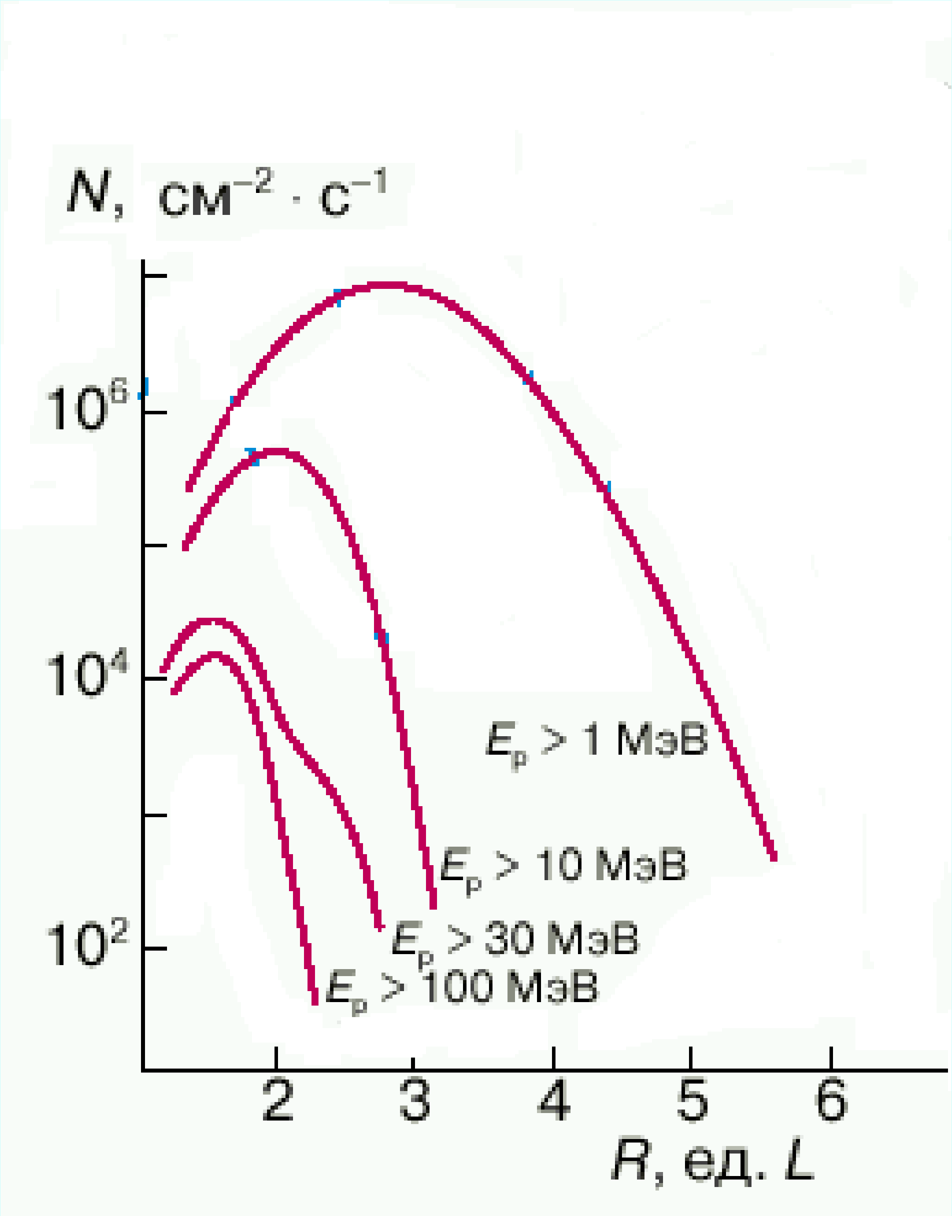
Solar and magnetospheric particle dynamics during magnetic storms of July 23-27, 2004

S.N. Kuznetsov, L.L. Lazutin, M.I. Panasyuk, L.I. Starostin, Yu.V. Gotseliuk,
N. Hasebe, K. Sukurai and M. Hareyama
- Moscow State University, Scobeltsyn Institute for Nuclear Physics,
Space Physics Division, Vorob'evy Gory, Moscow, 119992, Russia
- Research Institute for Science and Engineering, Waseda University,
3-4-1 Okubo, Shinjuku, Tokyo 169-8555 Japan

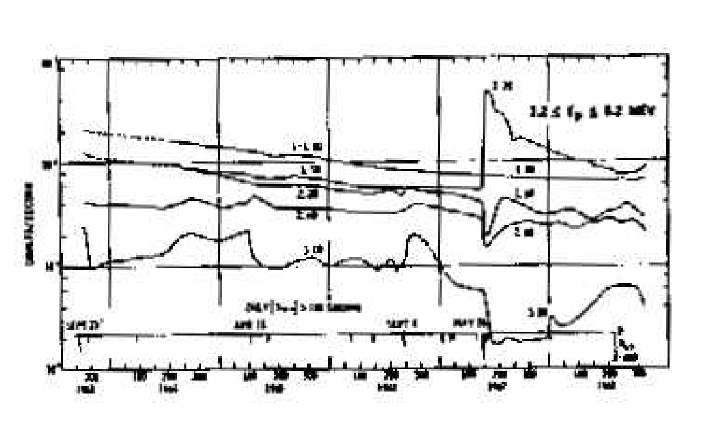
Abstract. It is a case study of energetic proton and electron dynamics in the magnetosphere during the chain of three magnetic storms 22-23,24-26 and 26-30 07. 2004. Solar proton penetration and dynamics inside the polar cap, quasitrapping region and inner magnetosphere were studied using Coronas-F and Servis-1 satellites. We found that during the main phase inner belt may be depressed and that solar 1-15 MeV protons were captured in the inner radiation belt at the recovery phases of all three magnetic storms.

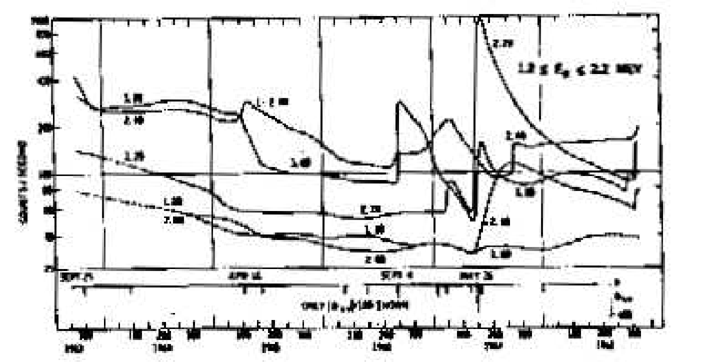


Proton population of the inner radiation belt is created by slow radial diffusion GCR albedo and atmospheric losses.

It is stable formation in general, but sometimes fast changes were registered during magnetic storms.

Two examples of the earlier observation of the fast intensity wariations are shown in this slide. The energy of the increasing proton flux is restricted by several MeV, in some cases by several tens of MeV

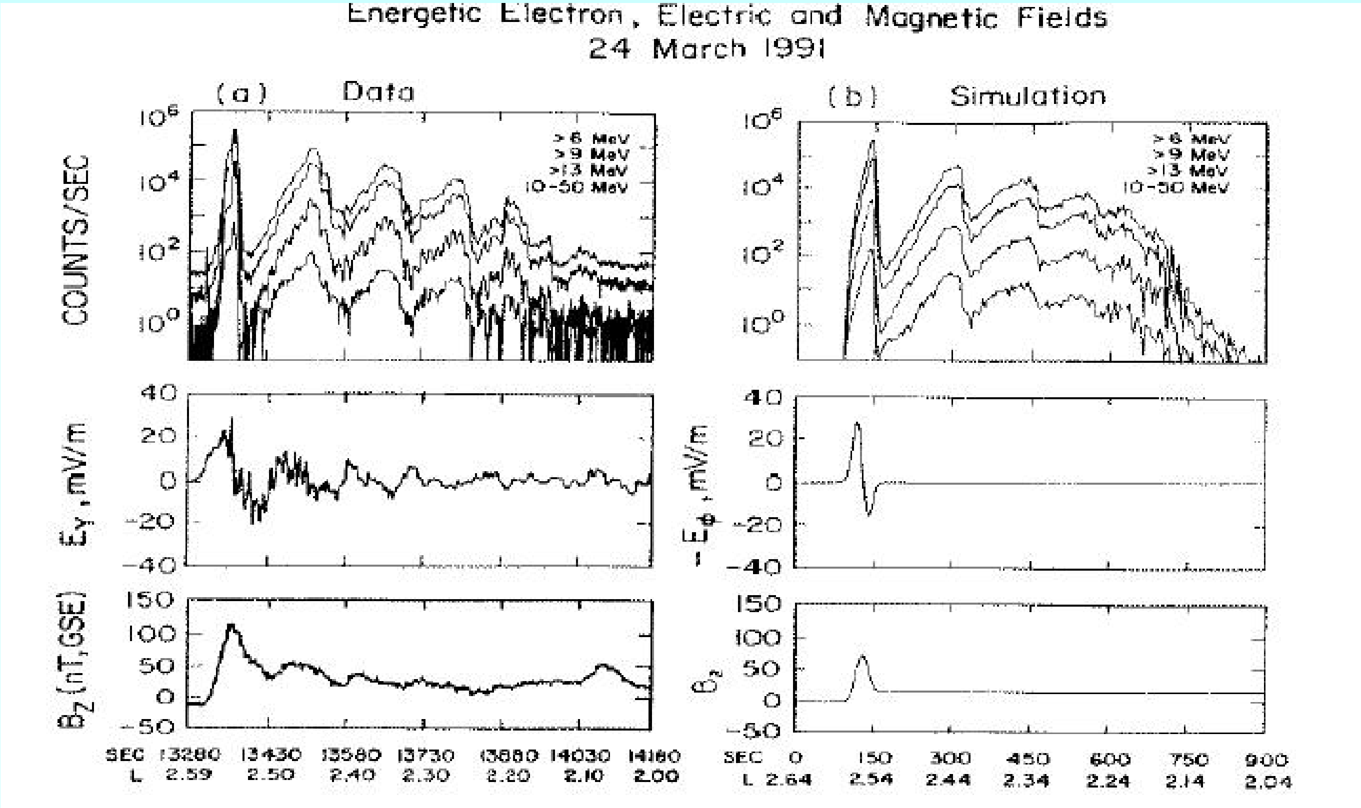




Bostrem et al., 1970

It was suspected that solar protons may be responsible for the increase of the proton belt population.

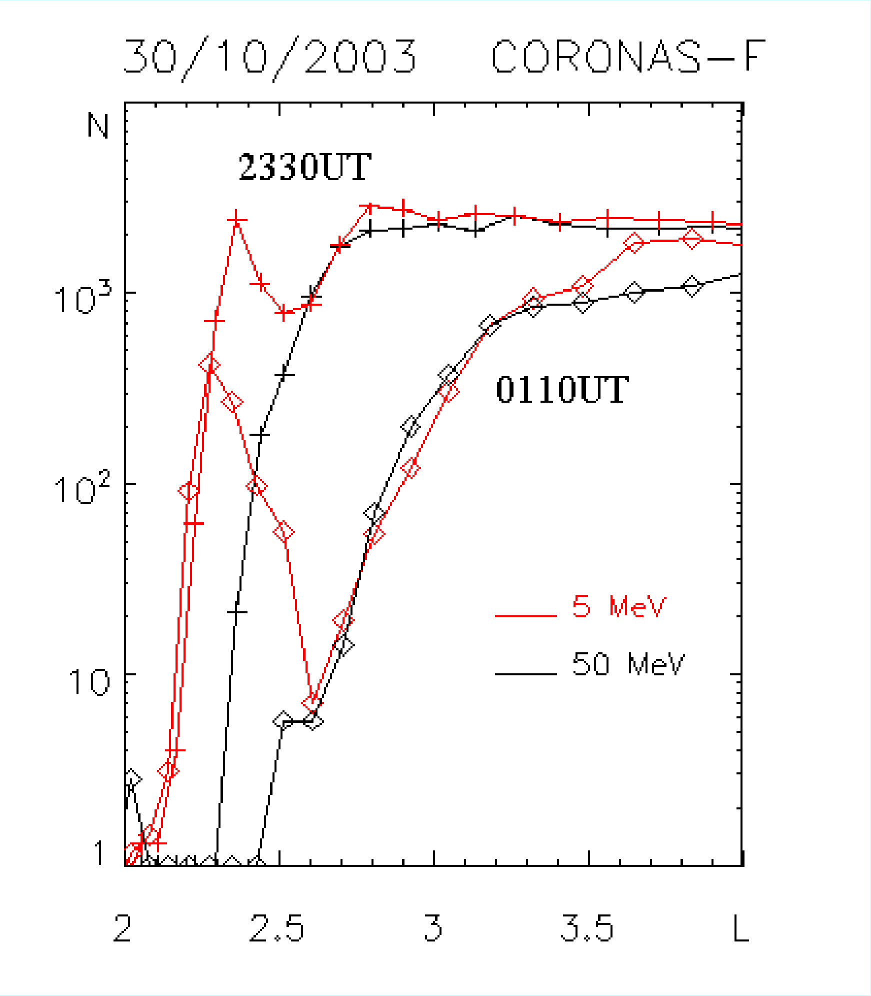
SC induced ExB injection and trapping

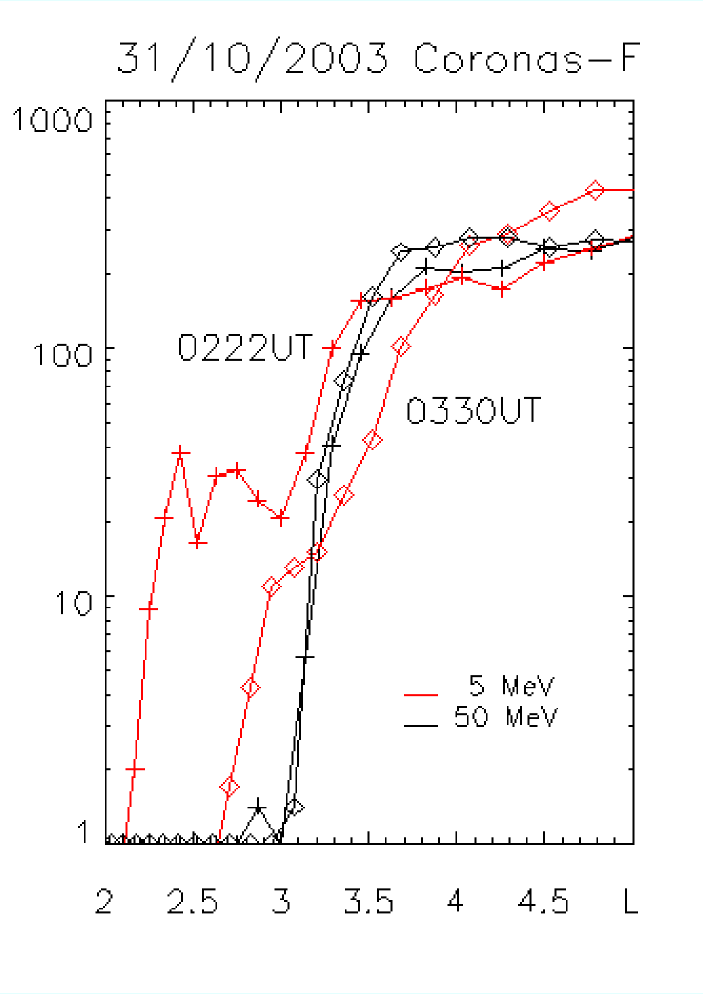


Acceleration by SC induced E-field was measured by CRRES detectors on March 24, 1991, and explained by Blake et al., 1995 and Tverskoy et al. 1995 The same mechanism was applied to solar protons.

