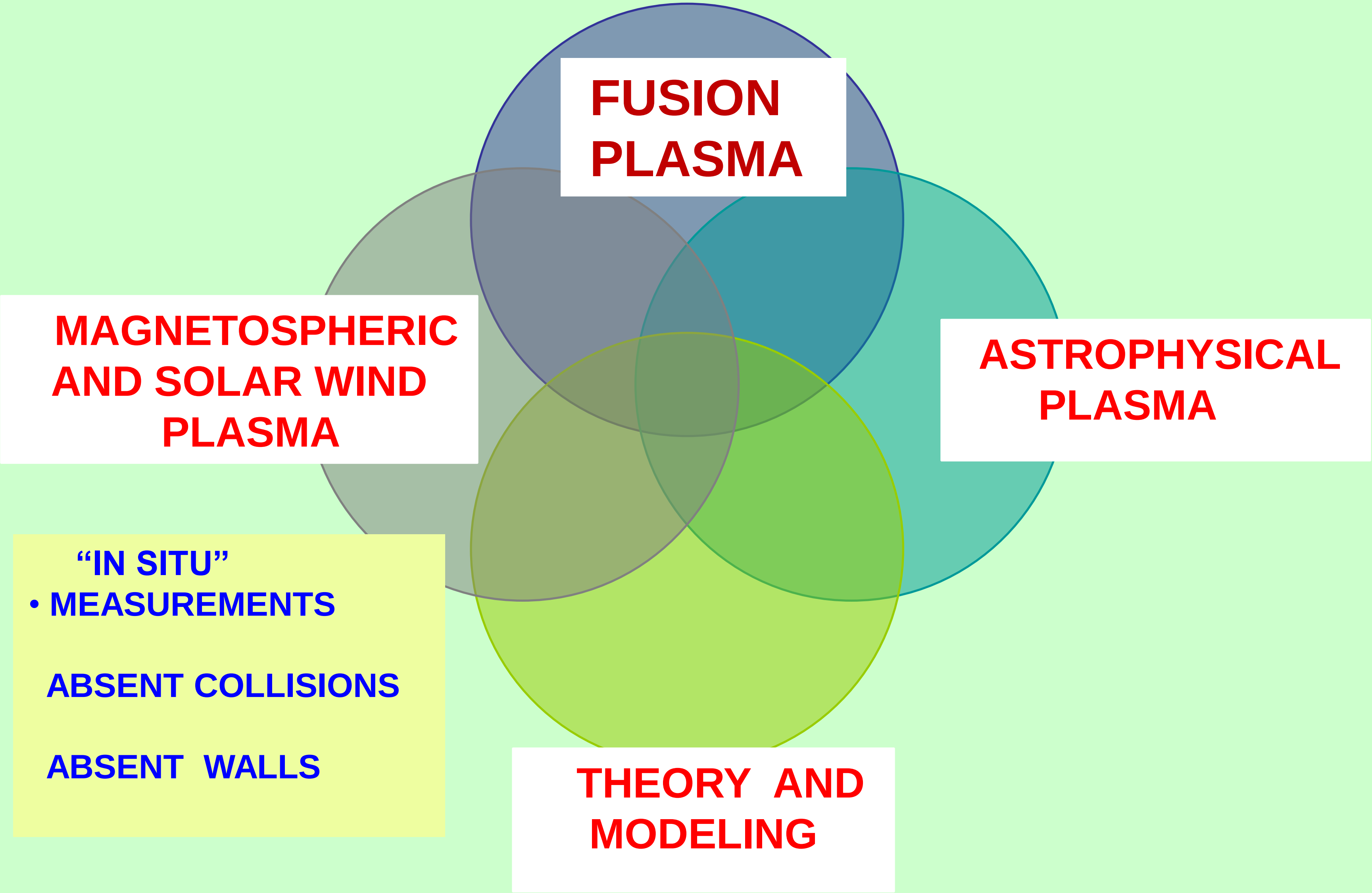
Plasmas in Astrophysics and in the Laboratory:



FUSION PLASMA

MAGNETOSPHERIC AND SOLAR WIND PLASMA

ASTROPHYSICAL PLASMA

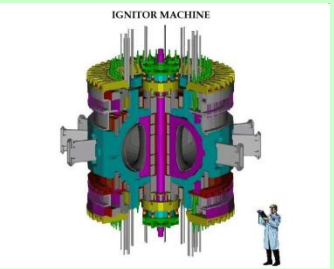
THEORY AND MODELING

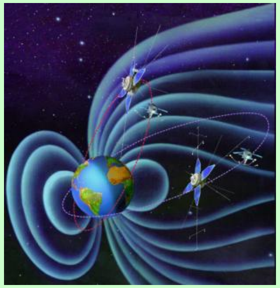
“IN SITU”
- MEASUREMENTS

ABSENT COLLISIONS

ABSENT WALLS

Plasmas in Astrophysics and in the Laboratory:I





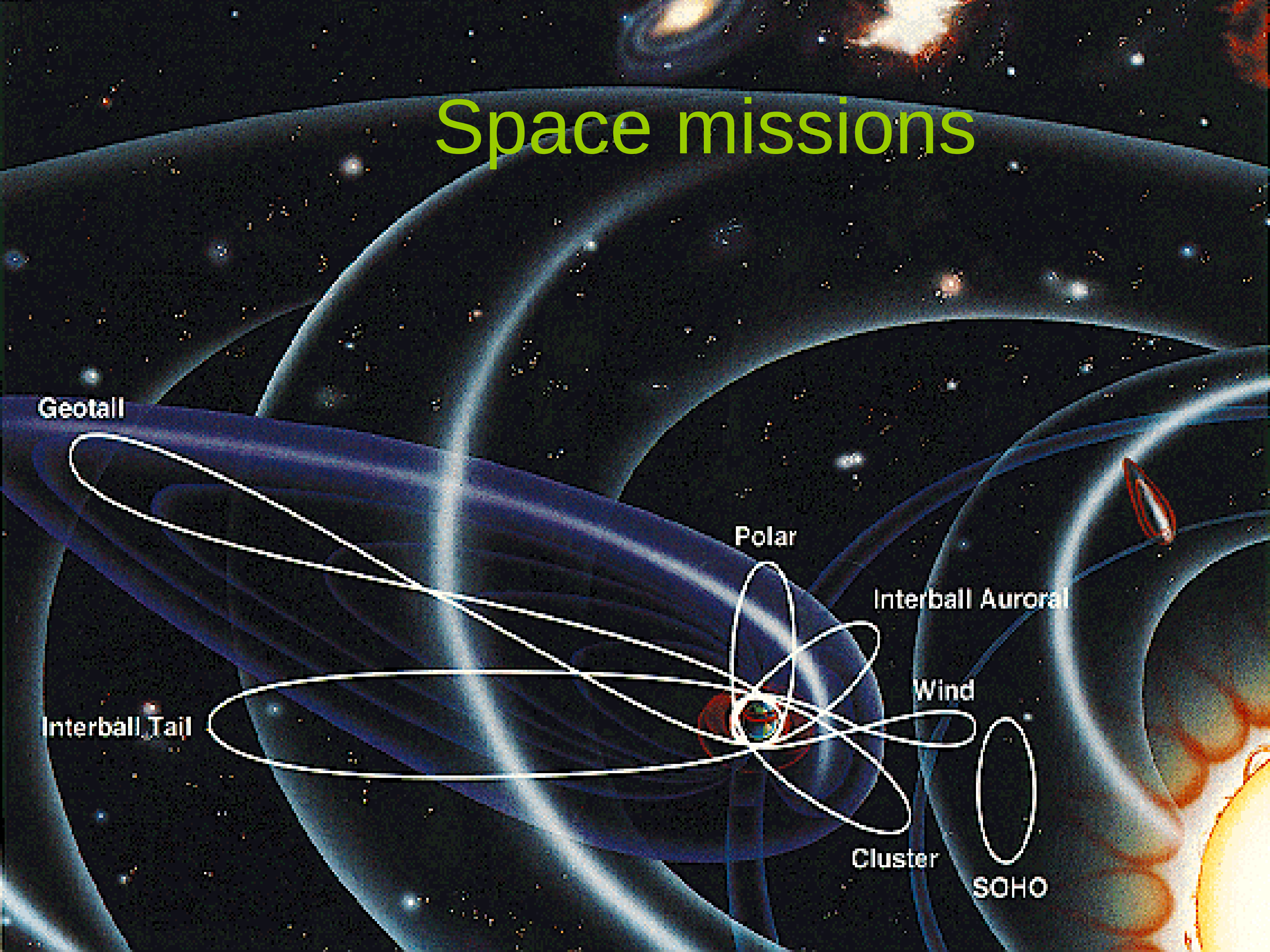
CURRENT SHEETS

LESSONS LEARNED FROM "IN SITU" MEASUREMENTS

LEV ZELENYI

Space Research Institute RAS

Space missions

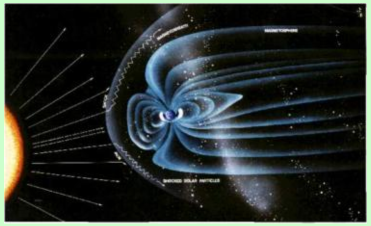


WHAT WE HAVE LEARNED FROM THE MAGNETOSPHERE ?

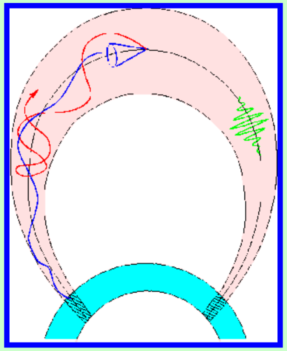
Charles F. KENNEL

SSB CHAIR

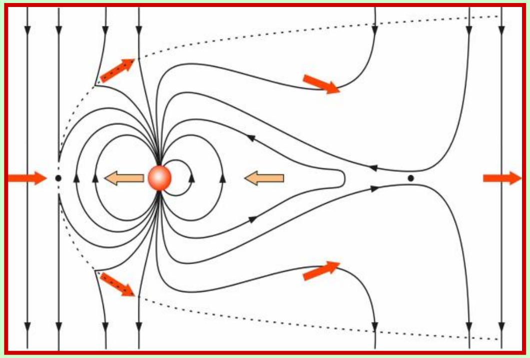
- **COLLISIONLESS SHOCKS**



- **WAVE-PARTICLE INTERACTIONS IN RAD.BELTS & PLASMASPHERE**



- **RECONNECTION**



Solar plasma

- 1946 - R.Giovanelli, A theory of chromospheric flares, Nature, 1946

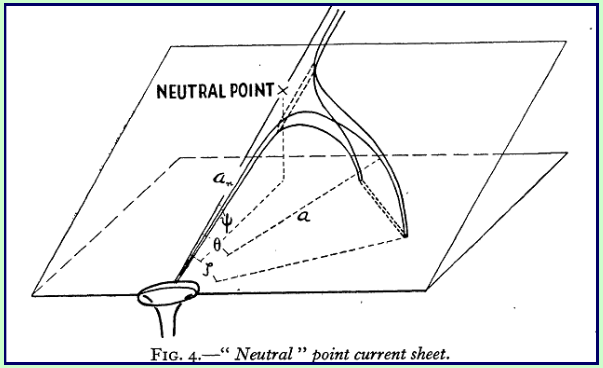
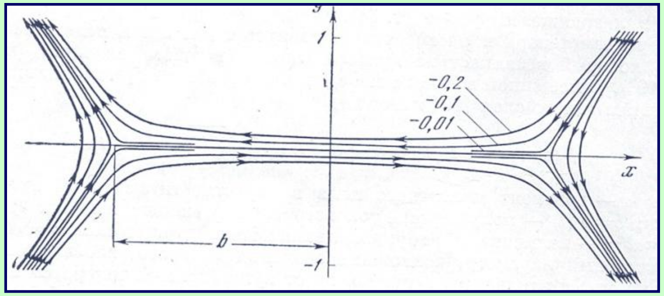
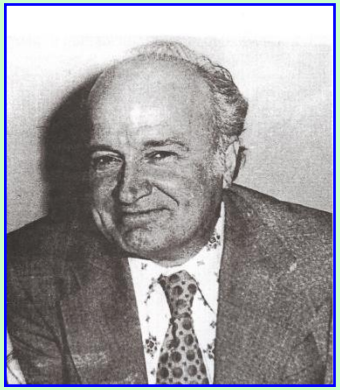


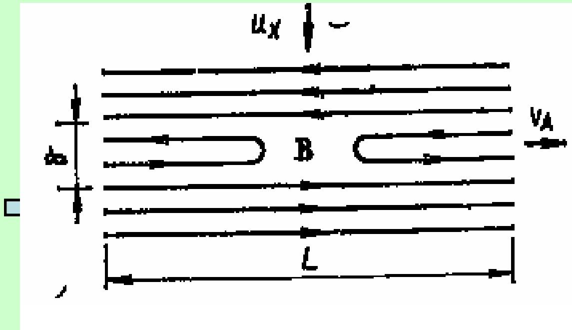
FIG. 4.—" Neutral " point current sheet.

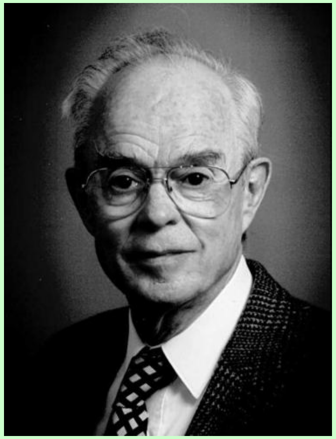
- 1956-– S.Syrovatsky, MHD theory of thin current sheets in Solar corona





1957 – E. Parker, Sweet's mechanism for merging magnetic fields in conducting fluids, 1957

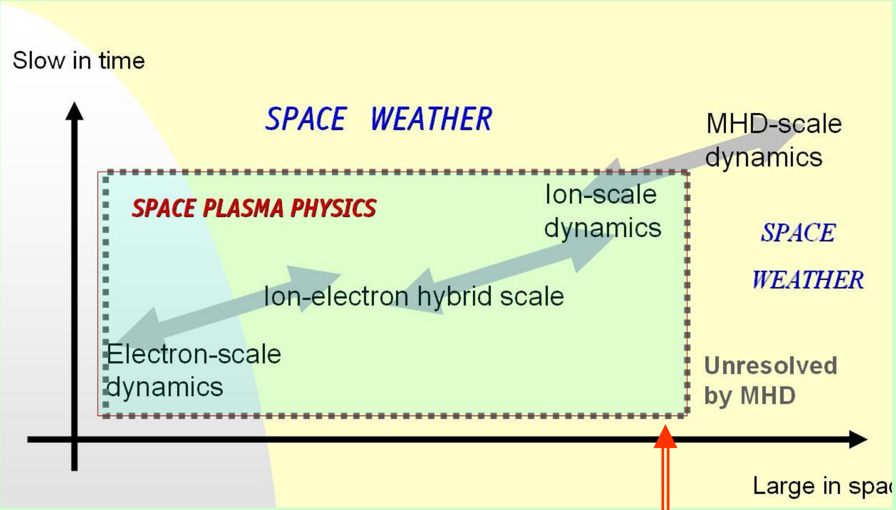




1958 – P. Sweet, The neutral point theory of solar flares,

MHD & KINETIC RECONNECTION

MHD _PETSCHEK



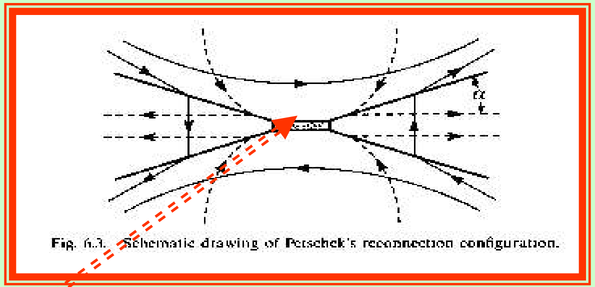
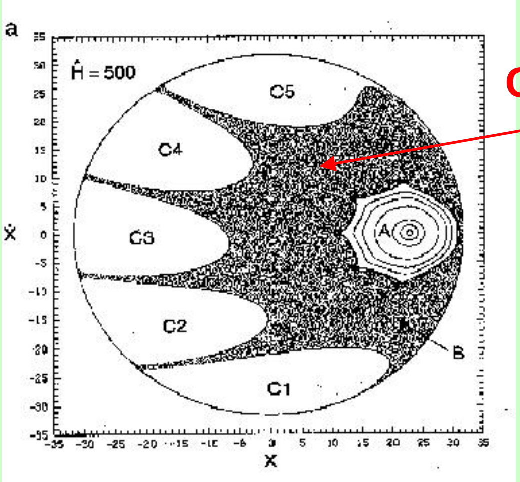


Fig. 6.3. Schematic drawing of Petschek's reconnection configuration.

R_{Li}~ 6-7 Re

EQUATIONS OF PARTICLE MOTION ARE NON-INTEGRABLE EVEN IN A SIMPLEST TAIL-LIKE GEOMETRIES AND PARTICLE DYNAMICS IS GENERALLY CHAOTIC !



CHAOS

Chen. Palmadesso. 86

IMPORTANCE OF HALL EFFECT !!!

What we have learned else ??

after 9 ICS conferences, tens Chapman conferences, thousands of meetings (AGU, EGU, COSPAR, IAGA…………..)

*Electrostatic solitary waves

** Nonadiabatic resonant beamlets

Speiser orbits

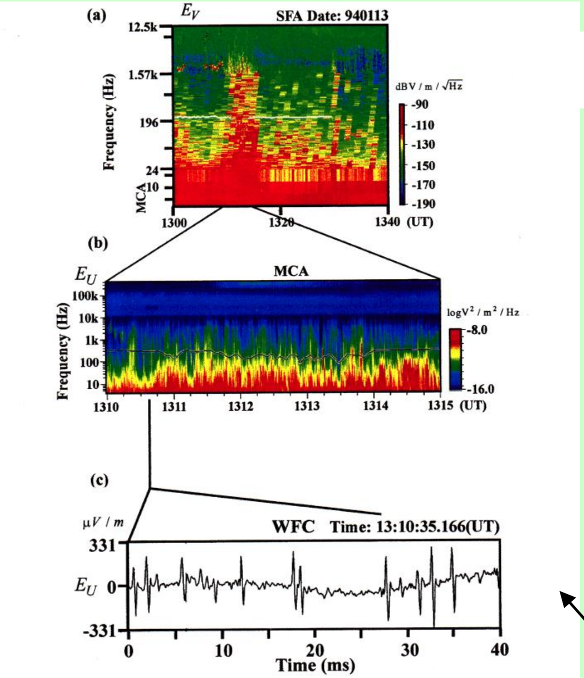
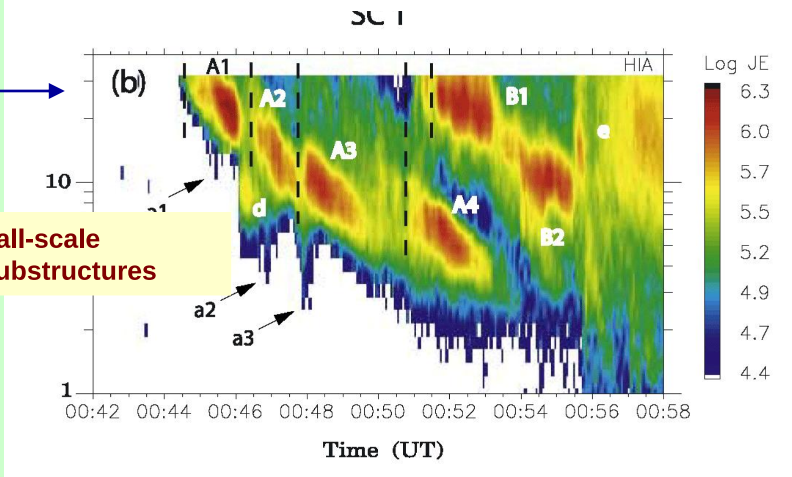


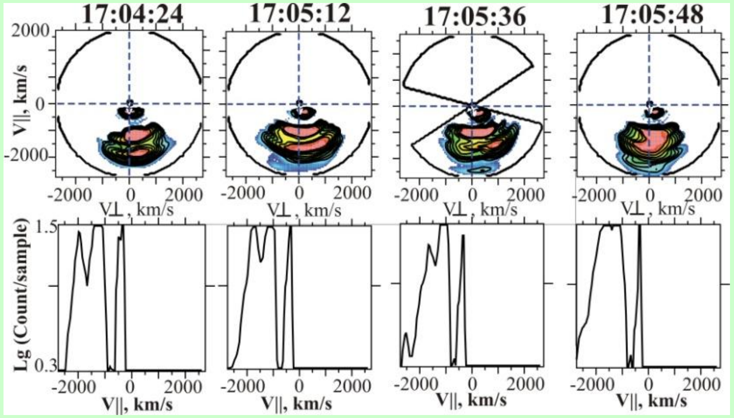
Plate 2. Frequency-time spectrograms for (a) SFA and (b) MCA and (c) waveform of the broadband electrostatic noise (BEN) observed in the plasma sheet boundary layer (PSBL) on January 13, 1994. The isolated bipolar waveforms of the BEN are initially reported by *Matsumoto et al.* [1994b]. They are termed after their waveforms as electrostatic solitary waves (ESW).

