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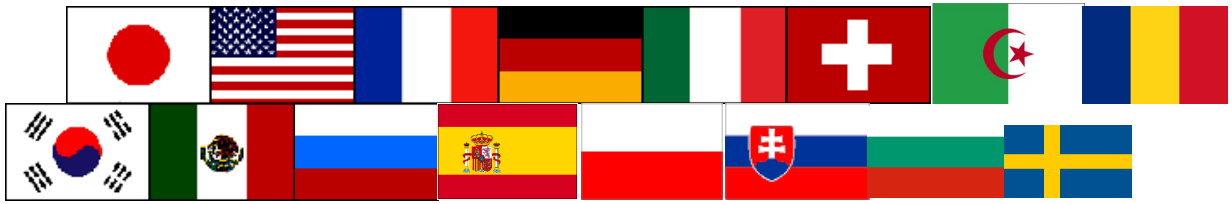
MATHEMATISCH-
NATURWISSENSCHAFTLICHE FAKULTÄT

Institut f. Astronomie u. Astrophysik



"Doing astronomy by looking downward"

The JEM-EUSO Program

A. Santangelo*, P. Picozza, T. Ebisuzaki for the JEM-EUSO collaboration

**** Global Coordinator of the JEM-EUSO Collaboration***

ICRC 2015 5.08.2015, Den Haag, The Netherlands

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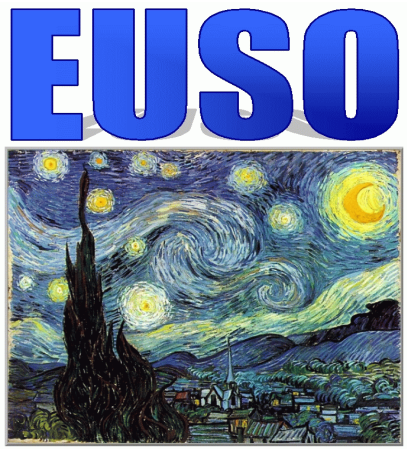

2001- 2004

Heritage of the ESA EUSO study

Part I

The EUSO concept: exploring the UHE Universe from space

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JEM-EUSO Science objectives

- **Astrophysics and Physics from E>5.×10^{19}eV focusing at E~10^{20} eV (and above)**:

○ Main Science Objectives:

A. Olinto ID 735

- *identification of UHE sources*
- *measurement of the energy spectra of individual sources*
- *measurement of the trans-GZK spectrum*

○ Exploratory objectives:

E. Iwotschkin ID0585

G. Vankova ID0899

- *discovery of UHE Gamma-rays*
- *discovery of UHE neutrinos*
- *study of the galactic and local extragalactic magnetic field*
- *"Top-Down" scenario*

- **Atmospheric Science**

M. Frias ID1283

- *Nightglow*
- *the transient luminous events (TLE)*

K. Kudela ID0914

- *meteors and meteoroids*

IDs refers to ICRC IDs

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"Take home" message:

Physics and Astrophysics at E>5.×10^{19} eV

But also… Explore new physics in the energy range E≈10^{20}-10^{21}eV

Highest statistics and therefore largest exposures at extreme energies

$$E \approx 10^{20-21}\,eV$$

Lower Energies are important for overlapping with current generation observatories with significant statistics…

$$E < 5\times 10^{19}\,eV$$

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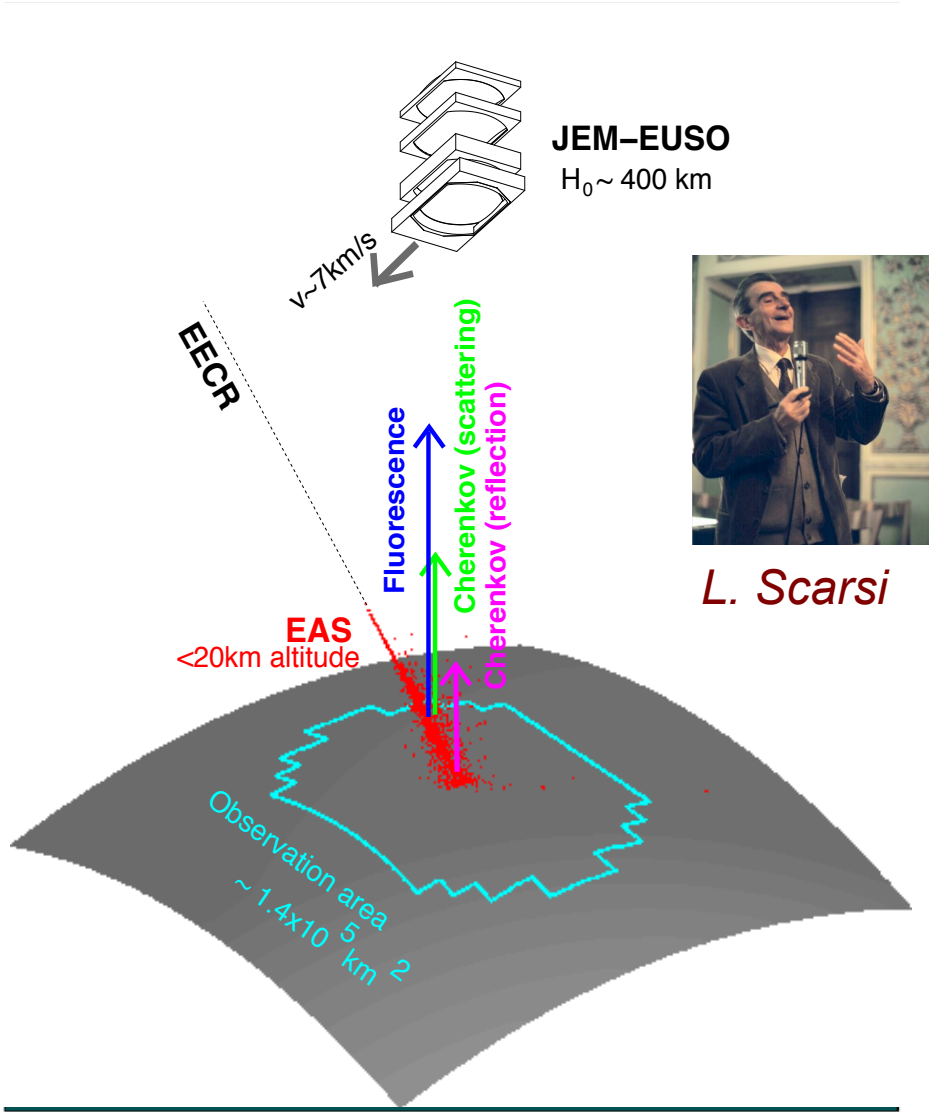
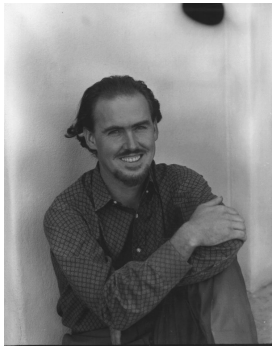
Technique: fluorescence from space

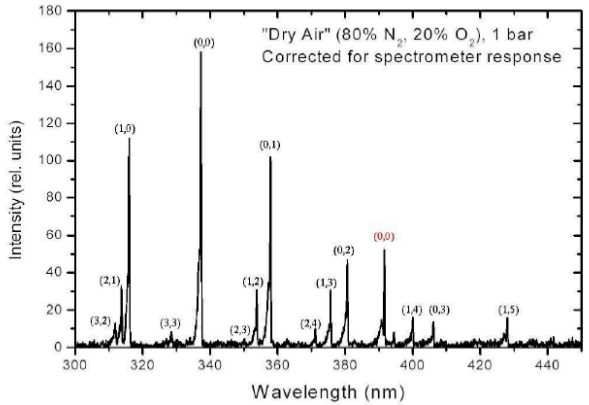


L. Scarsi



J. Linsley

Y. Takahashi



330 – 400 *nm*, UV

$$e^- + N_2 \rightarrow N_2^{*+} + e^- \ (+e^-)$$

$$e^- + N_2 \rightarrow N_2^{*+} + e^- \ (+e^-)$$
$$N_2^{*+} + e^- \rightarrow N_2^*$$

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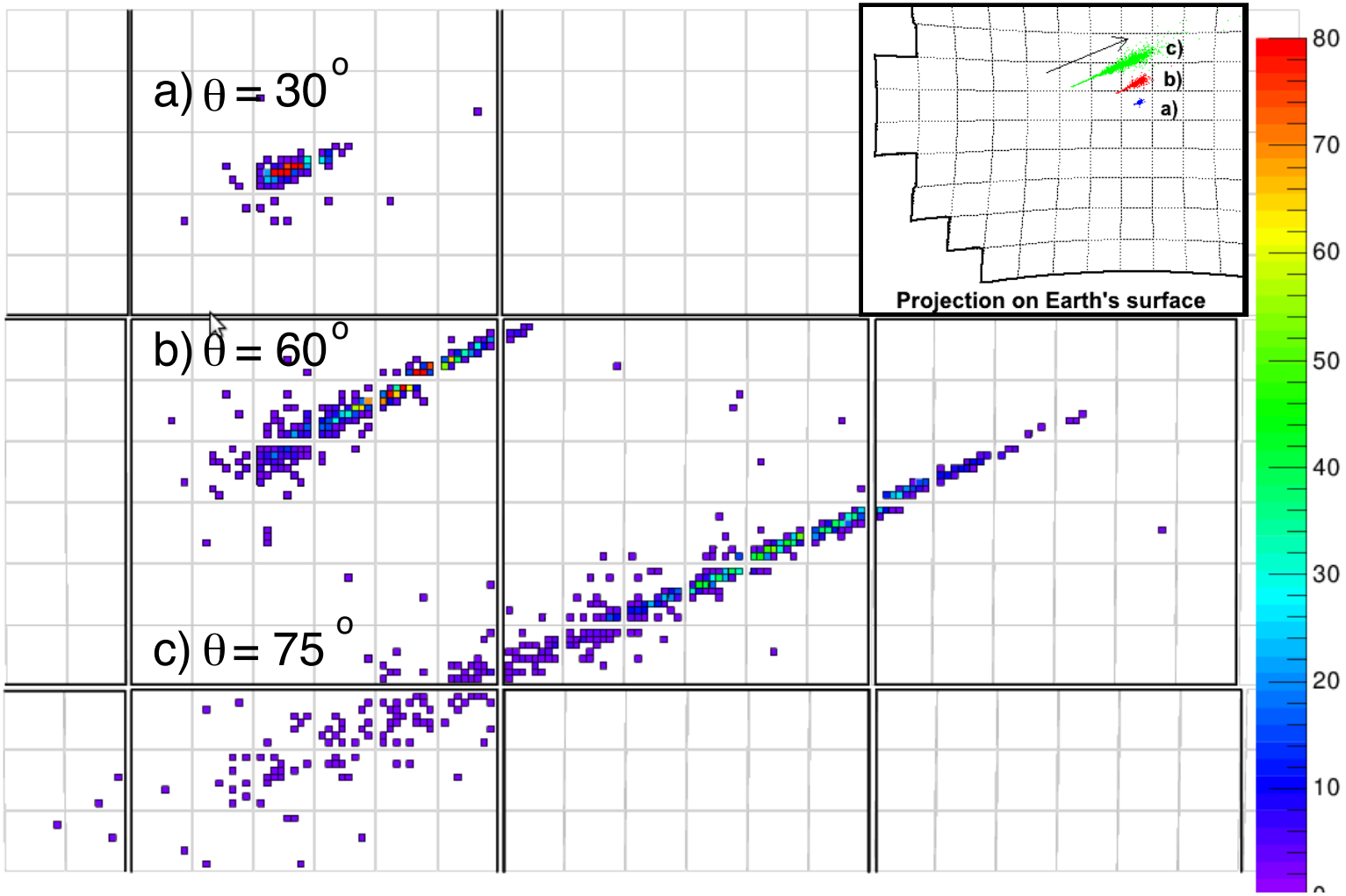
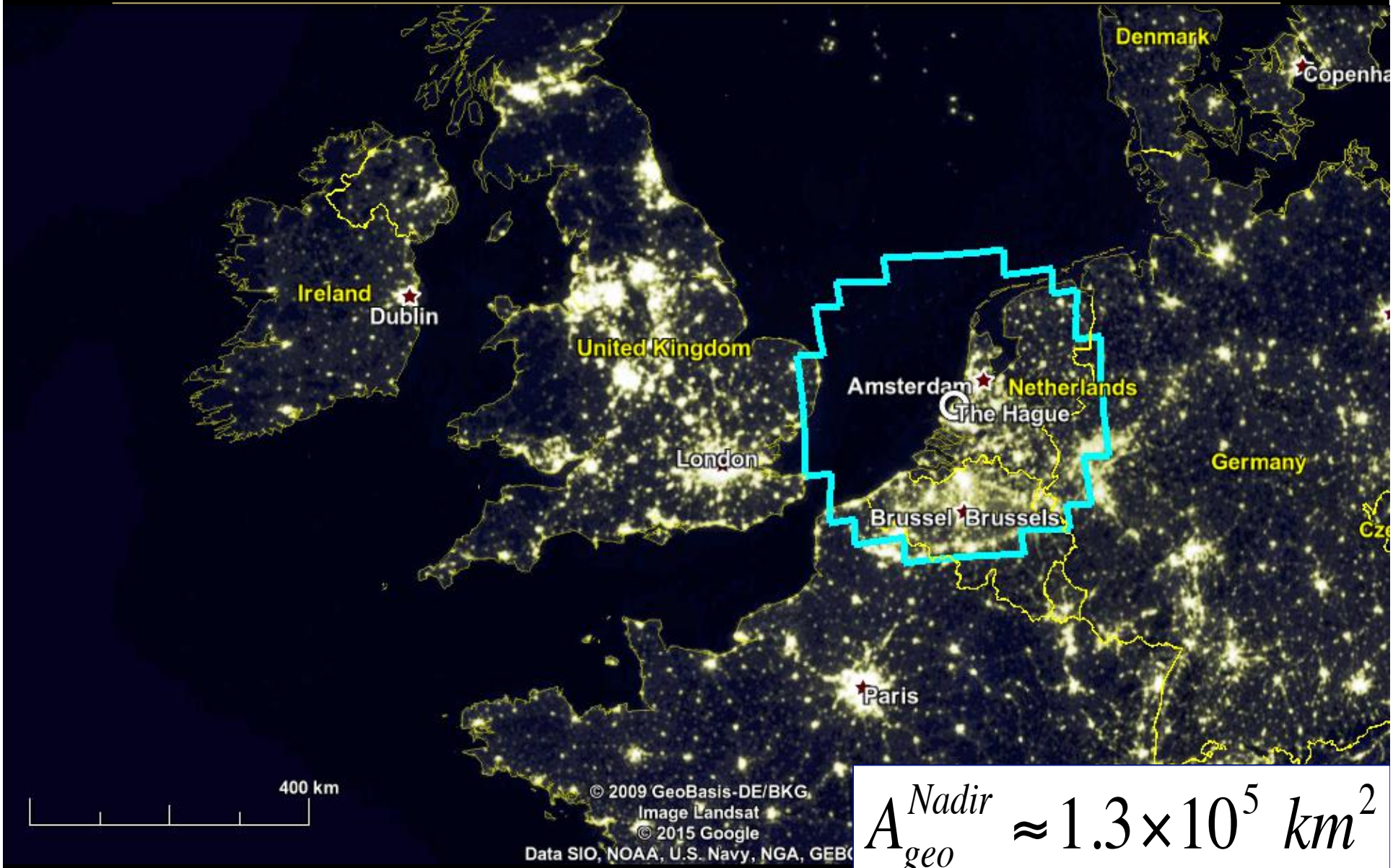
EAS tracks



