EMBRY-RIDDLE Aeronautical University

User Feedback and Future Possibilities on Using CCMC For Our Magnetospheric Physics Research Projects

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Acknowledgements: *Emily Hyatt, Thomas W Moore, Alex Sjogren, Eric Adamson, Antonius Otto, CCMC, Cluster FGM, CIS, EFW and RAPID instrument teams*

CCMC workshop , Key Largo 18th of January, 2012

Outline

Introducing our past and current research projects, discuss how CCMC models have been and currently are used in these research projects and ***what we would like to do in future using CCMC***

- **Introduction to Research Projects**

- **Kelvin-Helmholtz instability (KHI) at the LLBL**
- **Ionospheric Signatures of the (KHI)**
- **Large scale Magnetosheath structure for various IMF conditions**
- **Formation, dynamics and particle energization in CDC.**

Kelvin-Helmholtz instability (KHI) at the LLBL

Observations of KH: (Scopke, Fairfield, Fujimoto, Hasegawa, Nykyri, Foullon, Taylor etc.)

Simulations of KH: (Miura, Belmont, Wu, Wei, ..)

Miura: Viscous diffusion (momentum transport) coefficient:

$D=10^9 m^2 s^{-1}$

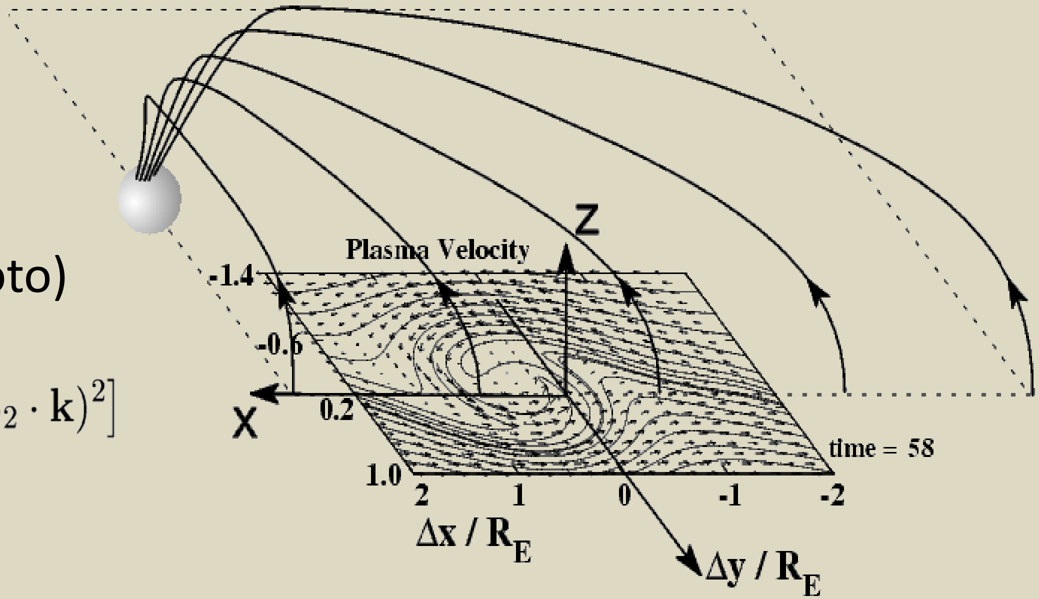
Borovsky, 1998; Fujimoto, 1998: Cold dense plasma sheet for northward IMF

Mass transport (Otto, Nykyri, Fujimoto)

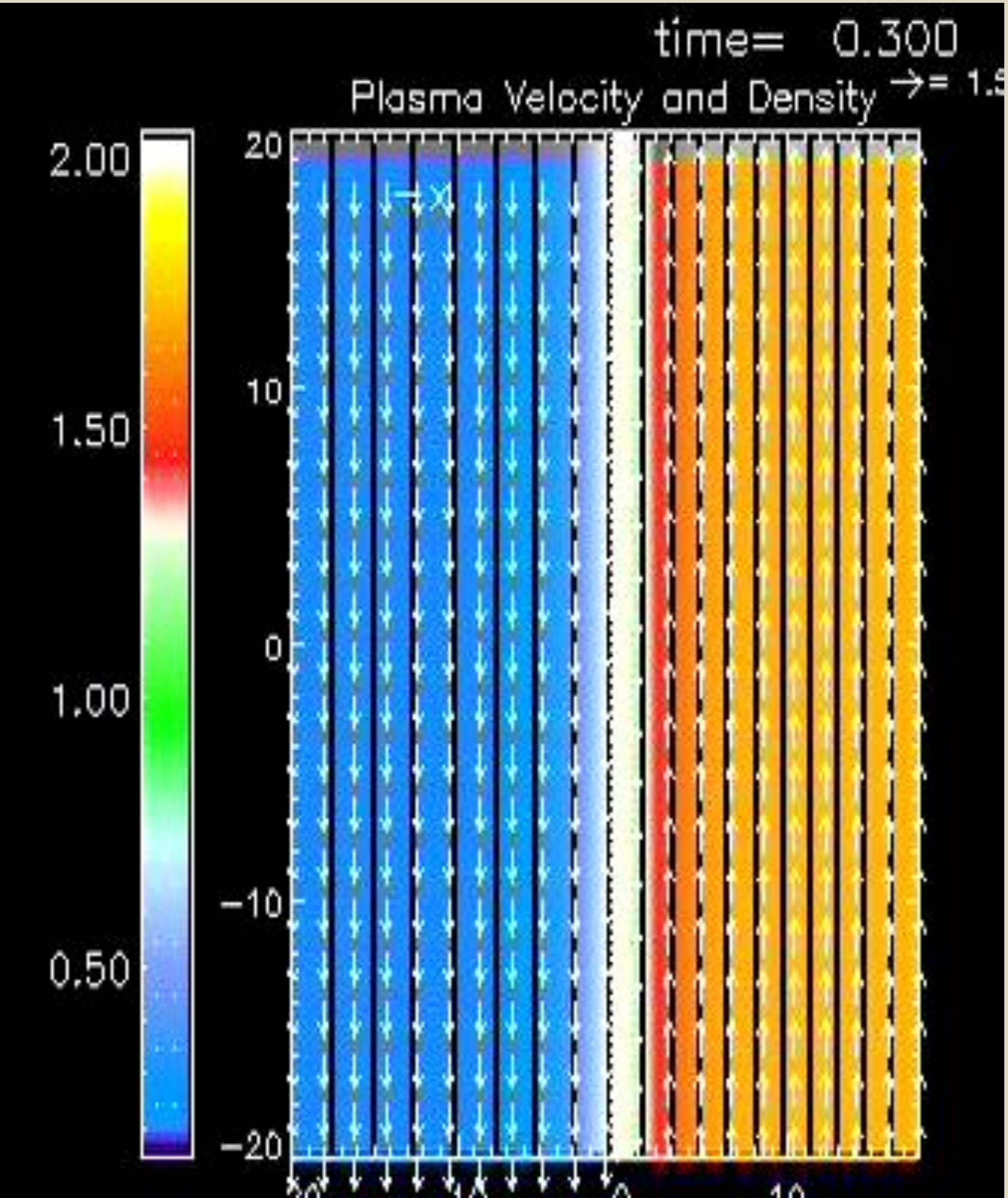
.

$$[(\mathbf{V}_1 - \mathbf{V}_2)\cdot \mathbf{k}]^2 > \frac{n_1+n_2}{4\pi m_0 n_1 n_2}\left[(\mathbf{B}_1\cdot\mathbf{k})^2 - (\mathbf{B}_2\cdot\mathbf{k})^2\right]$$

For strongly northward IMF B·k≈0



Kelvin-Helmholtz instability (KHI) at the LLBL



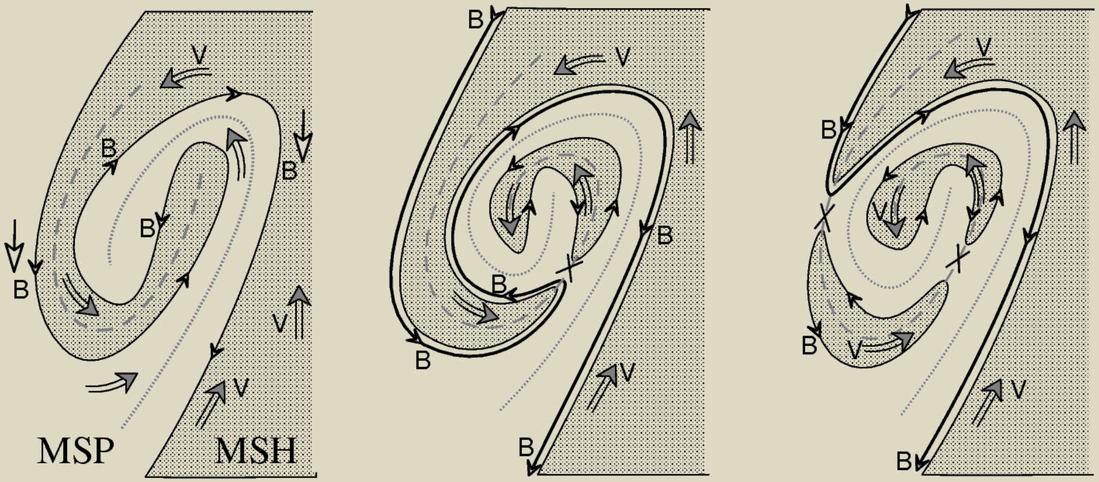
MHD simulation of KHI

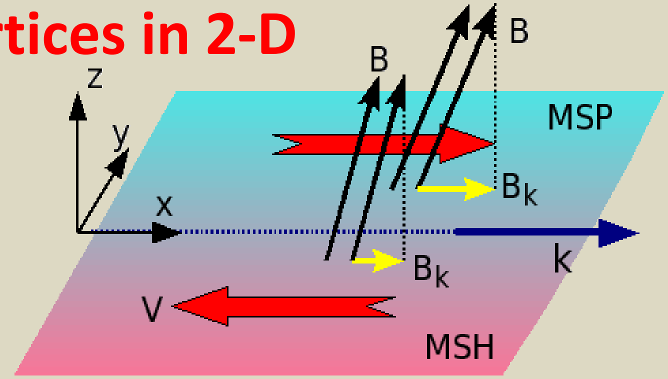
- Lines are magnetic field lines
- Arrows are plasma velocity vectors
- Color code represents plasma density

