Joint Experiment Missions for the Extreme Universe Space Observatory

POEMMA: The PrObe of Extreme Multi-Messenger Astrophysics

M. Bertaina – University & INFN Torino

April 22nd, 2021

Laboratori Nazionali di Frascati - INFN

POEMMA Collaboration

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University of Utah: D. R. Bergman
Colorado School of Mines: J. Eser, F. Sarazin, L. Wiencke,
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ITALY: Universita di Torino: M. E. Bertaina, F. Bisconti, F. Fenu, A. Liberatore, K. Shinozaki: Gran Sasso Science Institute: R. Aloisio, A. L. Cummings, I. De Mitri; INFN Frascati: M. Ricci, INFN Tor Vergata: L. Marceli, U. of Rome Tor Vergata: P. Picozza
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NORWAY: F. Oikonomou
SLOVAKIA: IEP, Slovak Academy of Science: S. Mackovjak
SWITZERLAND: University of Geneva: A. Neronov

50+ SCIENTISTS FROM 24+ INSTITUTIONS (10 COUNTRIES)
OWL, JEM-EUSO, AUGER, TA, VERITAS, CTA, FERMI, THEORY

Credits for this presentation to A. Oliinto, J.F. Krizmanic, T.M. Venters, M. Bustamante & C. Guepin

NASA Probe Studies for 2020 Decadal Survey

- NASA funding 10 Probe Class (below 1B$) Mission (18 mos) Studies in Preparation for the 2020 Decadal Survey
- PI responsible for the final report (due NLT Dec 2018)
- NASA will submit these studies to the Decadal Survey
- Decadal Survey Committee will have the option to prioritize any of these mission concepts, or recommend a competed line of Probes (similar to Explorers)
- Selection based on Science Merit (cost, schedule)

	PI	Affiliation	Short title	Design Lab/Prog Office
	Camp, J.	NASA's GSFC	Transient Astrophysics Probe	IDC/PCOS-COR
	Cooray, A.	Univ. California, Irvine	Cosmic Dawn Intensity Mapper	TeamX/ExEP
	Danchi, W.	GSFC	Cosmic Evolution through UV spectroscopy	IDC/PCOS-COR
	Glenn, J.	Univ. of Colorado	Galaxy Evolution Probe	TeamX/ExEP
	Hanany, S.	Univ. of Minnesota	Inflation Probe Mission Concept Study	TeamX/ExEP
	Mushotzky, R.	Univ. of Maryland	High Spatial Resolution X-ray Probe	IDC/PCOS-COR
POEMMA	Olinto, A.	Univ. of Chicago	Multi-Messenger Astrophysics	IDC/PCOS-COR
	Plavchan, P.	Missouri State Univ.	Precise Radial Velocity Observatory	No design lab funded/HQ grant
	Ray, P.	Naval Research Lab	X-ray Timing and Spectroscopy	IDC/PCOS-COR
	Seager, S.	MIT	Starshade Rendezvous	TeamX/ExEP

Astroparticle Physics Questions:

What are the sources of the **Ultra-High Energy Cosmic Rays** (UHECRs)?

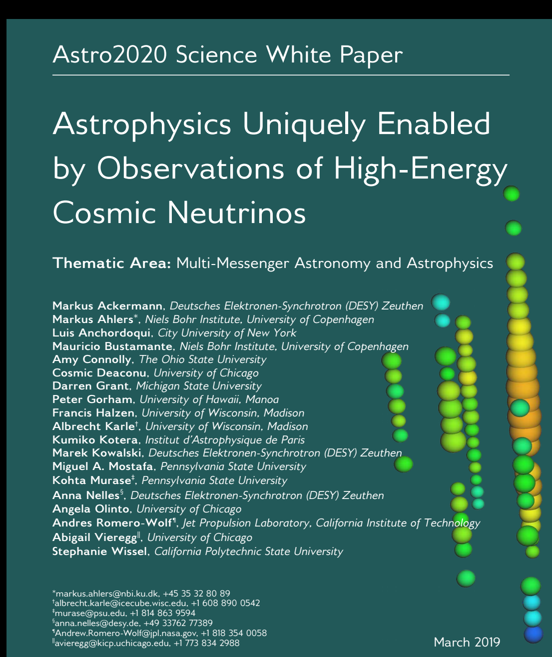
Measure Spectrum, Composition, Anisotropies $E>10^{19}$ eV = 10 EeV

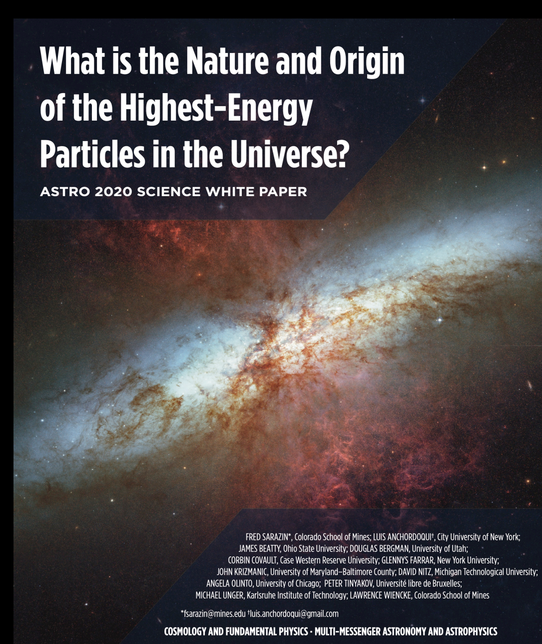
What are the sources of **Astrophysical Neutrinos**?

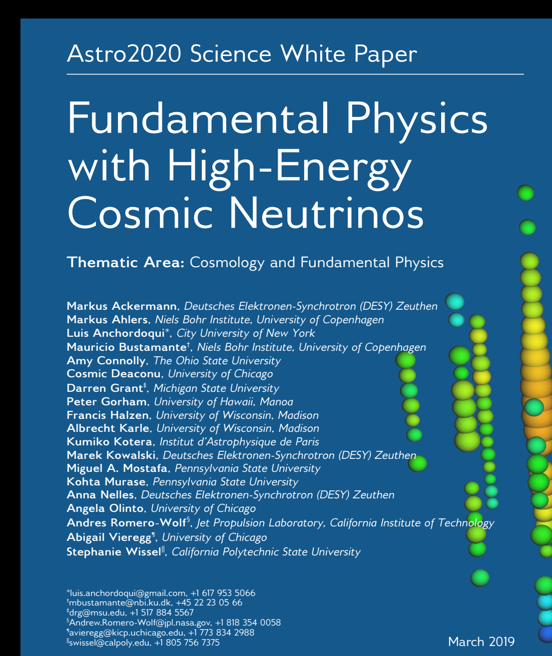
Multi-Messenger coincidence gamma-ray, gravitational waves, and neutrinos
with $E > 10^{16}$ eV = 10 PeV

What is the physics and astrophysics at energies >> "ground-based" accelerators?

Are there Extra-Dimensions, Supermassive Dark Matter, Topological Defects?



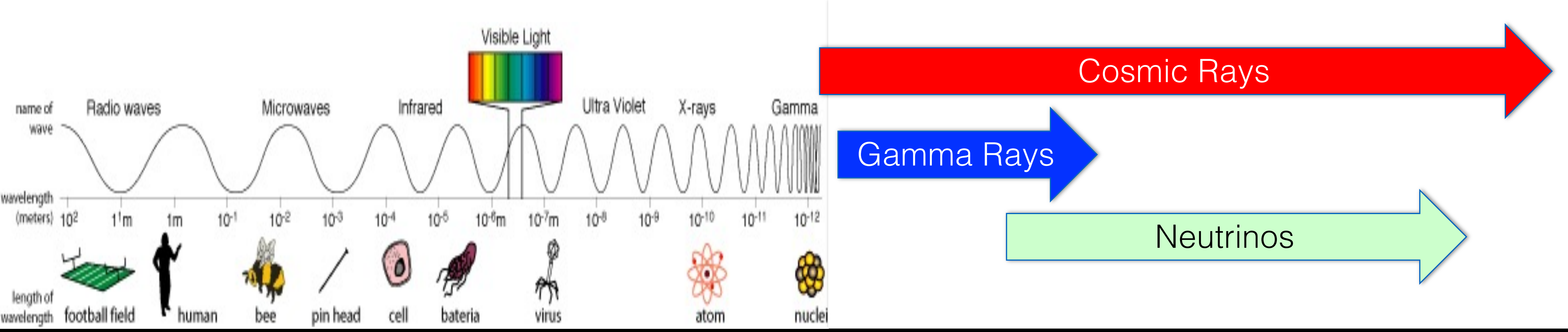




Cosmic Particles

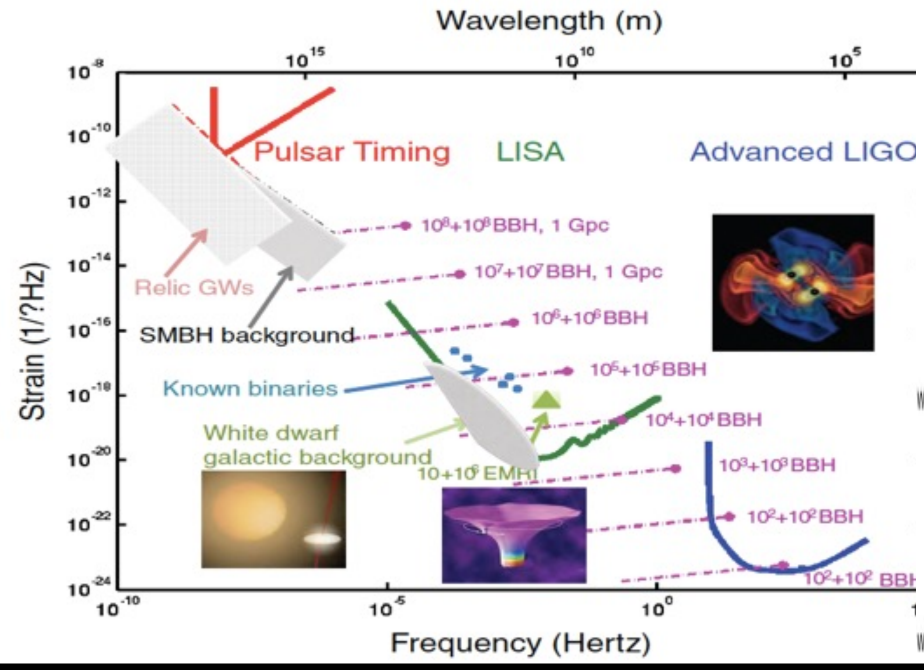
Cosmic Rays = relativistic atomic nuclei: Hydrogen (protons), He, heavier elements

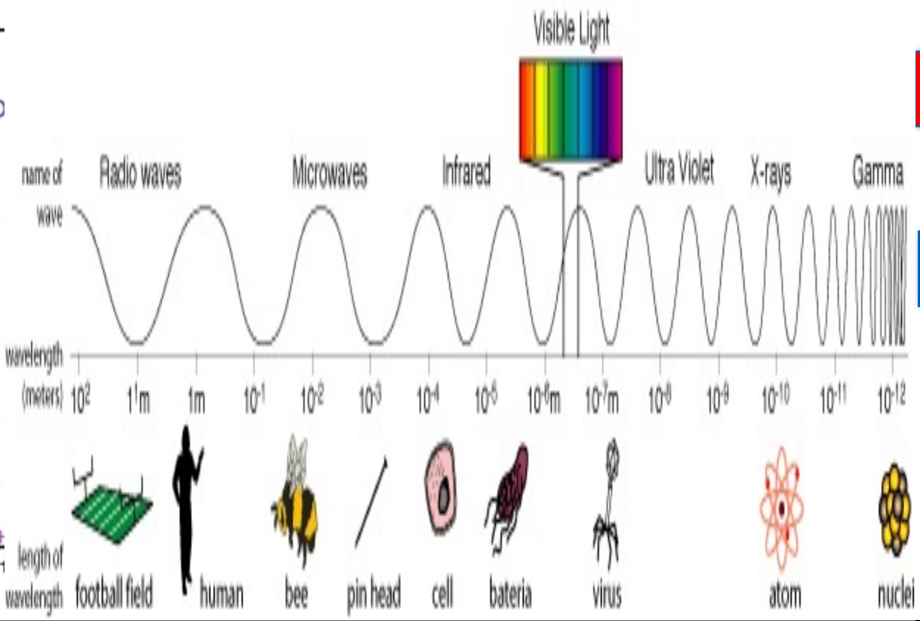
~ double the energy range for Astrophysics

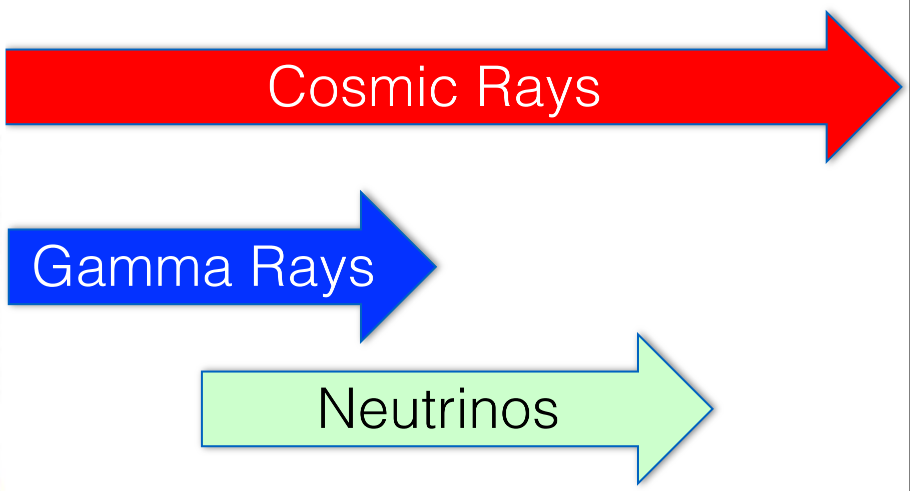


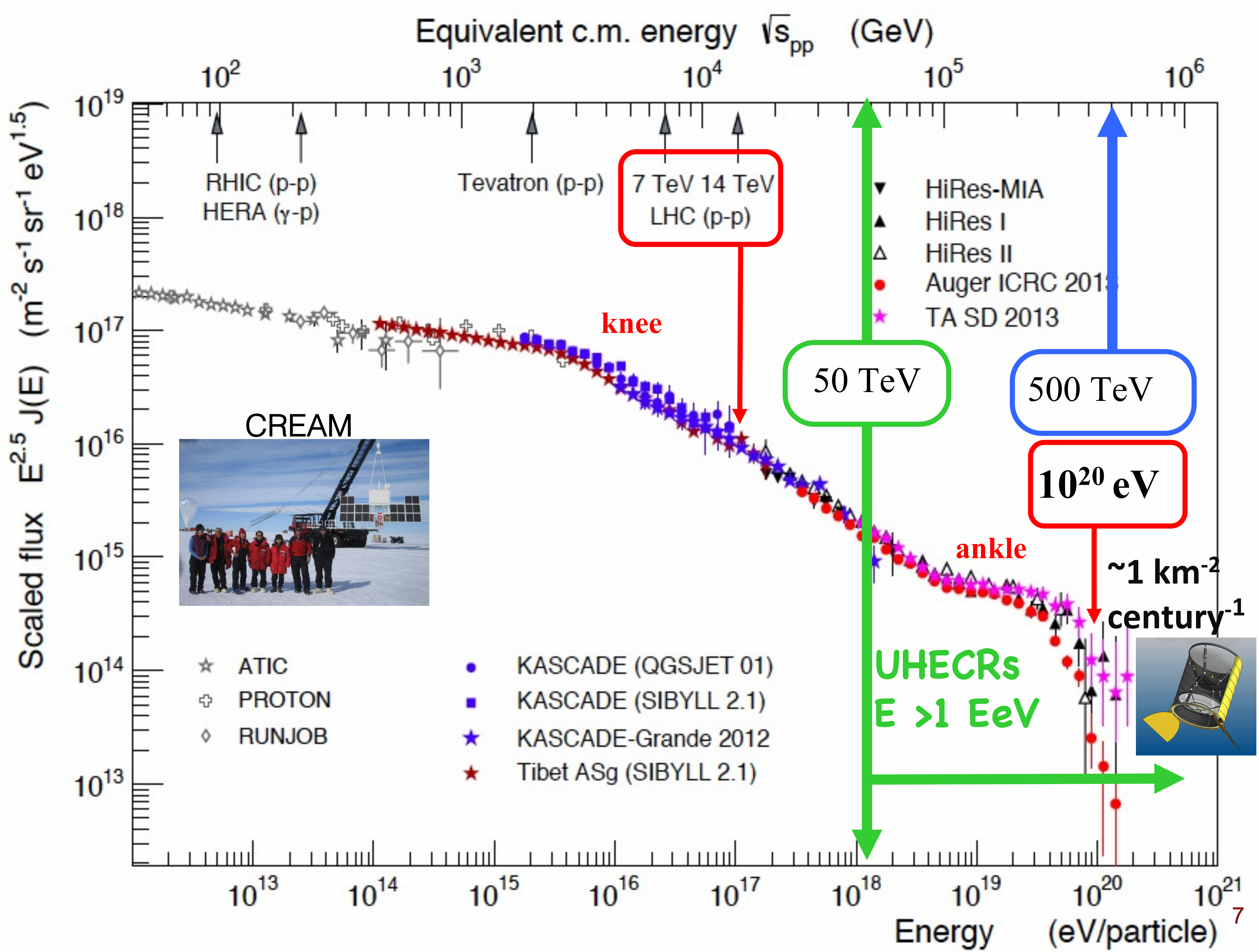
Multi-Messengers

~ triple the energy range for Astrophysics : 40 orders of magnitude

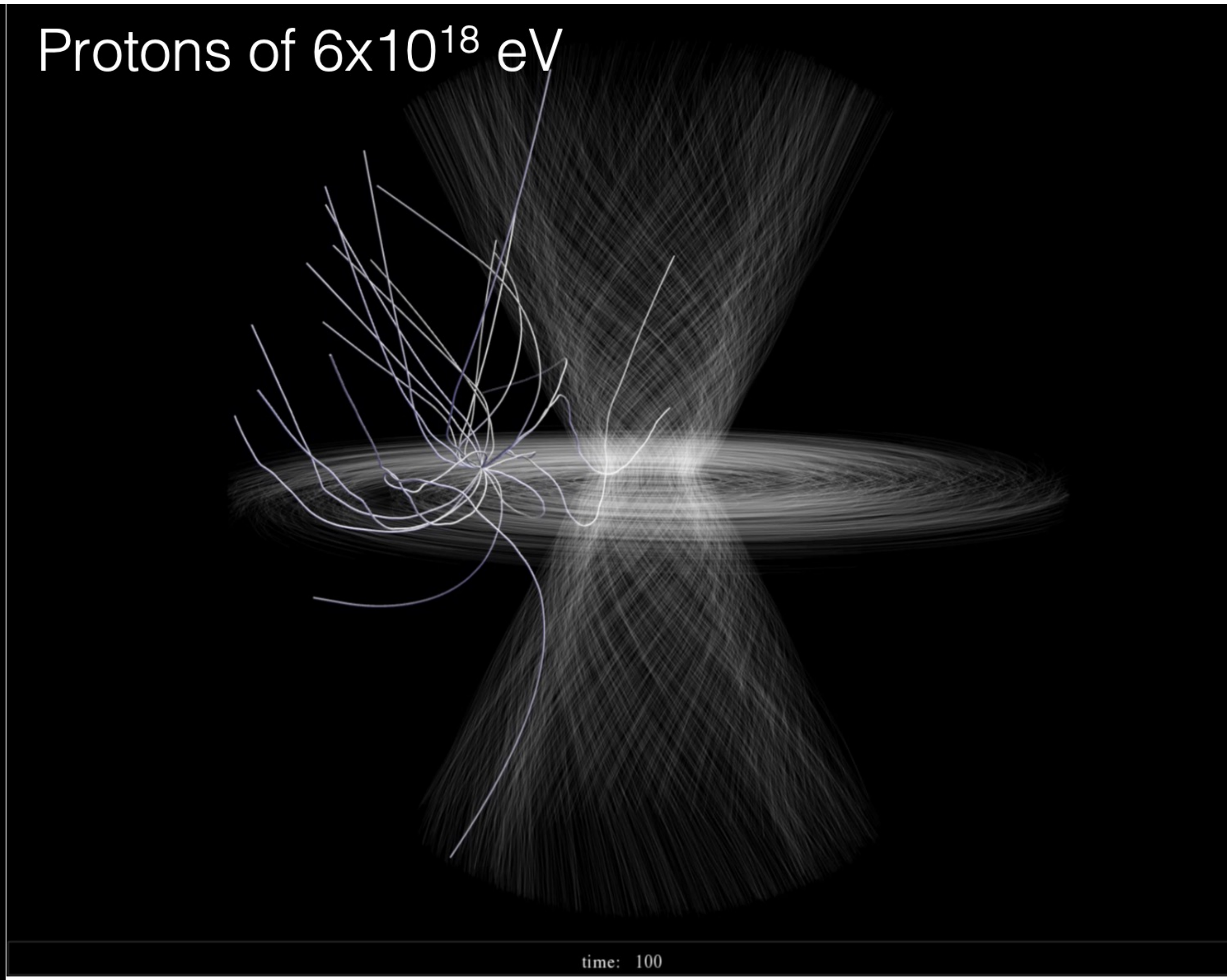






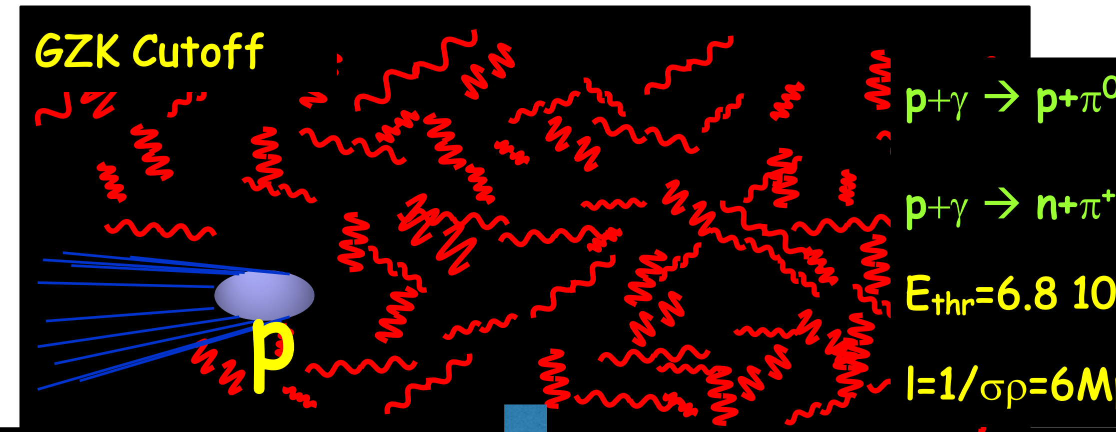


Equivalent c.m. energy √s_pp (GeV)
10^2
10^3
10^4
10^5
10^6
Scaled flux E^2.5 J(E) (m^-2 s^-1 sr^-1 eV^1.5)
10^19
10^18
10^17
10^16
10^15
10^14
10^13
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
knee
50 TeV
500 TeV
10^20 eV
CREAM
ankle
~1 km^-2
century^-1
UHECRs
E >1 EeV
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
Energy (eV/particle)

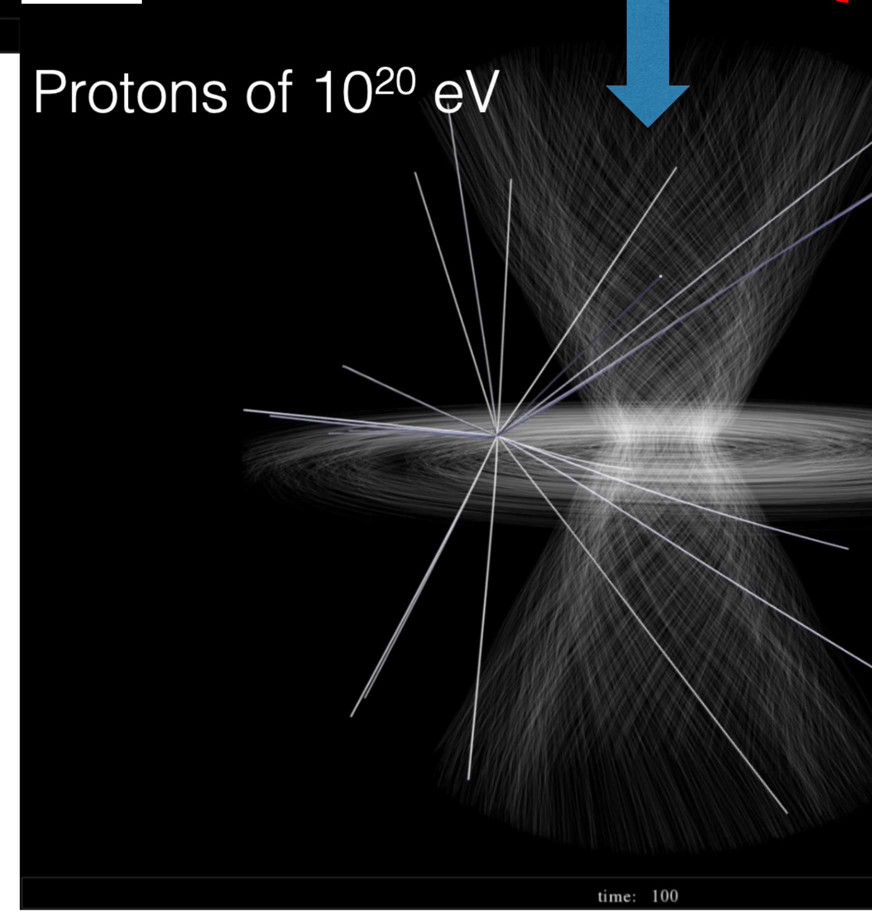


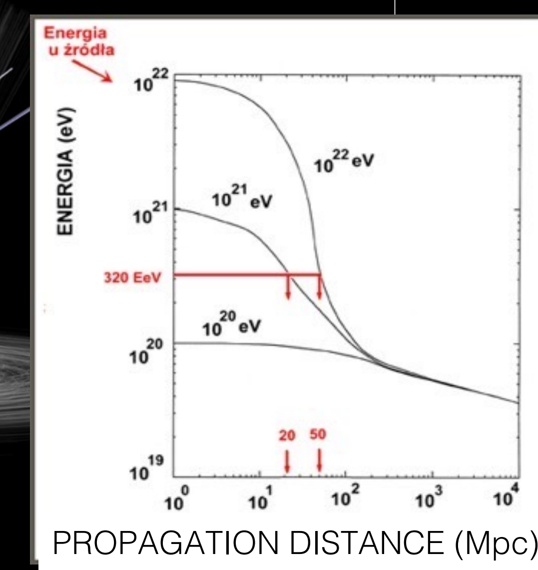
(G. Farrar & J. Sandstrom, NASA)

NOT POSSIBLE TO TRACK BACK THE SOURCES

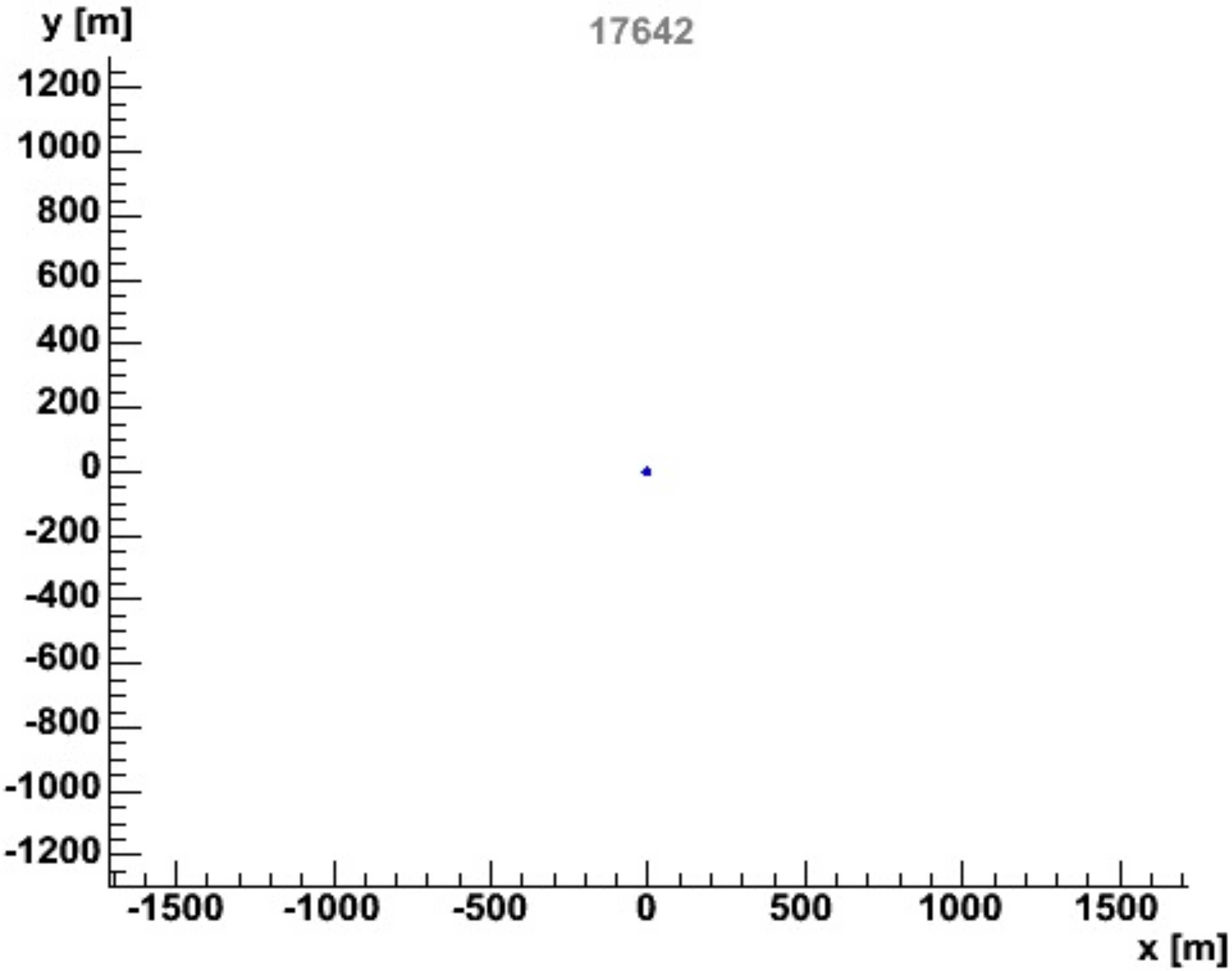


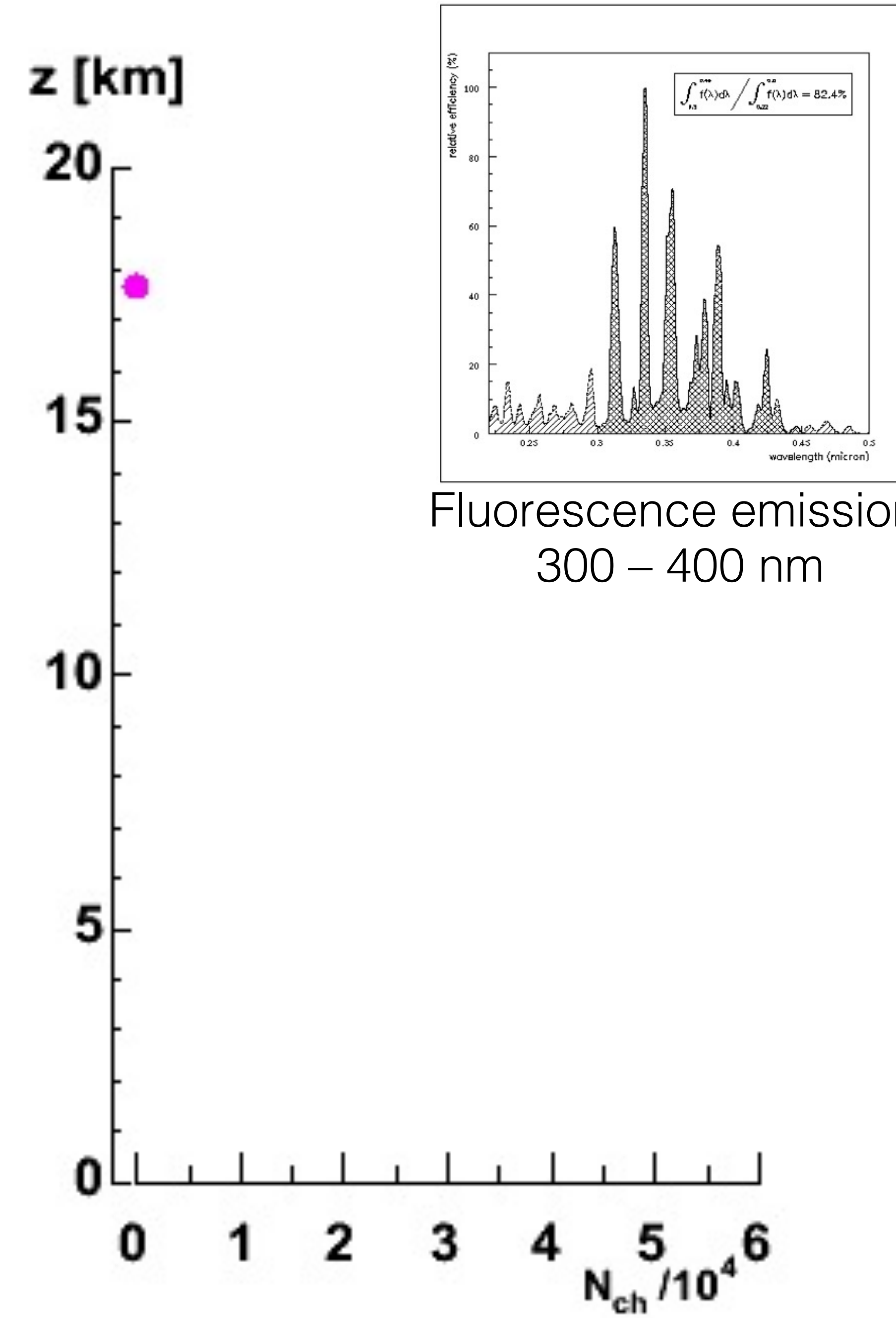
POSSIBLE TO TRACK BACK THE SOURCES



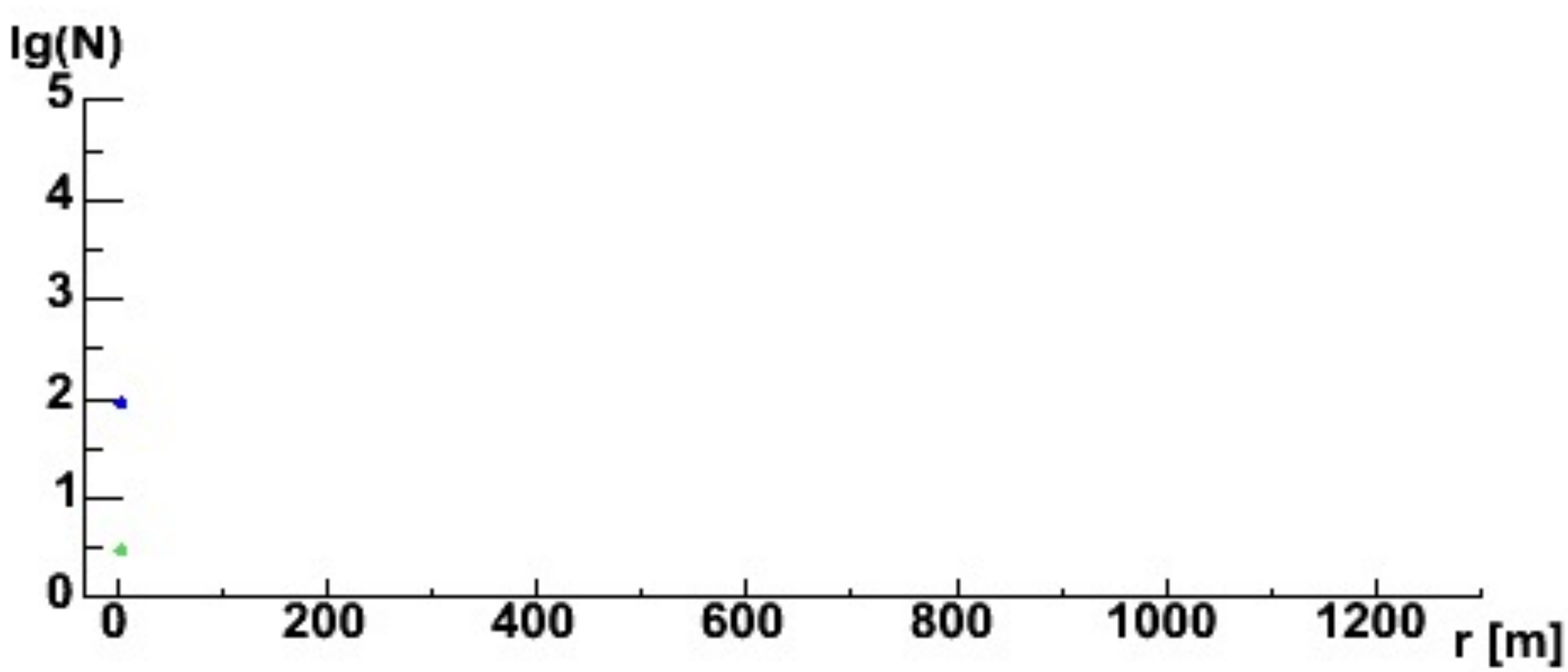


Cosmic rays with energy E> $7 \cdot 10^{19}$ eV must have their sources within 50Mpc





Fluorescence emission
300 – 400 nm



Proton 10^{14} eV

h^{1st} = 17642 m

hadrons muons

neutrons electrs

J.Oehlschlaeger,R.Engel,FZKarlsruhe

Leading Observatories of Ultrahigh Energy Cosmic Rays

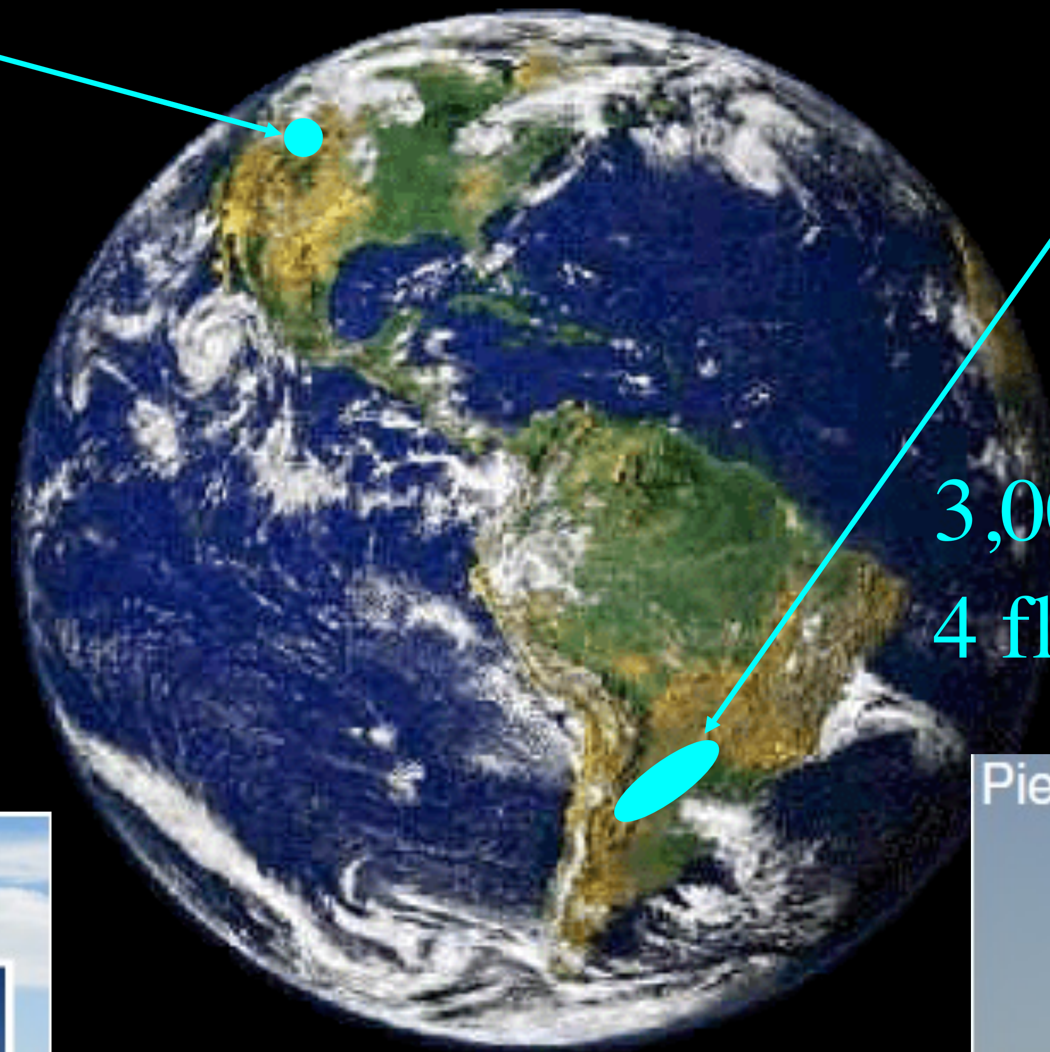
Telescope Array

Utah, US

(5 country collaboration)

