MAGNETIC FIELD CONFIGURATION IN THE PLACE OF SOLAR FLARE AND FLARE X-RAY SOURCES

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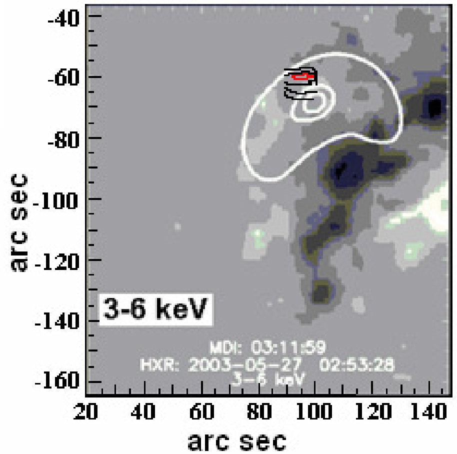
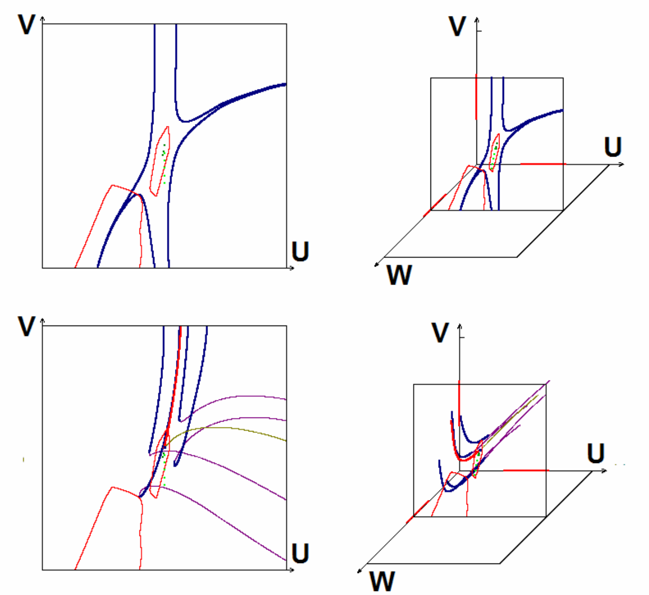
$$\frac{\partial \mathbf{B}}{\partial t} = \mathrm{rot}(\mathbf{V}\times\mathbf{B}) - \frac{1}{\mathrm{Re}_m}\mathrm{rot}\left(\frac{\sigma_0}{\sigma}\mathrm{rot}\mathbf{B}\right)$$

$$\frac{\partial \rho}{\partial t} = -\mathrm{div}(\mathbf{V}\rho)$$

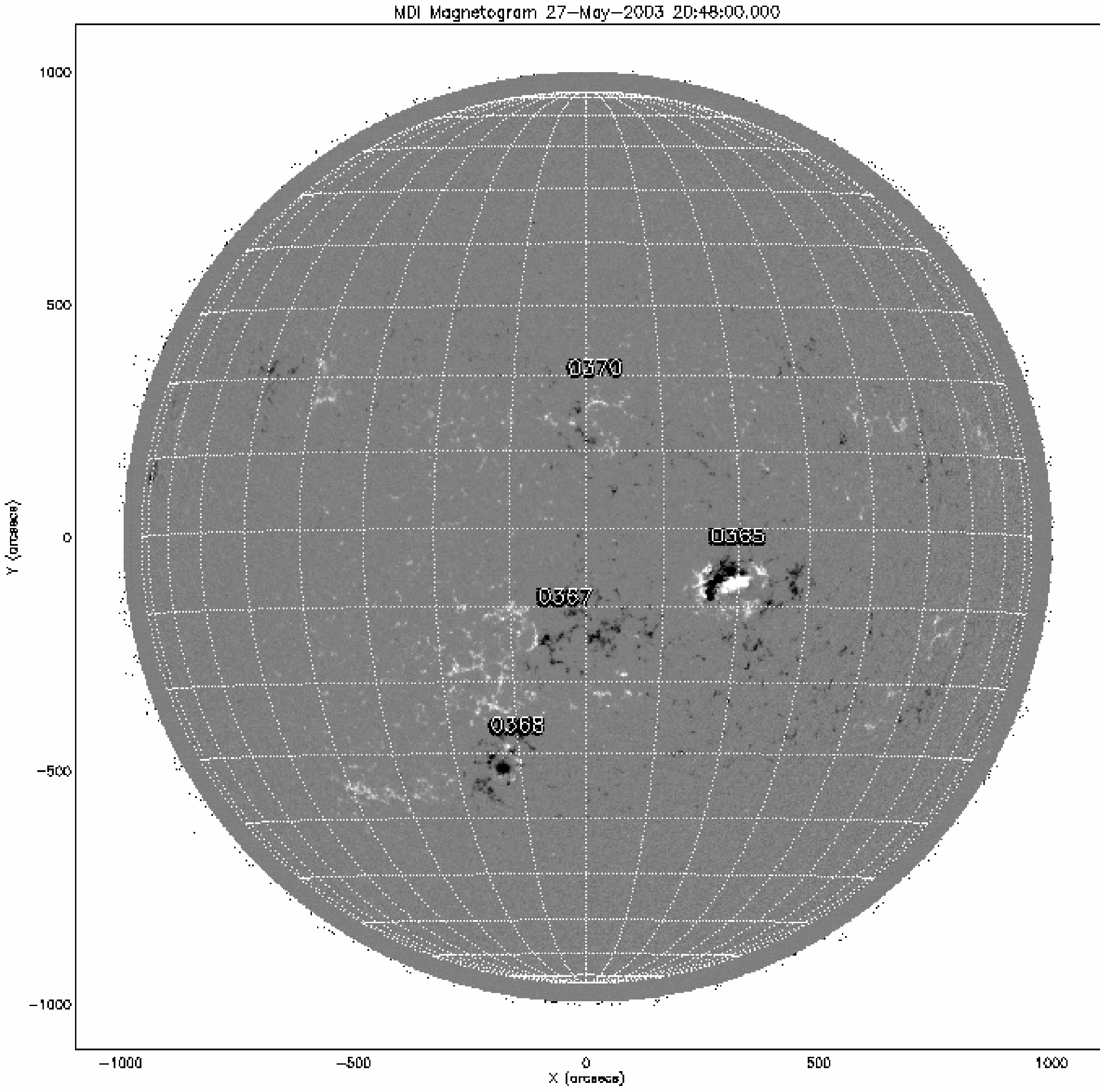
$$\frac{\partial \mathbf{V}}{\partial t} = -(\mathbf{V},\nabla)\mathbf{V} - \frac{\beta}{2\rho}\nabla(\rho T) - \frac{1}{\rho}(\mathbf{B}\times\mathrm{rot}\mathbf{B}) + \frac{1}{\mathrm{Re}\rho}\Delta\mathbf{V} + G_g\mathbf{G}$$

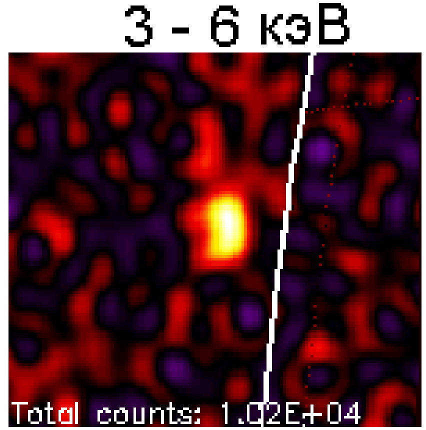
$$\frac{\partial T}{\partial t} = -(\mathbf{V},\nabla)T - (\gamma-1)T\mathrm{div}\mathbf{V} + (\gamma-1)\frac{2\sigma_0}{\mathrm{Re}_m\sigma\beta\rho}(\mathrm{rot}\mathbf{B})^2 - (\gamma-1)G_q\rho L'(T) + \frac{\gamma-1}{\rho}\mathrm{div}\left(\mathbf{e}_\parallel\kappa_{dl}(\mathbf{e}_\parallel,\nabla T) + \mathbf{e}_{\perp 1}\kappa_{\perp dl}(\mathbf{e}_{\perp 1},\nabla T) + \mathbf{e}_{\perp 2}\kappa_{\perp dl}(\mathbf{e}_{\perp 2},\nabla T)\right)$$

