UHECR 2018 Conference

Paris, France

(8-12 October 2018)

The space road to UHECR observations: challenges and expected rewards

For the JEM-EUSO Collaboration

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JAMAIS SANS ELLES

Mixity & gender equity

E.T. d' Orion @parizot etienne.parizot

Extreme Universe Space Observatory

The international JEM-EUSO Collaboration

- E.U.S.O. Extreme Universe Space Observatory

16 countries, ~350 members

Detect UHECR-induced air showers from space (+ neutrinos)

- Widely approved science case (no need to comment it here!)

- Funded by national institutions and space agencies around the world

NASA, РОСКОСМОС, esa, JAXA, agenzia spaziale italiana, cnes CENTRE NATIONAL D'ÉTUDES SPATIALES …

- On-going activity: development of the EUSO program

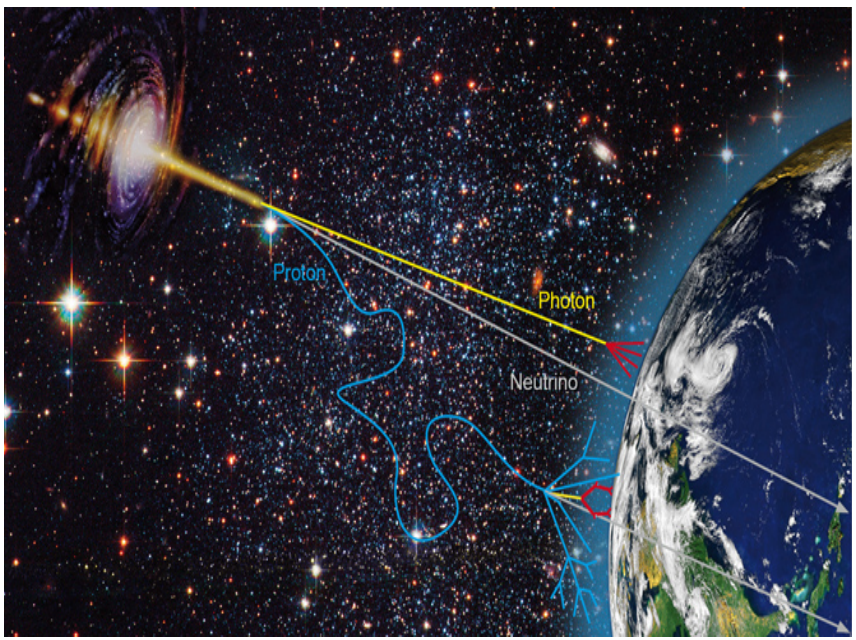
"Space road to UHECR observations" Or stairway to heaven!

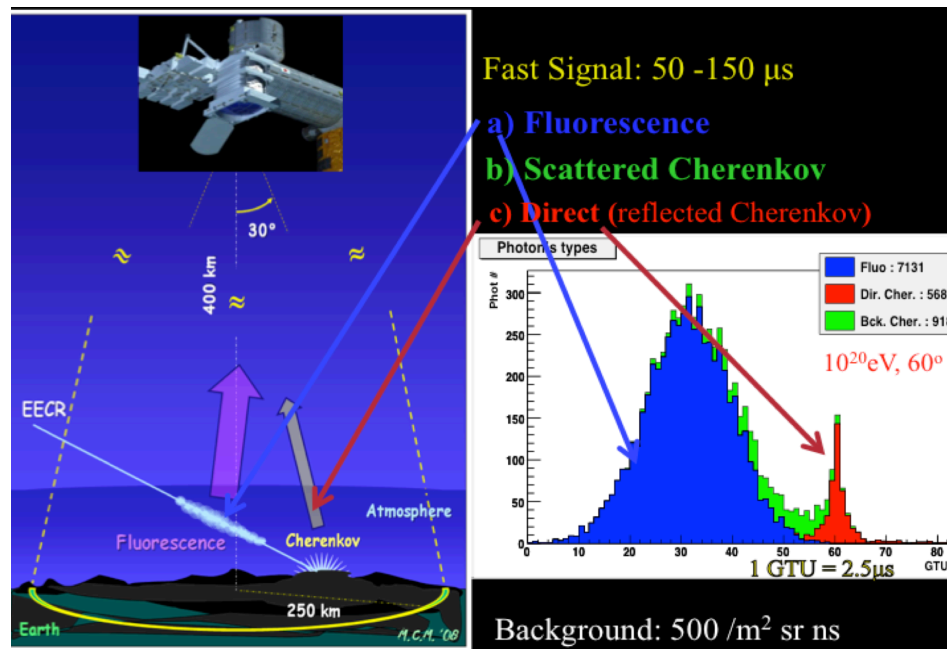
Observational strategy

- Same as FD (fluorescence detectors) on the ground

  2D + time → 3D imaging of atmospheric air showers

  - Shower axis → arrival direction
  - UV fluorescence light → "calorimetric" energy measurement
  - Grammage depth of the maximum shower development (Xmax) → "some" information about the nature of the cosmic ray





Why go to space ?

Statistics

→ game changing!

10 times larger exposure is reachable in a first significant step

Then… <u>sky is the limit!</u>

→ “a factor 10^5 to go!” (A.O.)

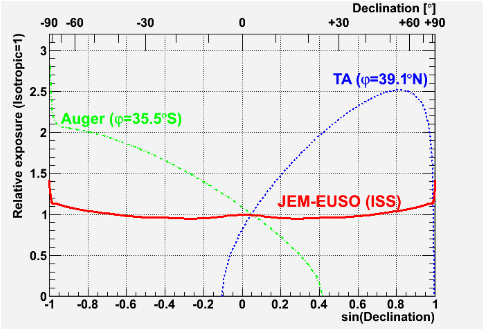
Full sky coverage

→ crucial step forward!

Large scale anisotropy assessment becomes much more powerful…

…and precise:

- same energy scale
- same systematics
- uniform exposure (within <10%)

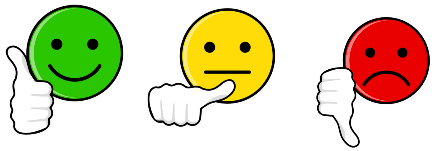


Single instrument

→ no "deployment", land owners, etc. ;-)

Why go to space ?

Precision



➡ From good to acceptable to "worth improving" (workable compromise)

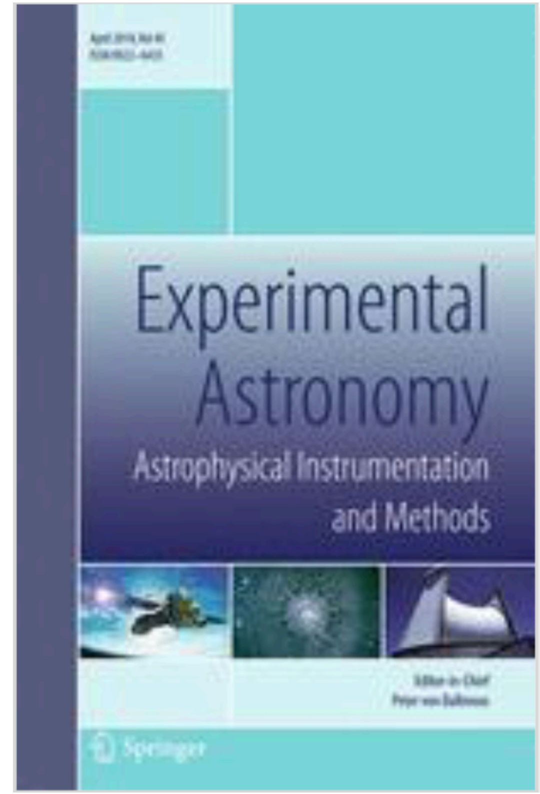
Angular reconstruction

Energy reconstruction

Mass reconstruction

Exposure control

➡ We gained appropriate experience and control along the development of the JEM-EUSO program

