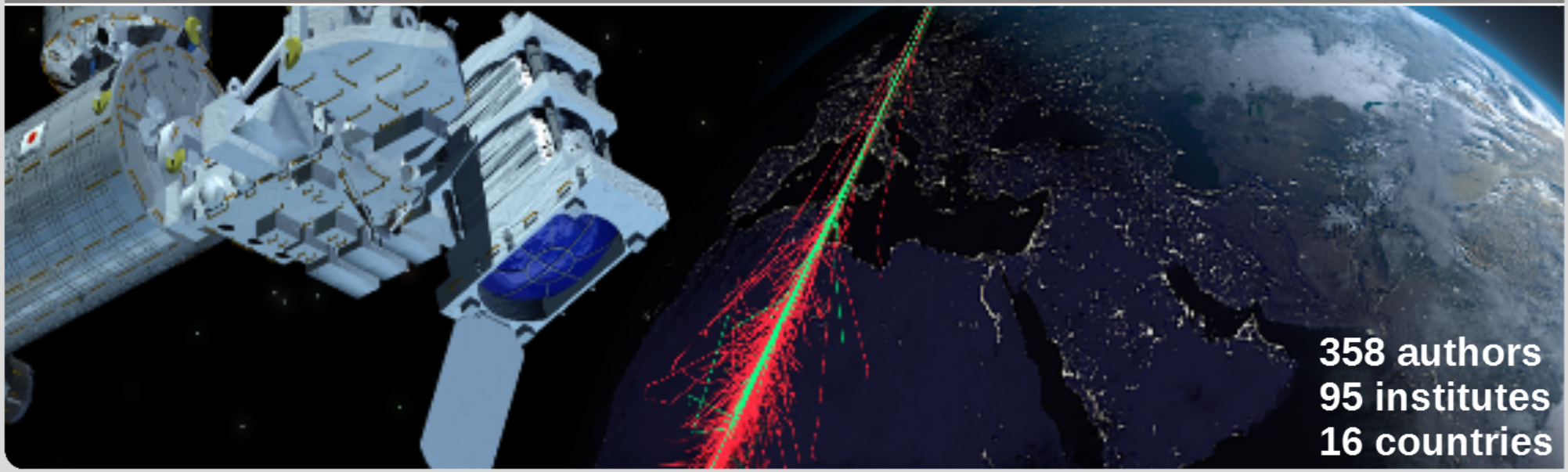
Karlsruhe Institute of Technology

The path towards measuring Cosmic Ray Air Showers from Space

Francesca Bisconti

KSETA Workshop 2017 13-15 February 2017 - Durbach



Outline

- **Motivation for a space-based project like JEM-EUSO**
- **Observation technique**
- **Telescope design**
- **Current experiments**
  - EUSO-TA
  - EUSO-Balloon
- **Future experiments**
  - EUSO-Super Pressure Balloon with SiECA (SiPM camera prototype)
  - Mini-EUSO
  - K-EUSO
- **Overview**

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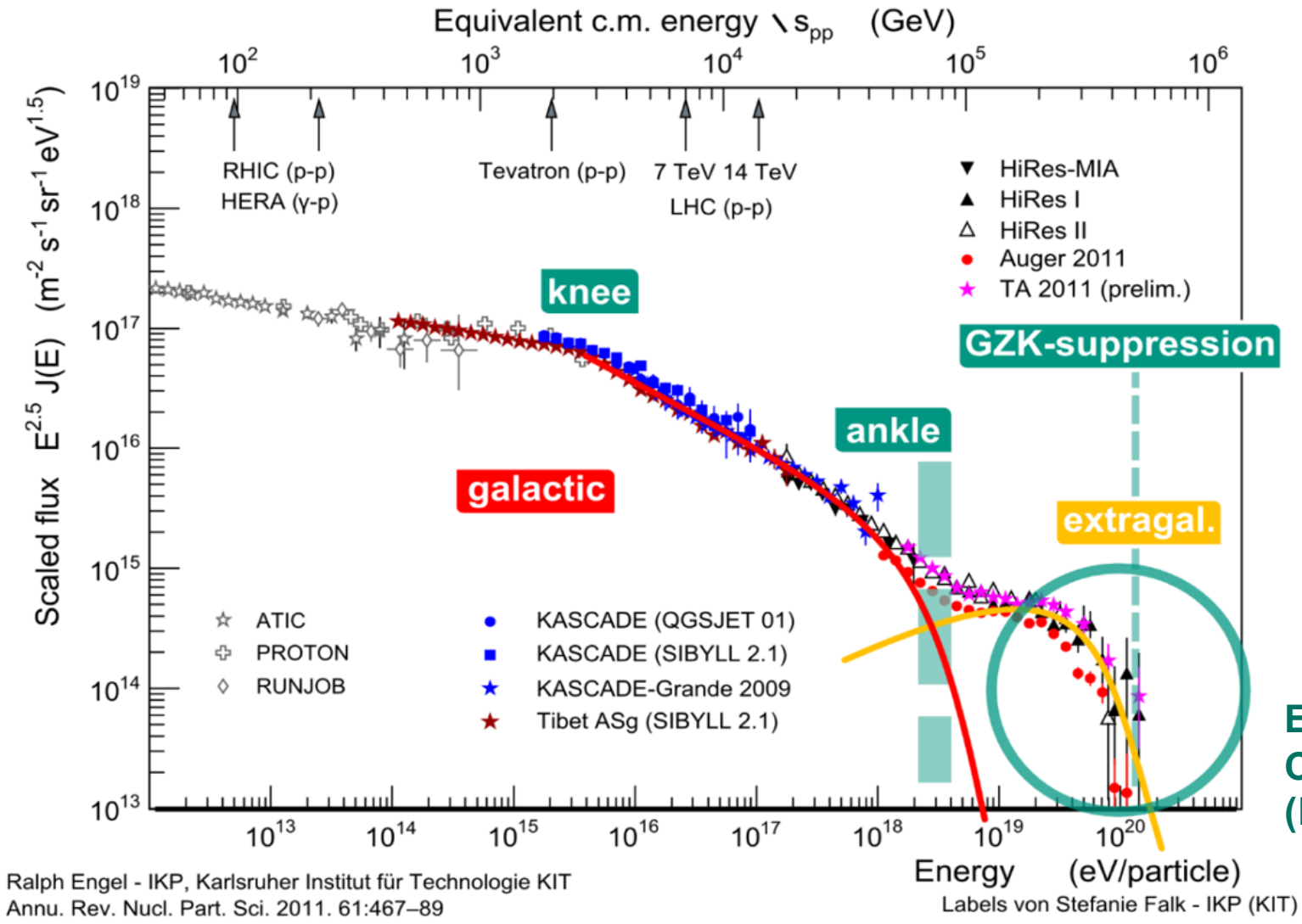
Project motivation



Extreme Energy Cosmic Rays (EECR)

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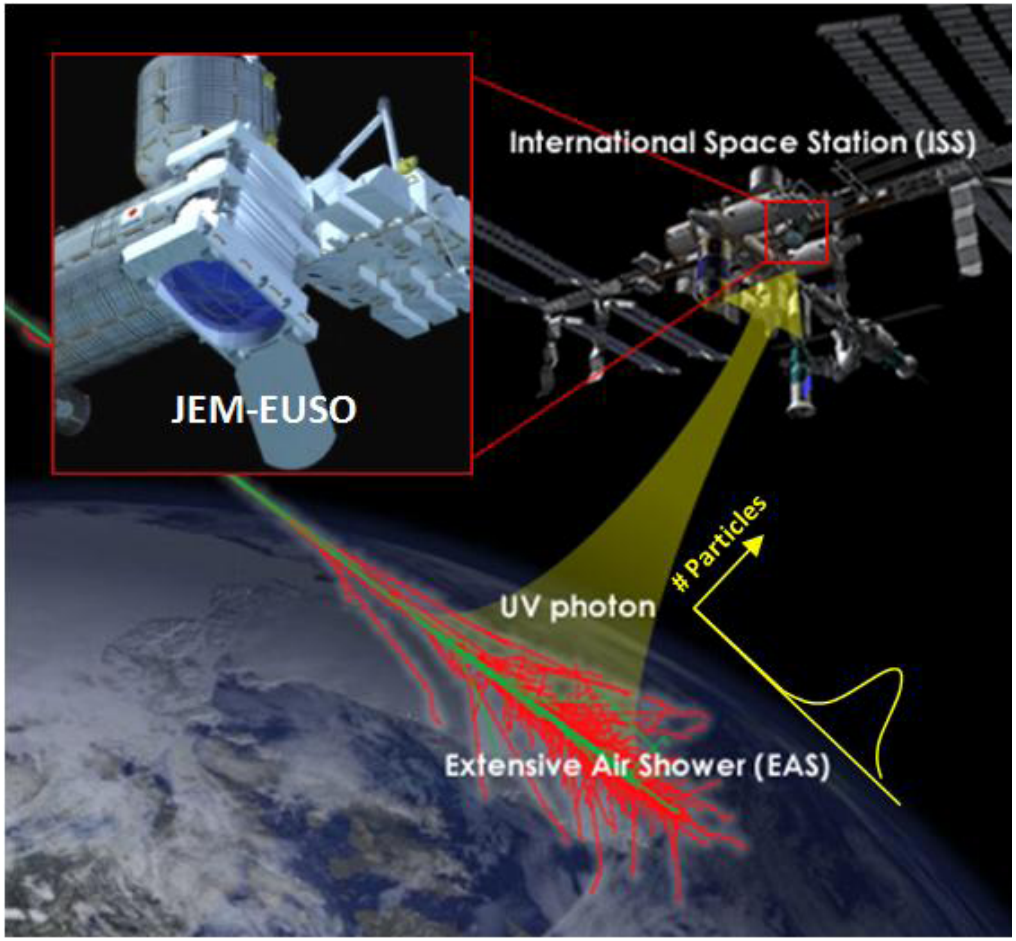
JEM-EUSO

Extreme Universe Space Observatory onboard Japanese Experiment Module



Method:
Fluorescence detection
(atmosphere as calorimeter)

Large field of view:
$\pm$ 30° by double sided spherical Fresnel lenses

At 400 km (ISS altitude):
$2 \cdot 10^5$ km^2 (nadir mode)
up to 10^6 km^2 (tilted mode)

No need for stereo:
400 km >> shower length

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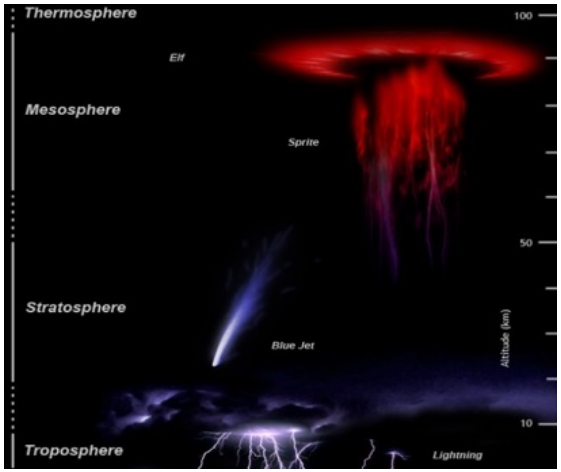
Exploratory scientific objectives

Astrophysics and Cosmology

- **Main Science Objectives:**
  - Identification of Ultra-High Energy Cosmic Rays (UHECRs) sources
  - Measurement of the energy spectra of individual sources
  - Measurement of the trans-GZK spectrum
- **Exploratory objectives:**
  - Discovery of UHE neutrinos
  - Discovery of UHE Gamma-rays
  - Study of the galactic and local extragalactic magnetic field

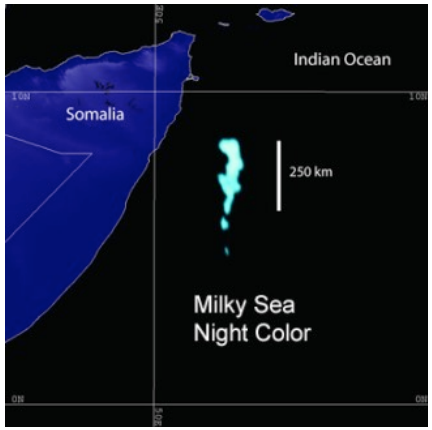
Atmospheric Science

- Nightglow
- The transient luminous events (red sprites, elves, blue jets)
- Slow events (meteors)



Earth Science

- Animal and plant bioluminescence



A new window on the unknown

- Search for nuclearites made of Strange Quark Matter (SQM)

