Simulation studies for the Mini-EUSO detector

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for the JEM-EUSO collaboration

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Abstract

Mini-EUSO is a mission of the JEM-EUSO program flying onboard the International Space Station since August 2019. Since the first data acquisition in October 2019, more than 35 sessions have been performed for a total of 52 hours of observations. The detector has been observing Earth at night-time in the UV range and detected a wide variety of transient sources all of which have been modeled through Monte Carlo simulations. Mini-EUSO is also capable of detecting meteors and potentially space debris and we performed simulations for such events to estimate their impact on future missions for cosmic ray science from space. We show here examples of the simulation work done in this framework to analyze the Mini-EUSO data. The expected response of Mini-EUSO with respect to ultra high energy cosmic ray showers has been studied. The efficiency curve of Mini-EUSO as a function of primary energy has been estimated and the energy threshold for Cosmic Rays has been placed to be above 10^{21} eV. We compared the morphology of several transient events detected during the mission with cosmic ray simulations and excluded that they can be due to cosmic ray showers. To validate the energy threshold of the detector, a system of ground based flashers is being used for end-to-end calibration purposes. We therefore implemented a parameterization of such flashers into the JEM-EUSO simulation framework and studied the response of the detector with respect to such sources.

Mini-EUSO

Space-borne fluorescence telescope of JEM-EUSO missions

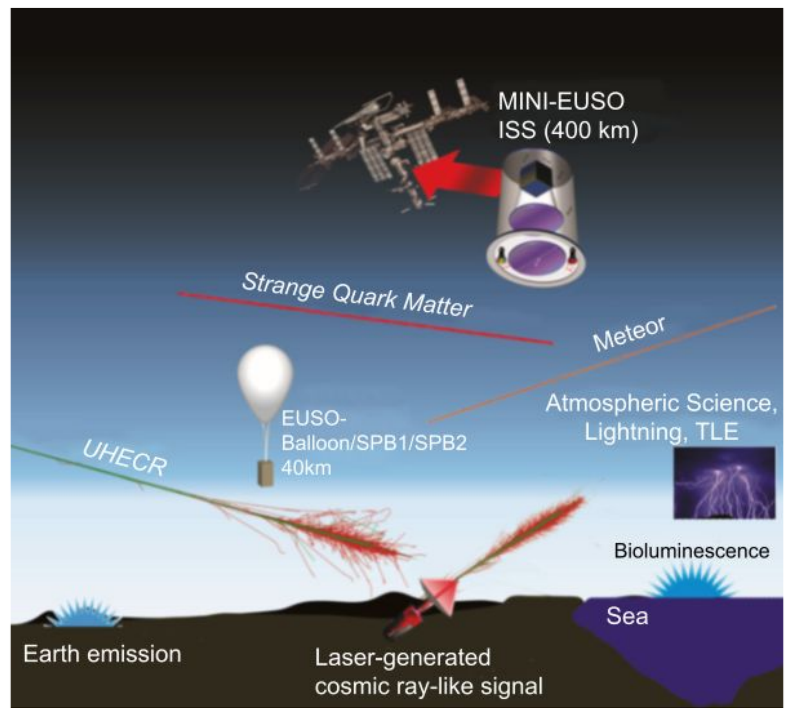

Figure 1: Mini-EUSO mission summarised in one diagram. From the ISS, Mini-EUSO will observe a variety of phenomena in the UV range, in addition to creating a high resolution UV map of the Earth.

