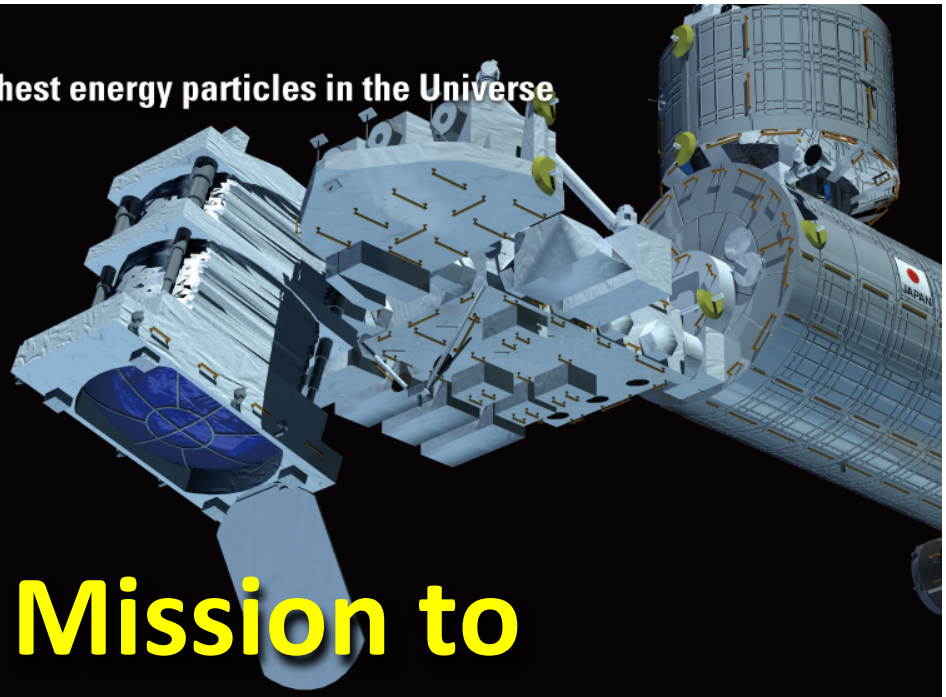
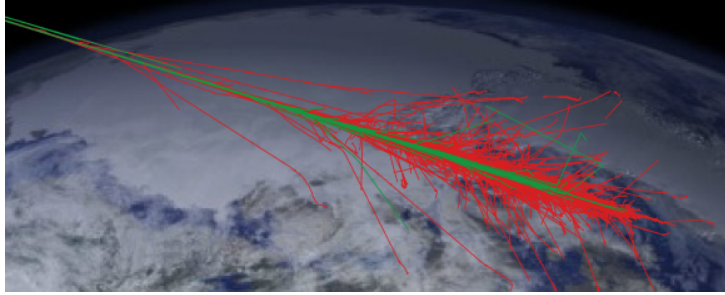
JEM-EUSO on ISS explores the origin of the highest energy particles in the Universe



The JEM-EUSO Mission to Explore the Extreme Universe from Space

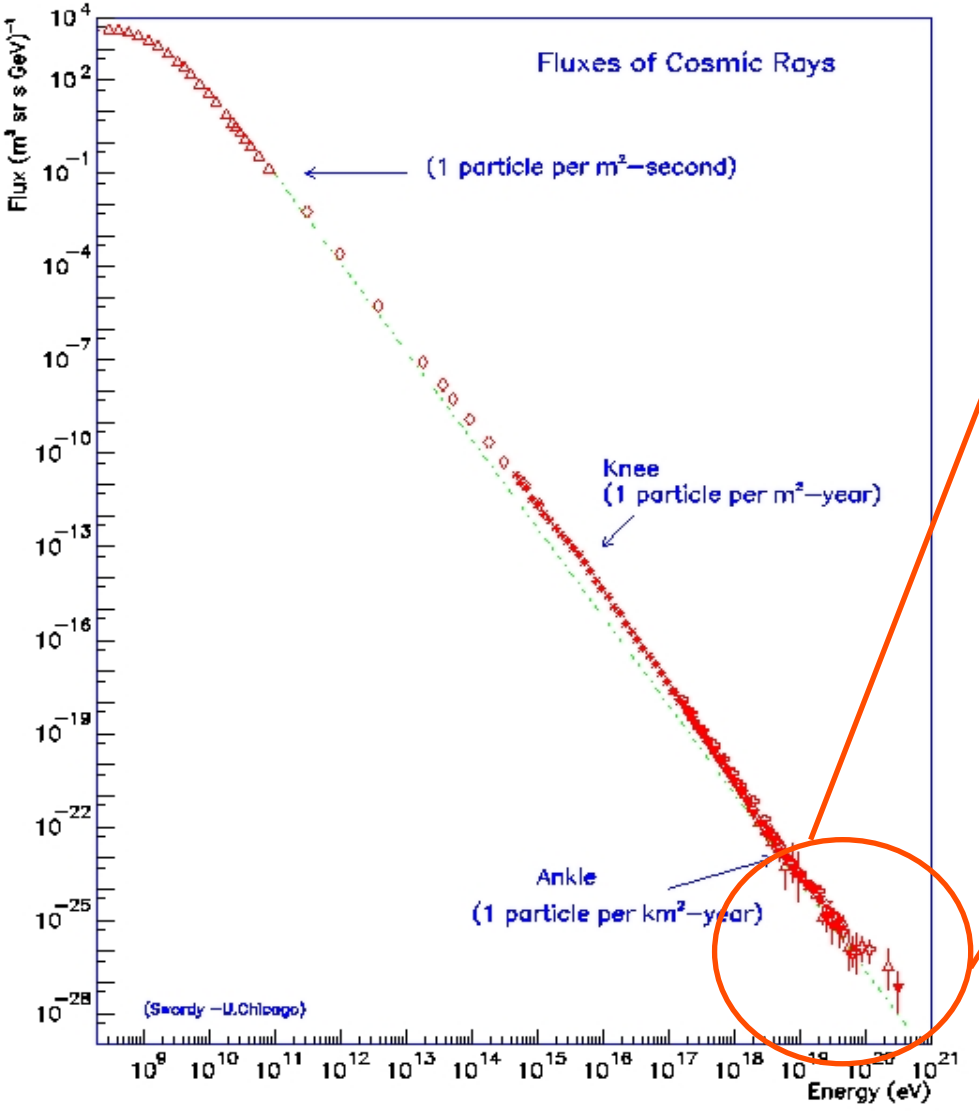
M.Ricci
INFN-SPACE/3
Laboratori Nazionali di Frascati
18 Sept. 2013

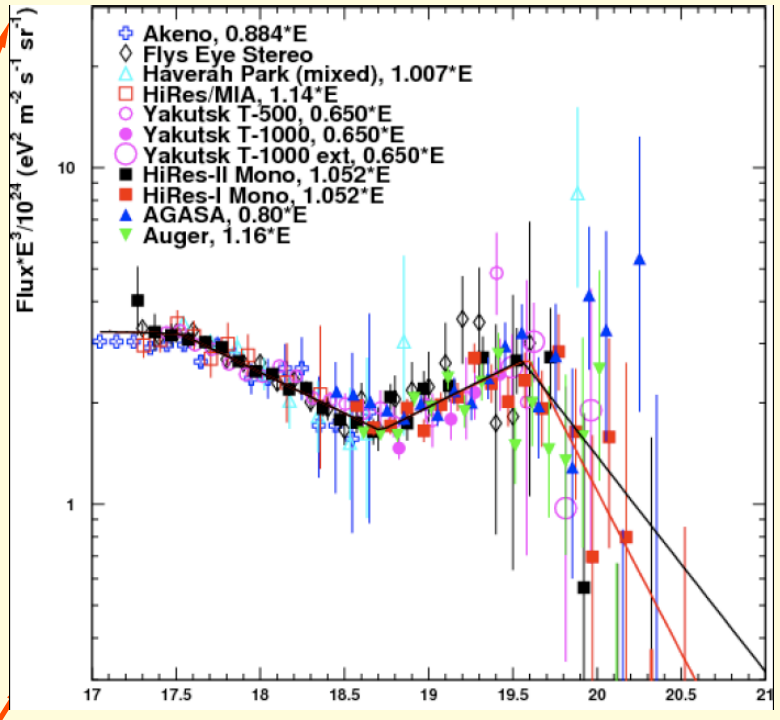


JEM-EUSO collaboration 13 Countries, 80 Institutes as of March, 2013

The Scientific Case:
Exploring the Universe at
Ultra High Energies

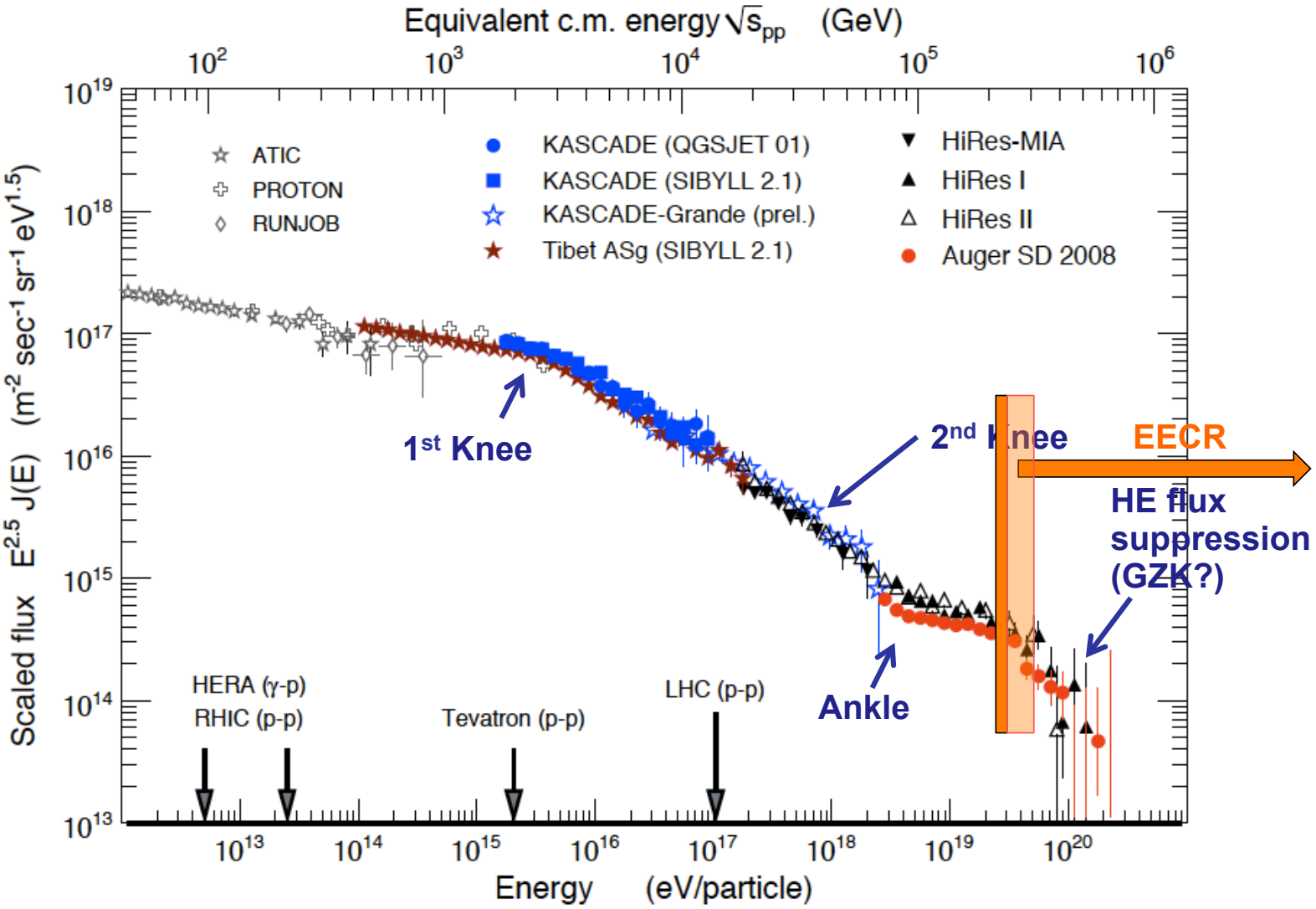
UHE ⟶ $E > (5\text{-}6)\times 10^{19}$ eV ($\sim 10^{16}$ keV)





Their Origin, their Nature and even their Route to Earth presents an extraordinary puzzle

UHE or EE region

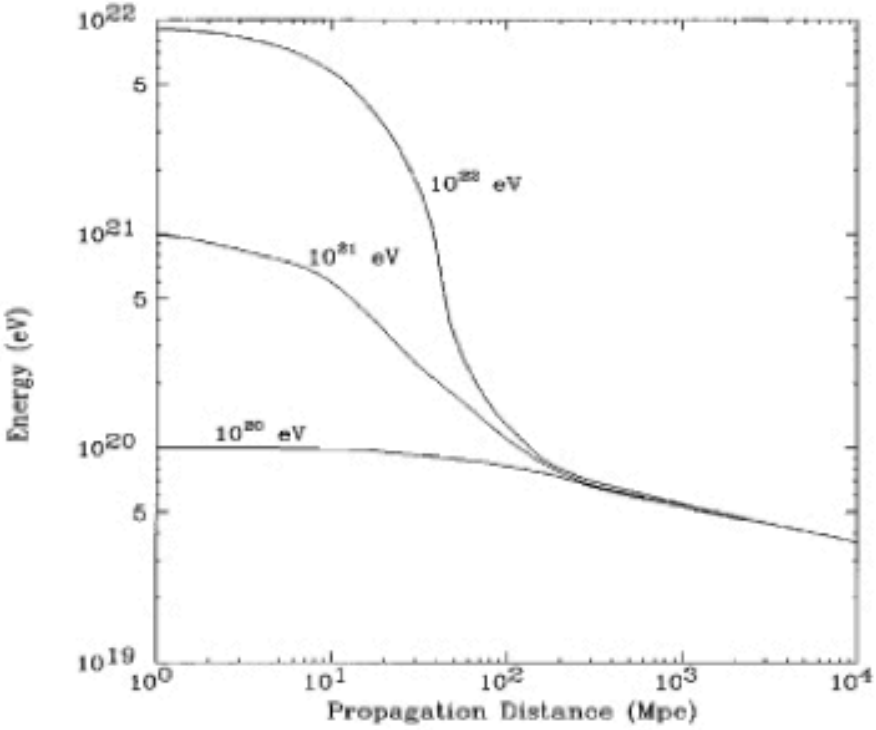


UHECR Physics – The main questions

- *Spectrum features - GZK effect?*
- *Sources?*
- *Mass composition?*
- *Anisotropy?*

The GZK (Greisen Zatsepin Kuzmin) Limit

$$p + \gamma_{cmb} \rightarrow \Delta^{+} \rightarrow p + \pi^{0}$$
$$\rightarrow \Delta^{+} \rightarrow n + \pi^{+}$$



- When this process is energetically allowed (~ 5 x 10^{19} eV), space becomes opaque to cosmic rays
- Sources of CR with energies above the GZK limit must be 'close', < 100 Mpc
- ie: within the well known local galactic cluster...
- No known acceleration sites for such high energies...

Current Observatories of Ultrahigh Energy Cosmic Rays

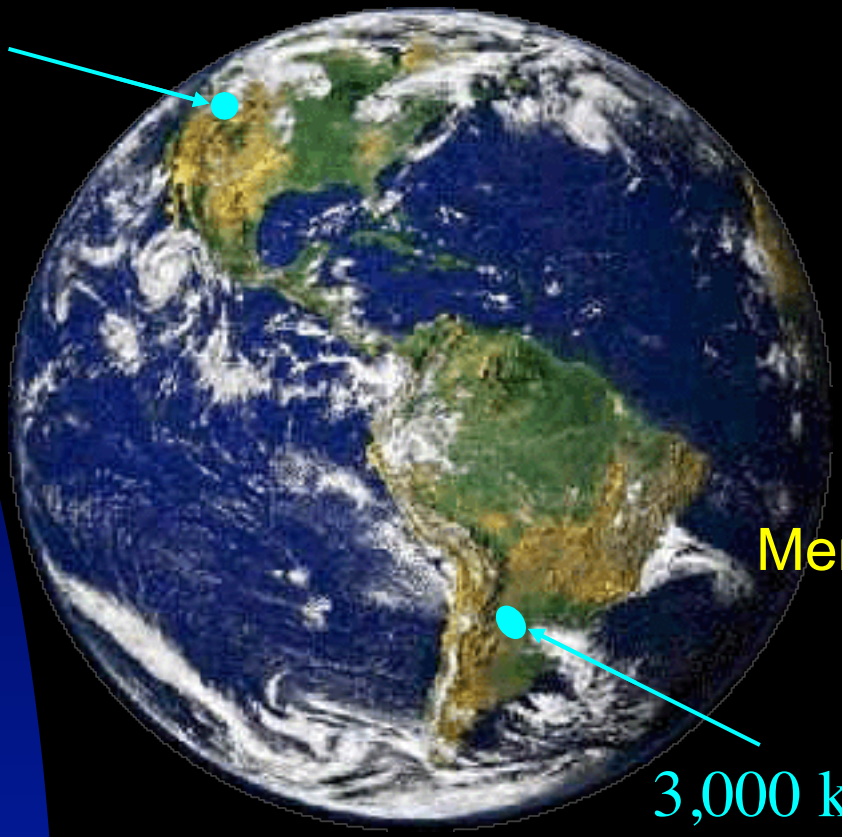
Telescope Array

Utah, USA

(5 country collaboration)

700 km^2 array

3 fluorescence telescopes



Pierre Auger Observatory

Mendoza, Argentina

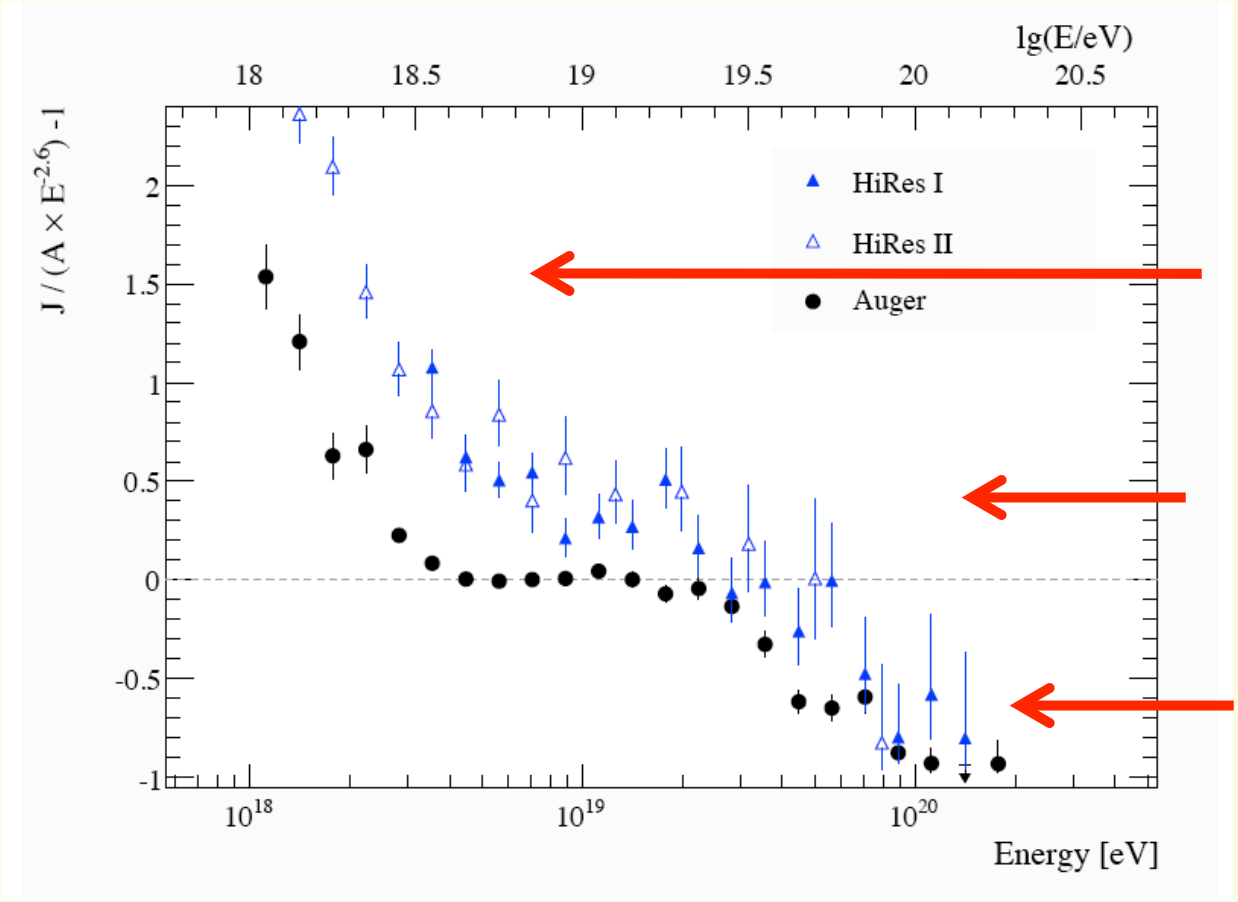
(19 country collaboration)