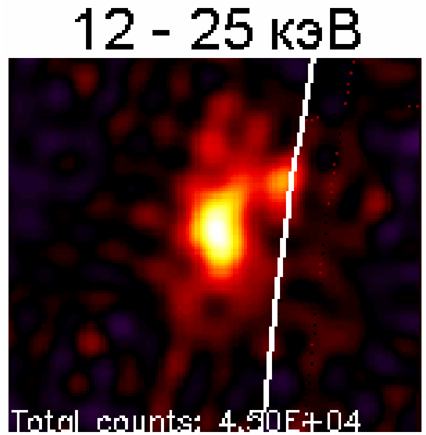


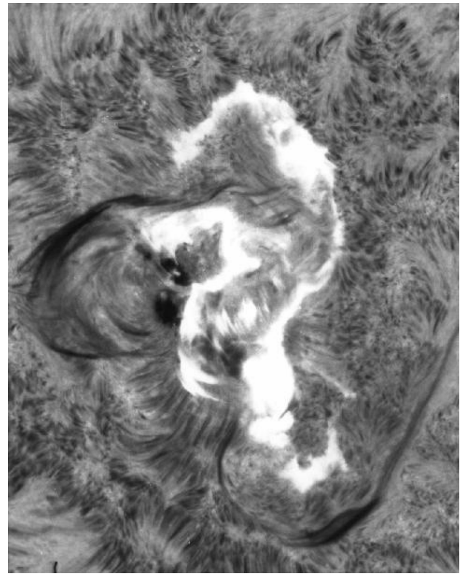


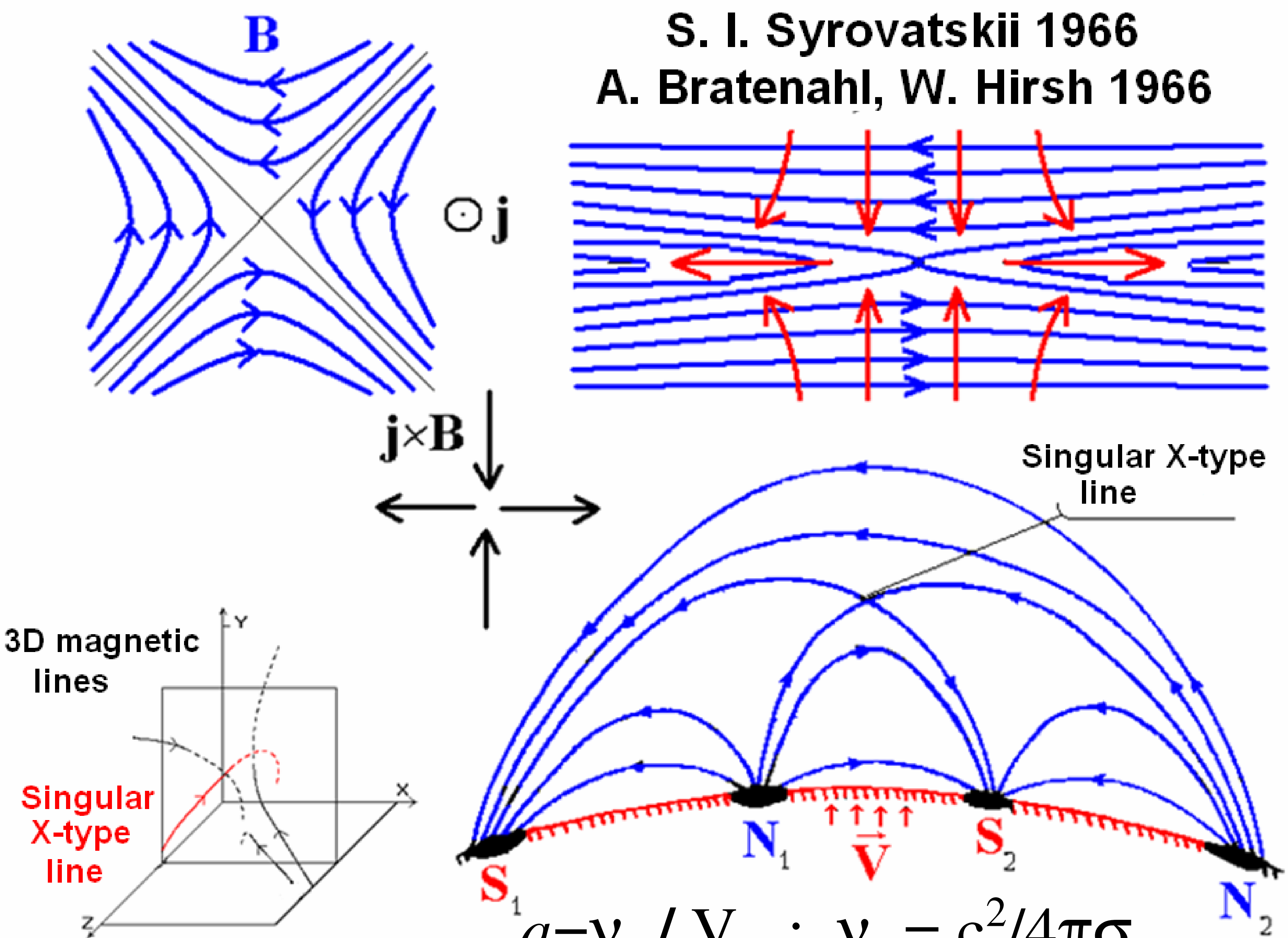
SOLAR FLARE OCCURS IN THE SOLAR CORONA ON HEIGHTS 15 - 30 THOUSANDS KILOMETERS, WHICH IS 1/40 – 1/20 OF SOLAR RADIUS.