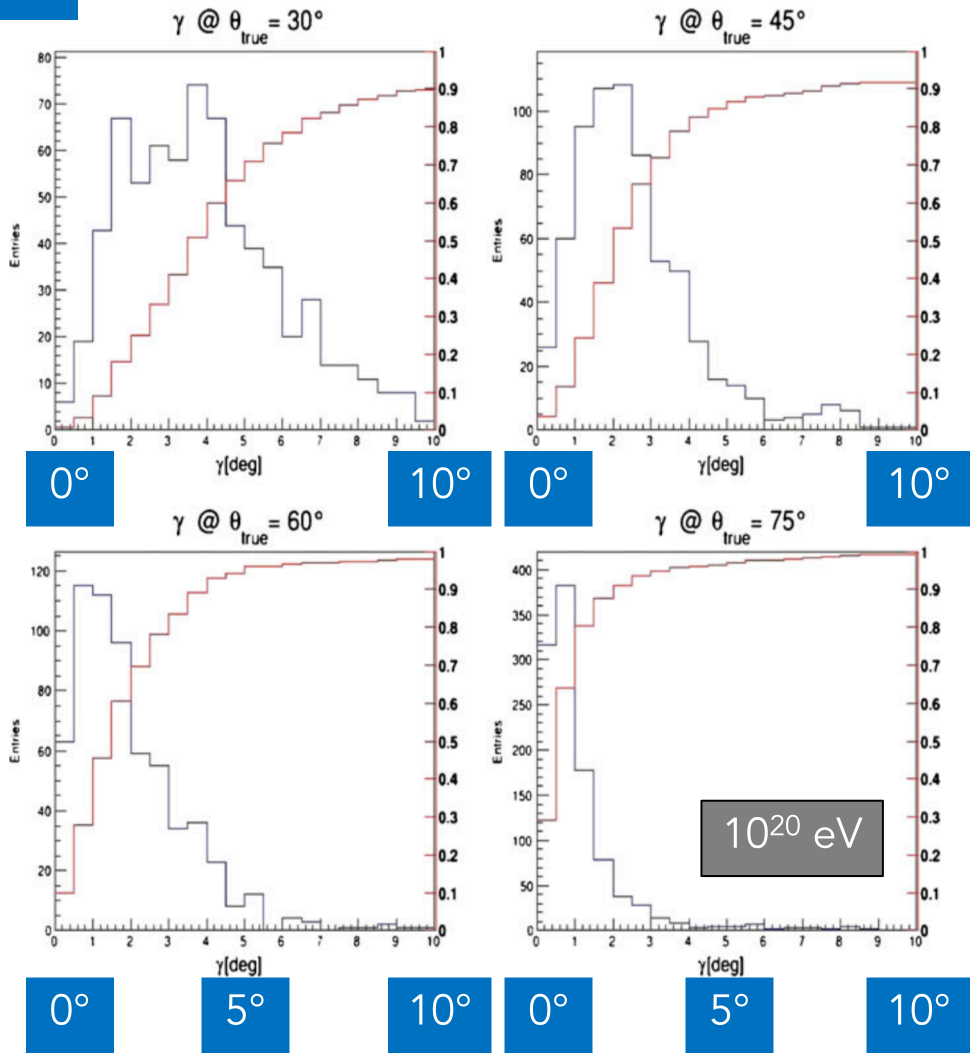


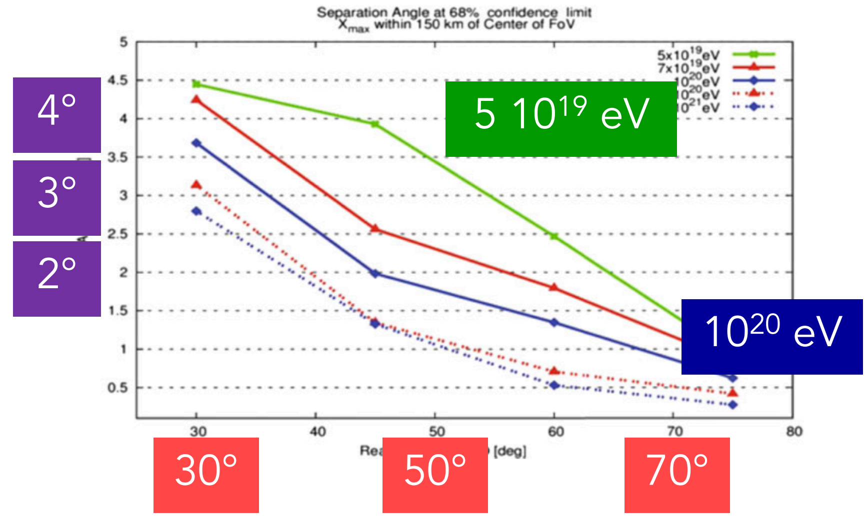
2015 JEM-EUSO's special issue of Experimental Astronomy

(16 detailed refereed papers)

Angular reconstruction

ΔΘ

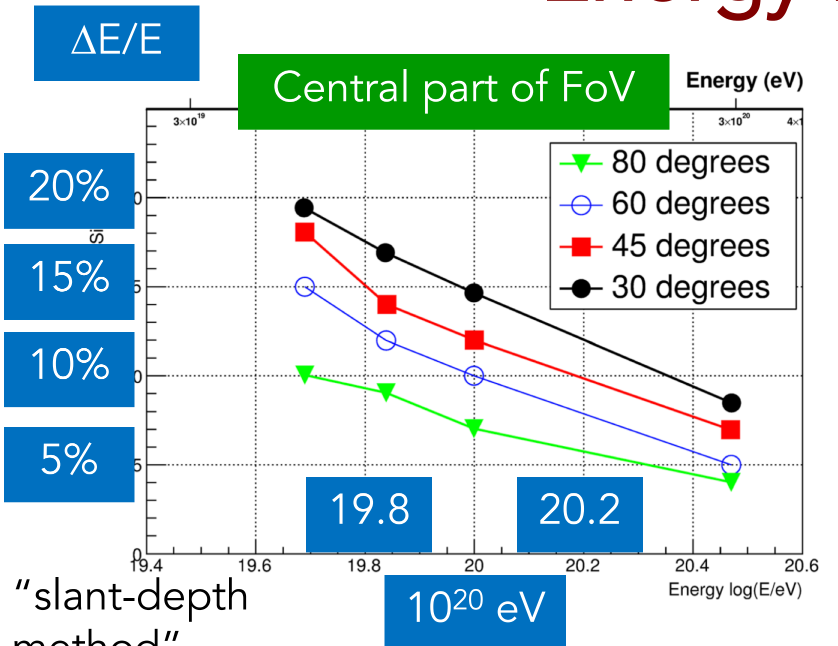




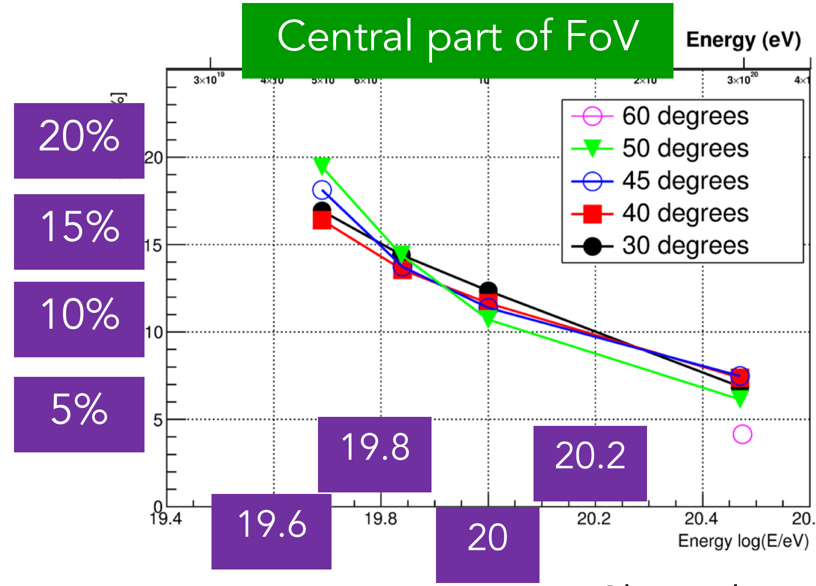
Xmax within 150 km of FoV center

Definitely good enough!

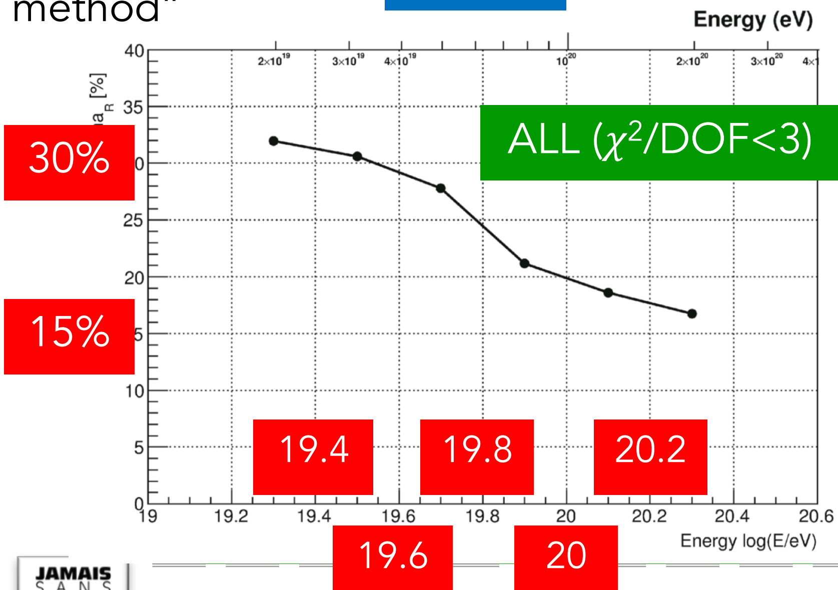
Energy reconstruction



"slant-depth method"



"Cherenkov method"

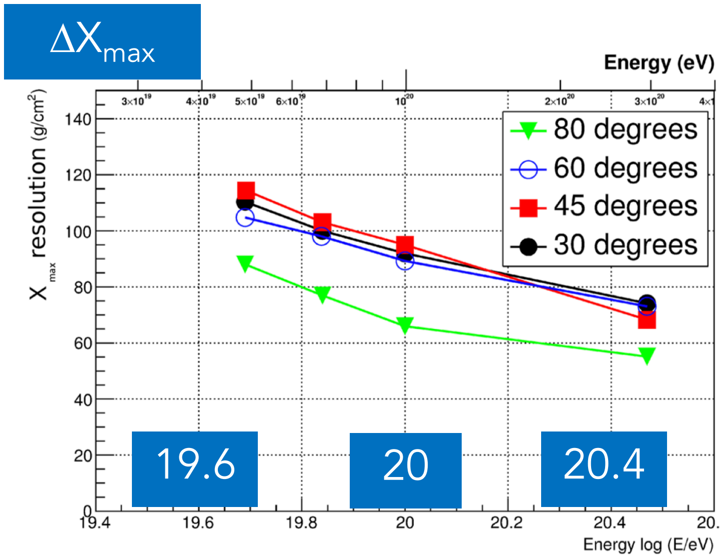


NB: some good, some less good, but we know which ones!

NB: higher precision is of little use in case of low statistics!

