

EUSO@TurLab: An experimental replica of ISS orbits

M. Bertaina^{1,2,a}, A. Bowaire^{1,3}, S. Cambursano¹, R. Caruso^{4,5}, G. Contino^{4,5,b}, G. Cotto^{1,2}, F. Crivello¹, R. Forza^{1,2}, N. Guardone^{4,5}, M. Manfrin^{1,2}, M. Mignone², R. Mulas^{1,2}, G. Suino^{1,2}, and P.S. Tibaldi¹ for JEM-EUSO Collaboration

¹Dipartimento di Fisica, Università degli Studi di Torino, Italy

²Istituto Nazionale di Fisica Nucleare – Sezione di Torino, Italy

³Université de Nice Sophia Antipolis, France

⁴Dipartimento di Fisica, Università degli Studi di Catania, Italy

⁵Istituto Nazionale di Fisica Nucleare – Sezione di Catania, Italy

Abstract. The EUSO@TurLab project is an on-going activity aimed to reproduce atmospheric and luminous conditions that JEM-EUSO will encounter on its orbits around the Earth. The use of the TurLab facility, part of the Department of Physics of the University of Torino, allows the simulation of different surface conditions in a very dark and rotating environment in order to test the response of JEM-EUSO's sensors and sensitivity. The experimental setup currently in operation has been used to check the potential of the TurLab facility for the above purposes, and the acquired data will be used to test the concept of JEM-EUSO's trigger system.

1. Introduction

In this work, we introduce the TurLab [1] laboratory (defined TurLab in the following) as a facility in preparatory steps of the JEM-EUSO project [2]. The aim of JEM-EUSO is the detection of fluorescence and Cherenkov light produced by Extensive Air Showers (EAS) generated by Extreme Energy Cosmic Rays (EECRs, energy $E > 5 \times 10^{19}$ eV) impinging the Earth's atmosphere.

The Atmosphere works as a detector for EECRs and, at the same time, is the main source of JEM-EUSO's noise, namely the UV background. Possible atmospheric conditions creating fluctuations in the background luminosity are: a) variations of night glow due to natural, slowly varying sources whose light is being reflected through Earth albedo (e.g. Moon in different phases, diffuse star light, airglow); b) artificial sources, e.g. city lights; c) Transient Luminous Events (TLE) in the lower and upper Atmosphere (e.g. Lightnings, Elves and Sprites); d) luminous phenomena, much slower than the speed of light, like meteors. Recognising the highly-variable luminous conditions of the Atmosphere is the main task of the trigger system, and simulations of different background conditions have been made to implement and improve the trigger logic [see Sect. 2]. The use of TurLab gives the opportunity of reproducing experimentally variable luminosity conditions and different possible light sources, recreating orbit sights and events on the JEM-EUSO scale. TurLab represents an ideal condition for testing JEM-EUSO Focal Surface (FS) elements, electronics and trigger system at real work conditions.

The paper is organised as follows: in Sect. 2 we present computer simulations; TurLab is described in

Sect. 3, while Sect. 4 gives a list of different possible configurations presently tested; the actual set up is described in Sect. 5 and obtained results are summarised in Sect. 6. It will be shown that with TurLab we can reproduce experimentally light patterns which have the characteristics of those simulated, but with the advantage of taking into account several effects (noise, fluctuations, etc.) which are difficult to model in an appropriate way in simulations.

2. Simulations

A preliminary and parallel work to reproduce the variations of UV background was performed with computer simulations. Starting from known data of the lowest light emission from Earth in UV range [3] (measured at night, in the middle of the ocean, without Moon), and using data from DMSP (Defense Meteorological Satellite Program) [4], we evaluated the light intensity which is going to be seen by JEM-EUSO due to artificial sources compared to the expected nightglow background. More details are reported in [5]. Knowing that the standard nightglow background condition on oceans is $500 \text{ ph}/(\text{m}^2 \cdot \text{ns} \cdot \text{sr})$, and that it results in $1.0 - 1.4 \text{ phe}/\text{pix}/\text{GTU}^1$ depending on the pixel's location on the Focal Surface of JEM-EUSO, we produced simulations of counts due to possible different scenarios.

