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

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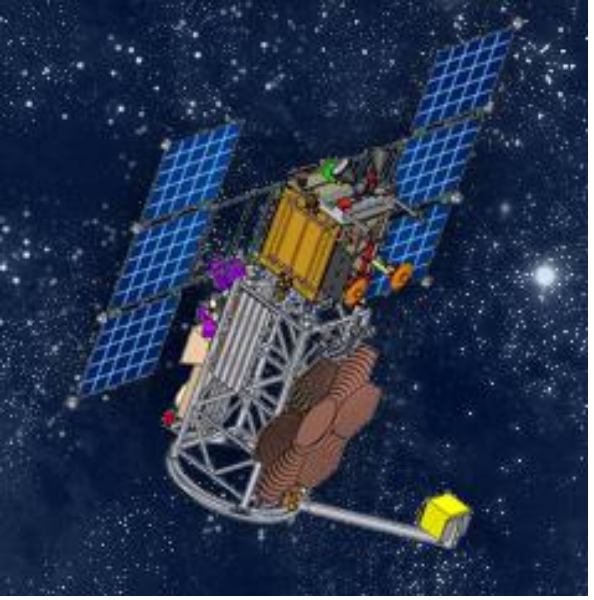
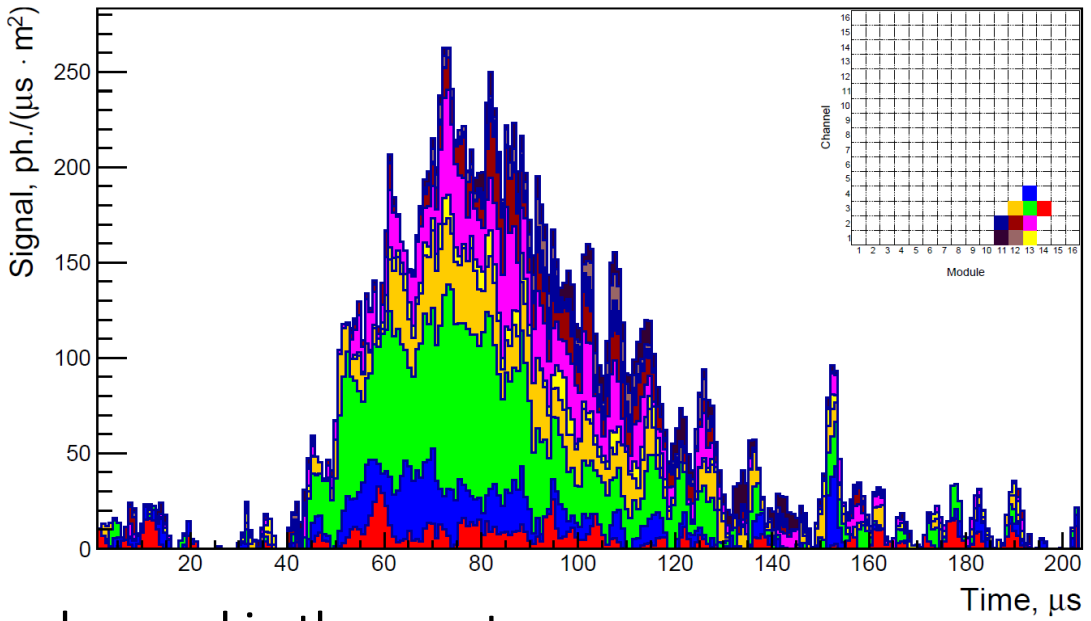
The TUS detector on board Lomonosov satellite

