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UV night background estimation in South Atlantic Anomaly

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Abstract: The JEM-EUSO experiment at the International Space Station will detect the Earth night side UV light produced by UHECR due to their interaction with the atmosphere. The estimation of UV background in different conditions is necessary to precise the estimation of the experiment's operational efficiency. In this article, we estimate an intensity of UV light during night inside the South Atlantic Anomaly and discuss its influence to the JEM-EUSO operational efficiency. Three sources of UV ligth were considered, galactic cosmic rays, airglow and Cherenkov light produced by trapped electrons in the detector lenses. For galactic cosmic rays a model based on simulation of cosmic rays trajectories in the geomagnetic field and secondary particle production in the atmosphere was used. Airglow production is evaluated by AURIC model [1] estimations. The trapped electrons influence is evaluated using the GEANT 4 package [2, 3].

Keywords: JEM-EUSO, UHECR, South Atlantic Anomaly, galactic cosmic rays, airglow, trapped electrons, Cherenkov light

1 Introduction

Some physical mechanism can restrain measurements of the UV signal produced by extensive air showers created by ultra high energy cosmic rays (UHECR) in the South Atlantic Anomaly with the JEM-EUSO detector at the International Space Station. Geographical and time dependencies of UV light intensities at Earth night side in wavelength range 300 - 400 nm still need further investigation. Actual measurements suggest a latitudinal dependency of the UV intensity [4]. There are not many experimental data on UV emissions and energetic electrons simultaneously measured at low altitudes, but contrary to high latitude UV nightglow production related to particle precipitation in the regions of aurora and outer radiation belt, a mechanism of the mid-latitude UV enhancements is still unknown. In this article we investigate the level of UV background in the South Atlantic Anomaly and its influence to the JEM-EUSO operational efficiency [5]. In this study we consider three possible sources of higher level of ultraviolet background (UV BG hereafter) in South Atlantic Anomaly (SAA). The first considered source is UV BG created by galactic cosmic ray (GCR) interactions with atmosphere. Second considered source is airglow production in the SAA. Third is interaction of electrons trapped in the Earth radiation belts with the JEM-EUSO optics, where relativistic electrons can create Cherenkov photons in the lenses.

2 Galactic cosmic rays

Galactic cosmic rays from interstellar space enter the heliosphere where they are modulated [6] and a part of them reach 1 AU and enter the Earth's magnetosphere. The magnetosphere acts as filter to cosmic rays with variable transparency for different energies of cosmic rays. We evaluate UV BG created by GCR over entire Earth surface in reference [7] without taking SAA into account. We use measured AMS-01 proton and helium spectra from precursor fligth onboard the Space Shuttle Discovery mission STS-91 [8, 9]. Because the published AMS spectra do not include the SAA region we need additional simulation to find magnetosphere transparency in SAA. To test a hypothesis that GCR in SAA can produce a significantly bigger amount of UV BG in comparison with other regions on Earth we evaluate a magnetosphere transparency for a set of points on the meridian line crossing SAA at International Space Station (ISS) altitude (382 km). Along the meridian line we set 11 points with latitudinal step of 10° from -50° to 50°, covering latitudinal extension of ISS orbit with inclination 51.6°. The used backtracing method for particles trajectories evaluation in geomagnetic field is described in [10, 11, 12]. Specifically for this simulation we evaluate for every of the selected points 576 directions (one direction per solid angle of 0.0109 sr) of incoming cosmic rays covering half sphere directed outward to space. For every direction we simulated 20 thousands energies with incremental rigidity step 0.01 GV from 0.01 GV till 200 GV. As unmodulated spectrum of protons at 1 AU we take the spectrum from region 10 of the AMS-01 measurements [9]. However, this is the spectrum at 1AU from 1998 and we want to estimate a spectrum for the years 2017 to 2020, where situation in both periods can be similar because JEM-EUSO will measure during declining phase of solar activity with reaching similar solar minimum condition as was in 1998. The intensities of cosmic rays are evaluated from transmission functions constructed from allowed trajecto-

