JEM-EUSO collaboration 16 Countries, 93 Institutes, 351 people

The EUSO-SPB2 mission

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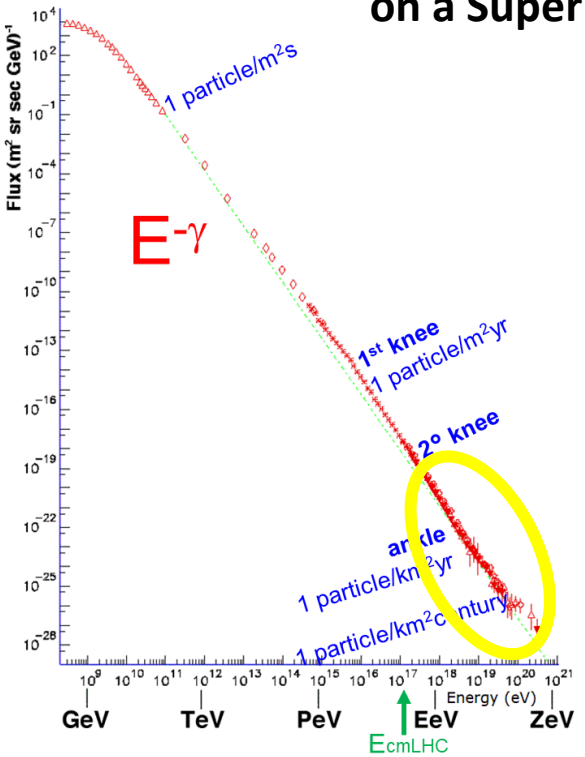
Particles and Cosmology

16th Baksan School on Astroparticle Physics

Outline

Extreme Universe Space Observatory on a Super Pressure Balloon 2

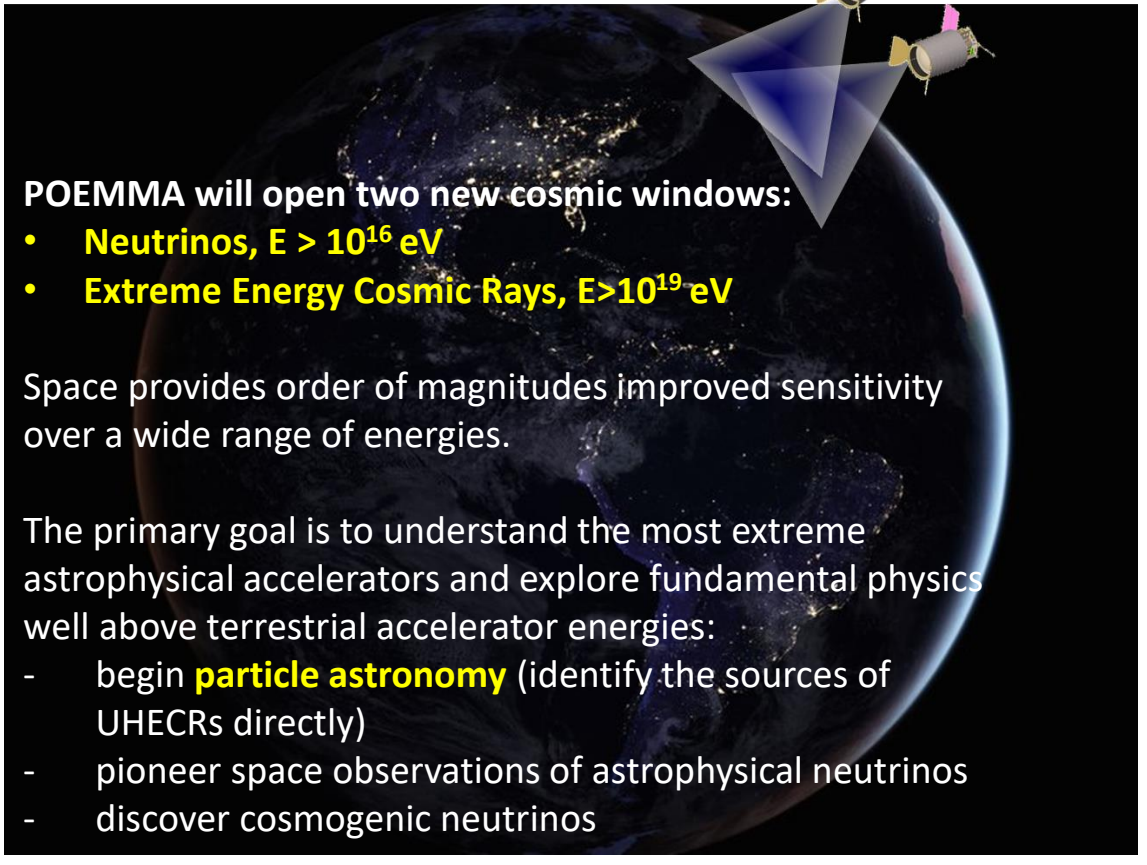


- origin of UHECRs is still unknown
- sources are extragalactic

- POEMMA
- JEM-EUSO program
- EUSO-SPB2
  - Goals
  - Fluorescence detector
  - Cherenkov detector

POEMMA: Probe Of Extreme MultiMessenger Astrophysics

NASA astrophysics probe mission concept study based on OWL 2002 study, JEM-EUSO, EUSO-SPB experience, and CHANT proposal



POEMMA will open two new cosmic windows:

- **Neutrinos, E > 10^{16} eV**
- **Extreme Energy Cosmic Rays, E>10^{19} eV**

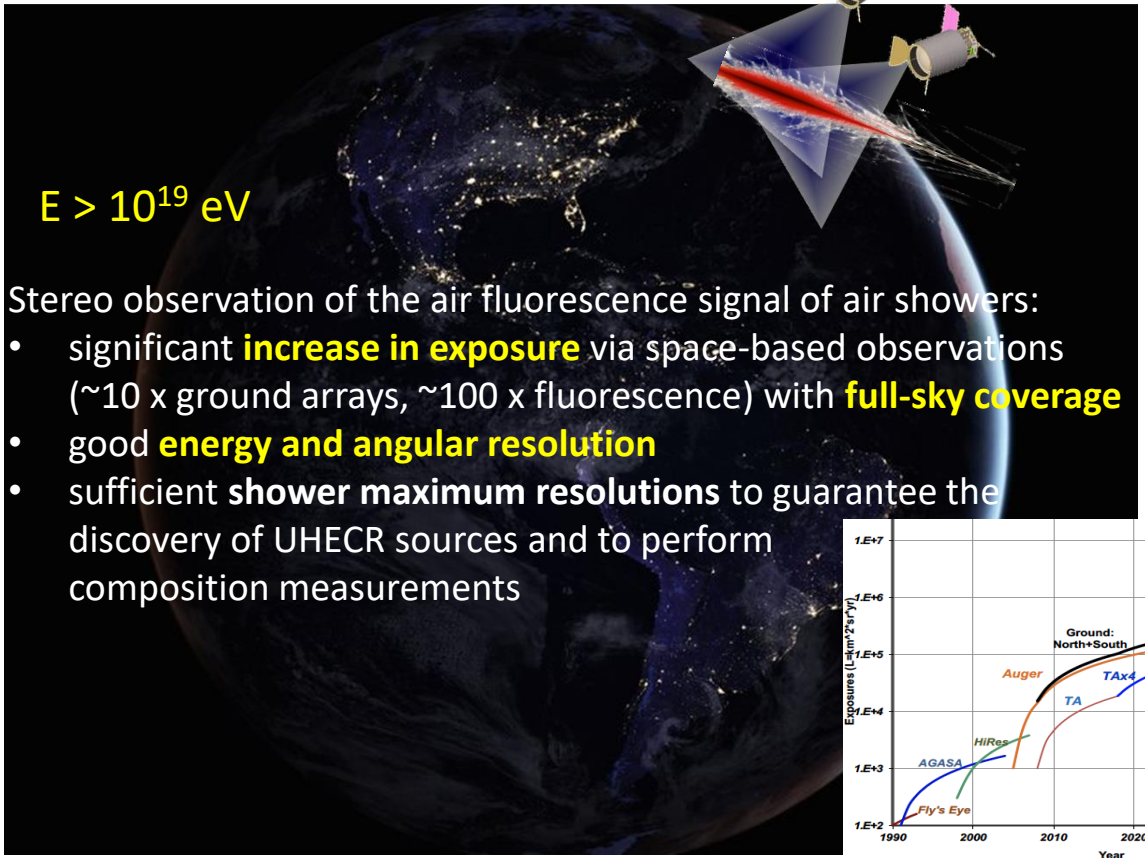
Space provides order of magnitudes improved sensitivity over a wide range of energies.

