

Solar cosmic ray generation by solar flares.

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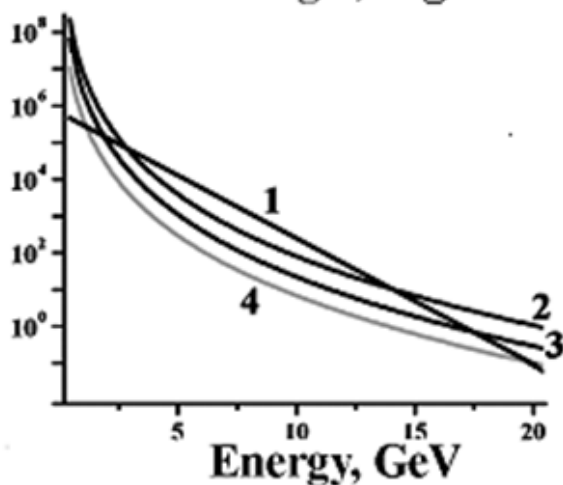
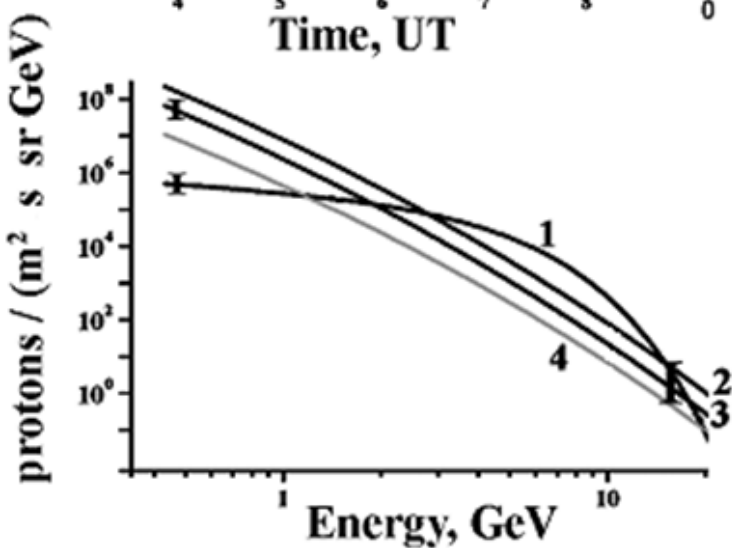
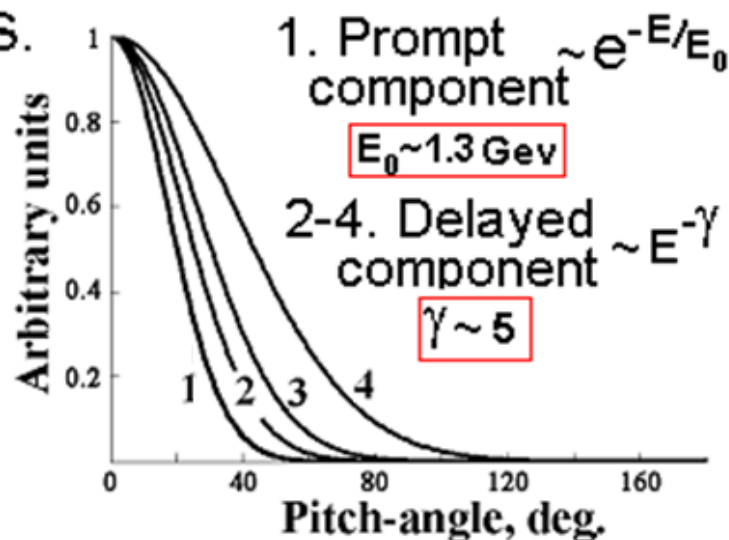
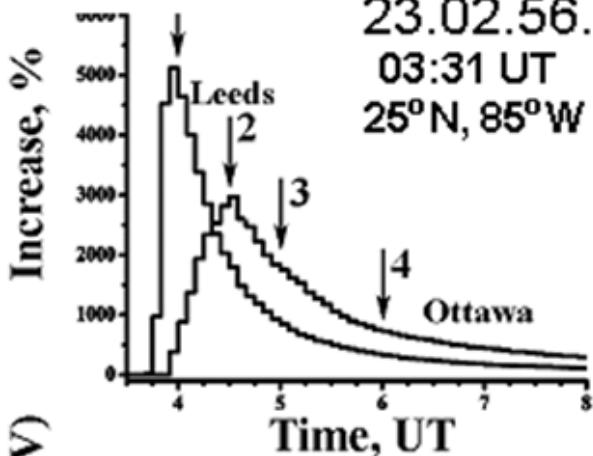
Some solar flares are accompanied by pulses of protons with the energy up to 20 GeV. The proton acceleration takes place during the magnetic reconnection at a solar flare. The duration of prompt proton ejection from the Sun is ~10 min. It does not exceed time of a solar flare. But the duration of proton pulses arriving to the Earth orbit and measured with the GOES spacecraft is order of several days. This time is determined by solar wind flow and diffusion in the interplanetary space. The proton flux tail is not depended on the flare position, but the measured proton flux demonstrates two types of the front structure. The sharp front ~20 min is observed if the flare appears on the West of the solar disk. The long front order of several hours is demonstrated the proton flux generated by eastern solar flares. The sharp front appears at particle traveling along magnetic line connecting the flare and the Earth. These particles arrive without Columbus scattering. They initiate the beam instability, and following particles are transported due to diffusion. The scattering initiate the change of the spectrum. The protons traveling across the magnetic lines arrive to the Earth orbit after the delay of 3 - 5 hours. It is much faster than the solar wind. One of possibility for such fast arriving is the turbulent diffusion initiated by beam instability of the prompt proton component.

- Cosmic rays are studied for 100 years, but their origin is still not clear.
- Sun - is an astronomical observatory. Due to its proximity to the Earth, we can get information, which does not come to us from other stars.

- John N. Bahcal

Relativistic protons.

23.02.56.
03:31 UT
25°N, 85°W

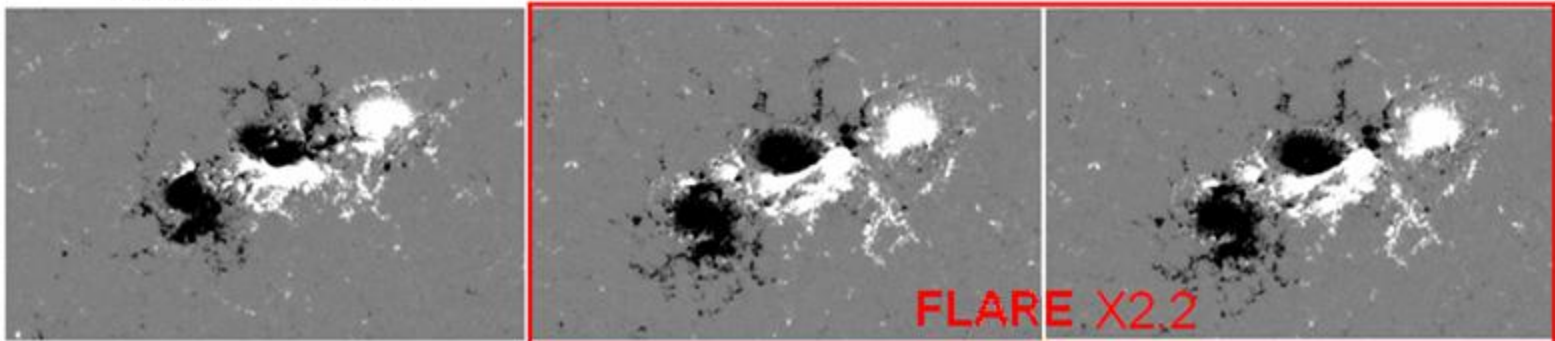
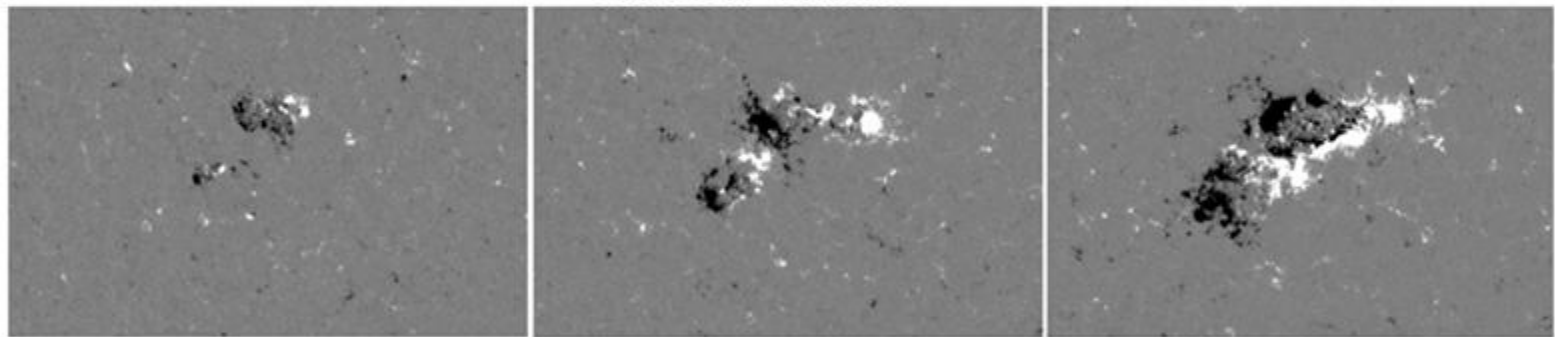
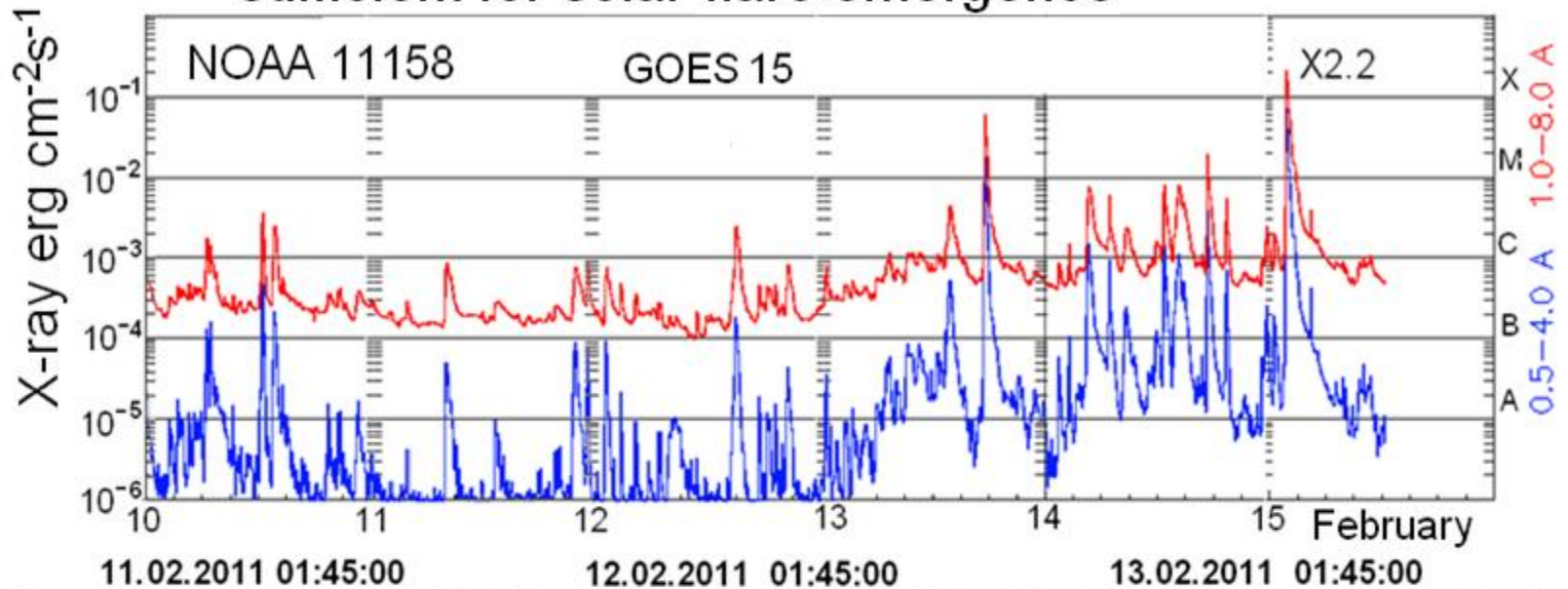


Podgorny et al.
2010,
Astronomy Reports.

