Diamagnetic Cavities - High-Latitude, Dayside Source of Energetic Particles in the Earth's Magnetosphere.

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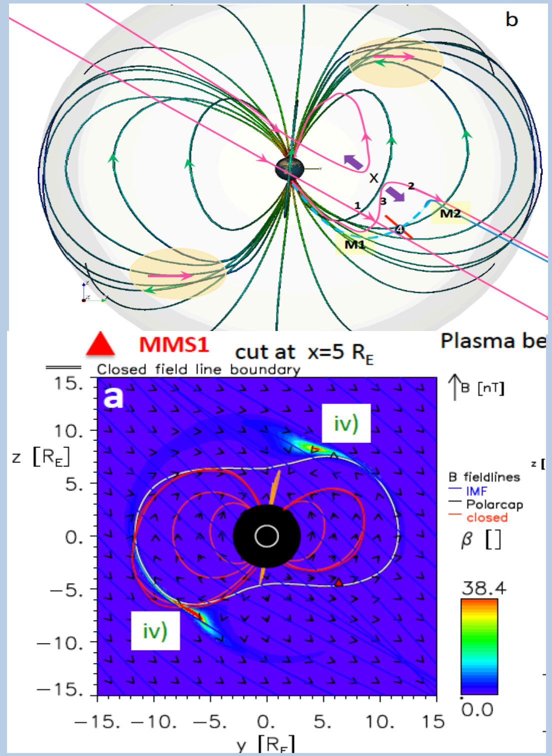
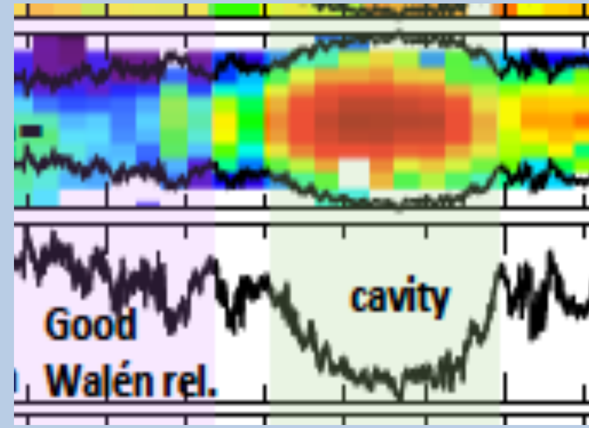
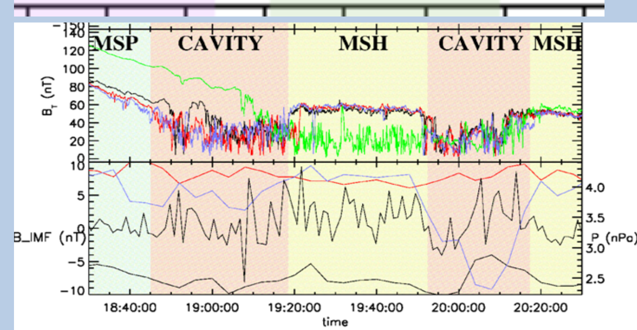
Motivation:

- How much mass do dayside diamagnetic cavities contain?
- Can the 100s of keV energetic particles in the cavities provide portion of the seed population for radiation belts?
- What are the detailed physical mechanisms allowing transport of these particles deeper to the
l inner magnestoshere?







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NASA

NSF

CSAR: Center for Space and Atmospheric Research

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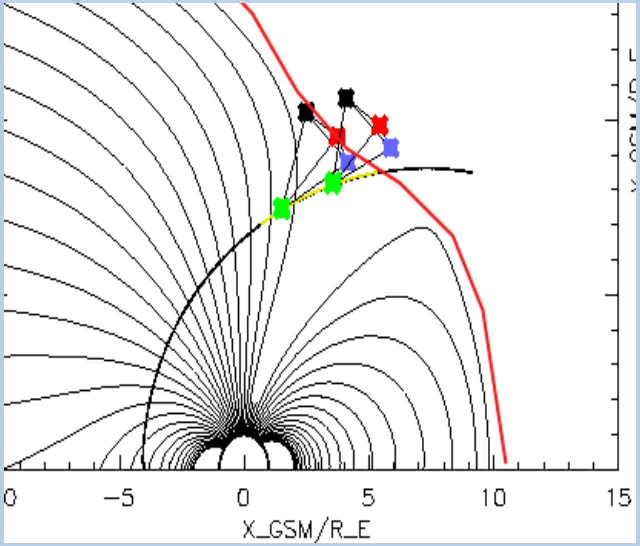
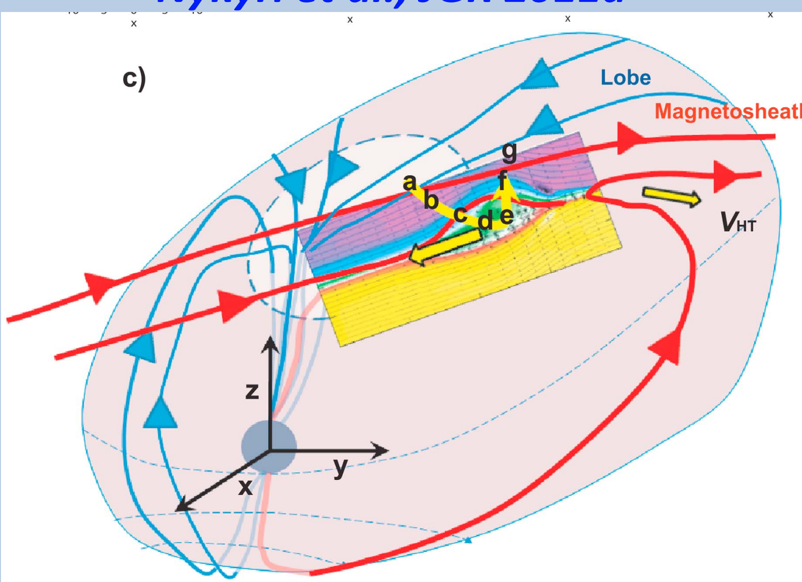
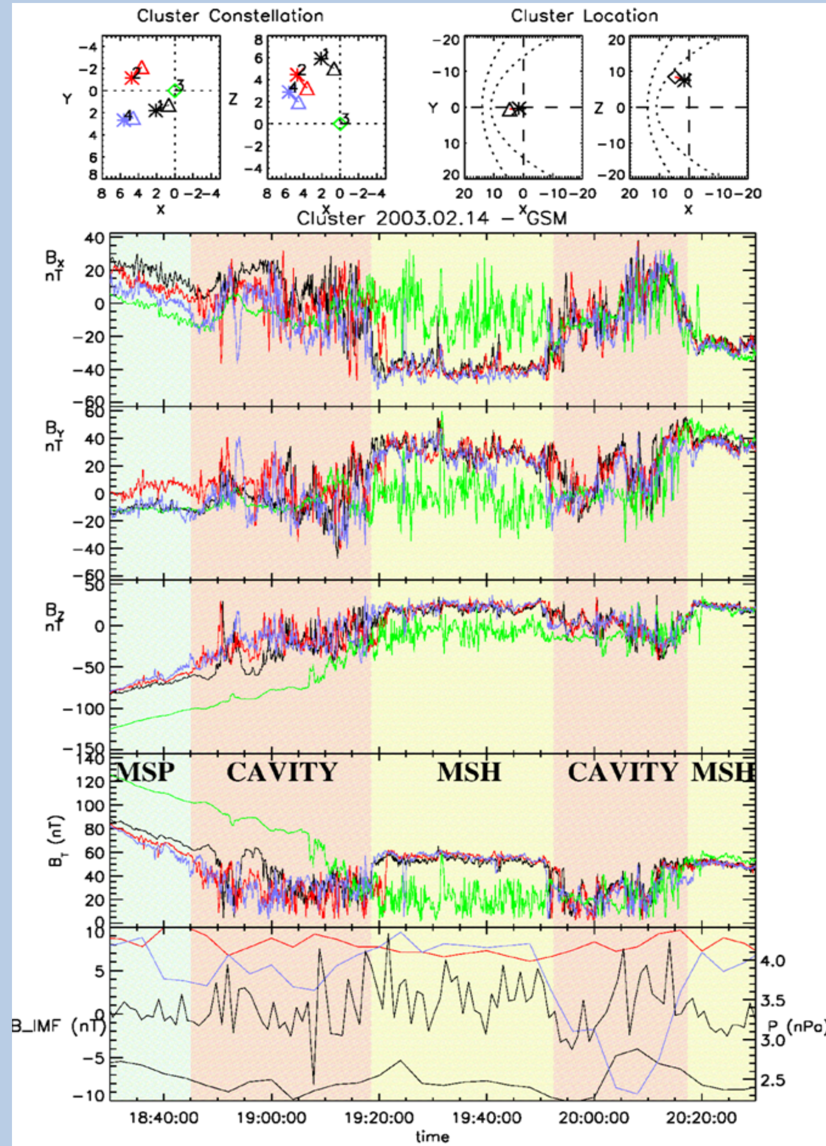
MMS virtual community workshop, April 7th, 2021

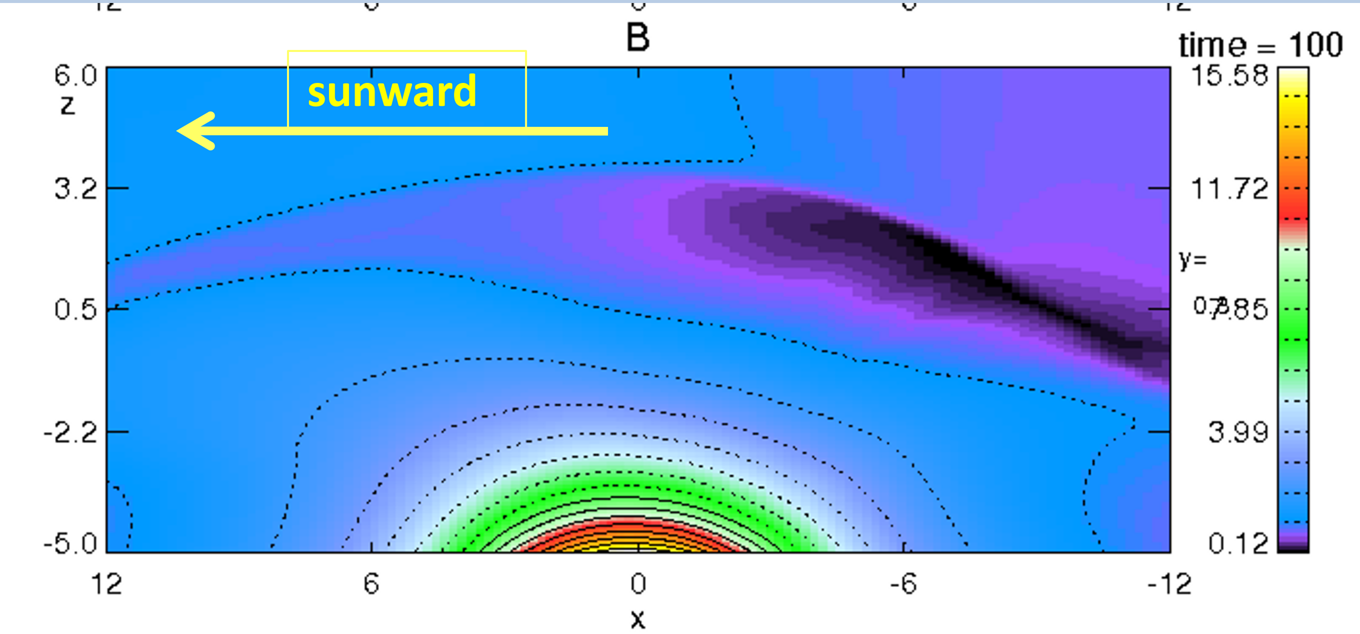
Background: Observations of Structure of Diamagnetic Cavity in Northern hemisphere with Cluster at 5000 km separations