Wave length,

$$\lambda = 4\ R_E$$

Two Mechanisms for Reconnection in KHI Vortices in 2-D





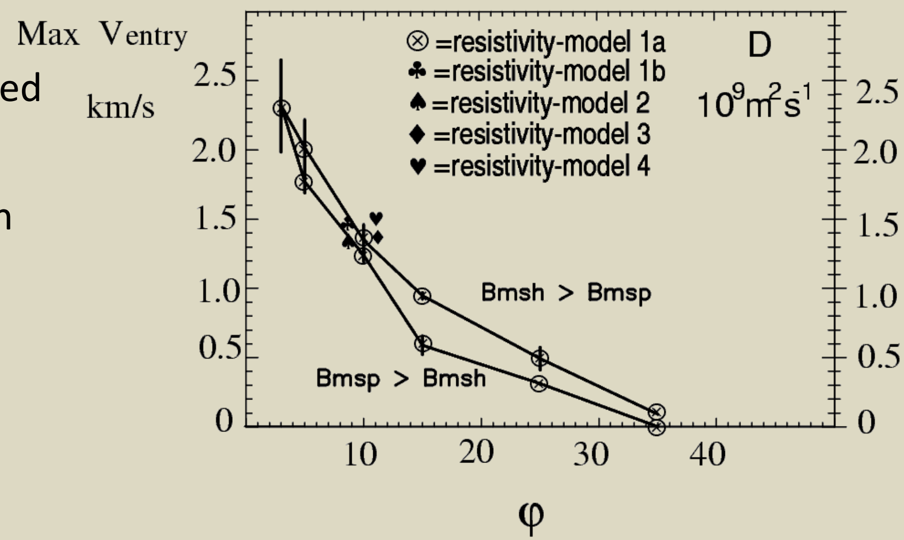
1. Initial conditions contains

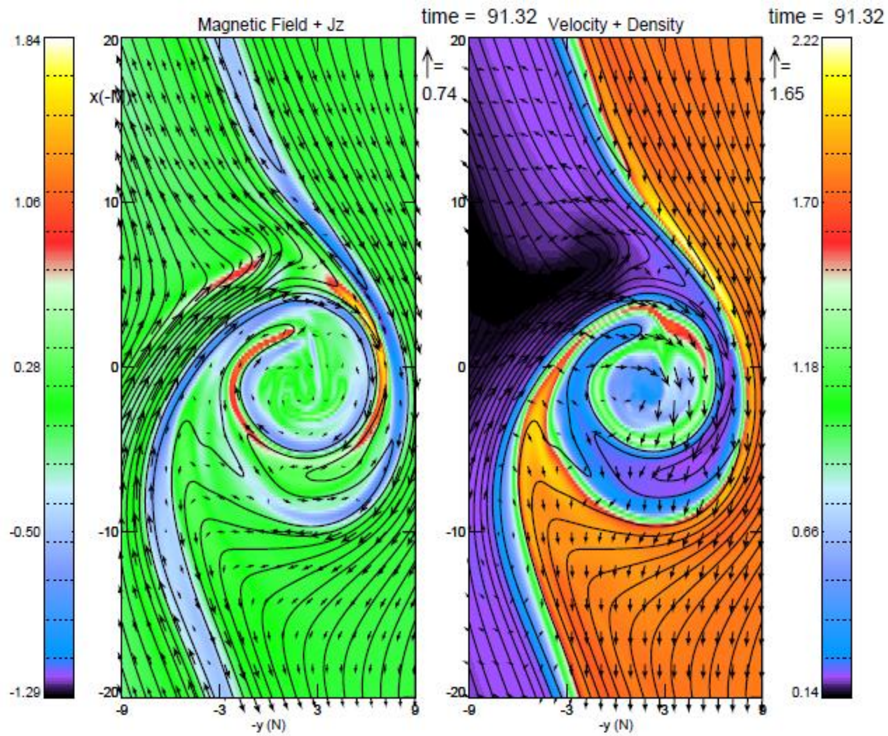
B_0 || k =>

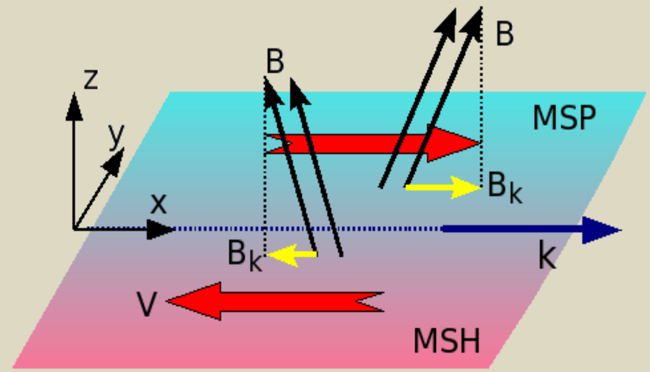
- Vortex motion generates anti-parallel magnetic field. Current density ~ n, B_0.
- **This does not require a pre-existing current layer (magnetic shear)!**

Mass transport rate:

- Mass transport rate consistent with observed plasma transport for northward IMF.
- Mass transport occurs always from the high density into the low density region!
- Mass diffusion coefficient of $10^9 m^2 s^{-1}$ (1-3 km/s * 1000 km)

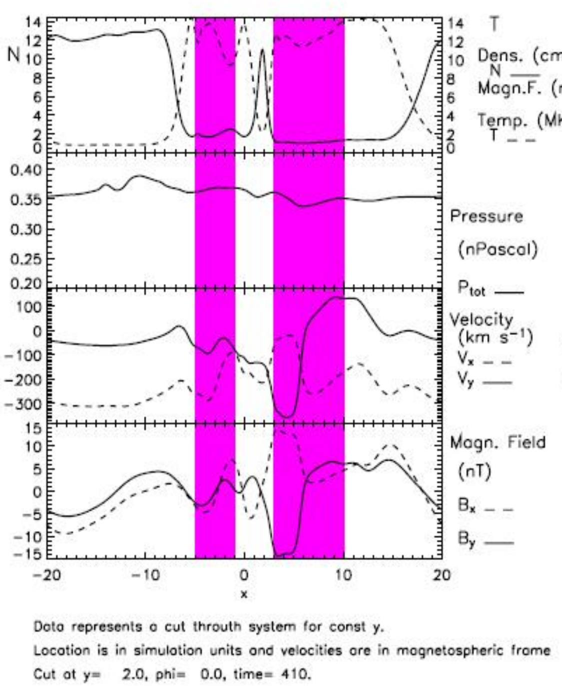


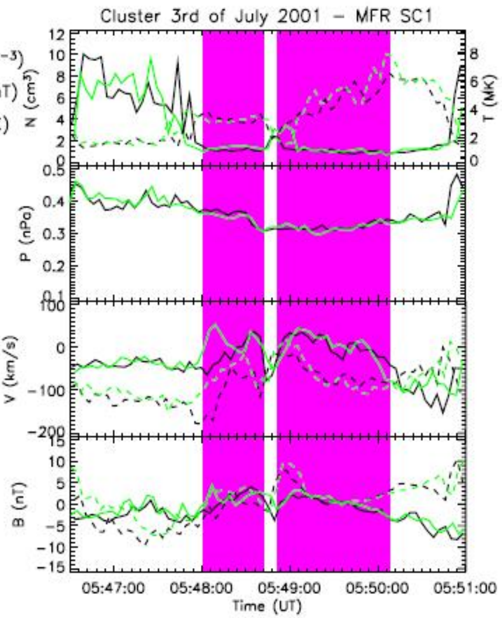




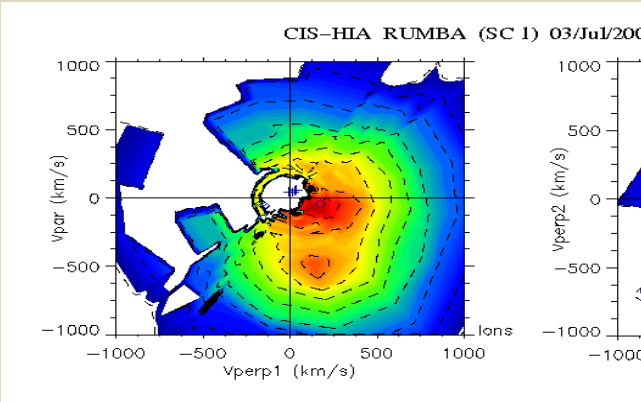
2. If magnetic field lines are anti-parallel in the KH plane=>

- Plasma mixing in the tearing island
- But: Unclear whether plasma is transported onto closed geomagnetic flux

