The EUSO mission to study UHECR from space: status and perspectives

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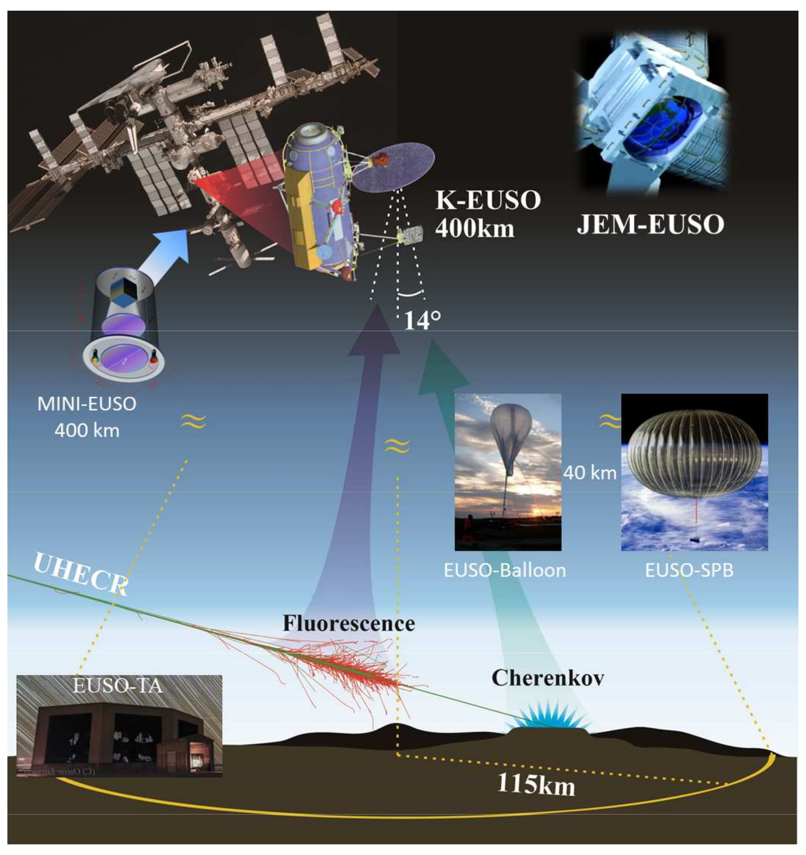
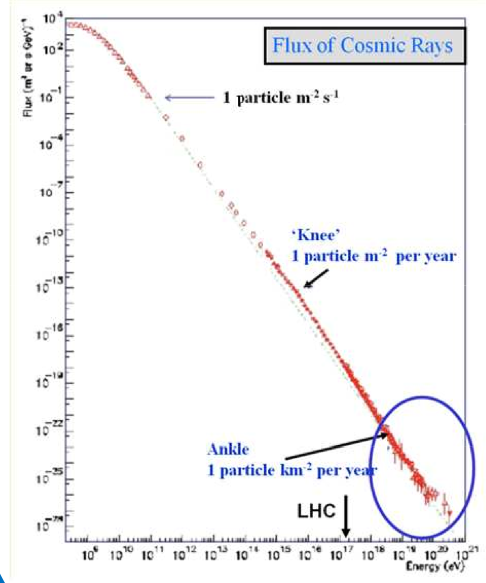
EUSO

Extreme **U**niverse **S**pace **O**bservatory

EUSO is a new type of observatory which observes transient luminous phenomena occurring in the Earth's atmosphere.
The instrument is planned to be attached to ISS for a 3 years long mission.
The main objective of EUSO is to study the Extreme Energy Cosmic Rays, EECR ($E > 5\times10^{19}$ eV), which are the most energetic component of the cosmic radiation.





Observation from space has two main advantages:

1. The target volume is far greater than possible from the ground
2. Full sky coverage

Physics and Astrophysics from $E > 5\times10^{19}$ eV, focusing at $E\sim10^{20}$ eV (and above):