Nykyri et al., JGR 2011a

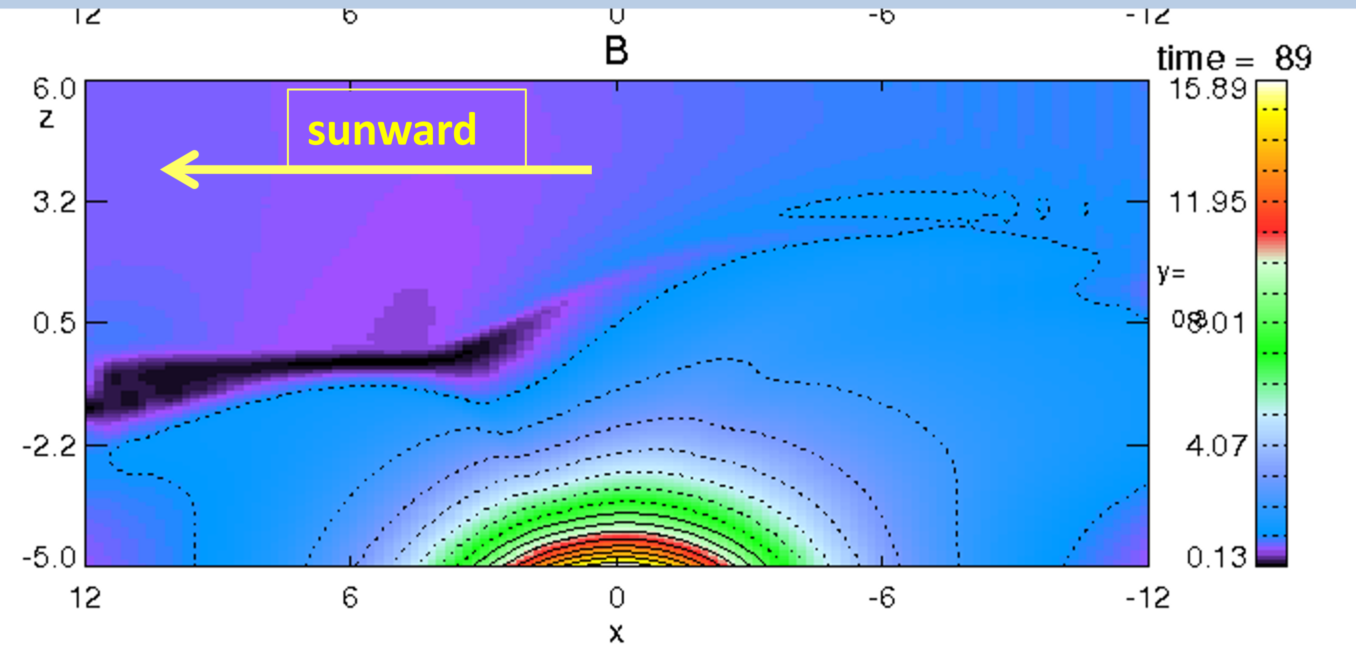






IMF Bz > 0

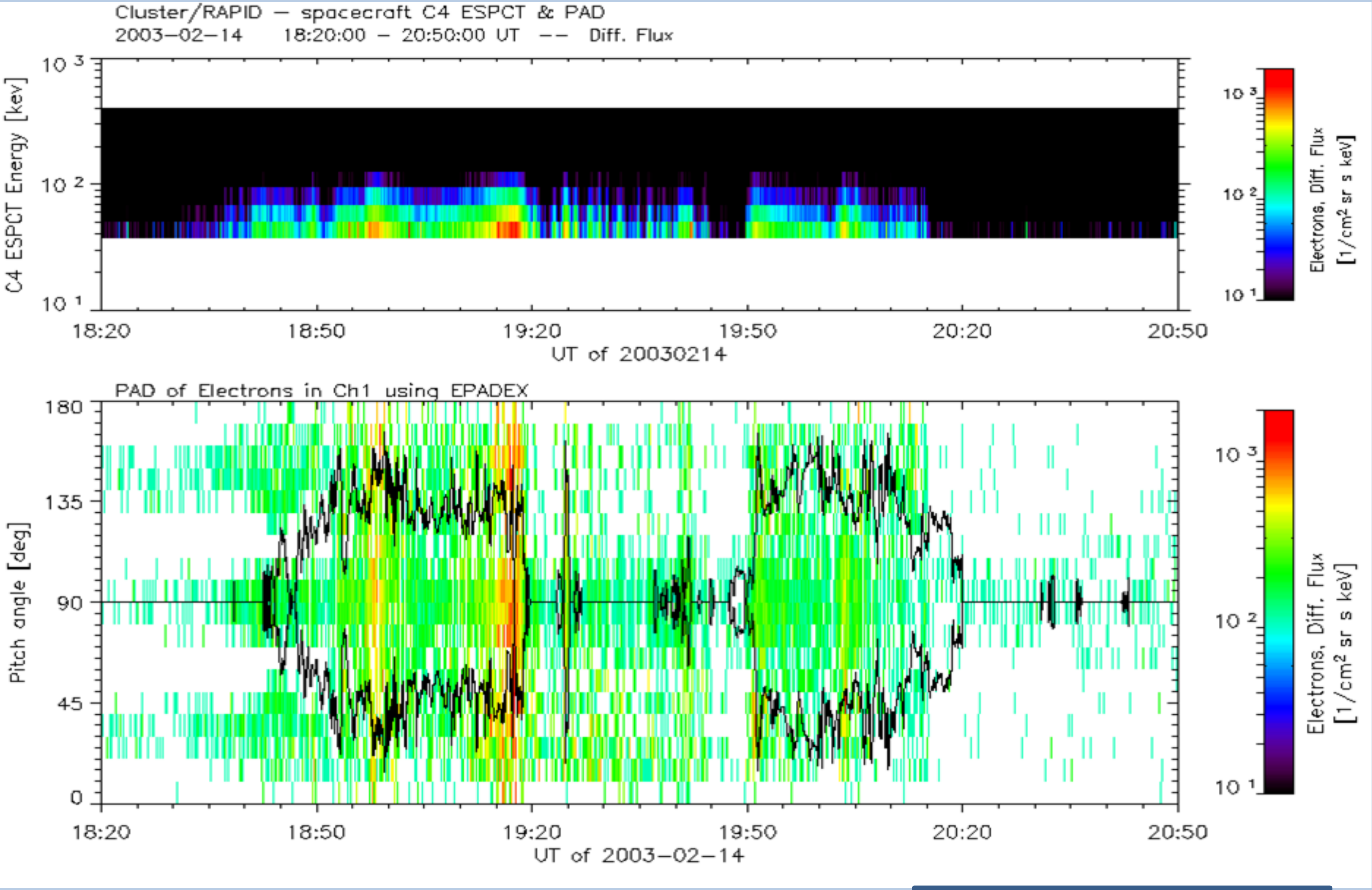
- When IMF turns southward, the cavity moves sunward



IMF Bz < 0

Nykyri et al., 2011a,b

Electron pitch angles and trapping condition assuming adiabatic electron motion



Nykyri et al., 2012

Trapping angle=

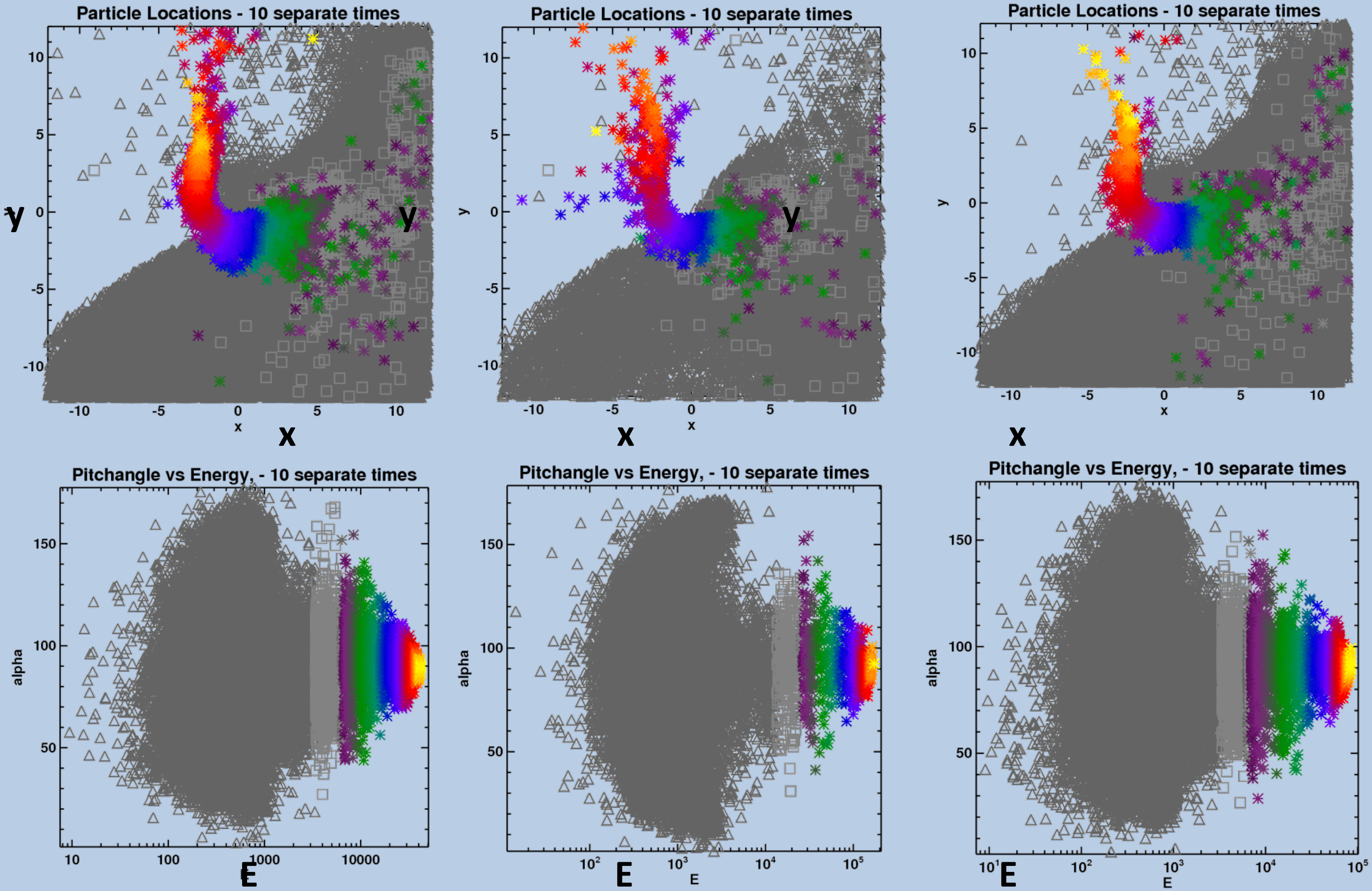
$$\alpha = \tan^{-1}\left(\frac{1}{\sqrt{\frac{B_{msh}}{B_{cavity}} - 1}}\right)$$

Test Particle Simulations in 3-D High-Resolution Cusp Model

B_0 = 40 nT, L = 1 R_E | B_0 = 80 nT | L = 2 R_E

Particle drift paths:

Particle Distrib:



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

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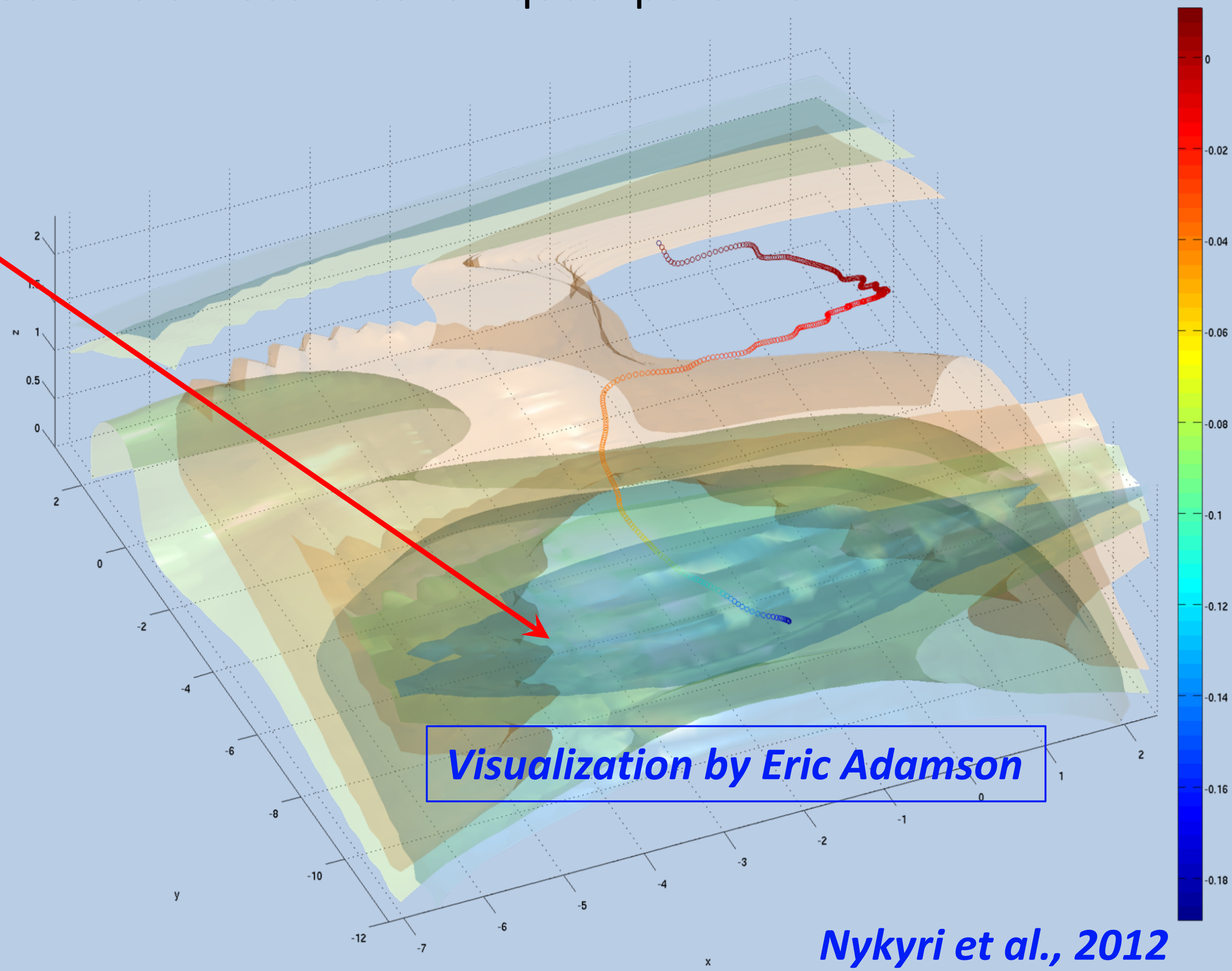
Nykyri et al., 2012

