# The Investigation of the Neupert Effect in Faint Solar Flares on AVS-F Data

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***Abstract*. The Neupert effect is the empirical result that for many solar flares the time derivative of the soft X-ray emission temporal profile is similar to the temporal variation of the hard X-ray emission. This correlation implies that the same energetic electrons which produce the observed hard X-ray emission during solar flare also heat the plasma that produces the soft X-ray emission. However, such effect is not clearly observed in some part of intensive solar flares according to data of SMM, BATSE, RHESSI and so on. The results of faint solar flares (B and C classes by GOES classification) investigation on AVS-F data onboard CORONAS-F satellite are discussed. Hard X-ray and gamma-ray emission up to several MeV was observed during some solar flares of B and C classes by AVS-F apparatus. The Neupert effect was observed during some faint flares and some events with temporal profiles behaviour contradict typical for this effect one were registered. It allows to suppose that emission of several faint solar flares contain sufficient contribution of nonthermal component as well as more intensive ones.**

***Keywords*: faint solar flares, Neupert effect, AVS-F**

## I. INTRODUCTION

During many solar flares a temporal variation of the radio and hard X-ray flux are similar to behaviour of a derivative of a temporal profile of the soft X-ray one. This phenomenon (the Neupert effect) was first mentioned in 1968 [1] and related with processes of generation of solar flares emission in radio, hard and soft X-ray energy ranges, because of the same energetic electrons produced the observed hard X-ray and microwave emission also heat the plasma that produces the soft X-ray emission. The radio emission during solar flares produced in several processes, in particular by nonthermal electrons synchrotron emission (this process well correlates with processes of formation of hard X-ray bremsstrahlung emission of the same nonthermal electrons) and by bremsstrahlung emission of electrons in solar atmosphere. Thus, hard X-ray emission is formed together with radio emission and in a radio band the behaviour of solar flares temporal profiles is similar to the Neupert effect [2]. The typical example of the Neupert effect in C4.7 solar flare on August 31, 2002 [3] is shown in Fig. 1. Significant correlation between behaviour of a time derivative of soft X-ray flux temporal profiles in range 0.5-4 Å and hard X-ray count rate in the energy band of 20-100 keV was observed.

About 80% of solar flares of class more than X1 correspond to the Neupert effect according to SMM/HXRBS data [4], approximately 75% ones of classes more than C4 correspond to the Neupert effect on RHESSI data [3]. In analysis of CGRO/BATSE data only flares with statistically significant flux in energy band $E_\gamma > 0.3$ MeV taking into account and it was found that about of 50% solar flares correspond to the Neupert effect [5].

However sufficient part of solar flares (both strong and faint) is inconsistent with the Neupert effect. In particular, according to SMM data analysis it was shown that in accelerated electrons with energies above 25 keV may be even more energy than in the soft X-ray emitting thermal plasma [6]. Moreover so called partial Neupert effect was observed during some flares on YOHKOH and RHESSI data [6], [7] when flaring region was asymmetrical. In such cases (for example, during solar flare November 2, 1991 [8]) Neupert effect was observed from one footpoint of loop but other footpoint showed an impulsive peak in both the hard and soft X-ray emissions from the same location [6].

## II. BRIEF DESCRIPTION OF AVS-F APPARATUS ONBOARD CORONAS-F SATELLITE

The AVS-F (Amplitude-Time Sun spectrometry) apparatus [9], [10] was intended to study characteristics of fluxes of hard X-rays and $\gamma$-rays from solar flares and to detect other non-stationary fluxes of cosmic $\gamma$-rays. The experiment was conducted within frameworks of the CORONAS (Complex ORbiting ObservatioNs of the Active Sun) international project onboard the special-purpose automatic station CORONAS-F during time period from 31.07.2001 to 06.12.2005.

