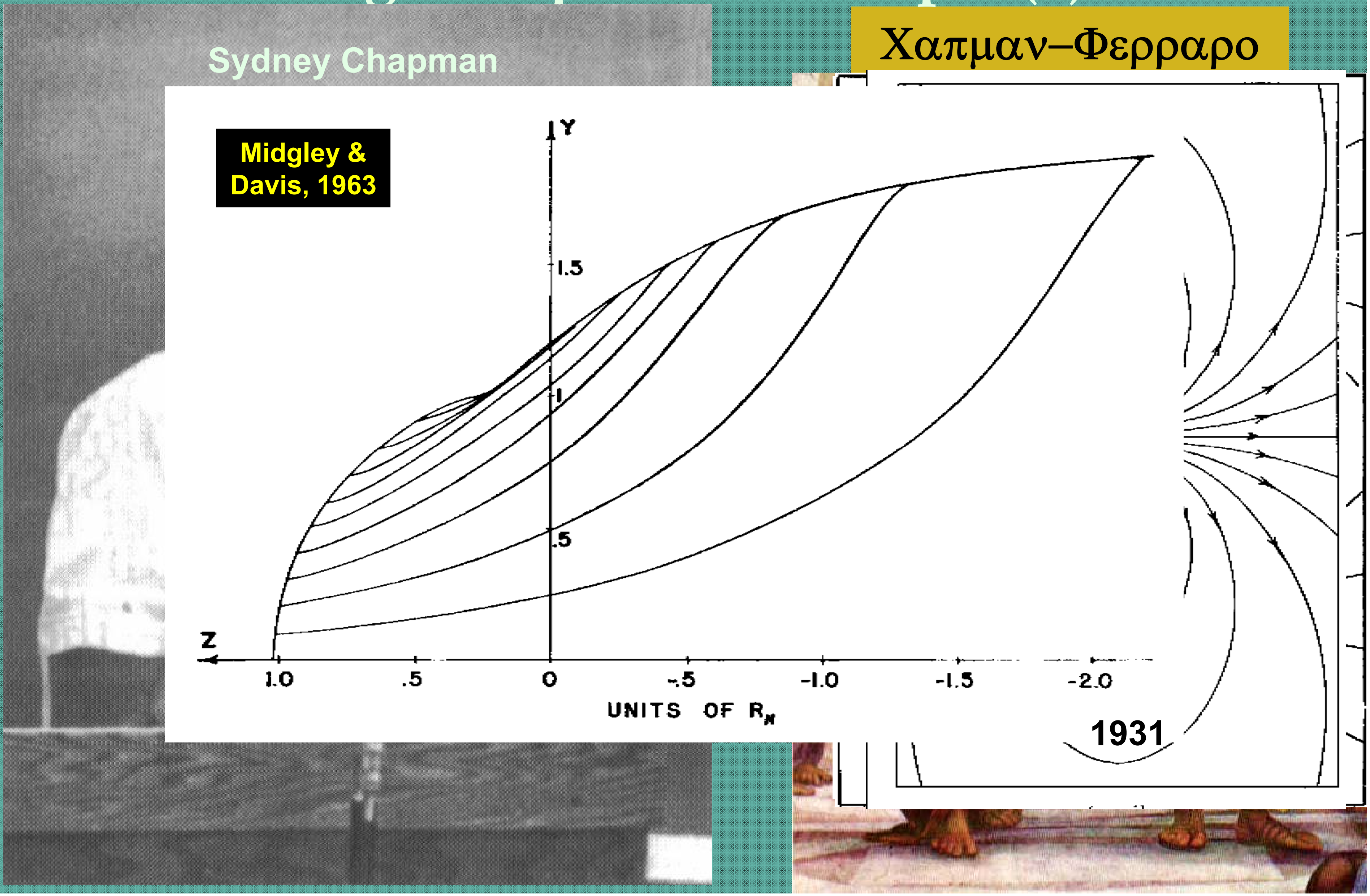
From the Chapman-Ferraro Magnetosphere To the Dungey-Alfvén Magnetosphere

- **Two Magnetosphere Types**
  - Chapman-Ferraro
  - Dungey-Alfvén
- **Chapman-Ferraro Type**
  - Hands-off, no-touch vacuum coupling
- **Dungey-Alfvén Type**
  - Hands-on, bow shock-to-ionosphere Alfvén coupling
- **Hybrid Type**
  - Chapman-Ferraro type usually dominates

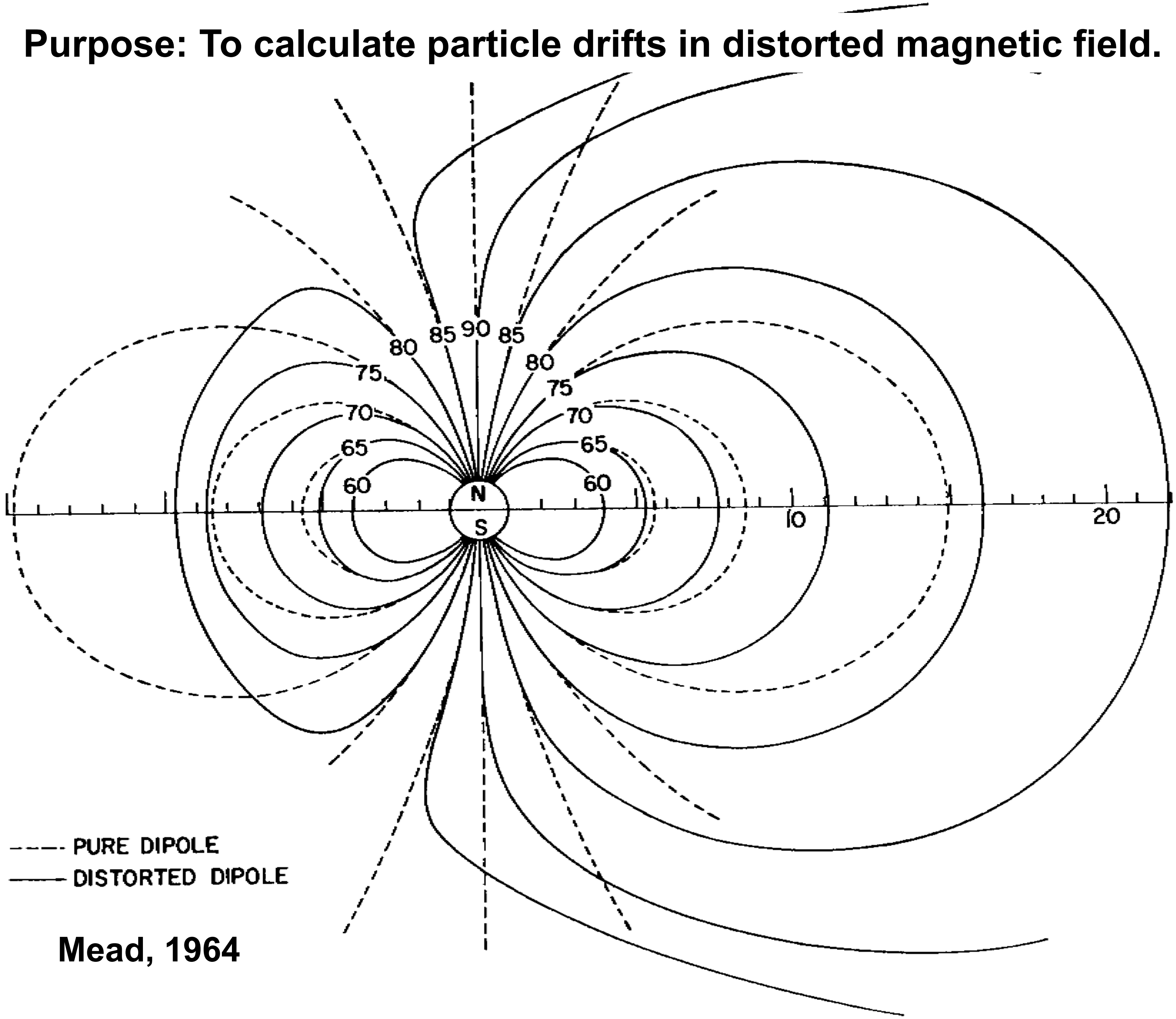
Chapman-Ferraro Magnetosphere

Dungey-Alfvén Magnetosphere

Highlights in the History of Magnetospheric Concepts (1)

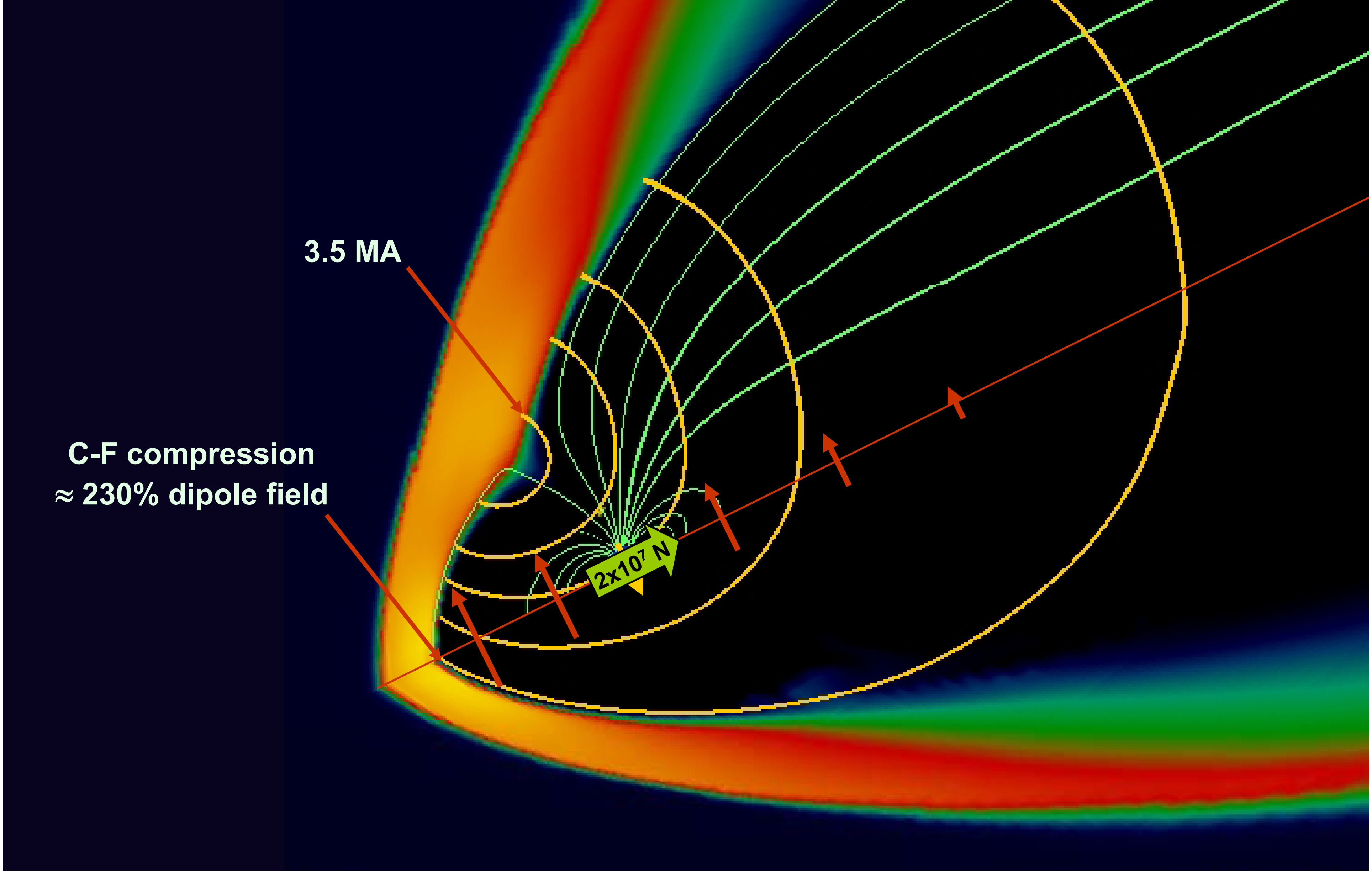


Purpose: To calculate particle drifts in distorted magnetic field.