Prompt collisionless component arrives without collisions along magnetic lines. They move with the proton velocity.

Delayed component is isotropic (diffusion?)

Large and complex magnetic field is necessary but not sufficient for solar flare emergence

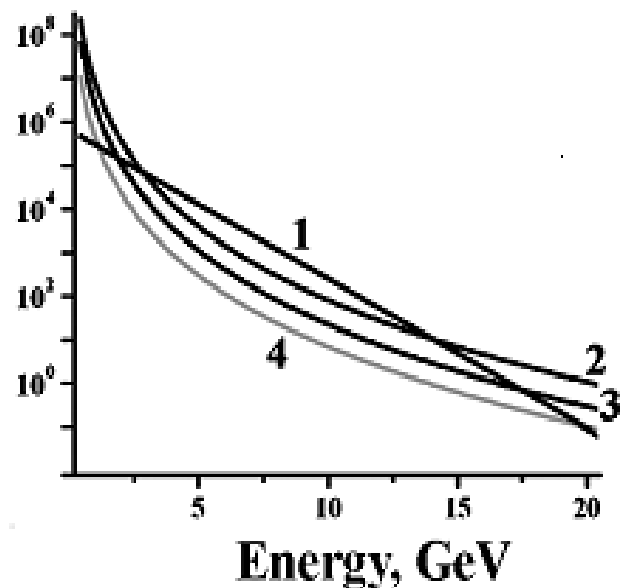
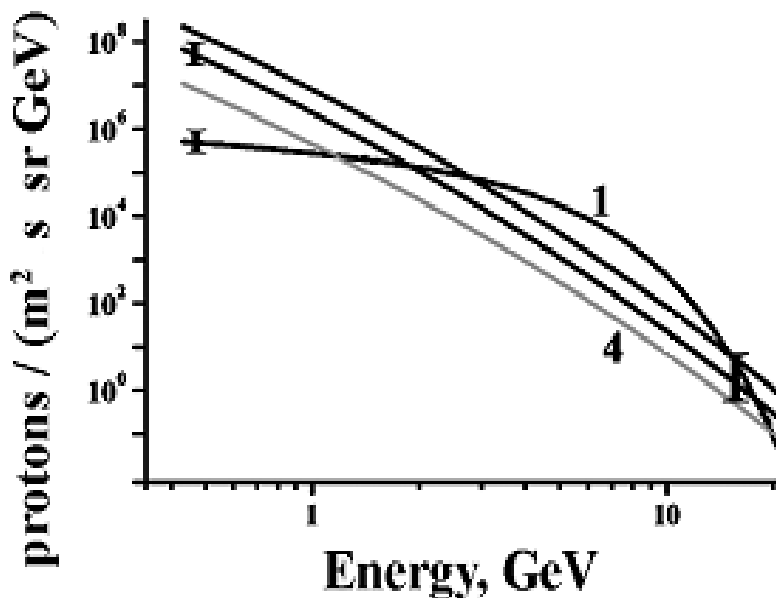
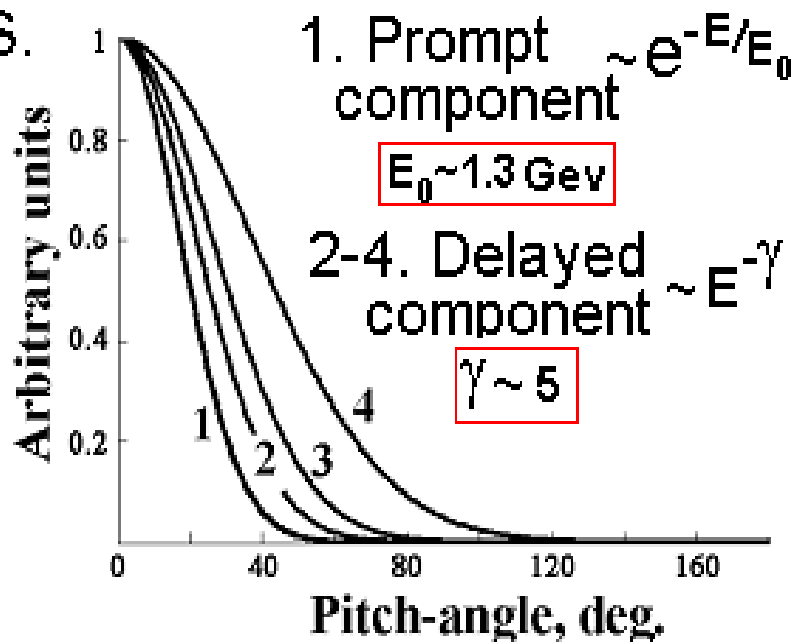
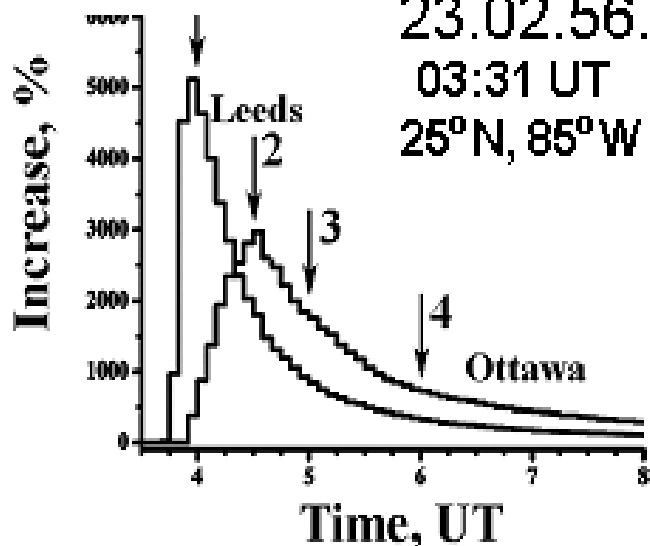


Relativistic protons.

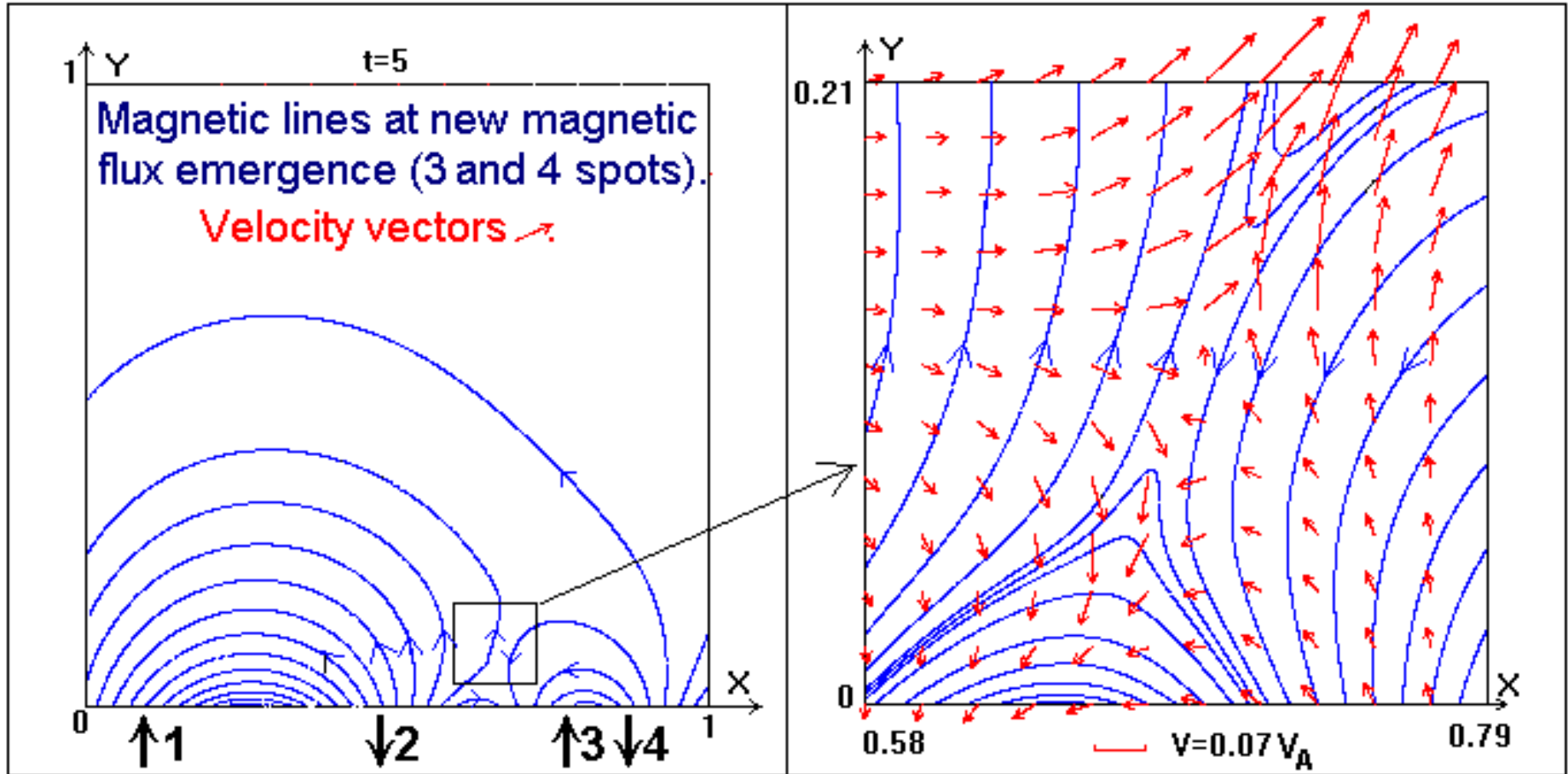
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03:31 UT

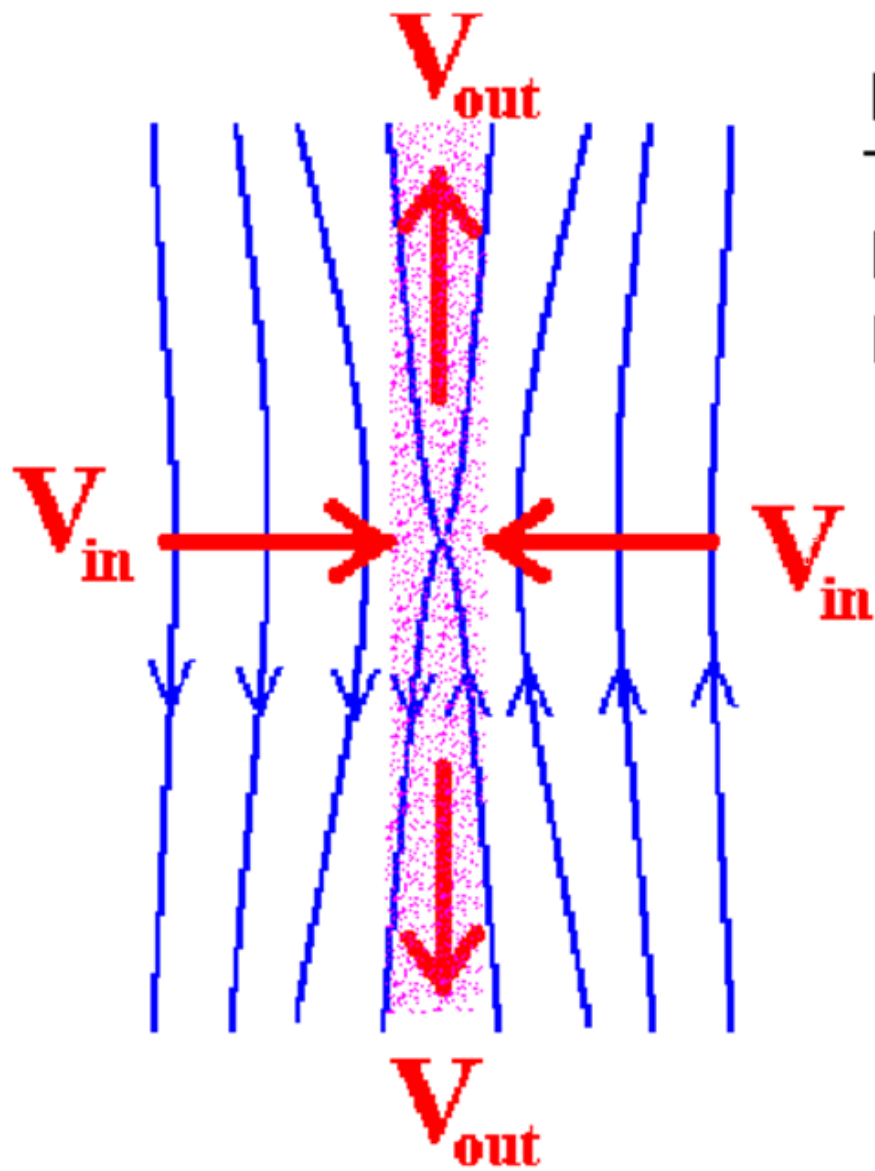
25°N, 85°W



MHD simulation of magnetic field and plasma above AR.
Spots approximation by vertical magnetic dipoles. $\mathbf{j} \times \mathbf{B}$ force
accelerates plasma along CS, producing 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.