Figure 1 shows the results of two simulations recreating the expected counts: a) & b) crossing Central Italy, with a series of urban areas, of different extension, alternated with dark rural areas and the sea; c) & d) during a passage over one of the Aeolian islands, i.e., an insulated and very localised light source. The result is comparable to real measurements obtained with the BABY balloon [6], in which the luminosity level increases by 1–2 orders of

^a e-mail: bertaina@to.infn.it

^b e-mail: giovanni.contino@ct.infn.it

¹ $\text{phe}/\text{pix}/\text{GTU}$ is photoelectrons per pixel per Gate Time Unit (GTU) of JEM-EUSO, see Sect. 5.

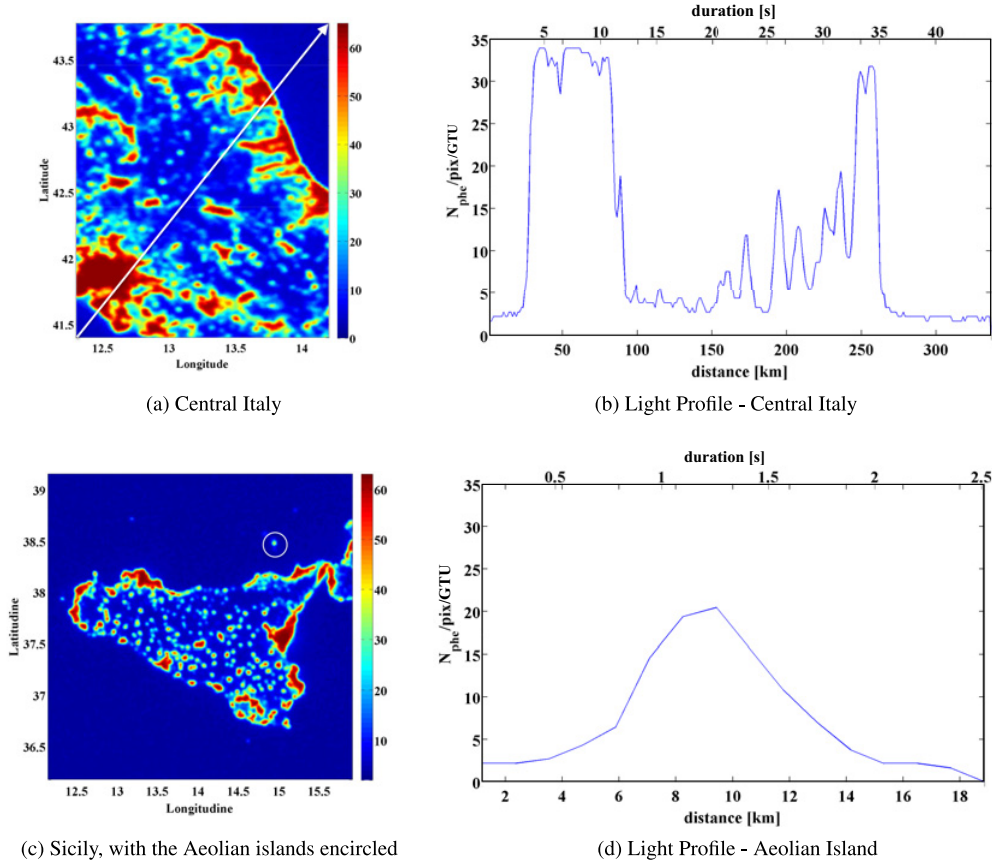


Figure 1. Simulations: the pictures on the left represent DMSP original data of the geographical areas considered in the simulation. The plots on the right show the expected counts (light profile, expressed in $N_{\text{phe}}/\text{pix}/\text{GTU}$) for JEM-EUSO as a function of both spatial extension and temporal duration, in the direction of the arrow in a) and across the circle in c).

