Large Scale Calorimeters for High Energy Astrophysics

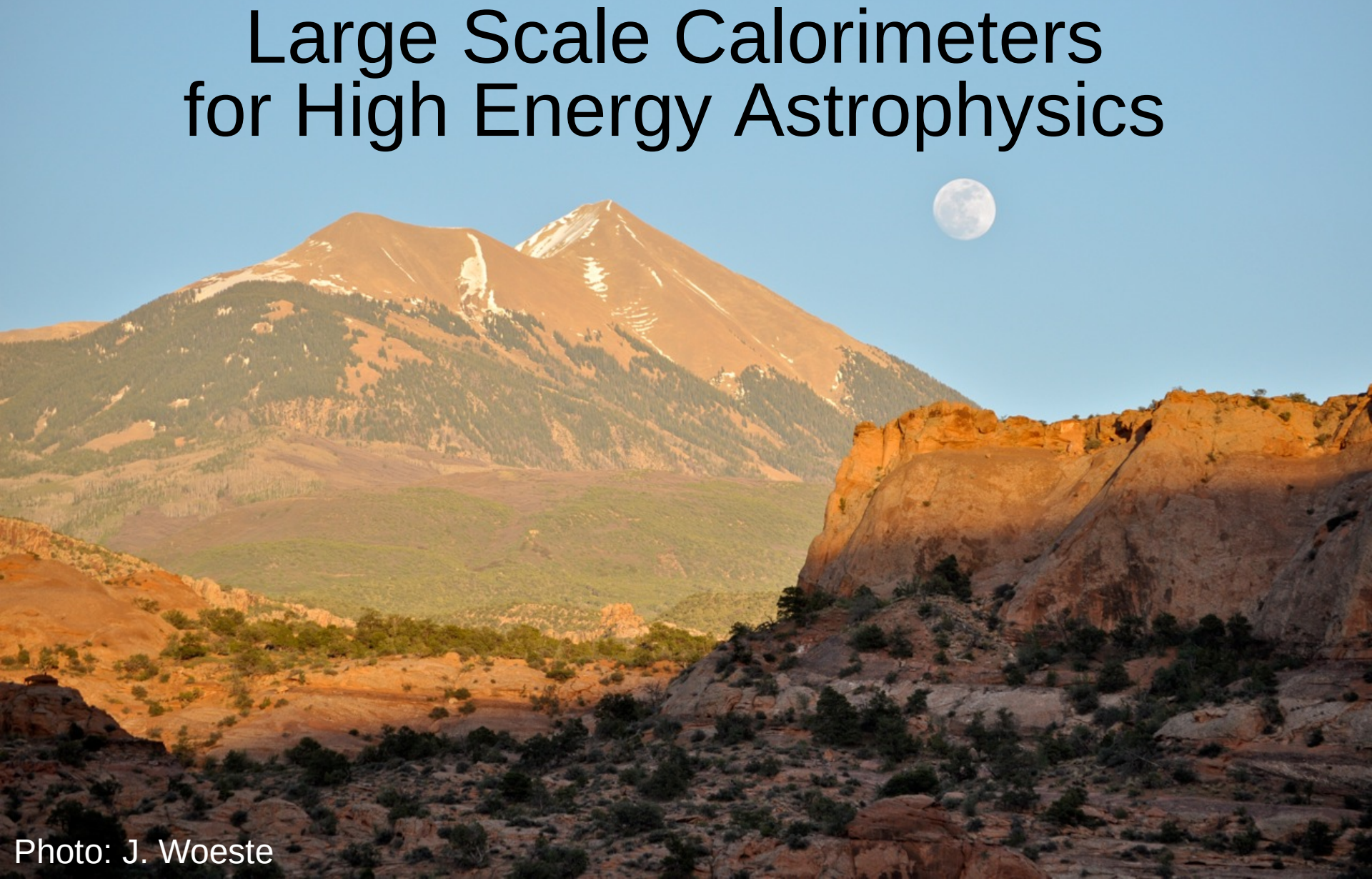


