



**Joint Experiment Missions-**  
**Extreme Universe Space Observatory**

# Search for Ultra High Energy Cosmic Rays from Space – The JEM-EUSO program

M. Bertaina – Univ. & INFN Torino  
for the JEM-EUSO Collaboration  
ICRC 2019

# N.33 JEM-EUSO Program Related Contributions @ ICRC2019

## JEM-EUSO:

- 1- M.B.: Search for Ultra-High Energy Cosmic Rays from Space - The JEM-EUSO program – 25/7 @14:00 CRI1
- 2 - F. Fenu: Results from the First Missions of the JEM-EUSO Program – 25/7 @14:15 CRI1
- 3 – A. Haungs: Silicon Photomultipliers for Orbital Ultra High Energy Cosmic Ray Observation - 25-26/7 PB 171 CRI
- 4- F. Fenu: Simulations for the JEM-EUSO program with ESAF - 30/31/7 PB 162 CRI

## EUSO-TA:

- 5 - F. Bisconti: EUSO-TA ground based fluorescence detector: analysis of the detected events - 26/7 @14:45 CRI3
- 6 - L. Piotrowski: Results and status of the EUSO-TA detector - 25-26/7 PB 145 CRI
- 7 - K. Shinozaki: Trigger developments for the fluorescence detector of EUSO-TA and EUSO-SPB2 - 25-26/7 PB 213 CRI
- 8 - Z. Plebaniak: Calibration of EUSO-TA detector with stars – 30-31/7 PB 203 CRI1

## EUSO-SB1:

- 9 - K. Shinozaki: An estimation of the exposure of air shower detection by the EUSO-SPB1 mission – 25-26/7 PB 214 CRI
- 10 - A. Diaz Damian: EUSO-SPB1: Flight Data Classification and Air Shower Search Results – 30-31/7 PB 159 CRI
- 11 - J. Eser: Results of the EUSO-SPB1 flight – 30-31/7 PB 161 CRI
- 12 - C. Vigorito: A Method for Cloud Mapping in the FoV of the IR Camera during the EUSO-SPB1 Flight - 30-31/7 PB 231 CRI
- 13 - C. Vigorito: WRF and Radiative Methods for Cloud Top Height retrieval along EUSO-SPB1 Trajectory – 30-31/7 PB 232 CRI
- 14 - F. Bisconti: Machine Learning Approach for Air Shower Recognition in EUSO-SPB Data – 30-31/7 PB 233 CRI

## EUSO-SB2:

- 15 - K. Krolik.: Cherenkov Light from Horizontal Air Shower – 25-26/7 PB 186 CRI
- 16 - N. Otte: Development of Cherenkov Telescope for Detection of UHEs with EUSO-SPB2 & POEMMA – 25-26/7 PB 186 CRI
- 17 – L. wiencke: The Extreme Universe Space Observatory on a Super-Pressure Balloon II Mission - 30-31/7 PB 236 CRI
- 18 – V. Scotti: The Data Processor of the EUSO-SPB2 Telescopes - 30-31/7 PB 141 CRI
- 19 – J. Szabelski: CR Mass Composition @ $10^{18}$  eV with HAS Cherenkov Light Balloon Measurements - 30-31/7 PB 220 CRI
- 20 – R. Diesing: UCIRC2: A cloud monitor for EUSO-SPB2 – 25-26/7 PB 156 CRI

## Mini-EUSO:

- 21– M. Bertaina: The EUSO@Turlab Project:Tests of Mini-EUSO Engineering Models - 25-26/7 PB 142 CRI
- 22 – F. Bisconti: Mini-EUSO engineering model: tests in open-sky condition - - 25-26/7 PB 143 CRI
- 23 – F. Fenu: Space Debris Detection and Tracking with the Techniques of Cosmic Ray Physics - - 25-26/7 PB 159 CRI
- 24 - M. Casolino: The MINI-EUSO mission to study UV emissions from the ISS - 30-31/7 PB 151 CRI
- 25 – V. Kungel: UV Laser System Test of Mini- EUSO - 30-31/7 PB 178 CRI

## TUS:

- 26– M. B.: An air-shower-like event registered with the TUS orbital detector - 30-31/7 PB 148 CRI
- 27 – K. Shinozaki:Search for nuclearites by he satellite-based TUS air fluorescence detector - 30-31/7 PB 284 DM

## POEMMA:

- 28– A. Olinto: POEMMA: Probe Of Extreme Multi-Messenger Astrophysics – 29/7 @ 18:15 CRI
- 29 – M. Hall Reno:A new calculation of Earthskimming very- and ultra-high energy tau neutrinos – 30/7 @ 14:15 NU

## Simulations & Others:

- 30 - A. Cummings: Sensitivity to Atypical Tau Initiated EAS for a High-Altitude Optical Cher. Detector - 27-29/7 PB 95 GRI&N
- 31 – A. Cummings: A More Complete Phenomenology of Tau Lepton Induced Air Showers - 27-29/7 PB 96 GRI&N
- 32 - J. Krizmanic: E2E Modeling of the EAS Signals from Cosmic vs for Space-based Experiments - 27-29/7 PB 110 GRI&N
- 33 – F. Kajino: Study for Nuclearites and Interstellar Meteoroids using High Sensitivity CMOS Camera – 30-31/7 PB 274 DM

# JEM-EUSO

## International collaboration

- 16 countries, 350+ researchers



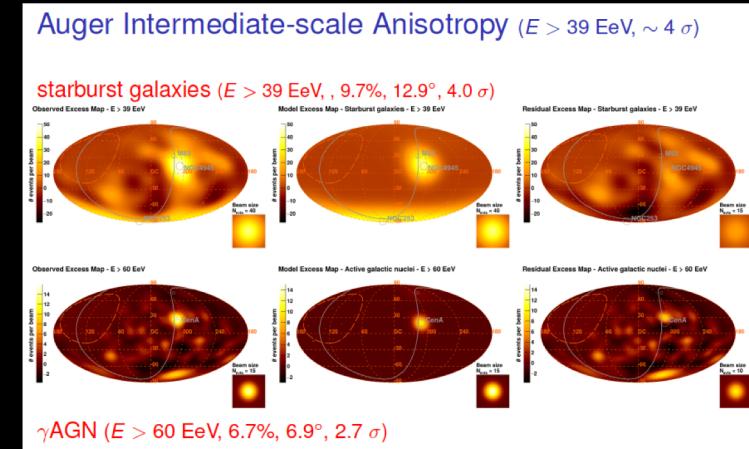
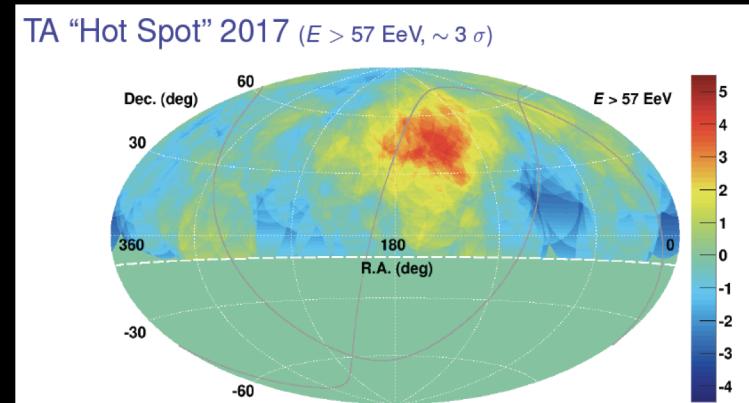
- Science Evaluated positively by ESA, NASA, Roscosmos and national agencies
- Funding for detectors and precursors ongoing in all countries



# The origin of UHECRs still requires an answer.... A significant increase in exposure is needed

Space offers the following opportunities:

- a) Complementarity to ground-based observation
- b) Potential 10x larger annual exposure than ground-based experiments
- c) Full sky coverage



