Study of the 28 October 2003 and 20 January 2005 solar flares by means of 2.223 MeV gamma-emission lines

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Abstract

We have modeled the time history of captured, 2.223 MeV line time profile of gamma-emission and studied some characteristics of two powerful solar flares and surrounding medium by means compared the modeling with the observational data.

The research leads for the 28 October, 2003 event to the confirming in main the previously found properties for three other solar flares.

In case of 20 January, 2005 we are compelled to recognize singularity of this solar event.

I. Method

We have developed an approach to determine the most probable profile of plasma density in the solar photosphere and adjoining levels during the period of a flare. The accelerated particle spectra and their evolution may be estimated by the method too.

Several key publications:

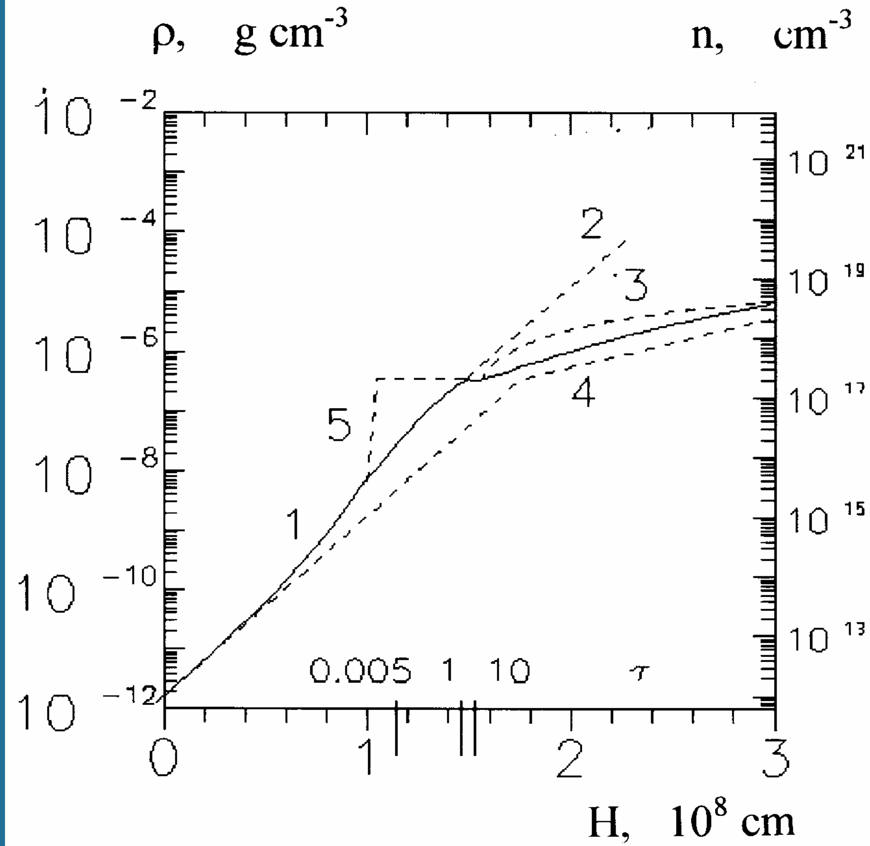
Kuzhevskij, B.M., Kuzhetsov, S.N., and Troitskaia, E.V., Adv. Space Res. 22(7), 1141-1147, 1998.

Kuzhevskij, B.M., Miroshnichenko, L.I. and Troitskaia, E.V. Astronomy Reports. 49, 566-577 (in English), 2005.

E. V. Troitskaia, W. Q. Gan, B. M. Kuzhevskij and L. I. Miroshnichenk_Solar Physics. 242, 2007.

Modeling: Monte-Carlo simulation of processes with energetic neutrons, making allowance for:

(1) possible energetic neutron escape from the Sun;
(2) gravitational neutron-Sun interaction;
(3) thermal motion of decelerated neutrons;
(4) neutron decay;
(5) neutron deceleration in elastic collisions with hydrogen nuclei, with due account for the energy and angular dependencies of cross-sections for *np*-scattering;
(6) neutron captures by hydrogen ^1H, with the production of deuterium ^2H and gamma-quantum of 2.223 MeV;
(7) non-radiative neutron absorption on 3He;
(8) gamma-ray absorption in the solar atmosphere in dependence on solar flare central angle;
(9) time profile of initial neutron production;
(10) initial neutron spectra;
(11) altitude dependence of surrounding matter density.



