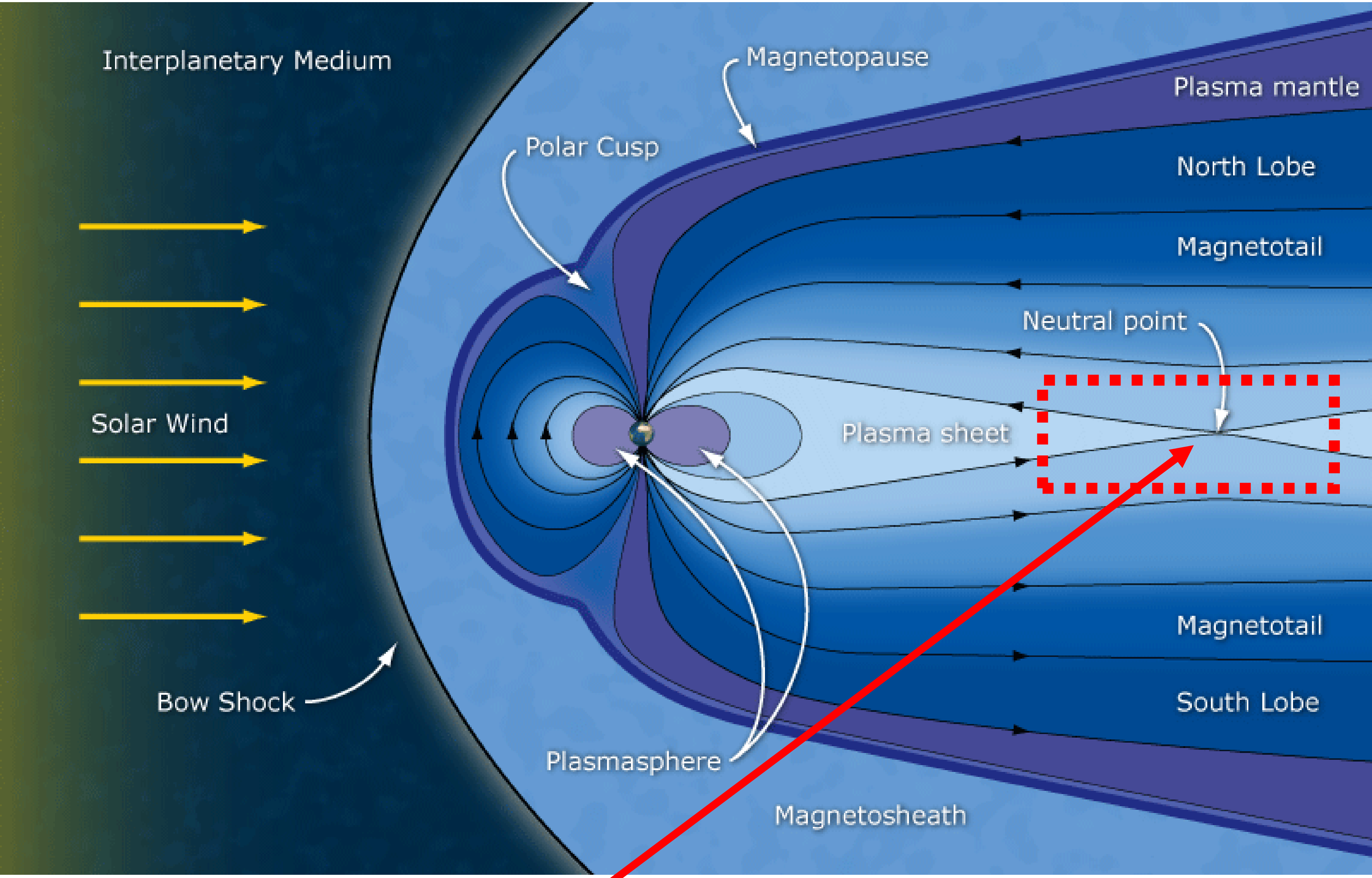
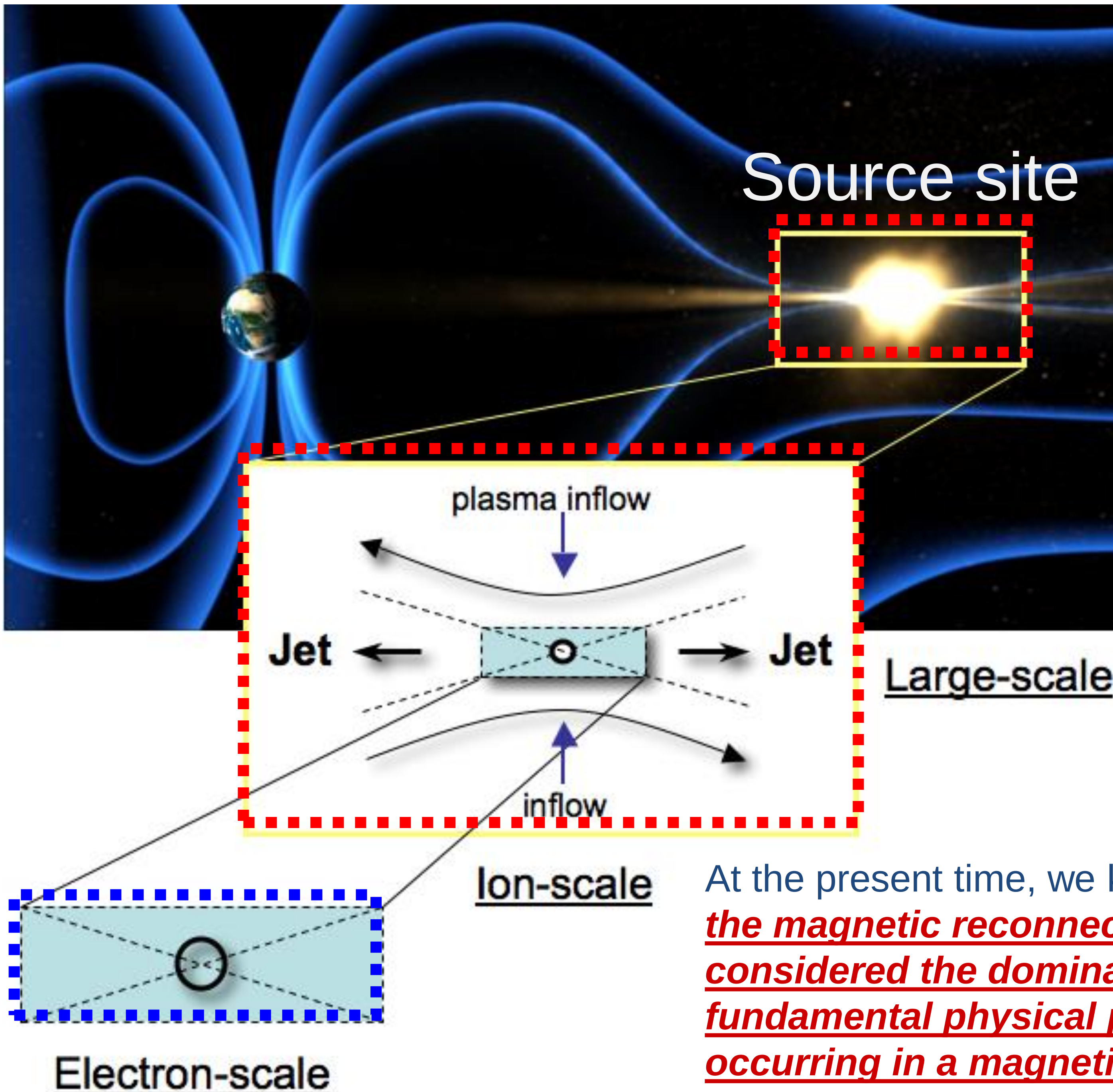
Anatomy of the Pulsating Double Layer Source in the Earth's Magnetotail

for the first time,
we propose the whole procedure
of source evolution leading to a cyclic mode
composed of two alternating and distinct phases.

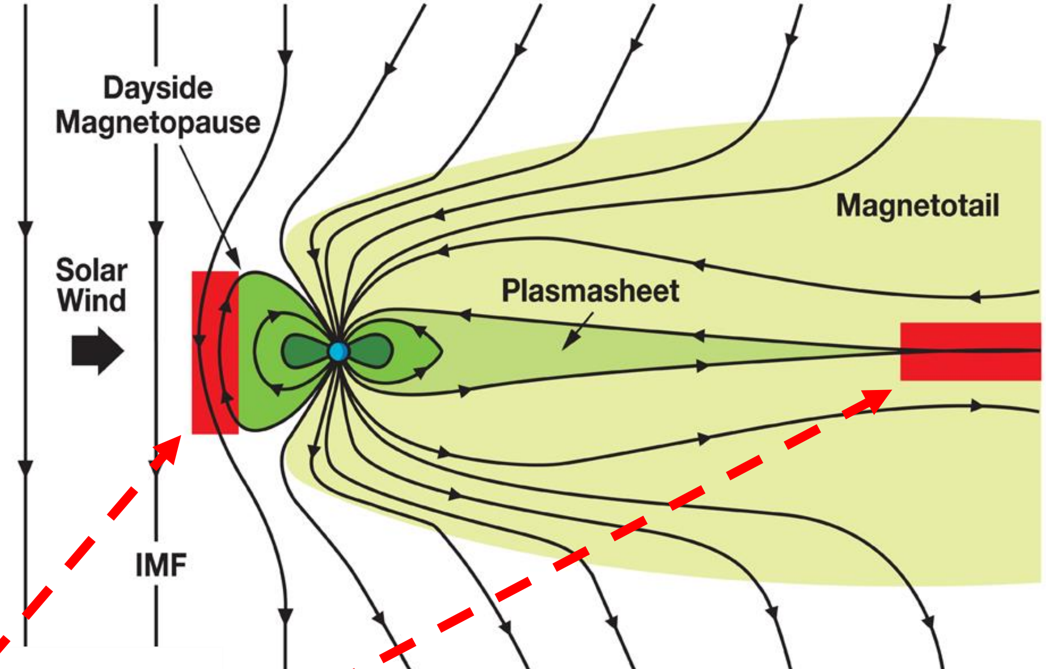
Sarafopoulos Dimitrios,
Demokritus University of Thrace, Greece

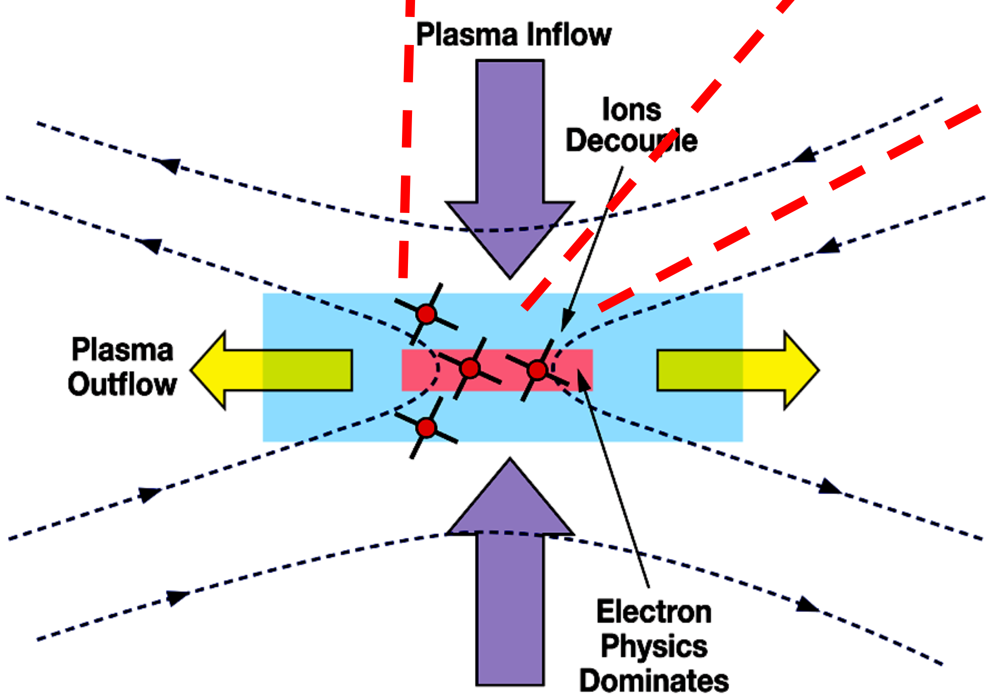


Source site, The “Twin-DL structure”



At the present time, we know that ***the magnetic reconnection is considered the dominant and fundamental physical process occurring in a magnetized plasma***





The Magnetospheric Multiscale (MMS) mission

12 March, 2015

is comprising four identically instrumented spacecraft, in order to understand the microphysics of **magnetic reconnection** by determining the kinetic processes occurring in the electron diffusion region that are responsible for collisionless magnetic reconnection, especially how reconnection in initiated.

We mention that,

Hannes Alfvén

(1908-1995, Nobel prize 1970)

was explicit in his condemnation of the reconnection concept. He characterized it as an

"erroneous concept"

and the relative magnetospheric and solar wind physics as a

"pseudoscience".

IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. PS-14, NO. 6, DECEMBER 1986 1986

Double Layers and Circuits in Astrophysics

HANNES ALFVÉN, LIFE FELLOW, IEEE

....

B. Magnetic Merging—A Pseudoscience

Since then I have stressed in a large number of papers the danger of using the frozen-in concept. For example,

....

viously erroneous concept. Indeed, we have been burdened with a gigantic pseudoscience which penetrates large parts of cosmic plasma physics. The monograph [5] treats the field-line reconnection (merging) concept in sections I.3, II.3, and II.5. We may conclude that anyone who uses the merging concepts states, by implication, that no double layers exist.

could DLs be formed in the Earth's magnetotail

(???)

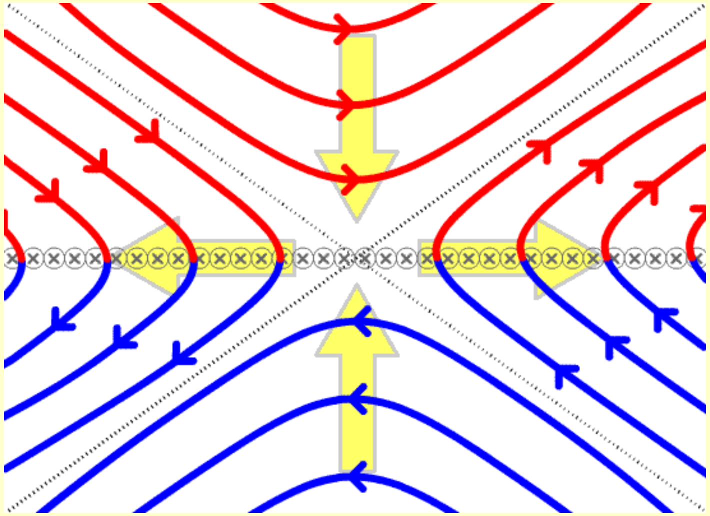
could DLs produce energetic particle populations in the Earth's magnetotail

(???)

Probably YES

The X-type reconnection reconfigurates the magnetic field.

Is it the mechanism converting magnetic energy into energetic particles ??



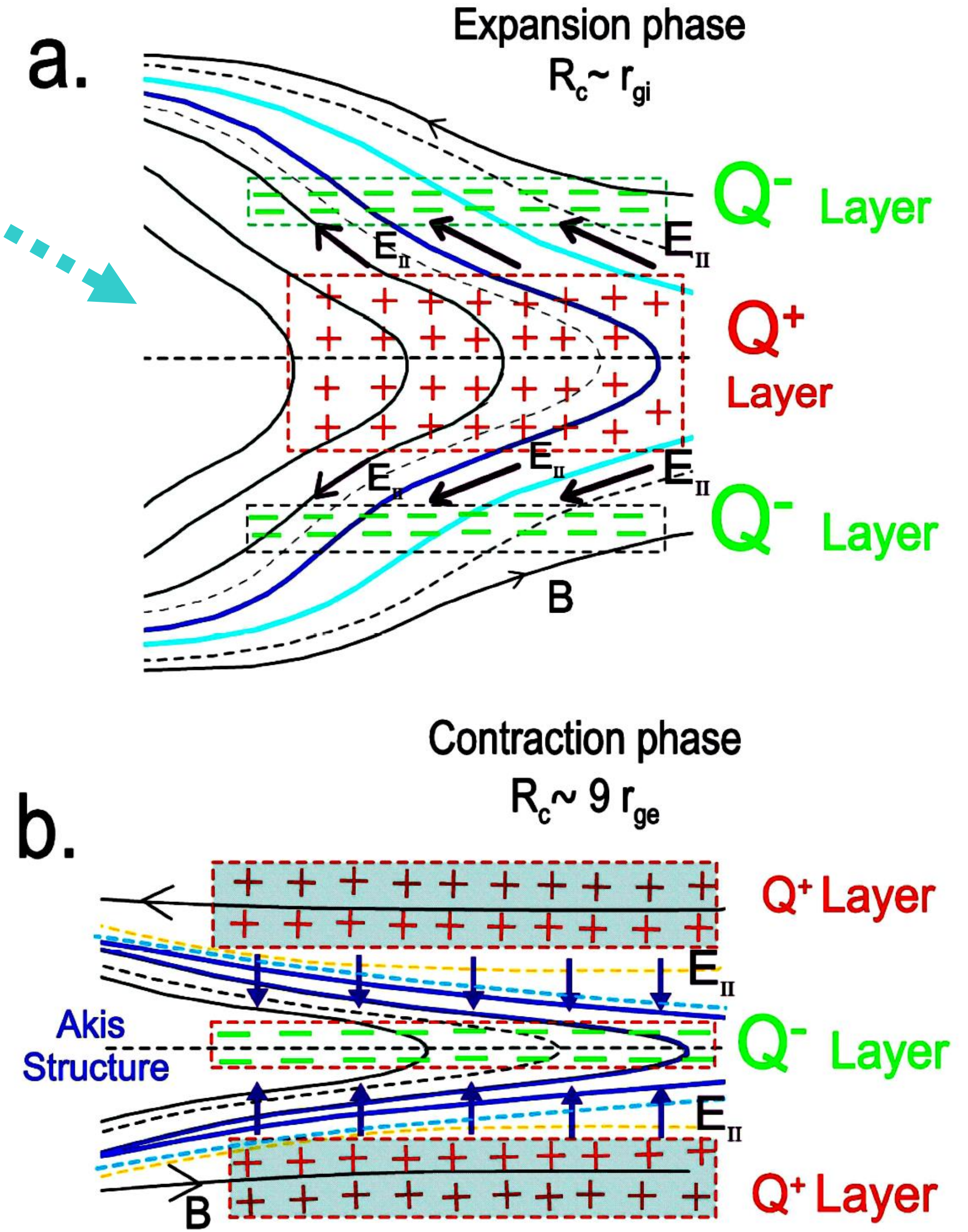
"Reconnection is commonly considered to be a means for accelerating particles to high energies. … It is thus interesting that *no such particles have been reported for the solar wind reconnection events* [at the magnetopause]."

