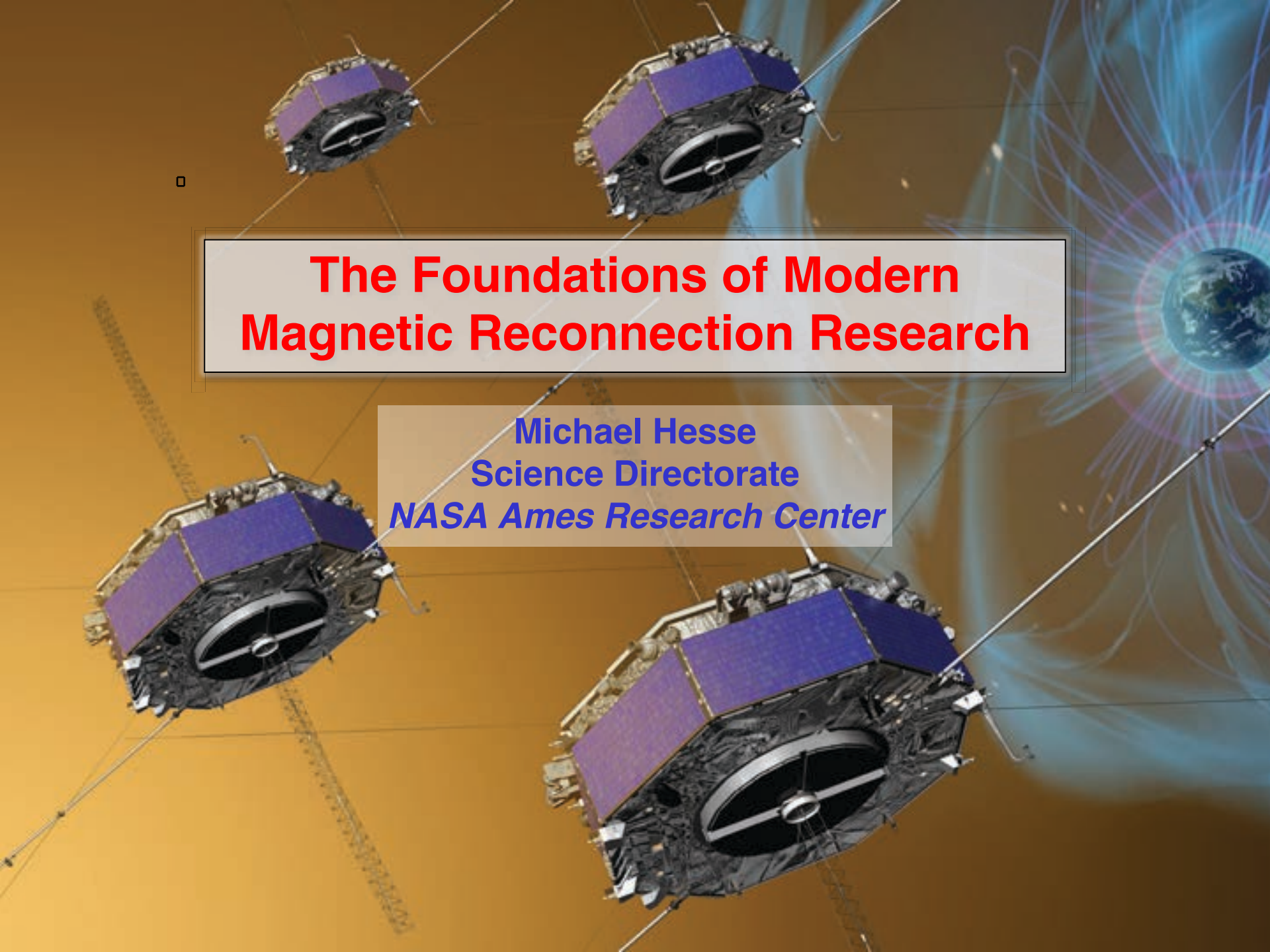


The Foundations of Modern Magnetic Reconnection Research

Michael Hesse
Science Directorate
NASA Ames Research Center

Ames Research Center

Overview

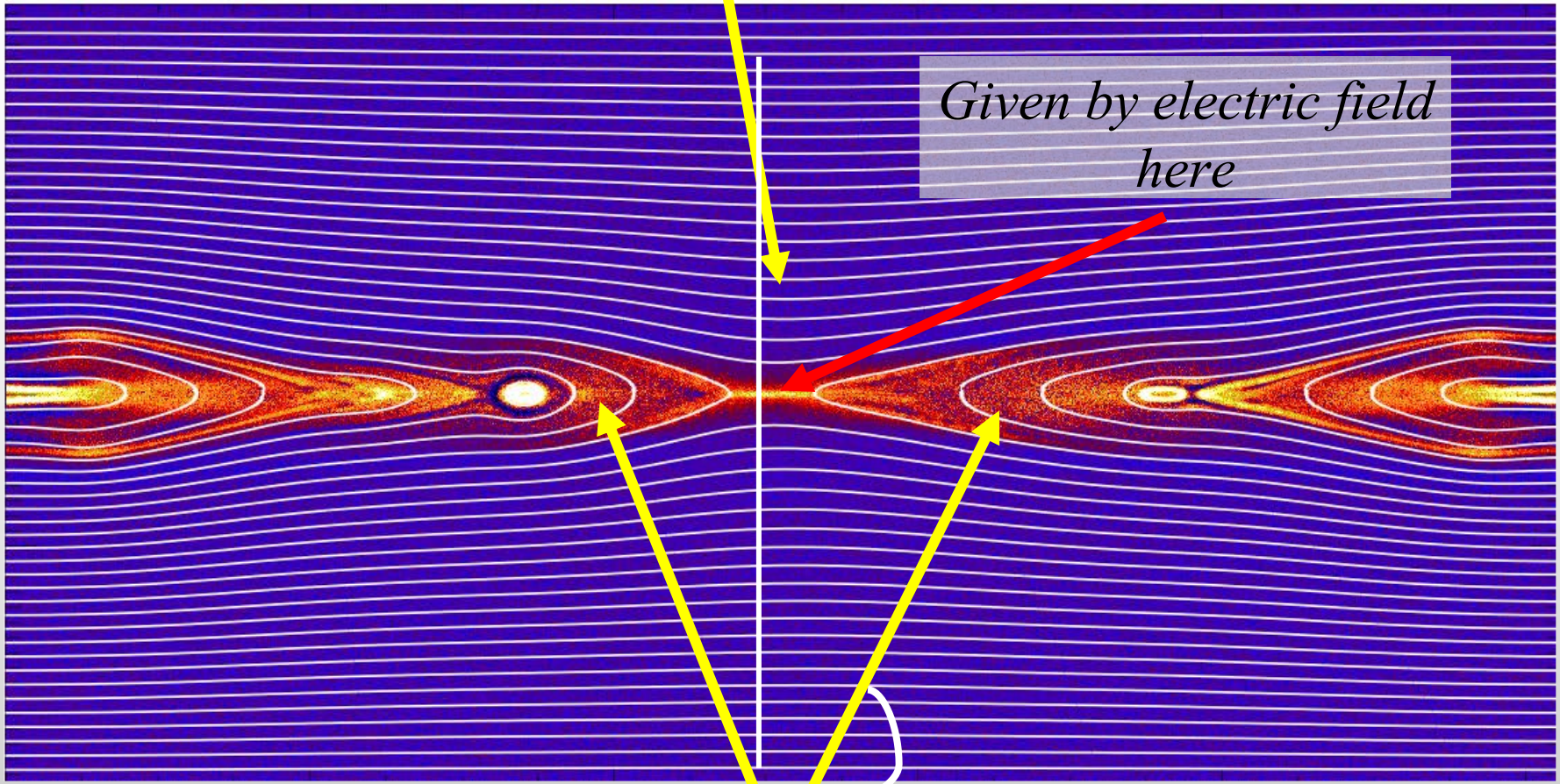
What do we know:
- Basic physics of the diffusion region
- What balances the electric field acceleration?
- Turbulent vs laminar “resistance”
- Model prediction
- MMS data

Open questions
- Microscale
- Intermediate scale
- Macroscale

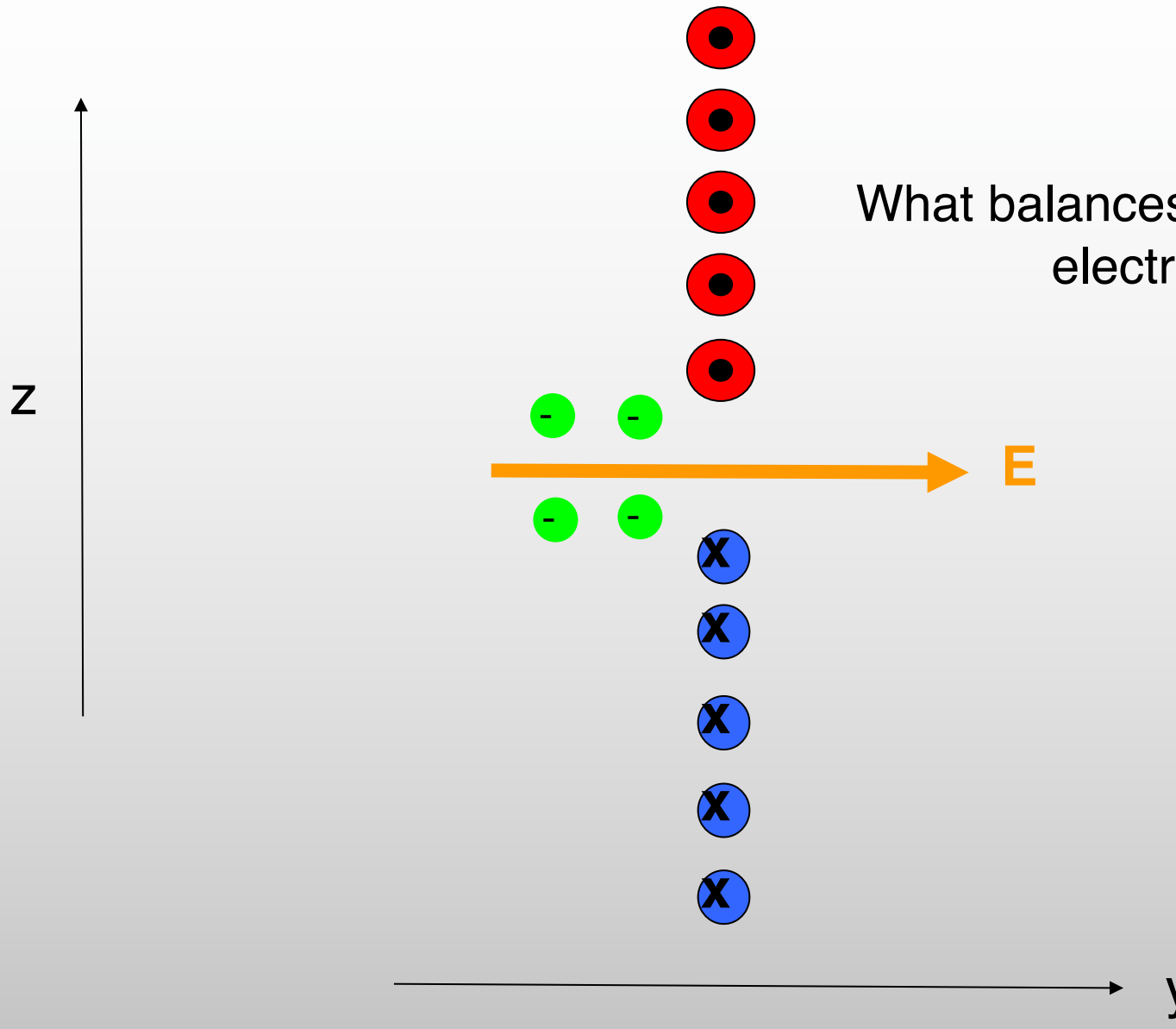
A key beginning

Conclusions and look ahead

Reconnection E Field



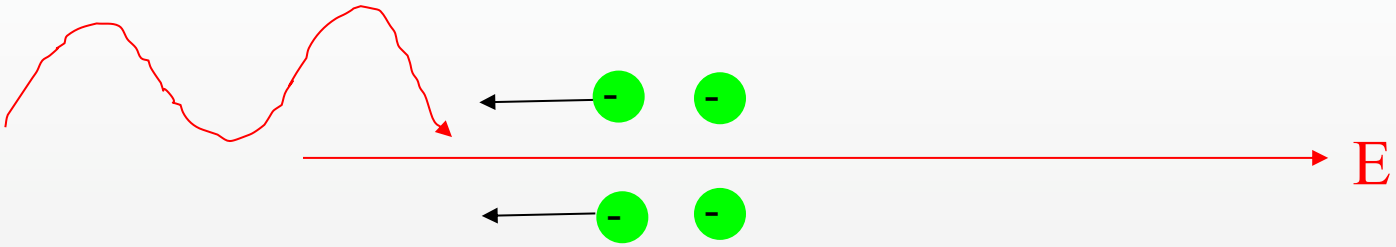
Side view



What balances the force of the electric field?