The primary goal is to understand the most extreme astrophysical accelerators and explore fundamental physics well above terrestrial accelerator energies:

- begin **particle astronomy** (identify the sources of UHECRs directly)
- pioneer space observations of astrophysical neutrinos
- discover cosmogenic neutrinos

POEMMA: UHECR

Direct pointing to sources is possible at the highest energies where ground statistics is lowest

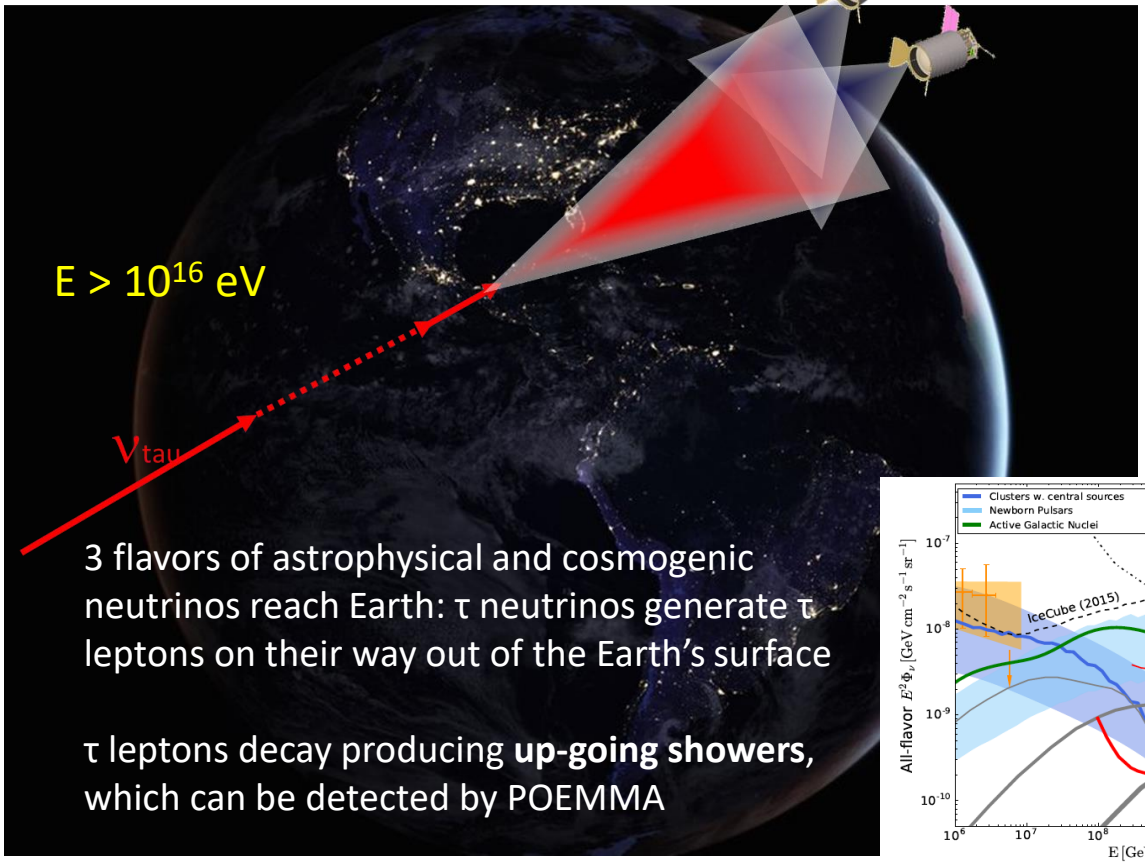


Stereo observation of the air fluorescence signal of air showers:

- significant **increase in exposure** via space-based observations (~10 x ground arrays, ~100 x fluorescence) with **full-sky coverage**
- good **energy and angular resolution**
- sufficient **shower maximum resolutions** to guarantee the discovery of UHECR sources and to perform composition measurements

POEMMA: neutrinos

Observe neutrinos signal through the Cherenkov signal from upward-moving EAS induced by τ decays in the atmosphere

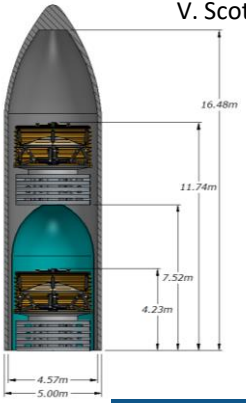


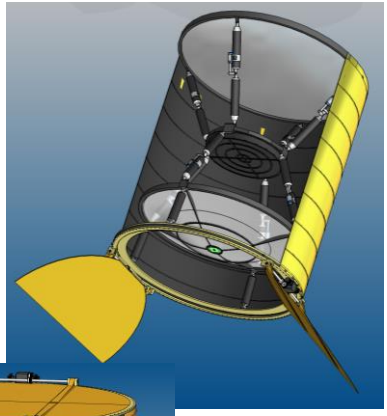
POEMMA: the mission

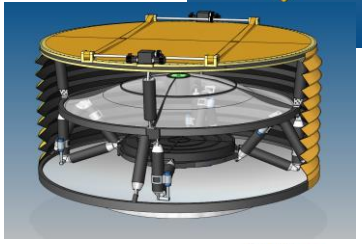
Class B Mission, 3-year
LEO 525 km, 28.5° inclination
300 km to 25 km separation
Phase A start 2023 - Launch 2029

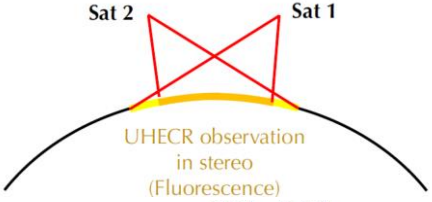
Two 4 meter F/0.64 **Schmidt telescopes**
45°FoV
Hybrid focal surface (MAPMTs and SiPM)
3mm linear pixel size: 0.084° FoV