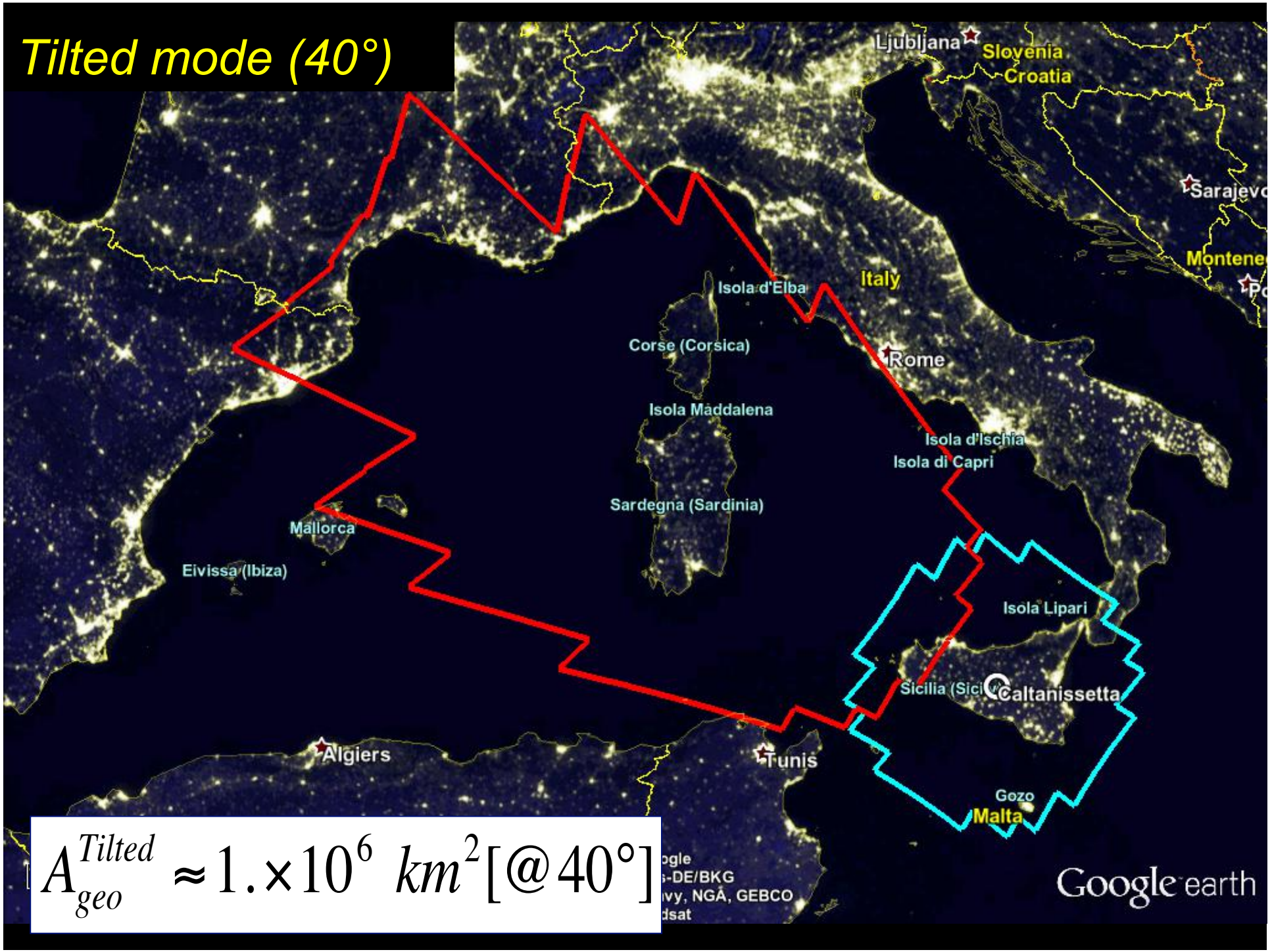
Two advantages: 1. Monitored Area

$$\approx few \times 10^{12}\ tons$$



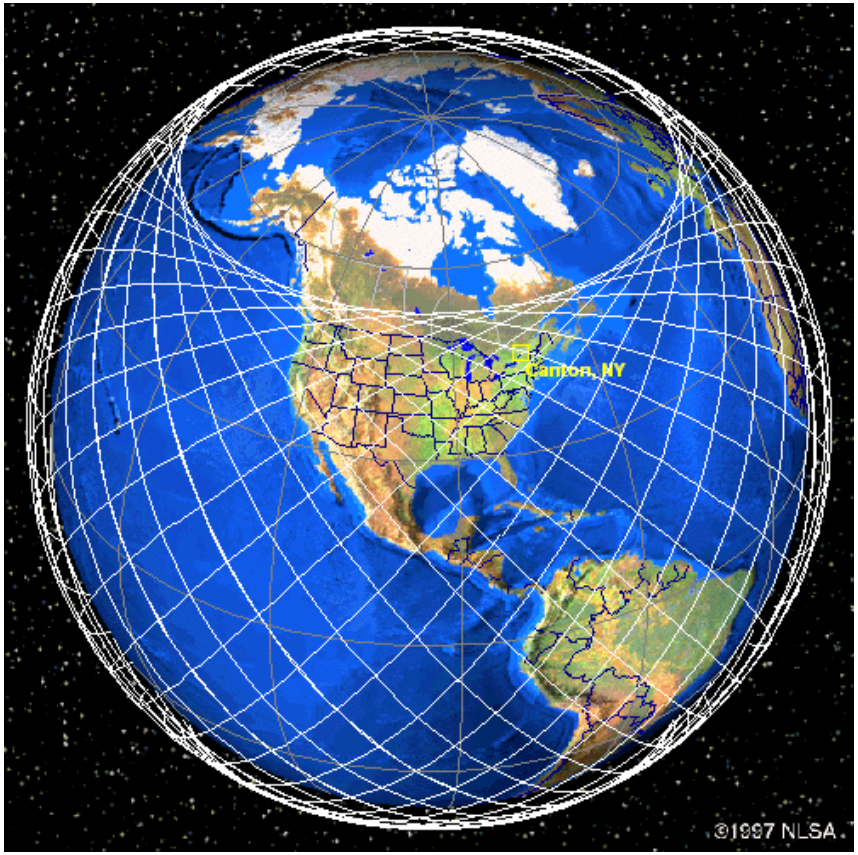
$$A_{geo}^{Nadir} \approx 1.3 \times 10^{5}\ km^{2}$$

Adams et al. , Astr. Part. Phys. 2013

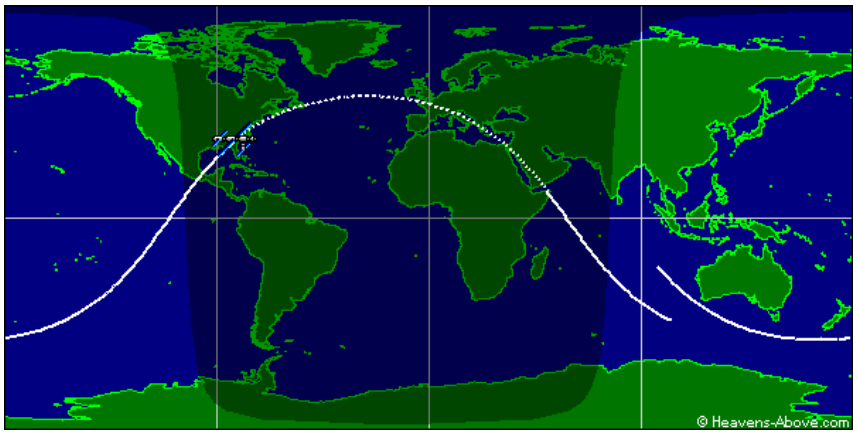

Tilted mode (40°)
Ljubljana
Slovenia
Croatia
Sarajevo
Italy
Isola d'Elba
Corse (Corsica)
Rome
Isola Maddalena
Isola d'Ischia
Isola di Capri
Sardegna (Sardinia)
Mallorca
Eivissa (Ibiza)
Isola Lipari
Caltanissetta
Algiers
Tunis
Gozo
Malta
$A_{geo}^{Tilted} \approx 1.\times 10^{6}\ km^{2}[@40°]$
Google earth

2. ISS Orbit→ Full sky Coverage…

4π coverage



http://www.nlsa.com/



Inclination: 51.6°
Height: ~400km

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

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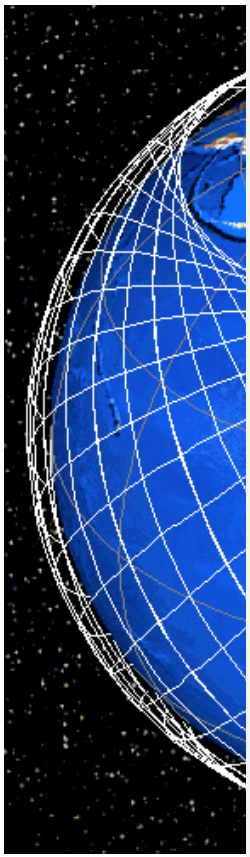
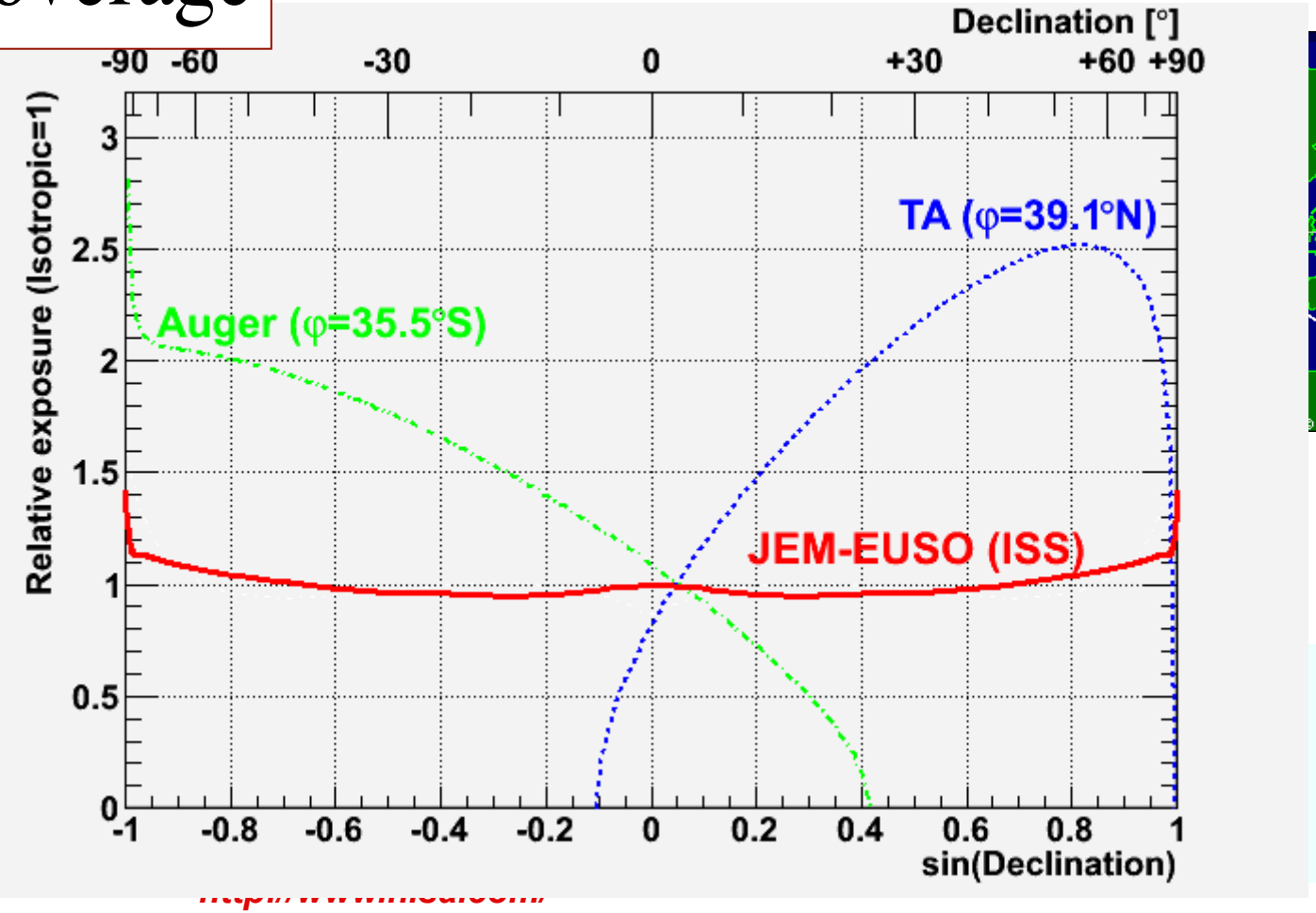
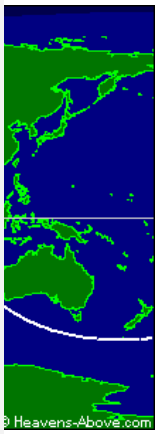
2. ISS Orbit→ Full sky Coverage…

