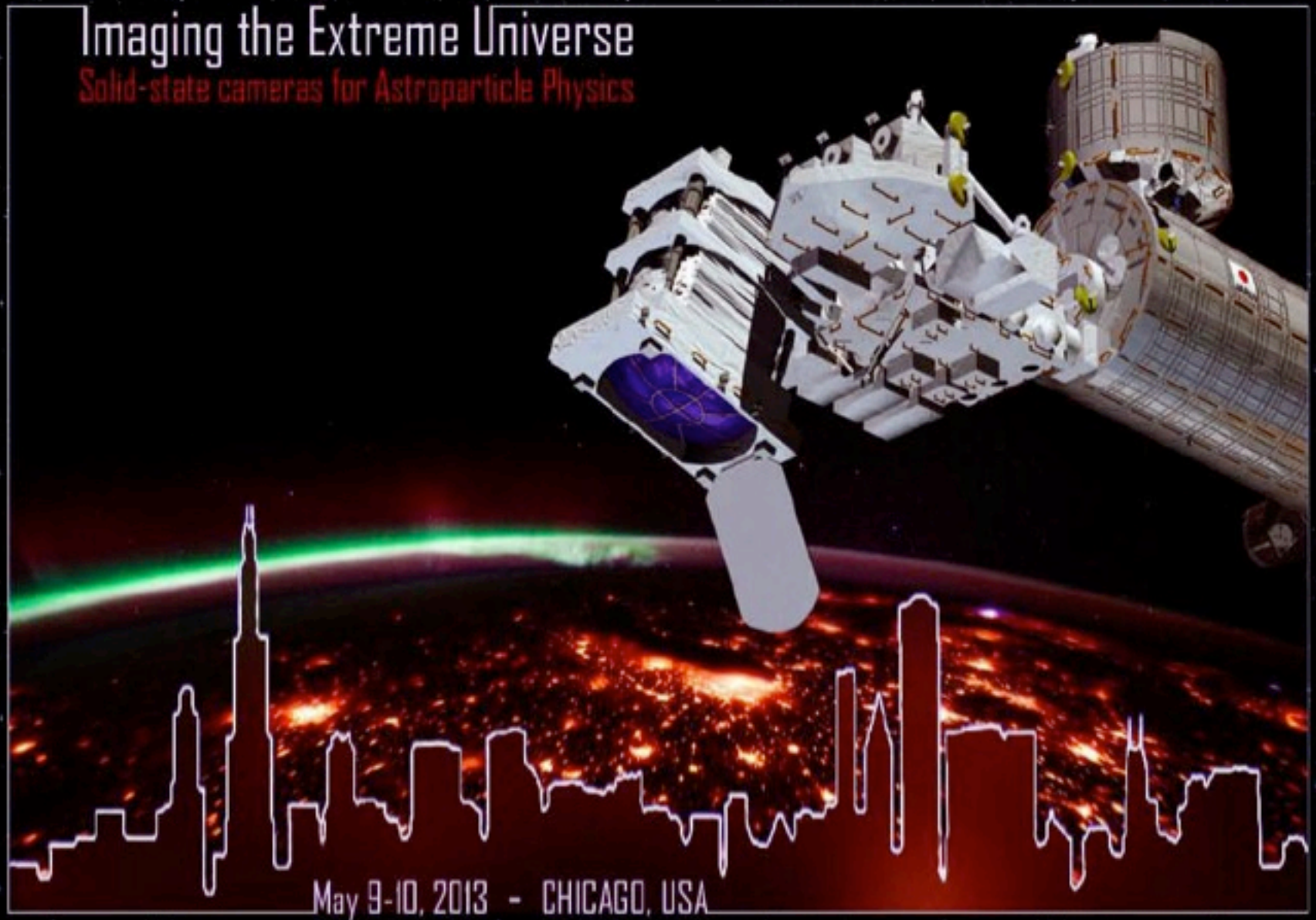
Imaging the Extreme Universe

Solid-state cameras for Astroparticle Physics



KICP

THE UNIVERSITY OF CHICAGO

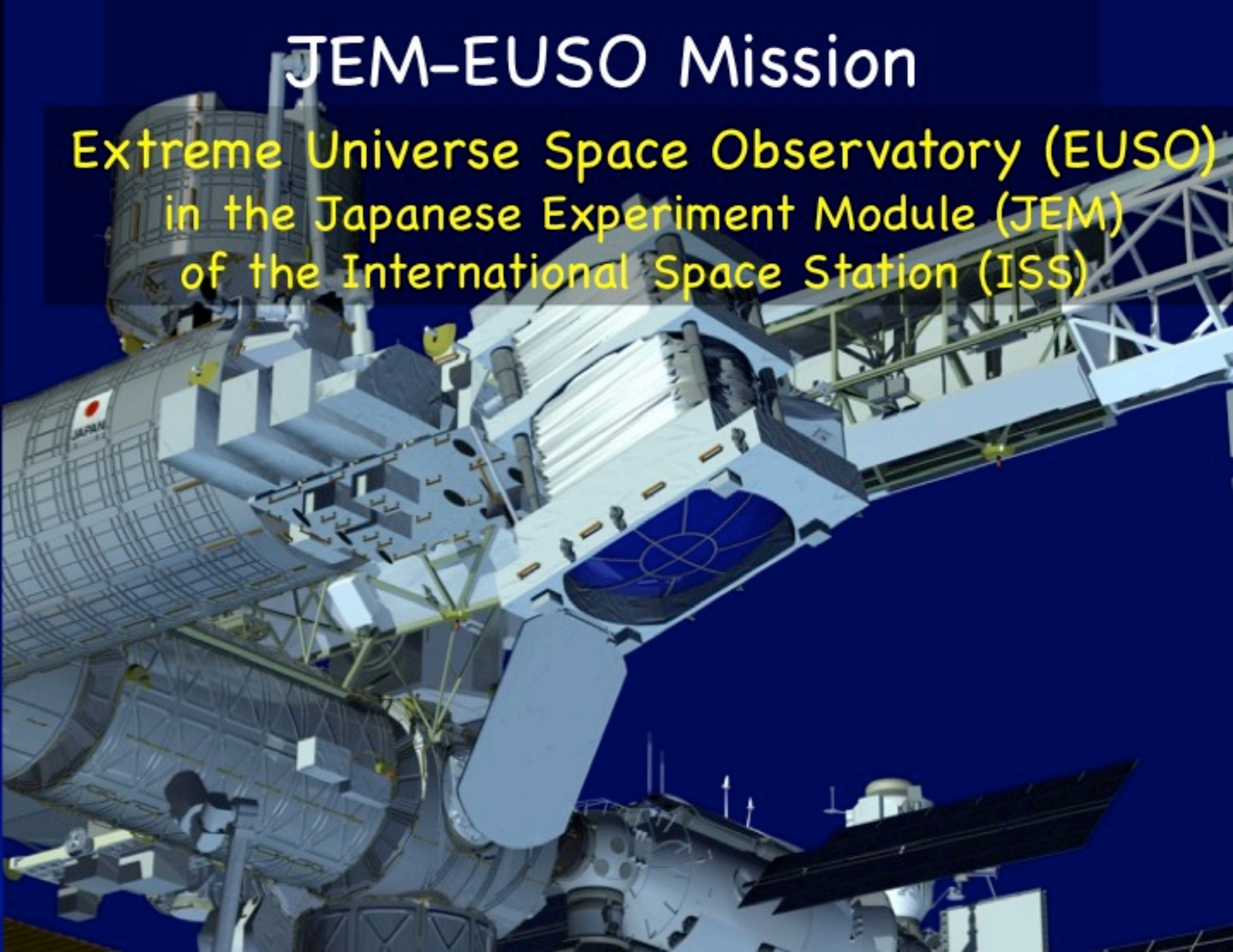

WELCOME to KICP!!

JEM-EUSO Science Overview

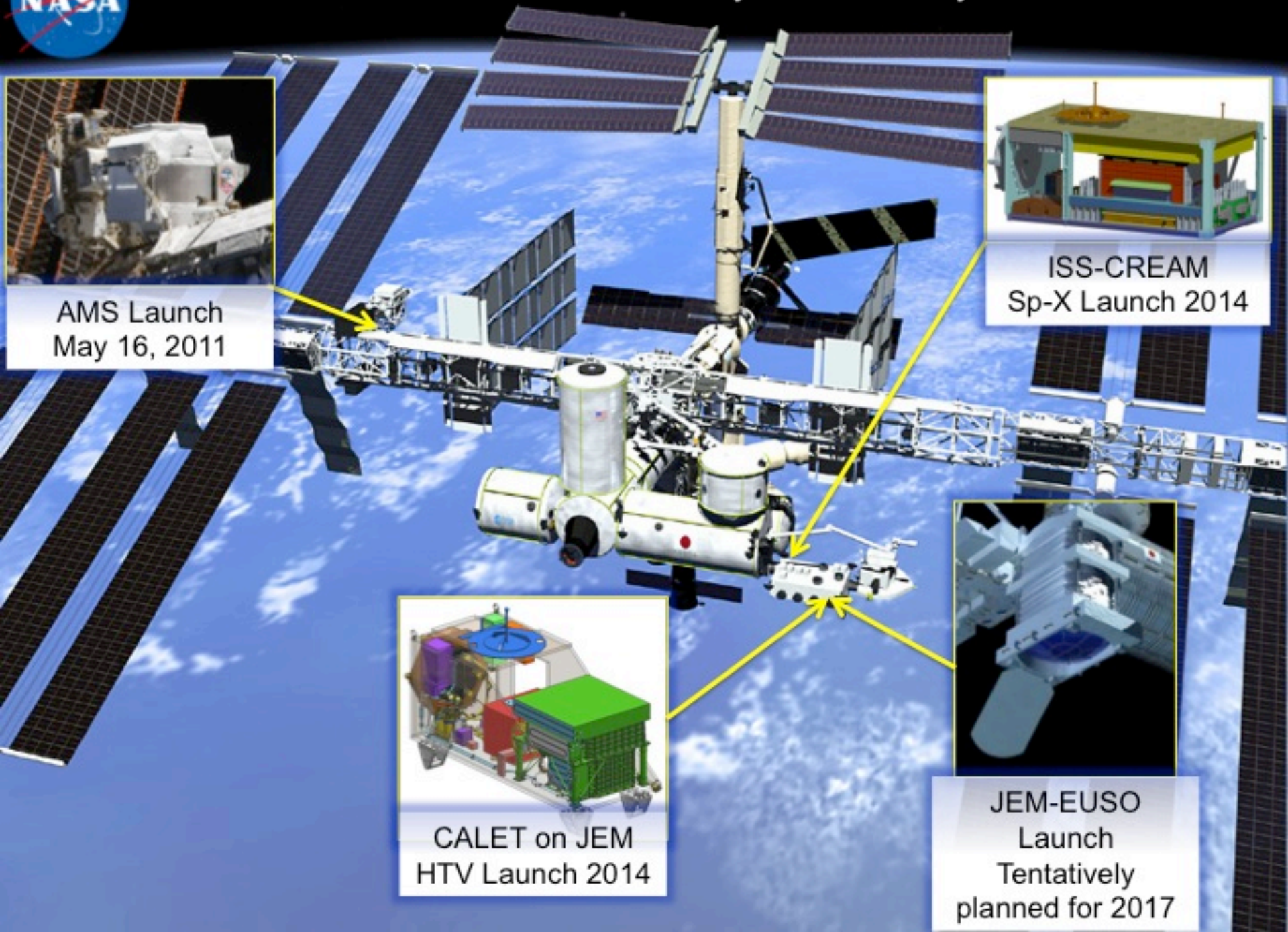
Angela V. Olinto
The University of Chicago

JEM-EUSO Mission

Extreme Universe Space Observatory (EUSO) in the Japanese Experiment Module (JEM) of the International Space Station (ISS)



View from NASA: "Cosmic Ray Observatory on the ISS"



JEM-EUSO Mission

きぼう, Kibo = Hope

JEM-EUSO Mission

Japan, USA, Korea, Mexico, Russia, Europe: Bulgaria, France, Germany, Italy, Poland, Slovakia, Spain, Switzerland

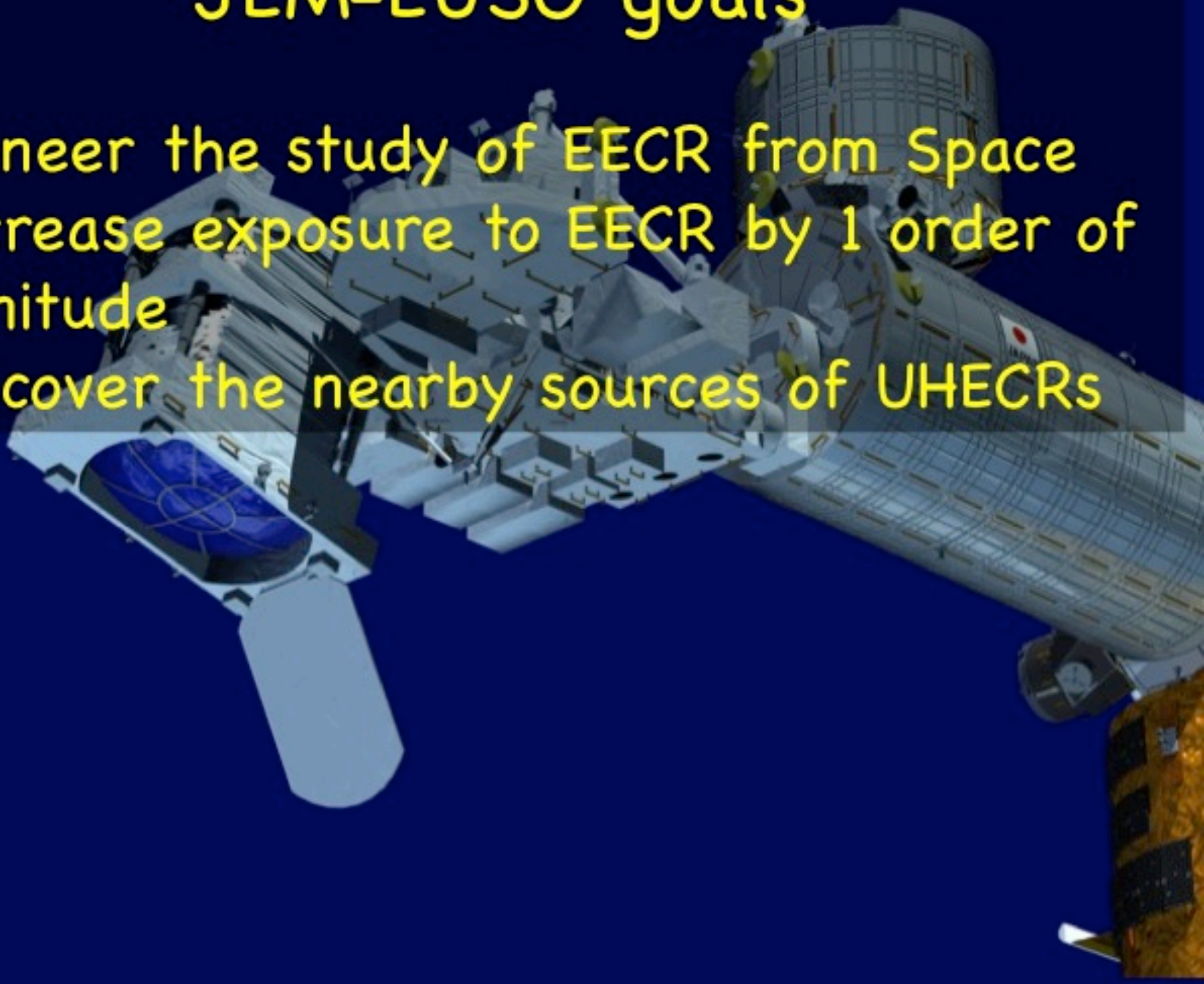
13 Countries, 73 Institutions, 250 researchers

Leading institution: RIKEN

PI: Piergiorgio Picozza

JEM-EUSO goals

- pioneer the study of EECR from Space
- increase exposure to EECR by 1 order of magnitude
- discover the nearby sources of UHECRs