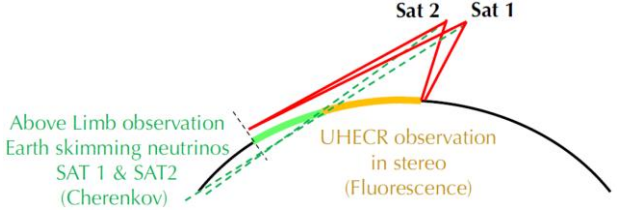
Mass	1,550 kg
Primary Mirror diameter	4 m
Corrector Lens diameter	3.3 m
Focal surface diameter	1.6 m
Aperture	6 to 2 m^2
Instrument power	550 W
Science data	1 GB/day





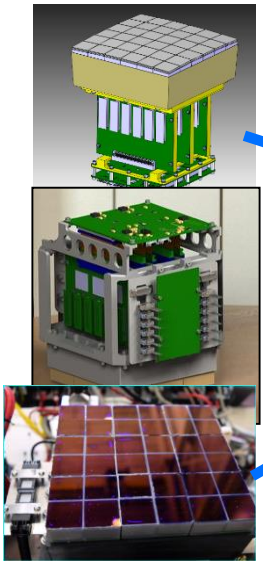




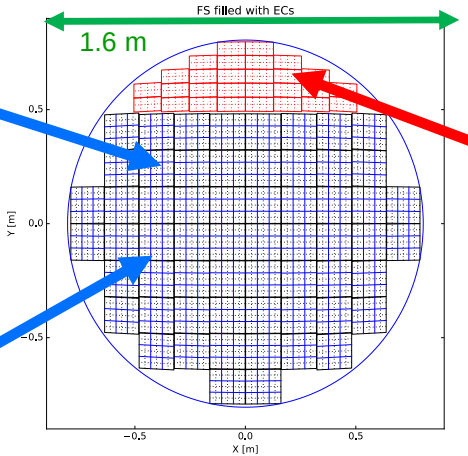


POEMMA: hybrid focal surface

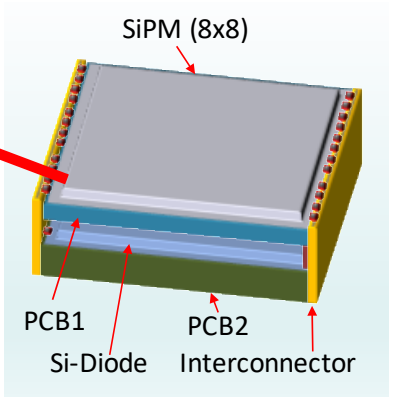
UV Fluorescence detection with MAPMTs 1µs sampling



~ 150k pixels



Cherenkov detection with SiPMs ~10 ns sampling



60 Photo Detector Modules (PDMs)

= 138,240 pixels

64 channels Multi-Anode PMT with BG3 filters

1 PDM = 36 MAPMTs = 2,304 pixels

28 SiPM Focal Surface Units (FSUs)

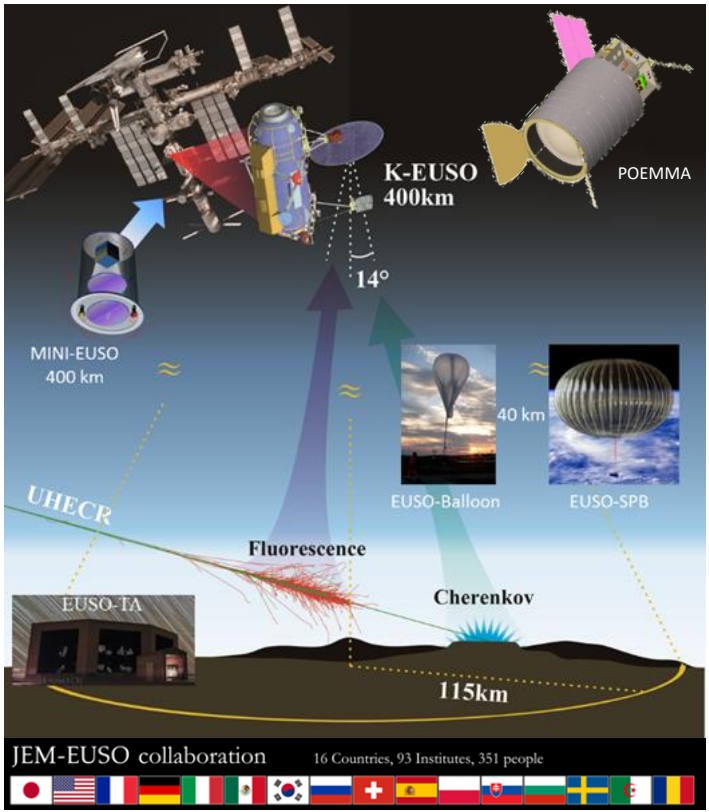
=14,336 pixels

1 FSU= 64x4x2 = 512 pixels

The JEM-EUSO program: UHECR from space

Joint Experiment Mission - Extreme Universe Space Observatory

- **EUSO-TA**: ground detector installed in 2014 at Telescope Array site (USA), currently operational
- **EUSO-Balloon**: 1st flight from Timmins, (Canada) by the French Space Agency, 2014, technology demonstrator
- **EUSO-SPB1**: NASA ultra long duration flight from Wanaka (New Zealand); launched in April 2017
- **MINI-EUSO**: precursor on International Space Station (ISS) approved by Italian and Russian Space agencies; launch in 2019, UV background measurements
- **EUSO-SPB2:** build upon the EUSO-SPB1 experience to pave the way towards the POEMMA mission, launch in 2022
- **K-EUSO:** bigger telescope on ISS in 2022, equipped with Schmitd optics. Approved by Roscosmos. It could reach 4 x PAO exposure

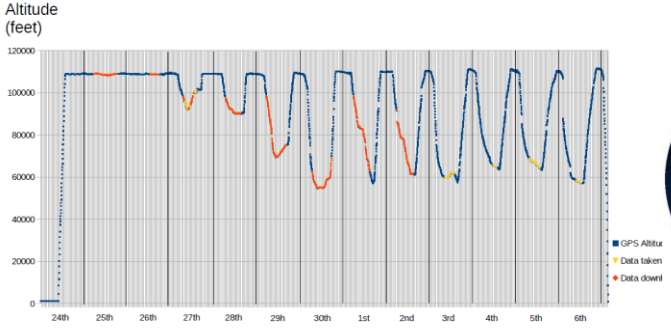


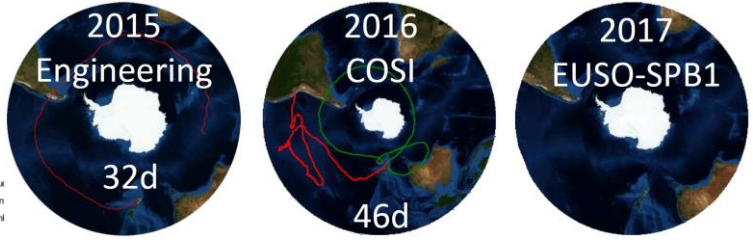
EUSO-SPB1 experience

Goals:

- Measure of EAS signals by looking down on the Earth's atmosphere from suborbital space with a fluorescence detector
- Measure of the UV emission over the ocean and over clouds
- Search for fast UV pulse-like signatures from other objects

Flown as NASA mission of opportunity from Wanaka,NZ in 2017
Targeted flight duration: 100 days