Energy bin size = "effective ΔE"

Xmax reconstruction



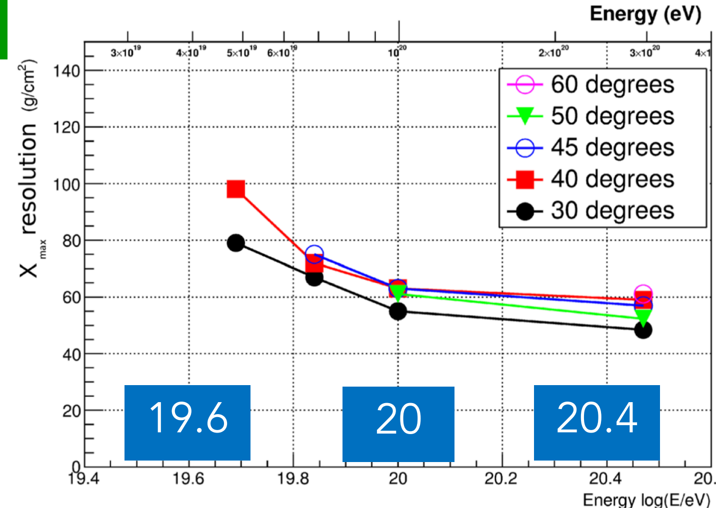
"slant-depth method"

Central part of FoV

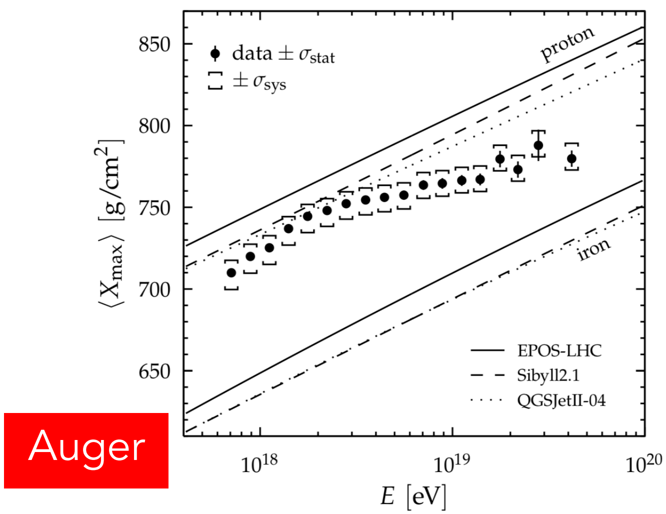
100 g/cm²

60 g/cm²

40 g/cm²



"Cherenkov method"



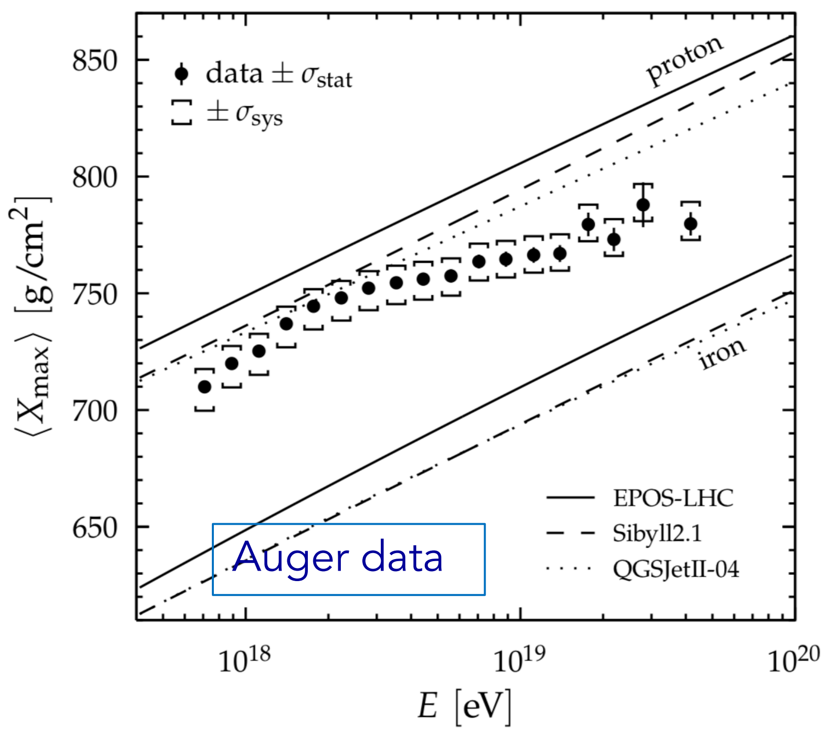
Poor Xmax resolution is the main drawback of space-based detection

But…

✧ Comments about mass discrimination (I)

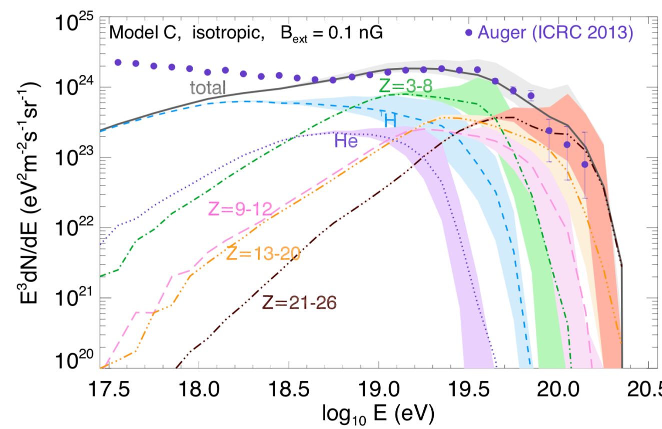
Those who remain convinced that protons dominate all the way up to the highest energies should not be worried that JEM-EUSO cannot be precise on Xmax!

Neither should those who think the transition to ~Fe is completed at E ≥ 10^{20} eV…



NB: I am kidding, of course, but not only!

Not so many nuclei can survive above 10^{20} eV



Of course, we'd love to isolate a subdominant fraction of protons if it exists, but they'll cluster anyway, whether we identify them of not!

=> Statistics is the key!

✧ Comments about mass discrimination (II)

A space-based instrument can actually do a lot for composition studies!!!

~10 times more events than Auger/TAx4 means ~100 times more FD events!

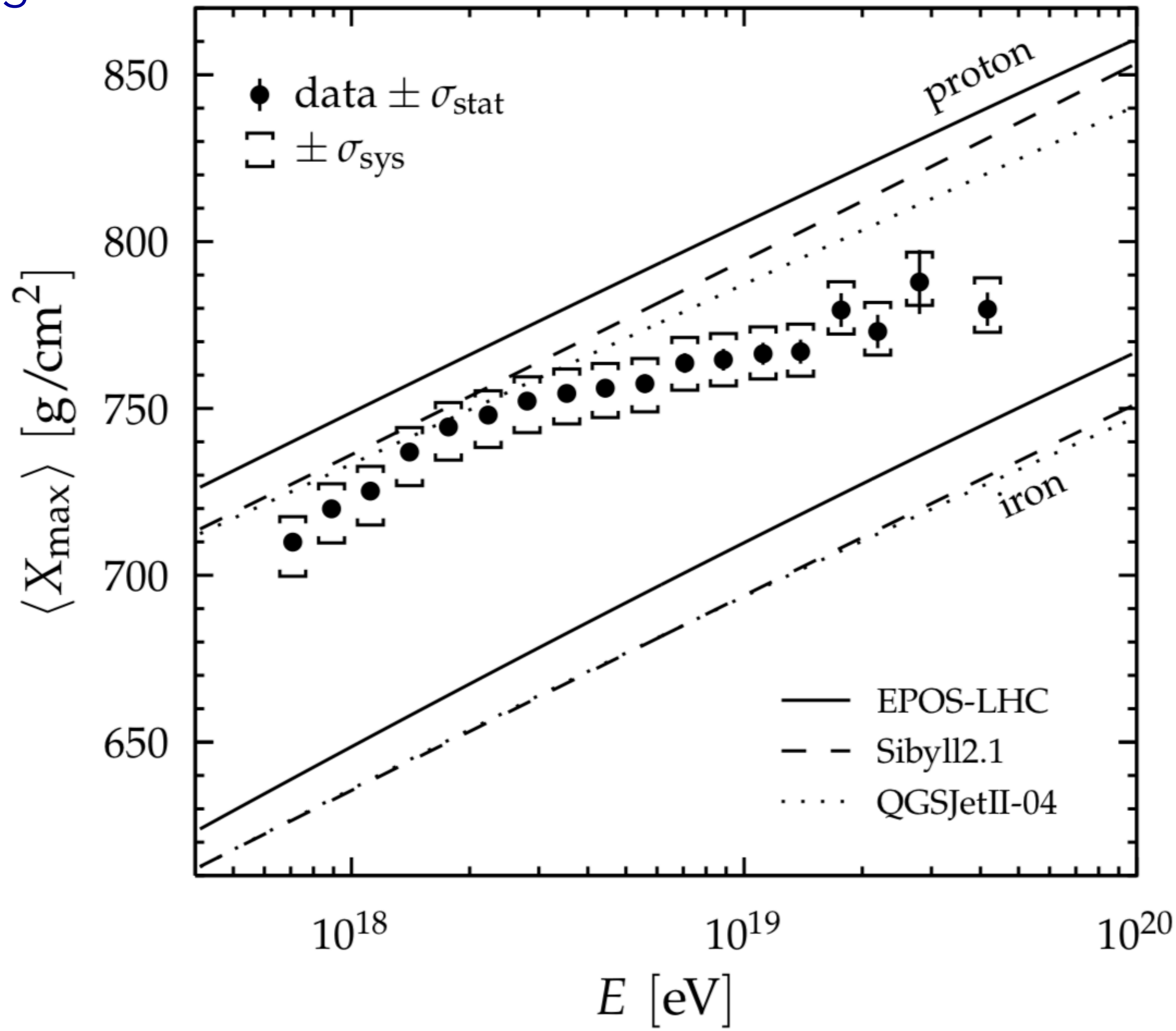
Precision on <Xmax> ≈ precision on Xmax / sqrt(N) !

With 100 showers above 10^{20} eV, ~80 g/cm^2 lead to ~8 g/cm^2 precision on the average!