Basic density model of the solar atmosphere (*1*) and four modified models (*2-5*). Only fragments differing from the curve (*1*) are shown. Parameter τ is the optical depth for a wavelength of 500 nm, the level τ = 0.005 corresponds to the top of the photosphere with $n=1.5 \cdot 10^{16}$ cm^{-3} .

The relative abundance of $^3He/^1H$ is taken to be 2×10^{-5}

The time history of initial neutron production is assumed to be similar to that of total fluence of $^{12}C+^{16}O$ nuclear de-excitation lines in the range of 4.1-6.4 MeV.

Calculations are made with SINP code for neutrons with energies of 1-100 MeV that are the most important ones for the 2.223 MeV line production.

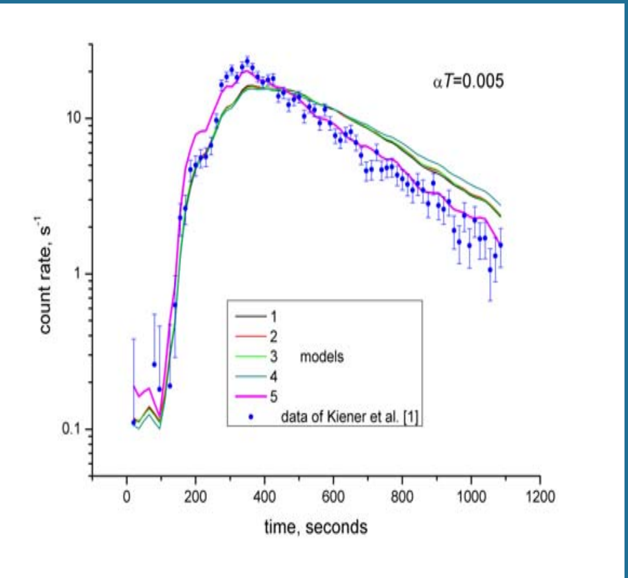
The primary neutrons are assumed to be emitted isotropically in the lower half-space (towards the Sun) from the levels with densities less than 5×10^{15} cm^{-3}.

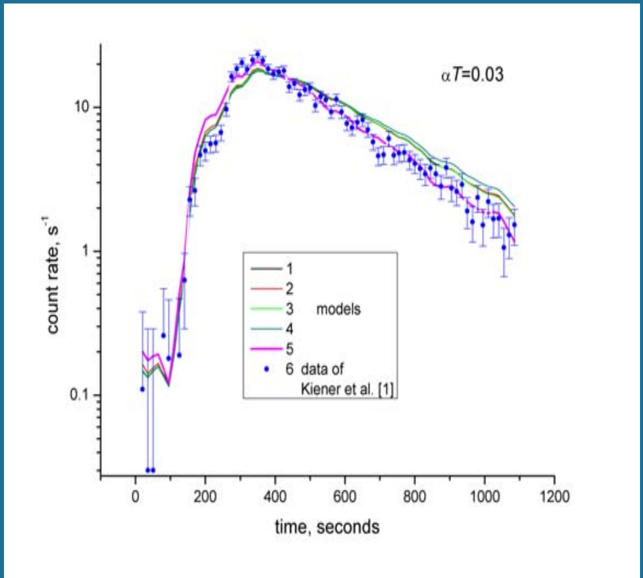
As a basic density model (m=1) we have used the standard astrophysical model HSRA (Harvard-Smithsonian model together with a model Spruit of convection zone.