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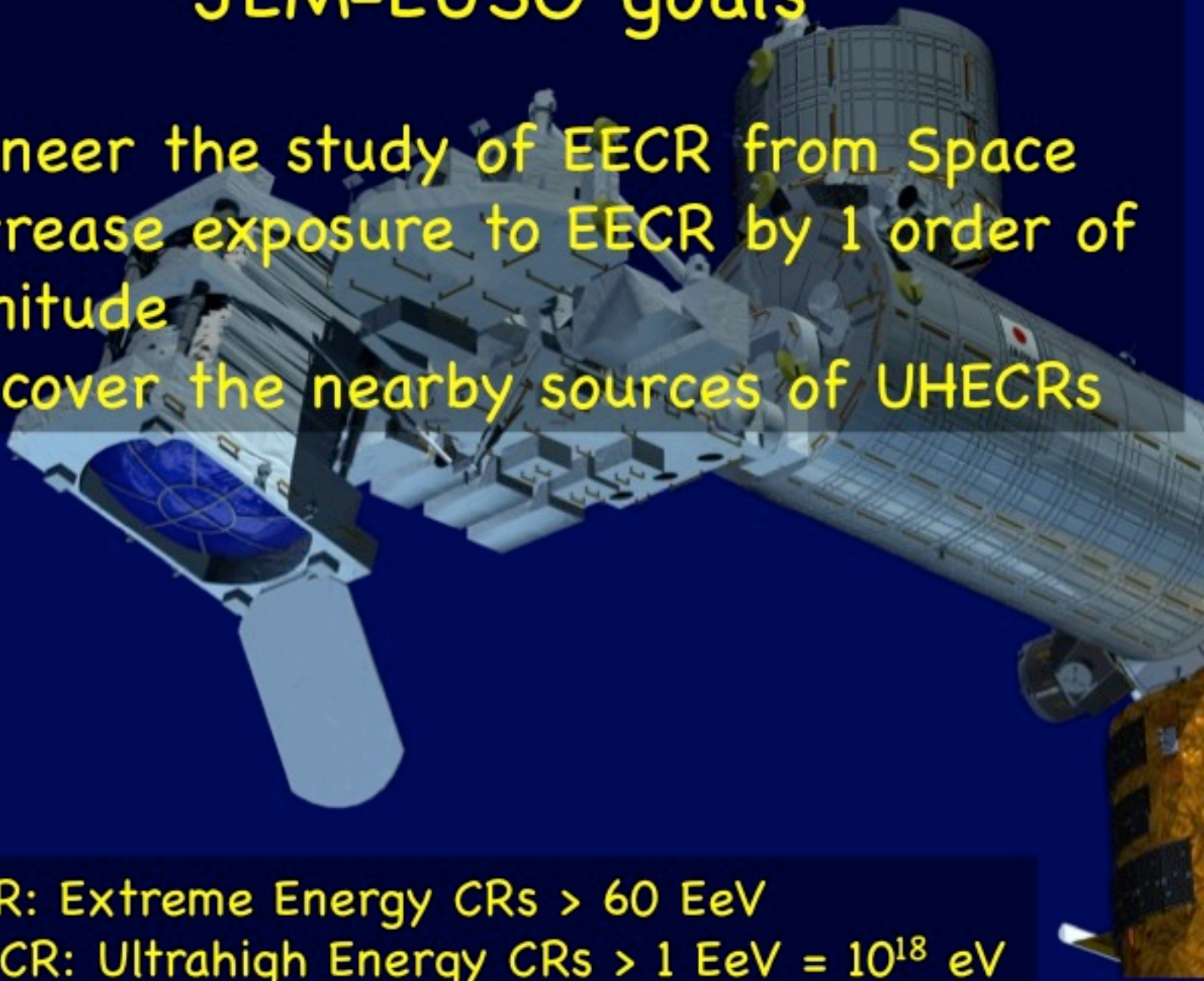
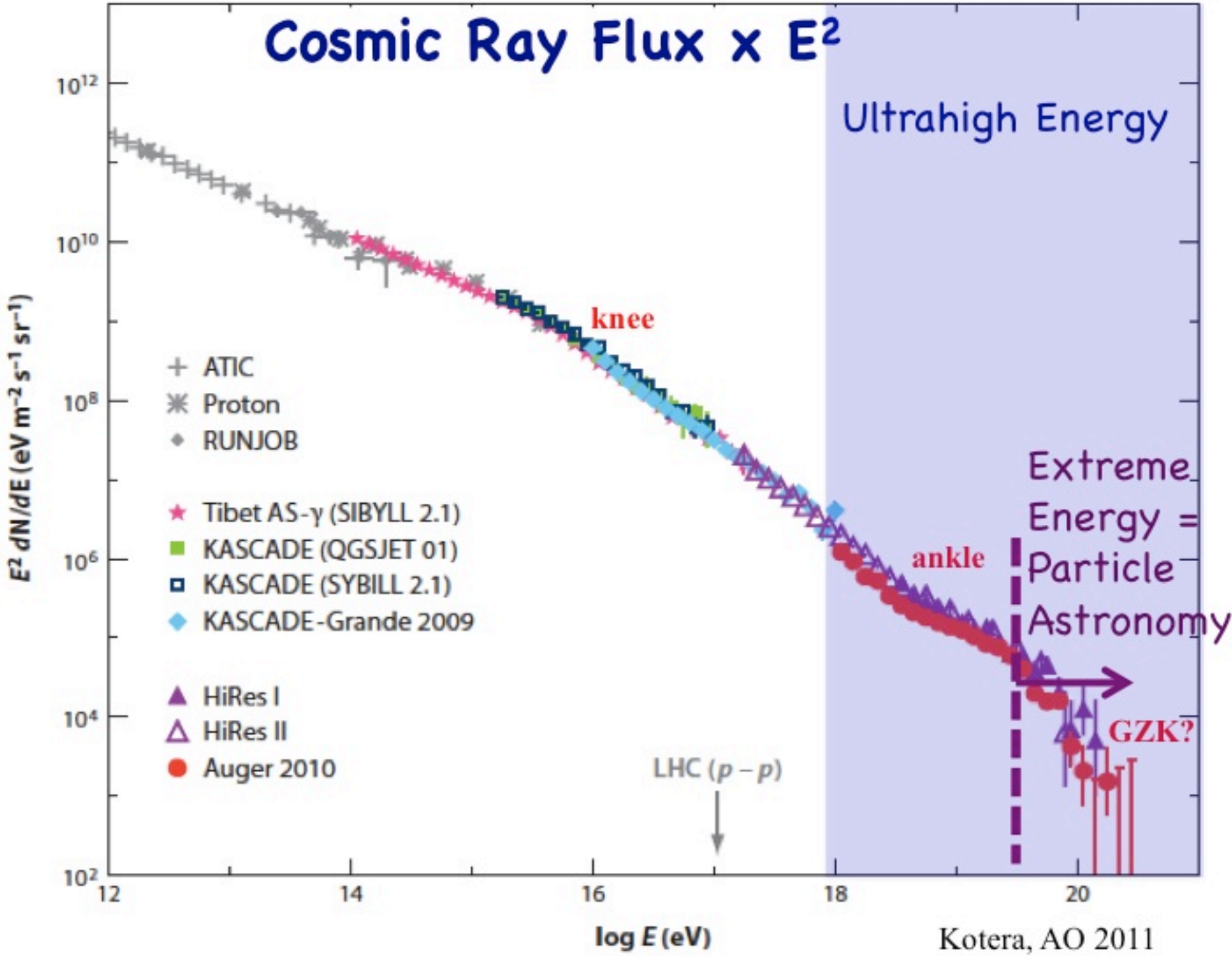
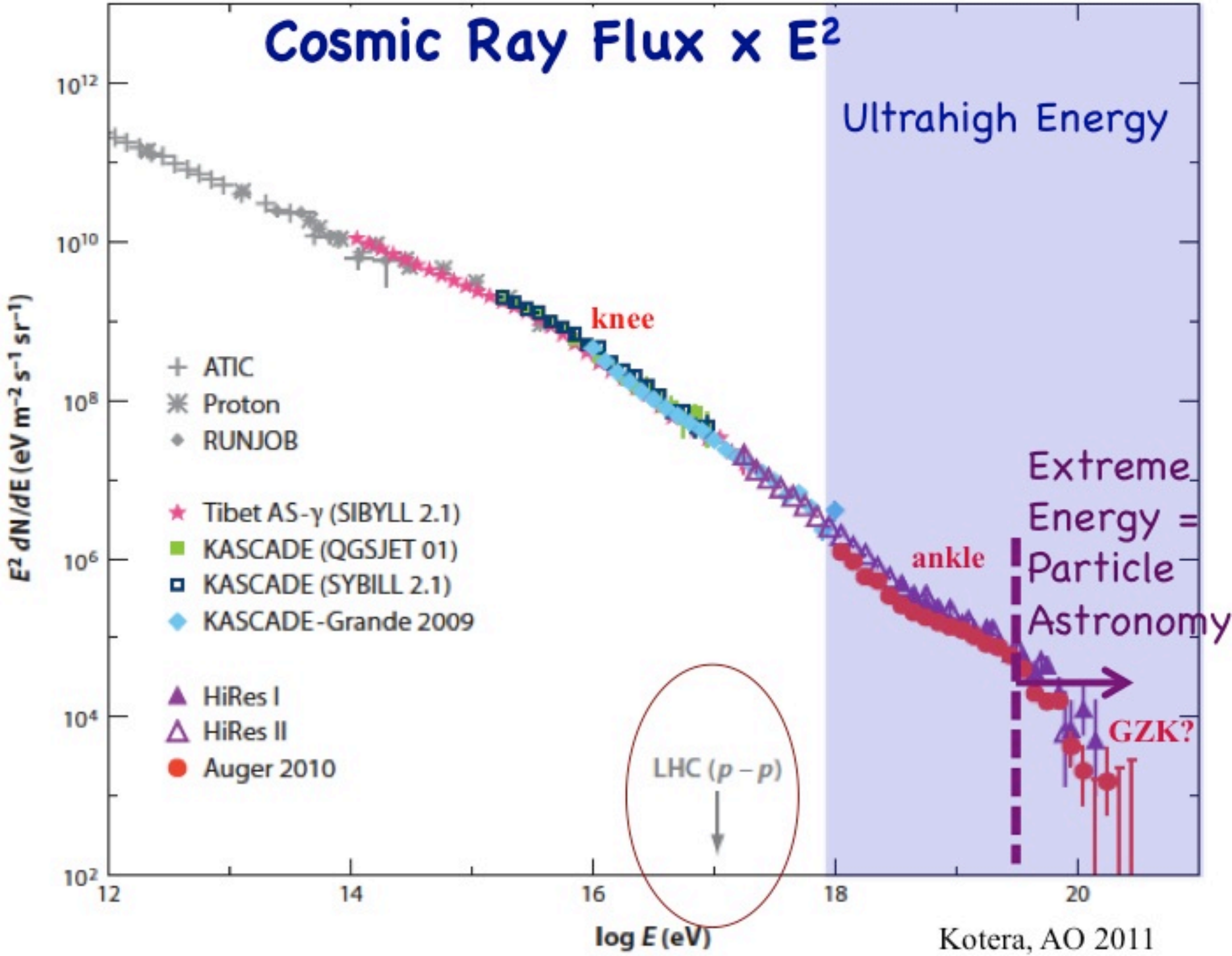


EECR: Extreme Energy CRs > 60 EeV
UHECR: Ultrahigh Energy CRs > 1 EeV = 10^{18} eV



Kotera, AO 2011



Kotera, AO 2011

Current Observatories of Ultrahigh Energy Cosmic Rays

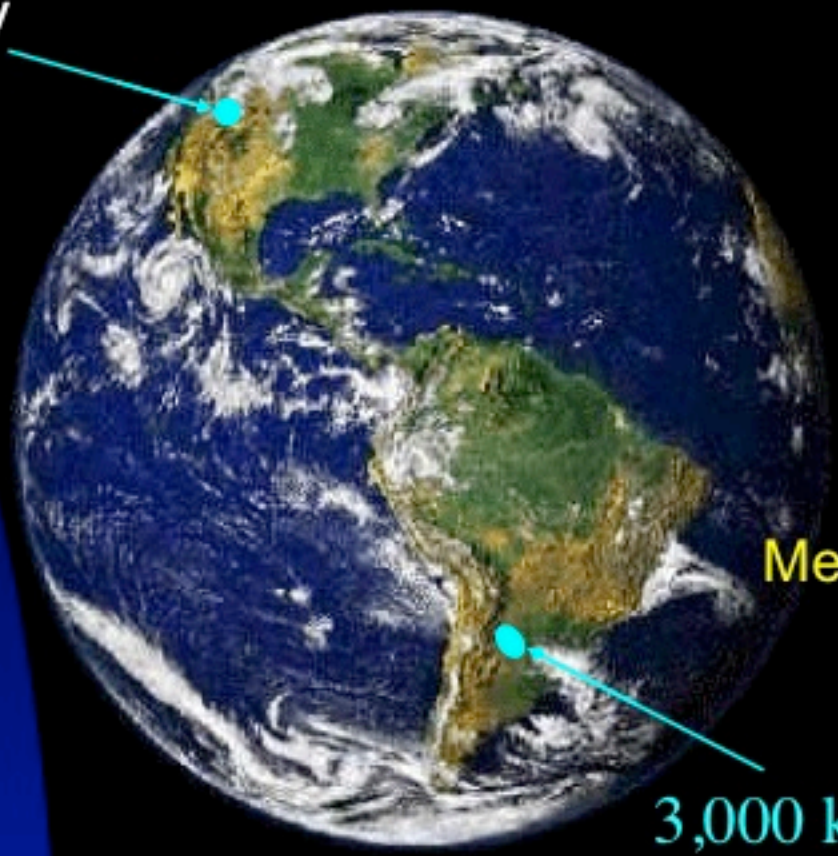
Telescope Array

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

Recent Results

E>20 EeV Cosmic Rays are EXTRAGALACTIC

Recent Results

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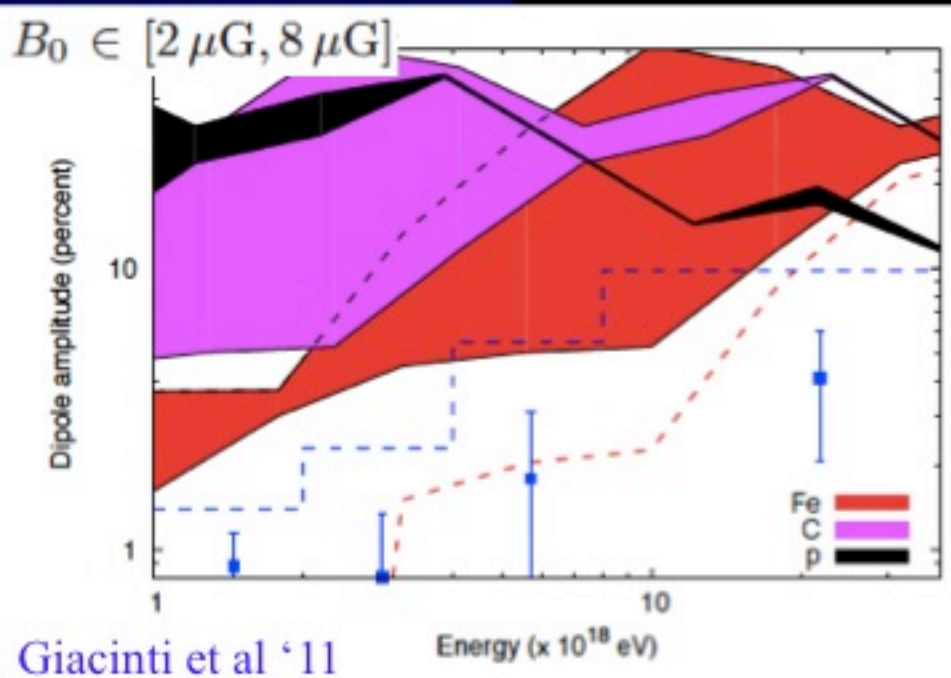
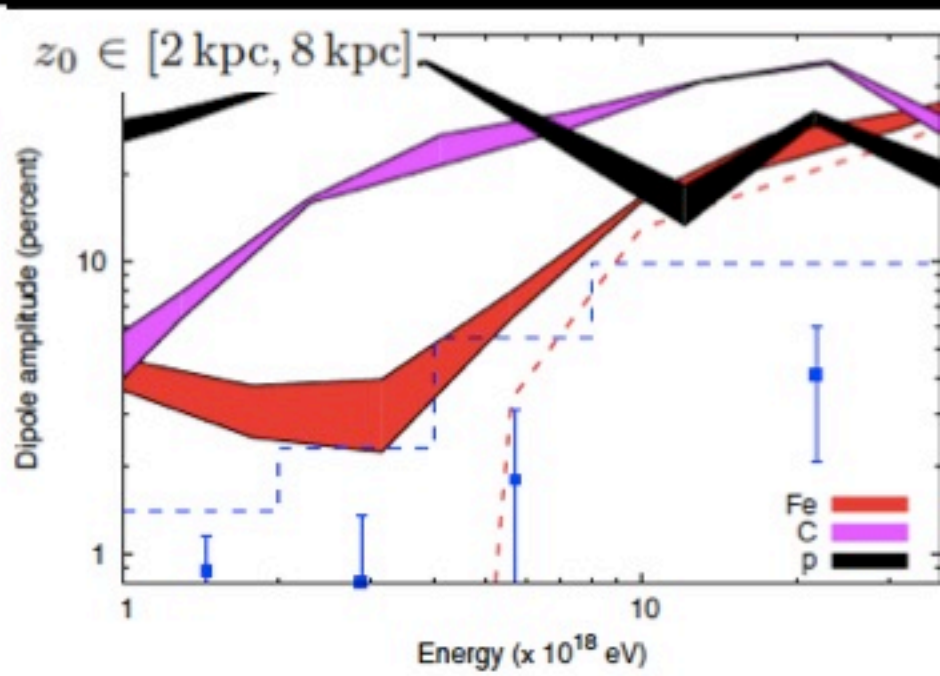
Auger Anisotropy limits: rule out Galactic protons to CNO as dominant CR component E > 1 EeV and Fe above 20 EeV





Giacinti et al '11

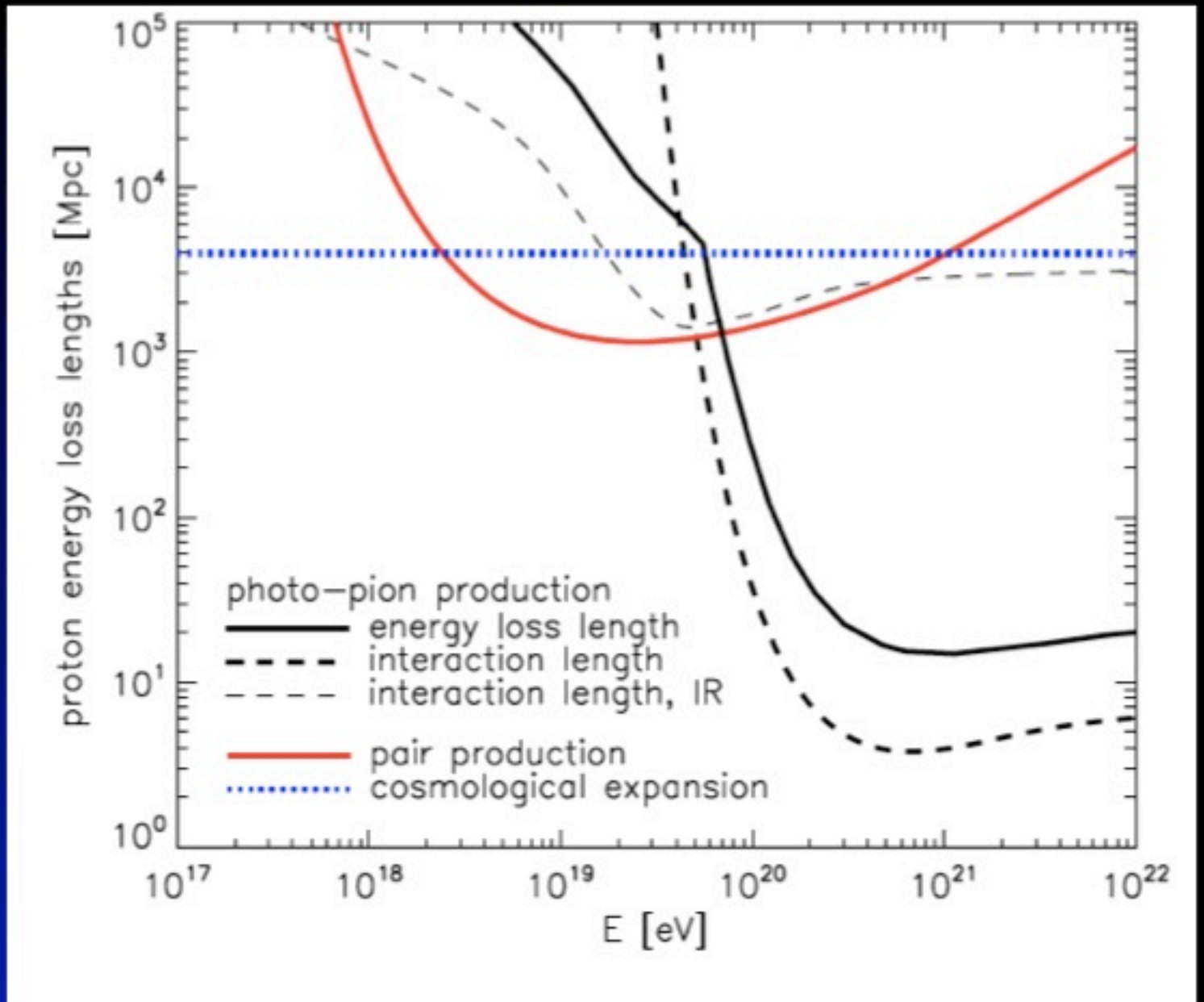
Recent Results

E>20 EeV Cosmic Rays are EXTRAGALACTIC

Implies a GZK* feature in the spectrum

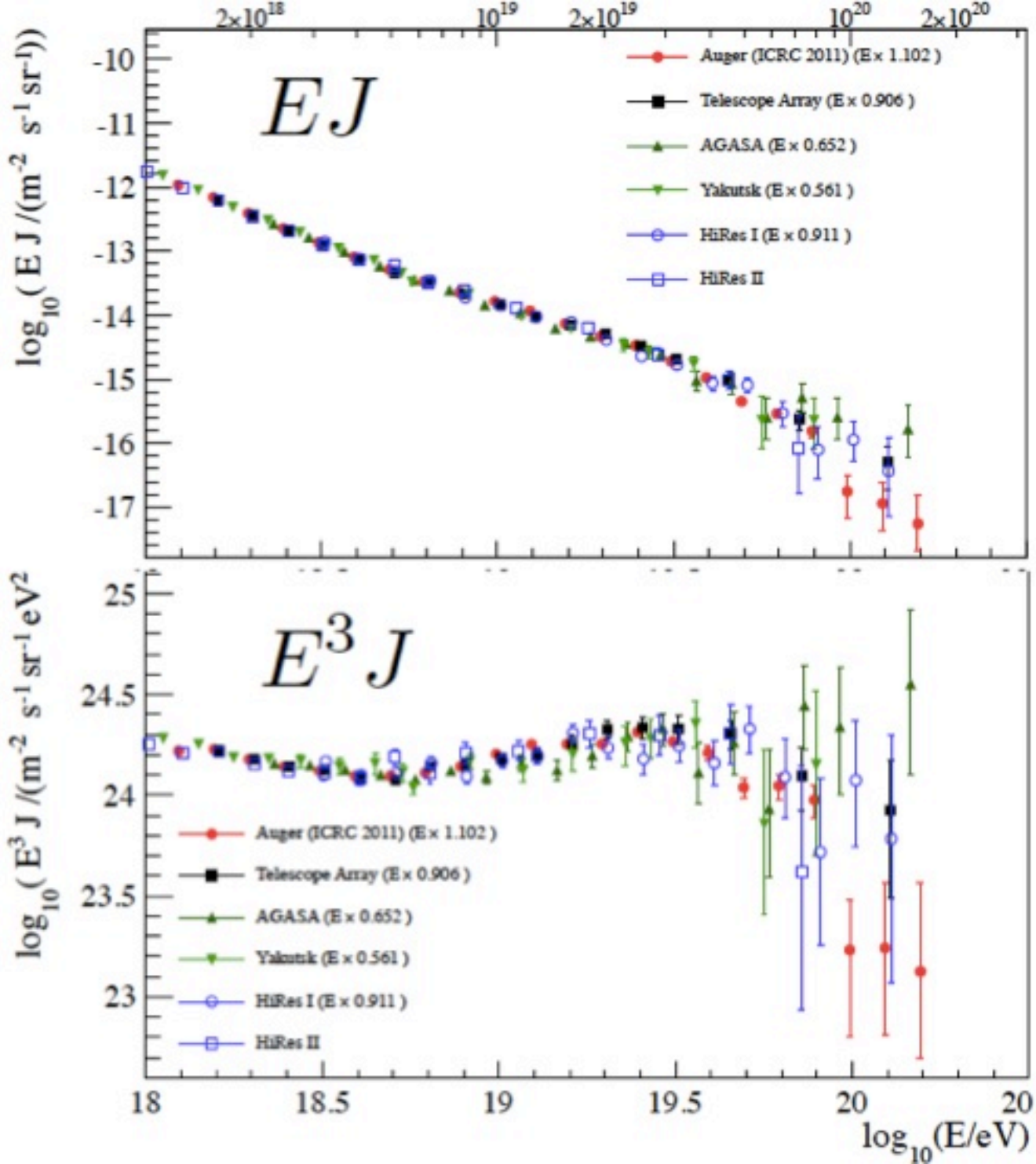
(*Greisen-Zatsepin-Kuzmin)

