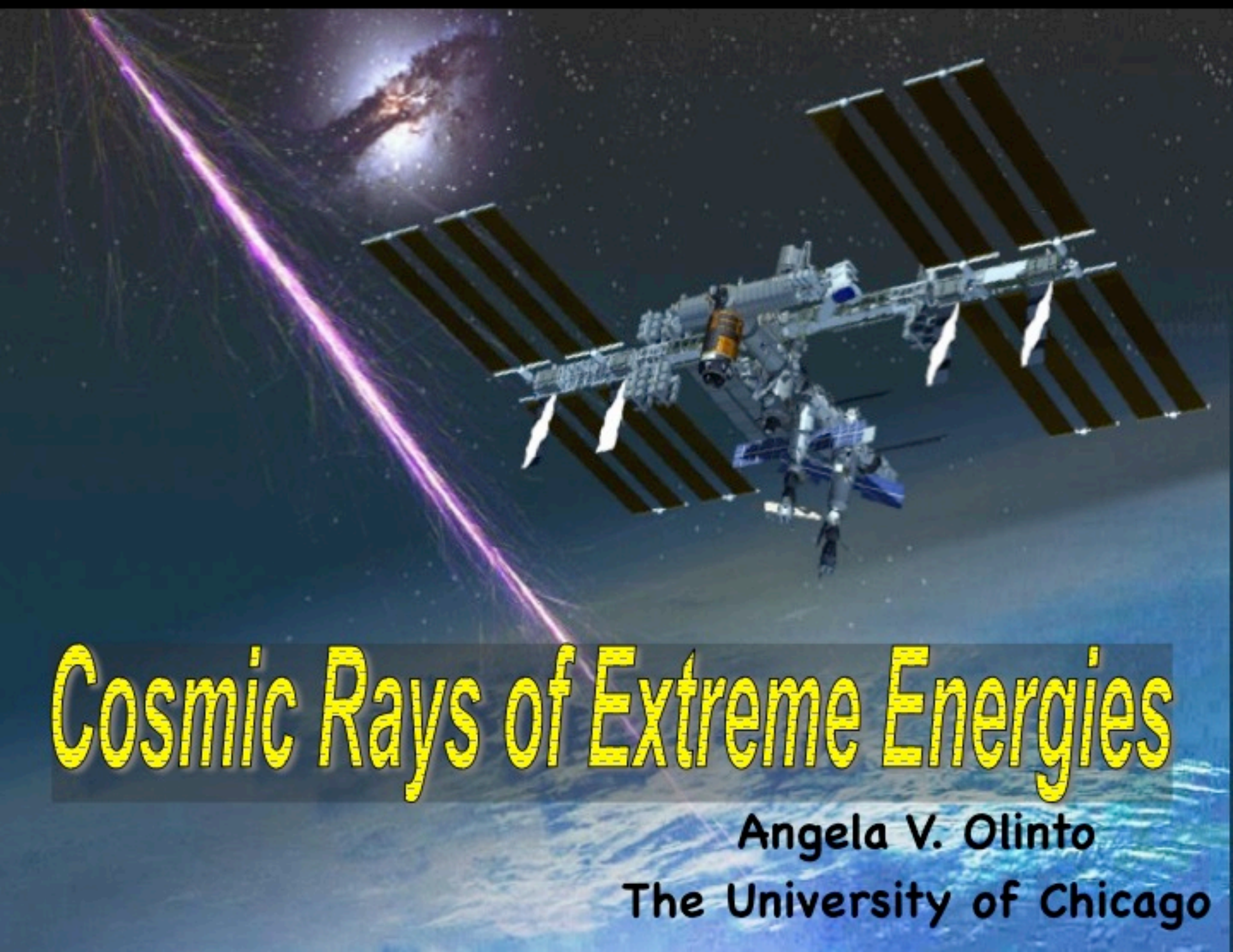


Cosmic Rays of Extreme Energies

Angela V. Olinto
The University of Chicago

Particle Astronomy Begins

This Decade marks the beginning of Particle Astronomy (ie, the identification of cosmic particle accelerators):

First π^0 decay signal id'ed (Fermi W44 & IC443, Feb'13)

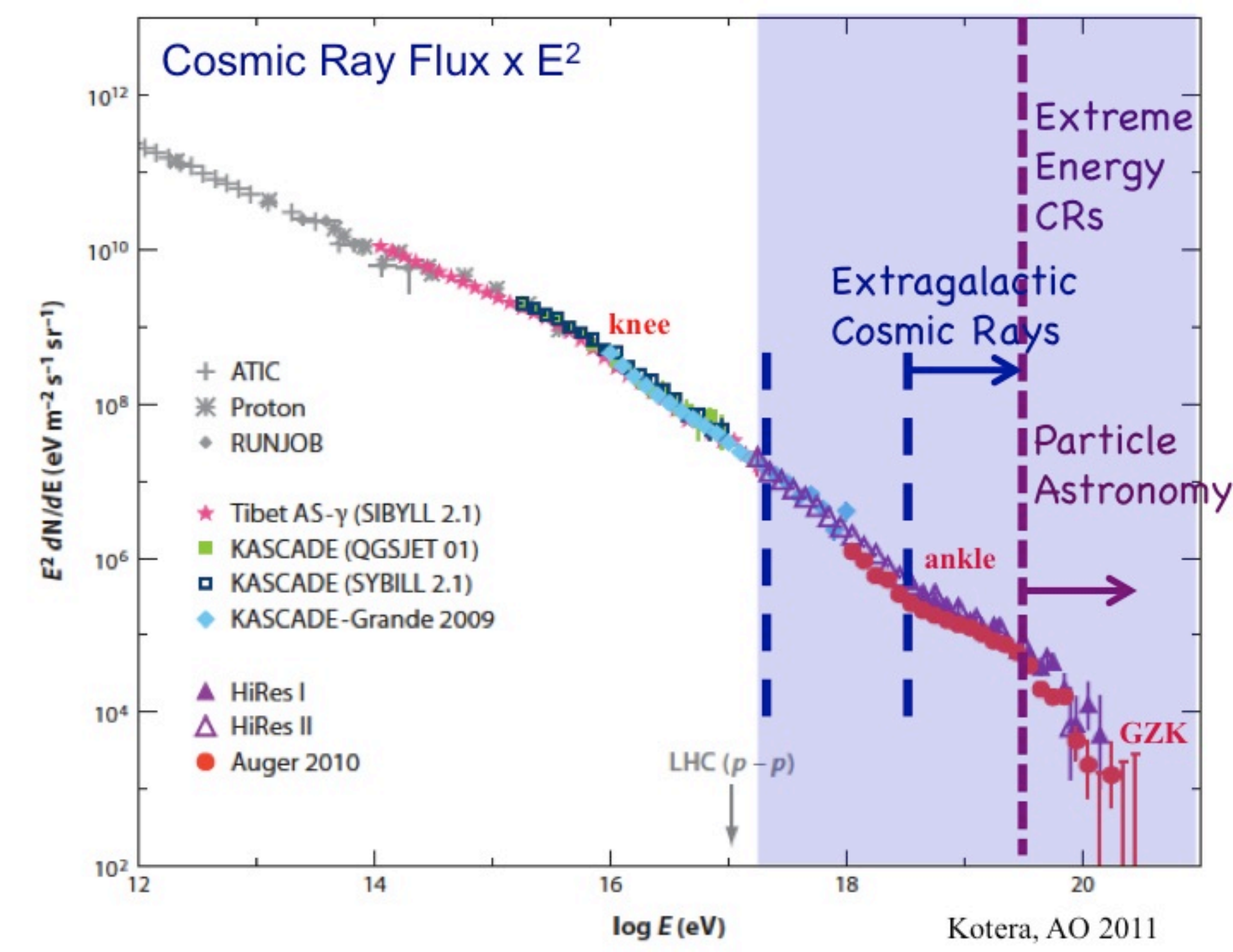
PeV neutrinos first observed (IceCube, Apr'13)

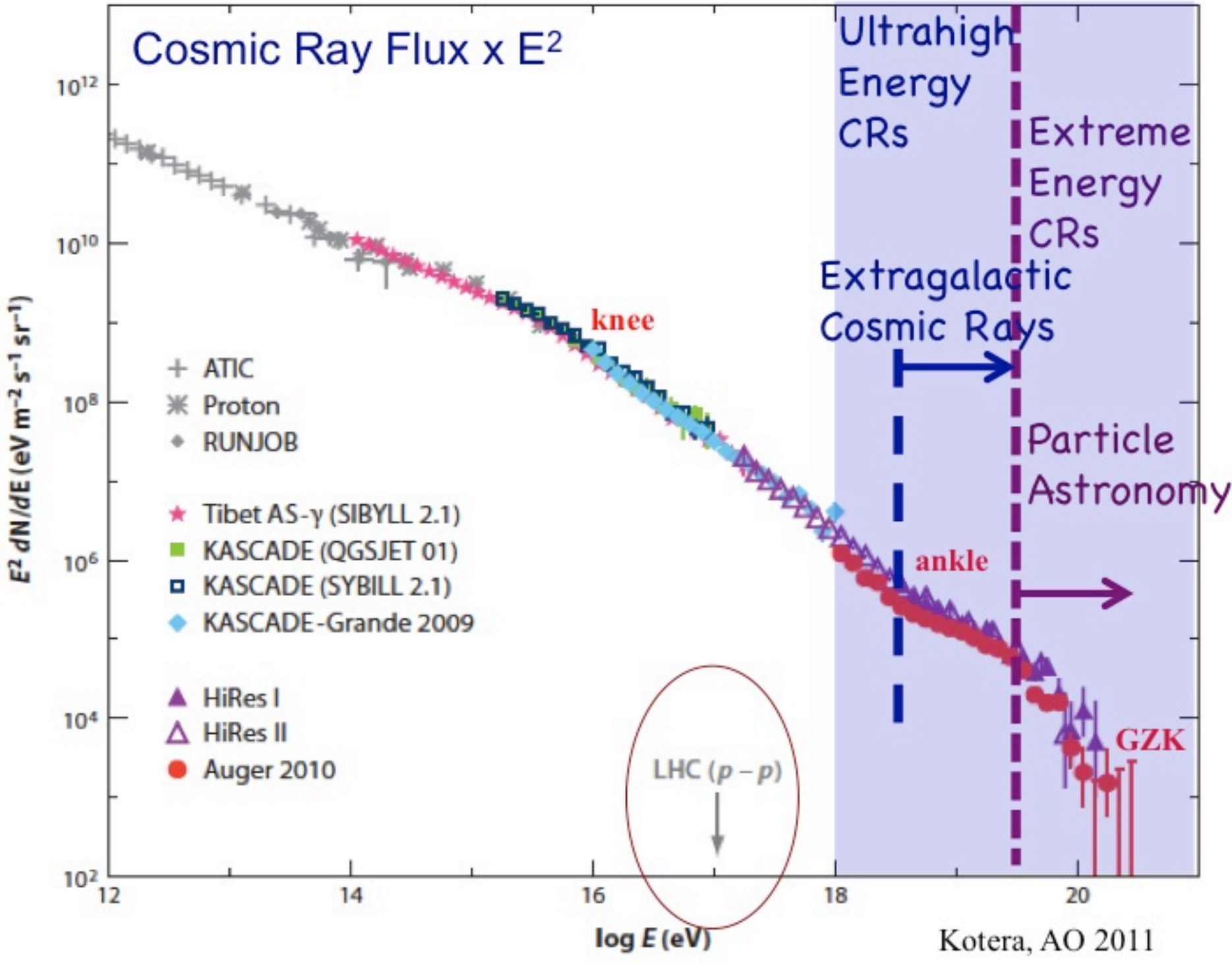
Anisotropies observed in Cosmic Ray distribution:

- Large Scale at Intermediate Energies (Milagro, Tibet, IceCube)
- Hints at Ultrahigh Energies (Pierre Auger, Telescope Array)

Cosmic Magnetic Fields allow direct pointing above ~10 EeV (protons) and Z 10 EeV (nuclei w/ charge Z).

UHECRS are now known to be extragalactic above 1 EeV (protons) & 20 EeV (iron)


Cosmic Ray Flux x E²
Extreme Energy CRs
Extragalactic Cosmic Rays
Particle Astronomy
knee
ankle
GZK
LHC (p – p)
ATIC
Proton
RUNJOB
Tibet AS-γ (SIBYLL 2.1)
KASCADE (QGSJET 01)
KASCADE (SYBILL 2.1)
KASCADE-Grande 2009
HiRes I
HiRes II
Auger 2010
E² dN/dE (eV m⁻² s⁻¹ sr⁻¹)
log E (eV)
10¹²
10¹⁰
10⁸
10⁶
10⁴
10²
12
14
16
18
20
Kotera, AO 2011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Current Observatories of Ultrahigh Energy Cosmic Rays

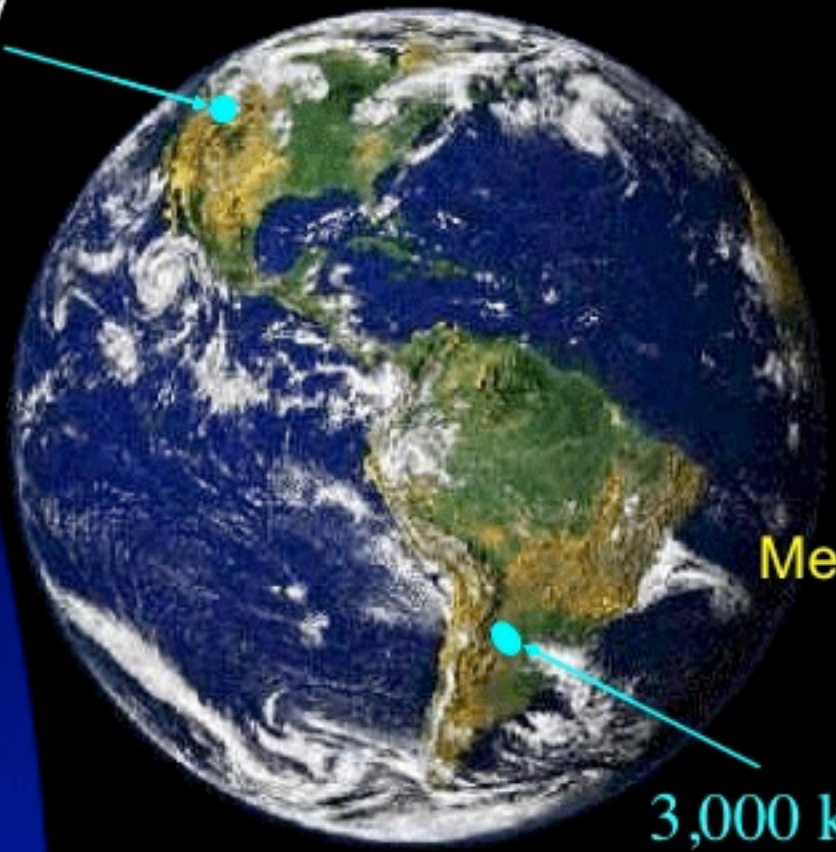
Telescope Array

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

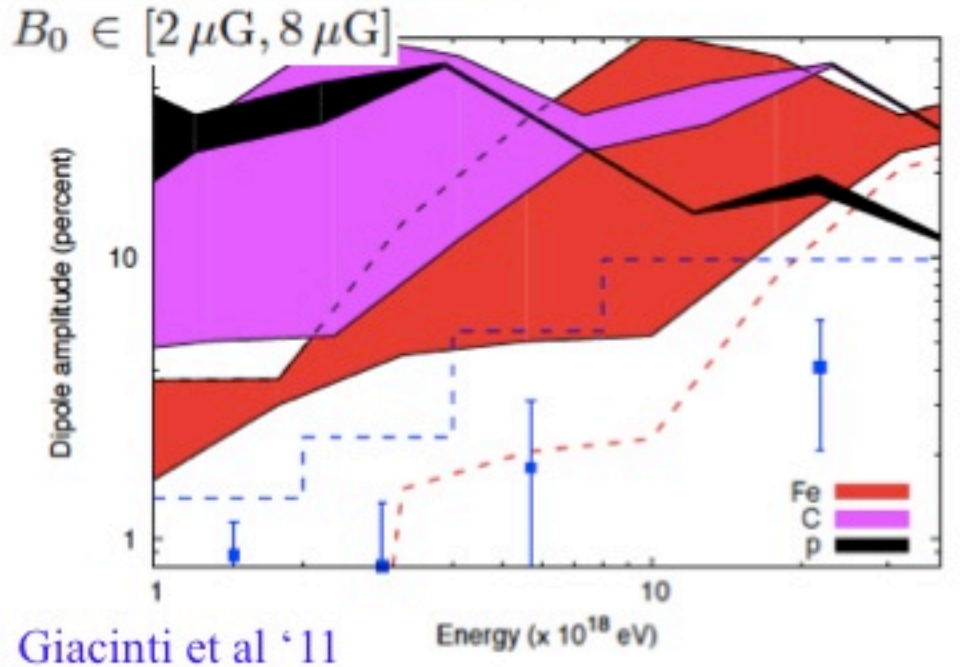
Recent Results

E>20 EeV Cosmic Rays are EXTRAGALACTIC

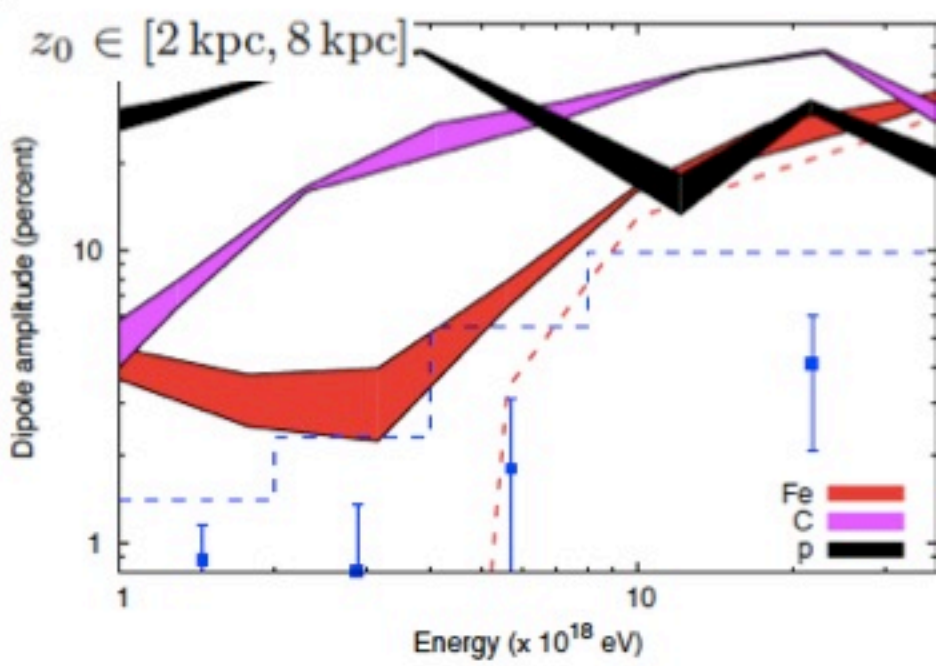
Recent Results

E>20 EeV Cosmic Rays are EXTRAGALACTIC

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



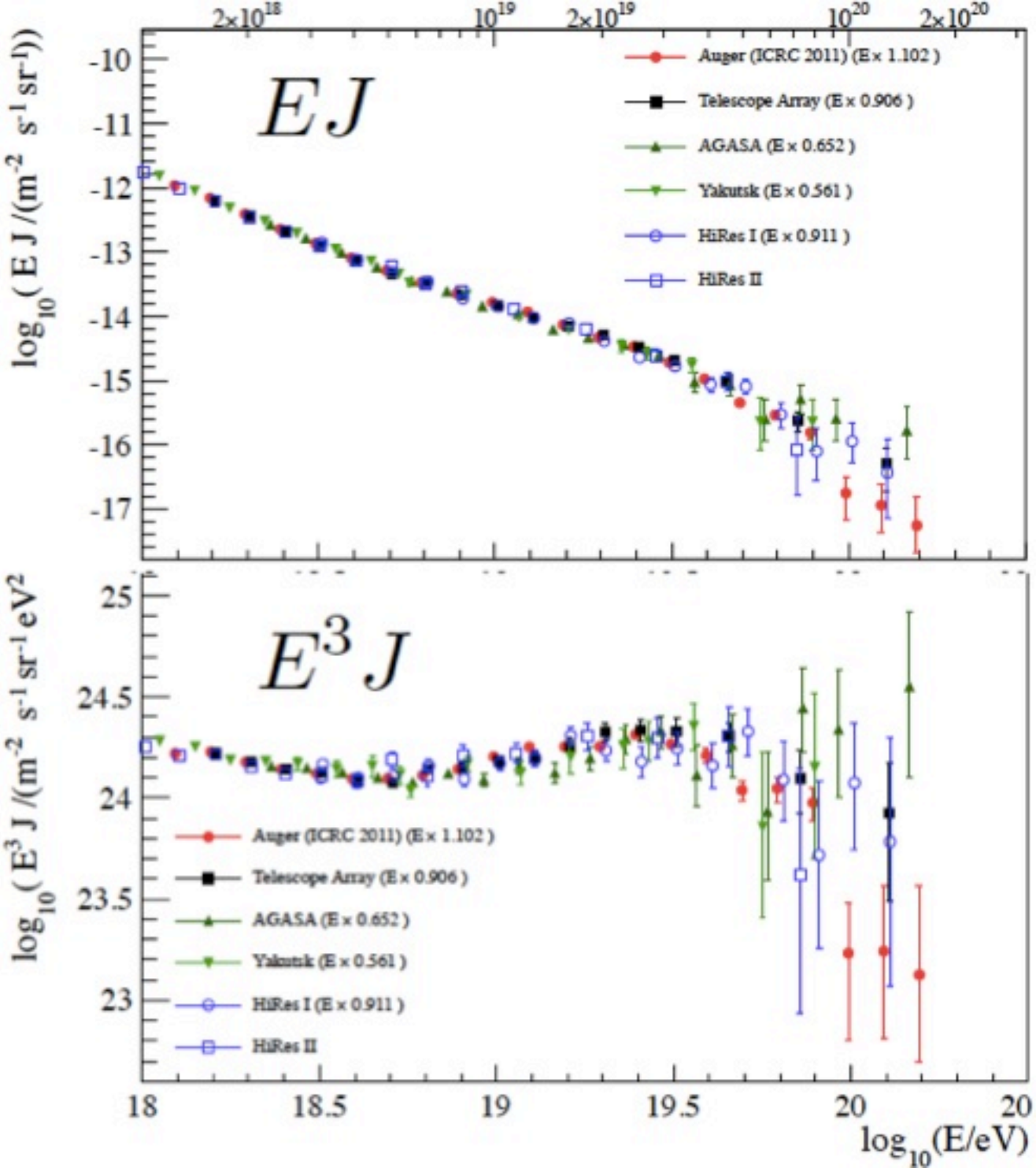
Recent Results

E>20 EeV Cosmic Rays are EXTRAGALACTIC

Implies a GZK* feature in the spectrum

(*Greisen-Zatsepin-Kuzmin)