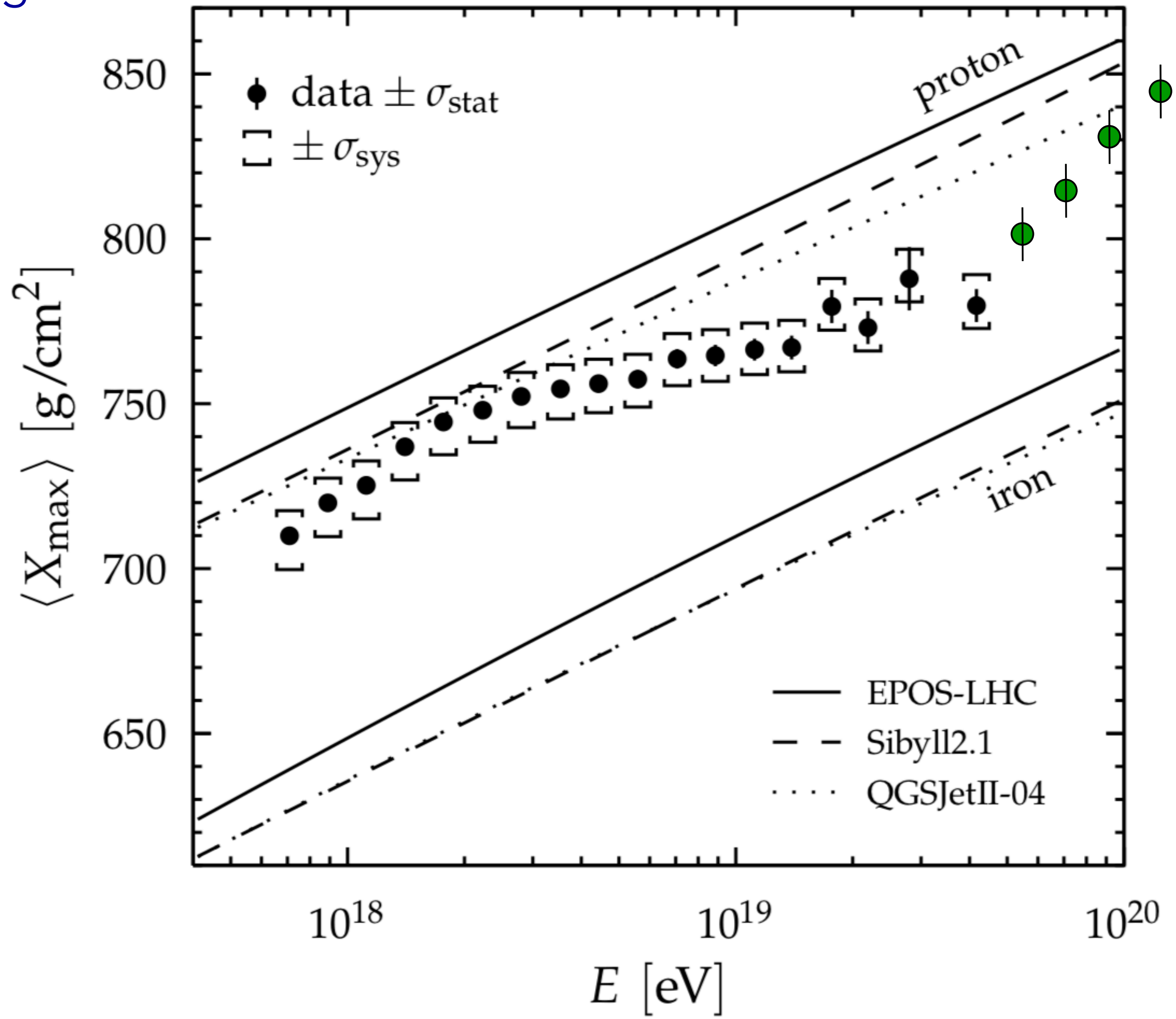
(+ systematics of course, but the trend will be clear, and one can "calibrate" on Auger/TAx4 at lower energy!)

=> Statistics is the key!

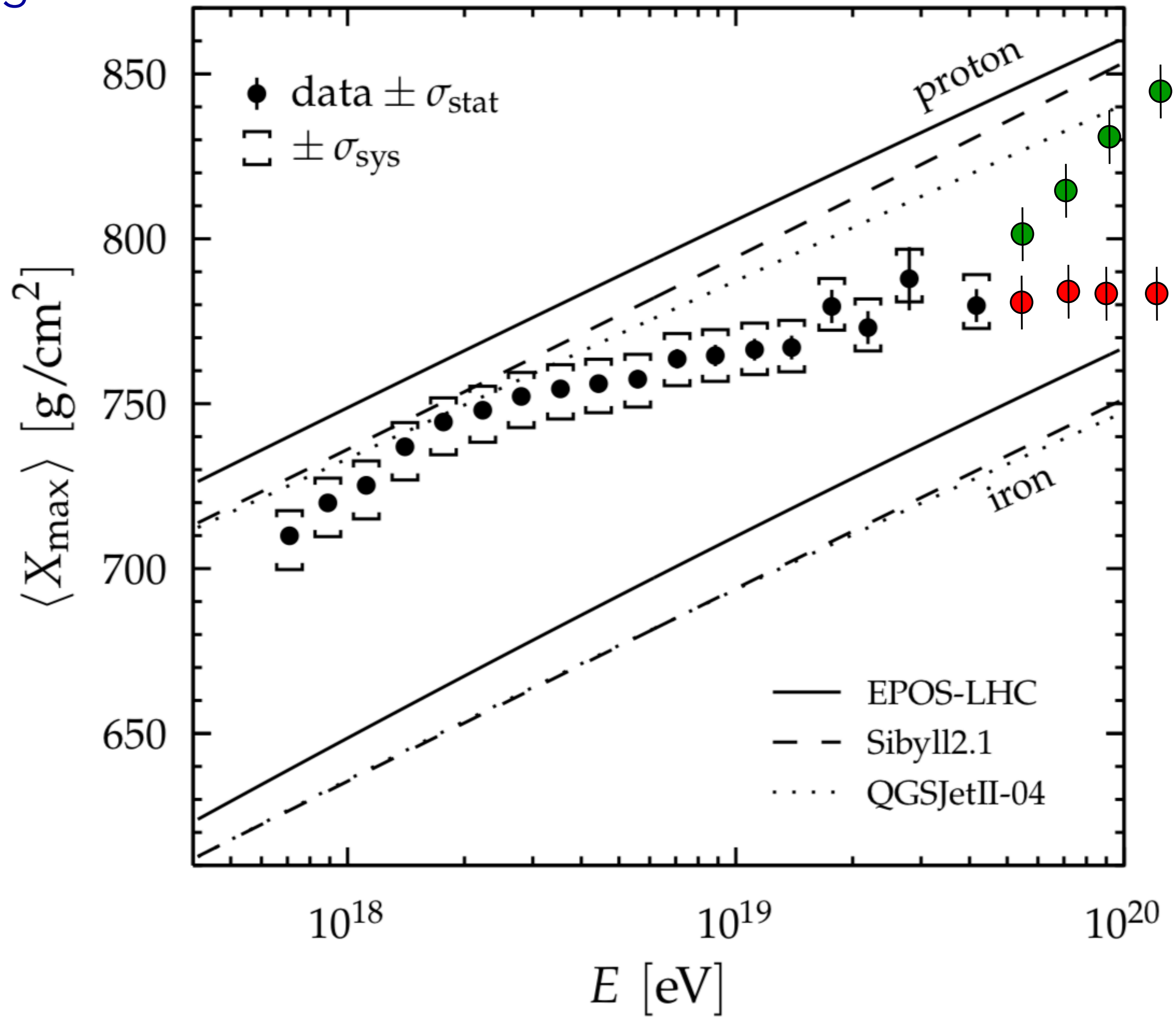
✧ Imagine:


850
800
750
700
650
$\langle X_{max} \rangle$ [g/cm^2]
10^{18}
10^{19}
10^{20}
E [eV]
data $\pm\, \sigma_{stat}$
$\pm\, \sigma_{sys}$
proton
iron
EPOS-LHC
Sibyll2.1
QGSJetII-04

✧ Imagine:


data ± σ_{stat}
± σ_{sys}
proton
iron
EPOS-LHC
Sibyll2.1
QGSJetII-04
850
800
750
700
650
$\langle X_{max} \rangle$ [g/cm^2]
10^{18}
10^{19}
10^{20}
E [eV]

- Imagine:



data ± σ_{stat}
± σ_{sys}
proton
iron
EPOS-LHC
Sibyll2.1
QGSJetII-04
850
800
750
700
650
$\langle X_{max} \rangle$ [g/cm^2]
10^{18}
10^{19}
10^{20}
E [eV]

Why go to space ?

- Not to compete with ground detectors, but to complement them!

Space detectors will not do precision shower physics (although see below)

(only access to global variables, with limited precision)

However, **statistics** is also desperately needed!

Central goal: DRAW A MAP OF THE UHECR SKY AT 10^{20} eV

Right in the cut-off!
(where very few sources dominate)

=> complementarity!

The EUSO approach would make little sense if Auger and TA did not exist,
but it makes tremendous sense in relation with them!

From Auger & TA: get knowledge of composition, energy scale, low energy flux, shower dev.

To Auger & TA: gives indirect cross calibration, full sky completion & extension above 10^{20} eV

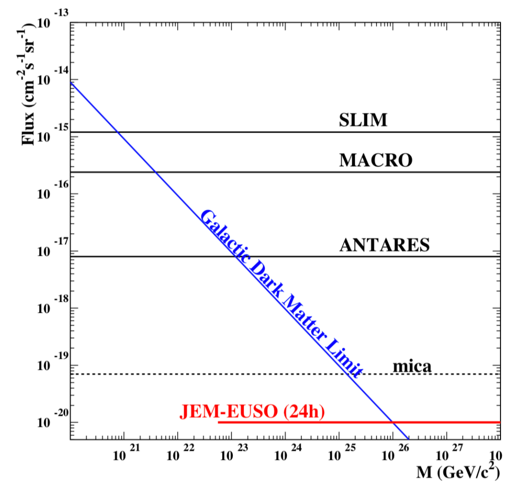
Why go to space ?

- Some extra things that we can do from space:
  - Atmospheric science (TLEs, clouds, ionosphere…)
  - Oceanic science (bioluminescence, "white sea", monitoring…)

UV
IR
LIDAR…

  - Interplanetary bodies, meteorites… (huge science case!)
  - Nuclearites

Exp. Astron. (2015) 40, 253

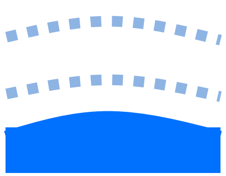


  - Neutrinos!

