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Absorption of 2.22 MeV solar flare gamma-rays and determining of the solar plasma density altitude profile

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Abstract

We supplement our previous model calculations of the 2.223 MeV solar flare gamma-rays time profiles by means of the consideration non-central flare and the calculations of the 2.223 MeV gamma-line τ-constant time profiles. Then we apply the proposed in our previous works method of the solar plasma density altitude profile definition, using the 2.223 MeV time profile, to the gamma-ray experimental data for the March 22, 1991, 22:42:51 UT solar flare. It is shown that, on the assumptions used, the most probable models of the altitude profile of the solar plasma during flare periods are the models with higher photospheric concentrations compared with the quiet Sun model.

1 Introduction:

In our previous works we have calculated the propagation of solar flare neutrons (Kuzhevskij \& Troitskaia, 1989), production of the solar flare 2.233 MeV γ-line (Kuzhevskij, Kuznetsov \&Troitskaia, 1998), and its absorption in the solar atmosphere (Kuzhevskij \& Troitskaia, 1998) and proposed the method for determining the solar plasma altitude profile during flare periods. The calculations were made for an instantaneous neutron source with energies 1-100 MeV and the power-low spectra within the same energy interval, using Monte-Karlo simulation. We made allowance for (i) neutron deceleration in elastic collisions between neutrons and hydrogen nuclei with due account of 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 with deuterium and γ-quantum production; (vi)γ-ray absorption in the solar atmosphere in the case of central flares. In the present work we apply the previously proposed method for a γ-ray solar event. For this purpose the model calculations of the absorption were made in the case of a non-central flare and, then, the τ-constant time profiles were calculated.

2 Experimental data:

The solar flare was recorded on March 22, 1991, 22:42:51 UT by the PHEBUS instrument on the GRANAT observatory (Terekhov et al., 1995). The flare was associated with the active region of coordinates S26E28. Optical and X- classes of the flare are 3B and X9.4, respectively.

γ-emission in the line 2.223 MeV was recorded with duration ≈550 seconds, which comparable with calculated γ-line duration in the case of instantaneous source.

The data on radioemission reveal the impulsive character of the flare. The radio emission 15.4 GHz began at 22:43 and ended at 22:46 UT. The II type radio burst, connected with the shock wave, lasted from 22:47 till 22:55 (Sladkova et al., 1998).

Besides that, in this event the photons with maximum energies 65-124 MeV was recorded (Terekhov., 1995). The duration of burst in all energetic intervals from 1-4 till 65-124 was ≈70 seconds with the main pulse duration of 25 seconds (from 75th till 100th seconds from the flare onset). The count rate in this interval was 8-14 times as greater as the count rate outside this 25-minutes interval.

All these circumstances enable the application of the model calculations with instantaneous neutron source to the solar flare 2.223 MeV γ-burst under consideration. It is necessary to note, that the averaging of experimental data for τ-constant calculations (Terekhov., 1995), is made at 40-50-seconds intervals, and the duration of the respective theoretical curves averaging is 40 seconds.

3 Model calculations:

The absorption of γ-rays for the case of non-central flare is taken into account by analogy with the case of central flare (Kuzhevskij \& Troitskaia, 1998). At 2.223 MeV the main mechanism of γ-rays reducing is Compton scattering by electrons. The mass coefficient of reducing is $\mu/\rho=0.08329$ cm^2 g^{-1}(Nemets 1975). The isotropy of γ-production is assumed. All the depth of the solar atmosphere is subdivided on the thin spherical layers, thin enough to assume its density to be homogeneous. The thickness of the passed way of γ-emission within one layer l is depended on the heliocentric angle a of the flare:

$$l = -(r-d)\cos a + \sqrt{(r-d)^2 \cos^2 a - d^2 + 2rd}\ ,$$

where r is the radius of the spherical layer, d – the thickness of the layer. The absorption, due to propagation through the layer is calculated, using the statistical weights technique.

Following the earlier works, for instance, (Kuzhevskij, Kuznetsov \&Troitskaia, 1998), we made calculations of the ejected γ-ray profiles for five models of solar plasma density (fig.1}: the basic astrophysical model (1) and four deformed models for the calculations. The primary neutrons were assumed to be emitted normally downwards with the power-law primary neutron spectrum ~E^{-S}, where s = 0,1,2,3. The calculations were made for the neutron issue, placed at the central solar angle 37.5°, correspondingly to the studied flare

The resulting time profiles at s=0 and 2 of ejected 2.223 MeV γ-emission are shown in fig.2. It can be seen that the profiles of γ-emission have the character, close to the profiles in the case of a central flare, which were examined in (Kuzhevskij \& Troitskaia, 1998), and the differences between them was discussed in connection with the possibility of determining of the solar plasma density model in many cases, using the present-day instruments.

