

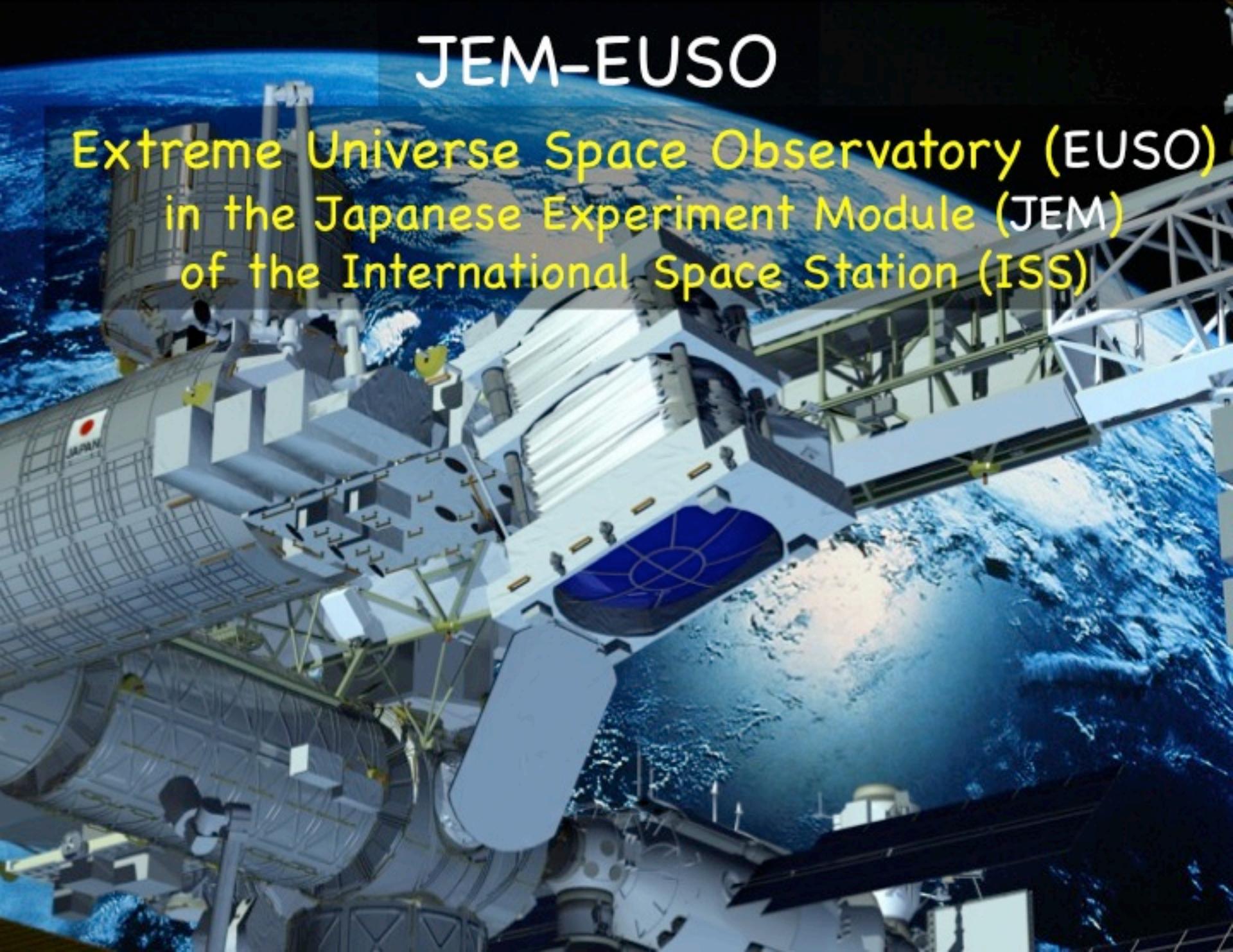
Extreme Energy Particles with JEM-EUSO

Angela V. Olinto

The University of Chicago

JEM-EUSO

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”



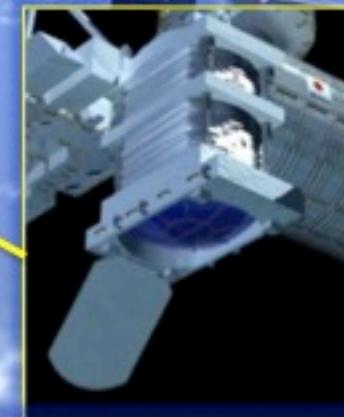
AMS Launch
May 16, 2011



ISS-CREAM
Sp-X Launch 2014



CALET on JEM
HTV Launch 2014



JEM-EUSO
Launch
Tentatively
planned for 2017

JEM-EUSO



Japan, USA, Korea, Mexico, Russia, (Algeria)

Europe: Bulgaria, France, Germany, Italy,
Poland, Slovakia, Spain, Switzerland

14 Countries, 300 researchers

Leading institution: RIKEN



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

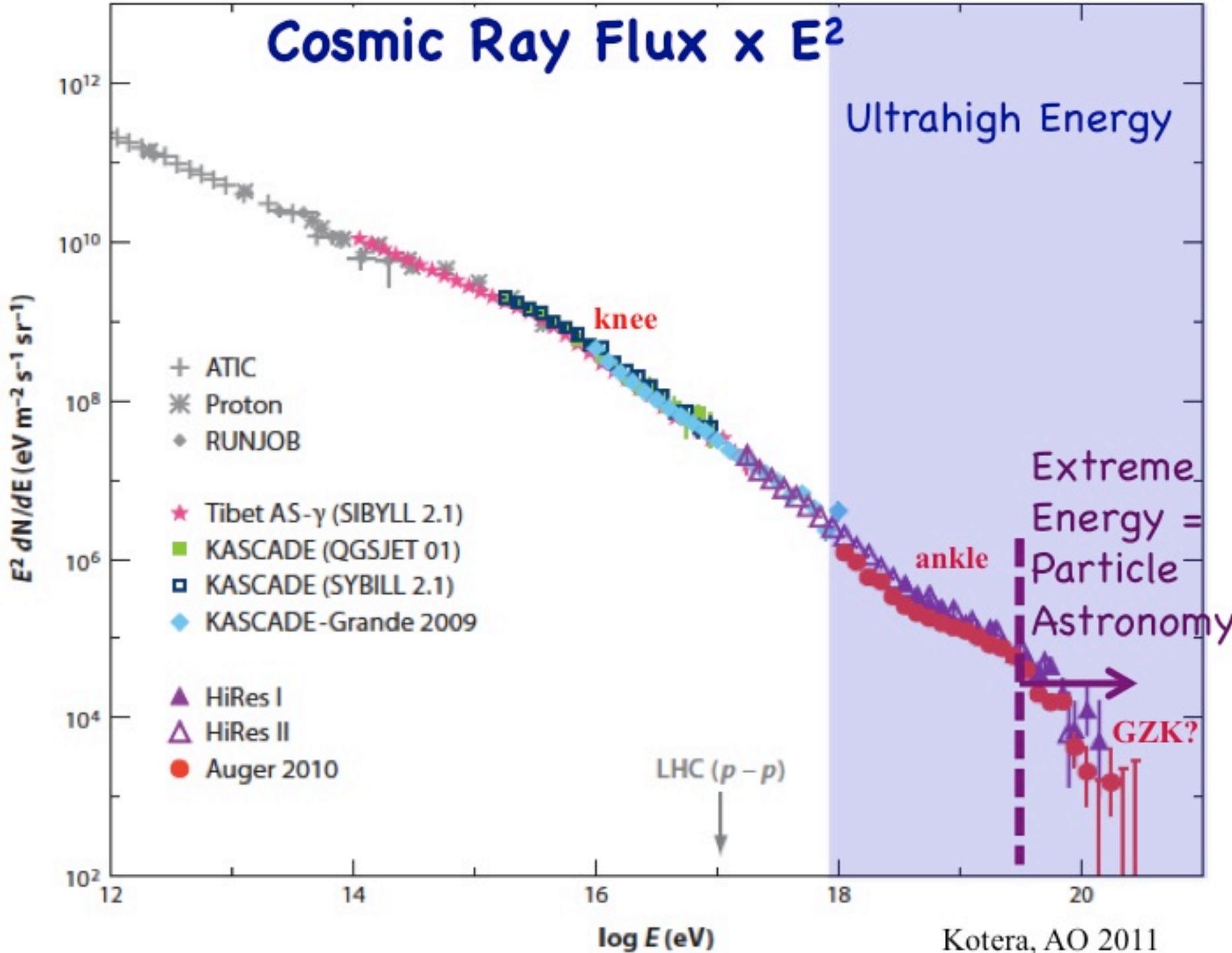
JEM-EUSO main goals

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

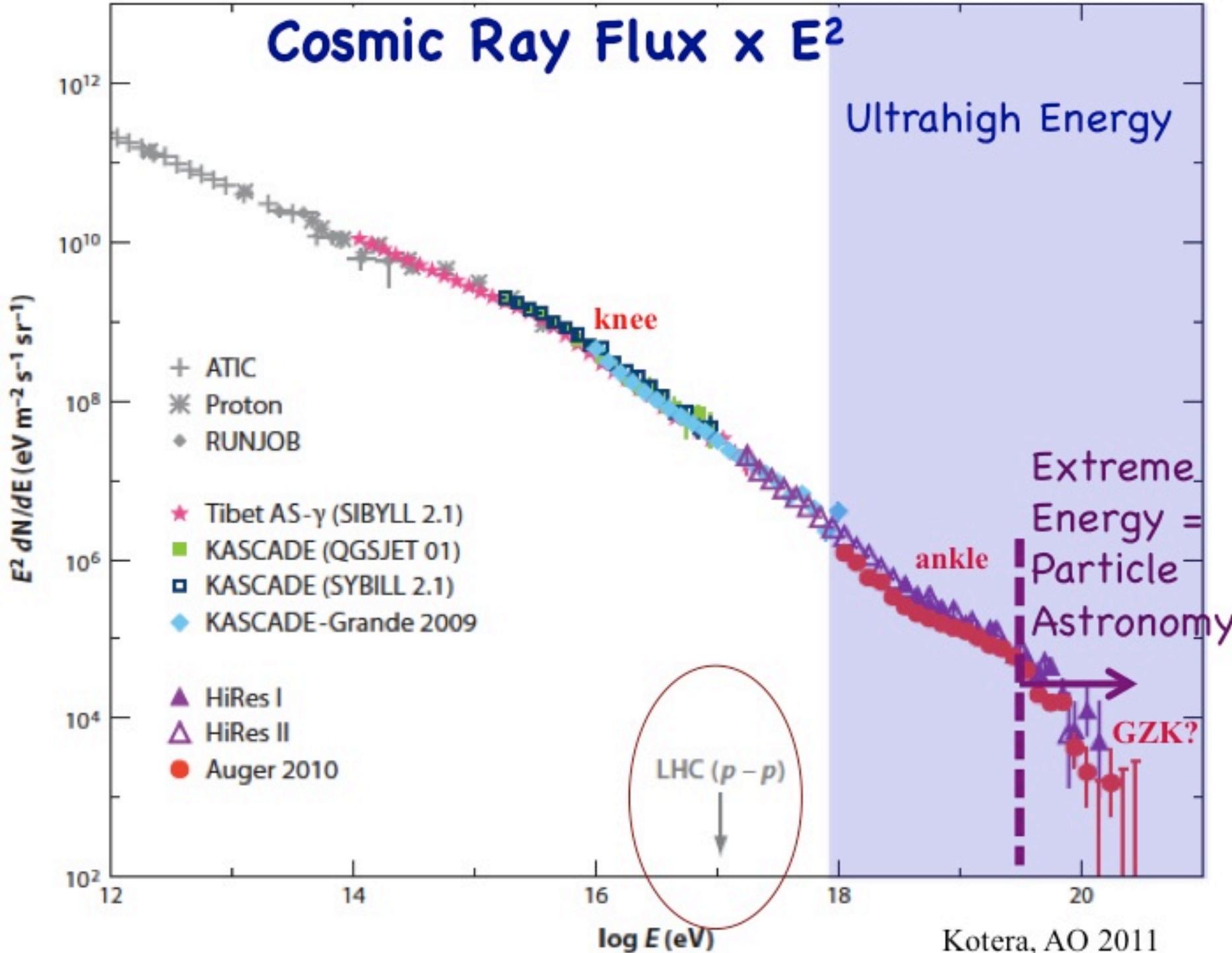
EECR: Extreme Energy CRs > 60 EeV

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

Cosmic Ray Flux $\times E^2$



Cosmic Ray Flux $\times E^2$





In a decade, we can probe
particle interactions at
 $>300 \text{ TeV CM}$
from Space!!!

Current Observatories of Ultrahigh Energy Cosmic Rays

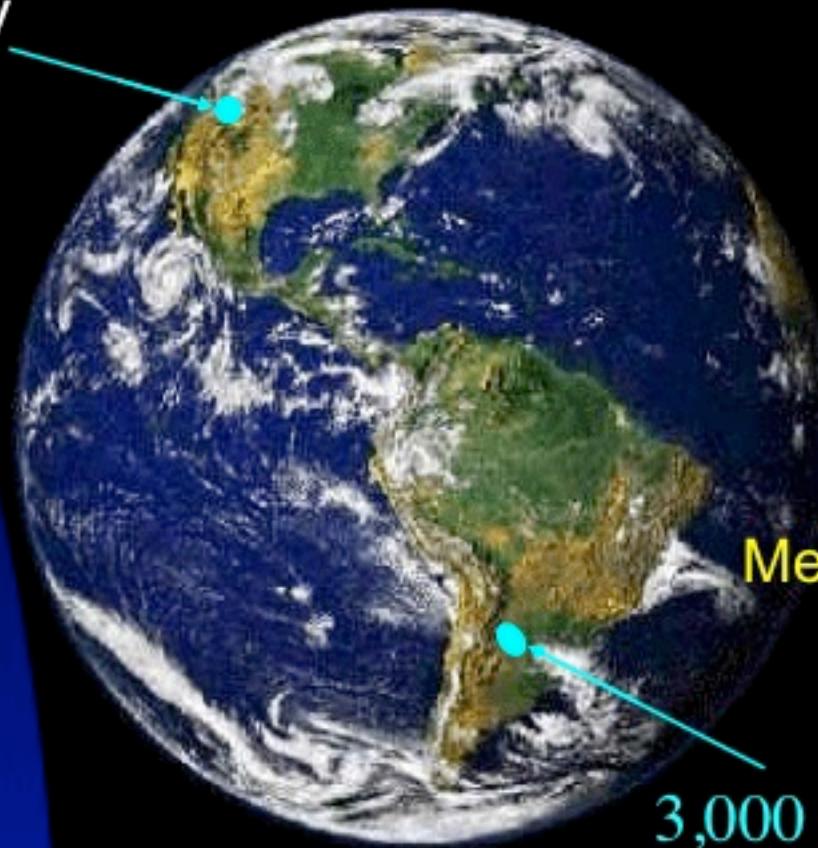
Telescope Array

Utah, USA

(5 country
collaboration)

700 km² array

3 fluorescence
telescopes



Pierre Auger
Observatory

Mendoza, Argentina

(19 country
collaboration)

3,000 km² array

4 fluorescence telescopes

The Pierre Auger Observatory

Argentina

Australia

Brasil

Bolivia*

Croatia

Czech Rep.

France

Germany

Italy

Mexico

Netherlands

Poland

Portugal

Romania*

Slovenia

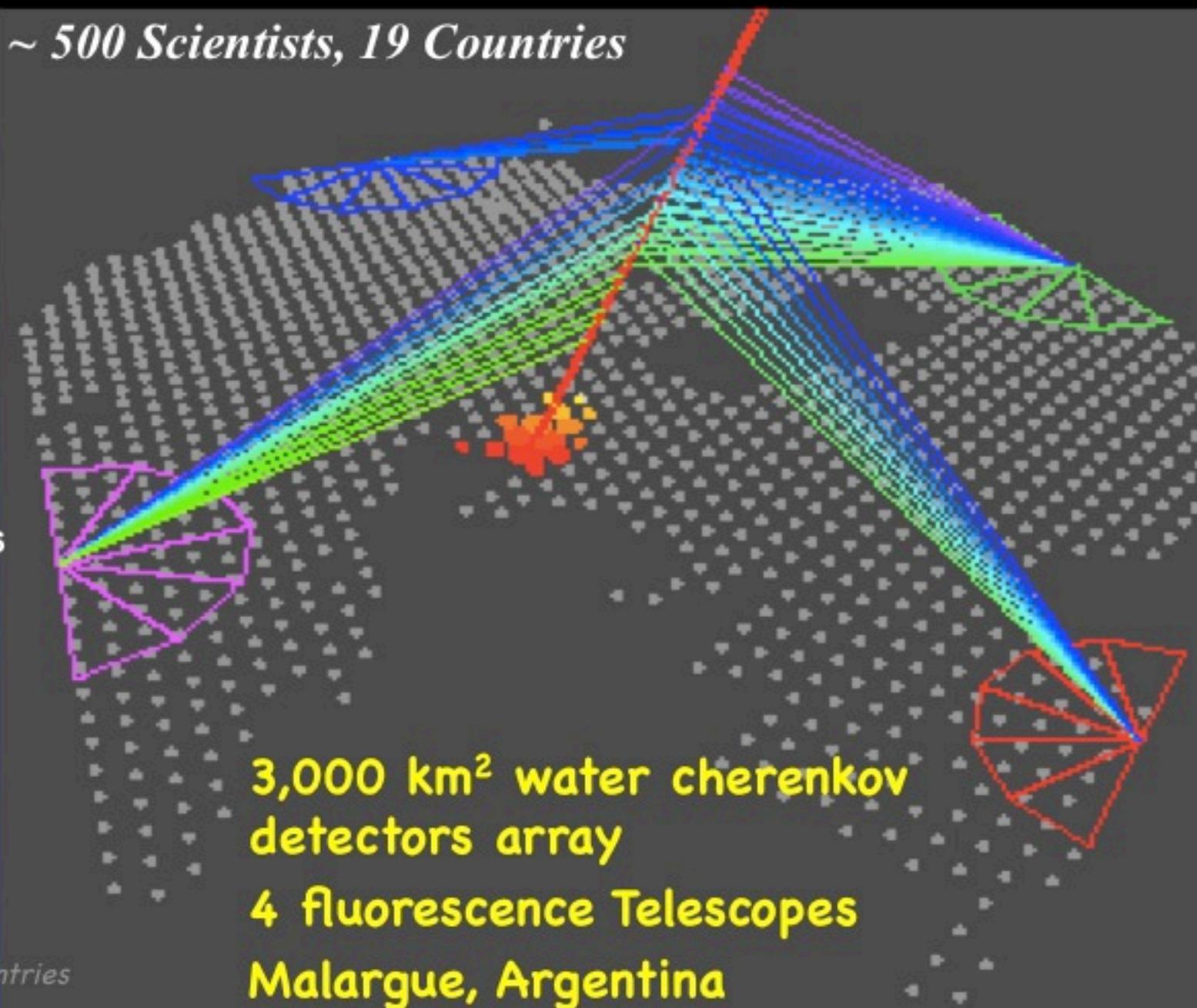
Spain

UK

USA

Vietnam*

~ 500 Scientists, 19 Countries



3,000 km² water cherenkov
detectors array

4 fluorescence Telescopes

Malargue, Argentina

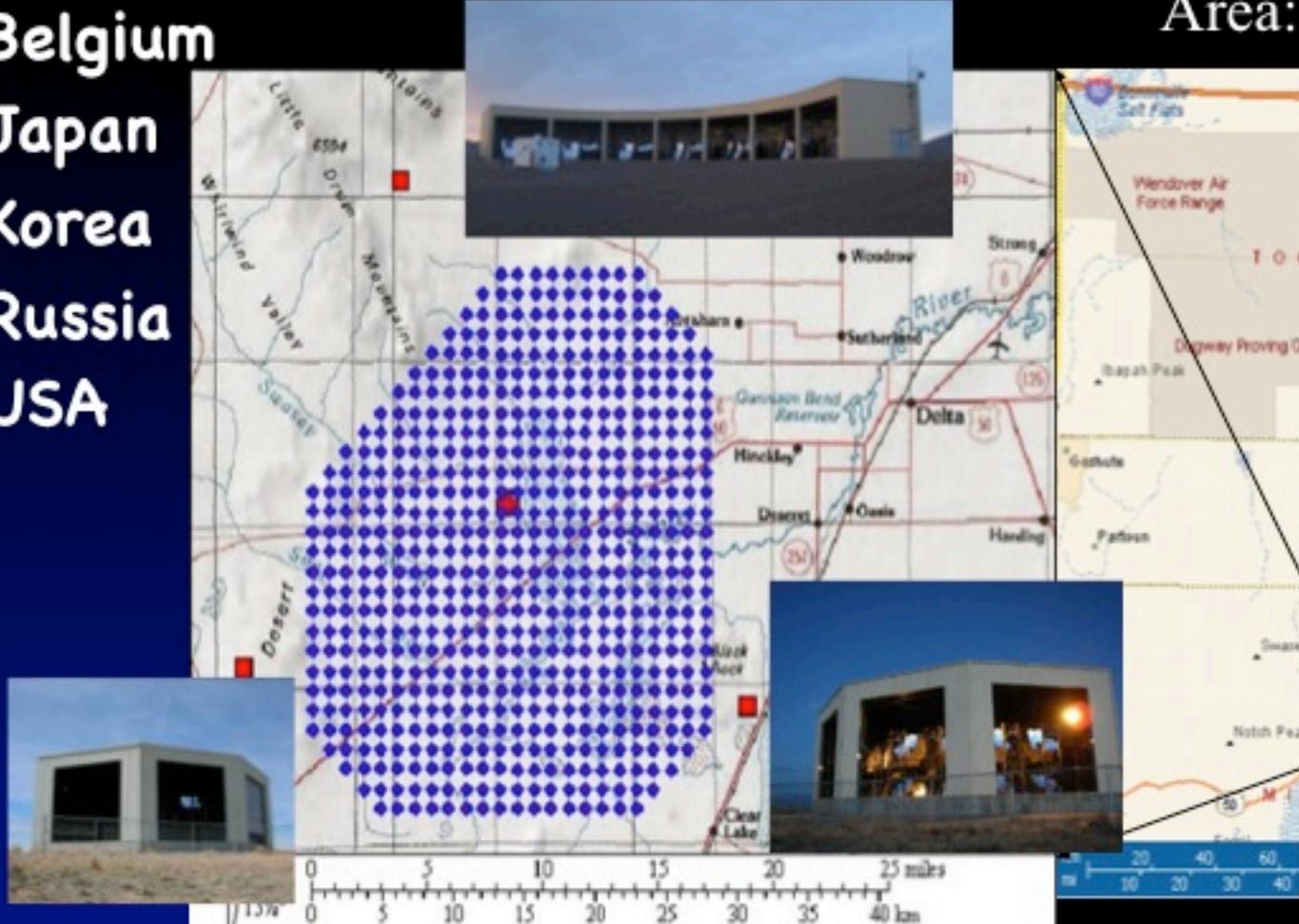
*Associate Countries

Fluorescence telescopes overlooking the site



Telescope Array

Belgium
Japan
Korea
Russia
USA



Area: 680 km²



3 FD stations overlooking an array of
507 scintillator surface detectors (SD)
complete and operational as of ~1/2008.

Recent Results

$E > 20$ EeV Cosmic Rays are EXTRAGALACTIC

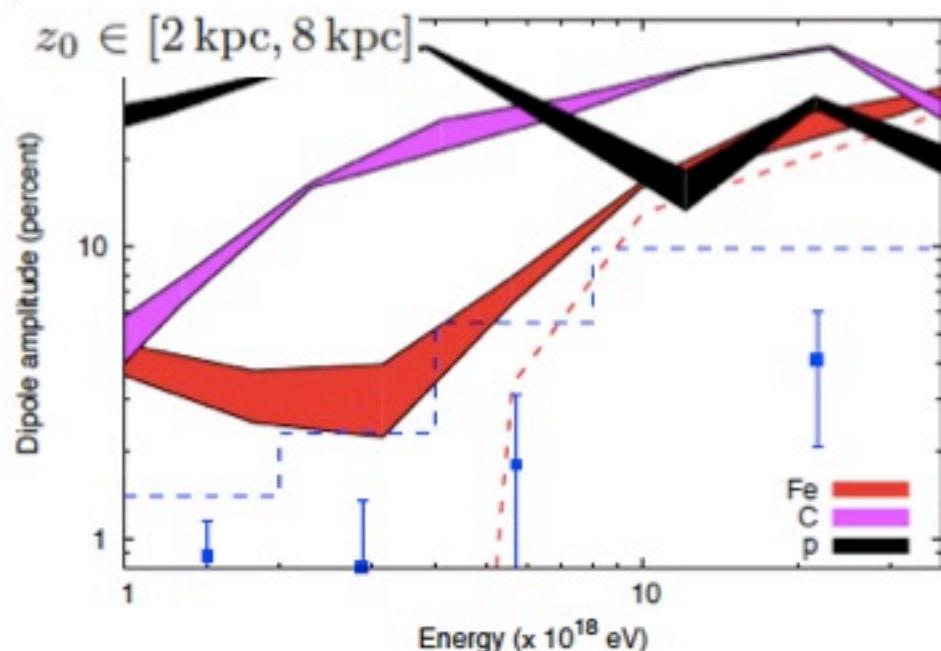
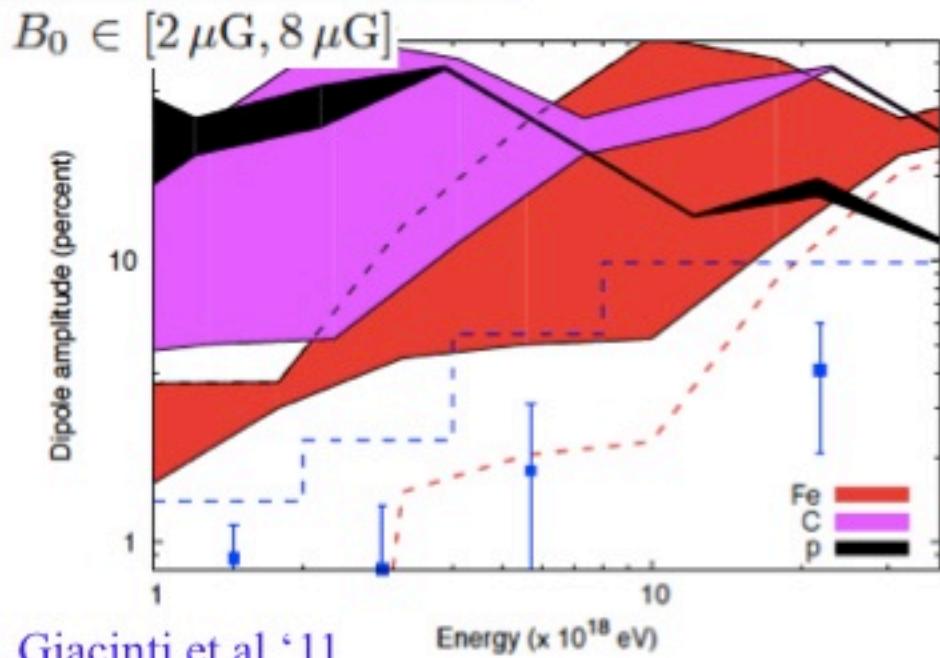


