Time profile of the 2.223 MeV gamma-line emission and some features of the 16 December 1988 solar event

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Abstract

We have studied the formation of 2.223 MeV gamma-line, arising of solar flare neutron captures on hydrogen in the photosphere and lower levels. Applying the results of calculations to the 1988 December 16 solar flare (exactly, to its third, last gamma-emission peak) enable us to deduce the enhanced density in the whole thickness of photosphere in the period of this flare like it was previously found for two other flares [6]. We also conclude that the charged particle spectrum evolve during the decay phase of corresponding charged particles acceleration process. The spectral index αT in Bessel representation changes from 0.005 up to 0.1 with the meaning 0.03 for the best approximation of whole the peak. Character of ion spectral evolution confirms previous result found by another method [1].

1. Introduction

It is well known that 2.223 MeV γ-line can be used for determining charged particles spectra [7], their angular distribution [3] and photospheric ^{3}He abundance[8]. In [5, 6] the 2.223 MeV line time profile analysis was applied for determining the most probable character of the solar photosphere and adjoining levels altitude density profile during the period of flare. Gan [1] for the first time applied the time profile of the line to deduce the spectral evolution of the charged particles. In the most of above studies the data on 4–7 MeV γ-emission were also necessary for the analysis.

Using the previous method [5,6], we could determine the spectral index of initial energetic neutrons produced in nuclear reactions in the process of flare simultaneously with deducing the most probable solar plasma density vertical profile. Now we revise the method and apply it to study the flare. A new approach

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enables us to deduce the spectral index of accelerated particles and its evolution simultaneously with deducing the surrounding plasma density altitude profile.

2. Methods

The calculations of neutron propagation in the solar matter and 2.223 MeV γ-line production are made using Monte-Carlo simulation. We make allowance for (i) neutron deceleration in elastic collisions with hydrogen nuclei, with due account for the energy and angular dependencies of *np*-scattering cross-sections; (ii) possible energetic neutron escape from the Sun; (iii) gravitational neutron-Sun interaction; (iv) thermal motion of decelerated neutrons; (v) neutron decay; (vi) neutron captures by hydrogen H, with deuterium and γ-quantum production; (vi) gamma-ray absorption in the solar atmosphere in dependence of solar flare central angle, (vii)non-radiative neutron absorption on ^{3}He, (viii)the time profile of initial neutron production — it is assumed to be proportional to that of ^{12}C+^{6}O gamma-line emission, (ix)initial neutrons spectra and (x)altitude dependence of surrounding matter density.

Calculations are made for neutrons with energies of 1–100 MeV which are the most important ones for the 2.223 MeV neutron capture gamma-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 $5 \cdot 10^{15}$ cm^{-3}.

A number of studies shows that the density of solar plasma during the flare is not discribed by the standard astrophysical model of quiet Sun. Some of such works are cited in [4]. For determining possible distortions of density model from experimental data we have composed four addition models representing smaller and larger densities in photospheric and subphotosphecic levels as compared with quiet model. Five modelsare presented in Fig.1, where H is deepness from the 10^{12} cm^{-3} level. Now we use the spectra of neutrons, calculated in [2] for 3 values of accelerated ions spectral indices αT in presentation of modified Bessel function of the second order.

3. Results

In Fig. 2 (a) it is presented the best approximation of experimental time profile fluxes[1]. It corresponds to the case of $\alpha T = 0.03$ and model 5 with the density enhancement in the thickness of photosphere. The rest 4 approximations are also shown. The best approximations for other cases are shown in the Table 1 (column “All”). For study possible evolution of αT index during the accelerative phase of the flare we made the same calculations for three segments of the time history. The best approximations for all the cases are summarise in the Table 1. The “absolute” best approximations selected for every of two decay time segments

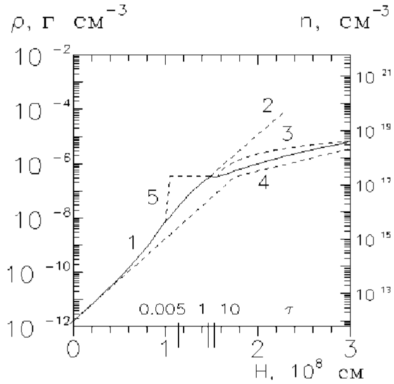

Fig. 1. Basic density model of the solar atmosphere (1) and four distorted models (2–5). Only fragments differing from the curve (1) are shown. τ is the optical depth for a wavelength of 500 nm, the level $\tau = 0.005$ corresponds to the top of photosphere.