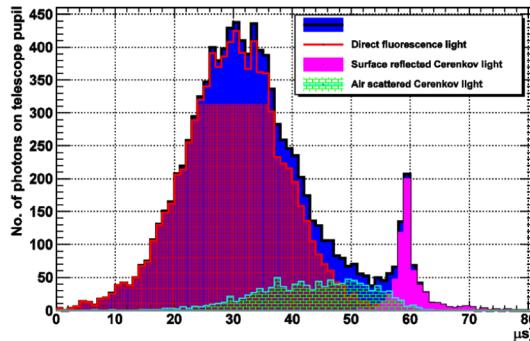
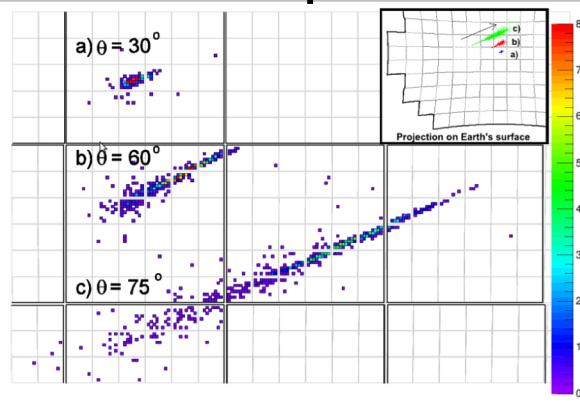
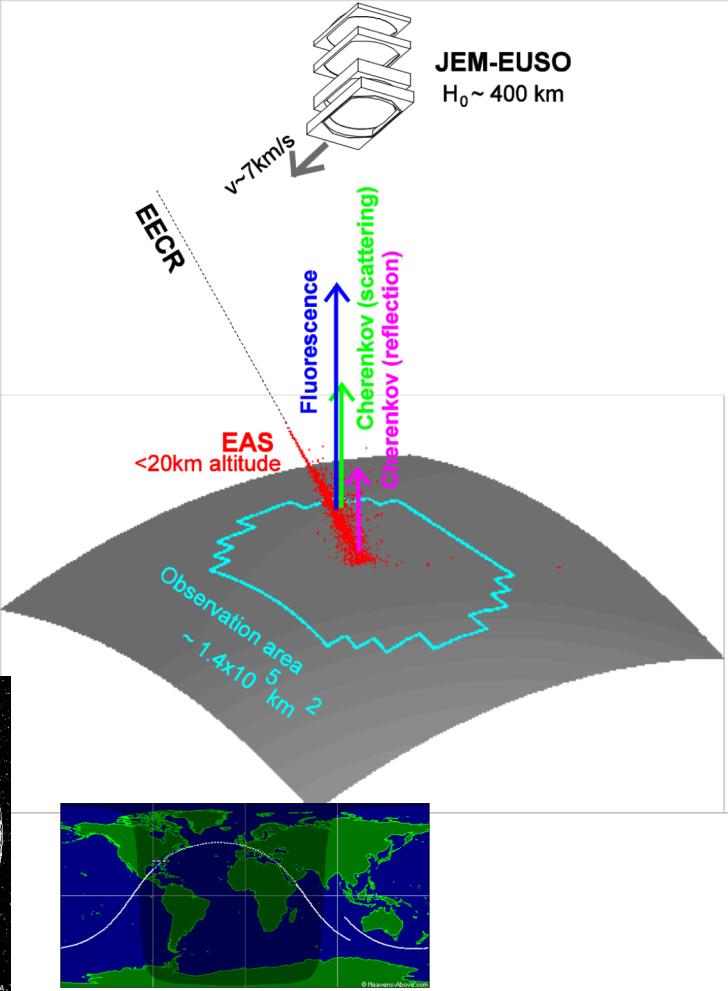
# Scientific challenges:

- Sensitivity to energies below GZK cutoff (if threshold is at higher energies, very few statistics and no inter calibration with ground-based experiments!).
- Light conditions continuously varying (ISS speed 7.5 km/s —> night/day change every 45 minutes).
- Atmospheric conditions (clear sky, clouds, lightning, cities and anthropic light) continuously changing.

# Technological challenges:

- » Low power consumption (<1kW for JEM-EUSO -  $3 \times 10^5$  pixels)
- » Low mass (~1-2 tons for JEM-EUSO)
- » Low telemetry (300 kbit/s for JEM-EUSO on ISS)
- » Radiation hard instrumentation
- » Space-qualified instrumentation (need to increase TRL)

# JEM-EUSO Observation Principle

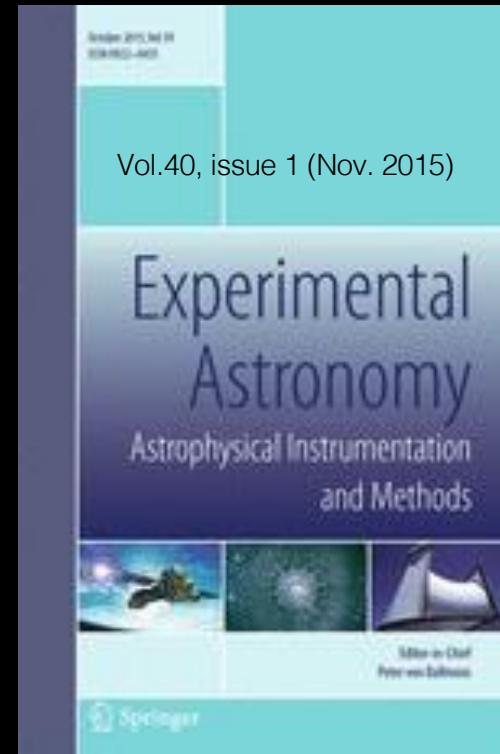


$\Delta t \sim 50 - 150 \mu\text{s}$

$\Delta t \sim 20 - 60 \text{ GTUs}$   
(1 GTU = 2.5  $\mu\text{s}$ )

# Special Issue on the JEM-EUSO Mission

- 15 papers addressing science and technology of JEM-EUSO
- The EUSO-Balloon pathfinder
- The JEM-EUSO instrument
- Ground-based tests of JEM-EUSO components at the Telescope Array site, "EUSO-TA"
- Space experiment TUS on board the Lomonosov satellite as pathfinder of JEM-EUSO
- The JEM-EUSO observation in cloudy conditions
- Calibration aspects of the JEM-EUSO mission
- JEM-EUSO: Meteor and nuclearite observations
- JEM-EUSO observational technique and exposure
- Ultra high energy photons and neutrinos with JEM-EUSO
- Science of atmospheric phenomena with JEM-EUSO
- Performances of JEM-EUSO: energy and X max reconstruction
- The atmospheric monitoring system of the JEM-EUSO instrument
- The infrared camera onboard JEM-EUSO
- Proposal of a Computing Model Using GRID Resources for the JEM-EUSO Space Mission



From the JEM-EUSO Misson → to the JEM-EUSO Program

# JEM-EUSO PROGRAM

EUSO-TA (2013- )

EUSO-Balloon (2014)

TUS (2016-17)

