Estimation of JEM-EUSO experiment duty cycle based on Universitetsky Tatiana measurements

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Abstract: JEM-EUSO experiment will search for UV light produced by UHECR interaction with atmosphere from International Space Station. We have estimated a duty cycle for JEM-EUSO experiment from UV light measurements provided by Universitetsky Tatiana satellite. The duty cycle and stability of UV light signal during measurements are presented. An alternative method based on the real ISS trajectory and the analytical evaluation of UV moonlight intensity for the estimation of JEM-EUSO duty cycle is also presented.

Keywords: JEM-EUSO, nightglow, UV background light, UHECR.

1 Introduction

1.1 JEM-EUSO duty cycle

The JEM-EUSO experiment [1] will search for UV light produced in interactions of ultra high energy cosmic rays (UHECR) with atmosphere on the Earth's night side. The duty cycle of JEM-EUSO detector on low earth orbit was estimated some years ago from the calculations [2,3] based on ISS trajectory simulation and moonlight intensity simulations along this trajectory. ISS trajectory was simulated for one year long period with minute timesteps. The moonlight was estimated from the Moon position and phase at evaluated positions. The duty cycle was evaluated as a time during the night when UV intensity from moon light was less than the selected value. This approach do not take into account another sources of UV light on the Earth night side (i.e. zodiacal light, integrated faint star light) and partly also changes in ISS trajectory due to loosing altitude because of a slight atmospheric drag and the following boosts to higher altitude of ISS occurring from time to time. To take into account another sources of UV light and their influence to the duty cycle estimation of JEM-EUSO experiment we have used an Universitetsky Tatiana [4,5,6] data from the measurements in the period from 2005 till 2007. To estimate an effect of the real ISS trajectory we have used the data from [7] and the moonlight simulation along the real trajectory.

1.2 Universitetsky Tatiana satellite

The Universitetsky Tatiana was a satellite of Moscow State University launched on 20th January 2005 from the Plesetsk spaceport in RF, measuring near UV (310-400nm) light on the orbit with the inclination of 82^{o} and the altitude 950 km [4,5,6]. The detector field of view (15^{o}) corresponds to observing atmospheric surface of 250km in diameter. Satellite was operational until March 2007.

2 Method and Results

2.1 JEM-EUSO duty cycle simulation for ISS orbit

ISS trajectory was provided by NASA SSCweb [7]. For every position of ISS during the period of Universitetsky

Tatiana measurements we have evaluated a position of the Sun (solar zenith angle) and Moon (Moon phase and lunar zenith angle) and calculated the UV moonlight intensity I_{Moon} (θ, α) at low orbit in the range 300-400 nm by formula (1) from [3].

$$I_{Moon}(\theta,\alpha) \approx 1.55\times10^{4}\times\cos\theta\times \times10^{-0.4(1.5|\alpha|+4.3\times10^{-2}\alpha^{4})}\, ph/(m^{2}.ns.sr) \quad (1)$$

Where θ is lunar zenith angle and α is Moon phase. For the night defined by solar zenith angle bigger than 109.18^{o} we have evaluated the duty cycle for a set of moonlight induced background values. The results are presented in figure 1.

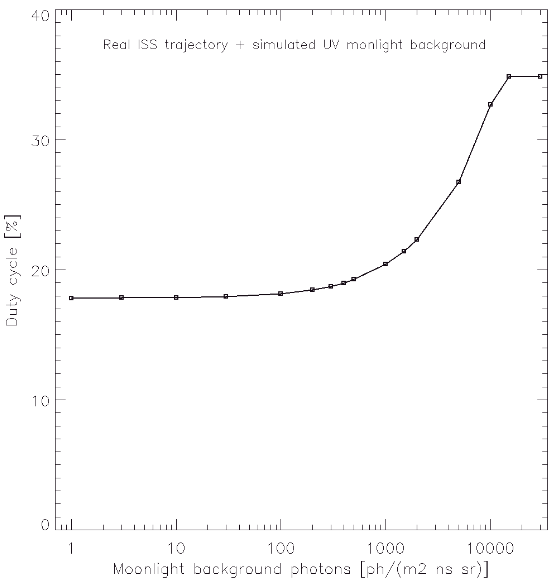

Figure 1. Duty cycle evaluated from real ISS trajectory in years 2005 till 2007 and simulated moonlight BG light.

