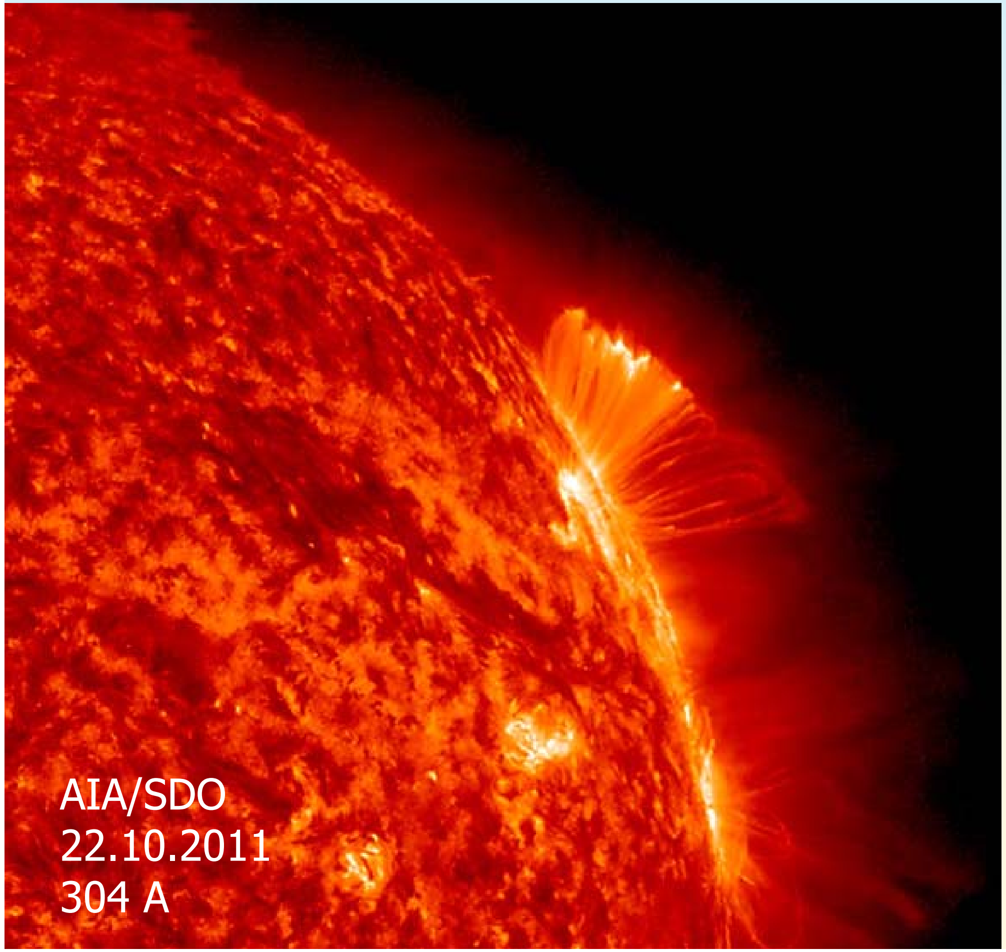
How X-ray solar flare observations from different points of the heliosphere can help in forecast of space weather ?

M.A.Livshits

IZMIRAN, Troitsk, Moscow, Russia

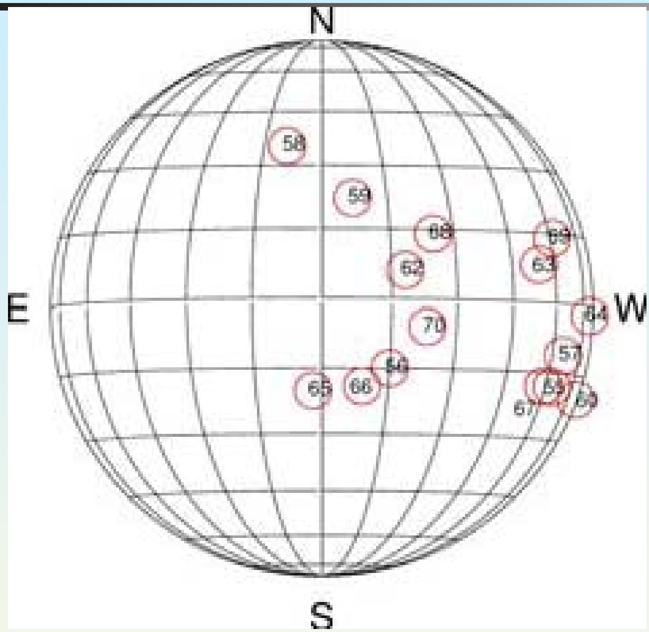


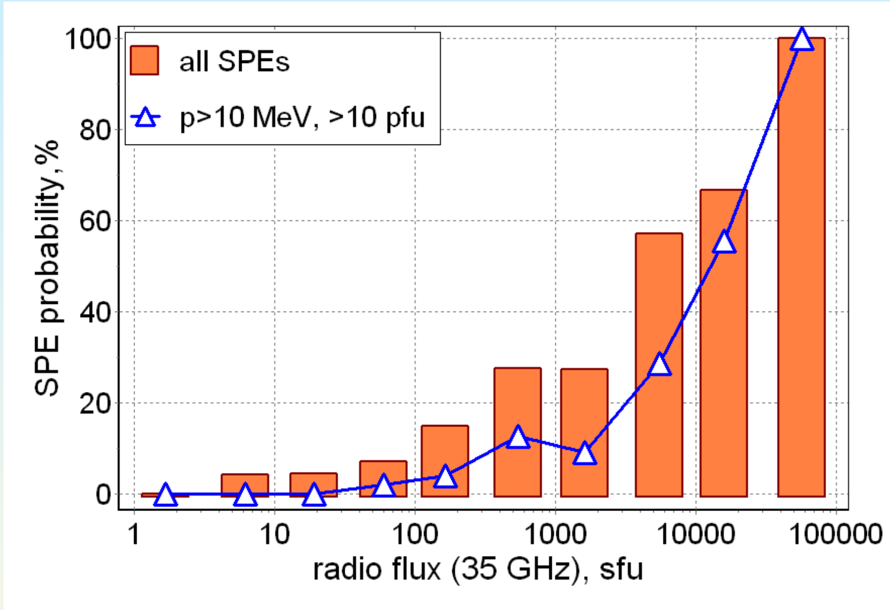
Space Weather and Plasma in Space IsraSWAPS-2013

Content

- Introduction. Statistics. Space Weather Forecast for 2 cases – 1-2 days after the flare observations and prediction of flare activity and space weather up to 15 days.
- Mars Odyssey Observations
- Mars Odyssey: flare active regions: rise and motion behind the western solar limb
- Mars Odyssey/HEND and RHESSI observations of solar flares that occurred on the back side of the Sun
- Anomalies of the space weather: huge magnetic storms (Grechnev, Chertok et al. 2013), large Forbush effects with weak or out of magnetic storms (13-17 July 2005)
- Conclusions

The Base of the modeling of forecast of the space weather





Belov, A., Garcia, H., Kurt, V., Mavromichalaki, H.

"Proton enhancements and their relation to the X-ray flares during the three last solar cycles".

Sol. Phys. 229, 135. 2005

“Properties of Ground Level Enhancement Events and the Associated Solar Eruptions during Solar Cycle 23”
N. Gopalswamy et al., SpSciRev 2012,171, 23

“Properties of solar X-ray flares and proton event forecasting“- A. Belov, Adv. Sp. Res 2009 43, 467

Study of the flare activity of AR in days preceeding data of the forecast

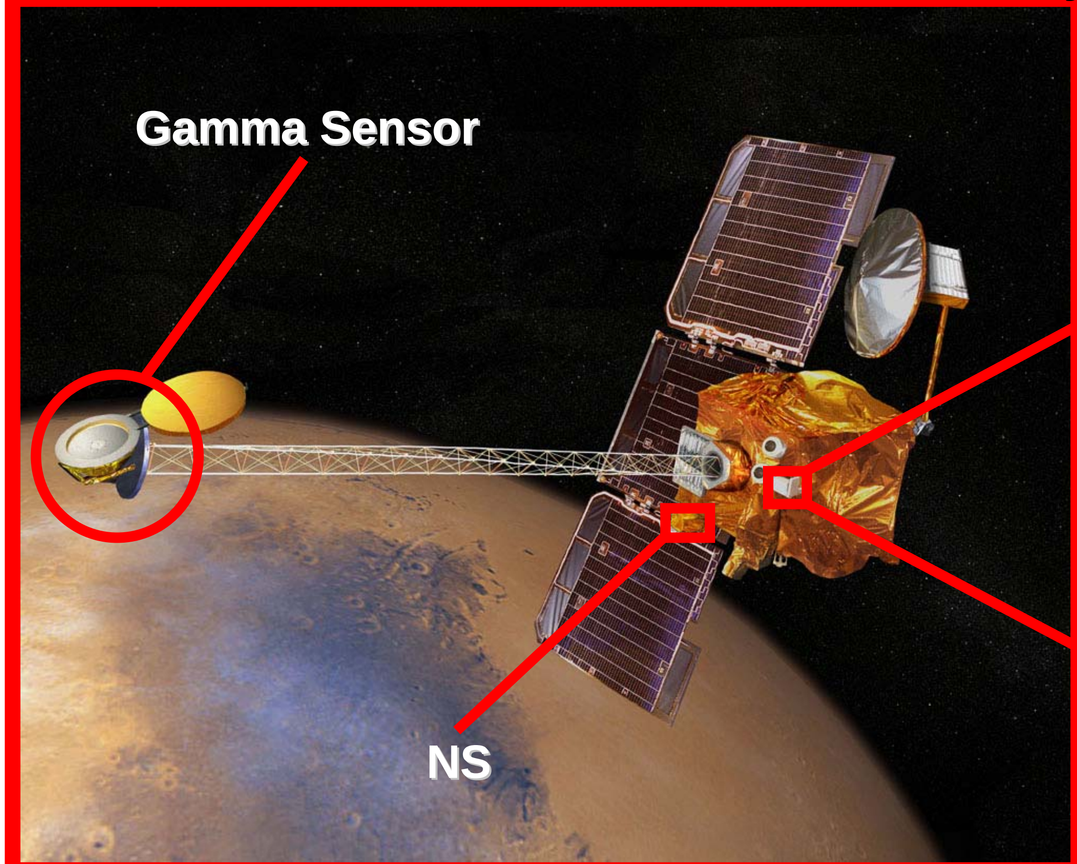
The purpose of this talk is to show availability of HEND/ Mars-Odyssey using for study of some problems of space weather and solar flare physics.

Mars-Odyssey – launched in April 2001,

around Mars –from 23.10.2001 to July, 2011

2001 Mars Odyssey

Gamma-Ray Spectrometer (GRS)



High Energy Neutron Detector - HEND

Dr. Igor Mitrofanov,
Sp Res Ins RAS
Principal Investigator of this experiment.

HEND (Mars-Odyssey 2001) for solar flares

main characteristics:

- Two detectors
- Energy range: photons from 30 keV to 2,5 MeV

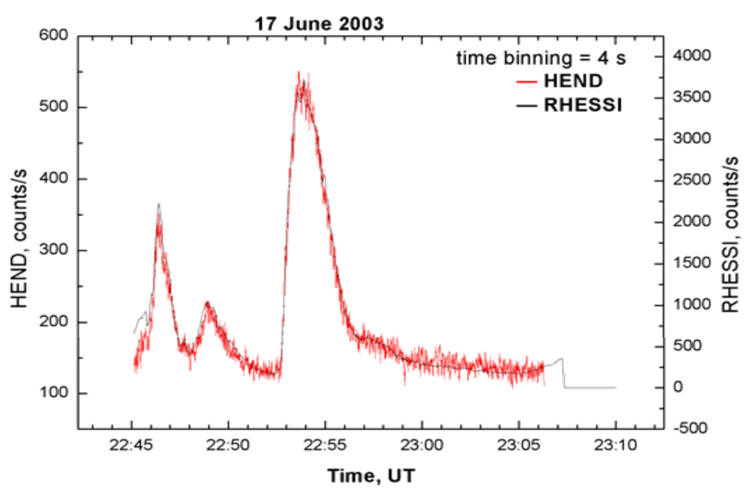
- Temporal resolution:
- Profiles: X-ray   0.25 s (>80 keV);
  Gamma-ray - 1 s (>330 keV).

