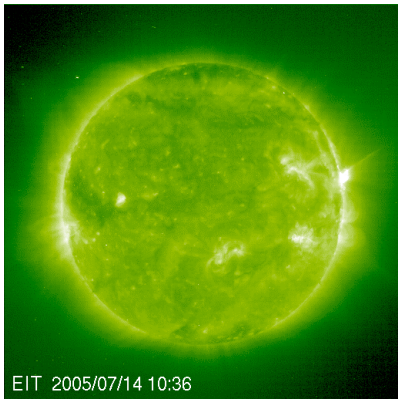
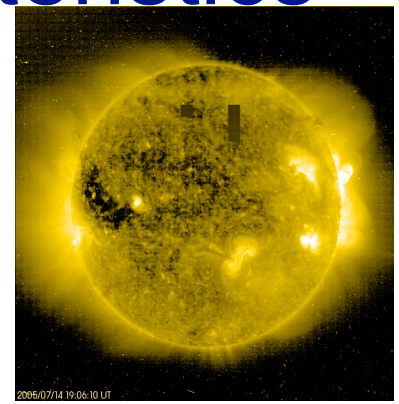


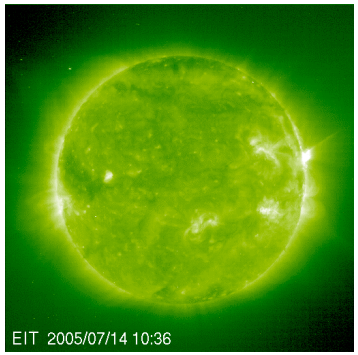

# Forbush effect characteristics as a possible indicator of the solar source location.

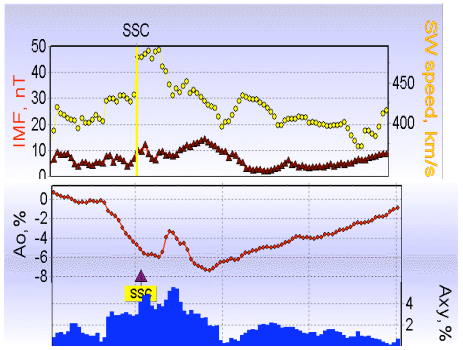


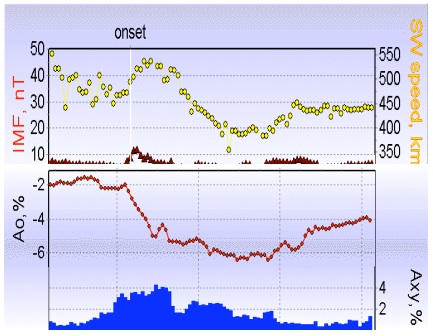

Eroshenko, E.(1), Belov, A.(1), Papaioannou, A.(2), Abunin, A.(1), Mavromichalaki, H.(2), Oleneva, V.(1), Asipenka, A.(1), Yanke, V.(1)

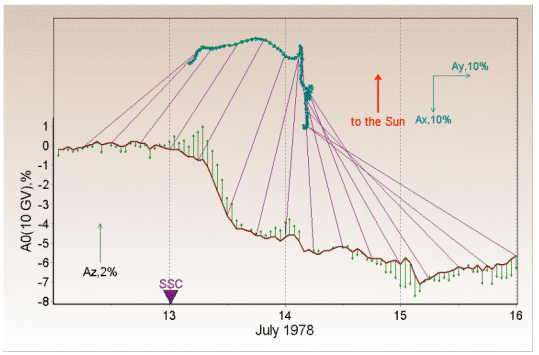
***1) Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation RAS (IZMIRAN), 142190, Troitsk, Moscow region, Russia***

***2) Nuclear and Particle Physics Section, Physics Department, University of Athens***




- **Direct reason of majority large Forbush effects (FEs) is propagating disturbance of the solar wind caused by CME**

Possible correlation between several parameters of FEs and characteristics of the ICME and solar sources has been studied in many works (e.g. Cane, Sinno, Barnden, Iucci, Villoresi, Belov);

In almost all papers the analysis of FEs has been performed:

-for relatively short periods

-for a small number of events;

-on the basis of one to three individual neutron monitors.

Since that time large amount of data is accumulated that gives the new chances for investigations.

- **In this work we analyze non-recurrent FEs related to CMEs and associated with solar flares.**

- **The tendencies for the FEs distributed by different heliolongitudinal groups of their solar sources :**

- -in a behavior of CR anisotropy;
- -in a relation of the anisotropy to the FD magnitude;
- -in a delay of the onset time relatively to a disturbance commencement;
- -in a decrement of the FD (speed of a decrease of CR density during the main phase of the FE)

**Statistical analysis of such events requires a big volume of data**

# Data and Methods

Two data bases have been used as a working tools:

-information on all the soft X-ray flares recorded by the satellites of GOES series since autumn 1975 (ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_FLARES/XRA_FLARES/).

- database on the interplanetary disturbances and Forbush effects.

Why do we need such a database?

FD in the counting rate of each station may show a different depth, time profile and even a different onset time of the FD.

**So, it is necessary to use the global CR characteristics which are independent on the local position of a detector.**

FE space characteristics: CR density and anisotropy derived from data of the world wide NMN by the global survey method (GSM)

# Database on the Forbush effects and interplanetary disturbances.

**CR** variations:

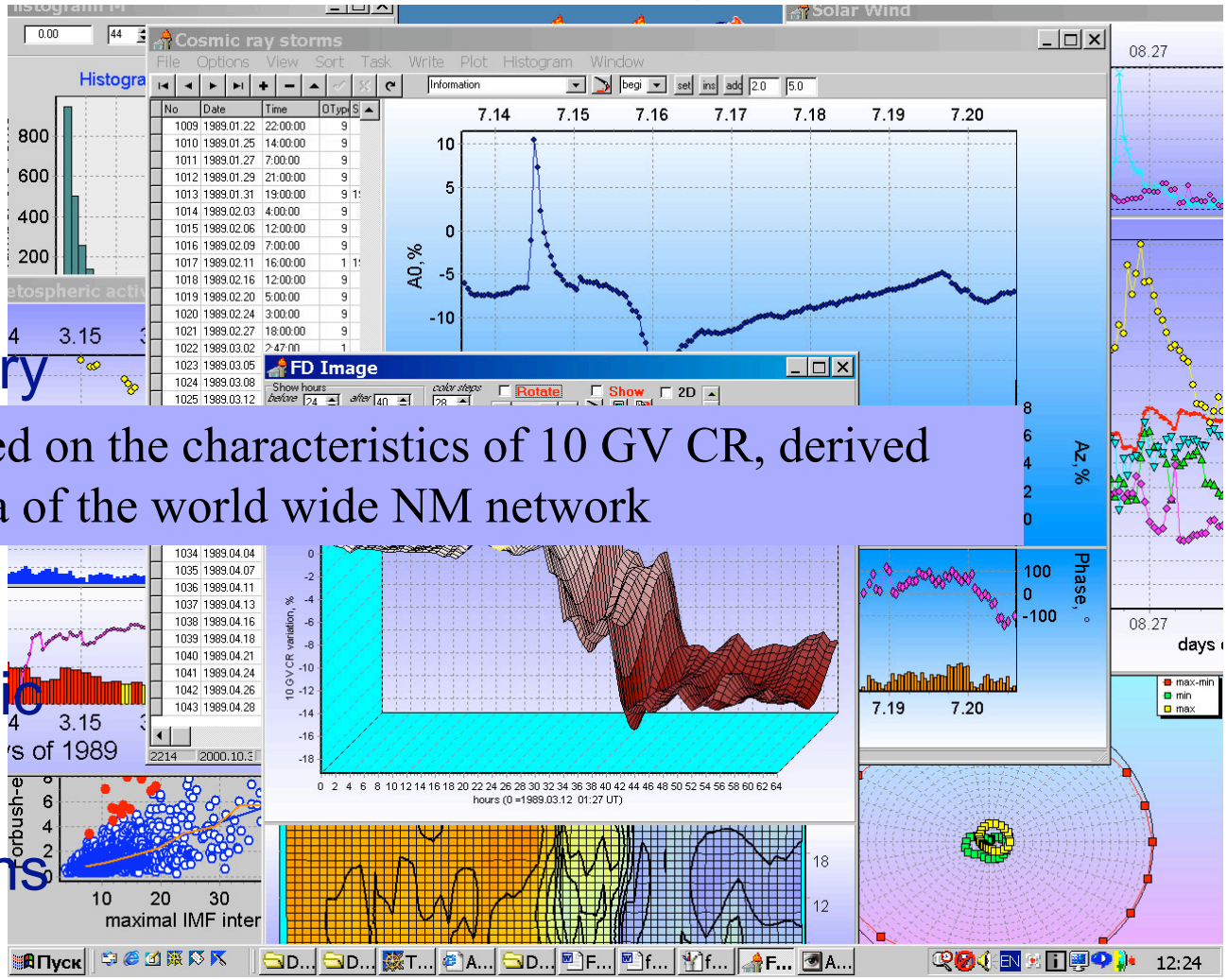
density and anisotropy

Solar

Interplanetary

Geomagnetic

Observations




maximum values of FDs and CR anisotropy, the onset and FE maximum times, duration of the FD,IMF and SW parameters, Ap and Dst indices of geomagnetic activity.