    => POEMMA !

  - High-altitude showers!

- Shower development: competition between decay and new interactions



Development in low density atmosphere

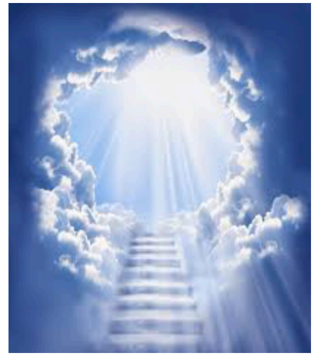
- More muons
- More missing energy
- Possibly different shower profile

…may be extremely interesting!

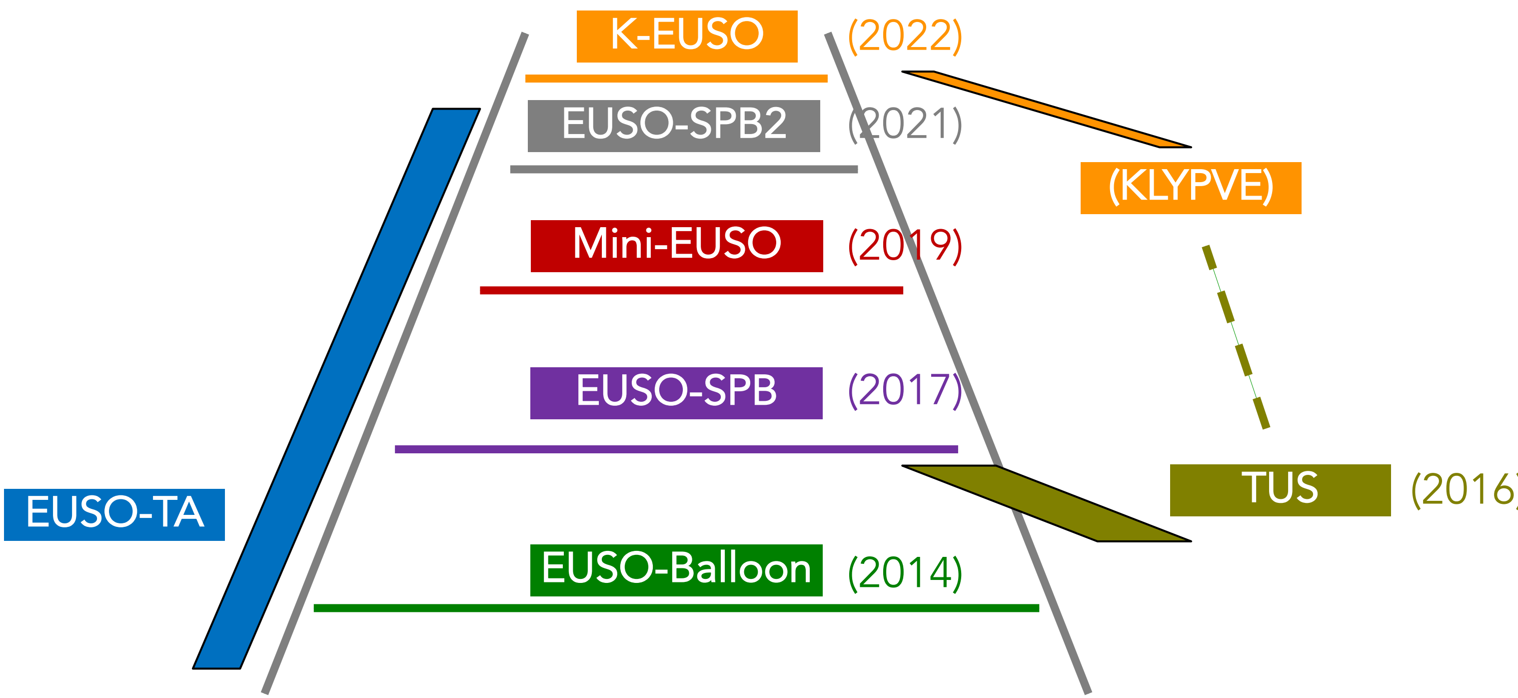
The JEM-EUSO Program

Development of a complete program to reach heaven!

Step by step…



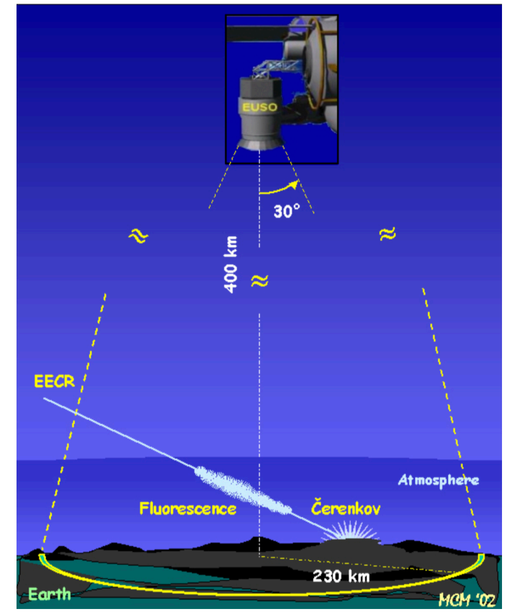
POEMMA? (2030…)



The instrumentation

- From space:

=> larger distance => larger exposure
=> fewer photons => higher E threshold
=> large collection area required

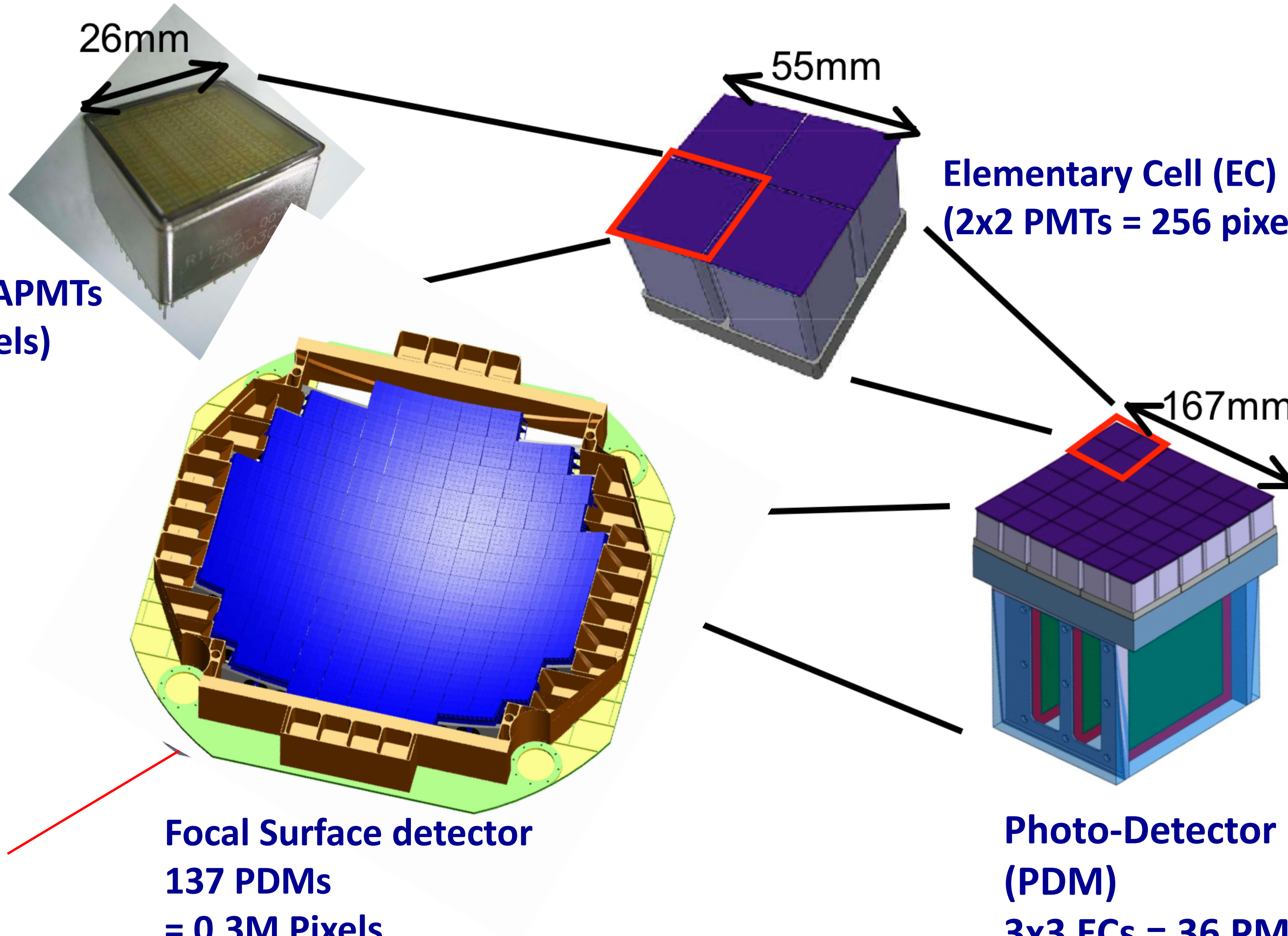


Optics: => large Fresnel lenses
=> large mirror (Schmidt camera)

Photosensors:
=> MAPMT (Hamamatsu 64 pixels)
=> SiPM (TBD)

x-EUSO-y	Lens	Mirror	MAPMT	SiPM
-Balloon - TA	✓		✓	
TUS		✓	✓	
-SPB	✓		✓	
Mini-	✓		✓	
-SPB2		✓	✓	✓
K-		✓	✓	
POEMMA		✓	?	✓

Focal surface: juxtaposition of "PDMs"



4932 MAPMTs
(8x8 pixels)

Elementary Cell (EC)
(2x2 PMTs = 256 pixels)