3,000 km^2 array

4 fluorescence telescopes

A key result of Auger South and HiRes

The Auger Collaboration (2008a), Abbasi et al. (2008), Bergman (2008), Fukushima (2011)



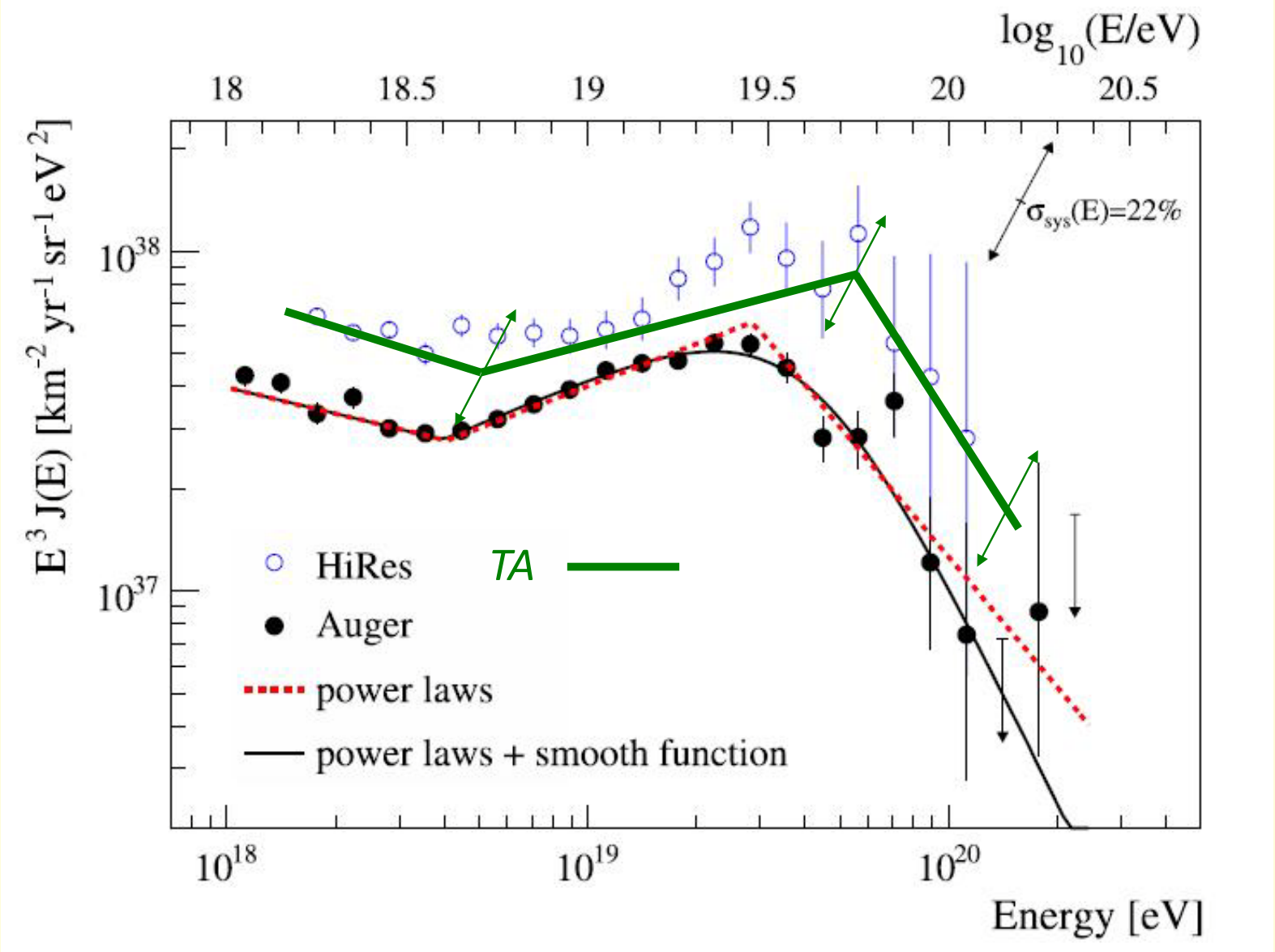
$\gamma_1 = 3.26 \pm 0.04$

$\gamma_2 = 2.59 \pm 0.02$

$\gamma_3 = 4.3 \pm 0.2$

Observation of a "flux suppression" in the spectrum: GZK feature (?)

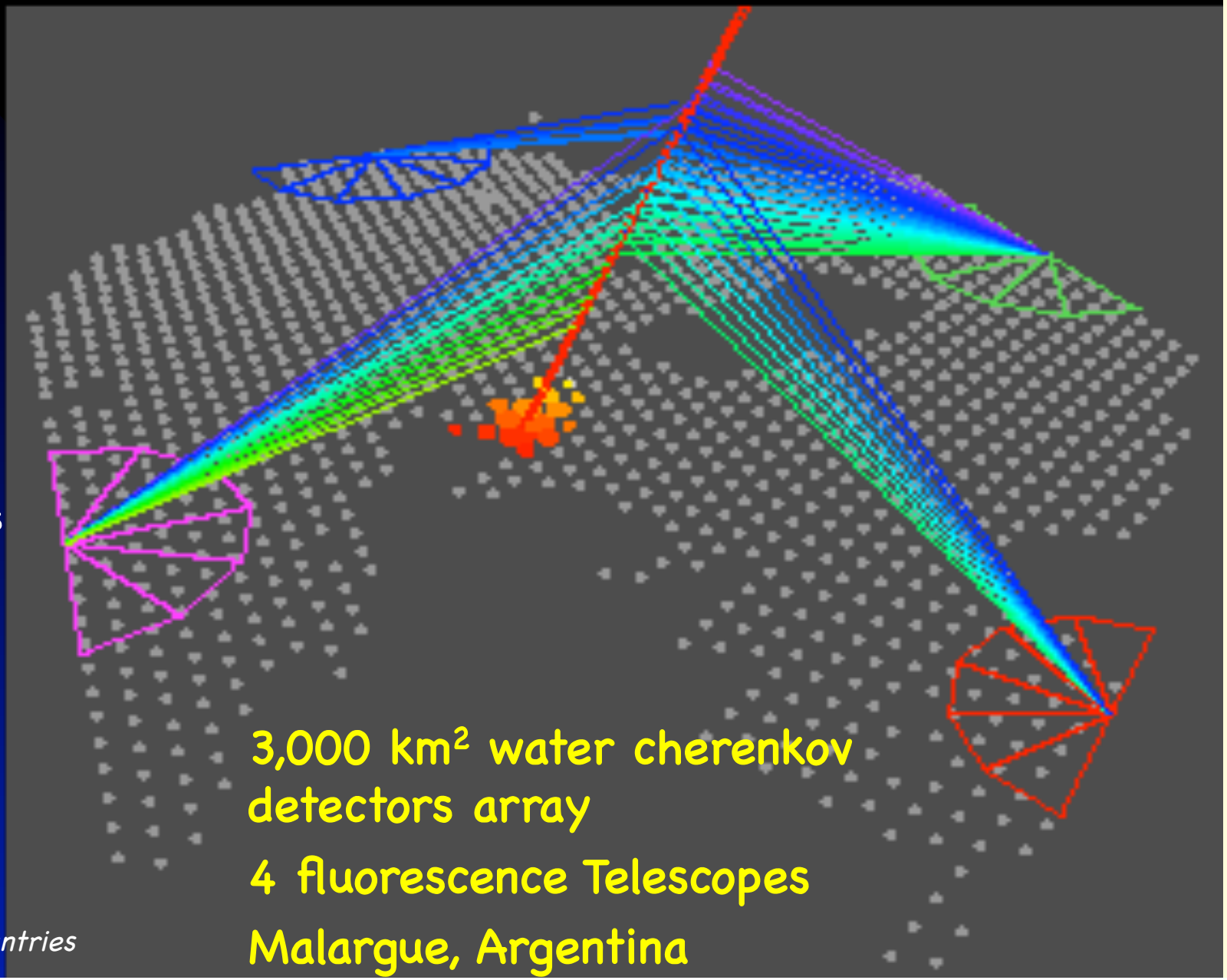
Recently confirmed by Telescope Array



The Pierre Auger Observatory

Argentina
Australia
Brasil
Bolivia*
Croatia
Czech Rep.
France
Germany
Italy
Mexico
Netherlands
Poland
Portugal
Romania*
Slovenia
Spain
UK
USA
Vietnam*

*Associate Countries



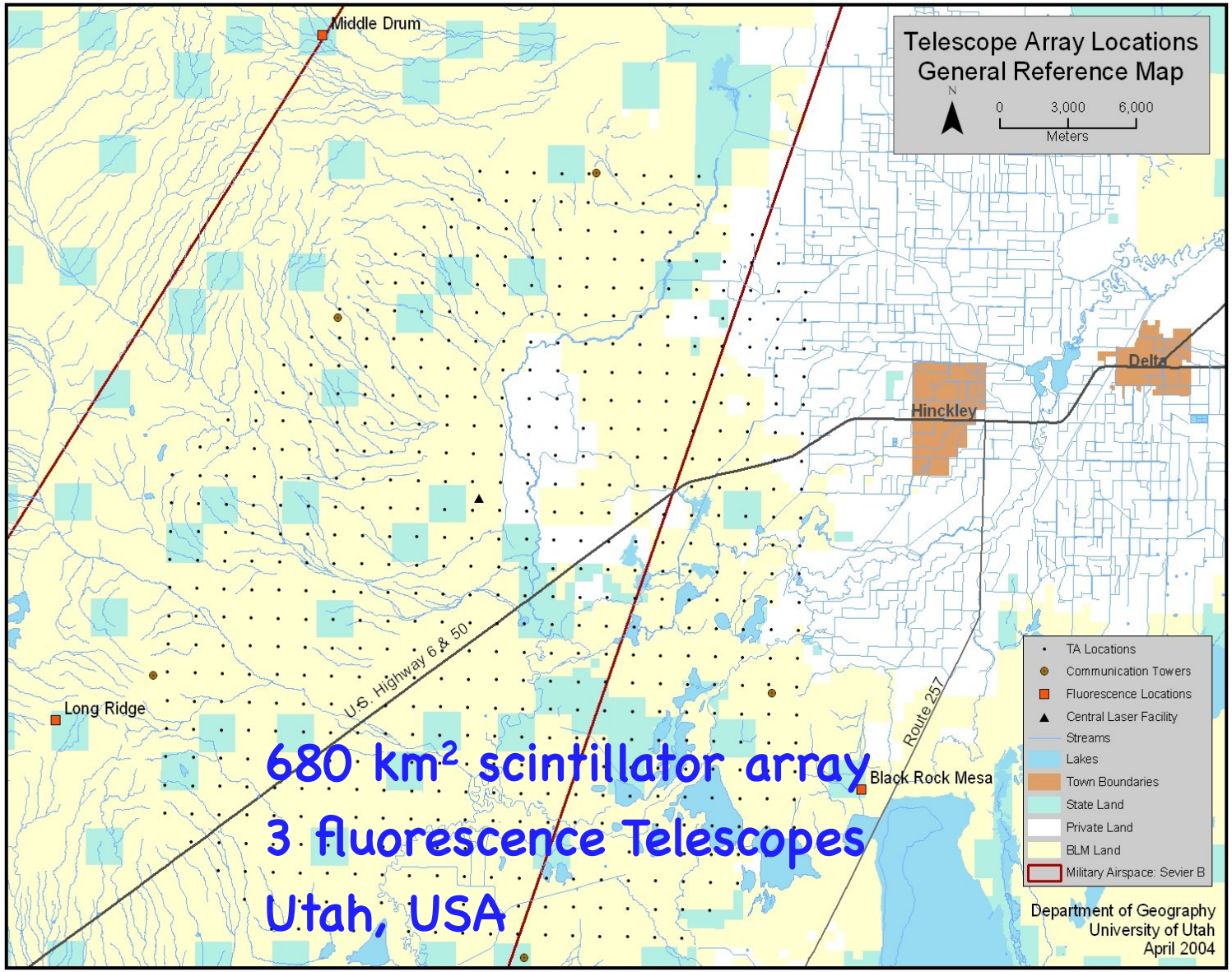
3,000 km^2 water cherenkov detectors array

4 fluorescence Telescopes

Malargue, Argentina

The Telescope Array (Evolution of Hi-Res)

Belgium
Japan
Korea
Russia
USA



How to find the Sources?

GET A LOT MORE DATA above 60 EeV

OVER THE WHOLE SKY

Auger + TA ~30 events/yr

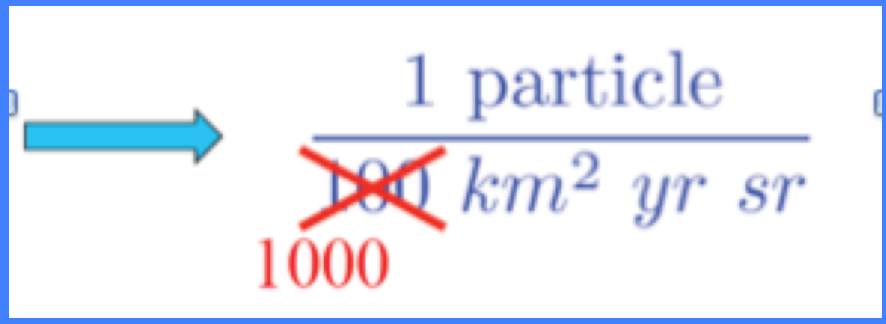
1 EeV = 10^{18} eV

UHECR status in just one word

Previous to Auger/HiRes/TA

$$\frac{1 \text{ particle}}{100\ km^2\ yr\ sr}$$

After Auger/HiRes/TA



A quantitative jump in exposure

(orders of magnitude: e.g., $10^3 \rightarrow 10^6$ km^2 yr sr)

is needed to effectively open such an astronomical window @ $E > 10^{20}$ eV

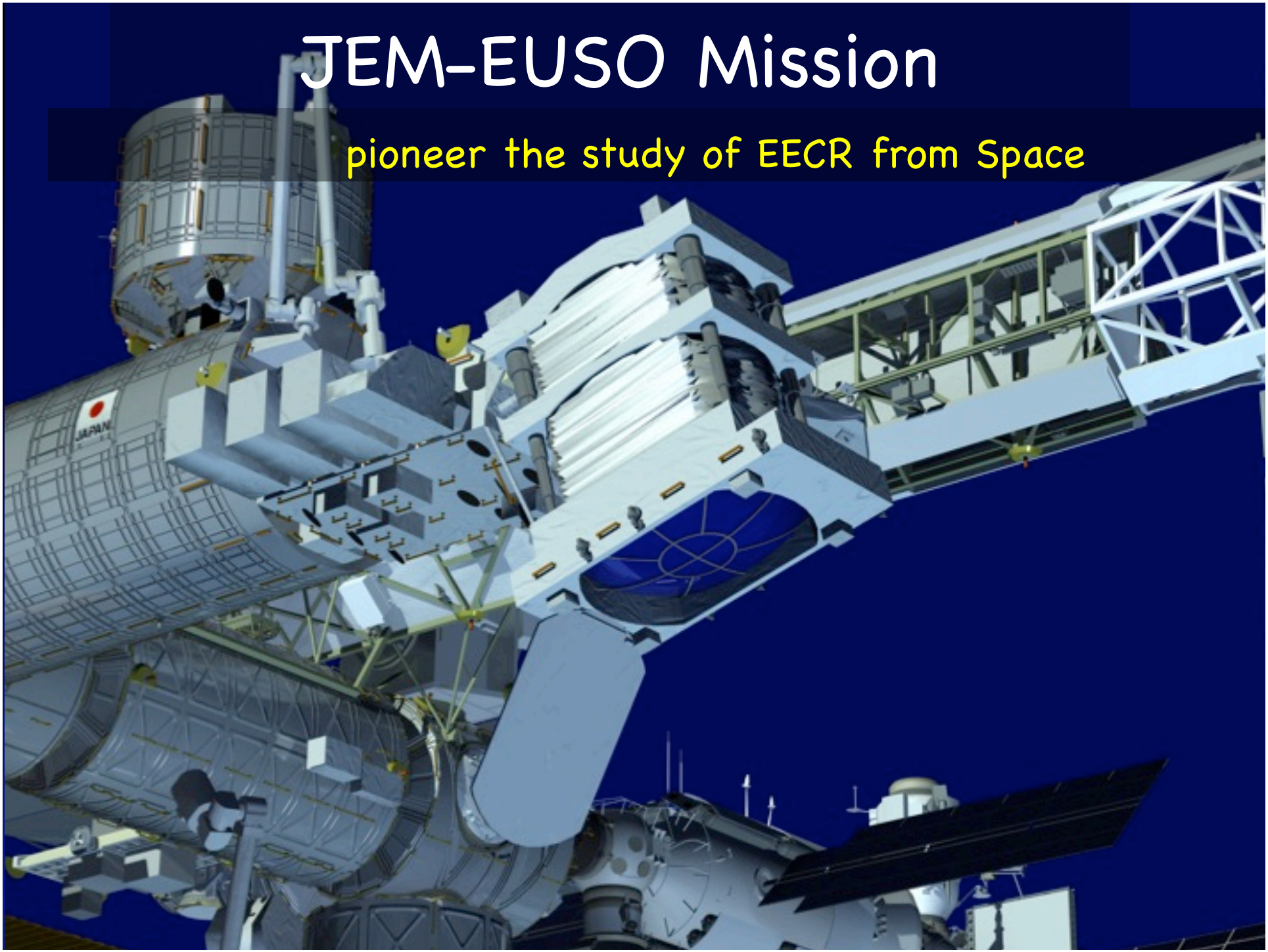
Go to SPACE!