Greisen-Zatsepin-Kuzmin effect



UHECR 2012

CERN



Tsunesada et al.
CERN WG '12

Recent Results

E>20 EeV Cosmic Rays are EXTRAGALACTIC

E>40 EeV GZK-like feature in the spectrum

Recent Results

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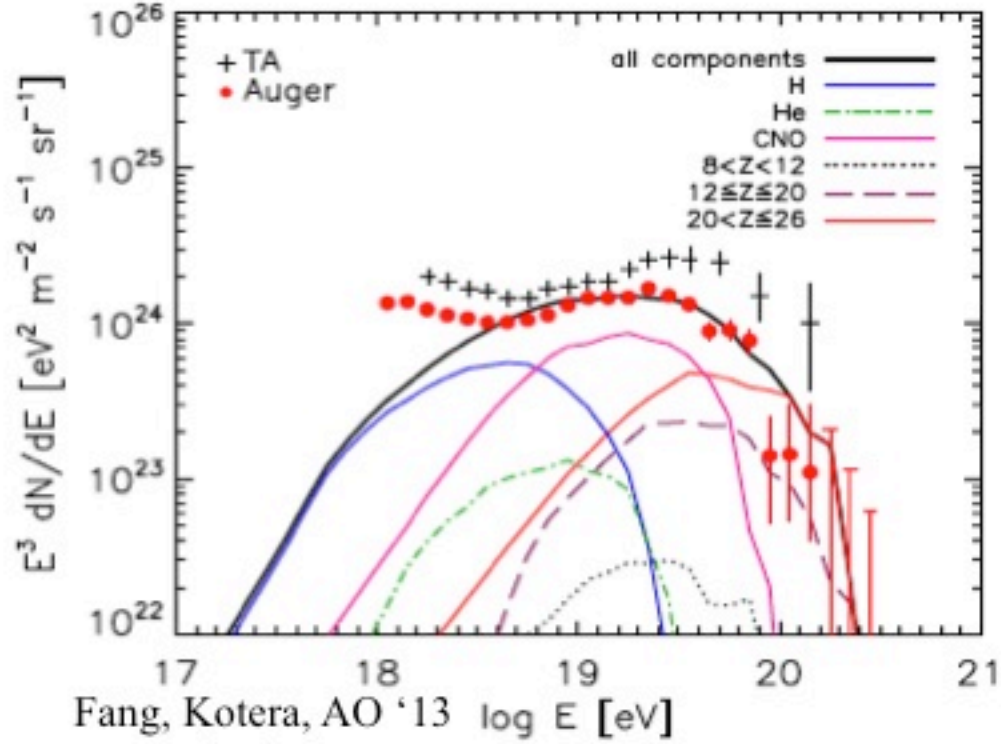
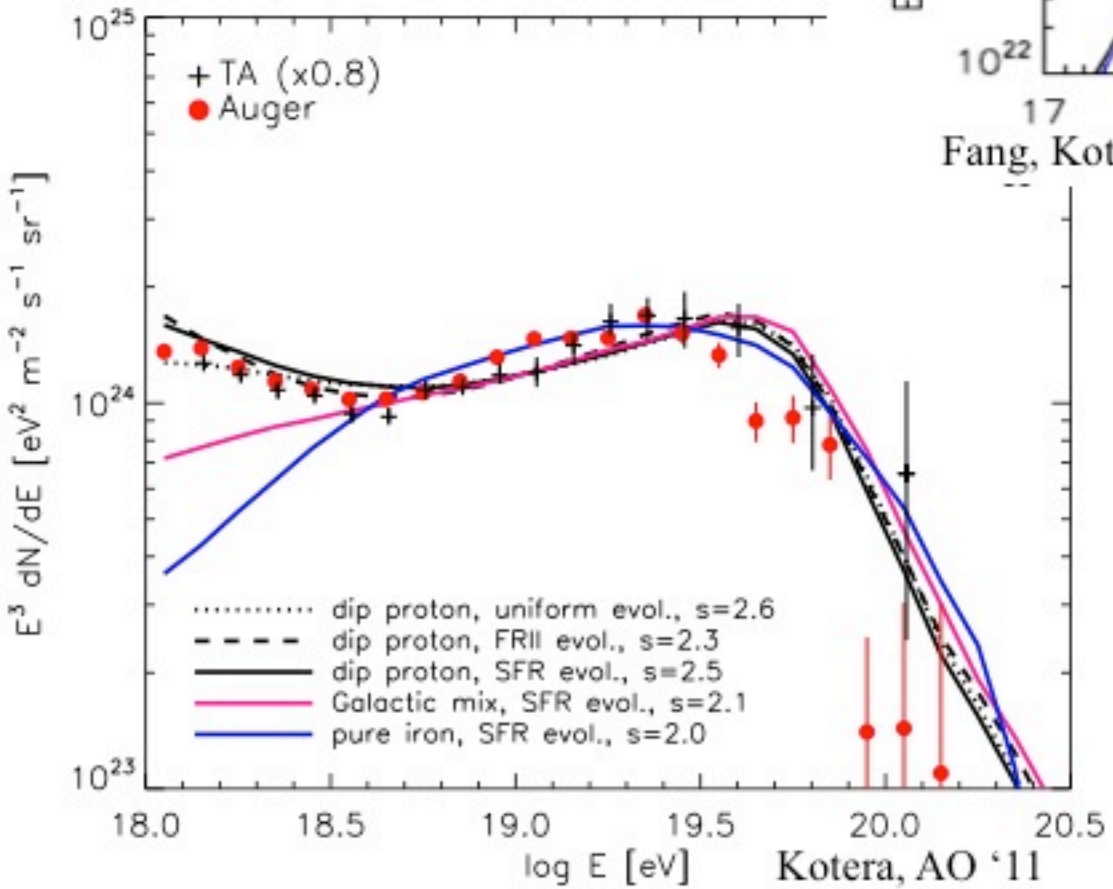
E>40 EeV GZK-like feature in the spectrum

or end of the injected spectrum, E_{max}?

GZK vs E_{max}



Fang, Kotera, AO '13



Kotera, AO '11

Recent Results

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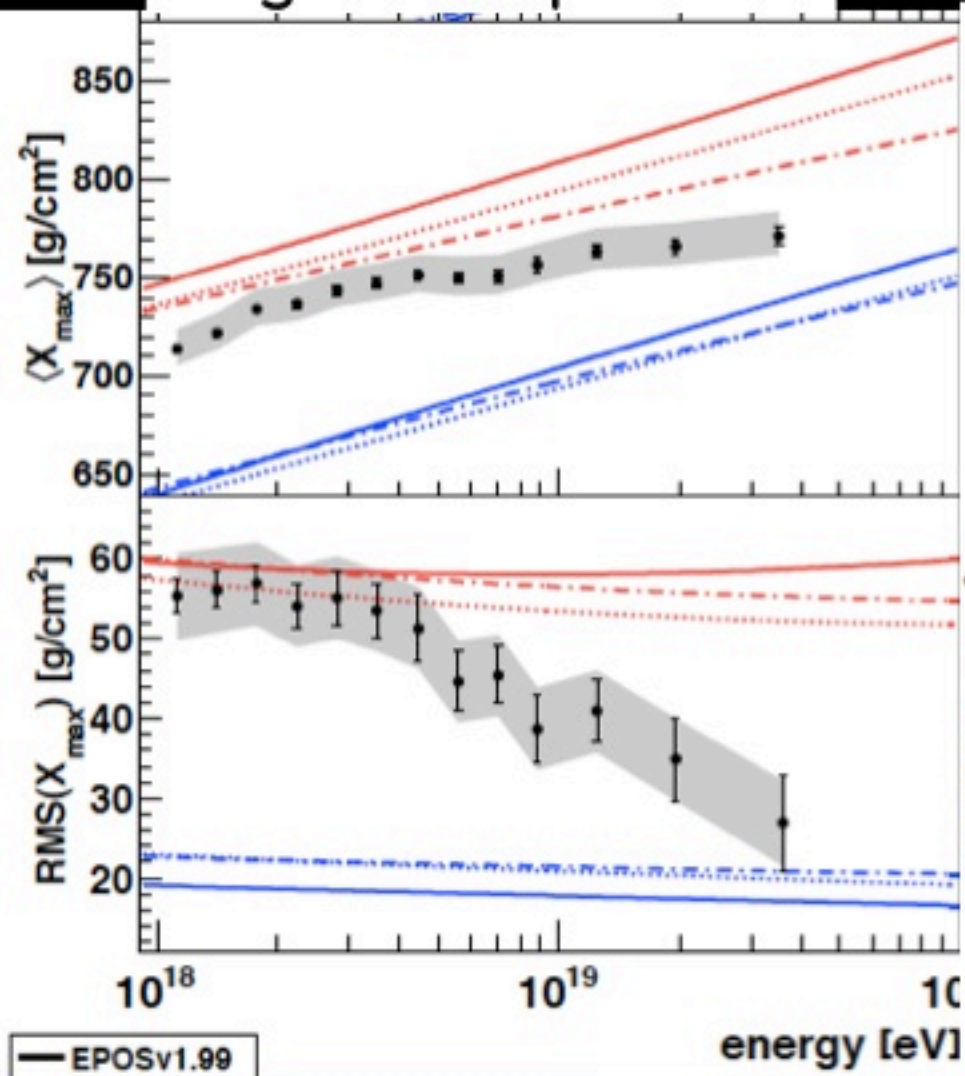
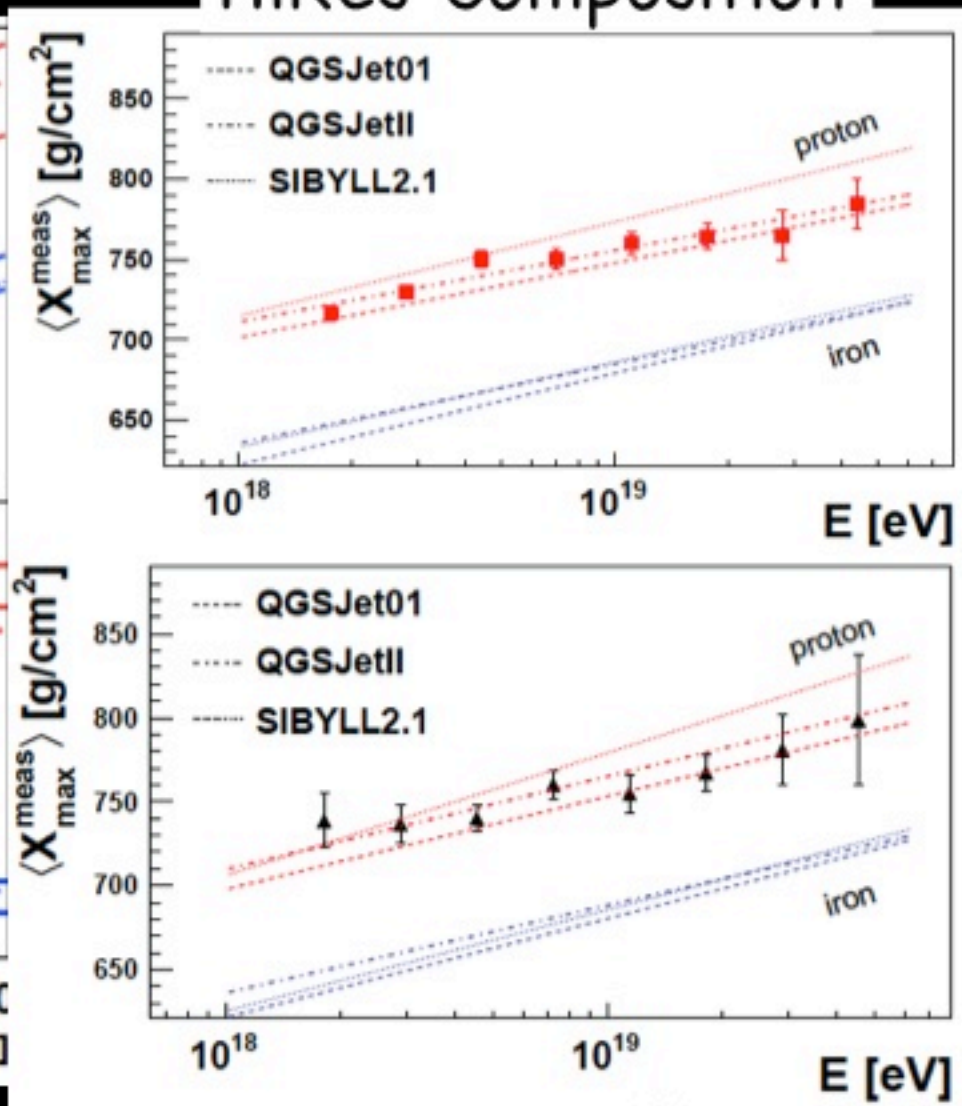
or end of the injected spectrum, E_{max}?

E>10 EeV Composition may be changing!

Auger Composition



HiRes Composition

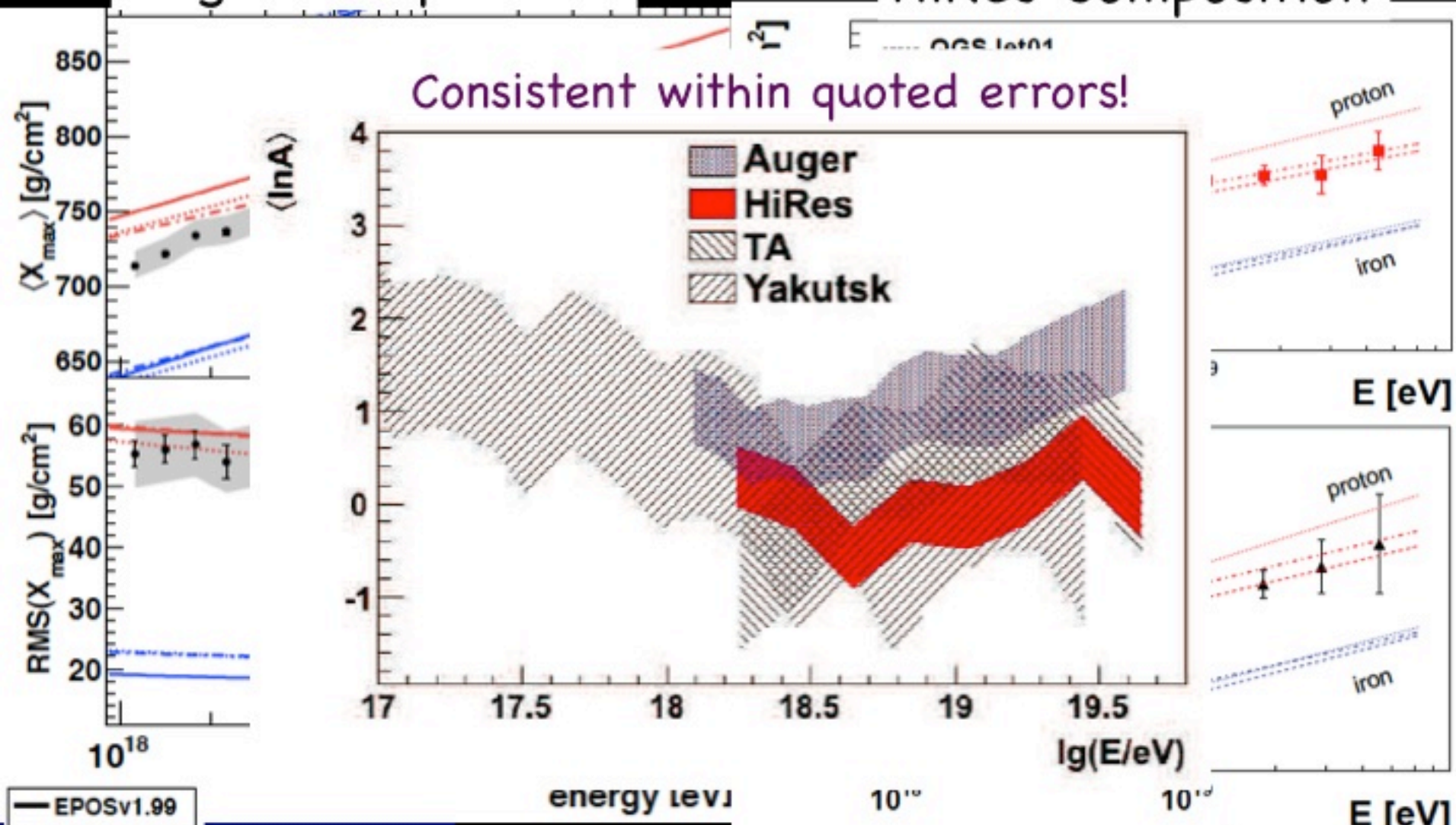


TA Composition

Auger Composition

HiRes Composition

Consistent within quoted errors!



TA Composition

Recent Results

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or maybe the HE interactions are changing!

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or maybe the HE interactions are changing!

How to sort out this conundrum?

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or end of the injected spectrum, E_{max}?

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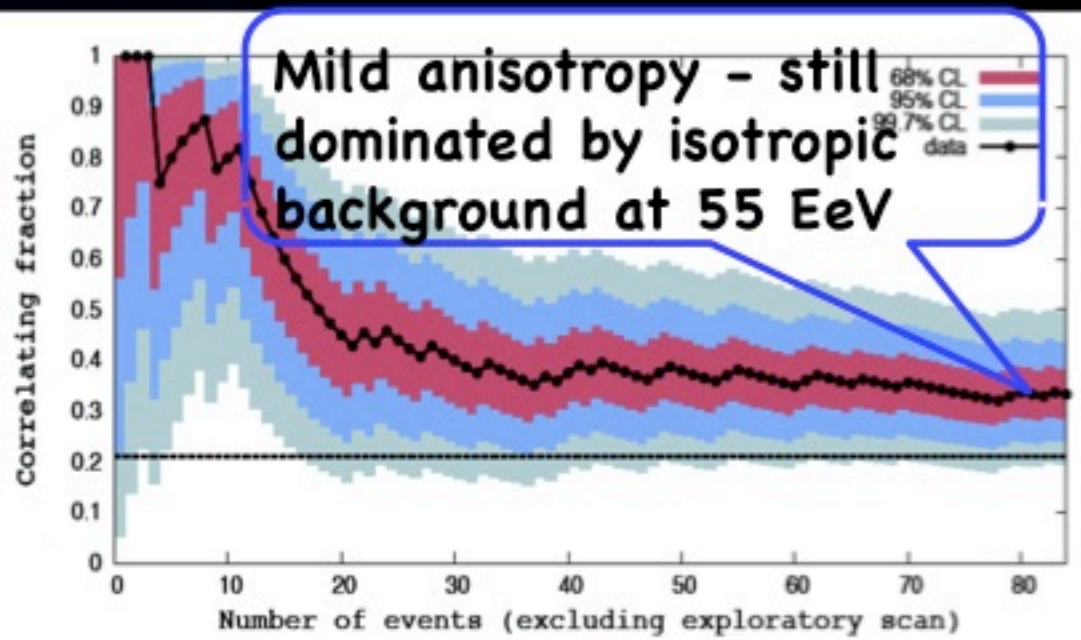
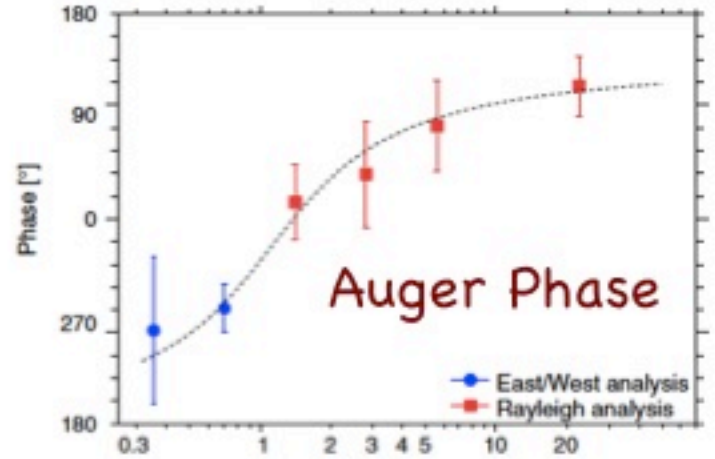
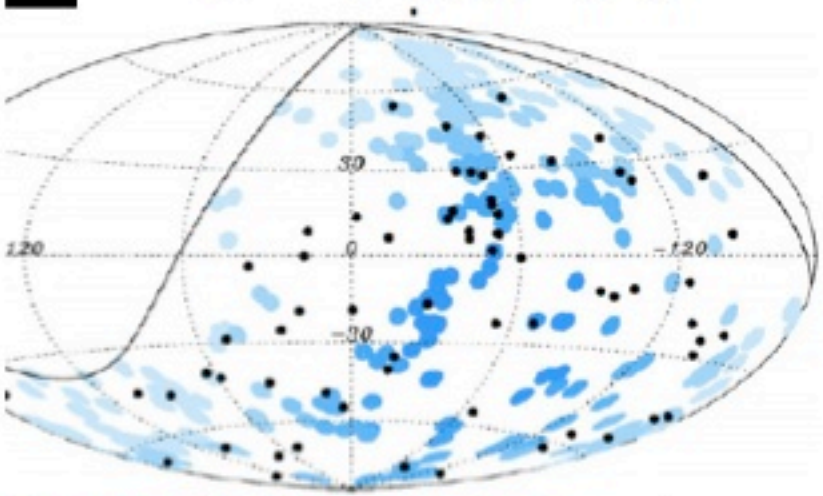
How to sort out this conundrum? Find the Sources!