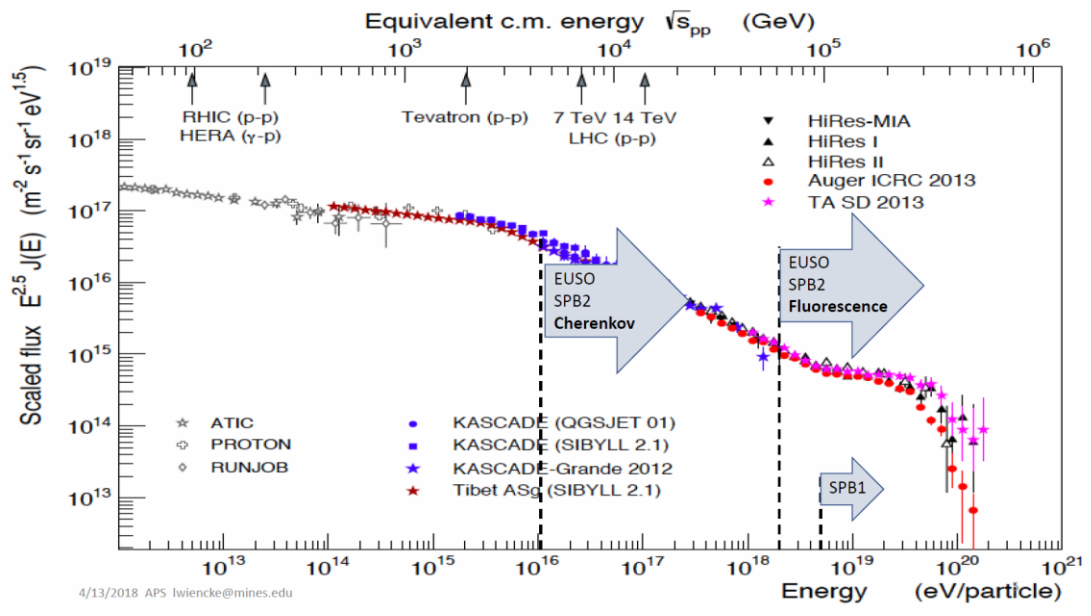


EUSO-SPB2 science goals

Detect fluorescence from above: confirm expectations from ground observations (lower energy threshold and larger acceptance relative to EUSO-SPB1)

New Unexplored Areas:

- Detect **Cherenkov light from cosmic rays from near space**
- Measure the **background of up-going τ** decays from cosmogenic ν
- Study **fluorescence from high altitude horizontal showers** in a nearly constant density atmosphere to check hadronic interactions at ultrahigh energies



EUSO-SPB2 technical goals

- Test instrumentation and methods for POEMMA
- First use of Schmidt Optics

Two telescopes:

- Cherenkov ~10 ns **E > 10^{16} eV**
- Fluorescence 1 uS **E > 10^{18} eV**

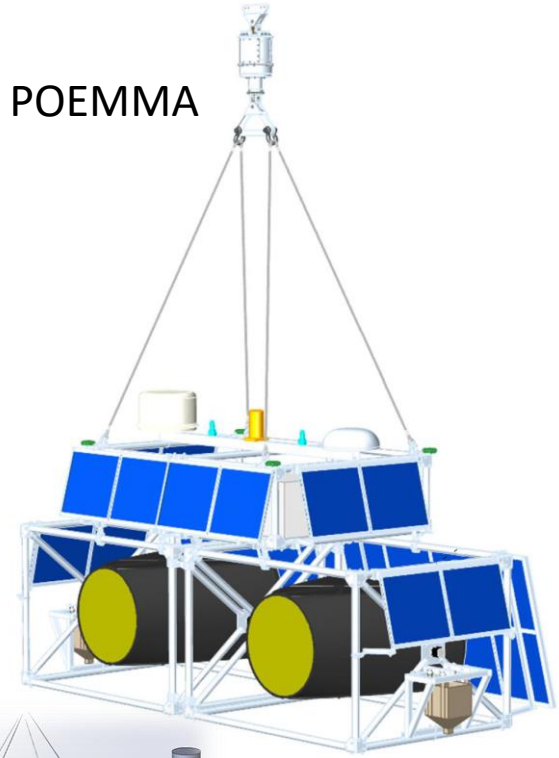
Same mechanical structure,
mirror, and corrector plate units

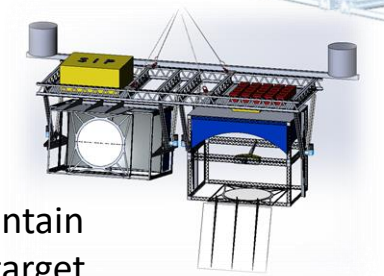
- Ancillary Devices: IR camera, AMON

In addition:

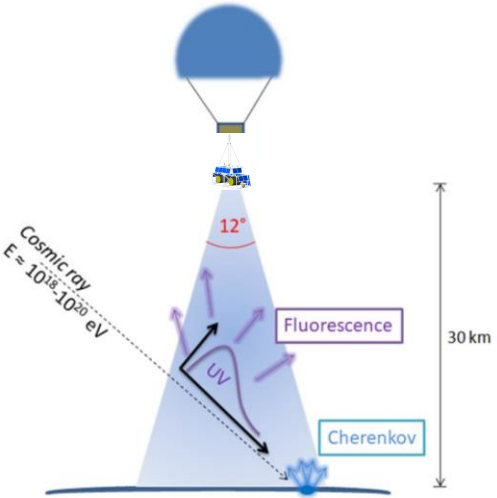
- tilting mechanism from nadir to 10° above the horizon
- SiPMs qualification for POEMMA
- in flight calibration with stars

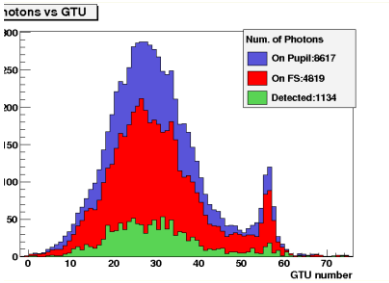
Preflight ground tests -US: Desert, Mountain
Stratospheric Flight (33.5 km): 100 day target





EUSO-SPB2 detection principle

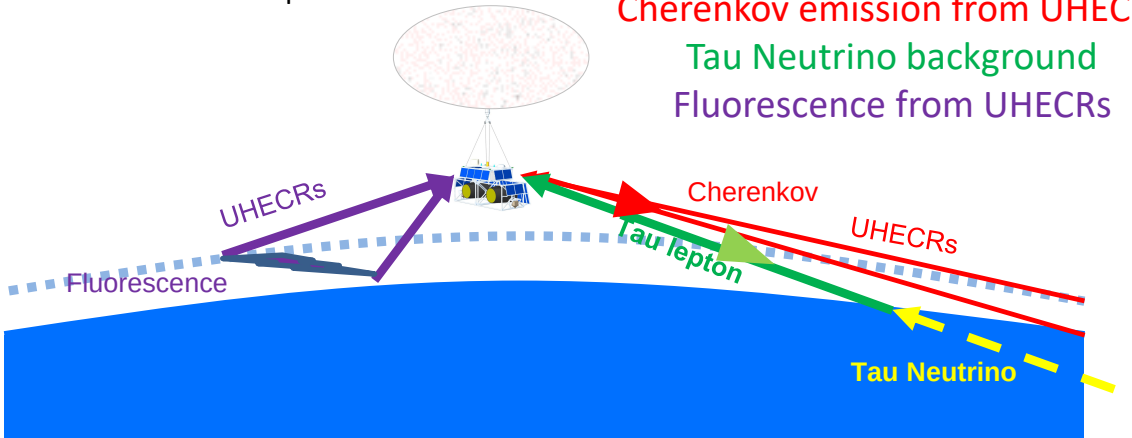




Fluorescence telescope will observe from above fluorescence and Cherenkov UV photons generated by EAS created by UHECR using the atmosphere as a calorimeter