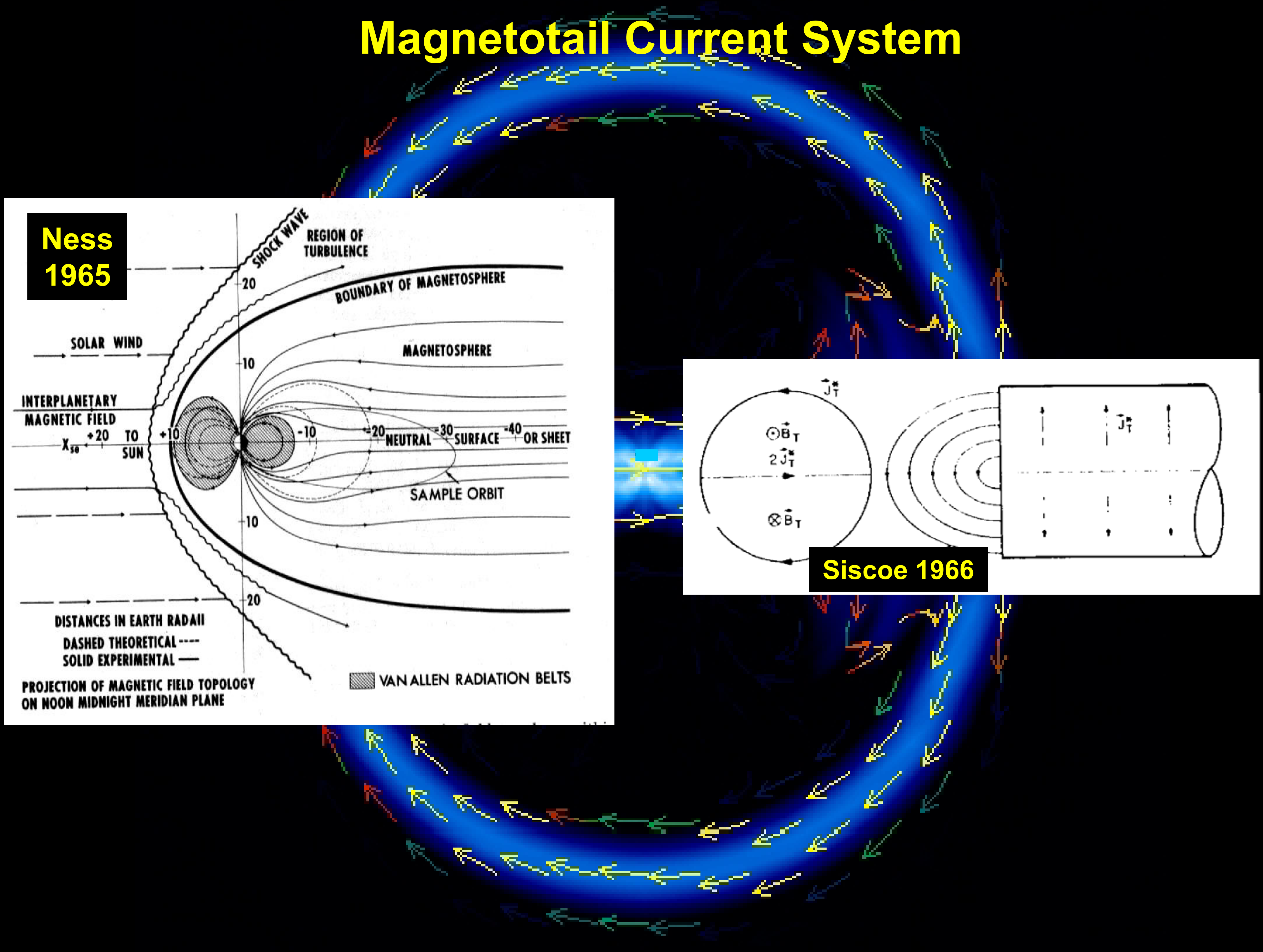


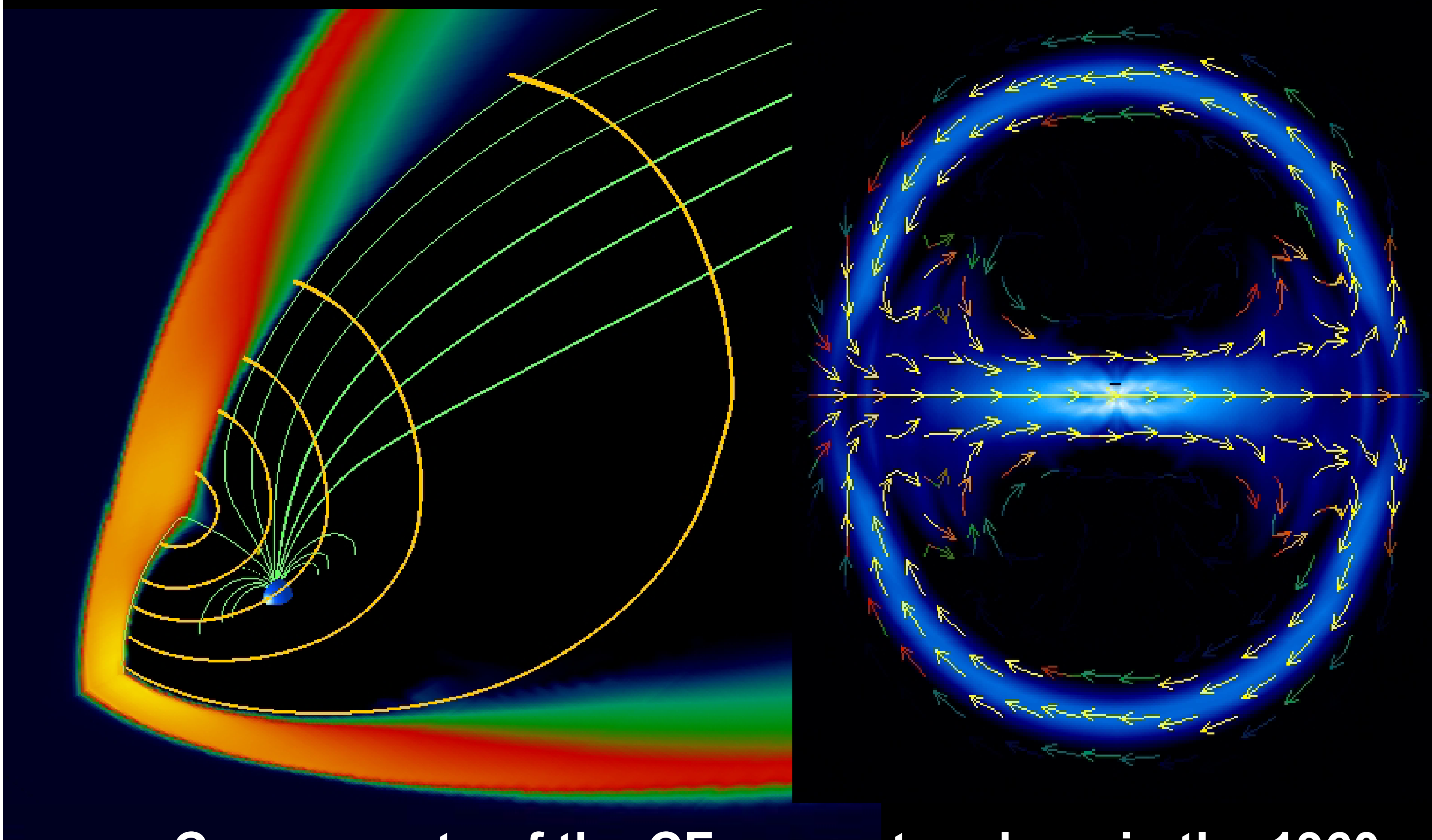
Mead, 1964

Properties of the Chapman-Ferraro Magnetosphere



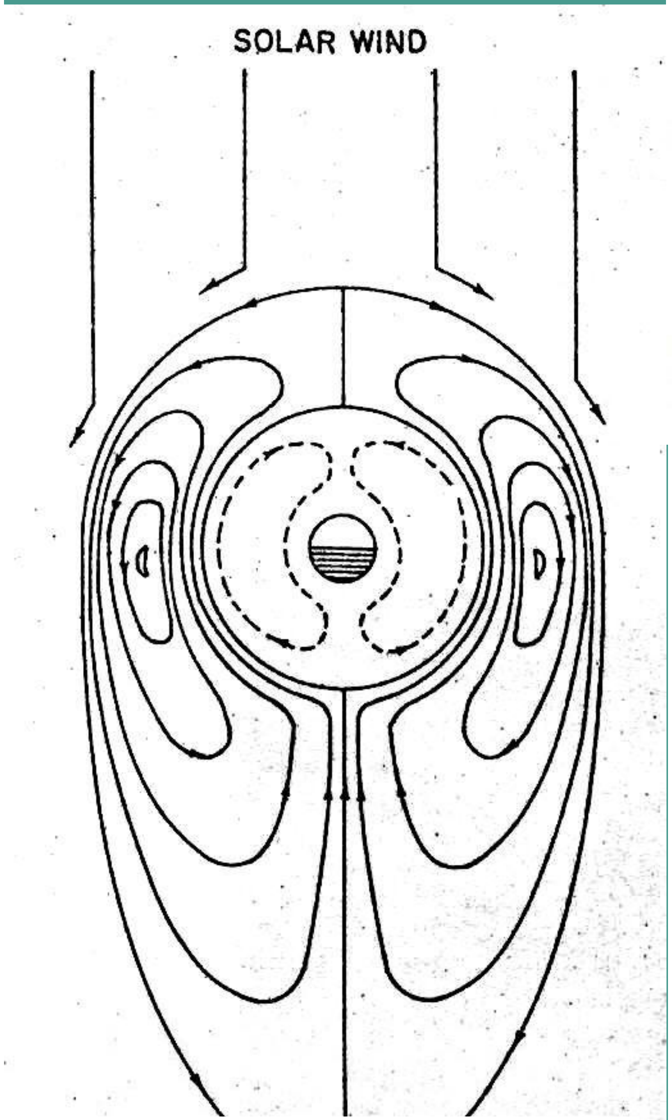
New Element
Magnetotail Current System



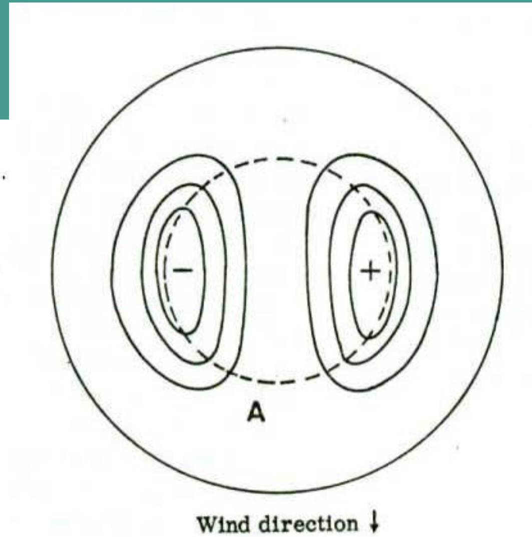


Components of the CF magnetosphere in the 1960s
Total field confinement and vacuum magnetic interactions

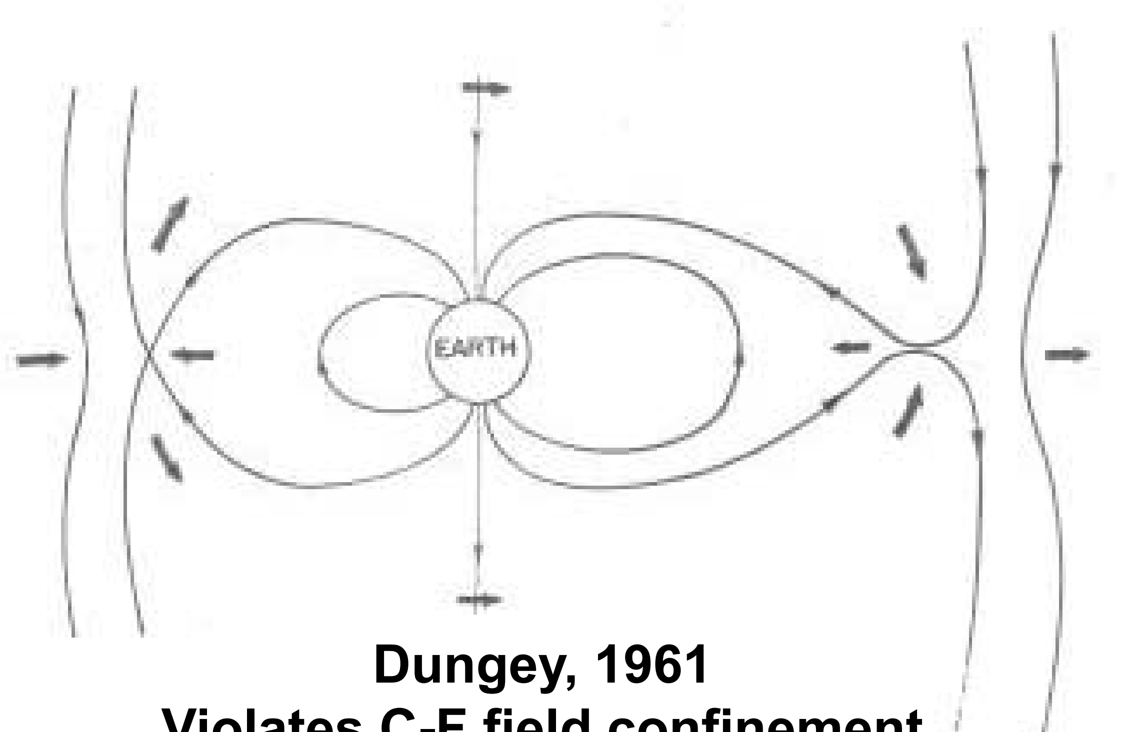
Things that did not fit the C-F picture



Axford and Hines, 1961

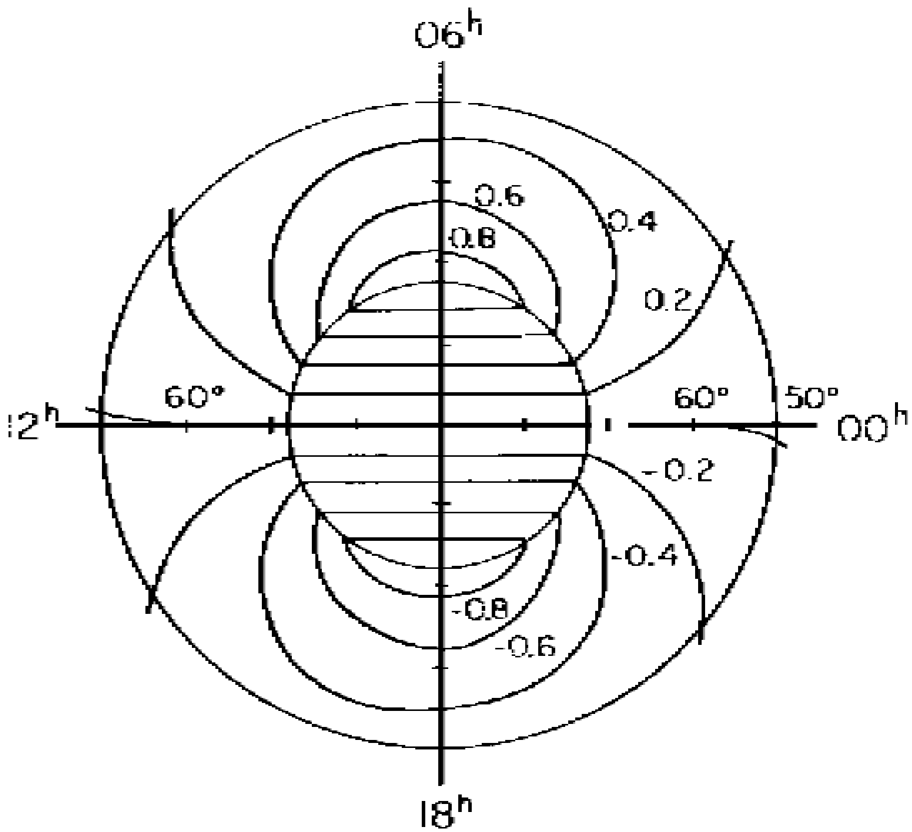


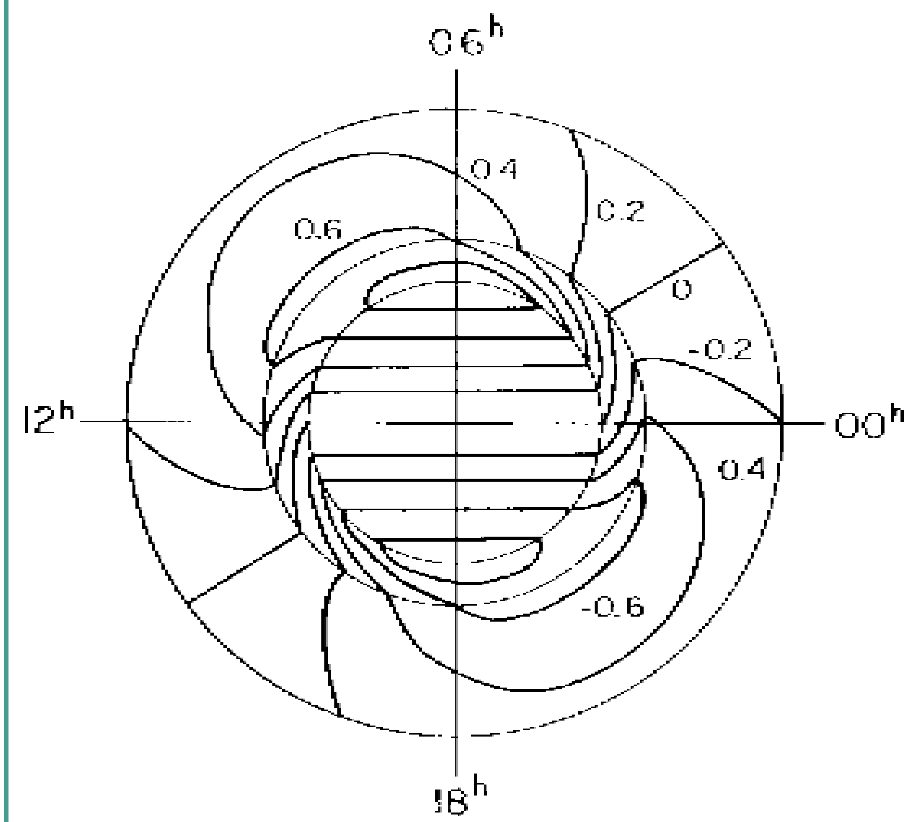
Two cell, sun-fixed ionospheric circulation pattern



Dungey, 1961
Violates C-F field confinement

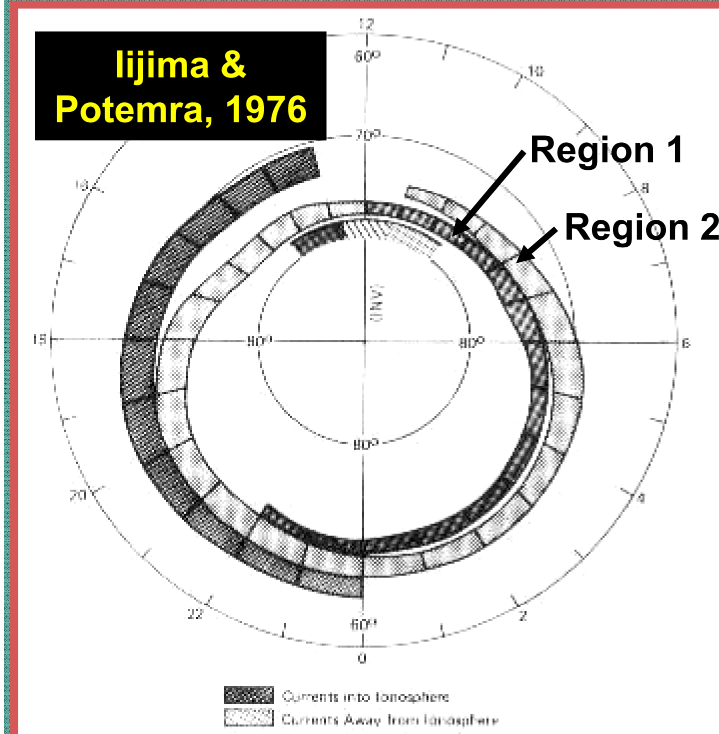
Vasyliunas MI Coupling Results 1970-1972

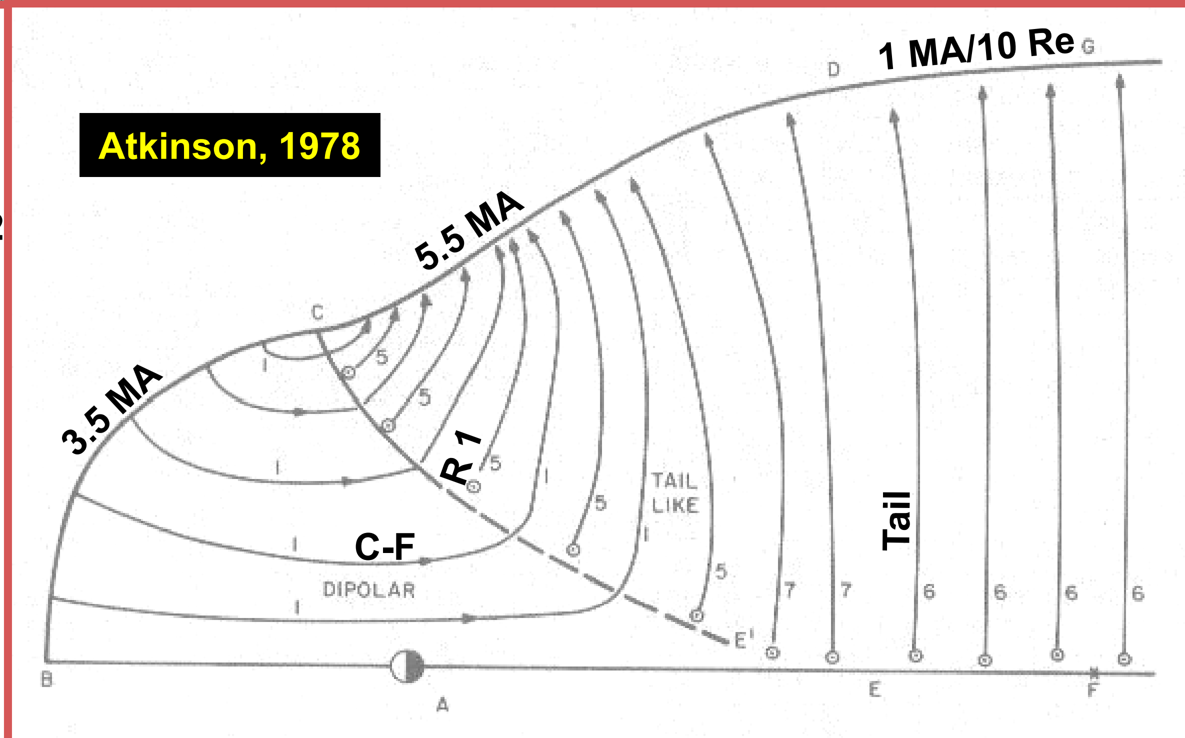




Violates C-F vacuum magnetic interactions

Ultimate Crisis to the CF Picture
Discovery of Strong Field-Aligned Currents





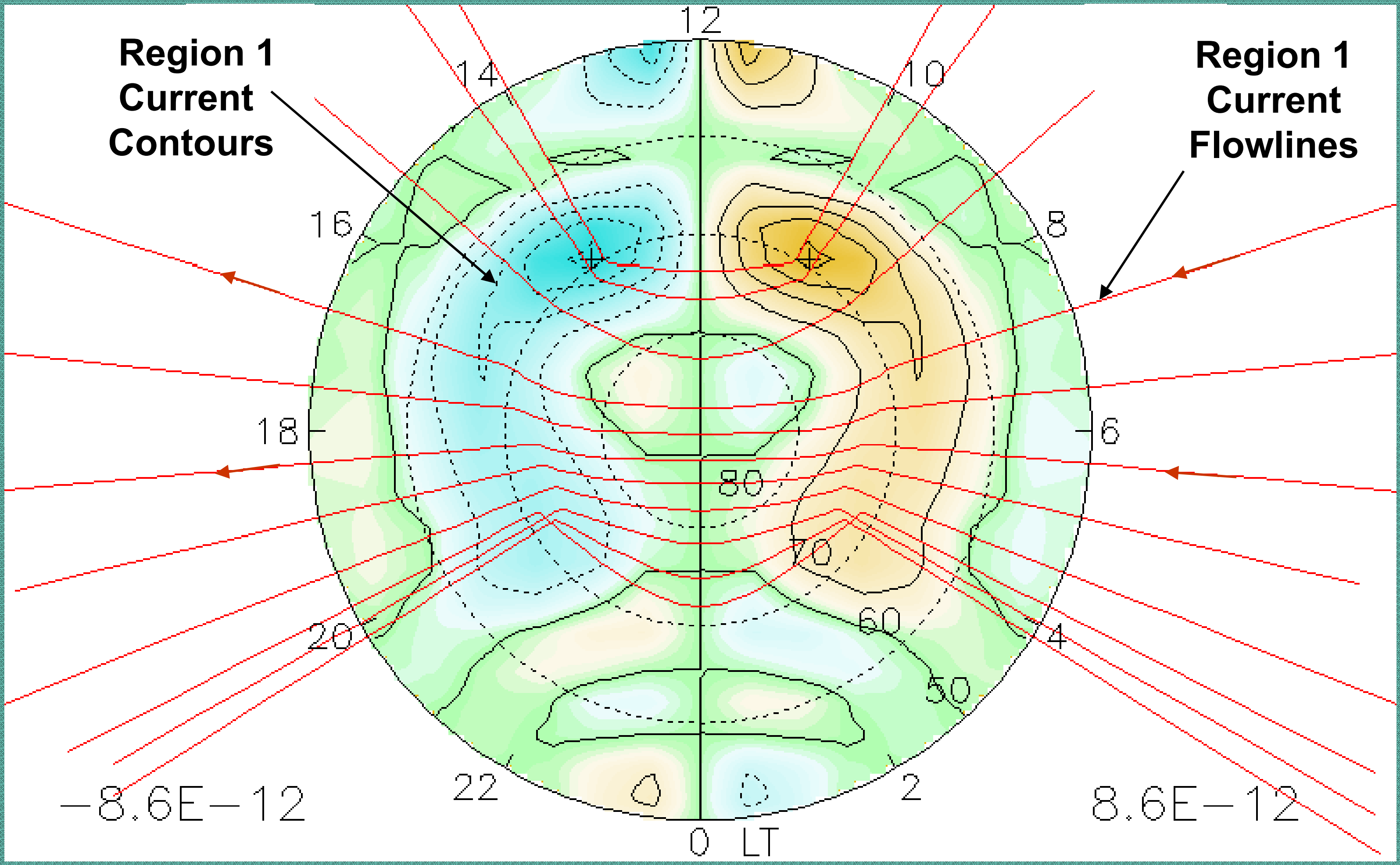
Total Field-Aligned Currents for Moderate Activity