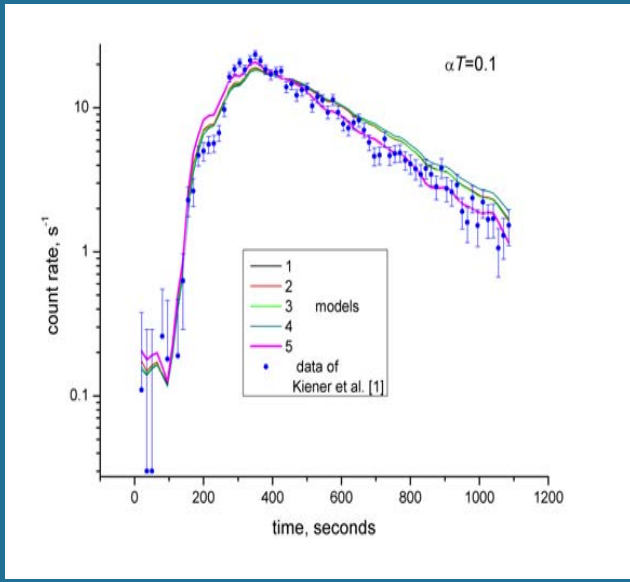
The flare of 28 October, 2003

- began at 9:41 UT, had its maximum at 11:10 and ended about 11:24 UT. It appeared in the NOAA active region 10486.
- Gamma-emission lasted about 15 min from 11:02 UT. We apply our method to investigate the 28 October 2003 solar flare of **X17.2/4B** importance with coordinates S16E08 [15] and present the results for this powerful and long-duration flare. The data on 2.223 MeV and summarized fluxes of 4.44 and 6.13 MeV gamma emission from **INTEGRAL** are used (Kiener J., Gros M., Tatischeff V. and Weidenspointner, A & A V. 445, P. 725-733, 2006).
- The calculations of time profiles of gamma fluxes were made in supposition of Bessel form (stochastic acceleration) of accelerated particles energy spectrum for three meanings of spectral parameter a*T*: 0.005, 0.03 and 0.1.

28 October 2003. Modeling and comparing with the observational data







The least square sums method reveals the best modeling time profile. It is the case of αT=0.03 and m=5. This means the density enhancement in the whole thickness of photosphere to $2\cdot 10^{17}$ cm^{-3} . We can also conclude from the Figure that m=5 begins to realize at the time about 400 s from the flare onset, at the rising phase m≠5.

Another conclusion is that the better fitting in the rising phase is αT=0.005 and, in the phase of decay the best fitting is αT=0.1 or 0.03.

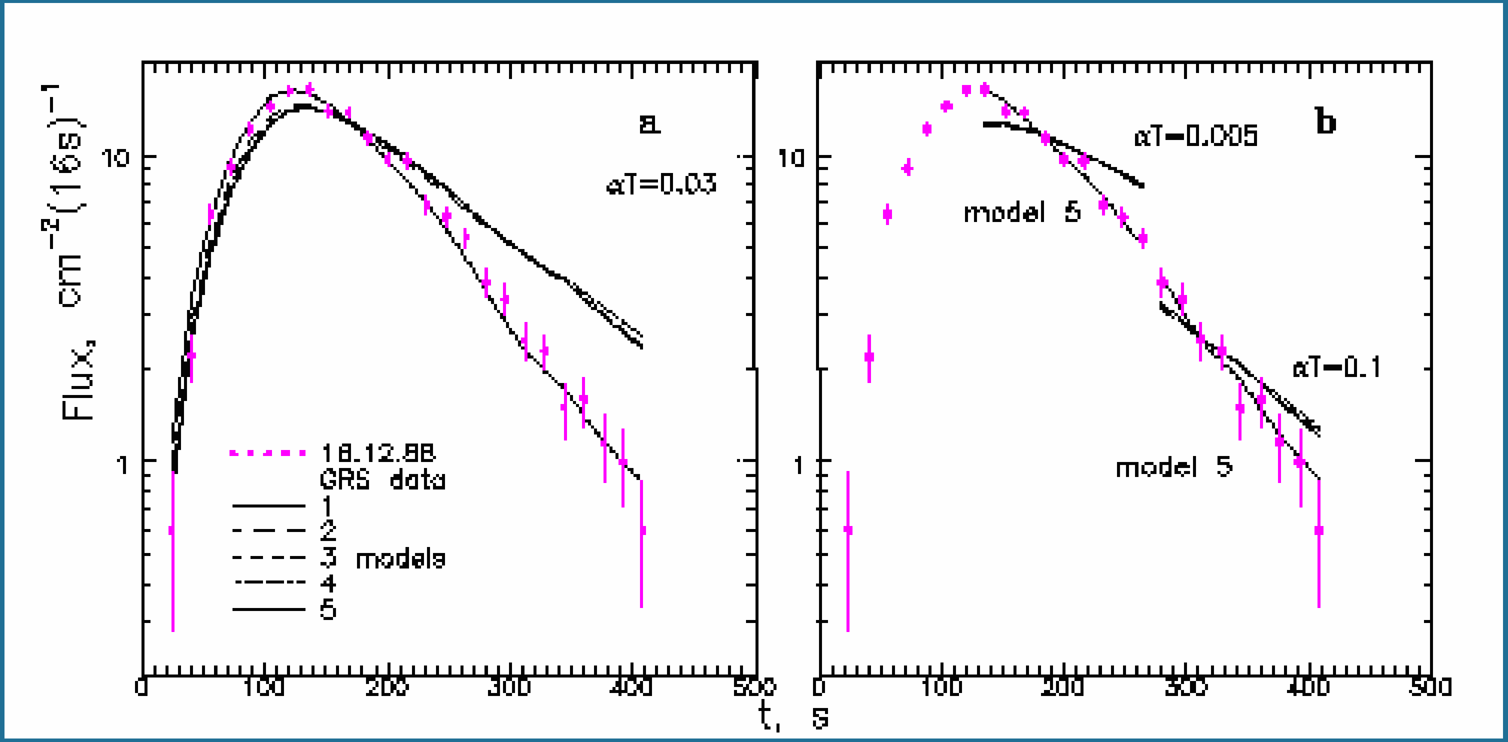
We can conclude that different parts of time profile have different parameters, but we can construct the total profile of parts that are the models of the event time history, although, with different parameters.