Paschmann, 2008, p. 5.

the ***Twin-DL*** *source is characterized by*

a cyclic mode **composed of two alternating and distinct phases**

(a *bistable structure-mechanism* like a flip-flop with two stable states)



Mechanical analogous

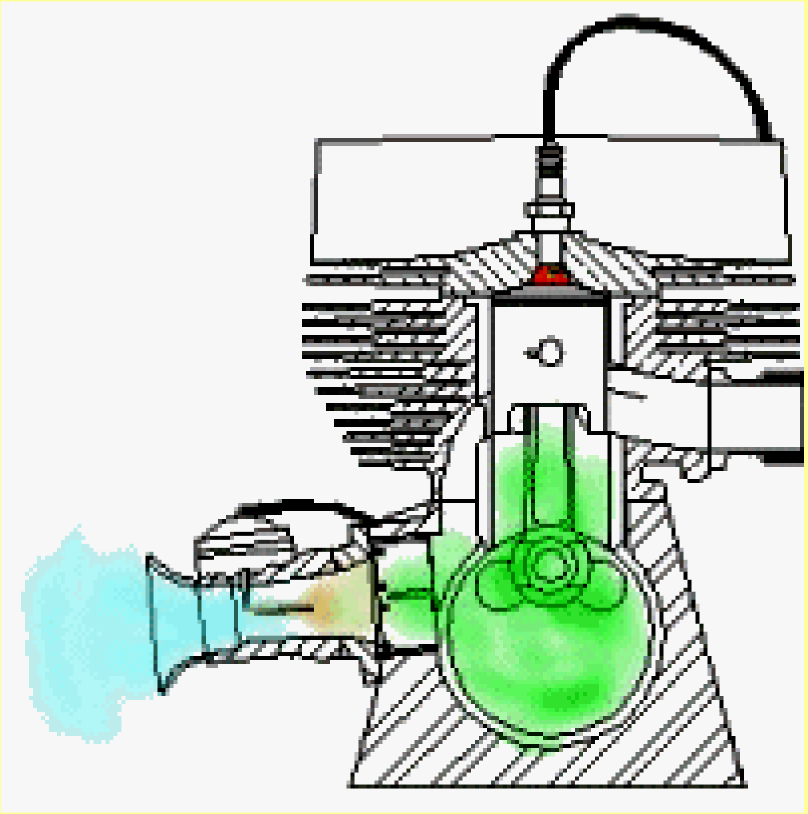
A **two-stroke** or

two-cycle engine

is a type of

internal combustion engine

which completes a power cycle in only one crankshaft revolution and with two strokes, or up and down movements, of the piston. This is accomplished by the end of the combustion stroke and the beginning of the compression stroke happening simultaneously and performing the intake and exhaust functions at the same time.



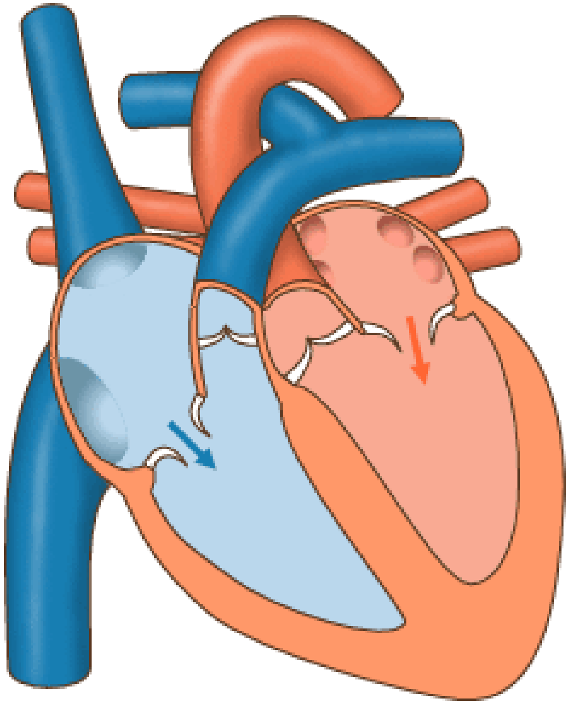
Cardiac cycle

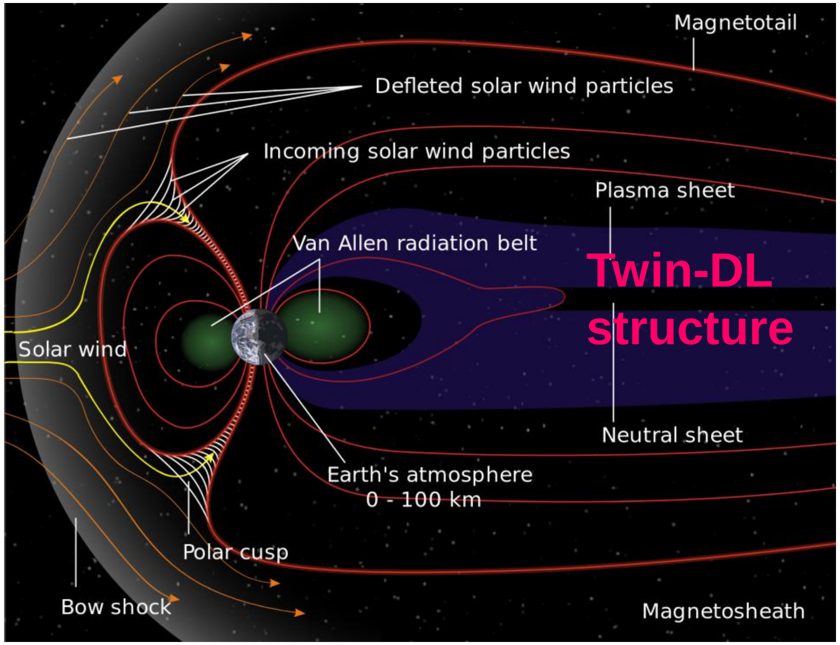
The **cardiac cycle** refers to a complete heartbeat from its generation to the beginning of the next beat, and so includes the

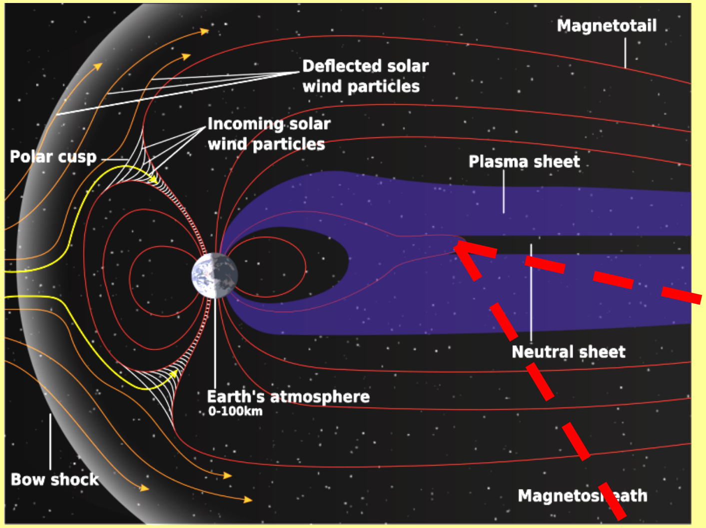
diastole / systole

and the intervening pause heart rate.

There is a transmission of a cardiac action potential through the heart's conduction system

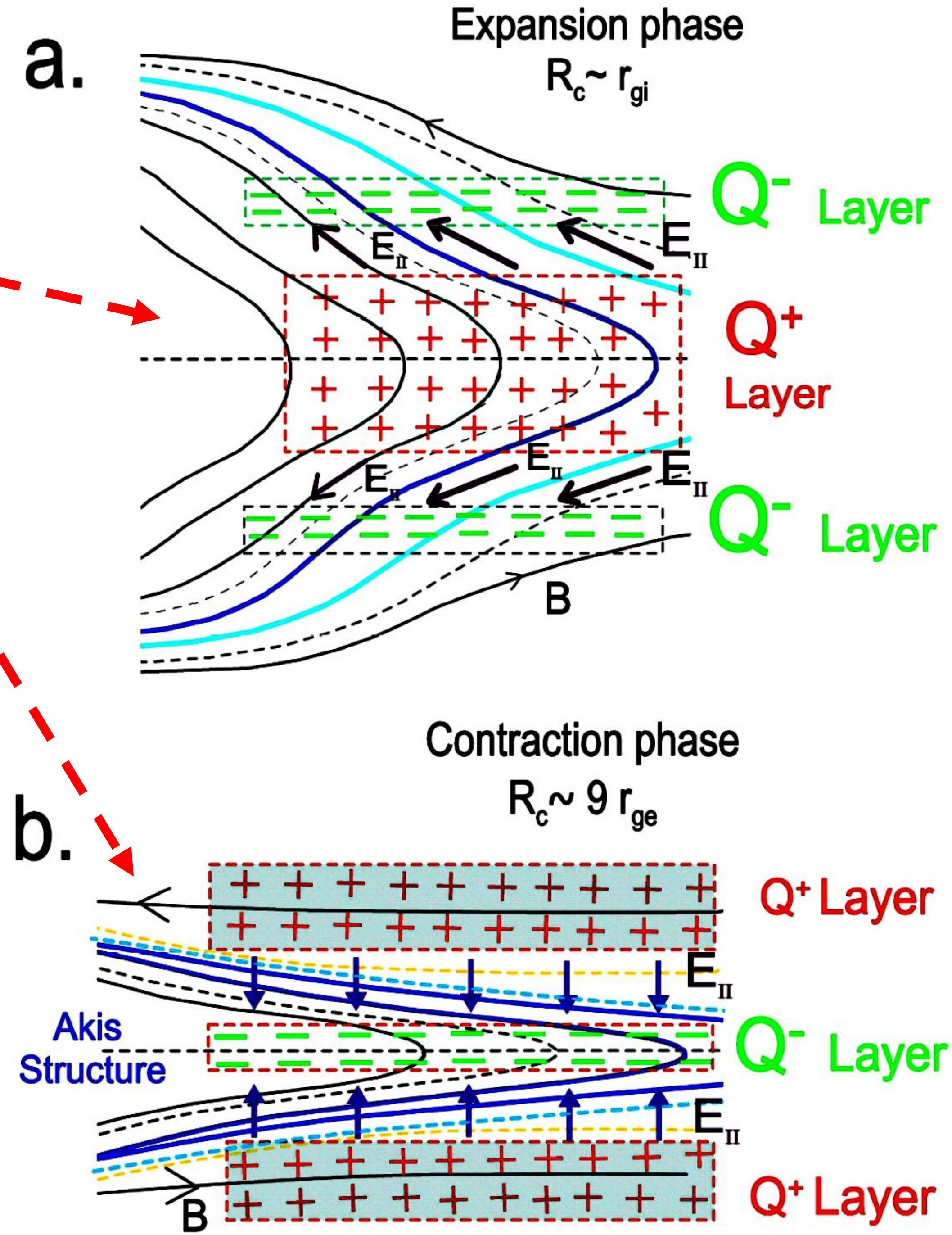






The major dfference between the two alternating and distinct phases is the ambipolar Electric Field.

The ambipolar electric field reverses its direction. We observe not only charge separation, but charge redistribution in each cycle as well.



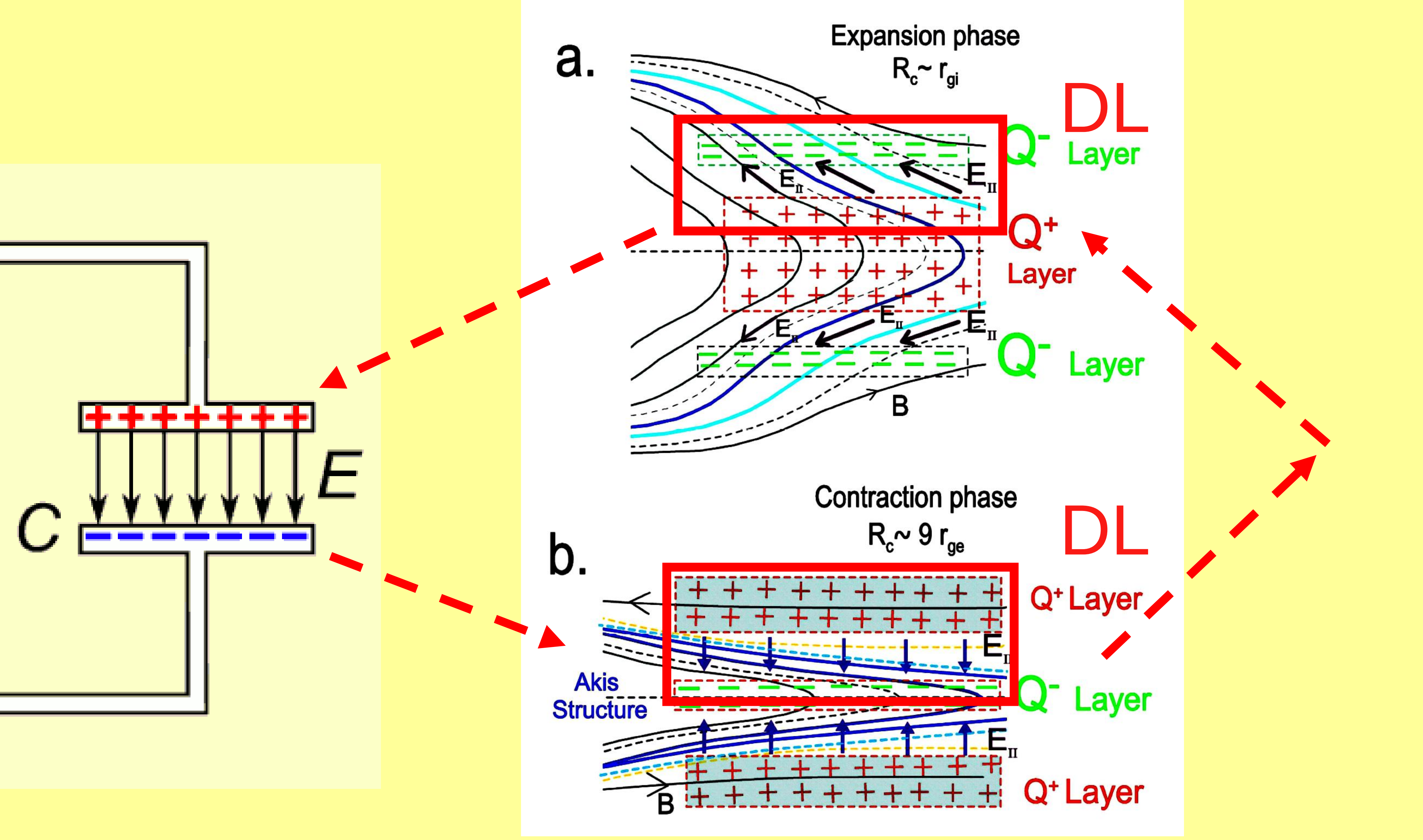


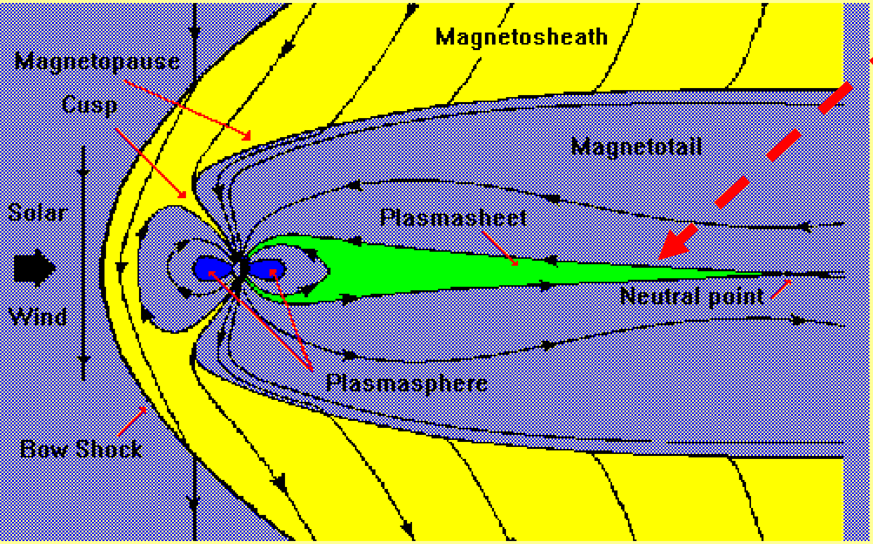
Fig. 8. Two distinct phases of the near-Earth PS corresponding to twin-DL structures with opposite polarities. The PS locally oscillates from the one phase to the other and vice versa, in many cycles repetitively. (a) The expansion phase ($R_c \simeq r_{gi}$) and (b) the contraction phase ($R_c \simeq 9r_{ge}$) are essentially associated with different geometries and functions of the akis structure.