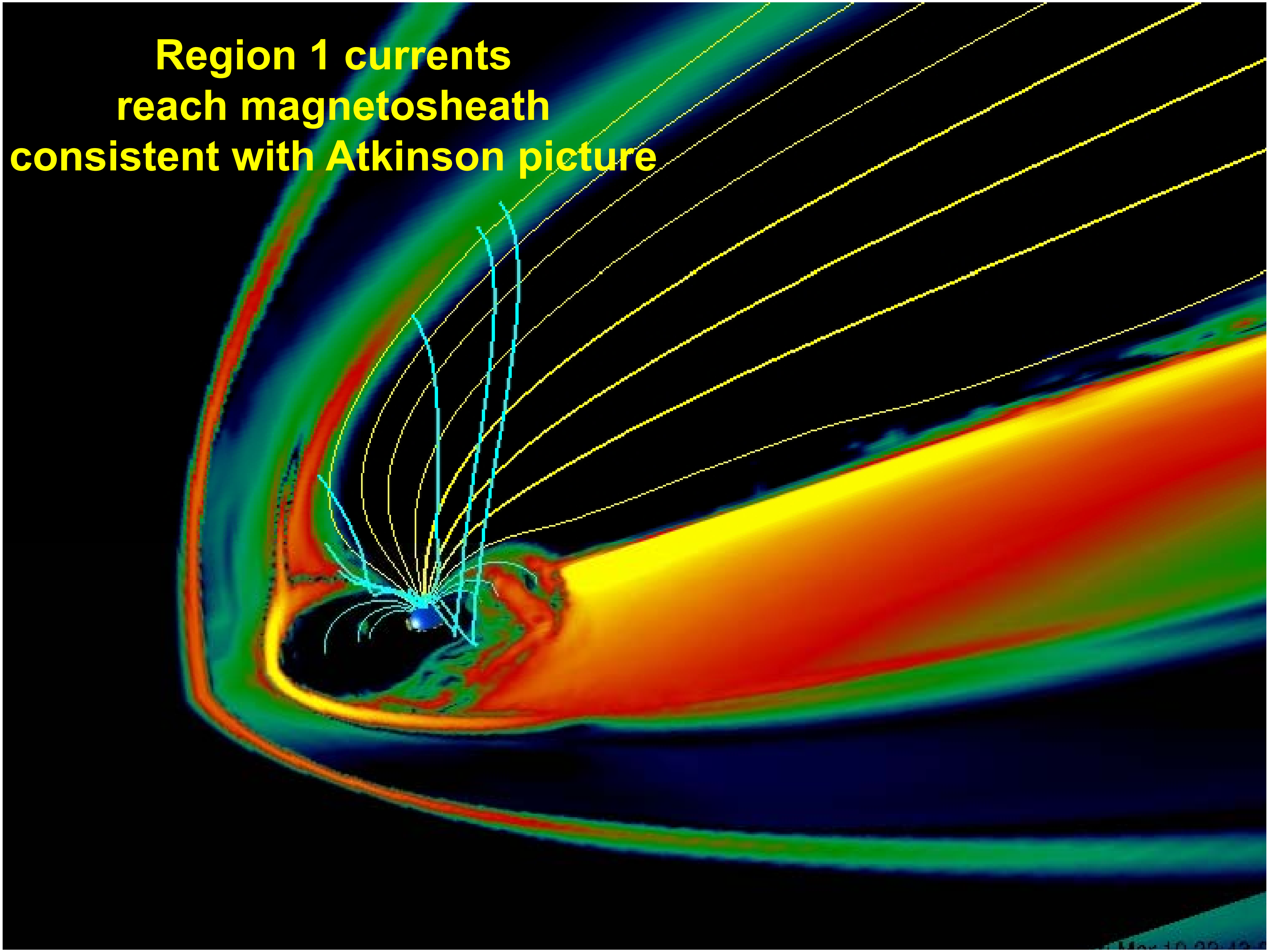
(IEF ~1 mV/m)

Region 1 : 2 MA
Region 2 : 1.5 MA

Question: How do you self-consistently accommodate the extra 2 MA?

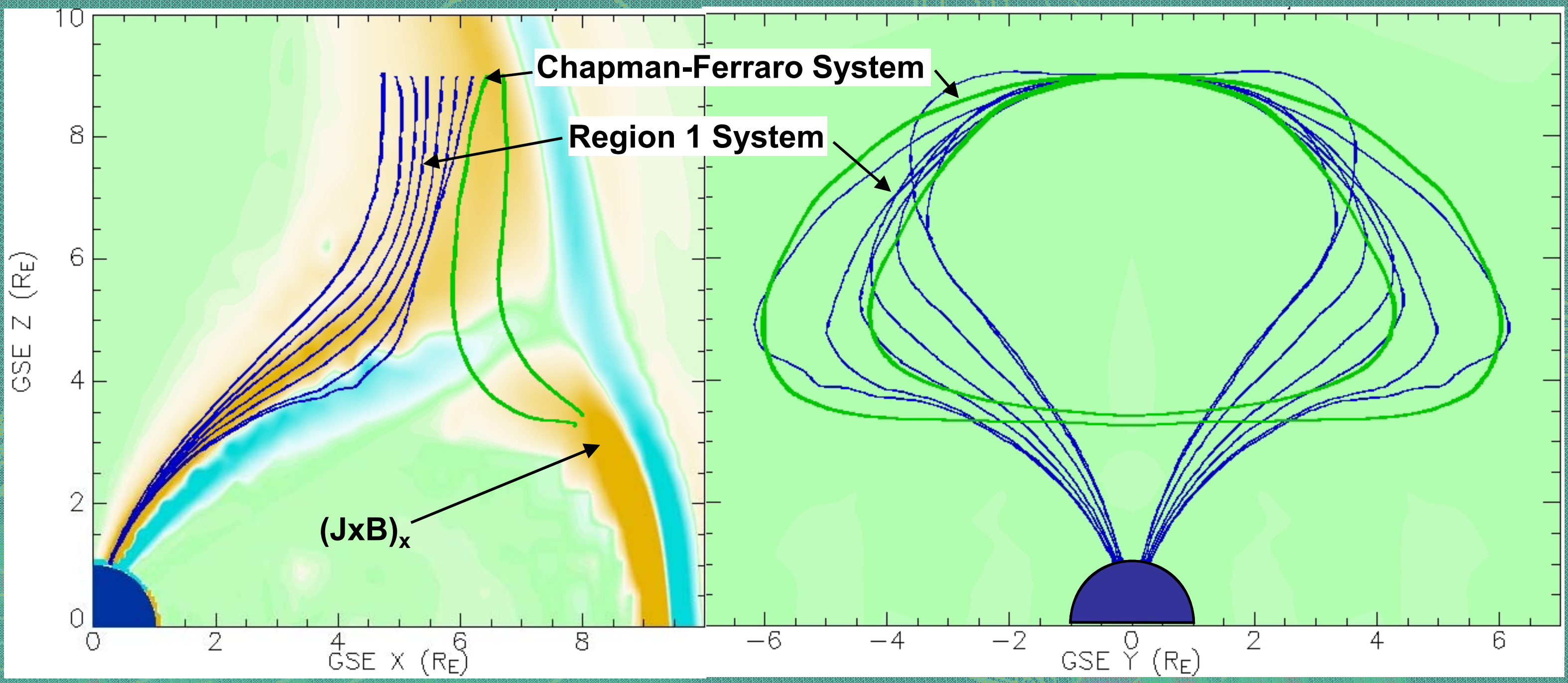
Appeal to MHD Simulations
Region 1 Currents
IMF = 5 nT South




Region 1 currents
reach magnetosheath
consistent with Atkinson picture

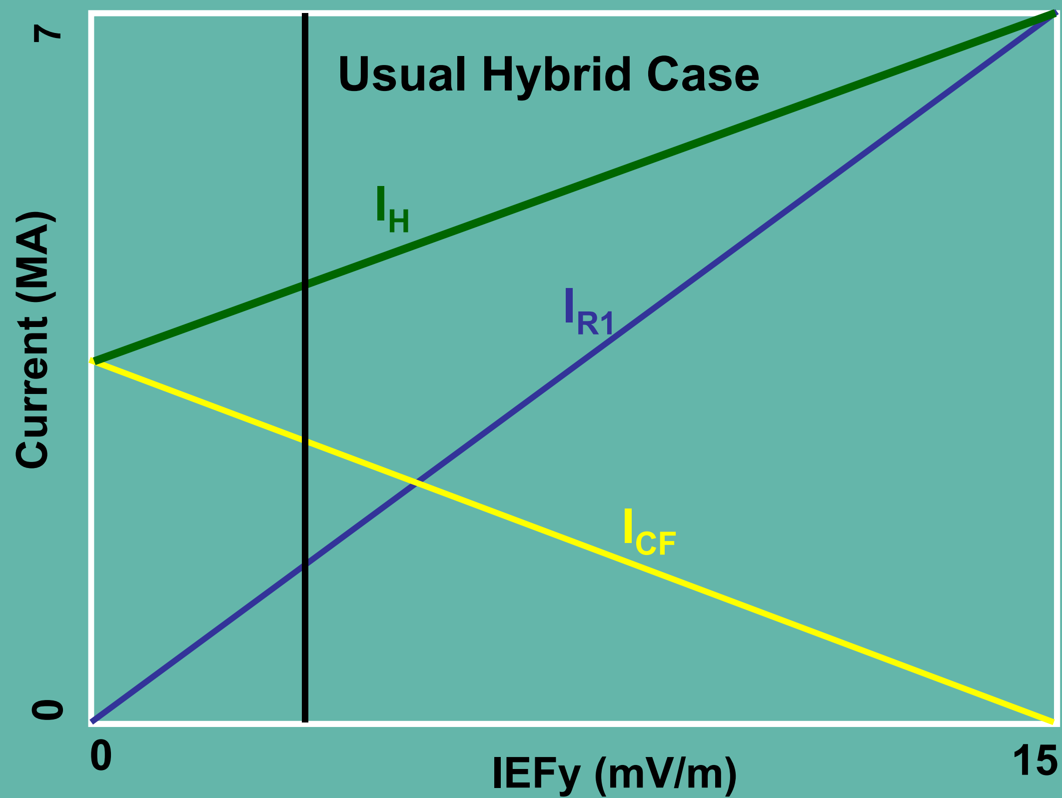
Q: How do you self-consistently accommodate an extra 2 MA current system?

A: You replace the Chapman-Ferraro current with it.



IMF = (0, 0, -5) nT

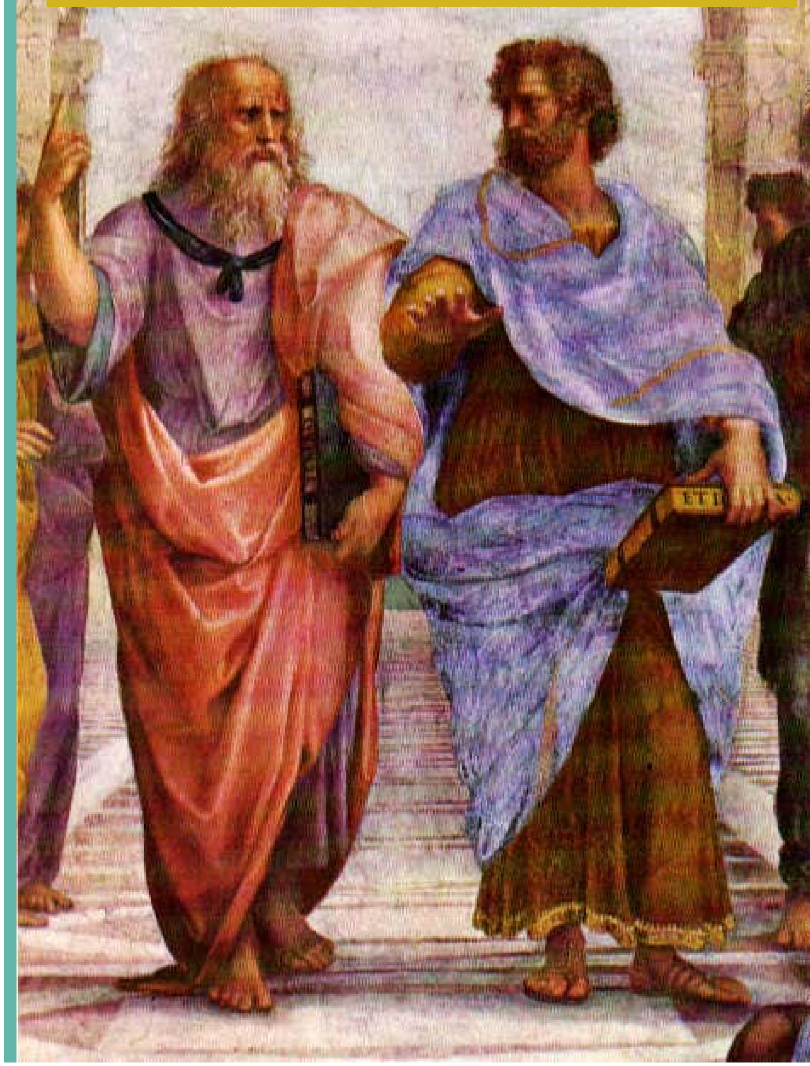
Current Quasi-Conservation Principle

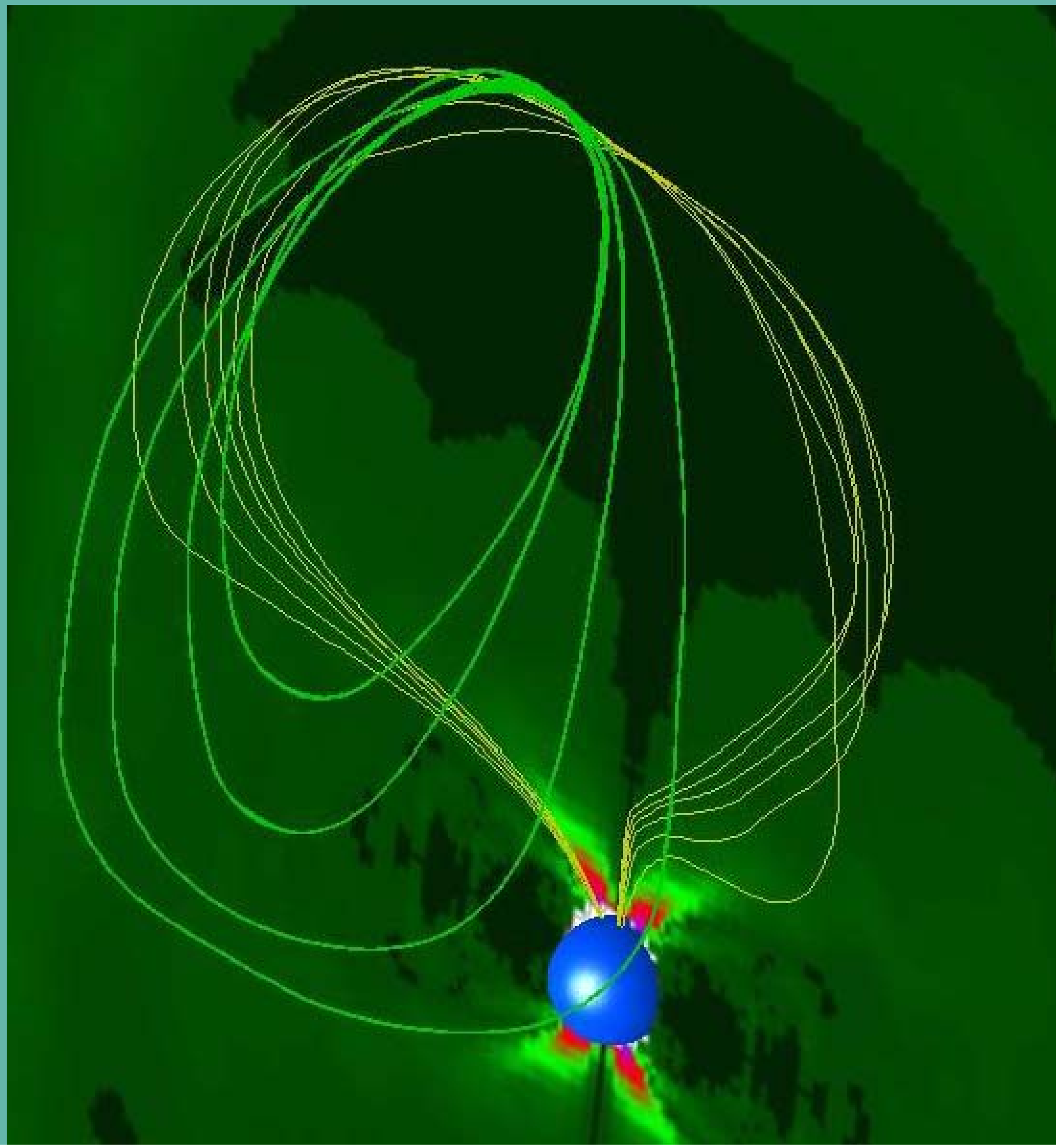


Highlights in the History of Magnetospheric Concepts (2)

Υβρίδιο

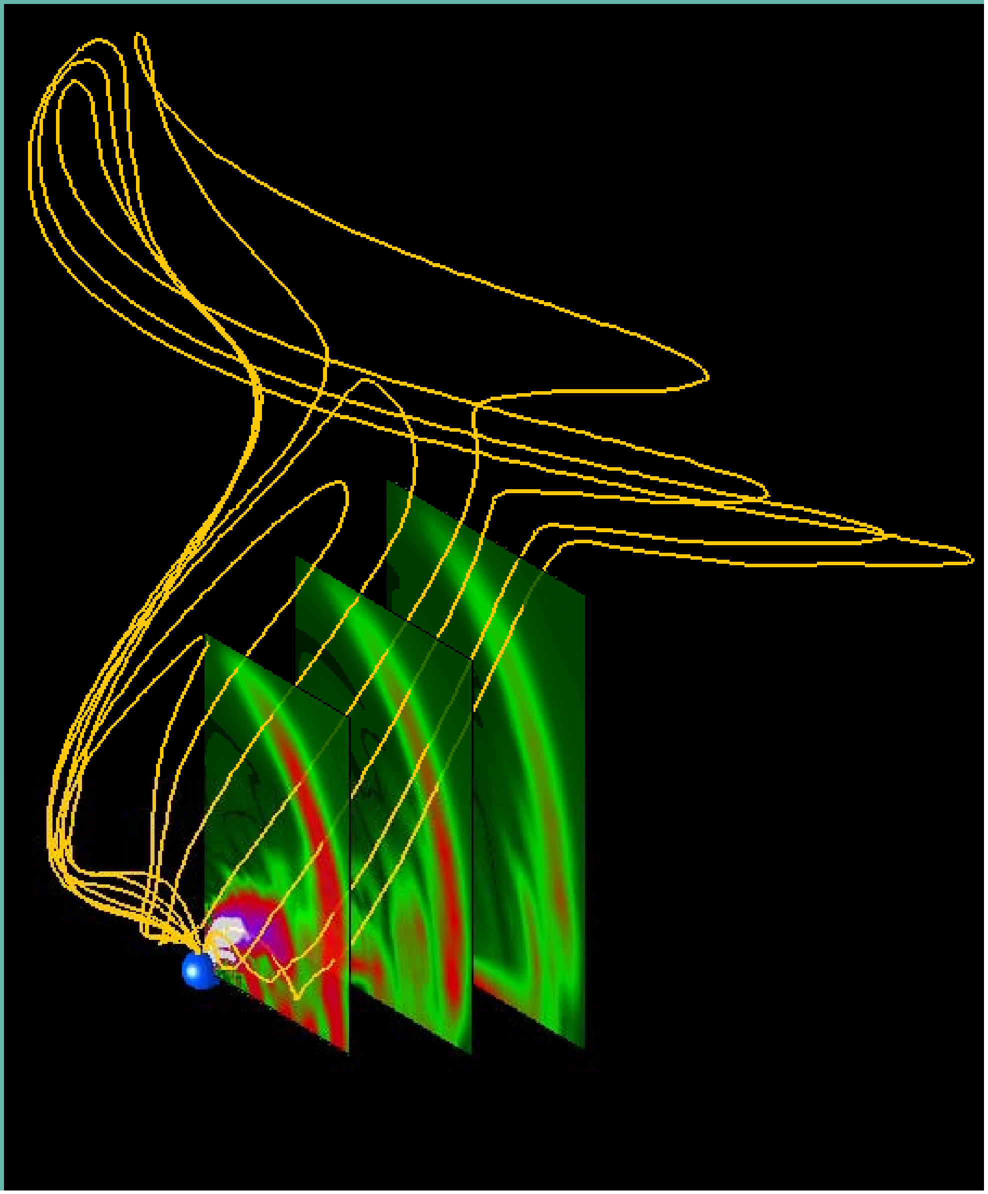
μέση οδός μαγνετοσφερα





Highlights in the History of Magnetospheric Concepts (3)

Dungey-Alfvén
ist die Ūber-Magnetosphaere



The Vasyliunas Criterion for Quantifying the Two Magnetosphere types

Vasyliunas (2004) divided magnetospheres into solar wind dominated (CF-like) and ionosphere dominated (DA-like) depending on whether the magnetic pressure generated by the reconnection-driven ionospheric current is, respectively, less than or greater than the solar wind dynamic pressure.

