Towards observations of nuclearites in Mini-EUSO

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Nuclearites and other heavy compact objects detection

Existence of heavy compact objects has been suggested many times throughout the years. One example is a nuclearite – a hypothetical stable nugget of strange quark matter. These objects may have originated in the early universe or could be produced in stellar phenomena, such as collisions of neutron stars. Especially in the first case, they can be an important component of dark matter.

According to de Rujula & Glashow, Nature, vol. 312, 1984, nuclearites:

- Could traverse through Solar System and Earth
- Could produce light tracks in the atmosphere due to compression of air
- Assumptions: cosmological origin, isotropic flux, "galactic speeds" of 250 km/s

Heavy compact objects other than nuclearites could also produce similar effects due to compression of air. They could be detected by meteor-observing experiments, with the following differences from meteors:

- Most of them should be much faster than the meteor maximal speed of 72 km/s
- Their lightcurves should be much flatter due to small losses of energy

The Mini-EUSO experiment

Mini-EUSO is a small orbital telescope, designed within the JEM-EUSO programme, observing the night-time Earth from the International Space Station (ISS) through a UV-transparent window inside the Zvezda module. The main properties are:

- two 25 cm diameter Fresnel lenses
- a Photon Detection Module (PDM) with 36 multi-anode photomultipliers (MAPMTs) encompassing 2304 pixels, 320-420 nm spectral acceptance
- 44°×44° field of view, >300 km on the ground

The PDM data is gathered in 3 time resolutions:

- **D1** – 128×2.5 μs frames, triggered; UHECR, TLEs, etc.
- **D2** – 128×320 μs frames (sums of 2.5 μs frames), triggered; lightnings, etc.
- **D3** – 128×41 ms frames (sums of 320 μs frames), continuous; UV background, meteors, nuclearites

Two levels of bright light protection (separate for each EC-unit: 2×2 MAPMTs):

- switch to lower gain in case of a few very bright pixels
- over-current protection

Ancillary devices include near IR and VIS cameras (5 s frames), a small silicone photomultiplier and photodiodes (for detecting day/night transitions)