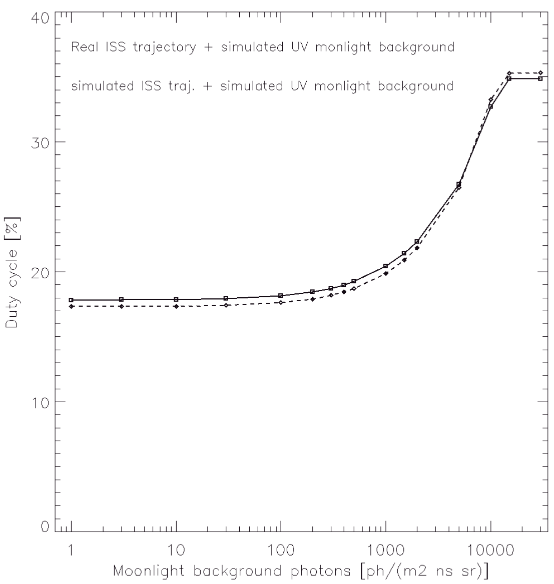

Figure 2. Duty cycle evaluated from real ISS trajectory (solid line) in comparison with simulated ISS on Keplerian orbit (dashed line).

It is possible to simulate the ISS trajectory by several ways. The simulation with a simple Keplerian orbit with an inclination of ISS trajectory gives the results similar to those evaluated with real ISS trajectory. Figure 2 shows the comparison between duty cycle for simulated and real ISS trajectory. Figure 3. show radius of in this article so called real ISS trajectory [7].

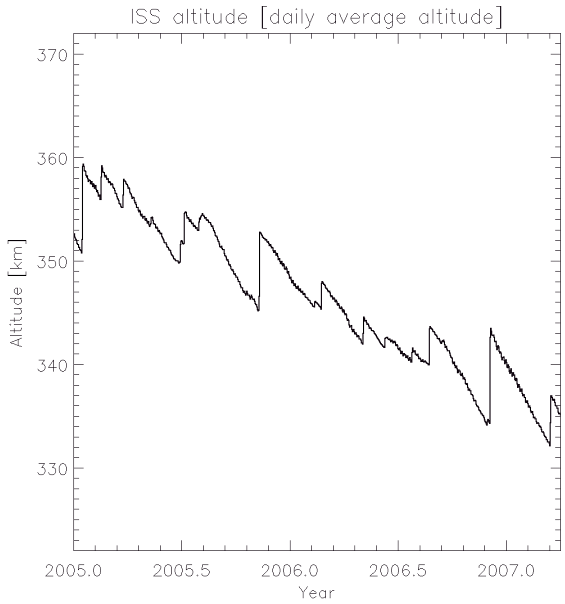

Figure 3. ISS altitude in 2005 till 2007. Boosts to higher altitudes.