To look down on the Atmosphere!

- increase exposure to EECR at least by 1 order of magnitude
- discover the nearby sources of UHECRs

JEM-EUSO Mission

pioneer the study of EECR from Space



Science Objectives

- **Main Objectives:**

  Astronomy and astrophysics through particle channel with extreme energies > 10^{20} eV

  - Identification of individual **sources** with high statistics
  - Measurement of the **energy spectrum** of individual sources
  - Understanding of the **acceleration processes** and source dynamics

- **Exploratory objectives:**
  - Detection of extreme energy **neutrinos**
  - Measurement of extreme energy **gamma rays**
  - Study the intensity and topology of Galactic and extragalactic magnetic fields
  - Global observation of **atmospheric** phenomena: nightglows, lightning and plasma discharges

How to find the Sources?

GET A LOT MORE DATA above 60 EeV

OVER THE WHOLE SKY

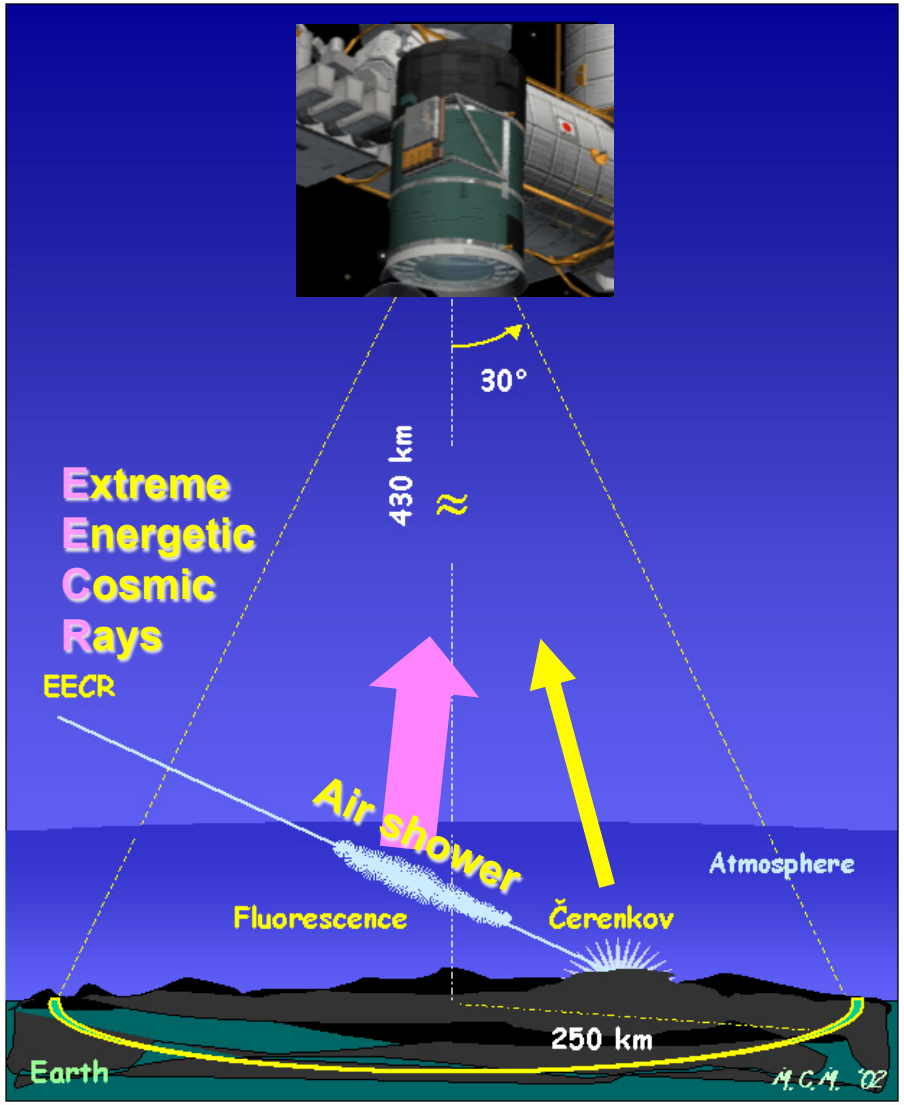
Auger + TA ~30 events/yr

JEM-EUSO

~200 events > 60 EeV/ yr

1 EeV = 10^{18} eV

JEM-EUSO Observational Principle



JEM-EUSO is a new type of observatory on board the International Space Station (ISS), which observes transient luminous phenomena occurring in the Earth's atmosphere.

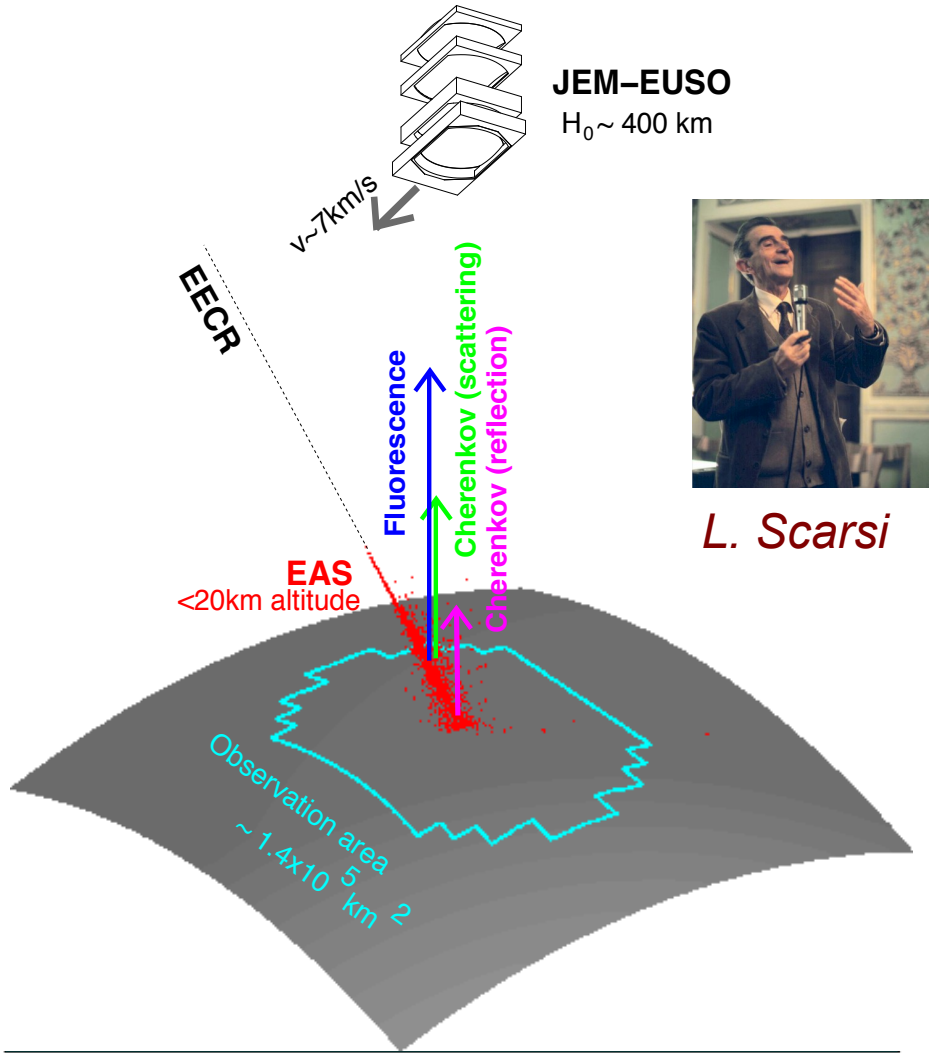
The telescope has a super wide field-of-view (60°) and a large diameter (2.5 m) and can operate in two modes: nadir and tilted

JEM-EUSO mission will initiate particle astronomy at ~10^{20}eV.

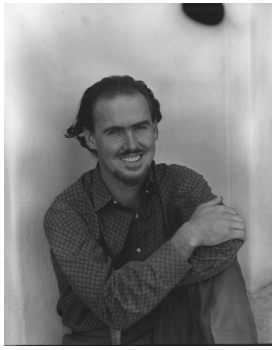
JEM-EUSO telescope observes fluorescence and Cherenkov photons generated by air showers created by extreme energetic cosmic rays

EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

Technique: fluorescence from space

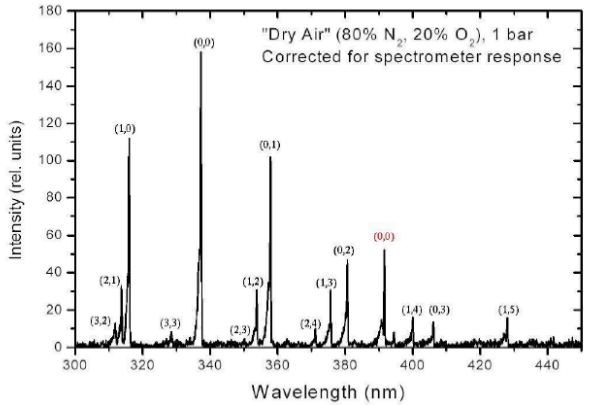


L. Scarsi



J. Linsley

Y. Takahashi



330 – 400 *nm*, UV

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

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

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

Two advantages:

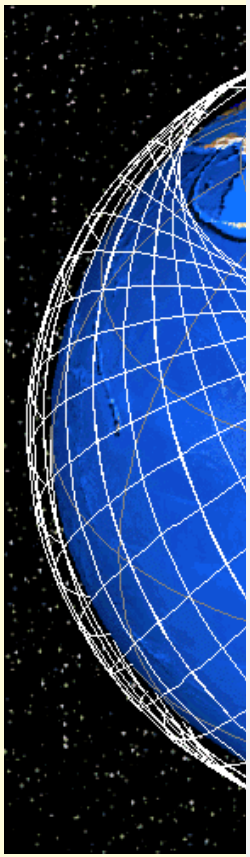
1. Monitored area

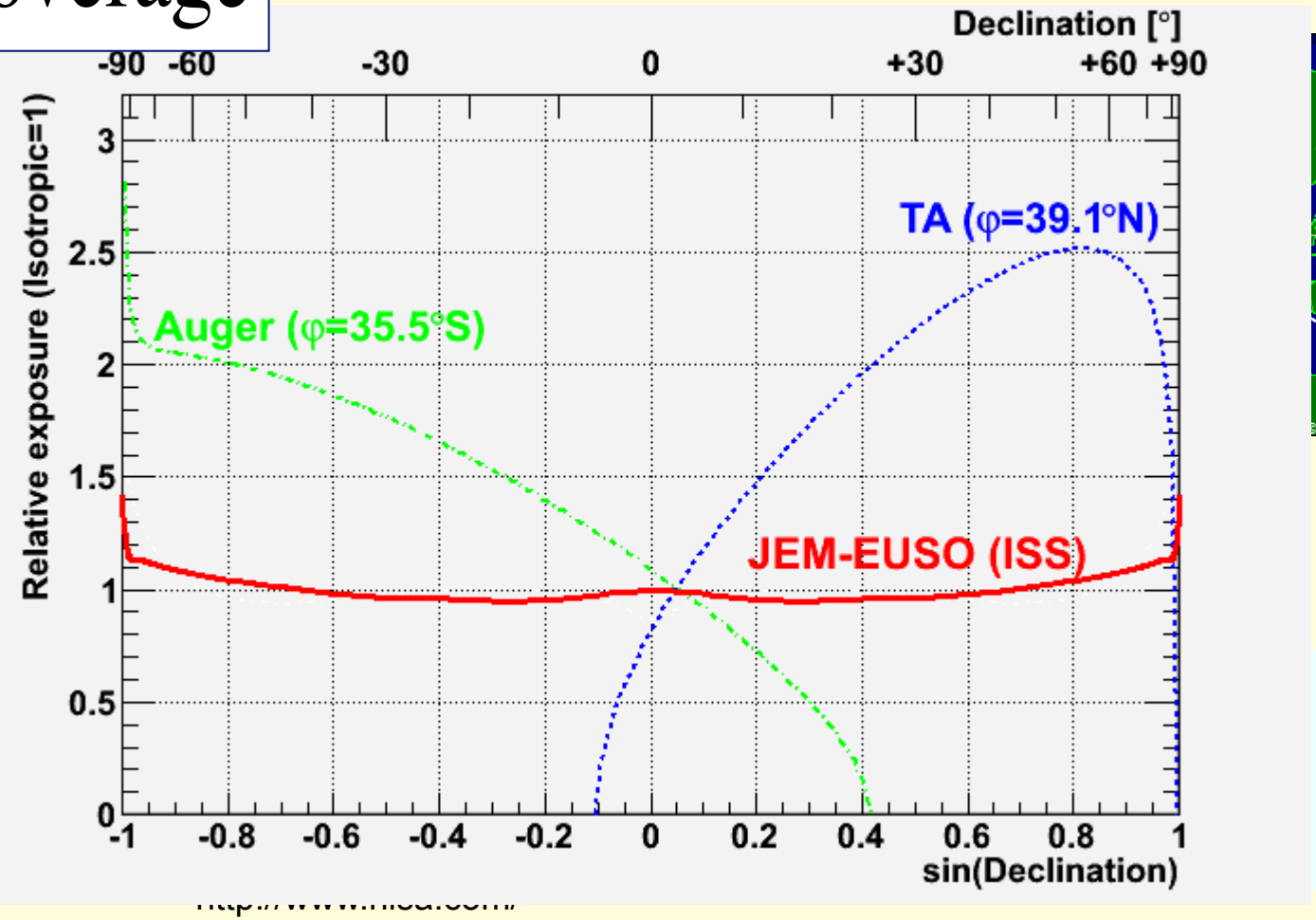
$$A_{geo}^{Nadir} \approx 1.3 \times 10^{5}\ km^{2}$$

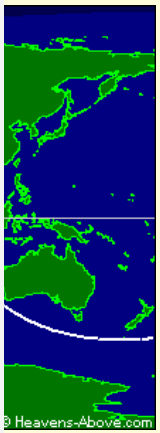
$$A_{geo}^{Tilted} \approx 1.\times 10^{6}\ km^{2}[@40°]$$