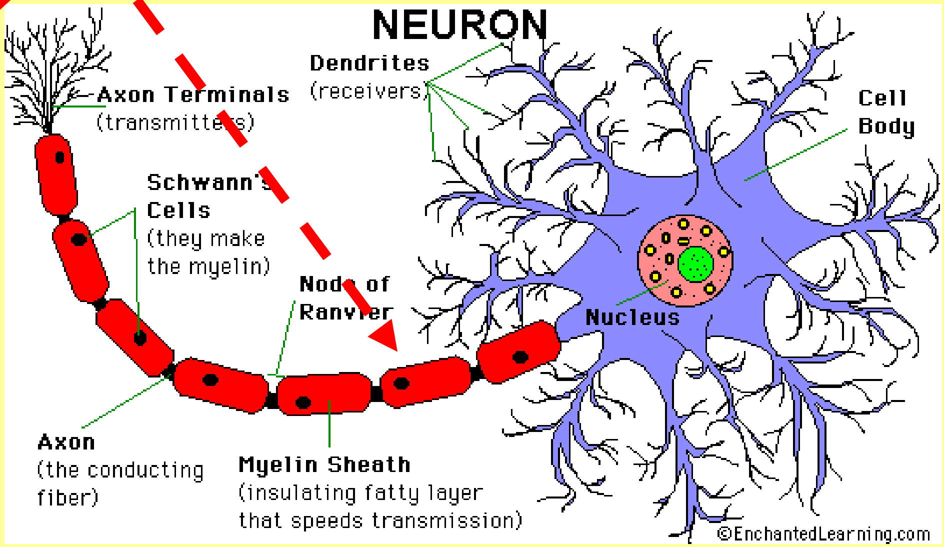
In the twin-DL structure we observe a

Polarization*, and then a*

Depolarization-Repolarization CYCLE,

like the one in a neuron cell.



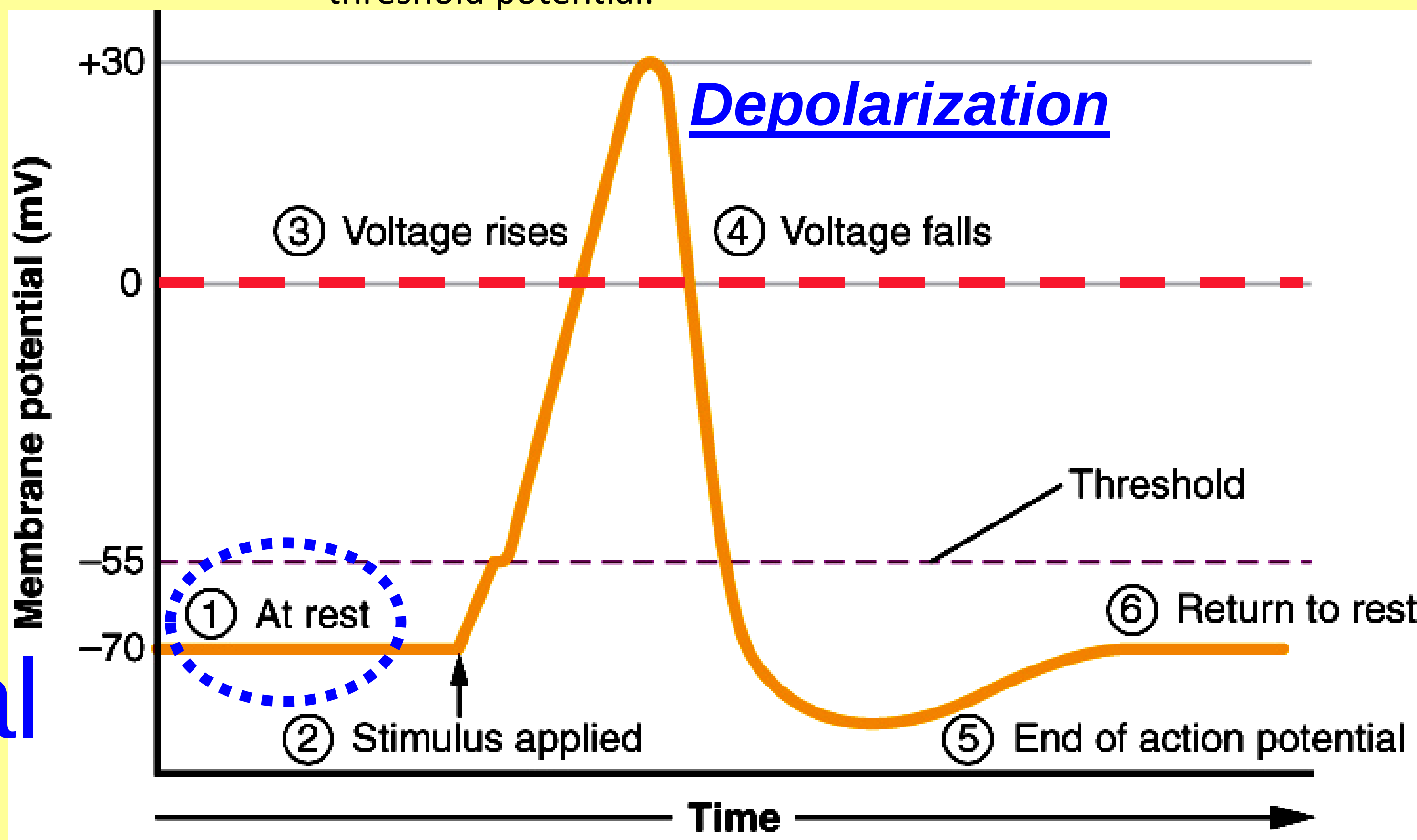


That is, we observe a

depolarization/Repolarization

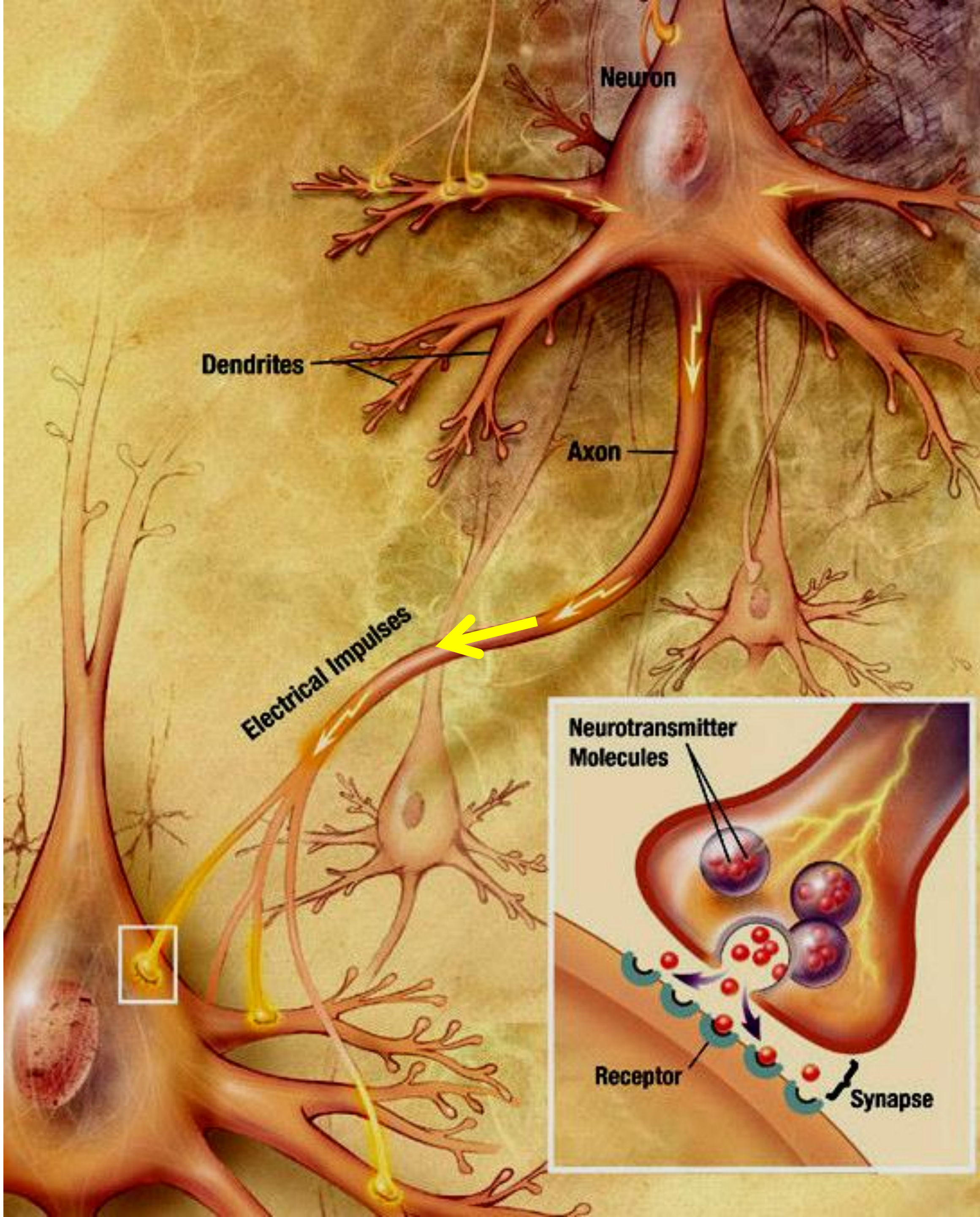
like the one in a neuron cell.

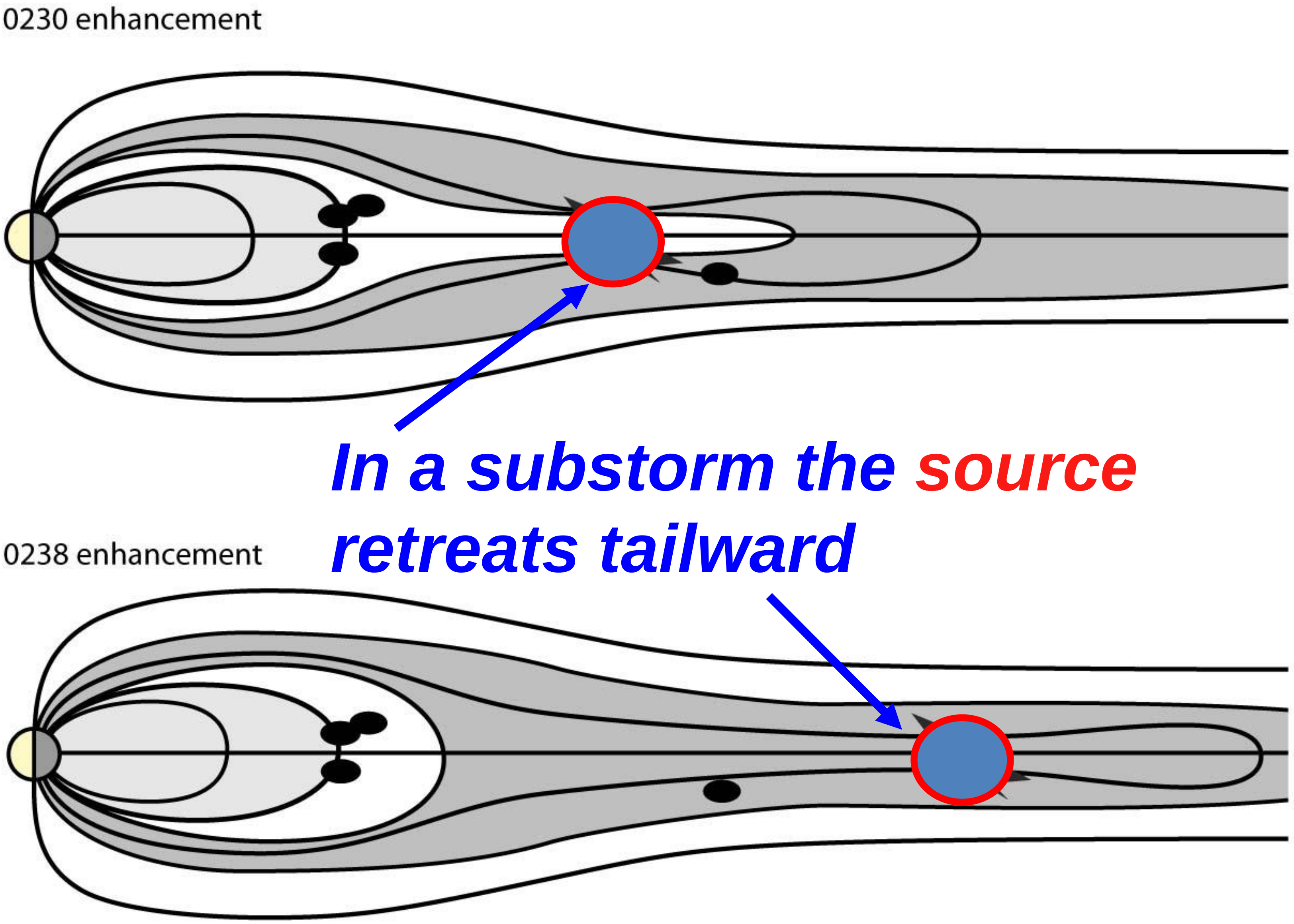
If, for example, a cell has a resting potential of –70mV, once the membrane potential changes to –50mV, then the cell has been depolarized. ***Depolarization is often caused by influx of cations, e.g. Na+ through Na+ channels***. These (voltage-dependent ion) channels open when an action potential begins, or at the threshold potential.



Resting Potential

A signal propagating down an axon to the cell body and dendrites of the next cell




0230 enhancement
In a substorm the source
retreats tailward
0238 enhancement

Have we observed a pulsating source?

We present only three events
occurring in central plasma sheet, in which **the Bz component of the magnetic field demonstrates a quasi-periodic** response
with periodicity T=15-60 s.

The negative Bz represents the most crucial parameter associated with an ACTIVE SOURCE.

For the following events the plasma persistently flows tailward.

the negative Bz represents the most crucial parameter that underlines the strong contrast to the normal magnetotail topology always characterized by positive Bz values.

B_z=0

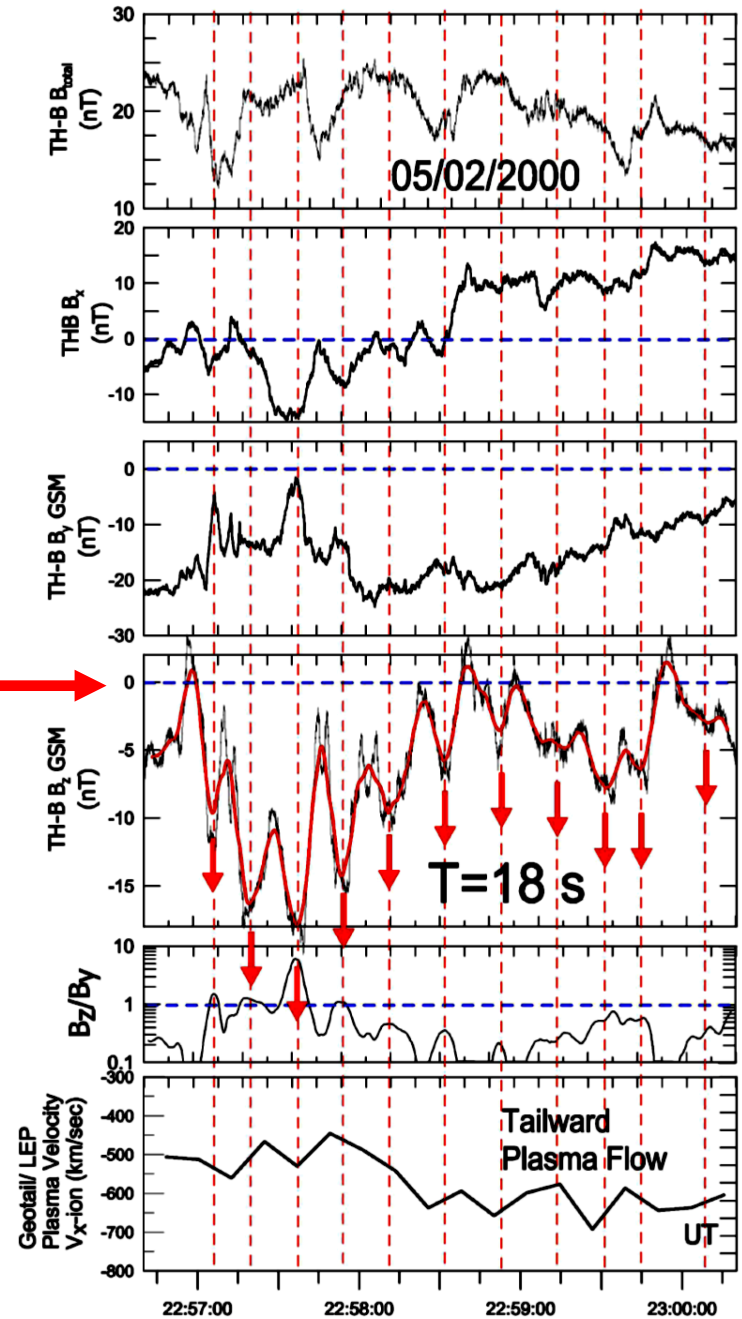
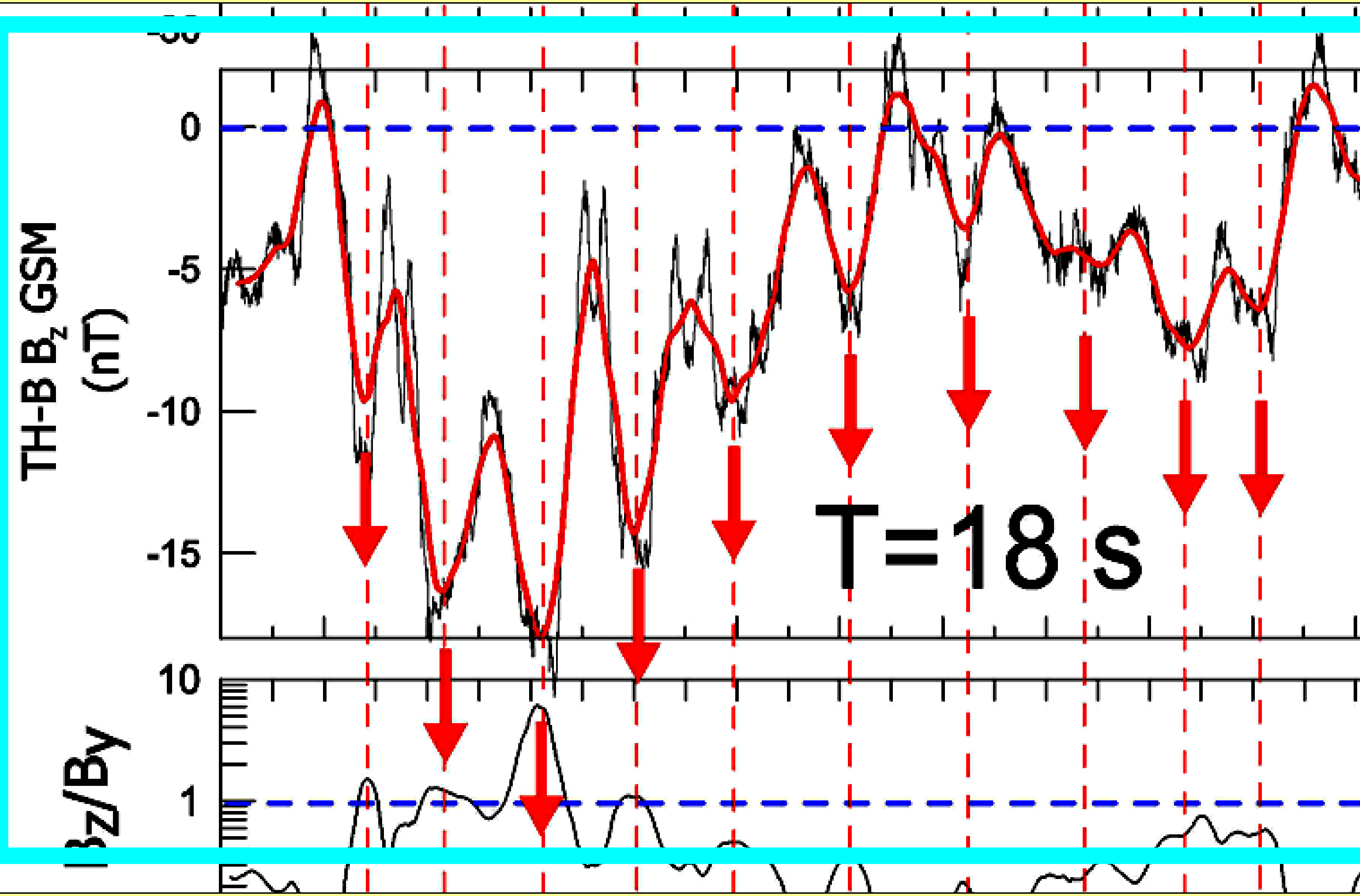


Fig. 1. Magnetic field components (in nTs) along with the V_x component of plasma velocity (in km s^{-1}) for an event occurred on 5 February 2000. The (marked with arrows) negative and quasi-periodic variations of B_z are characterized by T=18 s, while the plasma flows tailward.