The operative criterion is

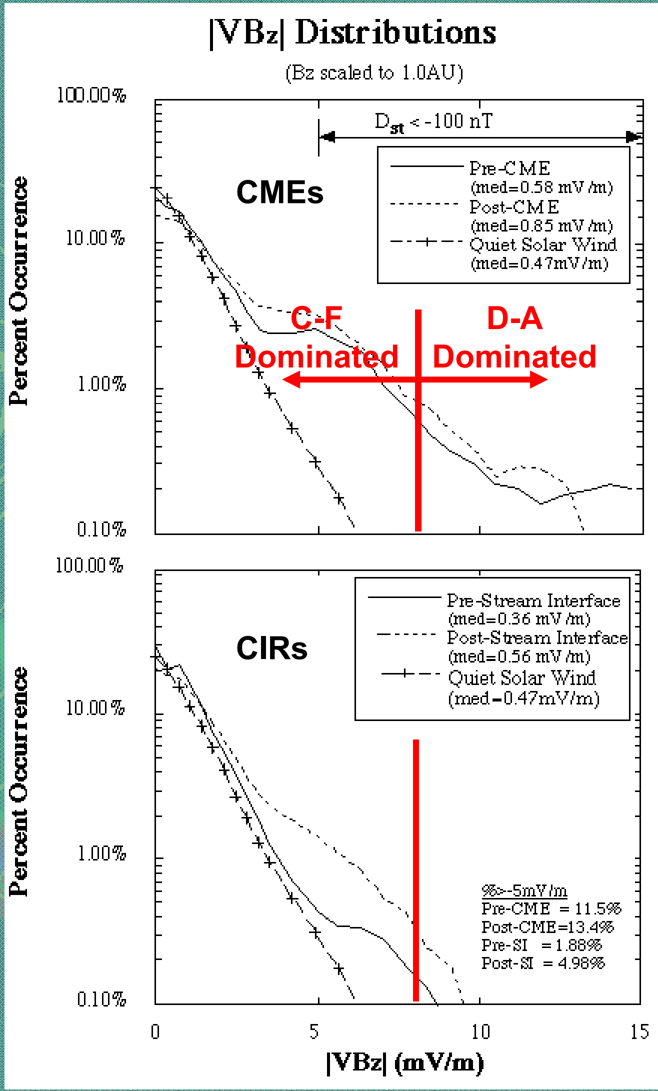
$\mu_o \Sigma_P V_A \varepsilon \sim 1$

Σ_P = ionospheric Pedersen conductance

V_A = Alfvén speed in the solar wind

ε = magnetic reconnection efficiency

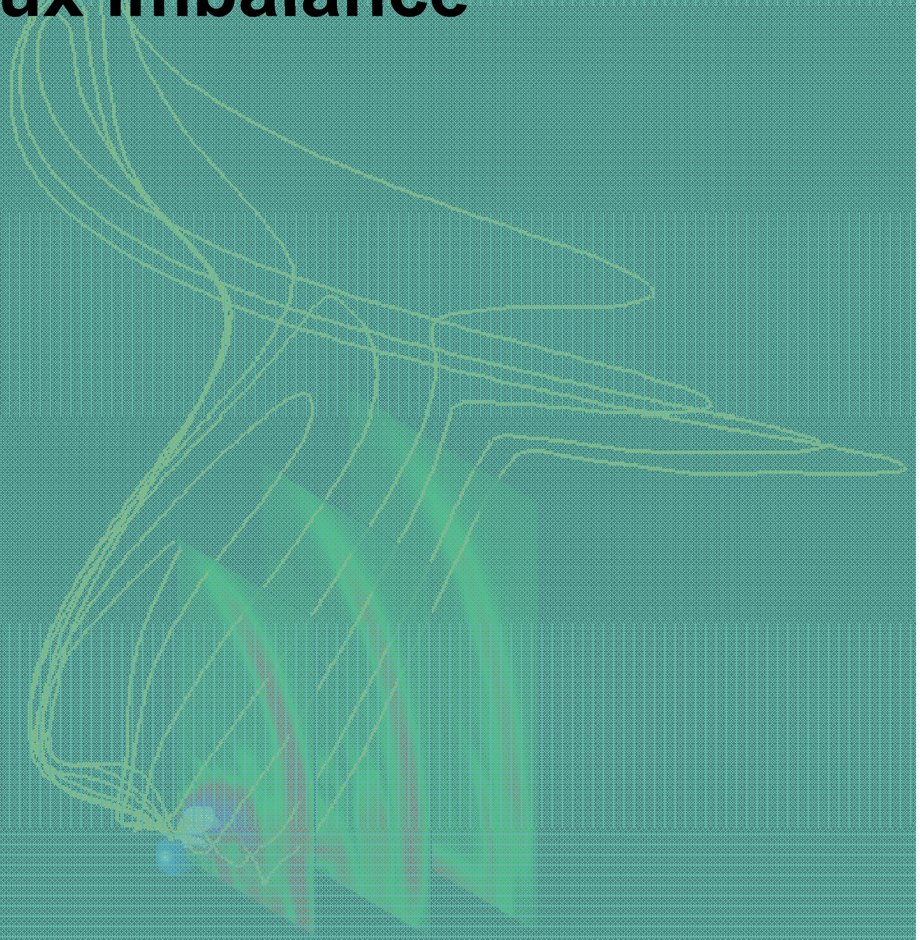
By this criterion, the standard magnetosphere is solar wind (C-F) dominated; the storm-time magnetosphere, ionosphere (D-A) dominated.



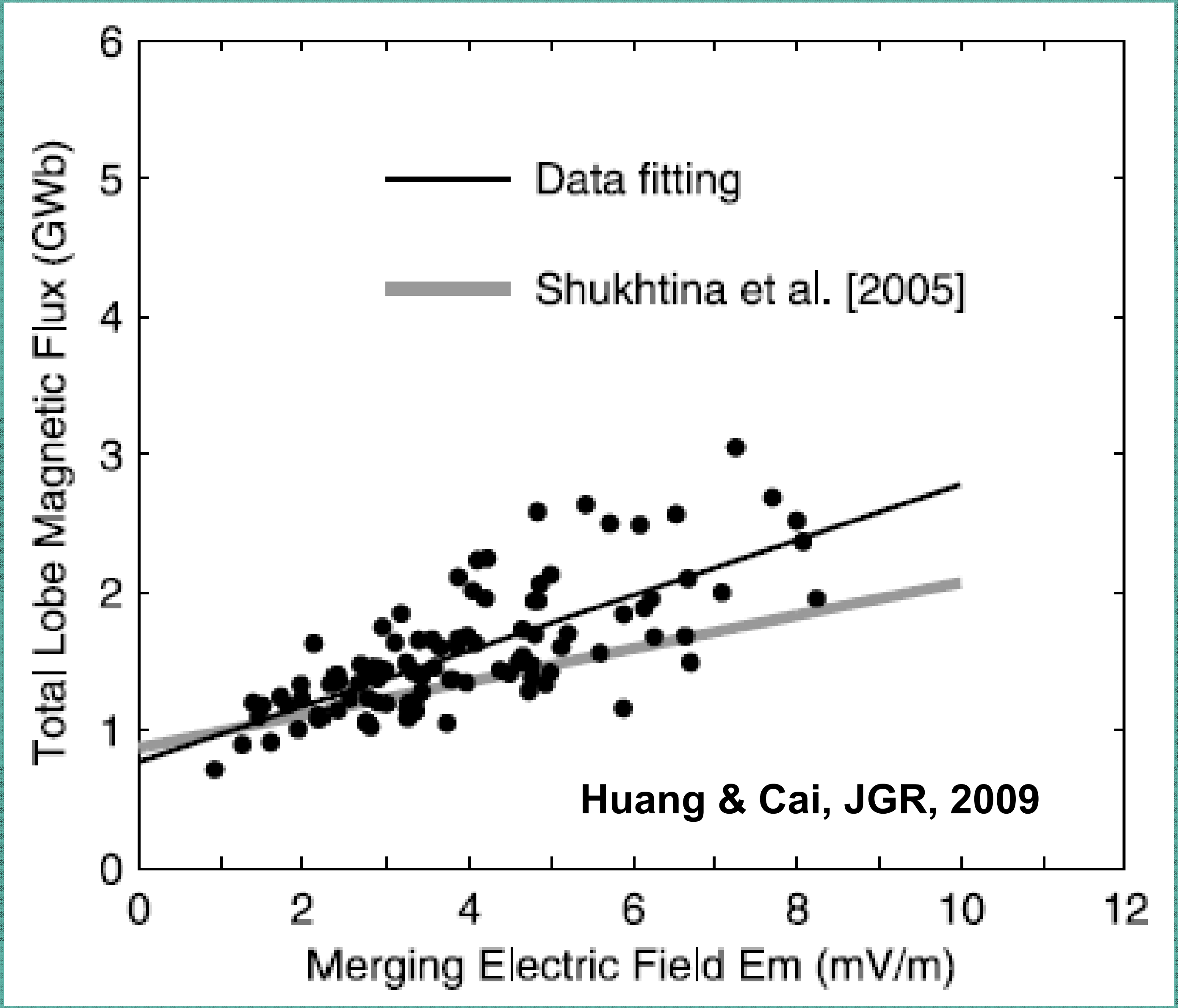
Lindsay et al., 1995

Properties of the Dungey-Alfvén Magnetosphere

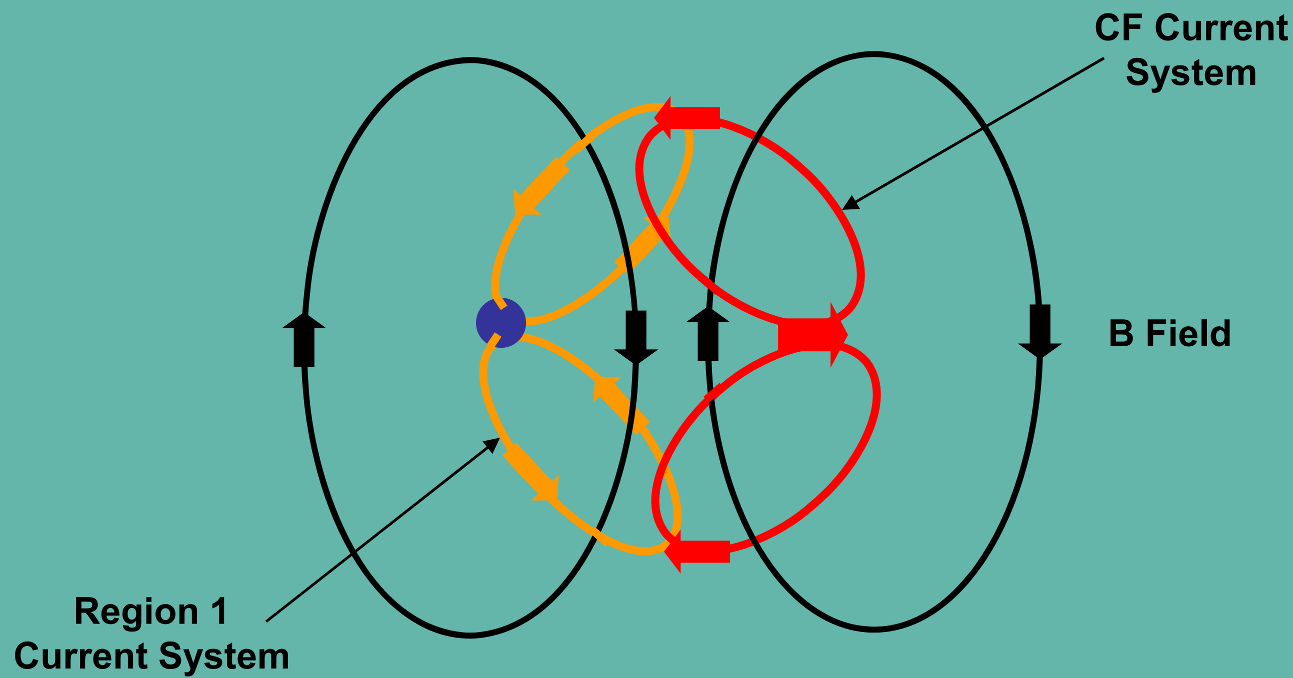
- **Huge dayside-nightside flux imbalance**



Massive Magnetic Flux Transfer



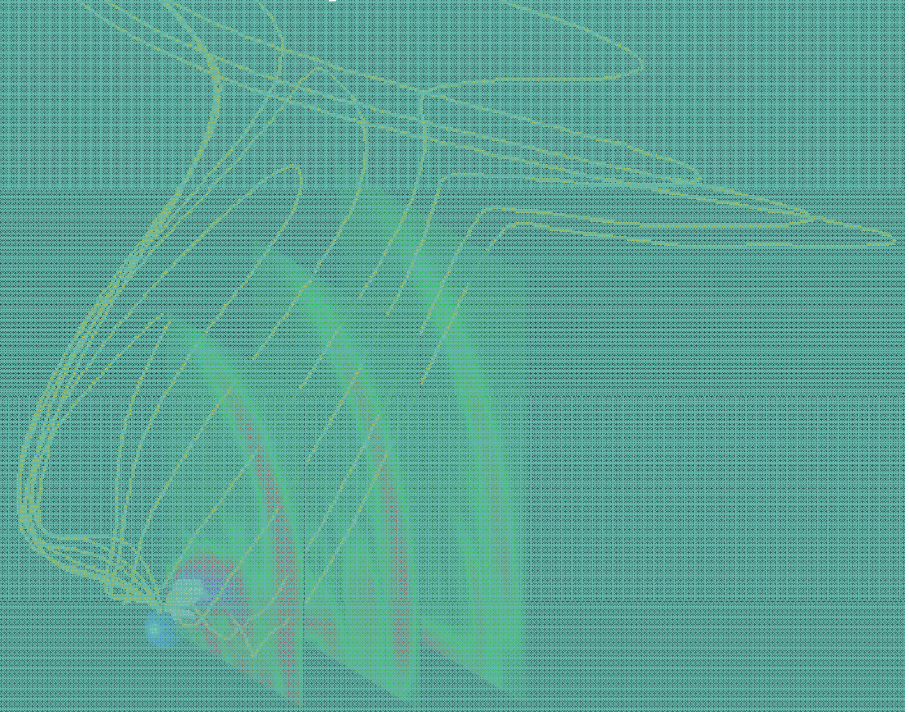
Explanation



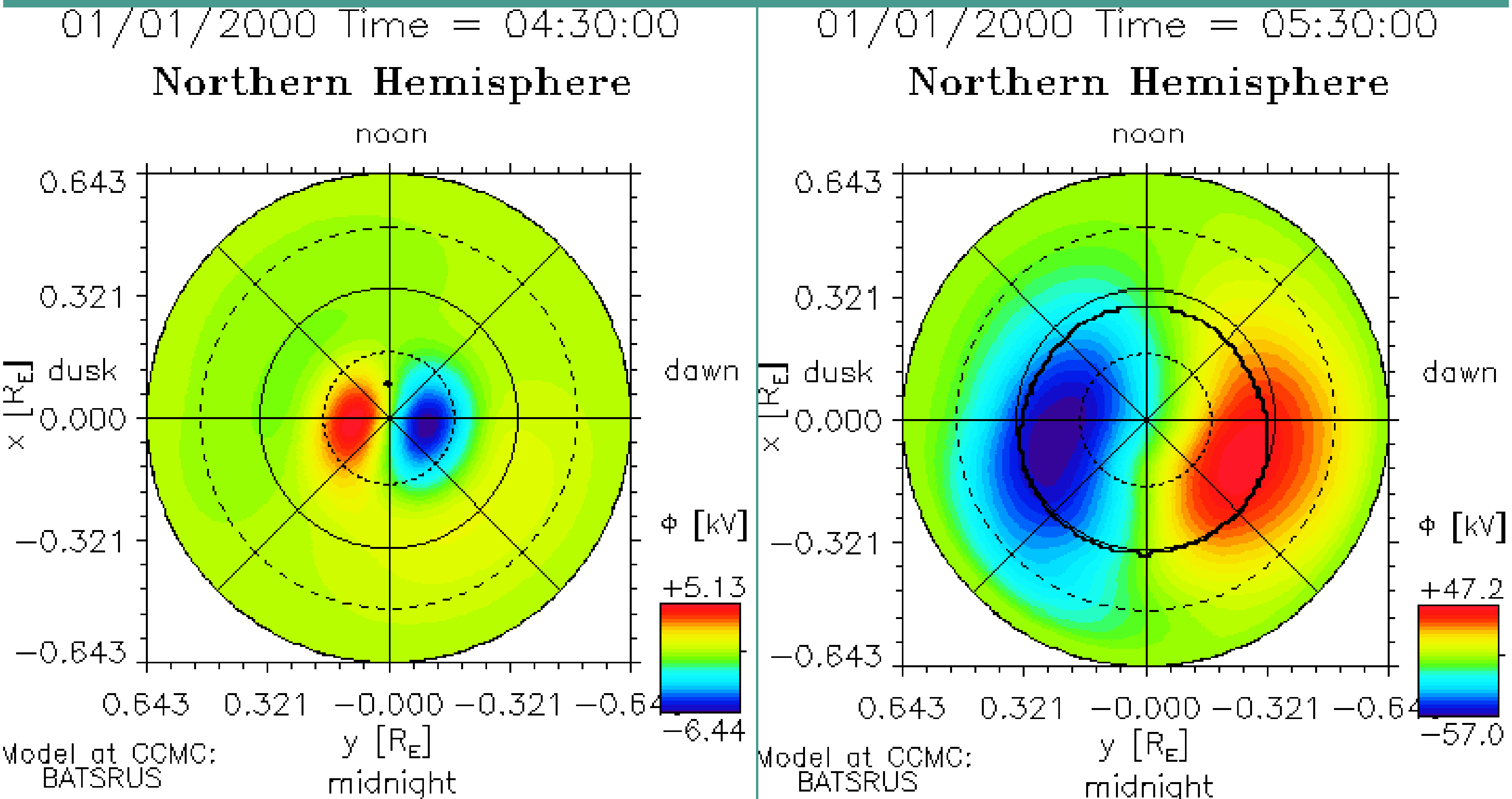
One consequence: Big EMF

Properties of the Dungey-Alfvén Magnetosphere

- **Huge dayside-nightside flux imbalance**
- - Trans-magnetospheric Potential >> Transpolar Potential (flux ablation)