1st Option: Wave-Particle Interactions

Fluctuating electromagnetic fields



-Involves special plasma conditions

-Variety of possible mechanisms

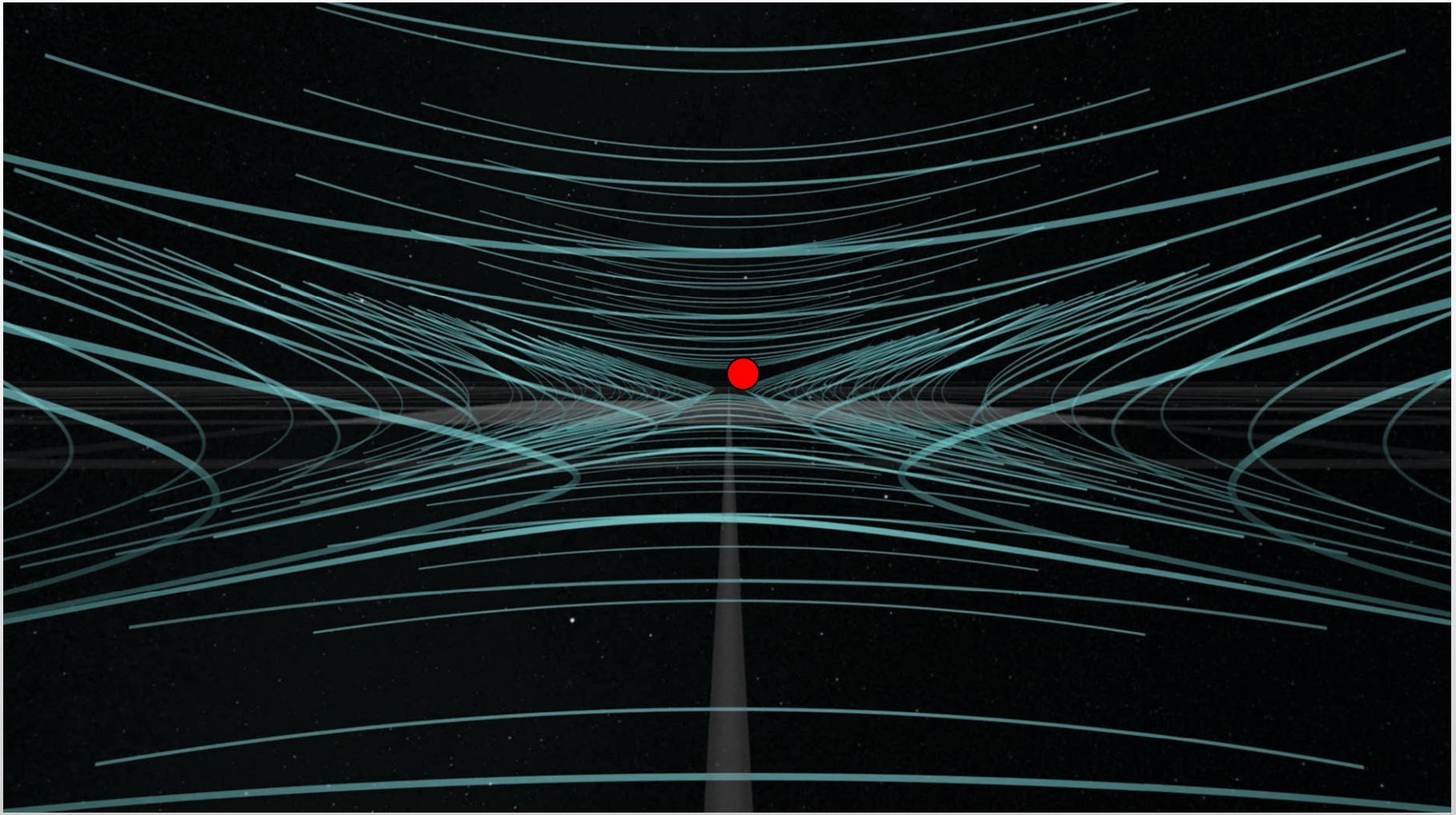
-Some of these effects are ubiquitous in space

-Implications of MMS results?