Cusp diamagnetic cavity Acceleration Mechanism

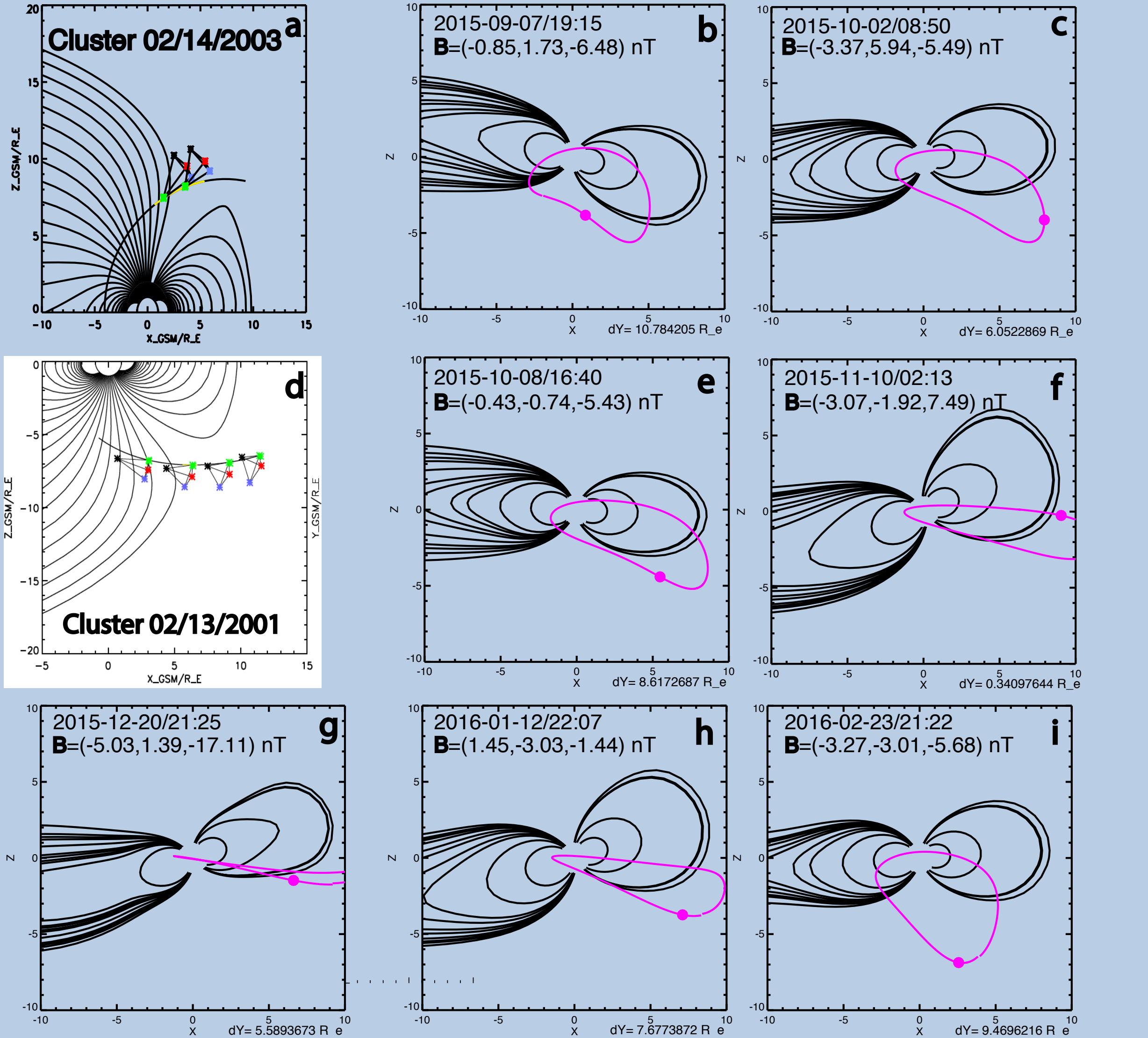
- Particles can be accelerated in diamagnetic cavities if particle drift paths coincide with the gradients of reconnection quasi-potential.

‘Potential’ isosurfaces



Nykyri et al., 2012

MMS Can Reach High-Latitudes



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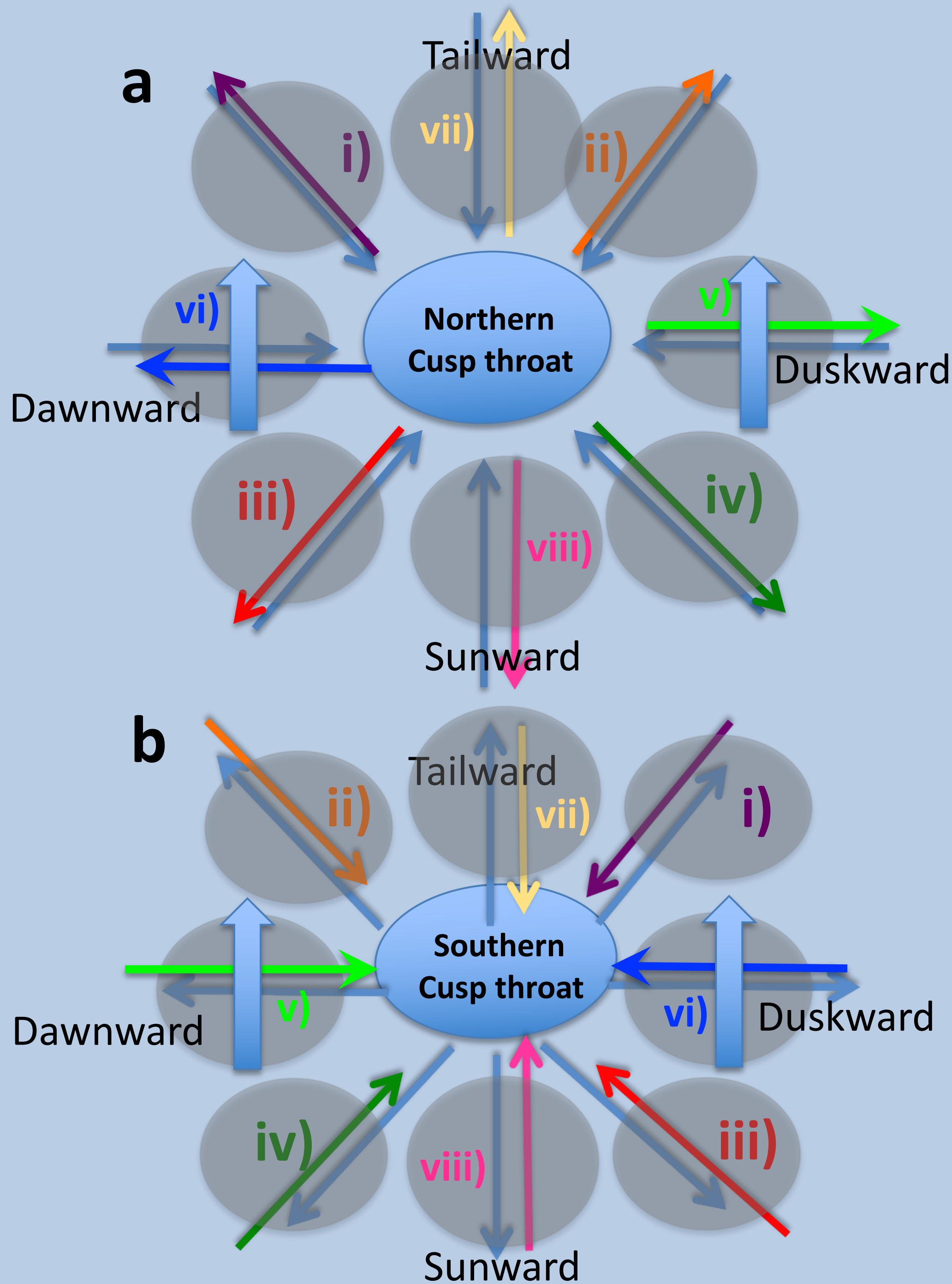
Nykyri et al., JGR, 2019a

Cavity Formation vs. Draped IMF orientation -paradigm after Cluster



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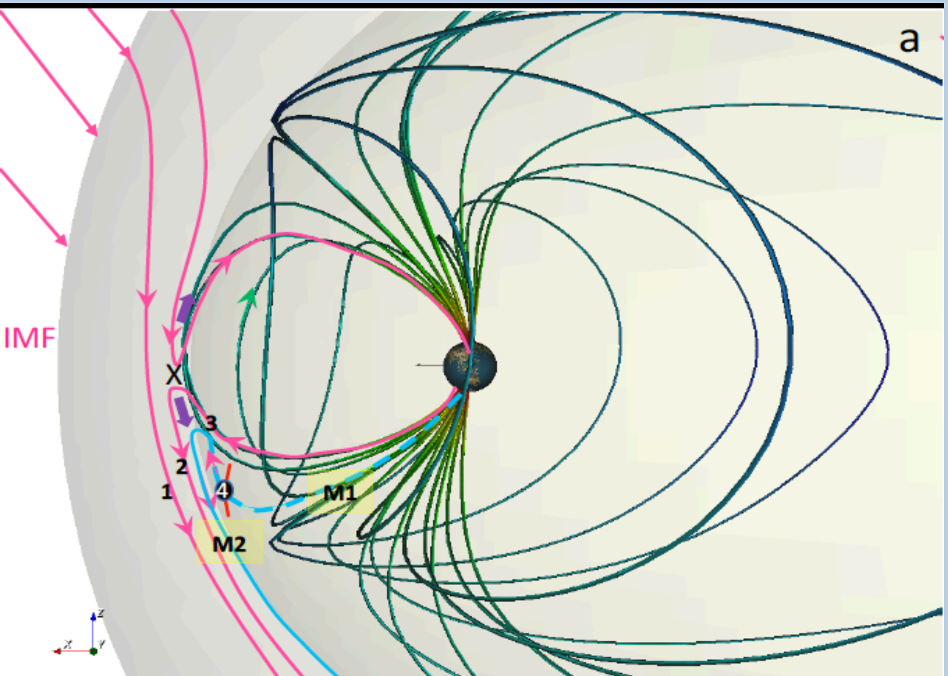
First MMS observations of high-energy particles in a magnetic bottle in an unexpected location- a new paradigm after MMS for cavity location