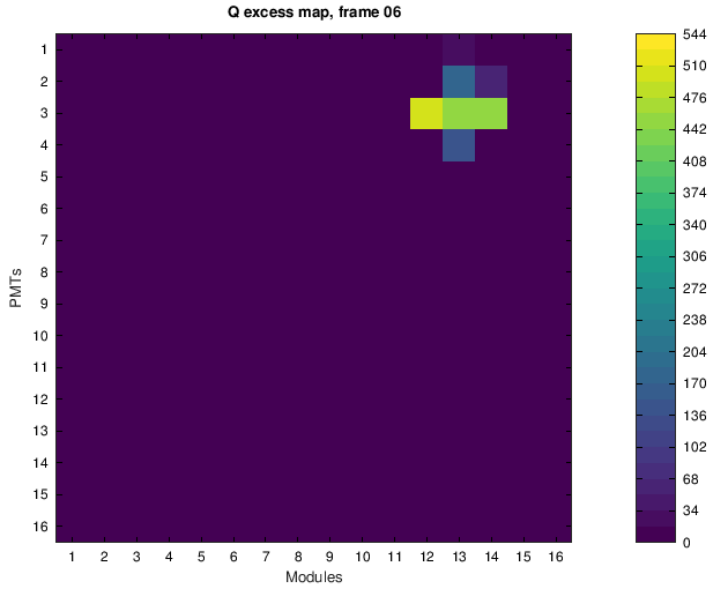


- ✓Mirror area is ~2 m^2. Provides high sensitivity of the detector.
- ✓Photo detector - 256 photomultiplier array with electronics providing registration with a time resolution 0.8 μs.
- ✓Pixel FOV is 10 mrad (5×5 km on ground), total FOV: 80×80 km.
- ✓Spectral range of measurements: 300-400 nm

Modes of TUS	Temporal resolution	Waveform duration
EAS	τ_0 = 0,8 μs	ΔT = 205 μs
TLE-1	τ_1 = 25,6 μs	ΔT = 6,6 ms
TLE-2	τ_2 = 0,4 ms	ΔT = 105 ms
METEOR	τ_3 = 6,6 ms	ΔT = 1,7 ms

EAS-like events in the TUS detector





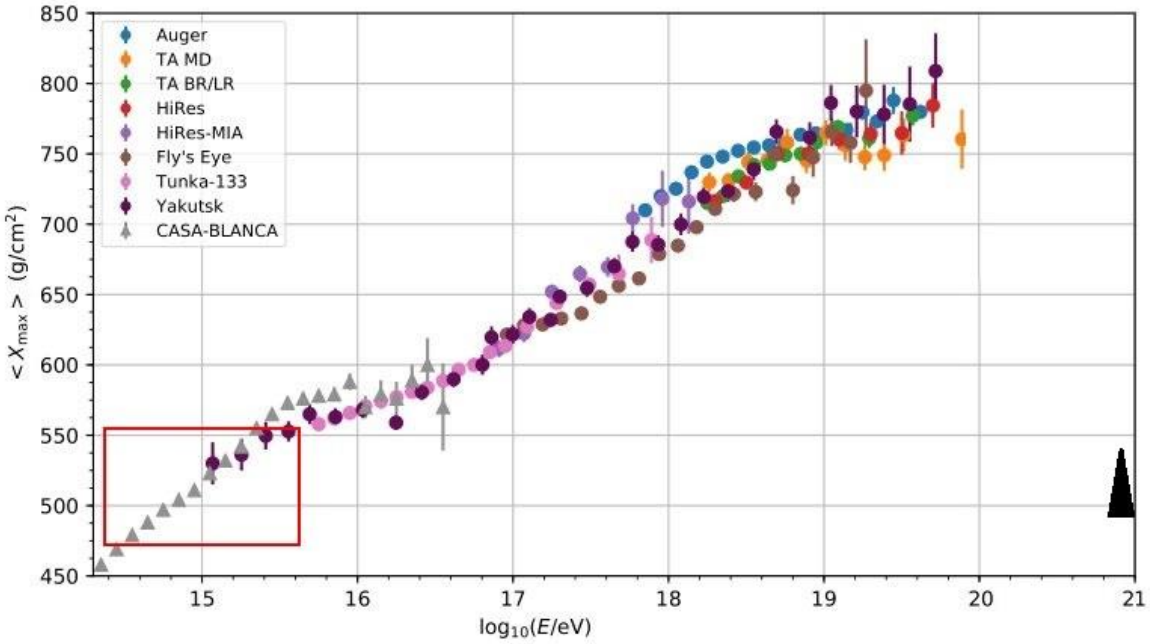
- ✓ Relativistic motion is observed in the event.
- ✓ The parameters of the primary particle were reconstructed under the assumption of an EAS.
- ✓ The exposure of the detector is small to expect reliable registration of at least a few events.
- ✓ However, the experiment demonstrated the efficiency of the technique, the ability to recognize and reconstruct relativistic motion, but also the problem: a wide variety of background phenomena.