Recent Results

$E > 20$ 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



Recent Results

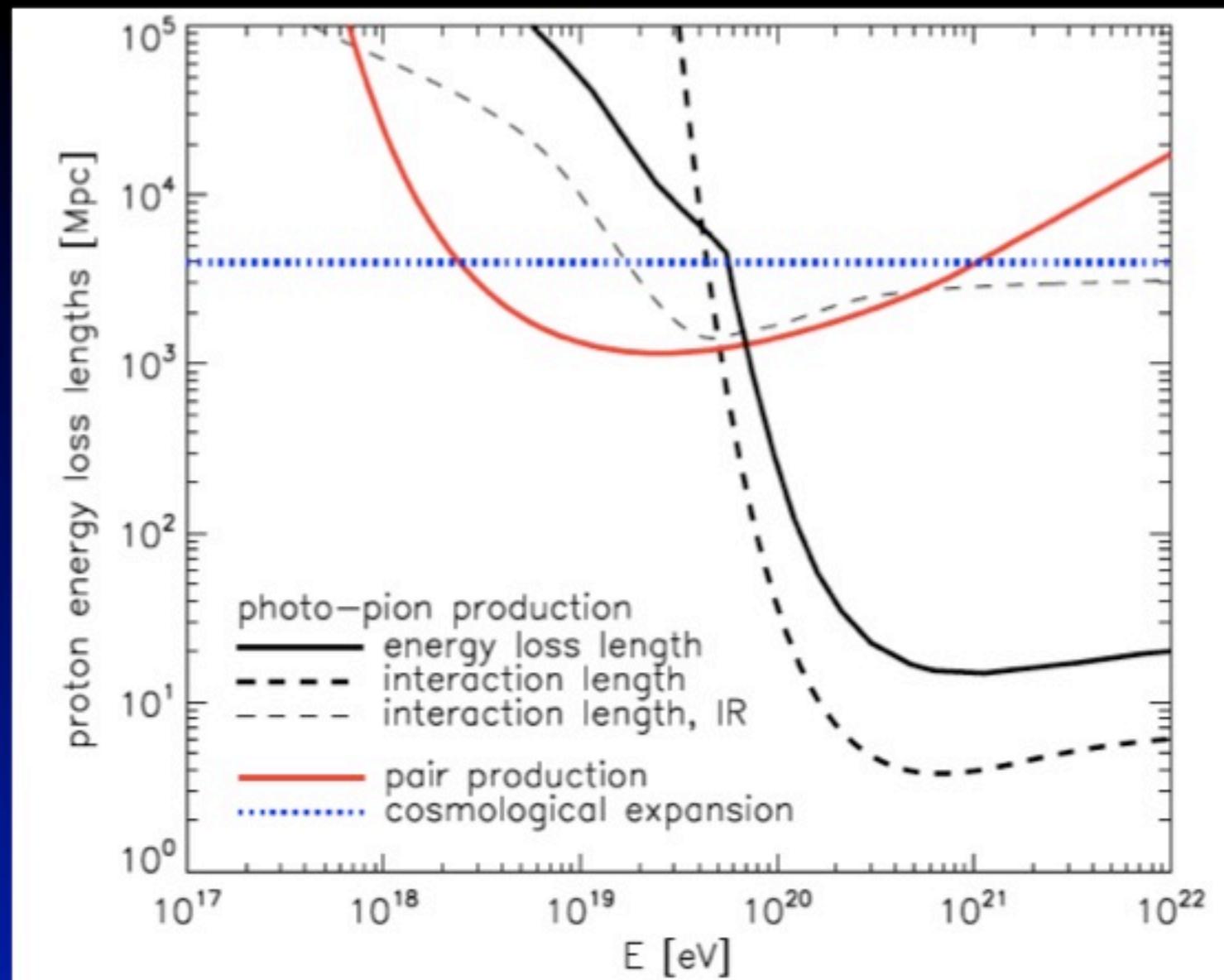
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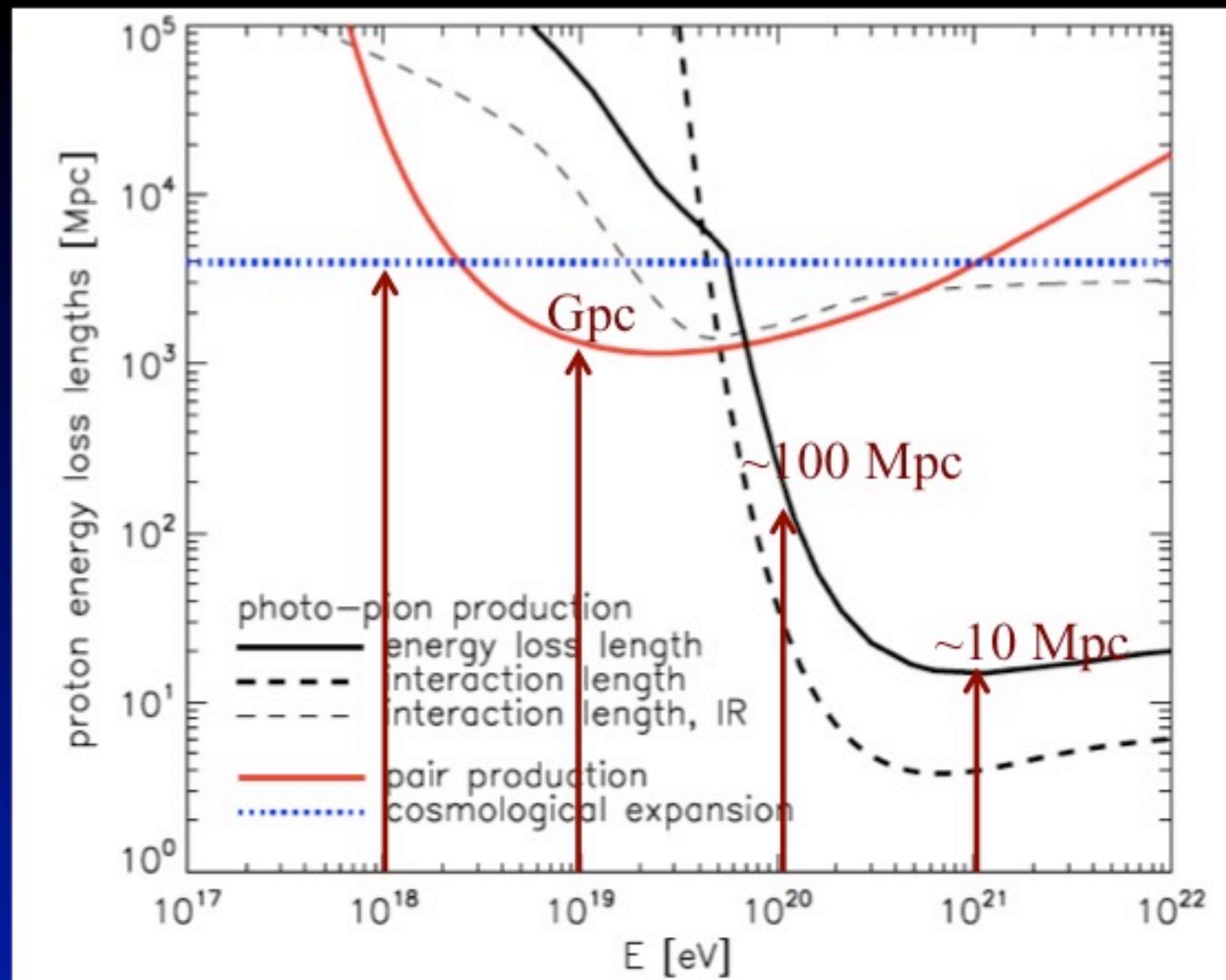
Implies a GZK* feature in the spectrum

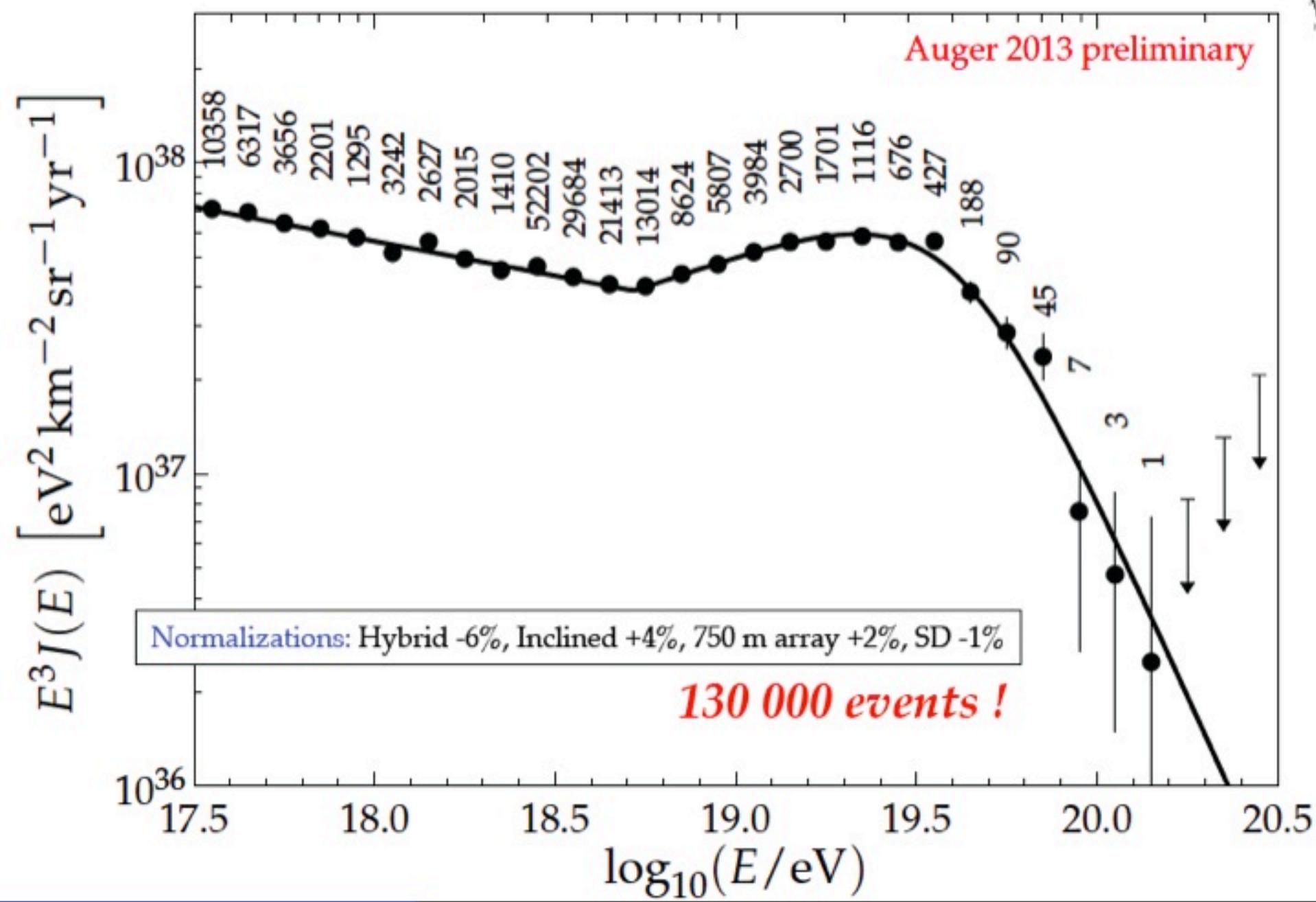
(*Greisen-Zatsepin-Kuzmin)

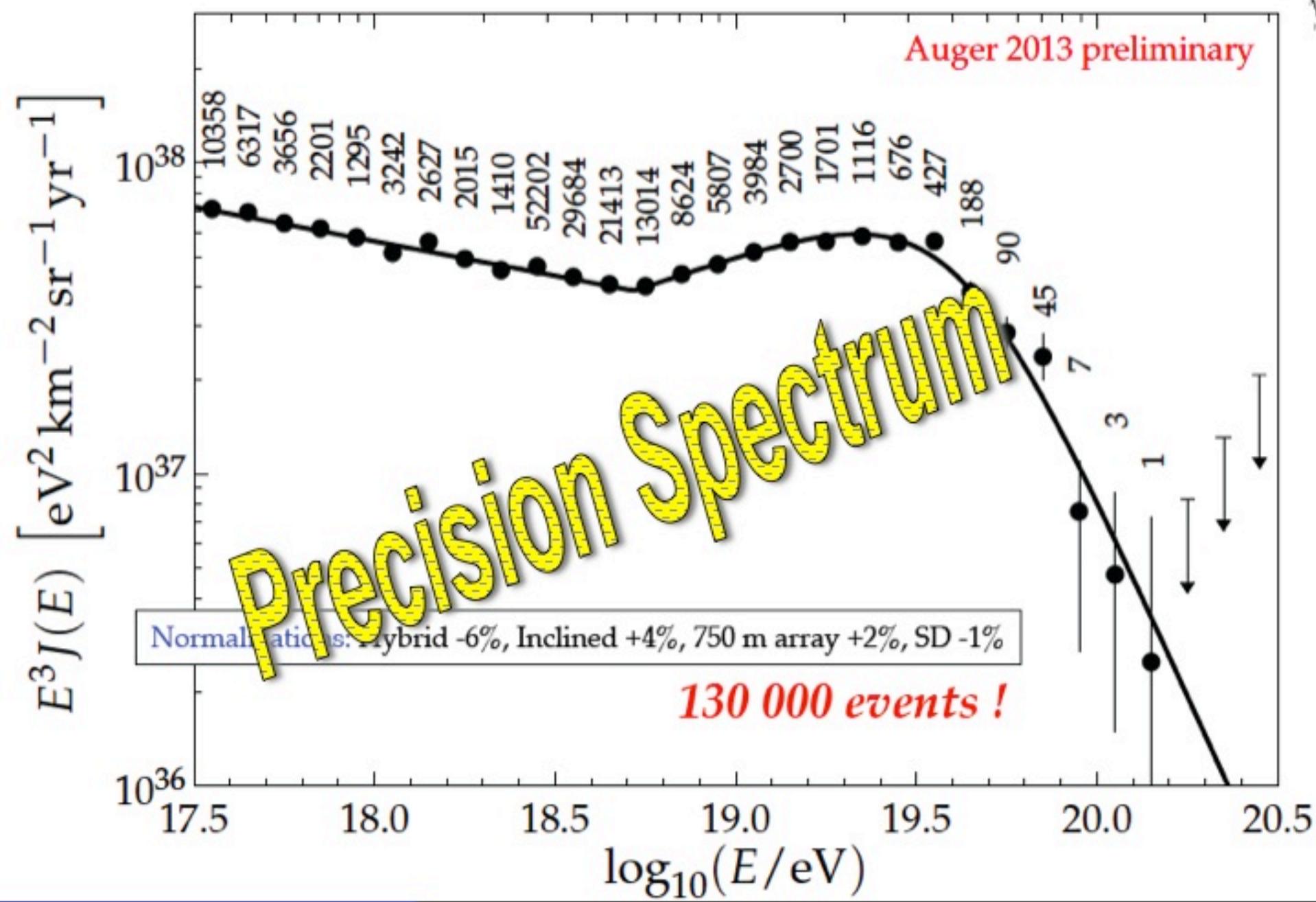
Greisen-Zatsepin-Kuzmin effect



Greisen-Zatsepin-Kuzmin effect



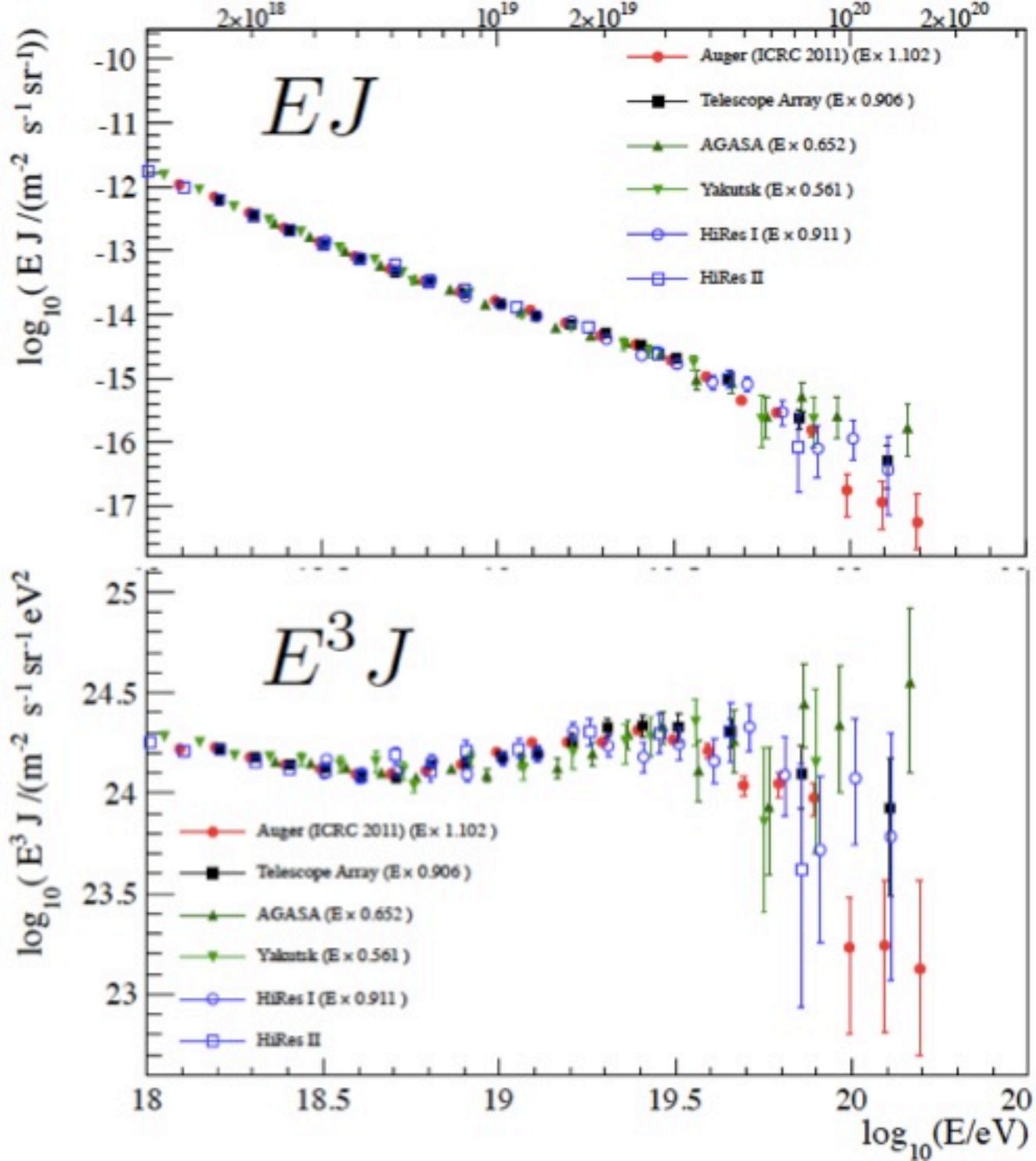




UHECR 2012

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

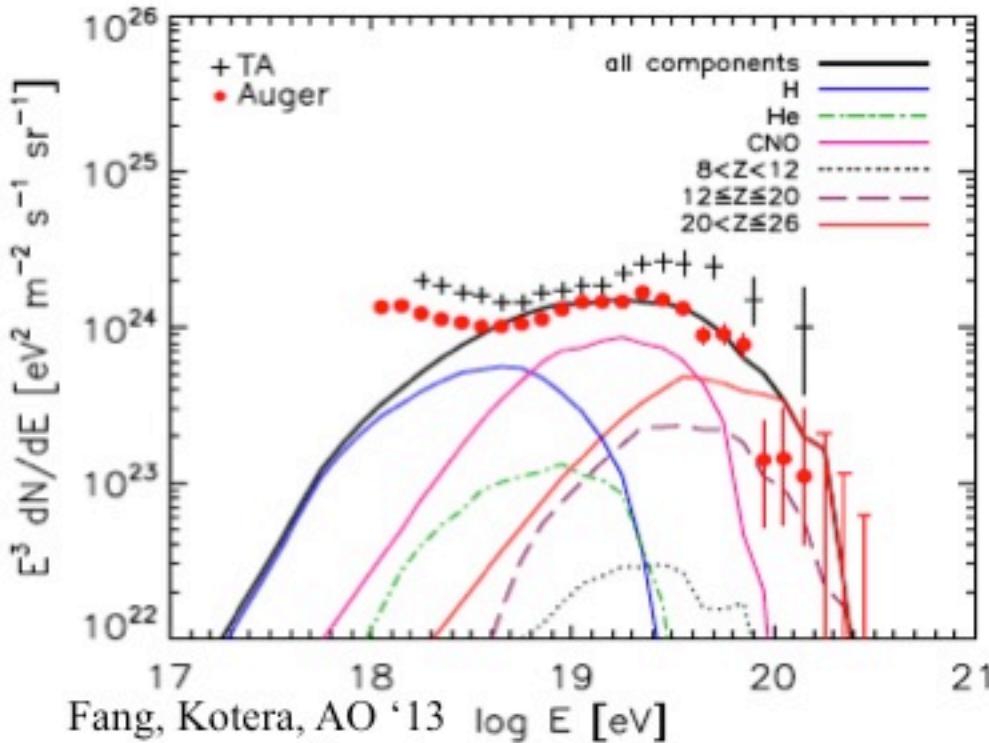
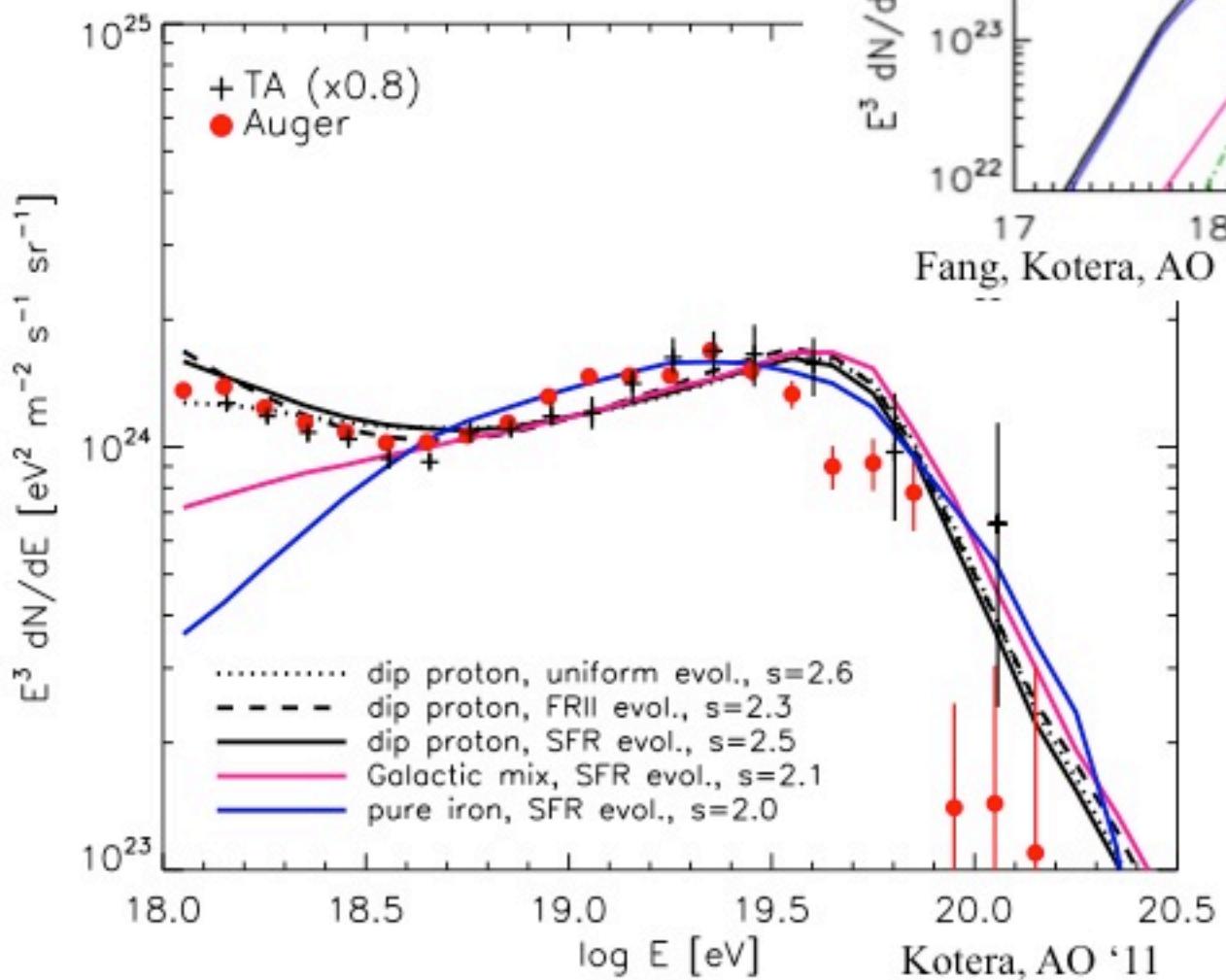
$E > 20$ EeV Cosmic Rays are EXTRAGALACTIC



$E > 40$ EeV GZK-like feature in the spectrum
or end of the injected spectrum, E_{\max} ?