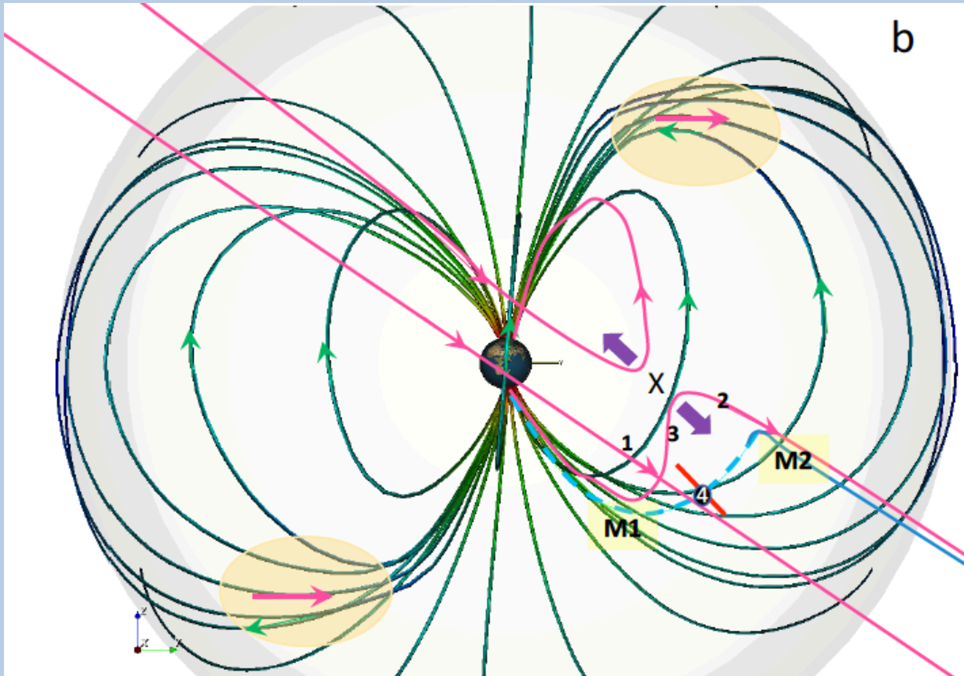
Nykyri et al., JGR, 2019a

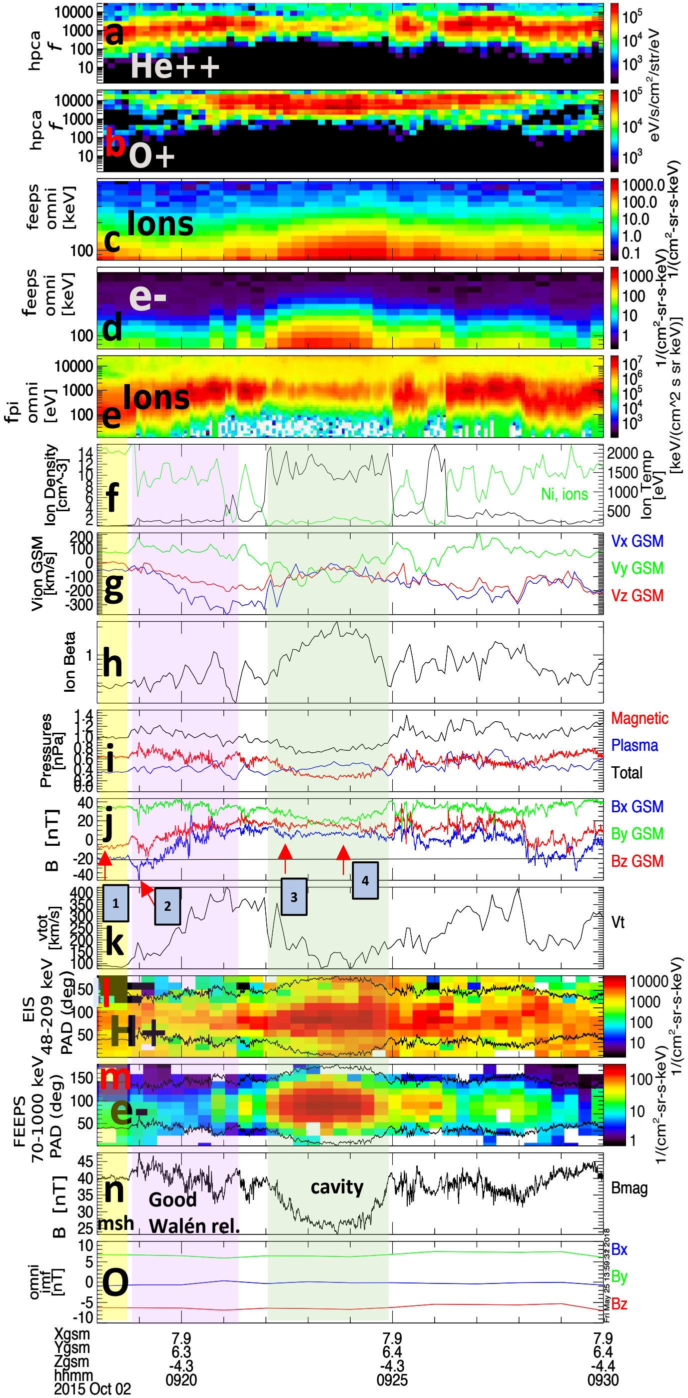
- IMF Orientation, MMS Trajectory and Magnetic field Topology from Tsyganenko 96 model

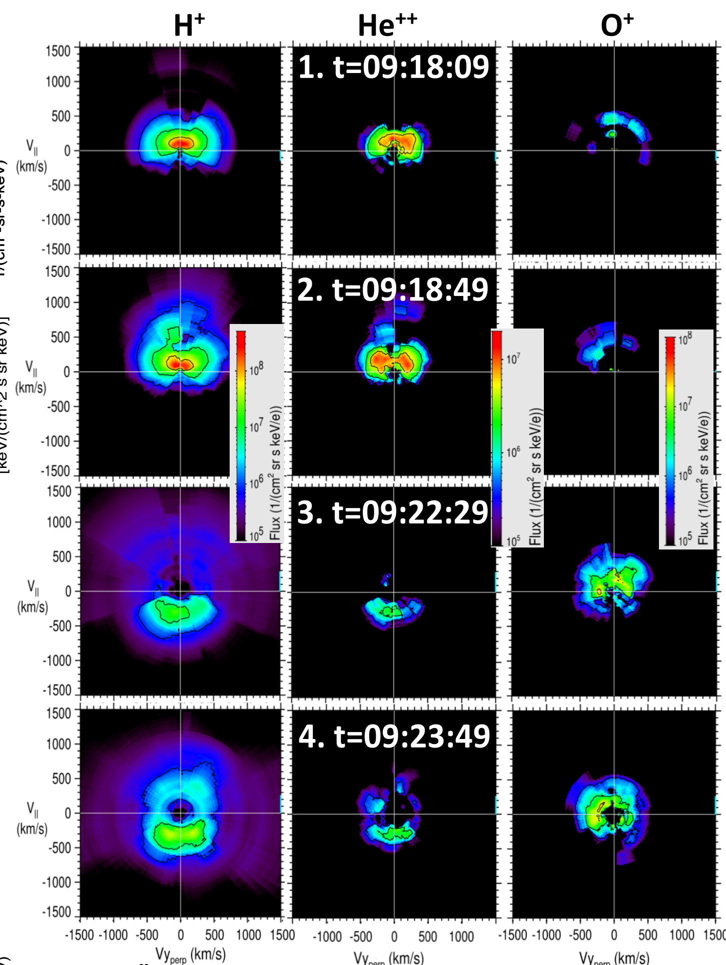
X-Z_{GSM} –plane, view from +Y

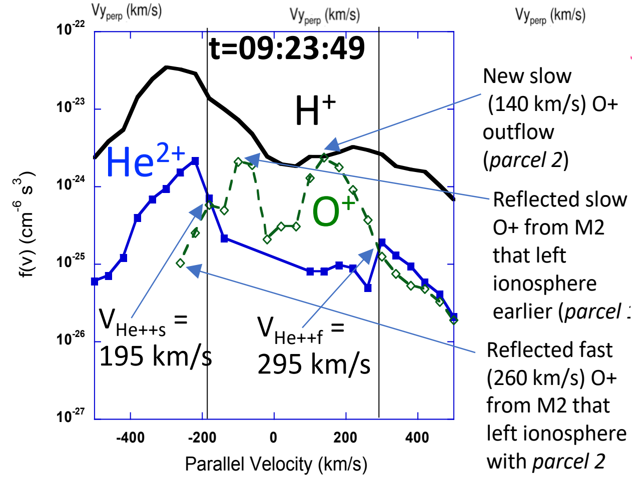


Y-Z_{GSM} –plane, view from +X



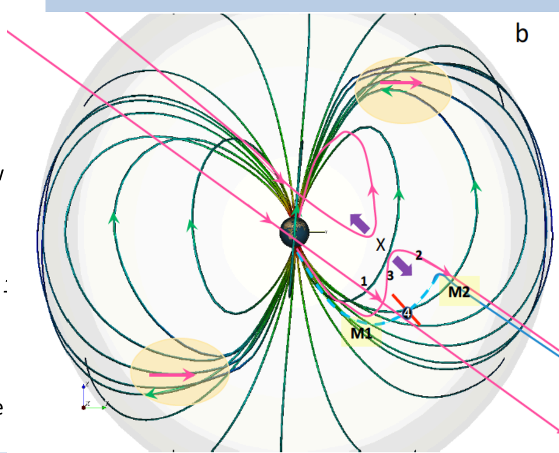




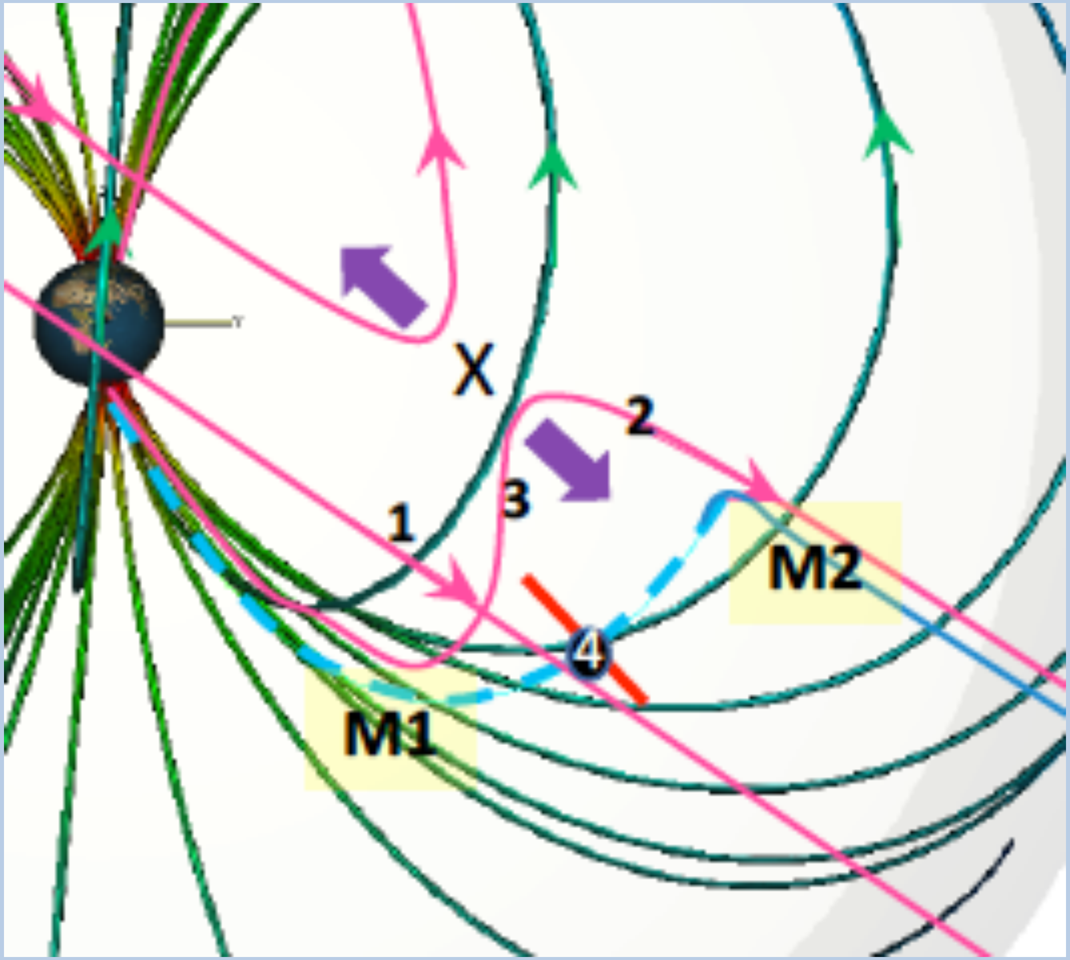


- MMS1 Observations between 9:18-9:30 during 4^{th} cavity encounter showing presence of trapped 70keV -1MeV electrons and 48-209 keV protons as well as ~10keV O+ and and He++.
- H+, He++ and O+ velocity distributions (MMS HPCA) reveal O+ ionospheric outflow through M1 which gets reflected back at M2.

Nykyri et al., JGR, 2019a



- Distance from MMS location to the reconnection site and M2 can be estimated using the fast and slow He++ and O+ parallel velocities observed by MMS in the cavity at t=09:23:49.