From RHESSI: $(ME)=5 \cdot 10^{49} \text{ cm}^{-3}$.

$T=3.1 \text{ keV}$ $n=10^{11} \text{ cm}^{-3}$.

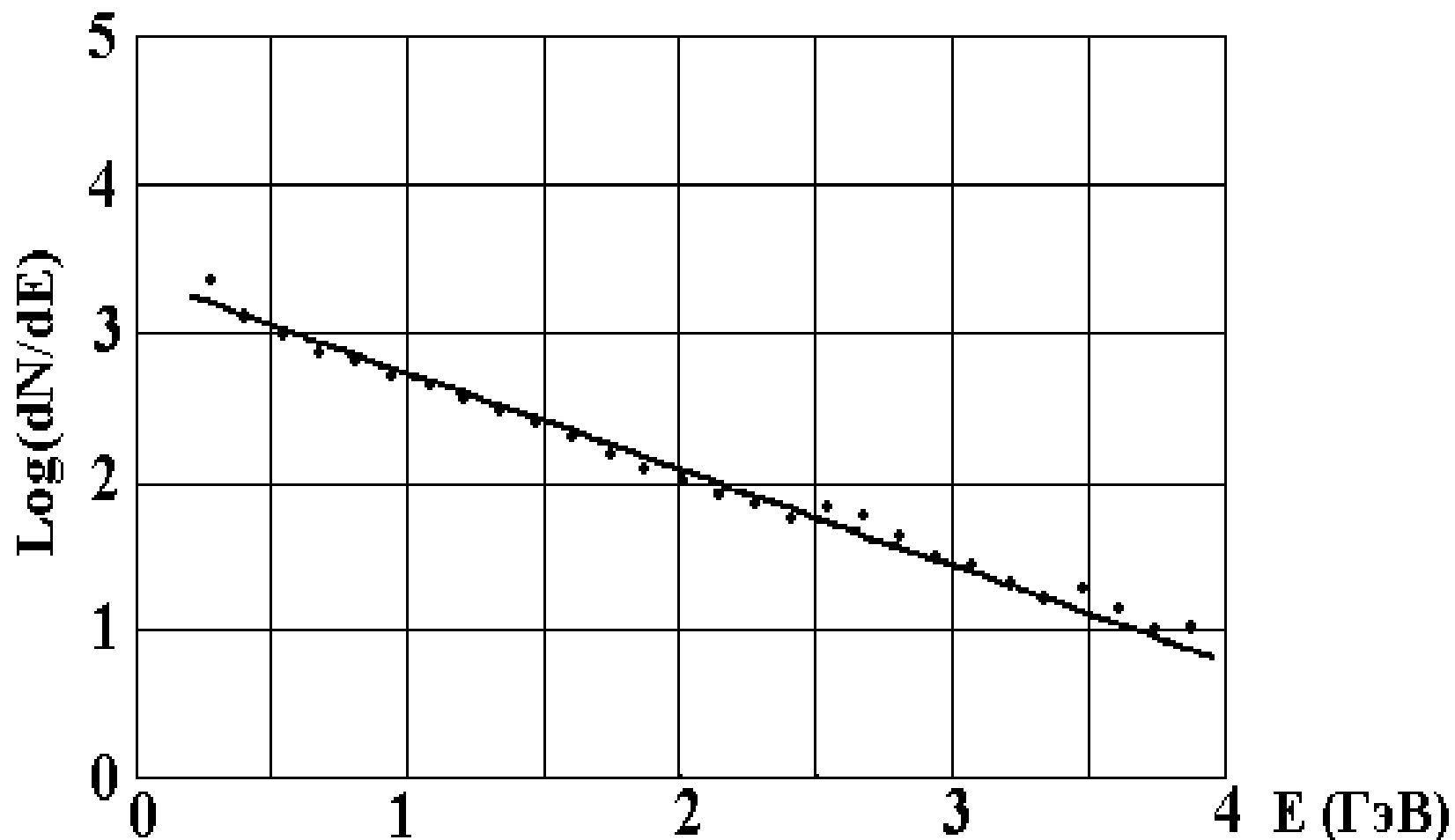
$B^2/8\pi = nkT \rightarrow B = 110 \text{ G}$.

$M = Nm_p \sim 10^{15} \text{ g}$ --- CME.

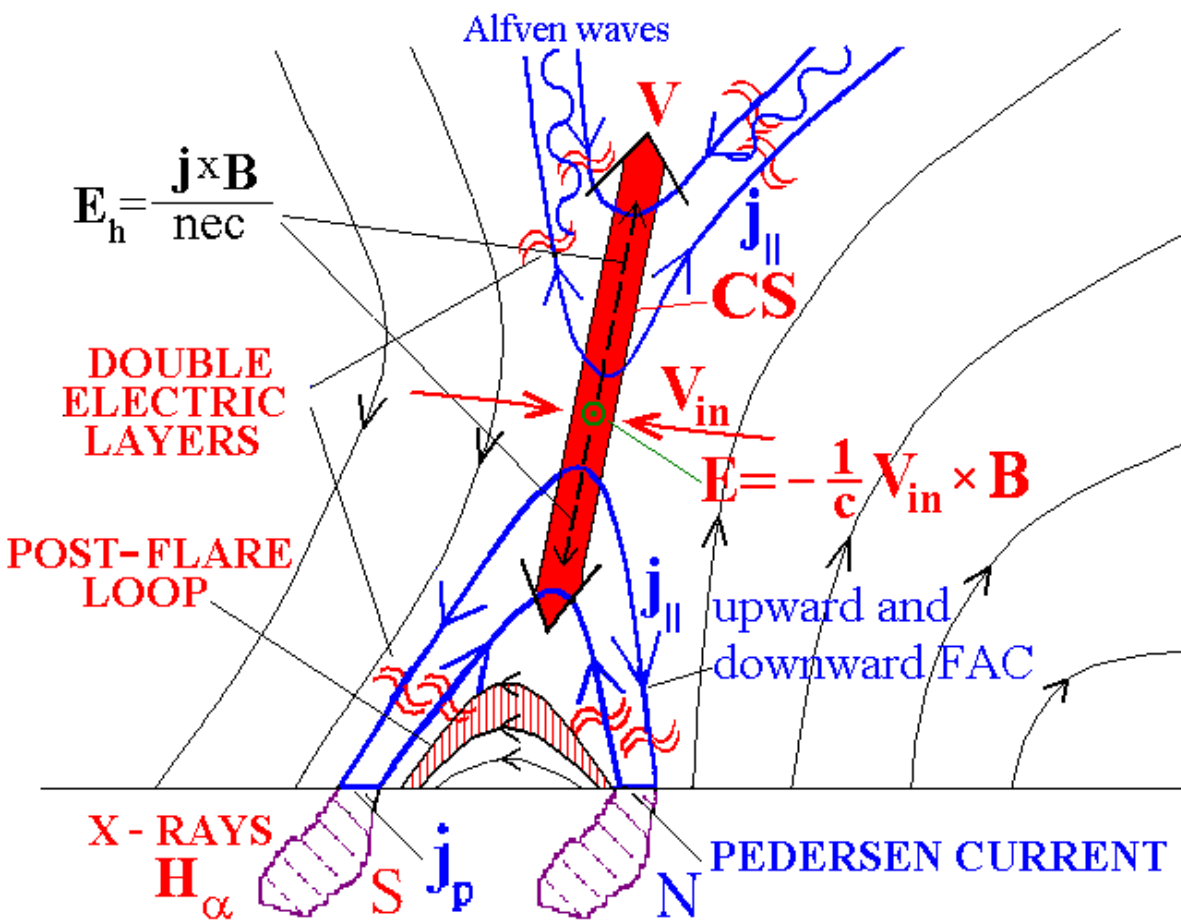
At $V_{in} = 2 \times 10^7 \text{ cm/s}$ and $L = 10^9 \text{ cm}$.

$E = V \times B / c$. $E = 20 \text{ V/cm}$.

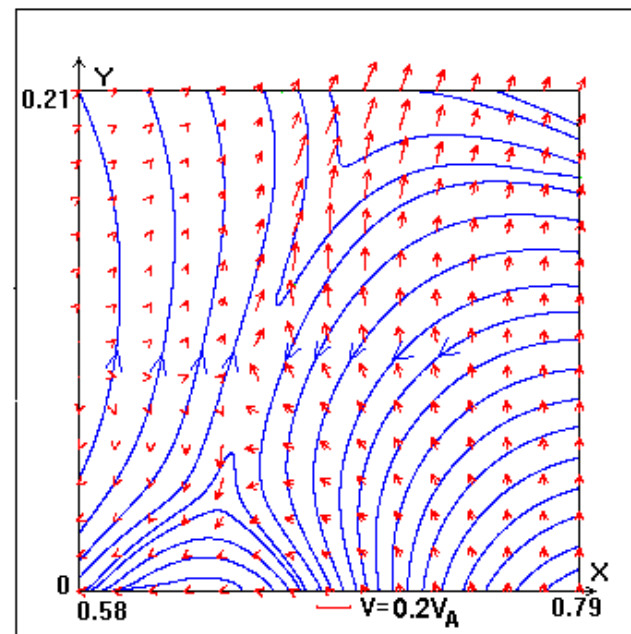
$W = 2 \times 10^{10} \text{ eV}$.



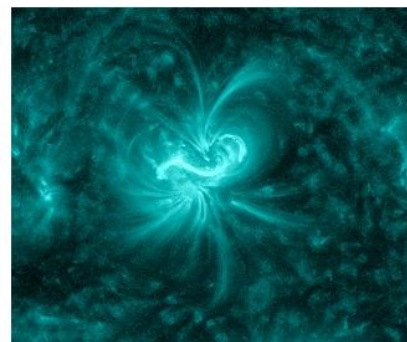
Вычисленный и измеренный спектры релятивистских протонов совпадают при скорости втекания плазмы, т. е. скорости магнитного пересоединения, $\sim 10^7 \text{ см/с}$.



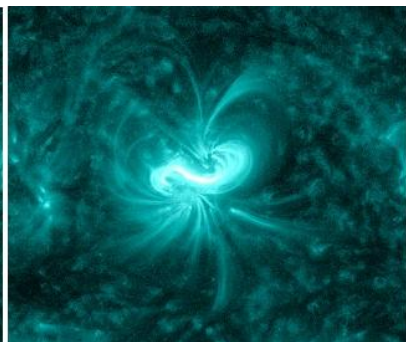
Electrons accelerated in FAC produce hard X-ray.