UHECR 2012 CERN



Tsunesada et al.
CERN WG '12

Recent Results

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Recent Results

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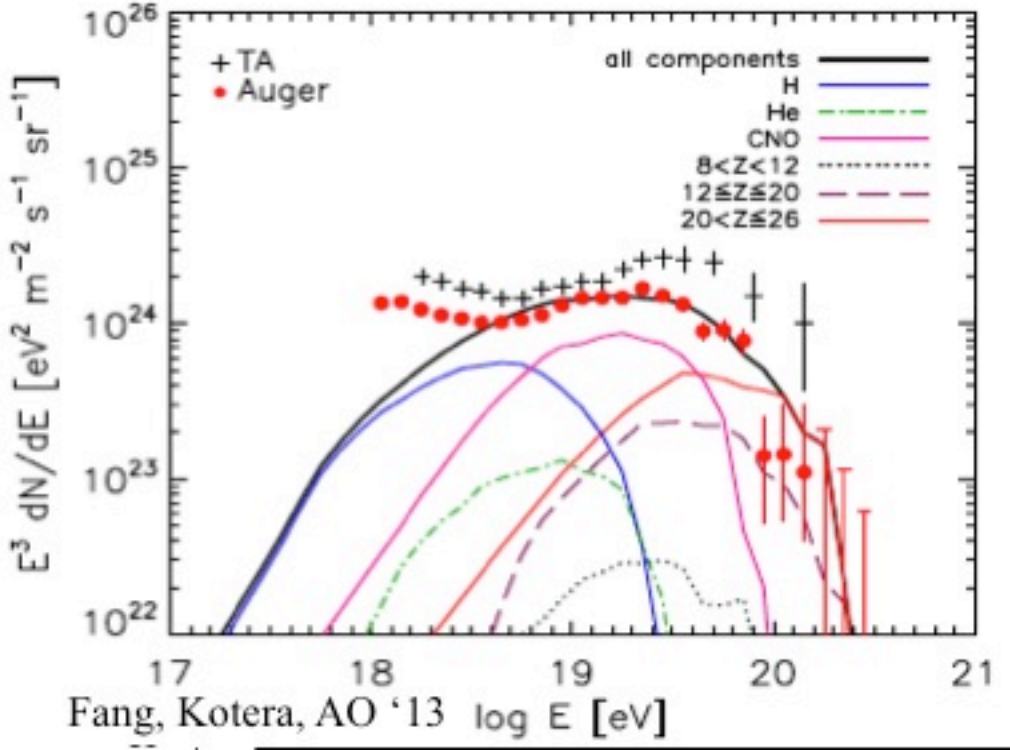
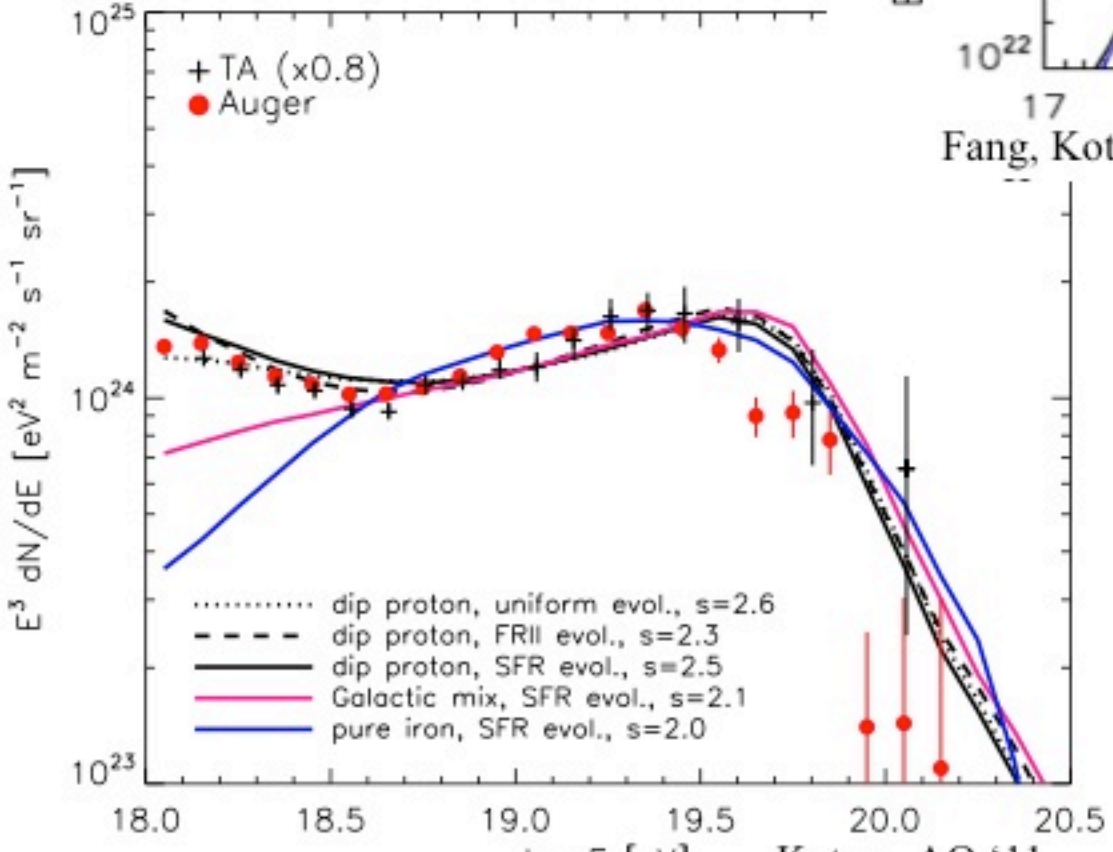
or end of the injected spectrum, E_{max}?

GZK vs E_{max}


+ TA
• Auger
all components
H
He
CNO
8<Z<12
12≦Z≦20
20<Z≦26
E^3 dN/dE [eV^2 m^{-2} s^{-1} sr^{-1}]
log E [eV]
Fang, Kotera, AO '13


+ TA (x0.8)
• Auger
dip proton, uniform evol., s=2.6
dip proton, FRII evol., s=2.3
dip proton, SFR evol., s=2.5
Galactic mix, SFR evol., s=2.1
pure iron, SFR evol., s=2.0
E^3 dN/dE [eV^2 m^{-2} s^{-1} sr^{-1}]
log E [eV]
Kotera, AO '11

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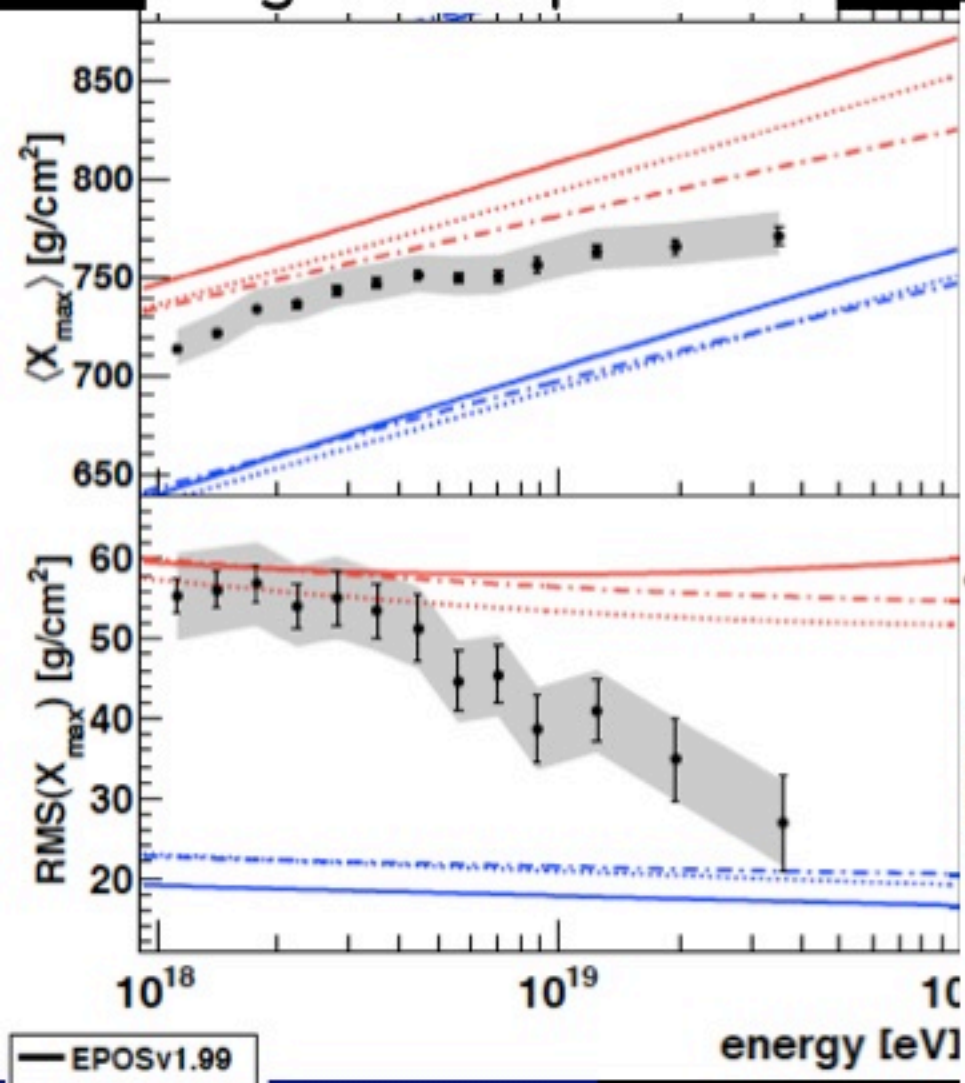
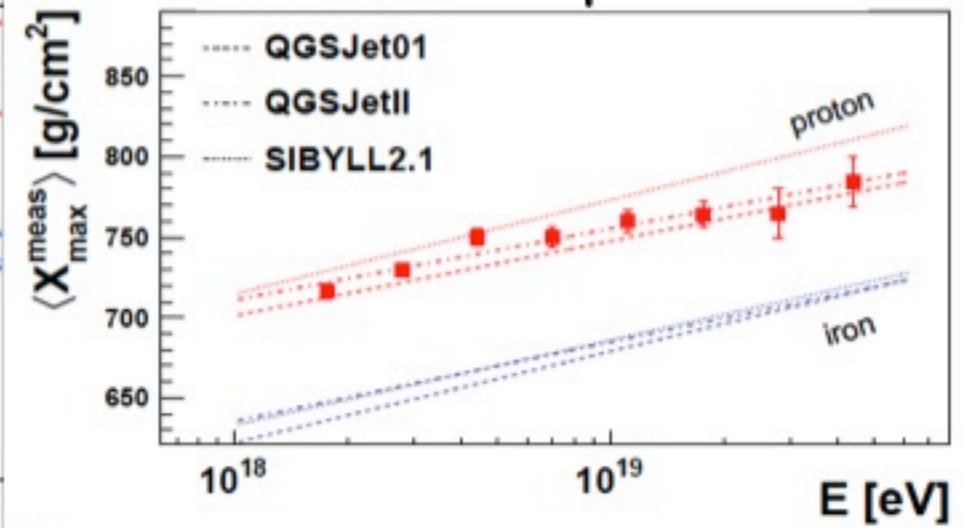
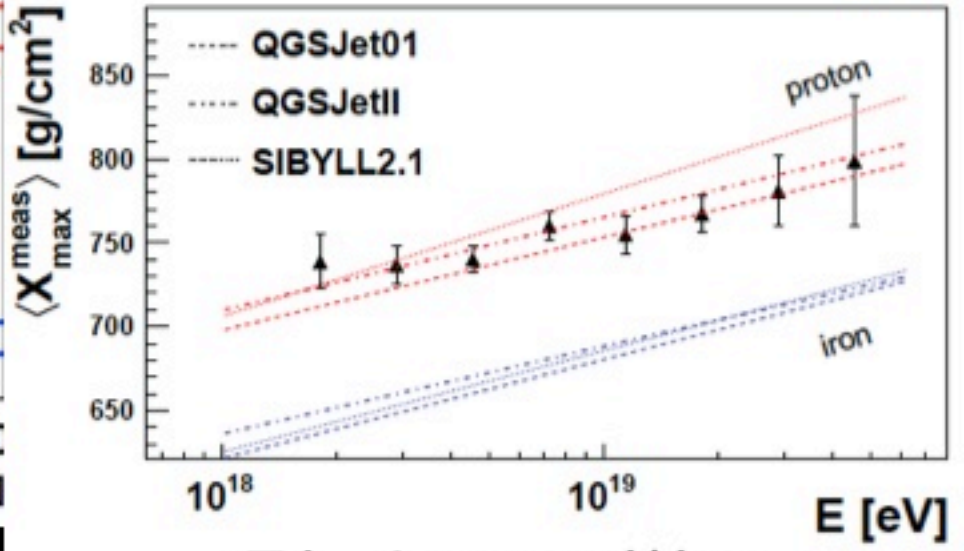
E>10 EeV Composition may be changing!

Auger Composition



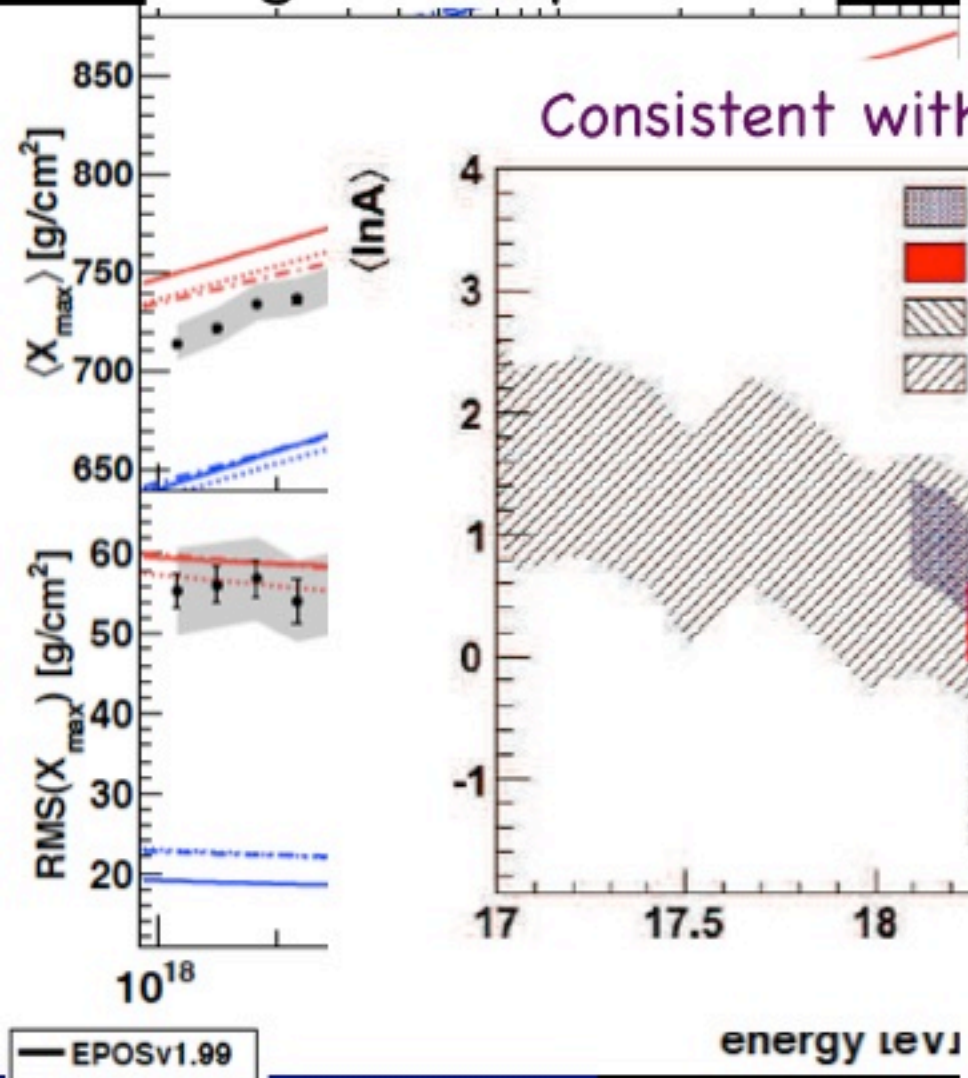
HiRes Composition



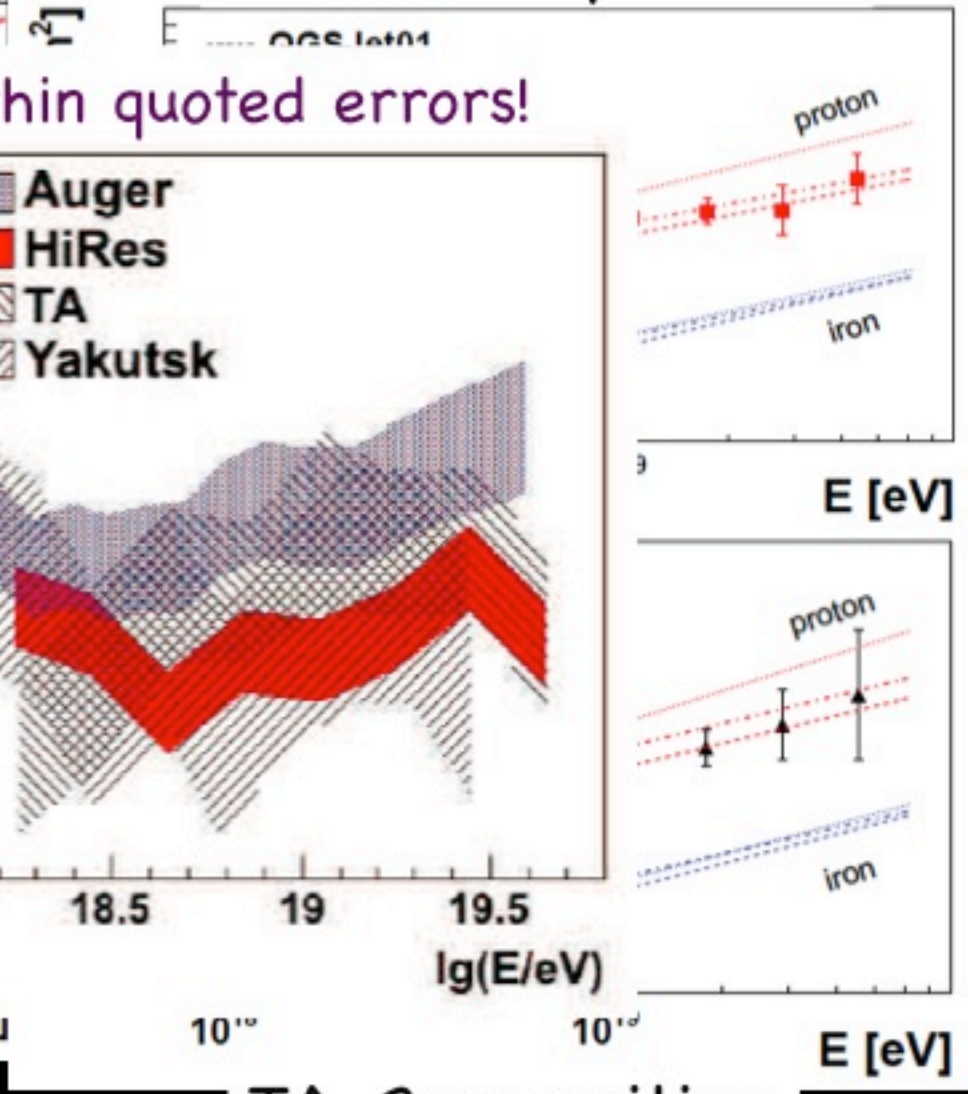


TA Composition

Auger Composition



HiRes Composition



TA Composition

Recent Results

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How to sort out this conundrum?