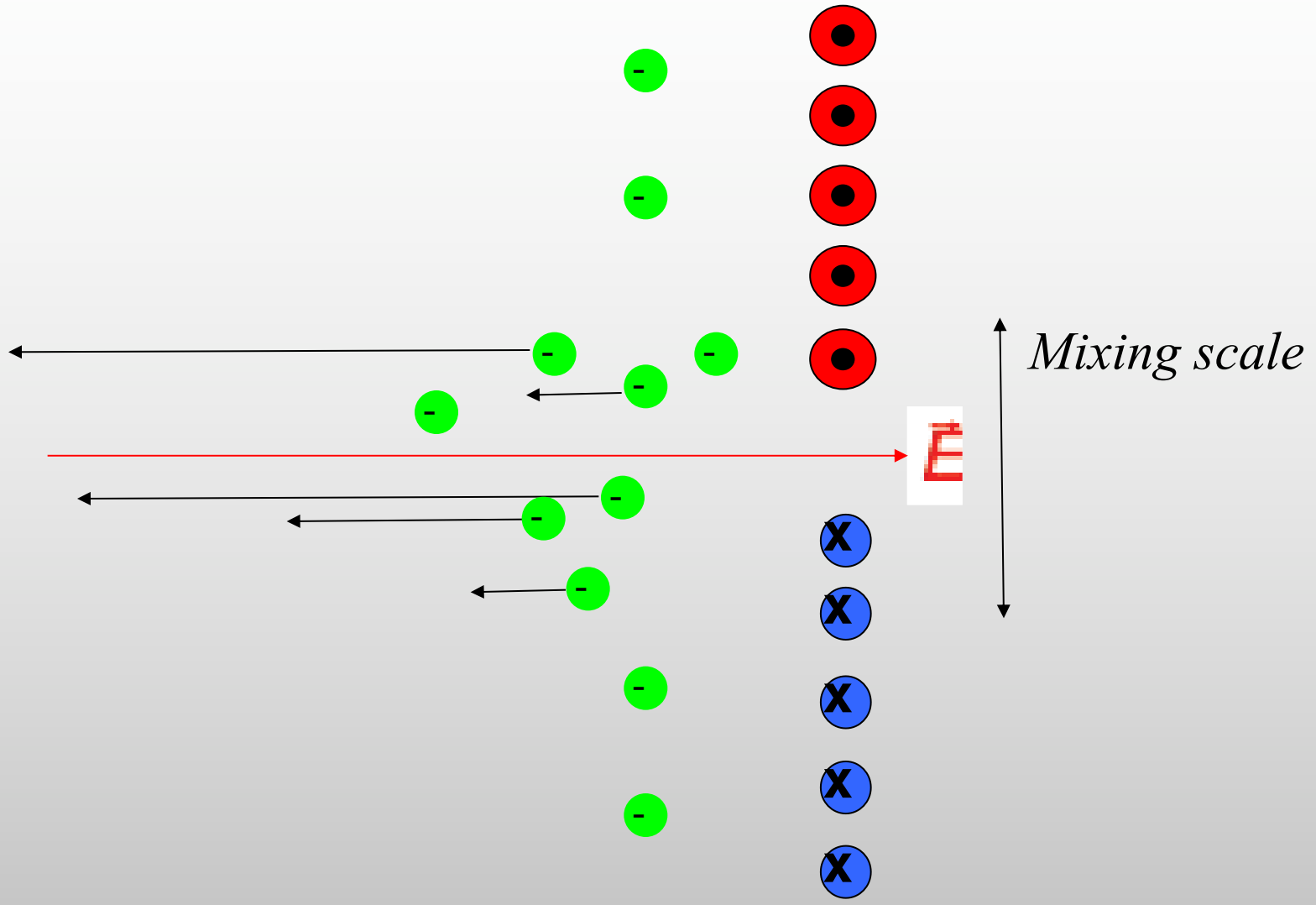
Ames Research Center

Anomalous resistivity
- basic Idea -

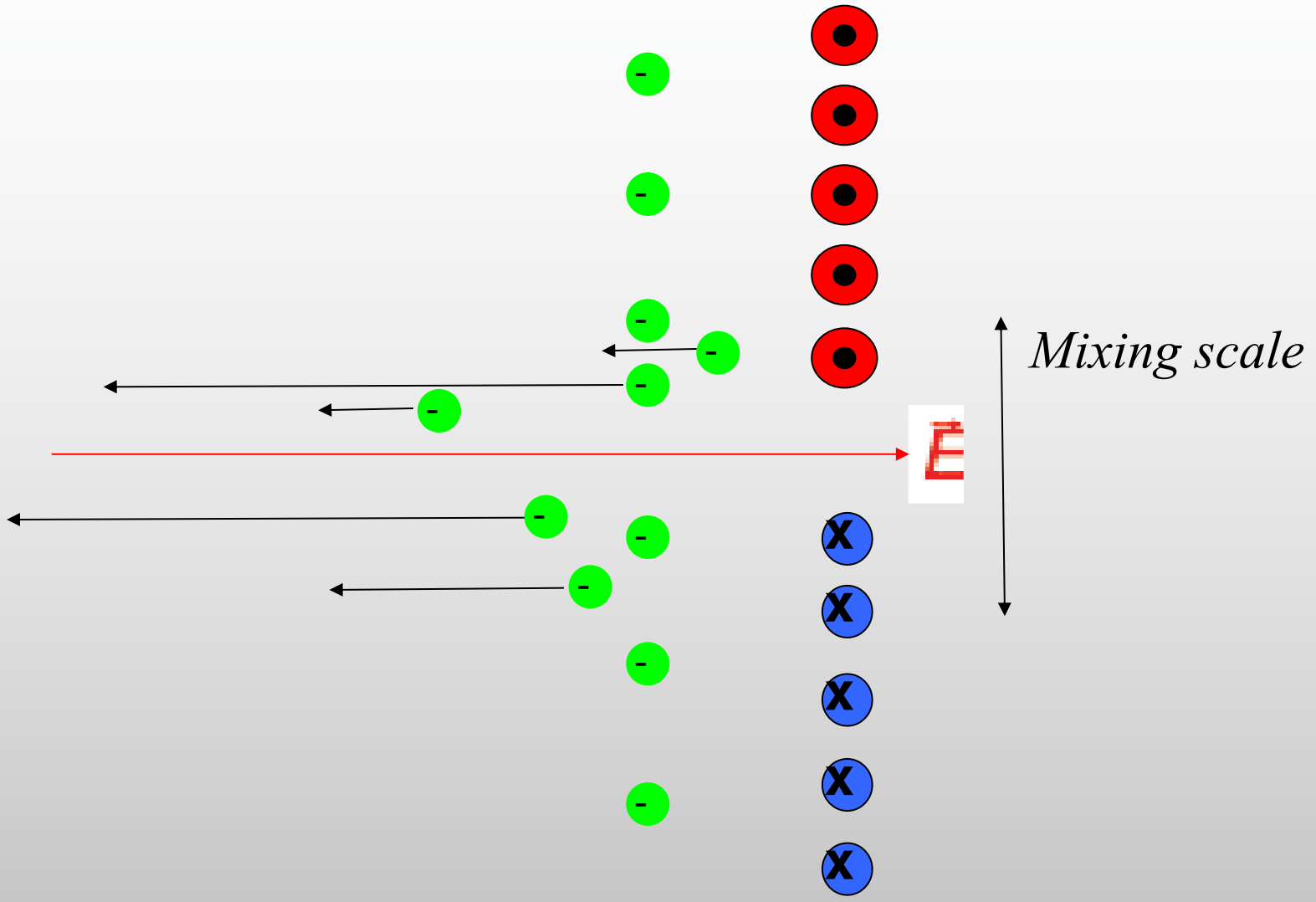
NASA



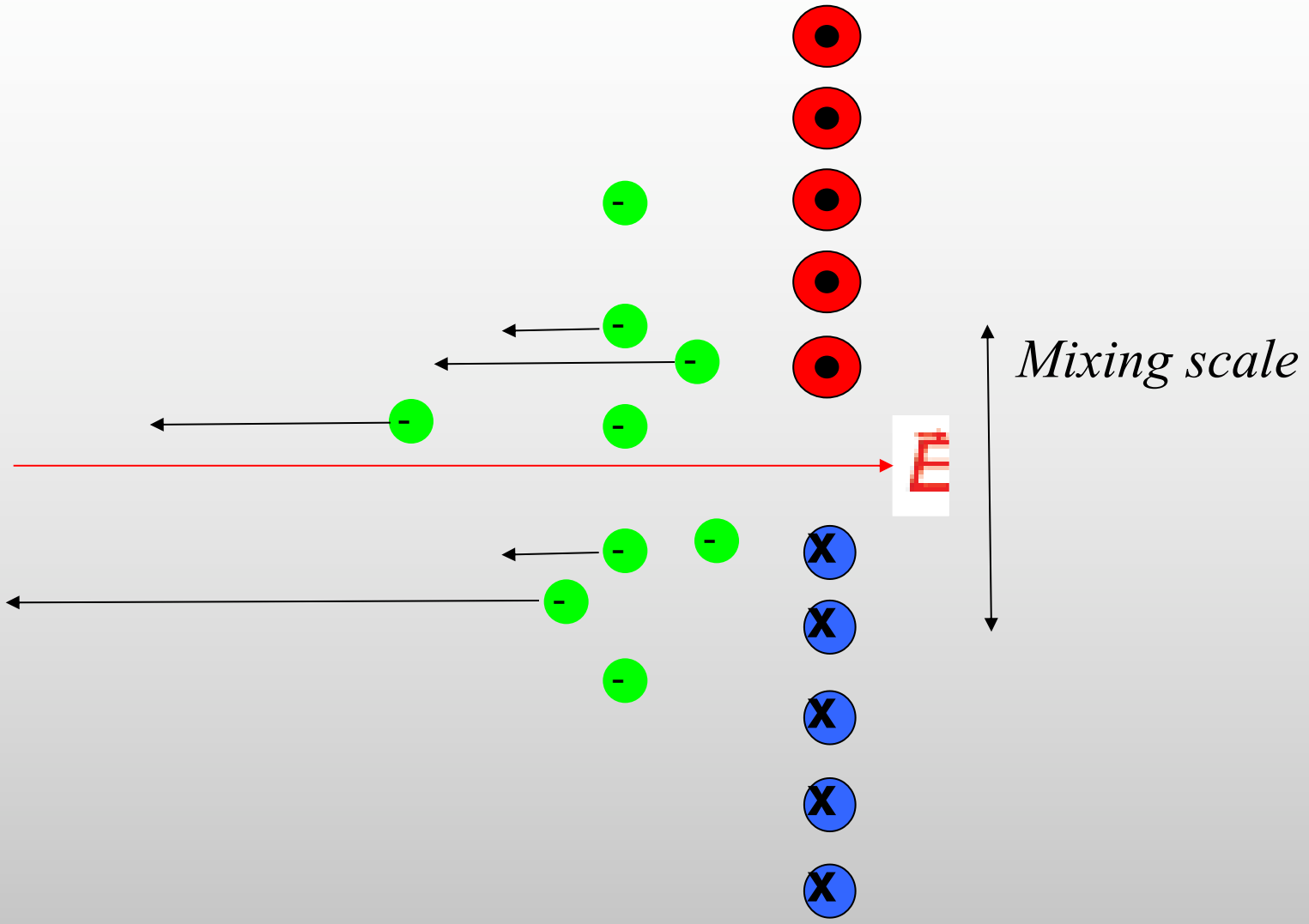
2nd Option: Mixing – Transient Orbits



2nd Option: Mixing – Transient Orbits

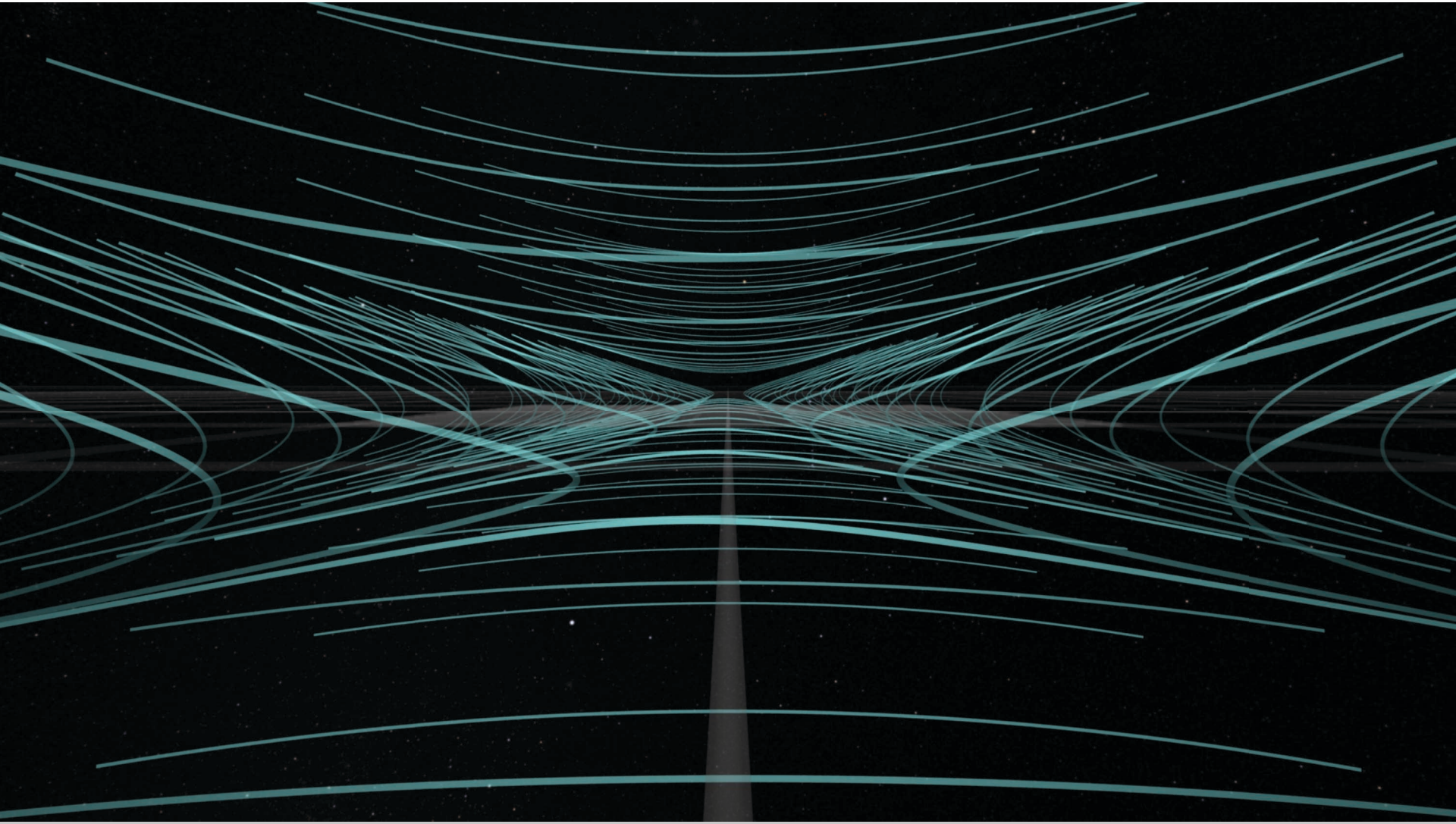


2nd Option: Mixing – Transient Orbits



Ames Research Center

Transient Orbit Inertia



Quasi-viscous model

Prediction:

- Thermal inertia effects balance electric field acceleration
- “Resistance” facilitated by interaction of accelerated electrons with adjacent magnetic field (“bounce motion”)
- Electric field (at stagnation point) given by pressure tensor divergence

Hesse et al., 1999,…

Ames Research Center

How to test this idea?