# Data and Methods

Only those FEs have been selected for analysis :

-identified with solar sources;

-followed by the shock (SSC);

-and separated each from the other by the time interval of 48 hours (about 230 FEs).

All they were divided in five groups by heliolongitude ranges of their solar sources:

E99-E46;  E45-E16; E15-W15; W16-W45; W46-W99.

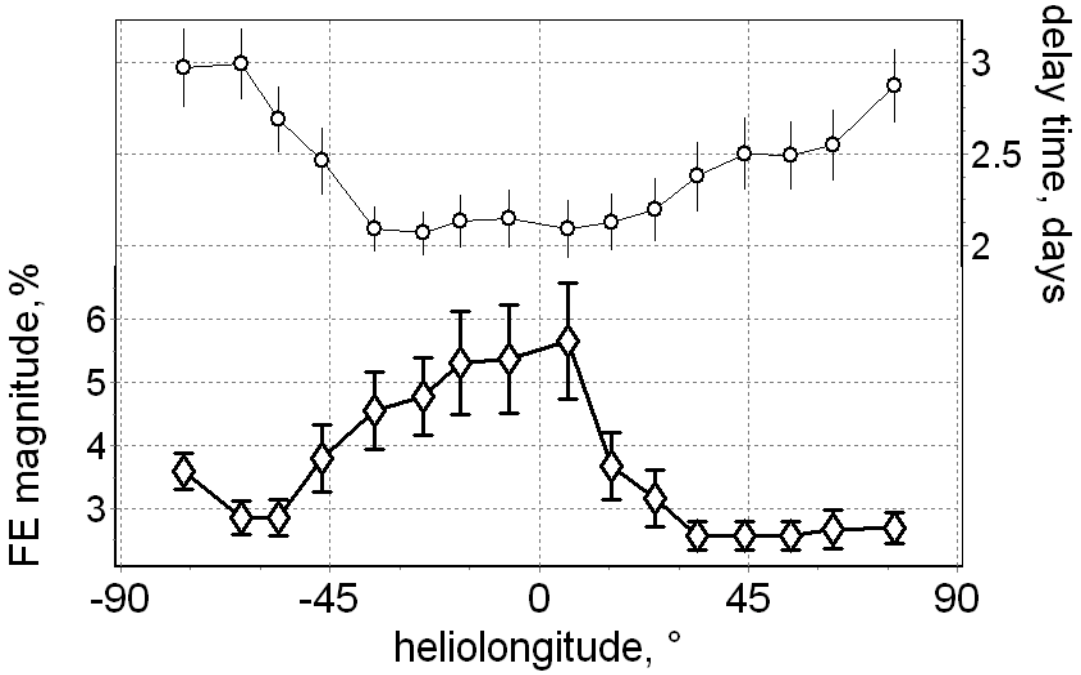
As the main tool of analysis the properties of the data bases have been used:

**-selection by different parameters**

**-various correlations**

**-statistical estimations**

# Discussion of the results




Magnitude and time delay of the FE onset as functions of the heliolongitude of associated flares (>X1 importance) (Belov et al, 2005).

# Table 1( part 1, eastern events).

## E99-E46; E45-E16; E15-W15; W16-W45; W46-W99

| | E99-E46 | | | | | E45-E16 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Magn | 2.88 ± 0.21 | 7.00 | 0.40 | 27 | | 2.35 ± 0.40 | 19.30 | 0.20 | 60 | |
| Axy_max | 1.78 ± 0.09 | 2.65 | 0.87 | 27 | | 1.84 ± 0.19 | 4.71 | 0.78 | 60 | |
| Az_range | 1.77 ± 0.11 | 3.33 | 0.97 | 27 | | 2.06 ± 0.11 | 4.36 | 0.52 | 60 | |
| Dmin | -0.47±0.04 | -0.18 | -1.01 | 26 | | -0.57±0.07 | -0.14 | -2.19 | 58 | |
| Dmax | 0.46 ± 0.14 | 3.95 | 0.17 | 26 | | 0.83 ± 0.46 | 27.13 | 0.19 | 58 | |
| Kpmax | 5.31 ± 0.25 | 7.00 | 2.33 | 27 | | 5.46 ± 0.19 | 9.00 | 2.67 | 60 | |
| Apmax | 4.63 ± 7.20 | 132.00 | 0.00 | 27 | | 79.77±8.99 | 400.0 | 12.0 | 60 | |
| Dst_min | 61.5 ± 7.2 | 0.0 | -145.0 | 27 | | -81.14 ± 9.6 | -9.0 | -472.0 | 60 | |
| Bmax | 16.70 ± 1.38 | 31.90 | 3.00 | 21 | | 18.58 ± 1.42 | 55.80 | 7.20 | 51 | |
| Vmax | 36.2 ± 17.2 | 738.0 | 306.0 | 19 | | 568.1±17.7 | 936.0 | 378.0 | 49 | |
| VmBm | 4.46 ± 0.46 | 8.77 | 1.82 | 19 | | 5.56 ± 0.62 | 11.84 | 1.61 | 48 | |
| HCStil | 54.50 ± 2.52 | 75.0 | 26.60 | 26 | | 56.62 ± 1.76 | 75.1 | 10.1 | 60 | |
| tmin | 28.12 ± 3.29 | 56.0 | -12.0 | 26 | | 23.26±2.26 | 59.0 | -12.0 | 58 | |
| tdmin | 14.38 ± 3.45 | 59.0 | 0.00 | 26 | | 11.62±1.81 | 58.0 | -10.0 | 58 | |
| AftoB | 0.190 ± 0.020 | 0.65 | 0.02 | 20 | | 0.179± 0.010 | 0.81 | 0.02 | 51 | |
| HLon | -63.15±2.48 | -46.0 | -90.0 | 27 | | -30.83±1.05 | -16.0 | -45.0 | 60 | |
| Axm | 0.122 ± 0.12 | 1.14 | -1.66 | 27 | | 0.206±0.102 | 2.42 | -1.72 | 60 | |
| Aym | 0.991 ± 0.17 | 2.32 | -0.88 | 27 | | 0.867±0.155 | 2.86 | -2.26 | 60 | |
| Axyb | 0.828 ± 0.091 | 1.68 | 0.00 | 27 | | 0.780 ± 0.062 | 2.94 | 0.07 | 60 | |

All the FEs associated with eastern sources, separated by 48 hours before and behind of each from other (ta>48, tb>48), in a whole about 90 events

Af, Axy_max, Dmin,Dmax, Apmax, Dst-max, Bmax, Vmax, HCStil, tmin, tdmin, AftoB, Axm, Aym, Axyb

# Table 1( part 2, central and western events).

E99-E46;  E45-E16; E15-W15; W16-W45; W46-W99

| | E15-W15 | W16-W45 | W46-W99 |
|---|---|---|---|
| Af | 9.17 ± 0.41 7.0 4.0 0.0 67 | 9.95 ± 0.44 7.7 4.0 0.5 41 | 1.86 ± 0.21 5.7 0.0 4.0 35 |
| Axy_max | 1.93 ± 0.12 5.01 0.60 67 | 2.13 ± 0.15 4.35 0.88 41 | 1.86 ± 0.16 5.78 0.97 35 |
| Ax_range | 1.07 ± 0.11 5.04 0.62 67 | 1.01 ± 0.11 4.14 1.01 41 | 1.85 ± 0.17 4.42 0.41 35 |
| Dmin | -0.65±0.07 -0.12 -2.40 59 | -0.79±0.14 -0.12 -4.99 39 | -0.99±0.04 -0.17 -1.24 20 |
| Tmax | 0.38 ± 0.03 1.16 0.12 54 | 1.03± 0.00 3.3 7.0 0.14 34 | 0.33 ± 0.03 0.53 0.10 30 |
| Apmax | 6.65 ± 0.19 8.32 2.67 67 | 6.09 ± 0.25 8.67 2.32 41 | 6.07 ± 0.19 8.32 3.00 35 |
| Apmax | 85.57 ± 7.64 126 12.0 67 | 108.1± 11.6 200.0 9.0 41 | 57.82±6.94 126.0 0.0 25 |
| Dst_min | -82.9±7.2 -10.0 -268.0 67 | -103.5±13.6 -10 -387 41 | -57.8±3.9 -19.0 -107.0 35 |
| Bmax | 17.82 ± 0.92 26.40 7.60 58 | 19.52±2.47 65.60 8.40 21 | 15.64±0.86 22.20 7.50 22 |
| Vmax | 669.0±17.0 918.0 337.0 66 | 686.8±30.7 1040 320 29 | 552.6 ± 21.2 806. 365. 32 |
| VmDm | 5.17±0.18 15.36 1.57 54 | 6.45±1.14 18.59 1.71 18 | 4.17 ± 0.17 7.56 1.63 31 |
| HCStil | 55.69 ± 1.79 72.80 8.40 67 | 55.98±3.05 75.10 14.60 41 | 52.28 ± 2.10 75.1 15.6 27 |
| tmin | 9.78±2.90 59.0 -19.0 59 | 10.44±2.28 41.0 -19.0 39 | 21.17±4.16 59.0 -19.0 30 |
| tdmin | 19.54±1.91 49.0 -18.0 59 | 9.18±1.92 47.0 -19.0 39 | 15.48±2.00 47.0 -9.0 30 |
| AftoB | 0.163±0.017 0.69 0.04 58 | 0.174±0.025 0.57 0.05 31 | 0.117±0.017 0.42 0.03 31 |
| HLen | 0.328±1.089 15.0 15.0 67 | 21.61 ± 1.966 15.0 17.0 41 | 61.629±2.085 90.0 15.0 35 |
| Axm | 0.305±0.117 3.77 -2.44 67 | 0.194±0.127 1.8 -1.91 41 | 0.100±0.162 3.29 -1.74 35 |
| Aym | 0.373±0.130 3.07 -1.53 67 | 1.20 ± 0.104 4.2 -1.97 41 | 1.005±0.135 4.52 -1.90 35 |
| | 0.736±0.065 2.52 0.06 67 | 0.741 ± 0.081 2.55 0.04 41 | 0.844±0.092 3.11 0.00 35 |