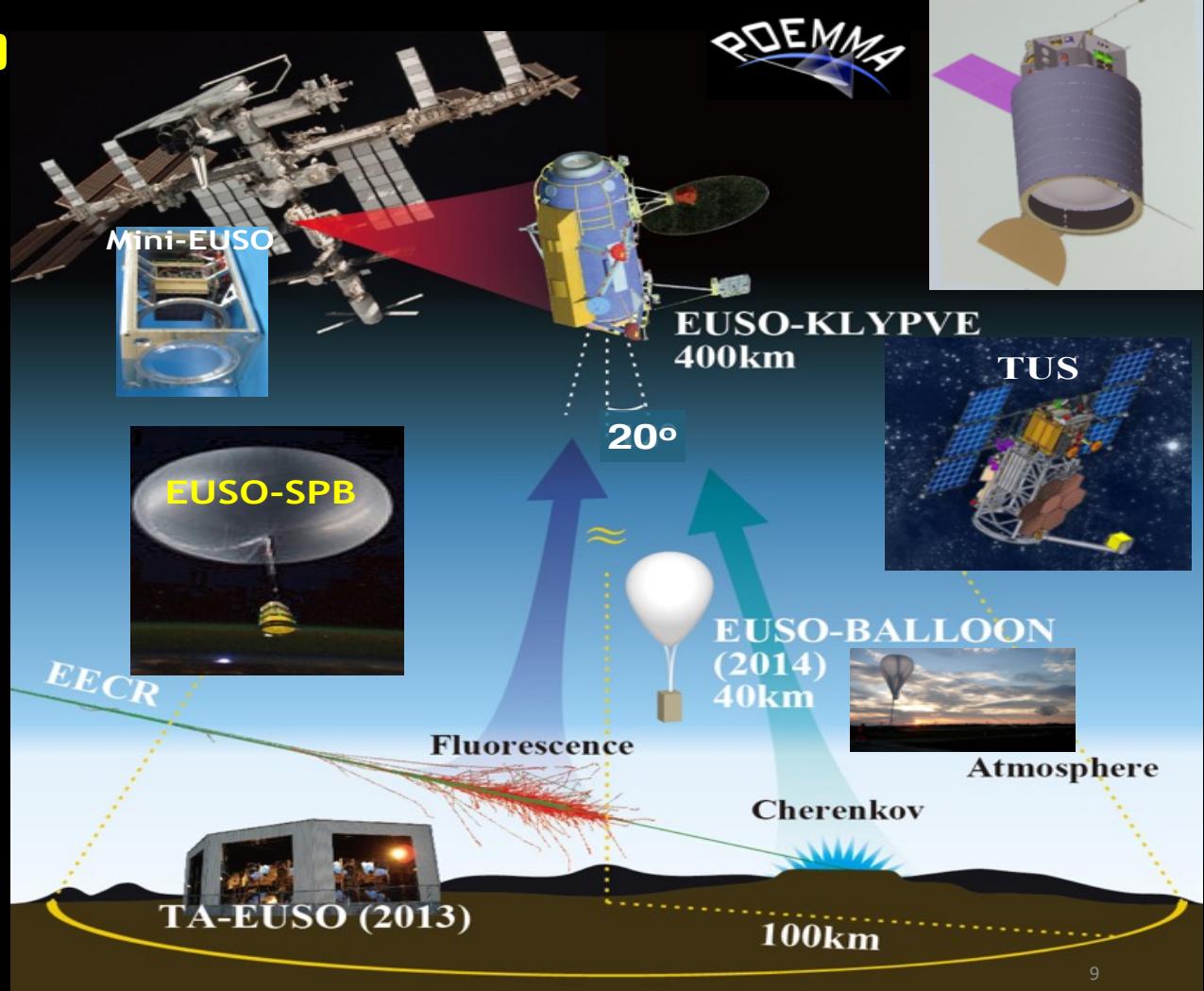
EUSO-SPB1 (2017)

Mini-EUSO (2019)

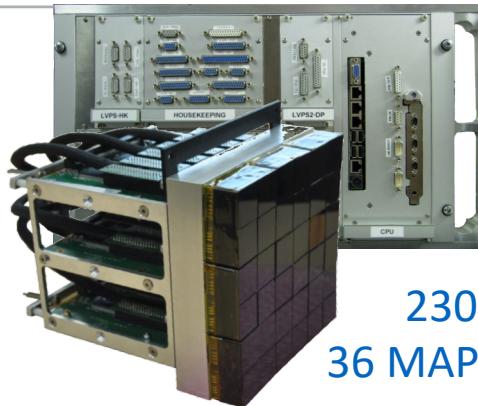
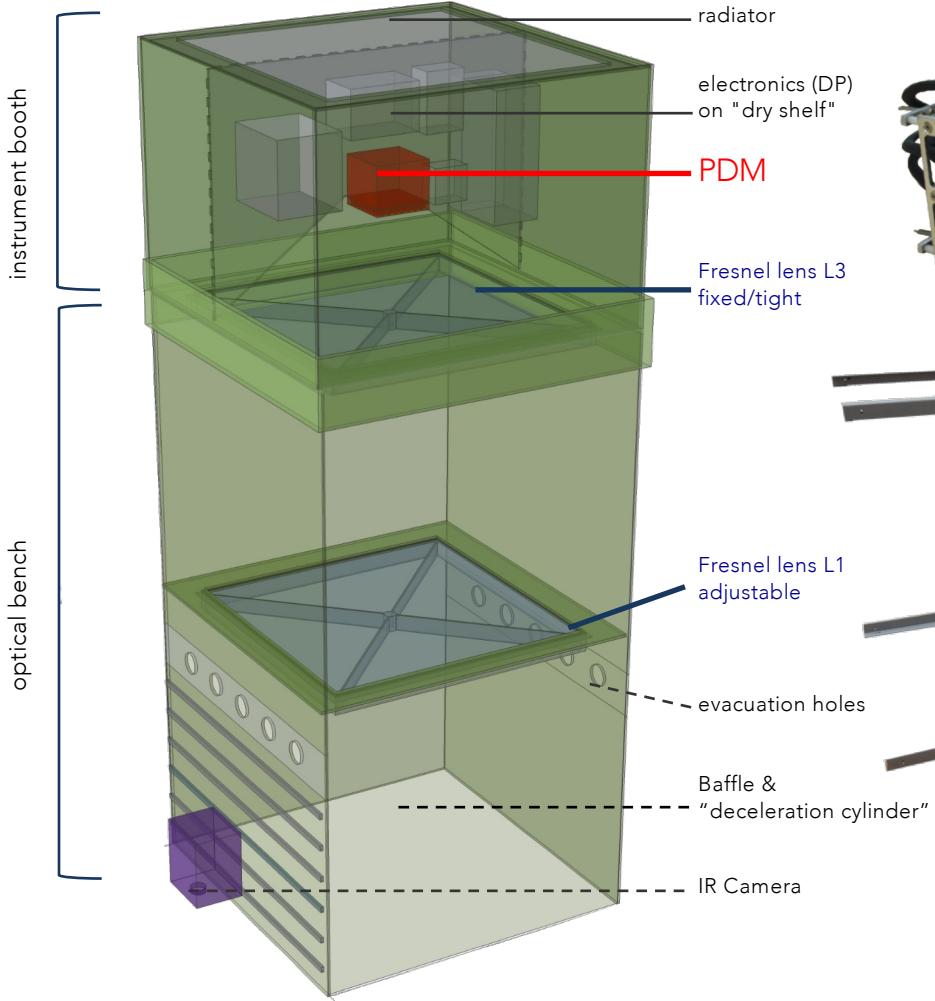
EUSO-SPB2 (2022)

K-EUSO (2023+)

POEMMA (2029+)



# EUSO-TA & Balloons detector



2304 channels =  
36 MAPMT x 64 ch/PMT

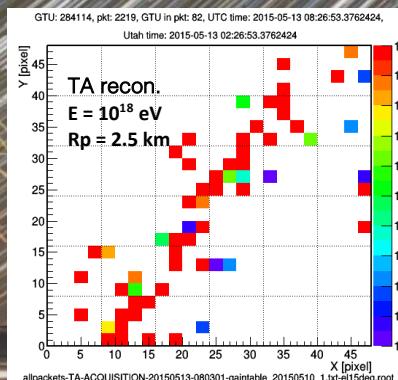
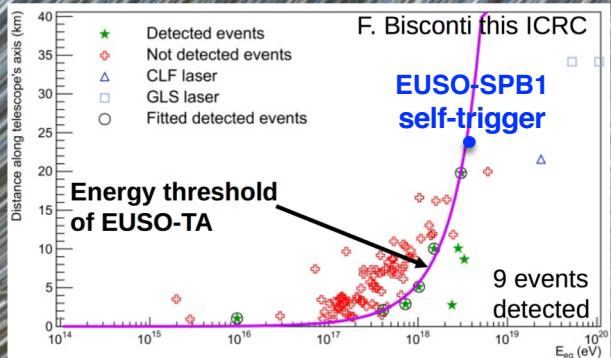