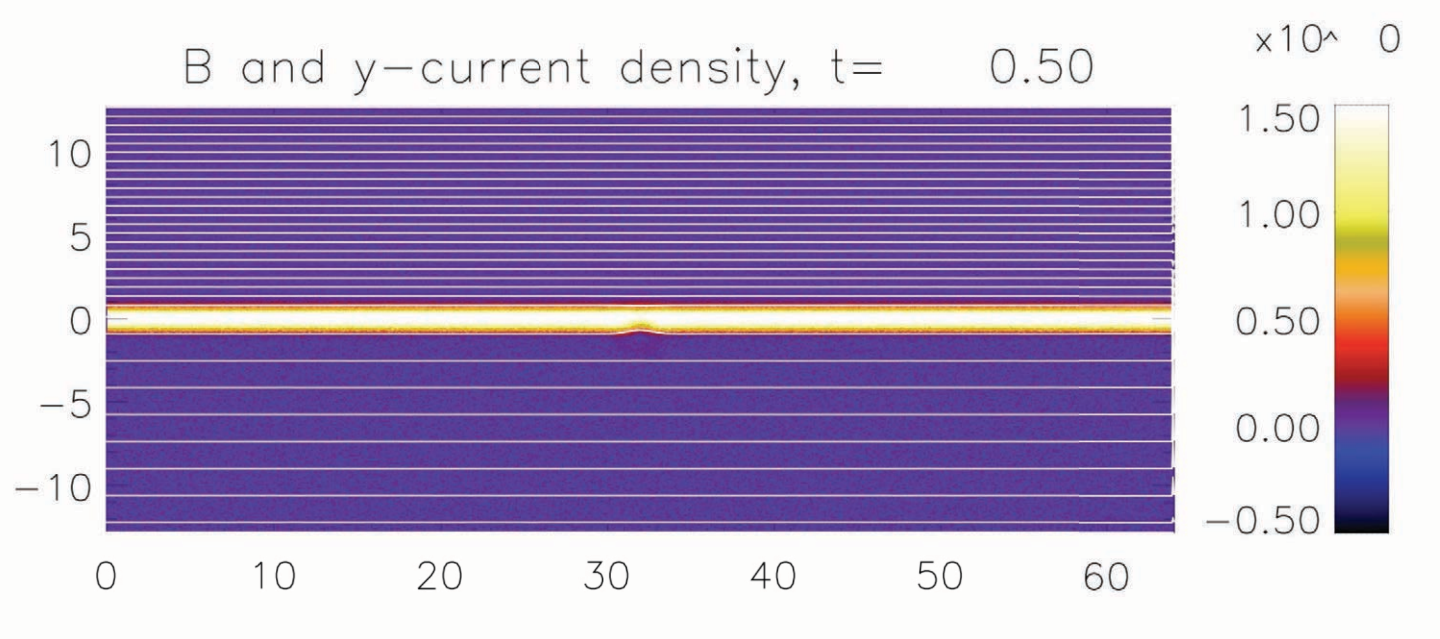
NASA

Key features:

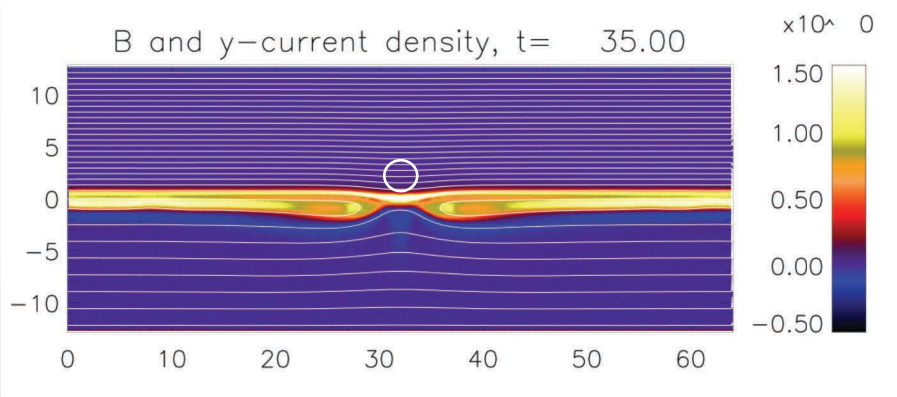
- Turbulence is (locally!) unimportant (if idea correct)
- Electron orbits are fairly undisturbed and can be complex
- Measurements should reflect this feature

Ames Research Center

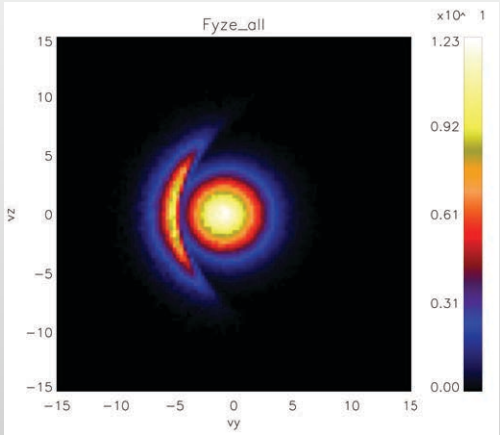
Asymmetric Reconnection at the Magnetopause and Elsewhere



Predictions for planar, asymmetric reconnection



In-plane, normal velocity

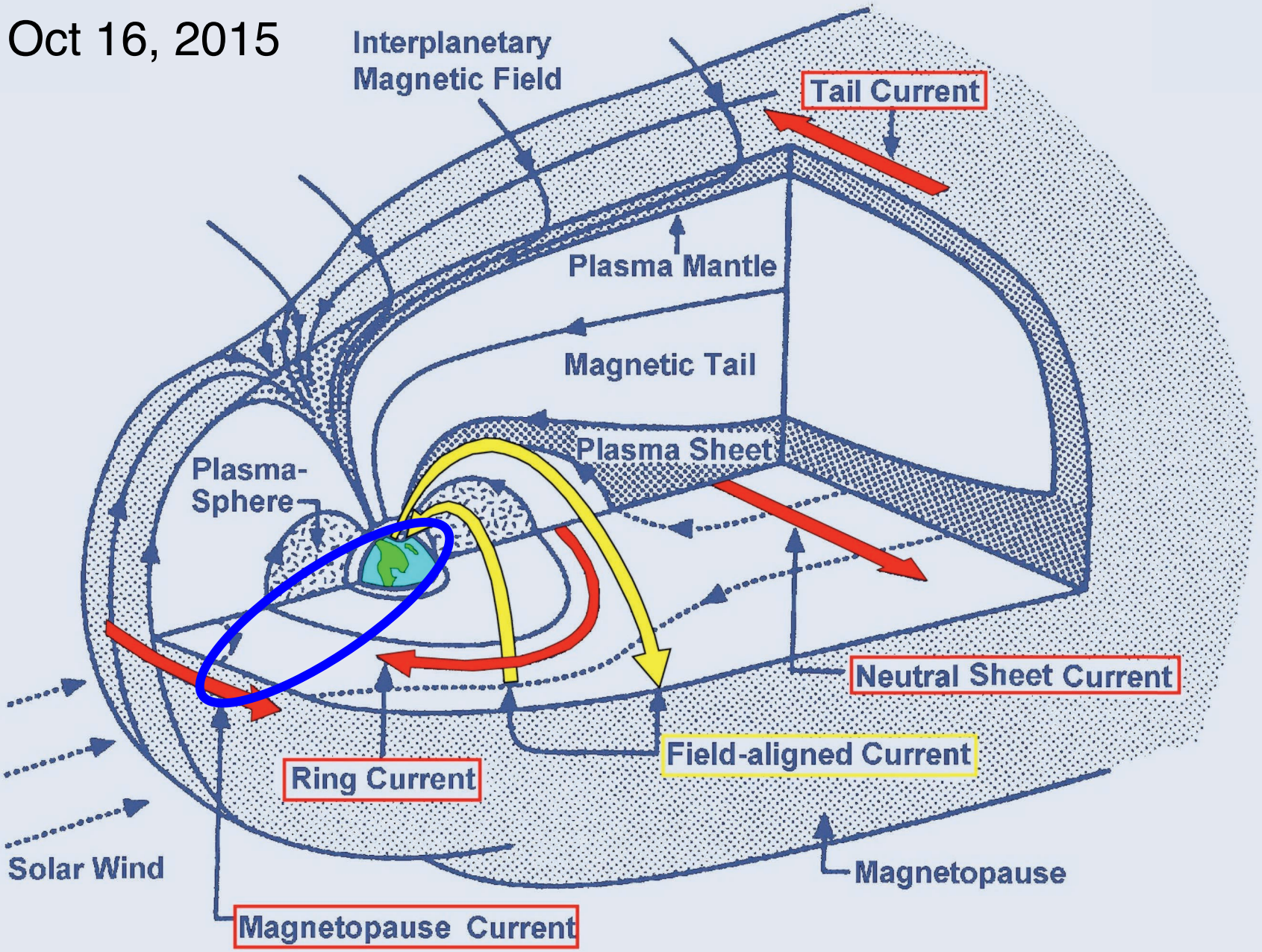


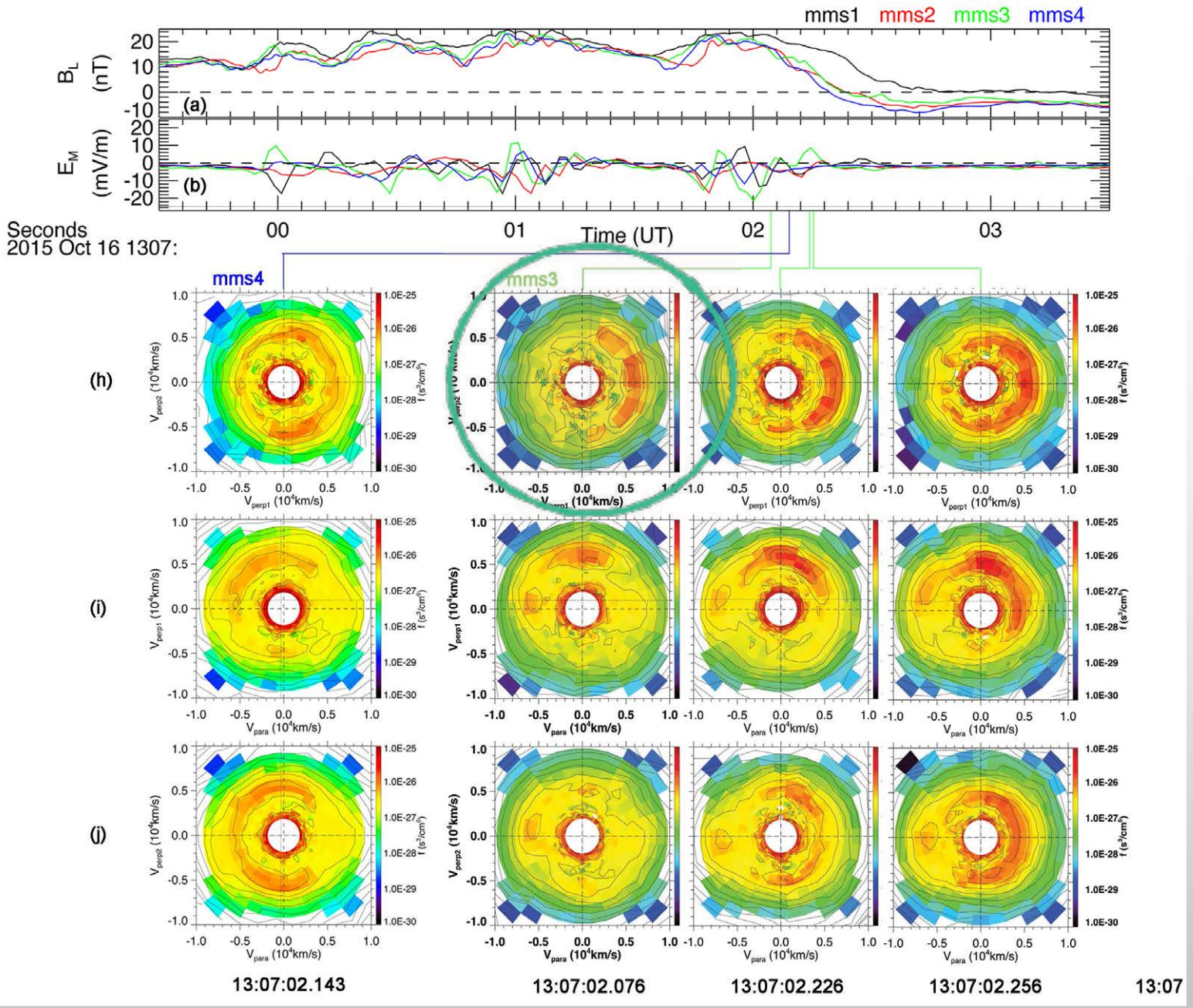
Out of plane velocity

Hesse et al., 2014

"Crescent"