CLUSTER

PSBL



Small-scale
ion substructures



GEOTAIL

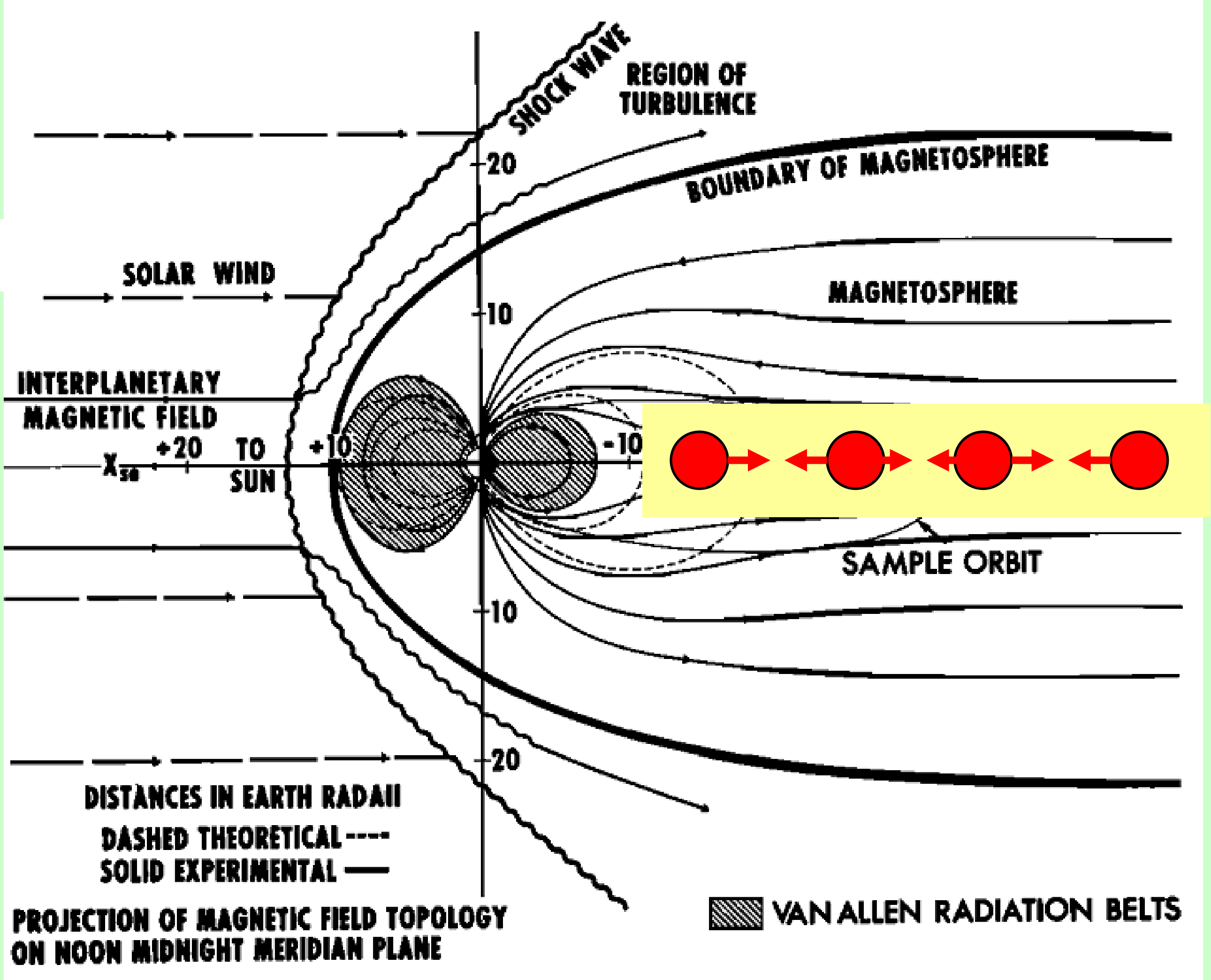
Earth Current sheet

Norman F. Ness

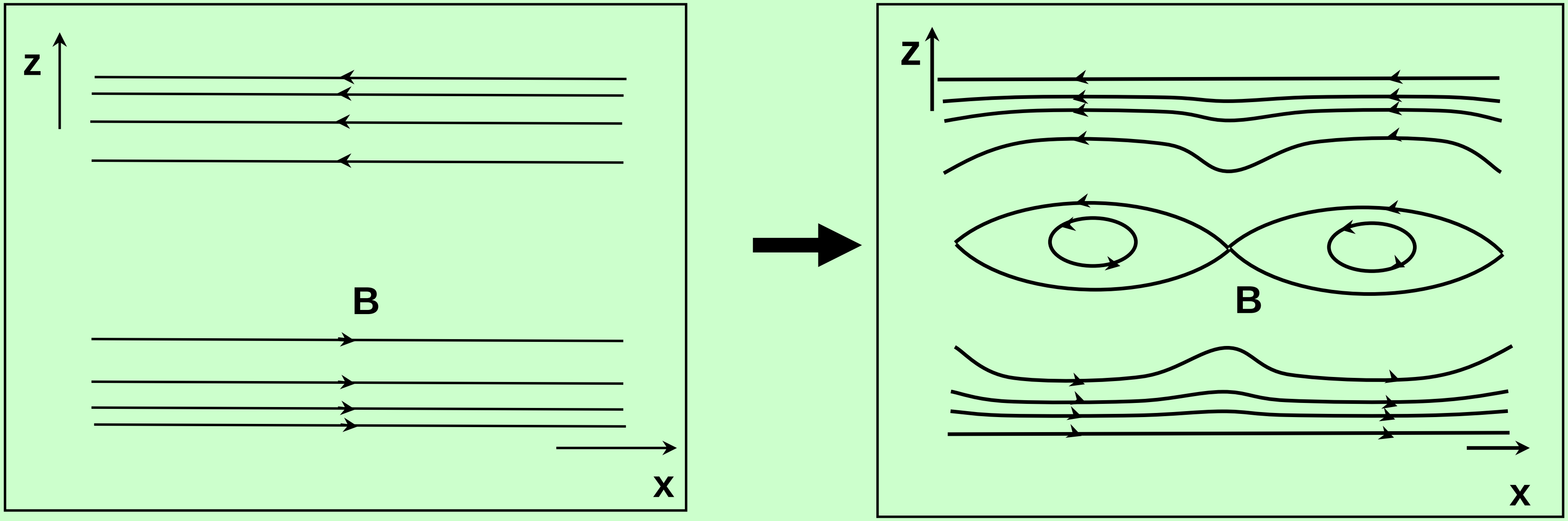
The Earth's Magnetic Tail[1]

Norman F. Ness

1965



SPONTANEOUS RECONNECTION IN COLLISIONLESS PLASMA



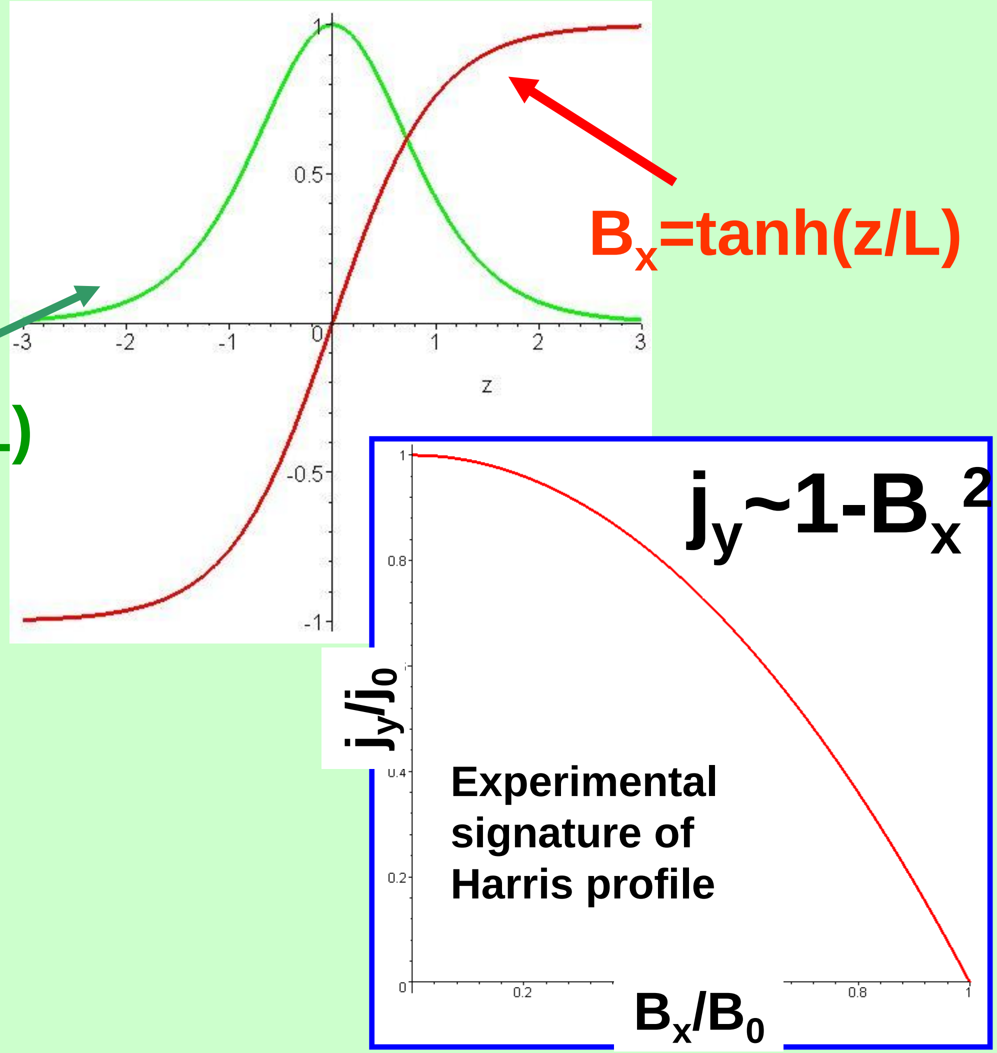
Spontaneous Reconnection == TEARING MODE

Harris model

On a plasma sheath separating regions of oppositely directed magnetic fields.

Harris E.G., Nuovo Chimento, 23, 115–119, 1962

MATHEMATICALLY ELEGANT SIMPLE 1D KINETIC MODEL
Erroneously used
by everybody
and everywhere



B_x=tanh(z/L)

j_y~n~$\cosh^{-2}$(z/L)

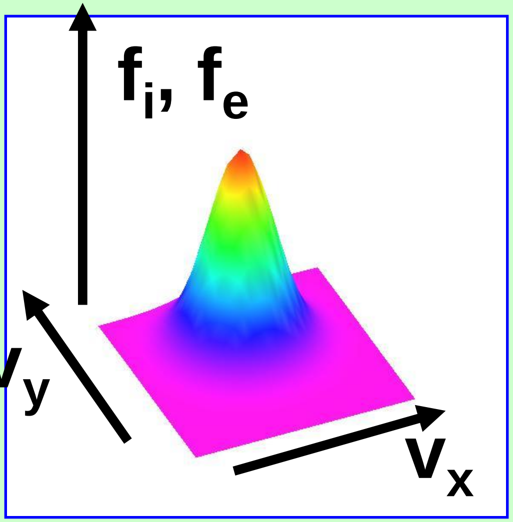
j_y~1-B_x^2

j_y/j_0

B_x/B_0

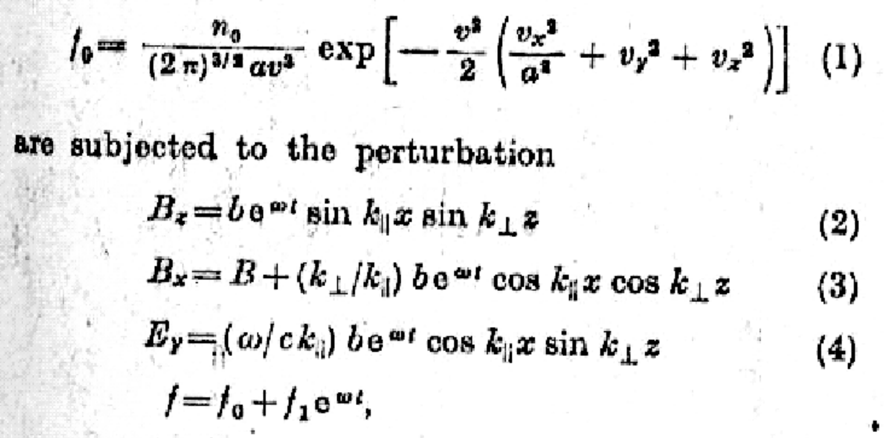
Experimental signature of Harris profile

Shifted maxwellians



First steps in theory of CS stability.

The “Mirror Instability” for finite particle gyro-radius.
Harold P. Furth, Nuclear Fusion, 1962



$$f_0 = \frac{n_0}{(2\pi)^{3/2} a v^3} \exp\left[-\frac{v^2}{2}\left(\frac{v_x^2}{a^2} + v_y^2 + v_z^2\right)\right] \quad (1)$$

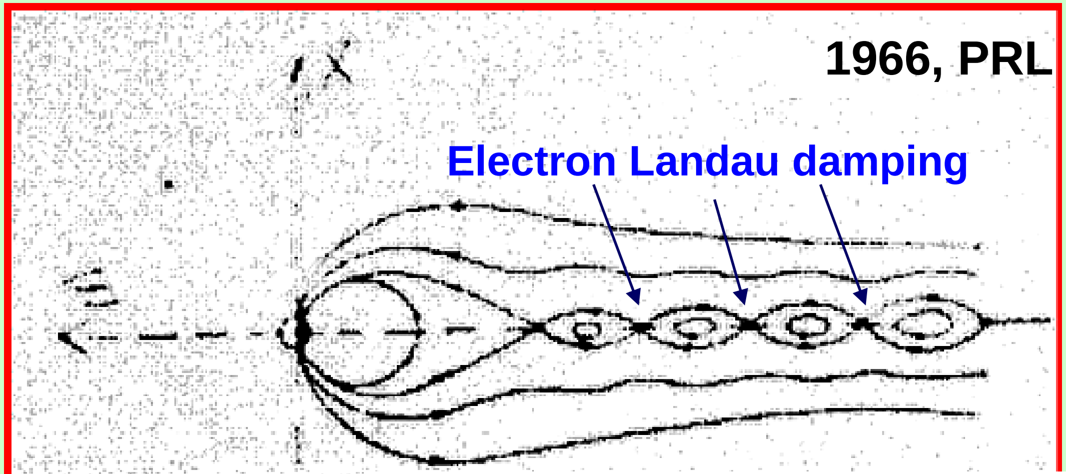
are subjected to the perturbation

$$B_z = b e^{\omega t} \sin k_\parallel x \sin k_\perp z \quad (2)$$

$$B_x = B + (k_\perp / k_\parallel)\, b e^{\omega t} \cos k_\parallel x \cos k_\perp z \quad (3)$$

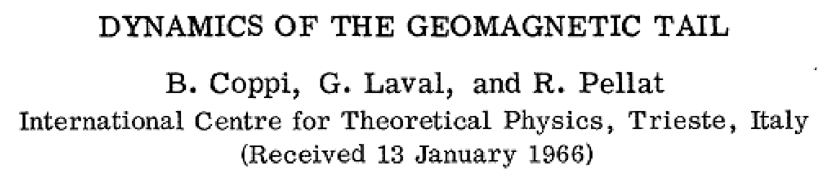
$$E_y = (\omega / c k_\parallel)\, b e^{\omega t} \cos k_\parallel x \sin k_\perp z \quad (4)$$

$$f = f_0 + f_1 e^{\omega t},$$



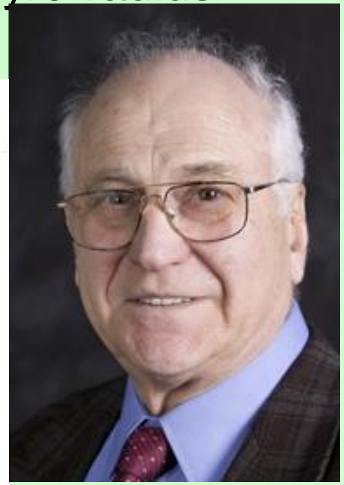
1966, PRL

Electron Landau damping



DYNAMICS OF THE GEOMAGNETIC TAIL

B. Coppi, G. Laval, and R. Pellat
International Centre for Theoretical Physics, Trieste, Italy
(Received 13 January 1966)



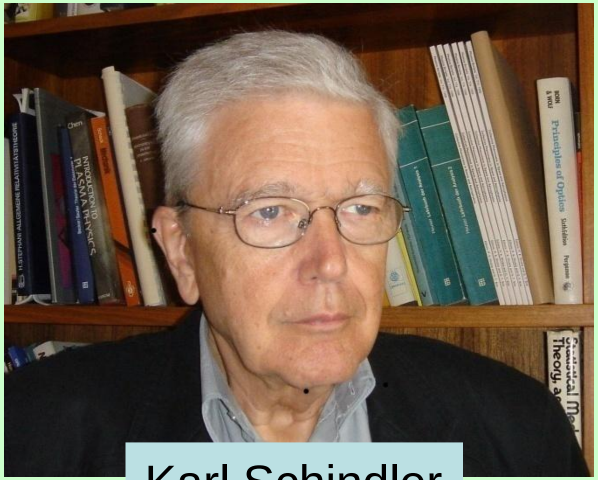
Bruno Coppi

Guy LavaL

Rene Pellat

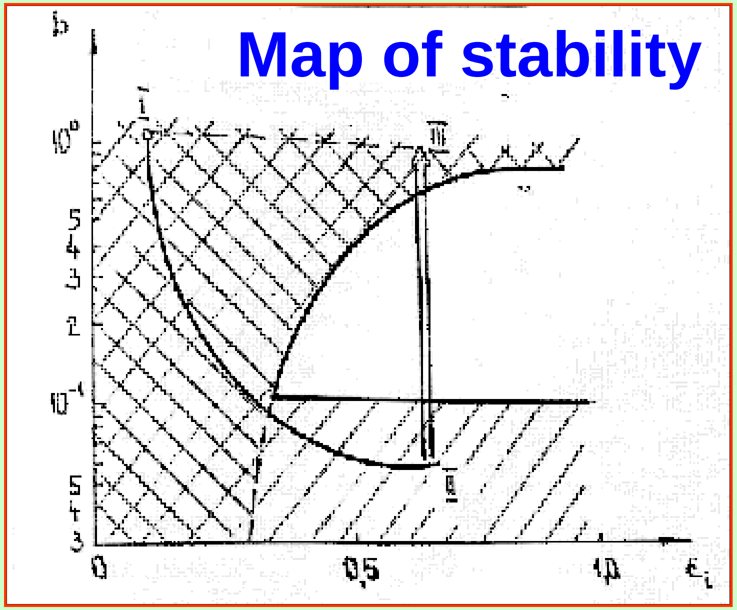
Bz - destruction of electron Landau damping.

Electron stabilization.



Karl Schindler

ION MODE


Map of stability

A Theory of the Substorm Mechanism

K. SCHINDLER

1974, JGR

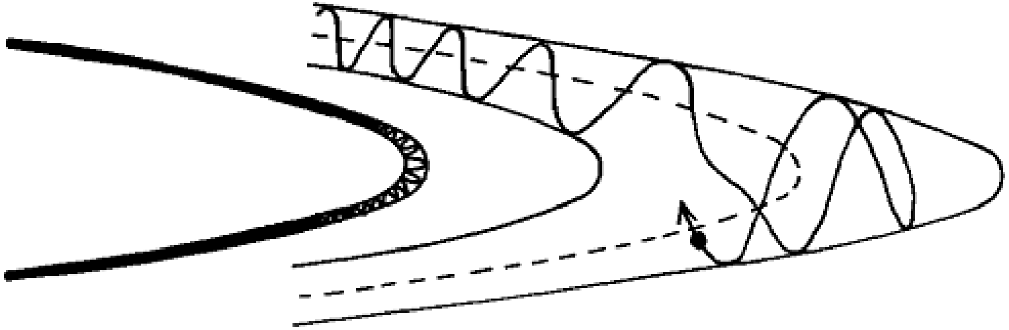


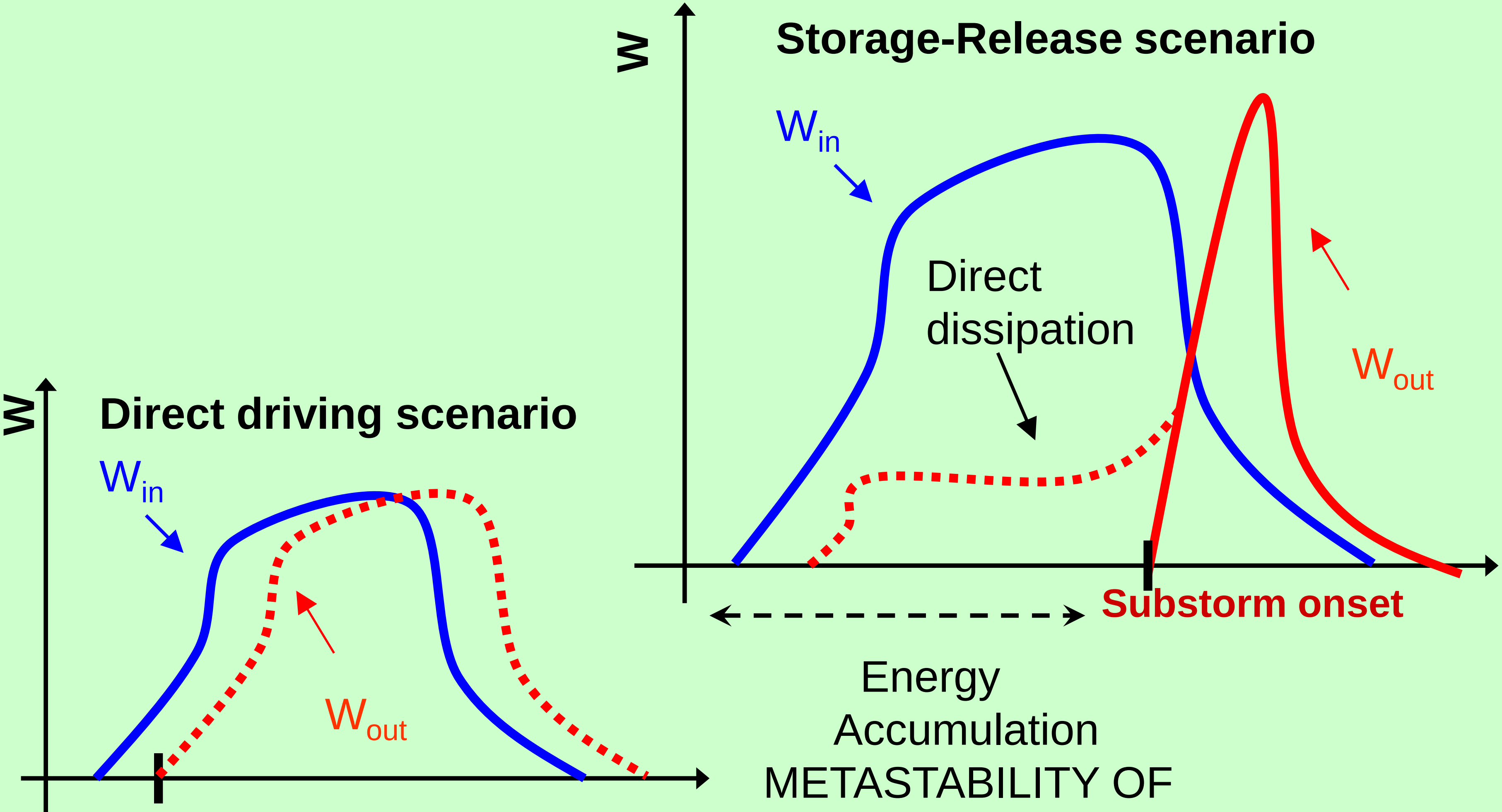
Fig. 4. Regime of ion tearing: the electrons are gyroscopic, and the ions see a neutral sheet. The ion motion perpendicular to the plane shown is unidirectional on either side of the broken line.

