Joint Experiment Missions-
Extreme Universe Space Observatory

An overview of the JEM-EUSO program and results

ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International Cosmic Ray Conference
12–23 July 2021

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

ICRC 2021

N.25 JEM-EUSO Program Related Contributions @ ICRC2021

JEM-EUSO:

1 - M.Bertaina: An overview of the JEM-EUSO program and results – 389 - 15/7 @ 18:00

EUSO-TA:

2 – Z. Plebaniak: Study of the calibration method using the stars measured by the EUSO-TA telescope – 841 – 16/7 @ 18:00

EUSO-SPB2:

3 – J. Eser: Science and mission status of EUSO-SPB2 – 235 – 15/7 @ 18:00
4 - M. Bagheri: Overview of Cherenkov Telescope on board EUSO-SPB2 for the detection of ultra-high energy neutrinos – 1091 - 14/7 @ 18:00
5 – G. Osteria: The Fluorescence telescope on board EUSO-SPB2 for the detection of ultra-high energy cosmic rays – 403 – 15/7 @ 18:00
6 – G. Filippatos: Expected performance of the EUSO-SPB2 Fluorescence telescope – 330 - 16/7 @ 18:00
7 – T. Paul: Model independent search for macroscopic dark matter with EUSO-SPB2 – 490 - 16/7 @ 18:00
8 – R. Diesing: UCIRC2: EUSO-SPB2's infrared cloud monitor – 489 - 16/7 @ 18:00
9 – V. Kungel: EUSO-SPB2 telescope optics and testing – 867 – 21/07 @ 12:00

TUS:

10 – P. Klimov: Main results of the TUS experiment on board the Lomonosov satellite – 598 – 15/7 @ 18:00
11 – F. Fenu: Estimation of the exposure of the TUS space based cosmic ray observatory – 752 – 16/7 @ 18:00

Mini-EUSO:

12 – M. Casolino: Mini-EUSO on board the International Space Station: launch and first results – 886 - 15/7 @ 18:00
13 – L. Piotrowski: Towards observation of nuclearites in Mini-EUSO – 1181 – 13/07 @ 18:00
14 – K. Shinozaki: Measurement of UV light emission of nighttime Earth by Mini-EUSO for space-based UHECR observat. – 1165 - 16/7 @ 18:00
15 - F. Fenu: Simulation studies for the Mini-EUSO detector – 757 - 16/7 @ 18:00
16 – M.Bertaina: The EUSO@TurLab project in view of Mini-EUSO and EUSO-SPB2 missions – 614 - 16/7 @ 18:00
17 – A. Golzio: A study on UV emission from clouds with Mini-EUSO – 417 – 19/7 @ 18:00
18 – L. Marcelli: Observation of Transient Luminous Events with the Mini-EUSO telescope on board the ISS – 971 – 19/7 @ 18:00
19 – G. Cambie': Integration and qualification of the Mini-EUSO telescope on board the ISS – 1001 - 21/7 @ 12:00
20 – M. Battisti: Overview of the Mini-EUSO μs trigger logic performance – 411 – 21/7 @ 12:00

K-EUSO:

21 - F. Fenu: A performance study of K-EUSO space based observatory – 754 - 16/7 @ 18:00

POEMMA:

22 – A. Olinto: The roadmap to the POEMMA mission:– 863 - 13/7 @ 12:00
23 – T. Venters: Astrophysical implications of ν ToO observations with space-based and suborbital Cher. detectors – 1337 – 16/7 @ 18:00
24 – C. Guepin: Probing the properties of SHDM annihilating or decaying into ν with UHE ν experiments – 1033 – 16/7 @ 18:00
25 – J. Krizmanic: nuSpaceSim: A comprehensive simulation for modeling of optical and radio signals from EAS induced by ν – 14/7 @ 18:00

JEM-EUSO International collaboration

- 17 countries, 350+ researchers

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

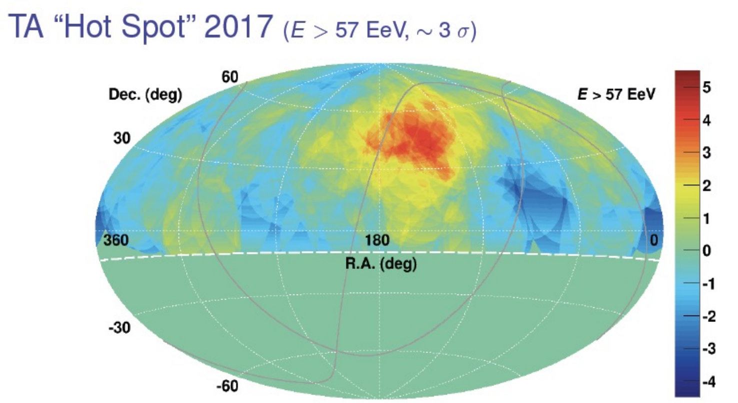
The origin of UHECRs still requires an answer….
A significant increase in exposure is needed

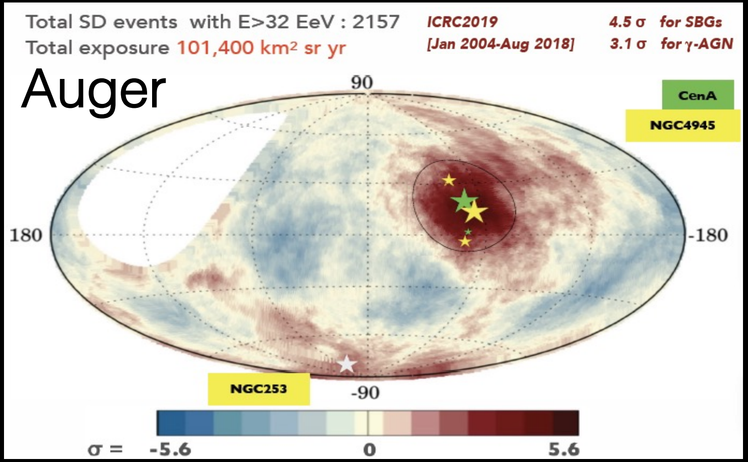
Space offers the following opportunites:

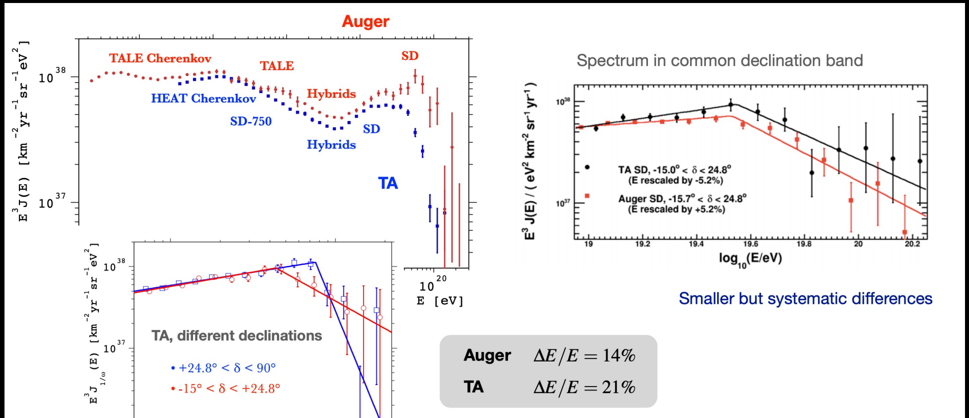
a) Complementarity to ground-based observation

b) Potential 10x annual exposure vs ground-based observatory

c) Full sky coverage



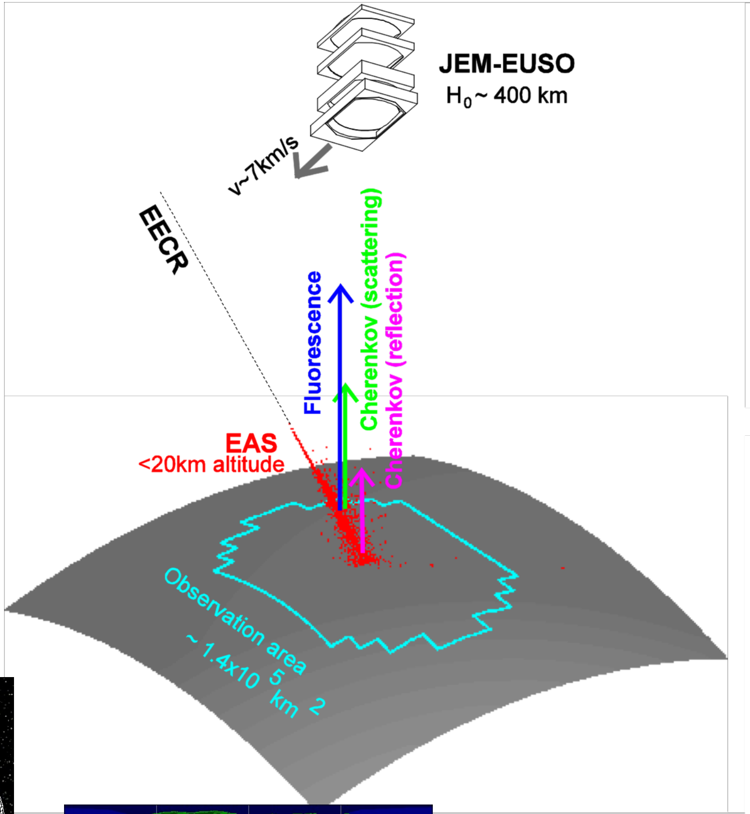


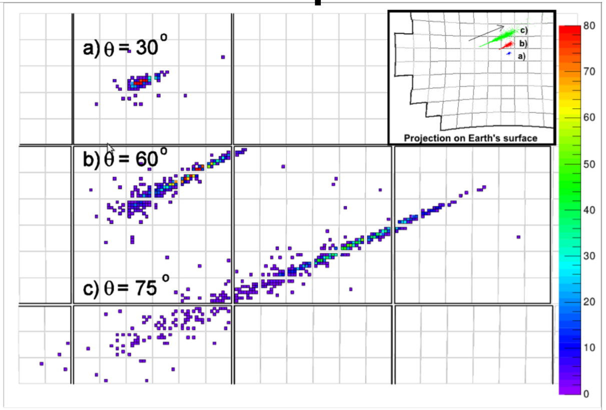


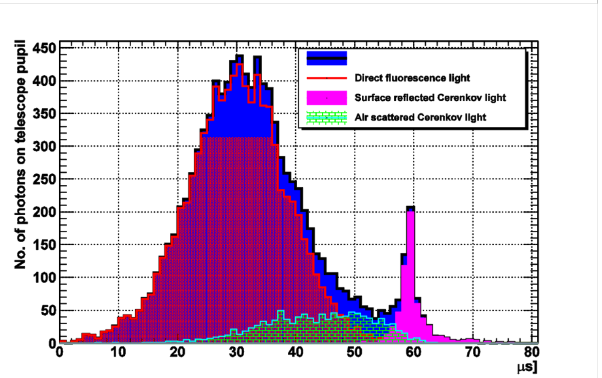
(Auger-TA Spectrum Working Group ICRC 2019 & TA, arXiv:1801.07820)

