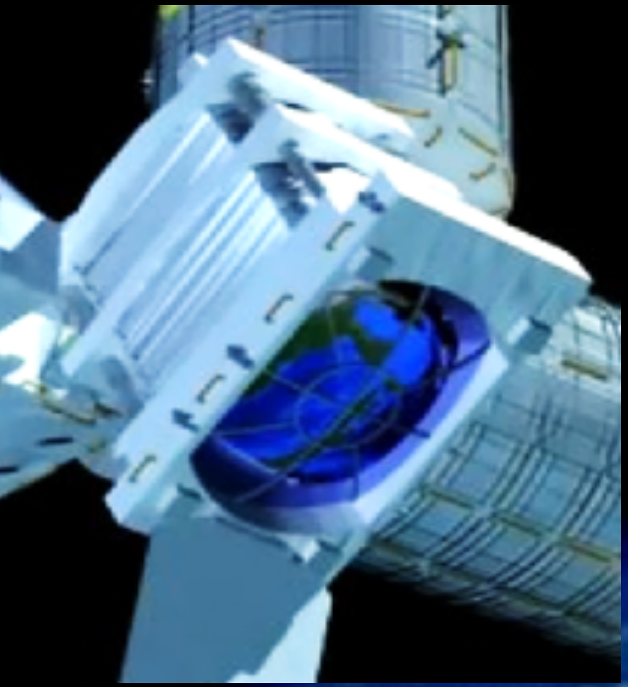


Extreme Universe Space Observatory

Search for UHE Cosmic Rays from Space - the JEM-EUSO program

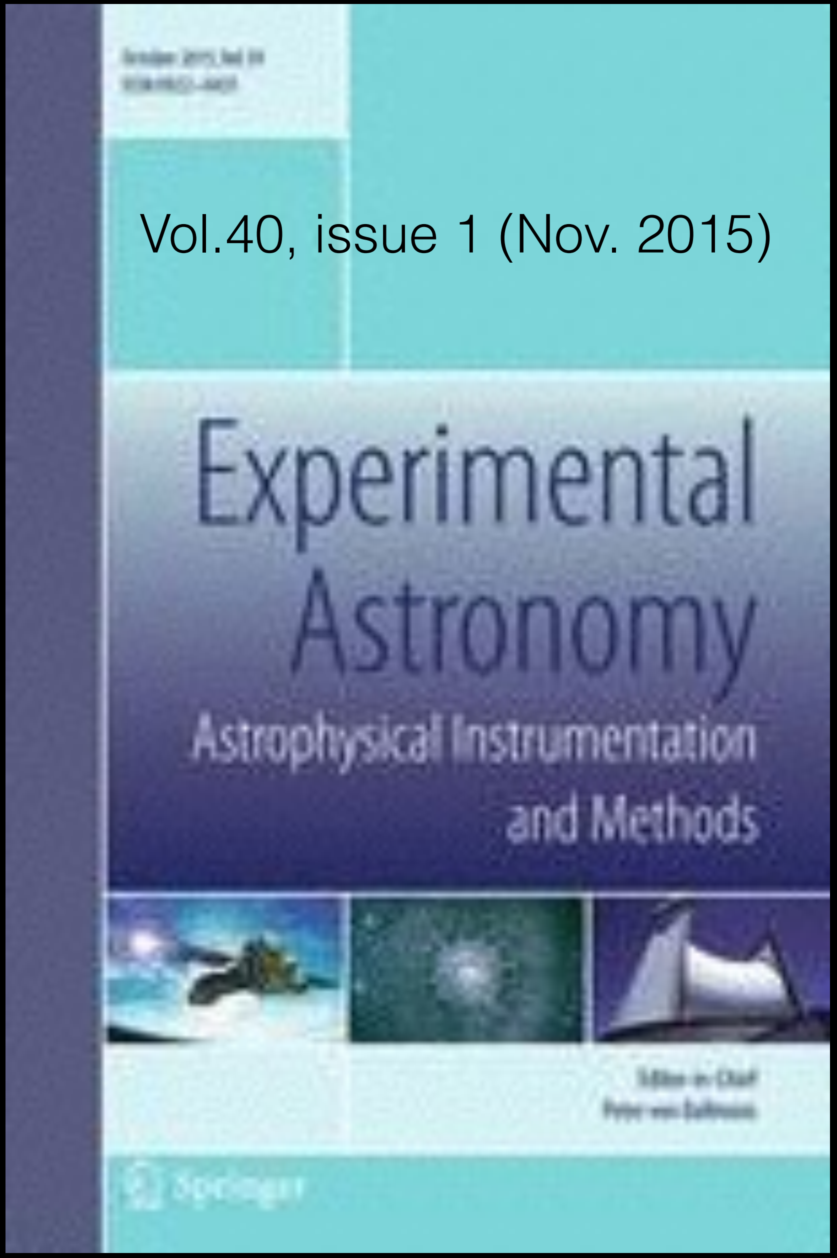
M. Bertaina – Univ. & INFN Torino
for the JEM-EUSO Collaboration

Vulcano Workshop 2018

Special Issue on the JEM-EUSO Mission

- 15 papers addressing science and technology of JEM-EUSO

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

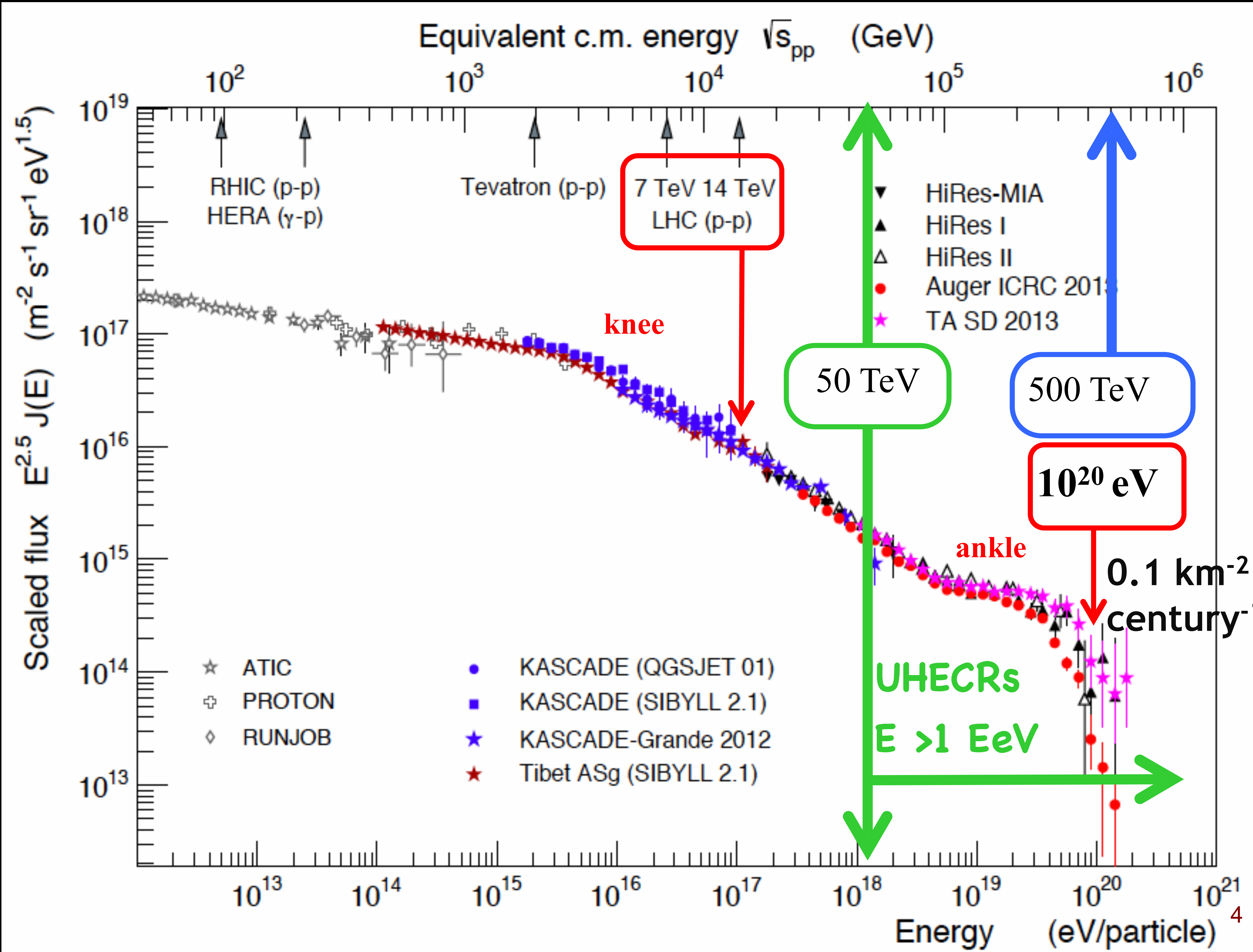


JEM-EUSO
International collaboration

- 16 countries, 350+ researchers

- Science Evaluated positively by ESA, NASA, Roscosmoc and national agencies

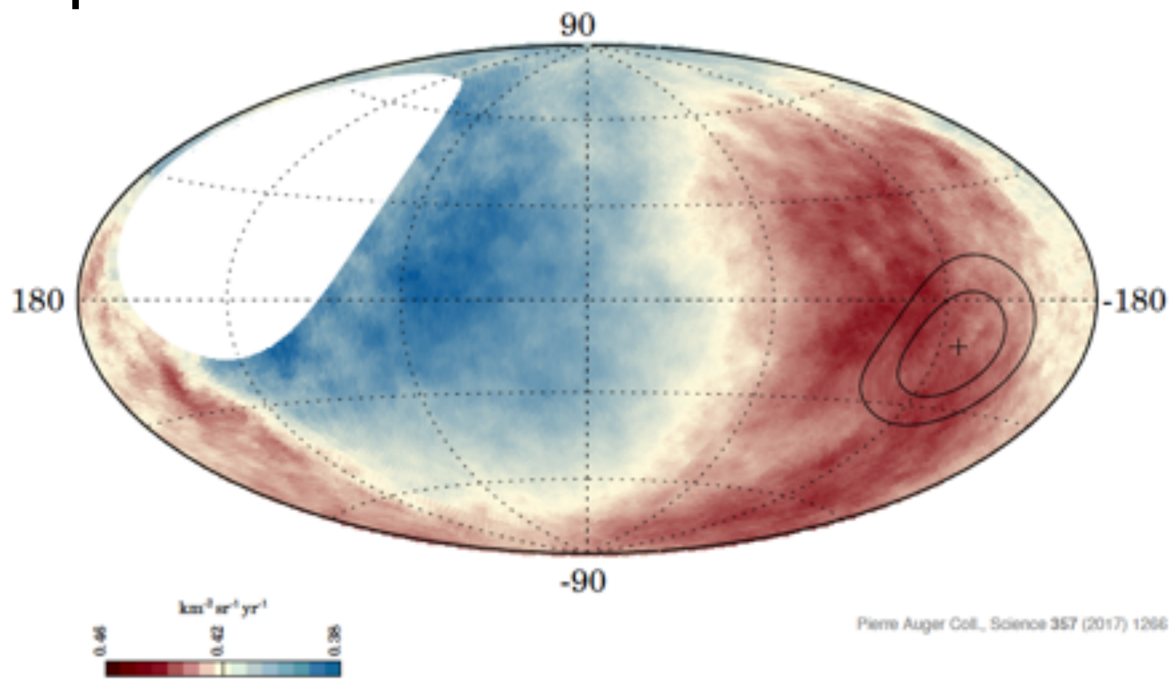
- Funding for detectors and precursors ongoing in all countries



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
ankle
0.1 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)

Auger Large-scale Anisotropy ($E > 8$ EeV, $(6.5^{+1.3}_{-0.9})$%, 5.2 σ)

Dipole Above 8 EeV = 5.2σ!!

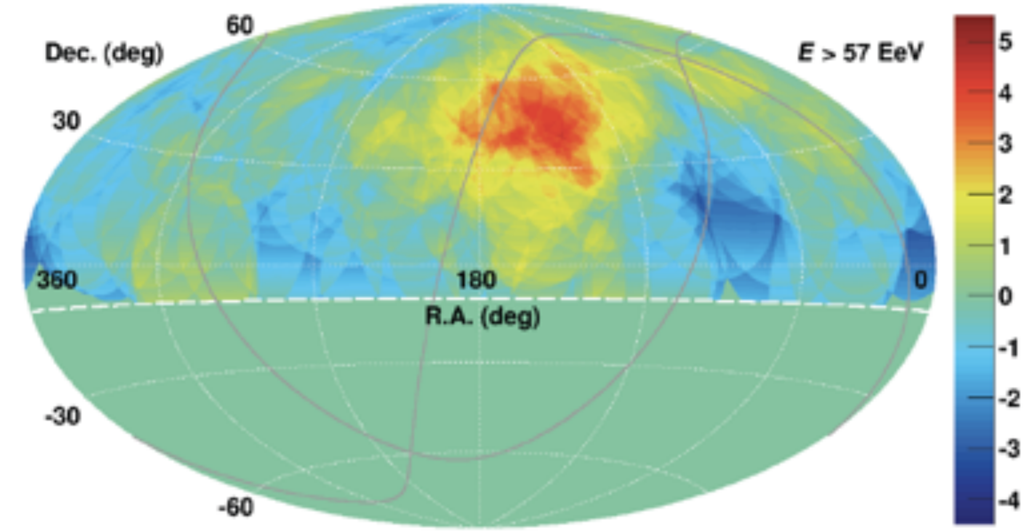


Pierre Auger Coll., Science 357 (2017) 1266

ExtraGALACTIC SOURCES!!!

Hot Spot Above 57 EeV ~3σ

TA "Hot Spot" 2017 ($E > 57$ EeV, $\sim 3\ \sigma$)

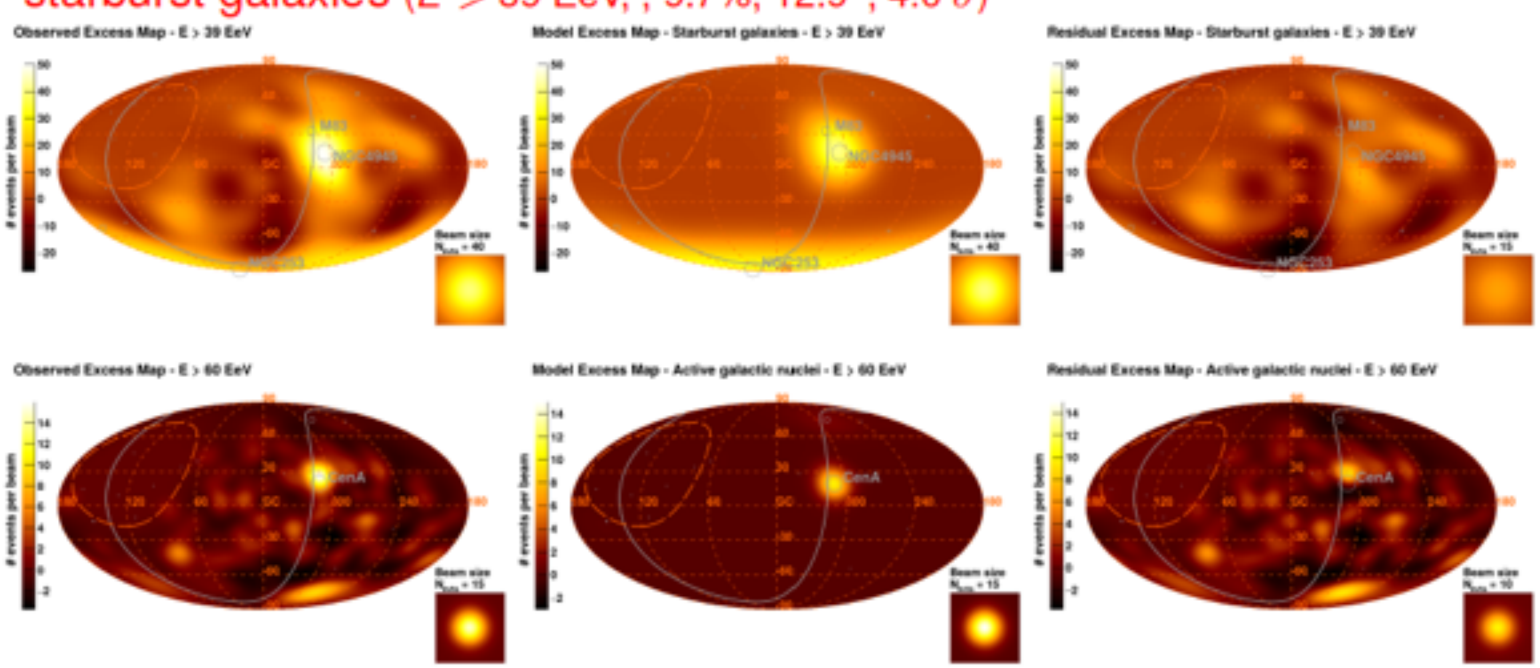


Total events: 143
Observed: 34
Expected : 13.5

Best circle center: RA=144.3°, Dec=+40.3°
Best circle radius: 25°
Local significance : 5 σ
Global significance : 3 σ

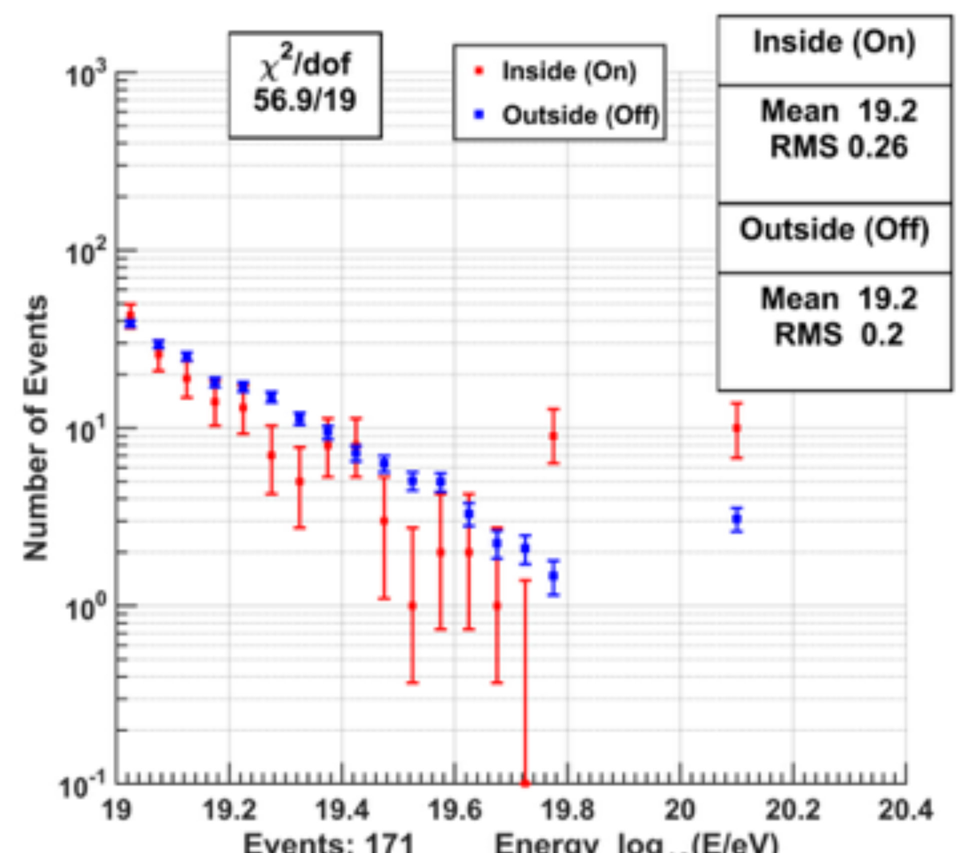
Auger Intermediate-scale Anisotropy ($E > 39$ EeV, $\sim 4\ \sigma$)

starburst galaxies ($E > 39$ EeV, , 9.7%, 12.9°, 4.0 σ)

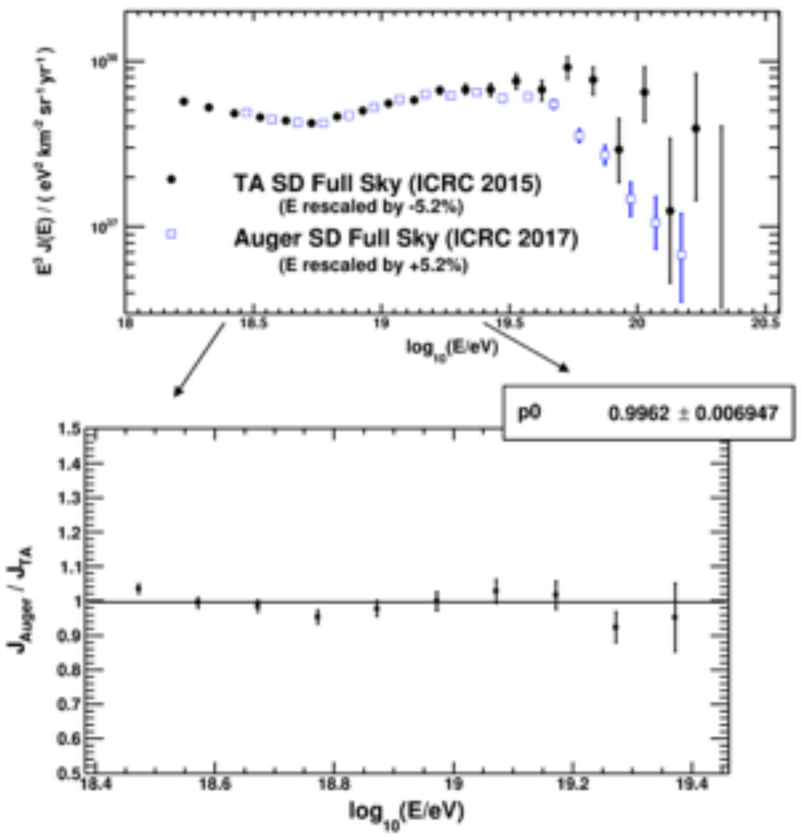


γAGN ($E > 60$ EeV, 6.7%, 6.9°, 2.7 σ)

Pierre Auger Coll., ApJ. Lett. 853 (2018) L29



Rescale Auger and TA energies

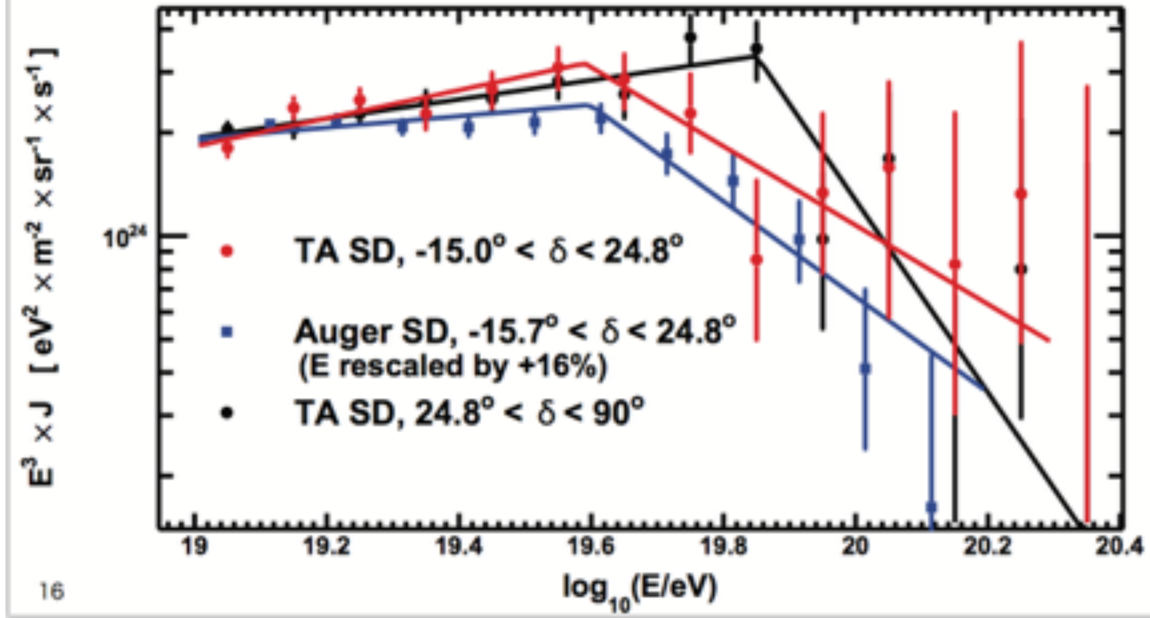


- Constant rescaling factor of 5.2%
  - From fitting ratio of fluxes Auger/TA into a unity in the ankle region
  - Auger energies *raised* by 5.2%
  - TA energies *lowered* by 5.2%
- Agree in the ankle region $10^{18.4}$ eV < E < $10^{19.4}$eV after rescaling
- **Difference above $10^{19.4}$ eV persists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

D. Ivanov - ICRC 2017

Declination Dependence /Spectrum Anisotropies?

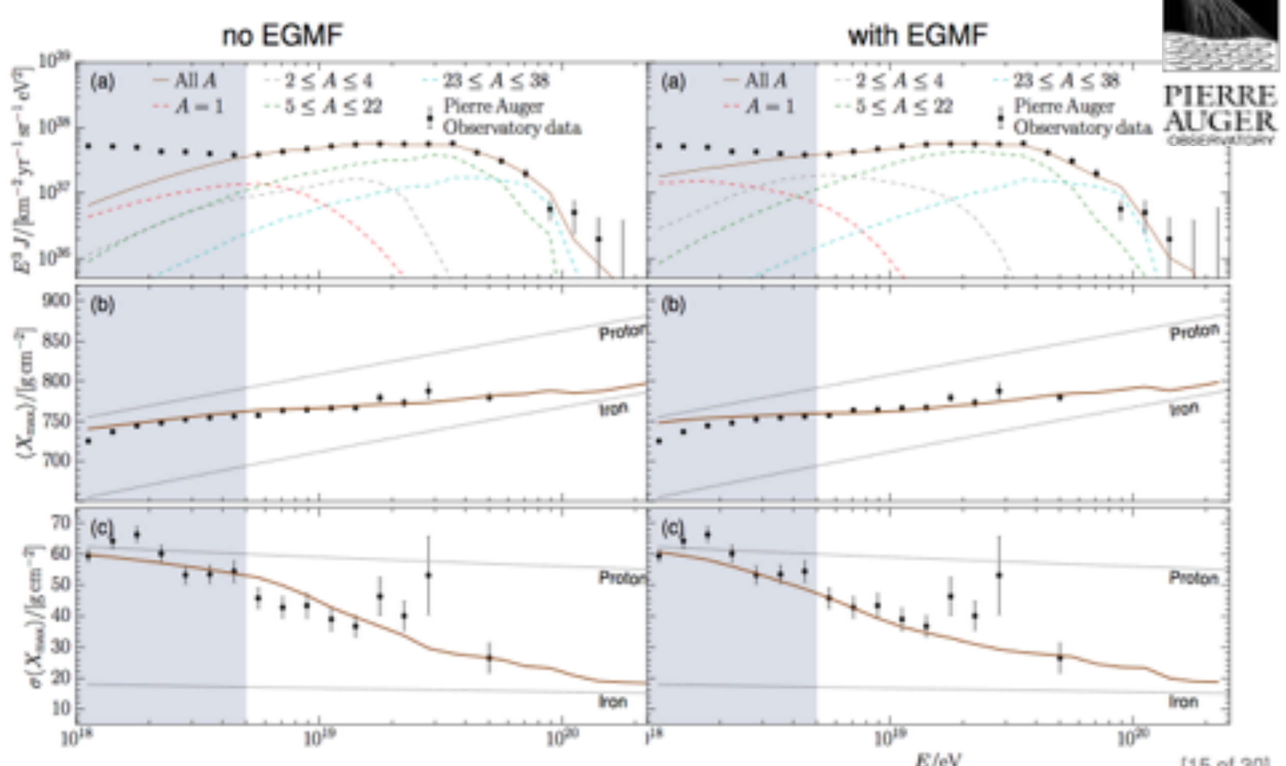
D. Ivanov, CRI236 (Poster)
JP. Lundquist, CRI194 (Jul 18)
D. Ivanov, CRI 231 (JUl 18)



Y. Tsunesada - ICRC 2017

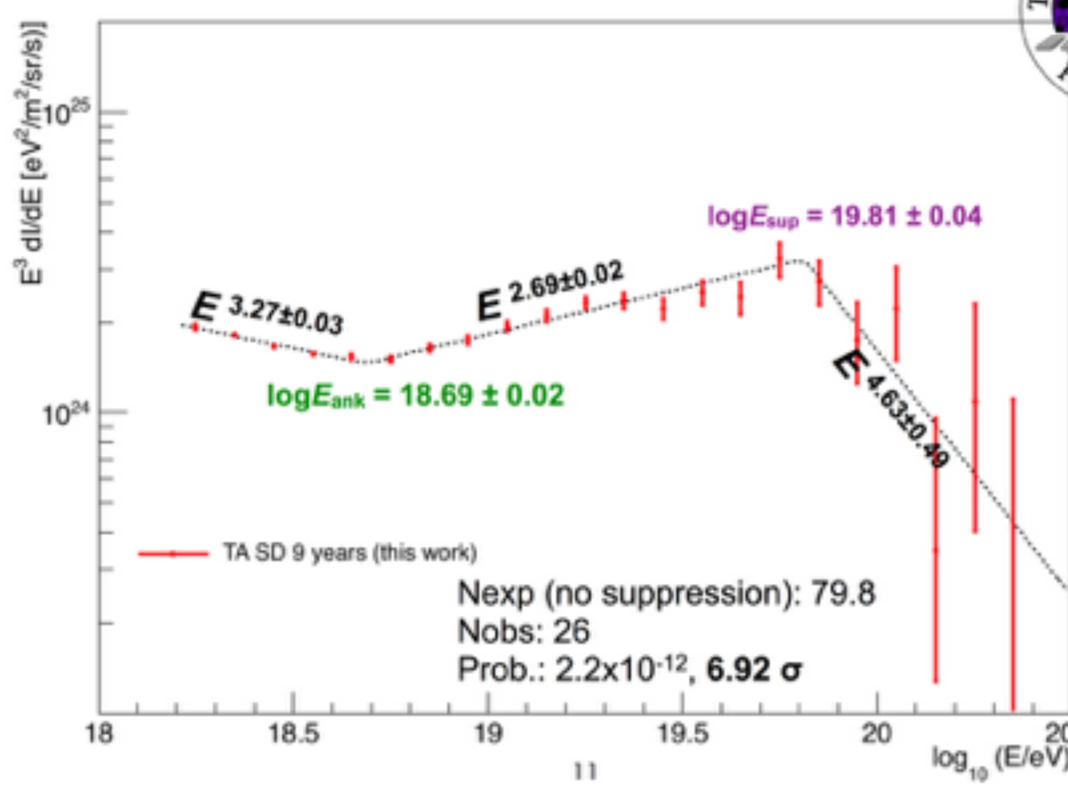
Combined Fit of Spectrum and X_{max} Distributions

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

Power-Law Fit



Y. Tsunesada - ICRC 2017

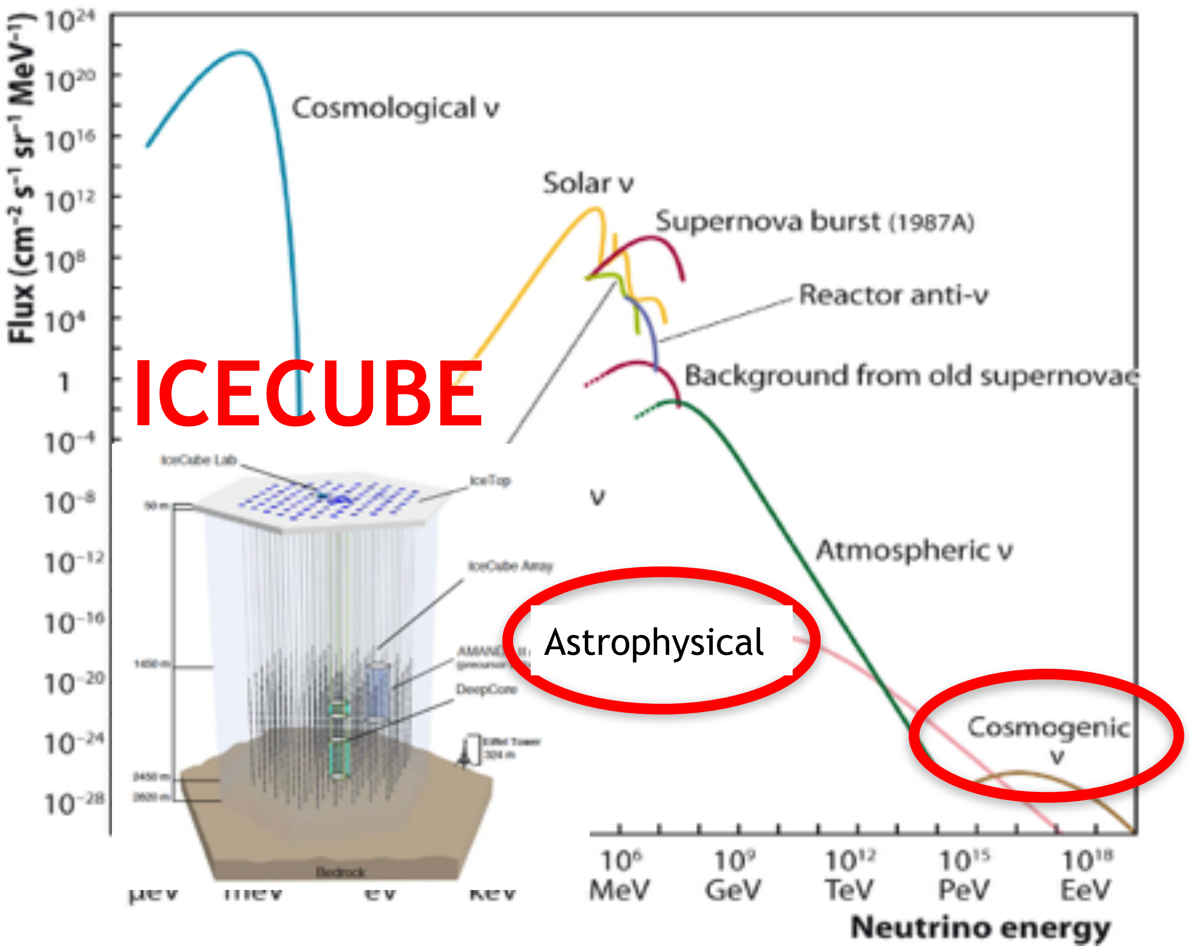
How many UHECRs > 60 EeV?

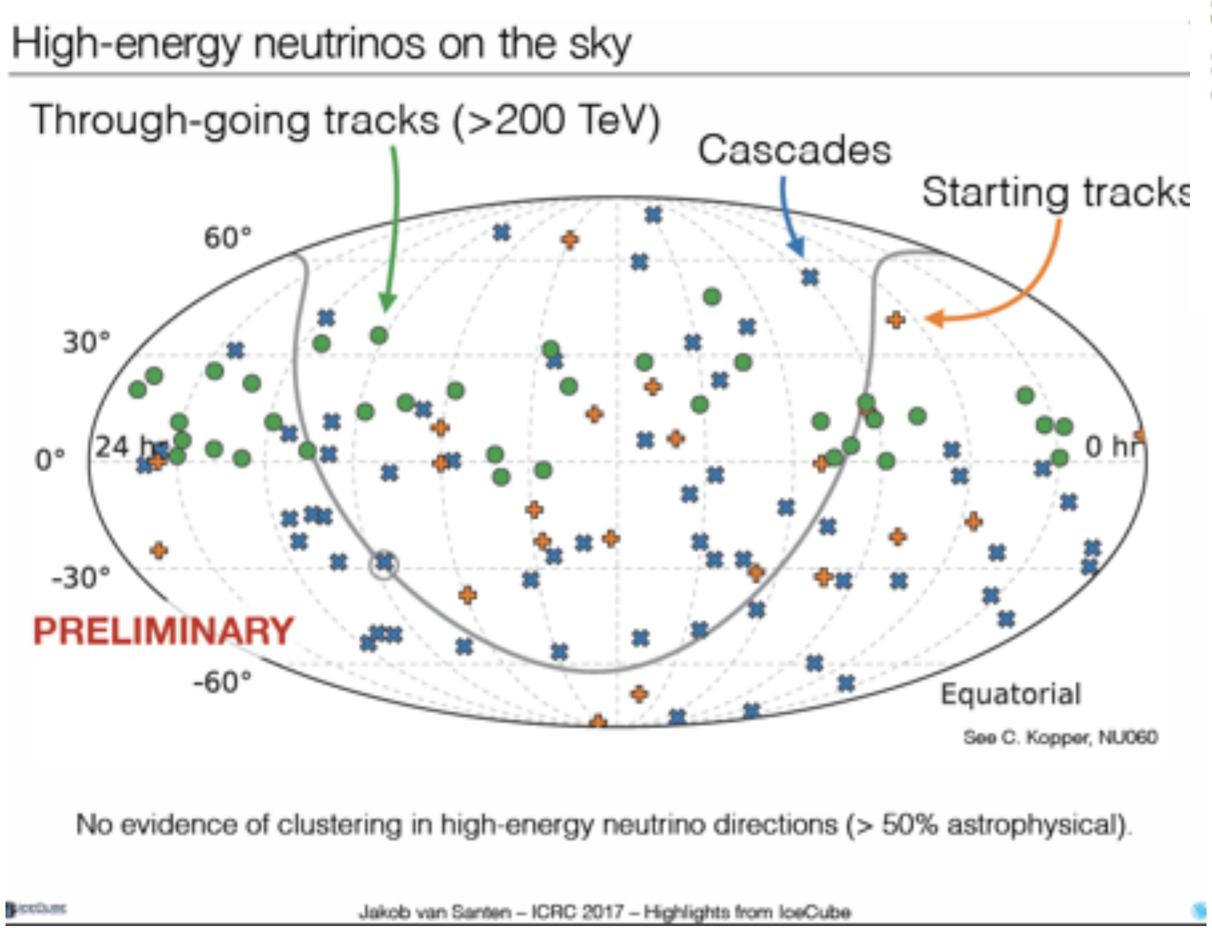
- Auger w/ 3,000 km^2
- ~25 events > 60 EeV/ yr
- Telescope Array w/ 700 km^2
- ~5 events > 60 EeV/ yr
- Auger + TA ~ 30 events/yr

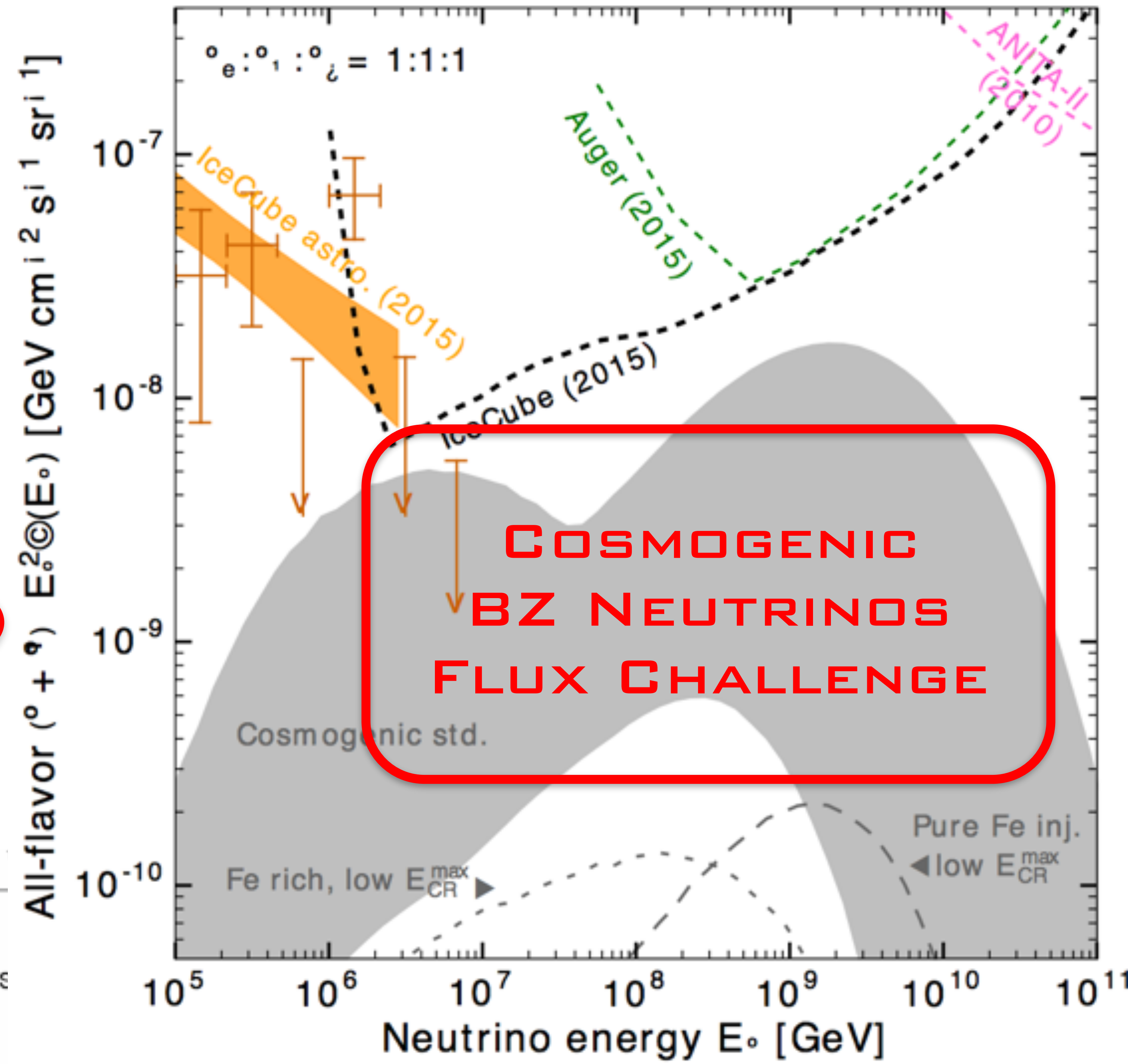
5 o.o.m to go!

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

~3.4 10^6 events/yr







Statistically Limited

Go to SPACE!

To look down on the Atmosphere!

How many UHECRs > 60 EeV?

