ESTIMATION OF JEM-EUSO EXPERIMENT OBSERVATION EFFICIENCY[1]

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JEM-EUSO experiment will search for UHECR by monitoring UV light produced in their interaction with atmosphere from International Space Station. We have estimated an operational duty cycle for JEM-EUSO experiment along the ISS trajectory by the analytical evaluation of possible UV light sources on the Earth nightside. Main sources are UV moon light and UV background intensities created by nightglow and stars. Effect of artificial sources of UV light in populated areas is also estimated.

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1. Introduction

1.1. *JEM-EUSO observation efficiency*

The JEM-EUSO experiment [1,2] will search for UV light produced in interactions of ultra high energy cosmic rays (UHECR) with atmosphere on the Earth's night side. We estimated operational duty cycle for JEM-EUSO detector on low earth orbit previously from Universitetski Tatiana satellite measurements [3,4,5] and from simulations based on moonlight intensity evaluation along ISS trajectory [6]. In second approach ISS trajectory was traced with one minute time-steps. The moonlight was estimated [7,8] from the Moon position and phase at evaluated ISS positions. The operational duty cycle was evaluated as a time during the night when UV intensity from reflected moon light was less than the selected allowed value. Because JEM-EUSO deal with reflected (not direct) moon light, presence of Moon over the horizon does not necessarily mean that we cannot measure showers. At maximum reflected moon light is roughly 30 times higher than moonless UV background over the oceans. Let us also note that because of the orbital position of JEM-EUSO detector, we can also partly measure with clouds in the observed FOV [9]. Previous approach from [8] did not take into account another sources of UV light on the Earth night side i.e. nightglow, zodiacal light, integrated faint star light and artificial lights. In this article we present simulation counting with these sources.

1.2. *DMSP satellite program*

We use Defense Meteorological Satellite Program [10] database annual averages of cloud free moonless light intensities on the earth night side for estimation of artificial lights influence to JEM-EUSO operational efficiency. Data in 30 arcseconds grid on surface describe light pollution of cities mainly in visible range (350 – 2000 nm in 63 levels scale). We assume UV intensity proportional to visible and estimate UV intensity over oceans in DSMP data to be equivalent to intensity 500 UV photons/(m^2 sr ns). Intensity over oceans in DSMP data is described by values 2 (31.8 % from used data set) and 3 (50.9 % from data set). We set value 2.62 to be so called oceanequivalent i.e. UV intensity estimated for cloud free and moonless conditions over oceans. To find city position we take data with value 3 times higher than oceanequivalent intensity i.e. 7.8, level 8 and higher in DMSP data.

Let us note that UV light spectrum produced by different cities differ significantly. Many kinds of lamps are used over the world and no one of them significantly dominates [11]. For example Chicago, Tokyo and Hong Kong images [12] in visible part of spectrum has different colors. Orange color of Chicago and Hong Kong is probably sign of domination of sodium lamps in the city, green light of Tokyo is due to metal halide lamps. Both lamps have different spectrum in UV [11], sodium lamp do not emit in UV. Sodium lamps and mercury lamps are mainly used for the street lighting. From the fact that some cities will be in UV less visible than in DSMP data we conclude that used DSMP data can be used for conservative estimation of city light effect for JEM-EUSO measurements.

2. Method and Results

2.1. *JEM-EUSO duty cycle simulation for moonlight and UV background*

We use ISS trajectory provided by NASA SSCweb [13]. For every position of ISS during the period from 2005 till 2007 (period selected to have simulation comparable with estimation based on 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 reflected UV moonlight intensity I_{Moon} (θ, α) at low orbit in the range 300-400 nm [10]. For the night defined by solar zenith angle higher than 109.18^{o} we have evaluated the duty cycle for a set of moonlight induced background values. We add a nominal oceanequivalent background intensity I_{BG} to every point along ISS trajectory to add to model influence of UV background created by nightglow, zodiacal light and integrated faint star light. Total UV intensity is evaluated as

$$I = I_{SUN} + I_{MOON} + I_{BG} \quad (1)$$

I_{SUN} is equal zero, because in the operational duty cycle only points on the night side (i.e. where solar zenith angle is higher than defined value) are counted, I_{BG} is set to 0 and 500 UV photons / (m^2 sr ns) (discussion about possible another values of I_{BG} is in the 2.3 part of the article).

