A drone-borne installation for studying the composition of cosmic rays in the range of 1–1000 PeV by registering the reflected Cherenkov light of EAS

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Introduction

The SPHERE project is an experiment aimed at ultra-high energy cosmic ray studies by means of reflected Cherenkov light. The idea dates back to 1970-s when it was proposed by Russian astrophysicist A.E. Chudakov, after 20 years leading to the creation of the SPHERE project. We explore the proposed new implementation of the SPHERE detector, SPHERE-3, highlight its main goals and overview our latest developments in analysis methods.

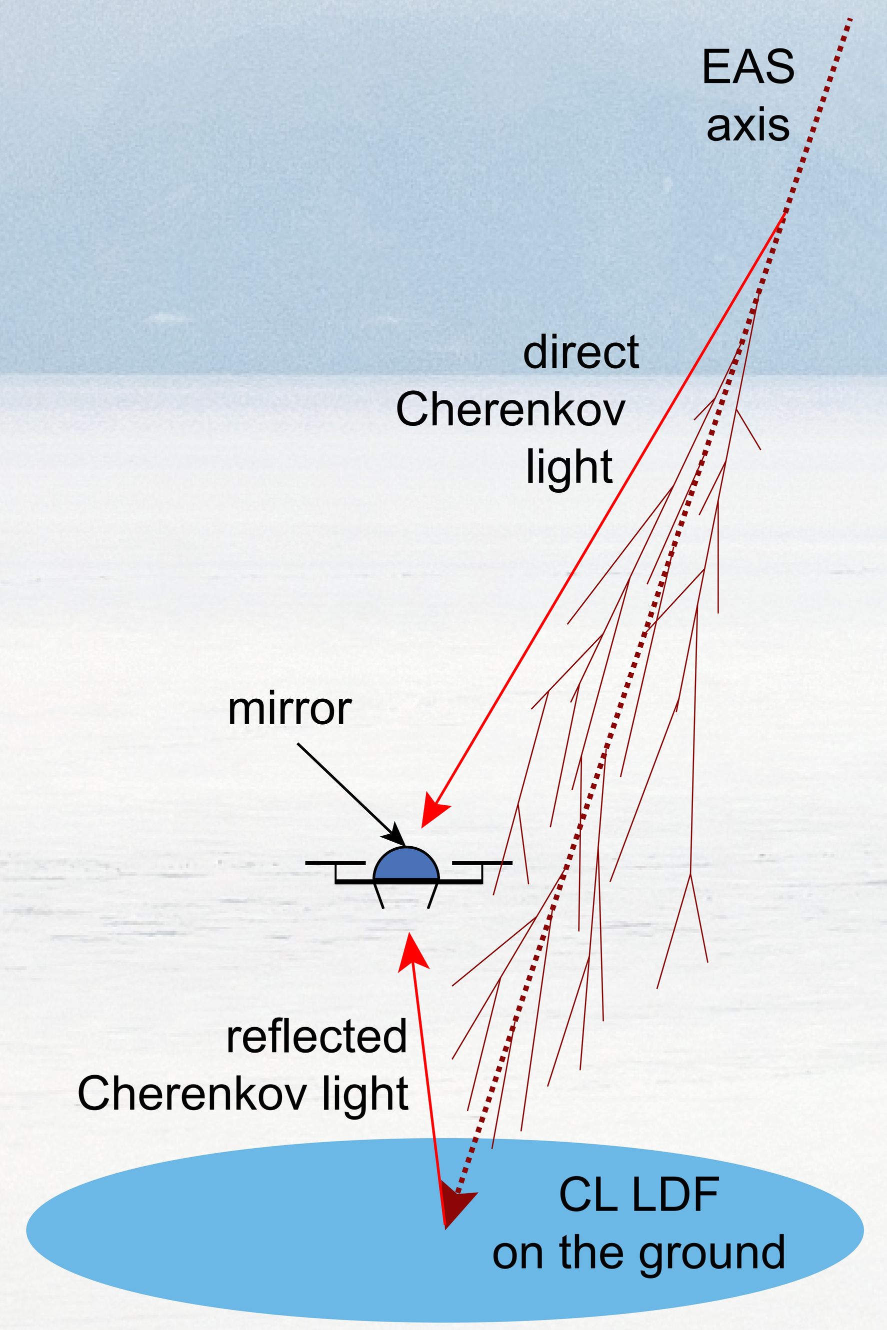

Fig. 1:The SPHERE-3 detector operation

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Observation method

The compact detector is lifted at an altitude of 500–3000 m. It is equipped with a Schmidt camera looking down at the flat reflecting surface of the snow. EAS Cherenkov light falling on the snow is reflected and then collected by the detector, allowing reconstruction of the shower properties.