Double-boundary effect.

Trapping on closed orbits during penetration boundary retreat





General idea of the trapping mechanism:

During the recovery of the magnetic field at the magnetic storm recovery phase protons will find inself at the closed shells if recovery time Tr is smaller than the magnetic drift period Td. Adiabatic motion will be conserved only for energetic particles if

$$Td << Tr$$

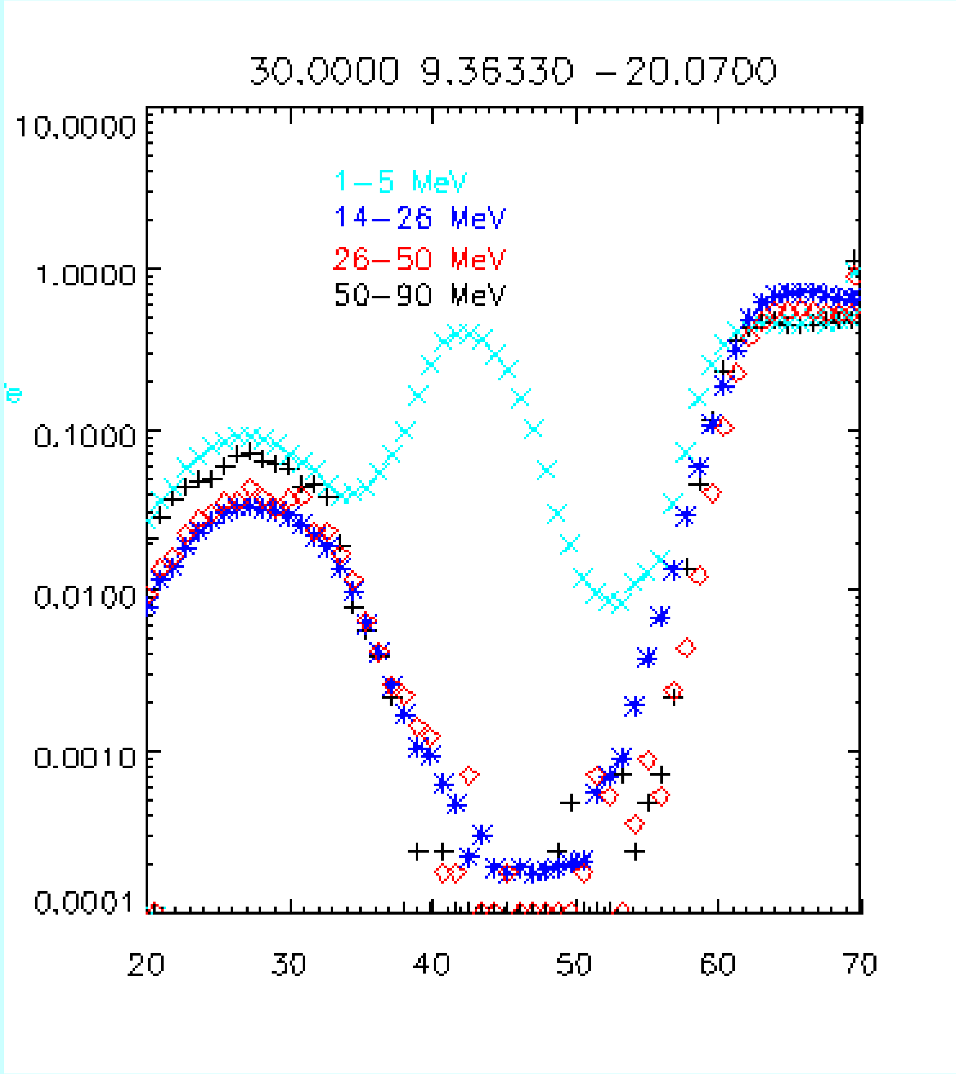
Which means that PB of 1-15 MeV protons will remain for some time at the old position while 50 MeV protons will trace the retreate of the PB due to recovery of the magnetosphere configuration.

The efficiency of the trapping depends on the relation of the particle magnetic drift velocity and the rate of the magnetosphere reconfiguration.

Typical time of the magnetosphere reconstruction equals to several minutes.

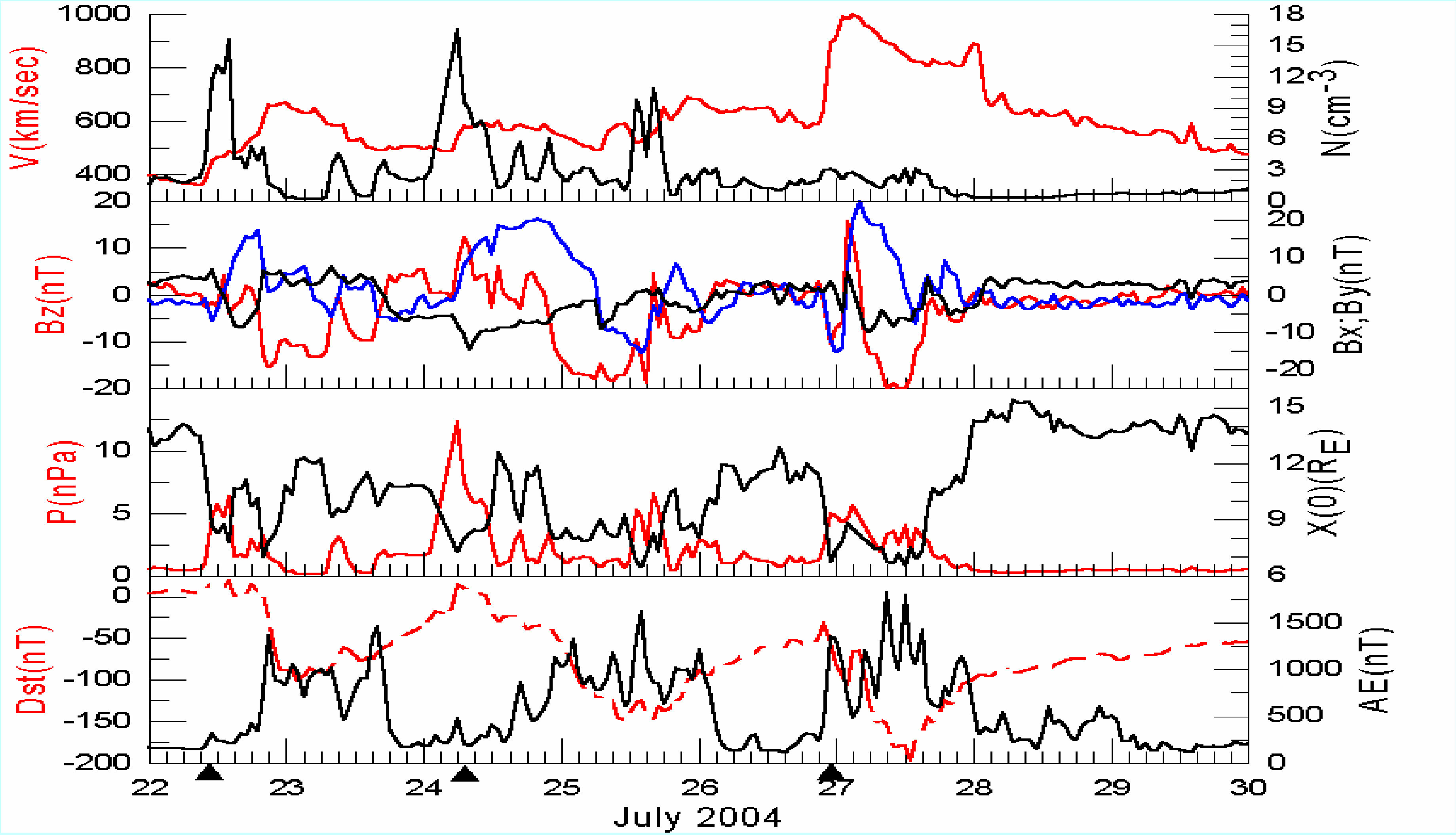
Magnetic drift periods for 1 MeV abut 15 minutes therefore low energy protons will be transferred to the closed drift orbits and only recently arrived ones will follow latest PB position.

50 MeV protons magnetic drift period at L= 3 is about 20 s. Magnetosphere reconfiguration will be too slow for them. Adiabatic invariant will be conserved and therefore fast drifting energetic protons will trace latest position of the penetration boundary.

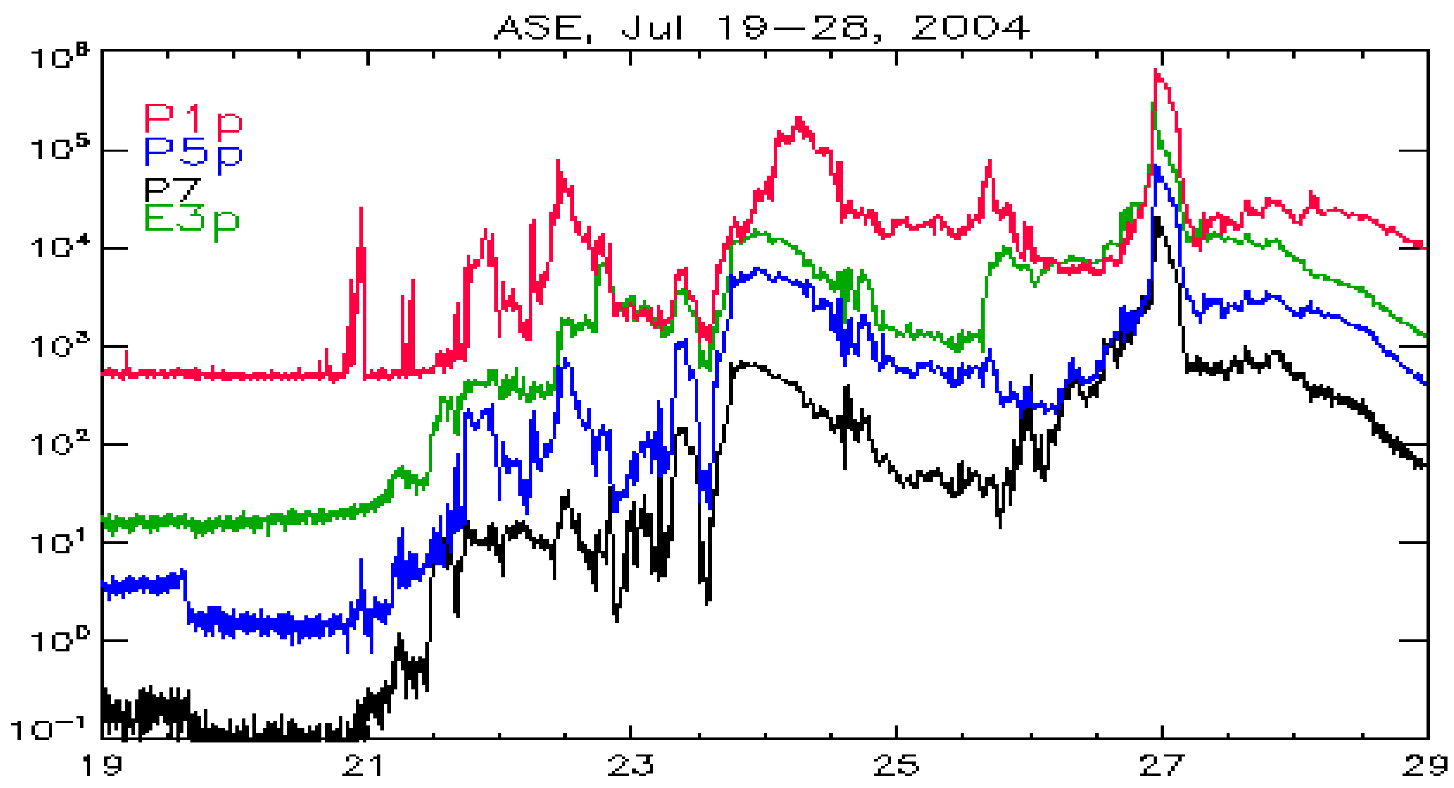


Decrease of the precipitating protons does not mean that trapped protons desappear as well.

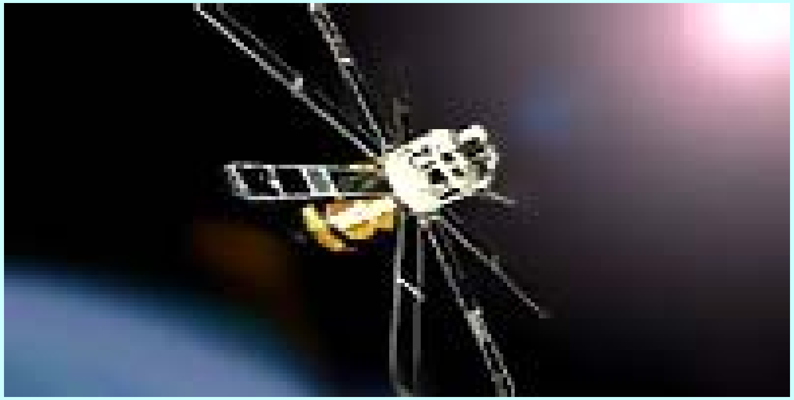
We can see freshly trapped SCR ower the BMA.



V(km/sec)
N(cm^{-3})
Bz(nT)
Bx;By(nT)
P(nPa)
X(0)(R$_E$)
Dst(nT)
AE(nT)
July 2004



ASE, Jul 19–28, 2004
P1p
P5p
P7
E3p
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
19
21
23
25
27
29



CORONAS- F
2001-2005
Altitude 500 km
polar orbit.

Protons: 1-5 MeV, 14-26 MeV, 26-50 MeV, 50-90 MeV

Electrons: 0.3-0.6 MeV, 0.6-1.2 MeV, 1.2-3 MeV

Space Environment Reliability Verication Integrated System 1 (SERVIS-1)

carring Light Particle Detectors (LPDs), protons and electrons in energy range 1.2 . 130 MeV and 0.3 . 10 MeV, respectively,

Altitude of 1000 km and inclination of 100 deg on solar synchronous orbit since November, 2003.

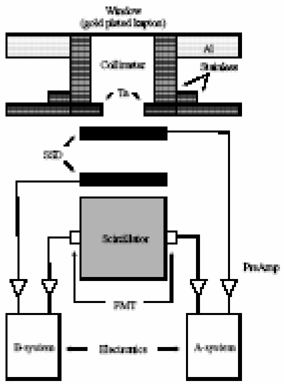


Figure 3. A configuration of the LPD system. A-system is usually operated, and B-system is backup one when A-system is breakdown.

Table 2. Characteristics of SERVIS-1 LPD.