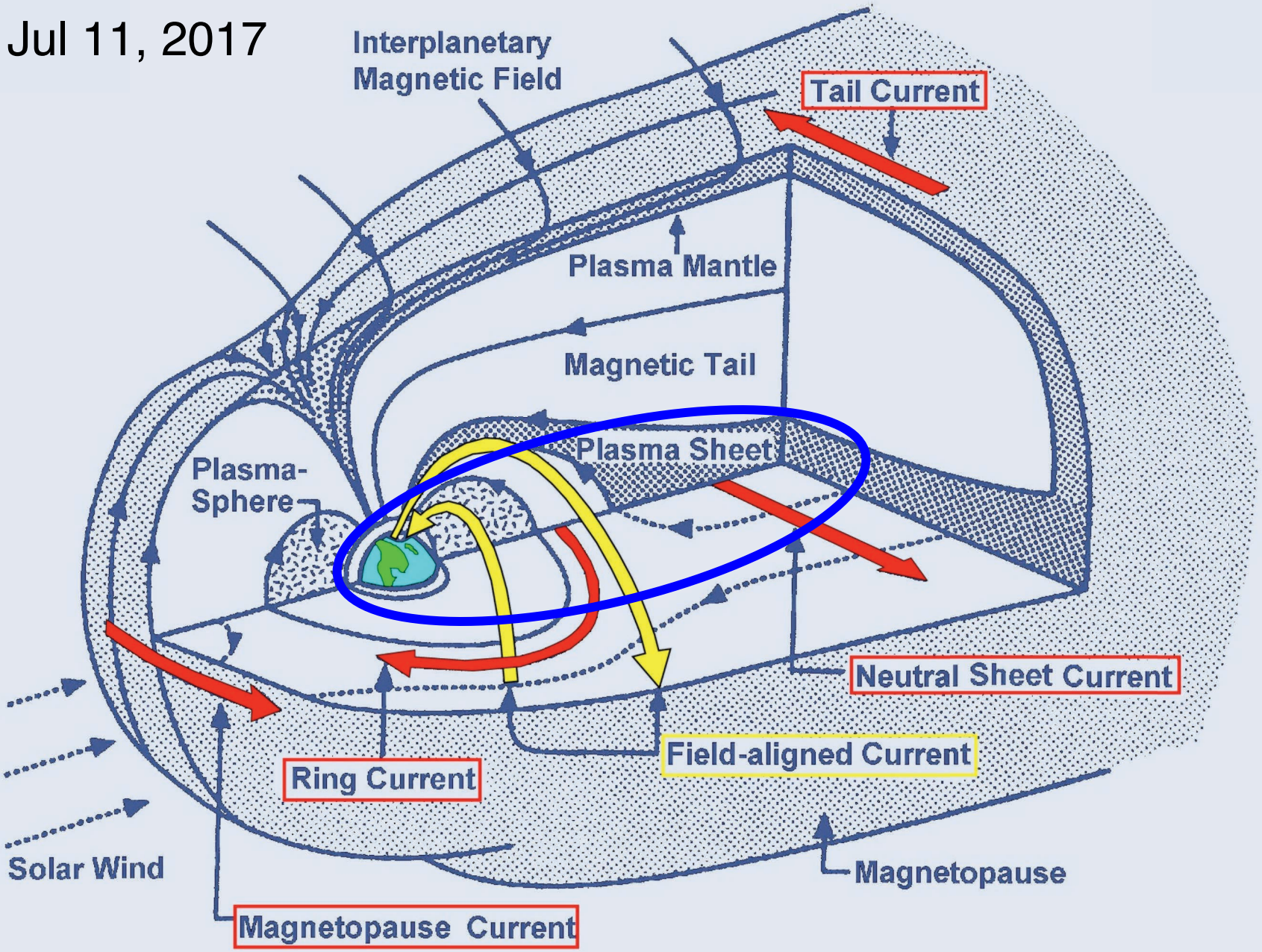
Oct 16, 2015


Interplanetary
Magnetic Field
Tail Current
Plasma Mantle
Magnetic Tail
Plasma Sheet
Plasma-
Sphere
Neutral Sheet Current
Field-aligned Current
Ring Current
Solar Wind
Magnetopause
Magnetopause Current

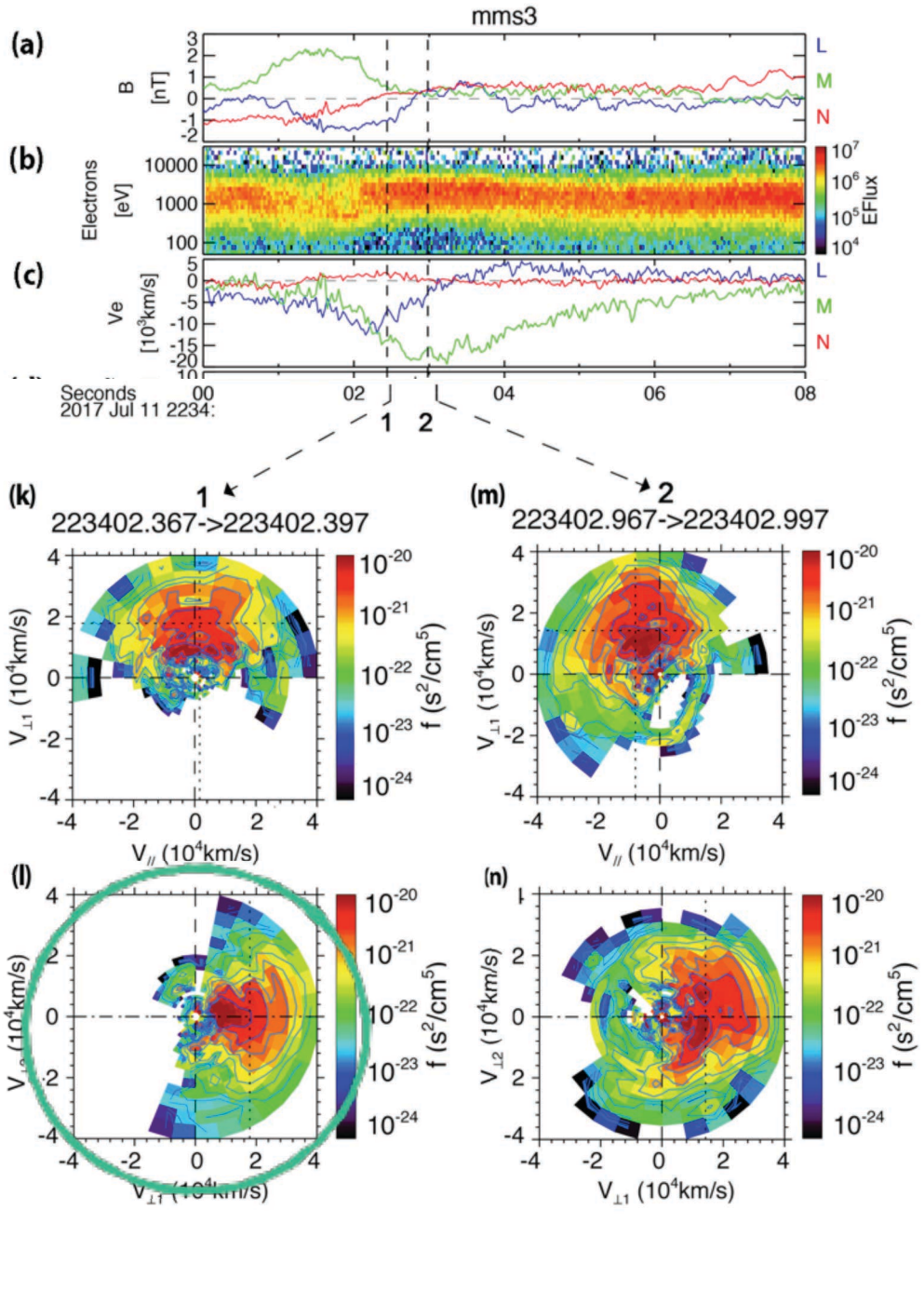


Burch et al., 2016

Jul 11, 2017


Interplanetary
Magnetic Field
Tail Current
Plasma Mantle
Magnetic Tail
Plasma Sheet
Plasma-
Sphere
Neutral Sheet Current
Field-aligned Current
Ring Current
Solar Wind
Magnetopause
Magnetopause Current

Ames Research Center



Tail event, Torbert et al., Science, under rev.

Ames Research Center

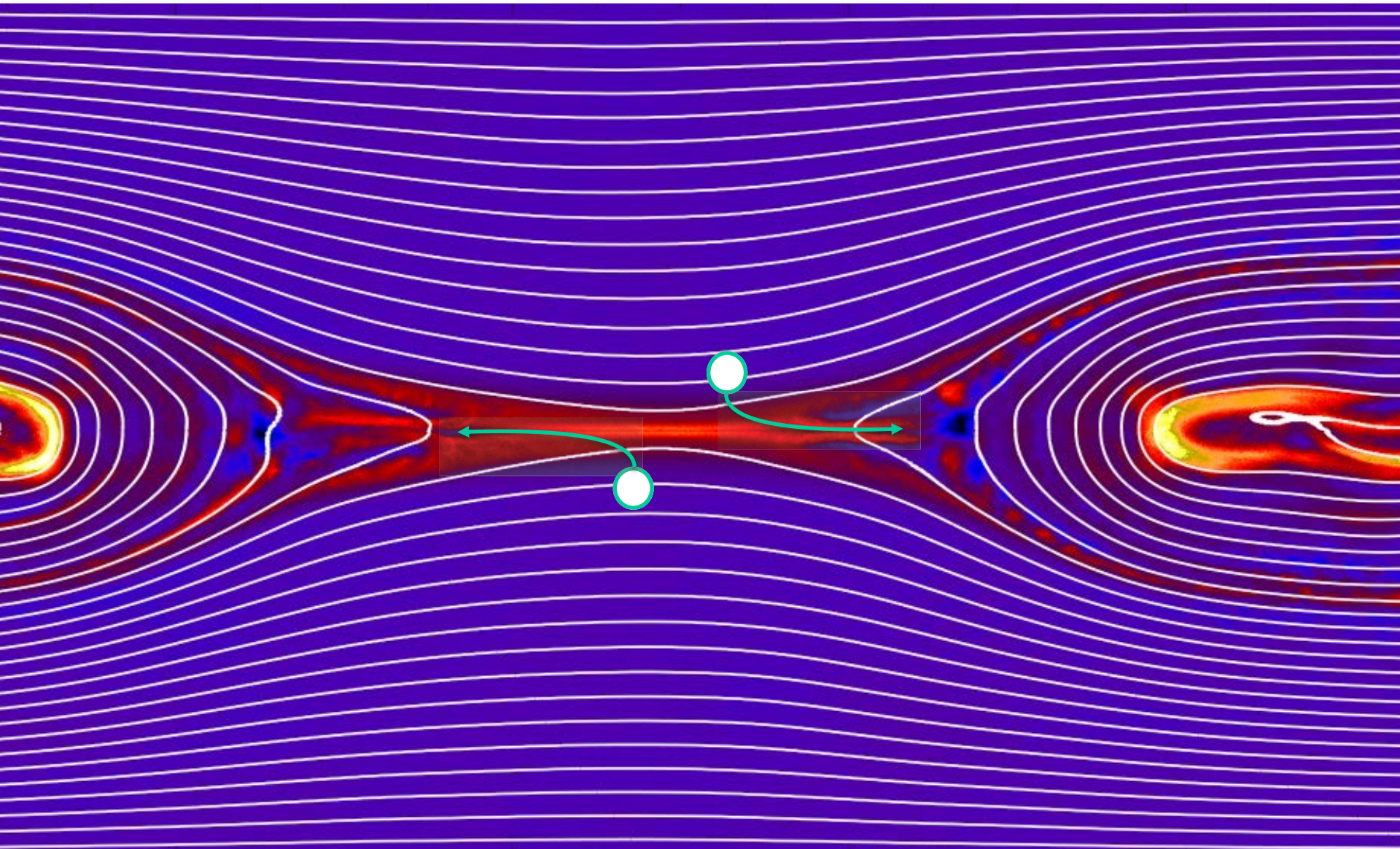
Why?