700 km^2 array

3 fluorescence telescopes



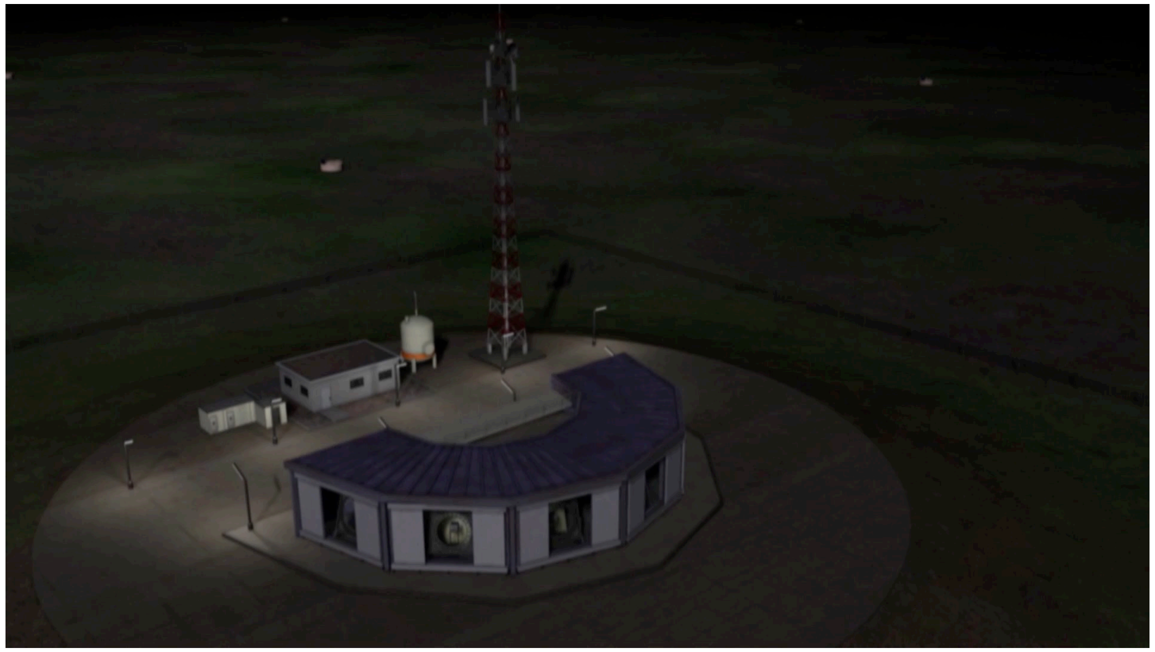
Pierre Auger Observatory

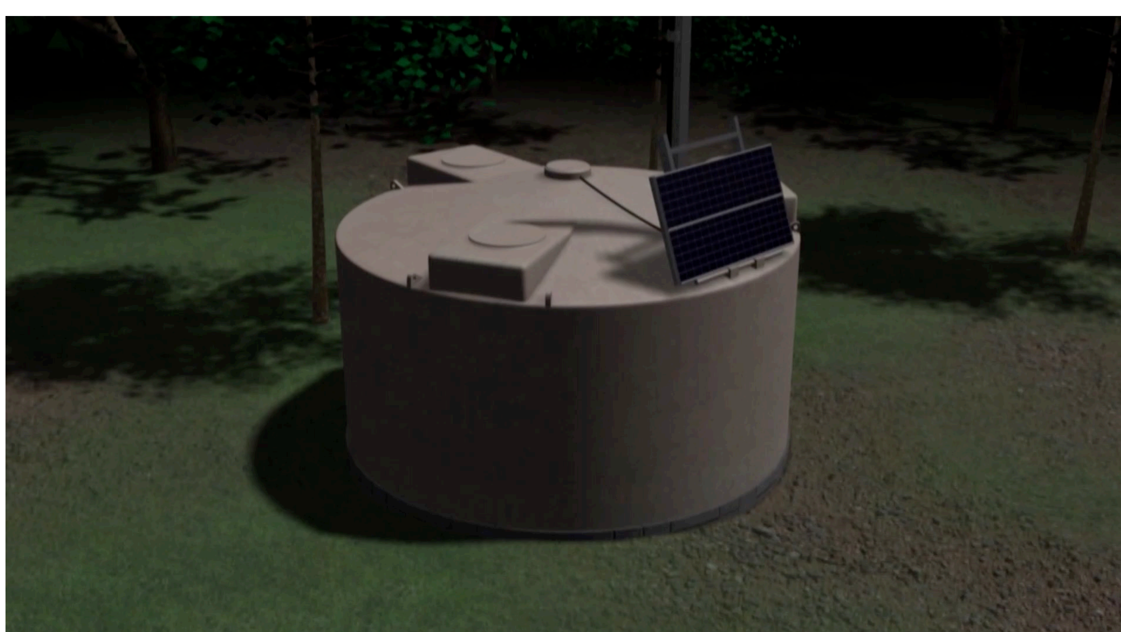
Mendoza, Argentina

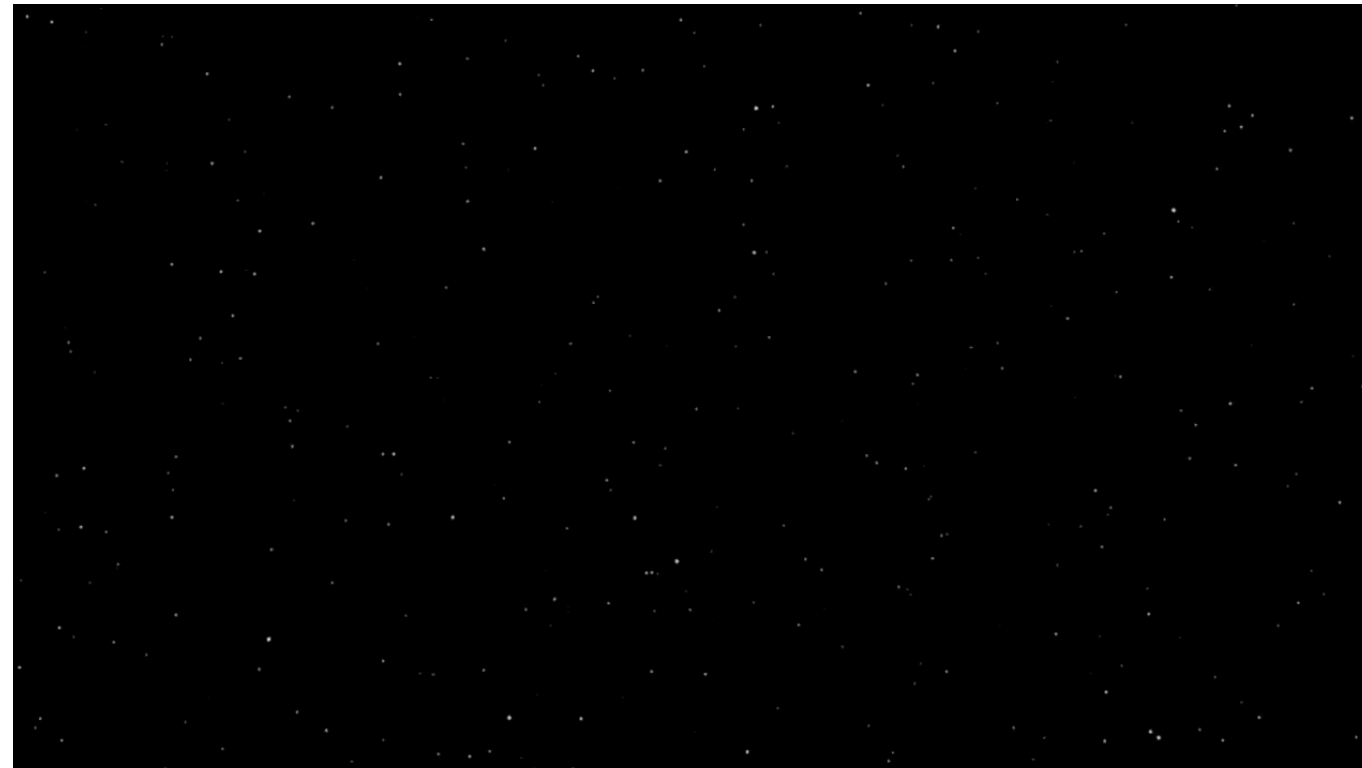
(19 country collaboration)

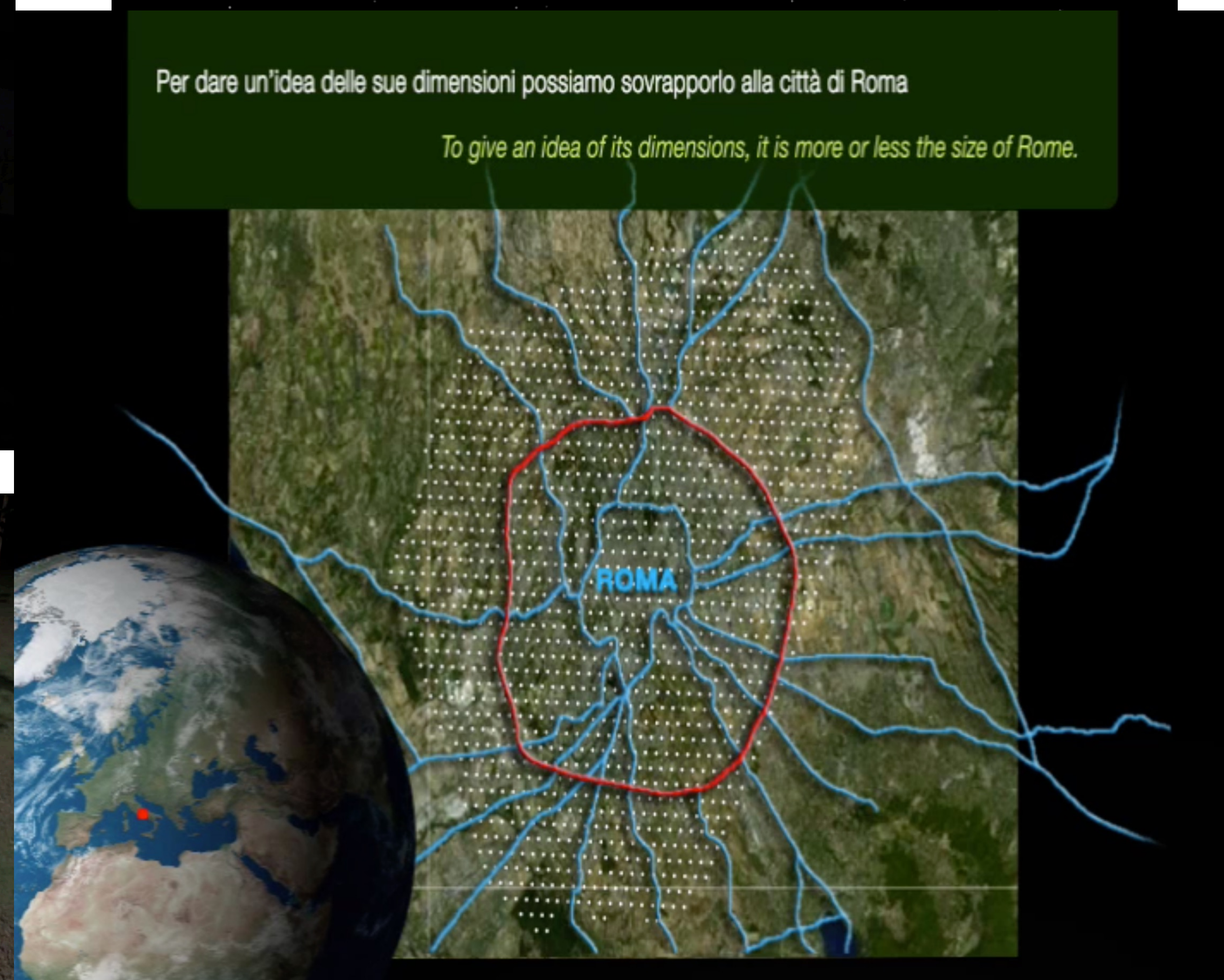
3,000 km^2 array

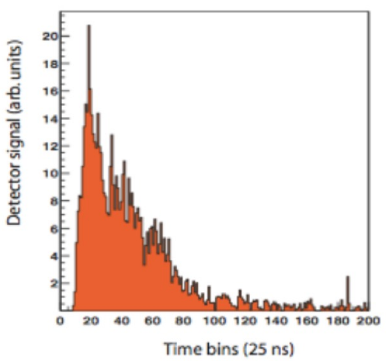
4 fluorescence telescopes

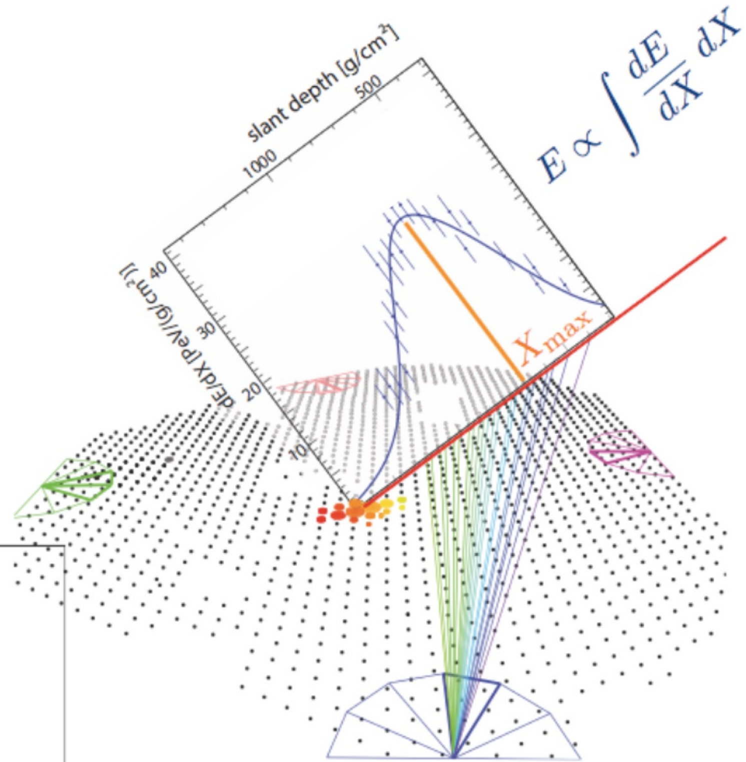







Per dare un'idea delle sue dimensioni possiamo sovrapporlo alla città di Roma
To give an idea of its dimensions, it is more or less the size of Rome.
ROMA



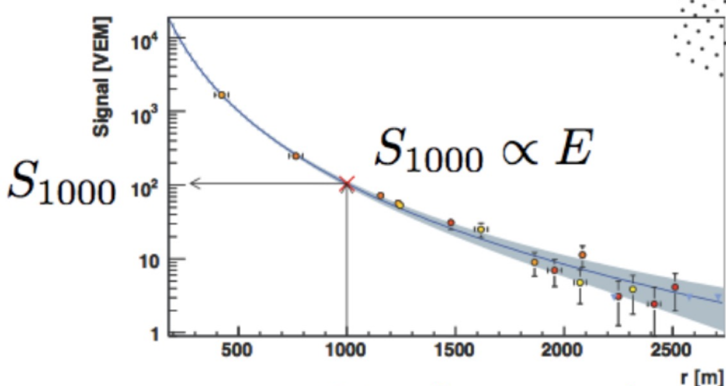


FD: calorimetric energy measurement
(13% duty cycle)

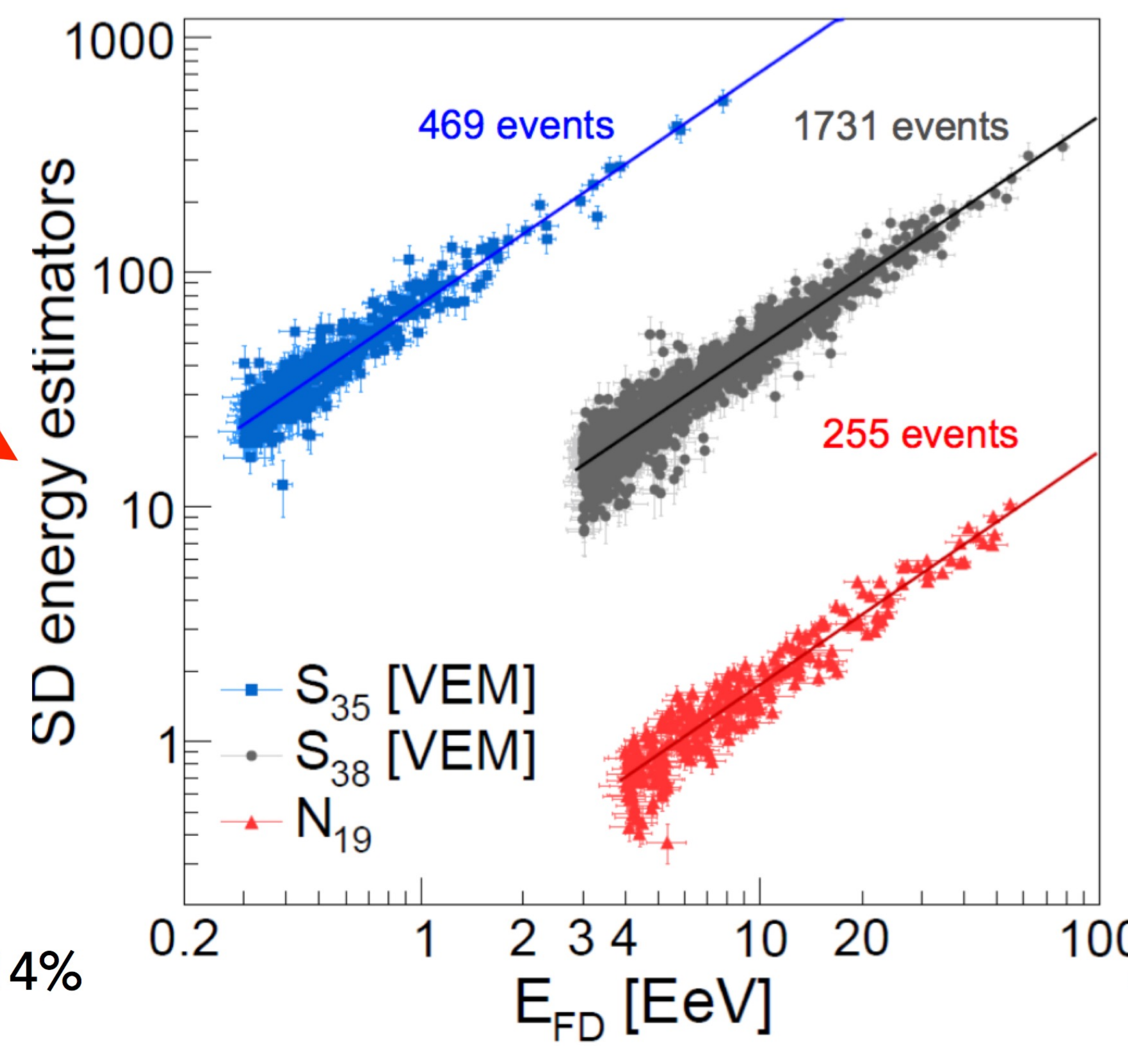
$$E_{Cal} = \int_0^\infty dX \, \frac{dE}{dX}$$

$$E_{Tot} = E_{Cal} + \underline{E_{Inv}}$$

(evaluated from data, as $E_{Inv} \propto N_\mu$)



SD: shower size at ground as energy estimator.



Hybrid events: absolute calibration of the full SD sample

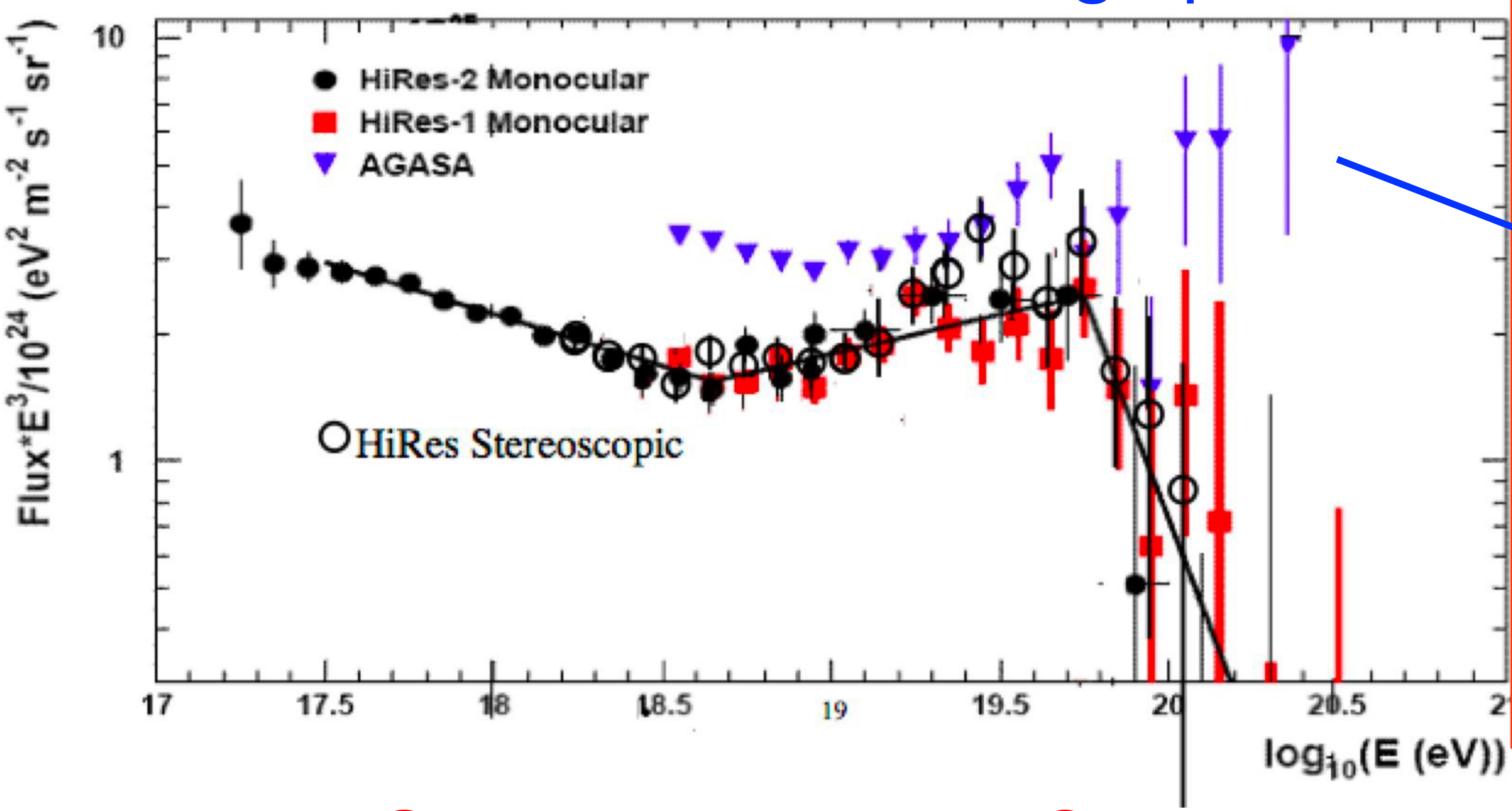
In the Pierre Auger Observatory:
Energy resolution: 15% for vertical events
Energy systematic uncertainty : FD energy scale 14%

A. Castellina

THE IMPORTANCE OF AN HYBRID DETECTOR

Experimental situation in early 2000s

AGASA: continuing spectrum

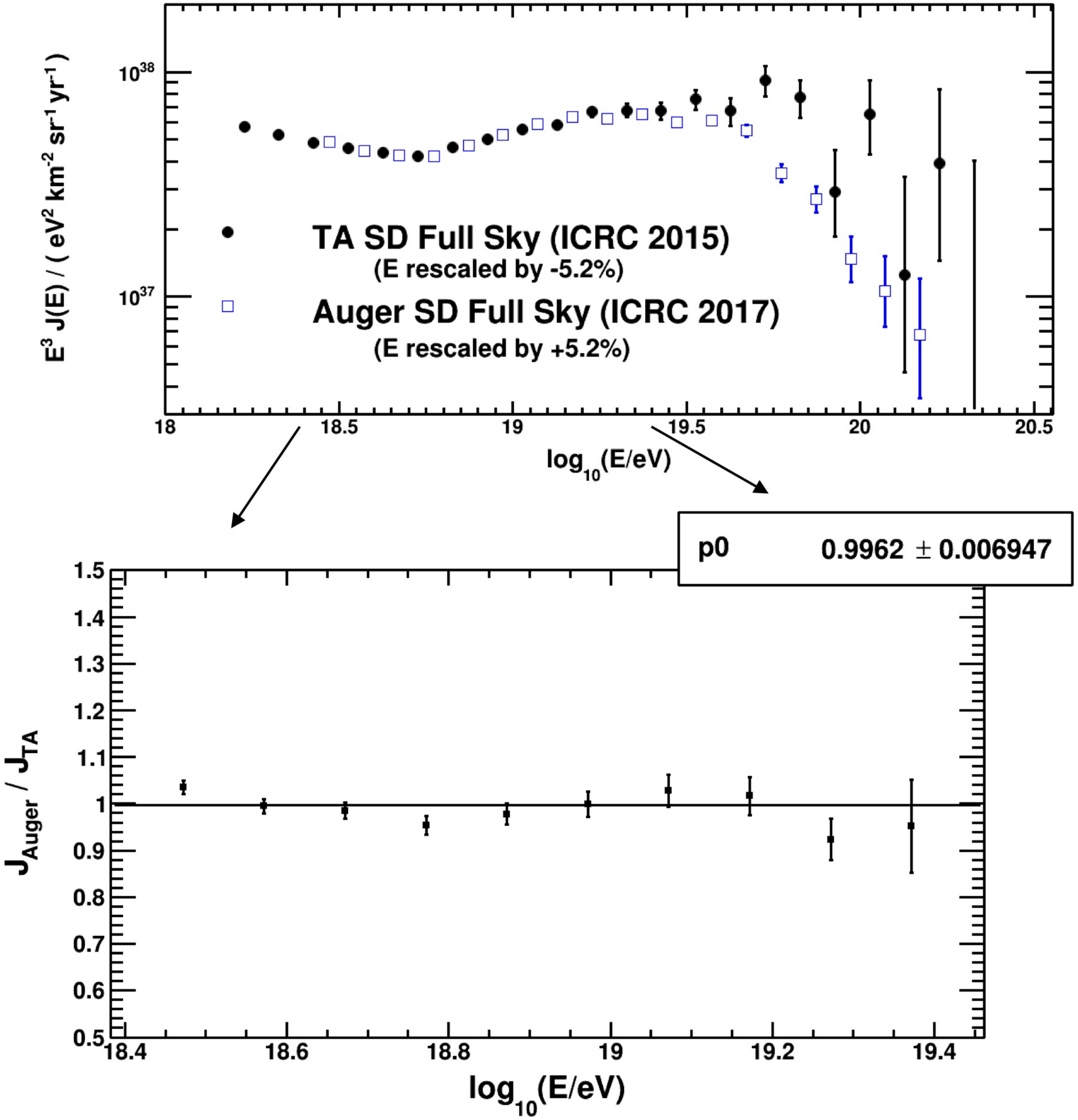


Many hypotheses have been offered, suggesting UHE CRs are due to:

- Bottom-up models: some variant of the same mechanism valid for lower energies
- Top-down models: created at UHE - due to decay of a very heavy parent particle (GUT or supersymmetry models), or perhaps due to topological defects in the Universe
- Neutrino interactions in intergalactic space
- Exotic astrophysics: AGNs, , jets, GRBs - little is known about gamma ray bursters or UHE CRs, so maybe there is a connection!
- Magnetic field models: maybe intergalactic space has a larger magnetic field than expected, so charged particles do not point back to sources even at UHE
- Violation of Lorentz invariance - would solve the GZK puzzle

HiRes: GZK suppression @ 5σ level

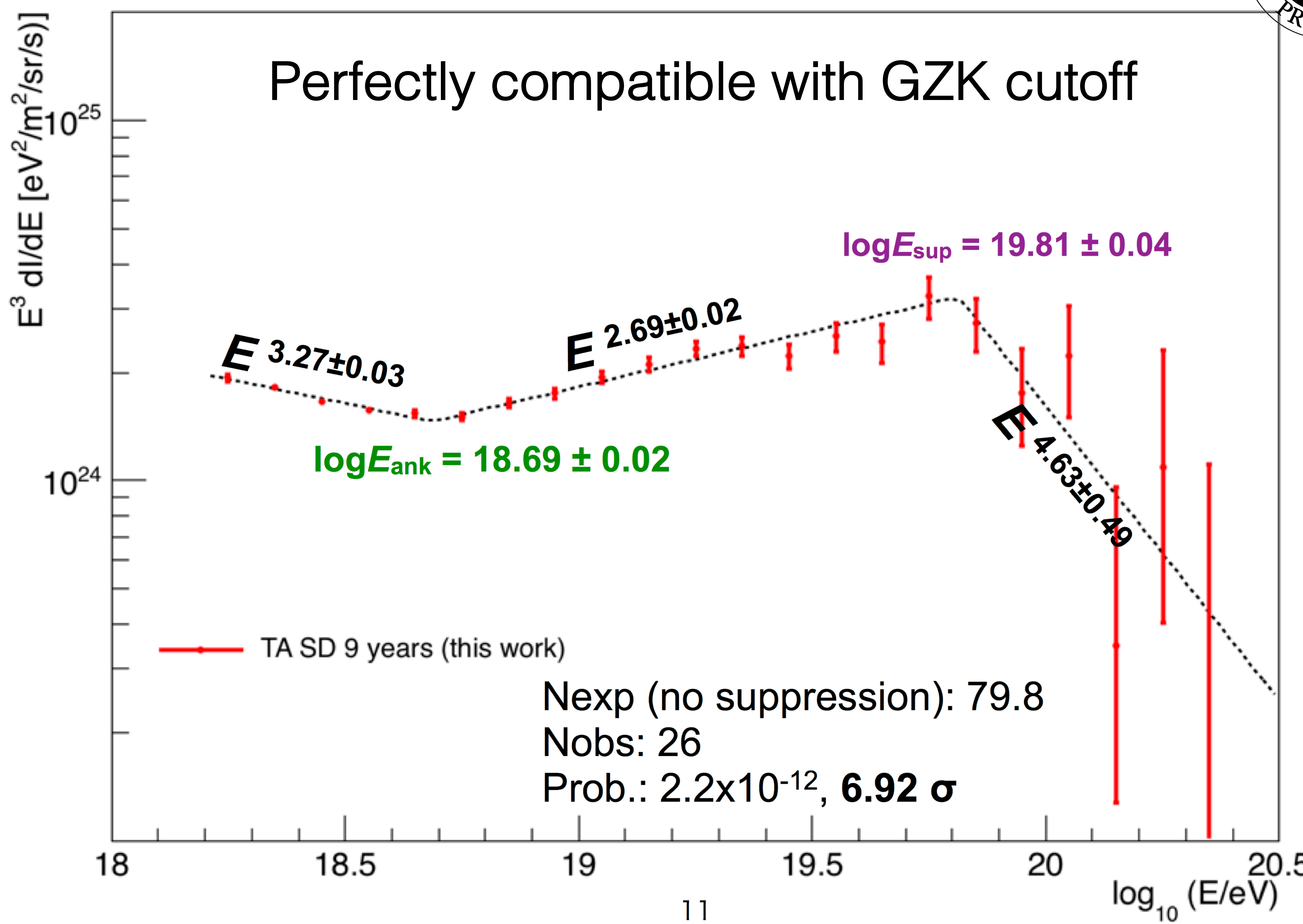
Rescale Auger and TA energies



- Constant rescaling factor of **5.2%**
  - From fitting ratio of fluxes Auger/TA into a unity in the ankle region
  - Auger energies *raised* by 5.2%
  - TA energies *lowered* by 5.2%
- Agree in the ankle region $10^{18.4}$ eV < E < $10^{19.4}$eV after rescaling
- **Difference above $10^{19.4}$ eV persists after locking energy scales of experiments**

8

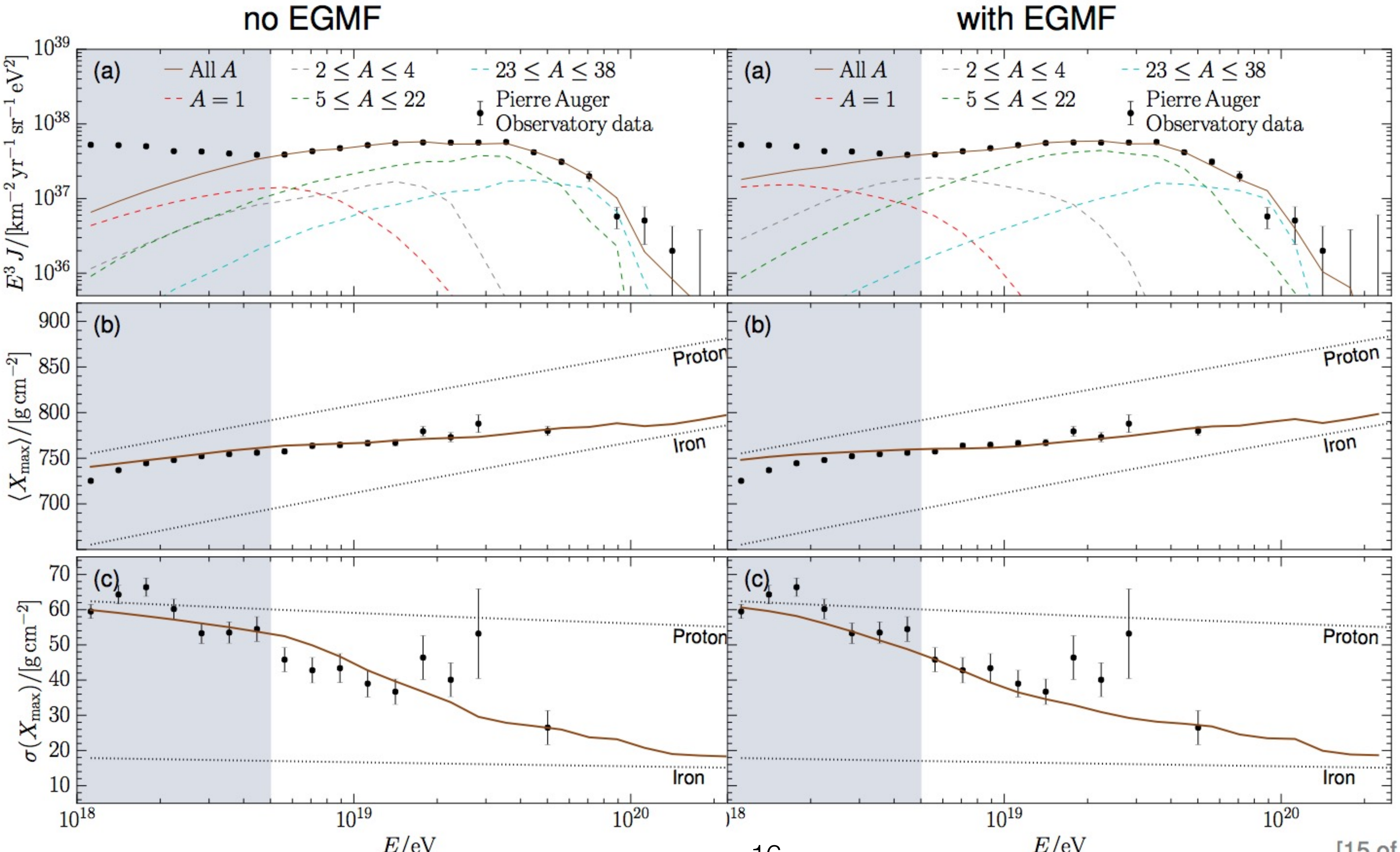
Power-Law Fit



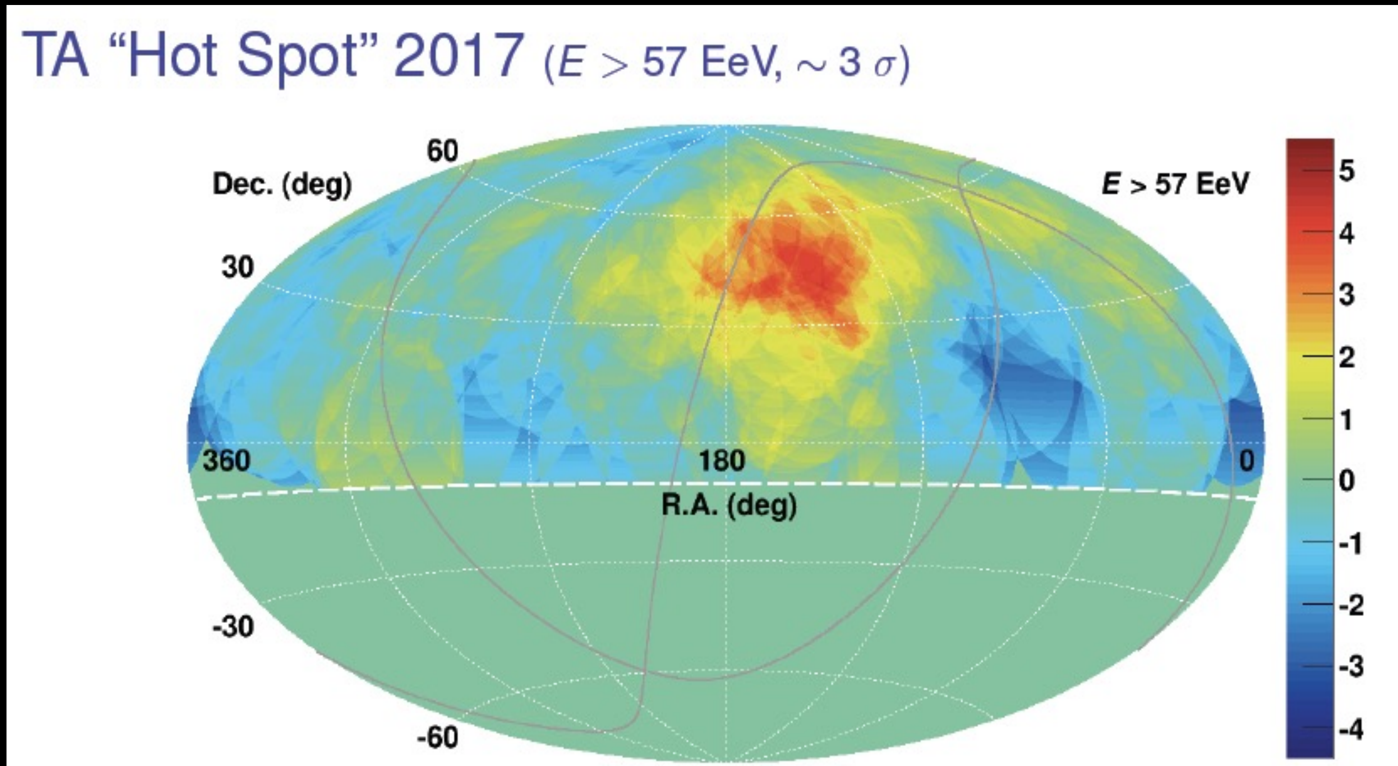
Y. Tsunesada - ICRC 2017

Combined Fit of Spectrum and X_{max} Distributions

rigidity-dependent cutoff at source: $E_{max} = R_{cut}\, Z$, power law injection $E^{-\gamma}$, propagation with CRPropa3, Gilmore12 EBL, Dolag12 LSS



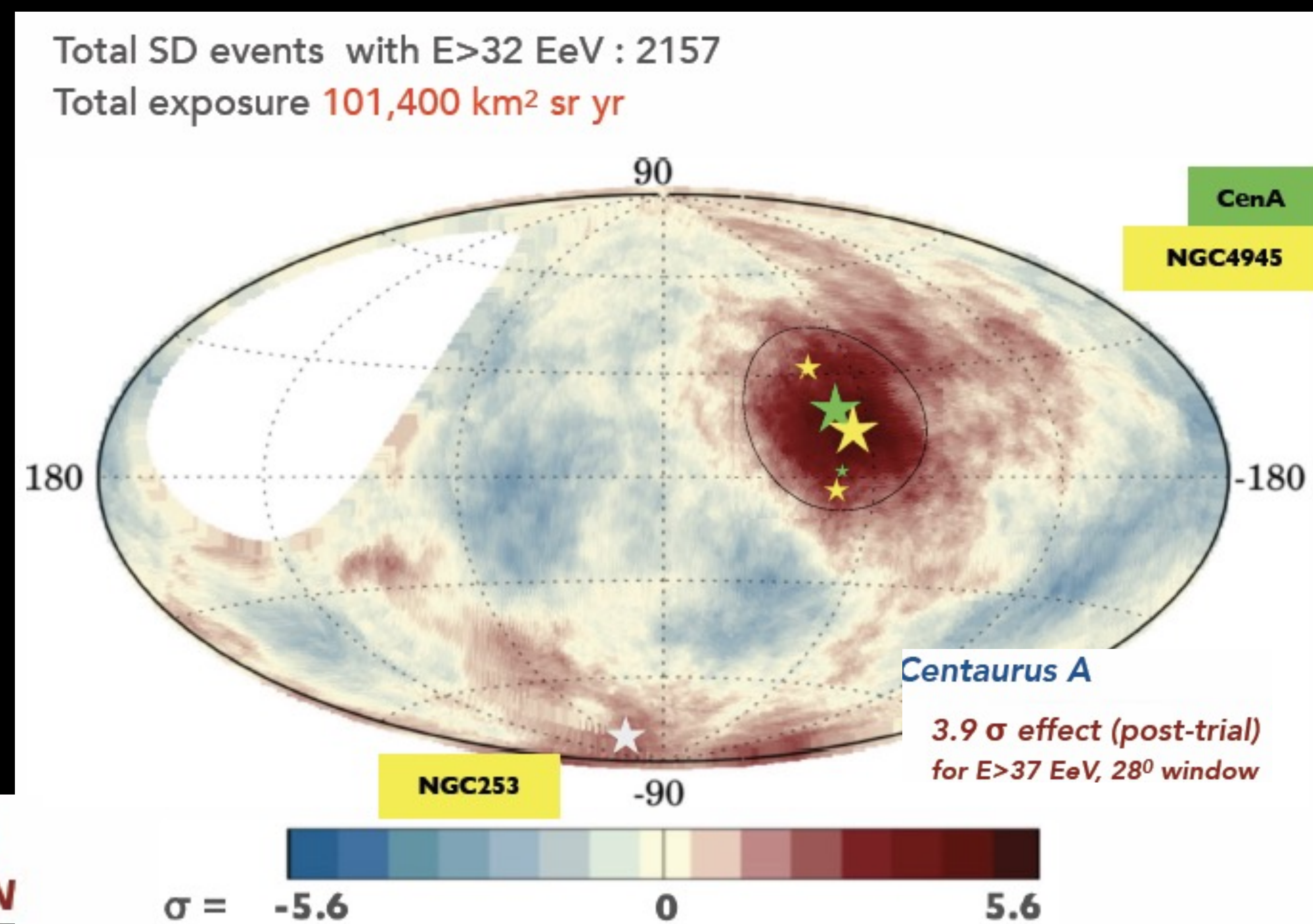
M. Unger - ICRC 2017



TA

Anisotropy hints @ E > 40 EeV

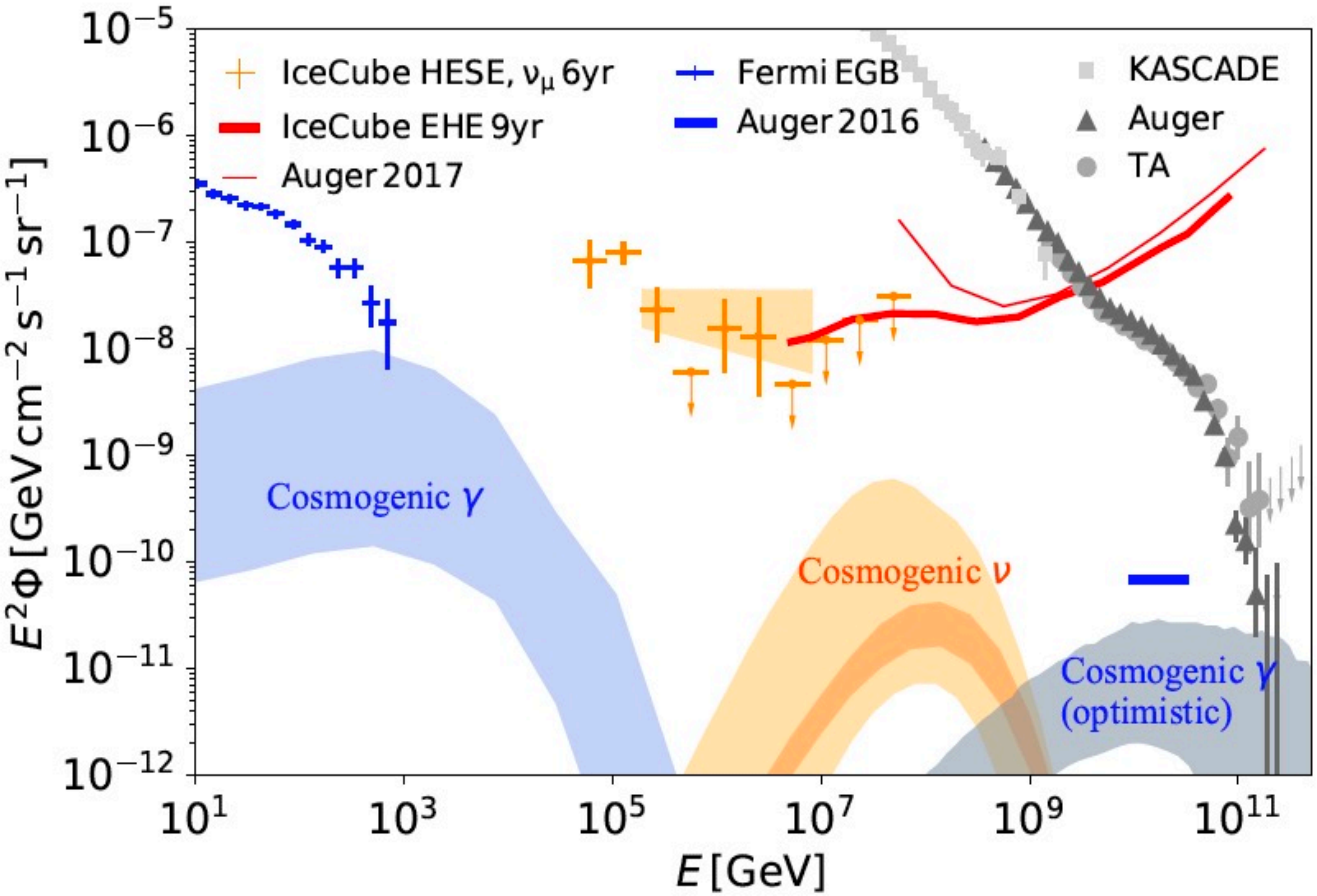
Auger



ICRC2019 — *4.5 σ for SBGs*

[Jan 2004-Aug 2018] — *3.1 σ for γ-AGN*

Cosmogenic Messengers



Batista et al, arXiv:1903.06714.pdf

What makes high-energy cosmic ν exciting?