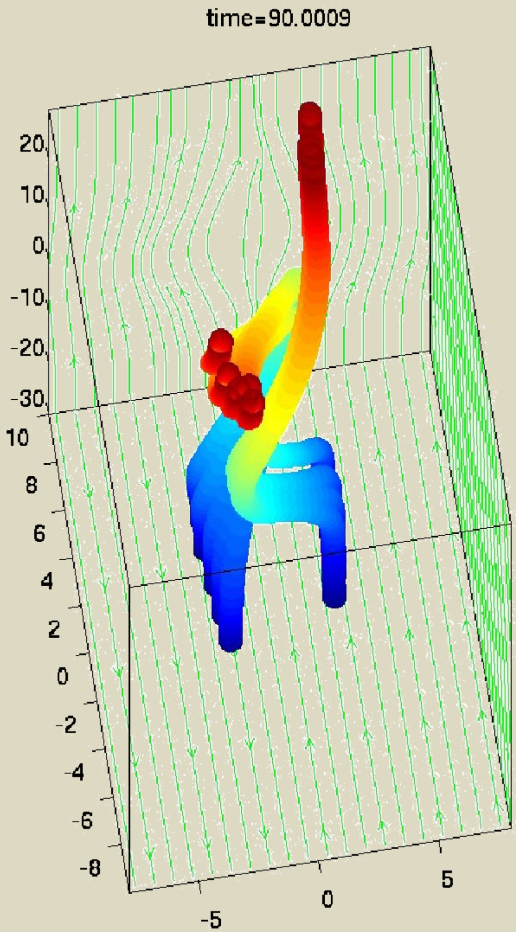


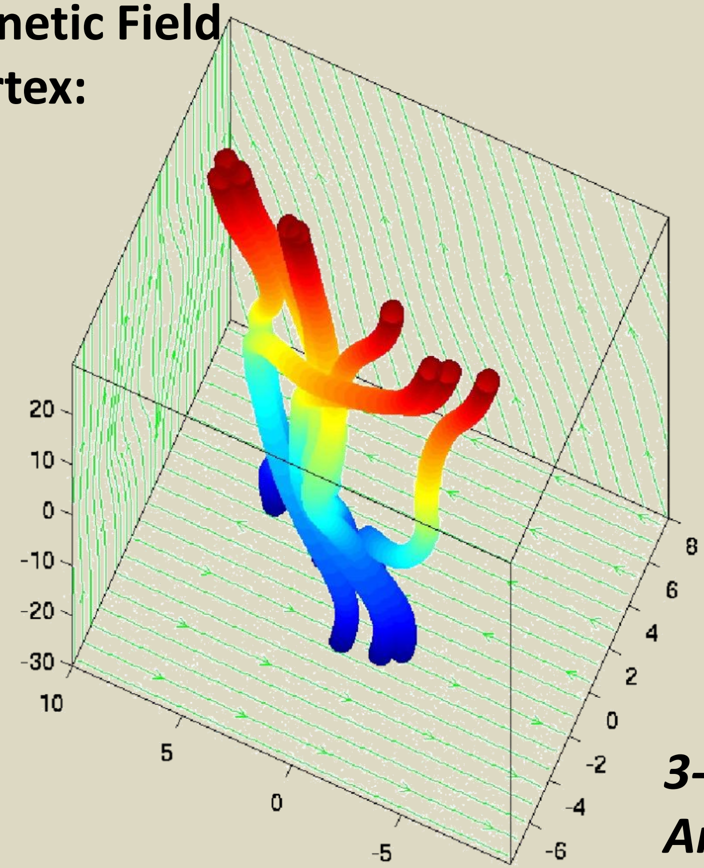


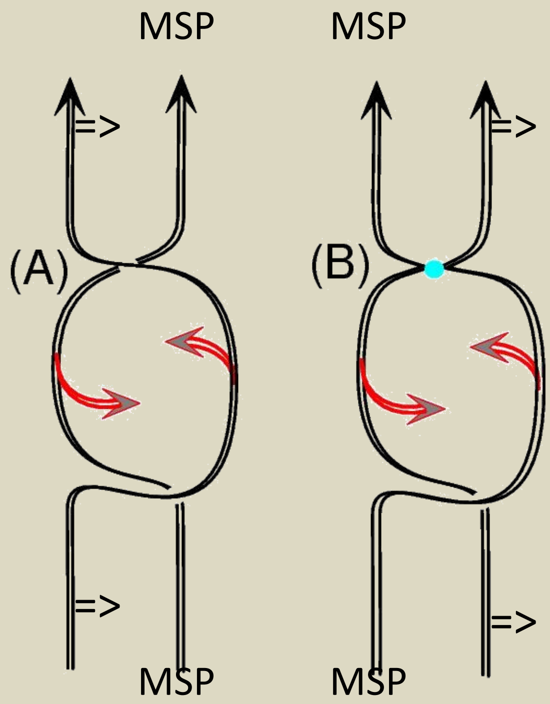
Nykyri et al. 2006b



3-D dynamics of Magnetic Field Lines in KHI vortex:







3-d simulations Courtesy of Antonius Otto

In 3-D the previous 2-D dynamics is present but also new dynamics comes to play: interchange motion moves MSP flux into MSH and vice versa.

Limitations of local KH simulations

- The local simulations have finite box size, so the final fate of the reconnected plasma blobs can not be determined

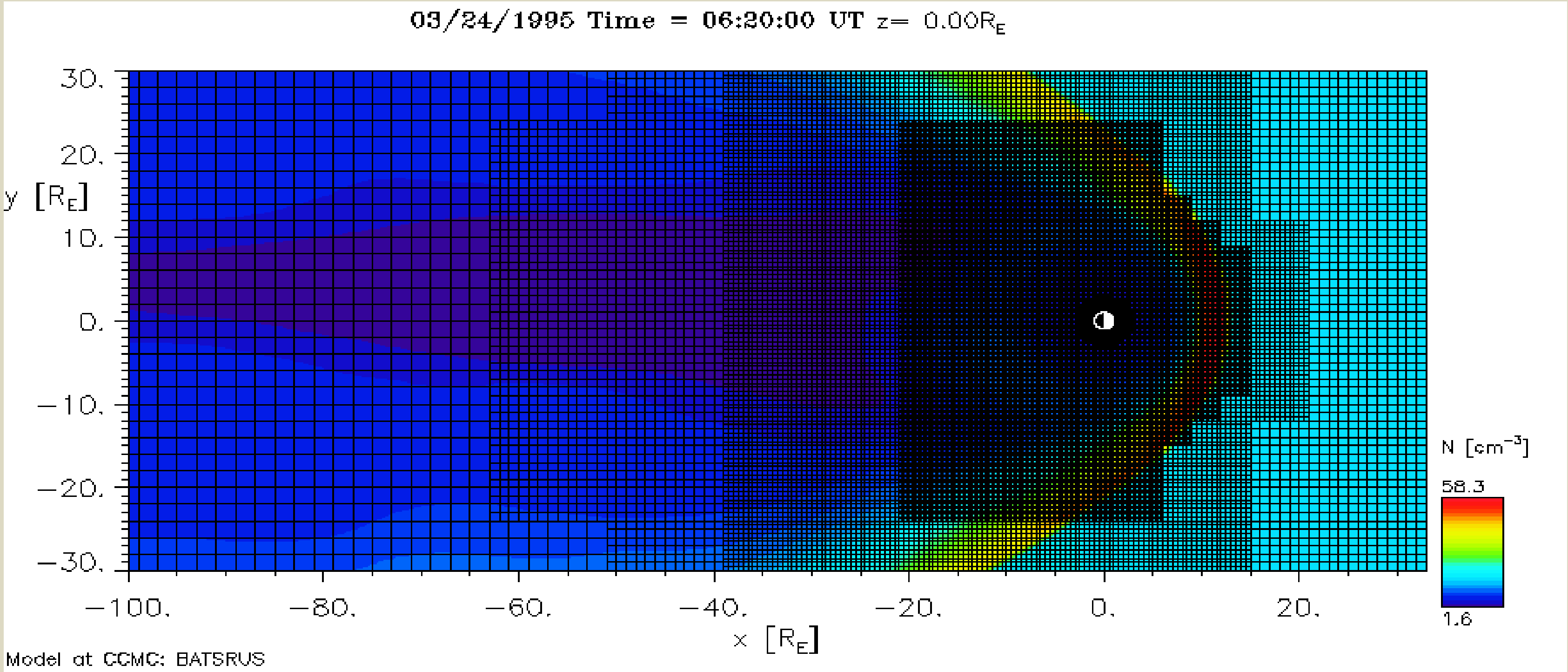
- CCMC 3-D Global MHD Magnetospheric physics model could be pushed to resolve Kelvin-Helmholtz instability and reconnection in vortices

Our past use of CCMC in KHI studies

- In 2004 I visited NASA Goddard and I was helped by CCMC team to try simulate the *Fairfield and Otto,* KHI-event observed by Geotail

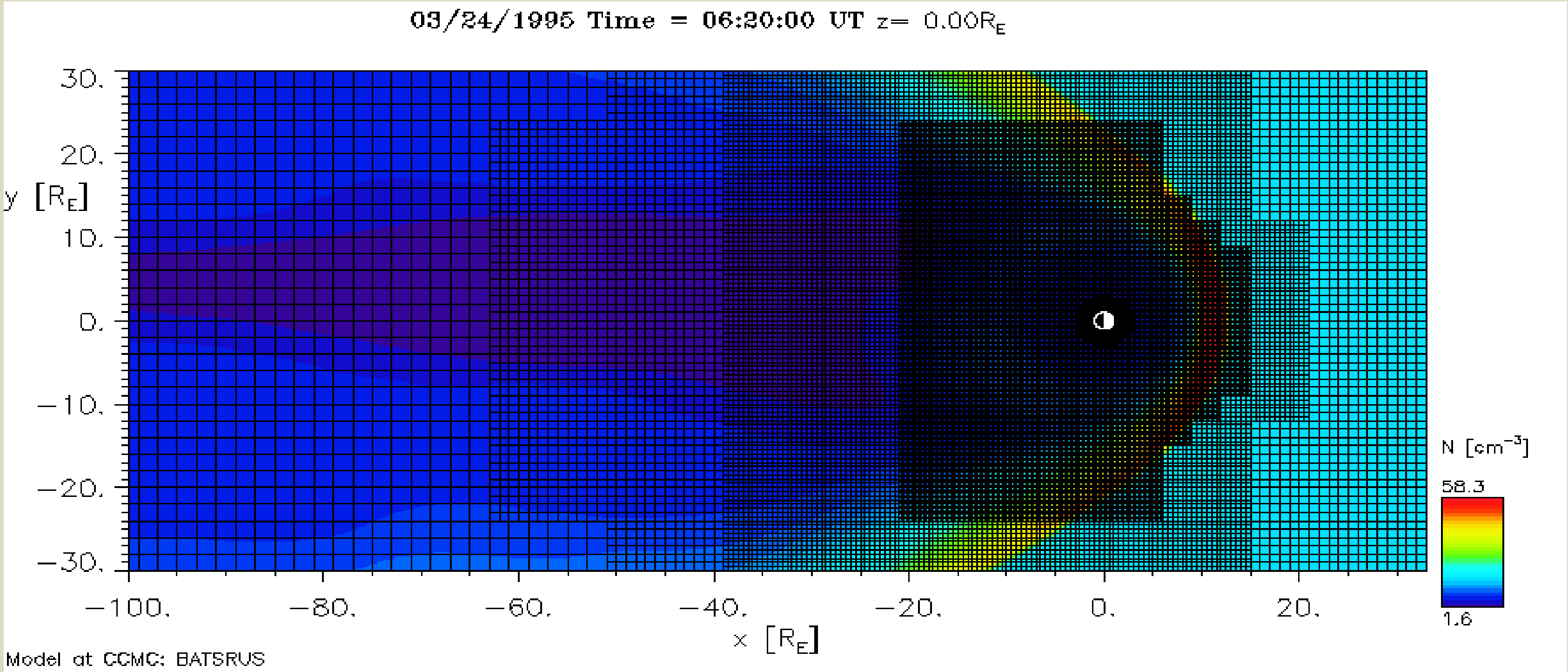
Our past use of CCMC in KHI studies

- We used BATSRUS and placed 1/8 R_E grid at the location of Geotail path and surrounding regions but did not find evidence of KHI



