The background model in the energy range from 0.1 MeV up to several MeV for low altitude and high inclination satellites.

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Abstract. The gamma-ray background physical origin for low altitude orbits defined by: diffuse cosmic gamma-emission, atmospheric gamma-rays, gamma-emission formed in interactions of charged particles (both prompt and activation) and transient events such as electrons precipitations and solar flares. The background conditions in the energy range from 0.1 MeV up to several MeV for low altitude orbits differ due to frequency of Earth Radiation Belts – ERBs (included South Atlantic Anomaly - SAA) passes and cosmic rays rigidity. The detectors and satellite constructive elements are activated by trapped in ERBs and moving along magnetic lines charged particles. In this case we propose simplified polynomial model separately for polar and equatorial orbits parts: background count rate temporal profile approximation by 4-5 order polynomials in equatorial regions, and linear approximations, parabolas or constants in polar caps. The polynomials’ coefficients supposed to be similar for identical spectral channels for each analyzed equatorial part taken into account normalization coefficients defined due to Kp-indexes study within period corresponding to calibration coefficients being approximately constants. The described model was successfully applied for the solar flares hard X-ray and gamma-ray emission characteristic studies by AVS-F apparatus data onboard CORONAS-F satellite.

1. Introduction
The gamma-ray background physical origin for X-ray and gamma-emission detectors installed onboard low altitude satellites defined by: diffuse cosmic gamma-emission, atmospheric gamma-rays, gamma-emission formed in interactions of charged particles (both prompt or activation) and Earth albedo neutrons [1, 2]. Prompt interactions caused due cosmic rays, transient events (magnetospheric electrons precipitations and charged particles originated in solar flares) and particles trapped in Earth Radiation Belts (ERBs) including South Atlantic Anomaly (SAA) region. Activation component occurs during ERBs and SAA passing and its influence lasts correspondingly half-life of nuclei formed in trapped particles interactions with detectors and construction elements. Respectively different prevalent background components, low altitude satellite orbit divided into areas of 4 types: polar cups and equatorial, ERBs, SAA regions. Events recognising and analysis is possible only in equatorial regions and polar cups.

The background conditions in the energy range from 0.1 MeV up to several MeV for low altitude orbits differ due frequency of ERBs and SAA regions passes and cosmic rays rigidity. Usually for low inclination orbit satellites a combination of Legendre polynomials used for background approximations – see, for example, [2, 3]. Its coefficients defined by cutoff rigidity for orbit inclination. Effects of detectors material and construction elements activation in ERB and SAA regions or moving along magnetic lines charged particles taken into account due activation analysis
because of satellite pass through this areas once per several days. In such cases most part of orbit might be classified as equatorial without loss of generality in spite of background count rate periodical structure – see, for example, figure 1.

![Figure 1. Modelled using Legendre polynomials (solid curve) and measured (points) background count rate for BATSE experiment onboard CGRO satellite in the energy band 30-40 keV. Adopted from [3].](image)

High inclination satellites enter SAA once per some days at least but it pass through ERB several times per day. Therefore such situation requires background model corrections due additional periodic components for each activated nuclei. It makes background model very complicated.

We suppose another solution. Taking into account the absence of event recognising possibility during SAA and ERBs passing we propose simplified polynomial model separately for polar and equatorial orbits parts.

2. The AVS-F apparatus short description
The AVS-F apparatus (Amplitude-Time Spectrometry of the Sun) (see, in particular, [4, 5] and references therein) was installed onboard the specialized automatic station CORONAS-F [6] operated since July, 2001 up to December, 2005. The apparatus was intended for the solar flares hard X-ray and gamma-ray emission characteristic studies and for gamma-ray bursts detection.