Energy range	
• Proton	1.2 – 150 MeV (6 bins)
• Electron	0.3 – 10 MeV (4 bins)
• Alpha particle	7 – 640 MeV (1 bin)
• Heavy ion	2 – 160 MeV/n (1bin)
Direction	Anti-sunward
Count rate	200 kcps max
Identification	$\Delta E \times E$ method
Count interval	4 sec
Geometric factor	0.17 – 0.26 cm^2 sr
Weight	4.2 kg
Power	7.5 watts
Size	$120 \times 120 \times 150$ mm^3

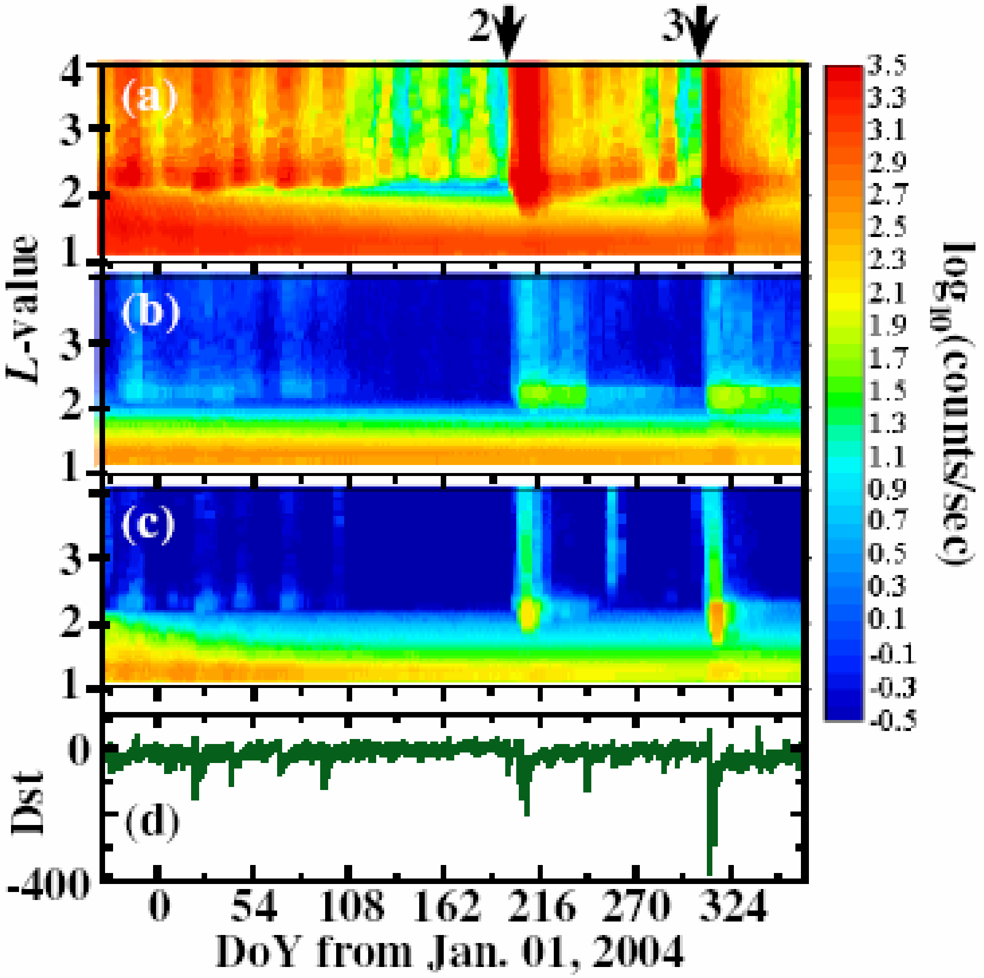
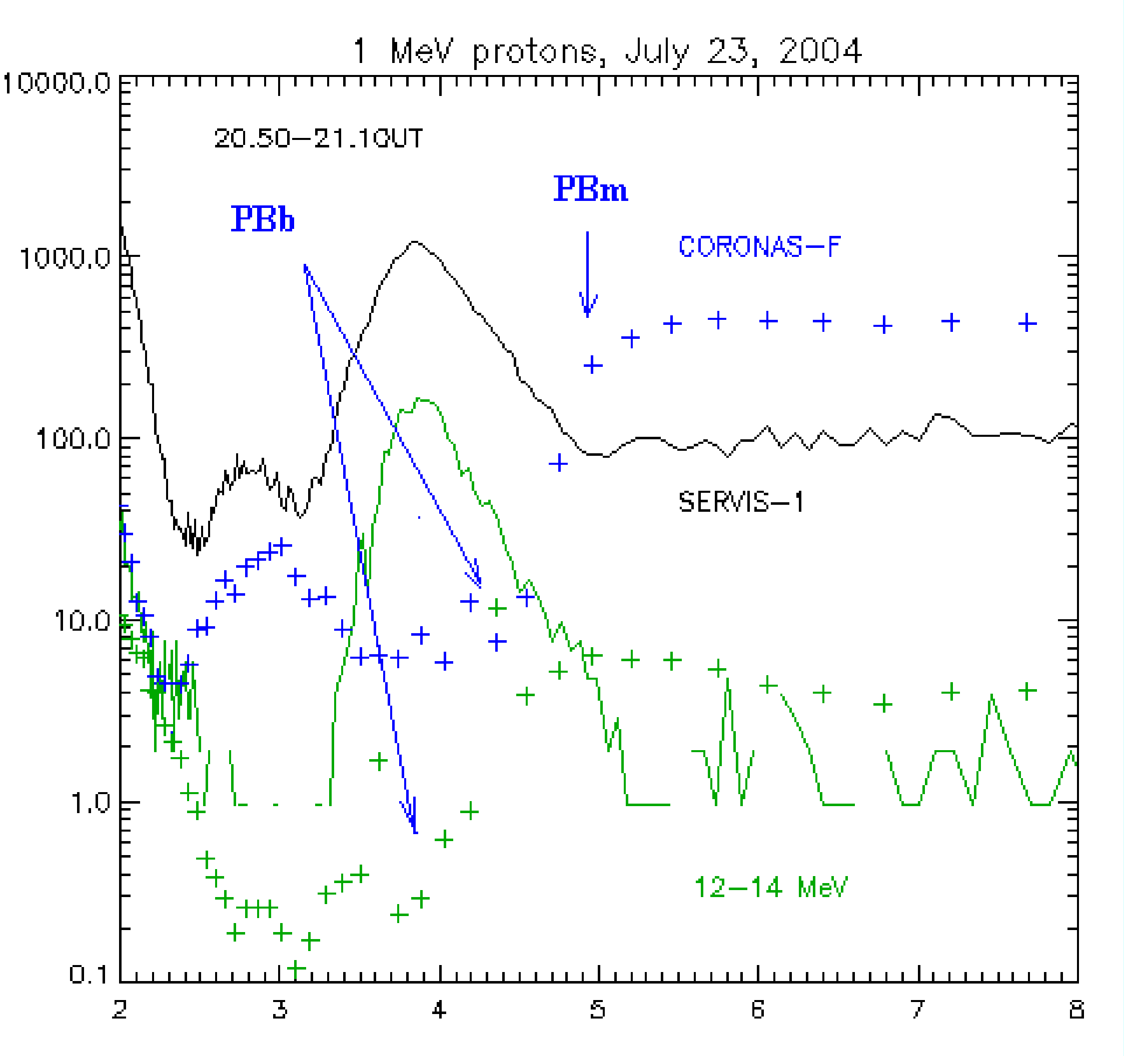


Figure 2. Daily average of particles count rate against *L* and time between December 2003 and December 2004 observed by LPD on SERVIS-1. (a) 1 – 2 MeV electrons, (b) 2 – 3 MeV electrons, (c) 12 – 20 MeV proton, (d) Dst index

29th International Cosmic Ray Conference Pune (2005)
00, 101.104

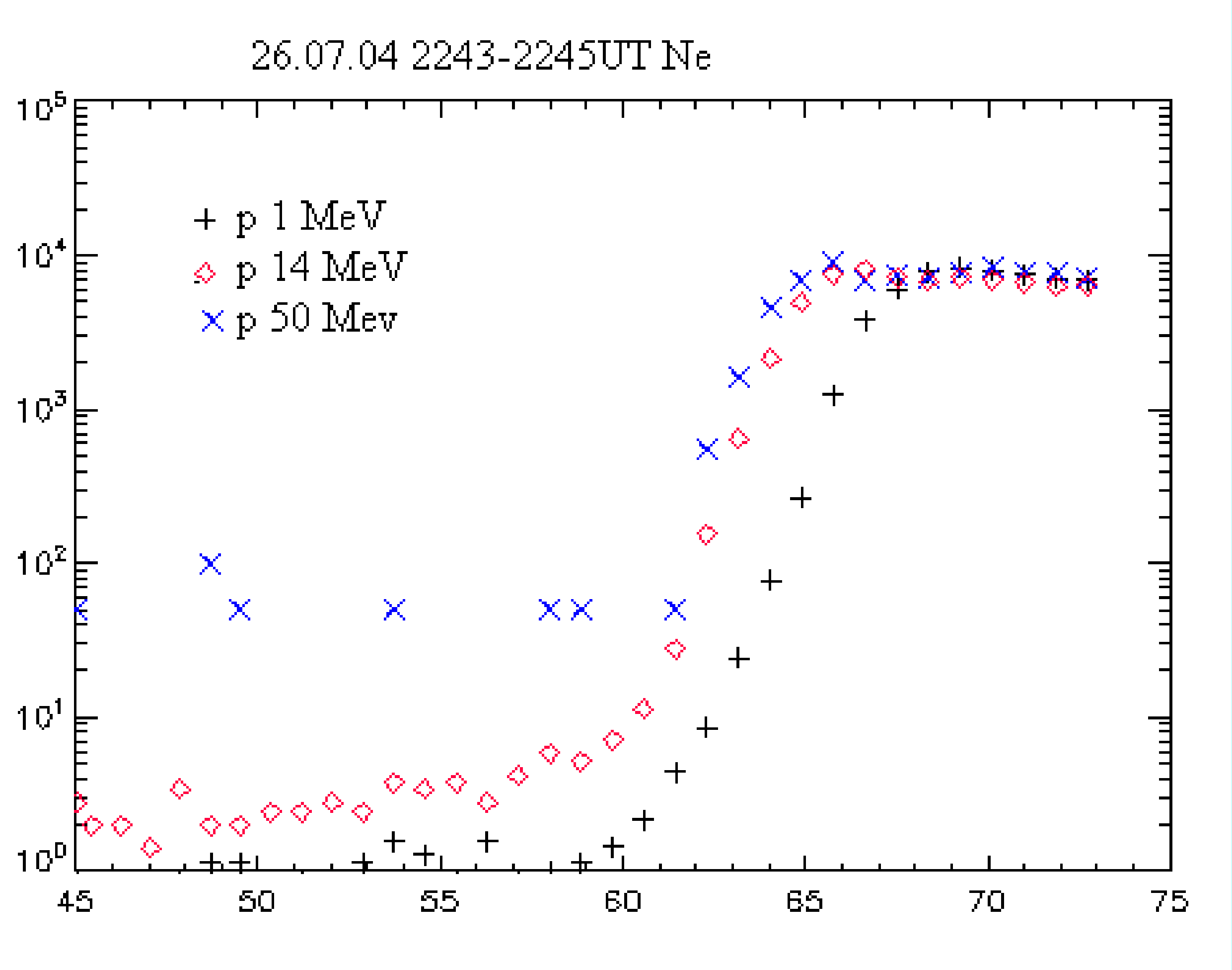
Space and Time Correlations of Particle Fluxes after Giant Flares in Radiation Belts Observed by Two Satellites, USERS and SERVIS-1

S. Kodaira et.al.
Waseda University,
Tokyo, Japan

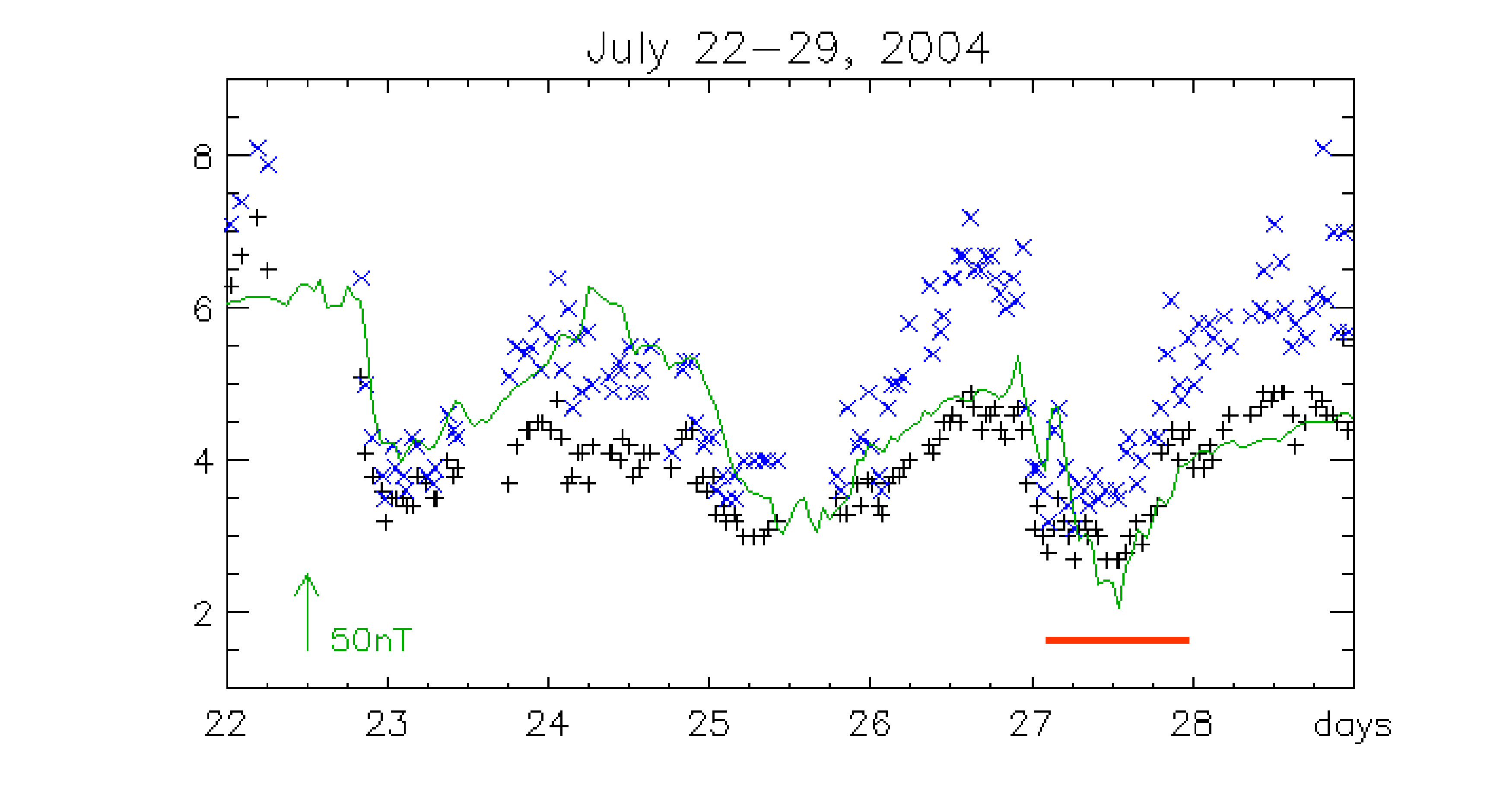


Radial (L) profiles of solar protons measuered at 500 km (C-F) and 1000 km (S-1).