Previous results

Flare	Position, class	Apparatus	Model (a) m	Model (b) m
22 March 1991	S26 E28 3B/X9.4	GRANAT	2 3	5 2
6 November 1997	S18 W64 2B/X9.4	Yohkoh	5	5
16 December 1988	1B/X4.7	SMM	$\alpha T=0.03$ $\alpha T=0.005$	m=5 m=5

In the last case it was also revealed the hardening of the spectrum with the time from $\alpha T=0.1$ to $\alpha T=0.005$ and the delay of the dencity enhancement to about 140 s.

16 December 1988 1B/X4.7 flare
SMM



Now we have a question about the **origin** of the revealed density enhancement. It may be either at the site of primary energy release at the top of magnetic flare loop in the corona or upper chromosphere or it may be connected with the magnetic structures in which the flare is developing. The first process – the response of the atmosphere to the sharp energy release is well studied by some authors. It can be from 1 to 5 cold condensations, moving downward in the front of shock wave (Bojko, Livshits, 1995).

Estimate the maxima grammage :

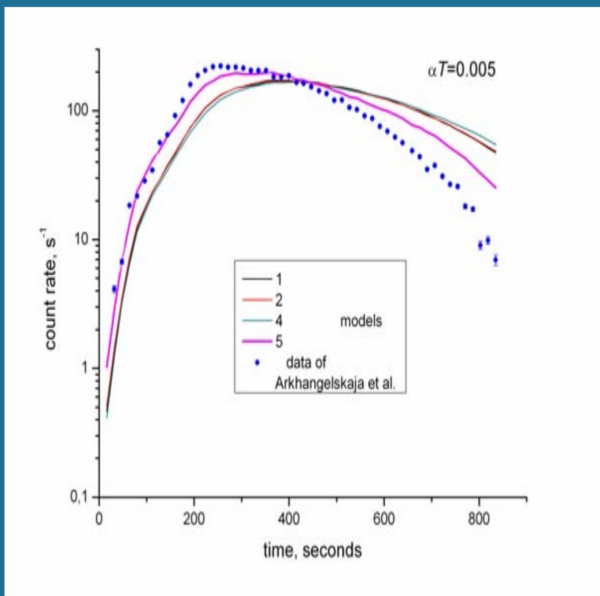
10^6 cm$\cdot 5 \cdot 10^{15}$ cm$^{-3} \cdot 1.67 \cdot 10^{-24}$ g $\cdot 5 = 0.04$ g$\cdot$cm^{-2}