# EUSO-TA

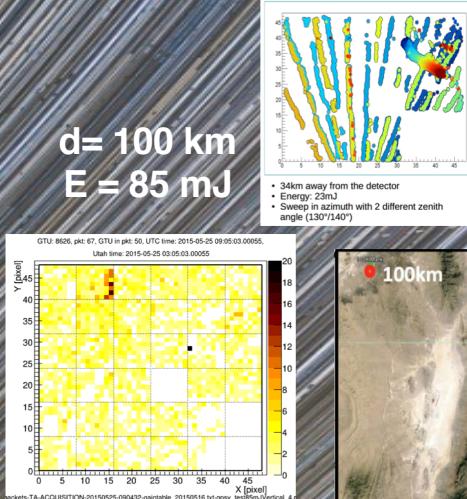
Instrument on its own + test platform for other pathfinders  
Currently under upgrade with Zynq board and self trigger

GLS laser campaigns

## UHECRs



$d = 100$  km  
 $E = 85$  mJ

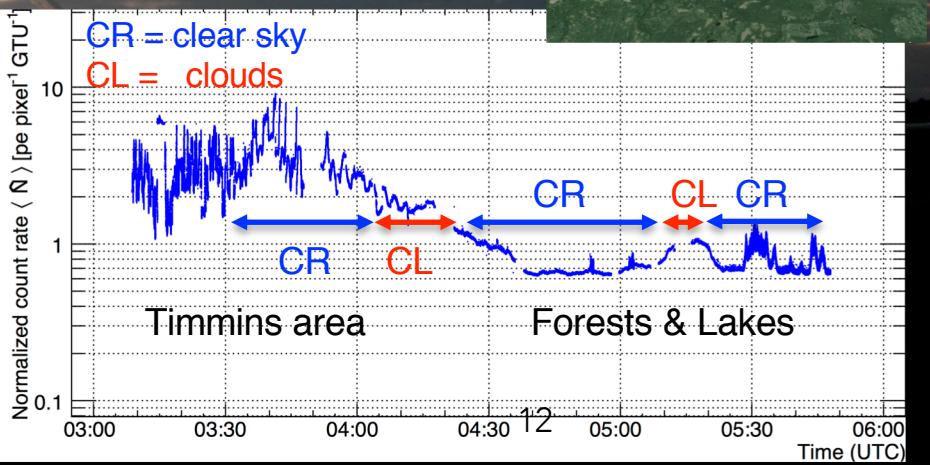
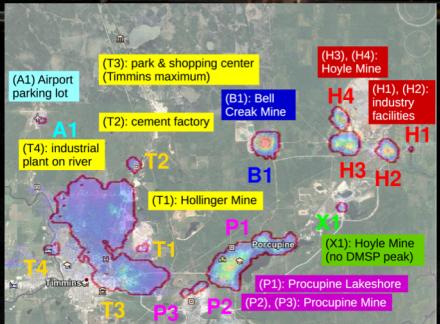
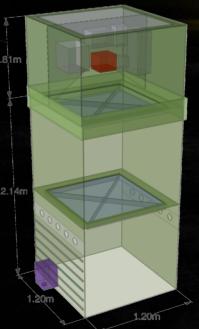
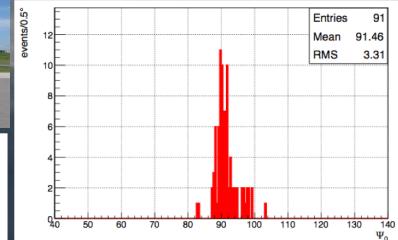
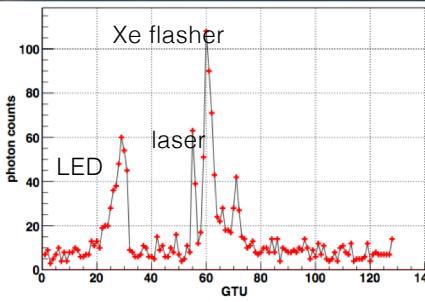
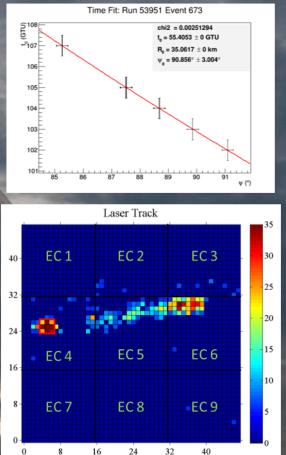


(C) Oscar Larsson

# EUSO Balloon

August 2014 Timmins, Canada

1 night flight @ 38 km a.s.l.  
data: 256,000 events

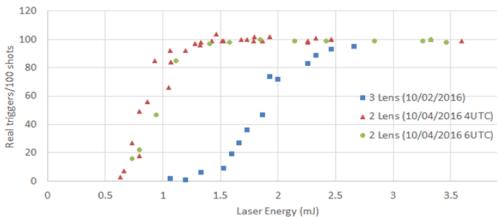
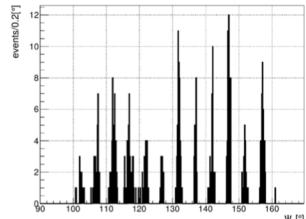


# EUSO-SPB1

(2017)

Angular resolution  
better than 1°

Energy-equivalent threshold measurement

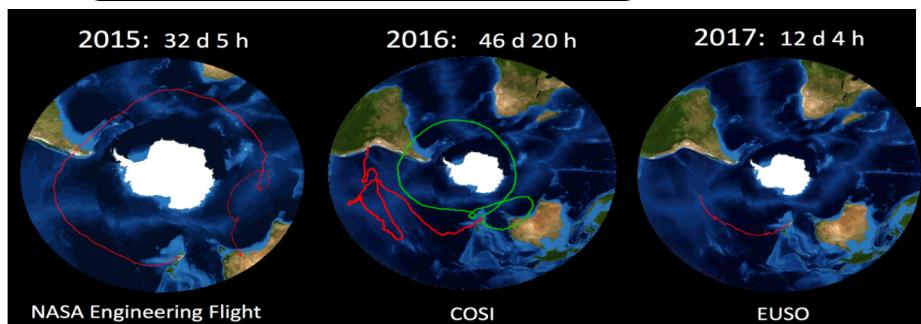


Nominally working instrument

(unfortunately... leaking balloon!)