Now we suggest to use for experimental data analysis the time history of the τ-constant, calculated from our 2.223 Mev γ-ray time profiles. The calculated τ-constant time profiles are shown in the fig. 3 and 4.

4 Comparing with experimental data:

We use the data, given in (Terekhov., 1995) on the τ-constant, deduced them at 5 points of the 2.223 MeV γ-line time profile. The moment of neutron injection is assumed to coincide with the moment of the channel 4-6 MeV γ-emission peak injection. The comparison with that of our calculated τ-constant time profiles, which are the closest to the experimental data presented at the fig. 4. The application to the data the least squares method reveals the best fitted curve. It corresponds to the case **s=0, model 2**. The second «candidate» is the case **s=0, model 3**.

5 Conclusion:

It is the first experience of application the method of determining the solar plasma density model by means of the analyzing a form of 2.223 MeV γ-line time profile. This method provides the unique possibility of investigation the deep photospherical and subphotospherical layers, because the noticeable fluxes of 2.223 MeV γ-emission can exit outside from the 15-18-grammage depth levels (Kuzhevskij \& Troitskaia, 1998). From the present analysis we conclude that for considered flare under made assumptions the most probable are the models with the enhanced density in deep photosphere, the value 0 of spectral index indicate that the neutron spectrum of the primary neutrons with energies 1-100 MeV have a flat or more complicate form.

This result is in accordance with the calculated spectra (Ramaty 1975), (Ramaty 1987), (Hua 1987), which have more complicate form than power-low ones, they are more hard in the region till 100 MeV.

For more accuracy of the method in further its development it is necessary to take into consideration some more circumstances: the altitude and angular distributions of primary neutrons, the time profile of their injection, the presence of ^{3}He as an addition loss of neutrons, and the temporal variations of density model.

Acknowledgment
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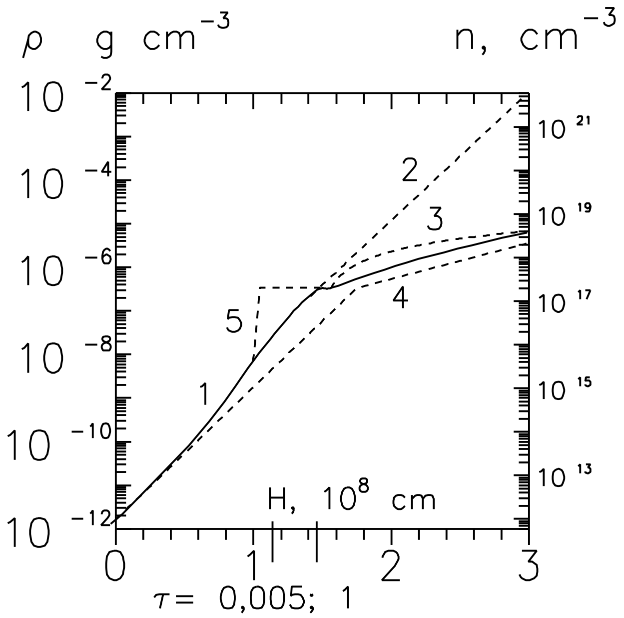

Figure1. Solid curve (1) is the basic density model, dashed curves (2-4) are our deformed models. Only fragments, differing from the main curve, are shown.