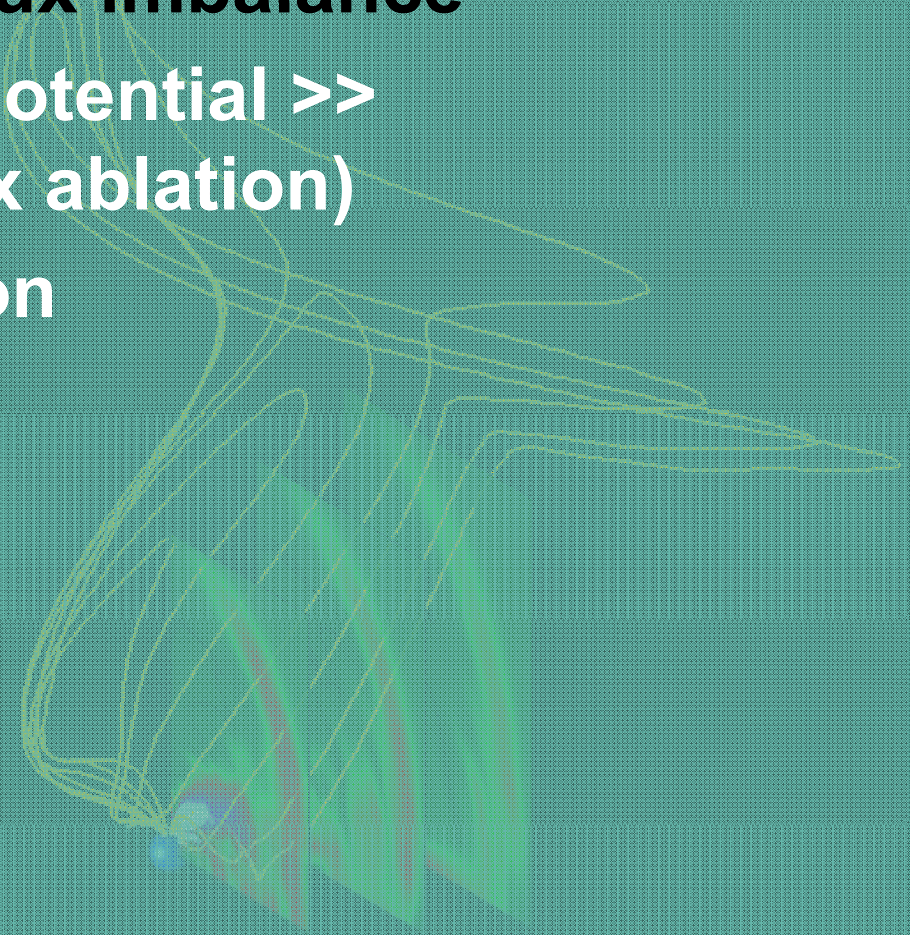
Natasha_Buzulukova_093008_1 CCMC Run
IMF Bz goes from +10 nT to -10 nT at 4:30

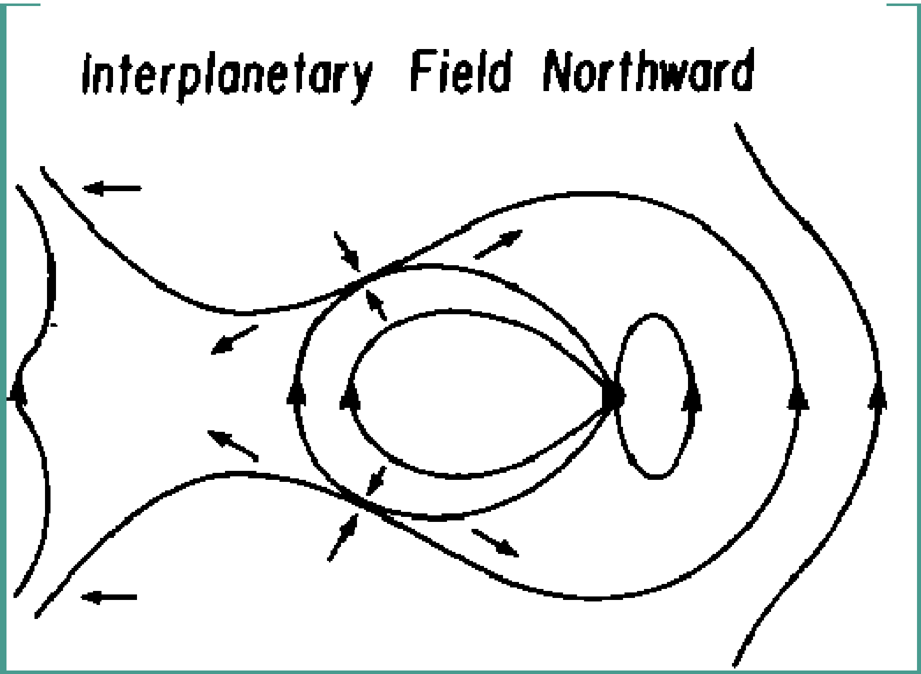


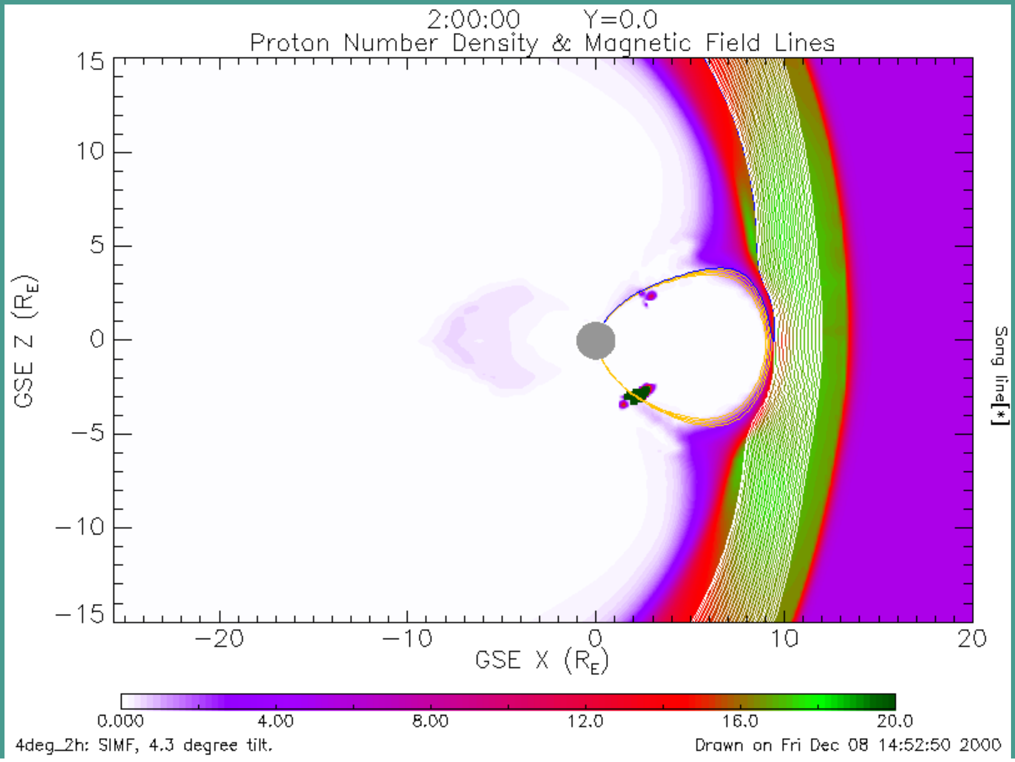
EMF = 257 kV

Properties of the Dungey-Alfvén Magnetosphere

- **Huge dayside-nightside flux imbalance**
  - Trans-magnetospheric Potential >> Transpolar Potential (flux ablation)
  - An aside on flux accretion

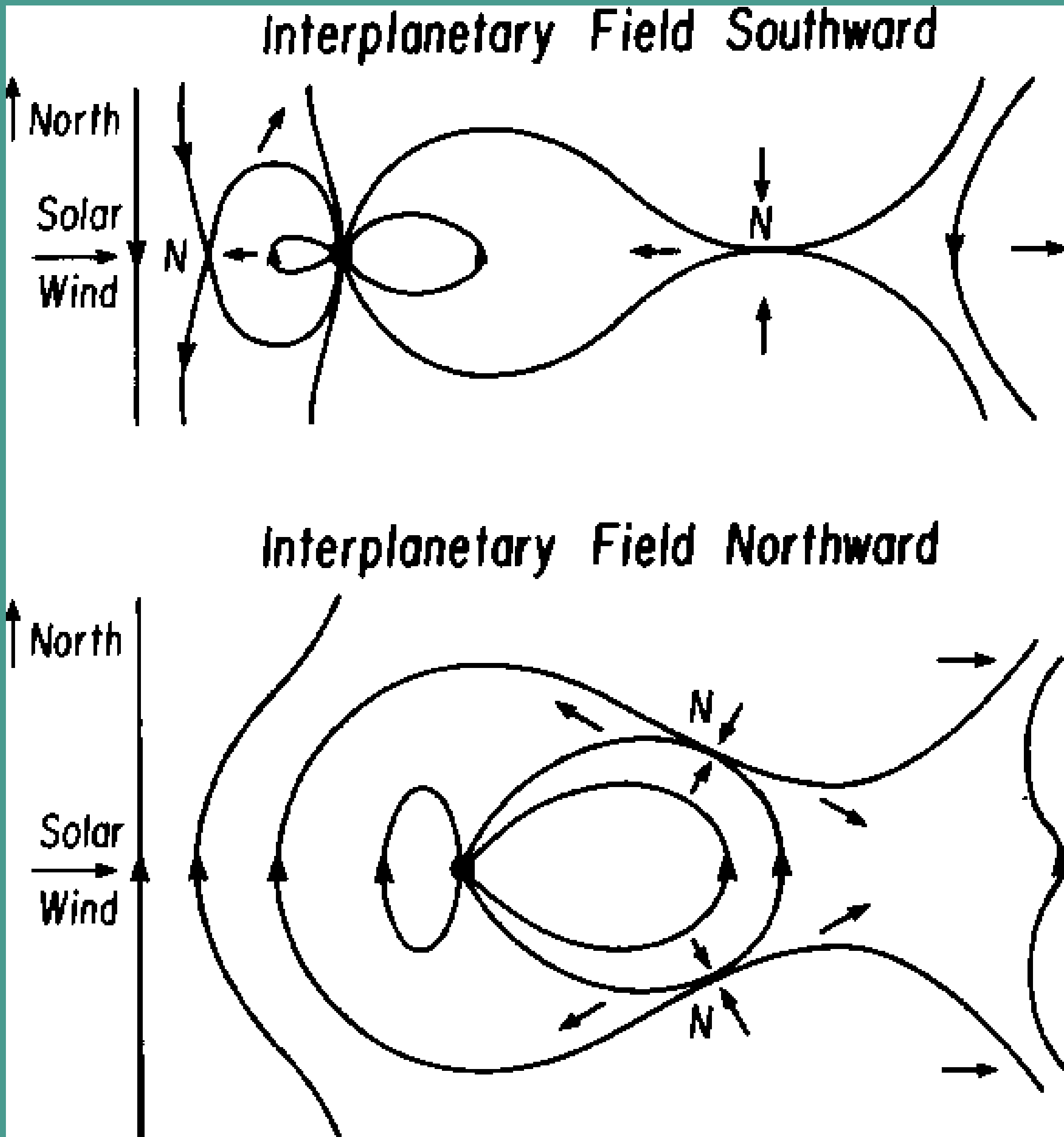



Interplanetary Field Northward


2:00:00 Y=0.0
Proton Number Density & Magnetic Field Lines
GSE Z (R_E)
GSE X (R_E)
15
10
5
0
−5
−10
−15
−20
−10
0
10
20
0.000
4.00
8.00
12.0
16.0
20.0
Song line[*]
4deg_2h: SIMF, 4.3 degree tilt.
Drawn on Fri Dec 08 14:52:50 2000

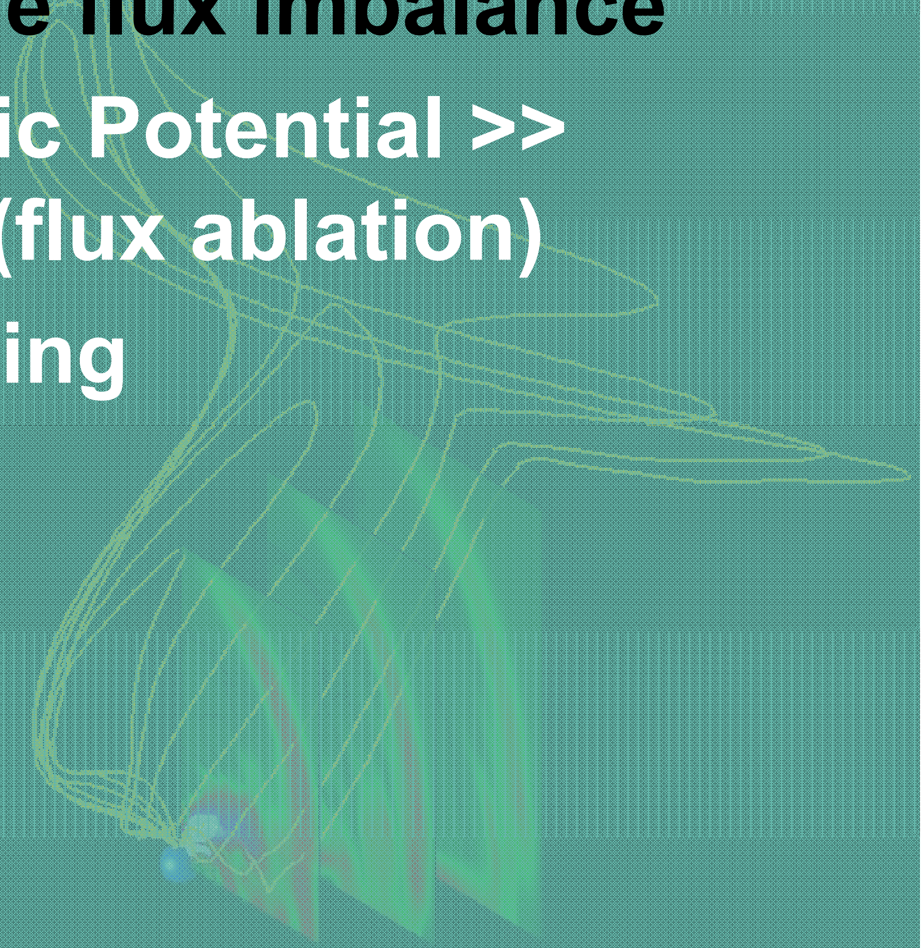
Dayside Shrinks by Flux Ablation

Dayside Grows by Flux Accretion

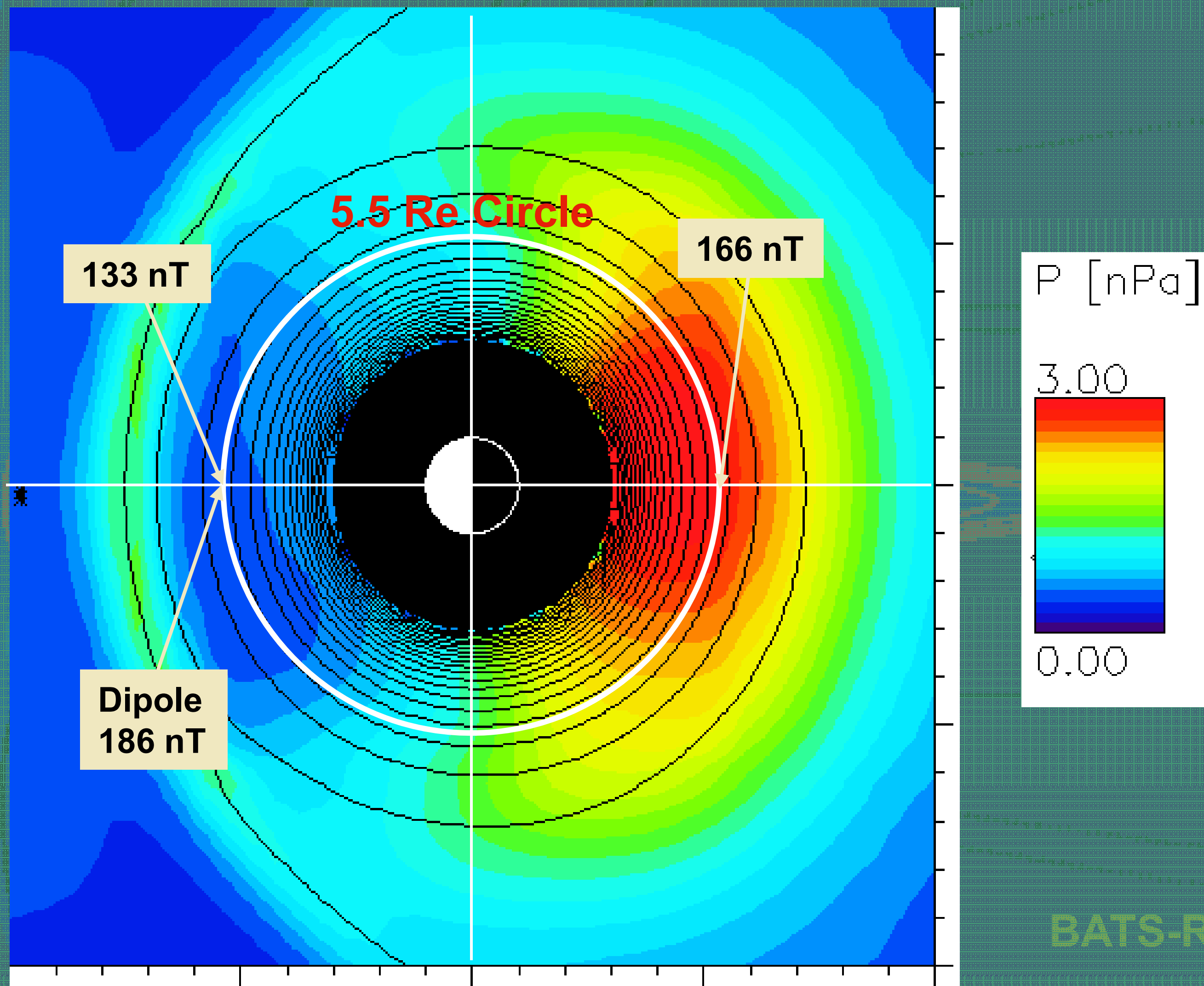


Properties of the Dungey-Alfvén Magnetosphere

- **Huge dayside-nightside flux imbalance**
  - - Trans-magnetospheric Potential >> Transpolar Potential (flux ablation)
  - - Dayside field weakening



Dayside Field Weakening



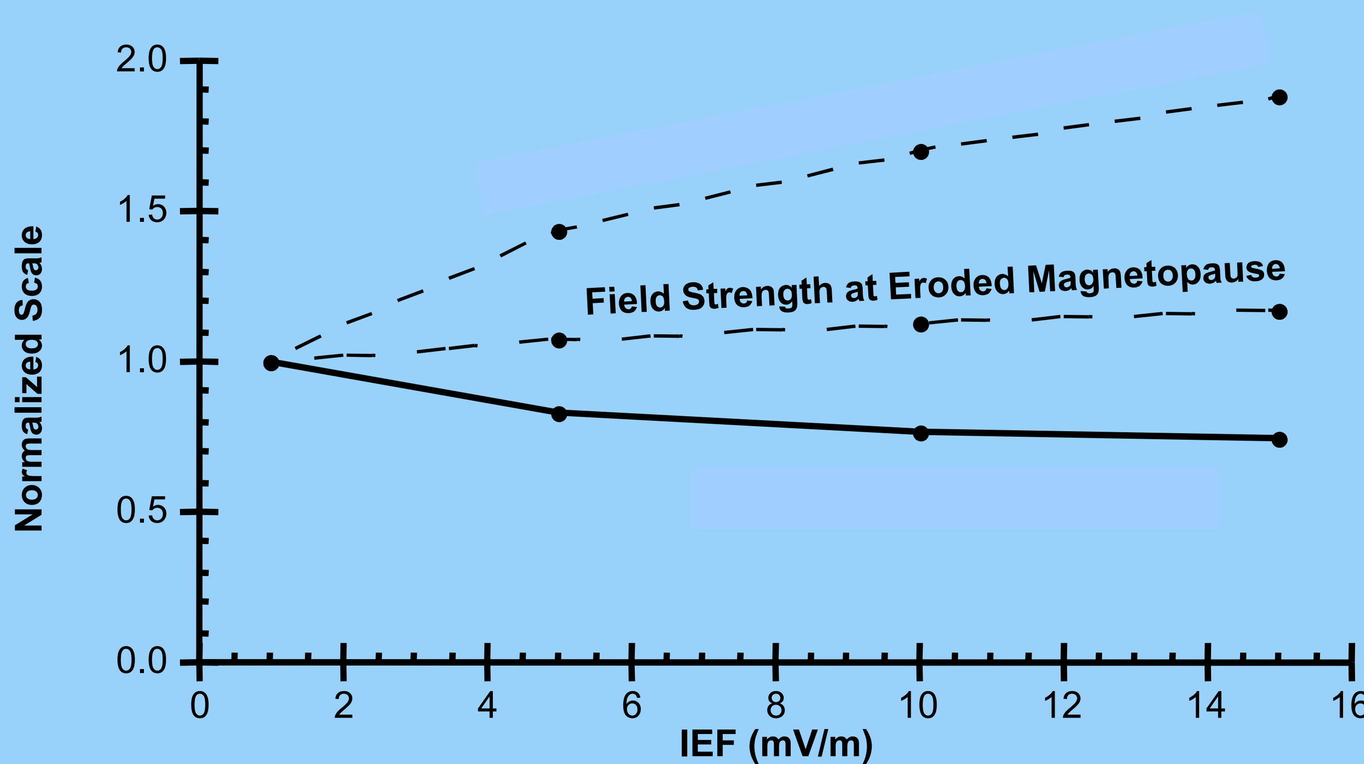
IMF = (0, 0, -20) nT

Properties of the Dungey-Alfvén Magnetosphere

- **Huge dayside-nightside flux imbalance**
- - Trans-magnetospheric Potential >> Transpolar Potential (flux ablation)