Nykyri et al., JGR, 2019a

L_{M1}= 2-2.5 R_E

$$V_{He_f^{++}} t_1 = L_R + L_{M1} + L_{M1}$$

$$V_{He_s^{++}} t_1 = L_R$$

$$L_R = \frac{2 V_{He_s^{++}} L_{M1}}{V_{He_f^{++}} - V_{He_s^{++}}} = 7.8 - 9.8\ R_E$$

$$L_{M2} = \frac{V_{O_f^+} - V_{O_s^+}}{2 V_{O_s^+}} L_{M1} = 0.9\text{-}1.1\ R_E$$

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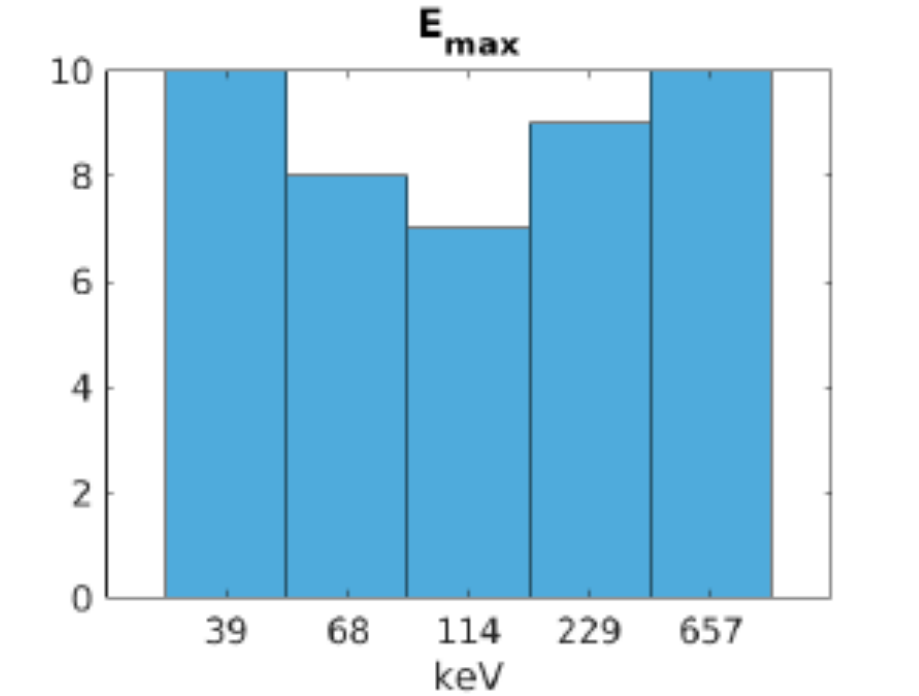
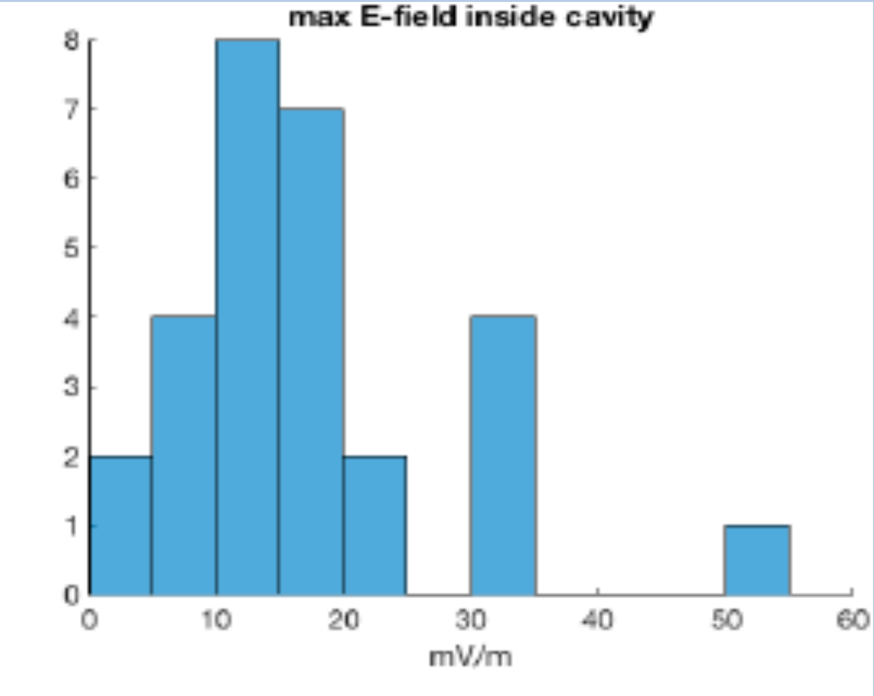
Statistics of the MMS observations of 44 diamagnetic cavities with High-Energy Electrons

- Statistics on cavity location consistent with formation both by low- and high-latitude reconnection, and some were not consistent with either (KHI, Foreshock transients?).
- Electric fields sufficient to produce acceleration up to 100s of keV.
- Electric fields in the cavities consistent mostly with ***–vxB*** electric field.

Burkholder et al., JGR, 2020c





A New Paradigm for Cavity Location after Cluster and MMS

1. IMF Bz <0, By > 0
- 3 locations

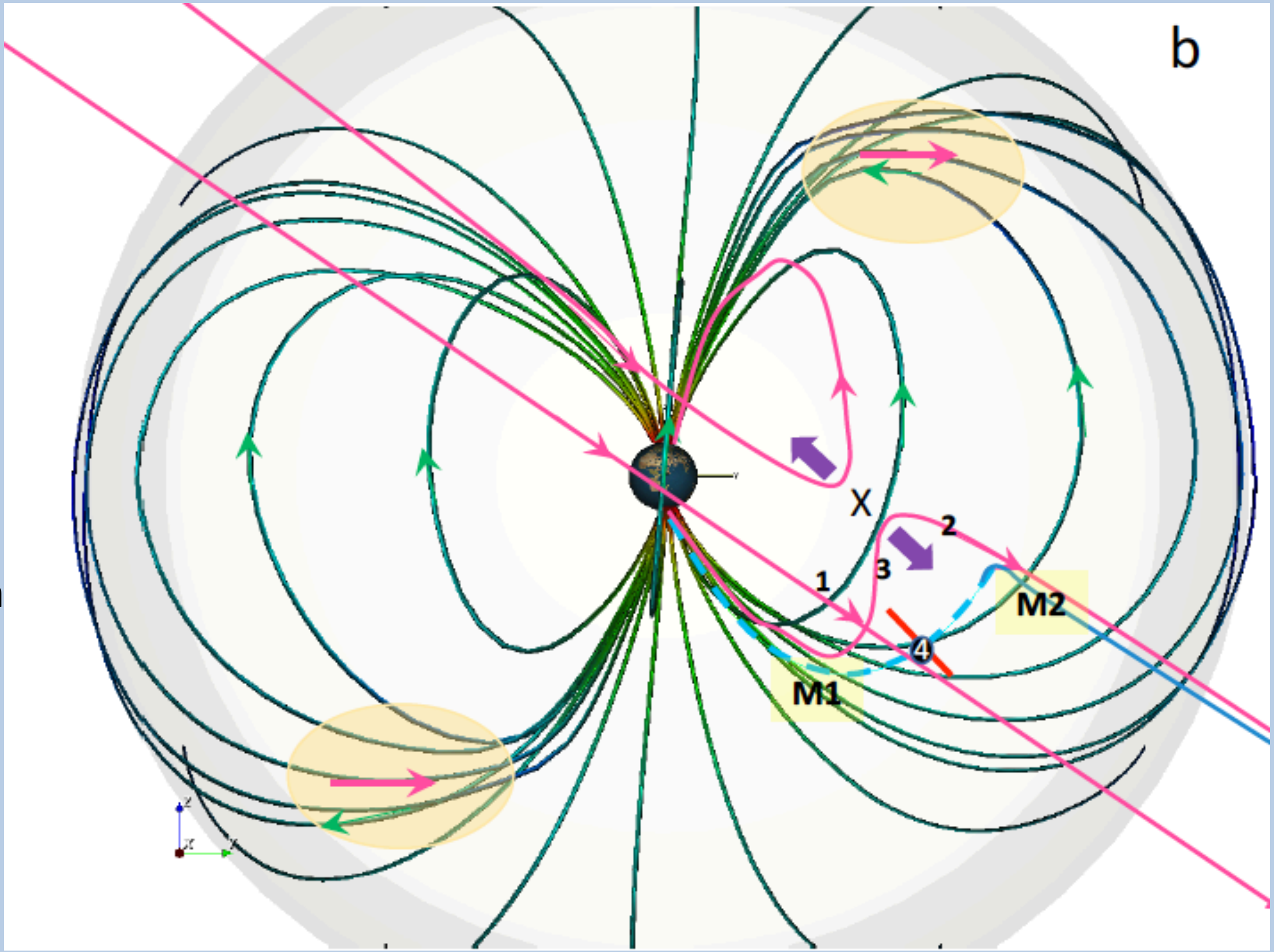
2. IMF Bz <0, By < 0
- 3 locations

3. IMF Bz > 0 Bz <0) (dominant)
- 2 +2 locations

4. IMF By > 0 By<0 (dominant)
- 2+2 locations

5. IMF Bx <0 (Bx>0) will add to draped IMF Bz Influence

6. Hybrid IMF for any given Dominant direction will slightly shift location Sunward, Duskward, Tail-ward or Dawnward



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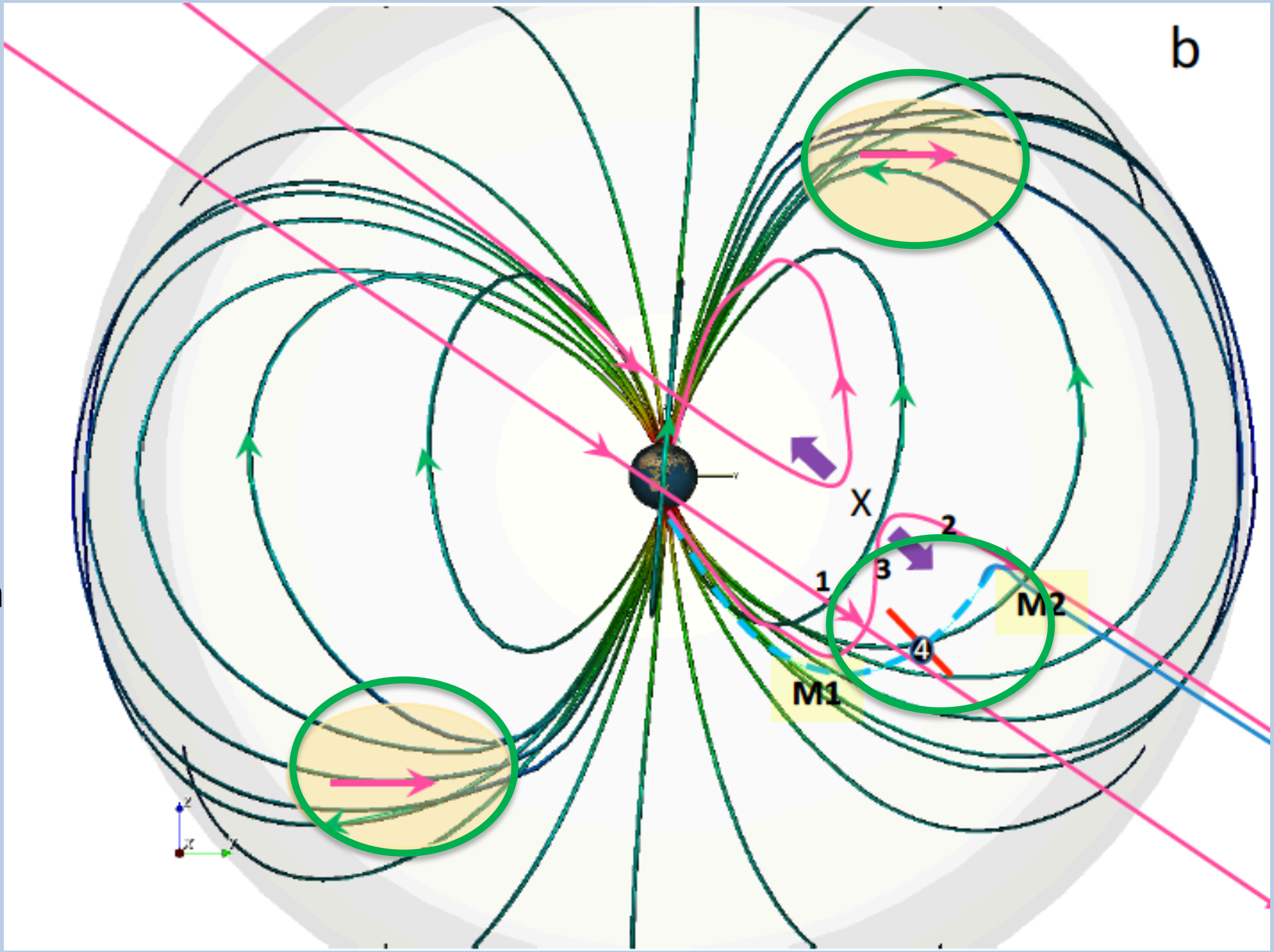

