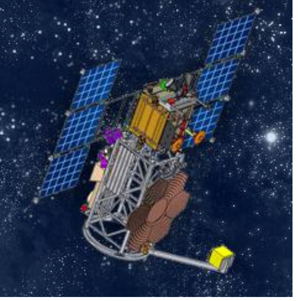

Relativistic dust grains: a new subject of research with orbital fluorescence detectors

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Abstract. TUS (Tracking Ultraviolet Set-up) was the world's first orbital detector aimed at testing the principle of observing ultra-high energy cosmic rays (UHECRs) with a space-based fluorescence telescope. TUS was launched into orbit on 28th April 2016 as a part of the scientific payload of the Lomonosov satellite, and its mission continued for 1.5 years. During this time, its exposure reached~1550 km^{2}sr yr for primary energy ≥400EeV, and a number of extensive air showers-like events were registered. The shape and kinematics of the signal in these events closely resembled those expected from UHECRs but amplitudes of the signal and some other features were in contradiction with this assumption. A detailed analysis of one of EAS-like events (TUS161003) revealed that a primary cosmic ray would need to have an energy ≥1 ZeV in order to produce a light curve of the observed amplitude, which is incompatible with the cosmic ray spectrum obtained with ground-based experiments. More than this, the slant depth of the shower maximum be the signal produced by a cosmic particle, was estimated as ≤500g/cm^2, which corresponds to cosmic rays around 1 PeV. We present a preliminary discussion of a hypothesis that the TUS161003 event and perhaps some other bright EAS-like events could be produced by relativistic dust grains, which were considered a possible component of the cosmic ray flux beyond the GZK cut-off some time ago.

1. The TUS detector. The TUS detector was the first space-based mission aimed for ultra-high-energy cosmic ray (UHECR) measurements. The detector was designed to register the fluorescent signal of extensive air showers developing in the night atmosphere of Earth in the UV range of 300-400 nm. The main components of TUS were a Fresnel mirror and a square-shaped 16×16 photodetector aligned to the focal surface of the mirror. The mirror had an area of nearly 2 m^2 and a 1.5 m focal distance. The field of view (FOV) of the telescope was 9°×9°.

2. The TUS161003 event. The TUS161003 event was registered on 3 October 2016 in approximately 100 km south-east from Minneapolis, MN, USA.

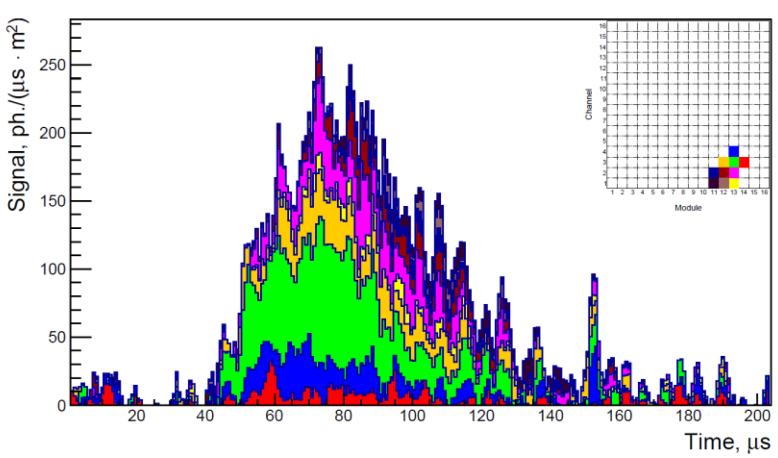

Figure 1: The light curve of the TUS161003 event and location of the hit channels.

No potential sources of artificial UV light were identified on ground. The signal was registered in perfect observational conditions without any noticeable clouds.

The light curve of the TUS161003 event and location of the hit channels in the focal surface are shown in Figure 1. The spatio-temporal dynamics of the signal found in 10 adjacent pixels was similar to what was expected from an extensive air shower basing on detailed simulations performed with ESAF. The arrival direction of the signal source was found to be θ= 44° ± 4°, ϕ = 50° ± 10°.

However, a primary cosmic ray, be it a proton or an iron nucleus, would need an energy ≥ 1 ZeV = 1000 EeV, which is at least three times higher than the most powerful cosmic ray event ever registered during more than 60 years of observations.

3. The TUS161003 event shower maximum.

The slant depth of the shower maximum was estimated from the light curve as ≤ 480-550 g/cm^2, which geometrically corresponds to altitudes ~7.5 – 8.5 km above the ground. This rules out a proton or an iron origin of the primary source of light since a particle with an energy ≥1 ZeV arriving at the zenith angle ~44° should produce and EAS that hits the ground before reaching its maximum.Conversely, the observed slant depth corresponds to an EAS generated by a cosmic ray with an energy around PeV, see Figure 2.

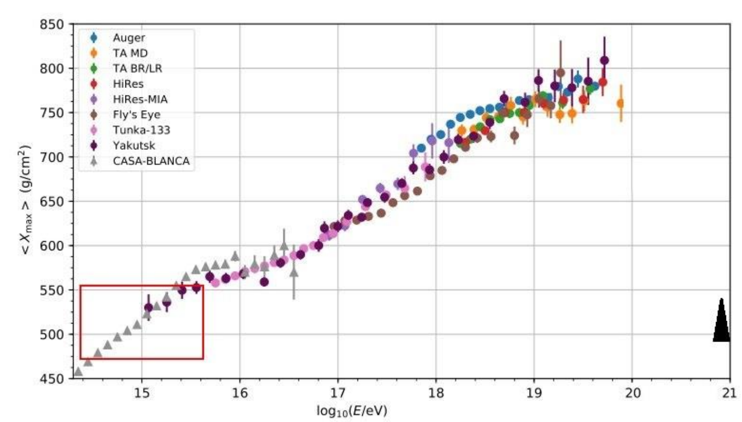

Figure 2: Mean depth of maximum of EASs vs. energy of primary cosmic rays according to data of different experiments. The red box shows the range of slant depths and respective energies estimated for the TUS161003 event. The black triangle shows estimations for the TUS161003 event.

4. Superposition model. Suppose we consider the atmosphere to be a target for a cluster of nucleons (a dust grain) containing N_n = 10^6 nucleons in atomic and molecular states, with the primary energy of E_0 ~ 10^{21} eV and energy per nucleon Nn = E_0/N_n = 10^{15} eV. Applying the superposition model to this impact process, one should expect as a final observable picture the sum of N_n EASs with the total energy approximately equal to E_0, excluding the bond energy summed over all nucleons of the cluster.

Conclusions. Orbital fluorescence telescopes aimed at observing UHECRs will provide an interesting opportunity for studying relativistic dust grains. The remarkable coincidence of the slant depth of a shower maximum generated by an RDG and that of the TUS161003 event suggests that this hypothesis is worth studying in detail. Following the superposition principle, one can check if an air shower generated by a relativistic dust grain that consists of 10^6 protons with an energy around 1 PeV is able to produce a light curve similar to that of the TUS161003 event or some other EAS-like events registered by TUS. The Mini-EUSO telescope that currently operates at the International Space Station and the future EUSO-SPB2, K-EUSO, and the POEMMA missions can extend the capabilities of TUS and the ground-based detectors and shed new light on this hypothesis.