The magnetic field distribution in active regions in the quiet time and during big solar flares

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Russia

In the recent years many controversial results about the magnetic field in active regions during flares are reported. The active region dynamics that produce strong flares are investigated. The main condition for X-class flare appearance is the big magnetic flux ($\Phi > 10^{22}$ Mx) in the active region. This condition is necessary but not a sufficient. The magnetic flux is calculationed using the normal magnetic component. The big flare appears above an active region with very complex magnetic field distribution. A bipolar active region does not produce a flare. There are no singular lines above a bipolar region, which can be responsible for a current sheet creation. During a solar flare, when the accumulated energy is fast released, the conservation of the magnetic field distribution in active regions during a flare takes place. This surprising fact follows from the analysis of the array data obtained with the SOHO and SDO. These results support the flare theory based on the slow magnetic energy accumulation in the coronal current sheet before a flare and its explosive realize due to current sheet instability.

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Solar Flare investigation

Two bright point appearance on the Sun 18 h before a big magnetic storm -- Carrington 1860

The term “SOLAR FLARE” -- Newton H. 1943.

Chromospheric phenomena ???

Energy release in the corona

Dungey J.W. -- 1958

Syrovatsky S.I. Current sheet theory -- 1962

Severny A.B. Pinch effect -- 1965

Brushlinsky K.V. et al., Podgorny A.I. Current Sheet MHD simulation -- 1980, 1981.

Yohkoh 1994 and RHESSI 2003 demonstration of flare energy release in the corona.

Podgorny A.I. and Podgorny I.M. MHD simulation of CS creation in corona before a flare 2005.

In this report we consider connection of active region dynamics and flares appearance

SOLAR FLARE DEPANDENCE ON MAGNETIC FIELD DYNAMICS IN ACTIVE REGION

Stepanov V. E. Solar flare. M. 1982. Big magnetic gradients in AR.
_Ishkov V.N. Astron. Astrophys. Trans. 20, 563 (2001). Big magnetic flux before a flare.
Chumak O.V. Astr. Rep 2008. Strong AR magnetic field variation during a flare.

Falconer D.A., Moor R.L., Gary G.A. Astrophys. J. **644**, 1258 (2006).
Leka K.D., Bames G. Astrophys. J. **656**, 1173 (2007).
Petrie G J.D., Sudol J.J. Astrophys. J. **724**, 1237 (2010).
Wang J., Zhao M., Zhou G. Astrophys. J. **690**, 862 (2009).
Kusano K., Maeshiroi T., Yokoyama T., Sakurai T. Adv. Space Res. **32**, 1917 (2003).

- Podgorny A.I., Podgorny I.M. Astron. J. 55, 626 (2011).
- Podgorny I.M., Podgorny A.I. Proc. Annual Seminar. Apatity. **33** P. 87. 2010. **35** P. *2012.*

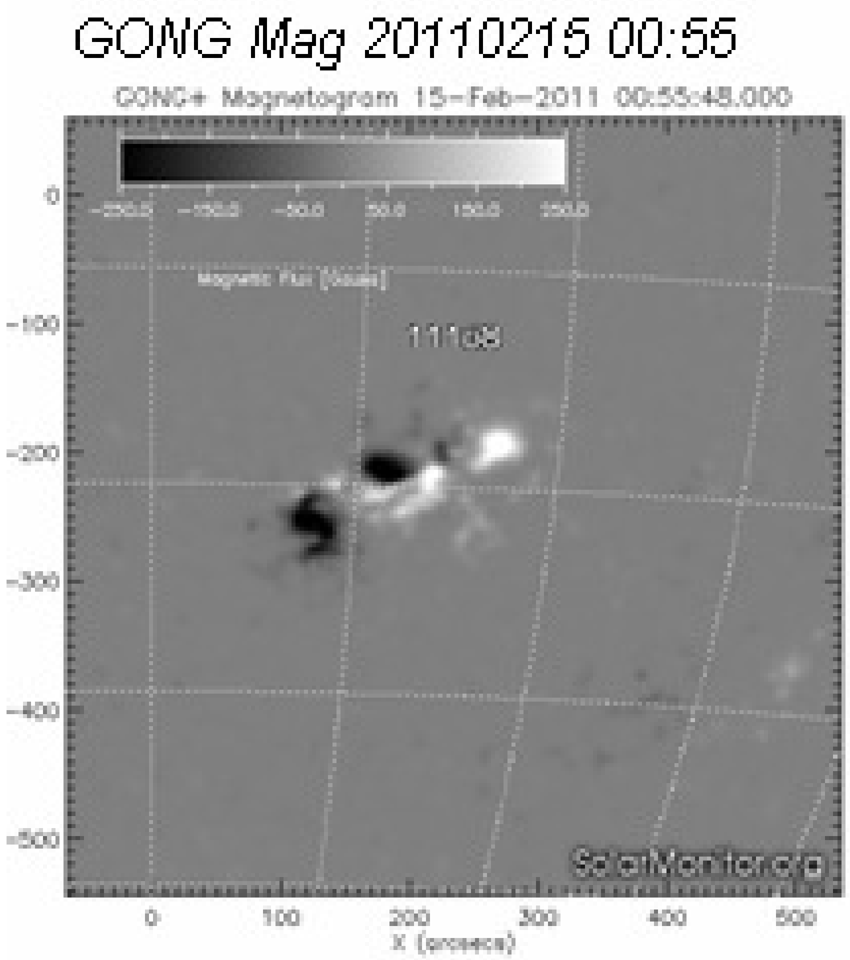
Podgorny I.M., Podgorny A.I. Journal of Atmospheric and Solar-Terrestrial Physics. **92**, 59–64 (2013).

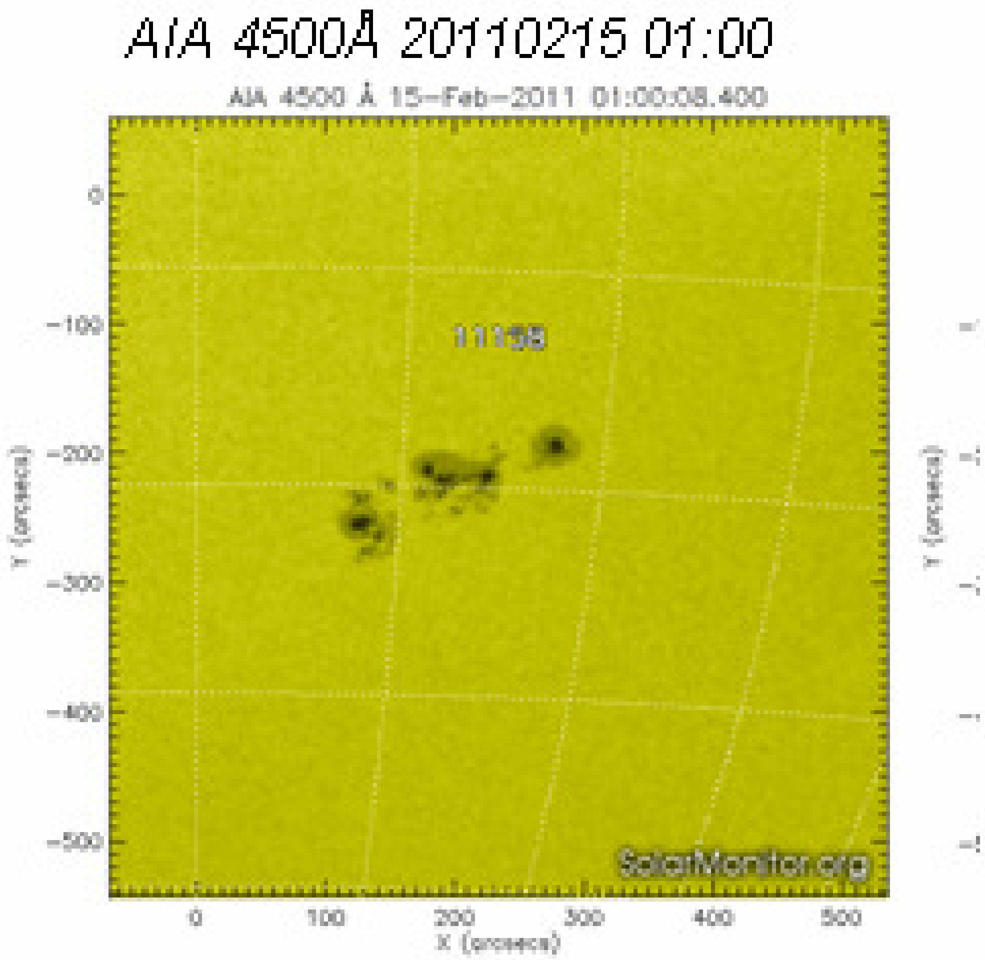
Podgorny A.I., Podgorny I.M., Meshalkina N. S. Geomagn. Aeronomy. Аэрон. 2013.

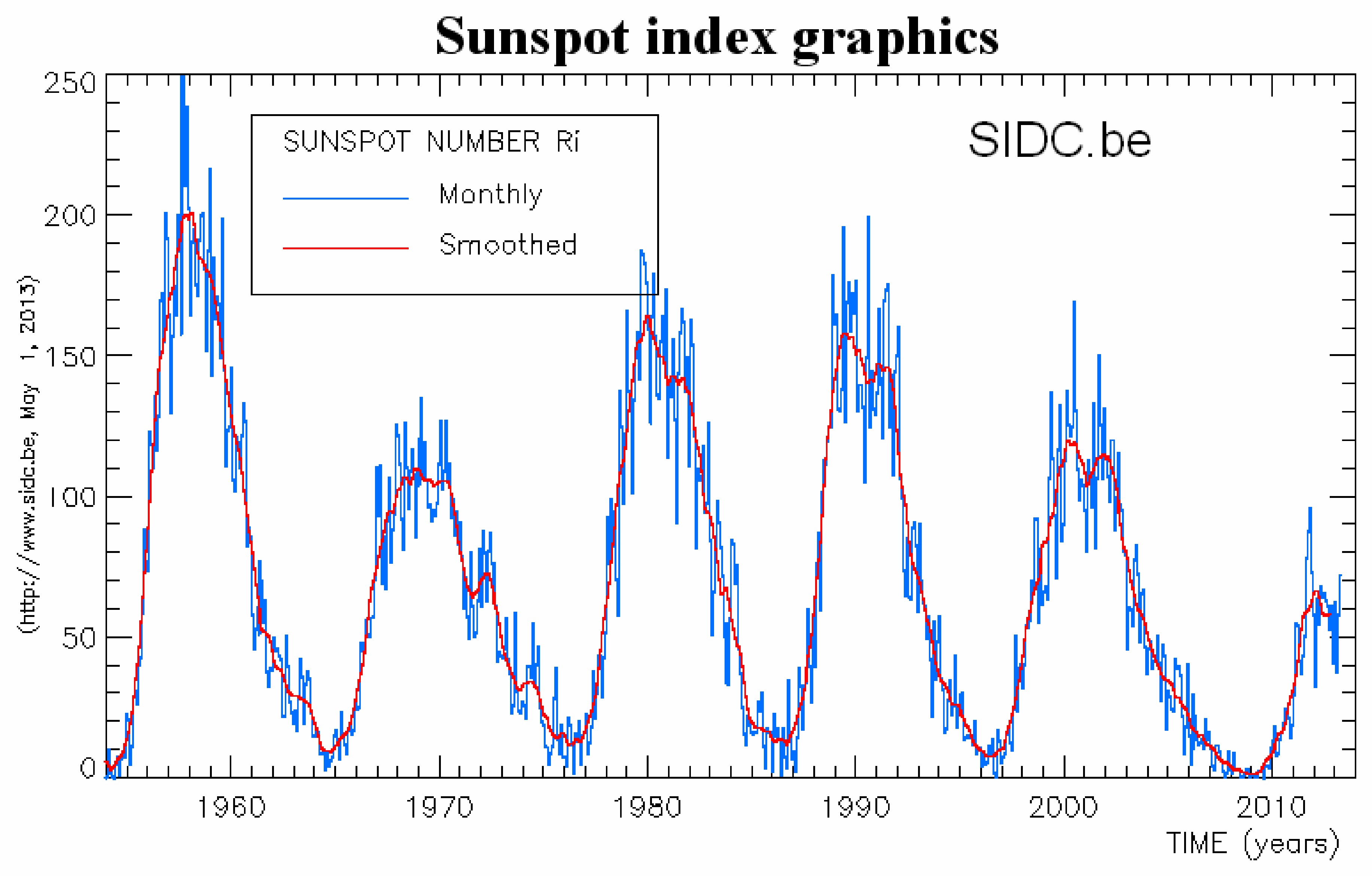
- Robbrecht E. Rhodes-ESPM-13. Report. (2011).