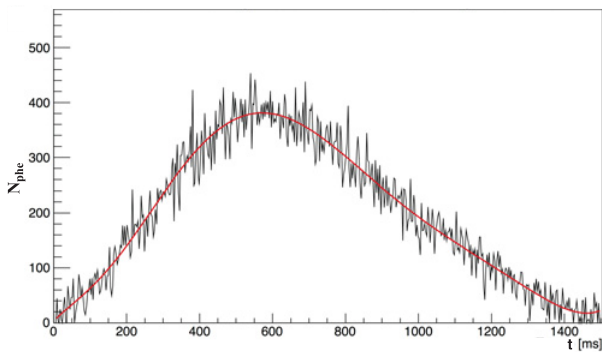


Figure 2. Simulation of a light profile of a meteor of magnitude $M = 2$ seen by JEM-EUSO [7]. The vertical axis shows the detected counts per GTU on the full instrument.

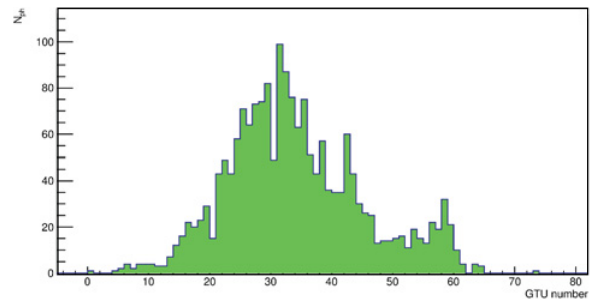


Figure 3. Light profile of a $2 \cdot 10^{20}$ eV proton EAS with zenith angle 60° simulated with the ESAF code [9]. The vertical axis indicates the detected photon-counts per GTU on the full instrument.

magnitude. The saturation in luminosity visible on the urban areas is an effect present in DMSP data.

Simulations were conducted in the past to recreate light profiles of other types of physical phenomena that will occur in the Atmosphere, namely meteors and EAS. Figure 2 shows the typical light profile expected at JEM-EUSO by a meteor of magnitude $M = 2$ obtained by a dedicated simulation code [7]. Figure 3 shows the typical light profile of a $2 \cdot 10^{20}$ eV EAS detected by JEM-EUSO. EASs are simulated in JEM-EUSO using a dedicated

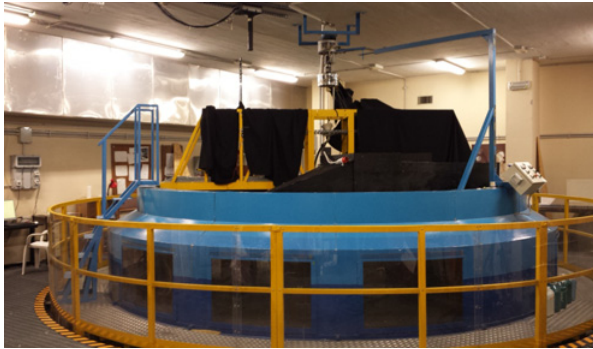
software named Euso Simulation and Analysis Framework (ESAF) [8].

3. The TurLab facility

TurLab is a laboratory, equipped with a 5 m diameter rotating tank, located at the Department of Physics of the University of Torino (see Fig. 4). The system has been thought mainly for studying fluid-dynamics problems where system rotation plays a key role in the fluid behaviour, as happens in atmospheric and oceanic flows

Table 1. Range of the tank speed. For the TurLab/ISS ratio, the ISS speed is assumed to be ~ 8 km/s.

	Rotation Speed	Speed at 2 m radius m/s	TurLab/ISS ratio
Minimum speed:	1 rotation in 20 minutes	10^{-2}	10^{-6}
Intermediate speed:	1 rotation in 2 minutes	10^{-1}	10^{-5}
Maximum speed:	1 rotation in 12 seconds	1	10^{-4}

**Figure 4.** The TurLab rotating tank. The black tube on the ceiling shows the collimator of the experimental setup used to mimic the JEM-EUSO telescope. The floating cables at its left are used to transfer the PMT signals to the electronics setup 25 m away from the tank.