4π coverage







… and uniform exposure

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Part II

The JEM-EUSO (or better the EUSO-) program

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The JEM-EUSO program (1)

- **Long Term: two mission profiles are being actively studied**. *The driving idea is to open the field of the observation from space of UHE particles at the dawn of the new decade, taking advantage of the ISS*

  - **JEM-EUSO** (configuration with DRAGON, launch in 2020?)
  - **K-EUSO mission** (Phase A passed, to be delivered to ROSCOSMOS in 2019)

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The JEM-EUSO program (2)

- **Long Term: two mission profiles are being actively studied** → *to open the field of the observation from space of UHE particles at the dawn of the new decade, taking advantage of the ISS*

  - **JEM-EUSO** (configuration with DRAGON, launch in 2020?)
  - **K-EUSO mission** (Phase A passed, to be delivered to ROSCOSMOS in 2019)

- **Near Term (or in operation): a series of scientific-technological steps** → **1)** *optimize our understanding of the observational technique, and* **2)** *develop engineering models that could later reduce the mission development schedule*

  - **EUSO Balloons** (First flight completed, New flights In preparation)
  - **MINI-EUSO** (on the ISS, approved by ROSCOSMOS and ASI)
  - **EUSO-TA** (On-ground, operating)

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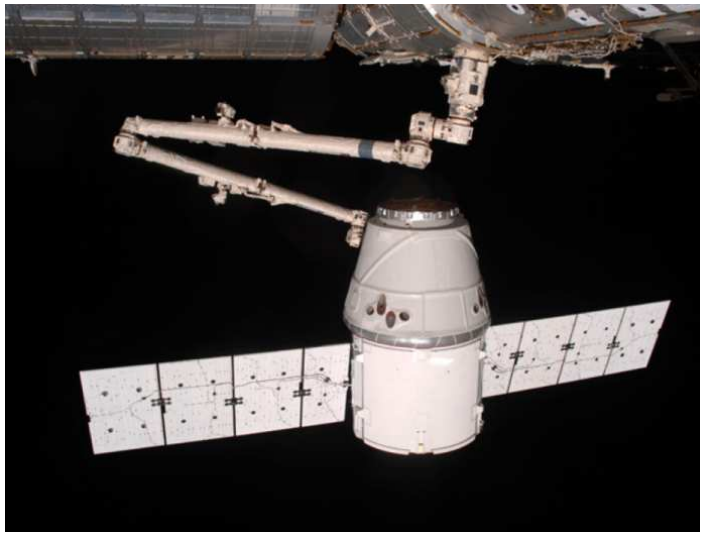
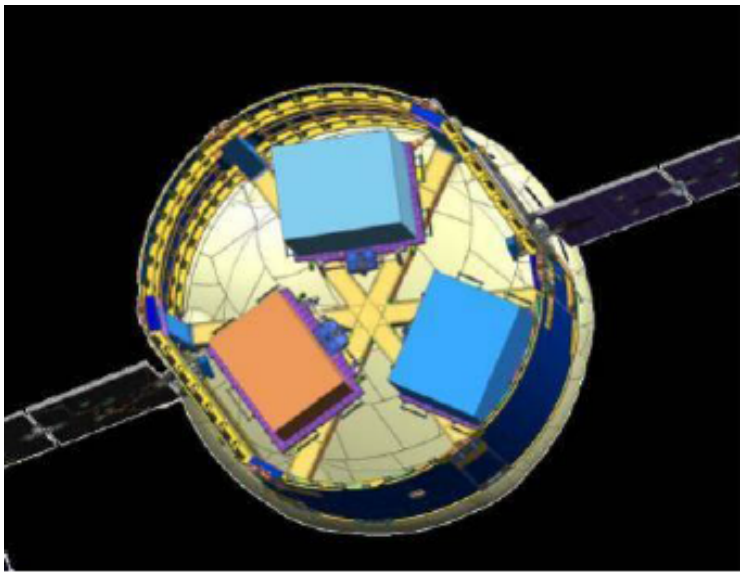
JEM-EUSO with DRAGON

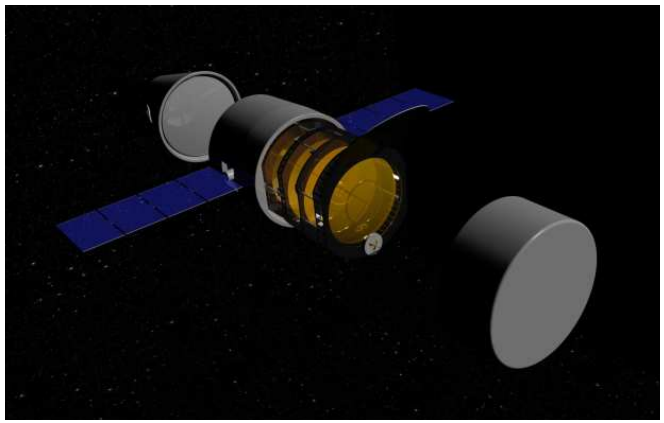
Credit NASA



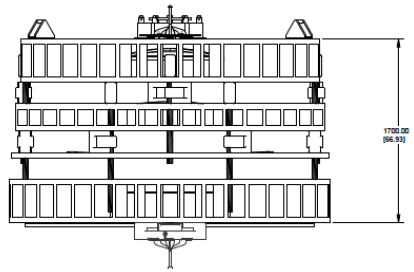
Space-X Dragon spacecraft captured by the remote manipulator arm of the ISS.



The Dragon's unpressurized module (the Trunk).



JEM-EUSO accommodated in the trunk in the **stowed configuration**. A number of design changes have been introduced.



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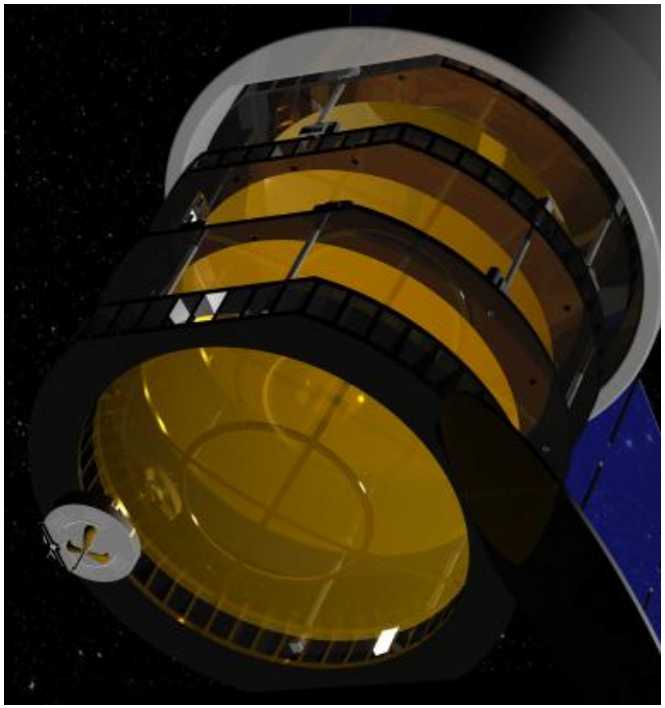
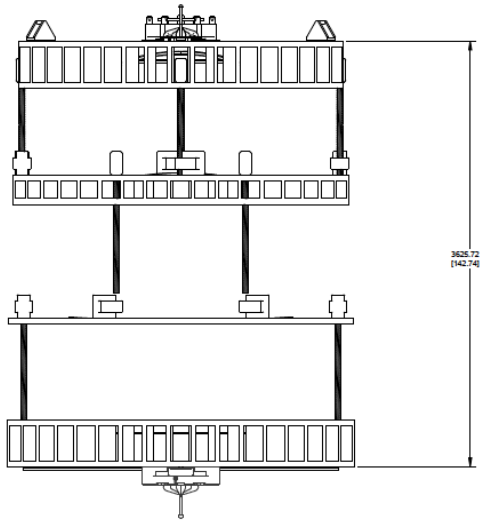
The Instrument with Dragon



Optics: three Fresnel lenses, front, middle and rear. The middle lens is finely manufactured to cancel chromatic aberration (PMMA+CYTOP).

Deployment mechanism: To bring the telescope from the stowed to the deployed configuration

FoV=±30°



Focal Surface: consisting of detectors PDM and of the associated electronics (Two levels trigger, CPU, HK…)

Atmospheric monitoring: Infrared Camera and LIDAR

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Major design change

Front Lens
∅ 2.5 m

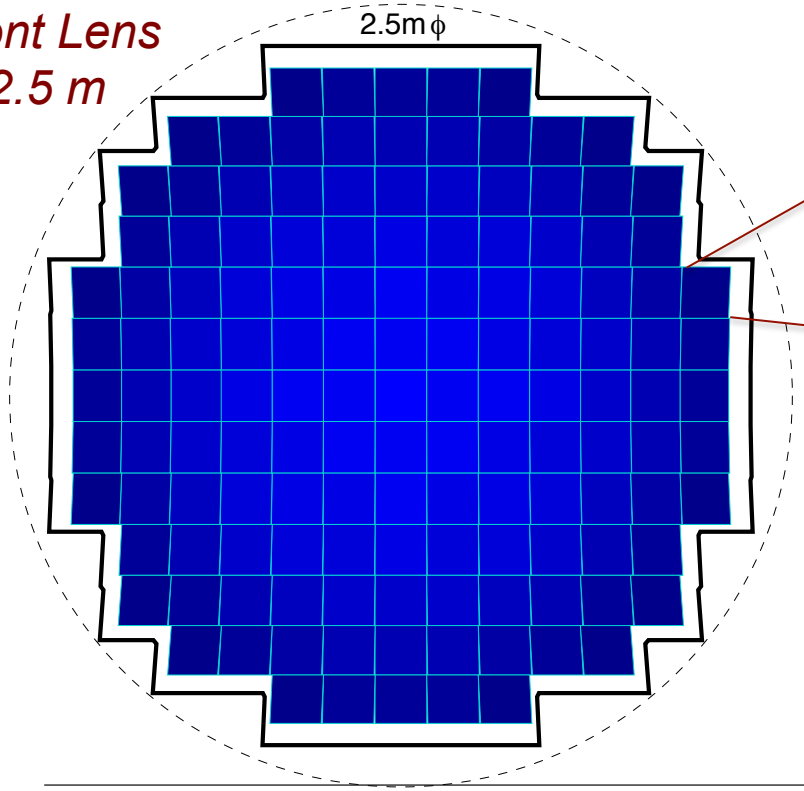
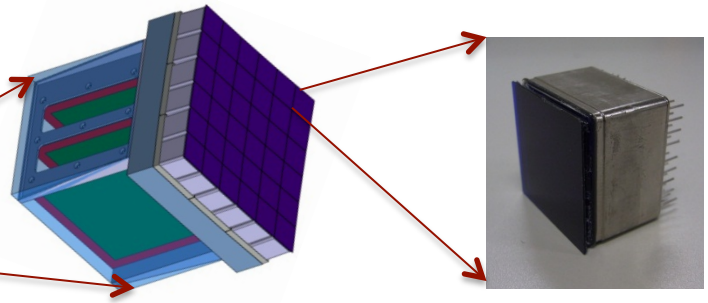


Photo Detector Module



MAPMT Hamamatsu
R11265-M64

Engineering model of the
PDM

	JEM-EUSO	
	JEM-HTV	JEM-Dragon
Lens dimensions	2650 × 1900 mm	2500 mm circular
Lens area	4.4 m^2	4.9 m^2
Pixel-angle-map	accordingly	accordingly
Focal surface diameter	2650 × 1900 mm	2200 mm circular shape
Lens thickness	10 mm	7 mm

- *137 PDMs*
- *Pixels: ≈3×10⁵*
- *Pixel size <3 mm*
- *Spherical Geometry*

$$S_{\mathrm{obs}}\,[\mathrm{km}^2] \;\sim\; 1.4\times10^5\cdot(H_0/400\;[\mathrm{km}])^2$$

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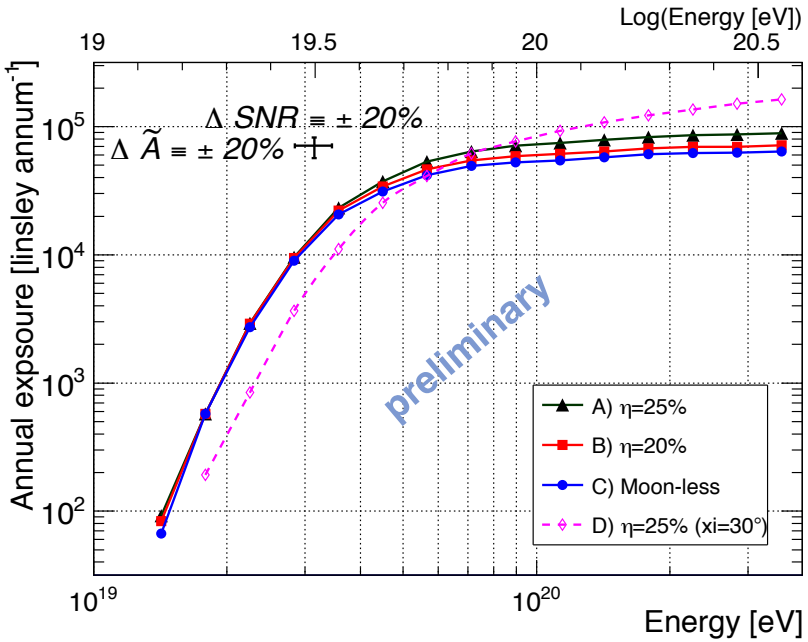
JEM-EUSO with Dragon (Performance)