1. They have the highest energies (TeV–ZeV)
   Particle: Probe physics at new energy scales
   Astro: Probe the highest-energy non-thermal astrophysical sources

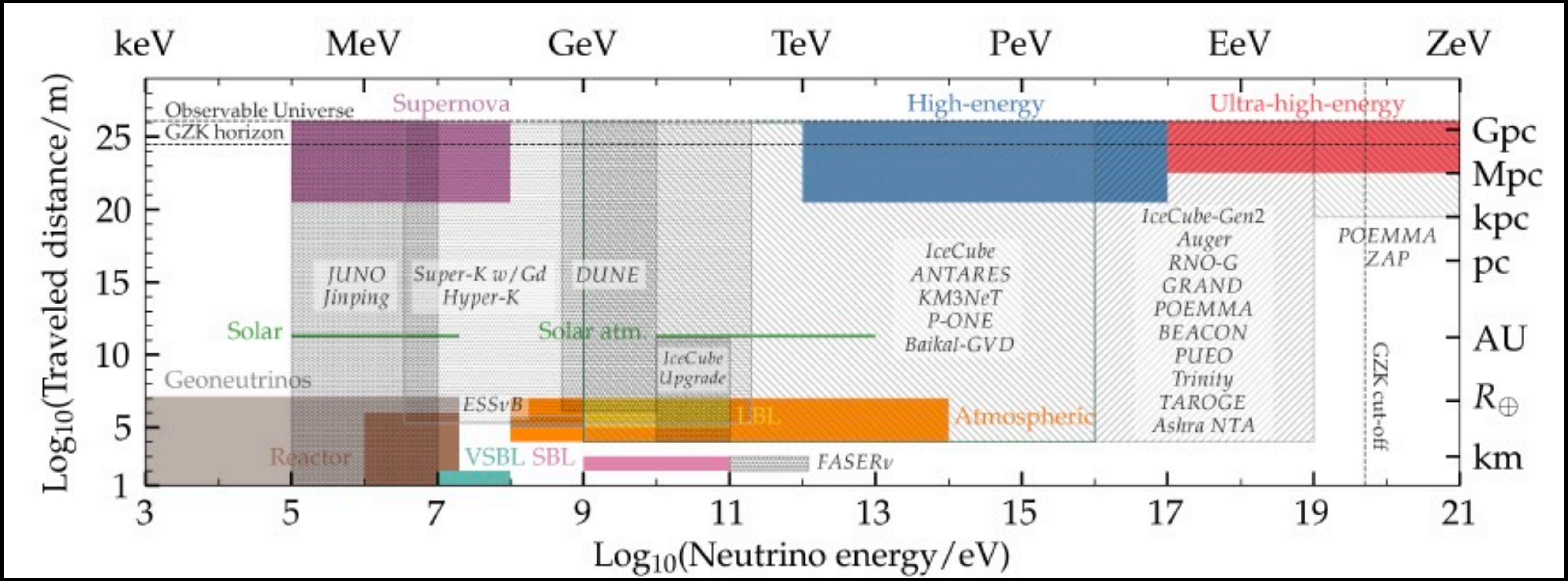
2. They have the longest baselines (kpc–Gpc)
   Particle: Tiny new-physics effects can accumulate and become observable
   Astro: Bring information from high redshifts ($z > 1$)

3. Neutrinos are weakly interacting
   Particle: New-physics effects may stand out more clearly
   Astro: Bring untainted information from distant sources

4. Neutrinos have a unique quantum number: flavor
   Particle: Versatile probe of flavor-sensitive new physics
   Astro: Can reveal the neutrino production mechanism

Energy Threshold and Range

UHE Neutrinos

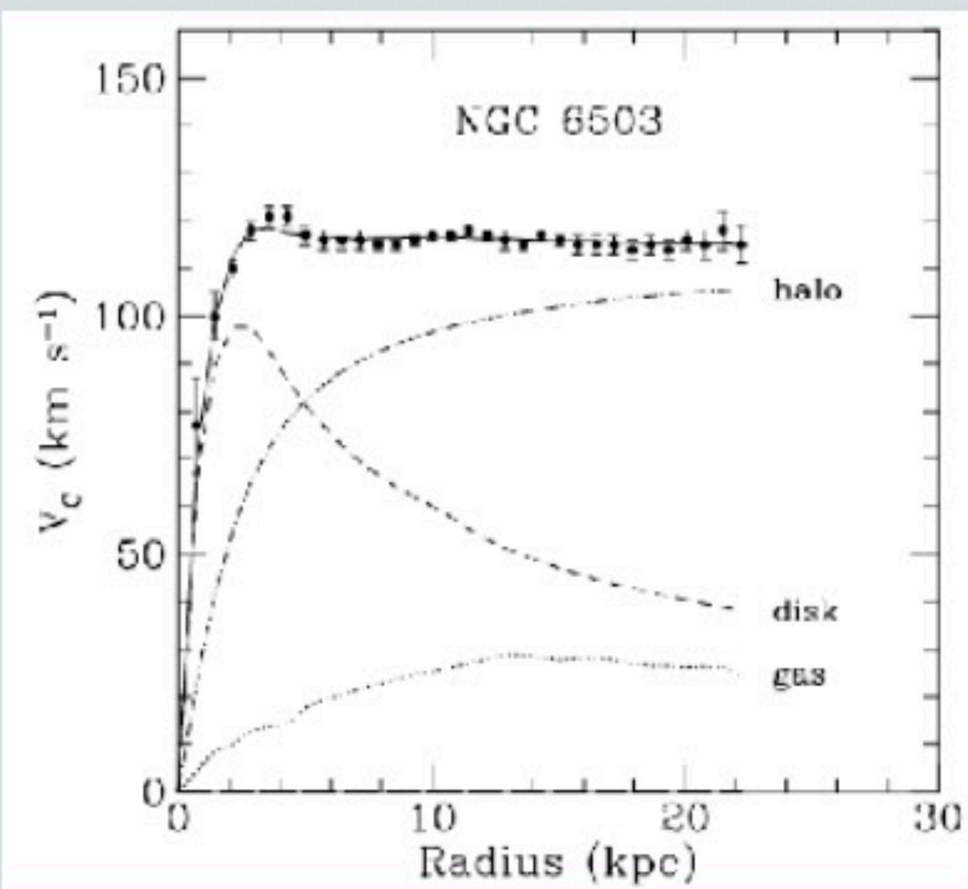


Ackermann, et al, arXiv:1903.04333
Agarwalla et al, Snowmass2021, LOI, (M. Bustamante)

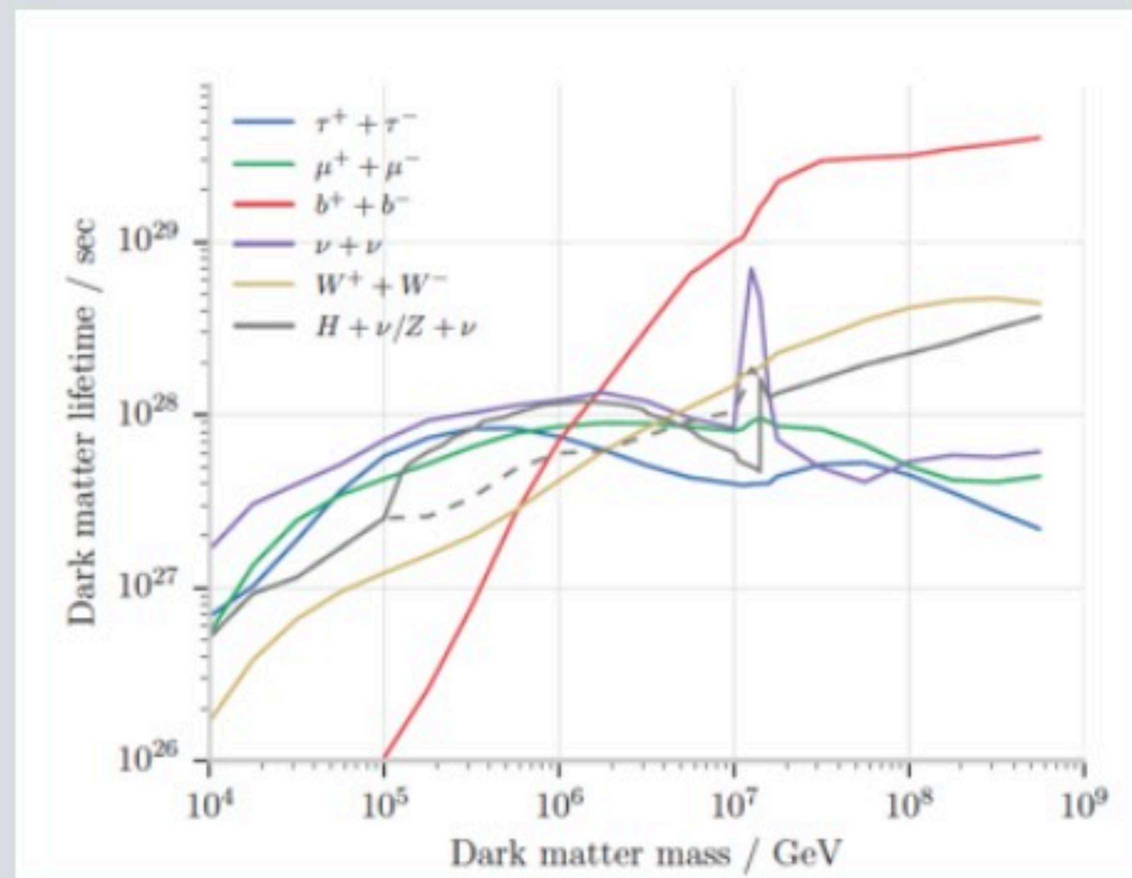
The dark matter problem

- existence firmly established by variety of probes
- but nature still elusive
- various candidates proposed, such as axions, WIMPs, SHDM

- decay or annihilation to cosmic-rays, photons, neutrinos; indirect detection
- at the highest energies, various constraints from IceCube, Auger, Anita

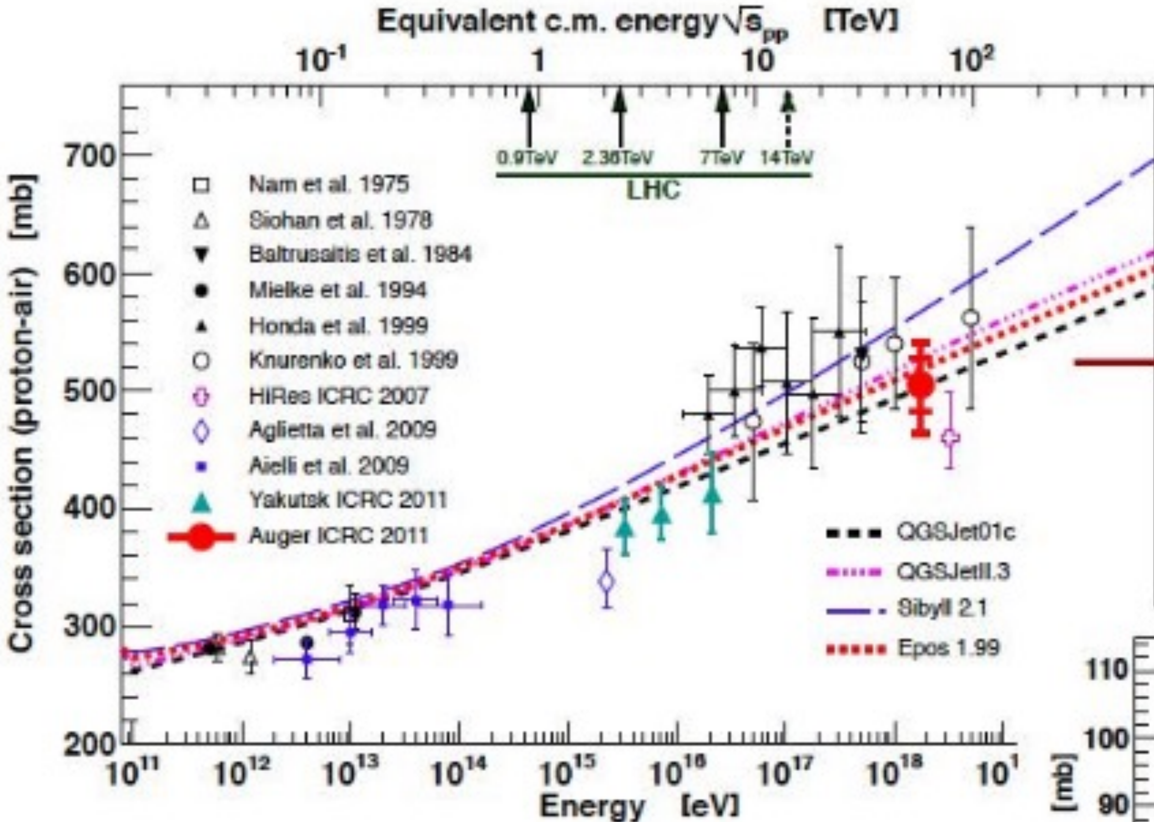


K. Begeman, A. Broeils and R. Sanders, 1991, MNRAS, 249, 523



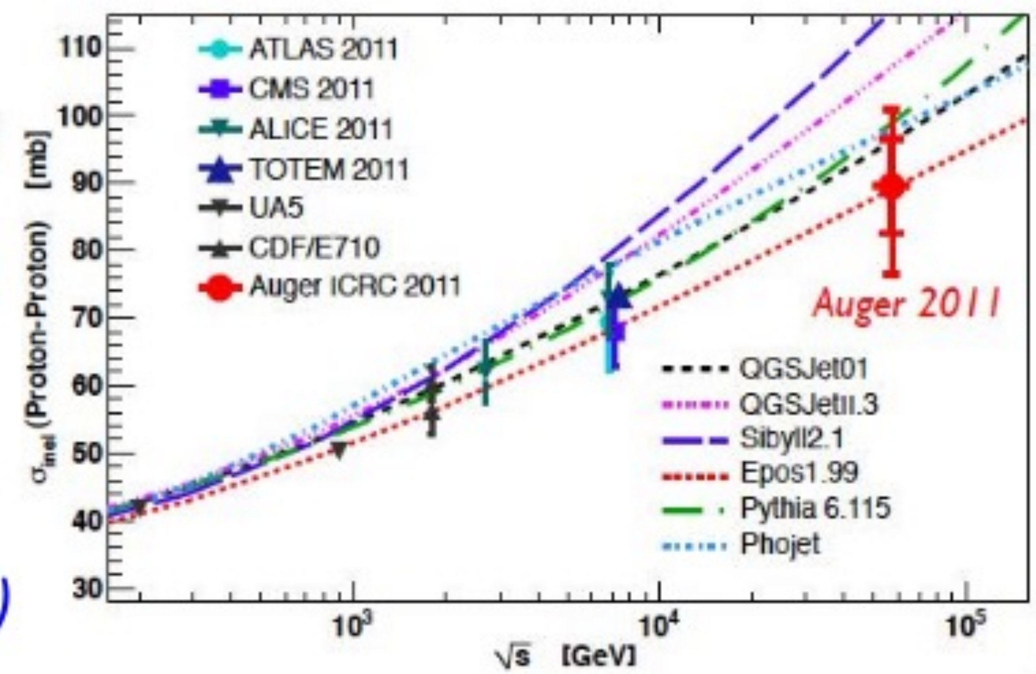
IceCube Collaboration (2018)

The Inelastic Cross-section Results



Conversion from p-air to p-p cross section always model-dependent

Glauber model



σ_{inel} = 73.6 ± 0.6+1.8-1.3mb (TOTEM)

σ_{inel} = 69.1 ± 2.4 ± 6.9 mb. (ATLAS)

At 60 TeV

σ_{inel} = 92 ± 7 + 9 -11 ± 7 mb. (AUGER)

- *ATLAS & CMS x-section slightly lower than TOTEM's & ALICE's*
- *The EPOS1.99 model describes the rise in the cross-section out to 60 TeV (Auger)*

Pinfold, ICRC 2013

How many UHECRs > 60 EeV?

- Auger w/ 3,000 km^2
- ~25 events > 60 EeV/ yr
- Telescope Array w/ 700 km^2
- ~5 events > 60 EeV/ yr
- Auger + TA ~ 30 events/yr

5 o.o.m to go!

- Earth - surface ~ $5\ 10^8$ km^2

~$3.4\ 10^6$ events/yr

Go to SPACE!

To look down on the

Atmosphere!

How many UHECRs > 60 EeV?

- Auger + TA ~30 events/yr

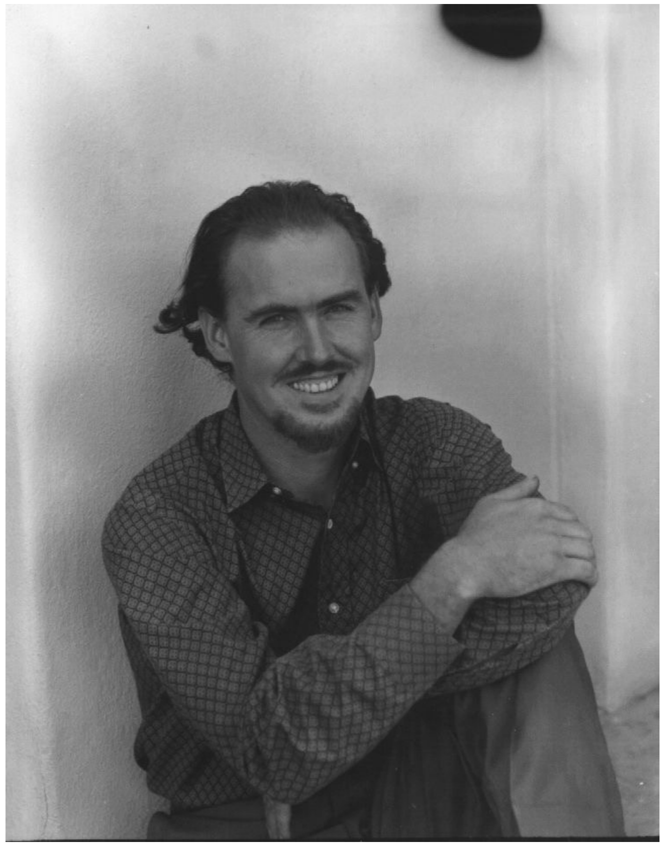
- **POEMMA**
- **~300 events > 60 EeV/y**

4 o.o.m to go!

- Earth - surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

1979, An idea* of John Linsley



John Linsley in 1979 in the Field Committee Report of NASA "Call for Projects and Ideas in High Energy Astrophysics for the 1980s"

The concept to observe, by means of Space Based devices looking at Nadir during the night, the fluorescence light produced by an EAS proceeding in the atmosphere

Y. Takahashi (1995): MASS: Maximum Energy Auger (Air Shower Satellite Italian Mission)

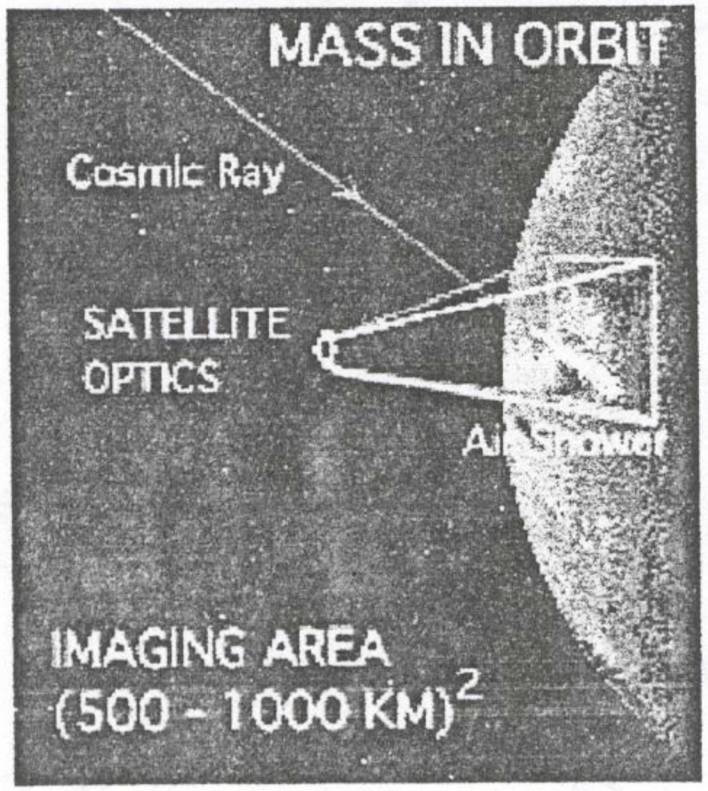
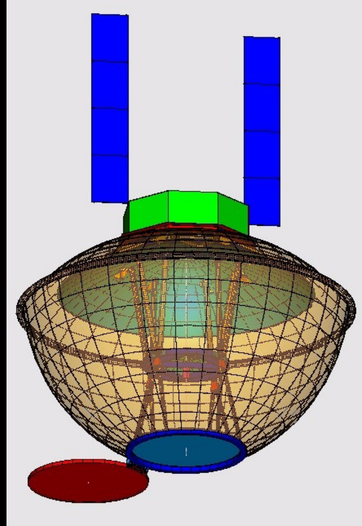


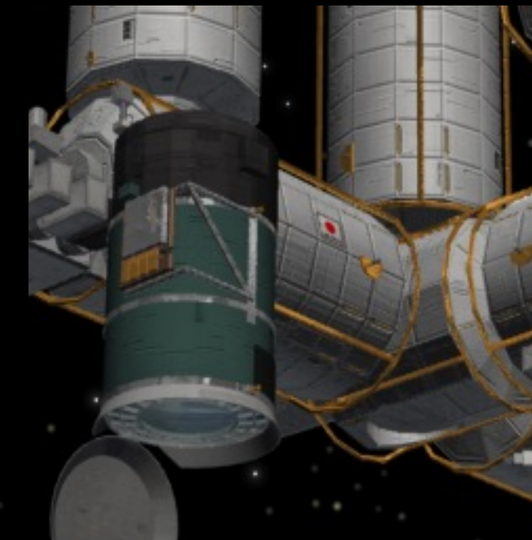
Fig. 3 Artist view of the MASS on orbit.



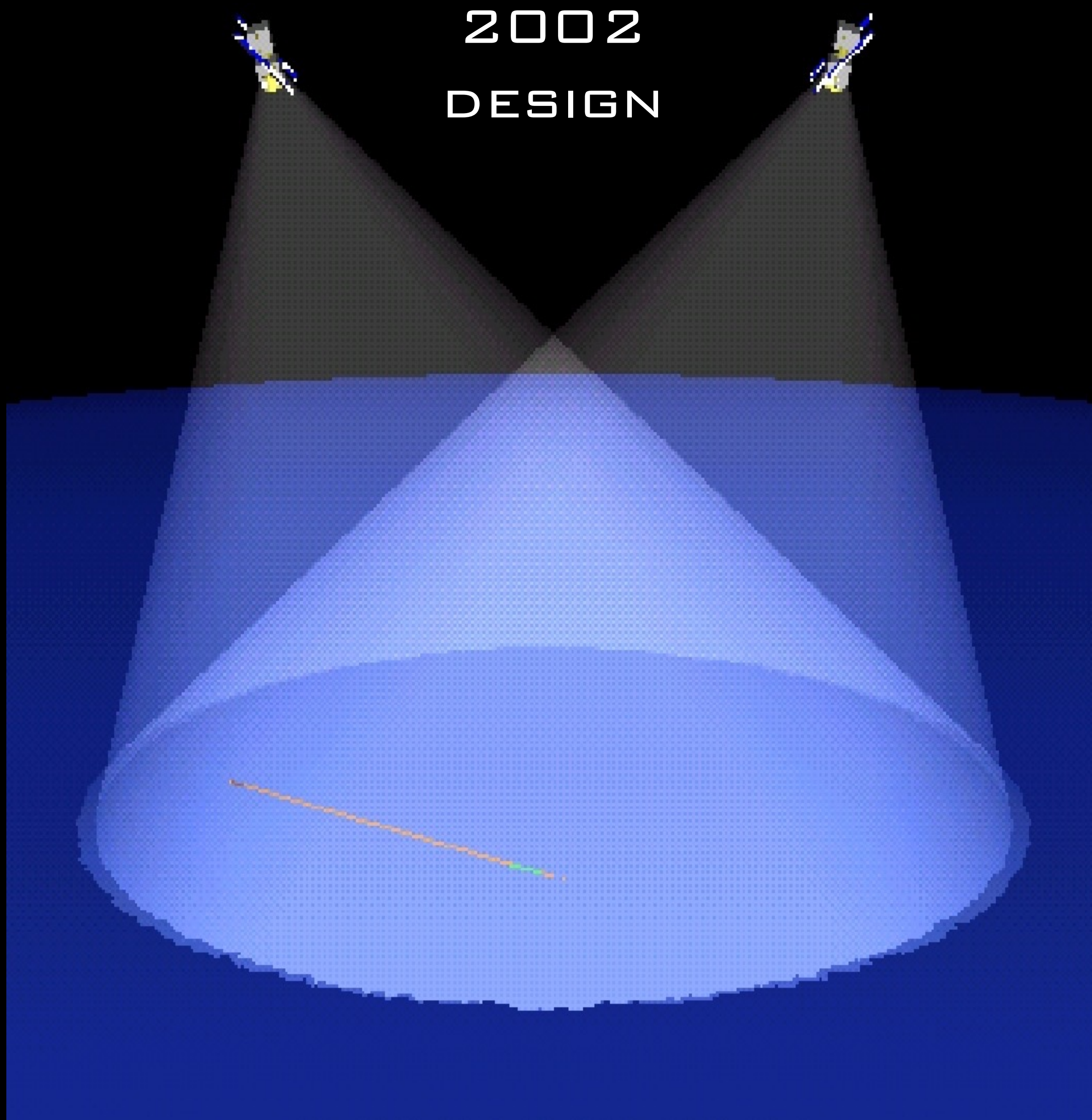
Orbiting
Wide-angle
Light-collectors

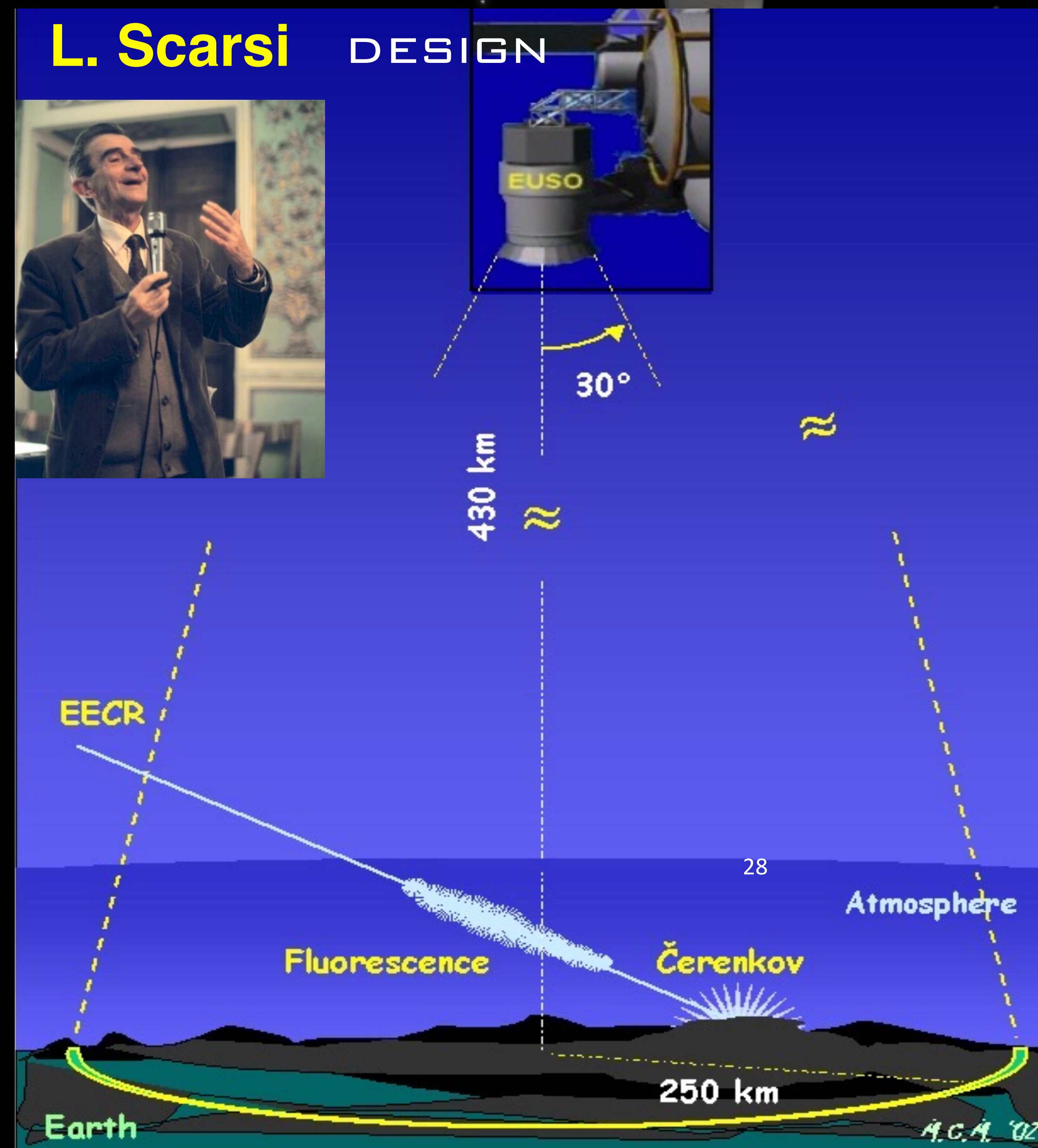
Extensive Air-shower Fluorescence from SPACE

EUSO
2002

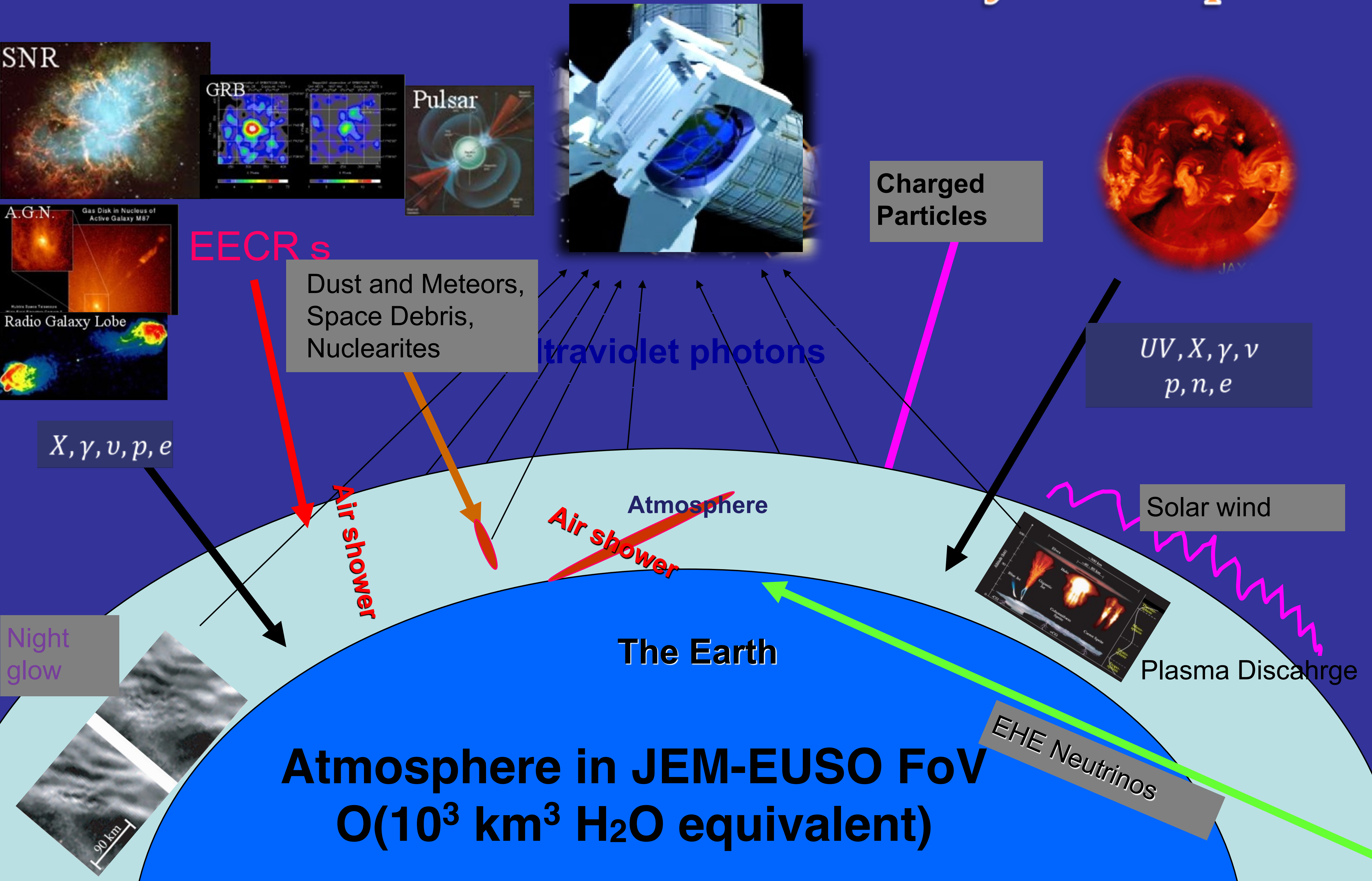


OWL
2002
DESIGN





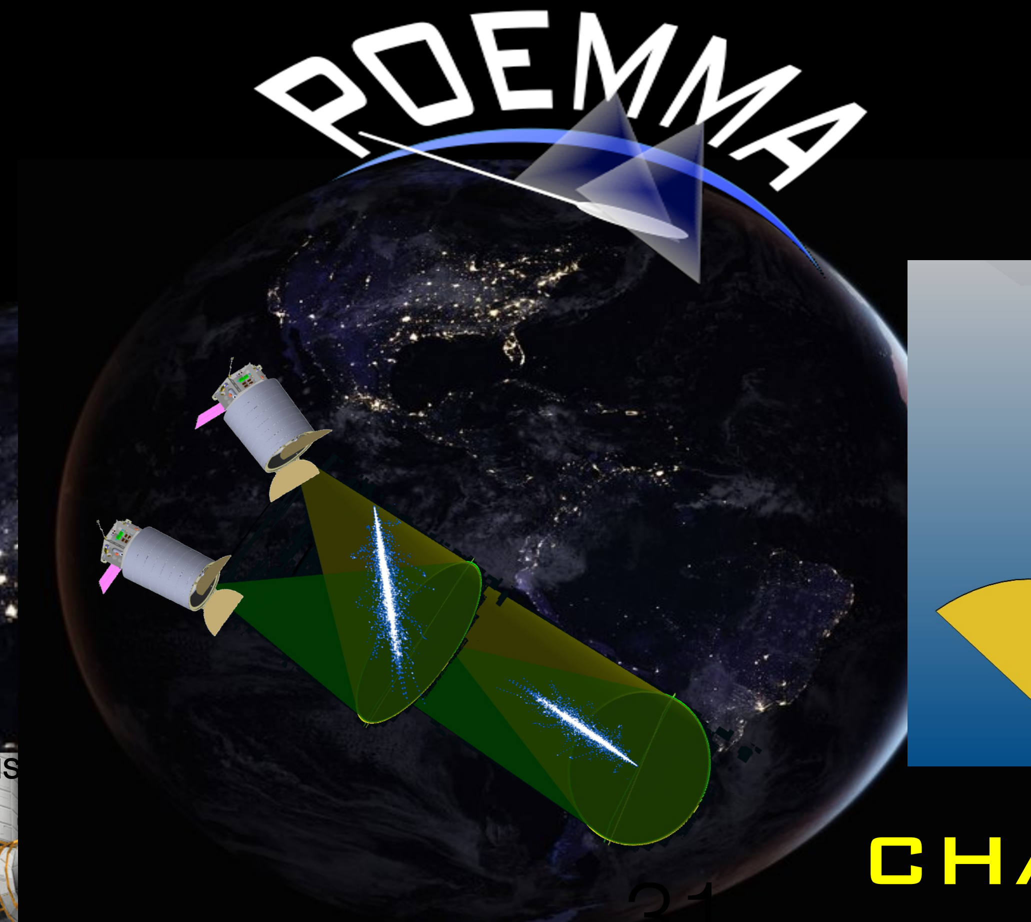
JEM-EUSO is
an Astronomical Earth Observatory from Space



Probe Of Extreme Multi-Messenger Astrophysics

UHECRs and Cosmic Neutrinos

POEMMA: Probe of Extreme Multi-Messenger Astrophysics



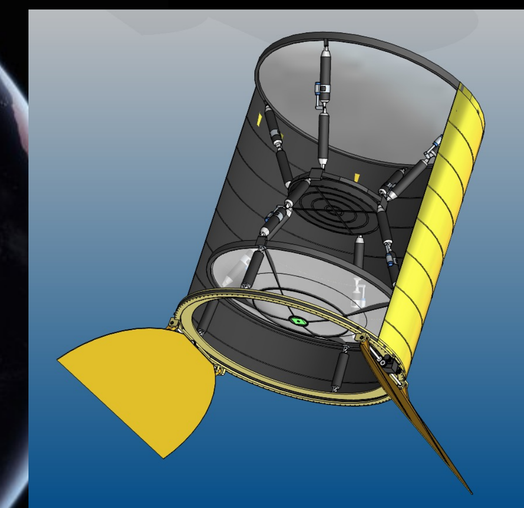
POEMMA Design based on:

OWL and JEM-EUSO studies,

EUSO balloon experience,

& CHANT concept

+ Legacy in Fluorescence from Ground



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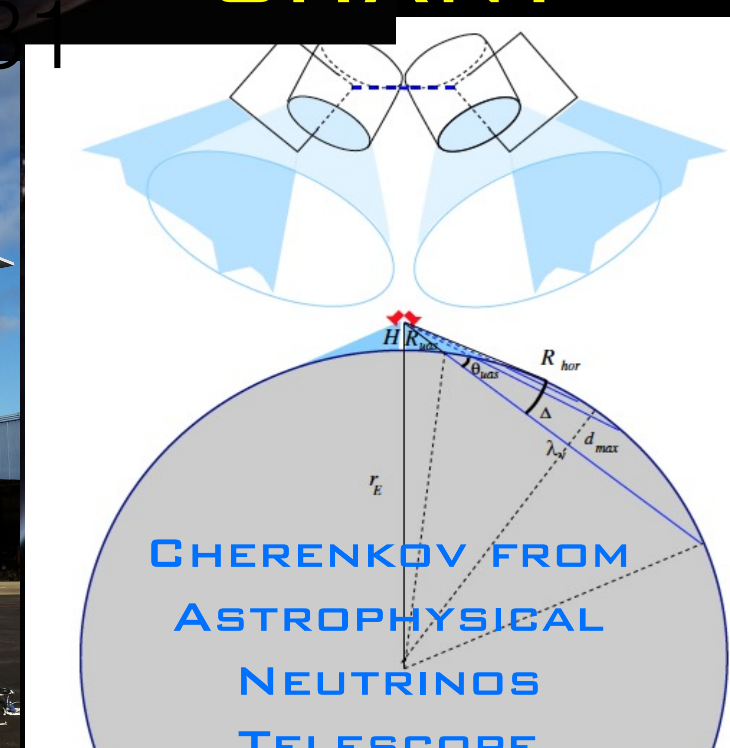


JEM-EUSO PROGRAM

EUSO-TA (2013-)

EUSO-Balloon (2014)

TUS (2016)

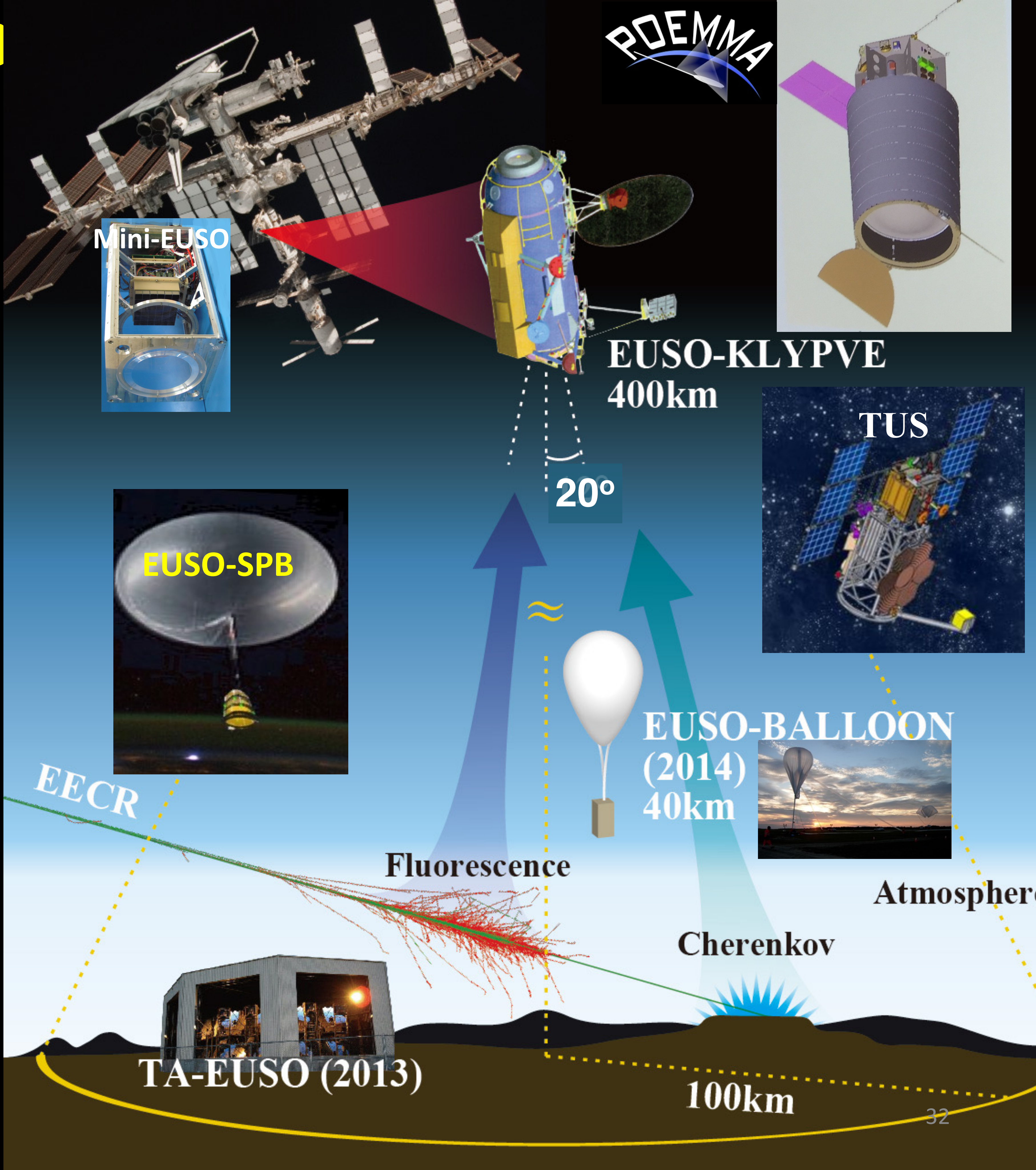
EUSO-SPB1 (2017)

Mini-EUSO (2019)

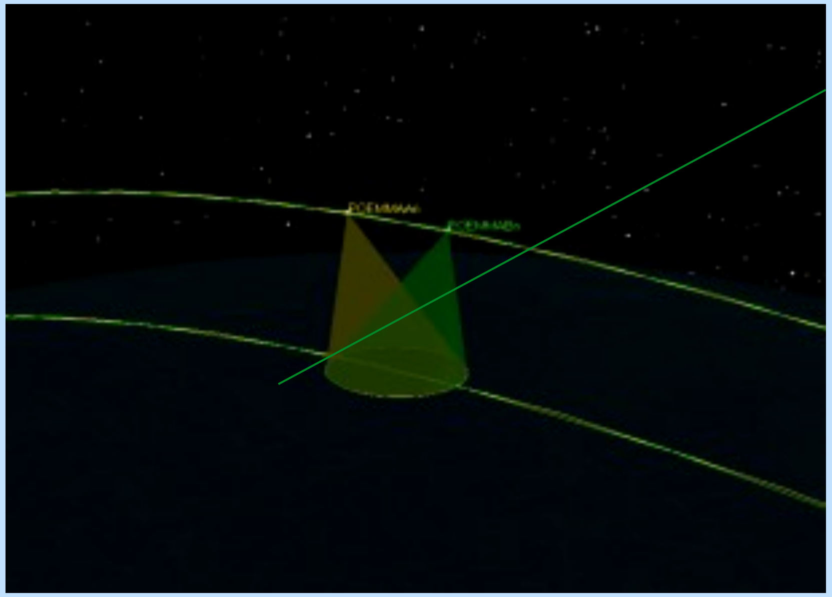
EUSO-SPB2 (2023)

