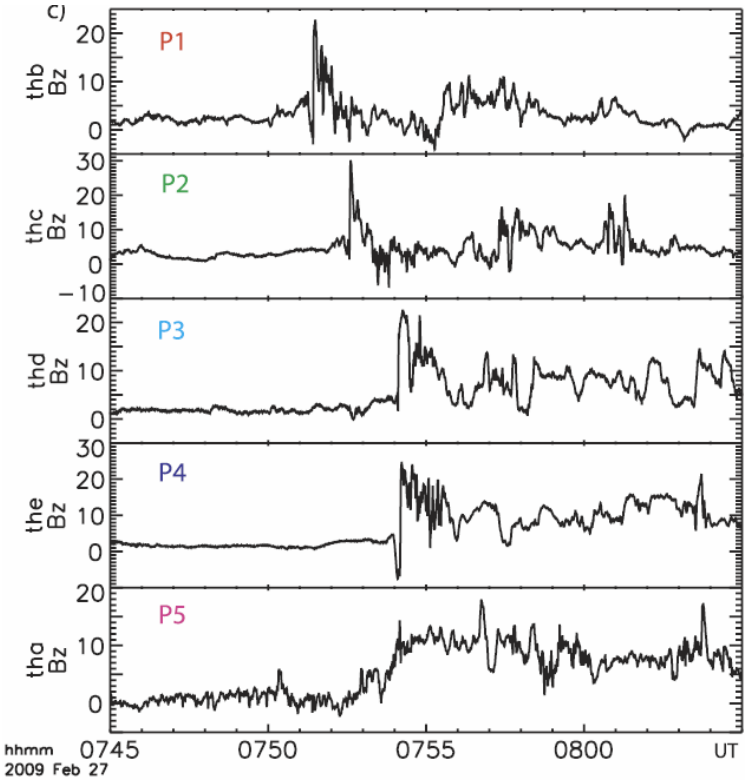
Dipolarization Fronts

- Dipolarization fronts (DFs) are rapid (a few sec), transient increases of magnetic field B_z component in the Earth's magnetotail current sheet.

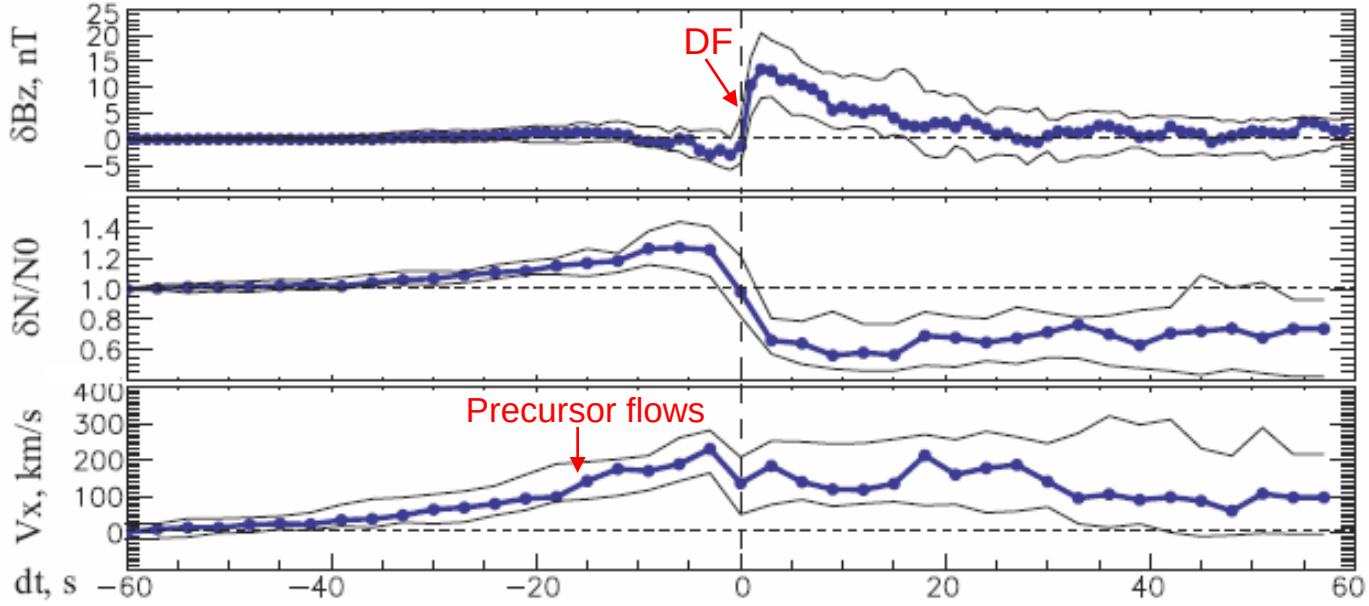




[Runov et al., GRL, 2009]

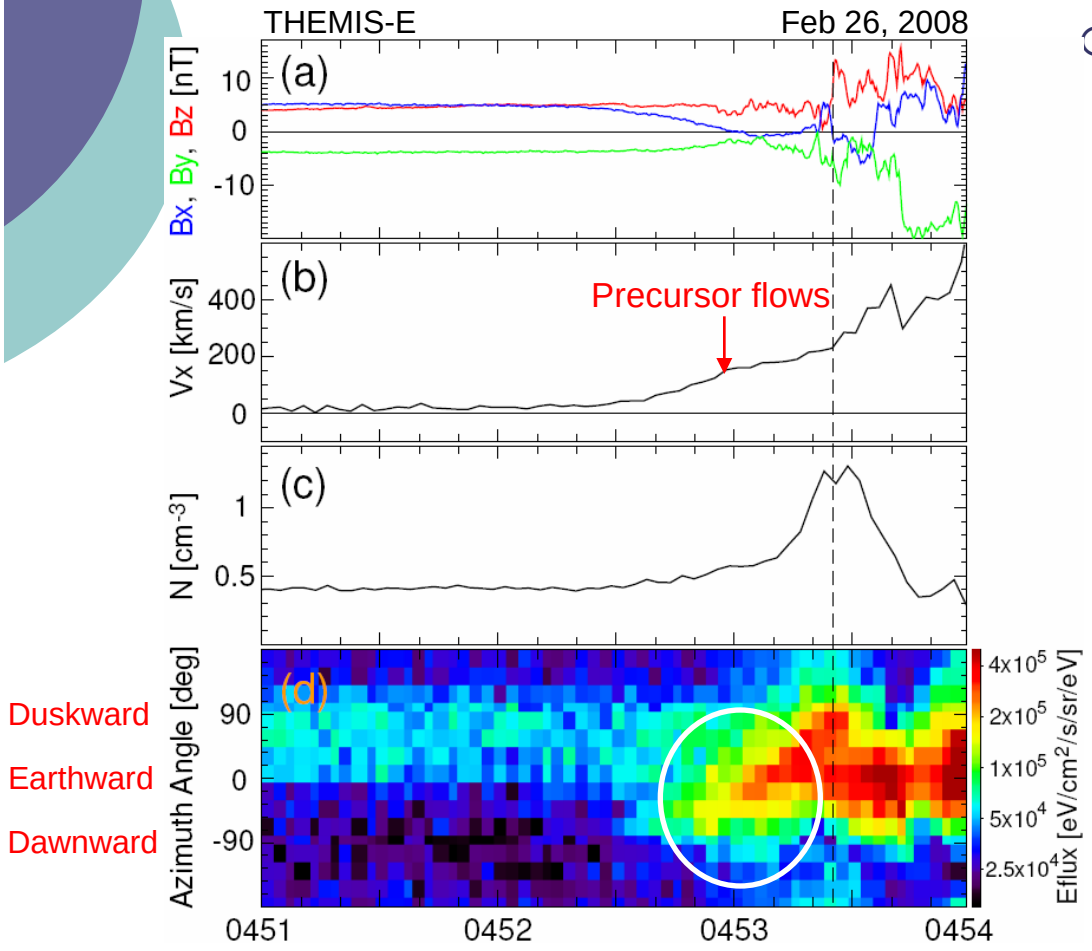
Earthward precursor flows in the CPS

- THEMIS observations of dipolarization fronts in the central plasma sheet show the existence of earthward precursor flows ~30 s before front arrivals.



[Runov et al., JGR, 2011]

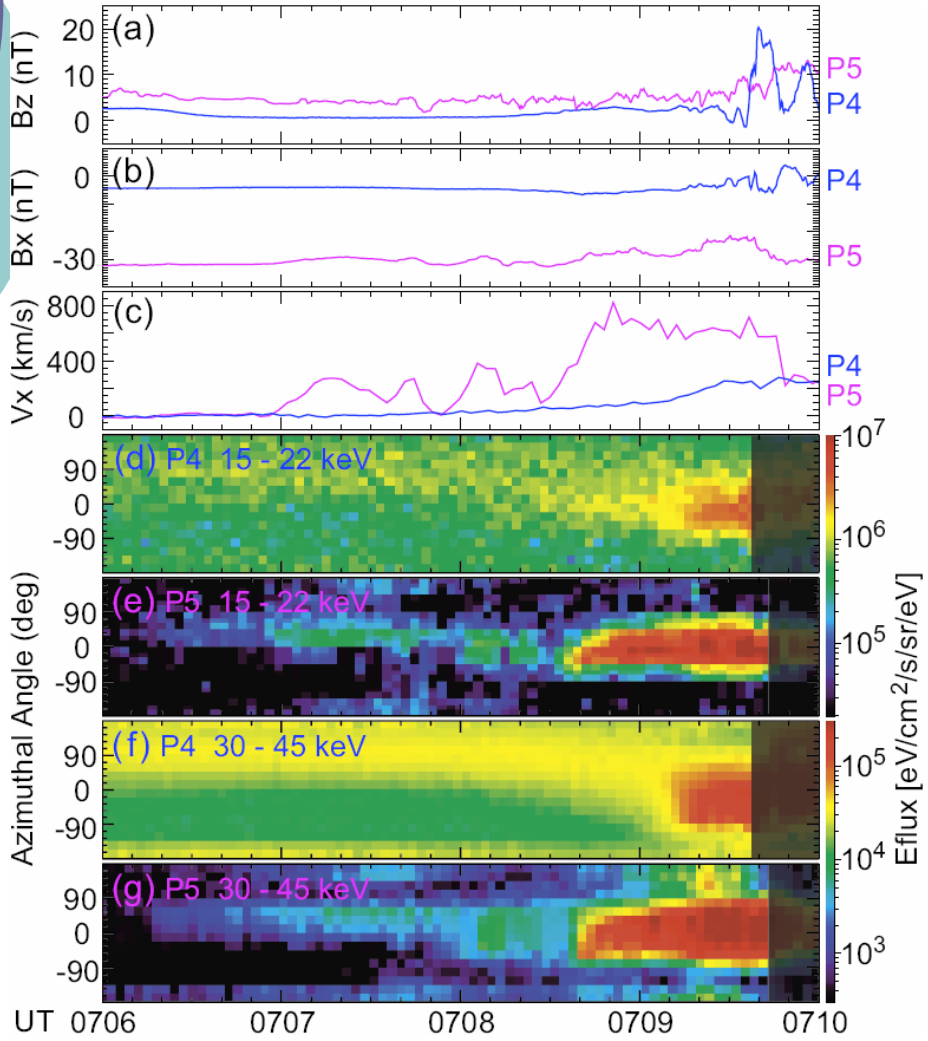
Ion azimuthal spectra in the CPS



[Zhou et al., JGR, 2011]