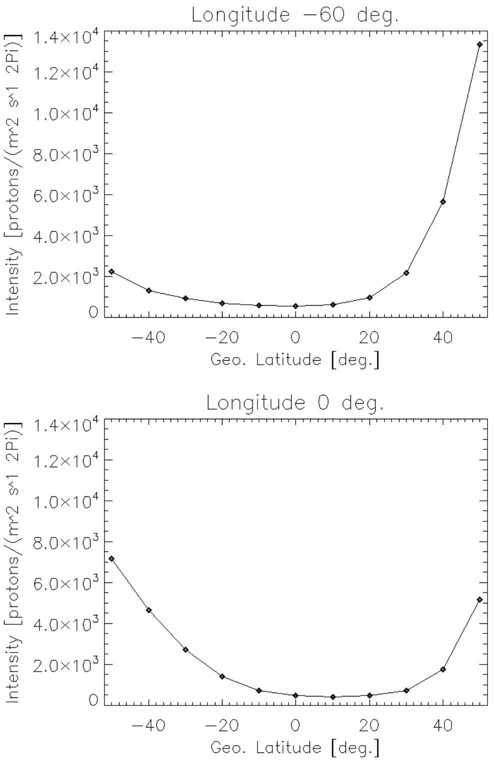

Figure 1: Intensities of cosmic rays proton component at altitude 382 km for two latitudinal profiles. For longitude 0° (bottom panel) and -60° (upper panel).

ries for used set of latitudinal points. The results for places at line with geographical longitude -60° crossing SAA and for comparison also for line with longitude 0° are presented in figure 1. The cosmic rays intensities decrease in equatorward direction, with a minimum close to the geomagnetic equator. Intensities in SAA region do not exceed numbers on similar latitudes at meridian line with longitudes 0°. Production of UV photons at longitudes with 0° was estimated [7] as very small (i.e. less than 0.01 percent) in comparison to other sources of UV BG (nightglow, zodiacal light, integrated star light) at the Earth's night side. Therefore also the number of photons produced by GCR in SAA will be very small. We can conclude that GCR do not increase background in SAA significantly and consequently do not affect operational efficiency of the JEM-EUSO experiment.

3 Airglow production

We present results of UV nightglow radiation in the wavelength range from 300 - 400 nm obtained by the AURIC model, which is computational tool for upper atmosphere radiation provided by Computational Physics, Inc. [1]. AURIC is able to compute dayglow and nightglow radiation for many spectral features. We calculate radiation in wavelength range of 300 - 400 nm for Herzberg I,II and Chamberlain radiation. Purpose of this study was to estimate the prominence of South Atlantic Anomaly in global UV nightglow radiation.

Computation was provided in a range of latitude from $-85.5°$ to $85.5°$ and a longitude from $-180°$ to $180°$. This area was divided into 12 bins in longitude and 35 bins in latitude (grid with 420 cells). The center of each

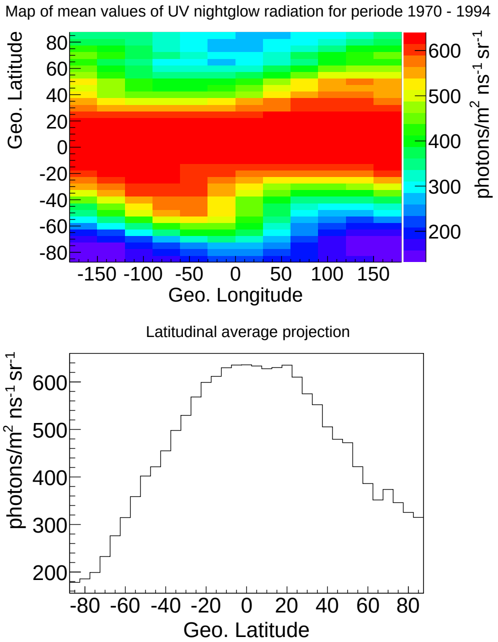

Figure 2: Top panel: Map of average values of UV nightglow radiation in March, June, September and December (together) for years in range from 1970 to 1994. Bottom panel: Latitudinal average projection of the map.