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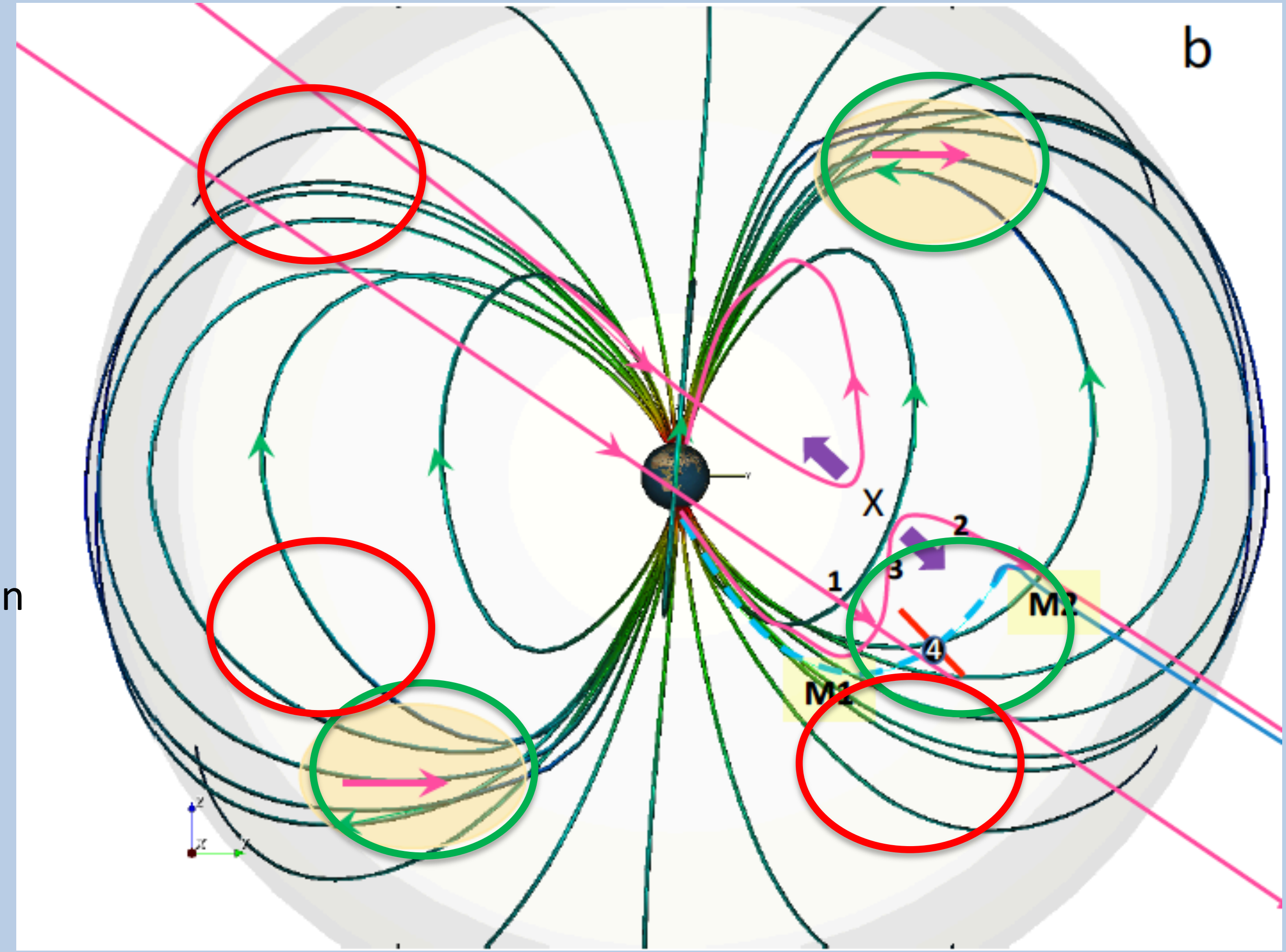

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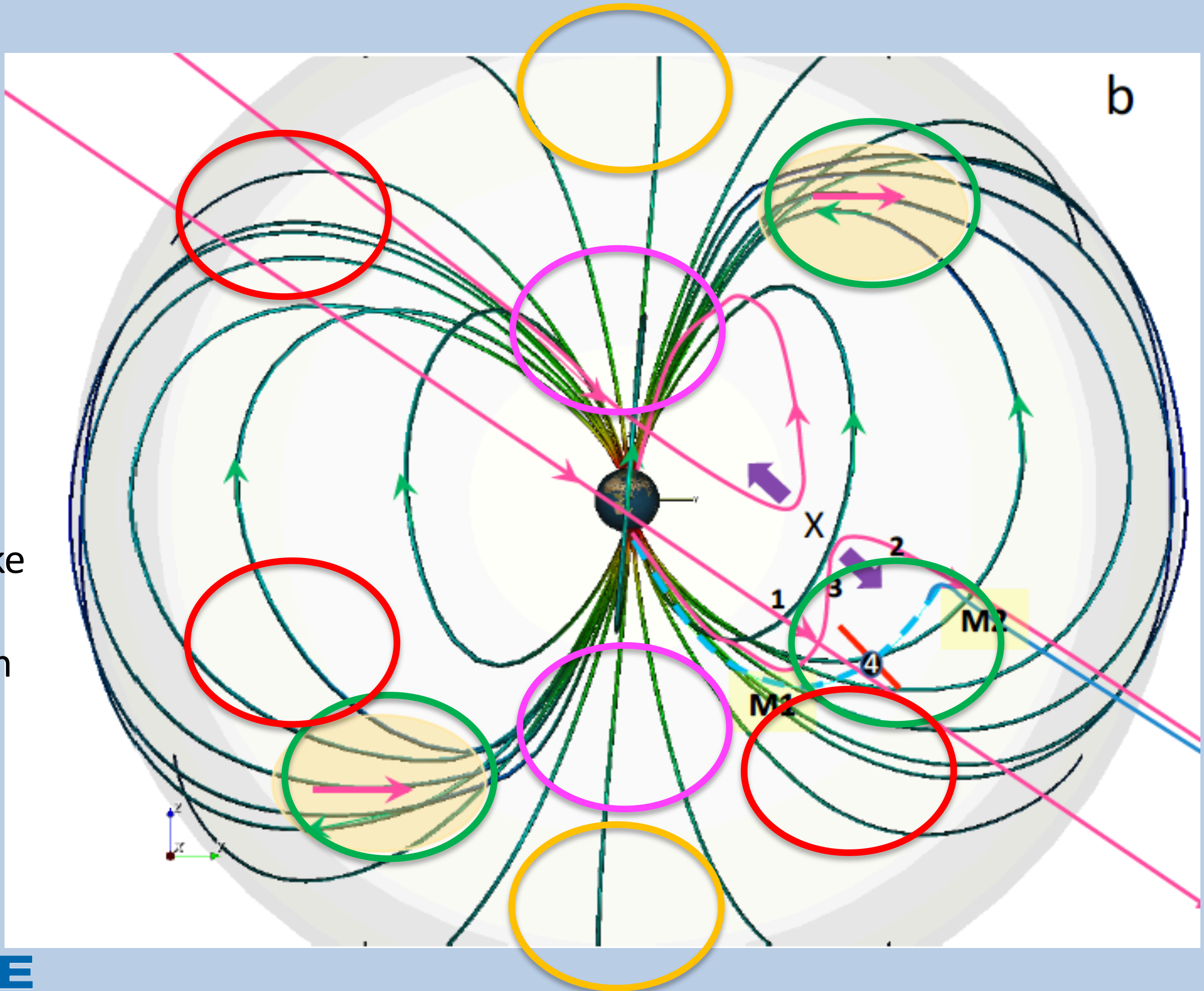
- 2+2 locations

5. IMF Bx <0 (Bx>0) will add to draped IMF Bz Influence (Bx<0, will act like Bz<0 and vice versa)

6. Hybrid IMF for any given Dominant direction will slightly shift location Sunward, Duskward, Tail-ward or Dawnward



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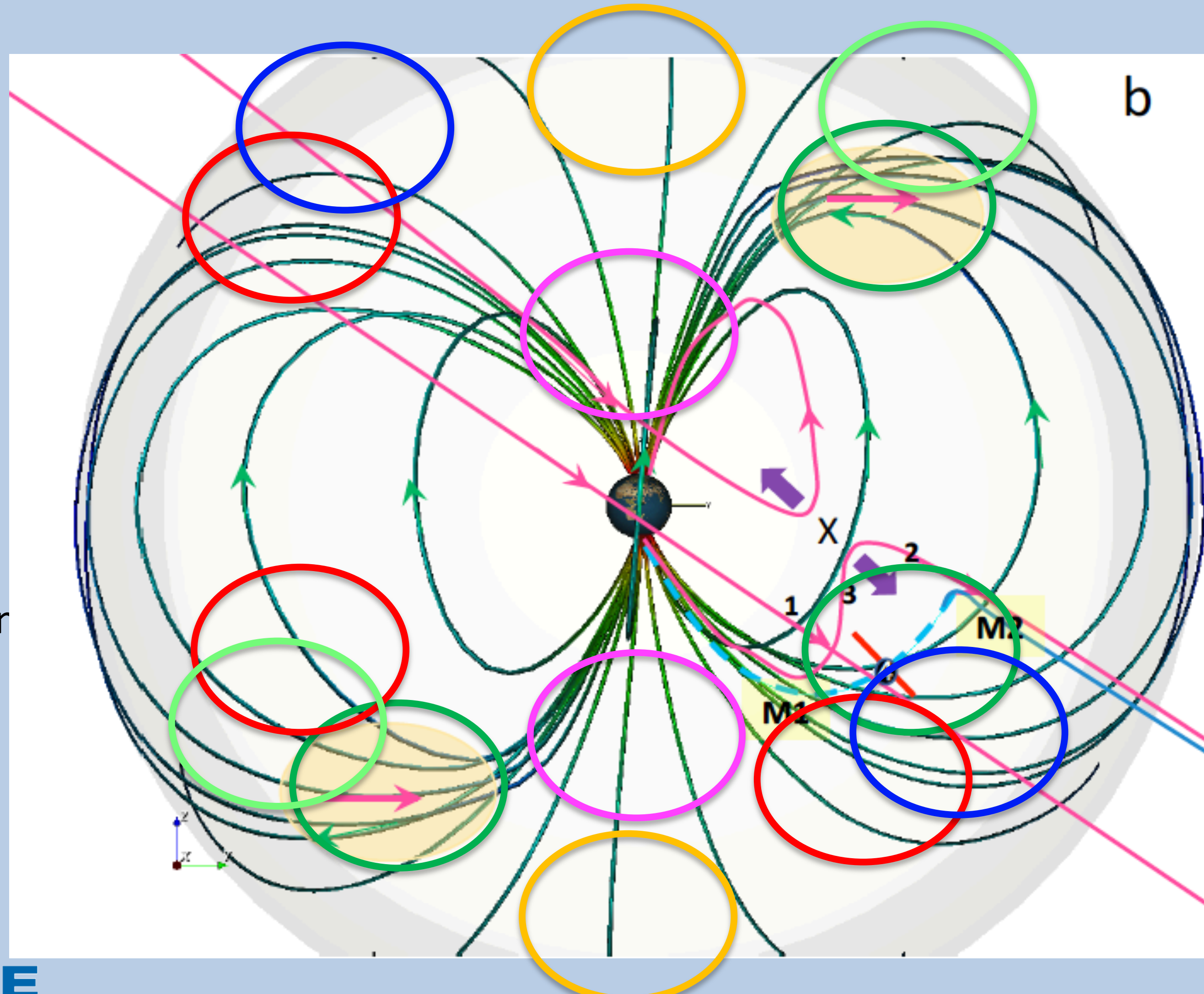