0
-5
-10
-15
TH-B B_z GSM (nT)
T=18 s
10
1
B_z/B_y

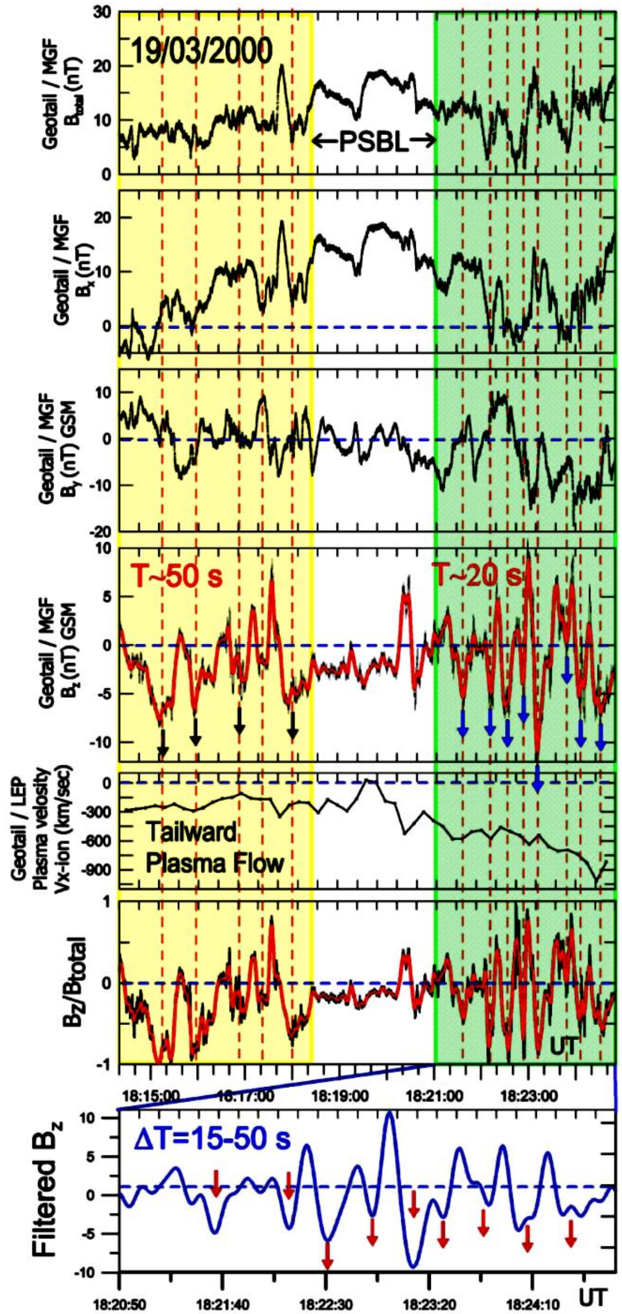
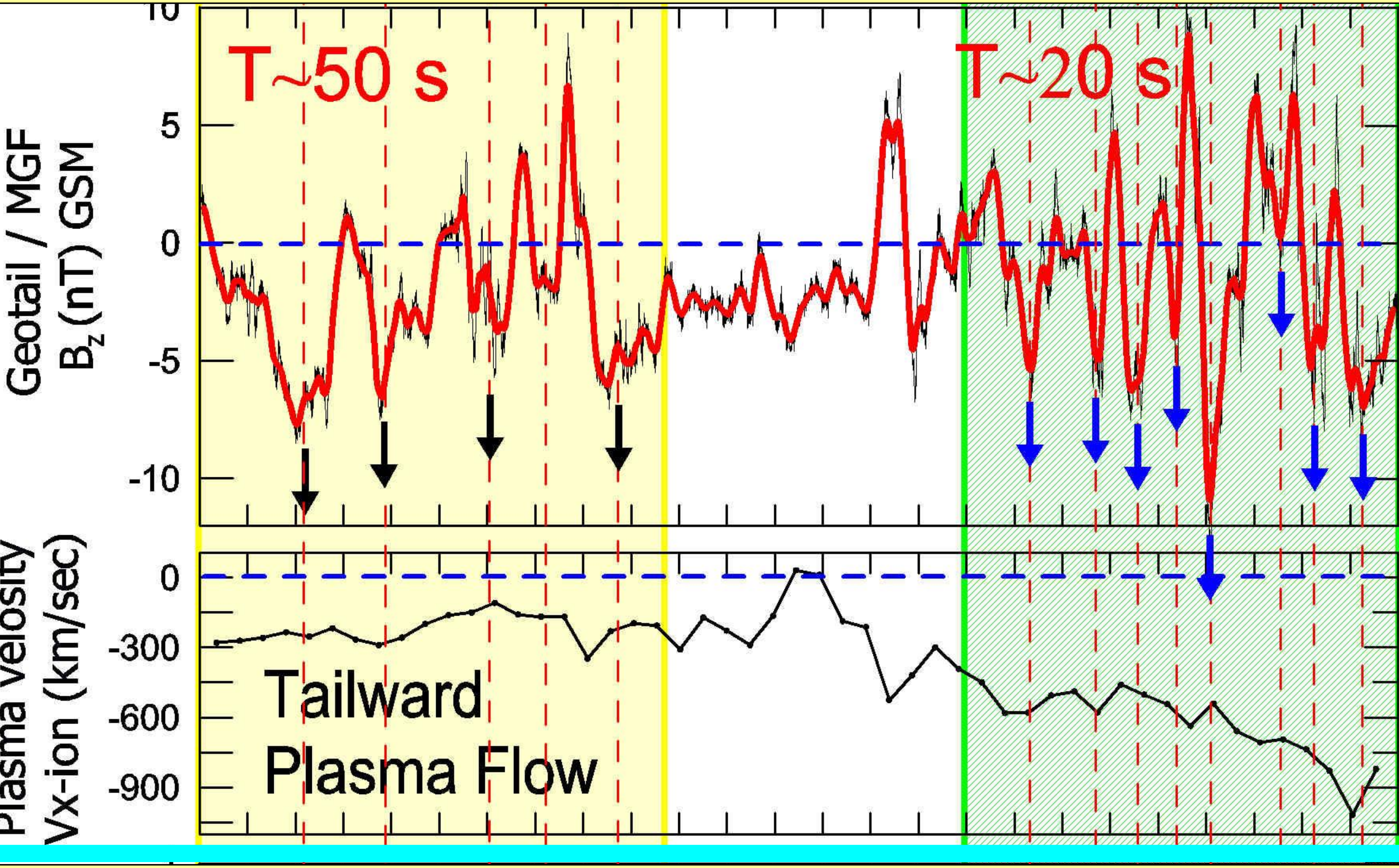


Fig. 3. Similar format as in Fig. 1 for an event recorded on 19 March 2000. The negative and quasi-periodic variations of B_z with $T \cong 20$ s occur with higher tailward plasma velocities than those with $T \cong 50$ s. The amplitude of fluctuations is significant only in CPS.


T~50 s
T~20 s
Geotail / MGF
B_z (nT) GSM
10
5
0
-5
-10
Plasma velosity
Vx-ion (km/sec)
0
-300
-600
-900
Tailward
Plasma Flow

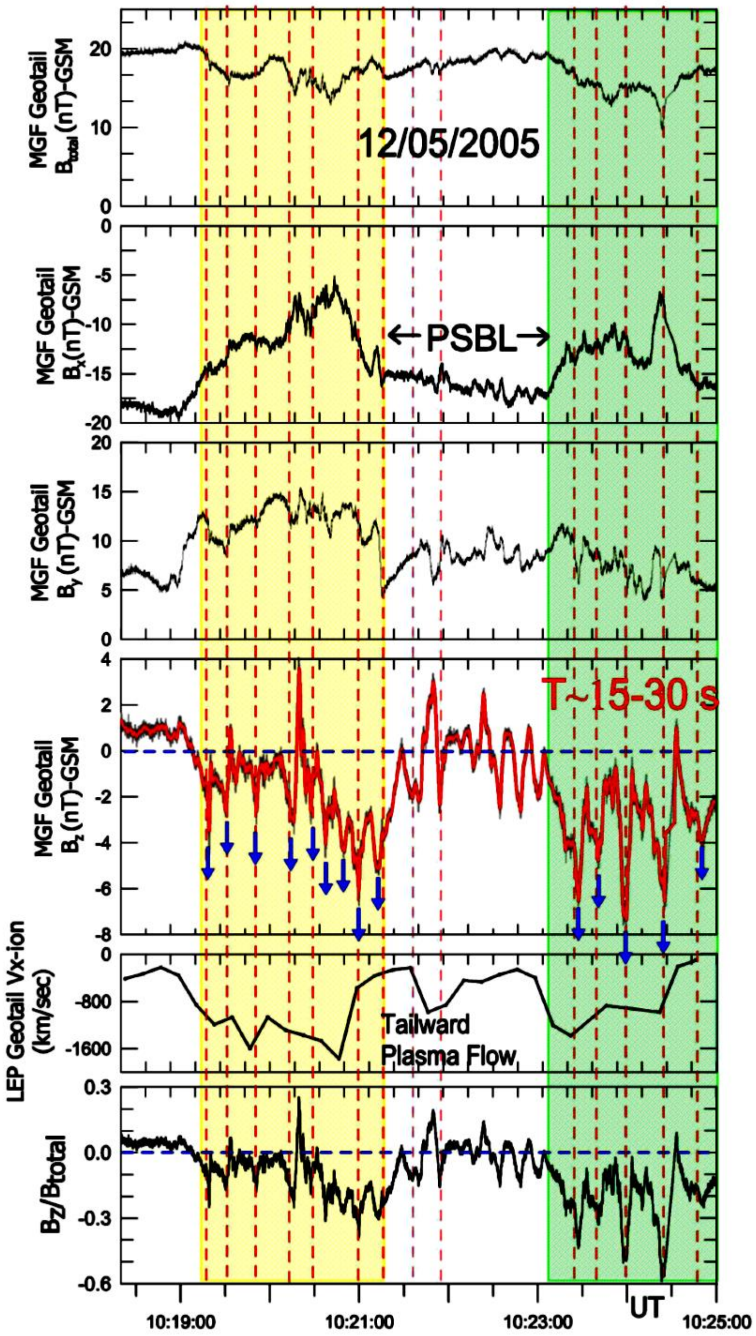
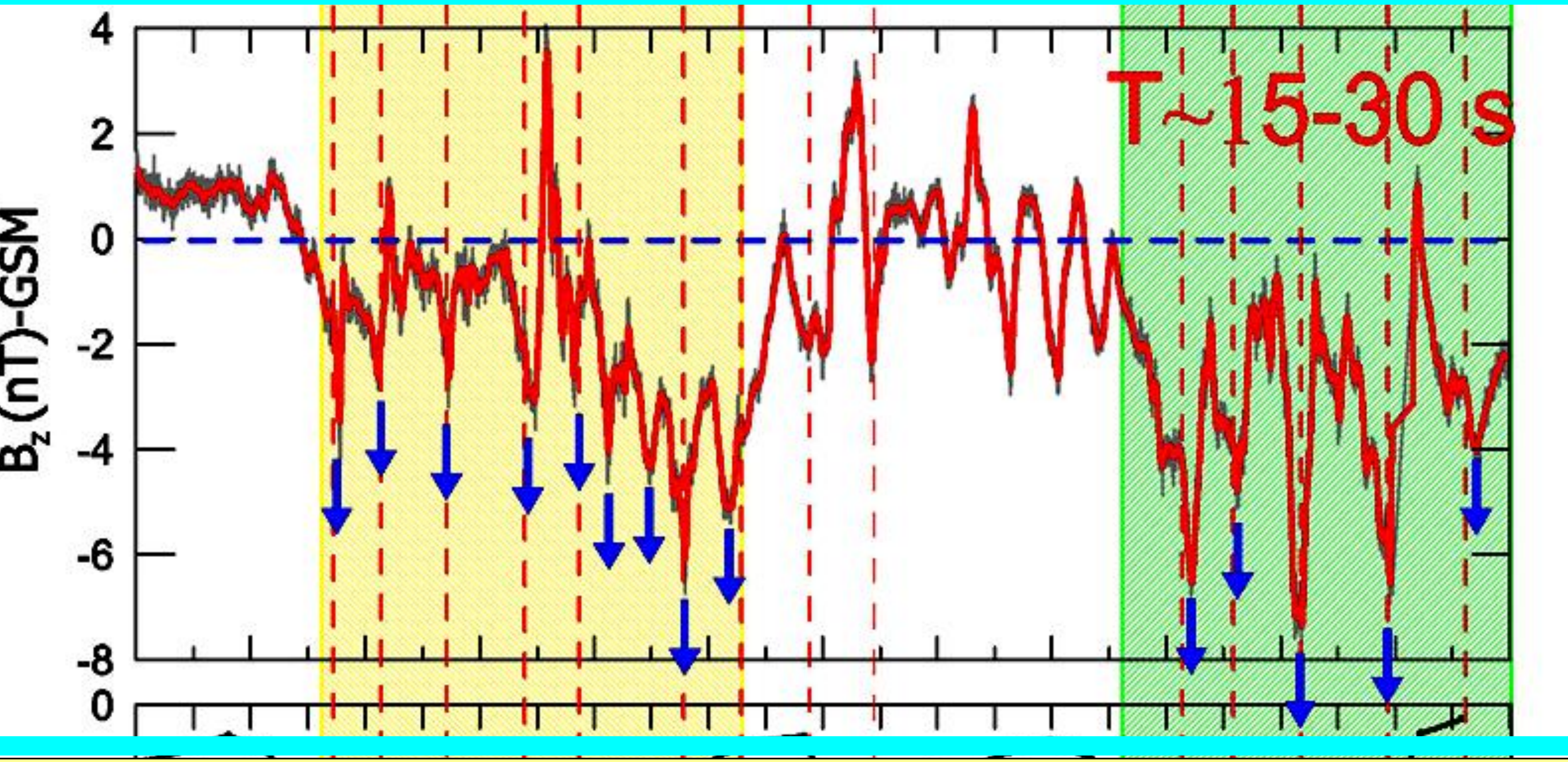
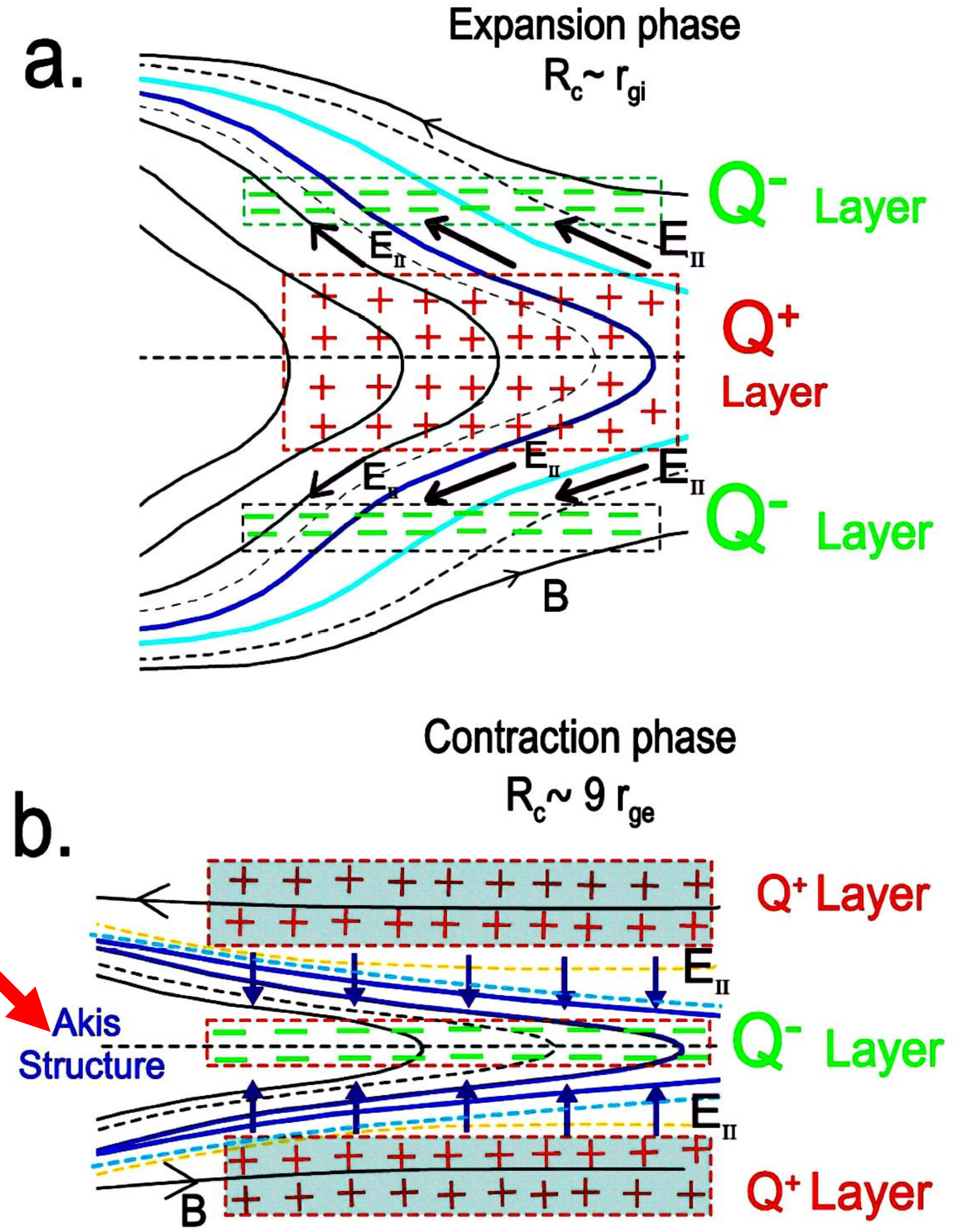