2.2. *City lights influence*

JEM-EUSO detector field of view (FOV hereafter) in nadir mode is 140 000 km^2 on the earth (value for 400 km orbit, depending on altitude of ISS [14]). We start with conservative approach to estimate effect of city lights to operational efficiency of experiment. In this approach we refuse from operational duty cycle measurements in detector PDMs where any city light with intensity over level 3 times higher than oceanequivalent background (i.e. 1500 ph/(m^2 sr ns)) appear in the PDM projection on the Earth surface. Let us note that this means that we exclude any PDM measurements where even one small city (resolution 30 arcsec in DSMP data give ~1 km resolution on Earth) was found in the PDM projection on Earth [1,15]. For every selected point of ISS trajectory (1 minute steps) all 137 PDMs projection on Earth was scanned for city appearance. If part of PDMs was city free, we count them in the operational efficiency of the experiment. The result compared to evaluation based just on moonlight effect is presented in figure 1. For allowed background 1500 ph/(m^2 ns sr) we get as city lights effect reduction of detector operational efficiency by 2%, from 21.43% for simulation counted only with moon light to 19.43% for simulation counted with moon light and city light. When UV oceanequivalent background (500 ph/(m^2 ns sr)) is taken into account, effect to duty cycle is 2.92% (from 21.43% to 18.51%). Every PDM contain 2304 PMT pixels (all JEM-EUSO detector has 315648 pixels). If only 2 of them will see city (two JEM-EUSO pixel are roughly one DMSP pixel) we conclude all PDMs to be blind.

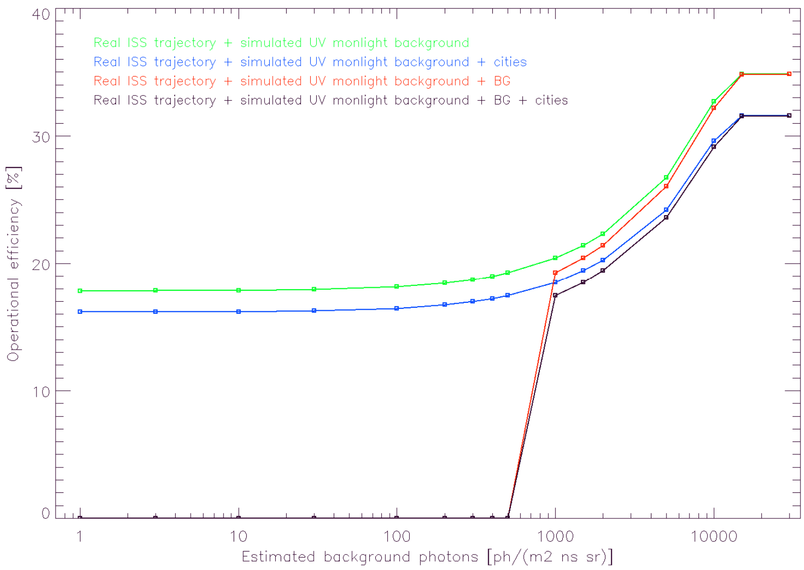

Figure 1. Operational duty cycle evaluated along real ISS trajectory in years 2005 till 2007 with simulated moonlight (green line), moonlight together with oceanequivalent UV background (red), moonlight together with oceanequivalent UV background (blue) and all sources i.e. moon, oceanequivalent background and cities together (black).

To summarize previous statements, at present stage, 1 bright pixel in the PDM is blinding the entire PDM. If the 1st trigger level could work at EC level (9 elementary cells in PDM), we could gain ~1% (from 18.51% back to 19%) in operational duty cycle.

2.3. *Higher background and Summary*

Intensity of UV background during moonless and cloudless night (from nightglow, zodiacal light and integrated faint star light) is still open question. However 500 ph/(m^2 ns sr) is to date the most expected value at ISS orbit. We made estimation for different values I_{BG} from 300 till 700 ph/(m^2 ns sr). Effect to operational efficiency with moon light and city lights counted together with UV background I_{BG} is presented in Table 1. For increasing or decreasing value of oceanequivalent background by 100 ph/(m^2 ns sr) is operational efficiency affected approximately by 0.2%.

Table 1. Oceanequivalent background influence on operational efficiency

I_{BG} [ph/(m^2 ns sr)]	Operational efficiency [%]
300	18.90
400	18.70
500	18.51
600	18.31
700	18.11

To summarize all effects taken in account in evaluation of operational efficiency see Table 2.

Table 2. Summary of all effects, I_{BG} in last column is 500 ph/ (m^2 ns sr)

$I_{Allowed}$ [ph/(m^2 ns sr)]	I_{SUN} > 109.18^o	I_{MOON} only [%	Cities only [%	I_{SUN} + I_{MOON} [%]	I_{SUN} + I_{BG} + I_{MOON} [%	I_{SUN} + I_{BG} + I_{MOON} + Cities [%]
1		50.00	90.14	17.83	0.00	0.00
10		50.11	90.14	17.85	0.00	0.00
100		51.14	90.18	18.14	0.00	0.00
300		53.45	90.18	18.72	0.00	0.00
500		55.92	90.26	19.25	0.00	0.00
1000	34.84	62.06	90.26	20.41	19.25	17.46
1500		**68.08**	**91.06**	**21.43**	**20.41**	**18.51**
5000		89.73	95.97	26.73	26.07	23.61
10000		97.85	98.81	32.69	32.20	29.15
15000		99.99	100.00	34.83	34.80	31.55
30000		100.00	100.00	34.84	34.84	31.58

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