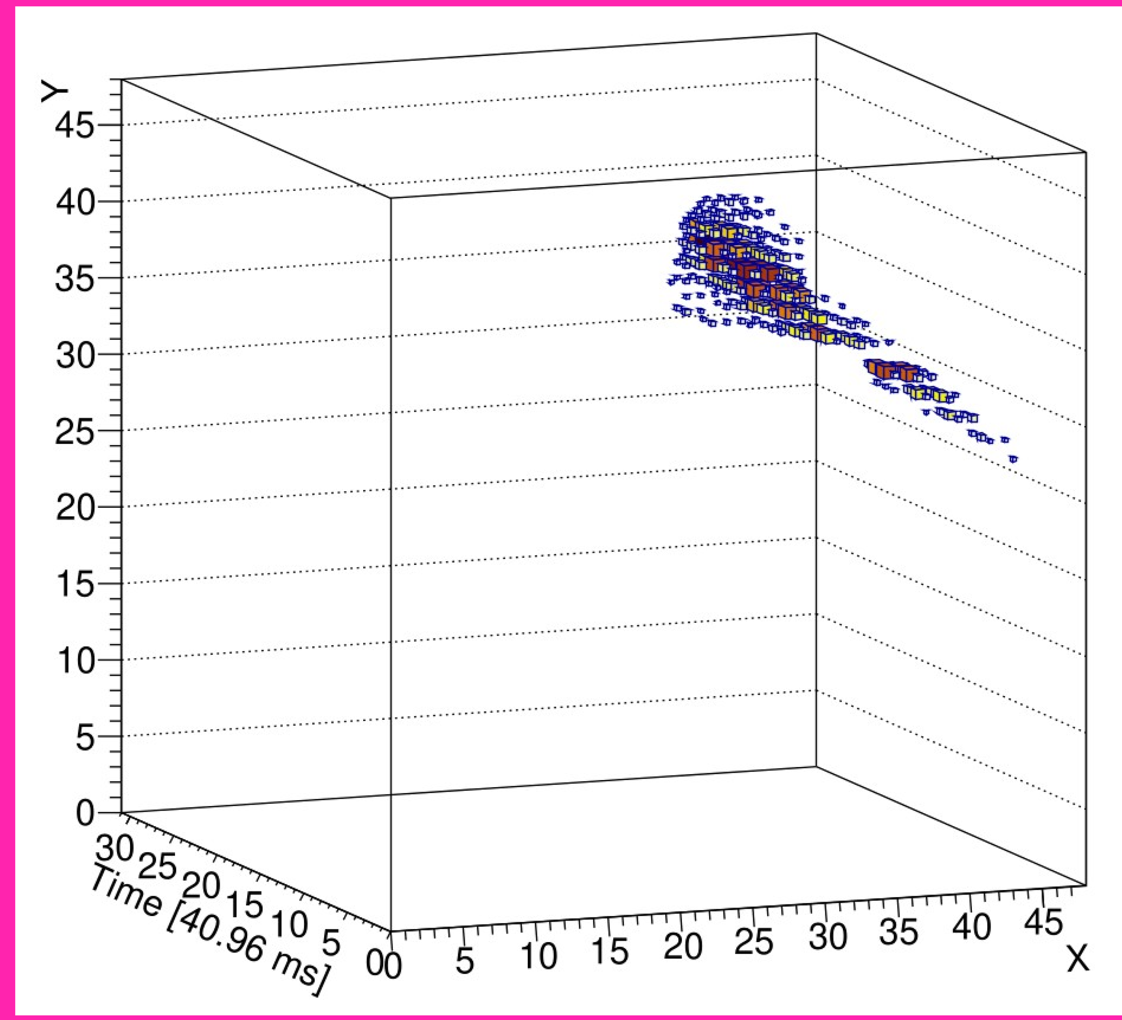

Fig. 1. An example of a meteor trace in Mini-EUSO after background subtraction

D3 offline trigger

As D3 data are untriggered, a dedicated off-line trigger has been created to detect variable events, currently with the main purpose of finding meteors. The main steps of the trigger are the following:

1) Divide the data into the chunks with the same gain
2) Estimate background for each pixel
3) Find frames over the background-based threshold for each pixel
4) Remove (pixel,frame) pairs without another pair in a 4 frames vicinity
5) Group the (pixel,frame) pairs into events using a KD-tree
6) Perform initial categorisation of events
7) Perform additional quality cuts on meteor candidates

Afterwards, basic meteor properties such as lightcurve, track on the PDM (fig. 1) and speed are obtained with simple and quick methods and stored in a database.