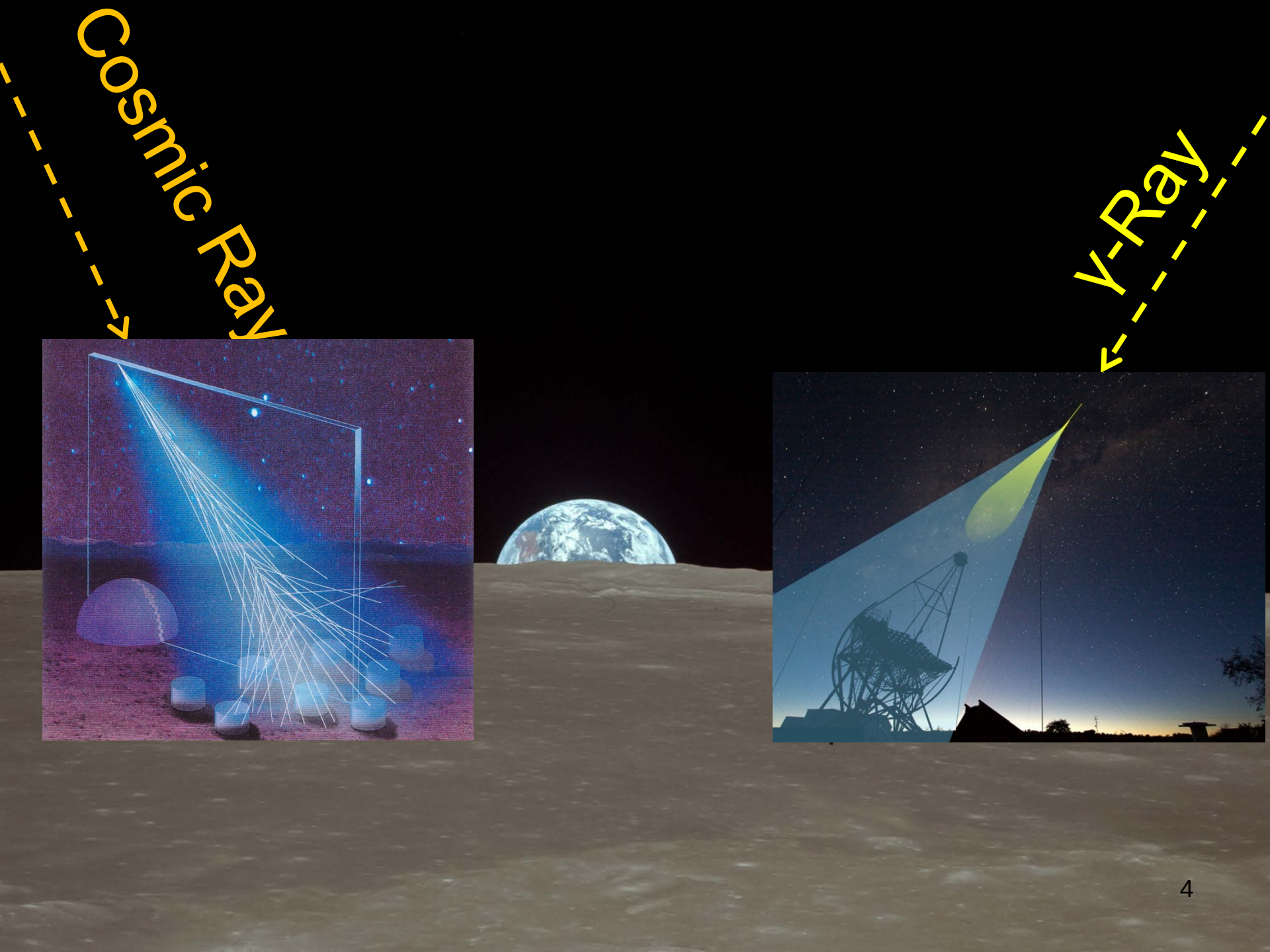
Photo: J. Woeste