Our past use of CCMC in KHI studies

- **Possible reason might have been the inadequate resolution: In order to resolve KHI, the numerical diffusion needs to be smaller than the diffusion produced by the KHI mechanism < $10^9 m^2 s^{-1}$**



Finite difference approximation of derivatives

Taylor series expansion for the value of f:

$$f_{i+1}^n = f^n(x_i + \Delta x) = \sum_{m=0}^{\infty} \frac{\Delta x^m}{m!} \left[\frac{\partial^m f}{\partial x^m}\right]_i^n$$

- The centered Leapfrog scheme is second order accurate: Truncation error $= O\left(\Delta x^2\right)$
- Similar to the forward differencing other difference formulas can be examined for the truncation error.

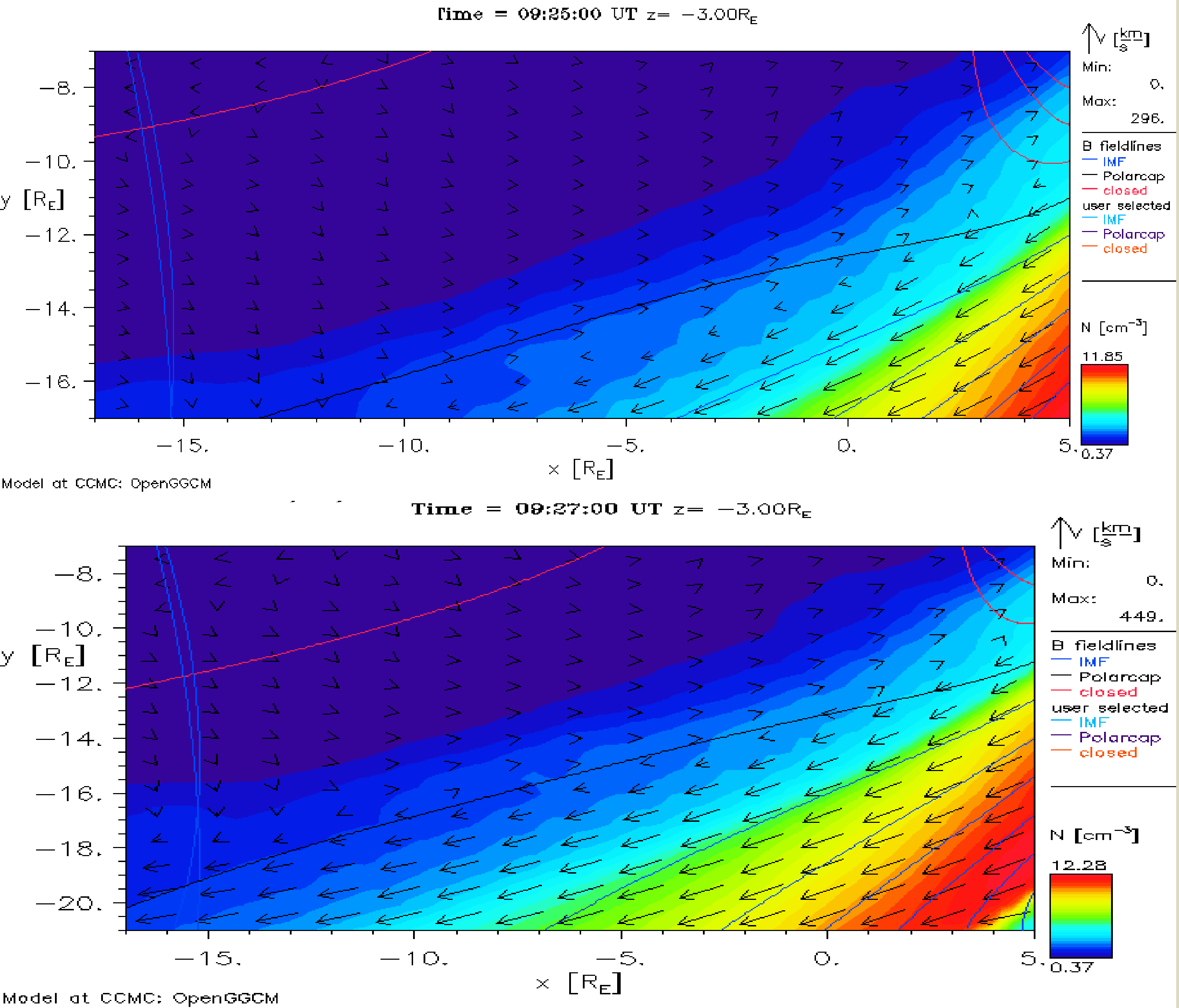
Case	Difference formula	Leading truncation error term
3pt sym	$\left(f'_{i+1} - f'_{i-1}\right)/2\Delta x$	$\Delta_x^2 f_{xxx}/6$
Forw diff	$\left(f'_{i+1} - f'_i\right)/\Delta x$	$\Delta_x f_{xx}/2$
Back diff	$\left(f'_i - f'_{i-1}\right)/\Delta x$	$-\Delta_x f_{xx}/2$
3pt asym	$\left(-1.5 f'_i + 2 f'_{i+1} - 0.5 f'_{i+2}\right)/\Delta x$	$-\Delta_x^2 f_{xxx}/3$
5pt sym	$\left(f'_{i-2} - 8 f'_{i-1} + 8 f'_{i+1} - f'_{i+2}\right)/12\Delta x$	$-\Delta_x^4 f_{xxxxx}/30$

In order to resolve current dependent resistive MHD reconnection in KH vortices with second order accurate scheme one needs minimum resolution of

$\Delta x^2 \sim 10^9 m^2$, => $\Delta x \sim 40$ km

Our current use of CCMC in KHI studies

- **Thomas W Moore** (ERAU M.S student) is doing his M.S thesis work on *“Signatures of Plasma heating events at LLBL associated with Kelvin-Helmholtz Instability and Kinetic Alfven waves”.*
- He found six new cases that look like KHI
- We are using CCMC to get The Large Scale Structure of the Magnetosheath at the vicinity of Cluster spacecraft, compare with the data and use these both to determine the best initial conditions for our local simulations of KHI.
- We also want to discuss here with the CCMC folks to do *high-resolution runs* of our list of events and see whether KHI can be resolved.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y [R_E]
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Min: 0.
Max: 296.
B fieldlines
IMF
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N [cm^-3]
11.85
0.37
Model at CCMC: OpenGGCM
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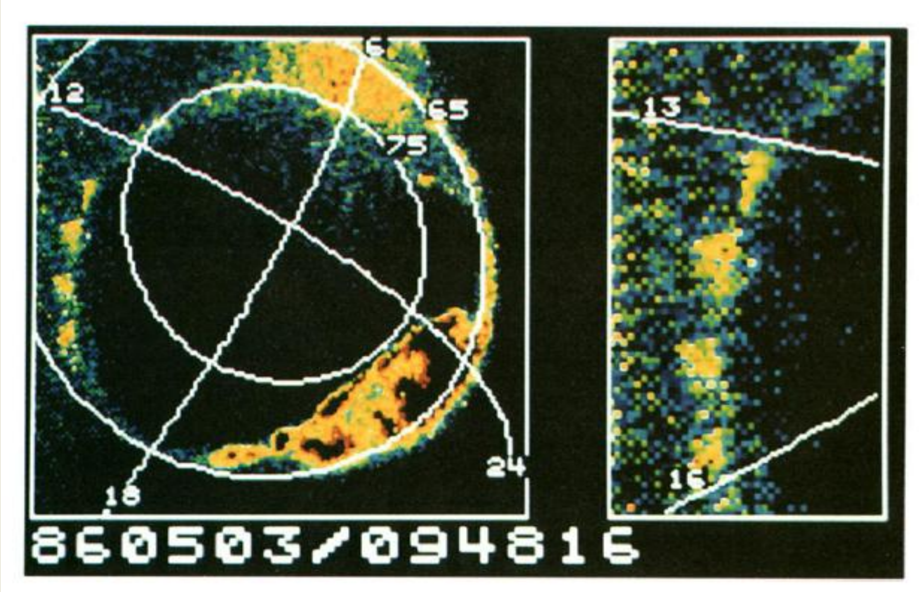
N [cm^-3]
12.28
0.37
Model at CCMC: OpenGGCM

GGCM run

Ionospheric Signatures of the (KHI)

Signatures?