  - Dayside field weakening
- - Magnetospheric erosion

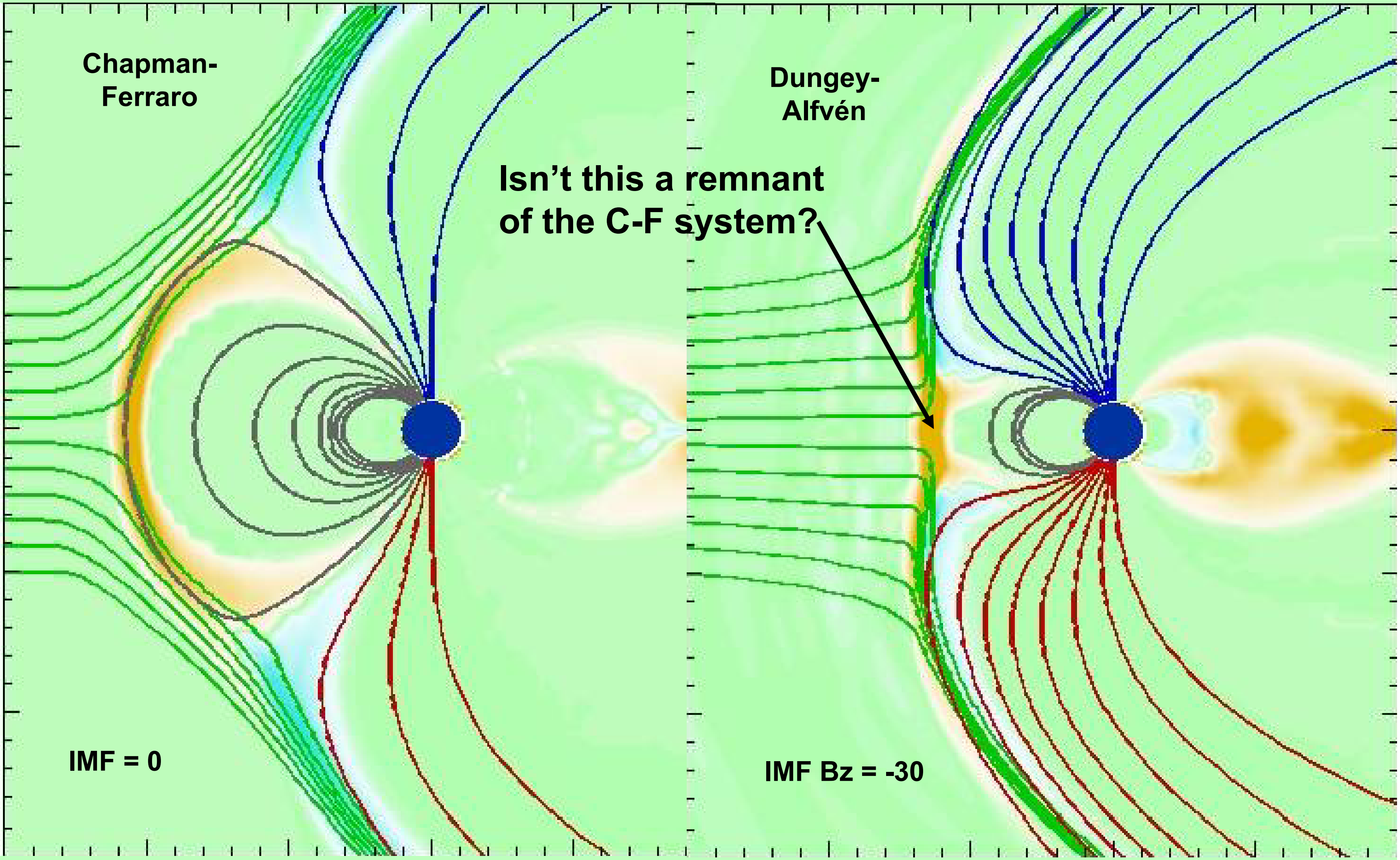
Equivalence of Magnetospheric Erosion and Region 1 Current System Buildup



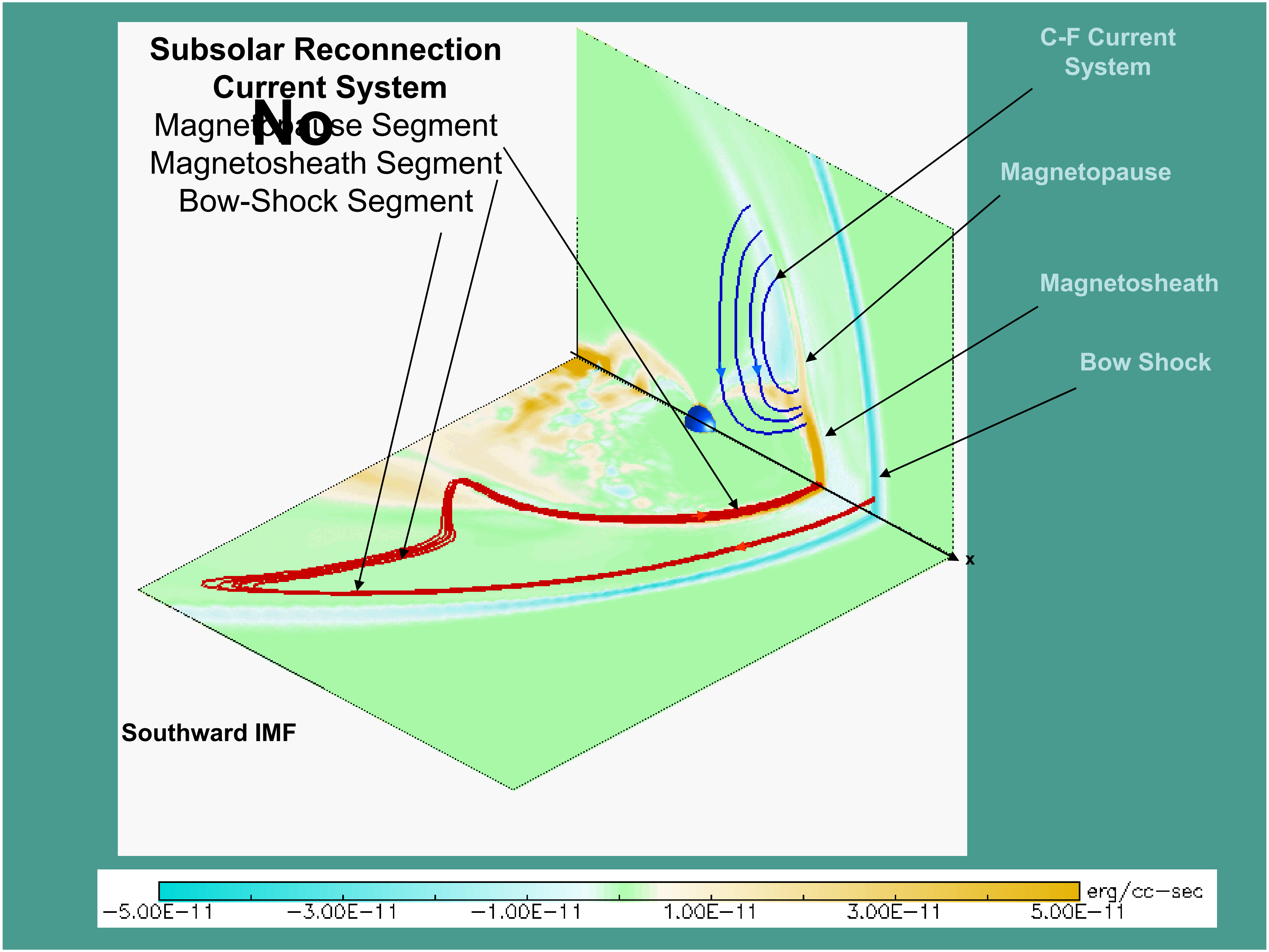
Boundary moves earthward to hold stagnation field strength ~ constant as region 1 current increases. This is magnetospheric erosion.

Properties of the Dungey-Alfvén Magnetosphere

- **Huge dayside-nightside flux imbalance**
  - Trans-magnetospheric Potential >> Transpolar Potential (flux ablation)
  - Dayside field weakening
  - Magnetospheric erosion
  - Cusps migrate equatorward & reconnection dimple develops



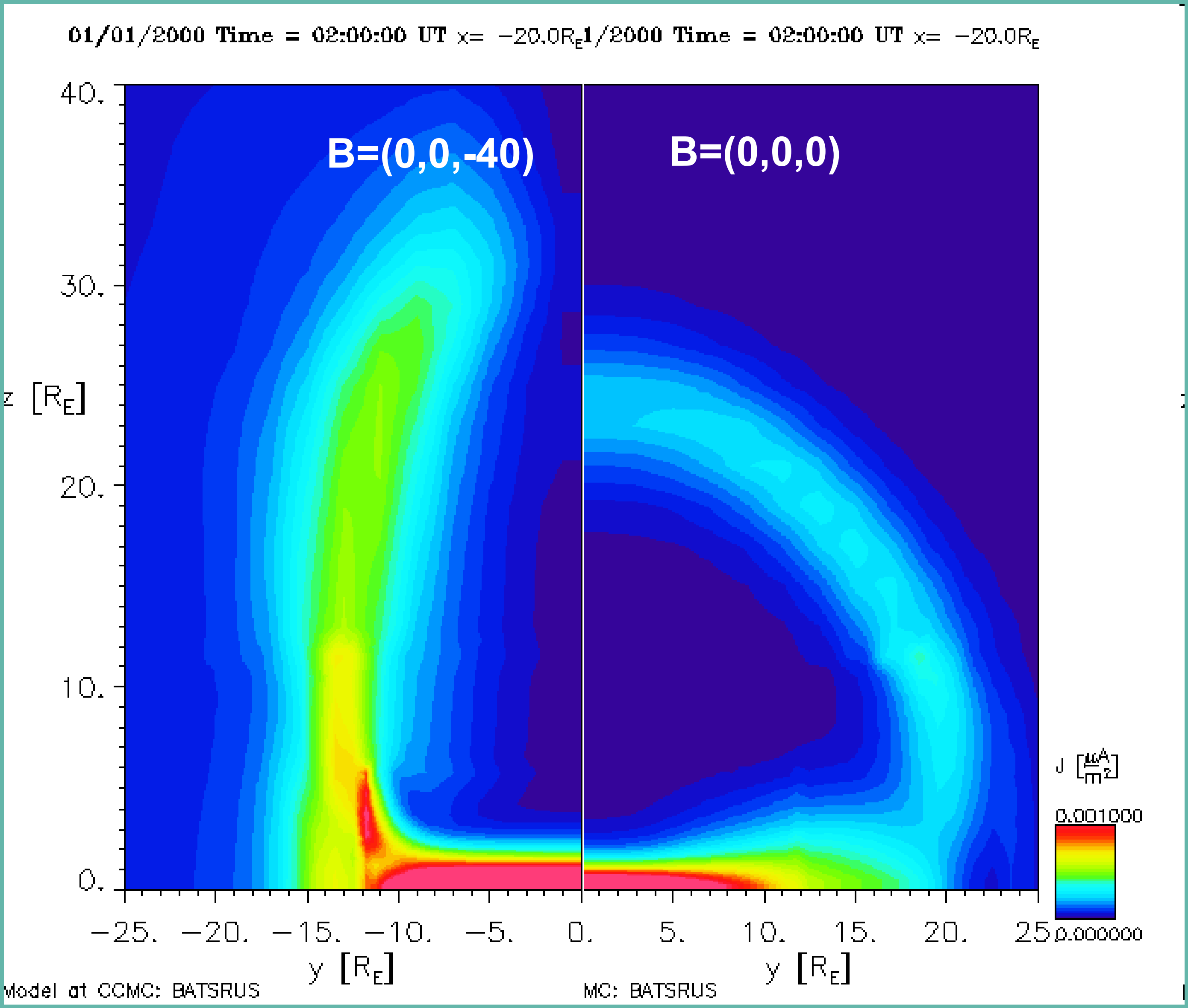
Chapman-
Ferraro
Dungey-
Alfvén
Isn't this a remnant
of the C-F system?
IMF = 0
IMF Bz = -30


Subsolar Reconnection
Current System
No
Magnetopause Segment
Magnetosheath Segment
Bow-Shock Segment
C-F Current
System
Magnetopause
Magnetosheath
Bow Shock
x
Southward IMF
erg/cc−sec
−5.00E−11
−3.00E−11
−1.00E−11
1.00E−11
3.00E−11
5.00E−11

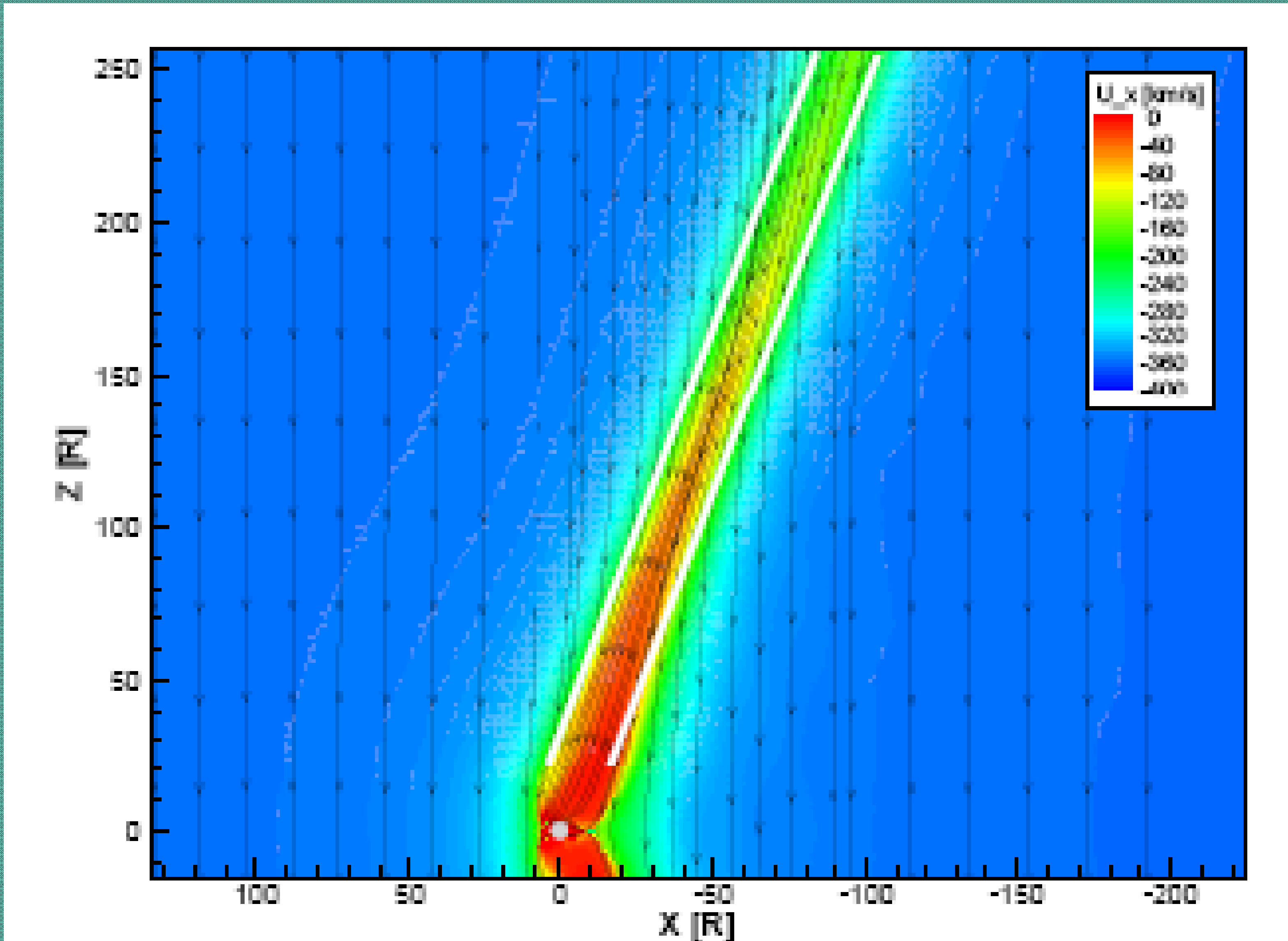
Properties of the Dungey-Alfvén Magnetosphere

- **Huge dayside-nightside flux imbalance**
  - **- Trans-magnetospheric Potential >> Transpolar Potential (flux ablation)**
  - **- Dayside field weakening**
  - **- Magnetospheric erosion**
  - **- Cusps migrate equatorward & reconnection dimple develops**
  - **- Tail morphs into wings**

Tail Morphing into Wings



Ridley (2007) Alfvén Wings

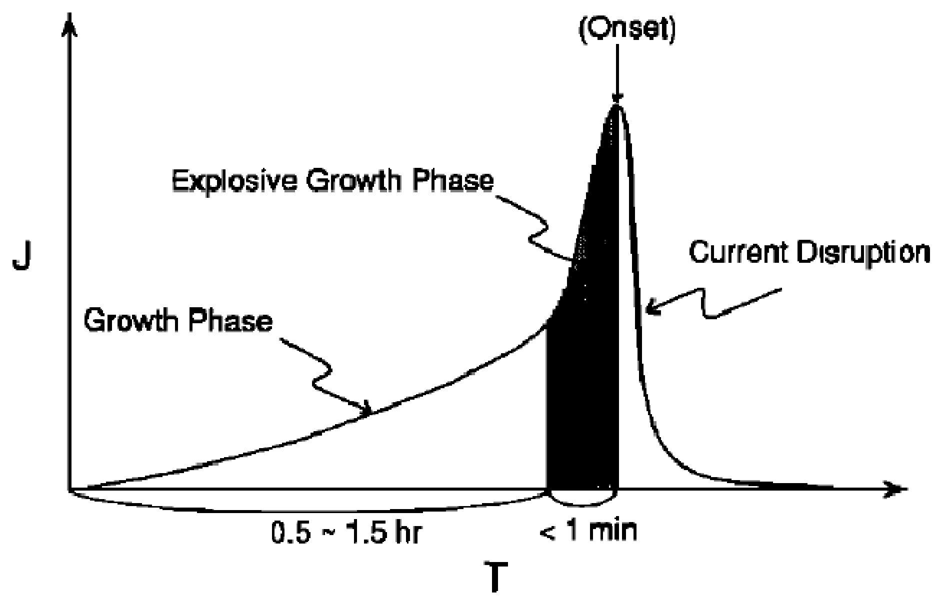


Properties of the Dungey-Alfvén Magnetosphere

- **Huge dayside-nightside flux imbalance**
- - Trans-magnetospheric Potential >> Transpolar Potential (flux ablation)
  - Dayside field weakening
  - Magnetospheric erosion
  - Tail morphs into wings
- - Cusps migrate equatorward & reconnection dimple develops
- - Sawtooth substorms (speculation)