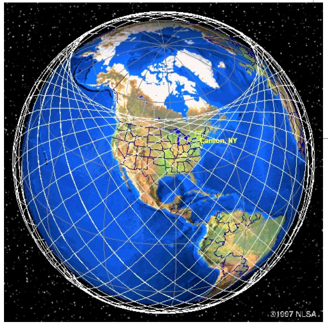
JEM-EUSO Observation Principle

JEM-EUSO Coll.
Astrop. Phys.
44 (2013) 76









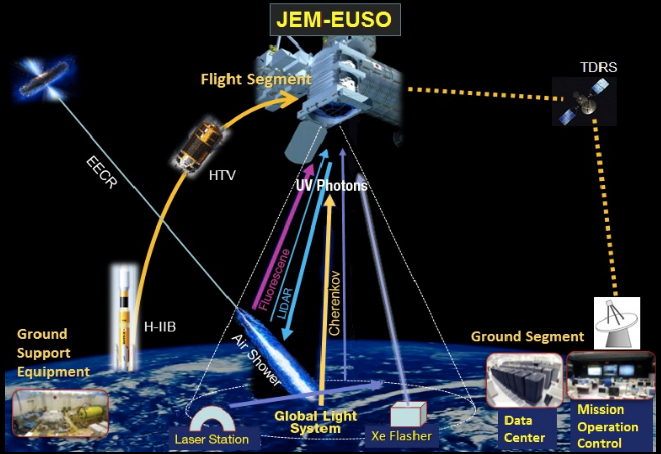
Δt ~ 50 - 150 μs

Δt ~ 20 - 60 GTUs

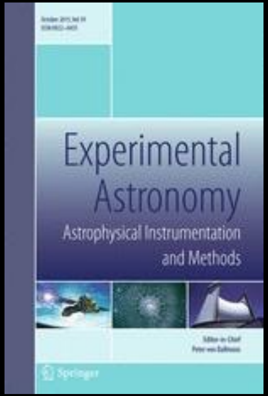
(1 GTU = 2.5 μs)

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

2006 - 2013

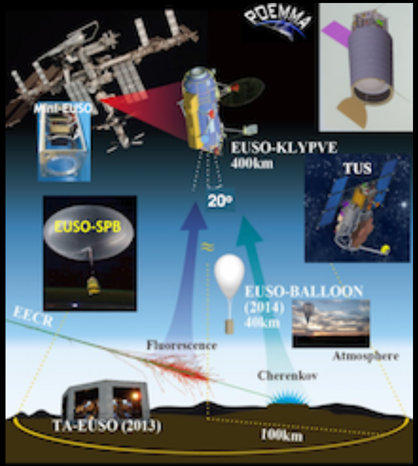


2013 - 2015



Vol. 40 (2015)

2013 – 2030+



ACCOMPLISHED MISSIONS (2013 – 2021)

Ground

EUSO-TA (2013-)

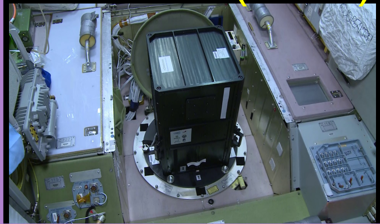
Stratospheric Balloons

EUSO-Balloon (2014)

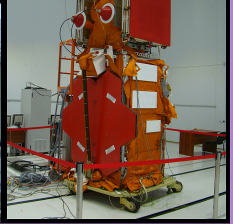
EUSO-SPB1 (2017)

Space

Mini-EUSO (2019-)



TUS (2016-17)



JEM-EUSO
PROGRAM

EUSO-TA (2013-)

EUSO-Balloon (2014)

TUS (2016-17)

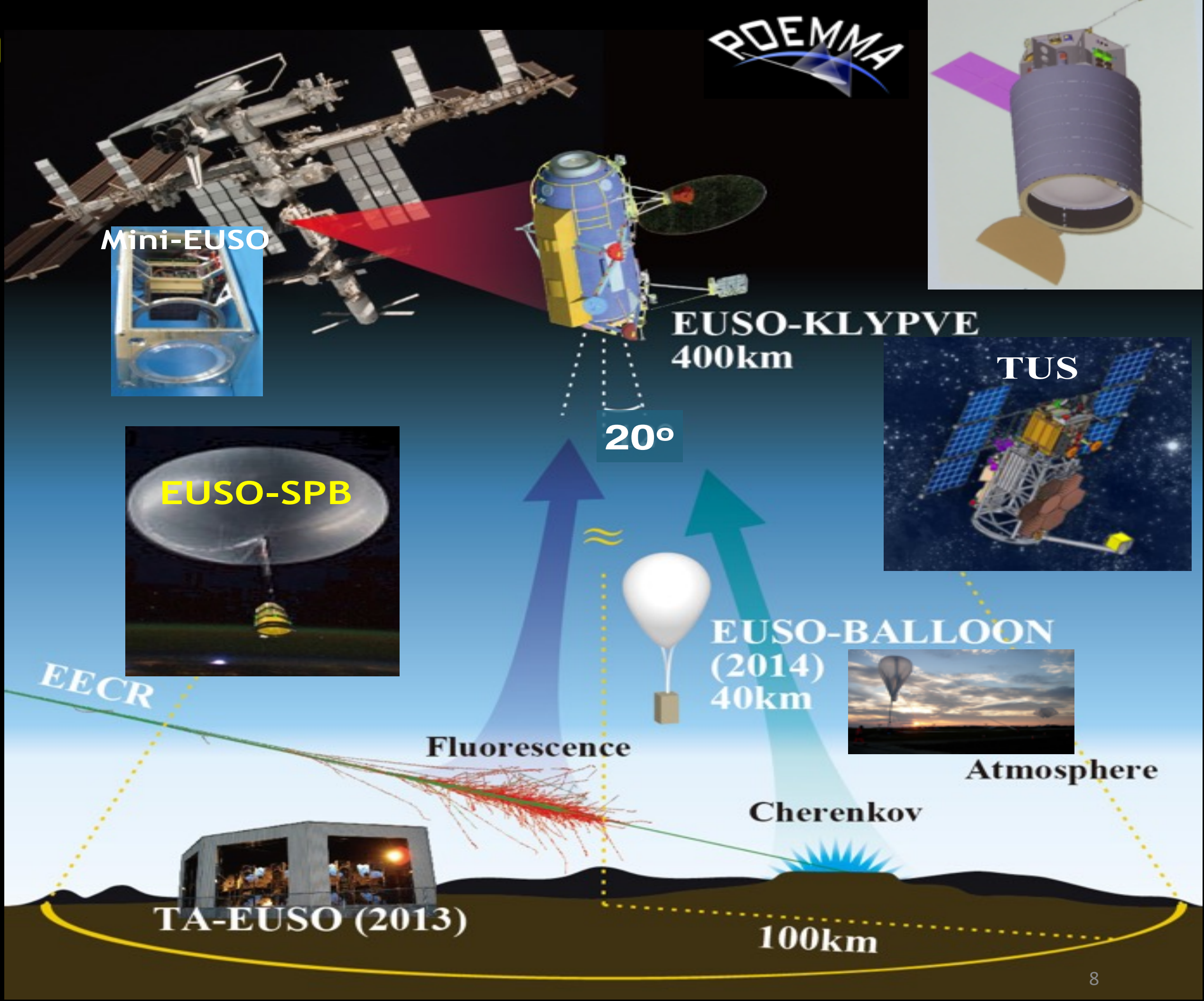
EUSO-SPB1 (2017)

Mini-EUSO (2019 -)

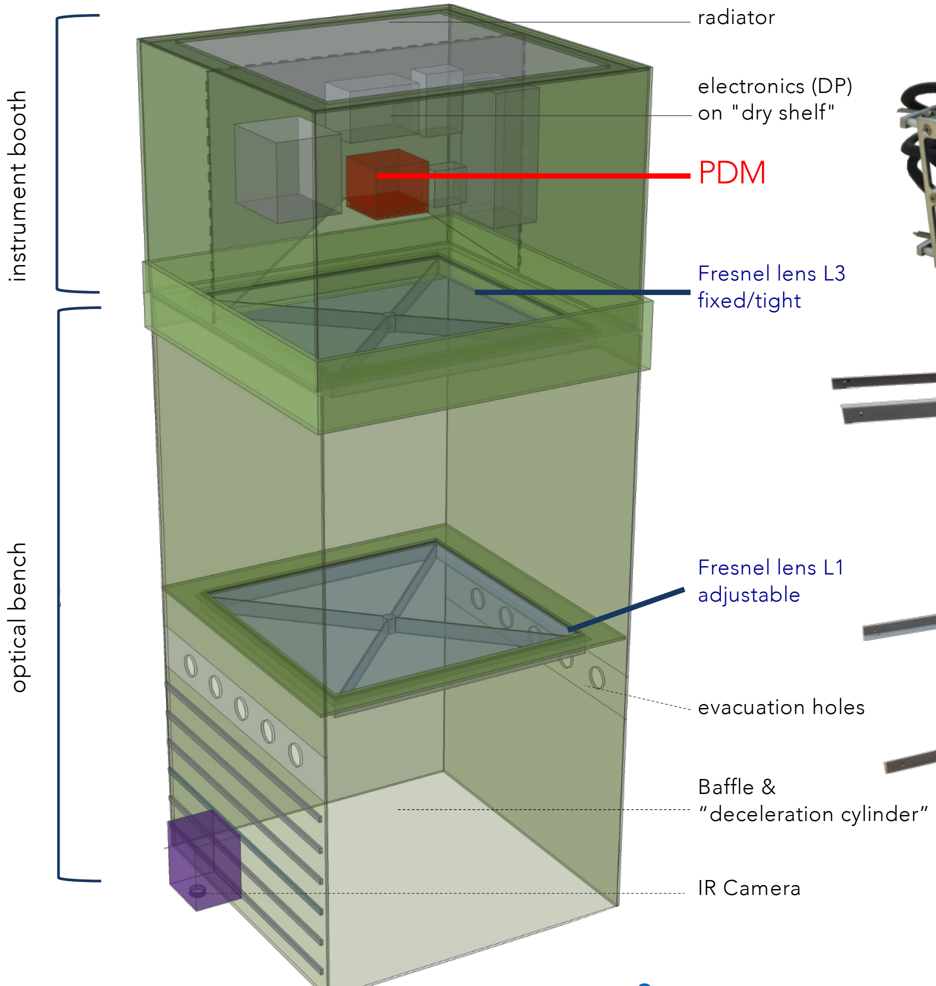
EUSO - SPB2 (2023)