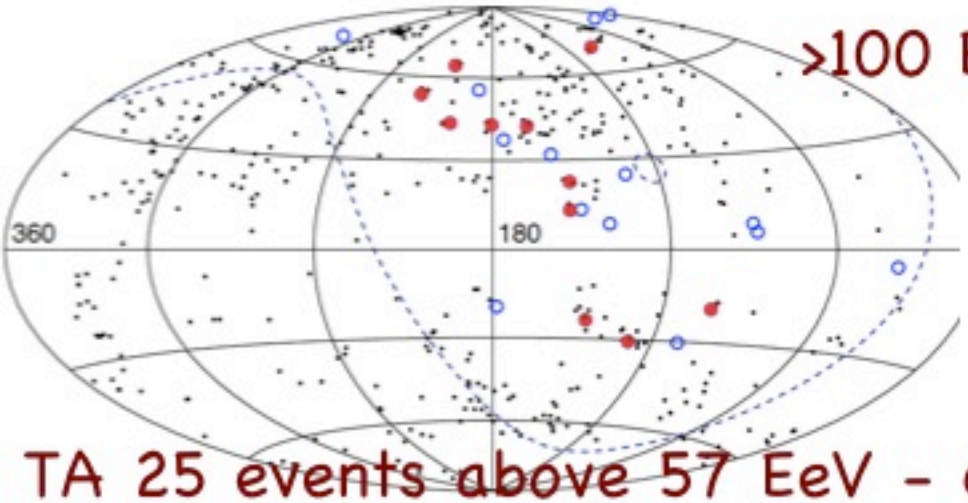
EECR Anisotropy Hints

E > 60 EeV



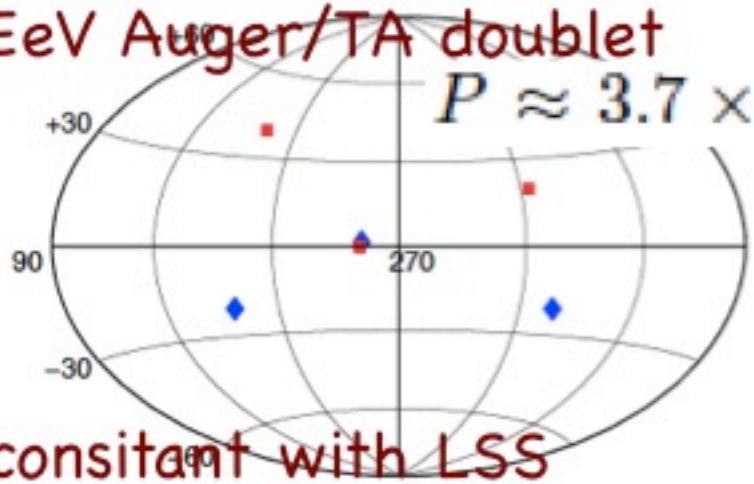






>100 EeV Auger/TA doublet

$P \approx 3.7 \times 10^{-3}$



TA 25 events above 57 EeV - consitant with LSS

How to find the Sources?

GET A LOT MORE DATA above 60 EeV!!!!

How to find the Sources?

GET A LOT MORE DATA above 60 EeV!!!!
GET A LOT MORE DATA above 60 EeV!!!!
GET A LOT MORE DATA above 60 EeV!!!!
GET A LOT MORE DATA above 60 EeV!!!!

OVER THE WHOLE SKY !!!!

How many EECRs > 60 EeV?

Before we see a source?

1,000 is a good o.o.m. estimate

Dipole from direction of Cen A in Auger >60 EeV:

(a posteriori) right ascension harmonic analyses

Anchordoqui, Goldberg & Weiler '11

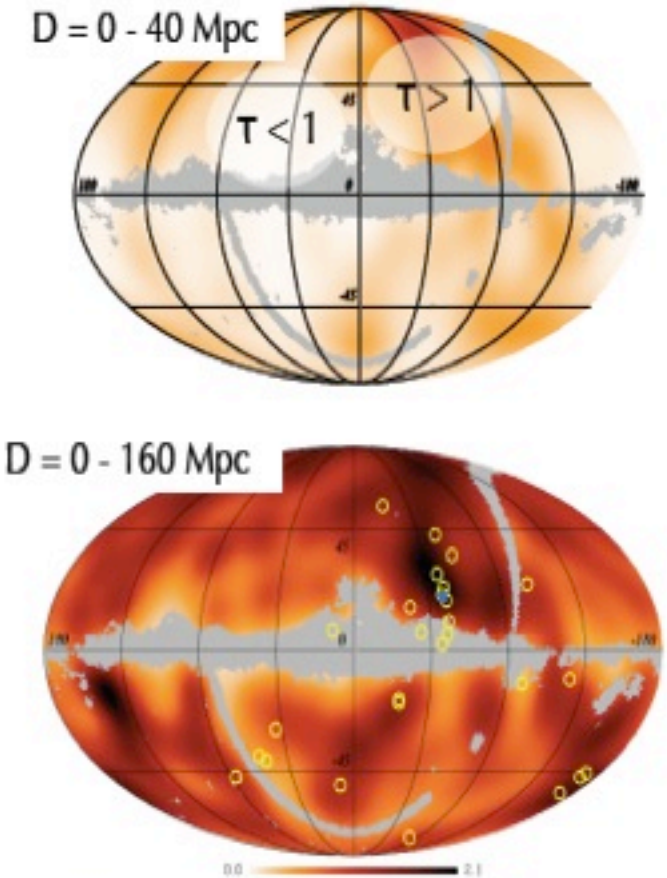
$$\alpha_d \hat{d} = \frac{3}{N} \int J(\hat{u})\ \hat{u}\ d\Omega$$

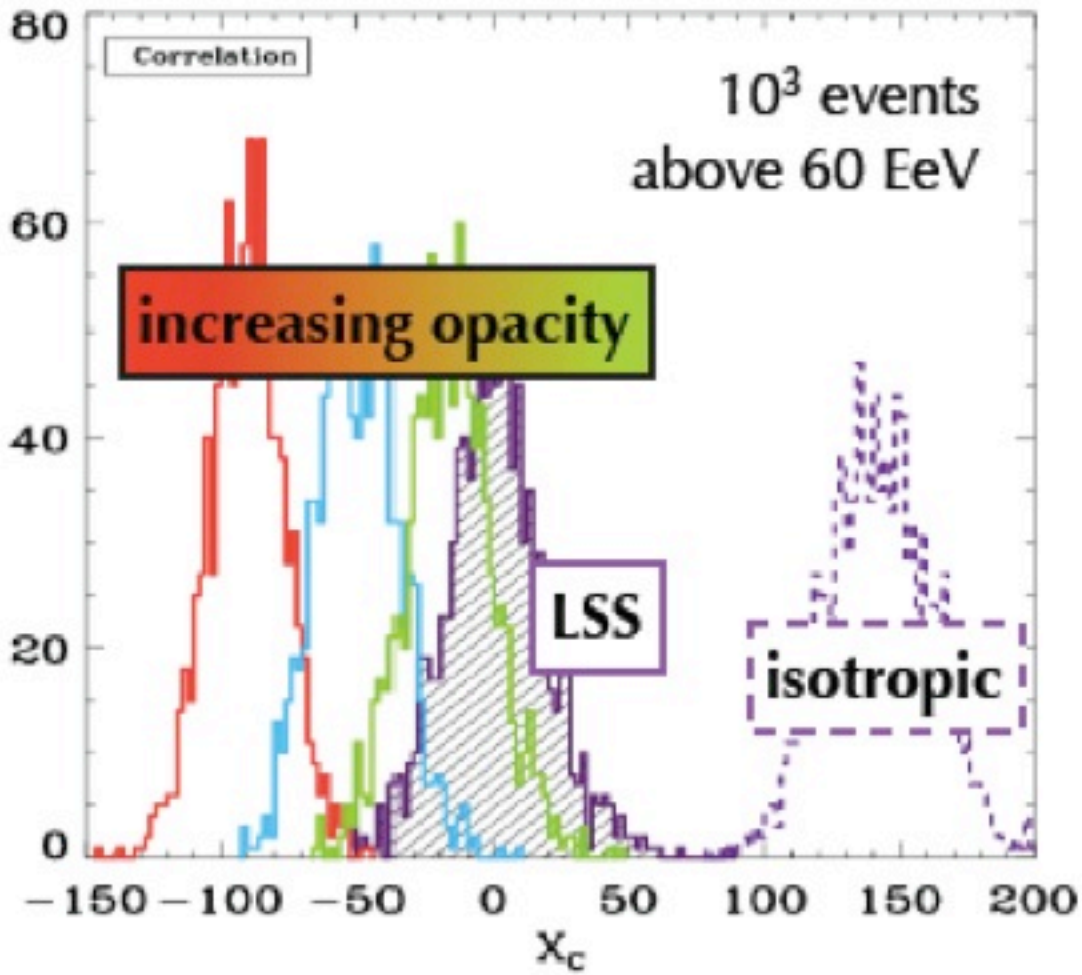
$\alpha_d = 0.25$

5 σ discovery requires 1,000 events

(with whole sky coverage)

Population Separation: need 1,000 events above 60 EeV





Kalli, Lemoine, Kotera '10

$$X_C = \sum_{i=1}^{N_{tot}} \frac{(N_i^T - \langle N_{i,\mathrm{LSS}}\rangle)(\langle N_{i,\mathrm{iso}}\rangle - \langle N_{i,\mathrm{LSS}}\rangle)}{\langle N_{i,\mathrm{LSS}}\rangle}$$

Current Observatories of Ultrahigh Energy Cosmic Rays

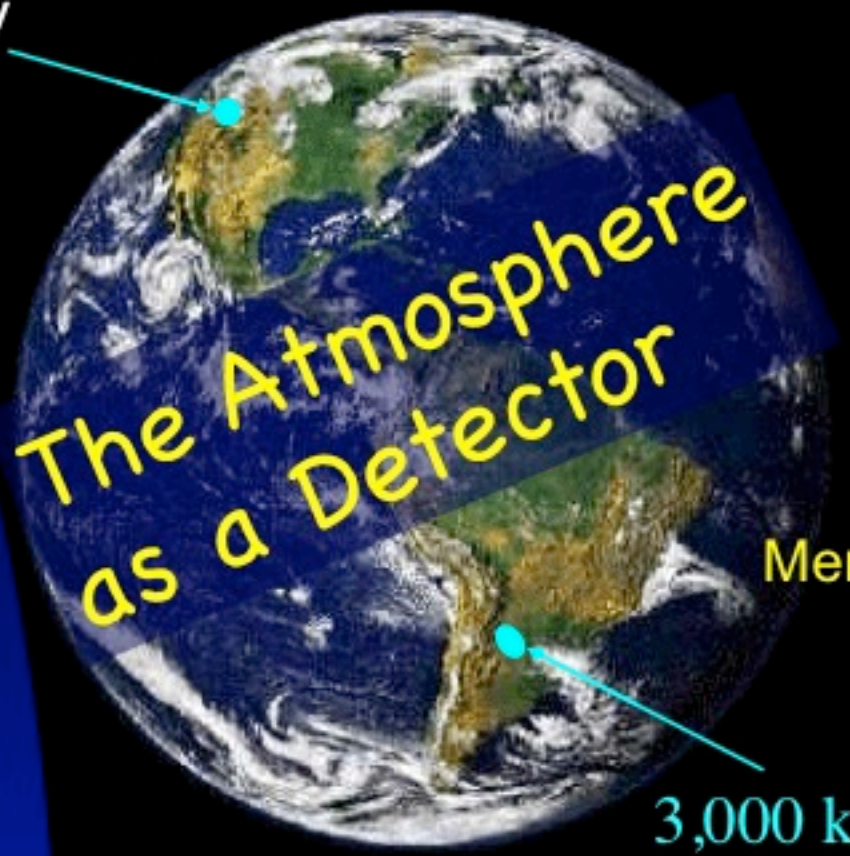
Telescope Array

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

How many EECRs > 60 EeV?

Auger w/ 3,000 km^2

~20 events > 55 EeV/ yr

Telescope Array w/ 700 km^2

~4.6 events > 55 EeV/ yr

Auger + TA ~30 events/yr

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~20 events > 55 EeV/ yr

Telescope Array w/ 700 km^2

~4.6 events > 55 EeV/ yr

Auger + TA ~30 events/yr

30+ years to reach 1,000

Earth - surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

How many EECRs > 60 EeV?

Auger w/ 3,000 km^2

~20 events > 55 EeV/ yr

Telescope Array w/ 700 km^2

~4.6 events > 55 EeV/ yr

Auger + TA ~30 events/yr

500 m to go!

Earth surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

Go to SPACE!

To look down on the Atmosphere!

How many UHECRs > 60 EeV?

Auger + TA ~30 events/yr

JEM-EUSO

~200 events > 60 EeV/ yr

Earth - surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

How many UHECRs > 60 EeV?

Auger + TA ~30 events/yr

JEM-EUSO

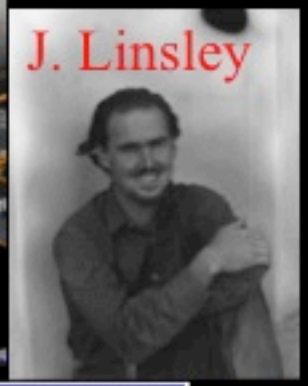
~200 events > 60 EeV/ yr

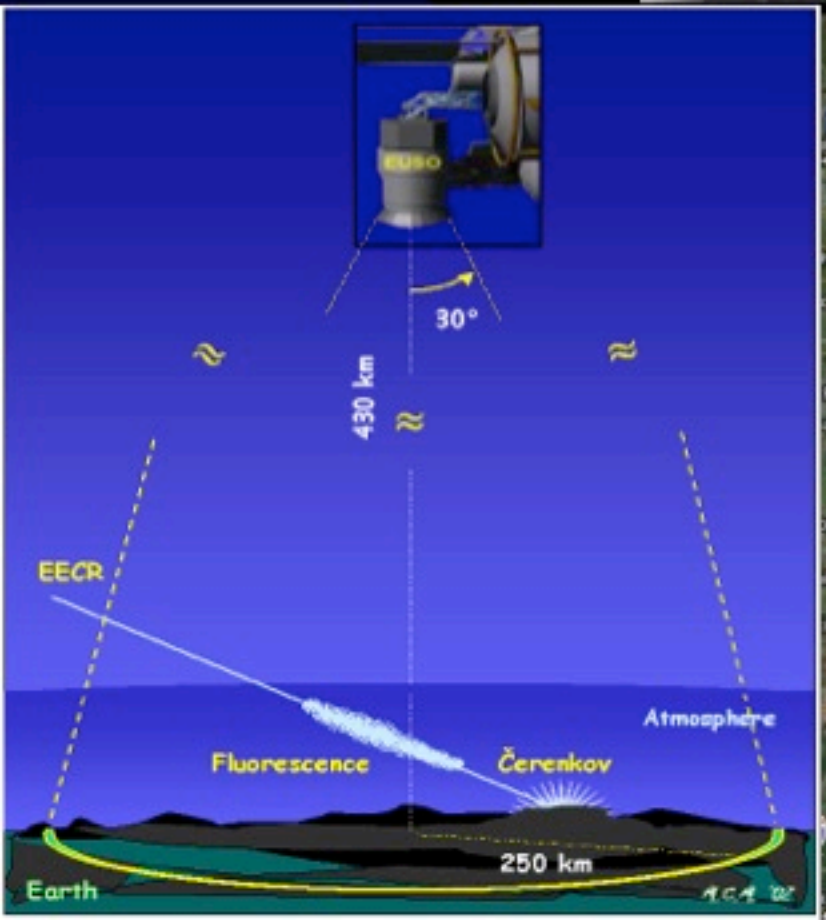
4 o.o.m to go!

Earth surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

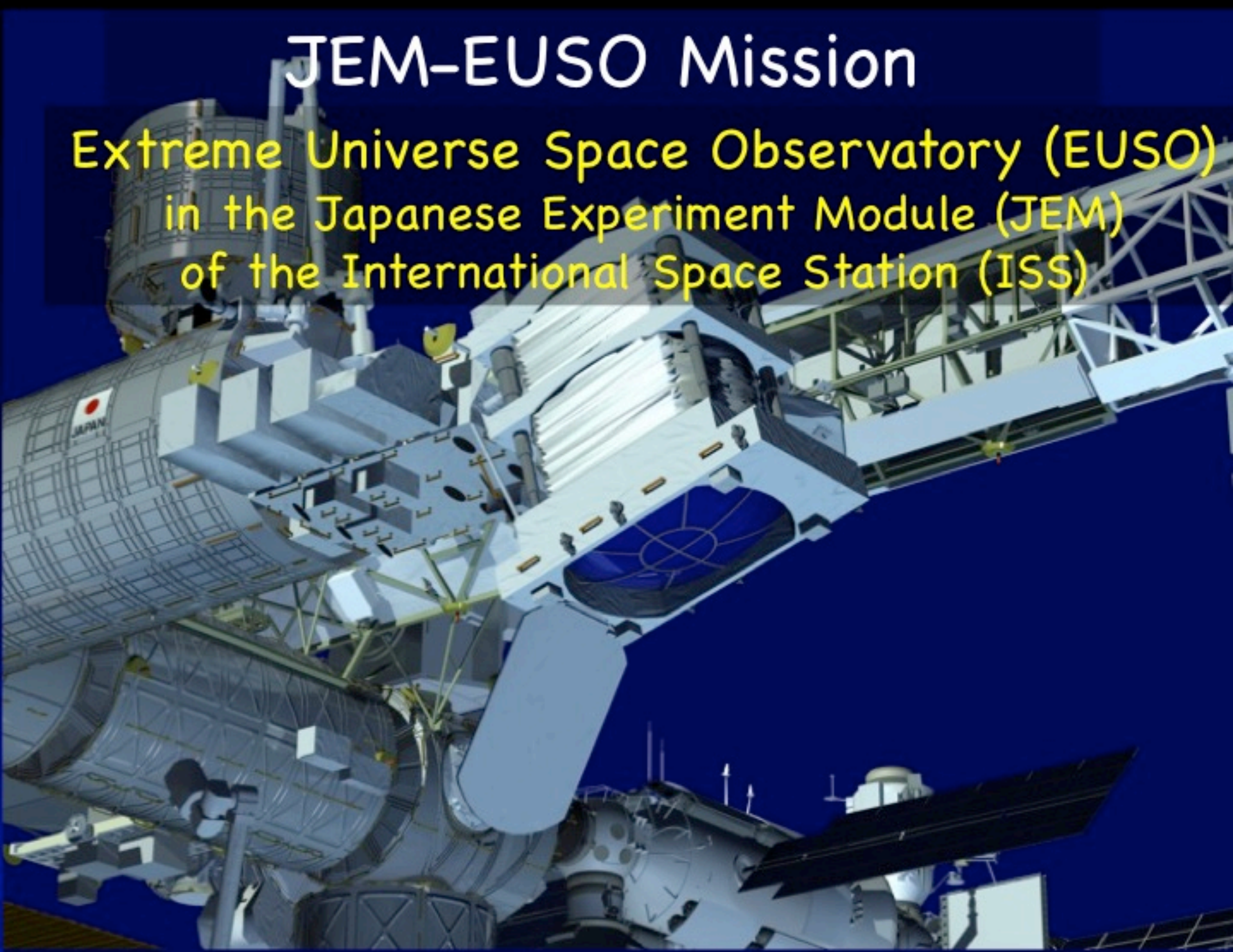
Fluorescence from SPACE



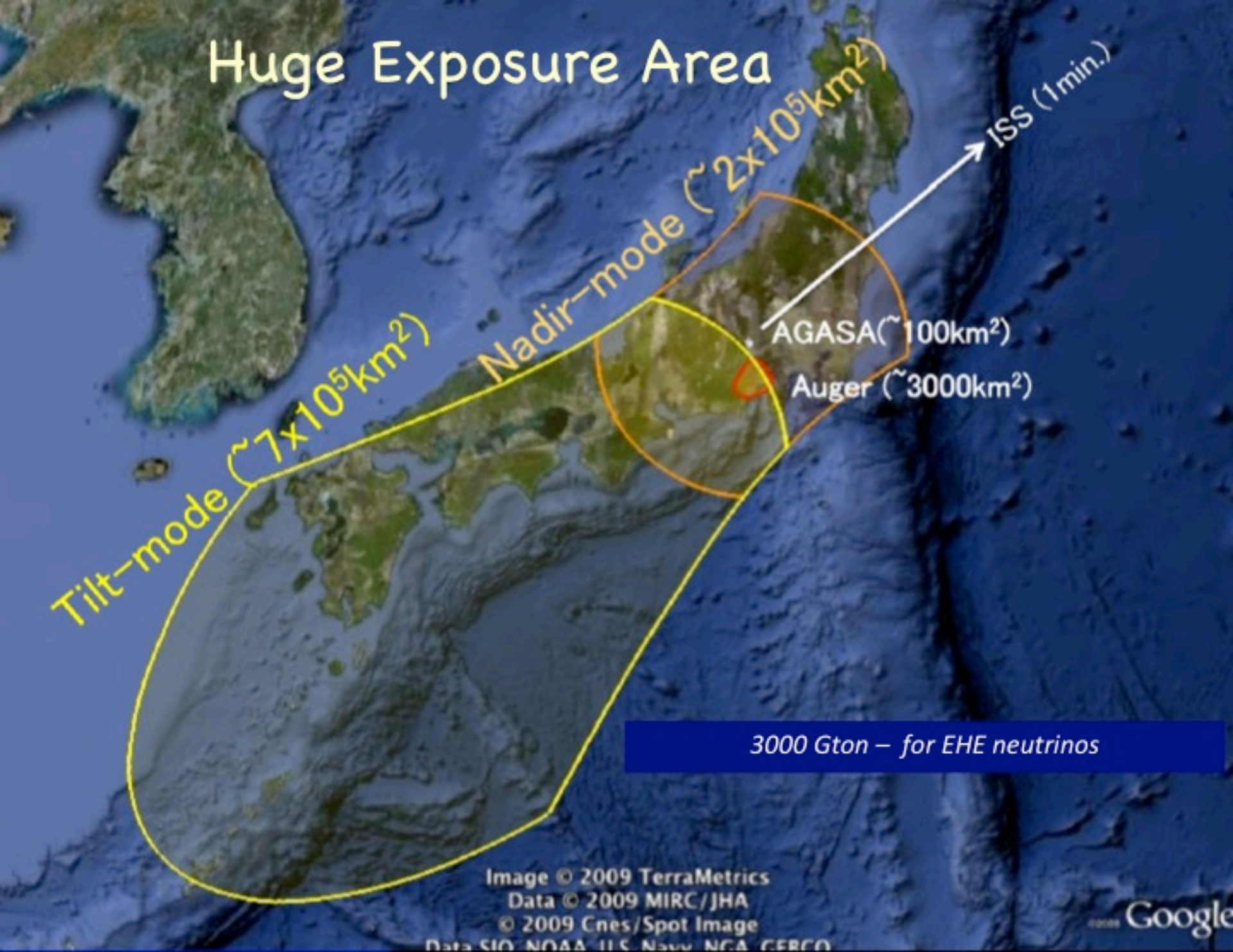


JEM-EUSO Mission

Extreme Universe Space Observatory (EUSO)
in the Japanese Experiment Module (JEM)
of the International Space Station (ISS)