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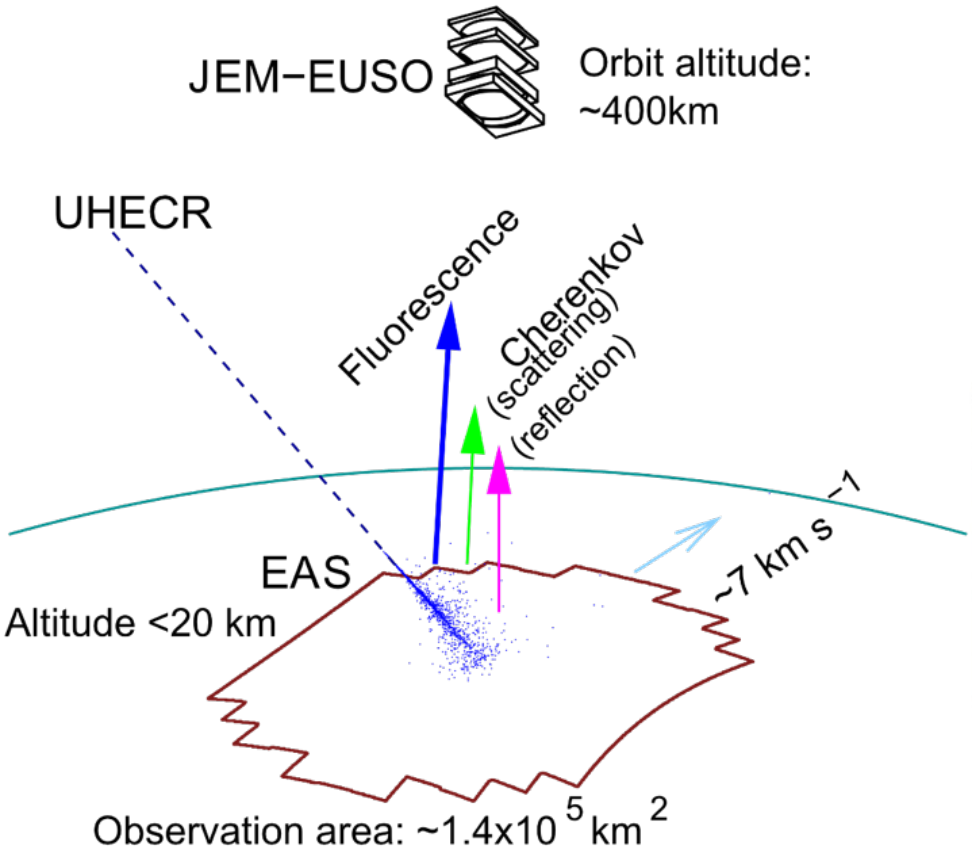
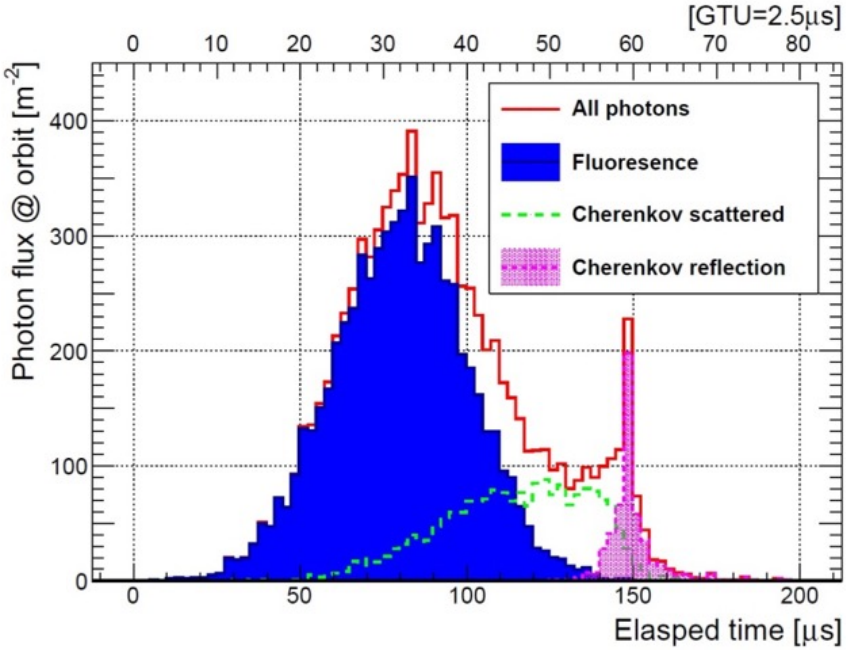
The observation technique



Background = 500 ph / m^2 sr ns
(from Tatiana satellite)

Fast signal: ~50-150μs



J.H. Adams Jr. et al. / Astroparticle Physics 44 (2013) 76–90

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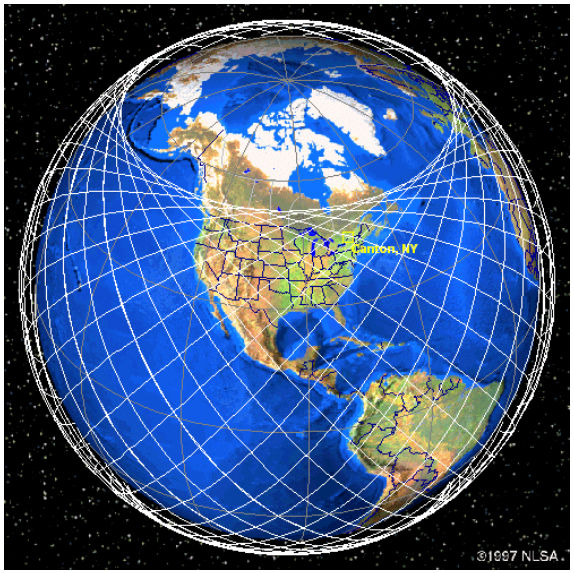
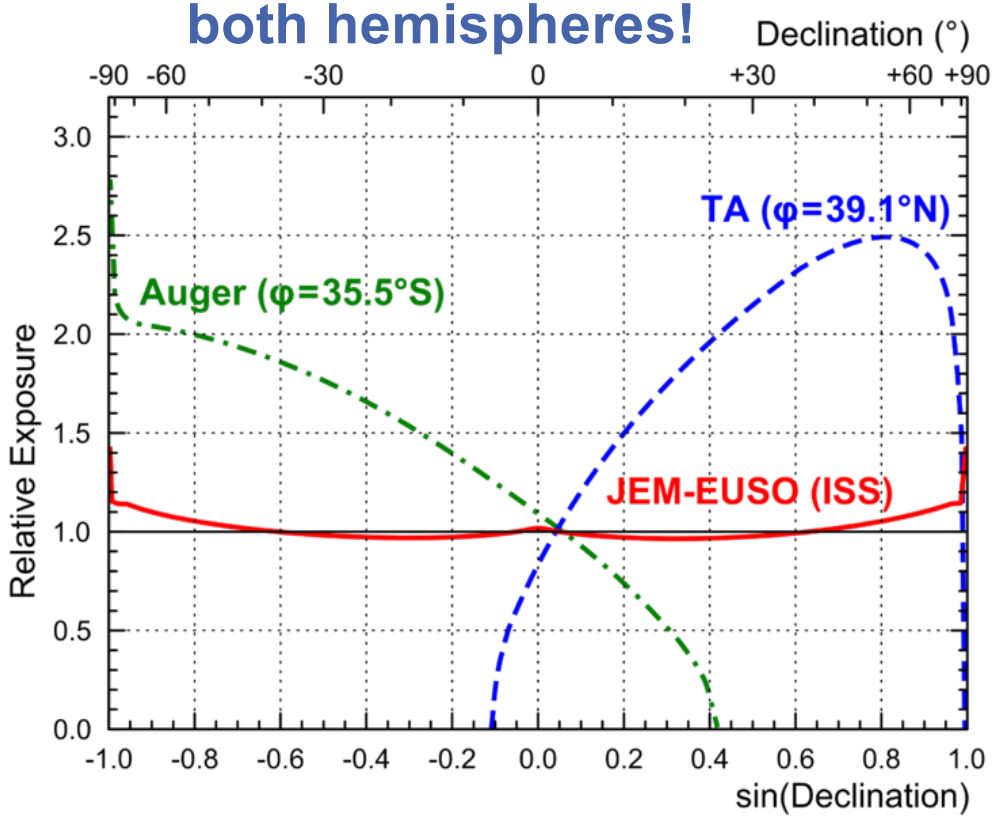
The observation technique

Nadir mode FOV
Tilted mode FOV



Uniform coverage of both hemispheres!



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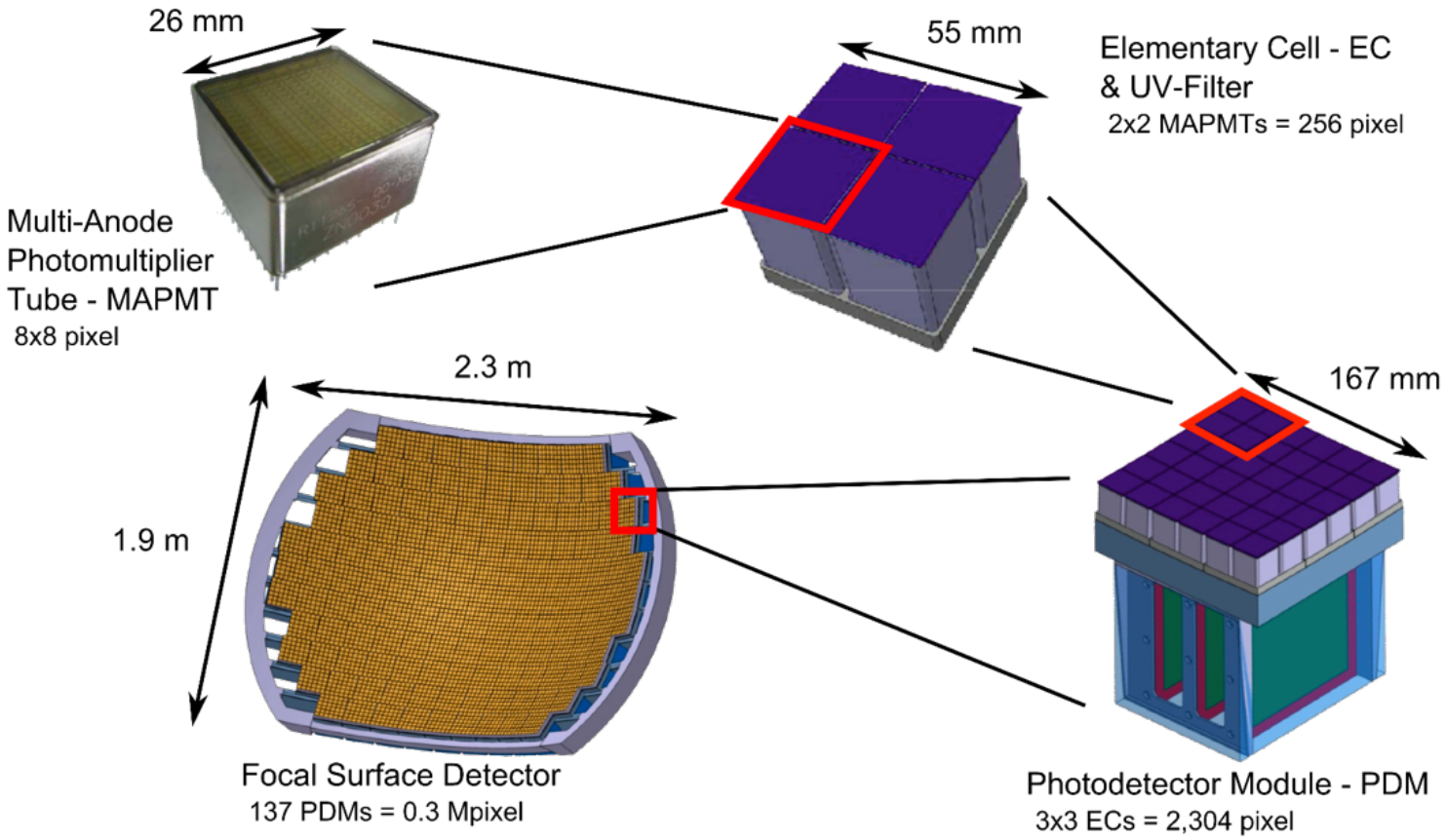
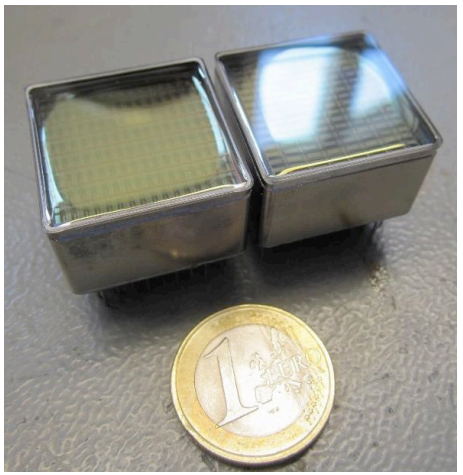
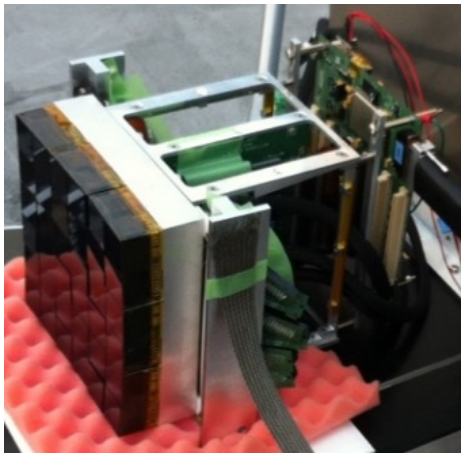
The focal surface detector

Hamamatsu R11265-113-M64 MOD2







Focal surface:

- prototypes of PDM available
- FOV of 1 PDM = 27 x 27 km^2 from space

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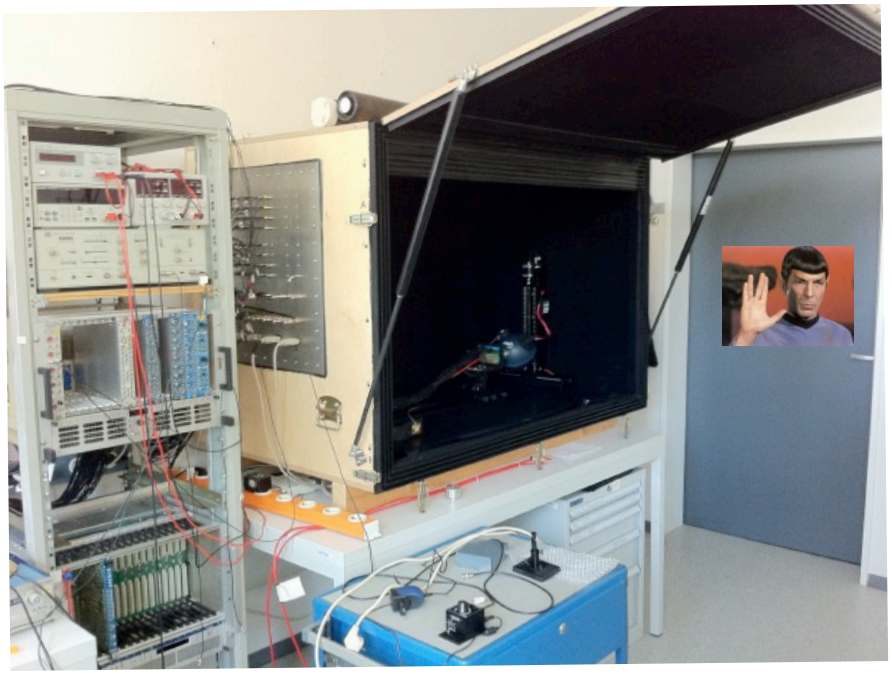
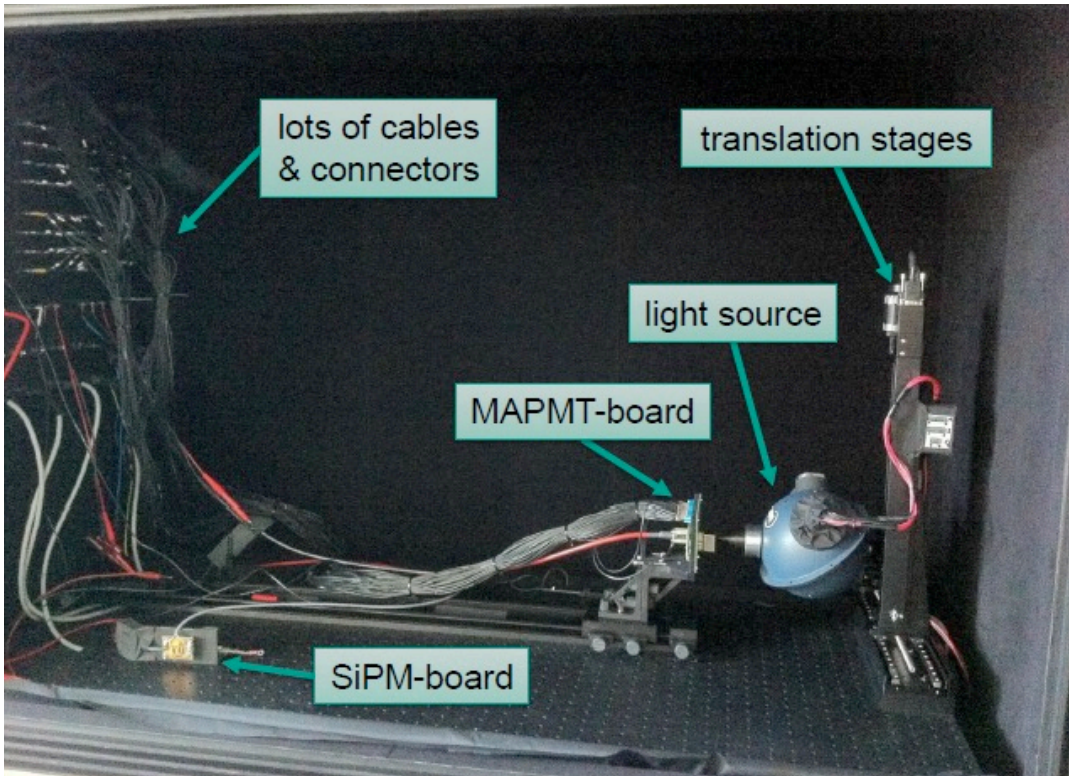
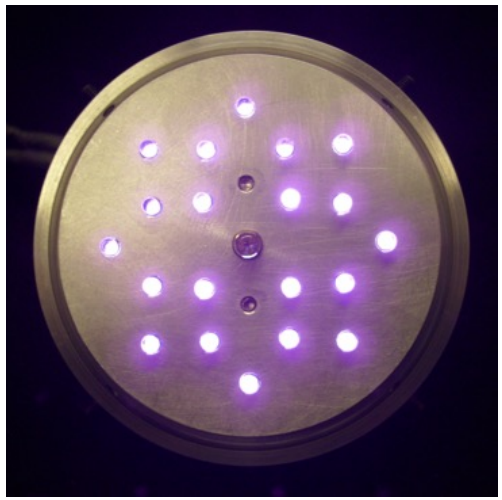
Single PhOton Calibration stand at Kit (SPOCK)







- **Uniform Lambertian light source**
- **Known output via NIST-Photodiode**

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Current experiments

- ✓ EUSO-TA
- ✓ EUSO-Balloon

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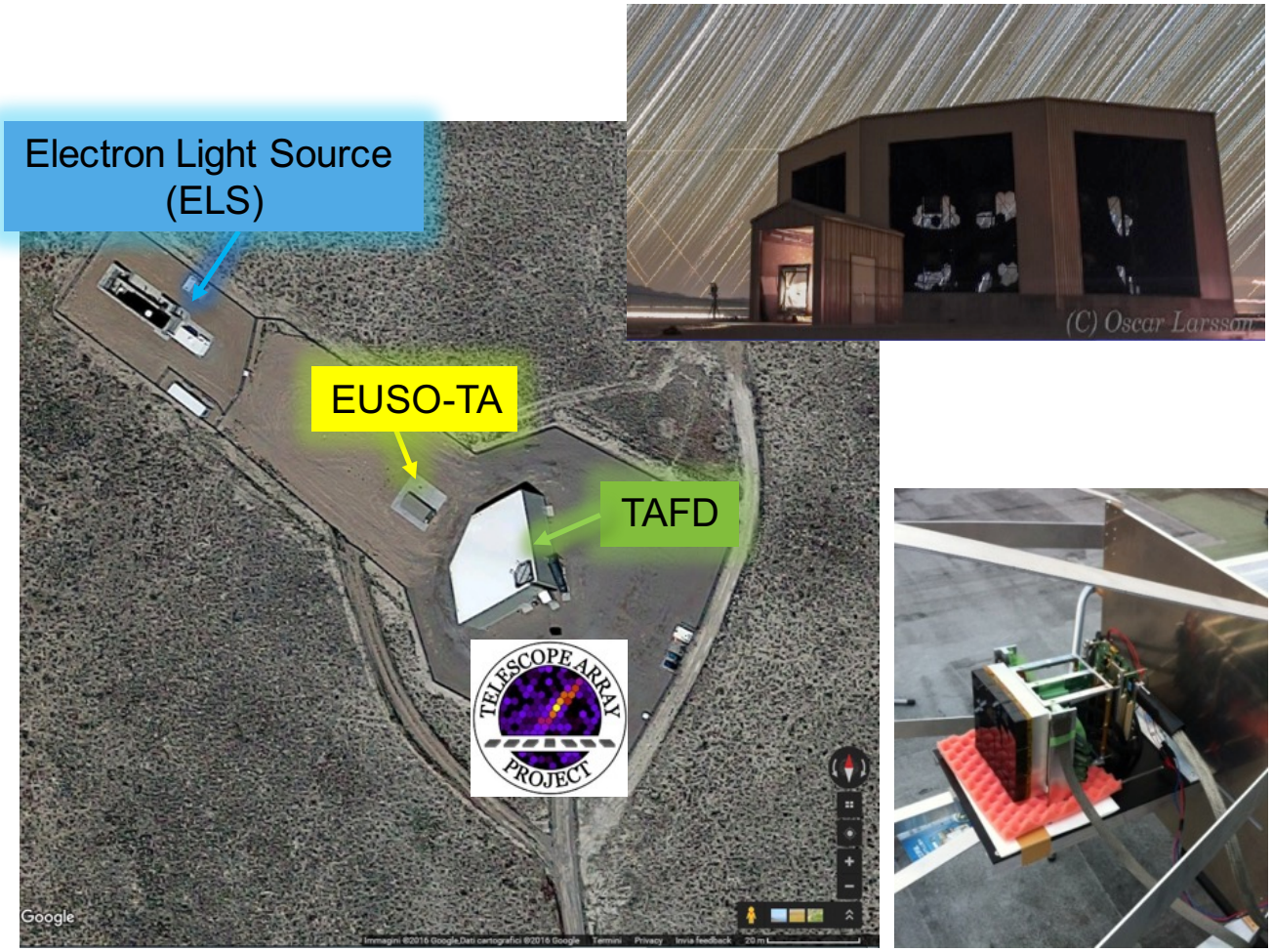
EUSO-TA at Telescope Array (Utah)

Characteristics

- Focal surface: 1 PDM (36 MAPMTs, 2304 pixels)
- Optics: 2 Fresnel lenses
- FOV: ±5.25°



Main purpose:

- Calibration (CLF and ELS)
- Detection of cosmic rays

Status: Active since 2015

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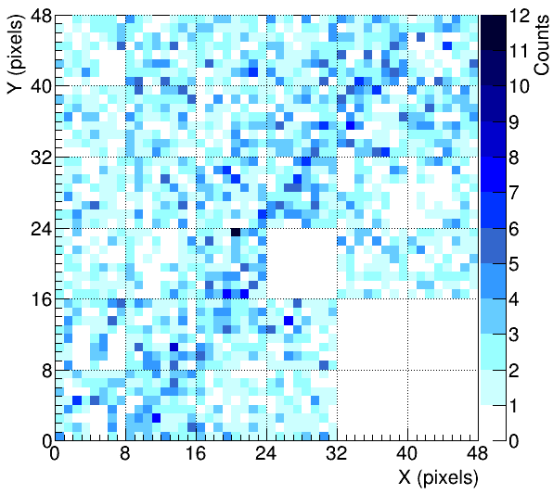
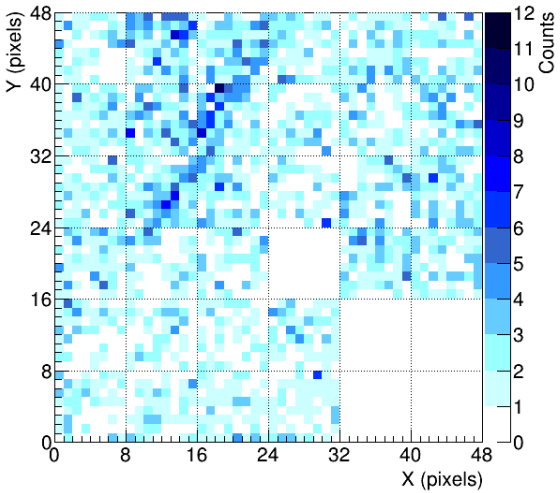
EUSO-TA first measurements