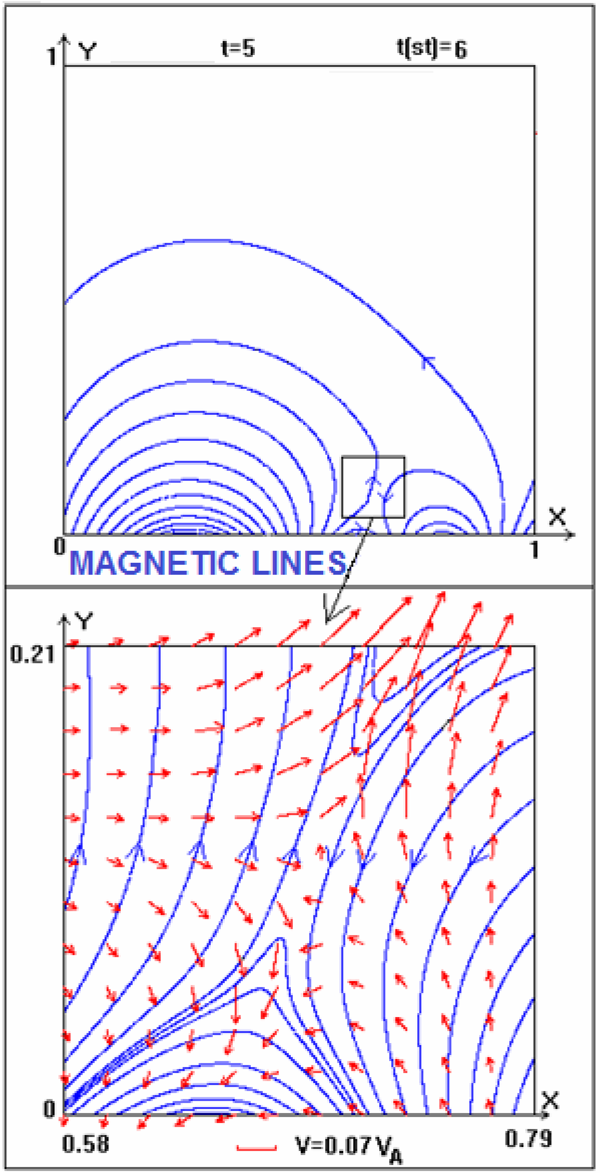


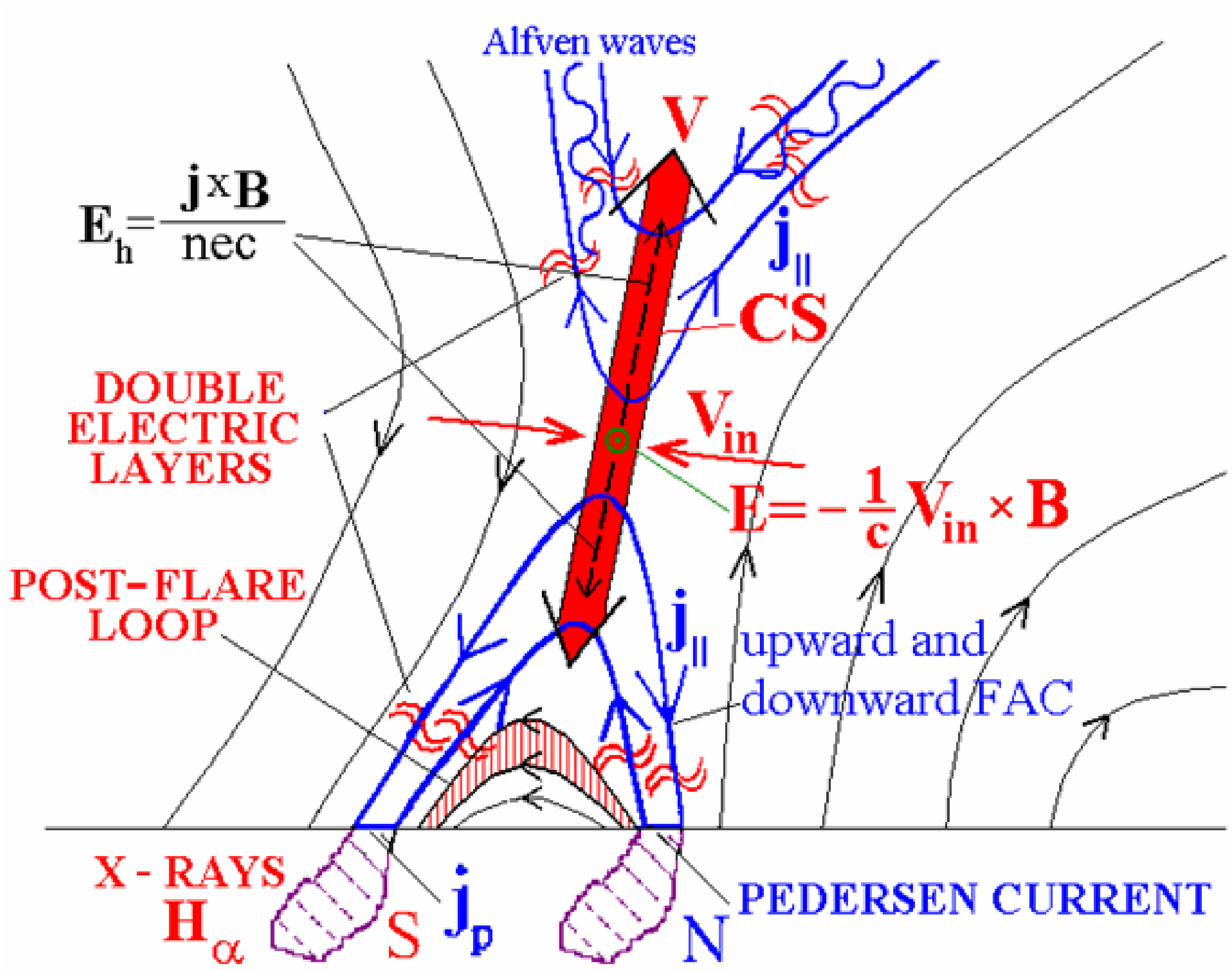
$$a = \nu_m / V_{in} \; ; \; \nu_m = c^2/4\pi\sigma$$

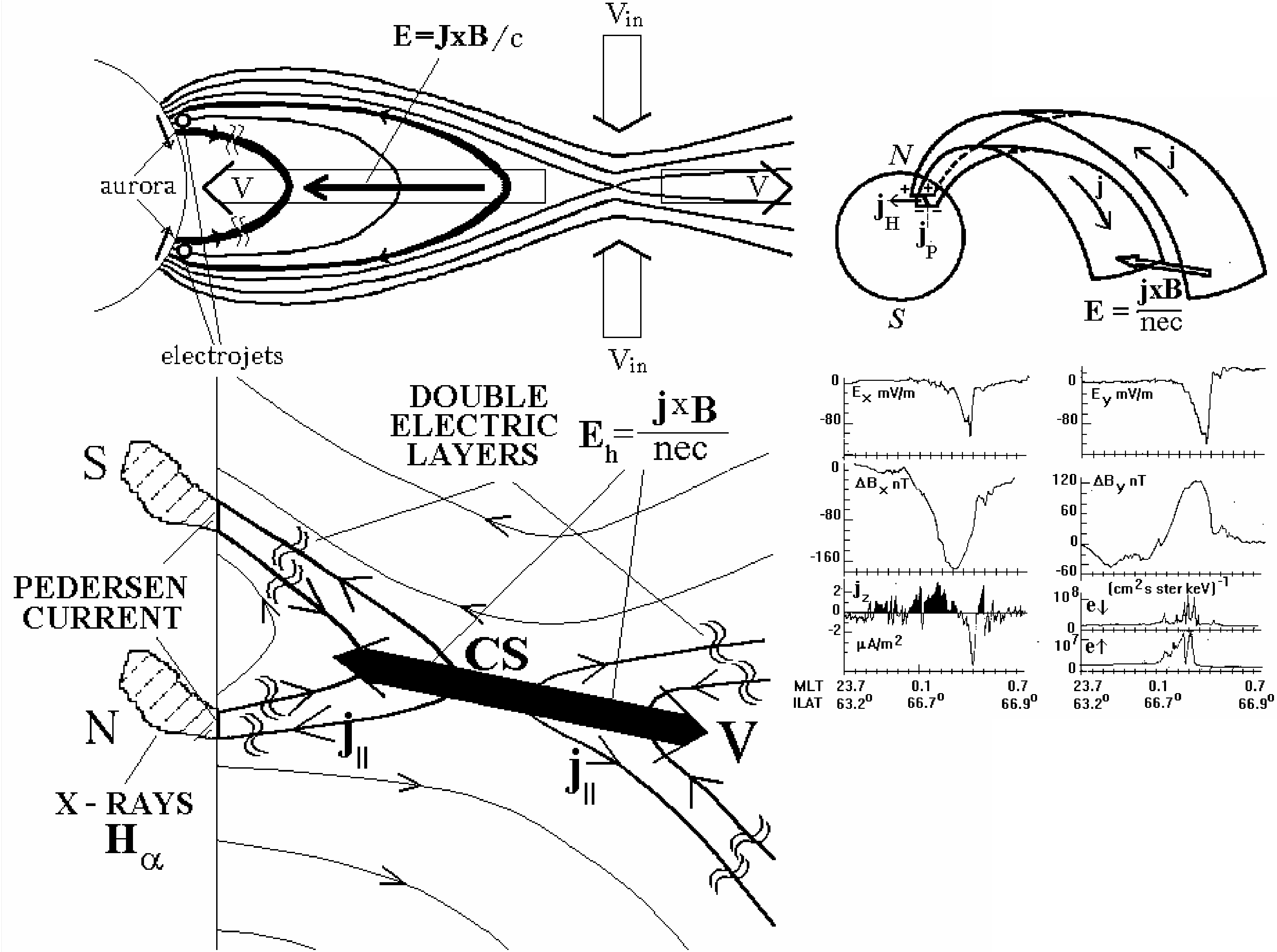
After the quasi-steady evolution the current sheet transfers into an unstable state. As a result, explosive instability develops, which cause the flare energy release.