- •Aurora bright spots in a row (Lui et al., 1989)
- •Spiral forms in all-sky optical data (Farrugia et al.,1989, Rosenqvist et al., 2007)



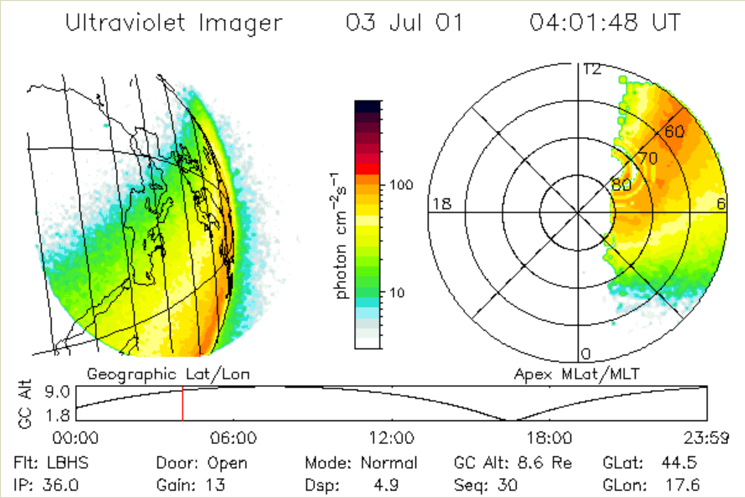
Lui et al. 1989

Our Current work:

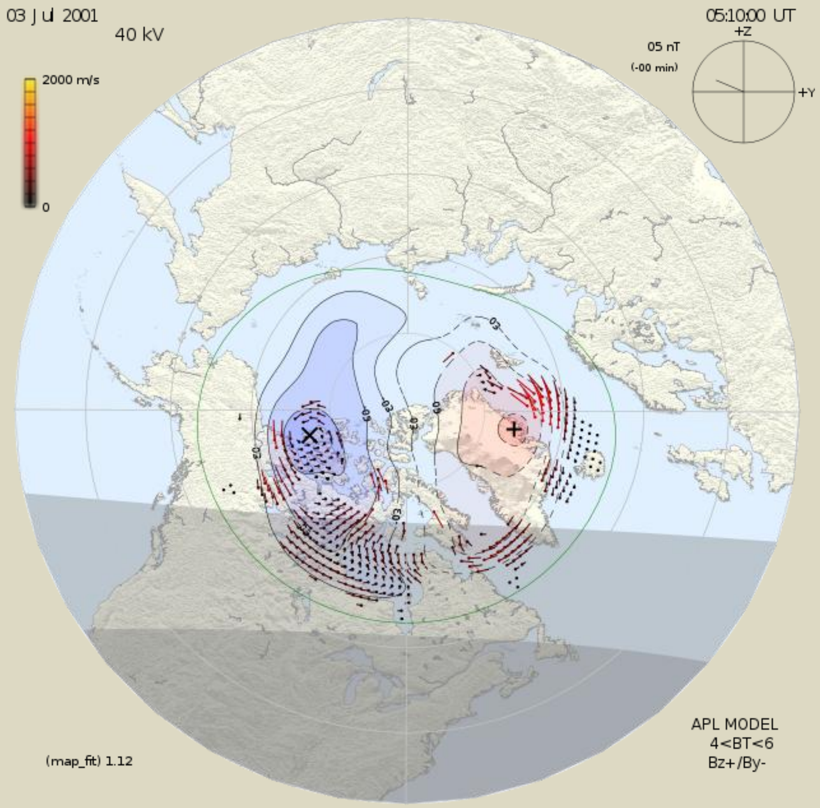
- **Emily Hyatt** (ERAU engineering physics M.S student) studies the ionospheric mapping of all old (published literature) and new KHI events (found by Thomas W Moore) and study optical, radar and ground magnetometer data for these events

Study Collected Data

- Polar/Image UVI
- Magnetometers
- SuperDARN
- All-Sky Optical Data



Polar UVI Data



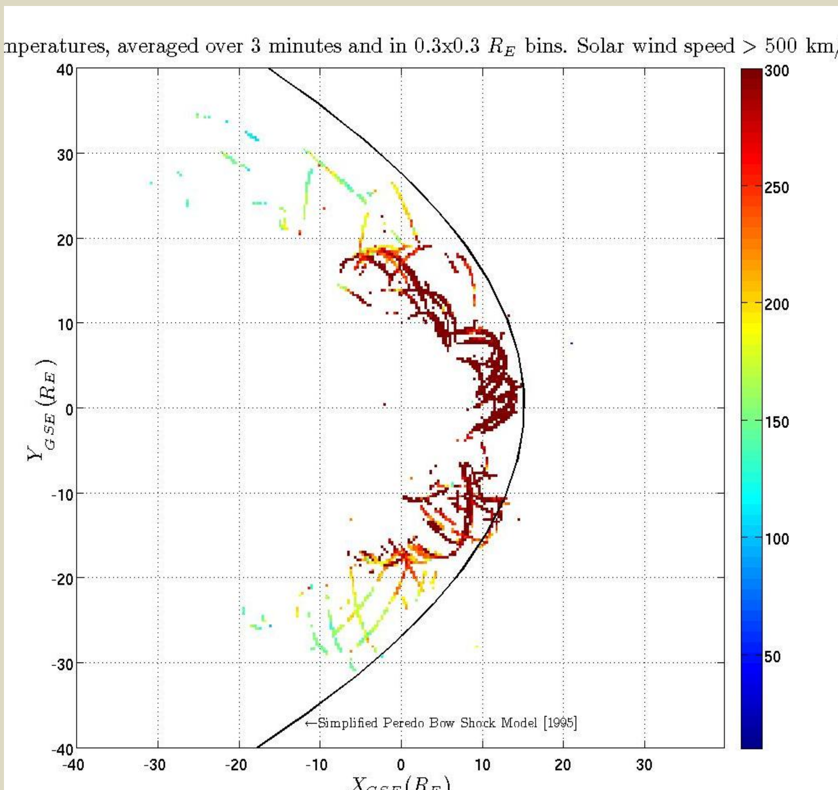
SuperDARN Radar Convection Map

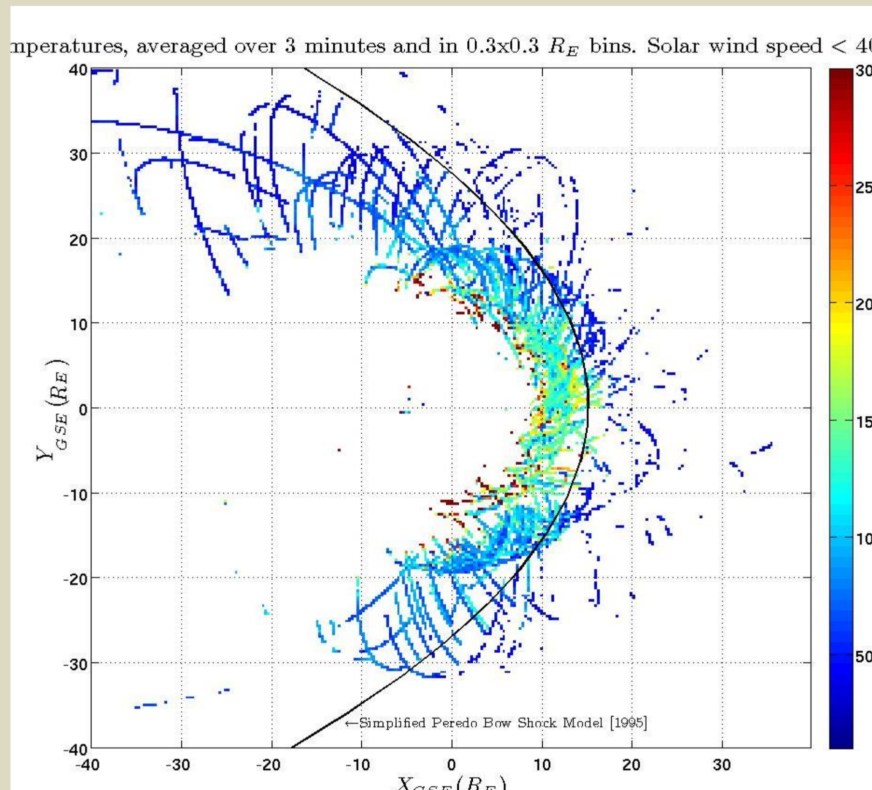
Potential use of CCMC for this study

- We are currently mapping field lines from KHI to Earth using semi-empirical Tsyganenko models
  - Have mapped all Cluster events, moving next to THEMIS KHI events
- This semester
  - Running local and global numerical MHD simulations
  - Study ionosphere also in Global simulations
  - Map field lines also with NASA CCMC MHD model

Large scale Magnetosheath structure for various IMF conditions

- CCMC can be utilized to study large scale magnetosheath properties and can be compared with our statistical study of manetosheath binned with various upstream conditions.
- Community use of CCMC for GEM magnetosheath focus group ‘magnetosheath challenge’.





Formation, dynamics and particle energization in CDC.