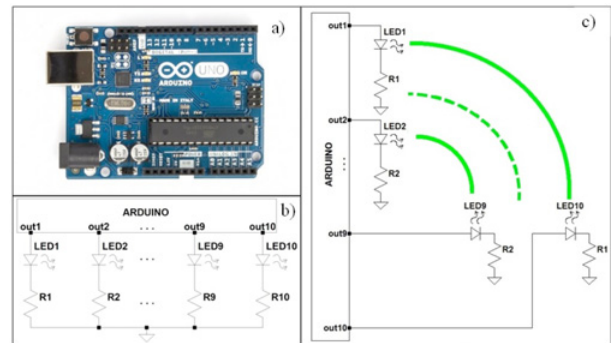
at different scales. The tank can be filled up to 70 cm of water (both fresh or salty) and can rotate with periods that span from about few seconds to several minutes. For fluid-dynamics experiments, the facility is equipped with many cameras and advanced systems for digital recording and data processing.

TurLab is located 15 m underground. So it is possible to work in extremely dark conditions and hence the room light can be totally controlled by researchers.

The tank is used to study different phenomena. A few examples are: a) it can be filled with fluids of different density to study fluid behaviour in stratified conditions both with or without rotation; b) convection can be generated and studied with different approaches; c) two fans can create an air flow, between about 1 m/s and 7 m/s, inducing waves on fluid surface and allowing the study of the air-water interaction or/and creating conditions of infinite fetch that can be deeply analysed with fluid-dynamics techniques or with two waves probes; d) the possibility of recreating different surface roughness can allow studies of fluid turbulent properties in the boundary layer; e) the facility can be used as a model of the rotating Earth system to simulate parts of terrestrial surface reproducing different environments (snow, grass, ocean, land as well as fog and clouds) and their albedo.

4. Experimental replica

The leading idea of the EUSO@TurLab project is reproducing the variations of luminosity and possible luminous events that JEM-EUSO will encounter during its mission. To realize an emulation of the orbits of the International Space Station (ISS) we use the rotating tank of TurLab with a series of different

**Figure 5.** The Arduino platform is shown in a). Pictures of the electronic circuits employed so far to mimic EASs (b) and elves (c) are displayed as well.

configurations to recreate the Earth views, and a Multi-Anode Photomultiplier (MAPMT) hung from the ceiling above the tank pointing towards nadir to mimic JEM-EUSO telescope.

The possibility of changing the tank rotation speed allows reproducing events of different temporal durations with the same configuration, representing scenarios of different spatial extensions as seen from the ISS rotating around the Earth. In Table 1, three configurations that were tested are shown with the corresponding speed of an object placed on the tank at a radius of 2 m, approximately the position of the MAPMT; this speed is then compared with the ISS speed in the third column.

Most relevant possibility at TurLab is changing the light conditions and light sources. The later can be distinguished between:

- direct light emitting sources;
- materials reflecting room light.

As direct light emitting sources, a variety of materials is used, with the intent of reproducing different kinds of phenomena:

- Urban areas are reproduced by means of LEDs in the visible range inside tubes of different dimension, so to have extended and intense lights directly pointing to the MAPMT.
- an oscilloscope producing Lissajous curves, for events such as meteors;
- LEDs driven by a pulse generator, for fast luminous events such as lightnings;
- LEDs peaked at ~ 350 nm or optical fibers driven by Arduino platform [10].