2. ISS Orbit → Full sky Coverage…

4π coverage

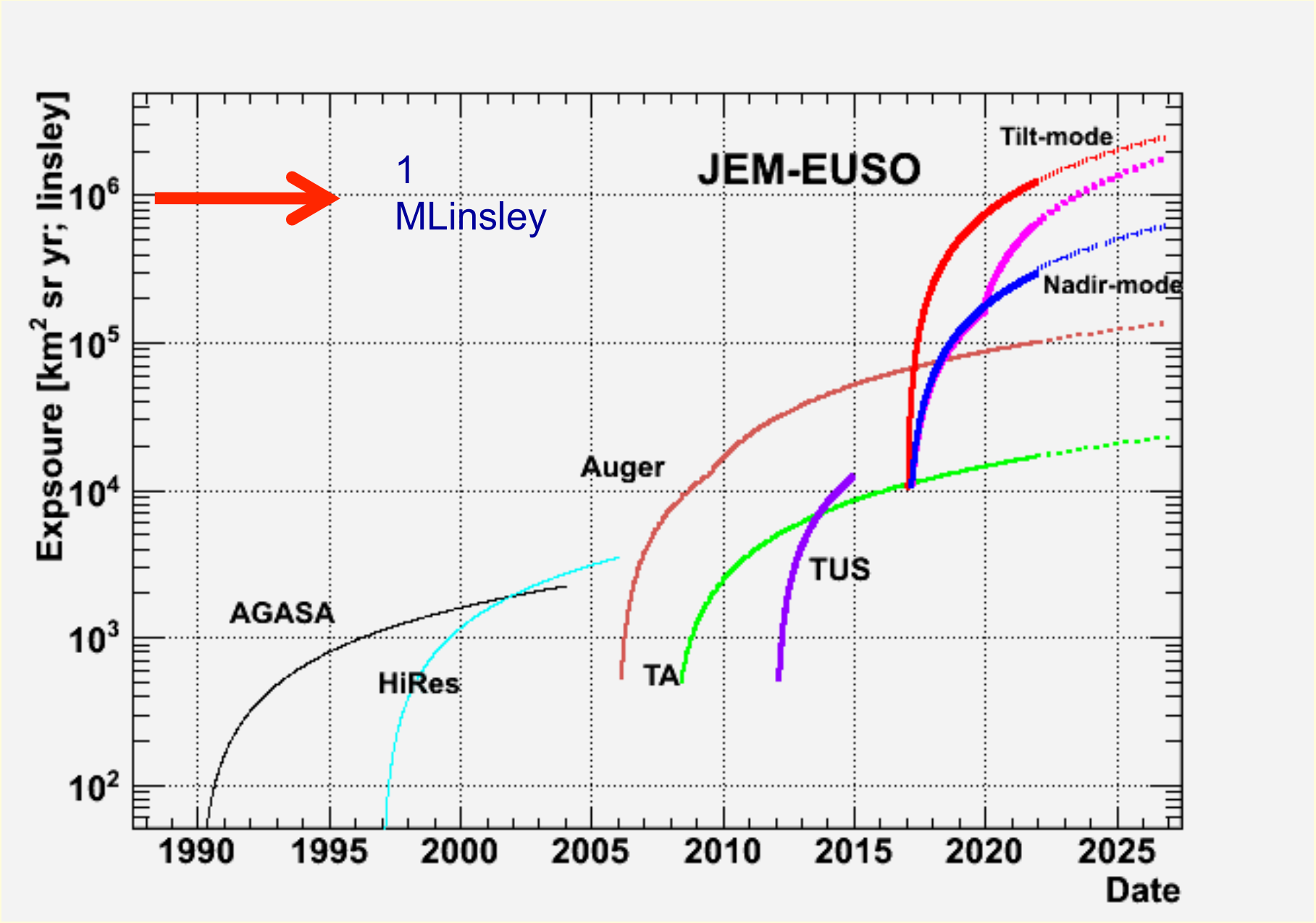






… and uniform exposure

Why JEM-EUSO? Large exposure + Full sky coverage



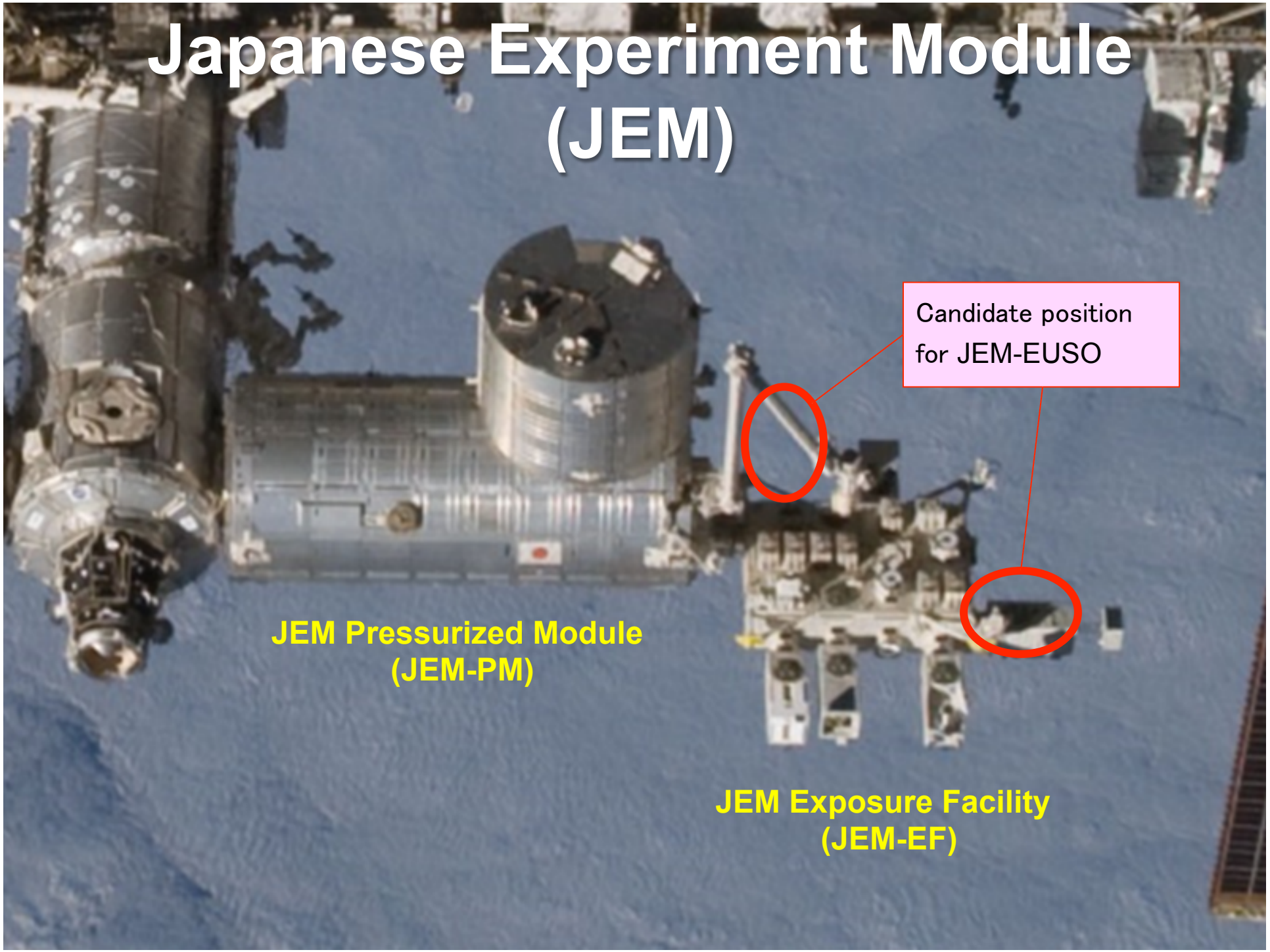
The Mission

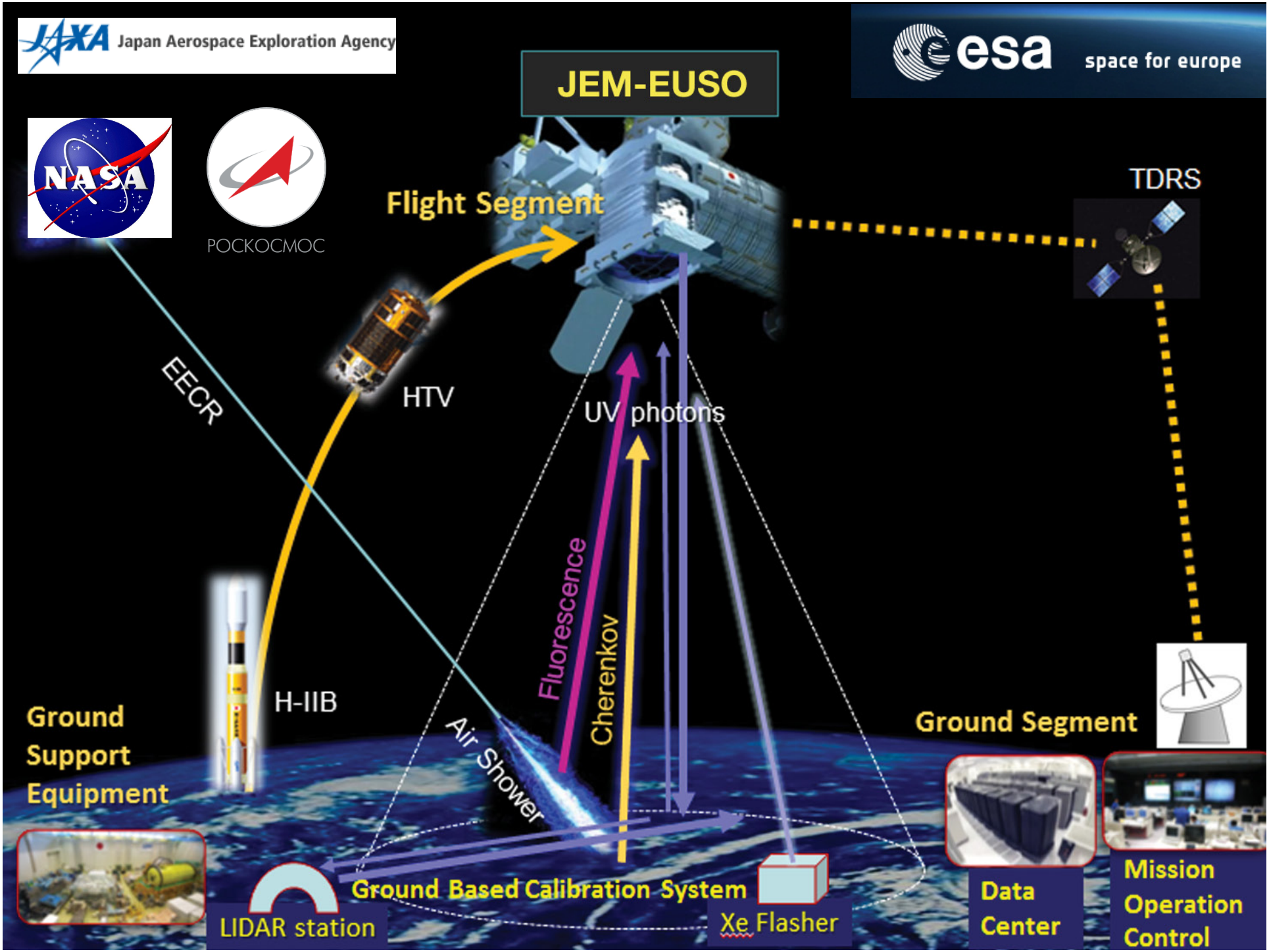
JEM-EUSO onboard the ISS

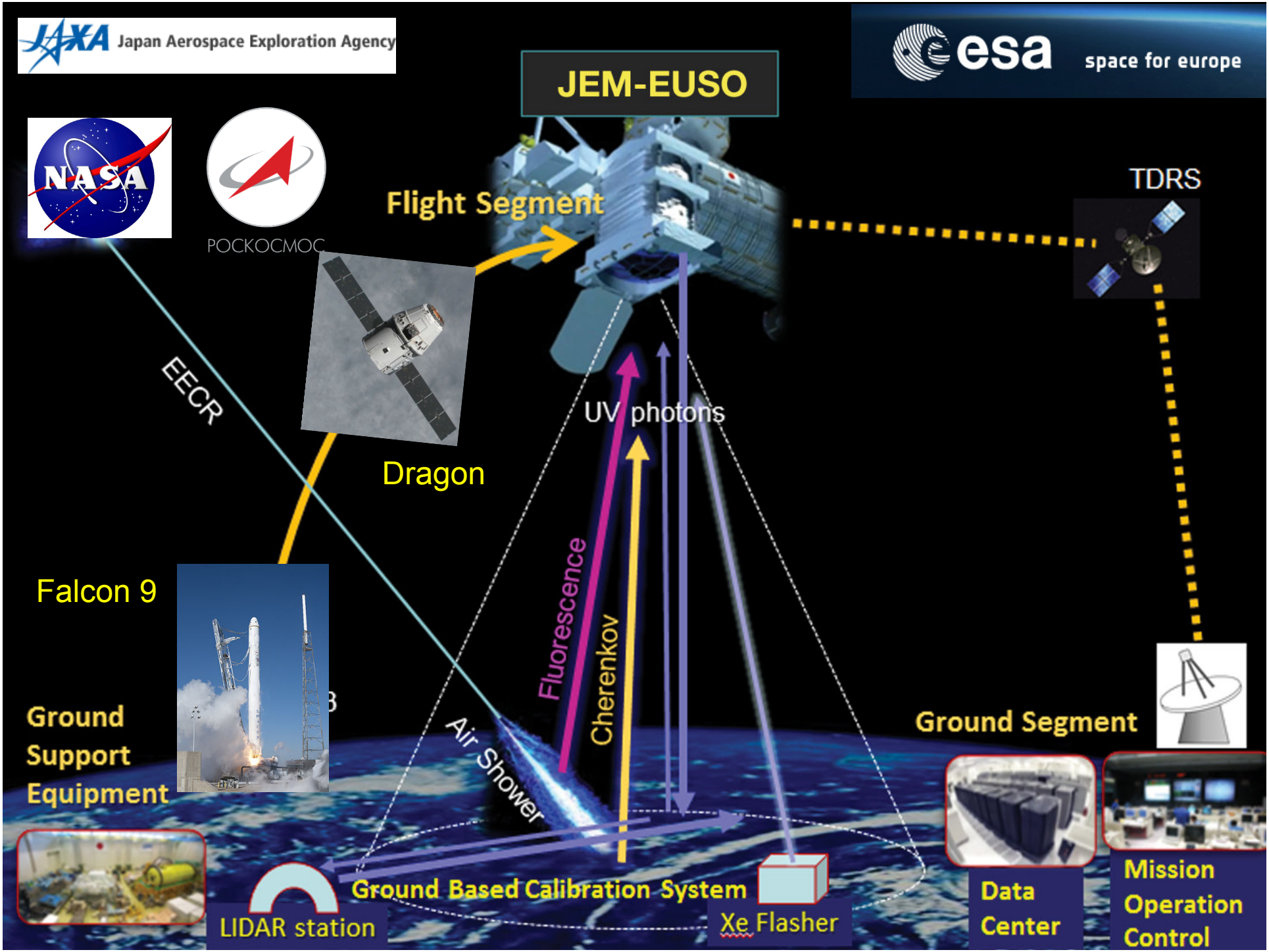
Japanese Experiment Module
(JEM)

きぼう, Kibo = Hope

Japanese Experiment Module (JEM)

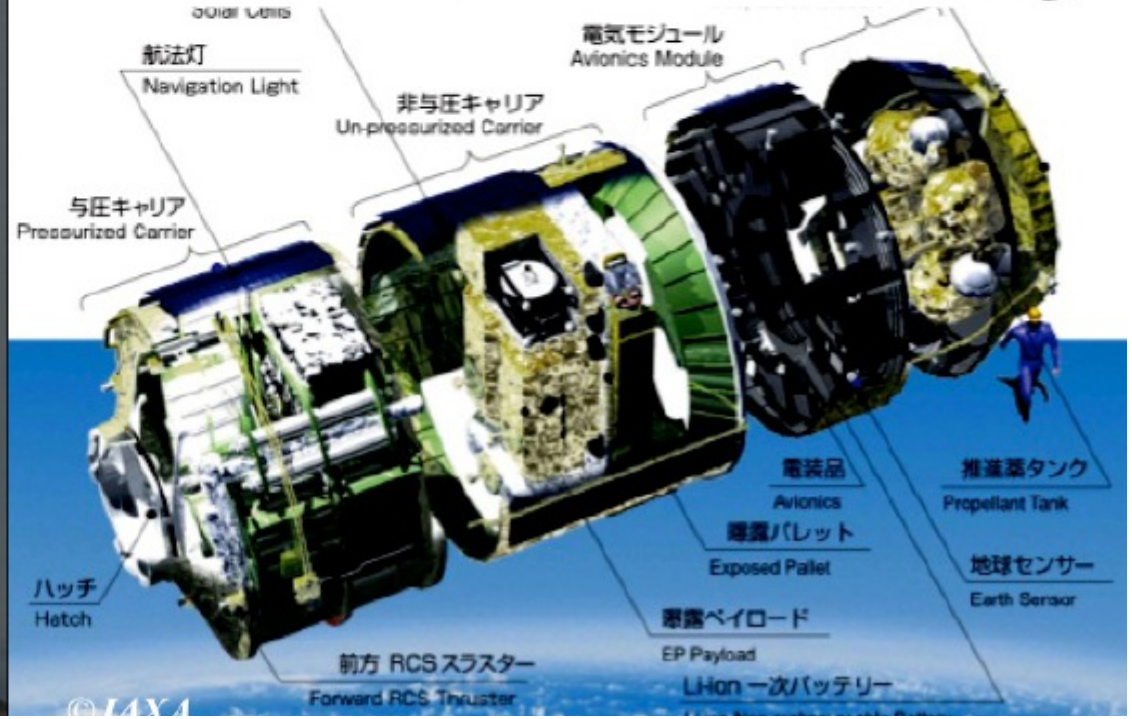



Japan Aerospace Exploration Agency
esa
space for europe
JEM-EUSO
NASA
POCKOCMOC
Flight Segment
TDRS
EECR
HTV
UV photons
Fluorescence
Cherenkov
H-IIB
Air Shower
Ground Support Equipment
Ground Segment
Ground Based Calibration System
LIDAR station
Xe Flasher
Data Center
Mission Operation Control

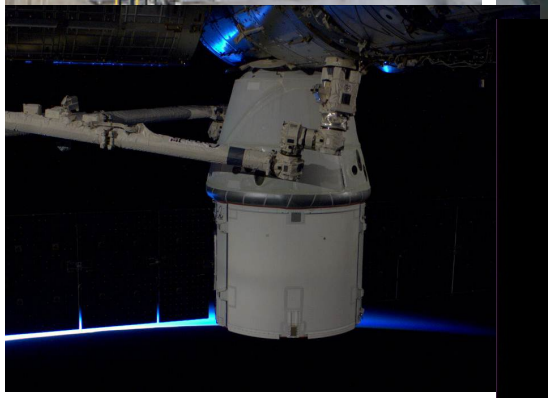

Japan Aerospace Exploration Agency
esa
space for europe
JEM-EUSO
NASA
POCKOCMOC
Flight Segment
TDRS
EECR
Dragon
UV photons
Fluorescence
Cherenkov
Falcon 9
Air Shower
Ground Segment
Ground Support Equipment
Ground Based Calibration System
LIDAR station
Xe Flasher
Data Center
Mission Operation Control

H-II Transfer Vehicle (HTV)

HTV is 4m across ~10 m long



Space X Falcon-9 rocket & Dragon spacecraft



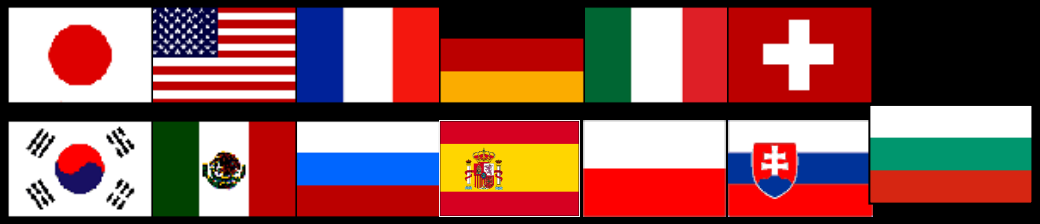
- Reusable
- Return cargo capability – 3 ton
- Pressurized and unpressurized cargo
- Two flights to ISS
- 6ton upload mass
- 14 m payload volume
- Optional trunk extension for a total of up to 4.3 m length, payload volume 34 m3

Mission aspects have been successfully studied by JAXA and RIKEN

Parameter	Value
Launch date	2017
Mission Lifetime	3+2 years
Rocket	H2B/FALCON-9
Transport Vehicle	HTV/DRAGON
Accommodation on JEM	EF#2
Mass	1938 kg
Power	926 W (op.) 352 W (non op.)
Data rate	285 kbps (+ on board storage)
Orbit	400 km
Inclination of the Orbit	51.6°
Operation Temperature	-10° to +50°

JEM-EUSO Collaboration

- Japan, USA, Korea, Mexico, Russia
- Europe: Bulgaria, France, Germany, Italy, Poland, Slovakia, Spain, Switzerland
- 13 Countries, 72 Institutions, more than 270 researchers
- RIKEN, Tokyo: Leading institution

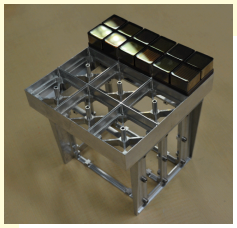


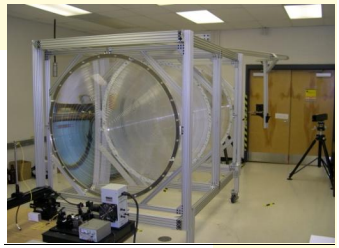
Space Agencies

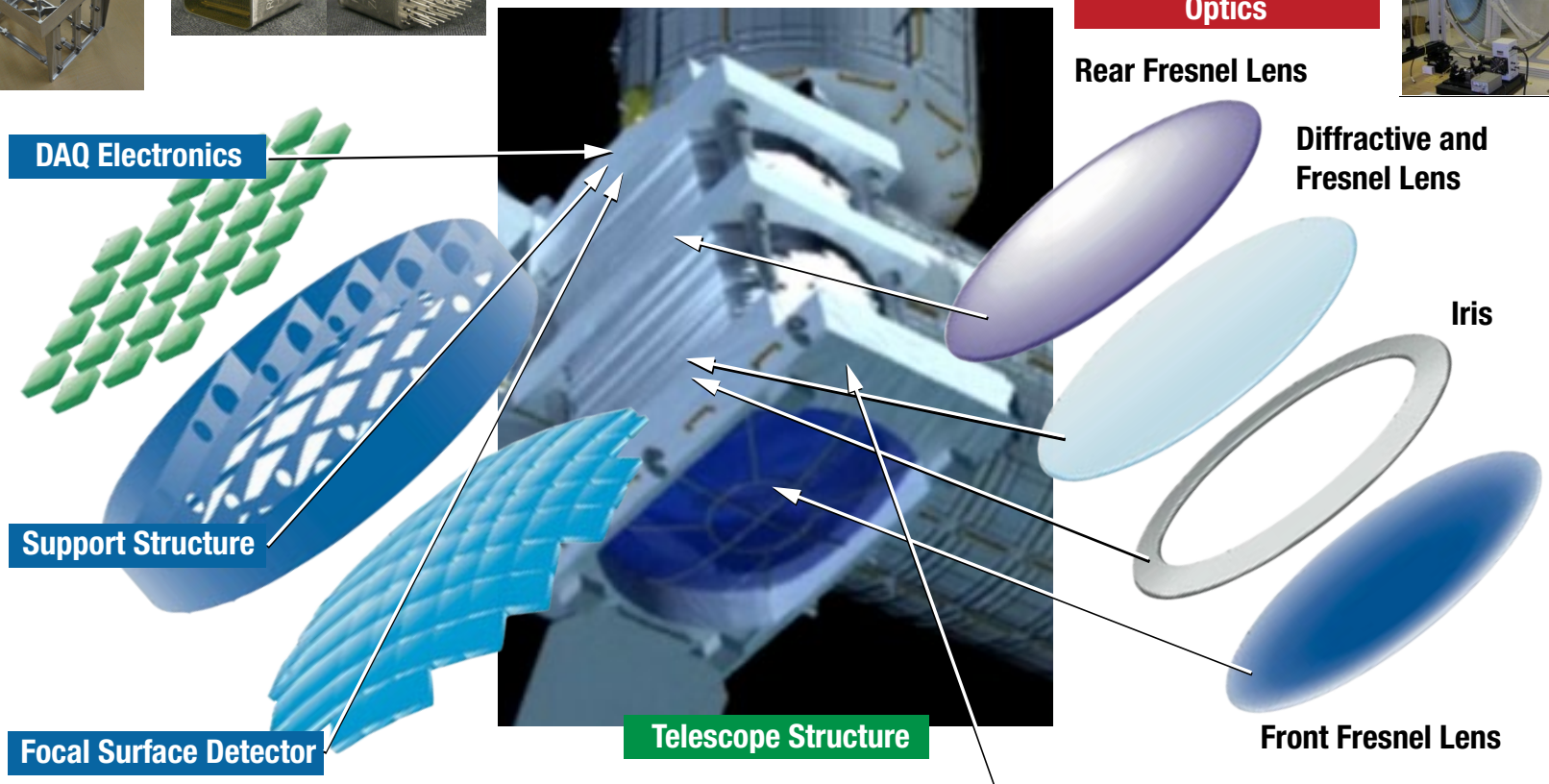
- JAXA : Japan
- ESA: Europe
- NASA : USA
- ROSCOSMOS : Russia
- National Space Agencies
  - ASI, CNES, DLR, etc