Focal Surface detector
137 PDMs
= 0.3M Pixels

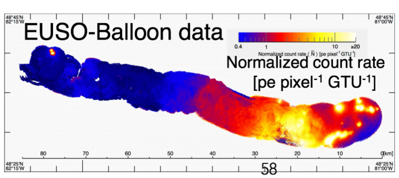
Photo-Detector Module (PDM)
3x3 ECs = 36 PMTS

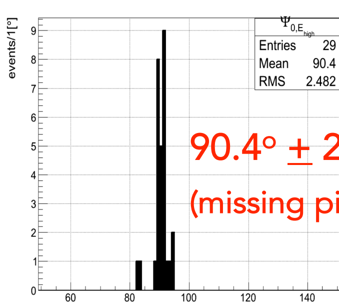
EUSO-Balloon (2014)

1 night flight with 1 PDM

Main innovations:
- front-end electronics (SPACIROC 1)
- HVPS (low consumption + switch)
- Efficient data processing
- Operation at 3 mbar

Main teachings:
- UV emissivity w/ or w/o cloud
- UV / IR anti-correlation (expected)
- Laser events reconstruction
- Serendipitous flash source detection

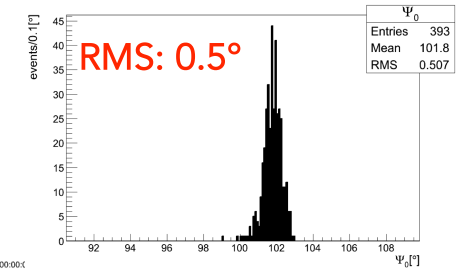


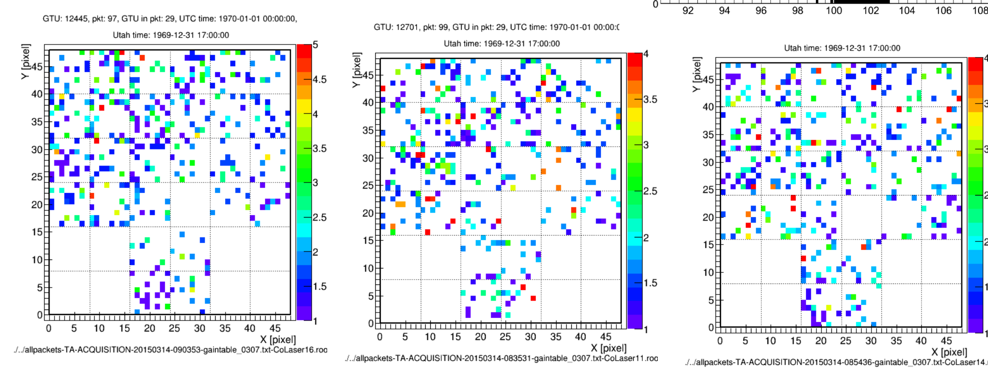


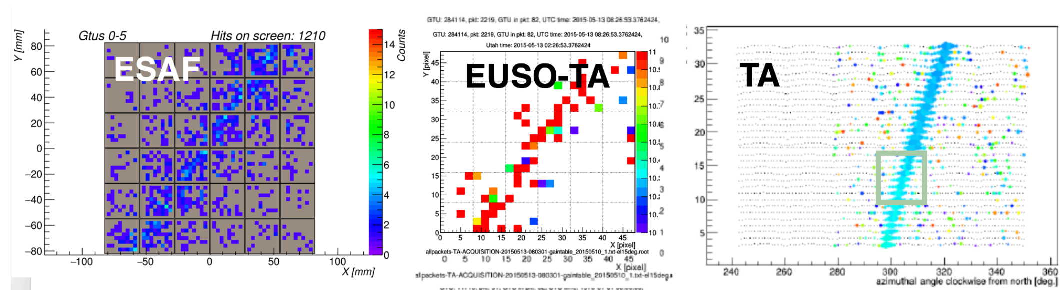
90.4° ± 2.5°
(missing pixels!)

EUSO-TA (since 2013 onward)

Instrument on its own
+ test platform for
other pathfinders



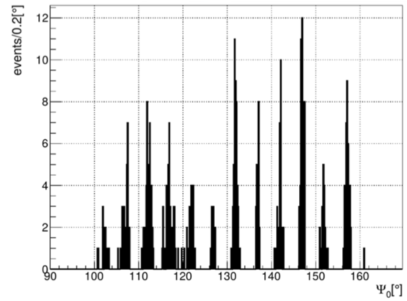




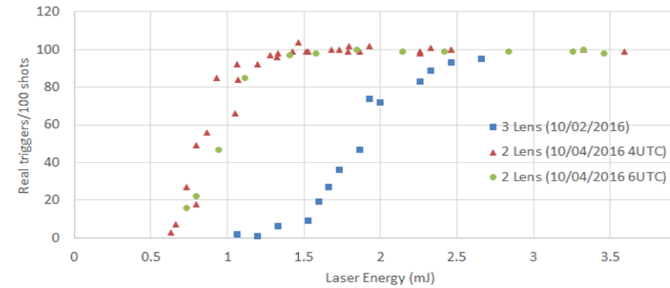
[20]

EUSO-SPB (2017)

Angular resolution better than 1°



Energy-equivalent threshold measurement



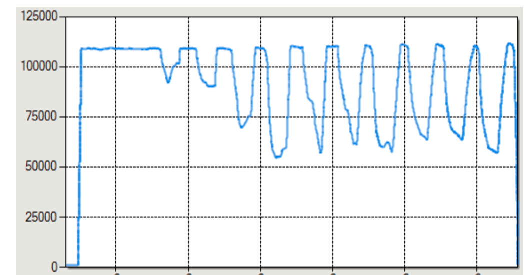
Would-be showers

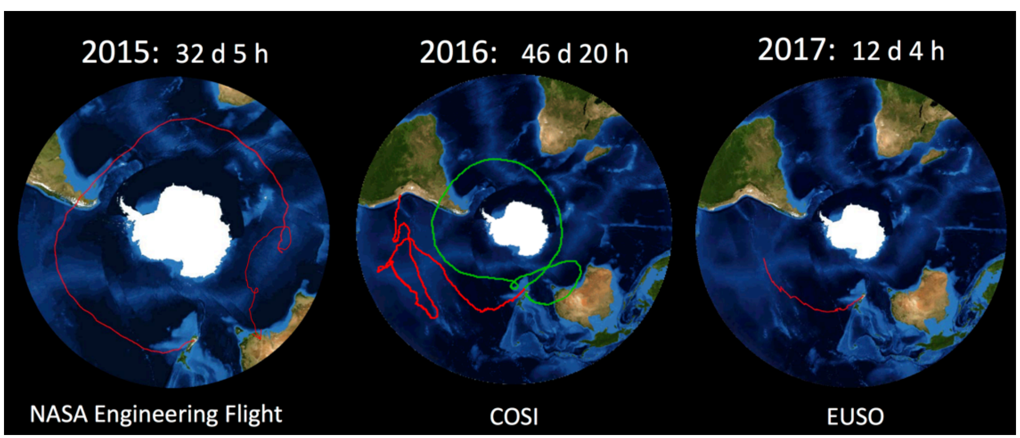
E_{th} ~ 3 Eev => ~1–2 showers expected per month

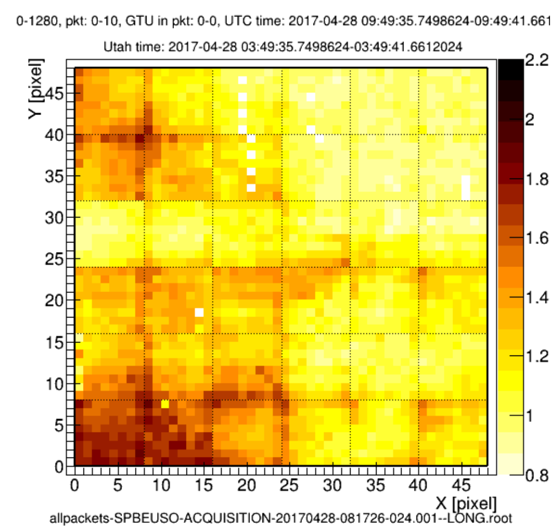
Main improvements:
- Upgraded electronics: SPACIROC 3
- Complete autonomous scheme with trigger
- Solar panels for long duration flight
- Optics performance + stability

Nominally working instrument

(unfortunately… leaking balloon!)



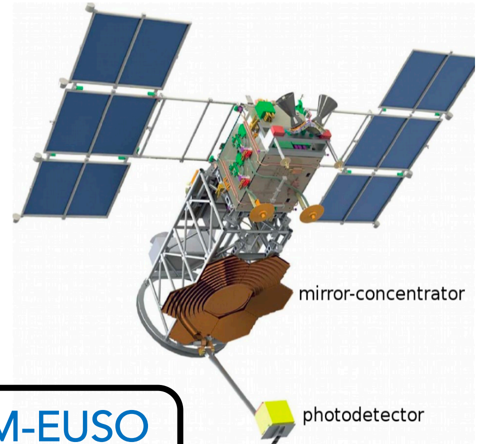




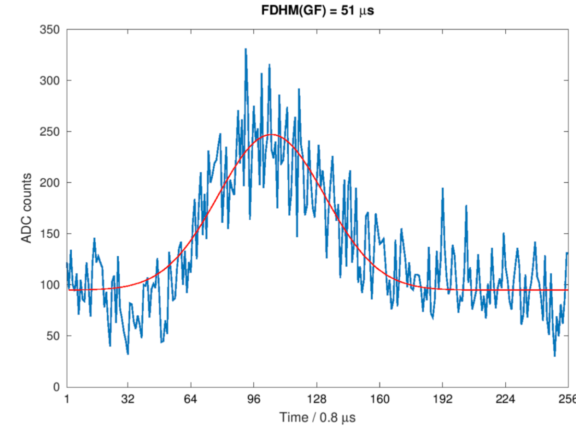
TUS

(since 2016)
free-flyer

РОСКОСМОС



Cf. talk by Pavel Klimov



First FD showers from space?