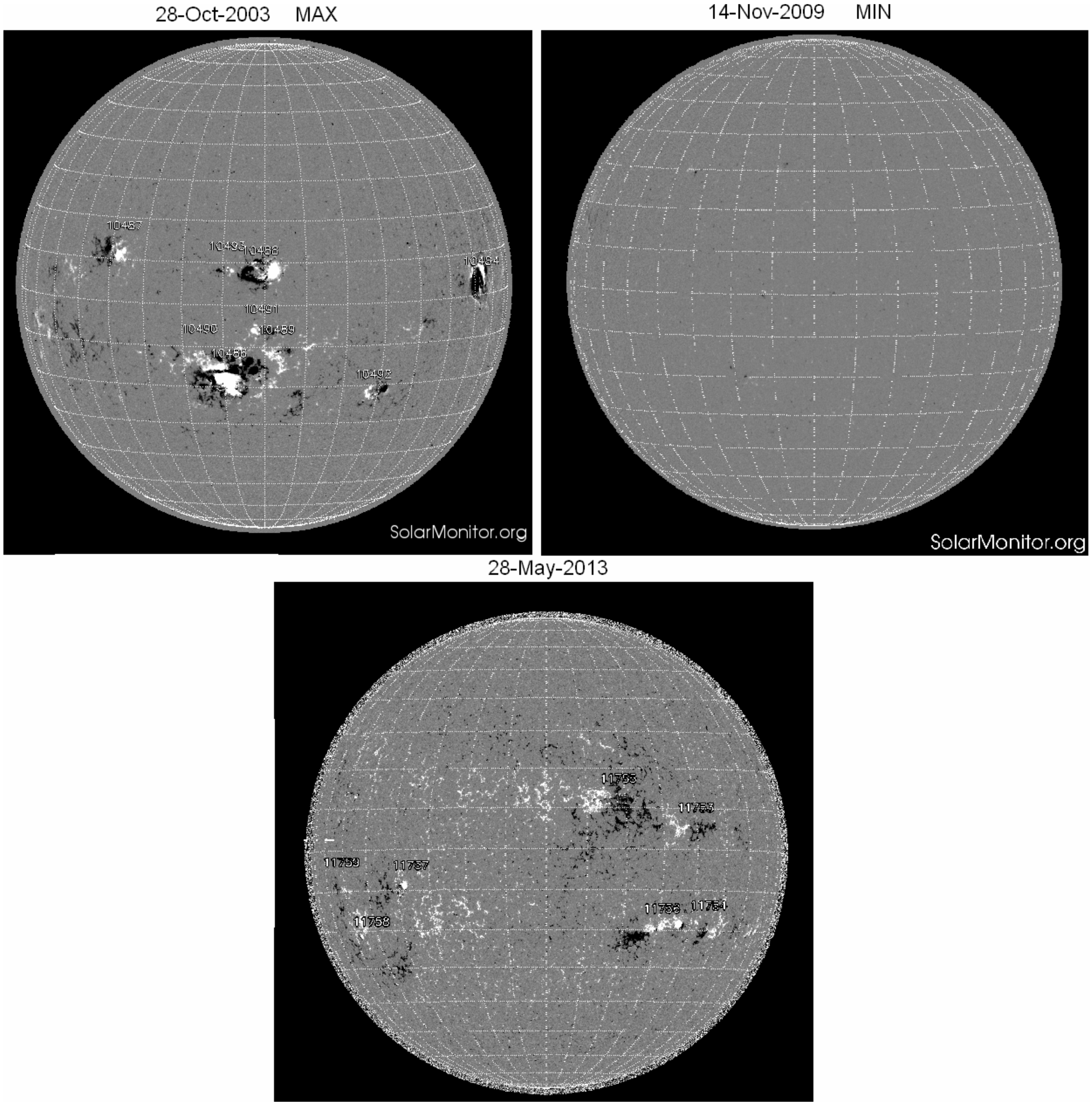
magnetogramme

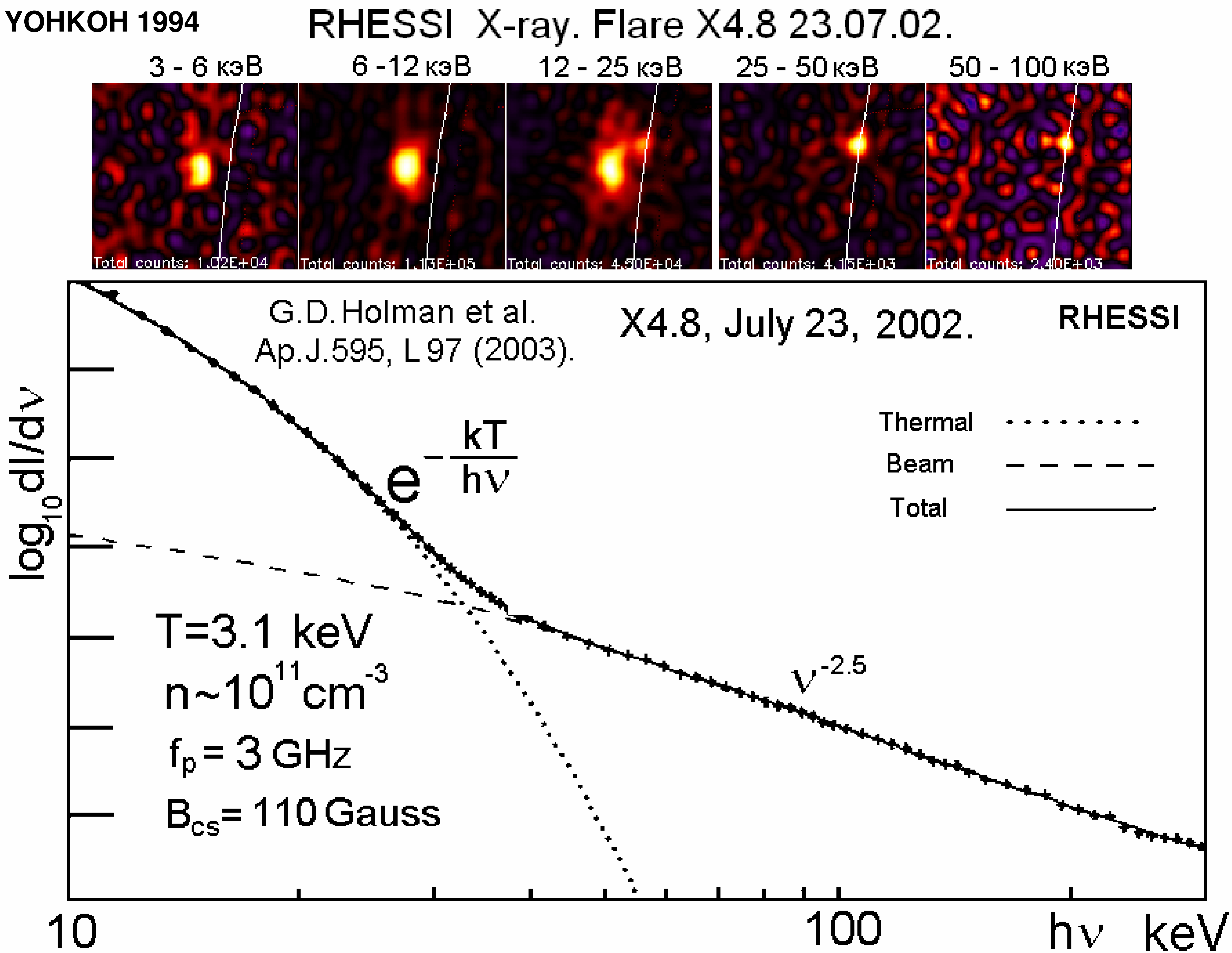
Solar spots

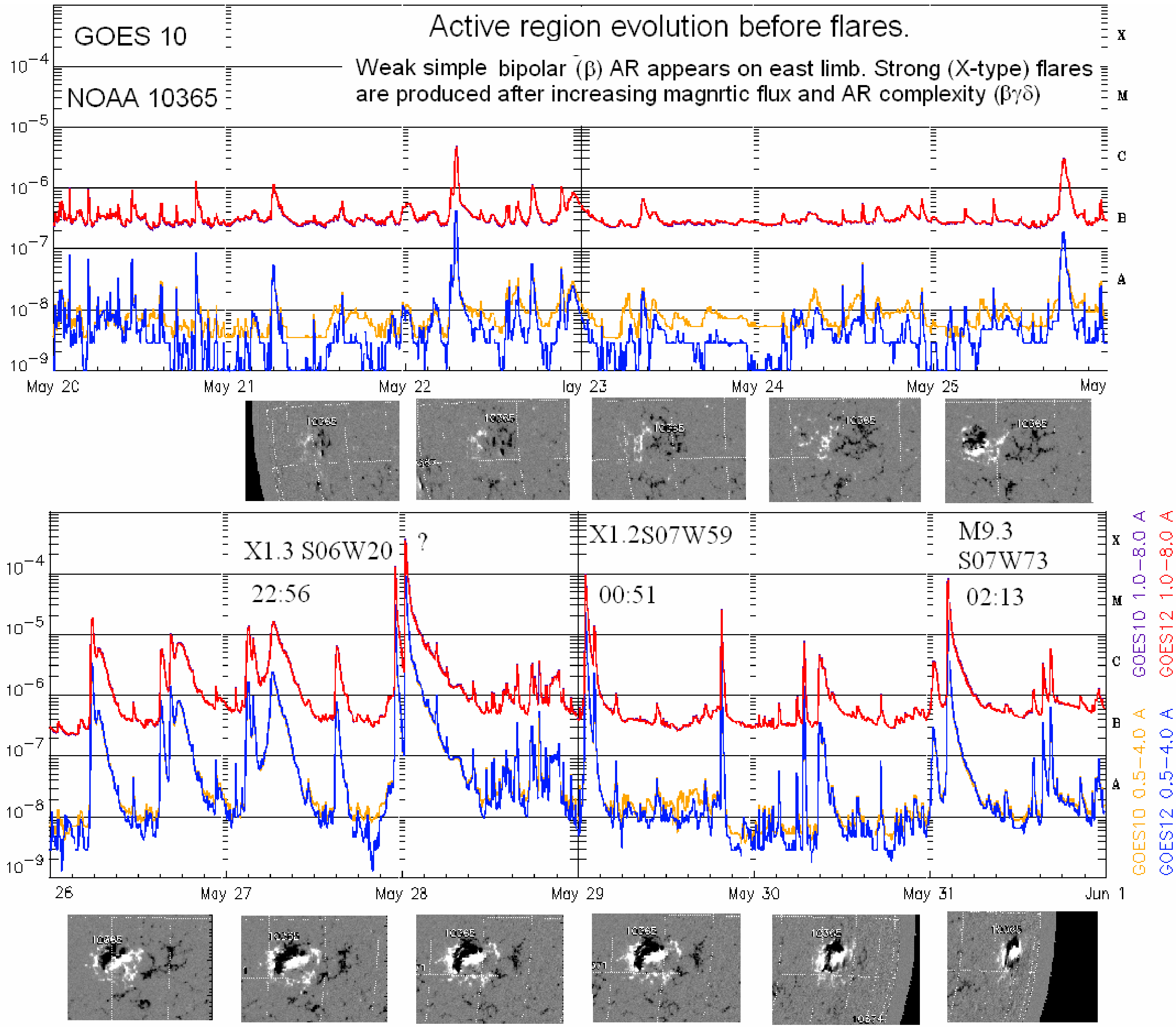





Sunspot index graphics
SUNSPOT NUMBER Ri
Monthly
Smoothed
SIDC.be
(http://www.sidc.be, May 1, 2013)
250
200
150
100
50
0
1960
1970
1980
1990
2000
2010
TIME (years)


28-Oct-2003 MAX
10487
10493
10488
10484
10491
10490
10489
10486
10492
SolarMonitor.org
14-Nov-2009 MIN
SolarMonitor.org
28-May-2013
11755
11753
11759
11757
11758
11756
11754


YOHKOH 1994
RHESSI X-ray. Flare X4.8 23.07.02.
3 - 6 кэВ
6 -12 кэВ
12 - 25 кэВ
25 - 50 кэВ
50 - 100 кэВ
G.D.Holman et al.
Ap.J.595, L97 (2003).
X4.8, July 23, 2002.
RHESSI
Thermal
Beam
Total
$e^{-\frac{kT}{h\nu}}$
$\nu^{-2.5}$
T=3.1 keV
$n \sim 10^{11} cm^{-3}$
$f_p = 3$ GHz
$B_{cs} = 110$ Gauss
$\log_{10} dI/d\nu$
10
100
$h\nu$ keV

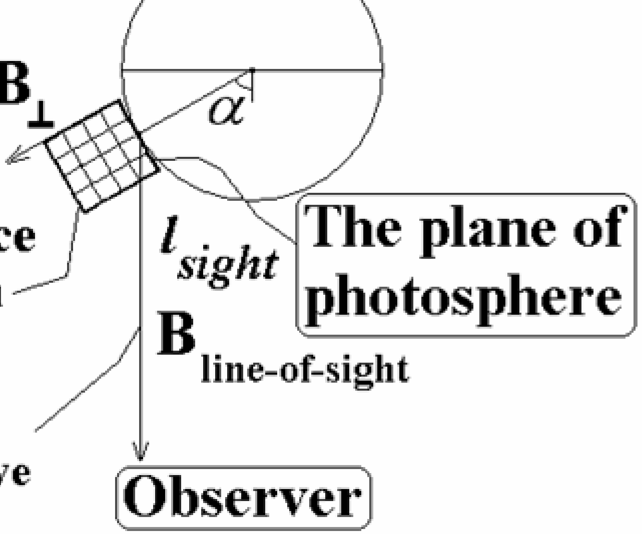


GOES 10
NOAA 10365
Active region evolution before flares.
Weak simple bipolar (β) AR appears on east limb. Strong (X-type) flares are produced after increasing magnrtic flux and AR complexity (βγδ)
X1.3 S06W20
22:56
?
X1.2S07W59
00:51
M9.3
S07W73
02:13
GOES10 1.0–8.0 A
GOES12 1.0–8.0 A
GOES10 0.5–4.0 A
GOES12 0.5–4.0 A
May 20
May 21
May 22
May 23
May 24
May 25
May 26
May 27
May 28
May 29
May 30
May 31
Jun 1
X
M
C
B
A

Potential magnetic field approximation

$$\mathbf{B} = \nabla \varphi_{\mathrm{m}}$$

$\Delta \varphi_{\mathrm{m}} = 0$ **is solved using finite-difference scheme in the region**



Boundary condition on the plane of photosphere: $\dfrac{\partial \varphi_{\mathrm{m}}}{\partial l_{sight}} = \mathbf{B}_{\text{line-of-sight}}$ **- inclined derivative**

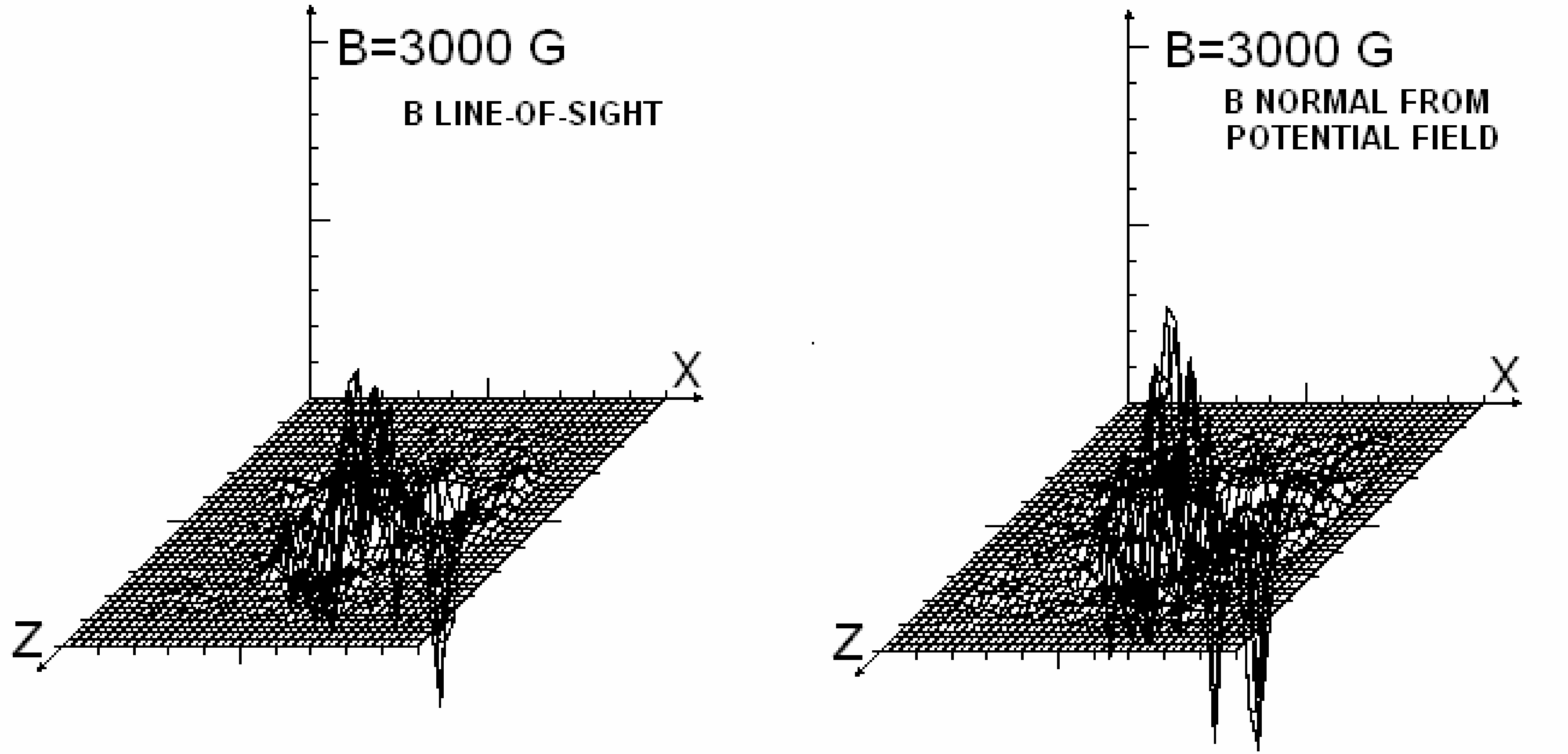
On the net corresponded to conservative relative to magnetic flux finite-difference scheme for solving MHD equations