ESAF

EUSO Simulation and and Analysis Software

An end-to-end simulation of the phenomenon from the light emission at the source, the propagation through the atmosphere, to the simulation of the detector response and its reconstruction algorithms which contains:

- Extensive Air Shower (EAS) development
- photon production
- transport through the atmosphere
- detector response for optics and electronics
- contains algorithms for the reconstruction of the primary parameters of the EAS

The exposure curve for cosmic ray detection

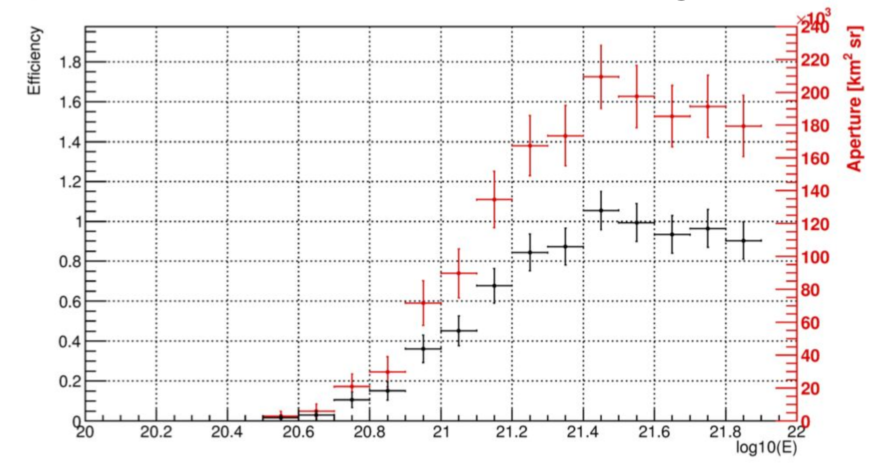

Figure 2: The detection efficiency (on the left axis, in black) and geometrical aperture (on the right axis, in red) are shown as a function of the EAS energy logarithm. A UV background level of 1 photoelectron/pixel/GTU was considered in both cases.