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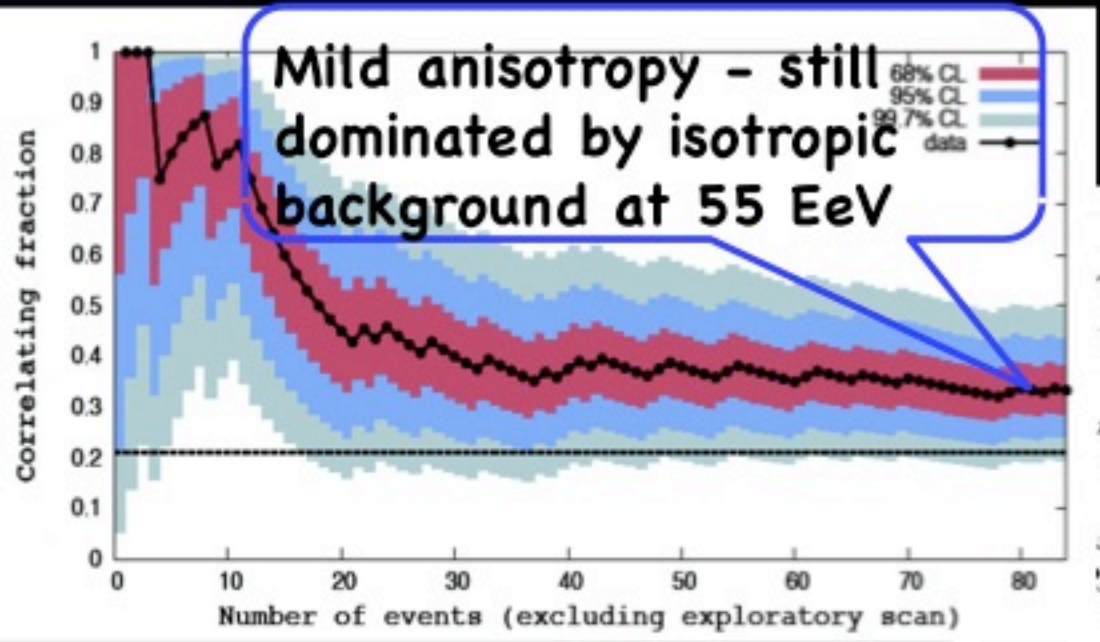
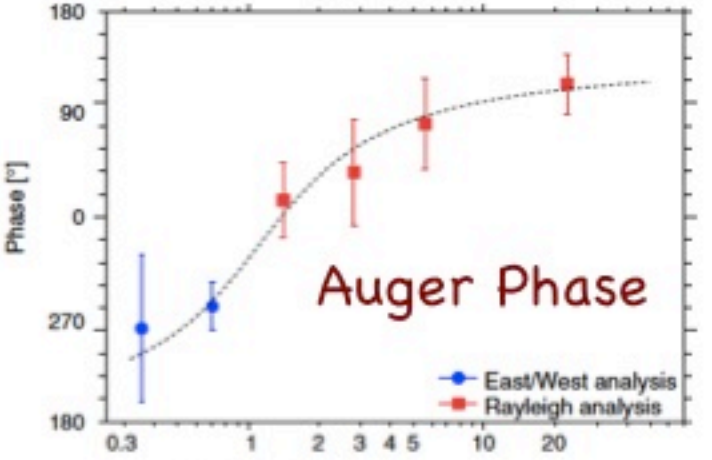
or maybe the HE interactions are changing!

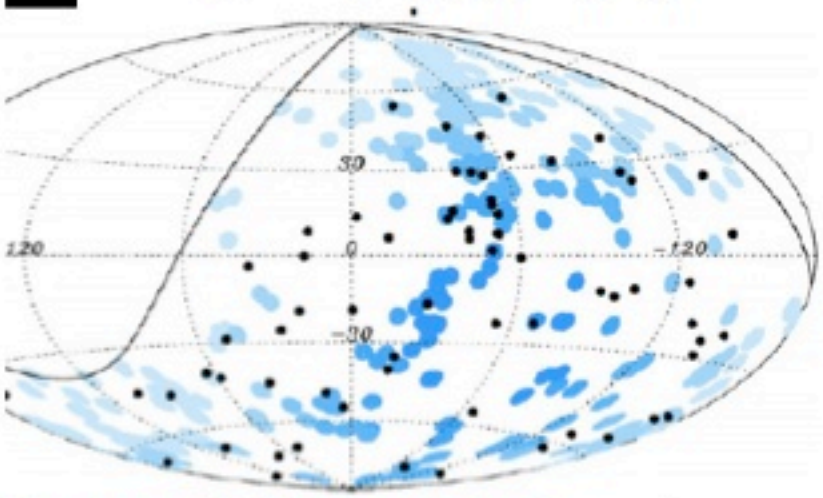
How to sort out this conundrum? Find the Sources!

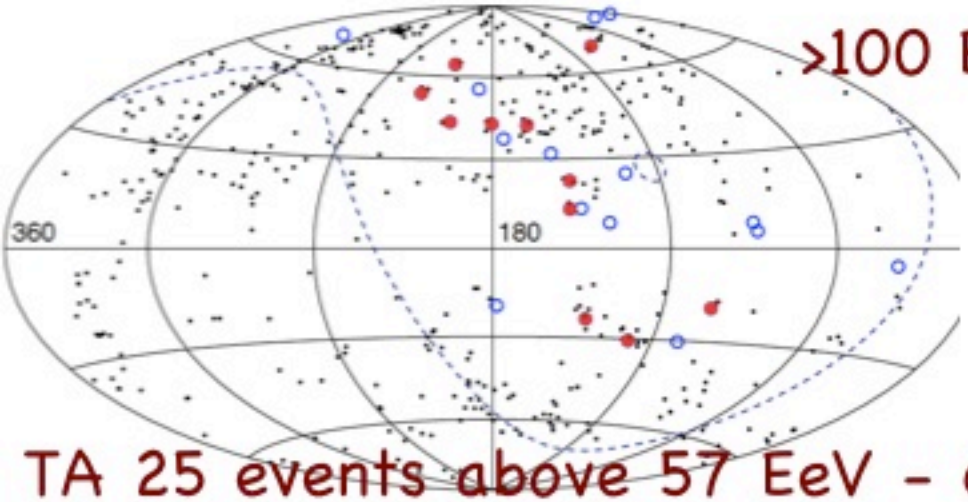
EECR Anisotropy Hints

E > 60 EeV



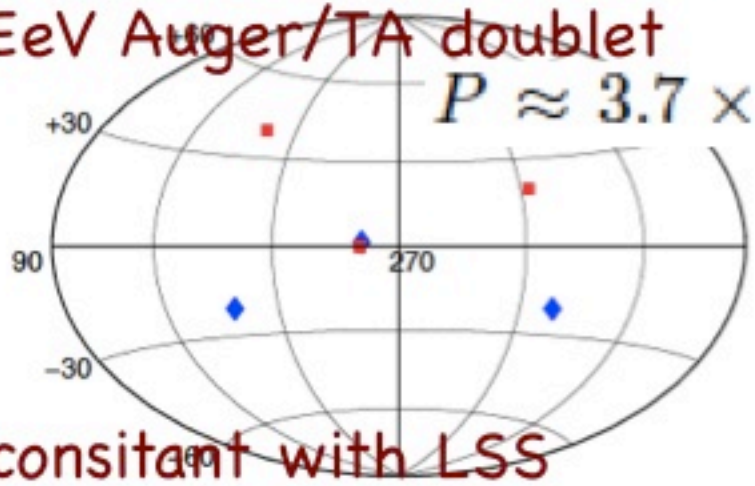






>100 EeV Auger/TA doublet

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



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

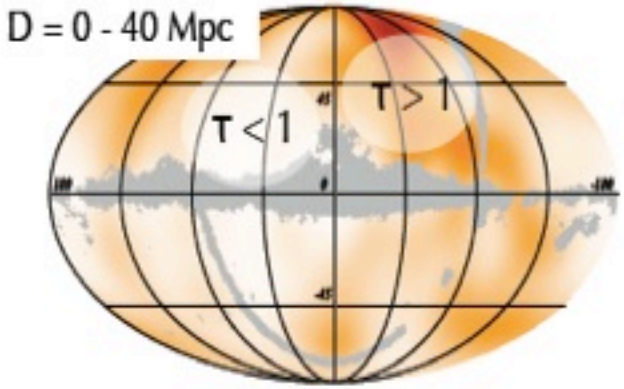
$$\alpha_d \hat{d} = \frac{3}{N} \int J(\hat{u})\, \hat{u}\, d\Omega$$

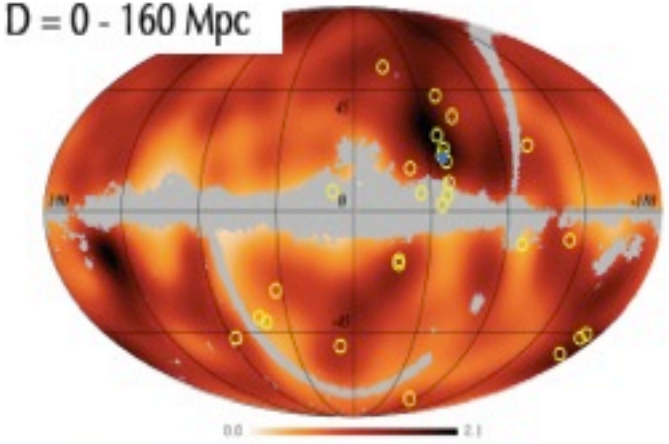
$\alpha_d = 0.25$

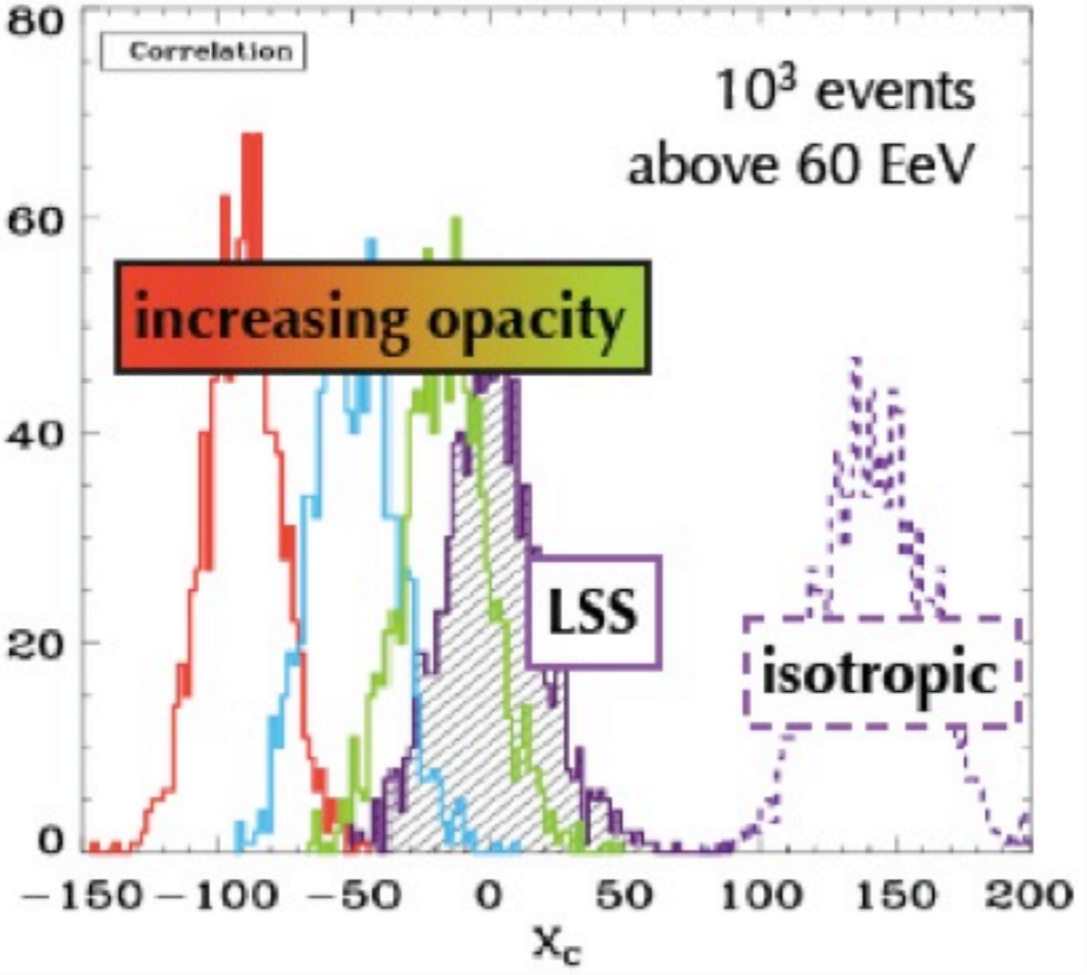
5 σ discovery requires 1,000 events

(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

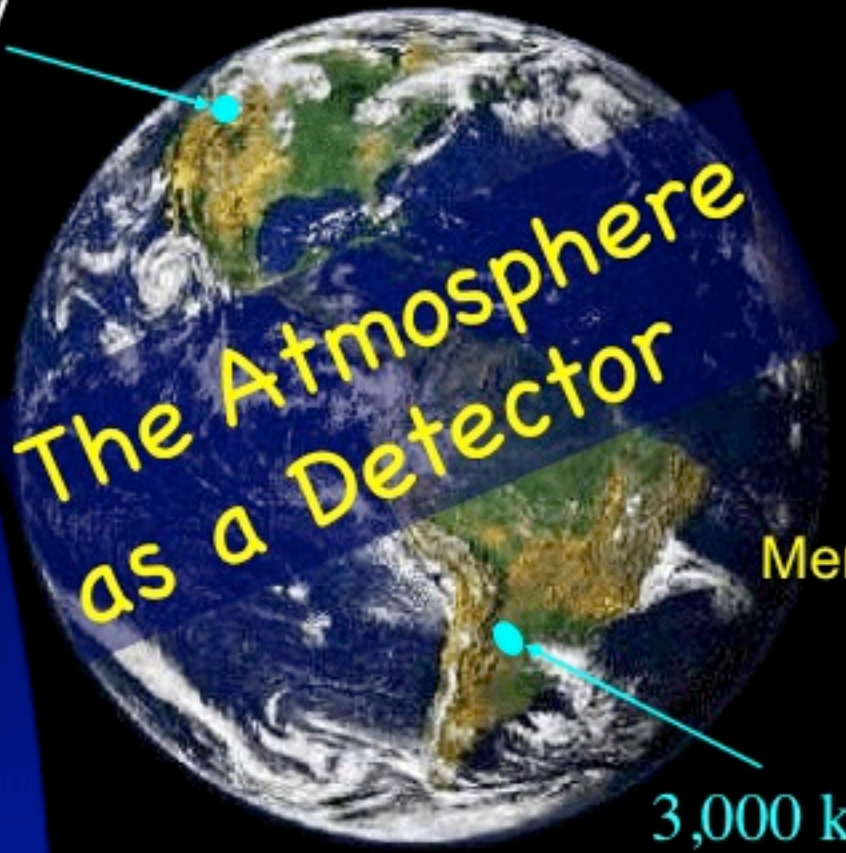
Telescope Array

Utah, USA

(5 country collaboration)

700 km^2 array

3 fluorescence telescopes



Pierre Auger Observatory

Mendoza, Argentina

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3,000 km^2 array

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How many EECRs > 60 EeV?

Auger w/ 3,000 km^2

~20 events > 60 EeV/ yr

Telescope Array w/ 700 km^2

~5 events > 60 EeV/ yr

Auger + TA ~ 25 events/yr

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Earth - surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

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Telescope Array w/ 700 km^2

~5 events > 60 EeV/ yr

Auger + TA ~ 25 events/yr

40 years to reach 1000

500 to go!

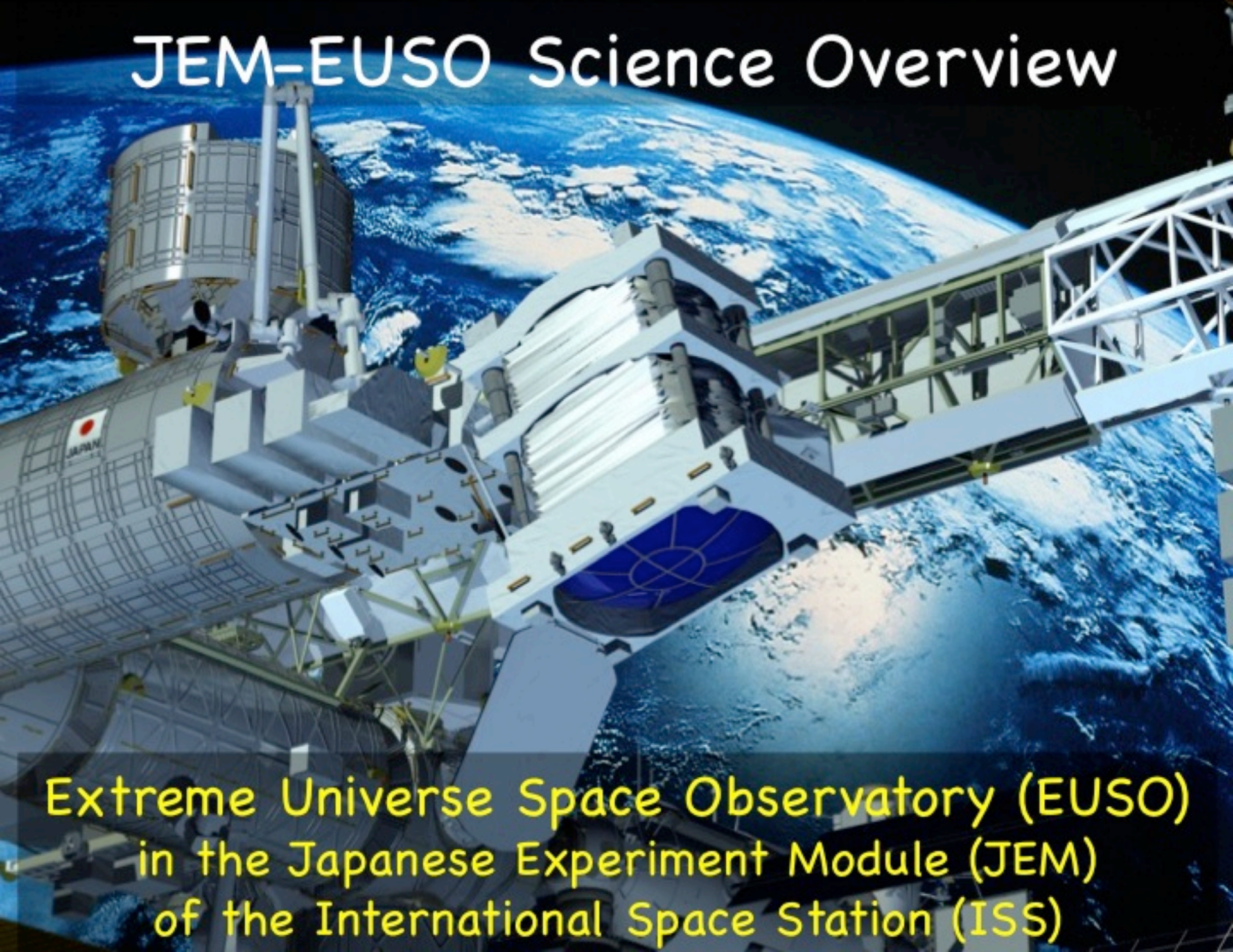
Earth surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

Go to SPACE!

To look down on the Atmosphere!