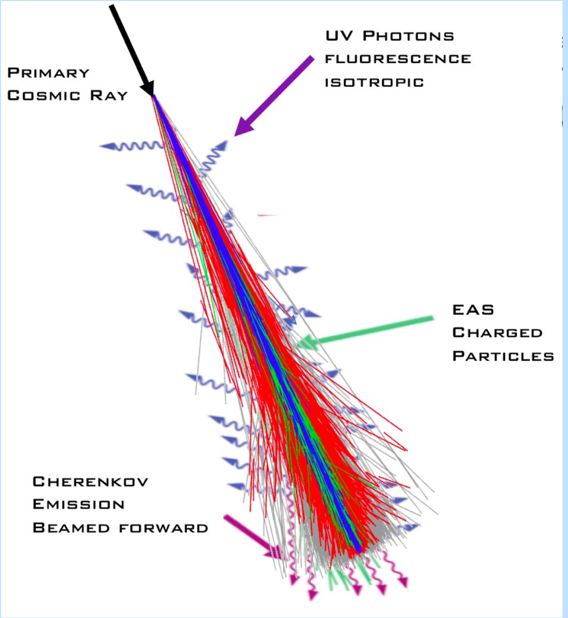
K-EUSO (2024+)

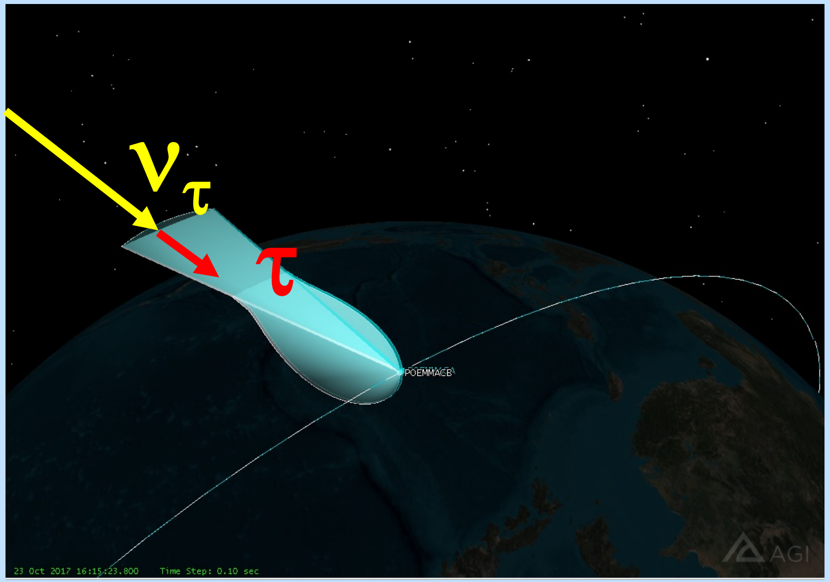
POEMMA (2028+)



Mission Concept







Stereo Viewing of UHECRs E ≳ 20 EeV
via Fluoresence: 10's of μsec timescale

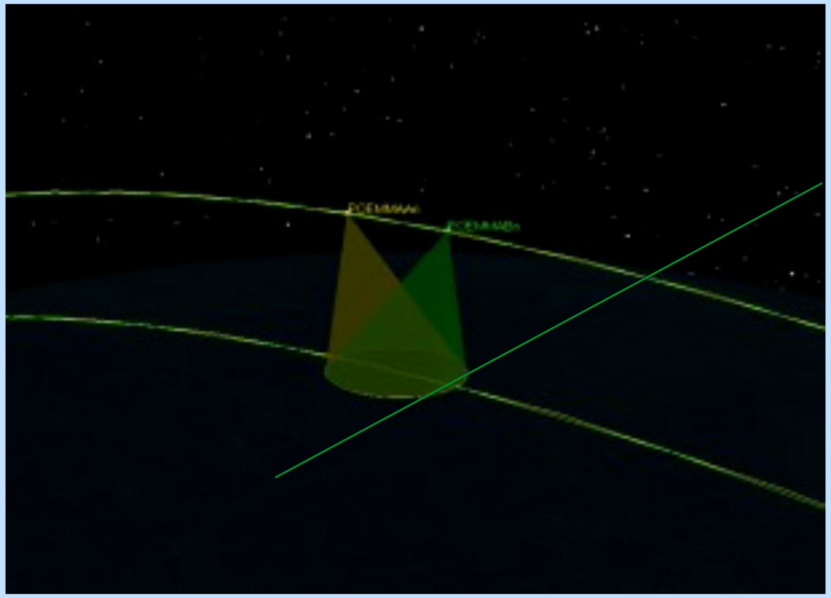
Upward τ-lepton EAS E ≳ 20 PeV
via Cherenkov: ~10 nsec timescale

POEMMA & Mission Description:
Summary of results presented in arXiv:2012.07945

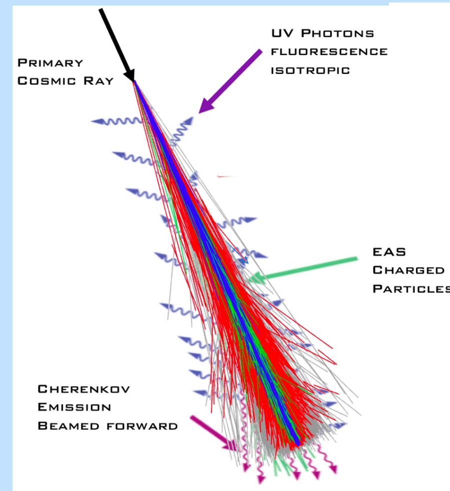
POEMMA UHECR & *UHE Neutrino Performance via air fluorescence* measurements.
Summary of results presented in PhysRevD.101.023012

POEMMA *VHE Neutrino Performance via optical Cherenkov measurements*.
Summary of results presented in PhysRevD.100.063010 and PhysRevD.102.123013

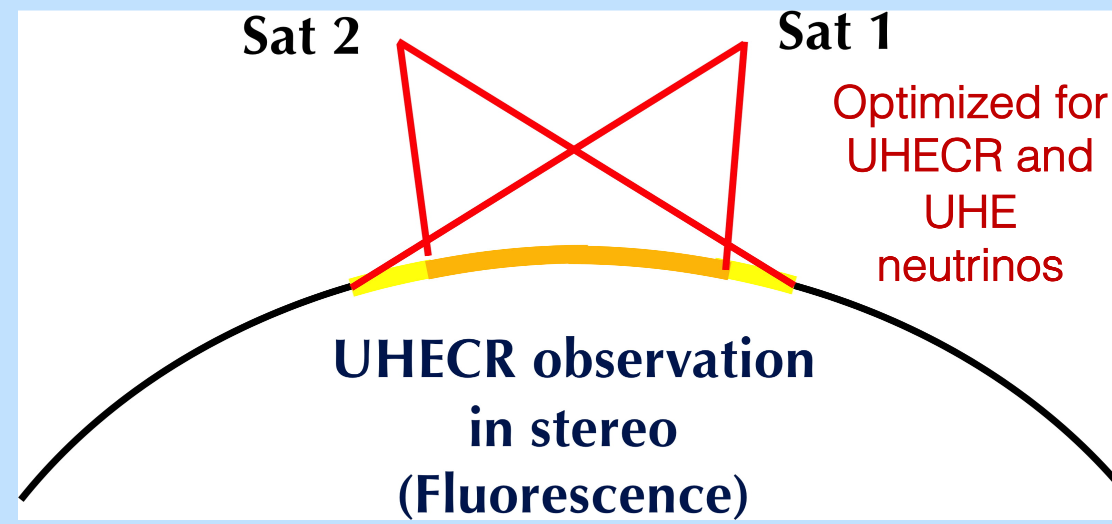
POEMMA Operational Modes: UHECR Stereo versus Limb-viewing Neutrino

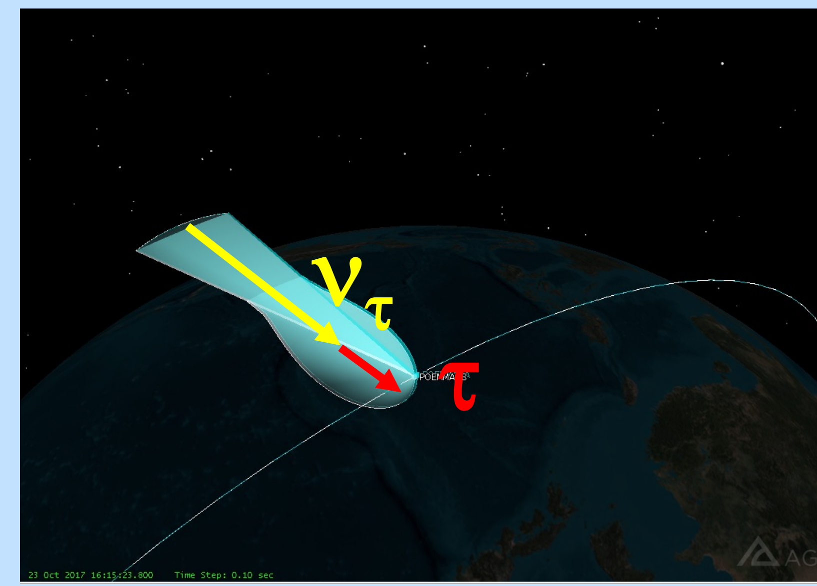


Stereo Viewing of UHECRs E ≳ 20 EeV
via Fluoresence: 10’s of μsec timescale

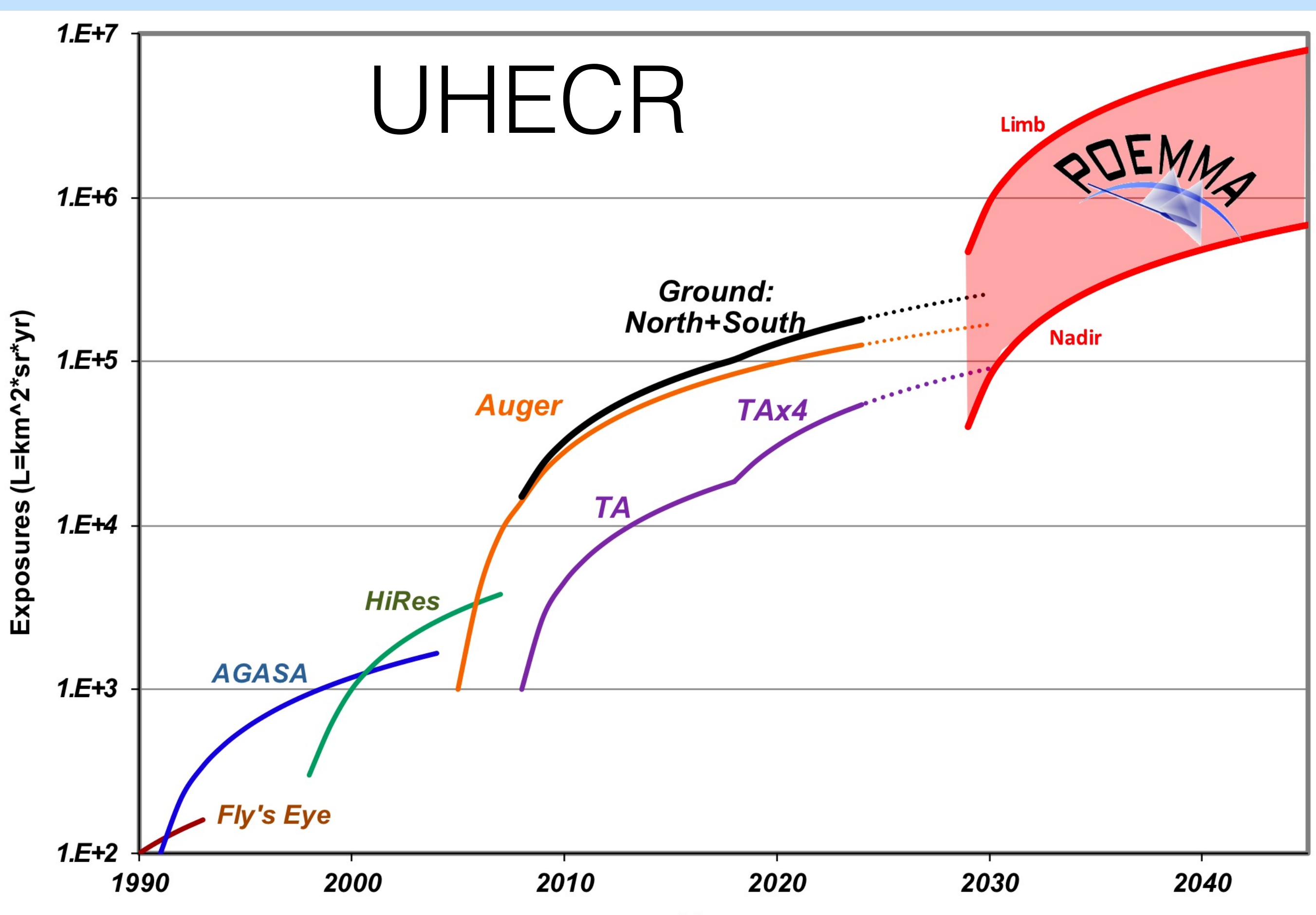


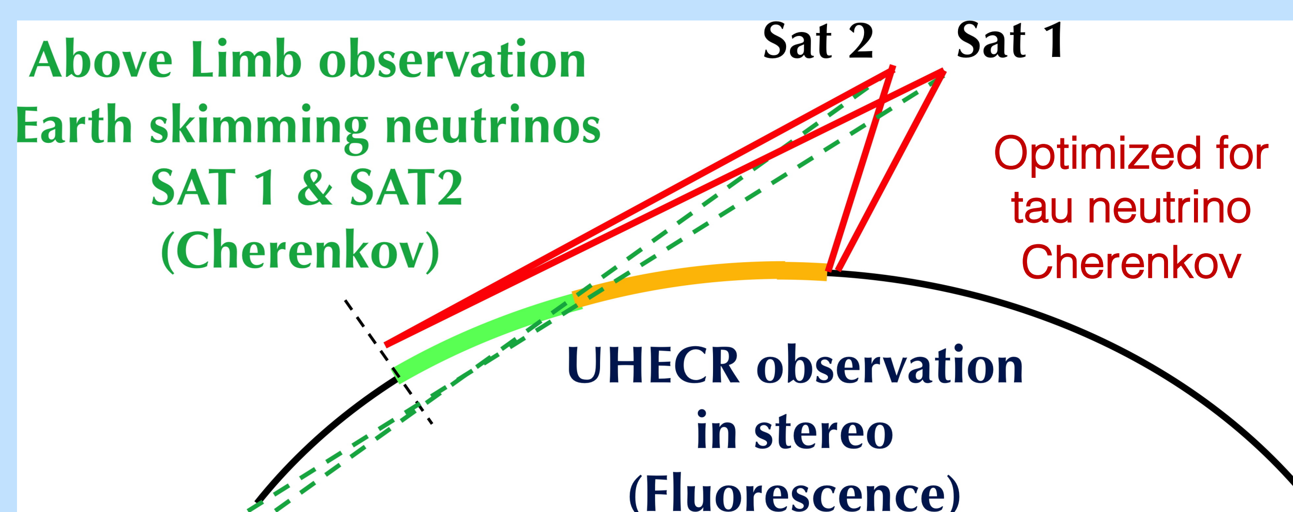
Dark, quasi-moon less nights:
Fluorescence Duty Cycle: 11%
Cherenkov Duty Cycle: 20%



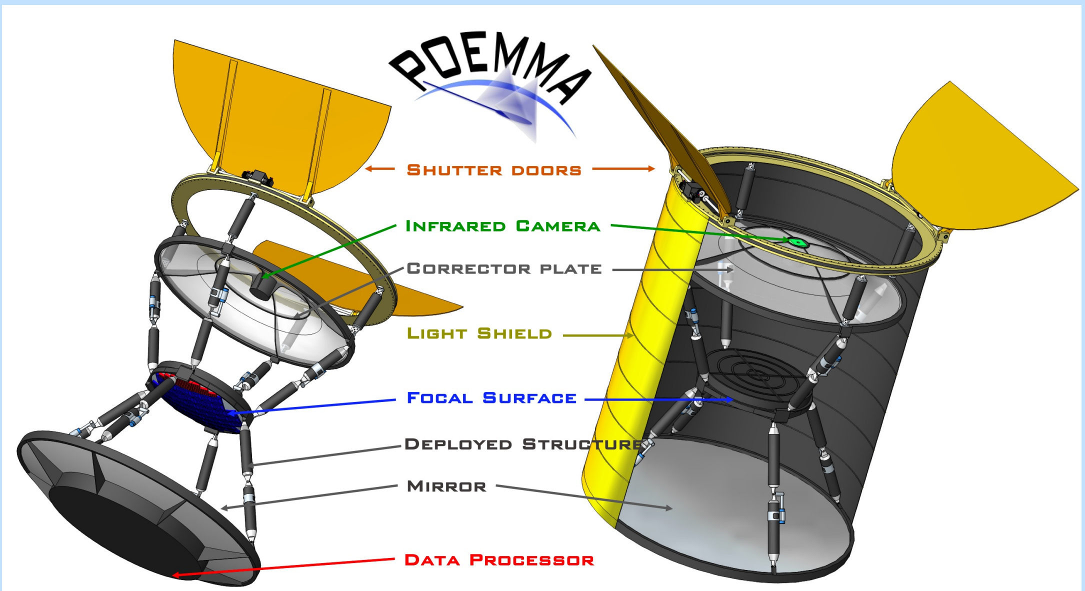


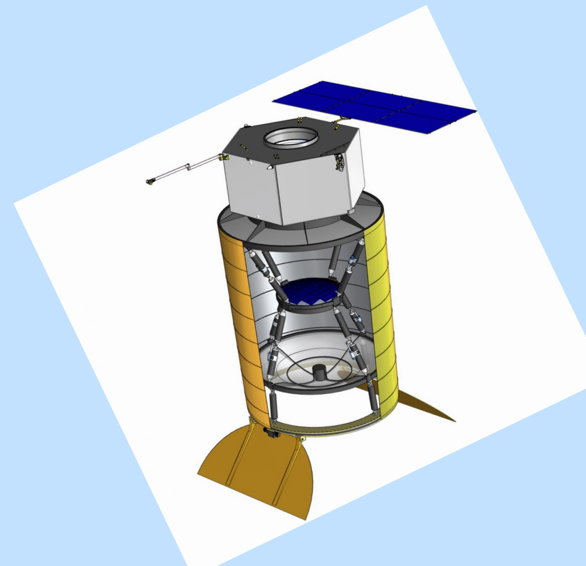
Upward τ-lepton EAS E ≳ 20 PeV
via Cherenkov: ~10 nsec timescale





POEMMA: Instruments defined by weeklong IDL run at GSFC





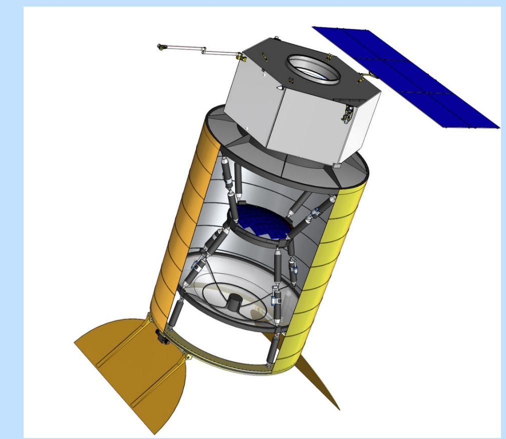
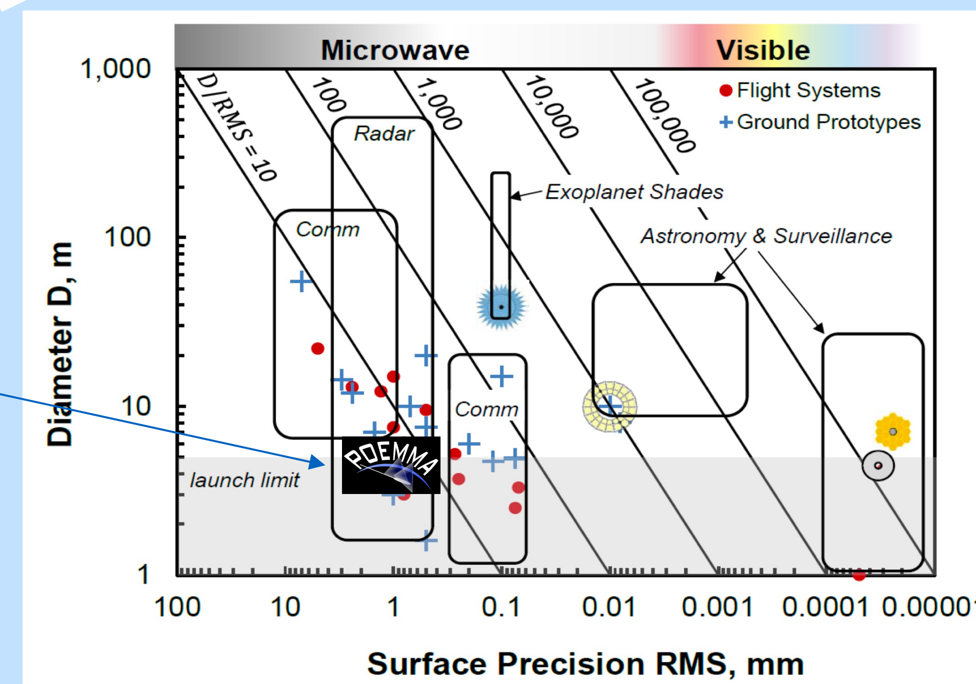


TABLE I: POEMMA Specifications:

Photometer	Components		Spacecraft	
Optics	Schmidt	45° full FoV	Slew rate	90° in 8 min
	Primary Mirror	4 m diam.	Pointing Res.	0.1°
	Corrector Lens	3.3 m diam.	Pointing Know.	0.01°
	Focal Surface	1.6 m diam.	Clock synch.	10 nsec
	Pixel Size	3 × 3 mm^2	Data Storage	7 days
	Pixel FoV	0.084°	Communication	S-band
PFC	MAPMT (1μs)	126,720 pixels	Wet Mass	3,450 kg
PCC	SiPM (20 ns)	15,360 pixels	Power (w/cont)	550 W
Photometer	(One)		Mission	(2 Observatories)
	Mass	1,550 kg	Lifetime	3 year (5 year goal)
	Power (w/cont)	700 W	Orbit	525 km, 28.5° Inc
	Data	< 1 GB/day	Orbit Period	95 min
			Observatory Sep.	~25 - 1000+ km

Each Observatory = Photometer + Spacecraft; POEMMA Mission = 2 Observatories

o Neutrino Telescopes

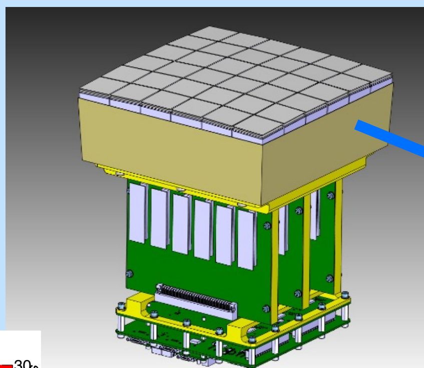


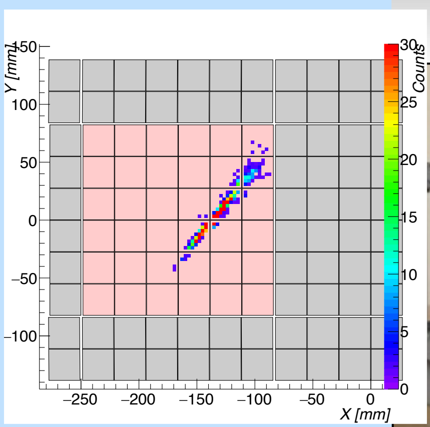
Imaging ~10^4 away from diffraction limit

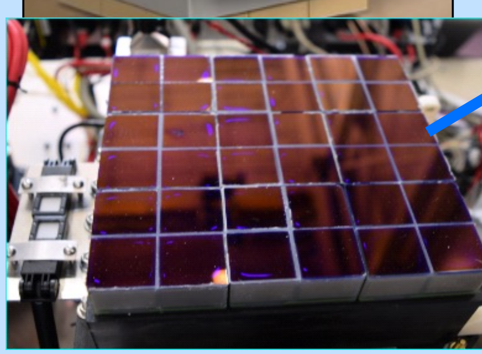
POEMMA: Hybrid Focal Plane

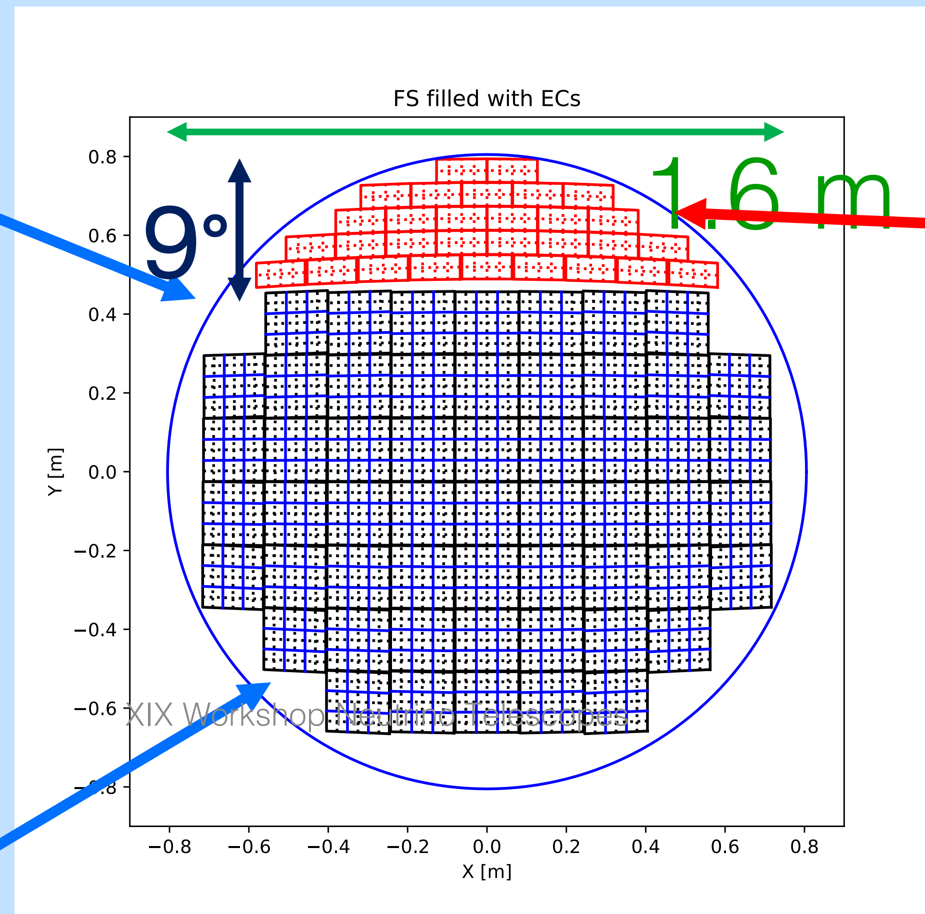
UV Fluorescence Detection using MAPMTs with BG3 filter (300 – 500 nm) developed by JEM-EUSO: 1 usec sampling

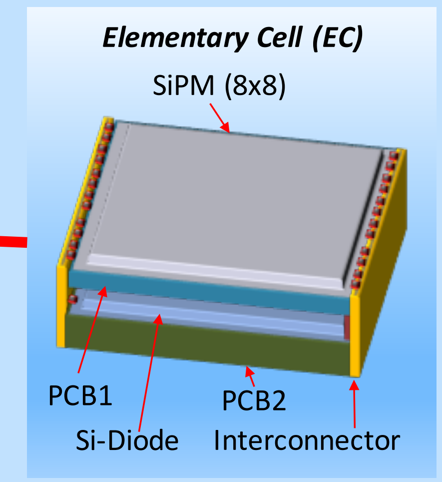
Cherenkov Detection with SiPMs (300 – 1000 nm): 20 nsec sampling









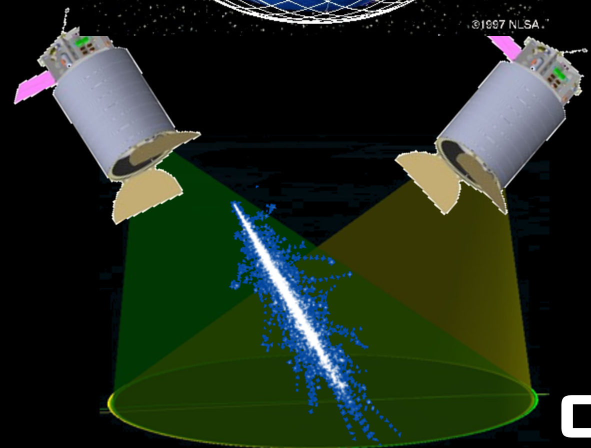


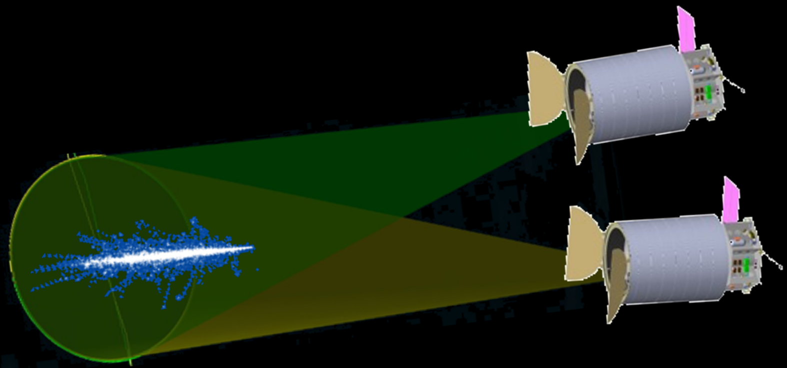
30 SiPM focal surface units
Total 15,360 pixels
512 pixels per FSU (64x4x2)
Si-Diode for LEO radiation backgrounds rejection

55 Photo Detector Modules (PDMs)= 126,720 pixels

1 PDM = 36 MAPMTs = 2,304 pixels

POEMMA

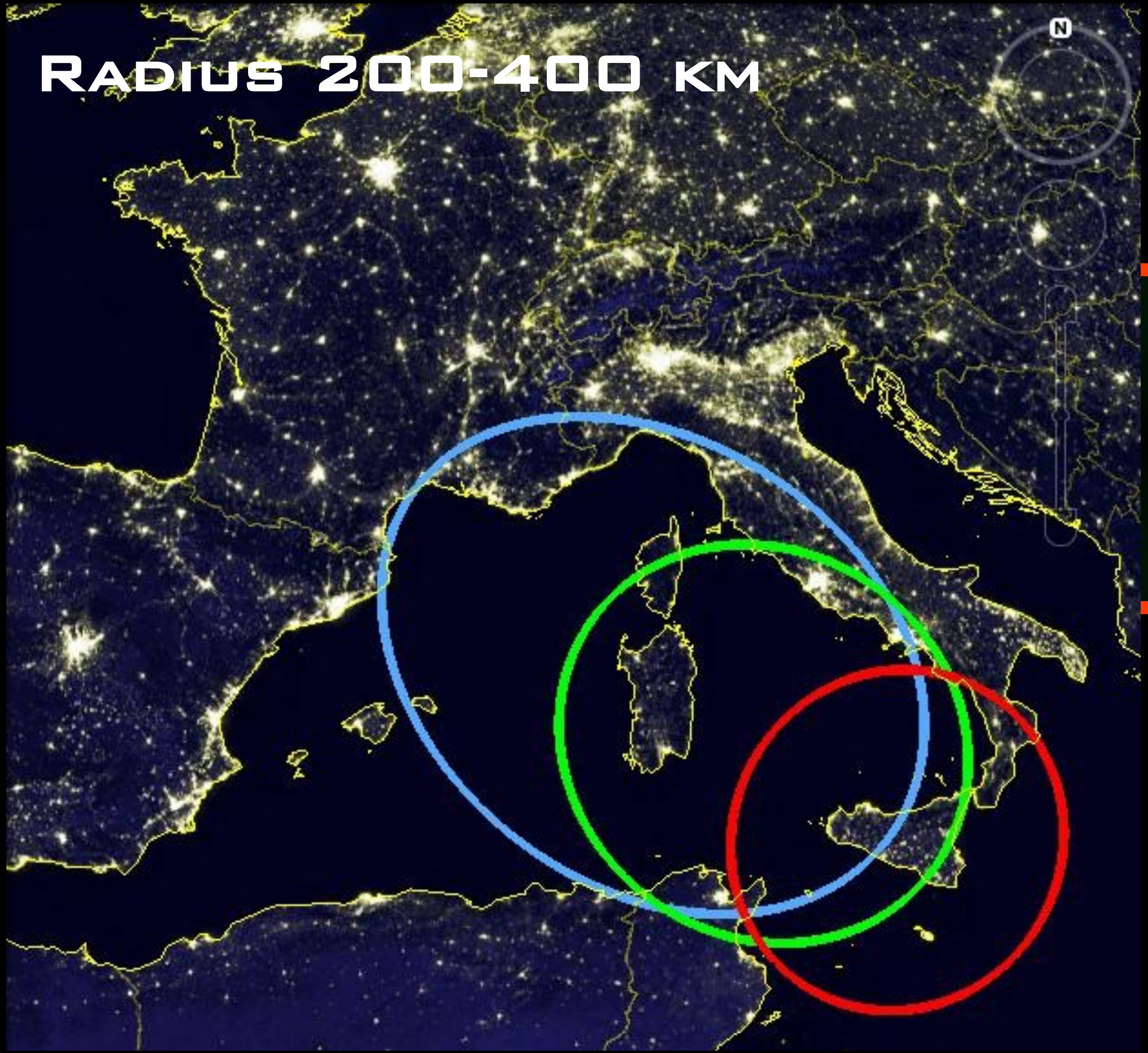




Observing Modes

Nadir for UHECR:

Radius 200-400 km



Limb for Neutrinos & UHECRs

Radius $2.6\text{-}3.7 \cdot 10^3$ km

Scientific challenges:

- Energy threshold below GZK cutoff (a factor of 2 higher energies means very few statistics and no inter calibration with ground 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.
- We need to test the capability of the instrument to adapt its working conditions to the different situations.
- We need to record and recognise the different atmospheric and anthropogenic conditions.

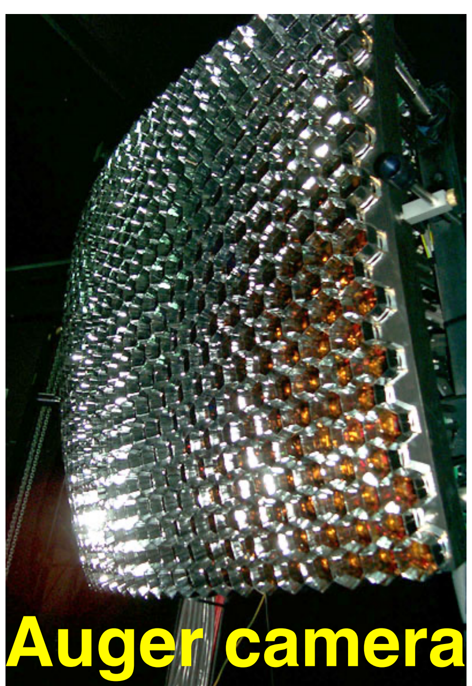
Technological challenges:

- Low power consumption (<1kW for POEMMA single tel. - >10^5 pixels)
- Low mass (~1.5 tons for POEMMA single tel.))
- Low telemetry (1 GB/day for POEMMA single tel.)
- Radiation hard instrumentation
- Space-qualified instrumentation (need to increase TRL)

Comparing Auger FD and POEMMA telescopes

	Auger (1 FD site)	EUSO-Balloons/TA	JEM-EUSO
mirror size	**6 x 11 m^2**	**1 m^2 lens**	**8.5 m^2**
FoV	6 x (30 x 30) deg^2	11 x 11 deg^2	4 x 4 deg^2/PDM
Ang. resolution	1.5 deg/pixel	0.2 deg/pixel	0.084 deg/pixel
Pixel size	**5x5 cm^2**	**3x3 mm^2**	**3x3 mm^2**
Camera size	6 x 440 pixels	2304 pixel	2304 pixel/PDM
EAS distance	40 km	1- 30 km	525 km
light intensity (@40km=1)	**1**	**>1**	**0.006**
time resolution	**100 ns**	**2.5 μs**	**1 μs**
signal acquisition	**charge integration**	**photon counting**	**photon counting**

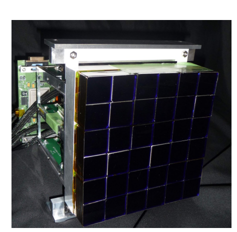
~1.2 m^2



Auger camera

~1.0 m^2

~0.03 m^2

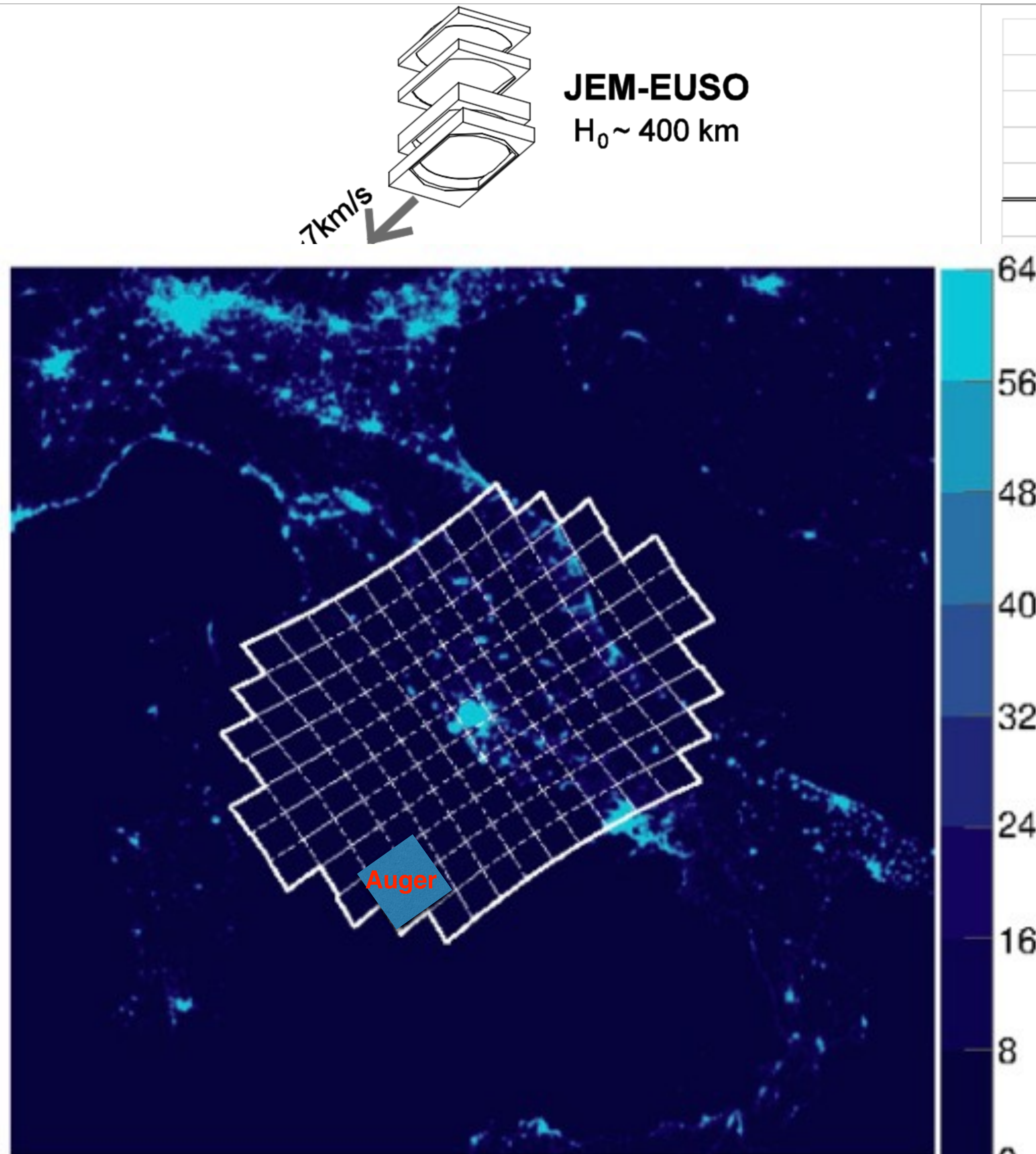


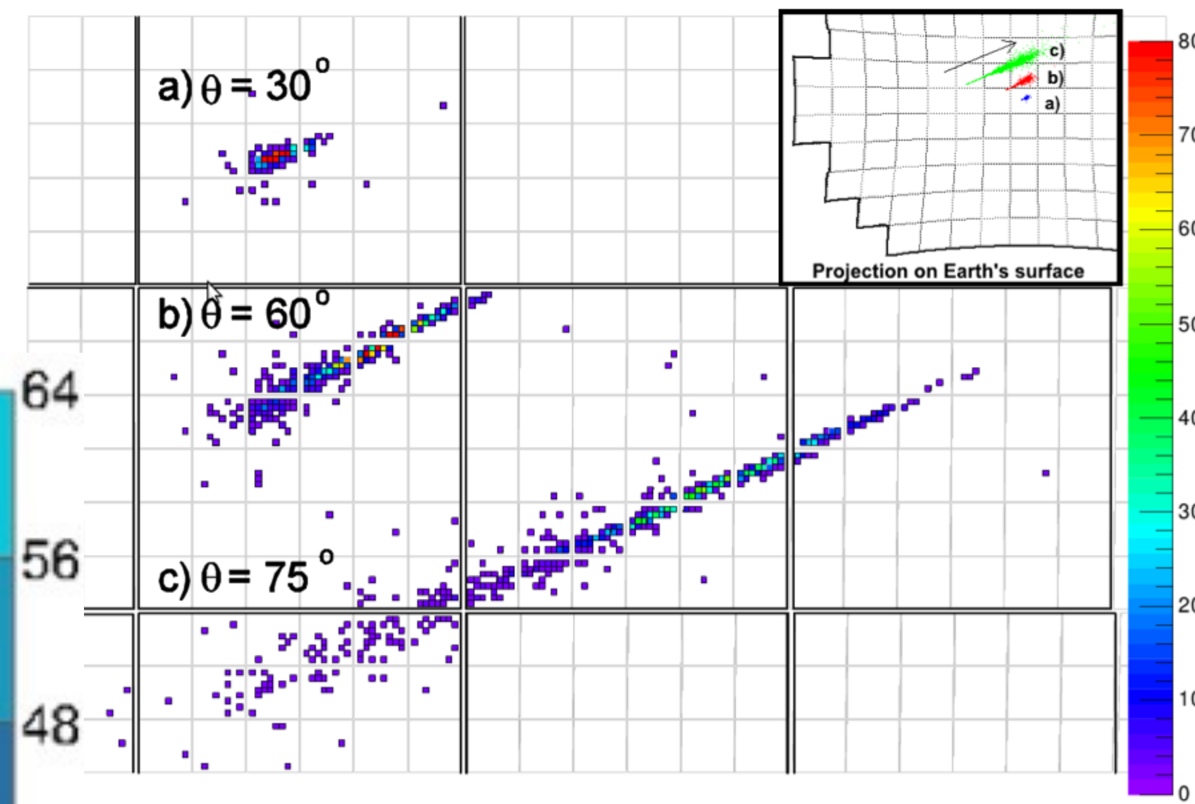
EUSO-SPB lens & camera

EUSO-SPB camera has ~100 times higher density of pixels

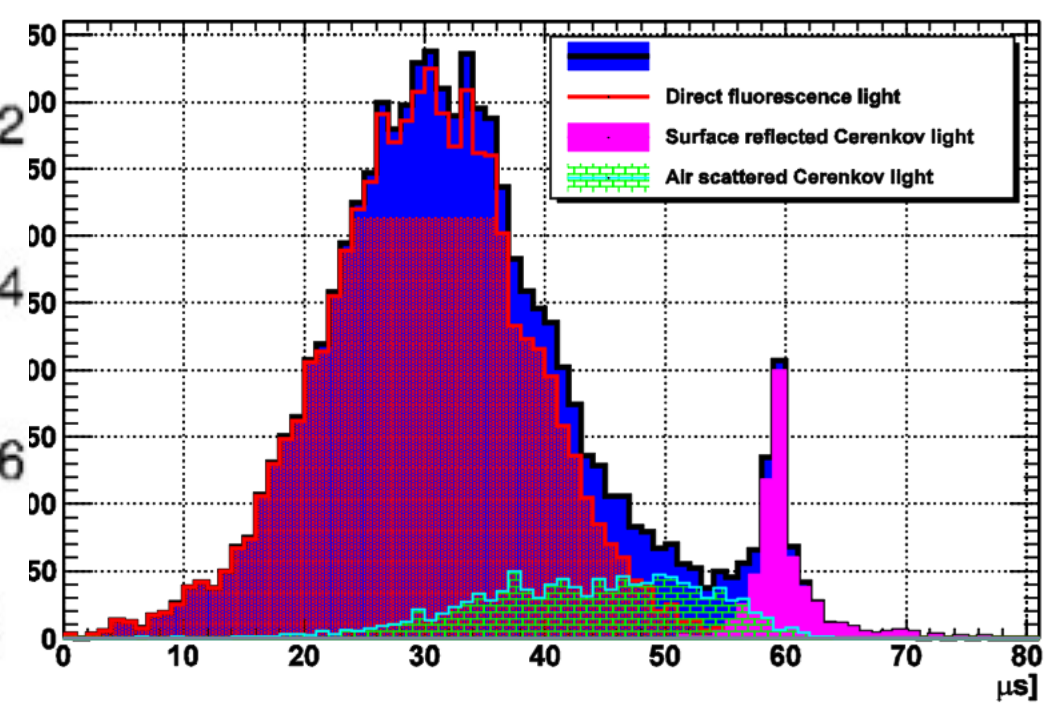
A significant difference in detectors, a technological challenge…