- Spectra --20 s (for spectra both in X- and Gamma ranges)

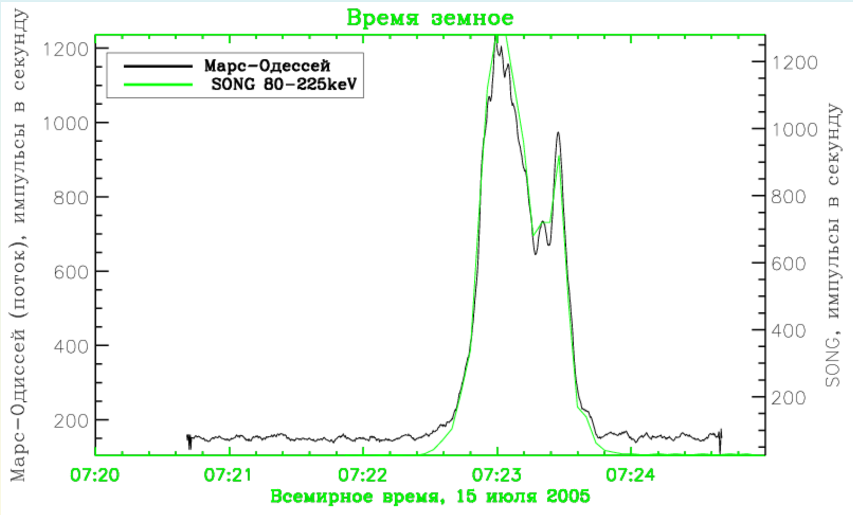
The Flare Catalogue

- *I.G. Mitrofanov , M.A. Livshits, V. I.Vybornov, D.V. Golovin, A.S. Kozyrev, M.L. Litvak, A.B. Sanin ,V.I. Tret'yakov , W. Boynton , D. Hamara*

Results for about 50 events – 2001-2011



Profiles by HEND and RHESSI (65 – 75 keV)



7:20 – 7:25 UT   14.07.2005

Profiles by HEND and CORONAS F

What the HEND data can help in study of the space weather ?

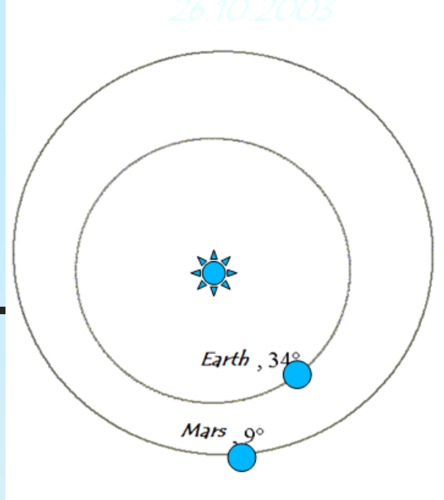
* Filling the gaps of RHESSI data, observations of flares from M3 to the largest events

** Mars Odyssey: rise and onset of the hard X-ray sources of flare active region

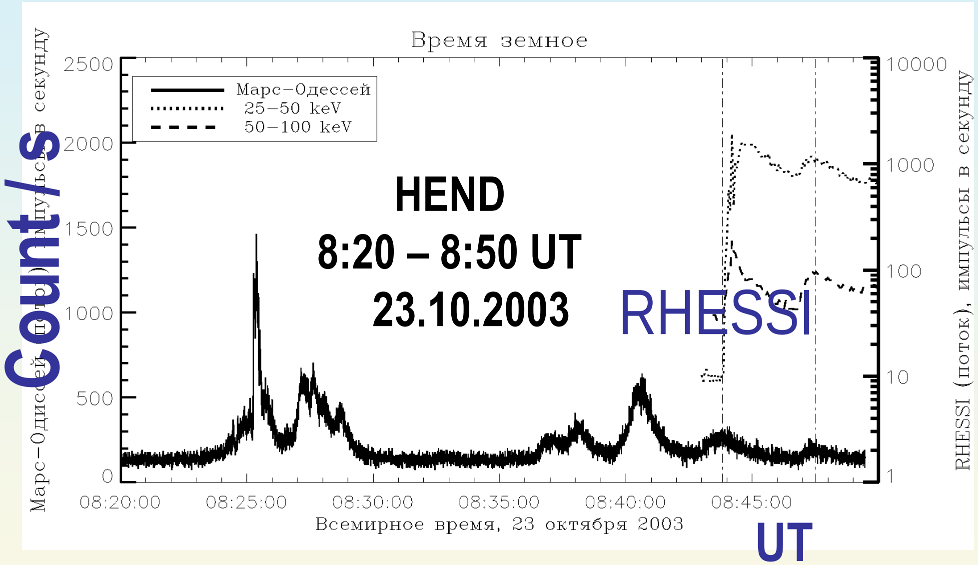
*** Mars Odyssey/HEND and RHESSI observations of solar flares that occurred on the back side of the Sun

**** Space Weather: Use the Mars-Odyssey data for forecast of space weather during 2003 and 2005

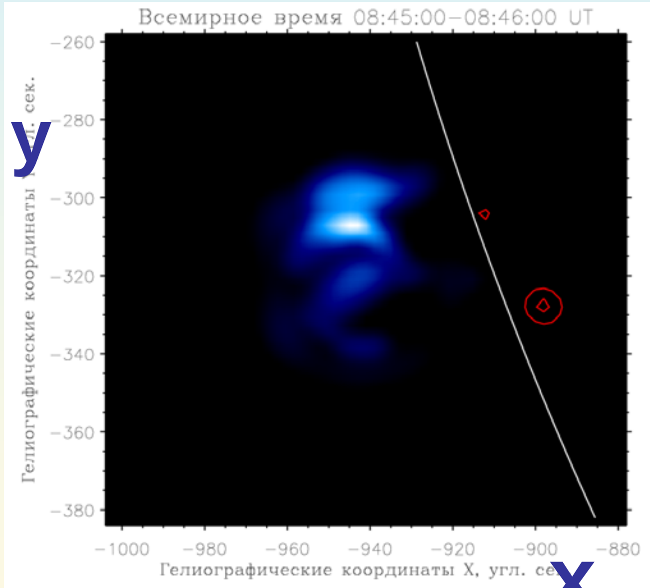
Filling the gaps of RHESSI data



2001,2003
2002,2004
....



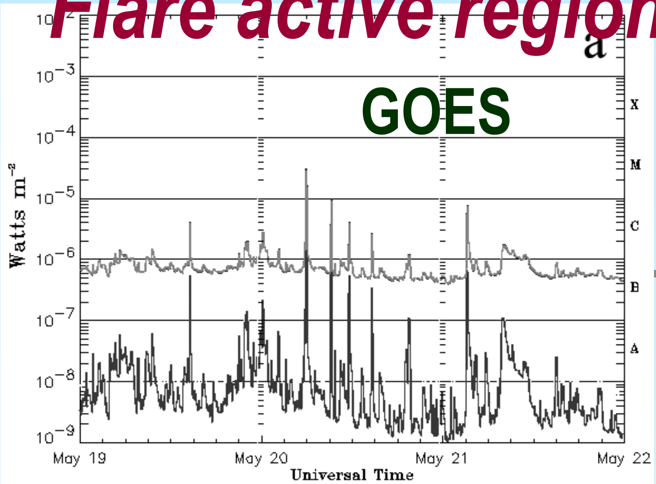
RHESSI-image
12-25 кэВ, 50-100 кэВ
8:45 – 8:46 UT

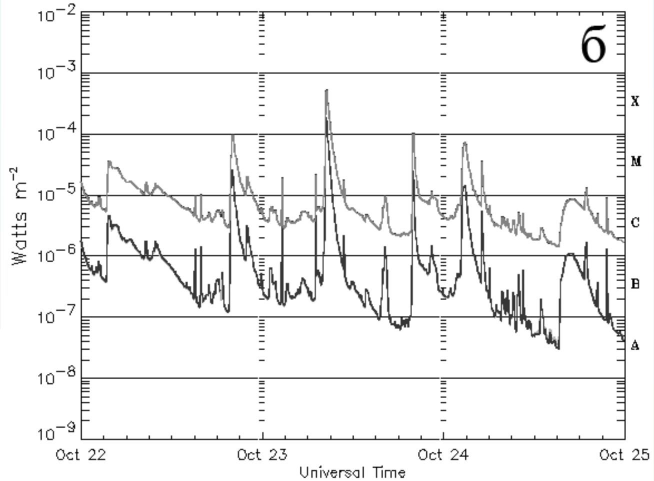


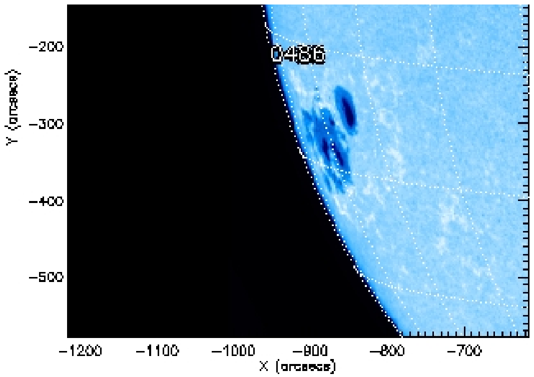
Profiles by HEND (60 – 260 keV)
and RHESSI (12 – 25 keV, 50 – 100 keV)

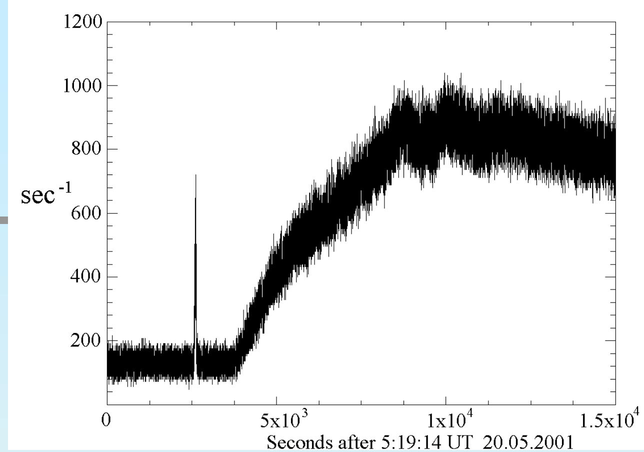
L. Kashapova & M. Livshits, Astronomy Reports, 52, 1015-1026, 2008