GZK vs E_{\max}



Recent Results

E>20 EeV Cosmic Rays are EXTRAGALACTIC

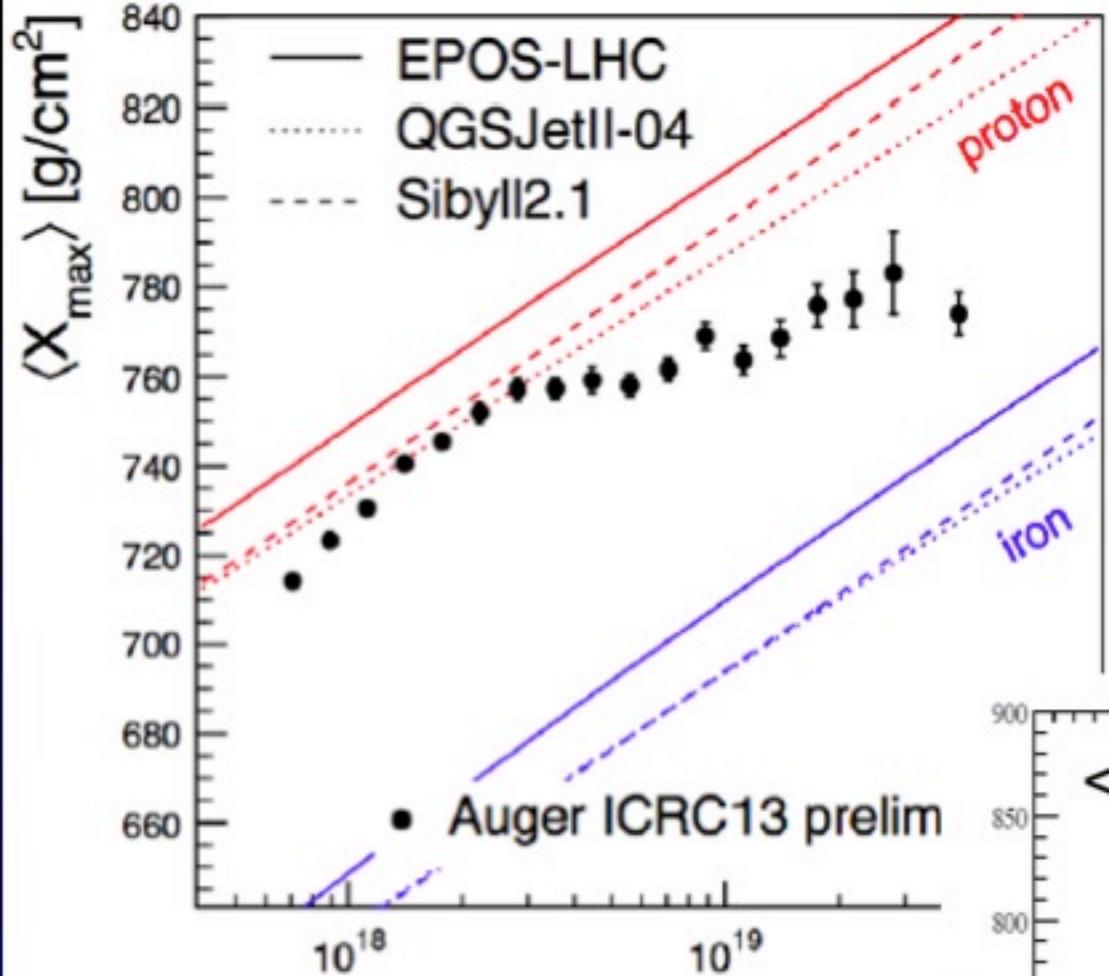


E>40 EeV GZK-like feature in the spectrum
or end of the injected spectrum, E_{\max} ?



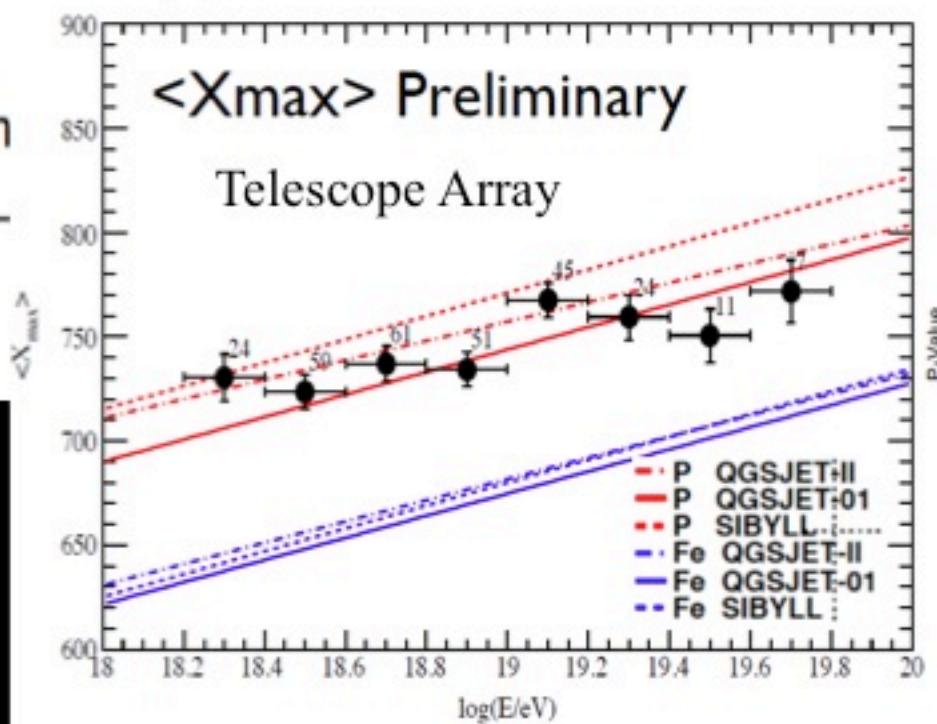
E>10 EeV Composition may be changing!

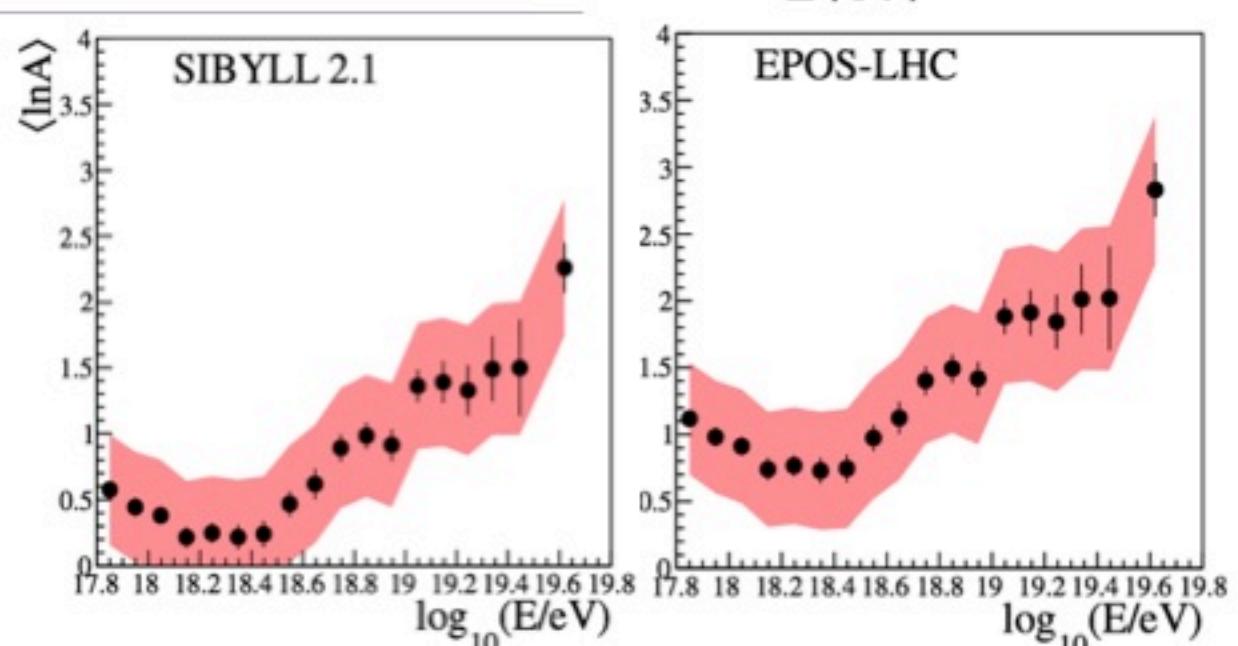
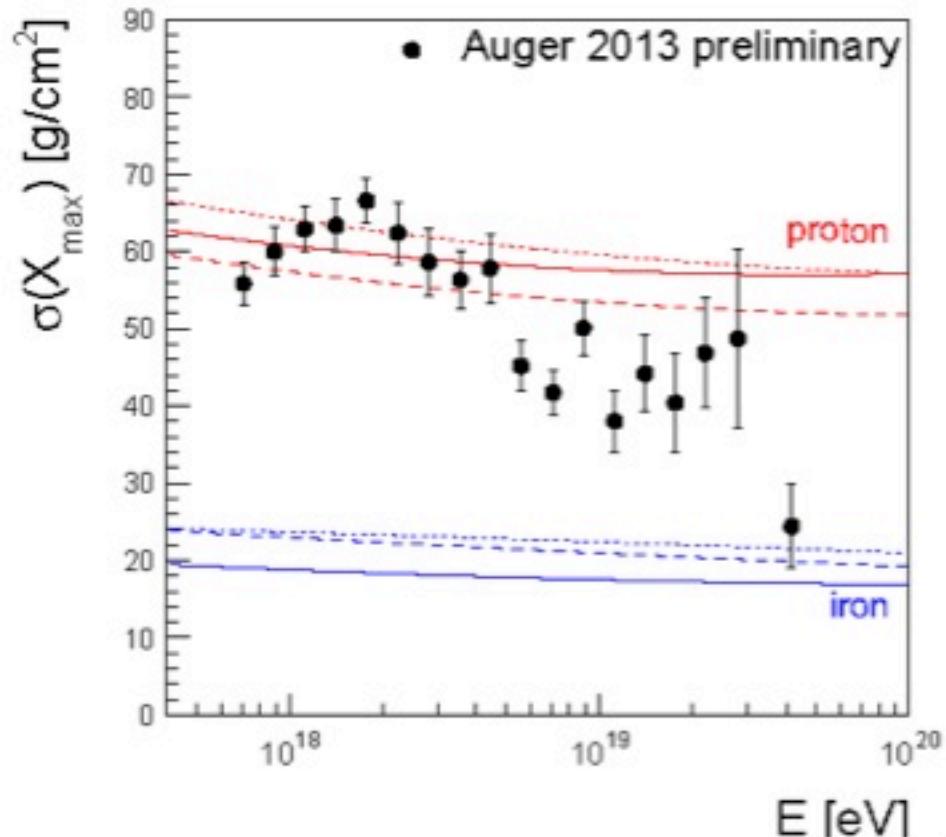
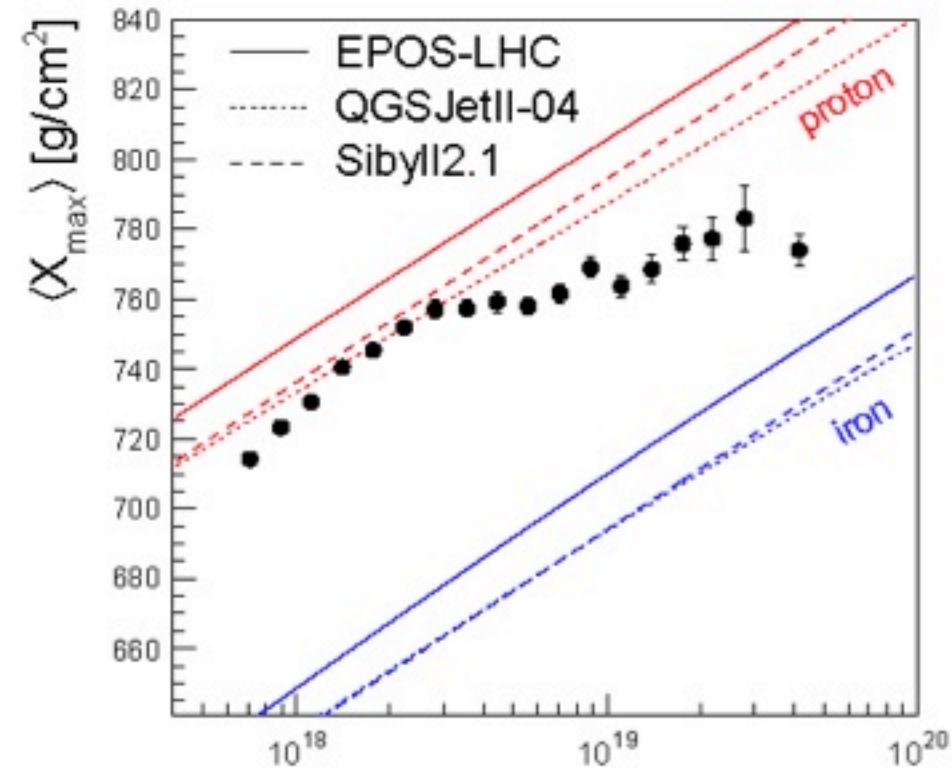




Auger sees change slope:
Change in Composition
or interactions

TA: not confirmed yet





Recent Results

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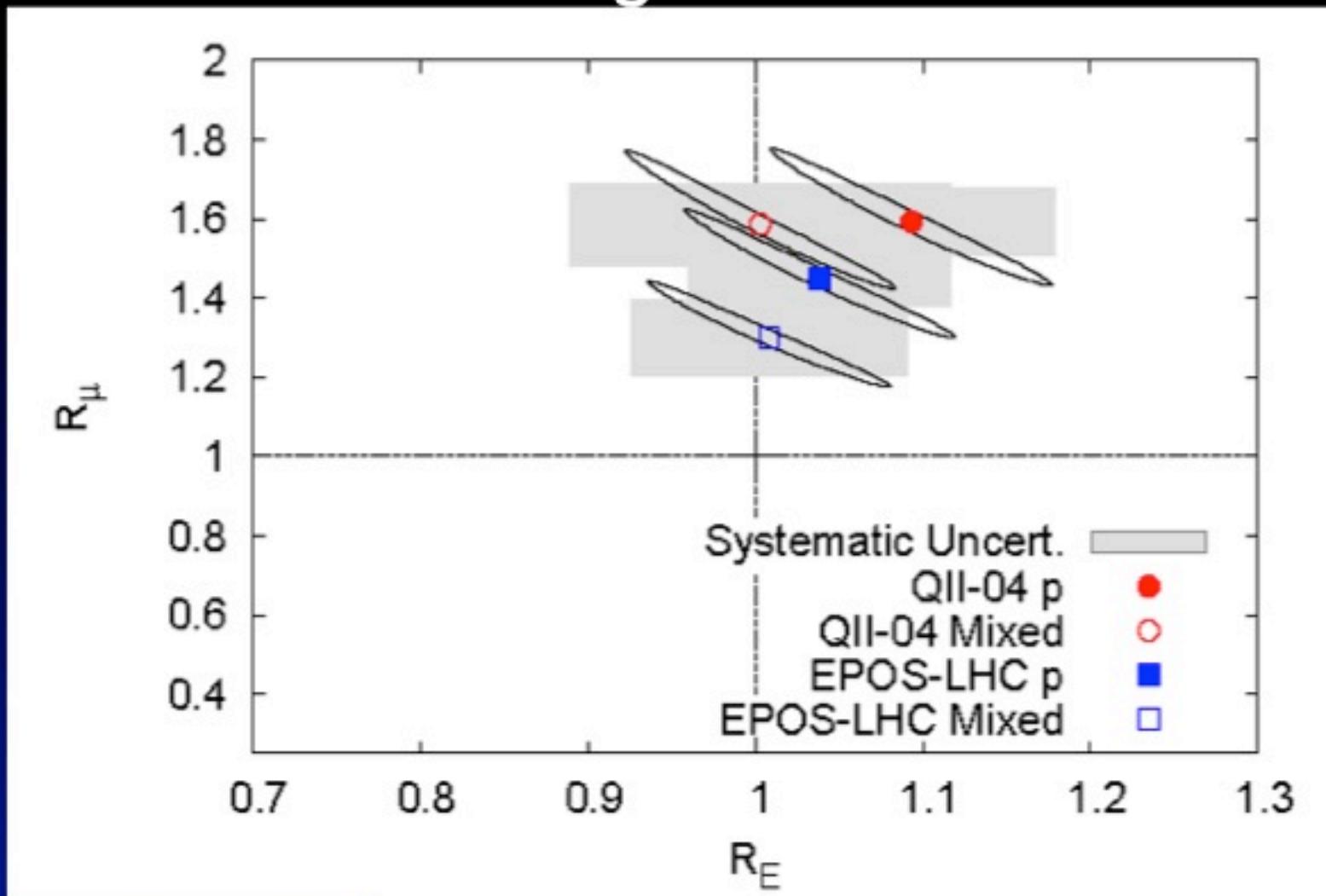
$E > 10$ EeV Composition may be changing!



or maybe the HE interactions are changing!

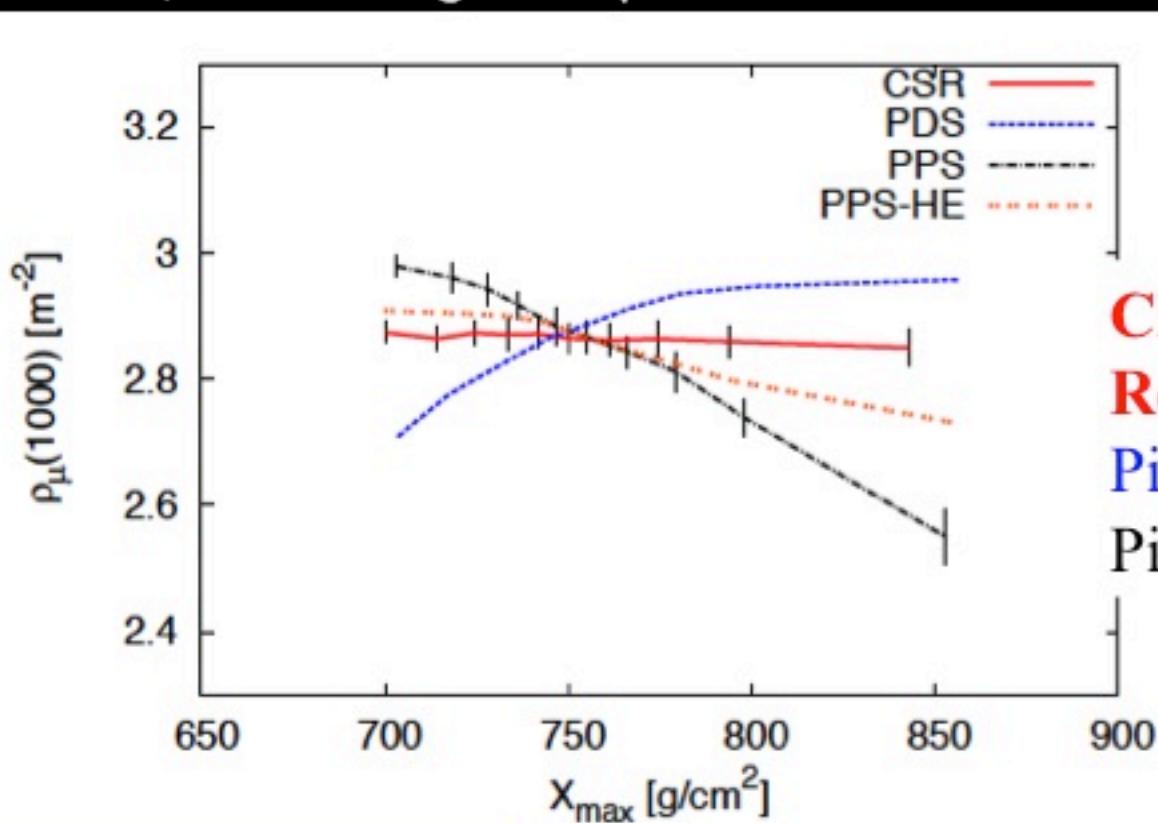


Auger Muons



Observe “too many” muons, even for Mixed Composition!

Inhibit E transfer from hadronic into EM shower,
by reducing the production or decay of π^0



**Chiral Symmetry
Restoration**
Pion decay suppression
Pion production suppression

Property Increased	Change in N_μ	Change in X_{max}
Cross-section	–	Decreased
Elasticity	–	Increased
Multiplicity	Increased	Decreased
Primary Mass	Increased	Decreased
π^0 Eng. Frac.	Decreased	–

Recent Results

E>20 EeV Cosmic Rays are EXTRAGALACTIC



E>40 EeV GZK-like feature in the spectrum
or end of the injected spectrum, E_{\max} ?



E>10 EeV Composition may be changing!



or maybe the HE interactions are changing!



How to sort out this conundrum?



Recent Results

E>20 EeV Cosmic Rays are EXTRAGALACTIC



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



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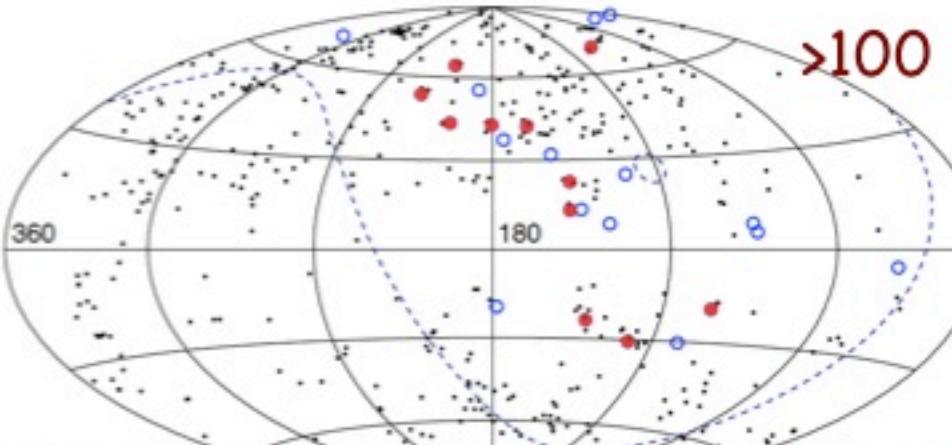
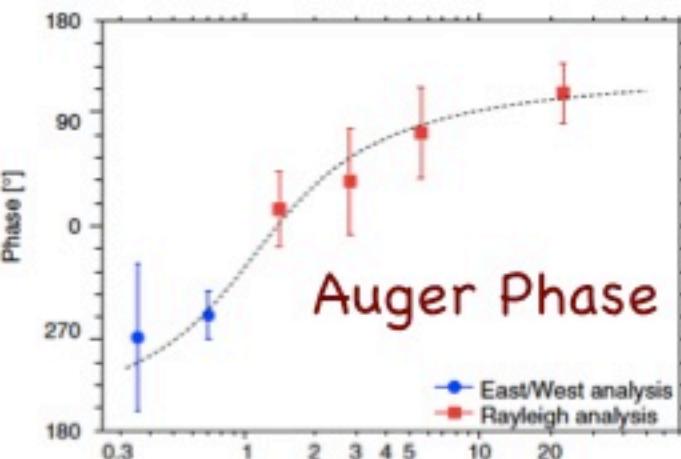
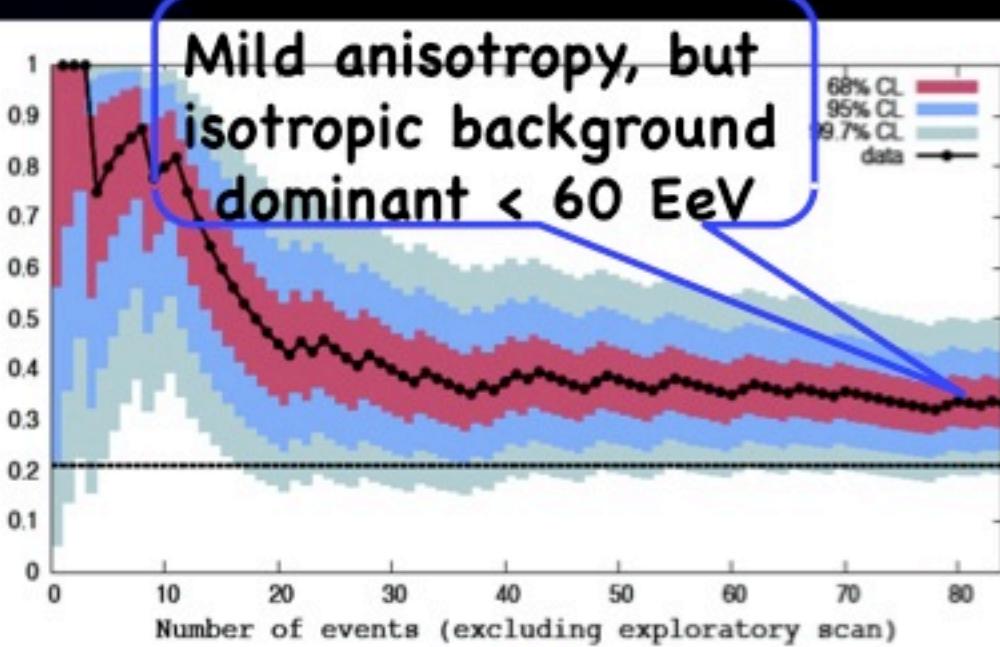


How to sort out this conundrum? Find the Sources!