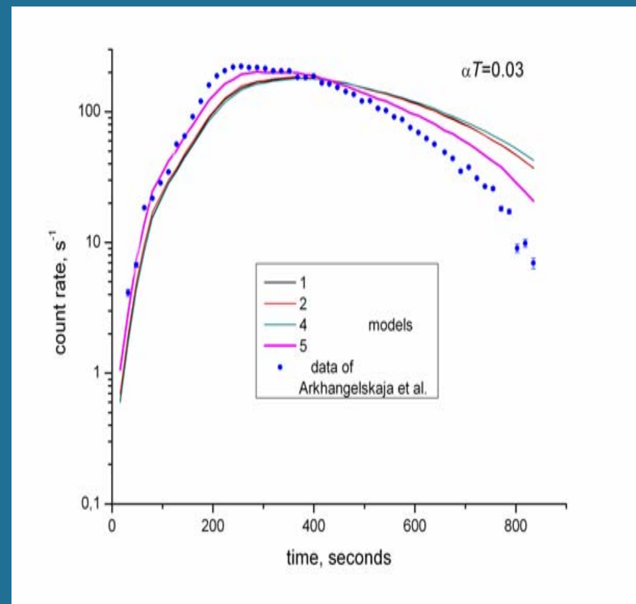
- Compare this grammage **0.04 g·cm^{-2}** with those one, required for thermalization of energetic neutron:

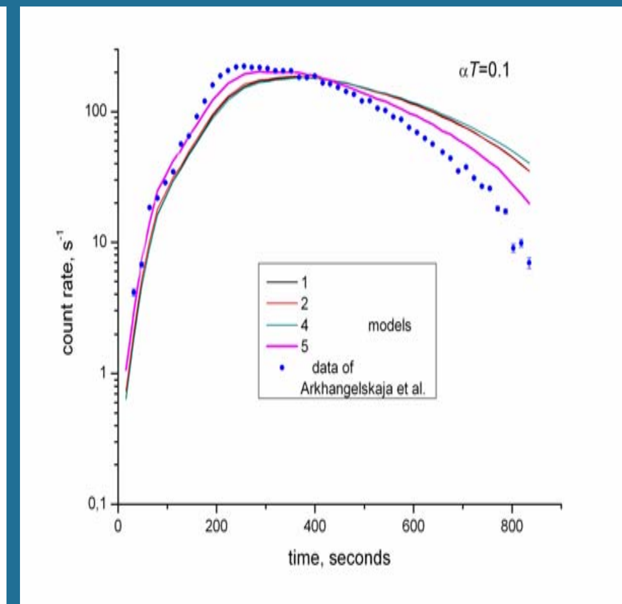
E_n, MeV	1	5	10	20	30	50
g/cm^2	2.0	2.6	3.6	4.4	6.2	10

- The most effective for producing 2.223 MeV gamma-line are neutrons with energies 10-50 MeV.
- We have to conclude that the reason of density enhancement is not the primary release of energy and the shock waves.