Details on the duty cycle and cloud coverage in *Adams et al., 2013 and Shinozaki ID0682*

Expected annual exposure for different criteria (from Moonless to duty cycle η∼25%)

$$A_{Ann.Exp.} = (5-9)\times 10^4\, linsley$$

This corresponds to *(6-10) times what attainable by the Pierre Auger Observatory*

T. Mernik ID0577, K. Shinozaki ID0682, A. Guzmán ID0570, F. Fenu ID0611

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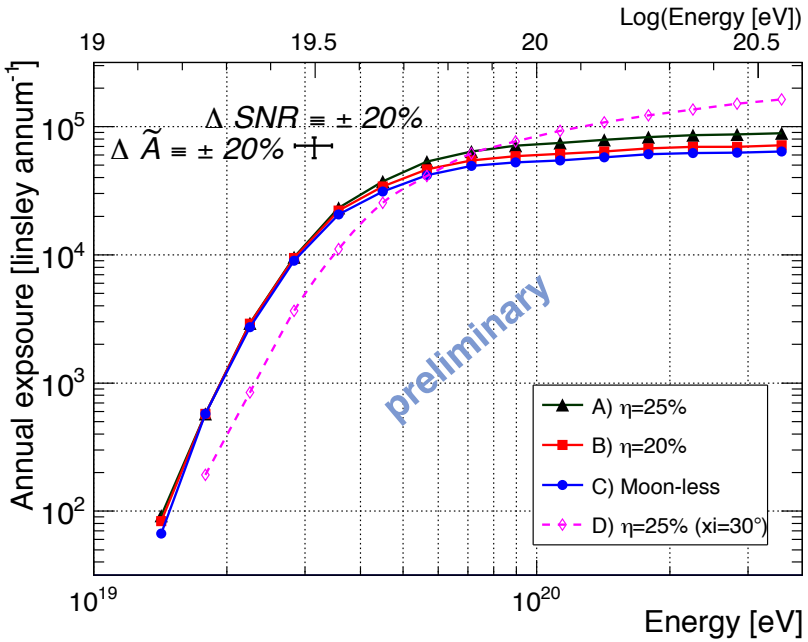
JEM-EUSO with Dragon (Performance)



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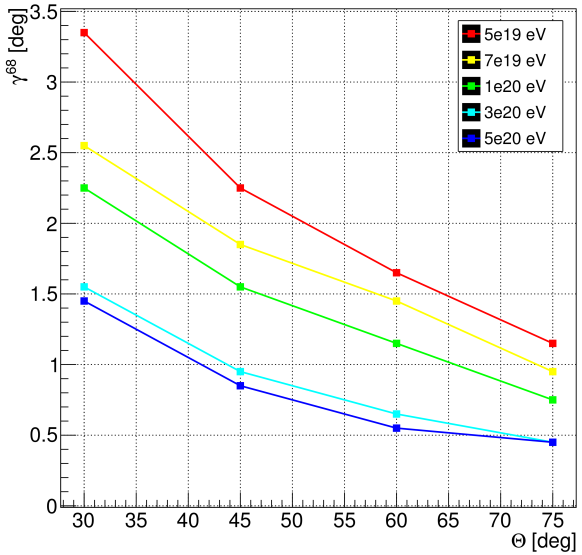

Angular resolution: it's improved with respect to JEM-EUSO with HTV and meets the requirements.

T. Mernik ID0577, K. Shinozaki ID0682, A. Guzmán ID0570, F. Fenu ID0611

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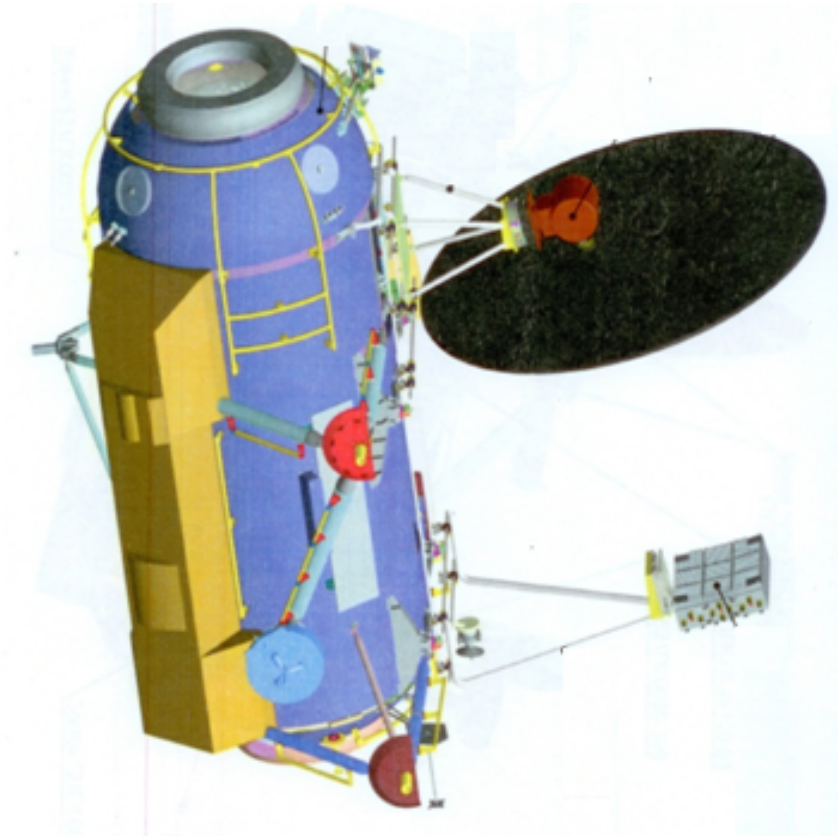
2014 development: KLYPVE-EUSO



Improved version of the KLYPVE mission

Hosted **onboard the Mini Research Module-1** module of the ISS Russian segment

The KLYPVE study is **led by MSU and ROSCOSMOS**

The study **passed the preliminary design stage** (pre-phase A study)

Technical Requirements have been defined.

M. Pansyuk ID 1165, F. Kajino ID0836, N. Sakaki ID0647

KLYPVE study is led by MSU and ROSCOSMOS

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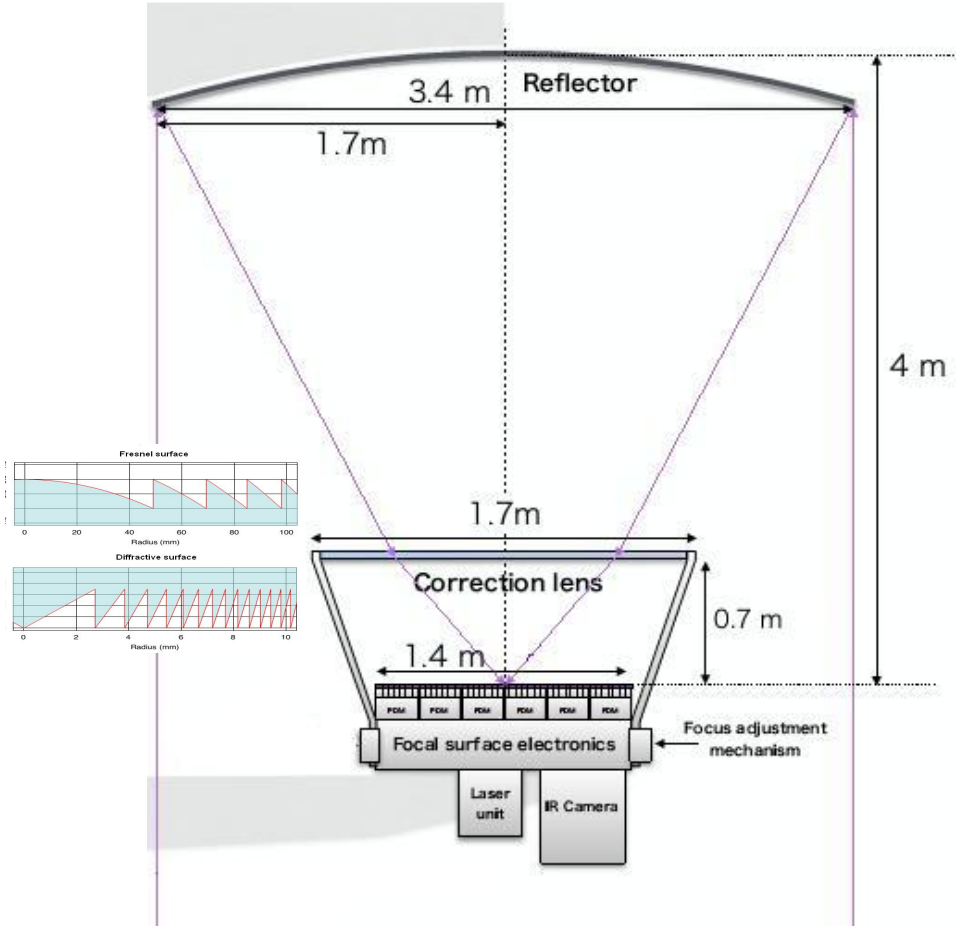
2014 development: KLYPVE-EUSO



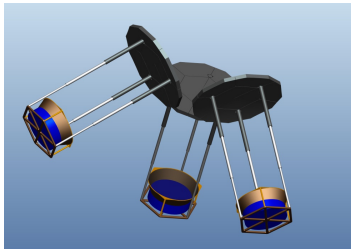
New design:

Based **on a reflector** (3.4 m ∅) + **Fresnel correcting diffracting lens** (1.7 m ∅)

The length is 4 m

The Focal Surface concept is the **JEM-EUSO's one: 52 PDMs, 1.2 x10^5 pixels**

The UV telescope is complemented by an **IR-CAM and a Laser Unit (for the LIDAR mode)**



FoV : ± 14˚ (Advanced version: ± 17˚)

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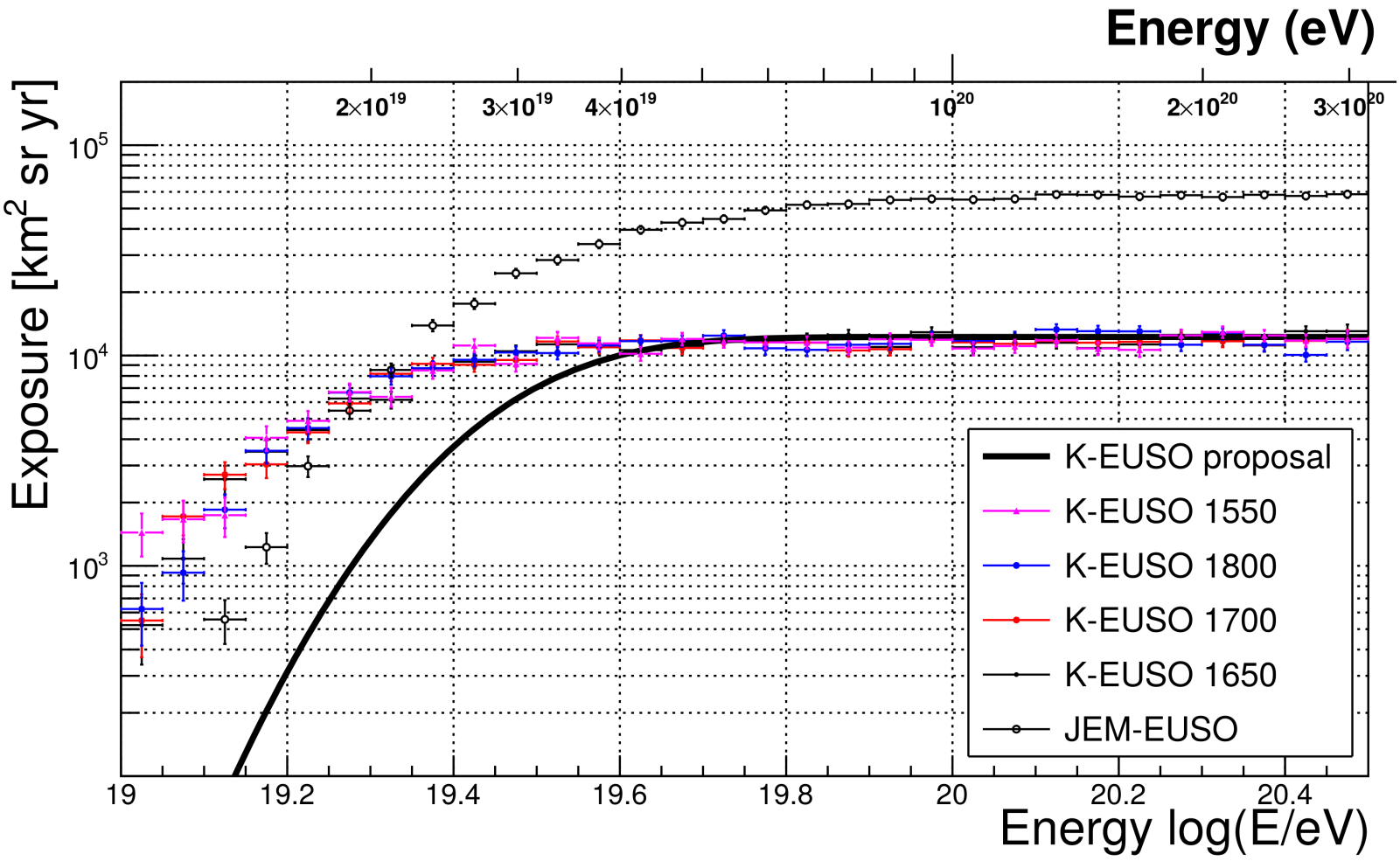
(ESAF) simulations on the exposure



Signal is brighter than in EUSO, the Expected annual exposure is about 2 times PAO‘s one