EECR Anisotropy Hints $E \sim 60$ EeV

Correlating fraction



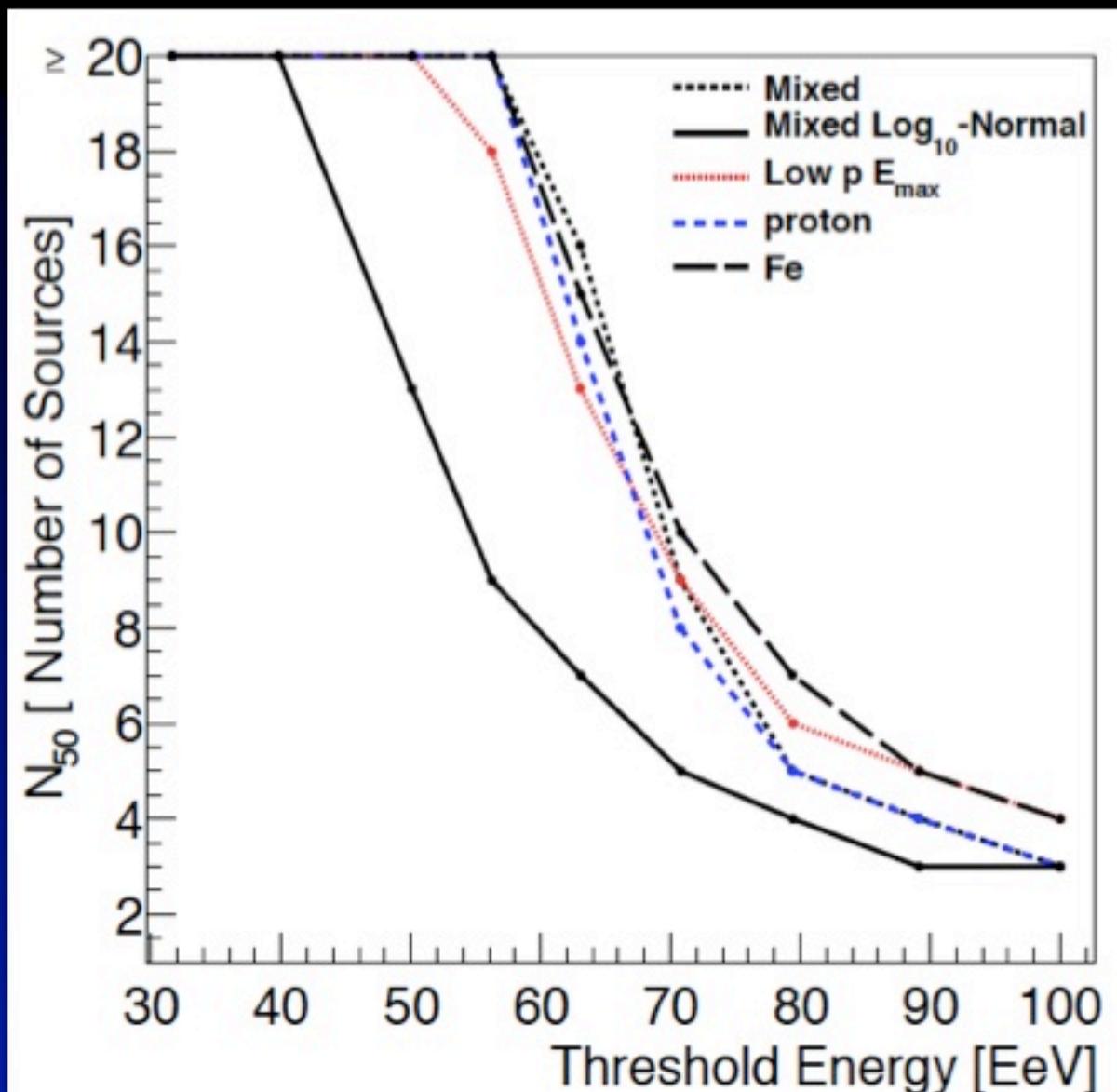
How to find the Sources?

How to find the Sources?

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

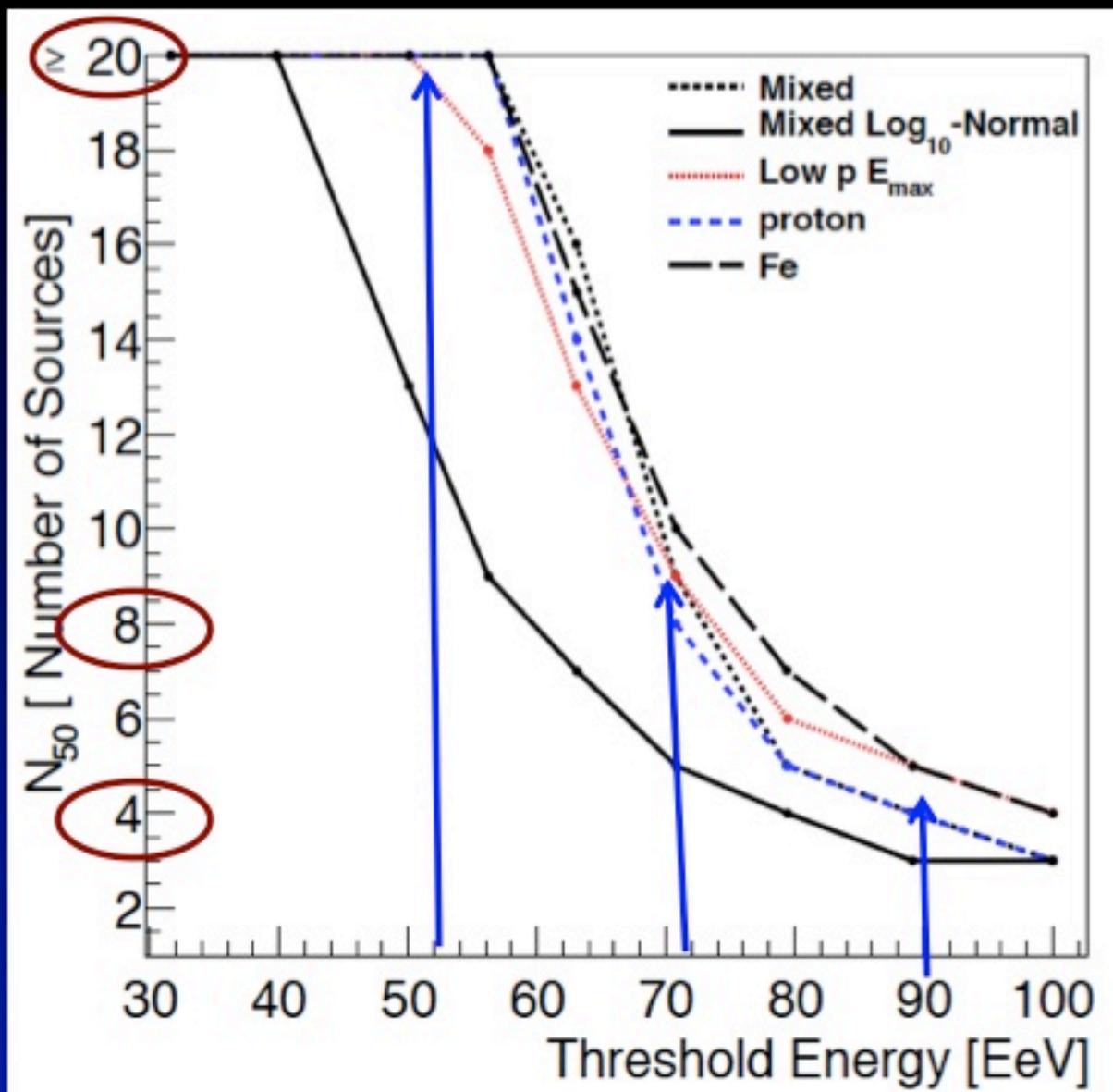
To detect sources

Observe at higher energies – fewer sources



To detect sources

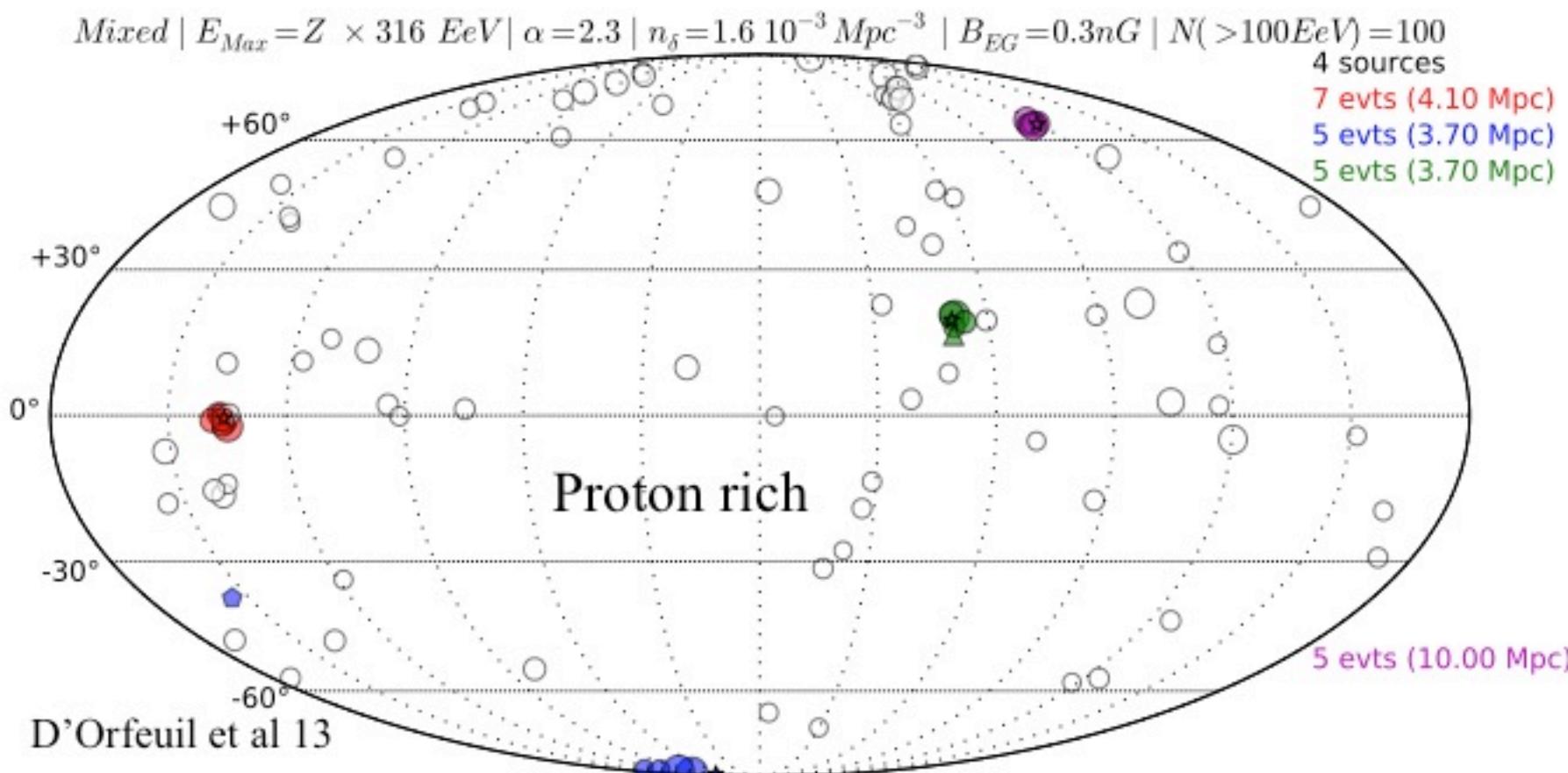
Observe at higher energies – fewer sources



To detect sources

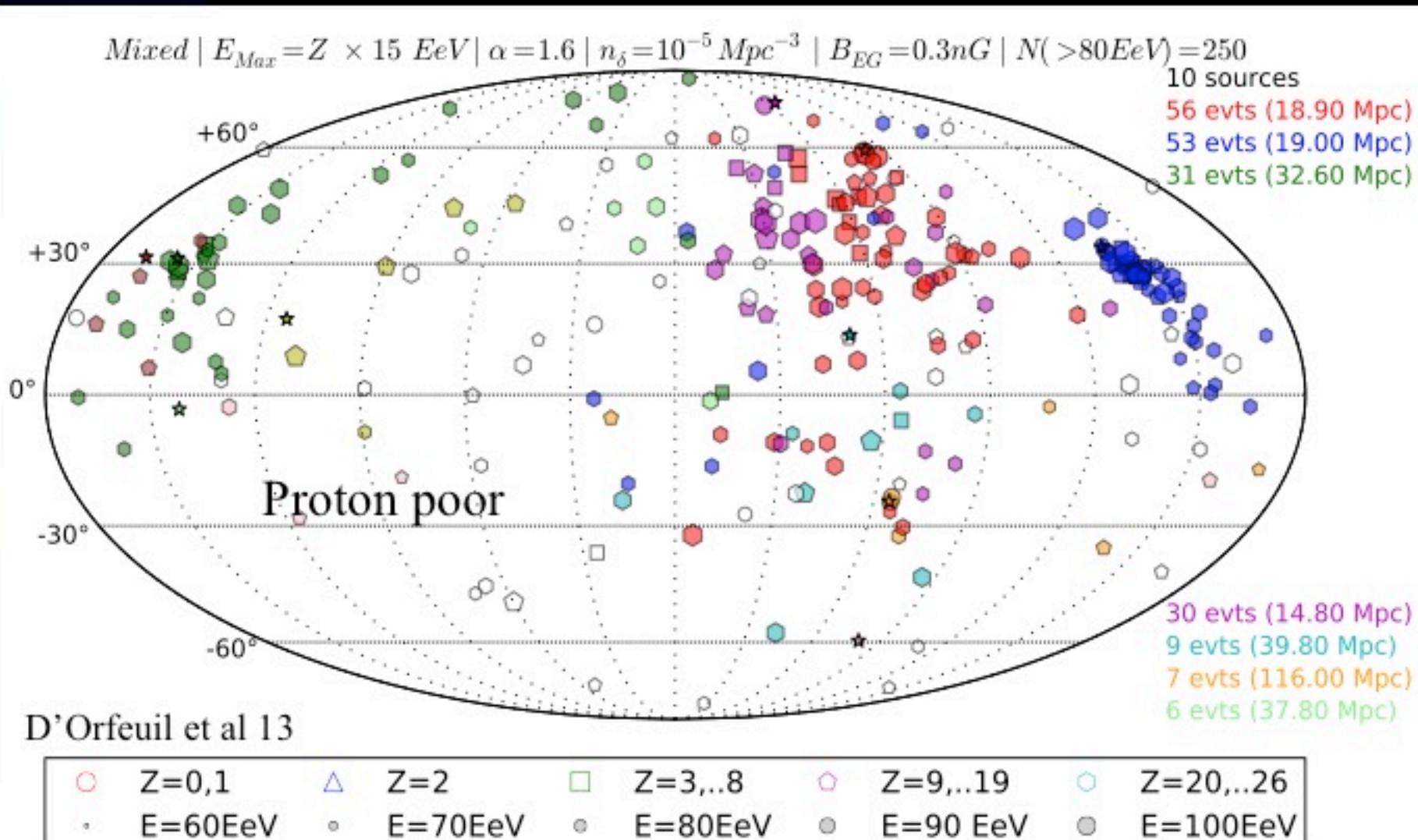
Increase statistics: ~1,000 events > 60 EeV

~100 events > 100 EeV



To detect sources

Increase statistics: ~1,000 events > 60 EeV
~100 events > 100 EeV



How many EECRs > 60 EeV?

Before we see a source?

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

How many EECRs > 60 EeV?

Before we see a source?

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

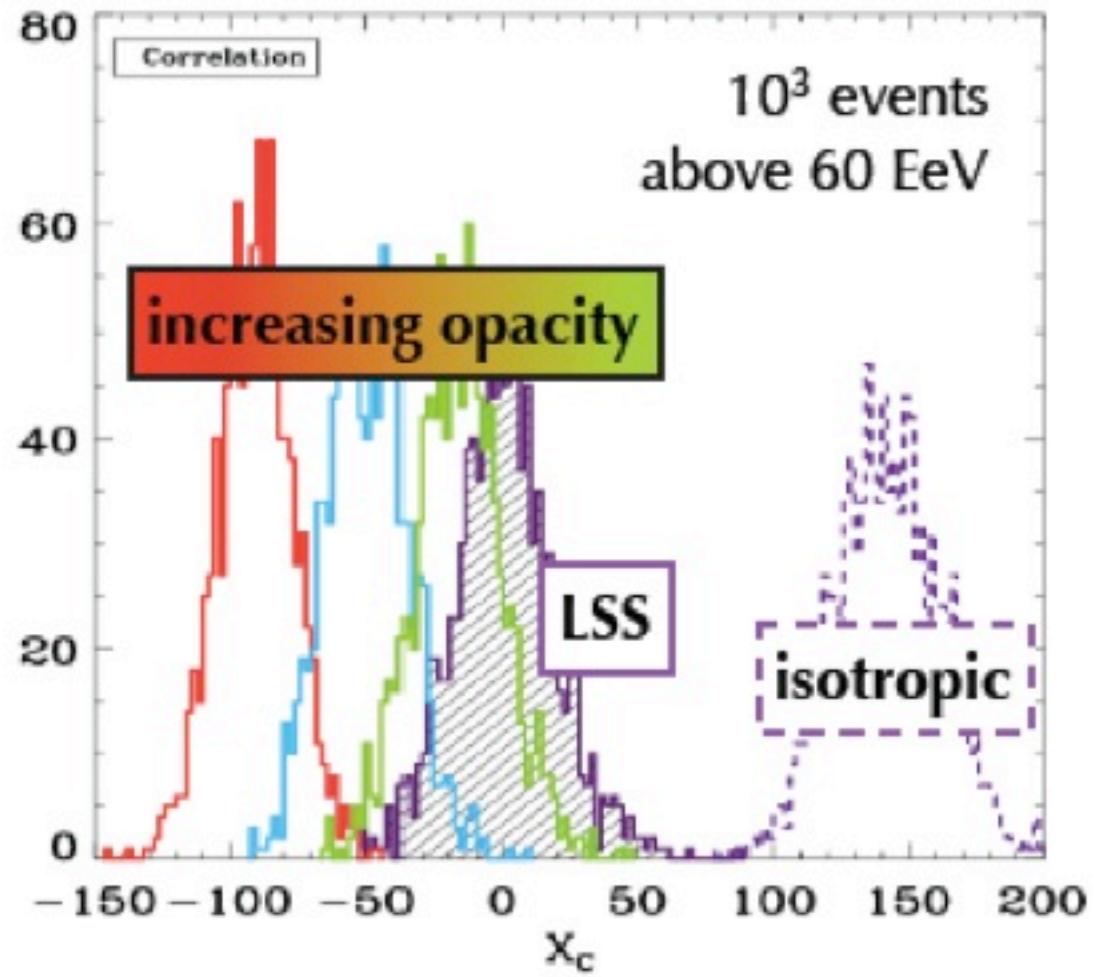
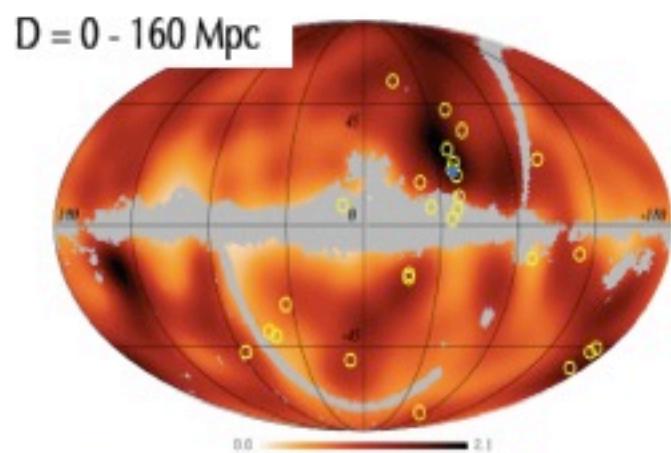
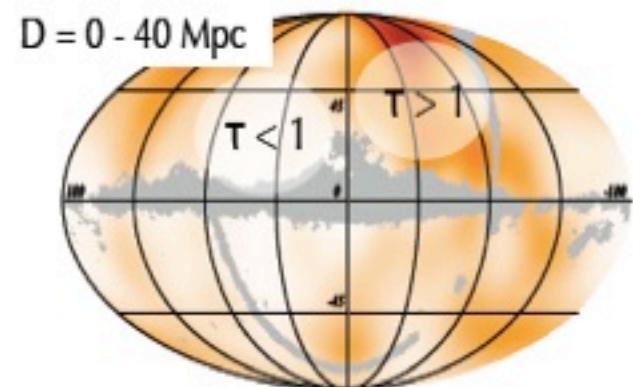
Dipole from direction of Cen A in Auger >60 EeV:
(a posteriori) right ascension harmonic analyses

Anchordoqui, Goldberg & Weiler '11

$$\alpha_d \hat{d} = \frac{3}{N} \int J(\hat{u}) \hat{u} d\Omega \quad \alpha_d = 0.25$$

5 σ discovery requires 1,000 events
(with whole sky coverage)

Population Separation: need 1,000 events above 60 EeV



Kalli, Lemoine, Kotera '10

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!!!!

OVER THE WHOLE SKY !!!!

Current Observatories of Ultrahigh Energy Cosmic Rays

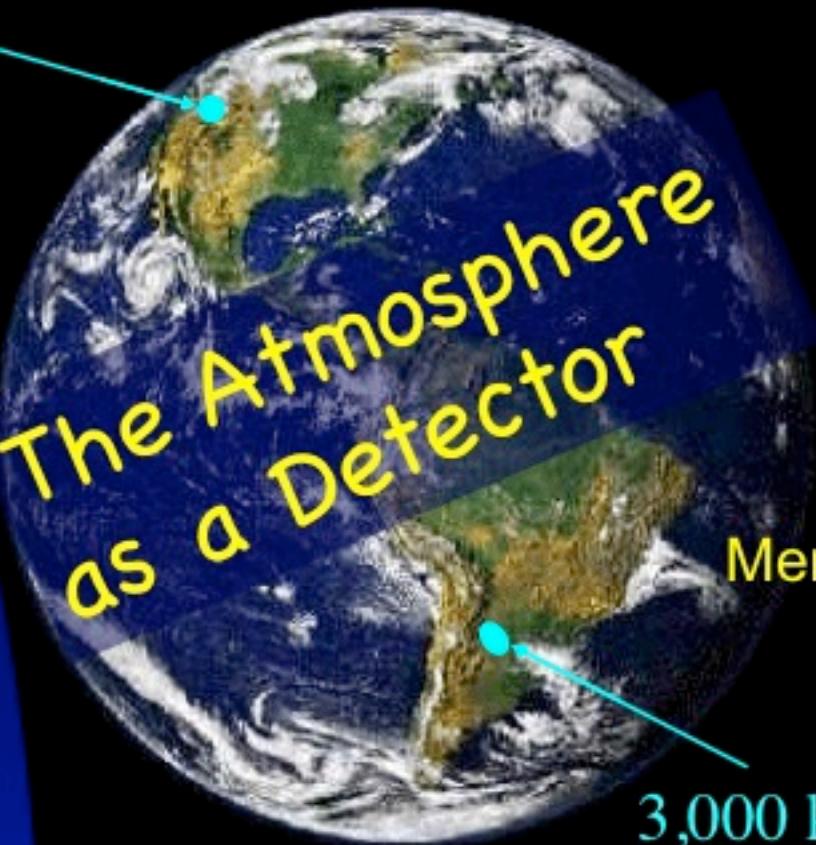
Telescope Array

Utah, USA

(5 country
collaboration)

700 km² array

3 fluorescence
telescopes



The Atmosphere
as a Detector

Pierre Auger
Observatory

Mendoza, Argentina

(19 country
collaboration)

3,000 km² array

4 fluorescence telescopes

How many EECRs > 60 EeV?