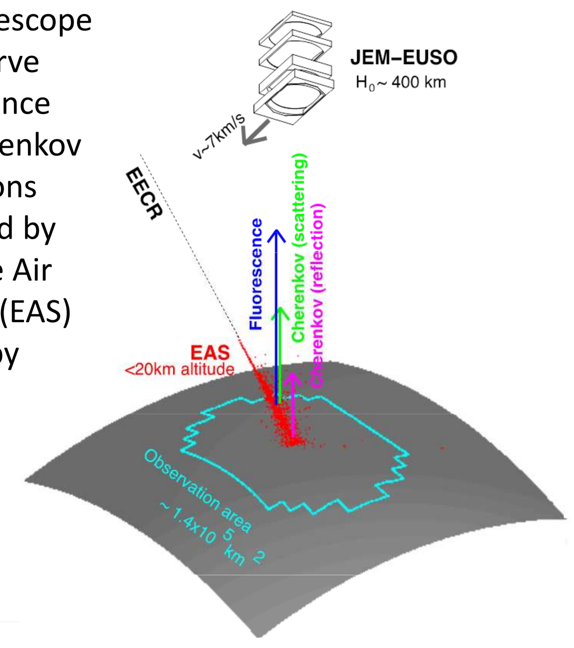
- Identification of EECR sources by high-statistics arrival direction analysis
- Measurement of the energy spectra of individual sources (spectral shape, flux, power)
- Understand and constrain acceleration and emission mechanisms

The telescope is an extremely-fast and highly-pixelized (~$3\cdot10^5$ pixels) digital camera with a large diameter (2.35 m) and a wide-Field of View (FoV, ±30°). It works in near-UV wavelength (290 - 400 nm) in single-photon counting mode. The telescope consists basically of four parts:

- **Optics**: 3 high transmittance optical Fresnel lenses focusing the arriving UV photons onto the Focal Surface
- **Focal Surface detector:** ~ 5000 Multi Anodic PhotoMultipliers Tubes of 64 pixels
- **Focal Surface electronics**: trigger, data acquisition and controls
- **Mechanical structure**

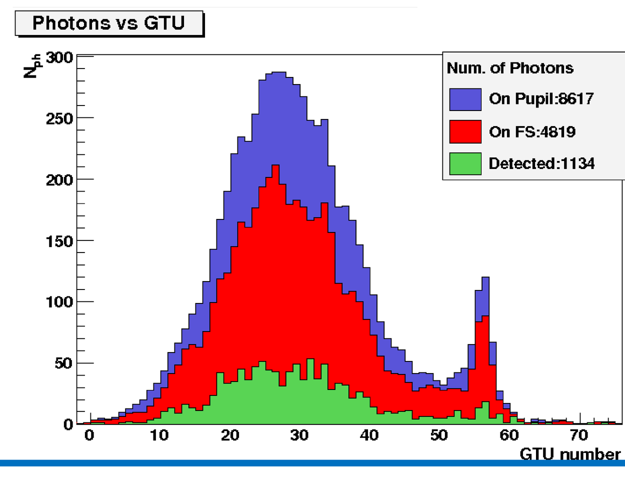
The apparatus is completed by an atmosphere monitoring system (Infra-Red camera and Lidar) and a calibration system.

EUSO telescope will observe fluorescence and Cherenkov UV photons generated by Extensive Air Showers (EAS) created by EECR.



The program

1. **EUSO-TA**: ground detector installed in 2013 at Telescope Array site (USA); currently operational
2. **EUSO-Balloon:** 1st balloon flight from Timmins (Canada) by the French Space Agency; August 2014
3. **EUSO-SPB**: NASA Ultra long duration flight from Wanaka (New Zealand); launch in April 2017
4. **MINI-EUSO**: precursor on the International Space Station approved by Italian and Russian Space agencies; launch in 2017
5. **K-EUSO**: bigger telescope on ISS, approved by Russian Space Agency; launch in 2019



EAS development time ~ 50 - 150 μs

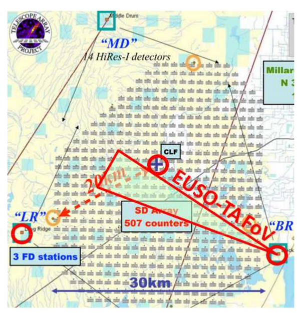
Simulation of the light profile observed at the entrance pupil and through the instrument