$$[\mathrm{rot}]\mathbf{B}=0 \quad [\mathrm{div}]\mathbf{B}=0$$

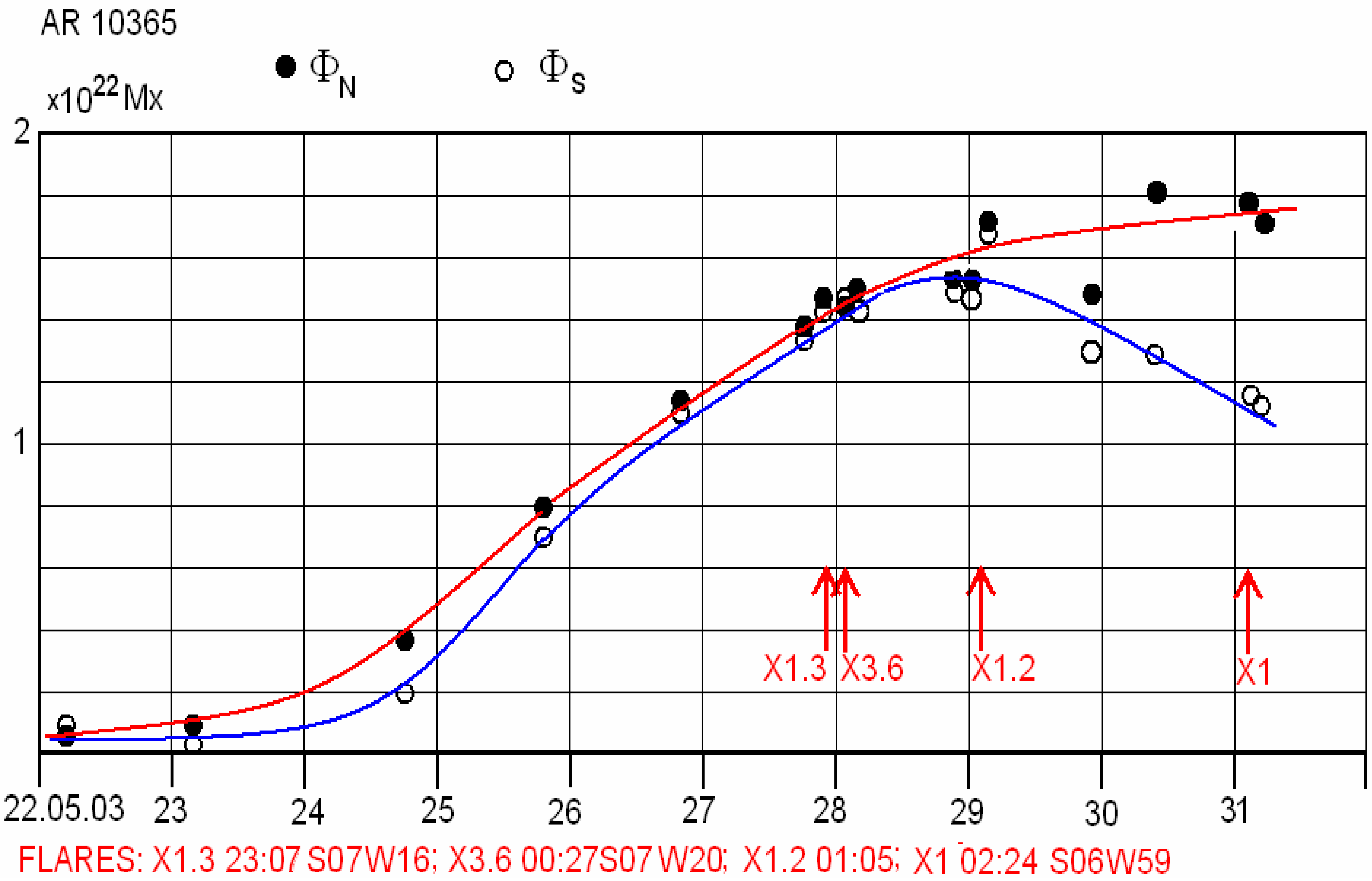
2 methods of $\Delta \varphi_{\mathrm{m}} = 0$ **solution:**

1. $\Delta \varphi_{\mathrm{m}} = 0$ **directly by iterations**
2. **By relaxation of diffusion equation** $\dfrac{\partial \varphi_{\mathrm{m}}}{\partial t} = \Delta \varphi_{\mathrm{m}}$

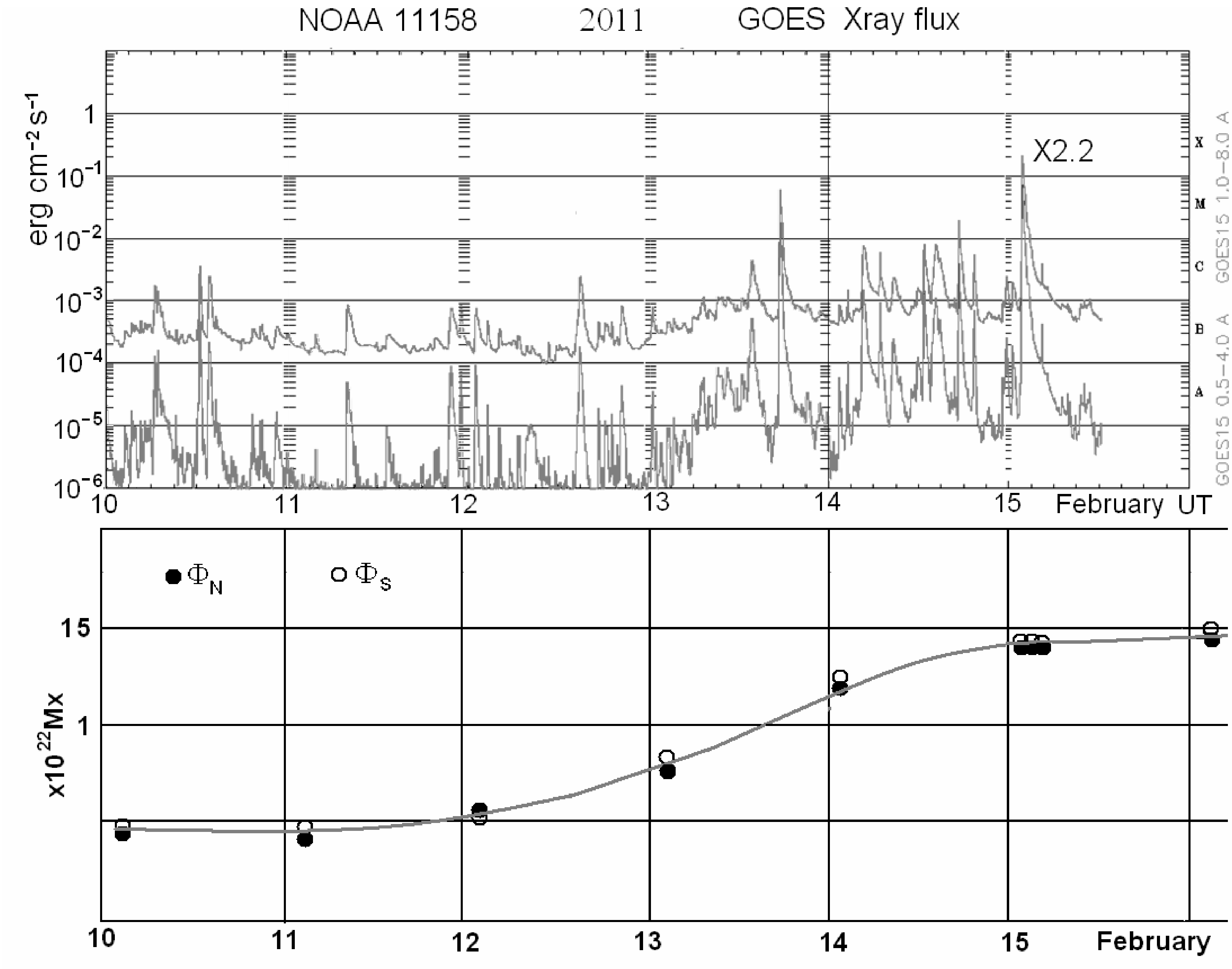
SOHO MDI magnetic field line of sight measurements and calculated photospheric normal component. Active region 10486. 2003-10-24 19:15

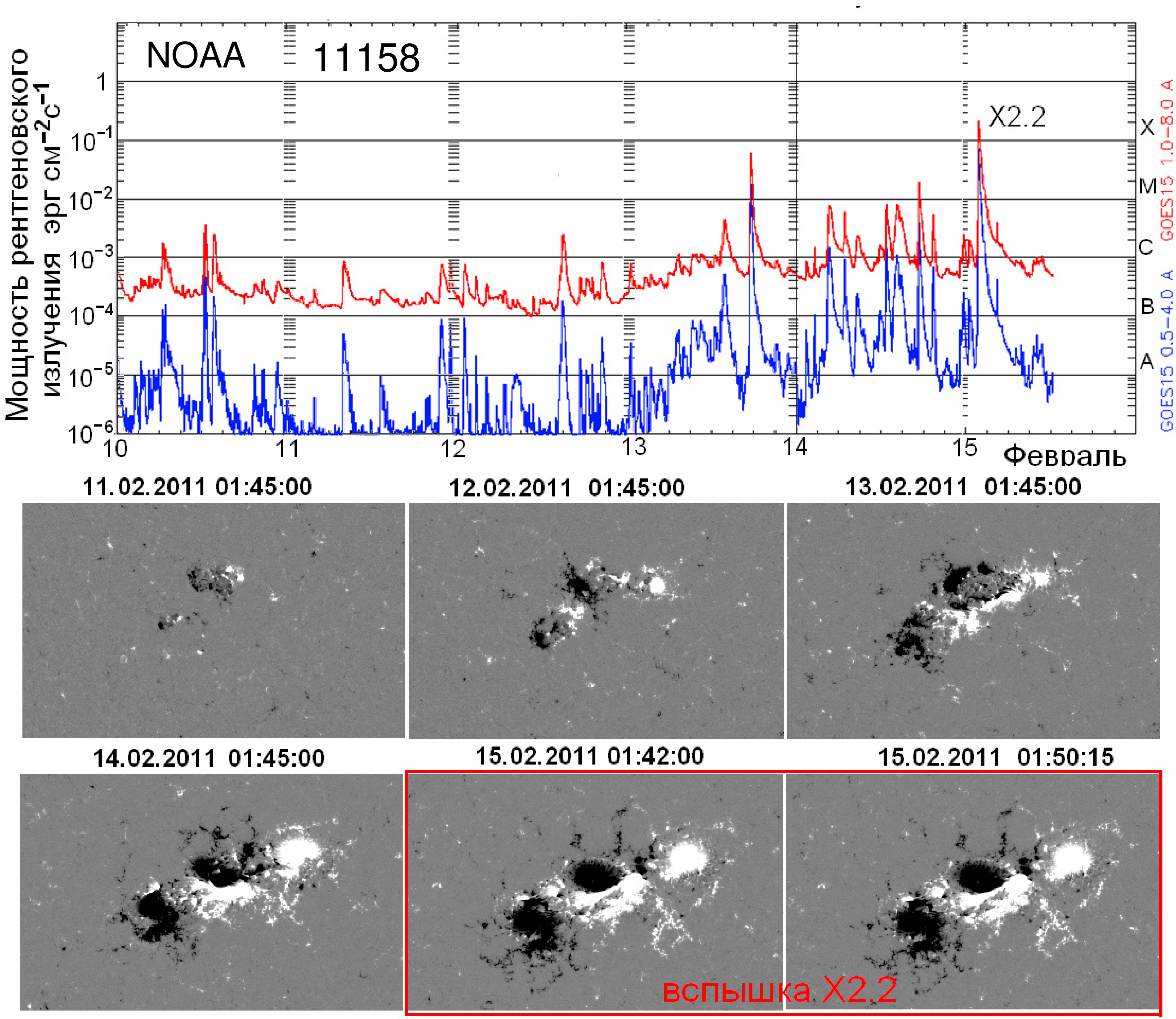


$\Phi_N = 4.2 \cdot 10^{22}$ Mx $\Phi_S = 2.7 \cdot 10^{22}$ Mx $\Phi_N = 6.4 \cdot 10^{22}$ Mx $\Phi_S = 4.1 \cdot 10^{22}$ Mx