Meteor simulations

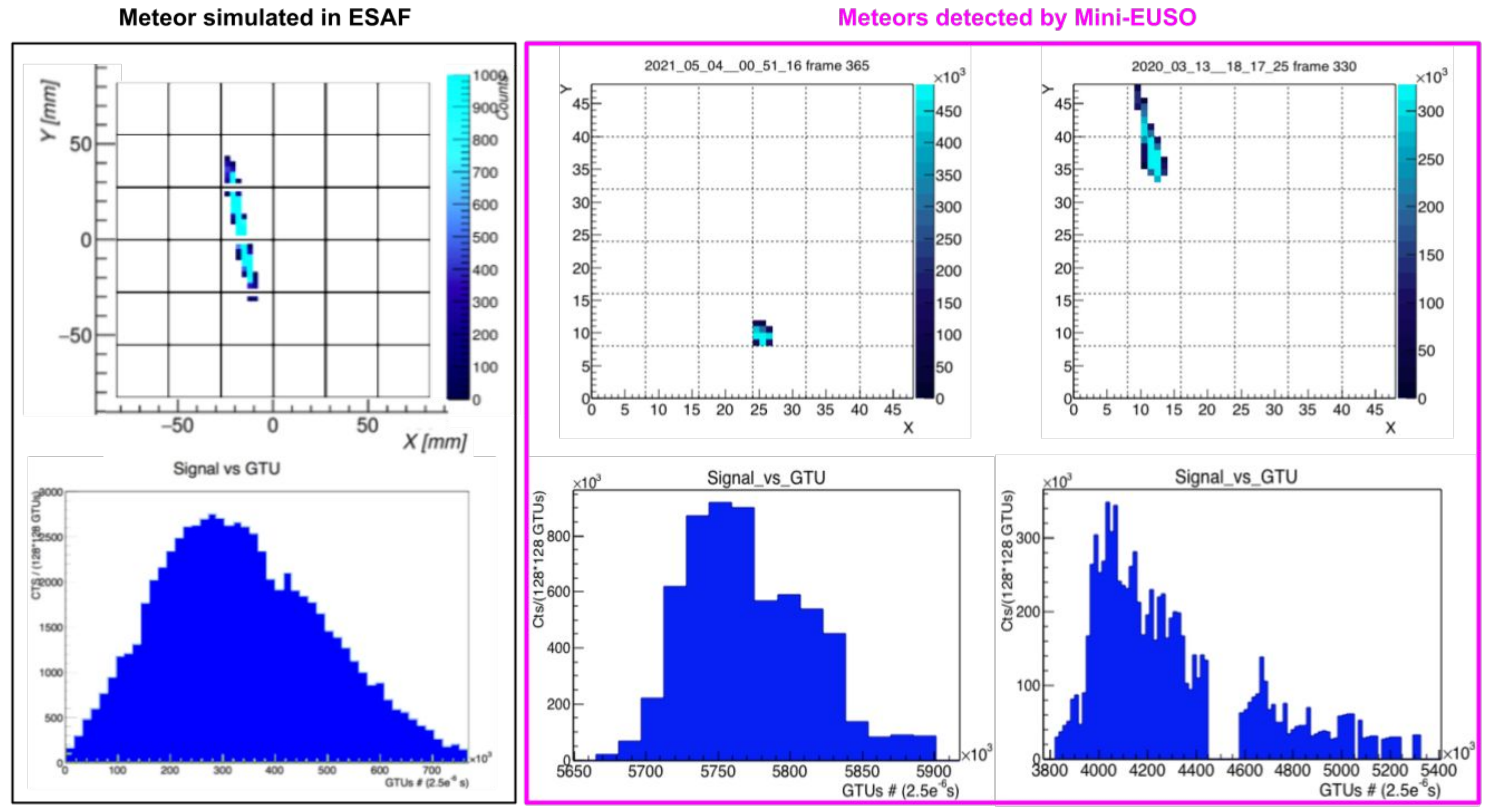

Figure 3: Left:Expected light track of a meteor of absolute magnitude M = +5 detected by Mini-EUSO (the effects of UV-nightglow are not included and a threshold has been applied at 30 counts). Bottom: Expected light profile. Each time bin on the x-axis corresponds to an integration time of 40.96 ms, the resolution of the level 3 data from Mini-EUSO. Centre & right: Example of meteors detected by Mini-EUSO. In the Mini-EUSO data, there are meteors with different brightness and time duration. Further analysis is currently ongoing.

Space debris simulations

A possible application of the Mini-EUSO detector is the monitoring of space debris. Such objects at orbital speeds are an increasing threat for space flight. Efforts are currently ongoing to develop new concepts of detectors for debris monitoring. Although the flight configuration of Mini-EUSO may not be optimal for this purpose, the technique has been tested also in view of future detectors of this kind. Simulations have been performed with steady sources moving in the field of view at orbital speed. The kinematics of such objects has been therefore simulated in the context of Mini-EUSO to estimate the maximal distance up to which detection is realistic. Given the estimate of the density of such events, it was possible to estimate the expected rate and to project it to the case of specifically designed detectors.