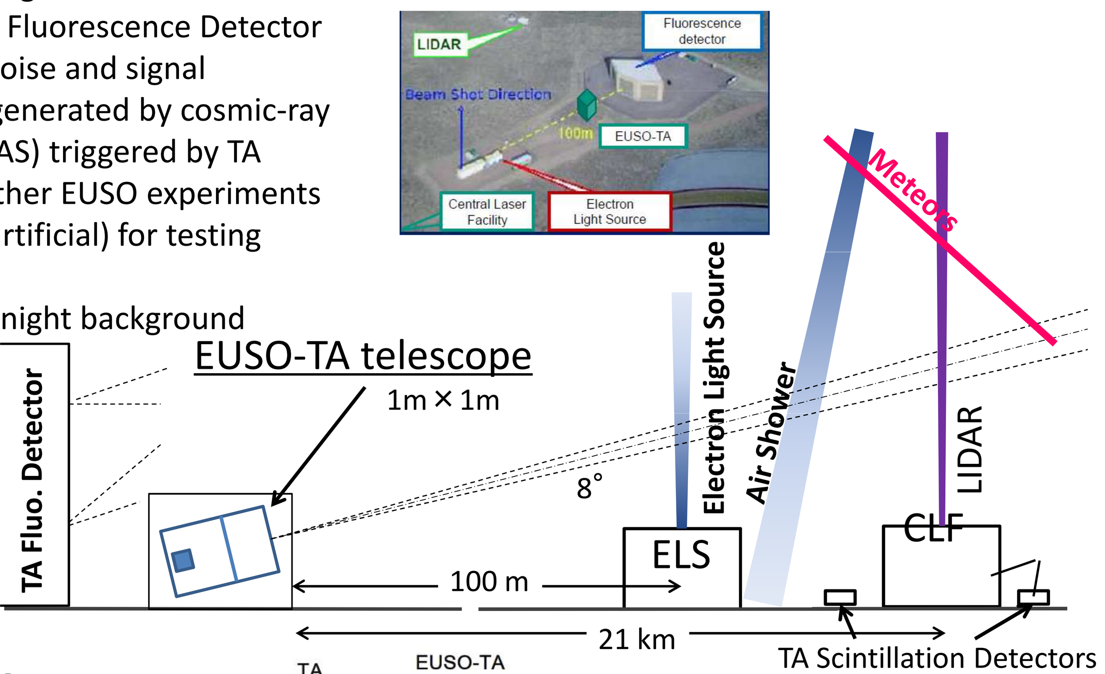
EUSO-TA

Main objective

bring to maturity the technologies for the EUSO telescope

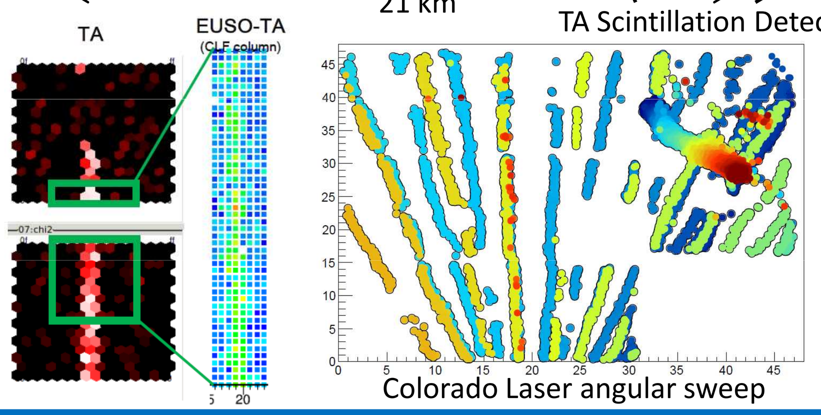
- Calibration with artificial light
- Cross-calibration with TA Fluorescence Detector through comparison of noise and signal
- Observation of UV light generated by cosmic-ray Extensive Air Showers (EAS) triggered by TA
- Tests of electronics for other EUSO experiments
- Gathering data (CR and artificial) for testing algorithms/software
- Measurement of the UV night background