Previous implementations of the SPHERE project used PMTs as sensitive elements and were lifted by a balloon. The proposed new detector uses SiPMs, a modern replacement for PMT. They are smaller, lighter and do not require high-voltage sources – all this makes the detector much lighter. The drone is proposed as a carrier because of its cost-effectiveness and mobility. The drone-borne detector is also directly scalable by using multiple drones to increase effective area.

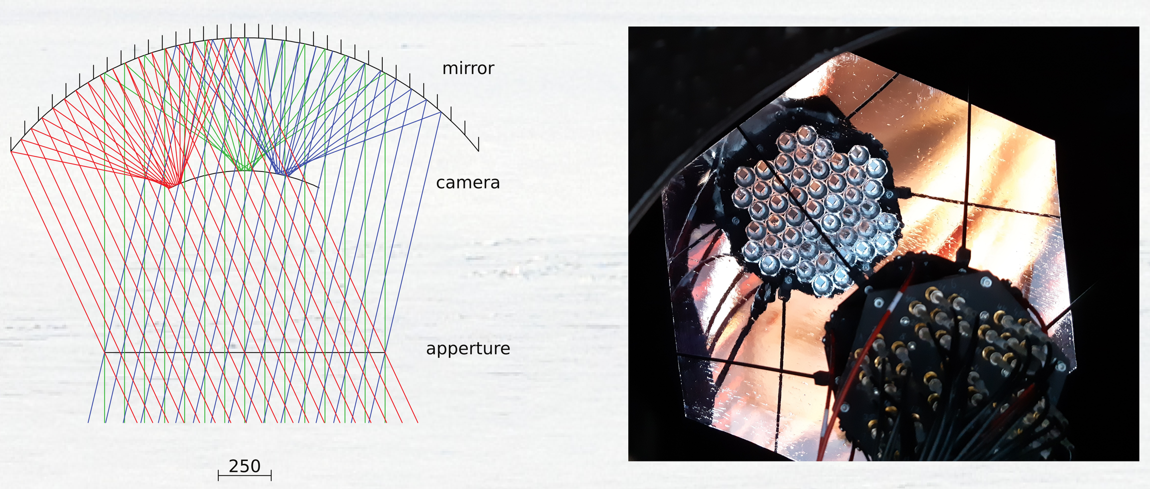

Fig. 2:Optical schema of the detector and prototype of the SPHERE-3 SiPM camera

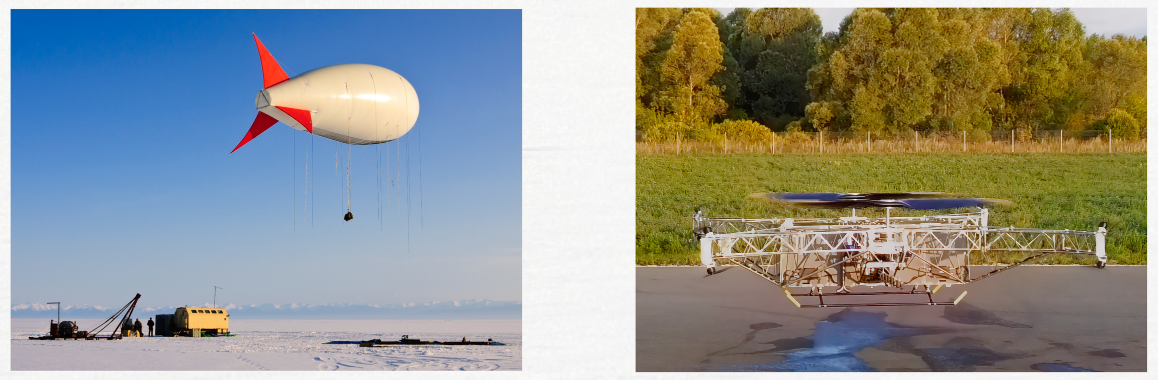

Fig. 3:The SPHERE-2 lifted by a balloon in March 2013 and an example of a heavy agricultural drone proposed as a carrier for the SPHERE-3 (Braeron ID-400A)