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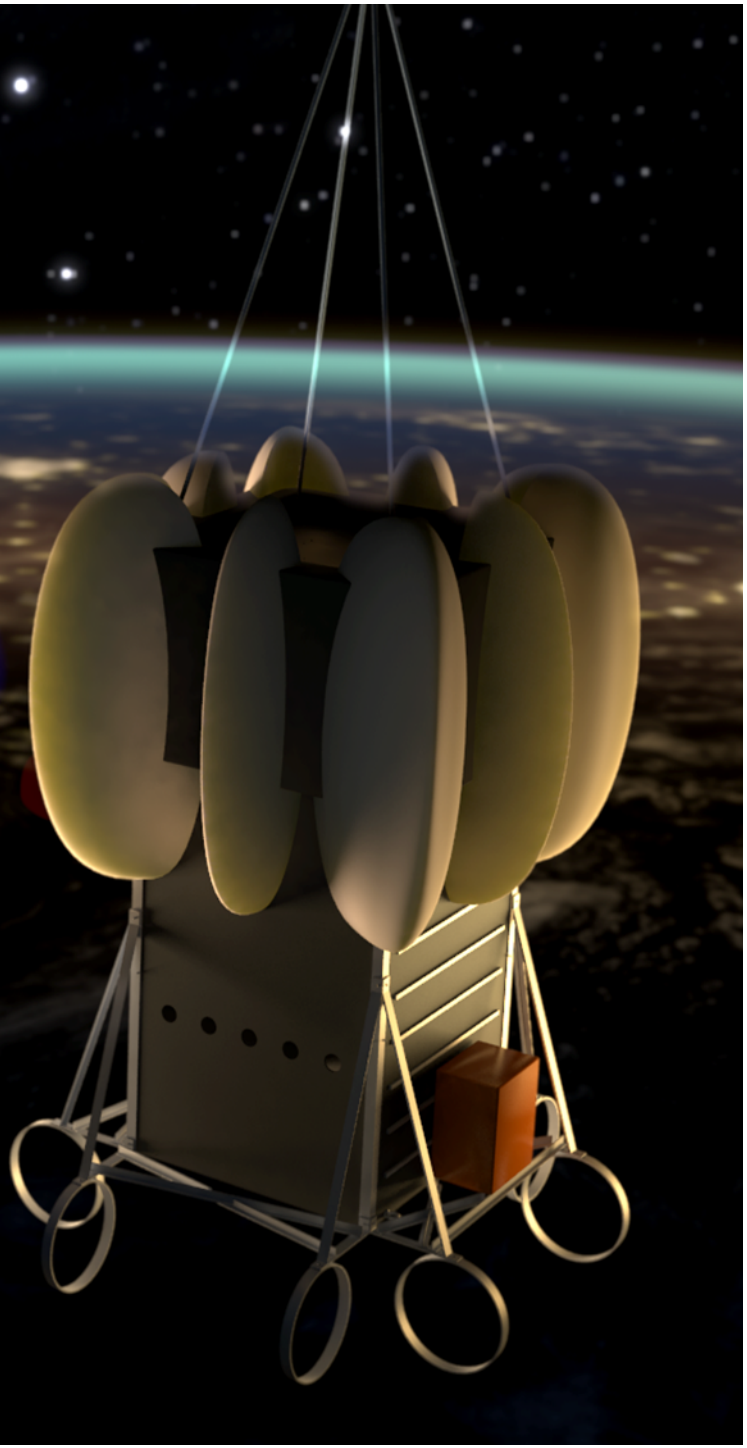
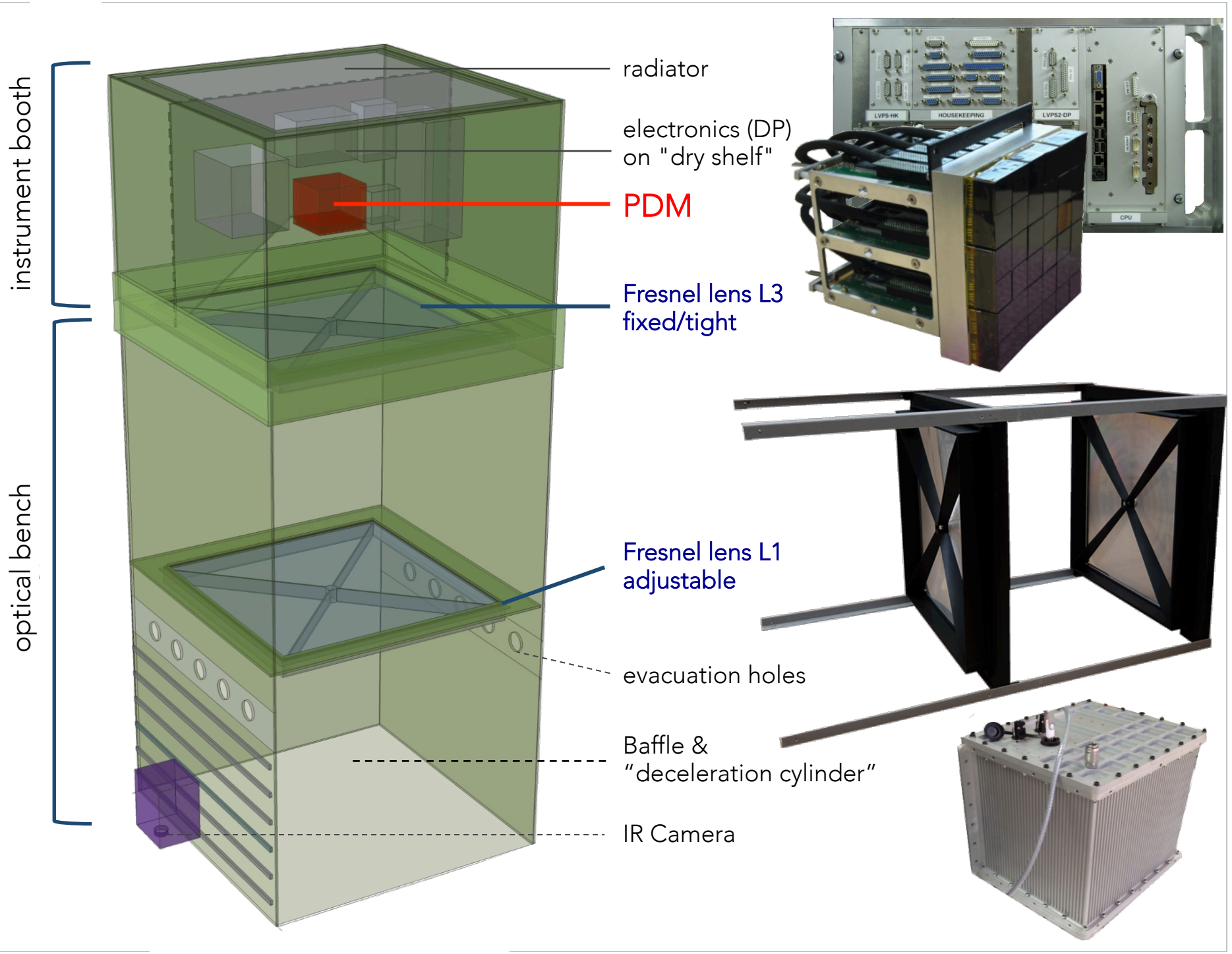
Part III

From „paper & computer work“ to real signals: the technique/technological pathfinders

EUSO-Balloon

- Test the key technologies and techniques for JEM-EUSO
- Test the JEM-EUSO EM
- Measure the background UV levels
- Search for background events that mimic air showers
- Detect the fluorescent signals of air showers from near space for the first time




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

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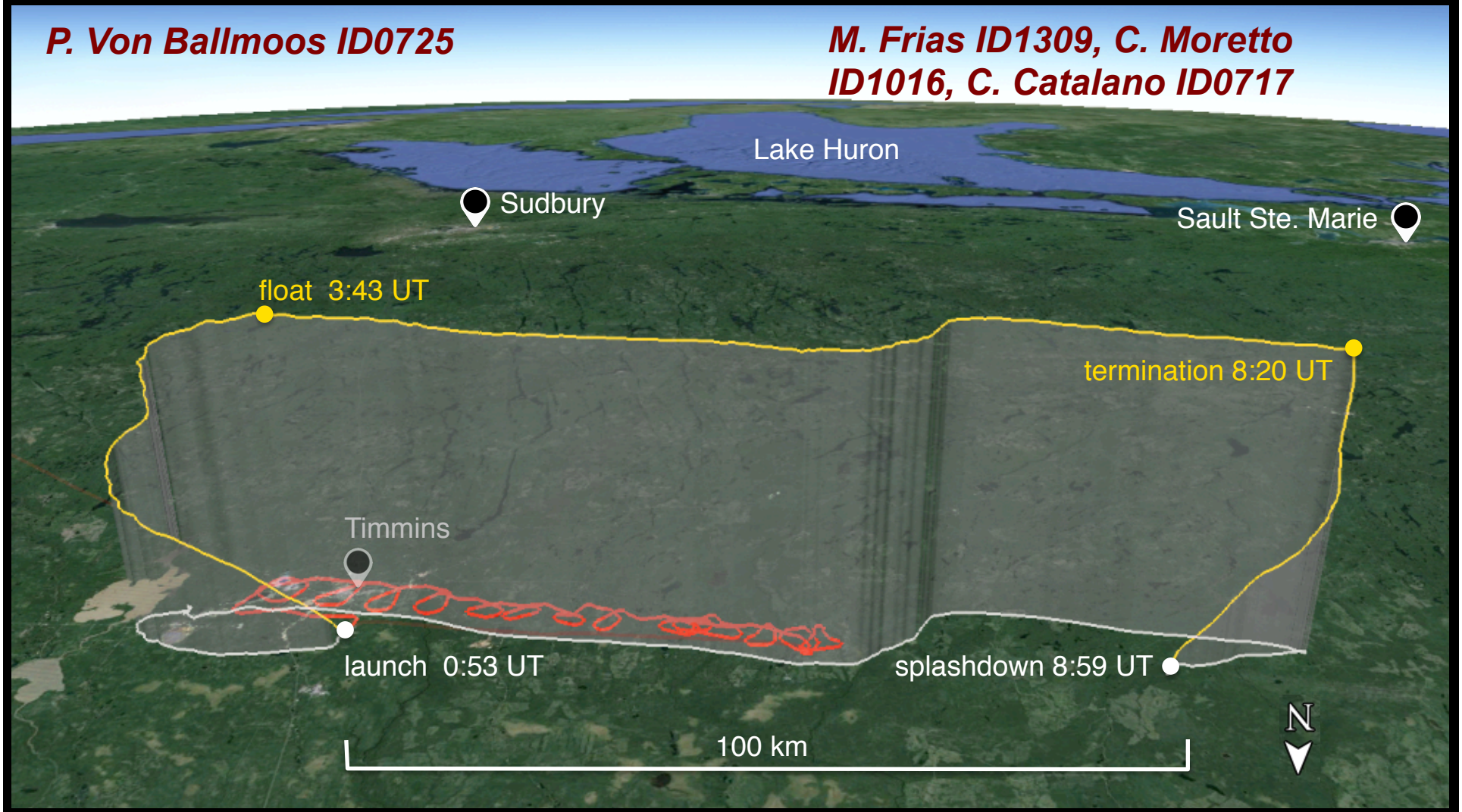
EUSO Balloon first flight (led by CNES)



EUSO-Balloon: was *launched on August, 24 2014 from Timmins, (Canada)*

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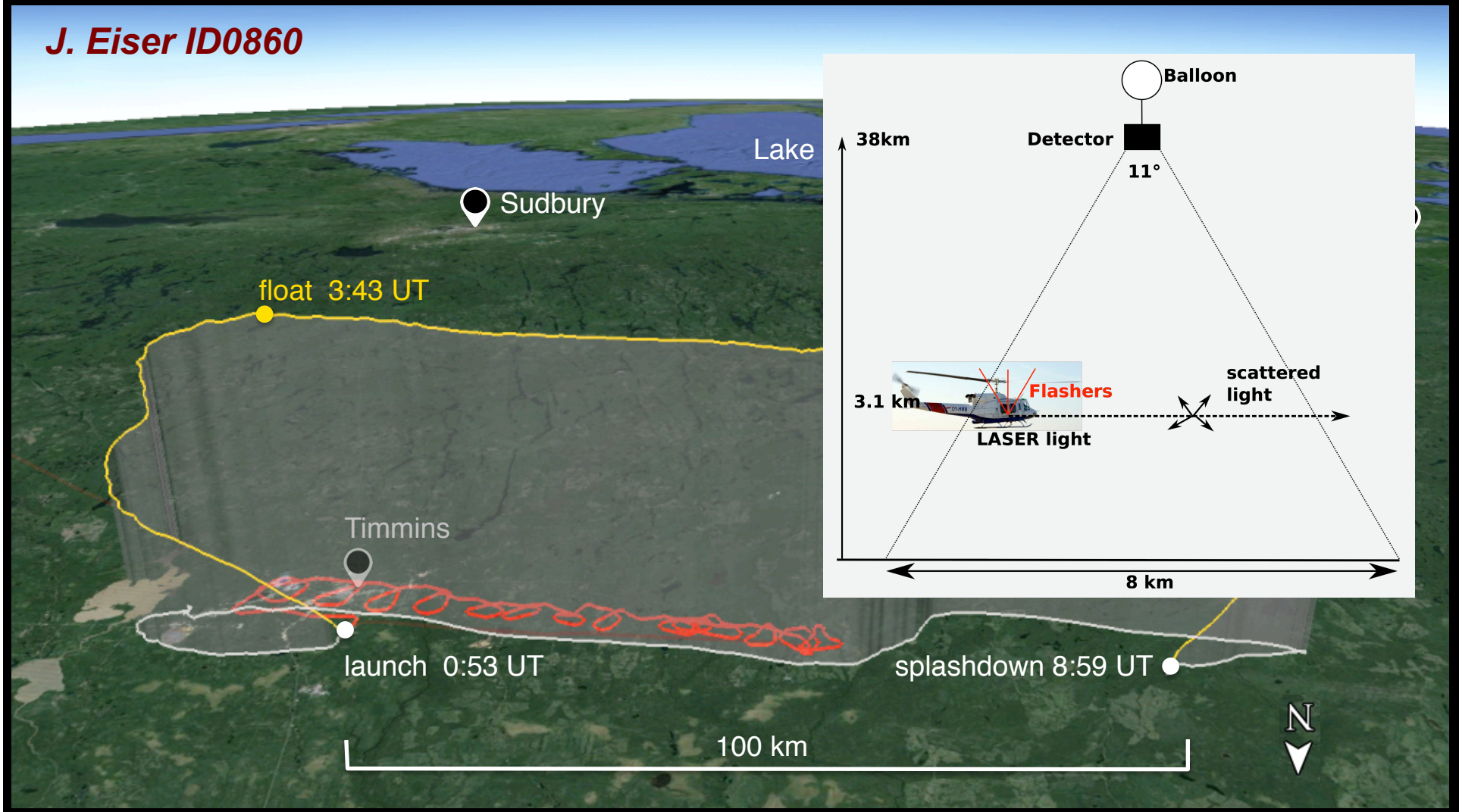
Artificial tracks! (supported by NASA)