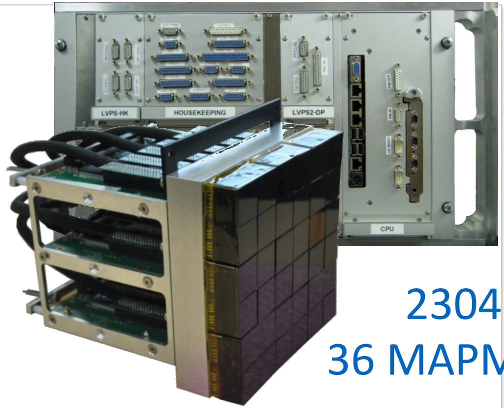
K-EUSO (2023+)

POEMMA (2029+)



EUSO-TA, Balloons & Mini-EUSO

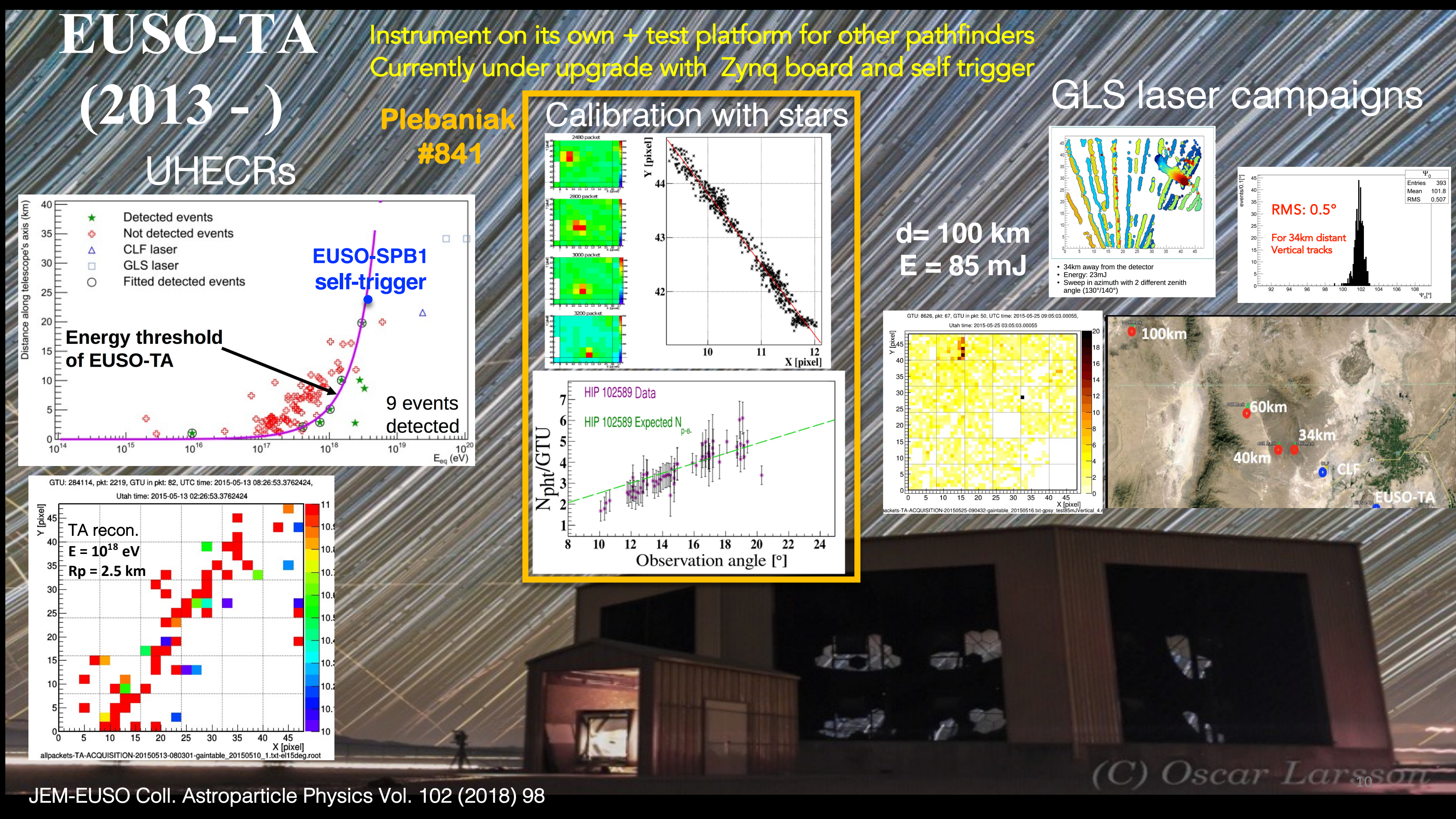




2304 channels =
36 MAPMT x 64 ch/PMT

2 fresnel lenses of 1x1 m^2 size

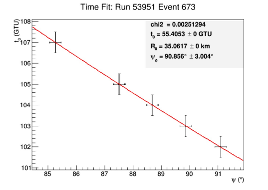
9

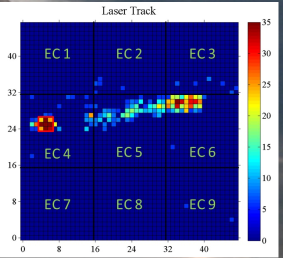

EUSO-TA
(2013 -)
UHECRs
Instrument on its own + test platform for other pathfinders
Currently under upgrade with Zynq board and self trigger
Plebaniak
#841
Calibration with stars
GLS laser campaigns
Detected events
Not detected events
CLF laser
GLS laser
Fitted detected events
EUSO-SPB1
self-trigger
Energy threshold
of EUSO-TA
9 events
detected
Distance along telescope's axis (km)
E_eq (eV)
Y [pixel]
X [pixel]
HIP 102589 Data
HIP 102589 Expected N p-e-
N pht/GTU
Observation angle [°]
d= 100 km
E = 85 mJ
34km away from the detector
Energy: 23mJ
Sweep in azimuth with 2 different zenith angle (130°/140°)
RMS: 0.5°
For 34km distant
Vertical tracks
Entries 393
Mean 101.8
RMS 0.507
GTU: 284114, pkt: 2219, GTU in pkt: 82, UTC time: 2015-05-13 08:26:53.3762424,
Utah time: 2015-05-13 02:26:53.3762424
TA recon.
E = 10^18 eV
Rp = 2.5 km
allpackets-TA-ACQUISITION-20150513-080301-gaintable_20150510_1.txt-el15deg.root
GTU: 8626, pkt: 67, GTU in pkt: 50, UTC time: 2015-05-25 09:05:03.00055,
Utah time: 2015-05-25 03:05:03.00055
100km
60km
34km
40km
CLF
EUSO-TA
(C) Oscar Larsson
10
JEM-EUSO Coll. Astroparticle Physics Vol. 102 (2018) 98

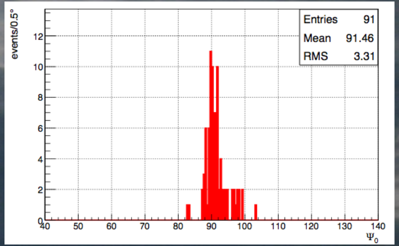
EUSO Balloon (2014)

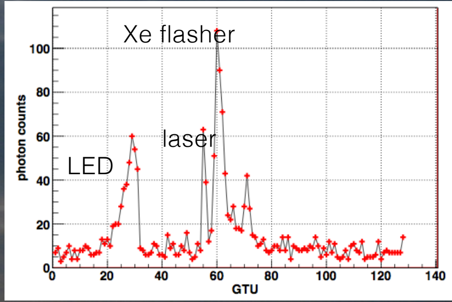
August 2014 Timmins, Canada

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

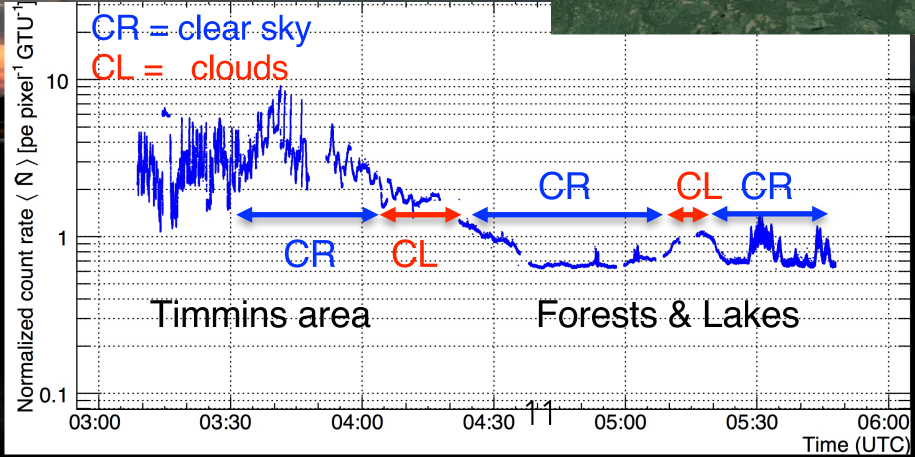


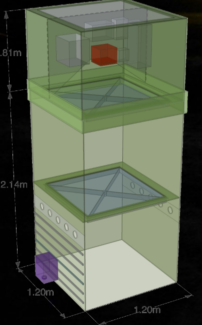


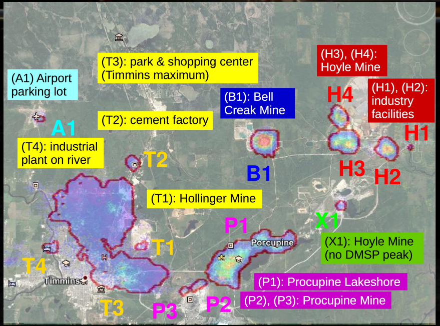




JEM-EUSO Coll.: Astroparticle Physics Vol. 111 (2019) 54
J. of Instrumentation Vol. 13 (2018) 05023