### Main improvements:

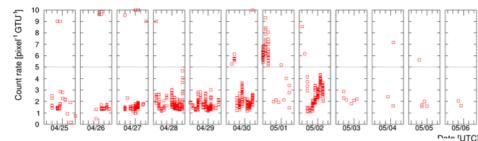
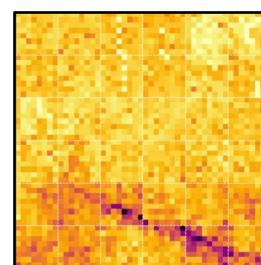
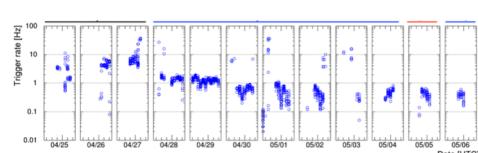
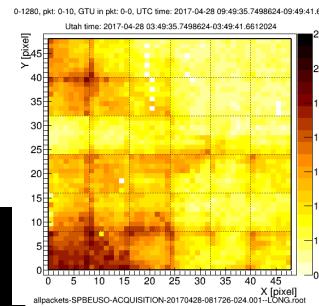
- Upgraded electronics: SPACIROC 3
- Complete autonomous scheme with trigger
- Solar panels for long duration flight
- Optics performance + stability



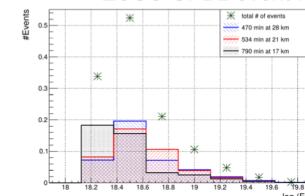
$6.3 \pm 0.9$

$10.6 \pm 2.3$

$\sim 1$



EUSO-SPB1 event rate

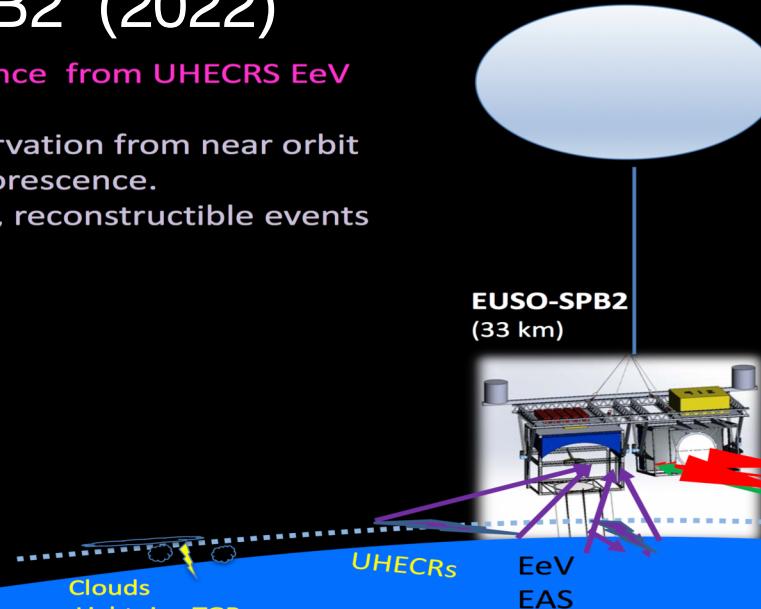


# EUSO-SPB2 (2022)

## Fluorescence from UHECRS EeV

First observation from near orbit with fluorescence.  
Obvious, reconstructible events

Stars



## Cherenkov Emission PeV

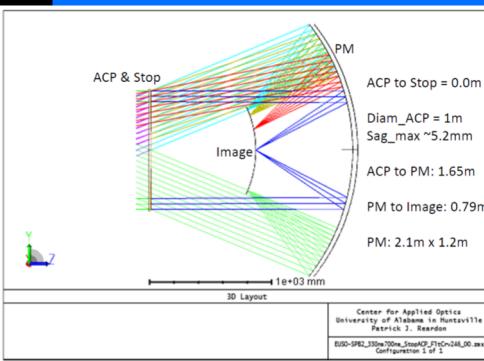
Above Limb  
First measurement of Cherenkov from near orbit altitude  
Demonstrate the CT is working at float

Below Limb  
Tau Neutrino Background to see what it is surprises?

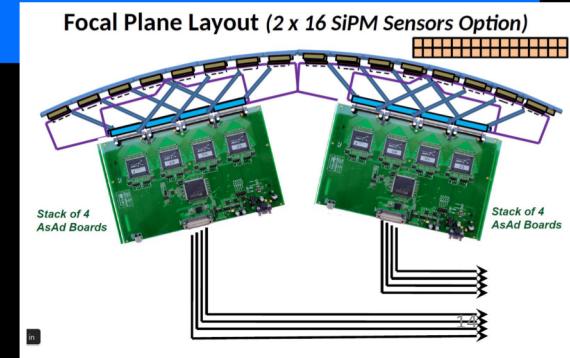
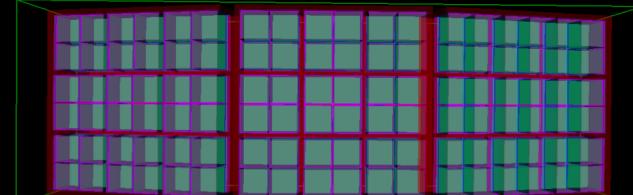
Stars

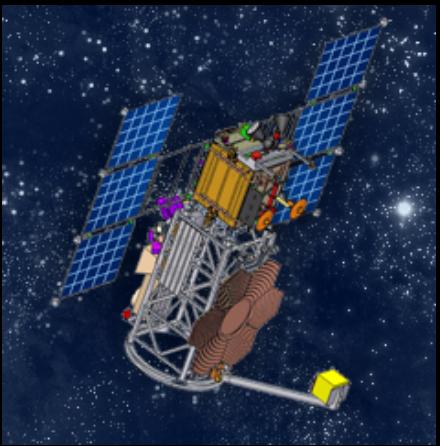


Limb is 5.8 deg below horizontal



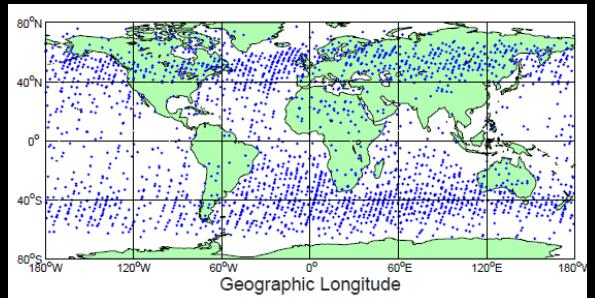
## Fluorescence FS



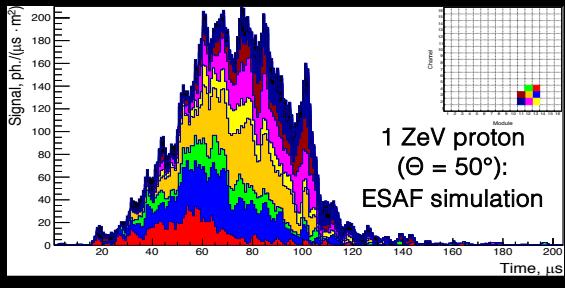
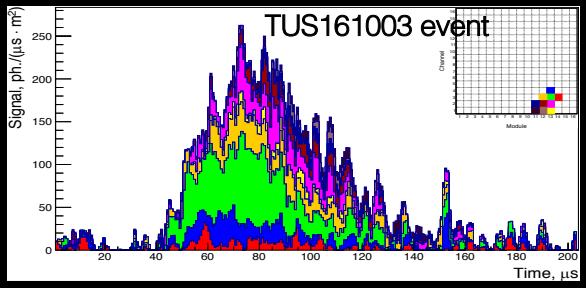
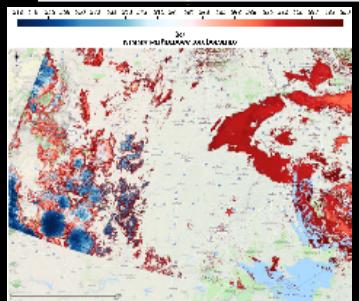
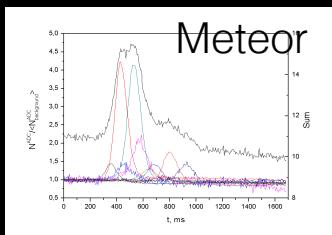
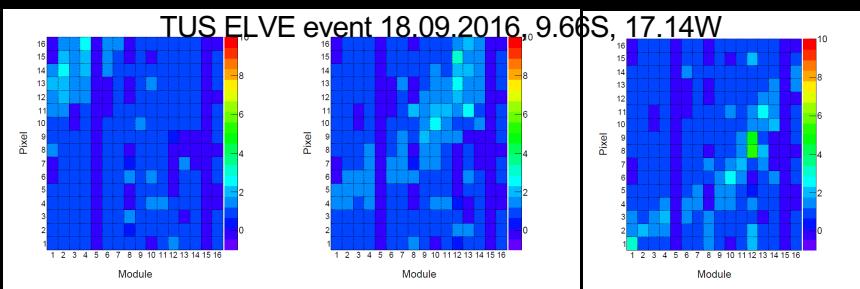