This apparatus constitutes the system of electronic for onboard data acquisition from two detectors: SONG-D [11] (CsI(Tl) scintillation detector with size Ø200 mm and 100 mm height, fully surrounded by plastic anticoincidence shield) for hard X-ray and $\gamma$-ray analysis in two bands 0.1-10 MeV (low energy band), 2-80 MeV (high energy band) and neutrons flux registration in energy range 10-300 MeV and XSS-1 [12], [13]

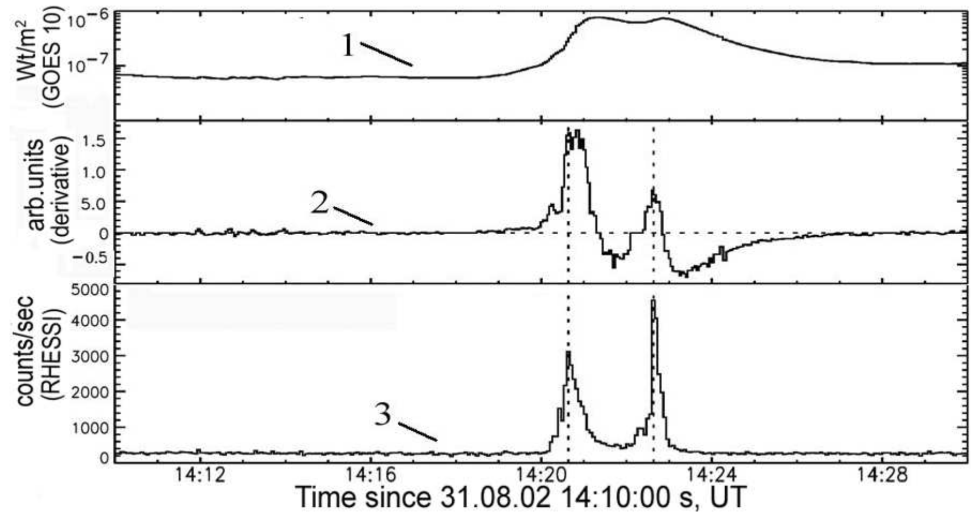


Fig. 1: The appearence of the Neupert effect during flare 31.08.2002(adopted from [3]): curves (1) and (2) show the soft X-ray emission temporal profile according to GOES-10 data in range 0.5-4 Å and its time derivative; count rate temporal profile of hard X-ray emission in band 20-100 keV on RHESSI data is presented at curve (3).

(CdTe semiconductor detector with size 4.9 mm×4.9 mm) for X-ray analysis in 3-30 keV band. The detector's thresholds and amplification coefficients were changed approximately on 1% per month during apparatus operation [14], [15]. The energy resolution of the system was $\sim 13.0\%$ for $\gamma$-quanta from $^{137}\mathrm{Cs}$ with energy $\mathrm{E}_\gamma = 0.662\,\mathrm{MeV}$ [15].

AVS-F apparatus operated in two modes: background and flare. In the background mode the integration times were 16 s in X-ray and low energy band and 128 s in high-energy one correspondingly; in the flare mode the integration times were 1 s in X-ray and low energy region and 4 s in high-energy one.

The discrimination between $\gamma$-ray and neutron events was performed by using the selection of events by the scintillation detector light pulse shape. There are two light-output components in CsI(Tl) scintillator (slow and fast with decay times $\mathrm{t_{slow}} \approx 7\,\mu\mathrm{s}$ and $\mathrm{t_{fast}} \approx 0.5 \div 0.7\mu\mathrm{s}$ correspondingly) and their intensities depends from the average ionization density produced by charged particles in the detector material. In the AVS-F apparatus the method based on the integration of the signal from the SONG-D photomultipliers preamplifier in two time intervals was used. First interval $\mathrm{t}_1$ was the time period in which the total charge $\mathrm{Q_{tot}} = \mathrm{Q_{slow}} + \mathrm{Q_{fast}}$ was collected and second one $\mathrm{t}_2$ was the time during which the slow fluorescence component $\mathrm{Q_{slow}}$ was collected. The values of $\mathrm{Q_{tot}}$ and $\mathrm{Q_{slow}}/\mathrm{Q_{tot}}$ were digitized by two 8-bit ADC for each recorded event and transferred as two-dimensional matrix to the system microprocessor controller for subsequent processing.