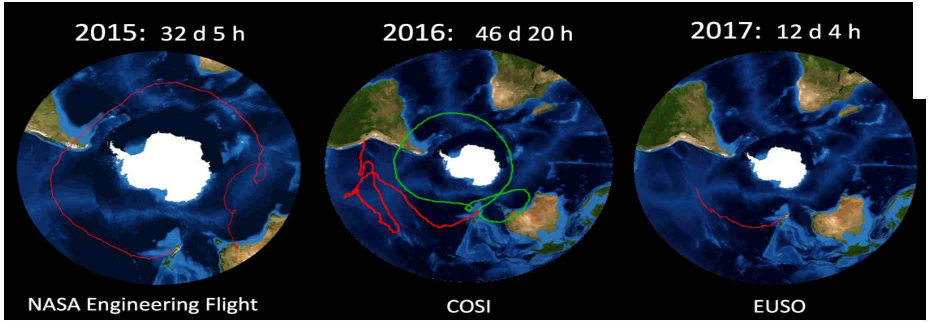






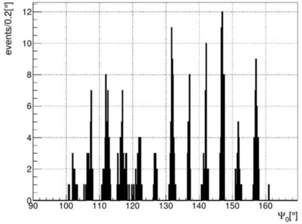
EUSO-SPB1 (2017)

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

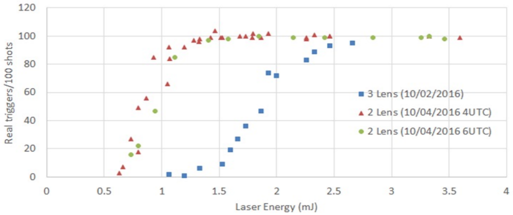


6.3±0.9 10.6±2.3 <1

Angular resolution better than 1°

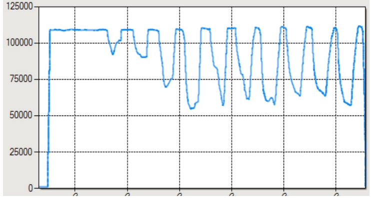


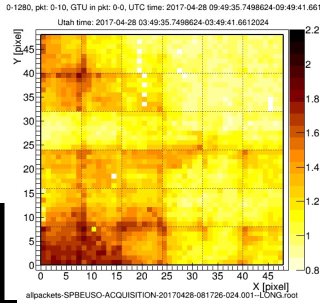
Energy-equivalent threshold measurement

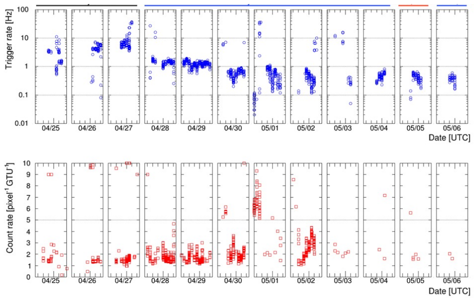


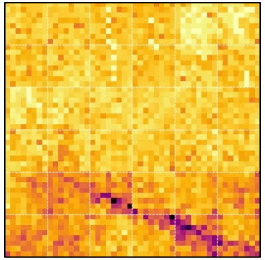
Nominally working instrument

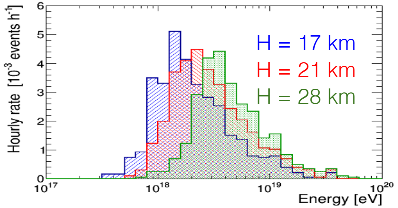
(unfortunately… leaking balloon!)











Fluorescence: UHECRs EeV

First observation of UHECRs from near-orbit altitude with the fluorescence technique

Search for Upward Event Candidates

EUSO-SPB2
Wanaka NZ
2023

Cherenkov: PeV

Above Limb:

First Observation of Cosmic Rays from near-orbit altitude with the Direct Cherenkov Technique

Below Limb:

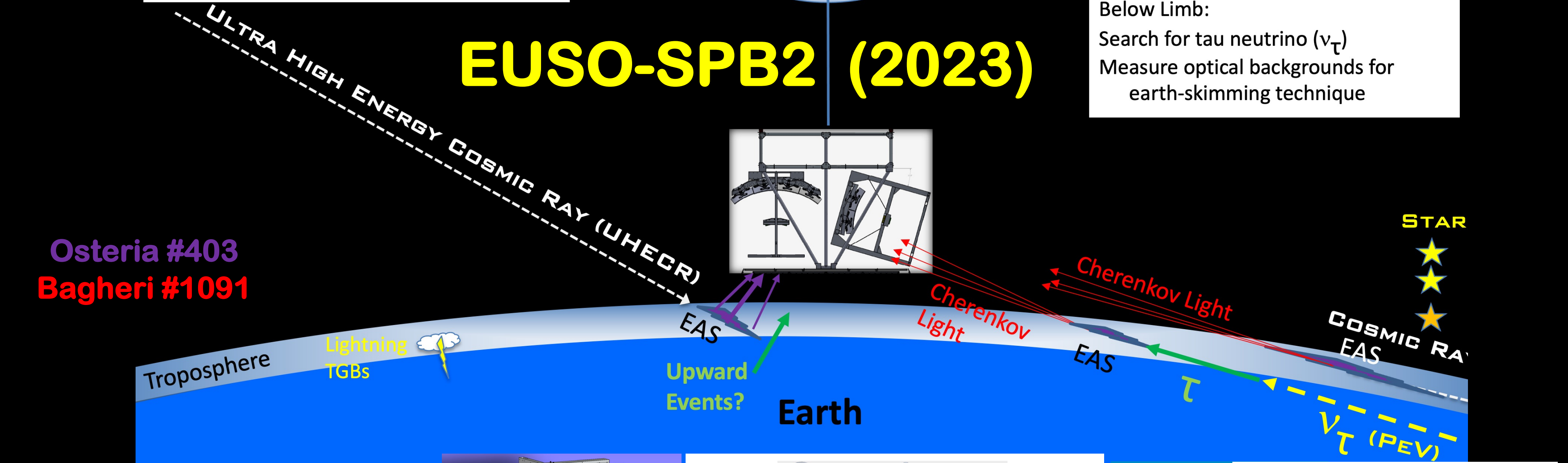
Search for tau neutrino (ν_τ)

Measure optical backgrounds for earth-skimming technique

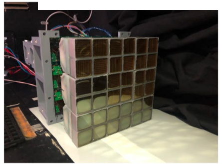
EUSO-SPB2 (2023)

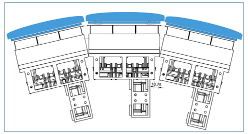
Osteria #403

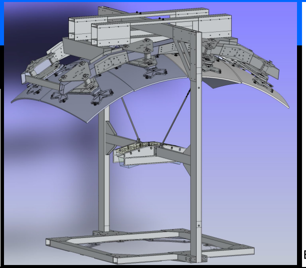
Bagheri #1091

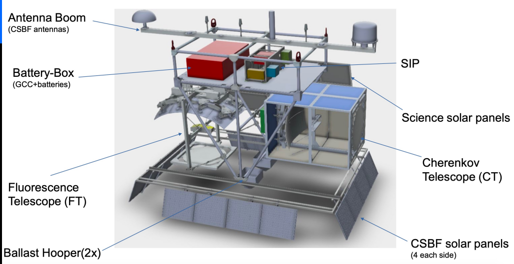


Fluorescence Tel.

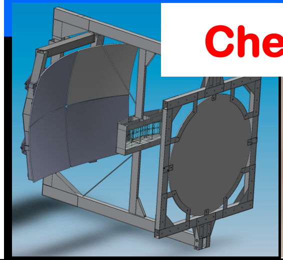








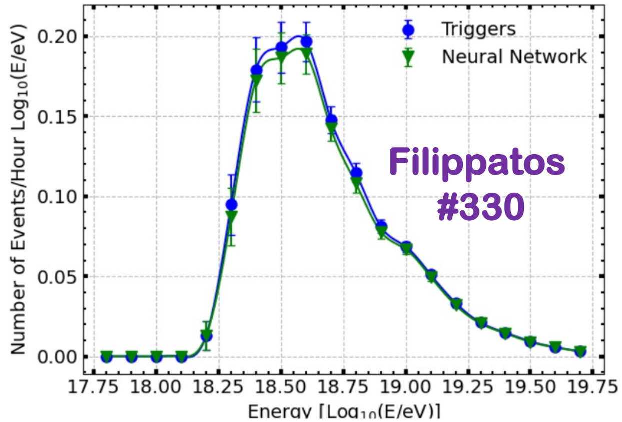
Cherenkov Tel.