Auger w/ 3,000 km²

~20 events > 60 EeV/ yr

Telescope Array w/ 700 km²

~5 events > 60 EeV/ yr

Auger + TA < 30 events/yr

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30+ years to reach 1,000

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Earth - surface ~ $5 \cdot 10^8$ km²

~ $3.4 \cdot 10^6$ events/yr



How many EECRs > 60 EeV?

Auger w/ 3,000 km²

~20 events > 60 EeV/ yr

Telescope Array w/ 700 km²

~5 events > 60 EeV/ yr

Auger + TA < 30 events

50,000 to go!

Earth surface $\sim 5 \cdot 10^8$ km²

~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

How many UHECRs > 60 EeV?

Auger + TA ~30 events/yr

JEM-EUSO

~200 events > 60 EeV/yr



Earth - surface $\sim 5 \cdot 10^8 \text{ km}^2$

~ $3.4 \cdot 10^6$ events/yr

How many UHECRs > 60 EeV?

Auger + TA ~30 events/yr

JEM-EUSO

~200 events > 60 EeV/yr

40,000 to go!

Earth surface $\sim 5 \cdot 10^8 \text{ km}^2$

$\sim 3.4 \cdot 10^6 \text{ events/yr}$



Fluorescence from SPACE

J. Linsley



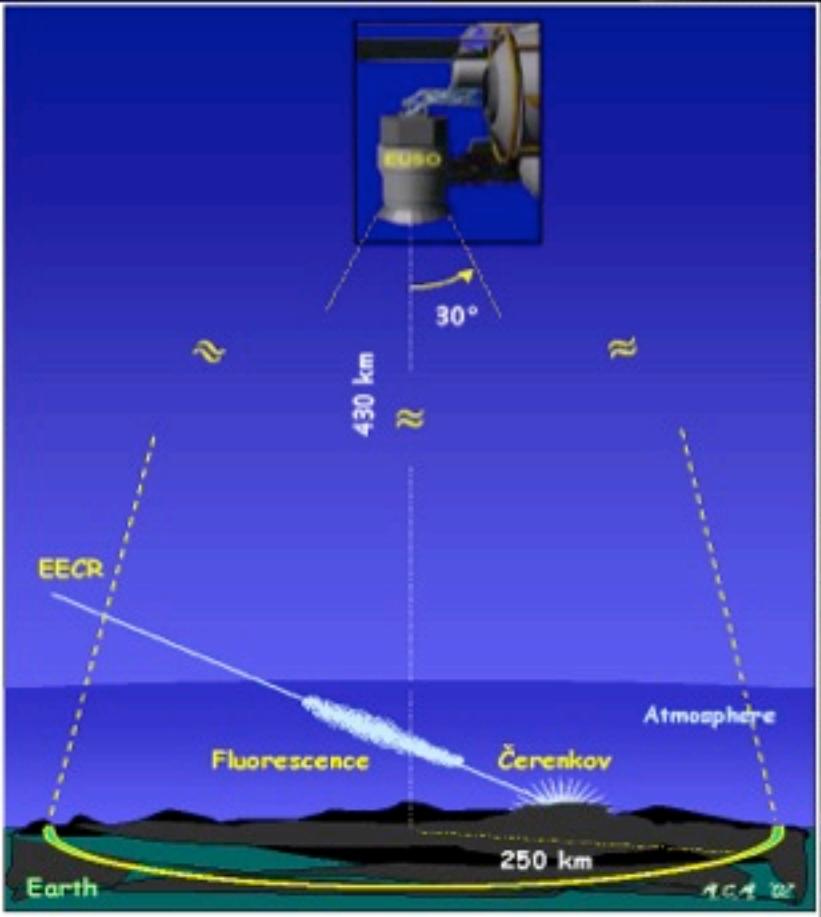
Y. Takahashi



Nadir

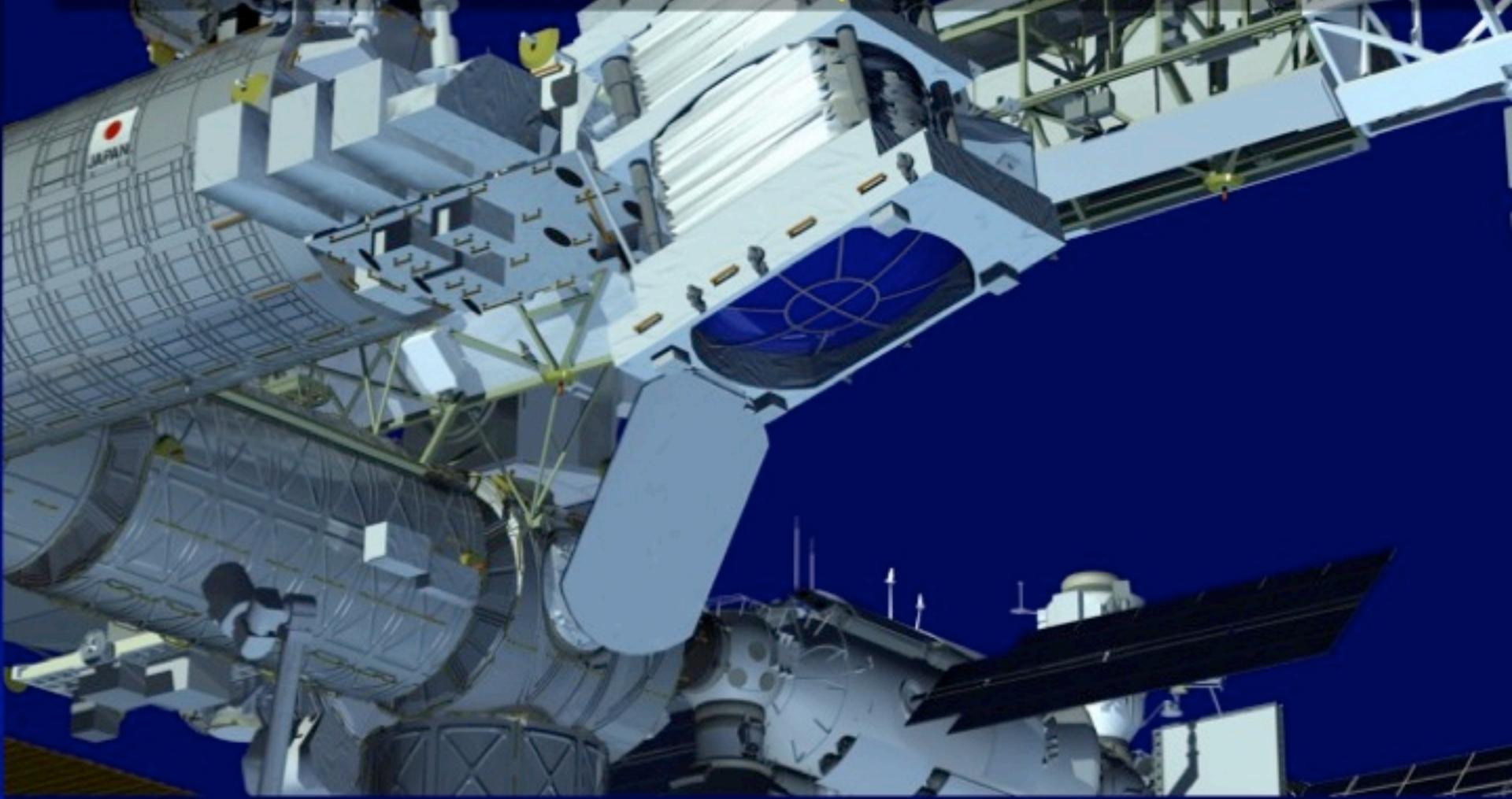


Tilt



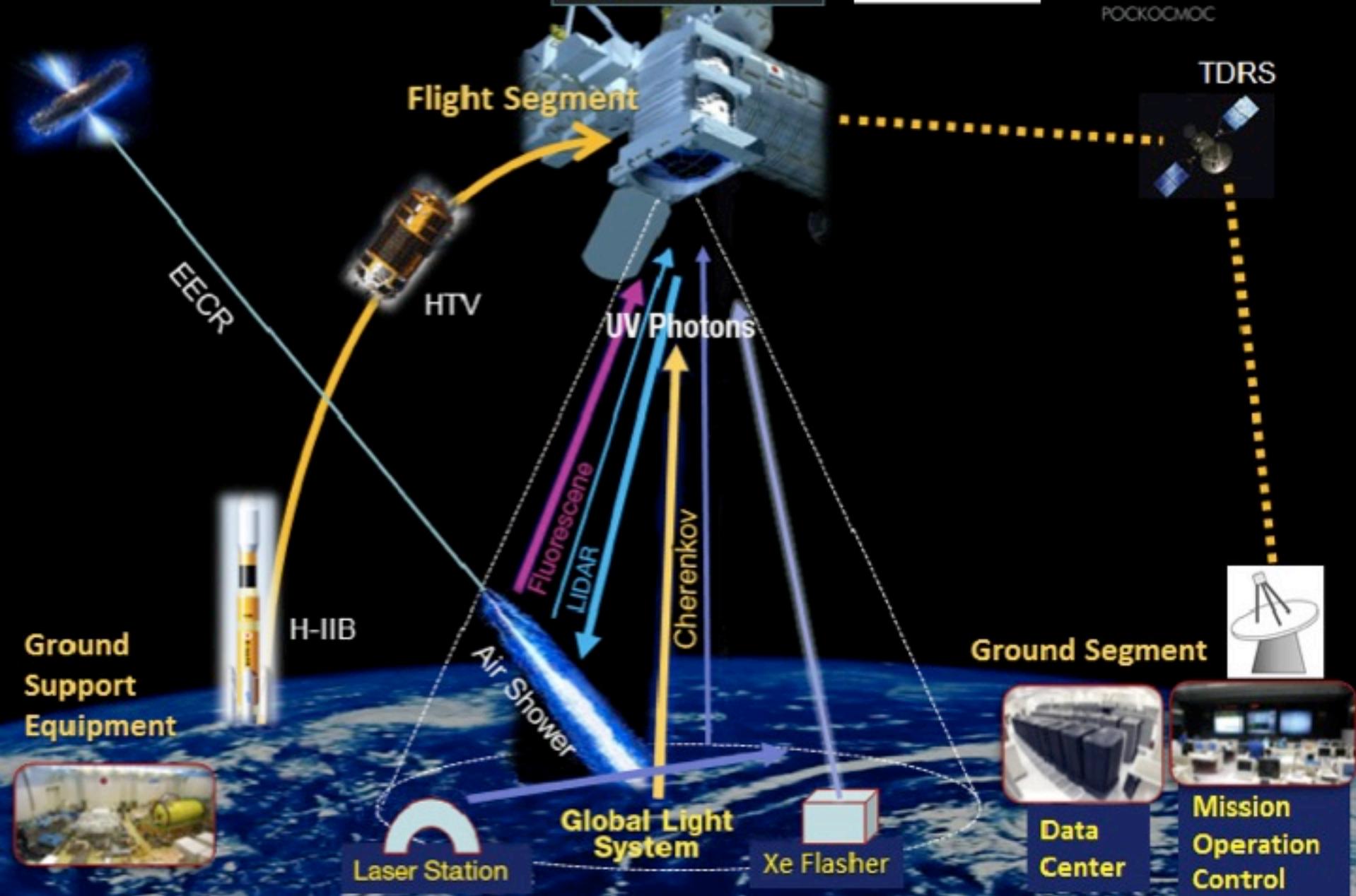
JEM-EUSO Mission

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

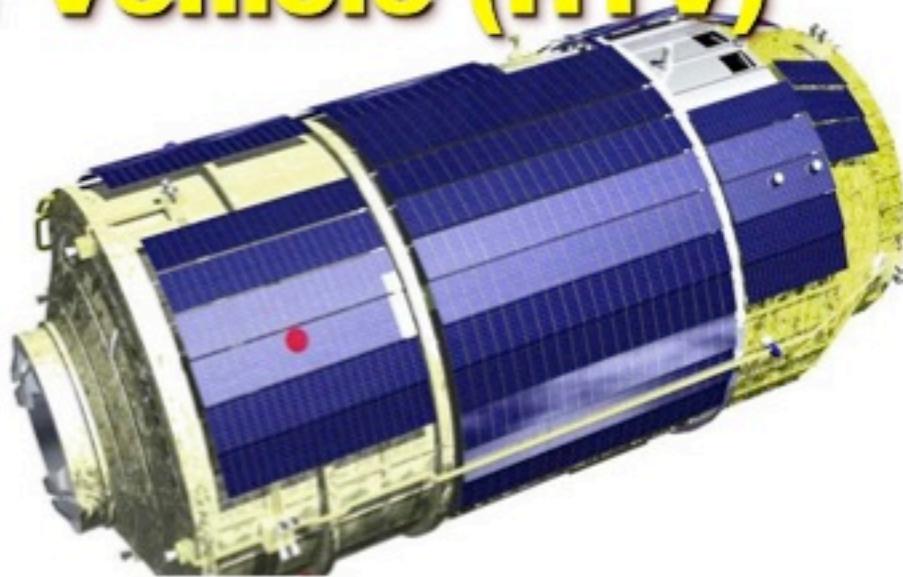
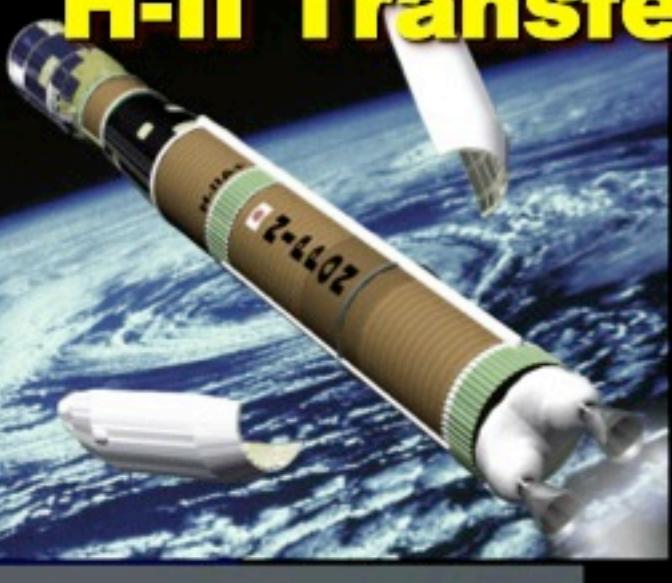


JEM-EUSO Mission

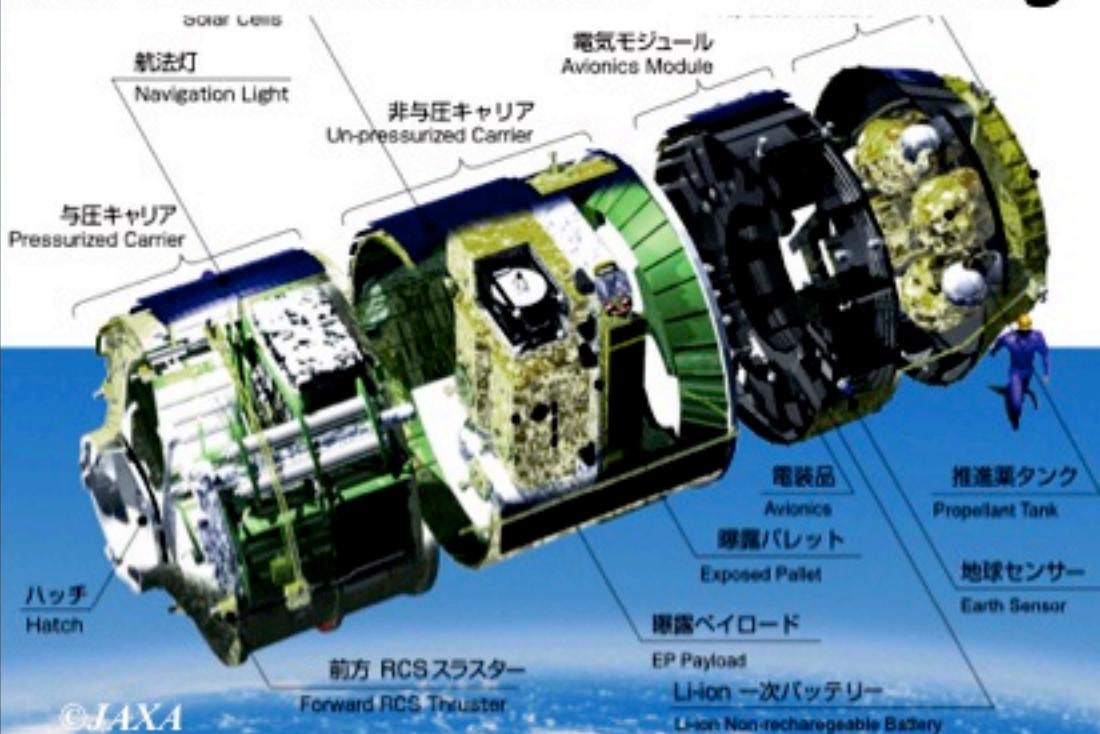
Parameter	Value
Launch date	2017
Mission Lifetime	3+2 years
Rocket	H2B or Falcon9
Transport Vehicle	HTV or Dragon
Accommodation on JEM	EF#9
Mass	~1200 kg
Power	926 W (op.) 352 W (non op.)
Data rate	285 kbps (+ on board storage)
Orbit	~400 km
Inclination of the Orbit	51.6°
Operation Temperature	-10° to +50°

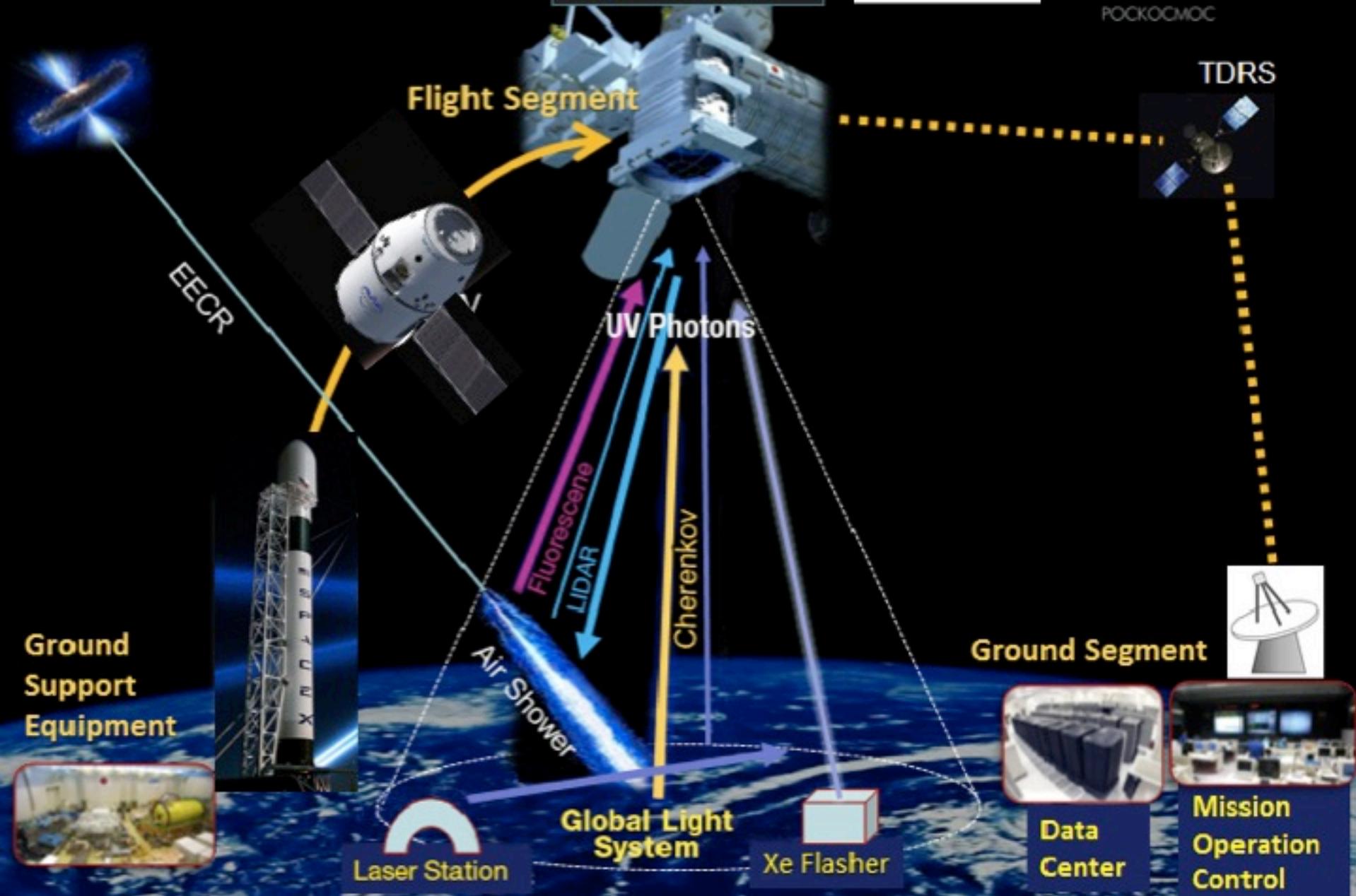


H-II Transfer Vehicle (HTV)



HTV is 4m across ~10 m long





A photograph of the International Space Station's robotic arm holding the white cylindrical SpaceX Dragon cargo ship against a backdrop of Earth's atmosphere.