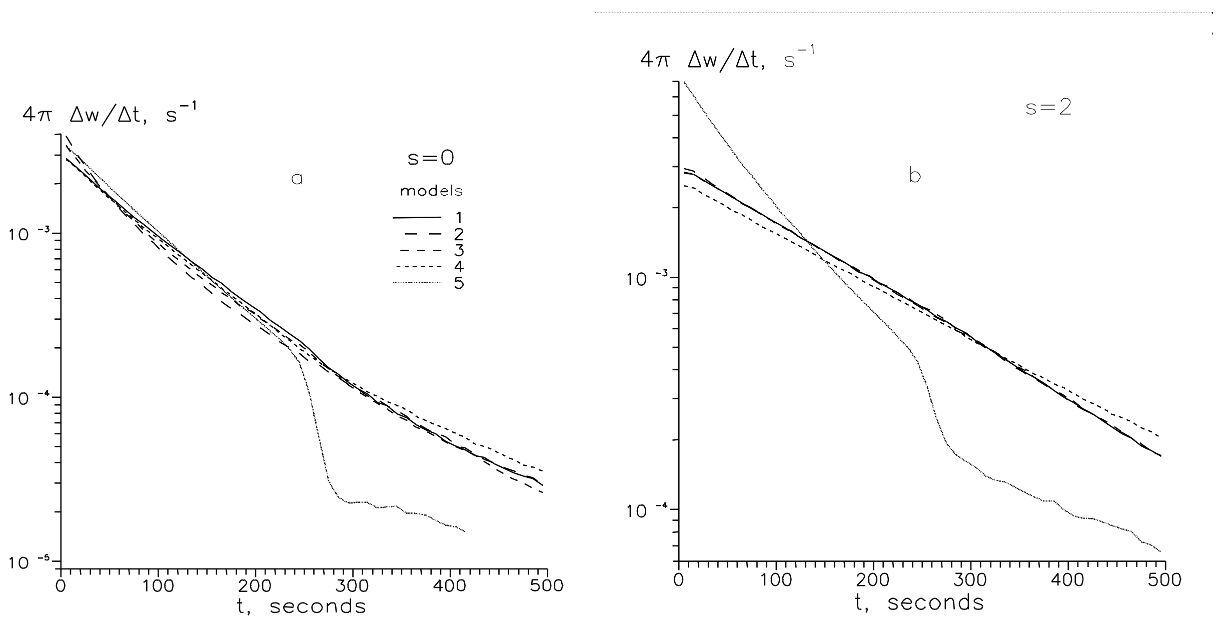

Figure 2. 2.223 MeV γ-ray time profiles.

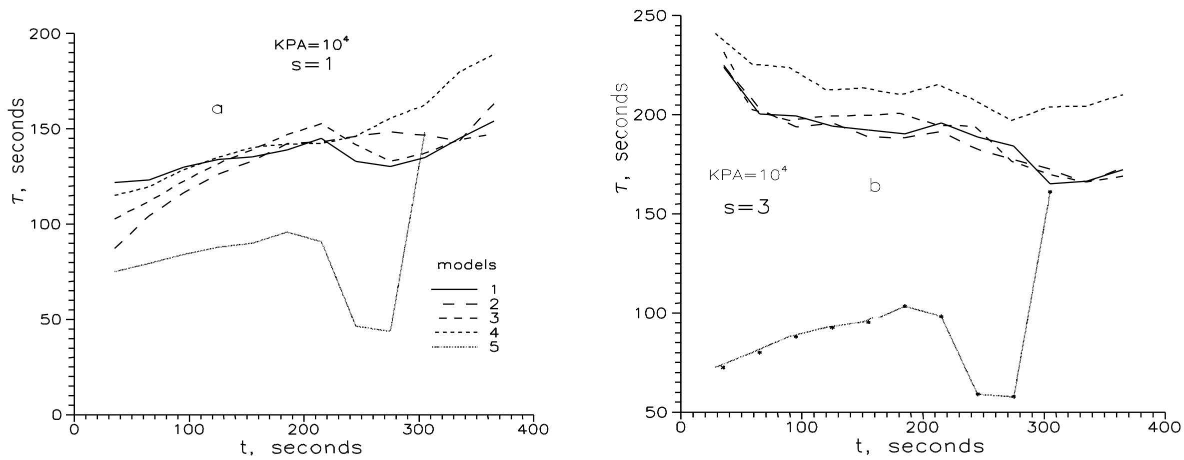

Figure 3. τ-constant time profiles.

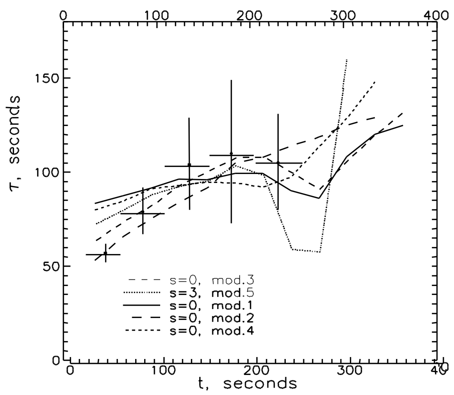

Figure 4. The fitting of experimental data by the calculated τ-constant time profiles.