Tearing instability in plasma configurations

Galeev, A. A., Zelenyi, L. M. JETP, 1976

Albert Galeev

Two scenarios of magnetospheric activity



Substorm onset

Energy Accumulation

METASTABILITY OF MAGNETOTAIL CONFIGURATION

SPONTANEOUS RECONNECTION::

- CHANGE OF MAGNETIC TOPOLOGY **(Formation of X/O lines)**

  Non trivial problem in collisionless plasma

  (only LANDAU damping)

- **Observational constraints:**

  possibility to accumulate magnetic flux –

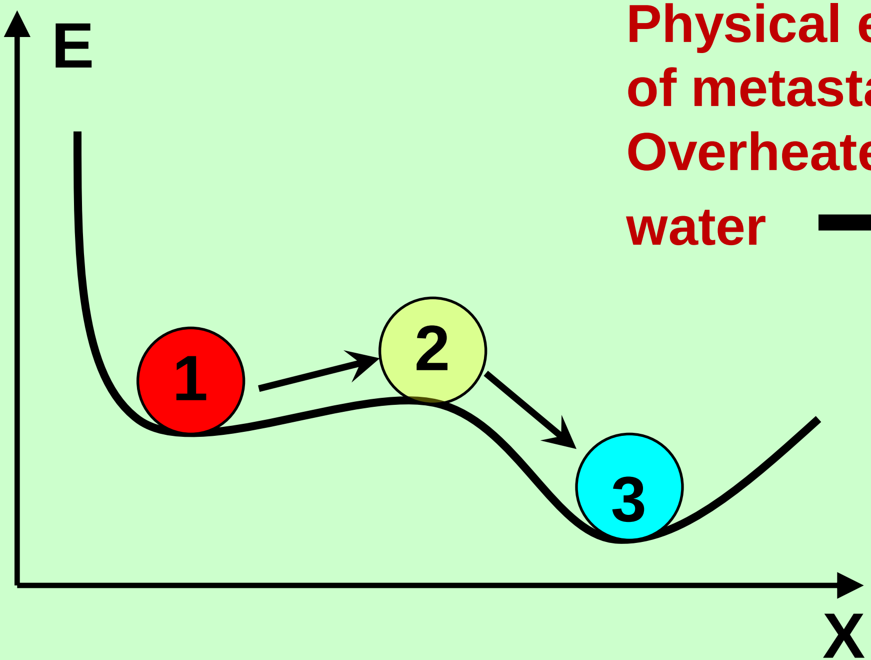
  possibility quickly release stored energy—

- **METASTABILITY**

  - **HARRIS SHEET PARADIGMA- OVERSTABILITY**
  - **Realistic models of CS – anisotropy , bifurcations , steepening**
  - **Stability properties of anisotropic CS- and their free energy reservoirs**
  - **Overlapping of tearing/kink/sausage modes**
  - **ACCELERATION**

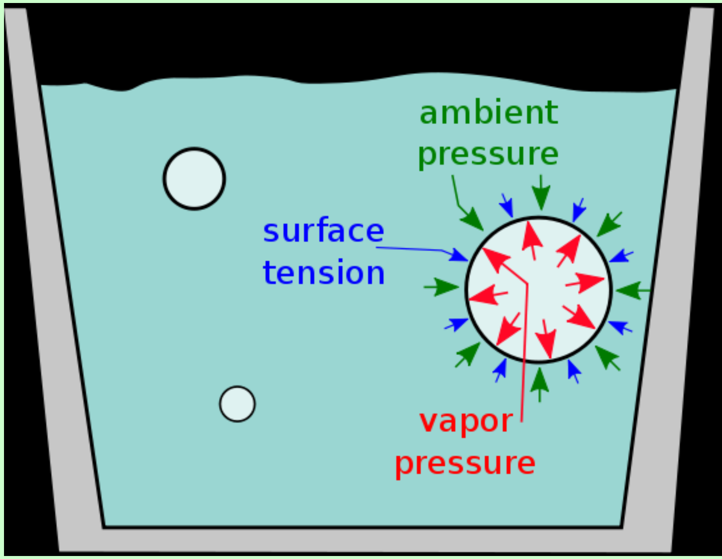
Metastability

Metastability is a general scientific concept which describes states of delicate equilibrium. A system is in a metastable state when it is in equilibrium (not changing with time) but is susceptible to fall into lower-energy states with only slight interaction.



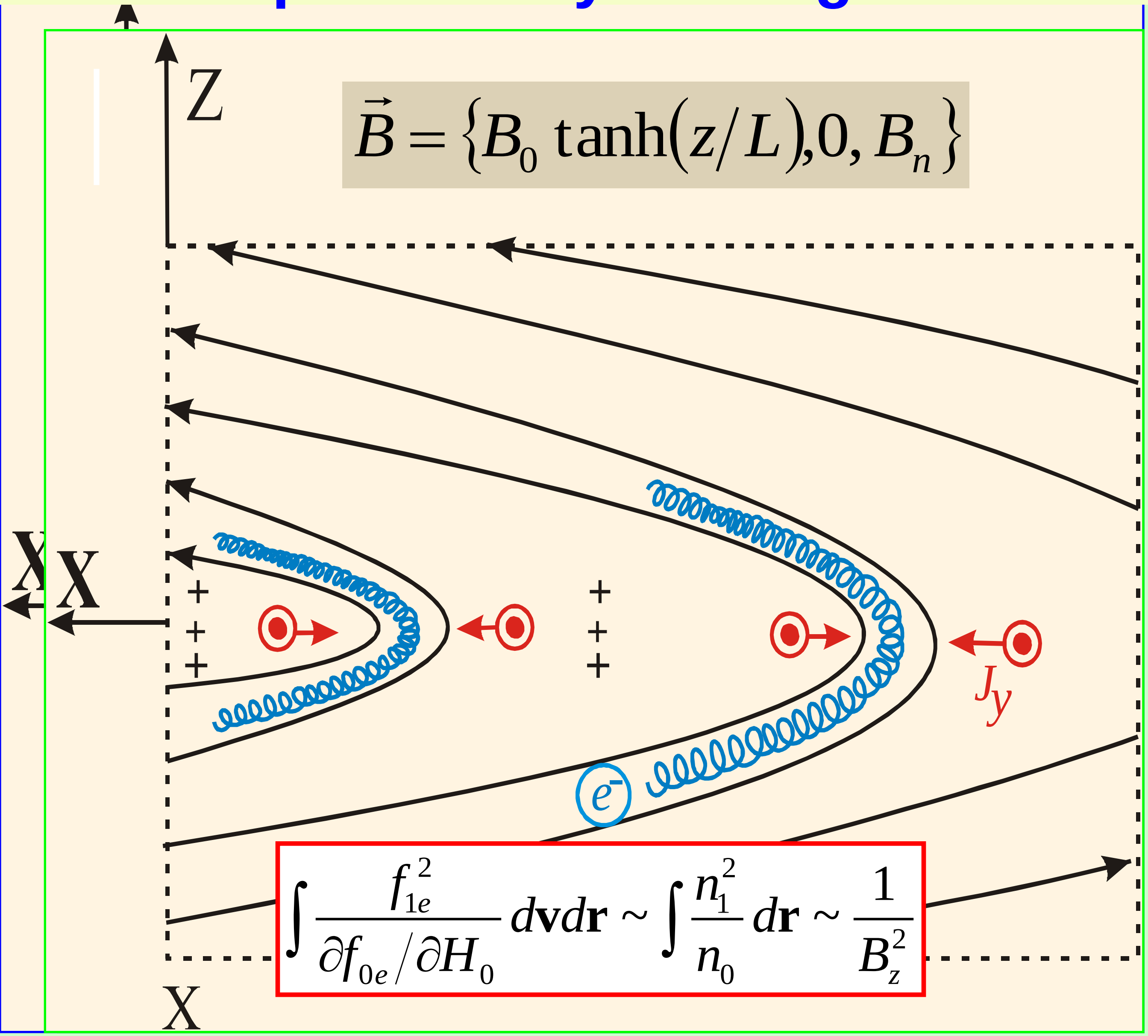
A metastable system with a weakly stable state (1), an unstable transition state (2) and a strongly stable state (3)

Physical example of metastability Overheated clean water



In order for boiling to occur, the vapor pressure must exceed the ambient pressure plus a small amount of pressure induced by the surface tension

Stabilization of **ion tearing** mode by the compressibility of magnetized electron

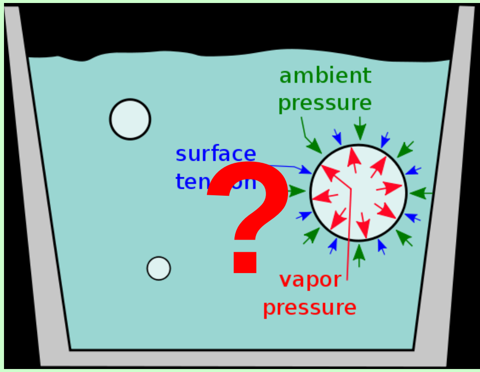


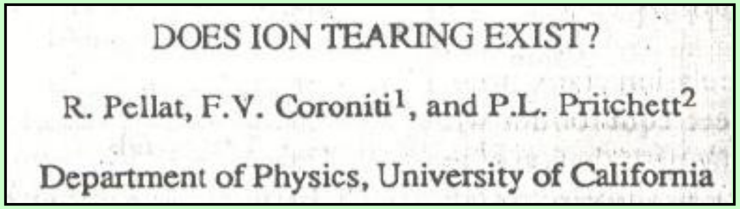
$$\vec{B} = \{B_0 \tanh(z/L), 0, B_n\}$$

$$\int \frac{f_{1e}^2}{\partial f_{0e}/\partial H_0} d\mathbf{v} d\mathbf{r} \sim \int \frac{n_1^2}{n_0} d\mathbf{r} \sim \frac{1}{B_z^2}$$

ABSOLUTE STABILITY OF HARRIS TYPE FIELD REVERSAL with $|B_z| > 0$

B_z effects =
OVERSTABILITY
for HARRIS model



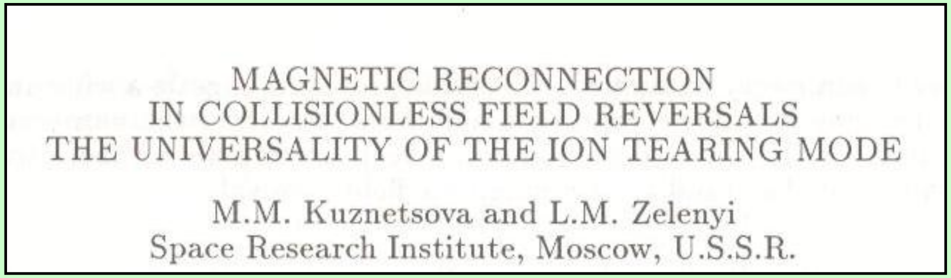


DOES ION TEARING EXIST?

R. Pellat, F.V. Coroniti[1], and P.L. Pritchett[2]

Department of Physics, University of California

In conclusion, neither pitch-angle diffusion nor stochastic orbit diffusion removes the stabilizing effect of electron compressibility. Cross-field spatial diffusion can result in an unstable electron tearing mode, but to reach the ion tearing regime requires diffusion rates which are inconsistent with the initial assumed equilibrium. Thus, within our present state of knowledge, there is no parameter space for an ion tearing mode.



MAGNETIC RECONNECTION
IN COLLISIONLESS FIELD REVERSALS
THE UNIVERSALITY OF THE ION TEARING MODE

M.M. Kuznetsova and L.M. Zelenyi
Space Research Institute, Moscow, U.S.S.R.

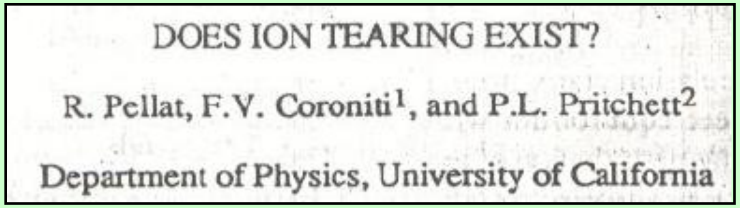
Concluding this paper we would like to summarize all possible mechanism of the destabilization of the tearing mode (spontaneous reconnection) which exists according to our present understanding of the problem:

1) Pitch angle diffusion (external or intrinsic), studied in this paper.
2) Magnetic shear (By field).
3) Collisions even very weak
4) Violation of the WKB approach for long-wavelength perturbations (kL<Bz/B0).

DEAD END !

For HARRIS CS MODEL

INTENSE DISPUTES OF 1990-ies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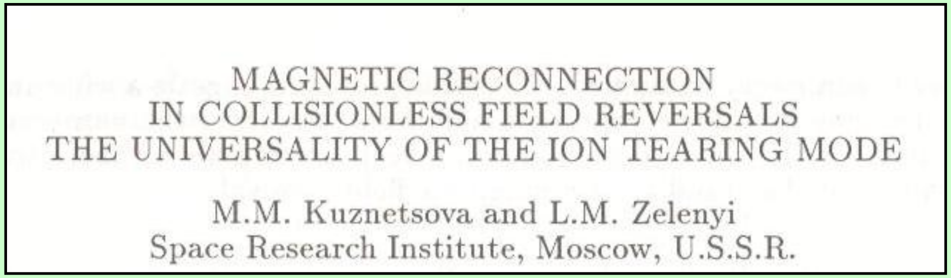
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4) Violation of the WKB approach for long-wavelength perturbations (kL<Bz/B0).

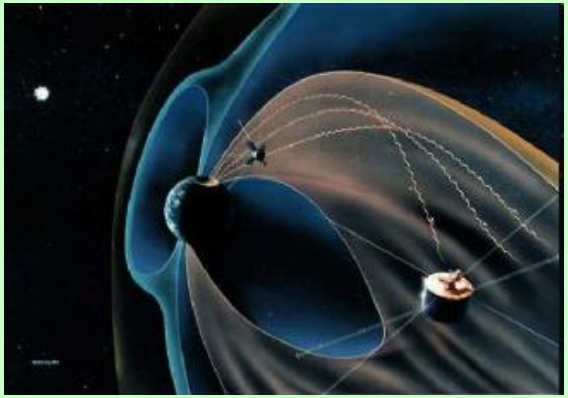
DEAD END !

For HARRIS CS MODEL

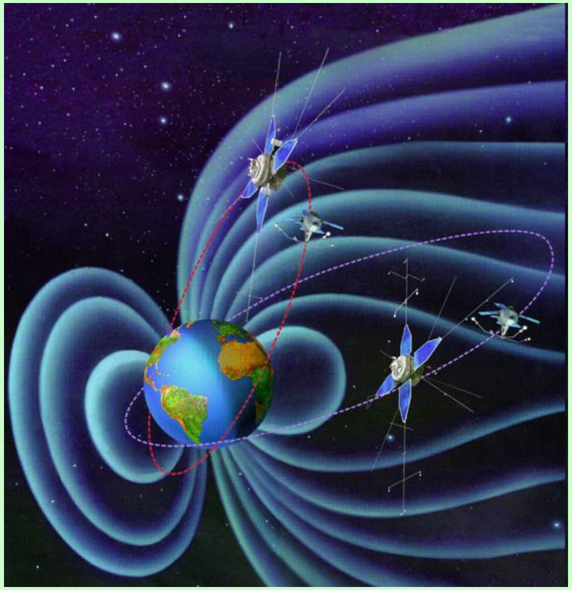
It is necessary to develop a <u>new model</u> of realistic current sheet compatible with 4-point CLUSTER observations of real current profiles and recalculate its stability properties

MULTIPOINT spacecraft observations of magnetotail processes

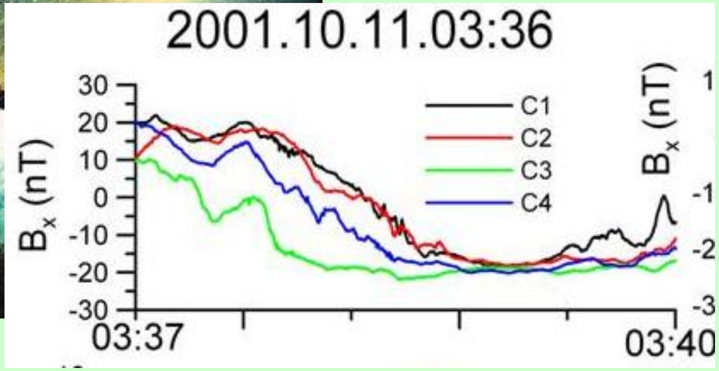
Geotail (1)



Interball (2+2)



Cluster (4) + Double Star (2)



THEMIS(5)

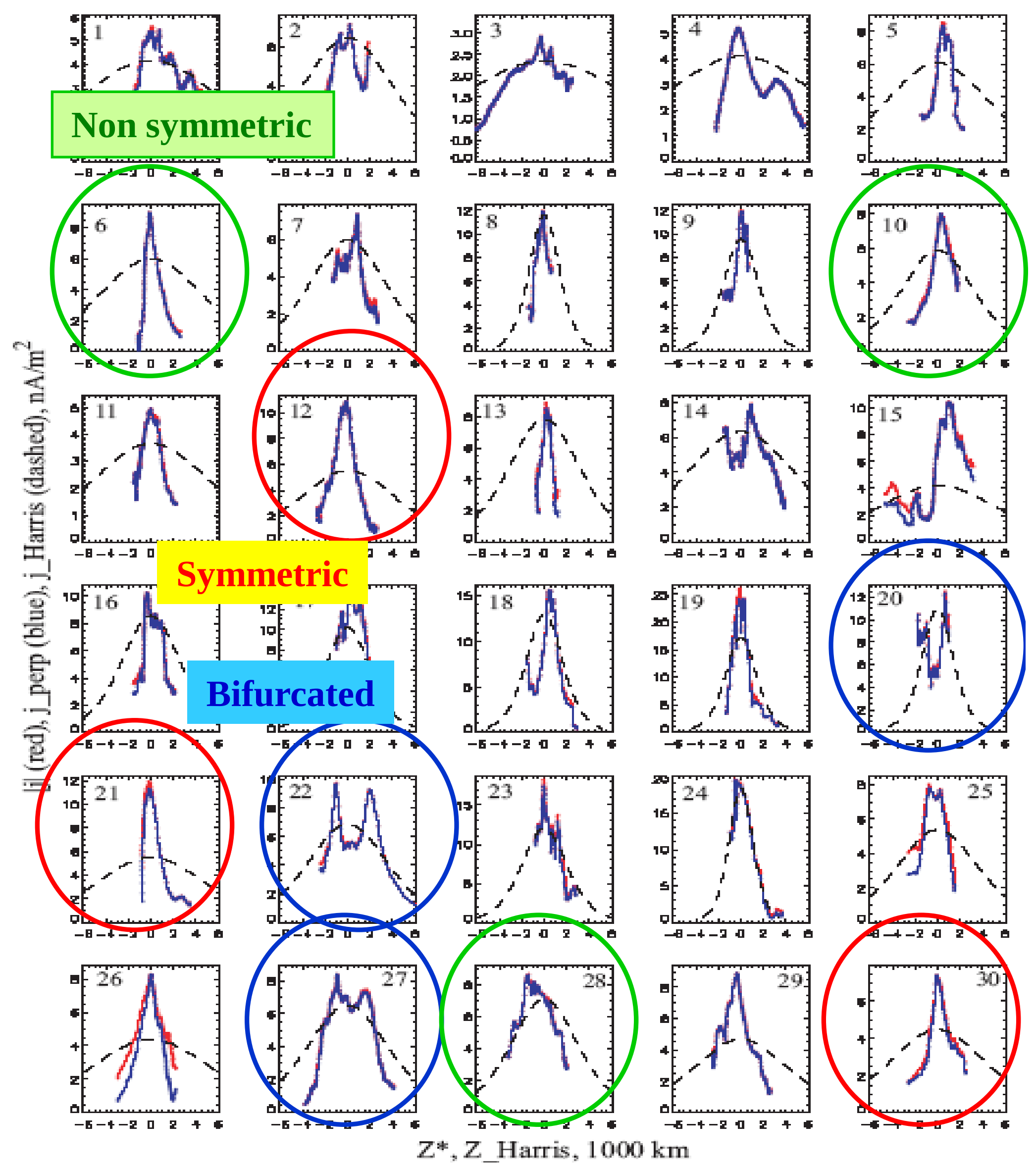
CLUSTER

CS OBSERVATIONS

Runov et al., 2006 collection

Nakamura et al., 2006

Super thin (<1000km) current sheet predicted by Syrovatsky

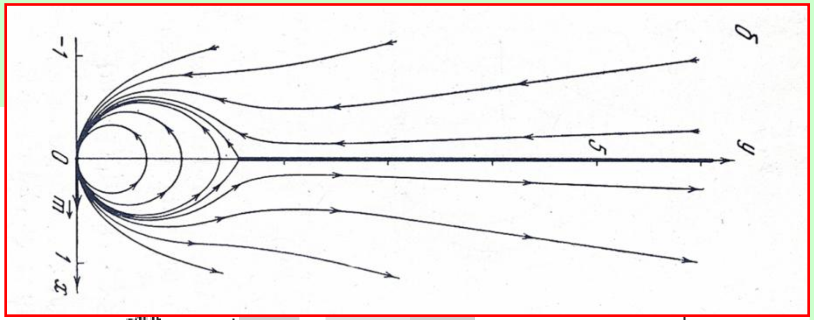


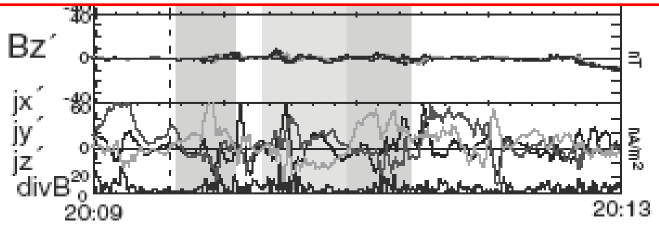
Non symmetric

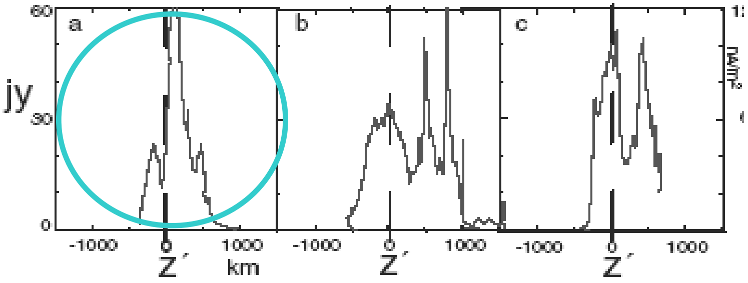
Symmetric

Bifurcated

Profiles of absolute values of the current densities j (blue) and $j_\perp$ (red) versus the effective vertical coordinate Z^*, calcula
Dashed lines show the corresponding Harris profiles.