cell was used as input geoposition for the AURIC code. We calculate UV radiation for 4 months (March, June, September, December) from 1970 to 1994 (1994 is the last year in the AURIC parameters database). And for all months in years 1990 and 1994. The value of the nightglow radiation at given position for the period of interest (years in range 1970 - 1994 and separate years 1990, 1994) was obtained in the following way. In each month only one night was taken from day 20 to 21. We assume that radiation is not changing dramatically during one month. For this night, which is defined by solar zenith angle $> 110°$, we obtain radiation for each full hour of local time. Final value was obtained as average of all values at given position for the period of interest.

We use the radiation obtained in this way to create a map of average values for the years from 1970 to 1994 (Fig. 2). From this picture we can see an area with increased values of radiation from $-20°$ to $-50°$ geographic latitude and from $-90°$ to $0°$ geographic longitude. This increase is not visible for example on east hemisphere (positive longitude) in same latitudes. However, this radiation is not bigger then other areas around equator (Fig. 2 bottom).

On figure 3 top panel the latitudinal average projection of map of mean values for year 1990 (close to solar maximum) and on figure 3 bottom panel the same picture for 1994 (close to solar minimum)is shown. From this figure and from figure 2 it is obvious that the average values of UV nightglow radiation during solar maximum are bigger than values of the nightglow radiation at the whole period (from 1970 to 1994) and the radiation during the year 1994 is lowest. There is no significant increase of radiation in SAA area for these two years with respect to other geopositions.

Figure 4 shows nightglow radiation for whole period from 1970 to 1994 only for June. In this case we can see that the area of SAA is most dominant, but still it does not

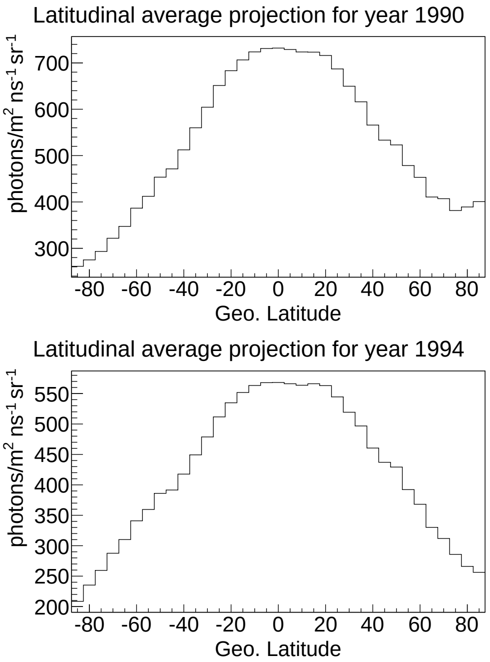

Figure 3: Top panel: Latitudinal average projection of the map of UV nightglow average values for all months in 1990. Bottom panel: Latitudinal average projection of the map of UV nightglow average values for all months in 1994.

reach bigger average values than average values of places with different positions on figure 2.

However in some periods we can observe maximum of produced UV light in the South Atlantic Anomaly, but generally this maximum does not exceed the usual maxima on the Earth surface. Thus, the influence of UV BG in SAA to JEM-EUSO measurements must be part of a wider study devoted to the UV BG, generally.