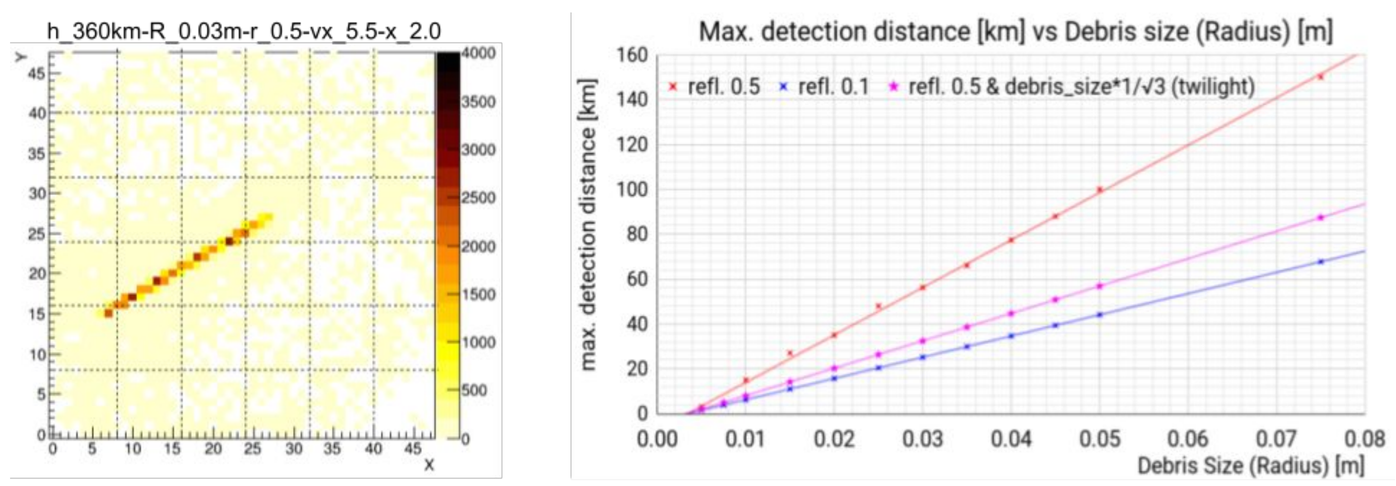

Figure 4: Space debris simulated in ESAF and maximum distance of space debris observable by Mini-EUSO from the ISS as a function of reflectance and size of debris derived from simulation study with ESAF.

Studies on ground transient sources

Flasher Event detected by Mini-EUSO

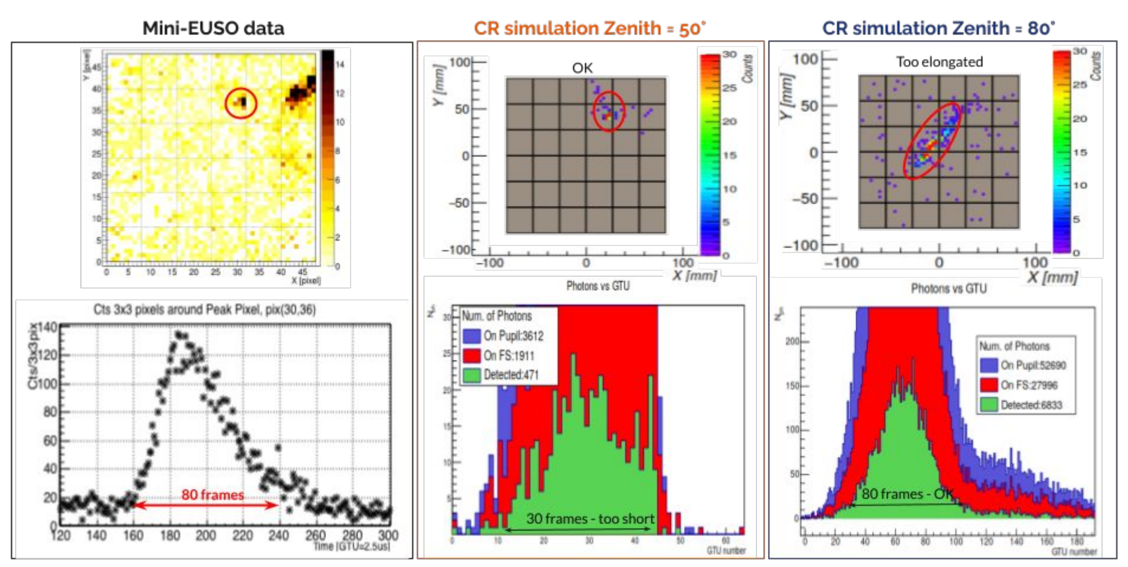

Figure 5: Focal plane view and light curve of Mini-EUSO signals and simulations. Left: Mini-EUSO event detected off the coast of Sri Lanka. Centre and Right: EAS simulated through ESAF with different energy and zenith angle. The simulation with $Z = 50^\circ$ and energy 5×10^{21} eV produce a footprint on the focal plane similar to the event but the light curve is too short, while the event at $Z = 80^\circ$ and energy 2×10^{22} eV correctly reproduce the light curve but has a different shape on the focal plane.