NASA

- In reality, something reduces instability growth, so that fluctuations are too weak to impact electron orbits
  - The plasma “around the X point” does not meet instability criteria
  - Linear instability theory does not apply because the plasma is strongly inhomogenous and dominated by transient particle orbits

Ames Research Center

Finite particle residence time

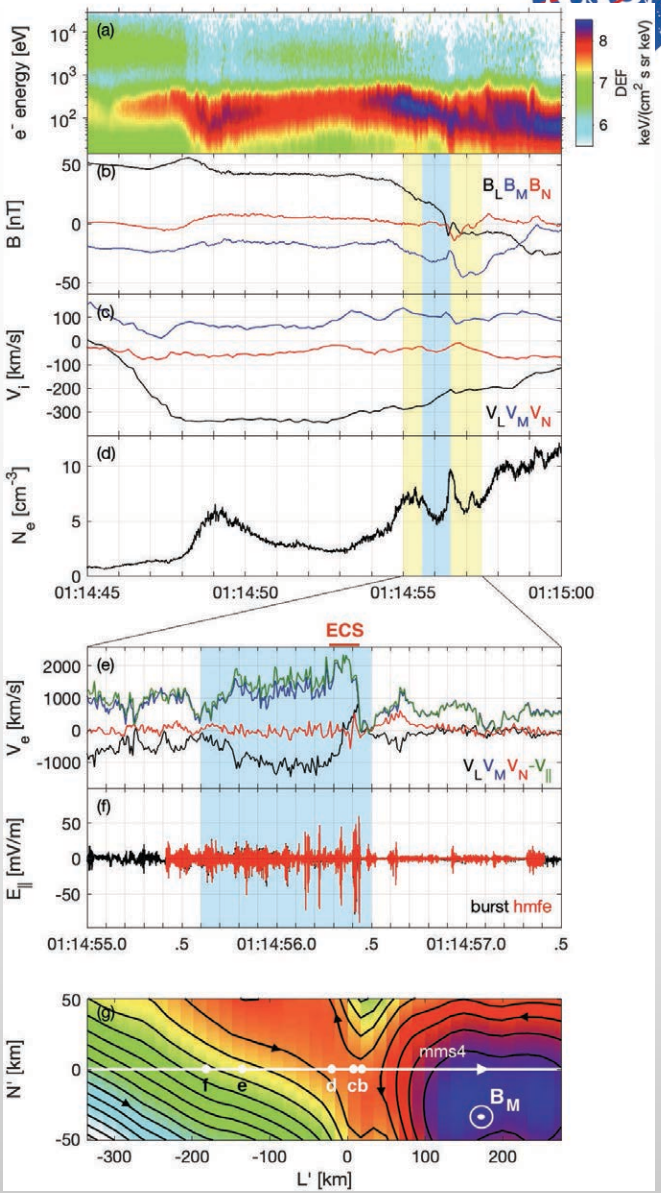


Open Questions: Microscale

- Diffusion region always laminar?

- 3D (see also below)

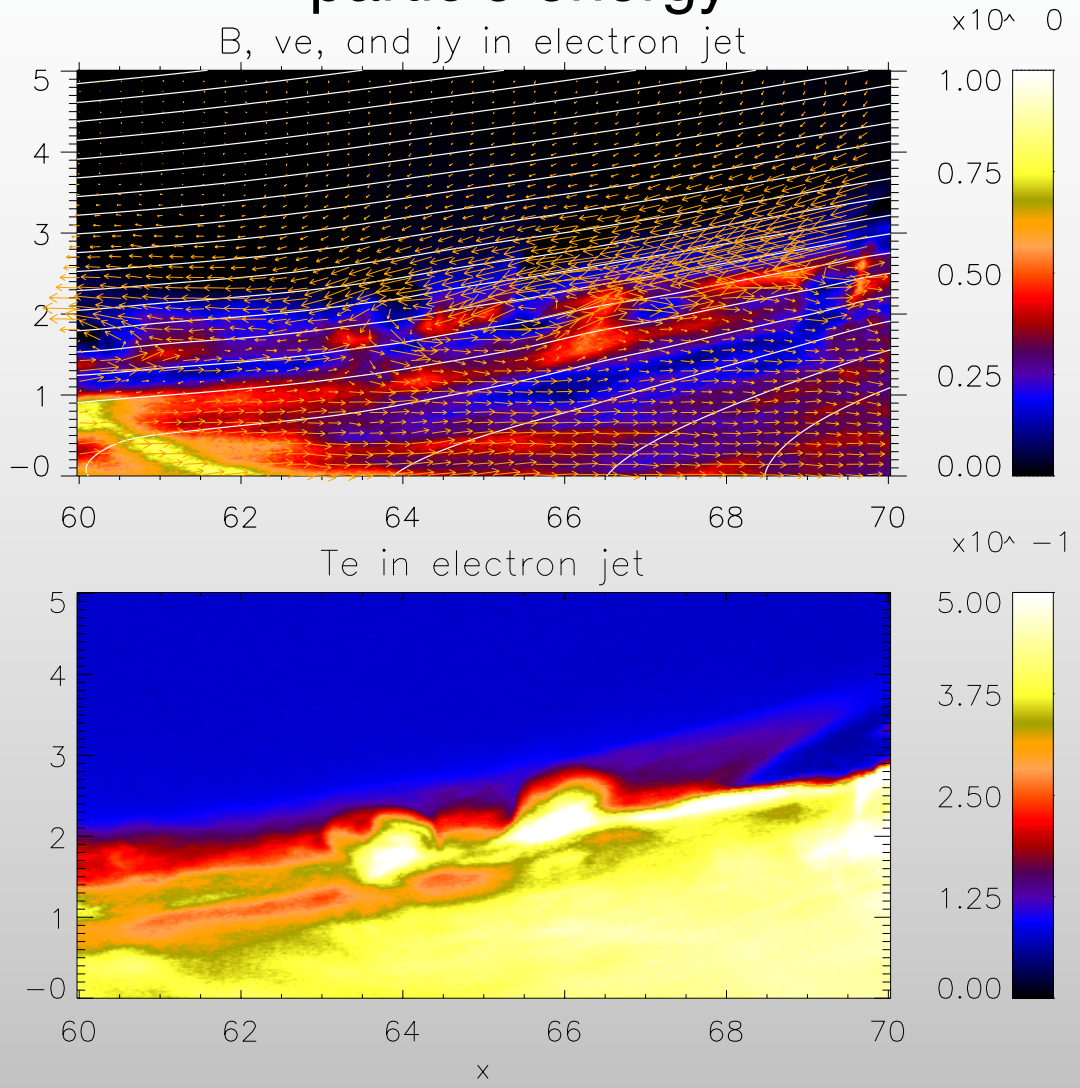
- Physics of the asymmetric diffusion region?



Khotyaintsev et al., 2019

Open Questions: Intermediate Scale

- What replaces slow shocks to convert Poynting flux to particle energy



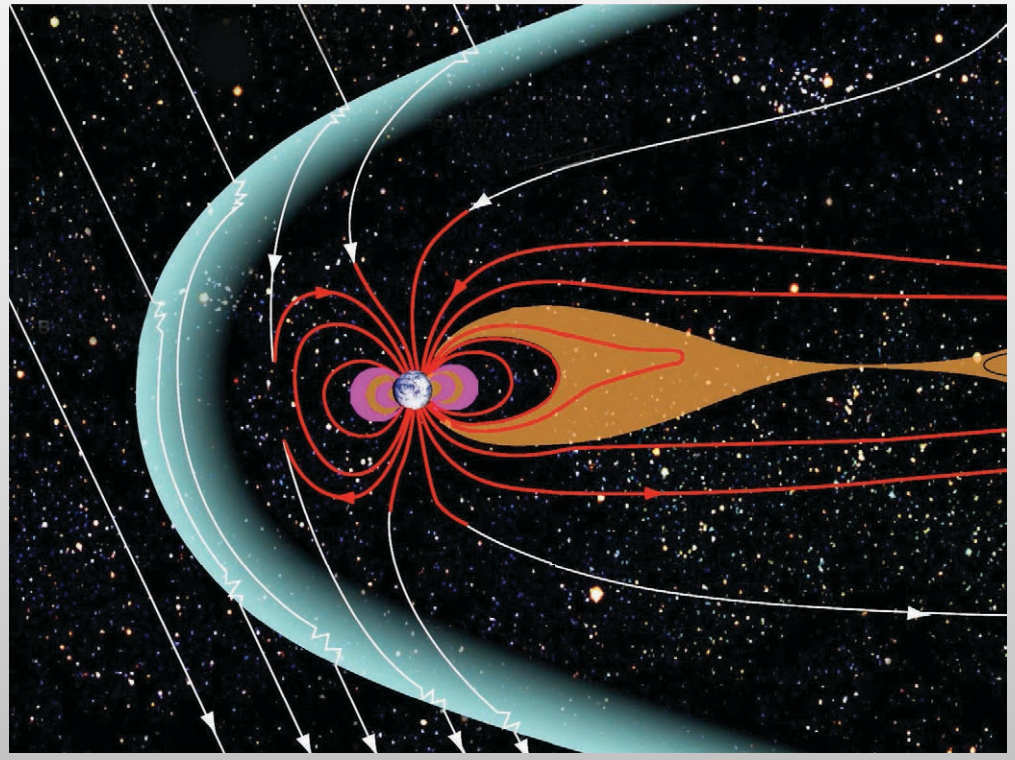
Ames Research Center

Open Questions: Intermediate Scale

NASA

- How does reconnection depend on inflow conditions, geometry of inflow?

- How does reconnection respond to changing inflow conditions, transition from one state to another?

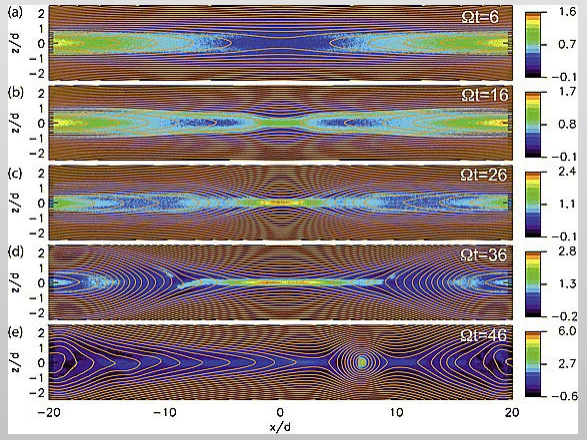


Open Questions: Intermediate Scale

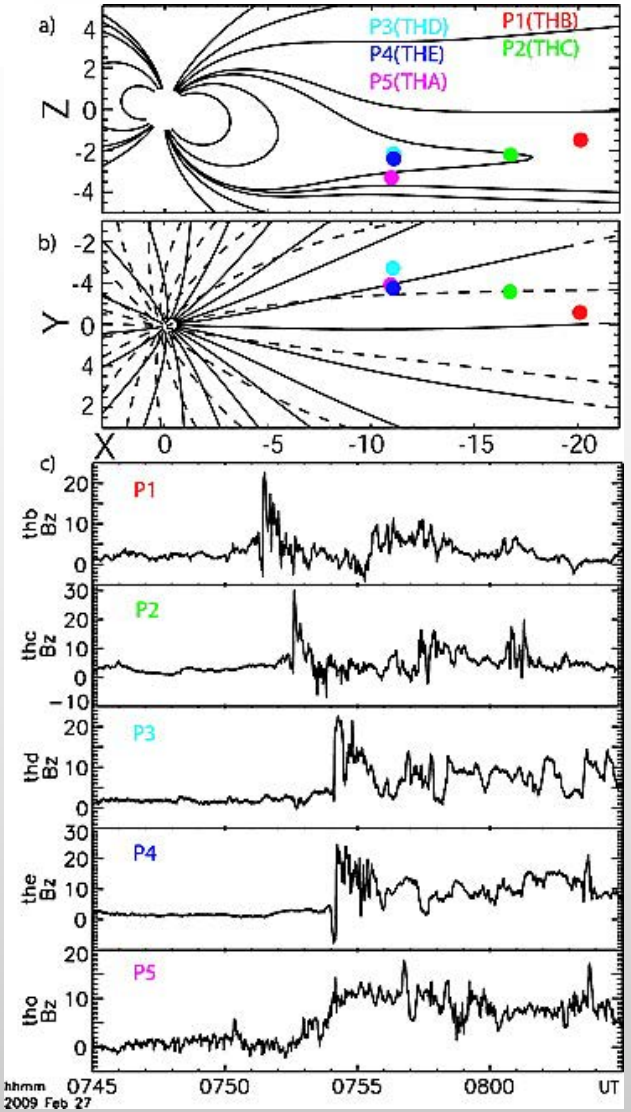
- How long are reconnection lines and why?