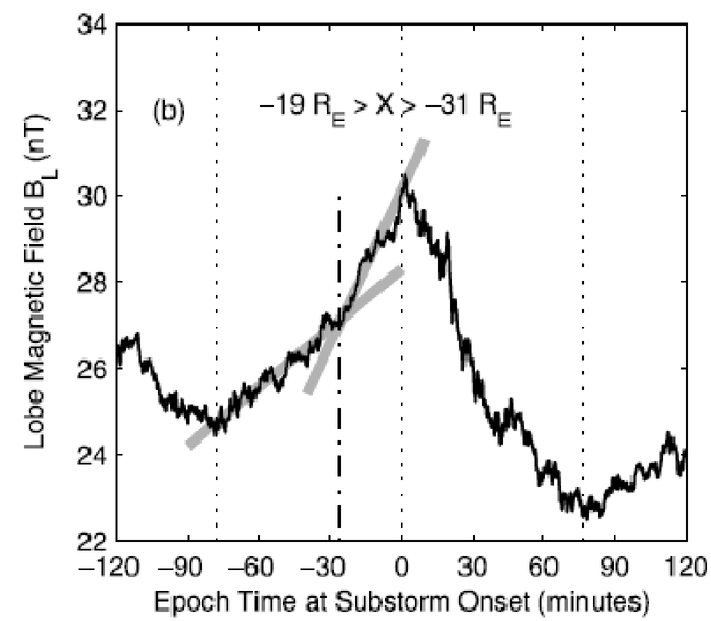
Regular Substorms

Ohtani et al., 1992

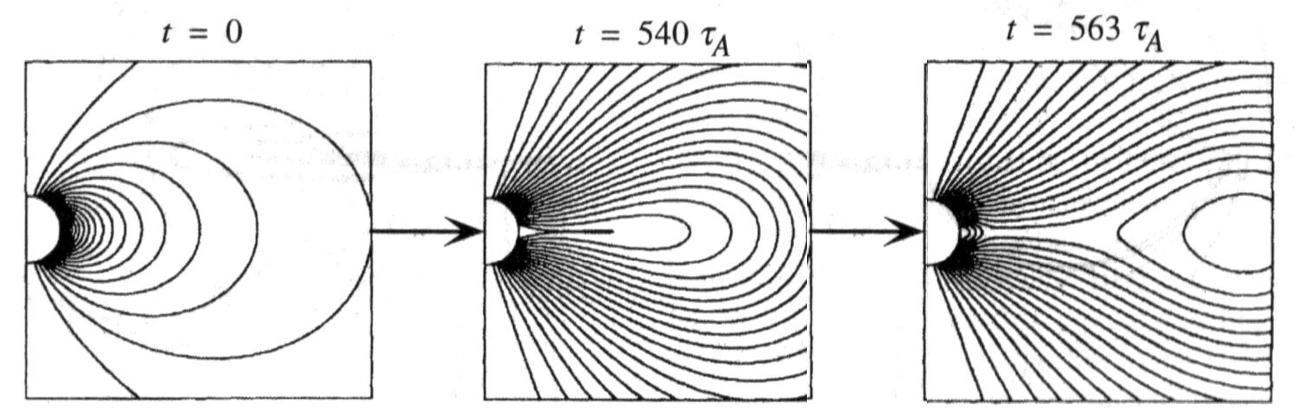


Sawtooth Substorms

Huang & Cai, 2009



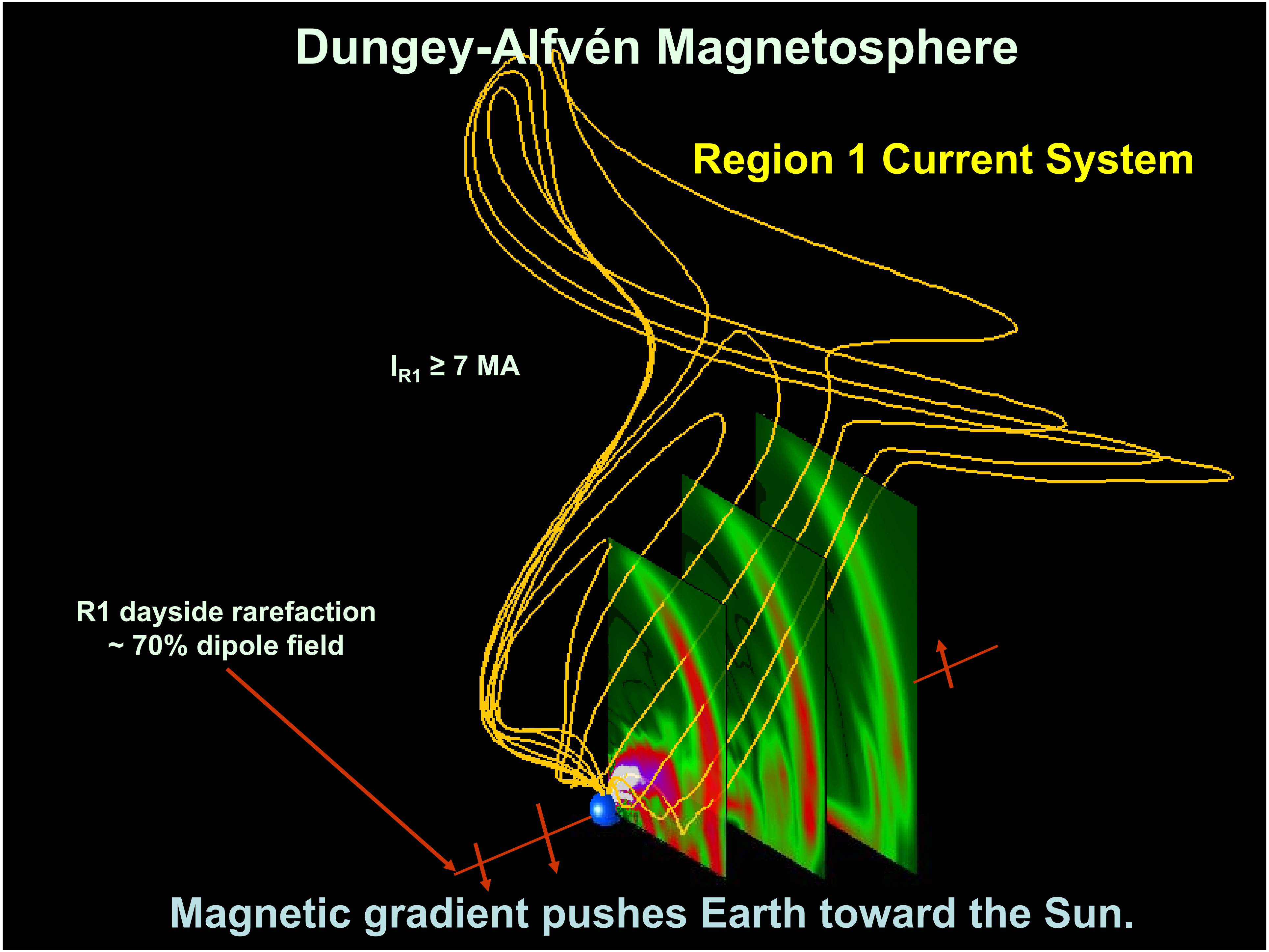
CMEs



Mikic and Linker

Properties of the Dungey-Alfvén Magnetosphere

- **Huge dayside-nightside flux imbalance**
  - Trans-magnetospheric Potential >> Transpolar Potential (flux ablation)
  - Dayside field weakening
  - Magnetospheric erosion
  - Tail morphs into wings
  - Cusps migrate equatorward & reconnection dimple develops
  - Sawtooth substorms
- **Force reversal and amplification**

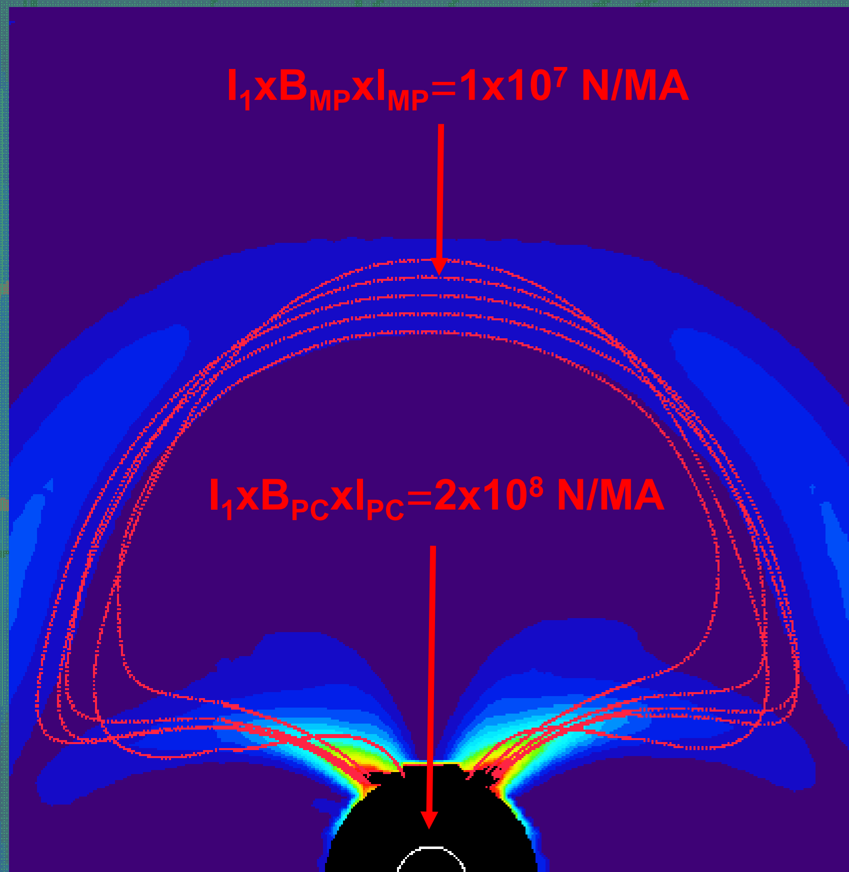


Dungey-Alfvén Magnetosphere
Region 1 Current System
$I_{R1} \geq 7$ MA
R1 dayside rarefaction
~ 70% dipole field
Magnetic gradient pushes Earth toward the Sun.

Region 1 Force Amplified by Dipole Interaction

Back of the envelope estimate

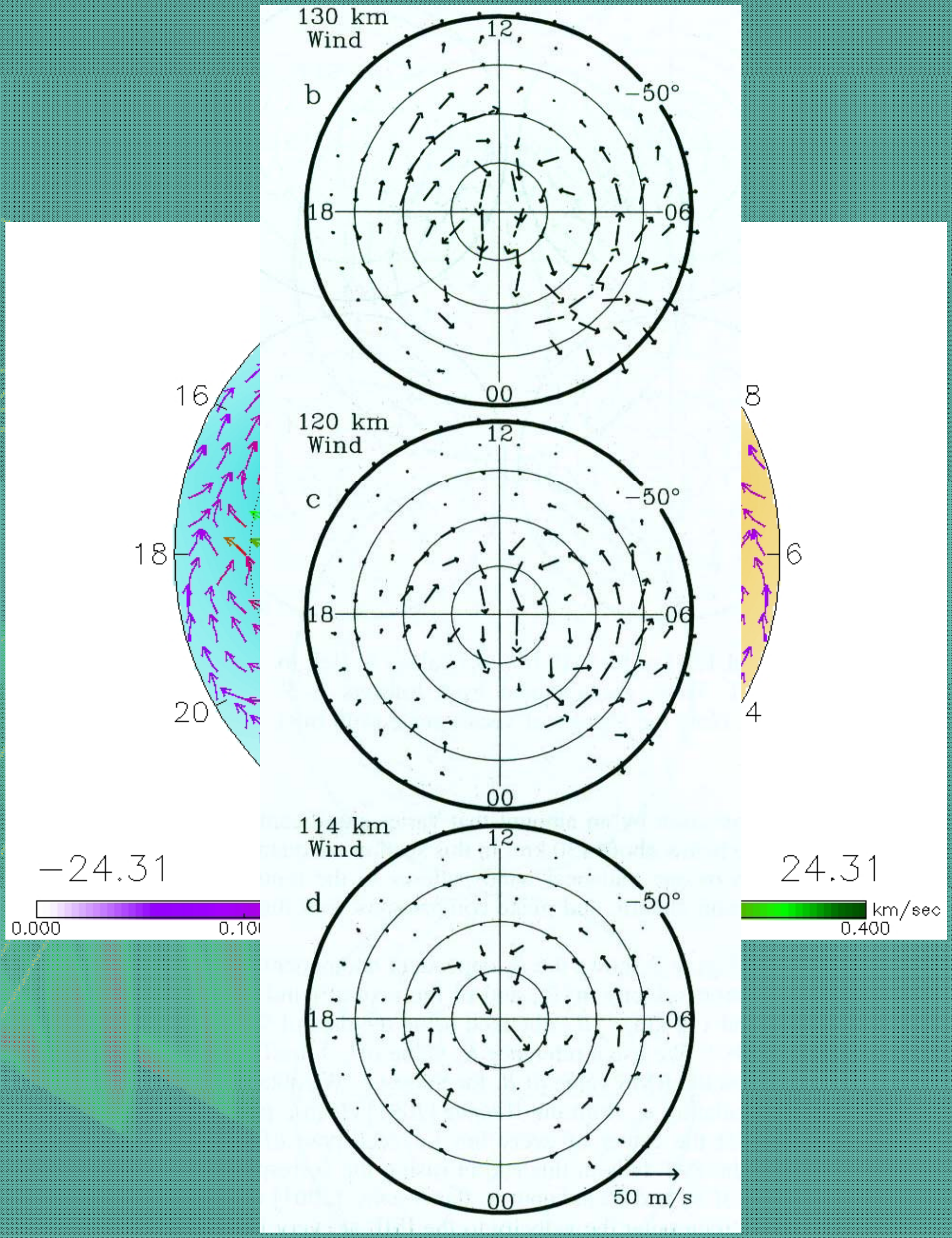
BATSRUS/CCMC



i.e., roughly an order of magnitude bigger

Atmospheric Reaction

- Region 1 current gives the J in the JxB force that stands off the solar wind
- And communicates the force to the ionosphere
- Which communicates it (amplified) to the neutral atmosphere as the flywheel effect

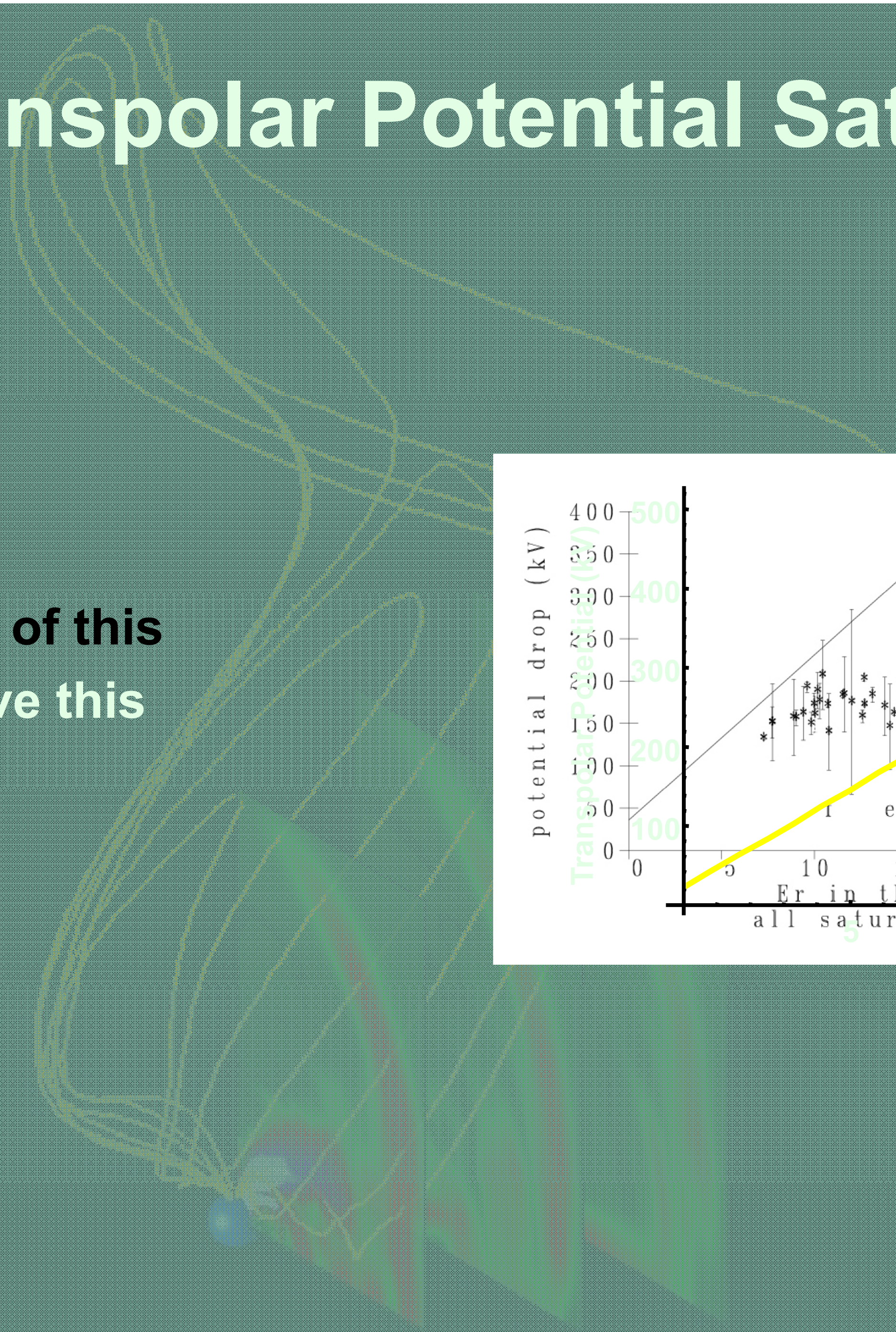


Richmond et al., 2003

Properties of the Dungey-Alfvén Magnetosphere

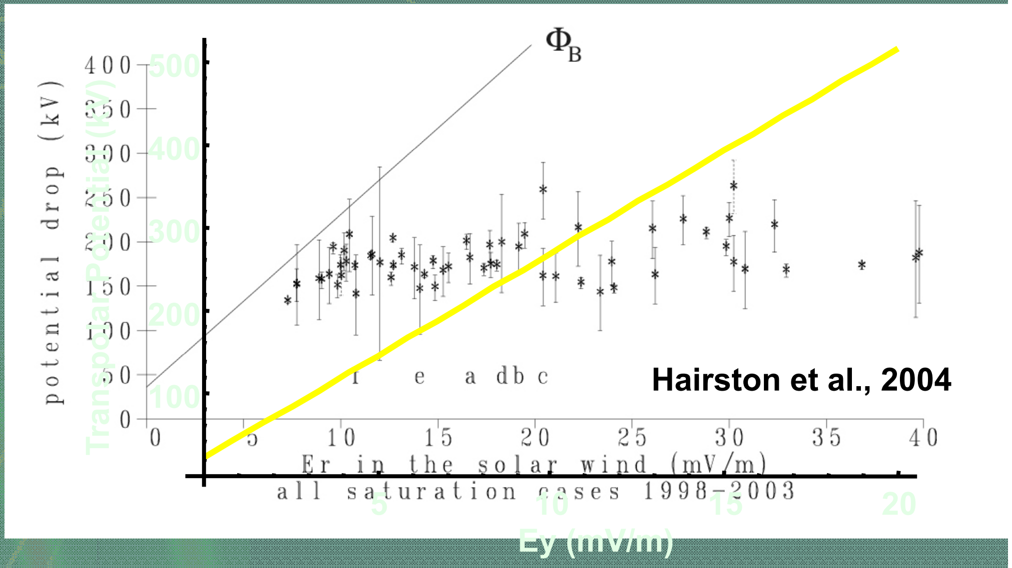
- **Huge dayside-nightside flux imbalance**
  - Trans-magnetospheric Potential >> Transpolar Potential (flux ablation) (aside on flux accretion for IMF Bz > 0)
  - Dayside field weakening
  - Magnetospheric erosion
  - Tail morphs into wings
  - Cusps migrate equatorward & reconnection dimple develops
  - Sawtooth substorms
- **Force reversal and amplification**
- **Transpolar potential saturation**

Transpolar Potential Saturation



Instead of this

You have this



The Hill SW-M-I Coupling Ansatz

$$\Phi_H = \frac{\Phi_R \Phi_I}{\Phi_R + \Phi_I}$$

Where:

Φ_H is the Hill transpolar potential.