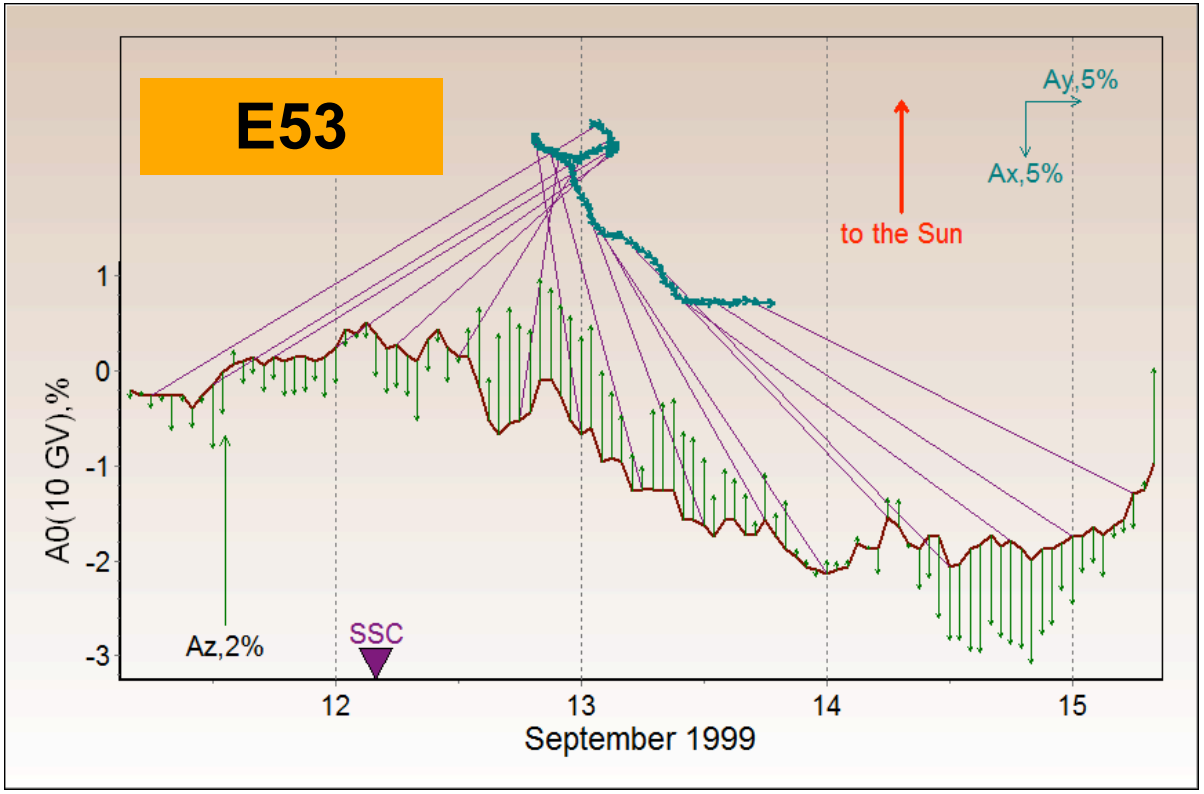
All the FEs associated with central and western sources, separated by 48 hours before and behind of each from other (ta>48, tb>48), in a whole about 150 events

Af, Axy_max, Dmin,Dmax, Apmax, Dst-max,Bmax, Vmax, HCStil, tmin, tdmin, AftoB, Axm, Aym, Axyb

# Table results. What can we see?

- Ratio Axym/Af increases toward the west longitudes.
- Tmin – is less for the centre than for a periphery, and less for the west than for the east sources.
- Dmin – is larger in the centre than by the sides, but maximum is clearly shifted to the west. It is because of the moving along the force lines. Particles rotating around these lines cannot come into disturbed region in advance.
- Events, characteristic  for each region.

# Examples of the events characteristic for each group



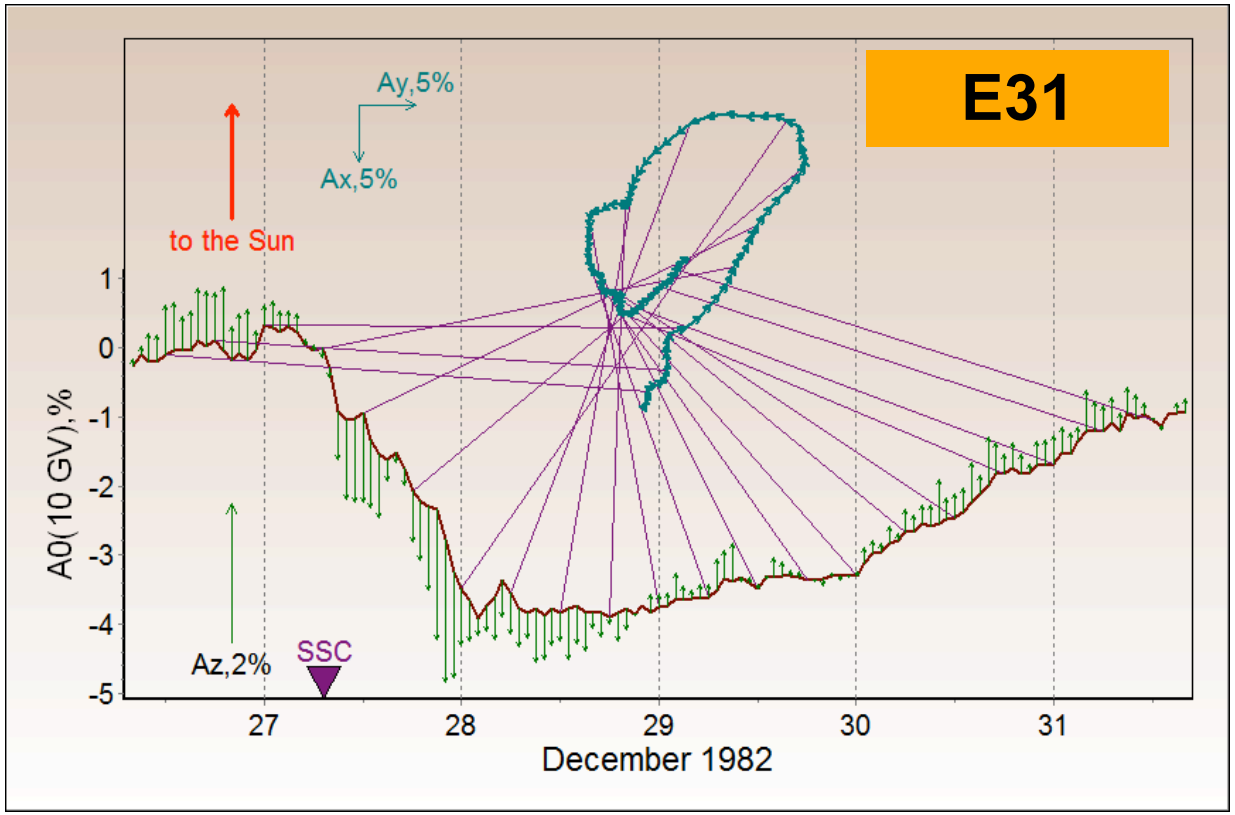

Behavior of the CR density and vector of the first harmonic of anisotropy during the FEs caused by far eastern sources

Small FD, small decrement, extended decrease, tmin – one day or more;

CR anisotropy is not big;

Significant change of the anisotropy direction occurs in a decrease phase up to its vector rotation;