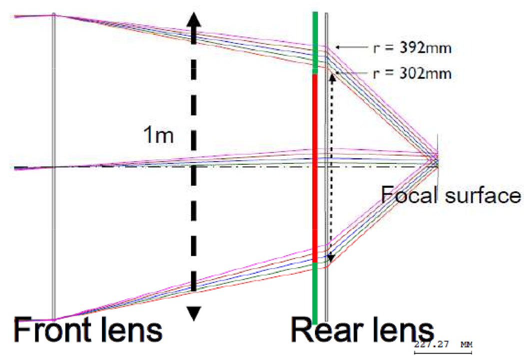
Artificial light

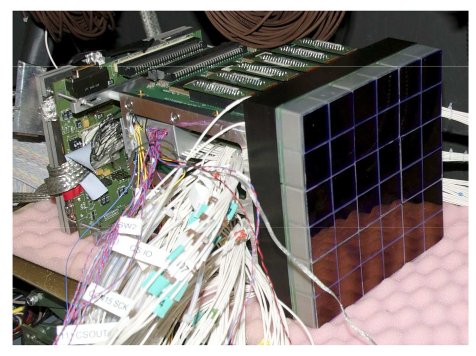
- Central Laser Facility (CLS) of TA
- LEDs
- Airplanes crossing the Field of View
- Colorado School of Mines movable laser
  - Distances: 24, 34, 40, 60, 100 km
  - Power: 0.5mJ up to 90mJ
  - Several inclination



The instrument

- 2 Φ1m Fresnel lenses
- 1 Photo Detector Module = 36 Multi-Anode PMT (MAPMTs)
- Concave focal surface
- UV transmitting filter (330-400 nm)
- Axis elevation: 26°
- FoV: ±5.5°
- Readout performed by one ASIC per MAPMT: 64 channels per ASIC



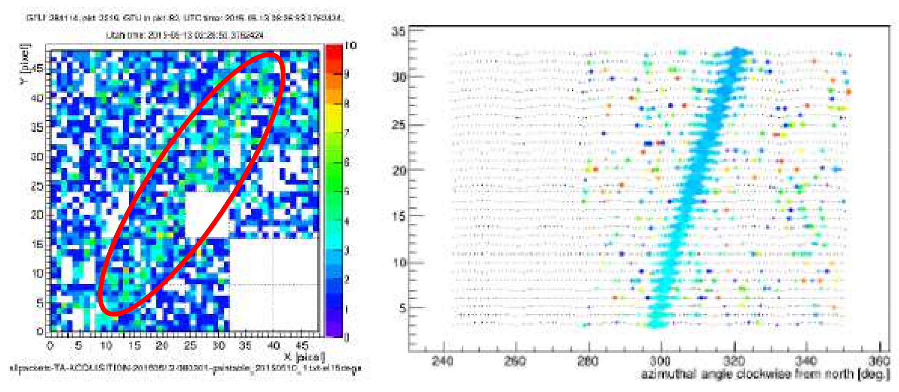


Cosmic Rays

Working modes:

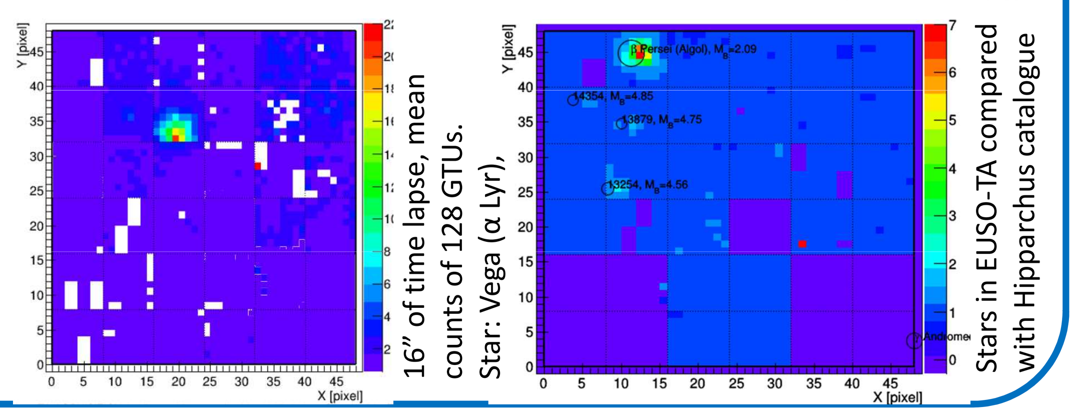
1. Internal trigger (not optimized for ground observations)
2. External (i.e. TA) trigger
3. Untriggered data taking

Until now we have 3 software triggered EAS events with TA reconstruction result. On the right an event with a reconstructed energy of $E = 10^{17.99}$ eV and a distance core-telescope of 2.5km is shown.