Flare active regions: motion behind the W-limb and rise

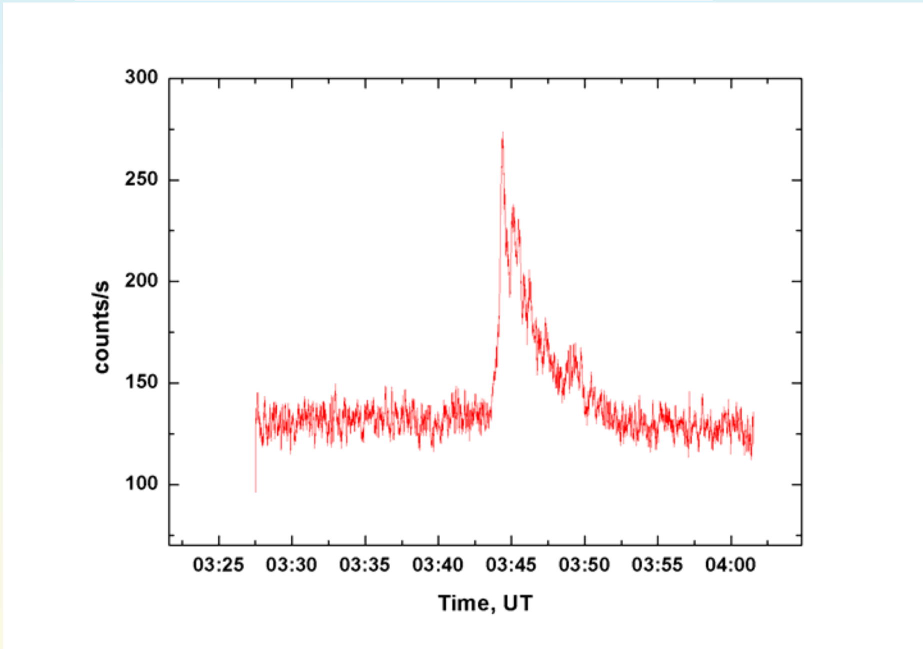








20.05.2001



AR 10468: rise

HEND, 60-260 keV, 4s

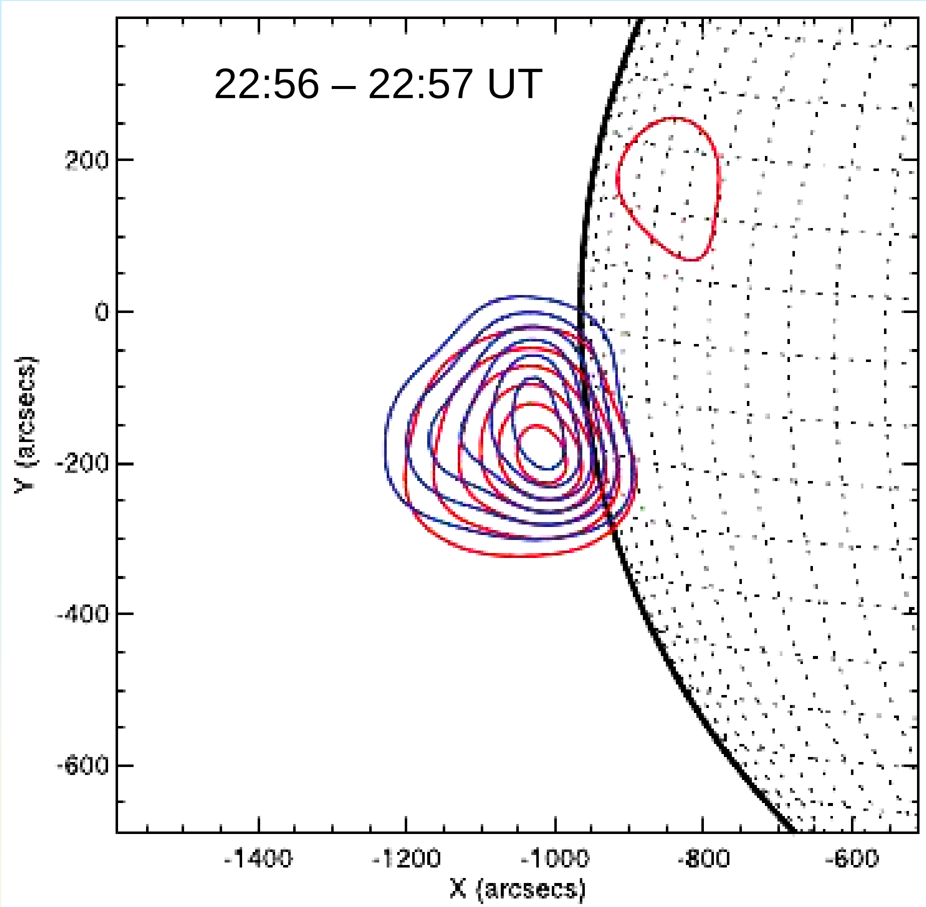
2003, October 21, 3:45 UT

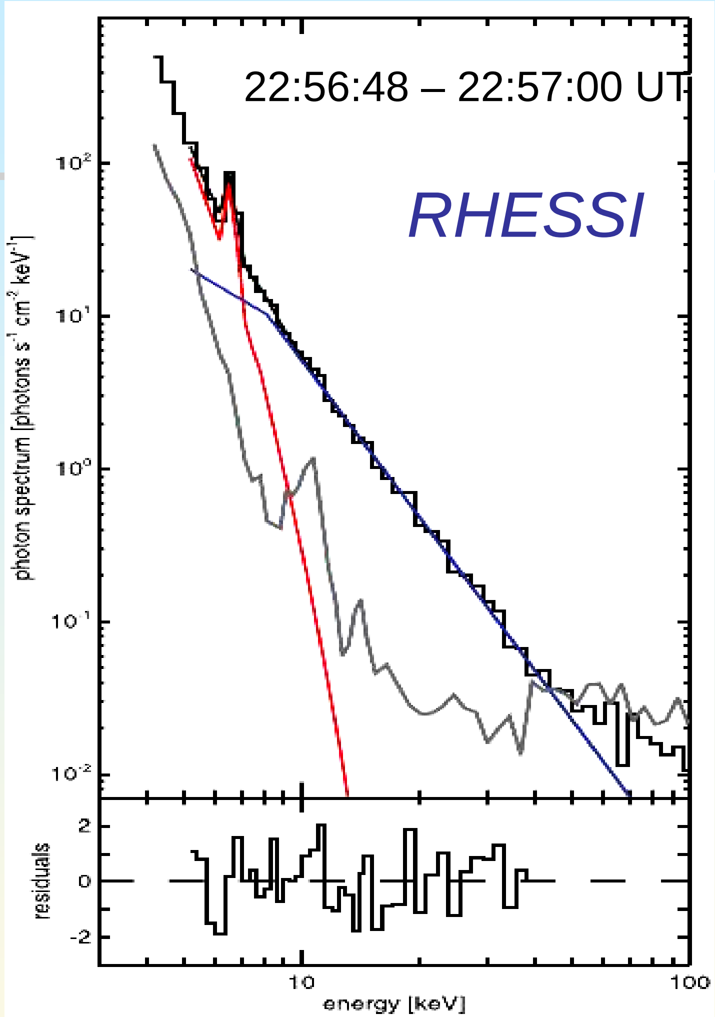
The Hard X-Ray Emissions from Partially Occulted Solar Flares

- *The hard X-ray source - at the footpoints of a loop*
- *The softer X-ray source (typically up to 50 keV) locates near to the top of the loop at the height about 30 000 km*
- *On the base of the RHESSI data this problem is studied in details in "HARD X-RAY EMISSIONS FROM PARTIALLY OCCULTED SOLAR FLARES"*

  Sa¨m Krucker and R. P. Lin Ap J, 673: 1181,2008
- *Mars-Odyssey data allow us to observe sources during more prolonged time and get more exact the flux ratio in X-ray sources near the top and footpoints of loops.*

Flares on the overside of the Sun -- Space Weather





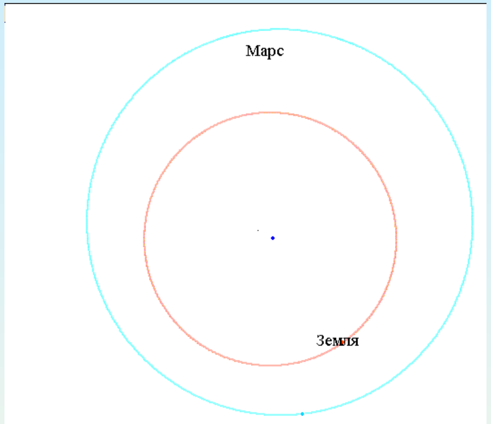
— 3-7 keV

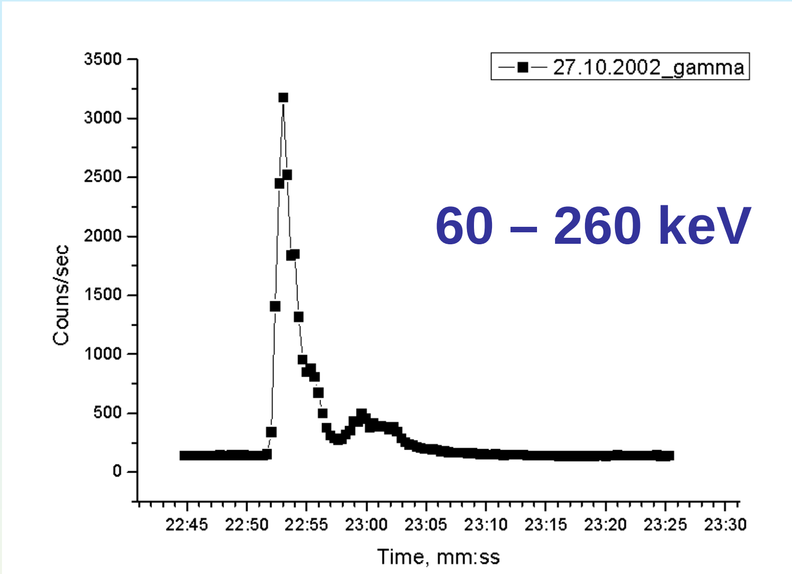
— 10-30 keV

SOLAR FLARE HARD X-RAY EMISSION FROM THE HIGH CORONA

Sa¨m Krucker, S. M. White, and R. P. Lin , ApJL, 669: L49–L52, 2007

Flares on the overside of the Sun – 27.10.2002 Mars-Odyssey



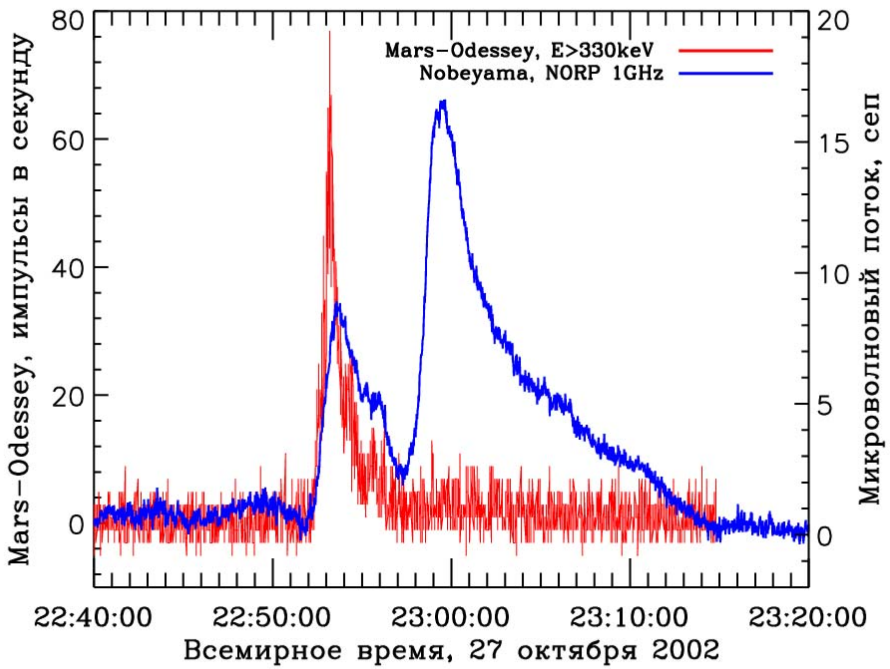


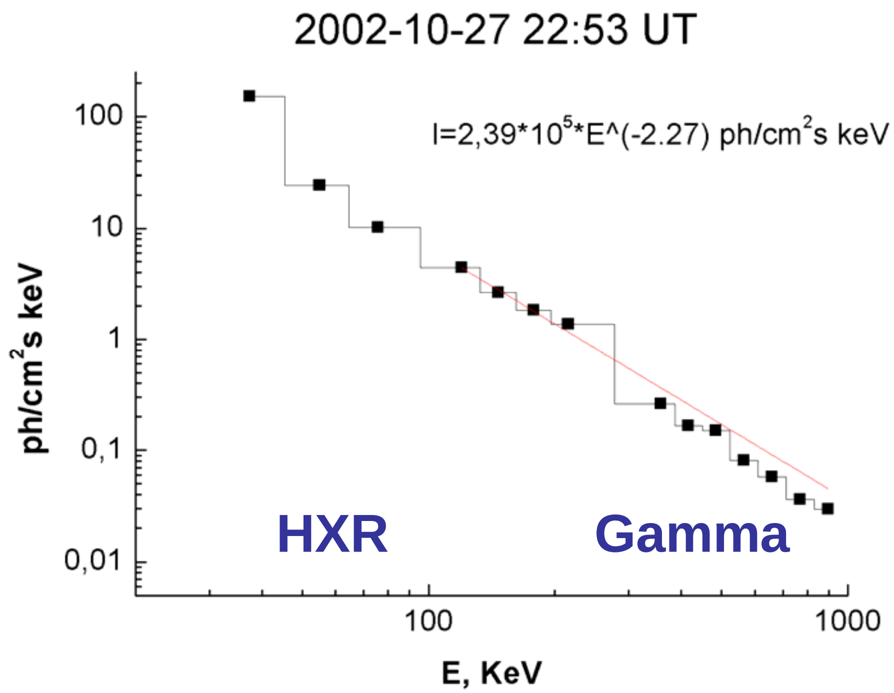
27.10.2002

The flare is at 45 degrees behind the E-limb for a terrestrial observer;
This flare happened on the disc nearby the W-limb
for a Martian observer (HEND)

- **2253 //// 2312 CUL C RSP 18-110 III/3**
- **2234 2234 2234 LEA U RBR 245 70**
- **2255 2255 2255 LEA U RBR 245 200**
- **2259 //// 2310 COM C RSP 30-80 II/3**