The Arduino platform (Fig. 5a) is used to control light sources with timing too extreme for the tank dynamic range or to recreate complicated luminous phenomena (such as Elves, Sprites, etc.). For our purposes, the main

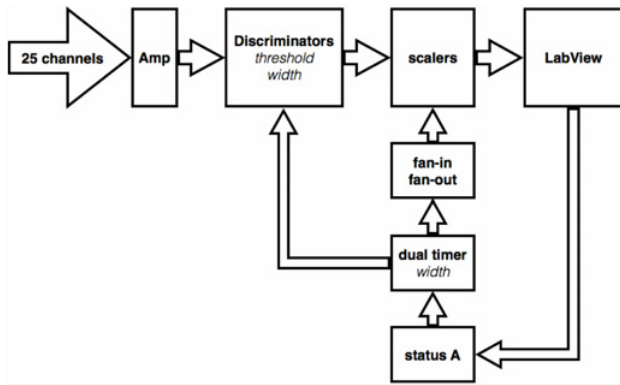


Figure 6. Layout of the electronics circuit currently employed to test the response of the PMT to the light scenes reproduced in the tank.

characteristic of Arduino is the possibility of a fast control of LEDs with a minimum timing of $2\ \mu\text{s}$. Till now we have recreated EECRs with a strip of 10 LEDs (Fig. 5c), and Elves with optical fibres arranged in a quarter circle and illuminated by LEDs (Fig. 5b). For the EECRs, we reproduce the variations of light intensity during the EAS development by varying the intensity of each LED using variable impedances.

Besides direct light sources we can use materials over the tank surface to obtain a replica of Earth albedo. We can change the illumination in the tank room so to have different responses using the same material. Presently, our room light sources are: a computer screen beside the tank and a remote controlled LED over the tank. Examples of used materials are: moss to mimic “green” regions such as forests, glass dust for highly-reflectant surfaces such as glaciers or snow, sand and bricks for land soils. Finally, it is possible to use two fans to create waves when the tank is filled with water, and white particles suspended in salty water to mimic clouds and fog.

5. The current setup

At present EUSO@TurLab apparatus consists of:

- a 5×5 pixel MAPMT: Hamamatsu R8900-M25 [11], hung from the ceiling and pointing towards nadir covered by a BG3 filter to select the light in the 300–400 nm band such as in JEM-EUSO;
- a 1" diameter focusing lens in front of the MAPMT;
- 25 cables, 25 m long, connecting the MAPMT with electronics;
- standard NIM and CAMAC electronics (see Fig. 6);
- a PC for acquiring measurements with LabView software.

The electronic system, currently employed in the measurement, is different from the JEM-EUSO one, however, it is based on the same detection principle of the single photon-counting. Therefore, it can give a fair representation of the potentiality of EUSO@TurLab to mimic the experimental situations that JEM-EUSO is expected to encounter, and test, at a first level

approximation, the trigger system of JEM-EUSO. By demonstrating this concept, in future it could host the prototypes of JEM-EUSO under development, to test their responses in a controlled environment.

The MAPMT, equipped with the lens, has a Field of View (FoV) equivalent approximately to its physical size, which is a squared inch, i.e., each pixel sees $(5 \times 5)\ \text{mm}^2$ at a 2 m distance. The solid angle is then of the order of 10^{-6} , the same magnitude of the FoV of one pixel in JEM-EUSO. By comparing the linear extension of TurLab’s and JEM-EUSO’s pixel FoV, it turns out that the ratio TurLab/JEM-EUSO is $(5\ \text{mm} / 600\ \text{m}) \sim 10^{-5}$, which has the same magnitude of the ratio of speeds (see Table 1). This means that in such a configuration it will be possible to reproduce the evolution of the light source entering and disappearing from the FoV of a pixel in very similar way as seen from the ISS. On the other hand, if the tank rotates at minimum speed, each rotation could mimic half of JEM-EUSO orbit, testing many light situations inside the same rotation. The two approaches complement themselves.

To measure luminosity the photon counting mode is used. The 25 signals from the MAPMT are amplified, discriminated and counted with NIM electronics, as shown schematically in Fig. 6. At the moment we cannot reproduce JEM-EUSO time scale, with a GTU of $2.5\ \mu\text{s}$ and a 25 ns double-pulse resolution. Therefore, we use 400 ns double-pulse resolution and a $40\ \mu\text{s}$ GTU. In this way we keep the same saturation characteristics in photon-counting as in JEM-EUSO. A very unwanted feature of the present electronics configuration is the delay in PC acquisition: we have 30 ms dead time for each measurement. Hence, for EUSO@TurLab, 1 GTU consists of $40\ \mu\text{s}$ sampled every 30 ms. However, if the data are processed offline, this is not a major issue at this stage.