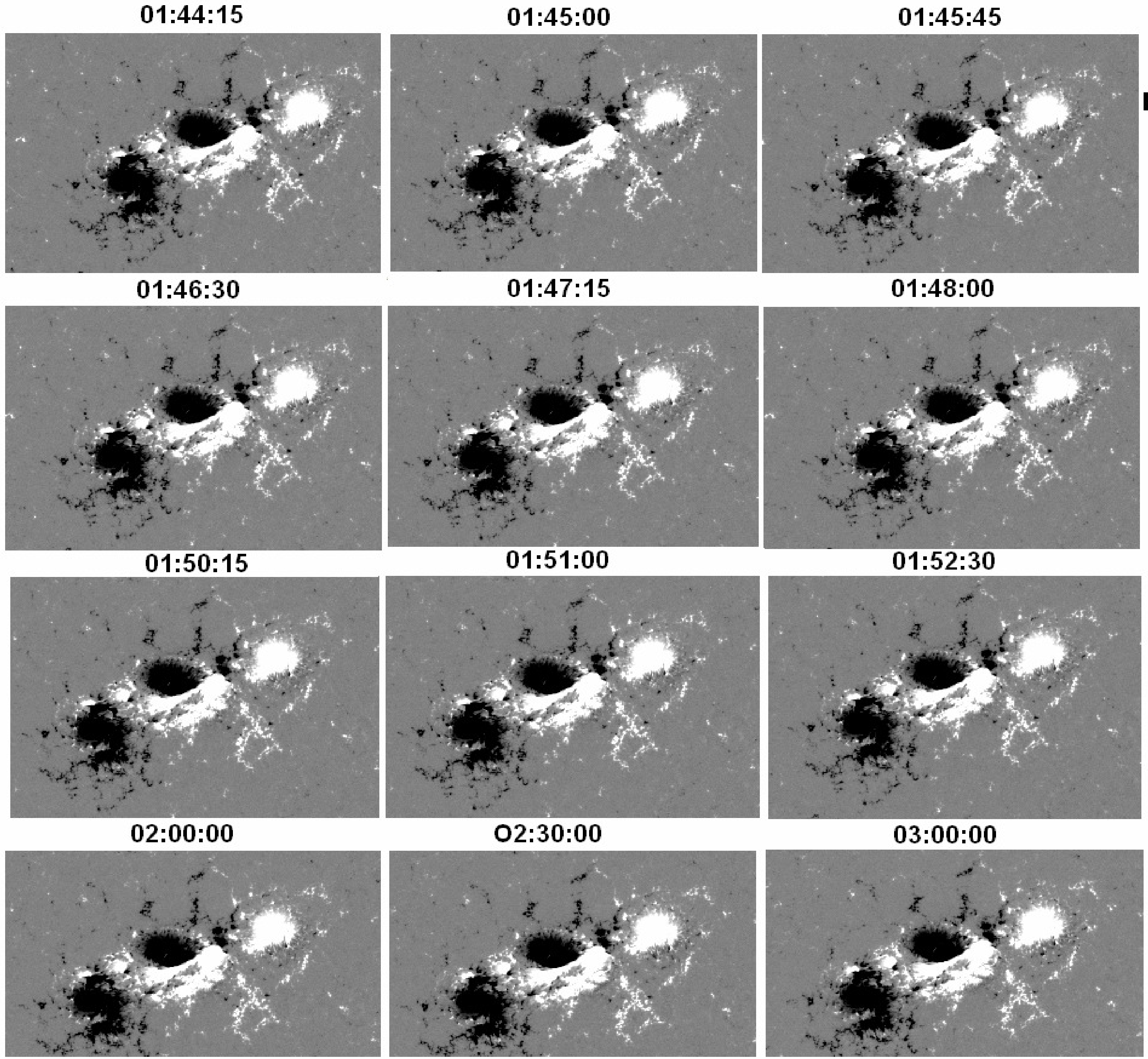


A. I. Podgorny, I. M. Podgorny. Astron. Reports. 55, 629 (2011).


NOAA 11158
2011
GOES Xray flux
erg cm^{-2} s^{-1}
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
X2.2
X
M
C
B
A
GOES15 1.0–8.0 A
GOES15 0.5–4.0 A
10
11
12
13
14
15
February UT
Φ_N
Φ_S
15
1
x10^{22}Mx
February



NOAA 11158
Мощность рентгеновского излучения эрг см$^{-2}$с$^{-1}$
X2.2
X
M
C
B
A
GOES15 1.0–8.0 A
GOES15 0.5–4.0 A
10 11 12 13 14 15 Февраль
11.02.2011 01:45:00
12.02.2011 01:45:00
13.02.2011 01:45:00
14.02.2011 01:45:00
15.02.2011 01:42:00
15.02.2011 01:50:15
вспышка X2.2



SDO magnetograms

NOAA 11158

βγδ

FLARE

Febrary 15, 2011.

X2.2 S21 W21

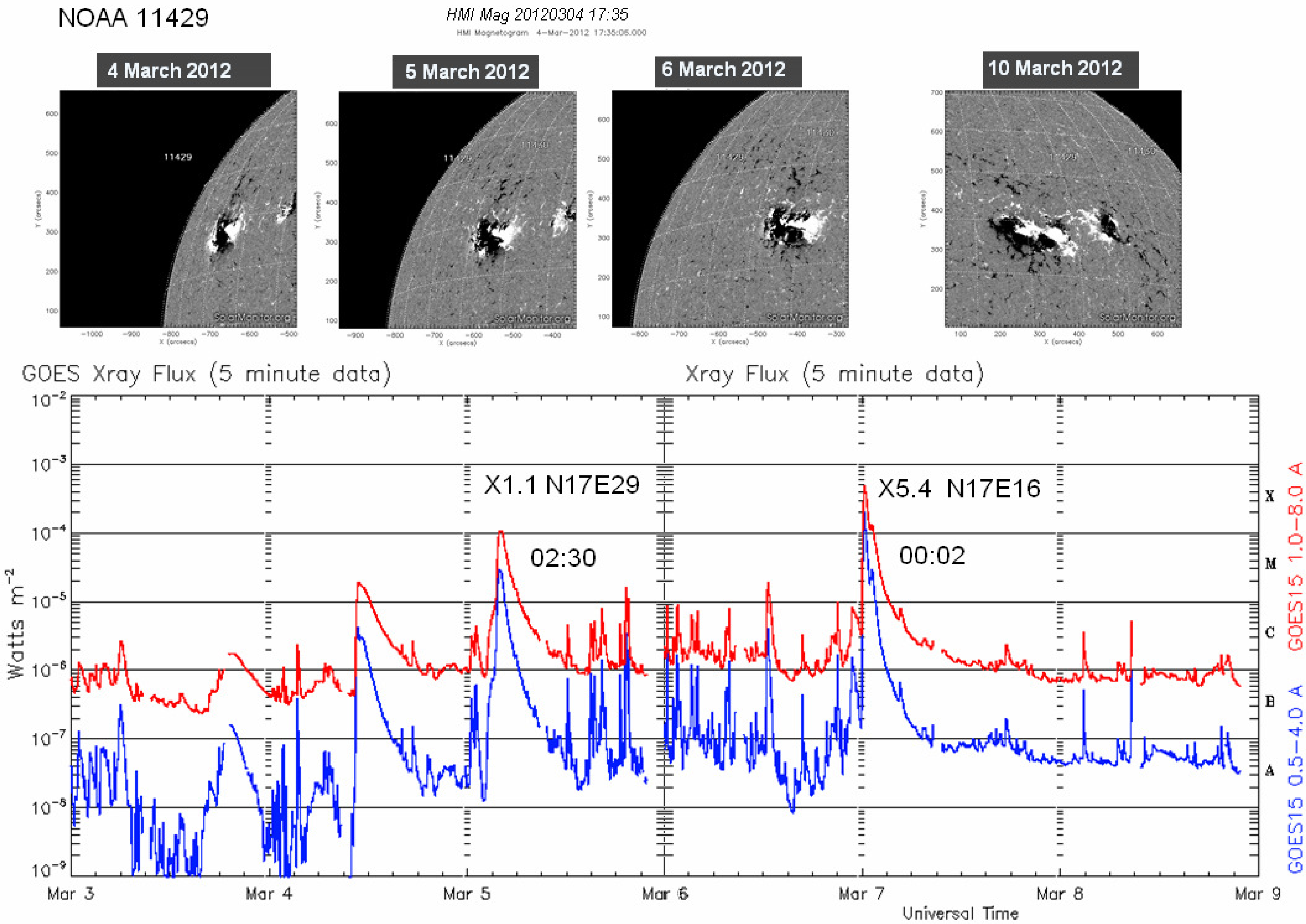
Start 01:44:00

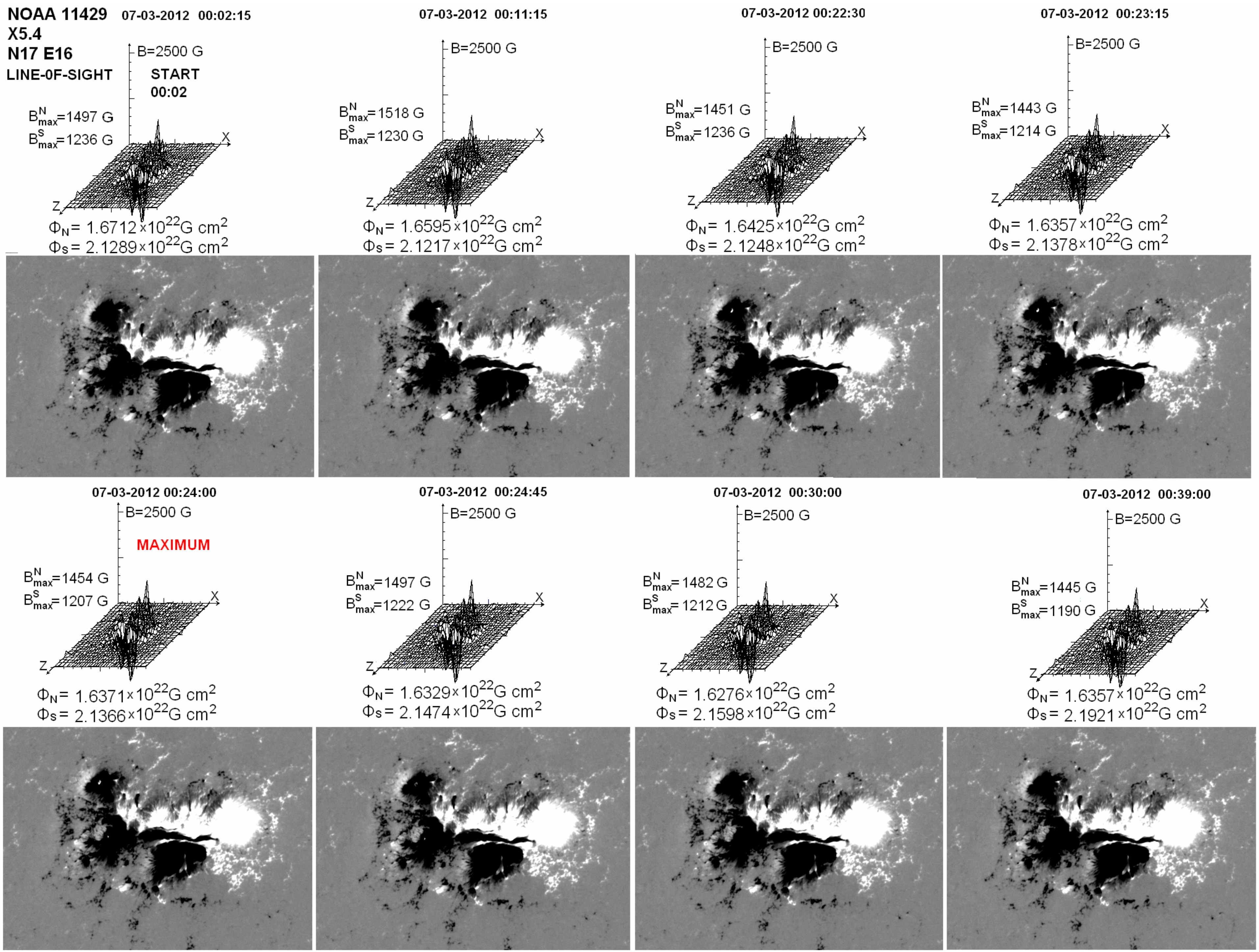
Peak 01:45:00

TABLE

Active region NOAA 11158. North and south magnetic fluxes during X2.2 flare 15.02.2011.

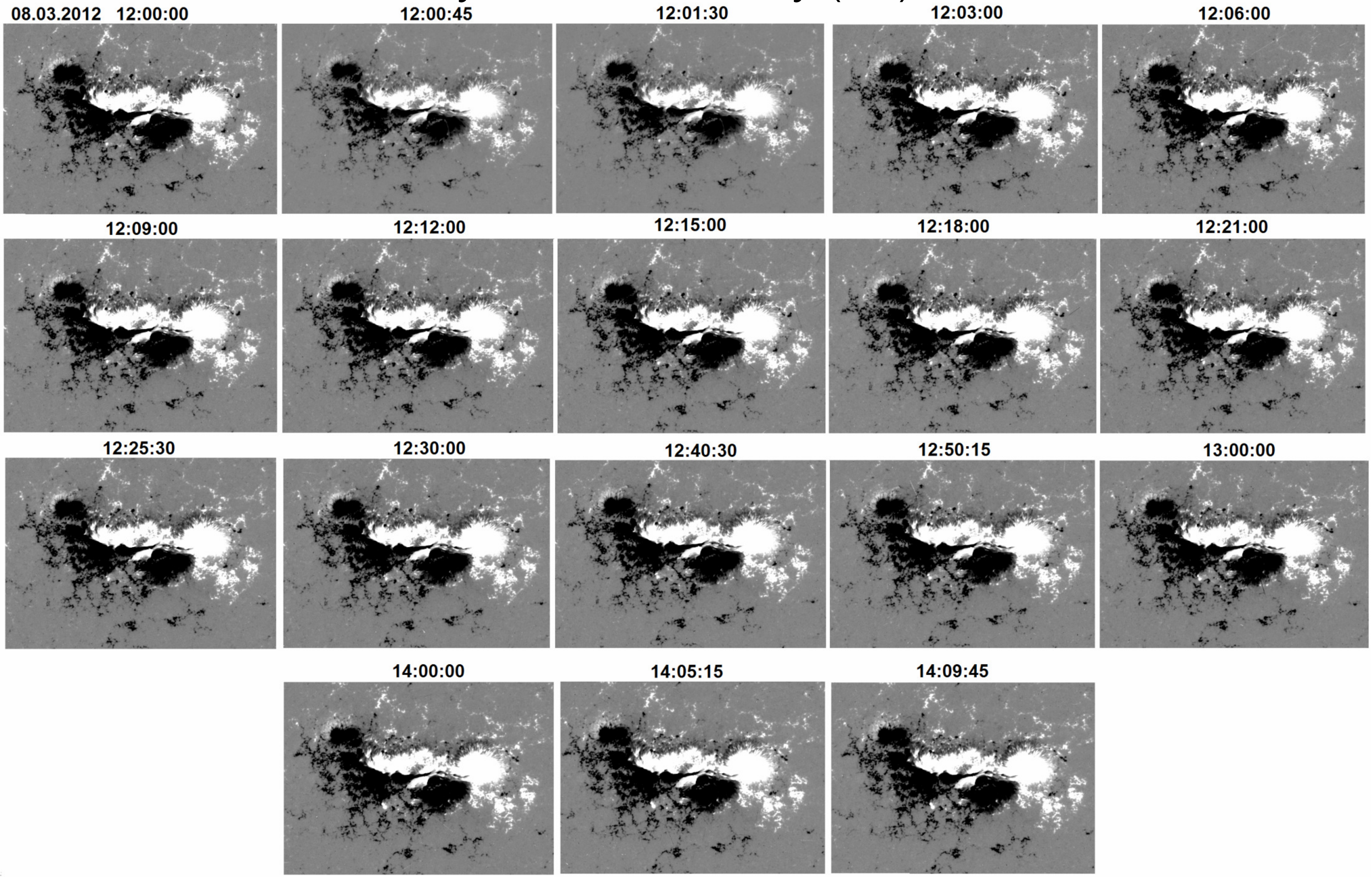
	Time	North flux (10^{22} Mx)		South flux (10^{22} Mx)	
		Normal component	Line-of-sight	Normal component	Line-of-sight
	01:28:30	1.381	1.323	1.419	1.338
	01:33:00	1.369	1.309	1.420	1.337
	01:37:30	1.377	1.321	1.415	1.335
	01:42:00	1.378	1.320	1.412	1.331
	01:42:45	1.375	1.315	1.415	1.331
	01:43:00	1.395	1.338	1.400	1.332
Flare start	01:44:15	1.376	1.319	1.417	1.335
Flare peak	**01:45:00**	**1.384**	**1.326**	**1.413**	**1.331**
	01:45:45	1.387	1.329	1.411	1.330
	01:46:30	1.386	1.327	1.412	1.330
	01:47:15	1.391	1.332	1.409	1.326
	01:48:00	1.387	1.318	1.412	1.320
Decay	01:50:15	1.378	1.318	1.403	1.320
	01:51:00	1.378	1.320	1.400	1.324
	01:51:45	1.379	1.321	1.400	1.318
	01:52:30	1.380	1.321	1.405	1.323
	01:54:00	1.372	1.312	1.400	1.316
	01:56:15	1.376	1.313	1.403	1.319
	02:00:00	1.387	1.323	1.414	1.328
	02:15:00	1.405	1.342	1.402	1.316
	02:30:00	1.409	1.346	1.406	1.319