- Auger + TA ~30 events/yr

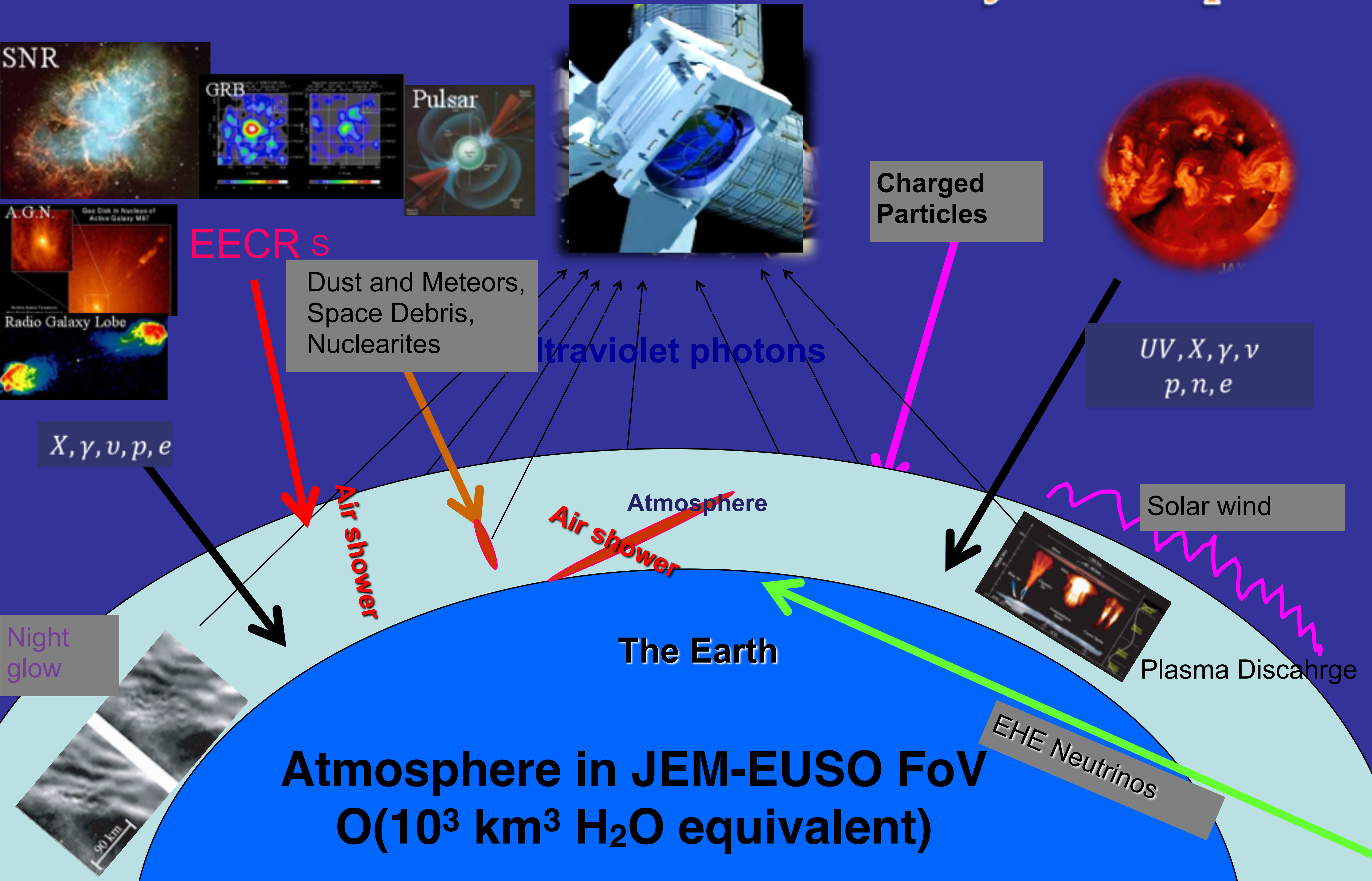
- **JEM-EUSO**
- **~200 events > 60 EeV/y**

4 o.o.m to go!

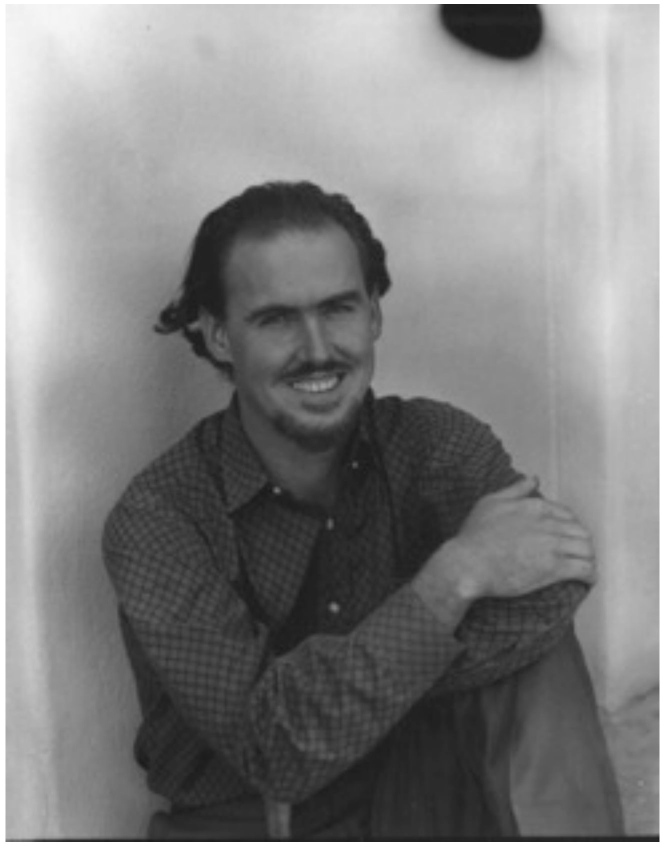
- Earth - surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

JEM-EUSO is an Astronomical Earth Observatory from Space



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)

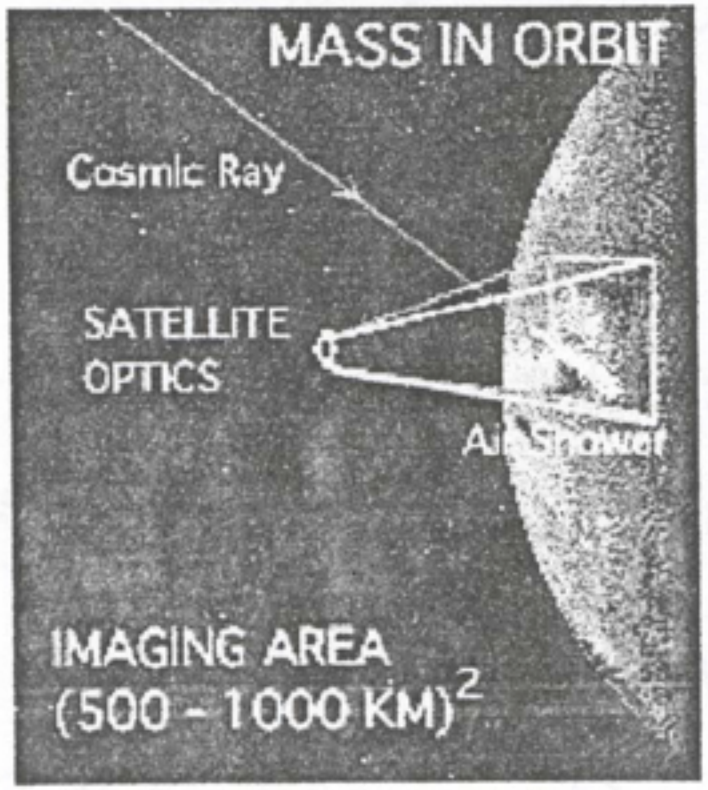
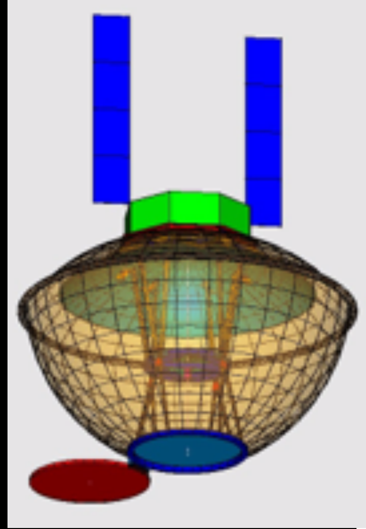


Fig. 3 Artist view of the MASS on orbit.

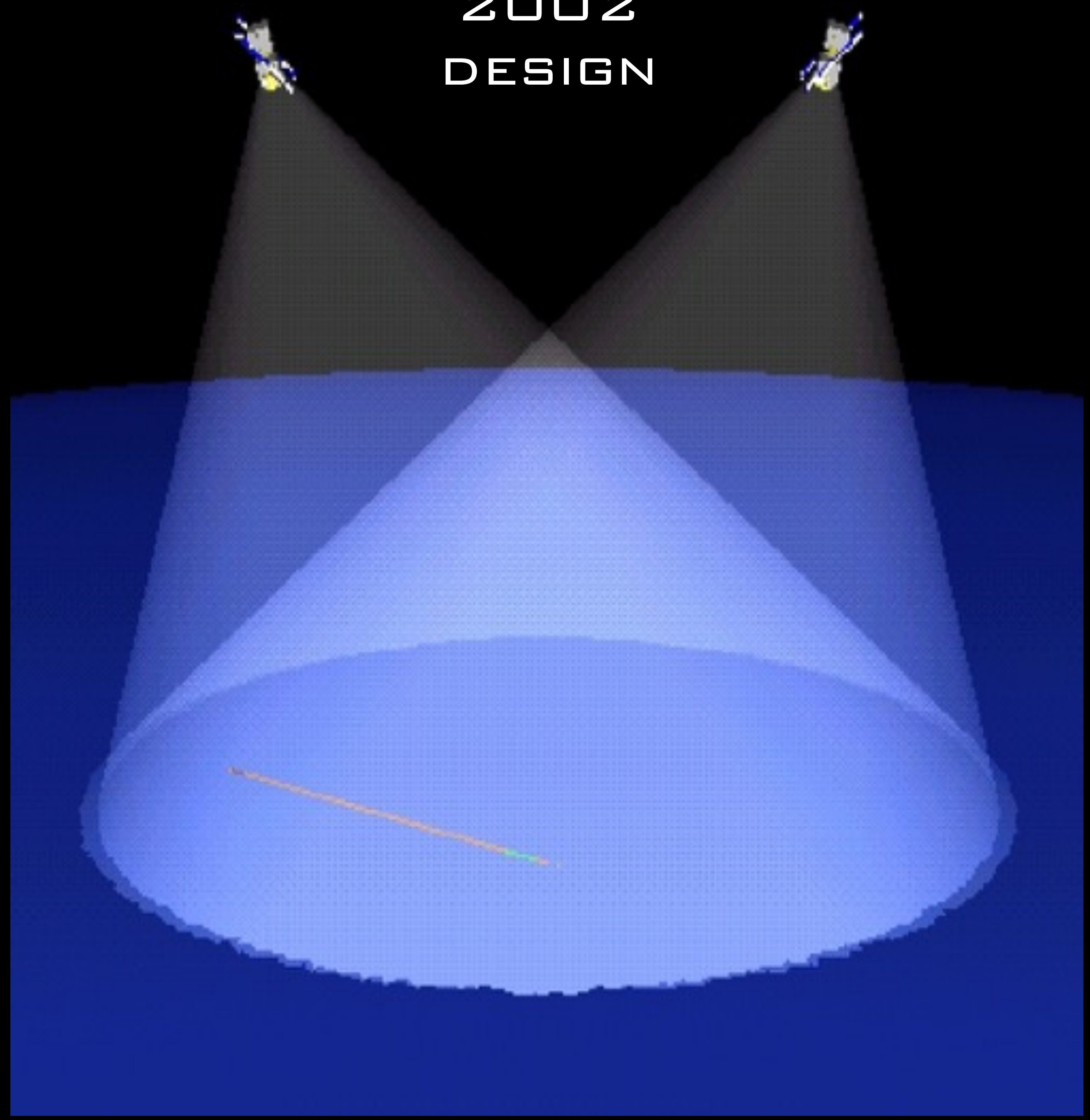
Extensive Air-shower Fluorescence from SPACE

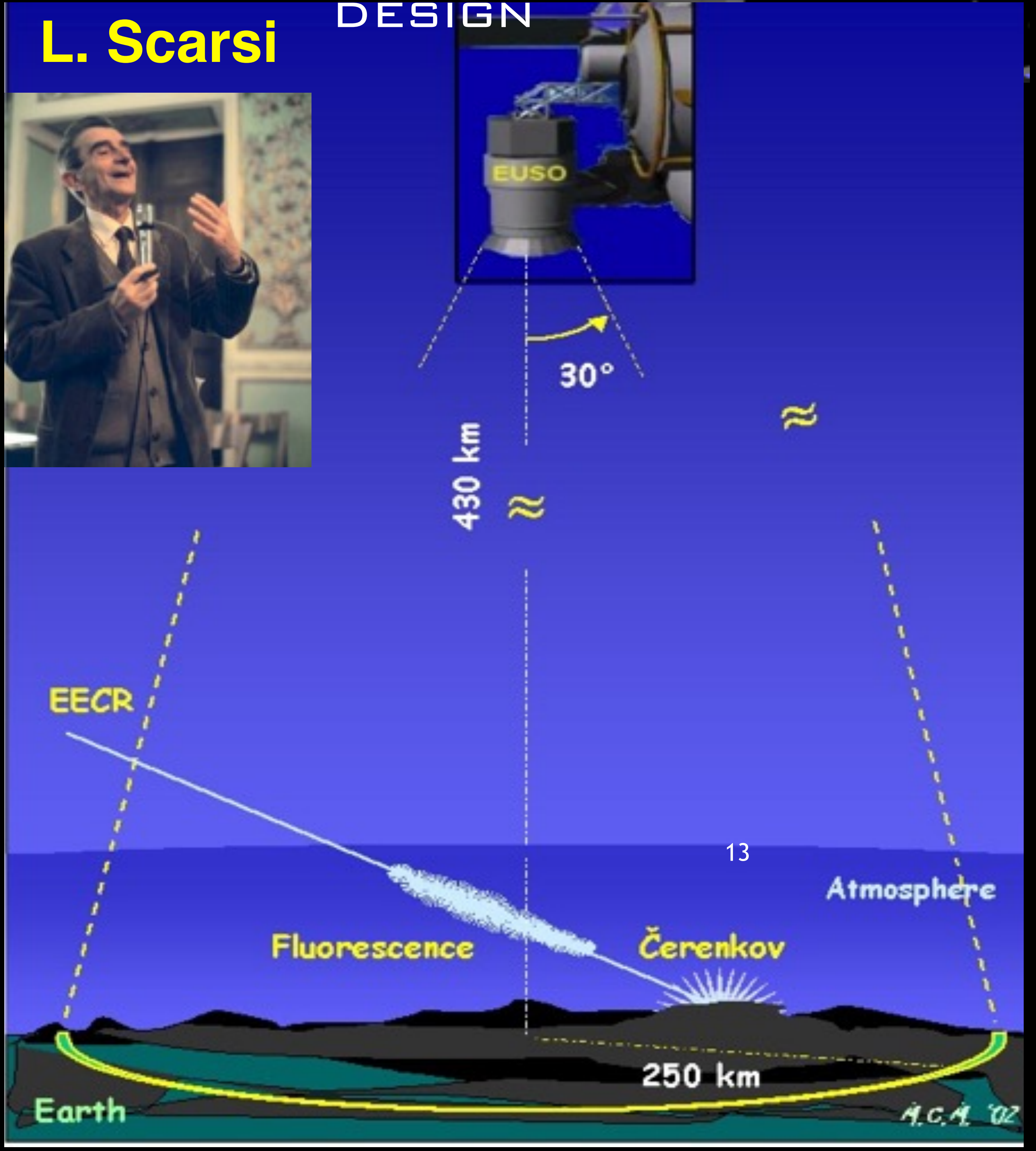


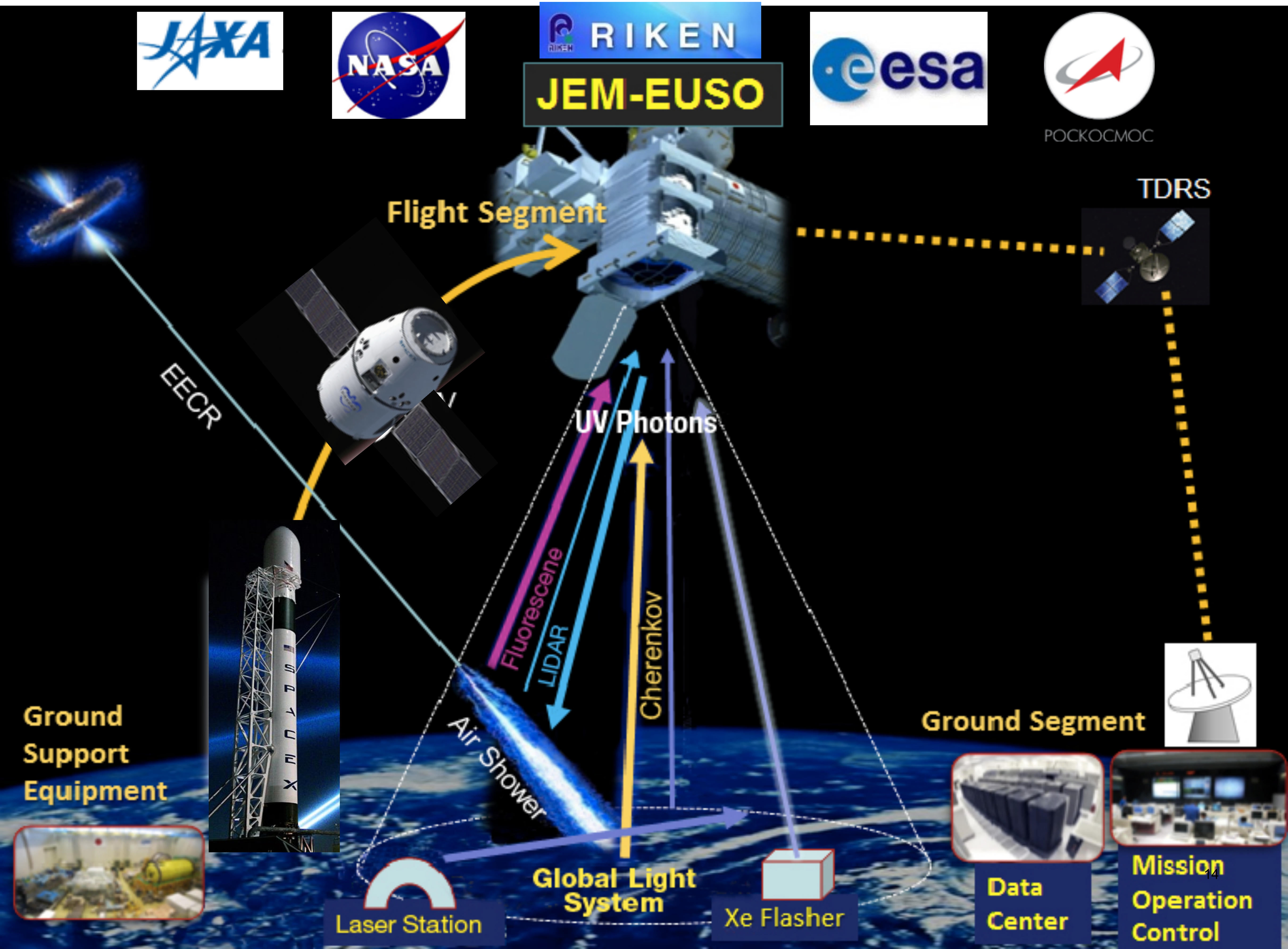
rbiting
ide-angle
ight-collectors

EUSO
2002
DESIGN

OWL
2002
DESIGN



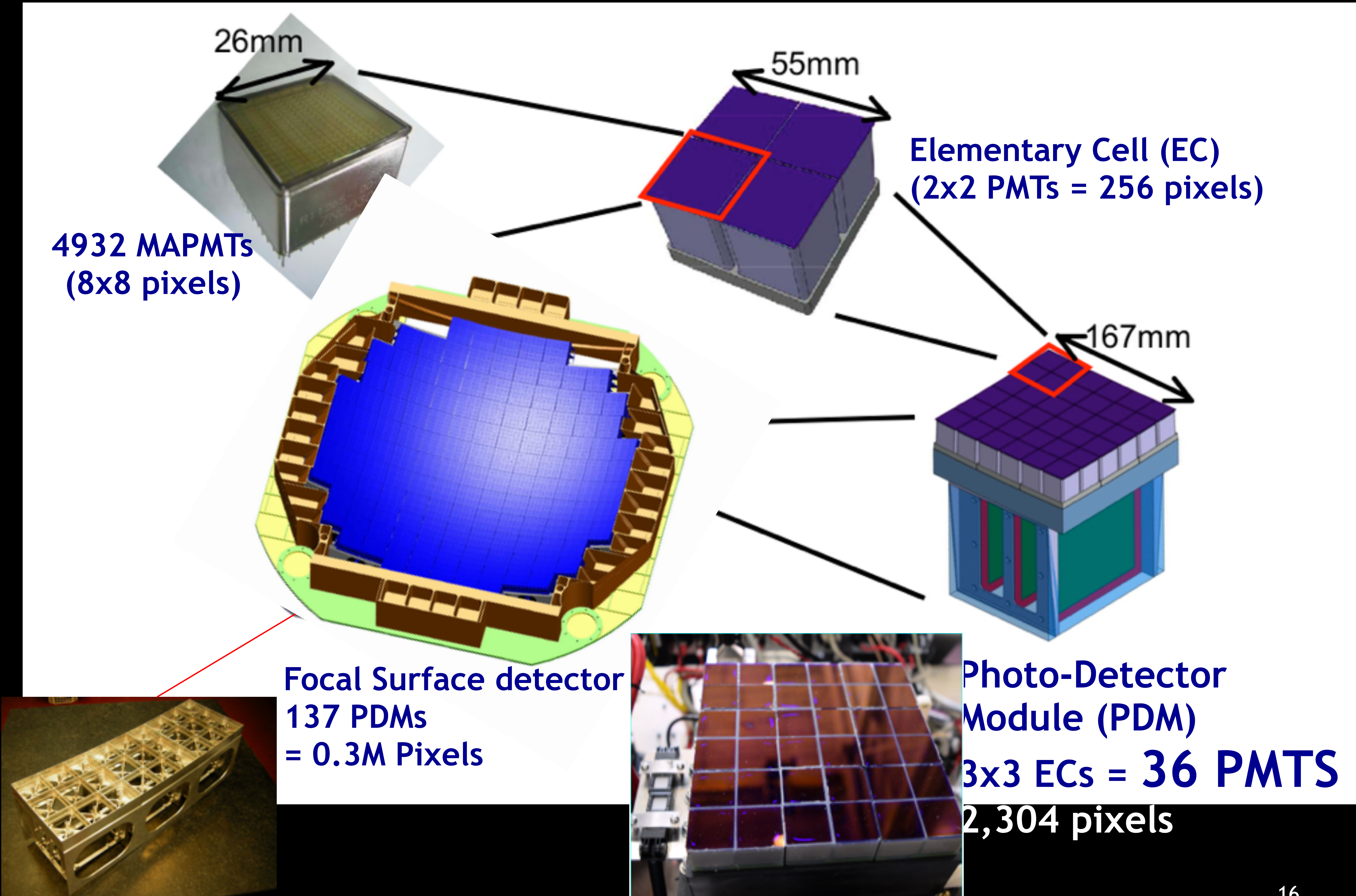



JAXA
NASA
RIKEN
JEM-EUSO
esa
РОСКОСМОС
TDRS
Flight Segment
EECR
UV Photons
Fluorescene
LIDAR
Cherenkov
Air Shower
Ground Support Equipment
Ground Segment
Laser Station
Global Light System
Xe Flasher
Data Center
Mission Operation Control

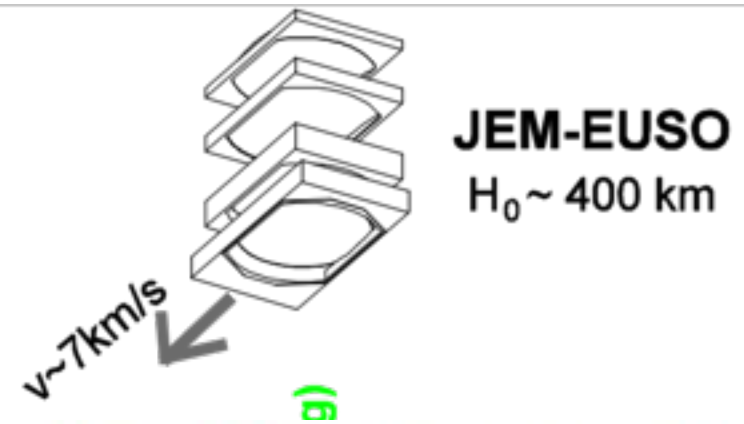
Science Instrument

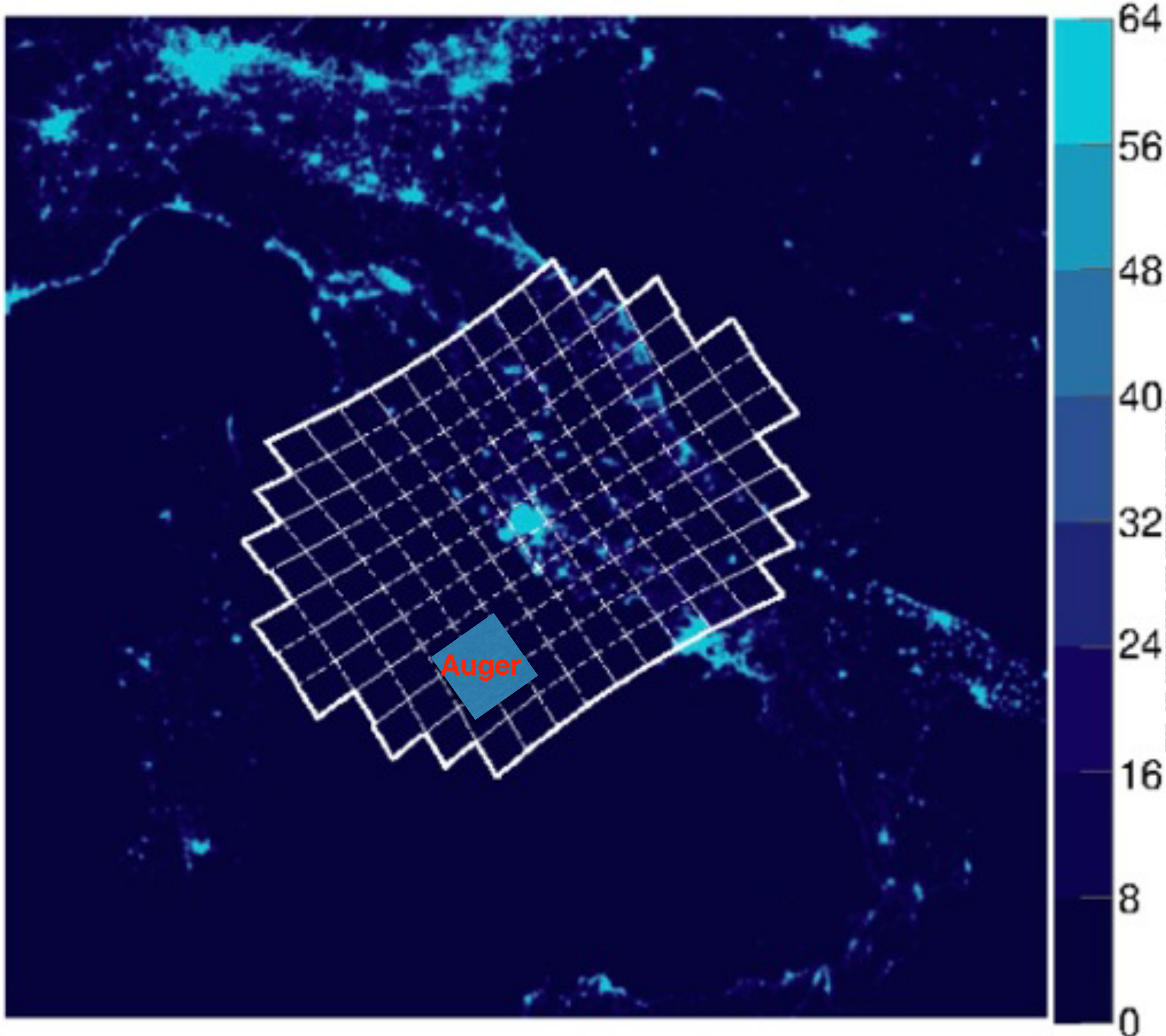
tics

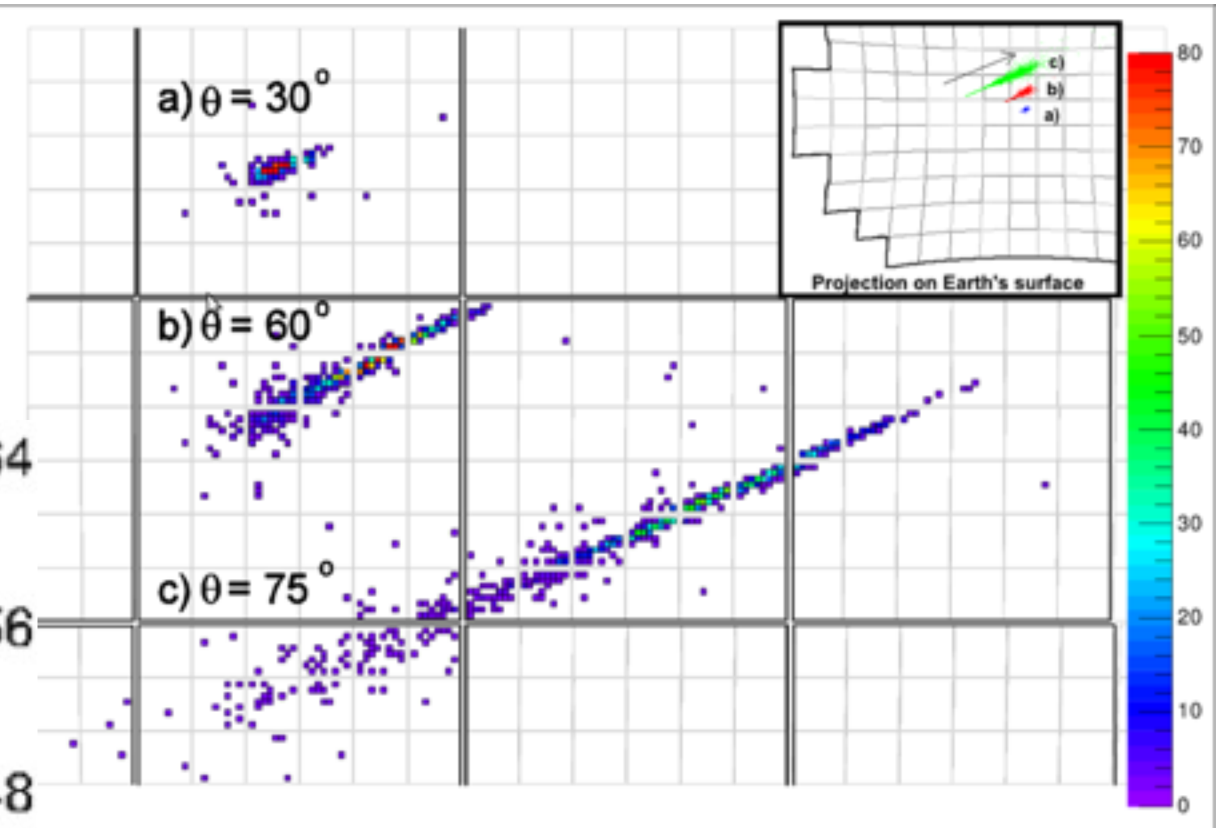
Focal Surface Detector

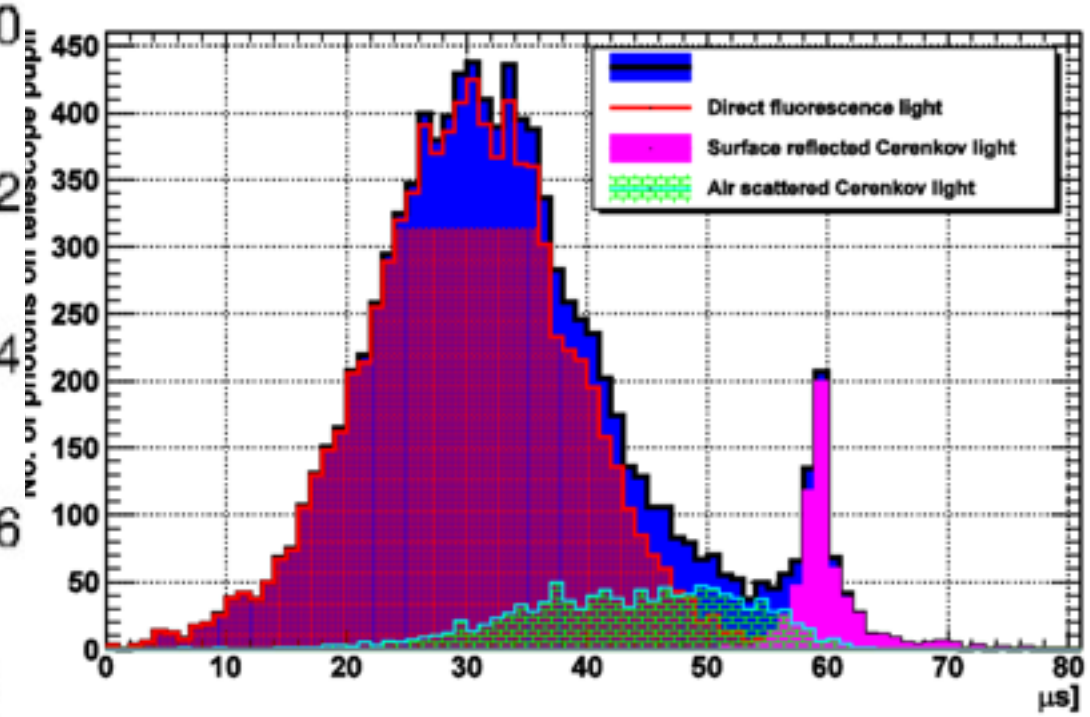


JEM-EUSO Observation Principle









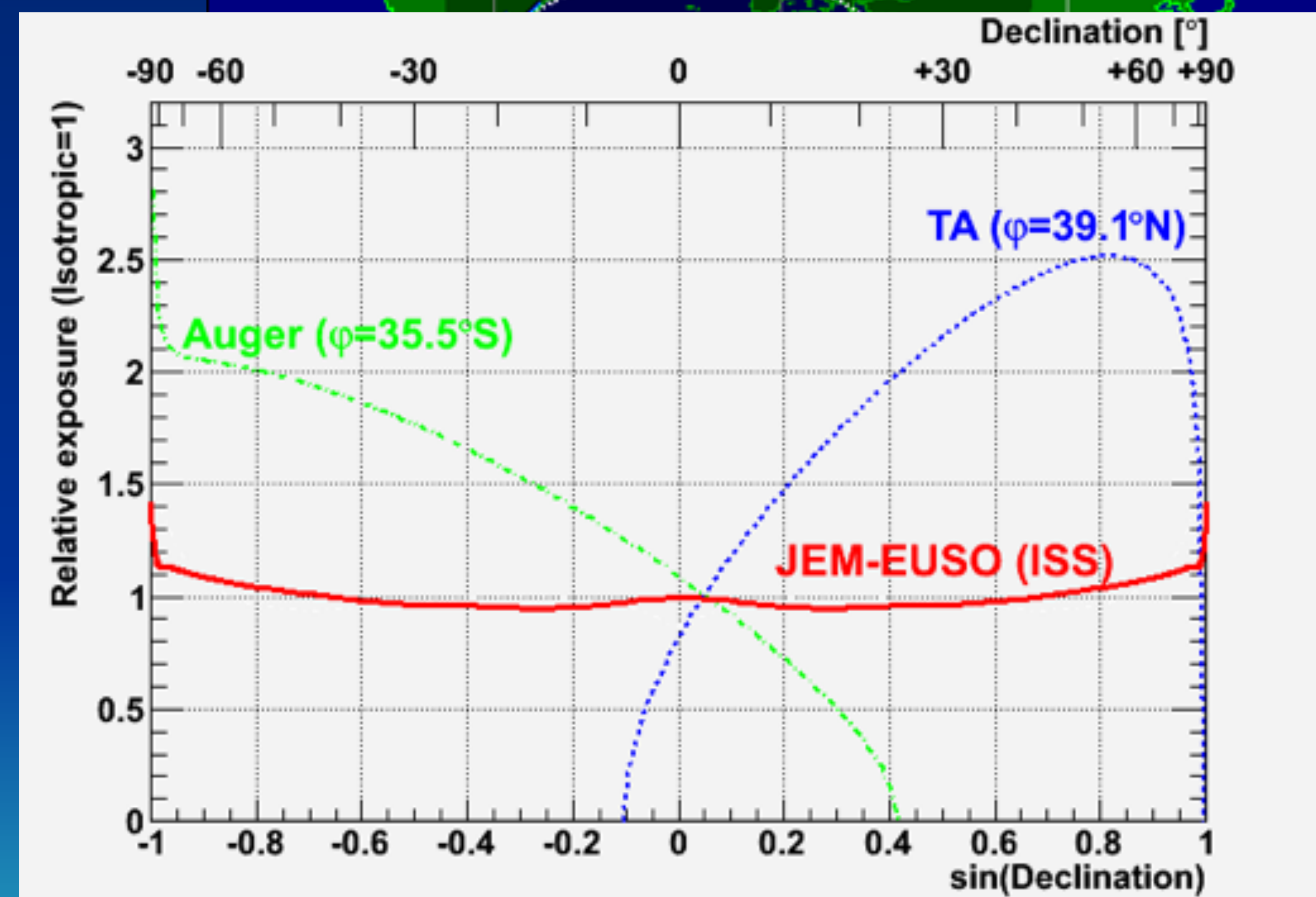
Δt ~ 50 - 150 μs

An idea of the monitored area (2)

Tilt angles: 0, 20, 30 deg.

ISS Orbit

http://www.nasa.com/



JEM-EUSO can observe the arrival direction of EECR very uniformly owing to the nature of the ISS orbit.