![Figure 2. Functional diagram of the AVS-F experiment.](image)
AVS-F instrument was the system of electronics for onboard data acquisition from the SONG-D (Solar Neutrons and Gamma-quanta) [7] scintillation detector developed by SINP MSU, and X-ray semiconductor spectrometer XSS-1 [8] constructed by MEPhI and IKI RAS in cooperation. AVS-F apparatus was developed basing on the block system of electronics and included electronics crate with power supplies and a set of functional blocks. AVS-F experiment functional diagram is presented in figure 2. SONG-D was the detector with 200 mm diameter and 100 mm height based on CsI(Tl) for hard X-ray and γ-ray analysis, fully surrounded by plastic anticoincidence shield. XSS-1 was CdTe detector for X-ray analysis with size 4.9 mm × 4.9 mm. According to the preflighting calibration data energy regions of the AVS-F apparatus were 3-30 keV in X-ray band (detector XSS-1), 0.1-10 MeV in low energy range and 2-80 MeV in high energy one (detector SONG-D). The onboard calibration was made every month due to 11 background lines: positron line of 0.511 MeV and characteristic for this apparatus background lines formed during the interaction of the protons and neutrons with the material of the detector and structural materials of the satellite. During the whole period of apparatus operation its energy ranges were varieties: the amplification coefficient was changed approximately on ~1.8 % per month and the detector threshold was increased at ~1 % per month [9, 10]. The energy resolution of the system was ~13.0% (~86 keV) for γ-quanta with energy 0.662 MeV from $^{137}$Cs [10].

3. Background modeling for AVS-F apparatus

The orbit inclination of CORONAS-F satellite was ~82.5° and it passed through the ERBs 4 times per each 90 min and SAA once per several days during at least 4 subsequently orbits. For such orbit the γ-events observations are possible only in equatorial orbit parts or polar caps and this orbits regions passing duration is not enough for de-excitation of activation lines. In this case we propose simplified polynomial model separately for polar and equatorial orbits parts: background count rate temporal profile approximation by 4-5 order polynomials in equatorial regions, and linear approximations, parabolas or constants in polar caps.

Typical dependence of the summarized AVS-F counts rate on geomagnetic latitude in the low- and high-energy gamma-bands is presented in figure 3. There are well-defined ERBs, polar caps, SAA and equatorial regions (1, 2, 3 and 5 correspondingly) in the high-energy and low-energy bands. Also the areas of precipitated from the external Earth radiation belt electrons bremsstrahlung registration [11] in the low-energy gamma-band were identified (4). Averaged count rates in each spectral channel (for the low- energy and high-energy ranges) were approximated by fourth- and five-degree polynomials.
(the example see at figure 4) at the equatorial orbit regions and by parabolic curves and linear functions at the polar ones ([5] and references therein). Procedure of event temporal profiles behaviour investigation by the AVS-F apparatus data includes background subtraction in each spectral channel both for SONG-D (82 channels of the low-energy range and 64 channels of the high-energy range) and XSS-1 (32 channels of the X-ray range) detectors following mentioned above method.

**Figure 4.** Typical latitudinal profiles of the AVS-F counts rate and their approximation in the low-energy (a) and high-energy (b) gamma-bands. Profiles on the equatorial parts of the CORONAS-F orbit are approximated by fourth-degree polynomials (orange curves), on the polar parts by linear functions (red lines).

**Figure 5.** Averaged through 4 orbits AVS-F background count rate in the energy band 0.1-20 MeV with its 4-degree polynomial approximation (a) and obtained polynomial in combination with data for January 12, 2005 solar flare (b).

**Figure 6.** AVS-F data with background subtraction for January 12, 2005 solar flare from XSS-1 with combination of GOES-12 temporal profile (a) and from SONG-D (b). Primary GOES-12 data with 3s time resolution was averaged to 15 s for visualization.
Figure 4 presents the mean typical latitudinal profiles of the AVS-F counts rate and their approximation in the low-energy (a) and high-energy (b) gamma-bands for October 2003. Profiles on the equatorial parts of the CORONAS-F orbit are approximated by the fourth-degree polynomials, ones on the polar cups fitted by the linear functions. The polynomials’ coefficients supposed similar for identical spectral channels for each analyzed equatorial part taken into account normalization coefficients defined due to Kp-indexes study within period corresponding calibration coefficients being approximately constants. Also taking into account the minimum count rate estimation in the geomagnetic equatorial region within geomagnetic latitude ±5° at the different orbits parts in supposition of its linear dependence on Kp-index averaged on 5 bins in time interval from −24 to −12 hours before the time of geomagnetic equator passing. The examples of minimum count rate estimations for background orbit parts during the end of October 2003 are listed in table 1. The estimated and measured values confirms in the interval ±1σ.