NOAA 11429
HMI Mag 20120304 17:35
4 March 2012
5 March 2012
6 March 2012
10 March 2012
GOES Xray Flux (5 minute data)
Xray Flux (5 minute data)
X1.1 N17E29
02:30
X5.4 N17E16
00:02
Watts m-2
GOES15 1.0–8.0 A
GOES15 0.5–4.0 A
X
M
C
B
A
Mar 3
Mar 4
Mar 5
Mar 6
Mar 7
Mar 8
Mar 9
Universal Time

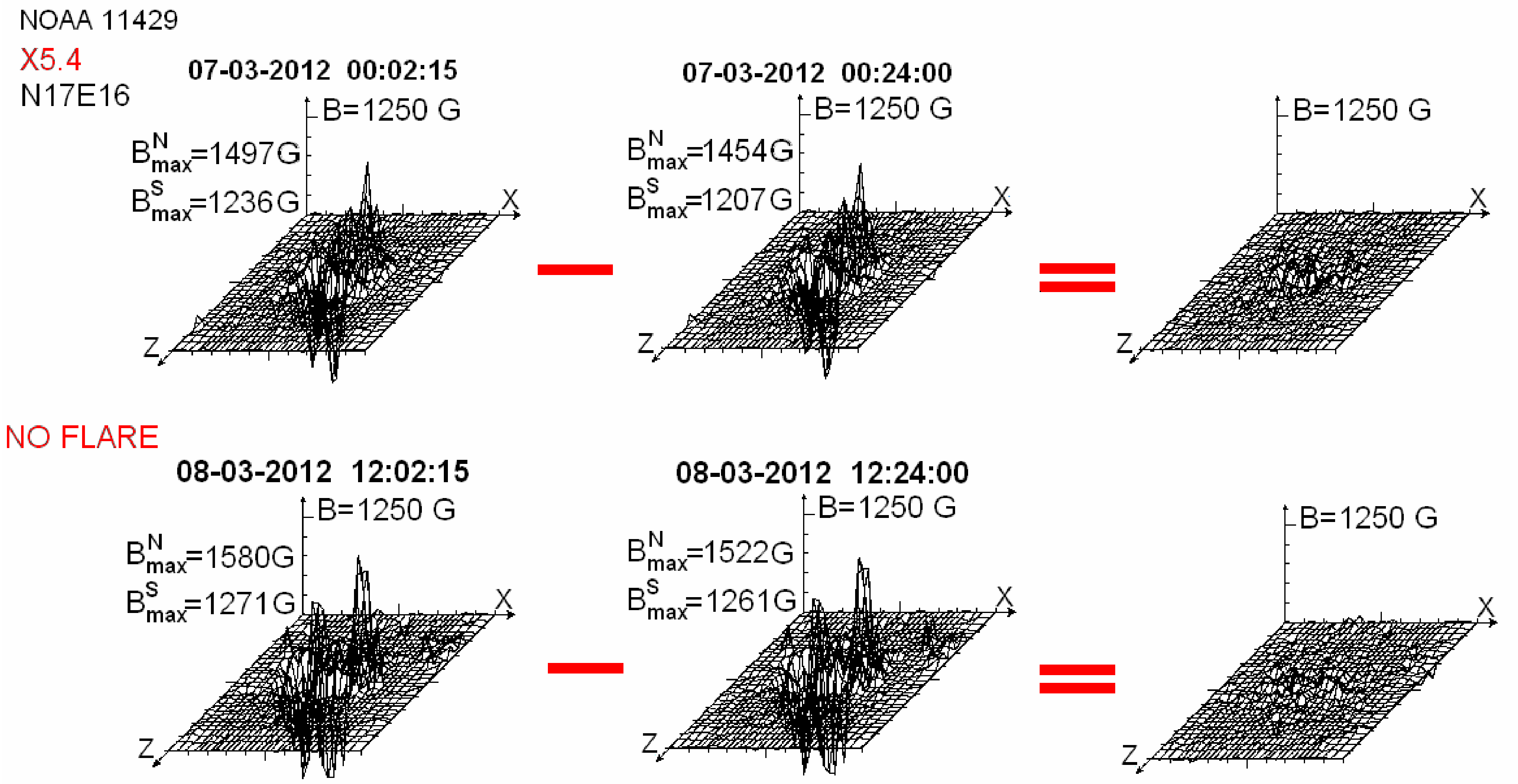

NOAA 11429
07-03-2012 00:02:15
X5.4
N17 E16
LINE-0F-SIGHT
B=2500 G
START
00:02
B^N_max=1497 G
B^S_max=1236 G
Φ_N= 1.6712×10^22 G cm^2
Φs= 2.1289×10^22 G cm^2
07-03-2012 00:11:15
B=2500 G
B^N_max=1518 G
B^S_max=1230 G
Φ_N= 1.6595×10^22 G cm^2
Φs= 2.1217×10^22 G cm^2
07-03-2012 00:22:30
B=2500 G
B^N_max=1451 G
B^S_max=1236 G
Φ_N= 1.6425×10^22 G cm^2
Φs= 2.1248×10^22 G cm^2
07-03-2012 00:23:15
B=2500 G
B^N_max=1443 G
B^S_max=1214 G
Φ_N= 1.6357×10^22 G cm^2
Φs= 2.1378×10^22 G cm^2
07-03-2012 00:24:00
B=2500 G
MAXIMUM
B^N_max=1454 G
B^S_max=1207 G
Φ_N= 1.6371×10^22 G cm^2
Φs= 2.1366×10^22 G cm^2
07-03-2012 00:24:45
B=2500 G
B^N_max=1497 G
B^S_max=1222 G
Φ_N= 1.6329×10^22 G cm^2
Φs= 2.1474×10^22 G cm^2
07-03-2012 00:30:00
B=2500 G
B^N_max=1482 G
B^S_max=1212 G
Φ_N= 1.6276×10^22 G cm^2
Φs= 2.1598×10^22 G cm^2
07-03-2012 00:39:00
B=2500 G
B^N_max=1445 G
B^S_max=1190 G
Φ_N= 1.6357×10^22 G cm^2
Φs= 2.1921×10^22 G cm^2
X
Z

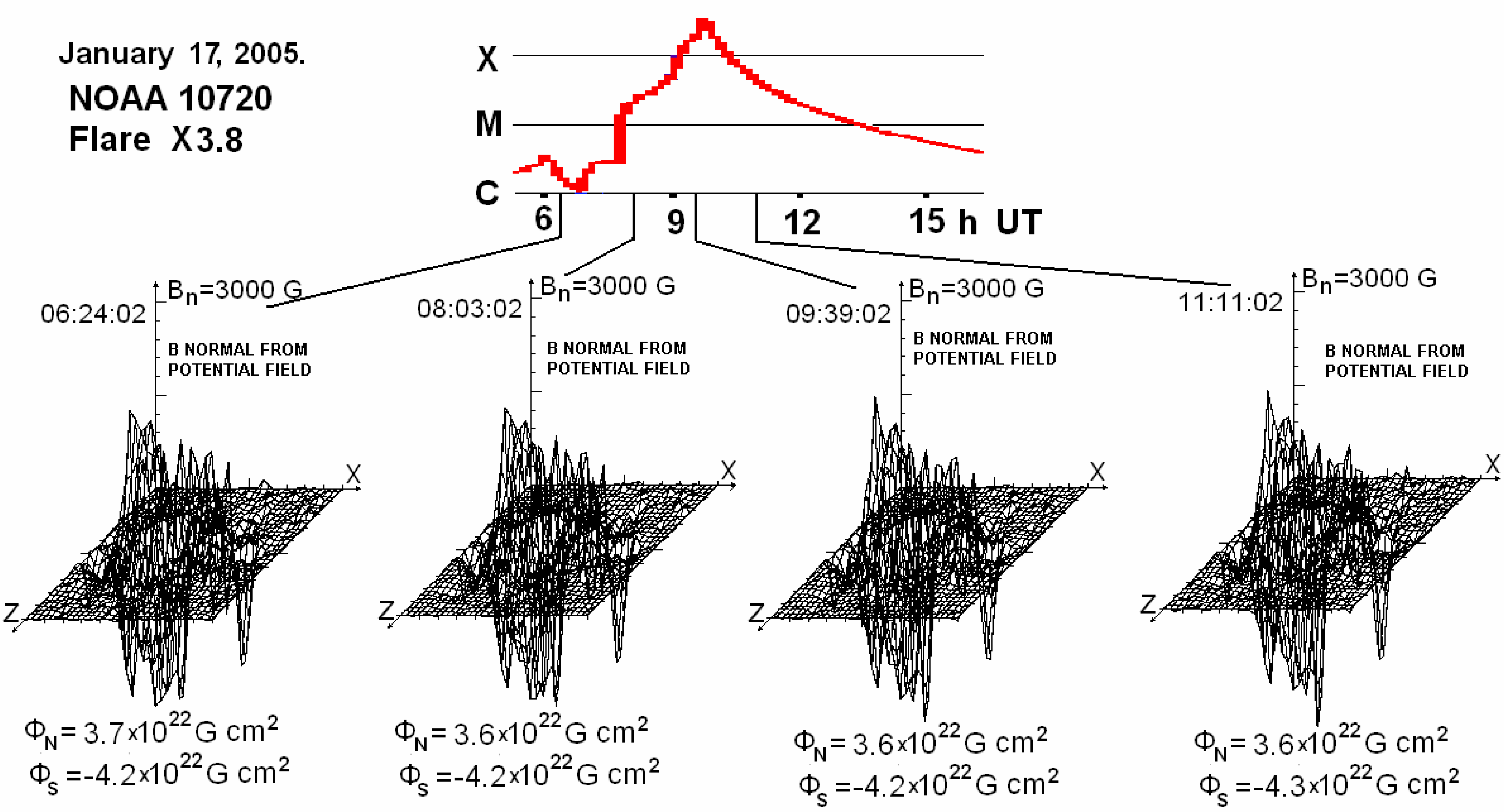
NOAA 11429

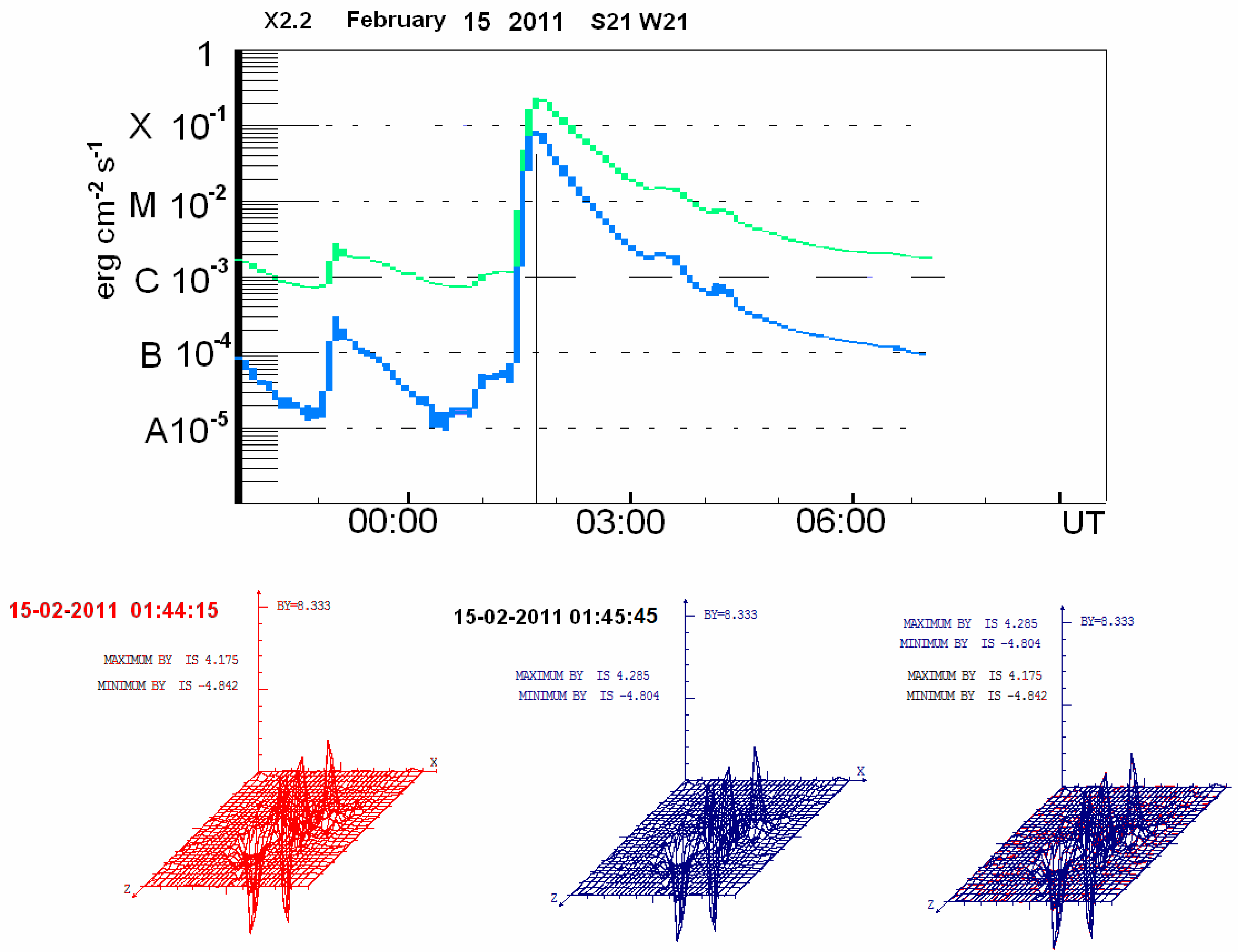
Time of very low flare activity (B8)