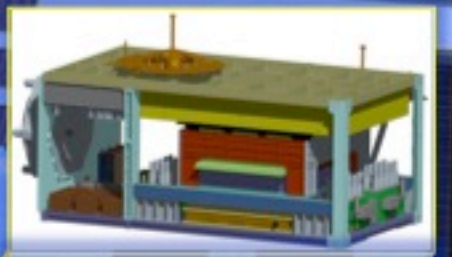
JEM-EUSO Science Overview



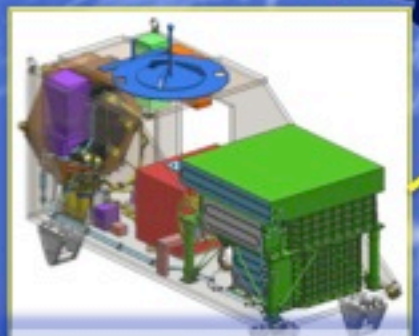
Extreme Universe Space Observatory (EUSO)
in the Japanese Experiment Module (JEM)
of the International Space Station (ISS)

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

AMS Launch
May 16, 2011



ISS-CREAM
Sp-X Launch 2014



CALET on JEM
HTV Launch 2014

JEM-EUSO
Launch
Tentatively
planned for 2017

JEM-EUSO Mission

Japanese Experiment Module (JEM)

きぼう, Kibo = Hope

JEM-EUSO Mission

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

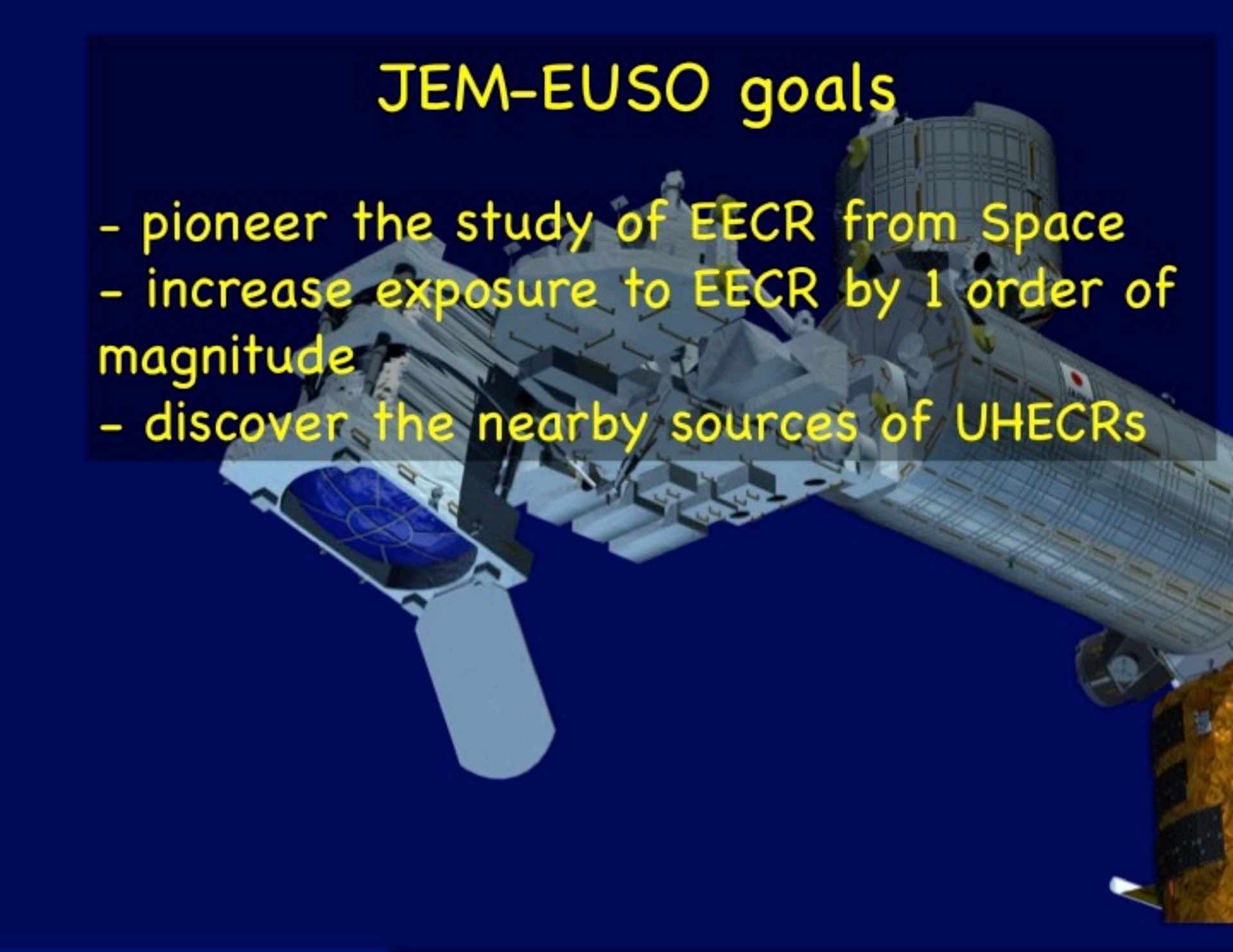
13 Countries, 73 Institutions, 250 researchers
Leading institution: RIKEN

PI: Piergiorgio Picozza

NASA JAXA esa РОСКОСМОС

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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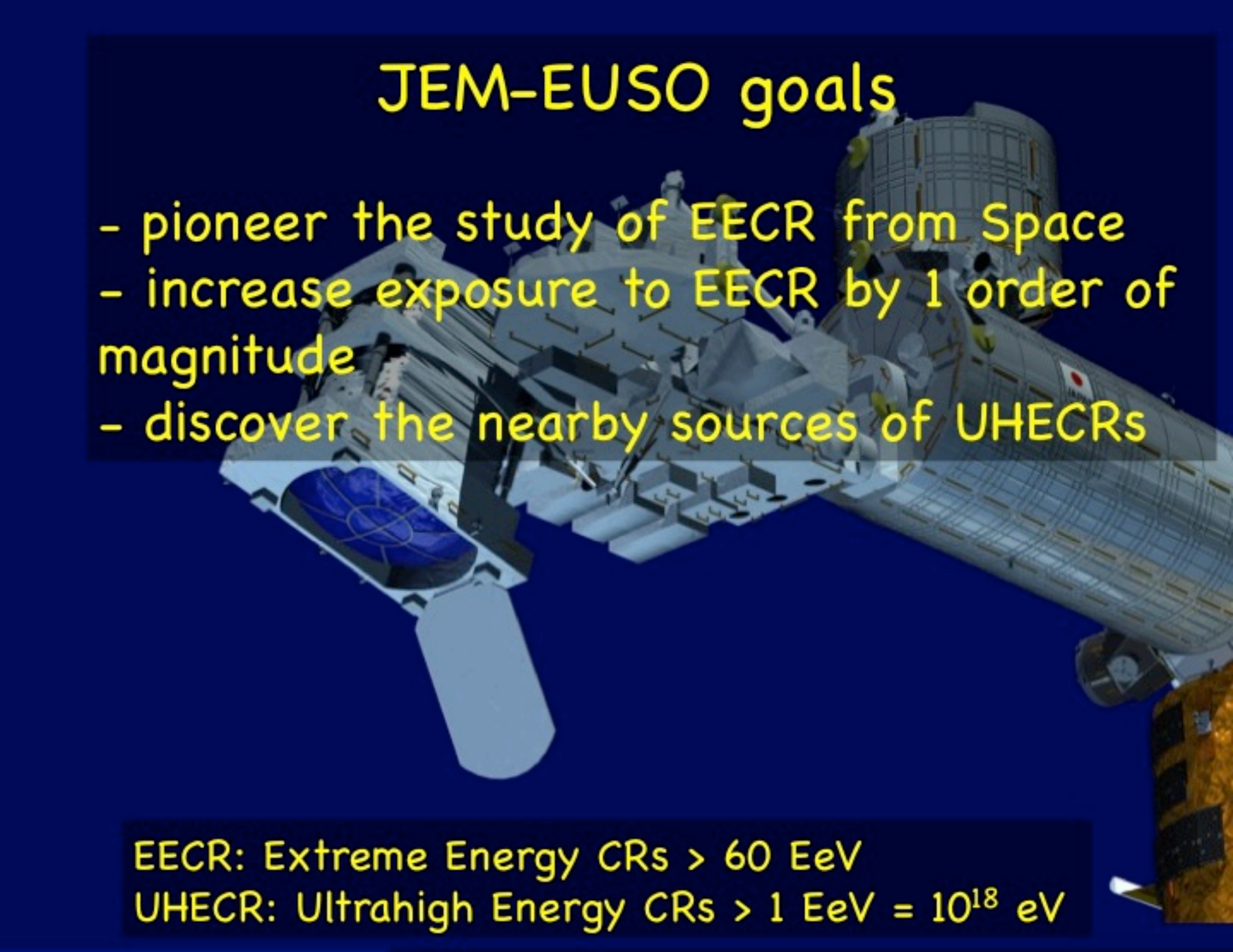


EECR: Extreme Energy CRs > 60 EeV
UHECR: Ultrahigh Energy CRs > 1 EeV = 10^{18} eV

How many UHECRs > 60 EeV?

Auger + TA ~25 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 ~25 events/yr

JEM-EUSO

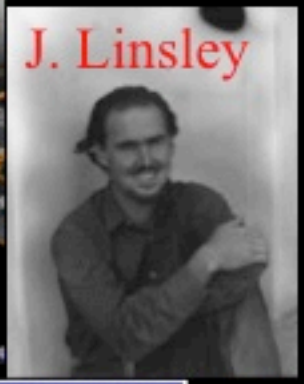
~200 events > 60 EeV/ yr

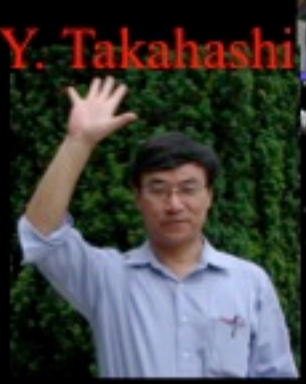
4 o.o.m to go!

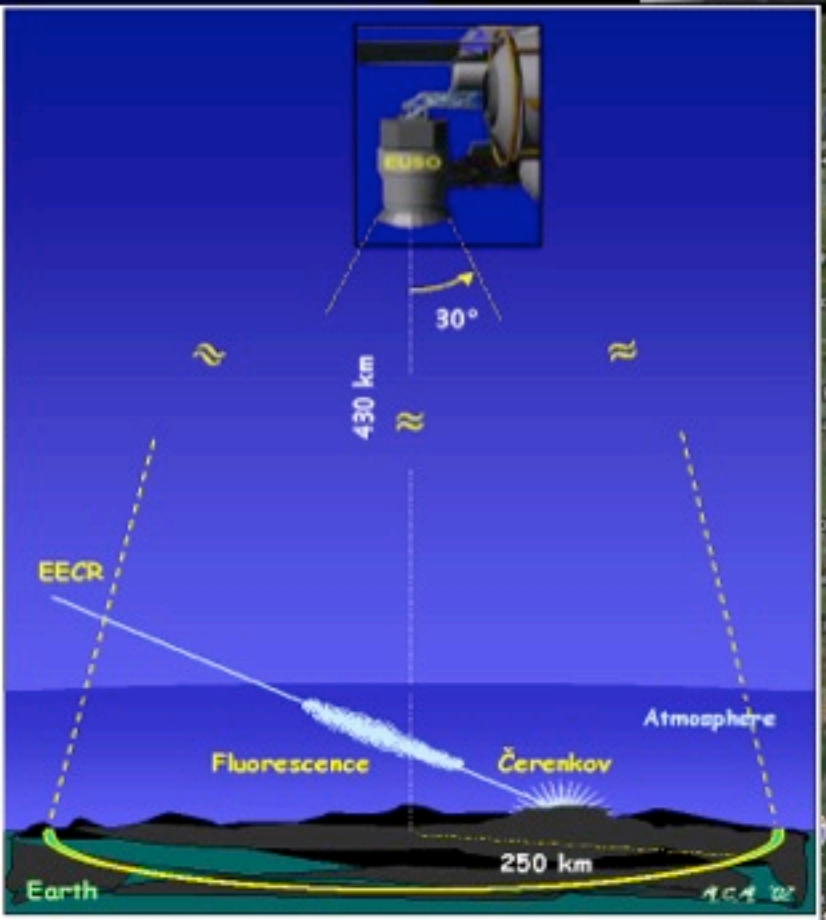
Earth surface ~ 5 10^8 km^2

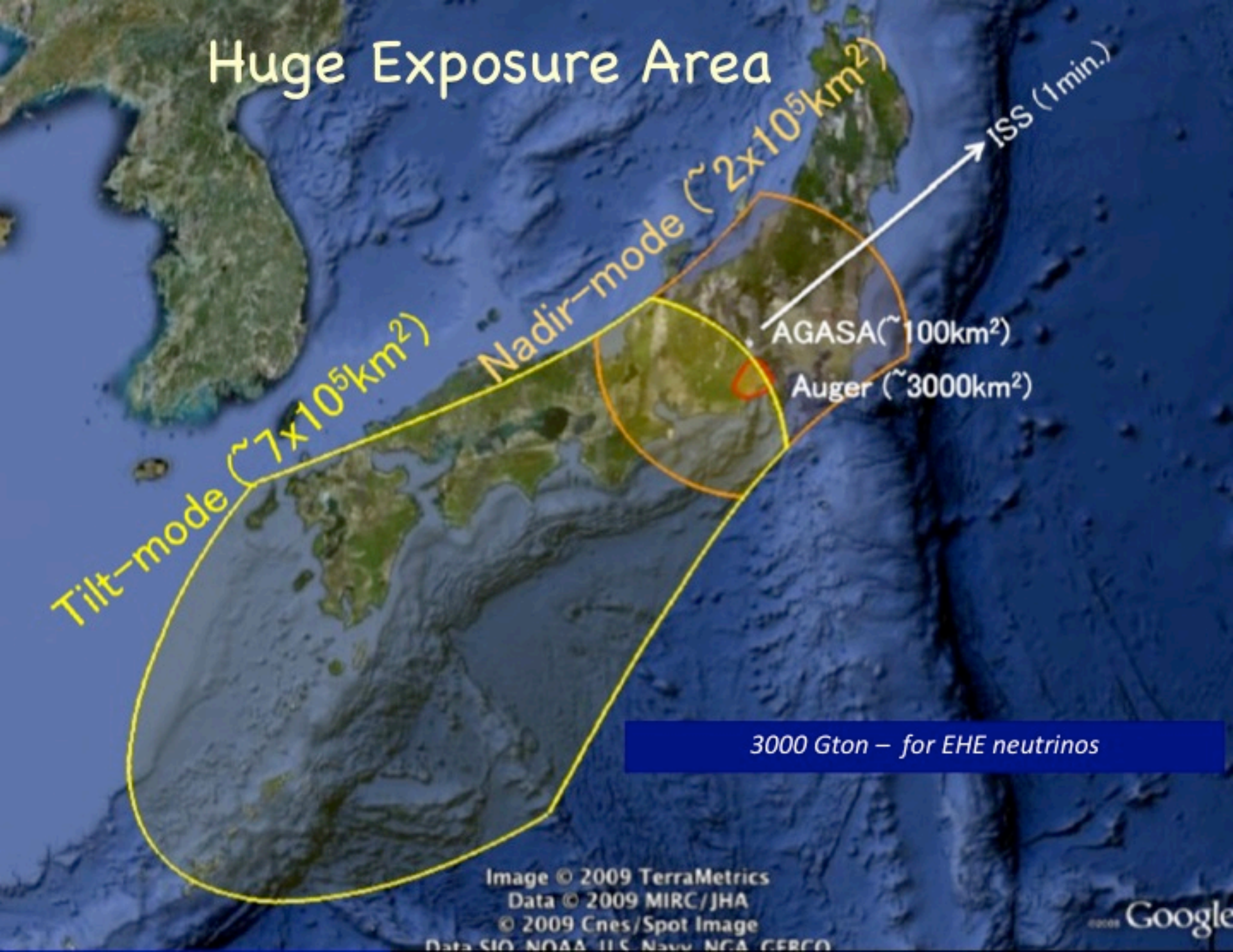
~3.4 10^6 events/yr

Fluorescence from SPACE



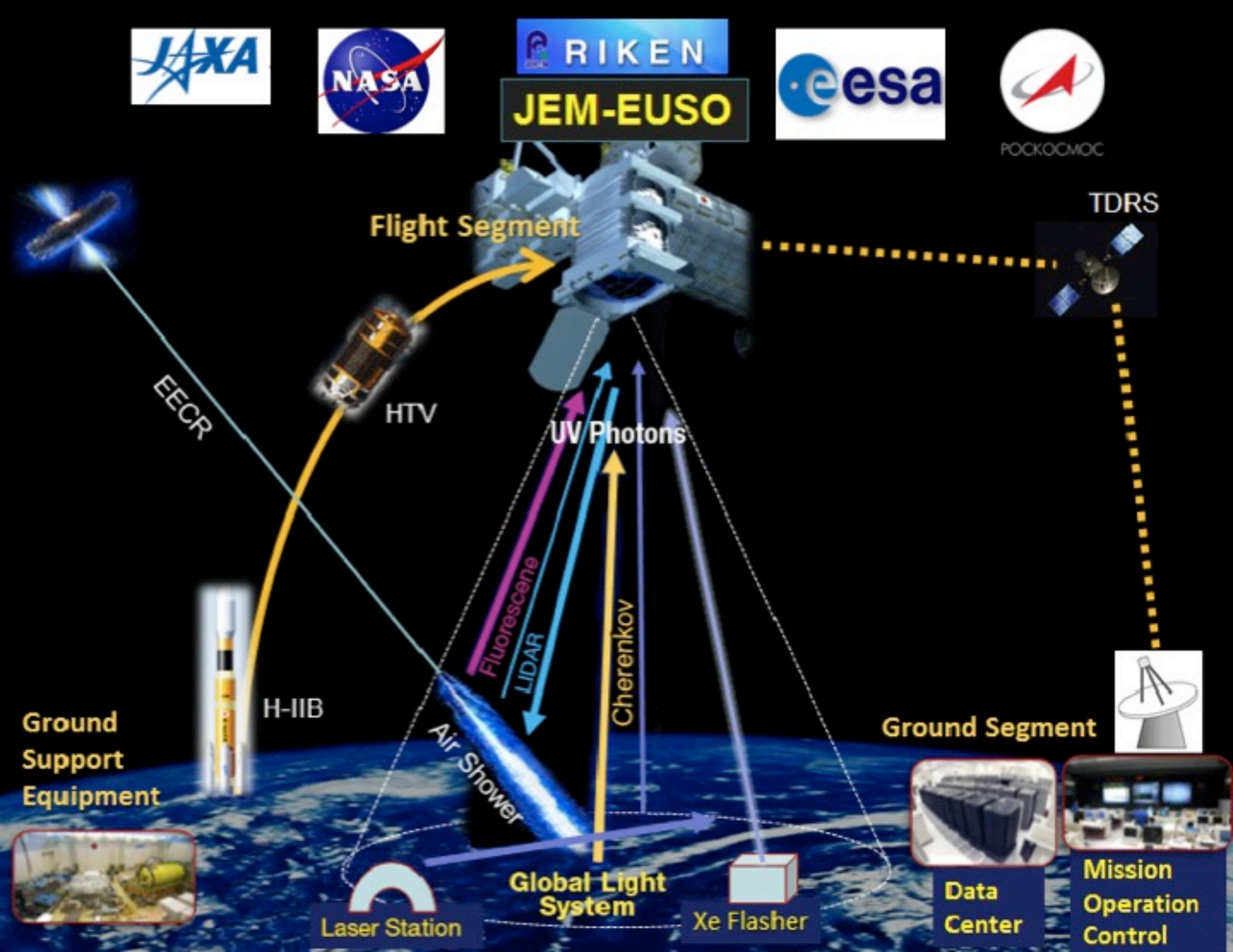


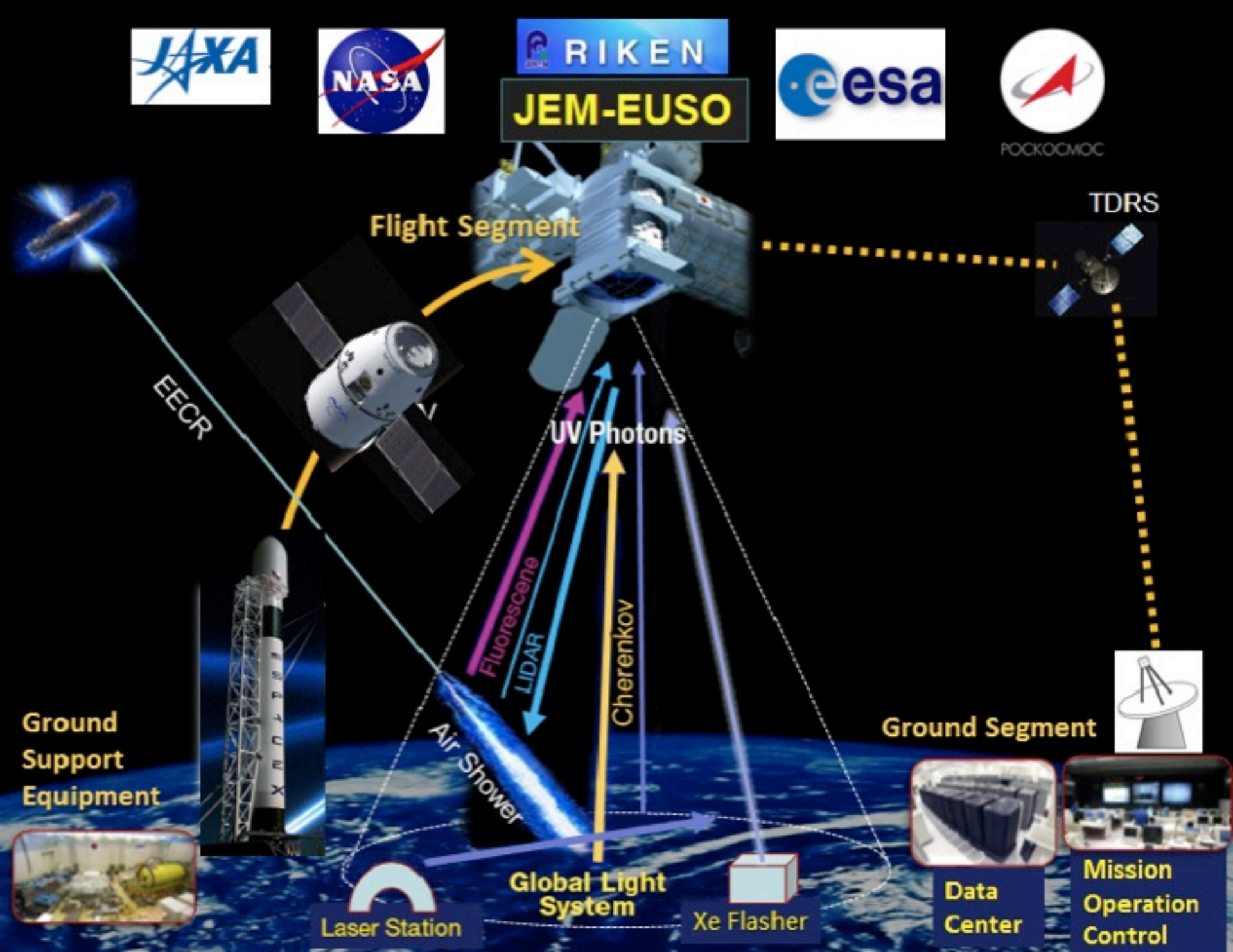



Huge Exposure Area
ISS (1min.)
Nadir-mode (~2x10^5km^2)
Tilt-mode (~7x10^5km^2)
AGASA(~100km^2)
Auger (~3000km^2)
3000 Gton – for EHE neutrinos
Image © 2009 TerraMetrics
Data © 2009 MIRC/JHA
© 2009 Cnes/Spot Image
Google