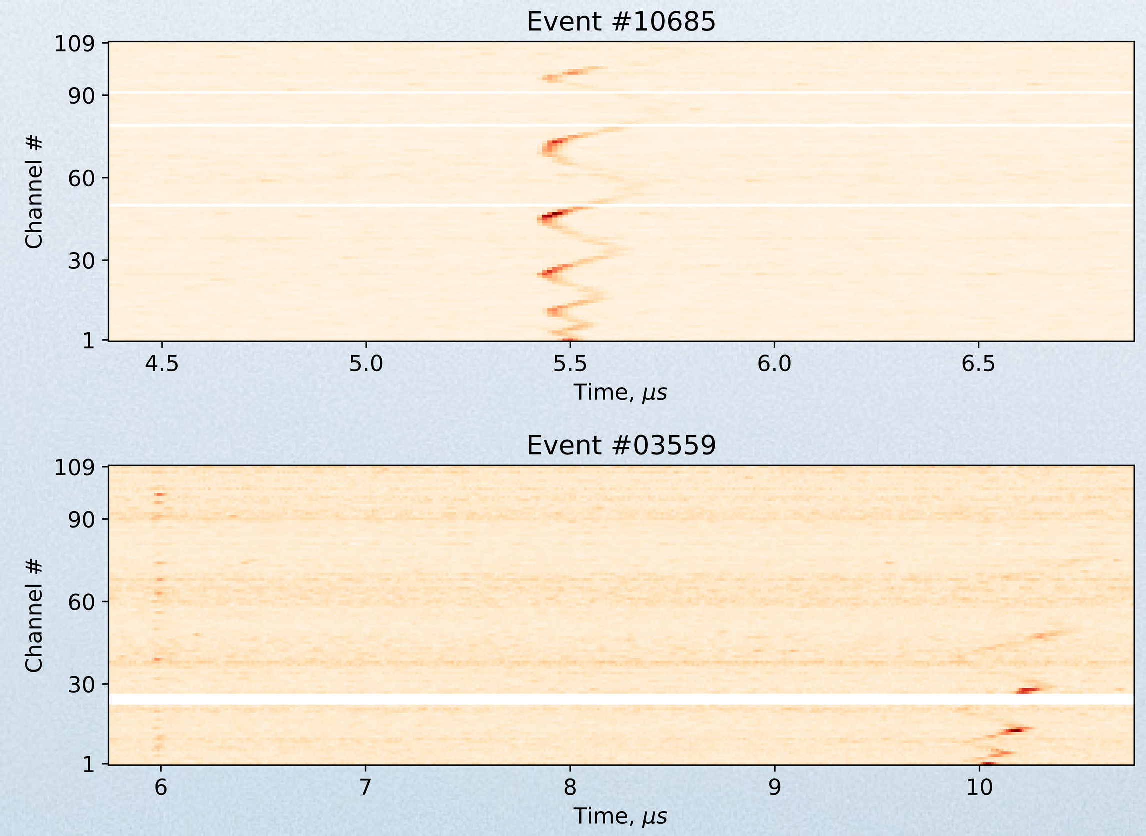

Fig. 4:Reflected and direct Cherenkov light as seen by the SPHERE-2 detector.