## III. Faint solar flares characteristics on AVS-F apparatus data

During investigation of some solar flares with classes B and C on GOES classification statistically sufficient flux was observed by AVS-F apparatus both in soft X-ray band (3-30 keV) and in energy band $\mathrm{E} > 50\ \mathrm{keV}$ [16]. In particular, $\gamma$-quanta with energy $\mathrm{E}_\gamma = 7.0 \pm 0.3\,\mathrm{MeV}$ was registered during January 12, 2005 solar flare (class B4.6, flare's beginning was at 20:08 UT, flare's end was at 20:13 UT on GOES data) [17].

There is not any strong correlation between presence or absence of high energy $\gamma$-rays and the intensity of soft X-ray emission during solar flares because of it was not any statistically significant count rate exceed above background level was observed during some flares with class M, for example, during event November 8, 2001 (class M4.2, flare lasts from 14:59 UT up to 16:00 UT, maximum of soft X-ray emission was at $\sim 15\!:\!35$ UT on GOES data).

According to AVS-F data about 50% of faint solar flares (classes B and C on GOES classification) for which statistically significant flux in energy band $\mathrm{E} > 100\ \mathrm{keV}$ was registered correspond to Neupert effect. The typical example of such event is class 1.1 solar flare January 3, 2005 presented at fig. 2. It is seen (taking into account the difference of time scales of GOES and AVS-F data) significant correlation between behaviour and maxima of a time derivative of soft X-ray emission temporal profile in ranges 1-8 Å and 3-30 keV and a structure of count rate temporal profile of hard X-ray and gamma emission in energy band 0.1-2 MeV similarly to the flare shown at fig 1.

Also the essential quantity of faint flares during which the effect Neupert was not observed was registered. Usually (by the preliminary results of the AVS-F database analysis) during such flares high energy gamma emission up to several tens of MeV was registered. Temporal profiles of one of such flares (7.01.2005, class B2.3) according to AVS-F and GOES data are presented at fig. 3. Correlation between behaviour of a time deriva-