JEM-EUSO Mission

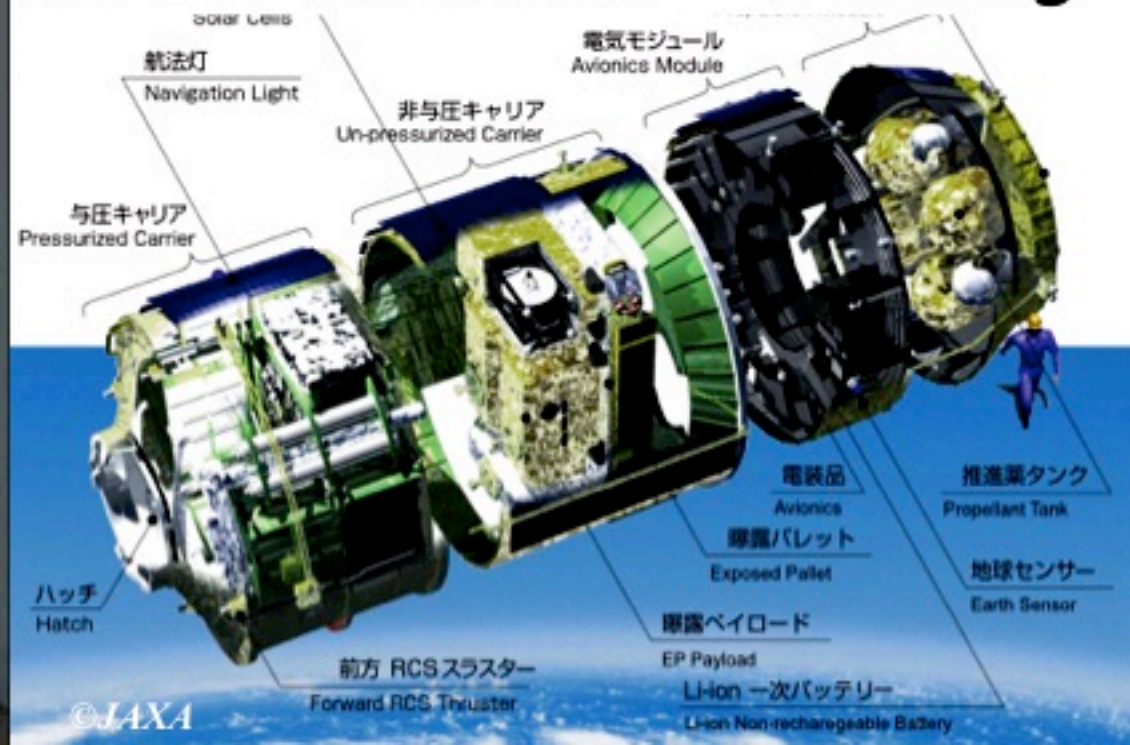
Parameter	Value
Launch date	2017
Mission Lifetime	3+2++ years
Rocket	H2B (or Falcon9)
Transport Vehicle	HTV (or Dragon)
Accommodation on JEM	EF#9 (or #2)
Mass	1.3 ton
Power	926 W (op.) 352 W (non op.)
Data rate	285 kbps (+ on board storage)
Orbit	400 km
Inclination of the Orbit	51.6°
Operation Temperature	-10° to +50°


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


JAXA
NASA
RIKEN
JEM-EUSO
esa
POCKOCMOC
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

H-II Transfer Vehicle (HTV)

HTV is 4m across ~10 m long



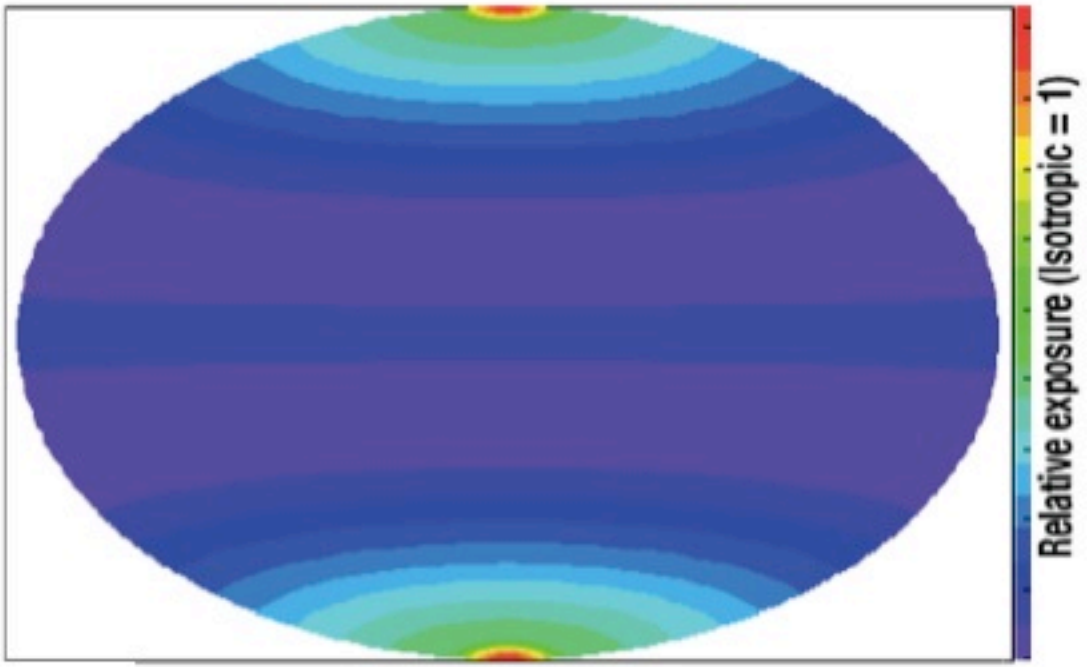

SpaceX
Dragon

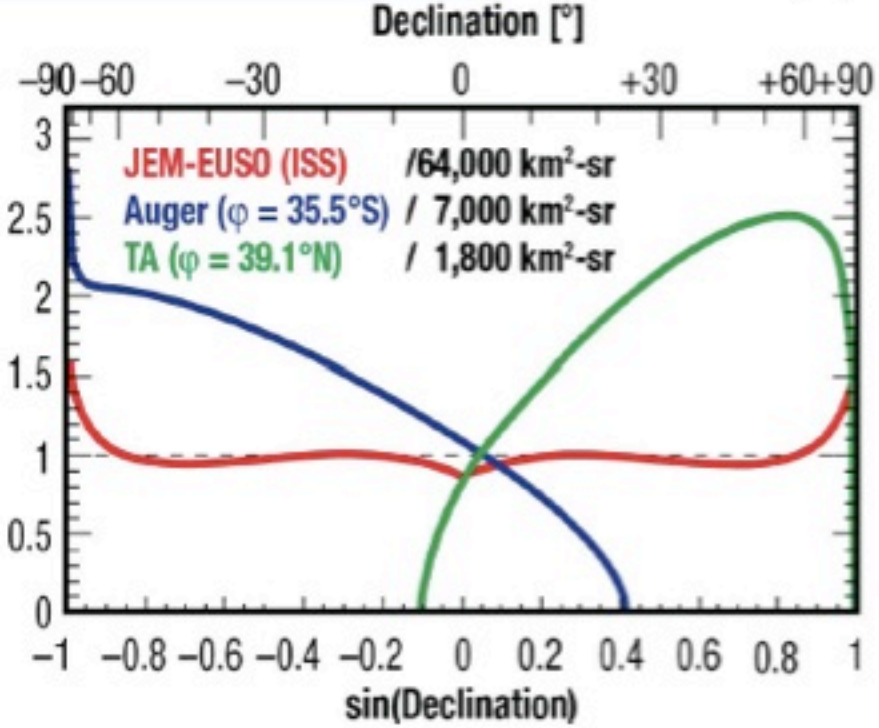
Full Sky Coverage
with nearly uniform exposure

The ISS ORBIT

Inclination: 51.6°
Height: ~400km

JEM-EUSO
Sky Coverage



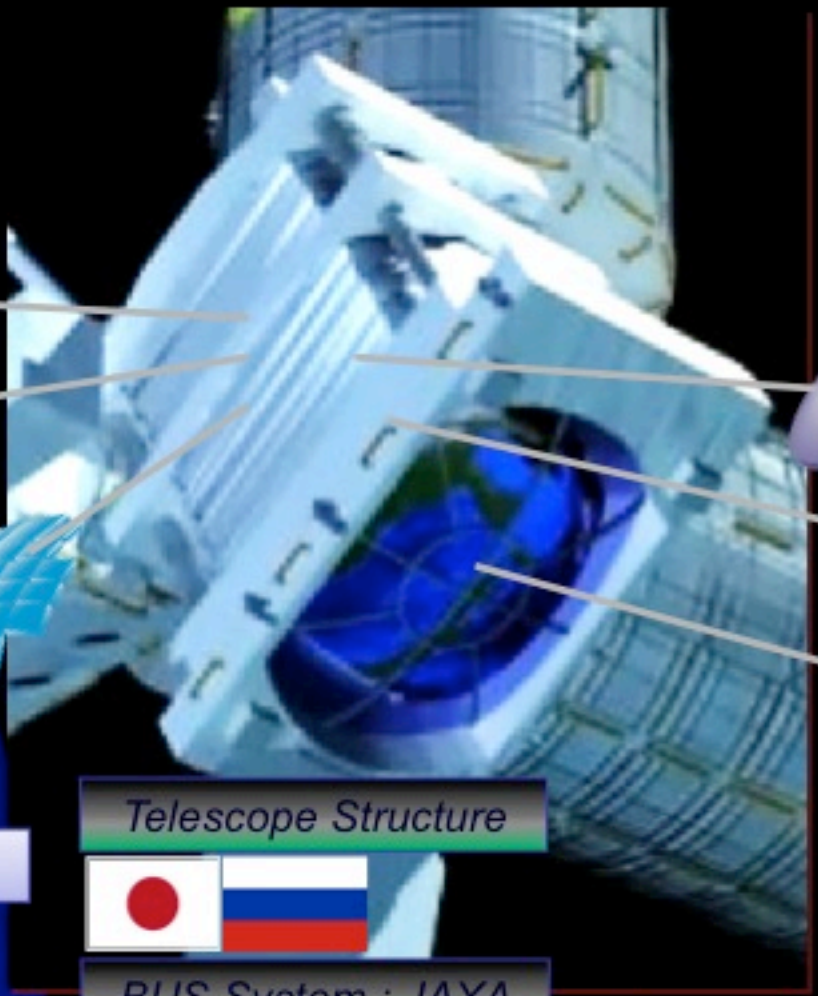


The UV Telescope Parameters

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

Housekeeping

BUS System : JAXA

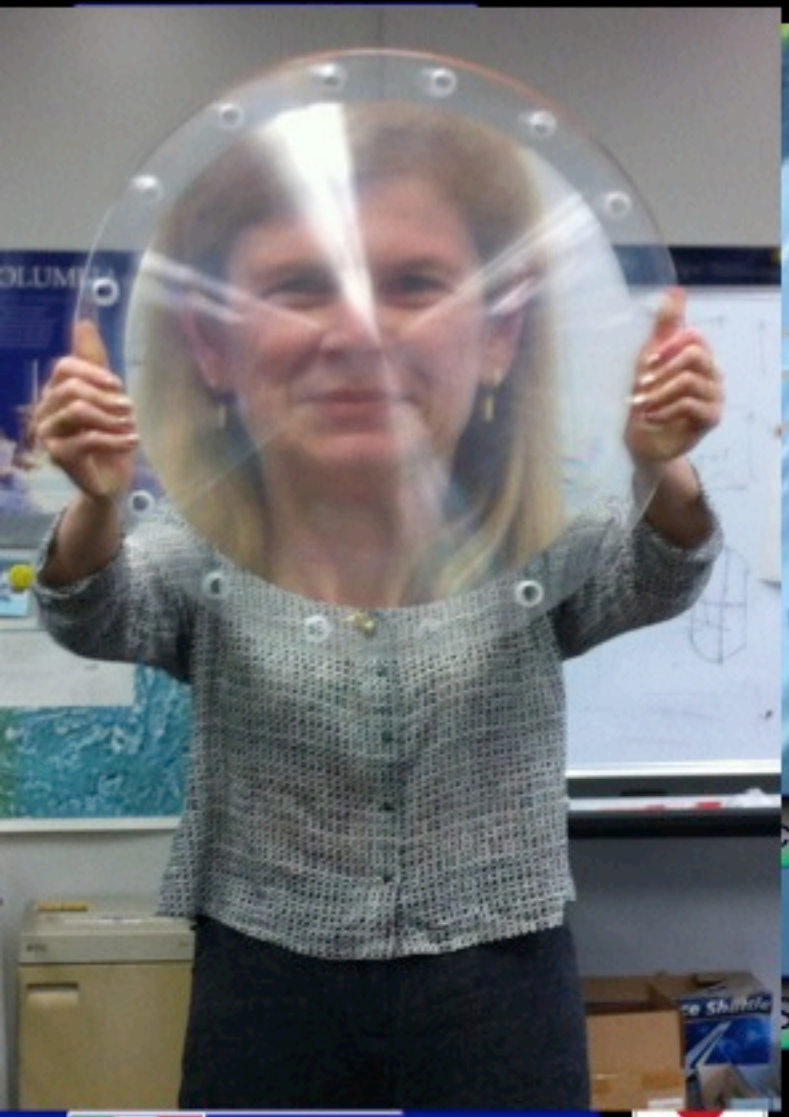
Ground Based Calibration

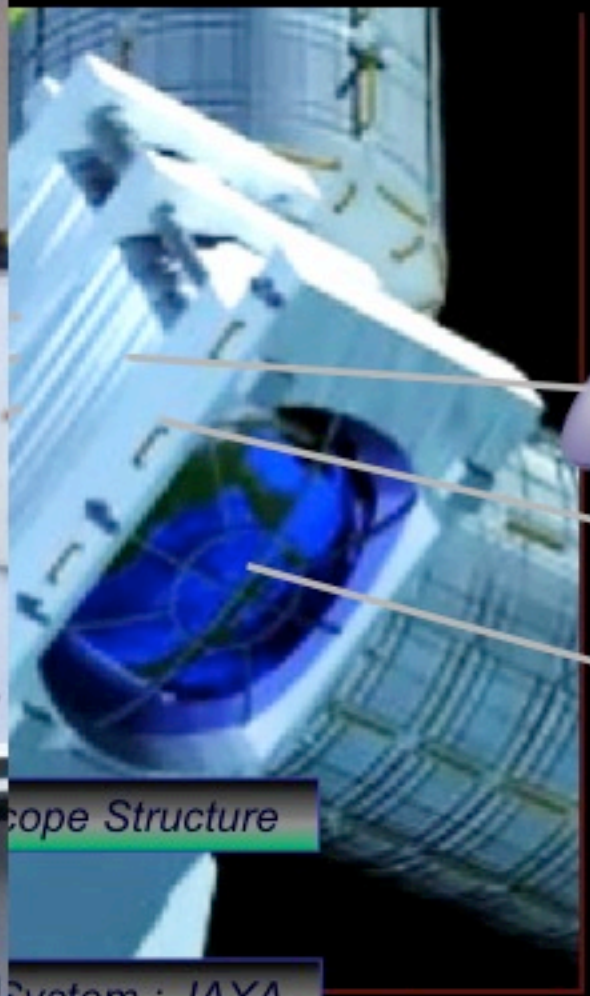
Atmospheric Monitoring

Ground Support Equipment

Simulation : Worldwide

Payload





Optics

Rear Fresnel Lens

Precision Fresnel lens

Iris

Front Fresnel lens

cope Structure

On-board Calibration

System : JAXA

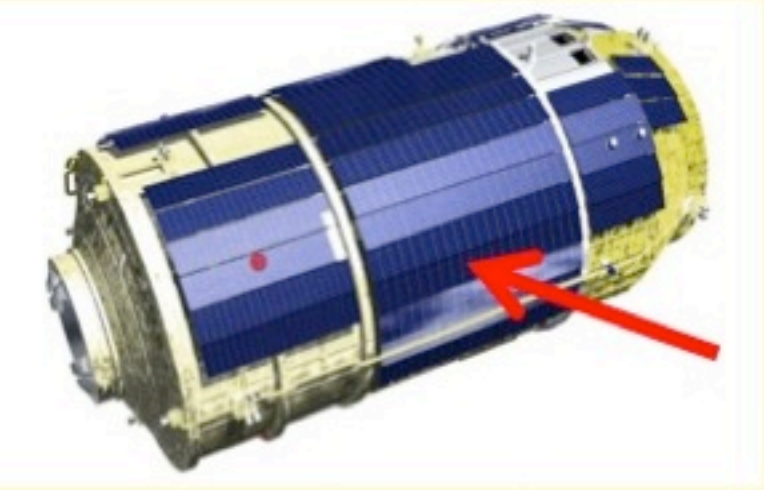
Ground Based Calibration

Simulation : Worldwide

Atmospheric Monitoring

Ground Support Equipment

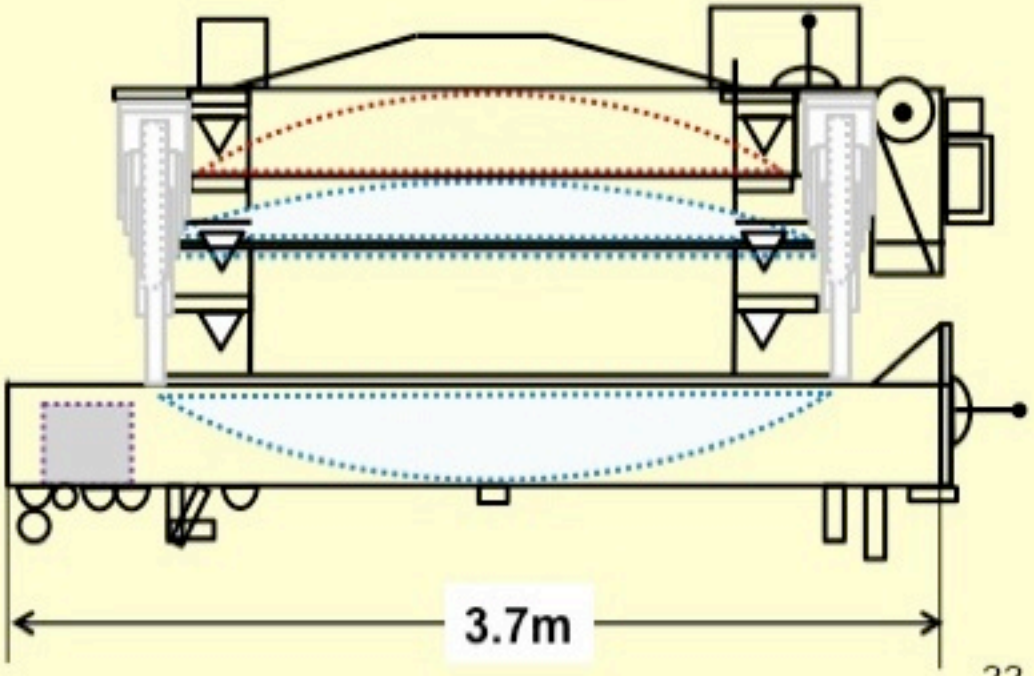
Science Instrument on HTV



H2B Transfer Vehicle (HTV)