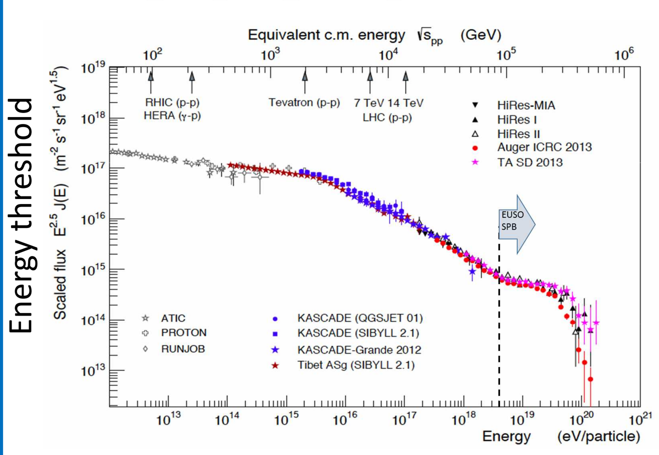


Stars and meteors

EUSO-TA has DC level (Poisson) background so it is able to see stars. Preliminary analysis shows that it can observe stars up to $M_B = 6.5$ on sums of 1280 frames (3.2 ms observation time). Very bright stars can be seen on single frames, the stacking allows us to get a good SNR, with negligible star movement on the sky compared to the angular size of our pixel. Meteors and moving of cloud possibly have been found, and are now under analysis. All the candidates cross the FoV in a time comprised between 1 and 2 seconds .