Nykyri et al. 2011a,b,c

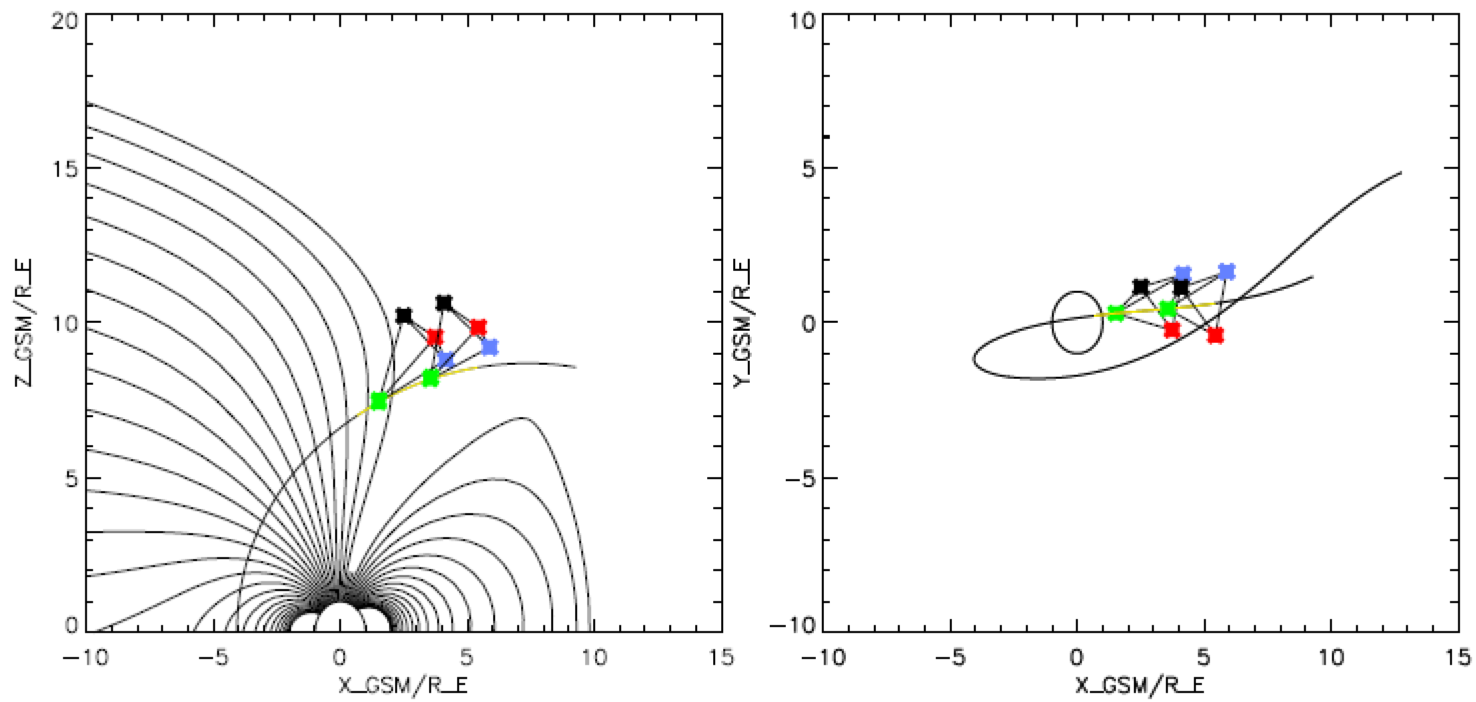


Figure 1. (left) Cluster trajectory on 14 February 2003 plotted on top of the magnetic field lines from Tsyganenko 89 model (T89) in GSM coordinates in *xz* plane and (right) trajectory and constellation plotted in *xy* plane. The T89 model uses the *Kp* index of 4. The circle is the Earth, the yellow line depicts Cluster trajectory between 1800 and 2100 UT, and Cluster constellation (magnified by factor of 3) is drawn with respect to sc3 position at 1830 UT and at 1945 UT.

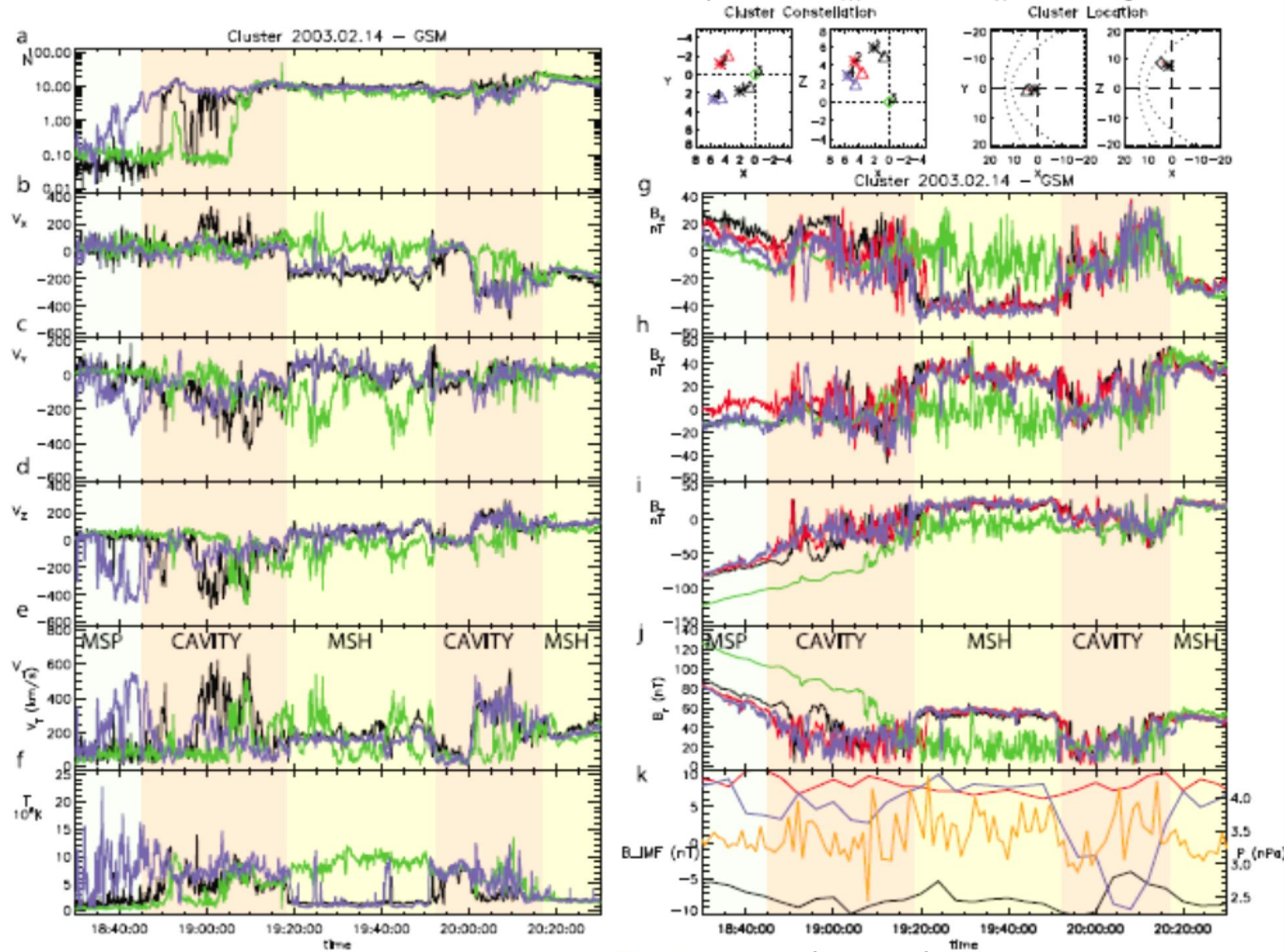
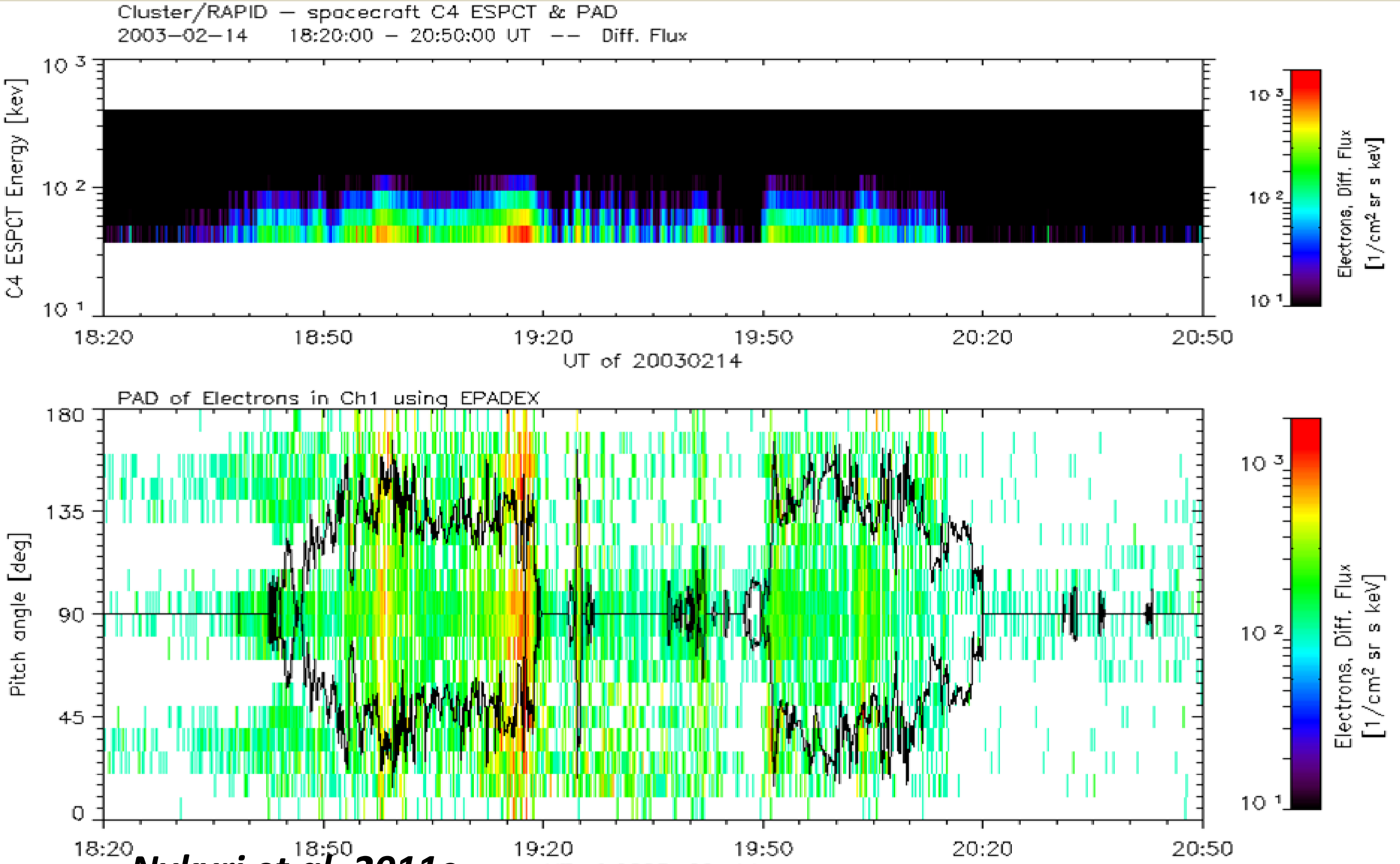