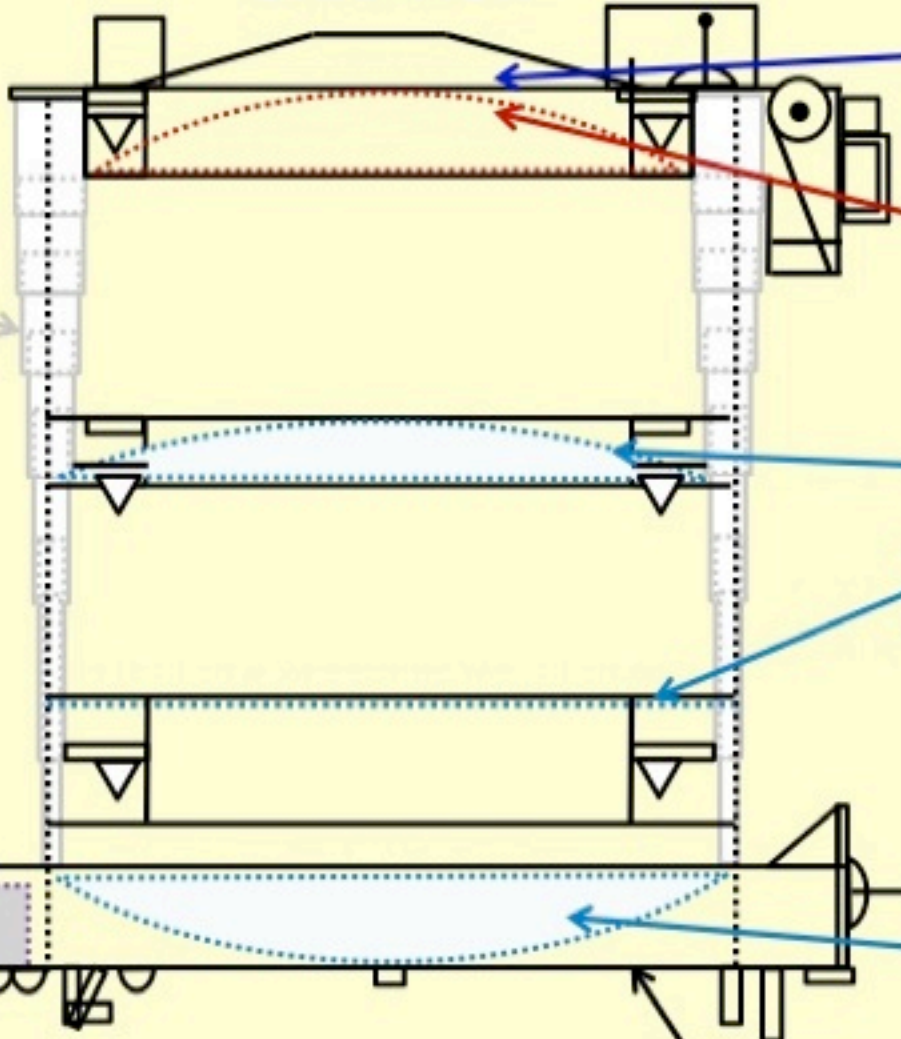
Stowing configuration to carry by HTV

Side view



Science Instrument

Side view



Focal Surface Detector and Electronics

Focal Surface

Deployment Mechanism

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

Rear Lens

Middle Lens

Atmospheric Monitoring System

Optics

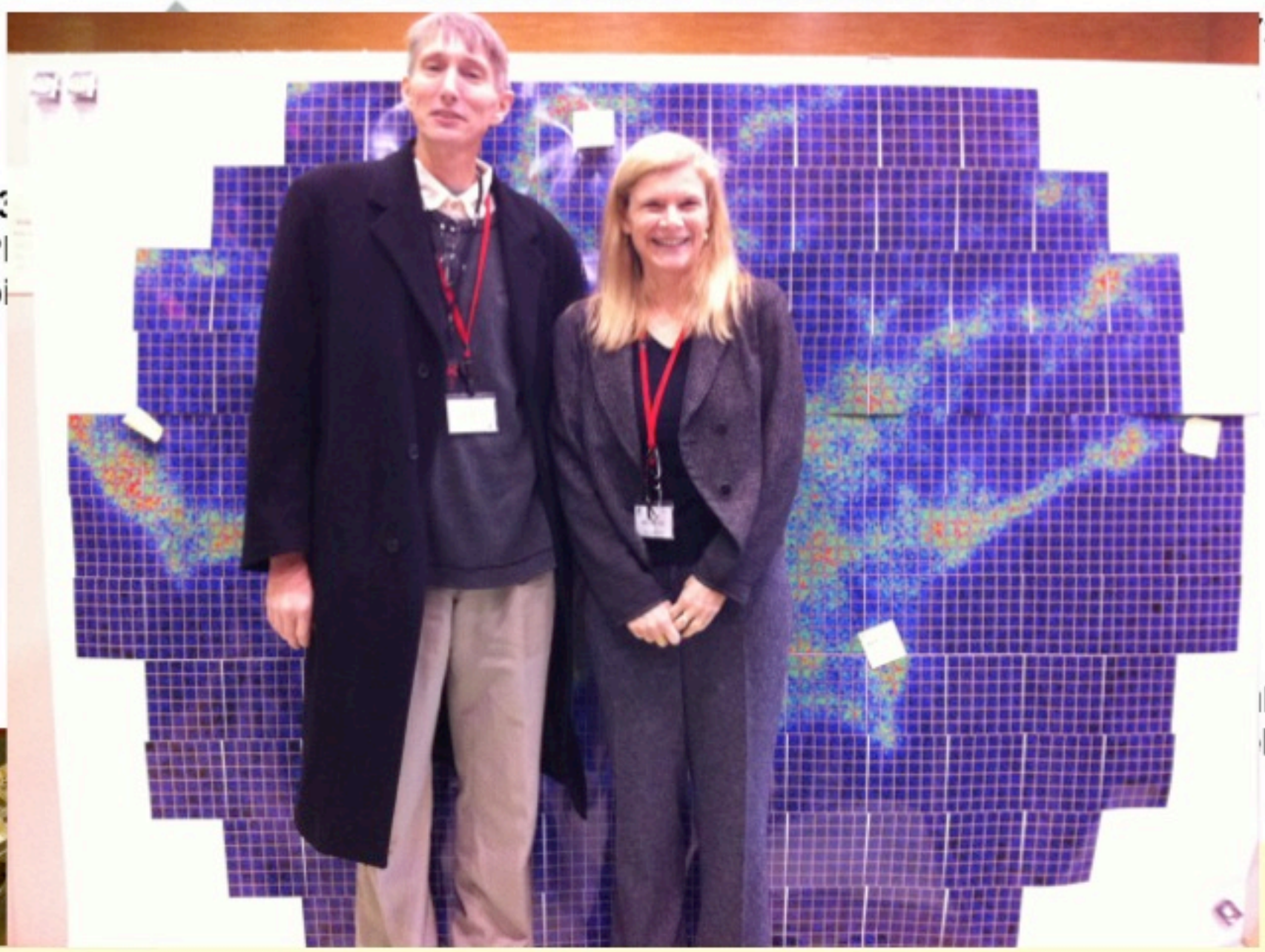
Front Lens

Pallet

Science Instrument

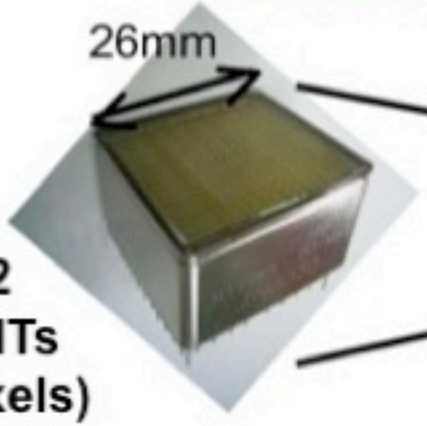
tics

Focal Surface Detector

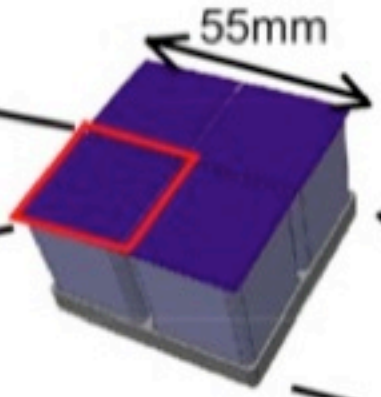


Focal Surface Detector

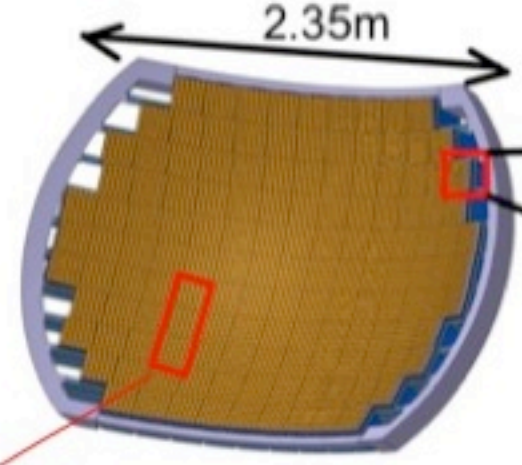
Y. Kawasaki, ID 0472
M. Ricci, ID 0335

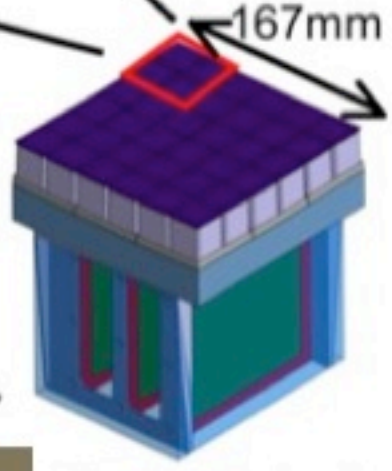


4932
MAPMTs
(8x8 pixels)



Elementary Cell
(2x2 PMTs = 256 pixels)





Focal Surface detector
137 PDMs
= 0.3M Pixels

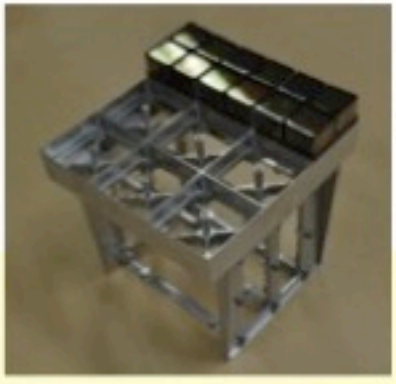


Photo-Detector Module
(3x3 ECs = 2,304 pixels

1 High Voltage / PDM

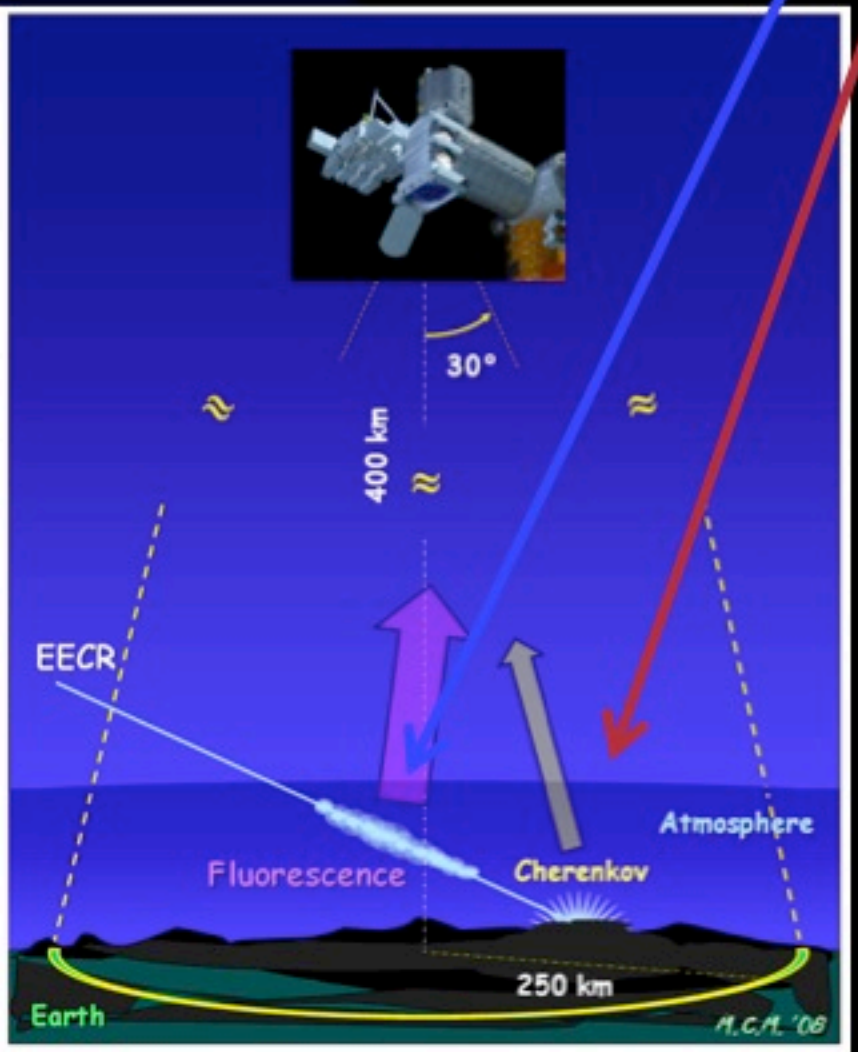
FAST SIGNAL

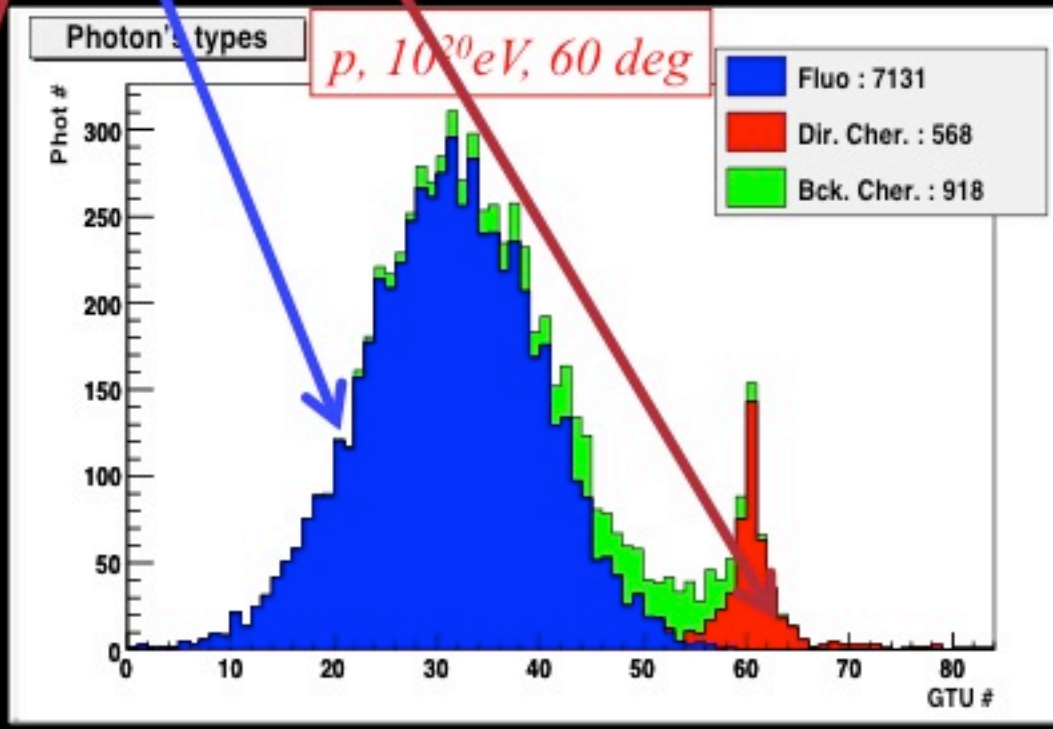
duration 50 -150 μs

a) Fluorescence

b) Scattered Cherenkov

c) Direct (diffusively reflected Cherenkov)



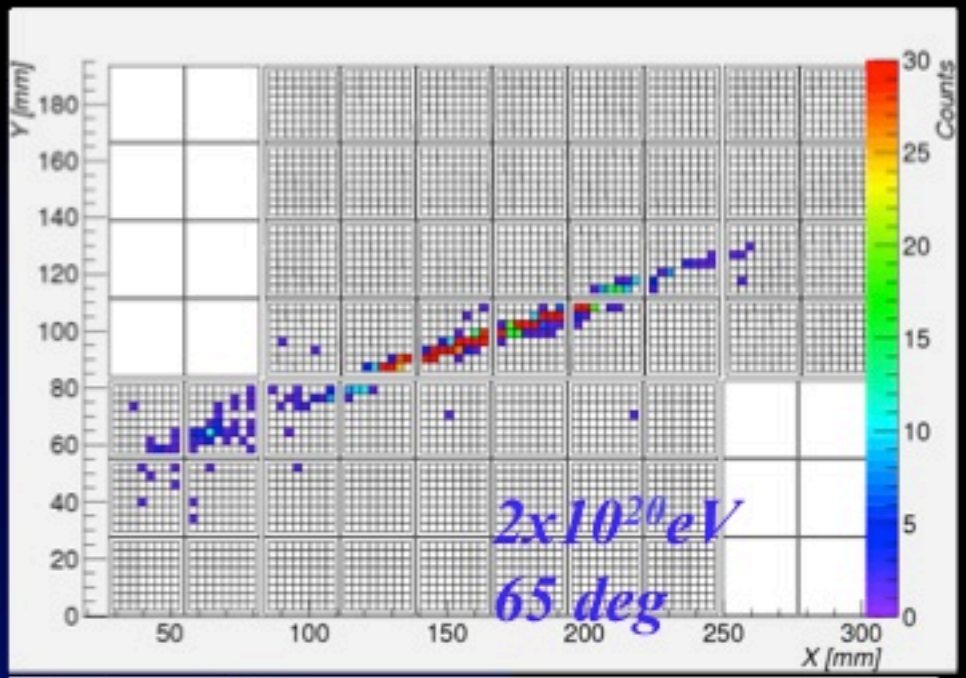


1 GTU gate time units = 2.5 μs

Background: 500 /m^2 sr ns

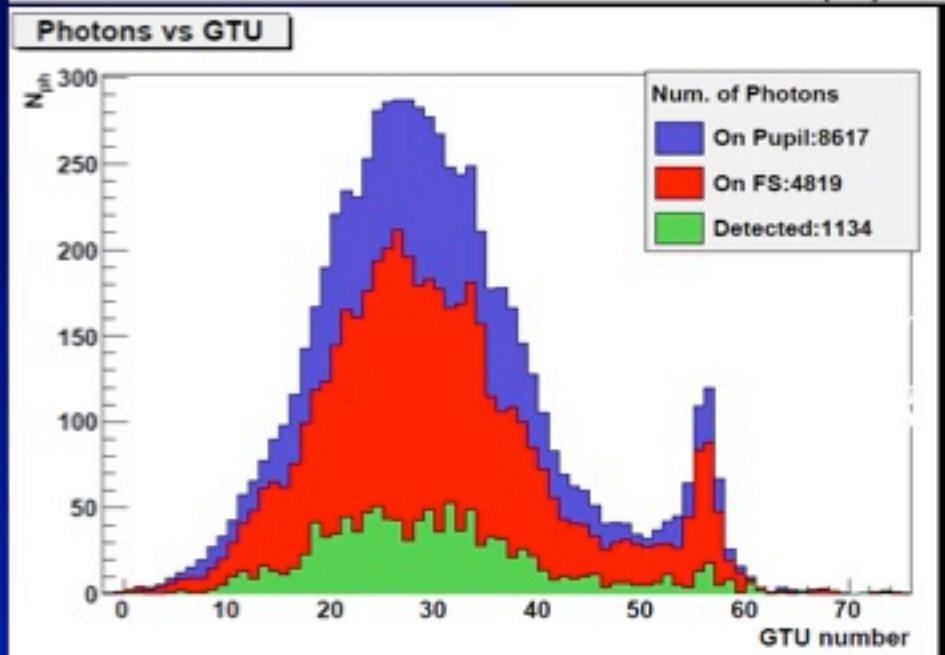
Result of end-to-end simulation

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



Simulated air shower image on the focal surface detector.