6. Results

Some of the configurations applied so far at TurLab are discussed in the following. The plots refer to the integral of the counts from all MAPMT pixels (left scale on the vertical axis) as a function of time as well as the average count/pixel (right scale on the vertical axis).

Time is expressed in GTU or seconds. We use seconds when we want to represent the real duration of recreated events; otherwise, using GTU, we consider the event as consecutive snapshots of JEM-EUSO GTUs. In this way, the 30 ms dead time between frames is not taken into account. Results obtained at TurLab are being used to test the JEM-EUSO trigger logic.

Figure 7 and Fig. 8 show the MAPMT counts during a complete 10 minute rotation of the tank. Different configurations are reproduced. In Fig. 7, the room light is the same for the two curves, with the LED over the tank ON. The green curve refers to the tank without any source on it, while the blue one represents the tank covered with a collection of different materials and direct light sources that were described in Sect. 4.

In Fig. 8, the two curves refer to different room light conditions with the tank covered with all the sources shown in Fig. 7. The LED over the tank is ON or OFF in blue or green curve, respectively. As predictable, the light

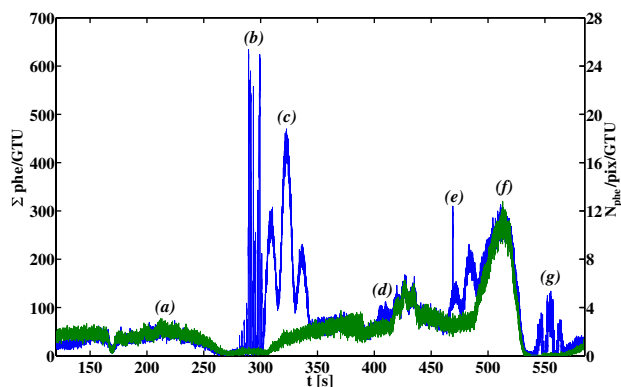


Figure 7. A 10 minutes rotation of the tank equipped without (green) and with (blue) different sources: a) moss; b) Arduino 10 LED strip; c) mirror; d) bricks; e) glass dust; f) sand; g) oscilloscope. See text for details.

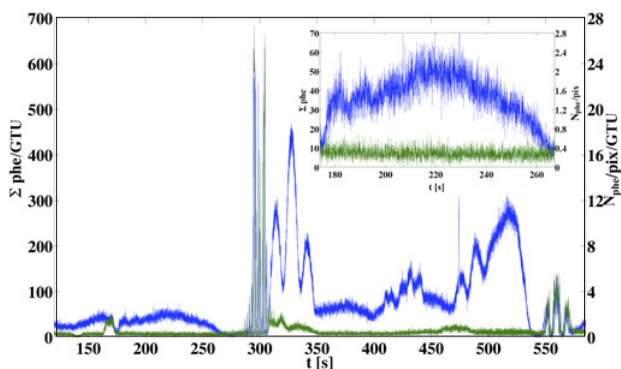


Figure 8. Response to different light conditions. The inset is a zoom on the 170 – 270 s region. See text for details.

emitting sources results are not affected, while there is a fundamental change in the response of different materials.

The inset in Fig. 8 is a zoom showing the minimum level of luminosity obtainable at TurLab. We have an average of 0.3 phe/pix/GTU, that is lower than 1.4 phe/pix/GTU expected for JEM-EUSO.

Comparing the different results in Fig. 7 and Fig. 8, one can see how the tank itself represents a source of light when it is sufficiently illuminated by room light, due to structures that are part of the tank: there are metal bars, a footbridge, and a wooden structure created for other experiments. All of these structures can be covered/painted with black to reduce their effect on luminosity. Some of them can be removed if necessary to reach a more uniform response. On the other hand they constitute natural inhomogeneities useful to test the capability of the system to adjust the thresholds for trigger purposes.