EUSO-Balloon: was *launched on August, 24 2014 from Timmins, (Canada)*

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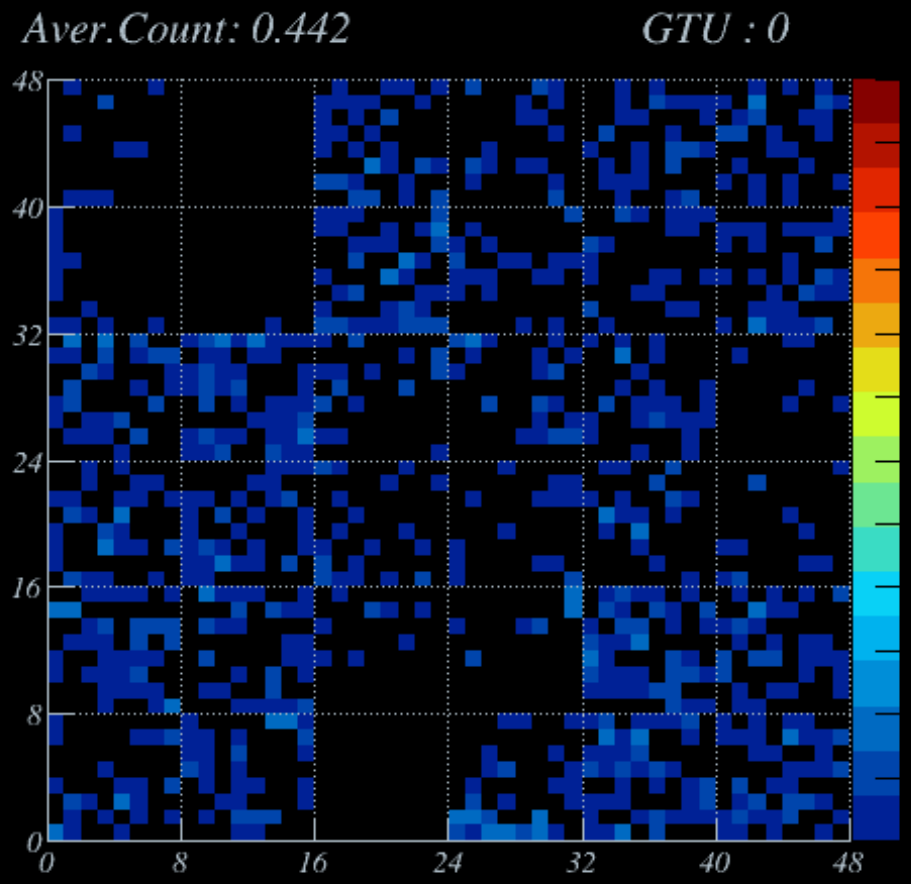
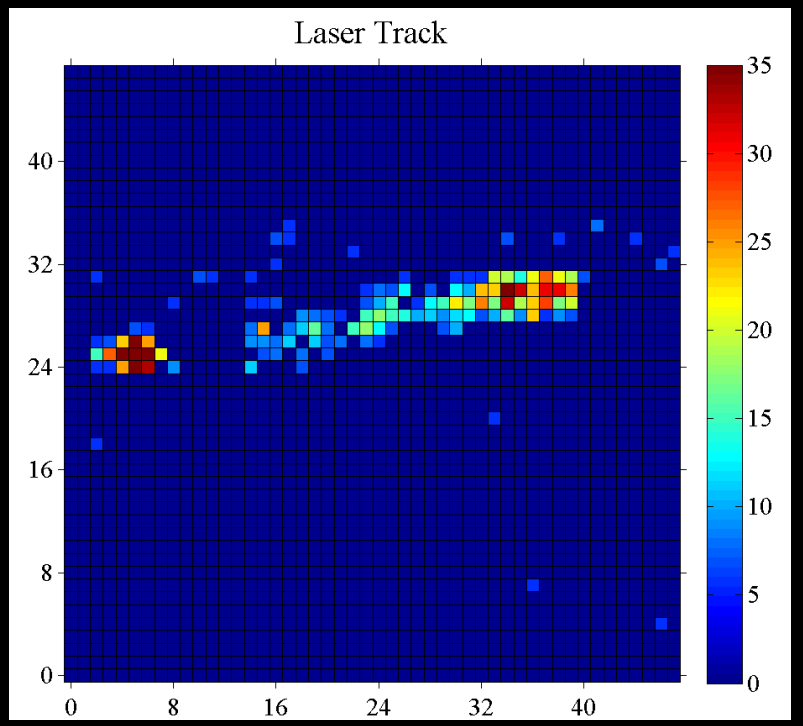
A typical detection





M. Bertaina ID 0890, S. Mackovjak ID 1302, J. F. Soriano ID 1008

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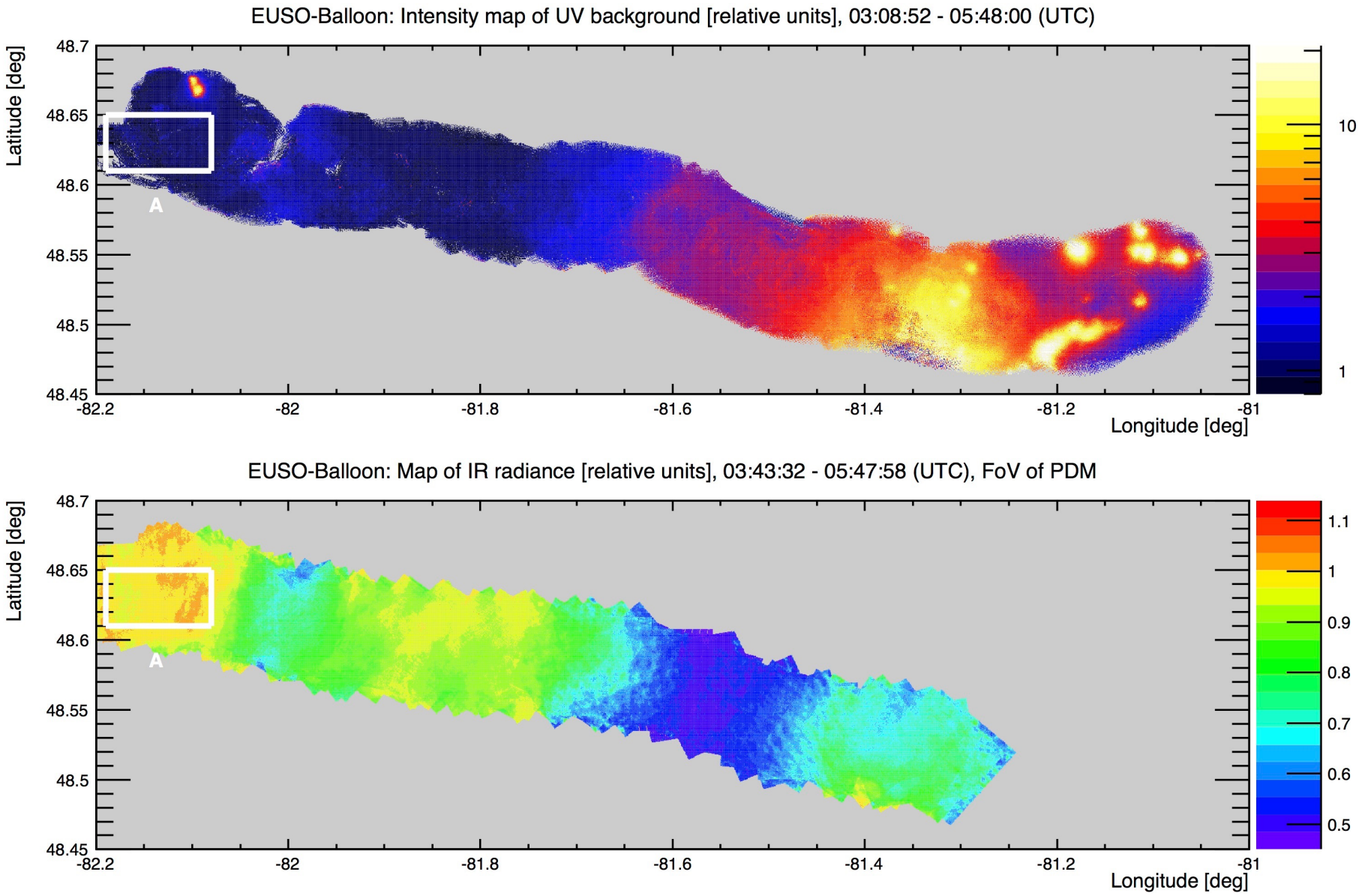
UV Background and Atmospheric Conditions



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SPB Flight under NASA leadership *(2017)*

Super Pressure Balloon (SPB)
Ultra Long Duration flight

First observations of UHECRs from near space: 20 nights

L. Wiencke ID0816
S. Bacholle ID0632

Photon Threshold	Events/ hour	Events/ dark period
200	0.42	50
300	0.18	21
400	0.09	11

Path of the successful 2015 flight by NASA, from Wanaka NZ

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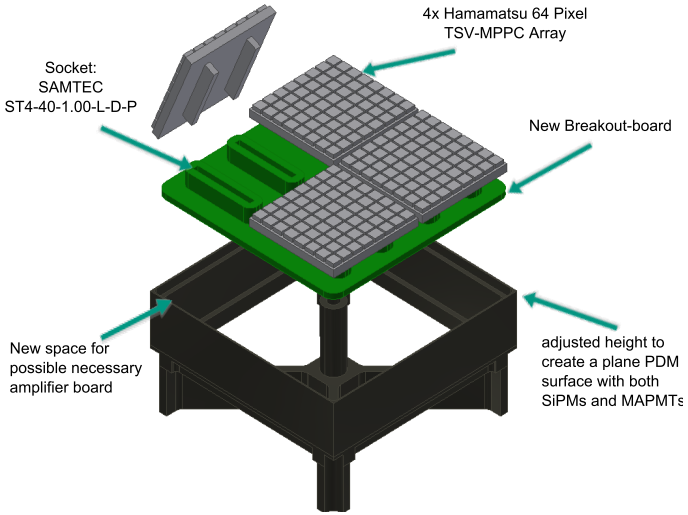
SPB Flight under NASA leadership *(2017)*



SPB-flight: Different Background conditions, transient atm. events

Test of a SiPM based detection element (a subset of the PDM)

A key development of the JEM-EUSO program

A. Haungs ID0643
M. Karus ID0661

Path of the successful 2015 flight by NASA, from Wanaka NZ

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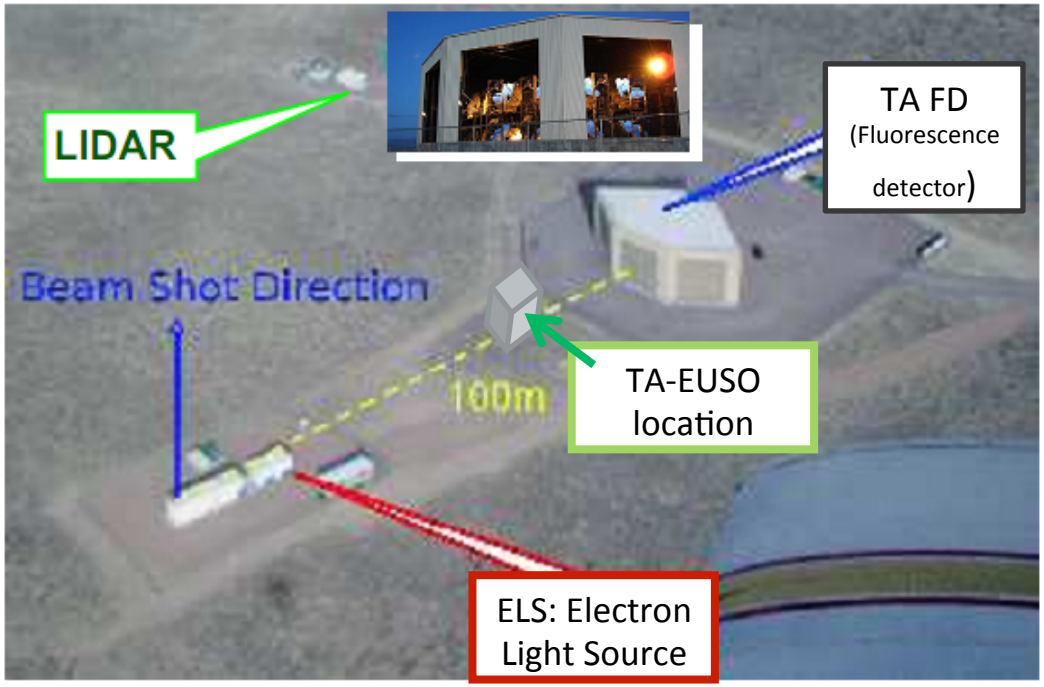
Pathfinders: EUSO-TA

EUSO-TA: *Cross-Calibration tests at the Telescope Array site* in Utah in collaboration with the ICRR in Tokyo and the TA collaboration

EUSO-TA is currently successfully operating taking a wealth of data

TA site, UTAH, Black Mesa



located at Black Rock Mesa FD Station

- *Electron Light Source at 100m*
- *Most nearby SD is at ~3.5 km*
- *Central Laser Facility ~21km*