The Instrument

Science Instrument:
UV Telescope + Atmospheric Monitoring

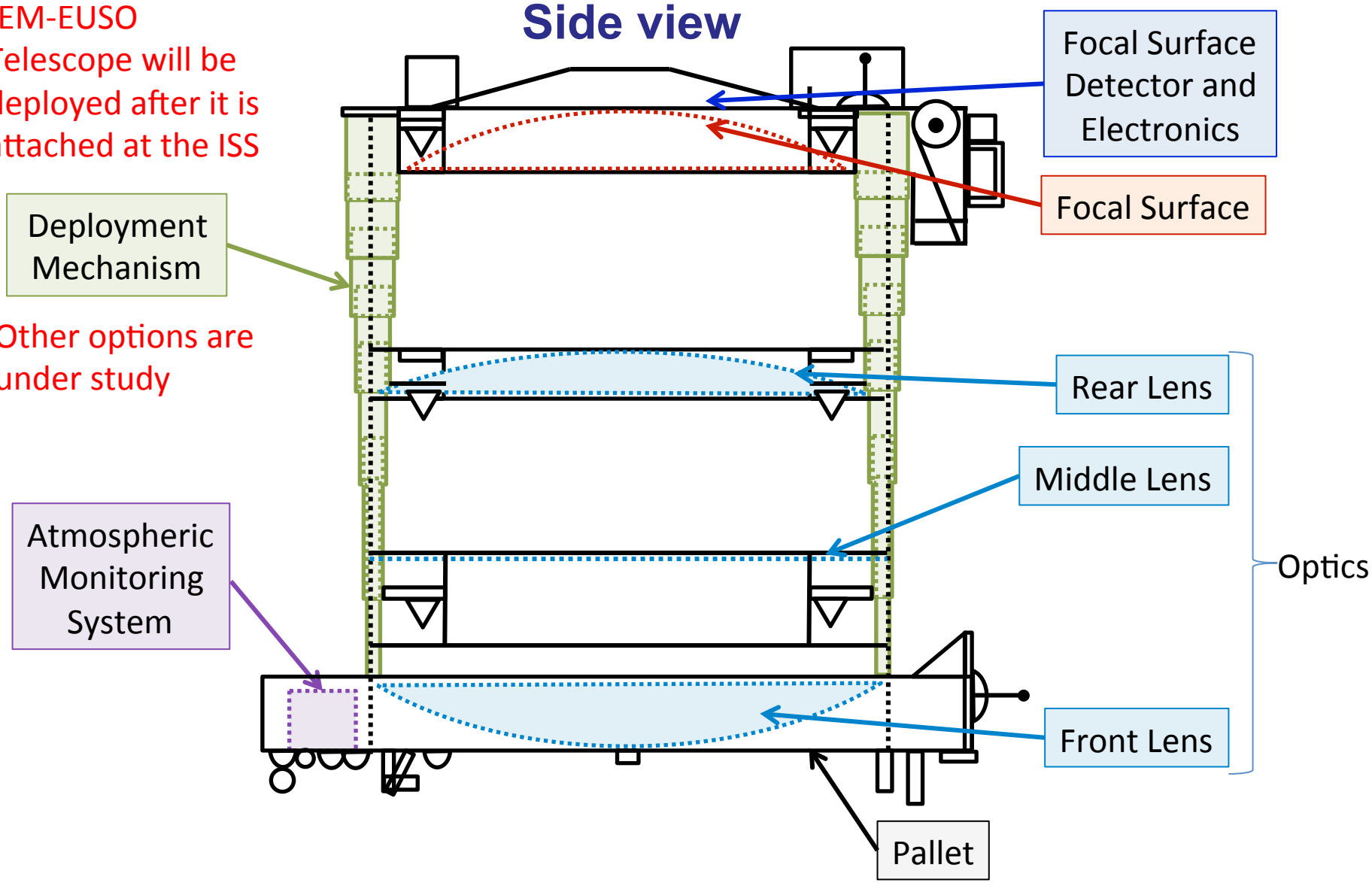






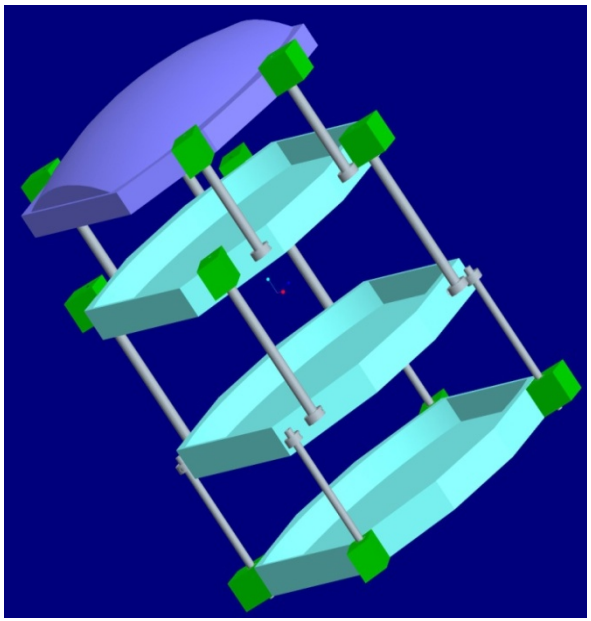
Science Instrument

JEM-EUSO Telescope will be deployed after it is attached at the ISS

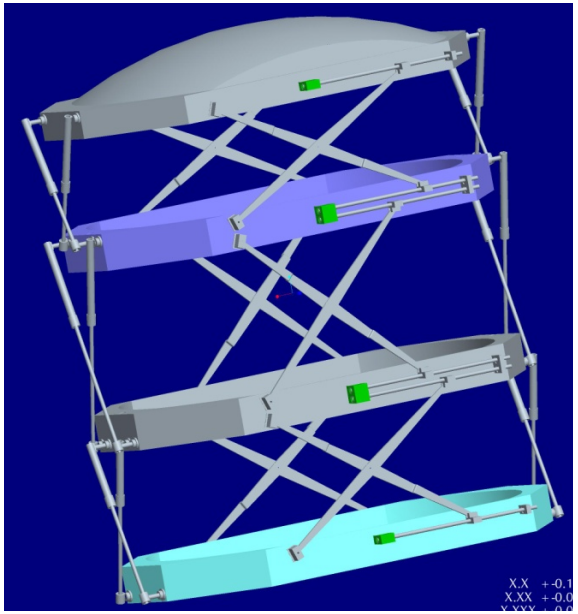


Extension Mechanism

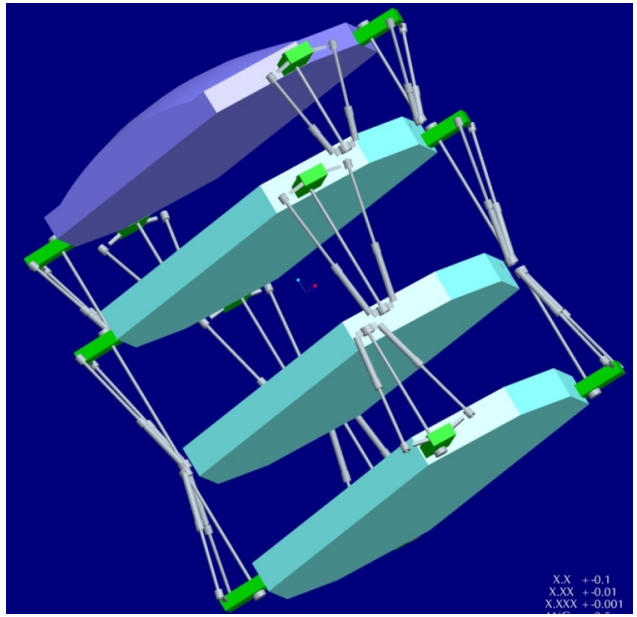
"Four screws"



"Pantograph" variant



"Pyramid" variant



1,3 allow more flexible lenses adjustments during detector operation because oh higher accuracy and more degrees of freedom
2,3 have more complicated electro-mechanics, but less weight

Being Studied at the Skobeltsyn Institute (Moscow)

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%

Atmospheric Monitoring System

- **IR Camera**

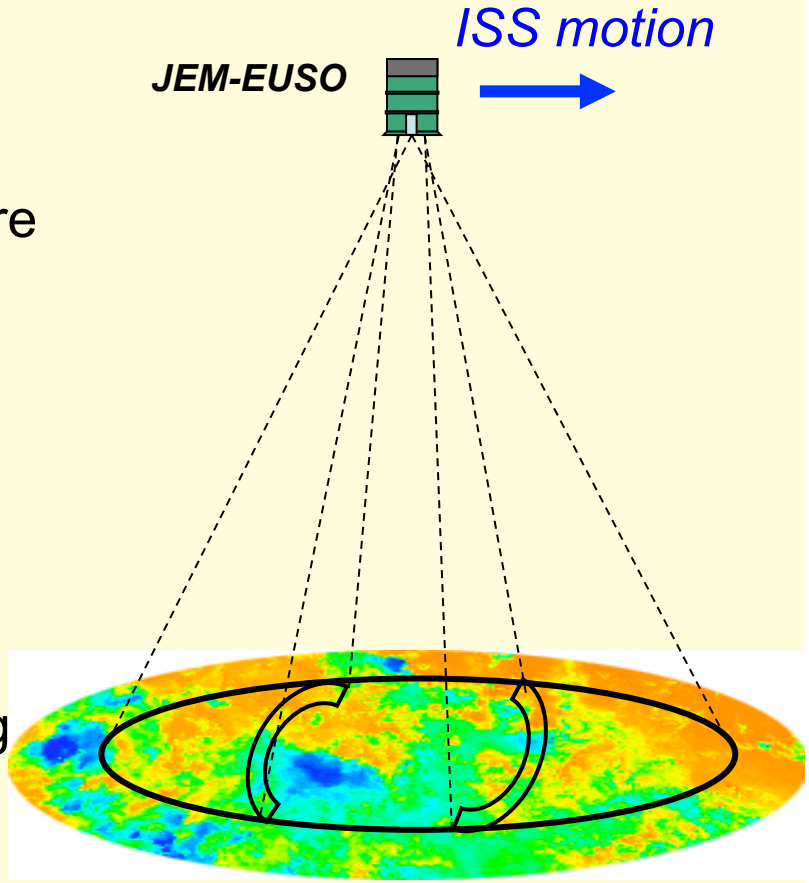
  Imaging observation of cloud temperature inside FOV of JEM-EUSO

- **Lidar**

  Ranging observation using UV laser

- **JEM-EUSO "slow-data"**

  Continuous background photon counting



- *Cloud amount, cloud top altitude*: (IR cam., Lidar, slow-data)
- *Airglow*: (slow-data)
- *Calibration of telescope*: (Lidar)

International Role Sharing

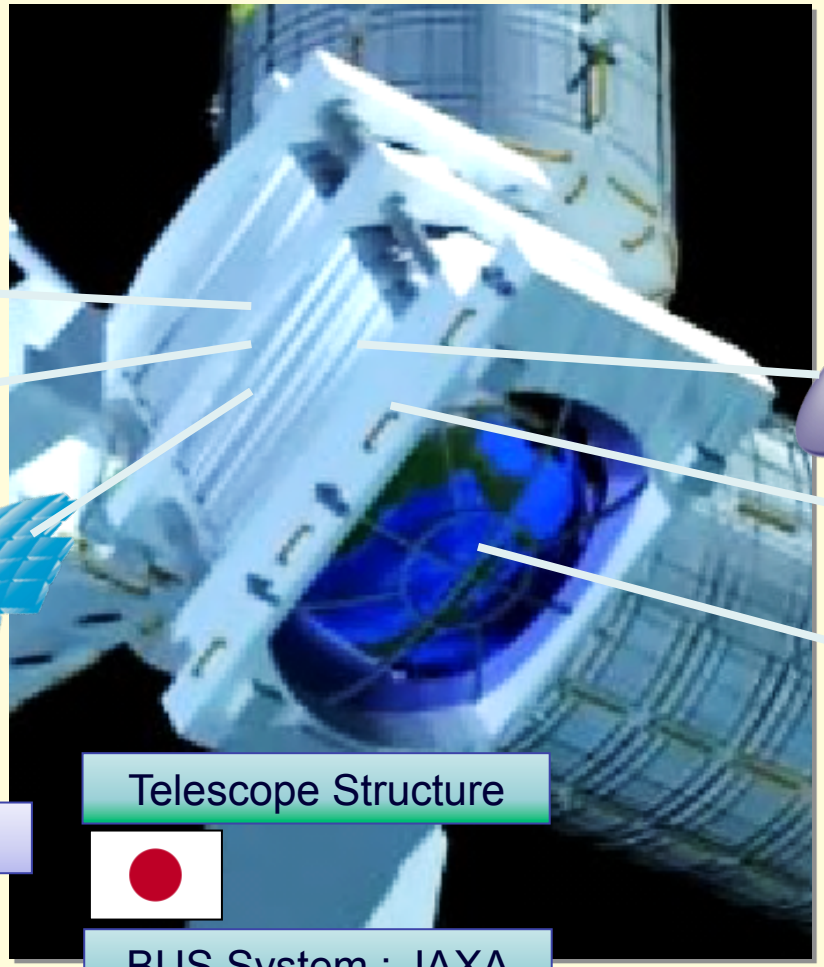
DAQ Electronics

Support Structure

Focal Surface Detector

Housekeeping

Simulation : Worldwide



Telescope Structure

BUS System : JAXA

Atmospheric Monitoring

Optics

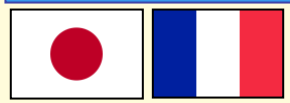
Rear Fresnel Lens

Precision Fresnel lens

Iris

Front Fresnel lens

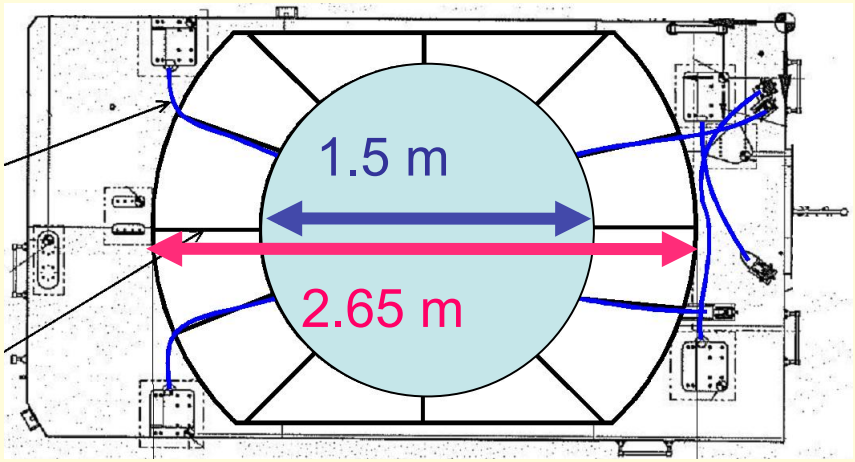
On-board Calibration



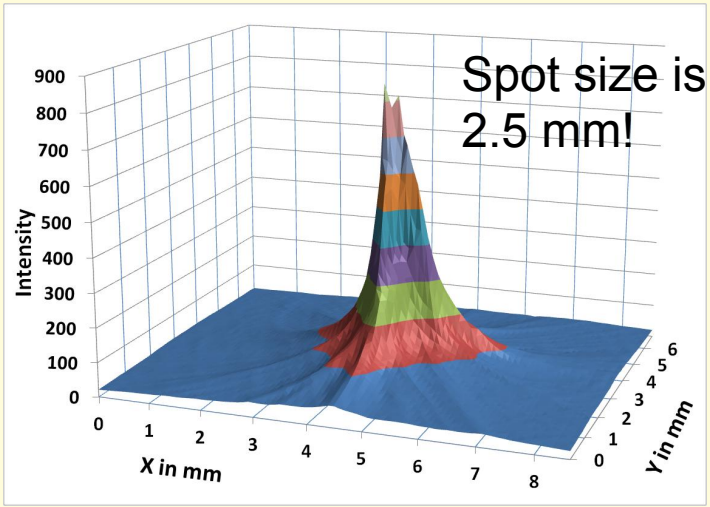
Ground Based Calibration

Ground Support Equipment

BBM of the Optics (Prototypes)

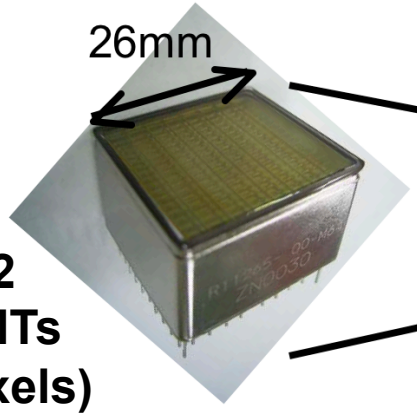


large diameter Fresnel lenses manufactured in Japan and tested in the US at the University of Alabama (Huntsville) and at MSFC (NASA)

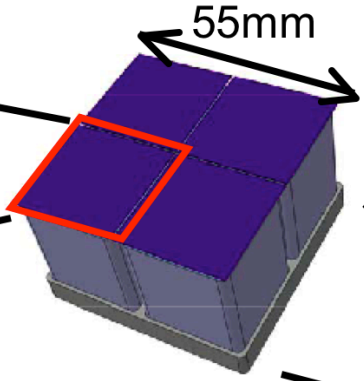


Tested performances meet already the requirements (or are close to it)