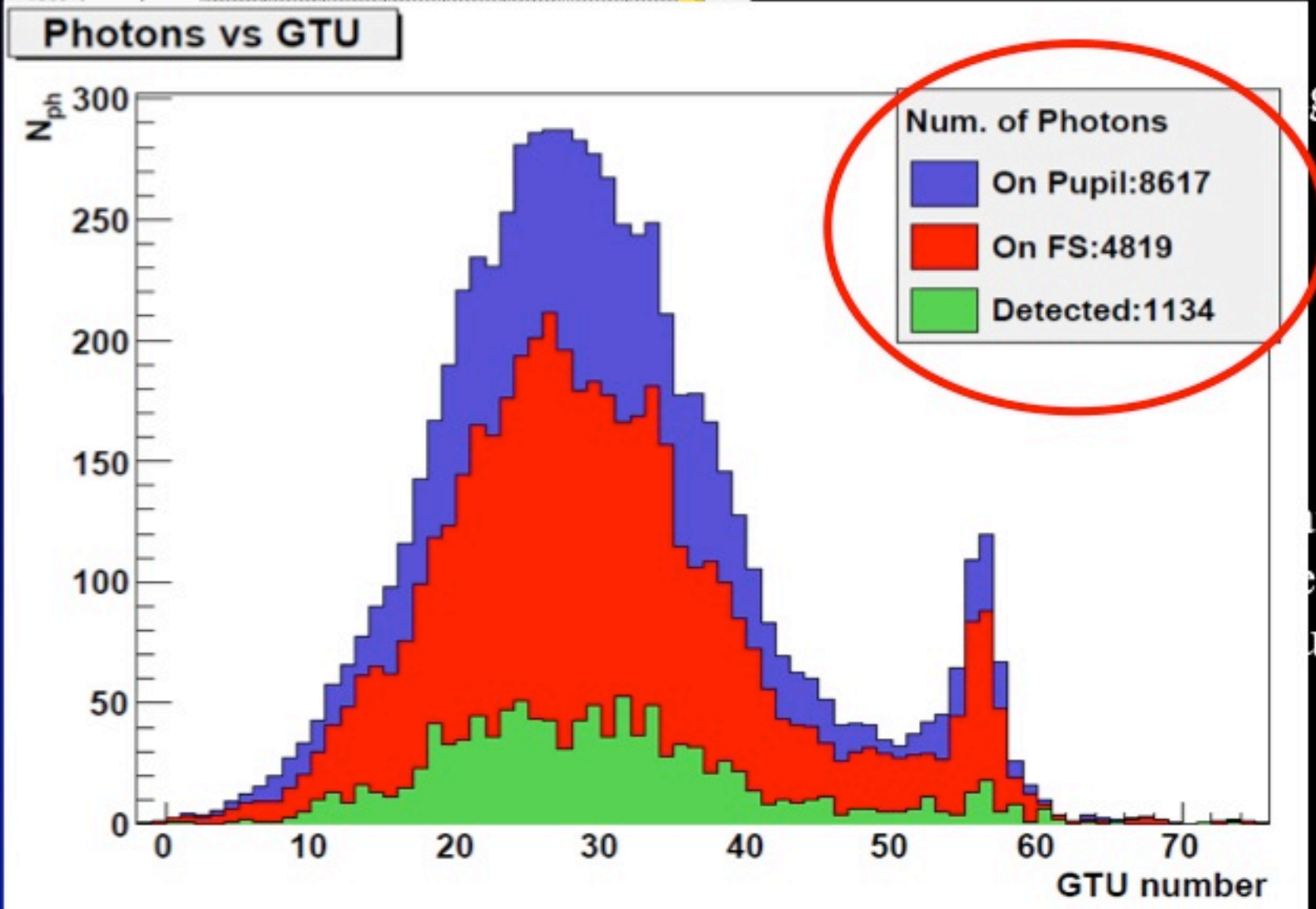
3 x 10^5 pixels



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



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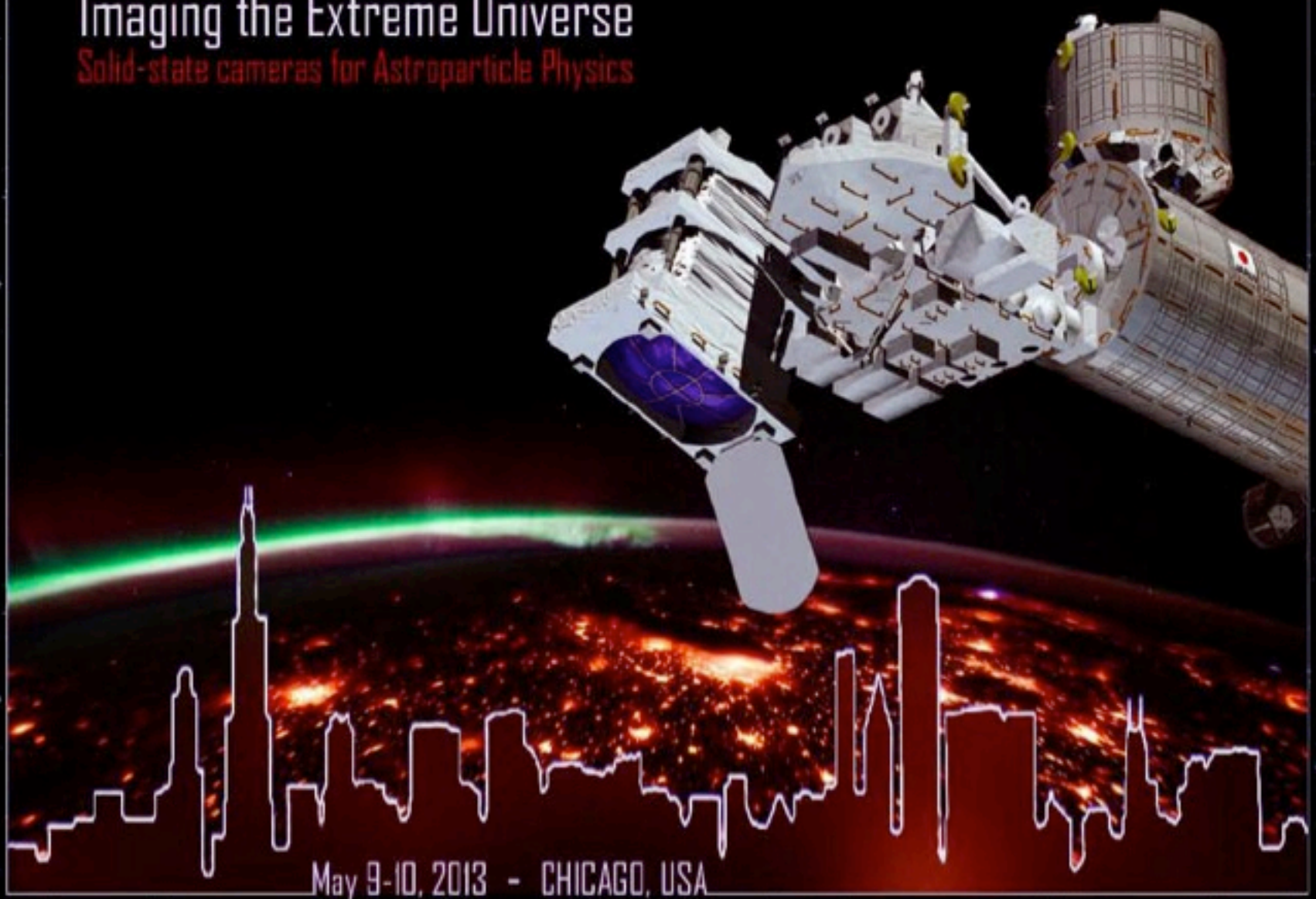
Unit

usly.

Imaging the Extreme Universe

Solid-state cameras for Astroparticle Physics

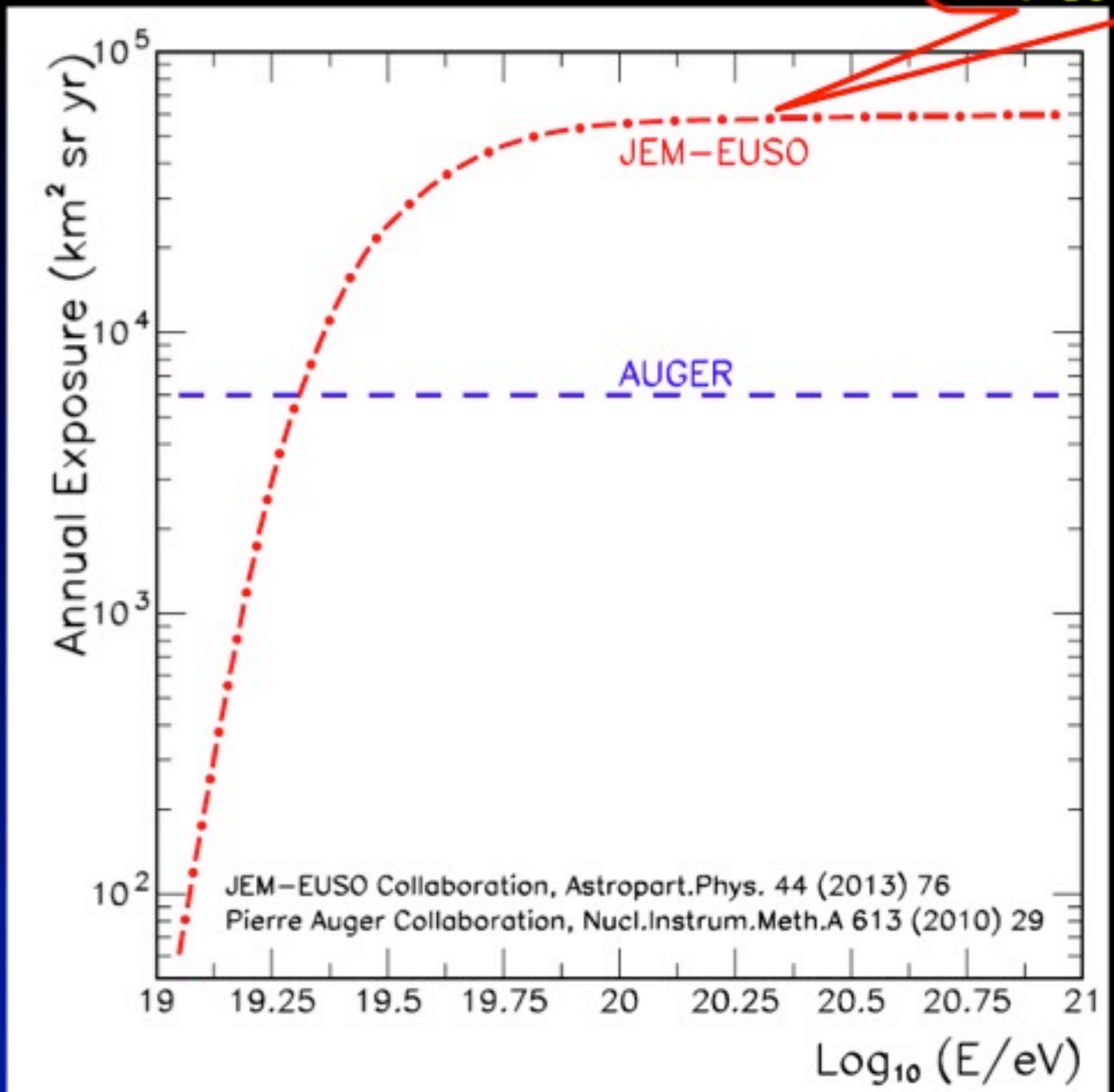


KICP

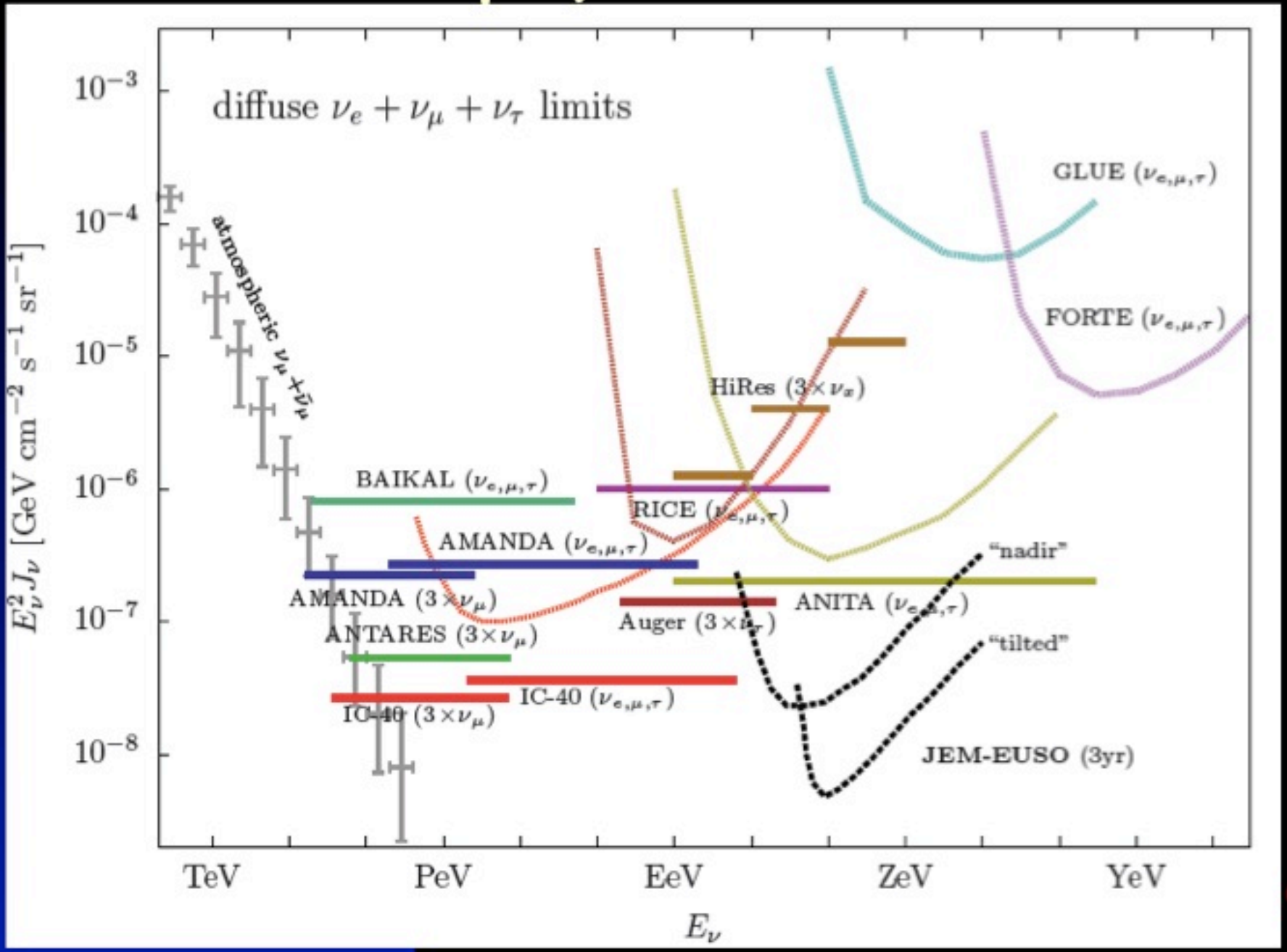
THE UNIVERSITY OF CHICAGO

JEM-EUSO

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



Serendipity: ZeV neutrinos

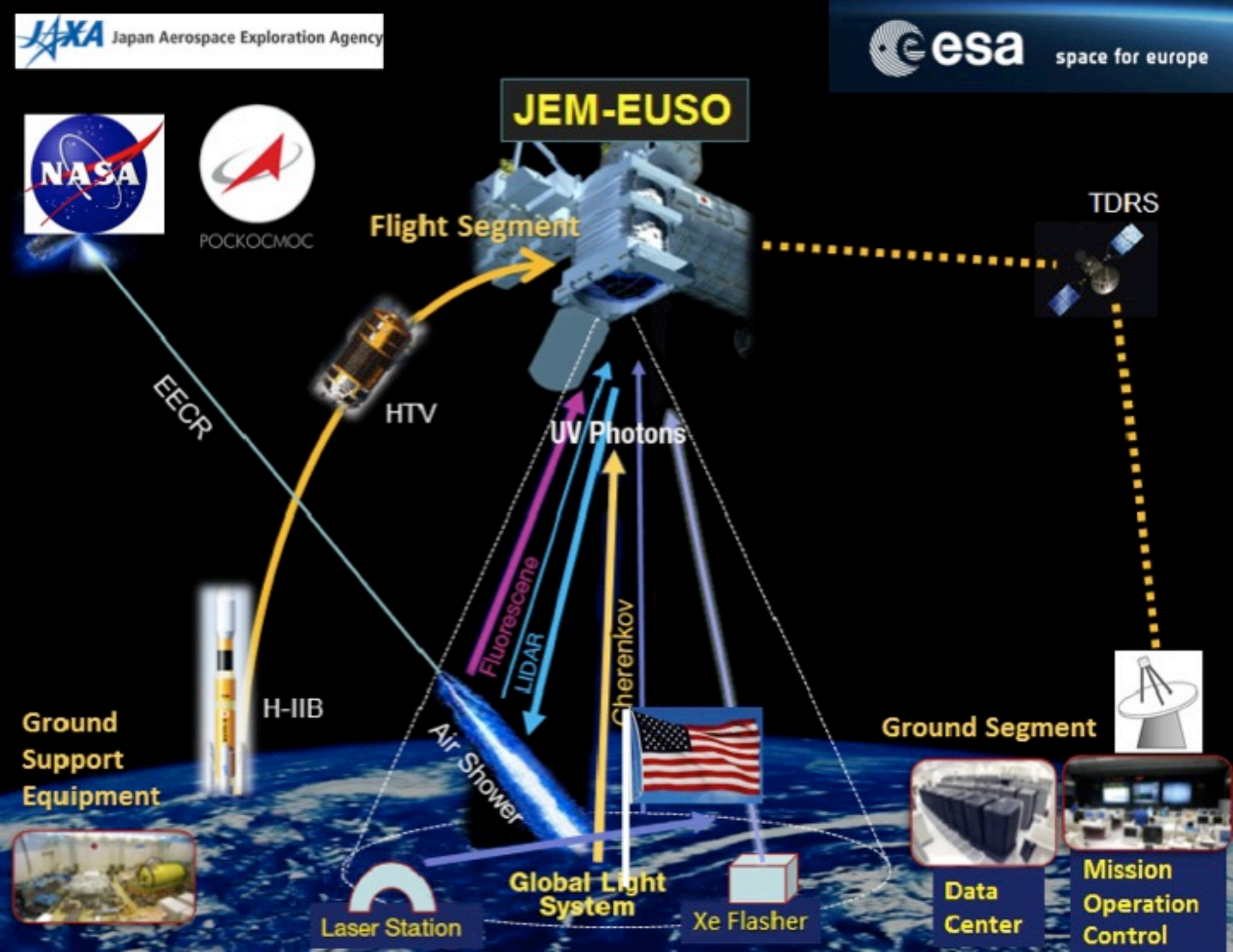


JEM-EUSO in USA

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


JAXA 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

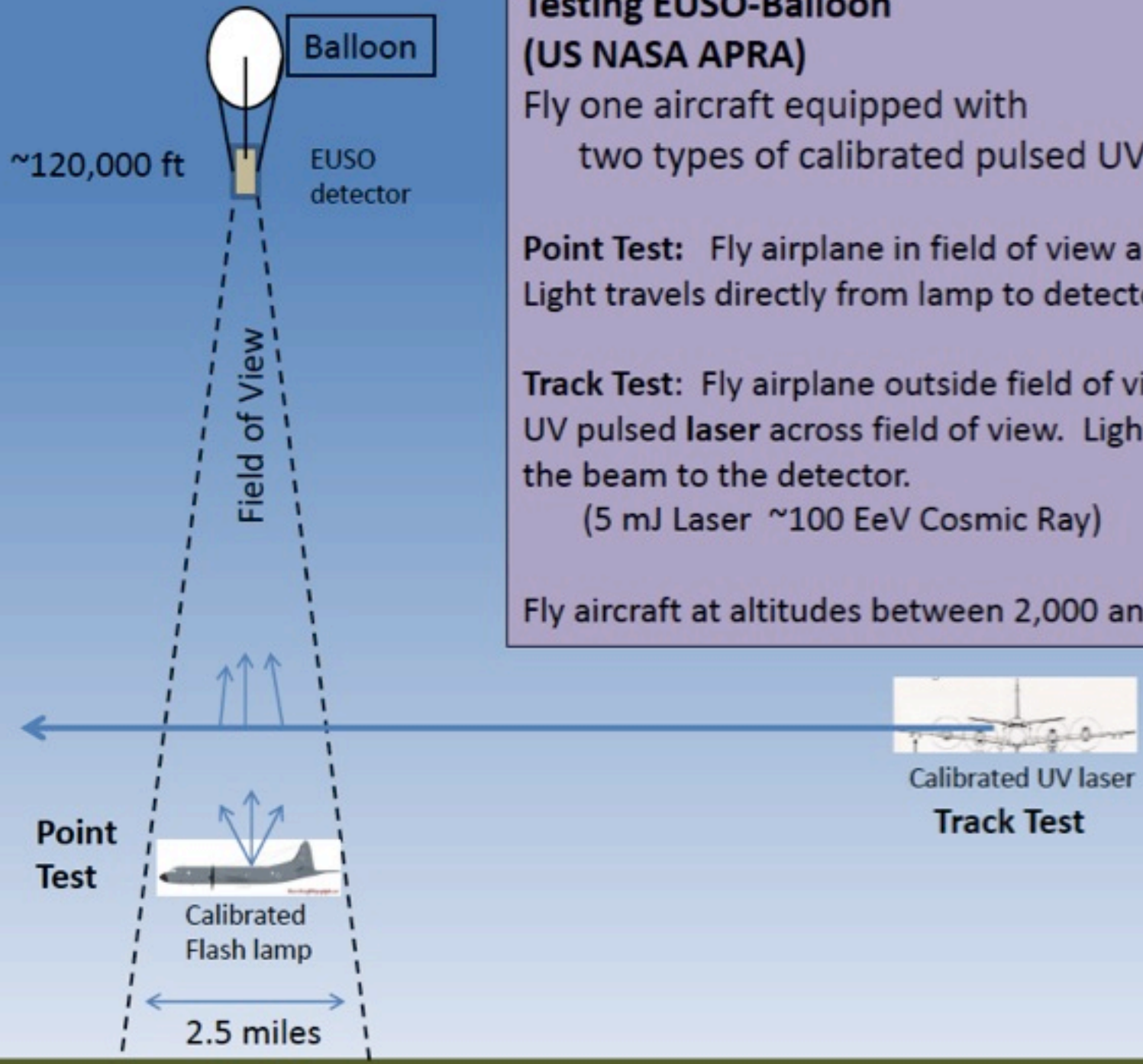
Global Light System

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)