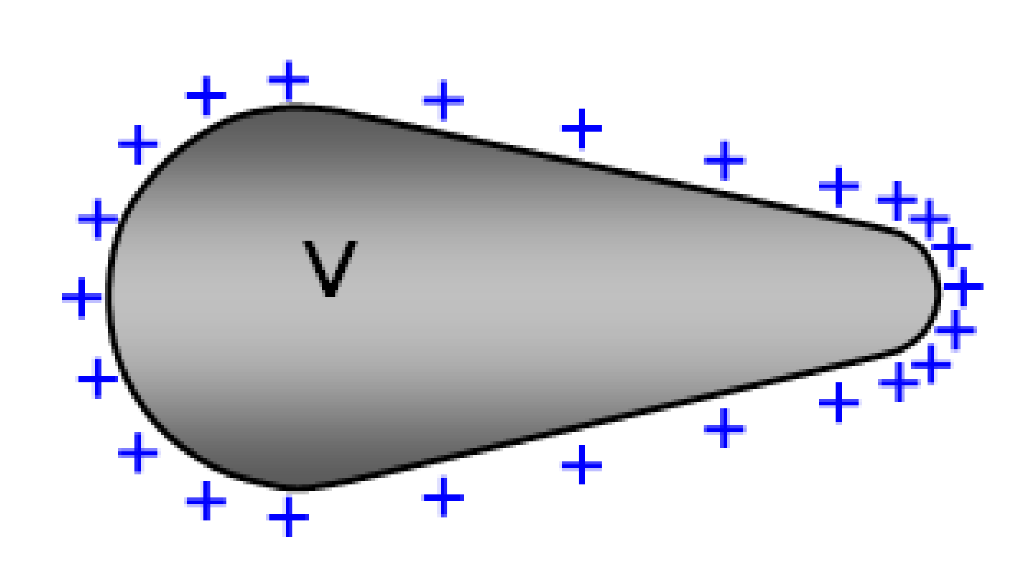
Fig. 5. Similar format as in Fig. 1 for an event recorded on 12 May 2005. The negative and quasi-periodic deflections of B_z with $T \cong 15$-30 s occur only in CPS, with tailward plasma velocities.

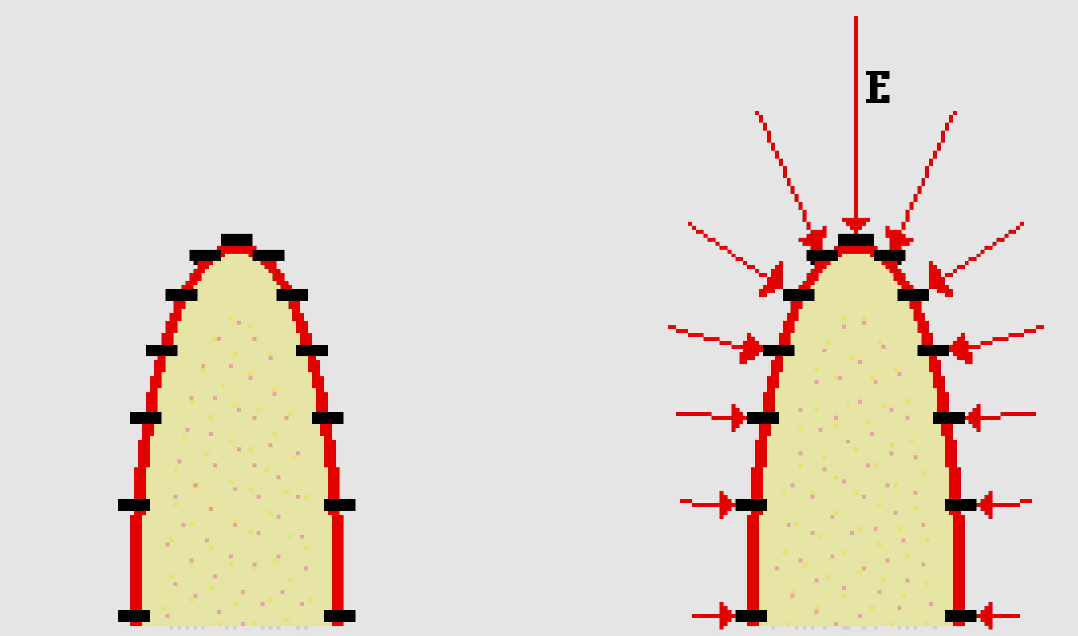

T~15-30 s
B_z (nT)-GSM
4
2
0
-2
-4
-6
-8
0

The <u>"akis structure"</u> is presumably a <u>precious structure</u> with novel features.



“Akis Structure”





Charge tends to accumulate in greater numbers at locations of greatest curvature. The electric field strength at these locations of greatest curvature is larger in magnitude.

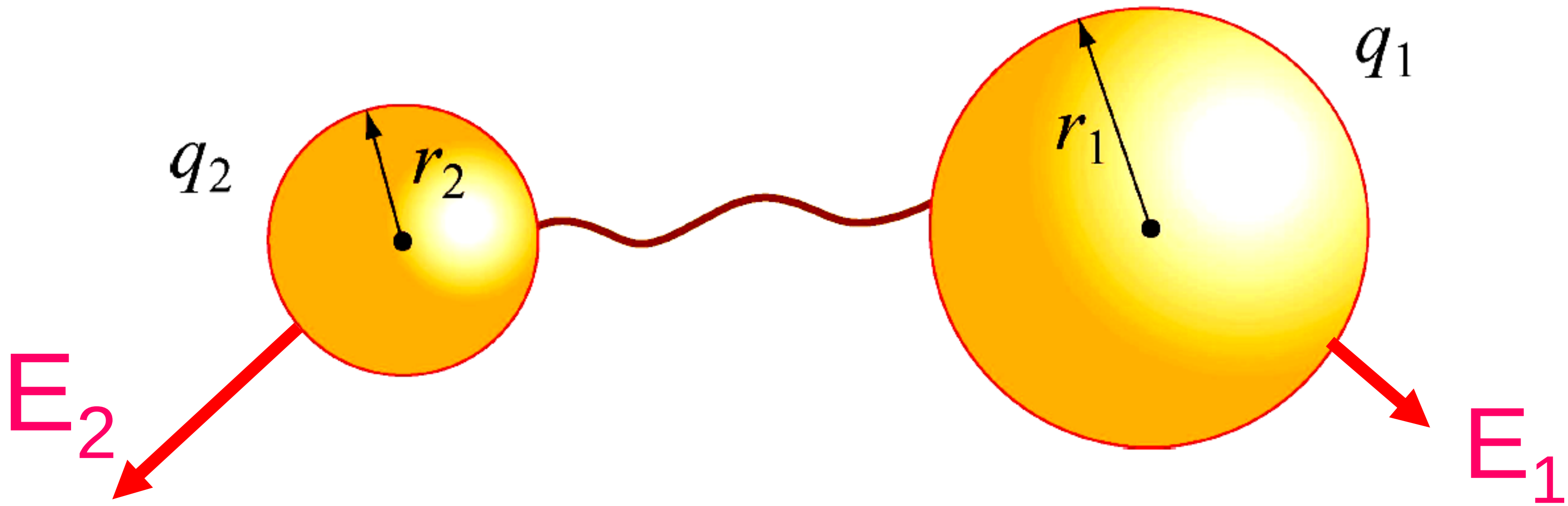
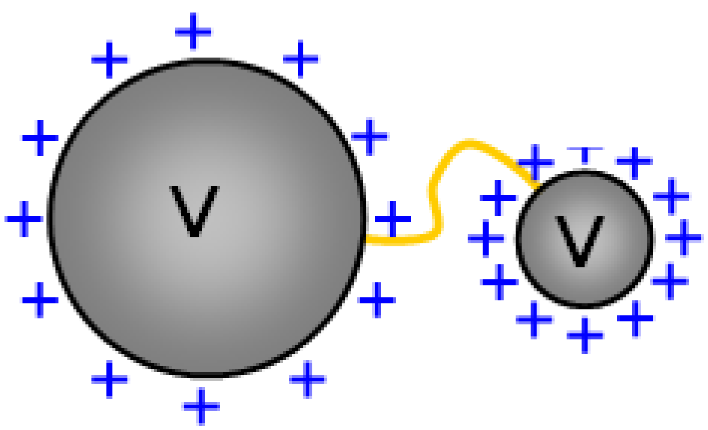


Figure 4.6.2 Two conducting spheres connected by a wire.



$$\frac{E_1}{E_2} = \frac{\sigma_1}{\sigma_2} = \frac{r_2}{r_1}$$

With the surface charge density being inversely proportional to the radius, we conclude that the regions with the smallest radii of curvature have the greatest σ. Thus, the electric field strength on the surface of a conductor is greatest at the sharpest point. The

Additionally

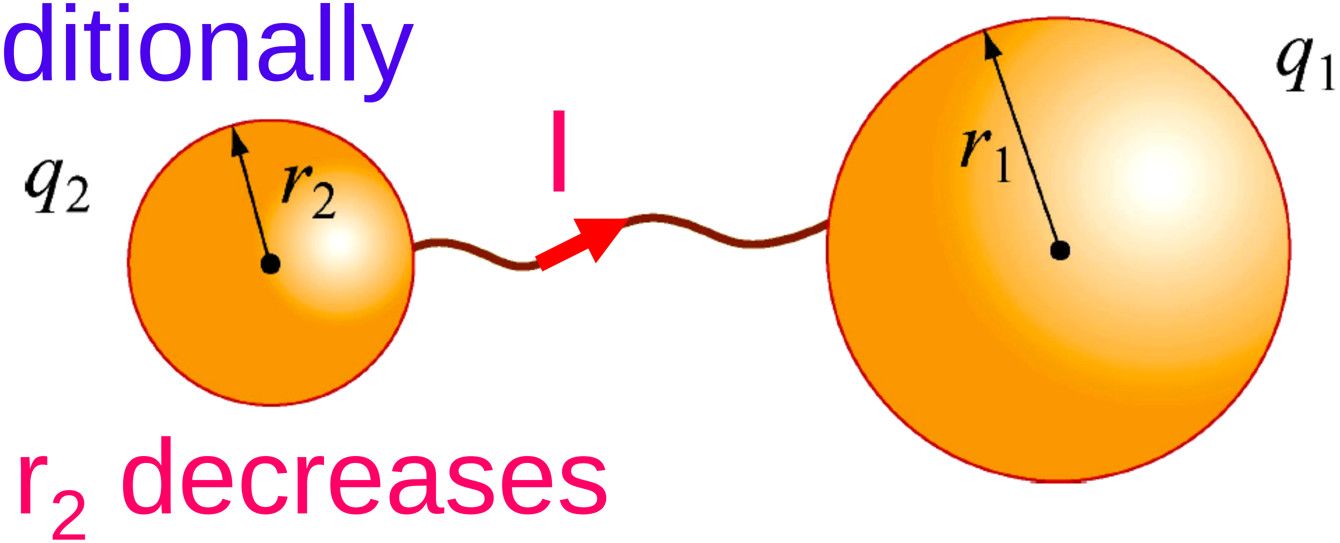
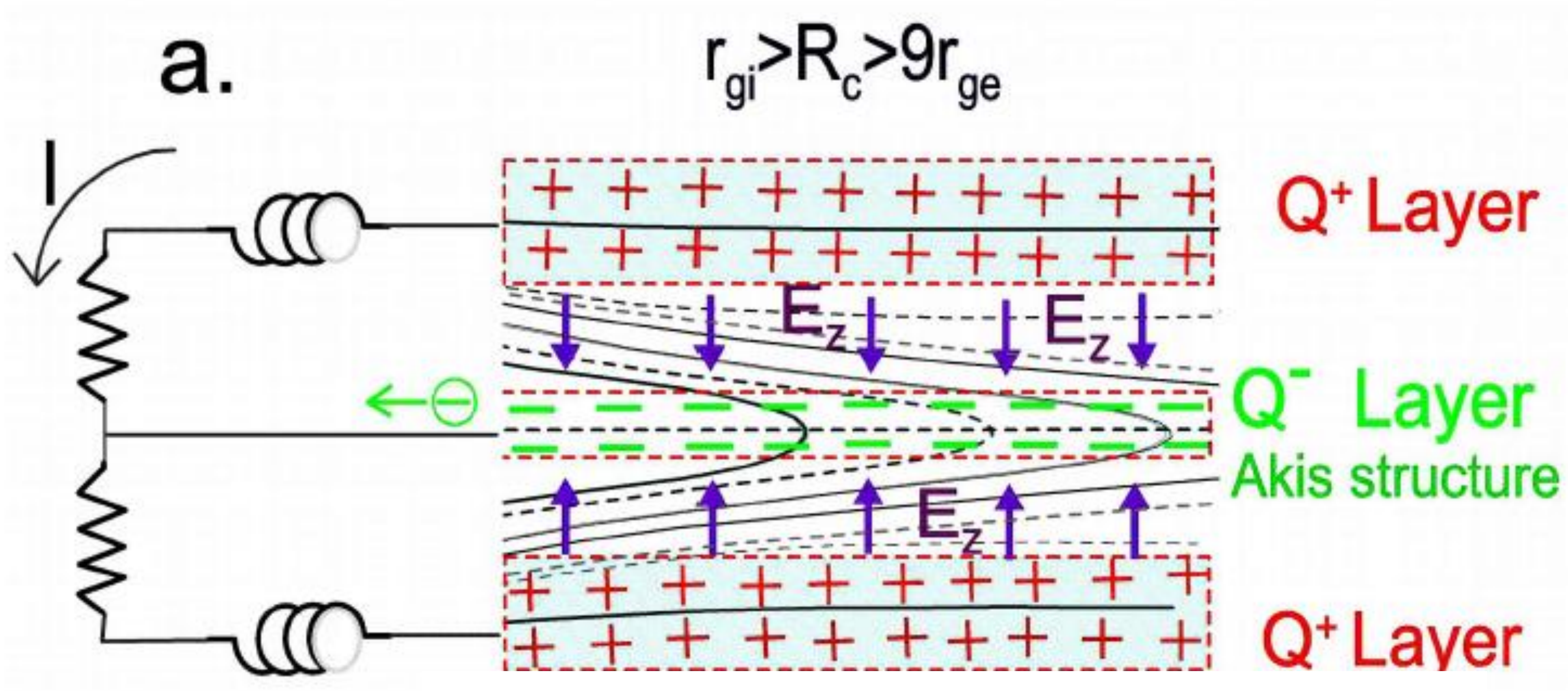


Figure 4.6.2 Two conducting spheres connected by a wire.