1 frame = 2.5 μs

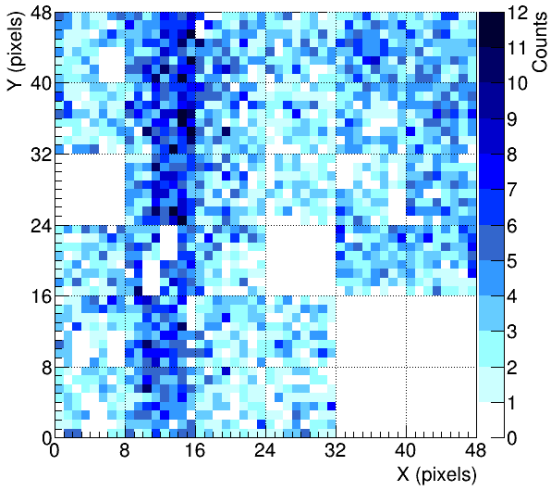
13 May 2015



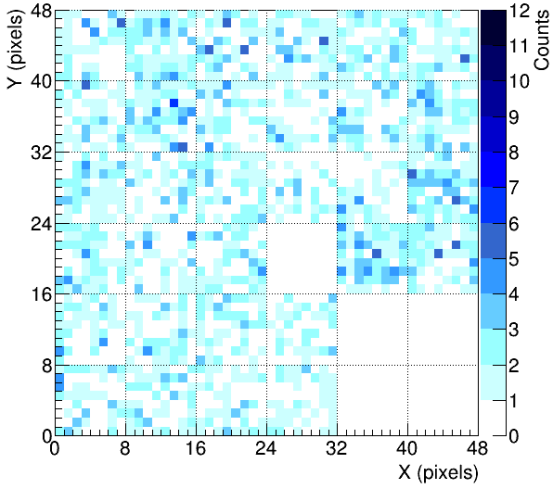
20 September 2015



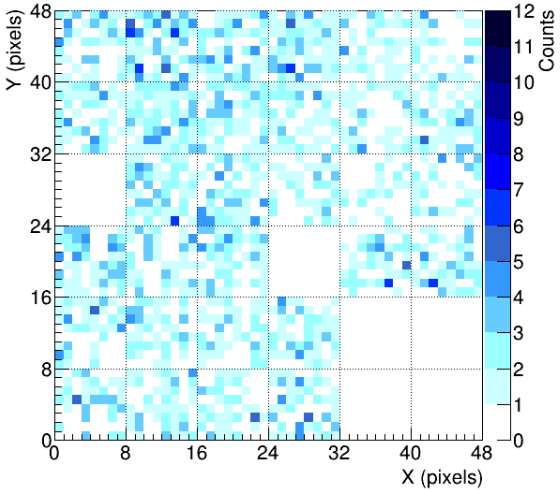
7 November 2015



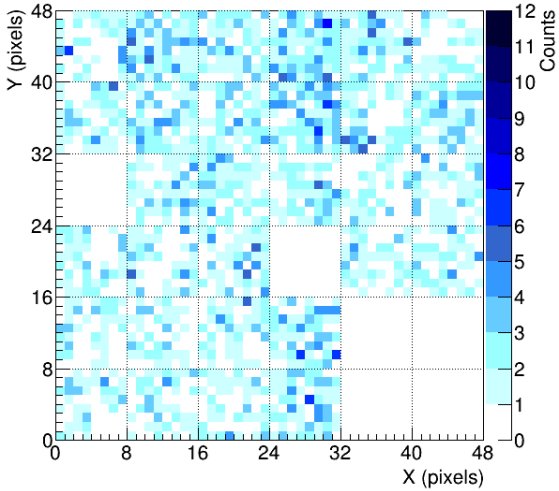
18 September 2015



15 October 2015



16 October 2015



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13th May 2015

Telescope Array event reconstruction

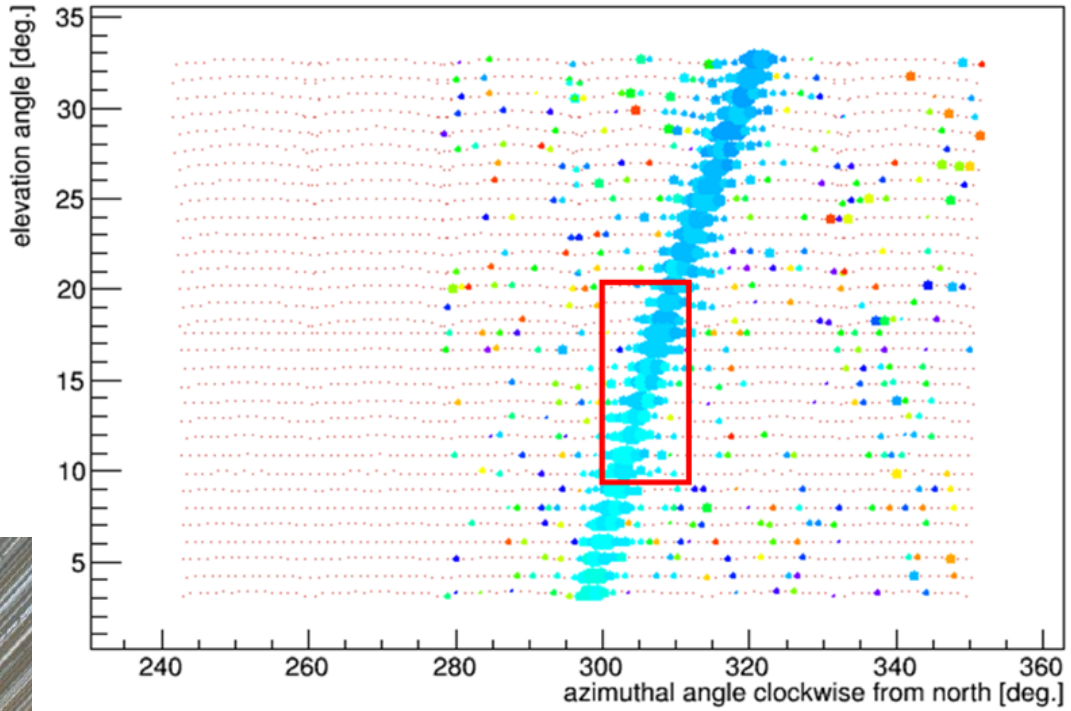
Telescope Array reconstruction

- Zenith = 35°
- Azimuth = 7° (clockwise from North)
- Impact parameter Rp = 2.5 km
- Core = (14.8 km, -10.9 km) respect CLF
- E = 10^{18} eV

EUSO-TA configuration

- EUSO-TA elevation = 15°

TA + EUSO-TA FOV



Field of view of
TA Black Rock Mesa fluorescence detectors
and EUSO-TA

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13th May 2015

Telescope Array reconstruction

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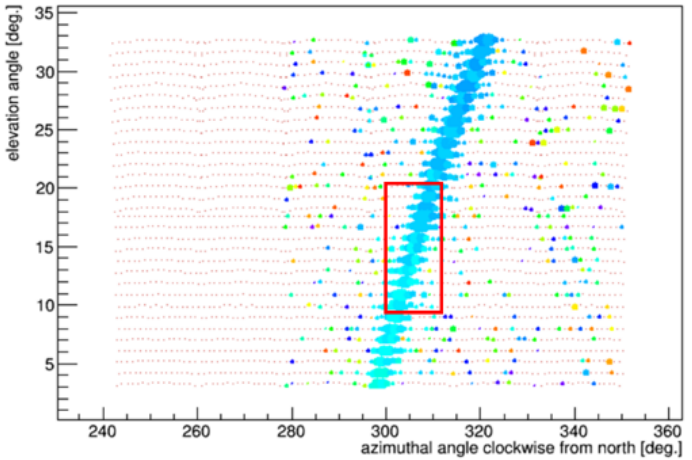
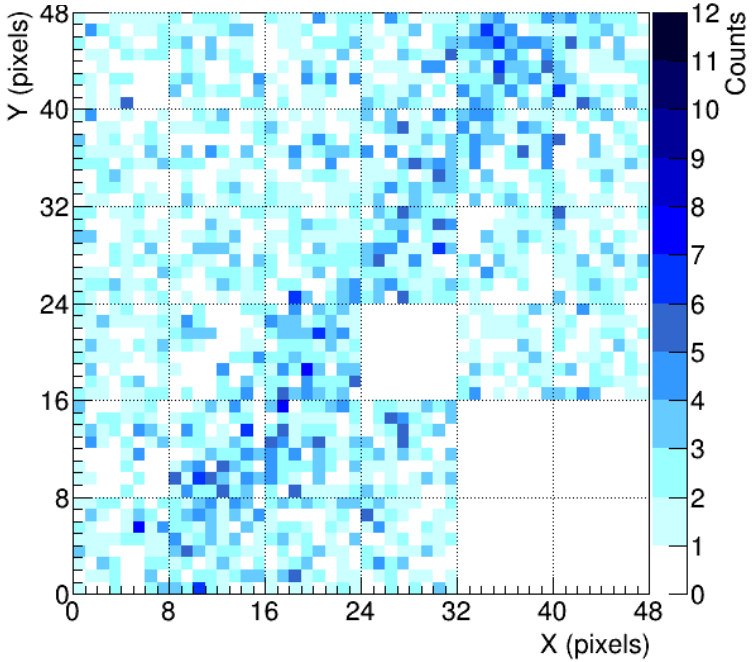
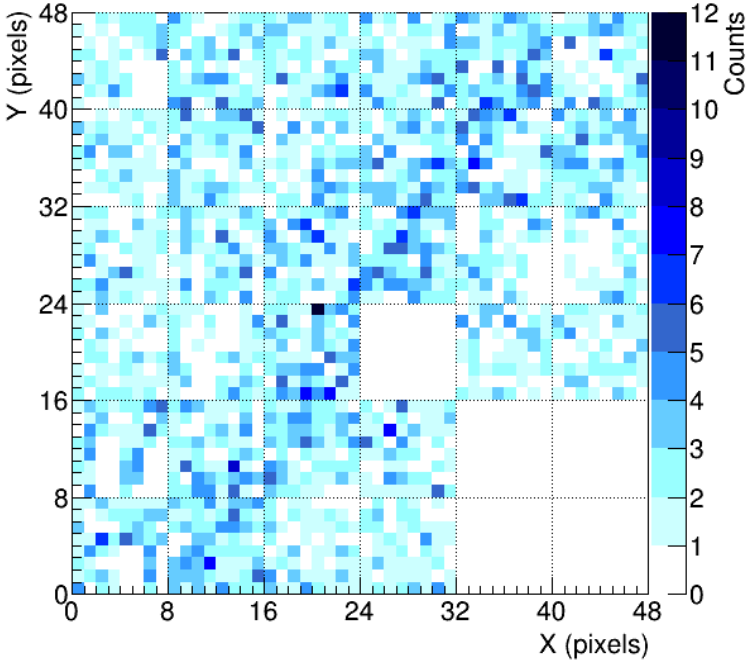


Offline simulation
+ background (from data)



Data



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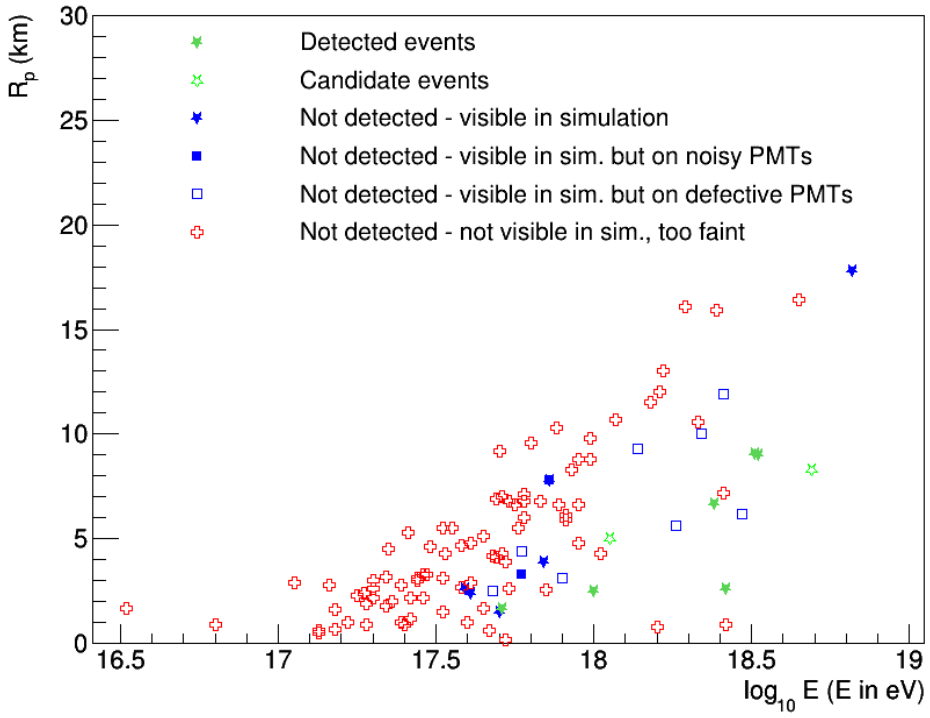
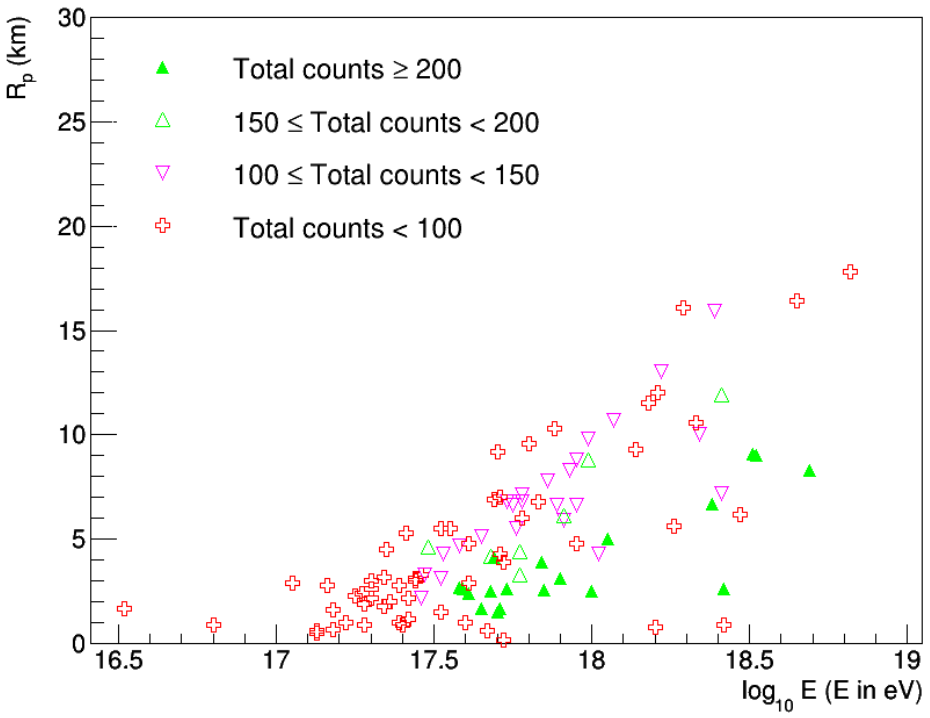
Detected and not detected events
Simulation study