In the following, examples of isolated events recreated at TurLab are presented. For all the results the light intensity can be changed simply by changing LED power.

Figure 9 shows the results obtained by using two LEDs illuminating the ceiling by means of small pinholes of different dimensions; for this and next two examples, the rotation speed is approximately 1 turn every 2 minutes. The result is comparable to a passage over two isolated metropolitan areas (see Fig. 1). The durations in time

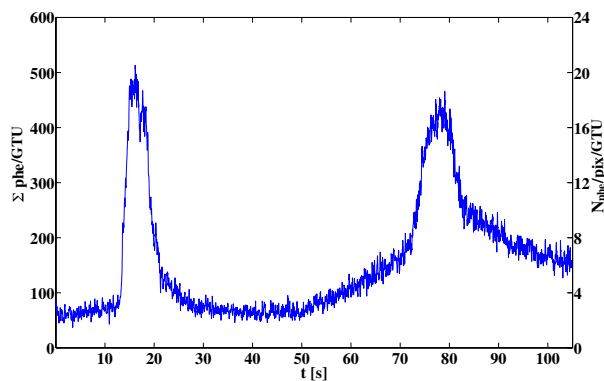


Figure 9. Simulation of a passage through two large urban areas of ~50–60 km if rescaled to ISS speed.

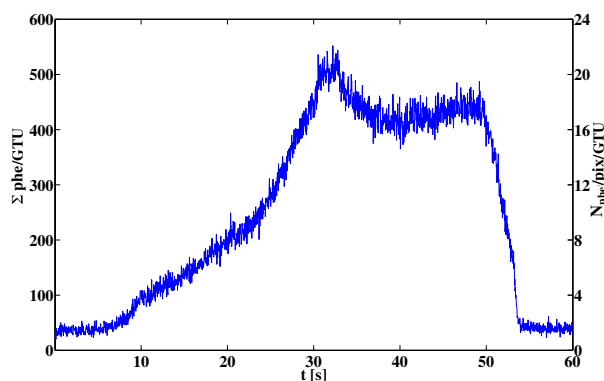


Figure 10. Extended luminous area of 300–400 km if rescaled to ISS speed.

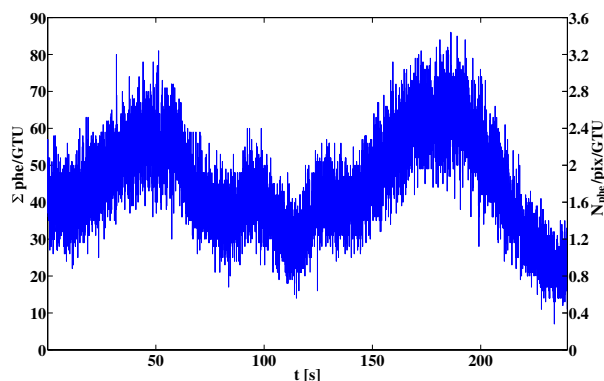


Figure 11. Reflected light using wooden panels. The luminosity variation is as expected from clouds.

are approximately of 7.5 s and 9 s, and the equivalent extensions, considering for ISS a 7(8) km/s speed, is 55(68) km, respectively. In Fig. 10, the LED has a much wider opening angle and produces a much more extended light source, representing a wider region of 300–400 km, such as the North Plane in Italy, center of Europe or US coastal areas.

Figure 11 shows the signal produced by light reflected by wooden panels. The variations in the light intensity are comparable with expectations from clouds.