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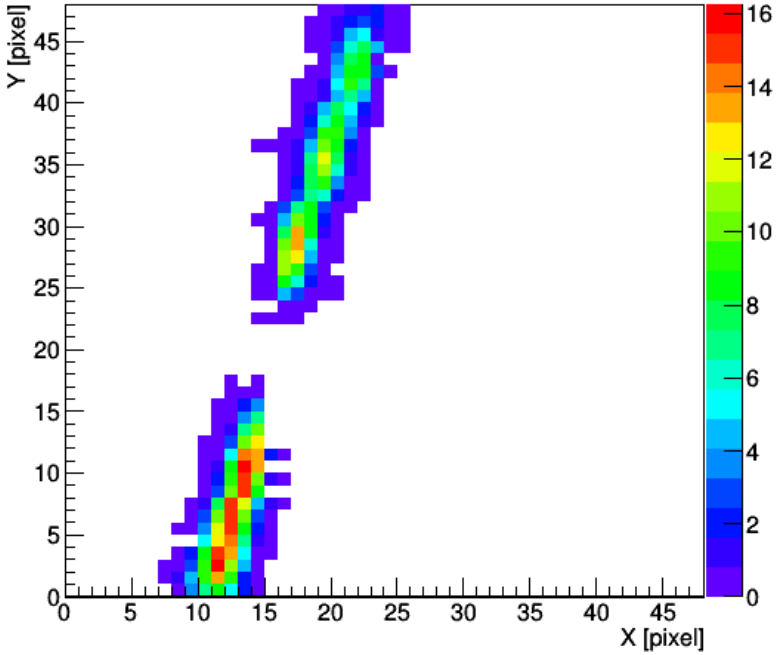
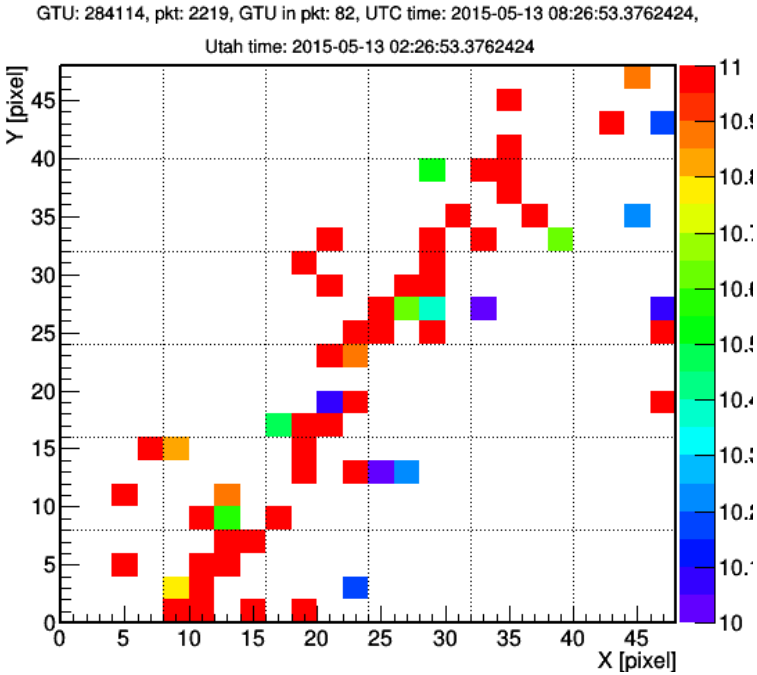
EUSO-TA results



Average of ~ 150 inclined shots of the Colorado School of Mines laser, 40 km from EUSO-TA (≃ 62mJ). **Actually tracks are seen up to from 100 km!**



A real cosmic ray: An UHECR event of low **(~10^{18} eV) energy** traversing **at ~ 2.5 km distance from EUSO-TA** visible as a track on a single GTU.

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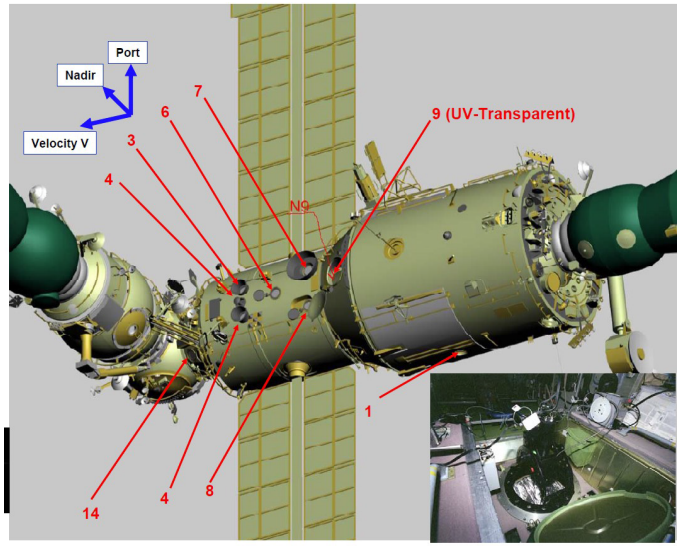
Pathfinders: Mini-EUSO



It will be hosted in the **Zvezda Module of the ISS. UV transparent Nadir looking window.**

Based on a proposal approved by ASI- the Italian Space Agency

Mini-EUSO is included, with the name **UV Atmosphere,** into the Russian **"Stage program of scientific and applied research and experiments"**

Flight is scheduled in 2017

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Science and technological objectives

a.1) ***UV emissions from night-Earth***
- Background from different lightning conditions, moon phases
- Background from different inclinations

a.2) *Map of the Earth in UV*

a.3) ***Study of atmospheric phenomena***

a.4) *Bioluminescence of Animal and vegetal*

a.5) ***Study of meteors and Search for Strange quark matter***

b.1) *Use of Fresnel lenses in space*

b.2) *Optimization of characteristics and performances of EUSO*

b.3) ***Raise the technological readiness level of the Hardware and test SiPM***

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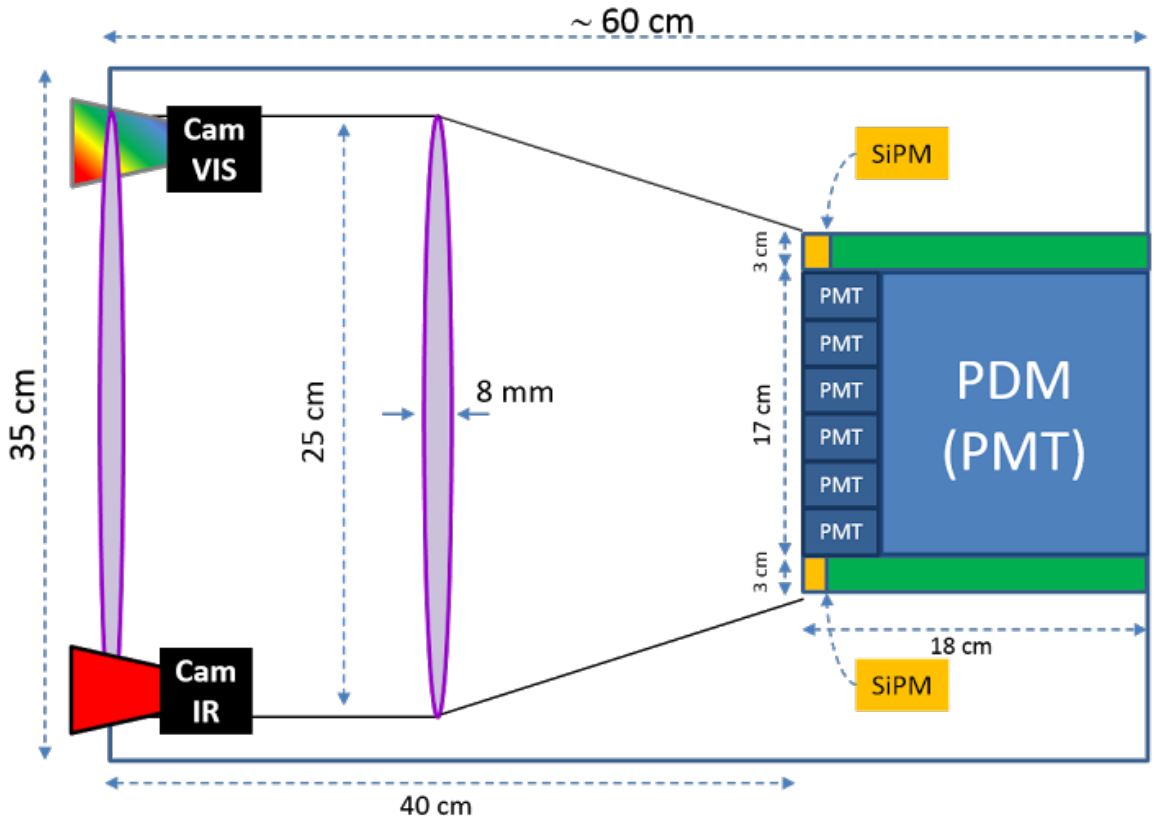
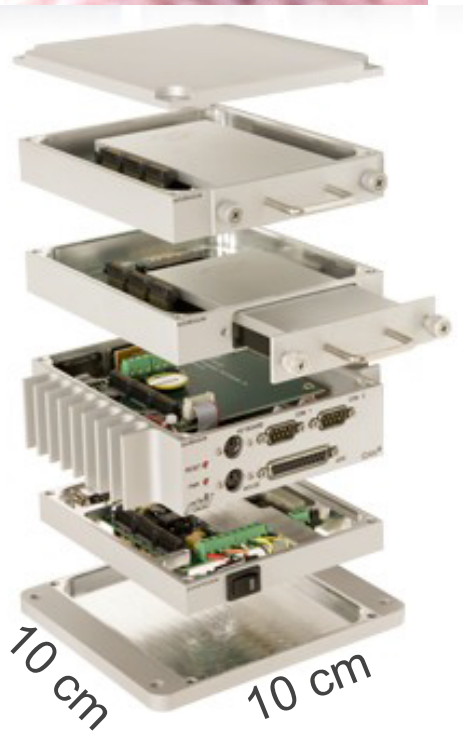
Mini-EUSO (2)





Mini-EUSO block scheme: a refractive optics based on two Fresnel lenses images UV light on 1 PDM (36 MAPMTs). A SiPM module is an option.

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Conclusions

- The JEM-EUSO program *is included in the roadmap* of the UHE Community and *the collaboration is expanding world-wide* with new partners

- *Prototypes and Models of the major elements* (Lenses, PDM, DP Unit) have been *produced and are being tested* to increase the TRLs levels.

- The Pathfinders (EUSO-TA and EUSO-Balloon) are providing exciting technical and science data: *we made the transition from "paper & Computer" work to prototyping and measurements.*

- *Mission concepts are actively studied: from K-EUSO to JEM-EUSO, but … **why not a free-flyer** in the context of the soon to come (2017) Medium-size calls in Europe (M5) and US (MIDEX)?*

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Thank you.

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Other 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*

Telemetry constrains!!!→ Be careful in comparing reduction from trigger to "reconstruction" efficiency

New JEM-EUSO mission profile using Falcon-9 and Dragon → improvements

Parameter	Value
Launch date	**tentative 2020**
Mission Lifetime	**3+… years**
Rocket	(H2B →) **Space X Falcon-9**
Transport Vehicle	(HTV →) **Dragon**
Accommodation on JEM	**EF #2 or EF #9**
Mass	(1770 kg →) **1150 kg**
Power	**926 W (op.) 352 W (non op.)**
Data rate	**285 kbps (+ on board storage)**
(ISS) **Orbit**	**400 km**
Inclination of the Orbit	**51.6°**
Operation Temperature	**-10° to 50°**

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The UV Telescope Parameters

Parameter	Value
Field of View	±30°
Monitored Area	>1.3×10^{5}km^2
Telescope aperture	≥2.5 m
Operational wavelength	290-430 nm
Resolution in angle	0.075°
Focal Plane Area	4.5 m^2
Pixel Size	<3 mm
Number of Pixels	≈3×10^5
Pixel size on ground	≈560 m
Time Resolution	2.5 μs
Dead Time	<3%
Detection Efficiency	≥20%

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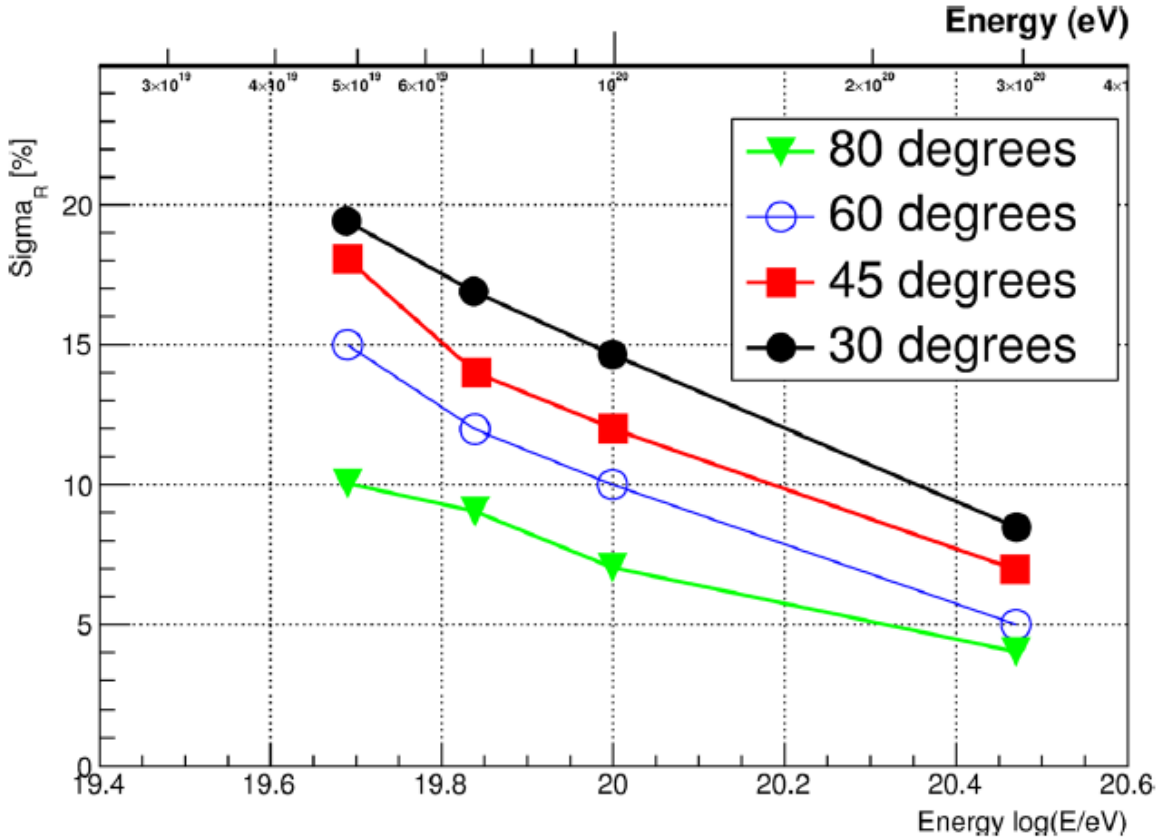
Energy resolution (HTV configuration)