$$\phi_{\rm rec} = (50 \pm 10)^\circ\,, \quad \theta_{\rm rec} = (44 \pm 4)^\circ\,.$$

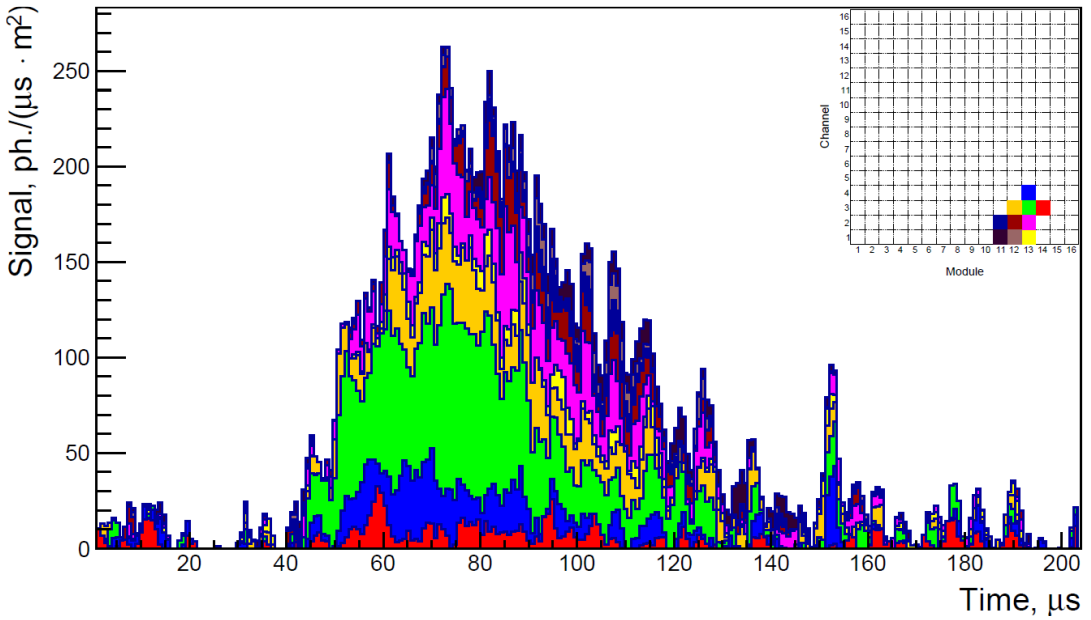
$$E \gtrsim 10^{21}\ {\rm eV}$$

Khrenov et al, JCAP, 2020

Xmax distribution



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.



TUS event Xmax estimation

1) The time interval between the maximum of the light curve and the moment when the signal decays to the background level is 60 us, which geometrically corresponds to the altitude of 7.5 km. This allows us to estimate the slant depth of the shower maximum as 550 g/cm^2.
2) We consider a sharp peak near 150 us as a Cherenkov one. It has a delay from the light curve maximum 70 us, and this means an altitude 8.5 km, which corresponds to the slant depth 480 g/cm^2.