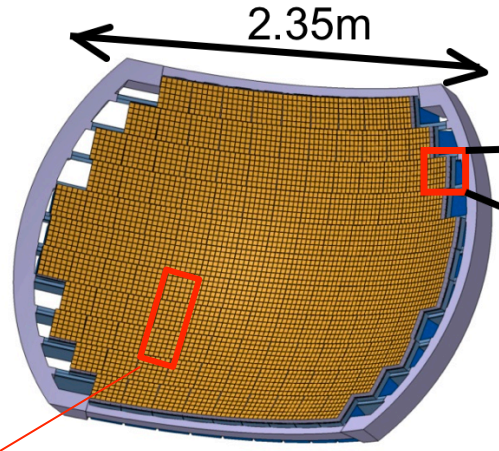
Focal Surface Detector

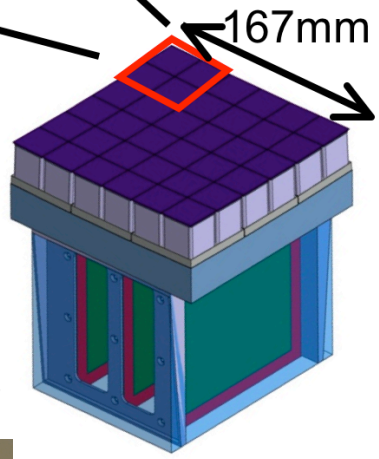


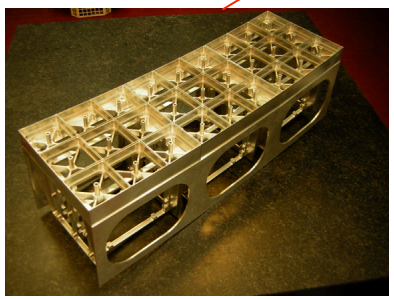
4932 MAPMTs (8x8 pixels)



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







Focal Surface detector 137 PDMs = 0.3M Pixels

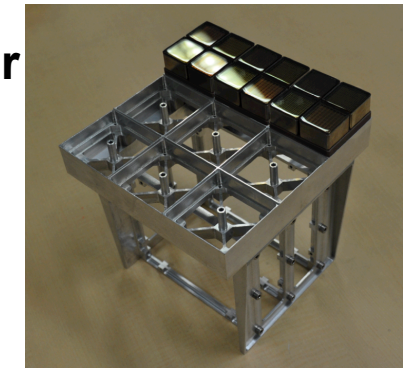
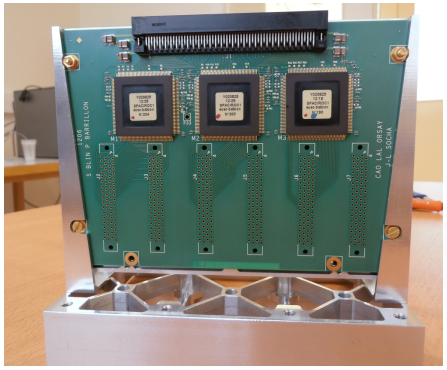


Photo-Detector Module (PDM) (3x3 ECs = 36 PMTS 2,304 pixels)

1 High Voltage / PDM

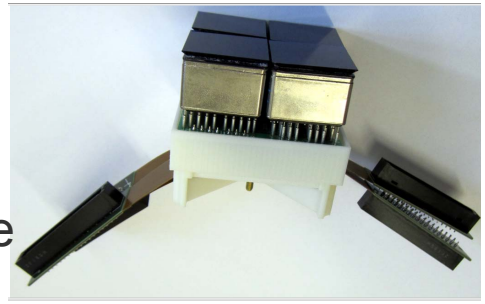
First EM of the PDM integrated in RIKEN

ASIC Board



Elementary Cell

Integration: 4 MAPMTs, filters, and the EC boards

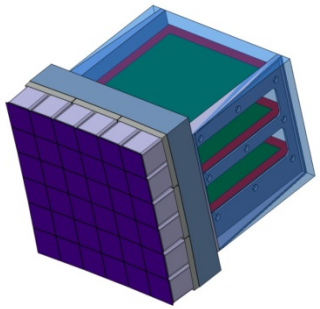


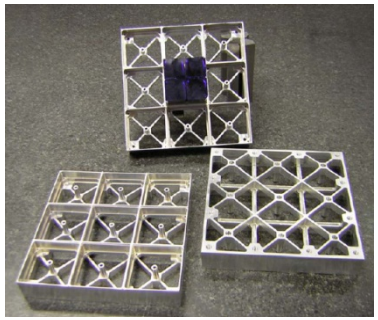
EM of the PDM Board

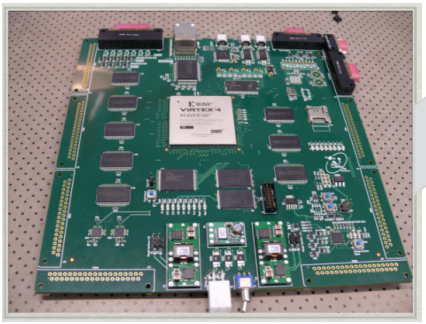
(I level trigger, +)

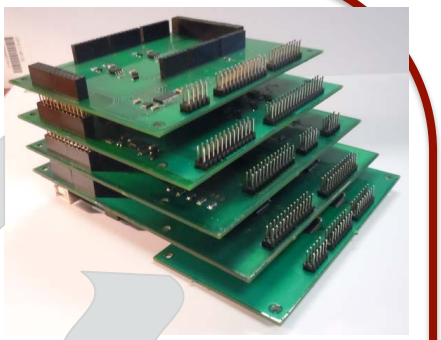
JEM-EUSO France, Germany, Korea, Italy and Japan

Electronic System

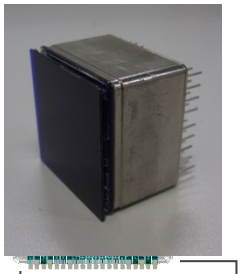








HK



FEE

ASIC
+FPGA

Count

9EC

137
PDM

PhotoDetector
Modules

PDM FPGA Board
Track Trigger

Cluster Control
Board

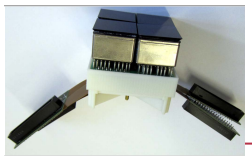
FPGA

Fine Trigger

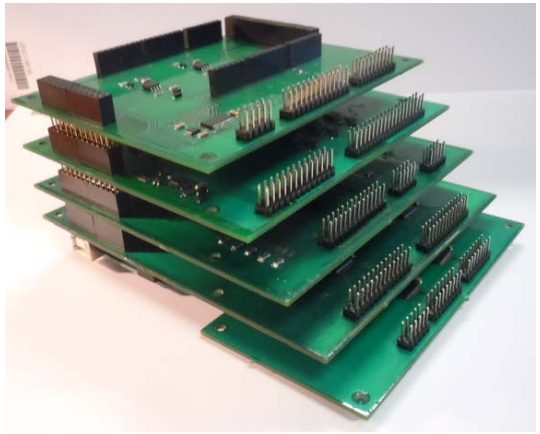
20
CCB

CPU
Spacewire
Clock Board
GPS
Data Storage
Software
HK

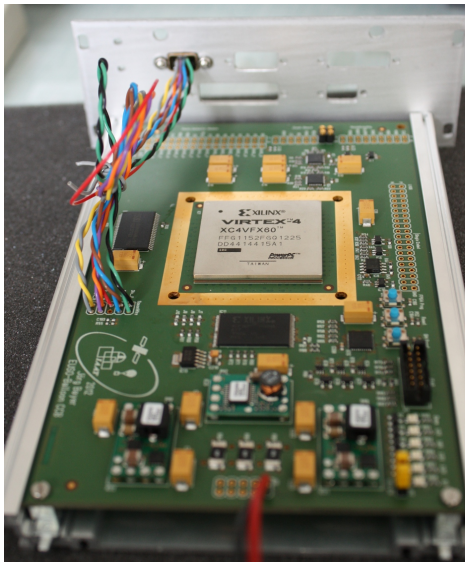
DP System



The Elements of the Digital Processor part



HK Boards

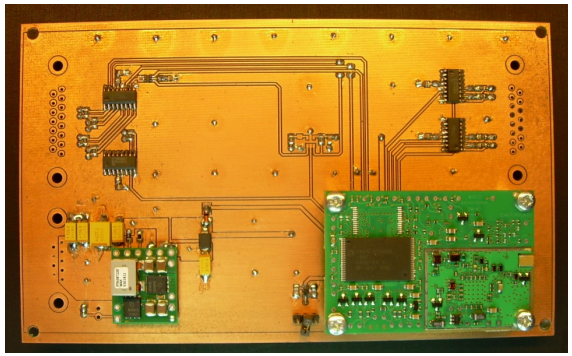


EM of the Cluster Control Board (II level trigger, +)

SpaceWire PCI Mk2

CPU, Arbor iTX-i2705

GPSR board prototype



Clock Board prototype

Road Map to JEM-EUSO
The Pathfinders

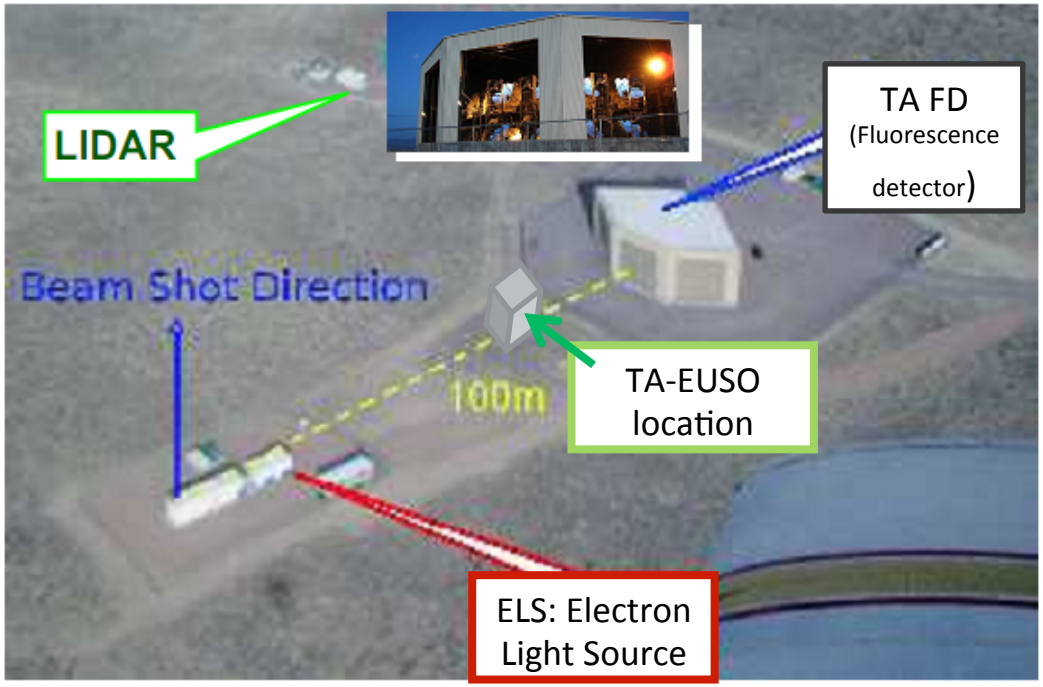
- EUSO – TA Test at Telescope Array site, Utah
- EUSO-Balloon Flight Campaign
- mini-EUSO: a precursor on board ISS

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

→ *Integration of the PDM in RIKEN near to completion; Data Taking Early Spring 2014*

TA site, UTAH, Black Mesa

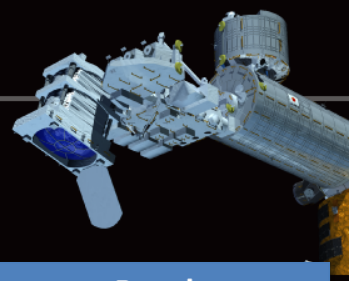


located at Black Rock Mesa FD Station

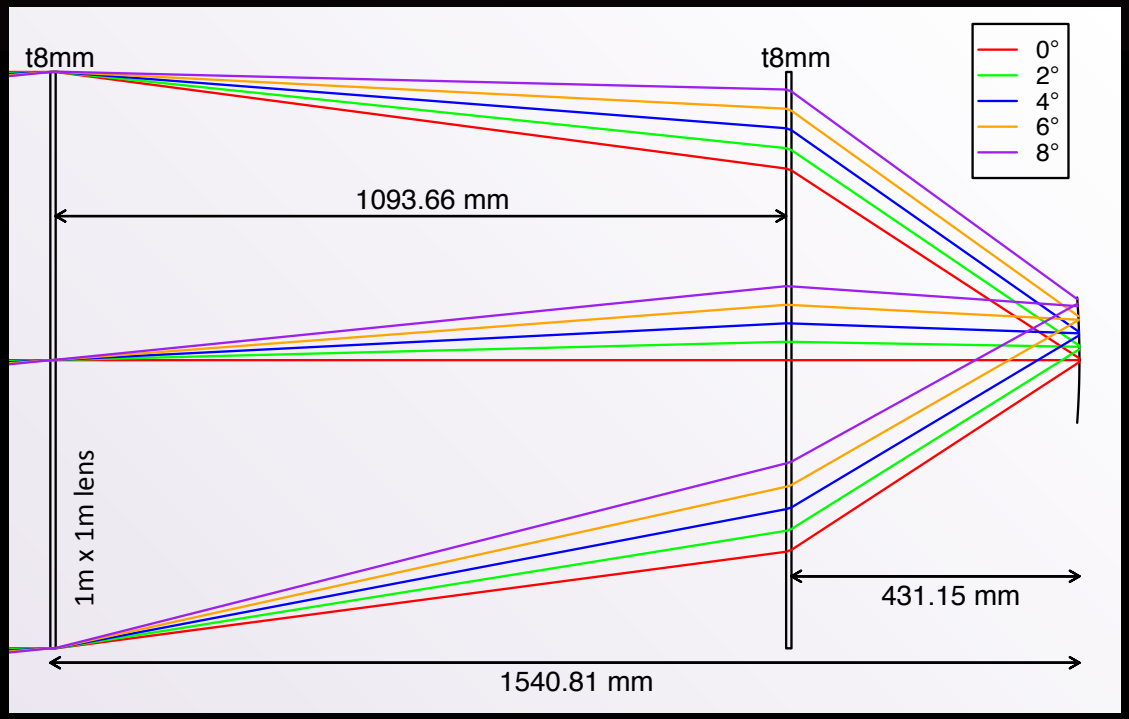
- *Electron Light Source at 100m*
- *Most nearby SD is at ~3.5 km*
- *Central Laser Facility ~21km*

EUSO-TA (2)

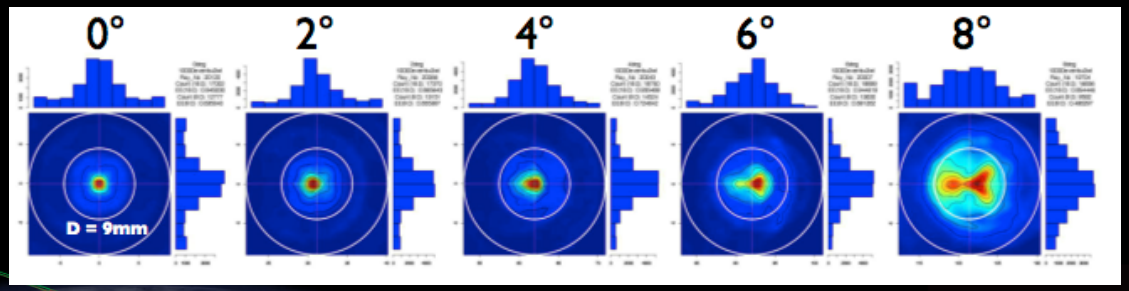
Lens have been installed, Focal Surface integration completed



EUSO-TA optics design

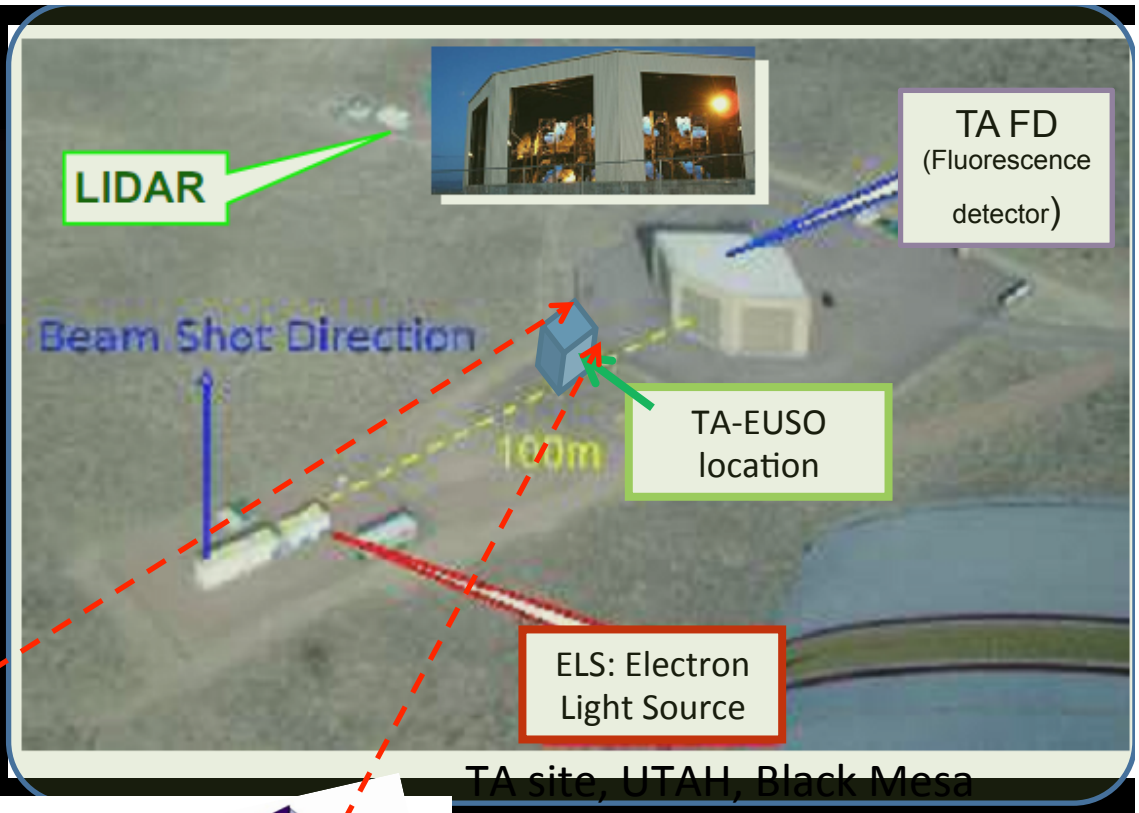


	Results
Optical system	**2 lenses sys.**
Focal length	**1562.18 mm**
FOV for a PDM	**±4°**
RMS spot size	**9 mm @ 0°**
Entrance pupil	**0.95 m²**
Base shape of lens	**Flat type**
Lens material	**PMMA-000**
Lens thickness	**8 mm**
FS curvature	**2505 mm**