# TUS (2016-2017)

## Tracking Ultraviolet Setup

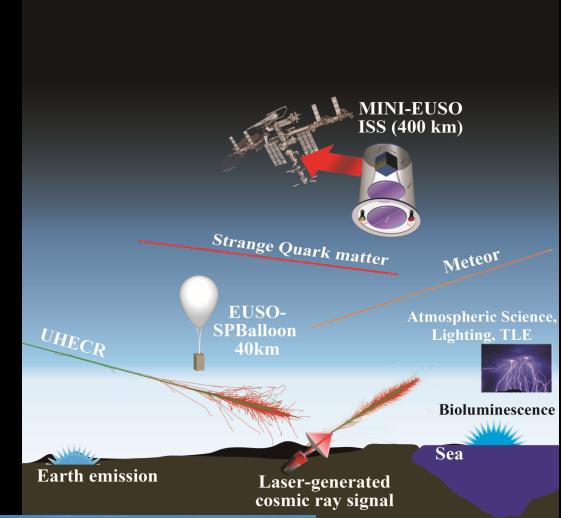
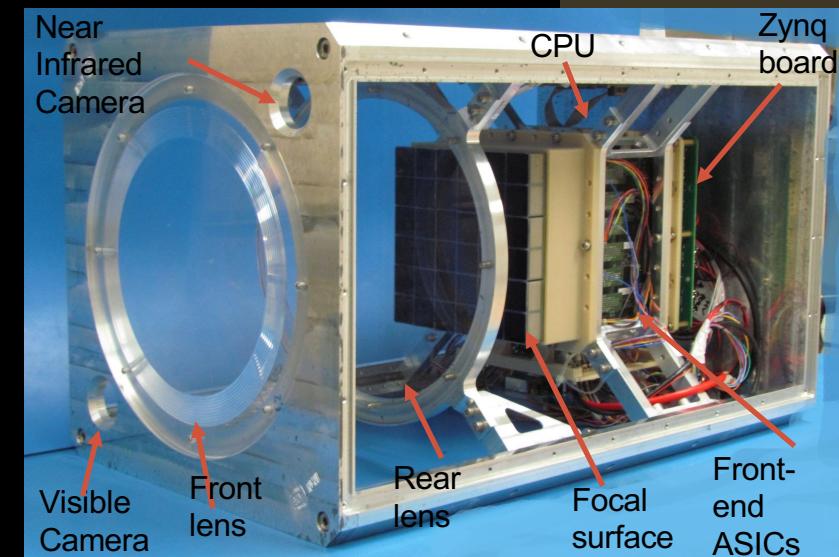
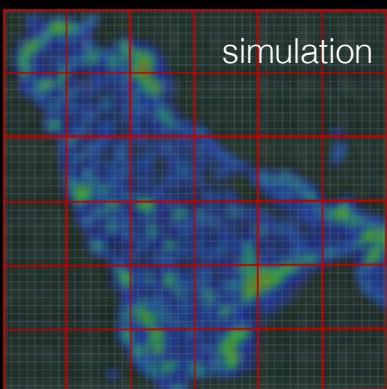
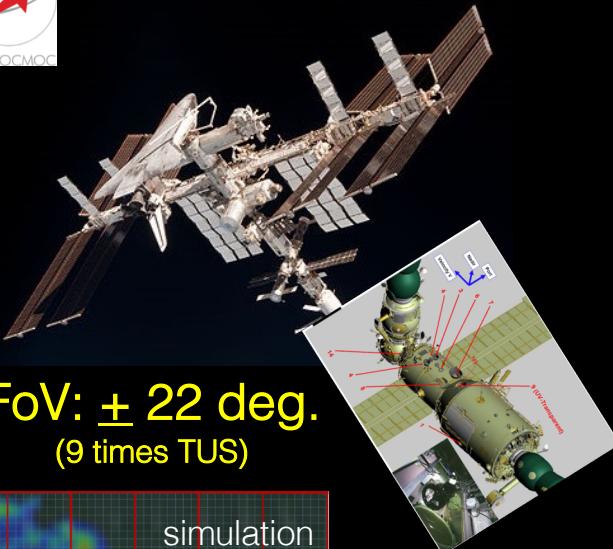


Mass	60 kg
Power	65 W
FOV	$\pm 4.5$ degree
Channels	16 modules of 16 PMTs
Pixel size	10 mrad ( $5 \times 5$ km)
Mirror area	$\sim 2$ m $^2$
Duty cycle	30%

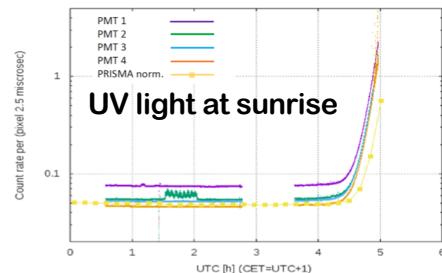
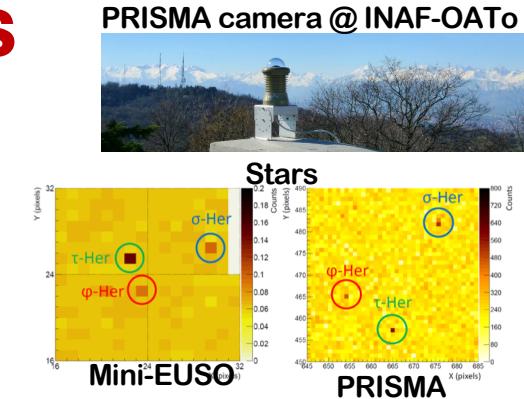
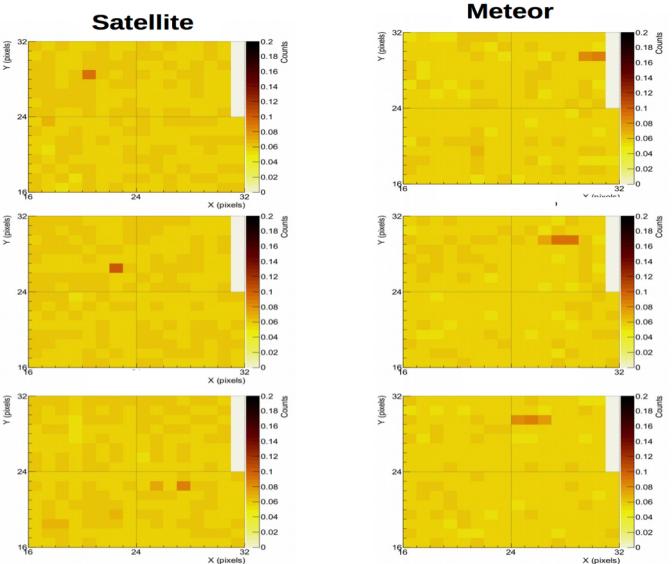
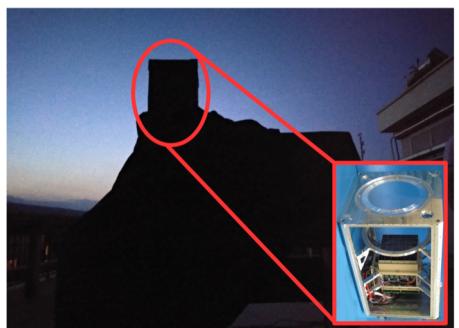
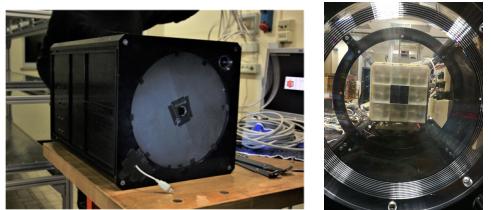