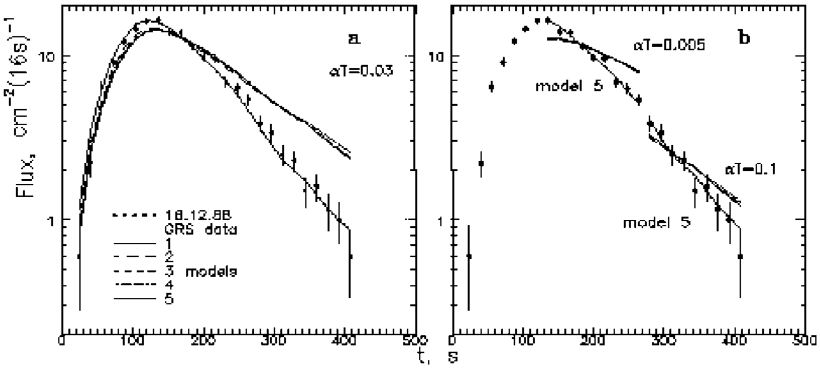

Fig. 2. Experimental 2.223 MeV γ-fluxes and the best approximation (a) for the mhole time profile, and (b) for two segments of the decay phase. Zero time corresponds to 1704 s after 08:26:23 UT [1].

are shown in Fig. 2 (b). They are $\alpha T = 0.005$ and model 5 and $\alpha T = 0.1$ and model 5 again.

4. Discussion

The application of renewed method for determining the most probable density altitude profile confirms the results of study the solar events of 6 November 1997 and 22 March 1991 [5,6],density enhancements in the deep layers was deduced for those flares too. Besides, the new approach enable to connect the 2.223 MeV time profile with the characteristics of acceleration process and reveal the trend of hardening the charged particles spectrum in the case of considered event of 16 December 1988. This conclusion confirms the results [1], which were deduced for this event and for several events more.

Table 1. The least square deviations calculation data from experimental ones

αT	Model	Σ Time interval All	24 s - 136 s	136 s - 264 s	280 s - 408 s
0.005	1	1.98E+02	3.94E+00	3.81E+01	3.16E+00
	2	1.87E+02	2.21E+00	3.71E+01	3.28E+00
	3	2.01E+02	2.07E+00	4.21E+01	3.19E+00
	4	2.12E+02	3.64E+00	3.92E+01	3.68E+00
	5	8.79E+00	2.98E+00	3.32E+00	1.14E+00
0.03	1	6.85E+01	1.56E+00	1.47E+01	1.85E+00
	2	5.26E+01	1.63E+00	1.04E+01	2.12E+00
	3	6.40E+01	1.46E+00	1.41E+01	2.03E+00
	4	6.95E+01	1.55E+00	1.35E+01	2.33E+00
	5	8.54E+00	3.09E+00	3.75E+00	3.98E-01
0.1	1	5.23E+01	1.44E+00	1.16E+01	1.63E+00
	2	3.76E+01	1.96E+00	7.37E+00	1.93E+00
	3	4.75E+01	1.62E+00	1.06E+01	1.82E+00
	4	5.23E+01	1.45E+00	1.03E+01	2.08E+00
	5	8.97E+00	3.08E+00	3.93E+00	3.39E-01

5. Conclusions

Two results, concerning key items of the development of solar flare, energy release and secondary effects are deduced by united method. For farther progress in its application it is important to use more additional information about the active process.

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6. References

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