Electrodynamic model of solar flare

Igor M. Podgorny using results of measurements on the satellite Intercosmos-Bulgaria-1300

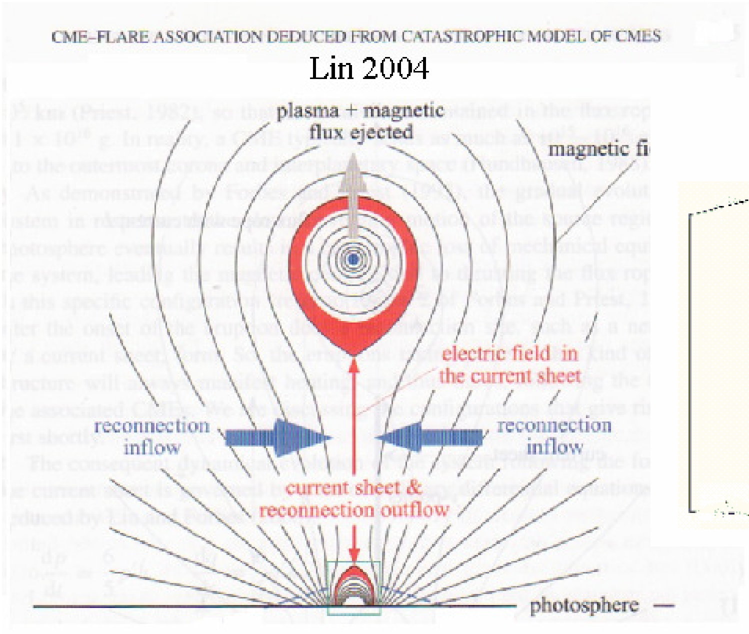


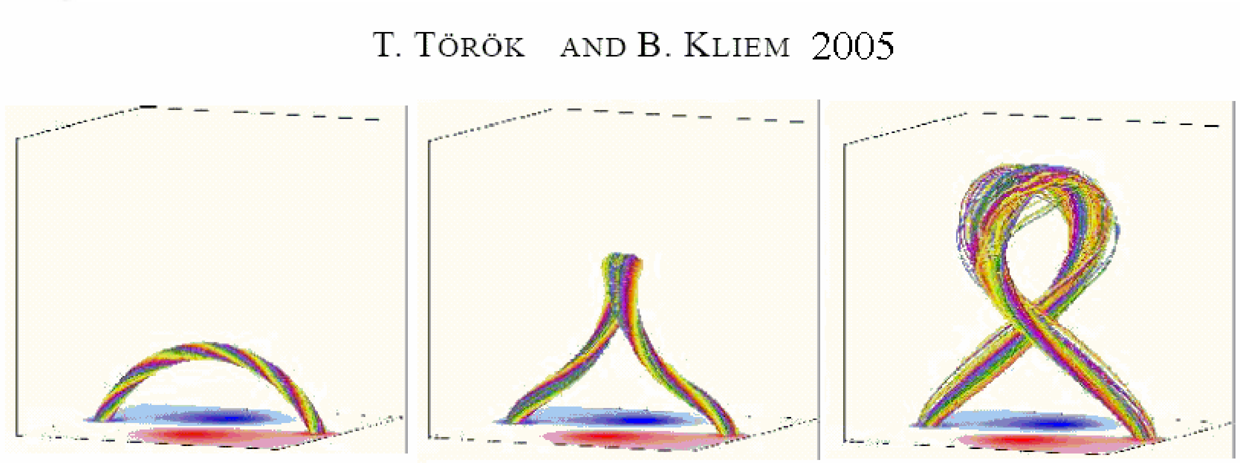




E=JxB/c
V_in
aurora
V
V
electrojets
V_in
N
j
j
j_H
j_P
S
E = jxB/nec
DOUBLE
ELECTRIC
LAYERS
E_h = jxB/nec
S
PEDERSEN
CURRENT
CS
N
j_||
j_||
V
X - RAYS
H_α
E_x mV/m
0
-80
E_y mV/m
0
-80
ΔB_x nT
0
-80
-160
ΔB_y nT
120
60
0
-60
j_z
2
0
-2
μA/m^2
(cm^2 s ster keV)^-1
10^8 e↓
0
10^7 e↑
0
MLT 23.7 0.1 0.7
ILAT 63.2° 66.7° 66.9°
23.7 0.1 0.7
63.2° 66.7° 66.9°

Examples of alternative models of the solar flare





To our mind it is difficult to explain appearing of the rope.

In any case to verify the validity of these models it is necessary to perform presented here MHD simulations for real active region.

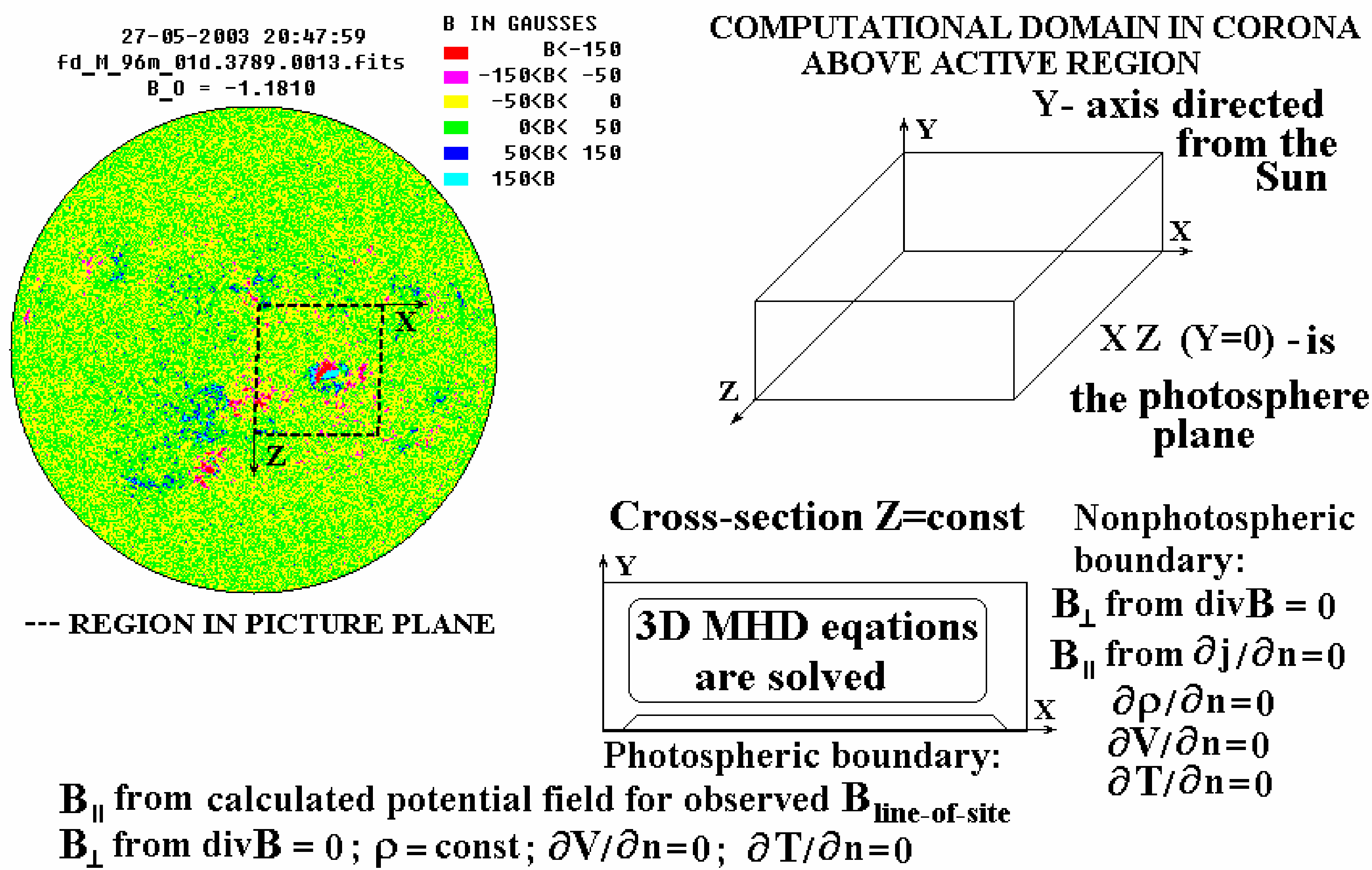
Now our aim is:

To find solar flare mechanism directly by MHD simulation in real active region.