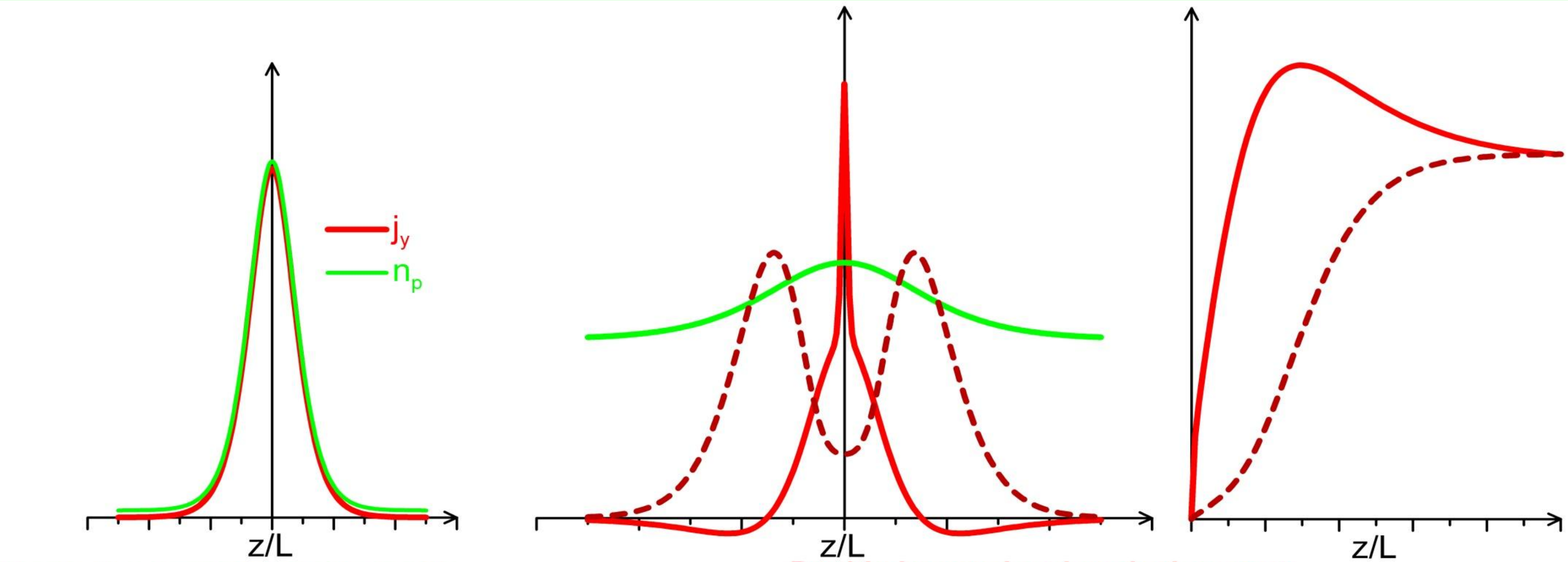




Nakamura et.al. SSR, 2006

Thin current sheets

ROLE OF ANISOTROPY



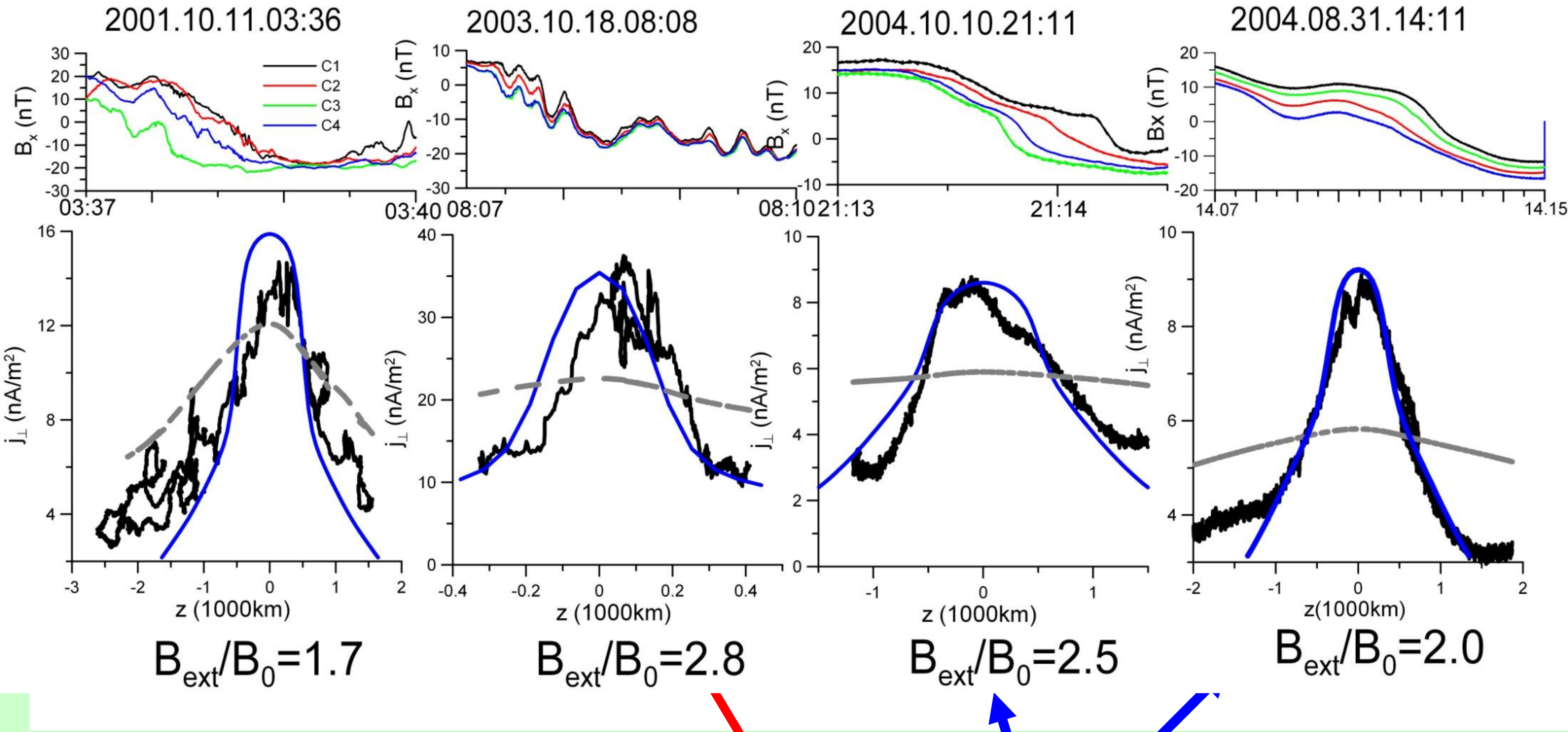
Harris-like current density profile coincides with plasma density profile

Double-humped and peaked current sheets are embedded inside plasma sheet

Realistic features of TCS: embedding, bifurcation,
overshoots, steepening

Fast CS crossing and the model of thin current sheet

Observations approximated by Thin CS model and Harris CS



Artemyev et al. 2008

Difference between experimental N_p, T_p, B_L and TCS model parameters <30%

Spatial scale ~ 200 km

Spatial scale < 1000 km

Energy principle for tearing mode.

Marginal stability.

$$\int_{-\infty}^{\infty}\frac{\vec B_1^2+\vec E_1^2}{8\pi}d\tau=-\int_{-\infty}^{\infty}\left(\vec j_1\vec E_1\right)d\tau$$

$$f_j=\frac{\partial f_{0j}}{\partial A_0}A_1+\tilde f_{1j}$$

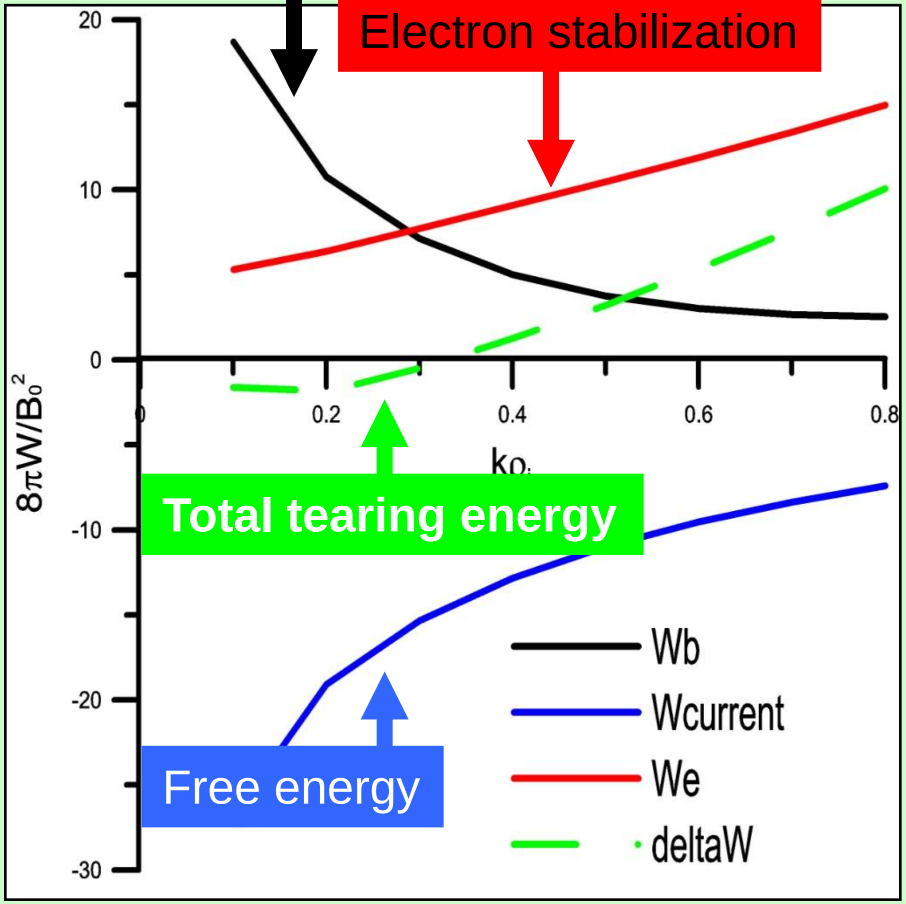
$$\overbrace{W_{tearing}}^{\text{deltaW}}=\int_{-\infty}^{\infty}\left\{\overbrace{\left|\nabla\times A_1\right|^2+\left|\nabla\varphi_1\right|^2}^{\text{Wb}}+\overbrace{\frac{4\pi}{c}\frac{\partial j_y}{\partial A_0}\left|A_1\right|^2}^{W_{\text{current}}\text{ = free energy}}+\overbrace{4\pi e\int_{-\infty}^{\infty}\frac{\tilde f_{1e}^{\,2}}{\partial\tilde f_{0e}/\partial\varphi_0}d\vec v}^{\text{We}}\right\}$$

$$\frac{1}{2}e\int_{-\infty}^{\infty}\frac{\tilde f_{1e}^{\,2}}{\partial\tilde f_{0e}/\partial\varphi_0}d\vec v\le\frac{1}{2}T_e\int_{-\infty}^{\infty}\tilde f_{1e}^{\,2}d\vec v\Bigg/\int_{-\infty}^{\infty}f_0d\vec v=\frac{1}{2}T_en_{0e}\frac{k^2\left|A_1\right|^2}{B_z},\qquad\frac{n_1}{n_0}=\frac{kA_1}{B_z}$$

Different components of tearing mode energy sufficient criteria of instability.

$$\boxed{\delta W < 0}$$

total tearing mode energy



Perturbation of magnetic field

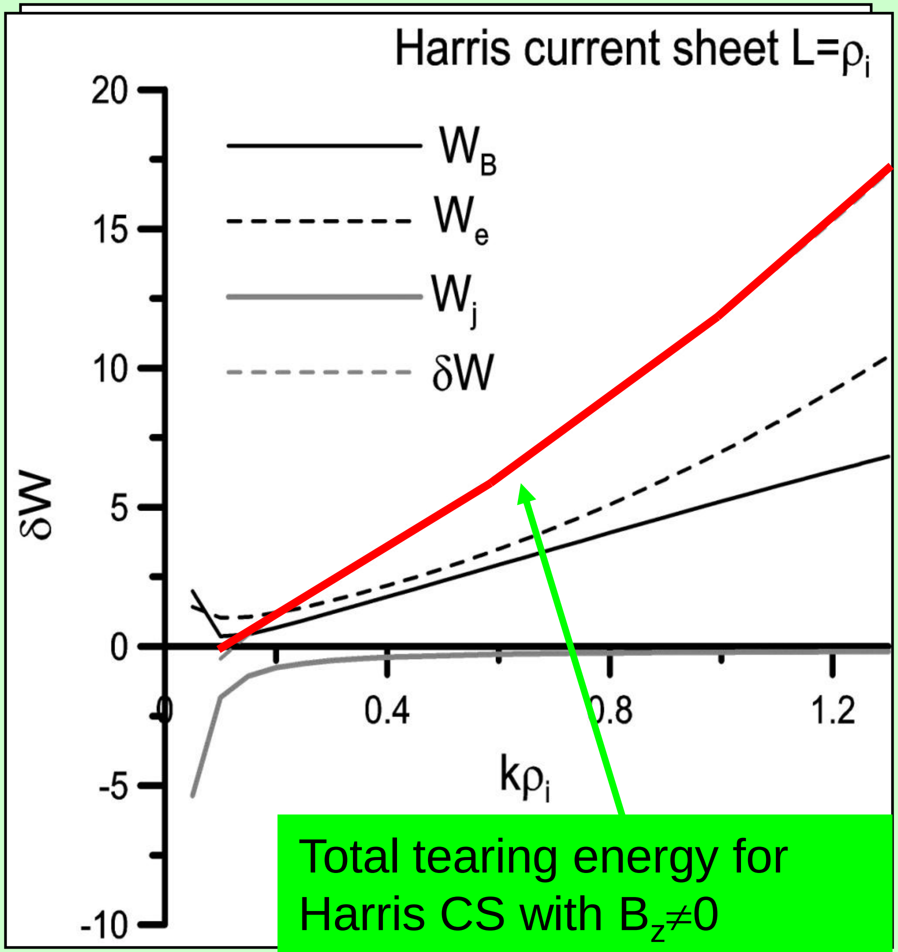
Electron stabilization

Total tearing energy

Free energy

components of energy $L = 0.7\rho_i \quad b_n = 0.1$

Ti/Te=3



Total tearing energy for Harris CS with $B_z \neq 0$

Embedding of observed CS and their sources of Free energy

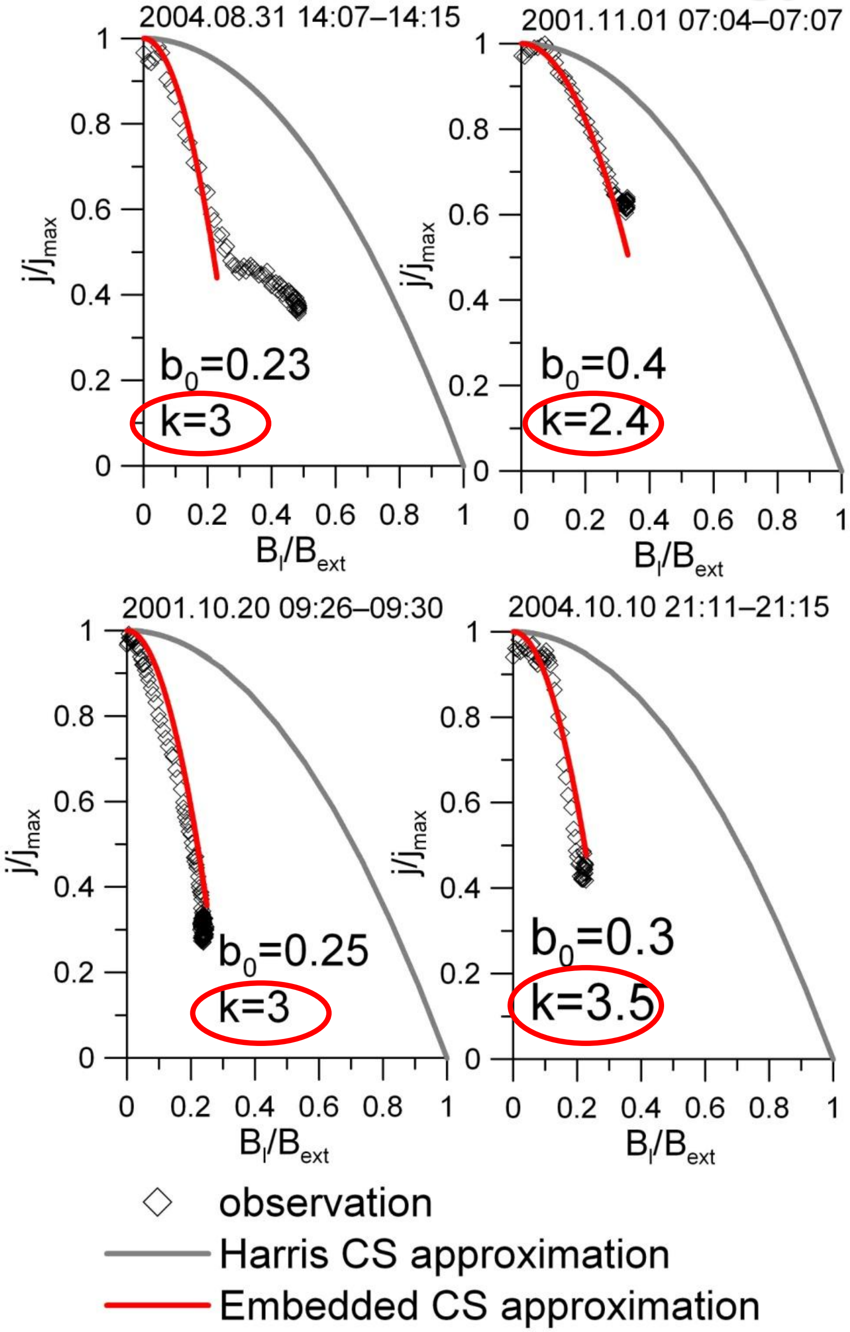
k=W$_{free}$(observed CS)/W$_{free}$(Harris CS)

$$\boxed{\begin{aligned} W_F &= \frac{1}{2c}\int_{-\infty}^{+\infty}\frac{\partial j}{\partial A_y}A_1^2\,dz \\ &= \frac{j_{\max}}{c}\int_{0}^{B_0}\frac{\partial\left(j/j_{\max}\right)}{\partial B_x}\frac{1}{B_x}A_1^2\,dB_x + \\ &\quad \frac{j_{\max}}{c}\int_{B_0}^{B_{ext}}\frac{\partial\left(j/j_{\max}\right)}{\partial B_x}\frac{1}{B_x}A_1^2\,dB_x \end{aligned}}$$

$$b_0 = B_0/B_{ext}\,,\qquad \mu = j_{\min}/j_{\max}$$

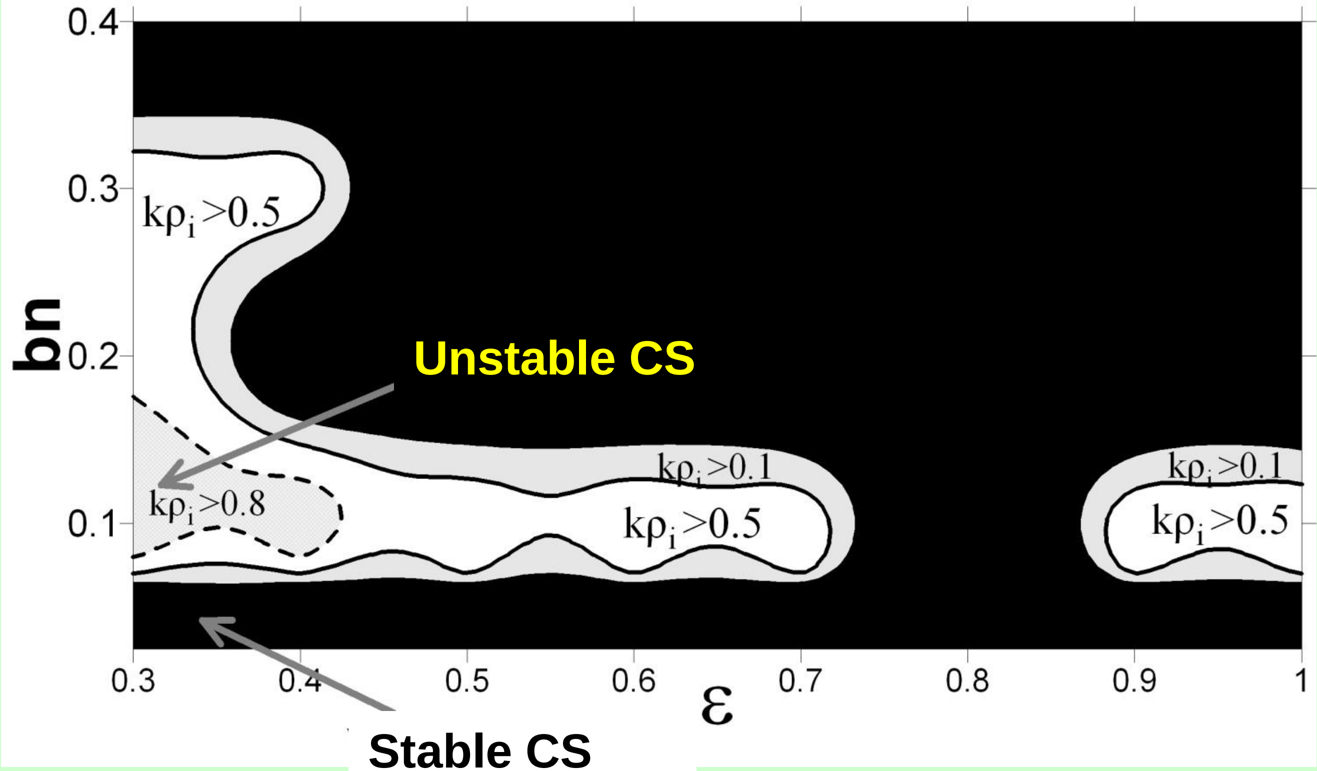
$$k = \left(1-\mu\right)/b_0 + \left(1-b_0\right)$$

“Free” energy of observed CSs is 2-3 larger than the one of corresponding Harris sheet