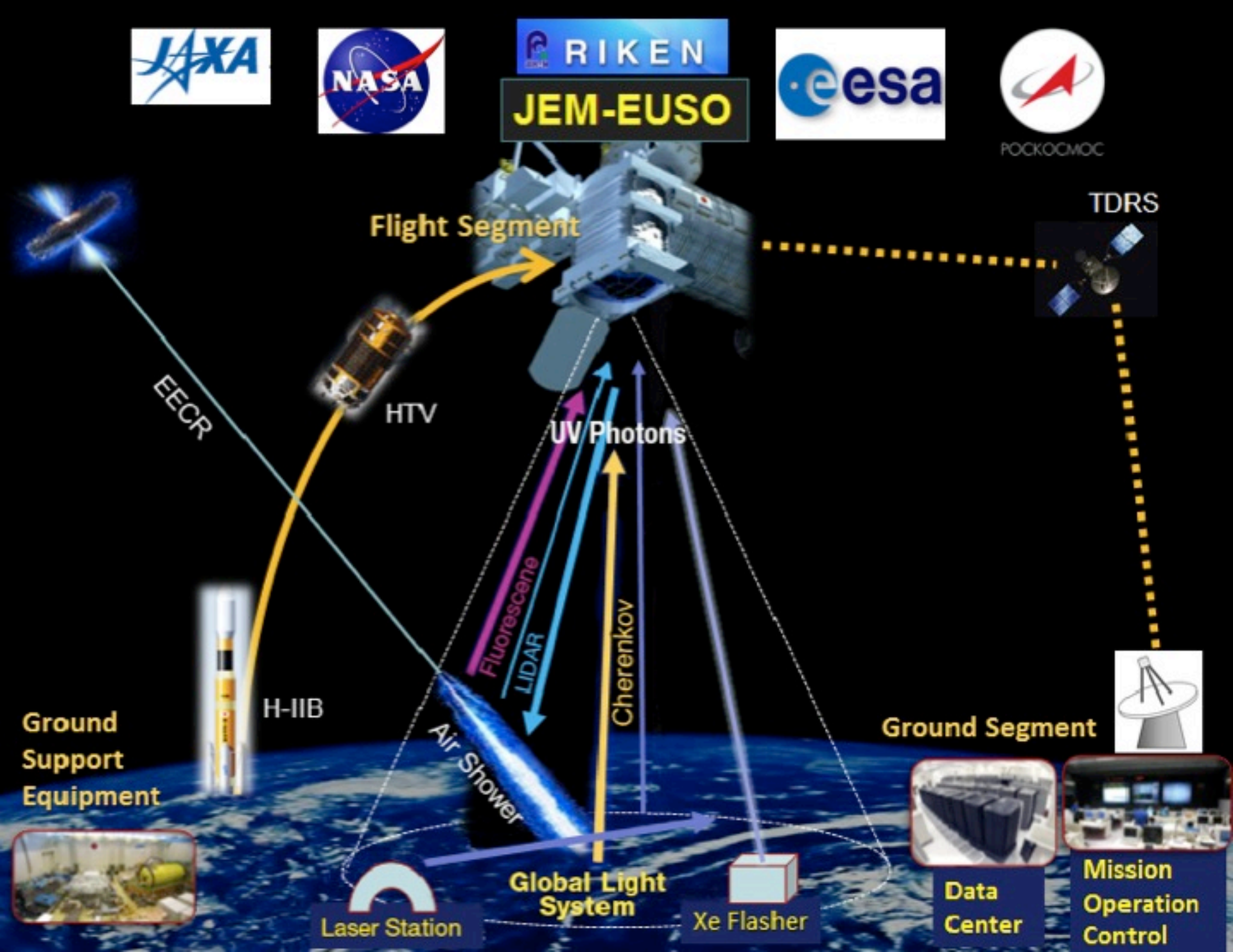
Huge Exposure Area

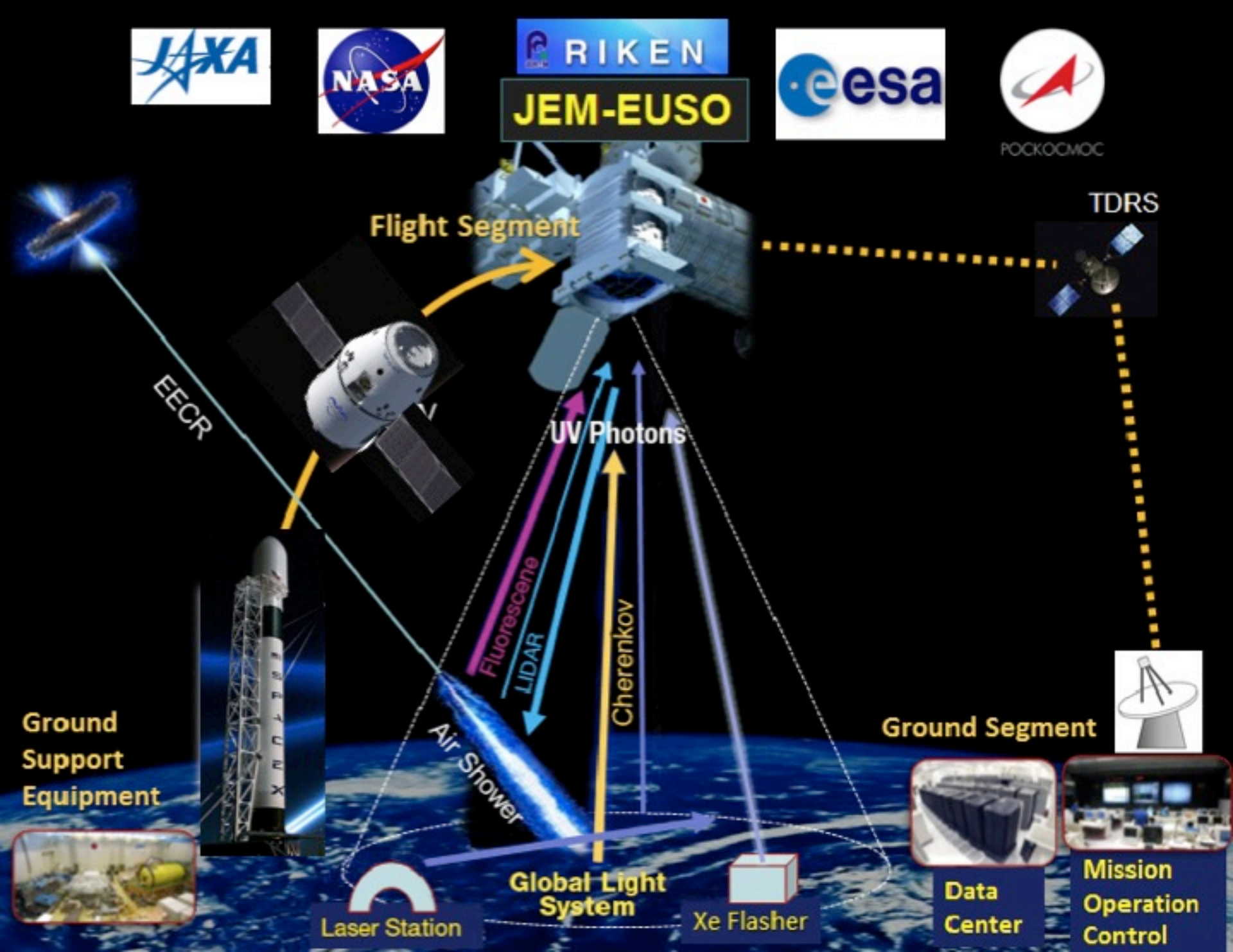


3000 Gton – for EHE neutrinos

JEM-EUSO Mission

Parameter	Value
Launch date	2017
Mission Lifetime	3+2 years
Rocket	H2B (or Falcon9)
Transport Vehicle	HTV (or Dragon)
Accommodation on JEM	EF#9
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°


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


JAXA
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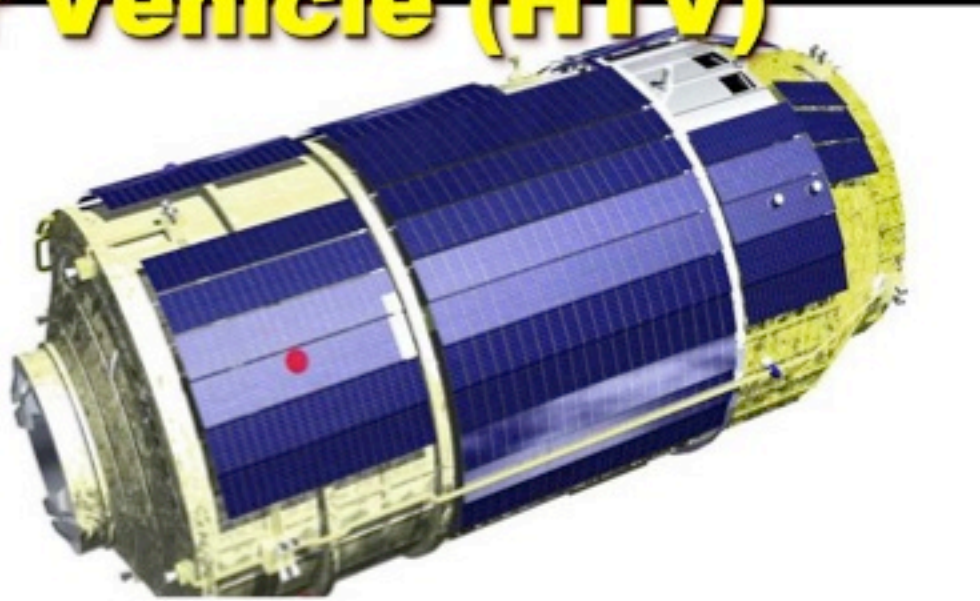
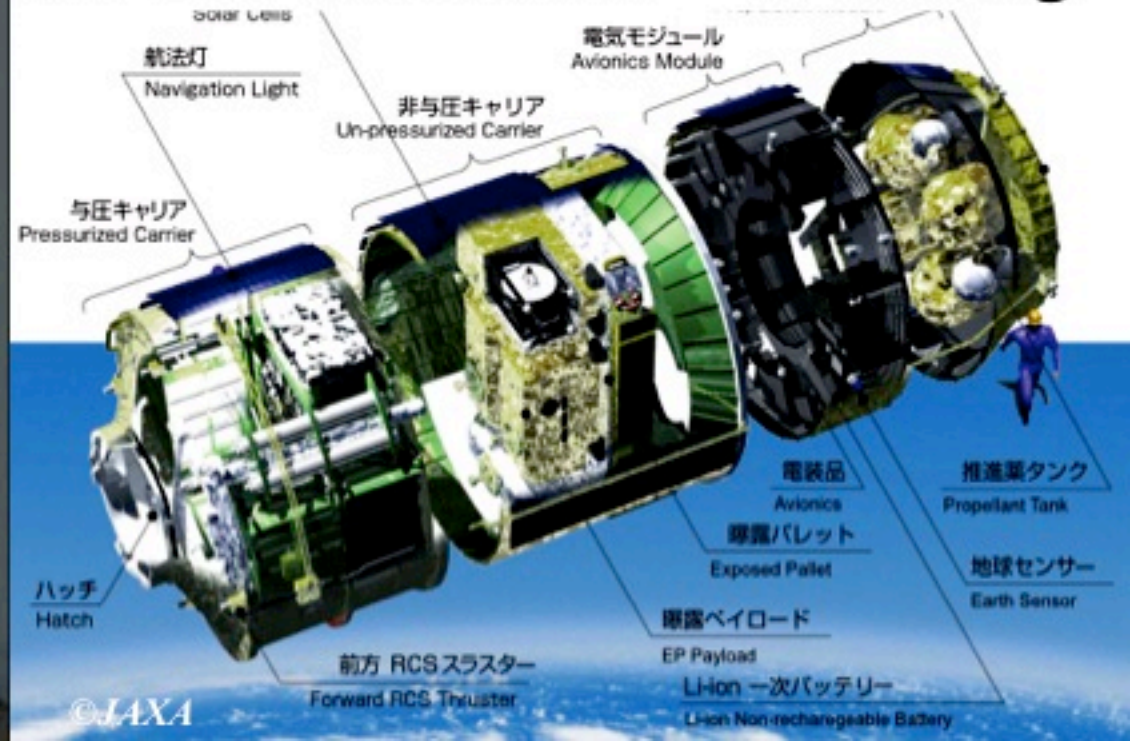
UV Photons
Fluorescene
LIDAR
Cherenkov
Air Shower
Ground Support Equipment
Ground Segment
Laser Station
Global Light System
Xe Flasher
Data Center
Mission Operation Control

H-II Transfer Vehicle (HTV)



HTV is 4m across ~10 m long



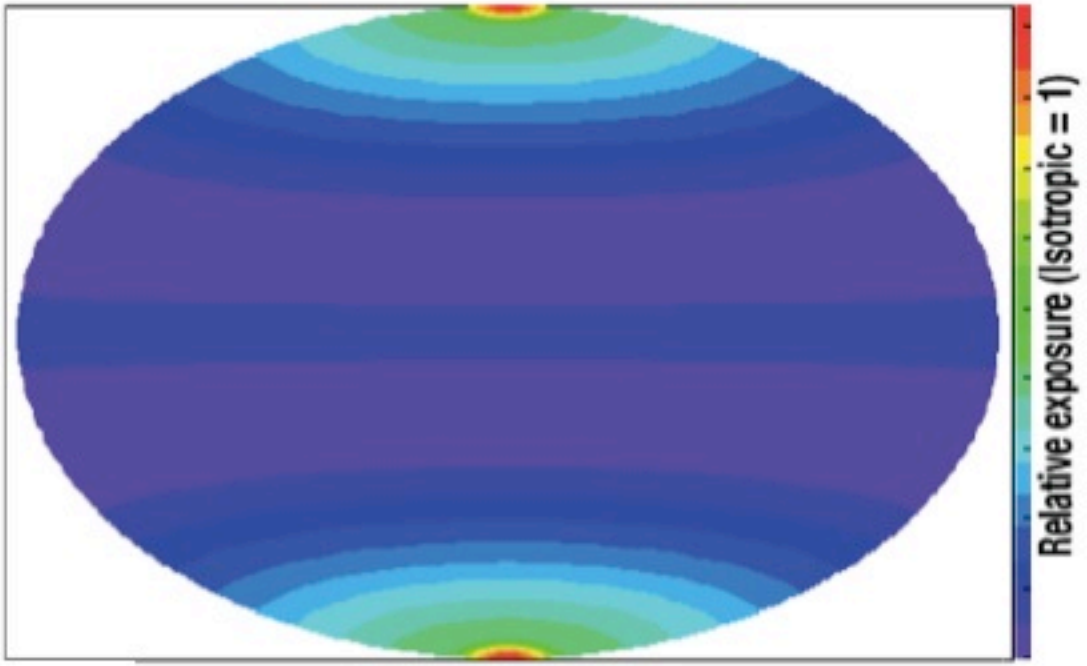

SpaceX
Dragon

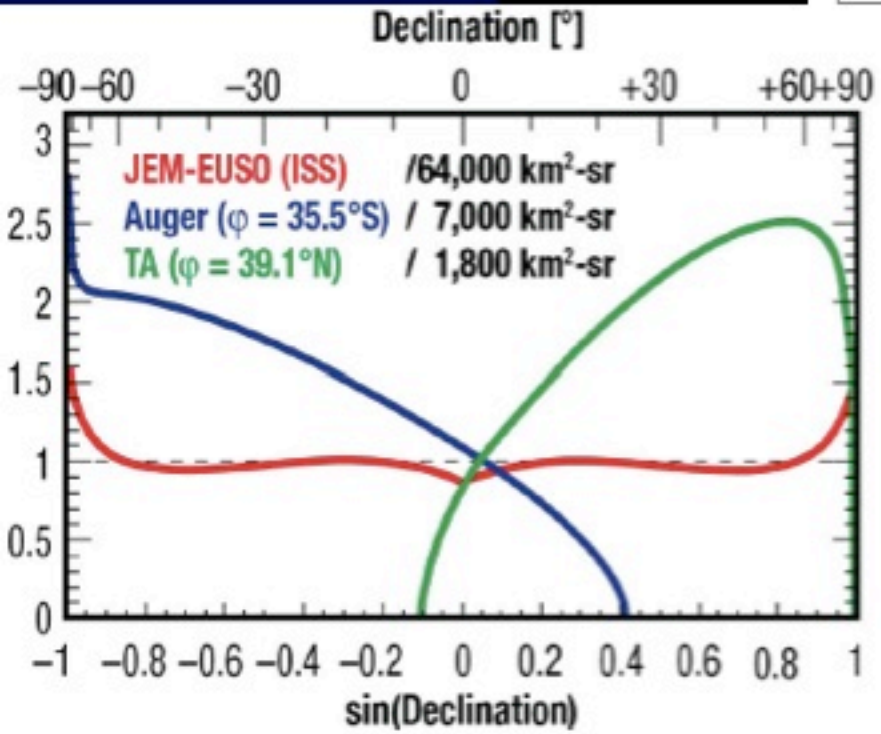
Full Sky Coverage
with nearly uniform exposure