Earlier:

Hypothesized the mechanism of the solar flare, which is then tested.

The main purpose of present study is to understand the magnetic field configuration near the current sheet in real situation in corona. An attempt is made to obtain a visual representation of the formation of a current sheet in the vicinity of a singular line from the configuration of the magnetic field.


27-05-2003 20:47:59
fd_M_96m_01d.3789.0013.fits
B_0 = -1.1810
B IN GAUSSES
B<-150
-150<B< -50
-50<B< 0
0<B< 50
50<B< 150
150<B
X
Z
--- REGION IN PICTURE PLANE
COMPUTATIONAL DOMAIN IN CORONA ABOVE ACTIVE REGION
Y- axis directed from the Sun
Y
X
Z
X Z (Y=0) - is the photosphere plane
Cross-section Z=const
Y
3D MHD eqations are solved
X
Photospheric boundary:
$B_{\parallel}$ from calculated potential field for observed $B_{\text{line-of-site}}$
$B_{\perp}$ from div$\mathbf{B} = 0$; $\rho = \text{const}$; $\partial V/\partial n = 0$; $\partial T/\partial n = 0$
Nonphotospheric boundary:
$B_{\perp}$ from div$\mathbf{B} = 0$
$B_{\parallel}$ from $\partial j/\partial n = 0$
$\partial \rho/\partial n = 0$
$\partial V/\partial n = 0$
$\partial T/\partial n = 0$

The numerical 3D simulation in corona above active region. The system of MHD equations for compressible plasma with dissipative terms and anisotropy of thermal conductivity is solved.

$$\frac{\partial \mathbf{B}}{\partial t} = \mathrm{rot}(\mathbf{V}\times\mathbf{B}) - \frac{1}{\mathrm{Re}_m}\mathrm{rot}\left(\frac{\sigma_0}{\sigma}\mathrm{rot}\mathbf{B}\right)$$

$$\frac{\partial \rho}{\partial t} = -\mathrm{div}(\mathbf{V}\rho)$$

$$\frac{\partial \mathbf{V}}{\partial t} = -(\mathbf{V},\nabla)\mathbf{V} - \frac{\beta}{2\rho}\nabla(\rho T) - \frac{1}{\rho}(\mathbf{B}\times\mathrm{rot}\mathbf{B}) + \frac{1}{\mathrm{Re}\rho}\Delta\mathbf{V} + G_g\mathbf{G}$$

$$\frac{\partial T}{\partial t} = -(\mathbf{V},\nabla)T - (\gamma-1)T\mathrm{div}\mathbf{V} + (\gamma-1)\frac{2\sigma_0}{\mathrm{Re}_m\sigma\beta\rho}(\mathrm{rot}\mathbf{B})^2 - (\gamma-1)\,G_q\,\rho L'(T) +$$

$$+\frac{\gamma-1}{\rho}\mathrm{div}\left(\mathbf{e}_\parallel\kappa_{dl}(\mathbf{e}_\parallel,\nabla T) + \mathbf{e}_{\perp 1}\kappa_{\perp dl}(\mathbf{e}_{\perp 1},\nabla T) + \mathbf{e}_{\perp 2}\kappa_{\perp dl}(\mathbf{e}_{\perp 2},\nabla T)\right)$$

The PERESVET program was developed

MAIN PUBLICATIONS:

A.I. Podgorny Solar Phys. 156,41,1995.

A.I. Podgorny, I.M. Podgorny

Solar Phys. 139, 125, 1992; 161, 165, 1995; 182, 159, 1998; 207, 323, 2002

Cosmic Research 35, 35, 1997; 35, 235, 1997; 36, 492, 1998

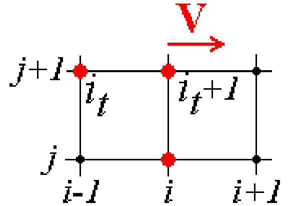
Astronomy Reports 42, 116, 1998; 43, 608, 1999; 44, 407, 2000; 45, 60, 2001; 46, 65, 2002; 47,696,2003; 48, 435, 2004; 49, 837, 2005; 52, 666, 2008; 54, 645, 2010

Comput. Mathem. Mathematical Phys 44, 1784, 2004

The principal difference between the numerical methods implemented in the program PERESVET and others. The main goal is to build the mostly stable finite-difference scheme. Stability must remain for maximally possible step Δt, to accelerate calculations maximally. The scheme must be stable even, if the Courant condition ($\boldsymbol{\Delta t V_w / \Delta x < 1}$) is violated, which is reached only for **implicit** schemes. But here there is no purpose to achieve high precision of approximation of differential equations by finite-difference scheme.

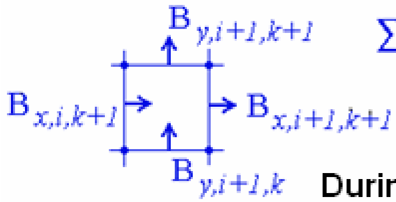
In the PERESVET program:

- Finite-difference scheme is upwind for diagonal terms.
- The scheme is absolutely implicit, it is solved by iteration method ($\Delta t V_w / \Delta x < 1$ is not necessary).



$$ {}^{(i_t+1)}\mathbf{u}_i^{j+1} = \mathbf{u}_i^{j} - \mathbf{v}\frac{\Delta t}{\Delta x}\left({}^{(i_t+1)}\mathbf{u}_i^{j+1} - {}^{(i_t)}\mathbf{u}_{i-1}^{j+1} \right) $$

- The scheme is conservative relative to magnetic flux [divB]=0



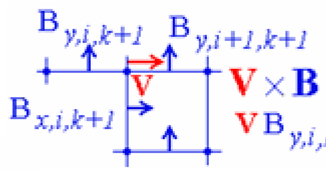
$$ \sum \mathbf{B}_n \Delta \mathbf{S} = 0 $$

Equivalency of equations

$\partial \mathbf{B} / \partial t = \mathrm{rot}(\mathbf{V} \times \mathbf{B}) + \nu_m \Delta \mathbf{B}$ and $\partial \mathbf{B} / \partial t = \mathrm{rot}(\mathbf{V} \times \mathbf{B}) - \nu_m \mathrm{rot}(\mathrm{rot}\mathbf{B})$

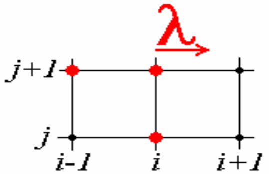
During dissipation relaxation of magnetic field, the current density $[\mathrm{rot}\ \mathbf{B}] \rightarrow 0$

- Nonsymmetrical (upwind) approximation V×B.



$\mathbf{V} \times \mathbf{B}$ contains $\mathbf{V} B_{y,i,k+1}$

Other methods:



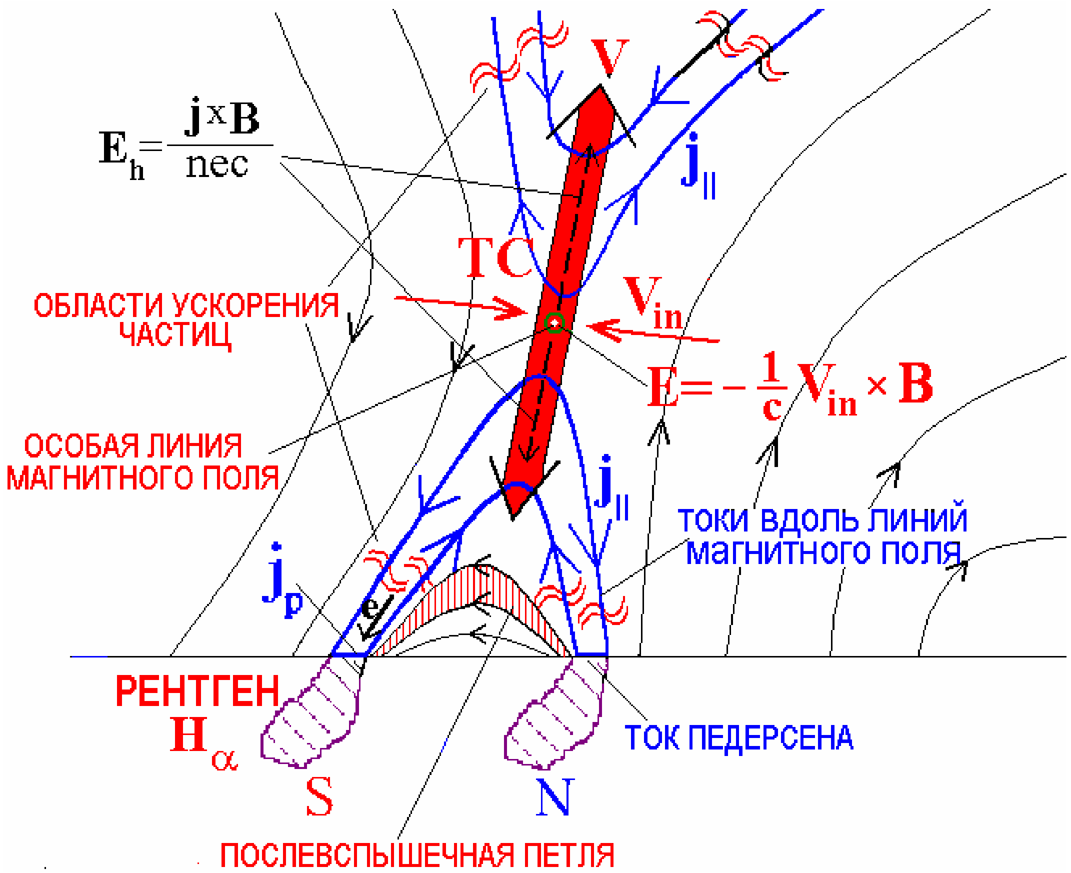
- Explicit finite-difference schemes
- Often Godunov type (Riemann waves)

$$ \mathbf{w}_i^{j+1} = \mathbf{w}_i^{j} - \lambda \frac{\Delta t}{\Delta x}\left(\mathbf{w}_i^{j} - \mathbf{w}_{i-1}^{j} \right) $$

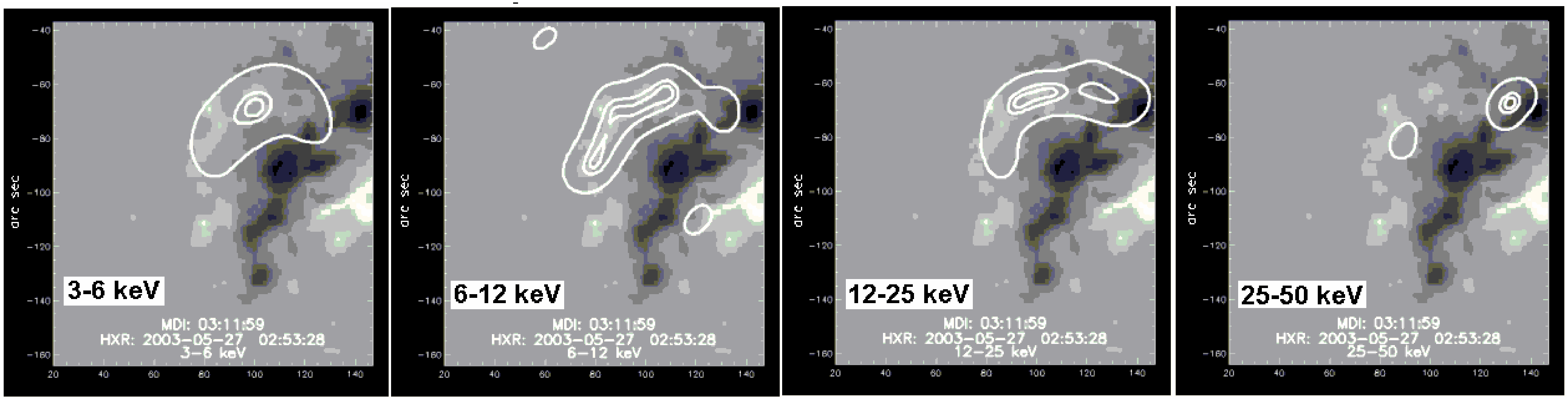
- The special methods are used to obtain high order approximation (FCT, TVD)
- Also Lagrangian schemes with further recalculation by interpolation on each step.
- Some schemes are also conservative relative to magnetic flux [divB]=0, but with symmetrical approximation V×B.

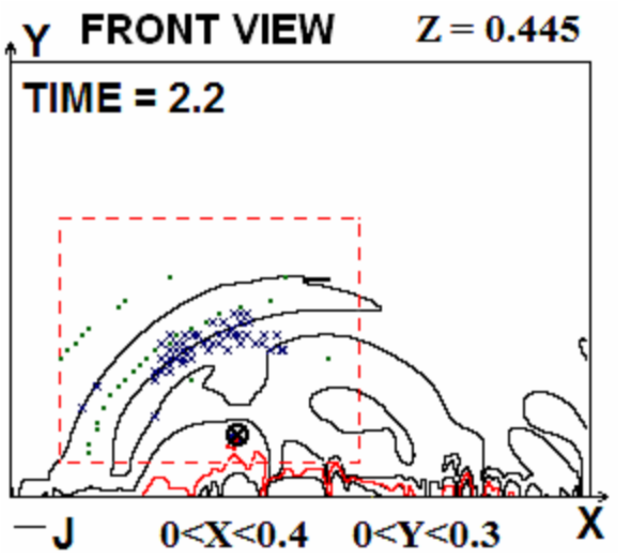
$\mathbf{V} \times \mathbf{B}$ contains $\mathbf{V}(B_{y,i+1,k+1} + B_{y,i,k+1})/2$

In spite of using specially developed numerical methods, the calculations are fulfilled rather slowly. So, to perform simulation on the personal computer (double core processor 1.6 GHz), the time scale must be strongly reduced.

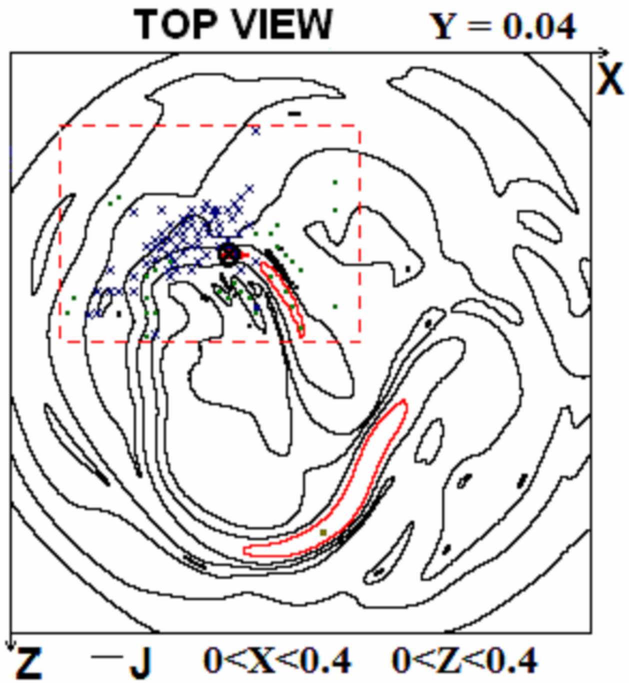


The graphical system of search of current sheet positions is created to compare with observed positions of thermal X-ray emission.