Penetration boundary (PB) position may be defined at the background level (PBb) or at the ½ of the maximum intensity (PBm).

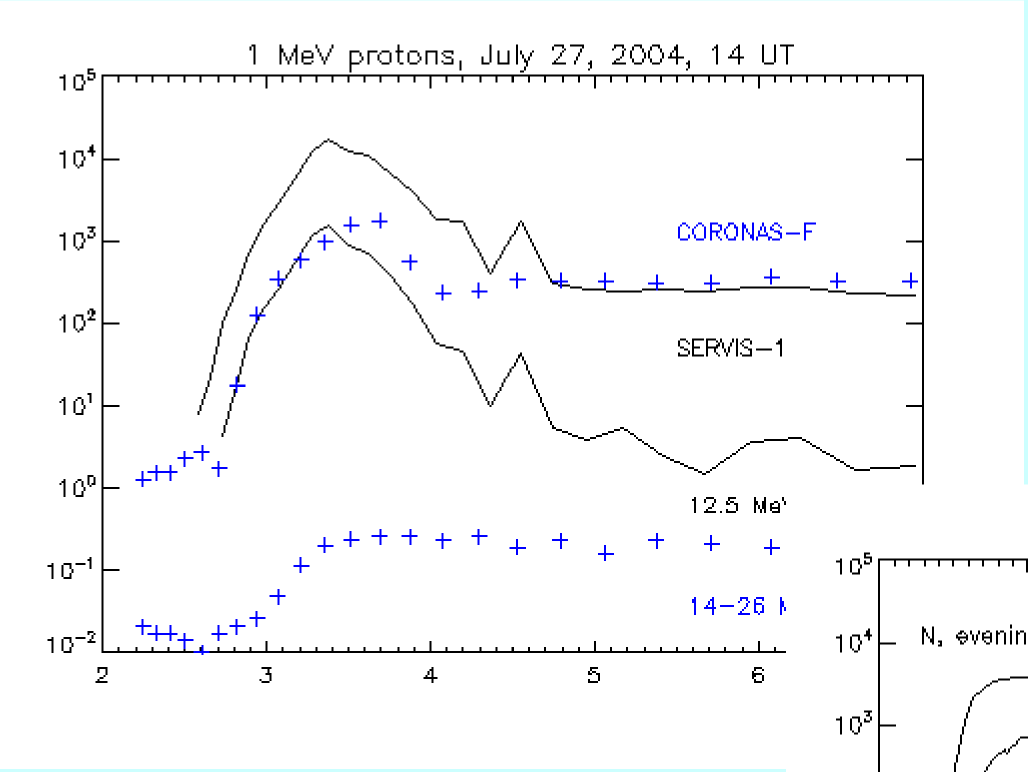


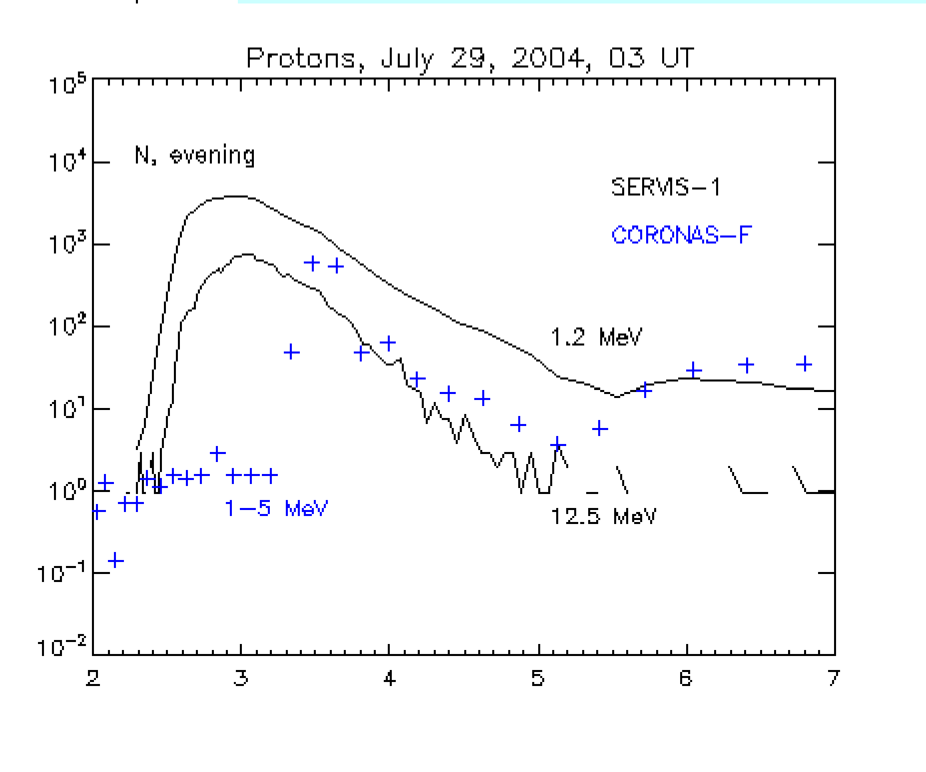
Energy dependence of the PB, Coronas-F, 26.07.04



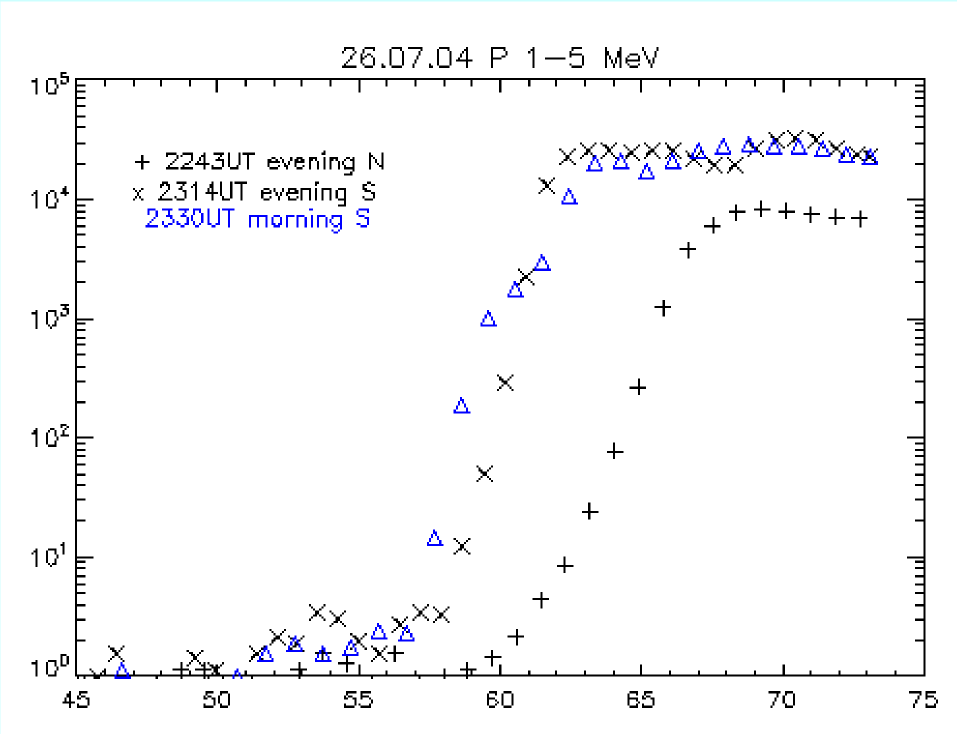
PBb and PBm dynamics using C-F 1-5 MeV proton data and Dst (solid line).

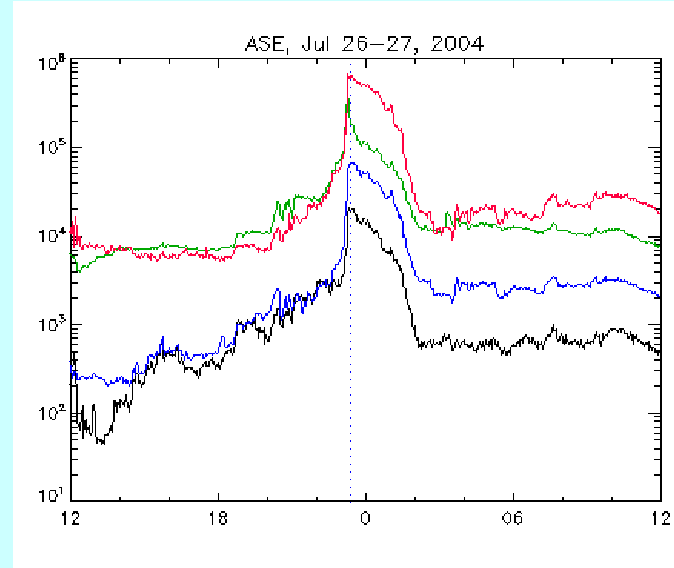
Границы захвата СКЛ по максимуму и по фону протонов 1-5 МэВ, Зеленая линия - -Dst-индекс.

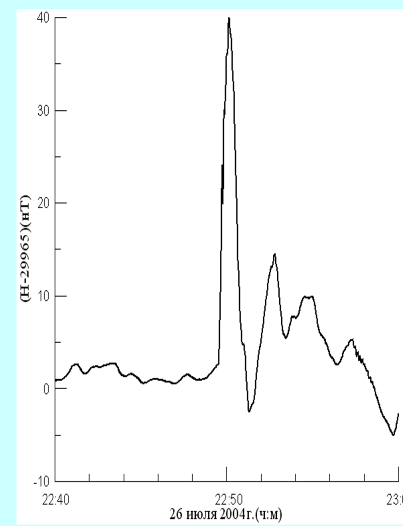




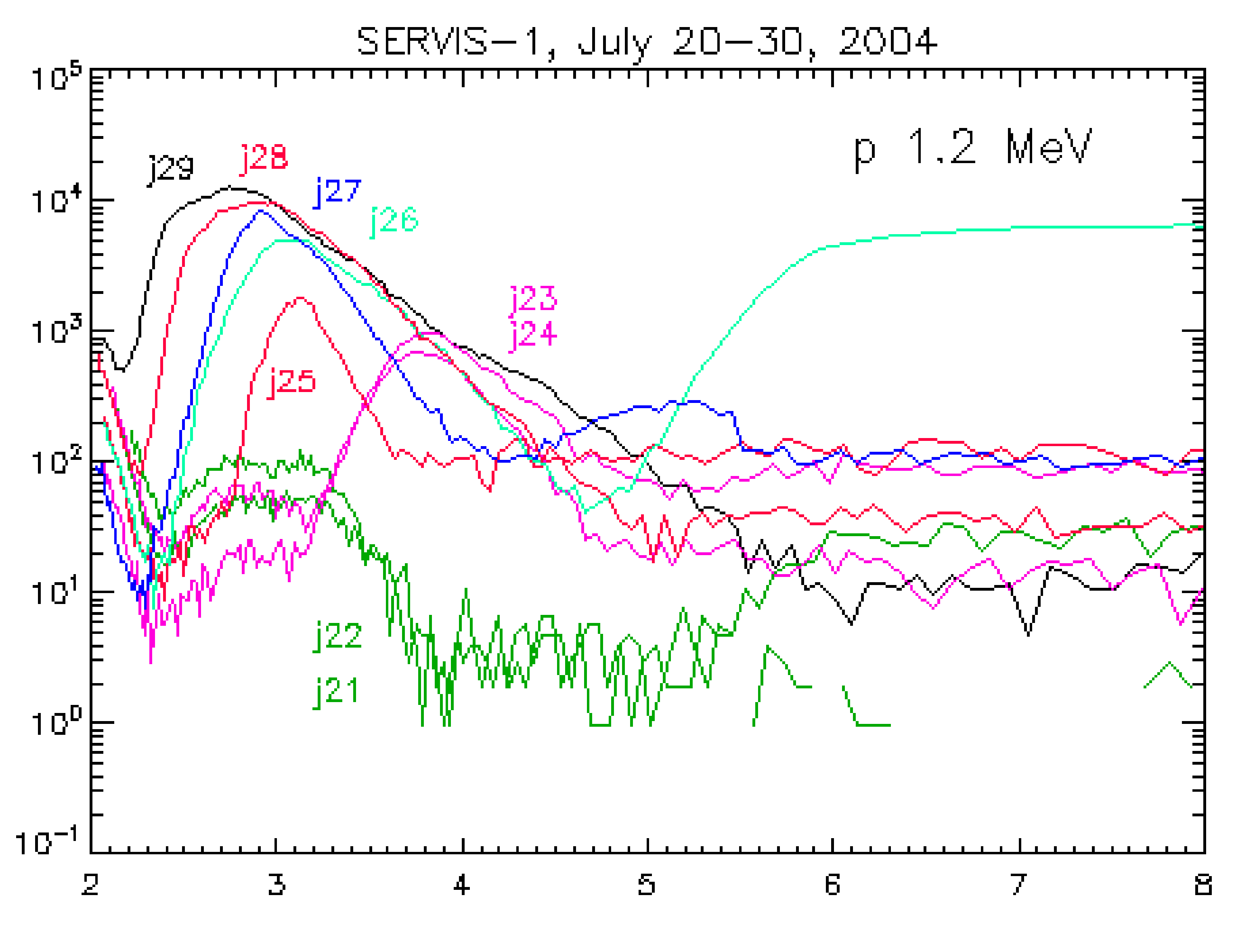
Trapping of solar protons sometimes does not allow to define PB.





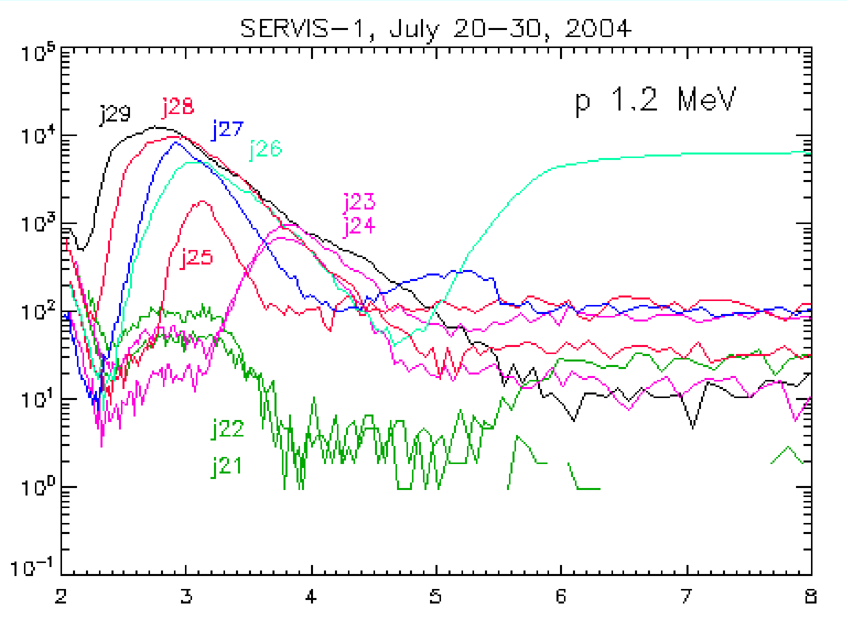


Earthward shift of the PB (C-F) after SC 26.07.04. Intensity increase was registered on all penetration region and was caused by SCR intensity increase outside the magnetosphere. Effect of SC injection was not registered.