Parameter space of TCS instability

$T_i/T_e=3$



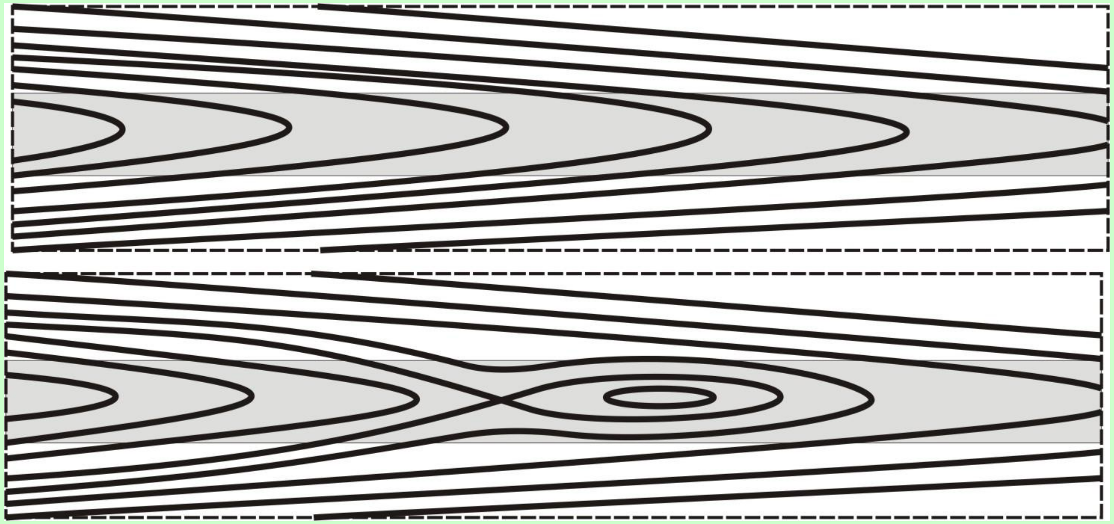
Unstable CS

Stable CS

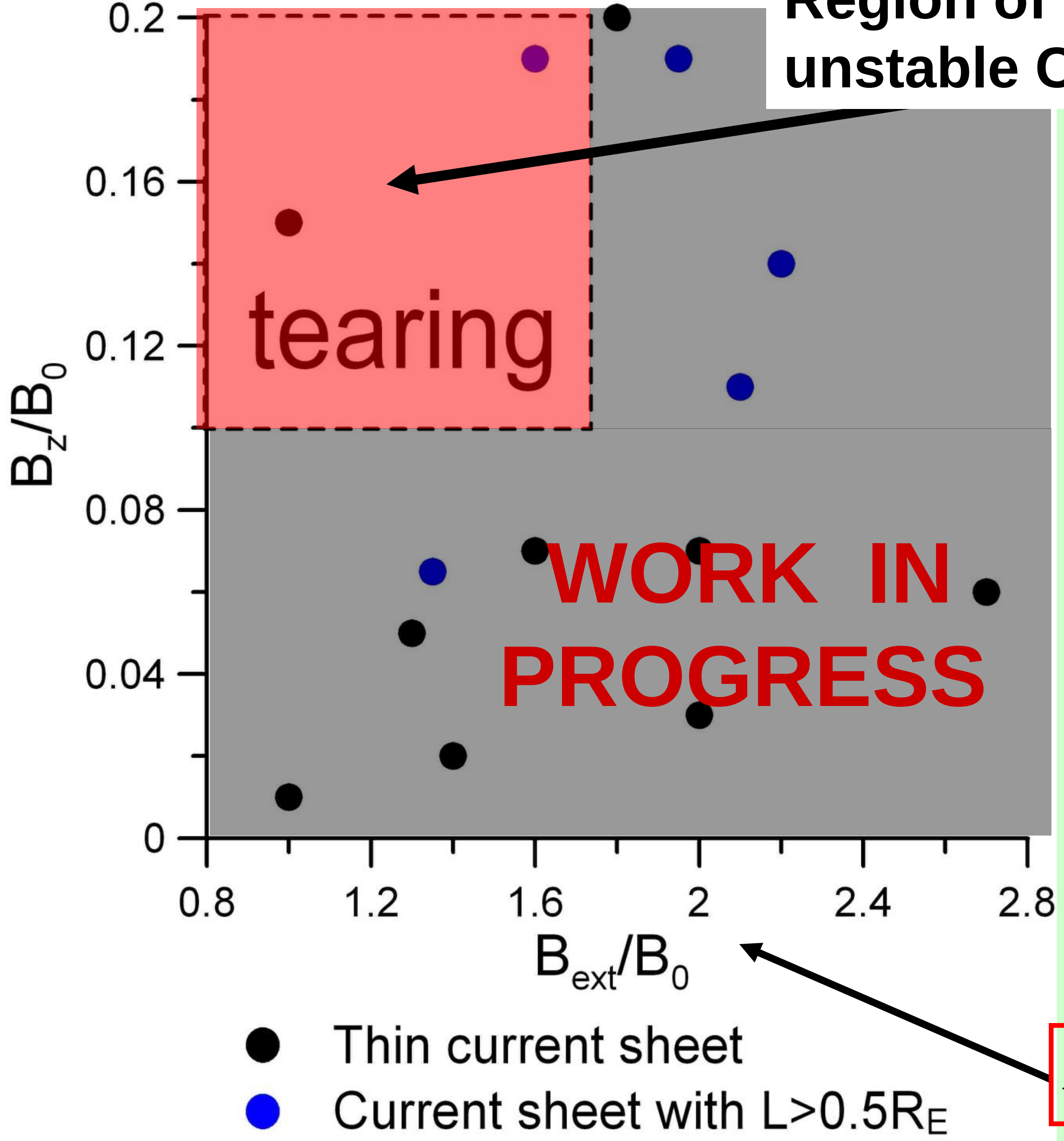
Integral instability window for all $0<kL<3$

Initial moment

NL mode growth



Linear theory and Cluster observations

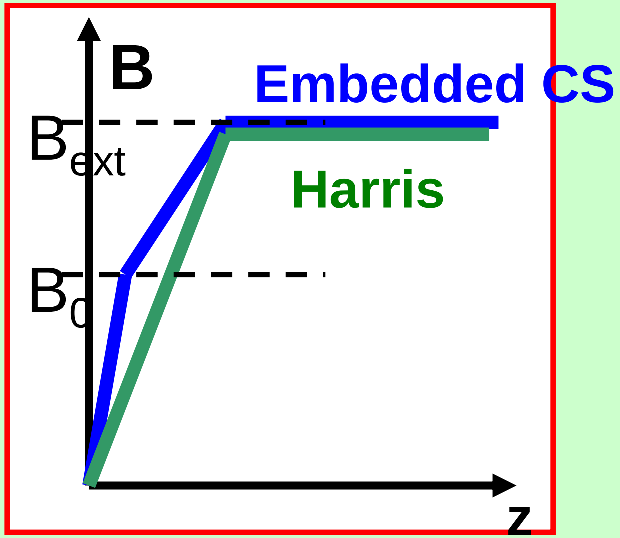


Region of unstable CS.

Measure of CS embedding can be presented as B_{ext}/B_0.

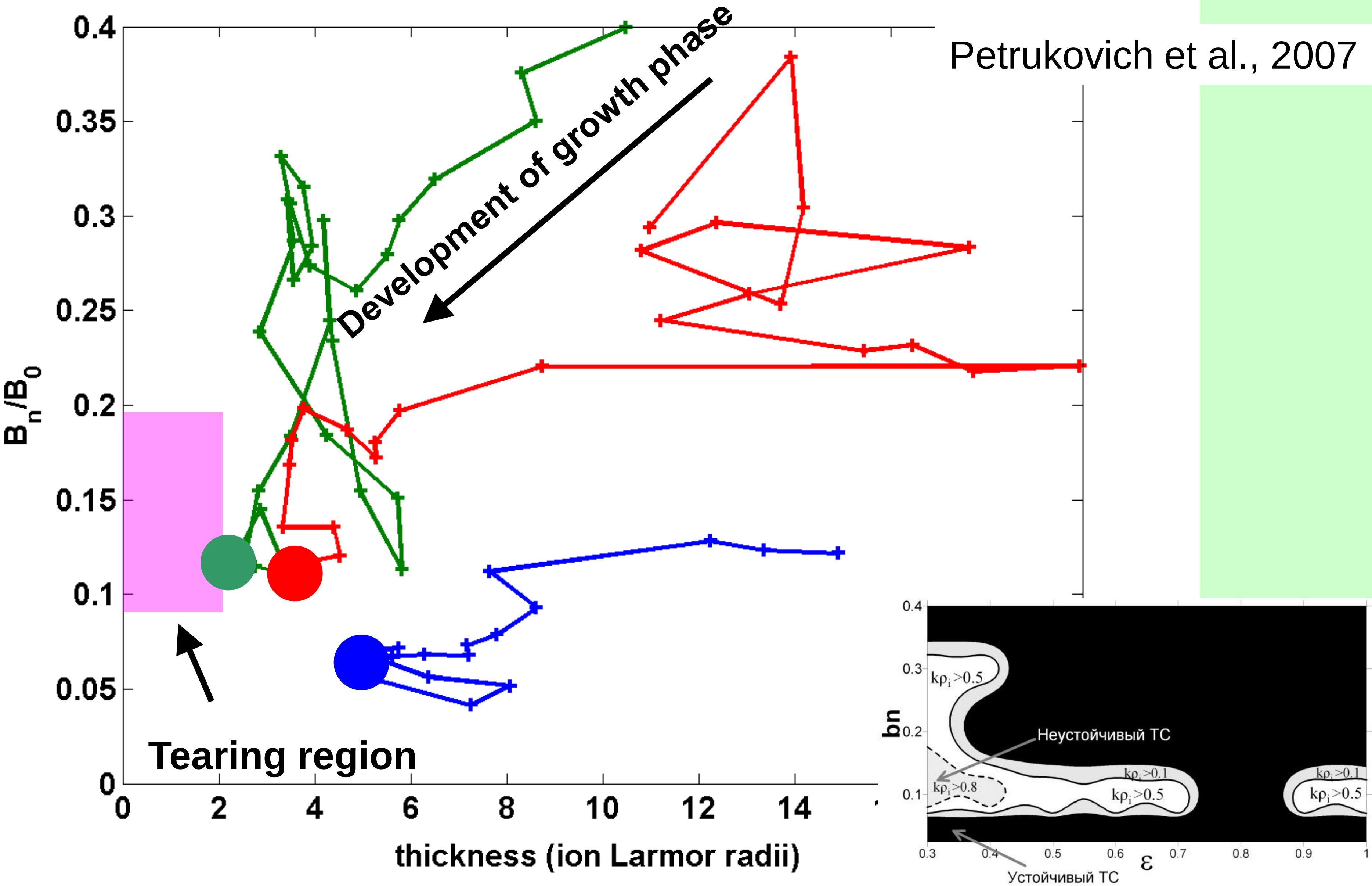
For Harris CS $B_{ext}/B_0=1$.

For TCS $B_{ext}/B_0>1$



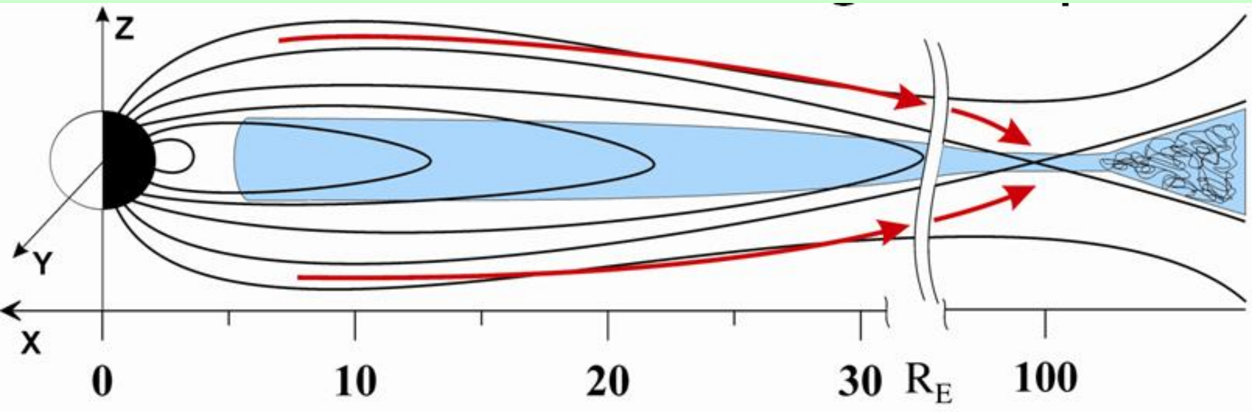
$$B_{ext}^2 = B_0^2 + \mu_0 p\left(z = L\right)$$

Evolution of metastable CS during the growth phase. Thinning & stretching towards instability.

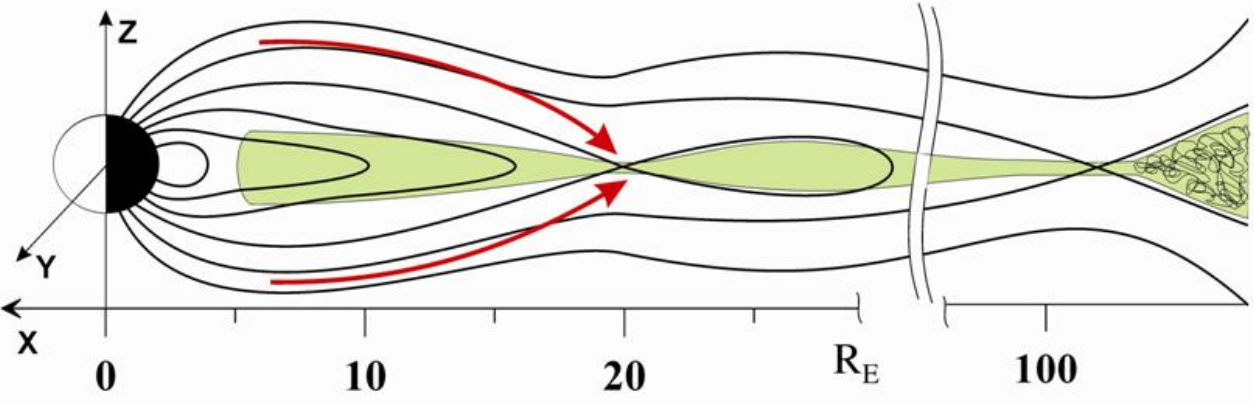


Petrukovich et al., 2007

Where reconnection could occur in the Earth’s magnetosphere ?

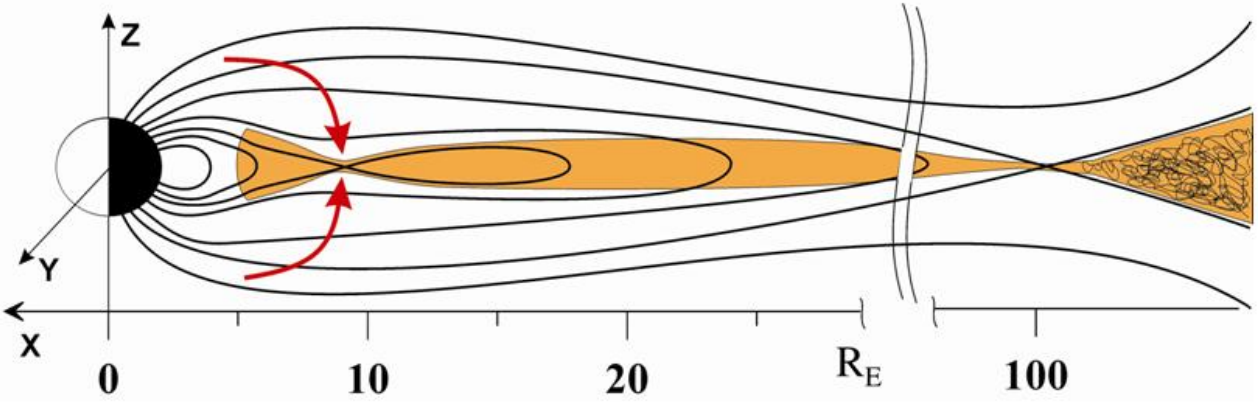


Quiet conditions
Topological distant tail reconnection



Middle tail reconnection

Baker et al. 1996
Petrukovich et al. 1998
Phan et al. 2000



Near Earth initiation

Lui 1991
Kan 1998

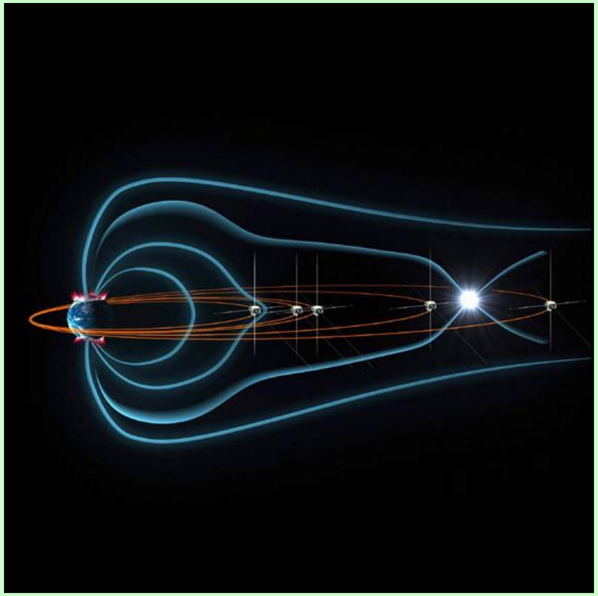
Tail Reconnection Triggering Substorm Onset

Science 2008

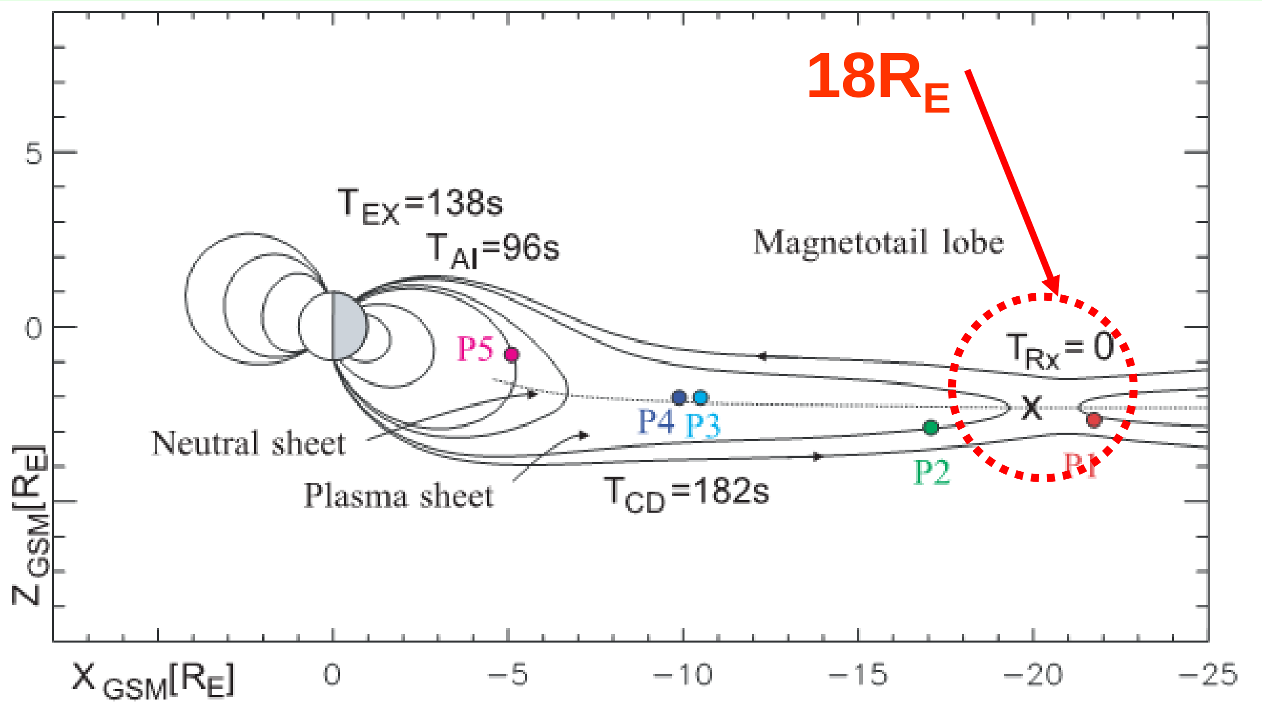
Vassilis Angelopoulos,[1*] James P. McFadden,[2] Davin Larson,[2] Charles W. Carlson,[2] Stephen B. Mende,[2] Harald Frey,[2] Tai Phan,[2] David G. Sibeck,[3] Karl-Heinz Glassmeier,[4] Uli Auster,[4] Eric Donovan,[5] Ian R. Mann,[6] I. Jonathan Rae,[6] Christopher T. Russell,[1] Andrei Runov,[1] Xu-Zhi Zhou,[1] Larry Kepko[7]

5 spacecraft

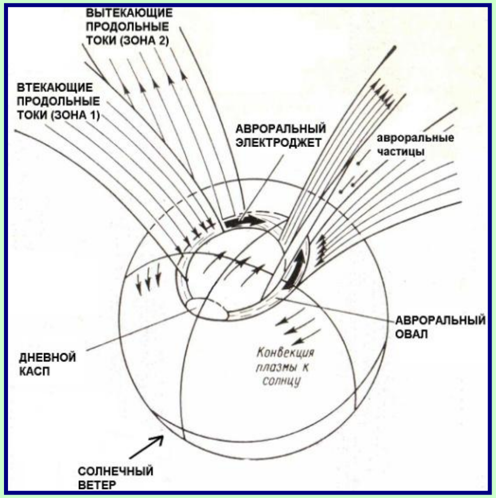
THEMIS PROJECT

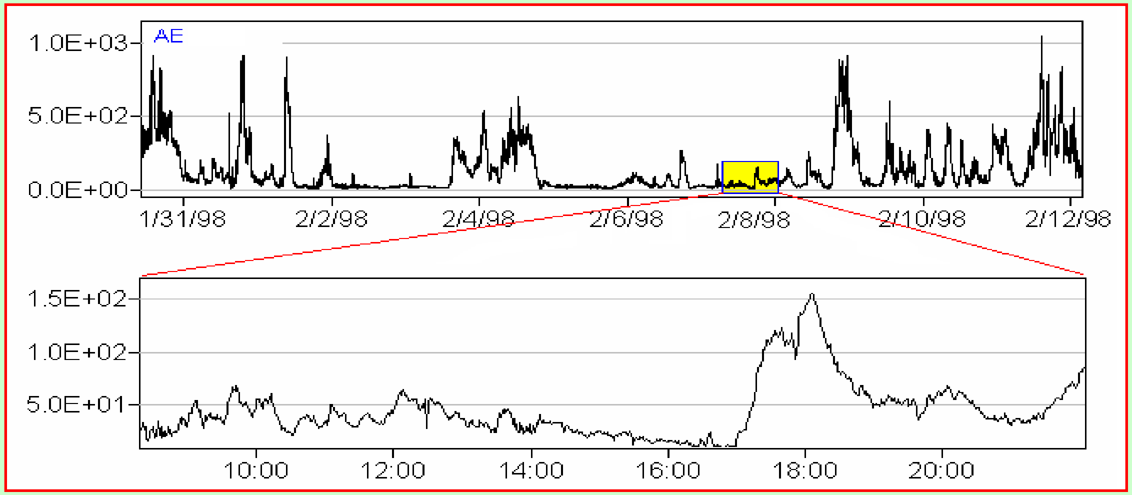


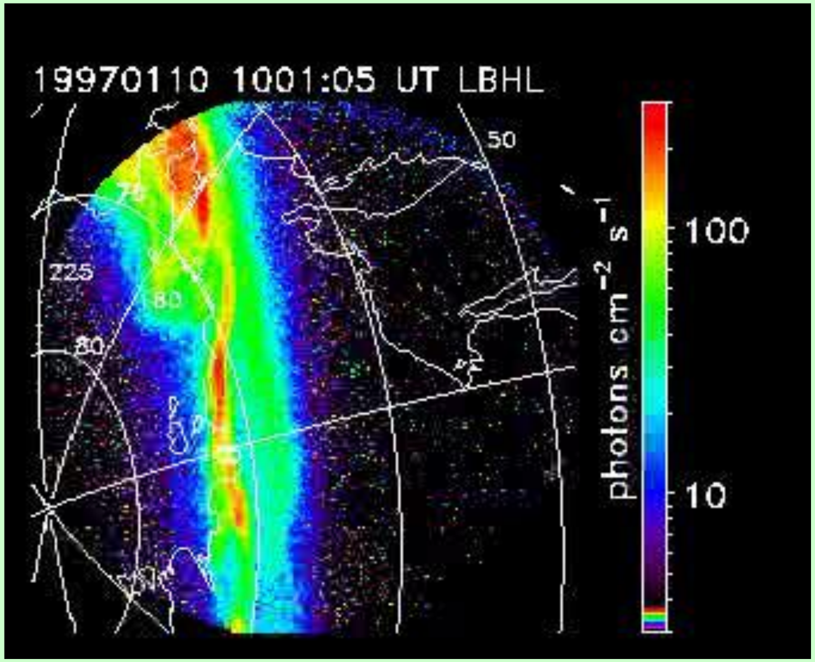
Hopes for breakthrough
in understanding
substorm initiations