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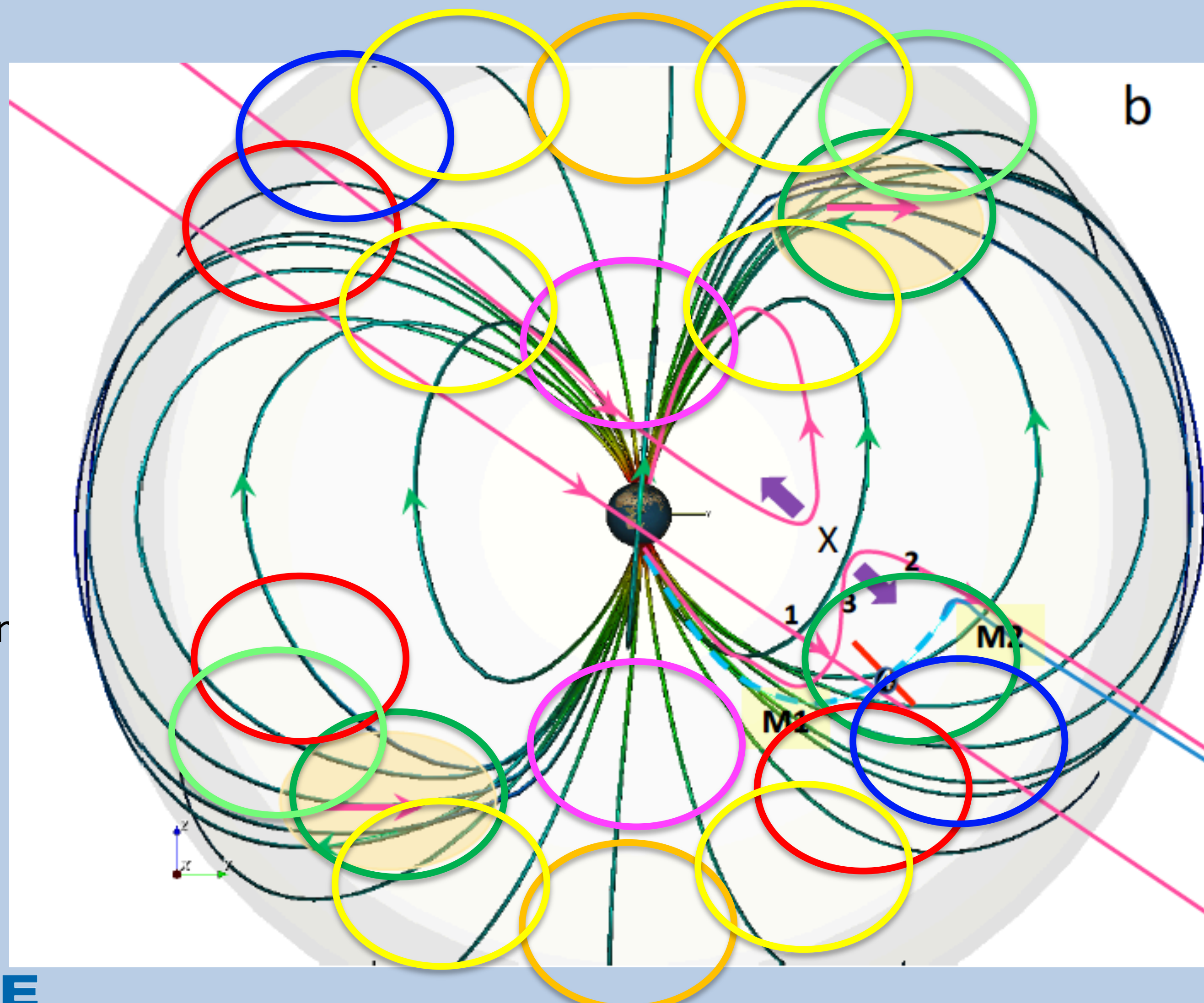

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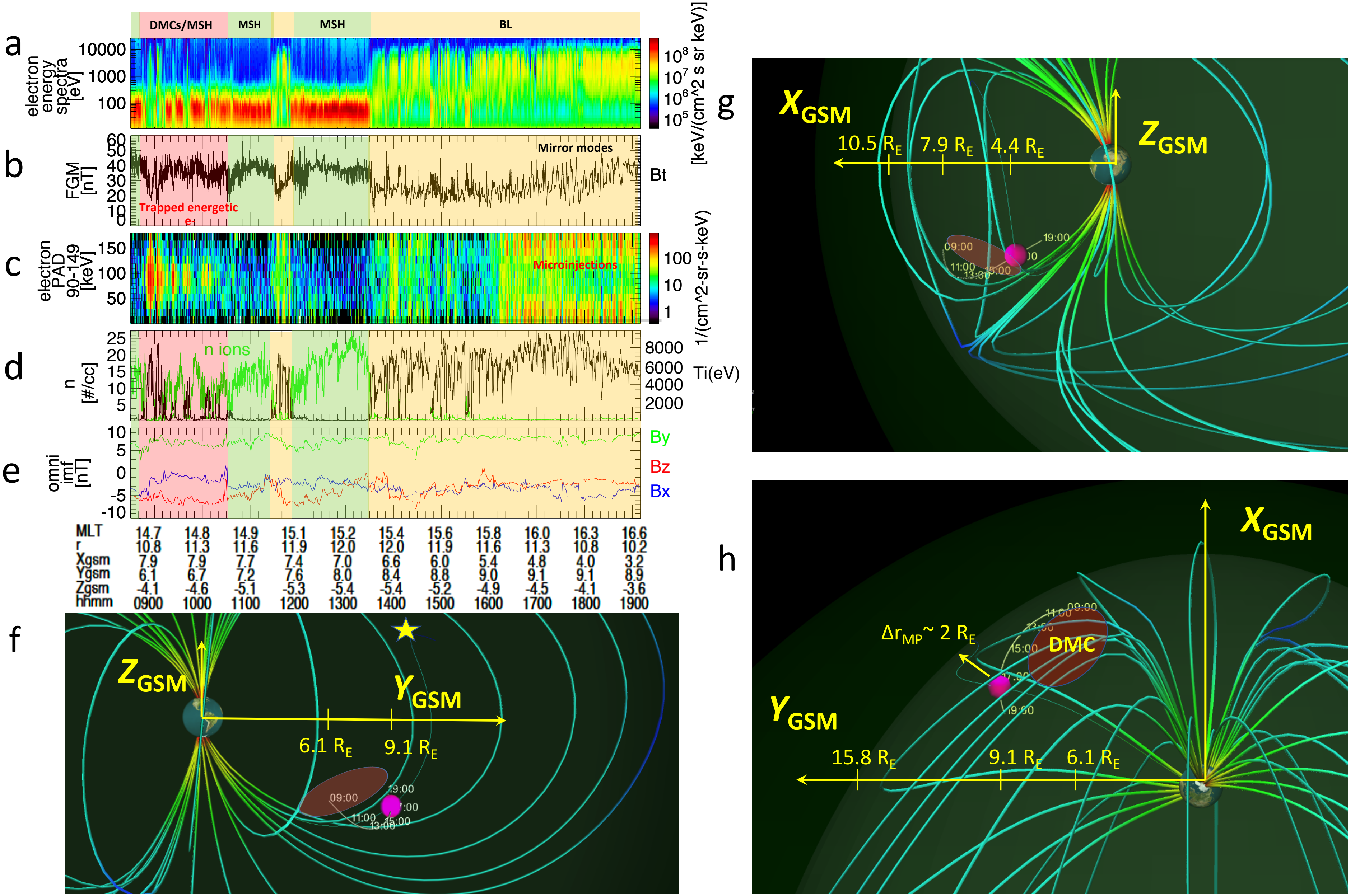
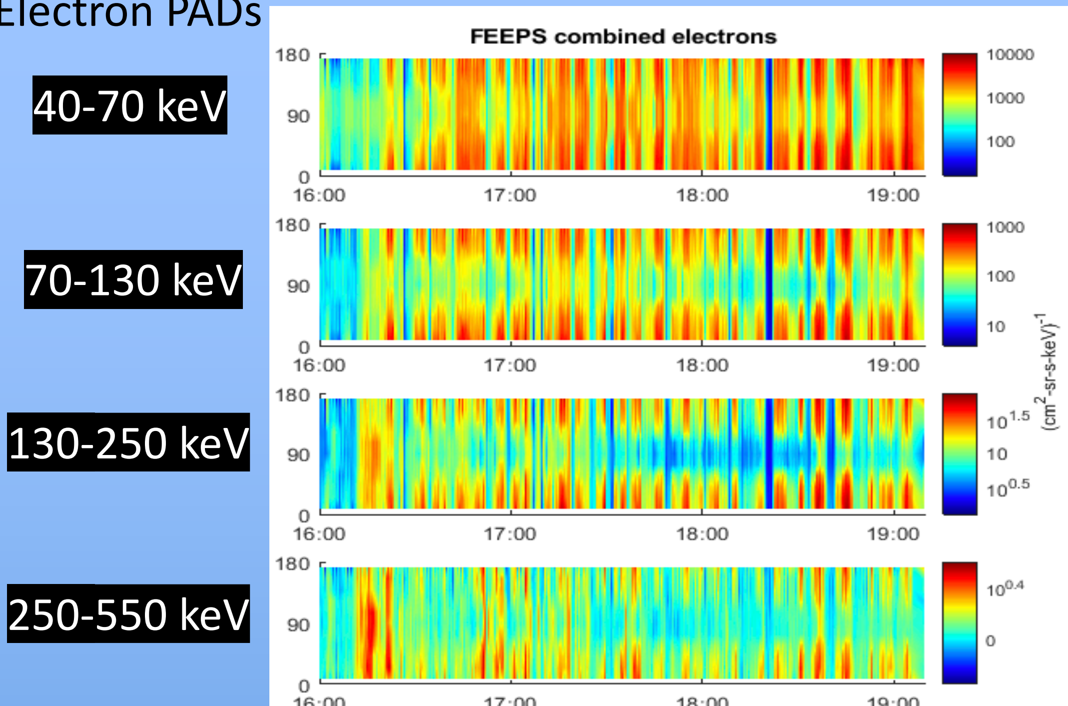
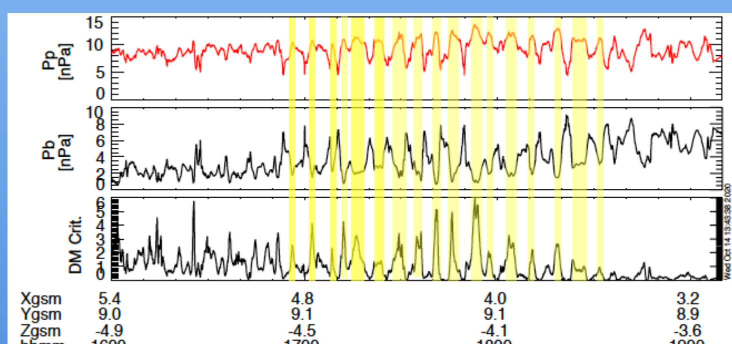


Nykyri et al., 20019a, 2021b

Particles from the diamagnetic cavities can be the source for the energetic electron microinjections.

Electron PADs

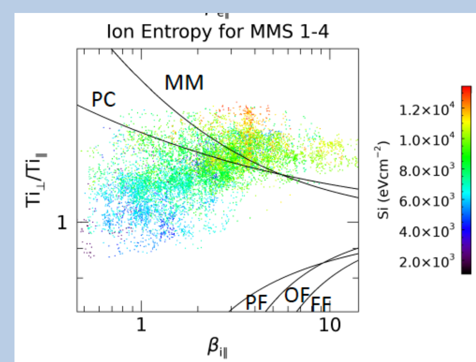




Nykyri et al., 2021b, submitted

- MMS observed for ~3 hrs 28-550 keV electron microinjections in the high-latitude magnetosphere 4 R_E away from the diamagnetic cavities.
- Dispersionless nature -> MMS near the source source region.
- Acceleration mechanism

In cavity creates Ion temperature anisotropy
→ Drift mirror instability



Mass content in the cavities for any given IMF orientation

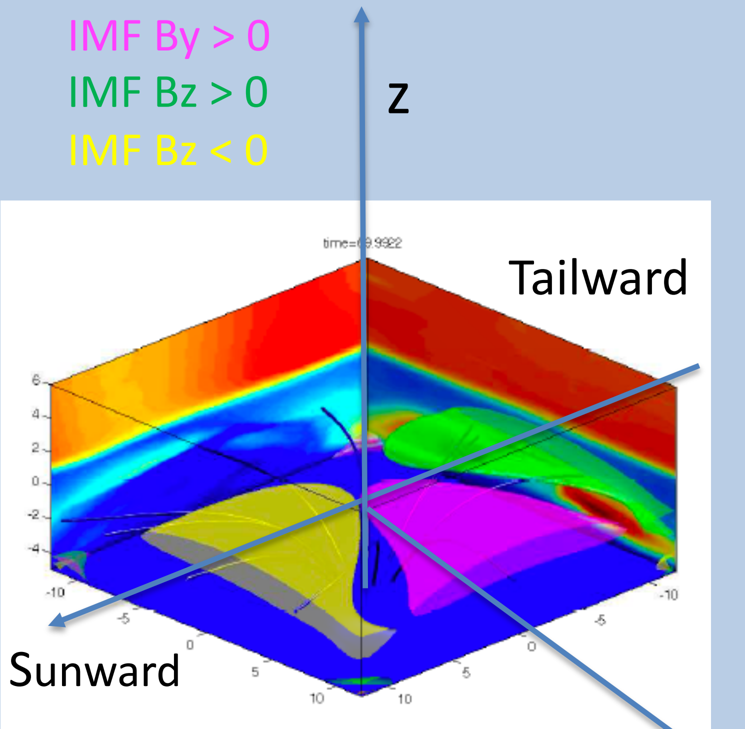


Fig. 2. Distribution of diamagnetic cavity position as indicated by high β region of cusp for strongly northward (green), purely $+B_{yIMF}$ (magenta), and strongly southward IMF (yellow).