JEM-EUSO Observation Principle



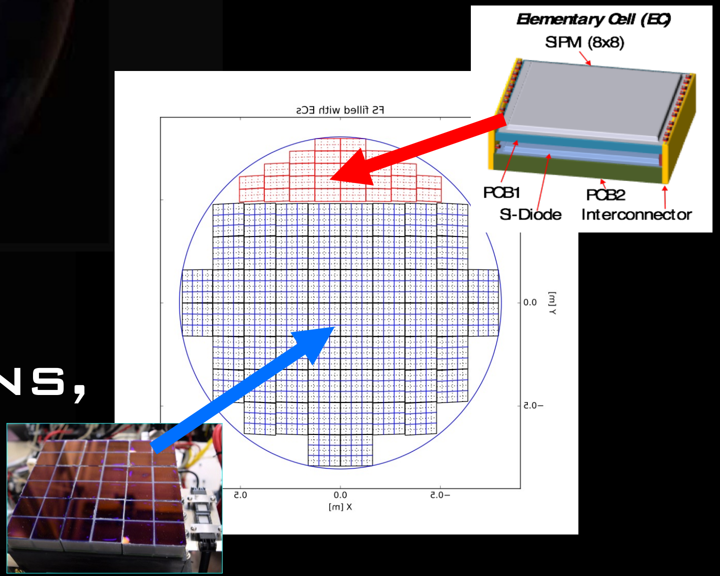


Energy: 10^{20} eV

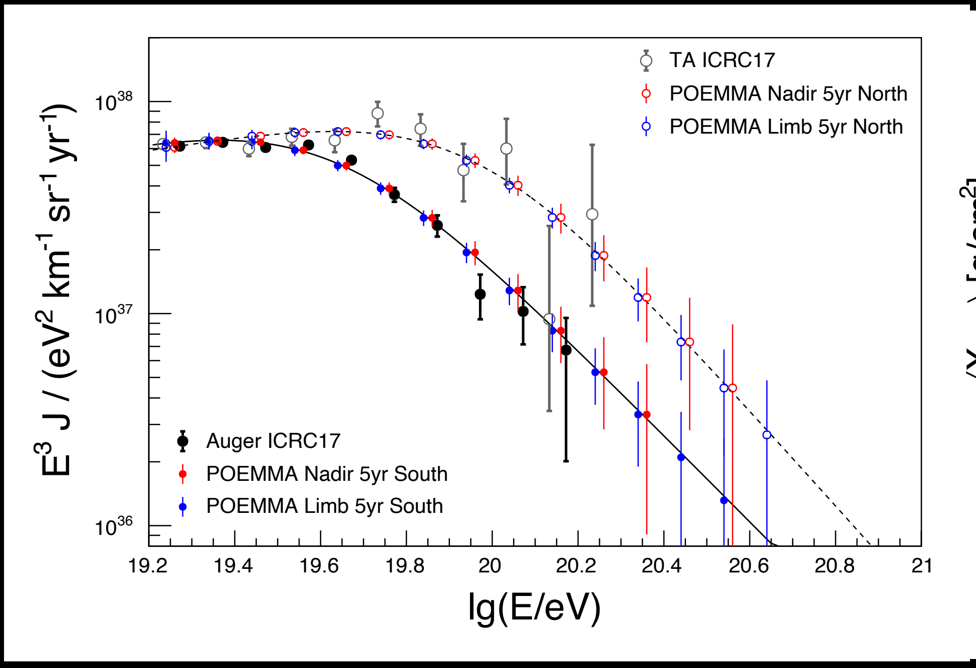


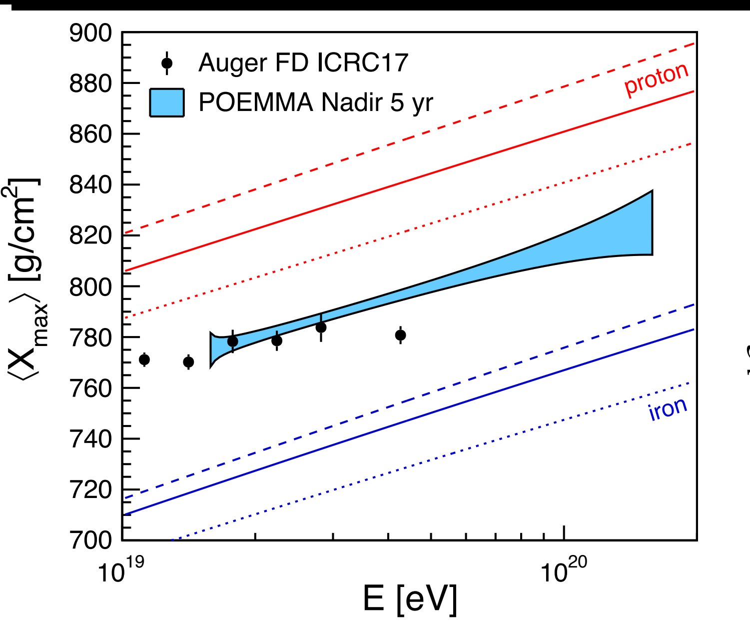
Δt ~ 50 - 150 μs

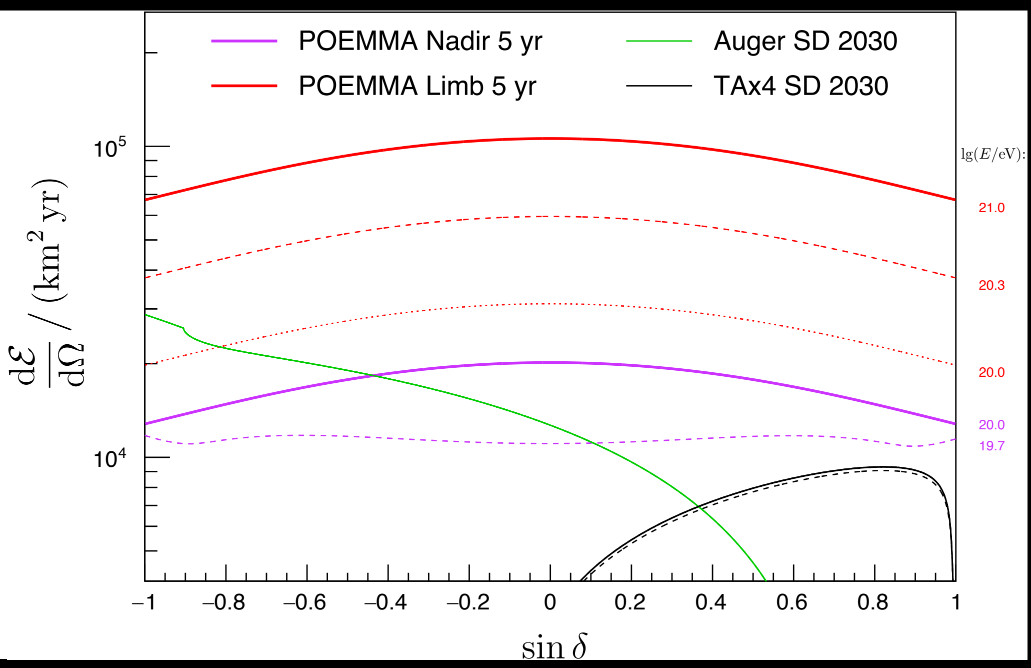
POEMMA UHECRs & νs



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



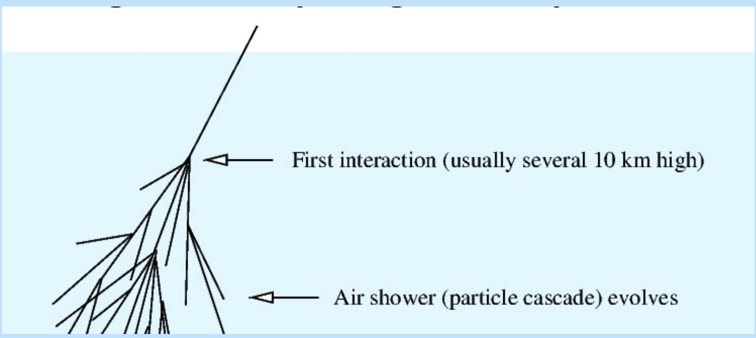


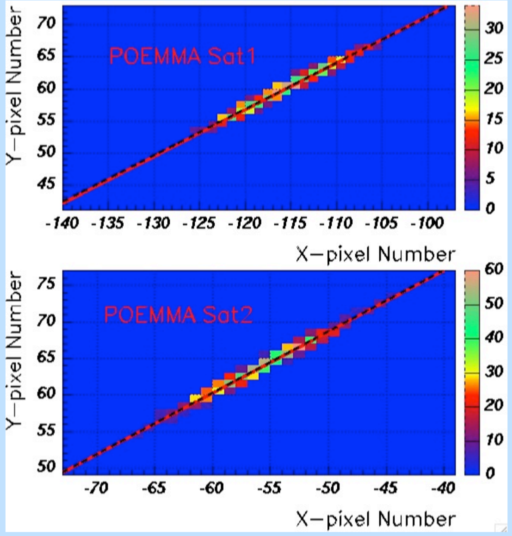


POEMMA: stereo reconstructed angular resolution: *see PhysRevD.101.023012*

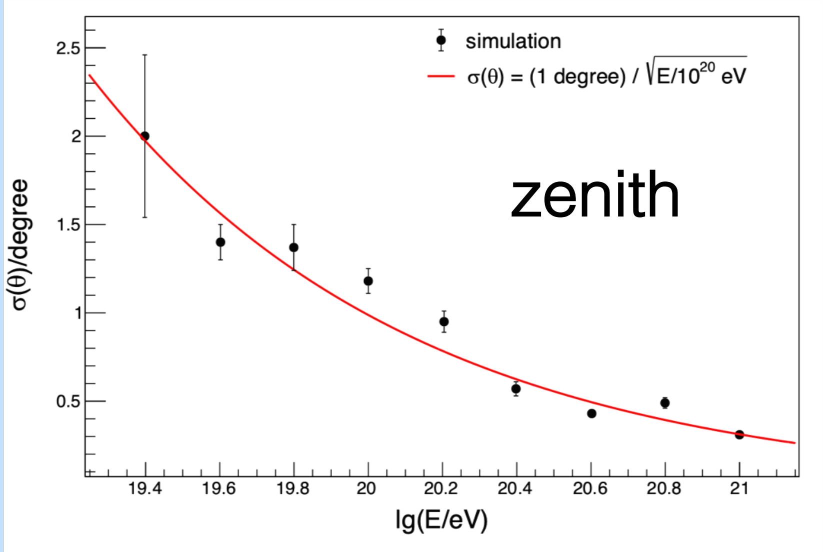
Excellent angular resolution → accurate determination of slant depth of EAS starting

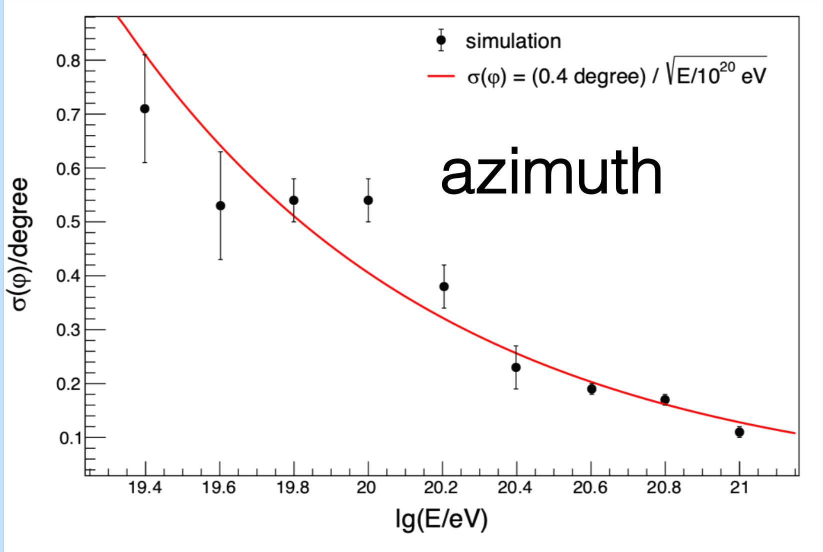
https://www.mpi-hd.mpg.de/hfm/CosmicRay/ShowerDetection.html

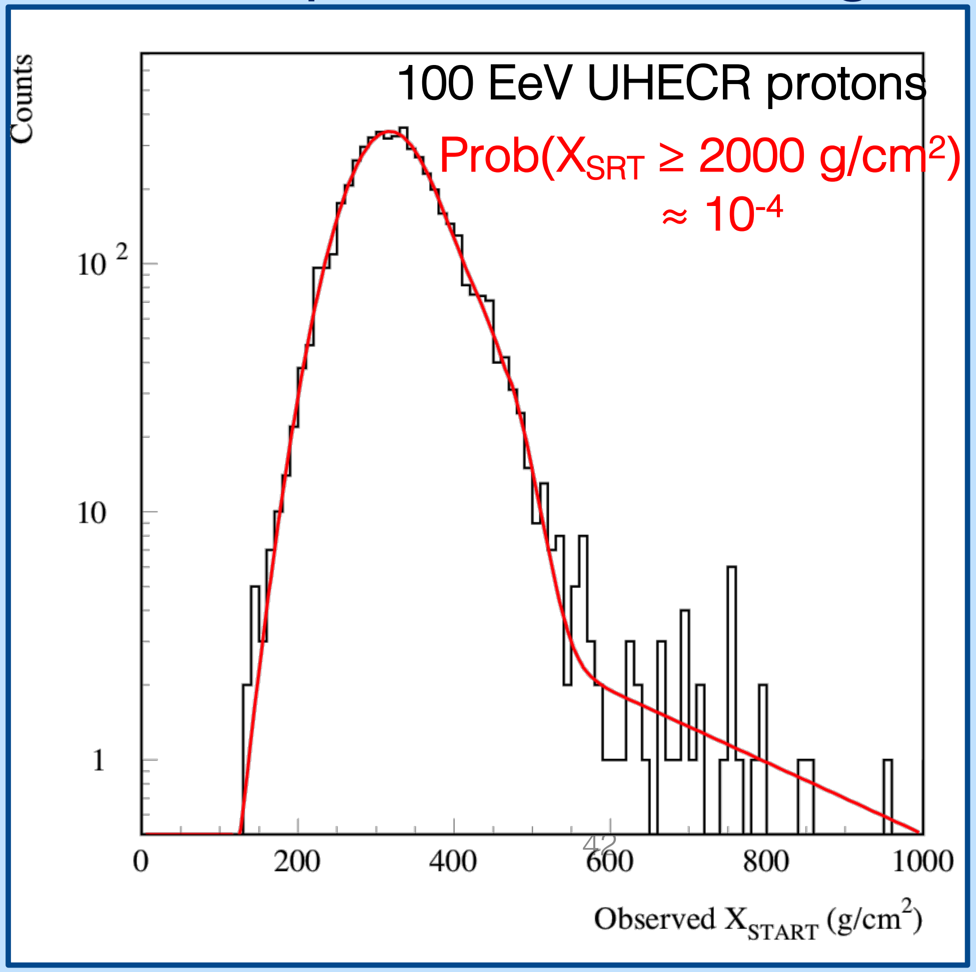




50 EeV simulated event







UHECR 100% proton assumption most conservative

Inelastic cross-section p - air

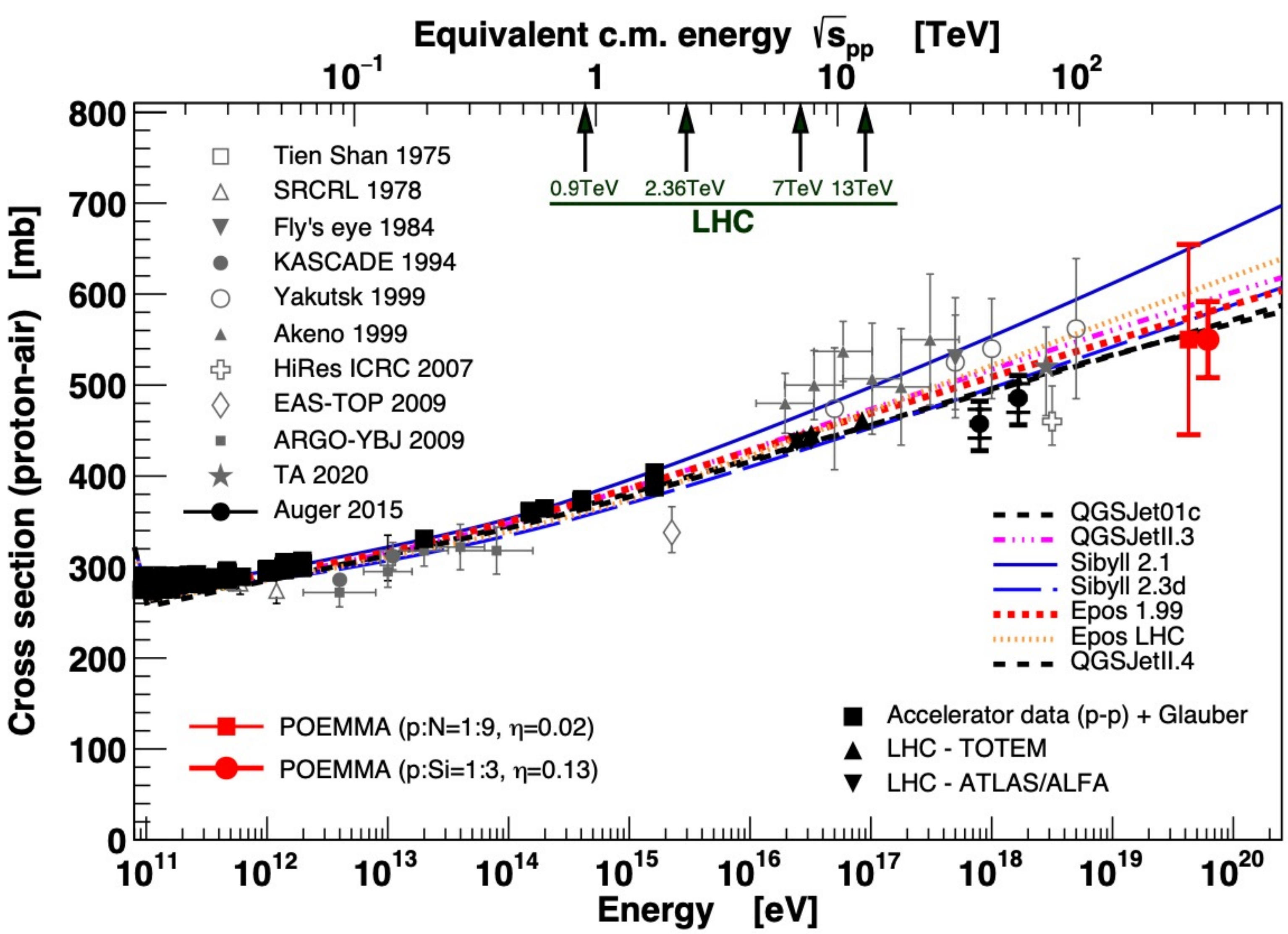


Figure 9. The UHE proton-air cross section as a function of proton energy and the projected UHE proton-air cross section measurement with POEMMA for two simplified UHECR composition scenarios (left p:N=1:9 and $\eta = 0.1 \times 0.2 = 0.02$, right p:Si=1:3 and $\eta = 0.25 \times 0.5 = 0.13$) shown by red markers, including error bars. The two points are displaced for clarity. Also shown is a compilation of accelerator data converted to a proton-air cross section using the Glauber formalism and measurements [61–69], including the Telescope Array [70] and Pierre Auger Observatory [54] results. The proton-air cross sections for the QGSJet [71, 72], Sibyll [73, 74], and EPOS [75] Monte Carlo programs are also shown.

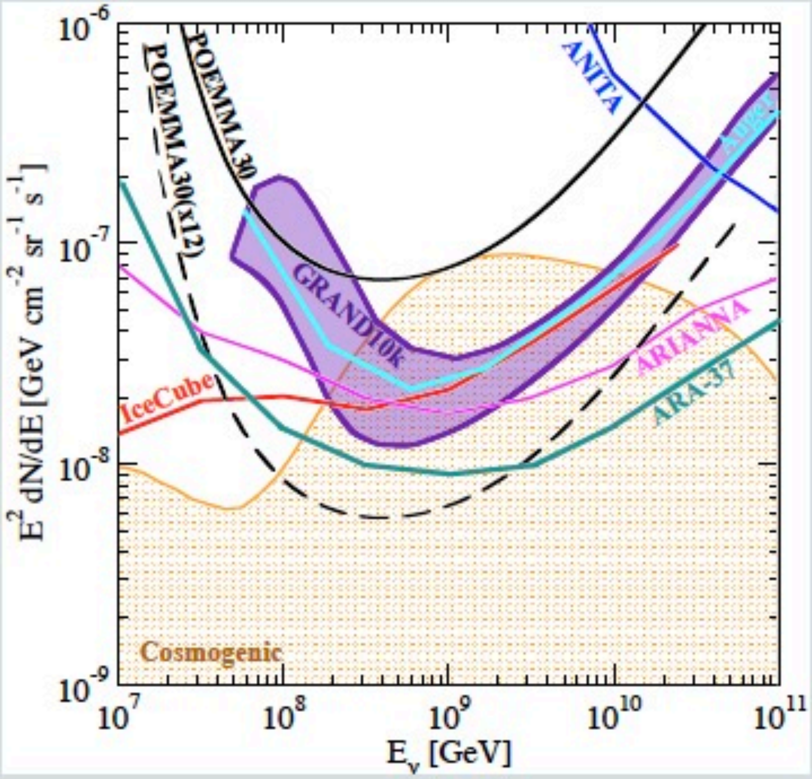
Diffuse neutrino performance & SHDM

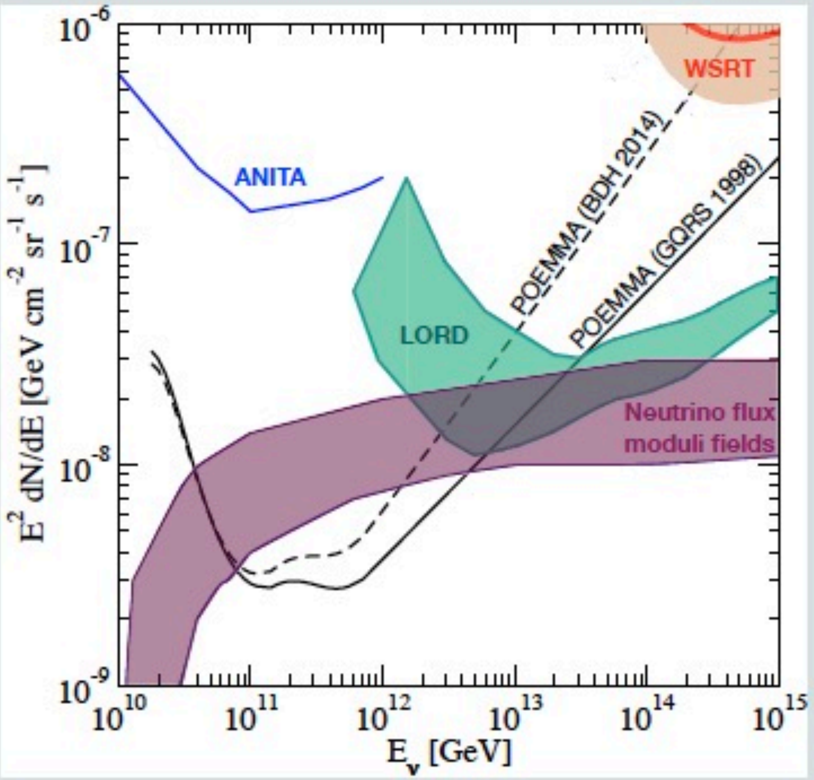
Unprecedented prospective constraints from very-high energy neutrino detectors

- specific channel: direct decay and annihilation to neutrinos
- unique contribution of neutrino detectors

- focus: POEMMA detection capability, above ~ 10^{16} eV
- Cherenkov and Fluorescence observation modes

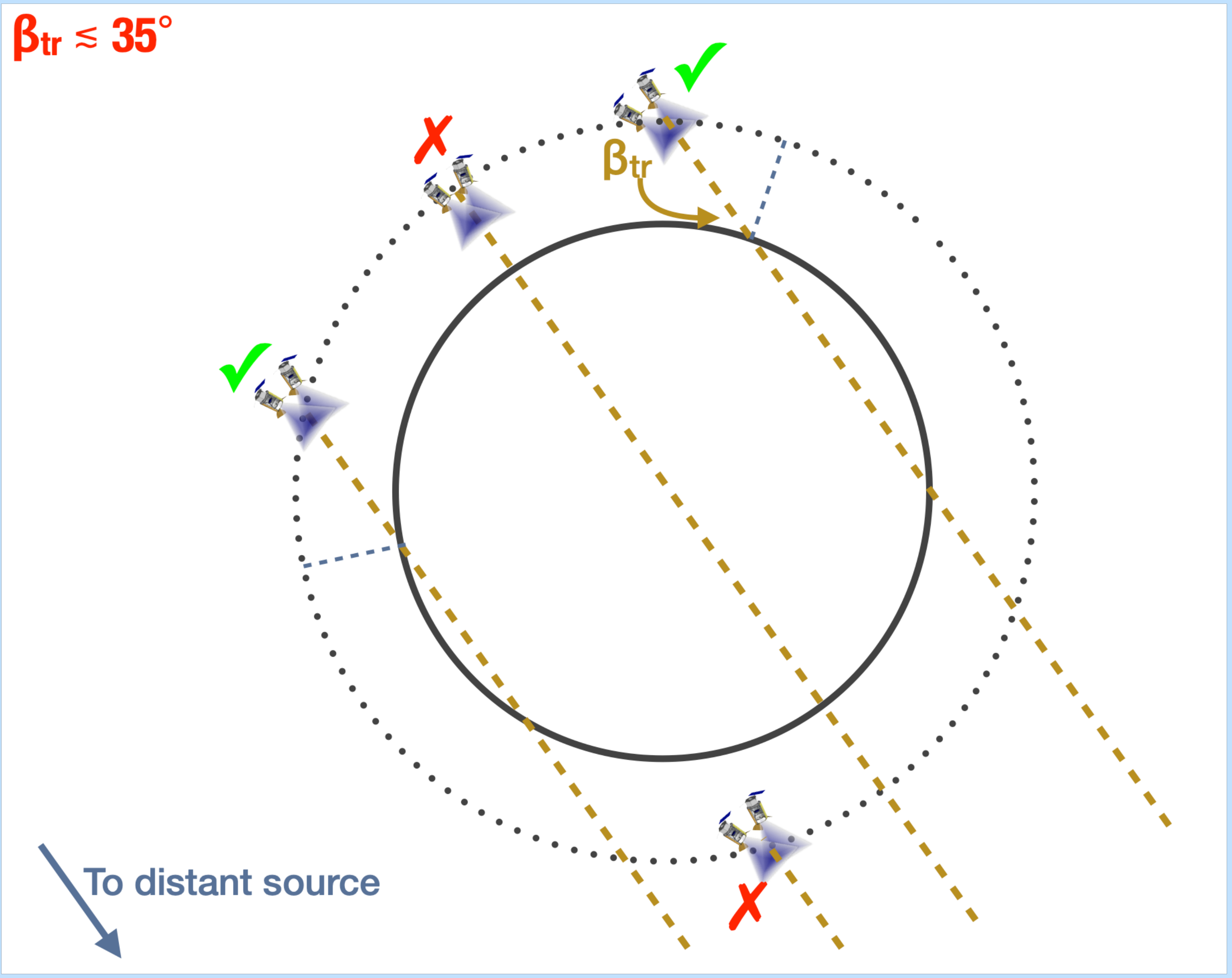
- for Cherenkov observation mode, two observation strategies: full sky coverage, or strategy optimized for dark matter detection

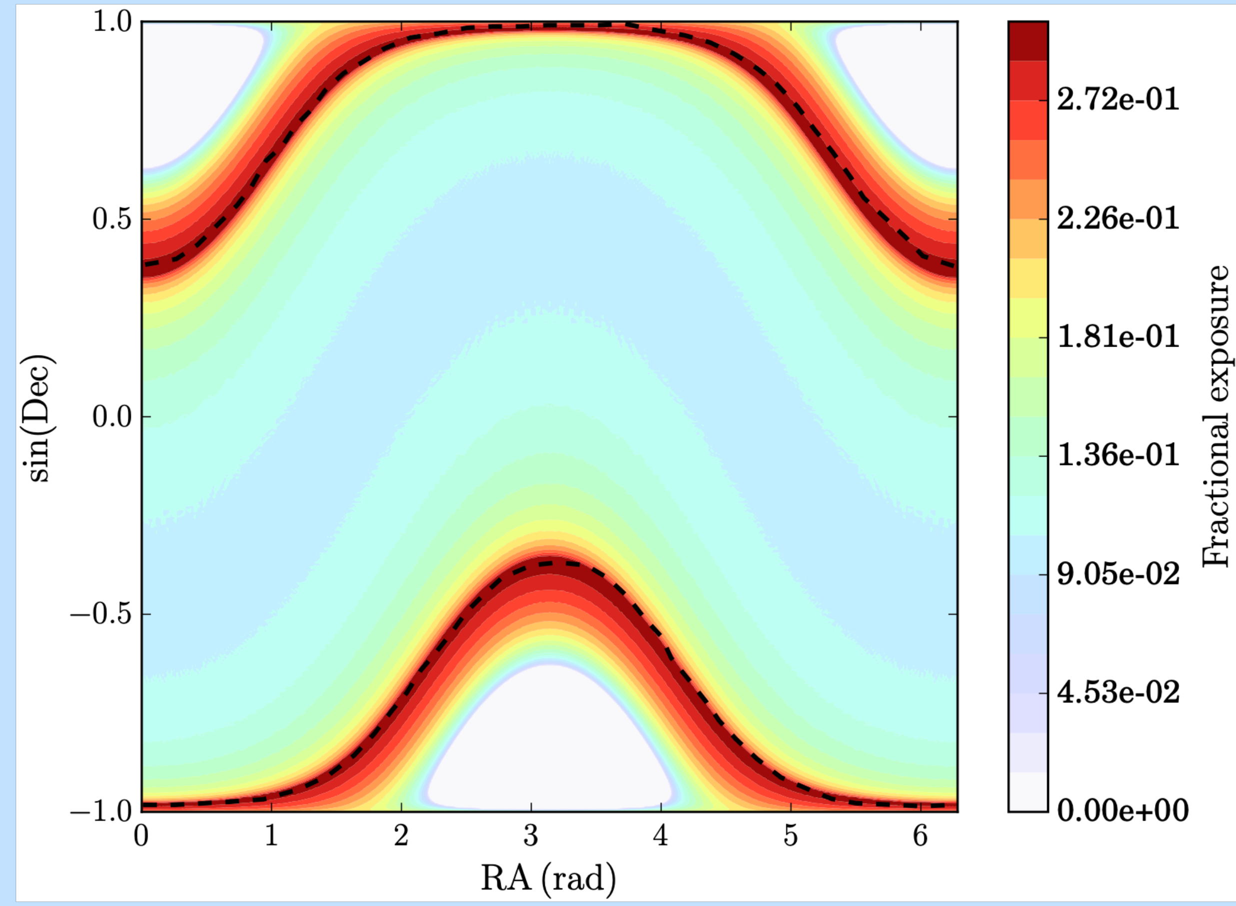


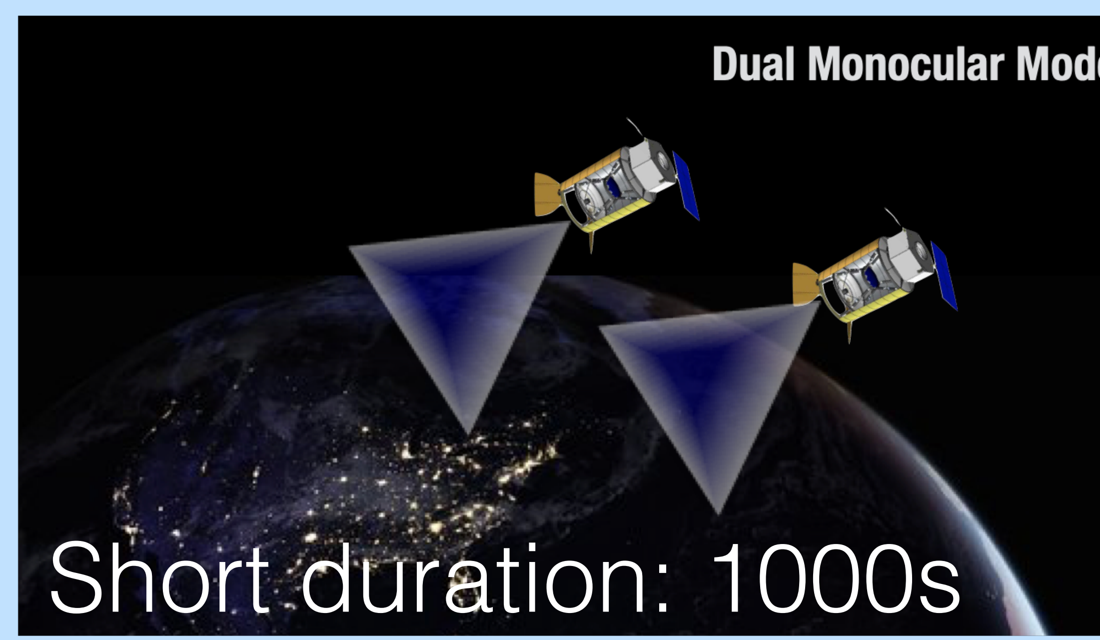


Olinto et al. 2020, submitted to JCAP

Exposure for ToO Observations







NEUTRINO: Target of Opportunity (ToO)

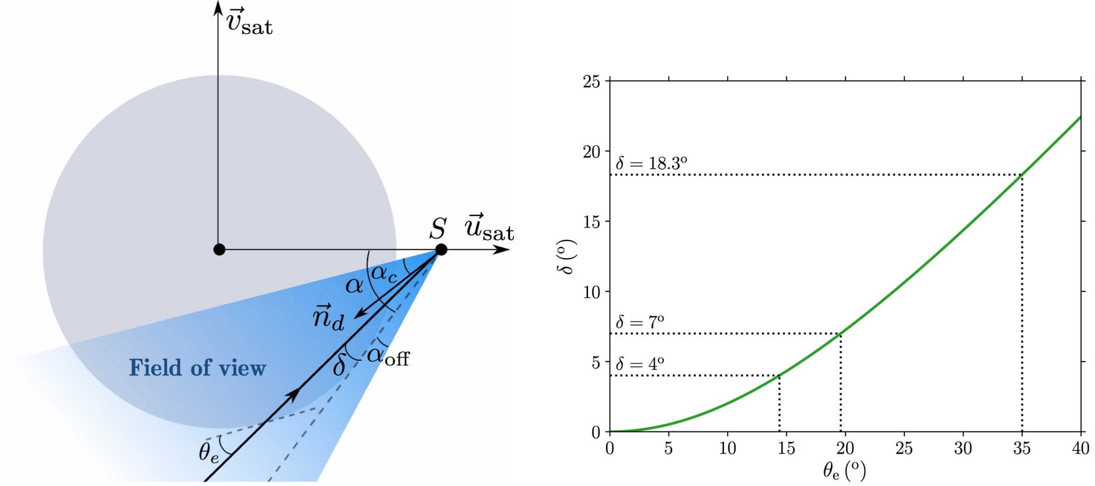


Figure 14. Left: Illustration of the geometrical configuration in the orbital plane (satellite position, $\vec{u}_{sat}$, versus satellite velocity $\vec{v}_{sat}$). The satellite is located at point S. The arrival direction of an EAS generated by a ν_τ is characterized by its Earth emergence angle θ_e and the corresponding angle away from the limb δ in the point of view of the satellite. The detector has a conical FoV of opening angle α_c, with an offset angle α_{off} (away from the Earth limb) and pointing direction $\vec{n_d}$. Right: Cherenkov viewing angle δ below the limb versus Earth emergence angle θ_e [77].

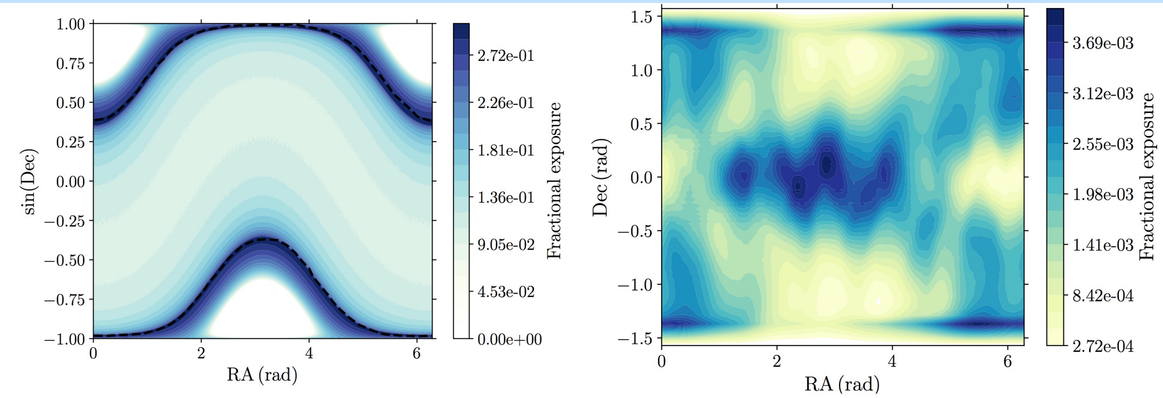


Figure 18. POEMMA cosmic neutrino sky coverage Left: Sky coverage for sources at a given orbital position in the sine of the declination and right ascension, without including the effect of the Sun, at a given time of the year for viewing angles to $\delta = 18.3°$ below the limb [2]. Right: The fractional neutrino sky exposure for one year in declination versus right ascension, assuming a defined variation in the POEMMA limb-pointing directions over the year to achieve full-sky coverage. The calculation takes into account the effects of the sun and moon on the duty cycle for observations [77].

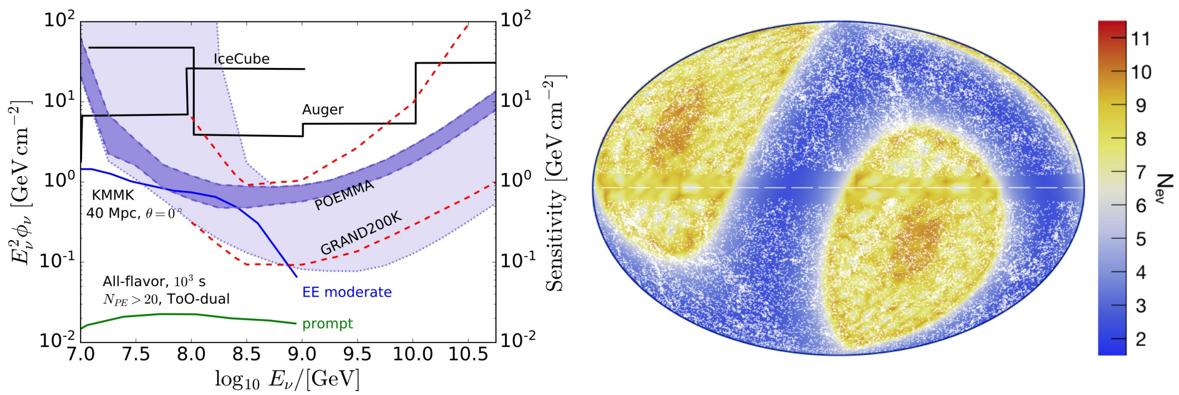
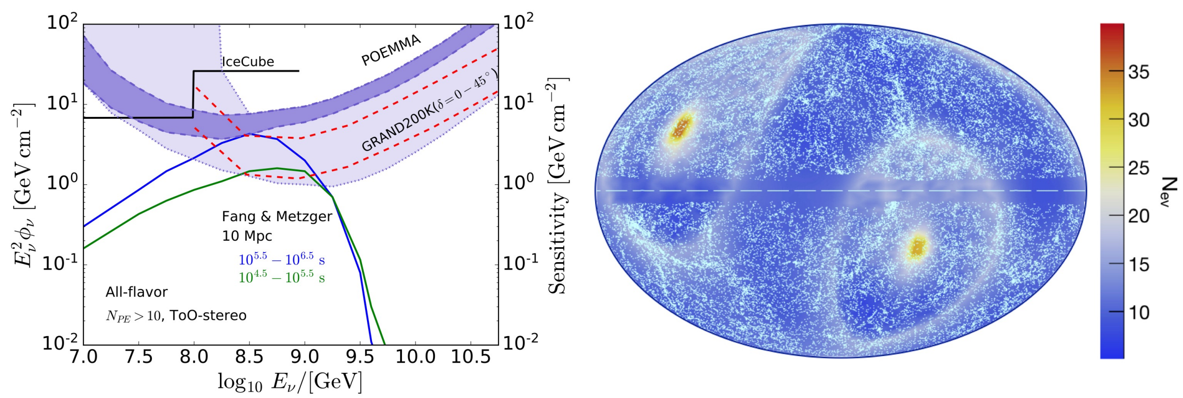
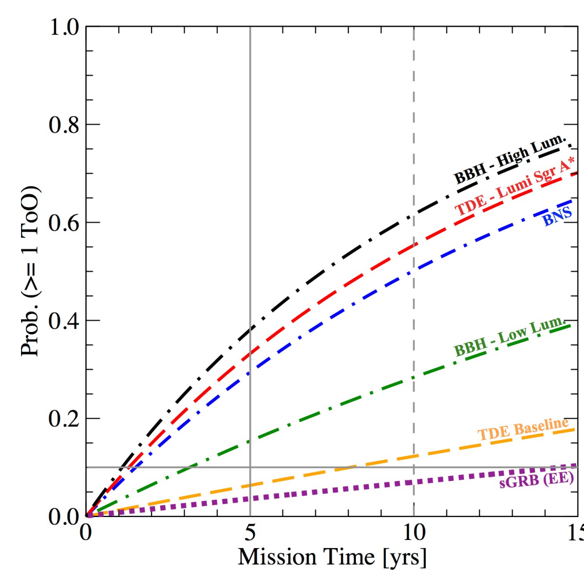


Figure 19. Left: POEMMA ToO sensitivity to a short, 1000 s burst shown by the blue band, where the dark blue band corresponds to source locations between the dashed curves in the sky coverage Figure 18. Also shown are all-flavor upper limits from IceCube and Auger (solid histograms) for neutrino searches within ±500 s around the binary neutron star merger GW170817 [145], the projected sensitivity of GRAND200k at zenith angles 90° and 94° [28], and models taken from Kimura et al. [95] of the all-flavor neutrino fluence from a short gamma-ray burst during the prompt and extended emission (EE) phases, assuming on-axis viewing ($\theta = 0°$) and a source at $D = 40$ Mpc. Right: Sky plot of the expected number of neutrino events with POEMMA as a function of galactic coordinates for the Kimura et al. [95] short gamma-ray burst with moderate EE model, placing the source at 40 Mpc. Point sources are galaxies from the 2MRS catalog [146]





Source Class	ν Horizon Distance	Mission Time for 10% Prob.	Model Reference
TDE $M_{SMBH} = 5 \times 10^6 M_\odot$ Lumi Scaling	128 Mpc	1.5 yrs.	[98]
TDE Base Scenario	69 Mpc	8 yrs.	[98]
BH-BH merger Low Fluence	43 Mpc	3 yrs.	[92]
BH-BH merger High Fluence	137 Mpc	1 yr.	[92]
NS-NS merger	16 Mpc	1.5 yrs.	[93]
sGRB Moderate Extended Emission	90 Mpc	14.5 yrs.	[95]

Table 2. Figure at left: Poisson probability of POEMMA detecting at least one ToO versus mission time for several modeled source classes. Table at right: Promising source classes for detecting at least one ToO event with POEMMA based on a Poisson probability of $\gtrsim 10\%$. Also included are the horizon distance for detecting one neutrino per ToO event, the mission time for 10% chance of detecting *geq*1 ToO event, and the model reference.