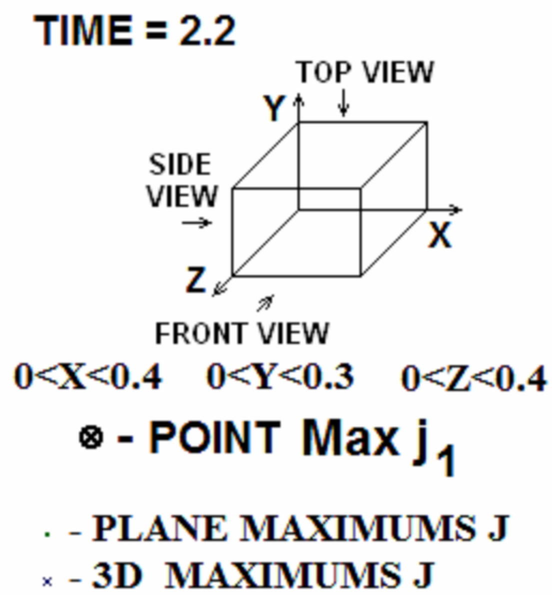


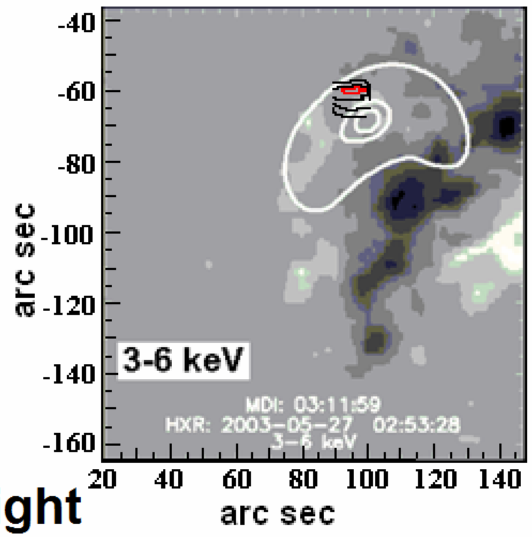


Along Solar Equator

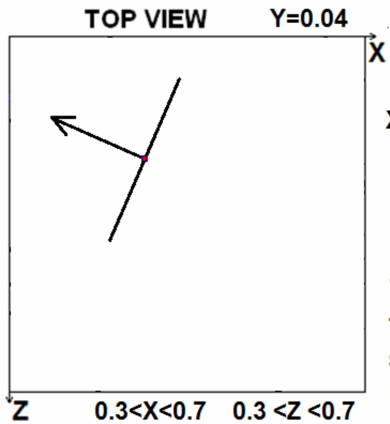


|| Photosphere





⊥ Line-of-Sight



|| Photosphere

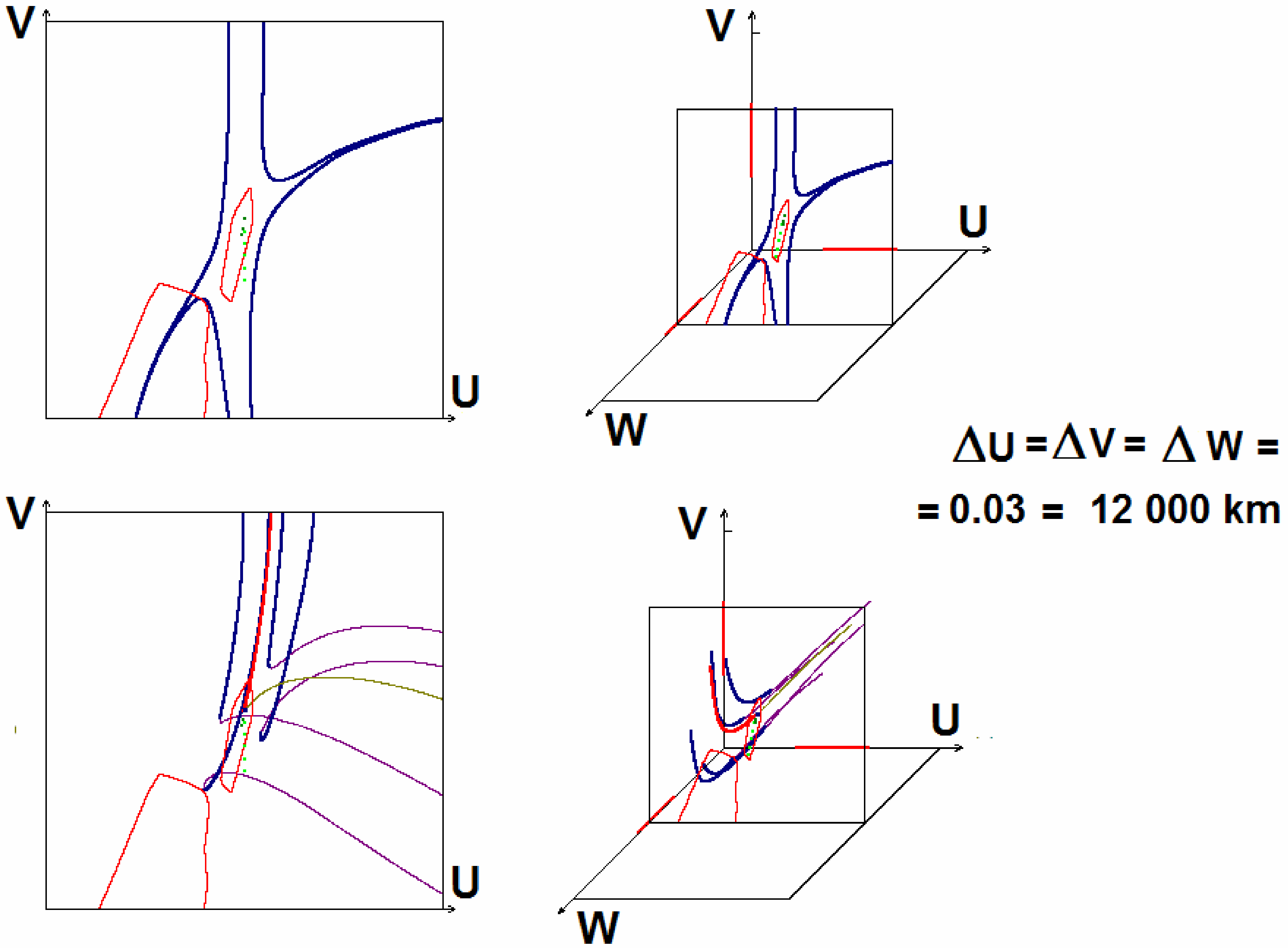
-B = (-0.179, -0.066, -0.093)

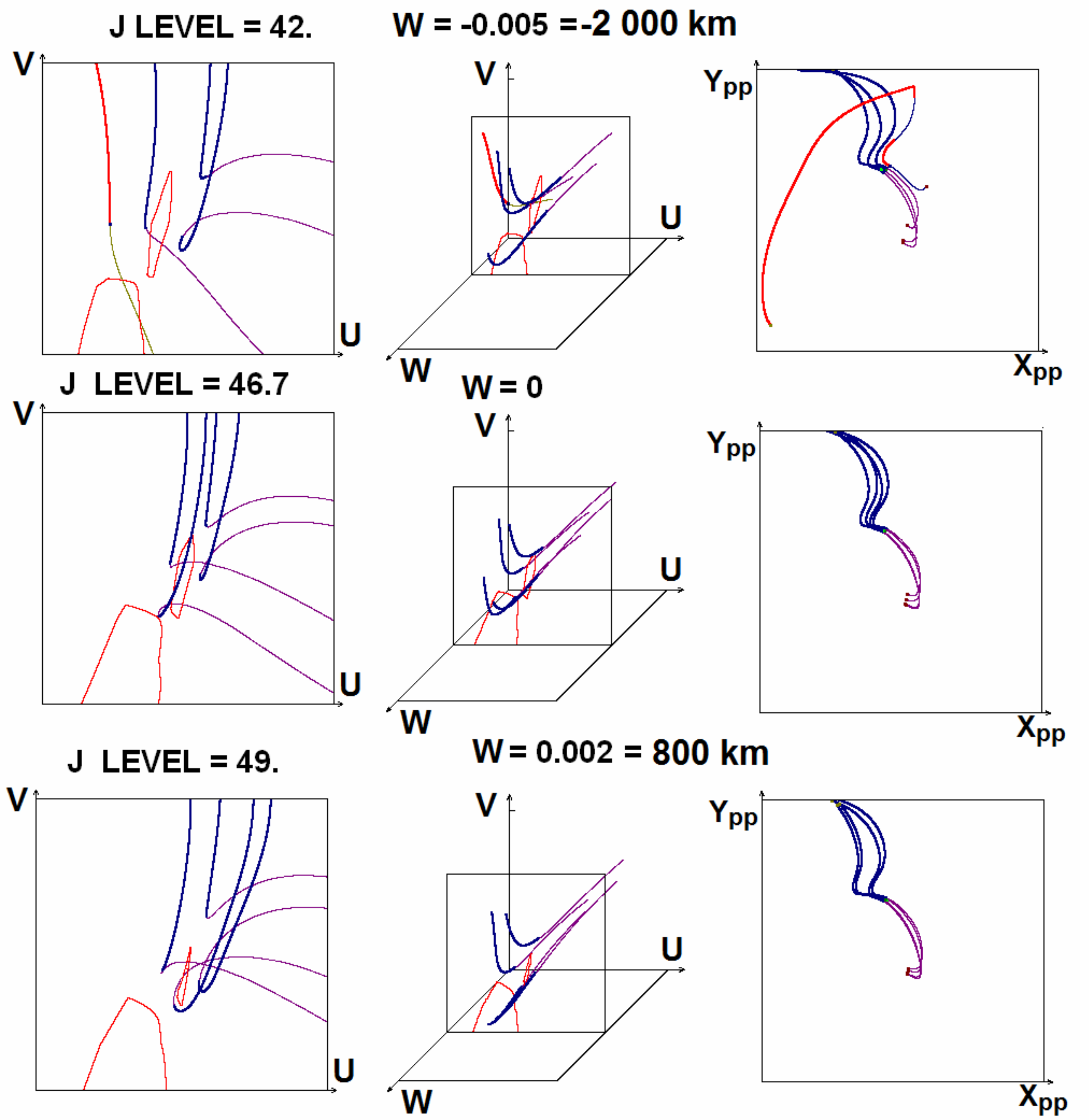
X-Y-Z POINT MAX J1 = (0.46, 0.04, 0.445)