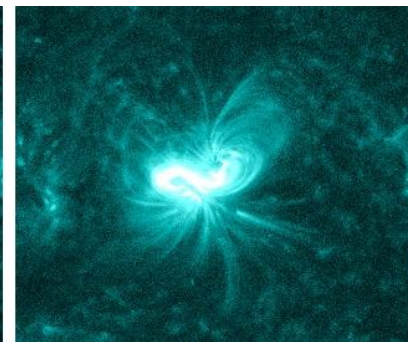
Results of current sheet creation in numerical MHD simulation. A sheet appears above an active region in the preflare state. Plasma inflows into a current sheet. Inside the sheet plasma acceleration takes place by $j \times B$ force producing CME.



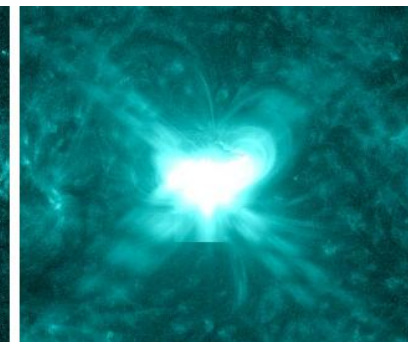
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17:12:46

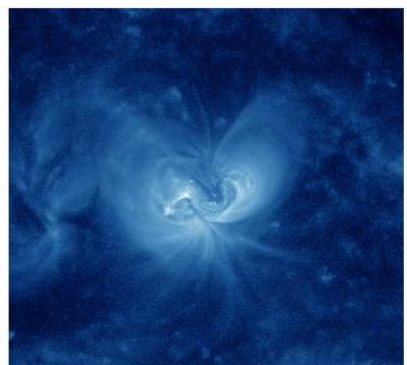


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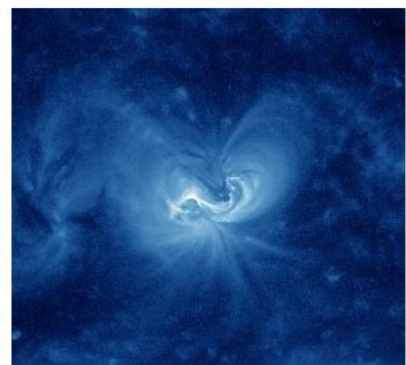


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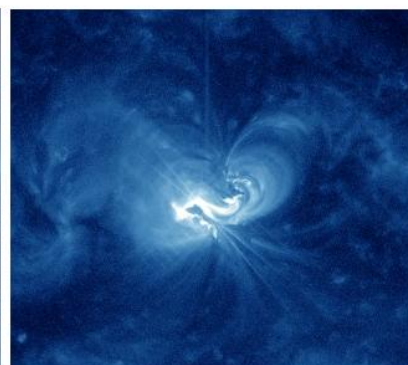
X1.6 AR12158
N11E05
 $t_0=17:21$
10.09.2014 UT
131A FeVIII,
FeXX, FeXXIII
0.4 MK, 10 MK,
16 MK



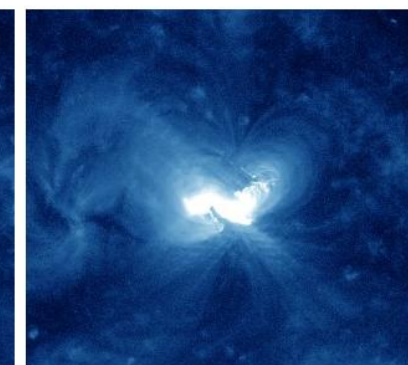
17:00:52



17:16:28



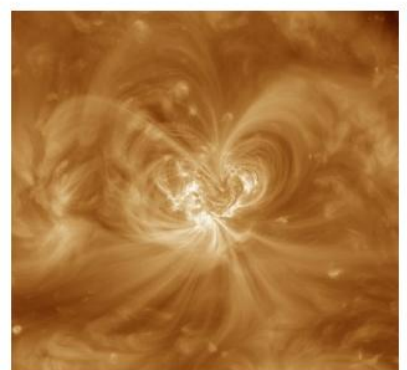
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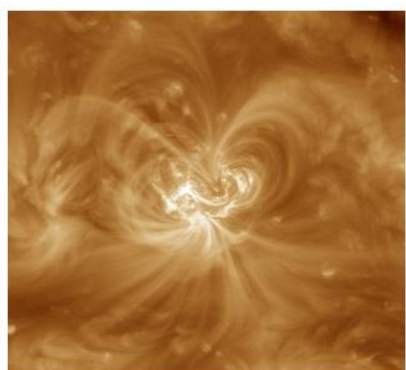
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335A FXVI
2.5 MK

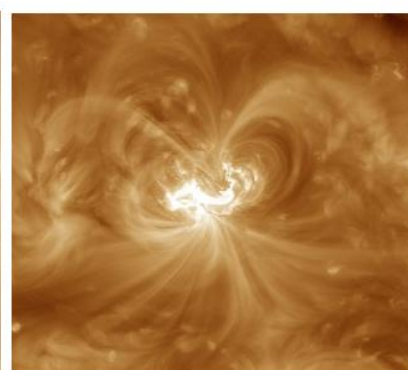
211XIV ac-reg cor 2 MK
335XVI ac-reg cor 2.5 MK



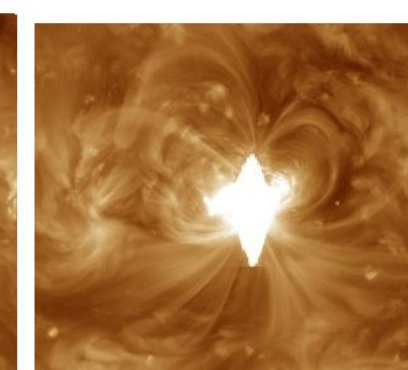
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17:10:55



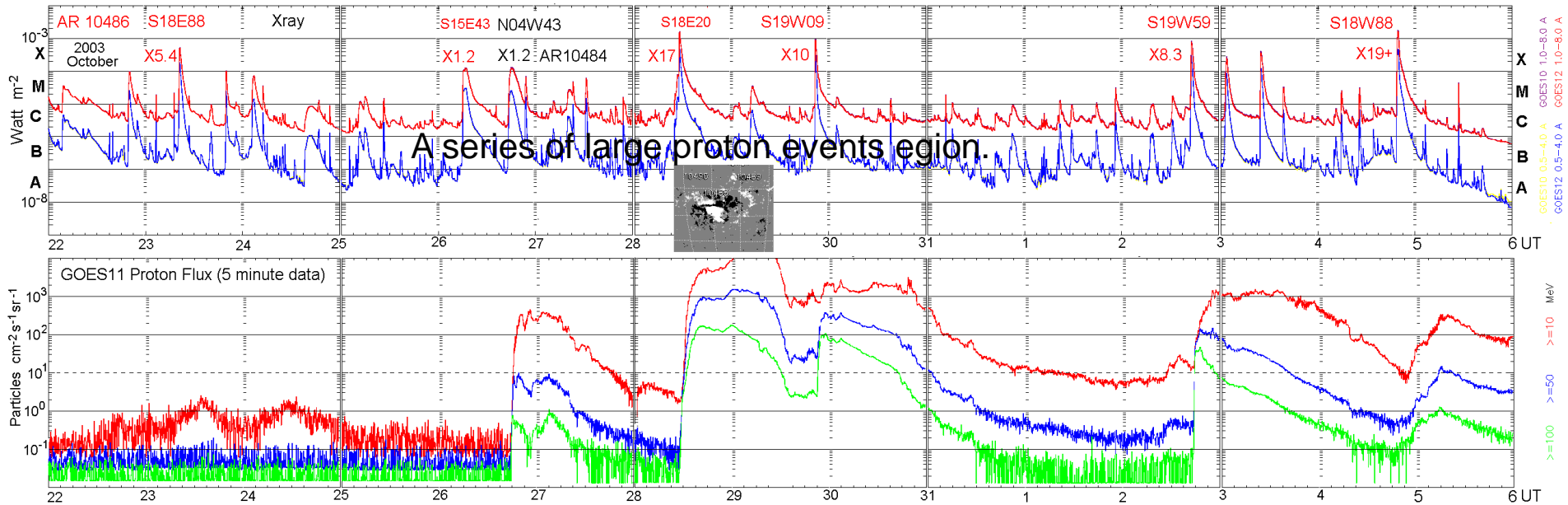
17:26:19



17:40:43

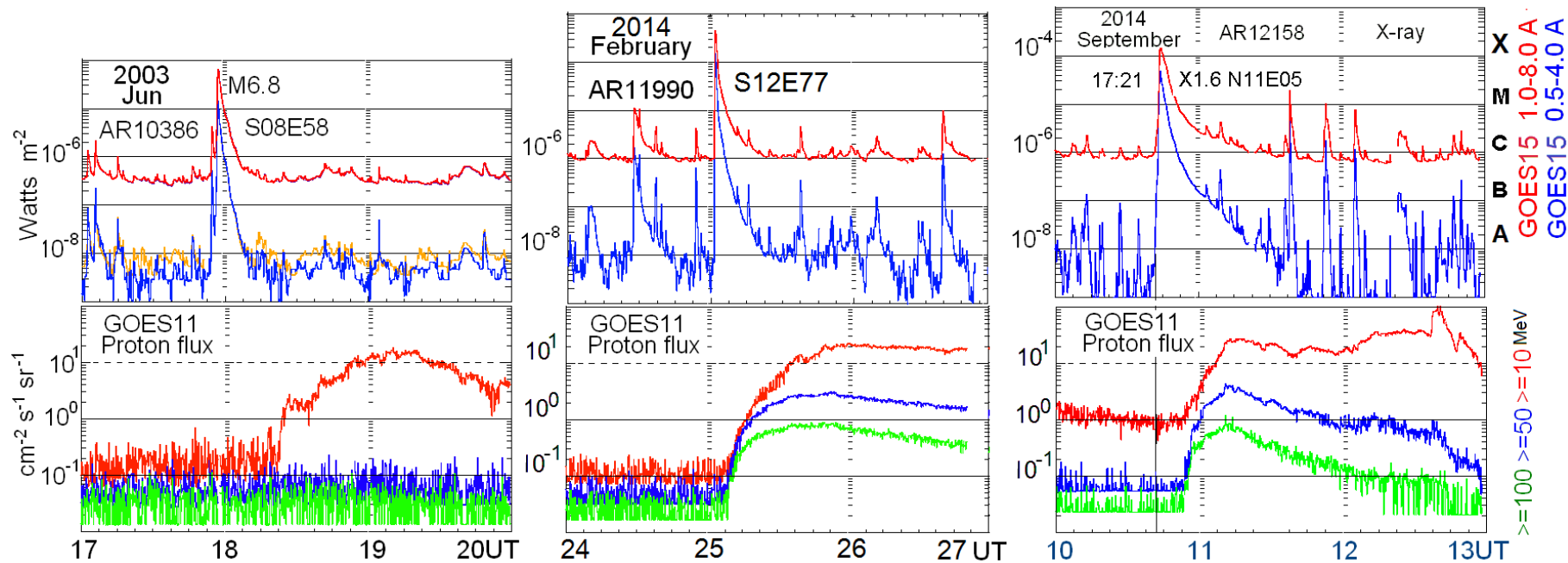
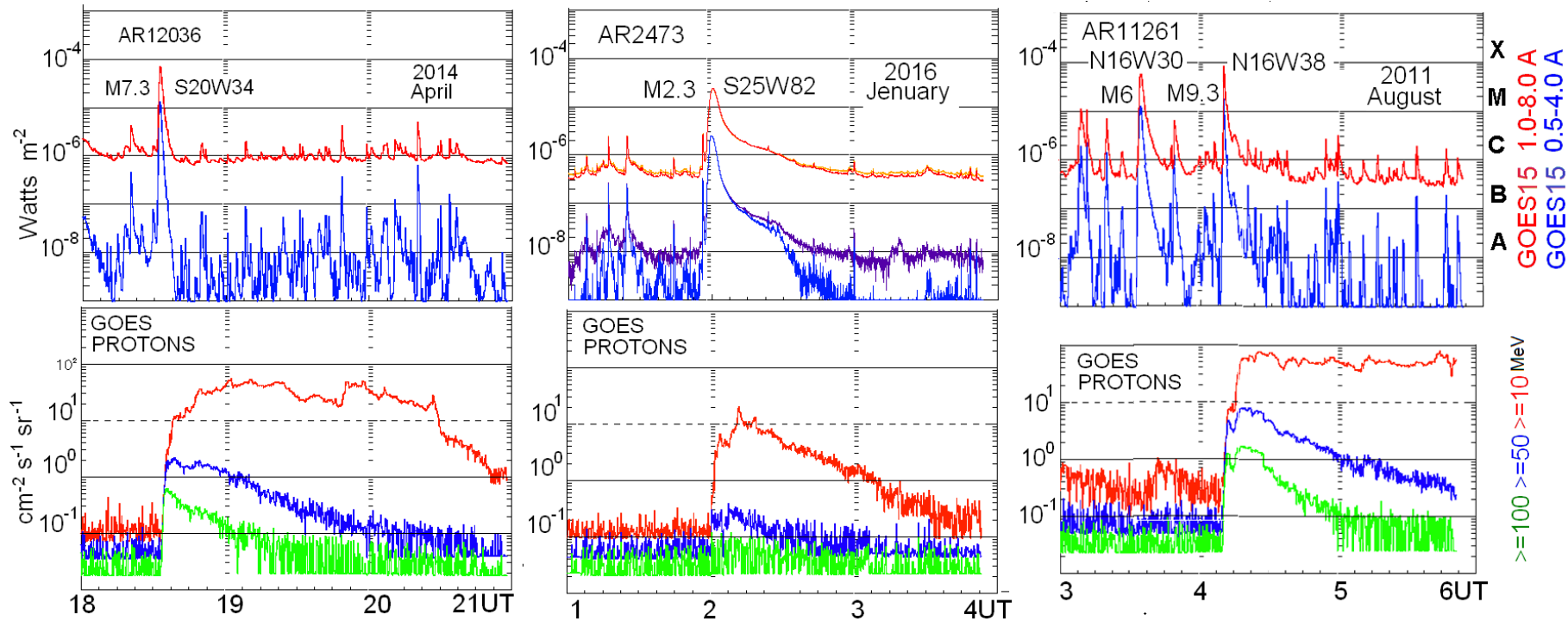
193A Fe XII
FeXXIV