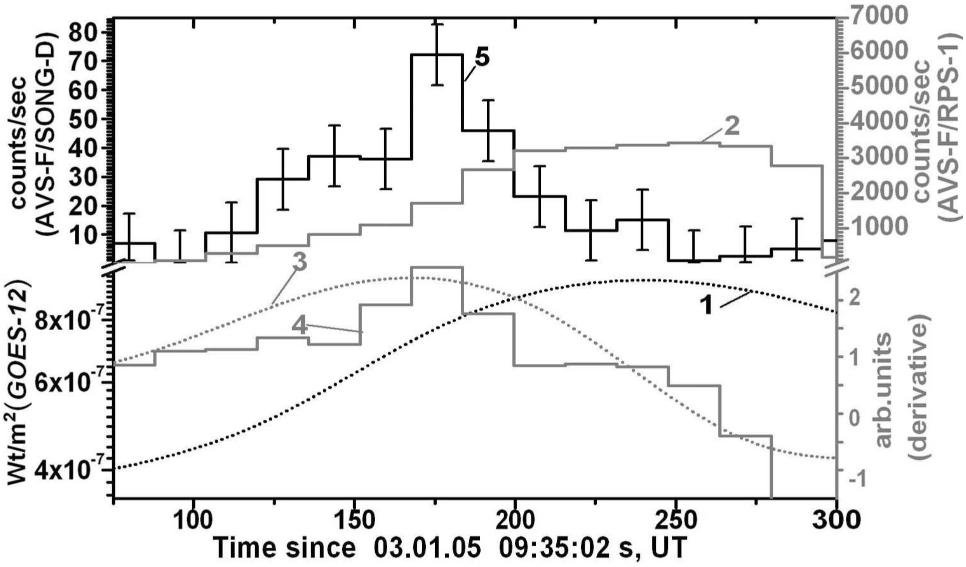


Fig. 2: The appearance of the Neupert effect during January 3, 2005 solar flare: curve (1) and histogram (2) show the temporal profiles of soft X-ray emission on data of GOES-10 in range 1-8 Å and of AVS-F/XSS-1 in energy band 3-30 keV; curve (2) and histogram (3) present their time derivatives; count rate temporal profile of hard X-ray and gamma emission in energy band 0.1-2 MeV on AVS-F/SONG-D data is shown at histogram (5).

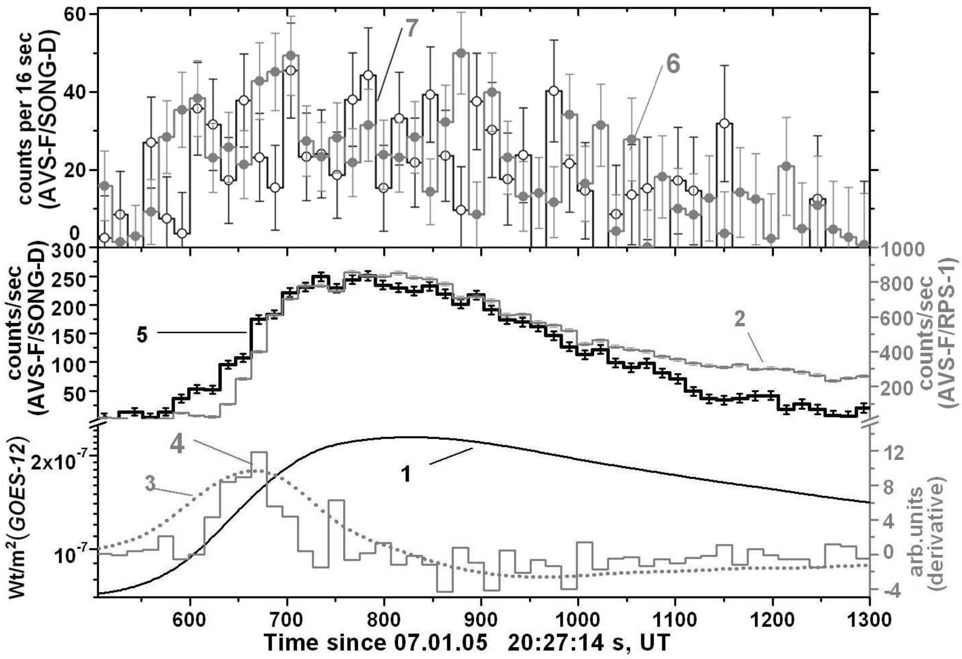


Fig. 3: January 7, 2005 solar flare temporal profiles in soft X-ray band on data of GOES-10 in range 1-8 Å and of AVS-F/XSS-1 in energy band 3-30 keV, their time derivatives — curve (2) and histogram (3) correspondingly; and this flare temporal profiles on AVS-F/SONG-D data in energy bands 0.1-20 MeV, 15-20 MeV and 4-8 MeV — histograms (5), (6) and (7) correspondingly.

tive of soft X-ray emission temporal profile in ranges 1-8 Å and 3-30 keV and a structure of count rate temporal profile of hard X-ray and gamma emission energy band $\mathrm{E} > 0.1$ MeV was not found at 99% significance level taking into account the difference of time scales of GOES and AVS-F data. But 95% correlation between temporal profiles in ranges 1-8 Å and 3-30 keV on GOES and AVS-F/XSS-1 data and 0.1-7 MeV on AVS-F/SONG-D data was observed during solar flare January 12, 2005 — see fig. 4.