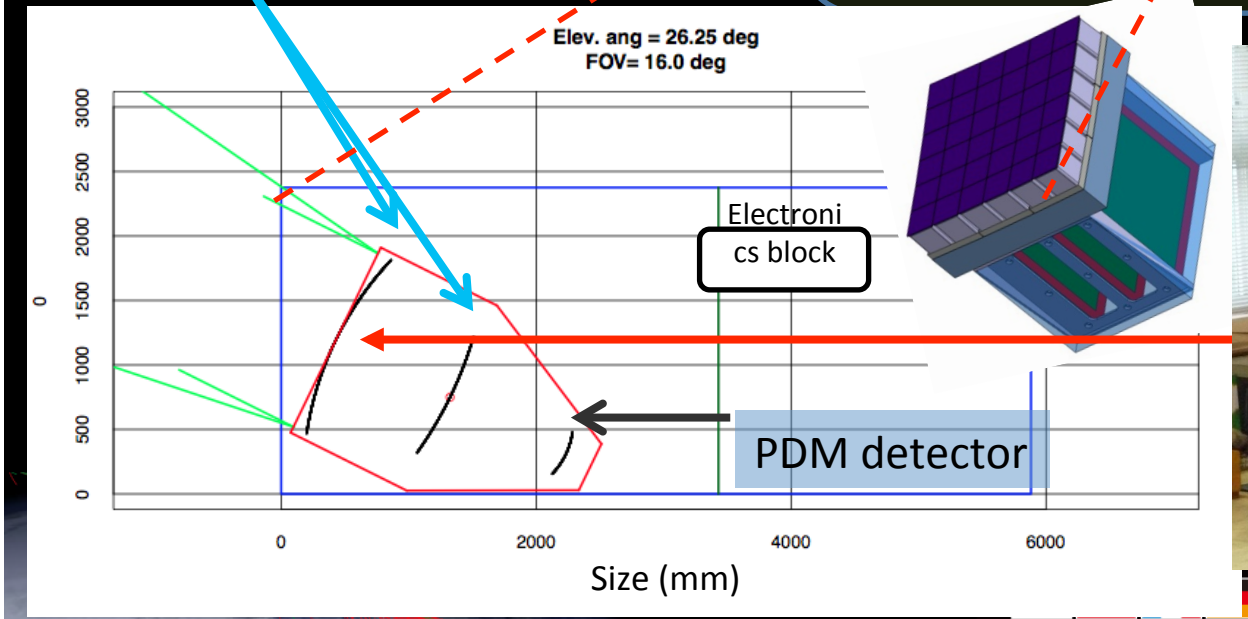
EUSO-TA

GROUND-EUSO
Detector at Telescope
Array site

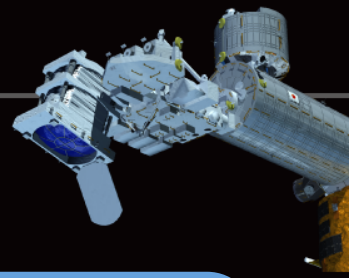


TA site, UTAH, Black Mesa

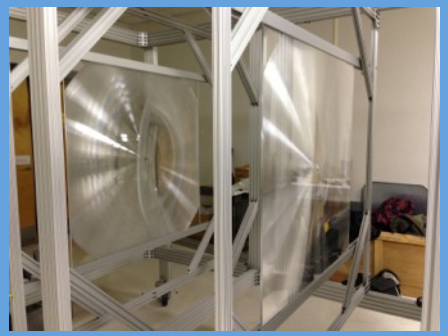
Lenses

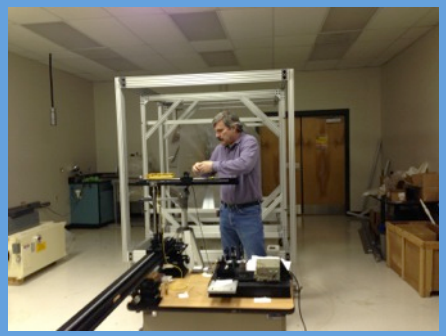


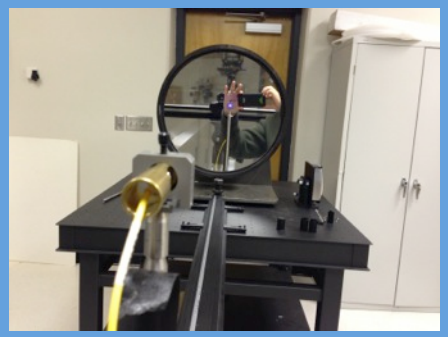
JEM-EUSO on ISS explores the origin of the highest energy particles in the Universe



EUSO-TA lenses test at UAH, Alabama (March 2013)



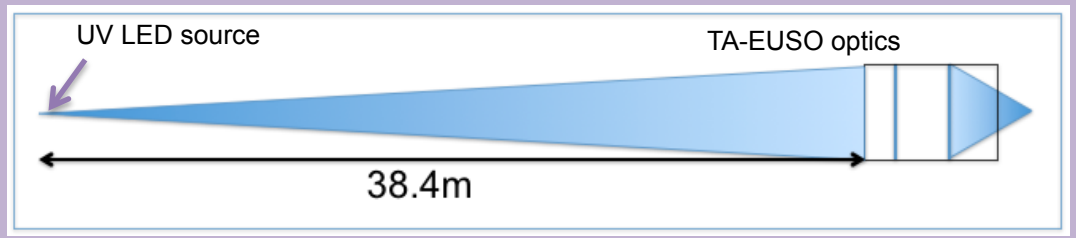




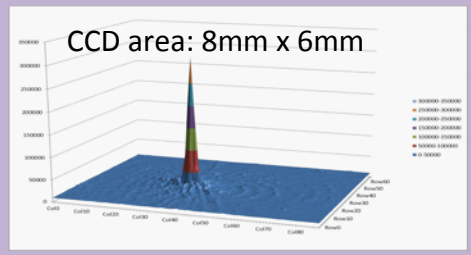
Optical transmittance: 65-67%
(Lenses were not cleaned.)

Raytracing sim. : 74%
(surface roughness 20nm RMS)

The lenses were moved into the long hallway outside the lab.

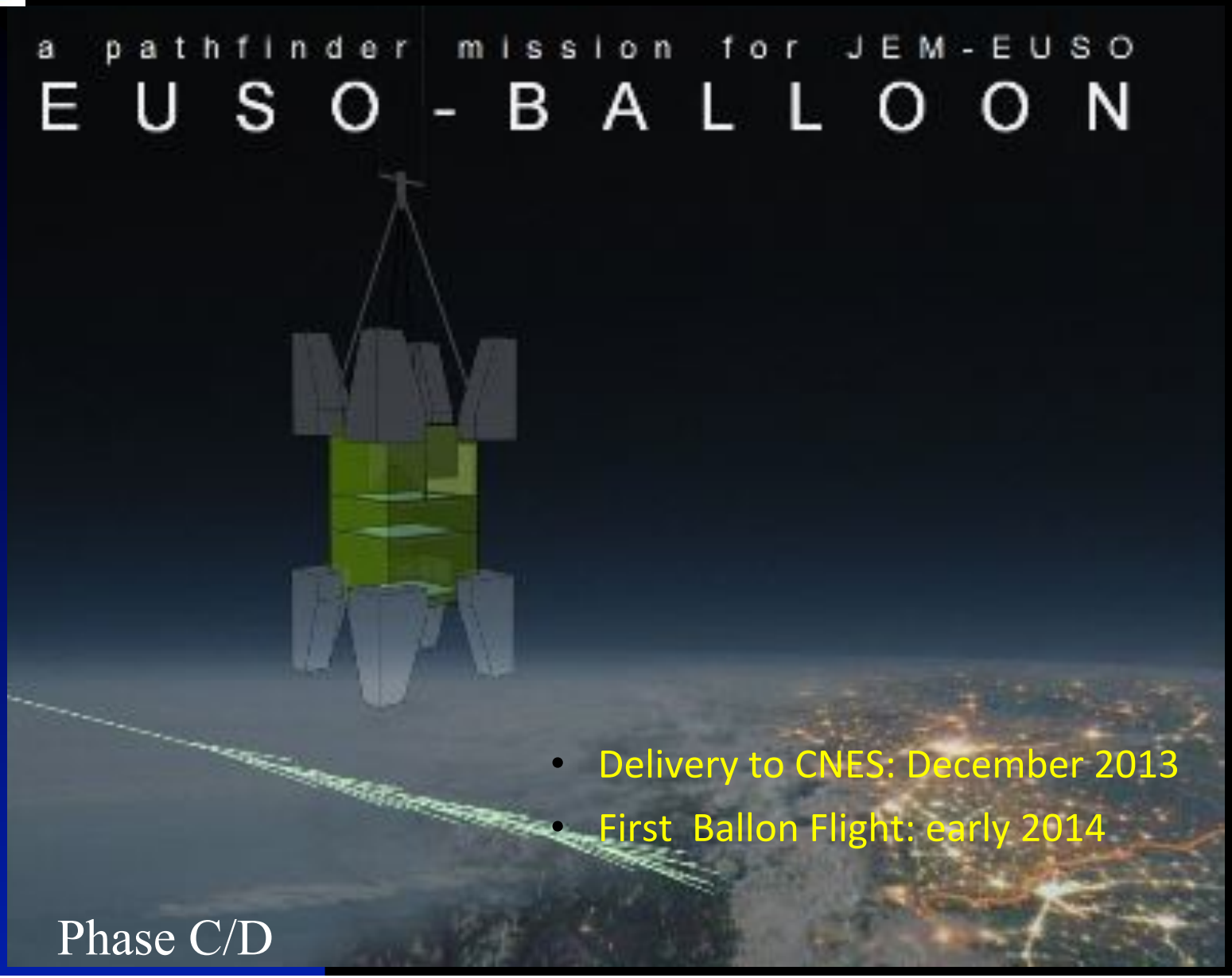


This image is taken at 48.2 cm from the back of the back lens. The area of the focal spot at half-maximum is 0.052 sq. mm.



JEM-EUSO collaboration 13 Countries, 80 Institutes as of March, 2013

EUSO Balloon - pathfinder

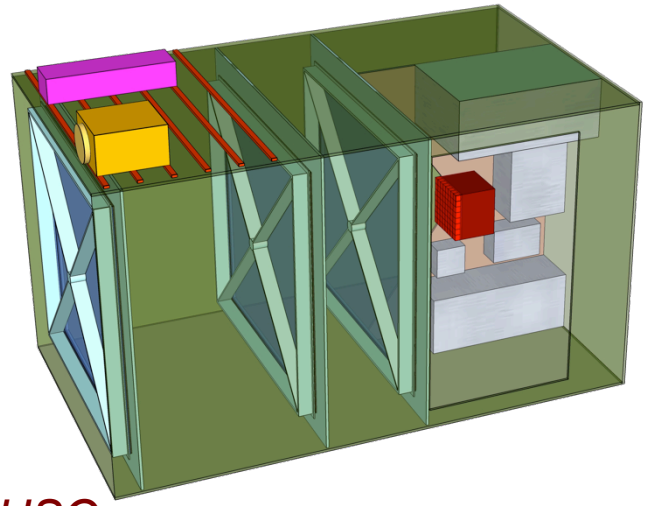


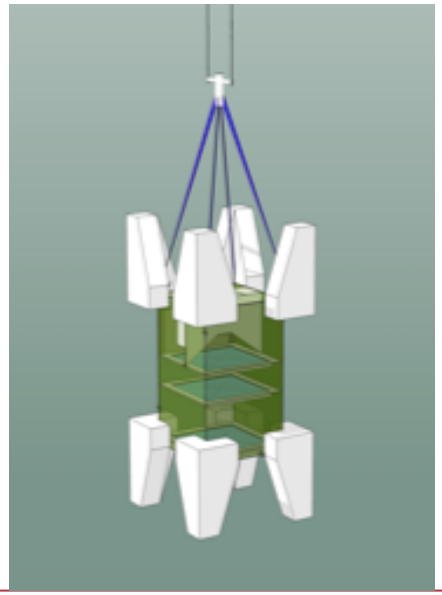
- Delivery to CNES: December 2013
- First Ballon Flight: early 2014

Phase C/D

EUSO-Balloon

- Look down from a stratospheric balloon with an UV telescope
  (PDM EM + 3 lenses system)
- *Engineering test*
- *Background test*
- Airshower from 40 km altitude



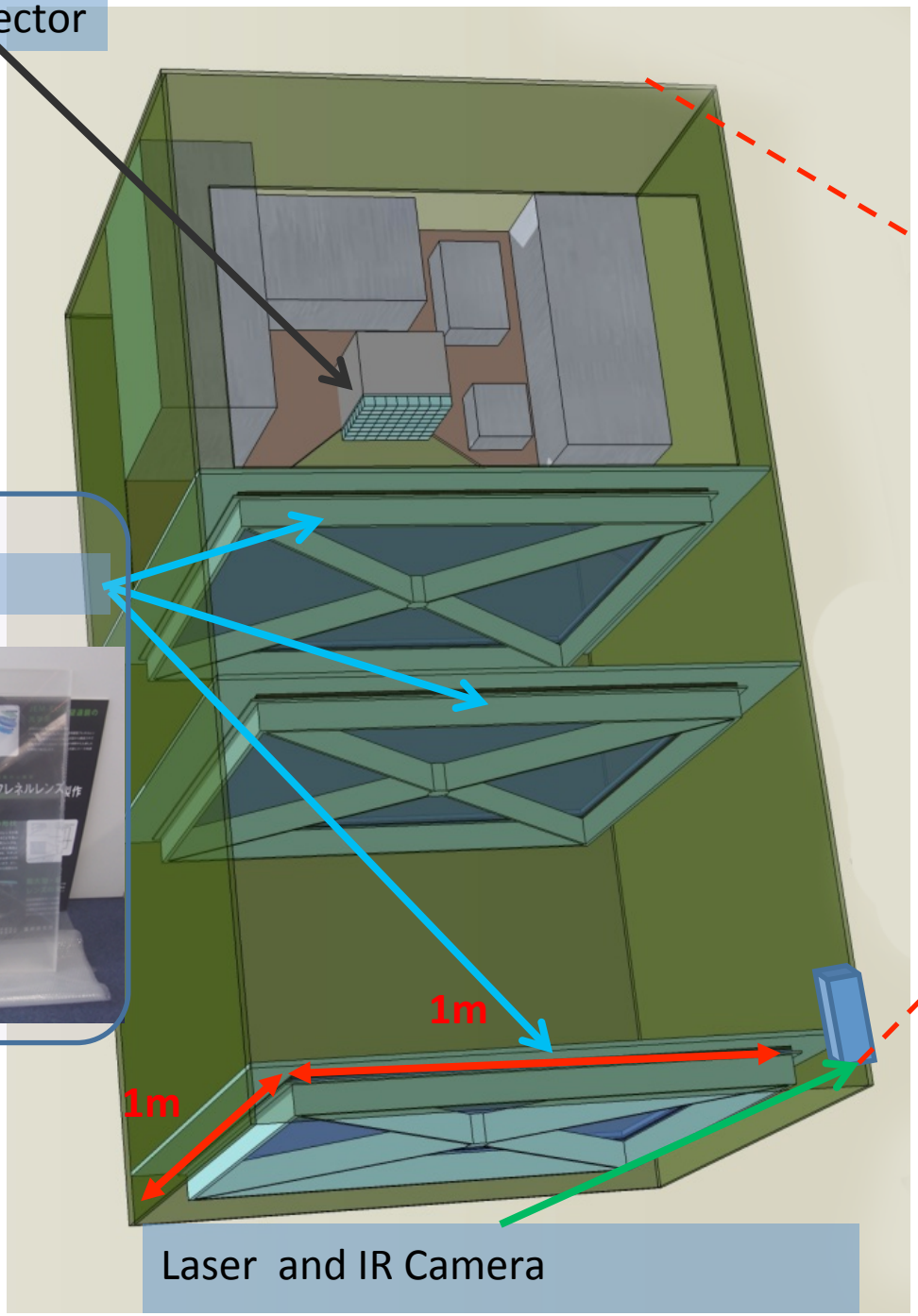


Rescaling JEM-EUSO

	JEM-EUSO	EUSO-Balloon
Height(km)	420	40
Diameter(m)	2.5	1
FoV/pix(deg)	0.08	0.25
Pixel@ground(km)	0.580	0.175
FoV/PDM(deg)	3.8	12
PDM@ground(km)	28.2	8.4
Signal Ratio	1	17.6
BG Ratio	1	0.9-1.8
S/√N	1	20-10
E_{thr}(eV)	$3x10^{19}$	$1.5\text{-}3x10^{18}$
Number of PDM	143	1

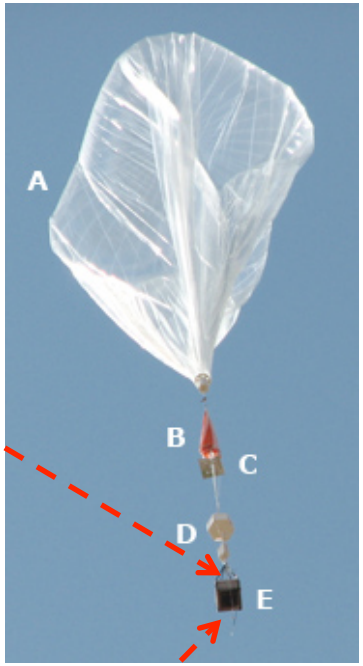
Electronics Detector

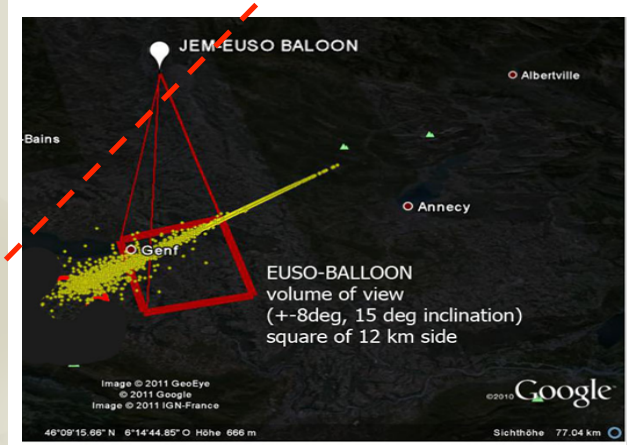
EUSO Balloon



Lenses

Laser and IR Camera



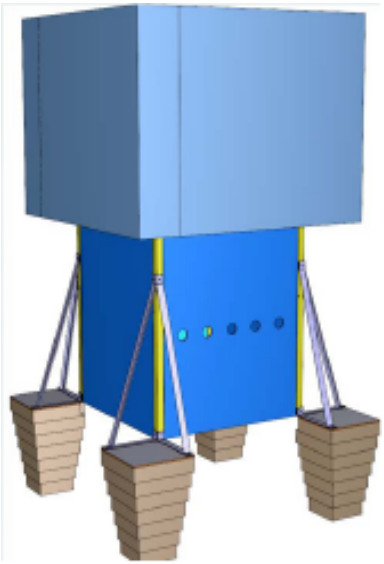


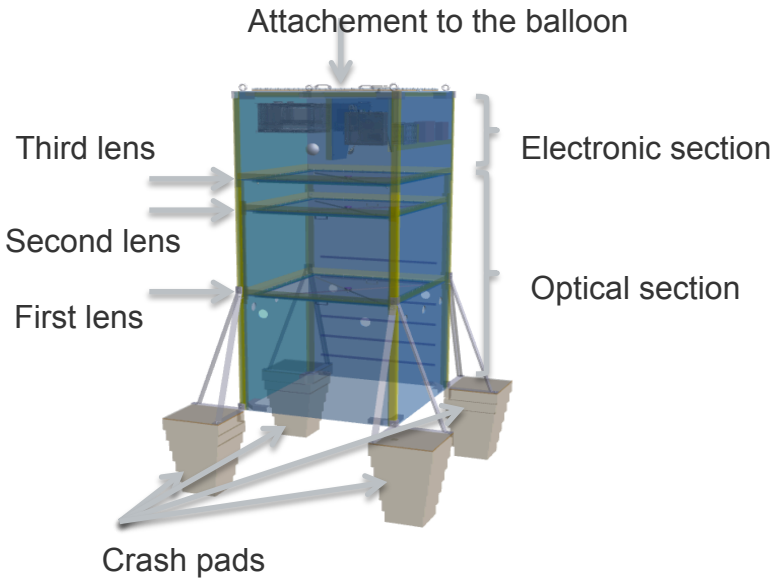
Simulations

EUSO-Balloon

EUSO-Balloon: Campaign and Mission managed by CNES (France)