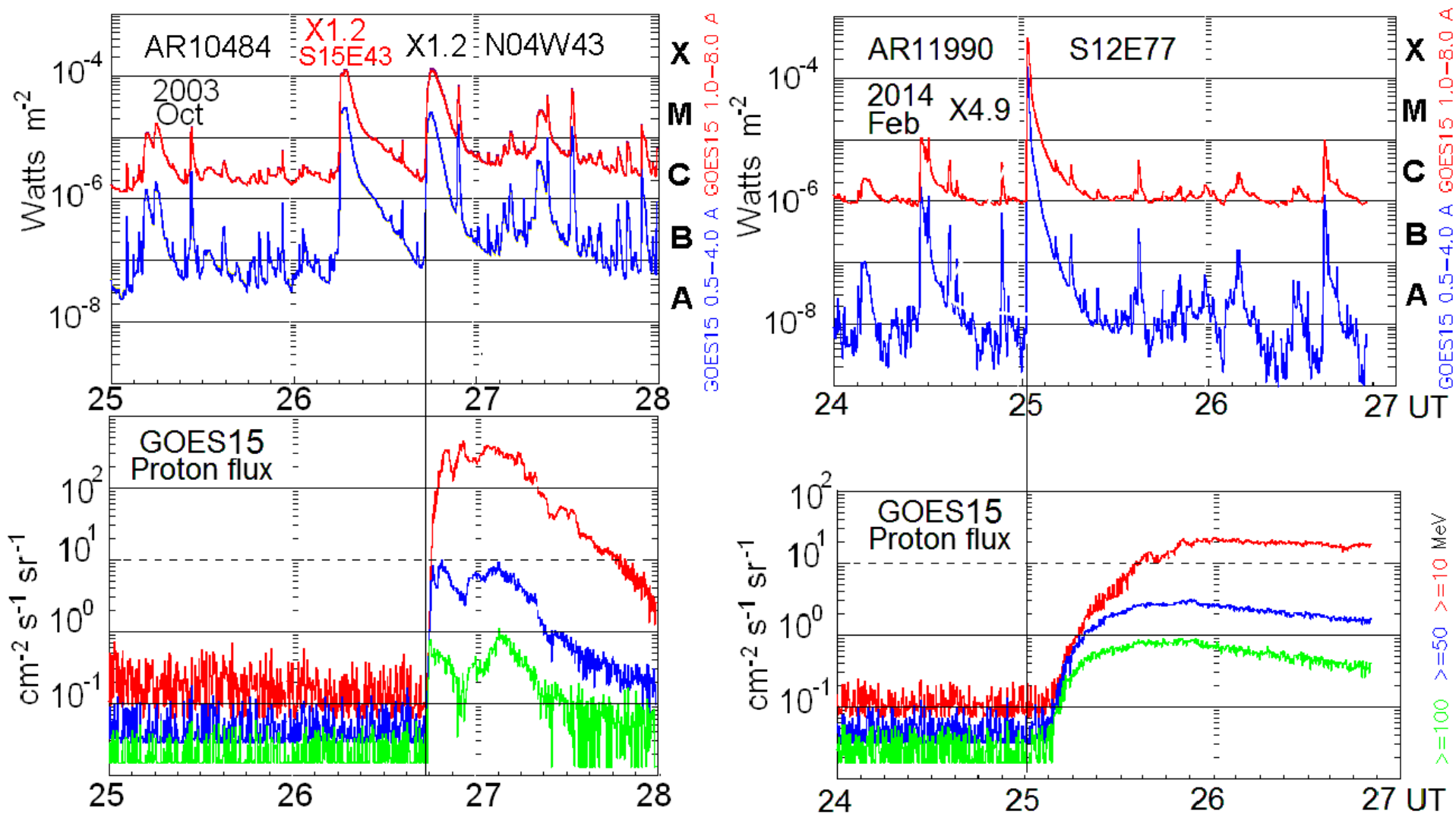
A SERIES OF LARGE PROTON EVENTS IN OCTOBER AND NOVEMBER 2003 ABOVE THE COMPLEX ACTIVE REGION. THERE IS NO CORRELATION BETWEEN THE VALUES OF FLARES AND PROTON FLUXES. NOT ALL X-CLASS FLARE CAUSED A PROTON FLUX.



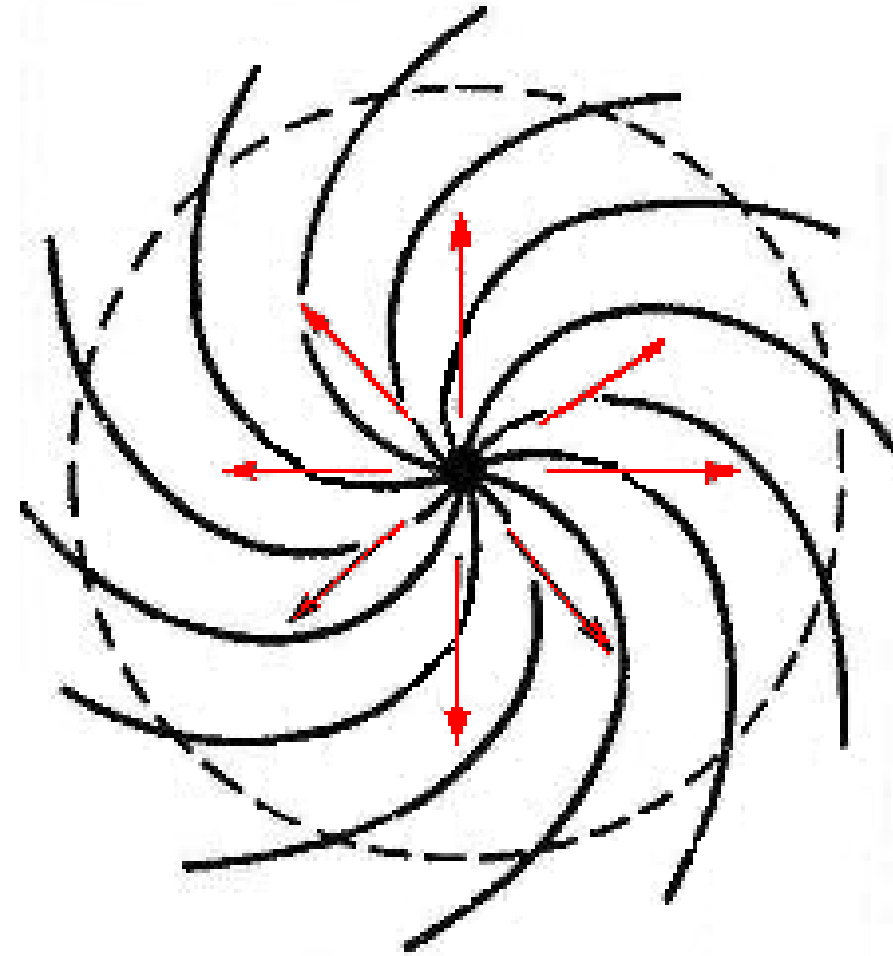
A series of large proton events region.

THE PROTONS FLUX DURATION IS THREE ORDERS OF MAGNITUDE SUPERIOR TO THE DURATION OF THE FLARE X-RAY RADIATION.





Large proton streams from western and eastern flares. Very large prompt proton stream with very steep front is observed only from a western flare.



Солнечный ветер -
расширение в вакуум
плазмы в магнитном
поле при
 $8\pi nW/V^2 > 1$.