Energy spectra of all faint solar flares registered by AVS-F apparatus are power-like without any features by results of preliminary data analysis [17]. Some thin structure with characteristic timescale 50-110 s was observed on temporal profiles of some faint events, for example on January 7 and 12, 2005 flares (classes B2.3 and

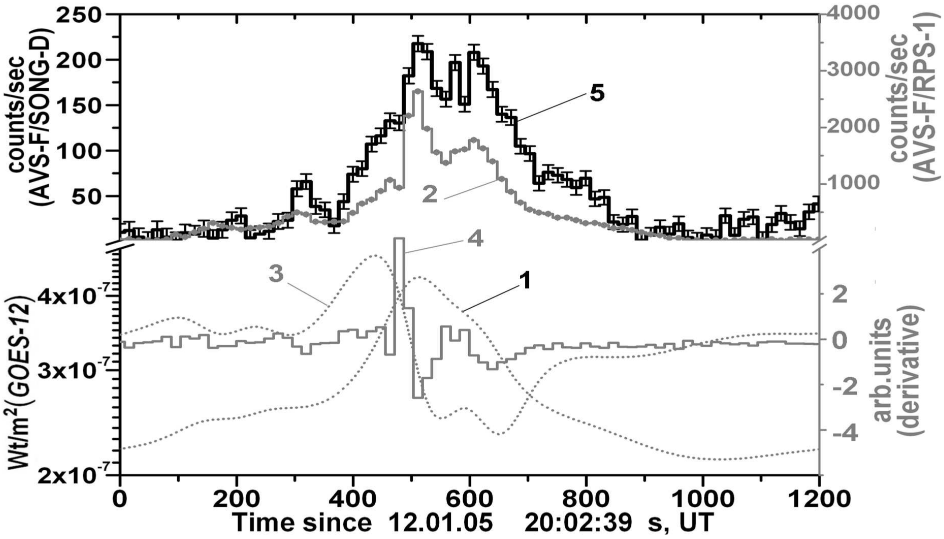


Fig. 4: January 12, 2005 solar flare temporal profiles in soft X-ray band on GOES-10 data in range 1-8 Å and of AVS-F/XSS-1 in energy band 3-30 keV, their time derivatives — curve (2) and histogram (3) correspondingly; and this flare temporal profile on AVS-F/SONG-D data in energy band 0.1-7 MeV — histogram (5).

B4.6 correspondingly) and on March 5, 2005 one (class B2.0) [16], [17].

## IV. Conclusions

Only about 50% of faint solar flares (classes B and C on GOES classification) for which statistically significant flux in energy band $\mathrm{E} > 100\ \mathrm{keV}$ was registered correspond to Neupert effect according to AVS-F data. Discordance of behaviour of hard X-ray and gamma emission temporal profiles and time derivative of soft X-ray emission temporal profiles during faint solar flares can indicate that in such flares occurs additional particles acceleration or dissipation of their energy, for example, due to turbulence. Besides if emission was formed mainly in the footpoint of the asymmetrical loop, the summarized temporal profiles (without spatial resolution) contradict Neupert effect even if in each footpoint such effect exists. The further studying of characteristics of faint solar flares corresponded to the Neupert effect or inconsistent with one allows to make clear many problems of faint solar flares origin and dynamics of particles acceleration during such weak events.