NB: Full partnership between JEM-EUSO collaboration and TUS/KLYPVE team

=> Improved design of the optics and focal surface of the original KLYPVE → **K-EUSO**

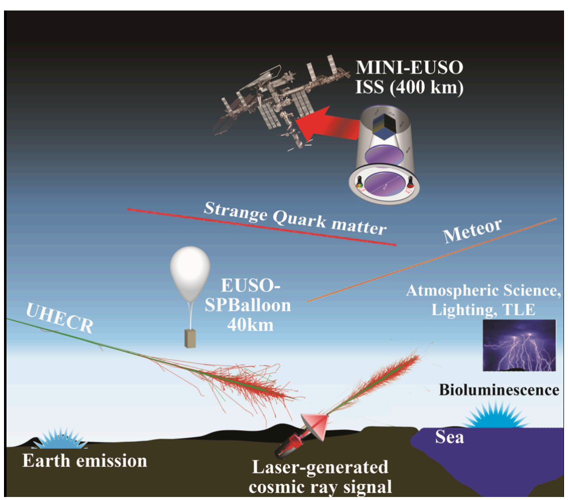
Mini-EUSO

(2019)
Inside ISS

a.k.a. UV-Atmosphere

РОСКОСМОС

asi agenzia spaziale italiana



- Same focal surface as EUSO-SPB1
- New electronics for the "PDM board"
- Implements different trigger modes

=> Multi-purpose instrument

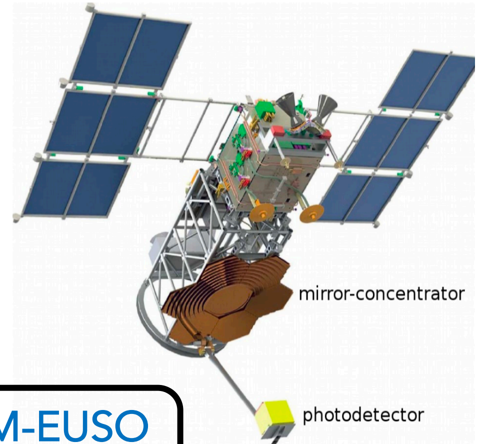
Key feature: large volume of data brought back on hard drives!

=> Detailed analysis of UV emissivity in various conditions (extremely useful in preparation of the next steps!)

TUS

(since 2016)
free-flyer

POCKOCMOC



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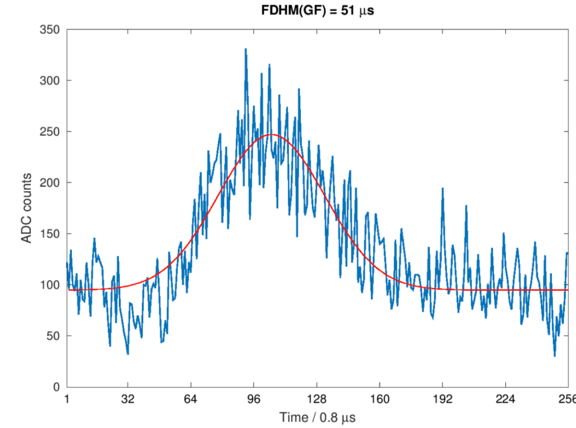

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Mini-EUSO

(2019)
Inside ISS

a.k.a. UV-Atmosphere

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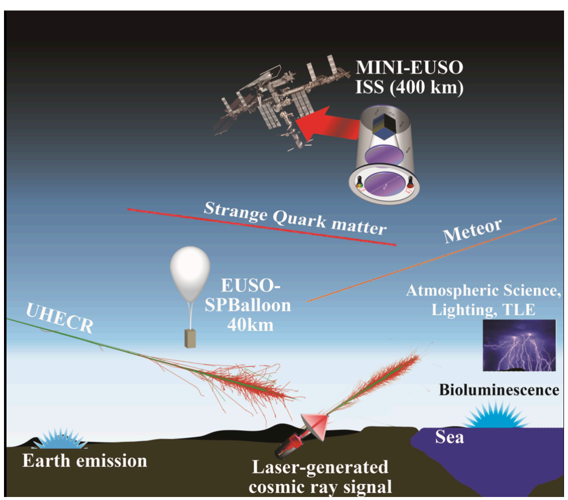
agenzia spaziale italiana



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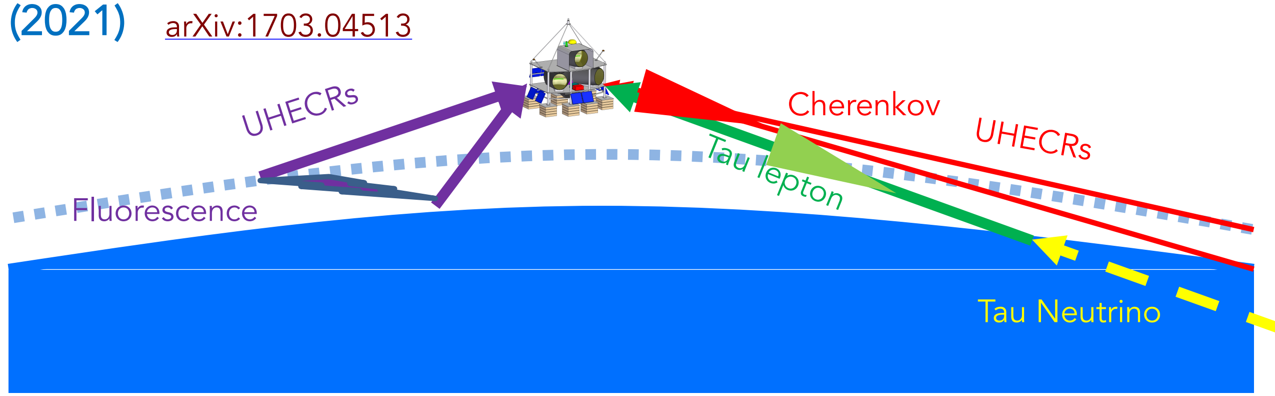
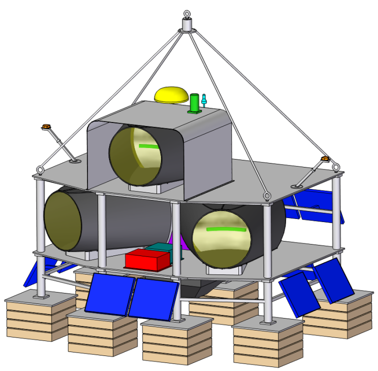
EUSO-SPB2 (2021) arXiv:1703.04513



Looking also horizontally towards the limb of the Earth
→ adds high-energy neutrinos to the science objectives!



A pathfinder to both K-EUSO and POEMMA

- 1 Fluorescence telescope, with 3 PDMs and shortened time unit (to improve signal/noise)
- 2 Cherenkov telescopes, with Si-PM and dedicated electronics

NB: first SiPM in space

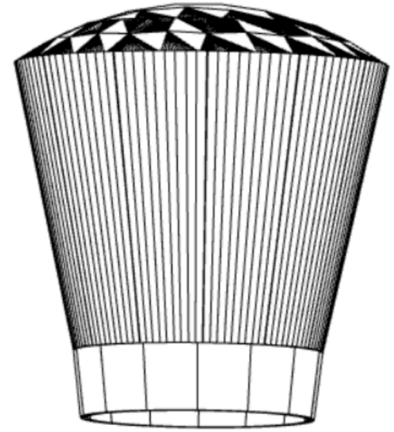
+ high-altitude showers!

K-EUSO (2022)

РОСКОСМОС

Improved design of the optics and of the focal surface of the original KLYPVE

- Schmidt optics
- Gen 3 EUSO PDM



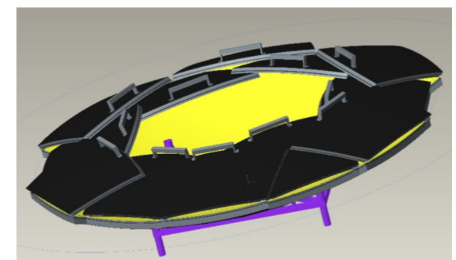
Cf. talk by Pavel Klimov

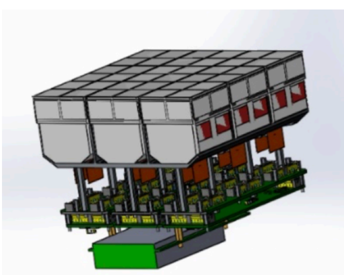
First major UHECR scientific mission in space!

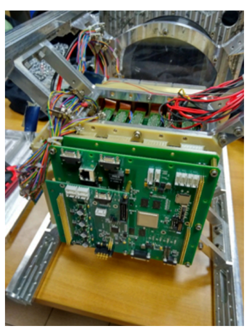
Auger x 2 in each hemisphere!

Address Auger/TA comparison in 1 year: above ~60 EeV, 100 events in North (TA) vs. 30 event in South (Auger)

Large scale anisotropies + hot spot(s)?