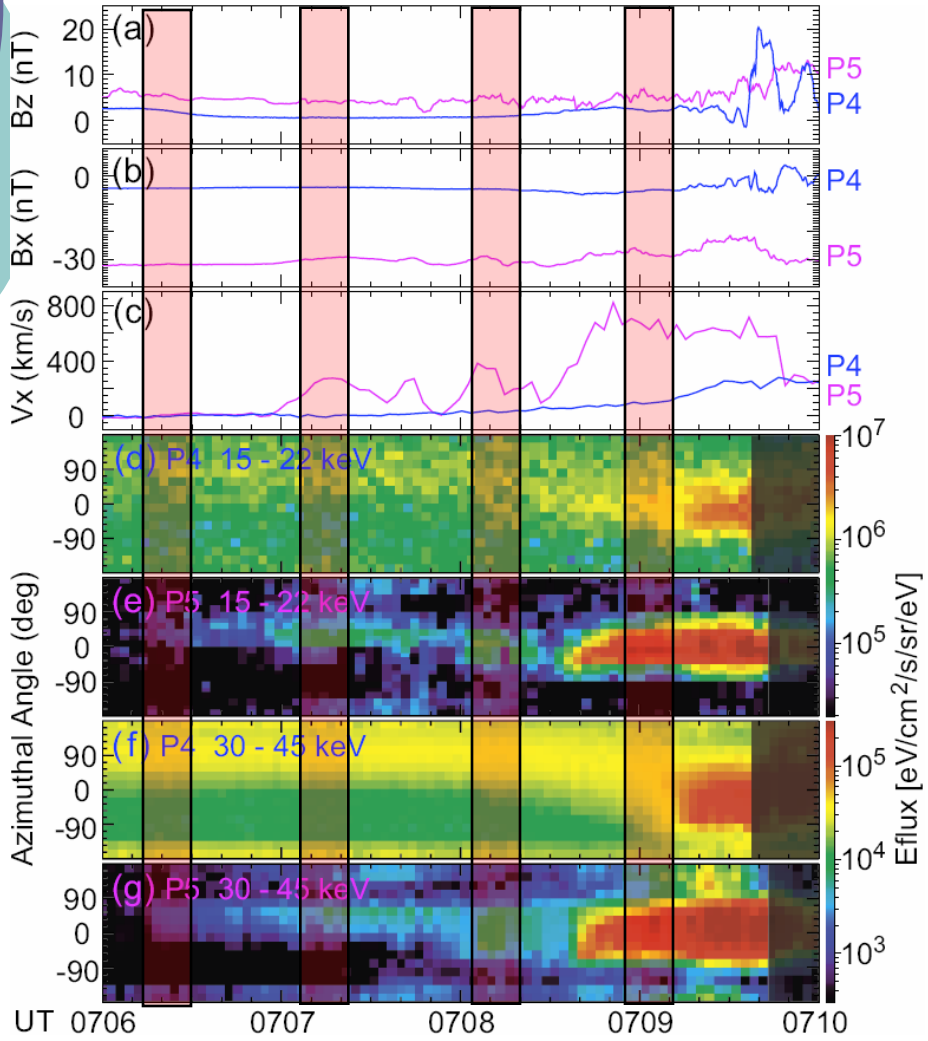
- We have examined the ion azimuthal angular spectra, to show that the earthward precursor flows are caused by the gradual appearance of a new earthward moving ion population, coexisting with the ambient plasma in the central plasma sheet upstream of the front.

Ion azimuthal spectra in the CPS and in the PSBL



- P4 in the CPS observed the new ion population ~30 sec before front arrival, with earthward precursor flows.
- P5 in the PSBL detected the new ion population as well, despite the less significant DF signatures in Bz. In fact, they appeared in the PSBL 2 more min earlier than in the CPS, and they resulted in stronger precursor flows.

Ion distribution functions in the PSBL



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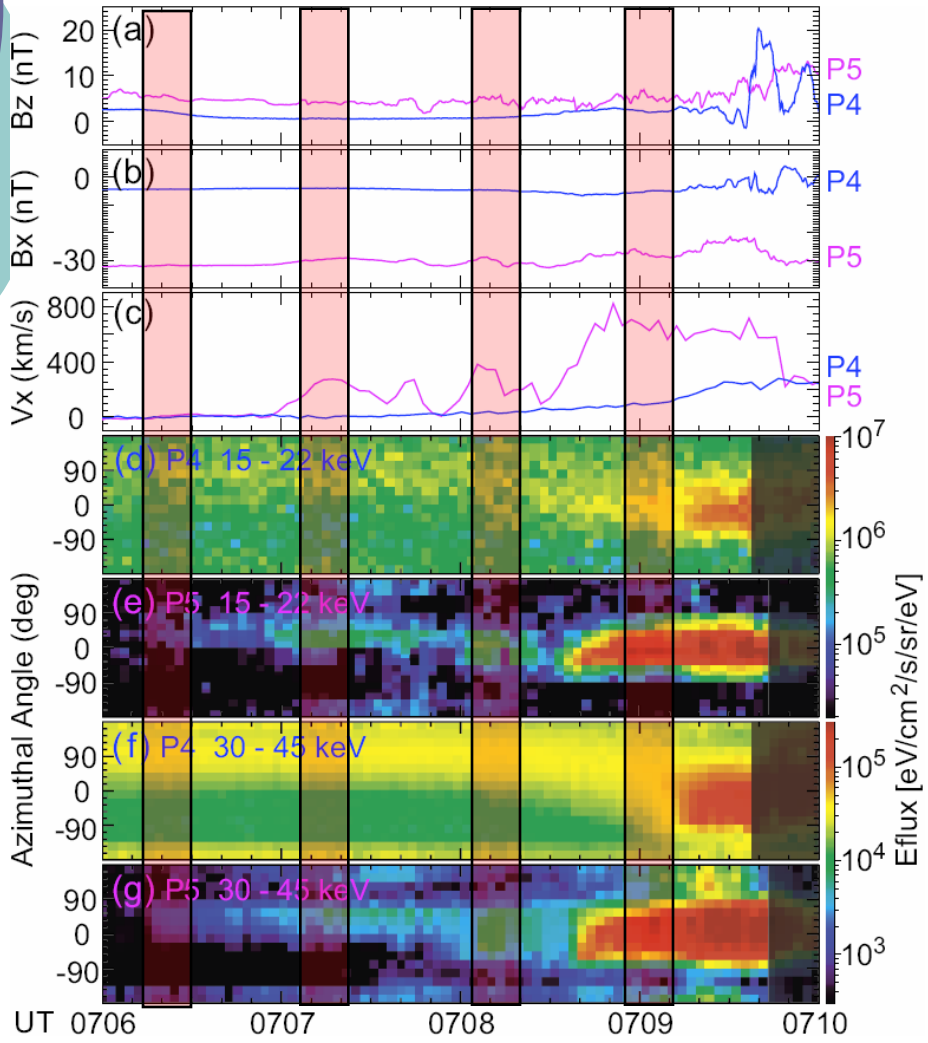

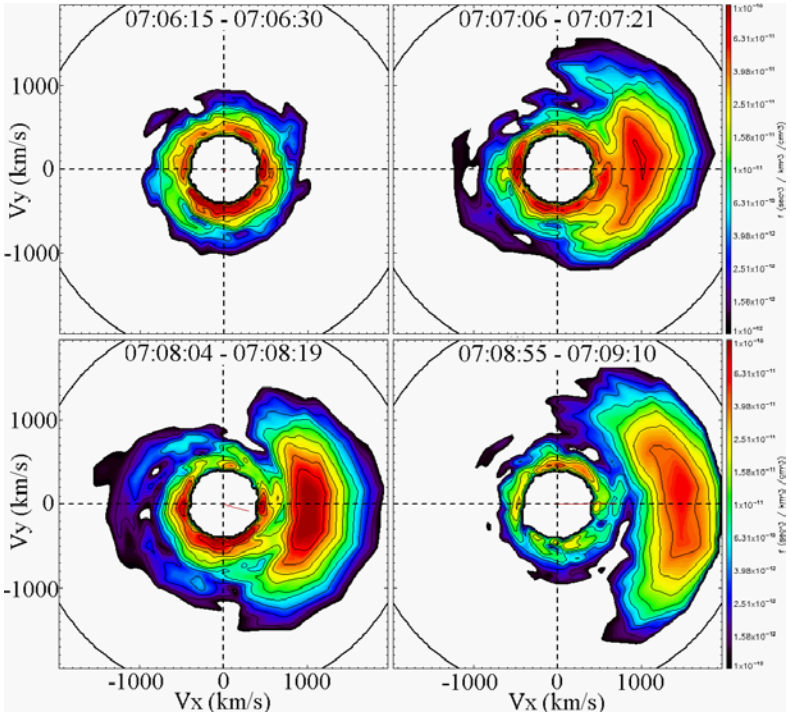

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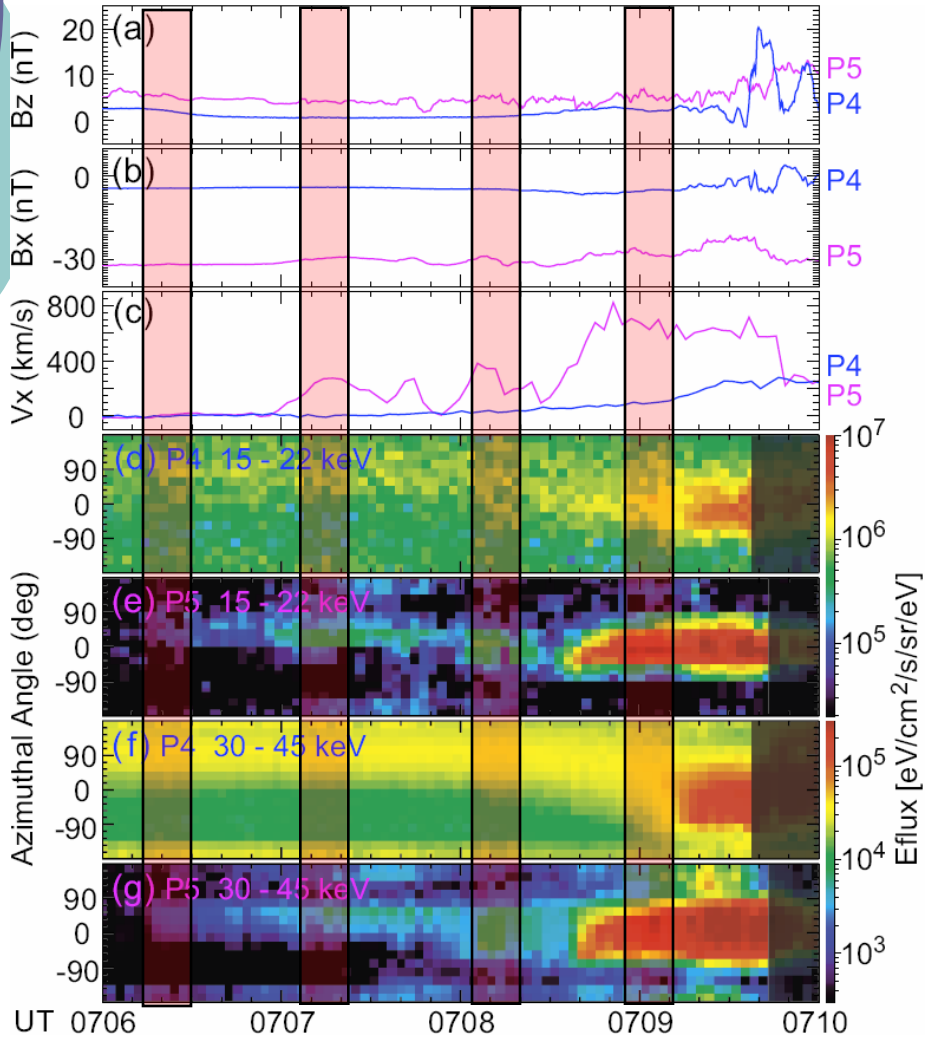
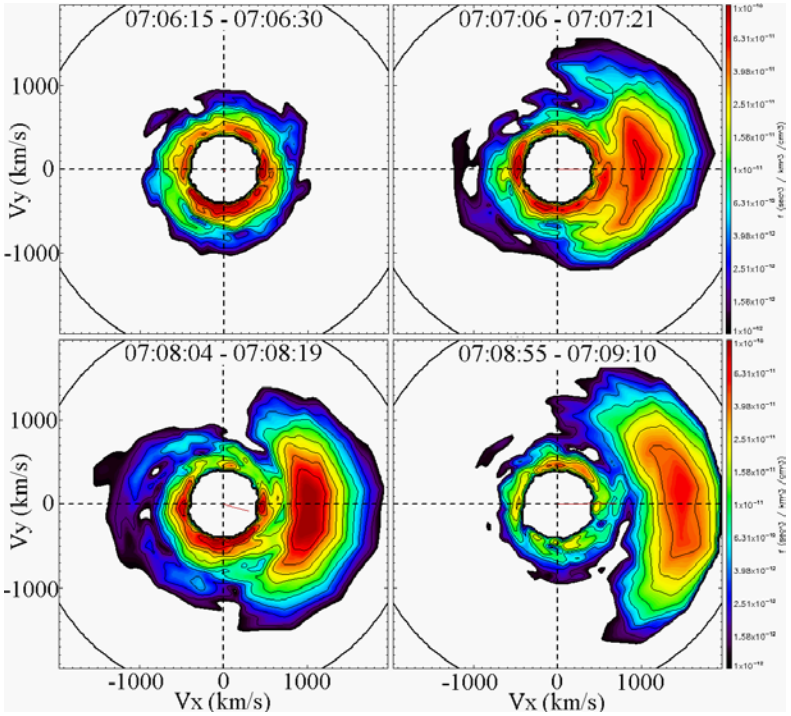
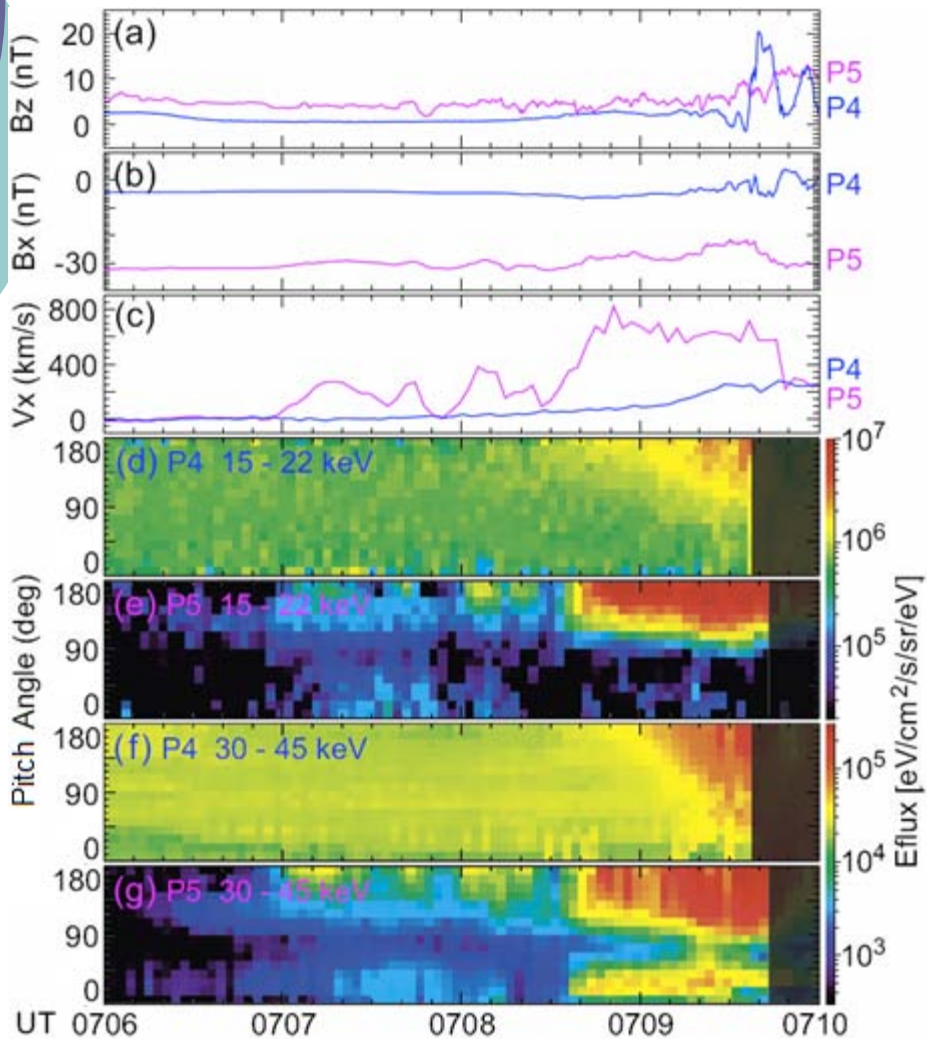