EUSO-SPB

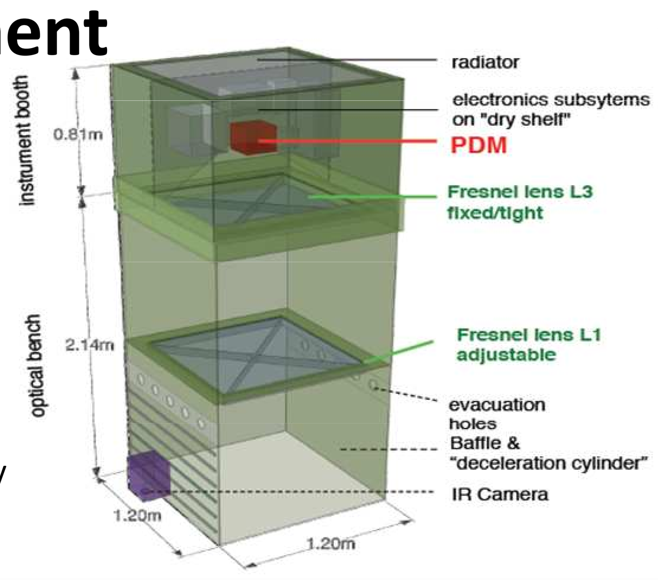


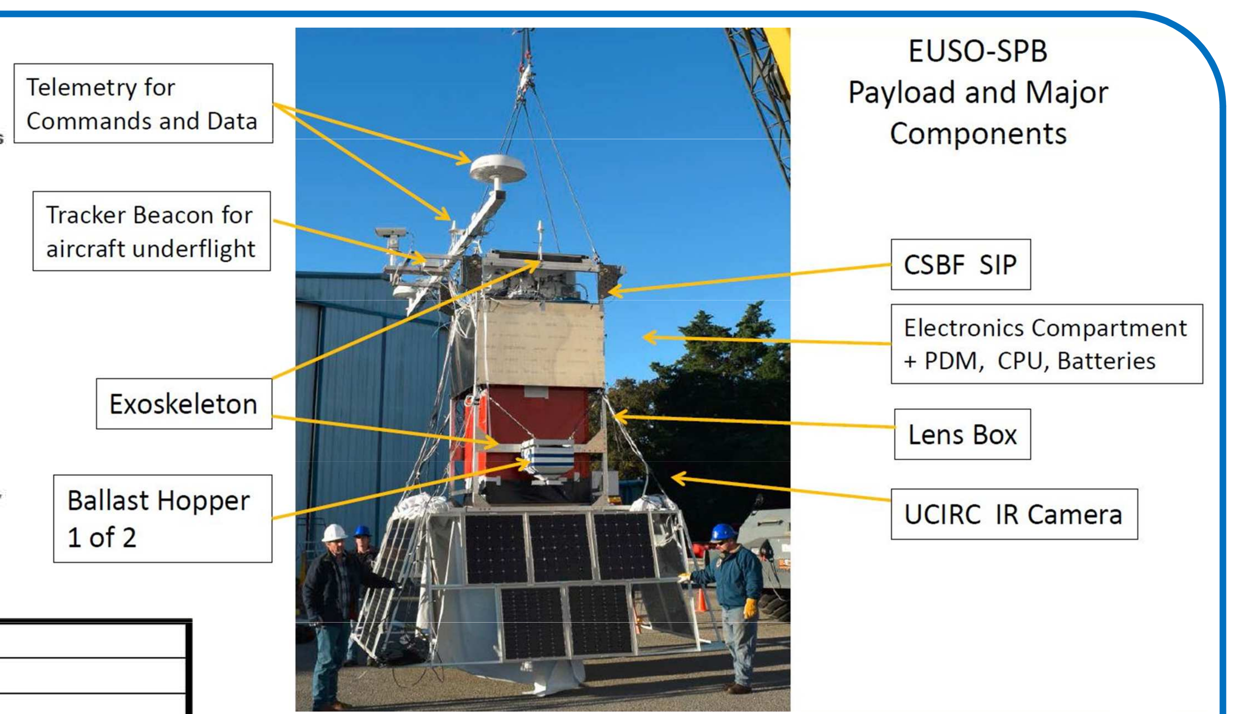
Scientific objectives

1. **First fluorescence observations of cosmic ray from above**
2. Measure UV background light at night from space
3. Search for faint and ultrafast UV signatures in the atmosphere from other phenomena
4. Establish methods and techniques for a future high energy astroparticle space observatory

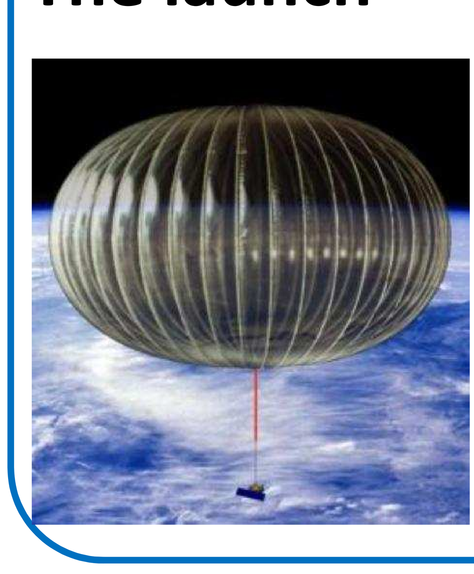
The instrument

The EUSO-balloon instrument first flew in 2014, by CNES. The detector reached float altitude at 38 km and collected data for one night. The payload was separated from the balloon at the end of the night. After descending by parachute, the detector landed in a small lake.

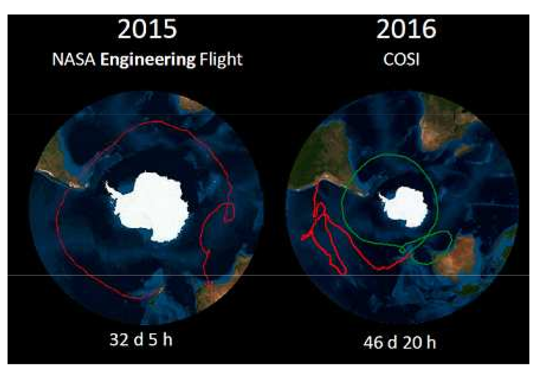


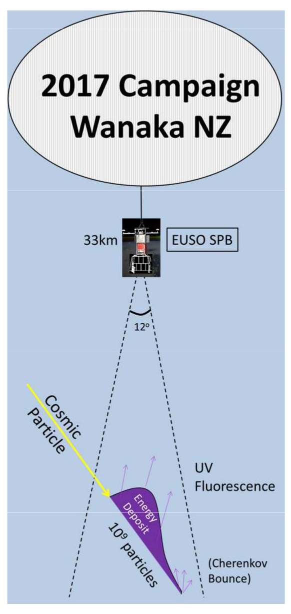


The launch



The SPB will be tracked from NASA's Columbia Balloon Facility. The launch window is open since March 25, 2017. Launching is very dependent on surface winds and other factors.