EUSO-SPB2 Design & Expected Performance

Telescopes	2	1 Fluorescence (FT)	1 Cherenkov (CT)
Energy Threshold		~5 EeV	~50 PeV
Sensor Type		MAPMT (Hamamatsu)	SiPM Hamamatsu (S14521-6050CN)
Wavelength Sensitivity		UV 300-420 nm (BG3 filter x QE)	no filter (~300-~900 nm)
Time Bin		1000 ns/bin	10 ns x 512 bins 12 bit
Pointing (zenith angle)		nadir	Limb +/- 10
FOV (instrumented)		3x(11x11) deg	6.4x12.8 deg
Number of Pixels		3x2304=6912 (3 48x48 PDMs)	16x32=512 (16 Vert x 32 Horz)
Pixel FOV (& size)		0.2x0.2 deg (2.8x2.8 mm)	0.4x0.4 deg (6.25 x 6.25mm)
Optics (modified Schmidt)	Spherical Mirror Glass, ROC 1659.8 mm	6 segments common focus + camera corrector/filter	4 segments bifocal separation 2 pixels horizontal
Entrance Pupil	1 m diameter	PPMA corrector plate	PPMA corrector plate

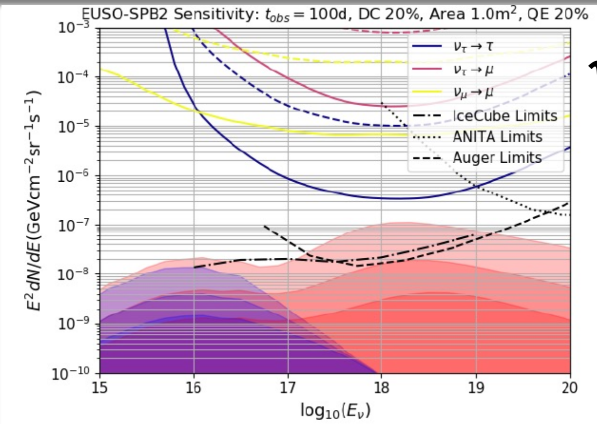
Fluorescence Telescope

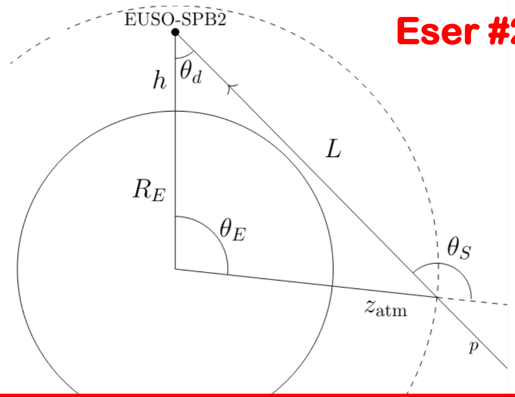


Filippatos #330

Cherenkov Telescope

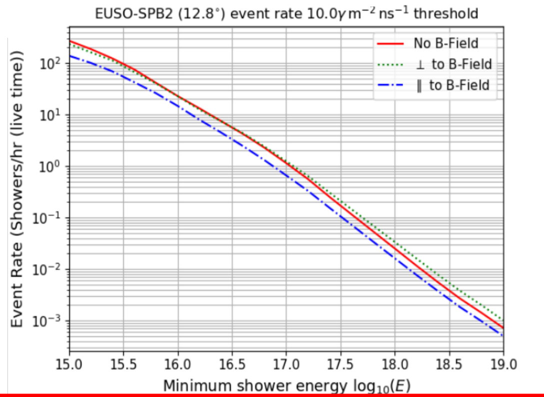
ν





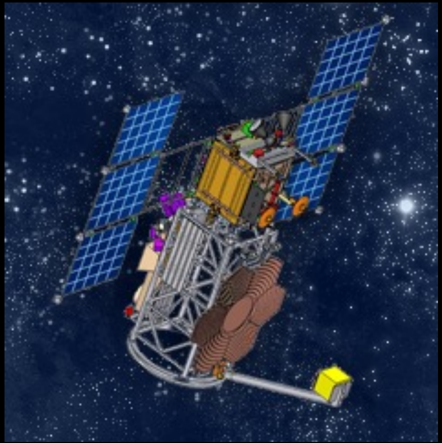
Eser #235

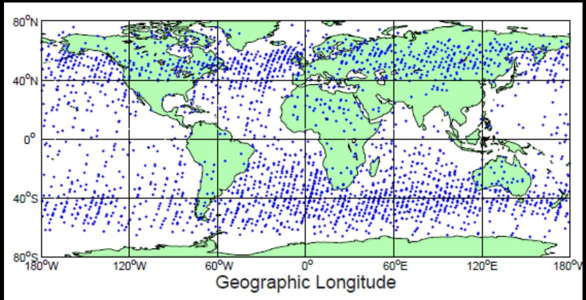
UHECR



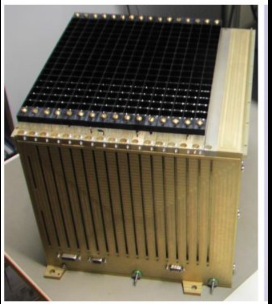
TUS (2016-2017)

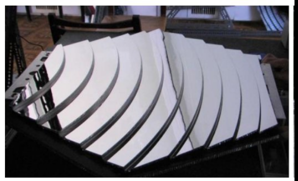
Tracking Ultraviolet Setup



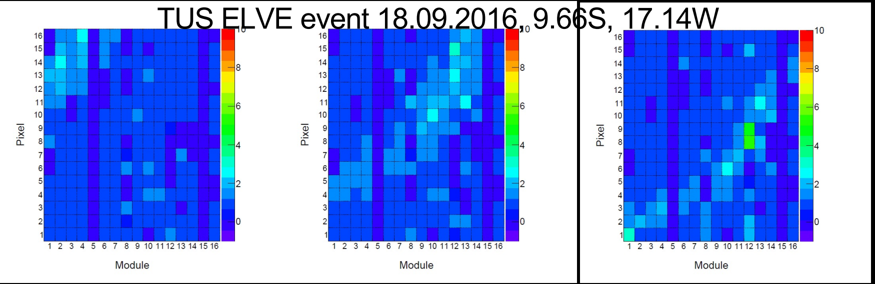


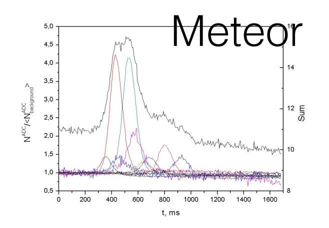
Klimov #598

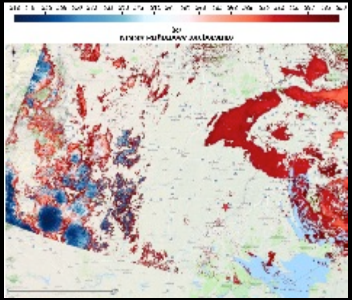


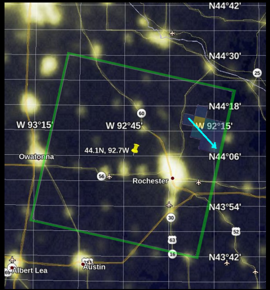


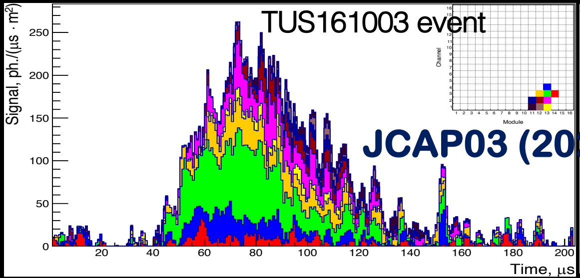
Mass	60 kg
Power	65 W
FOV	±4,5 degree
Channels	16 modules of 16 PMTs
Pixel size	10 mrad (5×5 km)
Mirror area	~2 m^2
Duty cycle	30%



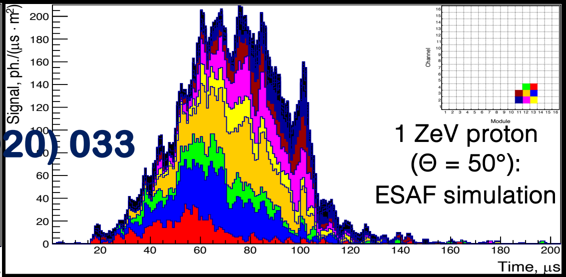








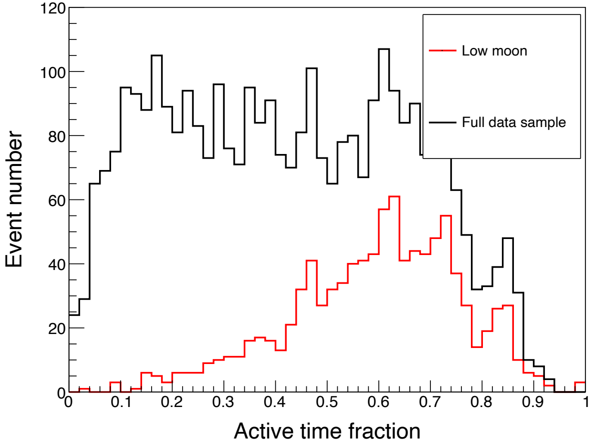
JCAP03 (2020) 033



Fenu #572

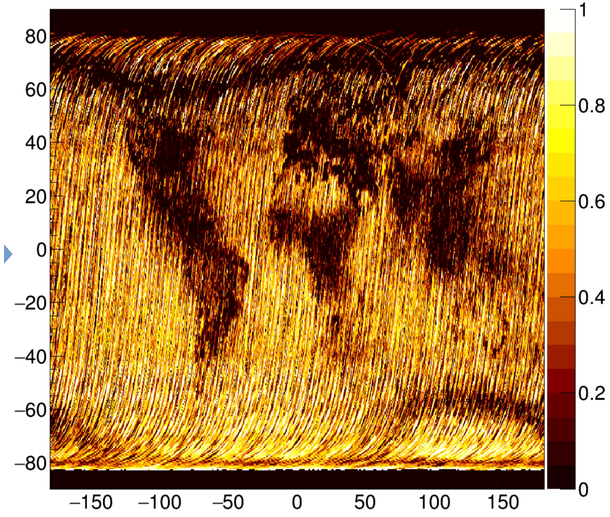
Estimation of TUS Exposure for UHECRs

Active time fraction



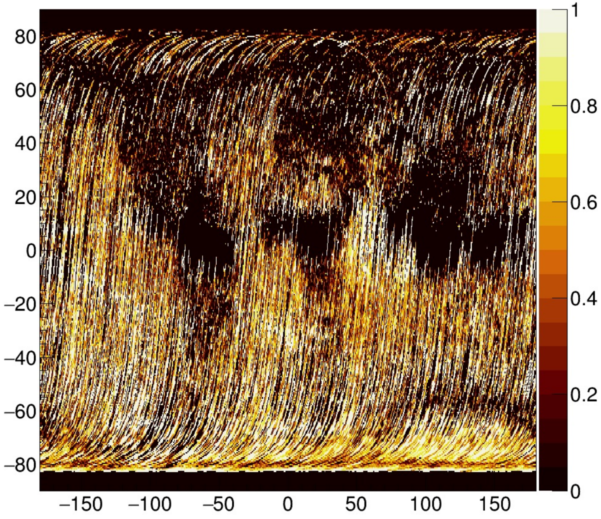
All data

Localized duty cycle



Cloud top < 4km

EMRatio

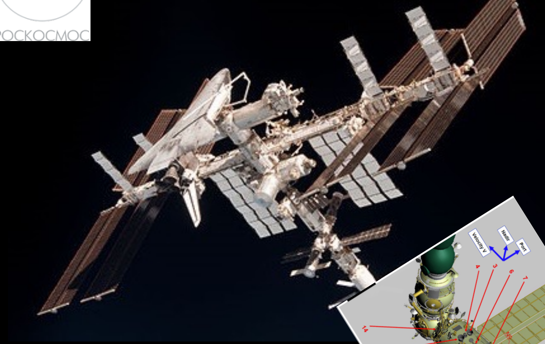


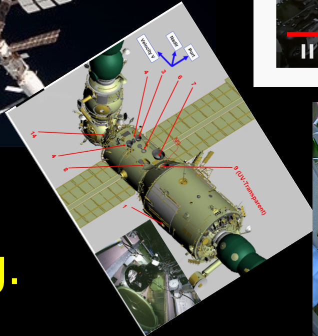
Current estimation of geometric exposure @ E >10^{21} eV: ~1550 km^2 sr yr