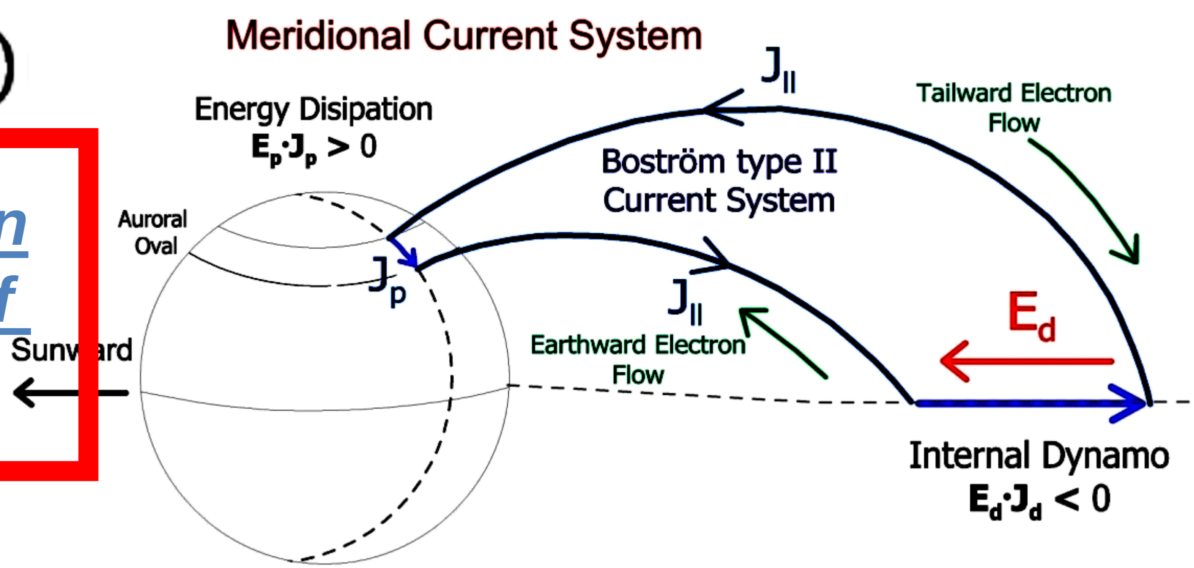
$$\frac{q_1}{r_1} = \frac{q_2 \downarrow}{r_2 \downarrow}$$

As the r_2 decreases the charge density σ_2 increases, while **a current flows towards the larger spherical conductor**



$$\mathcal{E}_L = -L(dI/dt)$$

Twin- DLs as an Integral Part of a Huge Circuit



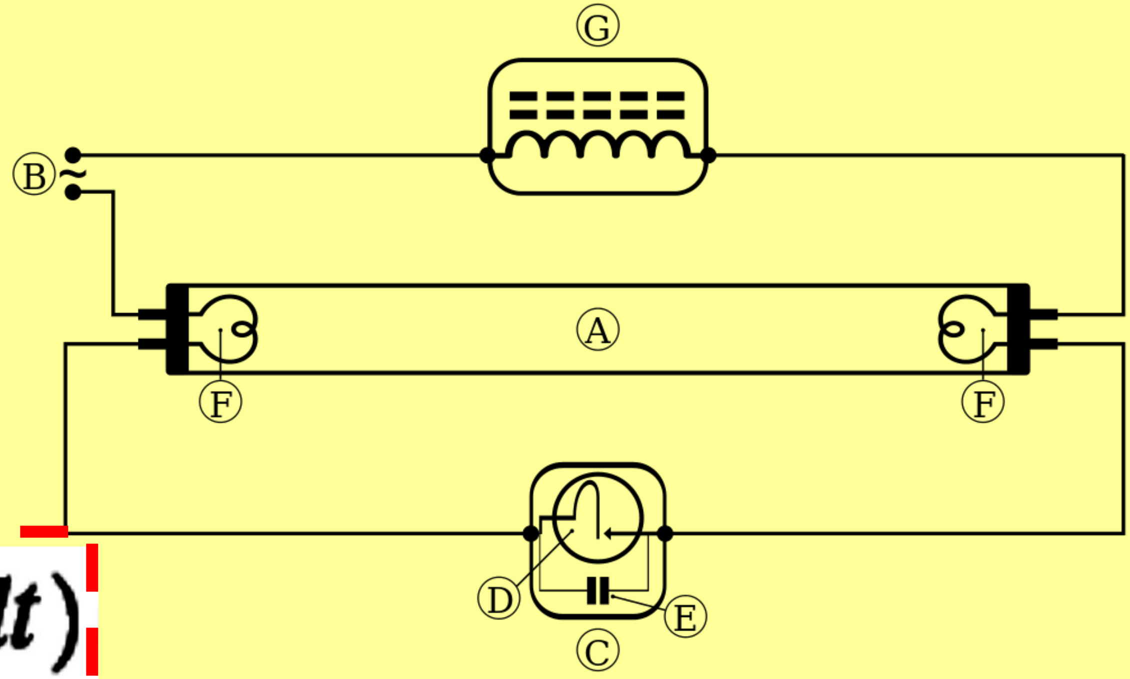
Every circuit which contains an inductance L is intrinsically explosive.

The inductive energy **$W_L = 1/2\ LI^2$** can be tapped at any point of the circuit. If we try to interrupt the current I, *the inductance tends to supply its energy to the point of interruption where the power $P = I\Delta V$ is delivered*

(ΔV is the voltage over the point of interruption and I the current at this point). This means that most of the

circuit energy may be released in a double layer, and if large, cause an explosion of the DL.

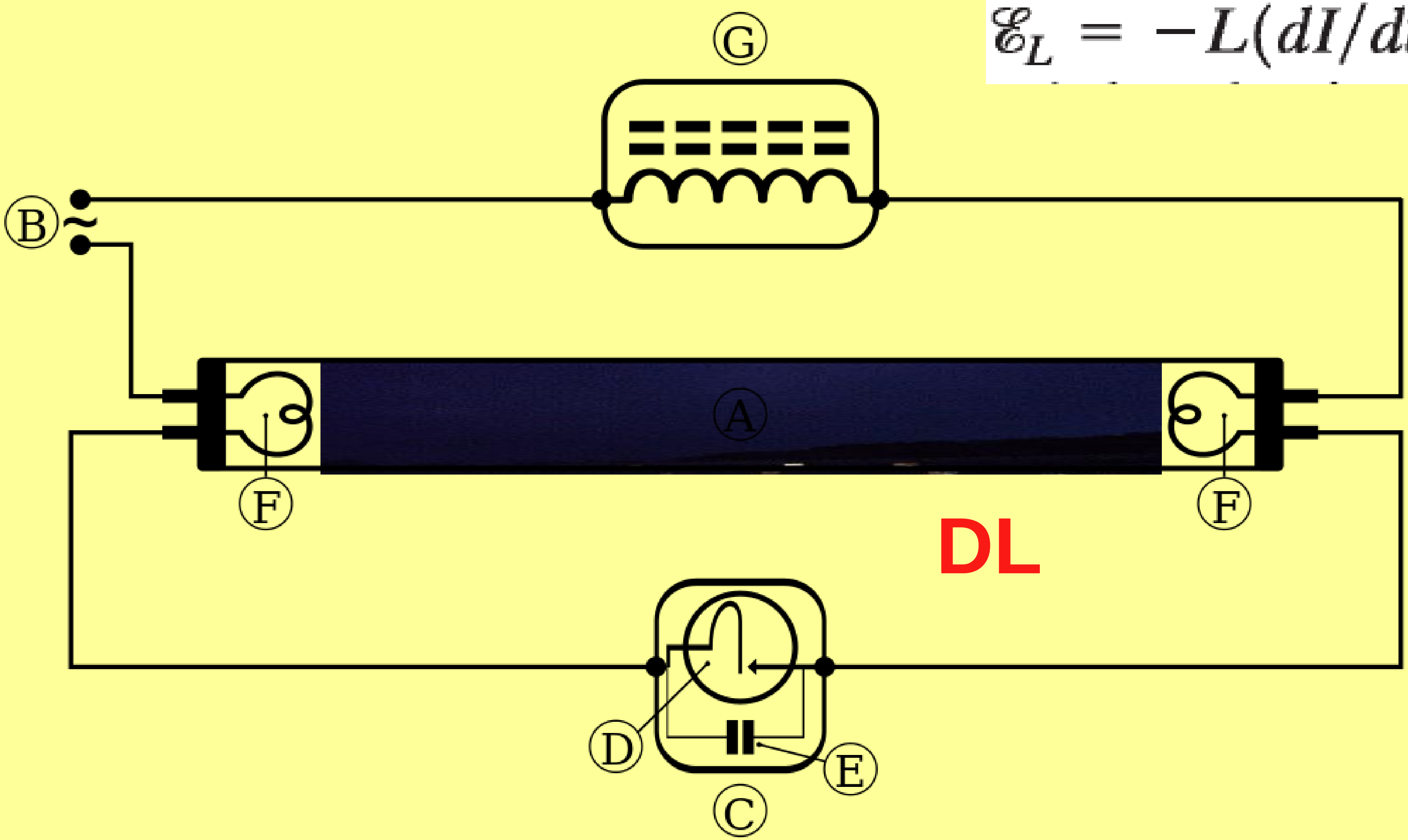
Fluorescent lamp



$$\mathcal{E}_L = -L(dI/dt)$$

When power is first applied to the circuit, there will be a **glow discharge** across the electrodes in the **starter lamp**. This heats the gas in the starter and causes one of the **bi-metallic contacts** to bend towards the other. When the contacts touch, the two filaments of the fluorescent lamp and the ballast will effectively be switched in series to the supply voltage. The current through the filaments causes them to heat up and emit electrons into the tube gas by **thermionic emission**. In the starter, **the touching contacts short out the voltage** sustaining the glow discharge, extinguishing it so **the gas cools down** and no longer heats the bi-metallic switch, which opens within a second or two. ***The current through the filaments and the inductive ballast is abruptly interrupted, leaving the full line voltage applied between the filaments at the ends of the tube and generating an inductive kick which provides the high voltage needed to start the lamp.***

$$\mathcal{E}_L = -L(dI/dt)$$



<u>The magnitude of the direct current has no influence on the magnitude of the induced emf; only the rate of change of the current counts.</u>

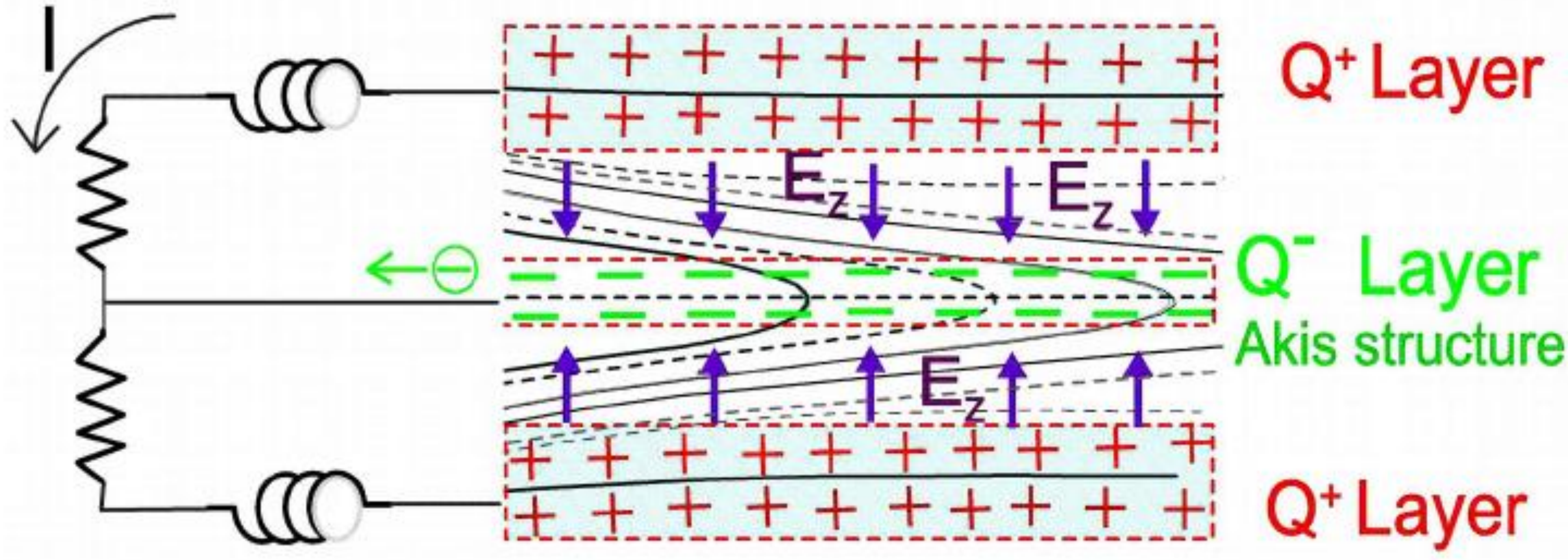
Ion energization

***An explosive phase is anticipated whenever an abrupt current reduction occurs in the huge magnetosphere circuit*.**

During this phase the ions will be jetting with significantly increased velocities.

$$V = LdI / dt$$

This potential drop may produce the populations of hundreds of keV detected in the Earth's magnetotail.



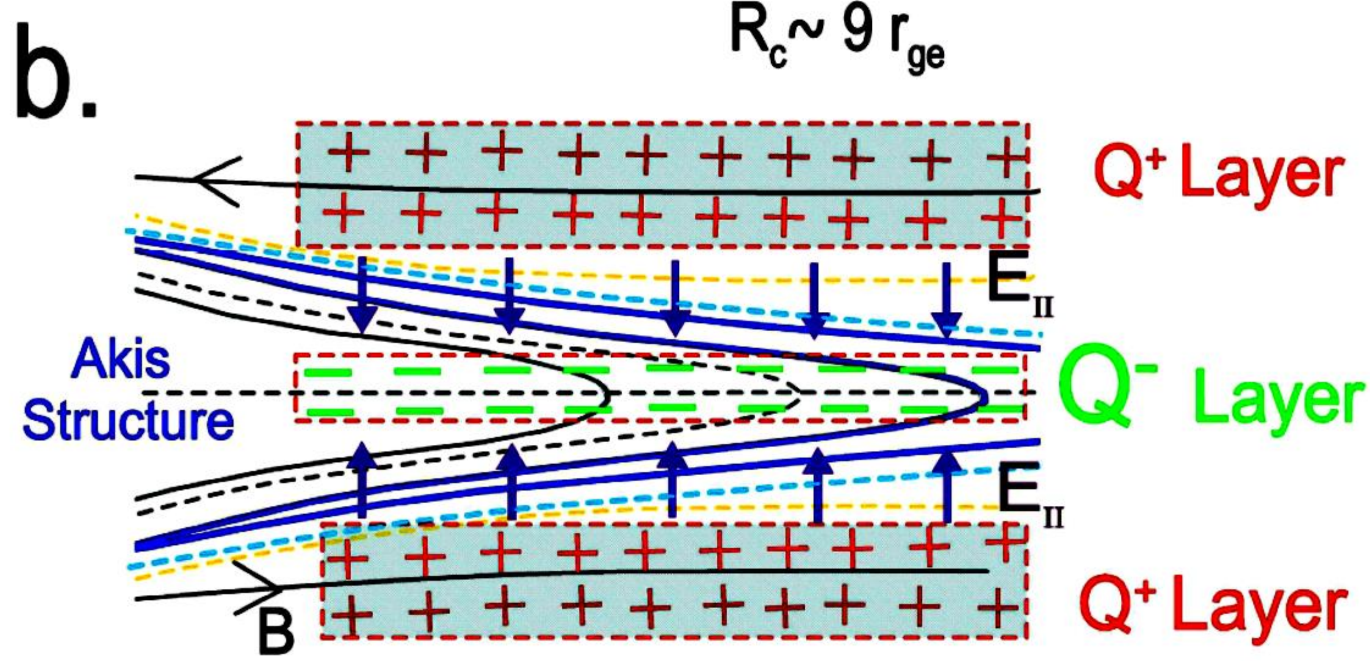
$$\mathscr{E}_L = -L(dI/dt)$$

What is determining the explosion condition??

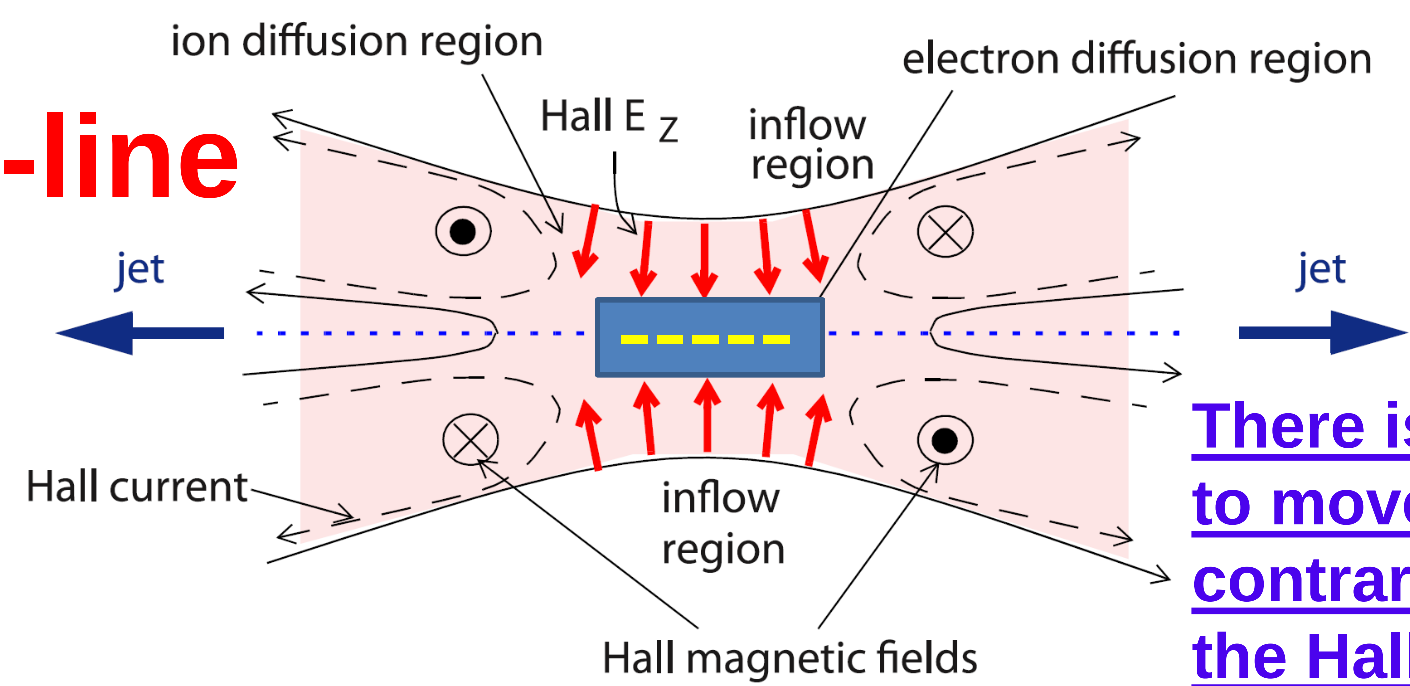
At the time, when the electron demagnetization rate abruptly increases,

at that very moment the Twin-DL system reaches its explosive phase.