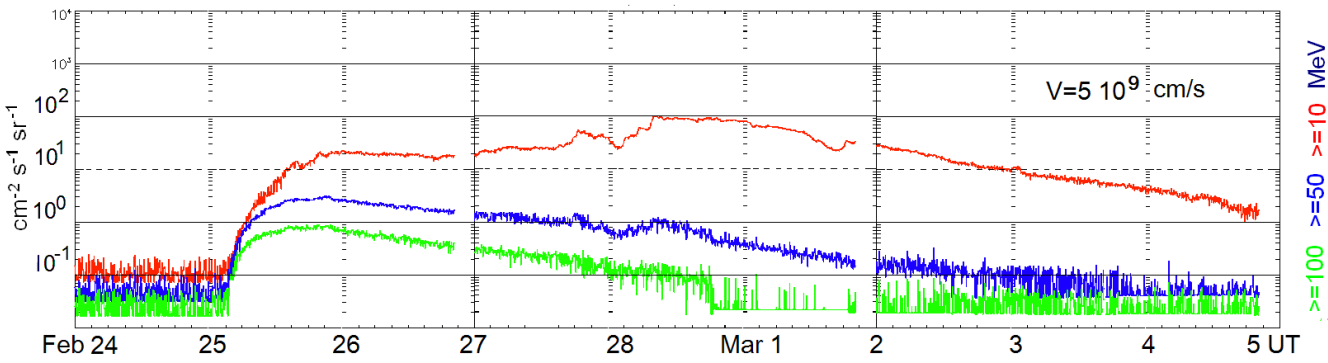
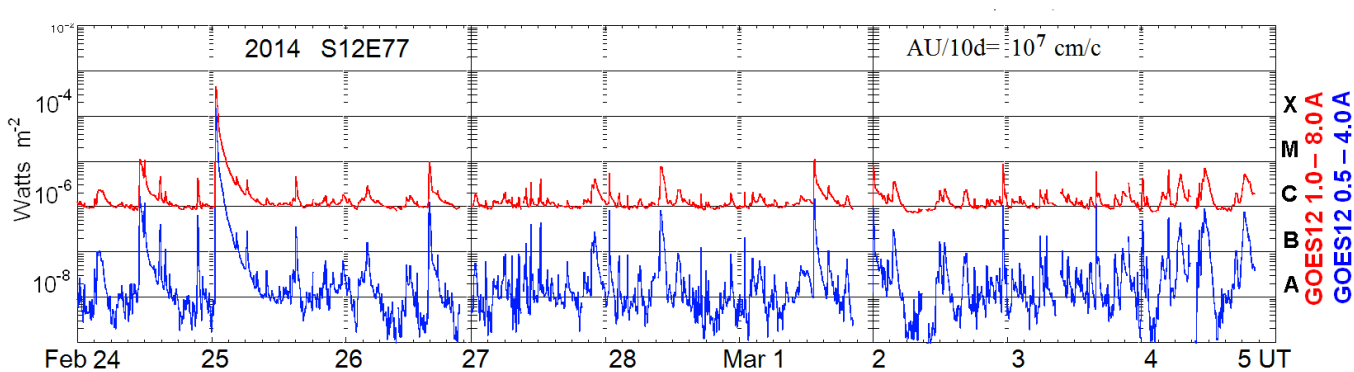
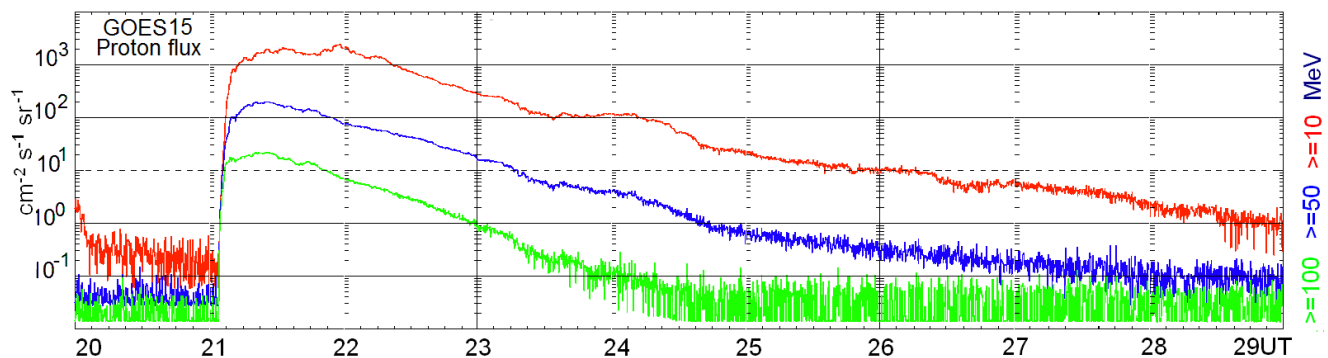
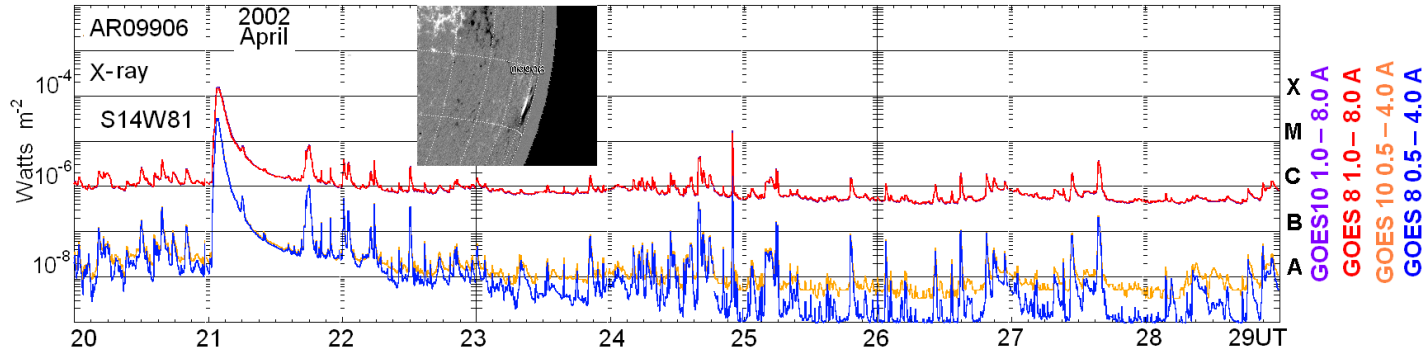
Protons from western flares. The front of prompt collisionless anisotropic proton flux that arrives with proton velocity can reach the Earth moving along the Archimed magnetic lines. The prompt proton flux is accompanying by isotropic diffusion flux.

Protons from eastern flares. Can arrive moving across the magnetic lines. The front arrives with the velocity 10^9 cm/s.

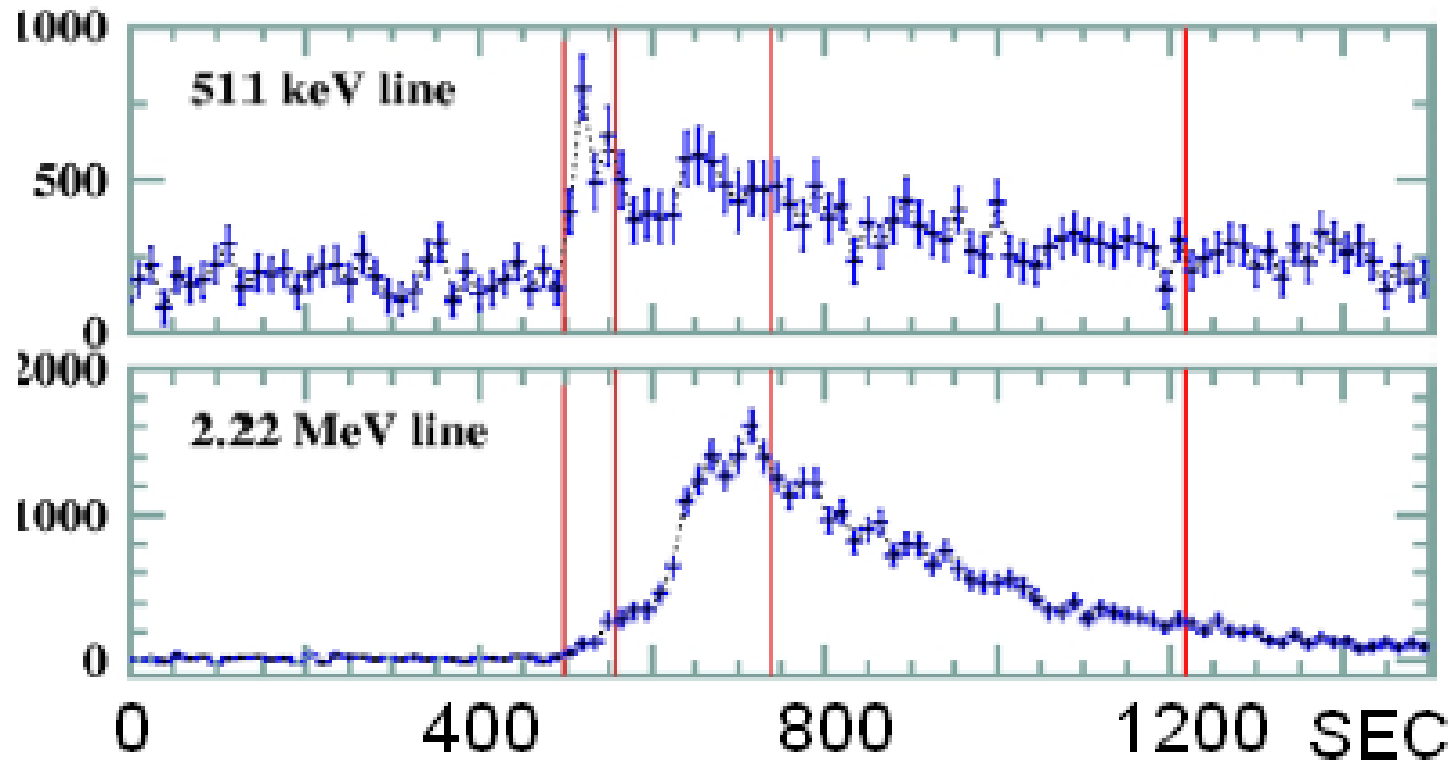
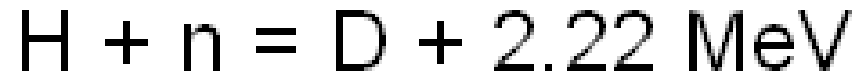
Why the collisionless flux is converted into diffusion one?
Are electromagnetic fluctuations appeared due to beam instability of the prompt component?

Why the delayed proton flux moving along magnetic lines from the western flares and delayed flux moving across the magnetic lines from the eastern flares are demonstrate the similar time dependence?

How the proton flux front of the eastern flares can move so fast ($V \sim 10^9$ cm/s) across the magnetic lines?



INTEGRAL October, 28. 2003.

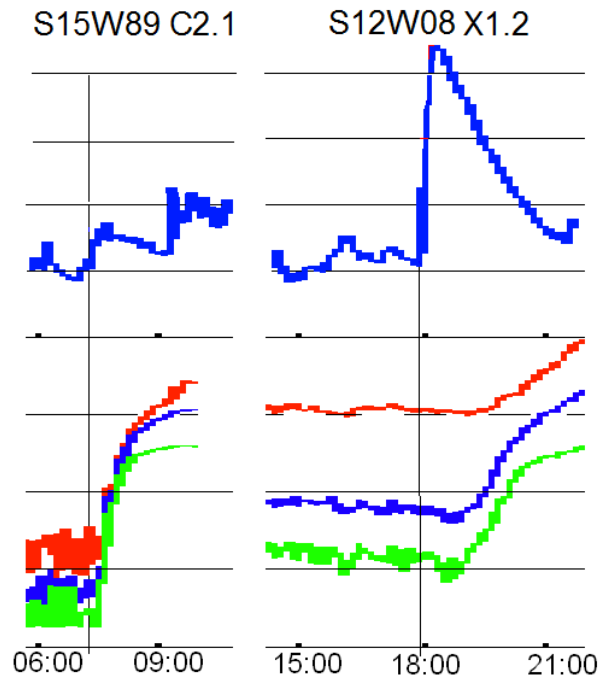
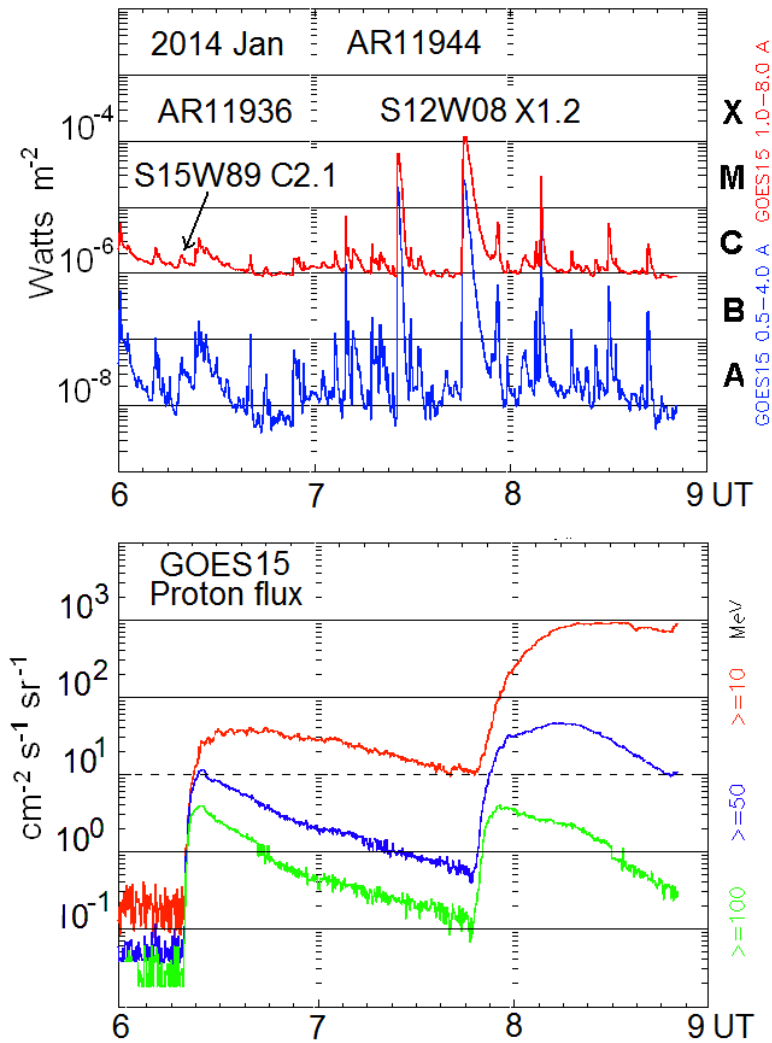


The durations of nuclear reactions in the Sun and flare X-ray radiation are the same, but they are 100 times smaller than the duration of the recorded proton flux.