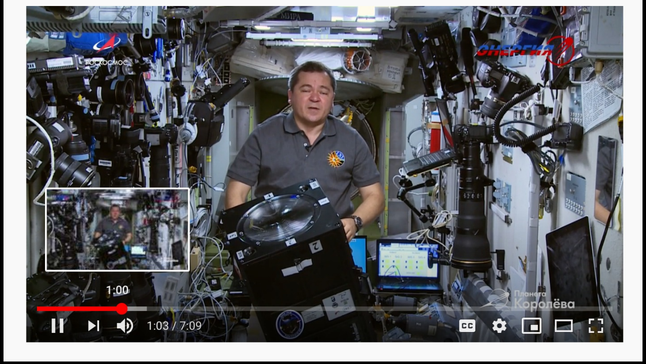
Using Merra-2 satellite data to associate cloud presence and compute exposure.

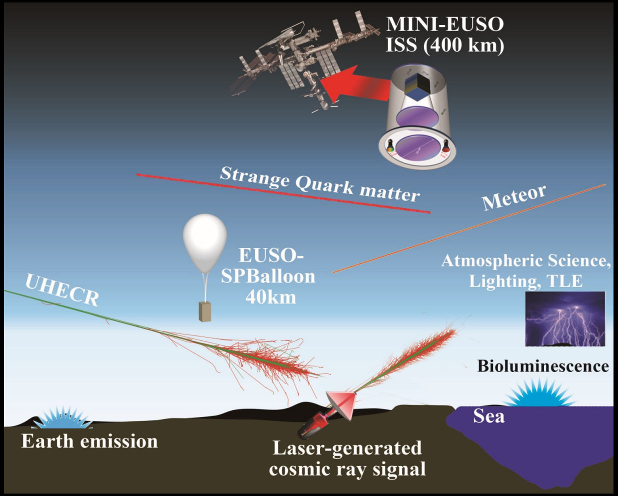
Mini-EUSO (2019 -)

Casolino #886



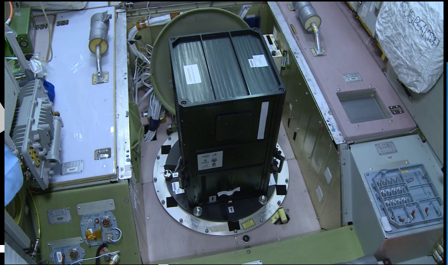


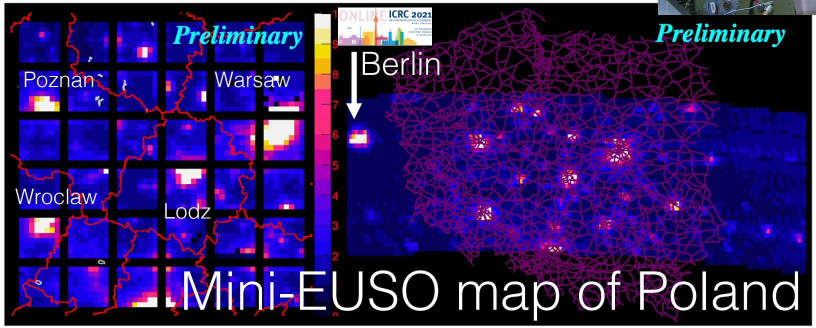




FoV: $\pm$ 22 deg.

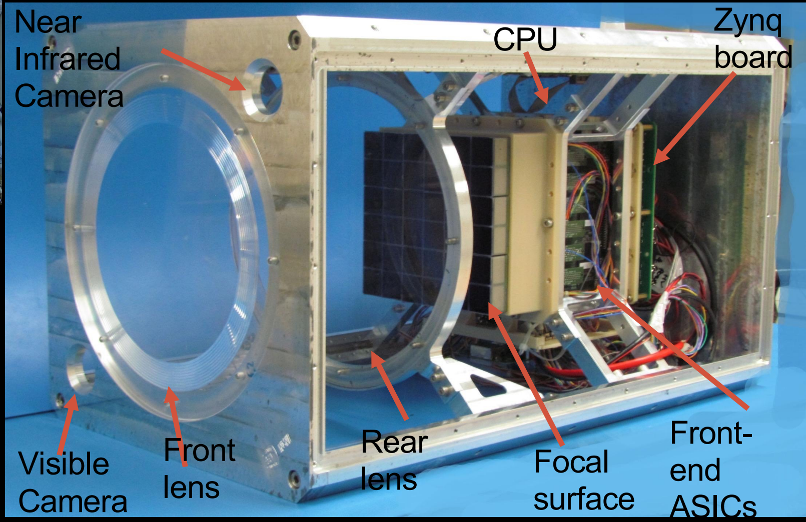
(9 times TUS)





Shinozaki #1165

2 fresnel lenses of 25 cm diameter



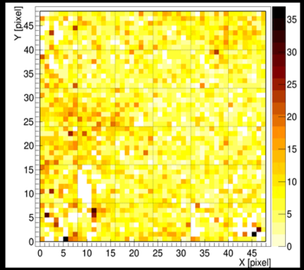
Examples of events' zoo detected by Mini-EUSO

(> 40 sessions, > 40h downloaded data)

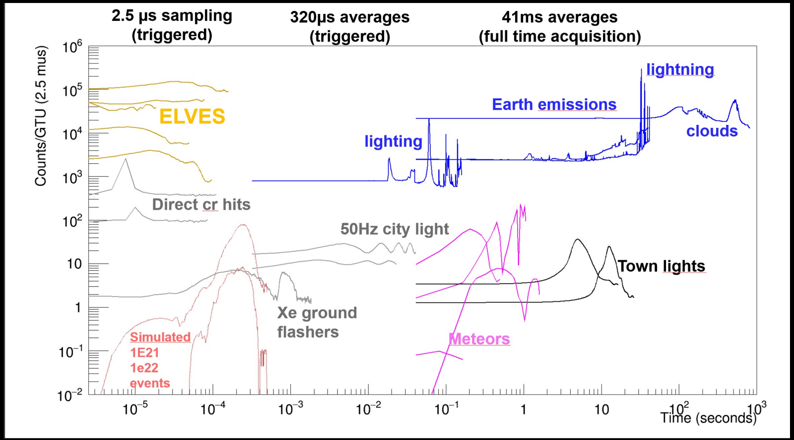
DATA with self trigger:
D1 : 2.5 μs res. (128 L1GTUs)
D2: 320 μs res. (128 L2GTUs)
D3: 40.96 ms res. (full movie)

Marcelli #971

TLEs

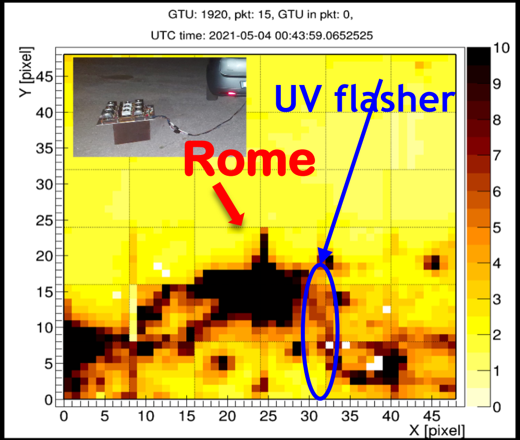


S. Bacholle et al. ApJS Vol. 253 (2021) 36



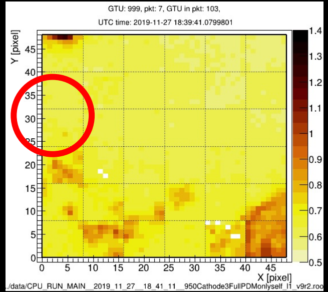
Battisti #411

Artificial sources



Piotrowski #1181

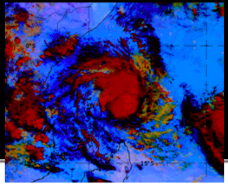
meteors

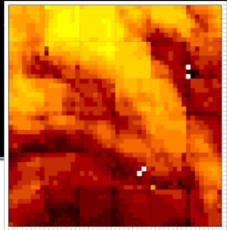


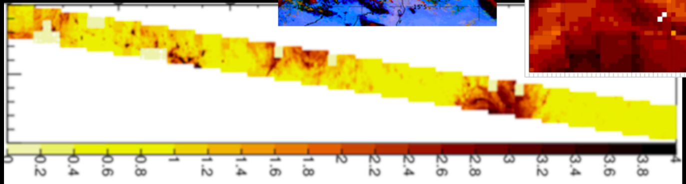
UV intensity on oceans
x2 EUSO-Balloon on forests
(direct airglow in Mini-EUSO)
Clouds: x2 – x4 (like EUSO-Ball.)