Ion distribution functions in the PSBL show very familiar kidney-bean-shaped structures prior to DF arrivals.

Ion pitch angle spectra in the CPS and in the PSBL



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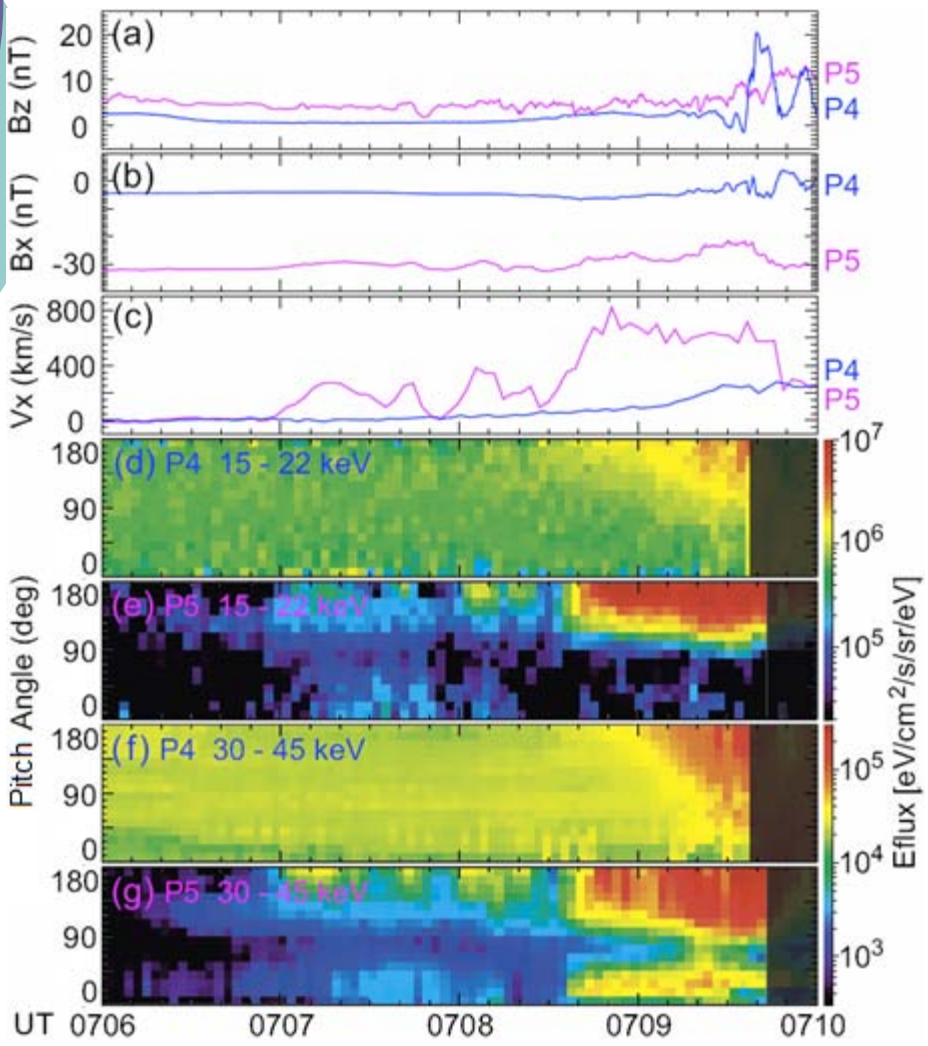
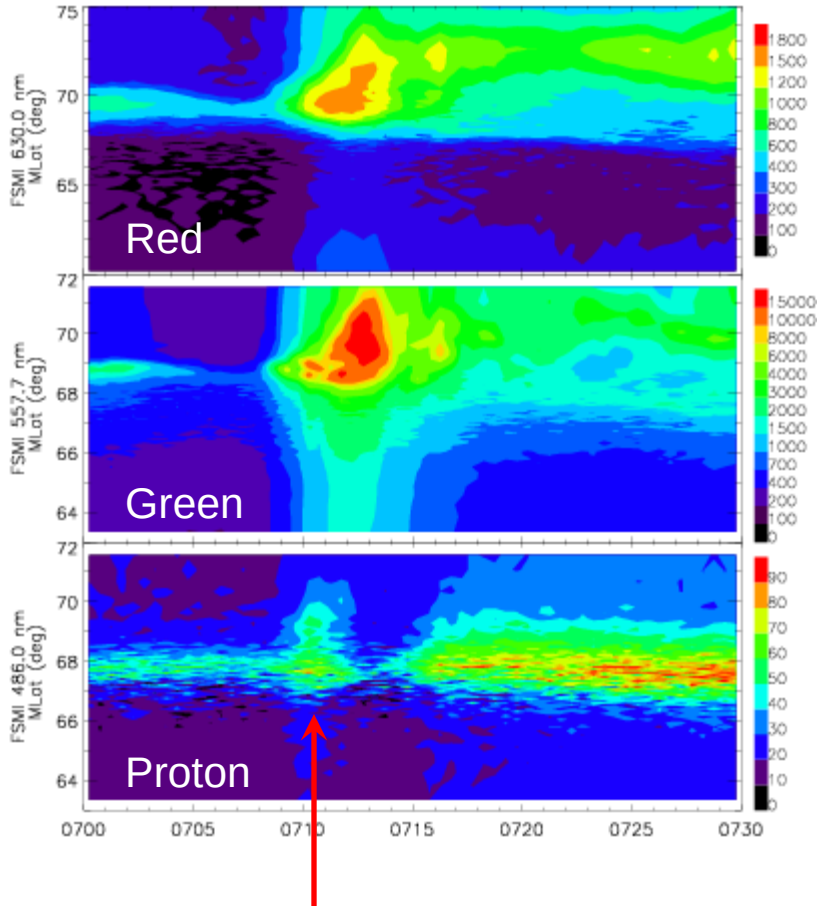
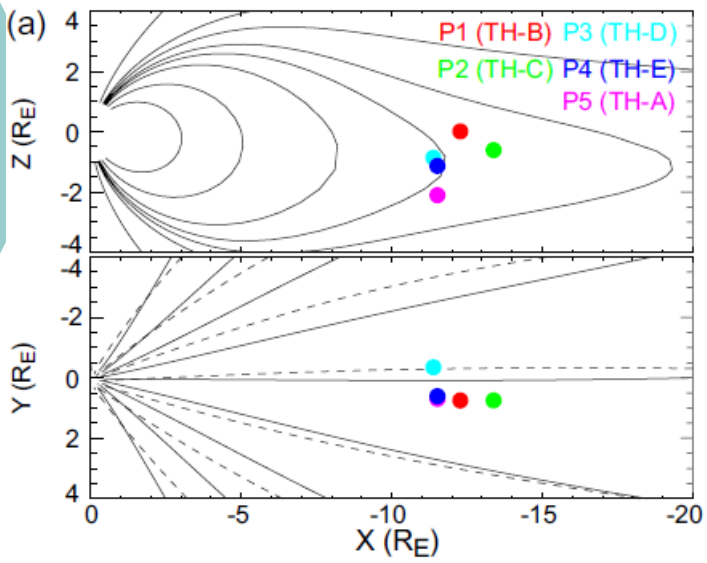
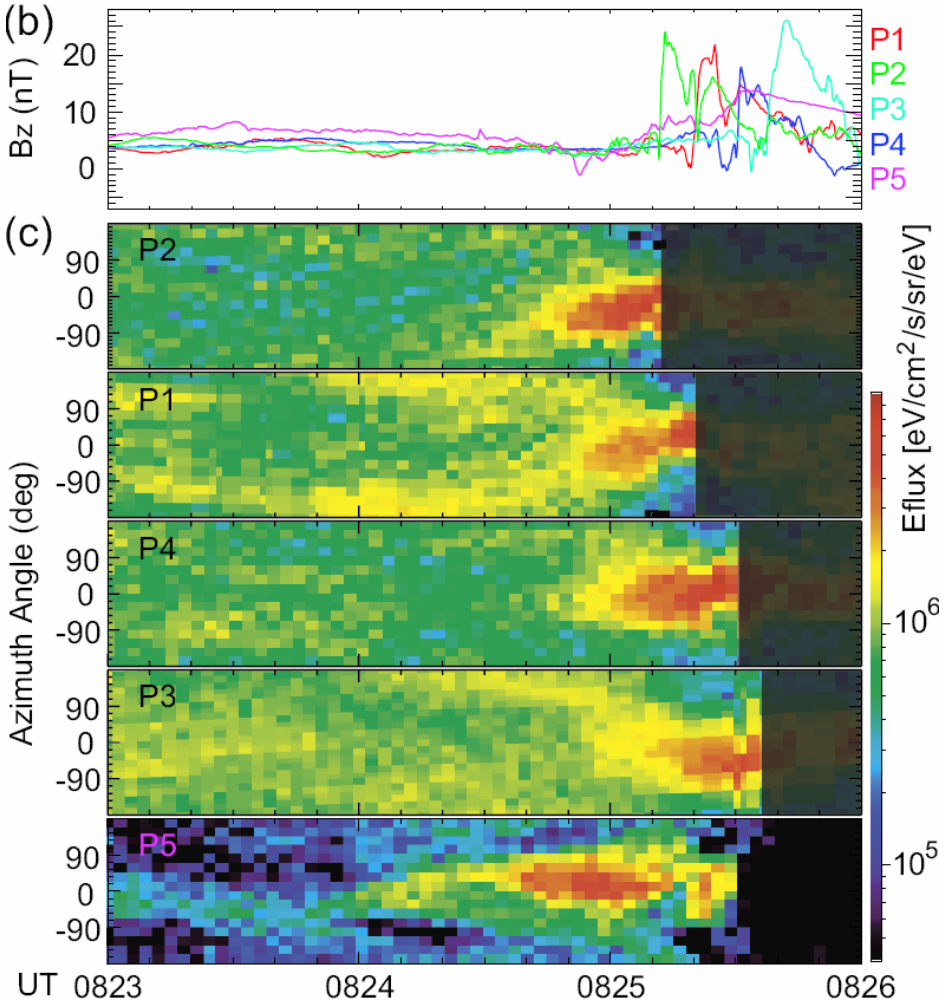