Figure 2

Nykyri et al. 2011a

Electron pitch angles and trapping condition assuming adiabatic electron motion

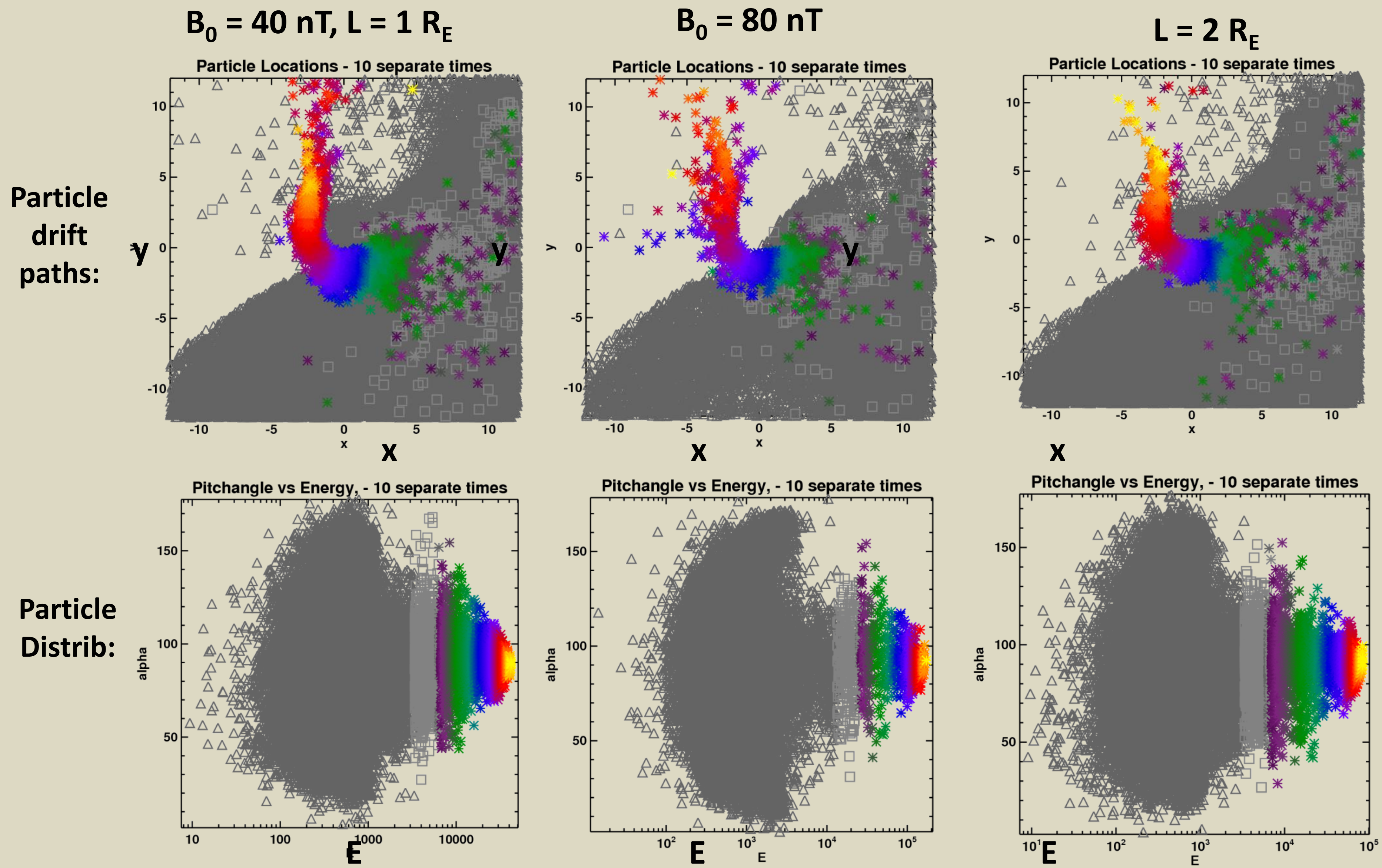


Nykyri et al. 2011c

- **Electrons with pitch-angles inside black envelope cannot directly originate from magnetosphere or bow shock**

$$\alpha = \tan^{-1}\left(\frac{1}{\sqrt{\frac{B_{msh}}{B_{cavity}} - 1}}\right)$$

Particle Acceleration in 3-D local cusp model



Max. Energy: ~50 keV ~200 keV ~100 keV

Courtesy of A. Otto

Cavity location for southward IMF (SIMF) vs northward IMF (NIMF)

A03228 NYKYRI ET AL.: STRUCTURE AND DYNAMICS OF CUSP DMC A03228

Local 3-D MHD cusp model *Simulation by E. Adamson*

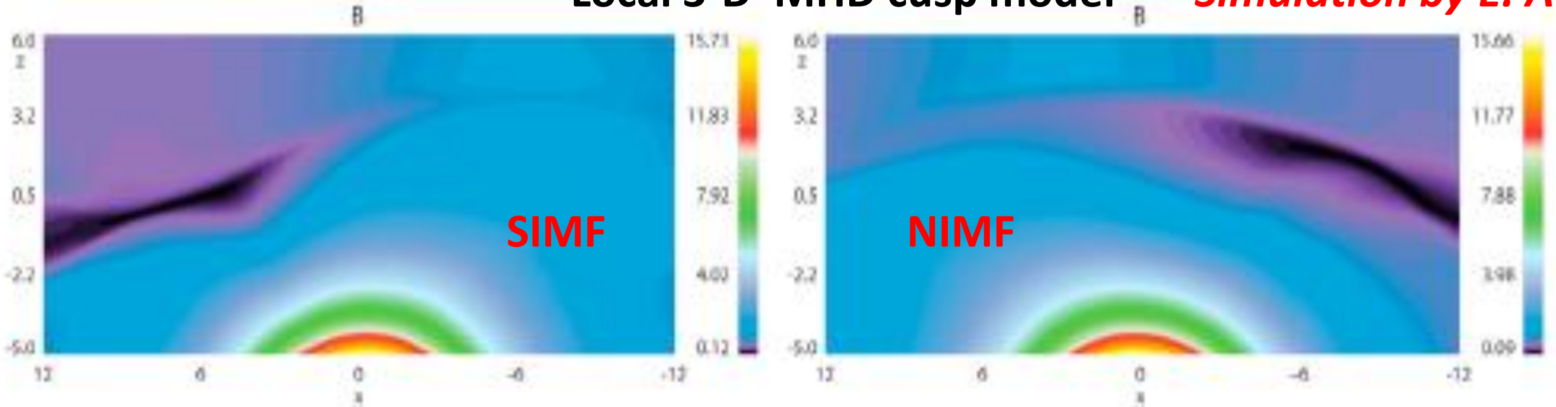
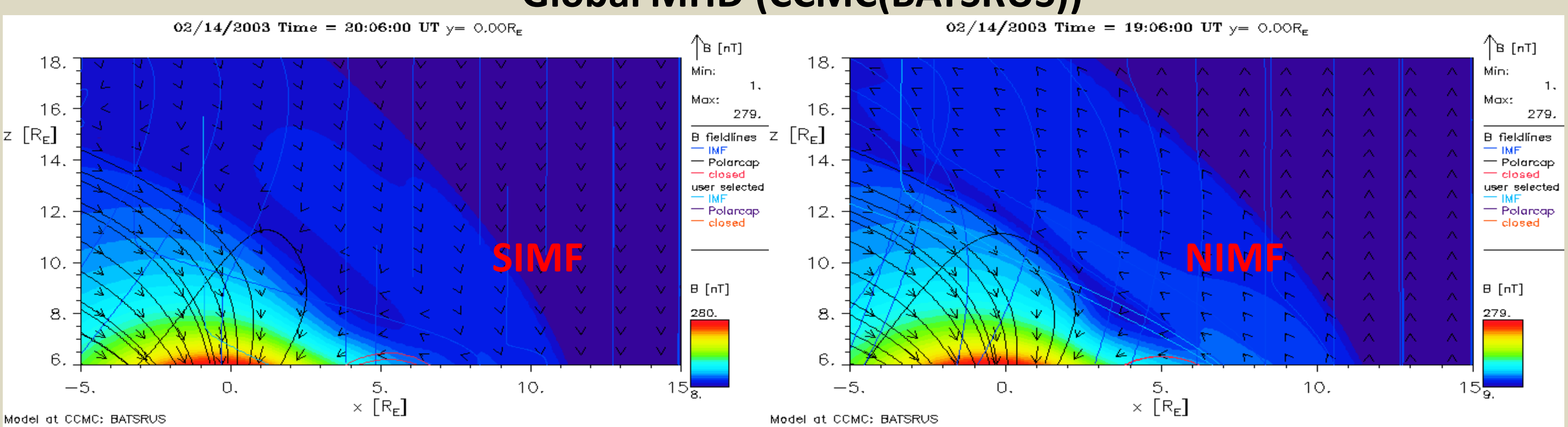


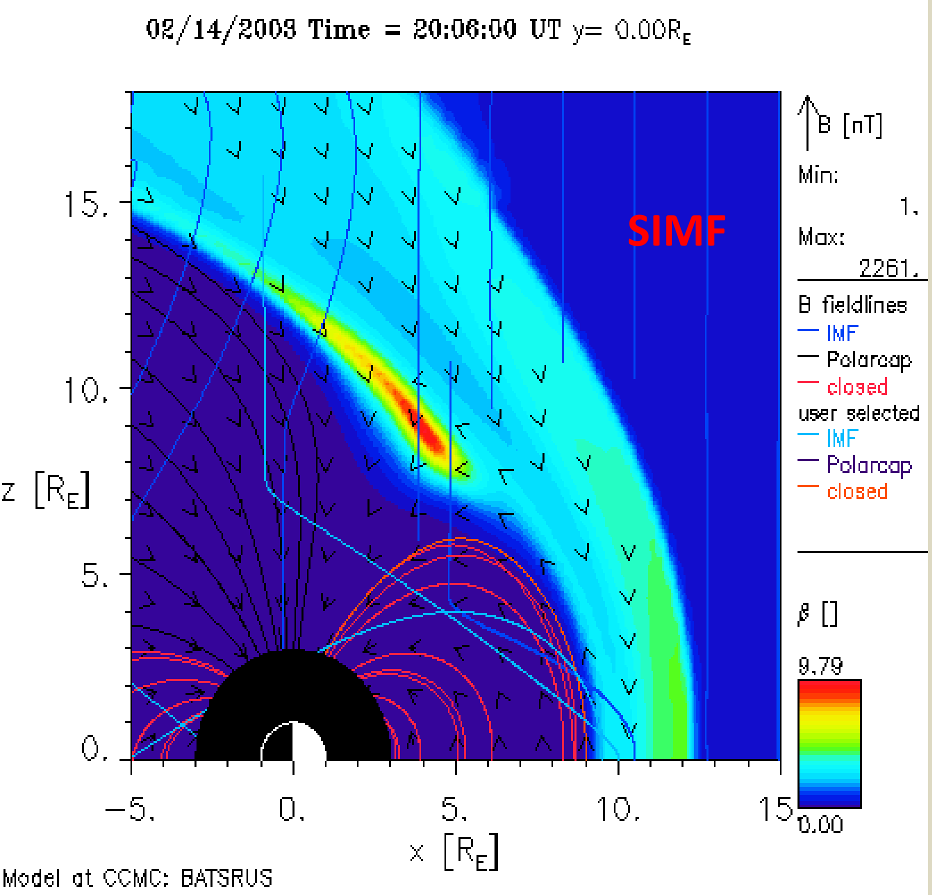
Figure 3. MHD simulations of the cusp for (left) southward and (right) northward IMF. Sun is to the left. Background color is the total magnetic field strength. The region of depressed magnetic field (cavity) is forming more sunward when IMF is southward.