The ISS ORBIT

Inclination: 51.6°
Height: ~400km

JEM-EUSO
Sky Coverage

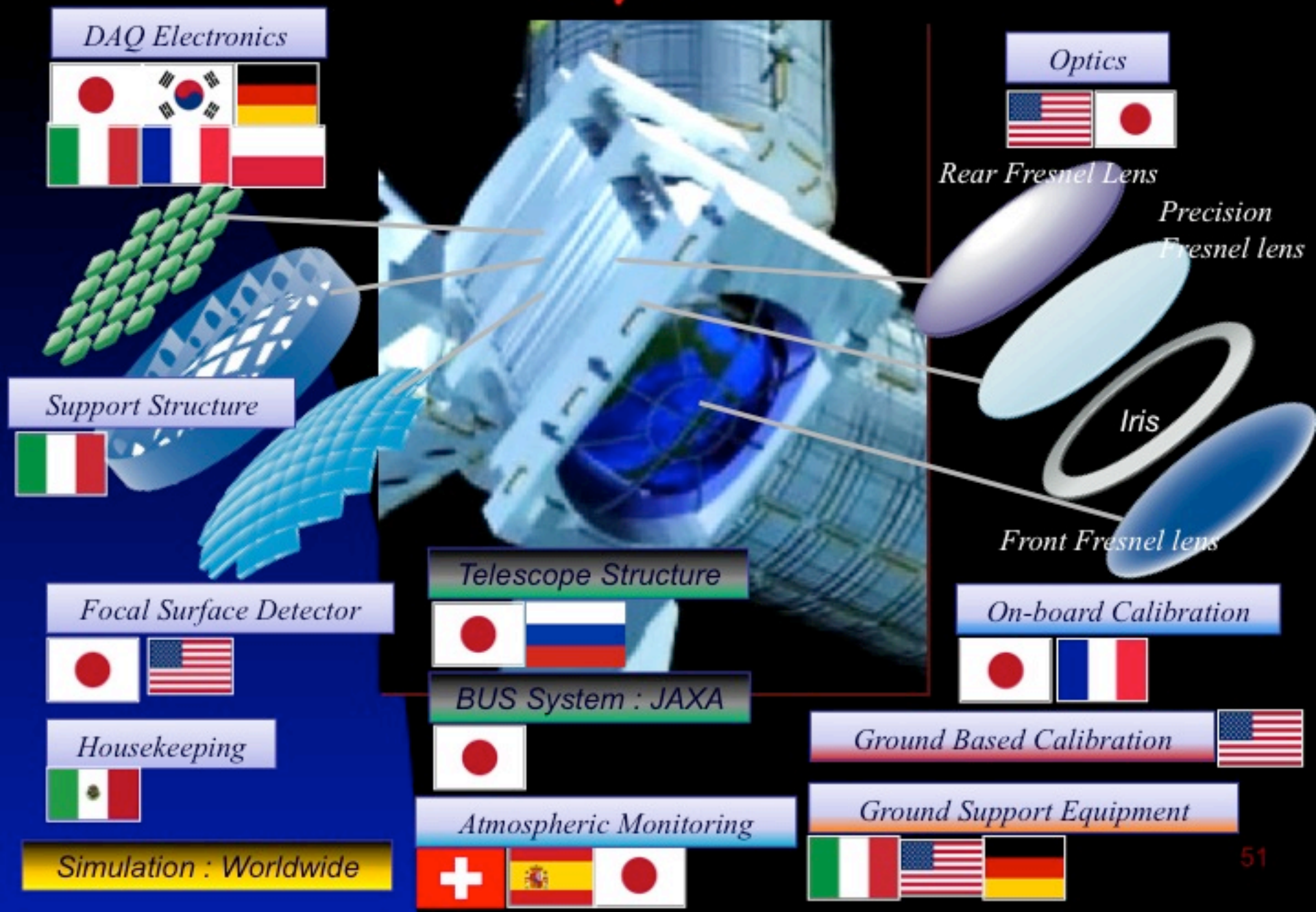




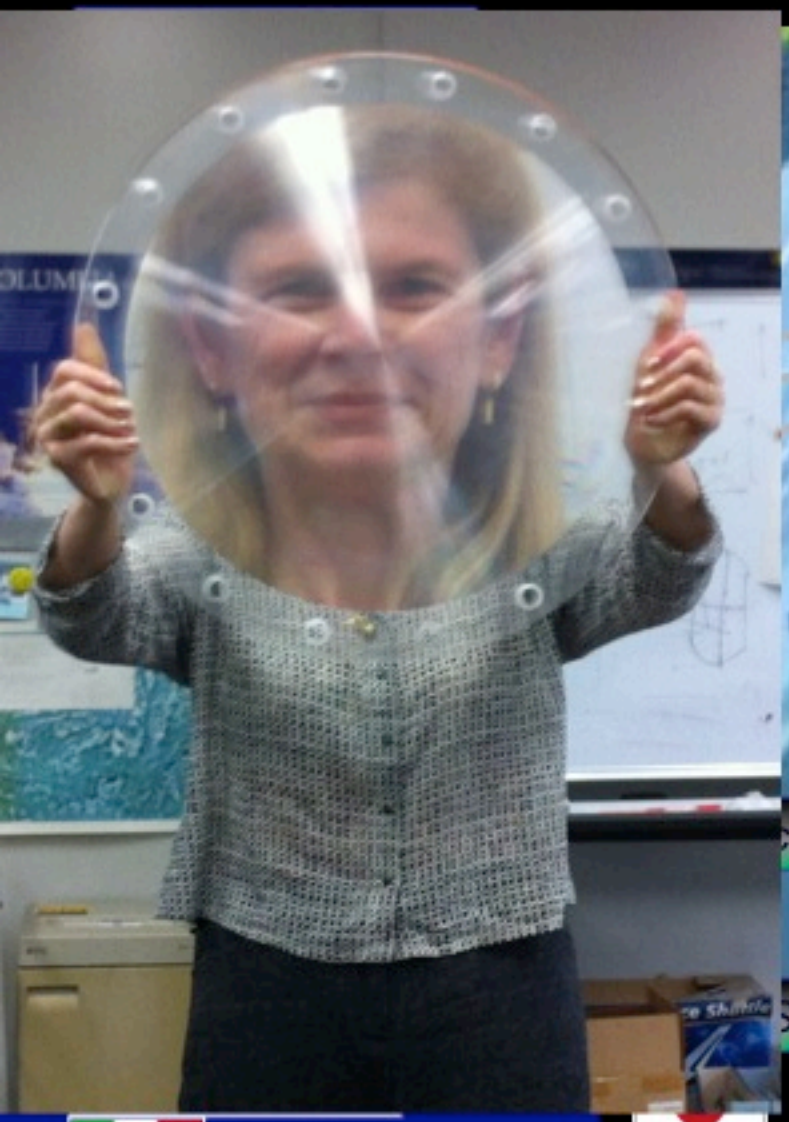
The UV Telescope Parameters

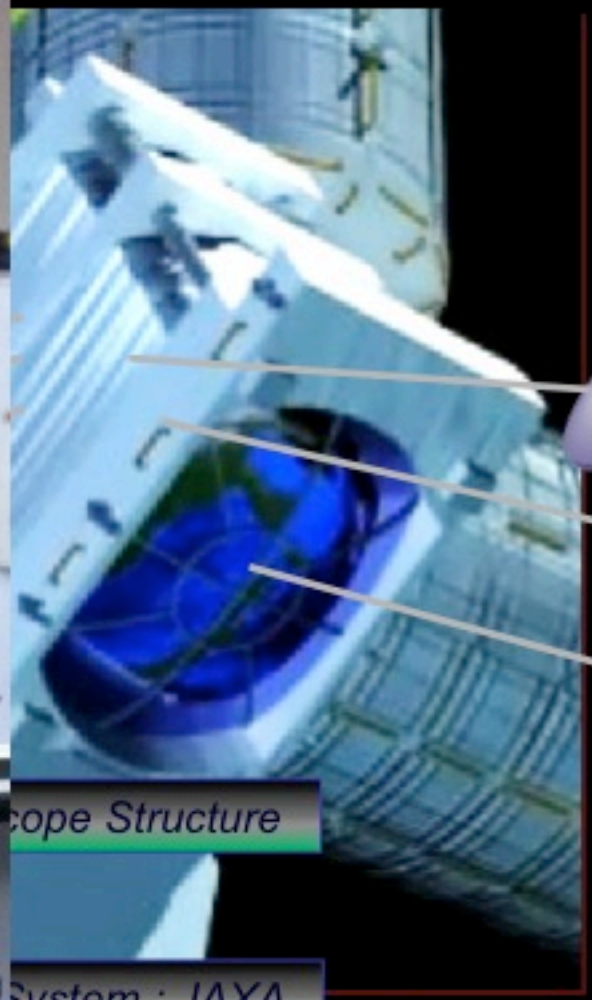
Parameter	Value
Field of View	±30°
Monitored Area	>1.3×10^{5}km^2
Telescope aperture	≥2.5 m
Operational wavelength	300-400 nm
Resolution in angle	0.075°
Focal Plane Area	4.5 m^2
Pixel Size	<3 mm
Number of Pixels	≈3×10^5
Pixel size on ground	≈560 m
Time Resolution	2.5 μs
Dead Time	<3%
Photo-detector Efficiency	≥20%

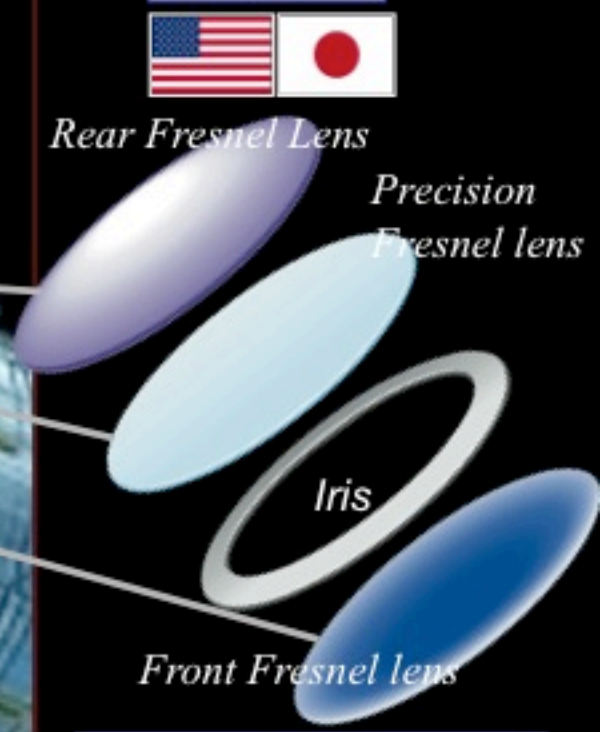
Payload


DAQ Electronics
Optics
Rear Fresnel Lens
Precision Fresnel lens
Iris
Front Fresnel lens
Support Structure
Telescope Structure
Focal Surface Detector
On-board Calibration
BUS System : JAXA
Housekeeping
Ground Based Calibration
Ground Support Equipment
Atmospheric Monitoring
Simulation : Worldwide

Payload







Optics

cope Structure

System : JAXA

On-board Calibration

Ground Based Calibration

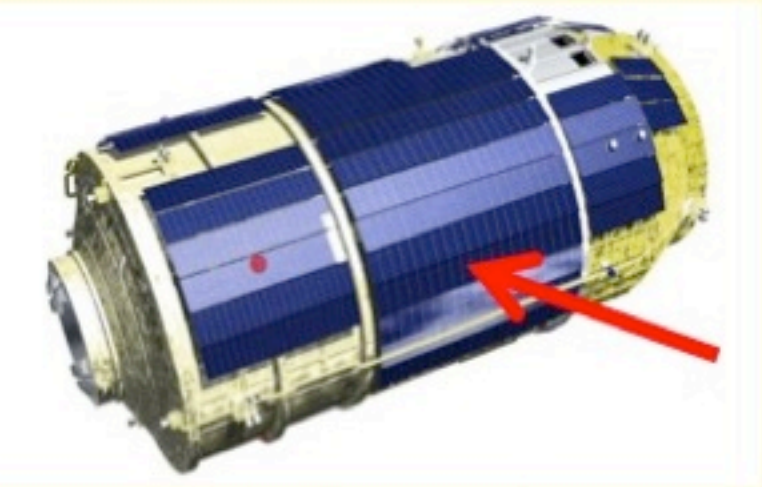
Ground Support Equipment

Atmospheric Monitoring

Simulation : Worldwide

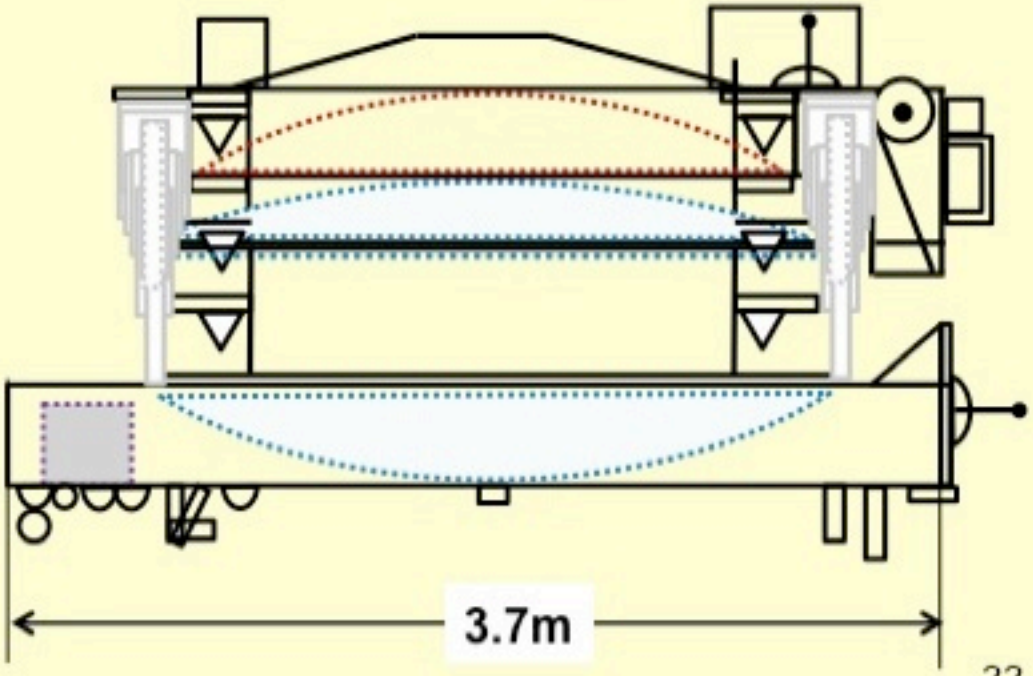
Science Instrument on HTV

Stowing configuration
to carry by HTV



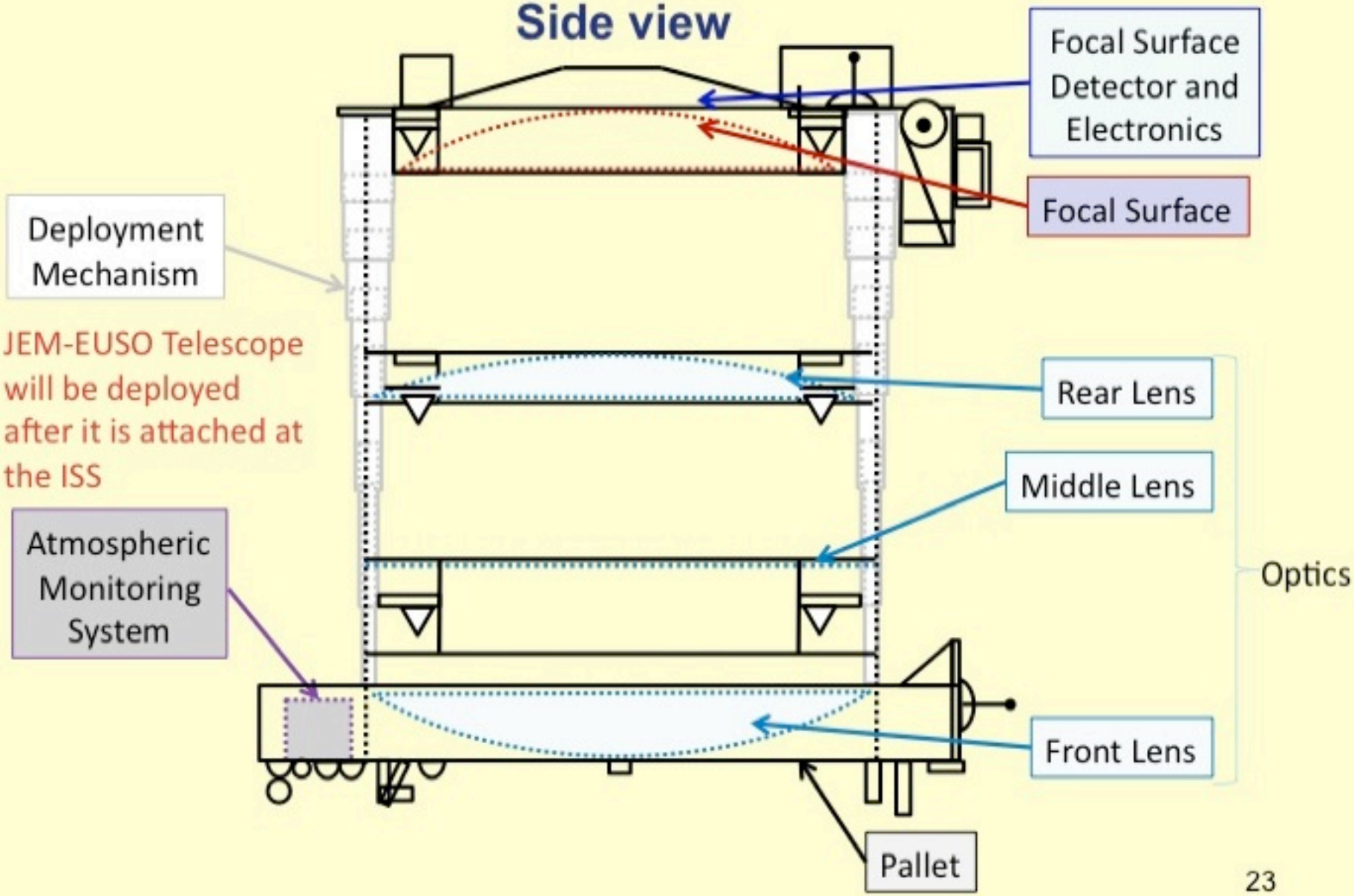
H2B Transfer
Vehicle (HTV)

Side view



Science Instrument

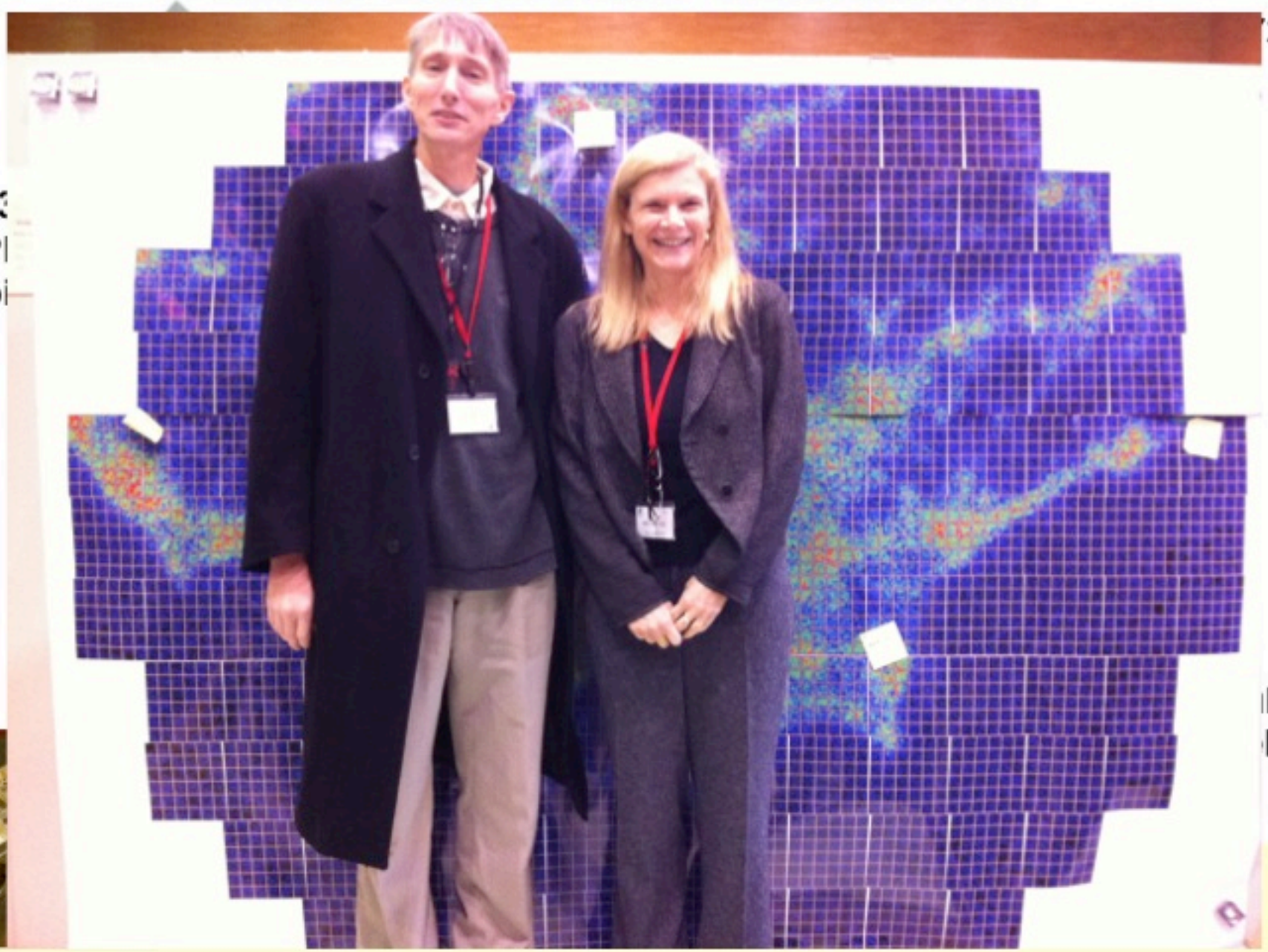
Side view



Science Instrument

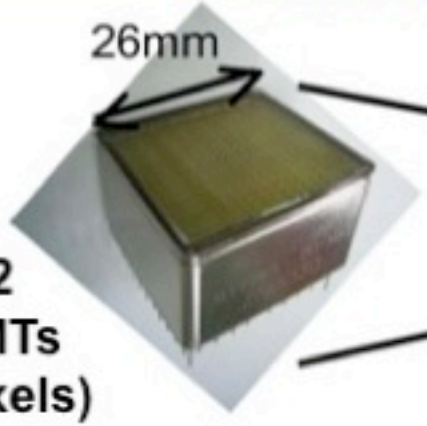
tics

Focal Surface Detector

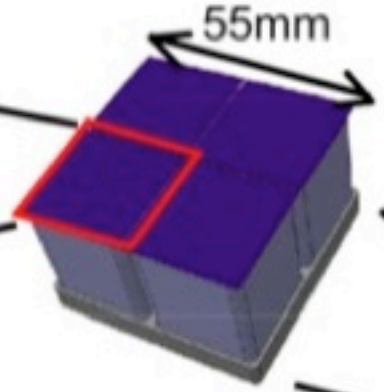


Focal Surface Detector

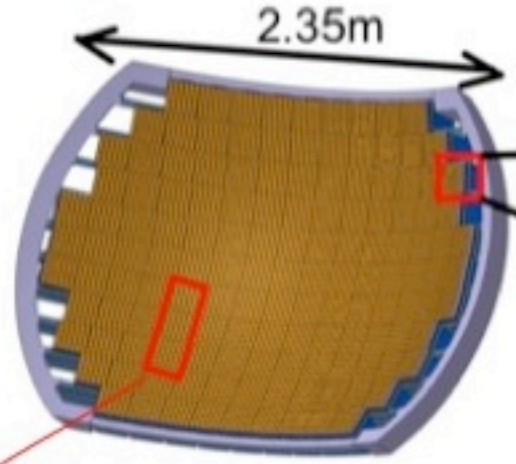
Y. Kawasaki, ID 0472
M. Ricci, ID 0335

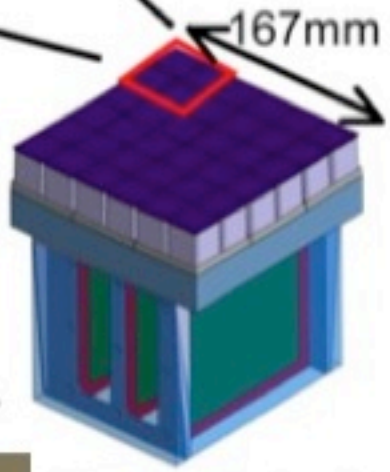


4932 MAPMTs (8x8 pixels)



Elementary Cell (2x2 PMTs = 256 pixels)