EAS development time ≈ 50 ÷ 150 μs

Cherenkov emission from UHECRs
Tau Neutrino background
Fluorescence from UHECRs



EUSO-SPB1 heritage: fluorescence telescope

Optics: 2 Φ1m Fresnel type lenses
+ UV filter (330-400 nm)
FoV = ±5.5°

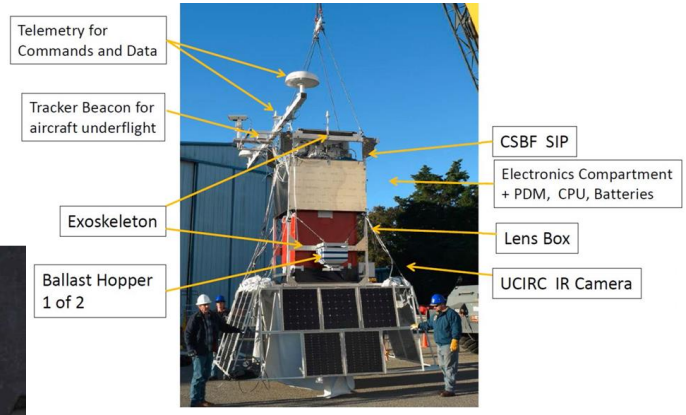
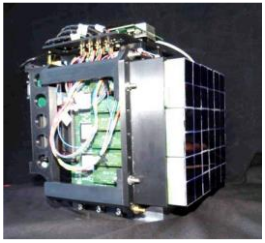
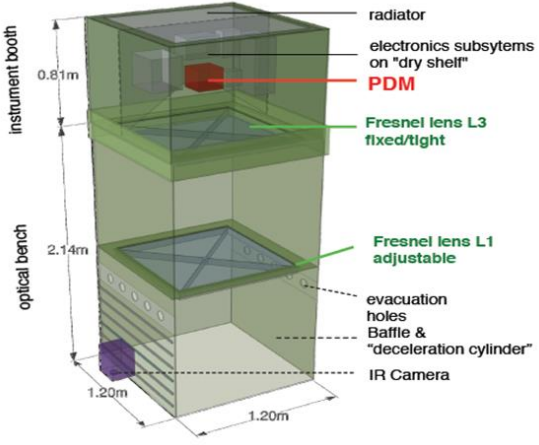


Photo Detector Module:
array of 36 Multi-Anode PhotoMultiplier Tubes (MAPMTs) of 64 pixels: 2304 channels

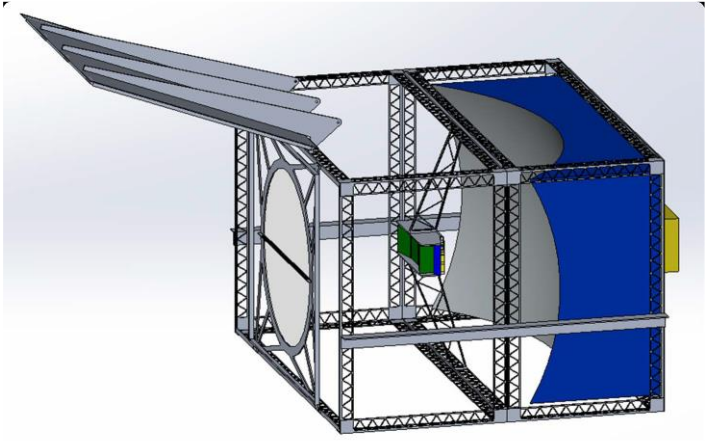


Data Processor: readout performed by one ASIC per MAPMT + multiple trigger levels to filter out noise and identify events of interest

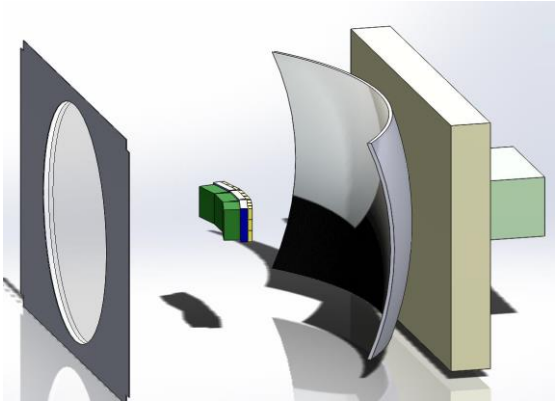


+ an **infrared camera** to provide complementary information on the observation conditions
+ a **SiPM Photo Detector** in a dedicated box

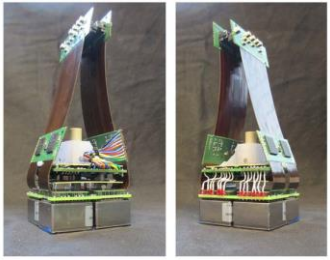
EUSO-SPB2 fluorescence telescope



Single Photoelectron Counting
1.0 μs time bins, 1 “video clip” = 128 time bins
~15 watts



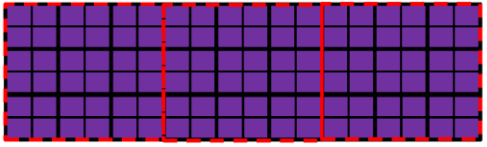
Schmidt optics
FoV: 15° × 45° normal mirror
Corrector Plate: 1 m^2
Image resolution: ~ few mm
Pixel size: ~3mm^2