# Examples of the events characteristic for each group



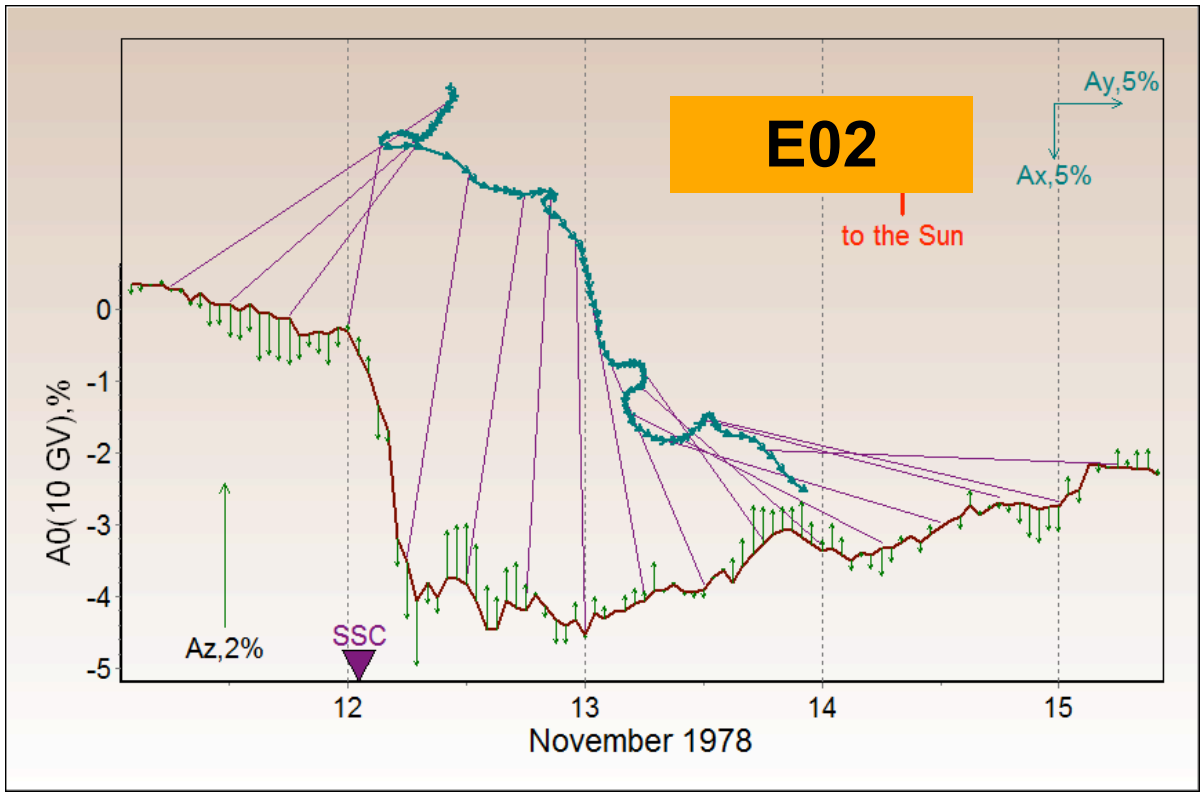

Behavior of the CR density and vector (diurnal) anisotropy during the FEs caused by the eastern sources

Effect with larger FD;

Faster getting of minimum (tmin< one day), slow recovery;

Behavior of anisotropy is very complicated: vector rotates during the whole FE.

# Examples of the events characteristic for each group




Behavior of the CR density and vector (diurnal) anisotropy during the FEs caused by the sources from central group

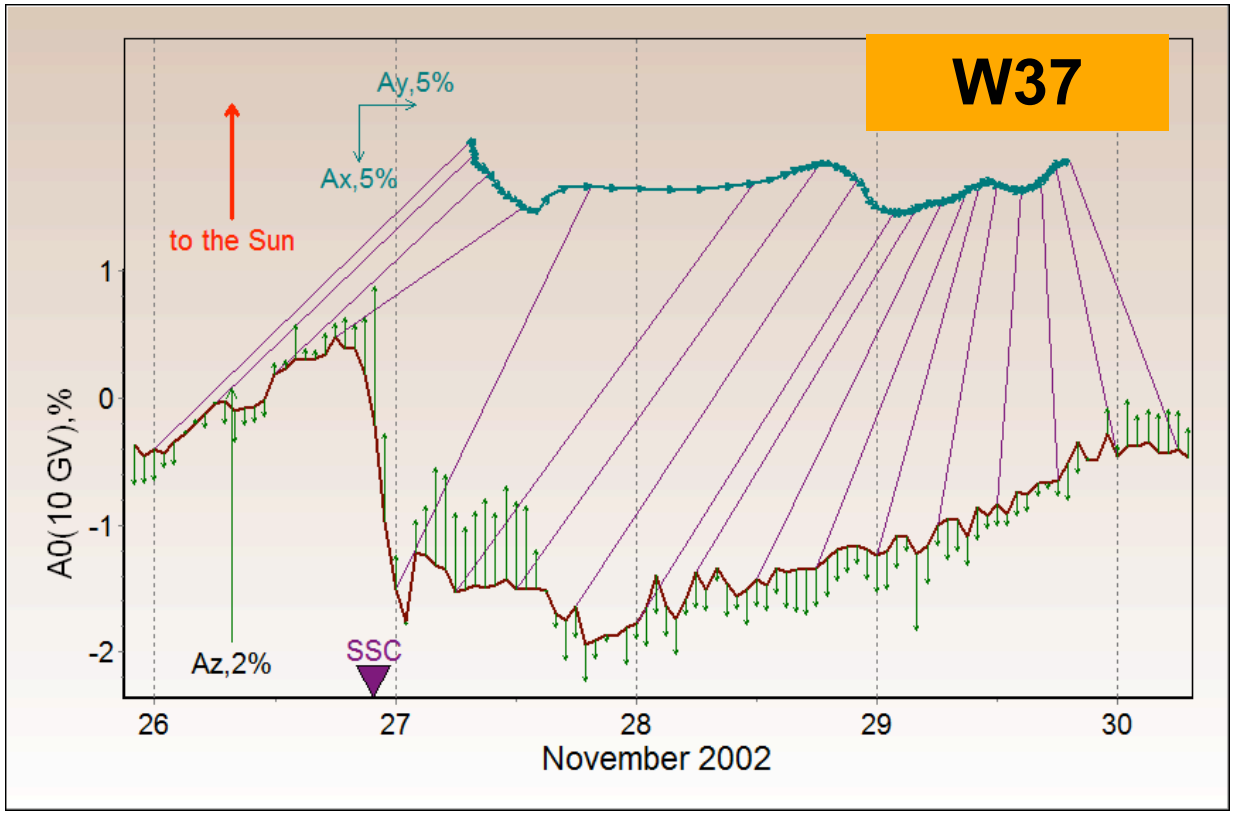
Large magnitude of the FD;

Fast getting of minimum (small tmin), large decrement;

More simple behavior of the Axy although still with some changes of direction;

Growing of the anisotropy in the main phase of FE.

# Examples of the events characteristic for each group




Behavior of the CR density and vector (diurnal) anisotropy during the FEs caused by western sources

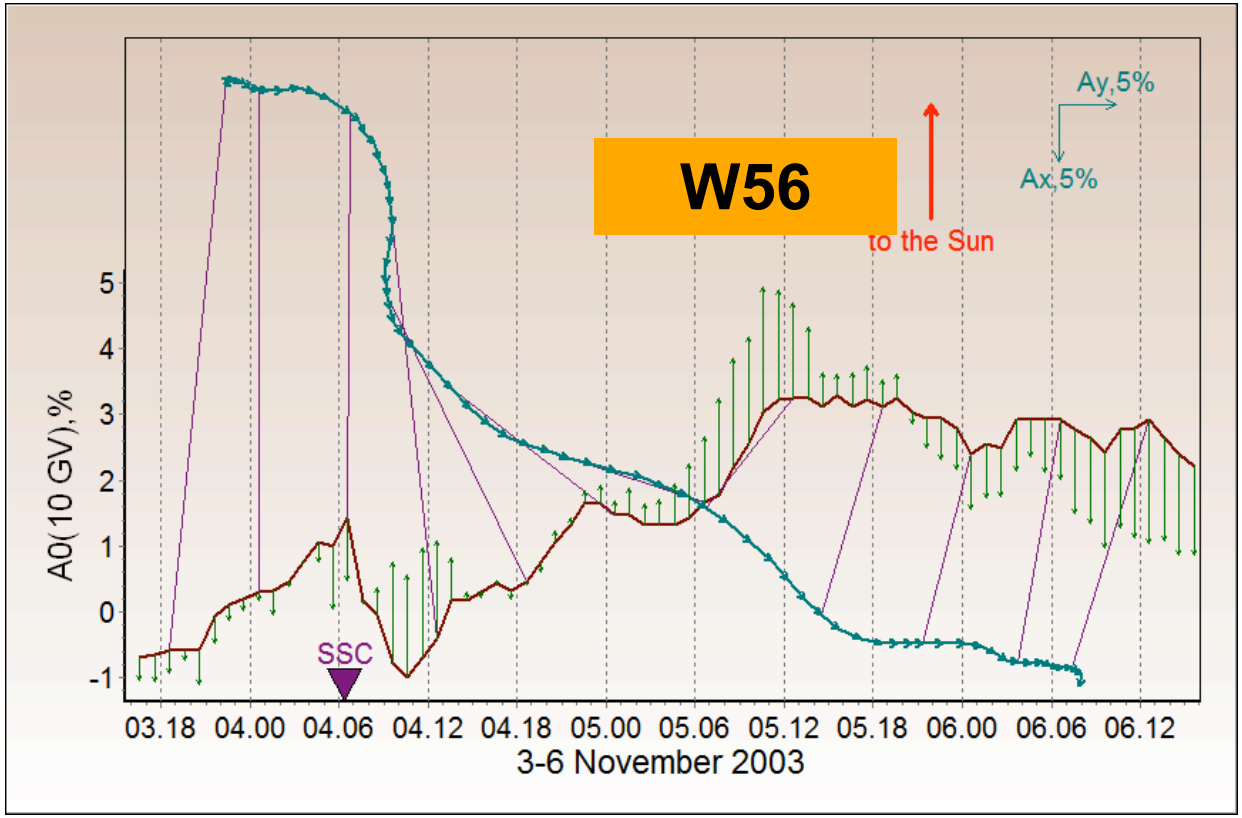
As a rule, not a big effect.