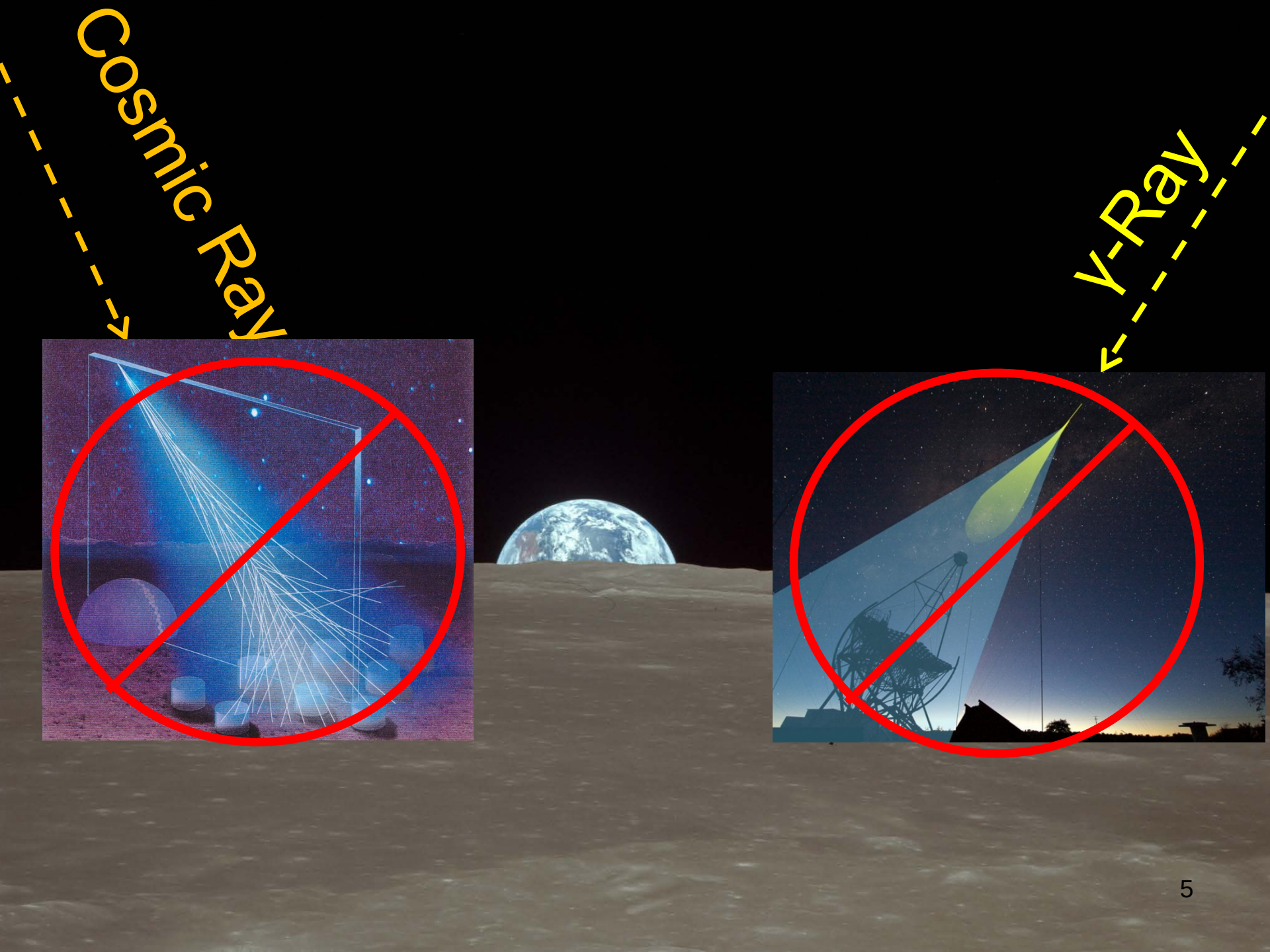
Lawrence Wiencke
Colorado School of Mines
lwiencke@mines.edu