Multiscale organization of geomagnetic activity





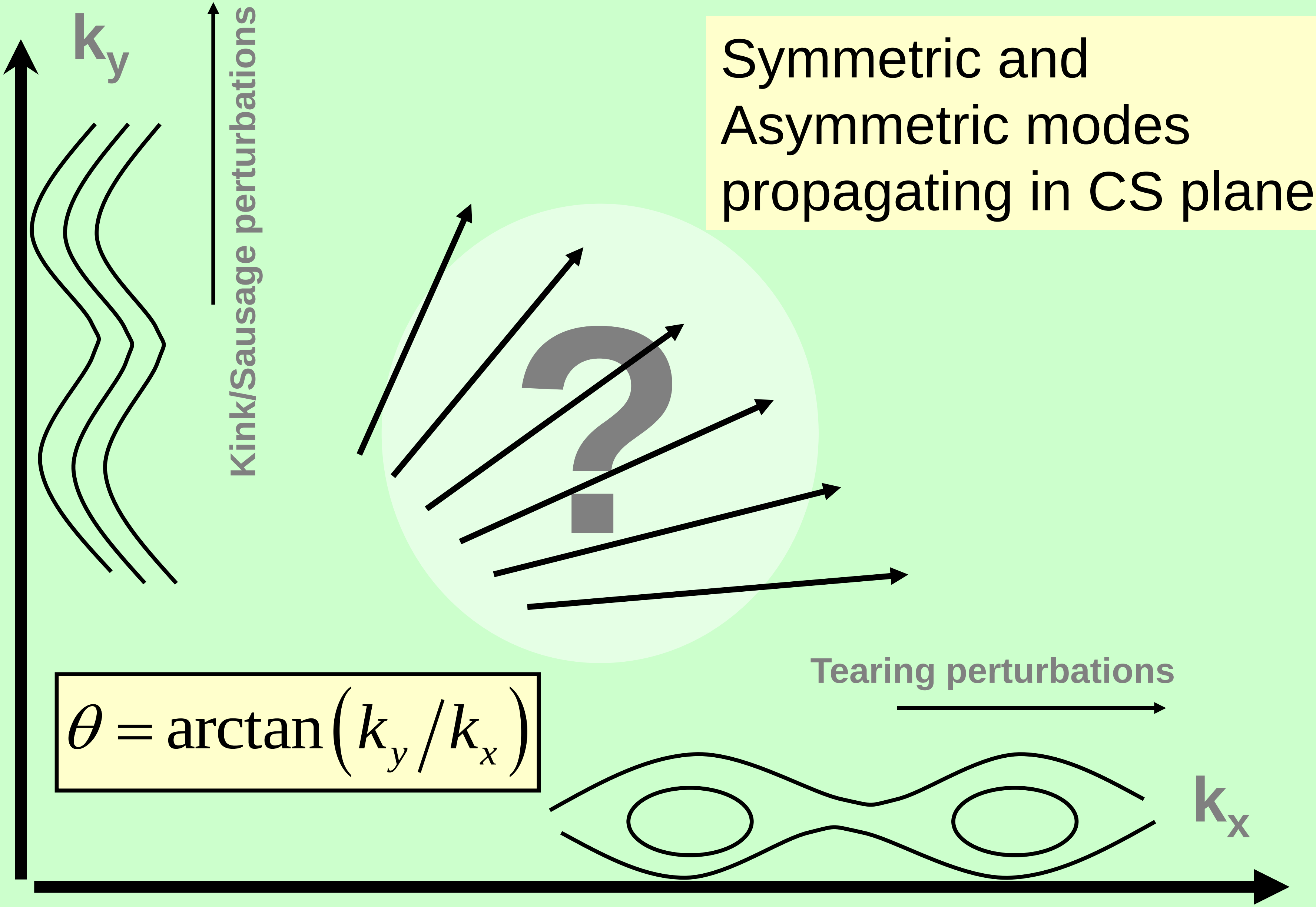


<u>Hierarchy of magnetospheric disturbances</u>

- **Geomagnetic storms**
- **Full-size substorms**
- **Substorm activations**
- **Pseudo-breakups**
- **Bursty bulk flows (BBFs)**
- **Impulsive structure of BBF events**
- **Plasma turbulence**

Eigenmodes of TCS

Symmetric and
Asymmetric modes
propagating in CS plane.



$$\theta = \arctan\left(k_y / k_x\right)$$

Two modes of low frequency EM perturbations.

$$\mathbf{A}_1 \sim \exp\left(i\mathbf{kr} - i\omega t\right)$$

$$\mathbf{k} = k\cos\theta\,\mathbf{e}_x + k\sin\theta\,\mathbf{e}_y$$

$$\frac{d^2\mathbf{A}_1}{dz^2} - 4\pi\left(\frac{k^2}{4\pi} - \frac{1}{c}\frac{\partial \mathbf{j}_0}{\partial \mathbf{A}_0}\right)\mathbf{A}_1 - 4\pi p_0\frac{k_x^2}{B_z^2}A_{1y}\mathbf{e}_y = -\frac{4\pi}{c}\mathbf{j}^{res}$$

Coulomb calibration $div\mathbf{A} = 0$

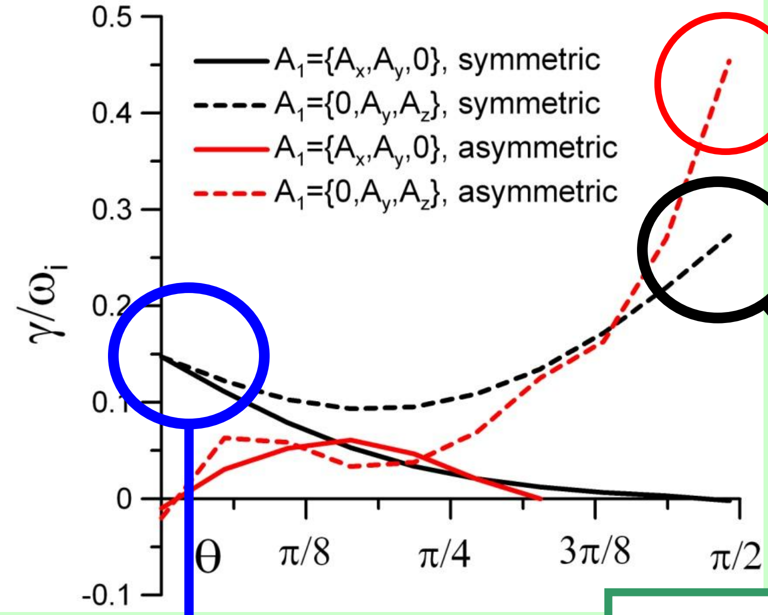
$$\mathbf{A}_1 = A_{1x}\mathbf{e}_x + A_{1y}\mathbf{e}_y$$

$$\mathbf{A}_1 = A_{1z}\mathbf{e}_z + A_{1y}\mathbf{e}_y$$

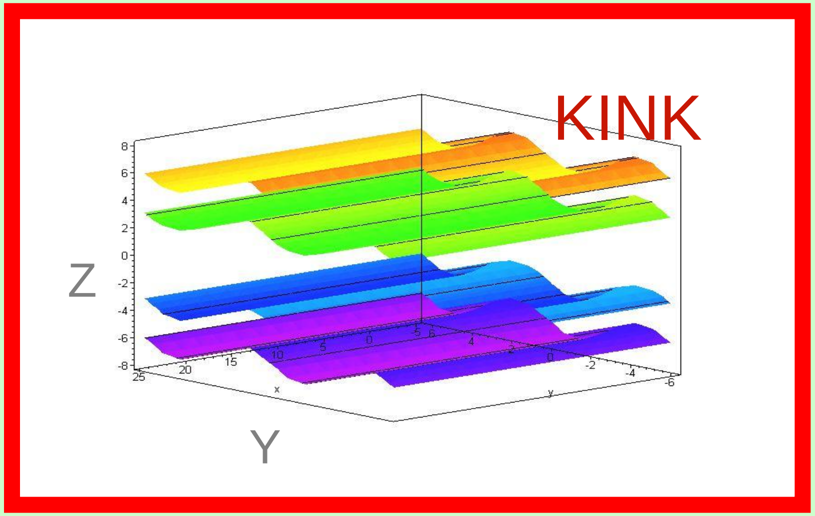
$$\begin{aligned}&d^2A_1/dz^2\\ &-k^2\left(1+0.5p_0B_z^{-2}\underline{\cos^4\theta}\right)A_1\\ &+0.5c^{-1}\left(\partial j_y/\partial A_0\right)\underline{\cos^2\theta}A_1\\ &= -j^{res}\left(z,\theta,A_1,t\right)\end{aligned}$$

$$\begin{aligned}&d^2A_{1y}/dz^2\\ &-k^2\left(1+0.5p_0B_z^{-2}\underline{\cos^2\theta}\right)\\ &+0.5c^{-1}\left(\partial j_y/\partial A_0\right)A_{1y}\\ &= -j^{res}\left(z,\theta,A_{1y},t\right)\end{aligned}$$

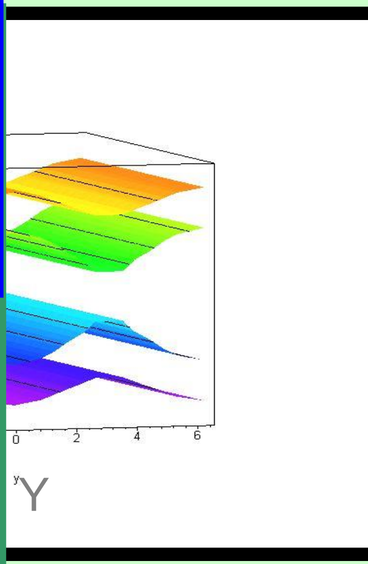
Multimode structure of TCS perturbations



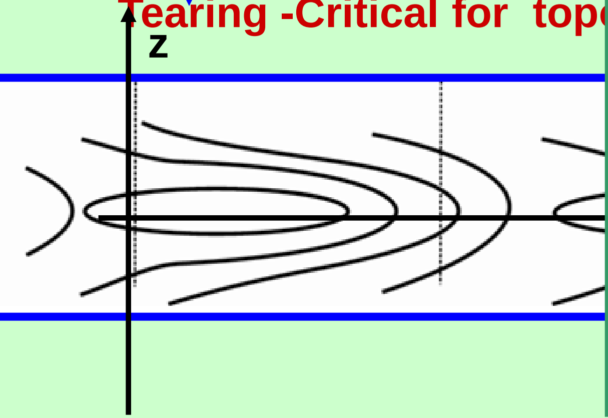
kink

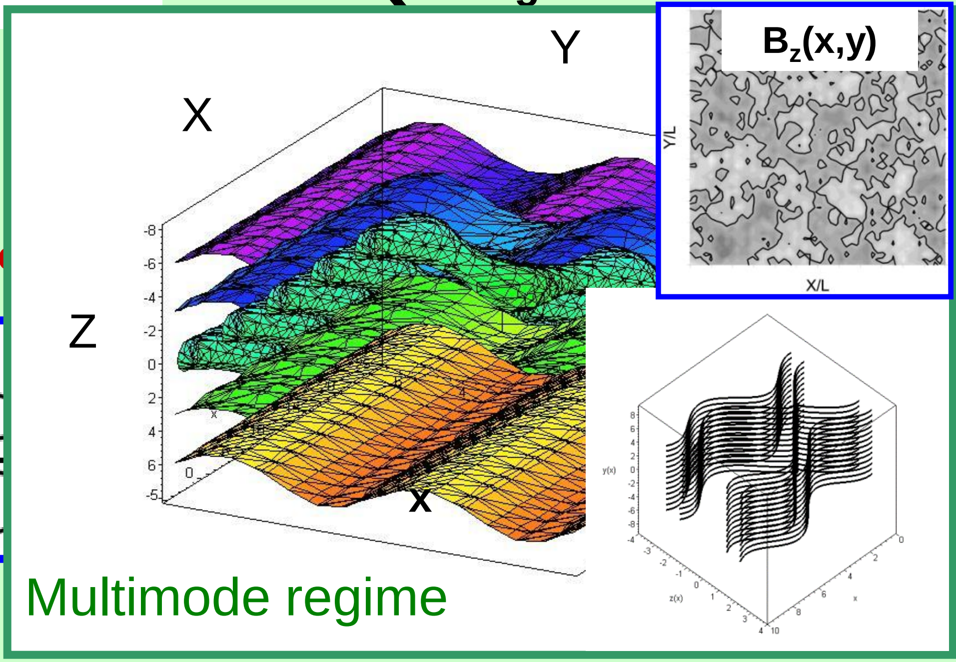


sausage



Tearing -Critical for top



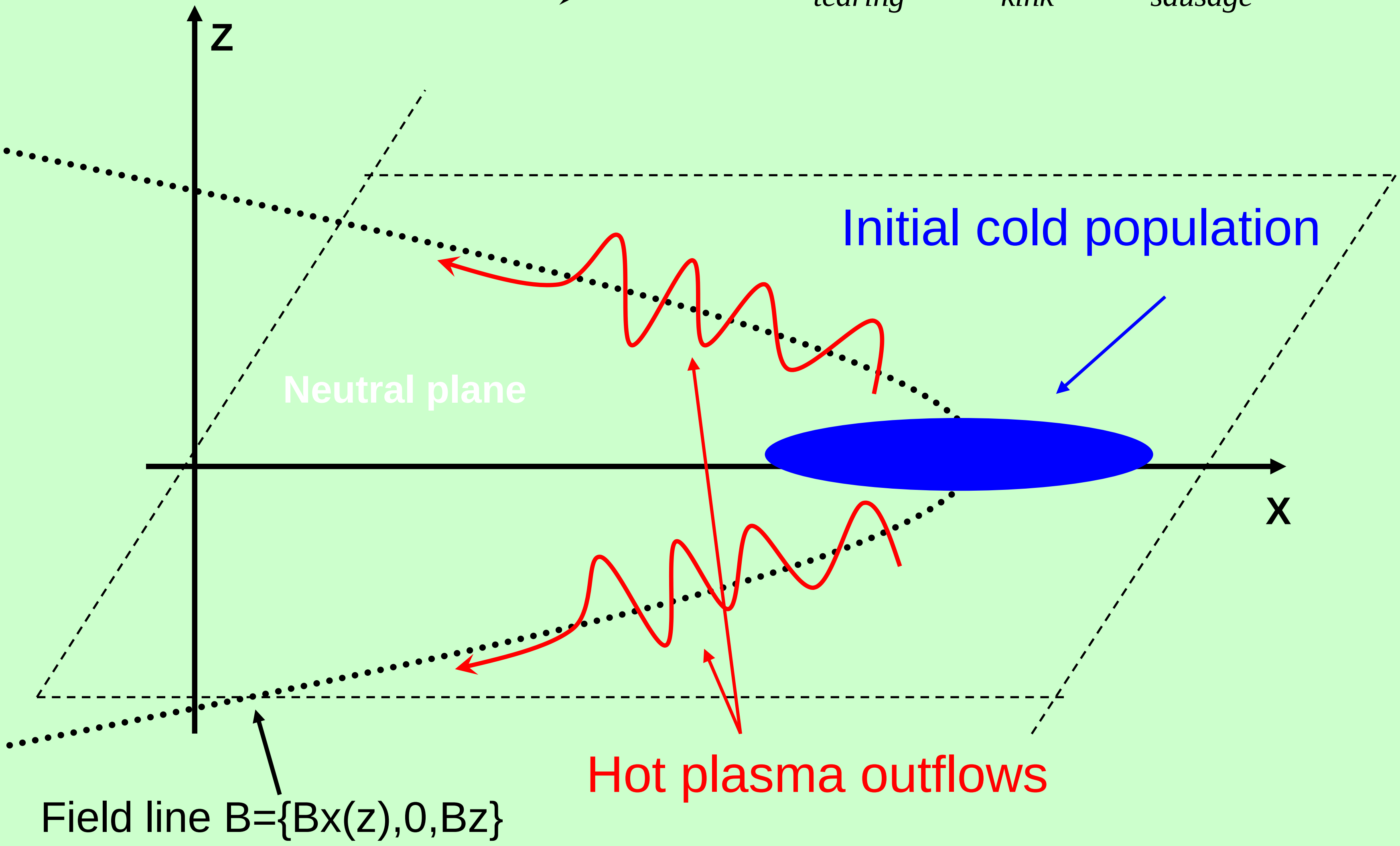


Multimode regime

Geometry of the system

Stationary field ⟶ $\mathbf{B}_0 = B_0 \tanh\left(z/L\right)\mathbf{e}_x + B_n\mathbf{e}_z$

Turbulent field ⟶ $\delta\mathbf{B} = \mathbf{B}_{tearing} + \mathbf{B}_{kink} + \mathbf{B}_{sausage}$



Initial cold population

Hot plasma outflows

Field line B={Bx(z),0,Bz}

Turbulent field

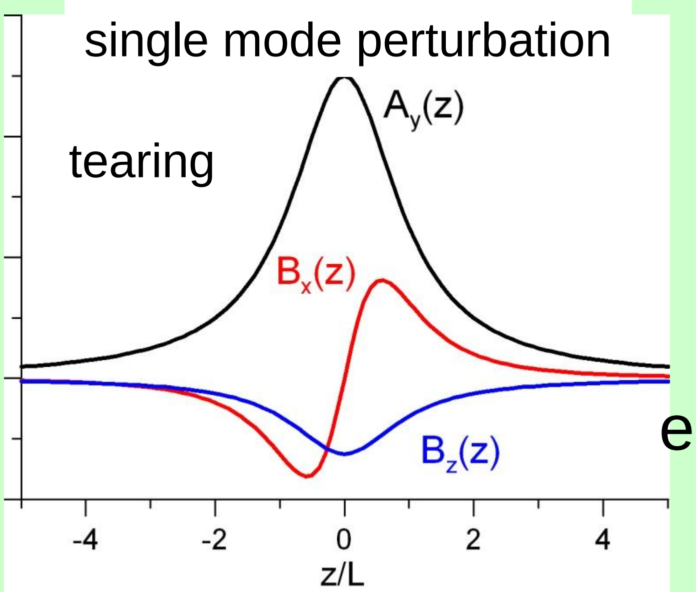
System parameters: $\delta\mathbf{B}_{\text{kink}}/B_0$, $\delta\mathbf{B}_{\text{tearing-sausage}}/B_0$

Tearing

$$\mathbf{A}_{\text{tearing-sausage}} = \sum_{k_x,k_y} A_y(z,k)\cos\left(k_x x + k_y y - t\omega\right)\mathbf{e}_y$$
$$\sum_{k_x,k_y} A_z(z,k)\sin\left(k_x x + k_y y - t\omega\right)\mathbf{e}_z$$

Kink

$$\mathbf{A}_{\text{kink}} = \sum_{k_x,k_y} A_y(z,k)\cos\left(k_y y - t\omega\right)\mathbf{e}_y$$
$$+\sum_{k_x,k_y} A_z(z,k)\sin\left(k_y y - t\omega\right)\mathbf{e}_z$$