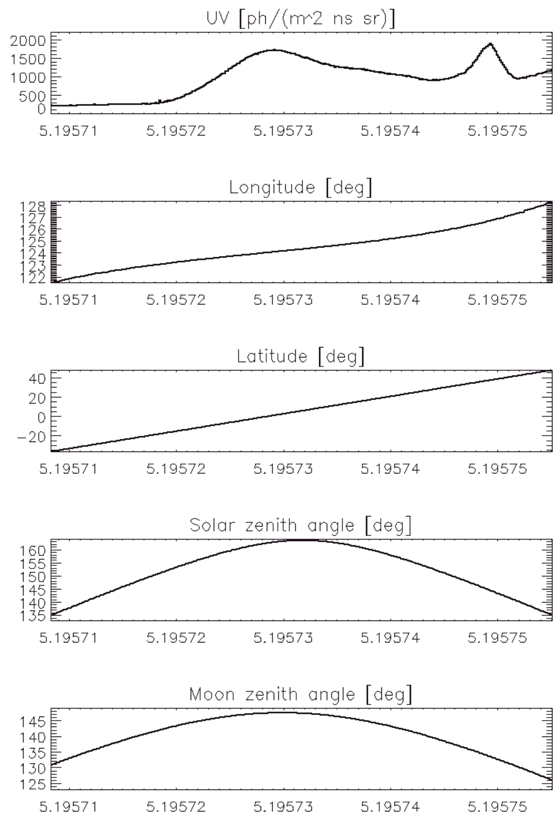

Figure 4. Example of Universitetsky Tatiana measurement. 24 minutes measurement starting at 14:34:44 11. march 2005. Time on figure in year units.

2.2 Tatiana duty cycle evaluation

We have evaluated a Sun position and Moon position for every Tatiana satellite measurement. We have used an integrated 4 second UV intensity data. Example of Universitetsky Tatiana measurements is presented on the figure 4. For the analysis we have used a data in latitudinal range of ISS trajectory i.e. ($-51,6^o$, $51,6^o$). We have selected only the night-time measurements. . As the night for Tatiana orbit we consider simple cut on the zenith angle [3] by solar zenith angle higher than 119.5^o. We apply the correction for UV intensity on Tatiana orbit to ISS orbit (~16.89% - the precise value depends on the exact Tatiana altitude) and the correction taking into account the difference between night definition for Tatiana orbit and ISS orbit. Figure 5 shows a duty cycle evaluated from Tatiana data corrected to ISS orbit together with duty cycle evaluated for real ISS trajectory and simulated moonlight (see the previous part of the article). The comparison shows the effects of other sources of UV background light to the duty cycle of the detector. For lower intensities of UV light limits i.e. under 1500 photons/(m^2 ns sr), other sources of UV light play significant role during moonless nights, that lead to decreasing duty cycle for lower allowed UV background thresholds.

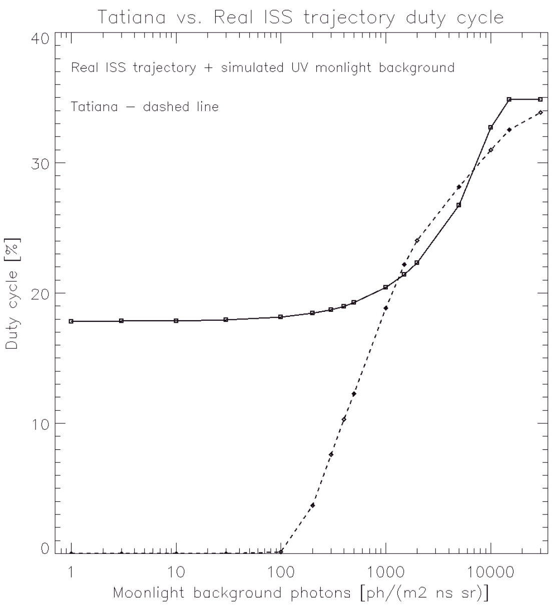

Figure 5. Duty cycle evaluated from real ISS trajectory (solid line) in comparison with duty cycle from Tatiana data (dashed line).

2.3 Night definition for JEM-EUSO duty cycle

The night definition by simple cut on the zenith angle could not be very precise approximation for JEM- EUSO measurements. It is possible that we will need to redefine night by shifting the Sun position 19.18^o under horizon as used in this article to a higher value. We have estimated a JEM-EUSO duty cycle for a set of solar zenith angles for allowed background of UV intensity less than 1500 photons/(m^2 ns sr). The estimation from Tatiana measurements is presented in Table 1. The change of solar zenith angle limit from 108^o to 120^o degrees decreases the JEM-EUSO duty cycle by about 3.8%.