Fast getting of the FD minimum-large decrement.

Very simple behavior of the anisotropy:

Large value but steady direction from east to the west

# Examples of the events characteristic for each group



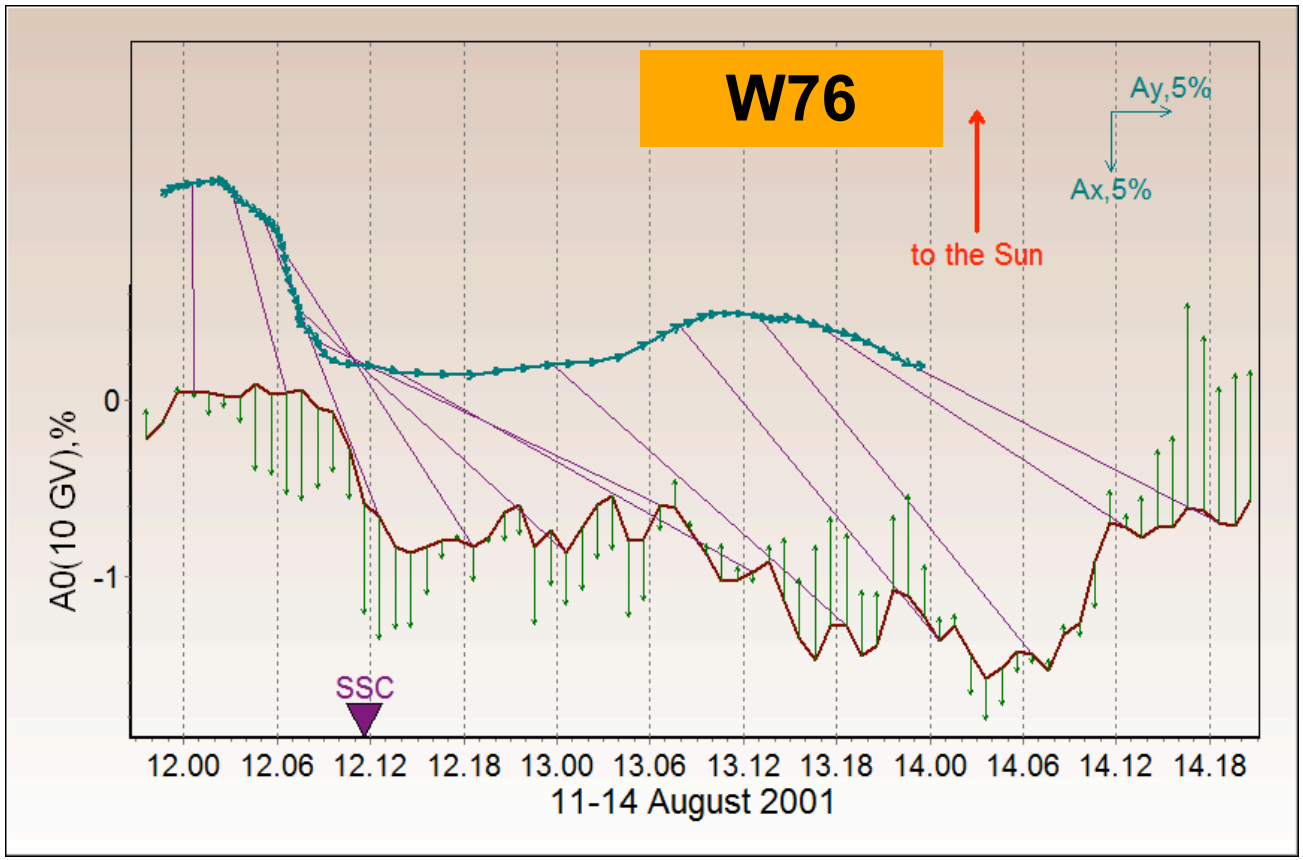

Behavior of the CR density and vector anisotropy during the FEs caused by far western sources

Very small, fast and short FD.

Big anisotropy, steady directed;

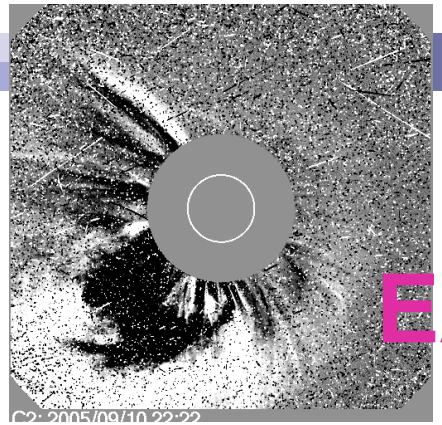
It remains of large value during long time even when the FD is already over. The Earth is apart of disturbed region but feels it long time through the CR anisotropy.

# Examples of the events characteristic for each group

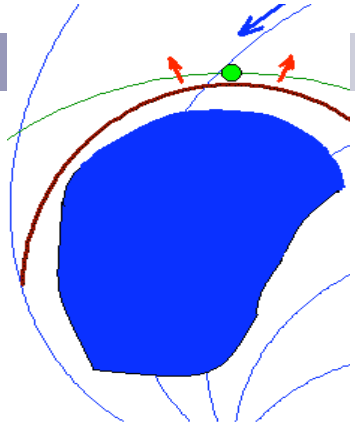



Behavior of the CR density and vector anisotropy during the FEs caused by far western sources

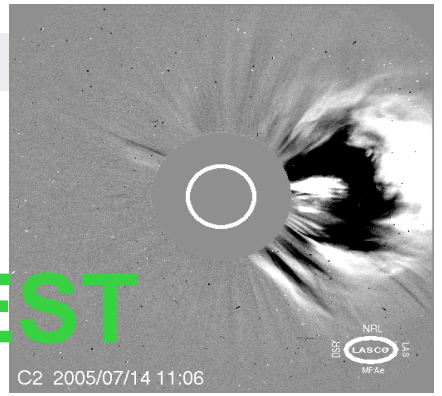
Similarly to the previous picture. Small FD.
Large anisotropy.
Steady direction (from east to the west).