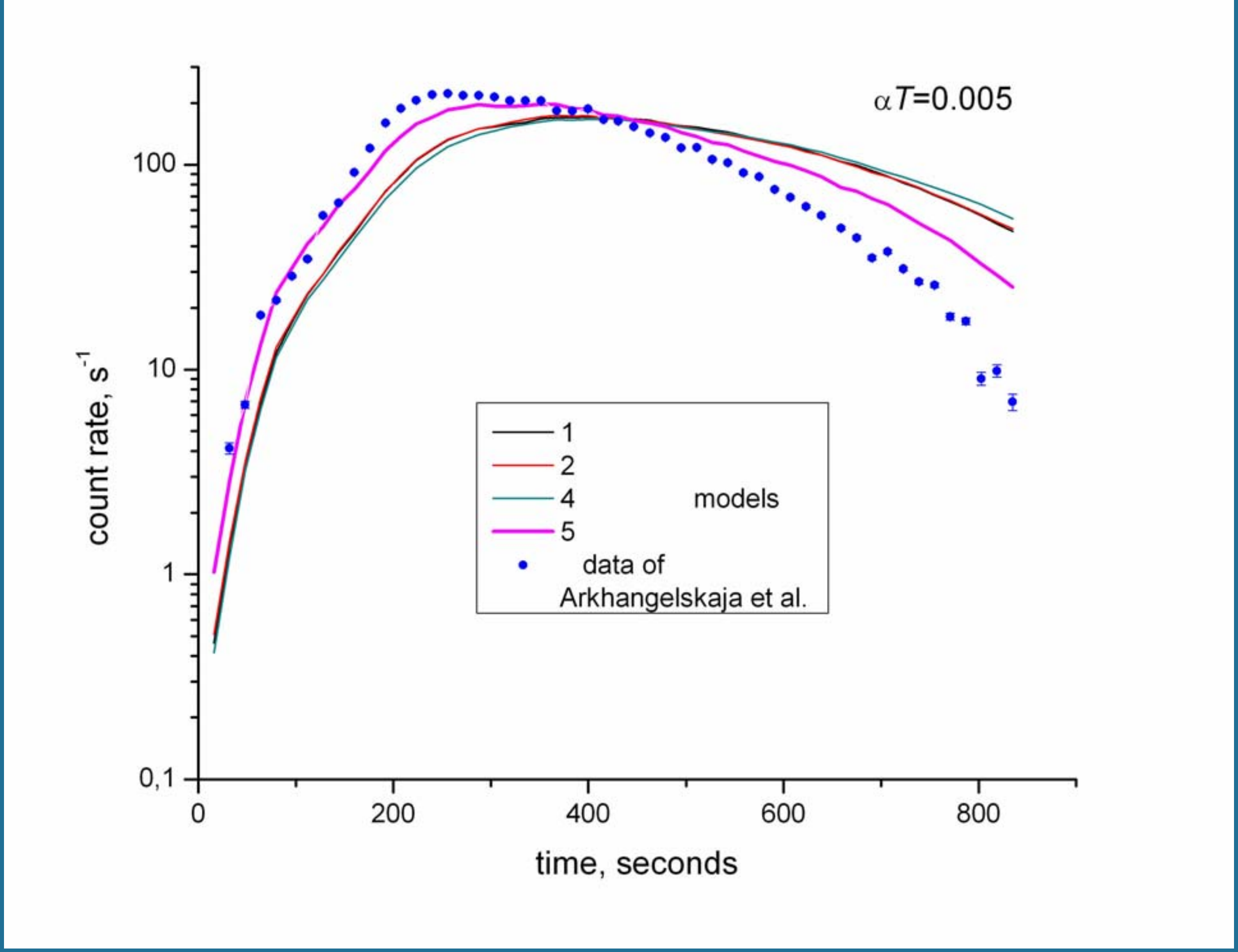
Solar flare 20 January 2005



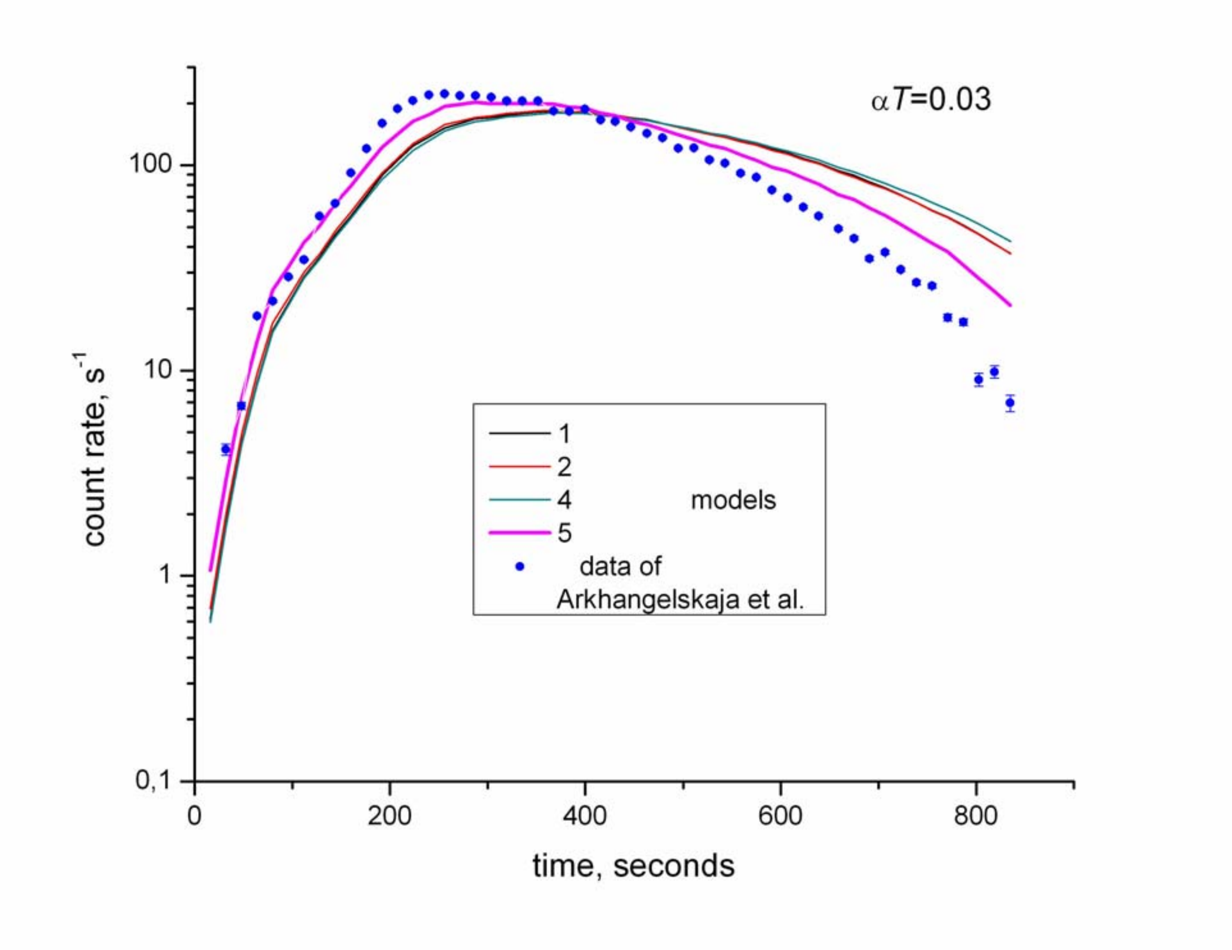




For this solar flare it is impossible to modeling the time profile using our method and we are compelled to recognize the impossibility to understanding this flare in the frame of our suppositions without additional ones.



αT=0.005
count rate, s-1
100
10
1
0,1
0
200
400
600
800
time, seconds
1
2
4
5
models
data of
Arkhangelskaja et al.