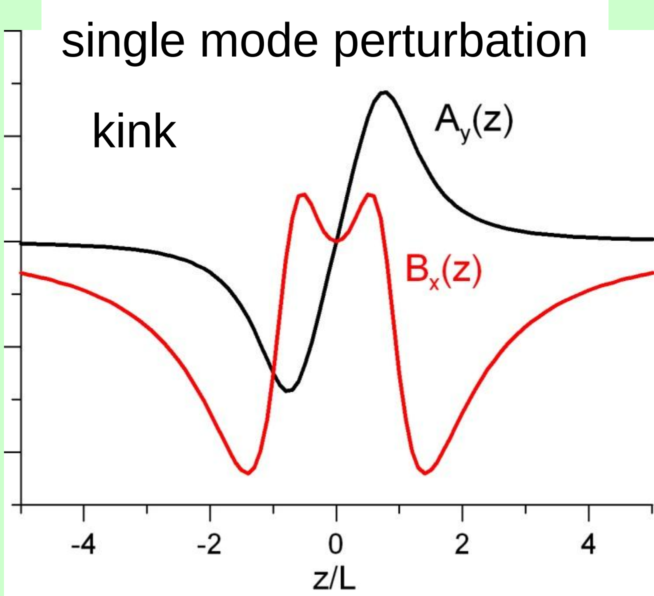


$$-A_y k_y + \frac{\partial A_z}{\partial z} = 0$$

$$\operatorname{Re}\omega = k_y v_D$$

↑

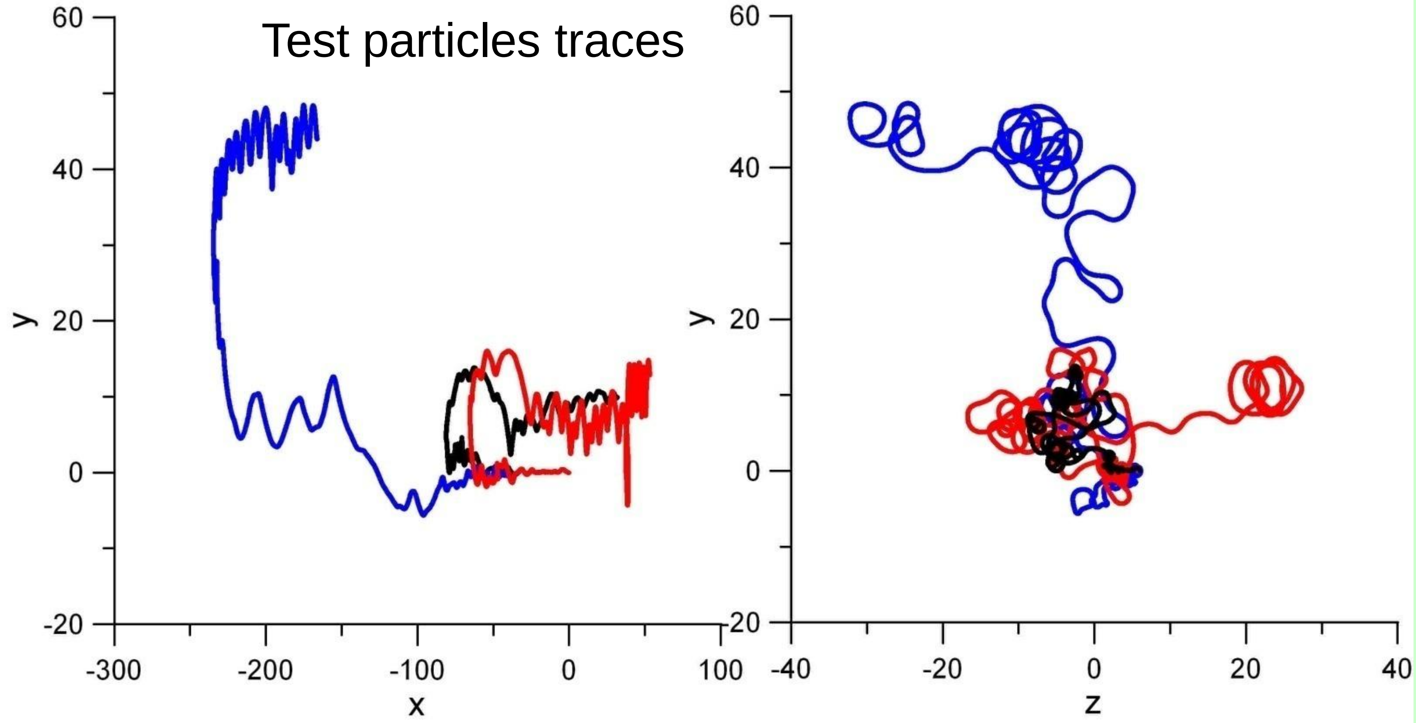
equal for all modes



spectrum $A \sim \left(1+k^2\right)^{-1}$

$$E_z = -\partial_t A_z, \quad E_y = -\partial_t A_y$$

Particle dynamics

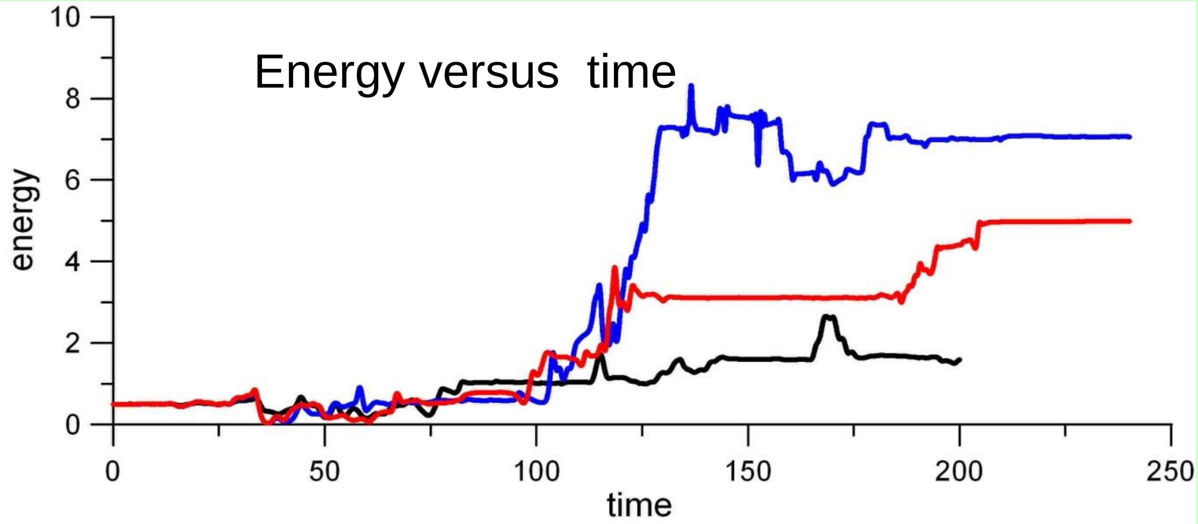


Test particles traces

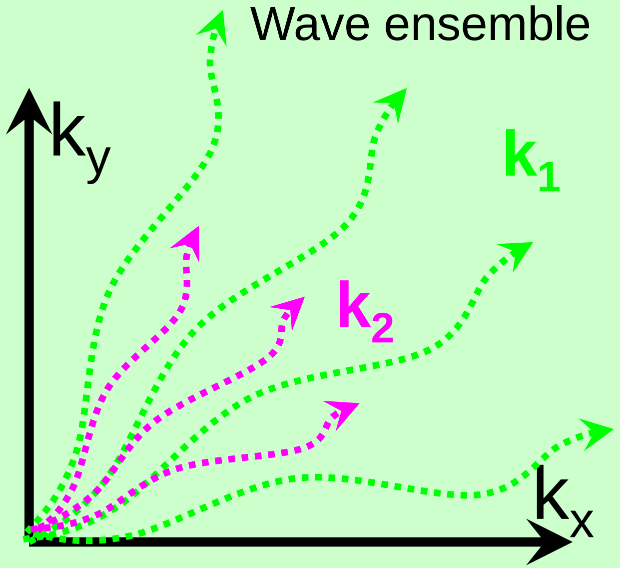
$\delta\mathbf{B}/B_0=0.3$

$\delta\mathbf{B}/B_0=0.5$

$\delta\mathbf{B}/B_0=0.7$

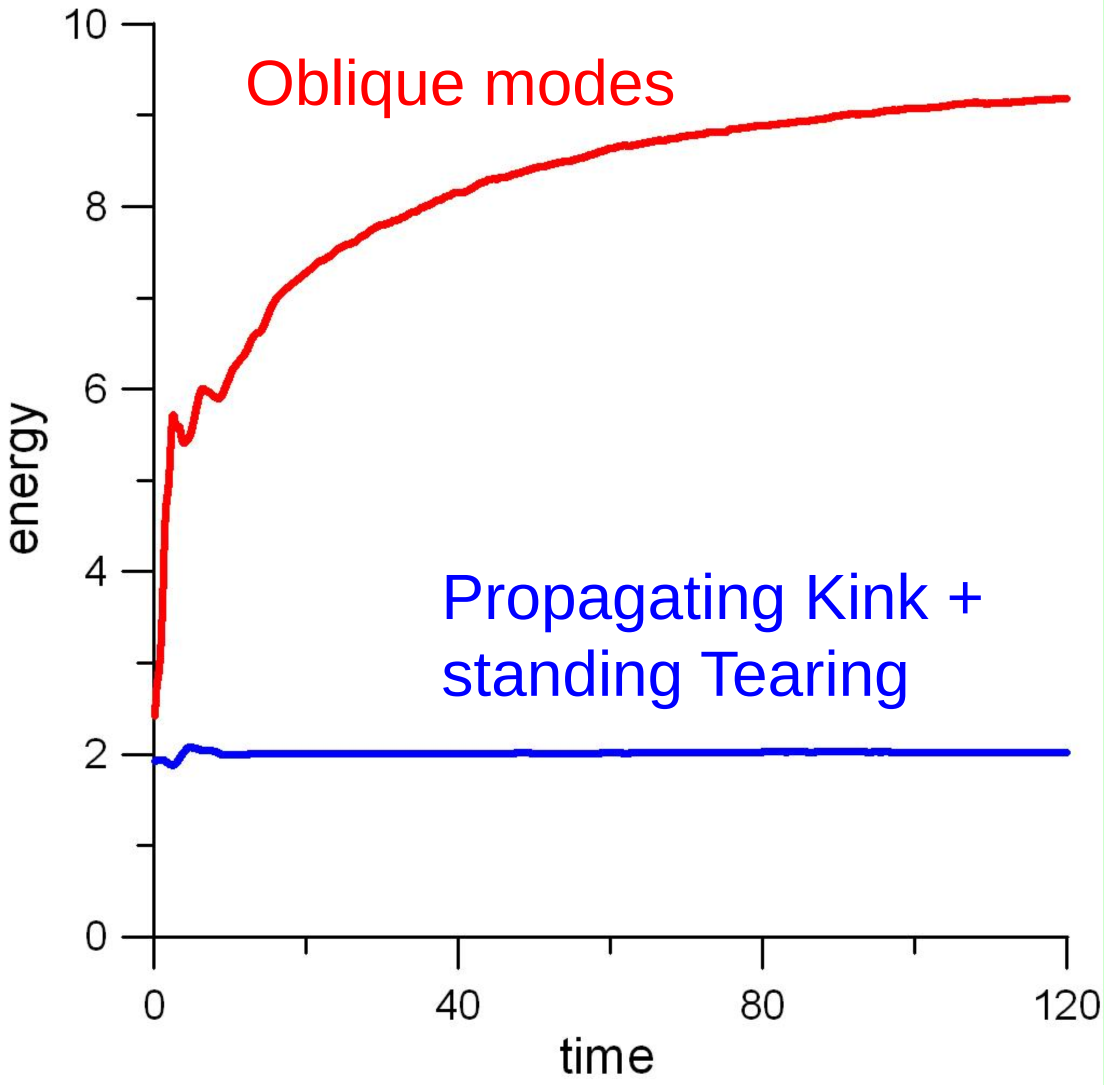


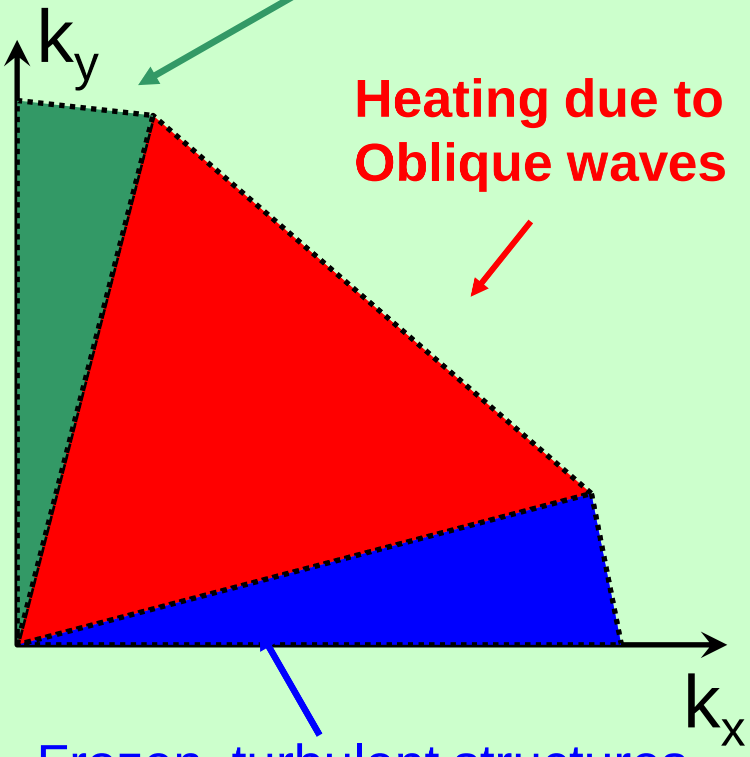
Energy versus time



Wave ensemble

Oblique propagation



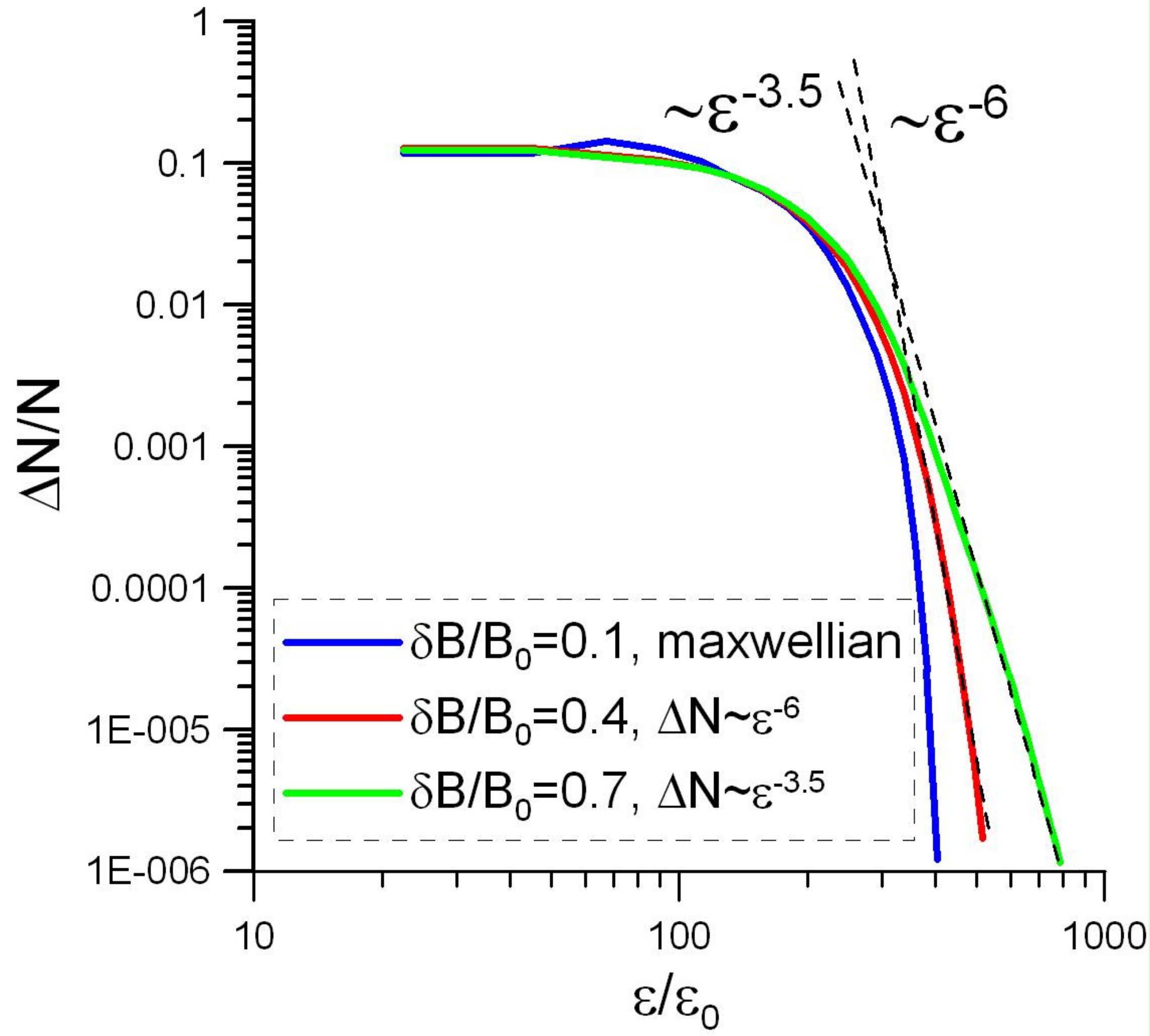


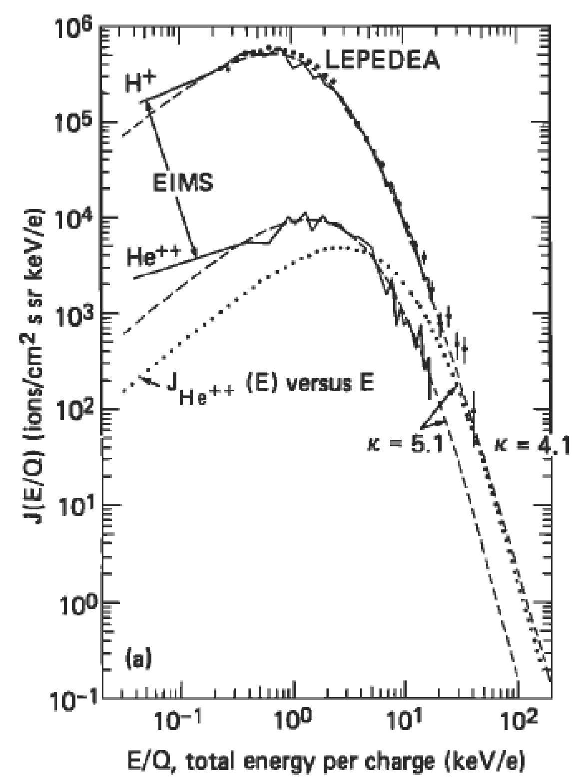
Absence of magnetic field nulls

Heating due to Oblique waves

Frozen turbulent structures

Formation of nonmaxwellian spectra

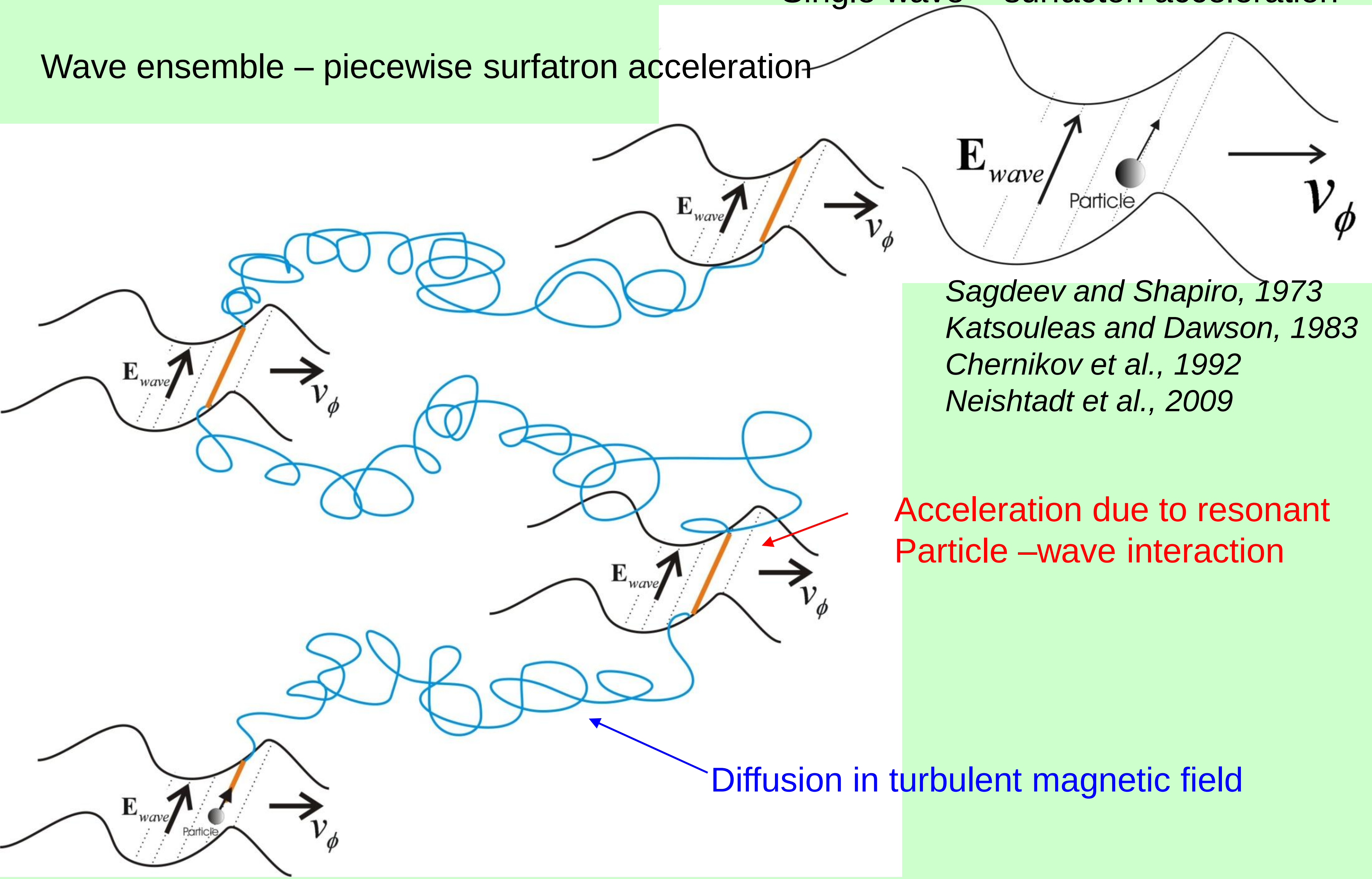




Christon 1989,JGR

Average spectra of energetic ions in the plasma sheet

Acceleration mechanism



Single wave – surfacton acceleration

Wave ensemble – piecewise surfatron acceleration

Sagdeev and Shapiro, 1973
Katsouleas and Dawson, 1983
Chernikov et al., 1992
Neishtadt et al., 2009

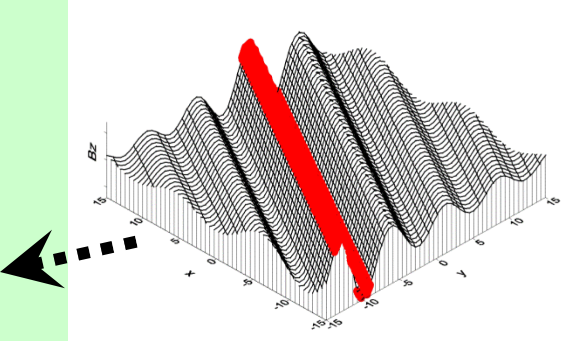
Acceleration due to resonant
Particle –wave interaction