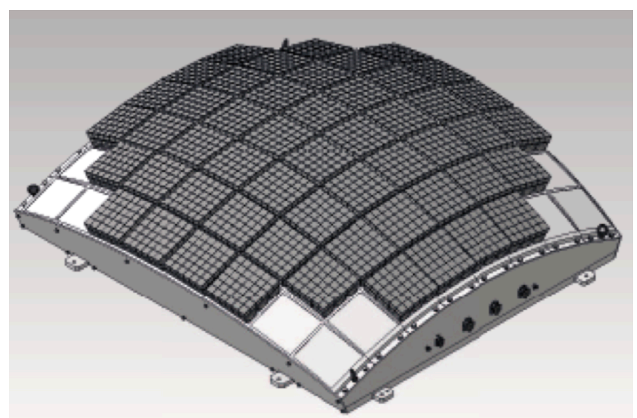




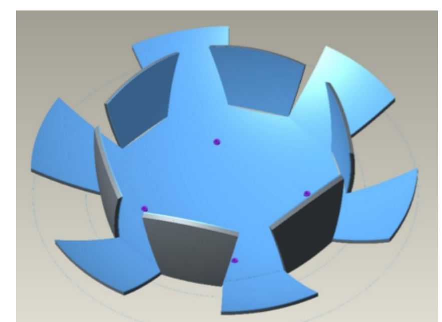


1 PDM

Prototype to be delivered early 2019



52 PDMs

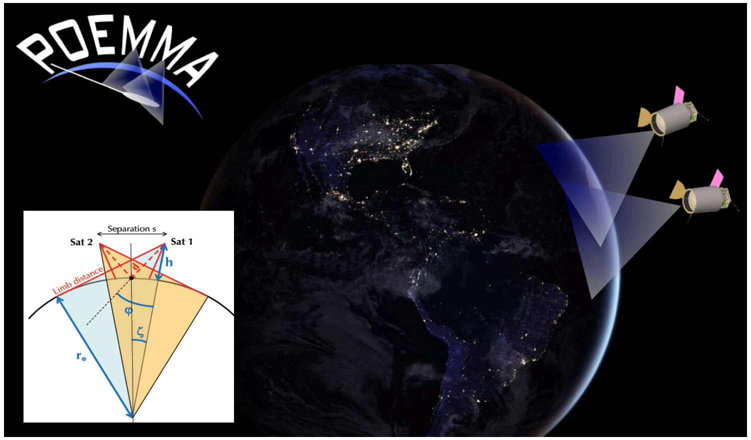


Deployable mirrors

POEMMA (>2030)

Probe Of Extreme Multi-Messenger Astrophysics

UHECR and neutrinos (direct Cherenkov light from tau decay shower)

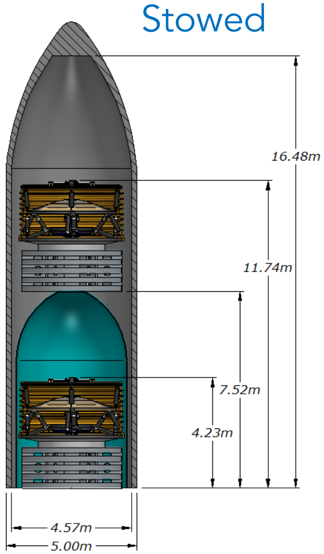


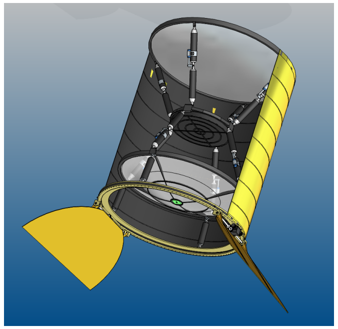
Selected as Probe study (8–10/34)

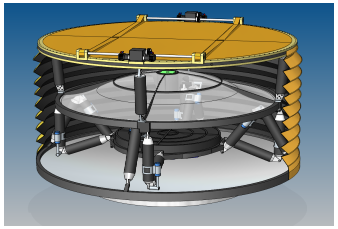
Funded for 18 month full study with NASA

Final design just finished and approved!

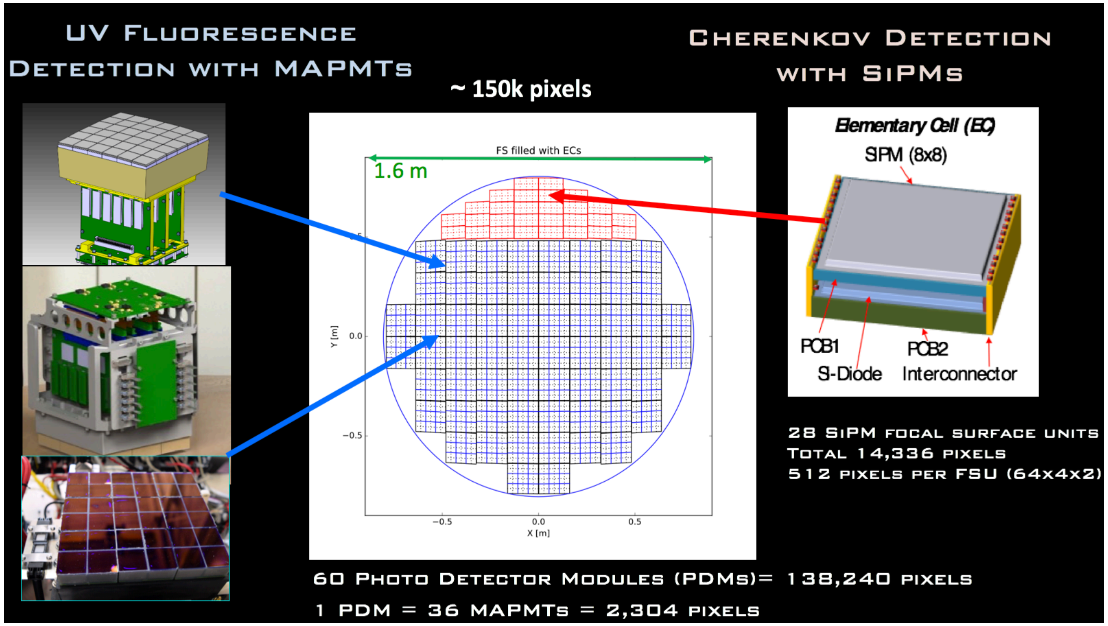
Stowed







POEMMA	
Mass/Instrument	1547 kg
Primary Mirror	4 m
Corrector Lens	3.3 m
Focal Surface	1.6 m
Aperture (m^2)	6 to 2
Power	550 W
Data (MB/day)	1043

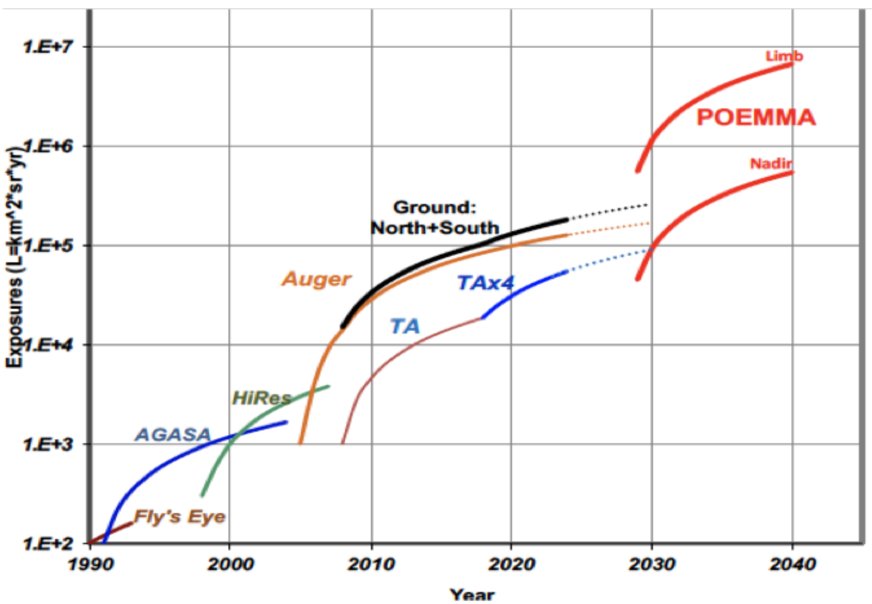


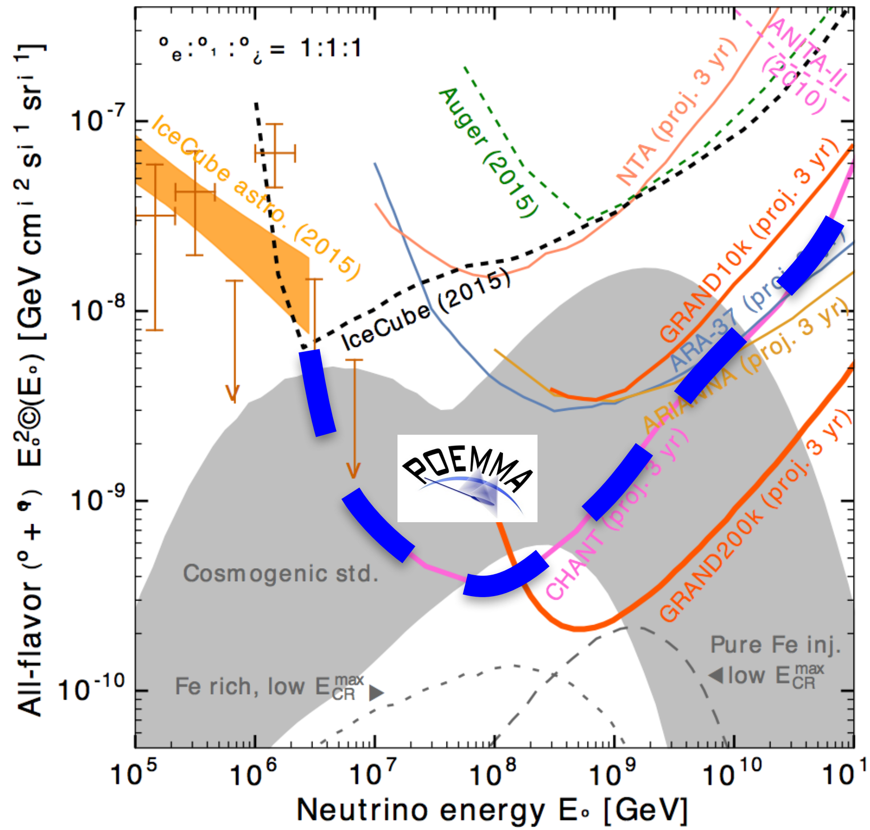
POEMMA (>2030)

UHECR and neutrinos

(direct Cherenkov light from tau decay shower)

Probe Of Extreme Multi-Messenger Astrophysics





Major steps forward

=> high statistics map of the UHECR sky

=> Cosmogenic neutrinos

=> major constraints on source models (composition / cosmological evolution)

=> Connection with IceCube neutrinos

Full deployment of the multi-messenger era!

The JEM-EUSO Program

So far so good!

Heaven is high, so the road is long… but it is straight!

What we have to do is clear, and we are doing it!