Visual evaluation of the "visible" simulated events



Evaluation of the total number of counts in the simulated events



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EUSO-Balloon

JEM-EUSO prototype at 40km altitude

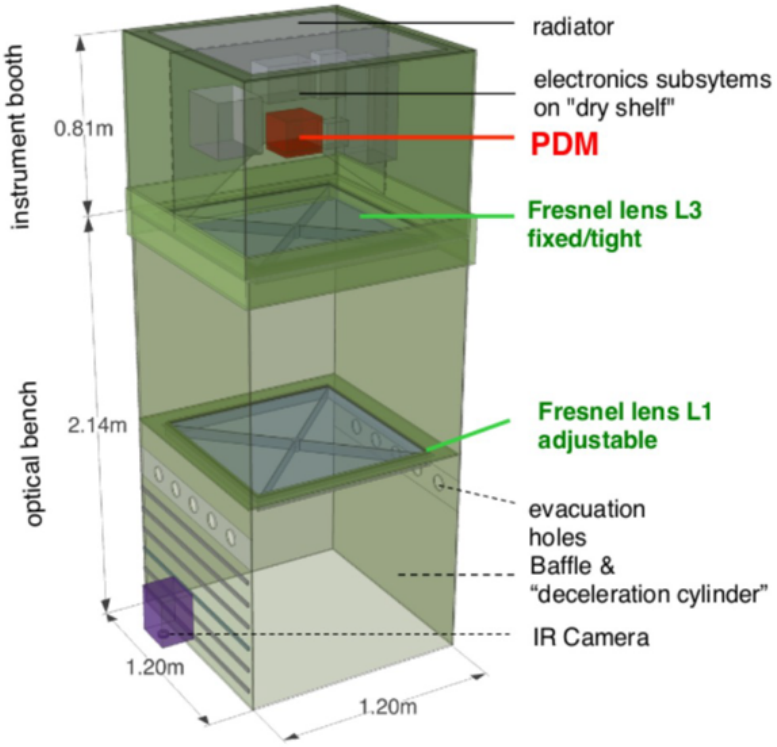
Characteristics:

- Focal surface: 1 PDM (36 MAPMT, 2304 pixels)
- Optics: 2 Fresnel lenses
- FOV: $\pm 6^{\circ}$

Main purposes:

- Engineering tests
- UV-background measurement

Status: Successful first flight in August 2014!



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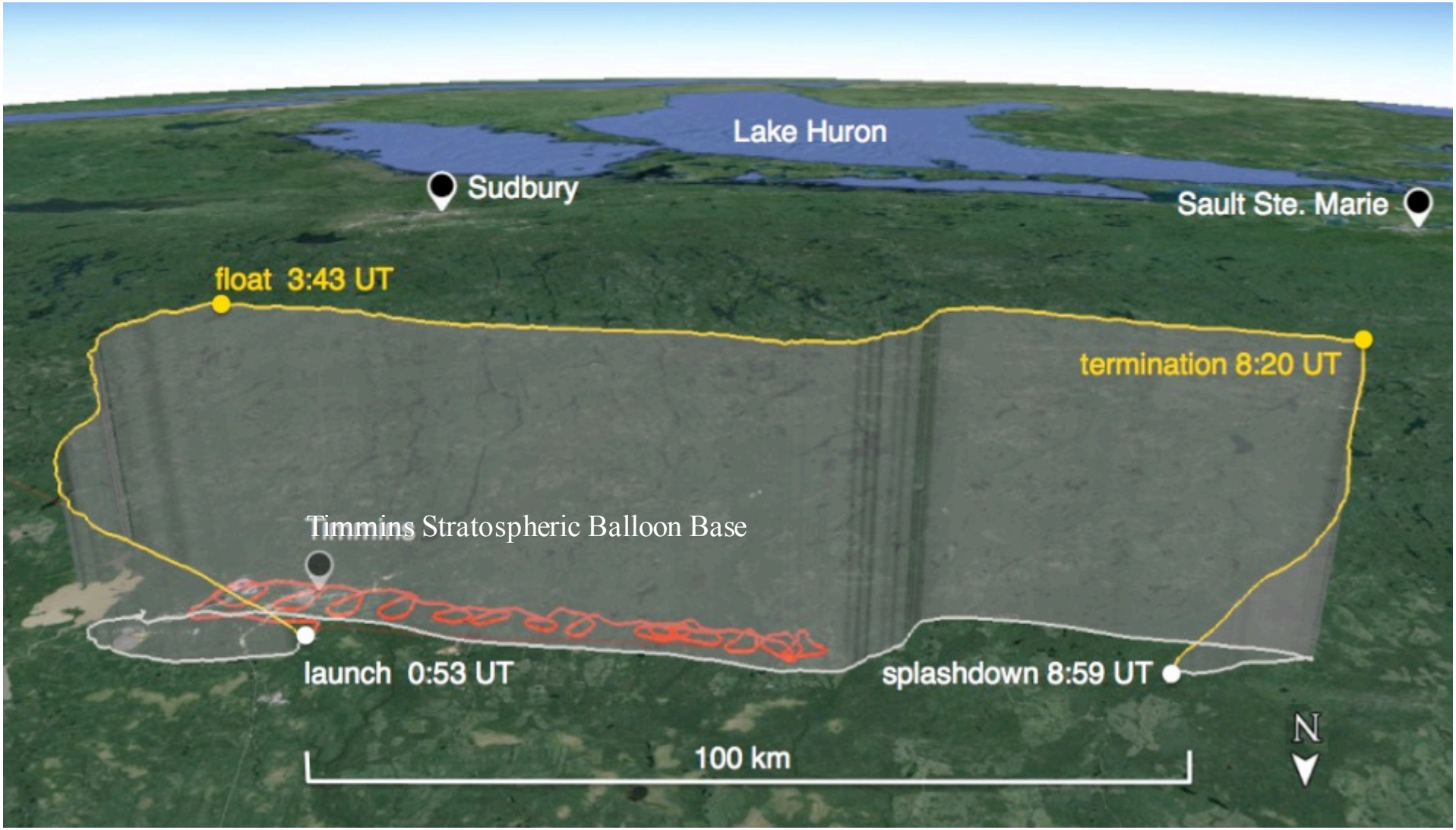
EUSO-Balloon

First flight from Timmins, Canada: 25th August 2014



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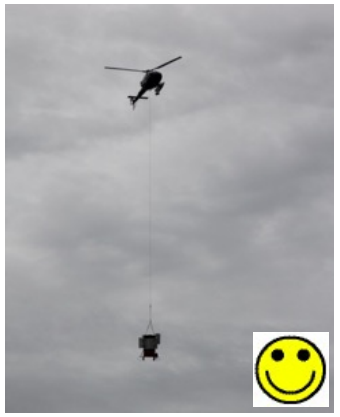
EUSO-Balloon

First flight from Timmins, Canada: 25th August 2014



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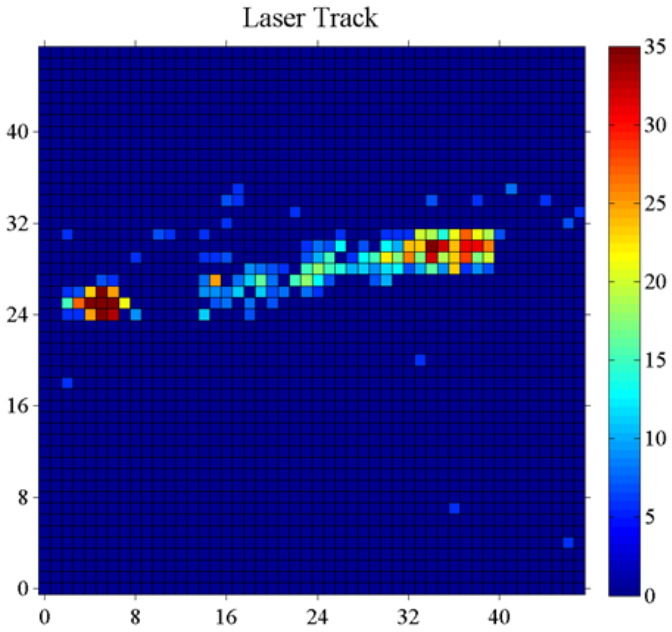
EUSO-Balloon

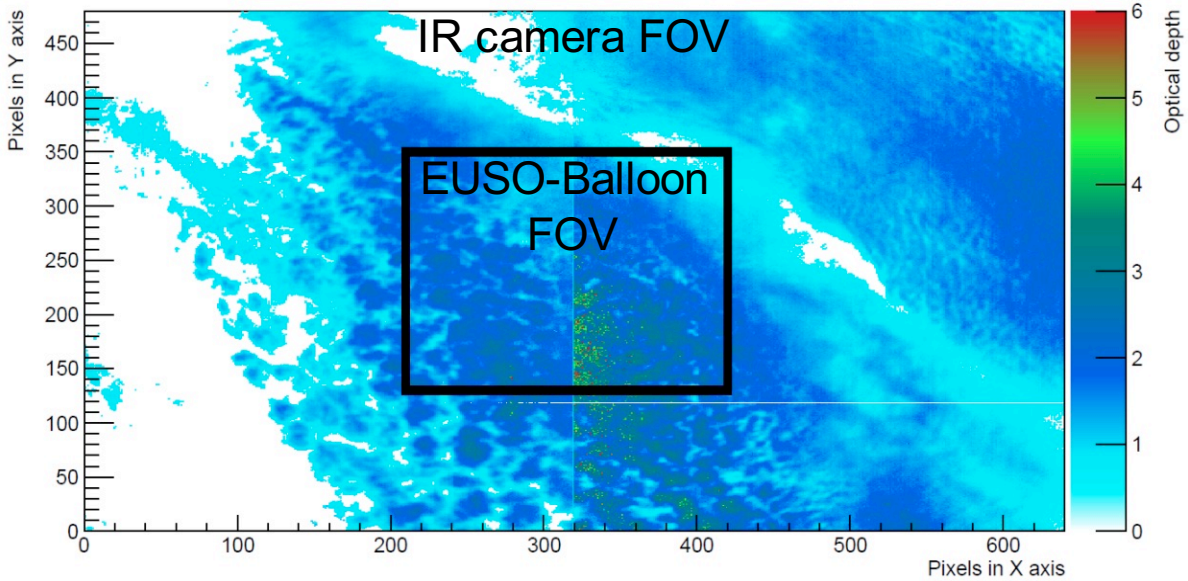
Preliminary results



~ 5h data available (IR camera and laser/flashers)

IR Camera

- One picture every 80 s
- Cloud attenuation
- Cloud top altitude
- Correction of EUSO-Balloon data to retrieve the intrinsic luminosity of laser/flashers