SpaceX
Dragon



Full Sky Coverage with nearly uniform exposure



<http://www.hlsa.com/> LSA

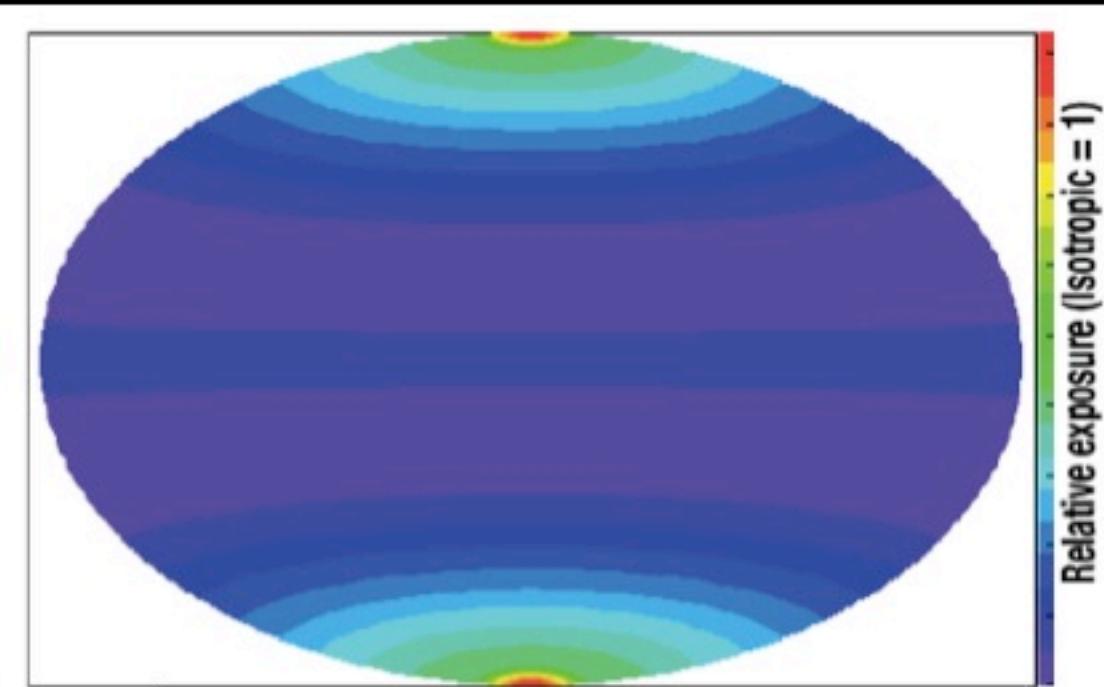
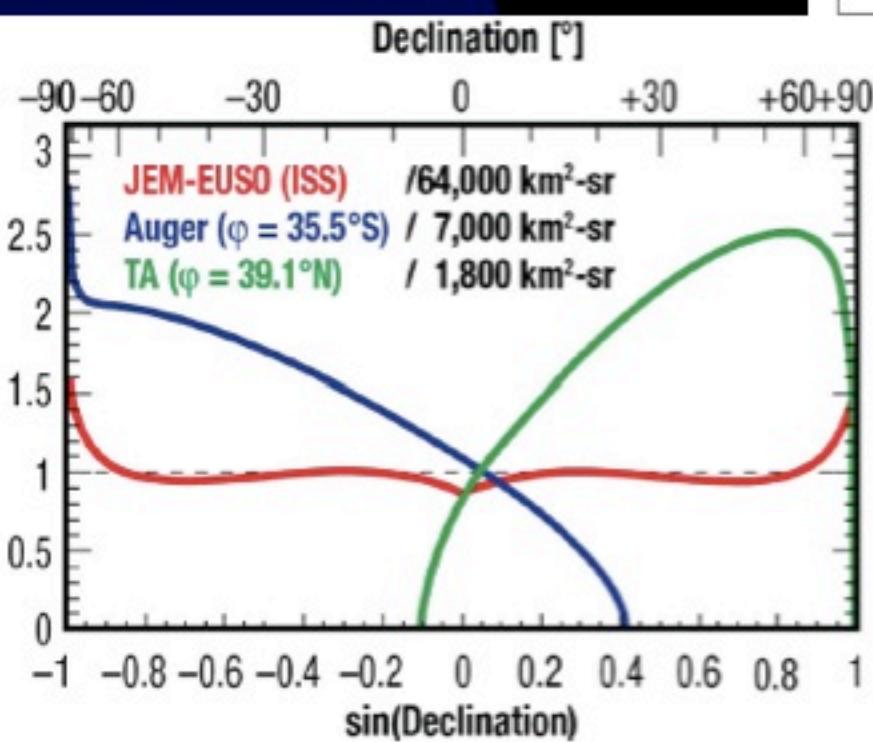
The ISS ORBIT



Inclination: 51.6°

Height: ~400km

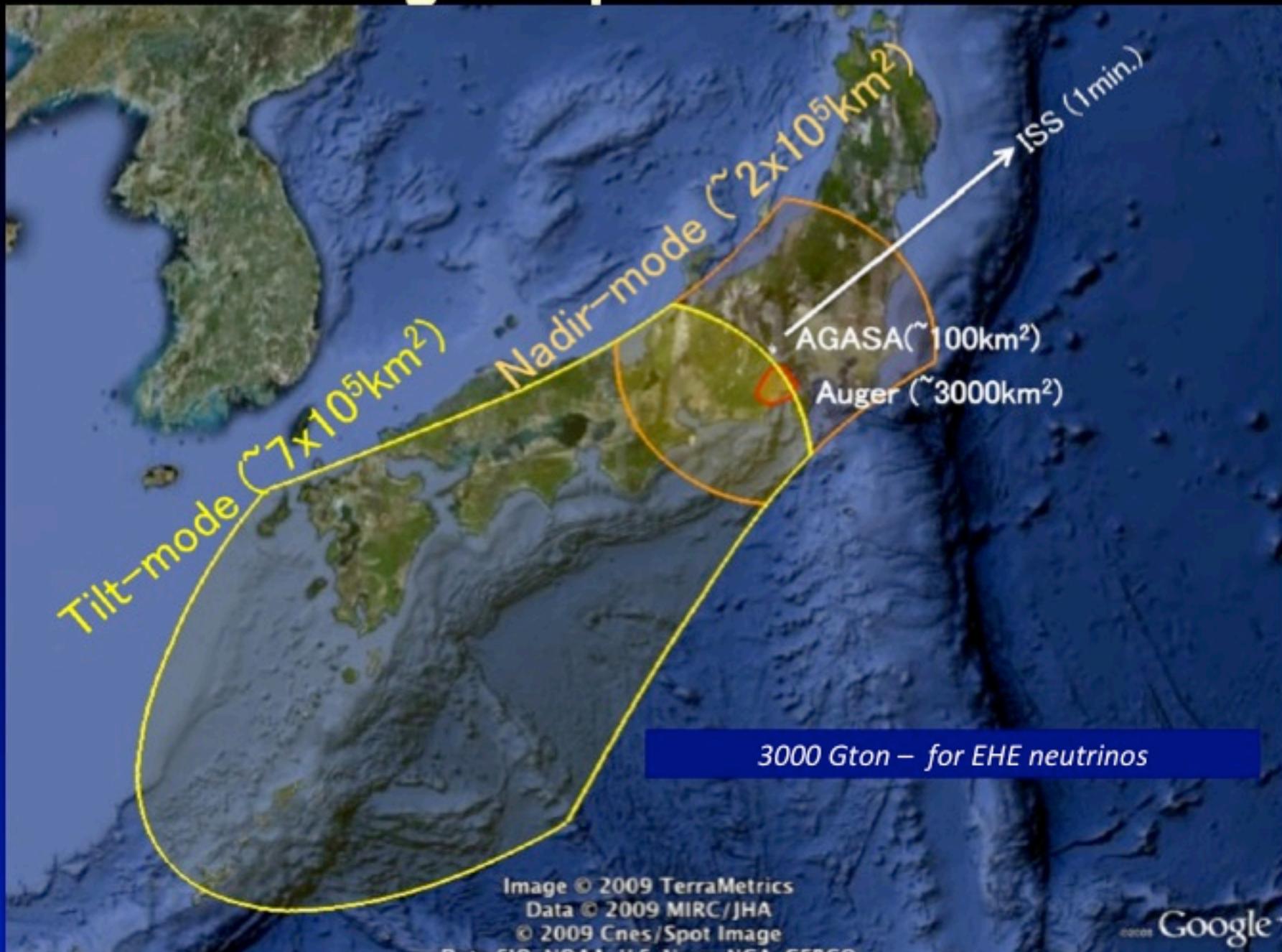
JEM-EUSO Sky Coverage



The UV Telescope Parameters

Parameter	Value
Field of View	$\pm 30^\circ$
Monitored Area	$>1.3 \times 10^5 \text{ km}^2$
Telescope aperture	$\geq 2.5 \text{ m}$
Operational wavelength	300-400 nm
Resolution in angle	0.075°
Focal Plane Area	4.5 m^2
Pixel Size	<3 mm
Number of Pixels	$\approx 3 \times 10^5$
Pixel size on ground	$\approx 560 \text{ m}$
Time Resolution	$2.5 \mu\text{s}$
Dead Time	<3%
Photo-detector Efficiency	$\geq 20\%$

Huge Exposure Area





Payload

DAQ Electronics



Support Structure



Focal Surface Detector



Housekeeping



Simulation : Worldwide



Telescope Structure



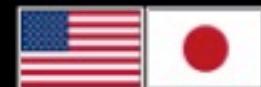
BUS System : JAXA



Atmospheric Monitoring



Optics



Rear Fresnel Lens

Precision Fresnel lens

Iris

Front Fresnel lens

On-board Calibration



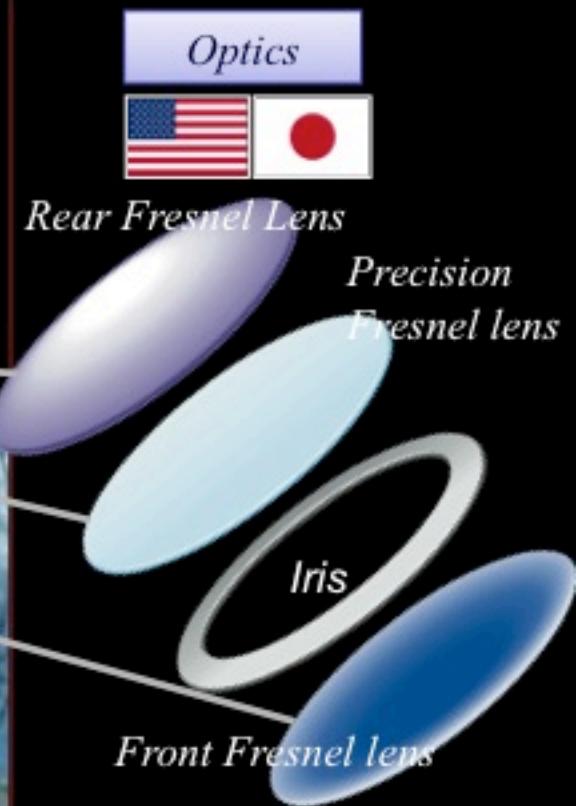
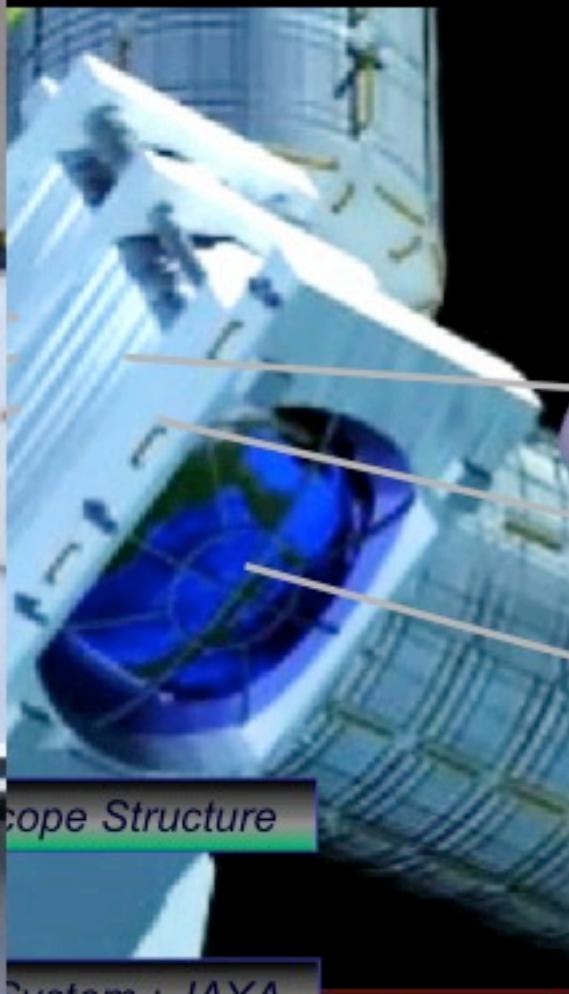
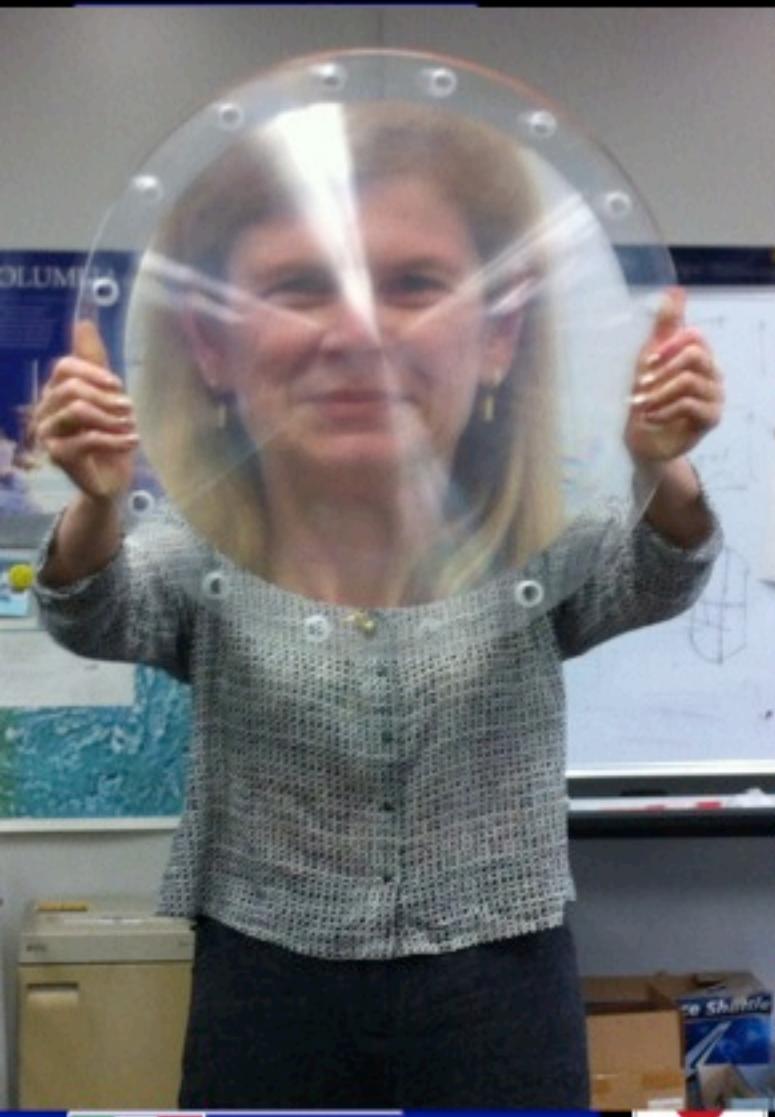
Ground Based Calibration



Ground Support Equipment



Payload



On-board Calibration



Ground Based Calibration



Ground Support Equipment



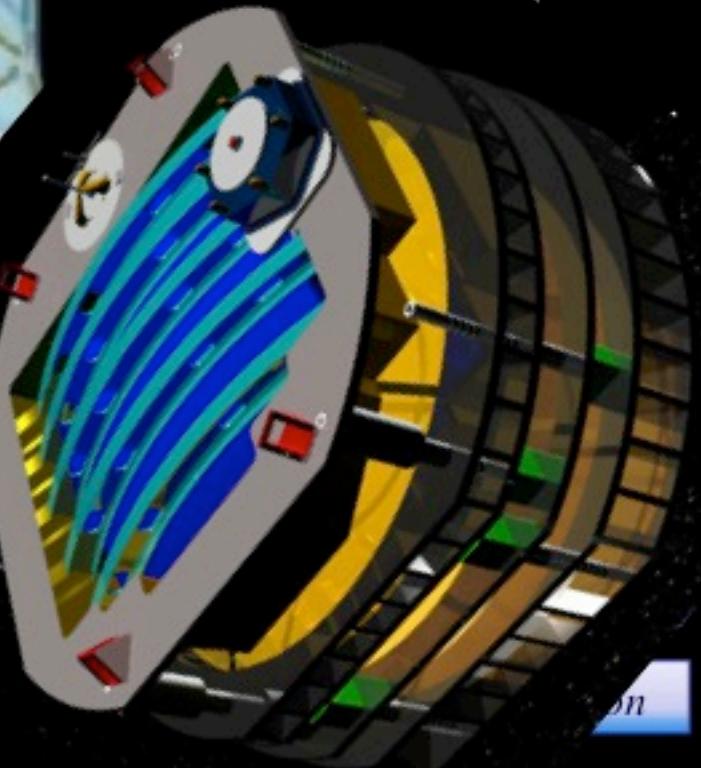
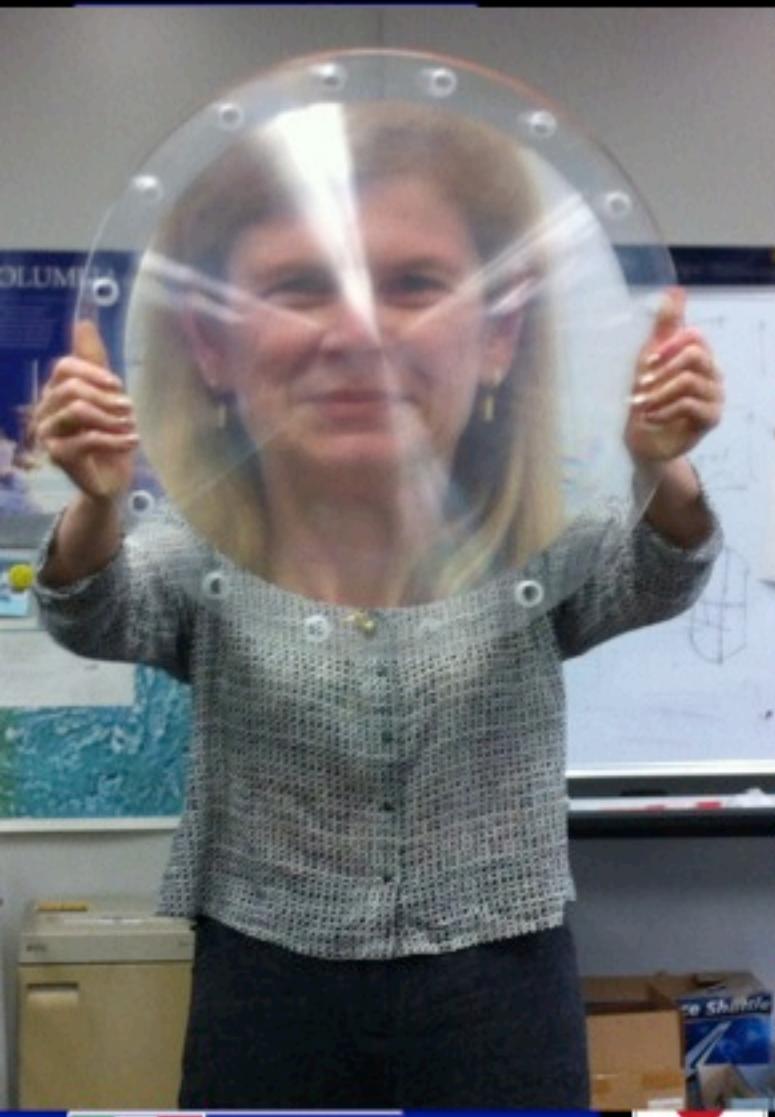
Simulation : Worldwide