αT=0.03
count rate, s-1
100
10
1
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200
400
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time, seconds
1
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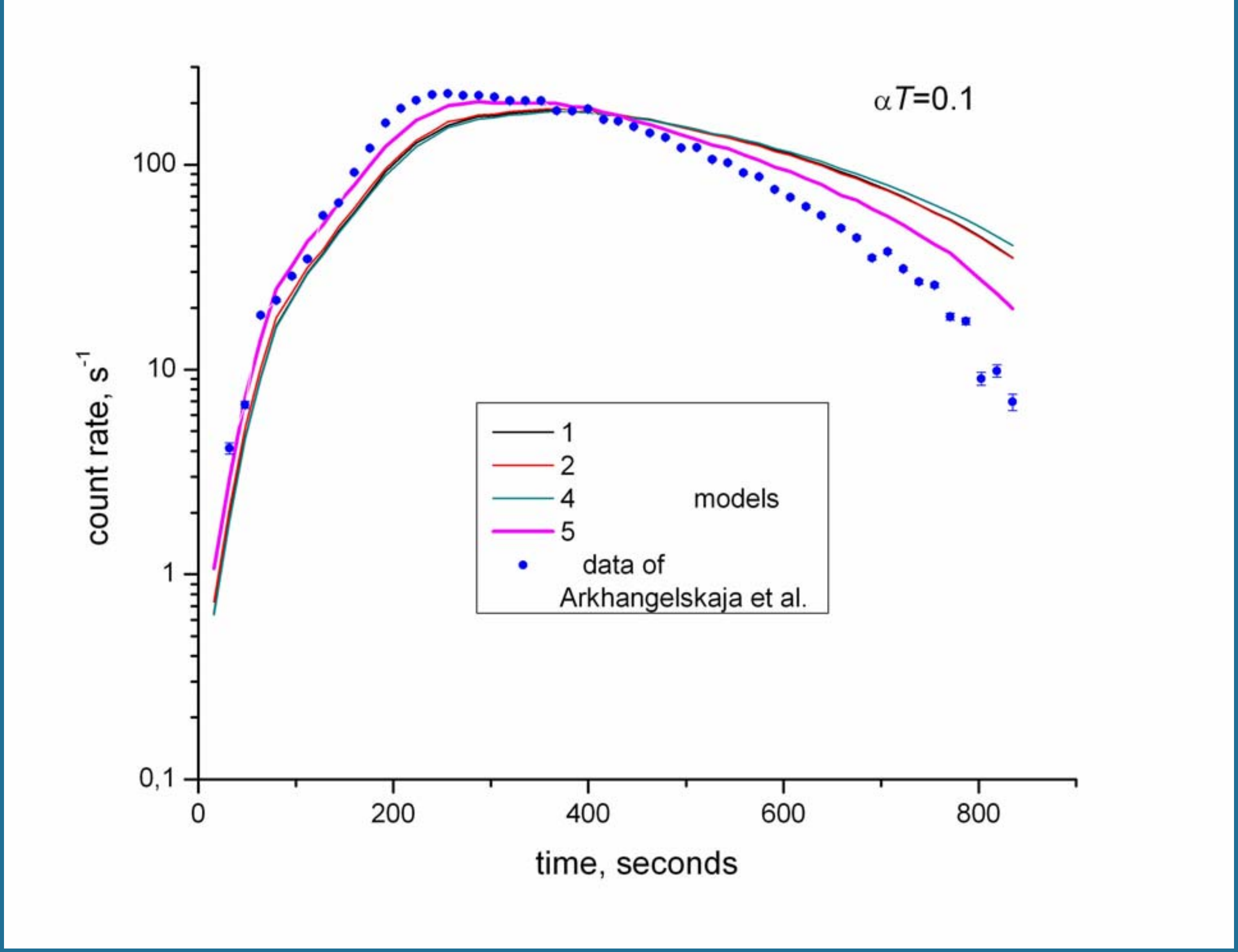
data of
Arkhangelskaja et al.



αT=0.1
count rate, s^-1
100
10
1
0,1
0
200
400
600
800
time, seconds
1
2
4
5
models
data of
Arkhangelskaja et al.

Discussion

- Too quick decay of gamma-emission, generated by neutrons, requires the loss of a part of protons or neutrons so that last ones couldn’t give the contribution to generation of 2.223 MeV gamma-rays.
- To satisfy this requirement we may suppose the confinement of a part of accelerated protons in any magnetic structure during the flare. If supposing the small enough quantity of the matter in this structure, we may conclude that these protons may not produce neutrons during the time of this flare.
- By this way we can explain the sharp decay of 2.223 MeV gamma-line data.

Discussion (continuation)

- Although the supposed explanation of our results doesn’t lead to contradictions, we ought to consider another possibility:
- In this event it is defined with good probability the radiative neutron absorption line 20.58 MeV generated in collisions by neutrons on ^3He. One of the factors, leading to appreciable line is the enhanced quantity of ^3He in accelerated particles in some flares (Arkhangelskaya et al., the report at this conference) and losses the neutrons in the reactions with ^3He:

$$n + {}^3He \rightarrow {}^4He + \gamma(20.58\ \text{MeV}).$$

Conclusions

1) In the present work we confirm for the 28.10.200 flare the previously conclusions about the density enhancements in the deep photospheric or subphotospheric layers that were made earlier for 3 flares. The hardening of particle spectra is also confirmed.
2) We have analyzed the reasons of the density enhancement in the subflare region and we have to conclude that the reason of density enhancement is not the primary release of energy and the shock waves. The origin may be connected with the magnetic loop in which the flare is developing.
3) It is shown that the 20.01.2005 flare can’t be modeled by usually realized parameters. Two possible explanations of the phenomenon are suggested.