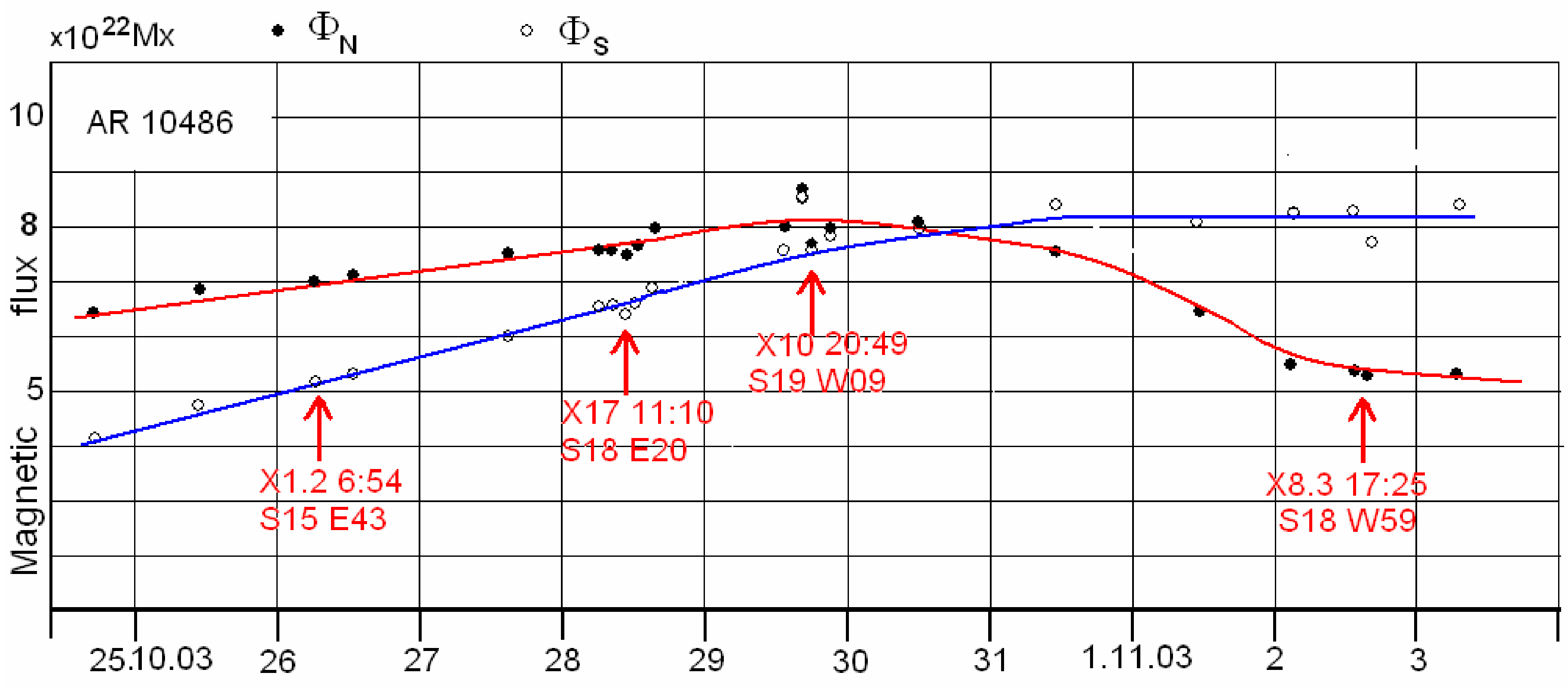
The distribution of the line-of-sight magnetic field component is not changed during a big flare – the normal and transversal components remain constant !




January 17, 2005.
NOAA 10720
Flare X3.8
X
M
C
6
9
12
15 h UT
06:24:02
08:03:02
09:39:02
11:11:02
B_n=3000 G
B NORMAL FROM POTENTIAL FIELD
X
Z
$\Phi_N = 3.7\times10^{22}$ G cm^2
$\Phi_S = -4.2\times10^{22}$ G cm^2
$\Phi_N = 3.6\times10^{22}$ G cm^2
$\Phi_S = -4.2\times10^{22}$ G cm^2
$\Phi_N = 3.6\times10^{22}$ G cm^2
$\Phi_S = -4.2\times10^{22}$ G cm^2
$\Phi_N = 3.6\times10^{22}$ G cm^2
$\Phi_S = -4.3\times10^{22}$ G cm^2

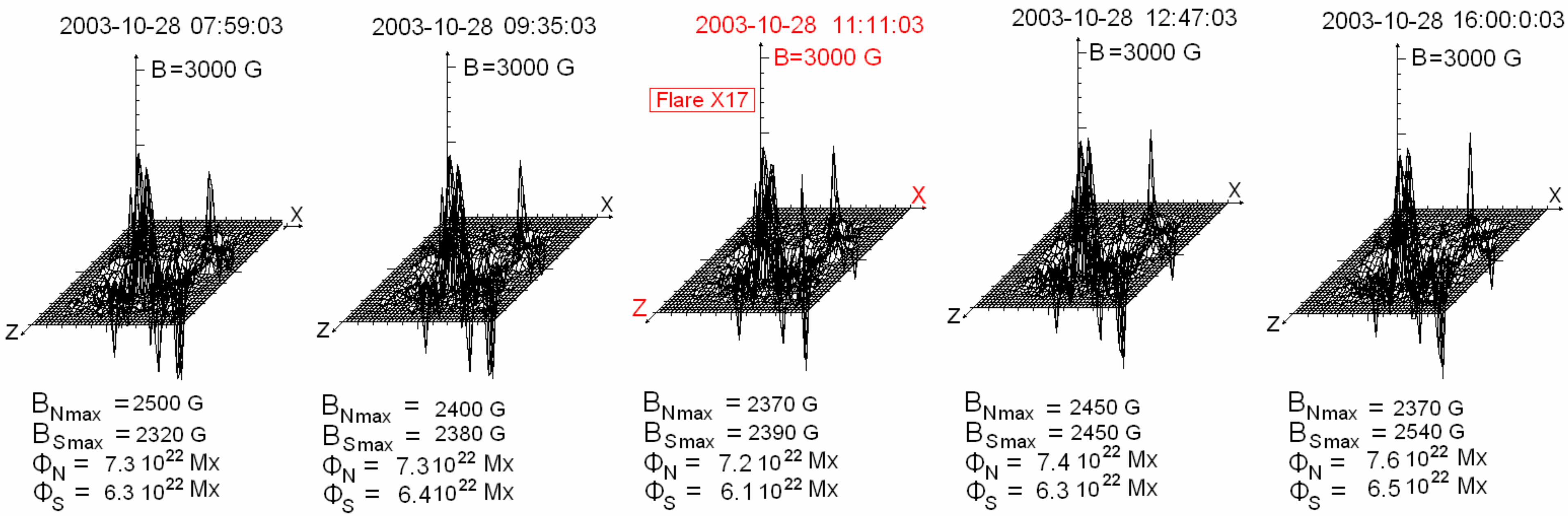


X2.2 February 15 2011 S21 W21
erg cm^{-2} s^{-1}
1
X 10^{-1}
M 10^{-2}
C 10^{-3}
B 10^{-4}
A 10^{-5}
00:00
03:00
06:00
UT
15-02-2011 01:44:15
BY=8.333
MAXIMUM BY IS 4.175
MINIMUM BY IS -4.842
X
Z
15-02-2011 01:45:45
BY=8.333
MAXIMUM BY IS 4.285
MINIMUM BY IS -4.804
X
Z
MAXIMUM BY IS 4.285
MINIMUM BY IS -4.804
BY=8.333
MAXIMUM BY IS 4.175
MINIMUM BY IS -4.842
Z

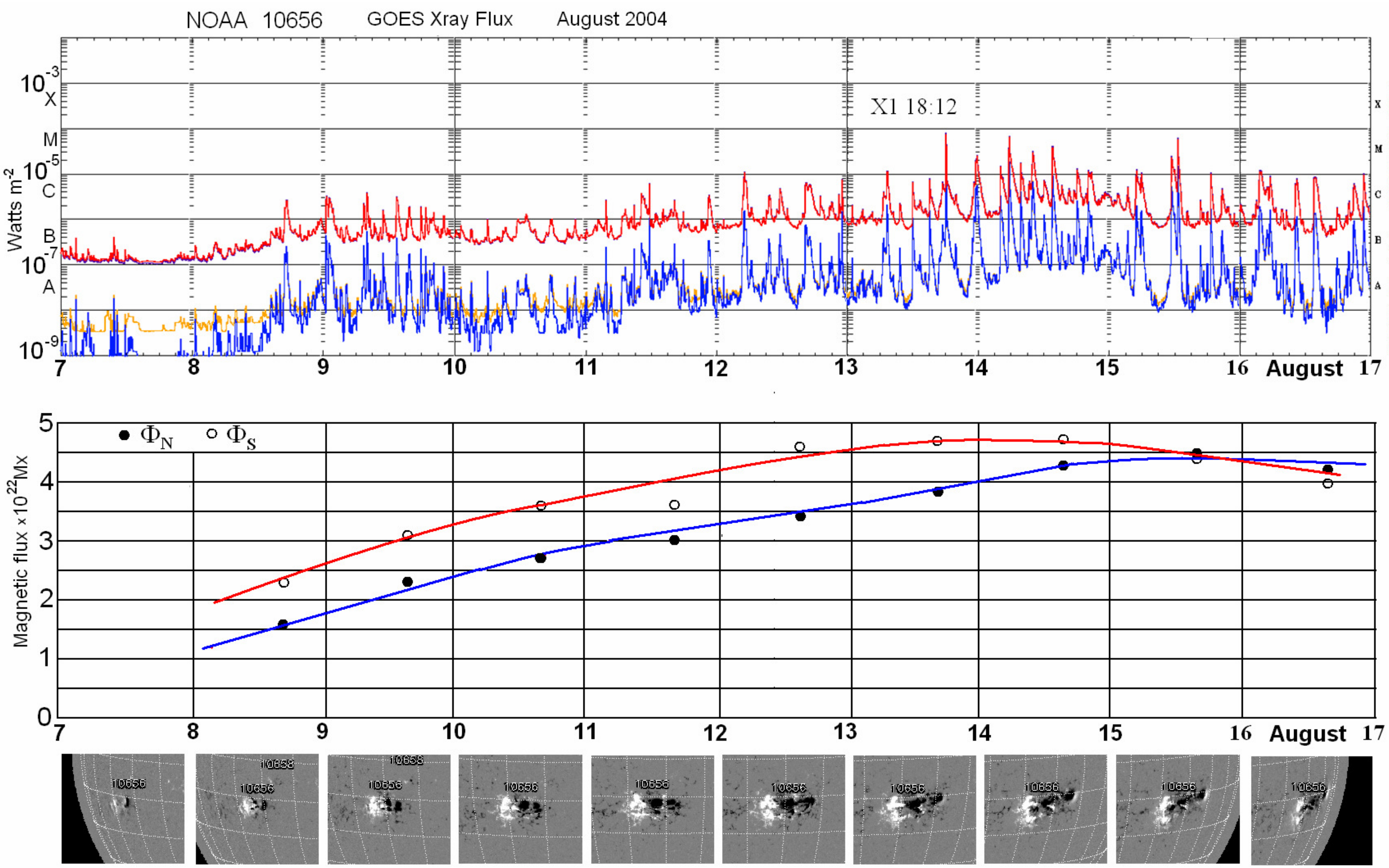


x10^22Mx
Φ_N
Φ_S
AR 10486
10
8
5
Magnetic flux
X1.2 6:54
S15 E43
X17 11:10
S18 E20
X10 20:49
S19 W09
X8.3 17:25
S18 W59
25.10.03
26
27
28
29
30
31
1.11.03
2
3

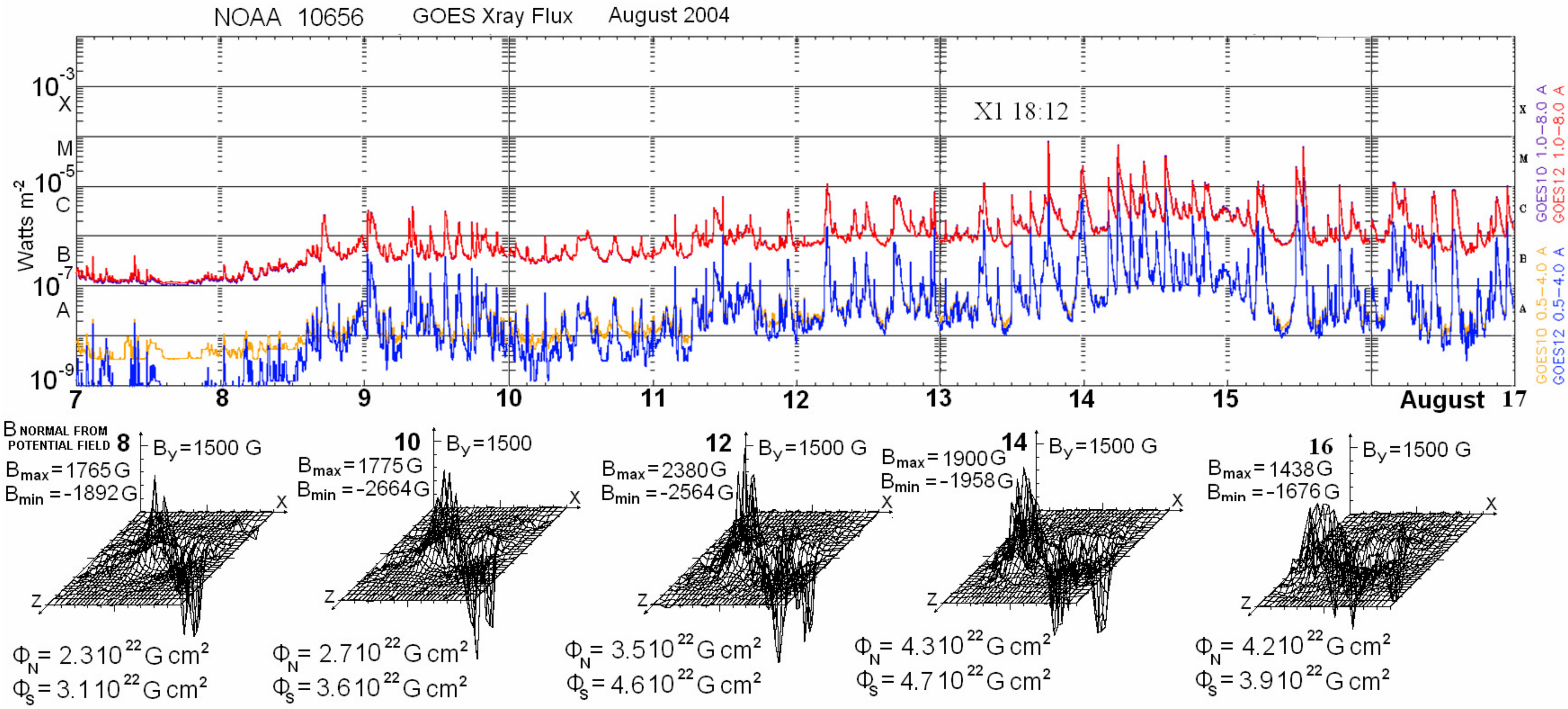
Line-of-sight magnetic field



The NOAA 10486 magnetic field is not a stationary one. But there are no strong characteristic peculiarity that appears on the photosphere during a flare.