Atmospheric Monitoring



Payload



Simulation : Worldwide



Atmospheric Monitoring

Ground

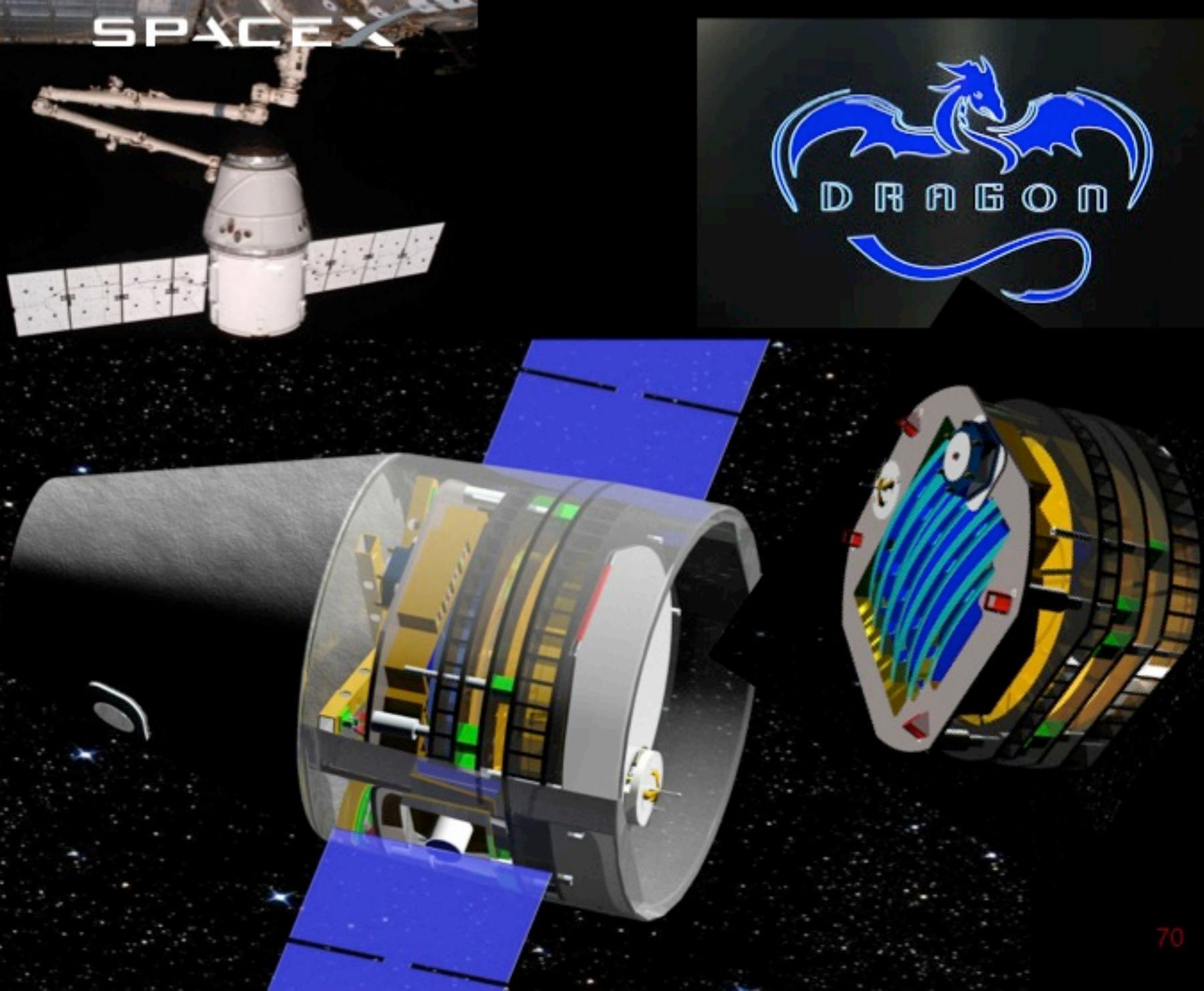
Station

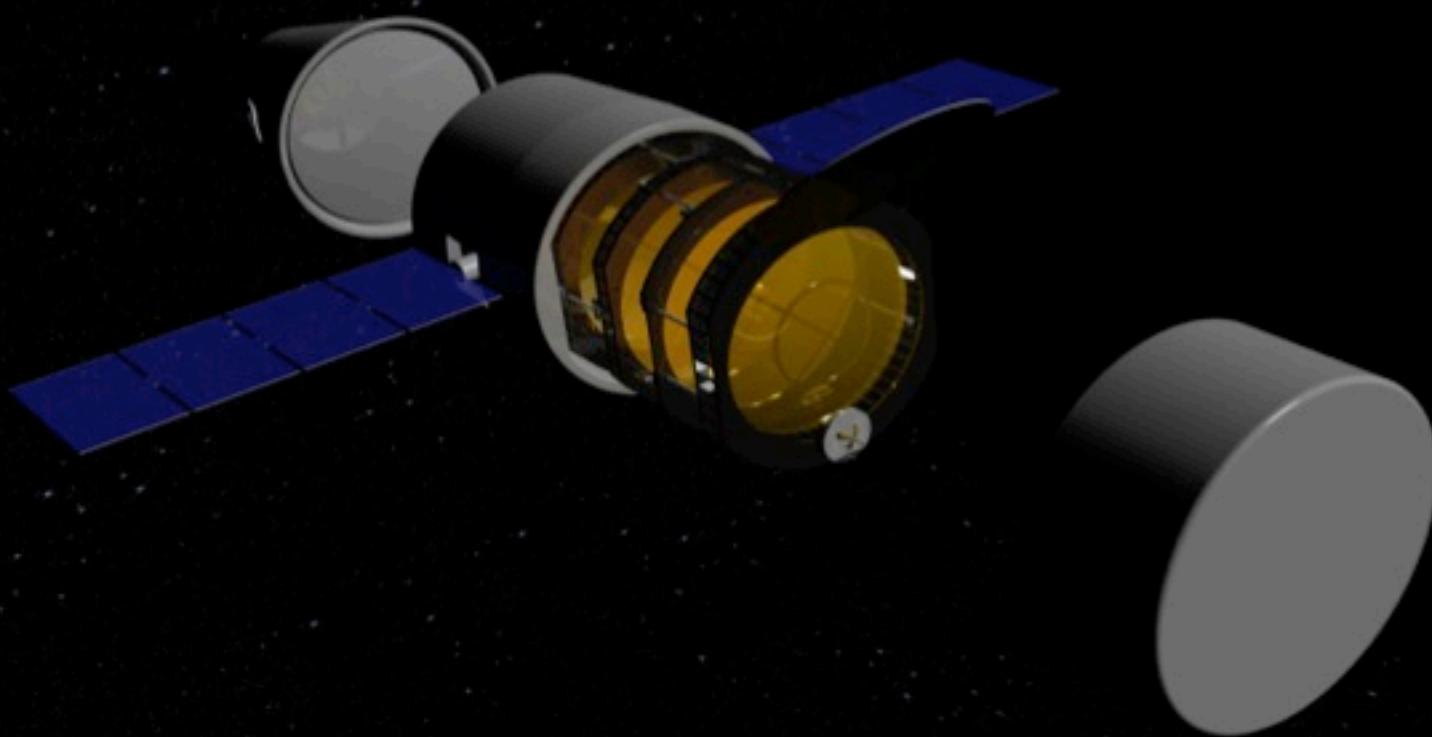


Ground Support Equipment



SPACEX

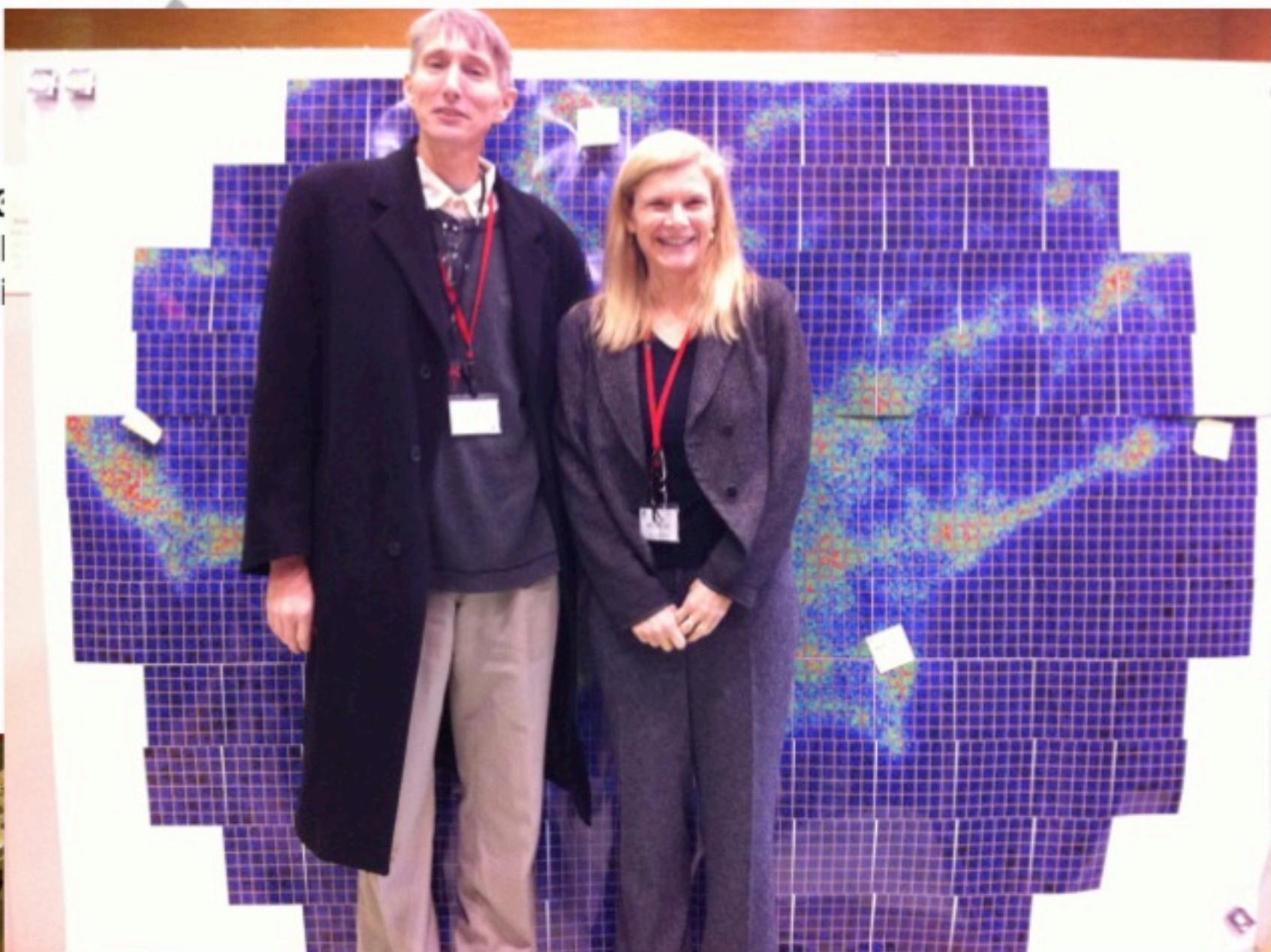




Science Instrument



Focal Surface Detector



493
MAP1
(8x8 pi

12

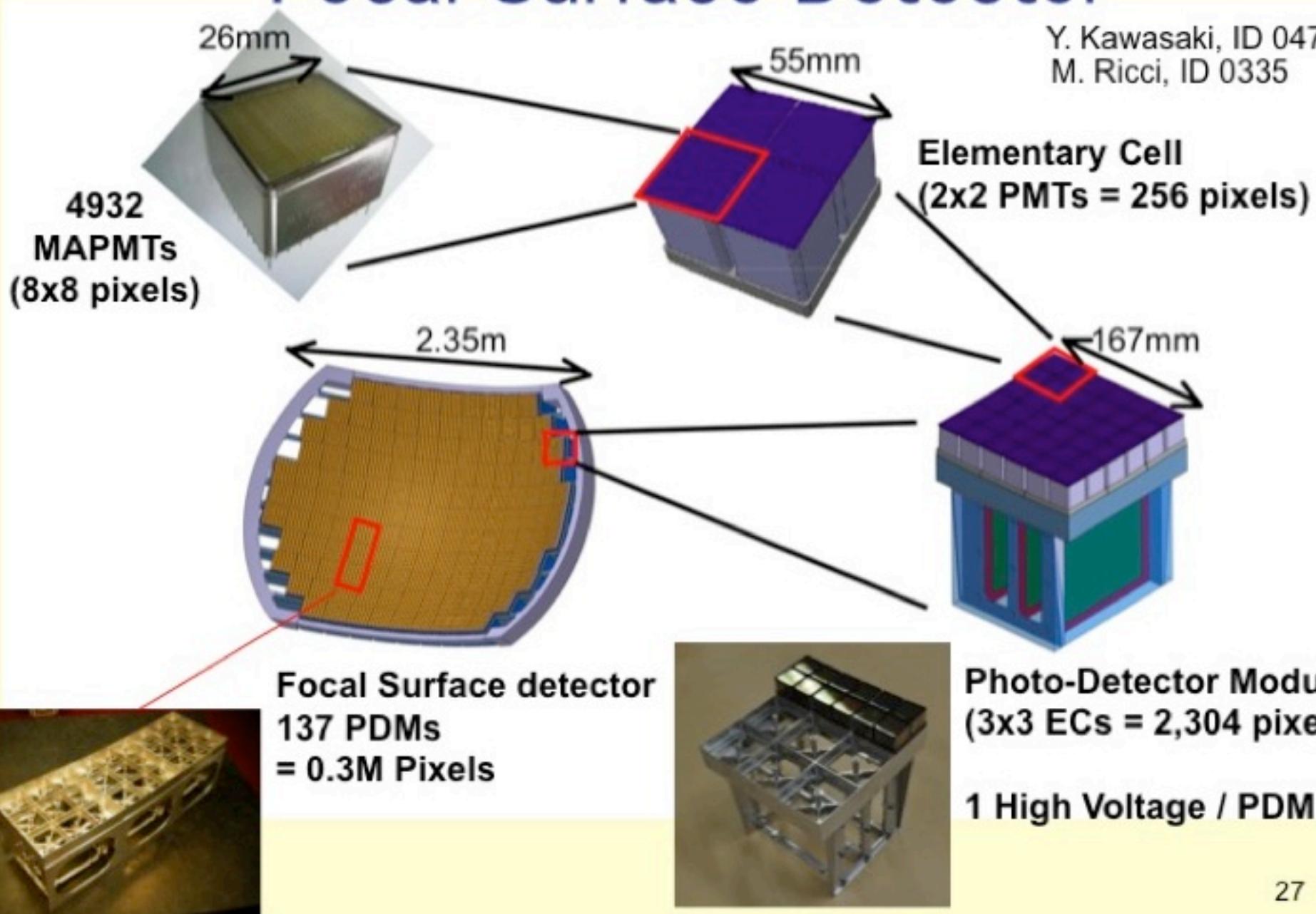
le
Is

The UV Telescope Parameters

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

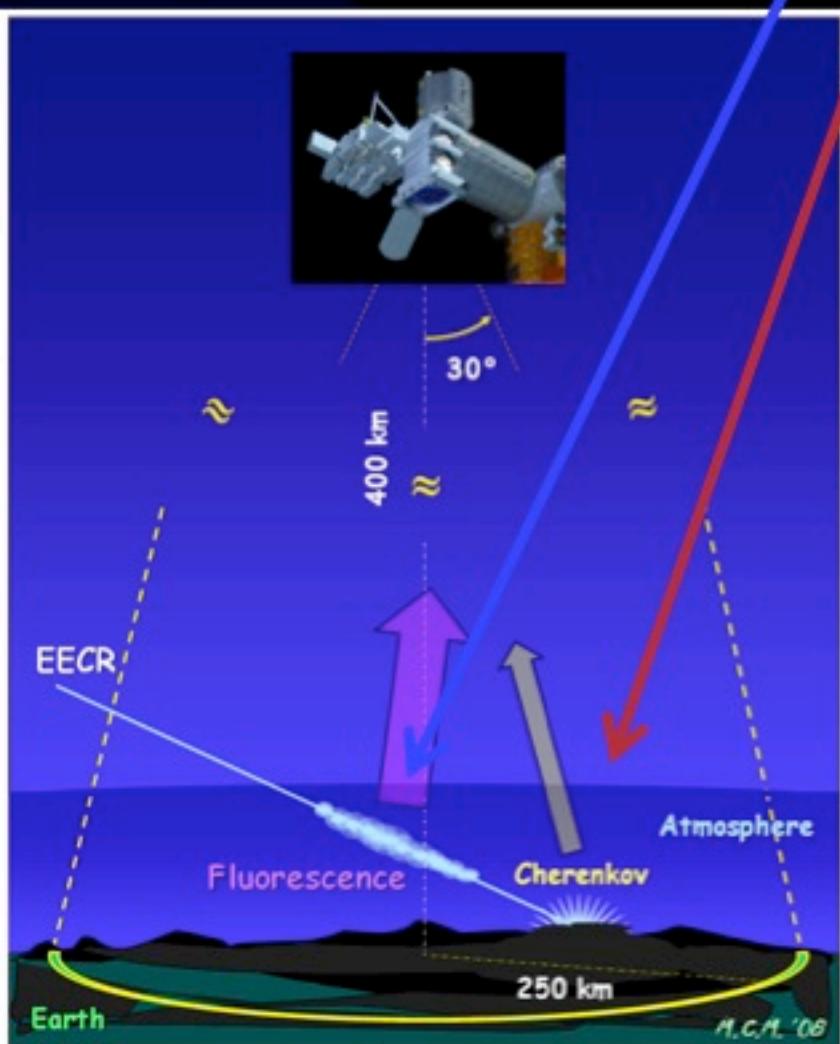
Focal Surface Detector

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

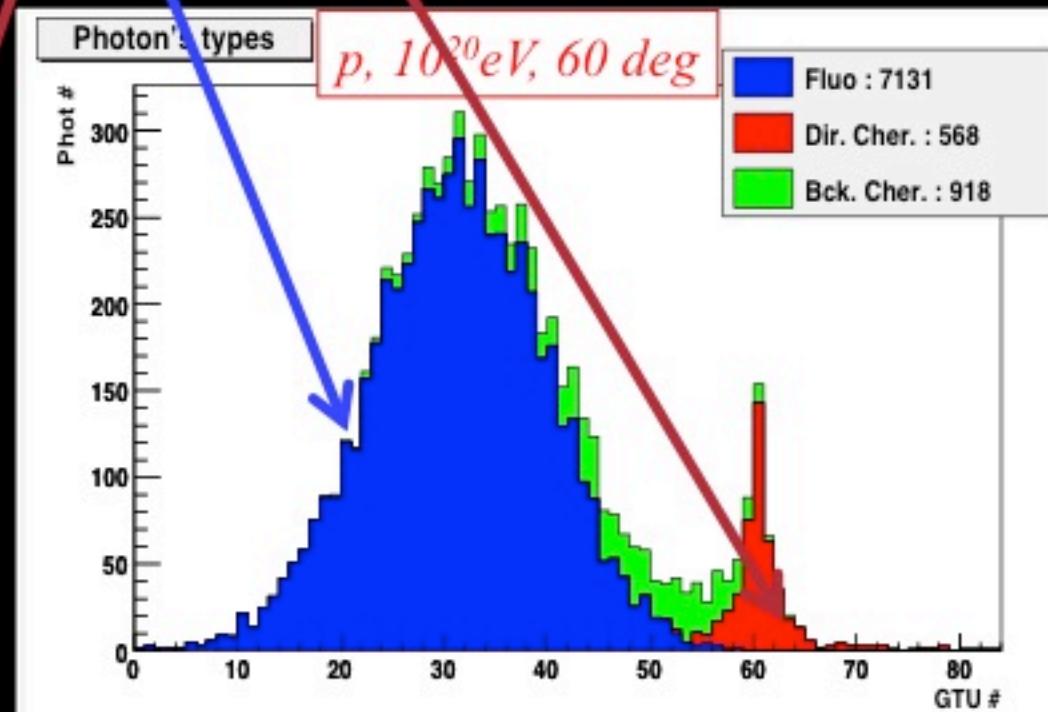


FAST SIGNAL

duration 50 - 150 μ s



- a) Fluorescence
- b) Scattered Cherenkov
- c) Direct (diffusively reflected Cherenkov)



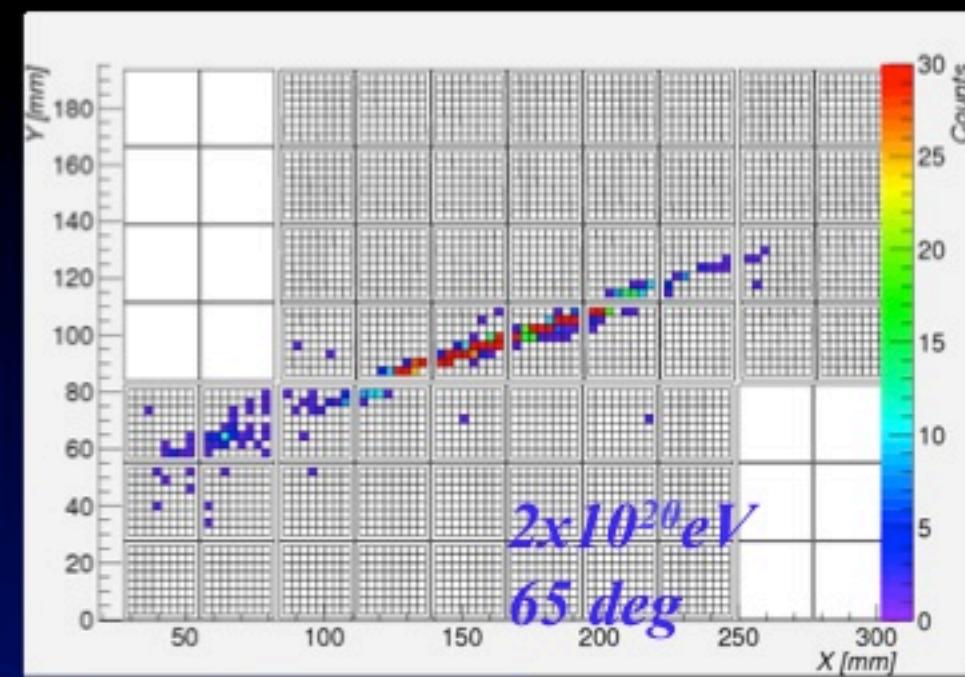
1 GTU gate time units = 2.5 μ s

76

Background: 500 /m² sr ns

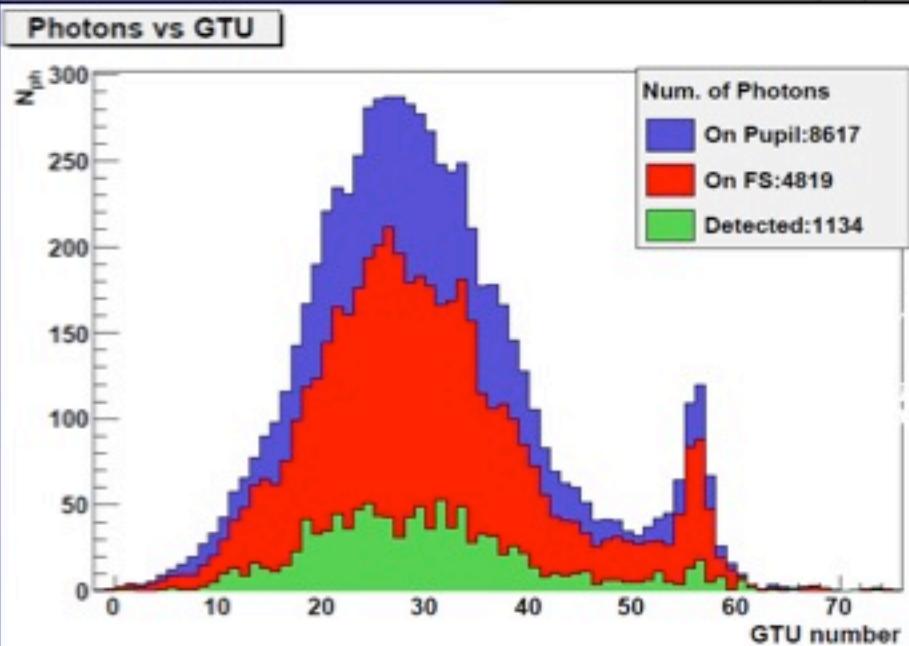
Result of end-to-end simulation

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



Simulated air shower image on the focal surface detector.

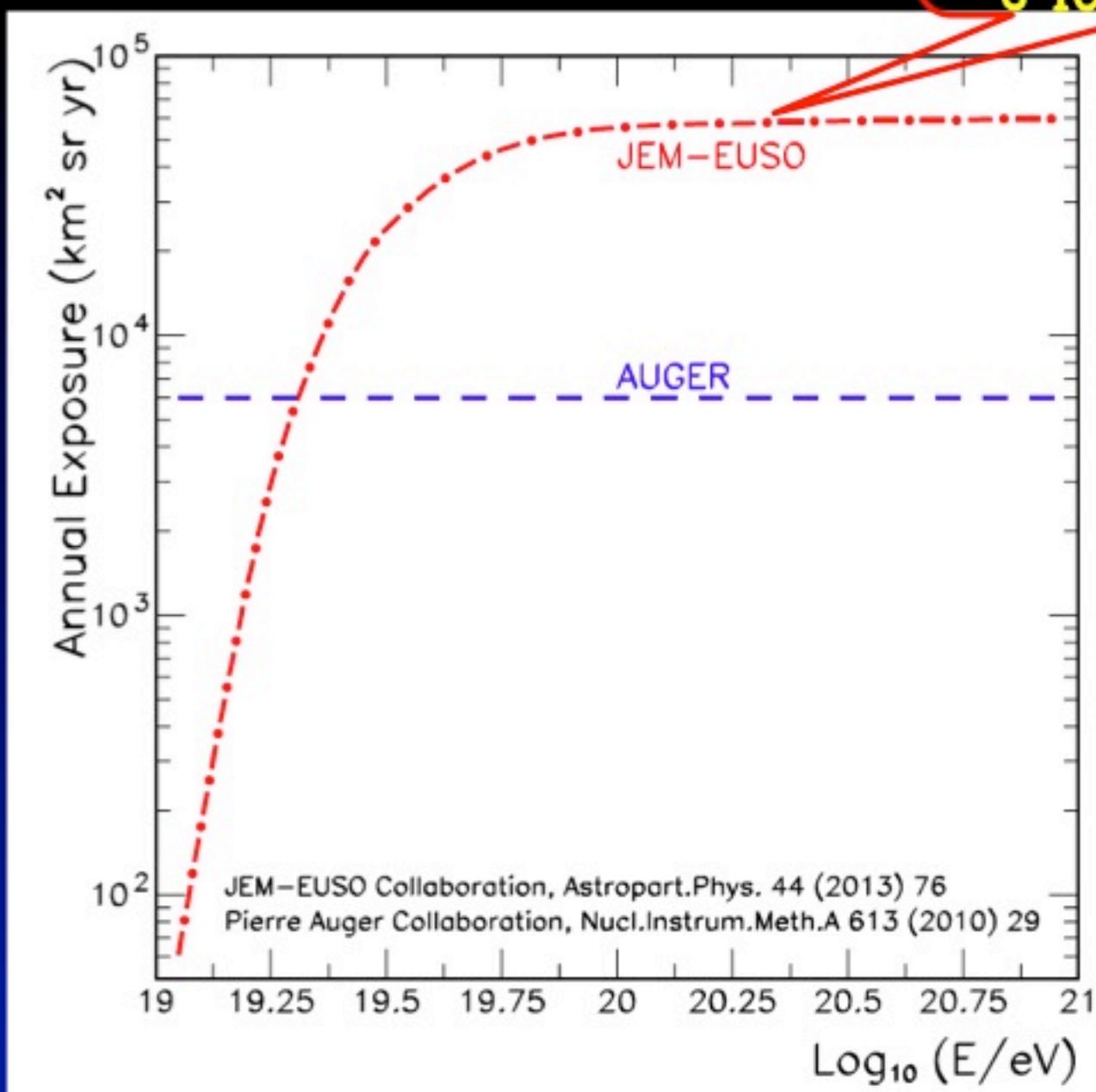
3×10^5 pixels



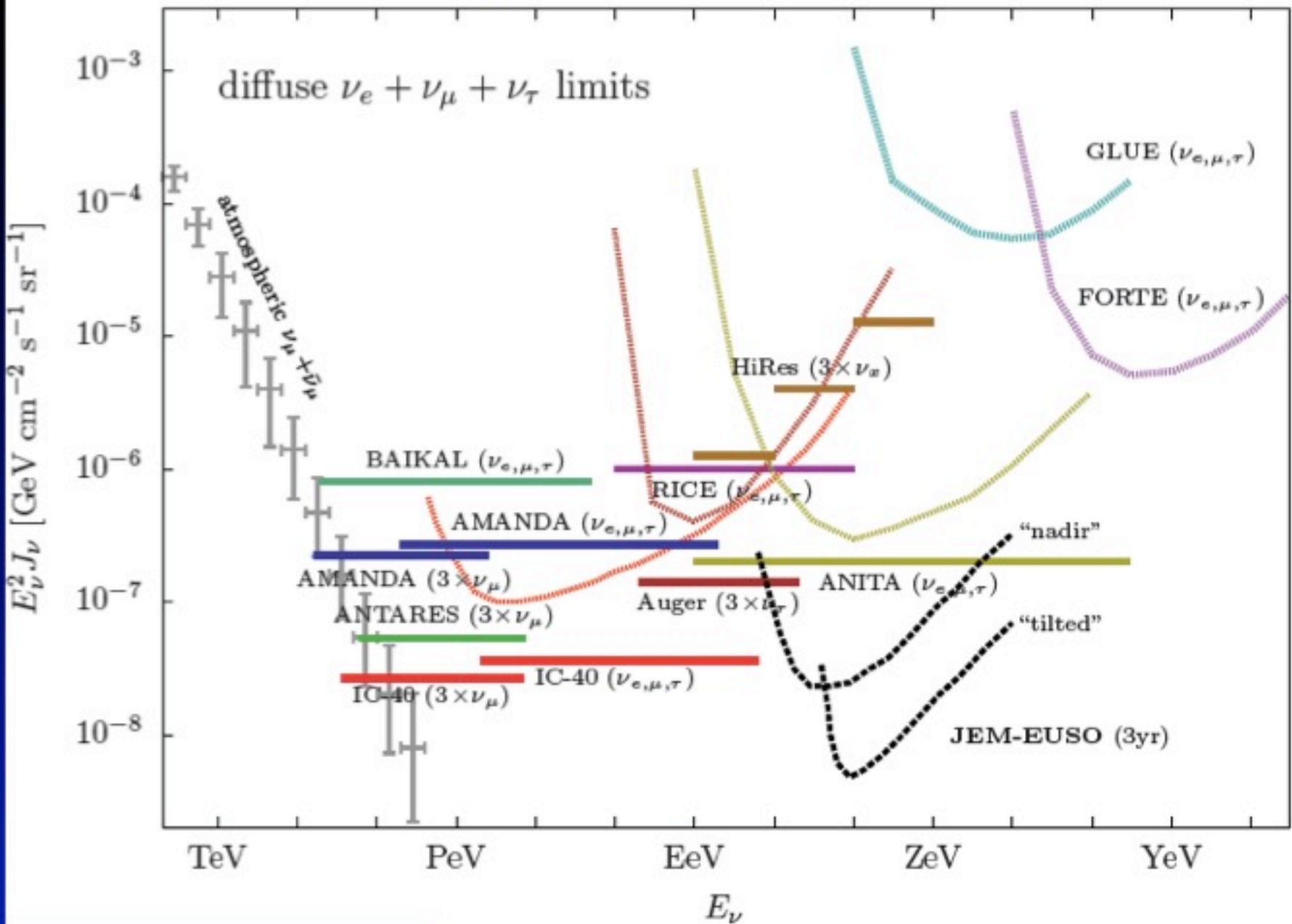
Detected photoelectrons are recorded every Gate Time Unit (GTU) of $2.5\mu\text{s}$ continuously.