## References

[1] W.M. Neupert. "Comparison of solar X-ray line emission with microwave emission during flares," *Astrophys. J.*, vol. 153, pp. L59-L64, 1968

[2] R. Talon, G. Vedrenne, A.S. Melioranski et al. // Solar Gamma-, X- and EUV radiation: proc. of the Symposium, Buenos Aires, Argentina, June 11-14, pp. 315-379, 1975

[3] A. Veronig. "The Neupert effect," *Hvar. Obs. Bull*, vol. 27, no. 1. pp. 47-58, 2003

[4] B.R. Dennis, D.M. Zarro."The Neupert effect: what can it tell us about the impulsive and gradual phases in solar flares," *Solar Physics*. vol. 146, pp. 177-190, 1993

[5] A. Veronig, B. Vrsnak, B.R. Dennis et al. "The Neupert effect and the electron-beam-driven evaporation model," Proc. of The 10th European Solar Phys. Meeting "Solar variability: from core to outer frontiers", 9 - 14 Sept. 2002, Prague, Czech Republic. Ed. A. Wilson. ESA SP-506, vol. 1., pp. 367-370, 2002

[6] Dennis B.R., Veronig A., Swatrz R.A. et al. "The Neupert effect and new RHESSI measures of the total energy in electrons accelerated in solar flares," *Adv. Space Res.*, vol. 32. no. 12. pp. 2459-2464, 2003

[7] V. Tomczak. "Yohkoh observations of the Neupert effect," *Astron. Astrophys*, vol.

[8] McTiernan J. M., Kane S. R., Loran J. M. et al. "Temperature and density structure of the 1991 November 2 flare observed by the YOHKOH soft X-ray telescope and hard X-ray telescope," *Astrophysical Journal Letters*, vol. 416. pp. L91-L93, 1993

[9] A.S. Glyanenko, Yu.D. Kotov, A.V. Pavlov et al. "The AVS-F experiment on recording rapidly changing fluxes of cosmic and gamma radiation prepared under the CORONAS-F project," *Instrum. Exp. Tech.*, vol. 42, no. 5, pp. 596-603, 1999

[10] A.I. Arkhangelskii and A.S. Glyanenko. "The MicroPC module application in the AVS-F apparatus onboard of the CORONAS-F satellite," *Modern Automat. Technolog.*, no. 3, pp. 30-34, 2004 (in Russian).

[11] S. N. Kuznetsov; K. Kudela, S. P. Ryumin et al. "CORONAS-F satellite: Tasks for study of particle acceleration," *Adv. Space Res.*, vol. 30, no.7, pp. 1857-1863, 2002

[12] V.M. Pankov, V. L. Prokhin, Yu.G. Shkurkin et al. "X-ray semiconductor (CdTe) spectrometer for solar flare and preflare studies" *Radiophys. Quant. Electron.*, vol. 39, no.11-12, pp. 1000-1005, 1996

[13] V.M. Pankov, V. L. Prokhin, N. G. Khavenson. "The RPS-1 X-ray CdTe spectrometer onboard the CORONAS-F satellite," *Solar System Res.*, vol. 40, no. 4, pp. 314-, 2006

[14] I.V. Arkhangelskaja, A.I. Arkhangelsky, Yu.D. Kotov et al. "The solar flare catalog in the low-energy $\gamma$-ray range based on the AVS-F instrument data onboard the CORONAS-F satellite in 2001-2005," *Solar System Res.*, vol. 40, no. 2, pp. 133-141, 2006

[15] I.V. Arkhangelskaja, A.I. Arkhangelskii, A.S. Glyanenko et al. "Inflight calibration and results of database treatment of AVS-F apparatus in experiment onboard satellite CORONAS-F," *Space science and technology*,vol. 9, no. 2, pp. 20, 2003 (in Russian)

[16] M.S. Kostina, I.V. Arkhangelskaja, A.I. Arkhangelsky et al. "Faint solar flares investigation on the data of AVS-F apparatus onboard the CORONAS-F Satellite", Proc. Scientific Session of the Moscow Engineering Physics Institute – 2008, Moscow: MEPhI, vol. 9, pp. 113-114, 2008 (in Russian)

[17] Arkhangelskaja I.V., Kostina M.S., Arkhangelsky A.I. et al. "Faint solar flares with hard X-ray and gamma emission observed by AVS-F onboard CORONAS-F satellite," Proc. 37th COSPAR Scientific Assembly, Canada, p. 121, 2008