New integrated digitization

BGA packaged
Spaciroc3 ASIC

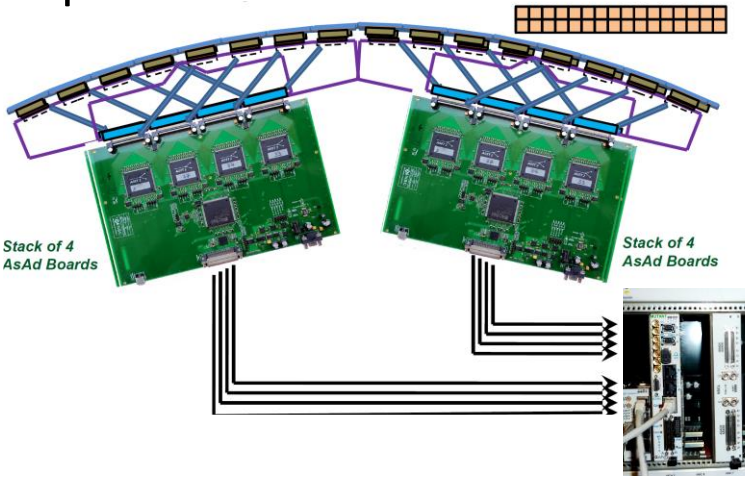
~45°

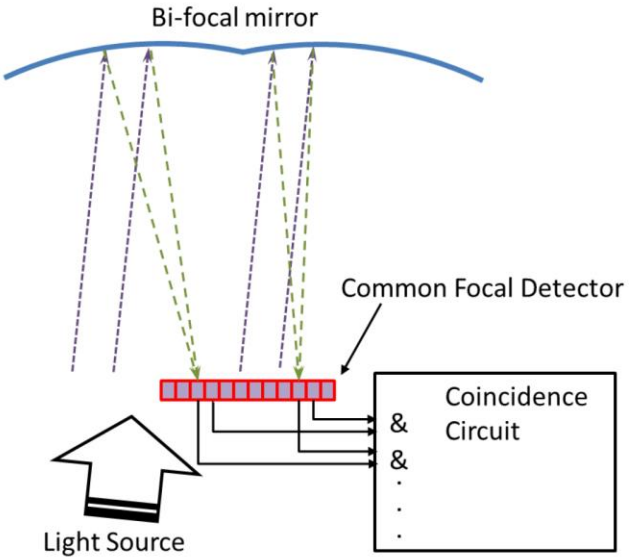


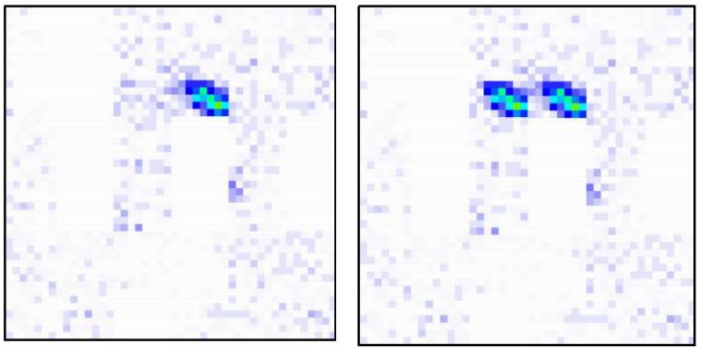
Baseline design is 3 PDMs

EUSO-SPB2 Cherenkov telescope

FoV: 5° × 45° bi-focal mirror
Camera with 5376 pixel
Pixel size: 3 × 3 mm^2 = 0.2° × 0.2°
Focal Plane: 2 × 16 SiPM
Read-out AGET ASIC + Zynq SOCs
10 ns time resolution

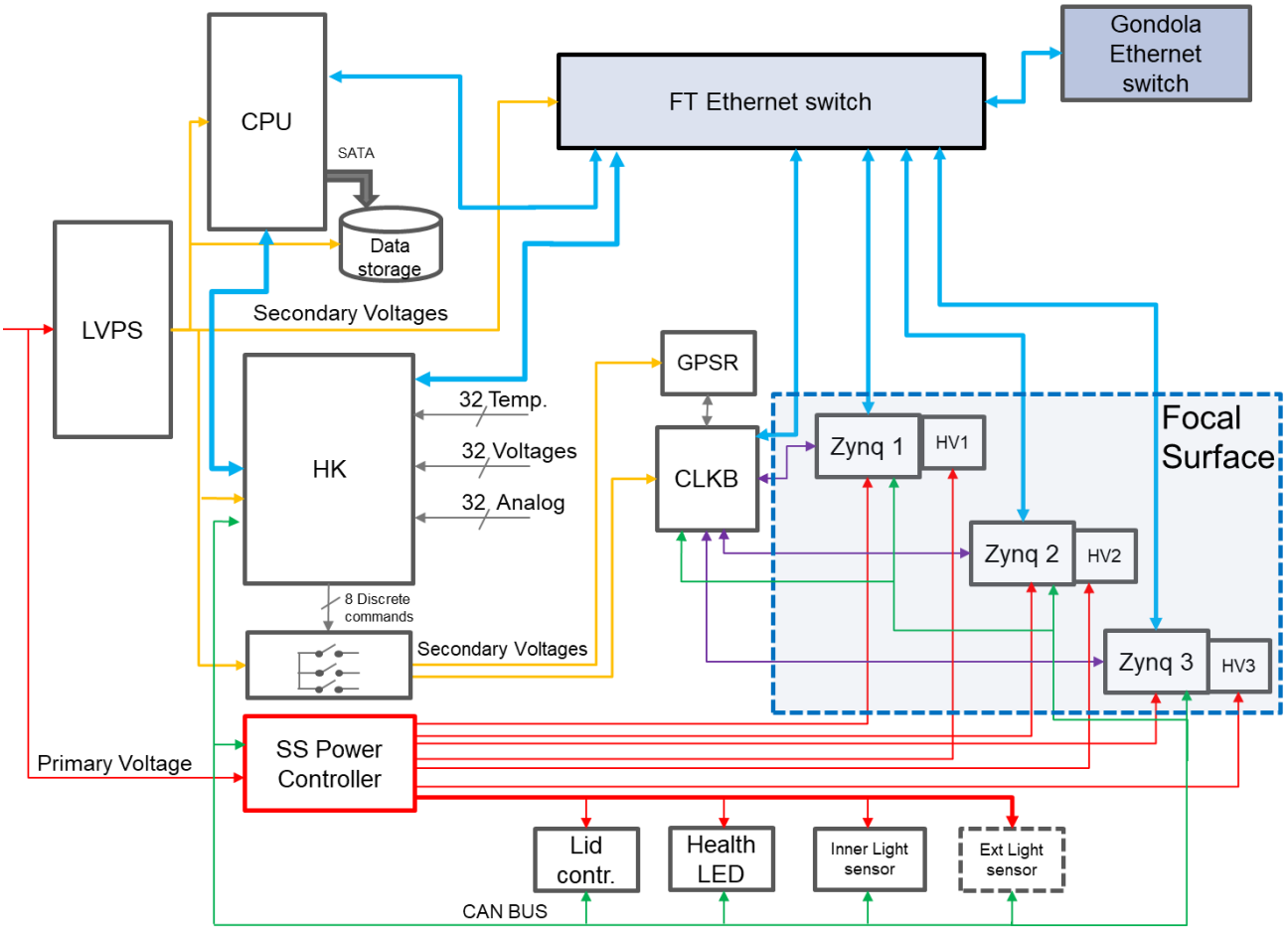






Std. mirror Bi-focal mirror

EUSO-SPB2 electronics



Summary

EUSO-SPB1: successful launch, 12 day flight in 2017

Most data downloaded (loss of half of telemetry, premature termination)

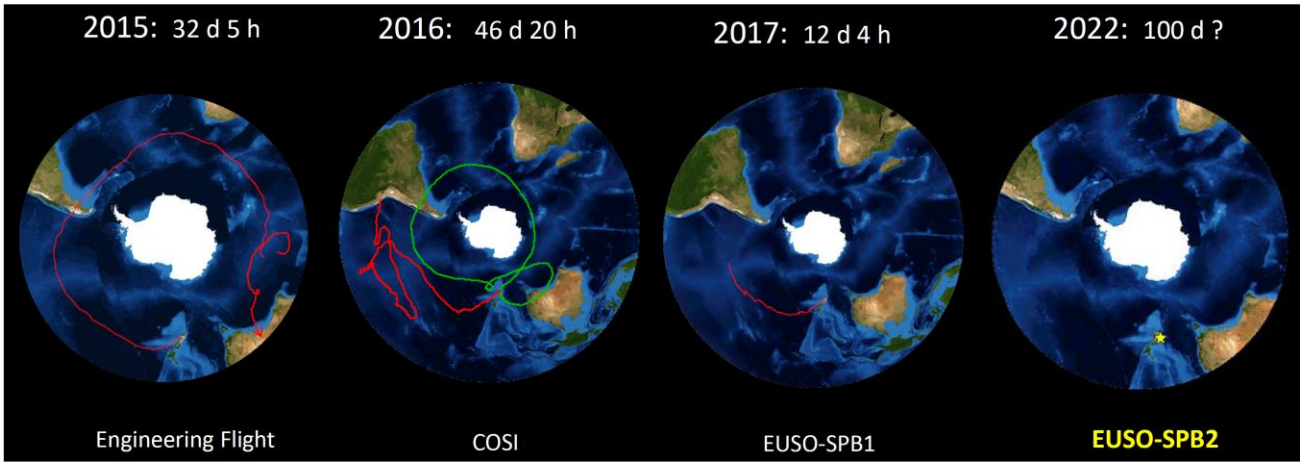
Detector performed well: stable, measured UV emission, direct CRs