Focal Surface detector
137 PDMs
= 0.3M Pixels

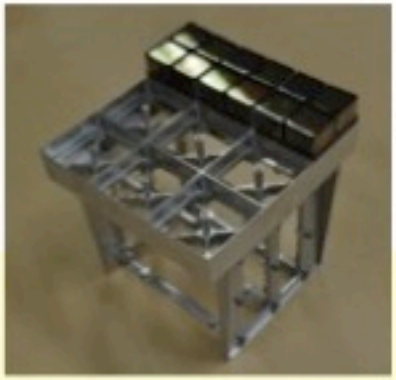


Photo-Detector Module (3x3 ECs = 2,304 pixels

1 High Voltage / PDM

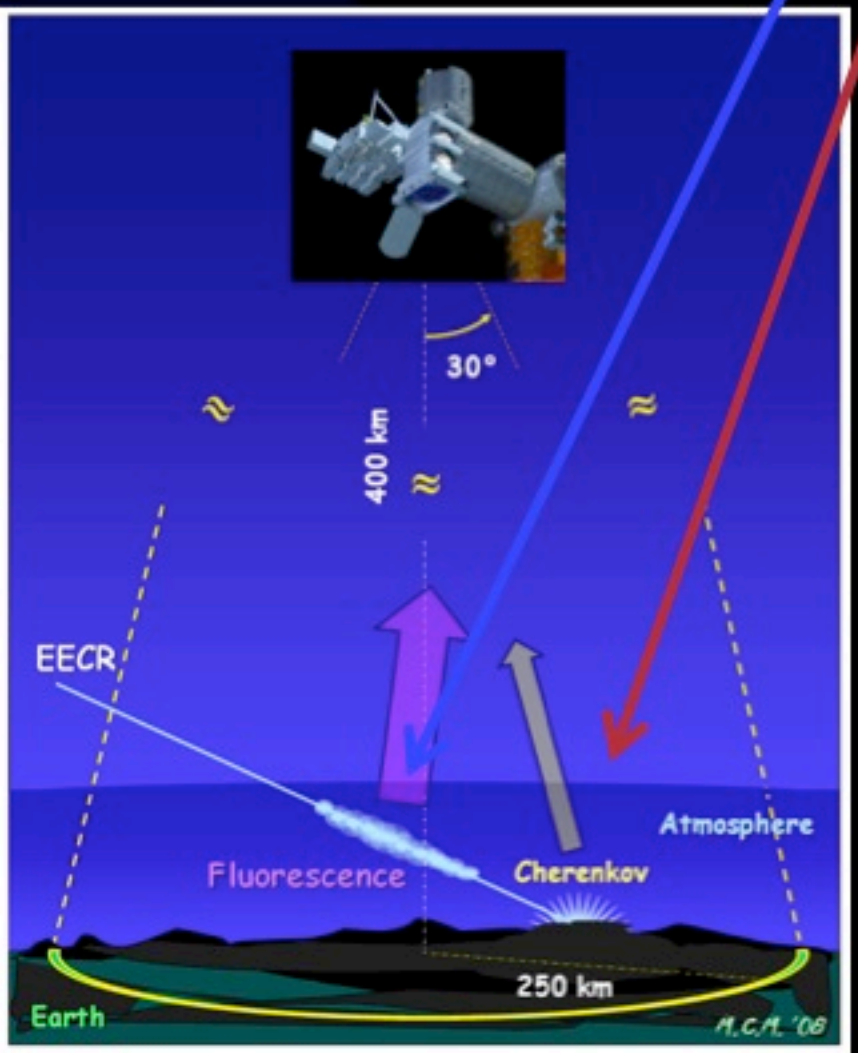
FAST SIGNAL

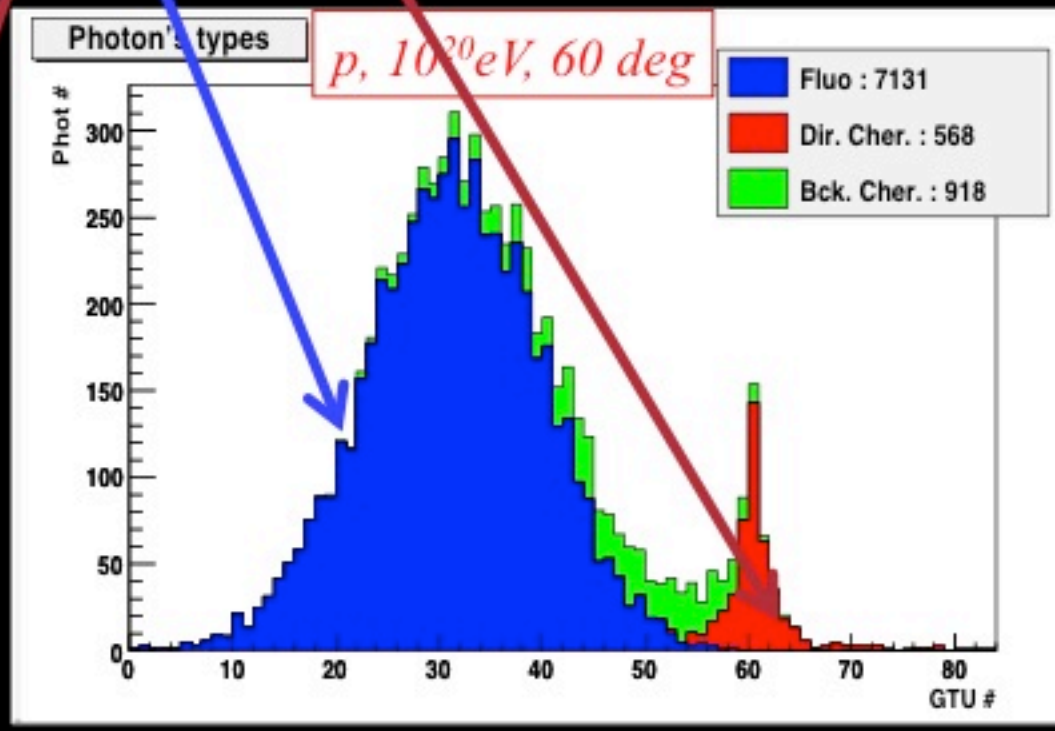
duration 50 -150 μs

a) Fluorescence

b) Scattered Cherenkov

c) Direct (diffusively reflected Cherenkov)



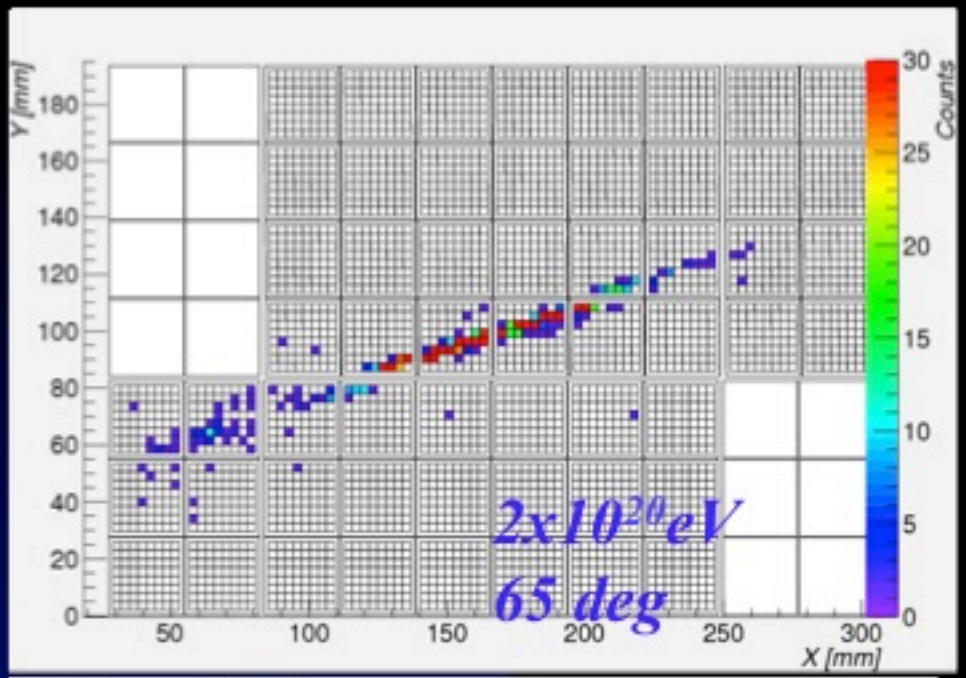


1 GTU gate time units = 2.5 μs

Background: 500 /m^2 sr ns

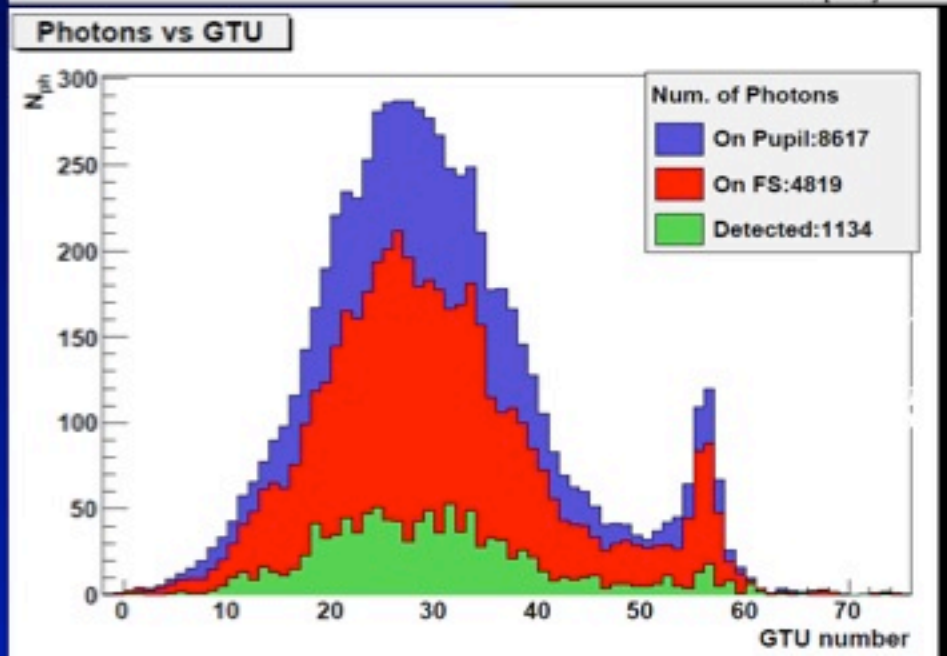
Result of end-to-end simulation

F. Fenu, ID 0829
K. Higashide, ID 1240
T. Mernik, ID 0633



Simulated air shower image on the focal surface detector.

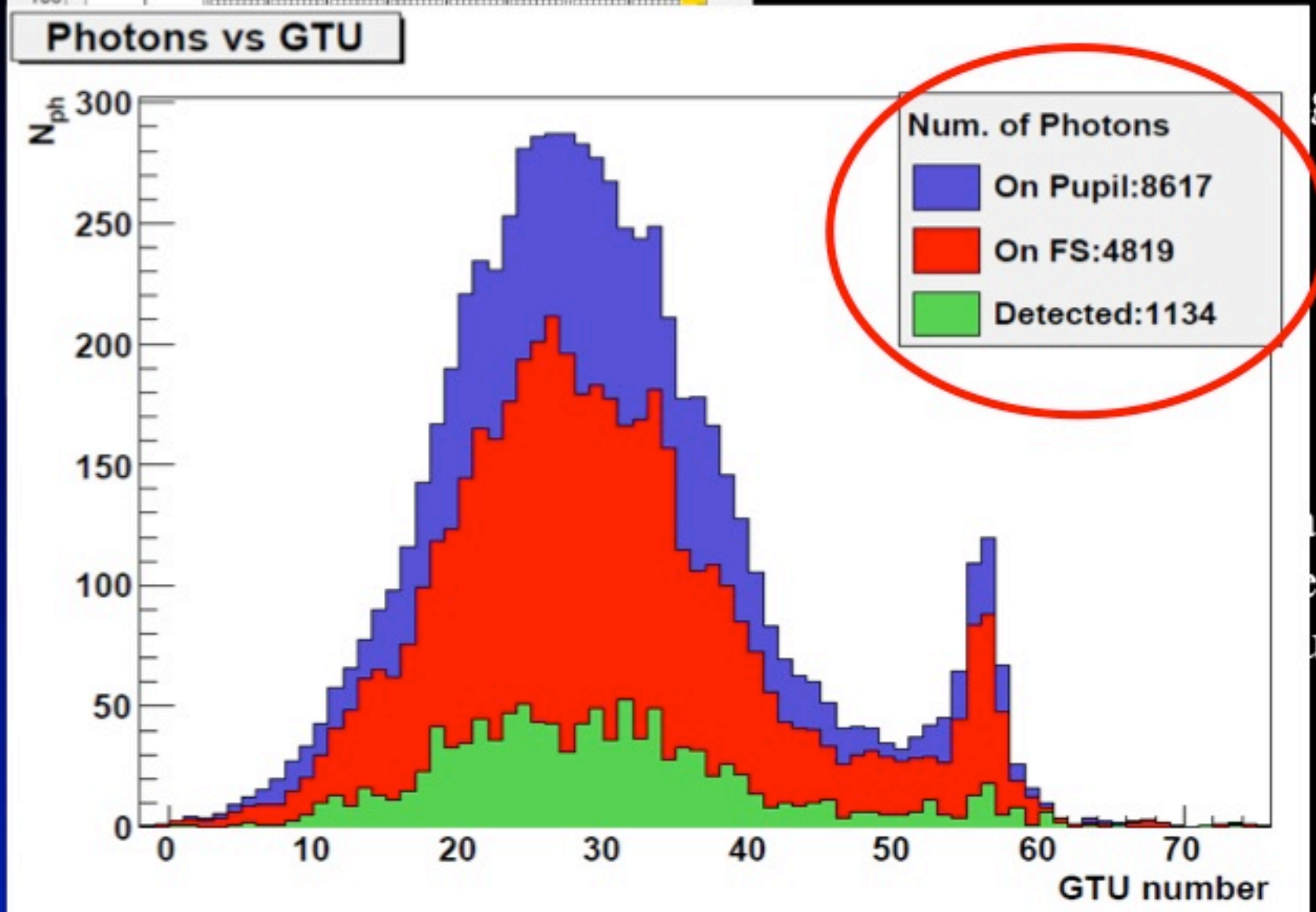
3 x 10^5 pixels



Detected photoelectrons are recorded every Gate Time Unit (GTU) of 2.5μs continuously.