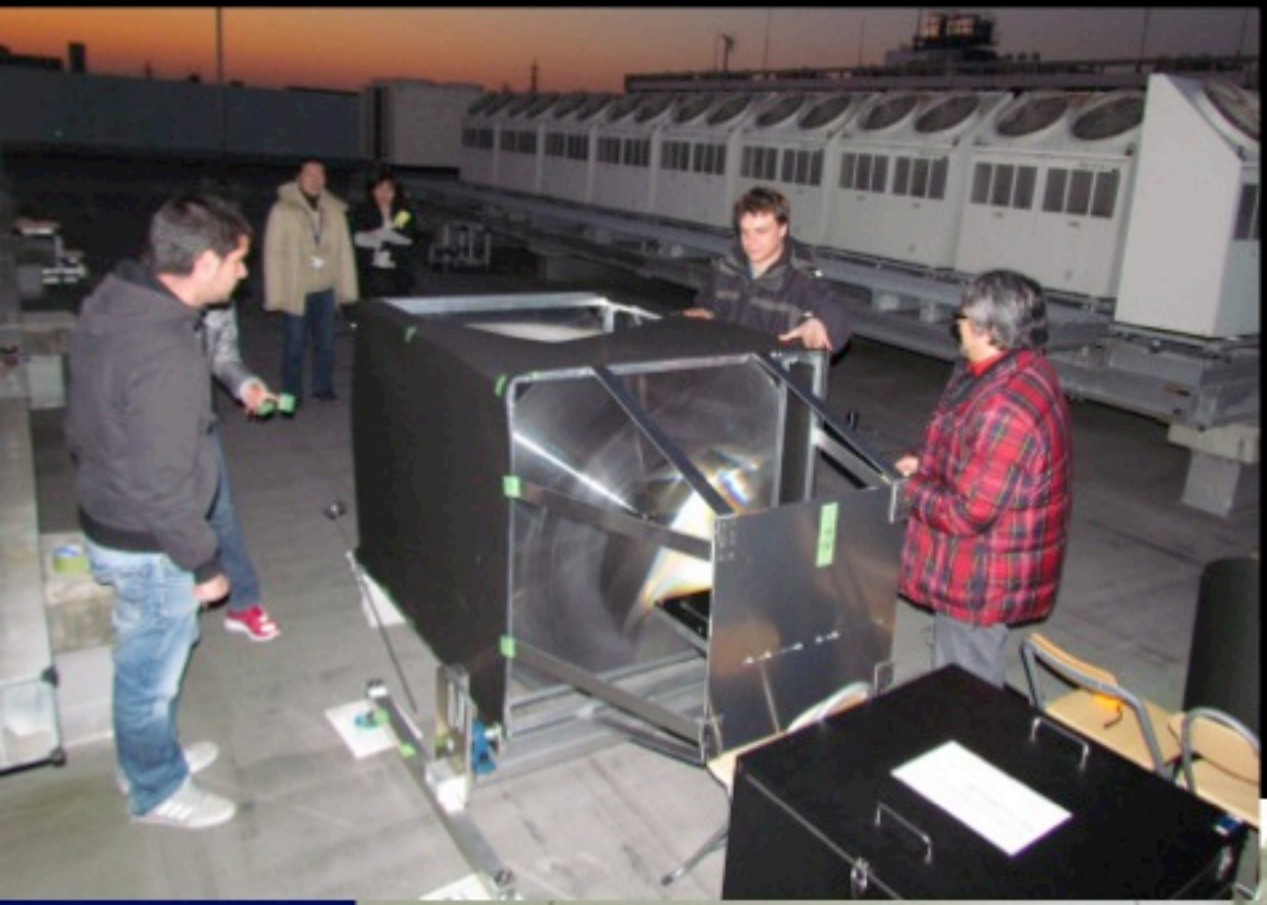
Fly one aircraft equipped with
two types of calibrated pulsed UV light sources.

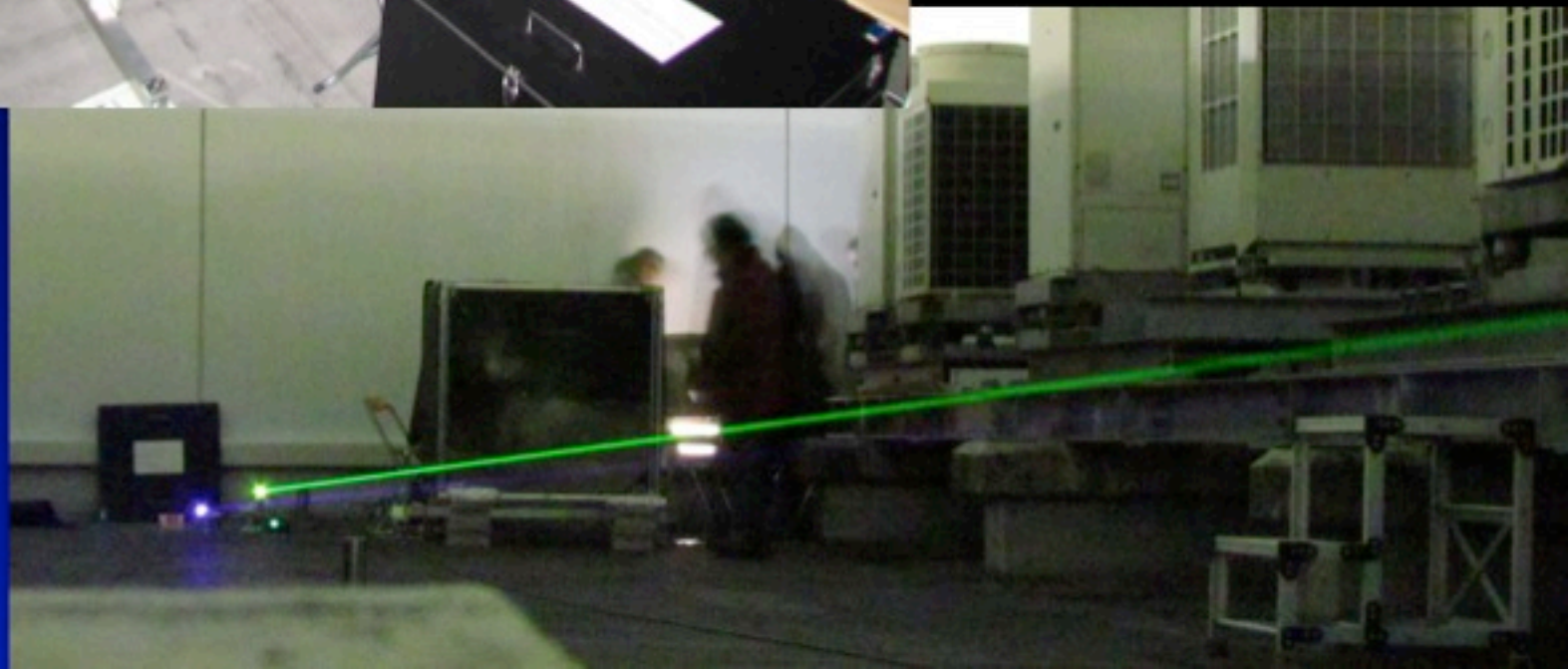
Point Test: Fly airplane in field of view and fire **flash lamp**. Light travels directly from lamp to detector

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.

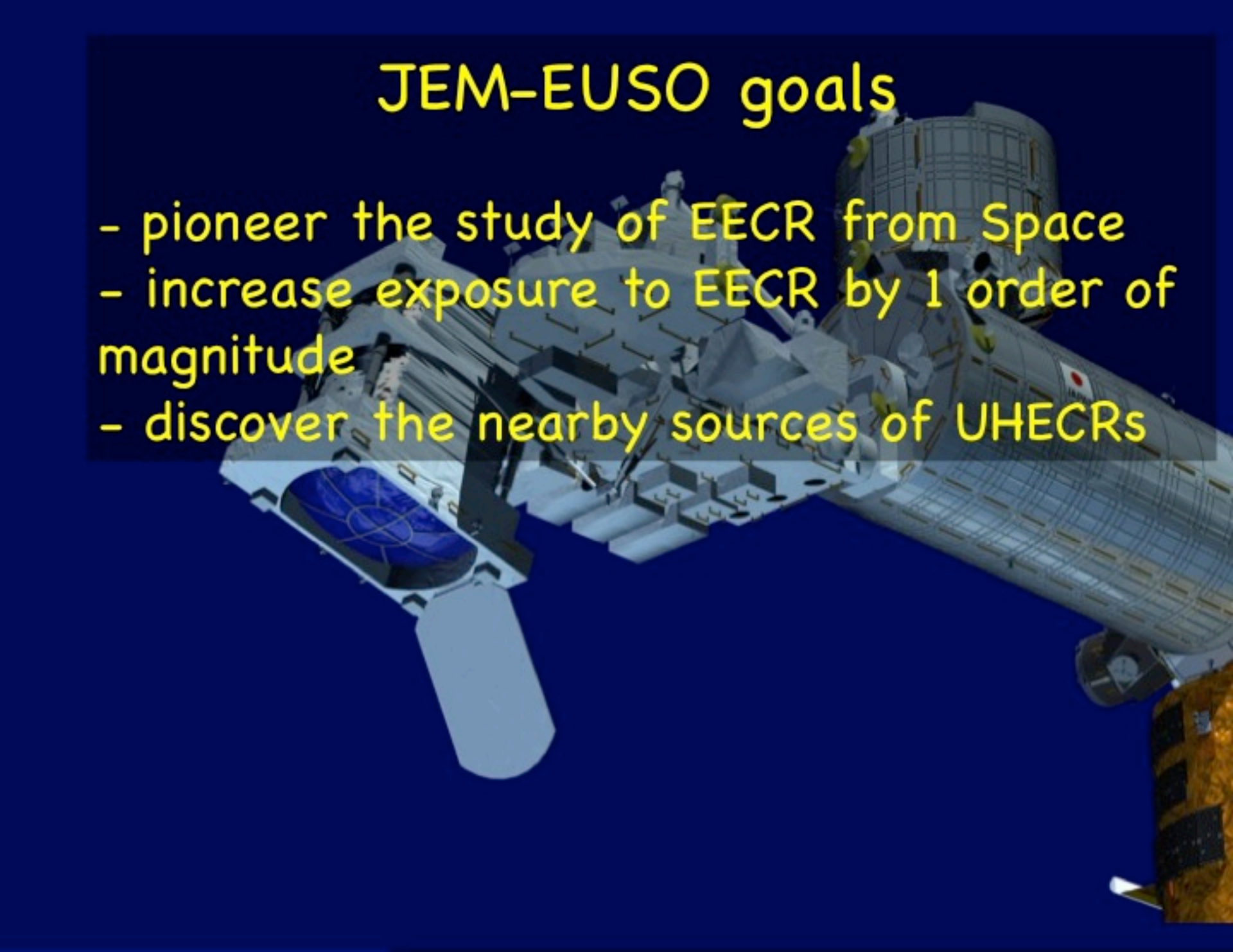
EUSO - Telescope Array



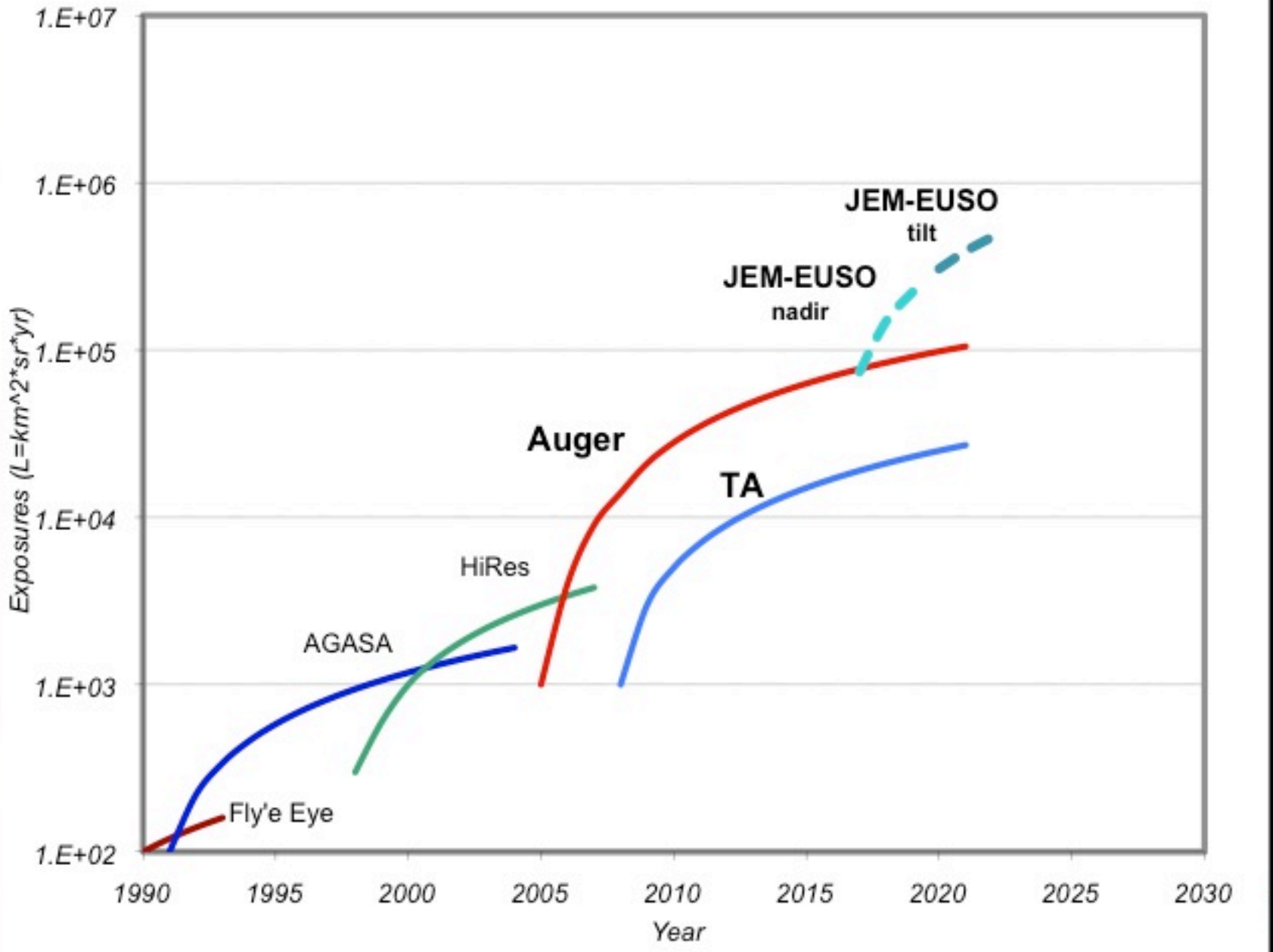


JEM-EUSO goals

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



Exposure History



How many UHECRs > 60 EeV?

Auger + TA ~30 events/yr

JEM-EUSO

~200 events > 60 EeV/ yr

4 o.o.m to go!

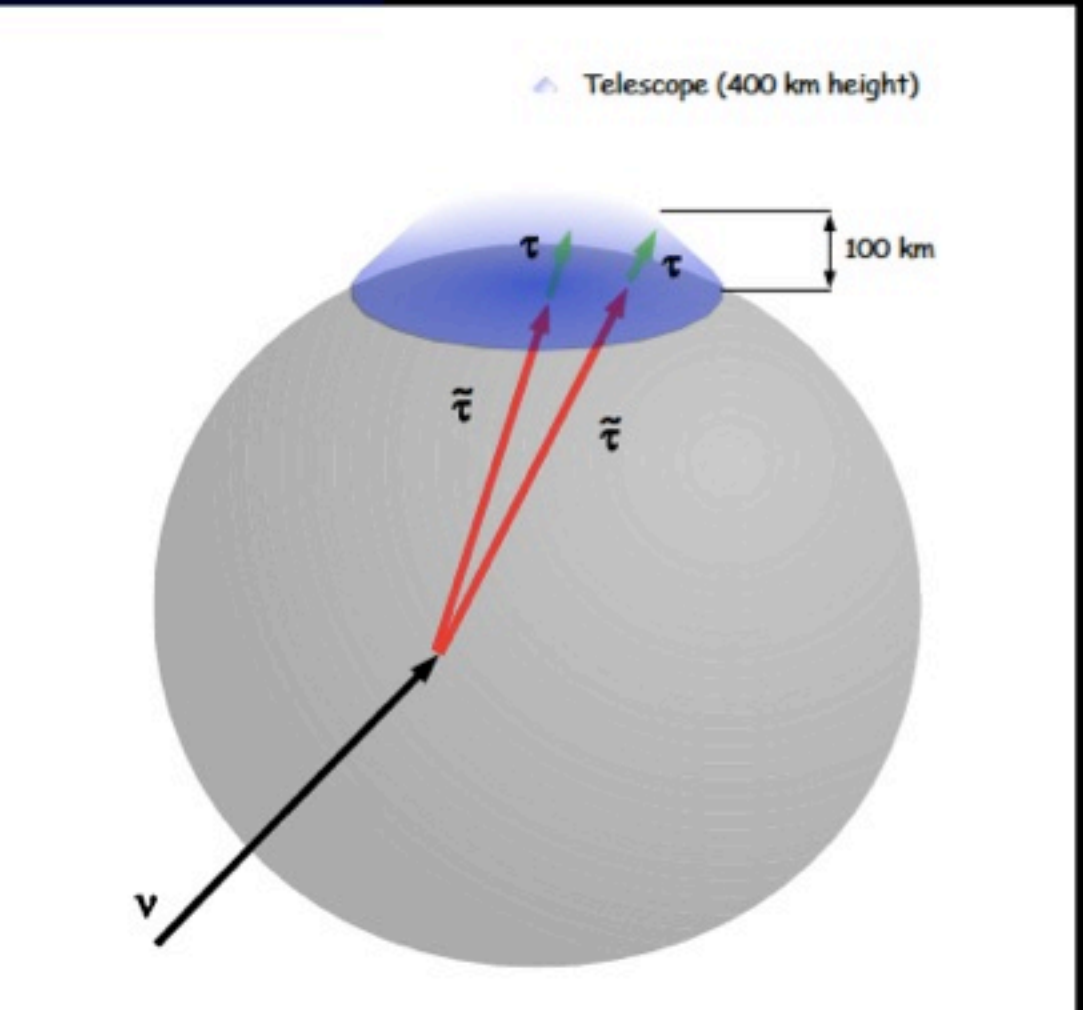
Earth surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

Serendipity: NLSP slepton

Gravitino is LSP (lightest supersymmetric particle)
slepton is the next to lightest (NLSP) long lived
SUSY breaking @ 5 10^6 GeV

signature:
coincident upwards taus



Albuquerque & de Souza '12


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


THANKS