EUSO-SPB2: improved **Multi-Telescope Instrument**, builds on SPB1 experience

Add unexplored areas: Cherenkov, neutrino backgrounds, High Altitude EASs

Scientific and technical pathway toward POEMMA

POEMMA will open two new cosmic windows: ν from astrophysical to cosmogenic, and Extreme Energy Cosmic Ray (> 10^{19} eV)



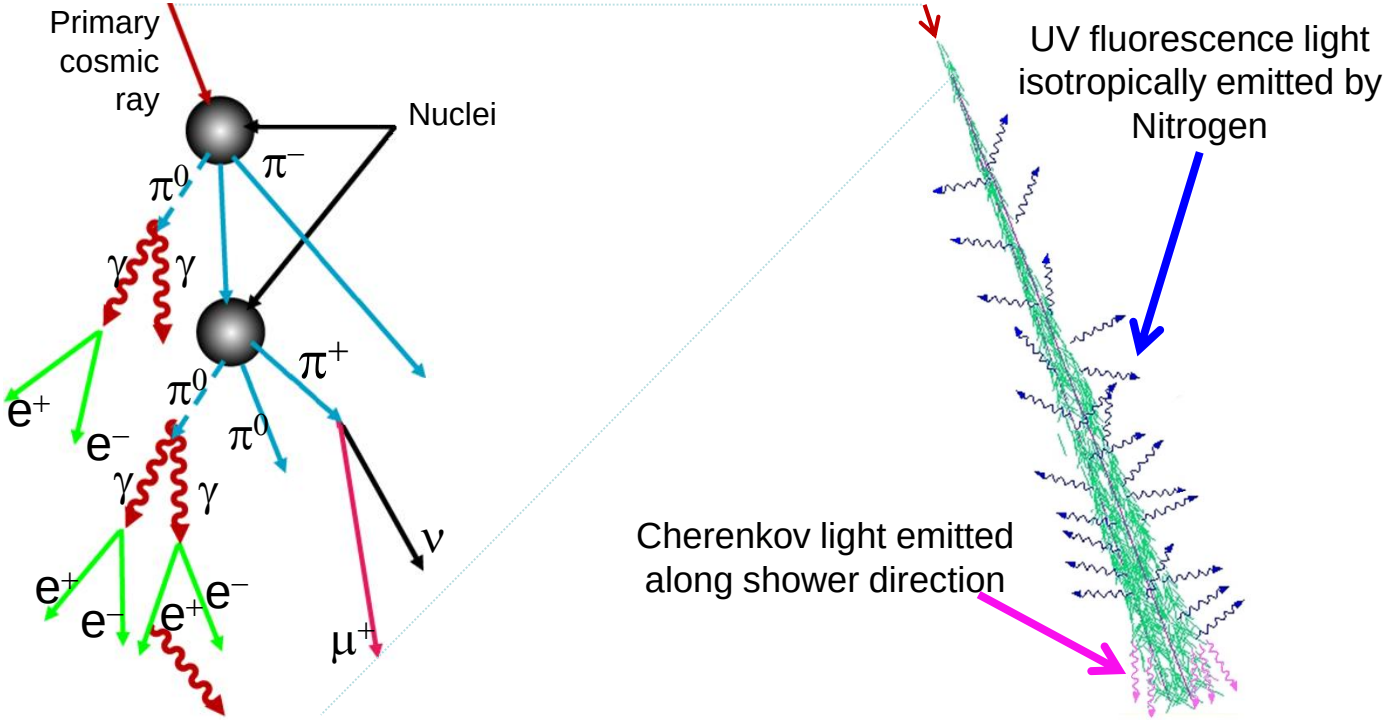
Спасибо!

Particles and Cosmology

16th Baksan School on Astroparticle Physics

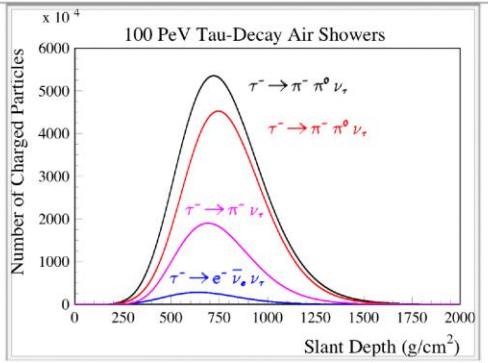

Extensive Air Showers

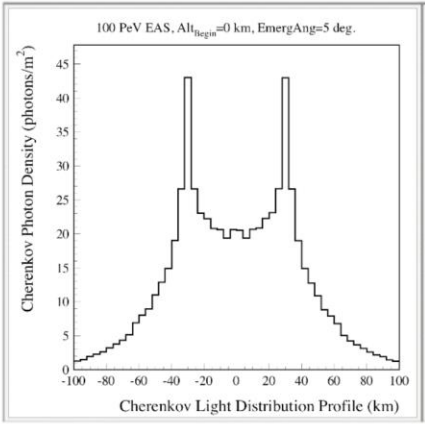
Above 10^{15} eV, cosmic rays can be studied only by indirect observation of Extensive Air Showers (EAS) produced by the interaction between primary Cosmic Ray and atmospheric molecules

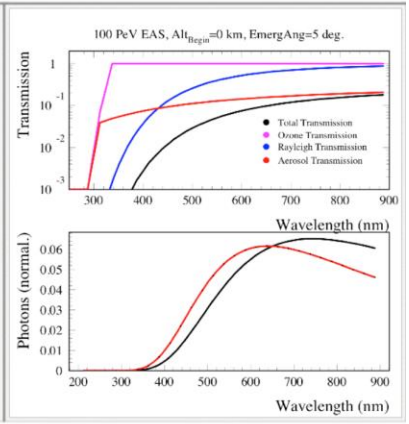


Cherenkov Emission and Propagation

- EAS and Cherenkov Generation
  - Greissen shower parameterization for EM showers; Gaisser parameterization for protons for hadron-initiated showers
  - Cherenkov light generated following Hillas (1982)
- Atmosphere Model
  - Rayleigh scattering treated as absorption vs. wavelength
  - Ozone profile and attenuation given by Krizmanic (1999)
  - Aerosol attenuation vs. wavelength given by Elterman (1968)