DF-associated proton aurora brightening (in Yasong Ge's talk)

One more Example





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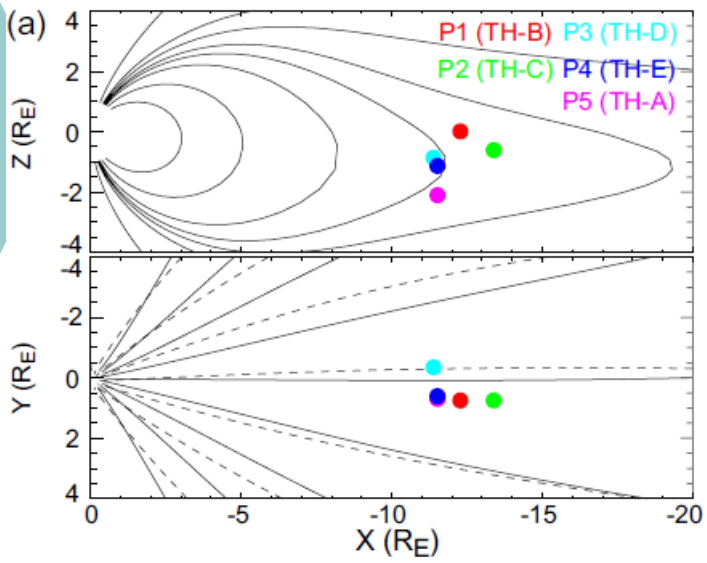
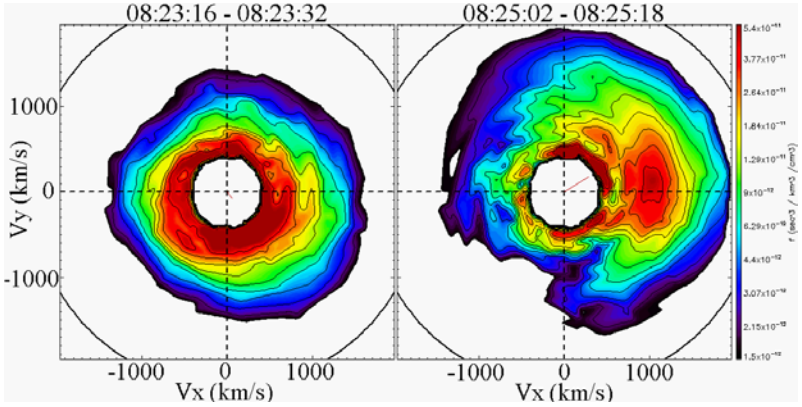
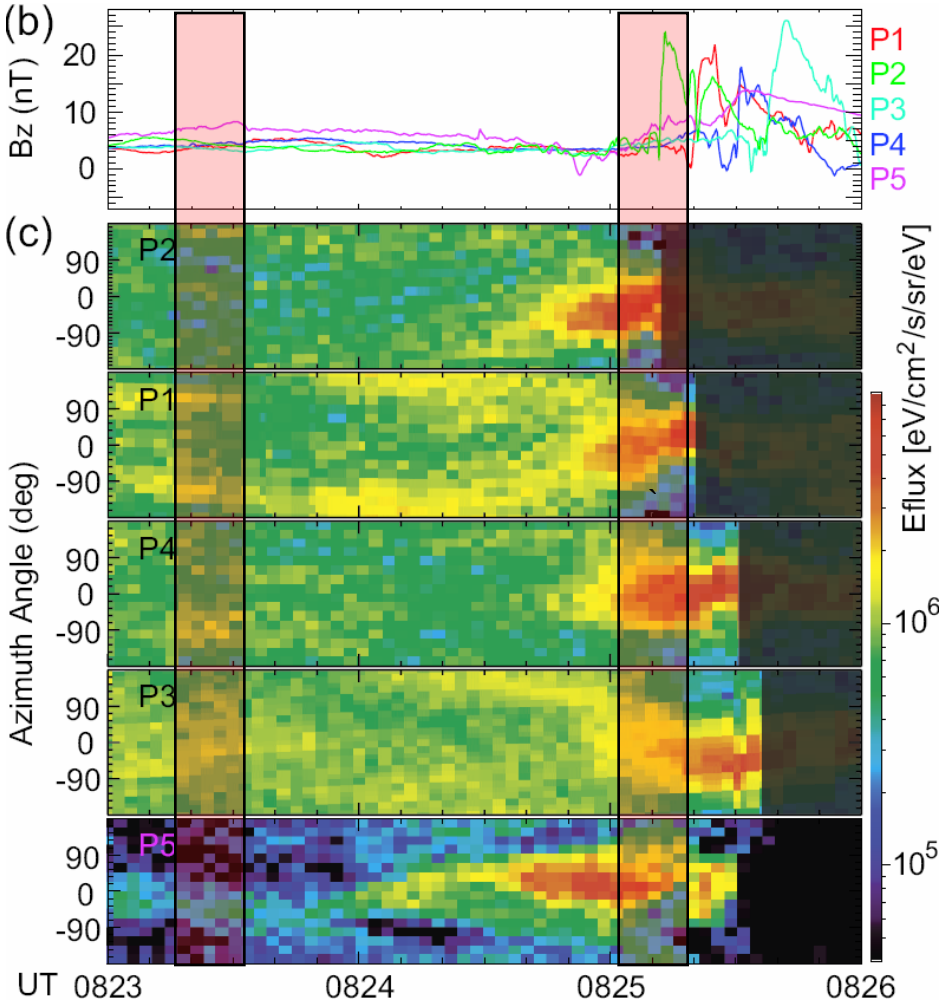


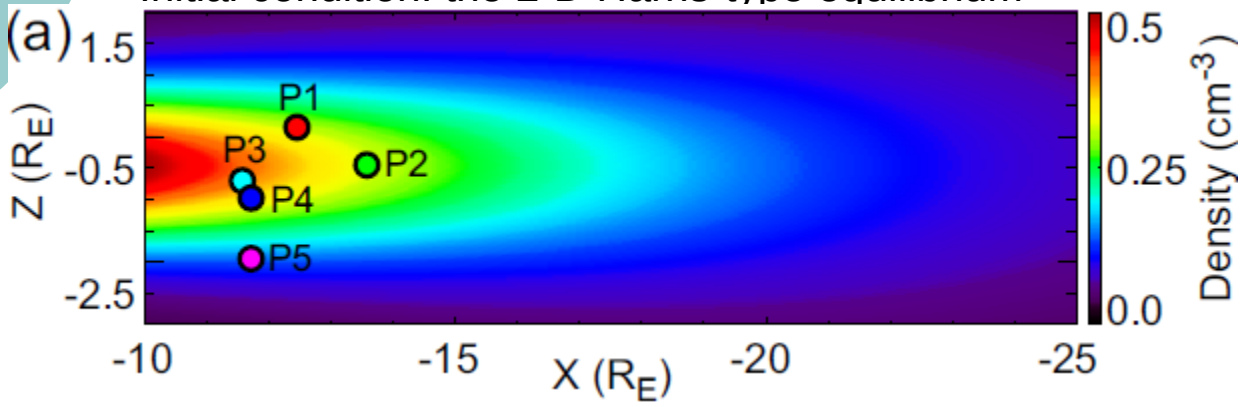




Simulation Setup

- We perform backward-tracing Liouville simulations to reproduce the observed ion spectra & distribution functions.

Initial condition: the 2-D Harris-type equilibrium



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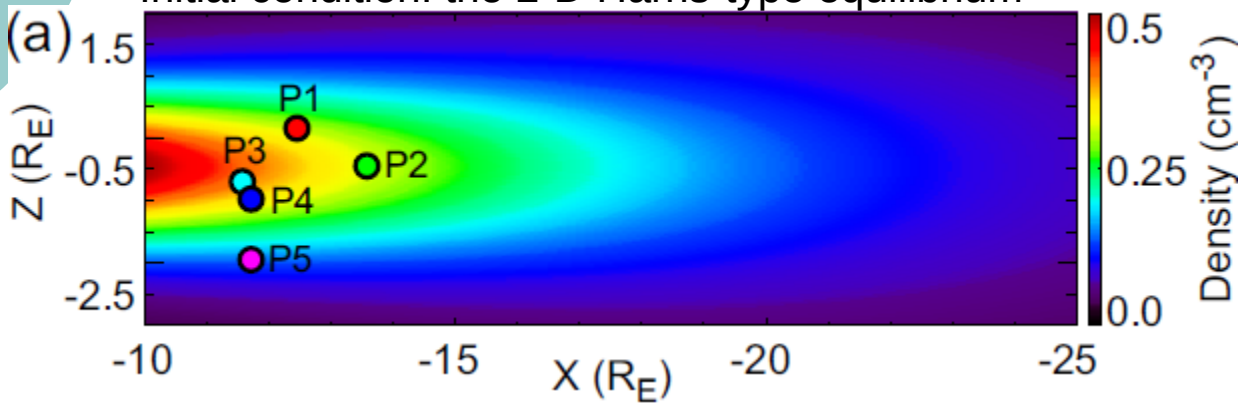
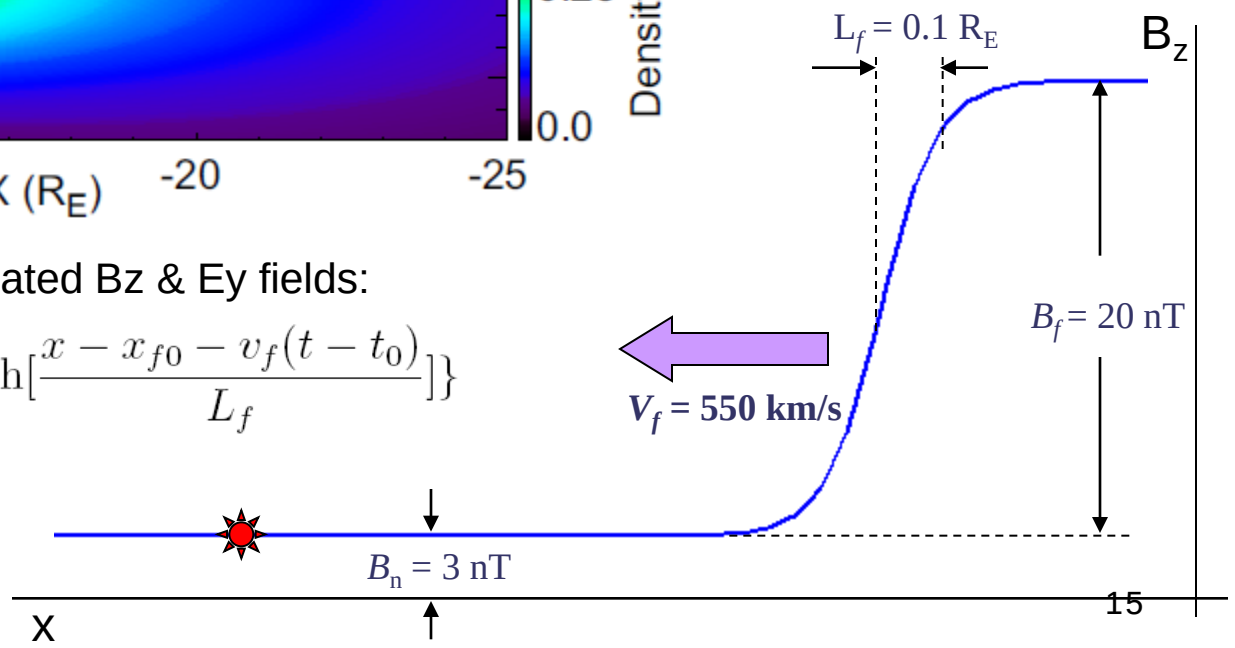