Радиальные профили вечерних пролетов над БМА

See comments at the next slide -



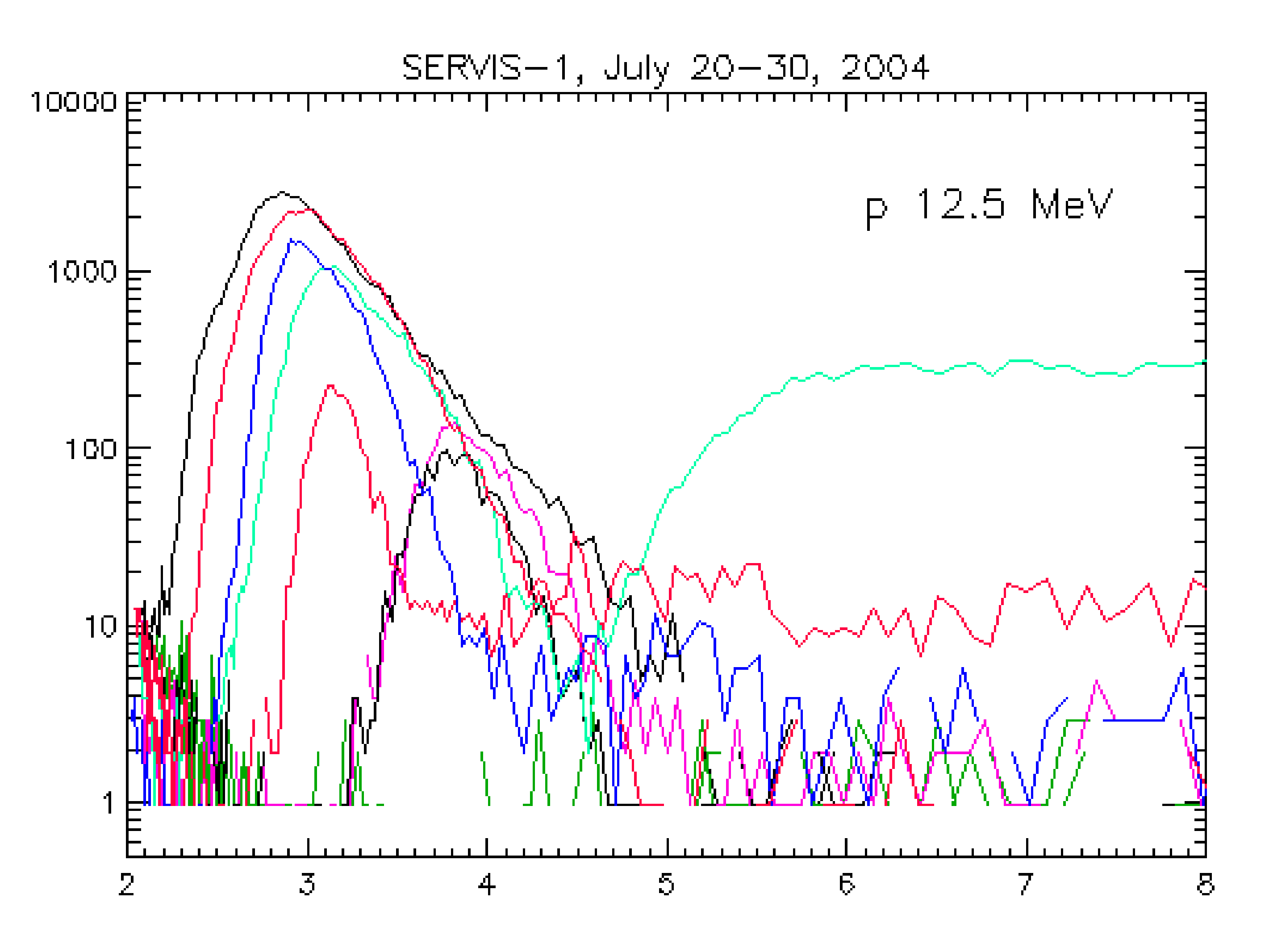
Radial profiles of 1.2 MeV protons (S-1) during the evening orbits over SA magnetic anomaly.

21 and 22.07 – maximum at L=3 corresponds to the typical 1 Mev proton inner belt profile. No effects of SC 22.07.04.

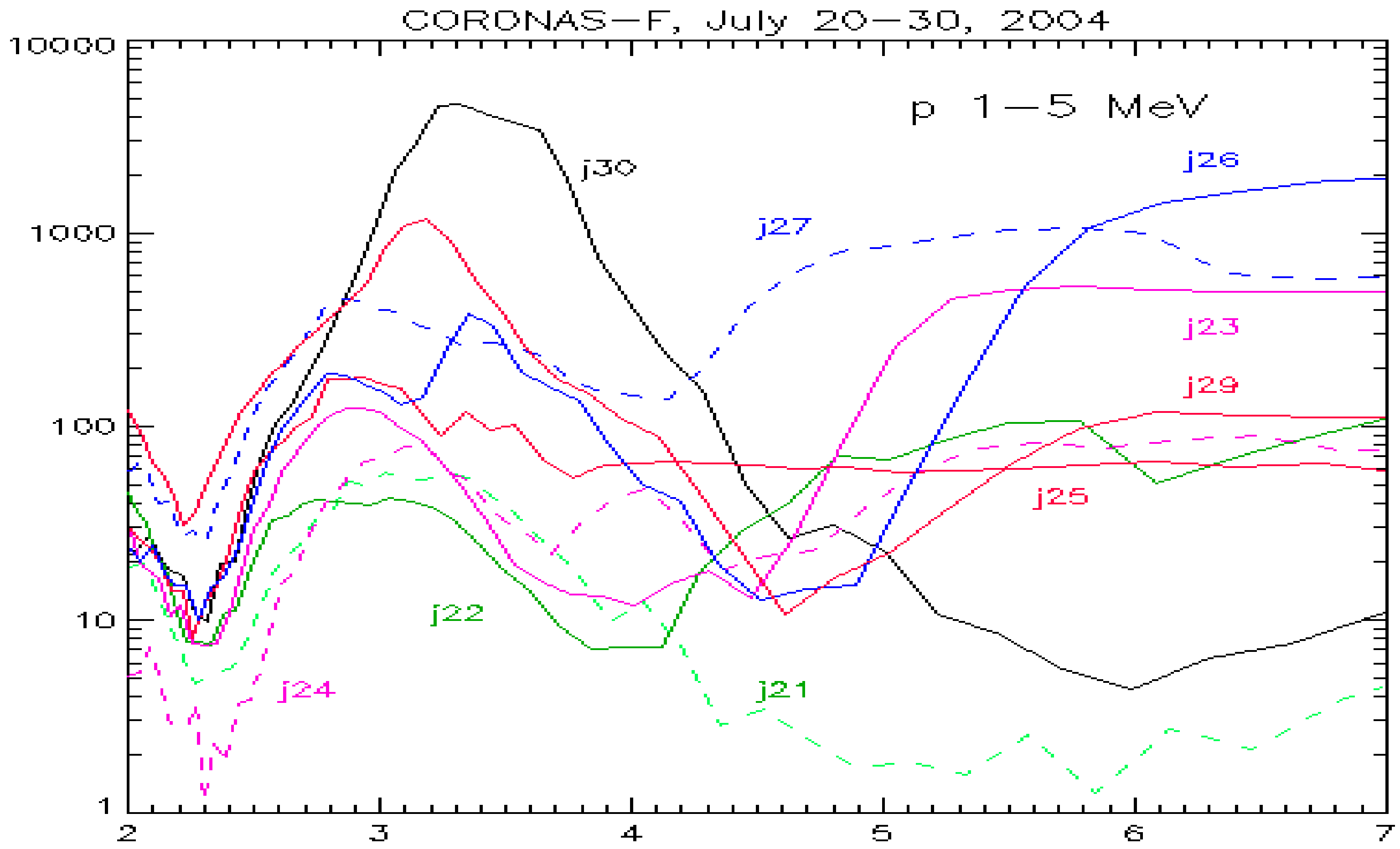
23 and 24.07.04. New maximum at L=3.8 arrived after PB retreat during the recovery phase of the first magnetic storm.

25.07.04. New maximum at L=3.1. Previously trapped protons escaped during the main phase and new trapping occurs during recovery phase of the second magnetic storm.

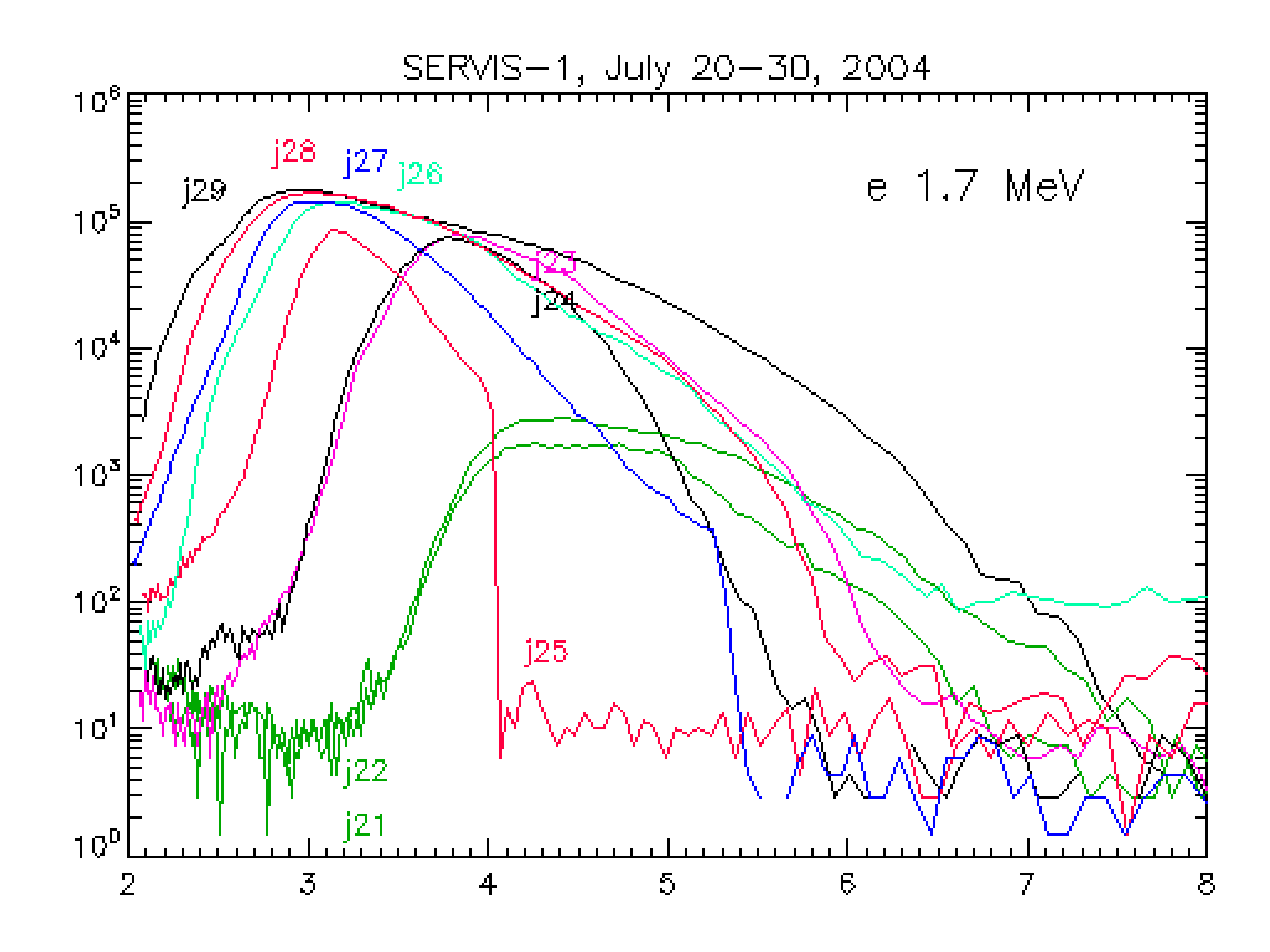
26-30.07.04. PB during the third magnetic storm does not approached too close to the 25.07 trapping region. Maximum gradually shifted to L=2.8 and intensity increased possibly due to the ExB drift by induced electric field.



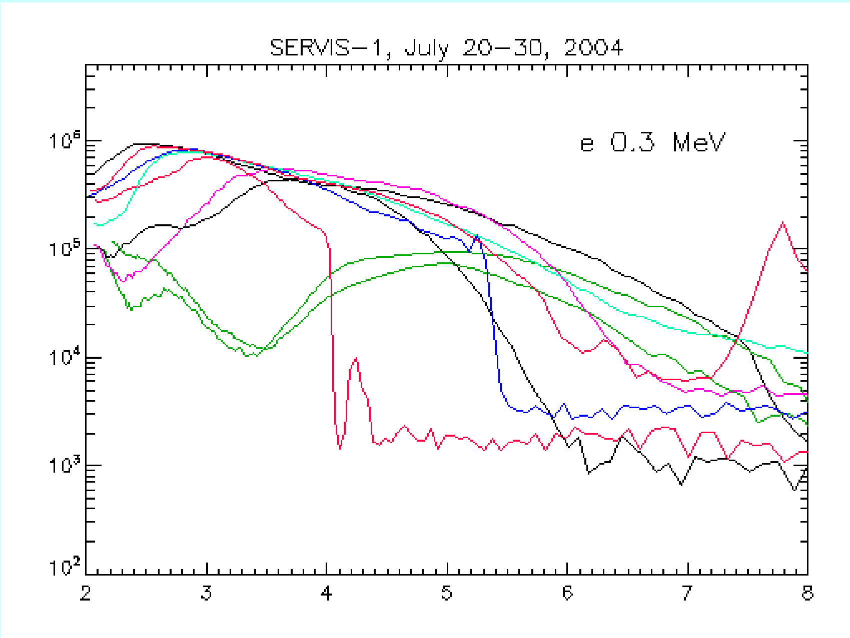
P 12.5 trapping profiles at S-1 are similar to 1.2 Mev ones.

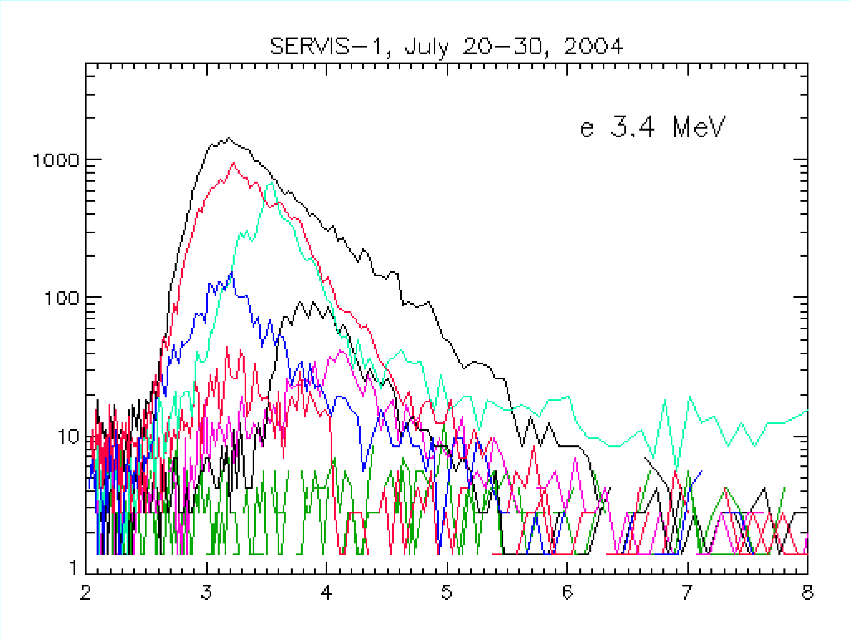


Coronas-F was too low to register some S-1 trapping effects. Only after 25.07 trapping of solar protons became visible.