Gamma-burst at 30–1000 keV



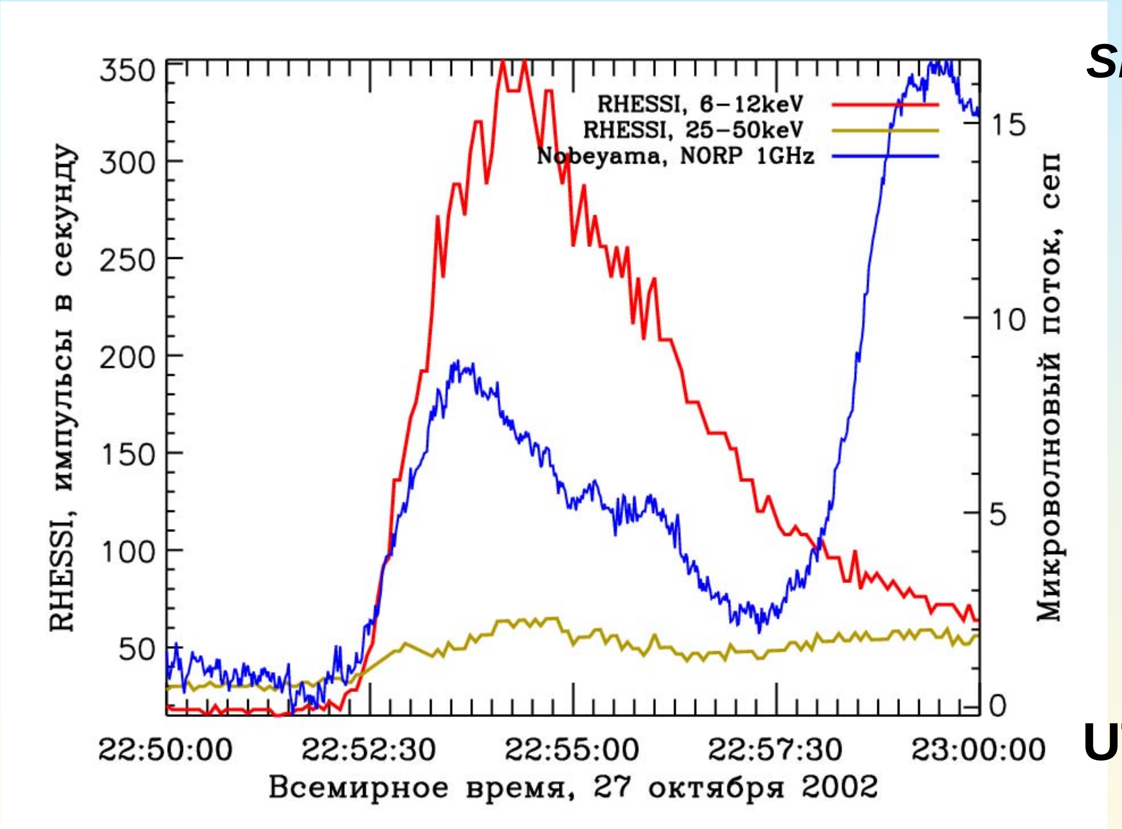


$I(h\nu) = 2.4 \cdot 10^{5} (h\nu)^{-2.27}$ photons cm^{-2} s^{-1} keV^{-1},

The energy in keV at 100-1000 keV, the flux is recalculated to the distance from the Sun to the Earth

This is one of the most powerful flares in the 23 cycle !

The first source of the X-ray and radio emission



SEP

UT

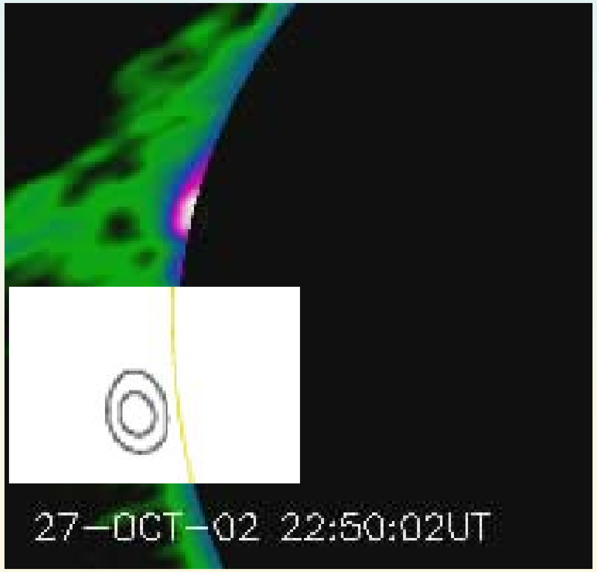
RHESSI
27.10.2002

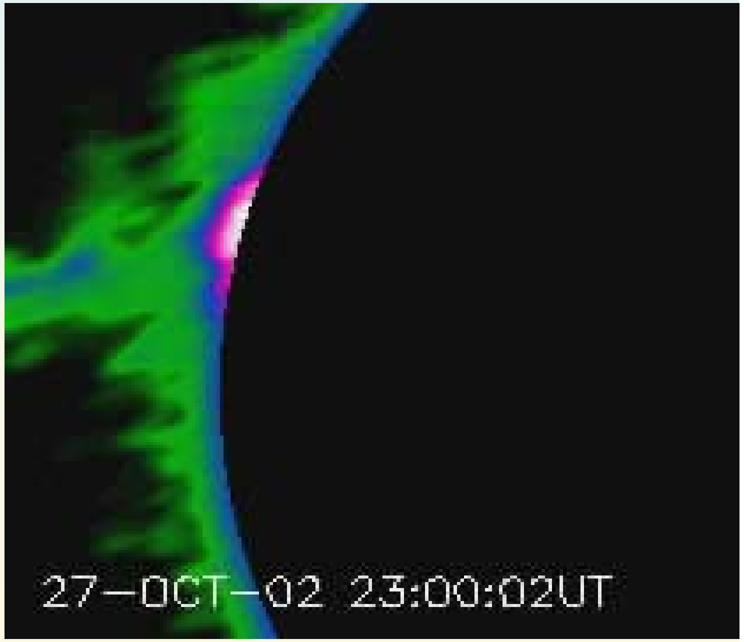
The second source ?

Nobeyama, Radio Heliograms (17 GHz)

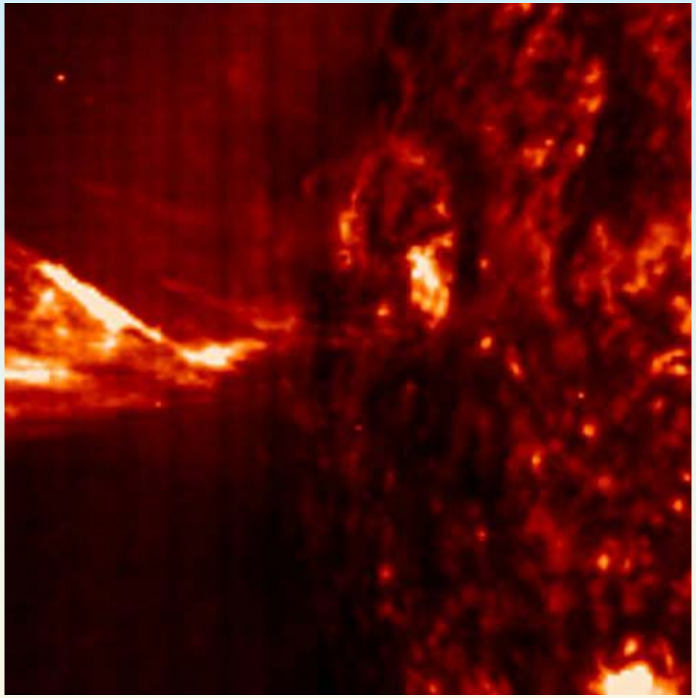
Event_ID	Date	Start (UT)	Peak (UT)	END (UT)	X (arcsec)	Y (arcsec)
PE20021027_2320 |	27-Oct-02	22:50:02	23:20:02	23:40:02	-1194	114

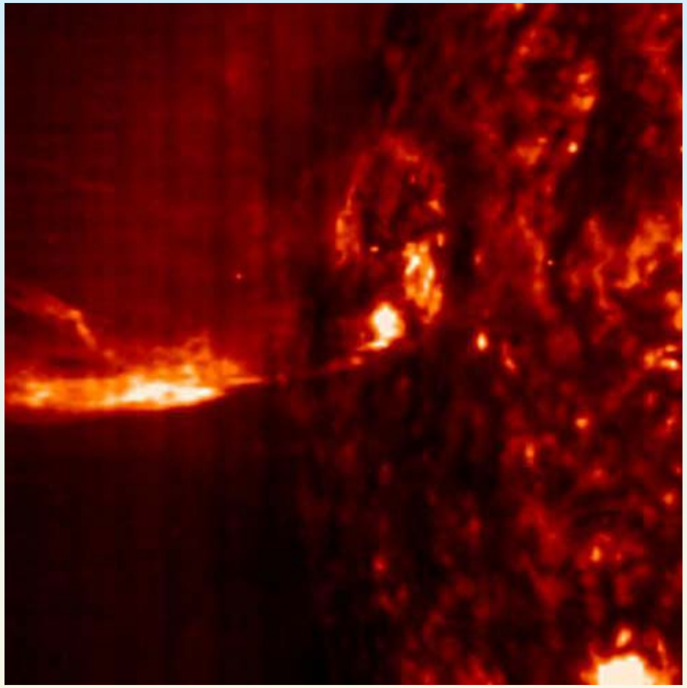
6-12 keV





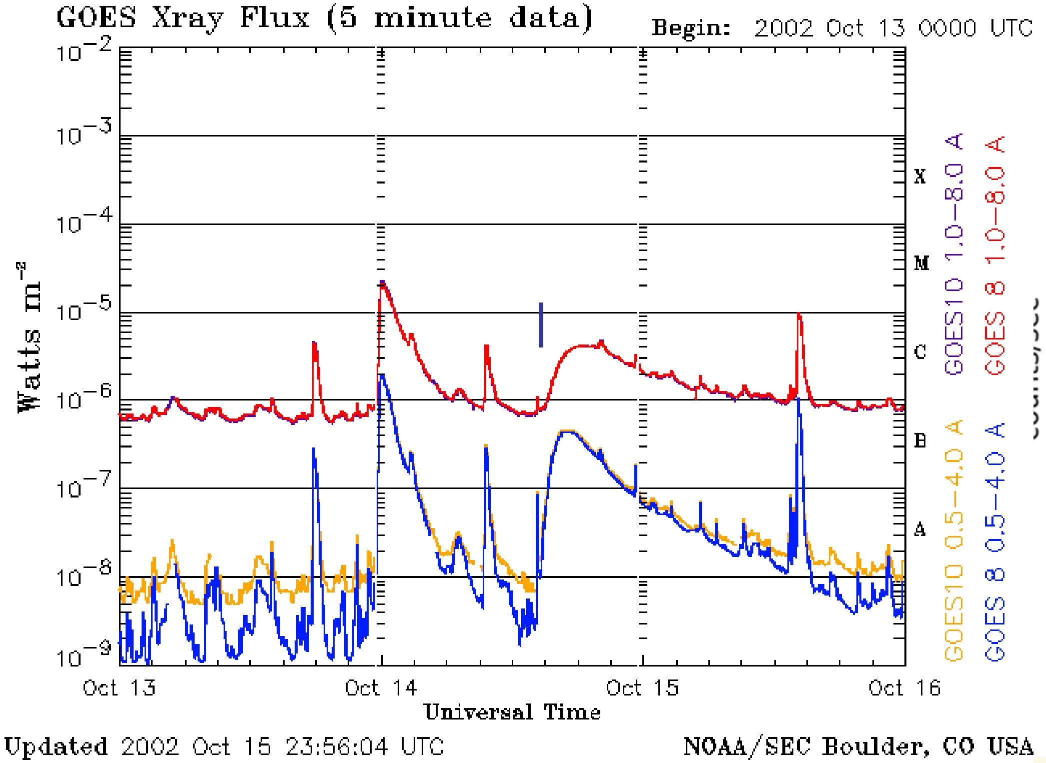
The second source ?