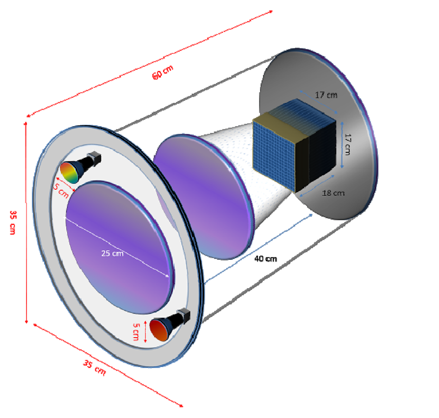


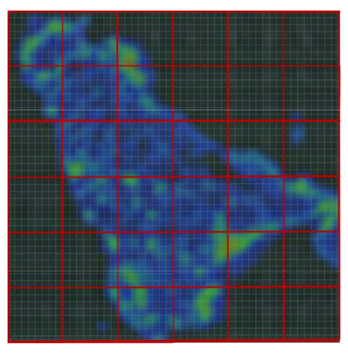
SPB Float Height	110,000 ft = 33.5 km
Weight	
Detector	2250 lbs
Payload	2700 lbs w/ SIP, Antennas, Empty Ballast Hoppers
Dimensions	1.2m x 1.2m x 3m
Power consumption	40 W Day, 70 W Night (assumes 20W PDM heater @ 50%)
Telescope	Refractor with 2 Fresnel lenses
FOV	11. deg (measured w/ stars)
Camera:	2,304 pixels; 36 MAPMTS (Hamamatsu R11265-113-M64-MOD2)
Data volume:	Downlinked ~1-1.5 Gb/day
Recorded	~3 GB/Day w/ 10 hour dark run
	with trigger rate of 0.2 Hz
Energy threshold	for h=33 km ~3 EeV
Ground equivalent Trigger Aperture	
	250 km^2sr @ 3 EeV to ~500 km^2 sr @ 10 EeV

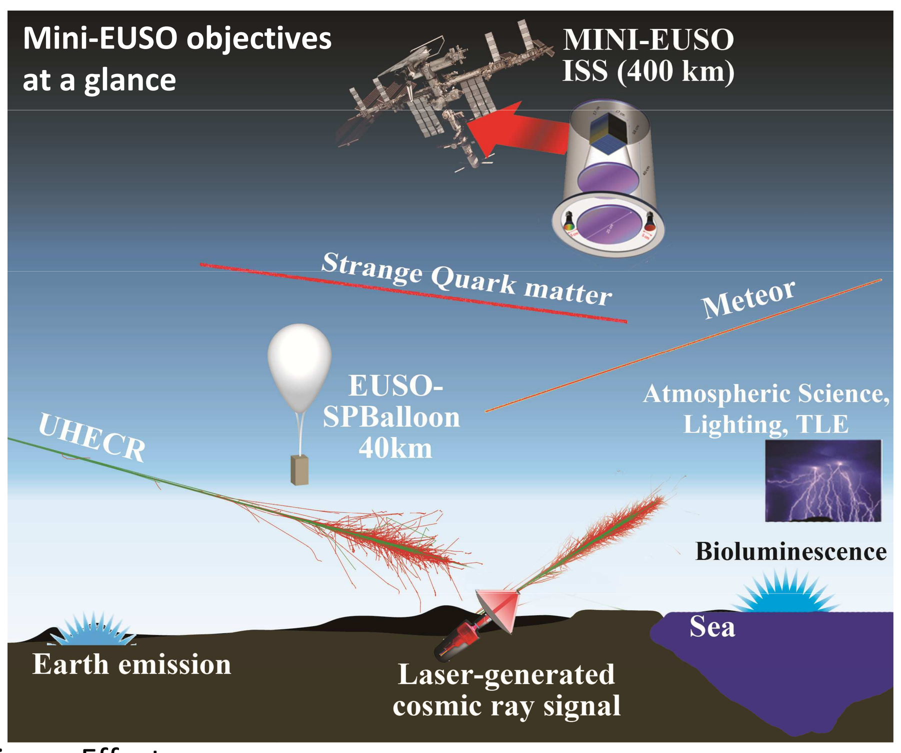
The SIP is built by the Colombia Scientific Balloon Facility and houses power, flight computers, telemetry systems, and the communication systems. It is able to determinate the actual pressure of the SPB during flight. It controls the ballast system which allows the payload to drop weight during flight if necessary. There is over the horizon communication to Palestine so that the balloon is controlled from there once the it is out of radio line of sight (5-6 hours of flight). The SIP also provides data path for the EUSO-SPB group to collect during flight.
The Iridium Pilot antennas sends the data signal back to the ground in addition to multiple GPS antennas and cameras.