- Why do BBFs have scale sizes of ~1RE?

- How are dipolarization fronts created and how do they interact with the plasma in their path?



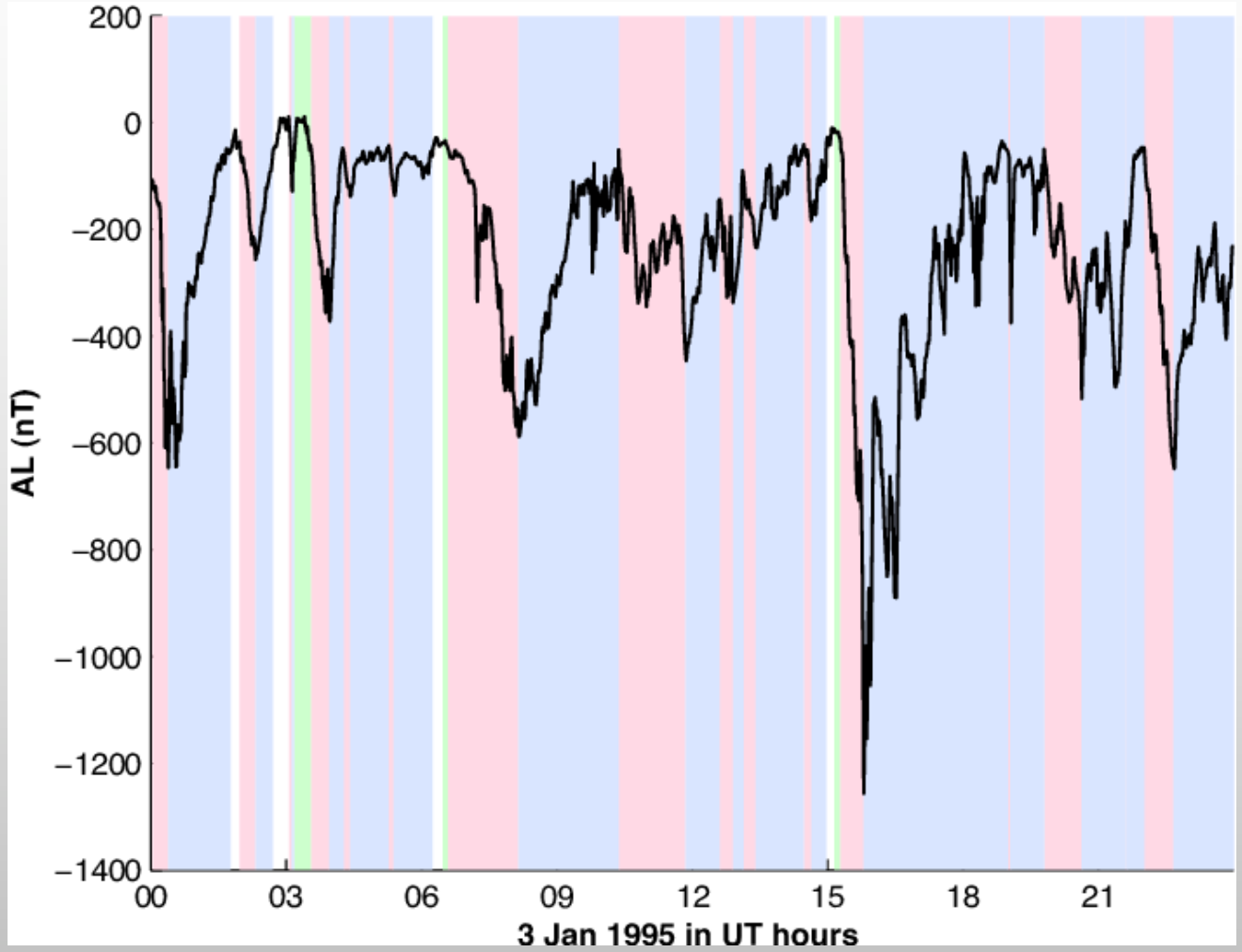
Sitnov and Swisdak, 2011



Runov et al., 2009

Open Questions: Intermediate Scale

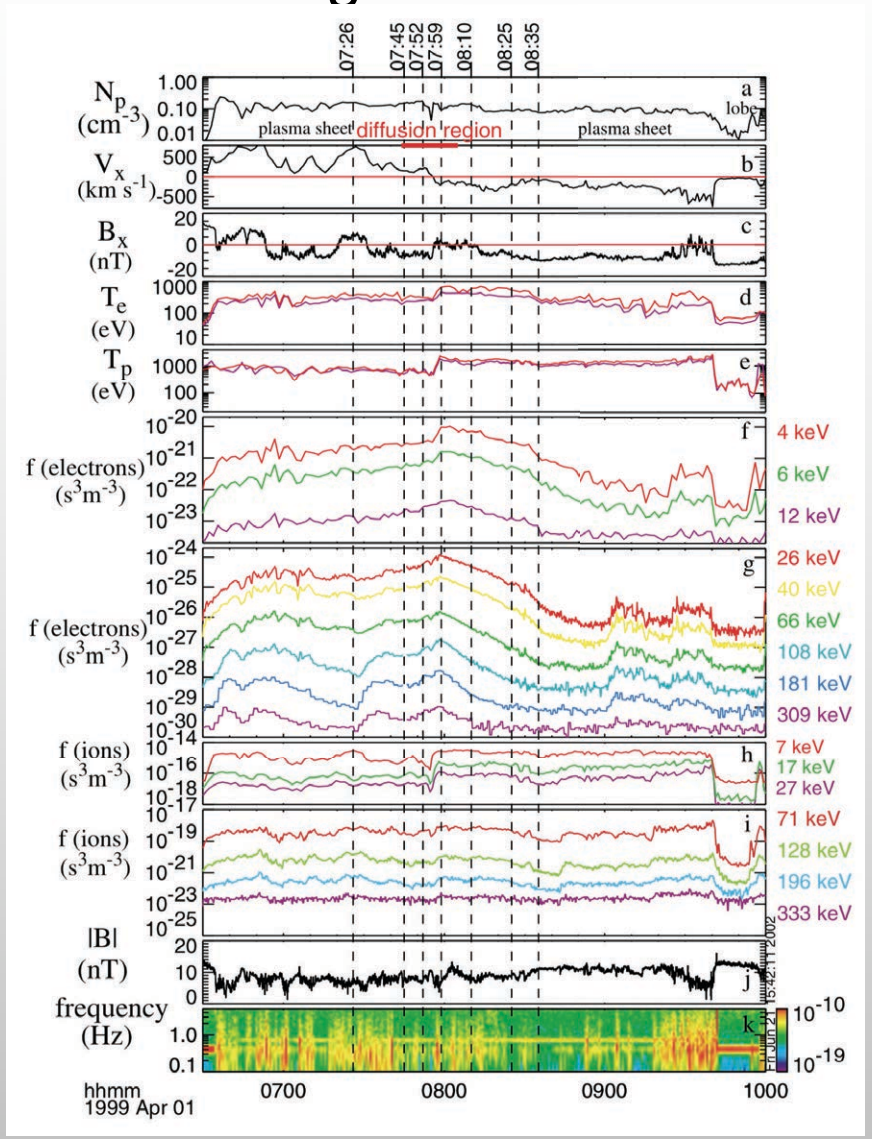
- Why does reconnection start (or not), stop and how?



Open Questions: Intermediate Scale

- Does reconnection directly accelerate energetic particles and, if so, how?

M. Øieroset et al., 2002



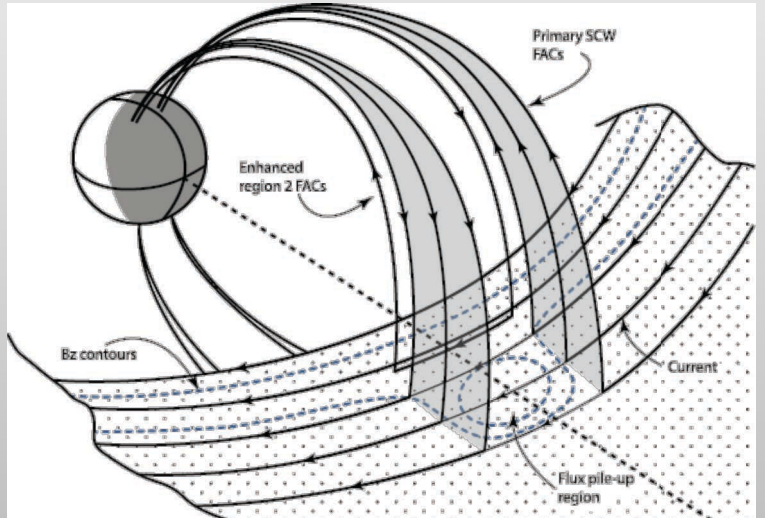
Open Questions: Large Scale

- How and why does the magnetosphere transition from isolated reconnection bursts to a big breakup?

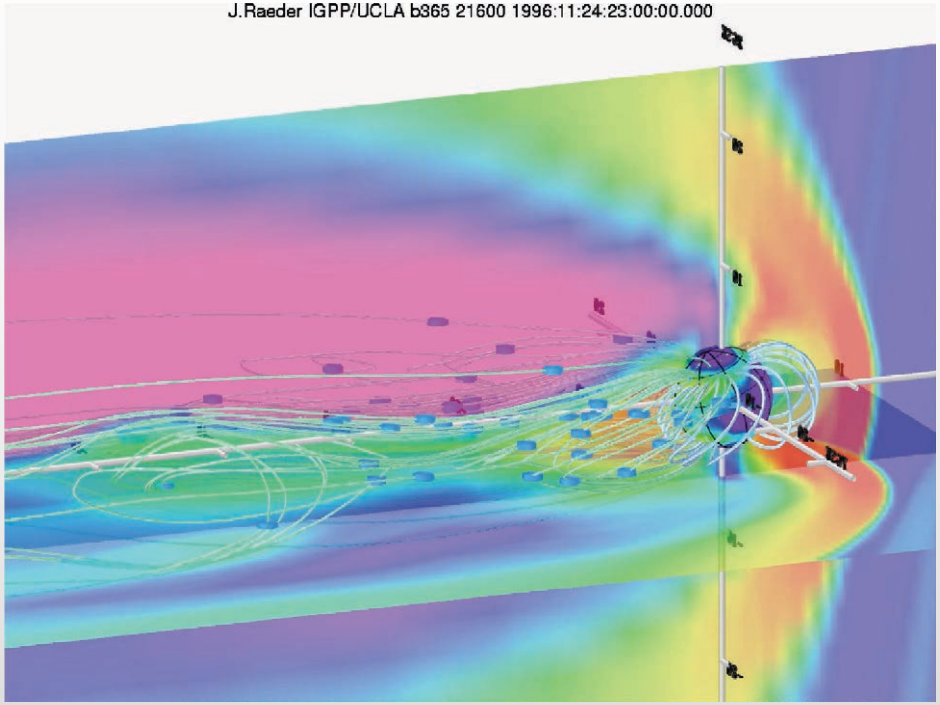
- How do individual reconnection bursts organize to produce large-scale substorm phenomena?