# Mini-EUSO

(scheduled to fly to ISS on August 22<sup>nd</sup> 2019)

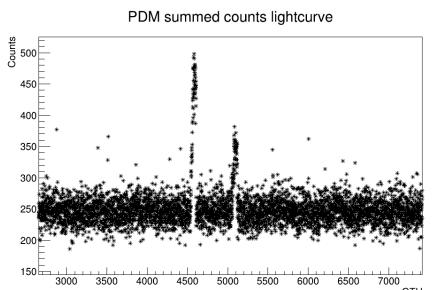


# Mini-EUSO E.M. ground tests

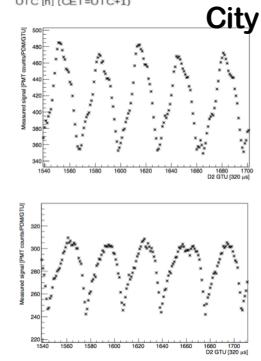
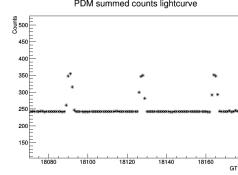
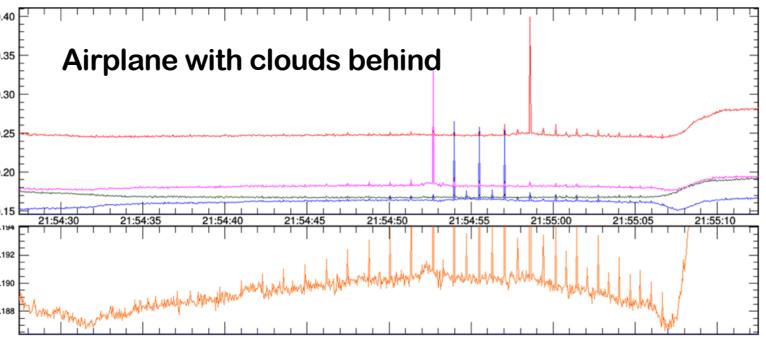


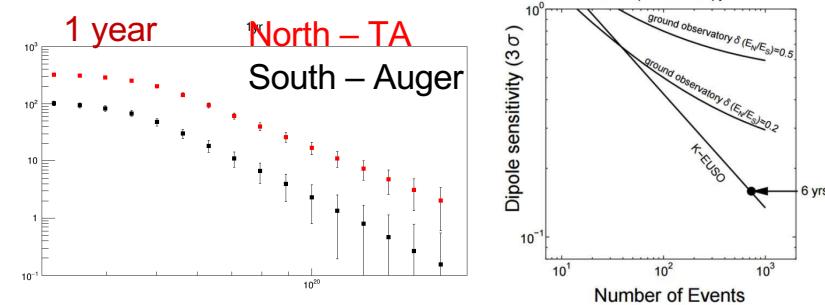
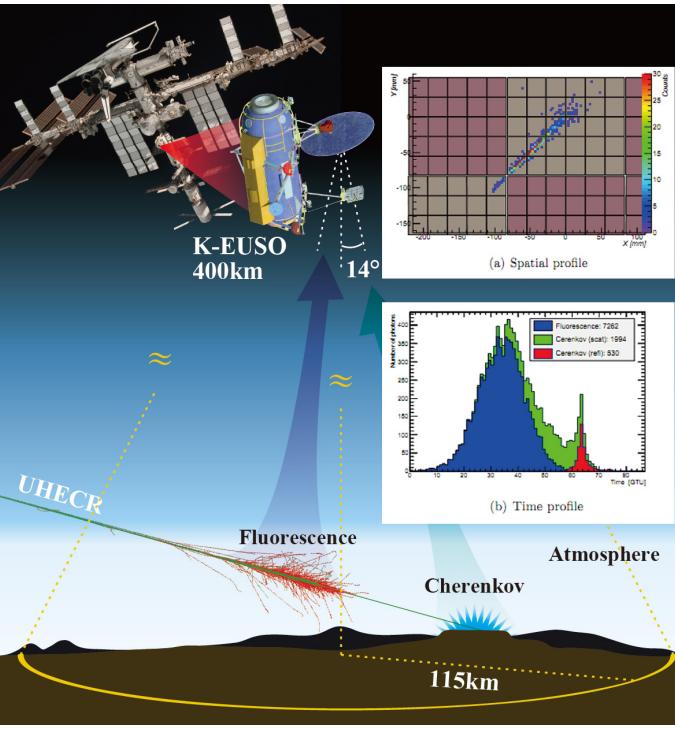
City lights

Airplane: D1: 1 GTU = 2.5  $\mu$ s



Airplane with clouds behind





# K-EUSO

The design of the detector should provide measurements of UHECR with a threshold near 50 EeV with statistics of ~100 events per year.

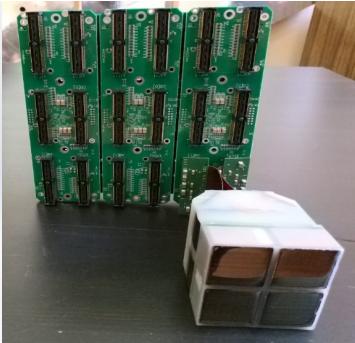
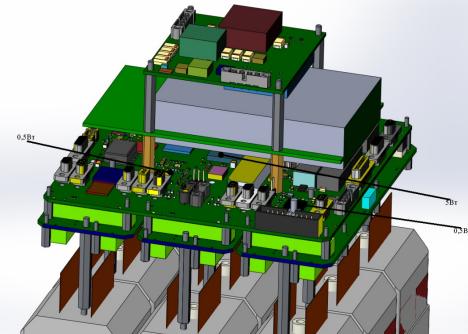
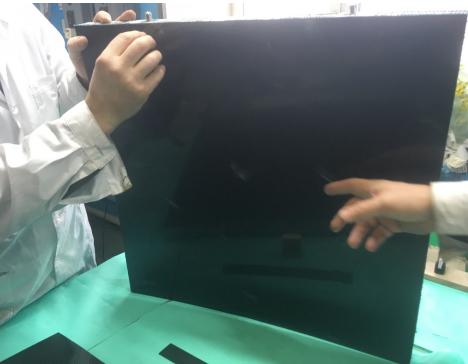
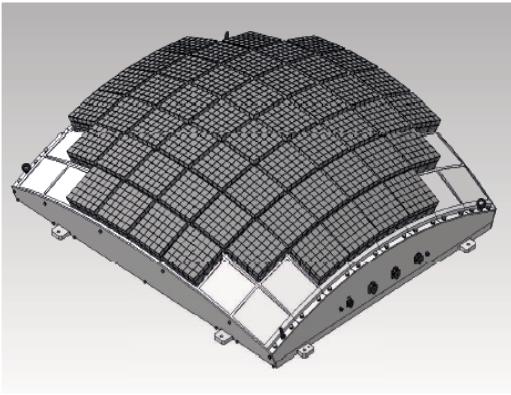


- Scientific objectives:  
UHECR fluorescent radiation measurements from space
- Placement:  
Russian Segment of the ISS
- Main technical parameters  
K-EUSO – Telescope with an optical Schmidt scheme (a large area of the entrance window and a wide field of view)
- ✓ Mirror diameter – 3.6-4 m
- ✓ Time resolution 1-2.5 us
- ✓ FOV 40 degrees.
- ✓ Angular resolution  $\sim 10^{-6}$  sr
- ✓ Mass  $\sim 500 - 850$  kg

# Prototype Phase with Energia

During 2017-19 the MSU has conducted a detailed study with Energia on prototyping the different parts of the instrument.