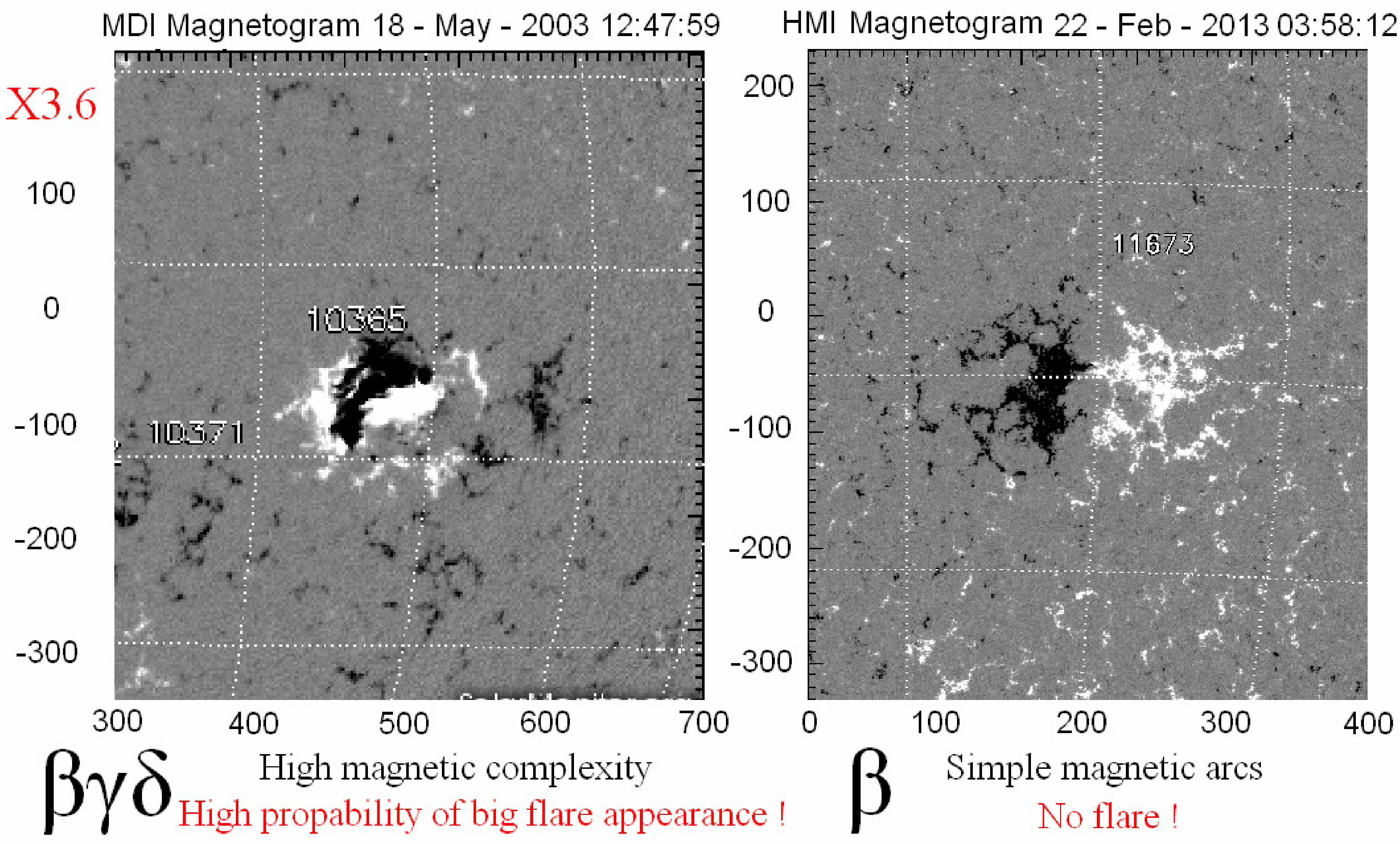


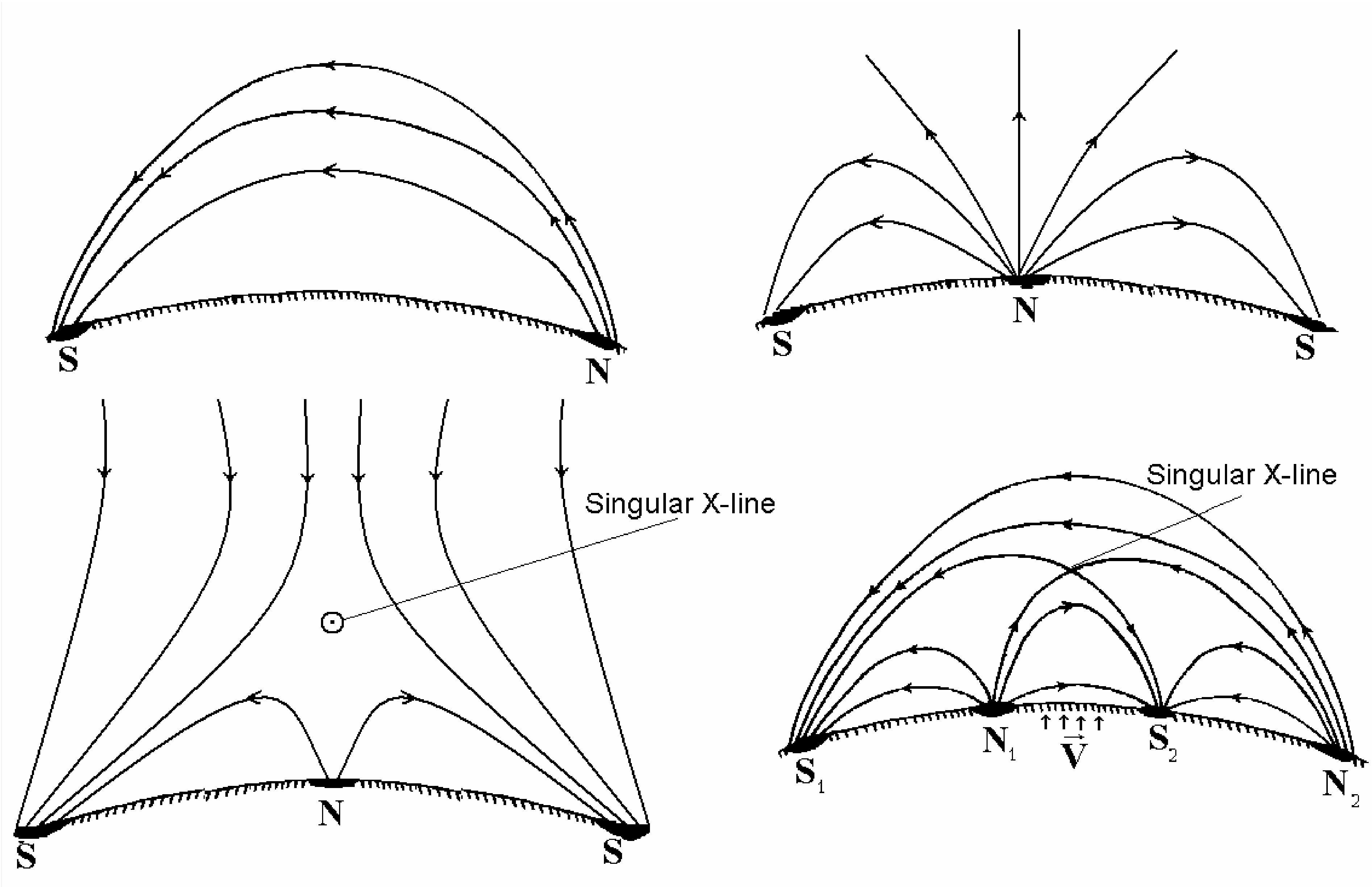
NOAA 10656 GOES Xray Flux August 2004
X1 18:12
Watts m-2
10-3
10-5
10-7
10-9
X
M
C
B
A
GOES10 1.0–8.0 A
GOES12 1.0–8.0 A
GOES10 0.5–4.0 A
GOES12 0.5–4.0 A
7 8 9 10 11 12 13 14 15 16 August 17
Φ_N Φ_S
Magnetic flux ×10^22 Mx
0 1 2 3 4 5
7 8 9 10 11 12 13 14 15 16 August 17
10656
10658

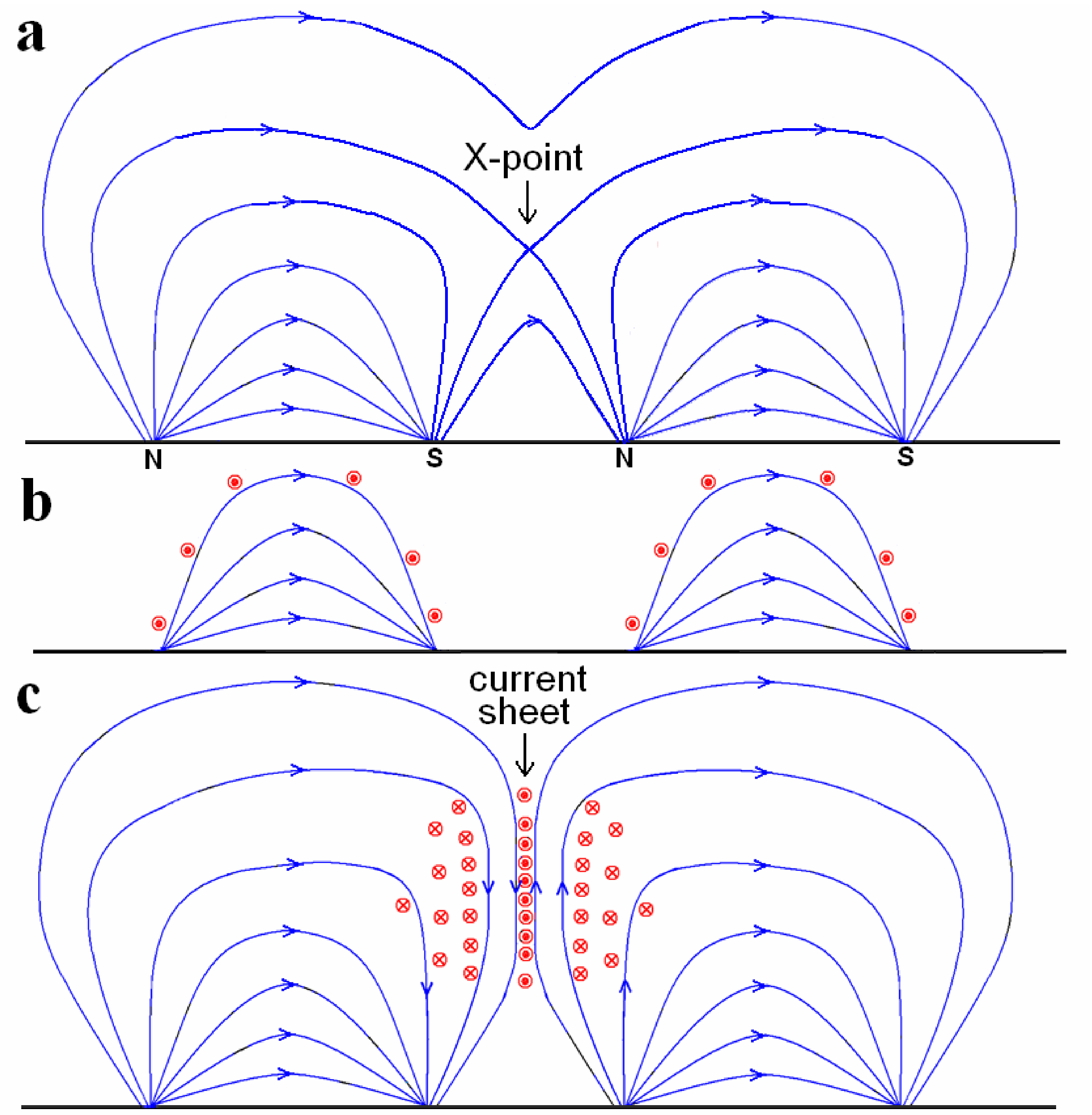


NOAA 10656 GOES Xray Flux August 2004
Watts m-2
10-3
X
M
10-5
C
B
10-7
A
10-9
X1 18:12
GOES10 1.0–8.0 A
GOES12 1.0–8.0 A
GOES10 0.5–4.0 A
GOES12 0.5–4.0 A
7
8
9
10
11
12
13
14
15
August 17
B NORMAL FROM POTENTIAL FIELD
8
By=1500 G
Bmax=1765 G
Bmin=-1892 G
ΦN= 2.3 10^22 G cm^2
ΦS= 3.1 10^22 G cm^2
10
By=1500
Bmax=1775 G
Bmin=-2664 G
ΦN= 2.7 10^22 G cm^2
ΦS= 3.6 10^22 G cm^2
12
By=1500 G
Bmax=2380 G
Bmin=-2564 G
ΦN= 3.5 10^22 G cm^2
ΦS= 4.6 10^22 G cm^2
14
By=1500 G
Bmax=1900 G
Bmin=-1958 G
ΦN= 4.3 10^22 G cm^2
ΦS= 4.7 10^22 G cm^2
16
By=1500 G
Bmax=1438 G
Bmin=-1676 G
ΦN= 4.2 10^22 G cm^2
ΦS= 3.9 10^22 G cm^2
X
Z

The flare appears above AR with the big magnetic flux and the complicated magnetic field inversion line.




