



## The observation of gamma-ray emission during January 20 2005 solar flare

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**Abstract:** The solar flare of 20.01.2005 (class X7.1) was the biggest one in January 2005 series. It was started at 06:36 UT, ended at 07:26 UT and the maximum of X-ray emission was at 07:01 UT by GOES data. AVS-F apparatus onboard CORONAS-F registered  $\gamma$ -emission during rising phase of this flare in two energy bands: 0.1-20 MeV and 2-140 MeV. The highest  $\gamma$ -ray energy was registered during this flare was  $137 \pm 4$  MeV. Some spectral peculiarity was observed in the region of 19.5-21 MeV on  $2.5\sigma$  level in time interval 06:44:52-06:51:16 UT and  $3\sigma$  level in 06:47:00-06:49:08 UT one. The possibilities of this feature treatment as previously not observed in solar flares spectra  $\gamma$ -line 20.58 MeV from neutron capture radiation on  $^3\text{He}$  are discussed.

## Discrimination of n/ $\gamma$ events in AVS-F

AVS-F (amplitude-time Sun spectrometry) apparatus [1-3] was installed onboard CORONAS-F satellite (NORAD catalog number 26873, ID 2001-032A). It operated from July 31 2001 to December 6 2005. The orbit of satellite was approximately circular oriented towards the Sun with inclination  $82.5^\circ$  and altitude  $\sim 500$  km. Gamma-rays were registered by AVS-F in two energy bands by CsI(Tl)-based SONG-D detector  $\varnothing 20$ cm and height of 10 cm [4]. The energy bands limits (energy deposition ranges of 0.1-11.0 MeV and 4.0-94.0 MeV by first time calibration data) are shifted during apparatus operation: the energy threshold and amplification coefficient of low-energy band changed on 1% and 1.8% per month correspondingly and on January 2005 the low-energy band boundaries were 0.1-20 MeV and high-energy ones were 2-260 MeV [3]. The  $\gamma$ -ray and neutron events discrimination was performed using the selection of events by the scintillation detector light pulse shape based on the dependence of the ratio of intensities of light-output components with different fluorescence decay times to the average ionization density produced by charged particles in the detector material [5]. A scintillation flash in

CsI(Tl) consists of two main fluorescence components with decay times  $\tau_{\text{fast}} \approx 0.5-0.7 \mu\text{s}$  and  $\tau_{\text{slow}} \approx 7 \mu\text{s}$ , and the ratio of the slow component intensity  $Q_{\text{slow}}$  to the fast component intensity  $Q_{\text{fast}}$  depends on the interacting particles specific ionization. The method employed in AVS-F instrument is based on the integration of the signal from the SONG-D photomultiplier's preamplifier in two time intervals in which the total charge  $Q_{\text{tot}} = Q_{\text{slow}} + Q_{\text{fast}}$  and slow fluorescence component  $Q_{\text{slow}}$  were collected. Values of  $Q_{\text{tot}}$  and  $Q_{\text{slow}}/Q_{\text{tot}}$  for each recorded event were digitized by two 8-bit analog-to-digital converters and transferred as two-dimensional matrix to the system microprocessor controller for subsequent processing. The system energy resolution was 13.0% for  $\gamma$ -quanta from  $^{137}\text{Cs}$  ( $E_\gamma = 0.662$  MeV). The integration time for all presented temporal profiles (excluding some ones which are separately mentioned) is 16 s for low energy  $\gamma$ -band and 128 s for high energy one [1, 3].