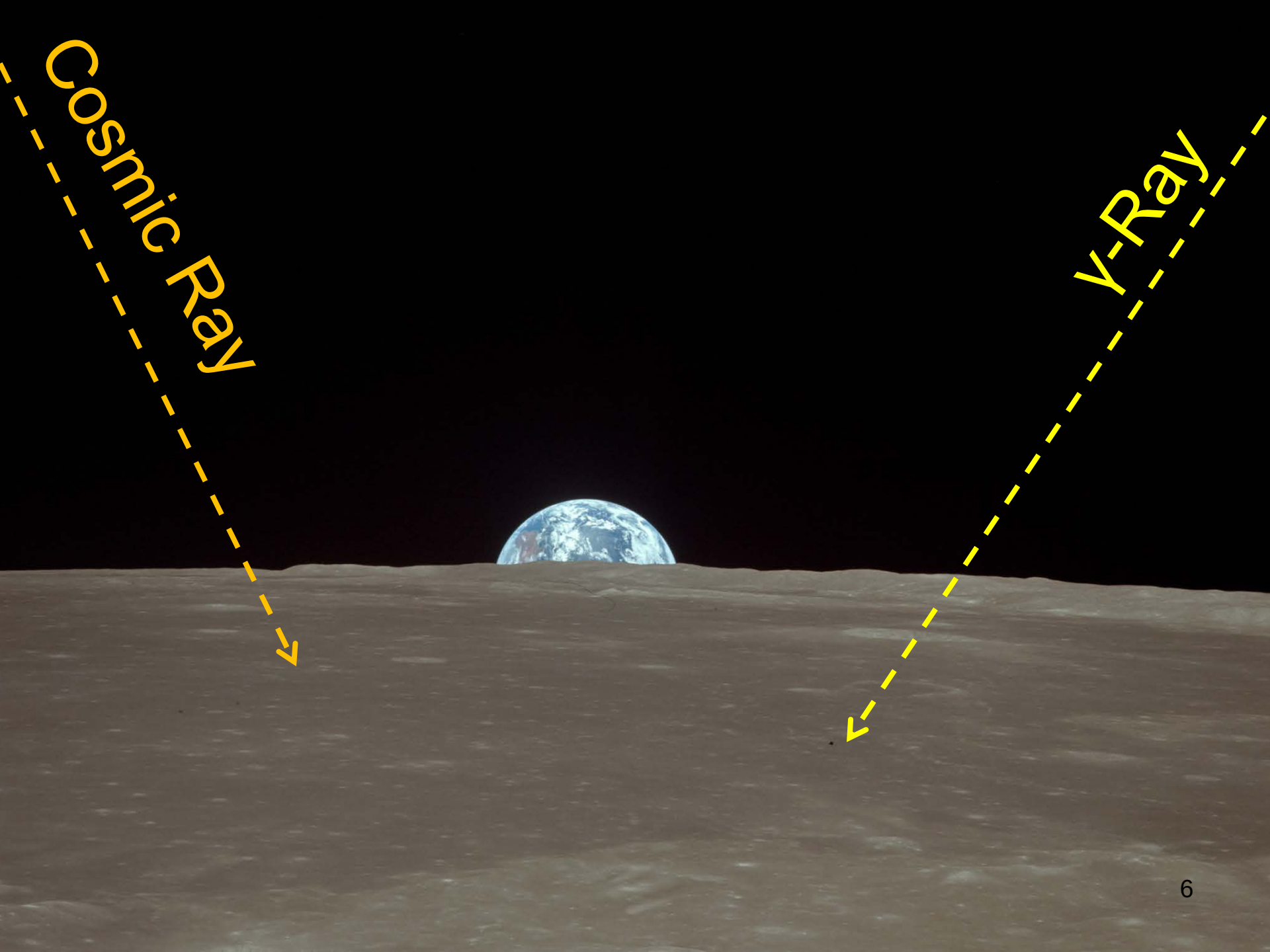
CPAD Instrument Frontier Meeting
UT Arlington Oct 6th 2015