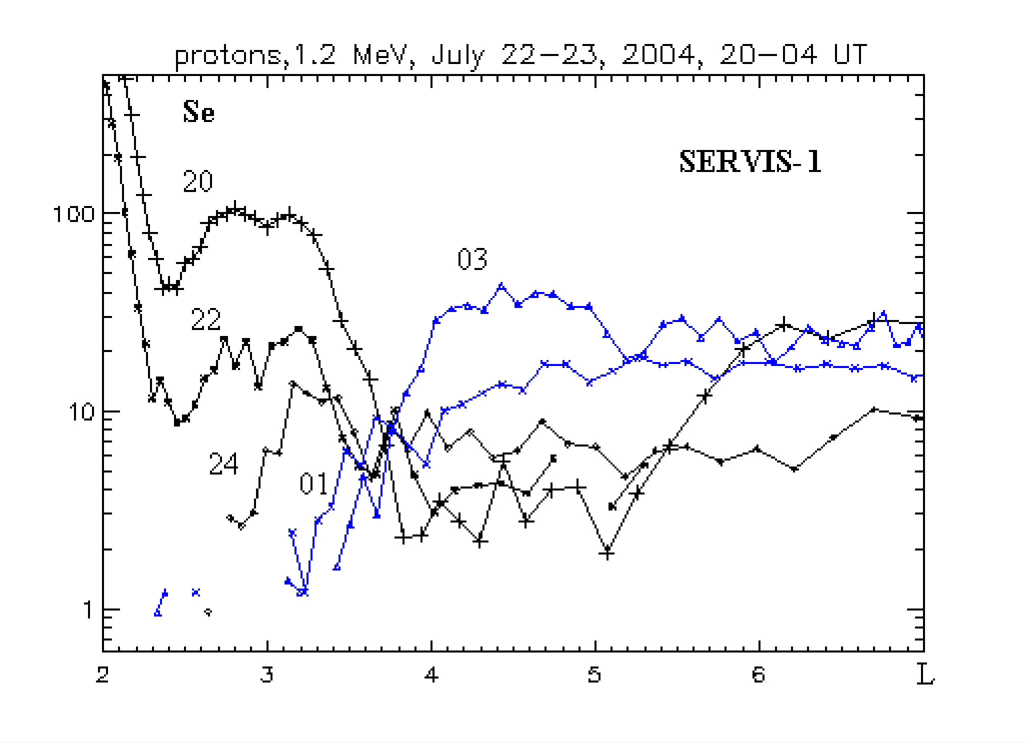


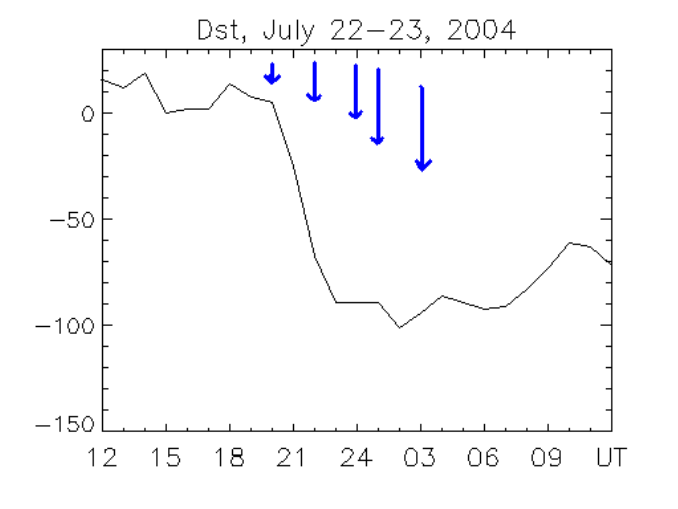
Relativistic electrons repeats some features of the solar protons; effects possibly are the same but sources are of magnetosphere origin.





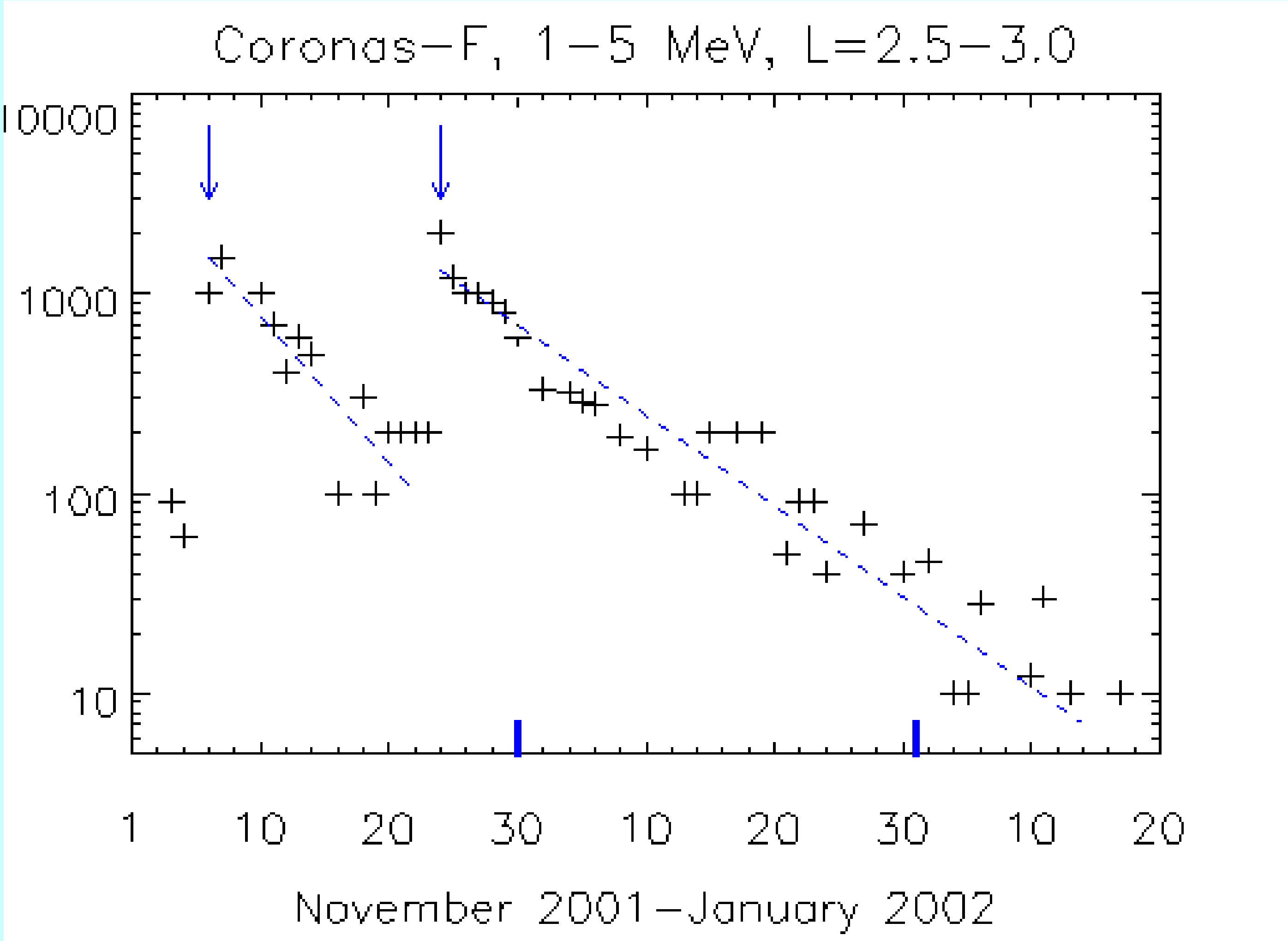
Sharp decrease of the electron flux at L>4 on 25.07 and L>5.4 on 27.07 may be caused by nonadiabatic effects.

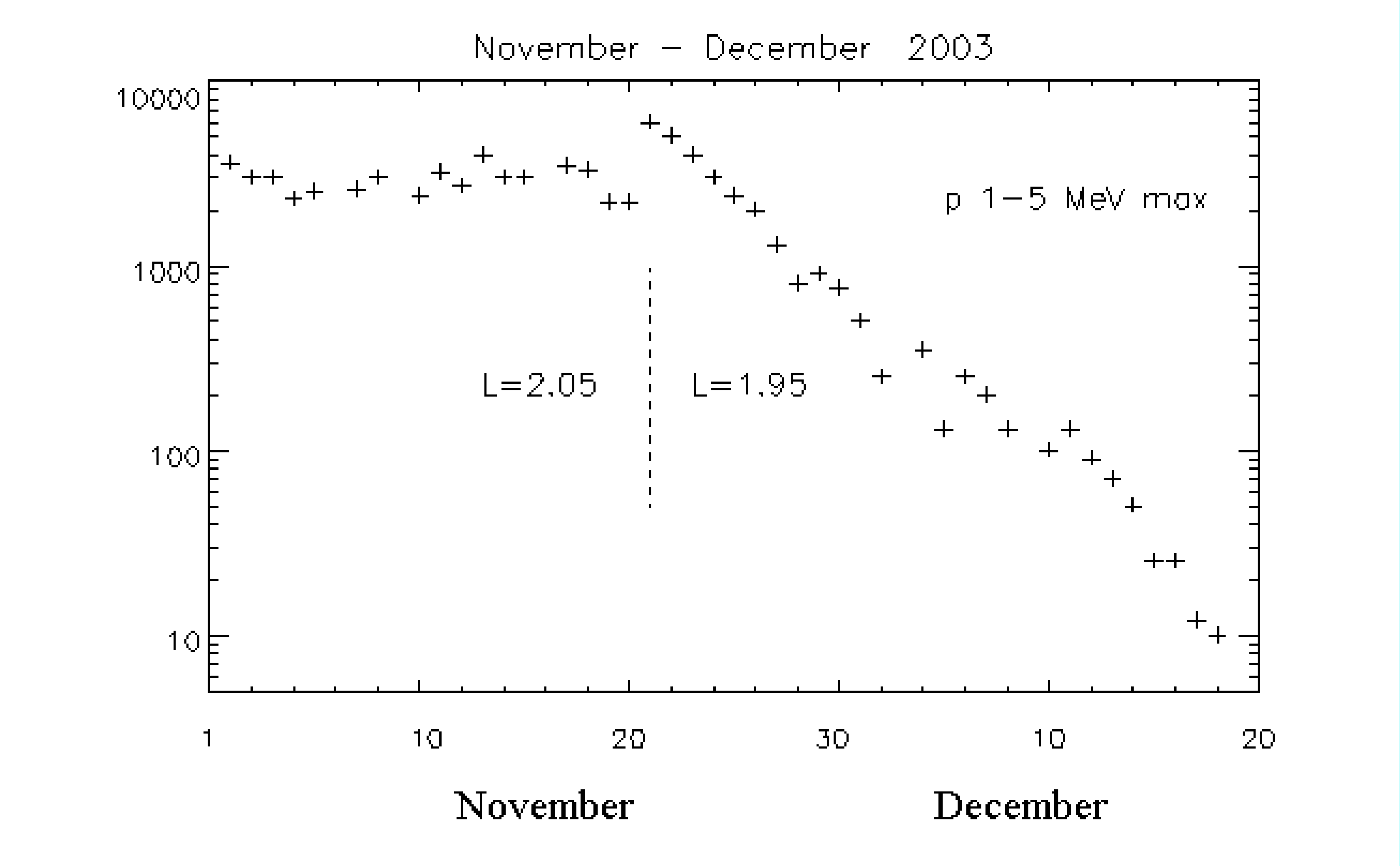




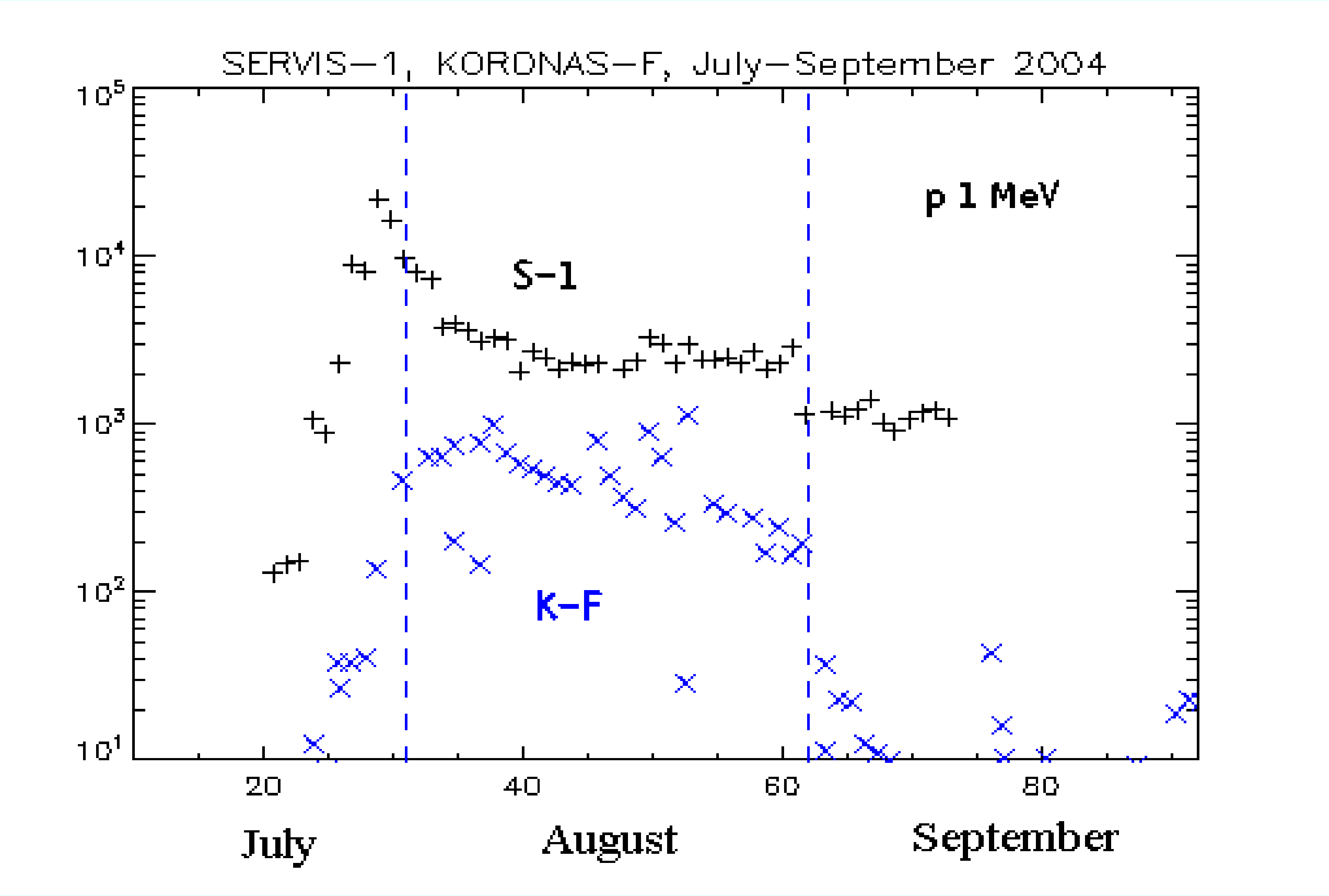
Decrease of the intensity maximum at L=2.7-3.2 from 20 to 34 UT July 22 during the main phase of the magnetic storm possibly caused by the adiabatic deceleration?