Adamson et al., Angeo, 2012

Lower energy particles (Cluster CIS fluxes about 10^7#/(cm^2sr s keV):

Mass of the plasma in a typical cavity created by high-latitude reconnection

M=nmV ~ (15x12x2/2)R^3= 10e6/m^3*1.67e-27 kg*4.6531e22 M=777 kg (assuming protons)

North+South -> M=2x777 kg =1554 kg

Mass of the plasma in a typical cavity created by low-latitude reconnection

M=nmV ~ (7.5x12x4/2)R^3= 2e6/m^3*1.67e-27 kg*4.6531e22 M=155 kg (assuming protons)

South only.

So for Bz<0 with By >0 or B<0, the total proton mass in cavities 1554kg+155 kg ~ 1710 kg. Assuming typical plasma sheet density during southward IMF of 0.5/cc, this volume would correspond to mass of only 38 kg.

The 40-70 keV proton and electron fluxes during dayside microinjections are 10^5#/(cm^2sr s keV).

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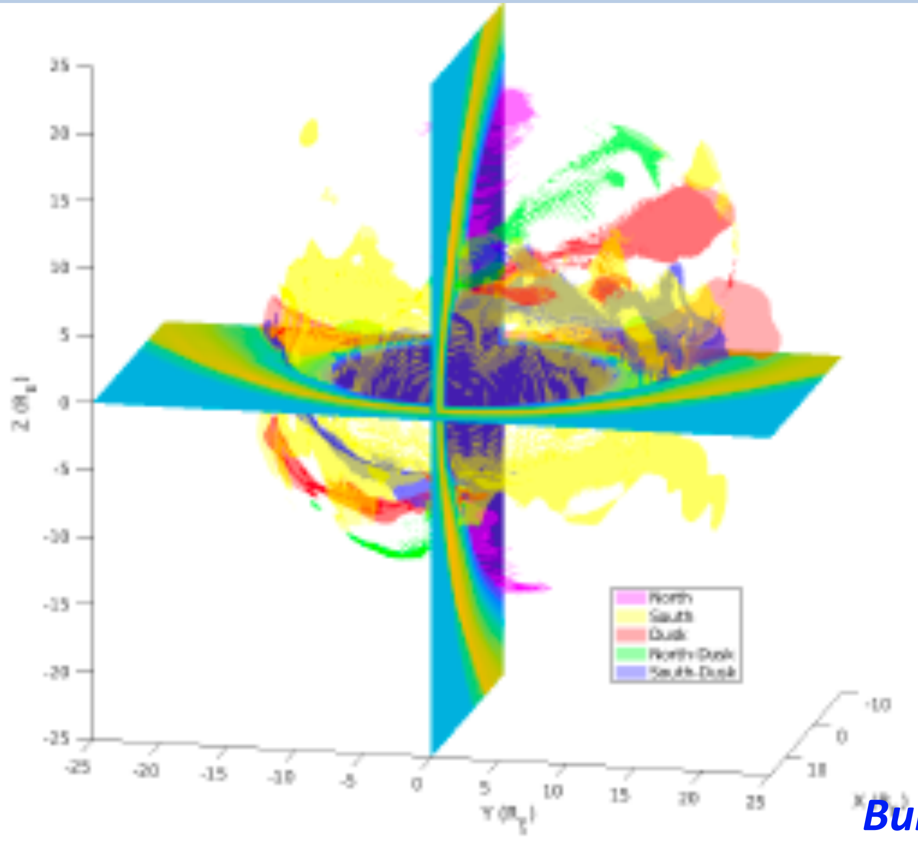
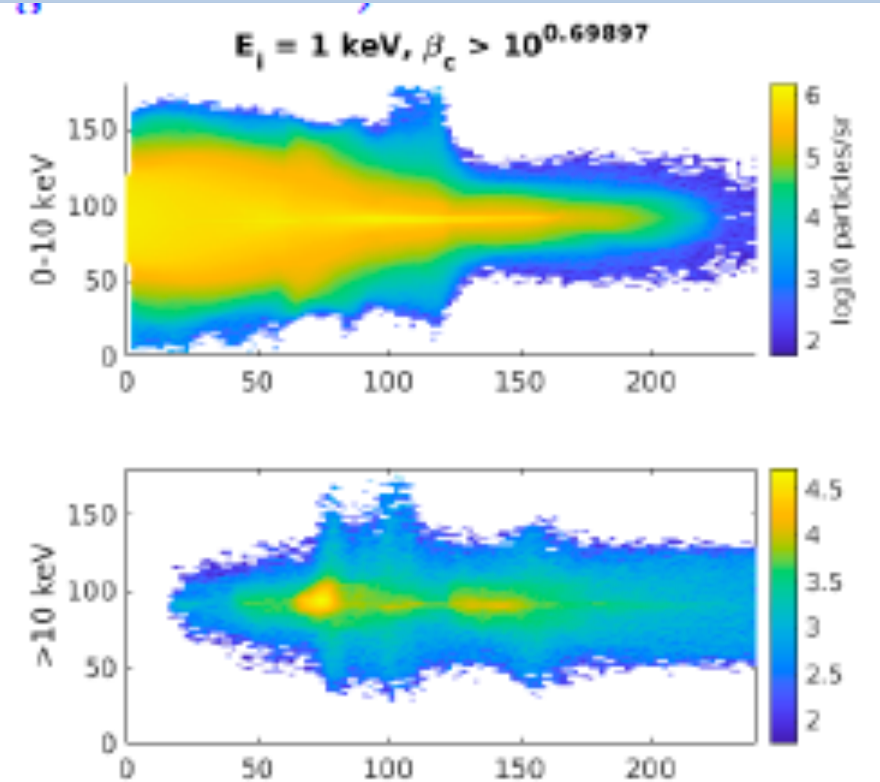
GAMERA global simulations of the cavity formation and particle energization

- Cavity acceleration energizes particles perpendicular to magnetic field

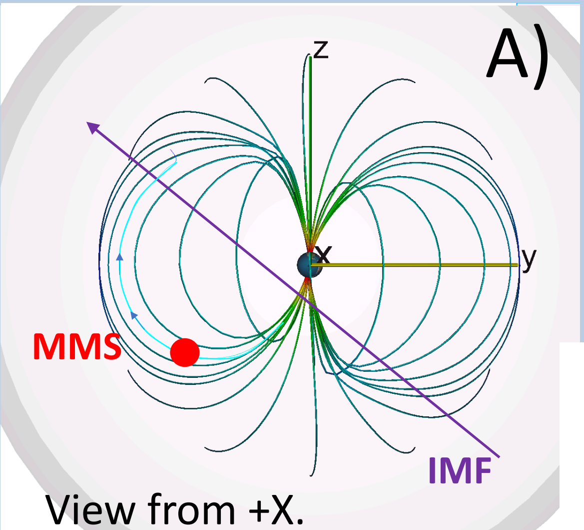
⇒ Possible source for temperature anisotropy and high-plasma beta in high-latitude magnetosphere capable for drive the drift mirror instability.



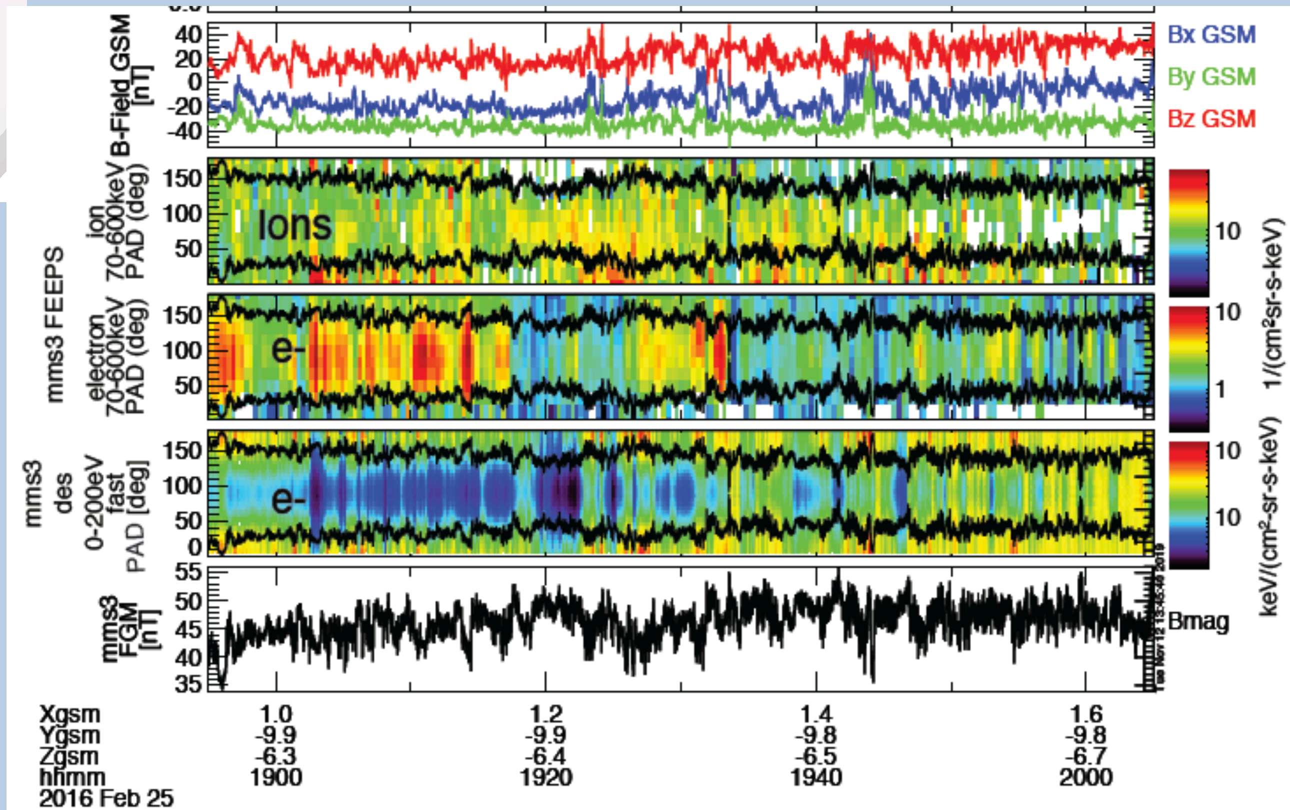


Burkholder et al., 2021, in preparation

Open questions: Interaction between KH waves, mirror-mode waves and diamagnetic cavities at high-latitudes?



- New MMS orbits at high-altitude cusp with *string-of pearls* separation with 2 spacecraft about 1000-2000 km apart and few in 100-200 km separations (together with TRACERS at low Altitudes and HSO fleet) would be ideal studying these processes



Nykyri et al., JGR, 2021a

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Conclusions

- Large, several R_E in size, diamagnetic cavities can be generated at high-latitudes by high-and low-latitude reconnection. Particles can can gain several 100s of keV if cavity remains stable for 4-5 minutes.

- For any given IMF orientation, at least 2 cavities form, one at northern and one at southern hemispheric, high-latitude magnetosphere.
- For Bz<0, By>0 and for Bz<0, By<0 we get additional cavities at southern hemisphere due to low latitude component reconnection.
- Mass in the cavities for Bz<0, By>0 and for Bz<0, By<0 is comparable to mass in near-earth magnetotail.
- The particles are accelerated in the cavities perpendicular to magnetic field which could explain the origin of strong temperature anisotropy, high plasma beta and make conditions ripe for drift mirror instability, which can drive energetic electron microinjections.
- These particles may gain access to inner magnetosphere and could contribute to radiation belt seed population.

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