Peculiarities from space

- *Far and almost constant distance* of the shower (no proximity effect)
- Shower is contained in the FOV: *observation of the entire profile*
- Possibility of *observing in cloudy conditions* (in most cases X_{max} above the cloud-top)
- *Less contamination* by Cherenkov
- *Efficient gamma/hadron separation* using different geographical areas
- Measurement of neutrino showers at high altitude *with less LPM effect*

JEM-EUSO Science requirements —> Telescope & Mission requirements

Parameter	Requirement value
Exposure at 100 EeV*	3 x 10^5 km^2 sr yr
at 50 EeV*	2 ×10^5 km^2 sr yr
Angular res. at 50 EeV	≤5°
at 200 EeV	≤2°
Energy res. at 50 EeV	≤30%
at 100 EeV	≤20%
$^{**}X_{max}$ res.	≤100 g/cm^2
$^{***}\langle X_{max} \rangle$ res.	≤50 g/cm^2

*For events which can be used for anisotropy studies
**For photon and neutrino discriminations
*** Determination of the average logarithmic mass

Parameter	Requirement value
Operational wavelength	300-400 nm
Field of View	±30°
Effective aperture	≈ 4 m^2
Pixel Field of View	≤ 0.06°
*Pixel size on the FS	≈3mm
Optics Throughput	>50%
Time Resolution	2.5 μs
Number of pixels	≈3.x10^5
Detection efficiency	≥30%
Dead Time	<3%

Parameter	Requirement value
Orbit altitude	400 km
Monitored Area	~10^5 km^2
Pixel size on ground	< 600 m
Mission Lifetime	≥5 yr
Launcher	HTV/Dragon
Orbit Inclination	51.6°
Duty cycle	≈20%

Technical challenges of the observation from space compared to UHECR detectors from ground

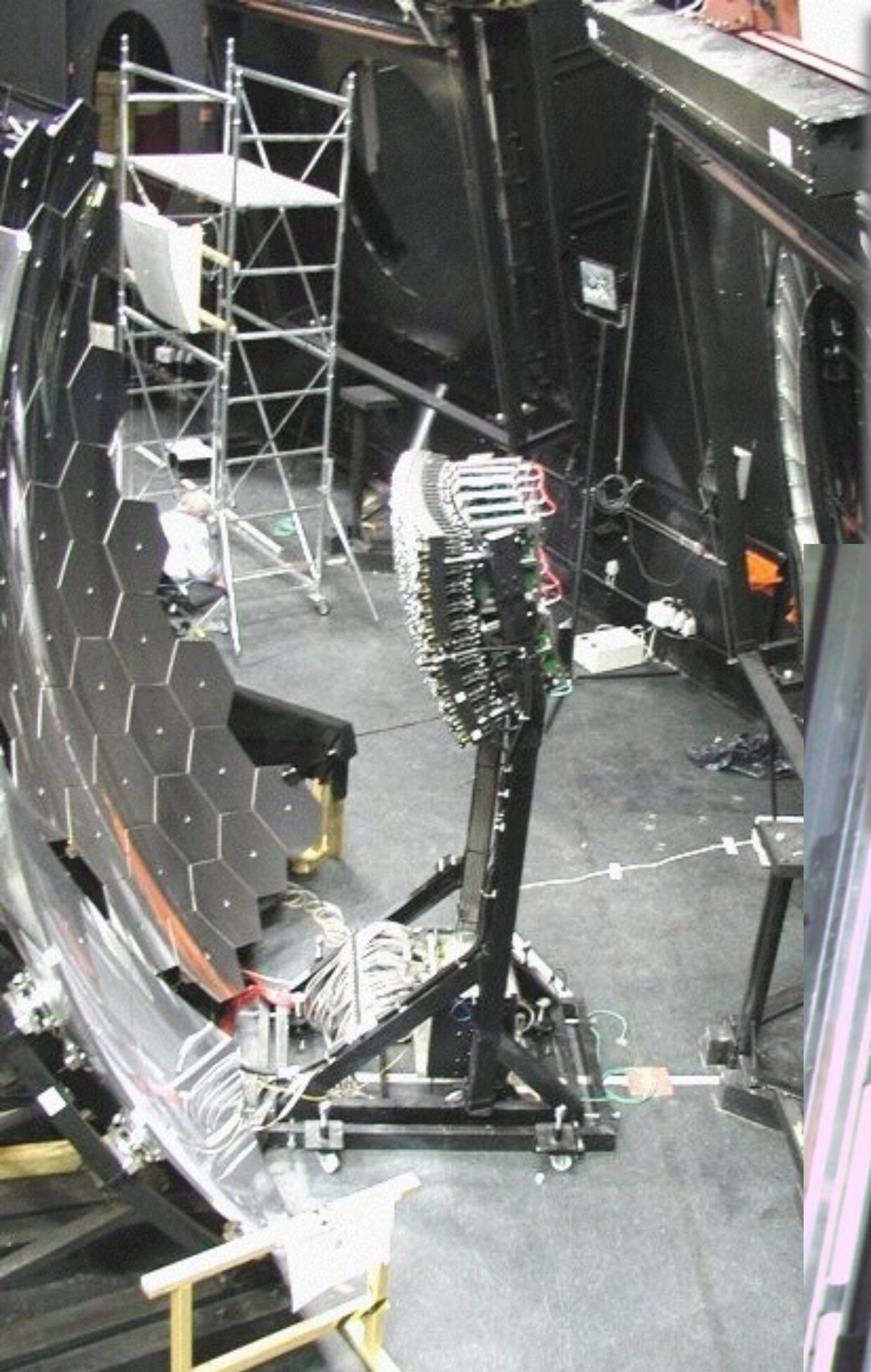
» Low power consumption (<1kW for JEM-EUSO - $3x10^5$ pixels)

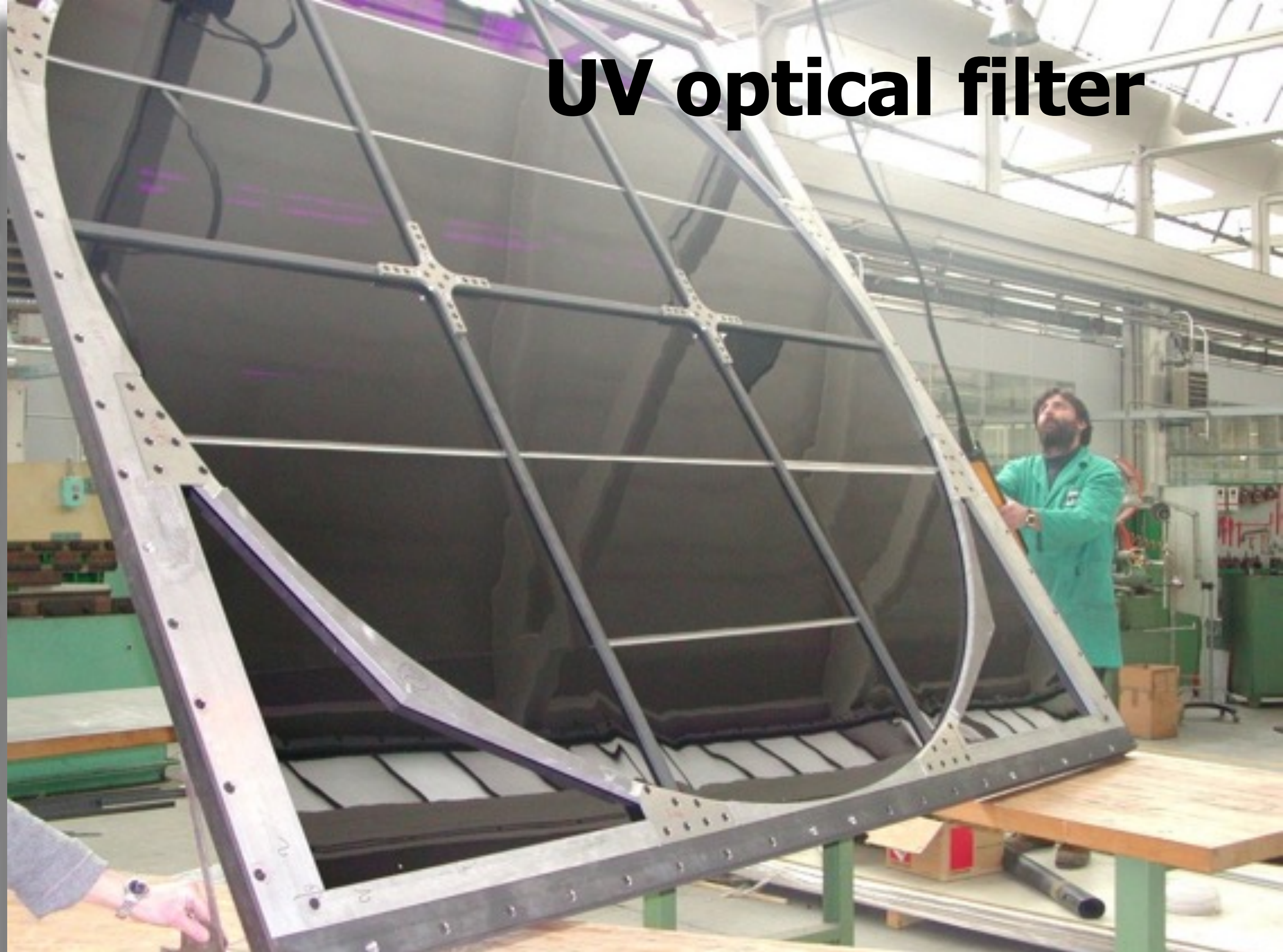
» Low mass (~1-2 tons for JEM-EUSO)

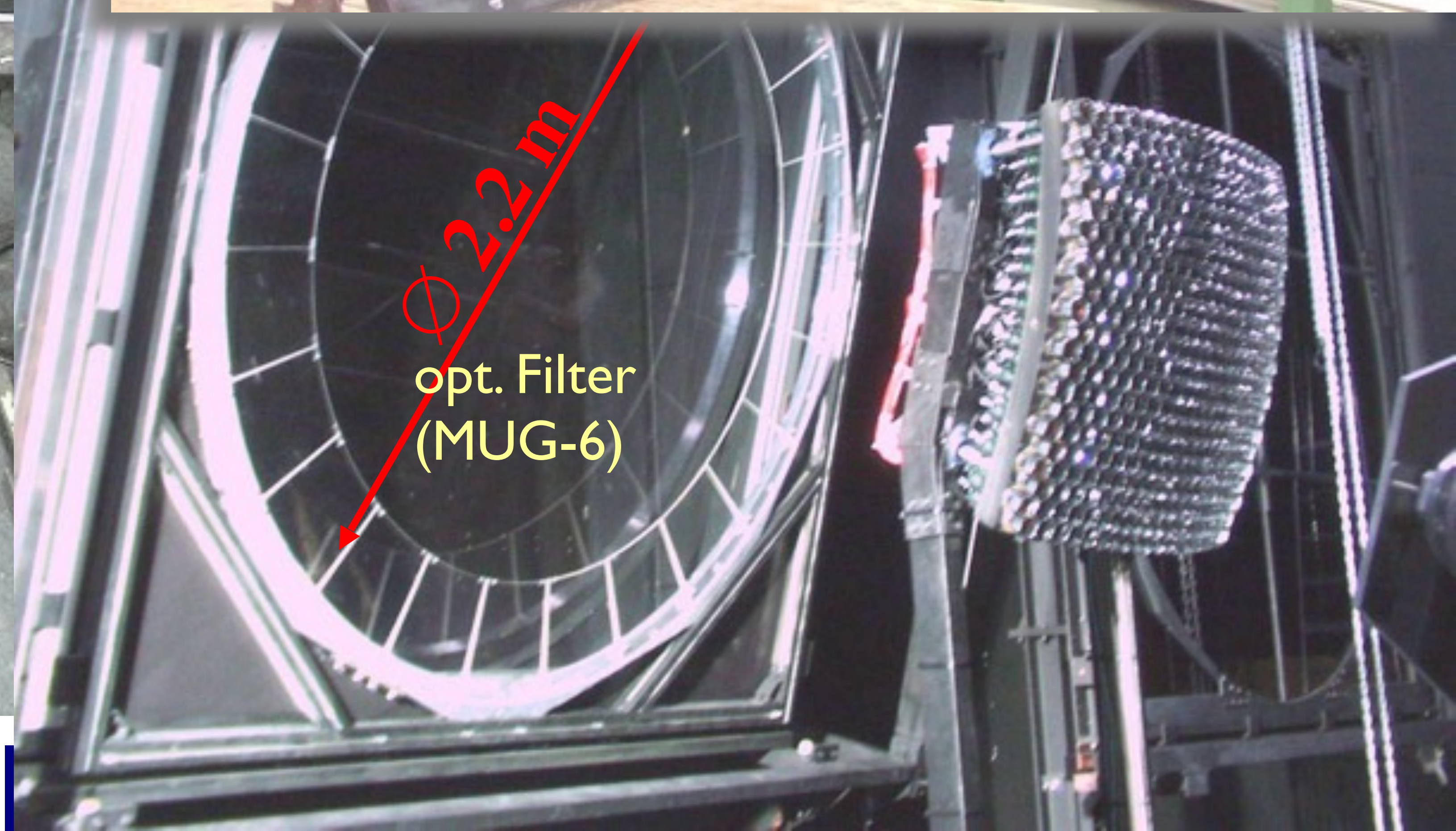
» Low telemetry (300 kbit/s for JEM-EUSO on ISS)

» Radiation hard instrumentation

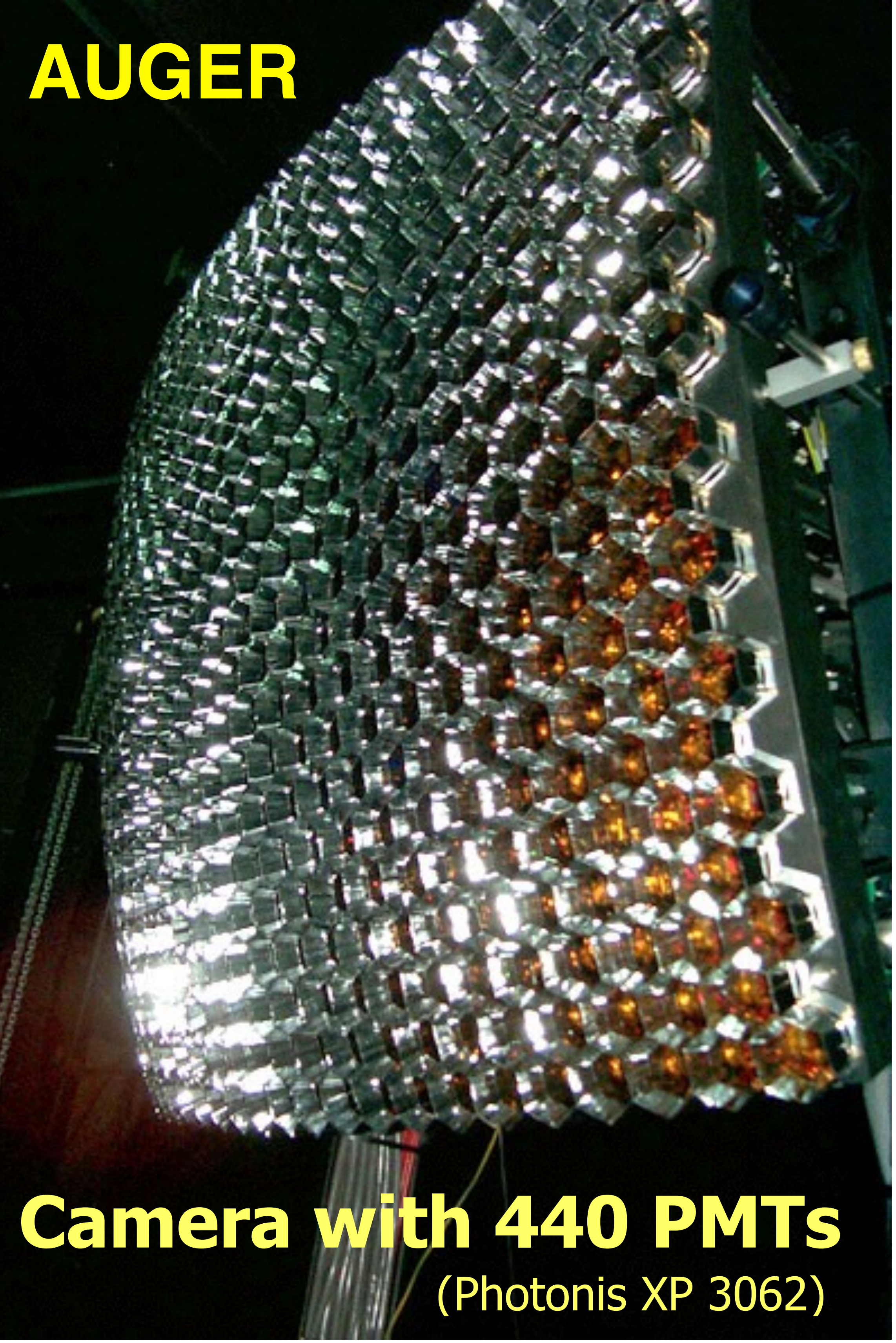
» Space-qualified instrumentation (need to increase TRL)



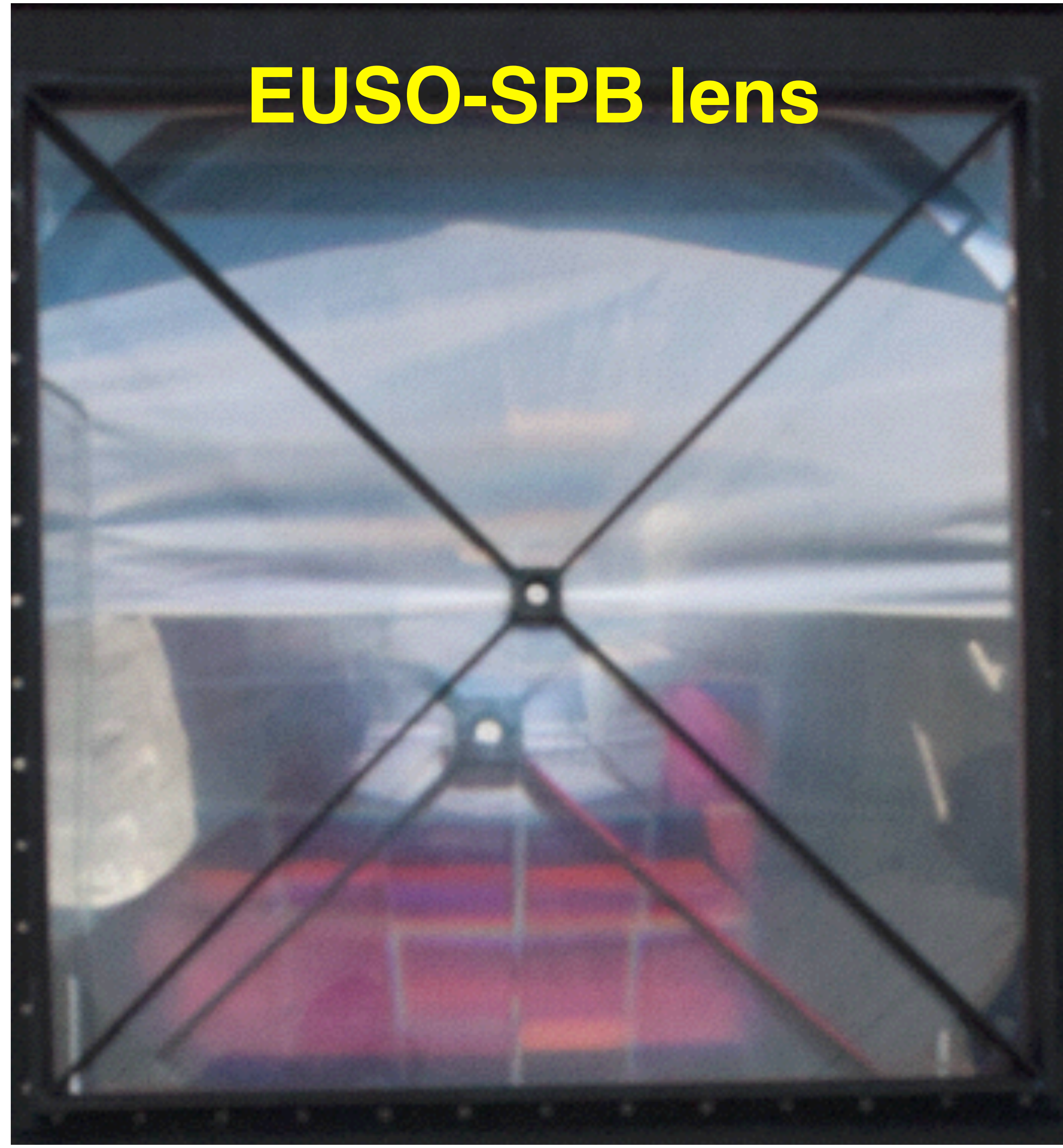


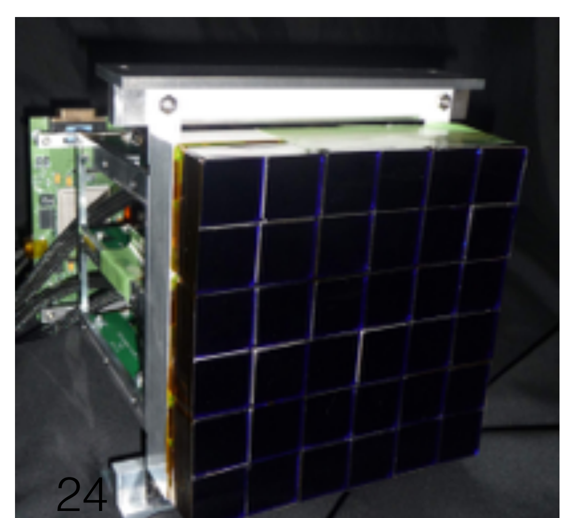


- Auger fl



FS of 1 mirror Auger
440 pixels (~5cm/pix)
~100x100 cm^2





FS of EUSO-SPB
2304 pixels (3mm)
17x17 cm^2

Comparing Auger FD and JEM-EUSO telescope

	Auger (1 FD site)	EUSO-SPB	JEM-EUSO
mirror size	6 x 11 m^2	1 m^2 lens	4m^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	0.075 deg/pixel
Pixel size	5x5 cm^2	1 pixel 3x3 mm^2	3x3 mm^2/pixel
Camera size	6 x 440 pixels	2304 pixel	2304 pixel/PDM
EAS distance	40 km	30 km	400 km
light intensity (@40km=1)	1	1.8	0.01
time resolution	100 ns	2.5 μs	2.5 μs
signal acquisition	charge integration	photon counting	photon counting

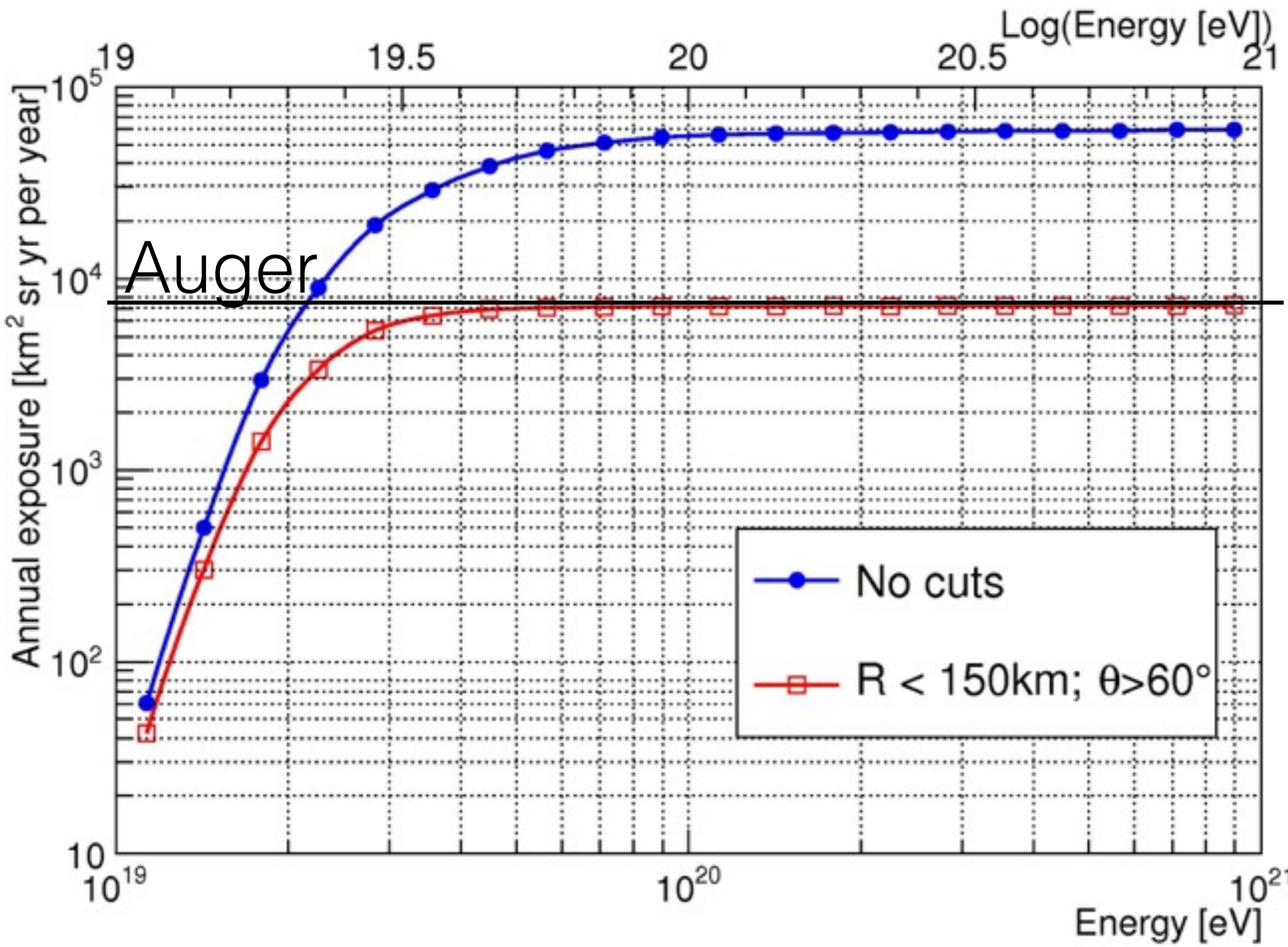
A significant difference in the detectors, a technological challenge…

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 anthropic conditions.

Annual Exposure nadir mode



~60,000 km² sr yr

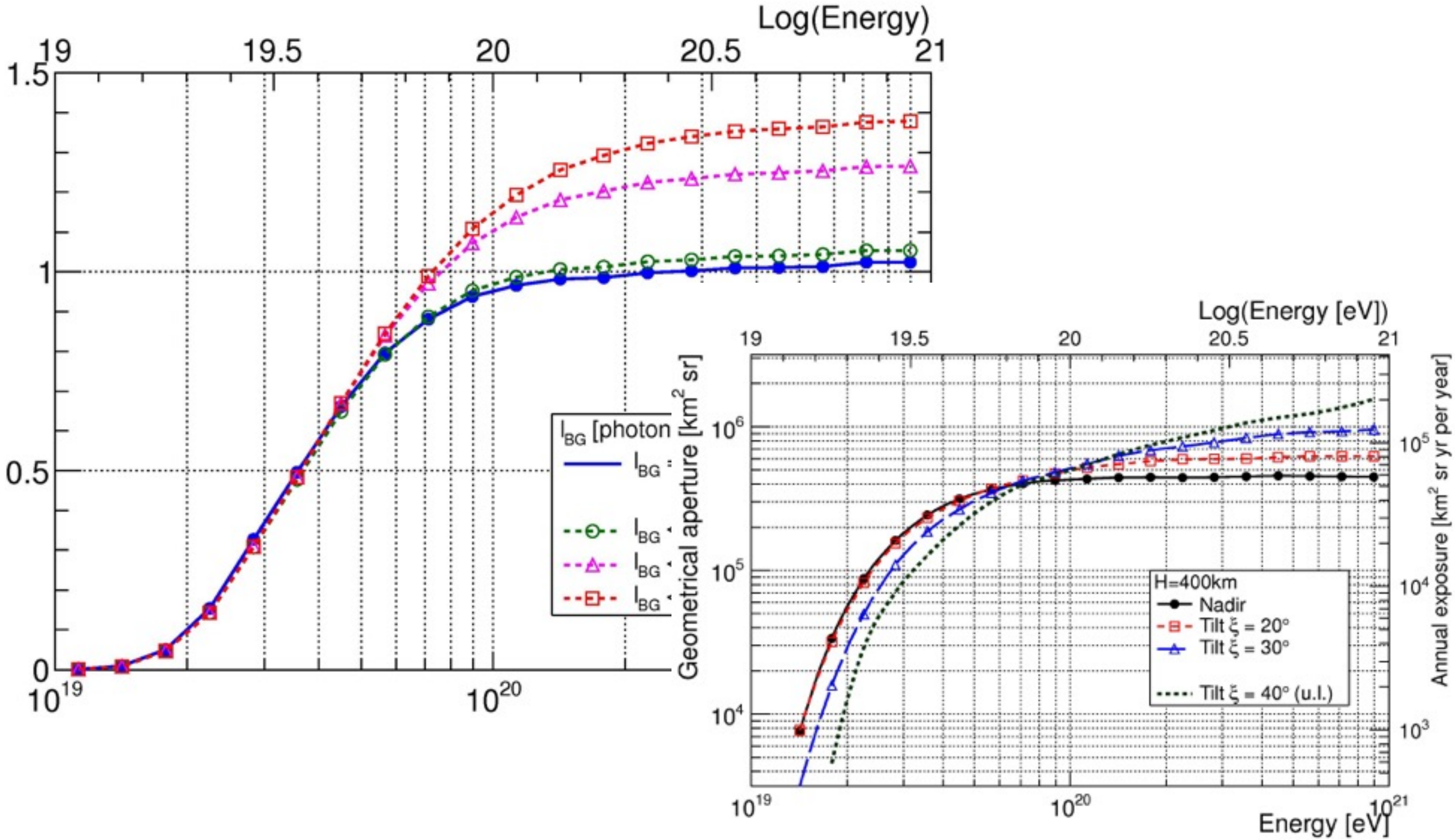
~7,000 km² sr yr

~9 times Auger
~50 times TA

- Observational duty cycle (brightness of the sky does not hamper UHECR measurements): ~20%
- Role of clouds: ~72%
- City lights inefficiency: ~7%
- Lightning ineff.: ~ 2%
- Aurorae ineff.: ~1%

- Conversion factor between Aperture and Exposure: ~13%

Aperture & Exposure for tilt modes and background levels



ξ = 20° : exposure 10-20% higher than nadir mode at E~10^{20}eV

ξ = 30°: exposure ~1.8 higher than nadir mode at E > 5x10^{20}eV

JEM-EUSO PROGRAM

EUSO-TA (2013-)

EUSO-Balloon (2014)

TUS (2016)

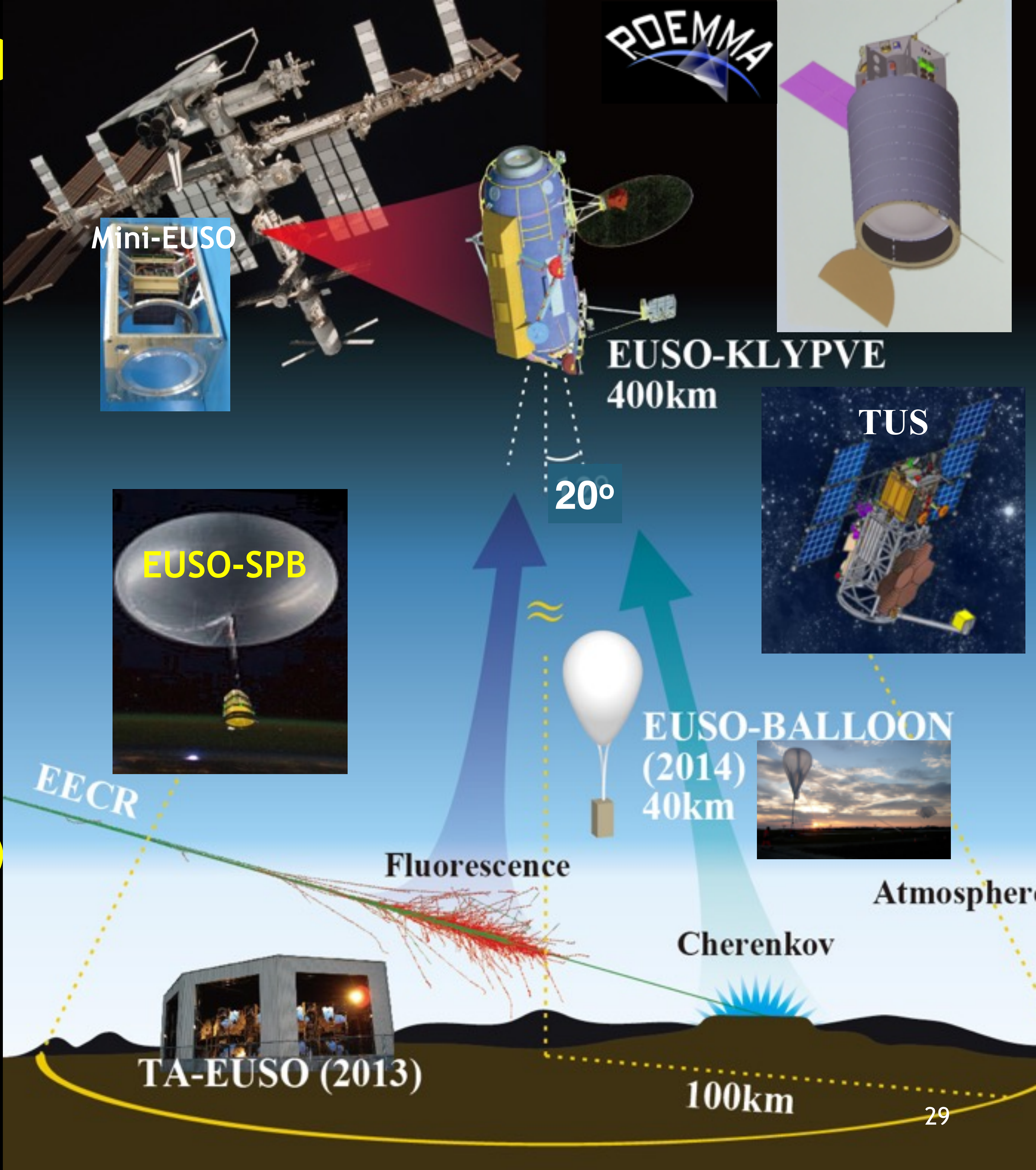
EUSO-SPB1 (2017)

Mini-EUSO (2018-19)

EUSO-SPB2 (2020-22)

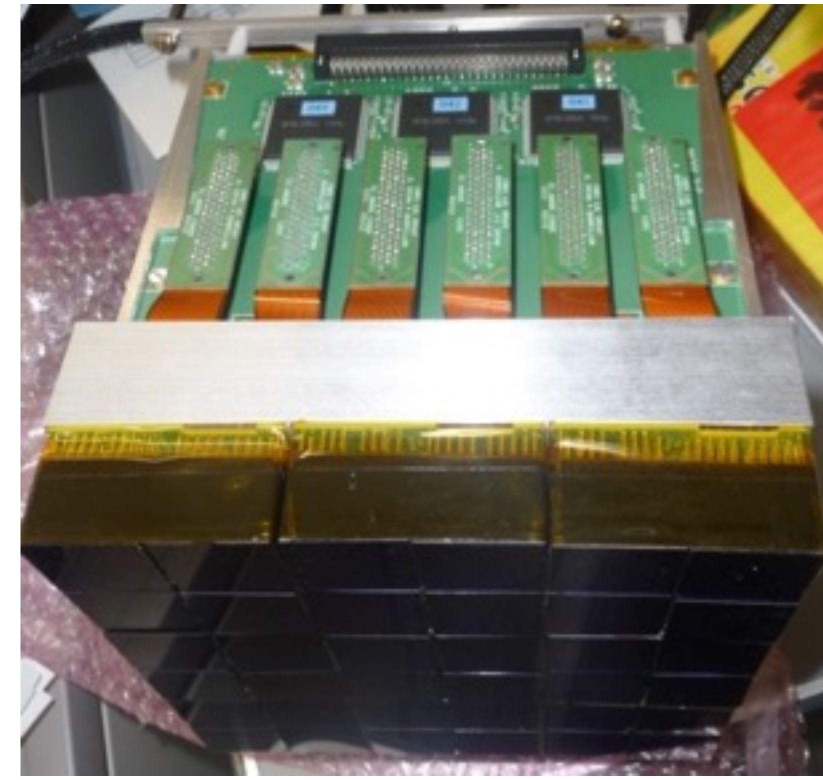
K-EUSO (2023+)

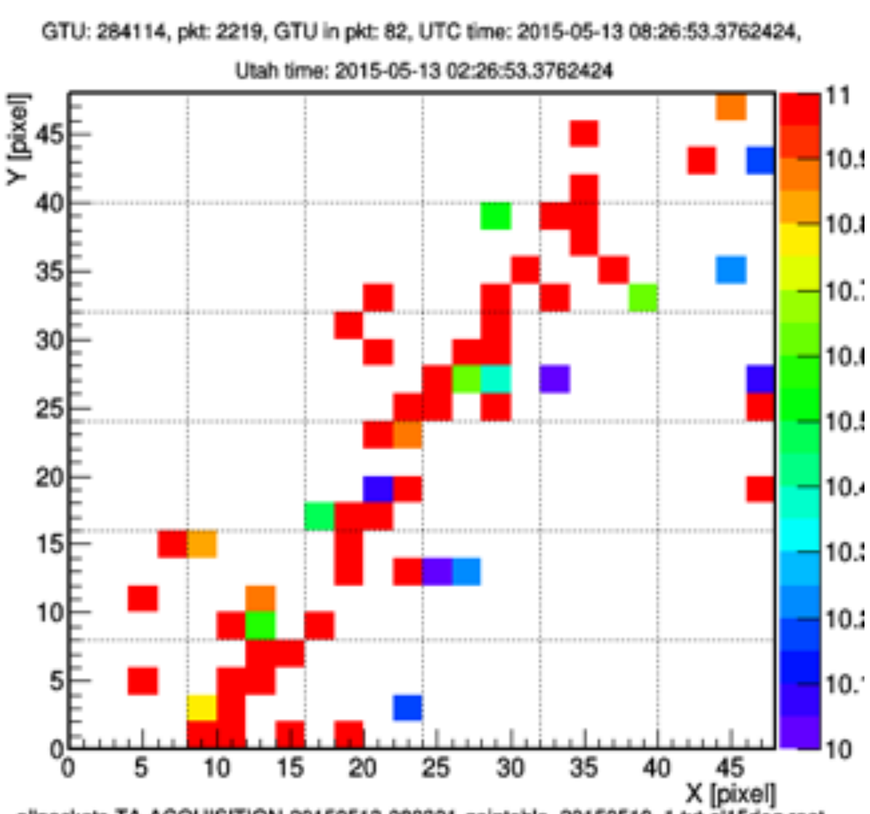
POEMMA (2028+)

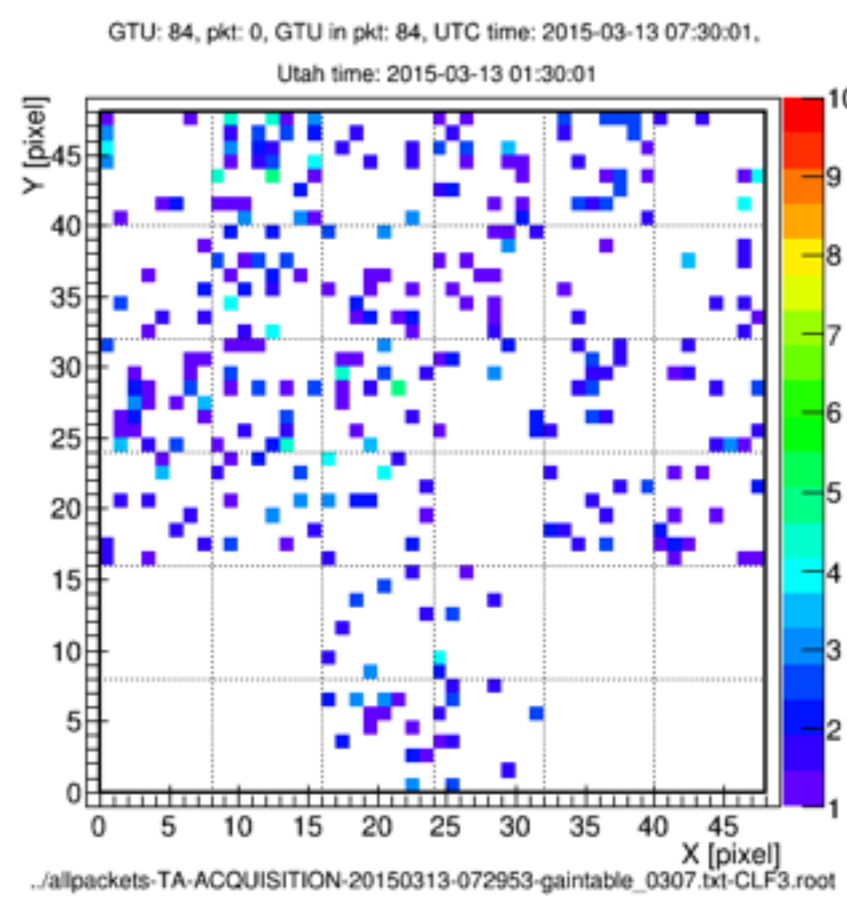


EUSO-TA


(C) Oscar Larsson




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
Y [pixel]
X [pixel]
allpackets-TA-ACQUISITION-20150513-080301-gaintable_20150510_1.txt-el15deg.root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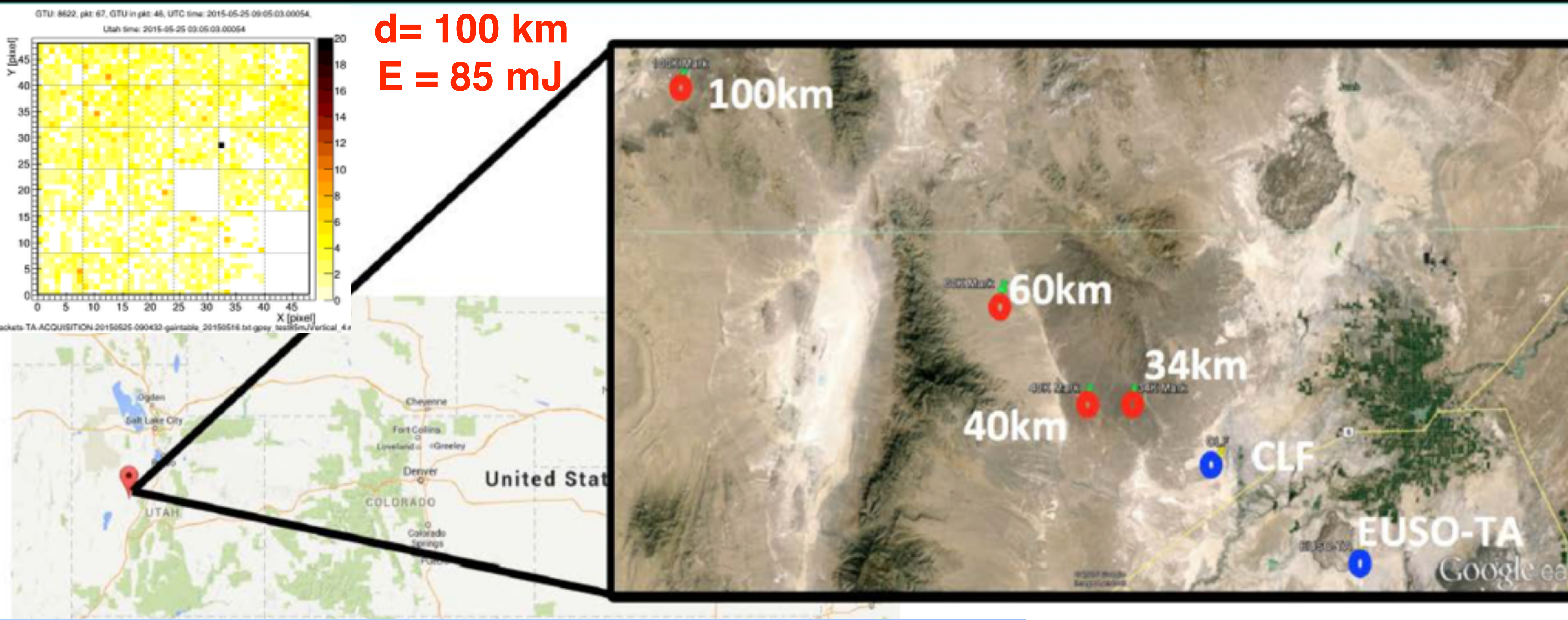
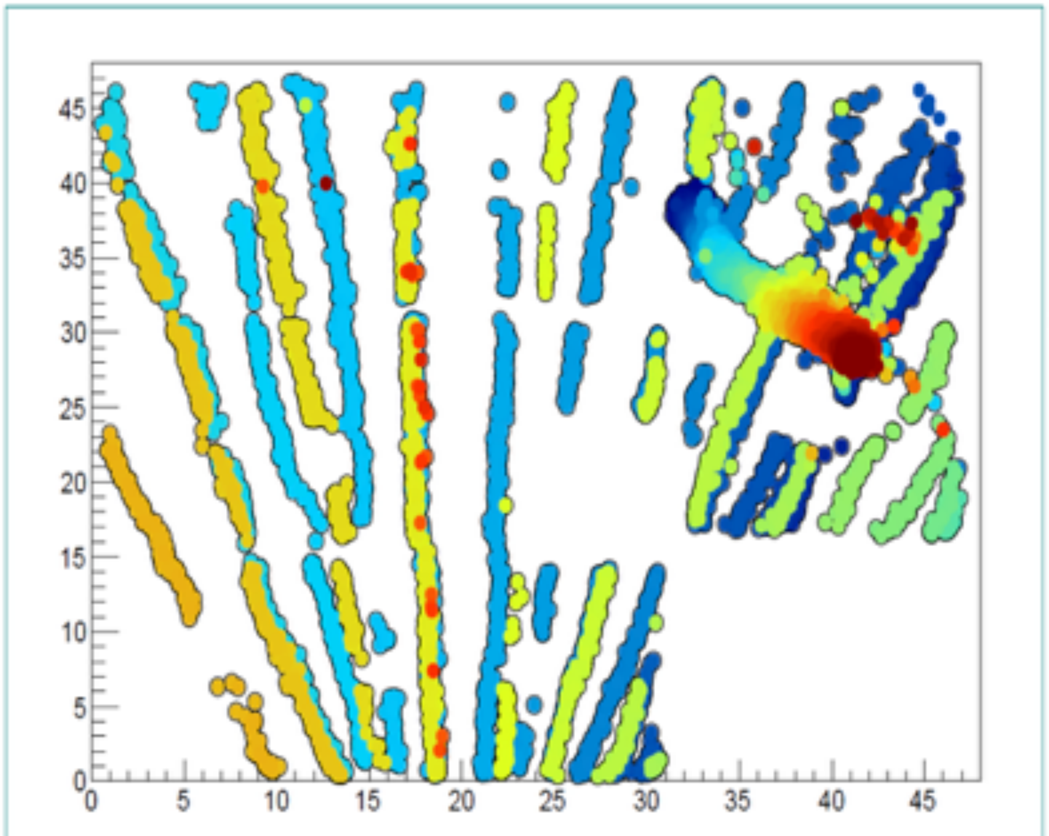
Utah time: 2015-03-13 01:30:01
Y [pixel]
X [pixel]
../allpackets-TA-ACQUISITION-20150313-072953-gaintable_0307.txt-CLF3.root