Earthrise Dec 24 1968 Bill Anders

Cosmic Ray
γ-Ray


Cosmic Ray
γ-Ray


Cosmic Ray
γ-Ray


Cosmic Ray
γ-Ray

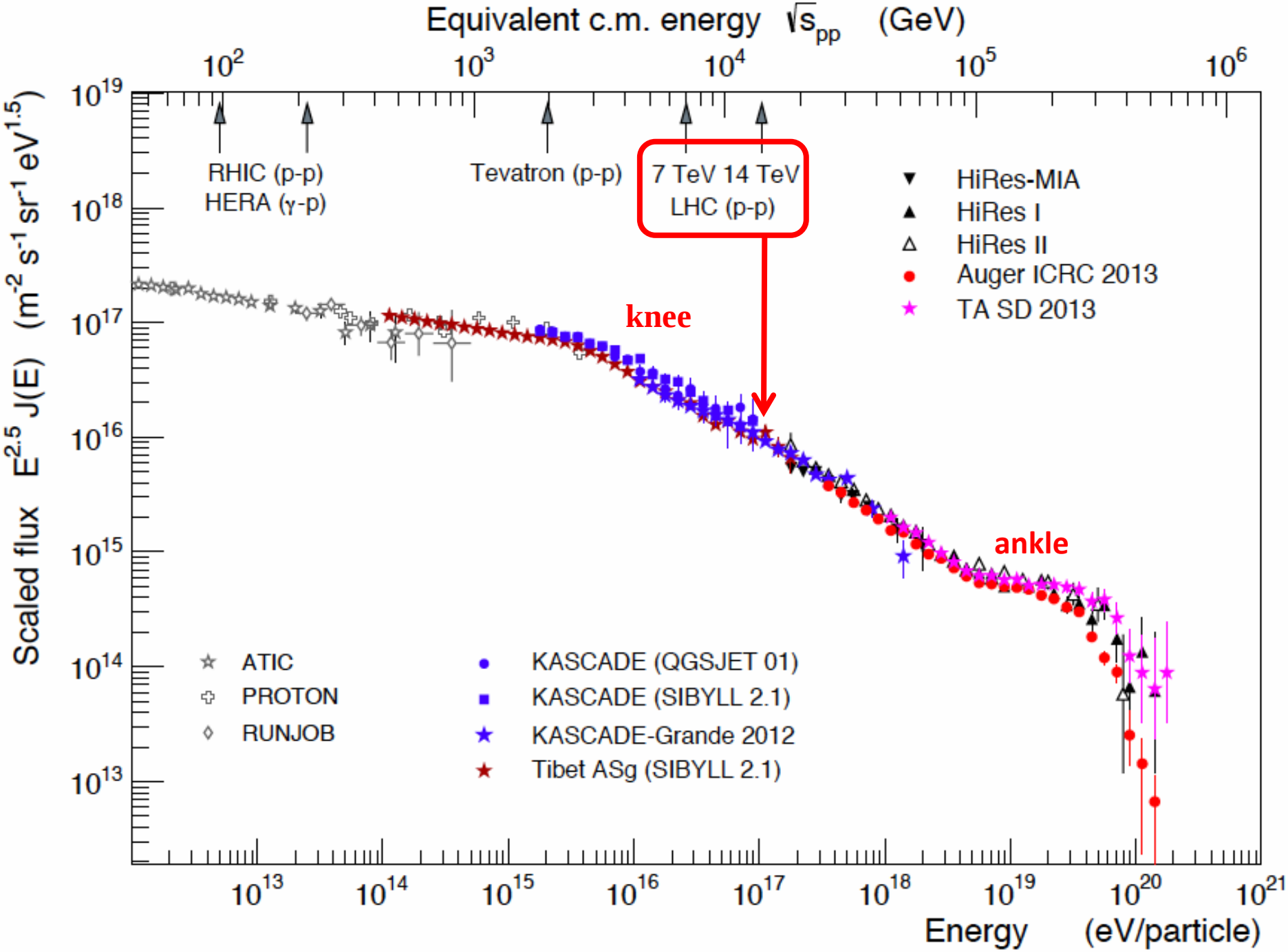
Earthrise Dec 24 1968 Bill Anders

Outline

Large Calorimeters (Ground)

Really Large Calorimeters (Space)

Technology Wish List

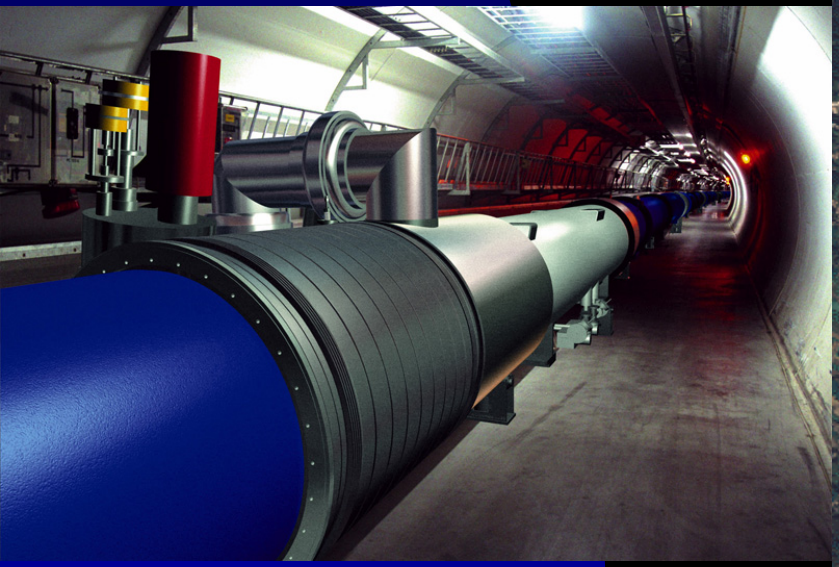

Equivalent c.m. energy √s_pp (GeV)
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
knee
ankle
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
Scaled flux E^2.5 J(E) (m^-2 s^-1 sr^-1 eV^1.5)
10^19
10^18
10^17
10^16
10^15
10^14
10^13
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
Energy (eV/particle)

Challenging Accelerators

to reach 10^{20} eV

LHC magnetic field,
radius ~ 10^{7} km (Sun - Mercury)

or 10 GT fields!