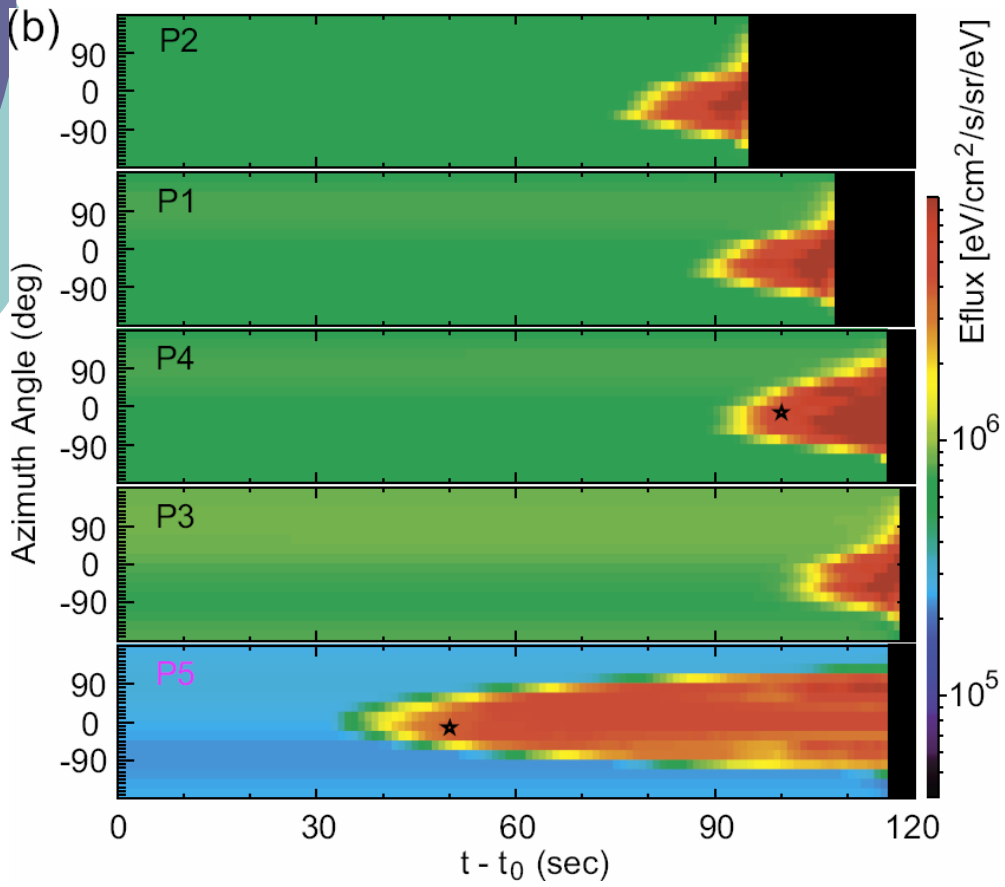
Superposed DF-associated Bz & Ey fields:

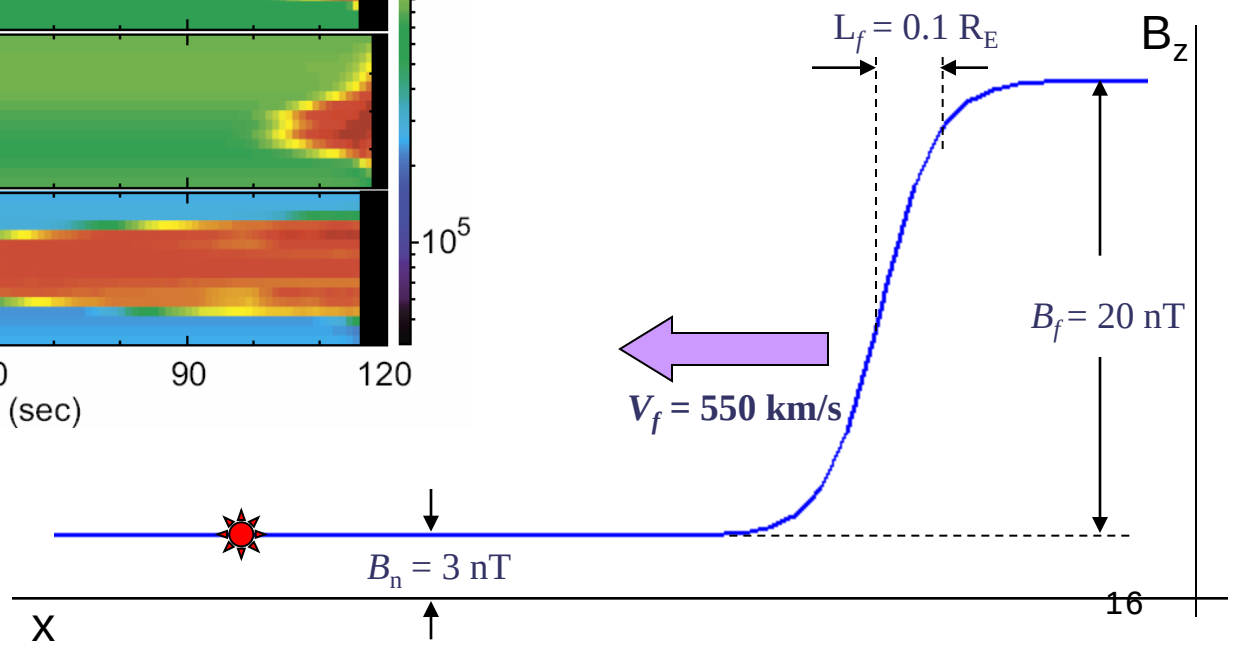
$$B_z(x,t) = \frac{B_f}{2}\{1 - \tanh[\frac{x - x_{f0} - v_f(t - t_0)}{L_f}]\}$$

$$E_y(x,t) = v_f B_z,$$



Simulation Results





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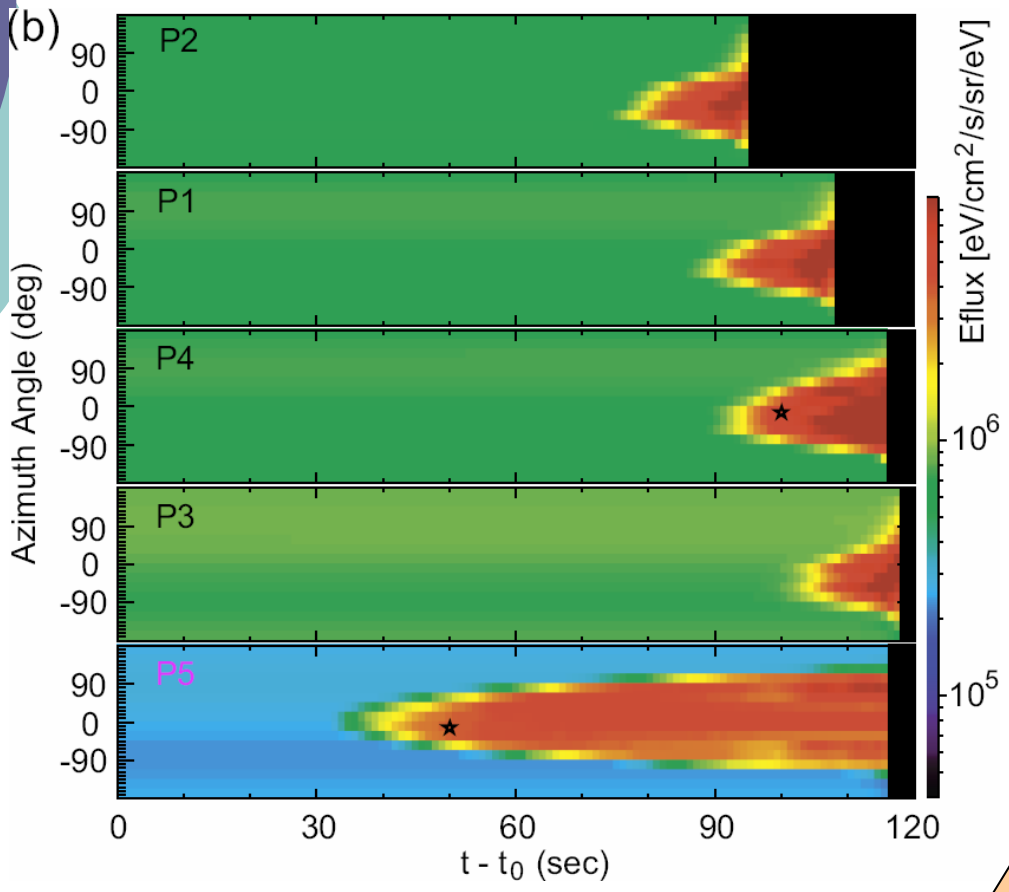
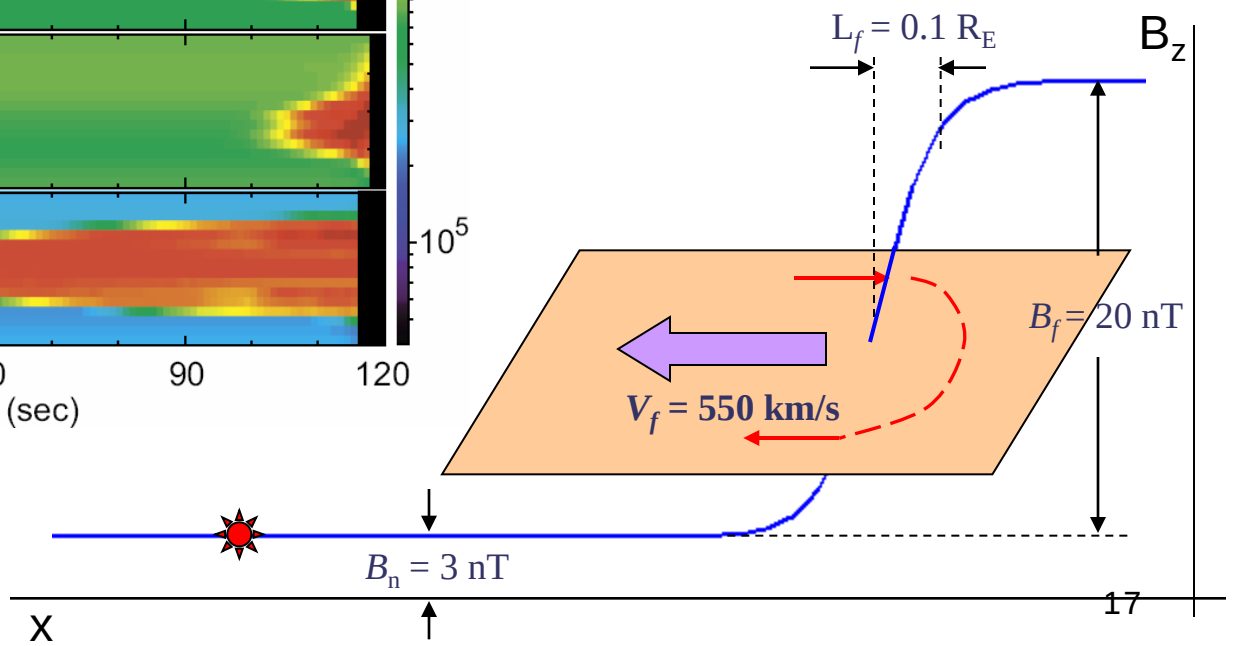


The new population ahead of DF is compose of ions that have been accelerated at and reflected by the front (Zhou et al., 2010, 2011).