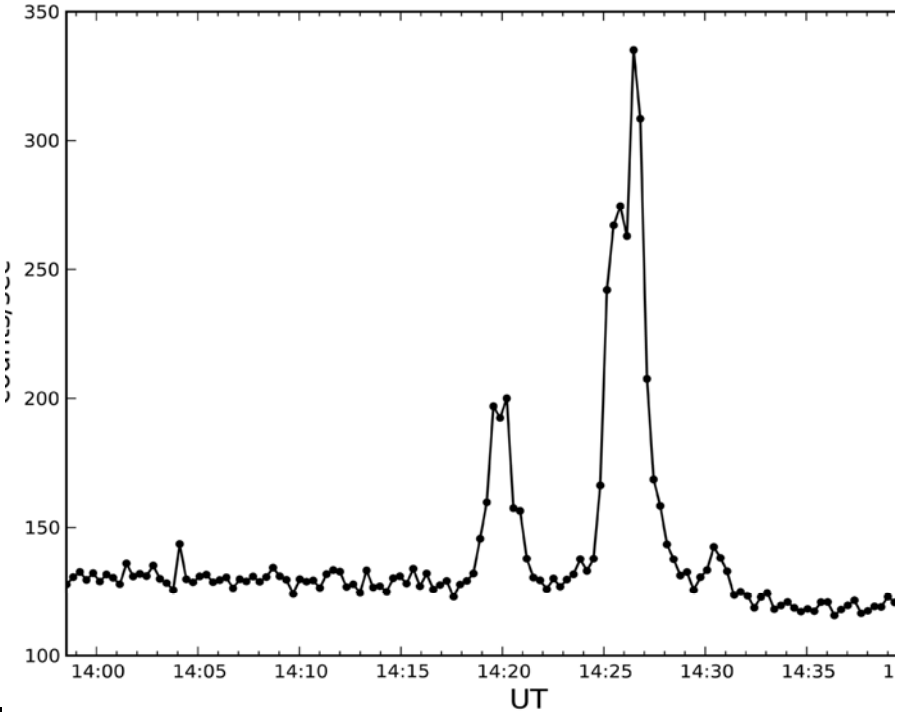




23:11:59 UT …304 A EIT/SoHO… 23:23:59 UT

The Flare on 14.10.2002

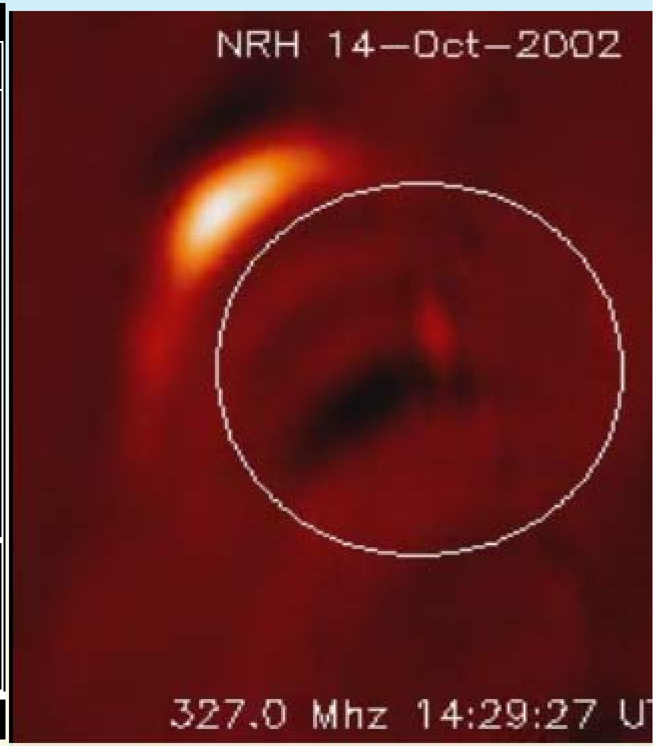




2030 + 1419 1423 1426 GO8 5 XRA 1-8A C1.3 4.7E-04

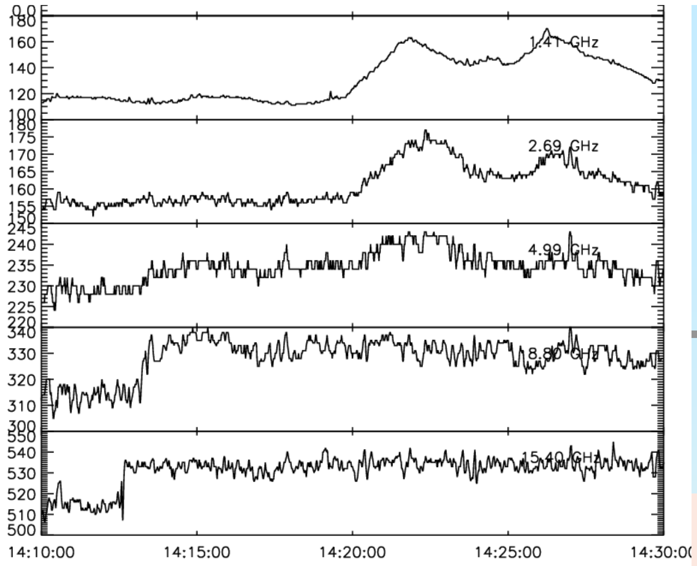
30 - 40 degrees behind the E-limb AR 10162

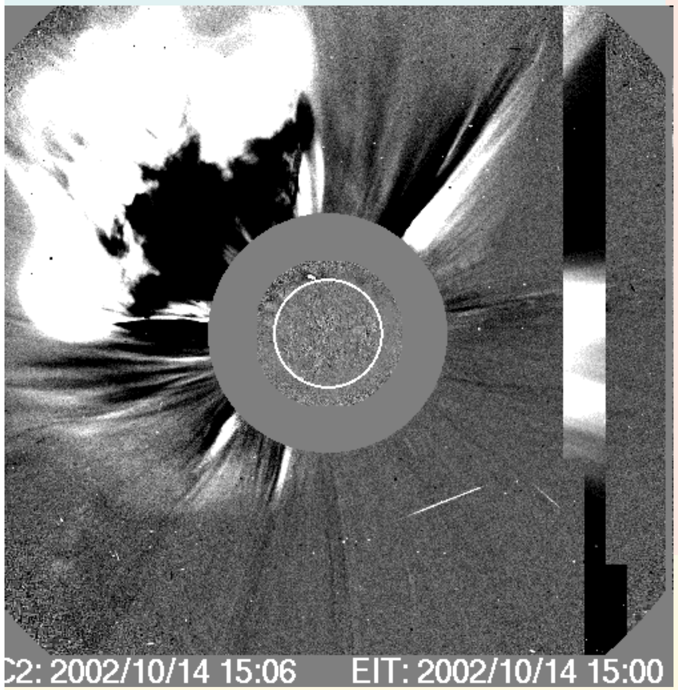
14.10.2002 – the second source

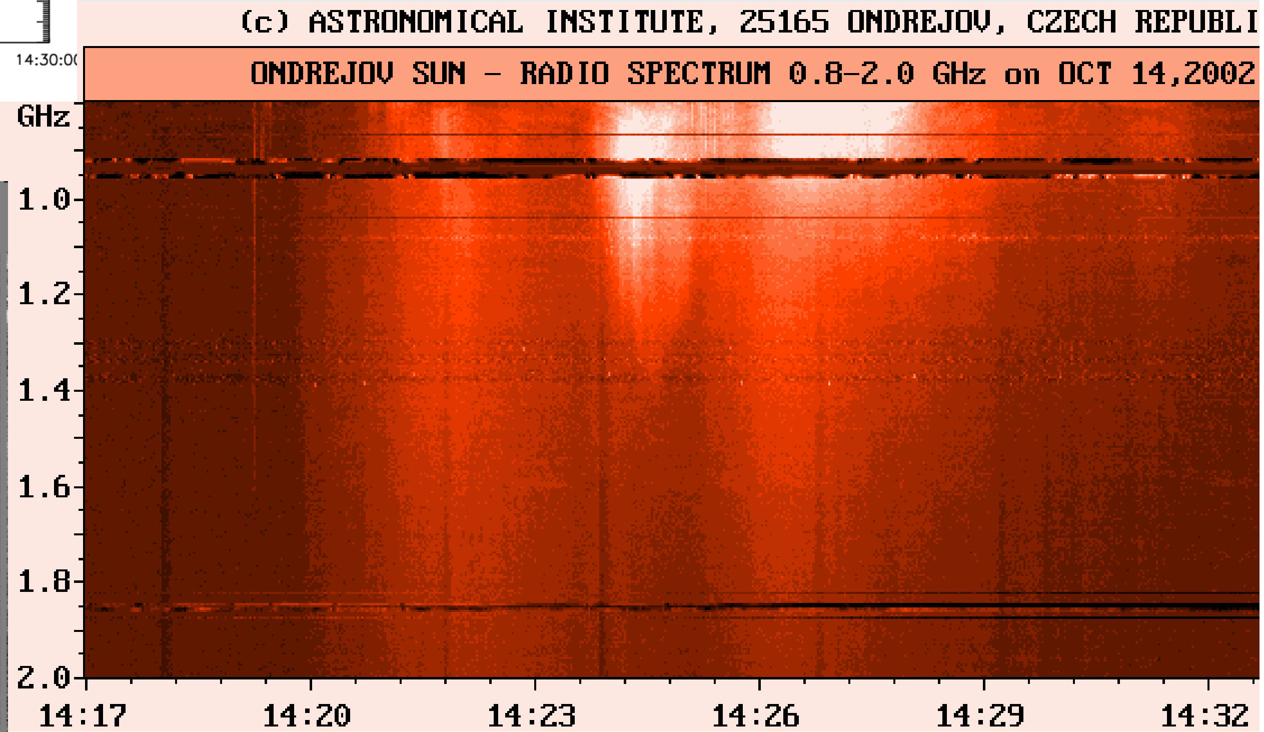


The origin of the second source

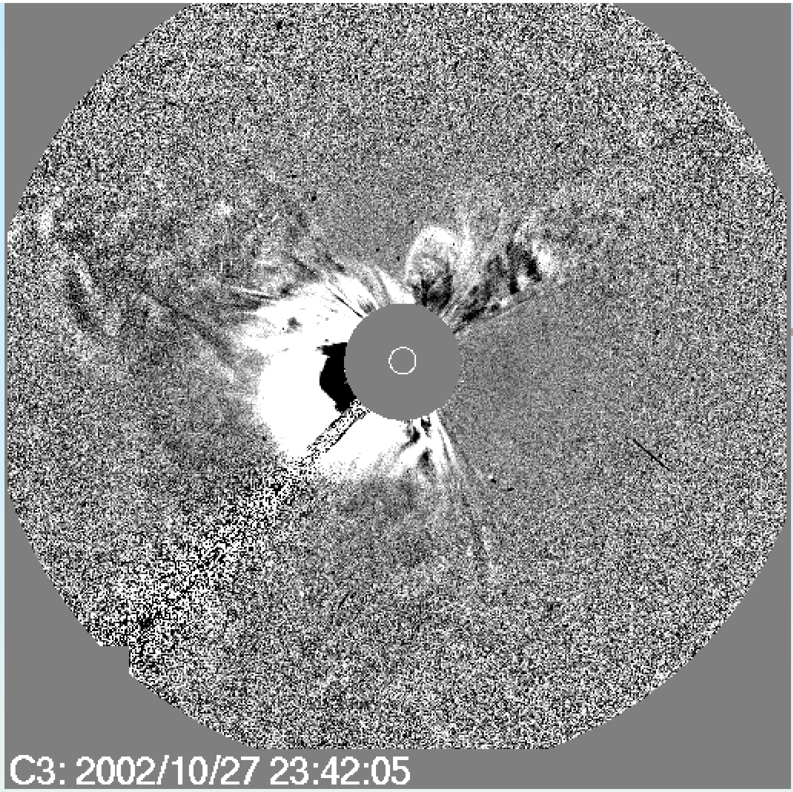
14.10.2002

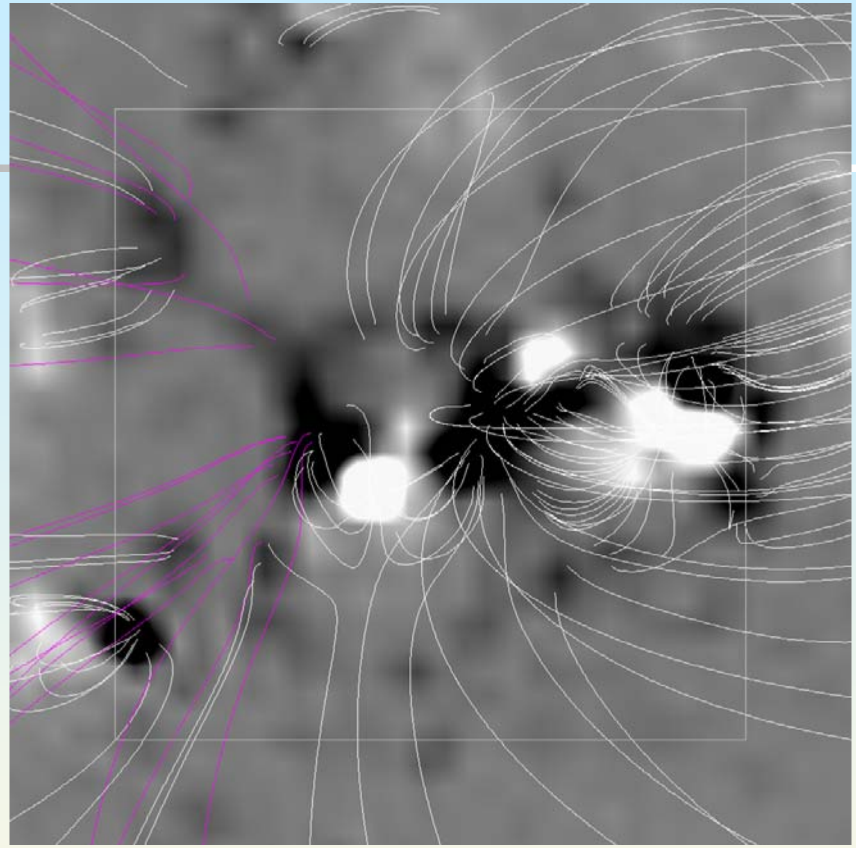


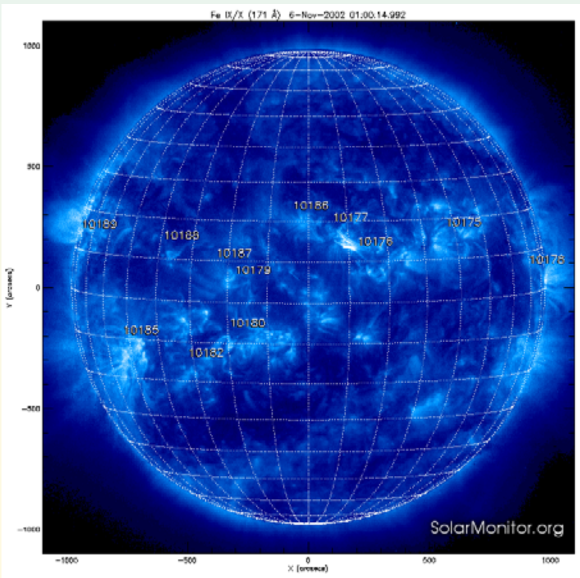




On the physics of phenomena







Potential magnetic field lines (MDI SoHO) +

Shape of loops from TRACE 171 A data on 06.11.2002 in AR 10180

Number of accelerated electrons in the source
Diffusion of accelerated particles

I (*hv*) = Io (*hv*) $^{-\delta}$ photons cm $^{-2}$ s $^{-1}$ keV $^{-1}$,

where Io *and δ depend on the time*

The accelerated electron flux is determined from the HEND data in frameworks of the thick target model while