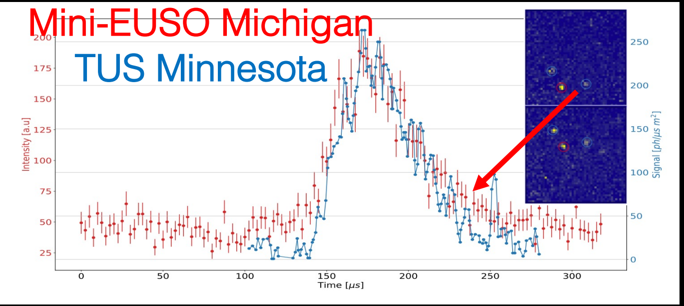
Golzio #417

clouds

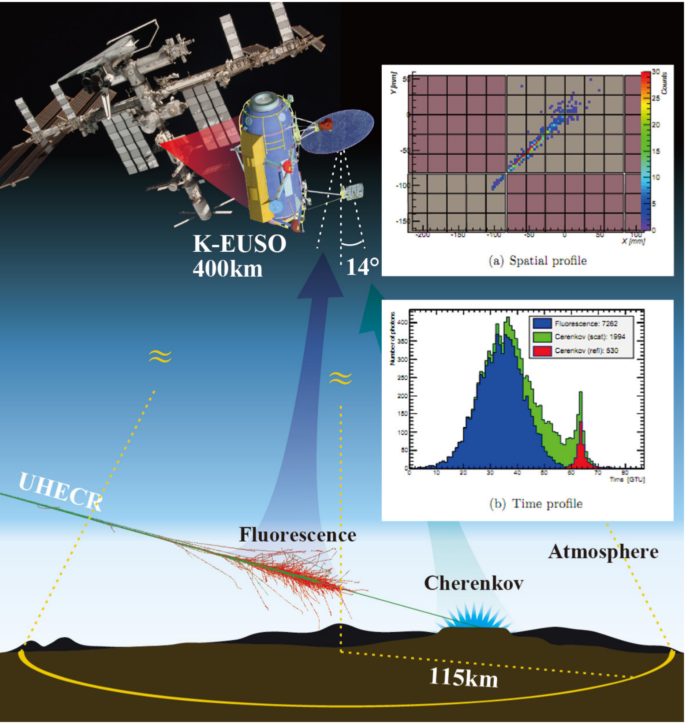


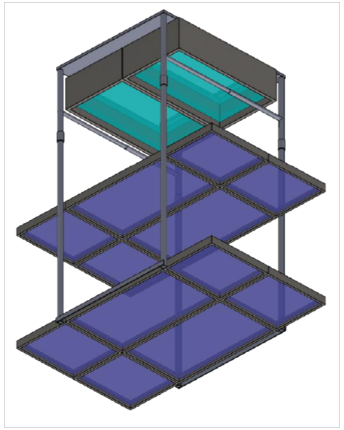


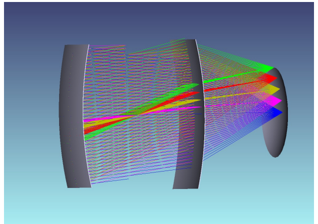




K-EUSO (2023+)







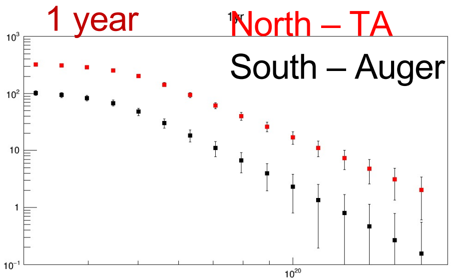
Fresnel lens system is much simpler from deployment point of view

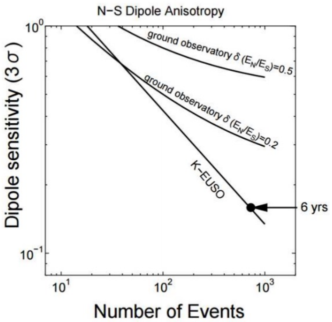
- Scientific objectives:
  UHECR fluorescent radiation measurements from space
- Placement:
  Russian Segment of the ISS

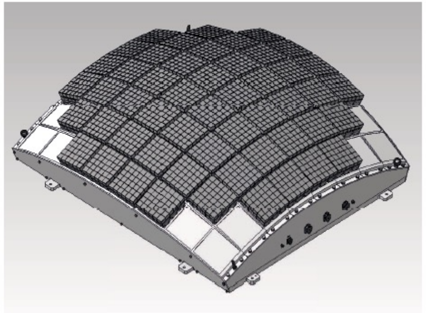
Main technical parameters

K-EUSO – Telescope with Fresnel lenses

- ✓ Mirror diameter – 1.3 m x 2.3 m
- ✓ Time resolution 1-2.5 us
- ✓ FOV 40 degrees.
- ✓ Angular resolution ~10^{-6} sr
- ✓ Mass ~ 500 - 850 kg



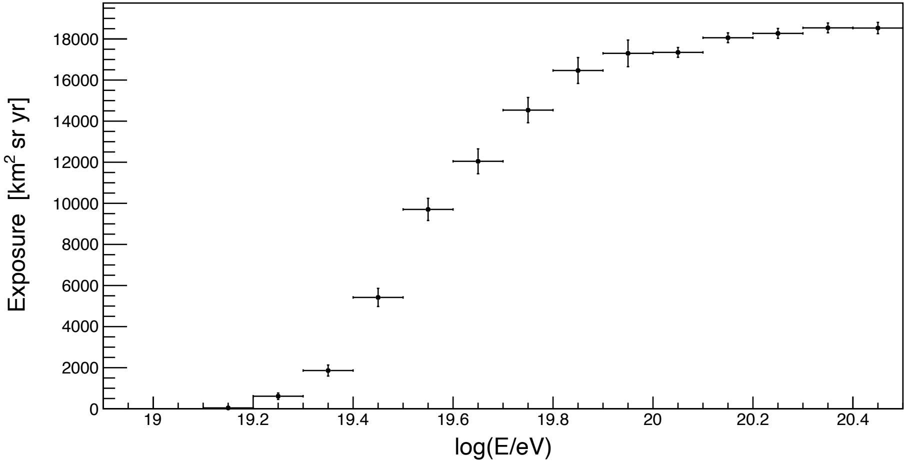




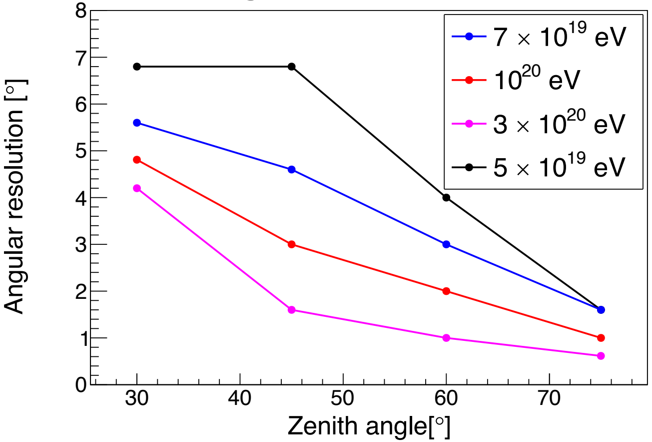
Fenu #754

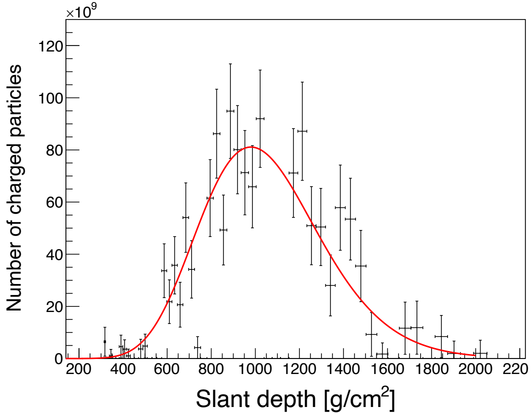
Performance Analysis

Annual Exposure



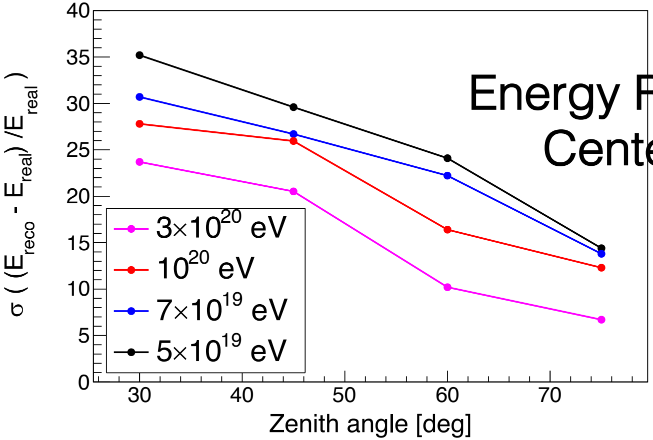
Angular Resolution





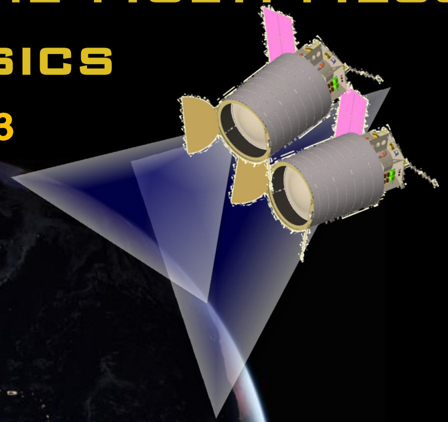
p
E=10^{20}eV
θ = 60°

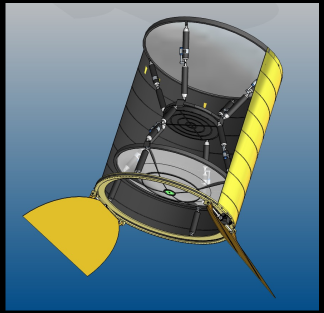
Energy Resolution Center FoV



POEMMA: Probe of Extreme Multi-Messenger Astrophysics

Olinto #863

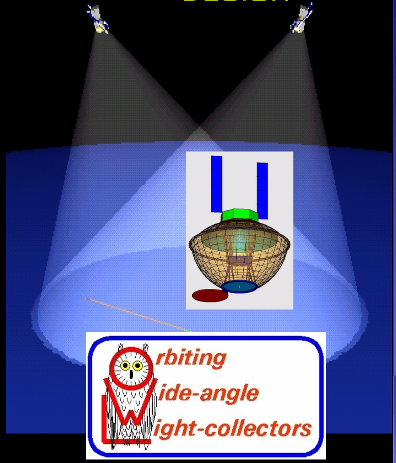




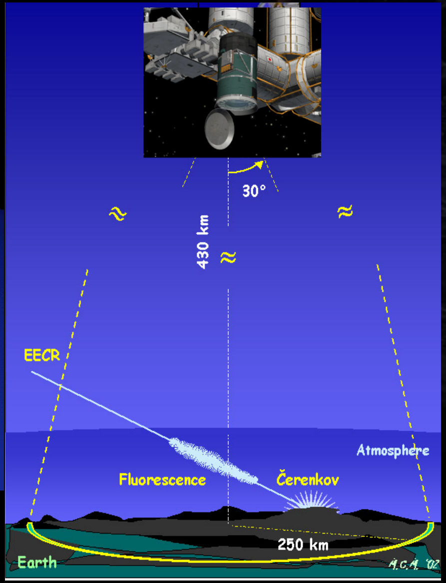
POEMMA Design based on:

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

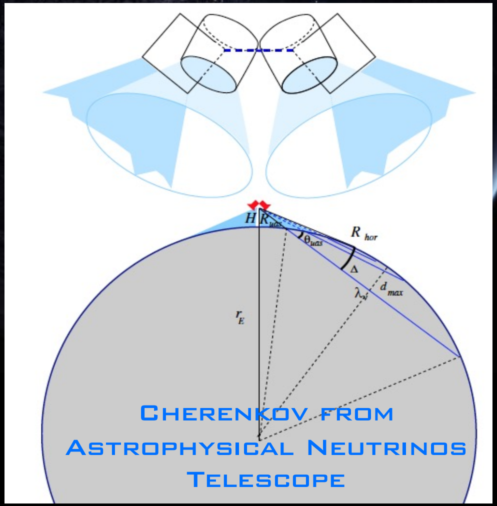
OWL
2002
design

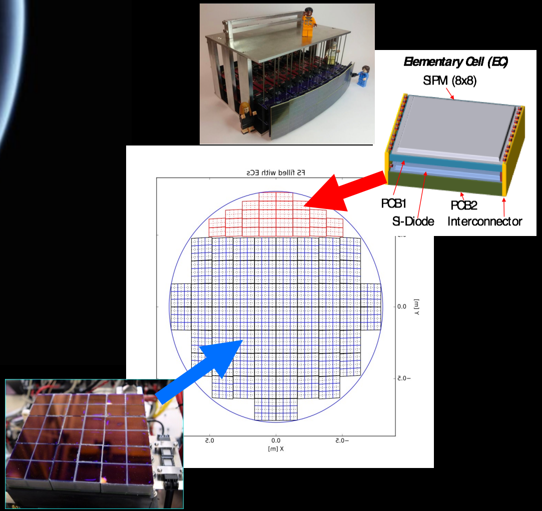


JEM-EUSO:
Extreme Universe Space Observatory



CHANT





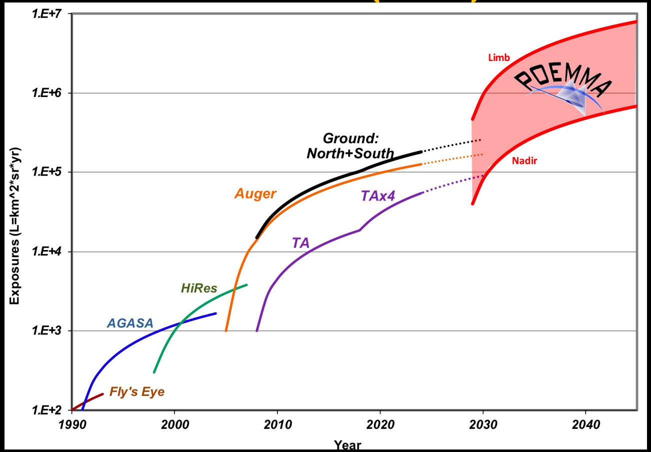
POEMMA

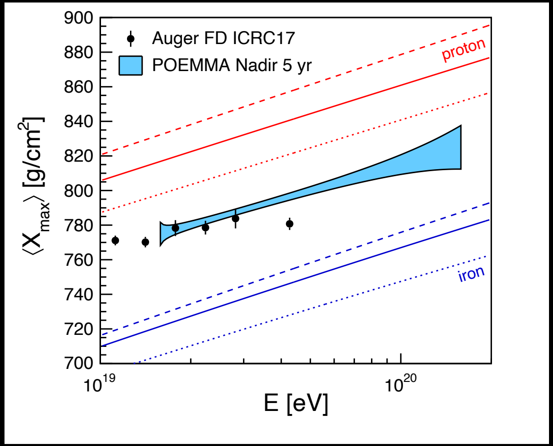
SIGNIFICANT INCREASE IN EXPOSURE, GOOD ENERGY, ANGULAR, AND SHOWER MAXIMUM RESOLUTIONS,

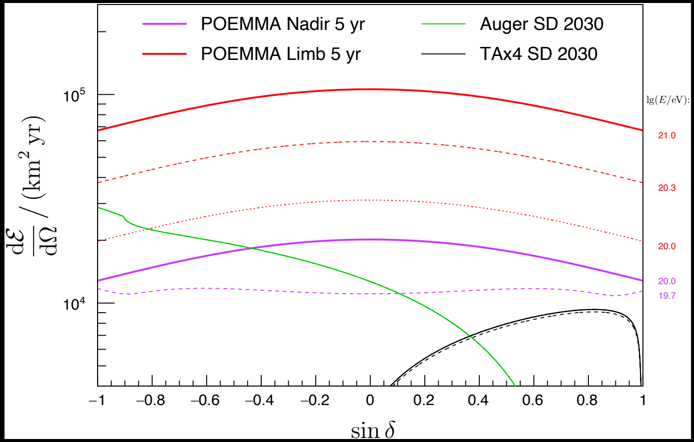
UNIFORM SKY COVERAGE TO GUARANTEE THE DISCOVERY OF UHECR SOURCES

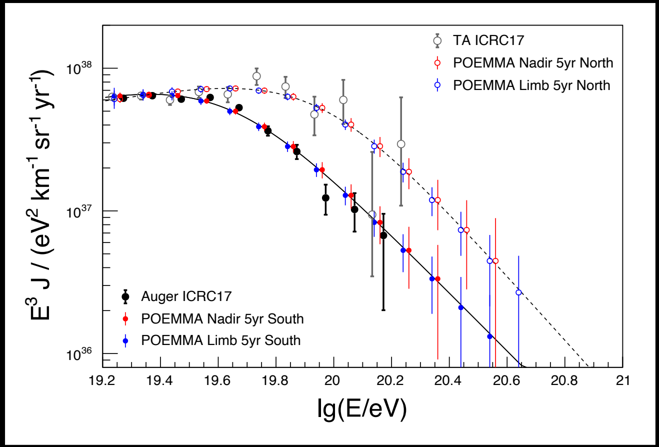
SPECTRUM, COMPOSITION, ANISOTROPY E>50 EeV

JCAP06 (2021) 007









ν_τ Exposure for ToO Observations

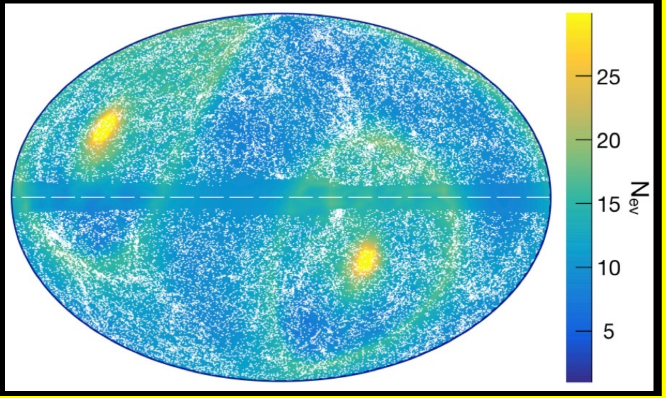
Long Bursts

Source Class	No. of ν's at GC	No. of ν's at 3 Mpc	Largest Distance for 1.0 ν per event	Model Reference
TDEs	1.4×10^5	0.9	3 Mpc	Dai and Fang [18] average
TDEs	6.8×10^5	4.7	7 Mpc	Dai and Fang [18] bright
TDEs	**2.7×10^8**	**1.7×10^3**	**128 Mpc**	**Lunardini and Winter [19] $M_{SMBH} = 5 \times 10^6 M_\odot$ Lumi Scaling Model**
TDEs	*7.7×10^7*	*489*	*69 Mpc*	*Lunardini and Winter [19] Base Scenario*
Blazar Flares	NA*	NA*	47 Mpc	RFGBW [20] – FSRQ proton-dominated advective escape model
lGRB Reverse Shock (ISM)	1.2×10^5	0.8	3 Mpc	Murase [16]
lGRB Reverse Shock (wind)	2.5×10^7	174	41 Mpc	Murase [16]
BBH merger	**2.8×10^7**	**195**	**43 Mpc**	**Kotera and Silk [21] (rescaled) Low Fluence**
BBH merger	**2.9×10^8**	**2.0×10^3**	**137 Mpc**	**Kotera and Silk [21] (rescaled) High Fluence**
BNS merger	**4.3×10^6**	**30**	**16 Mpc**	**Fang and Metzger [22]**
BWD merger	25	0	38 kpc	XMMD [23]
Newly-born Crab-like pulsars (p)	190	0	109 kpc	Fang [24]
Newly-born magnetars (p)	2.5×10^4	0.2	1 Mpc	Fang [24]
Newly-born magnetars (Fe)	5.0×10^4	0.3	2 Mpc	Fang [24]

Short Bursts

Source Class	No. of ν's at GC	No. of ν's at 3 Mpc	Largest Distance for 1.0 ν per event	Model Reference
sGRB Extended Emission (moderate)	1.1×10^8	800	90 Mpc	KMMK [17]

(*) Not applicable due to a lack of known blazars within 100 Mpc.



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-SPB1, EUSO-SPB2, Mini-EUSO and TUS) are going 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