Explanations

- The different observations at different latitudes are expected to be caused by the different orbits ions may follow in the upstream unperturbed current sheet after reflected by the front.

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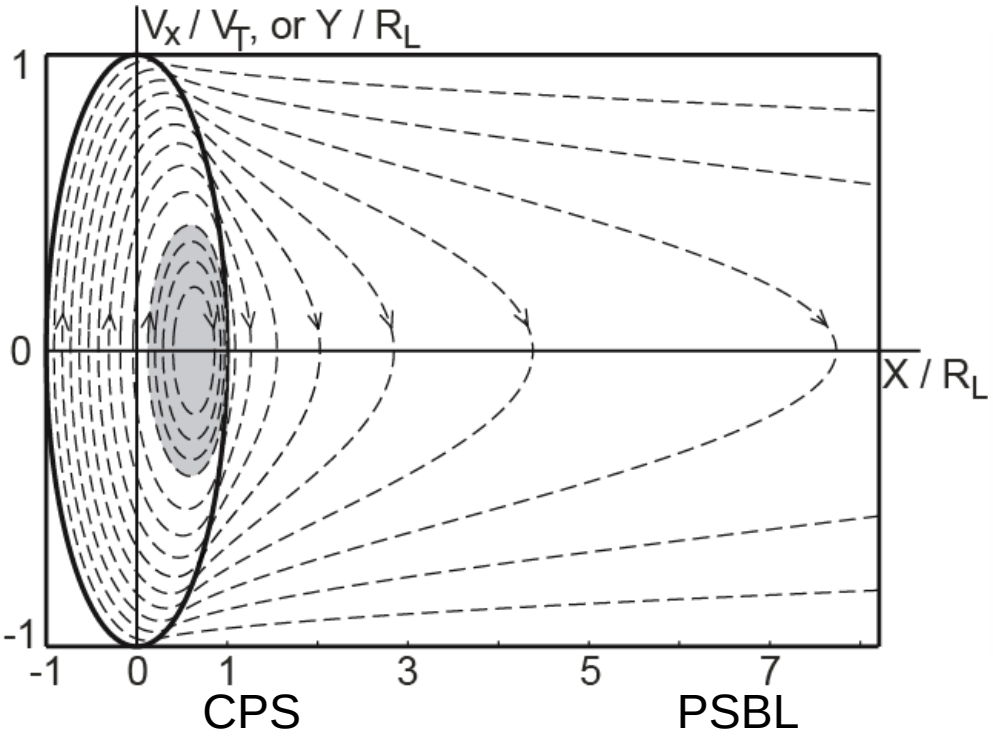

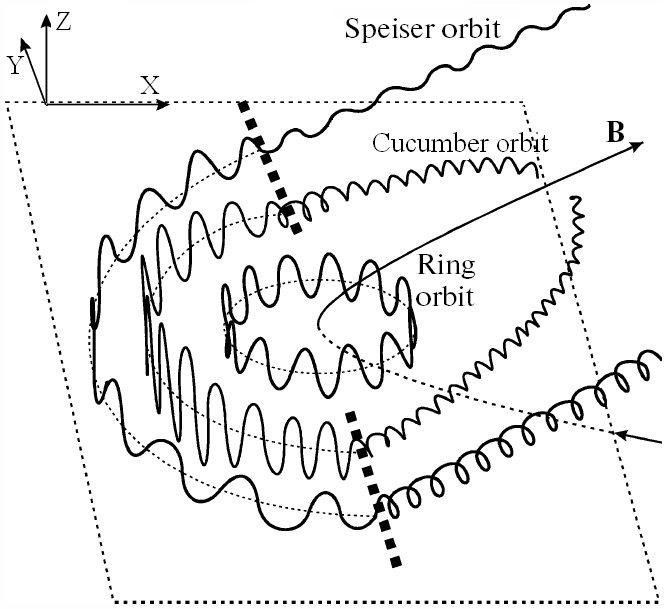

[Buechner & Zelenyi, JGR, 1989]

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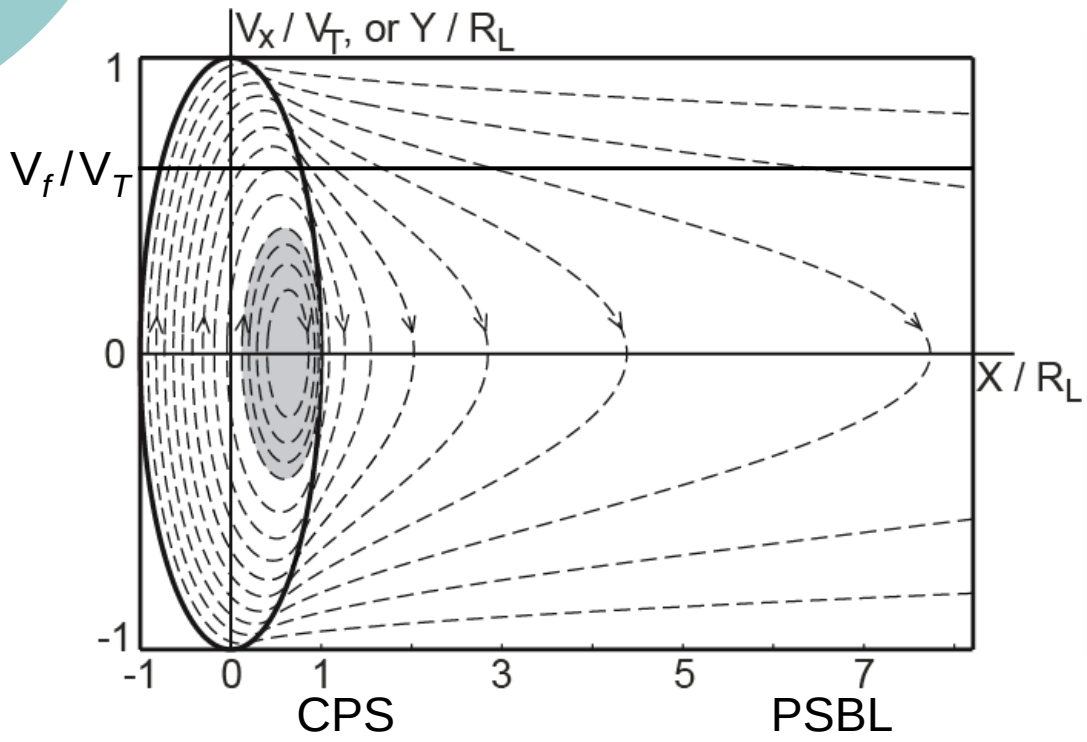

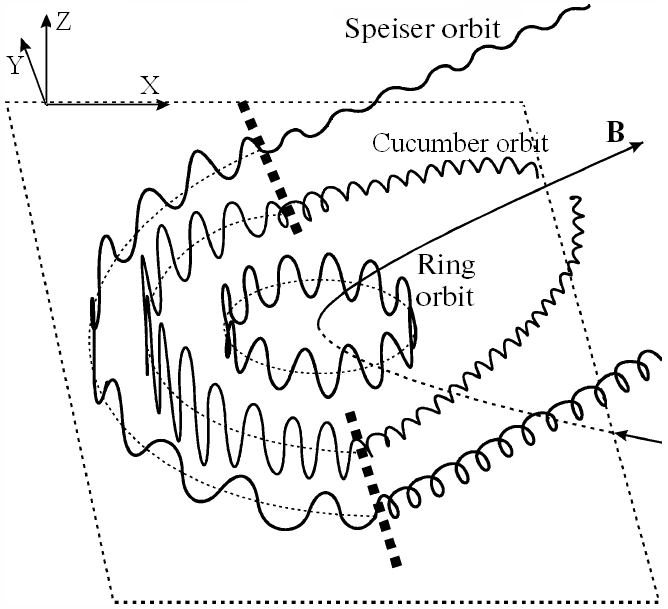

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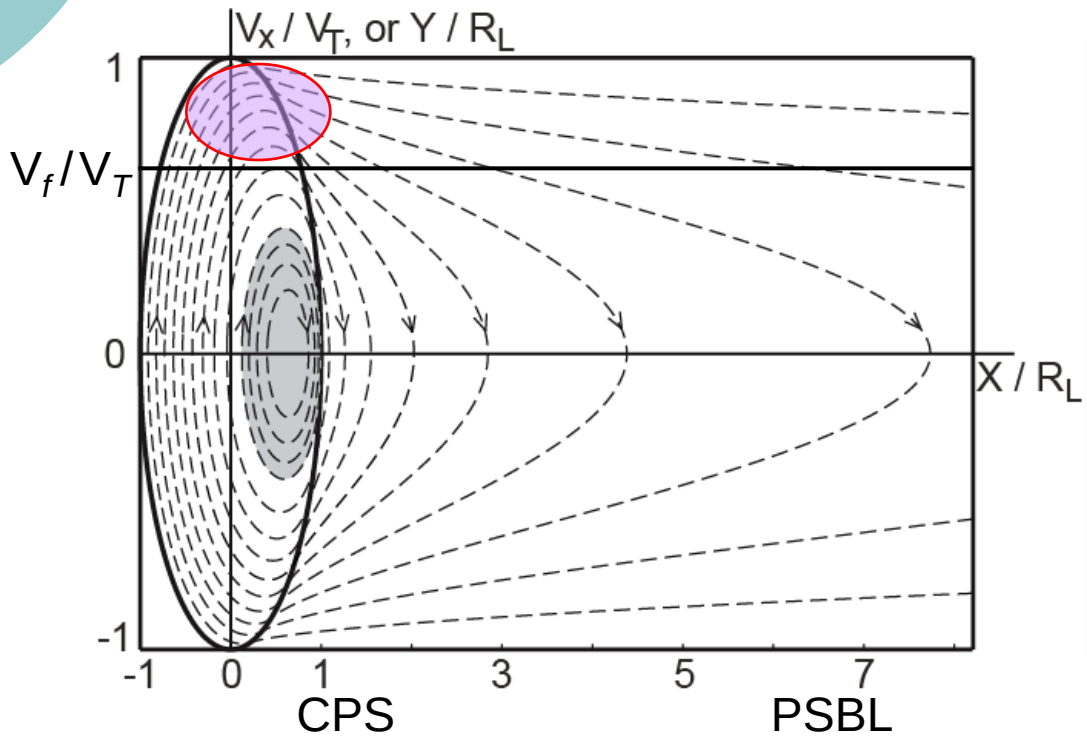

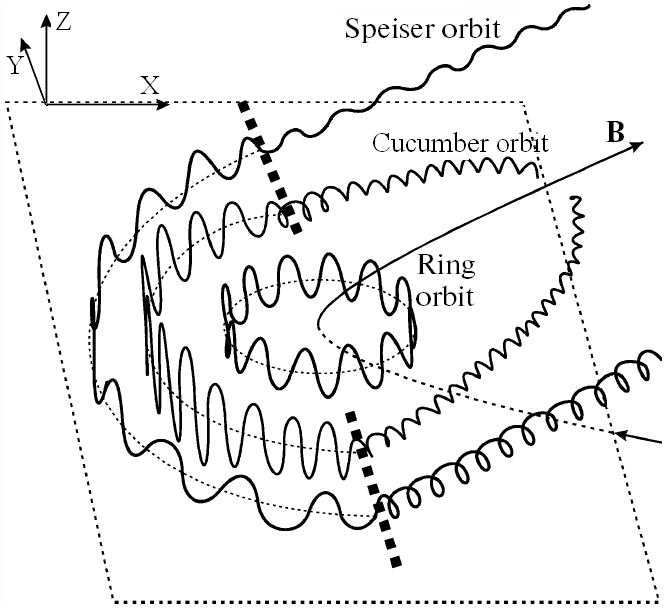

[Buechner & Zelenyi, JGR, 1989]