Figure 12 shows a replica of an EECR event by means of Arduino platform. We use a strip of ten LEDs, each connected to an Arduino pin output, illuminated with a

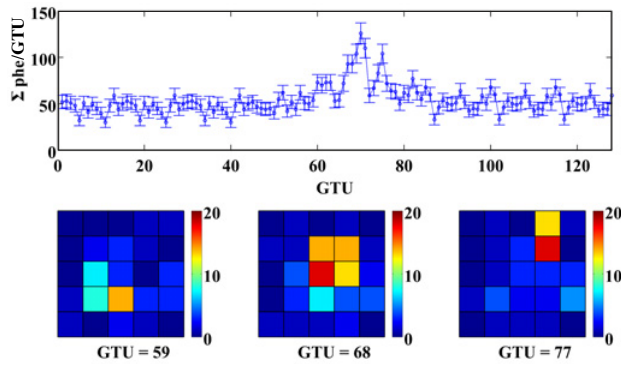


Figure 12. A replication with the Arduino platform of the signal expected in JEM-EUSO by a 2×10^{20} eV EECR. Top panel shows the light profile in 128 GTUs with the light excess due to the fired LEDs. Bottom panel shows the snapshot of 3 different GTUs during the event occurrence.

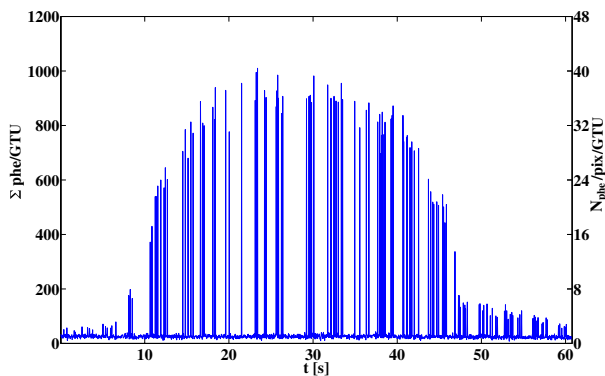


Figure 13. Reproduction of a lightning area.

60 ms period and 1 Hz repetition rate. Actual timing was created considering the 30 ms dead time of electronics configuration. It is possible to reach values between $2.5 \mu\text{s}$ and $25 \mu\text{s}$ when using JEM-EUSO electronics. The intensity of the light profile and the event duration is comparable to what is expected according to ESAF simulation (Fig. 3) for a 2×10^{20} eV EECR with 60° zenith angle.

Figure 13 shows the reproduction of a lightning area by means of a blinking led. Presently the light is controlled to avoid too intense pulses, however, the intensity can be increased. Taking into account the speed of the tank and the total duration of about 1 minute it would correspond for the ISS to a 400 km area.

7. Conclusions

The measurements presented in this paper represent the first successful steps of an on-going project aiming at using TurLab as a facility to mimic experimentally transient lights that JEM-EUSO is expected to see during its orbits flying on the ISS. We plan to improve further our setup in order to reach a more realistic representation of the JEM-EUSO system and of the physical processes it will monitor. TurLab could be used in future to test prototypes and precursors of JEM-EUSO. The data taken so far will be used to validate the logic of the 1st level of its trigger system.

This work was partially supported by the Italian Ministry of Foreign Affairs, General Direction for the Cultural Promotion and Cooperation.

References

- [1] <http://www.turlab.ph.unito.it>
- [2] T. Ebisuzaki et al, *Adv. Sp. Res.* **53**, 1499–1505 (2014)
- [3] G.K. Garipov et al, *Astrop. Phys.* **24**, 400–408 (2005)
- [4] <http://www.ngd.noaa.gov/dmsp>
- [5] J.H. Adams Jr. et al, *Astrop. Phys.* **44**, 76–90 (2013)
- [6] O. Catalano et al, *NIM A* **480**, 547–554 (2002)
- [7] M. Bertaina et al, *Exp. Astronomy*
DOI: 10.1007/s10686-014-9375-4, (2014)
- [8] C. Berat et al, *Astrop. Phys.* **33**, 221–247 (2010)
- [9] M. Bertaina et al, *Adv. Sp. Res.* **53**, 1515–1535 (2014)
- [10] <http://www.arduino.cc>
- [11] Y. Kawasaki et al, *NIM A* **564**, 378–394 (2006)