from the RHESSI spectra on the base of the thin target model at the plasma density in the plane of the sky n= 10^9 cm^-3.

The ration of these fluxes in situ and in the top of the large-scale loop is from 10 to 100 in various events

Conclusion 1

- *The terrestrial observer can register two sources of the X-rays and radio emission that arise sequentially after powerful flares on the back side of the Sun.*
- *The first source is associated with arrival of fluxes of accelerated electrons captured in the large-scale magnetic loop to the plane of the sky. The electron beams with energies of tens of keV propagate fast in the low corona up to distances comparable with R_sun. During this process the particle flux becomes much weaker and their spectrum is significantly softer. Estimate show that scattering of electrons on inhomogeneities of the magnetic fields effects on the evolution of characteristics of the beam.*
- *The second source is associated with appearance of the plasma of the gas-dynamic disturbance (MHD wave) above the limb.*

Development of statistic methods

Chertok et al.

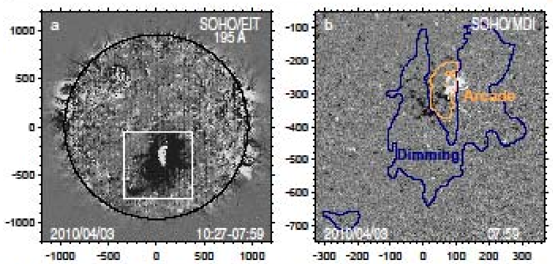


Figure 2. The 2010/04/03 eruption shown by the SOHO data: (a) the dimmings and arcade in the EIT 195 Å fixed-base difference image; (b) an enlarged part of the MDI magnetogram corresponding to a framed region in panel (a) with superposed dimming and arcade contours, determined by the quantitative criteria, described in the text.

Chertok et al.

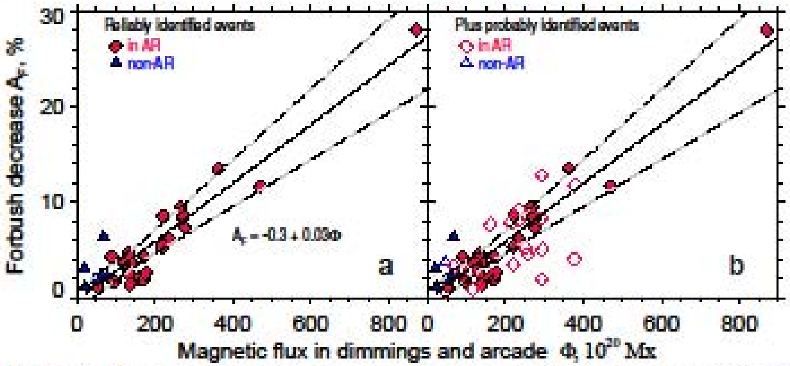


Figure 3. Dependence of the FD magnitude A_F on the summarized unsigned magnetic flux in dimmings and arcades Φ: a) for single geospace disturbances reliably identified with concrete solar eruptions (filled symbols); b) for all considered events including single and compound events with a probable solar source identification (open symbols). Here and afterwards the red diamonds denote eruptions in ARs, and blue triangles denote eruptions of quiescent filaments outside ARs. The dashed lines delimit the accepted deviation band.

EUV/magnetic Diagnostics of Solar Eruptions

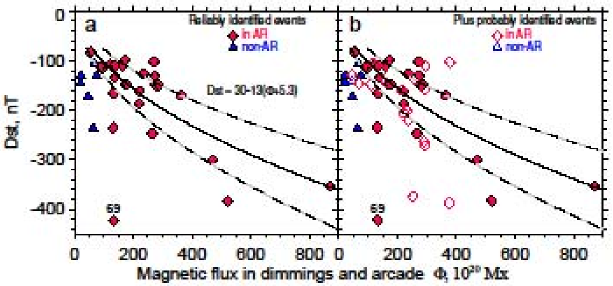
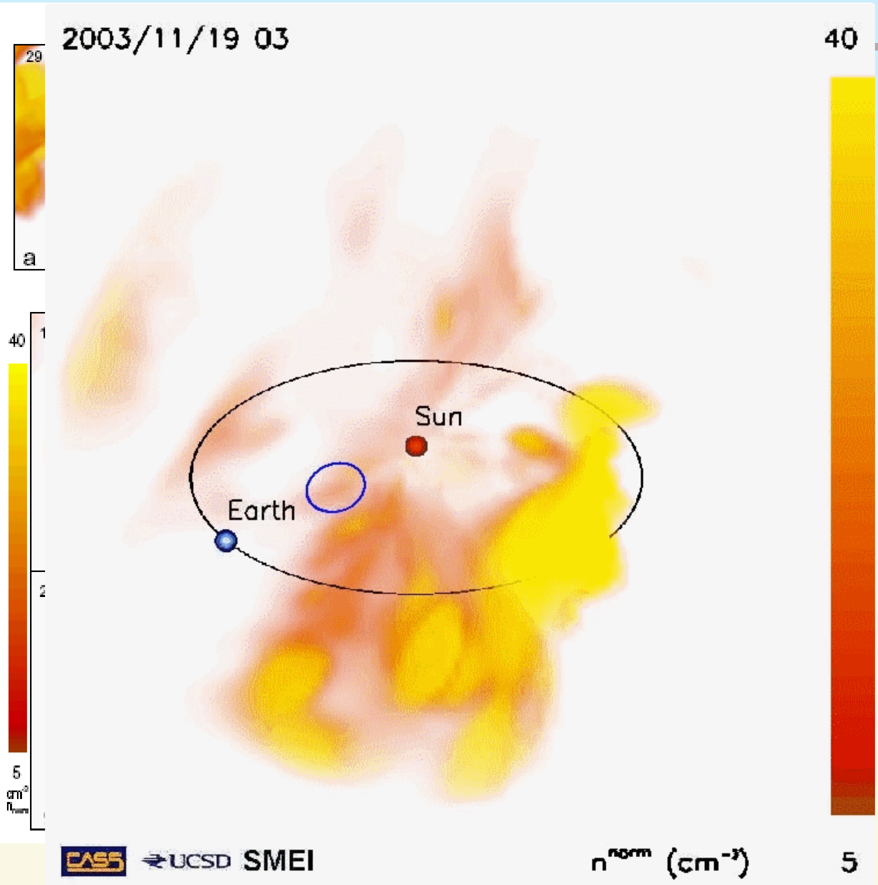


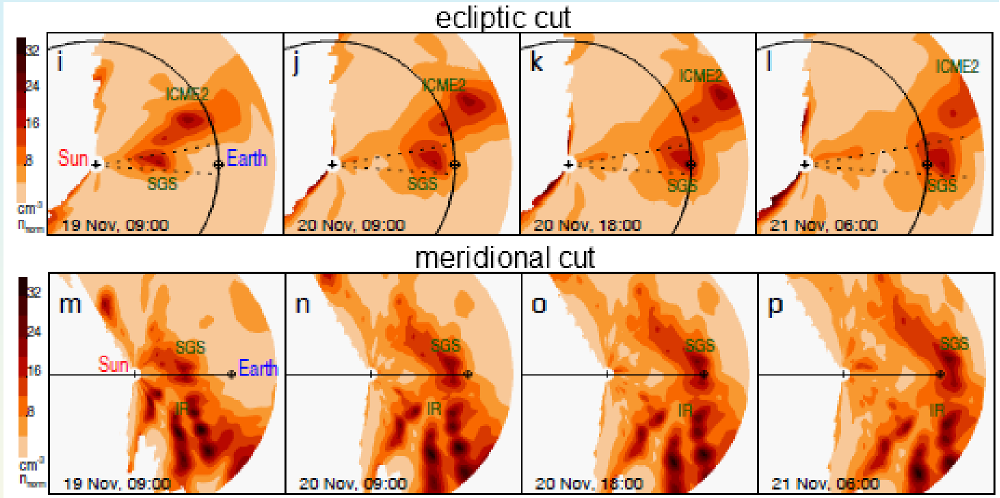
Figure 4. The same as in Figure 3 but for the dependence of the geomagnetic storm intensity (*Dst* index) on the eruptive magnetic flux Φ.

I.M. Chertok, V.V. Grechnev, A.V. Belov, A.A. Abunin "Magnetic Flux of EUV Arcade and Dimming Regions as a Relevant Parameter for Early Diagnostics of Solar Eruptions – Sources of Non-Recurrent Geomagnetic Storms and Forbush Decreases" Solar Phys. 2013

Combination of the strongest geomagnetic storm (Dst≈-422 нТл) with relatively small Forbush decreasing (≈4,7 %) 19-21.11.2003

Grechnev V., Chertok I., Uralov A., Belov A.
Filippov B., Slemzin V., Jackson B. ***2013, Sol. Phys.***

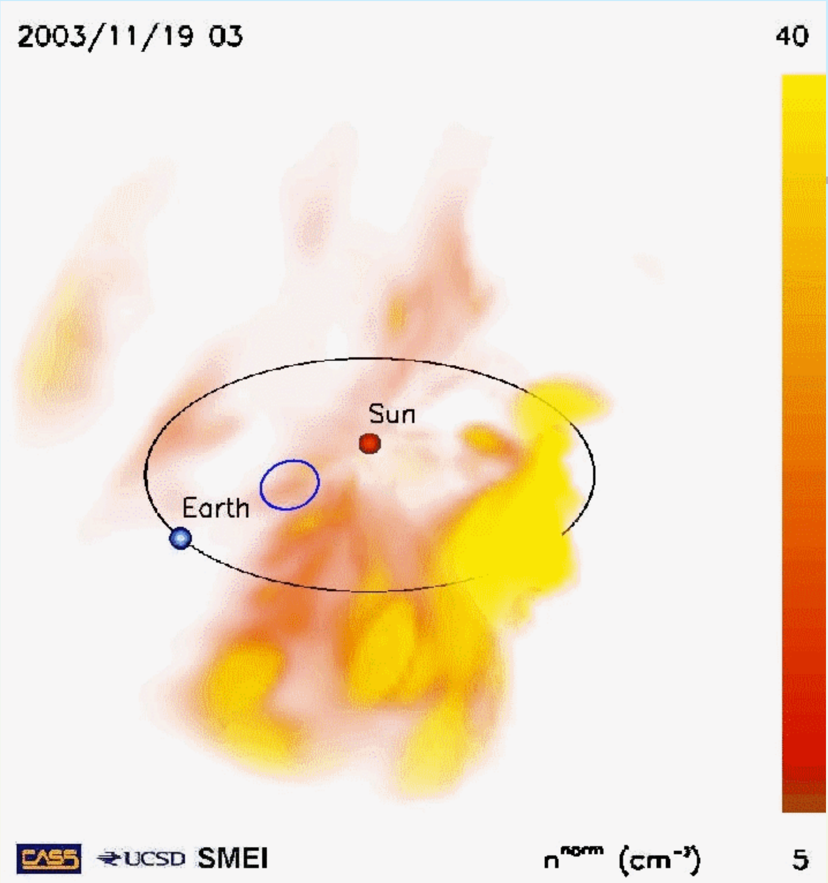




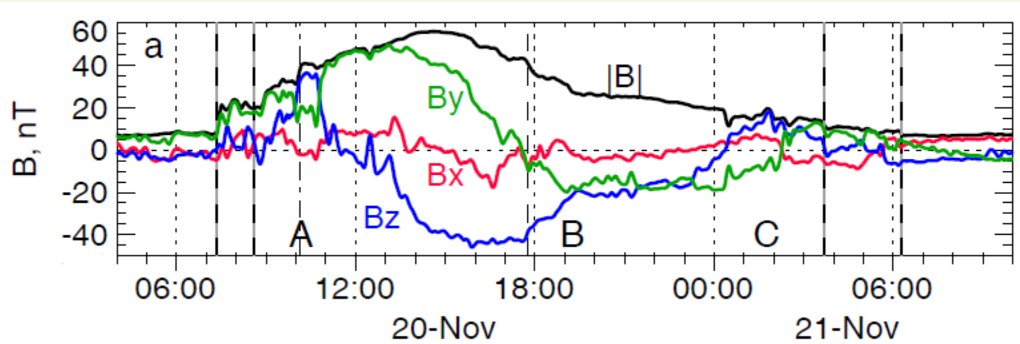
ICME1 and ICME2 were propagated toward the South from the ecliptic plane and could not to be a cause of the super storm