**The study has been successfully completed.**



Next steps:

- Integration and transportation studies
- Optimization of the mechanical structure to minimize events loss and adapt to EVA.
- Simulations of K-EUSO
- Phase B to finalize the detectors structure (changes are possible within current mass, power and dimensions)



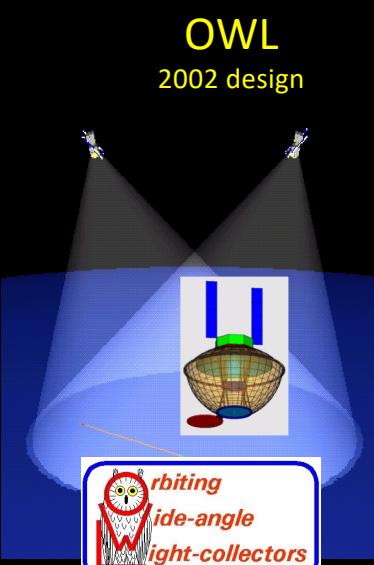
# POEMMA: Probe of Extreme Multi-Messenger Astrophysics



## See talk by A. Olinto

### POEMMA Design based on:

OWL and JEM-EUSO studies, EUSO balloon experience,  
& CHANT concept + Legacy in Fluorescence from Ground



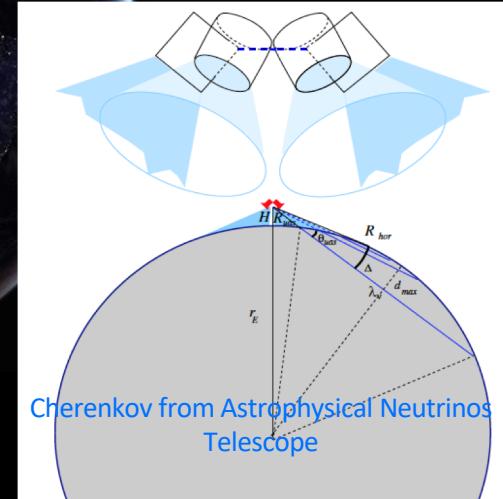
OWL  
2002 design



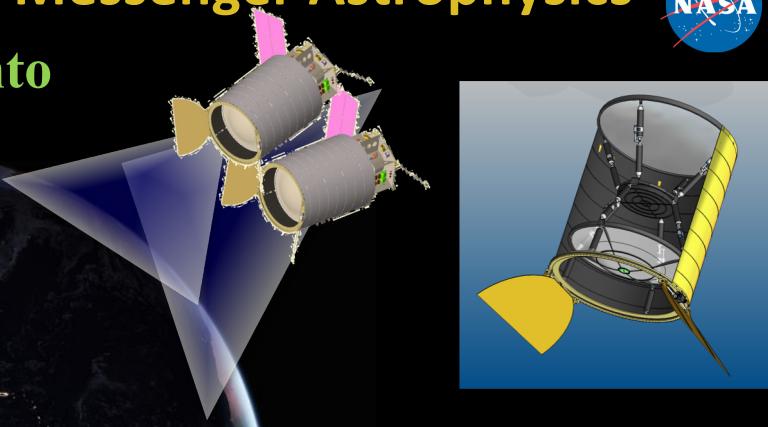
JEM-EUSO:  
Extreme Universe Space  
Observatory



EUSO-SPB1

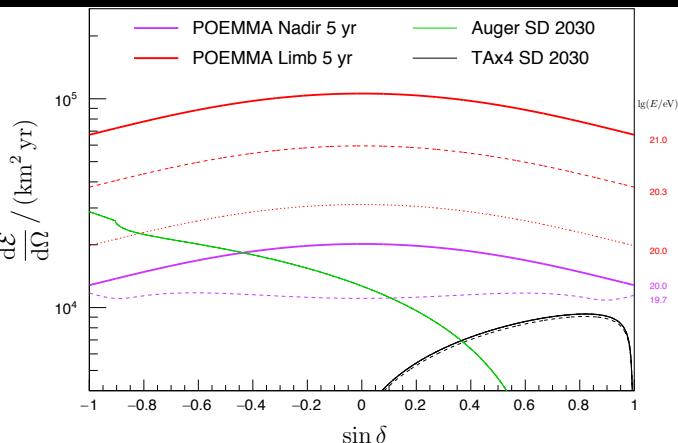
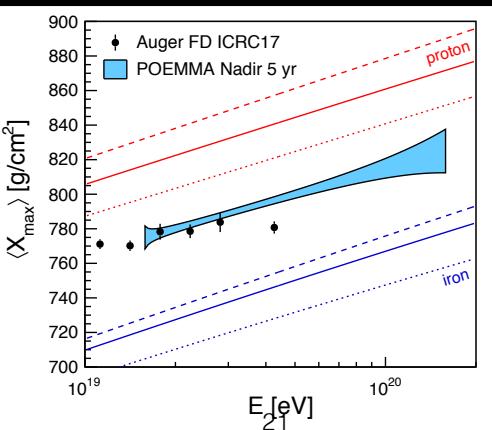
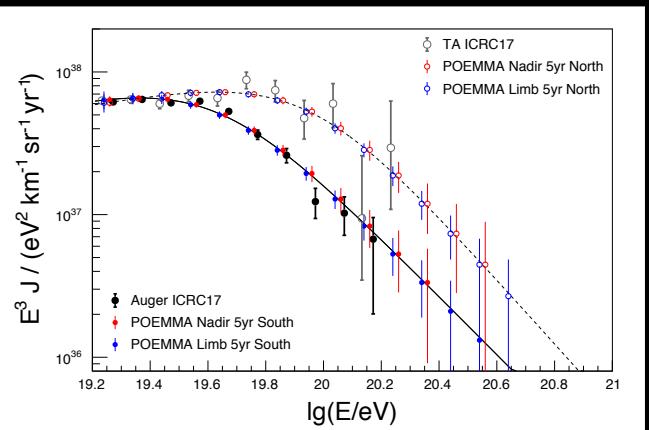
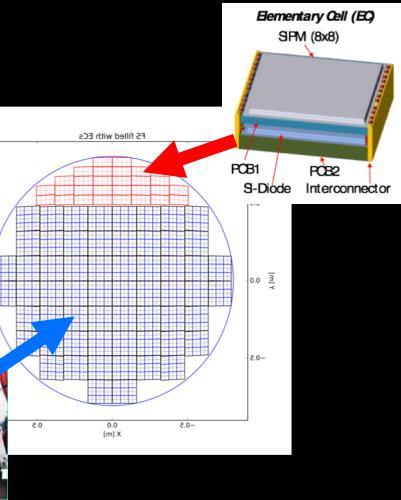


Cherenkov from Astrophysical Neutrinos  
Telescope



# POEMMA UHECRs & vs

significant increase in exposure  
 good energy, angular, and shower maximum resolutions,  
 Uniform sky coverage  
**to guarantee the discovery of UHECR sources**  
 Spectrum, Composition, Anisotropy E>50 EeV



# CONCLUSIONS

- The JEM-EUSO program **is an essential element of the roadmap** of the UHE Community
- Prototypes and Models of the major elements (Lenses, PDM, DP Unit) have been produced **and are being tested** to increase the Technical Readiness Levels.
- The first pathfinders (EUSO-TA and EUSO-Balloon) are providing exciting technical and science-oriented data: **the transition from paper work to prototyping and measurements has been done**.
- The small scale missions (EUSO-SPB%, Mini-EUSO and TUS) are expected to provide new scientific results.
- Large mission concepts are actively studied: **K-EUSO** is expected to provide first key results from space on the interpretation of UHECR science, and then **POEMMA** is expected to unveil the highest energy sky ever explored.

**THANK YOU**