Advantages

Despite the inability to compete with larger experiments in effective area and therefore statistics, the SPHERE project is aimed at maximizing its design advantages:

- Sensitivity to the near-axis region of the shower
- Integral probing of the CL distribution
- Rich telemetry, including atmosphere and surface conditions
- Cost-effectiveness
- Portability and flexible operation strategy

Table 1:Proposed detector characteristics

Parameter	Prototype	Target
Effective aperture, m^2	0.1	1.0
Viewing angle, °	±25	
Number of pixels	133	up to 1000
Max detector weight, kg	10	100
Flight altitude, m	500	2000

Analysis methods

Several original analysis methods were developed for the SPHERE project. The observed photon counts are traced back to surface-level EAS CL distribution using each pixel's individual field of view. Low-intensity flashes in SiPMs are processed with dedicated statistical deconvolution codes.

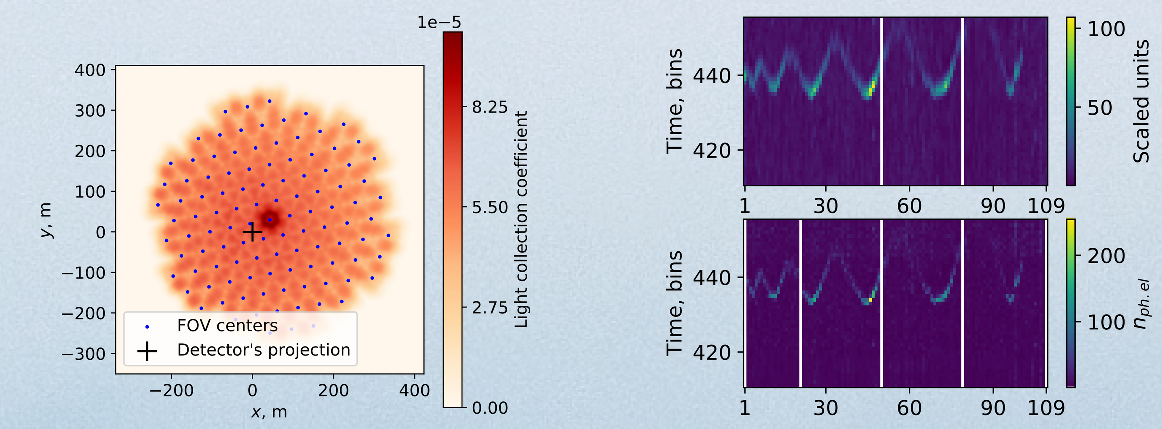

Fig. 5:FOV of the detector on the surface, analogous to the ground array but with large overlapping detectors (left). Statistical deconvolution procedure illustration (right).

The primary particle mass is estimated with integrated steepness parameter:

$$\eta = \int_{r_1}^{r_2} Q(r)\, r\, dr \Big/ \int_{r_3}^{r_4} Q(r)\, r\, dr \qquad (1)$$

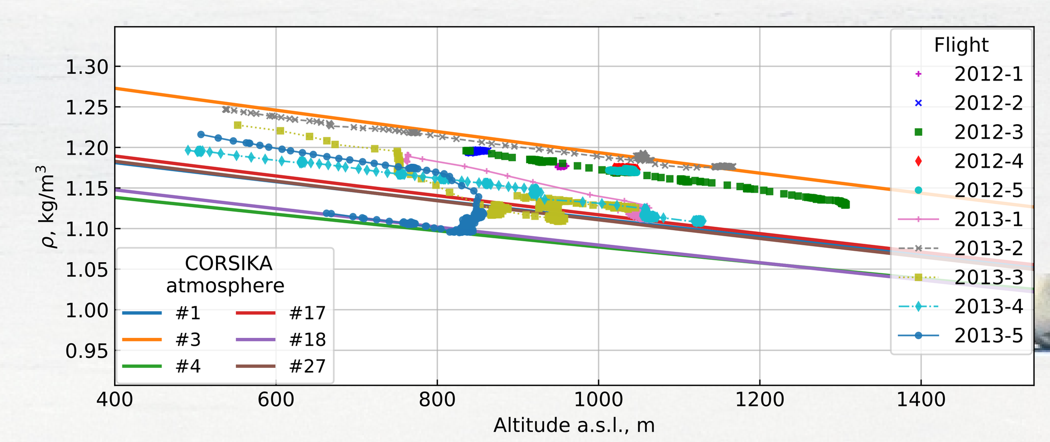

Fig. 6:Atmosphere density profile estimation from SPHERE-2 telemetry data

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