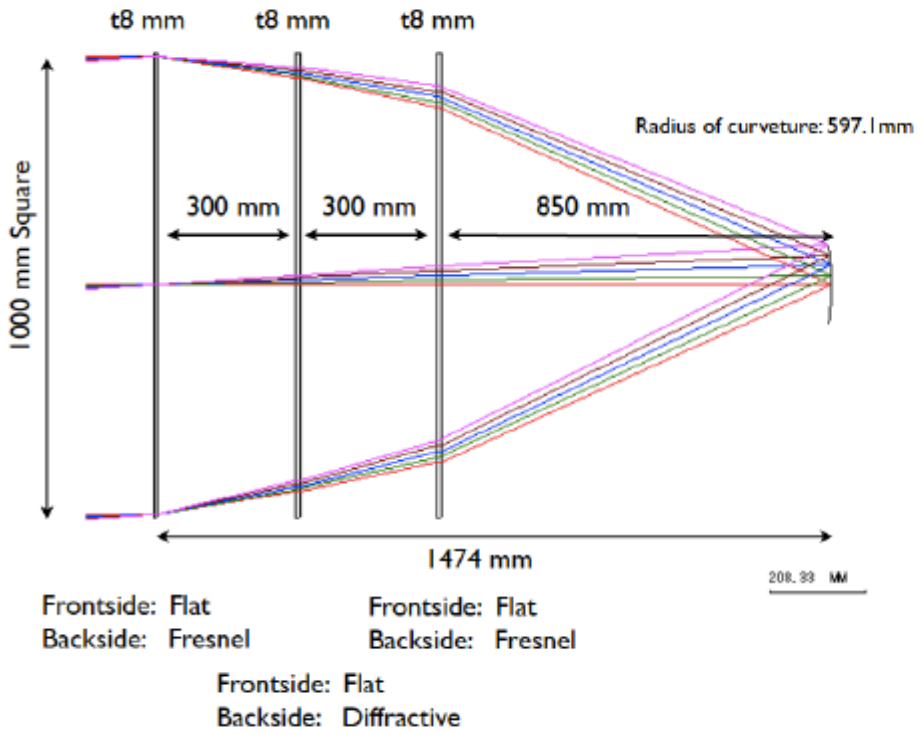
Will be *launched in Spring 2014 from Timmins, (Canada); Critical Design Review passed December 2012* and then → ***Implementation, Integration***

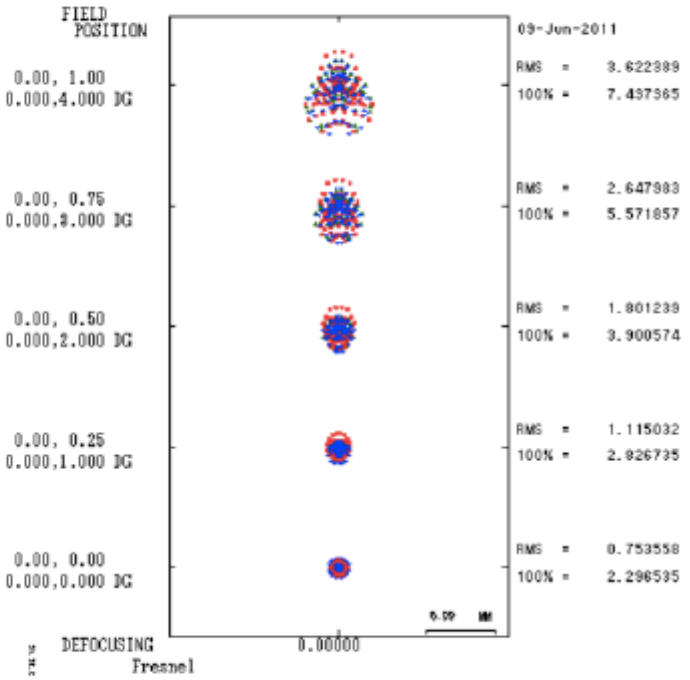




Payload architecture - driven by optical design

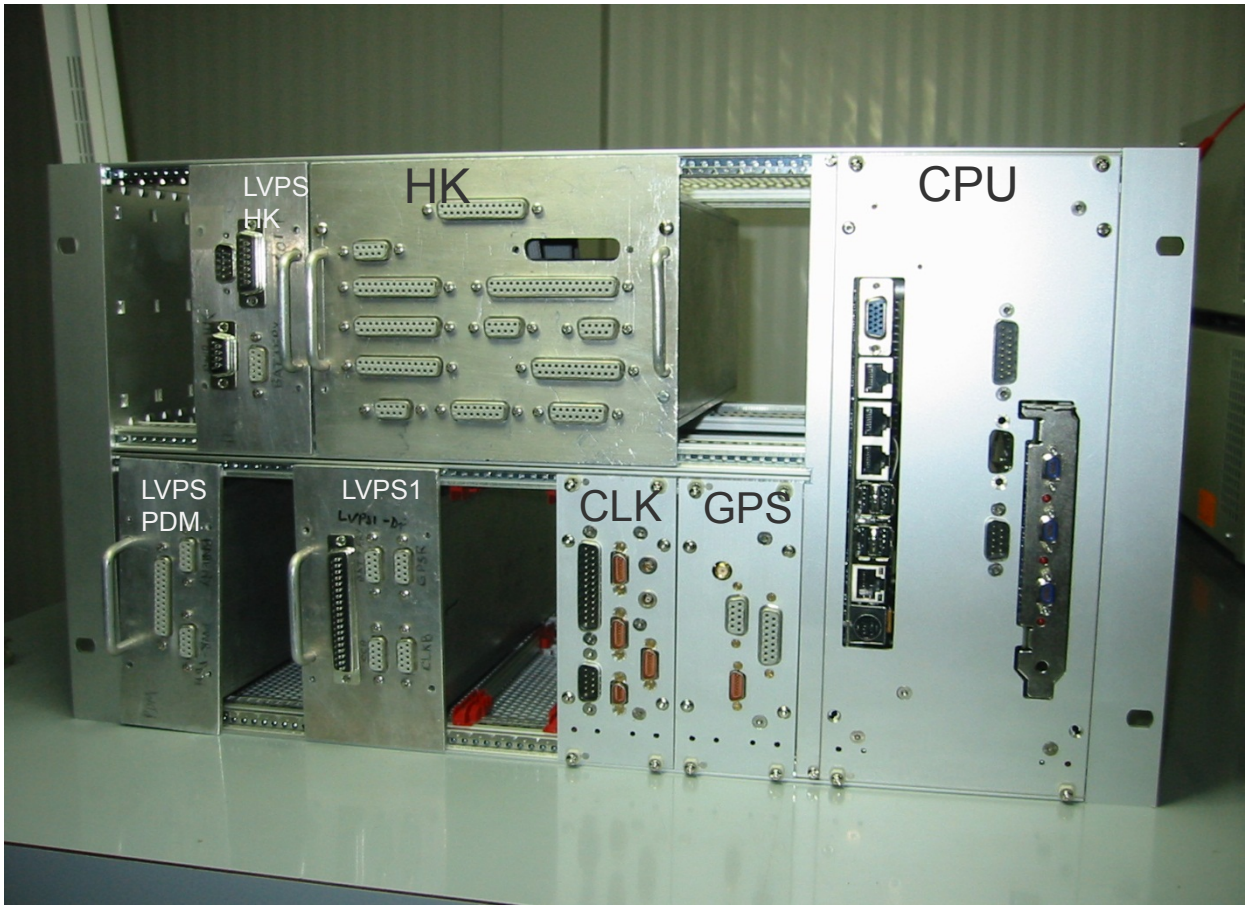
Objective : as representative as possible for JEM-EUSO
the present design (Y. Takizawa, 6.2011) is charactized by
a short focal lenght, 1.47 m and
a fairly large FOV of 8°



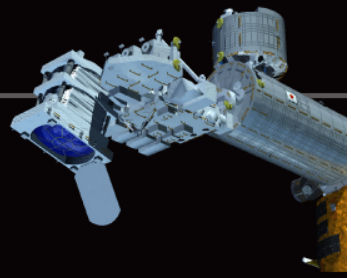


=> mass of FRESNEL lenses : 9.6 kg
=> rough dimension of telescope : 1 x 1 x 1.8 m

Integration of the Digital Processor Box
Napoli, Italy



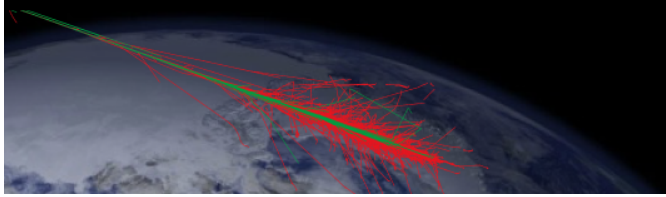
Integration of the CCB, the clock, the GPS, the CPU, the LVPS and the HK (for the EUSO-Balloon prototype)



mini-EUSO
A precursor of JEM-EUSO
on board ISS

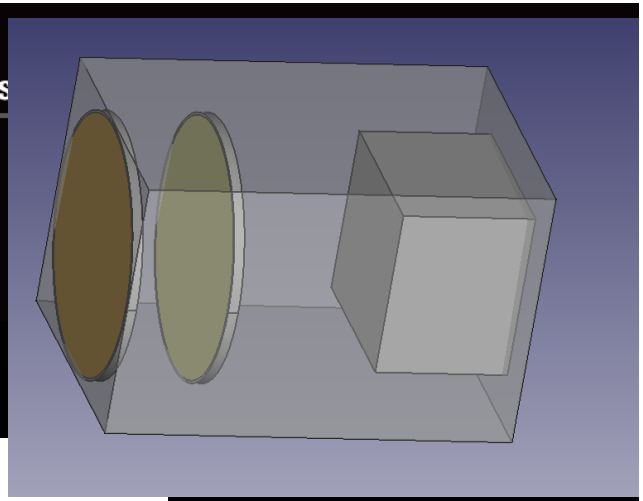
Proposed to ASI (Italian Space Agency) in response to a call 2012 for Human Spaceflight

Selected, July 2013
(Resources, upload mass, crew time)

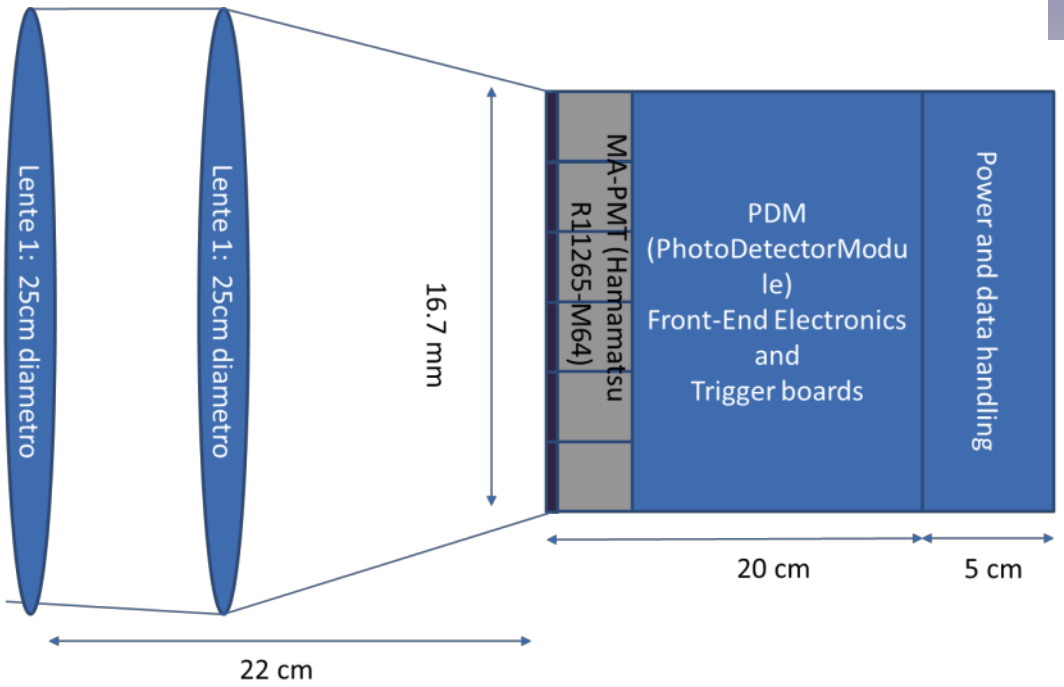


JEM-EUSO collaboration 13 Countries, 80 Institutes as of March, 2013

JEM-EUSO on ISS explores the origin of the highest energy particles



Bring one PDM (36 PMTs) and two Fresnel lenses (25 cm diam.) to ISS and expose it to an ISS UV window



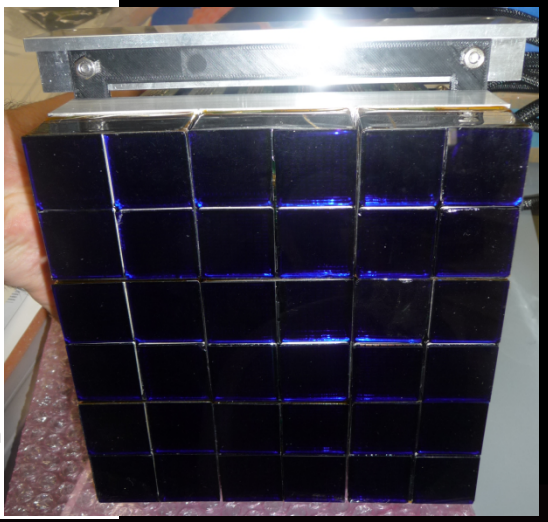
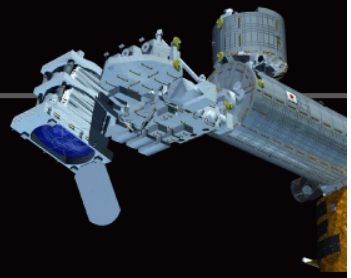


Figure 1 MINI-EUSO block scheme: Optical system with two Fresnel Lenses (25 cm diameter) focalizes UV light on a surface of 1 PDM, 36 multi-anode PMTS, total 2304 pixel

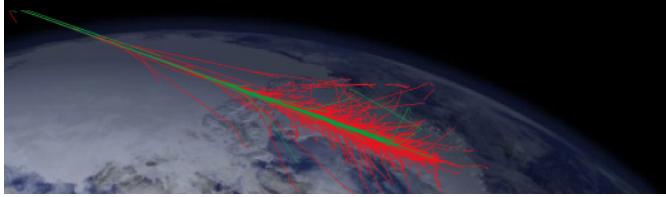
JEM-EUSO collaboration 13 Countries, 80 Institutes as of March, 2013



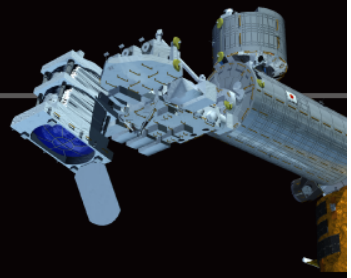
mini-EUSO Role Sharing

- RIKEN: Lenses
- France: EC-ASIC
- Corea: PDM board
- Italy: PMTs, CPU and LowVoltPS

Launch foreseen early 2015 (carried by astronaut)



JEM-EUSO on ISS explores the origin of the highest energy particles in the Universe



a) Scientific Objectives

a.1) Study of the Earth background in UV band with a resolution of 6.5 km on time scales of 2.5 μs over the entire planet.

a.2) Earth mapping in UV

a.3) Study of atmospheric phenomena

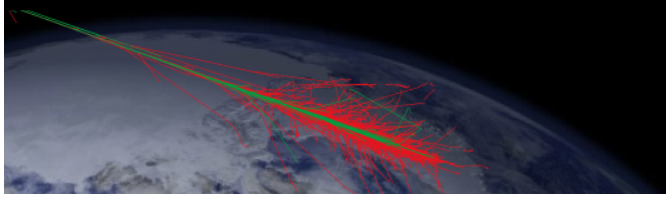
a.4) Study of meteor phenomena

b) Technological objectives

b.1) First use of Frensel lenses in space

b.2) Optimization and validation of JEM-EUSO observational features

b.3) Enhancement of the Technical Readiness Level (TRL) of some components of the JEM-EUSO detector



JEM-EUSO collaboration 13 Countries, 80 Institutes as of March, 2013

JEM-EUSO Current Status

- JEM-EUSO approved and funded by NASA →
- JEM-EUSO approved by Roscosmos Committee →
- JEM-EUSO approved by ESA and included in ELIPS program
- JEM-EUSO R&D approved and funded by several space agencies
- A/O from JAXA to be released

- The JEM-EUSO Instrument has been designed
- The performance have been simulated
- Key parts of the apparatus have been implemented
- Two pathfinder experiments are in progress, a new one is proposed
- Large consensus from the scientific community

(Good) News from NASA and Roscosmos

Last year's essential milestones:

The NASA Science Mission Directorate approved the JEM-EUSO APRA proposal (Refereed as Excellent and selected with a clear forward to the mission).

Funds are now flowing in the US: JEM-EUSO is now a mission studied by NASA.

Support of Tsniimash —>The Coordination Scientific and Technical Council (CSTC) of ROSCOSMOS has approved a wider participation of Russia to JEM-EUSO facilities on board ISS + mechanical structure.

The decision has been communicated to the *ISS Roscosmos* Manned Space Program Directorate

POCKOCMOC

Conclusions

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

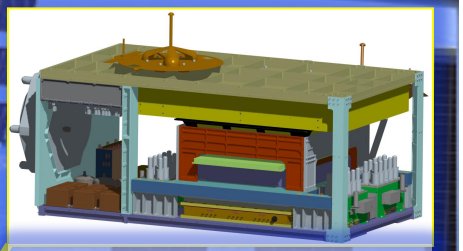
- *Prototypes and Models of the major elements* (Lenses, PDM, DP Unit) have been *produced and are being tested* to increase the TRLs levels.

- *The Pathfinders (EUSO-TA and EUSO-Balloon) are being completed* and will open a year of exciting measurements “on the field”

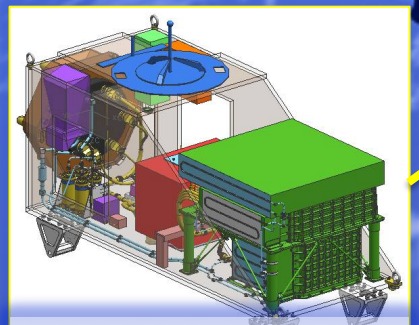
- *The program has advanced significantly in ESA, NASA and Roscosmos.* A (final) proposal to JAXA is due in the next few months: in the meantime we continue to shape the science, technology, and mission aspects of JEM-EUSO

View from NASA: “Cosmic Ray Observatory on the ISS”

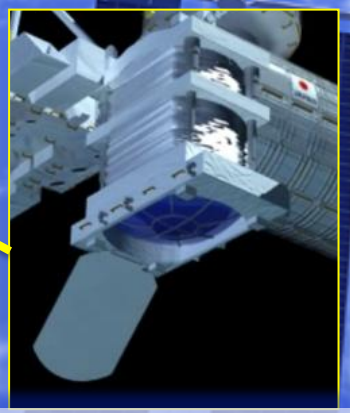
AMS Launch
May 16, 2011



ISS-CREAM
Sp-X Launch 2014



CALET on JEM
HTV Launch 2014



JEM-EUSO
Launch Tentatively
planned for 2017