T. M. Venters,et al.,
POEMMA's target of opportunity sensitivity to cosmic neutrino transient sources
[arXiv:1906.07209 [astro-ph.HE]].

Prospects for macroscopic dark matter detection: macro/nuclearites

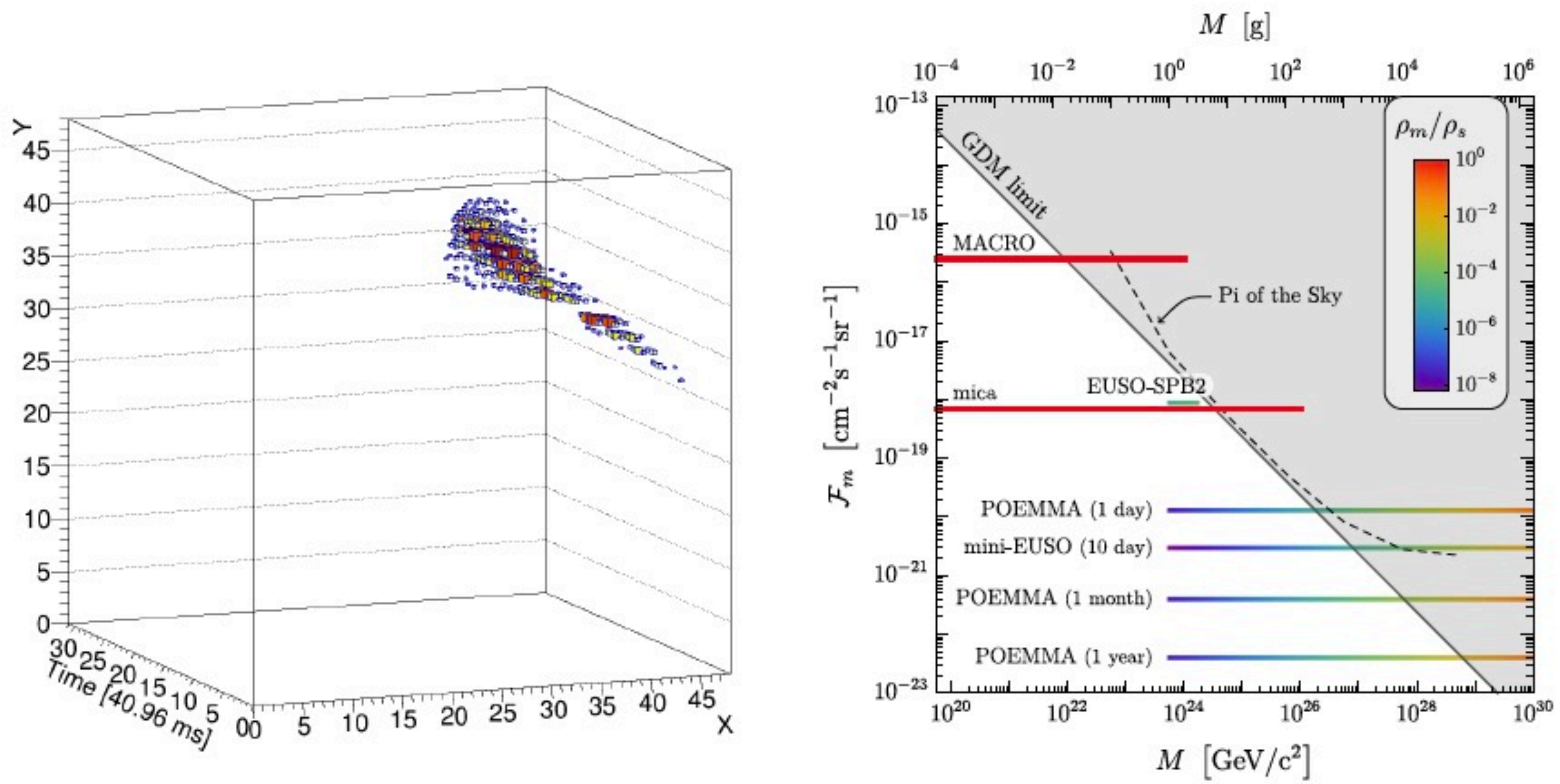


Figure 1: *Left:* A meteor track as observed by Mini-EUSO at a 40.96 ms sampling rate. The X and Y axis represent the pixels of the focal surface plotted versus time. The color scale and the size of boxes correspond to the number of counts deposited in a pixel. *Right:* The projected POEMMA 90% confidence level upper limit on the macro flux $\mathcal{F}_m$ (as a function of the macro mass M) resulting from null detection over different time spans of acquired data compared to EUSO-SPB2 [3], Mini-EUSO, and other experiments [4, 5, 6, 7]. The Galactic dark matter (GDM) limit is indicated for comparison.

JEM-EUSO
PROGRAM

EUSO-TA (2013-)

EUSO-Balloon (2014)

TUS (2016)

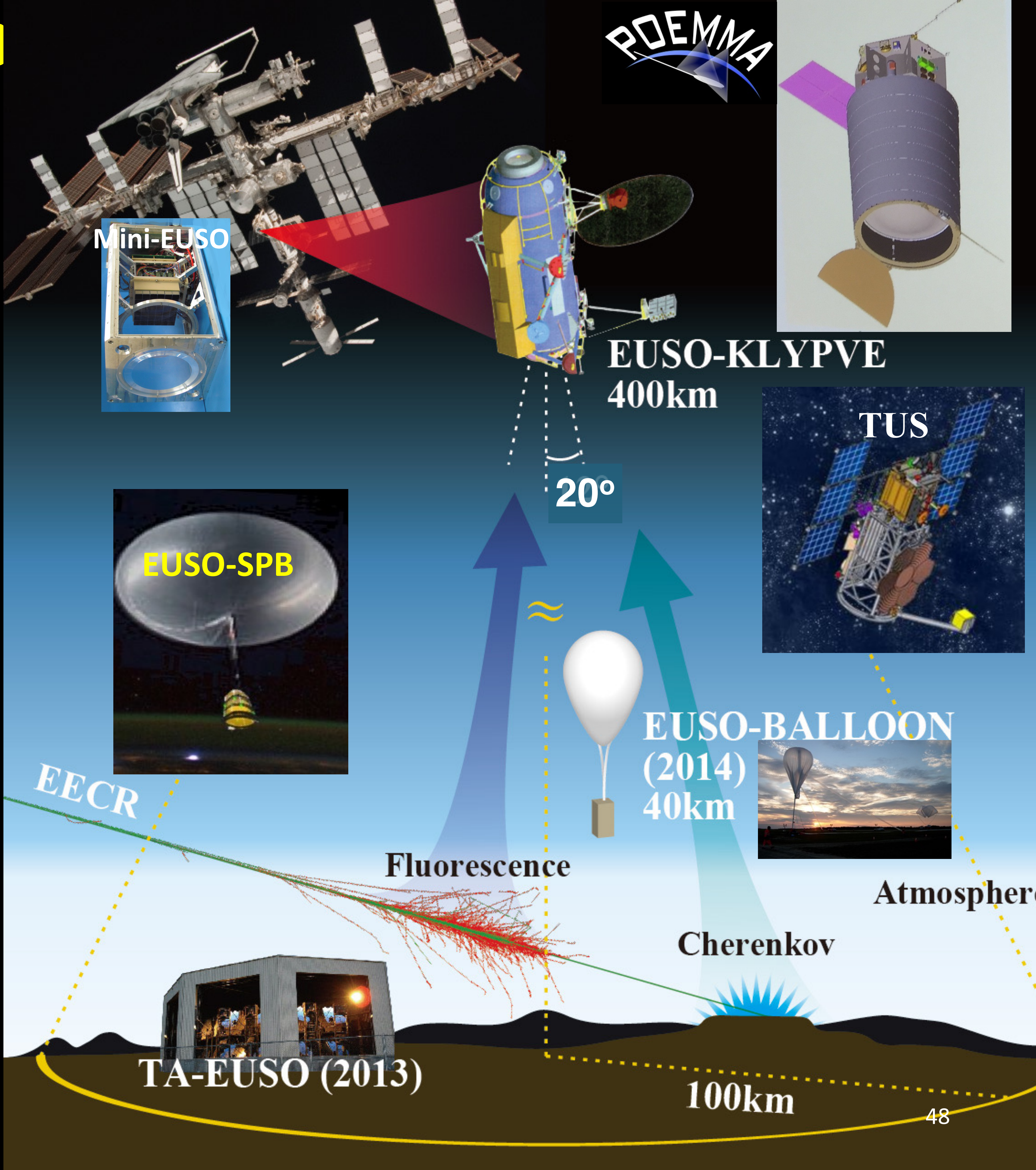
EUSO-SPB1 (2017)

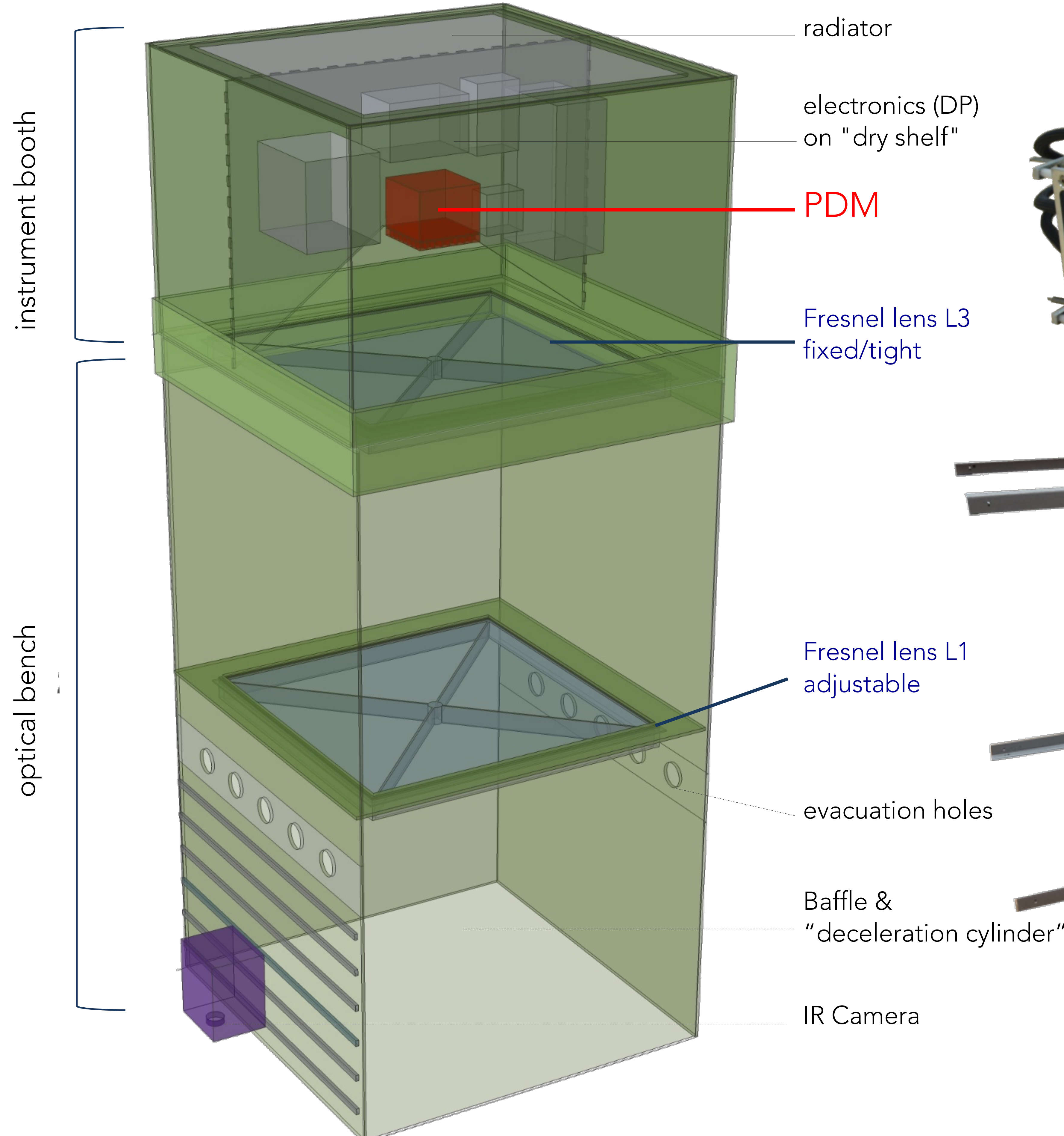
Mini-EUSO (2019)

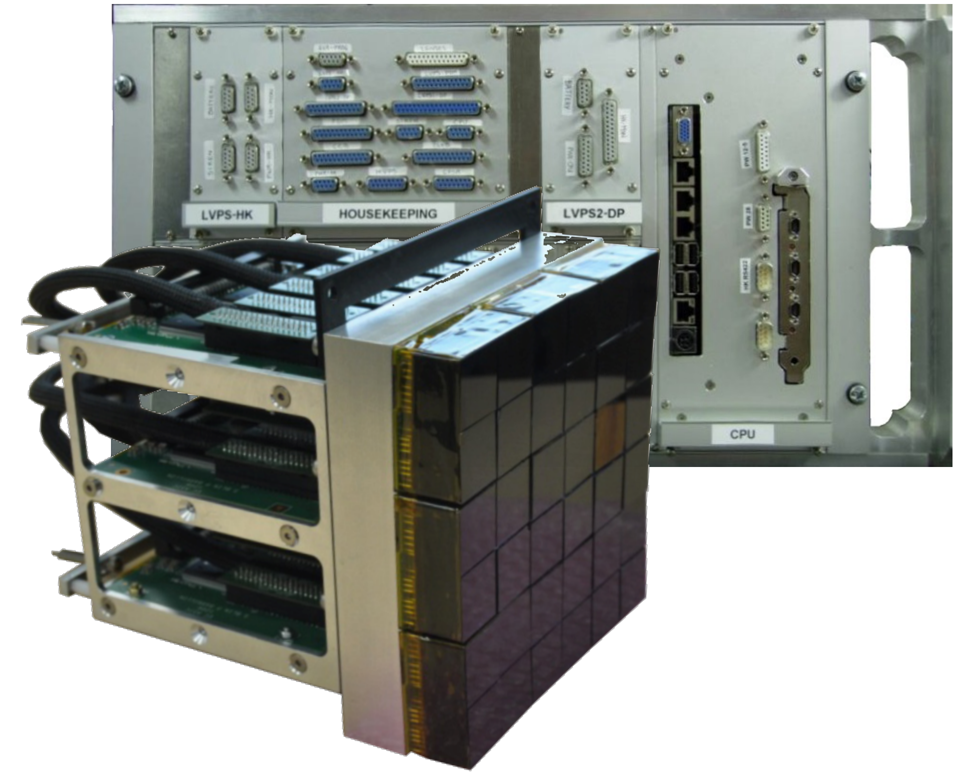
EUSO-SPB2 (2023)

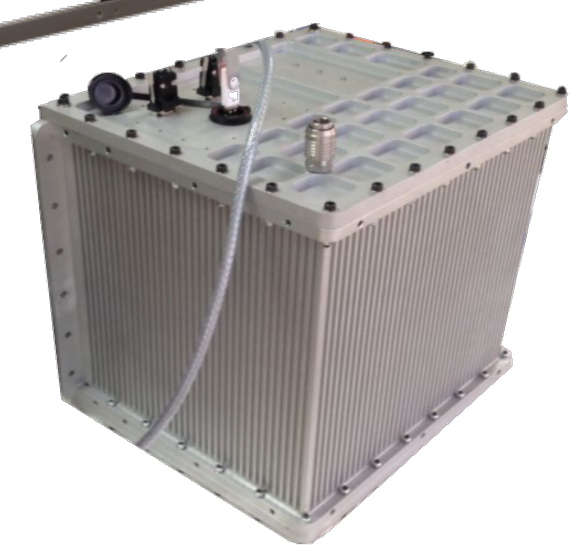
K-EUSO (2024+)

POEMMA (2028+)




instrument booth
optical bench
radiator
electronics (DP)
on "dry shelf"
PDM
Fresnel lens L3
fixed/tight
Fresnel lens L1
adjustable
evacuation holes
Baffle &
“deceleration cylinder”
IR Camera

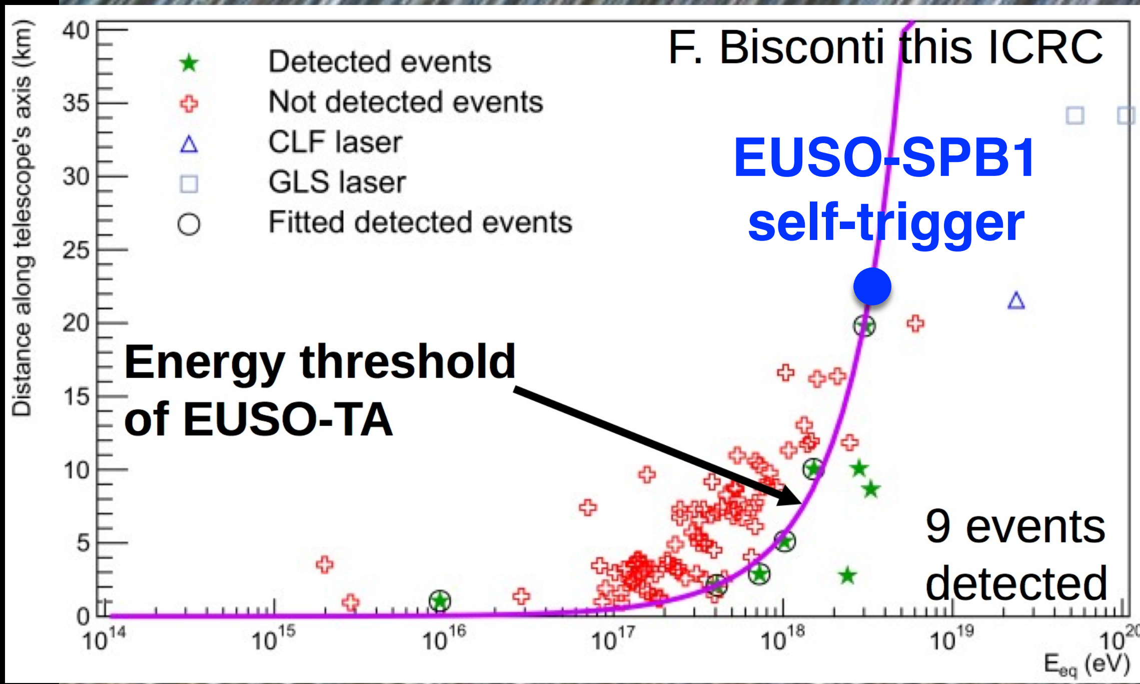

LVPS-HK
HOUSEKEEPING
LVPS2-DP
CPU

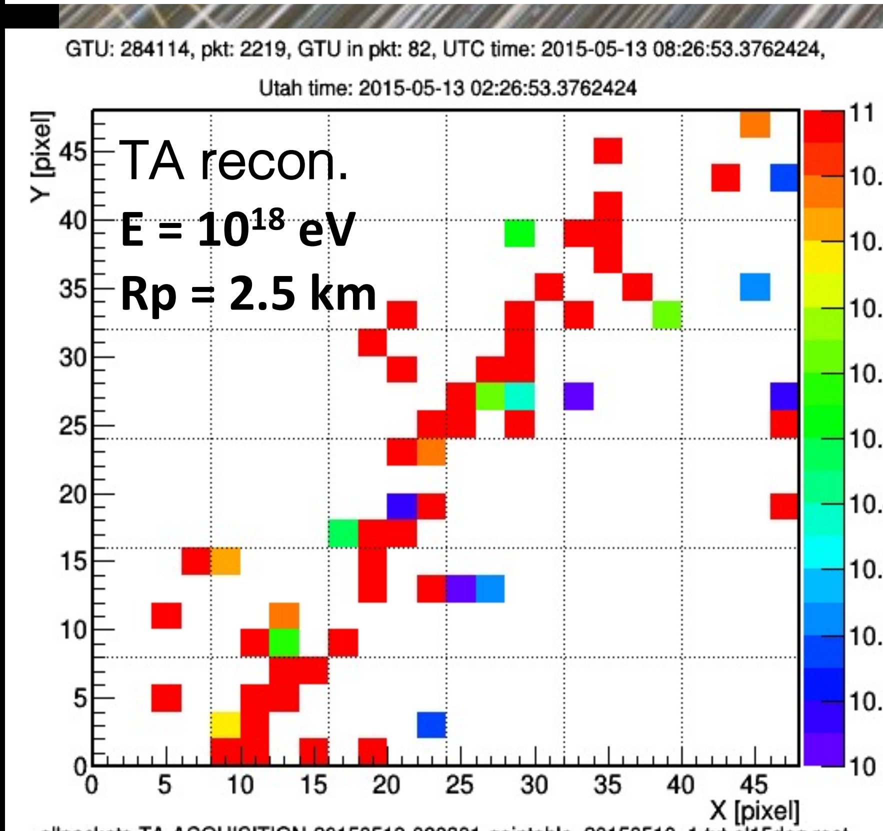


EUSO-TA

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

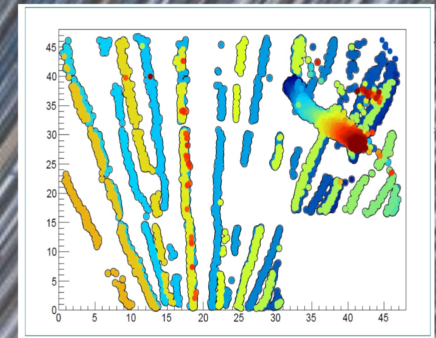
UHECRs



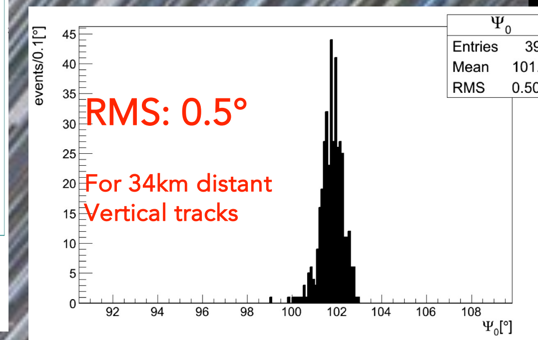


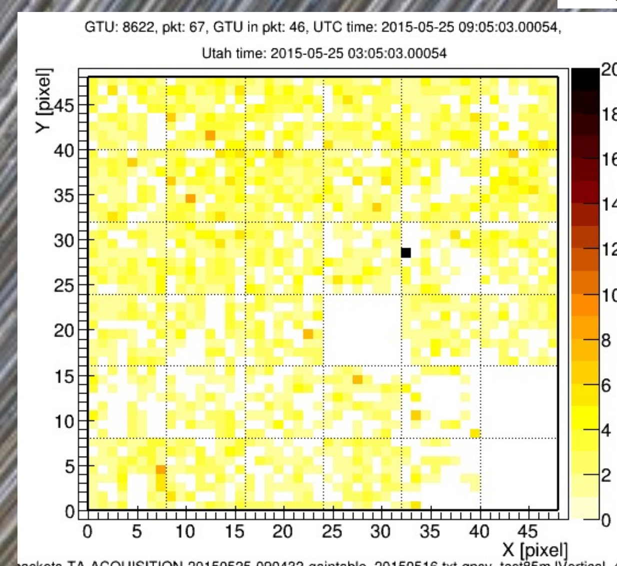
GLS laser campaigns

d= 100 km
E = 85 mJ



- 34km away from the detector
- Energy: 23mJ
- Sweep in azimuth with 2 different zenith angle (130°/140°)

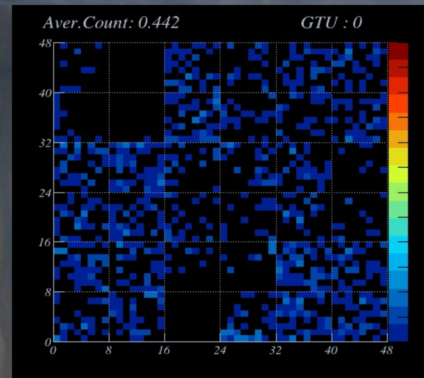


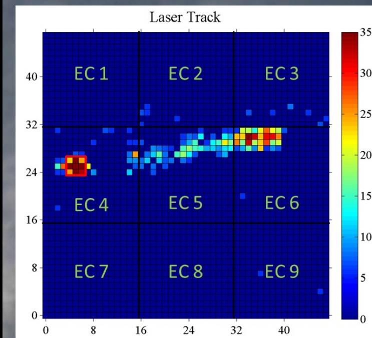


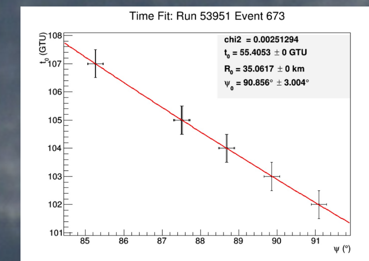
EUSO Balloon

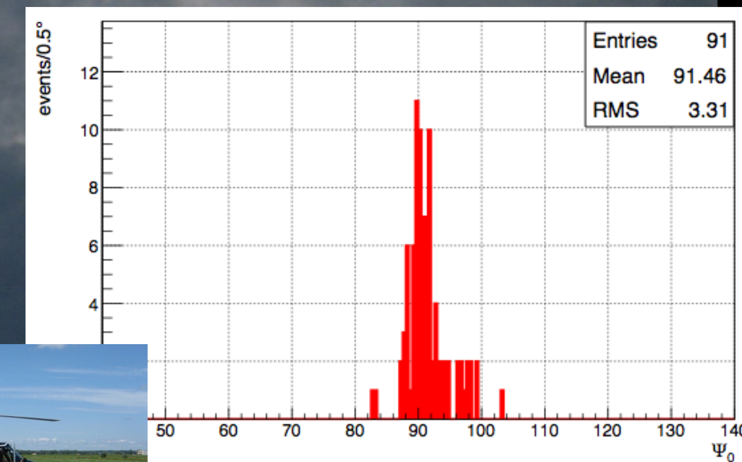
August 2014 Timmins, Canada

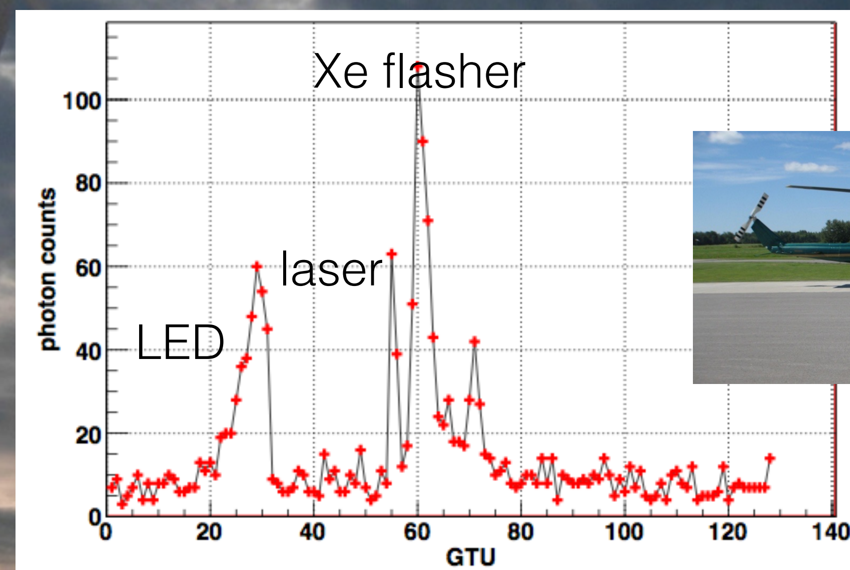
1 night flight @ 38 km a.s.l.
data: 256,000 events

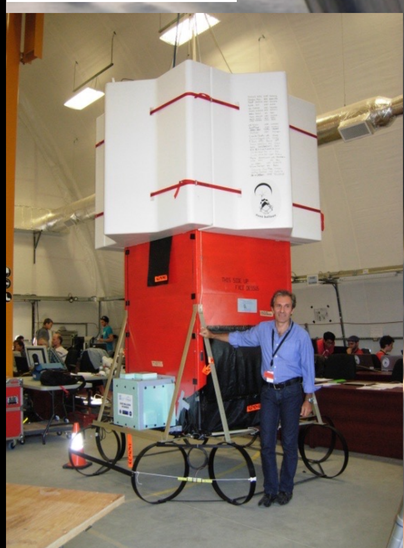


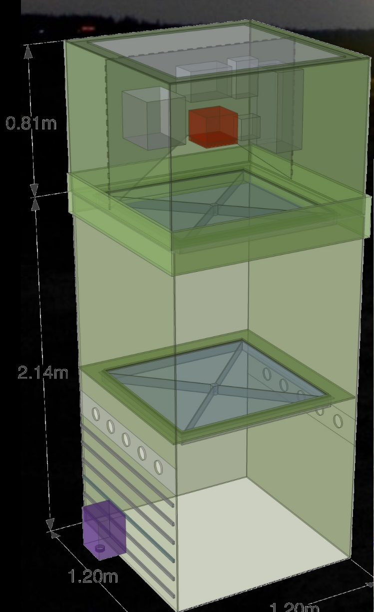


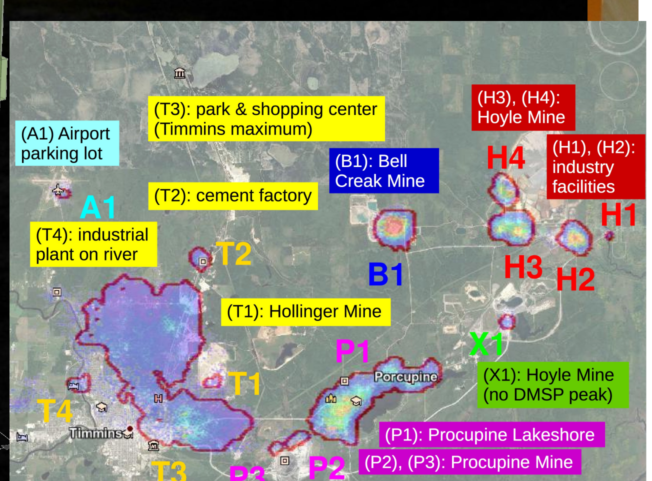


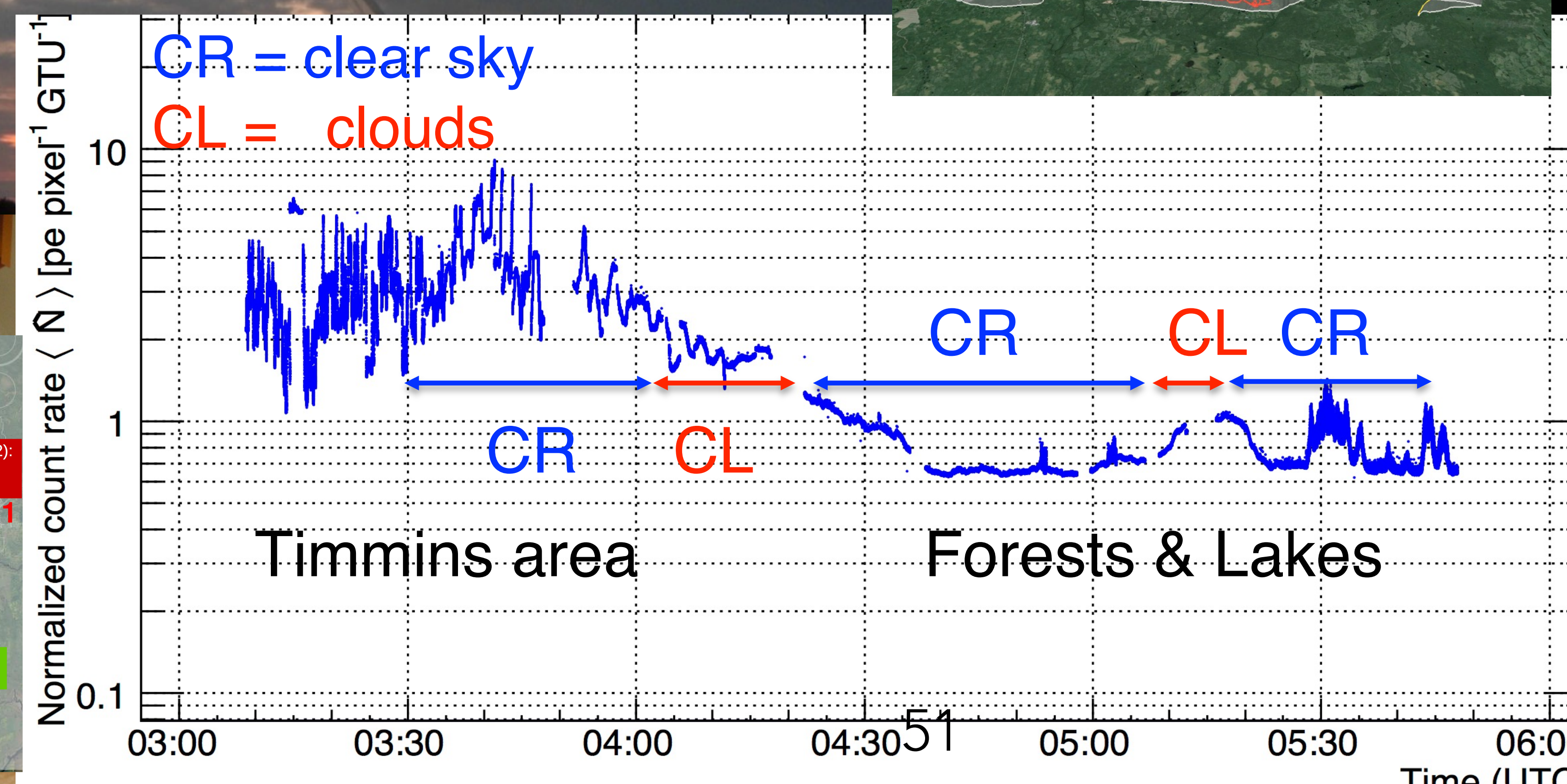








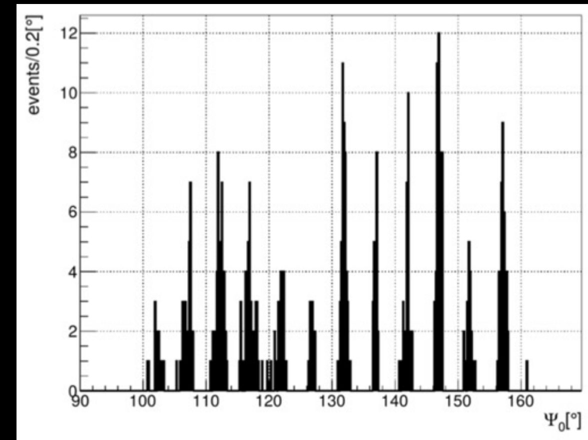




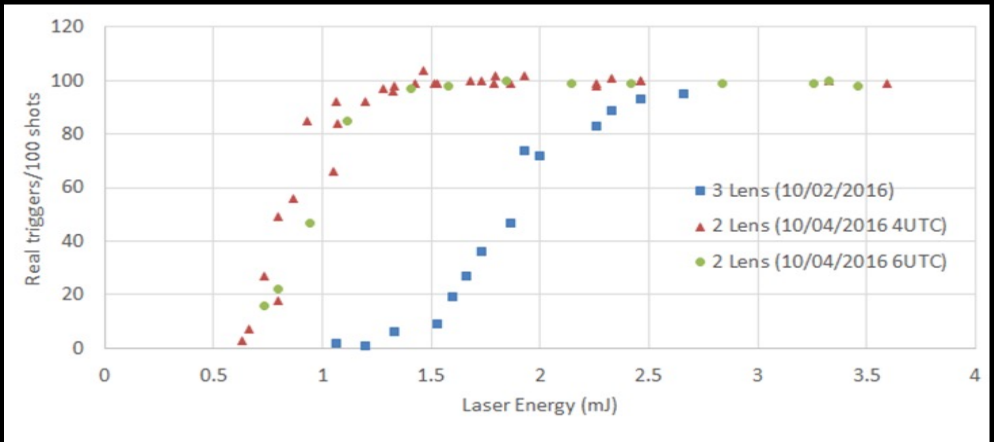
EUSO-SPB1

(2017)

Angular resolution better than 1°



Energy-equivalent threshold measurement

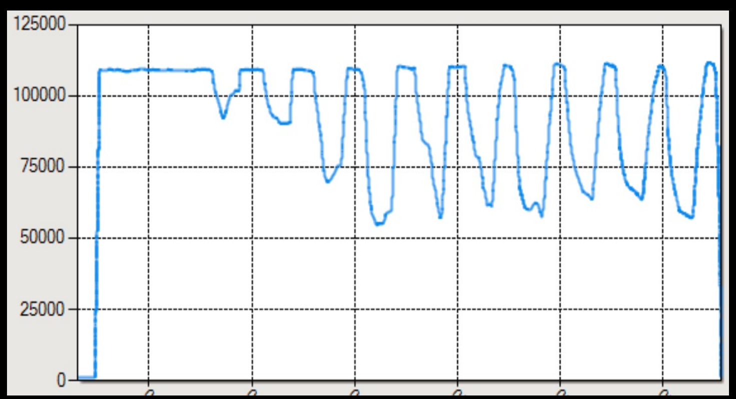


Would-be showers

E_{th} ~ 2 Eev => ~1–2 showers expected per month

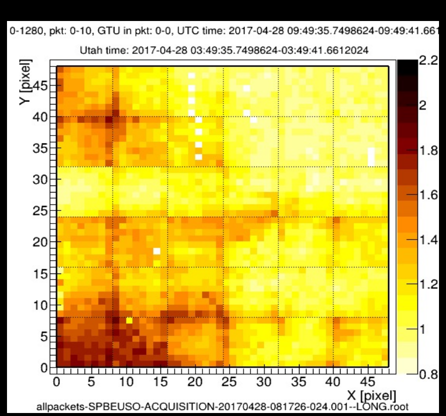
Nominally working instrument

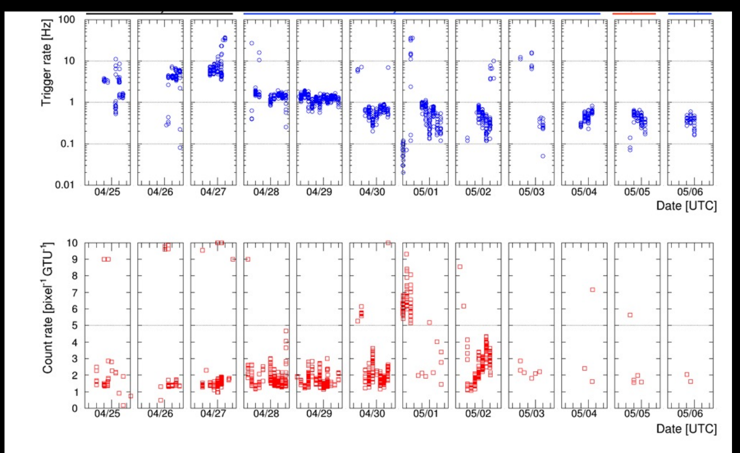
(unfortunately… leaking balloon!)