CLF and laser tests

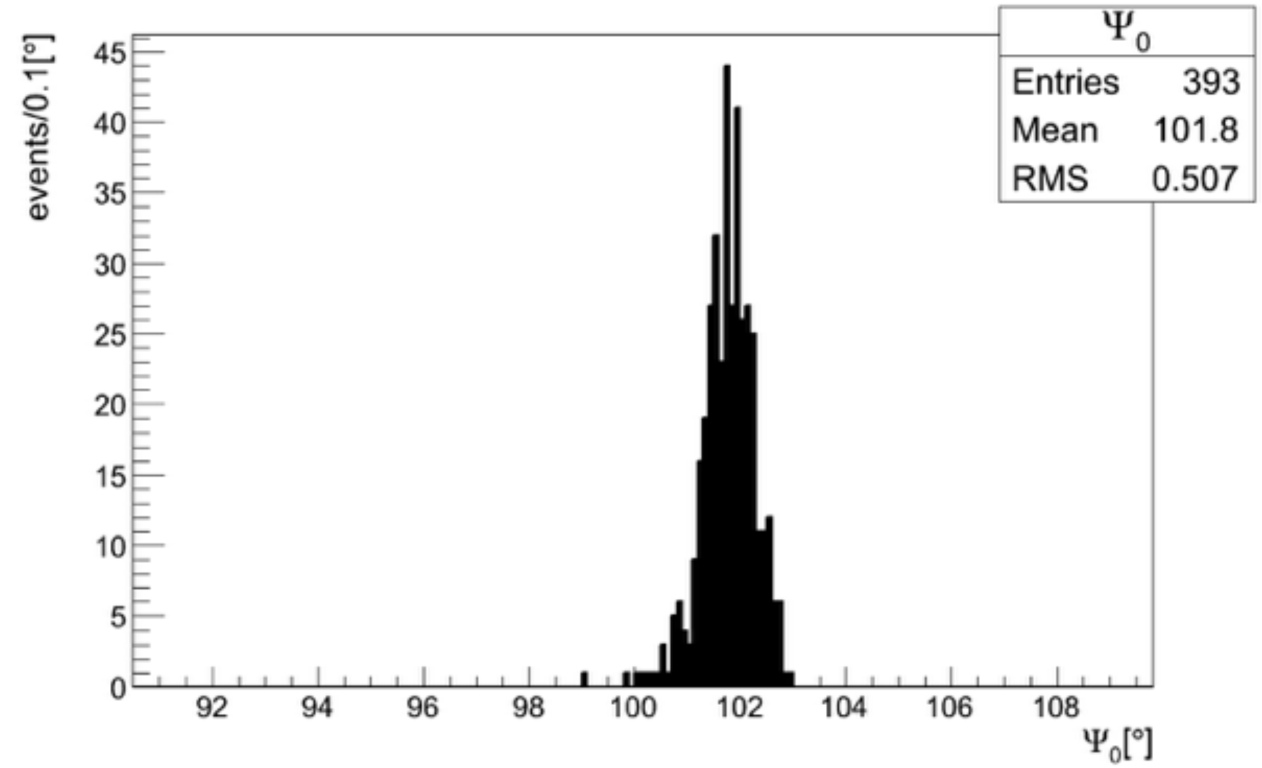
d= 100 km
E = 85 mJ



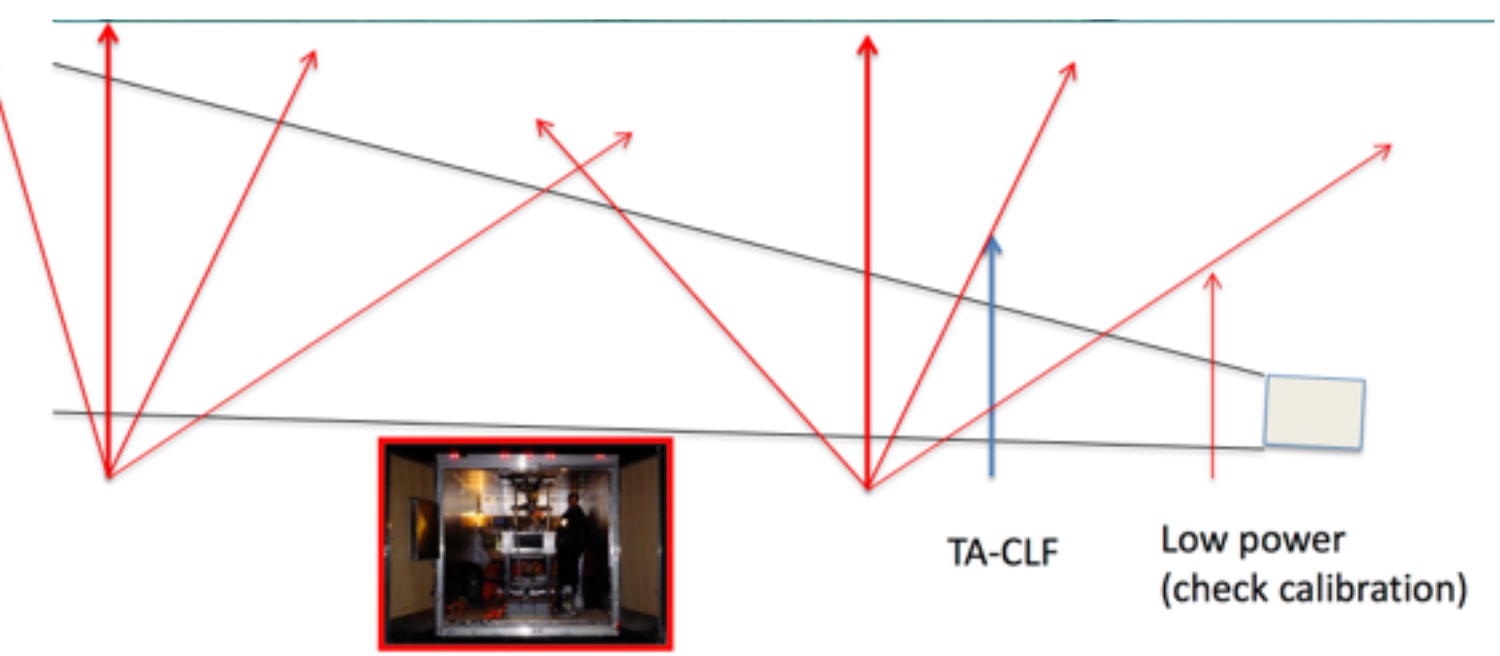
Laser direction reconstruction



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



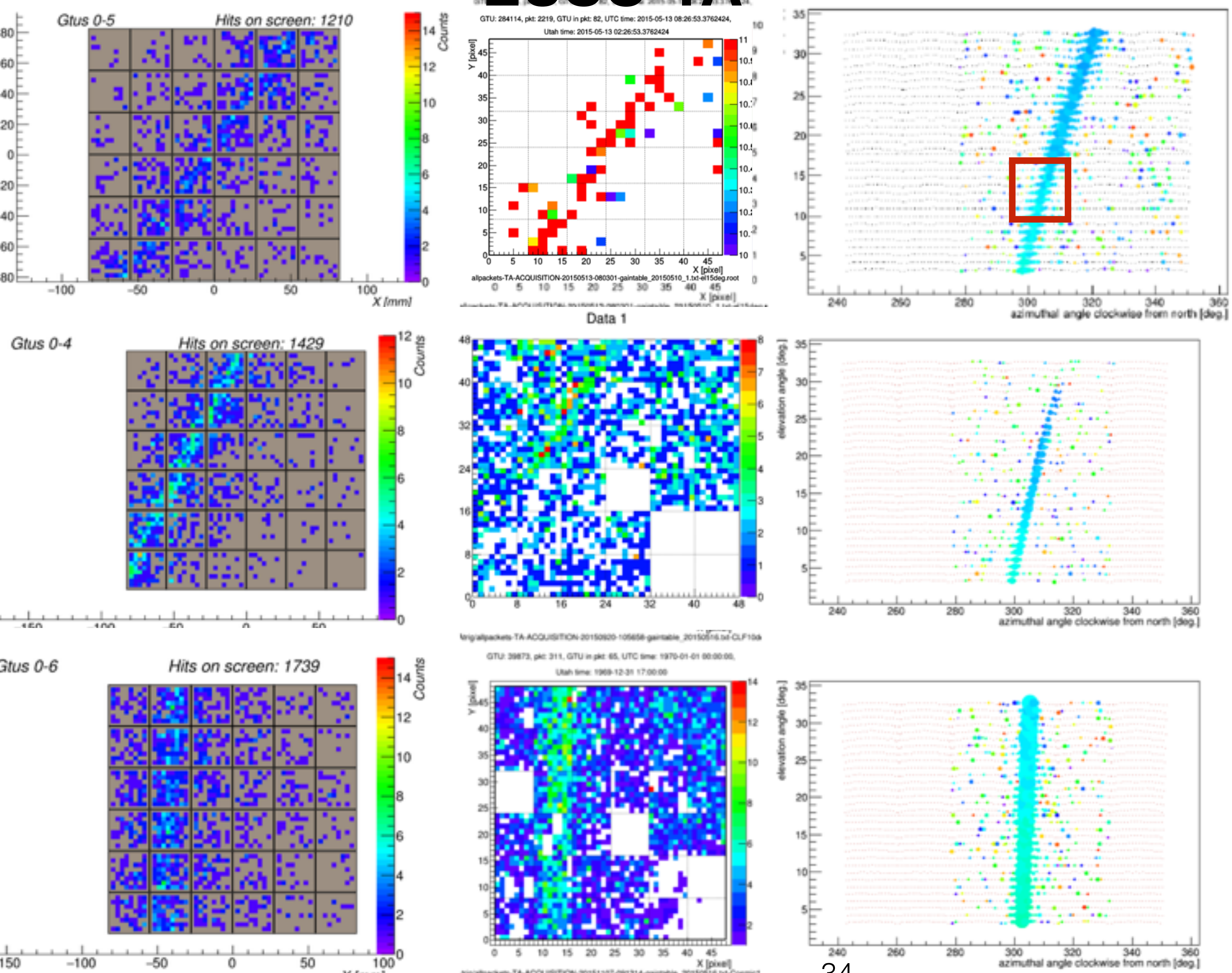
- GLS at 34km
- Telescope tilt 10°
- GLS zenith 90° (vertical)
- 2Hz
- Various energy settings 4, 6, 9, 12, 13, 15, 16, 17, 19, 20mJ
- 500 shots were fired (50 each setting)



EAS event view

3 software triggered EAS events with TA reconstruction

ESAF **EUSO-TA** **TA**

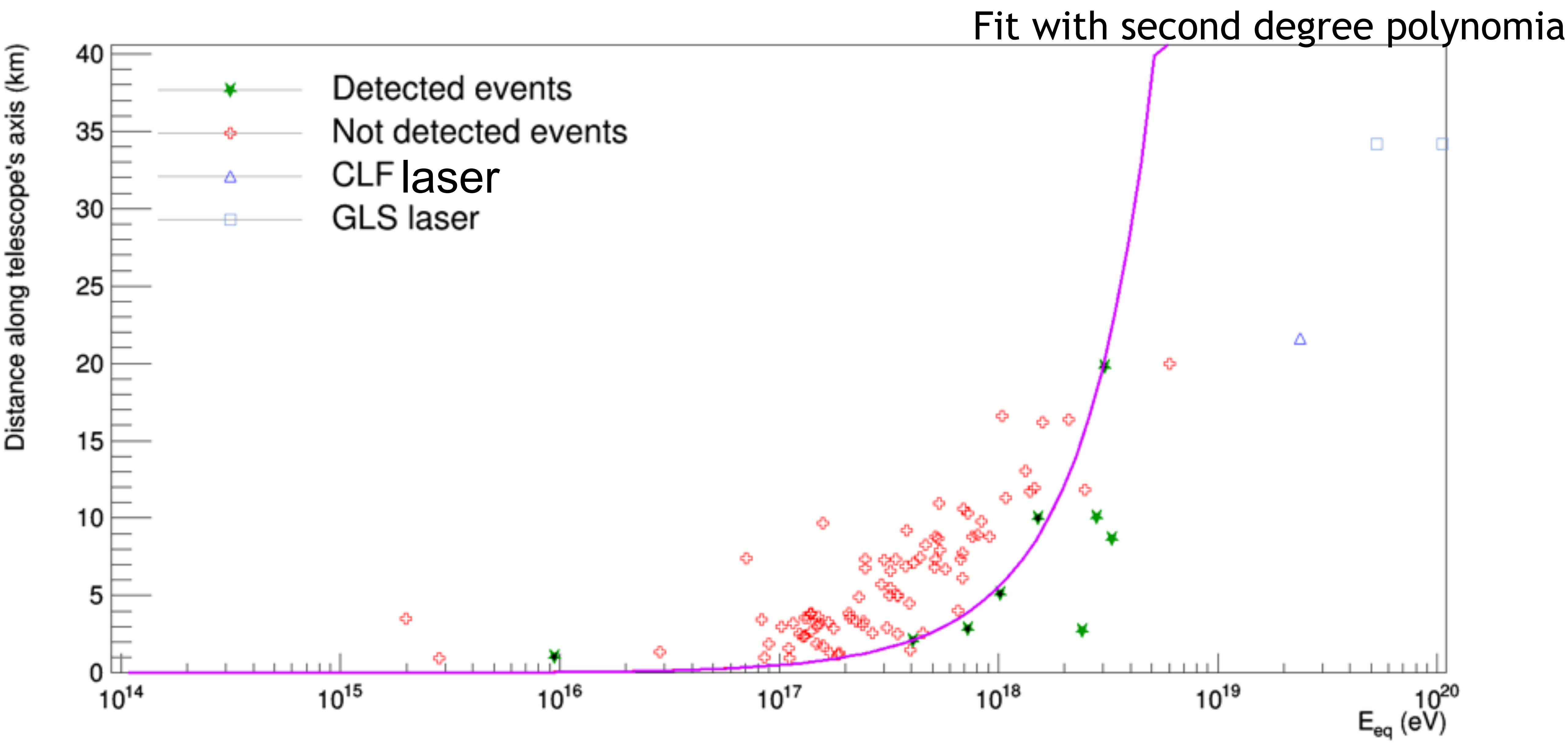


20150513-08:26:50.356
LogE = 17.99
Rp = 2.5km

20150920-10:59:19.309
LogE = 18.63
Rp = 6.7km

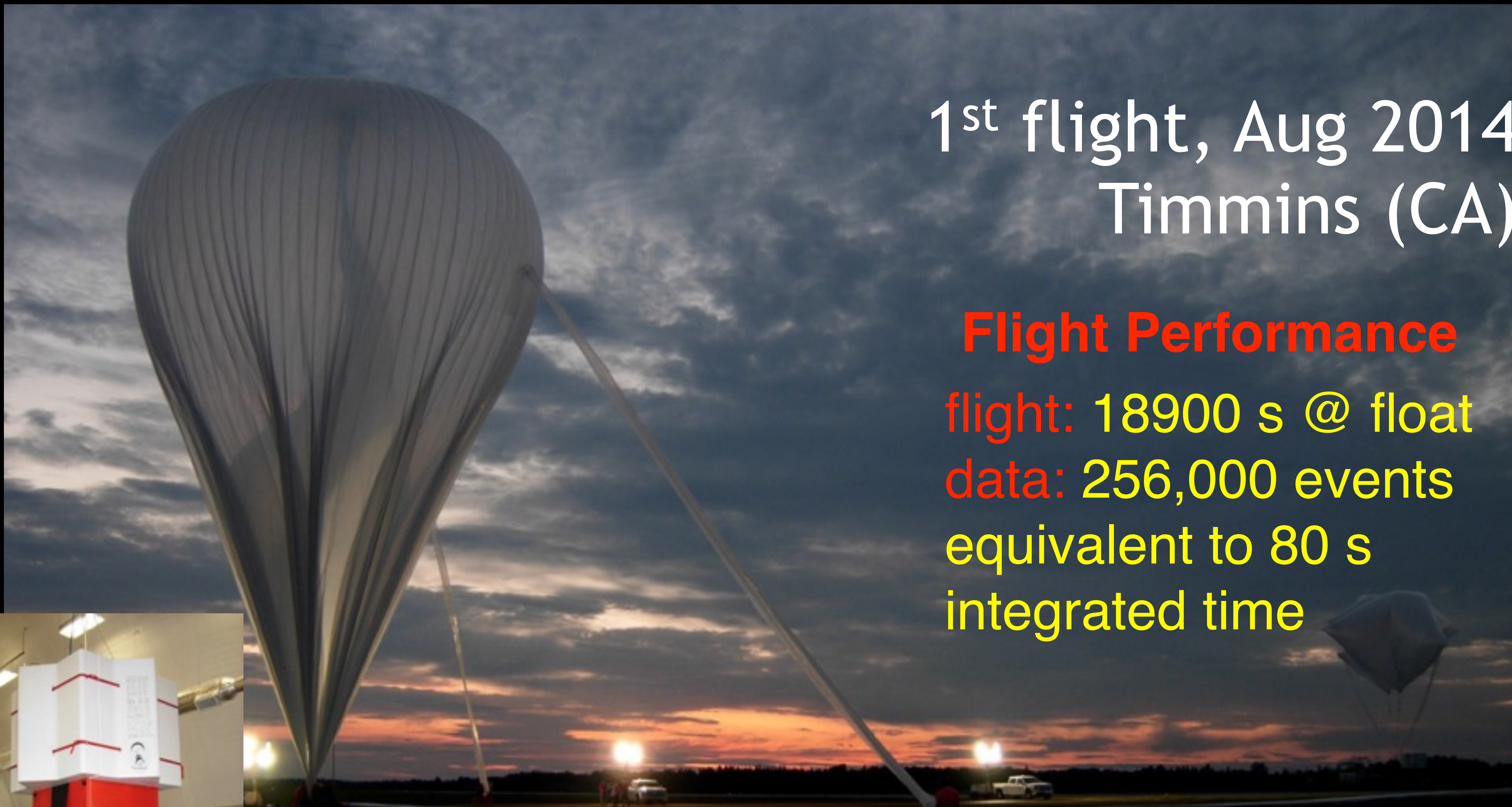
20151107-09:15:06.732
LogE = 18.37
Rp = 2.65km

$E_{equivalent}$ – Distance along tel. axis



Total of 9 events detected in coincidence with TA

2. EUSO Balloon flights

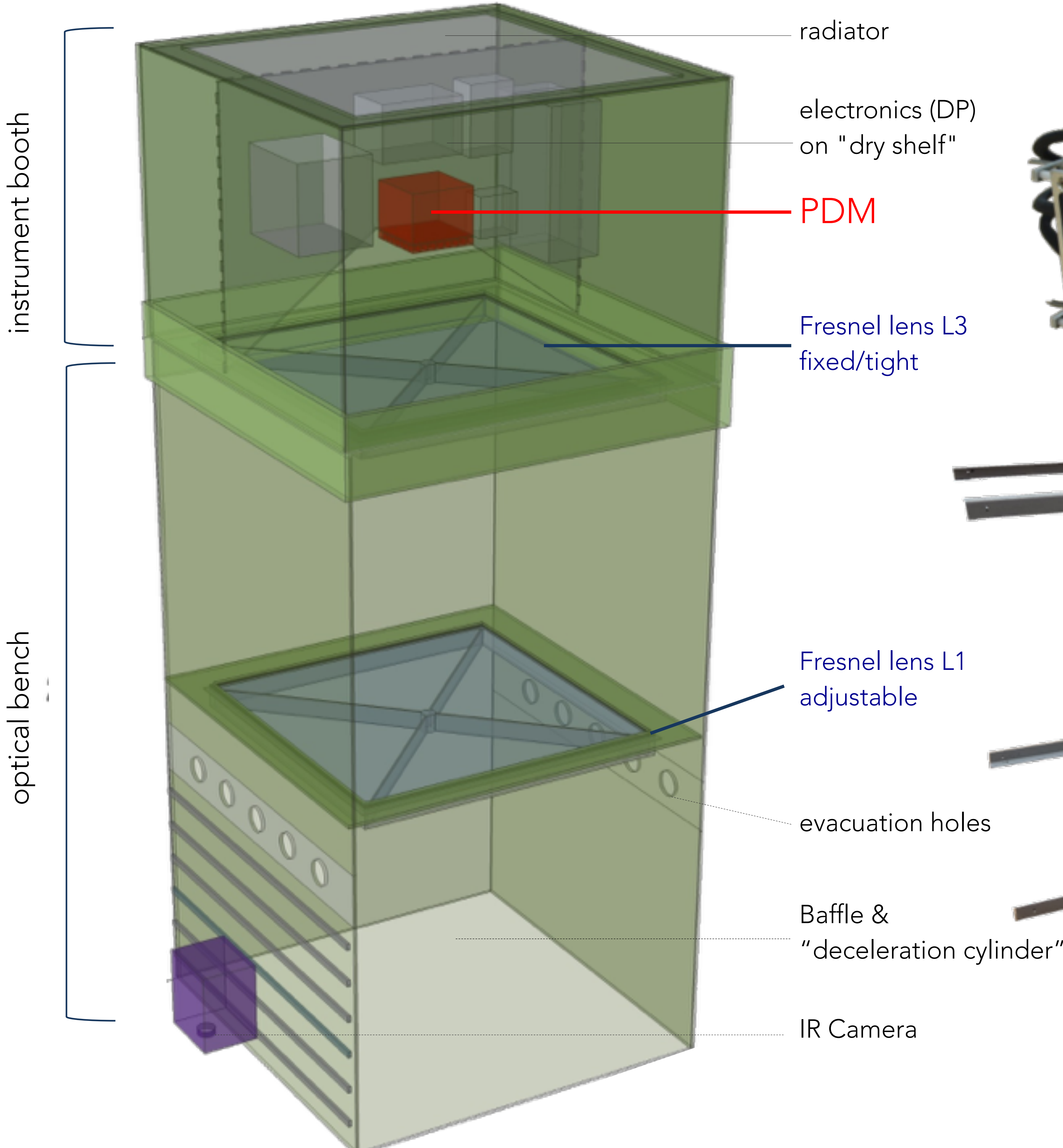


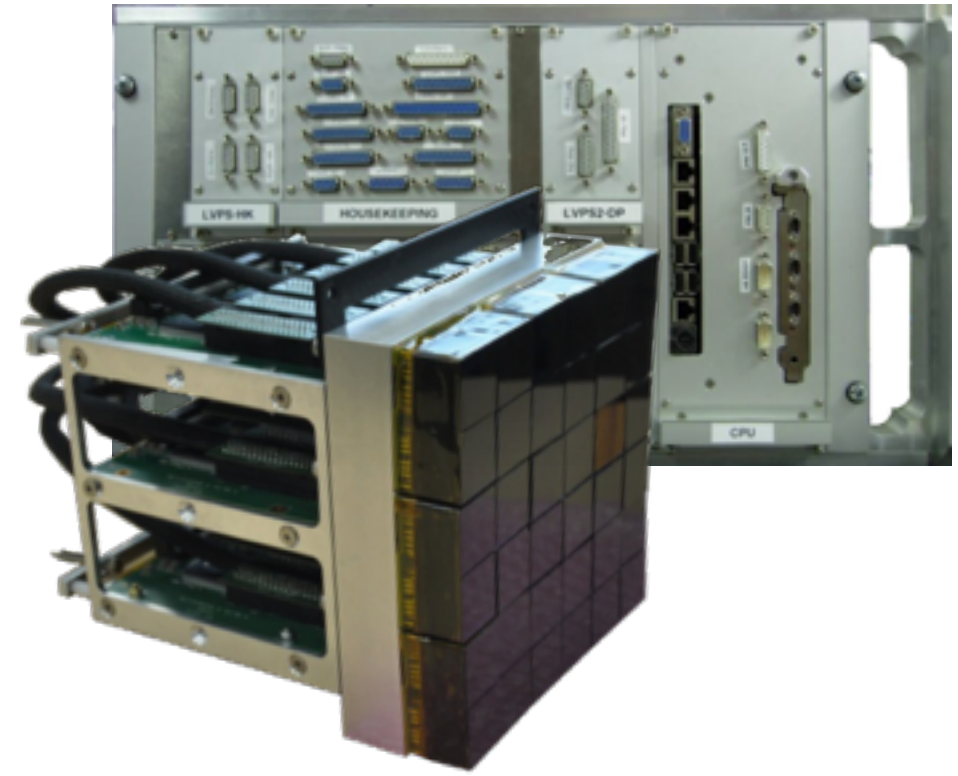
1st flight, Aug 2014
Timmins (CA)

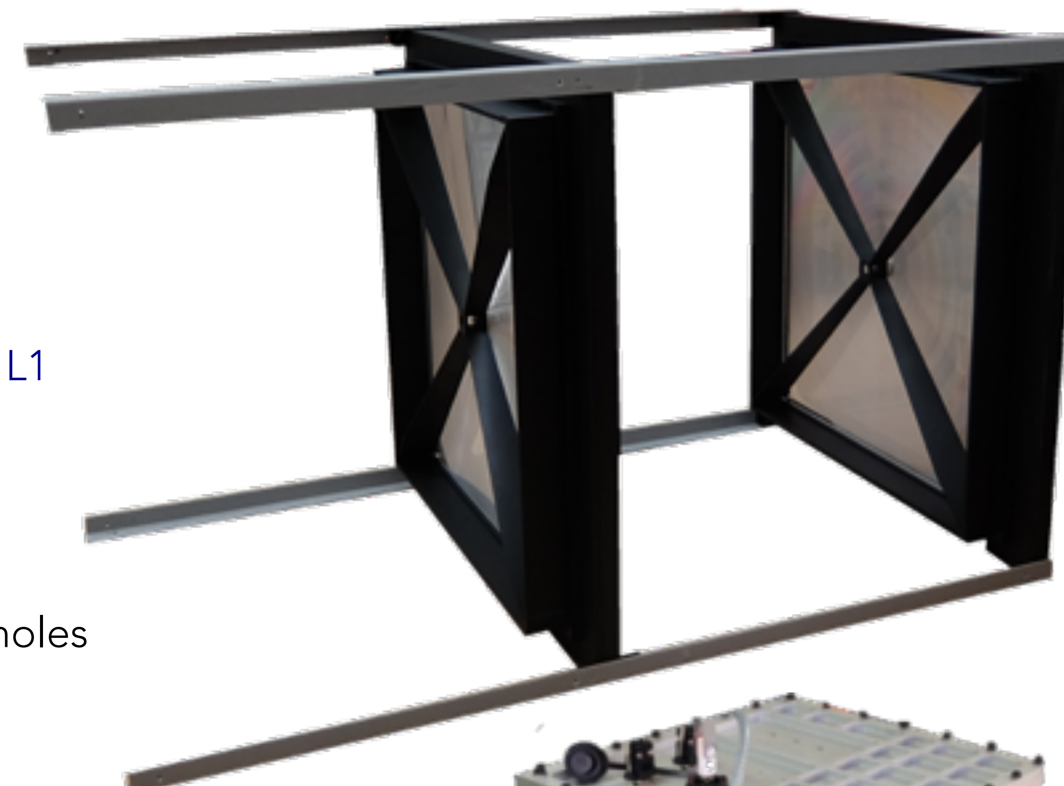
Flight Performance

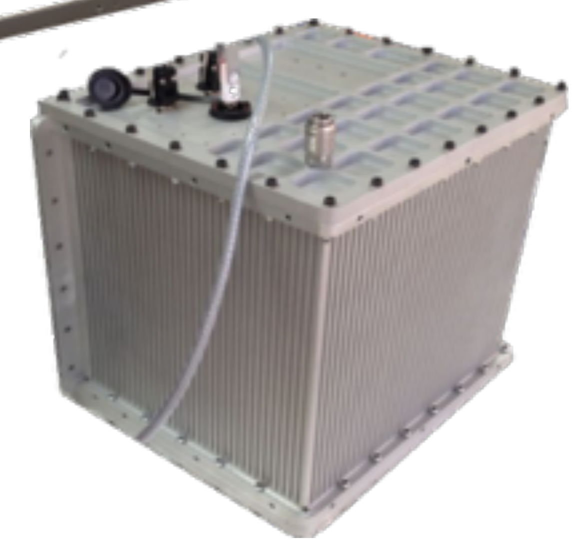
flight: 18900 s @ float
data: 256,000 events
equivalent to 80 s
integrated time

Payload built by JEM-EUSO collaboration
CNES (French Space Agency) mission

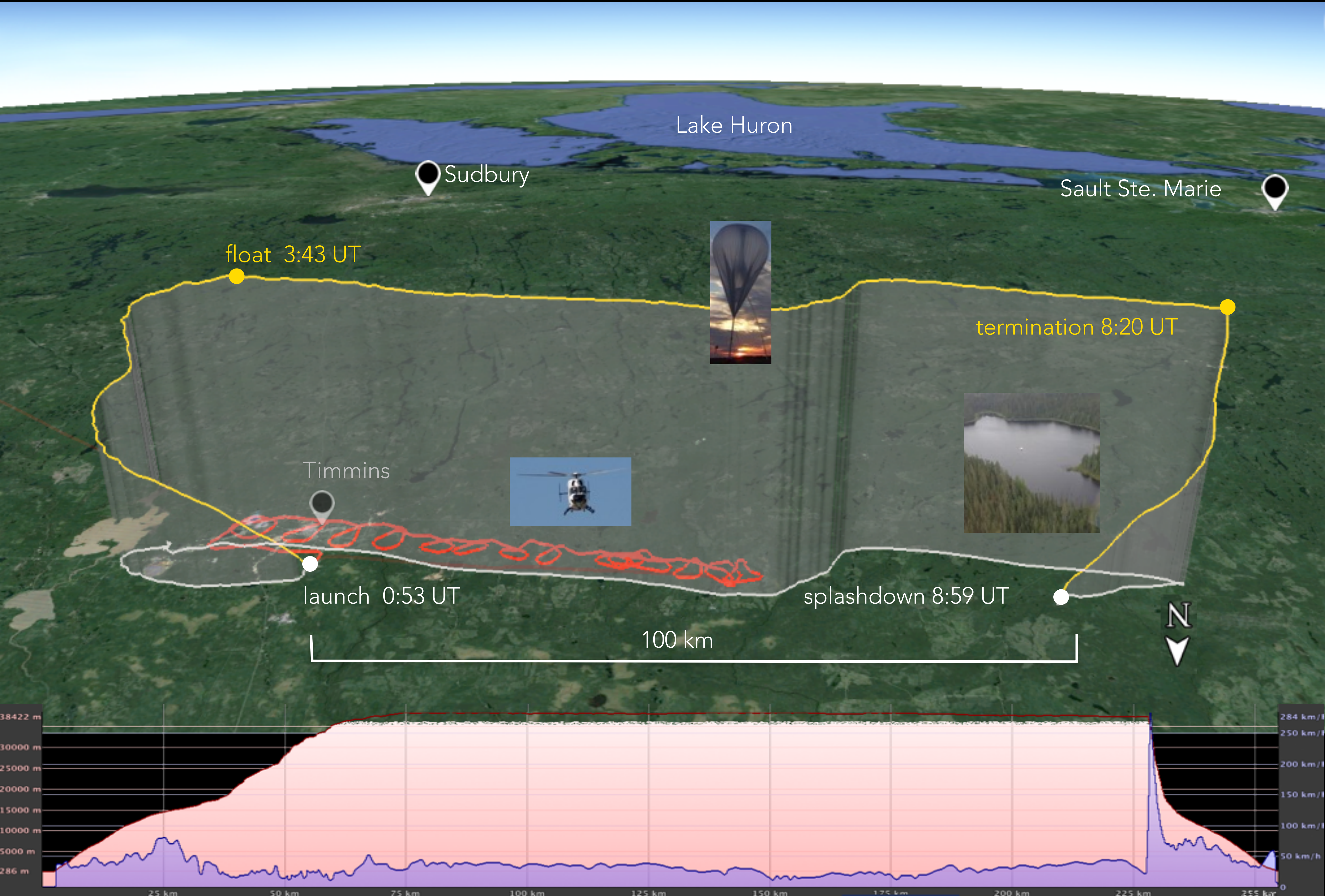

instrument booth
optical bench
radiator
electronics (DP)
on "dry shelf"
PDM
Fresnel lens L3
fixed/tight
Fresnel lens L1
adjustable
evacuation holes
Baffle &
"deceleration cylinder"
IR Camera

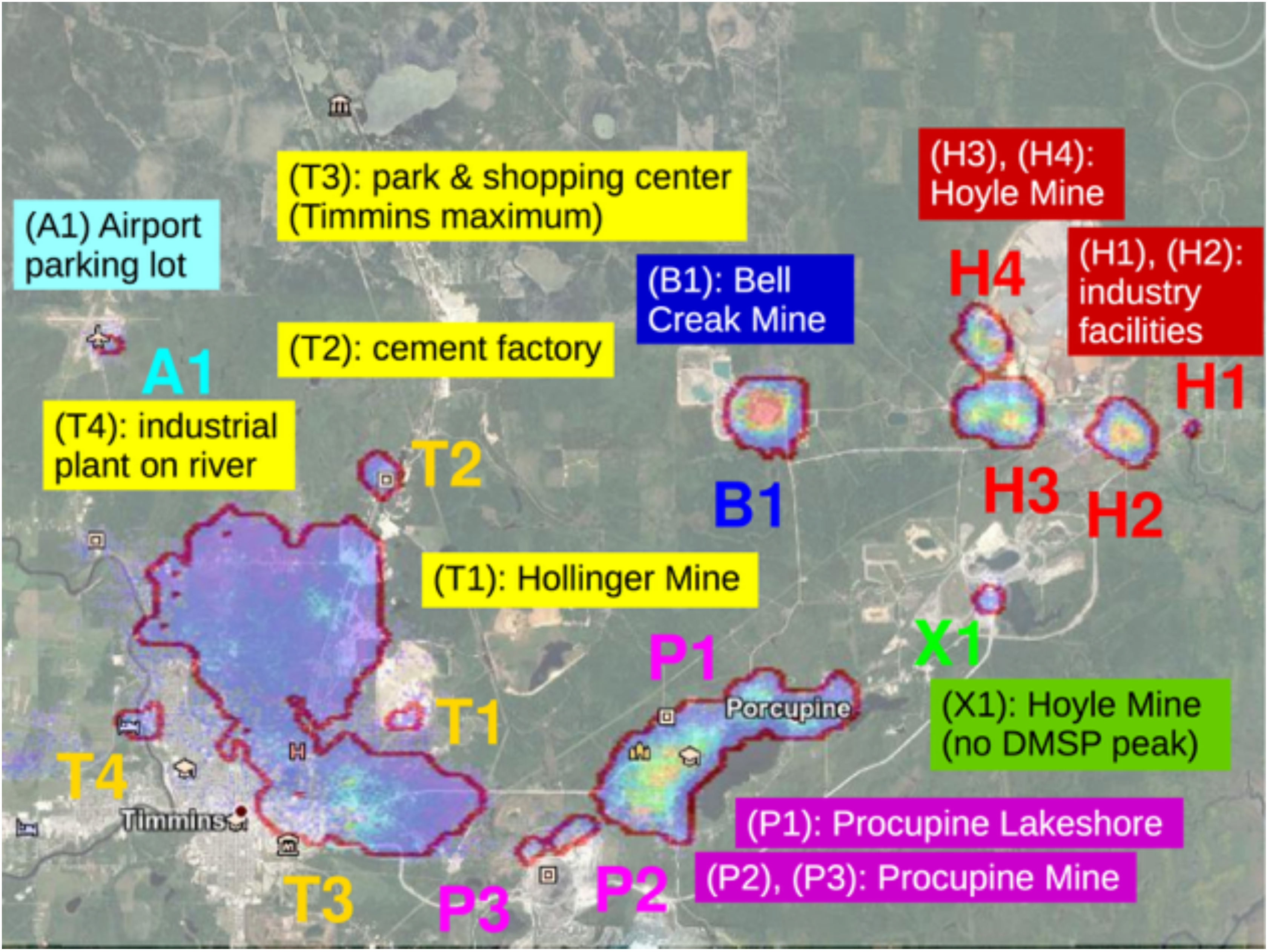






the balloon track and helicopter path

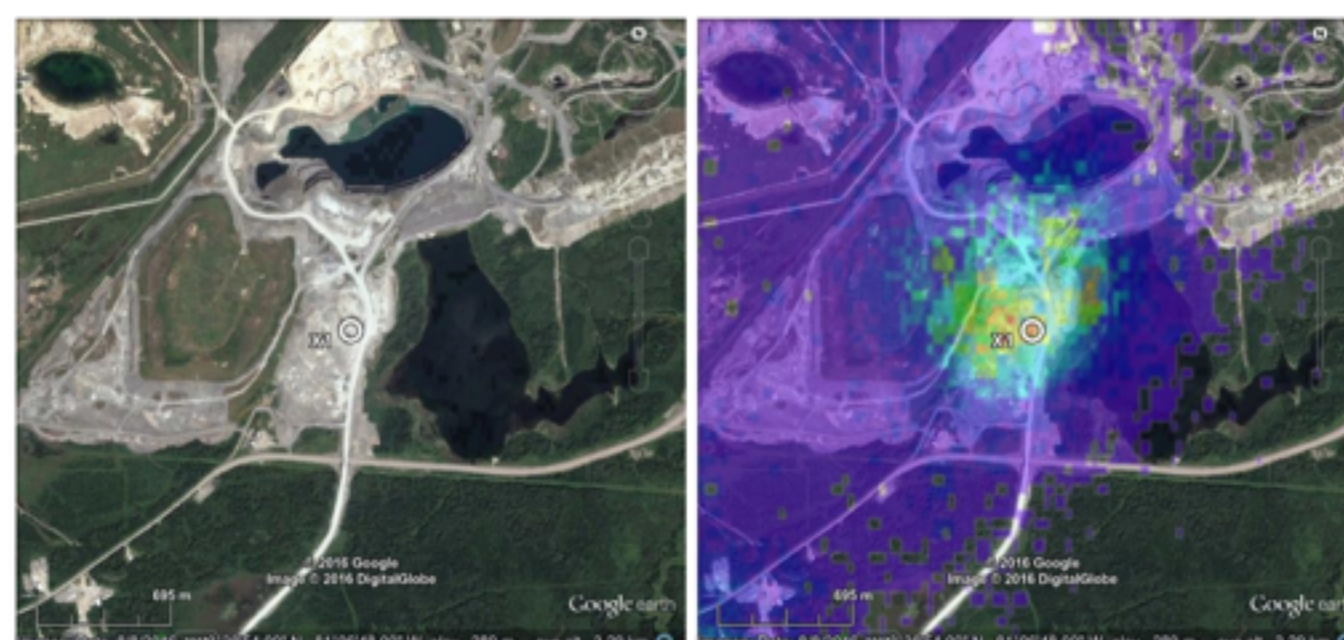




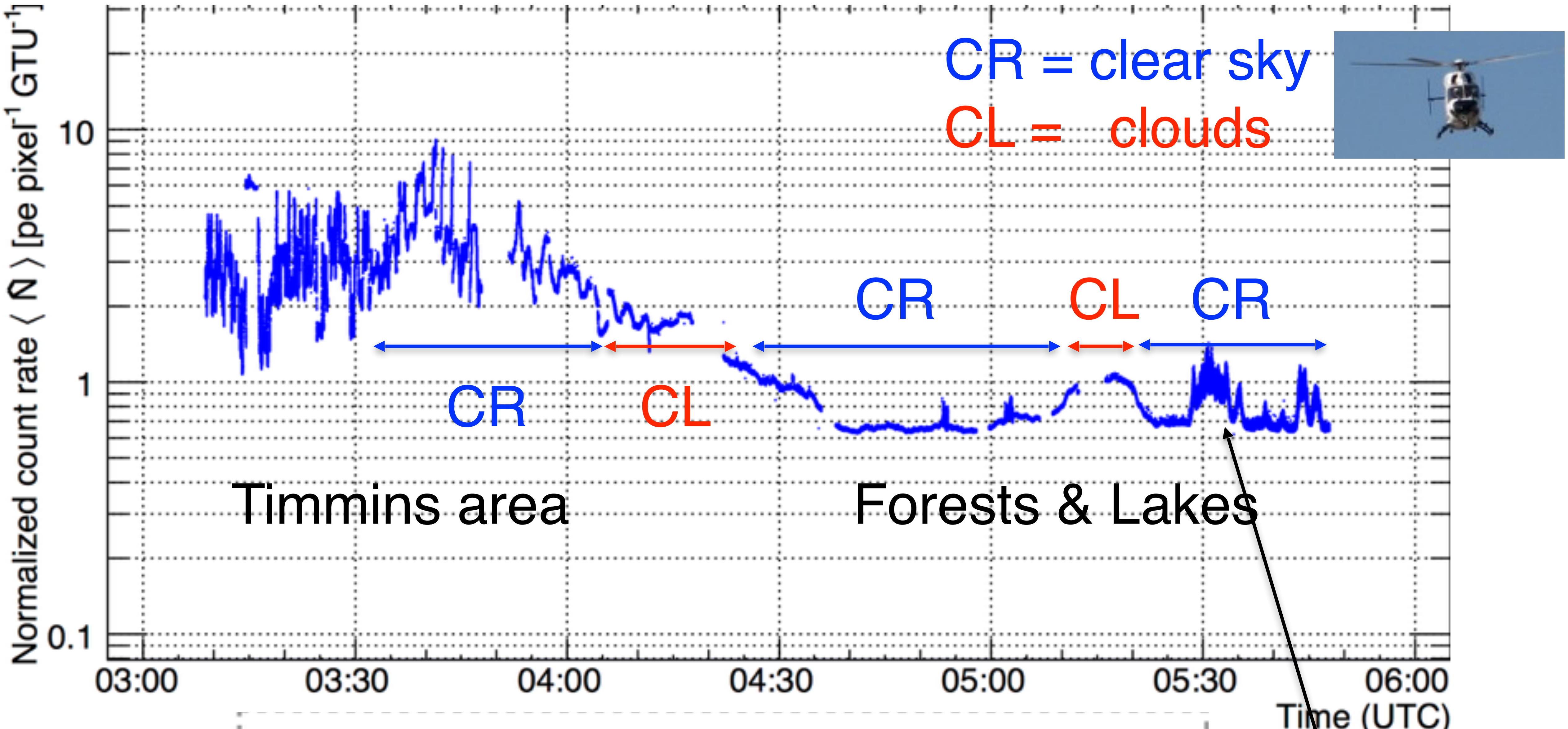
Very good matching with satellite images