Φ_R is the potential from magnetopause reconnection.

Φ_I is the potential at which region 1 currents generate .
a significant perturbation magnetic field at the reconnection site.

$$\Phi_R = \frac{57.6 E_{sw} F(\theta)}{P_{sw}^{1/6}}$$

Linear regime (small E_{SW})

$$\Phi_I = \frac{4608 P_{sw}^{1/3}}{\xi \Sigma_o}$$

Saturation regime (big E_{SW})

Ridley (2007) Alfvén Wings

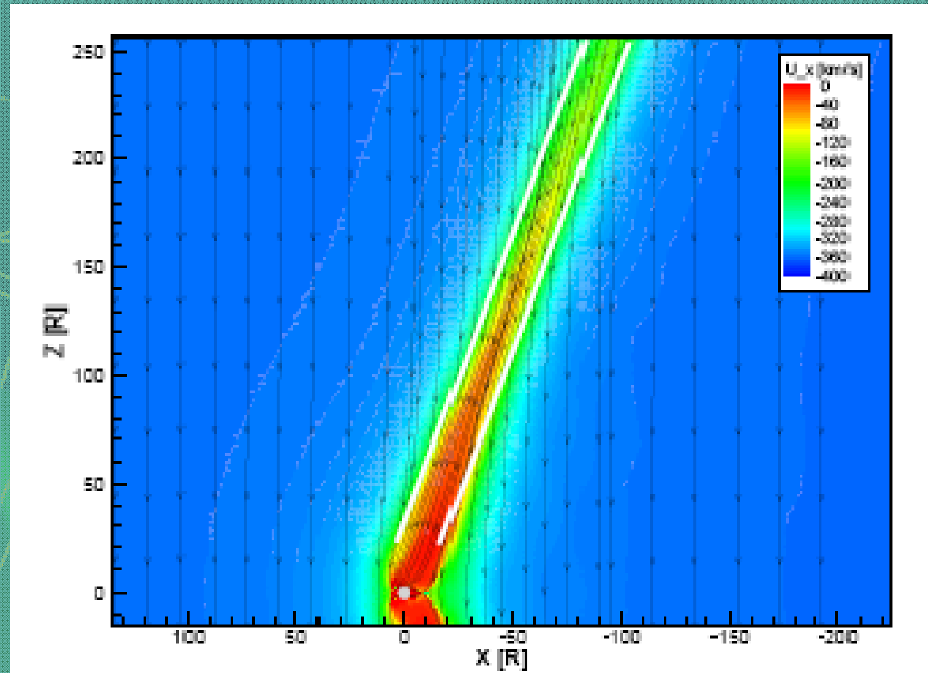
Electric field in Alfvén wings (Neubauer, 1980)

$$E_A = \frac{2\Sigma_A}{2\Sigma_A + \Sigma_P} E_{sw}$$

where

$$\Sigma_A = \frac{1}{\mu_o V_A \sqrt{1 + M_A^2}}$$

$$\Phi_A = E_A \pi R_{ms} \varepsilon_r$$



Extreme limit

$$\Phi_A = \frac{1300 P_{sw}^{1/3}}{\Sigma_P}$$

Compare Hill

$$\Phi_I = \frac{4608 P_{sw}^{1/3}}{\xi \Sigma_P}$$

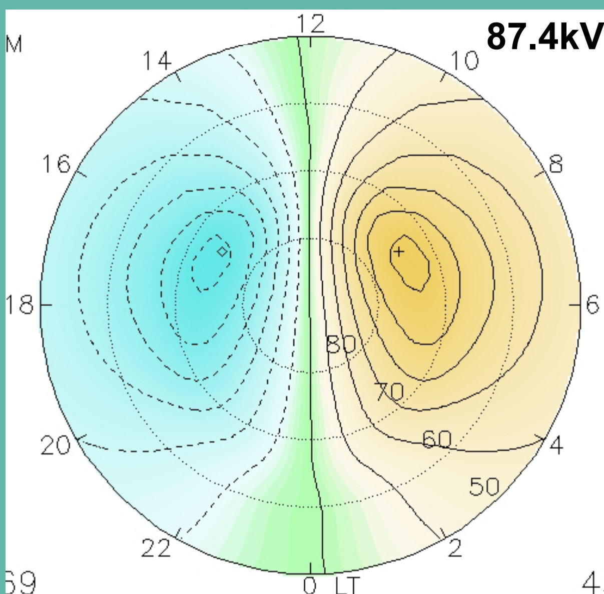
The Hill model gives the Alfvén wing potential in the appropriate limit

Properties of the Dungey-Alfvén Magnetosphere

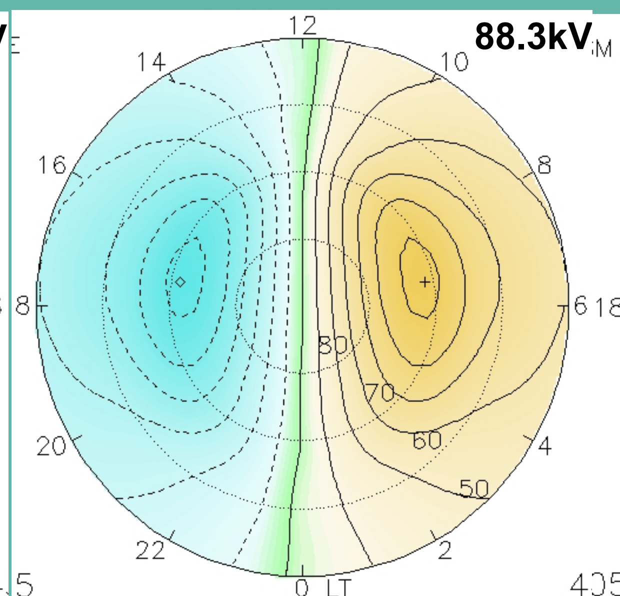
- **Huge dayside-nightside flux imbalance**
  - Trans-magnetospheric Potential >> Transpolar Potential (flux ablation)
  - Dayside field weakening
  - Magnetospheric erosion
  - Tail morphs into wings
  - Cusps migrate equatorward & reconnection dimple develops
  - Sawtooth substorms
- **Force reversal and amplification**
- **Transpolar potential saturation**
- **System-wide regulation of ionospheric conductance**

Weak Driving
IMF Bz = -5 nT
6 to 1 Summer to Winter Conductances

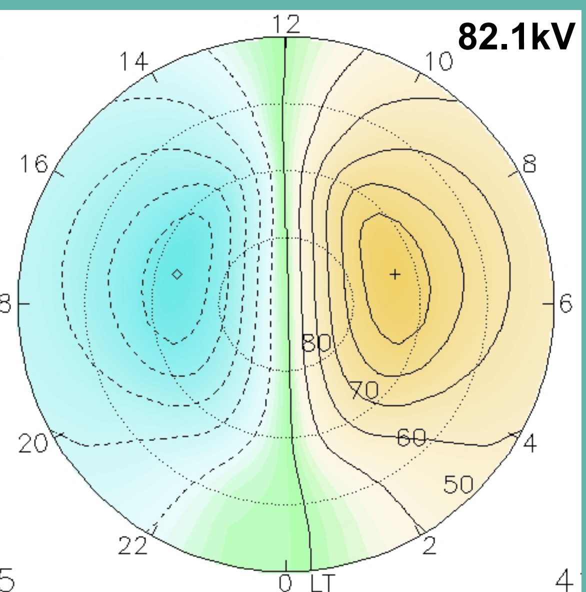
Summer



Spring/Fall

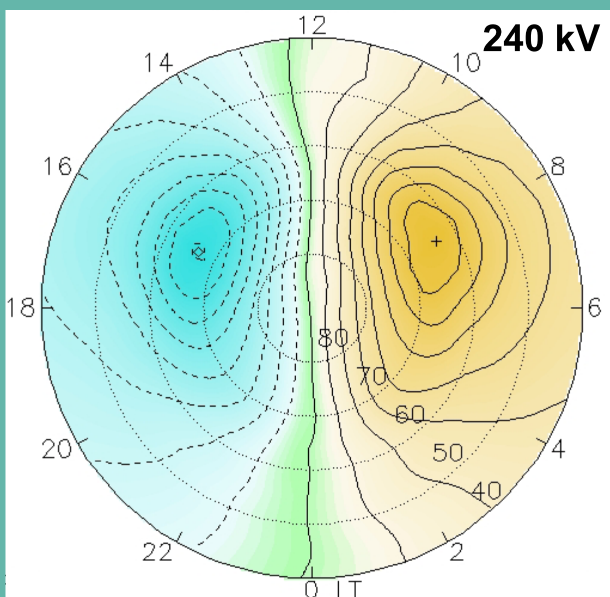


Winter

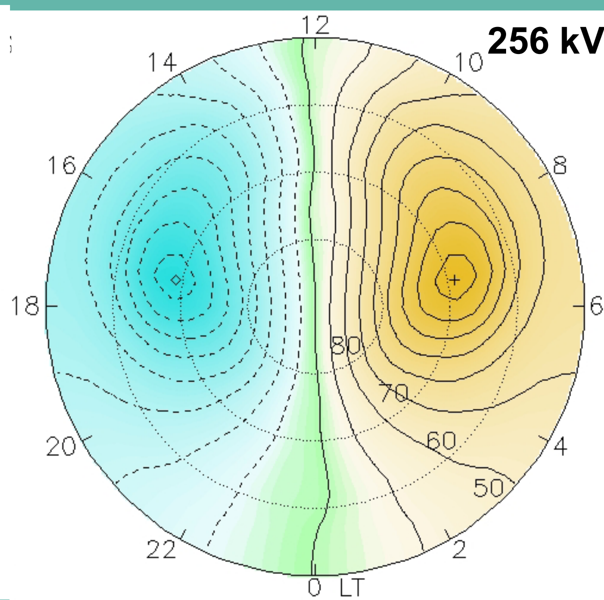


Strong Driving
IMF Bz = -30 nT
12 to 2 Summer to Winter Conductances

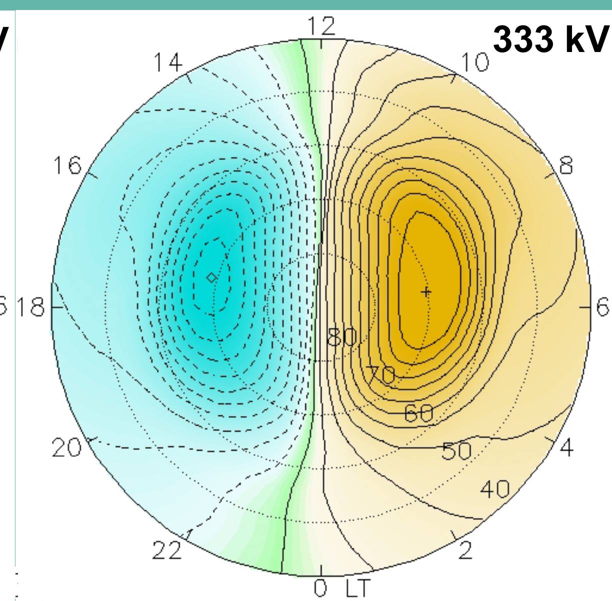
Summer



Spring/Fall

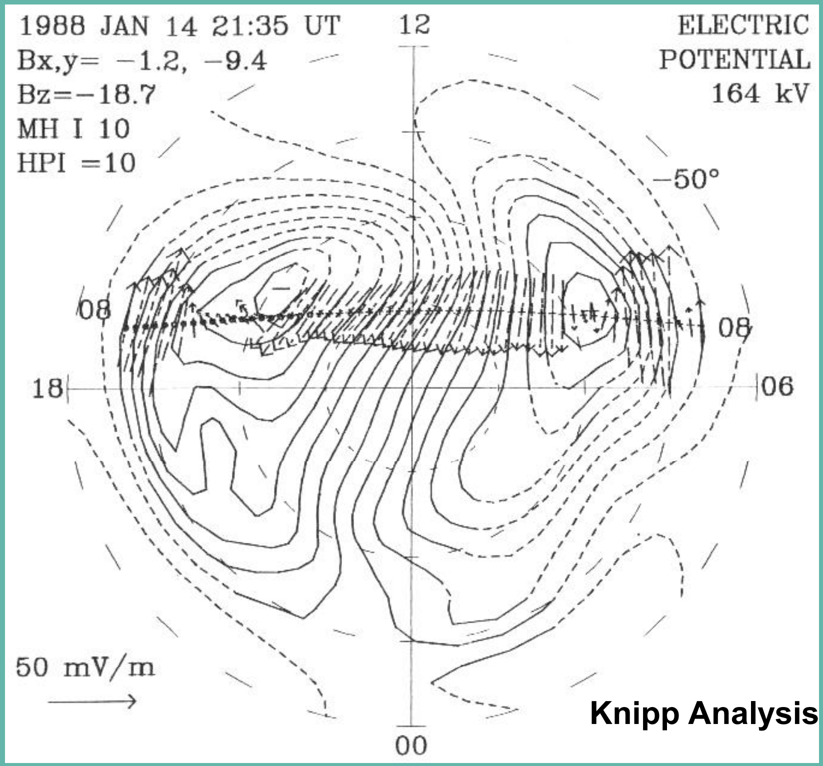


Winter

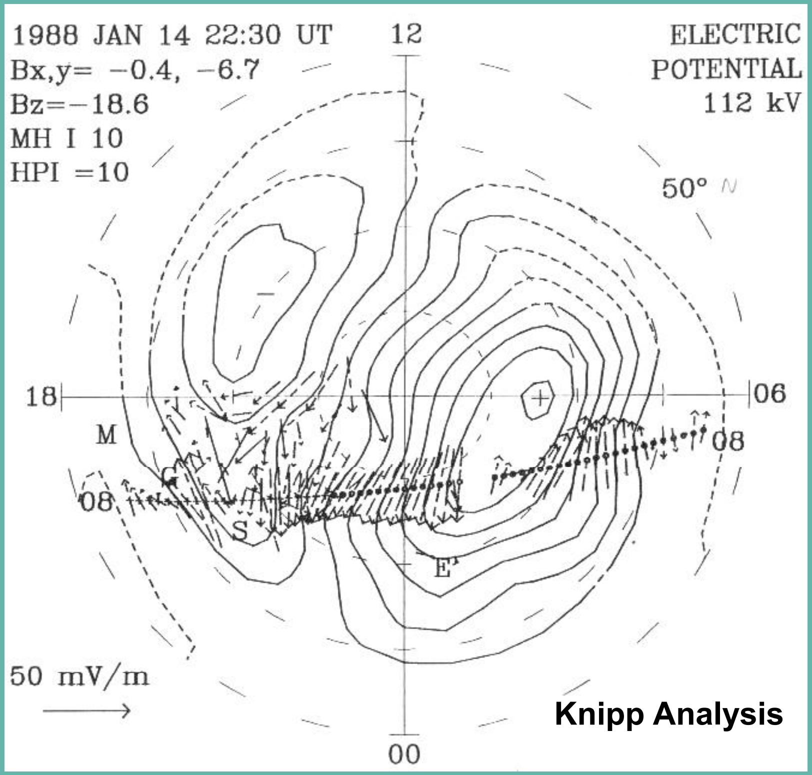


Interhemispheric Comparison
AMIE-Derived Potentials
1988 Jan 14 Storm

South/Summer



North/Winter



- Result: Counter to simulations, potential goes down in winter hemisphere!
- Inference: Reality (?) is like equal conductance case.

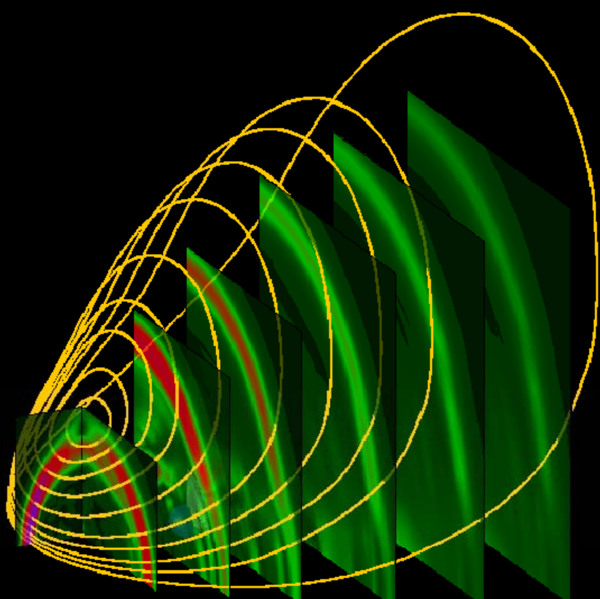
Summary of the
Properties of the Dungey-Alfvén Magnetosphere

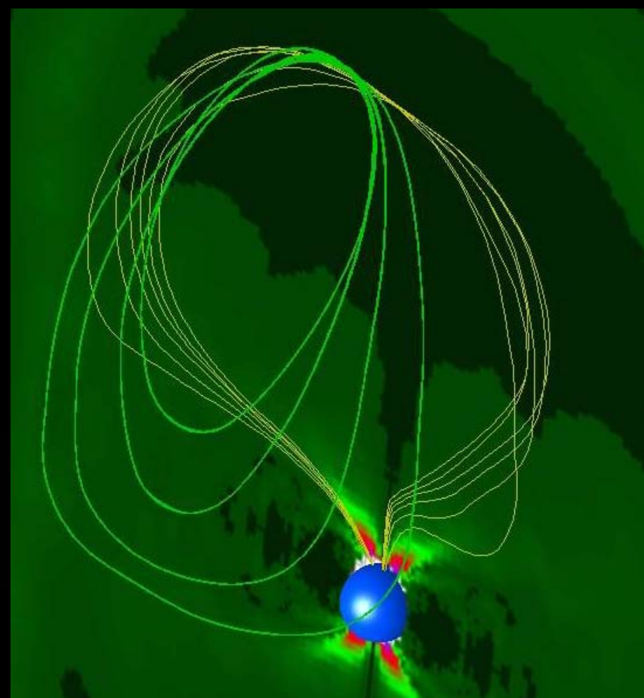
- **Huge dayside-nightside flux imbalance**
  - Trans-magnetospheric Potential >> Transpolar Potential (flux ablation) (aside on flux accretion for IMF Bz > 0)
  - Dayside field weakening
  - Magnetospheric erosion
  - Tail morphs into wings
  - Cusps migrate equatorward & reconnection dimple develops
  - Sawtooth substorms (TPE-analogs to CEMs?)
- **Force reversal and amplification**
- **Transpolar potential saturation**
- **System regulation of ionospheric conductance**

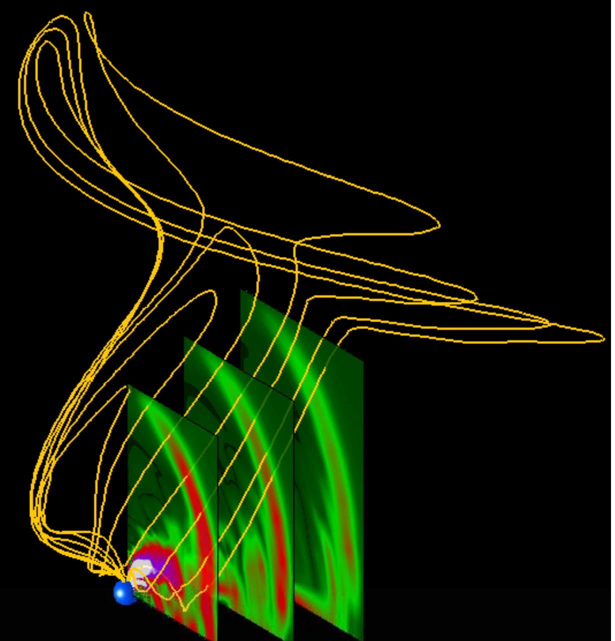
THE IDEAL

THE HYBRID

THE EXTREME







THE END