Main improvements:

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

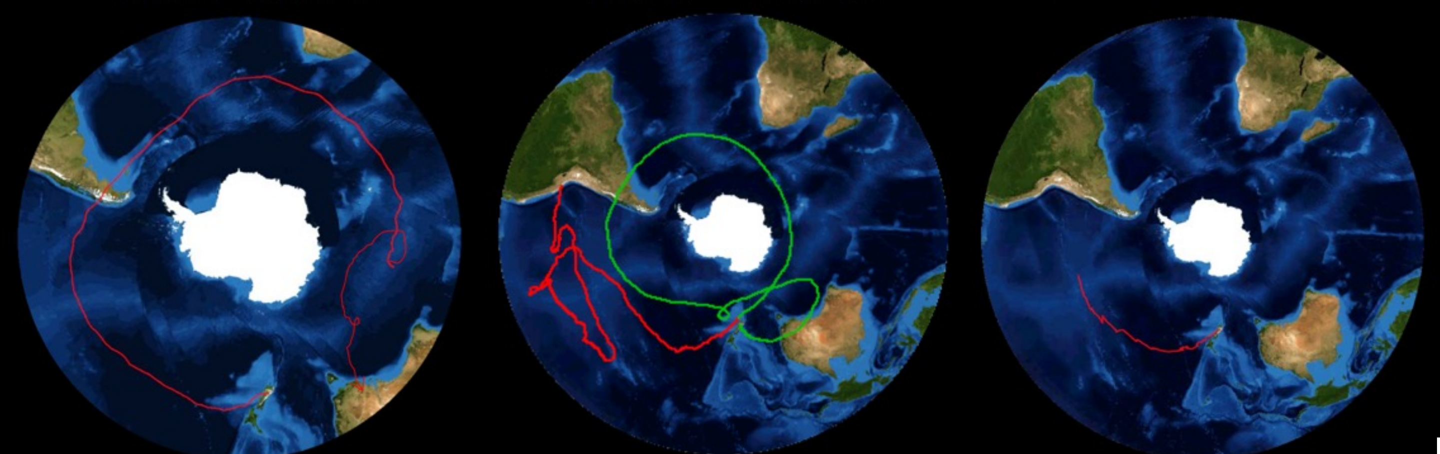




2015: 32 d 5 h

2016: 46 d 20 h

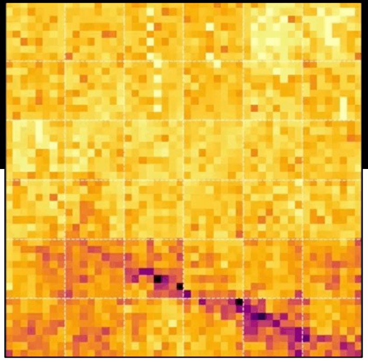
2017: 12 d 4 h



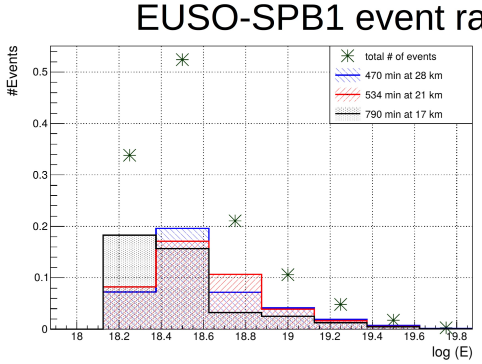
NASA Engineering Flight — 6.3±0.9

COSI — 10.6±2.3

EUSO — ~1

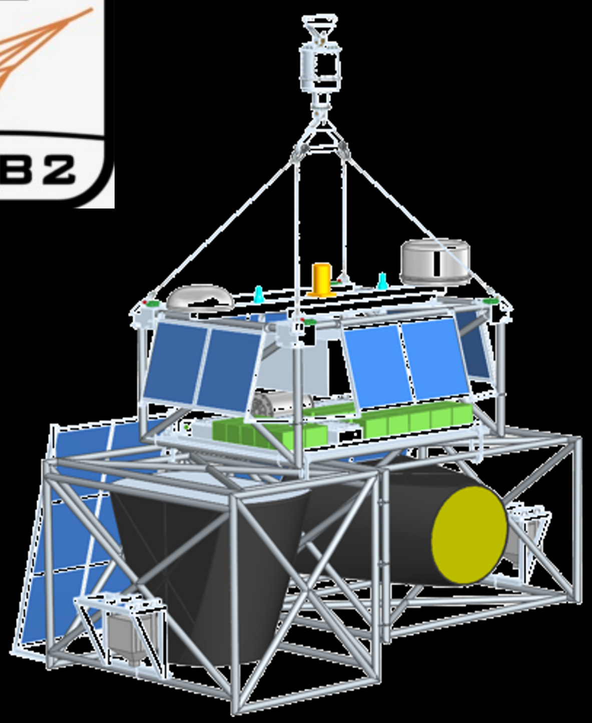


EUSO-SPB1 event rate



Upper limit on event rate (no cloud cover included):
1.26 ± 0.44
Events during the flight, assuming 9ECs

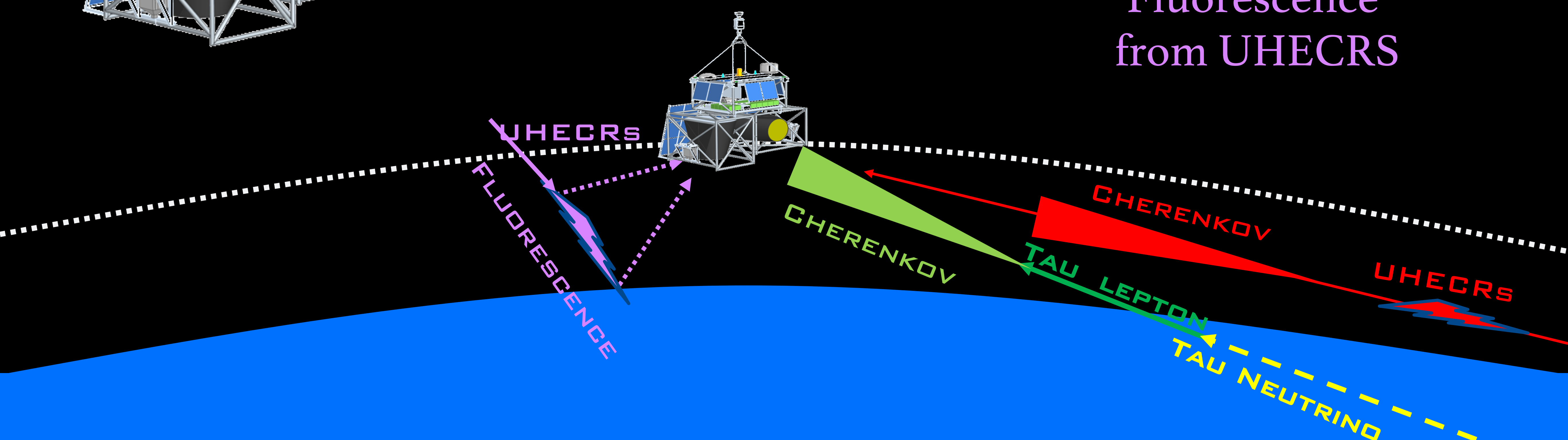
EUSO-SPB2 (2023)



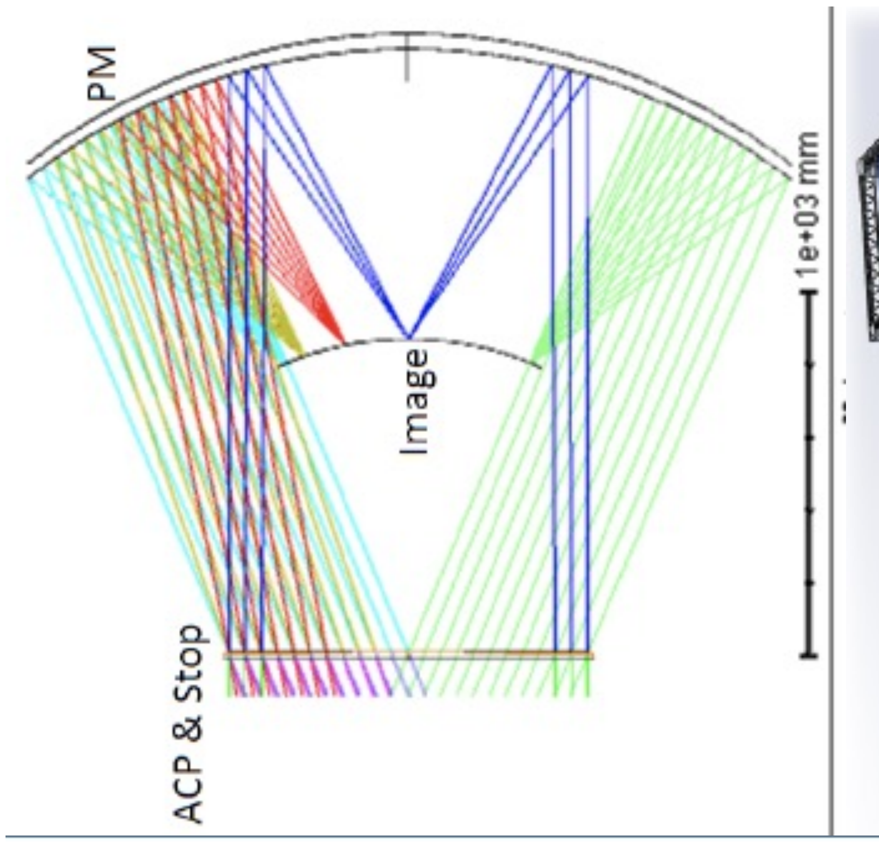
Cherenkov Emission from UHECRs

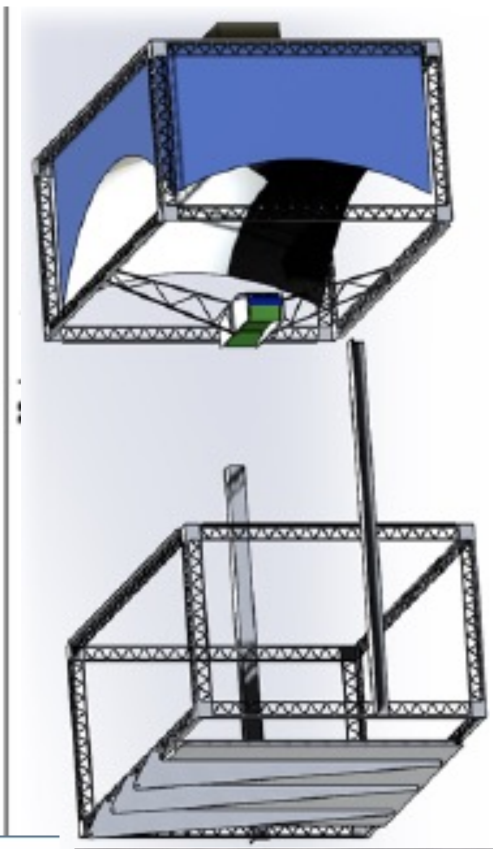
Tau Neutrino Background

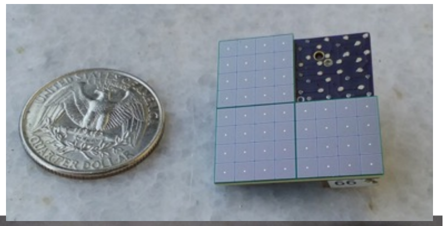
Fluorescence from UHECRS



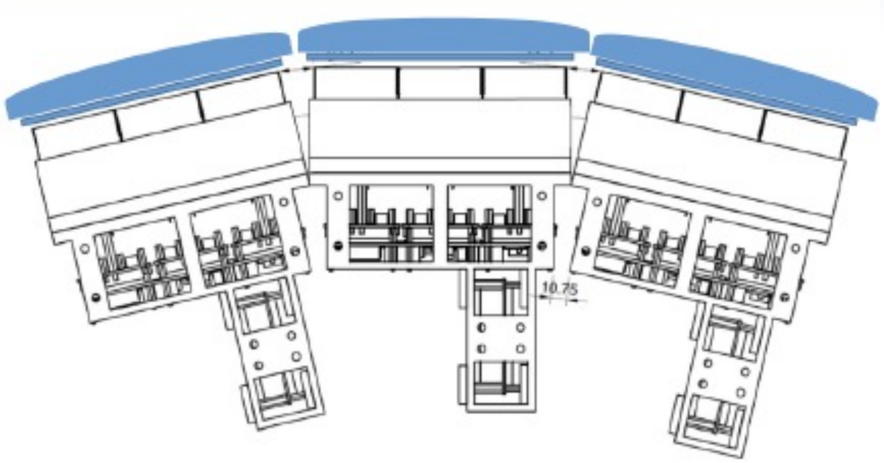
EUSO-SPB2

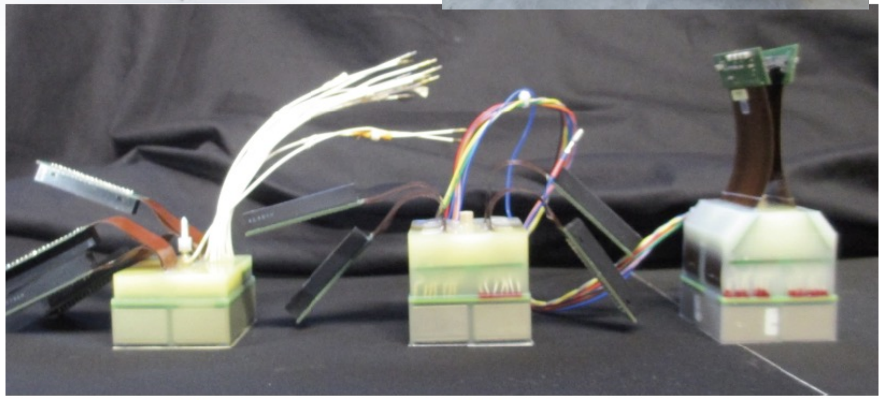






Cherenkov camera SiPMs





2014
4PMT

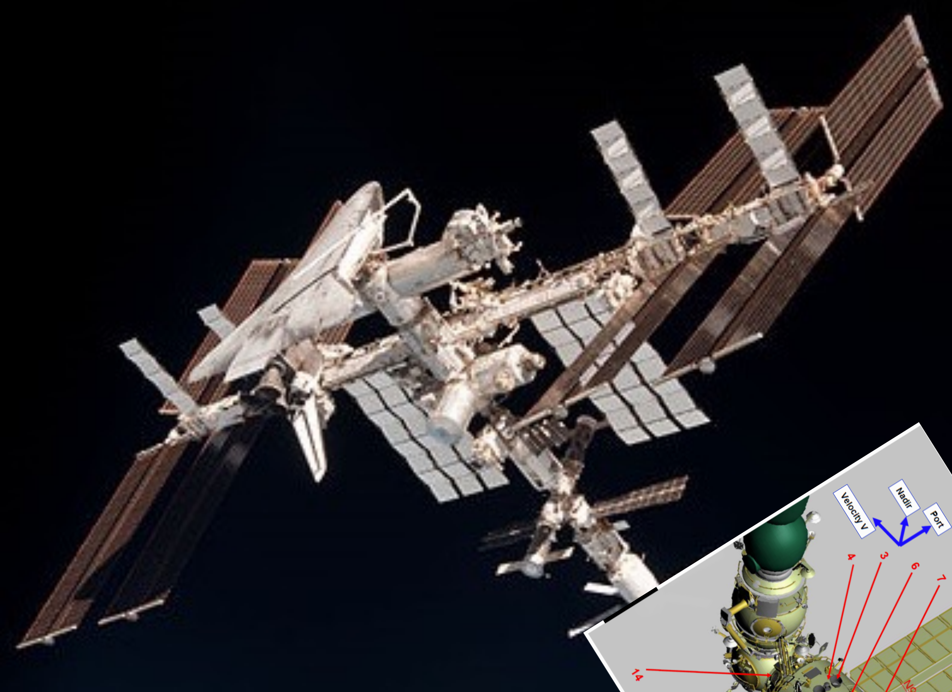
2016
4PMT
+ CW board

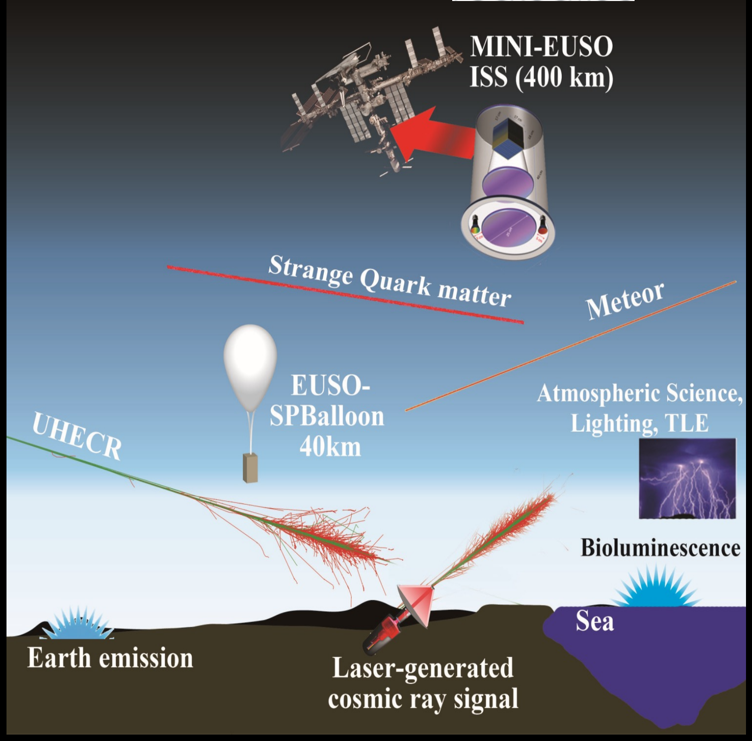
2018
4PMT
+ CW board
+ ASIC boards

Fluorescence camera MAPMs

Mini-EUSO/UV-ATMOSPHERE

(flew to ISS on August 22nd 2019)



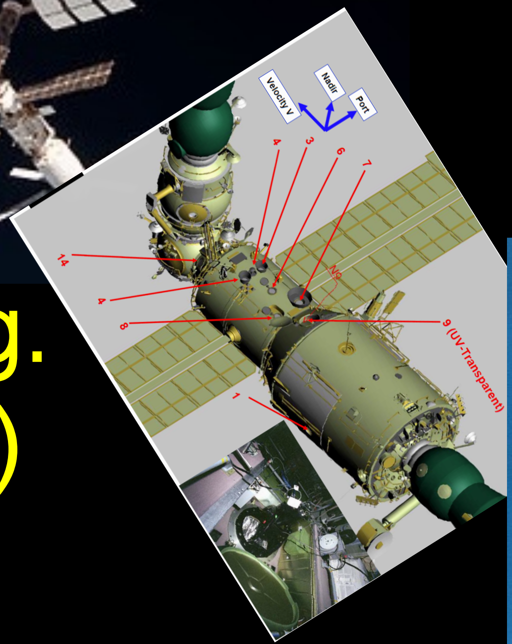


DATA with self trigger:

D1 : 2.5 μs res. (128 L1GTUs)

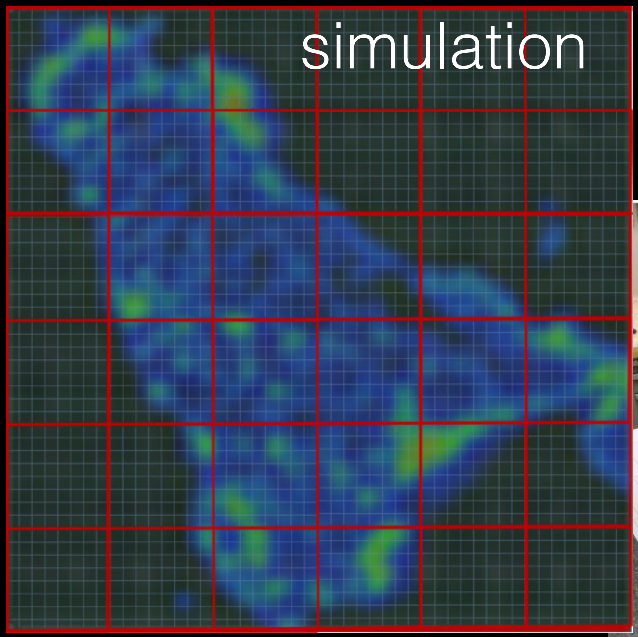
D2: 320 μs res. (128 L2GTUs)

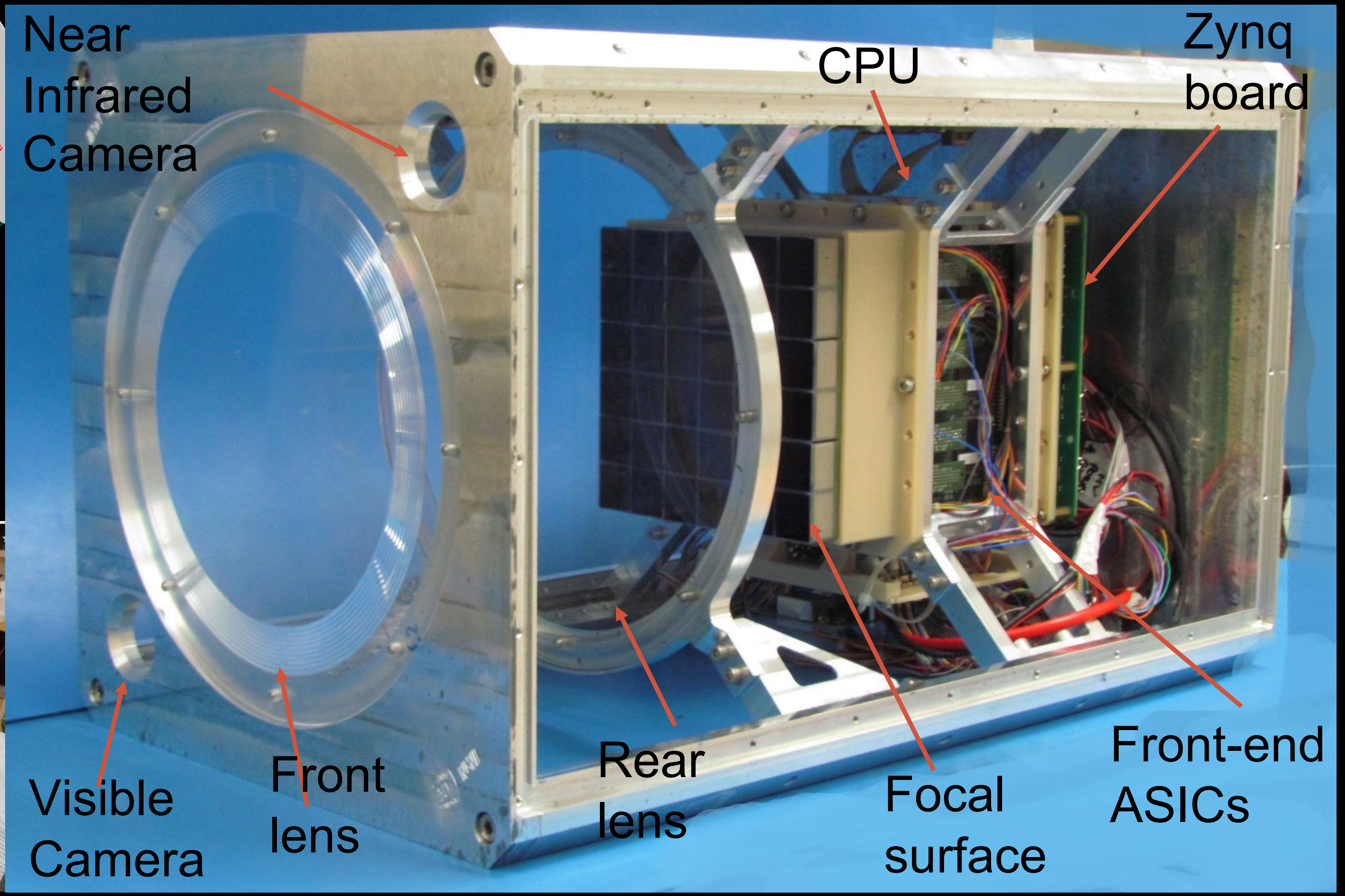
D3: 40.96 ms res. (full movie)



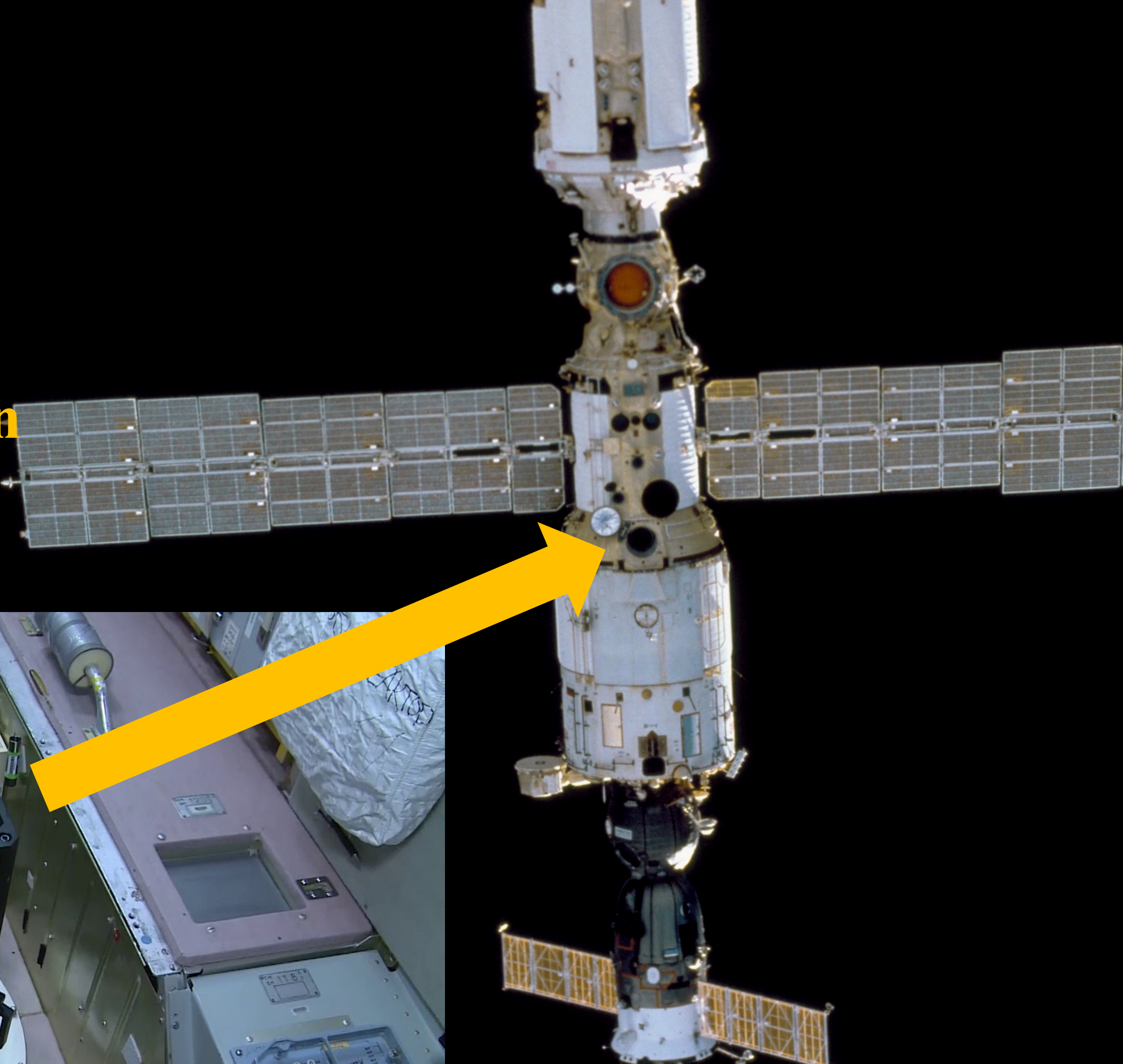
FoV: ± 22 deg.

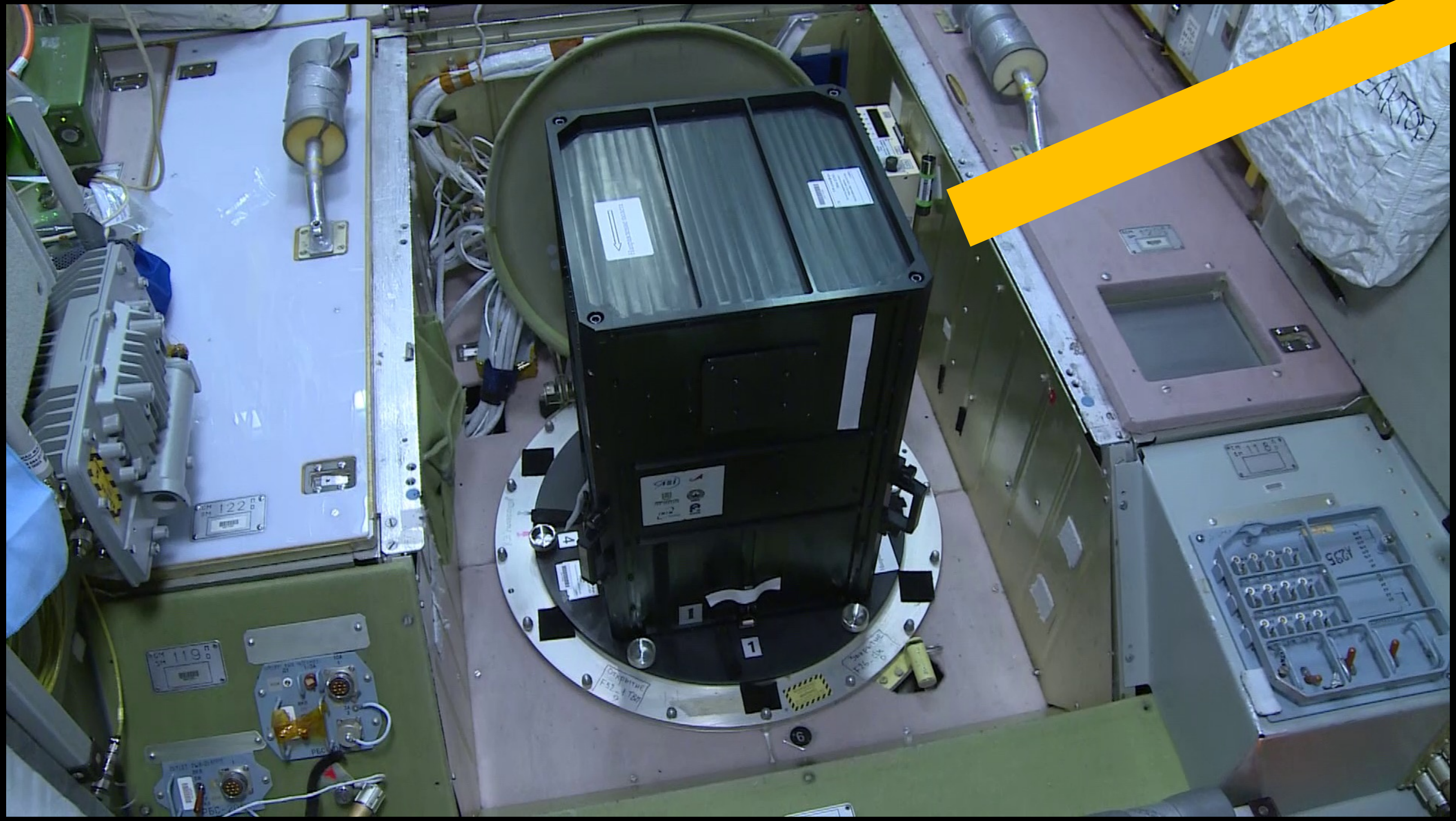
(9 times TUS)



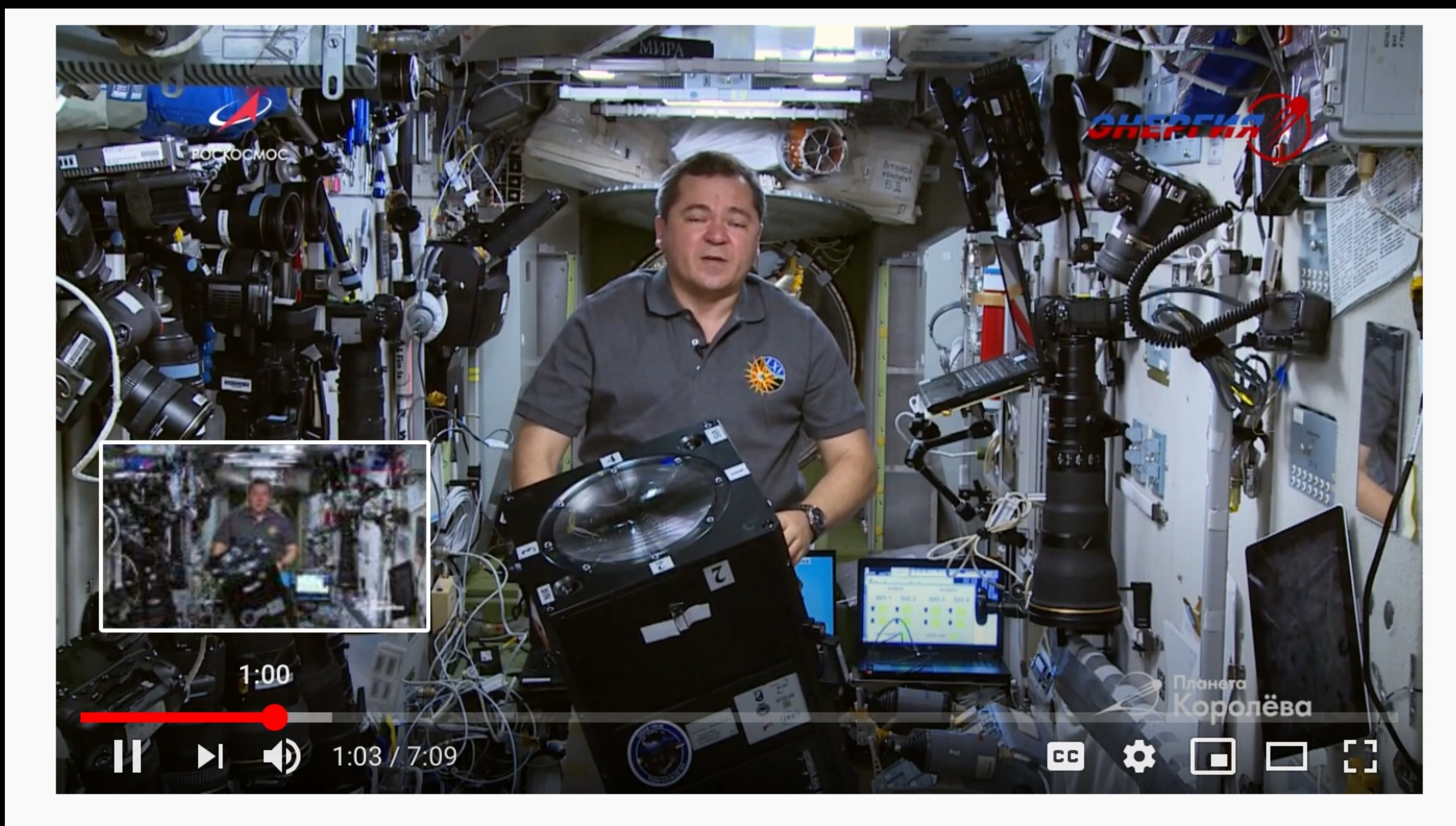


Uv transparent window,
Zvezda module,
International Space Station



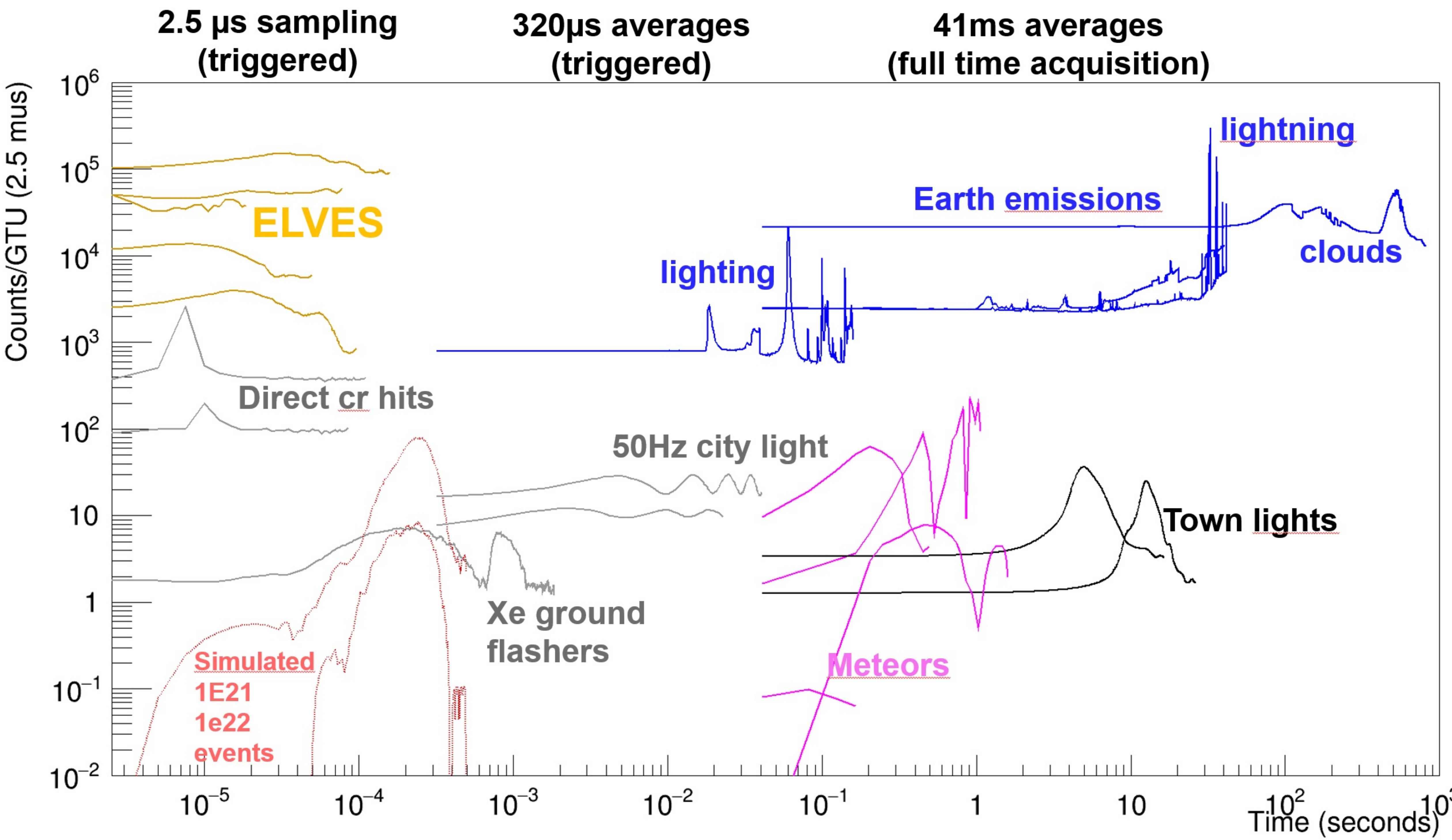


[https://www.youtube.com/watch?v=lX edBGVHc4o&t=62s](https://www.youtube.com/watch?v=lXedBGVHc4o&t=62s)



Sampling rate: µs, 100µs **AND** ms scale

S. Bacholle et al., "Mini-EUSO Mission to Study Earth UV Emissions on board the ISS", The Astrophysical Journal Supplement Series, Vol. 253, pag. 36 (2021), https://doi.org/10.3847/1538-4365/abd93d
https://arxiv.org/abs/2010.01937



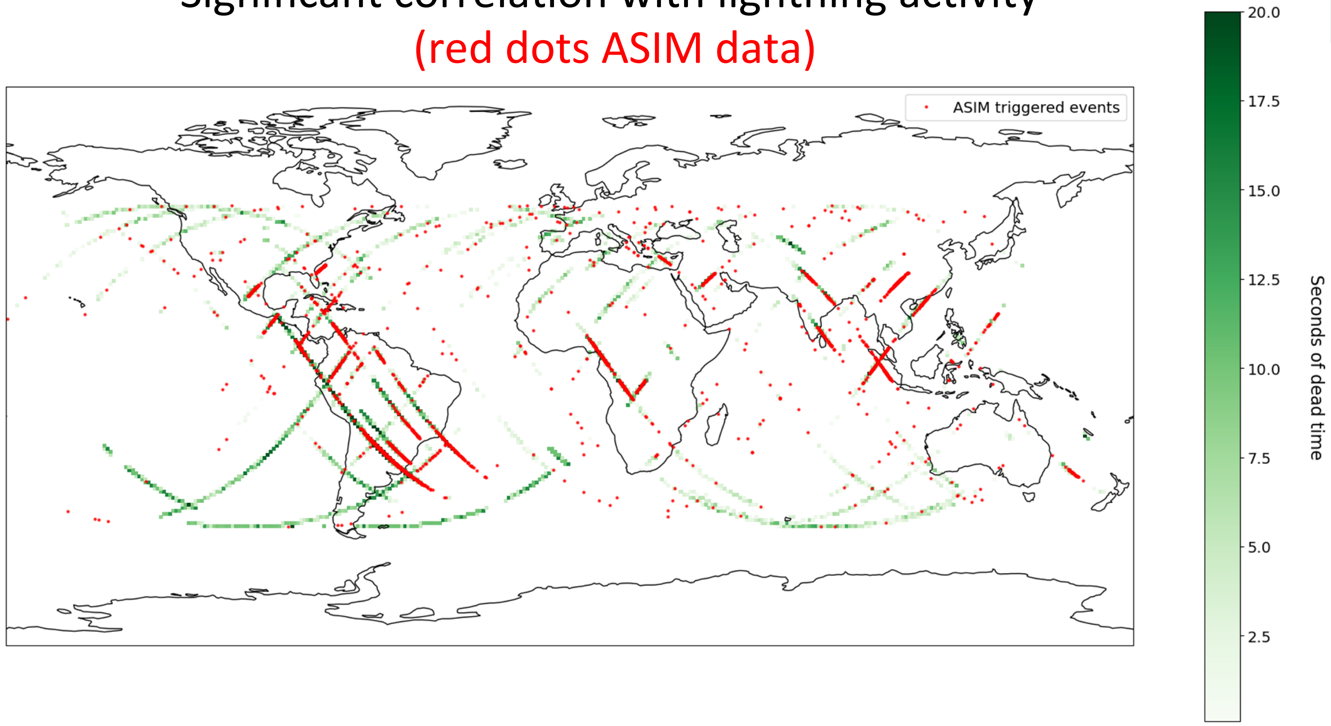
M. Casolino, L. Marcelli

Mini-EUSO - μs timescale trigger performances

Dead time (20-30%)

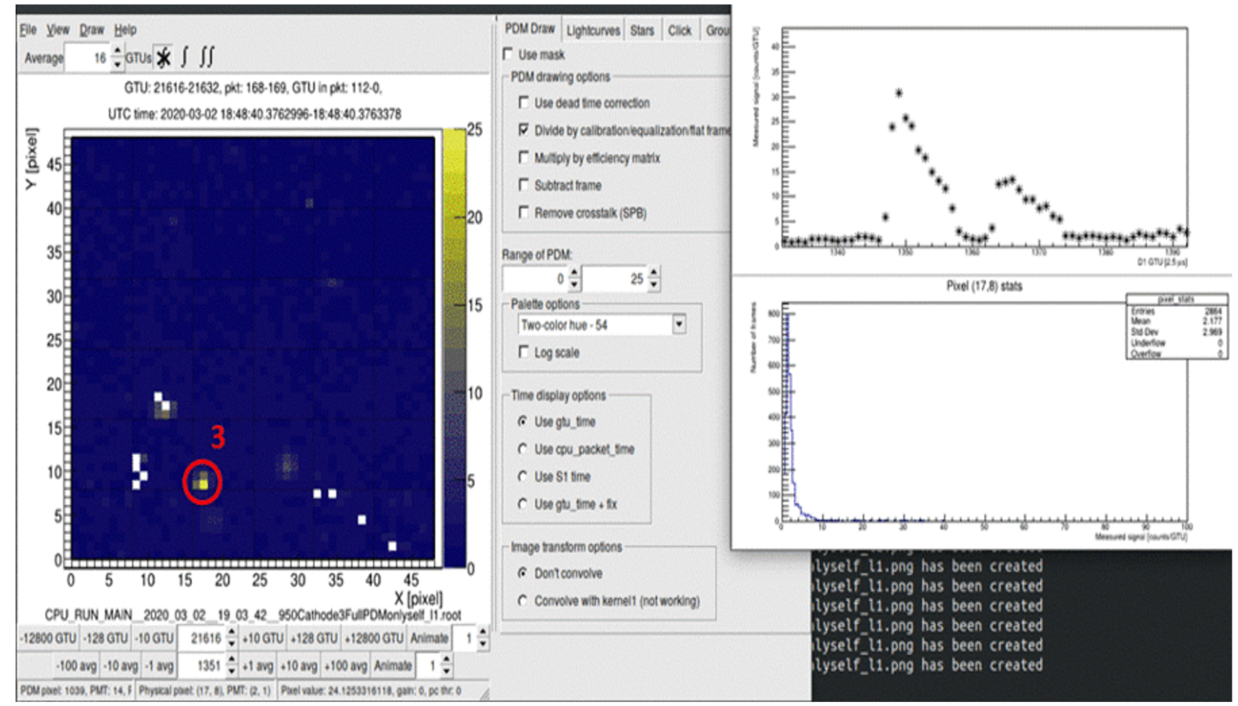
Significant correlation with lightning activity

(red dots ASIM data)

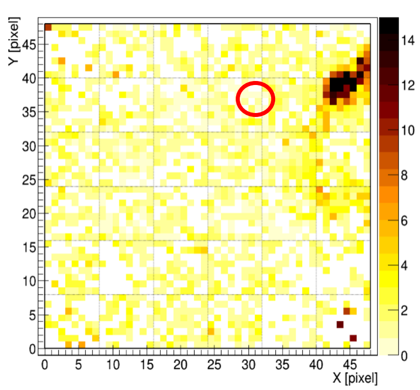


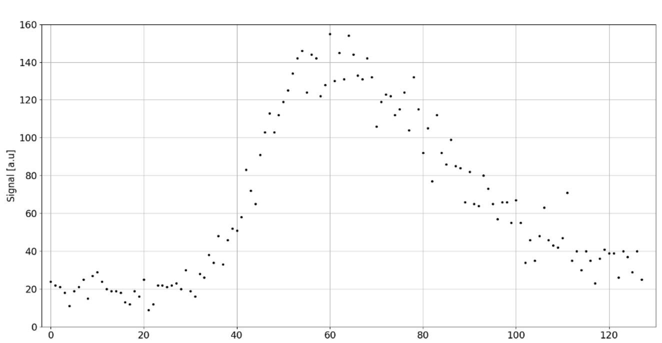
The same flasher triggered three different time. The event was located in a mountain region in China

Left: flat fielded focal plane view. Right: lightcurve of the most luminous pixel

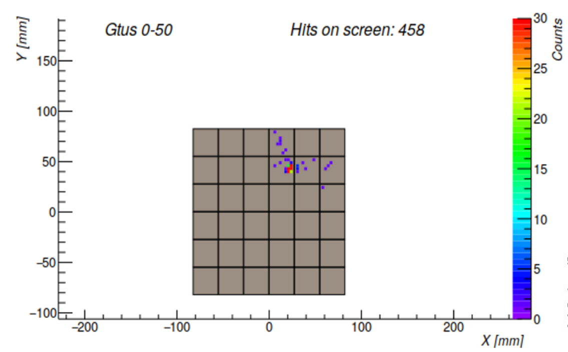


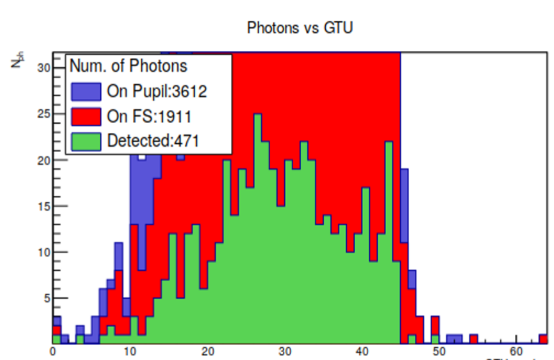
M. Battisti, F. Bisconti, P. Klimov, F. Fenu, A. Golzio