Examples of the temporal history of the trapped solar protons.

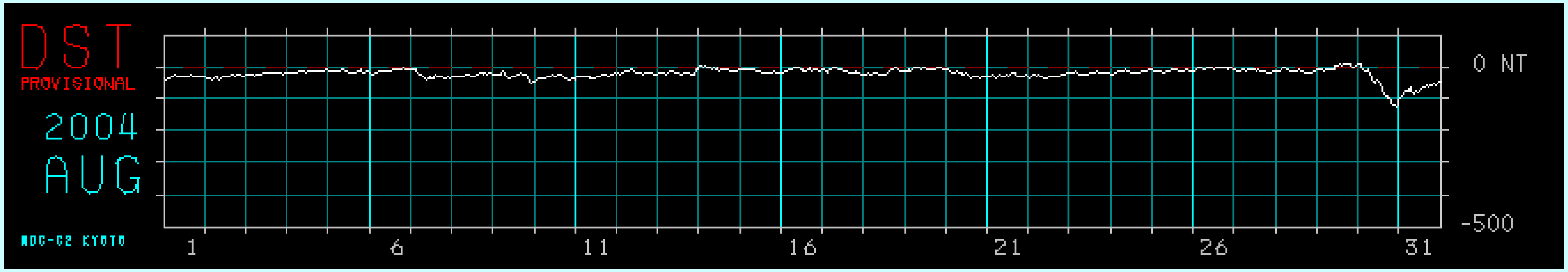


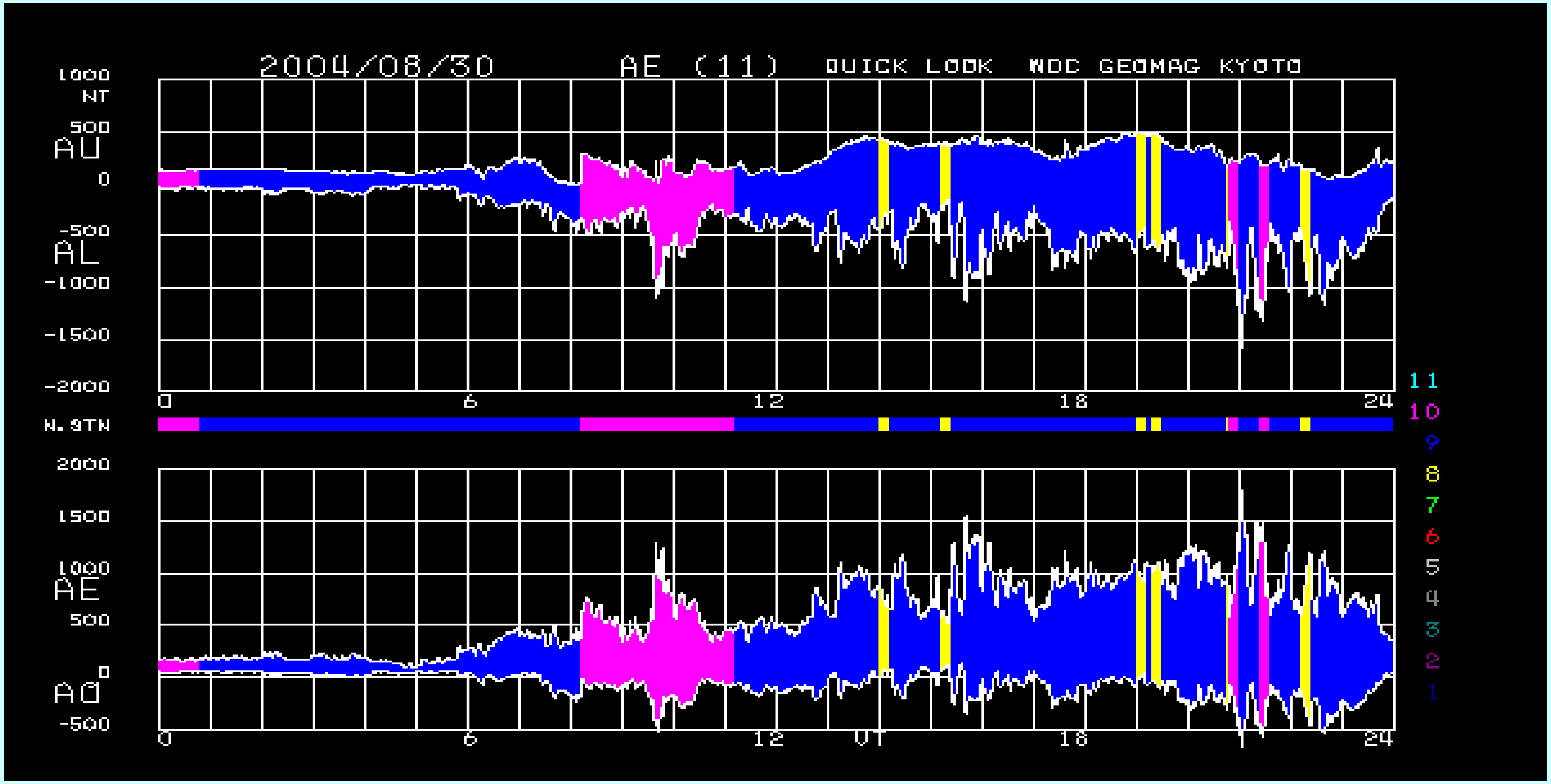


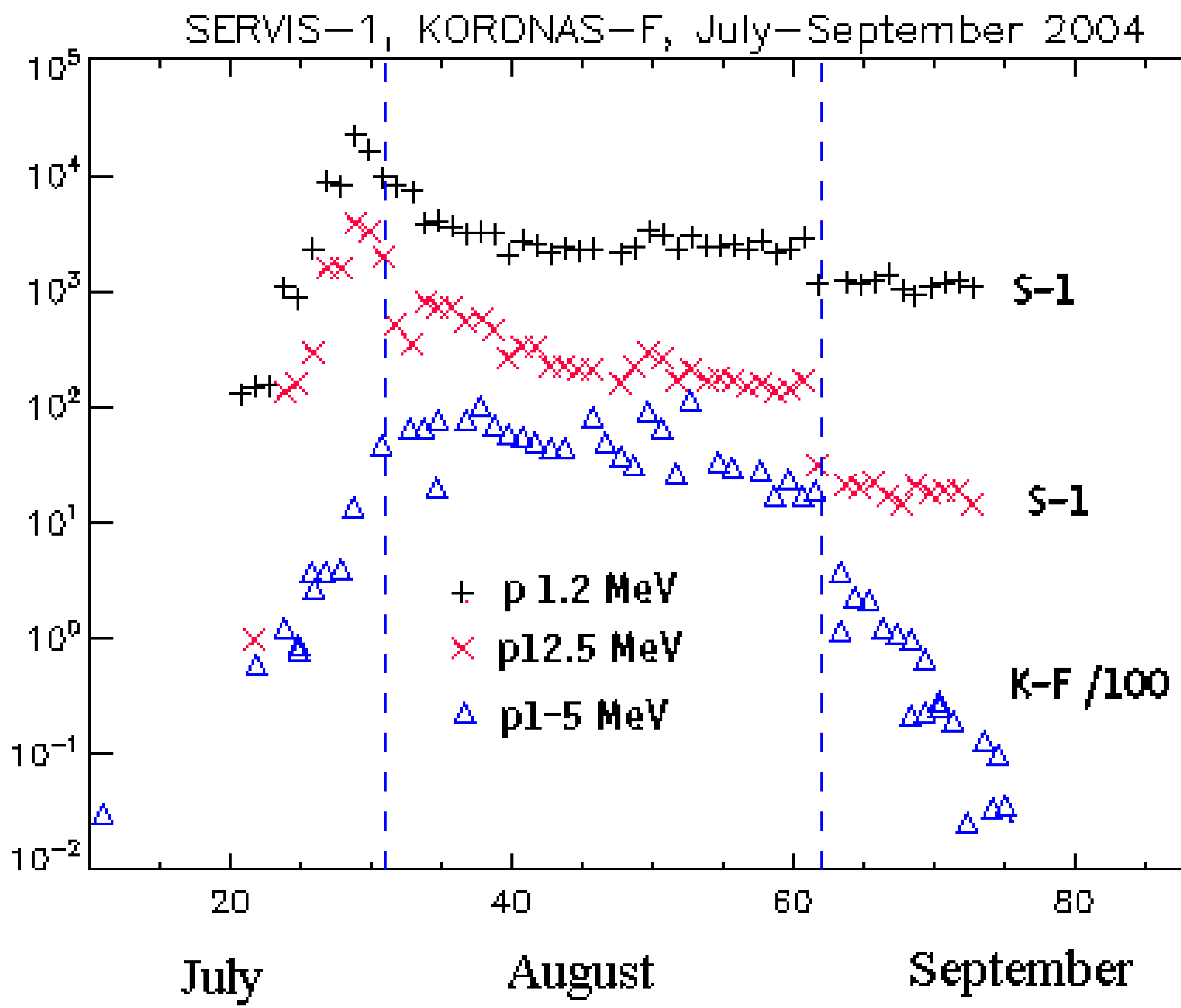
Two types of the temporal evolution – very slow changes and fast intensity decrease



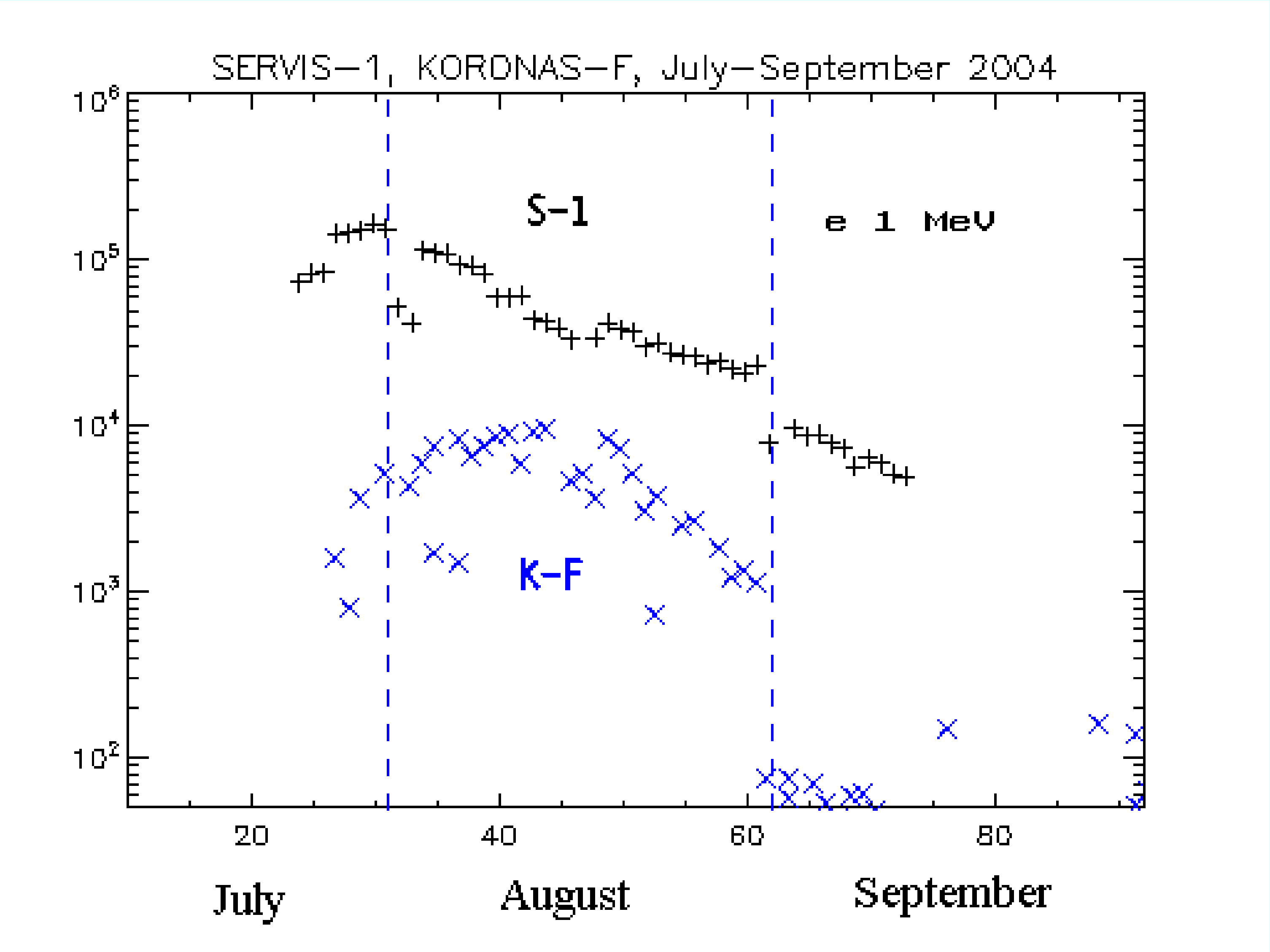
There were no magnetic storms until the end of August 2004 and trapped particles intensity decreased slowly. During the 30.08.04 moderate magnetic storm intensity fast decrease occurs.