Cloud coverage and optical depth in the IR at 05:15:51 UTC

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Future experiments

- EUSO-SPB
- Mini-EUSO
- K-EUSO

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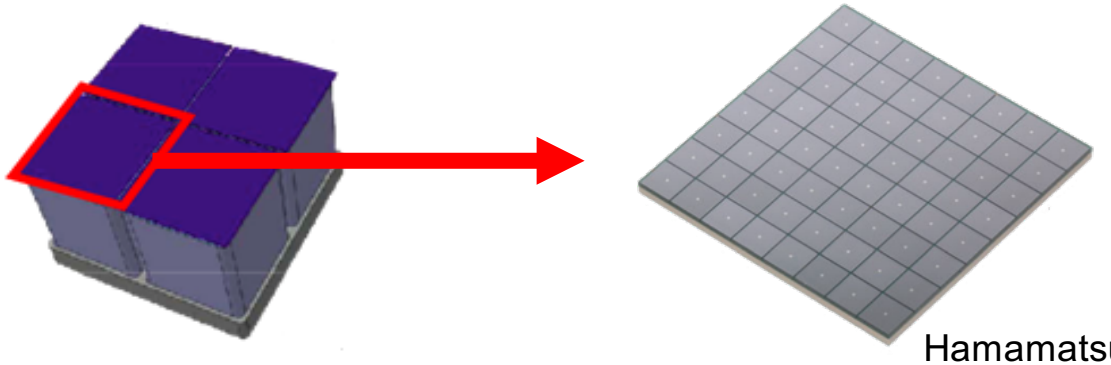
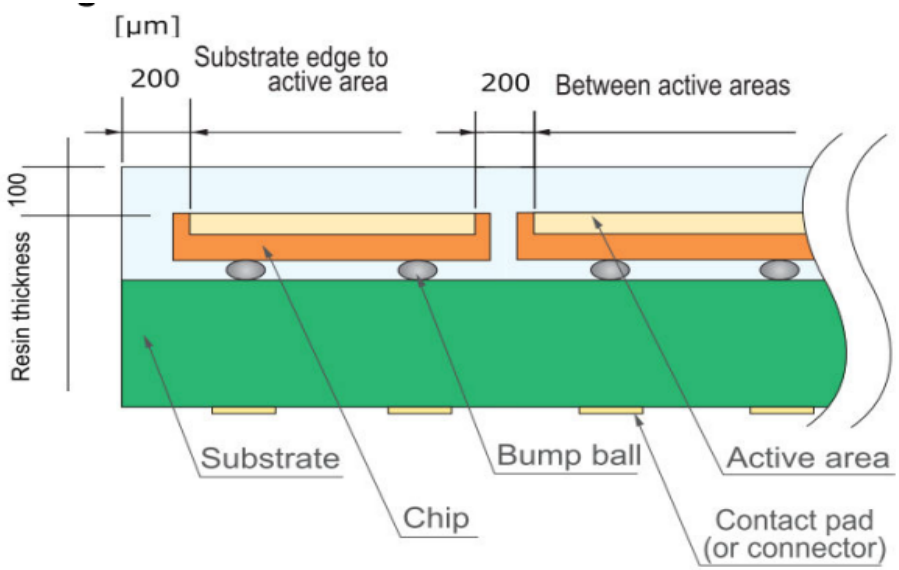
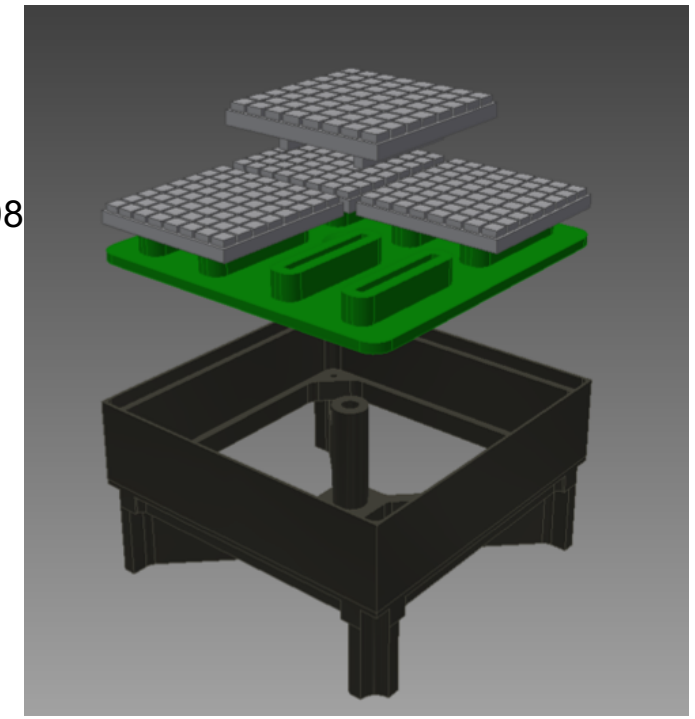
SiPMs option



Hamamatsu
S13361-3050AS-08

- ~ same pixel size
- 0.2 mm gap between pixels





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MAPMTs vs SiPMs

SiPMs already used in fluorescence detectors (FACT / FAMOUS)

	PMT	SiPM
PDE	**20-45%**	**20-60%**
Gain	10^6	10^6
TTS (Transit Time Spread)	**~1 ns**	**~1 ns**
Dynamic range	10^6	10^3
Dark noise rate	**~kHz** 	**~MHz** 
Behavior in magnetic fields		
Operation Voltage	**1000+ V** 	**50-70 V** 
Temperature sensitivity		
Robustness and compactness		

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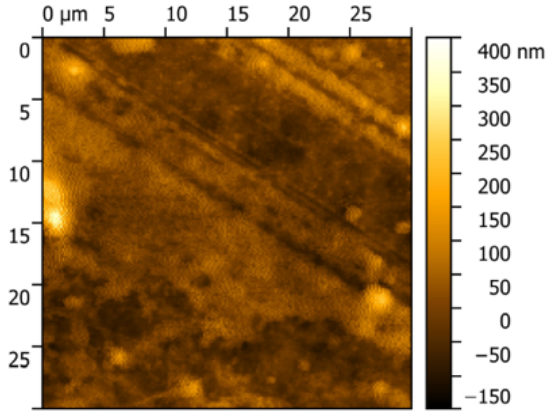
Investigation of SiPMs with an Atomic Force Microscope

before/after cooling

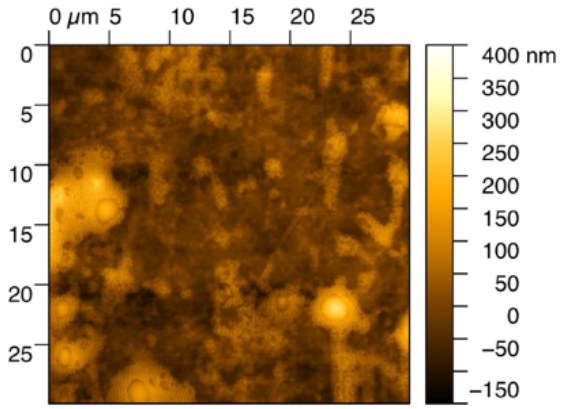
- Temperature tested: +25 → -42 °C
- No structural issues

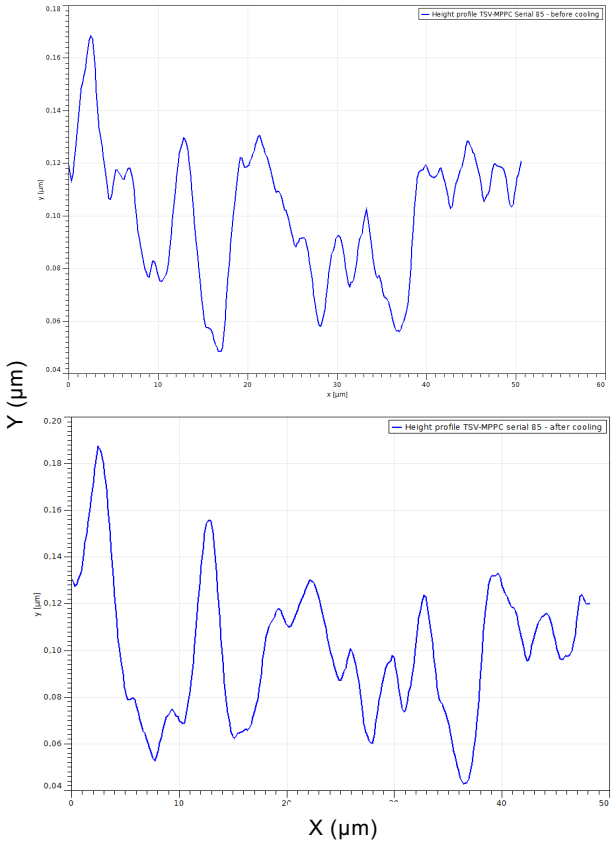
SiPMs are usable in space temperature conditions

Before cooling:

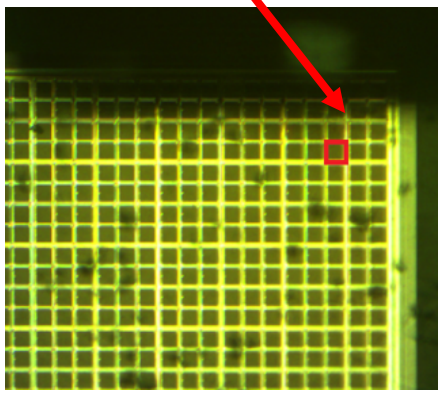


After cooling:





Screened APD Cell



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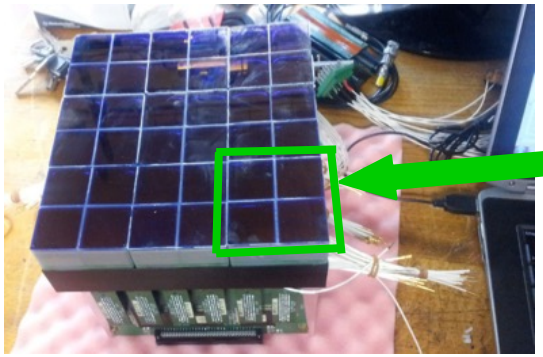
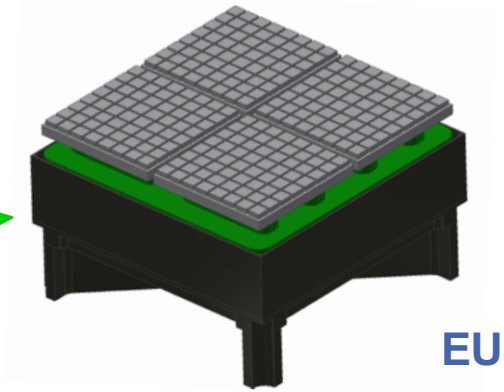
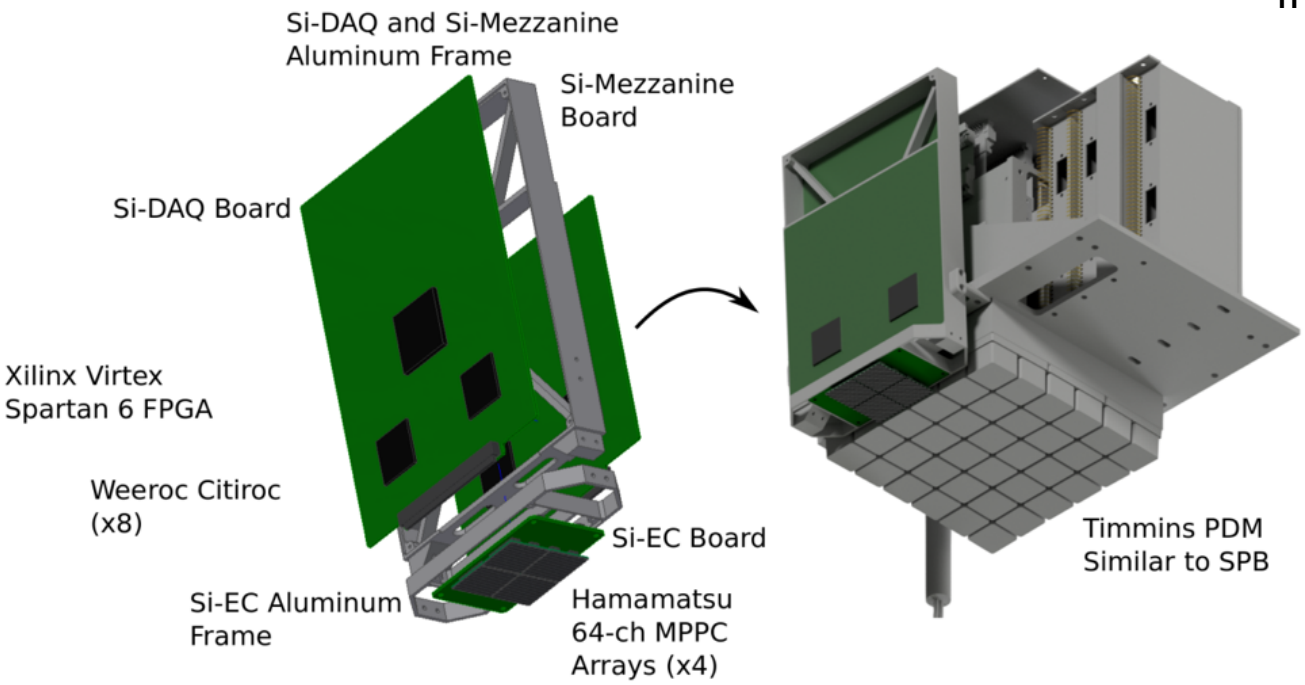
SiPM Elementary Cell Add-on camera (SiECA)





EUSO-Super Pressure Balloon

- Delivered to NASA
- Foreseen flight: Spring 2017 from Wanaka, New Zealand



William Painter
Max Renschler

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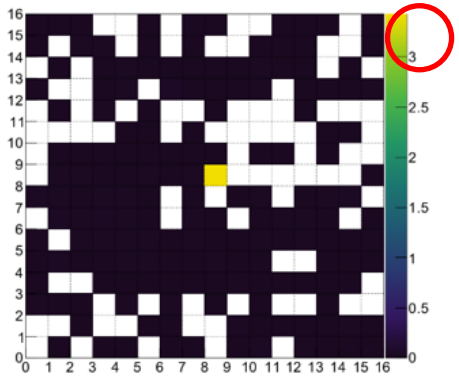
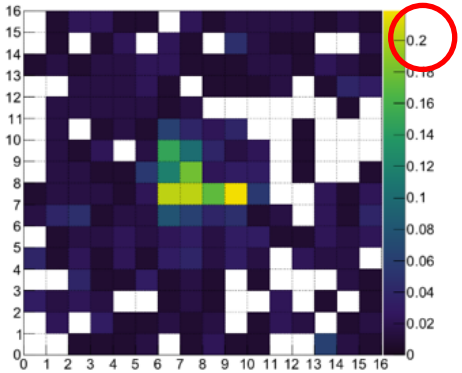
SiECA tests in SPOCK