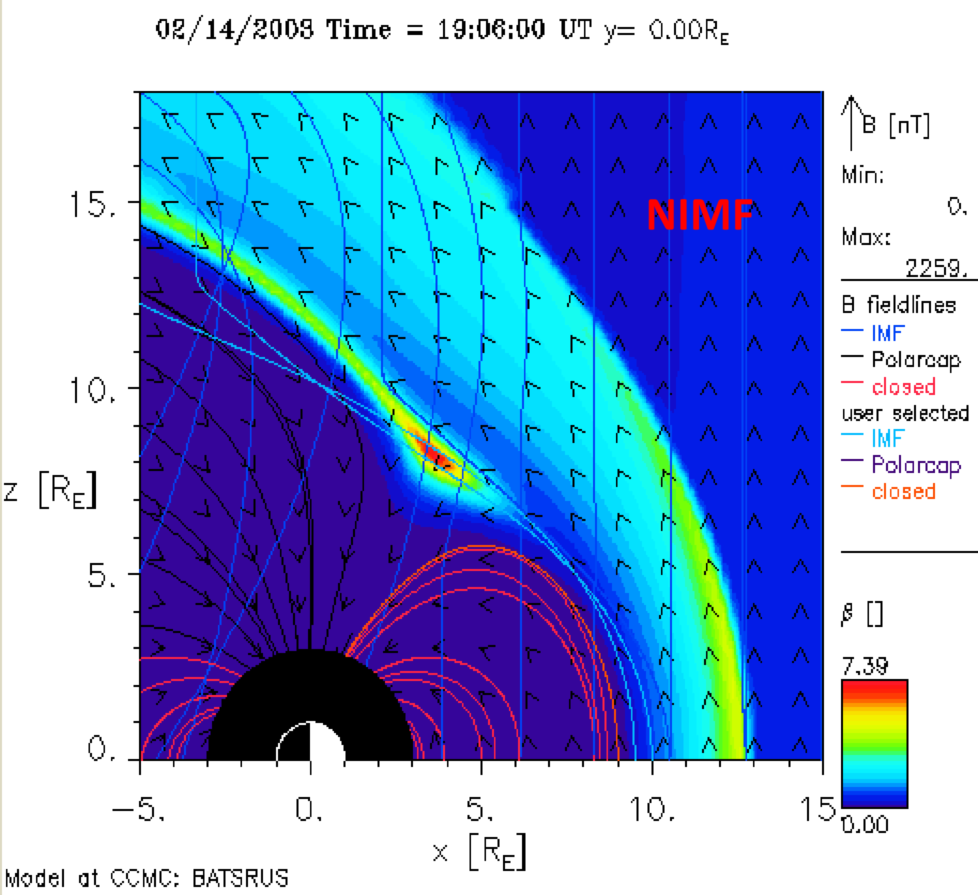
Global MHD (CCMC(BATSRUS))

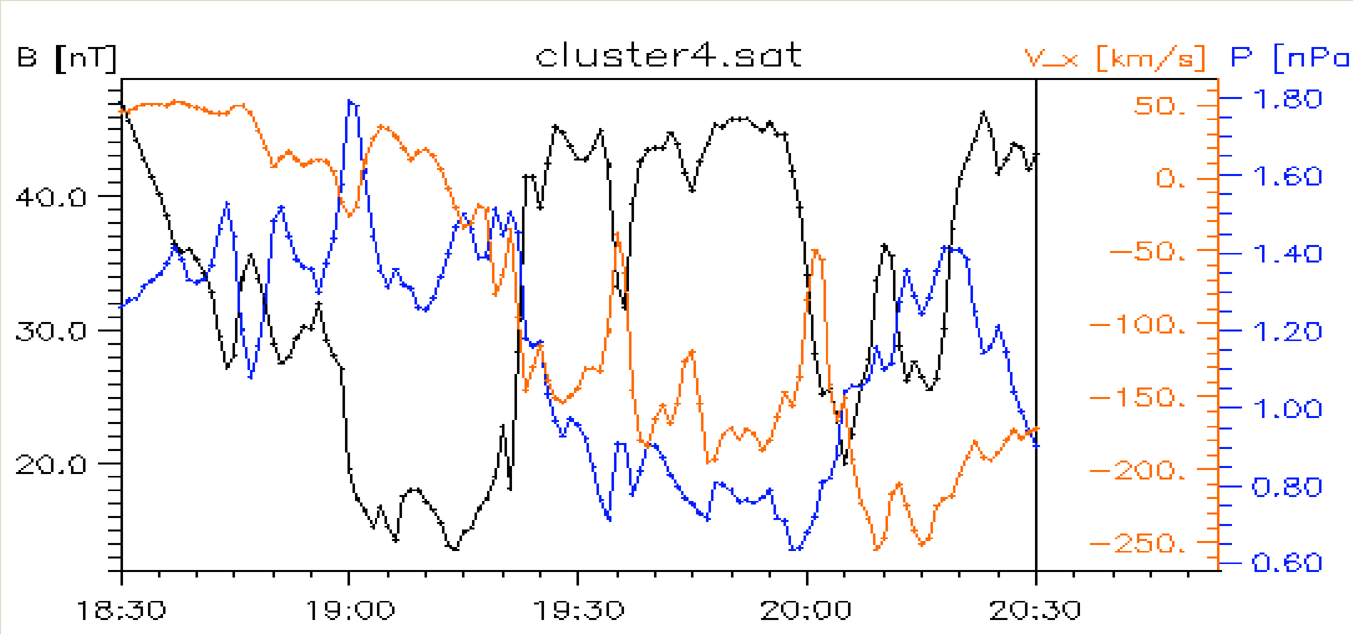


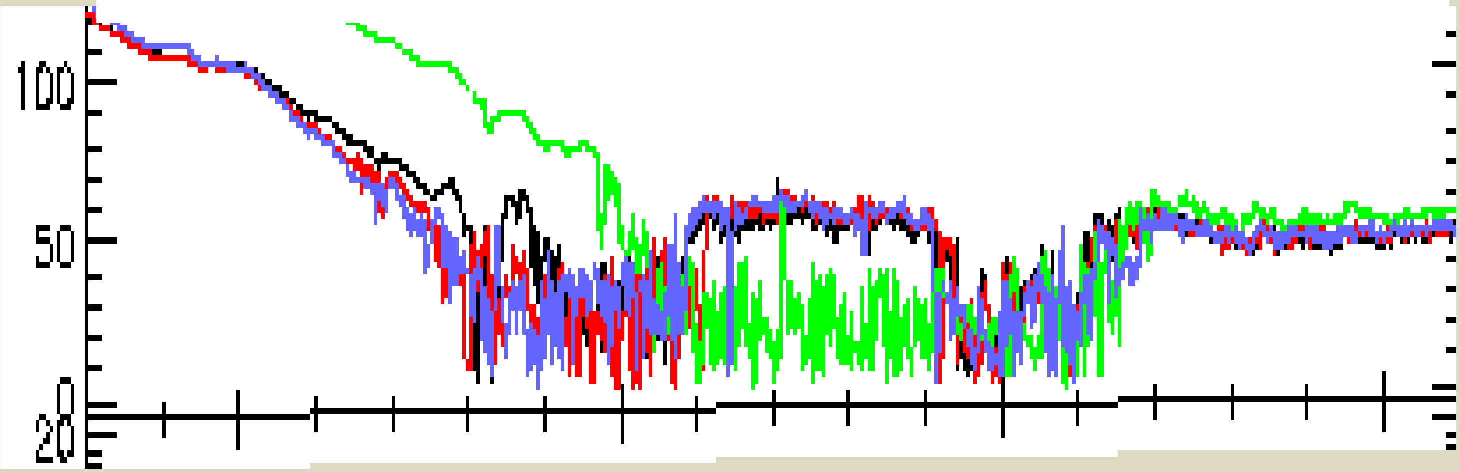
• **Cavity region with depressed B not clearly visible in CCMC plot of *B* (color bar issue)**

•**Cavity becomes visible in CCMC plot of Beta: for NIMF cavity extends more tailward**









- **Good qualitative match with Global MHD (BATSRUS) and Cluster observation of *B***

What we would like to do with CCMC for our CDC study

- Resolve CDC in Global MHD with highest possible resolution so that Cluster trace has best possible match with observations

- Place test particles in Global MHD inside CDC to study faith of the high-energy particles: where do they go?

Conclusions

- CCMC is a fantastic tool for getting the large scale structure of the magnetosphere and magnetosheath
- Our wish-list includes:

-40-70 km grid resolution in LLBL

-map field lines from KH vortex into ionosphere and study modeled convection maps and particle precipitation

-user adjustable color bars when plotting scalar quantities

-possibility to put test particles in simulation domain and trace where they are going

- Great tool for space physics education *(presentation on Friday about CCMC usage in ERAU)*