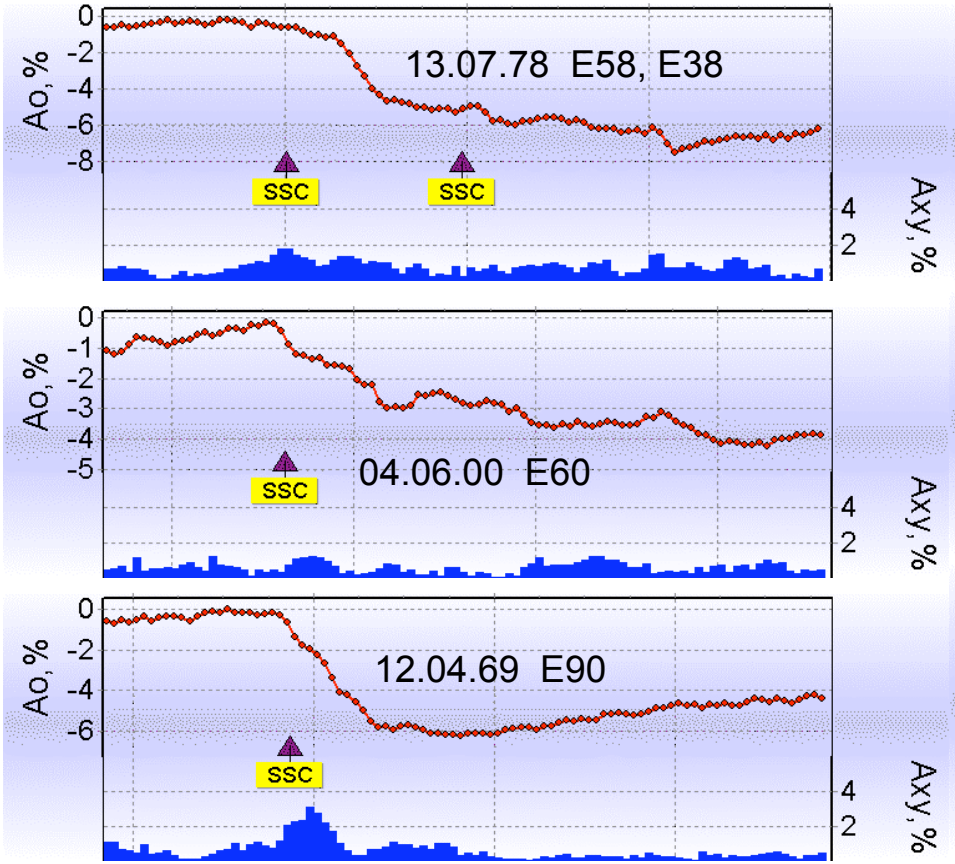


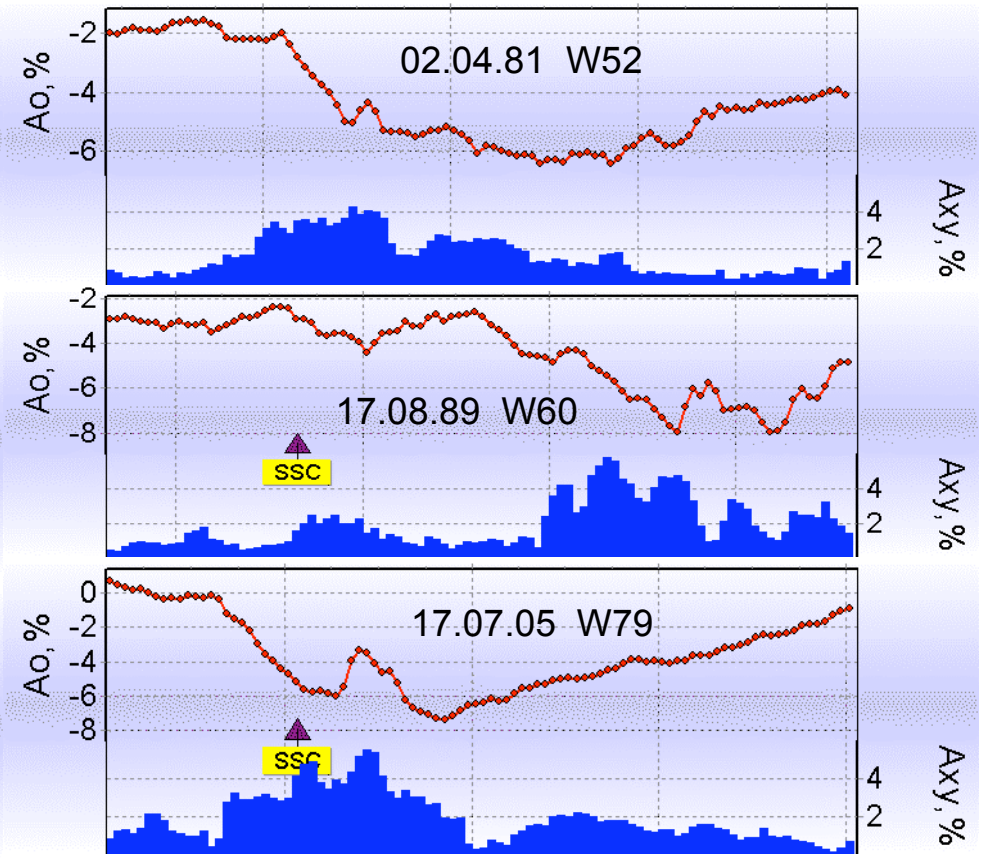

EAST



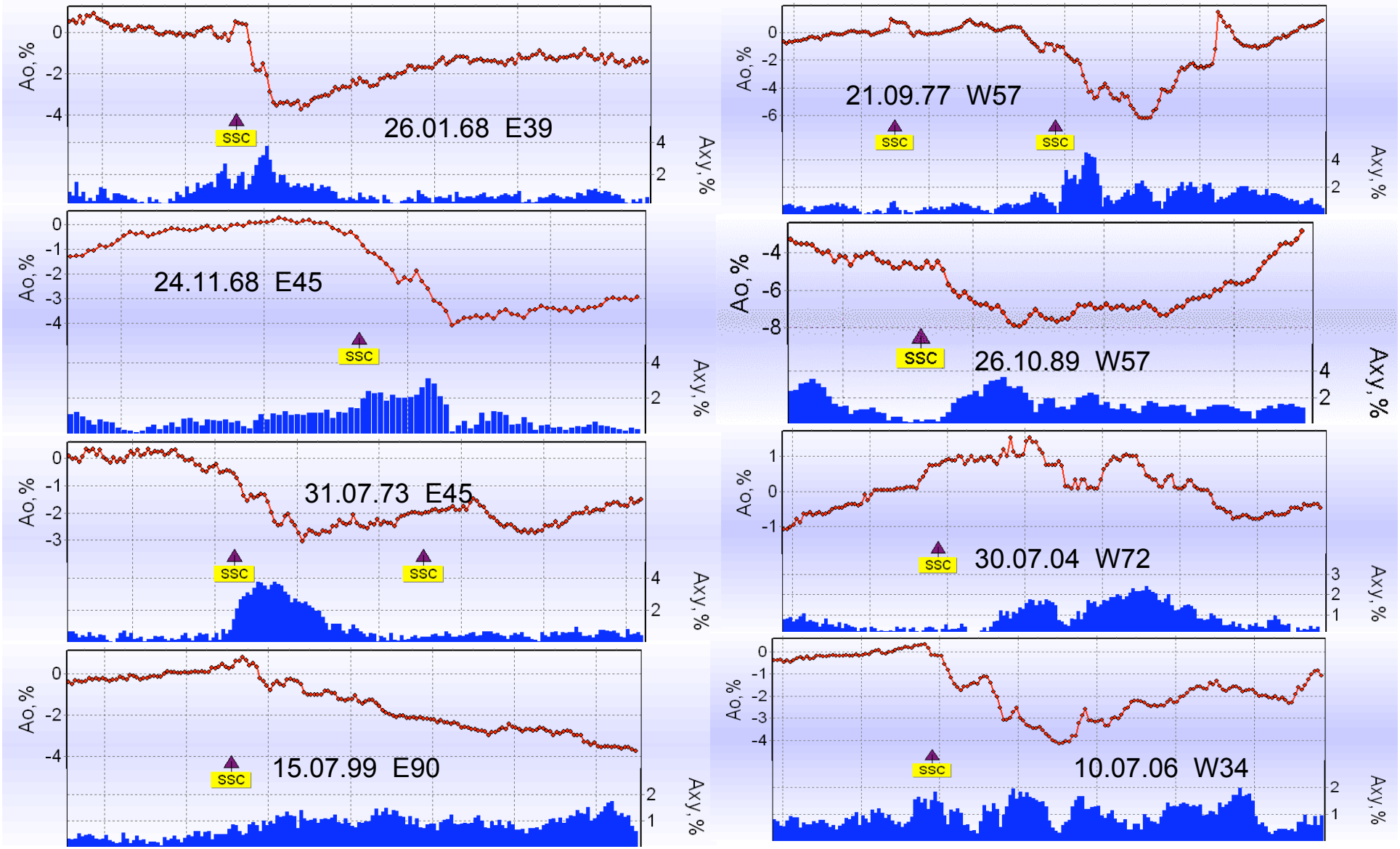
WEST



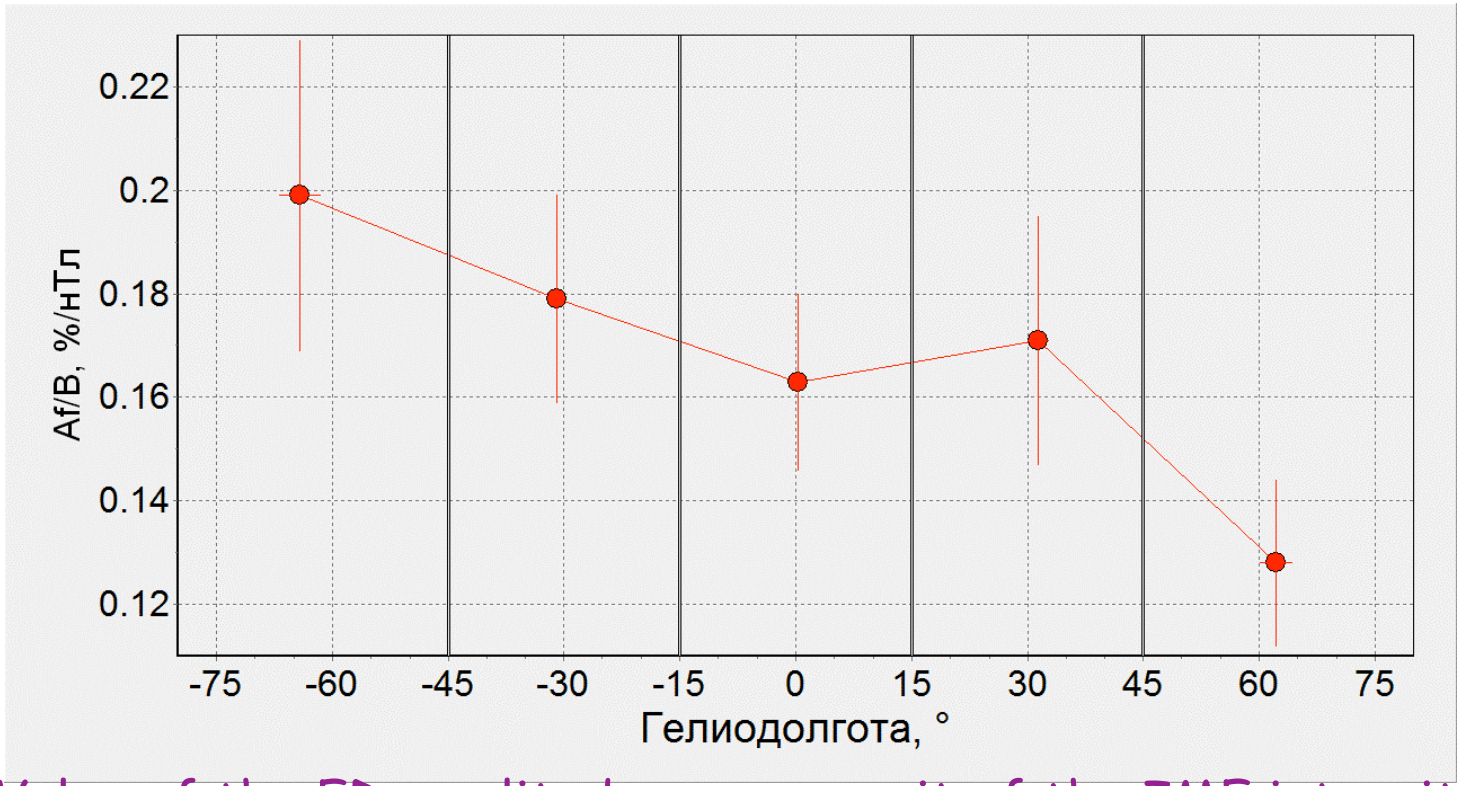




CR density (A0) and anisotropy (Axy) during the FEs from remote sources



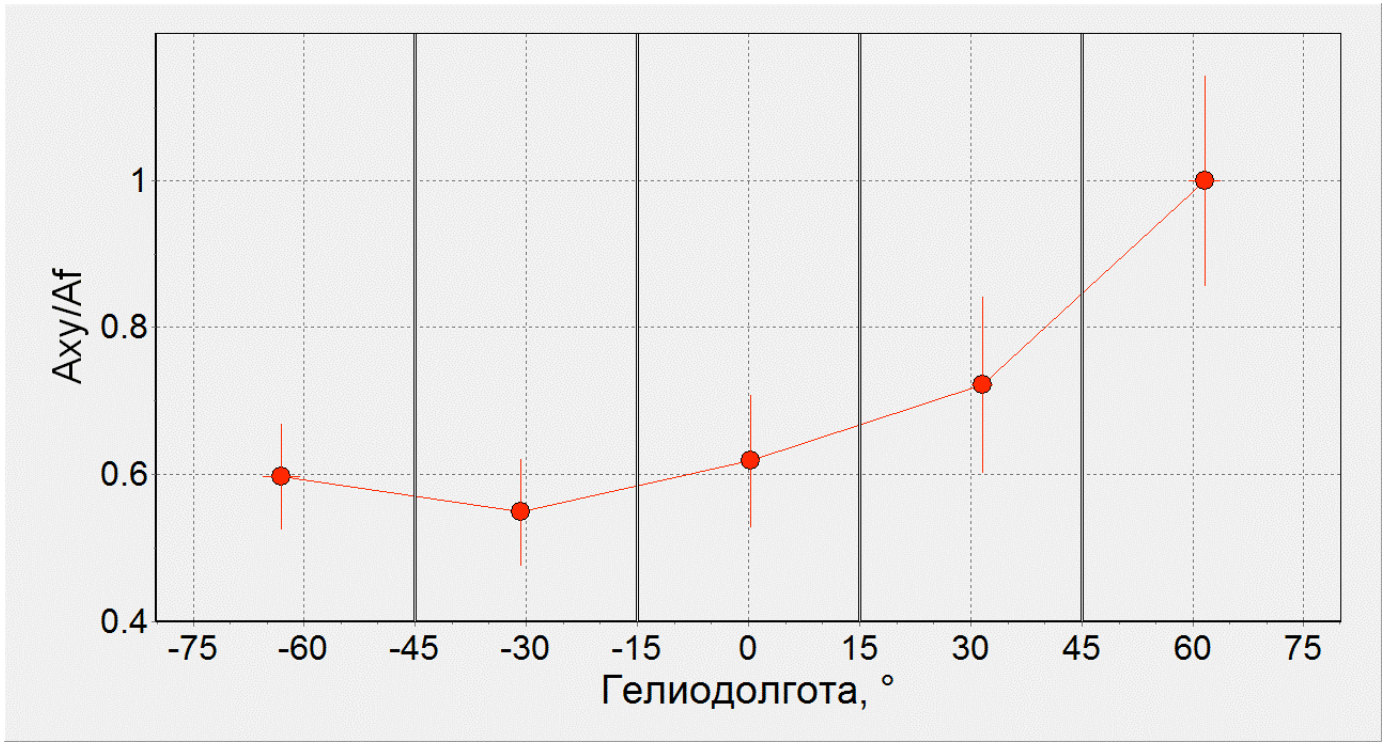

CR density (A0) and anisotropy (Axy) during the FEs from remote eastern and western sources. Axy is essentially larger for western events (4.46-W, 2.91- E)