4 Effect of trapped electrons

We use a SPENVIS AE-8 model [13] to estimate the intensity of the trapped electrons along ISS trajectory. A visualisation of intensity distributions with energies over 40 keV is presented in figure **??**. The higher intensities of electrons in the South Atlantic Anomaly and in the region over North America with high geomagnetic latitudes can be clearly seen. The maximum intensities in the center of SAA reaches values in order of millions of electrons per cm^2/s. The evaluated spectrum of trapped electrons from a solar maximum period in the center of the South Atlantic Anomaly was used as input for simulation of electrons in detector optics by the GEANT 4 package [2, 3]. The results show that one electron approximatelly produce 0.1 Cherenkov photons at the detectors focal surface. In the center of SAA, approximatelly to one square meter of detector lenses surface enter 10^{10} electrons per second. They produce $1 * 10^9$ photons per m^2 of FS per second, i.e. 1 photon per m^2 ns. This is approximatelly 1% in comparison to photons which pass the detector and reach the FS from the standard UV BG of 500 ph/(m^2 ns sr). This leads to conclusion that electrons trapped in non disturbed magnetosphere do not affect the JEM-EUSO operational duty cycle significantly.

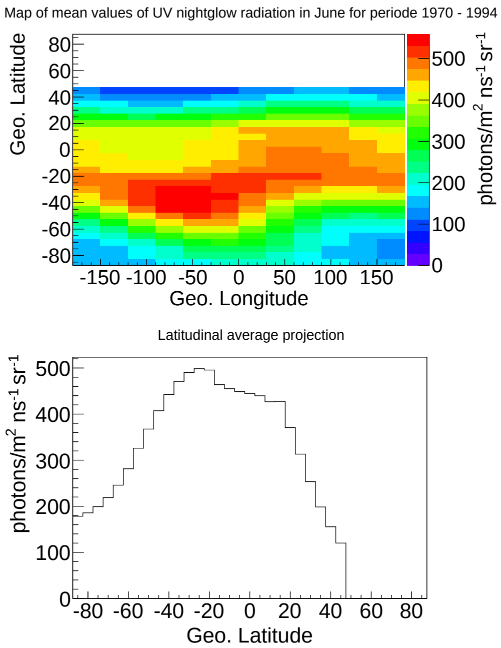

Figure 4: Top panel: Map of UV nightglow average values in June for years in range from 1970 to 1994. Bottom panel: Latitudinal average projection of the map.

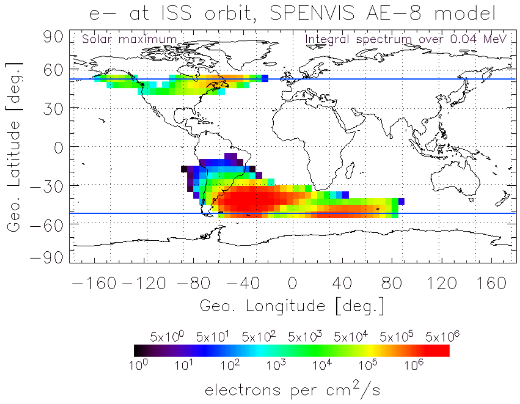

Figure 5: Intensities of the trapped electrons over areas covered by ISS trajectory evaluated from SPENVIS AE-8 model for solar maximum period. Blue lines show ISS trajectory bordes at geographical latitudes -51.6° and 51.6°.

But even if production of photons in the detector lenses during the periods with nondisturbed magnetosphere is small, during disturbed periods intensities of trapped electrons can increase by two orders of magnitudes. Also regions with high intensity of trapped electrons is extended far beyond SAA borders during geomagnetic storms [14]. This effect should be considered and we will estimate it in future.

5 Conclusions

We investigate three possible mechanism to produce a UV light during night inside South Atlantic Anomaly and their influence on JEM-EUSO detector measurements. While UV background from GCR is very small to have any influence to JEM-EUSO measurements, UV light produced by airglow should be considered. However not as special contribution in SAA but as influence of UV BG produced by airglow globally where the amount of produced UV light in the wavelength range of 300-400 nm depends on geographical position with maximum production in average around geomagnetic equator and on time. The trapped electrons increase UV background registered by the detector in the center of SAA due to production of Cherenkov light in the detector lenses by approximately about one (few) percent and do not affect the operational duty cycle. Possible influence of trapped electrons should be considered during periods with disturbed magnetosphere (with higher Kp or Dst index) and will be evaluated in near future.

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