3D-reconstruction of the plasma density of ICMEs accordingly to Solar Mass Ejection Imager data ***(Jackson et al., 2004)***

Two additional favorable circumstances for appearance of the superstorm

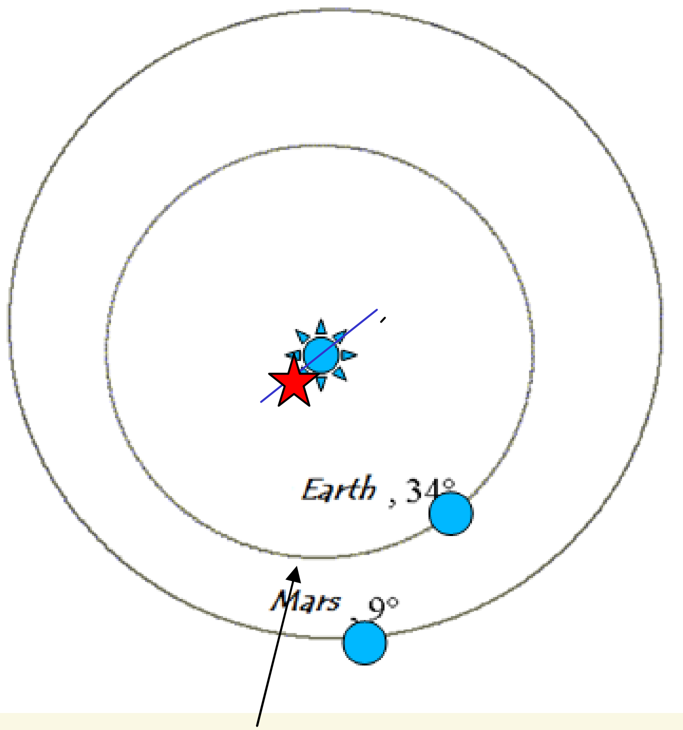


The middle of the magnetic cloud passes exactly to the magnetosphere of the Earth



The vector of the magnetic field in this cloud is oriented directly toward the South: the negative Bz~0,8×B

HEND (Mars-Odyssey)

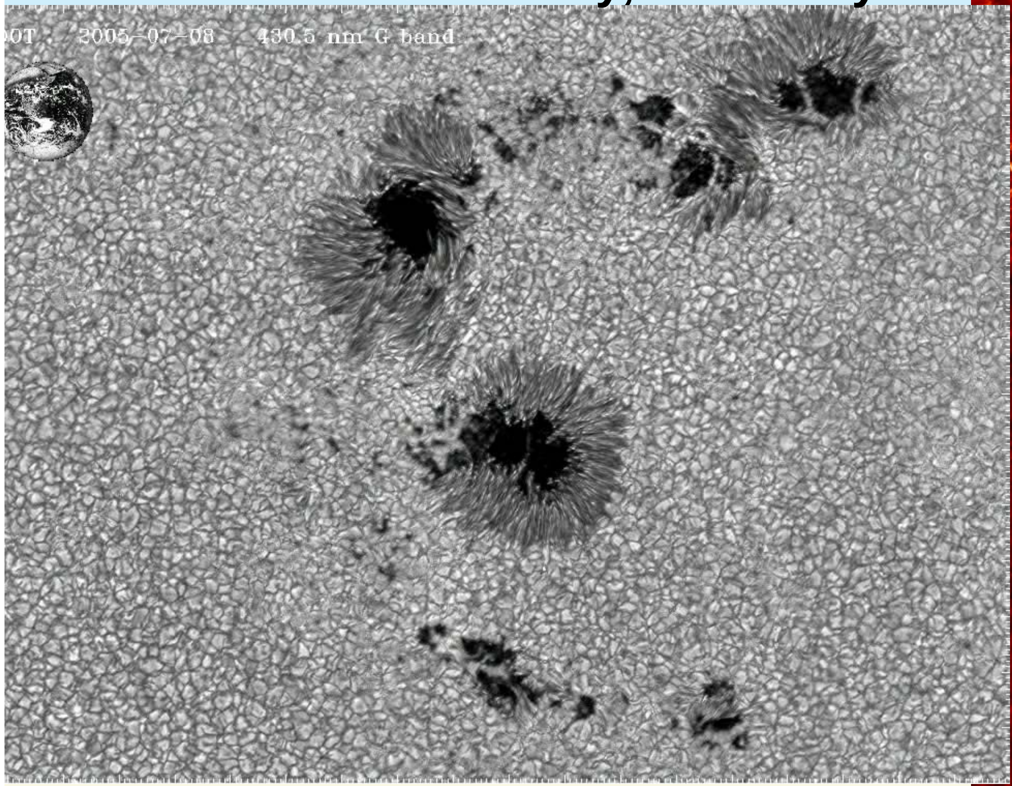


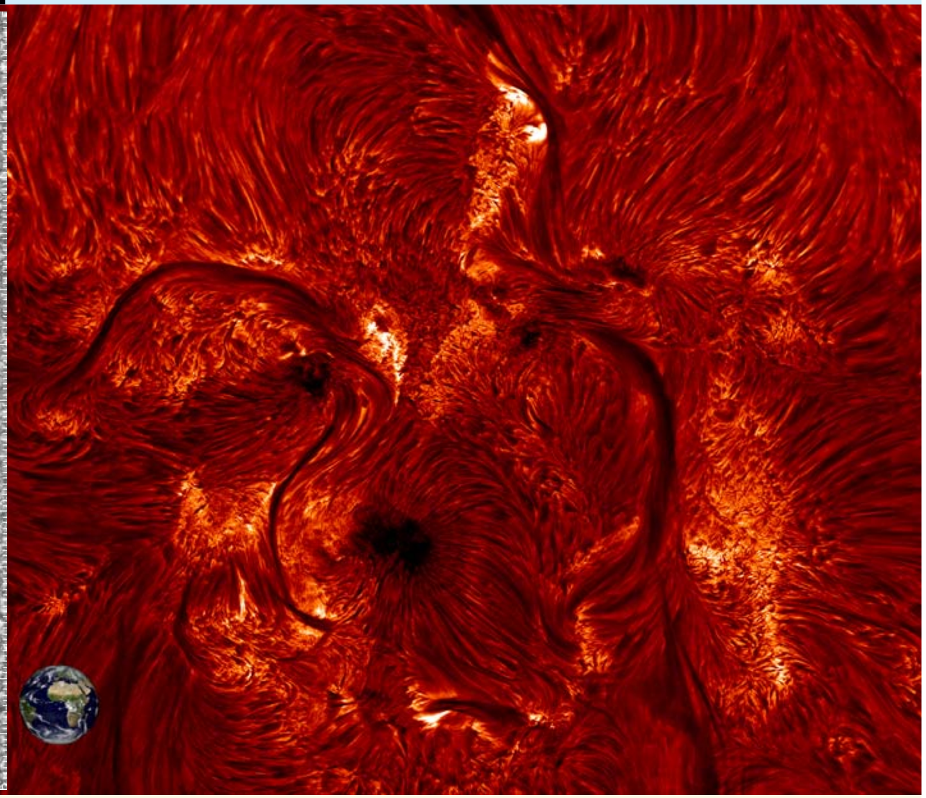
Mars
14 July 2005

Enhancement of activity AR 10786 on 5 – 14 July 2005

AR NOAA 10786
was at the west limb for the terrestrial observer on 14 July 2005.
Mars-Odyssey was 42 degrees eastern the Earth.
Thus, flares in this AR were observed by Mars-Odyssey as “on disk” flares.

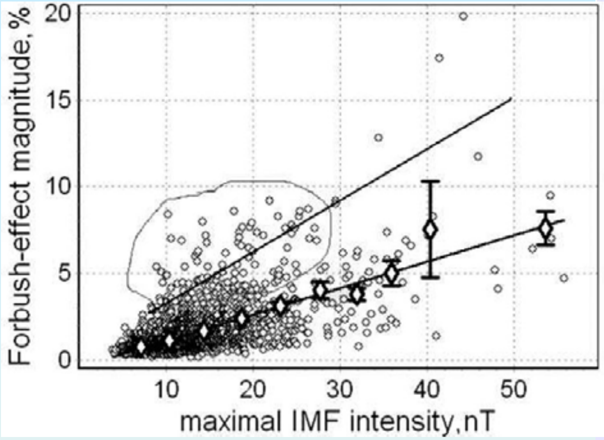
NOAA 10786 July,8 2005 by DOT





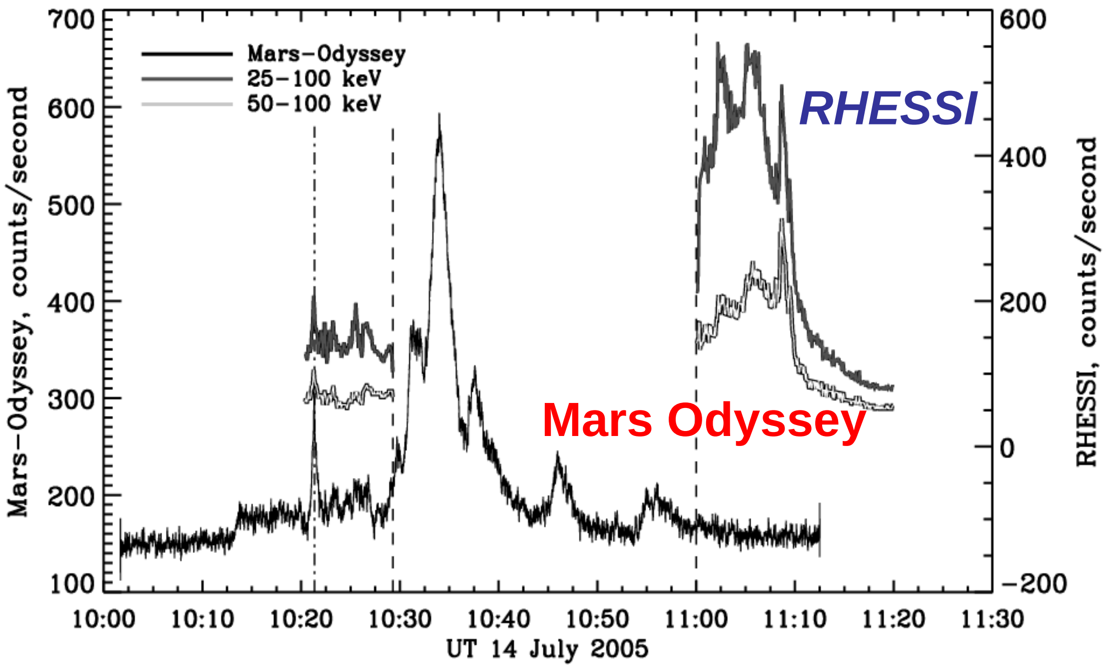
On July 14, 2005 this AR reached the west limb and produced two flares of class M9.1 and X1.2 with maxima of HXR bursts in 7:22 UT and 10:33 UT accordingly.