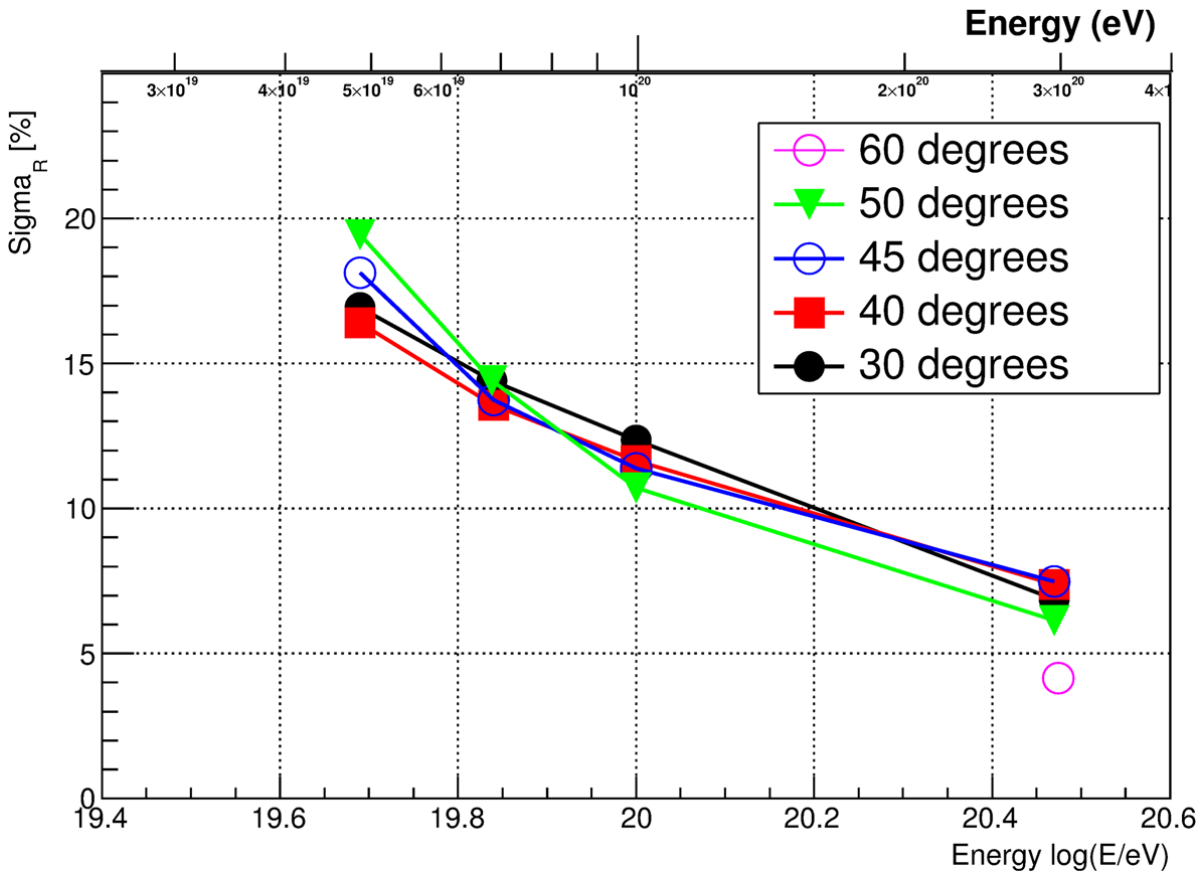


$$R = \frac{E_{reco} - E_{real}}{E_{real}}$$

Events impacting in the central
part of the field of view
namely in the inner
(+/-20,+/-20) km. The
geometry has been
reconstructed with
the slant depth method

The sigma of the R distribution

F. Fenu et al., Exp. Astron. 2014

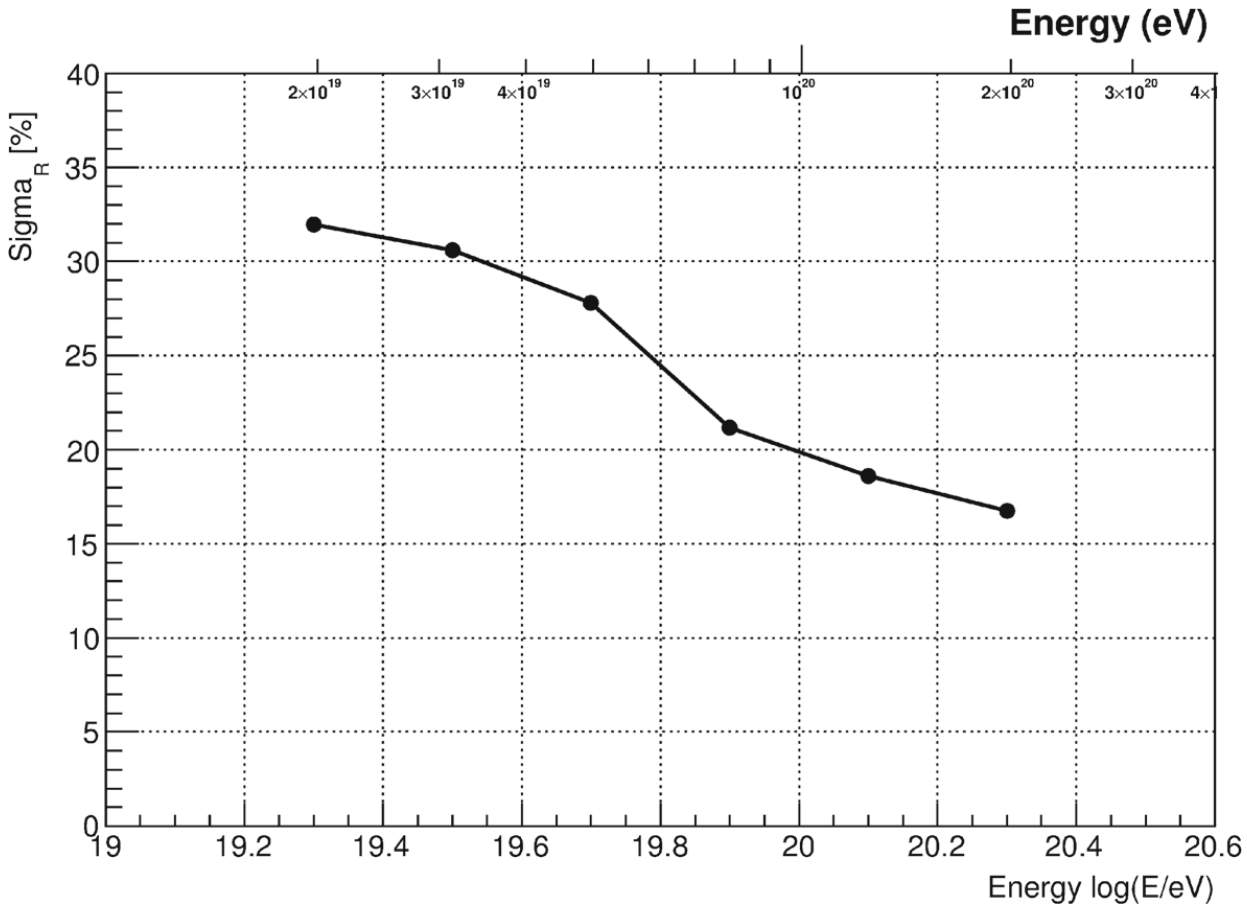


$$R = \frac{E_{reco} - E_{real}}{E_{real}}$$

Events impacting in the central part of the field of view namely in the inner (+/-20,+/-20) km. The geometry has been reconstructed with the Cherenkov Stamp method

The sigma of the R distribution

F. Fenu et al., Exp. Astron. 2014

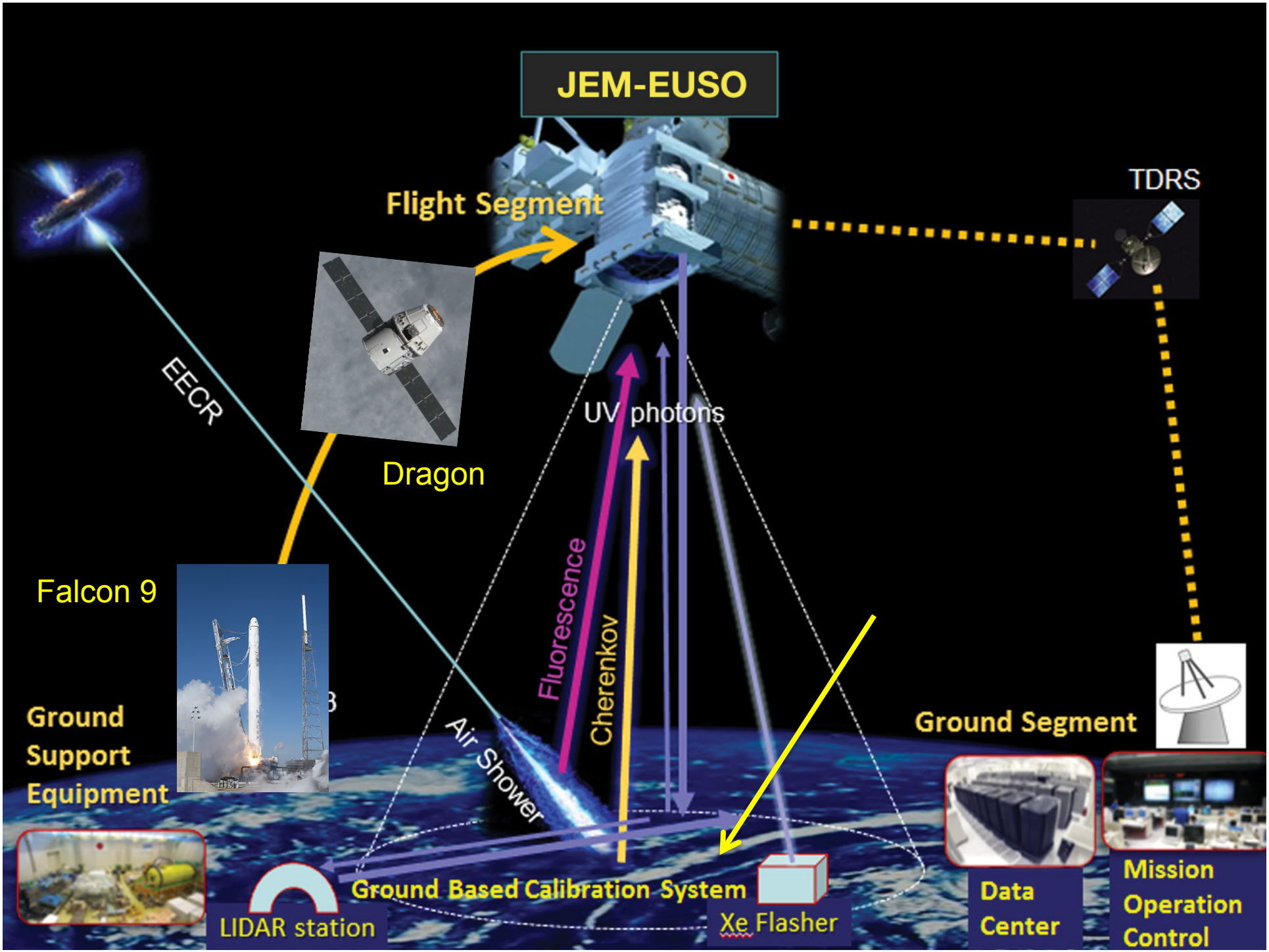


$$R = \frac{E_{reco} - E_{real}}{E_{real}}$$

All events

The sigma of the R distribution

F. Fenu et al., Exp. Astron. 2014


JEM-EUSO
Flight Segment
TDRS
EECR
Dragon
UV photons
Fluorescence
Cherenkov
Falcon 9
Air Shower
Ground Support Equipment
Ground Segment
Ground Based Calibration System
LIDAR station
Xe Flasher
Data Center
Mission Operation Control

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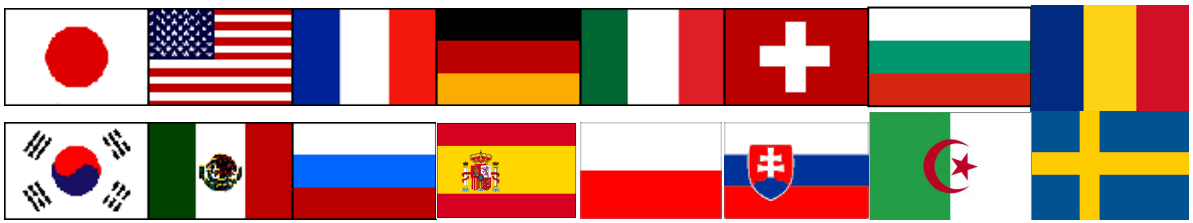
The JEM EUSO Collaboration (2015)

It's the research program of the JEM-EUSO collaboration

- Japan, Algeria, Korea, Mexico, Russia, USA
- Europe: Bulgaria, France, Germany, Italy, Poland, Romania, Slovakia, Spain, Switzerland, Sweden
- 16 Countries, about 80 Institutions, more than 300 researchers



A growing interest of the UHECR community to explore the space-option