# Parameter Af/B at different heliolongitudes of the sources.




Value of the FD amplitude per one unit of the IMF intensity is larger for the eastern events than for the western ones. It means the higher efficiency for the FE creation.
The Earth turned out to be in the periphery part of disturbance as if disturbance overtakes it. This part of disturbance is closed for the CR (in distinction of western effects), and FD herewith should be large enough and long lasted.

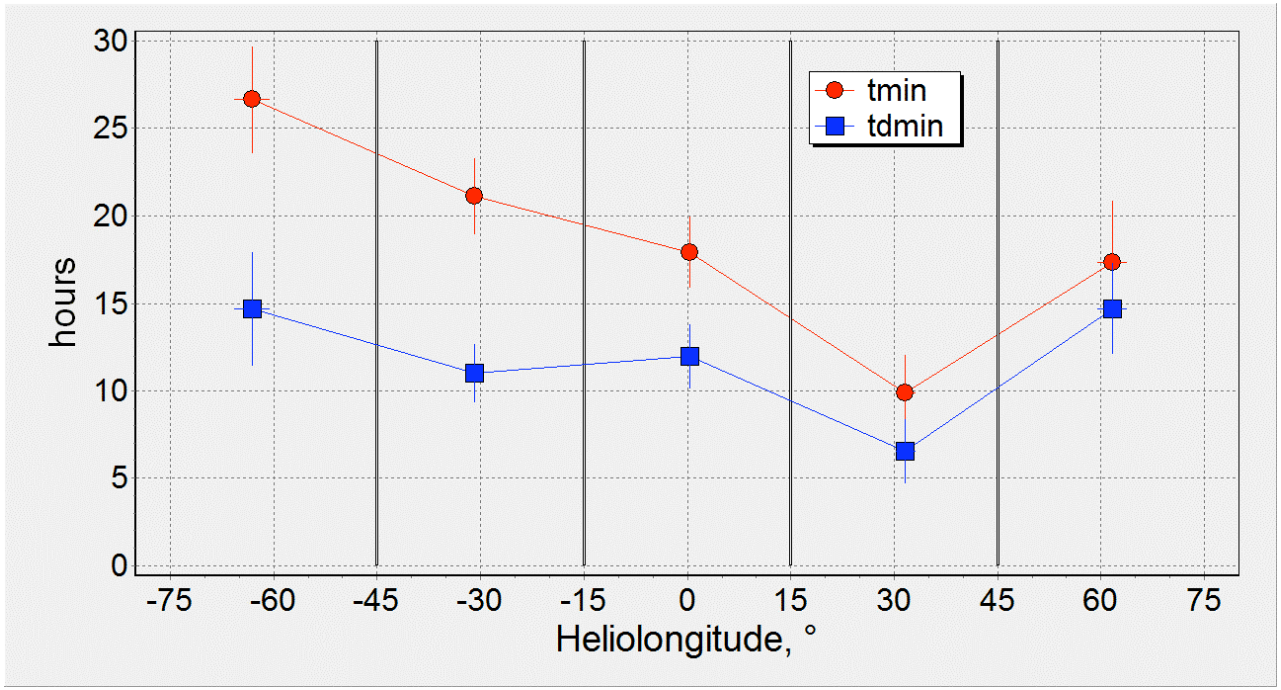
## Ratio of Axy to the amplitude of FD Af for different source heliolongitudes.