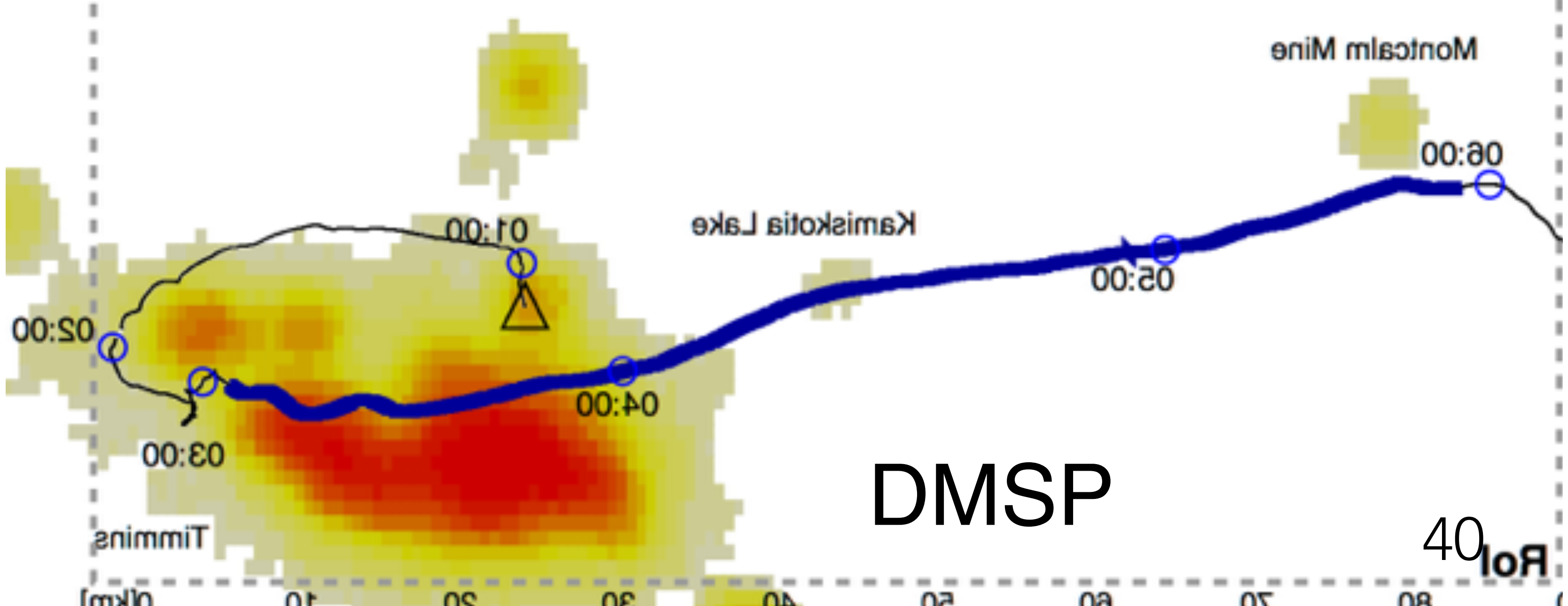
Recognition of hotspots not detected by DMSP satellite

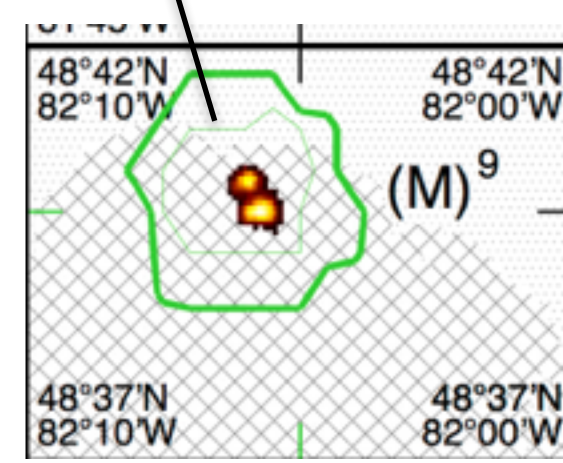
Hotspot (X1): Mining ground



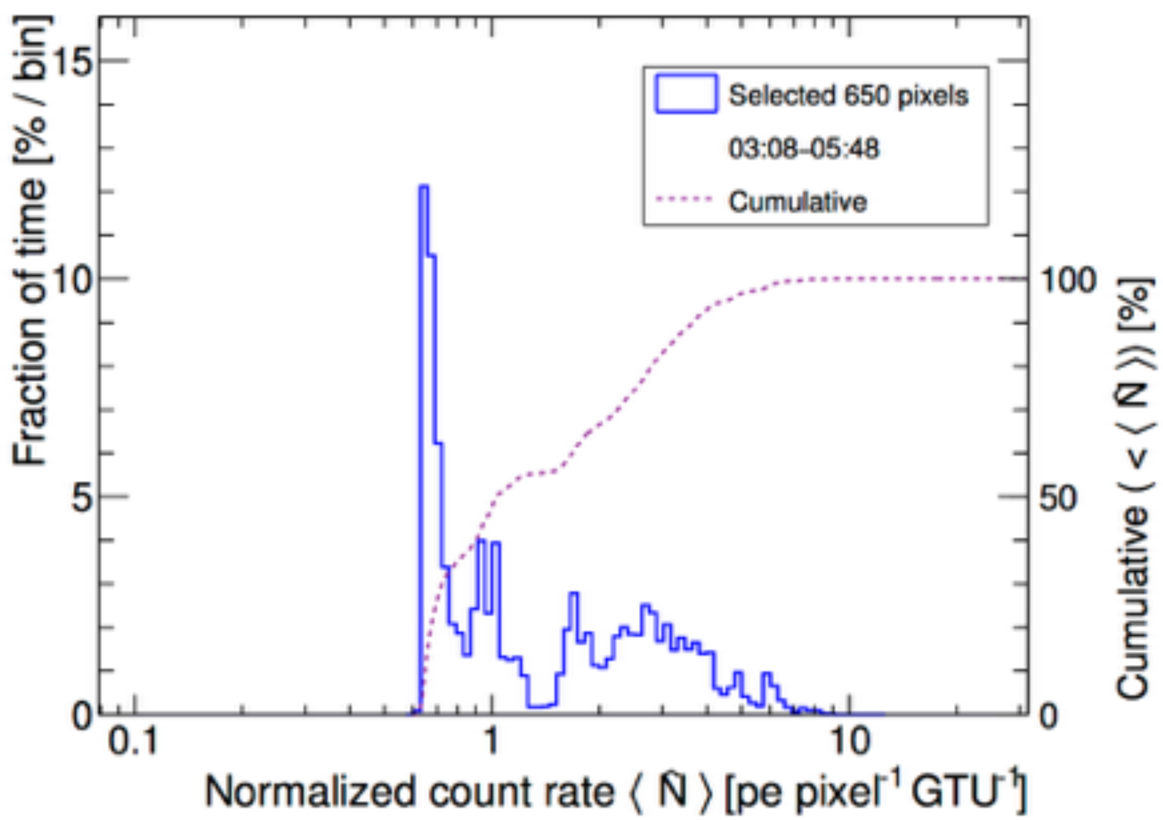
Average pixel count rate during flight







Implications for UHECR observation



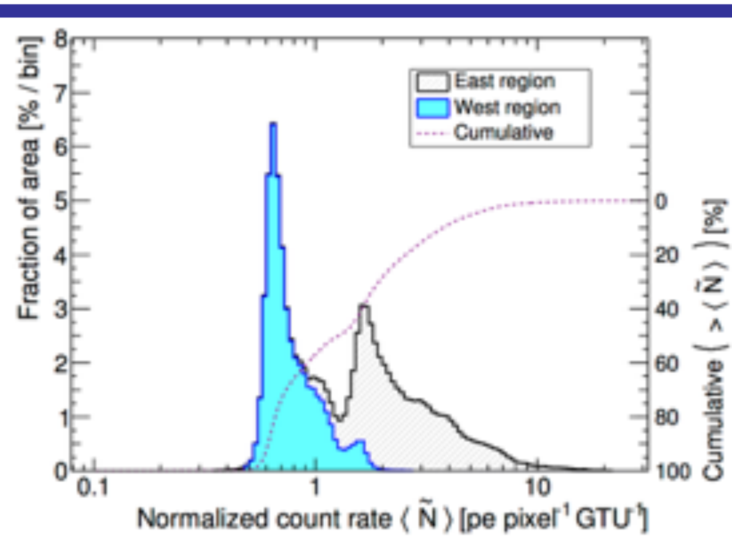
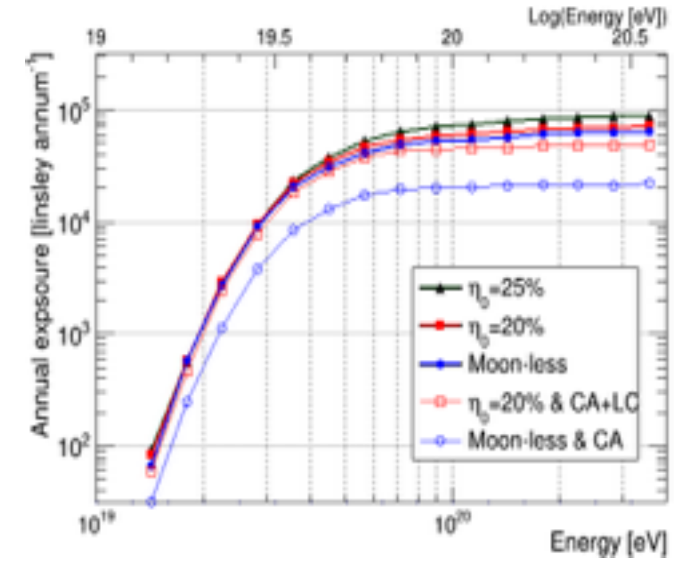


Figure 11: Areal $\langle \tilde{N} \rangle$ distribution in terms of the grid points with respect to the total $K = 3.79 \times 10^5$. The contributions from the east and west halves whose areas are even are displayed by the hashed and filled histograms, respectively. The cumulative fraction above the given $\langle \tilde{N} \rangle$ value is given by the dashed curve to the scale on the right.

JEM-EUSO exposure



$$A(E_0) \equiv \int_0^{T_0} \dot{A}\left(E_0, \bar{N}(T)\right) dT$$
$$= \int_0^{\bar{N}_{\rm lim}} \left[\dot{A}_0\left(\sqrt{\frac{N_0}{\bar{N}}} \cdot E_0\right) \cdot \left(\frac{\Delta T}{\Delta \bar{N}}\right)\right] d\bar{N}.$$

A = Exposure
E_0 = energy
N_0 = reference counts in dark condition
N = counts
T = time
T_0 = measurement time

Variations in exposure due to light variation can be calculated directly from the data

K. Shinozaki et al.: ID 074

EUSO-SPB Airglow - Starlight models:

I_0 = 300 - 320 photons m^{-2} sr^{-1} ns^{-1}
300 - 500 nm band

I_0 = 260 - 170 photons m^{-2} sr^{-1} ns^{-1}
300 - 400 nm band

a factor ~ 2 increase with clouds

estimation of uncertainties in progress

BaBy balloon (1998):
I_0 = **400 - 450** photons m^{-2} sr^{-1} ns^{-1} - (300 - 500) nm band

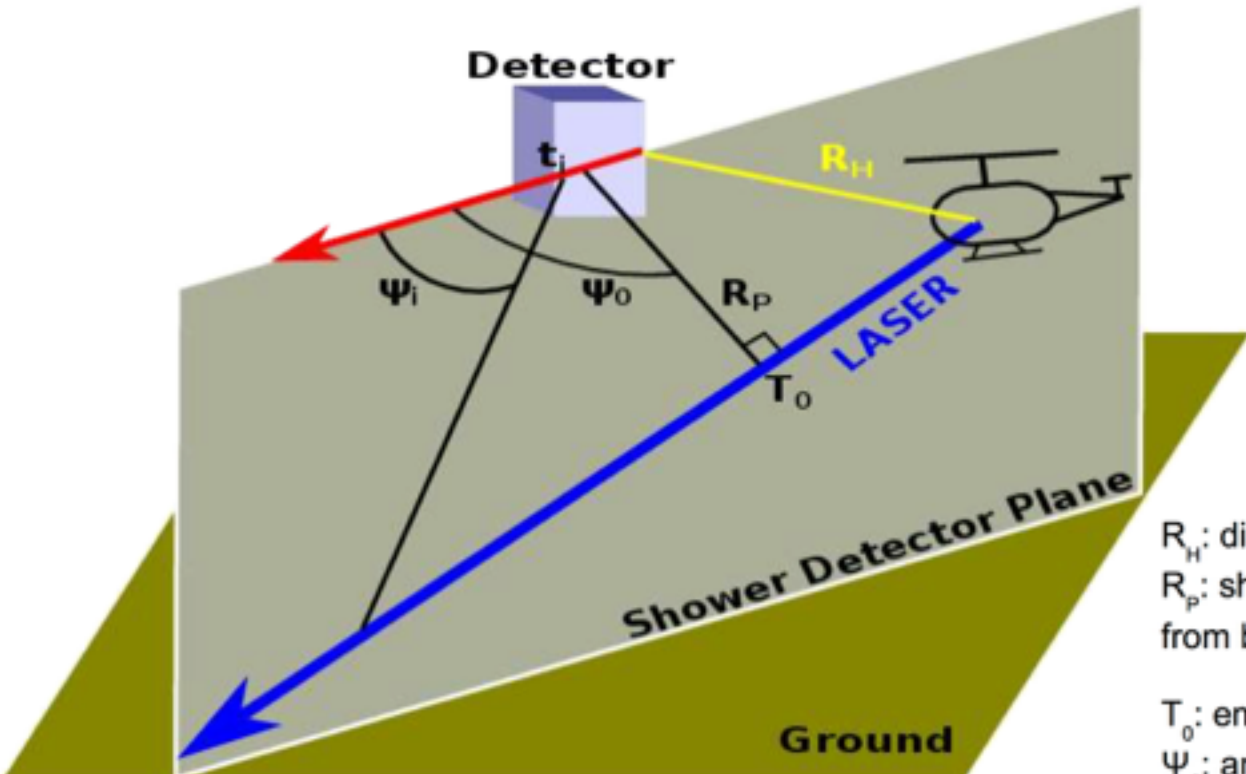
BaBy balloon (2002):
I_0 = **310** photons m^{-2} sr^{-1} ns^{-1} - (300 - 400) nm band

NIGHTGLOW balloon (2000):
I_0 = **300** photons m^{-2} sr^{-1} ns^{-1} - (300 - 400) nm band

Xe flasher and Laser events from NASA helicopter

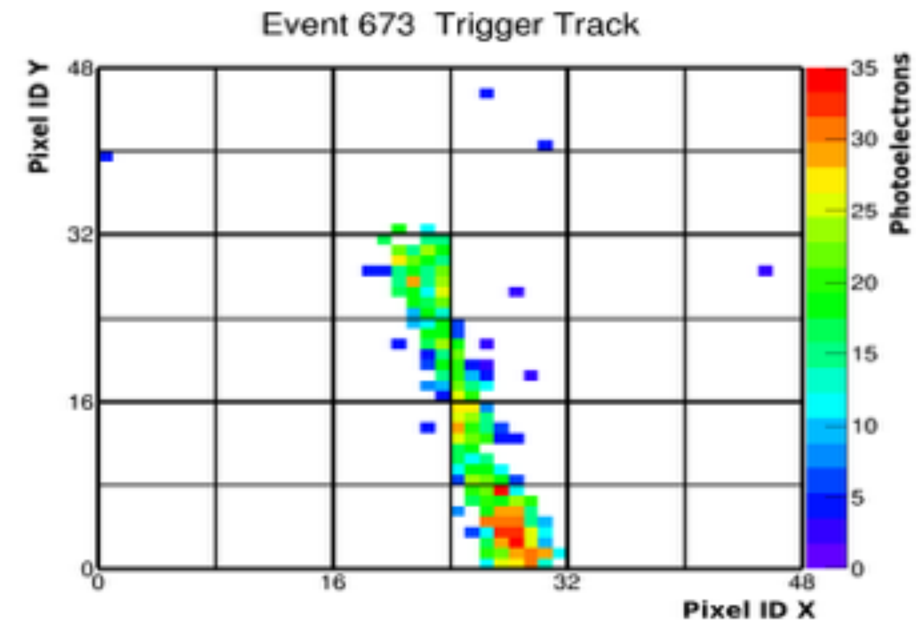
1261] [CRI054] Calibrating and Testing EUSO-SPB in Flight using a Laser and LEDs on an Aircraft

TRACK RECONSTRUCTION

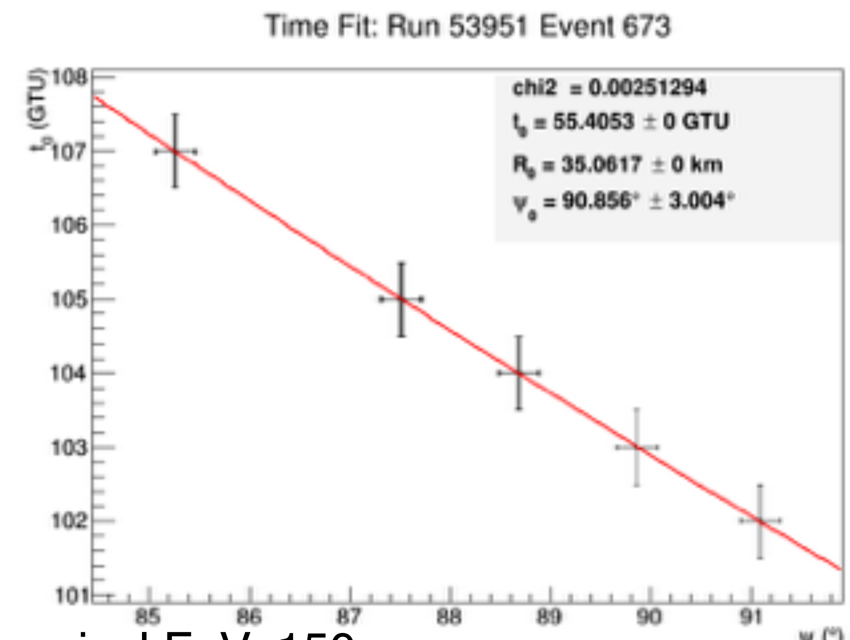


R_H: distance to laser
R_P: shortest distance from beam to detector

T_0: emission time at R_P
Ψ_0: angle to R_P in SDP
Ψ_i: angle in SDP



$$t_{i,\exp} = T_0 + \frac{R_p}{c}\tan\left(\frac{\pi}{4} - \frac{\Psi_i - \Psi_0}{2}\right)$$

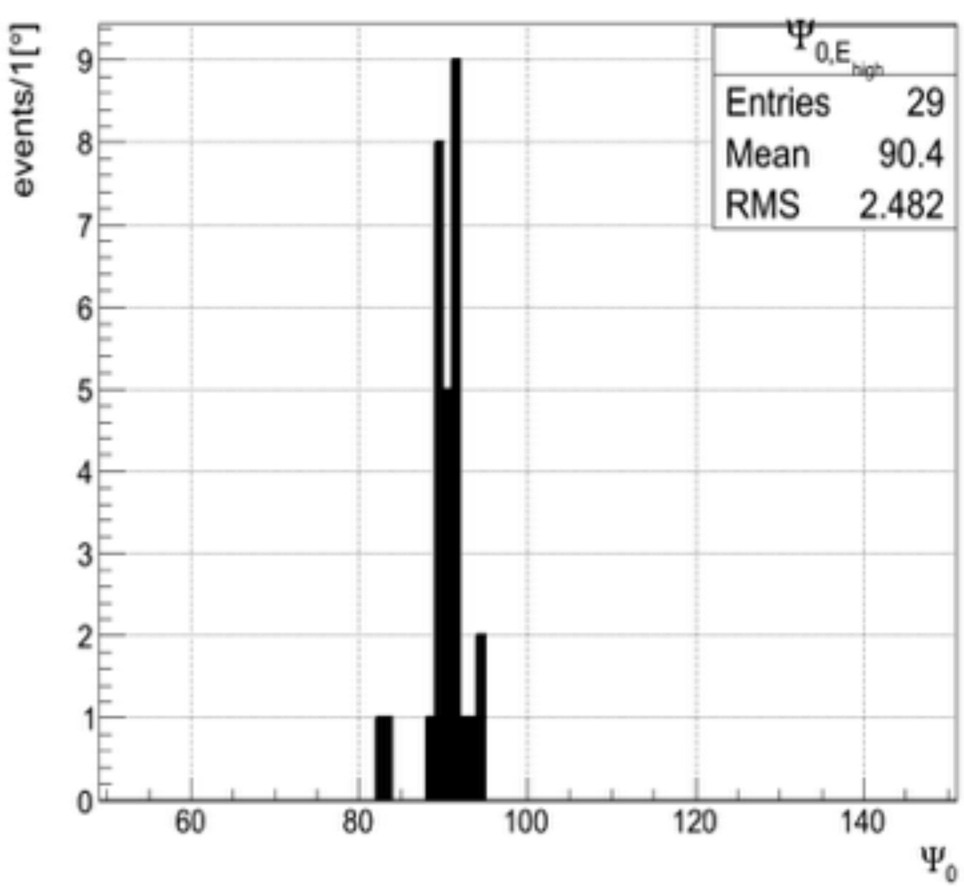


pixel FoV: 150 m
path crossed by light in 1 gtu = 750 m

2-parameters fit

<u>QUALITY CUTS:</u>

- $\chi^2 \leq 6$
- Track $\geq$ 6 GTU
- 1 Energy



<Ψ> = 90.4° ± 2.5°

RIGHT VALUE for Ψ: resolution improves to ~1° increasing track length (but low statistics).

EUSO-SPB1 flight, March 2017
Wanaka, New Zealand

NASA Mission. 2nd
Payload built by JEM-EUSO collaboration
New lenses, Focal Surface,
Improved Electronics

In principle up to 100 days flight!!!

Objective: First UV UHECR shower observation from above

EUSO-SPB1 flew as a mission of opportunity on 3rd NASA super pressure balloon test flight April 25- May 6th 2017

12 day flight, early termination

Preflight Ground tests of flight instrument in the desert
lasers, LEDs, aircraft, stars, meteorite

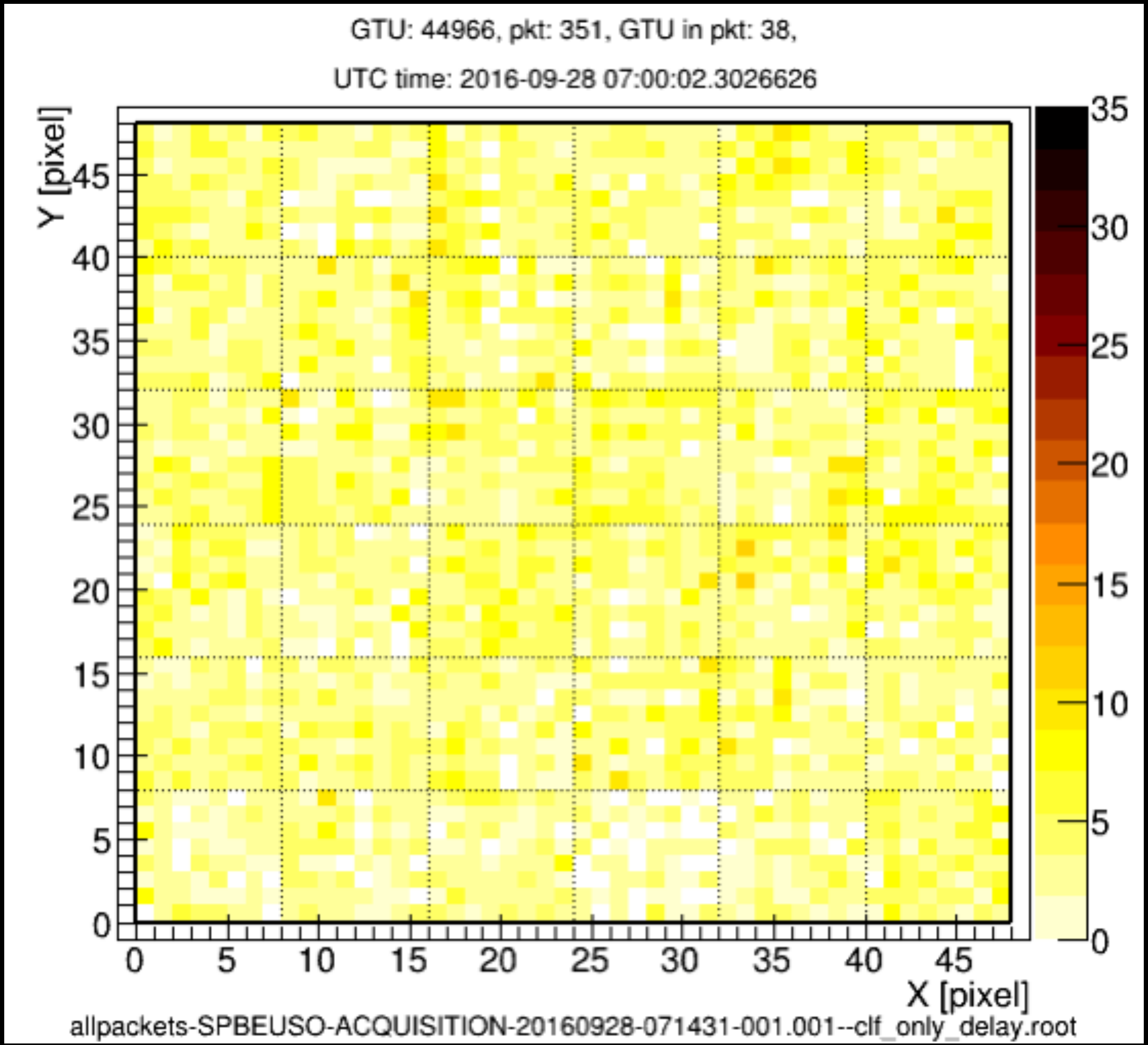
40 hours flight data - dark, moon down (28 hours downloaded)

Analysis of flight data is ongoing

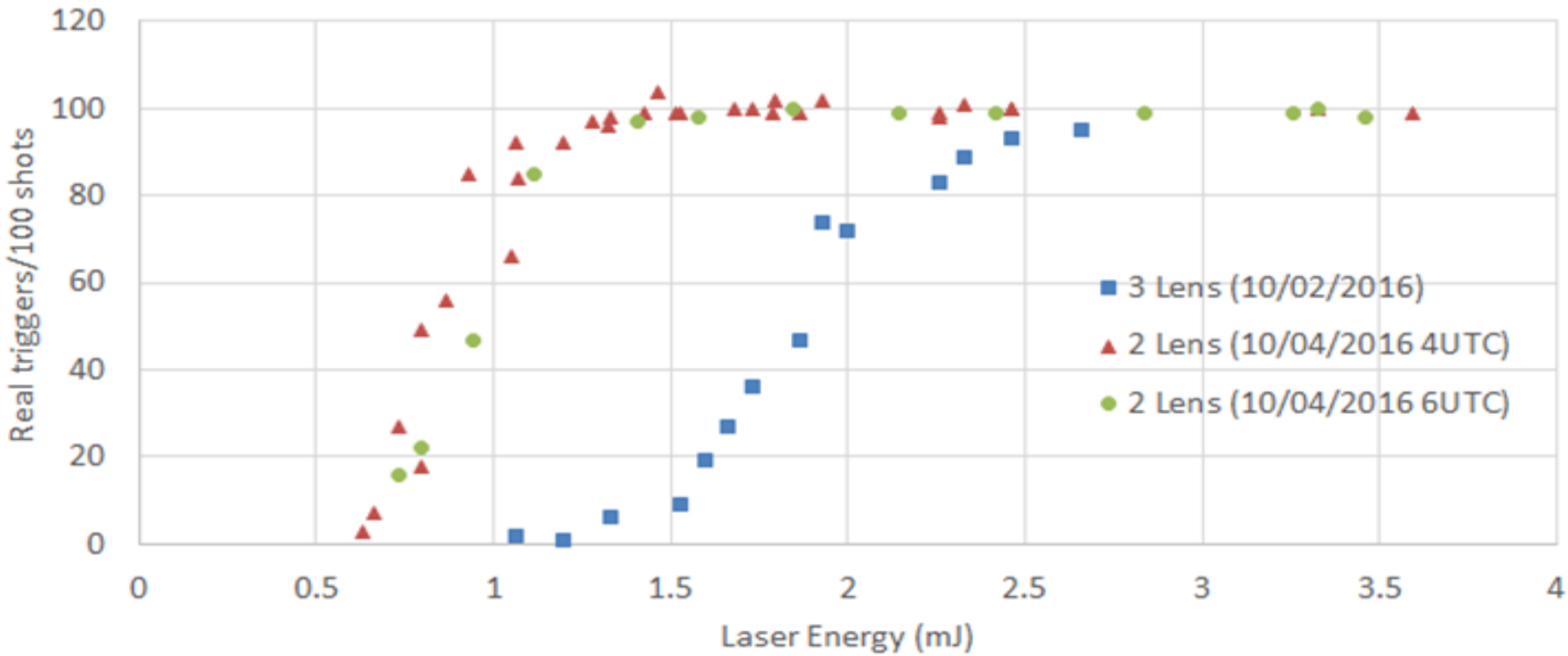
Tests in September 2016
Black rock mesa, Utah

Photo by Malek Mustafa

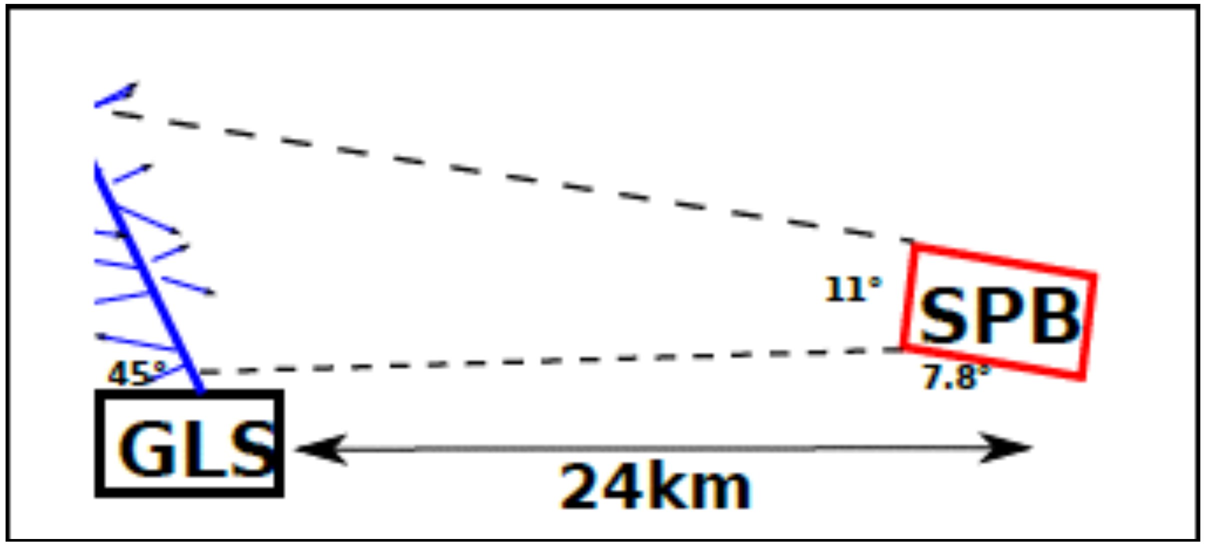
CLF Laser event with SPB



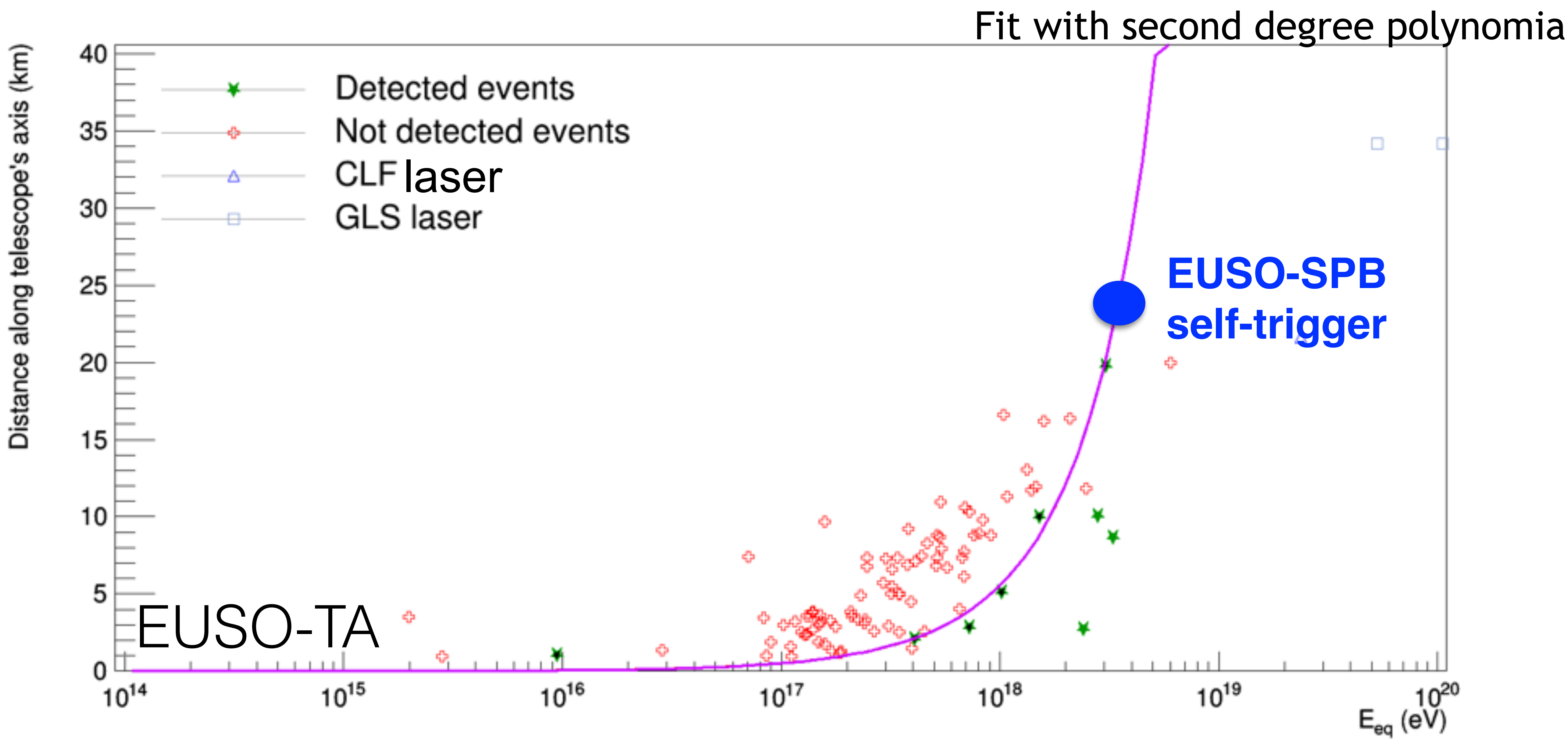
Trigger Threshold Measurement with Laser



Equivalent Energy Trigger Threshold ~ 3×10^{18} eV for EAS as viewed looking down from balloon height.



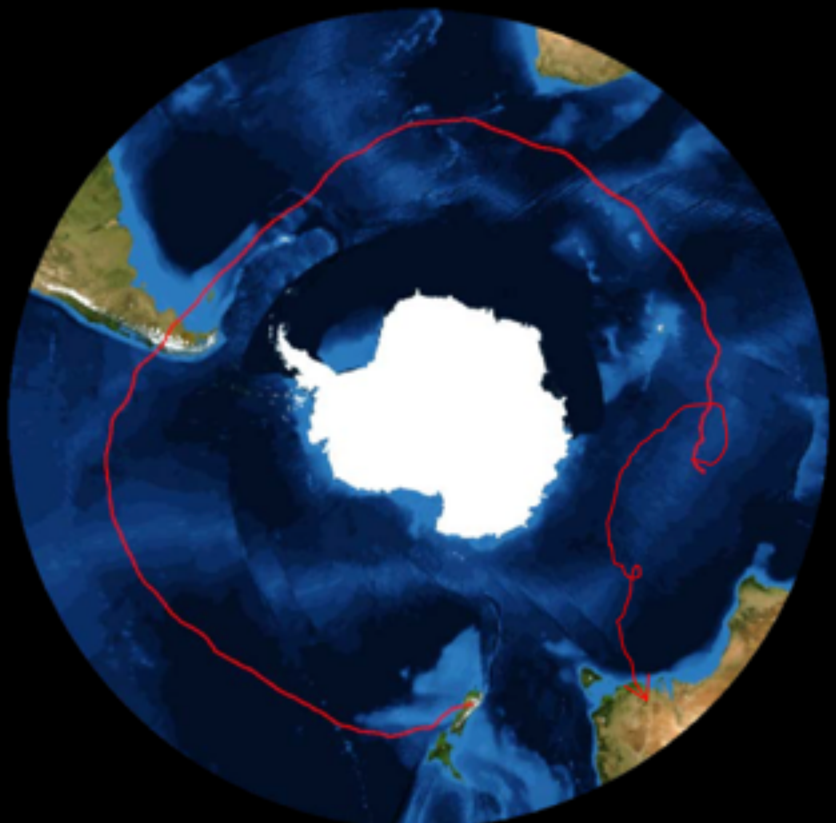
$E_{equivalent}$ – Distance along tel. axis