## The characteristics of January 20 2005 solar flare by AVS-F apparatus

January 20 solar flare was started at 06:36 UT on

GOES data and ended at 07:26 UT. This flare was accompanied by particles events (protons and neutrons, which were most intensive ones for period of the last 15 years) [6] and coronal mass injection. Active region NOAA 10720 (N14W61) was the source of this flare. Gamma-emission of January 20 flare in energy bands of 0.1-20 MeV and 2-260 MeV was observed by AVS-F apparatus during

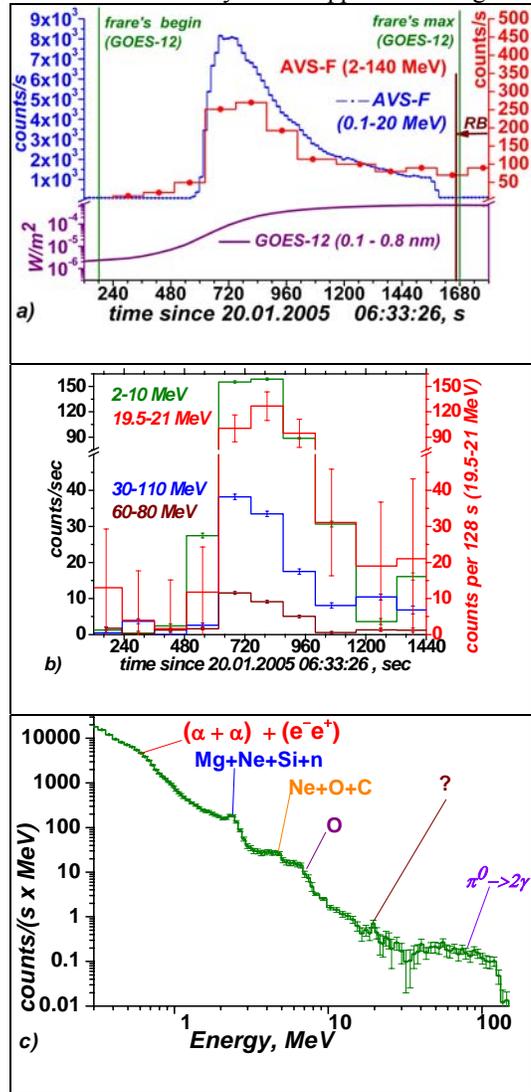


Figure 1: Solar flares January 20 2005 temporal profiles in by GOES data and in low and high energy  $\gamma$ -bands by AVS-F data (a), ones in different regions of AVS-F high-energy  $\gamma$ -band (b) and two-bands energy spectrum in time interval 06:44:52-06:51:16 UT by AVS-F data (c).