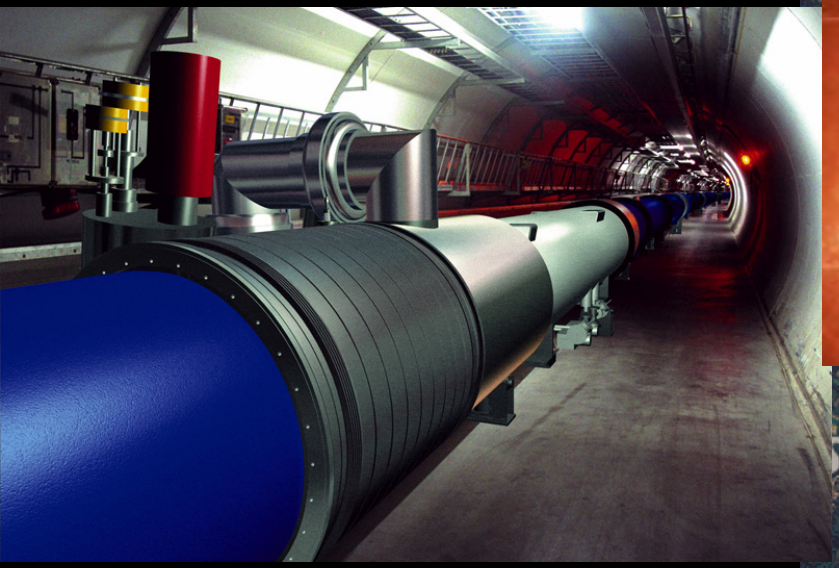


Challenging Accelerators

to reach 10^{20} eV

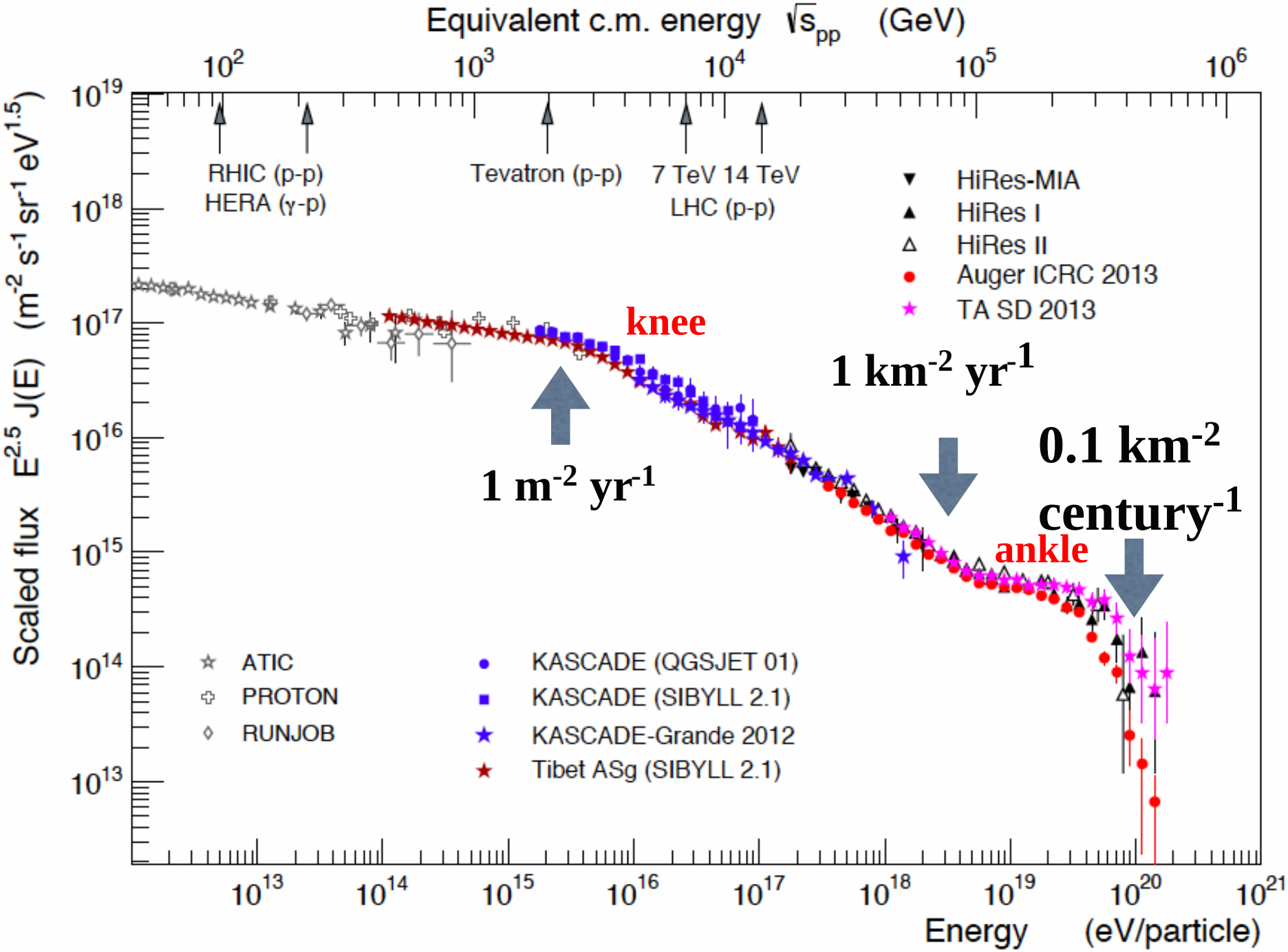
with LHC magnetic field,
radius ~ 10^7 km (Sun - Mercury)