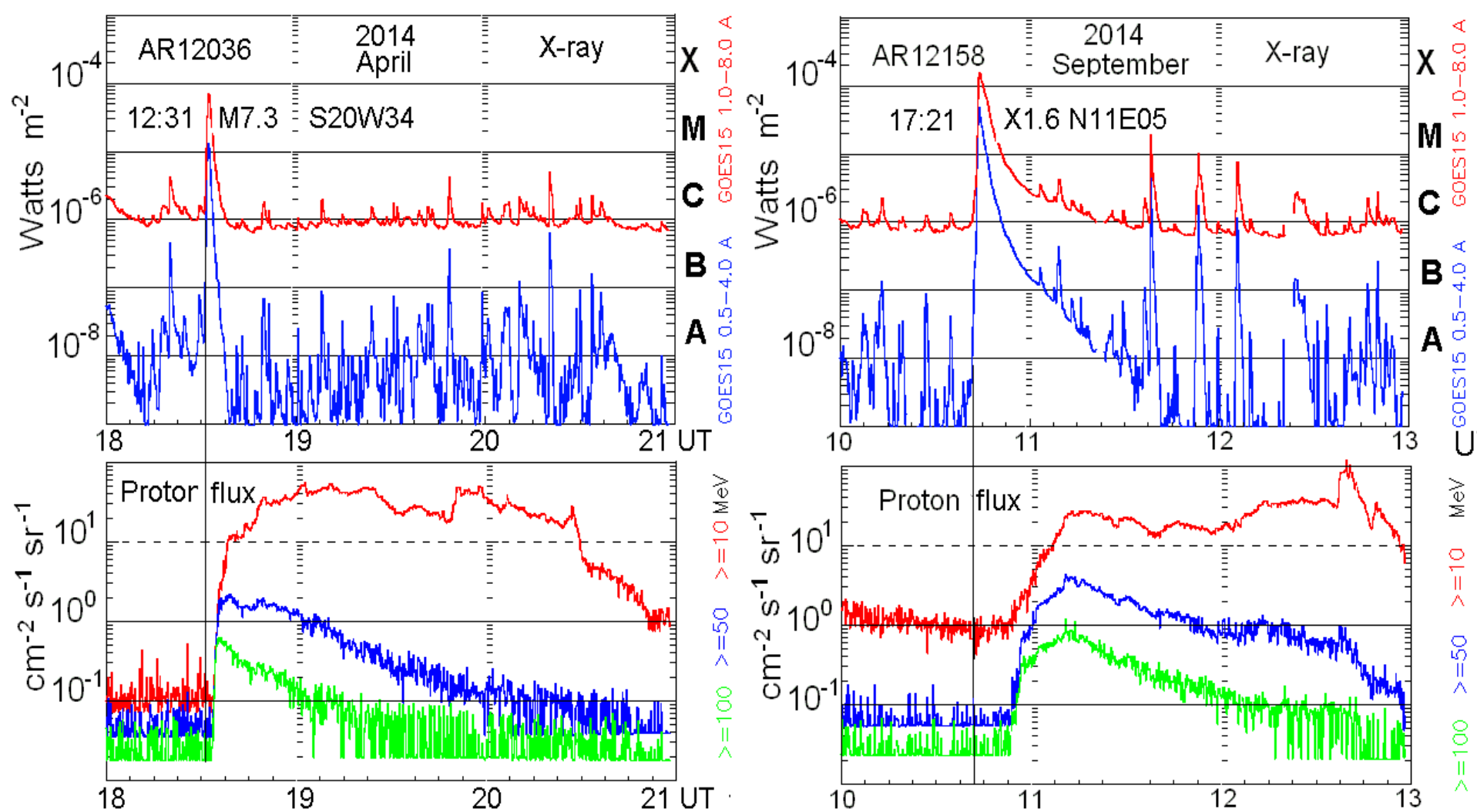
THE FRONT STRUCTURE OF PROTON FLUXES FROM WESTERN AND EASTERN FLARES ARE DETERMINED BY INTERPLANETARY MAGNETIC FIELD, BUT THERE ARE NO DIFFERENCES FOR THE LONG DELAYED PROTON COMPONENTS OF THESE FLARES.

THE POSSIBLE EXPLANATION:

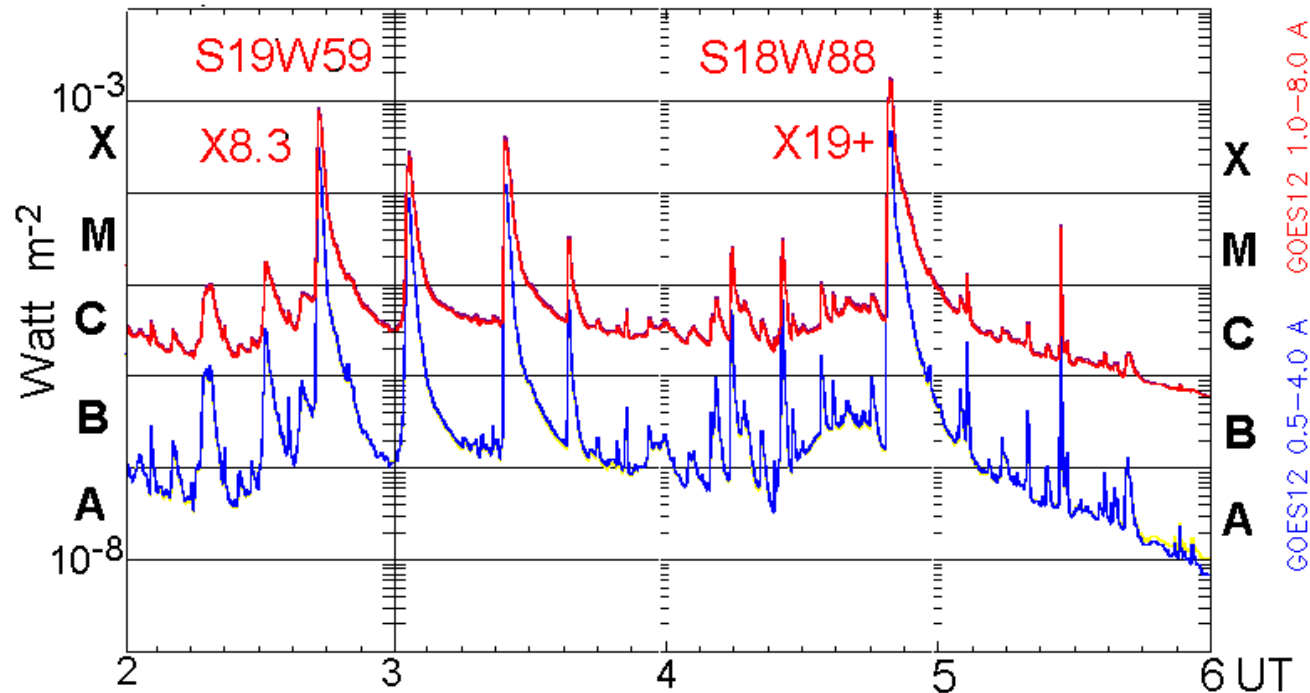
DIFFUSION CAN NOT DEPEND FROM THE MAGNETIC FIELD, IF SCATTERINGS ON ELECTROMAGNETIC FLUCTUATION ARE VERY STRONG ($\lambda \ll \rho$). SUCH FLUCTUATION CAN APPEAR AT BEAM INSTABILITY OF THE PROMPT PROTON COMPONENT.



**A VERY WEAK C2
FLARE NEVER CAUSES
A PROTON FLUX.
APPARENTLY, THE
MAIN X-RAYS WAS ON
THE BACK SIDE OF
THE SUN. PROTONS
HAVE ARRIVED TO
EARTH ALONG
MAGNETIC FIELD
LINES OF
ARCHIMEDES SPIRAL
FROM THE BACK SIDE.**

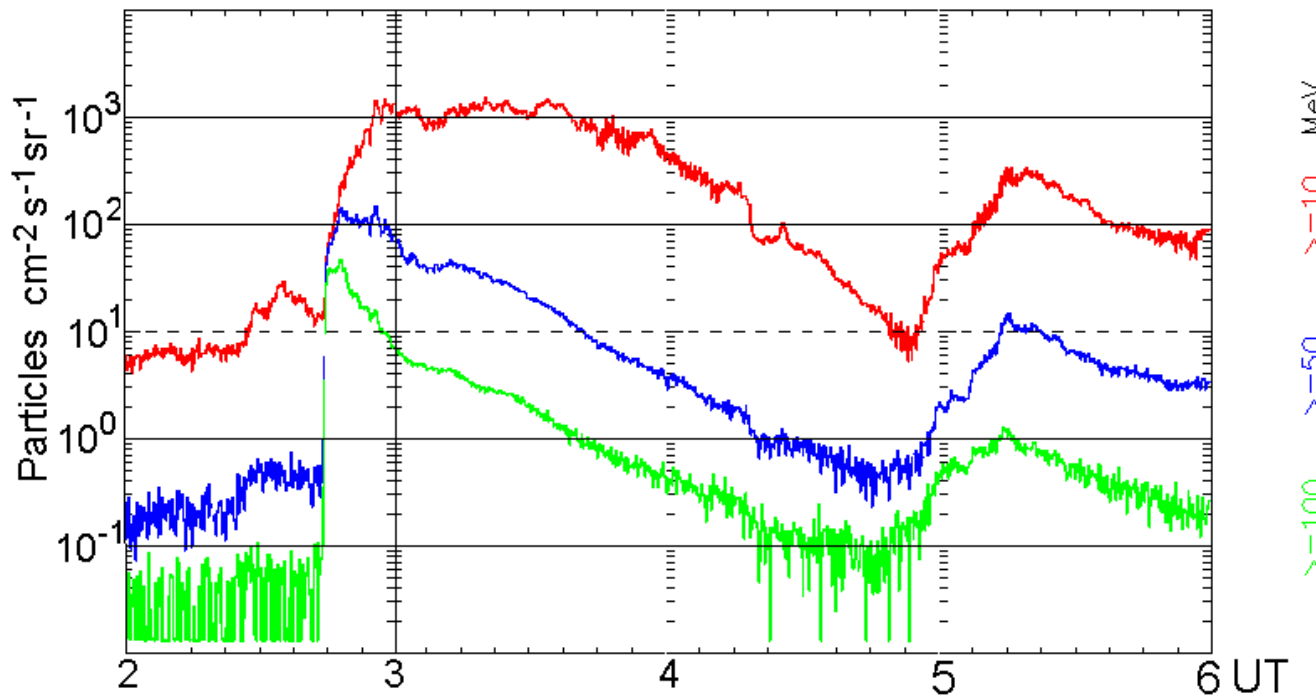


X1.6 N11E05 flare occurs near the center of the solar disk, but protons are reached the Earth only after 5 hours, whereas a steep front of protons from the western flare M7.3 S20W34 arrives through about 20 minutes. Delayed protons come through ~ 3 days.



UNUSUAL EVENT!

THE FRONT OF THE
GIANT WESTERN
PROTON STREAM IS
EXTENDED TO
ABOUT 10 HOURS.
THREE BIG FLARES
AND THE LARGE
CME CAN DISTORT
THE SPIRAL SHAPE
OF INTERPLANETARY
FIELD LINES.