Mini-EUSO

The main idea is to bring one single JEM-EUSO Photo Detector Module and two Fresnel lenses (25 cm diameter) to ISS to perform UV background measurements as a precursor for every missions in the UV range on ISS.







Scientific objectives

UV emissions from night-Earth:

- 6.5 km resolution, ± 51°
- time resolution from 2.5 μs and above
- noise from different lightning conditions, moon phase
- noise from different inclinations

Map of the Earth in UV

In addition:

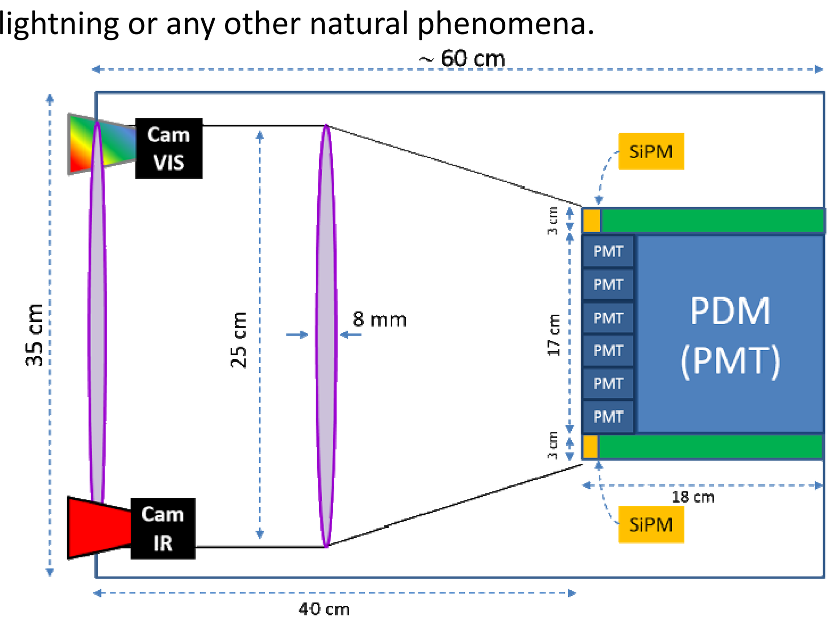
Atmospheric phenomena: lighting and Transient Luminous Effect
Bioluminescence of animal and vegetal organisms in the oceans, presence of hot aerosols in the atmosphere, monitoring volcano emissions
Meteors and slower events, with possible search for Strange Quark Matter and Space Debris assessment
Monitoring of human activities: UV emissions by agricultural crops, by industrial or civilian facilities
Cosmic Ray Showers

Mini-EUSO is a key-step in the development of space-based missions: it will determine the intensity of the natural UV background level seen from the ISS on a pixel size level of ~5×5 km2, and its sudden variations in space and time at km and ms scale level, as well as a long-term (month/year) and geographical differences (up to global scale level). Crucial information to understand the key parameters of telescopes for space-based missions for Ultra High Energy Cosmic Rays.
Mini-EUSO will allow a realistic estimation of the duty cycle of a space-based mission. In fact, the duty cycle can be reduced by to presence of city or any other artificial light, as well as due to lightning or any other natural phenomena.

The instrument

1. Optics: two Fresnel type lenses, each 25 cm in diameter. The optical system focuses the incoming light onto the Focal Surface for effective collection
2. Photo Detector Module: an array of 36 Multi-Anode PhotoMultiplier Tubes (MAPMTs), each with 64 pixels, resulting in a readout of 2304 channels.
3. Data Processing: multiple trigger levels are used to filter out noise and identify events of interest. Relevant data stored at regular time intervals depending upon the trigger.

The instrument also features both an infrared (IR) and a visible (VIS) light camera to provide complementary information on the observation conditions. A selective filter is placed on the Focal Surface, on the MAPMT. It allows through only the UV wavelengths of interest.
Test of advanced option, such as a SiPM Photo Detector Module (PDM) in a dedicated box.



Mini-EUSO will be placed in front of the UV-transparent window in the Russian Module of ISS, Zvezda: room temperature, at a sea level air pressure.
Started as a joint Russian-Italian project: approved by ROSCOSMOS and ASI.
It was approved by the JEM-EUSO collaboration in 2014.