Voltage to LED: 3 V

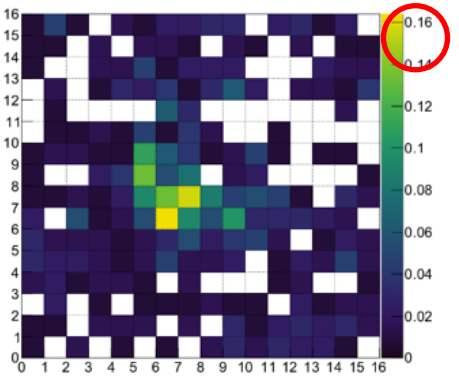
LED distance: 0 cm



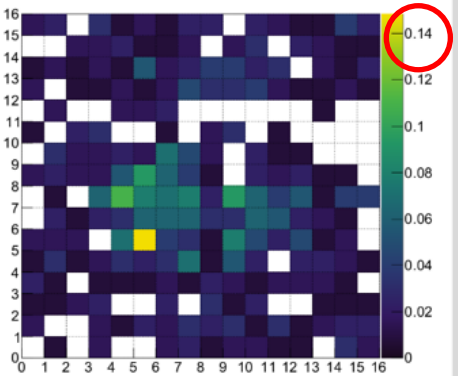
20 cm



30 cm

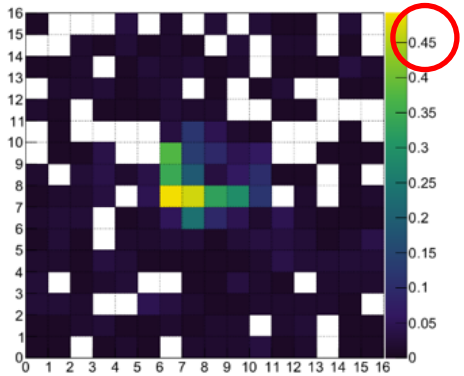


40 cm

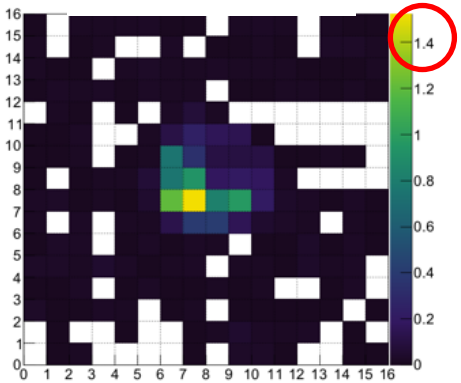


LED distance: 20 cm

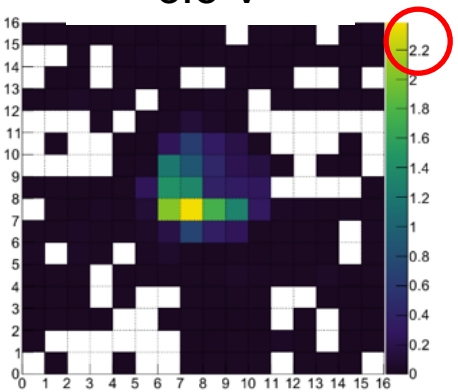
Voltage to LED: 3.1 V



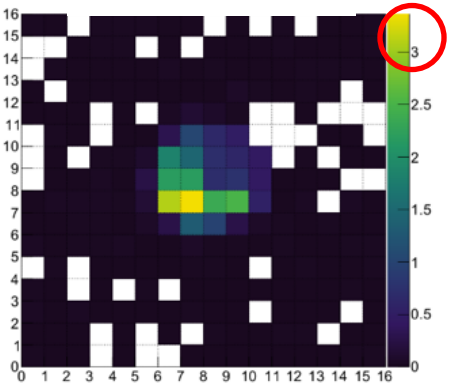
3.3 V



3.5 V



3.7 V



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The long journey of SiECA

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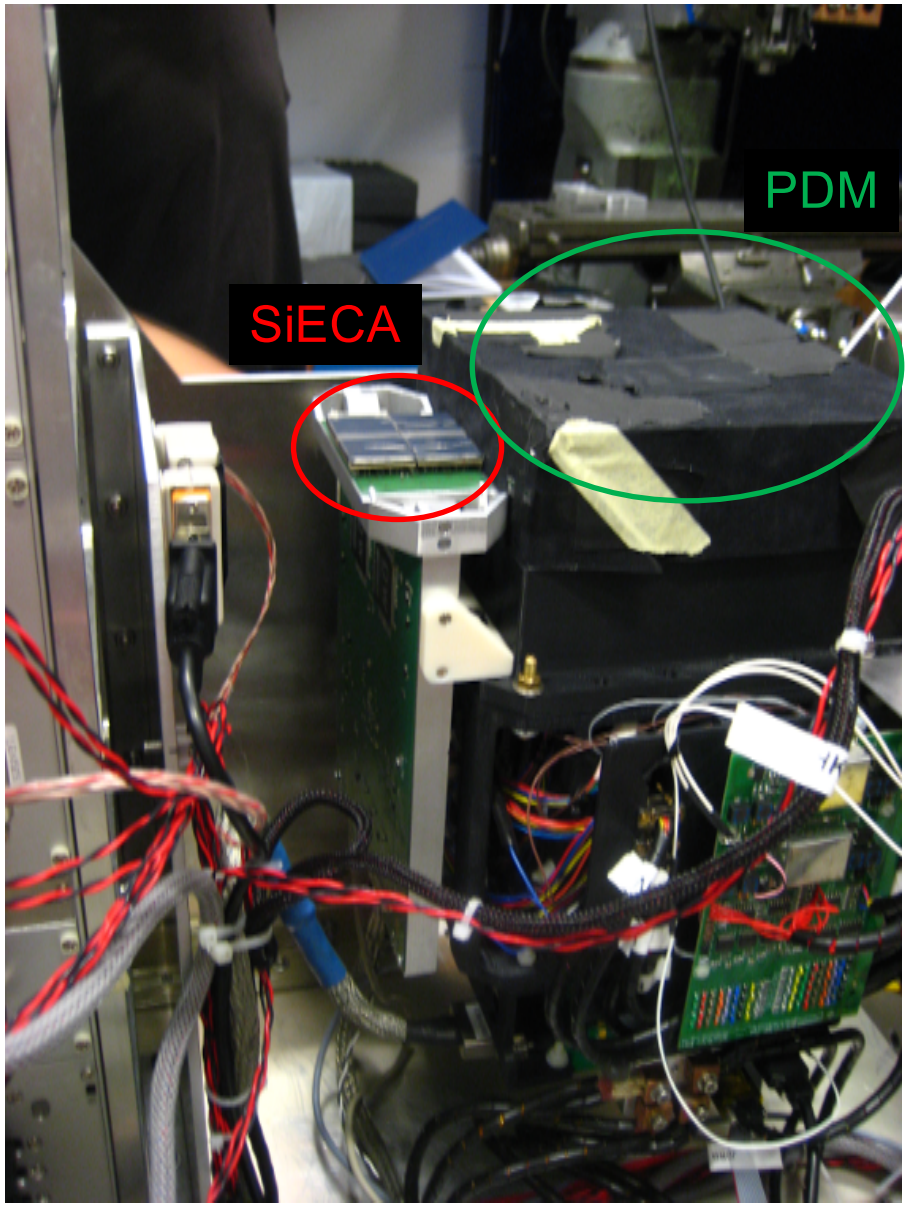
Integration of SiECA in EUSO-SPB



Mechanical integration of SiECA in EUSO-SPB electronics box

(PDM covered with black paper, SiECA covered with silicon tape)

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EUSO-Super Pressure Balloon (EUSO-SPB)

On board the long-duration balloon flight (NASA)

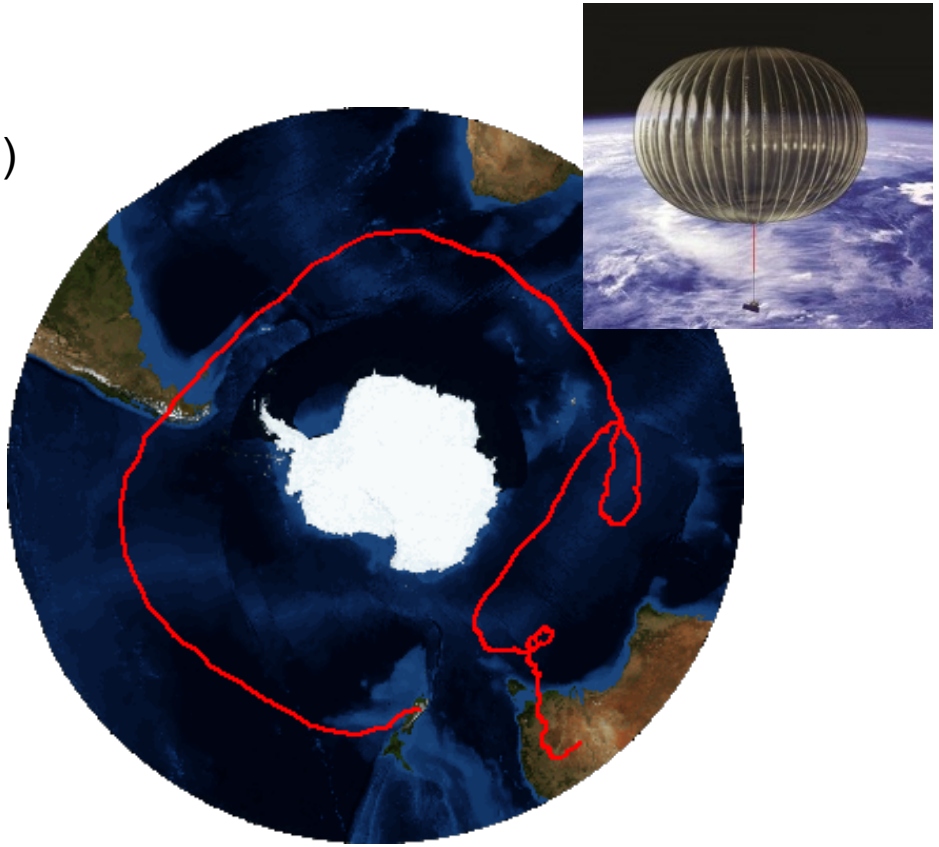
Characteristics:

- Focal surface: 1 PDM (36 MAPMT, 2304 pixels)
- Optics: 2 Fresnel lenses
- SiECA (SiPM camera)
- Altitude: 40 km
- FOV: ±6°

Main purposes:

- First EAS measurements from Space!!
- Engineering tests
- UV-Background measurement
- Test SiPM focal surface with SiECA

Status: Sent to NASA, delivered to New Zealand
Launch: Spring 2017



- NASA's first Super Pressure Balloon flight, March 2015, Wanaka, NZ
- Duration: 32 days, 5 hours, 51 minutes
- Flight altitude: ~33km

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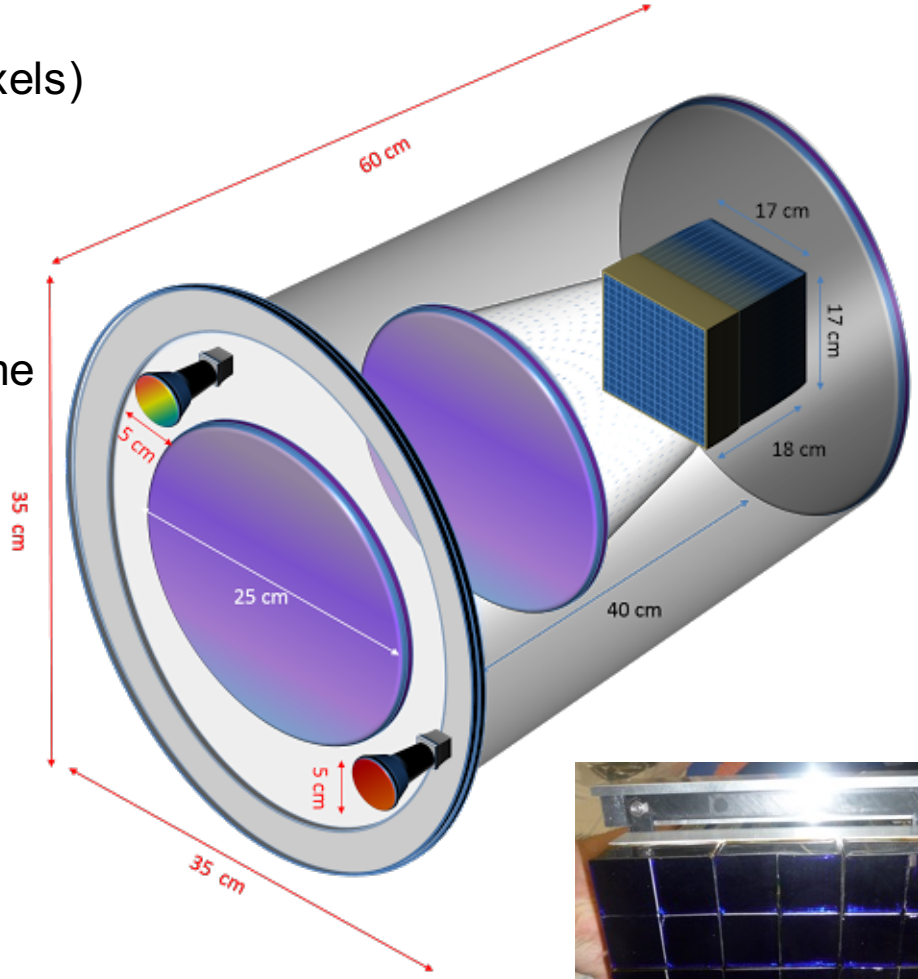
Mini-EUSO on the ISS