S
N
S
N
S
N
Singular X-line
S
S
Singular X-line
S_1
N_1
$\vec{V}$
S_2
N_2

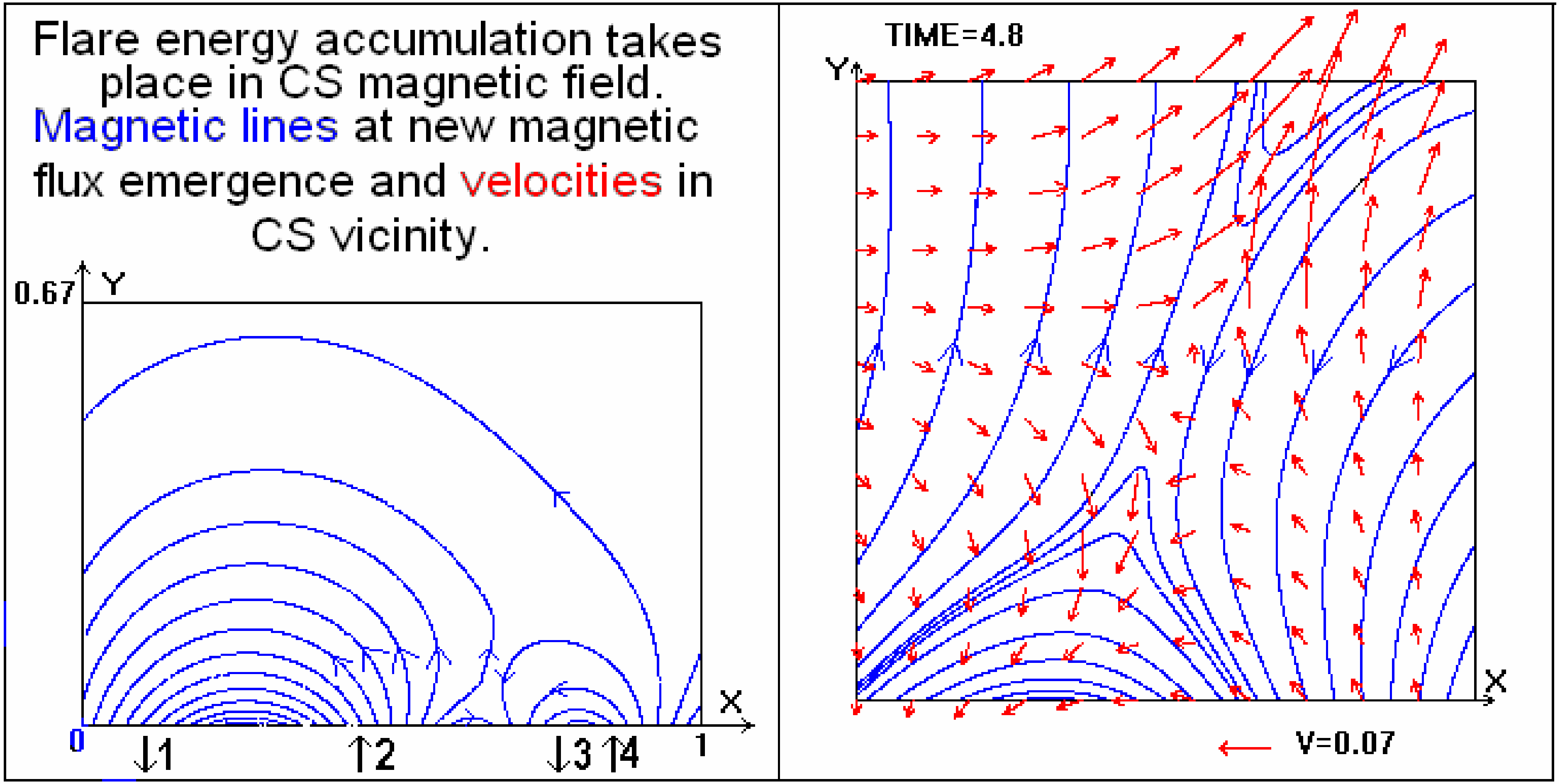


Magnetic lines of two fluxes in vacuum

Emerging fluxes in plasma

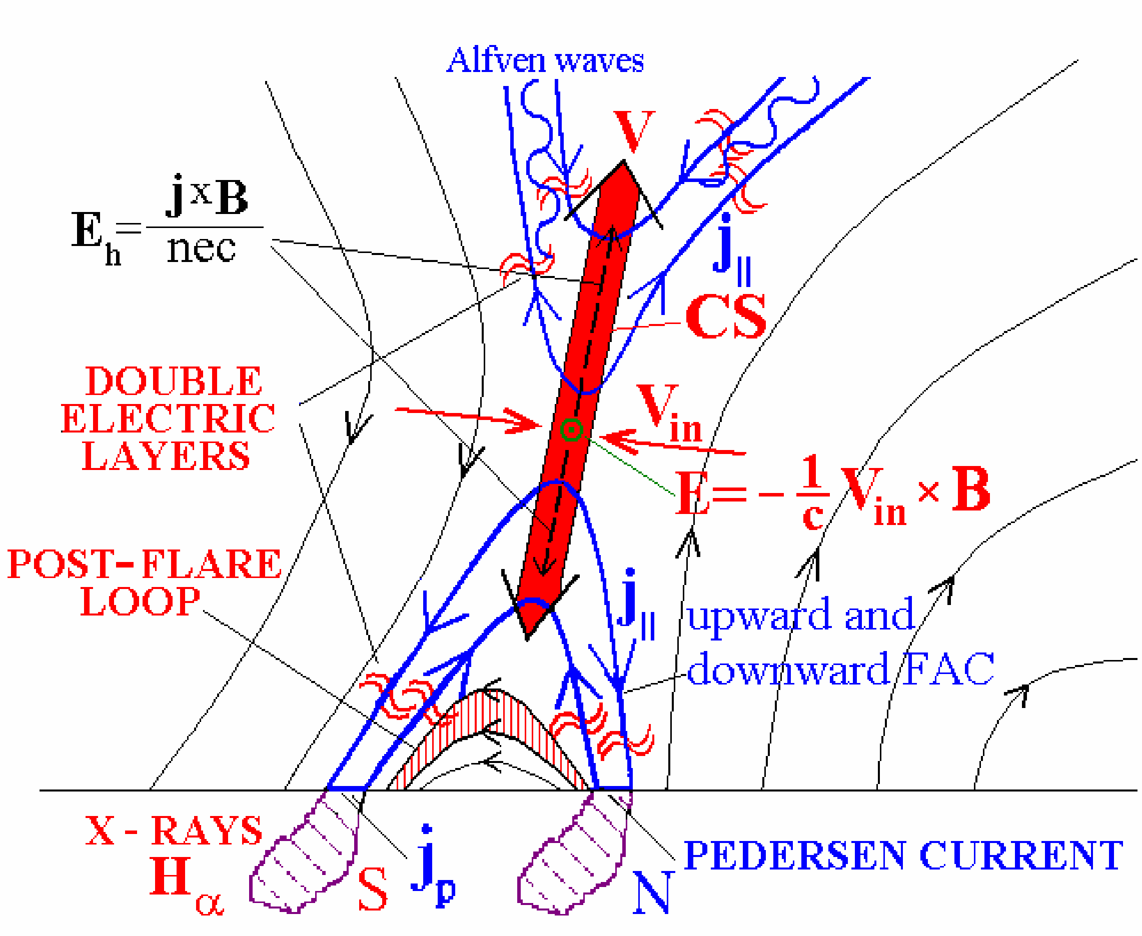
Current sheet creation due to magnetic fluxes expansion

The current layer appears when floating of the new magnetic flux near the oppositely directed old one. The j x B accelerates plasma along the layer - CME.

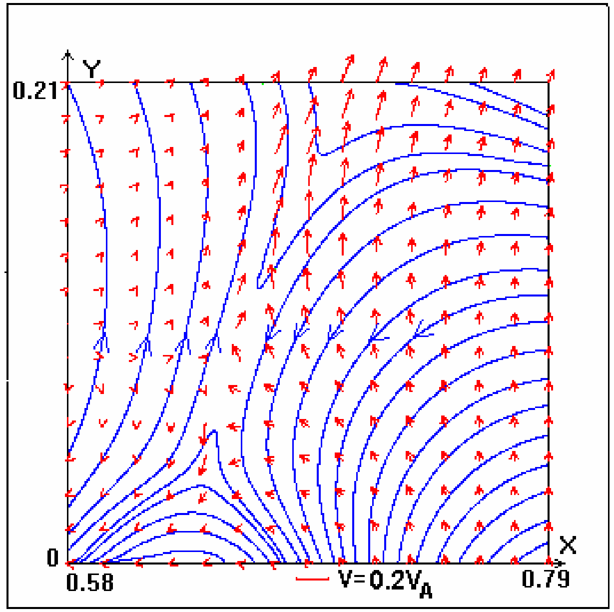


MHD simulation demonstrate that flares and CME are different manifestations of magnetic energy dissipation in the corona due to reconnection in a current sheet.

A current sheet is the only observable object in space that can accumulate slowly and quickly release energy. The geomagnetic current sheet was opened by the measurements on the satellite.



Electrons accelerated in FAC produce hard X-ray.



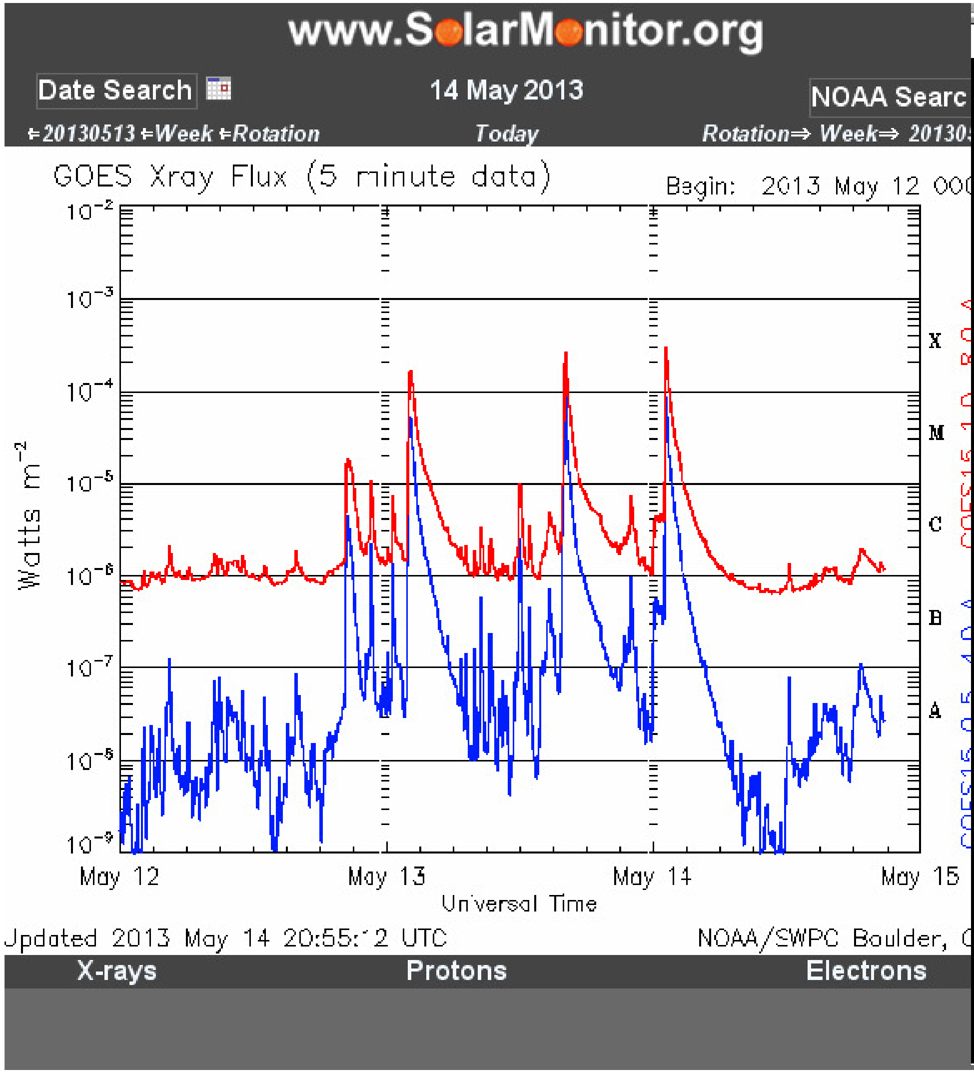
Results of current sheet creation in numerical MHD simulation. A sheet appears above an active region in the preflare state. Plasma inflows into a current sheet. Iside the sheet plasma acceleration takes place by **j**x**B** force producing CME.

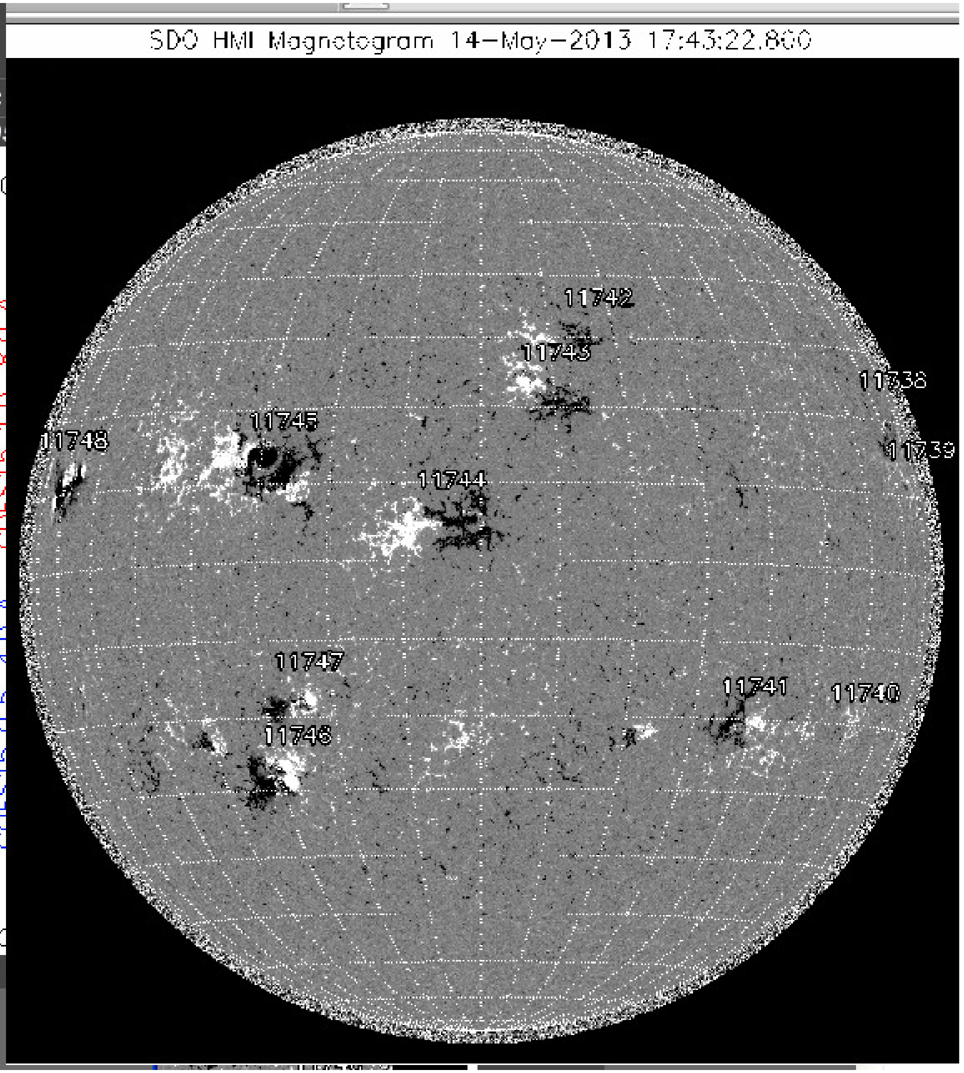
Conclusion

- A necessary condition for big flare appearing is AR magnetic flux increasing up to 10^{22} Mx.
- Big flares occur in the corona over AR with a complex (βγδ) magnetic field distribution.
- The bipolar region cannot produce a flare. The magnetic field in the corona above AR does not contain a singular line in the vicinity of which a current sheet can be formed.
- No change of the magnetic flux and magnetic field distribution in AR are generated at solar flare appearance.

Thank you!

БЛАГОДАРЯ!


www.SolarMonitor.org
Date Search
14 May 2013
NOAA Searc
⇐20130513 ⇐Week ⇐Rotation
Today
Rotation⇒ Week⇒ 20130
GOES Xray Flux (5 minute data)
Begin: 2013 May 12 000
Watts m^{-2}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
X
M
C
B
A
May 12
May 13
May 14
May 15
Universal Time
Updated 2013 May 14 20:55:12 UTC
NOAA/SWPC Boulder, C
X-rays
Protons
Electrons


SDO HMI Magnetogram 14-May-2013 17:43:22.800
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