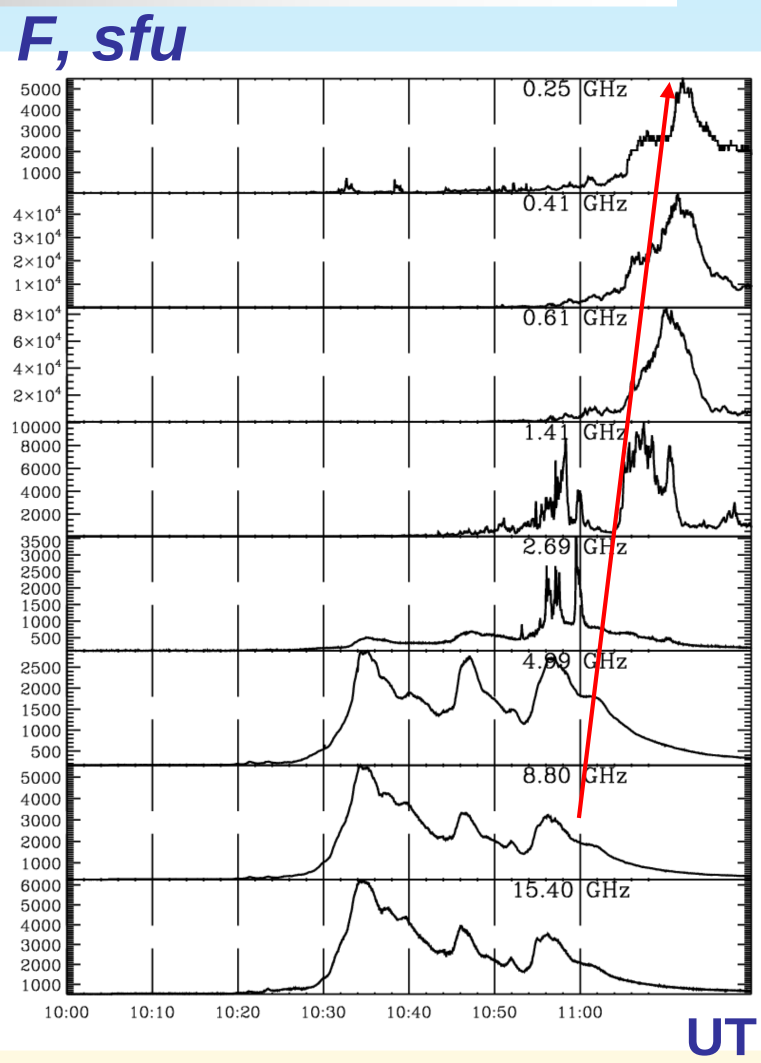
An Anomal Forbush decrease on 17.07.2005



Huge Forbush decrease arise on 17. July 2005 in the absence of a large disturbance in the near-Earth space: the solar wind velocity V=500 km/s and the magnetic field and its vertical component were less than 10 nT.

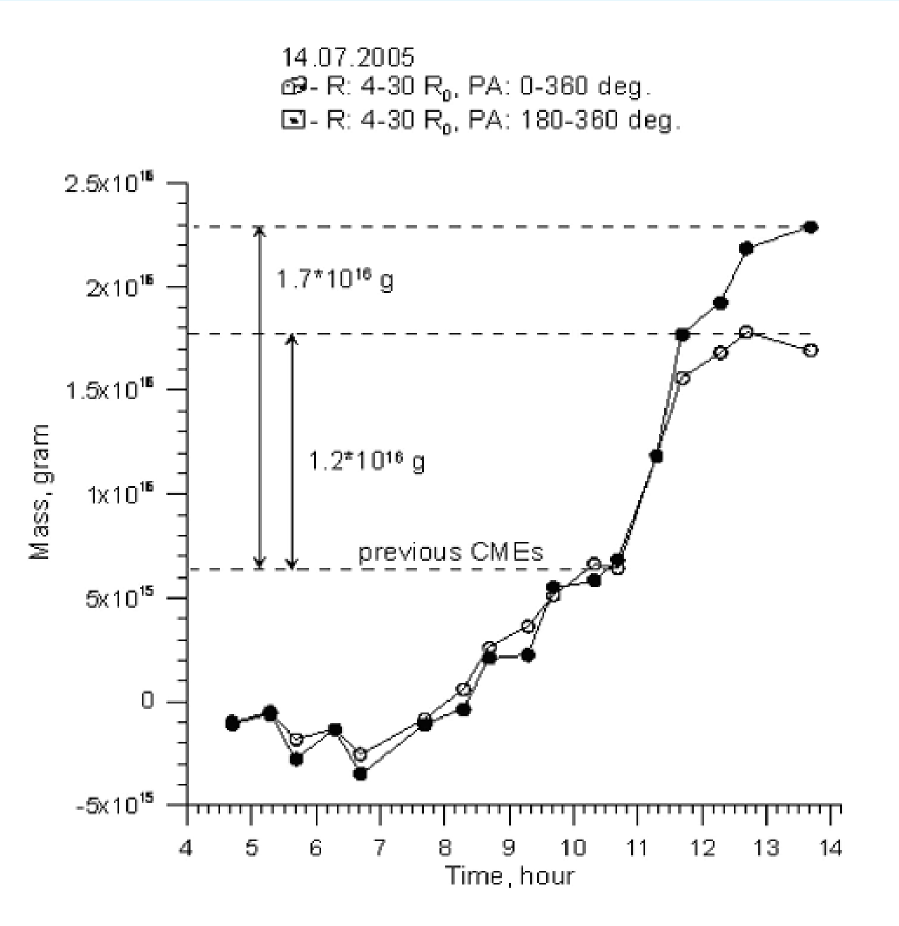
Features of the second flare on 14, July 2005



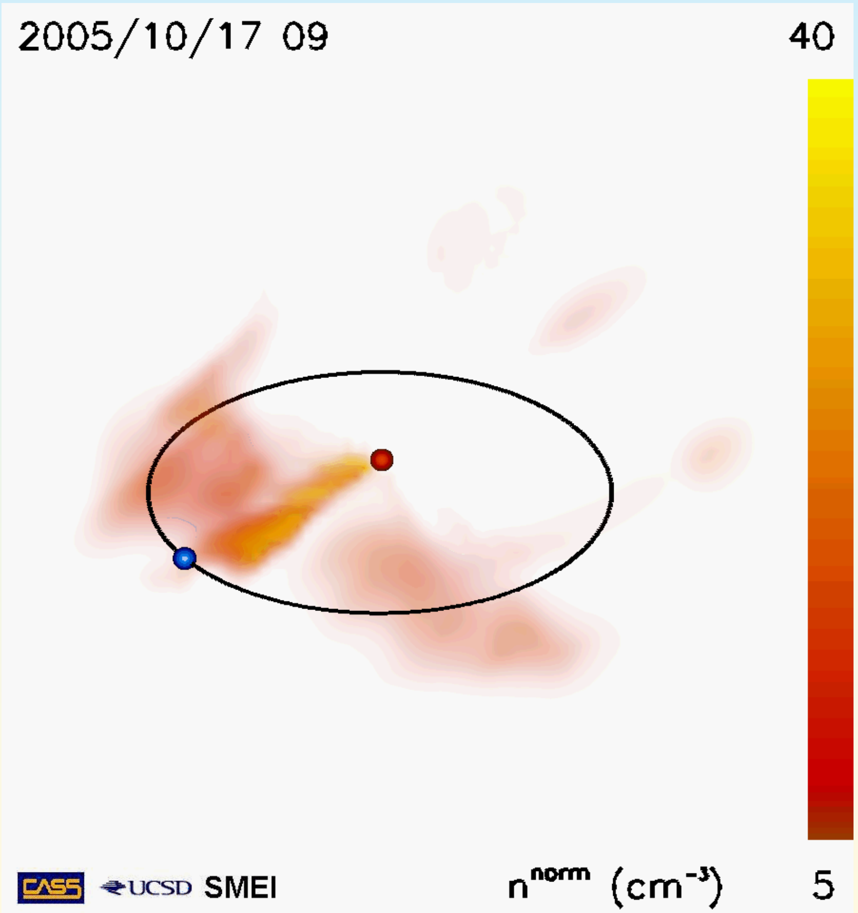


Two weak slow jets/CME arise on 10:13 and 10:36 UT Radio data allow us to conclude apparently that CME with V>2000 km/s (the radio burst of type II and the shock wave respectively) forms only in the end of the hard burst just after 11:04 UT.

Estimate of the mass ejection



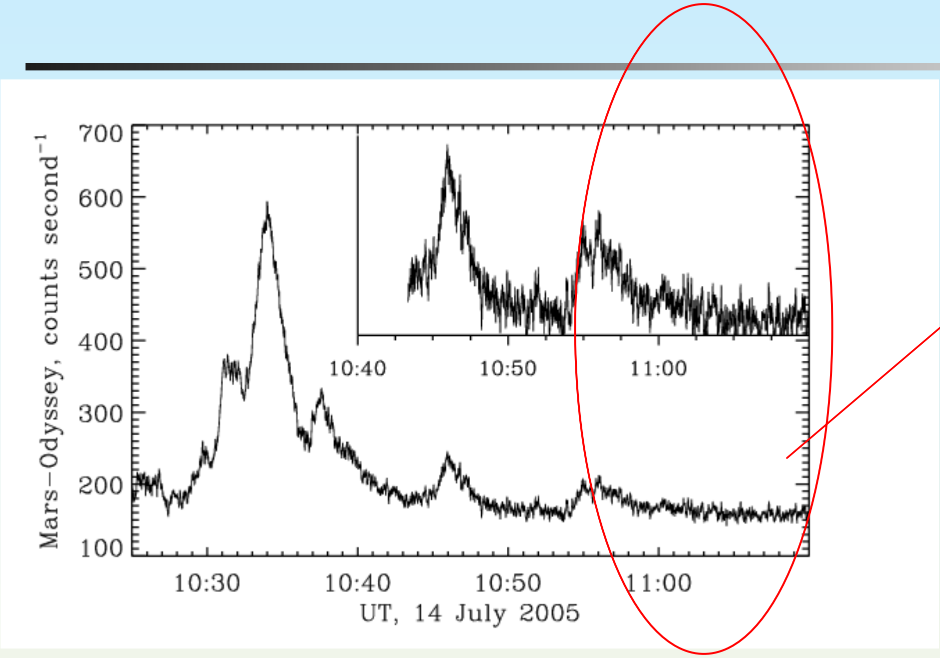
Solar Mass Ejection Imager - SME-imager

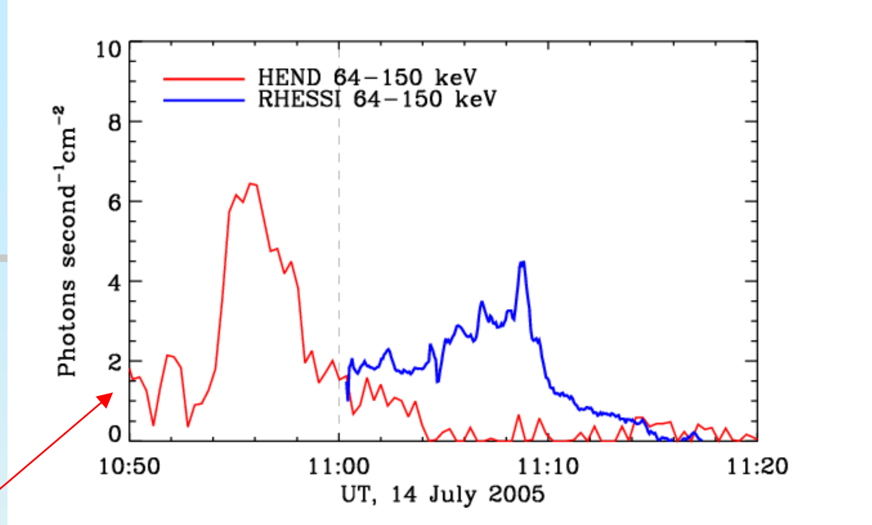


Conclusion 2

- *The flare on 14.05.2005 presents a rare kind of events. This type was named as **post-impulsive flare** and is an another way of development of the decay phase of flares, when post-eruptive loop system forms. Tnhis term was introduced by Demoulin et al. ApJ, 2012, **750**, 147.*
- *Unusual properties of CME are associated in this case with fast evolution of the current sheet located in the casp high in the corona. Note that namely this flare, the only one of 50 large flares observed with HEND, demonstrates directivity of the HXR.*

The second flare on 14th July 2005





On the late phase of the flare,
when HEND HXR intensity decays slowly,
a new peak of HXR emission is detected by RHESSI

General Conclusions

- ***How X-ray solar flare observations from different points of the heliosphere can help in forecast of space weather ?***
- It is clear that observations of active regions and flares before their appearance on the E-limb and after motion behind the W-limb can improve significantly the forecast of the space weather.
- Our results show that even indirect effects in the X-ray and radio ranges one can localize events on the back side of the Sun and estimate their effects on situation in the space weather.
- Now it becomes possible to start this work based on available data of space missions operated in various points of the heliosphere.

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Thank you for attention !