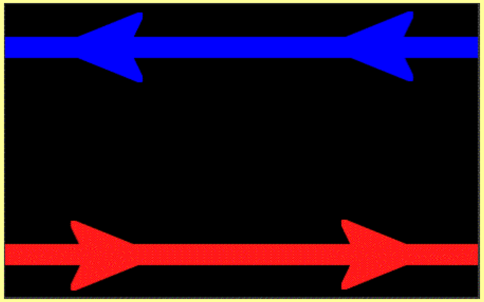
DLs



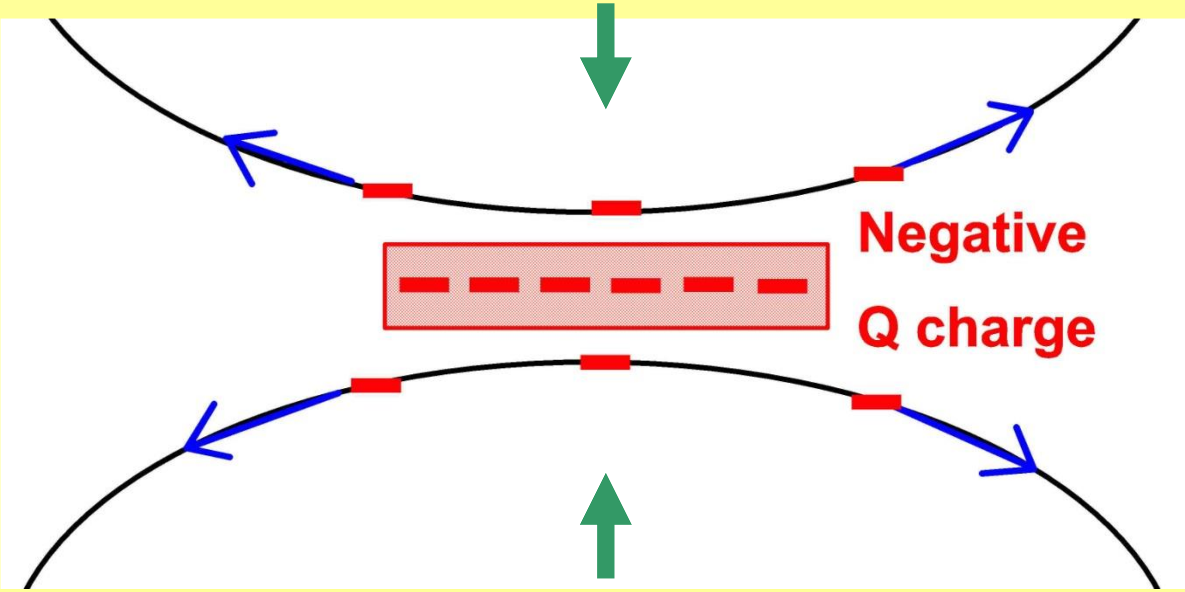
X-line



<u>**There is no way to move electrons contrary to the Hall Ez.**</u>



In the X-line model: The electrons will run away (along the magnetic field lines)
From the Electron Diffusion Region



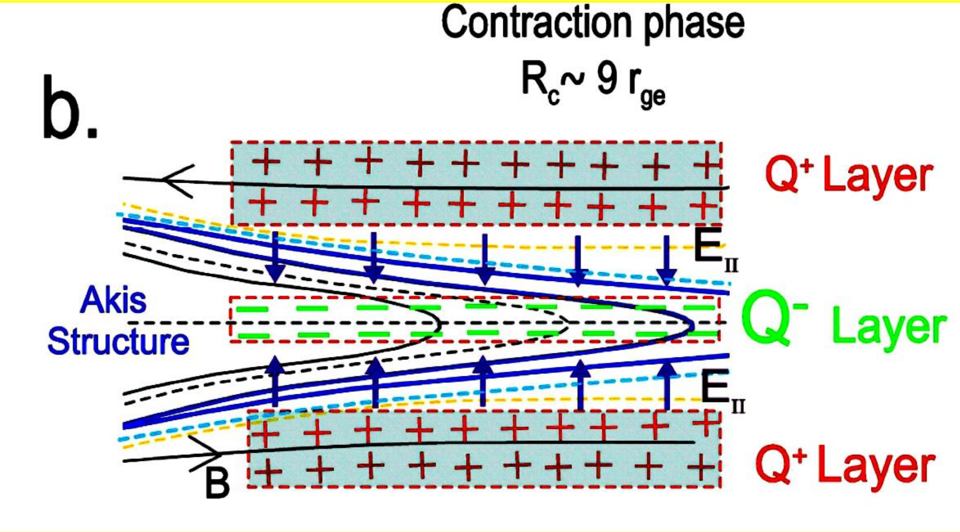
Conclusions:

We believe that Faraday's law can be experimentally validated, with the suggested model, more reliably than with the alternative X-type magnetic reconnection model incorporating the concept of "magnetic diffusion".

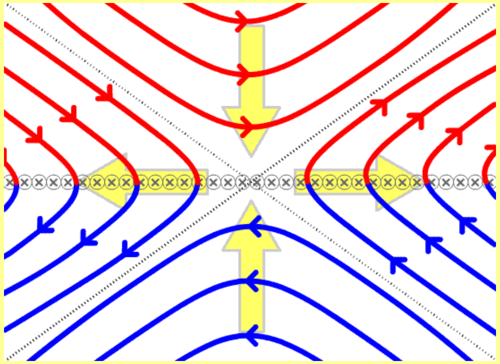
The presently proposed "akis structure" embedded in the whole magnetotail's current system is presumably a precious structure with novel features.

In summary:

The pulsating TWIN-DL STRUCTURE converts magnetic energy into particle energy.



The X-type reconnection ESSENTIALY reconfigurates the magnetic field.



Additionally,

1. The source will probably be triggered

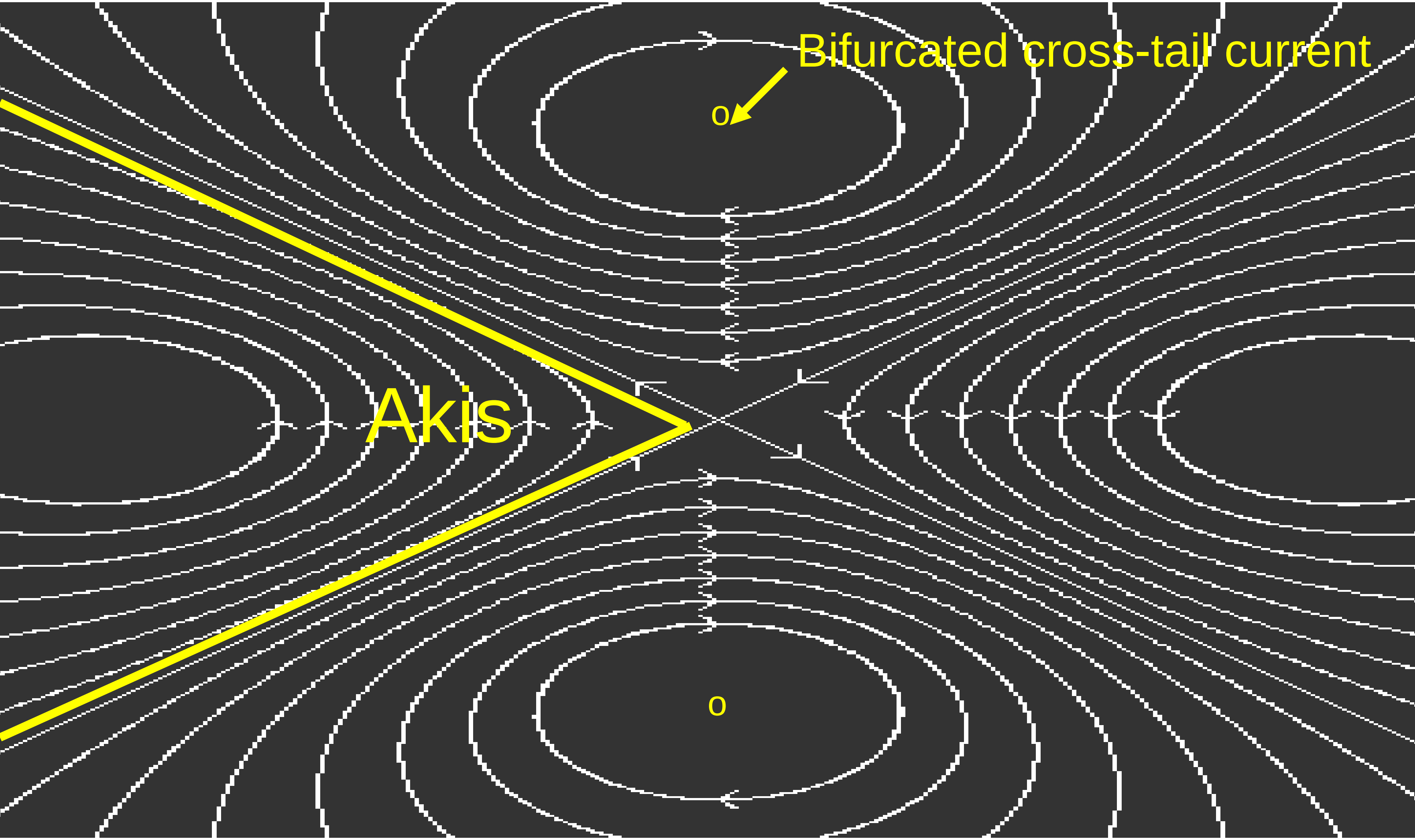
at that place,

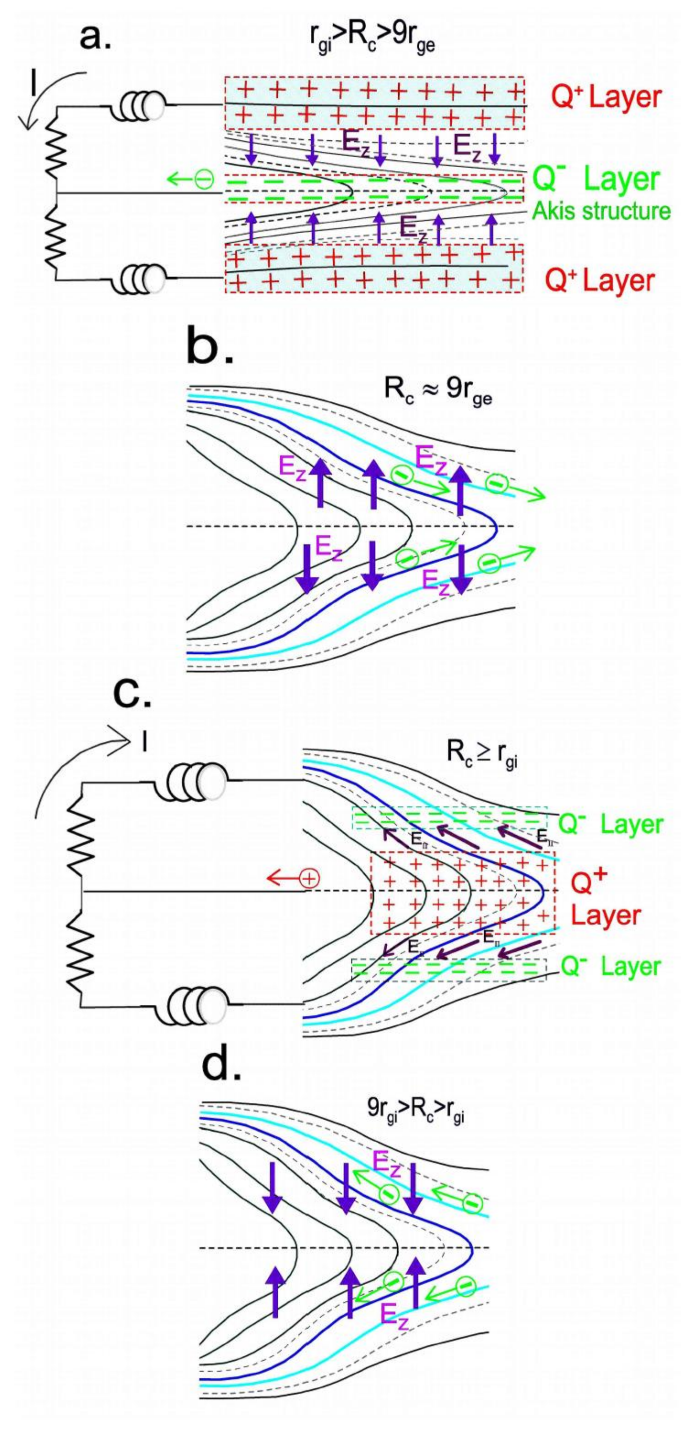
in which the condition for resonance is satisfied

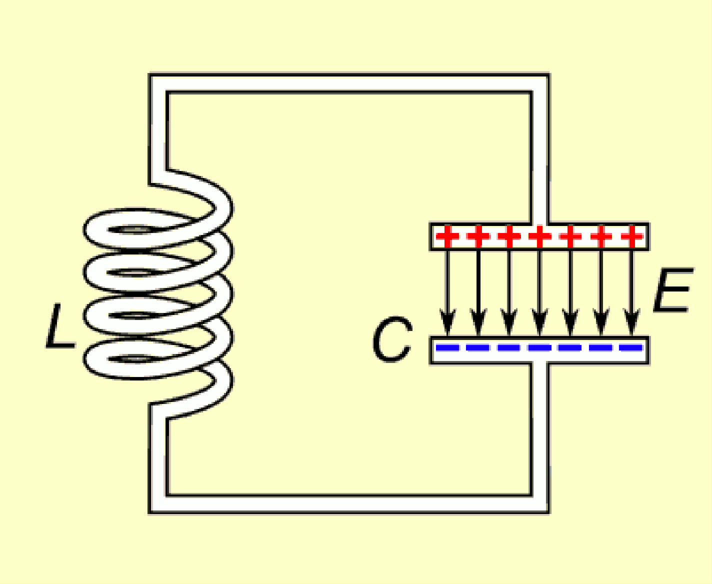
2. The resonance dramatically increases

the rate of energy conversion,

that is, the efficiency of the source.


Bifurcated cross-tail current
o
Akis
o


a.
$r_{gi} > R_c > 9r_{ge}$
I
Q+ Layer
E_z
E_z
Q- Layer
Akis structure
E_z
Q+ Layer
b.
$R_c \approx 9r_{ge}$
E_z
E_z
E_z
E_z
c.
I
$R_c \geq r_{gi}$
Q- Layer
Q+
Layer
Q- Layer
d.
$9r_{gi} > R_c > r_{gi}$
E_z
E_z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Open issues-magnetic reconnection

Further, the dissipation region is often turbulent with electrons and ions displaying weakly coupled, complex dynamics. The ongoing scientific issues related to magnetic reconnection span an enormous range of topics.

For instance we cite five major open issues :

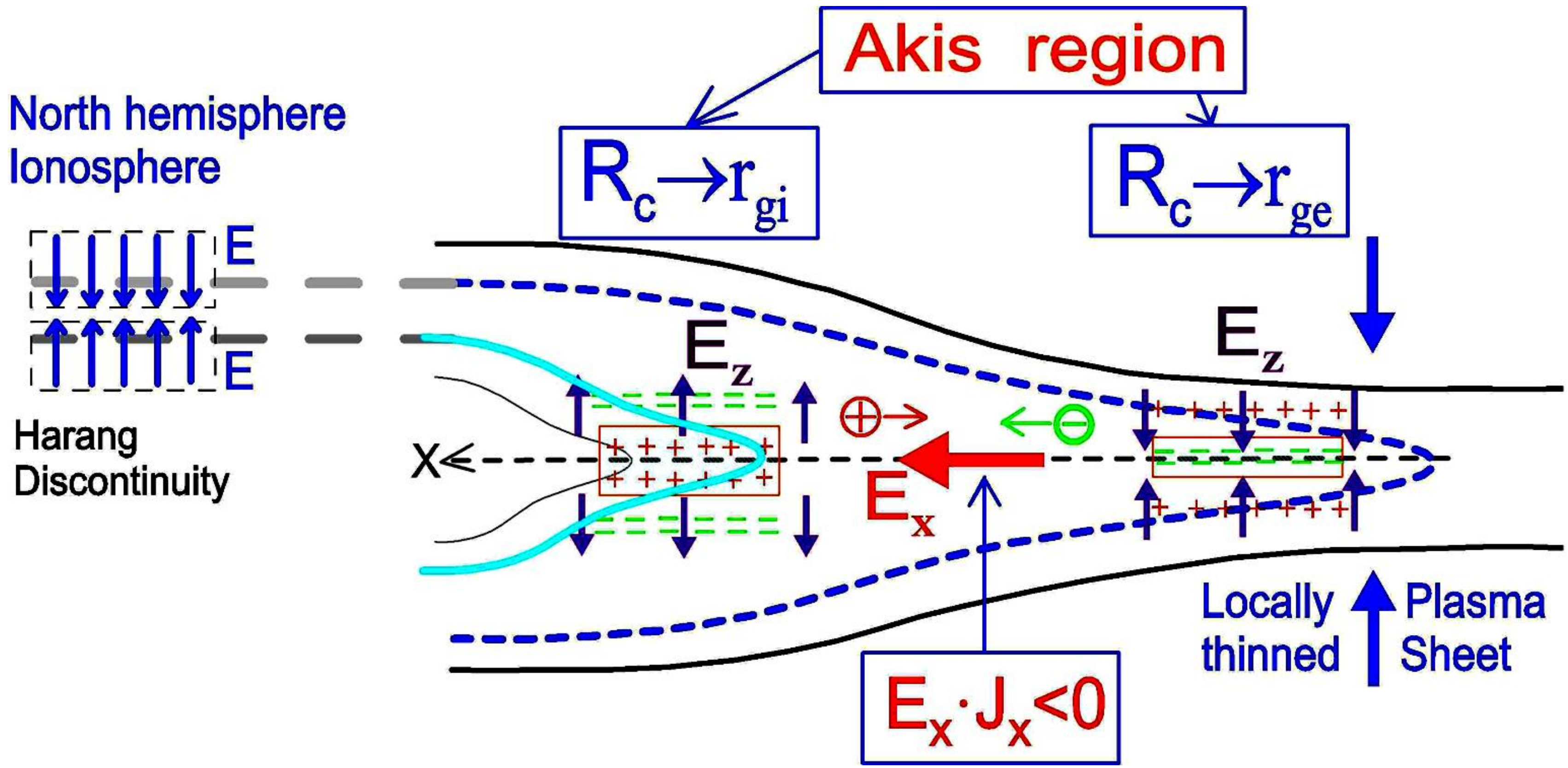
1]. The rate of magnetic reconnection;

2]. The onset of magnetic reconnection;

3]. Cross-scale coupling in large systems;

4]. Reconnection-driven particle heating and acceleration; and

5]. Reconnection in extreme astrophysical environments.