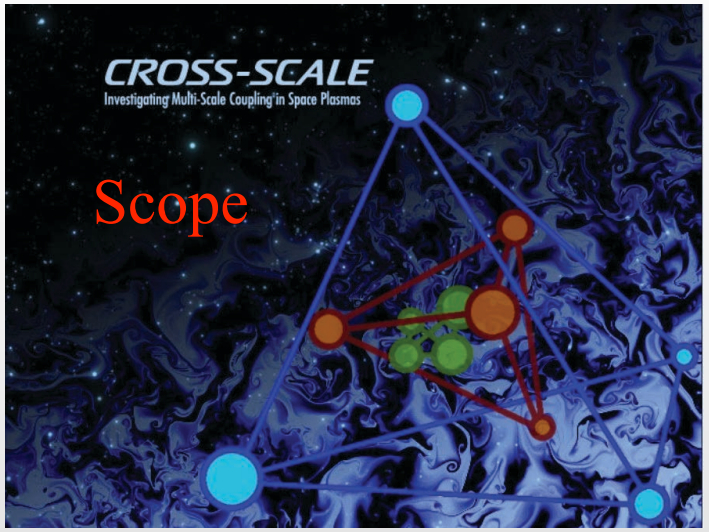
- How do “well-organized” current systems form from many small reconnection bursts? How well-organized are they anyway?

Kepko et al., 2015



Approaches





Possible strategy/challenge: use reduced measurement set to infer diffusion region

Ames Research Center

How to break a current layer

A.A. Galeev: Transformative Research

Tearing instability in plasma configurations

A. A. Galeev and L. M. Zelenyĭ

Institute of Cosmic Research, USSR Academy of Sciences
(Submitted December 9, 1975)
Zh. Eksp. Teor. Fiz. **70**, 2133–2151 (June 1976)

The development of tearing instability in plasma containing a neutral diffusive layer and a magnetic field with a small but finite component perpendicular to the sheet is discussed. The effect of this component on electron orbits in the neighborhood of the neutral sheet is to stabilize the electron tearing mode even for very small amplitudes of the normal field. The development of the ion tearing mode of given wavelength is found to be possible only in the "gap" corresponding to a certain restricted range of values of the normal magnetic-field component for which its effect on ion orbits in the neutral sheet can still be neglected whilst the stabilizing contribution of magnetized electrons to the plasma permittivity is already small. It is shown that gaps of this kind can appear only when the current in the sheet is large enough. When the value of the normal magnetic-field component lies below the instability region, the plasma states are metastable with respect to the excitation of the ion tearing mode.

PACS numbers: 52.35.En, 52.20.Dq

Nonlinear instability theory for a diffusive neutral layer

A. A. Galeev and L. M. Zelenyĭ

Institute of Space Research, USSR Academy of Sciences
(Submitted April 1, 1975)
Zh. Eksp. Teor. Fiz. **69**, 882–895 (September 1975)

A nonlinear theory of kinetic instability of collisionless plasma in a self-consistent magnetic field with a neutral layer is investigated. The case of a diffusive neutral layer is considered. A linear theory is developed for an arbitrary angle of propagation of growing perturbations, and quasilinear relaxation effects in the plasma distribution accompanying the instability development are discussed. A nonlinear mechanism leading to the suppression of instability is discussed in general terms. The results can be used to estimate the dissipation of the energy of the magnetic field in the model of a neutral layer discussed in this paper.

PACS numbers: 52.35.E

Ames Research Center

RECONNECTION IN THE MAGNETOTAIL*

A. A. GALEEV

Academy of Sciences of the U.S.S.R. Space Research Institute, Moscow, U.S.S.R.

1979

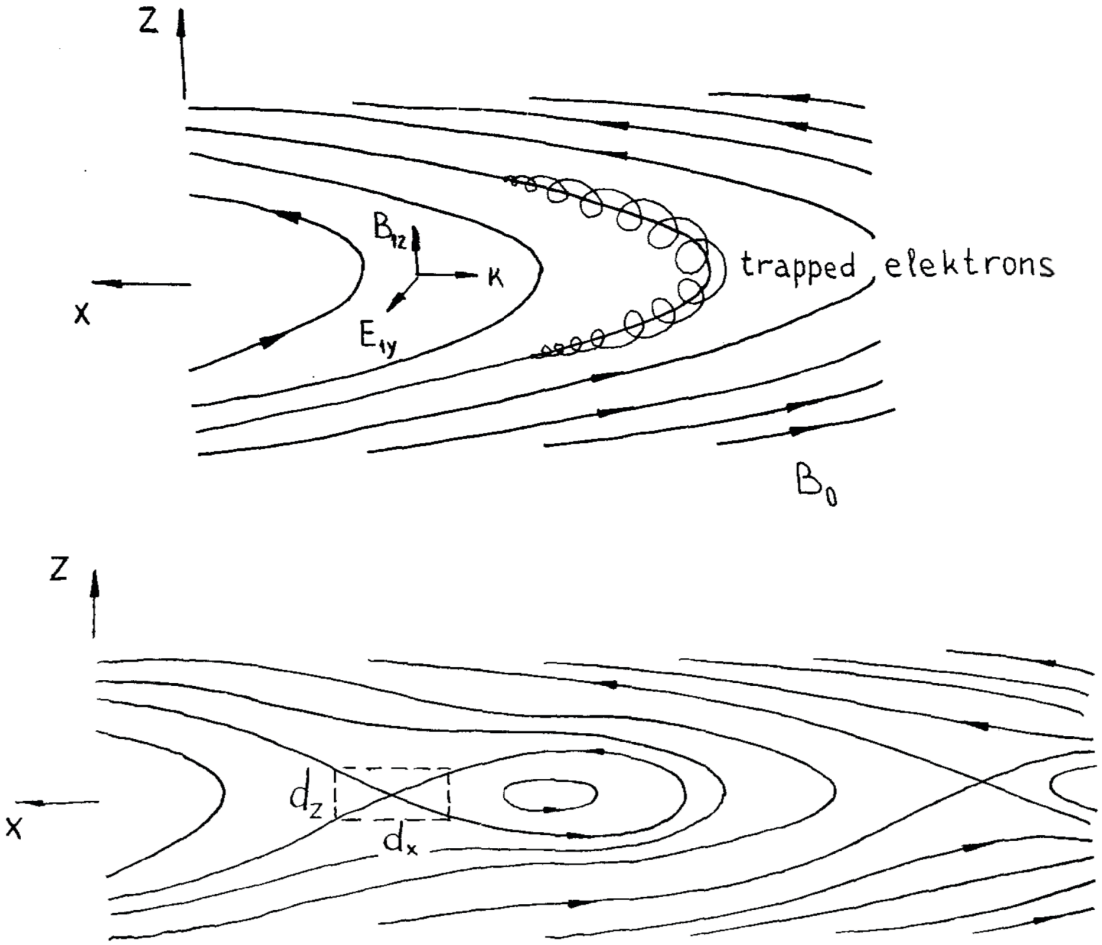
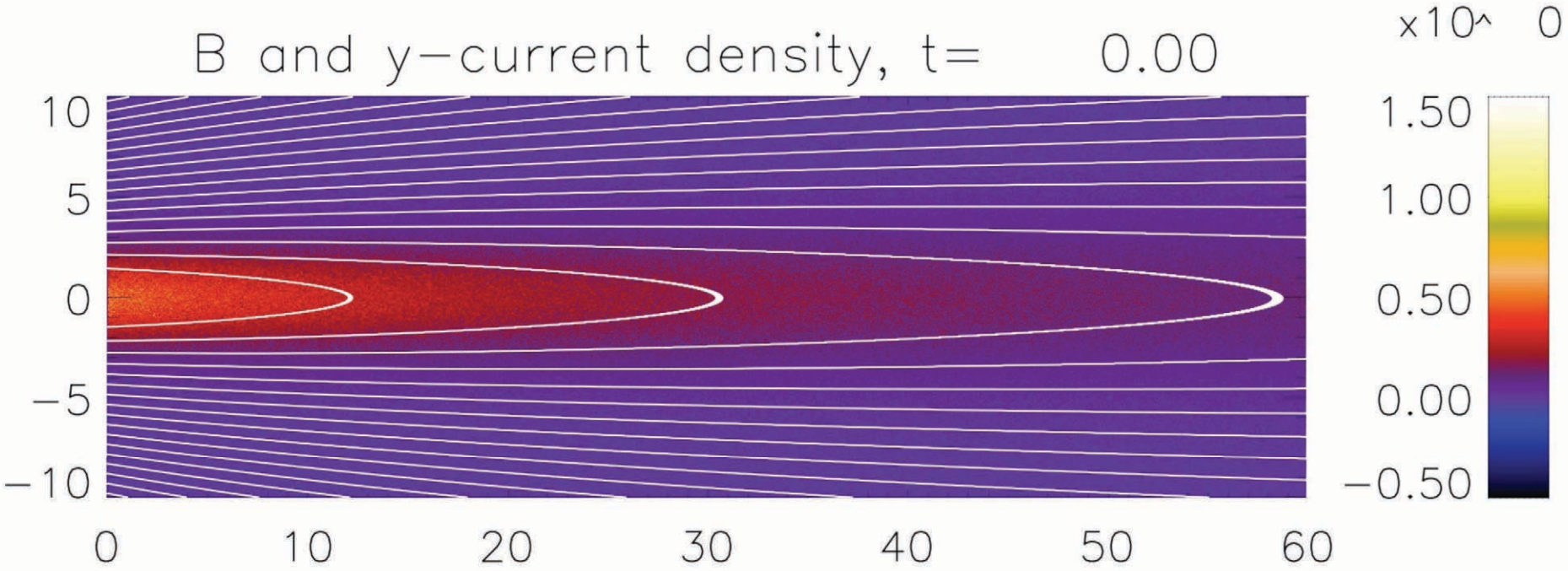


Fig. 4. Magnetic field model for the magnetotail with the superimposed tearing mode magnetic field.

Ames Research Center

Potsdam 1988

Tearing lives!



Hesse et al., 2001

Ames Research Center

Happy 55th Birthday

..to a world-leading research institution!

Ames Research Center

SUMMARY

- Earth's magnetosphere is a rich laboratory for the exploration of basic physical processes
- Magnetospheric structure and dynamics involves complex coupling processes between regions of different physics parameter regimes
- Magnetic reconnection is a key process facilitating magnetospheric dynamics
- Understanding how magnetic reconnection relates to the larger-scale environment is on of the most rewarding research topics in space physics
- Academician Galeev's work is fundamental to our understanding of magnetic reconnection, and his "offspring" continues to shape our research field