Ratio Axym/Af increases toward the west longitudes.

Anisotropy becomes very large, sometimes larger than FD amplitude, in the FEs from the far western sources. Since a disturbed region is open from the east, the recovery goes very fast, from east to west.

# The time of minimum of FD (tmin) and maximum decrement in the phase of FE decrease (tdmin)




These characteristics show how the event evolved. For example, the faster develop effect in the western region, the smaller and shorter it will be: a decrease has no time to evolve completely because of the Earth come out from disturbed region very quickly. On the contrary, eastern events occur more slowly, disturbed region as if overtakes the Earth. The most slow are the events from far eastern sources and the fastest events are from moderate western sources.

# Summary

Comparison of the FEs caused by solar sources (CME) from different portions of the solar disk reveals essential dependence of various characteristics of FEs on the source heliolongitude.

Direction of the anisotropy is more changeable for the eastern and central sources and more steady for the western ones.

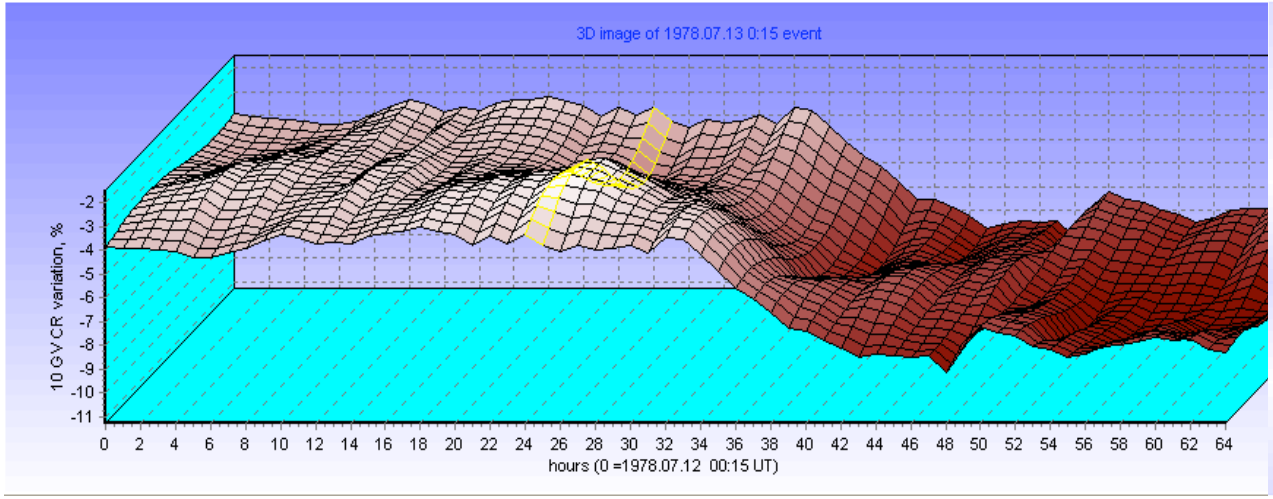
The effects associated with eastern CME develop most slowly

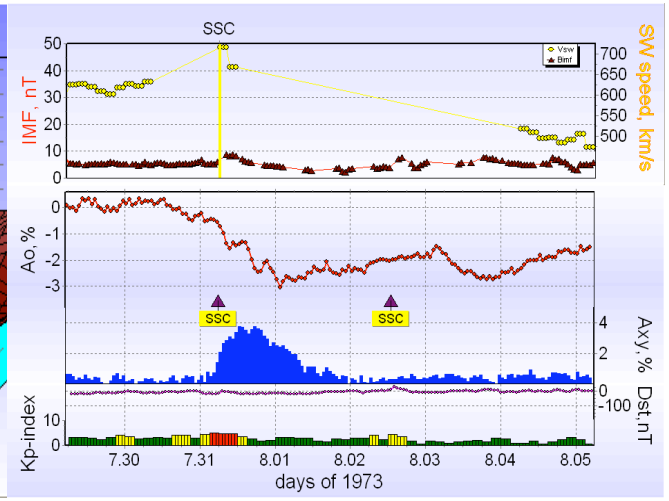
# Summary

The closer source to the western edge of the Sun the more anisotropic is the FE (the larger is a ratio of the observed anisotropy to the variations of CR density in this FE).

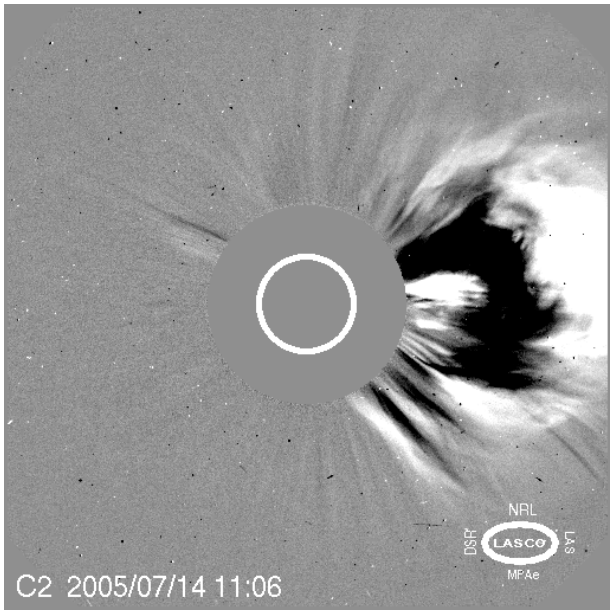
Group with moderately western sources is distinguished by their fast development (in particular, by quick getting of decrease minimum).

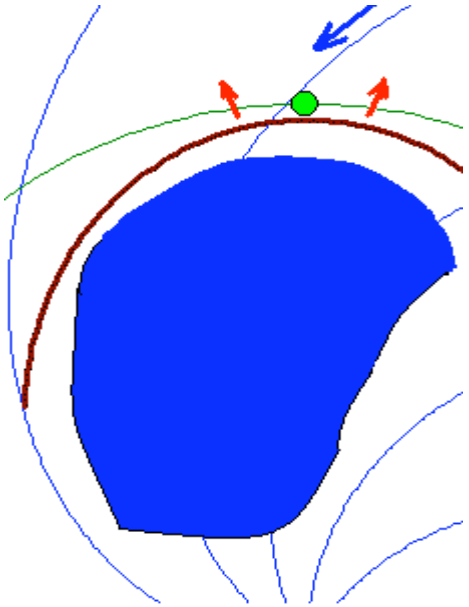
Further analysis can reveal also other parameters of the EFs essentially depending on the source heliolongitude that give additional information about arrival to Earth solar wind disturbance and have a prognostic value.

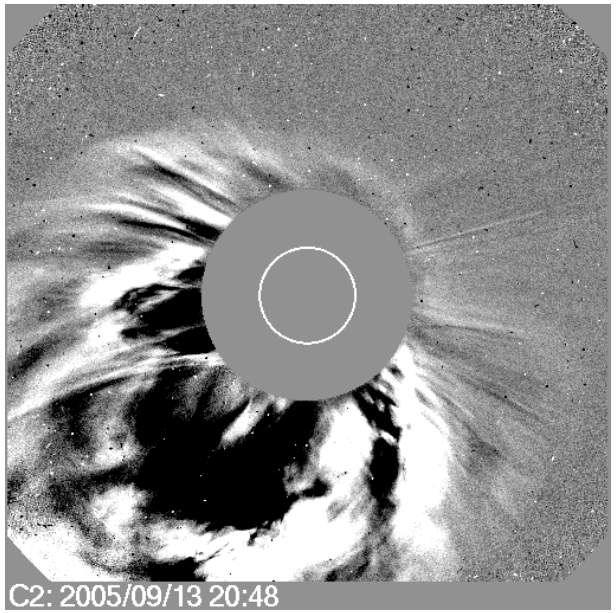

3D image of 1978.07.13 0:15 event
10 GV CR variation, %
hours (0 =1978.07.12 00:15 UT)


SSC
IMF, nT
SW speed, km/s
Ao, %
SSC
SSC
Axy, %
Kp-index
Dst, nT
days of 1973

# THANK YOU


NRL
LASCO
C2
MPAe
C2 2005/07/14 11:06




C2: 2005/09/13 20:48