Diffusion in turbulent magnetic field

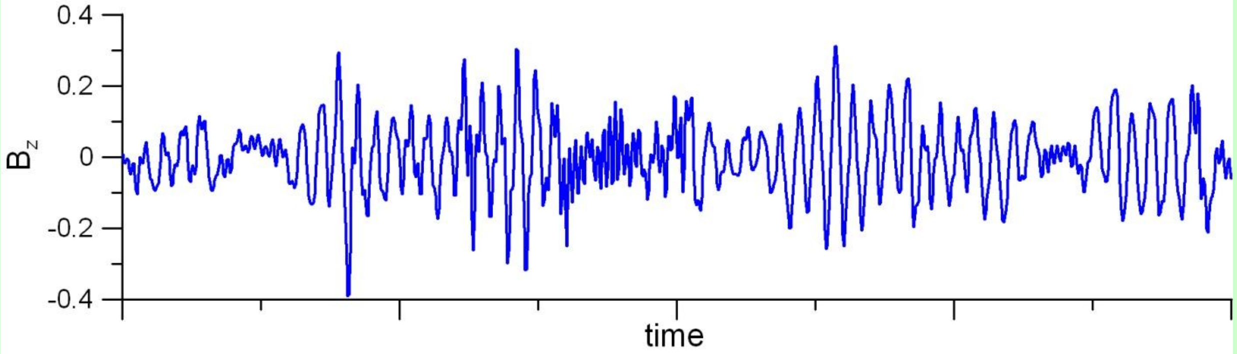
Intermittent wave structure

$$A \sim J_0\left(k_x x + k_y y - t\omega\right) \Rightarrow \delta B \sim J_1$$

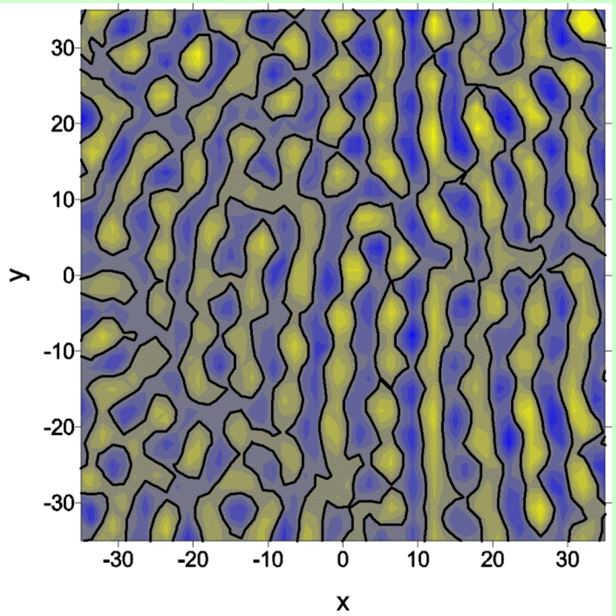
elementary wave mode



Ensemble of propagating NL structures



B_z field at z=0



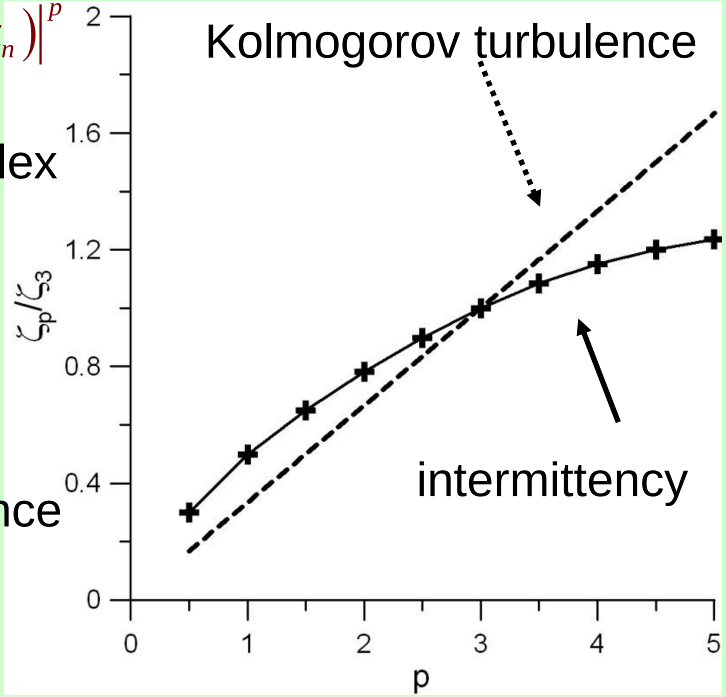
$$S_p(\Delta) = \sum_n \left|B(x_n + \Delta) - B(x_n)\right|^p$$

Structure function index

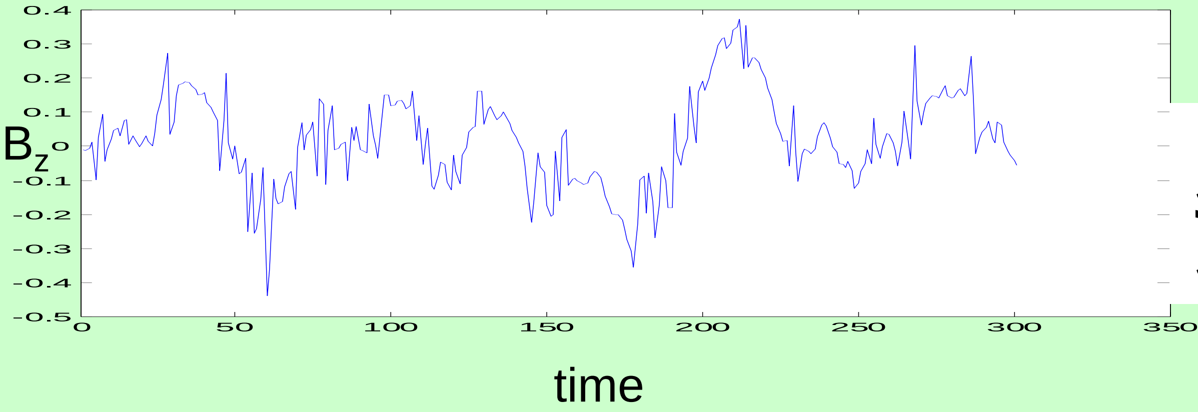
$$\zeta_p : \; S_p(\Delta) \sim \Delta^{\zeta_p}$$

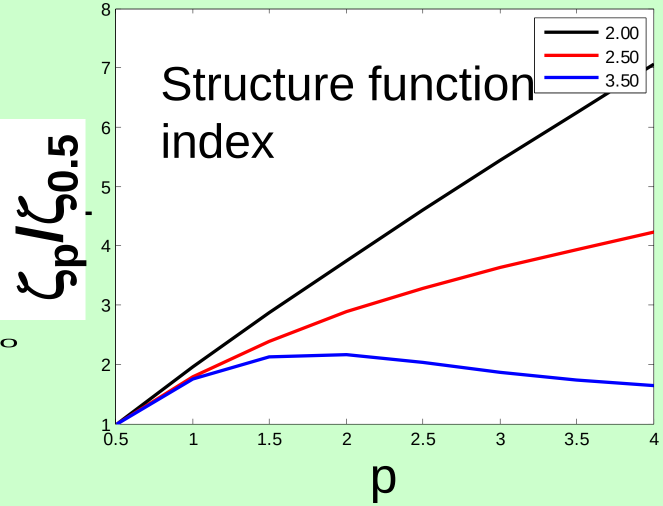
Kolmogorov turbulence

$$\zeta_p = p/3$$

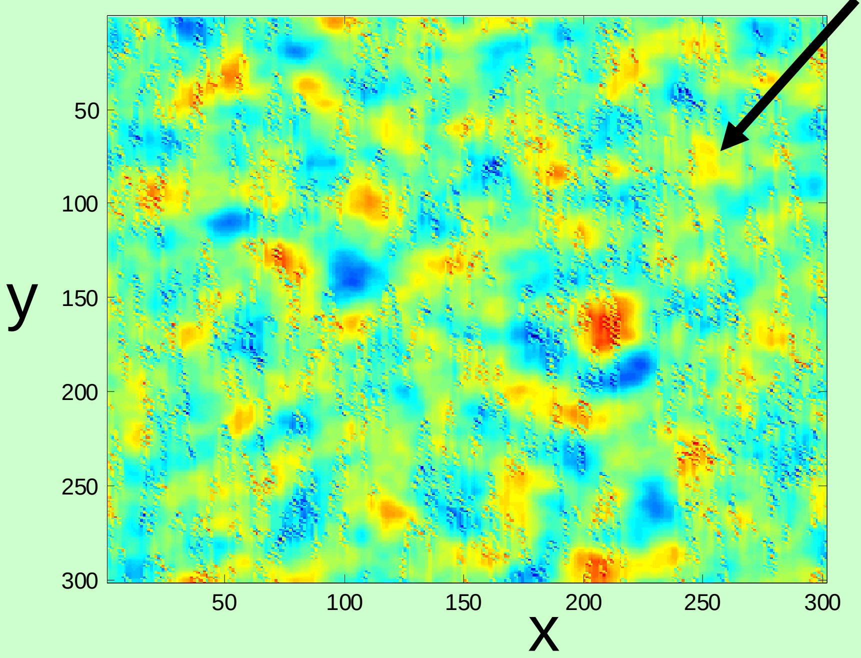


Intermittency

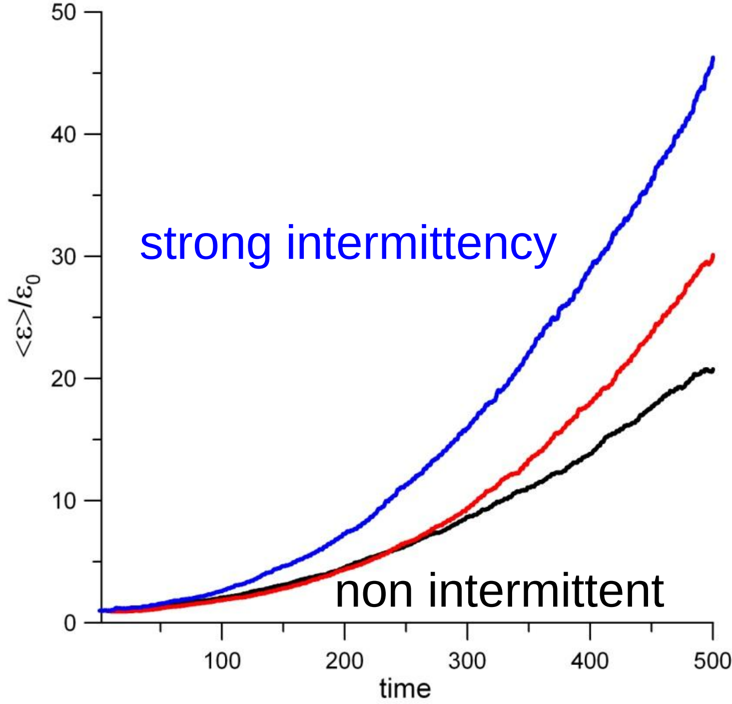




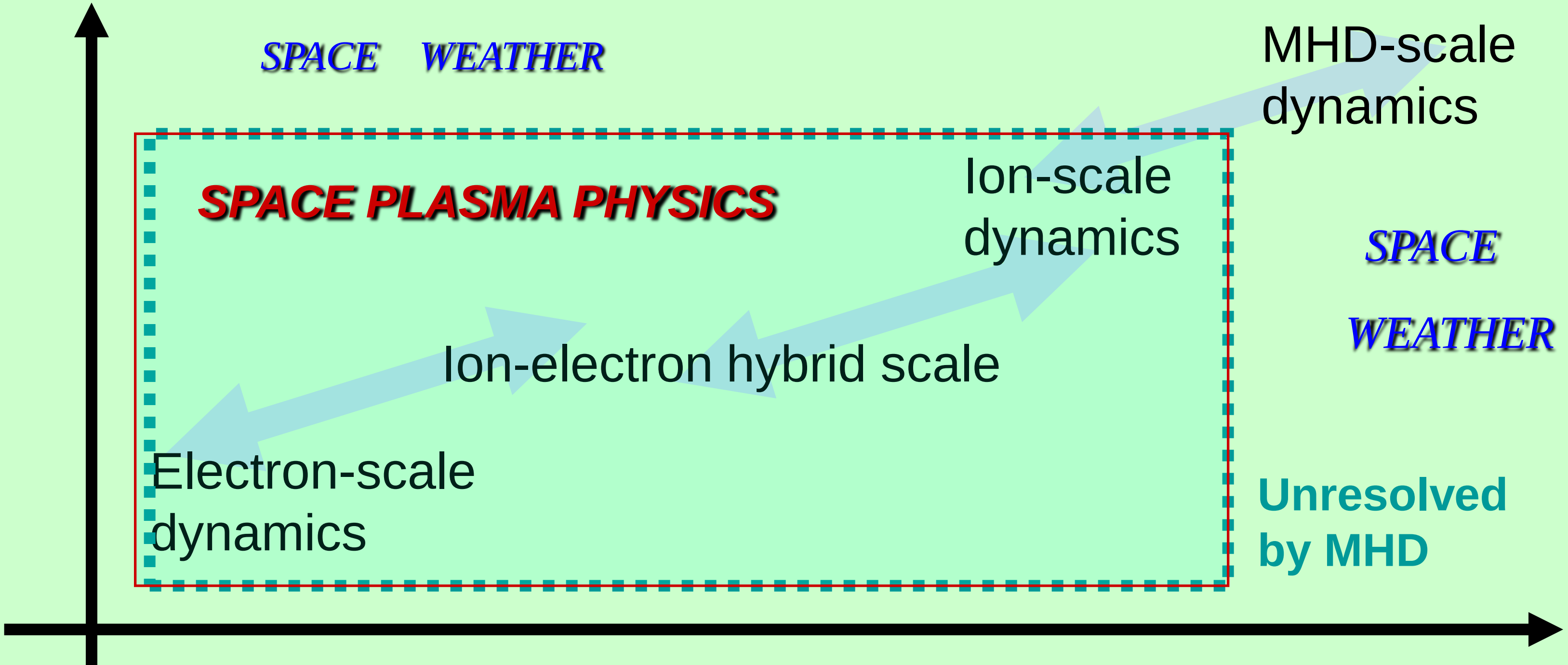
B_z field at z = 0



Nonlinear structures can be localized and form intermittent magnetic field affecting particle acceleration



Cross-Scale Coupling



Slow in time

SPACE WEATHER

MHD-scale
dynamics

SPACE PLASMA PHYSICS

Ion-scale
dynamics

SPACE

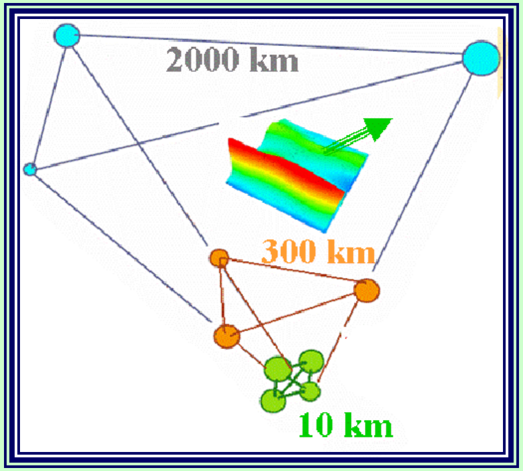
WEATHER

Ion-electron hybrid scale

Electron-scale
dynamics

**Unresolved
by MHD**

Large in space



**MULTISCALE SPACECRAFT SYSTEM
JAXA – ESA - RSA**

Conclusions:

- Configurations with magnetic field reversals (current sheets) are intrinsically metastable.
- For certain (quite narrow narrow region of parameters L, Bn) TCS can become unstable to tearing perturbation (contrary to the Harris one), which drives the spontaneous reconnection
- CS wave modes are effective particle accelerators by “piecewise surfatron” mechanism
- Tearing mode ingredient is necessary for particle acceleration. Importance of oblique modes

- More data (CrossScale+Scope+ROI) are needed
- Electron scales are still not resolved

- **LEV ZELENYI**

- **ANTON ARTEMIEV**
- **HELMI MALOVA**
- **ANATOLYI PETRUKOVICH**
- **VICTOR POPOV**
- **SERGEI RUBALKO**

THANK YOU FOR YOUR ATTENTION!

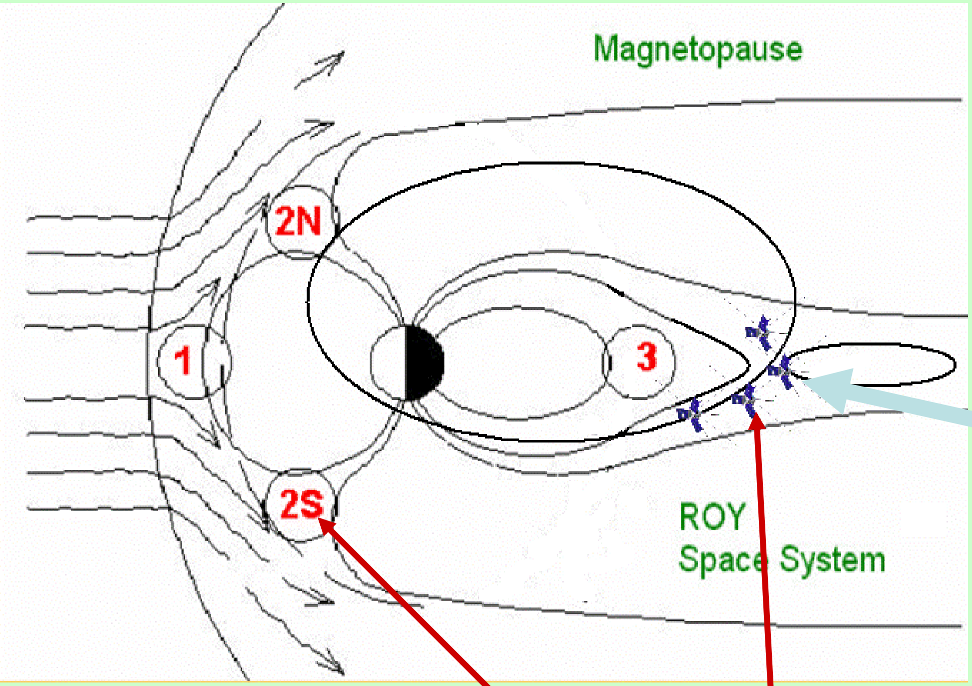
GRAZIE PER L'ATTENZIONE

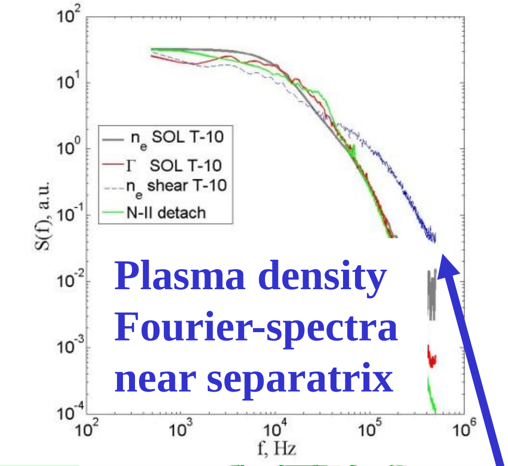
Moscow Kremlin- Outstanding example of Russian-Italian Cooperation

Earth’s Magnetosphere Studies Related to the Fusion Problems

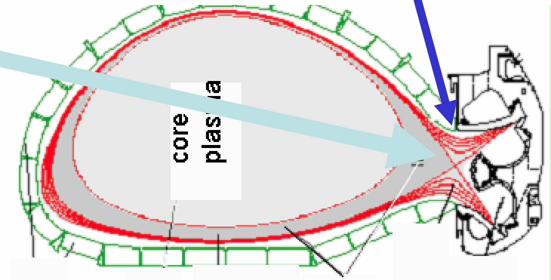
- Coupling of Alfvenic turbulence with electrostatic drift-wave turbulence
- Dynamics of Alfvenic cascade below the ion Larmor scale: mode conversion, dissipation, cascade termination?
- Anomalous transport caused by long-range correlation due to generalized scale invariance
- Transport barrier physics - improvement confinement regimes in tokamaks
- Reconnection and stochastic layers in the vicinity of X-point and separatrix
- Strong MHD turbulence

Critical problem of confinement in the vicinity of X-point and separatrix: transport problem and test of 2D/3D phenomenologies of strong MHD turbulence.





Plasma density Fourier-spectra near separatrix



tokamak

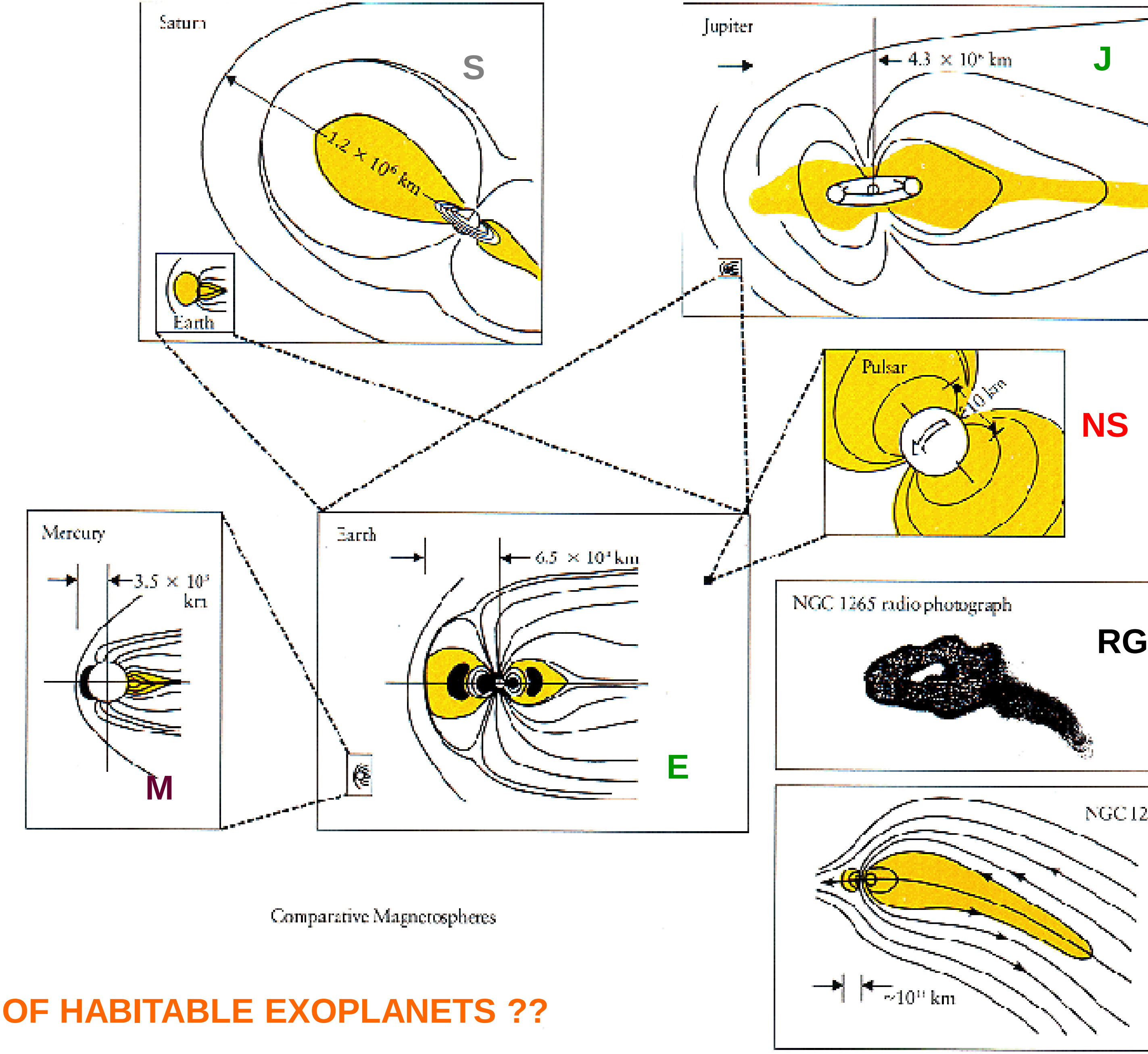
X-point small-scale magnetic topology < 1 cm :
impossible to measure in tokamaks

Measurements in neutral points (X-line, “sash”, cusps) of Earth’s magnetosphere as a test region. Reconnection physics.

UNIVERSALITY OF MAGNETOSPERIC TYPE INTERACTIONS

+SCALING FACTOR

HIERARCHY OF MAGNETOSPERIC SCALES



Comparative Magnetospheres

MAGNETOSPERES OF HABITABLE EXOPLANETS ??