Flasher Campaign at Piana di Castelluccio, Italy May 3rd/4th 2021

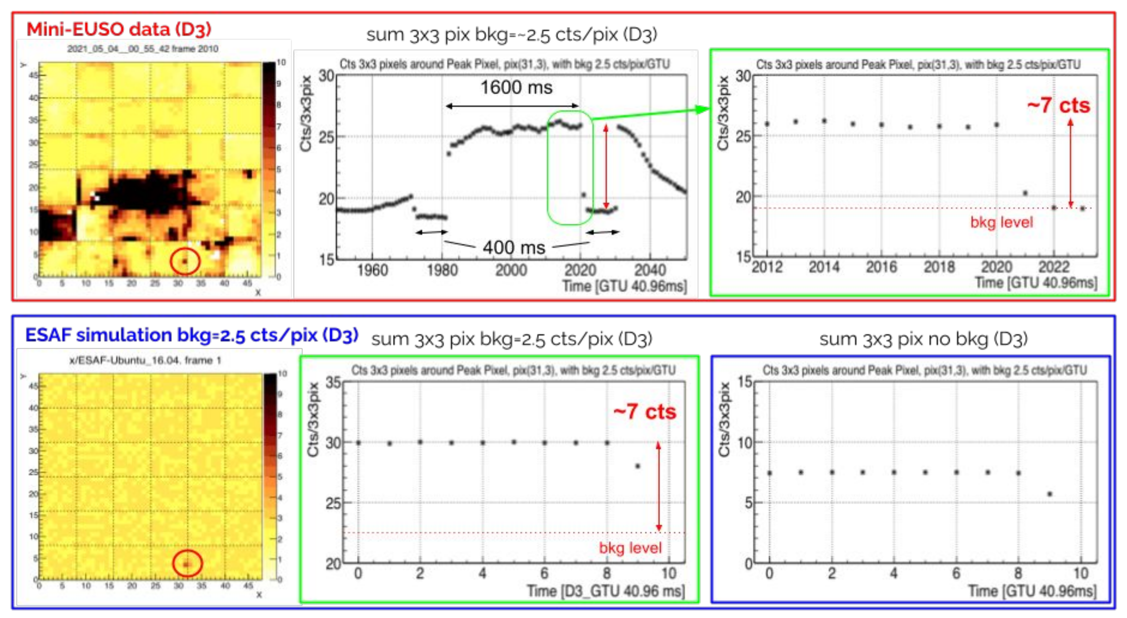

Figure 6: Top: Mini-EUSO flasher campaign event. Center shows the light evolution of summed counts of 3 by 3 pixels around the peak count pixel, indicated by red-circle on the left plot for a cycle of 1600 ms pulse. Transit of the 1600 ms pulse with 400 ms off before and after the pulse is clearly seen. Right shows the zoomed plot to the duration and timing where ESAF simulated the same event as shown in the bottom plots as following. Bottom: Reproduced flasher campaign event by ESAF. Center shows the light evolution of summed counts of 3 by 3 pixels around the peak count pixel, indicated by red-circle on the left plot with a background level of 2.5 cts/pix/GTU. Right shows the same as the center without background to see the signal counts clearly.

Conclusions

The Mini-EUSO detector has been successfully implemented in ESAF. Several kinds of atmospheric UV phenomena such as TLEs, blue jets and meteors, as well as space debris have been simulated by ESAF and compared to the Mini-EUSO data. Several kinds of UHECR events are simulated by ESAF and used to verify a ground-based flasher event observed by Mini-EUSO. The UV LED flasher campaign event has been also simulated using the photon counts data taken by a telescope on the ground, which consists of the same type of detector and electronics as Mini-EUSO detector. The next step is the absolute calibration of either or both of the detector and the flashers on the ground. Further detailed study on ESAF by means of the advantage of having real data obtained by Mini-EUSO onboard the ISS is ongoing to improve the simulation accuracy for better estimation of detector performance, verification of natural and artificial light sources, and to achieve the end-to-end calibration with ground based flashers and lasers.

Acknowledgements

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