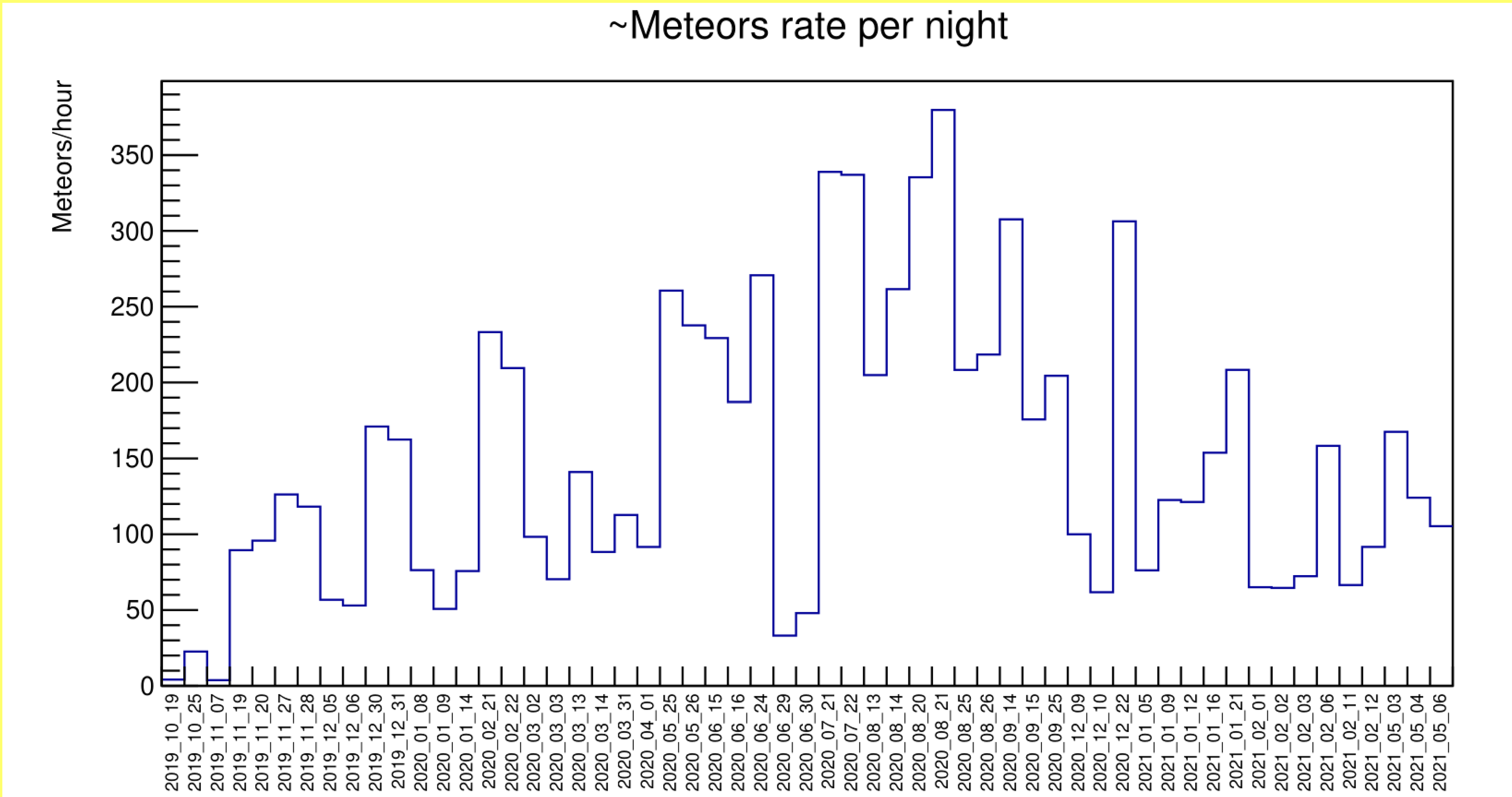

Fig. 2. Meteor candidates per hour for specific nights observed by Mini-EUSO

Meteor statistics

After every data taking session, only roughly 20% of the data is downlinked to the ground due to the ISS bandwidth limitations. The remaining data is periodically transported to Earth on USB pendrives. So far we have obtained:

- ~63 hours of data on the ground
- ~42 hours with nominal gain
- 5552 meteor candidates, including:
  - 616 false candidates (visual inspection)
  - → average false event rate of about 11%

The hourly rate of the observed meteor candidates can be seen in fig. 2. None of the analysed events has a semi-constant lightcurve, long-duration and measured speed significantly over 72 km/s, which excludes obvious heavy compact objects candidates. The two meteors of the longest duration are visible for 2.5 and 3.7 s.