Result of end-to-end simulation

F. Fenu, ID 0829
K. Higashide, ID 1240
T. Mernik, ID 0633

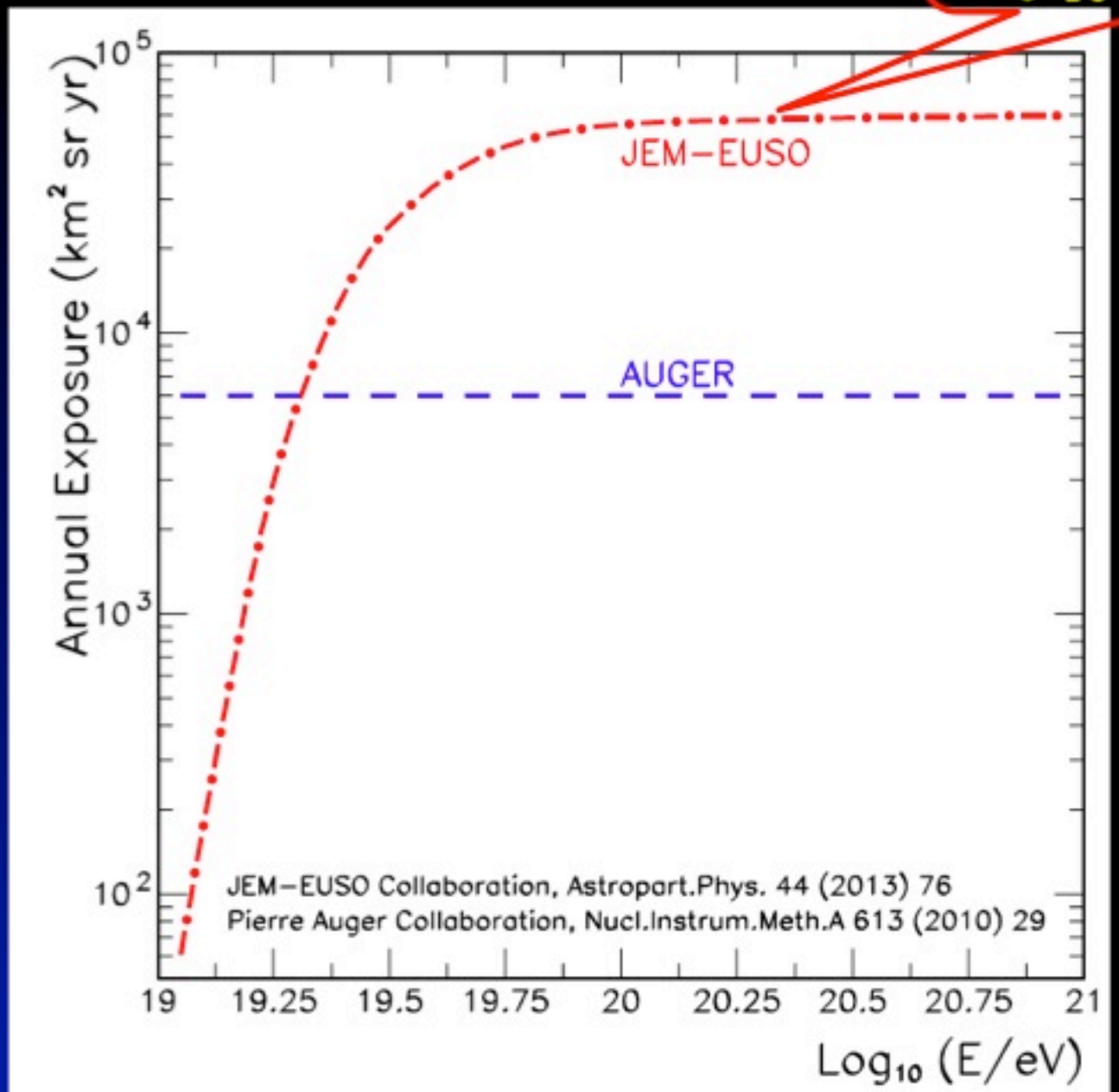


ge on

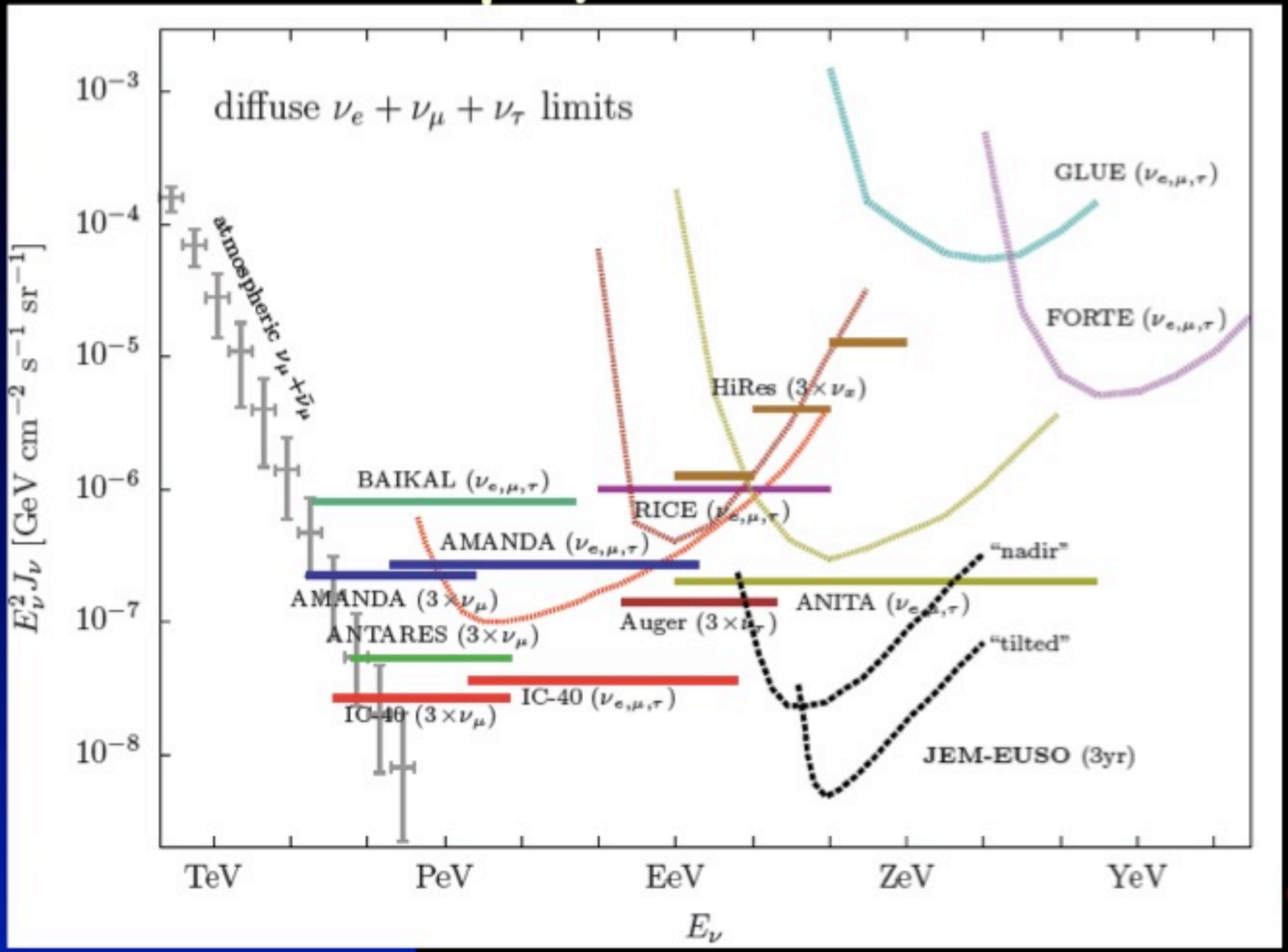
re
Unit
usly.

JEM-EUSO

annual exposure =
10 x Auger
6 10^4 km^2 sr yr



Serendipity: ZeV neutrinos

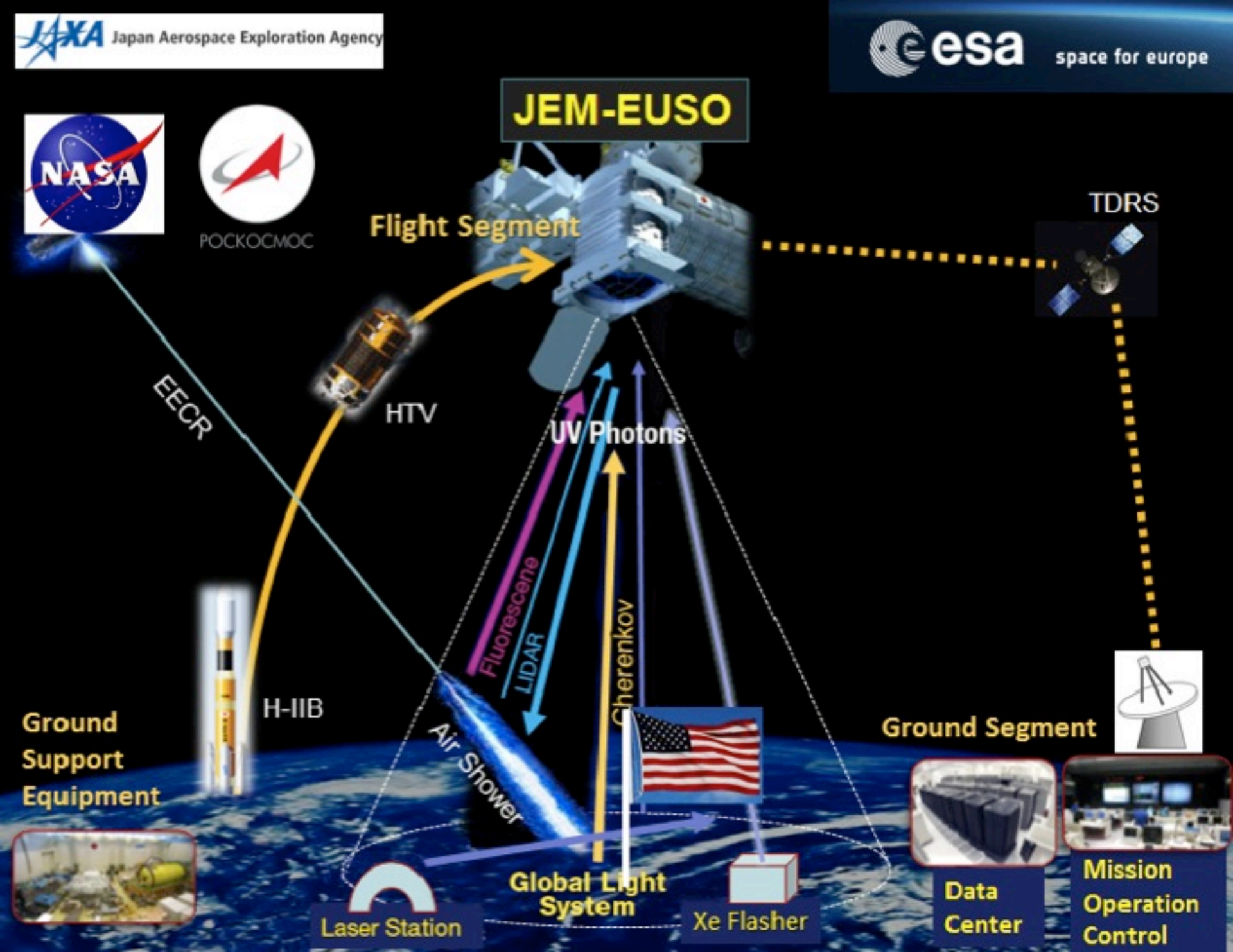


JEM-EUSO in USA

Institutions on NASA APRA Proposal:

University of Chicago, PI Institution
University of Alabama in Huntsville
Marshall Space Flight Center
University of Wisconsin-Milwaukee
Colorado School of Mines
Vanderbilt University

Other US Institutions in the Collaboration
University of California, Berkeley
University of California, Los Angeles
Fermilab
University of Kansas, Wichita
others interested in joining


Japan Aerospace Exploration Agency
esa
space for europe
JEM-EUSO
NASA
POCKOCMOC
Flight Segment
TDRS
EECR
HTV
UV Photons
Fluorescene
LIDAR
Cherenkov
H-IIB
Air Shower
Ground Support Equipment
Ground Segment
Global Light System
Laser Station
Xe Flasher
Data Center
Mission Operation Control

JEM-EUSO in USA

Global Light System

JEM EUSO GLS Some Candidate Locations

Location	Latitude	Elevation	Location	Latitude	Elevation
Jungfraujoch (Switzerland)	47°N	3.9 km	Chacaltaya (Bolivia)	16° S	5.3 km
Mt. Washington (NH, USA)	44° N	1.9 km	La Reunion (Madagascar)	21° S	1.0 km
Alma-Ata (Kazakhstan)	44° N	3.0 km	Cerro Tololo (Chile)	30° S	2.2 km
Climax (CO, USA)	39° N	3.5 km	Sutherland (South Africa)	32° S	1.8 m
Frisco Peak (UT, USA)	39° N	2.9 km	Pierre Auger (Argentina)	35° S	1.4 km
Mt Norikura (Japan)	30° N	4.3 km	South Island (New Zealand)	43° S	1.0 km
Mauna Kea (HI, USA)	20° N	>3.0 km			
HAWC Site (Mexico)	19° N	3.4 km			

EUSO Balloon – pathfinder

PI: P. von Ballmoos Phase C/D

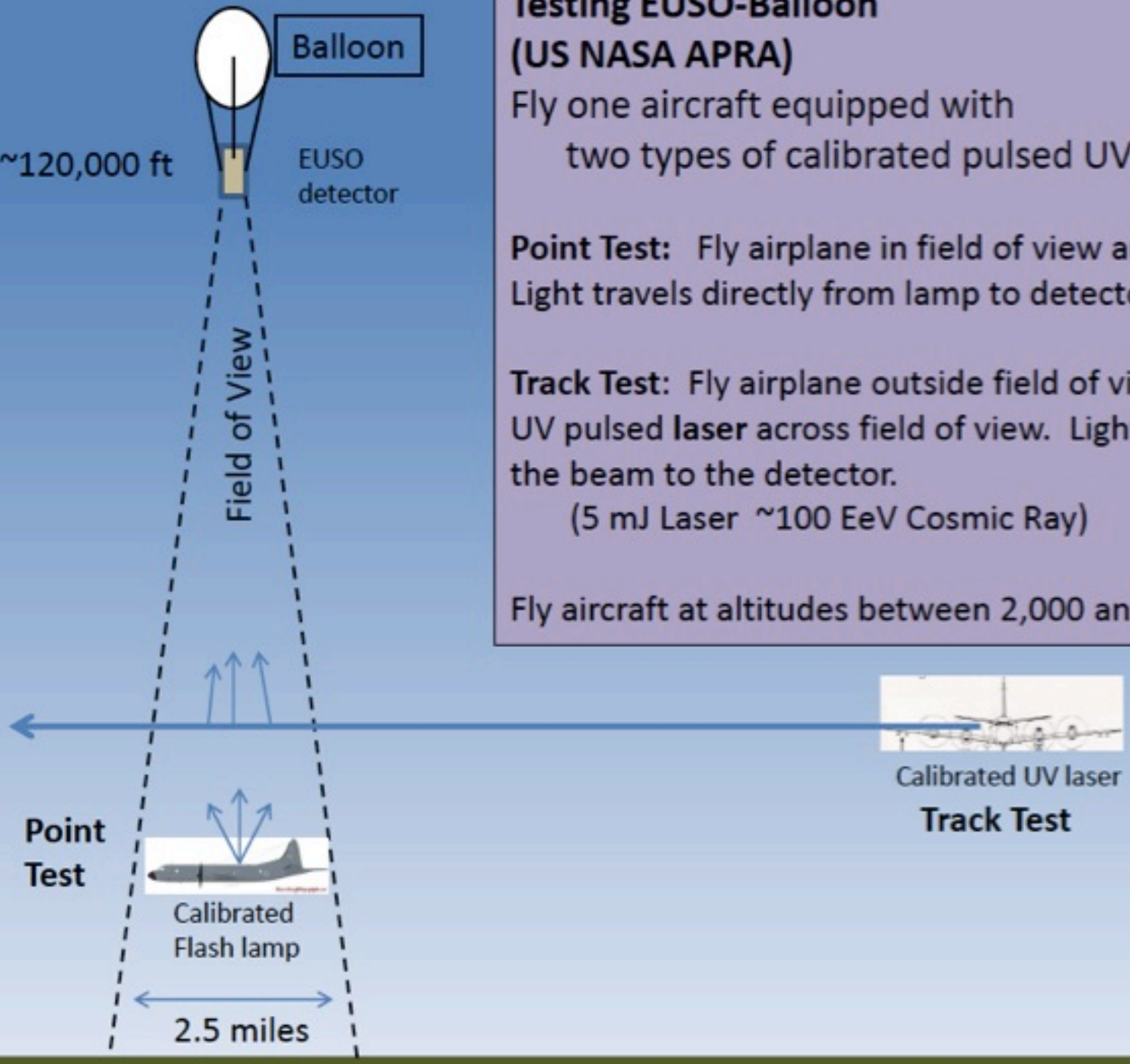
Testing EUSO-Balloon
(US NASA APRA)

Fly one aircraft equipped with
two types of calibrated pulsed UV light sources.

Point Test: Fly airplane in field of view and fire **flash lamp**. Light travels directly from lamp to detector

Track Test: Fly airplane outside field of view and shoot a UV pulsed **laser** across field of view. Light scatters out of the beam to the detector.
(5 mJ Laser ~100 EeV Cosmic Ray)

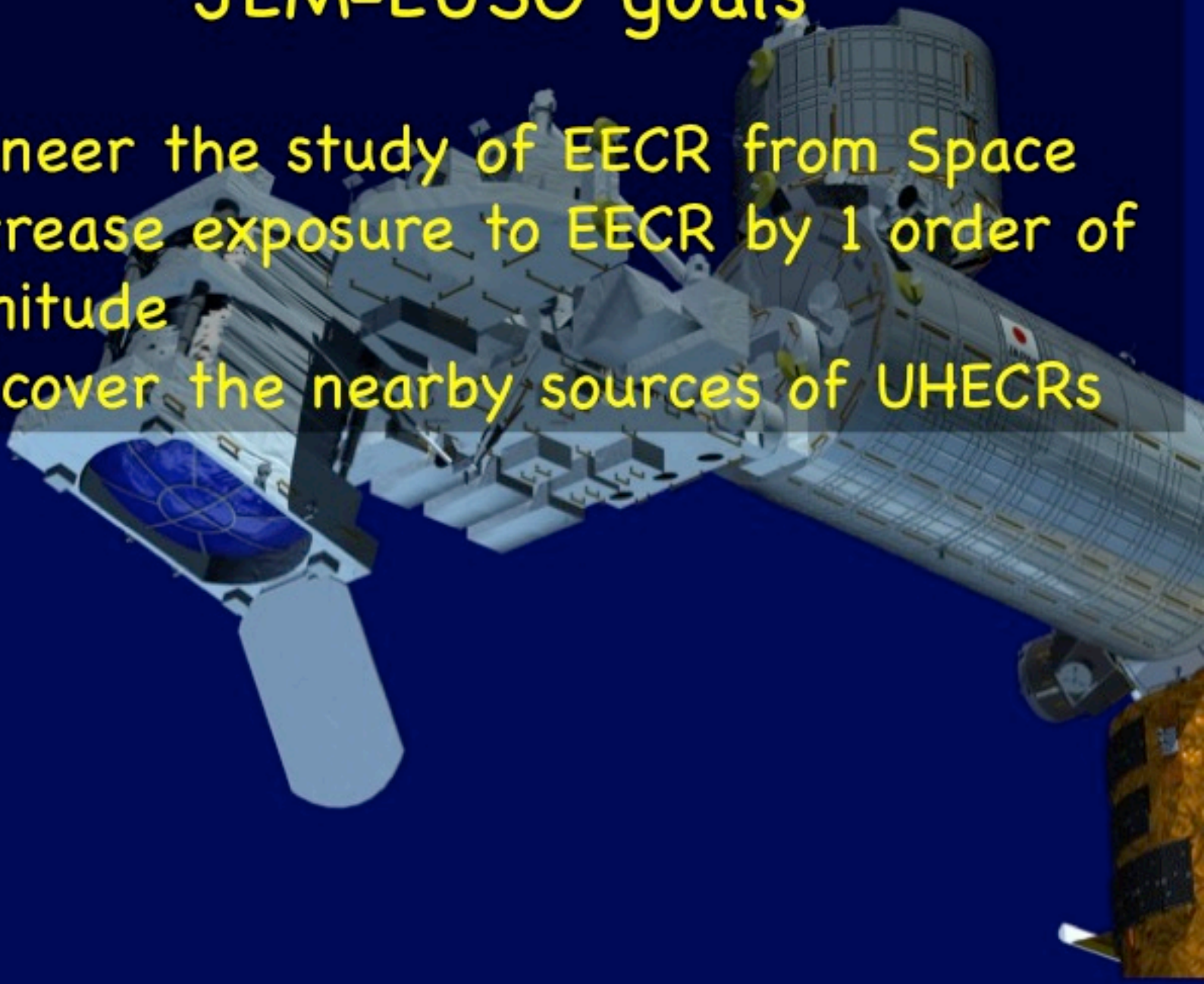
Fly aircraft at altitudes between 2,000 and 10,000 feet.



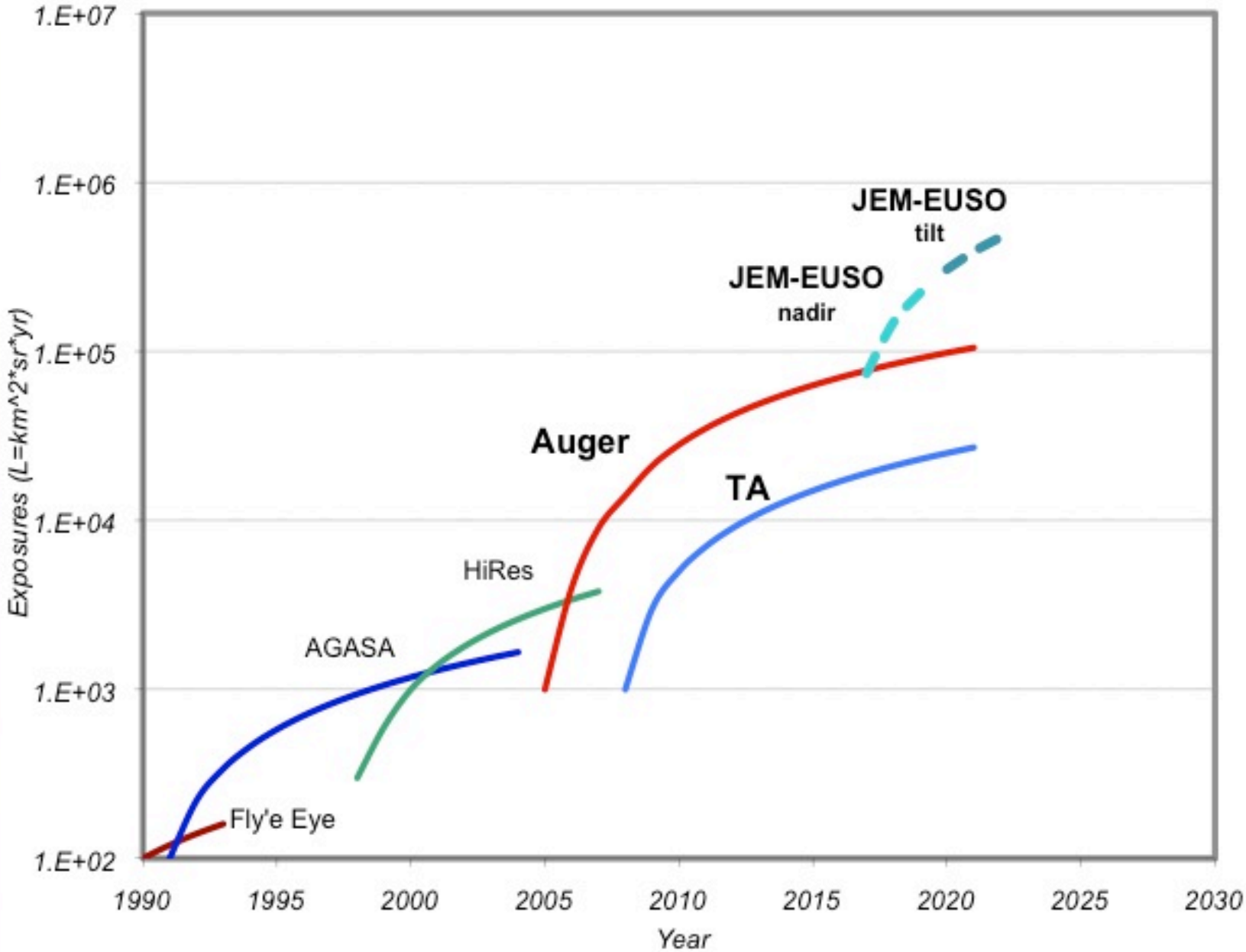
EUSO - Telescope Array

JEM-EUSO goals

- pioneer the study of EECR from Space
- increase exposure to EECR by 1 order of magnitude
- discover the nearby sources of UHECRs



Exposure History




In a decade, we can
discover the first
sources of EECRs
from Space!!!


THANKS