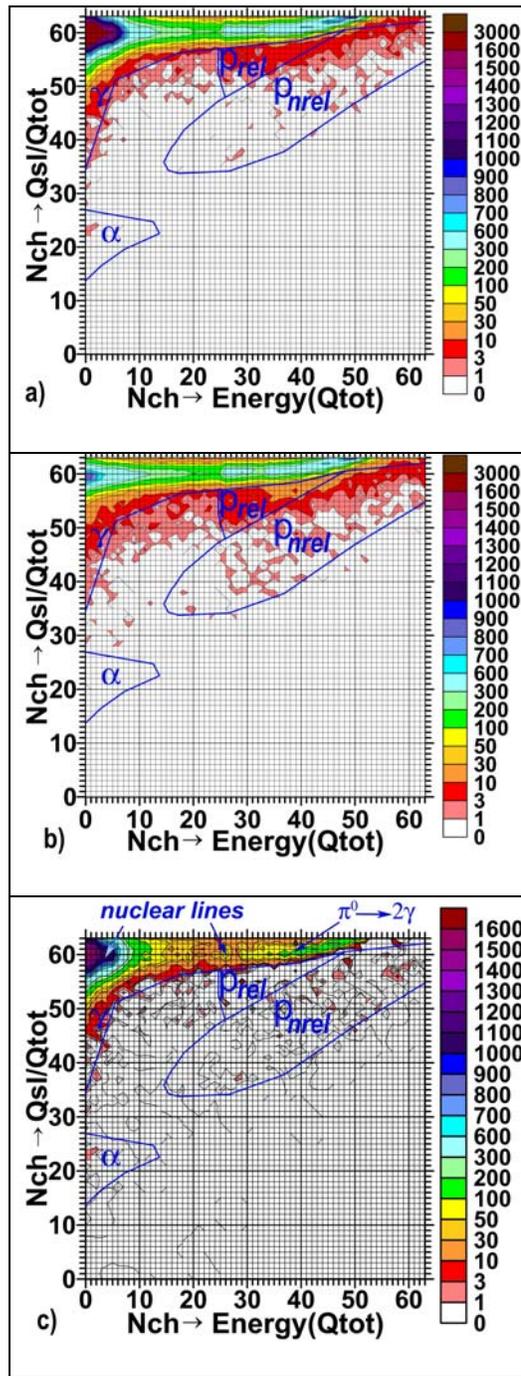


Figure 2: The ratio  $Q_{slow}/Q_{tot}$  in dependence of energy for January 20 solar flare in time interval 06:44:52-06:51:16 UT without (a) and with (c) background subtraction and for background (b).

X-ray emission rise by GOES data. The highest  $\gamma$ -ray energy was registered during this flare was  $137 \pm 4$  MeV. It was not observed statistical significance excess above background level in energy band 141-260 MeV. The count rate in low- and high-energy  $\gamma$ -bands droops to background level before maximum of X-ray emission by GOES data. January 20 flare's temporal profiles shape in  $\gamma$ -energy bands is very simple with one maximum and one in X-ray band by GOES data has one maximum too – see Figure 1a. Two bands energy spectrum of January 20 solar flare in time interval 06:44:52-06:51:16 UT by AVS-F data is shown at Figure 1c. Six spectral features were separated at this spectrum and 5 of them are typical for solar flares. Spectral feature in the region of 19.5-21 MeV was first observed in solar flare spectrum. Observed spectral features characteristics are presented in Table 1. All spectral features were observed during whole duration of  $\gamma$ -emission registered by AVS-F from this flare. Energy spectra in AVS-F high-energy band obtained from convolution of two dimensional distribution of ratio  $Q_{\text{slow}}/Q_{\text{tot}}$  in dependence of energy at axis  $Q_{\text{slow}}/Q_{\text{tot}}$ . Analysis of two dimensional distribution of ratio  $Q_{\text{slow}}/Q_{\text{tot}}$  in dependence of energy shows that in the time interval 06:44:52-06:51:16 UT only  $\gamma$ -emission observed from January 20 solar flare. Areas at two-dimensional distribution which correspond to registration of protons and  $\alpha$ -particles contain small amount of counts – see Figure 2. So, all spectral features at January 20 energy spectra by AVS-F data was caused only by  $\gamma$ -emission. This flare temporal profiles in AVS-F high energy  $\gamma$ -band in regions corresponding to nuclear lines (2-10 MeV), new observed spectral feature (19.5-21 MeV), pion line maximum 60–80 MeV and in region 30–110 MeV are shown at Figure 1b. It is seen, that behavior of temporal profile in the band 19.5-21 MeV correspond to nuclear lines one. Maxima in the regions 60–80 MeV and 30–110 MeV are shifted at some tens seconds (acquisition interval in AVS-F high energy  $\gamma$ -band is 128 s). So, spectral feature in 19.5-21 MeV band looks like nuclear line. The confidence level of this feature separation in summarized spectrum is  $2.4 \sigma$ , but in the flare maximum it separated at  $3 \sigma$  one.

Table 1. Spectral features observed during January 20 solar flare in interval 06:44:52–06:51:16 UT.