Launched on 25 April 2017

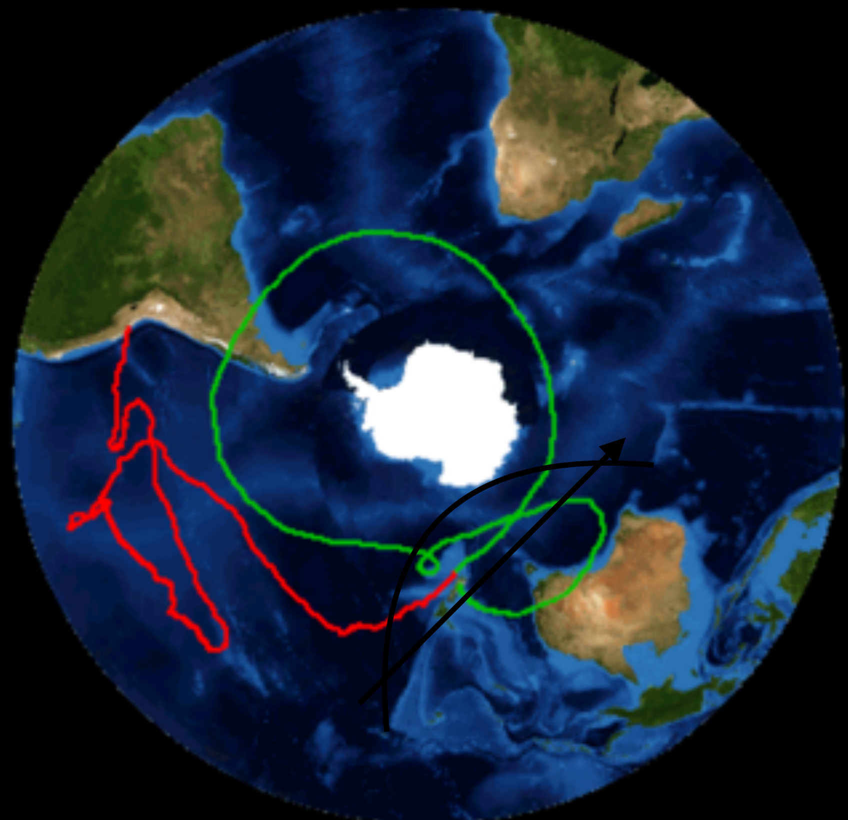
NASA Super Pressure Balloon

2015: 32 d 5 h

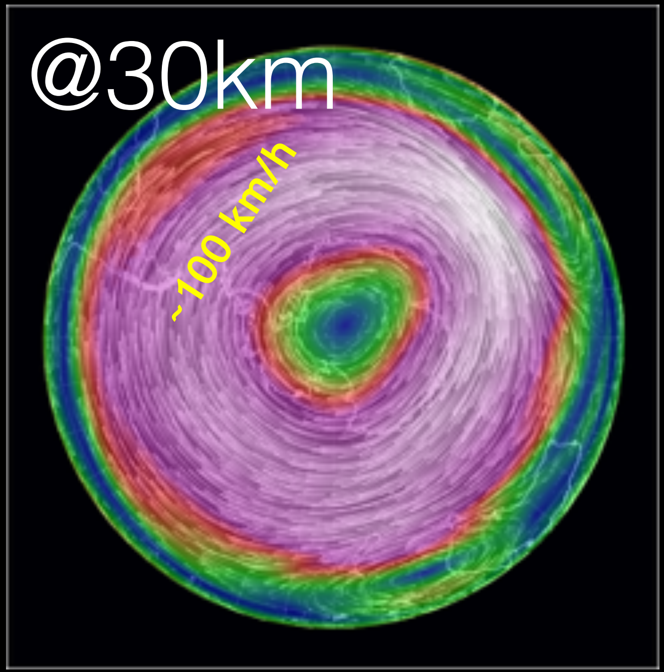


NASA Engineering Flight

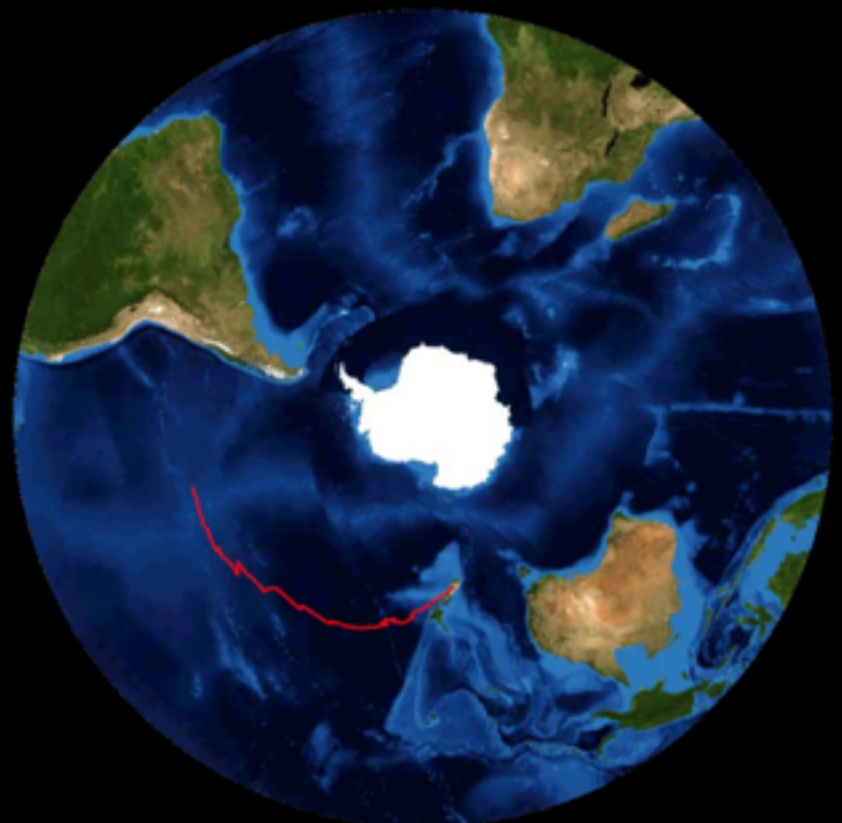
2016: 46 d 20 h



COSI

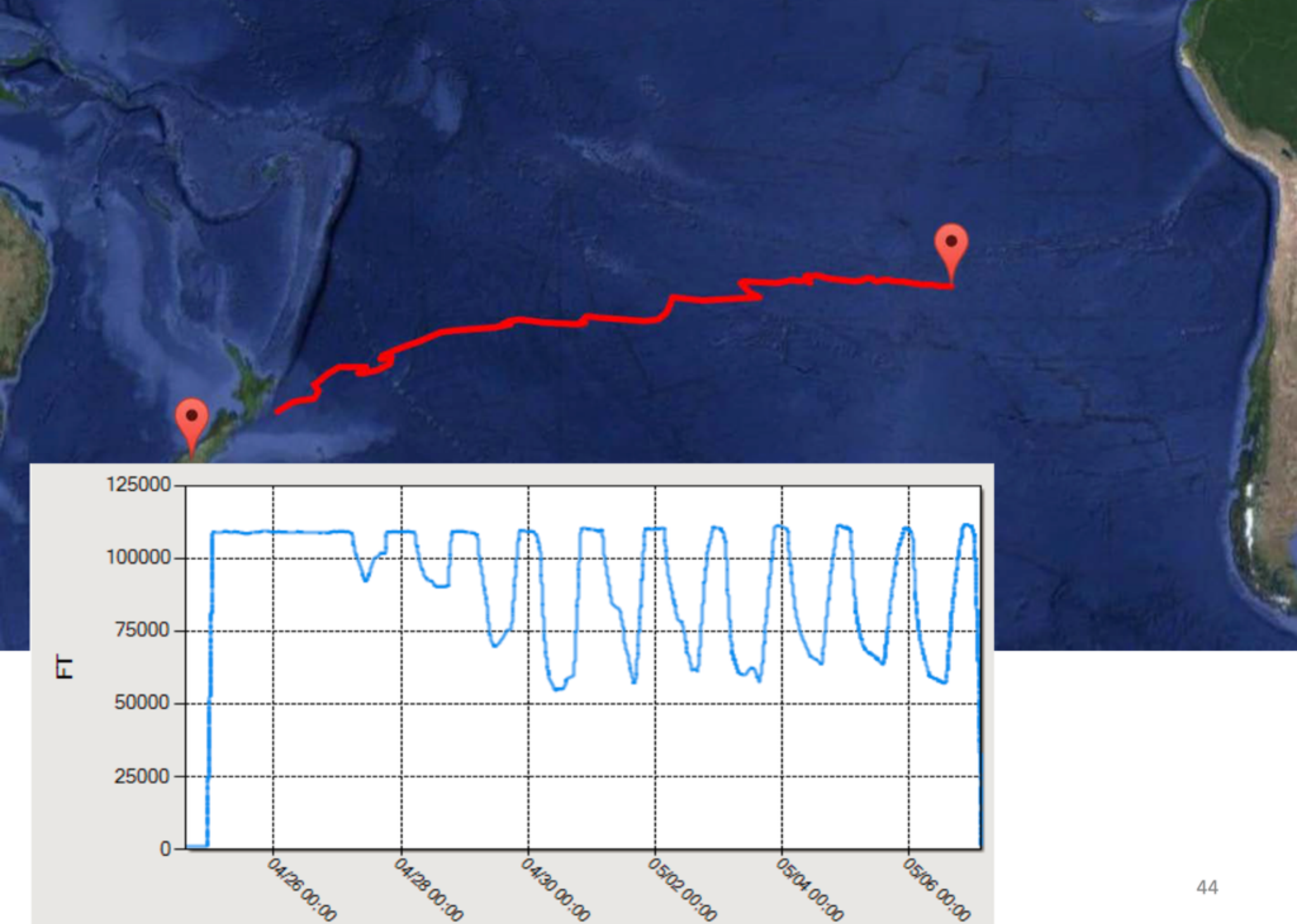


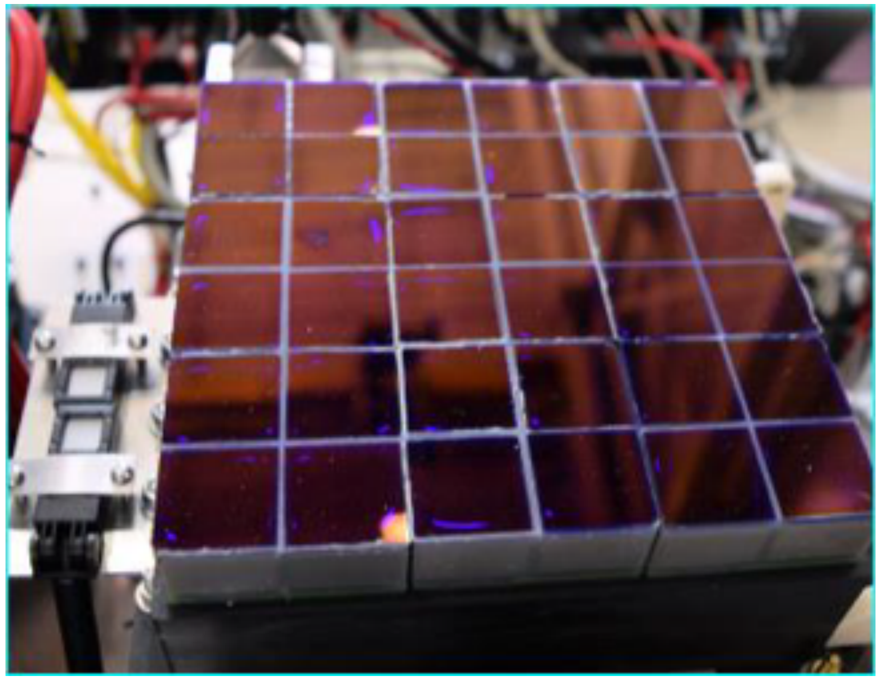
2017: 12 d 4 h



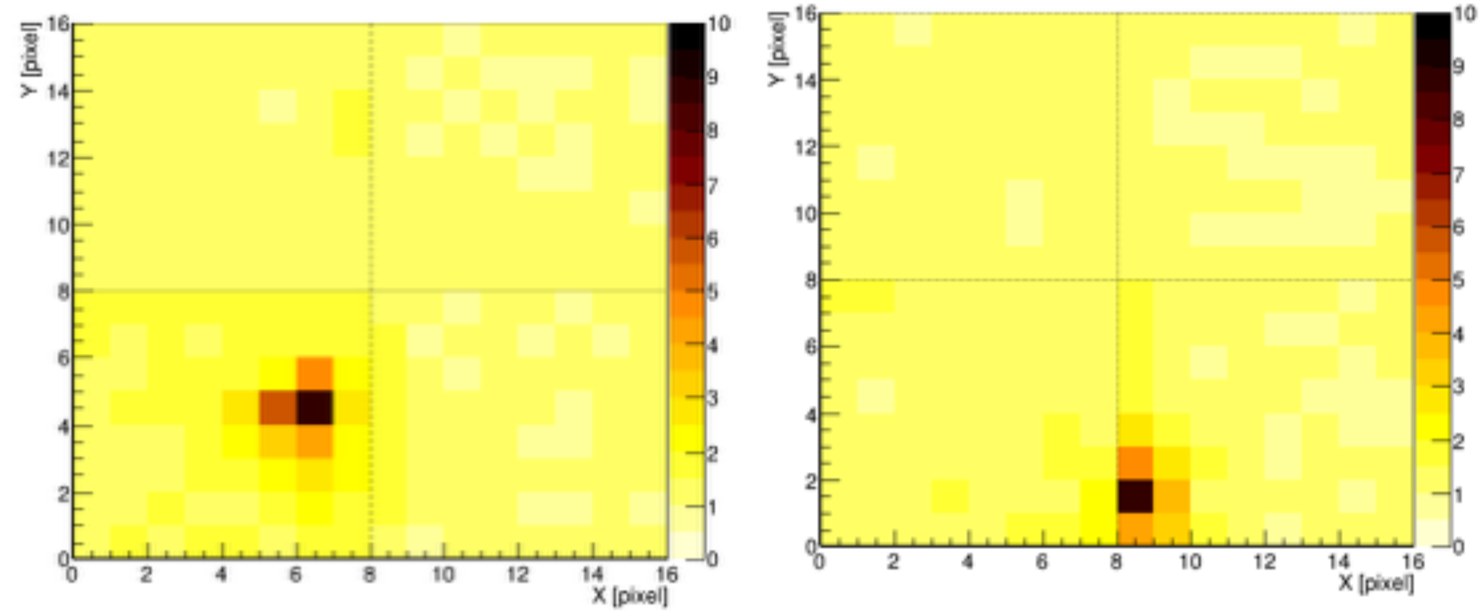
EUSO

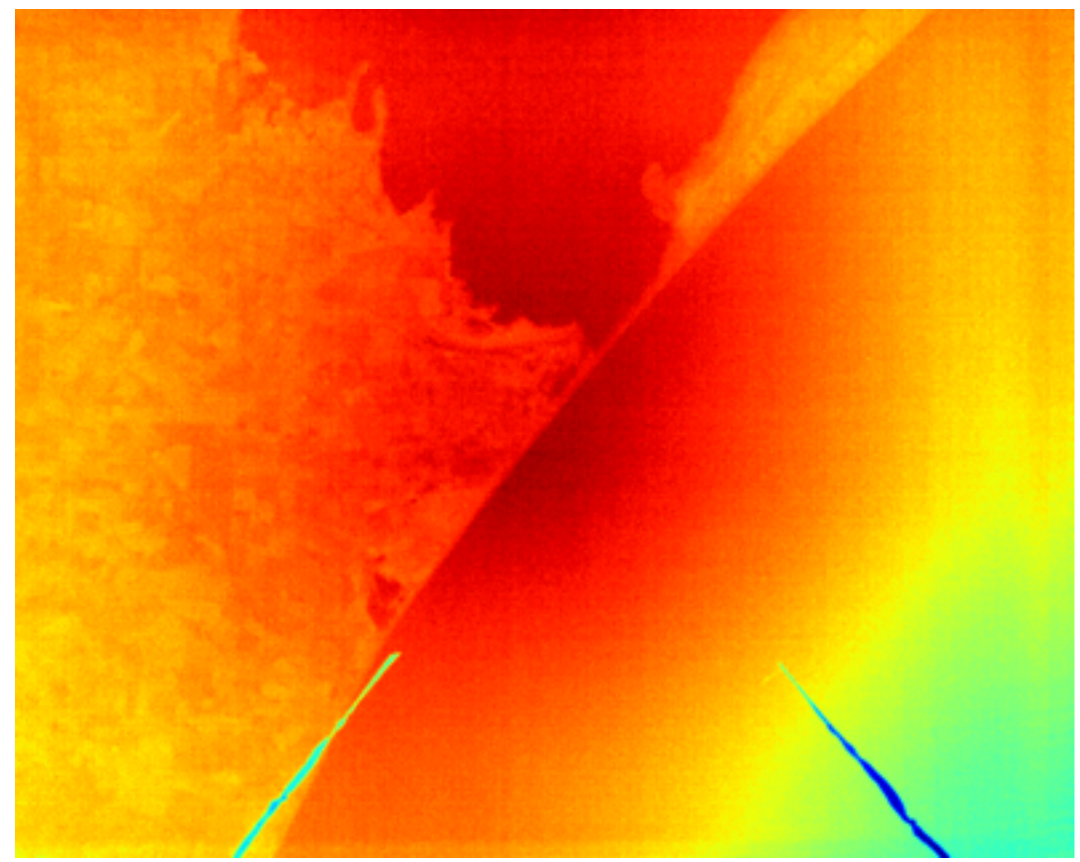
51


125000
100000
75000
50000
25000
0
FT
04/26 00:00
04/28 00:00
04/30 00:00
05/02 00:00
05/04 00:00
05/06 00:00

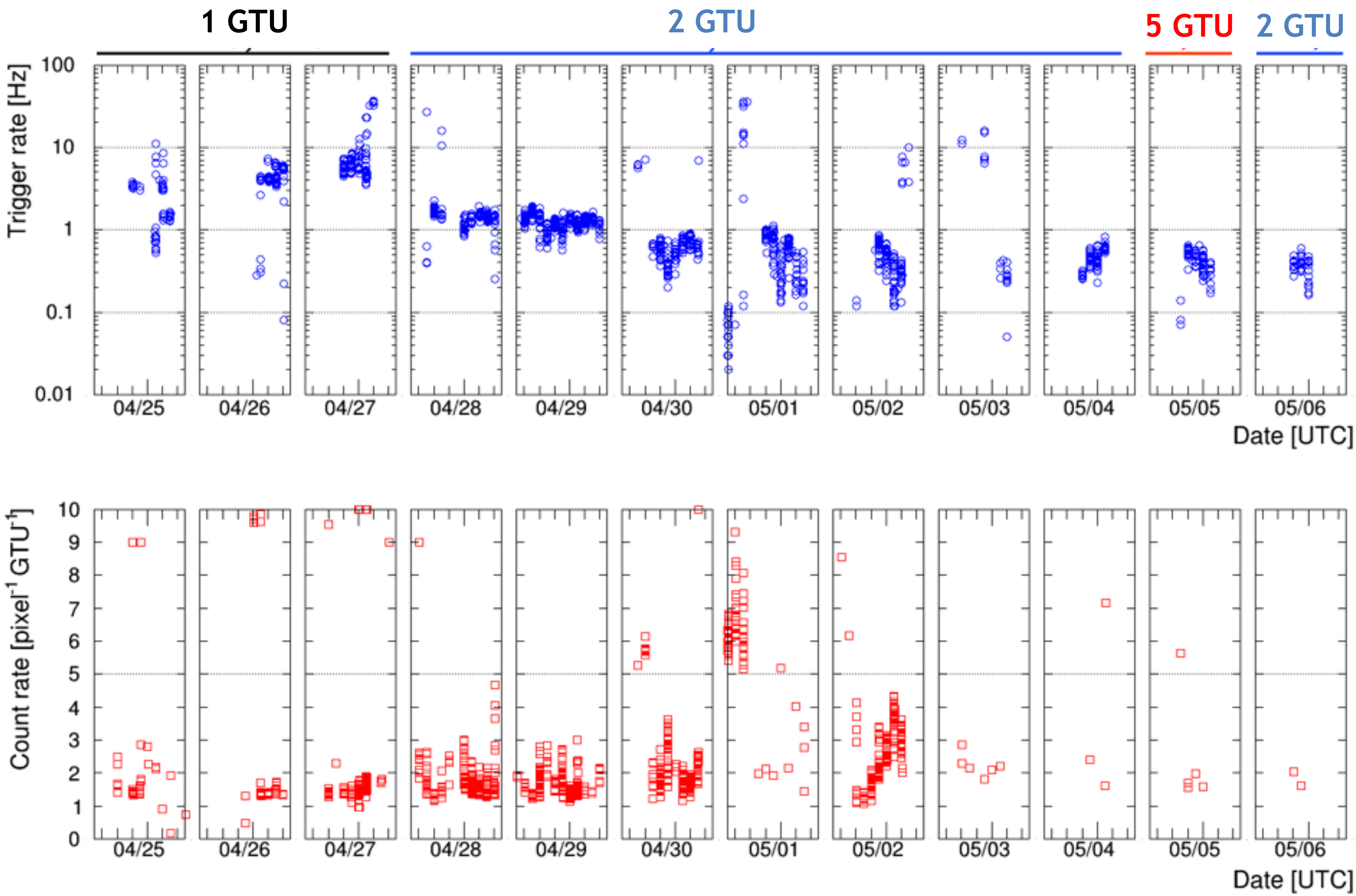


UV Camera: Light Source on Ground



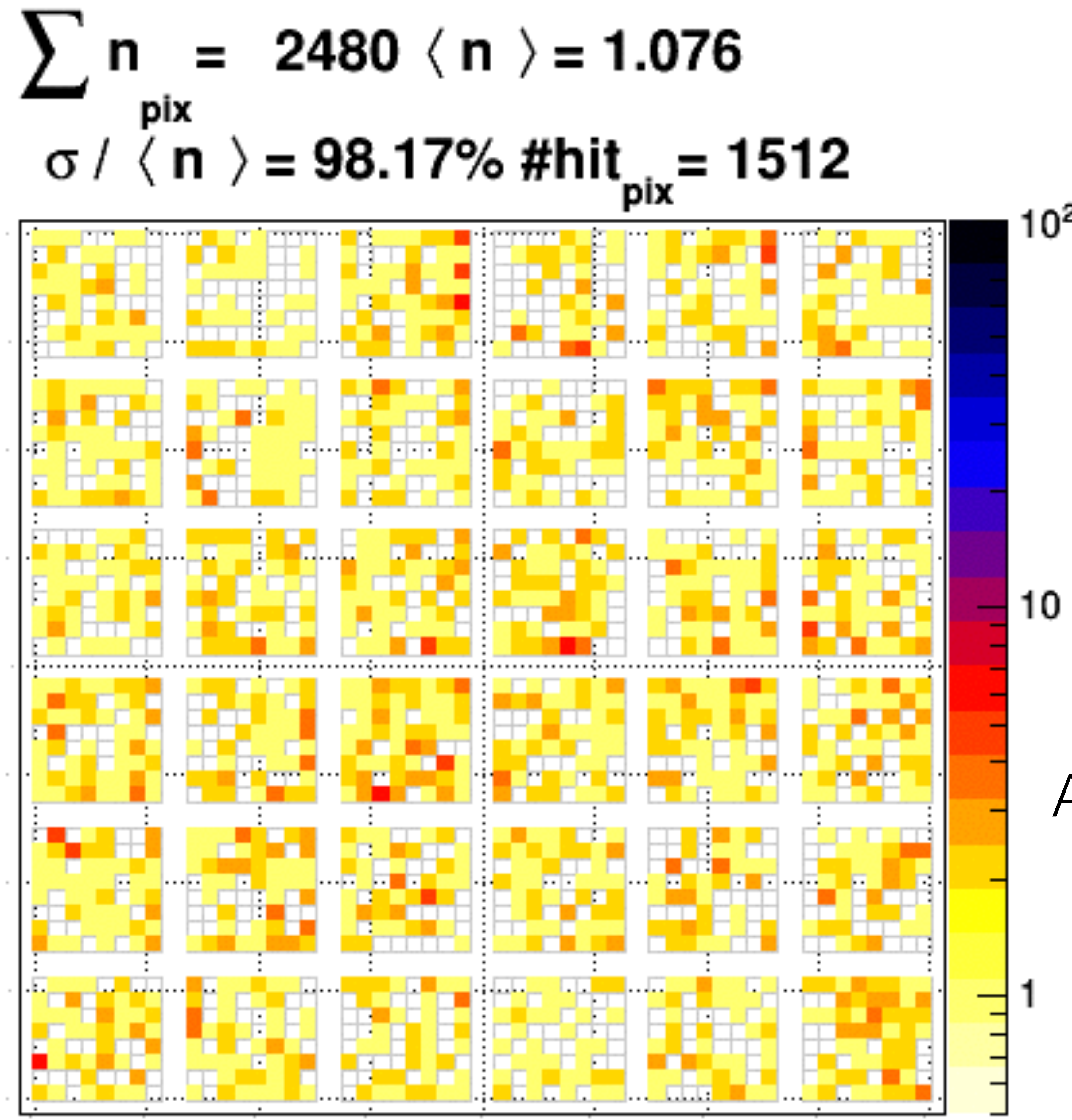


4/25/17 Top Right : A point light on the ground source as seen in the UV camera provides an insitu demonstration that the detector in flight was able to focus a point source. Lower Left: The location of the balloon when the ground source was recorded. Lower Right: The IR camera image from this time shows no cloud below. The shoreline of Lake Ellesmere is clearly visible.



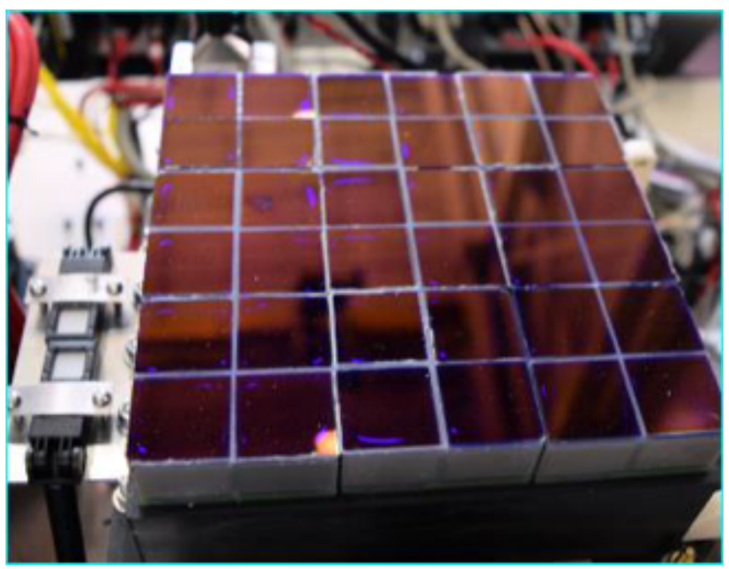
Internal L1 trigger logic tested

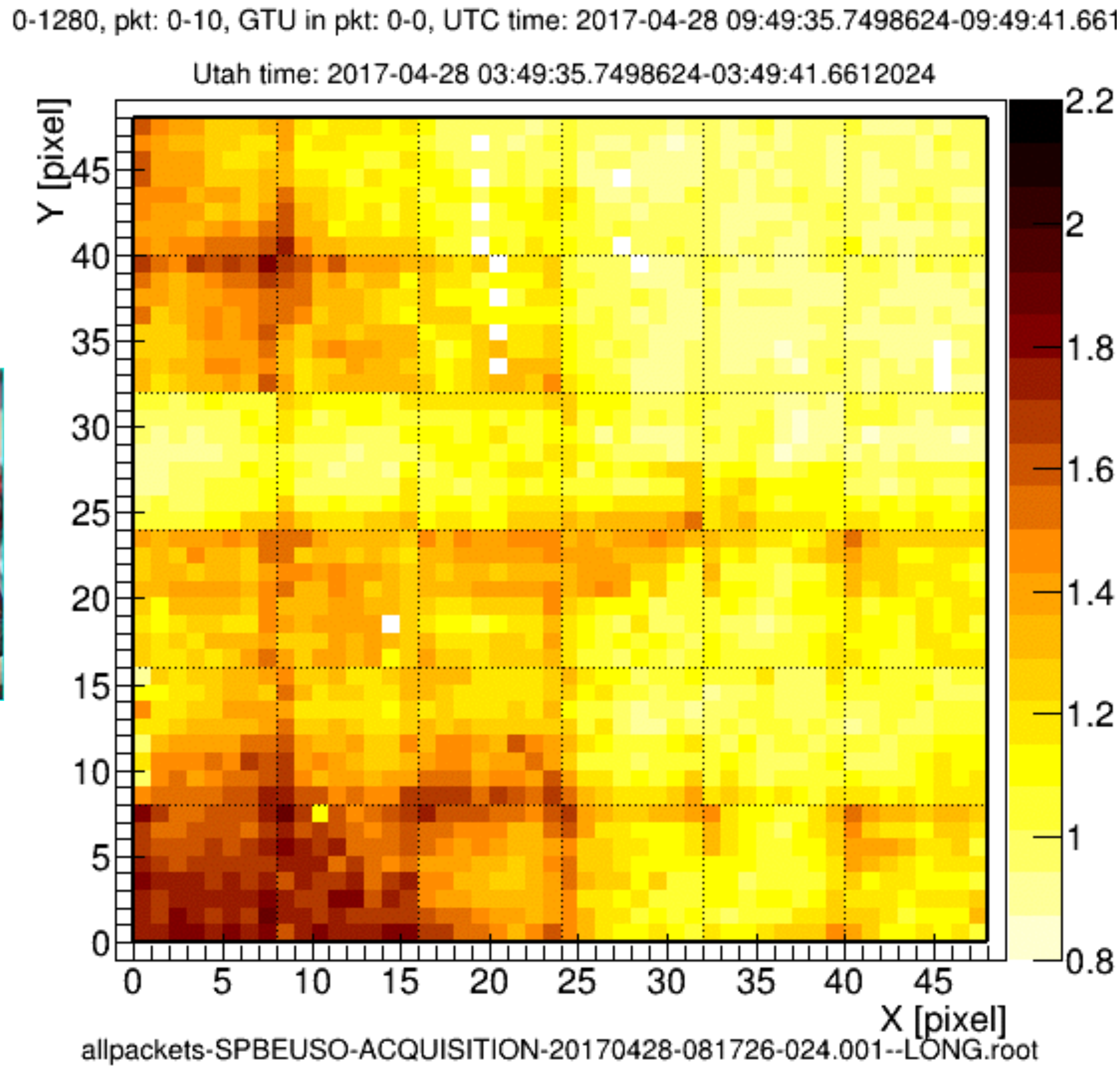
Low Energy Direct CR passing through camera

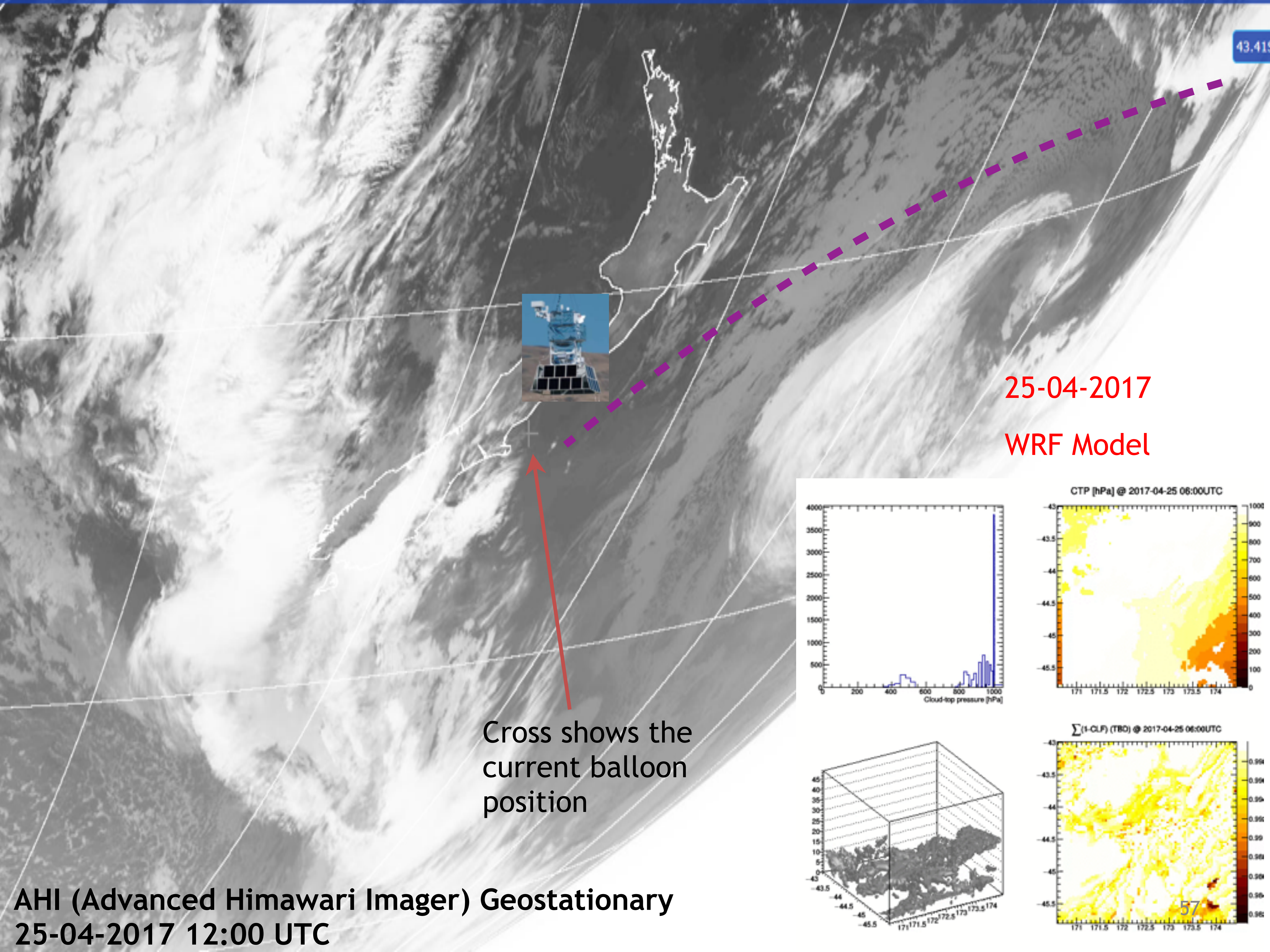


A confirmation that the trigger logic recognises track signals

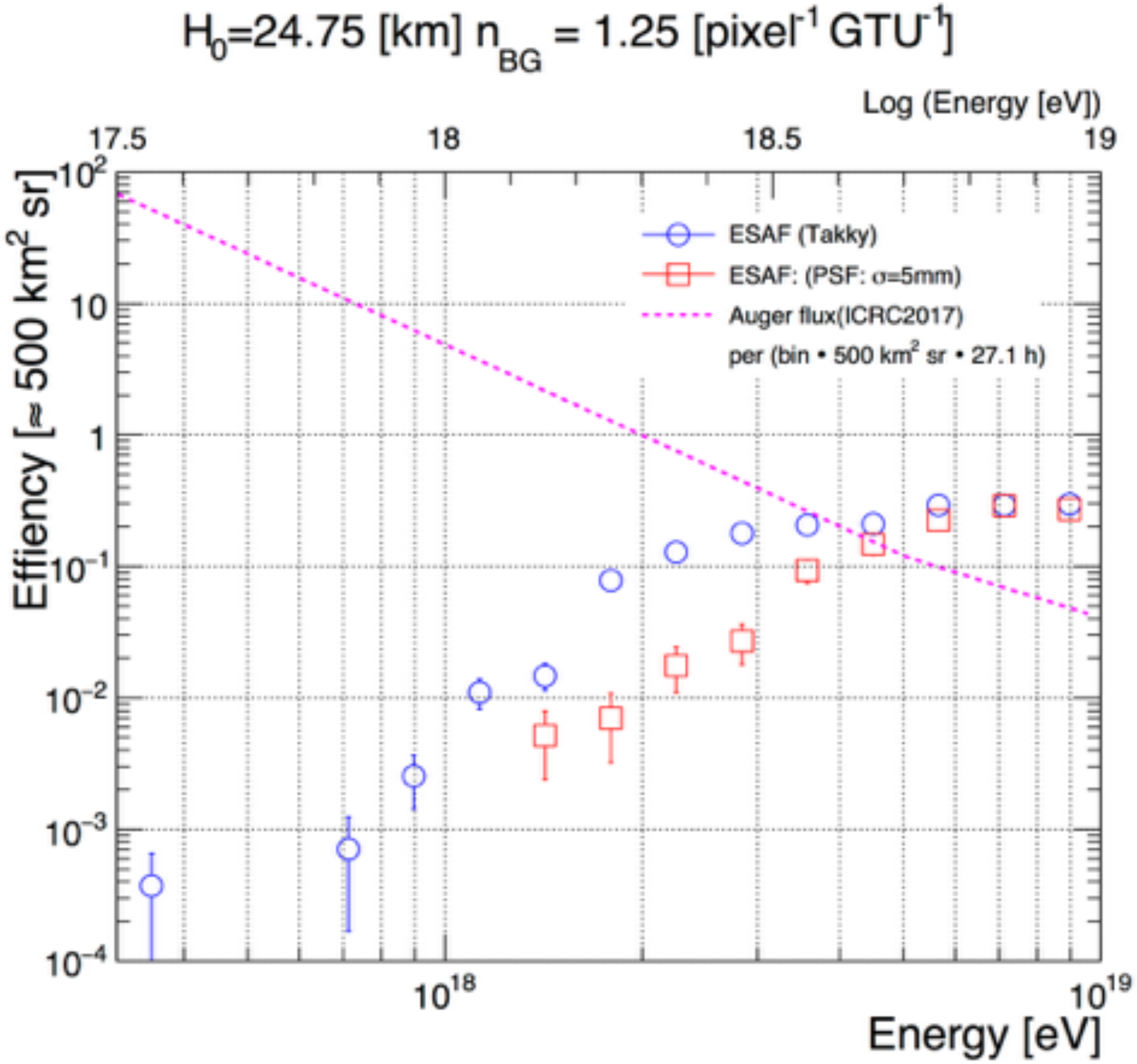
Background Variations in single photon counting camera also reveal clouds

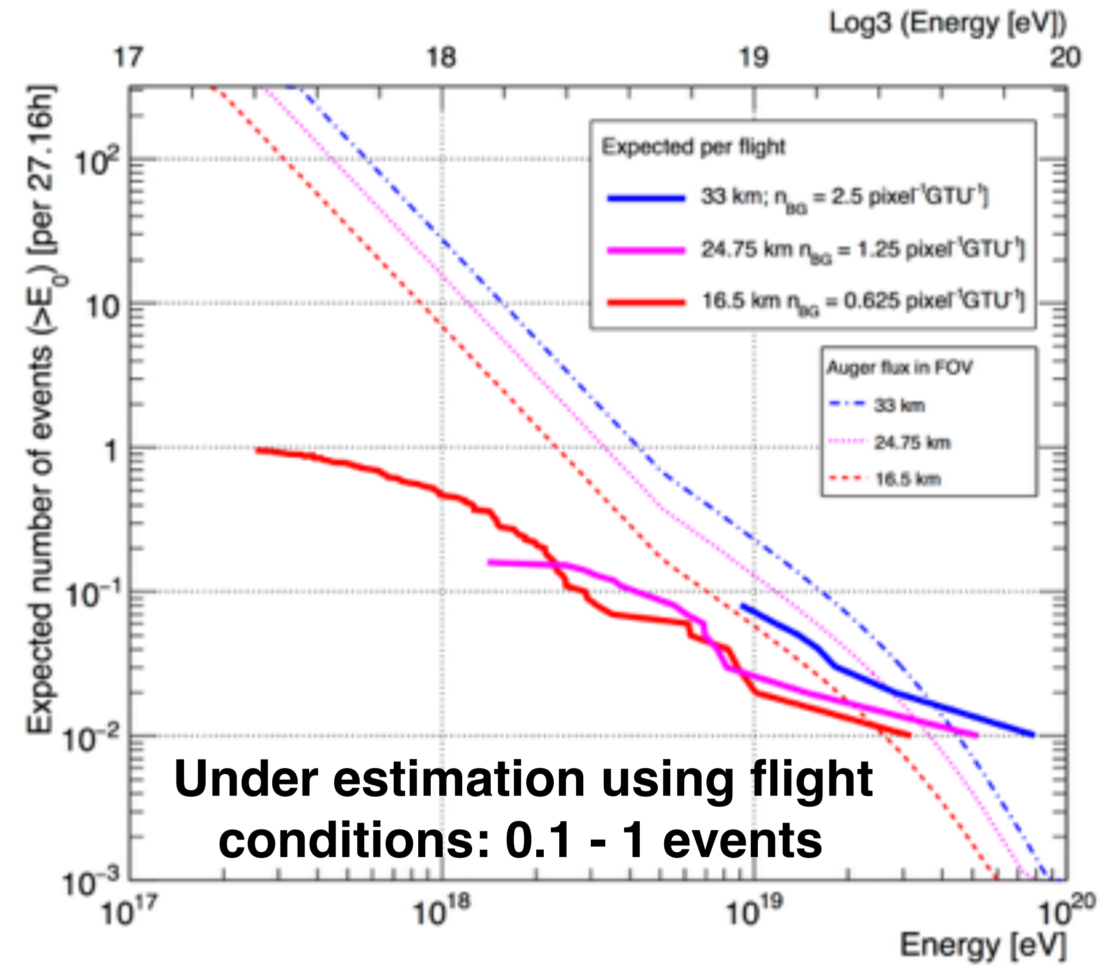


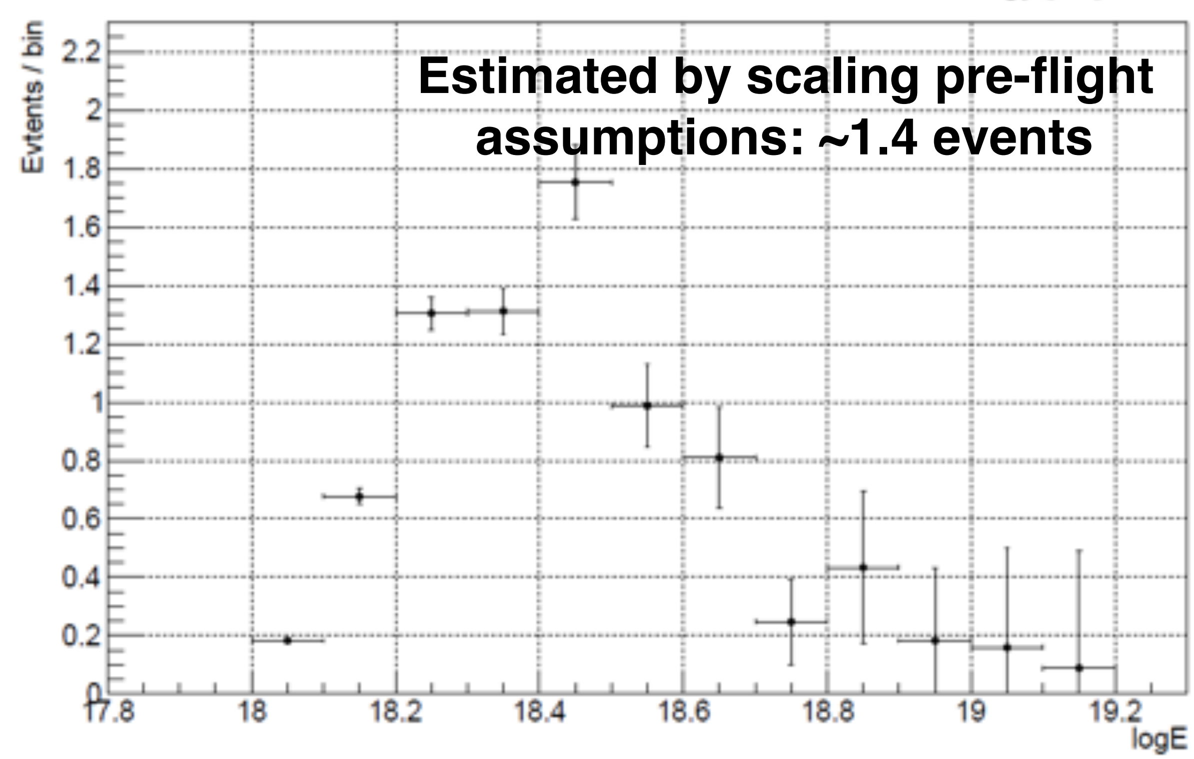



43.41
25-04-2017
WRF Model
CTP [hPa] @ 2017-04-25 06:00UTC
Cloud-top pressure [hPa]
∑(1-CLF) (TBO) @ 2017-04-25 06:00UTC
Cross shows the current balloon position
AHI (Advanced Himawari Imager) Geostationary
25-04-2017 12:00 UTC

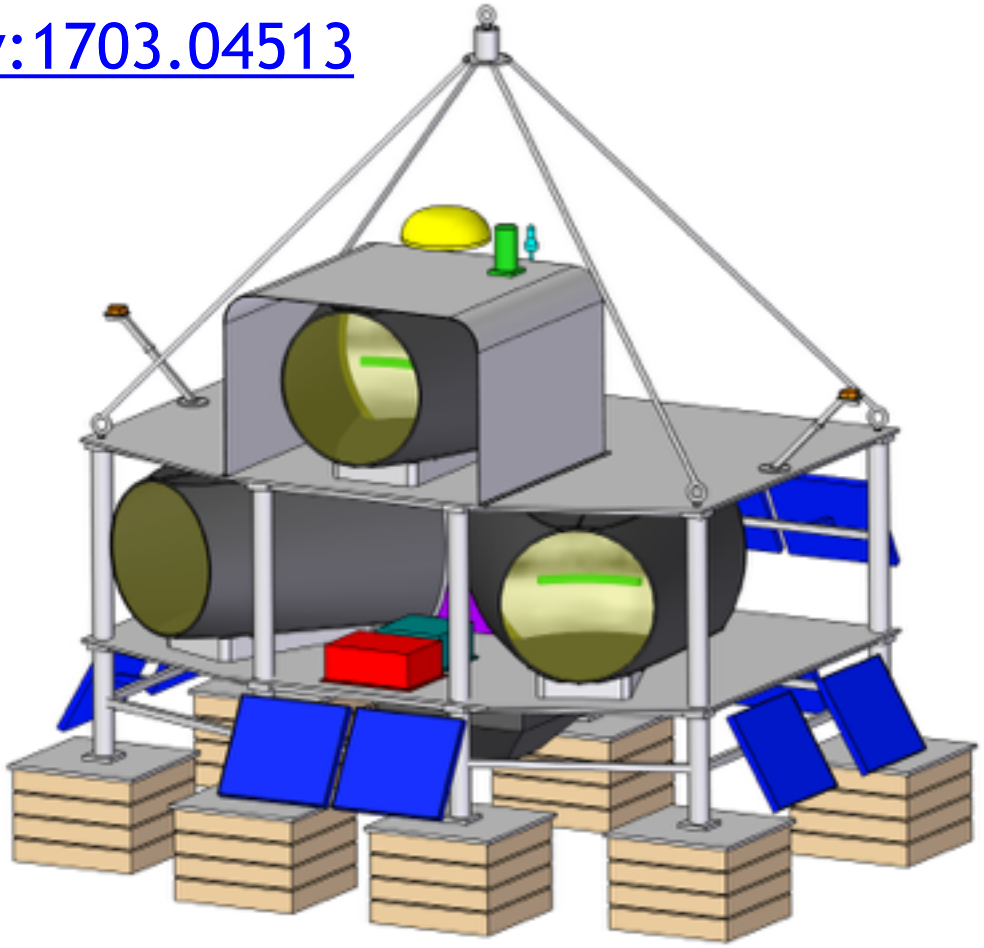
Expected Number of Events during this short flight:







Corrections for Clouds, Lower heights in progress arXiv:1703.04513



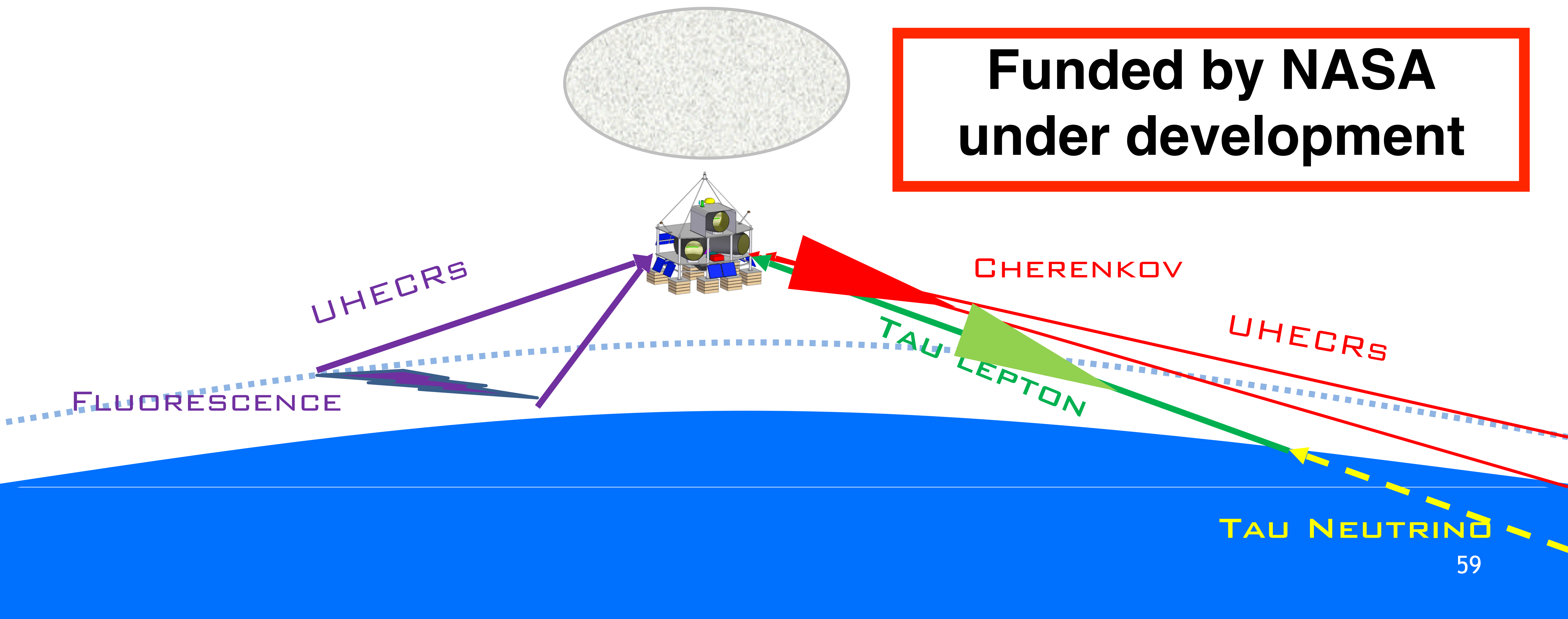
EUSO-SPB2

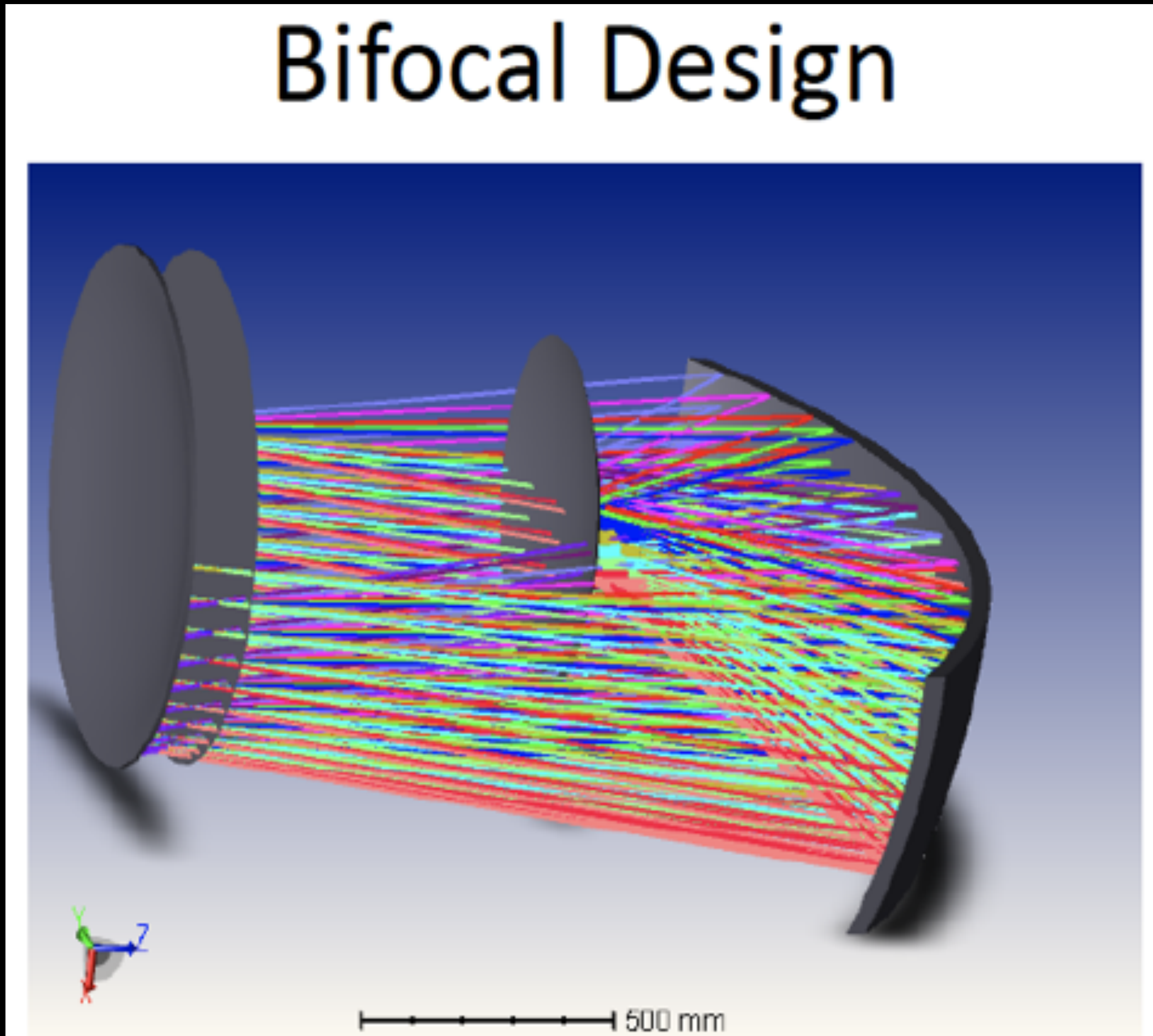
Cherenkov Emission from UHECRs

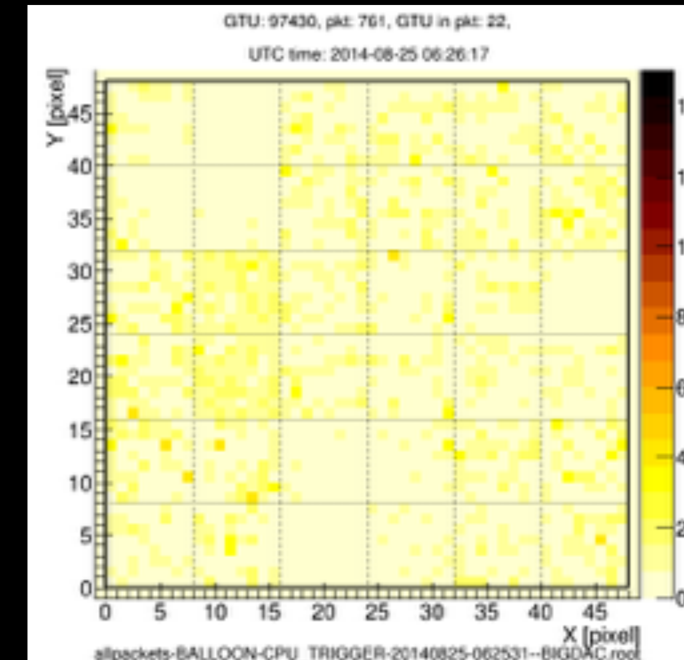
Tau Neutrino Background

Fluorescence from UHECRS

Funded by NASA under development



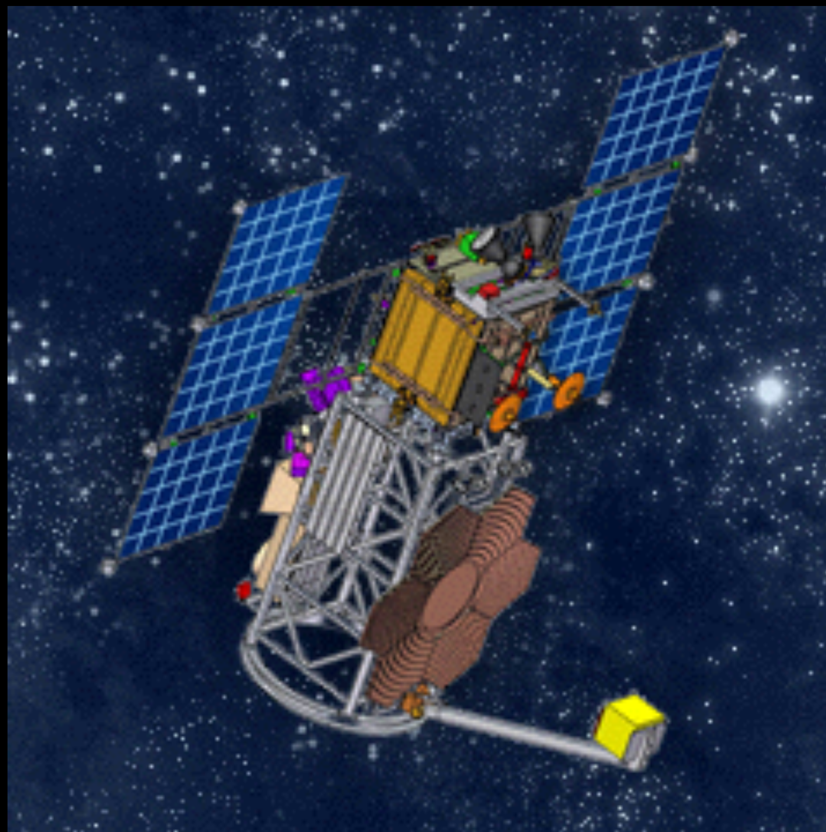




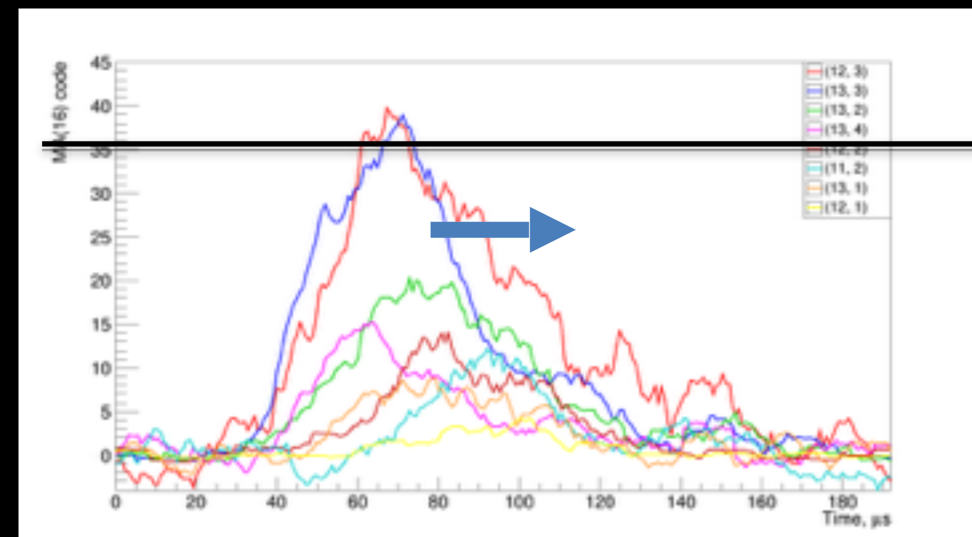
Cherenkov Telescopes
FoV 5° X 45° bi-focal mirror
FoV 5° X 45° normal mirror
Focal Surface
7cm x 70cm
signal duration: 10 - 50 ns

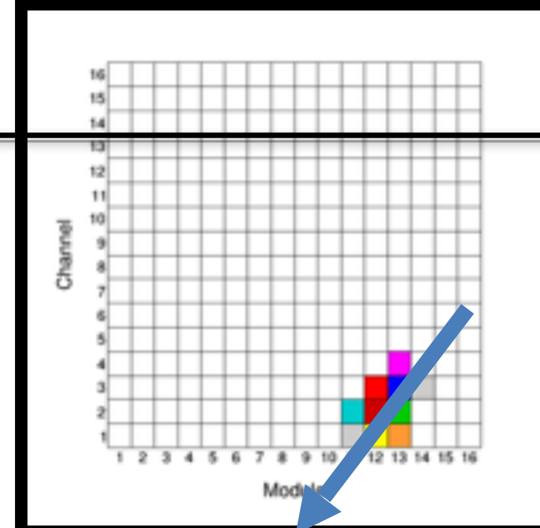
Fluorescence Telescope
FoV 15° X 45° normal mirror
Corrector Plate: 1m^2
Image resolution: ~ few mm
Pixel size: ~3mm square
signal duration: 1 - 20 μs

Challenges/Opportunities:
Space qualified SiPMs, ultra-fast ASICs, corrector lens development, bifocal mirror SPB stability



TUS

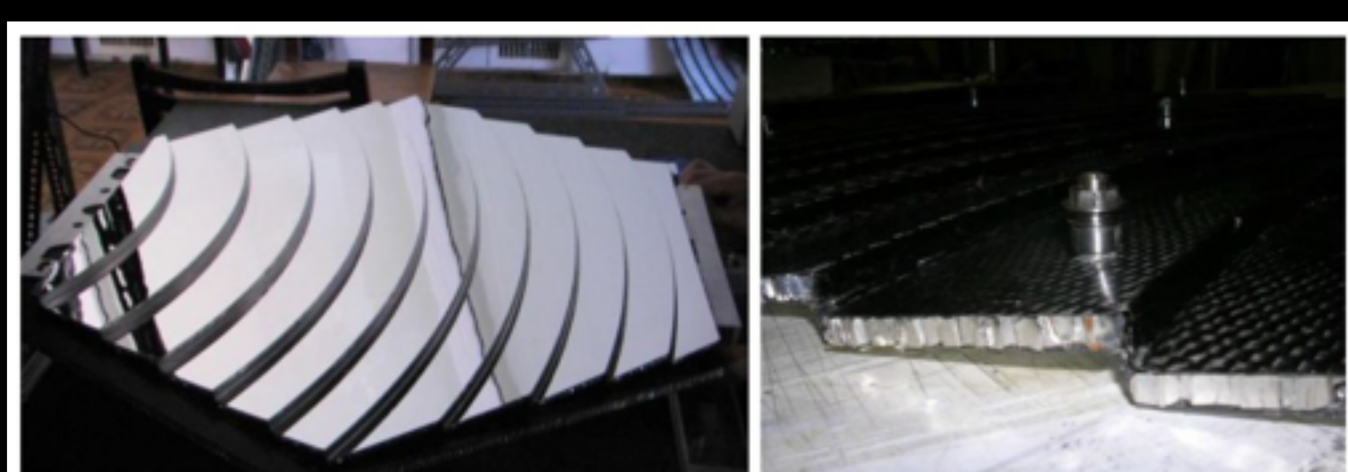




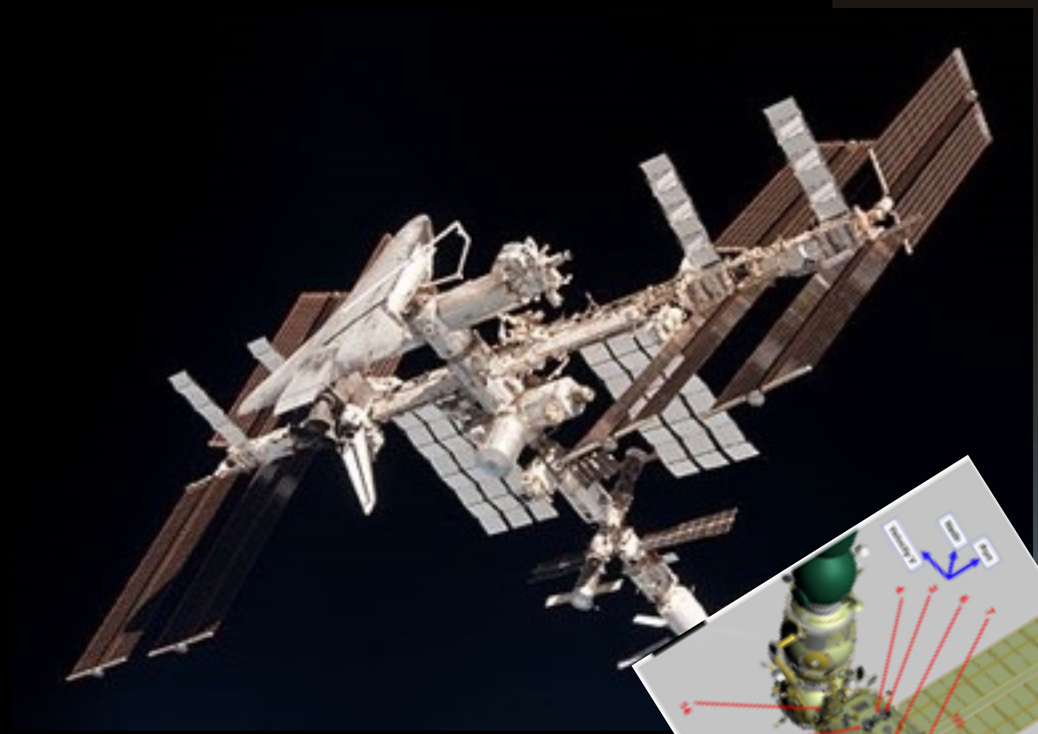
- Launched 2016
- 60kg 65W 2m^2 fs
- 256 channels (13 mm pixels)

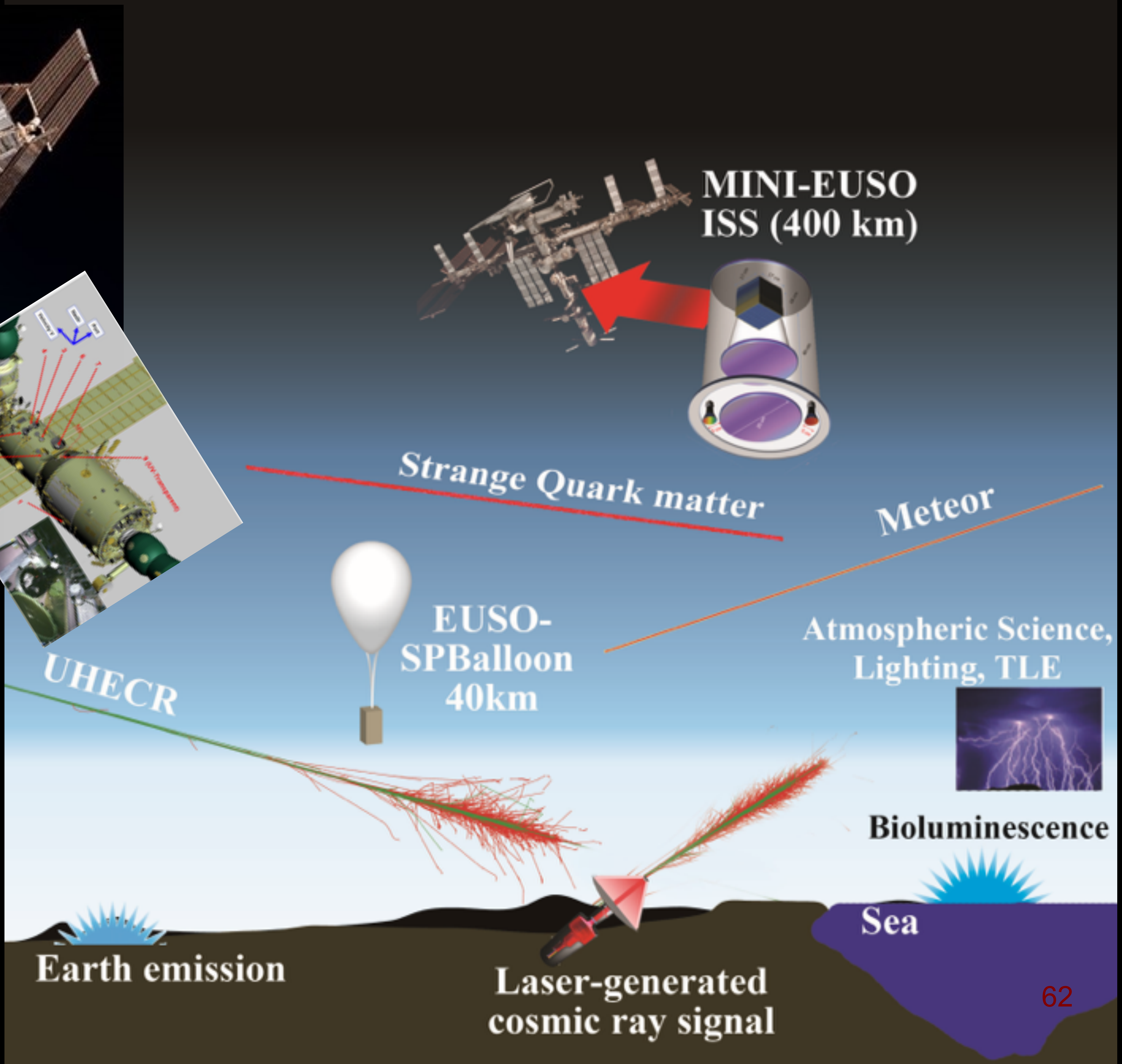
md/ch	A_{bg}	A_{max}	T_{max}, μs	$T_{1/2}$, μs
13/4	5.7	15	63	36
12/3	7.2	40	67.5	47
13/3	0.9	38	71.5	41
13/2	1.7	20	73.0	49
13/1	4.5	8.6	78	42
12/2	0.8	14	81	41
11/2	10.8	12.2	92	29
12/1	0.2	4.2	100	27

See talk by P. Klimov

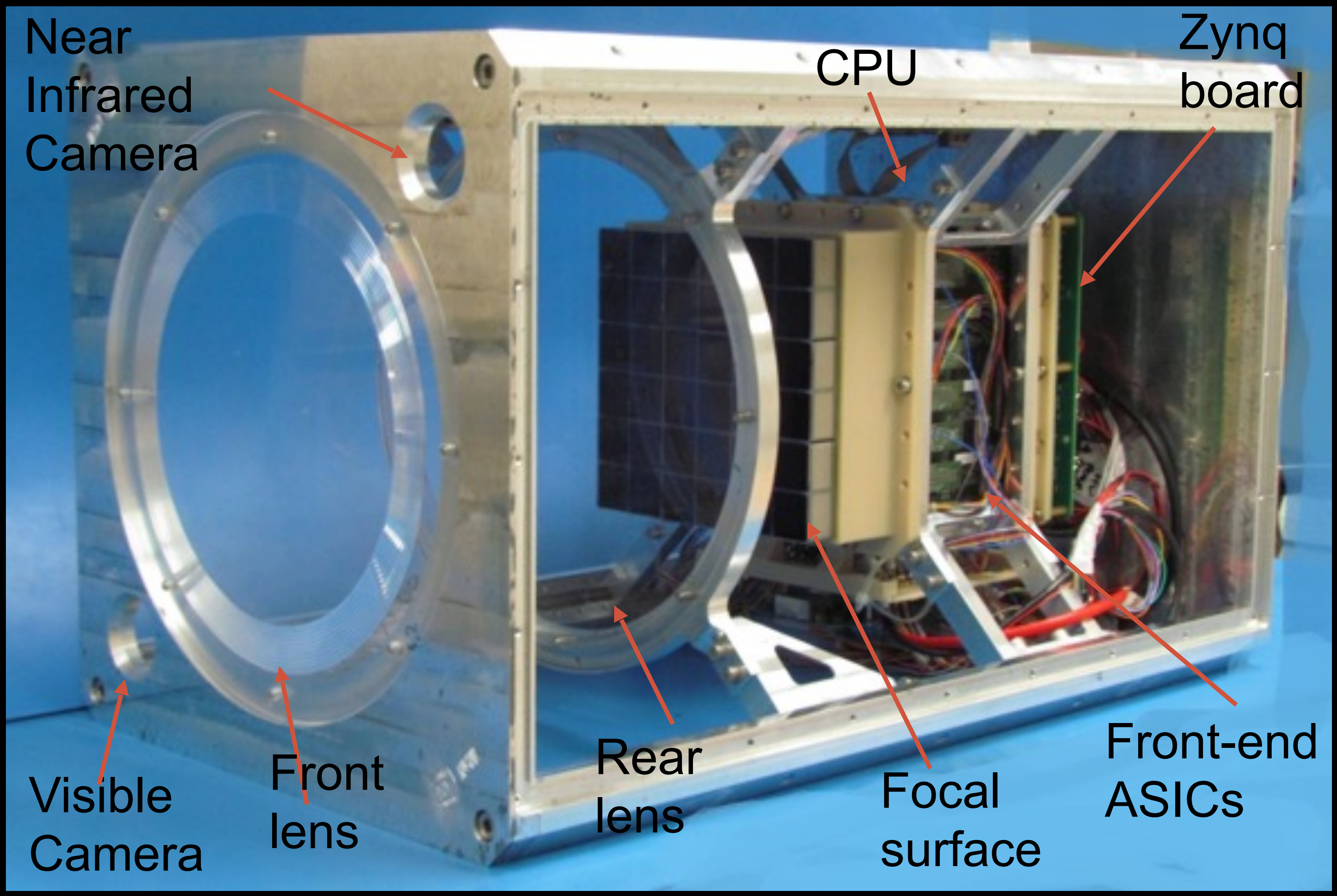


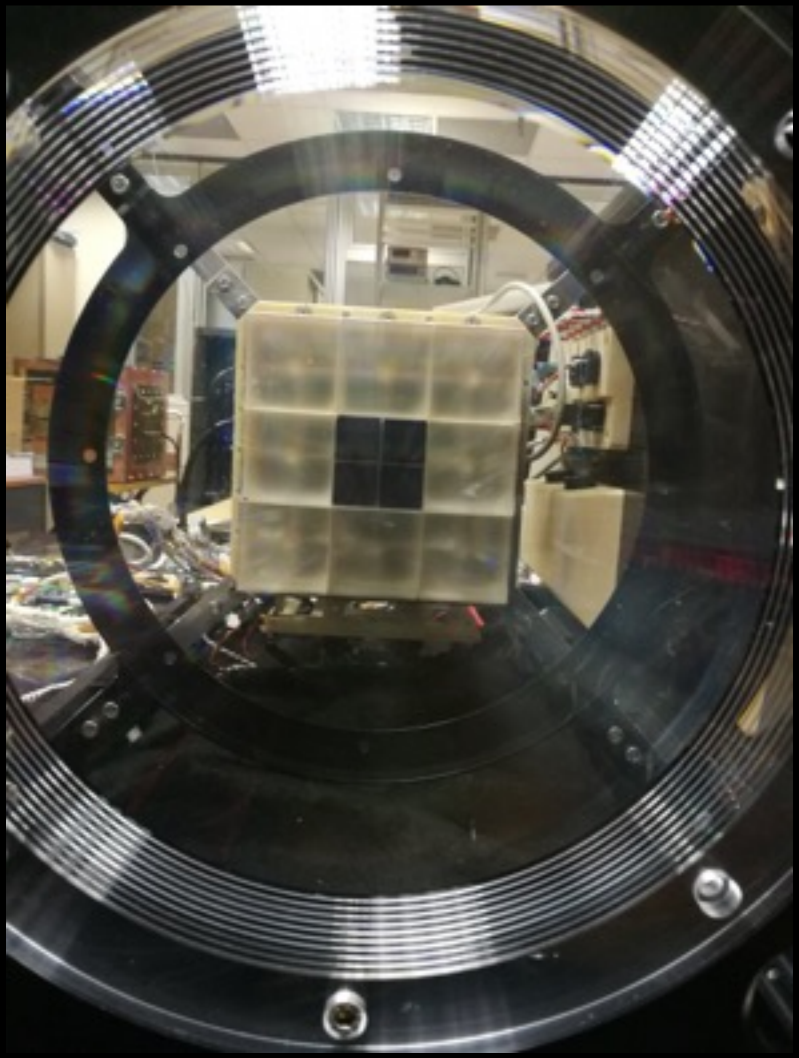
MINI-EUSO/UV-ATMOSPHERE

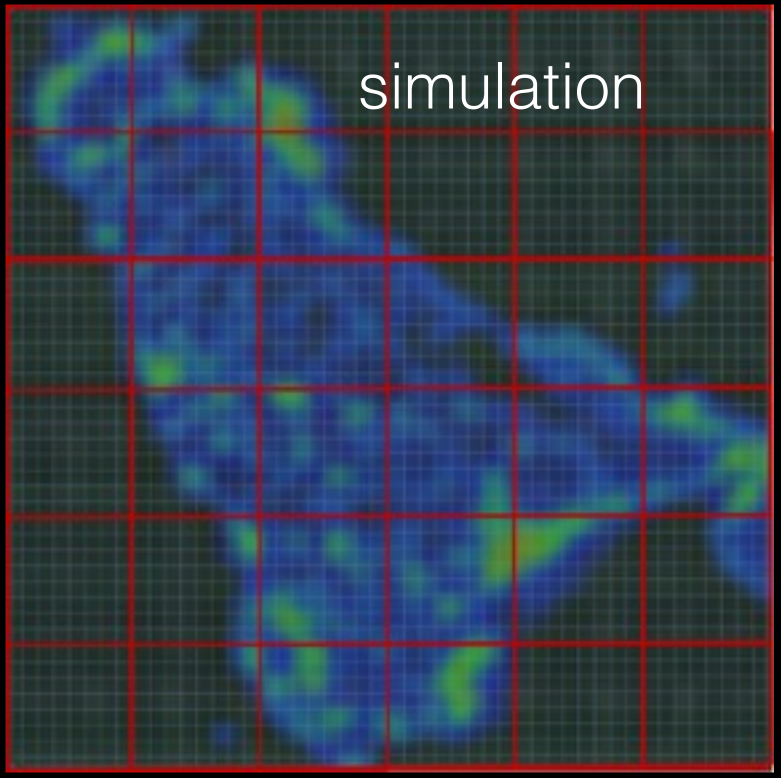




Mini-EUSO

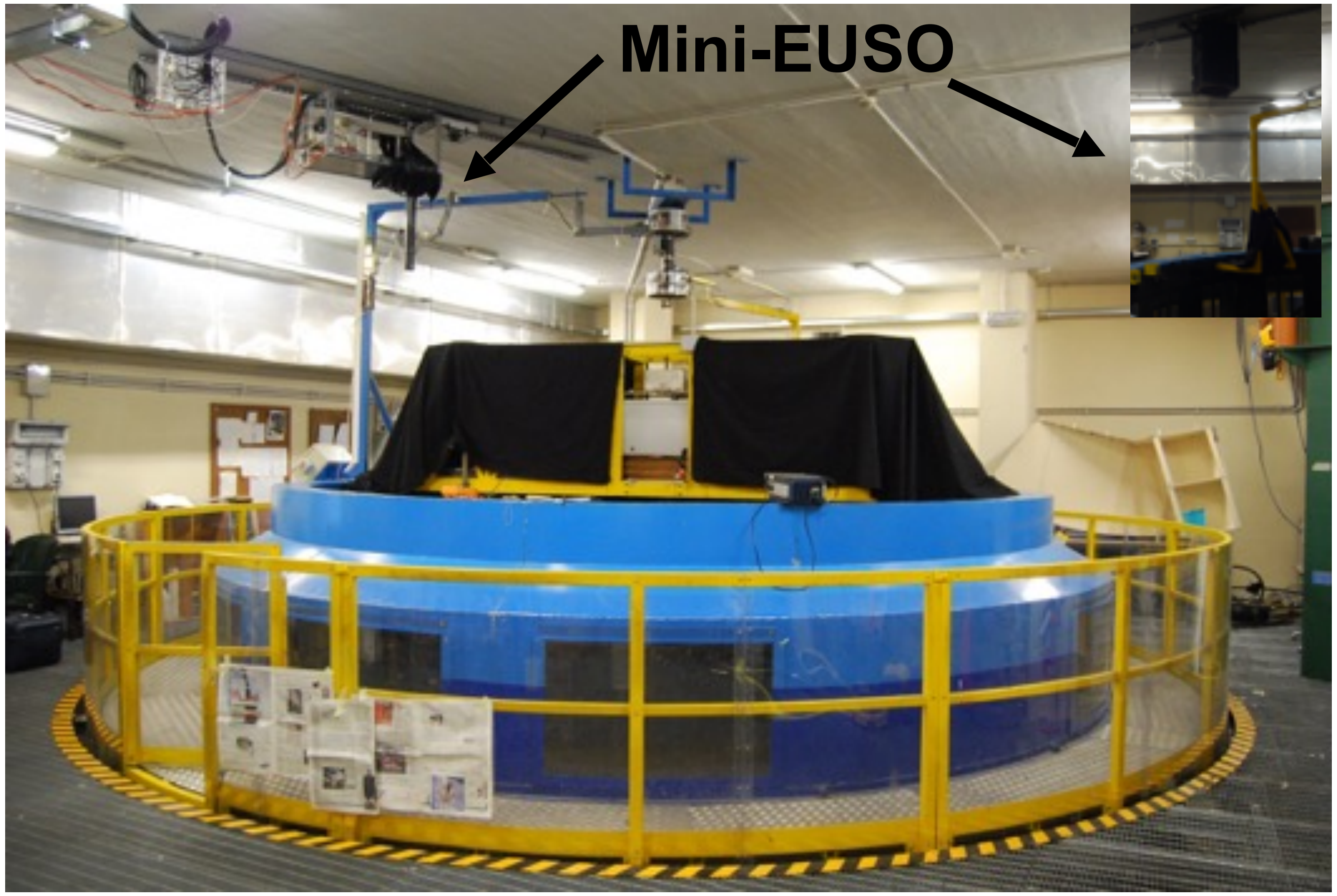


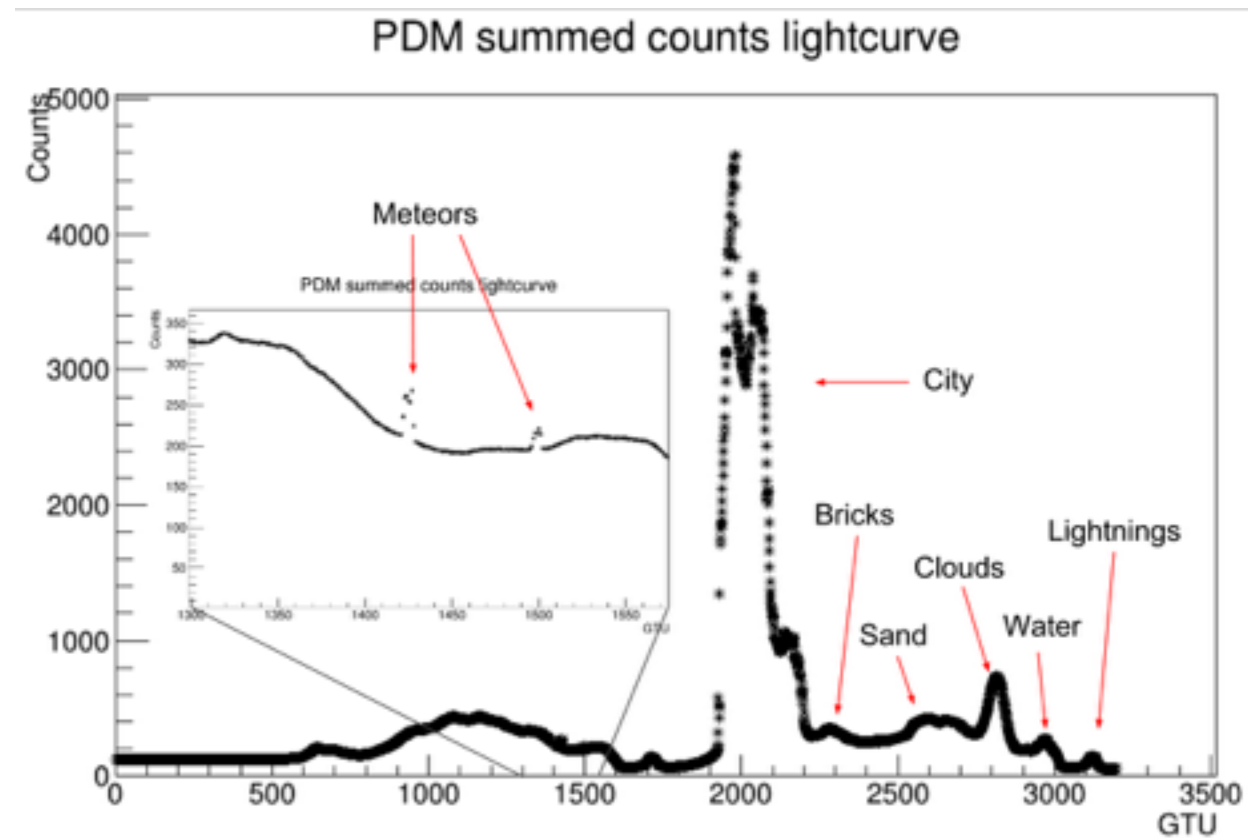




- Inside the ISS 2 Fresnel lenses and one PDM
- 60W @ 27V, 30 kg (2304 pix, 3 mm)
- Night observations About 40% orbit
- Nadir observations Off if ISS changes attitude
- Exchange of data disk 52TB/week

Mini-EUSO@TurLab (Univ. Torino)





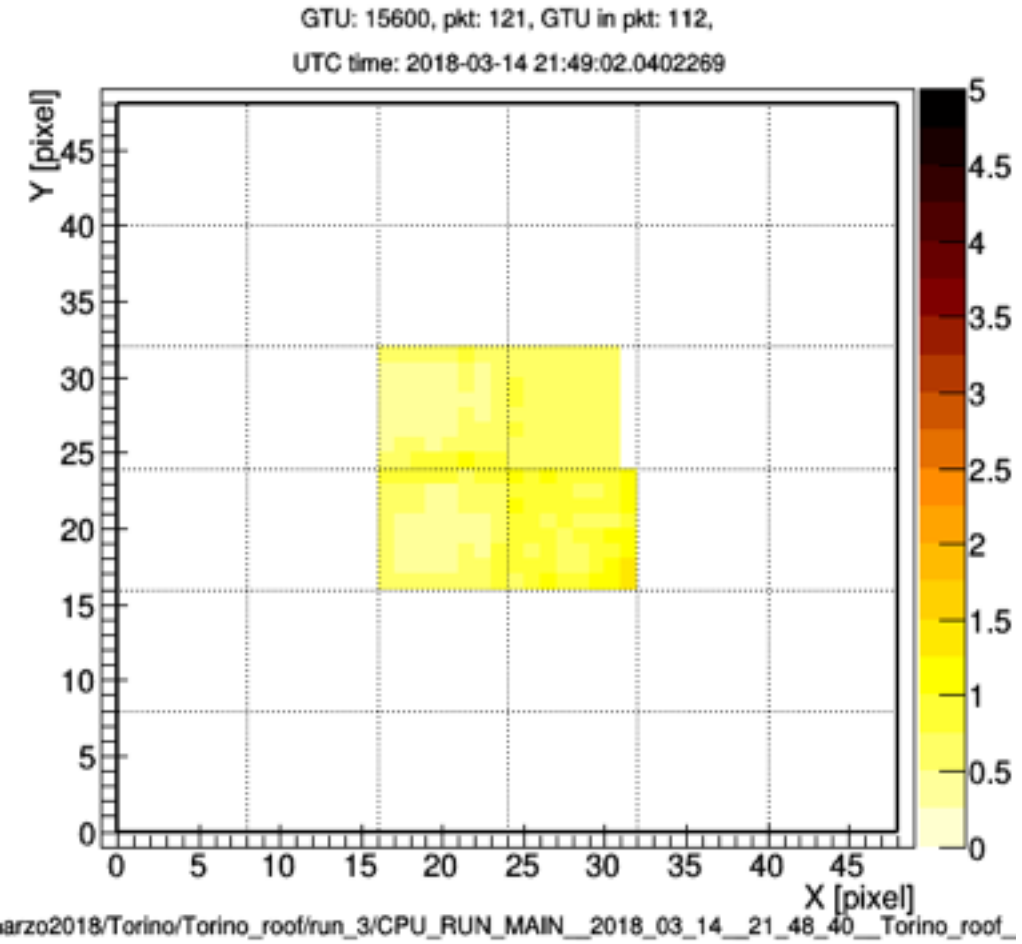
Mini-EUSO DATA:

D1 : 2.5 μs resolution

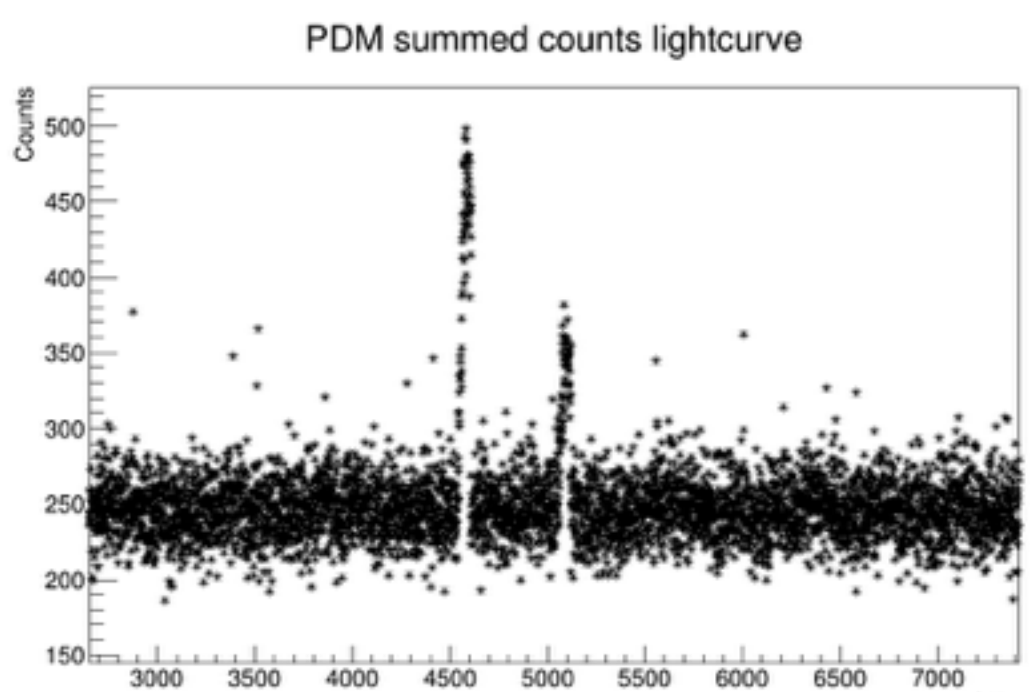
D2: 320 μs resolution

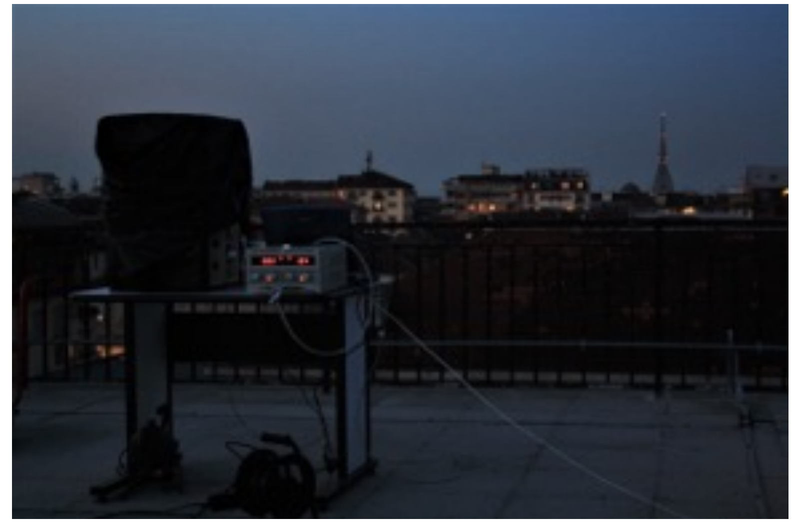
D3: 40.96 ms resolution

Mini EUSO in Torino & INAF-OATo

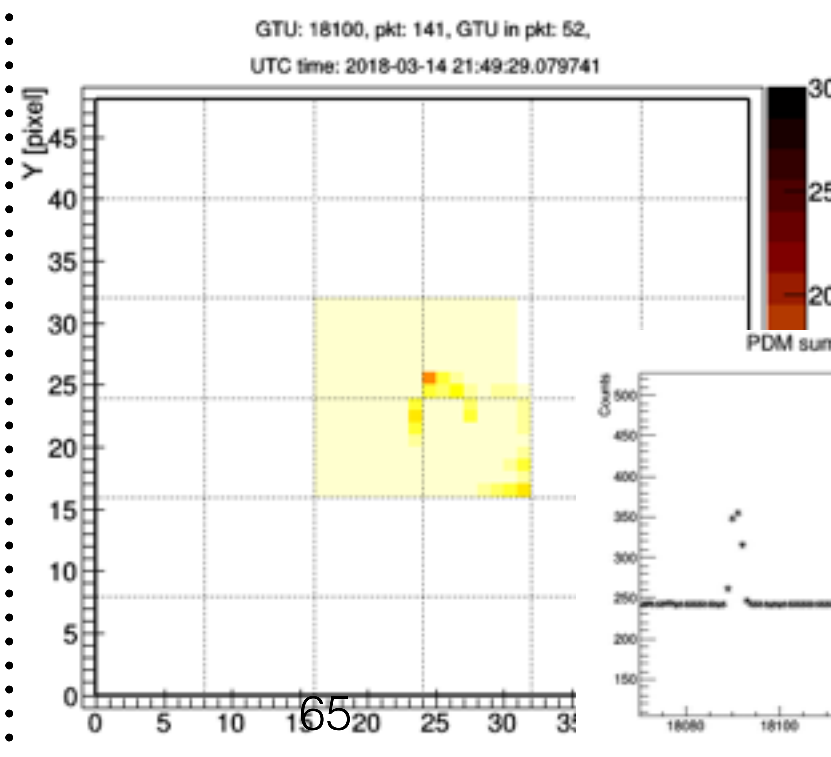


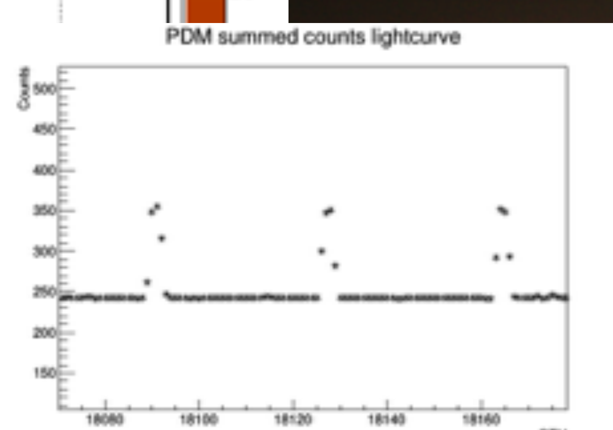
Plane crossing the FoV
(frame duration 40.96 ms)



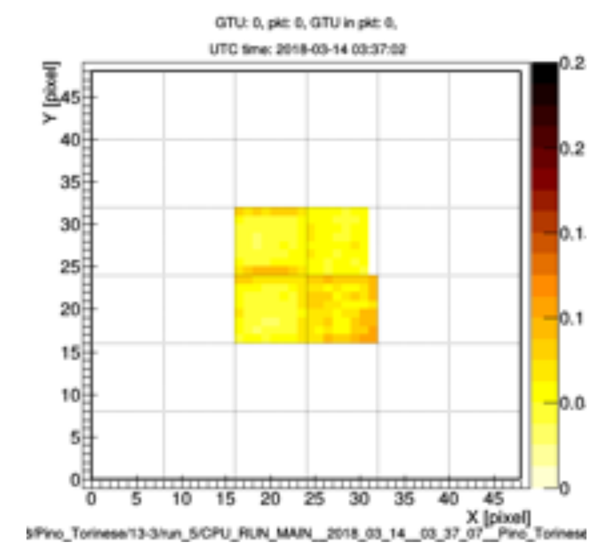


D1 lightcurve in self trigger mode. The system detects the two peaks coming from plane flashers. The same event was triggered by the L2 as well

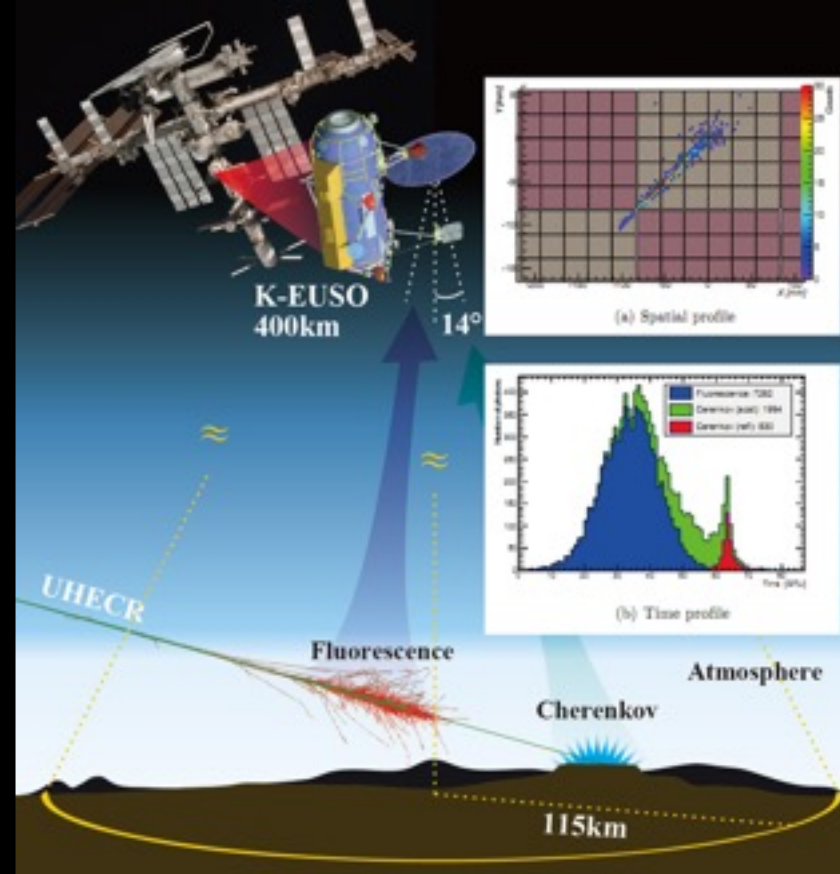


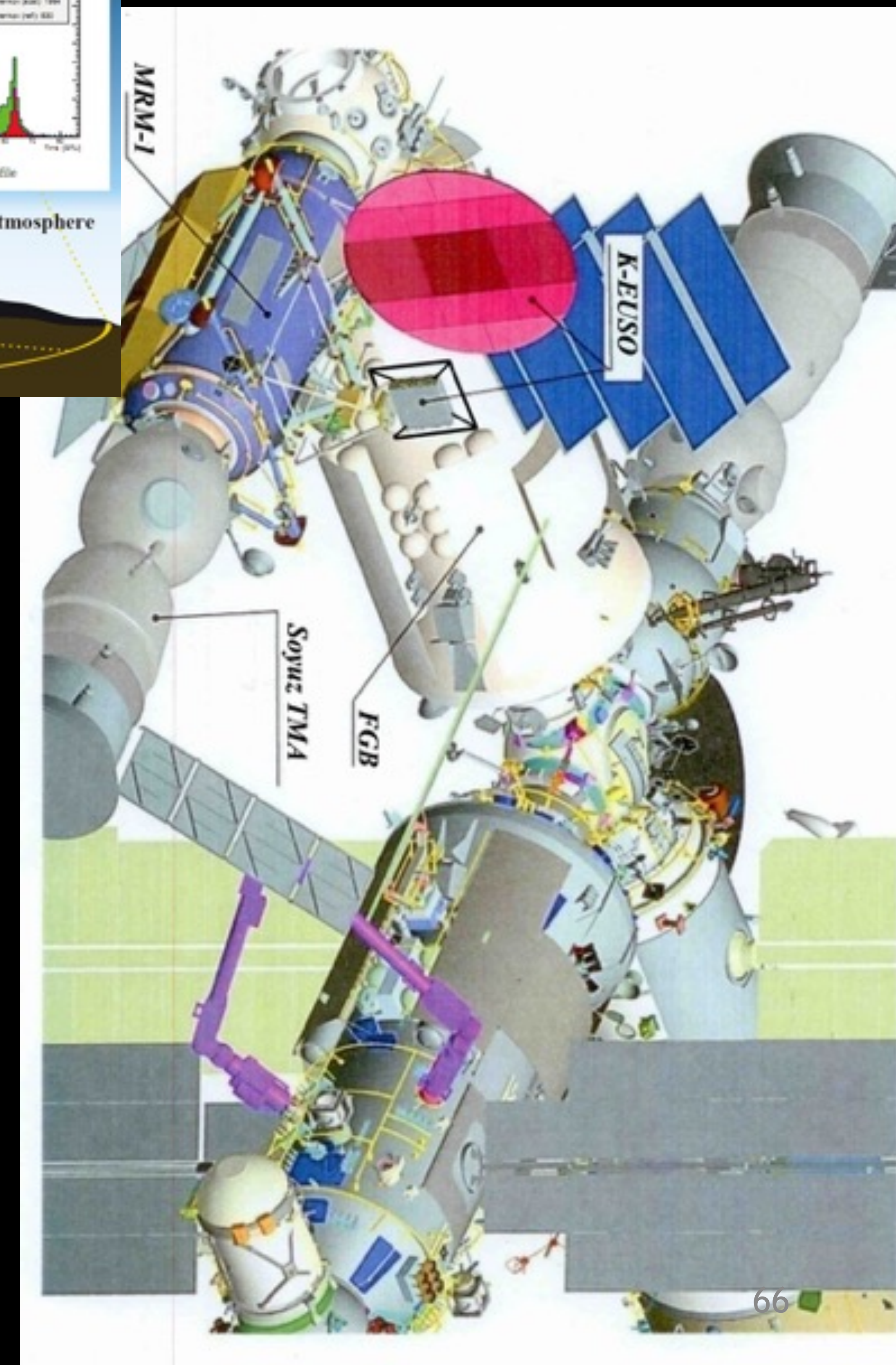


Few stars,
brightest: 11Her (HIP 79101) Mag. 4.20
1 Her (HIP 77760) Mag. 4.60
6 Her (HIP 78592) Mag. 4.70

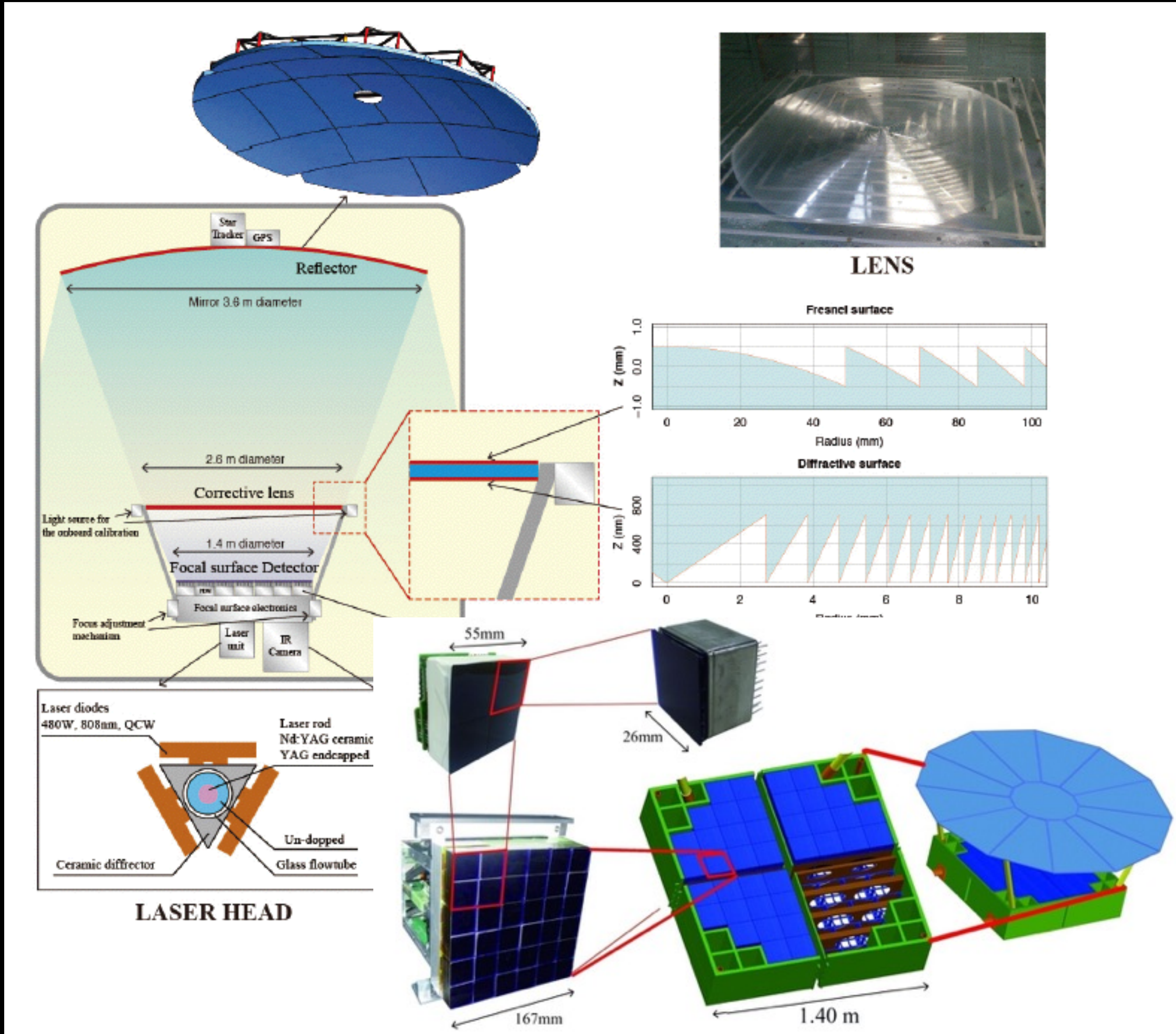


K-EUSO





- In the Russian Federal Space Program
- Passed the stage of preliminary design with Roscosmoc
- Technical requirements, accomodation, operations study performed by Energia space corporation
- Evolution of KLYPVE Russian detector (reflector)
- Launch in 2023

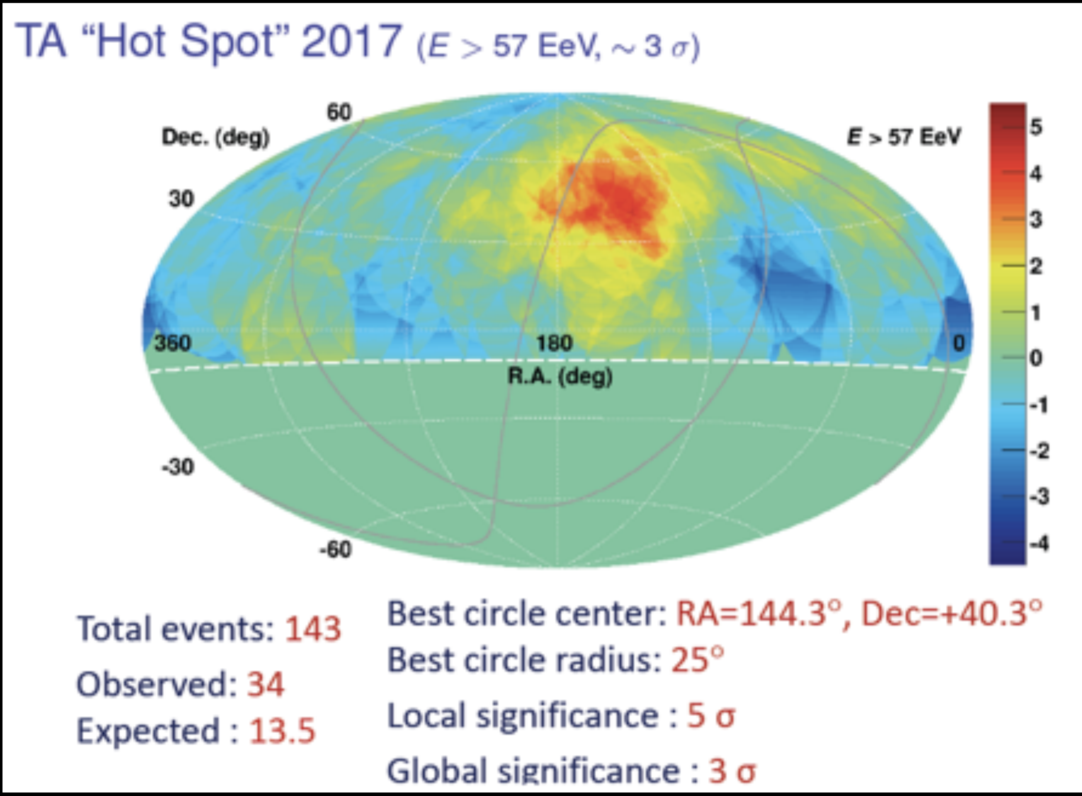


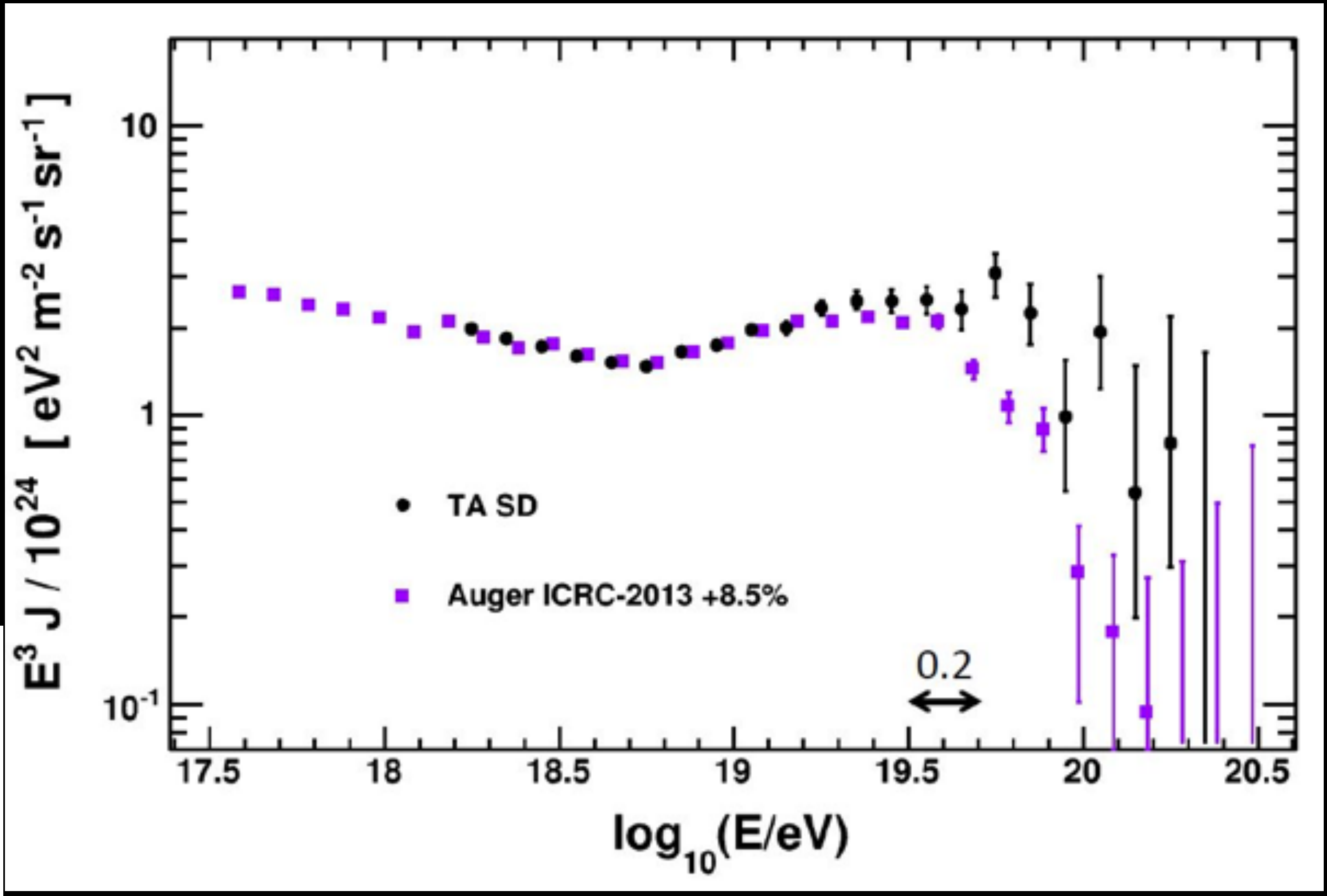
Star Tracker
GPS
Reflector
Mirror 3.6 m diameter
2.6 m diameter
Corrective lens
Light source for the onboard calibration
1.4 m diameter
Focal surface Detector
Focal surface electronics
Focus adjustment mechanism
Laser unit
IR Camera
LENS
Fresnel surface
Z (mm)
Radius (mm)
Diffractive surface
Laser diodes
480W, 808nm, QCW
Laser rod
Nd:YAG ceramic
YAG endcapped
Un-dopped
Glass flowtube
Ceramic diffrector
LASER HEAD
55mm
26mm
167mm
1.40 m

UHECR with K-EUSO: Spectral differences

Auger and TA spectra

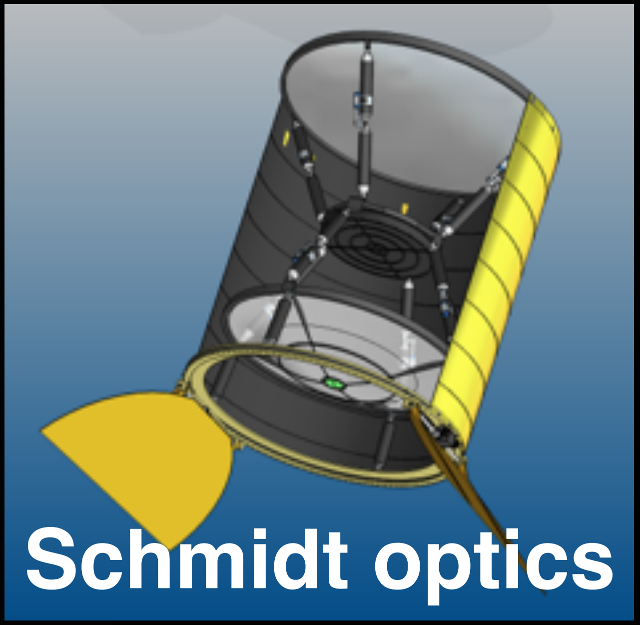
Need to rescale.
Is it correct?
Is it physics?
At GZK are they different+ Composition?





ICRC2015

K-EUSO annual exposure: ~ 2 x Auger



See talk by A. Olinto

POEMMA:

Probe of Extreme Multi-Messenger Astrophysics

UHECRs and Neutrinos

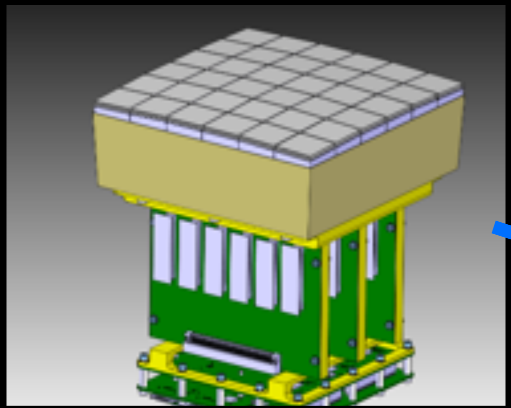
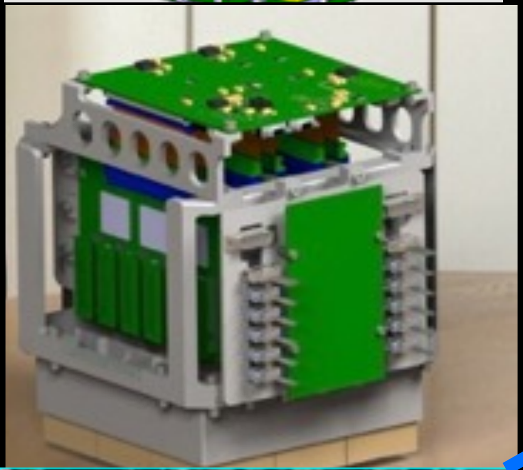
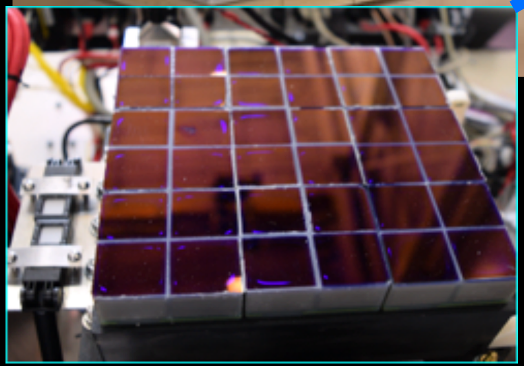
POEMMA

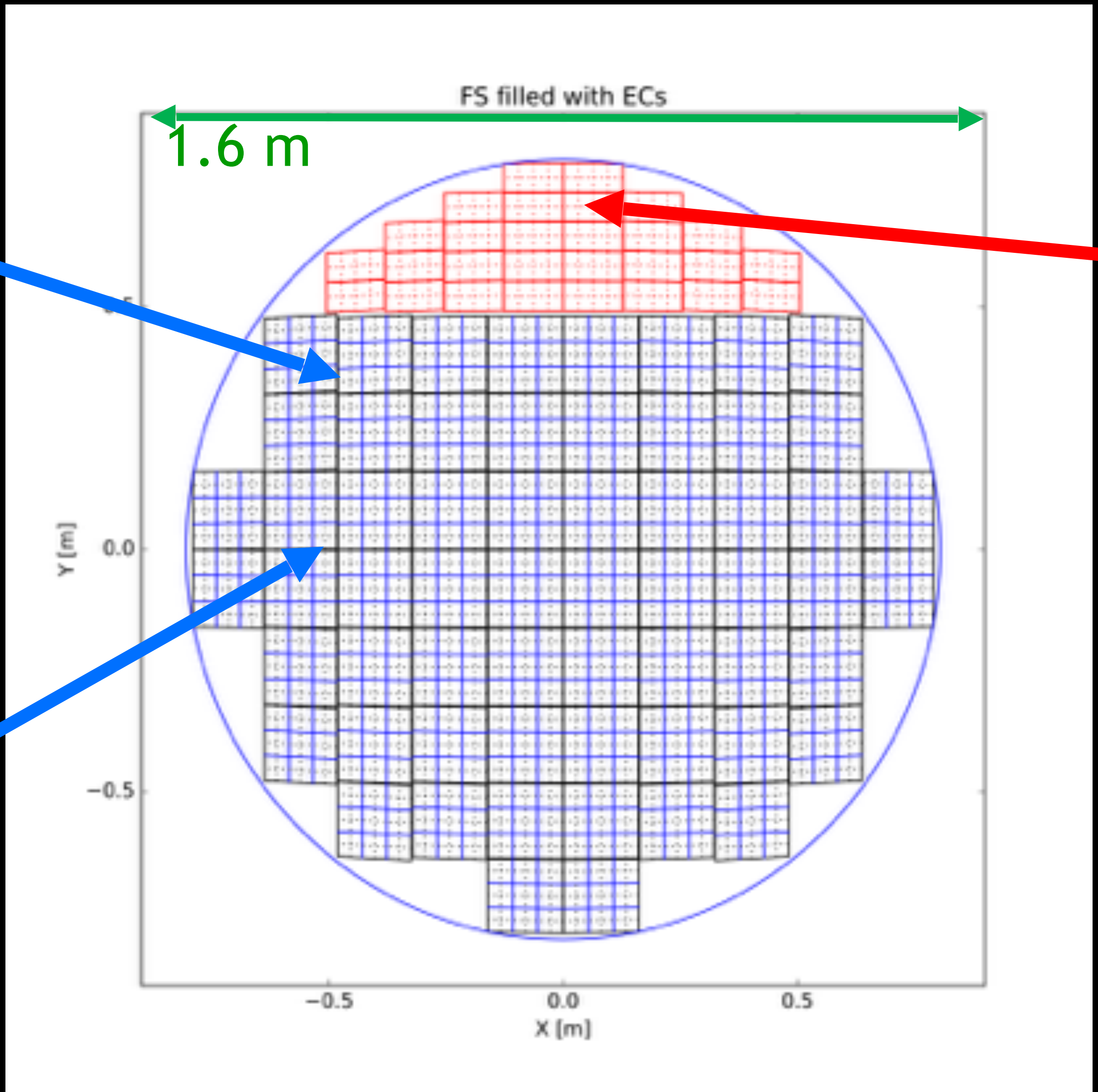
Hybrid MM Focal Surface

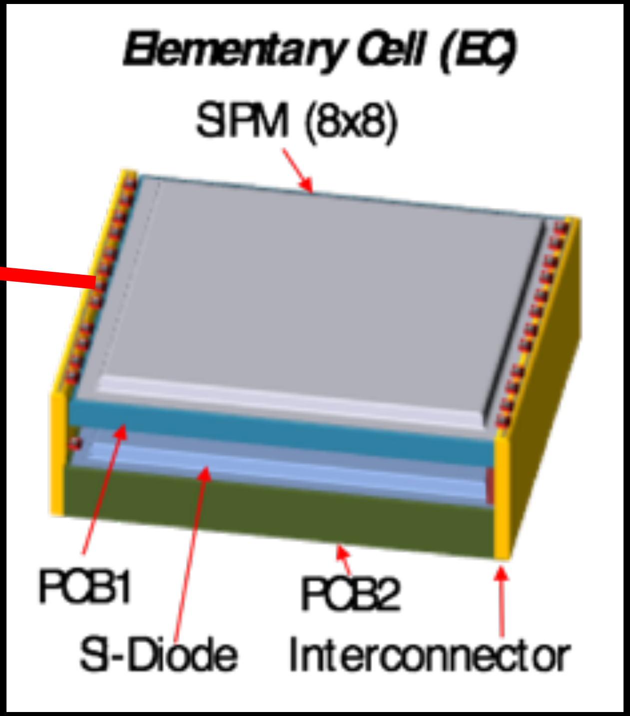
UV Fluorescence Detection with MAPMTs

Cherenkov Detection with SiPMs

~ 150k pixels



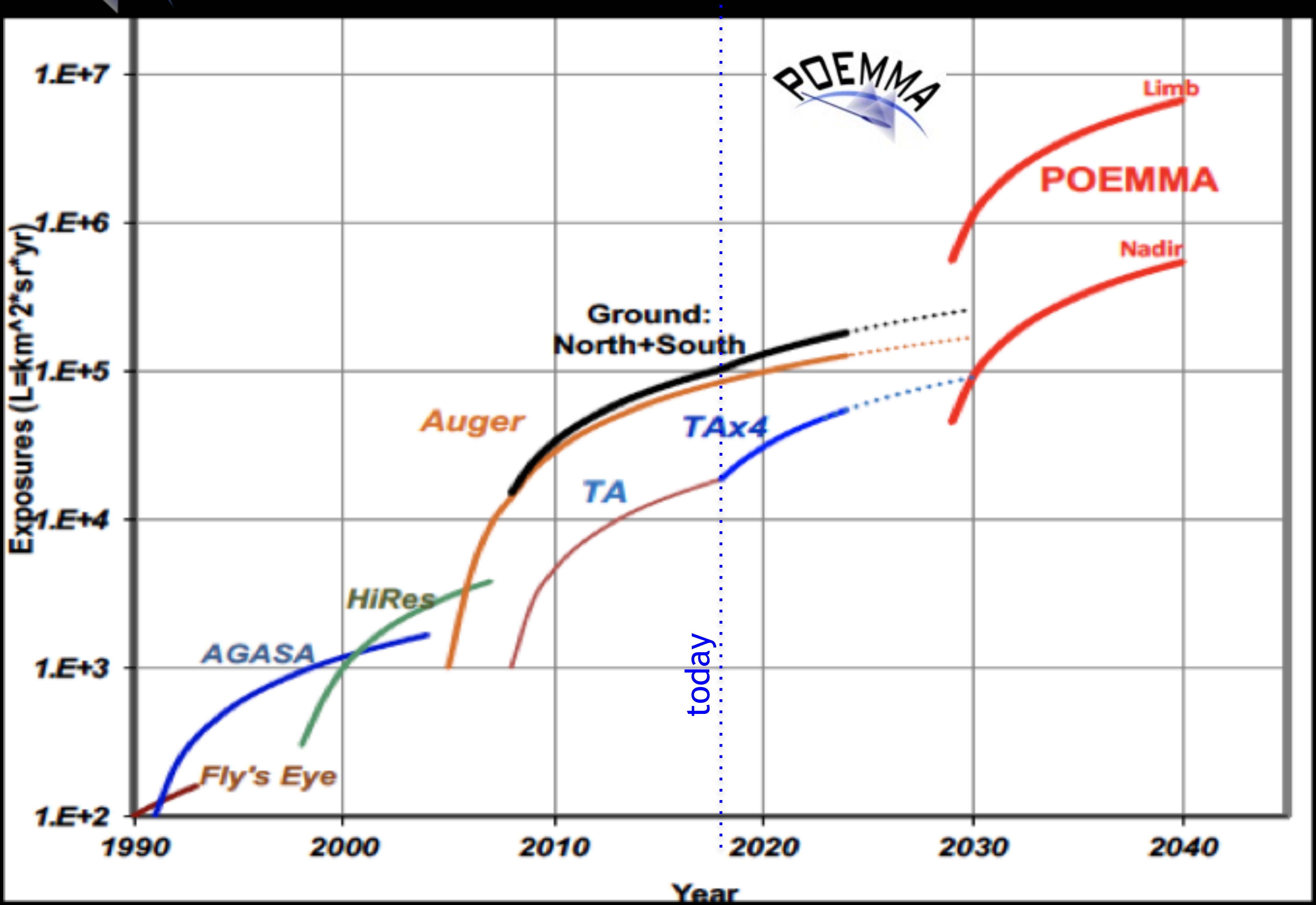


28 SiPM focal surface un
Total 14,336 pixels
512 pixels per FSU (64x4

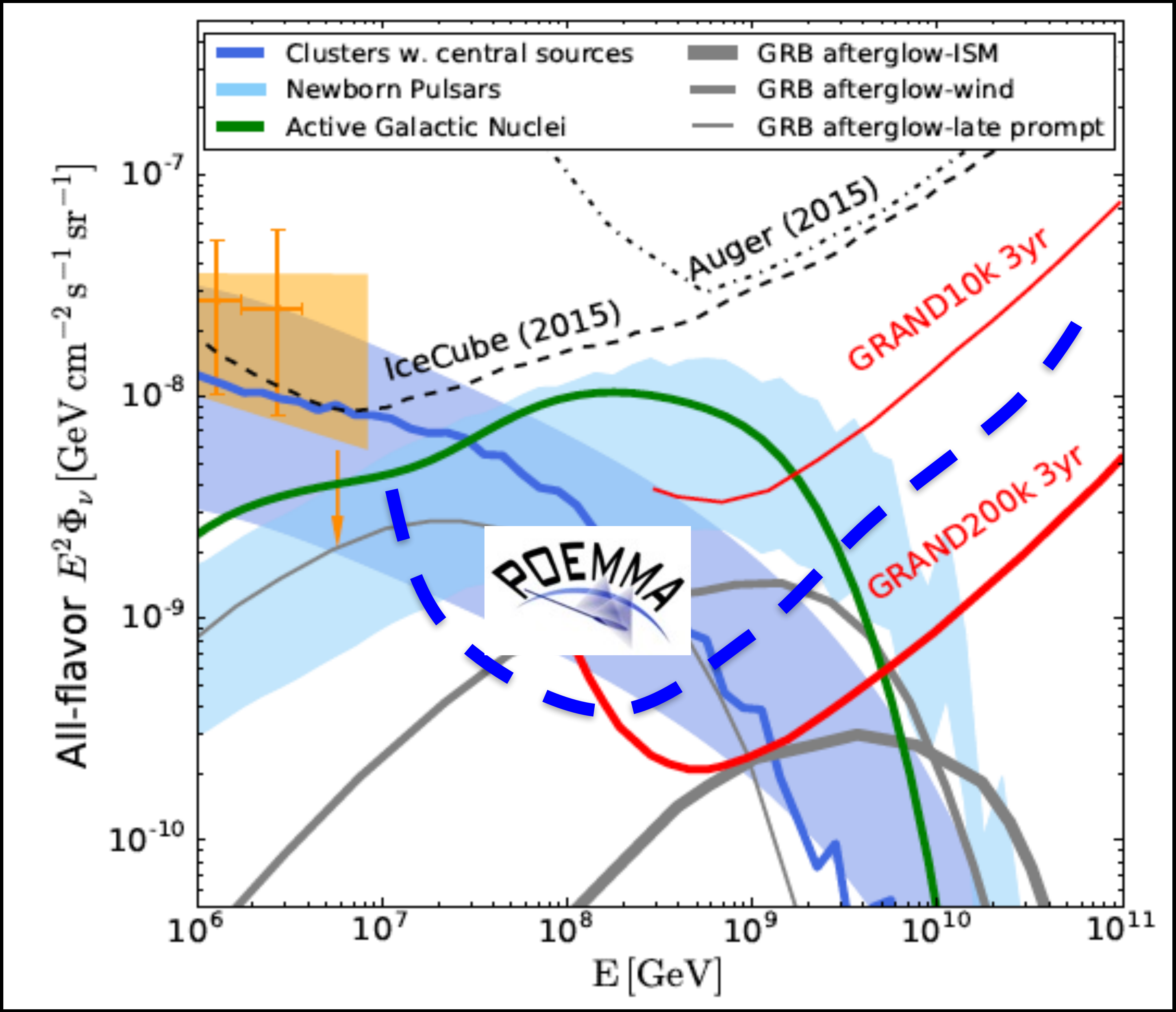
60 Photo Detector Modules (PDMs)= 138,240 pixels

1 PDM = 36 MAPMTs = 2,304 pixels

UHECR Exposure History



Neutrinos from UHECR may be seen first



GRAND Team 1708.05128

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 TRLs levels.
- The First Pathfinders (EUSO-TA and EUSO-Balloon) are providing exciting technical and science-oriented data: the transition from paper work to prototyping and measurements has been done.
- The small scale missions (EUSO-SPB, Mini-EUSO and TUS) are expected to provide new scientific results.
- Large Mission concepts are actively studied: K-EUSO is expected to provide first key results from space on the interpretation of UHECR science, and then POEMMA is expected to unveil the highest energy sky ever explored.

THANK YOU