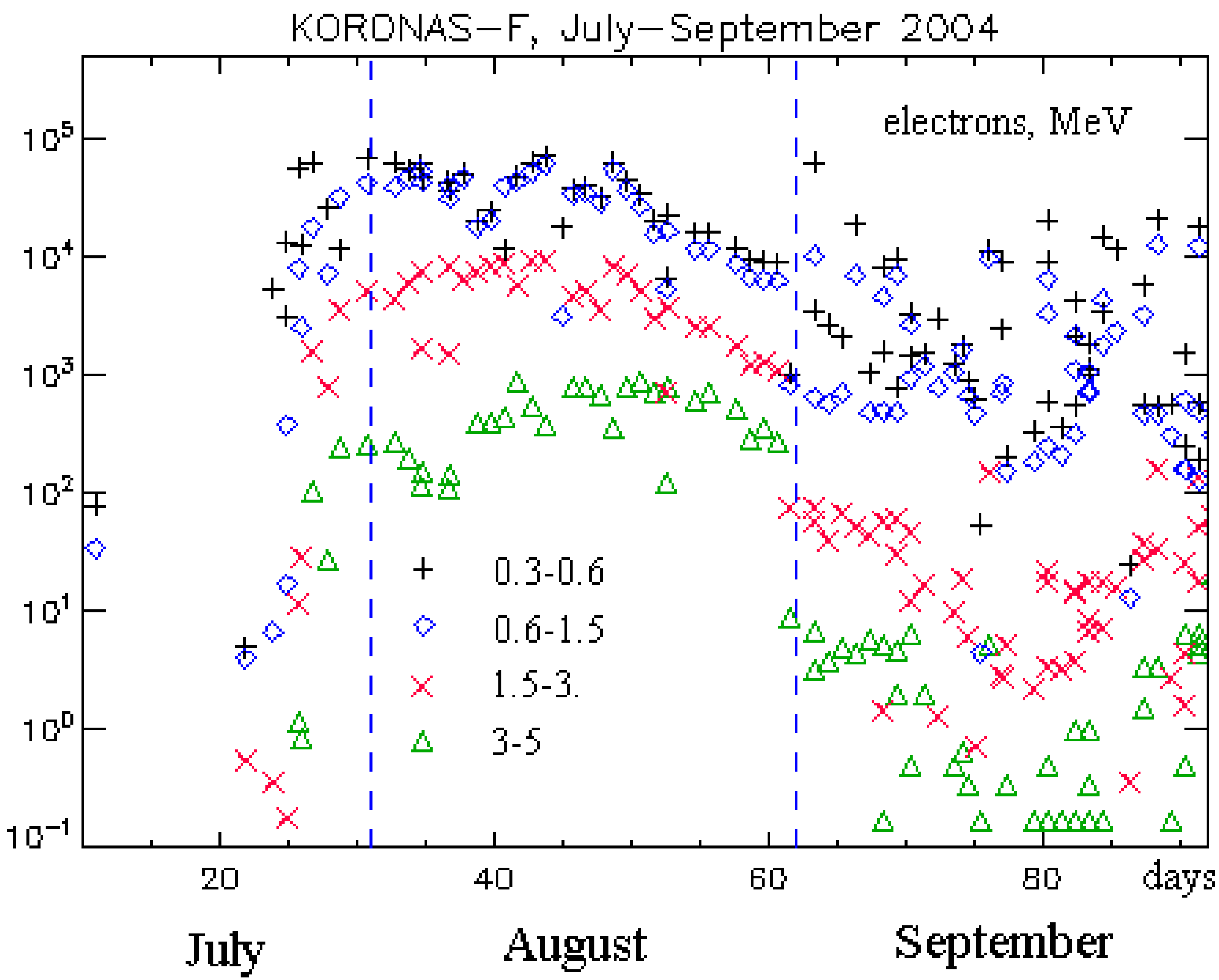

DST
PROVISIONAL
2004
AUG
WDC-C2 KYOTO
0 NT
-500
1
6
11
16
21
26
31


2004/08/30 AE (11) QUICK LOOK WDC GEOMAG KYOTO
1000
NT
500
AU
0
-500
AL
-1000
-1500
-2000
0
6
12
18
24
N. STN
11
10
9
8
7
6
5
4
3
2
1
2000
1500
1000
AE
500
0
AO
-500
UT

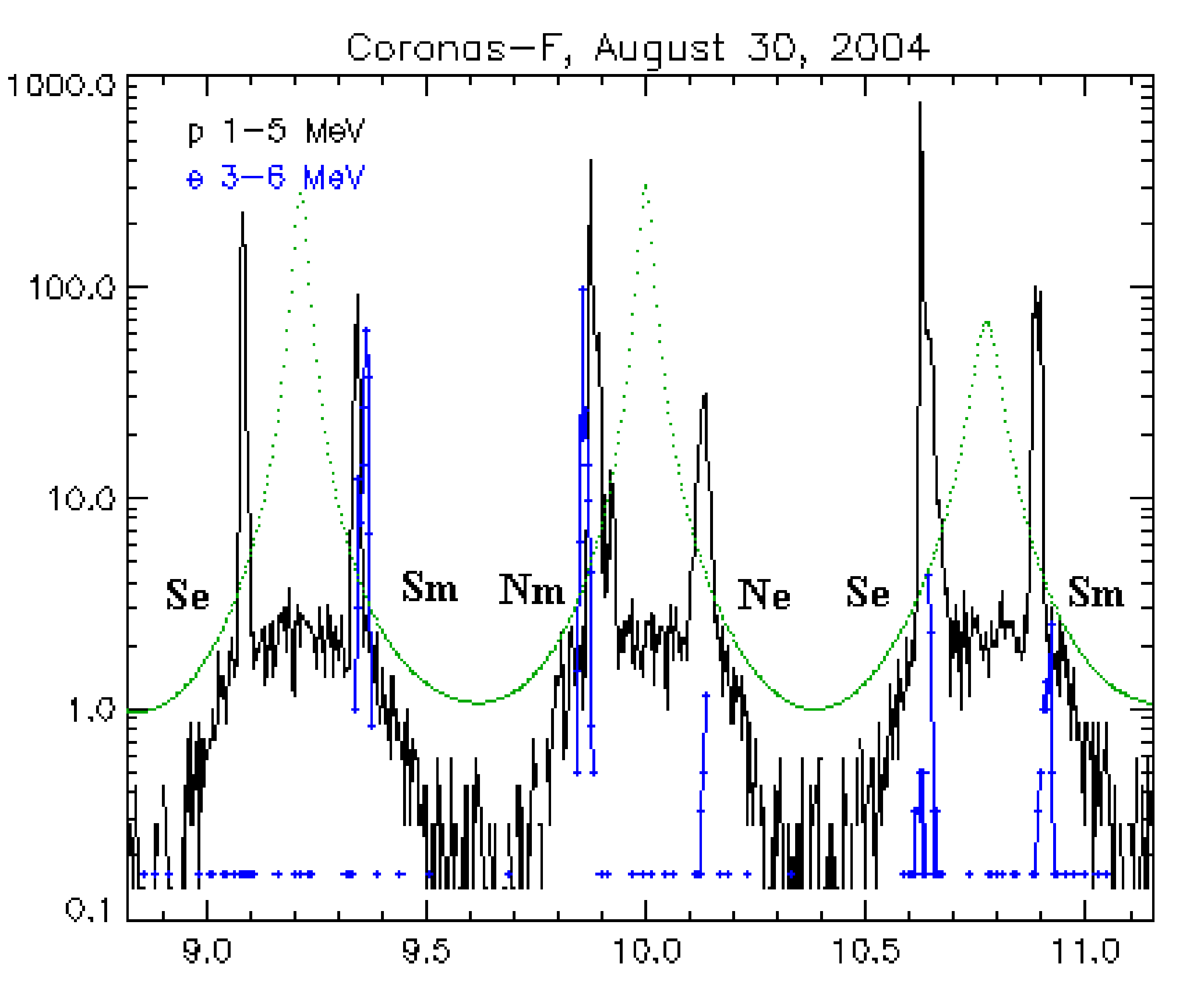


SERVIS−1, KORONAS−F, July−September 2004
10^5
10^4
10^3
10^2
10^1
10^0
10^−1
10^−2
20
40
60
80
p 1.2 MeV
p12.5 MeV
p1-5 MeV
S-1
S-1
K-F /100
July
August
September

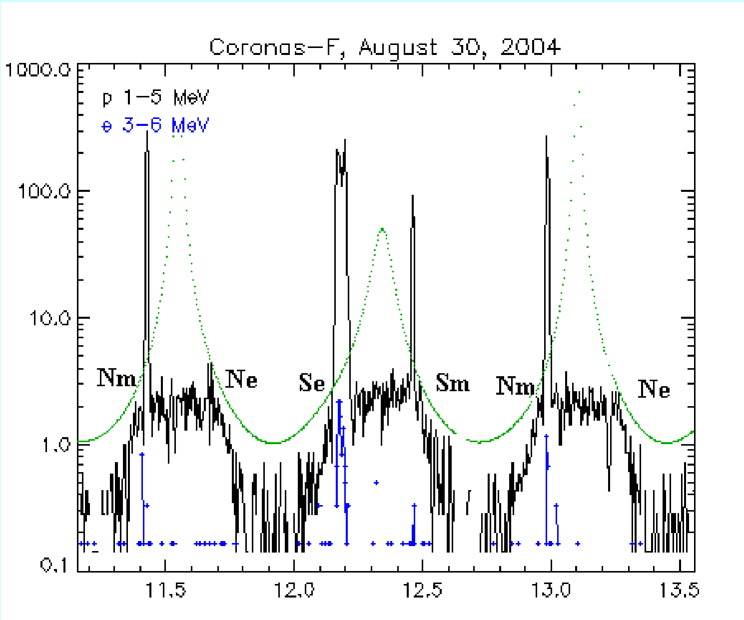

SERVIS–1, KORONAS–F, July–September 2004
10^6
10^5
10^4
10^3
10^2
S–1
e 1 MeV
K–F
20
40
60
80
July
August
September

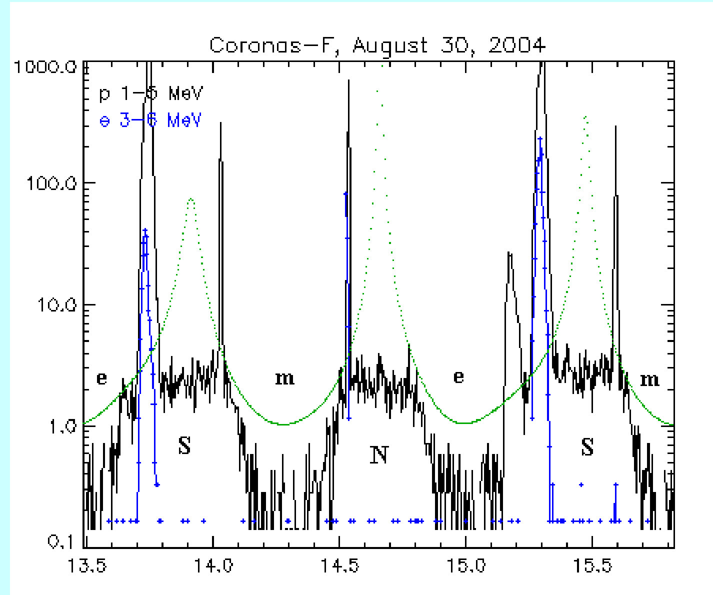


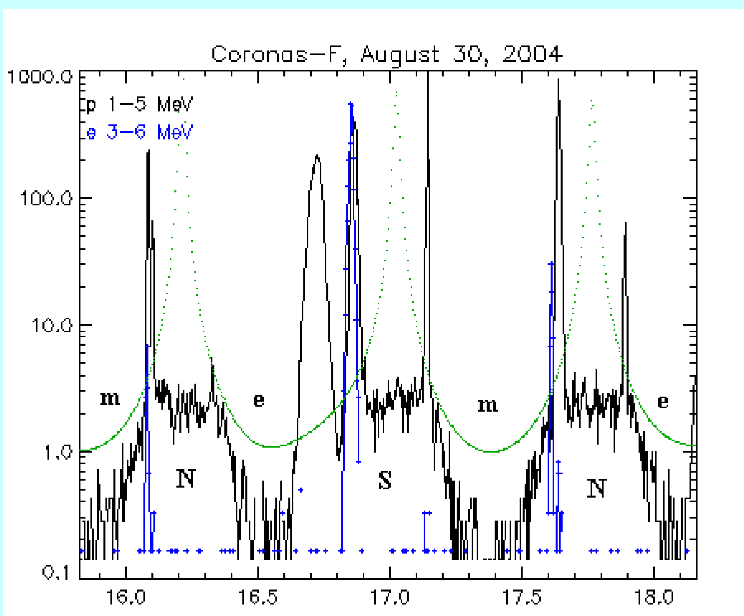
KORONAS–F, July–September 2004
electrons, MeV
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.3-0.6
0.6-1.5
1.5-3.
3-5
20
40
60
80
days
July
August
September

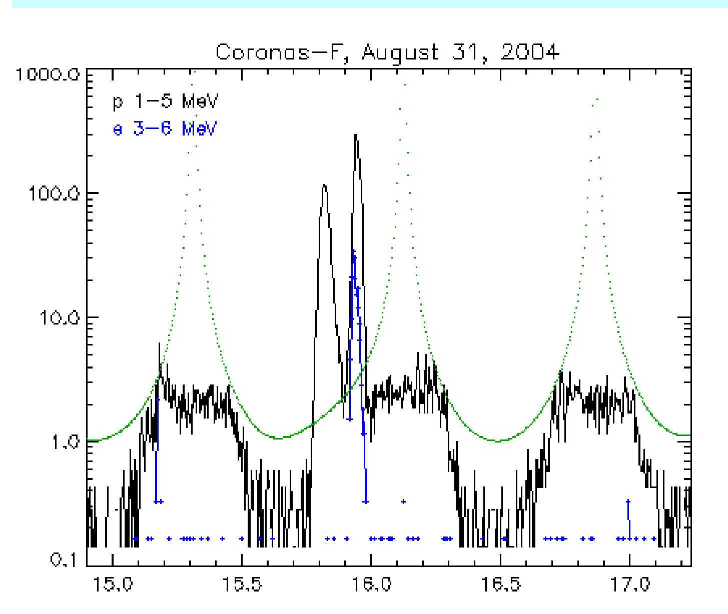


During long main phase of the 30.08 magnetic storm intense precipitation of the protons and electrons was registered by C-F (and S-1 as well (not shown). Possible reason – nonadiabatic effects.


Coronas–F, August 30, 2004
p 1–5 MeV
e 3–6 MeV
1000.0
100.0
10.0
1.0
0.1
11.5
12.0
12.5
13.0
13.5
Nm
Ne
Se
Sm
Nm
Ne


Coronas–F, August 30, 2004
p 1–5 MeV
e 3–6 MeV
1000.0
100.0
10.0
1.0
0.1
13.5
14.0
14.5
15.0
15.5
e
m
e
m
S
N
S


Coronas–F, August 30, 2004
p 1–5 MeV
e 3–6 MeV
1000.0
100.0
10.0
1.0
0.1
16.0
16.5
17.0
17.5
18.0
m
e
m
e
N
S
N


Coronas–F, August 31, 2004
p 1–5 MeV
e 3–6 MeV
1000.0
100.0
10.0
1.0
0.1
15.0
15.5
16.0
16.5
17.0

CONCLUSION

1. During strong magnetic storms proton radiation belt may be essentially changed. Earthward and outward movements of the PB may sweep away previously stable trapped particles and bring new belt population.

2. Solar cosmic rays became trapped to the proton belt (L = 2 – 4) during the recovery of the magnetosphere configuration (outward shift of the penetration boundary) at the strong magnetic storms.

This model can explain observed effects and may be regarded as a main source of the inner belt intensity increase there.

3. Effects of the SC-injection of solar protons and relativistic electrons into the inner magnetosphere were not found.

4. Trapping effect was restricted by 1-15 MeV protons. No significant effects were found in higher energies.

5. Additional acceleration of the trapped particles was recorded during late recovery phase. It possibly can be explained by ExB inward shift by induced electric field or/and electromagnetic waves.

6. Solar protons with small pitch angles remain trapped for weeks. Intensity decrease is smaller with larger pitch angles.

7. Decrease of the trapped electron and proton was accelerated by the precipitation during 20.08.04 magnetic storm. Effect is energy dependent, dropouts are large for the energetic protons and electrons. It can be explained by the particle precipitation when magnetic field line curvature became comparable with particle Larmor radius during the main phase of the magnetic storm.