JEM-EUSO

annual exposure =
10 × Auger
 $6 \times 10^4 \text{ km}^2 \text{ sr yr}$



Serendipity: ZeV neutrinos



JEM-EUSO in USA



University of Chicago, PI Institution

Colorado School of Mines

Fermilab

Marshall Space Flight Center

University of Alabama in Huntsville

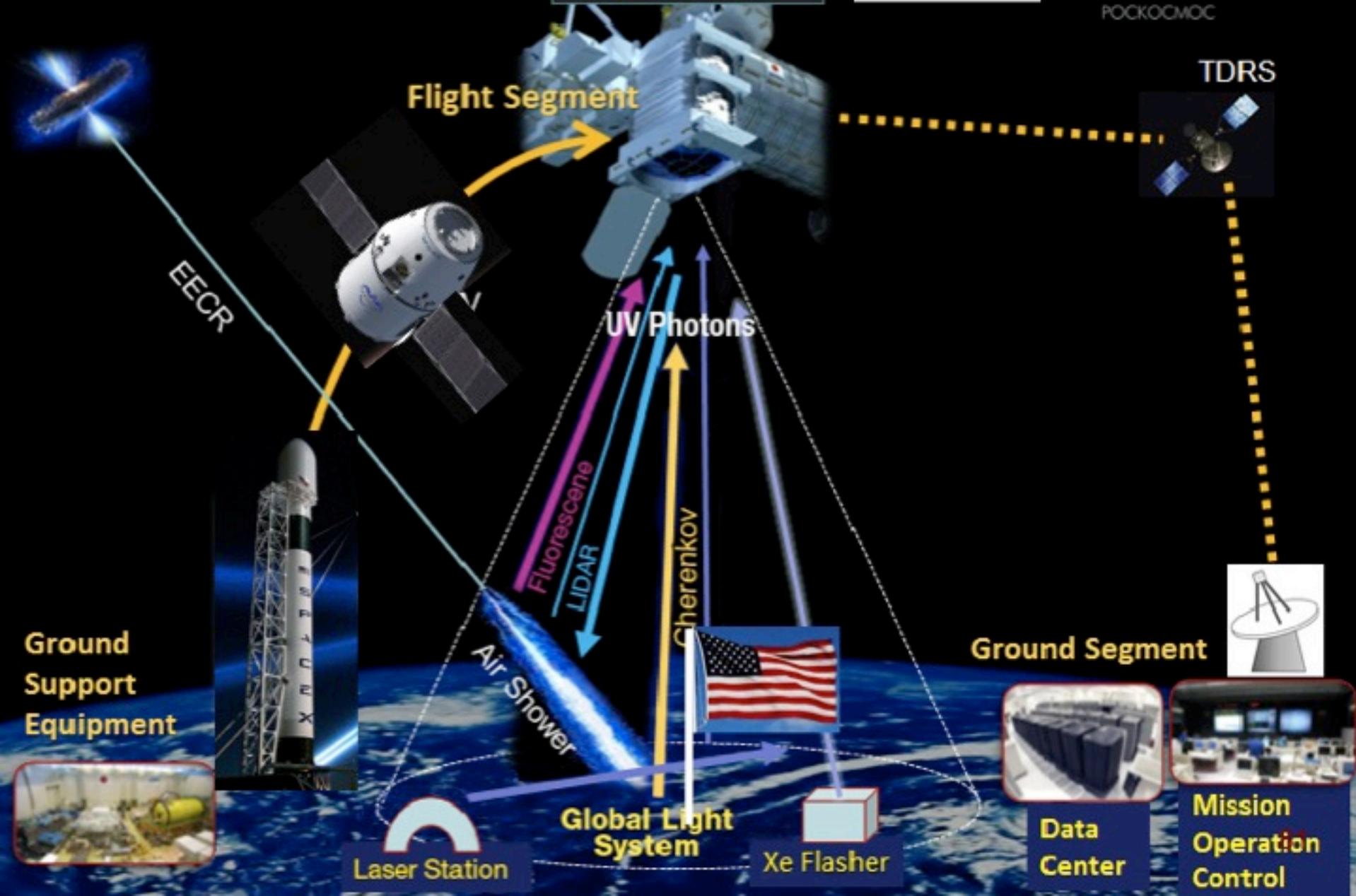
University of California, Berkeley

University of California, Los Angeles

University of Kansas, Wichita

University of Wisconsin-Milwaukee

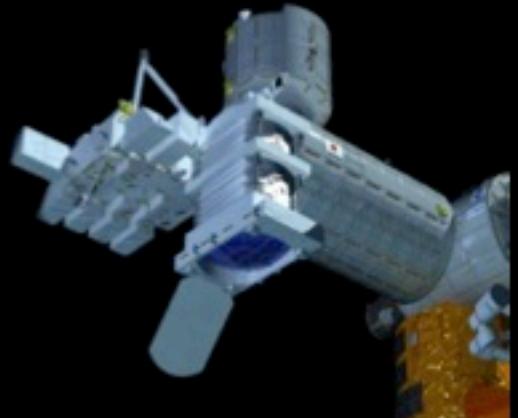
Vanderbilt University





JEM-EUSO in USA

Global Light System



25 4:06 PM

JEM EUSO GLS Some Candidate Locations



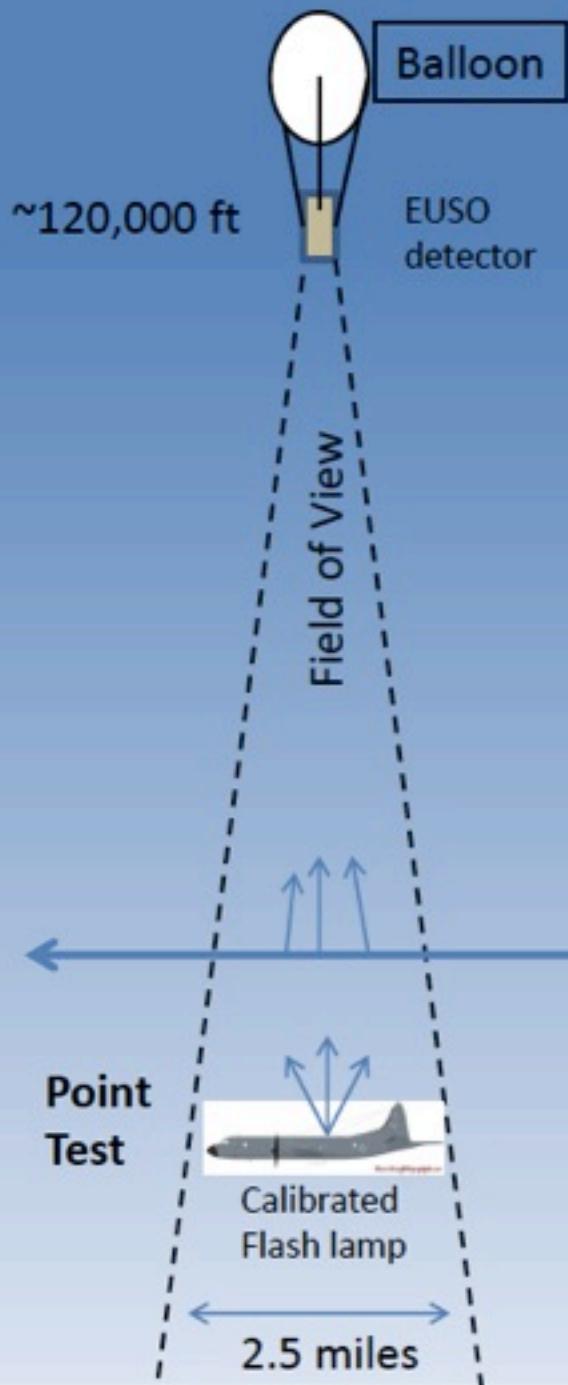
Location	Latitude	Elevation	Location	Latitude	Elevation
Jungfraujoch (Switzerland)	47°N	3.9 km	Chacaltaya (Bolivia)	16° S	5.3 km
Mt. Washington (NH, USA)	44° N	1.9 km	La Reunion (Madagascar)	21° S	1.0 km
Alma-Ata (Kazakhstan)	44° N	3.0 km	Cerro Tololo (Chile)	30° S	2.2 km
Climax (CO, USA)	39° N	3.5 km	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

a pathfinder mission for JEM-EUSO
E U S O - B A L L O O N



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)

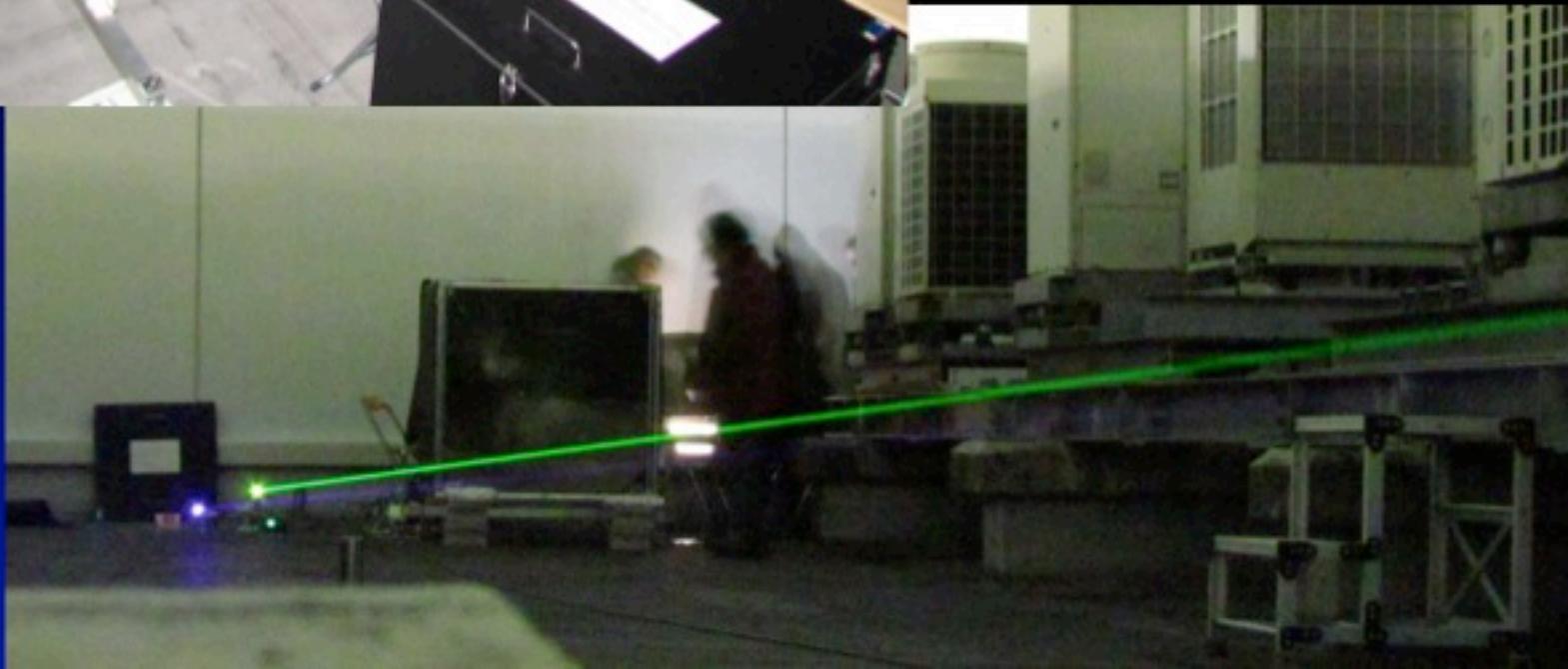
Fly aircraft at altitudes between 2,000 and 10,000 feet.



Calibrated UV laser

Track Test

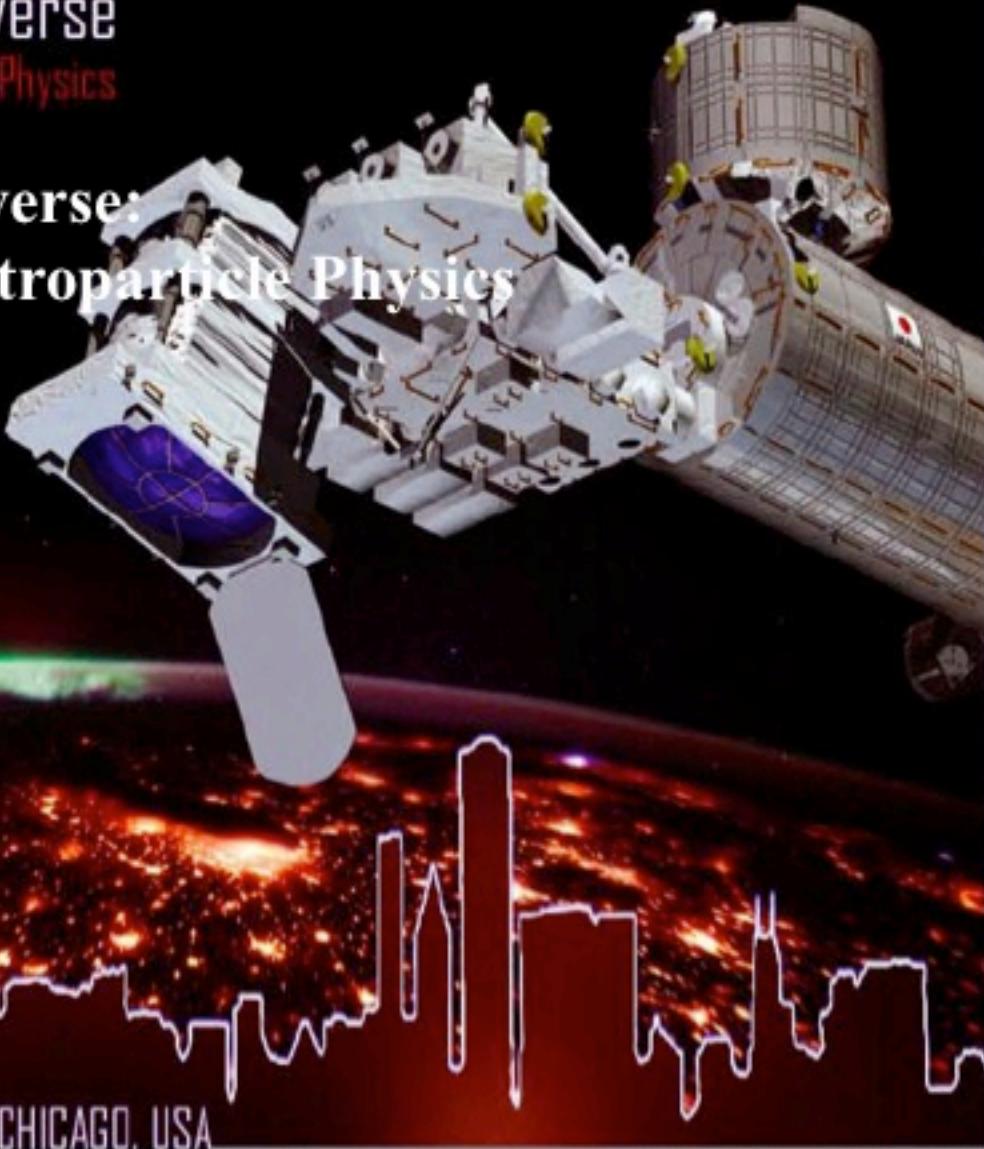
EUSO - Telescope Array



Imaging the Extreme Universe

Solid-state cameras for Astroparticle Physics

Imaging the Extreme Universe: Solid-state cameras for Astroparticle Physics

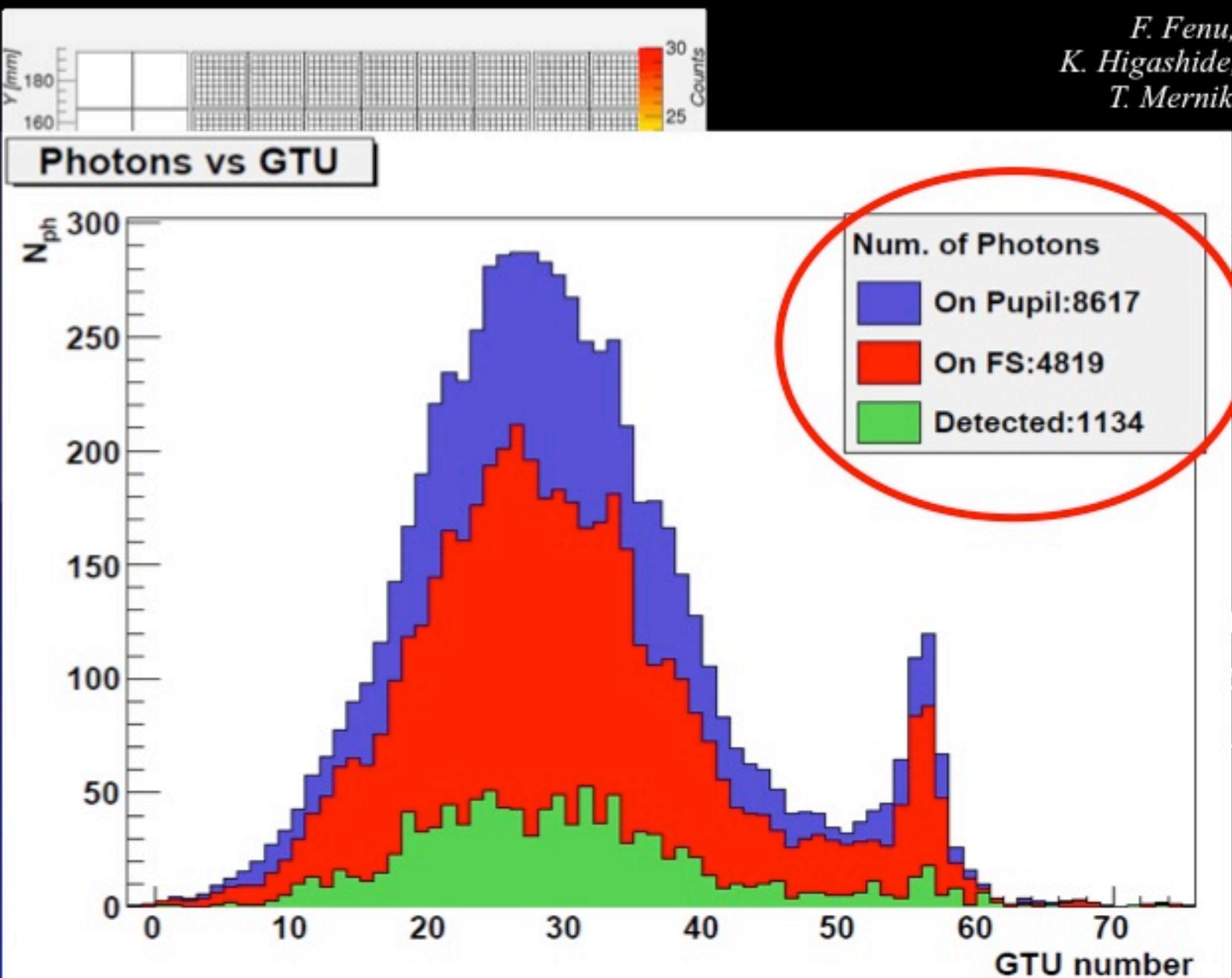


May 9-10, 2013 - CHICAGO, USA



Result of end-to-end simulation

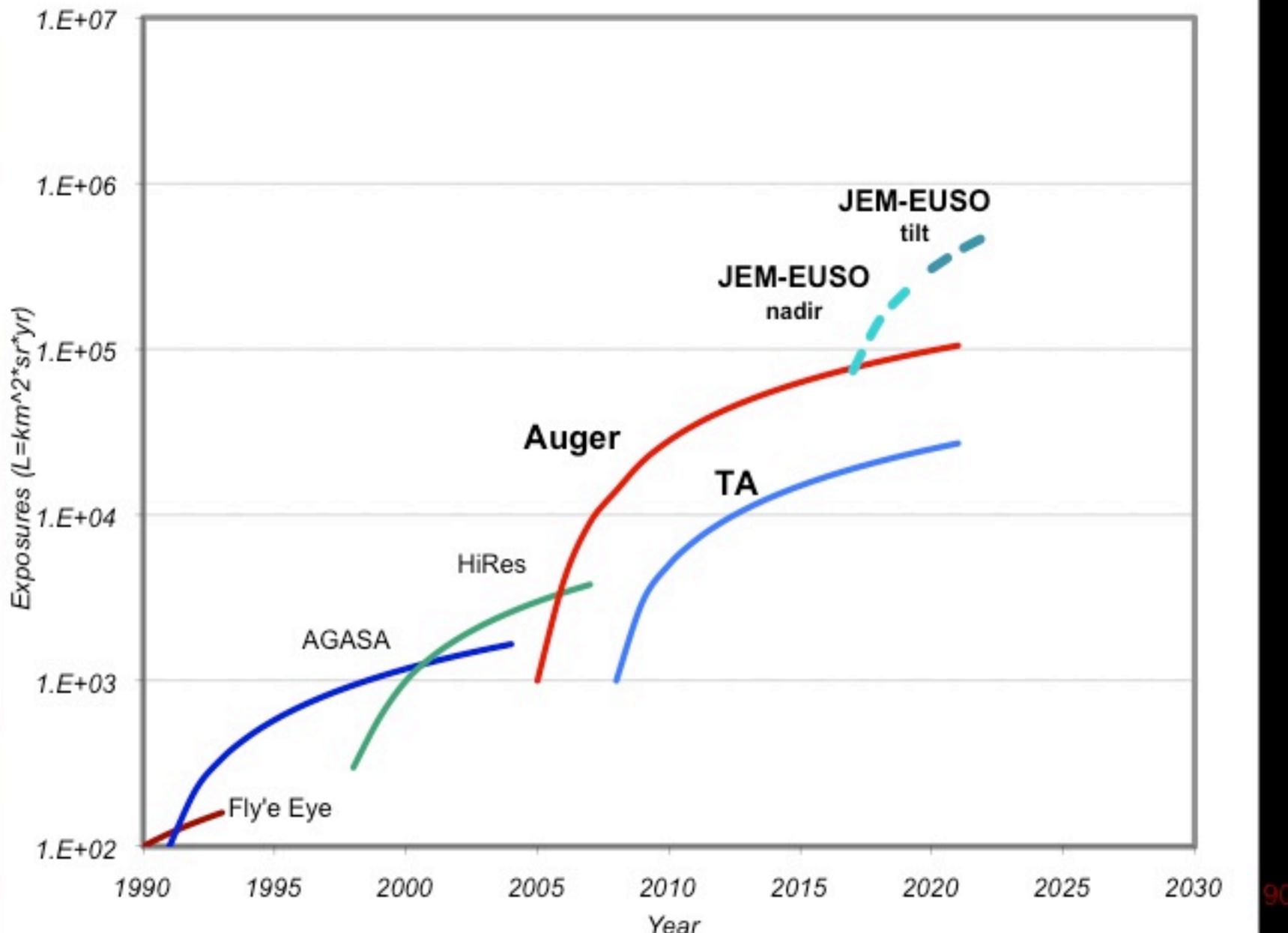
F. Fenu, ID 0829
K. Higashide, ID 1240
T. Mernik, ID 0633

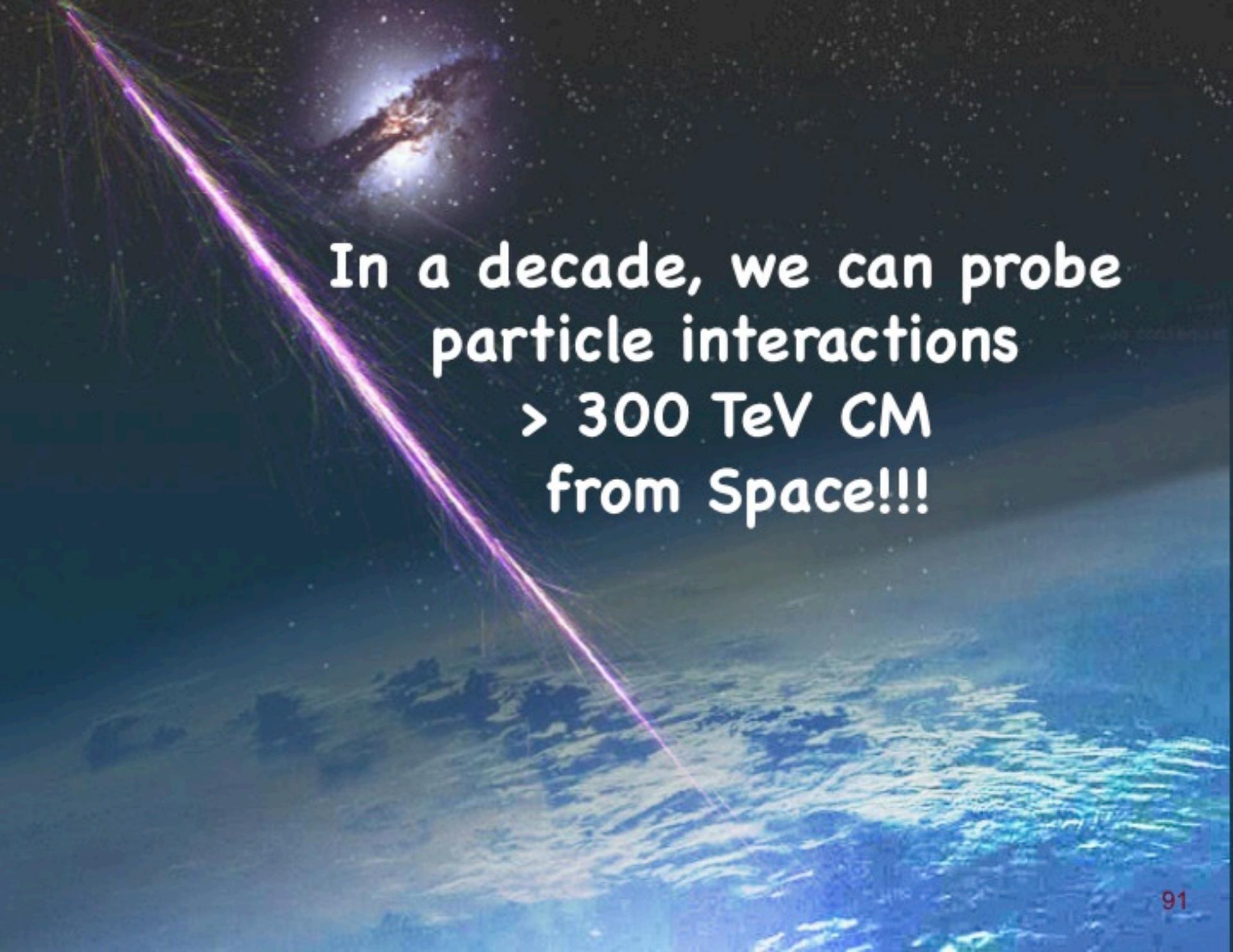


JEM-EUSO goals

- 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 probe
particle interactions
 $> 300 \text{ TeV CM}$
from Space!!!



THANKS