Akis region
$R_c \to r_{gi}$
$R_c \to r_{ge}$
North hemisphere
Ionosphere
E
E
Harang
Discontinuity
X
E_z
E_z
E_x
$E_x \cdot J_x < 0$
Locally
thinned
Plasma
Sheet

The resolution with continental drift took only some 40 years. With SMR, involving an electric field along the X-line has already persisted longer than that. The most of what can be claimed for SMR is that it is only a half-theory, at best. At worst, it has been badly proposed.

"Reconnection is commonly considered to be a means for accelerating particles to high energies. … It is thus interesting that *no such particles have been reported for the solar wind reconnection events* [at the magnetopause]."

Paschmann, 2008, p. 5.

"Reconnection is commonly considered to be a means for accelerating particles to high energies. … It is thus interesting that *no such particles have been reported for the solar wind reconnection events* [at the magnetopause]."

Paschmann, 2008, p. 5.

on dissipation, not recognizing the source of this dissipated energy. One must use the correct physics, the basis to get the correct mathematics, to solve any physical problem.

We still have many long standing, unsolved problems from the early days. [I] suggest that there is a possibility that the present paradigm may not be headed in the right direction. We have to recognize that several fundamental problems remain; … what is needed is not just improvements to traditional theories or a mopping up of residual problems. I am convinced that new thinking is needed to solve long standing unsolved problems.

Akasofu, 2007, p. v.

Emslie and Miller [2003] in *Dynamic Sun* noted that "Despite decades of observations in X-rays and gamma-rays, the mechanism for particle acceleration remains an enigma". We should, and can, learn from our research with the Earth's magnetosphere, for the Earth is our cosmic laboratory.

$$\mathbf{E} = \mathbf{E}^{es} + \mathbf{E}^{ind} = -\nabla\phi - \partial\mathbf{A}/\partial t \tag{3.36}$$

The two types of sources are clearly independent, with no necessary connection between them. Each source yields an electric field that acts in the same way upon charged particles. Any connection between the two depends on the medium involved.

3.12.6 Energisation to very high energies

The acceleration along the neutral line (the discharge) provides adequate particle energies so that, when the particles leave the neutral line with its small value of B and enters into regions of higher B in the surrounding magnetic field, it has sufficient magnetic moment to benefit from the betatron acceleration. As shown by Bulanov and Sasorov [1975], Pellinen and Heikkila [1978; 1984], for reasonable values of the magnetic field changes during the substorm, initially low energy particles can be energized to MeV energies in a few seconds. It is shown that the acceleration process consists of a direct acceleration by the electric field in the nonadiabatic region near the zero line and a betratron acceleration in the drift region. The characteristic energy of charged particles is determined in the nonrelativistic and ultrarelativistic limits. It is found that the energetic spectra have an exponential form in the high-energy range.

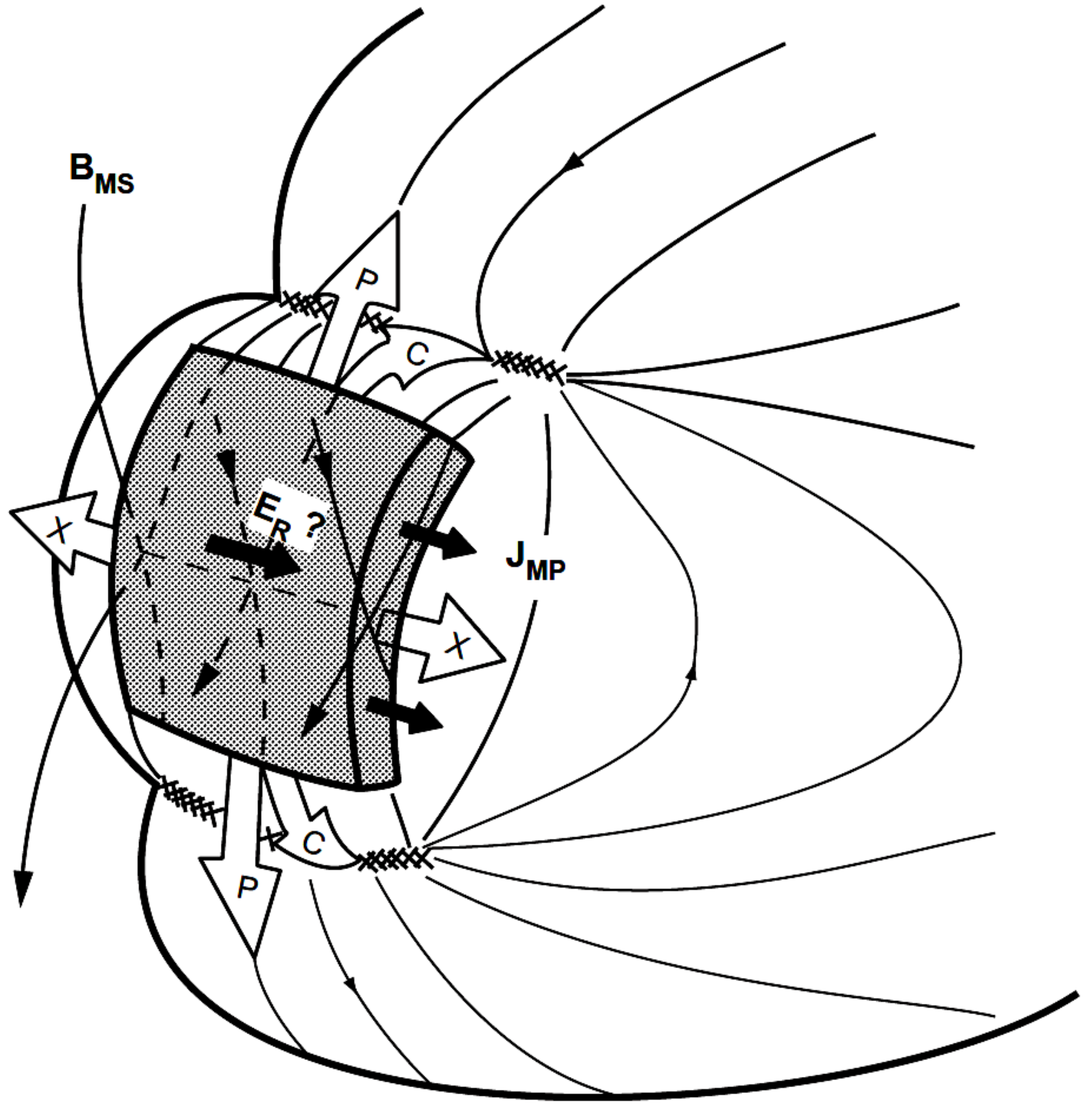
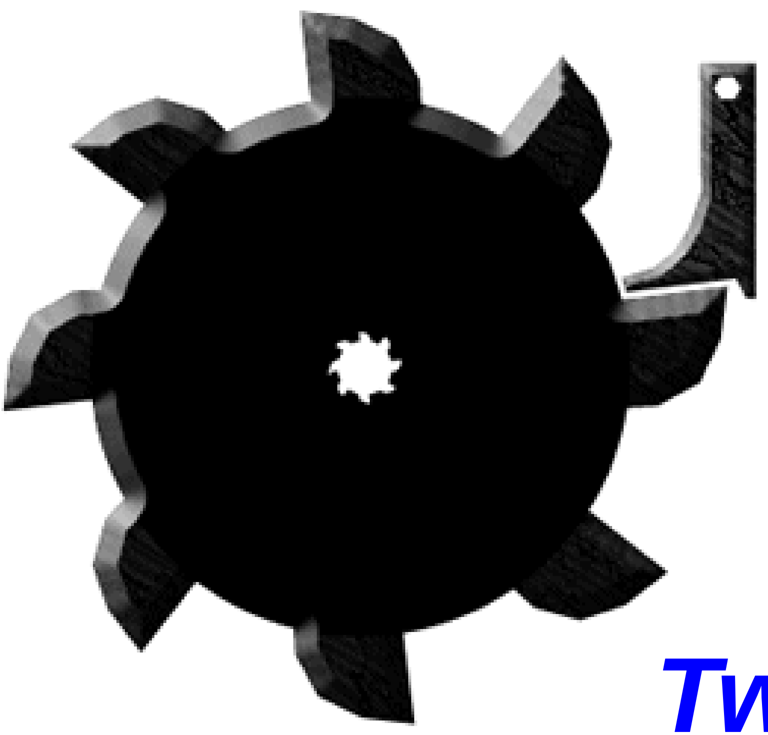


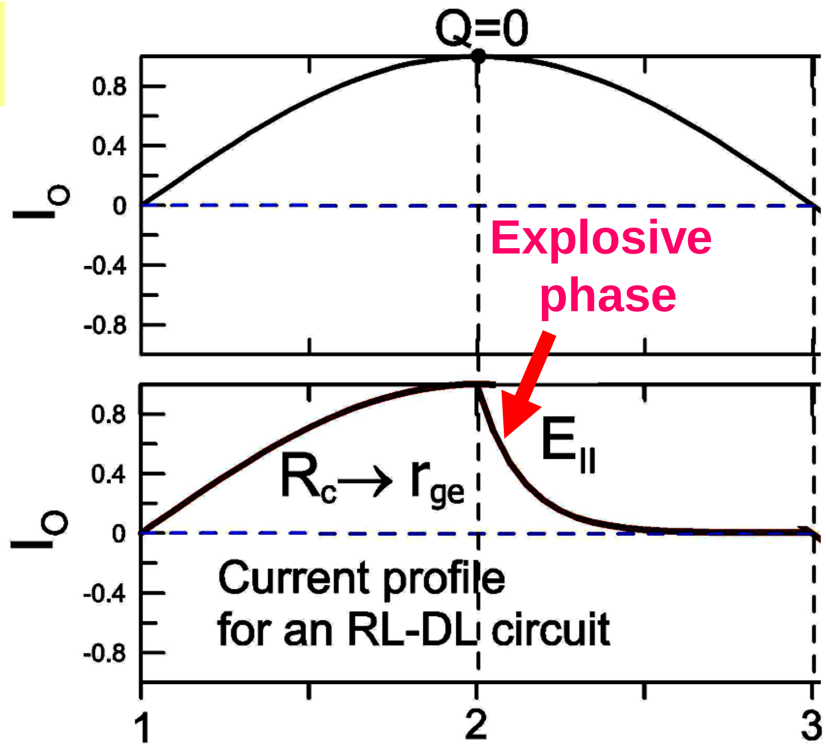
Figure 4.1 Standard Magnetic Reconnection (SMR) at the MP for southward IMF. The electric field is dawn dusk, parallel to the X line. It is parallel to MP current, thus $\mathbf{E} \cdot \mathbf{J}$ is positive, indicating dissipation. The possible source of the energy is not mentioned.
Source: Heikkila, 1978b, page 122.

All currents must be closed in any physical device in accordance with Kirchhoff's prin ciples; it must be so to analyse cause and effect by the sign of $\mathbf{E} \cdot \mathbf{J}$. The product $\mathbf{E} \cdot \mathbf{J} > 0$ is an electrical load, while the source of the dissipated energy is governed by $\mathbf{E} \cdot \mathbf{J} < 0$.
The dynamo region is generally neglected in space research. The source of the dissipated energy with $\mathbf{E} \cdot \mathbf{J} < 0$ is hardly ever discussed in space plasma physics.
Generalized (finite-B) magnetic reconnection. Schindler et al. [1988] advanced the idea of GMR. GMR uses $\mathbf{E} = \quad \partial \mathbf{A}/\partial t \quad \nabla \phi$, the real electric field.

A ratchet in action.

Each tooth in the ratchet together with the regions to either side of it constitutes a ***simple bistable mechanism.***





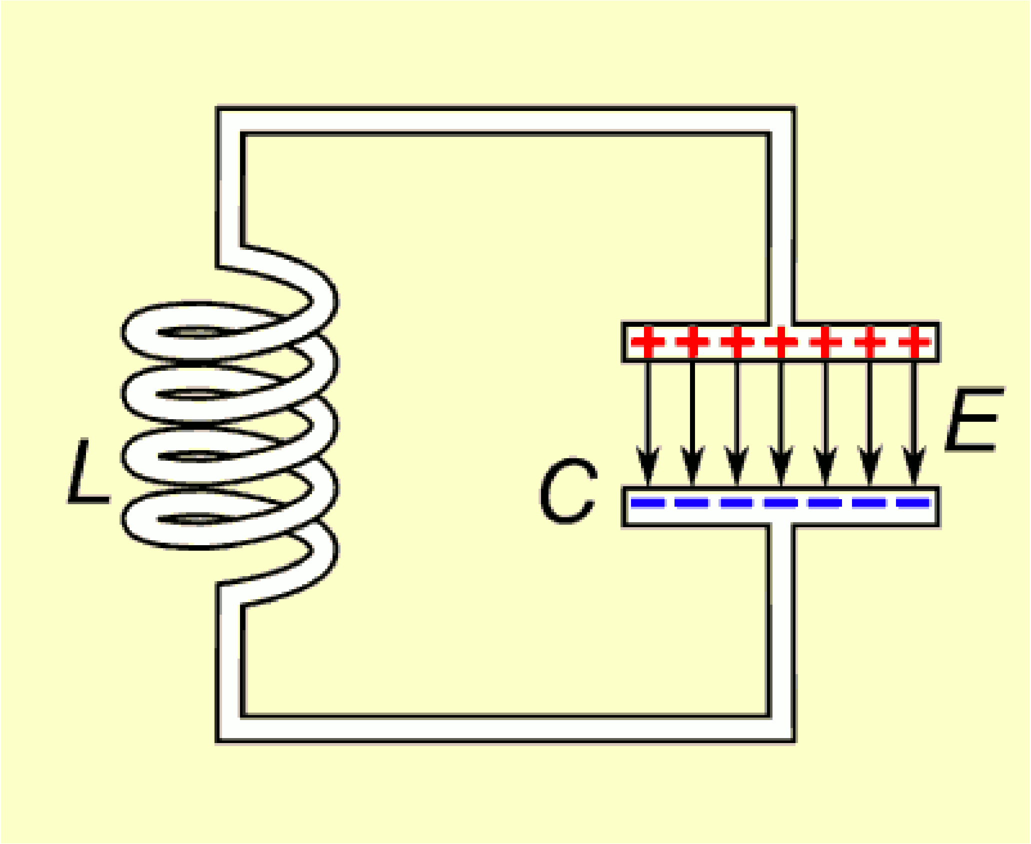
Two stable positions

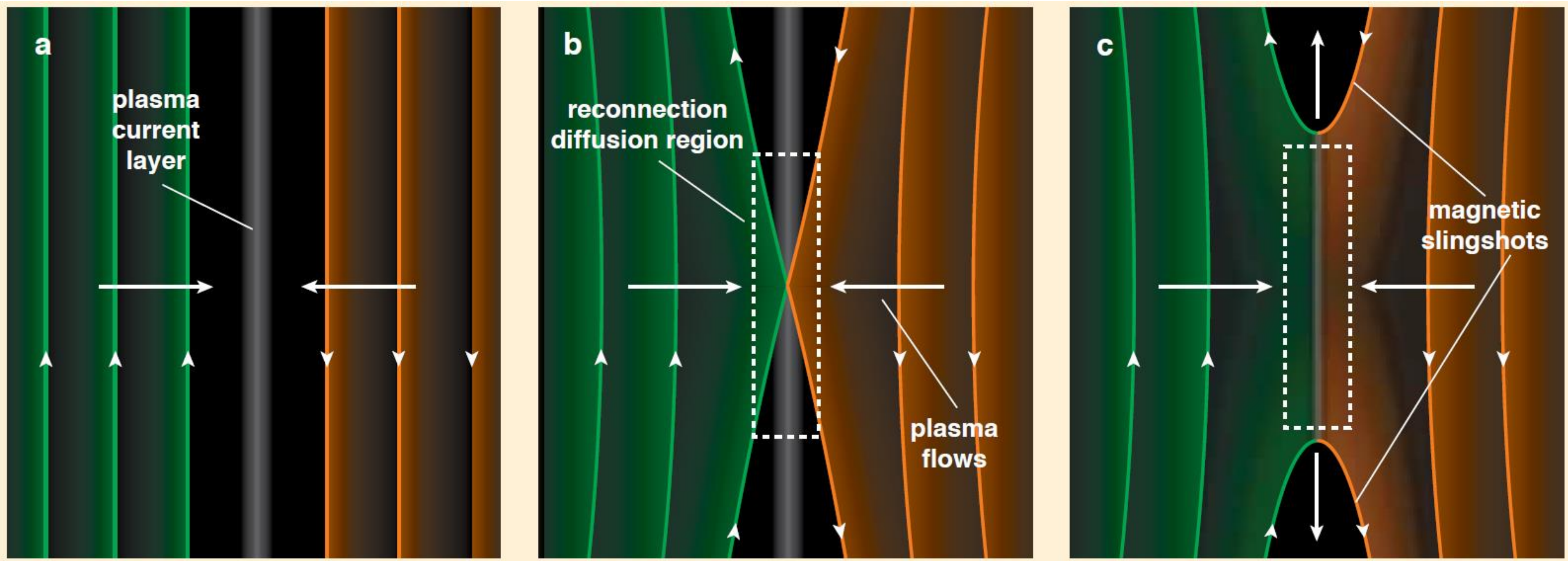
Animation illustrating the operation of a LC circuit, an RLC circuit with no resistance. Charge flows back and forth between the capacitor plates through the inductance. The energy oscillates back and forth between the capacitor's electric field *(E)* and the inductor's magnetic field *(B)* RLC circuits operate similarly, except that the

oscillating currents decay with time to zero due to the resistance in the circuit.

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$\omega_0 = \sqrt{\frac{1}{LC} - \left(\frac{R}{L}\right)^2}$$





tion in electrical circuits are negligible. What then produces "dissipation" in a collisionless plasma, allowing reconnection to occur, is the first great mystery of reconnection.

Does a sudden increase in the strength of "dissipation" set off reconnection? That's the third great mystery of reconnection.

magnetic energy in a macroscopic system. What determines the aspect ratio of the dissipation region and the rate of release of magnetic energy is the second great mystery of reconnection.