Solar zenith angle (deg.)	Duty cycle (%)
108	22.2
109	22.1
110	21.9
111	21.7
112	21.5
113	21.3
114	21.0
115	20.6
116	20.3
117	19.9
118	19.5
119	19.0
120	18.4

Table 1. The change of duty cycle with different night definition i.e. with different solar zenith angle threshold.

2.4 Time stability of UV background light

We evaluate average length $T_{AVG,Sza}$ of one continuous measurement during Tatiana operation period for different Sun zenith angles thresholds. Average length $T_{AVG,Sza}$ on the night Earth side is roughly 10 minutes and decrease with increasing solar zenith angle threshold.

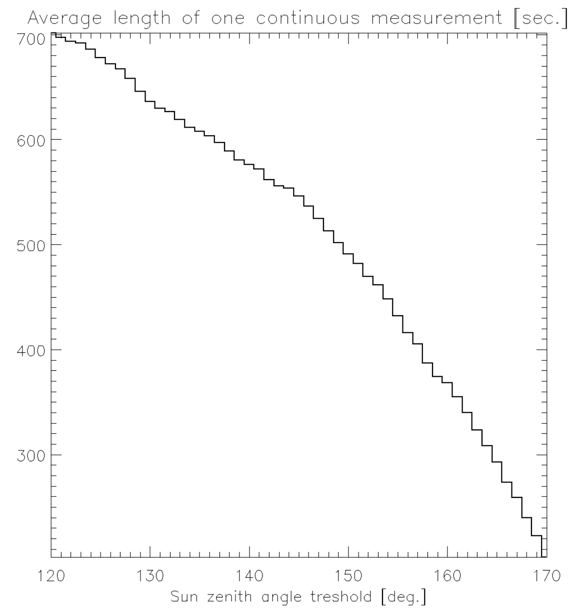

Figure 6. Average length of one continous Tatiana measurement as function solar zenith angle treshold.

The average length of measurements when UV intensity not change more than preselected percentage level we evaluate for plusminus 10, 20, 30 and 40% as function of Sza threshold. Results are presented on figure 7.

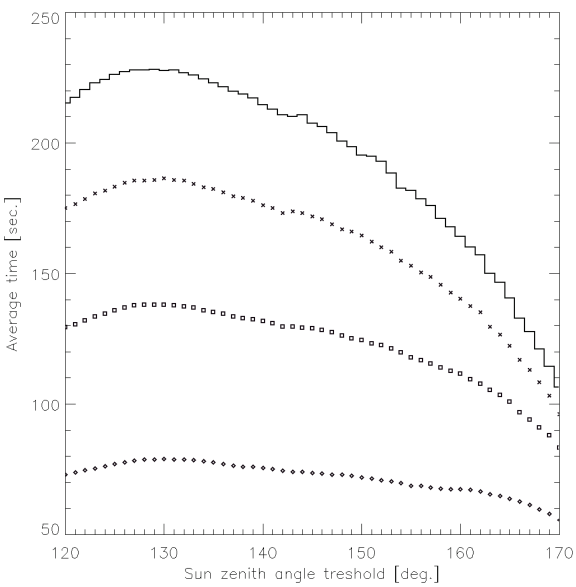

Figure 7. Average length of measurement when UV signal not change more than ±10% (diamonds), not more than ±20% (squares), ±30% (crosses) and ±40% (solid line).

Summary

We have estimated a duty cycle for JEM-EUSO detector at ISS orbit from Universitetsky Tatiana measurements for the set of allowed UV background thresholds. For the allowed background less than 1500 photons/(m^2 ns sr) we have got the duty cycle as 22% for the operational time of experiment. The influence of different night definitions to the duty cycle was presented. Alternative estimations based on simulation of ISS trajectory together with evaluation of amount of moonlight reaching ISS orbit leads for 1500 photons/(m^2 ns sr) to similar values of duty cycle. Difference between the real ISS trajectory and previously used trajectory simulations do not change the estimated values of duty cycle significantly. A more conservative estimation of the duty cycle which includes further cut on the Sun location lowers the duty cycle to 18.4%. This result is in agreement with the value assumed so far by the collaboration (19%).

Acknowledgements

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