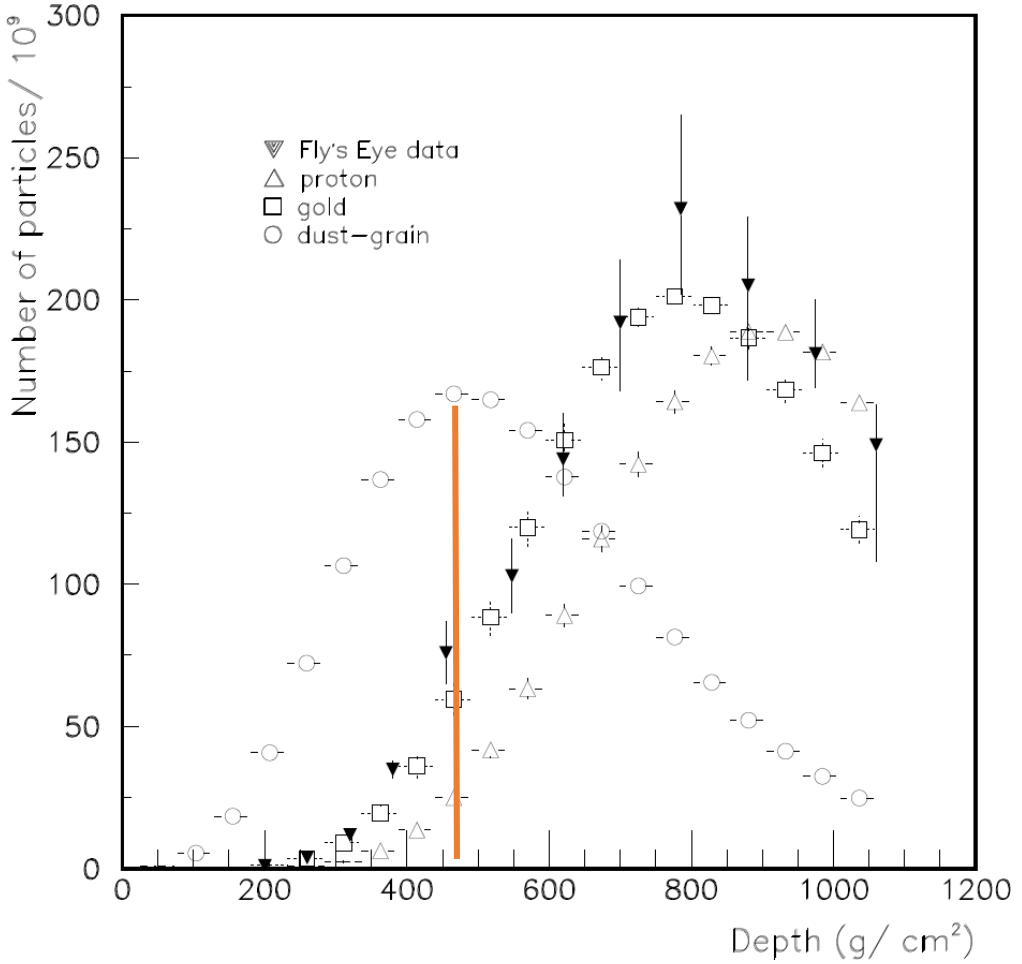
Superposition model

- If we consider the atmosphere as a target for cluster of nucleons (the dust grain) containing $N_n = 10^6$ nucleons in atomic and molecular states, with primary energy of $E_0 \approx 10^{21}$ eV. The energy per nucleon will be $E_n = E_0 / N_n = 10^{15}$ eV. Applying superposition model to this impact process, one should expect as a final observable picture the sum of N_n EASs with summary energy approximately equal to E_0, exclude the bond energy summed over all nucleons of the cluster. In case of silicon nuclei with number of nucleons in one nucleus A=28, the bond energy per nucleon of about ≈8MeV and number of nucleons-grain constituents $N_n = 10^6$ the energy spent on disintegration of all cluster constituents was of the order of 10^{14} eV- negligible to compare with RDG projectile energy.
- Thus in case of RDG impact with the atmosphere, superposition model predicted the main energy loss via ionization loss by EASs generated by nucleons-constituents of the grain. In the considered example every of those nucleons had energy $E_n \sim 10^{15}$ eV and $X_{max} < 500$ g/cm^2 as was observed in event TUS161003 with primary energy 10^{21} eV

Simulations of EASs produced by RDGs

Luis A. Anchordoqui, Cosmic dust grains strike again Phys. Rev. D 61, 087302 – Published 14 March 2000

- A detailed simulation of air showers produced by dust grains has been performed by means of the *AIRES* Monte Carlo code with the aim of comparing with experimental data. Our analysis indicates that extensive dust grain air showers must yet be regarded as highly speculative but they cannot be completely ruled out.
- What is more, the nucleons in each incident nucleus will interact almost independently. Consequently, a shower produced by a dust grain containing ***n*** nucleons may be modelled by the collection of ***n*** nucleon showers, each with ***1/nth*** of the grain energy.



L.A. Anchordoqui, M.T. Dova, T.P. McCauley, T. Paul, S. Reucroft and J.D. Swain,A pot of gold at the end of the cosmic raynbow"?, Nuclear Physics B Proceedings Supplements97(2001) 203 [astro-ph/0006071]

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.