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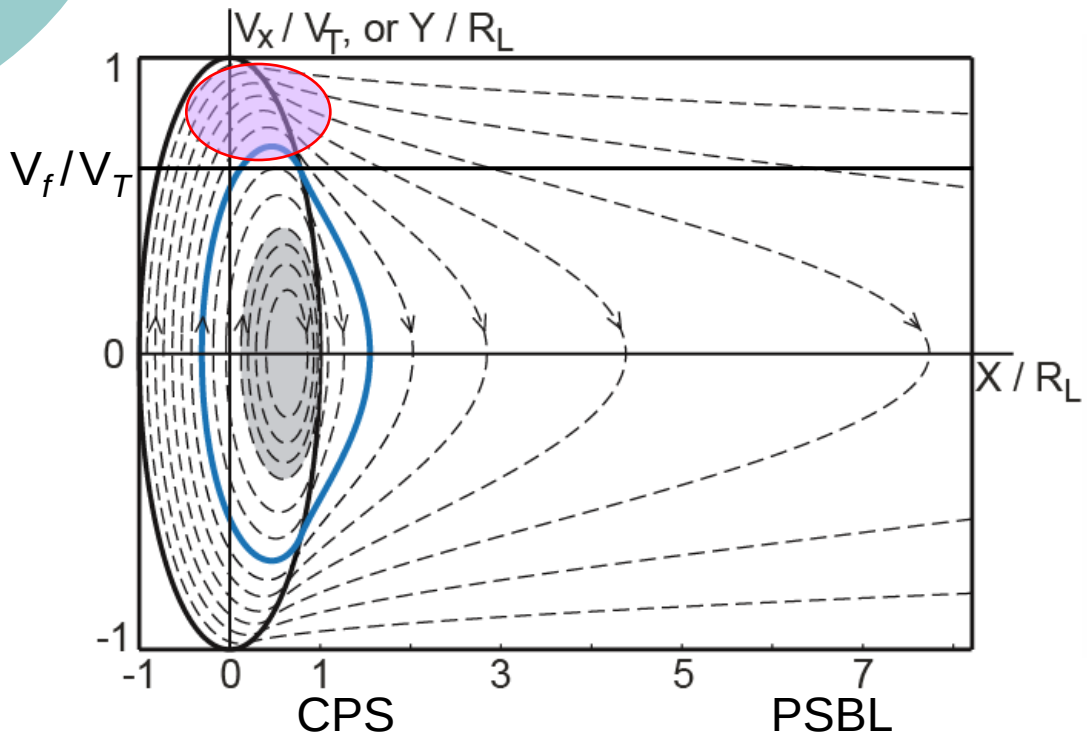
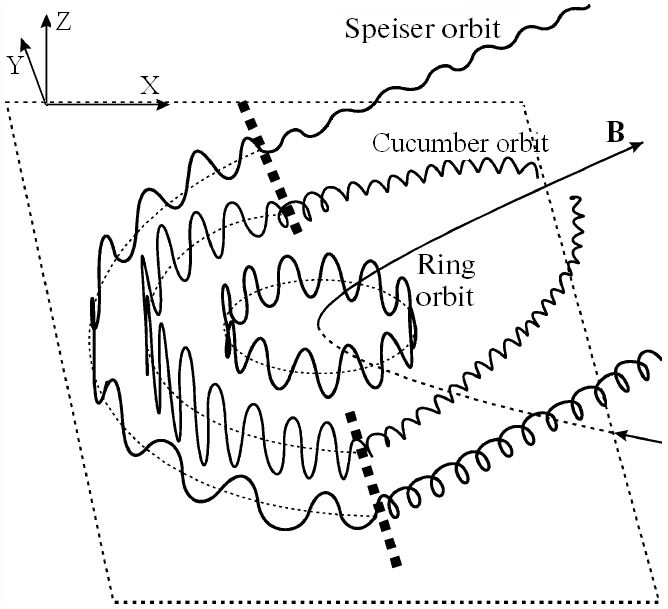
- Some reflected ions would stay in the CPS, being confined in a region characterized by their gyroradii (Zhou et al., JGR, 2011).





[Buechner & Zelenyi, JGR, 1989]

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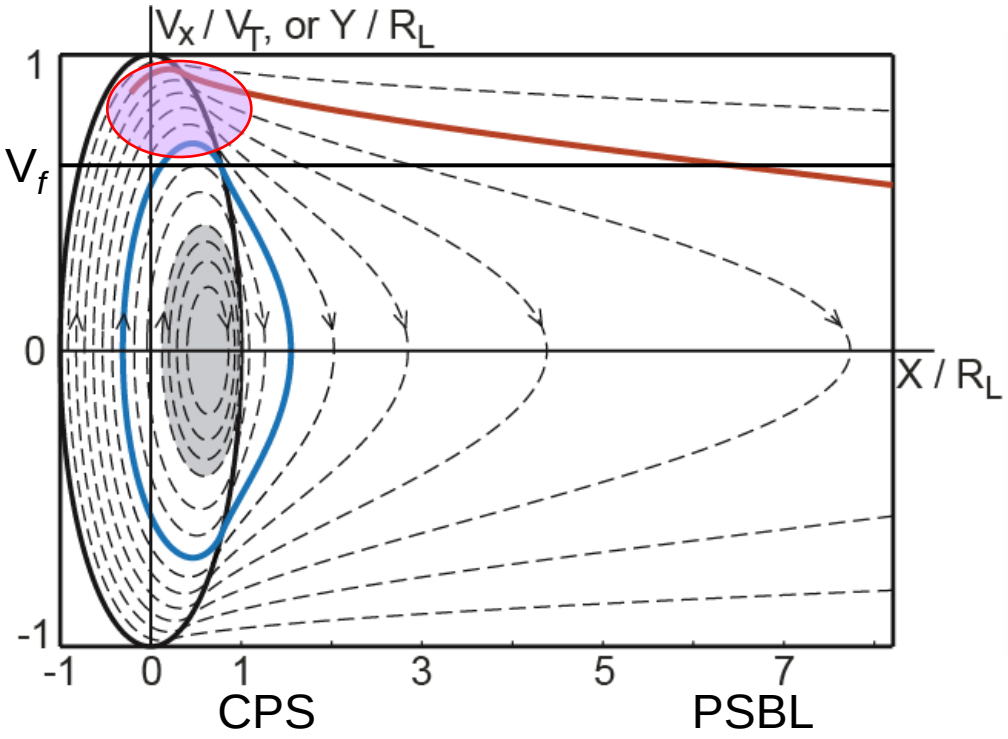
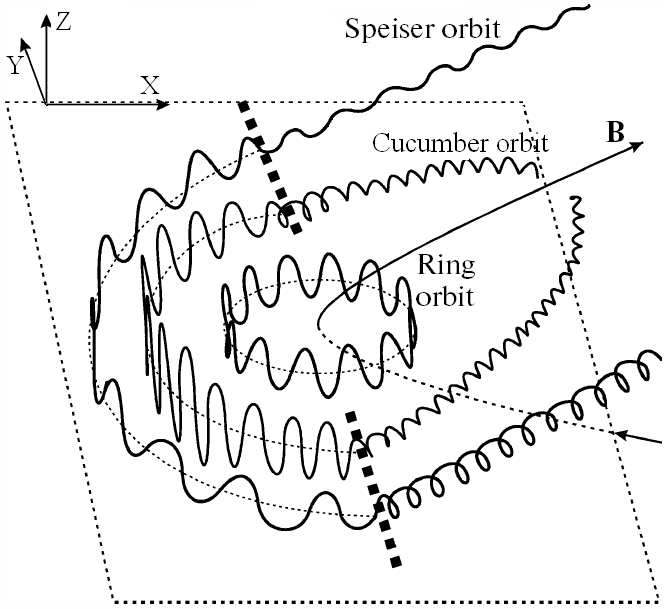
- Other reflected ions, as they depart the CPS towards the PSBL, could keep moving earthward far beyond their gyroradii. They could thus be observed in the PSBL much earlier than in CPS.





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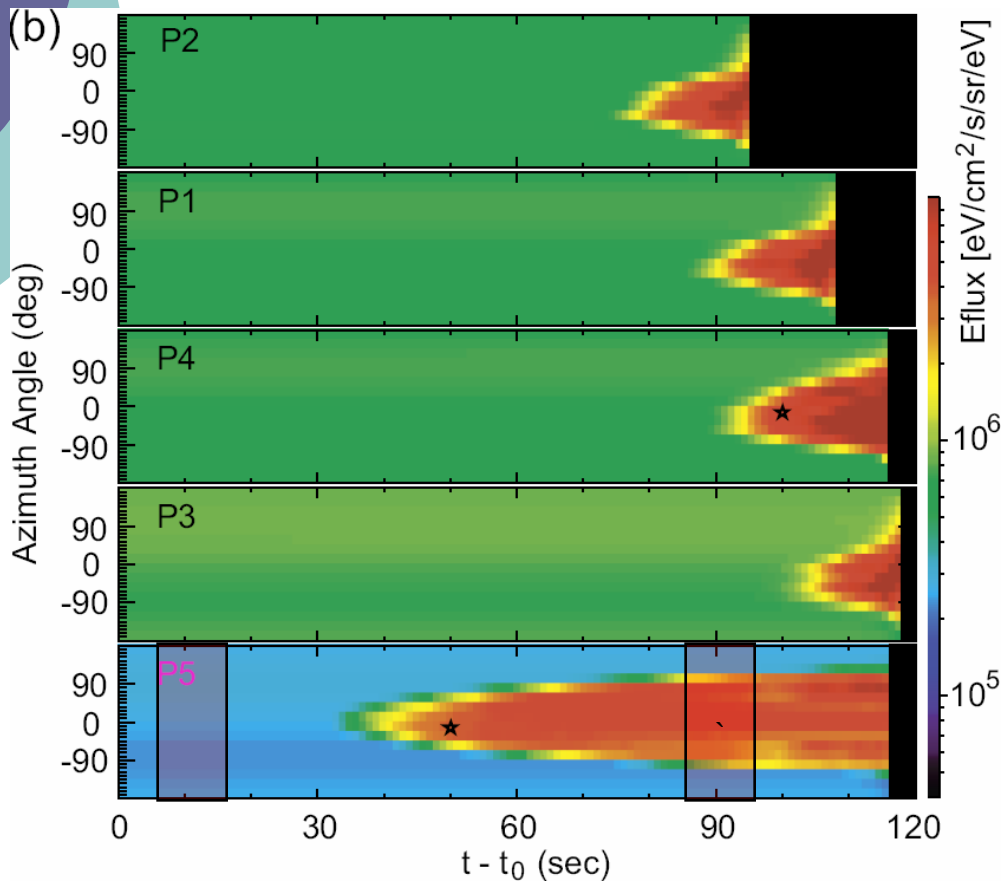
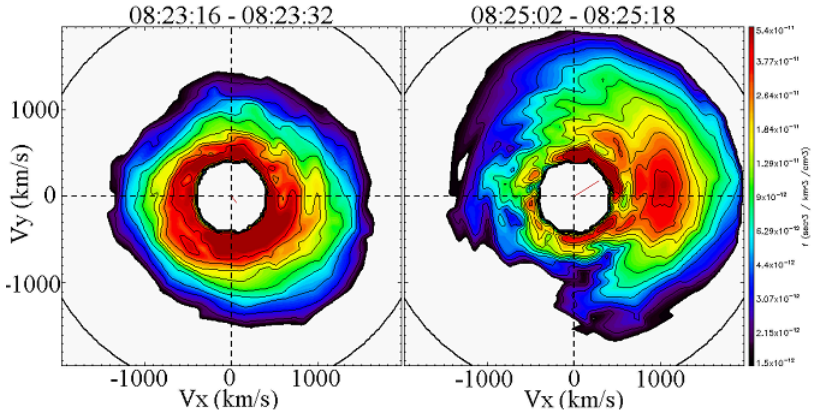
Simulation results



Observations in PSBL



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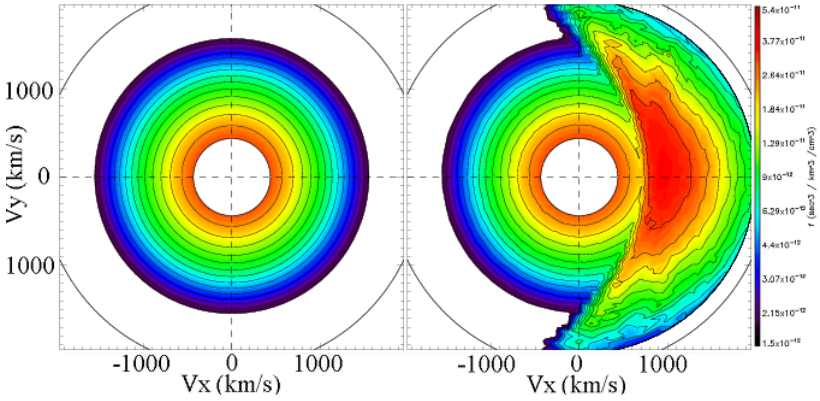

Simulation results

- The kidney-bean-shaped structure of the reflected population suggests:
  - The least energetic ions of the reflected population have dominant Vx component over Vy, with the value of Vf (the front propagating speed).
  - More energetic ions could have smaller, or even negative Vx component.