### Table 1. Background orbit parts characteristics for the end of October 2003 (adopted from [12]).

| Date | Start          | End            | Averaged counts rate | Kp series | <Kp> | Estimated min count rate |
|------|---------------|----------------|----------------------|-----------|------|-------------------------|
| 23   | 21:52:44      | 22:22:51       | 810±7                | 2 2 2 2 2 | 2.0  | 820±20                  |
| 24   | 19:36:05      | 20:06:12       | 931±8                | 2 2 2 2 4 | 2.4  | 910±20                  |
| 24   | 21:09:00      | 21:39:08       | 1043±8               | 2 2 2 4 5 | 3.0  | 1030±20                 |
| 25   | 20:25:08      | 20:55:20       | 979±8                | 3 3 2 2 4 | 2.8  | 990±20                  |
| 27   | 20:30:22      | 21:00:31       | 1017±8               | 3 3 4 3 2 | 3.0  | 1030±20                 |
| 30   | 19:53:01      | 20:19:21       | 1681±10              | 8 7 6 5 5 | 6.2  | 1690±20                 |

* Averaged counts rate on equator in the region of geomagnetic latitude ±5° in the energy band 0.1–17 MeV.

b Kp series from -24 to -12 hours before the time of geomagnetic equator passing.

The other example of background approximation presented at figure 5 for time period January 2005. Figure 6 shows such approximation type using for background subtraction during January 12, 2005 solar flare. This faint solar event with GOES class B4.6 lasts from 20:08 UT till 20:13 UT with maximum at 20:11 UT in energy range 1-8 A on GOES-12 data [13]. The polynomial from figure 5 used for background subtraction on SONG-D data and the result have shown at panel (b) at figure 6. Analogues polynomial used for XSS-1 data processing – see panel (a) at figure 6. For this flare the count rate temporal profile in the X-ray band on AVS-F data with background subtraction coincided at the 99% significance level with one on GOES-12 data. This fact also confirms applicability of presented model.

4. Conclusion

The gamma-ray background physical origin for low altitude orbits defined by: diffuse cosmic gamma-emission, atmospheric gamma-rays, gamma-emission formed in interactions of charged particles (both prompt and activation) and transient events such as electrons precipitations and solar flares. The background conditions in the energy range from 0.1 MeV up to several MeV for low altitude orbits differ due frequency of ERBs (included SAA) passes and cosmic rays rigidity. The detectors and satellite constructive elements are activated by trapped in ERBs and moving along magnetic lines charged particles.

In this case we propose simplified polynomial model separately for polar and equatorial orbits parts: background count rate temporal profile approximation by 4-5 order polynomials in equatorial regions, and linear approximations, parabolas or constants in the polar caps. The polynomials’ coefficients supposed similar for identical spectral channels for each analyzed equatorial part taken into account normalization coefficients defined due to Kp-indexes study within period corresponding to calibration coefficients being approximately constants. Also taking into account the minimum count rate estimation in the geomagnetic equatorial region at the different orbits parts in supposition of its linear
dependence on Kp - index averaged on 5 bins in time interval from −24 to −12 hours before the time of geomagnetic equator passing. The described model was successfully applied for the solar flares hard X-ray and gamma-ray emission characteristic studies by AVS-F apparatus data onboard CORONAS-F satellite. Presented model can be applied to detectors onboard other high inclination low altitude satellites within period corresponding to devices calibration coefficients being approximately constants.

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