Characteristics:
- Focal surface: 1 PDM (36 MAPMT, 2304 pixels)
- Optics: 2 Fresnel lenses
- Altitude: 400 km
- FOV: ±19°

Scientific objectives:
- First map of the Earth in UV during night time
- Study of atmospheric phenomena and bioluminescence at Earth
- Study of meteors

Technological objectives:
- First use of Fresnel lenses in space
- Optimization of characteristics and performances of EUSO
- Raise the technological readiness level of the Hardware

Status: Operation approved
Launch: October 2017



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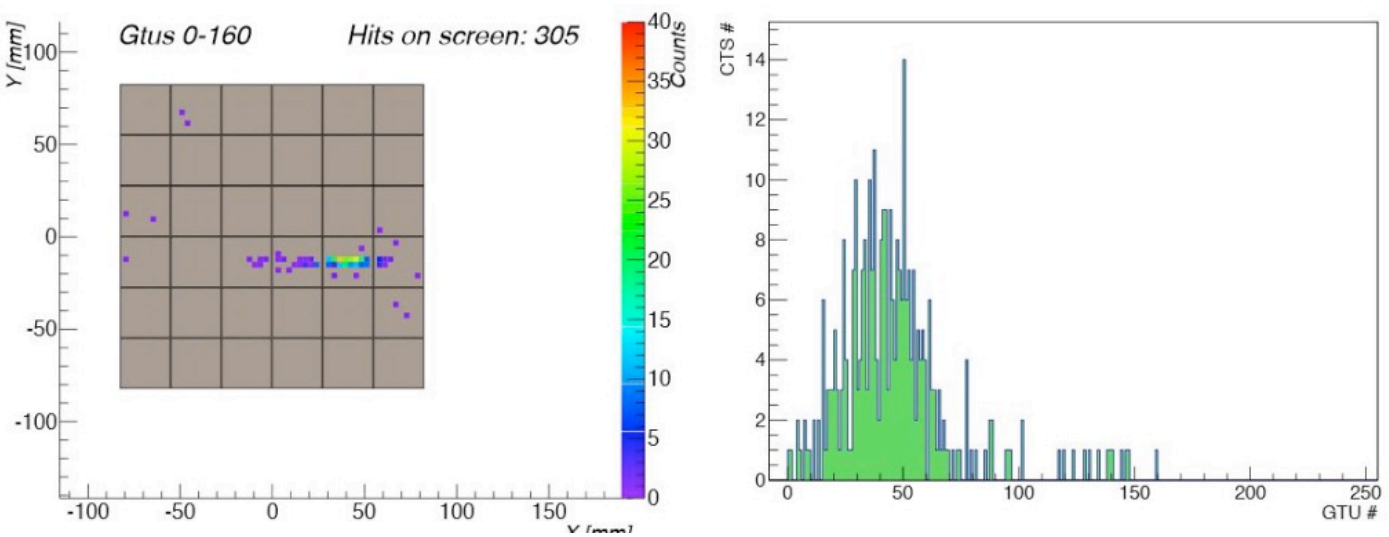
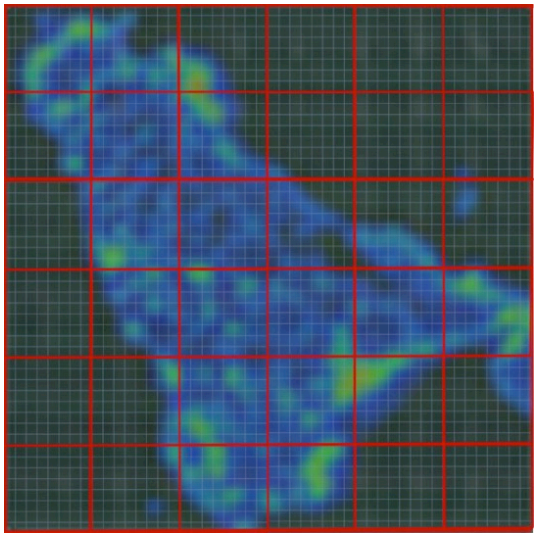
Mini-EUSO on the ISS





Left: Light profile observed in the Mini-EUSO for an E = 10^{21} eV cosmic ray event.
Right panel: number of photoelectrons vs time (1 GTU = 2.5 μs) for the same event.
(Simulation)

Sicily island (Italy) seen by Mini-EUSO (Simulation)

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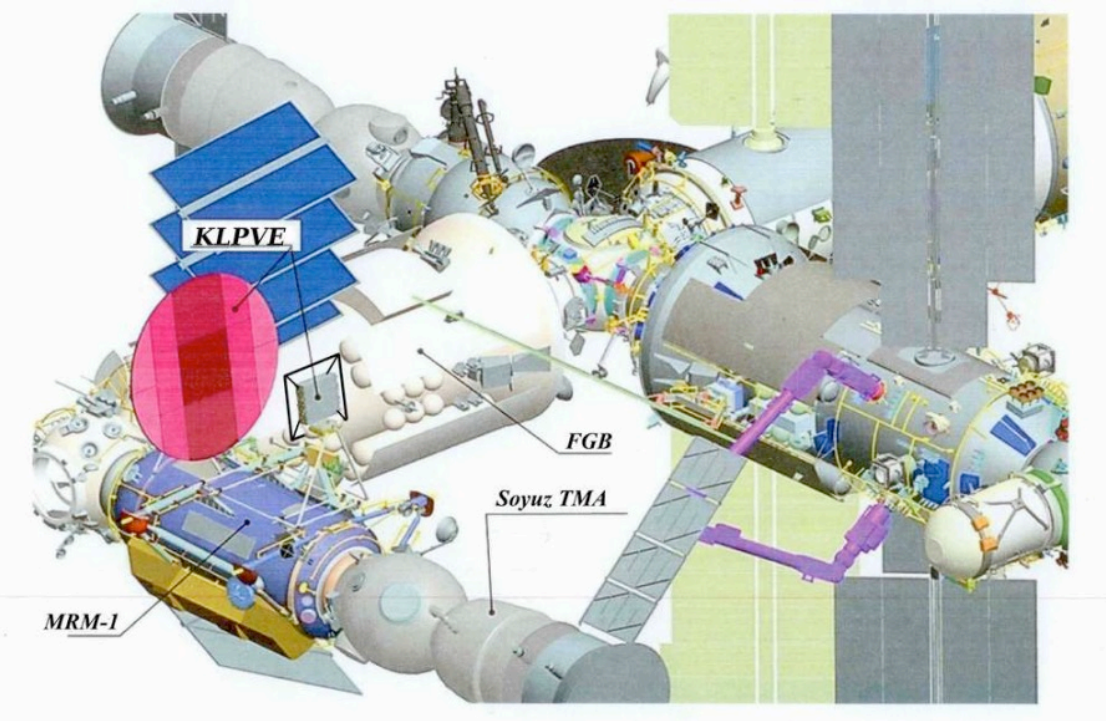
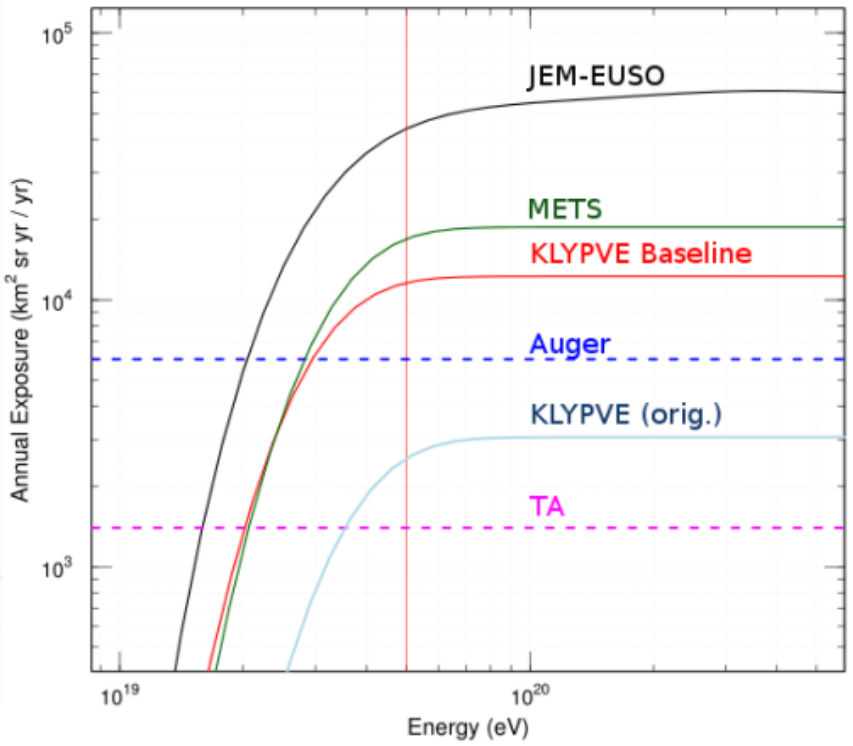
K-EUSO

JEM-EUSO mission currently suspended for funding problems

The foreseen space-based mission is K-EUSO joining the Russian project KLIPVE, smaller version with 52 PDMs and a mirror instead of lenses





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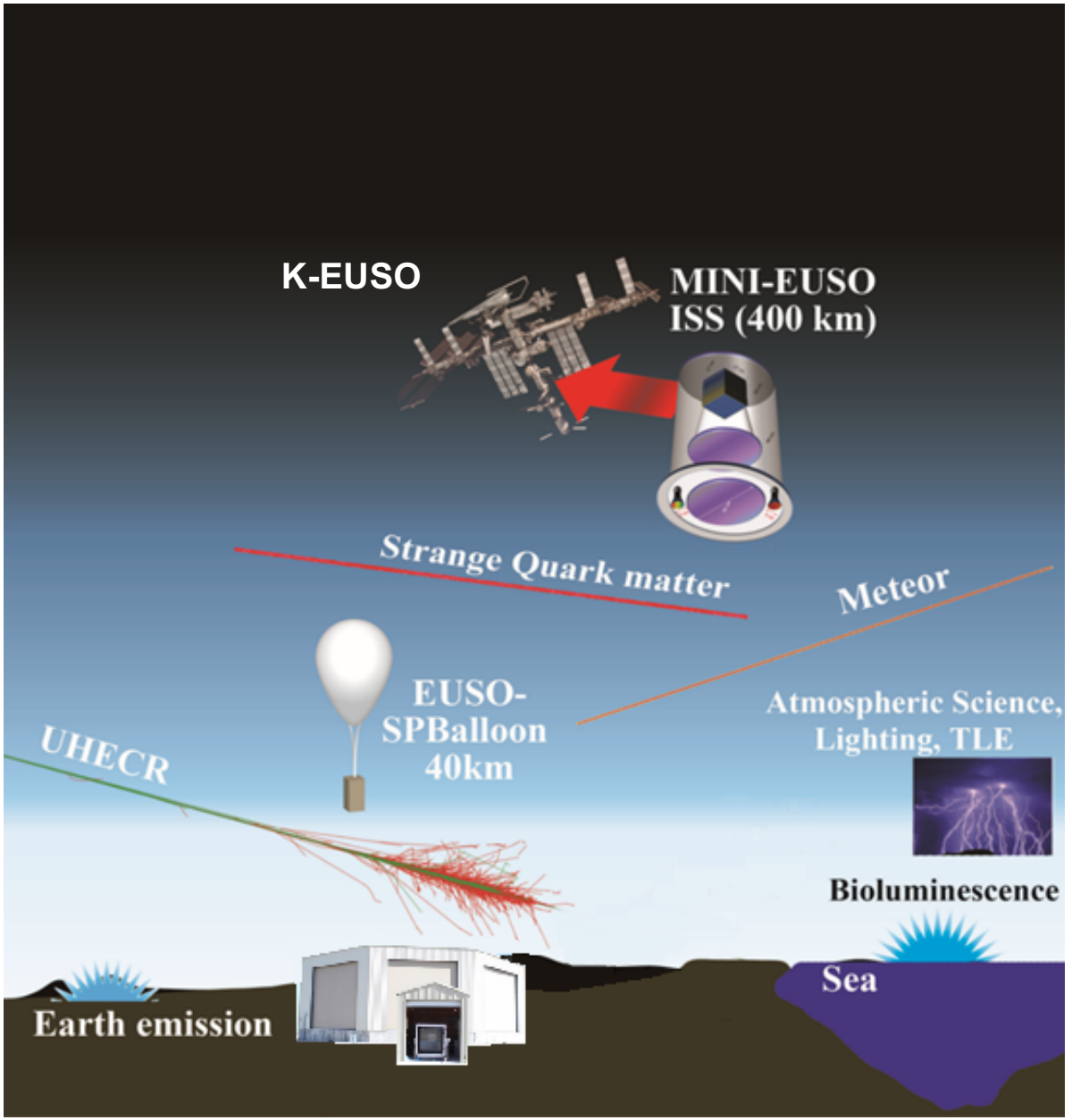
Overview



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