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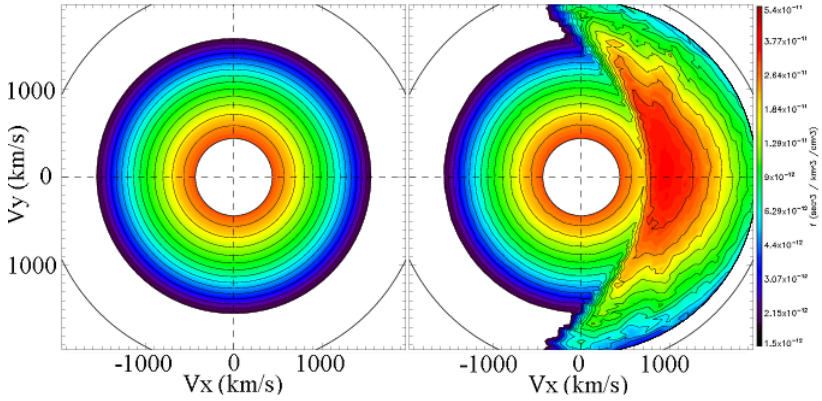

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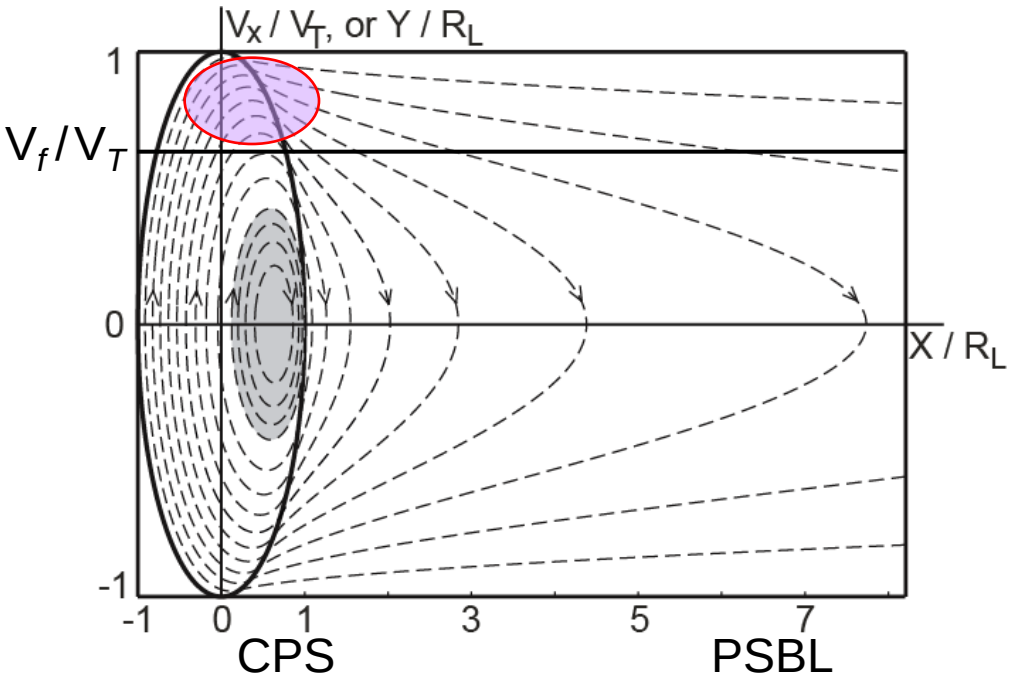

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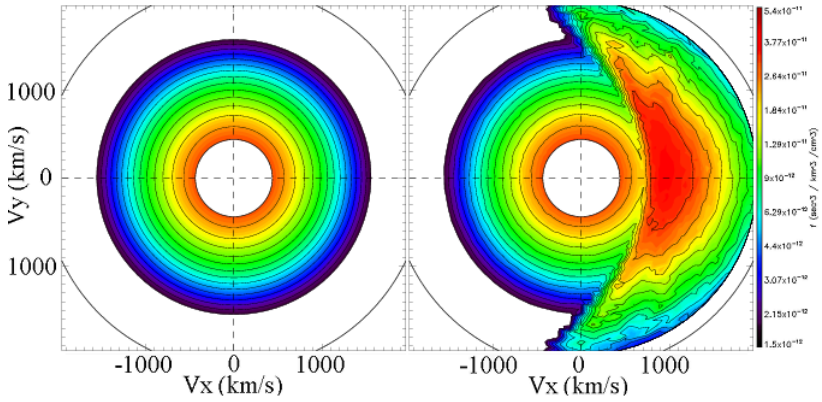

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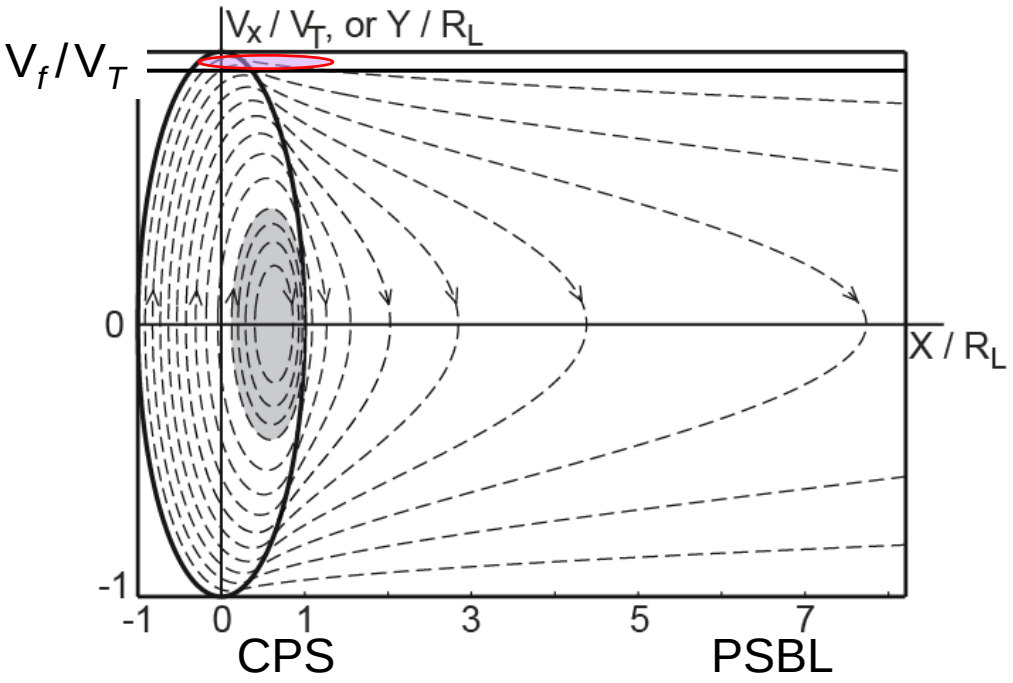

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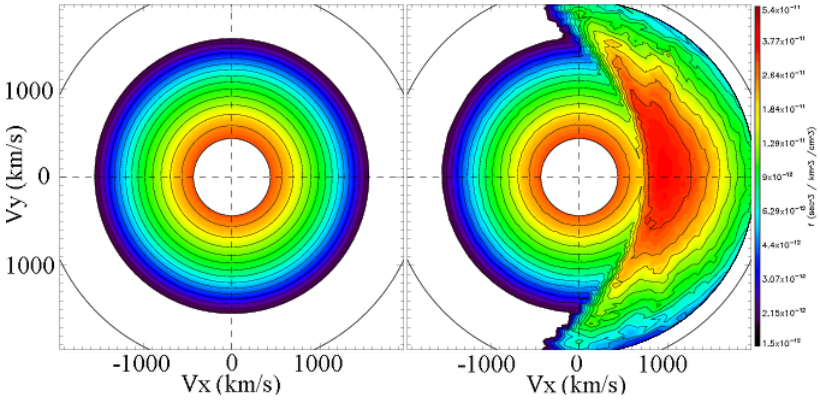

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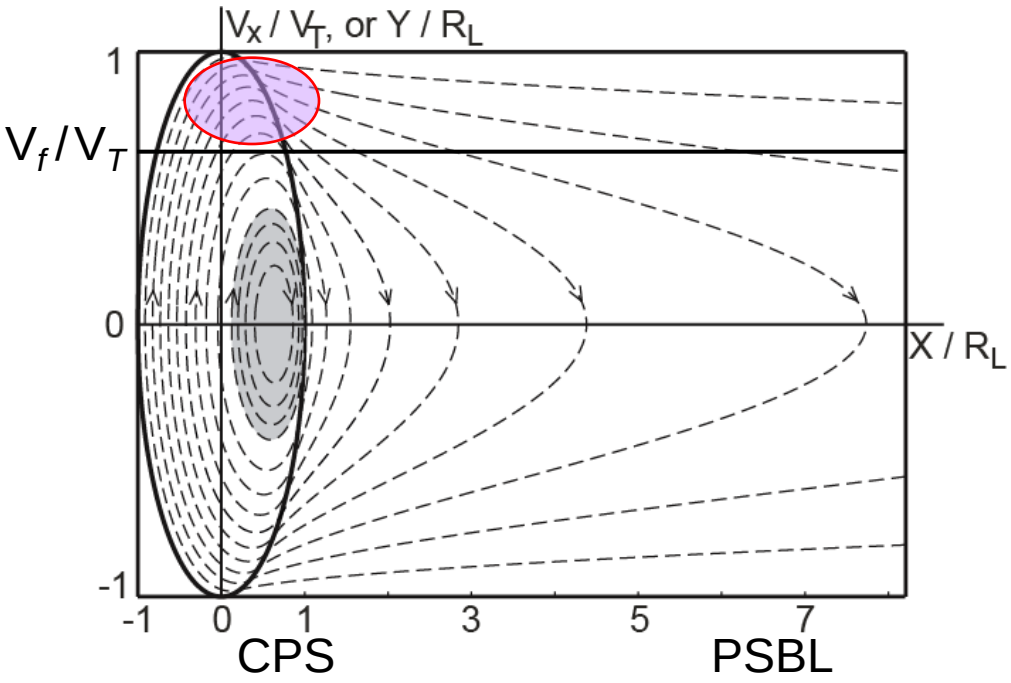

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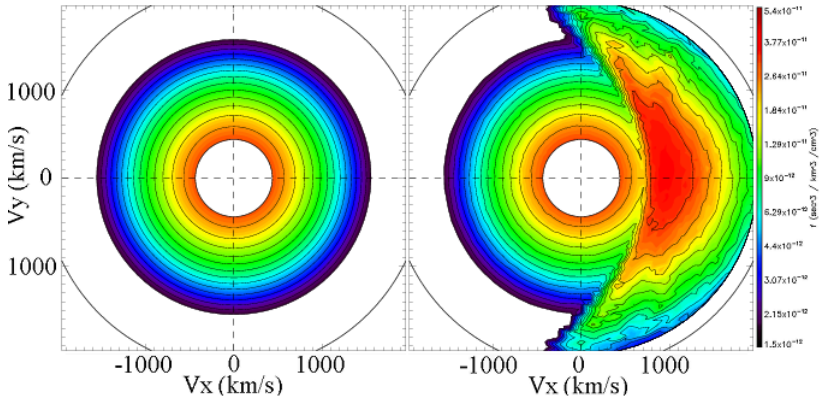

Summary

- One of the most interesting features associated with the earthward-propagating DFs is the appearance of earthward plasma flows well before front arrivals, which are caused by earthward moving ions that have been accelerated at and reflected by the front.

- These reflected ions, as a new population, are observed ~ 30 s before DF arrivals in the CPS, and a few more minutes earlier in the PSBL. They appear in the PSBL as a kidney-bean-shaped structure.

- These observational signatures are well reproduced by simulations, and are explained by the Buechner & Zelenyi (JGR, 1989) theory of ion motion in the current sheet.