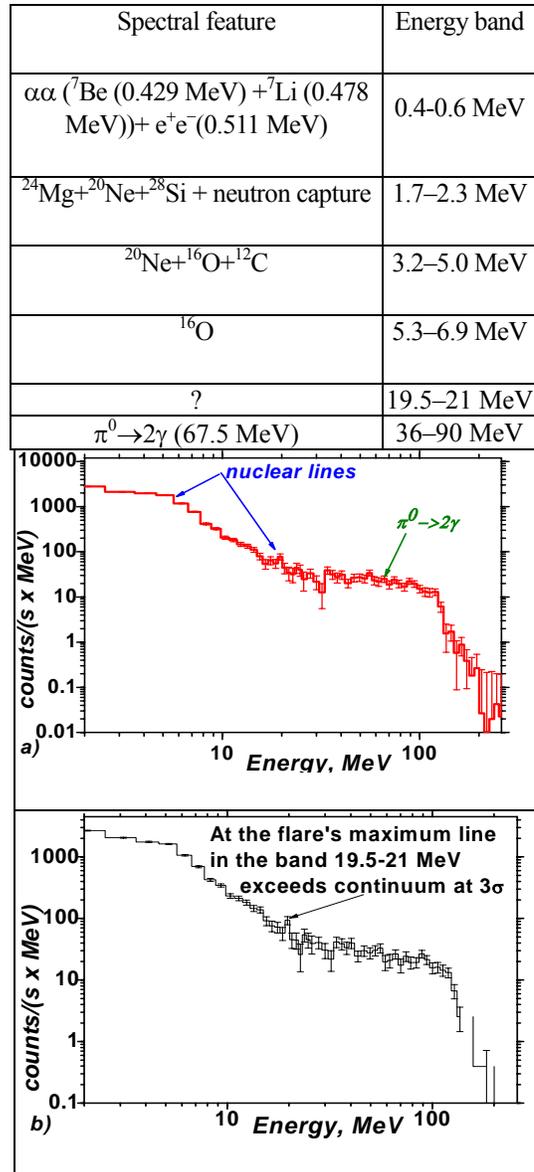


Figure 3: January 20 solar flare energy spectra in high energy  $\gamma$ -band: a) obtained from convolution of matrix at figure 2c (06:44:52-06:51:16 UT), b) corresponding maximum of high energy  $\gamma$ -emission (in time interval 06:47:00-06:49:08 UT).

## Discussion

We suppose that observed spectral feature in energy band 19.5-21 MeV perhaps can be explained as neutron capture line at  ${}^3\text{He}$  with energy 20.58 MeV. The possibility of this line observation in solar flares was first discussed in [8]. The preliminary values of intensity ratio between this line and other spectral features observed by AVS-F apparatus are presented in Table 2.

Table 2. Intensity ratio of spectral feature in 19.5–21 MeV band to other ones.

Spectral feature, MeV	Intensity ratio
1.7-2.3	1500±100
3.2-5.0	130±15
5.3-6.9	95±14

The abundance of  ${}^3\text{He}$  in solar atmosphere usually is estimated to be  $\sim 2 \times 10^{-5}$  of H primarily based on solar wind, coronal, and meteoritic measurements but in some works mentioned that accelerated  ${}^3\text{He}$  is sometimes enhanced by a factor of 1000 or even more over its solar concentration [9, 10]. In this case it is possible to obtain mentioned in Table 2 ratio between lines 2.223 and 20.58 MeV but for this conclusion it needs some additional calculations based on modern solar models.

## Conclusions

During January 20 solar flare (class X7.1) which was the biggest one in January 2005 series  $\gamma$ -emission during its rising phase in two energy bands: 0.1-20 MeV and 2-140 MeV observed by AVS-F apparatus onboard CORONAS-F satellite. The highest  $\gamma$ -ray energy was registered during this flare was  $137 \pm 4$  MeV, in energy band 140-260 MeV statistical significance excess above background level was not observed. Nuclear, annihilation, neutrons capture at  ${}^4\text{H}$  lines and spectral feature corresponding decay of neutral pions were observed in this flare energy spectrum during whole time of

this flare  $\gamma$ -emission registration by AVS-F.

Some spectral peculiarity was observed in the region of 19.5-21 MeV on 2.5 and 3 standard deviation level in time intervals 06:44:52-06:51:16 UT and 06:47:00-06:49:08 UT correspondingly. Perhaps it can be neutron capture line at  ${}^3\text{He}$  with energy 20.58 MeV if we make some additional assumptions about local concentration of  ${}^3\text{He}$  in solar atmosphere near flare region and neutron flux during this flare. Such conditions very likely for this flare because it accompanied by strong neutron GLE, which was the most intensive one for period of the last 15 years.

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