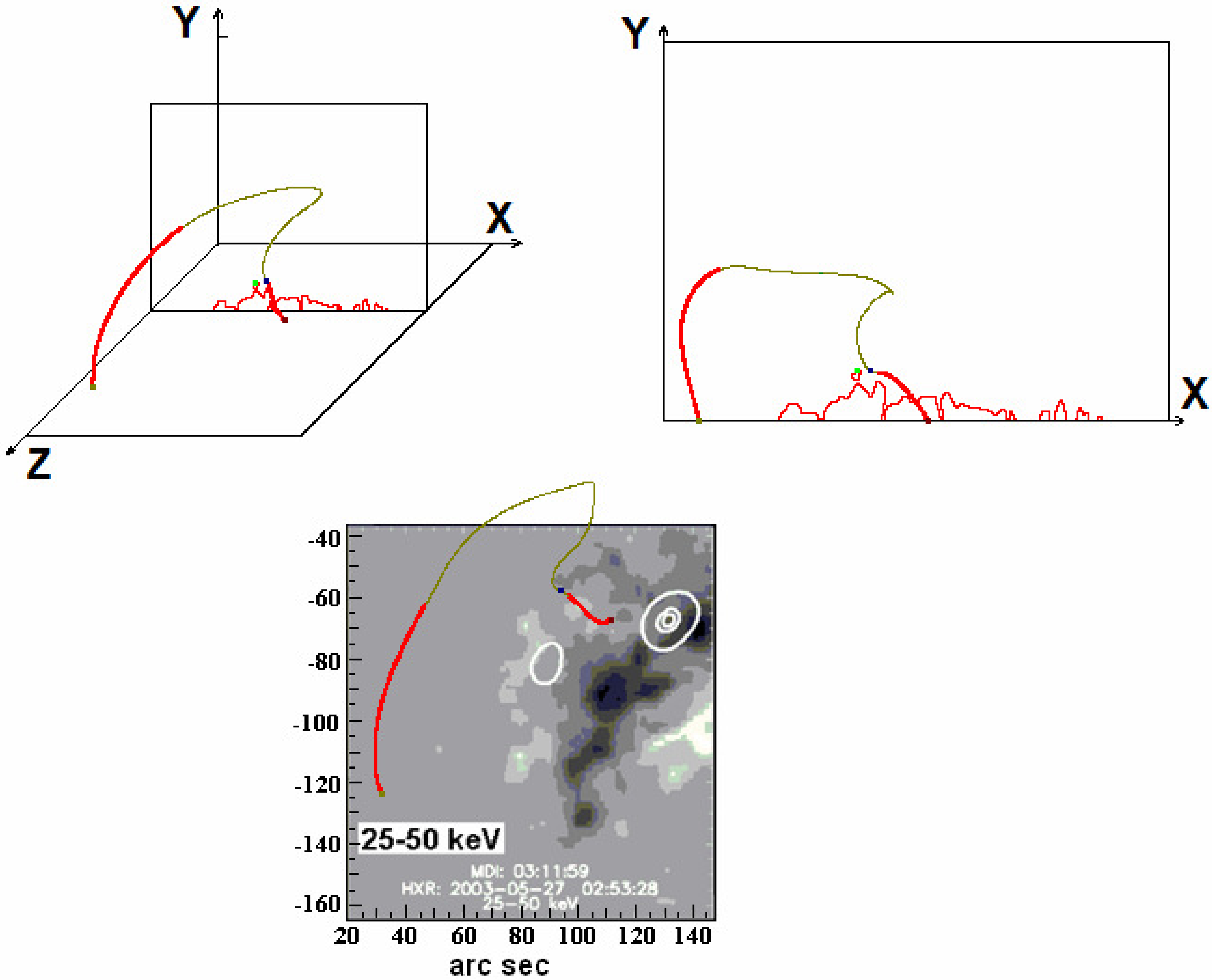
Length Unit 400 000 km

Y = 0.04 = 16 000 km

The plane of configuration of the magnetic field of the current sheet is inclined to the plane perpendicular to the photosphere at an angle of 18°


V
U
V
U
W
ΔU = ΔV = Δ W =
= 0.03 = 12 000 km
V
U
V
U
W


J LEVEL = 42.
W = -0.005 =-2 000 km
V
U
W
Ypp
Xpp
J LEVEL = 46.7
W = 0
J LEVEL = 49.
W = 0.002 = 800 km


Y
X
Z
Y
X
-40
-60
-80
-100
-120
-140
-160
20
40
60
80
100
120
140
arc sec
25-50 keV
MDI: 03:11:59
HXR: 2003-05-27 02:53:28
25-50 keV

1. The study of the magnetic field configuration near the current sheet in the corona above the active region 10365 flare May 27, 2003 at 02:53 showed that the physical meaning of the processes of accumulation and rapid release of the flare energy is best presented by the lines in the plane of the current sheet configuration which are tangential to the projections of the magnetic field vectors on this plane. From the picture of these lines it is easy to understand directions of magnetic $\mathbf{j} \times \mathbf{B}/c$ forces which are perpendicular to these lines.

2. The magnetic field configuration near the current sheet is complicated and it is difficult to understand the magnetic forces direction by analyzing the behavior of magnetic lines. However, the behavior of magnetic lines can be studied in detail using the developed graphical system which permits to present the line in arbitrary orientated subregion and to present the line projection on arbitrary plane.

3. Locations of the magnetic lines in the corona passing close to the current sheet and crossing the photosphere are analyzed. Since the calculated magnetic field is distorted near the photosphere due to numerical instabilities, the study only allows us to draw a preliminary conclusion about the possibility of crossing the photosphere by the magnetic line, arriving out of the current sheet, to the source of hard X-ray location. More accurate conclusions can be made after the calculation in real time scale, in which the instability near the photospheric boundary associated with abnormally rapid change of the magnetic field should be significantly suppressed.

To study the physical processes during solar flares and for development of solar flare prognosis on the basis of understanding its physical mechanism, it is necessary to solve further problems:

1. **Real-time** MHD simulation of flare situation in active region – application of supercomputer, parallelizing.

2. Modernizing of graphical system, which permits **to find fast** possible positions of flare emission sources from MHD simulation results.

Thank you!

Благодаря за вниманието!