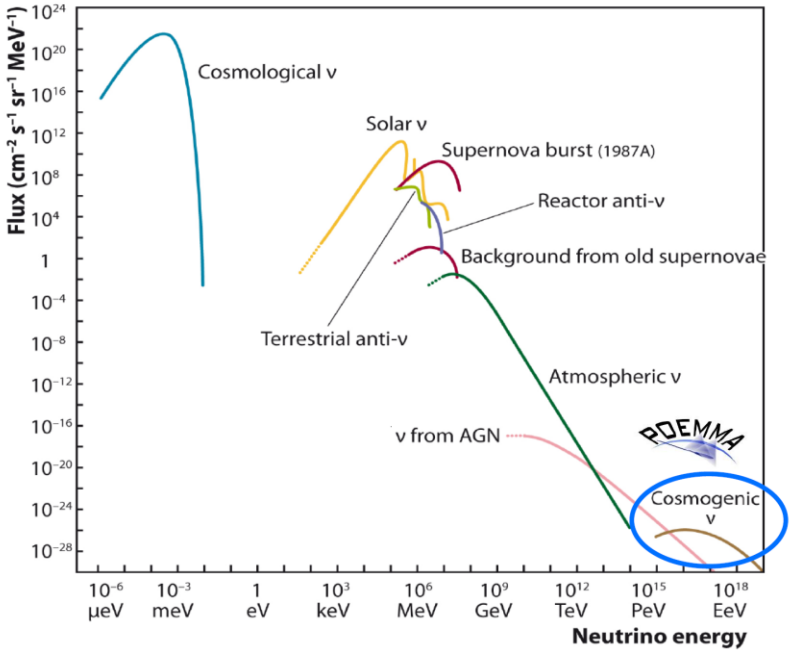




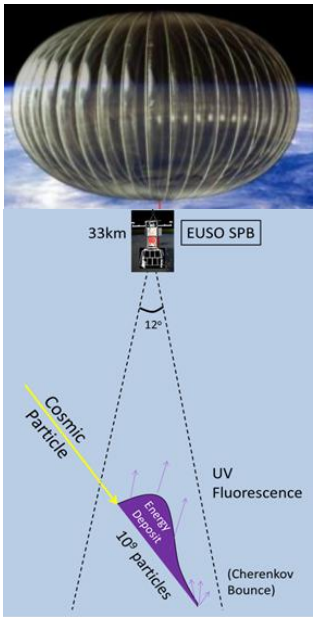


POEMMA neutrino observation

POEMMA designed to observe neutrinos with $E > 10^{16}$ eV through Cherenkov signal of tau decays.
The UHE neutrinos are expected to be born as ν_μ or ν_e.
Due to vacuum oscillations, however, the astrophysical and cosmogenic neutrino flux at the Earth is expected to be almost equally distributed among the three neutrino flavours ν_μ, ν_e, ν_τ
Some experiments search for ν_τ (ANITA, IceCube-Gen2, MAGIC…)
→ POEMMA will join the research!



EUSO-SPB1 specifications



- SPB: when the balloon reaches float altitude, "excess" helium pressurizes the balloon, ballast not required
- Looks down
- Operates at night when the moon is down

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 first EUSO-SPB1 flight

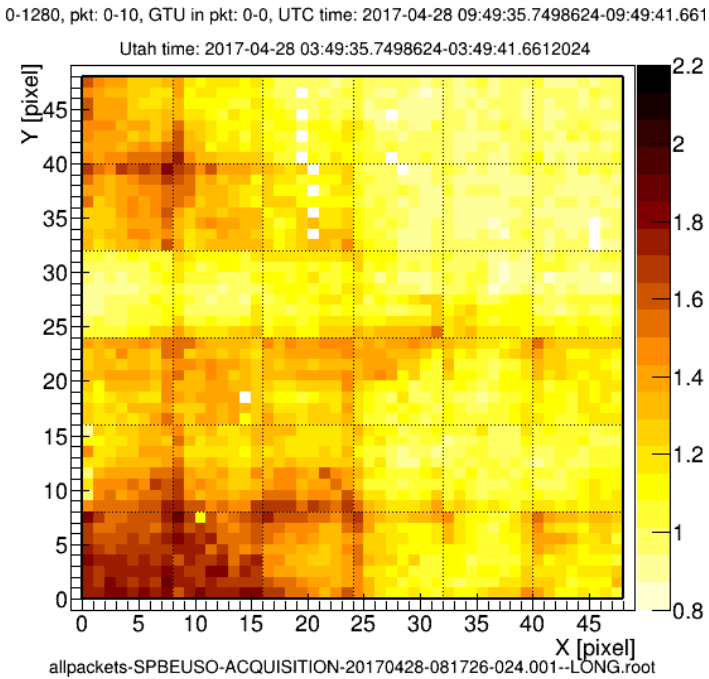
¾ of data downloaded before splash (30 of 40 hours collected) :

➢ 60 Gb ~30 hours data w/moon down, dark

	Data Taken	Data downloaded
Per day	0425: 34 min 0426: 100 min 0427: 276 min 0428: 370 min 0429: 338 min 0430: 304 min 0501: 172 min 0502: 330 min 0503: ~200 min 0504: 206 min 0505: 212 min 0506: 138 min	0425: 34 min 0426: 100 min 0427: 160 min 0428: 370 min 0429: 338 min 0430: 304 min 0501: 172 min 0502: 330 min
Total	2500 min → 41.7 h	1828 min → 30h

➢ Data Analysis in progress:

- searches for UHECR
- UV Background
- searches for optical transients in progress
- searches for man-made flashes (planes, strobe lights)

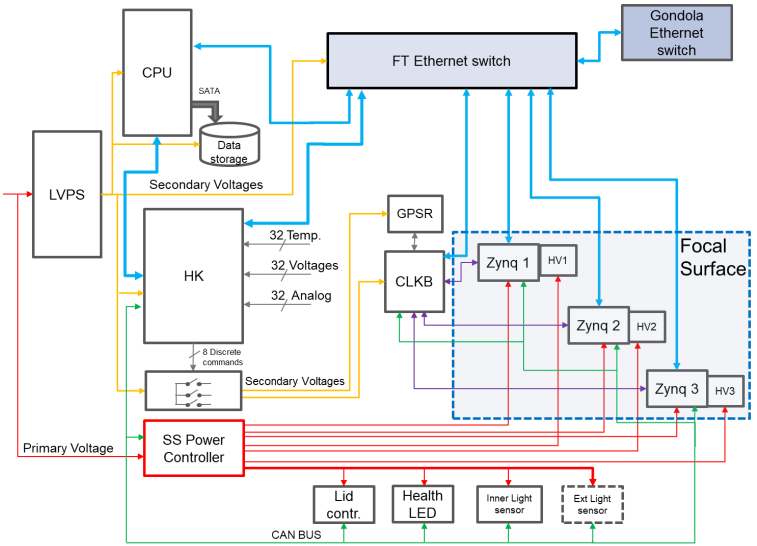


Clouds moving in the SPB FoV (averages of 1280 GTUs)

EUSO-SPB2 electronics

Main tasks:

- Interface with Flight Computer telemetry system
- Define Telescope operation mode
- Power ON/OFF the instrument
- Configure the FE electronics
- Start/Stop data acquisition and calibration procedures
- Synchronization of the data acquisition
- Tag events with GPS time and GPS position
- Manage trigger signals
- Data selection/compression and transmission to Flight Computer
- Monitor/Control/DAQ of some Ancillary Devices
- Monitor Voltages, Current and Temperatures (LVPSs, boards, FPGAs)



EUSO-SPB2 telemetry

SPB1 flew two Iridium Open Port systems:
~70 kbits/s each (one died after 6 days)

SPB2: 1 working Open Port @ 70 kbits/s
(2nd considered a spare)

70 kbits/s Data:

~15% Housekeeping + IR Camera
+ UV/Vis model
~45% Fluorescence Telescope
~40% Cherenkov Telescope

On Board Event Prioritization is Required

Current plan assumes SPB1 system
CSBF is looking into faster options, but timescale for availability and data rate not known at present