GOES12 1.0-8.0 A

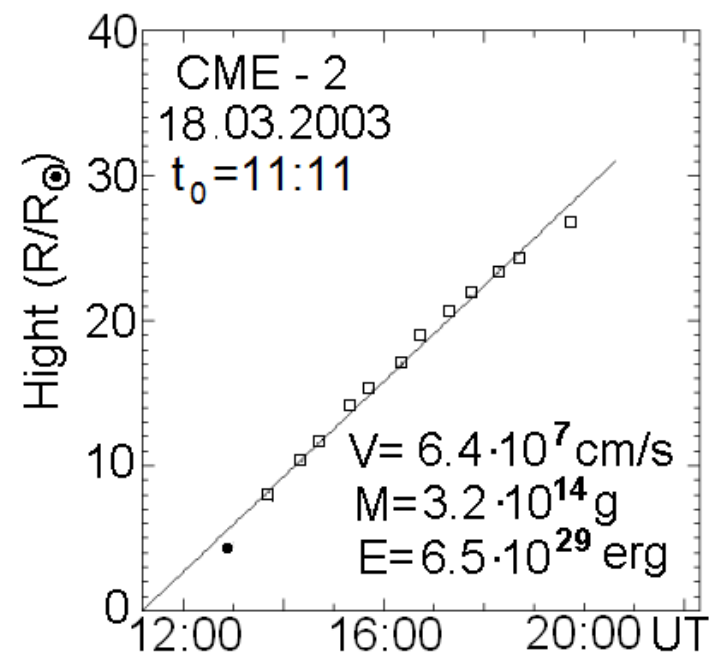
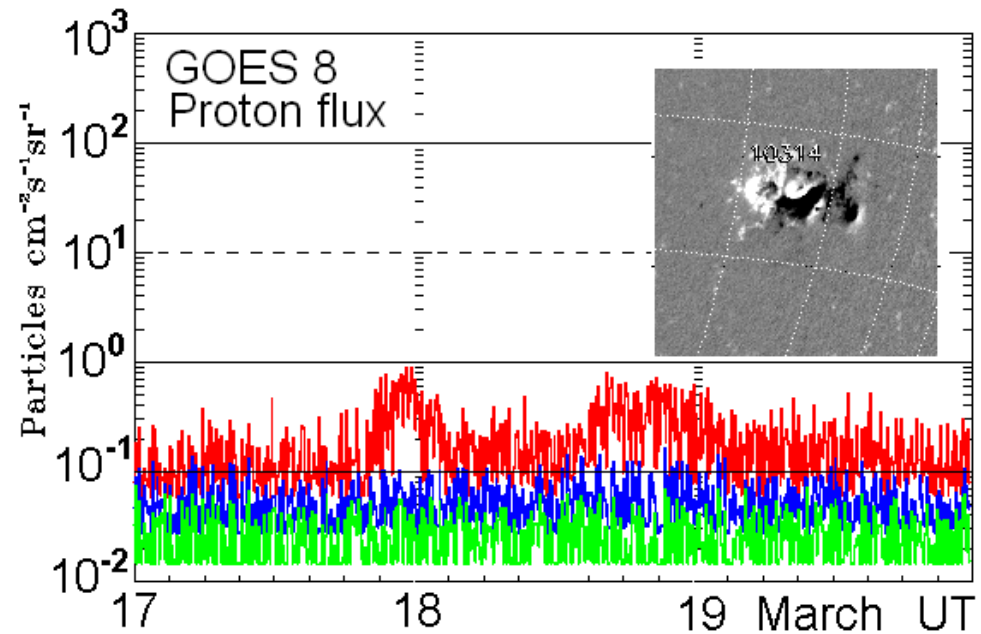
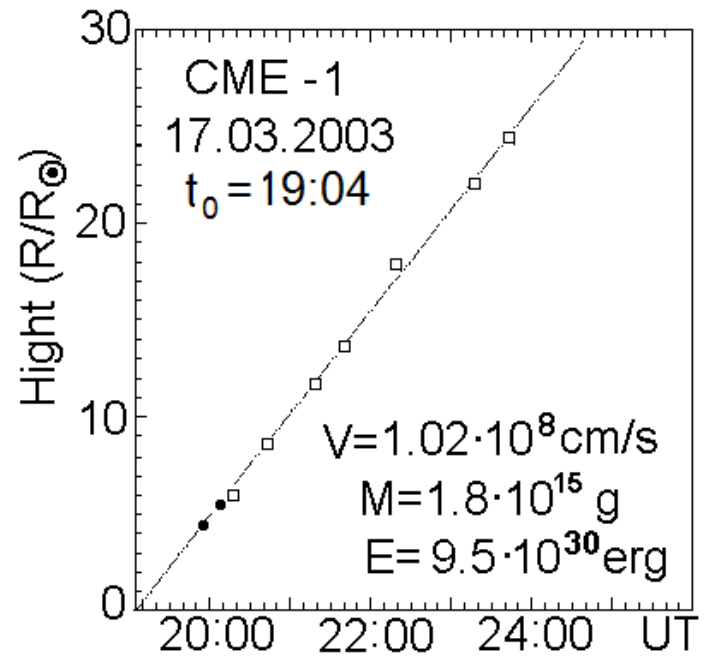
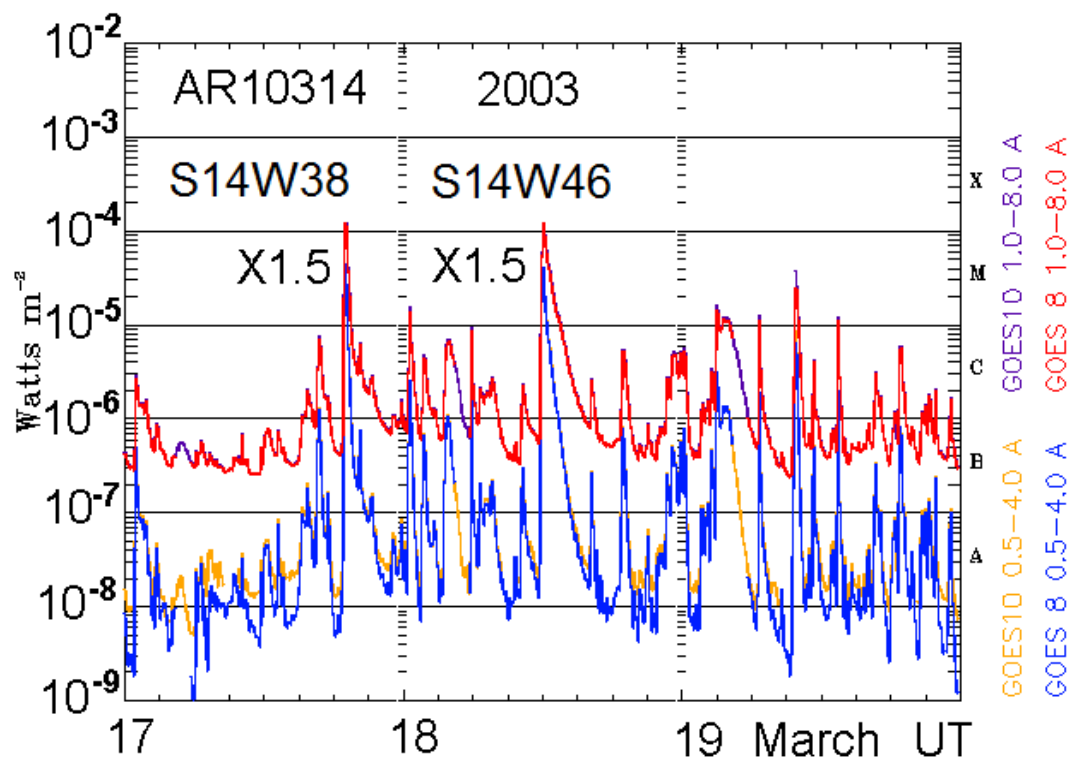
GOES12 0.5-4.0 A

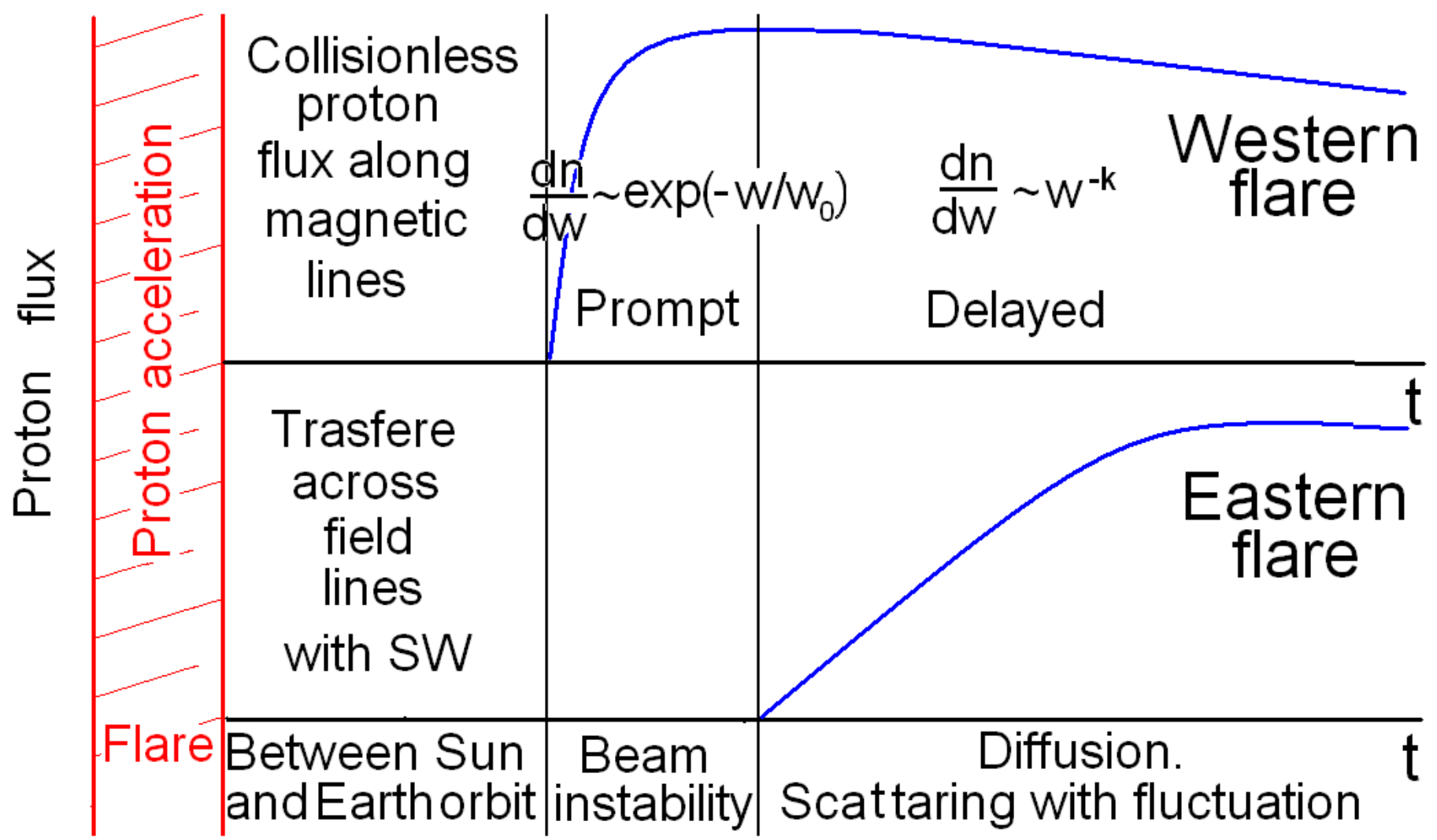
MeV

>=10

>=50

>=100





CONCLUSION.

1. The proton events are generated in the flare current sheet.
2. Four time scales of proton events:
 - a). The duration of the generation of accelerated protons is equal to the duration of the flare $t_{SF} \sim 20\text{-}30$ min.
 - b). The typical duration of the proton stream at the Earth orbit is equal to the propagation time of the solar wind $t_{SW} = 1\text{A.U.} / V_{SW} \sim 3$ days.
 - c). Time of arrival of the sharp front of relativistic proton from the western flare to the Earth's orbit is equal to the time of flight of protons along the Archimedes spiral $t_F \sim 1\text{A.U.} / c \sim 15 - 20$ min. The collisionless anisotropic stream carries information about the spectrum of protons.
 - d). Arrival of a gentle front of relativistic protons front from the eastern flare (across the magnetic lines) to the Earth's orbit is $t_D \sim 3 - 5$ hours. **The diffusion initiated by beam instability ???**

БЛАГОДАРЯ!

Thank you!