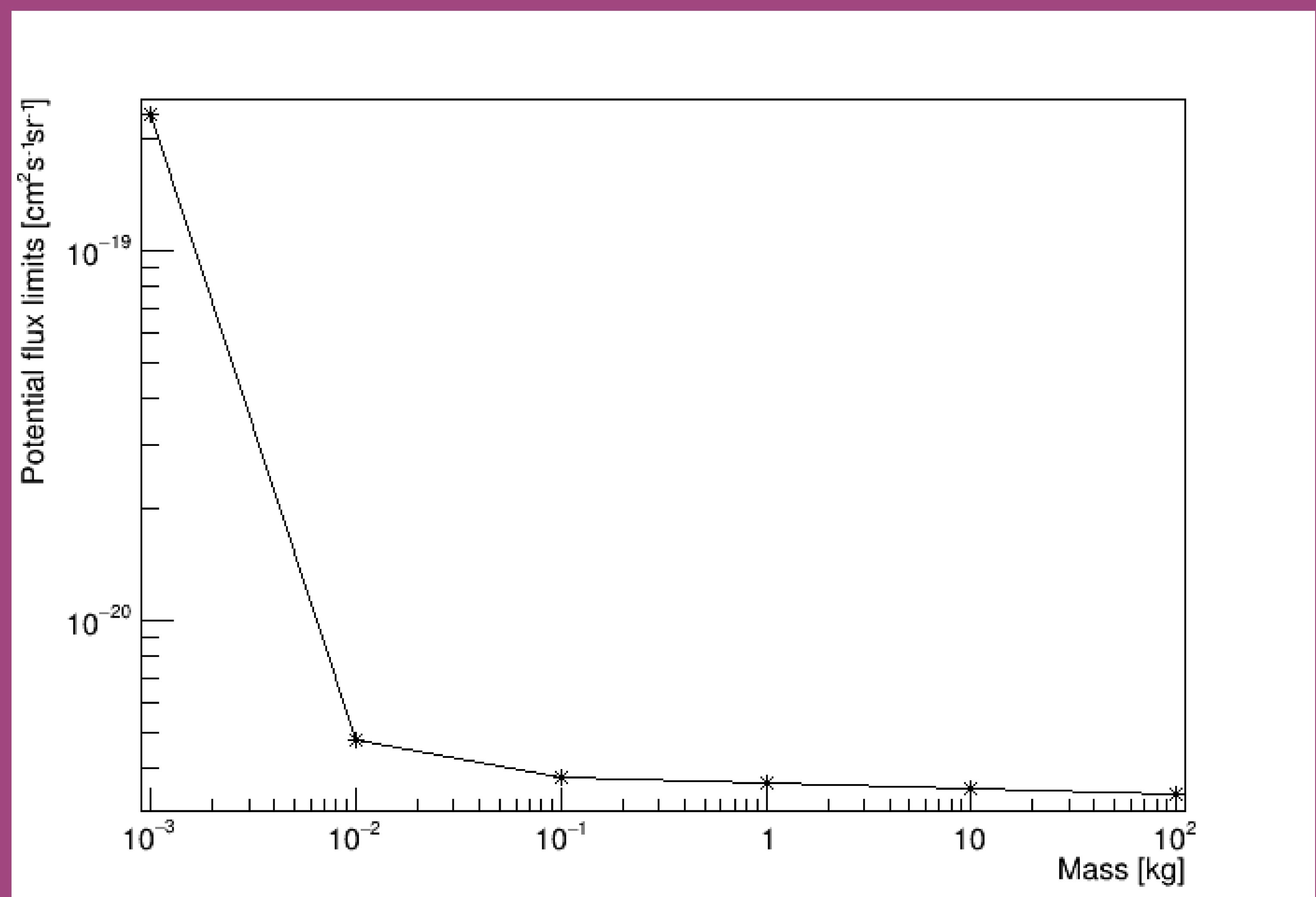

Fig. 3. Potential 90% C. L. flux limits on nuclearites after 42 h of Mini-EUSO observations in the nominal mode

Towards observations of nuclearites

Lack of detection can be claimed only after checking if the trigger can detect expected nuclearite tracks. This is best done simulating expected track over real data, as nuclearites are still hypothetical. We have not performed such efficiency estimation yet, thus we only very roughly estimate our sensitivity based on the detector parameters and observation time, with the following:

1. Calculate the side and top surface of the field of view pyramid *S*, trimmed at h_max
2. Calculate the magnitude of a nuclearite at $h\_max/2$
3. Calculate maximal Mini-EUSO PDM counts
4. Calculate the background 3σ below the nuclearite signal
5. Find the average fraction of time in which a nuclearite could be detected, t_d
7. Calculate the exposure for detection, as $E(m)=S(m)*t_d(m)*\pi$, where m is the mass of a nuclearite.

Assuming lack of detection of nuclearites in our data, such an exposure can be translated to a *potential* 90% C. L. flux limit $\Phi(m)=2.3/E(m)$. Such potential flux limits are shown in fig. 3.