80 frames

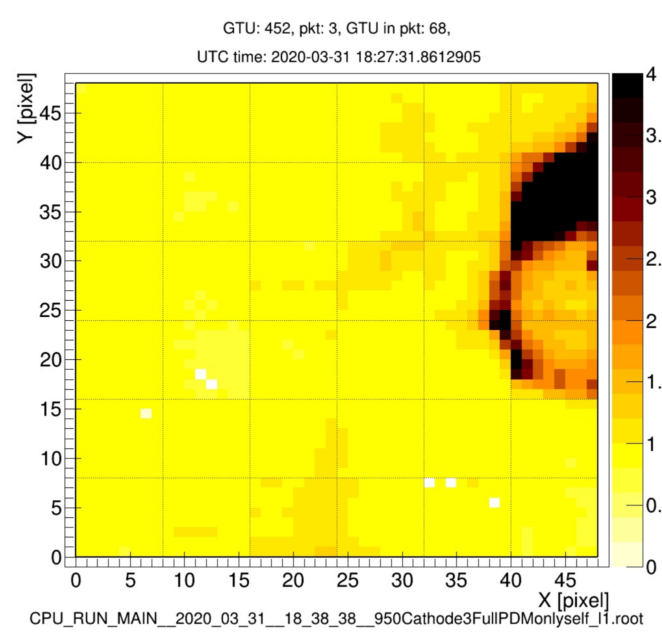


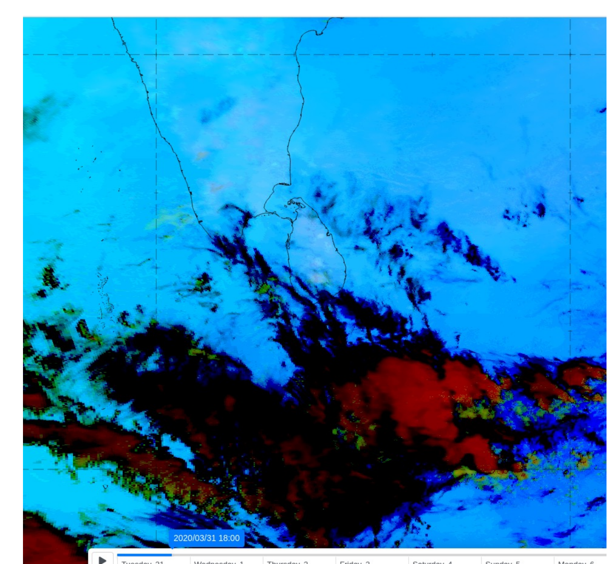


30 frames - too short

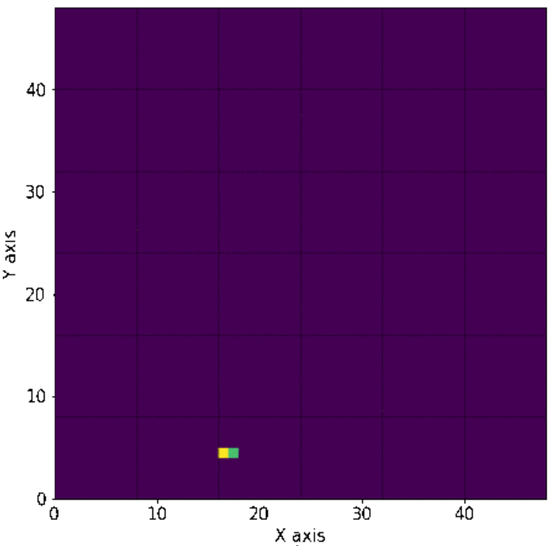
Mini-EUSO

$2x10^{22}$ eV p simulation

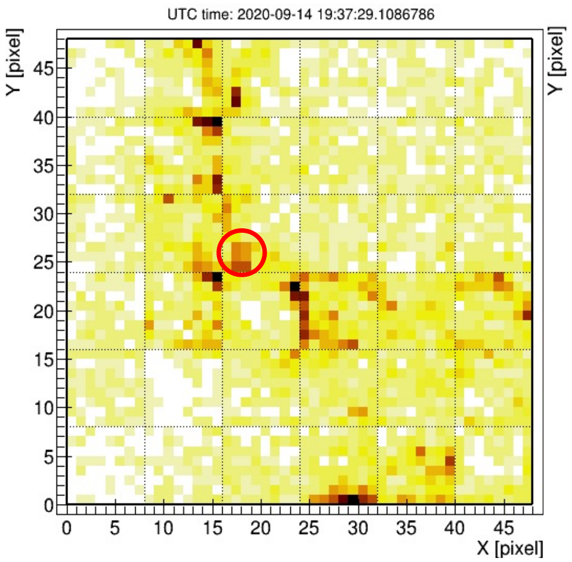




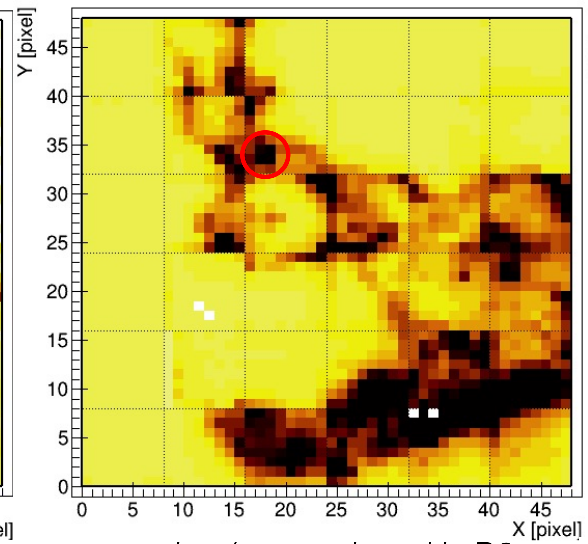
Lamezia Terme Event – Italy



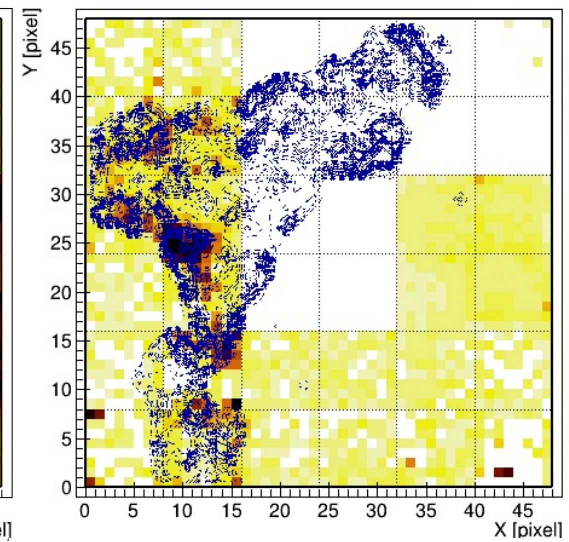
repeated event



visual event trigged in D1

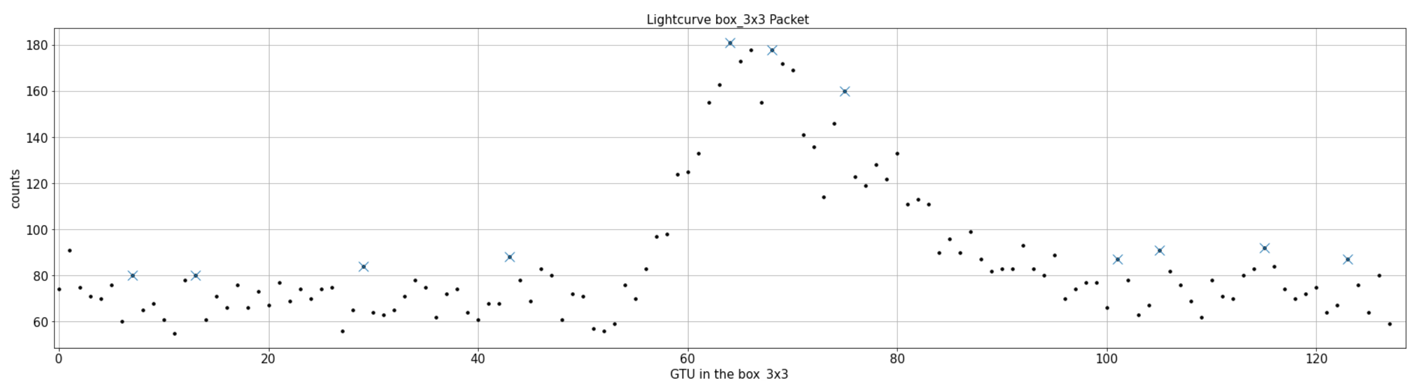


visual event trigged in D3



ISS movement

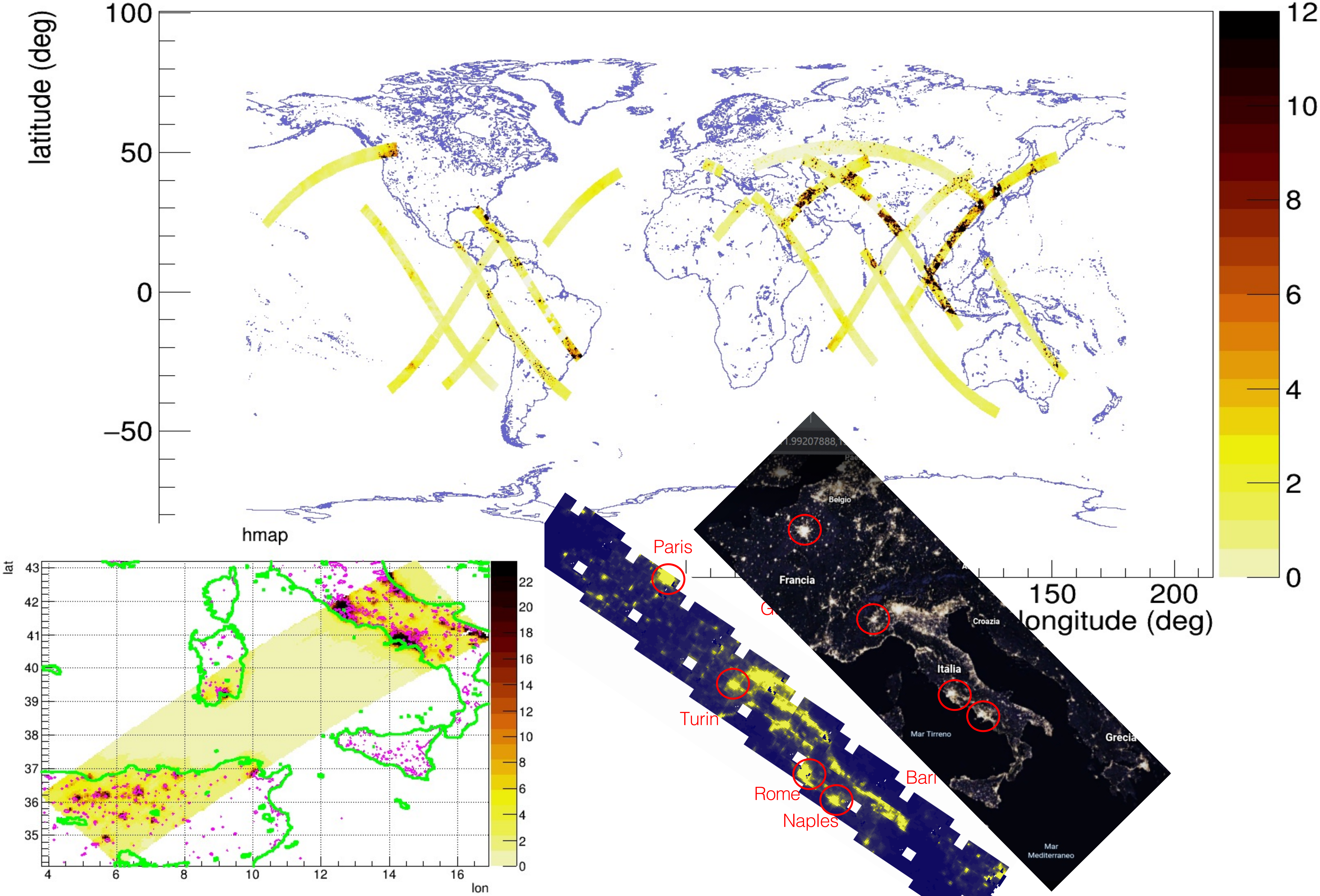
South Italy

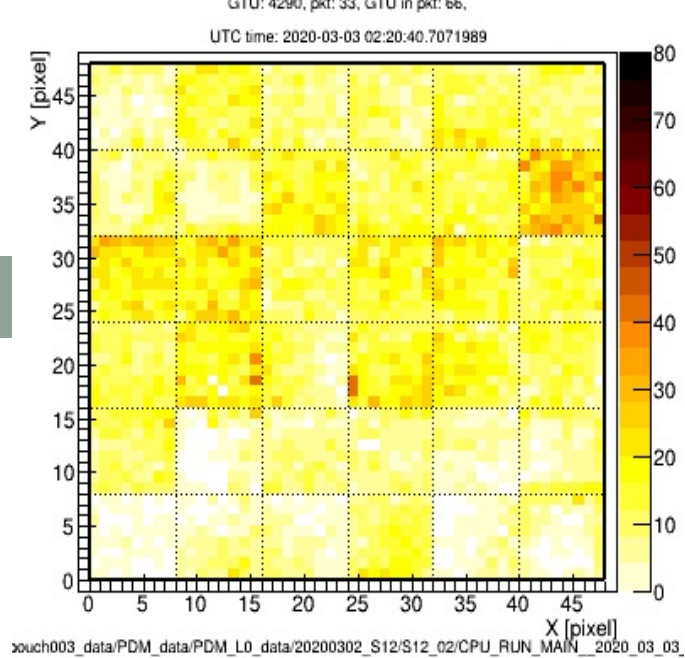


- These events have not been seen only over North America.
- A particular example is this event repeated several times with the same light curve on *September 14th, 2020*.
- With an in-depth analysis and the location of the *ISS*, it was possible to find the approximate geographic location of the event.
- The event with *ETOS* software and the *DMSP* map were superimposed and it was possible to see that it's clearly displayed around *Lamezia Terme International Airport* (*Calabria*) in Italy.

L. Piotrowski, F. Bisconti

UV Maps

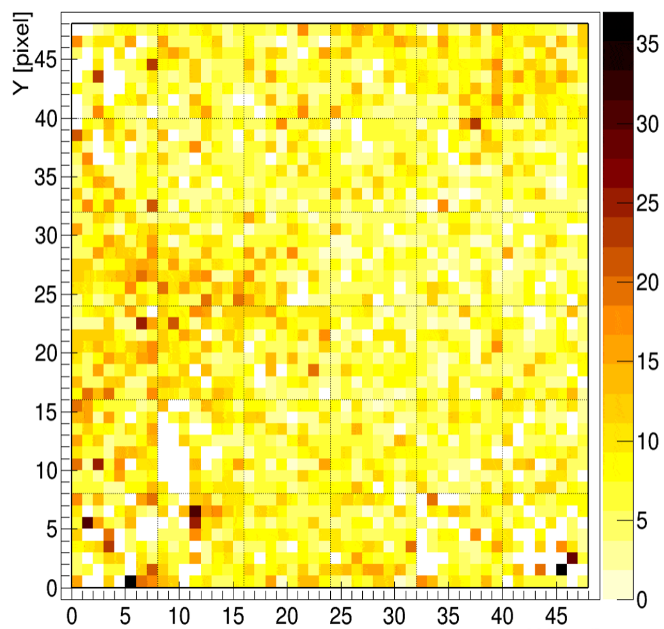


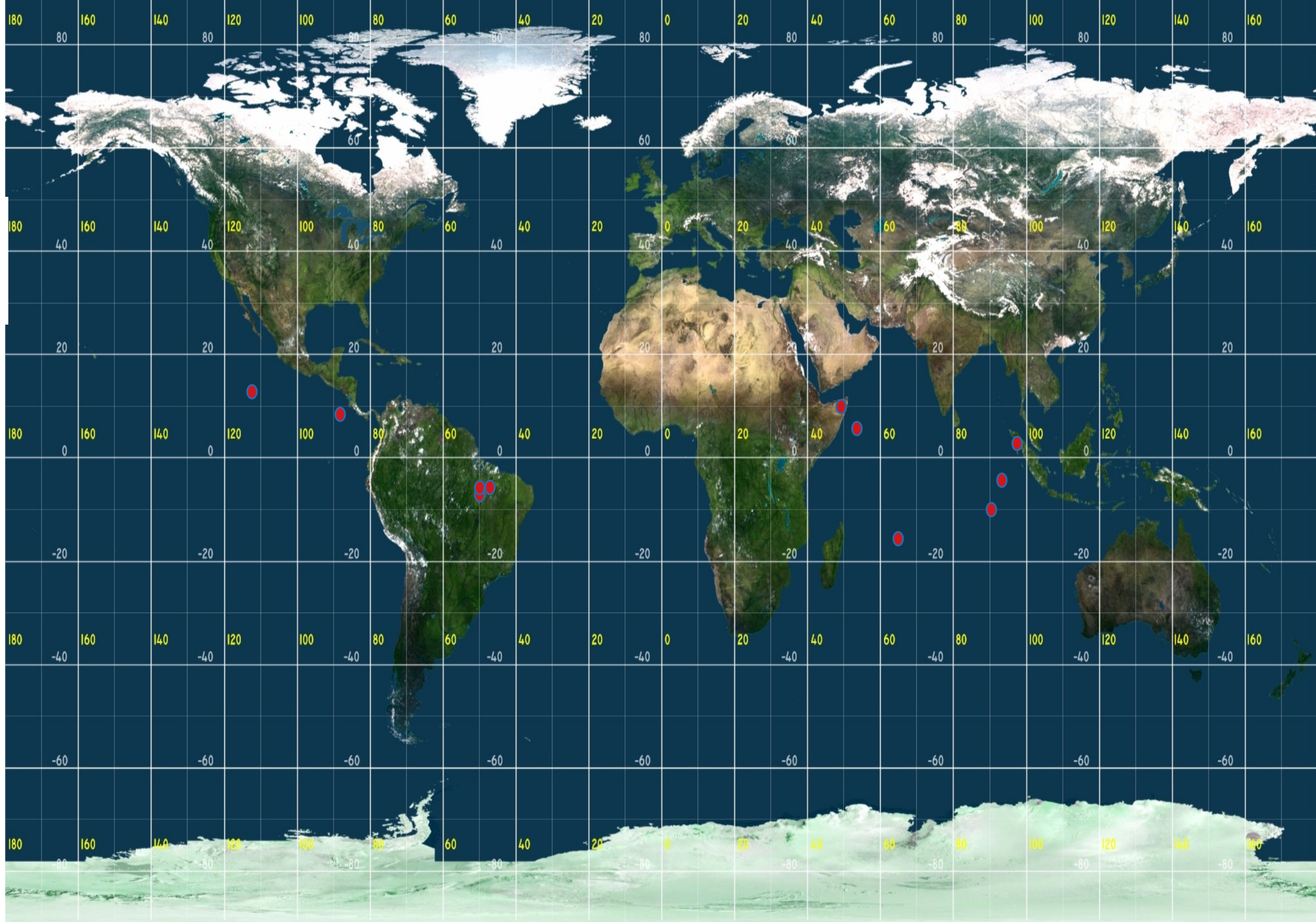


TLEs

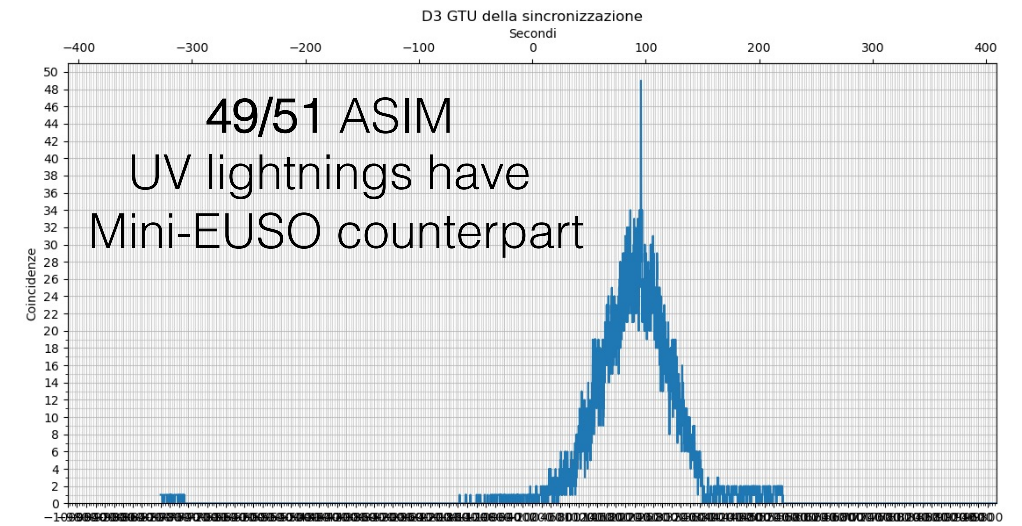
ELVES:

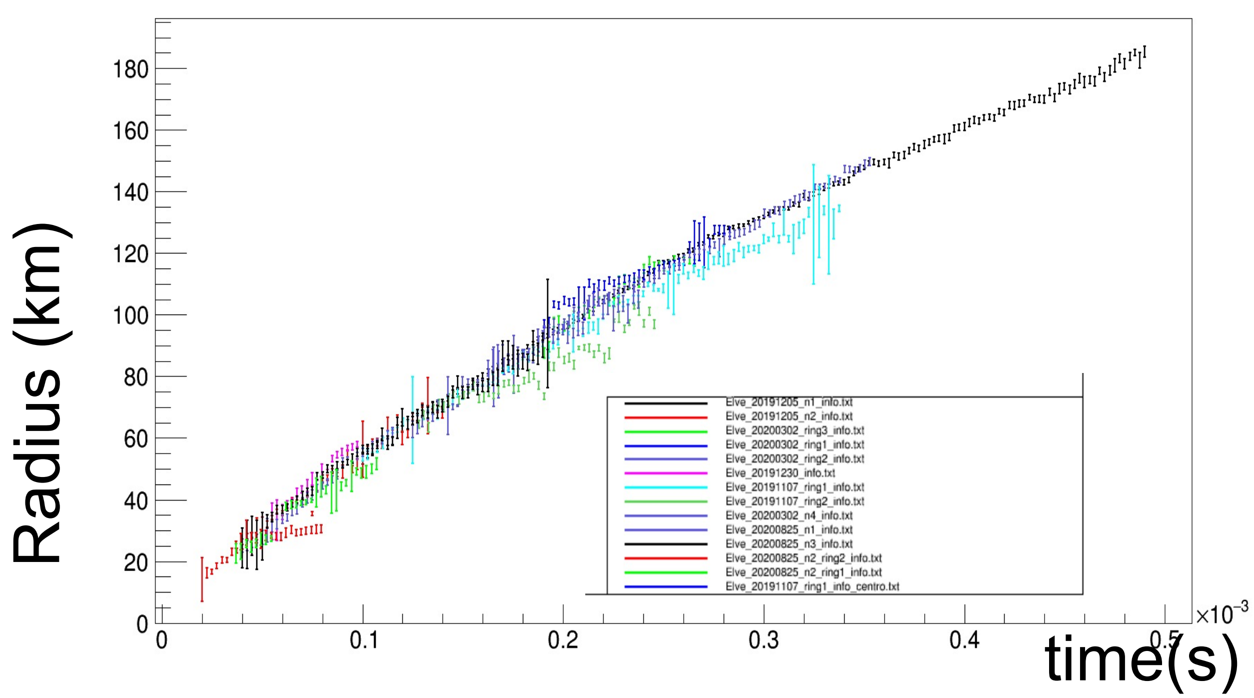
1) 2019, Nov 7
2) 2019, Dec 5 – n1
3) 2019, Dec 5 – n2
4) 2019, Dec 30
5) 2020, Mar 2 – n1
6) 2020, Mar 2 – n2
7) 2020, March 2 – n3
8) 2020, Mar 2 – n4
9) 2020, Aug 25 - n1
10) 2020, Aug 25 - n2
11) 2020, Aug 25 - n3



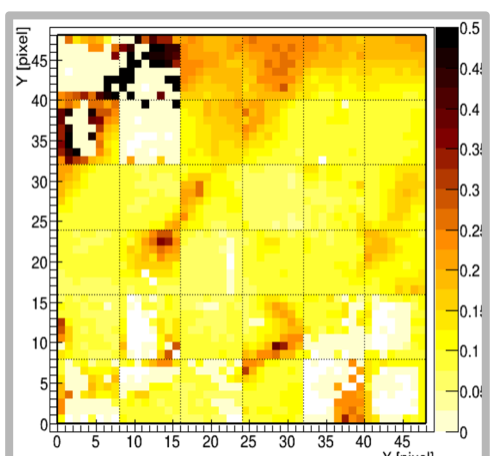


L. Marcelli, M. Casolino, M. Battisti, E. Arnone



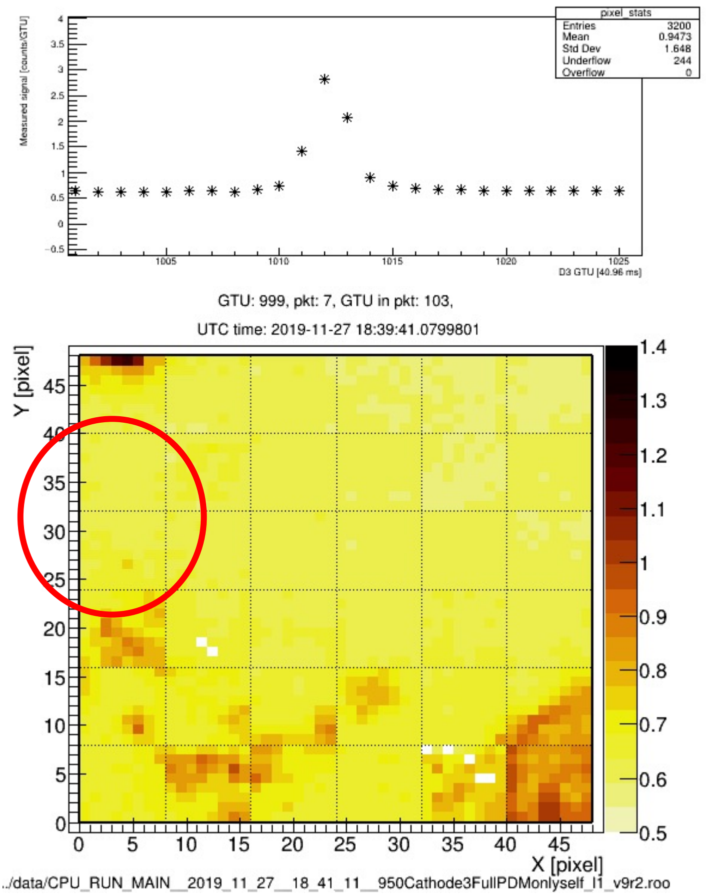


2 Elves - simultaneous detection with ASIM



Meteors

- Most of the meteors are detected where the background is lower
- The false positives rate is higher over continents



- Meteors
- Meteor candidates
- Noise
- Unidentified events

Detail from session 06

Current findings:

~1500 meteors

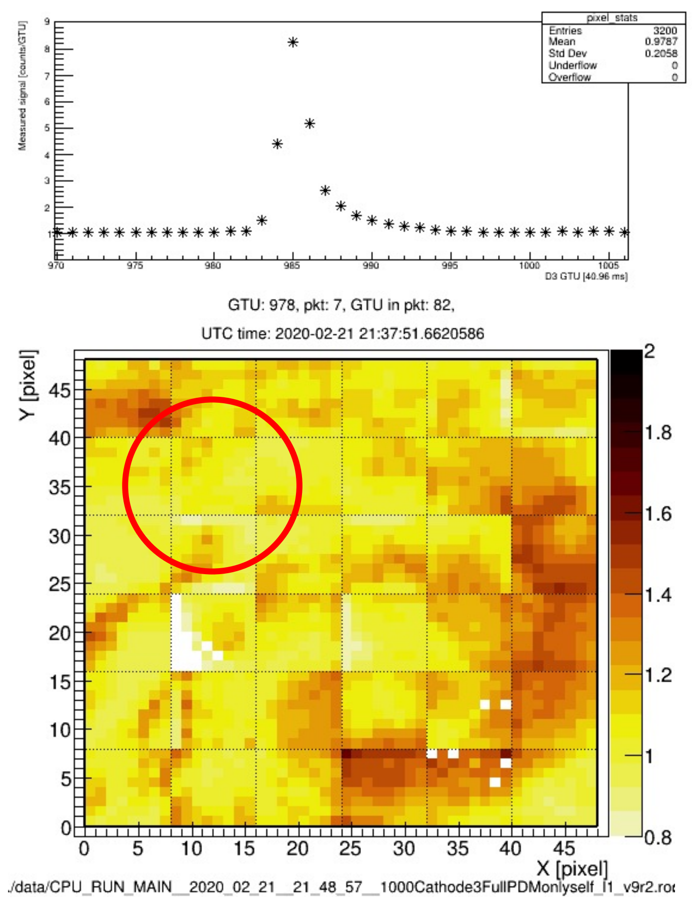
~1300 meteor cand.

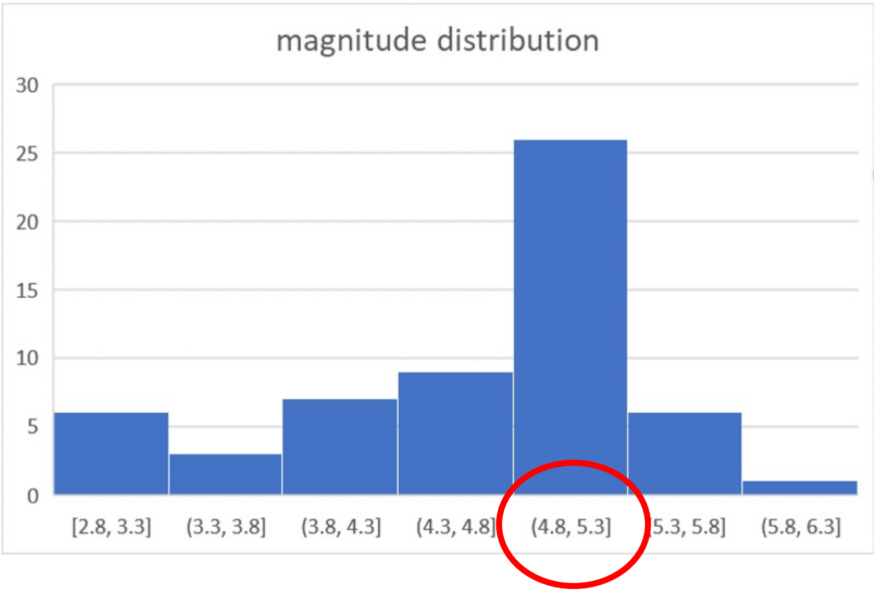
in ~1900 min

A. Cellino

Abs. mag	U-band flux (erg/s/cm^2/A)	mass (g)	event rate (Mini)
+7	$6.7 \cdot 10^{-12}$	$2 \cdot 10^{-3}$	0.4/s
+5	$4.2 \cdot 10^{-11}$	10^{-2}	2.4/min
0	$4.2 \cdot 10^{-9}$	1	0.11/orbit
−5	$4.2 \cdot 10^{-7}$	100	2.5/year

G. Abdellaoui et al., "Meteor studies in the framework of the JEM-EUSO program", *Planet. Space Sci.*, 143, 245 (2017)





With an efficiency of 8% the distribution peak is in a range of magnitude values of [+4.8,+5.3]

Considering S06 and S11 (moon 2%):

- Total number of observed meteors:
  $356 + 343 = 699$
- Total number of meteor candidates:
  $201 + 109 = 310$
- Total sessions duration:
  $282 + 168 = 450\ min$

Events rate:

1.5 events/min (only M)

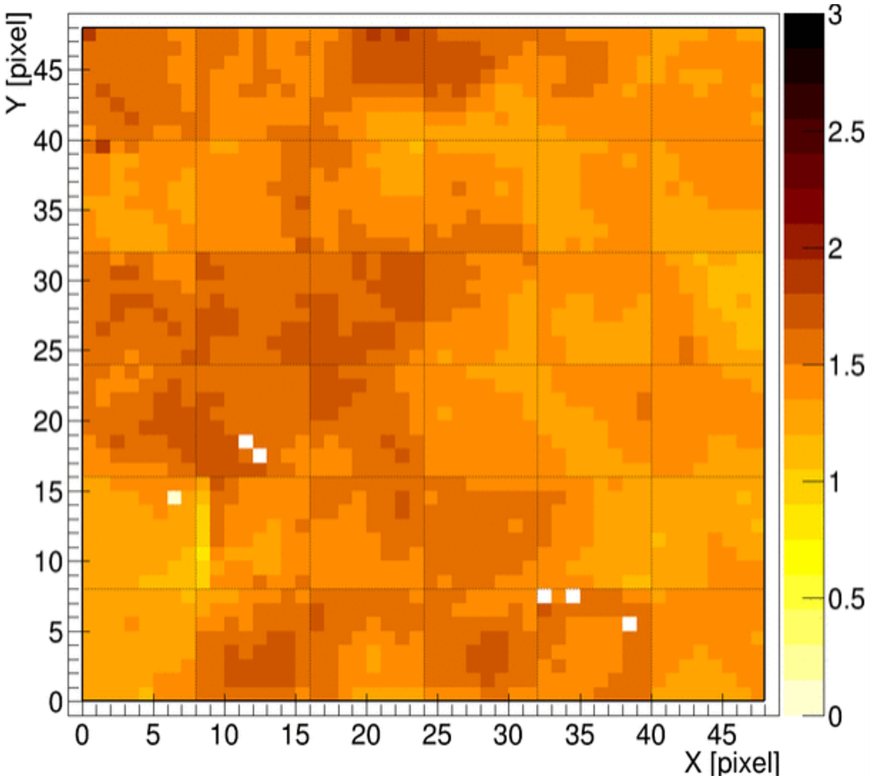
2.3 events/min (M+M?)

L. Piotrowski, D. Barghini, H. Miyamoto, S. Bertone & F. Reynaud

Clouds

K. Shinozaki,
A. Golzio & M. Manfrin

Diffuse light

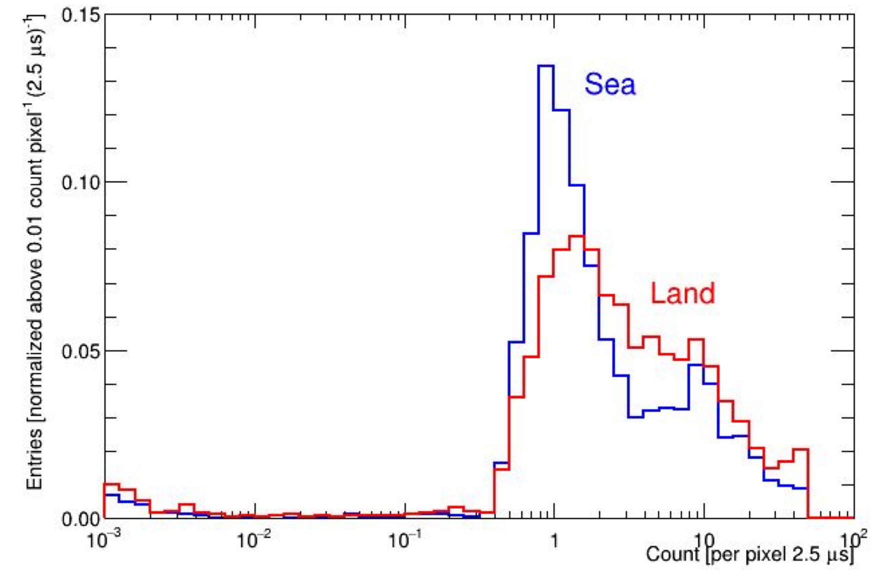


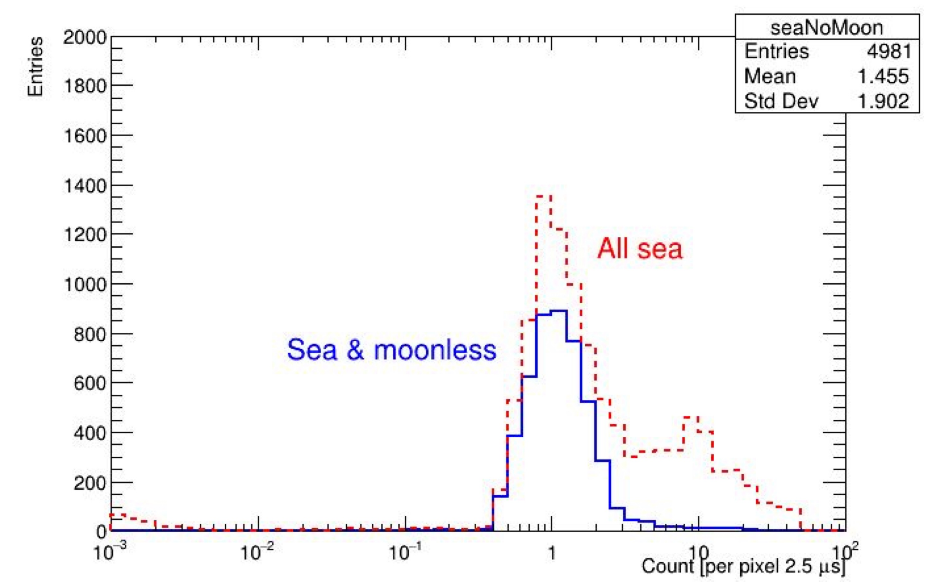
We see clouds: which ones?

Database
under preparation

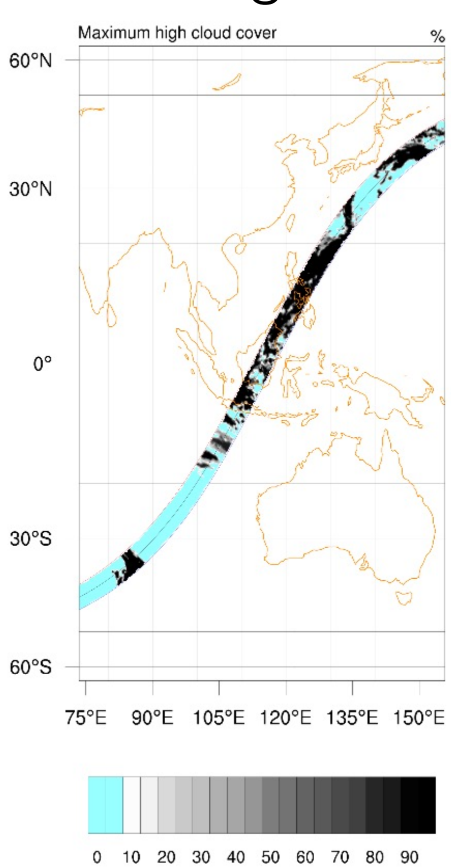
Climate Change Service

ECMWF

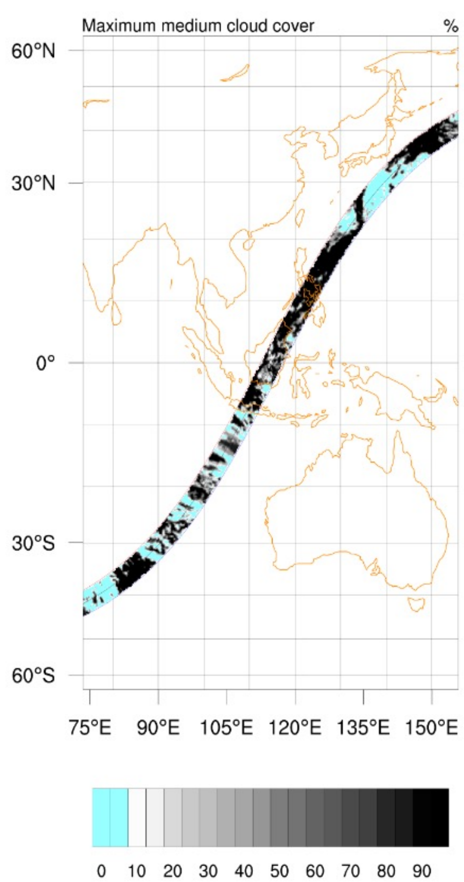




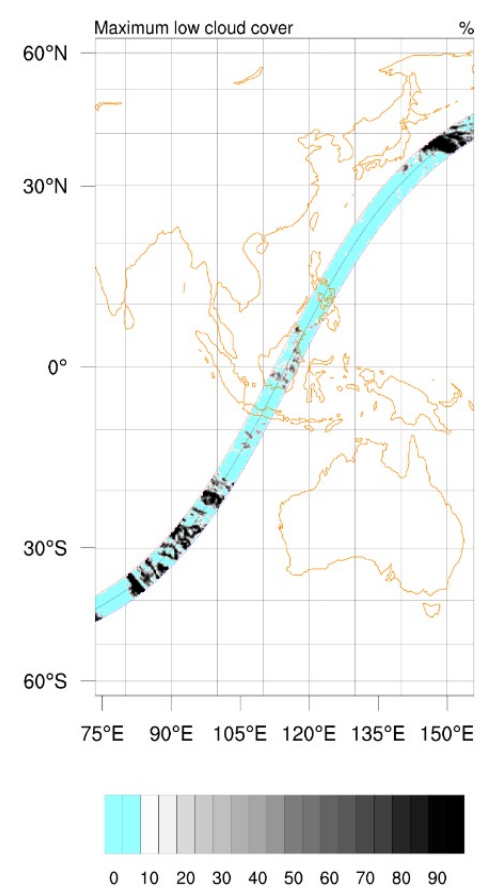
high



middle



low clouds



PRELIMINARY

(using same approach as EUSO-Balloon)

	Observation time [h]	Average rate [count / (pixel 2.5 µs)]
All data	25.9	5.2
Sea data	14.6 (56%)	4.5
Sea & no moon	7.0 (27%)	**1.5**

- For this condition, the average of 1.5 counts per pixel^{-1} 2.5 µs^{-1} is consistent with ~550 photons m^{-2} sr^{-1} ns^{-1} for 250--500 nm

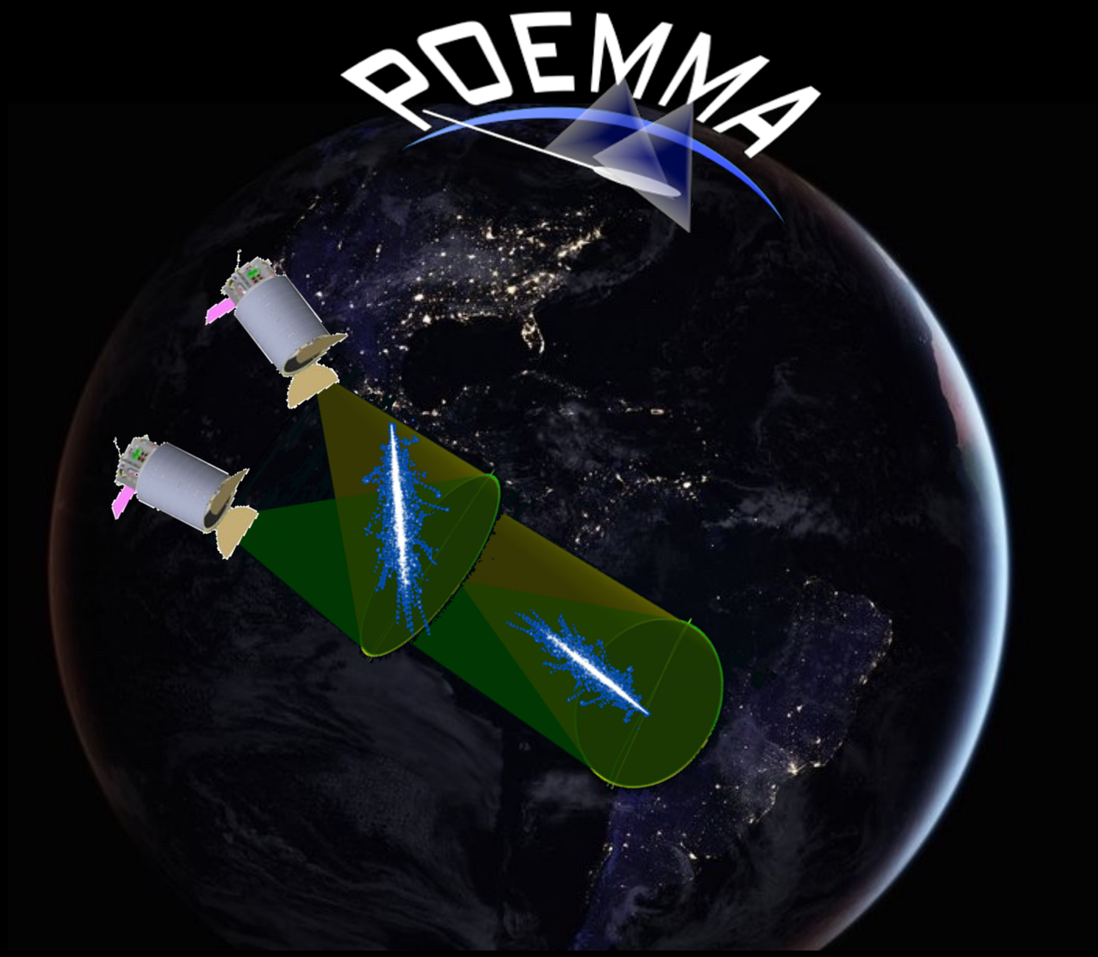
POEMMA + Mini-EUSO & EUSO-SPB2

Earth's Atmosphere = Particle Observatory :

- Discover the Origin of the Highest Energy Cosmic Rays ($E>10^{19}$ eV)

and

- Discover High energy Neutrino Emission ($E>10^{16}$ eV) from Astrophysical Events
- Study New Astro/Physics



Mini-EUSO

Multiwavelength Imaging New Instrument for Extreme Universe Space Observatory

EUSO-SPB2

Probe Of Extreme Multi-Messenger Astrophysics

Extreme Universe Space Observatory on a Super Pressure Balloon

THANK YOU