or **10 GT** magnets!



8.4 Tesla

27 km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7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
knee
1 km^-2 yr^-1
1 m^-2 yr^-1
0.1 km^-2 century^-1
ankle
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
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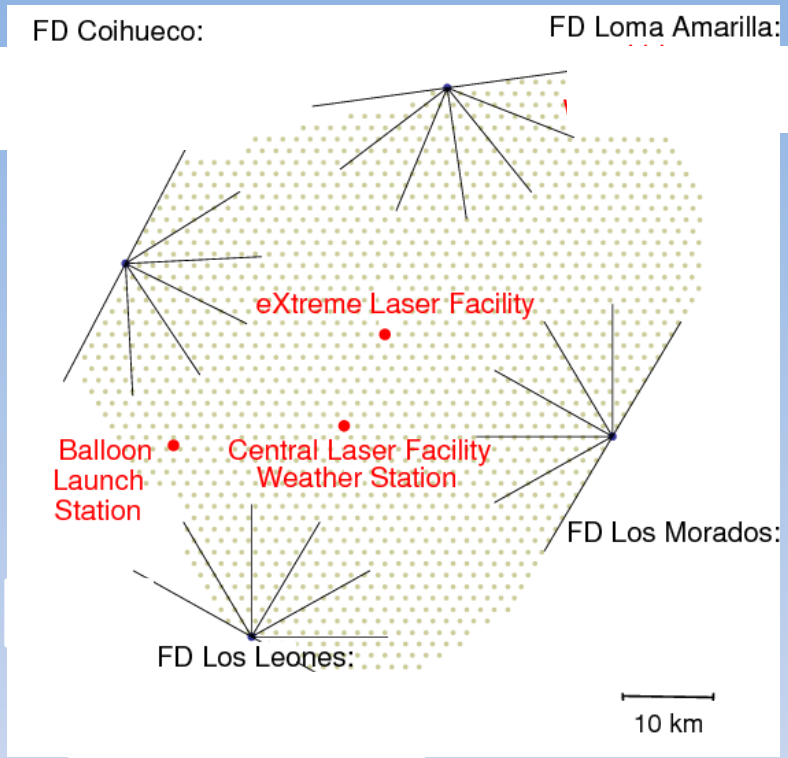
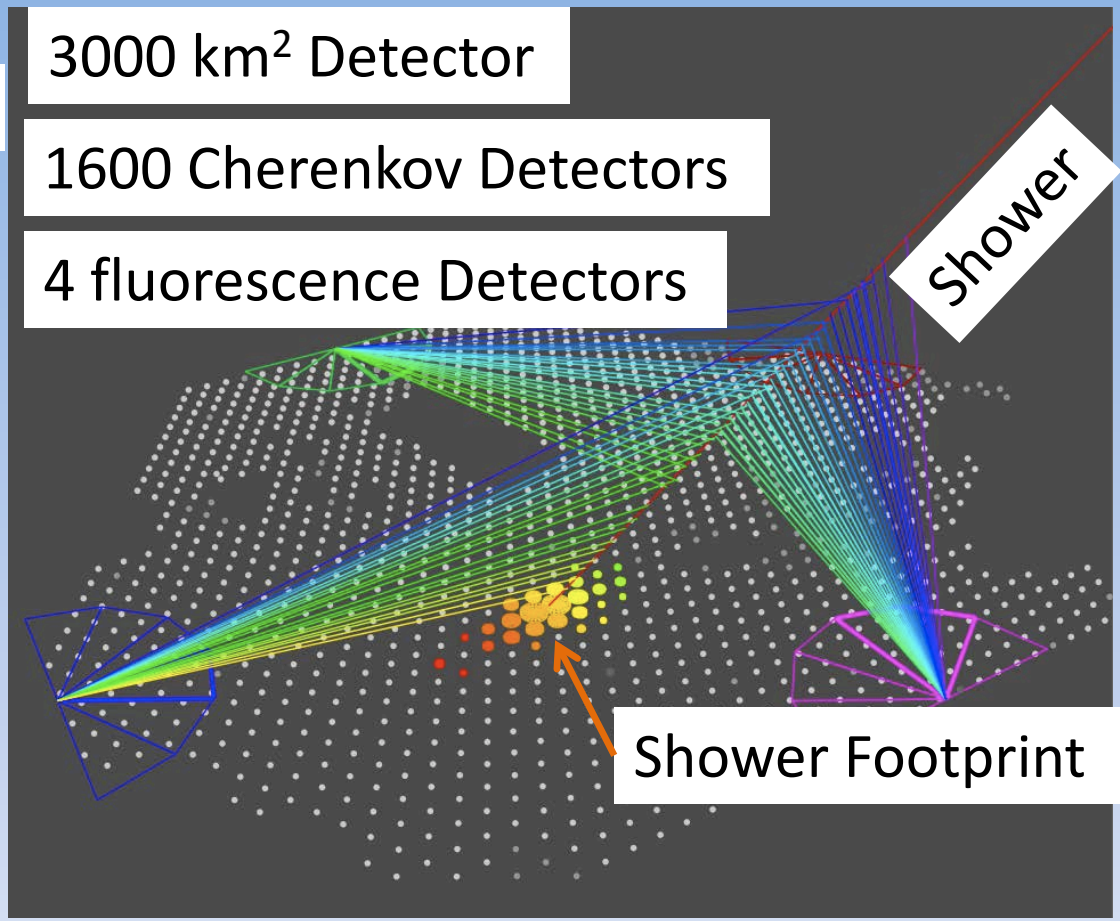
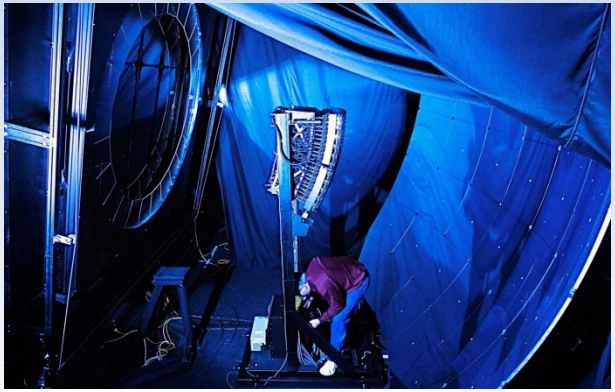
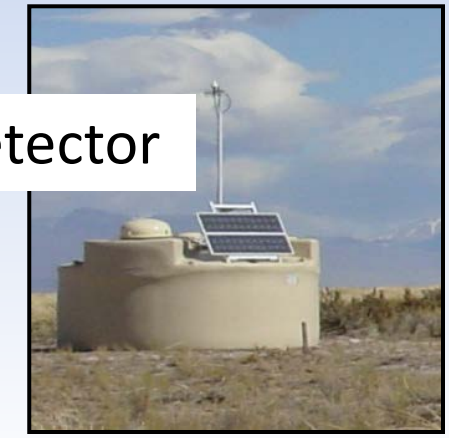
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
Energy (eV/particle)





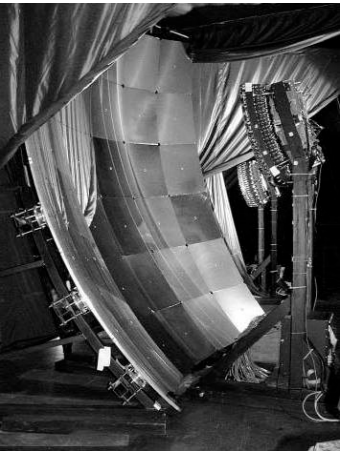


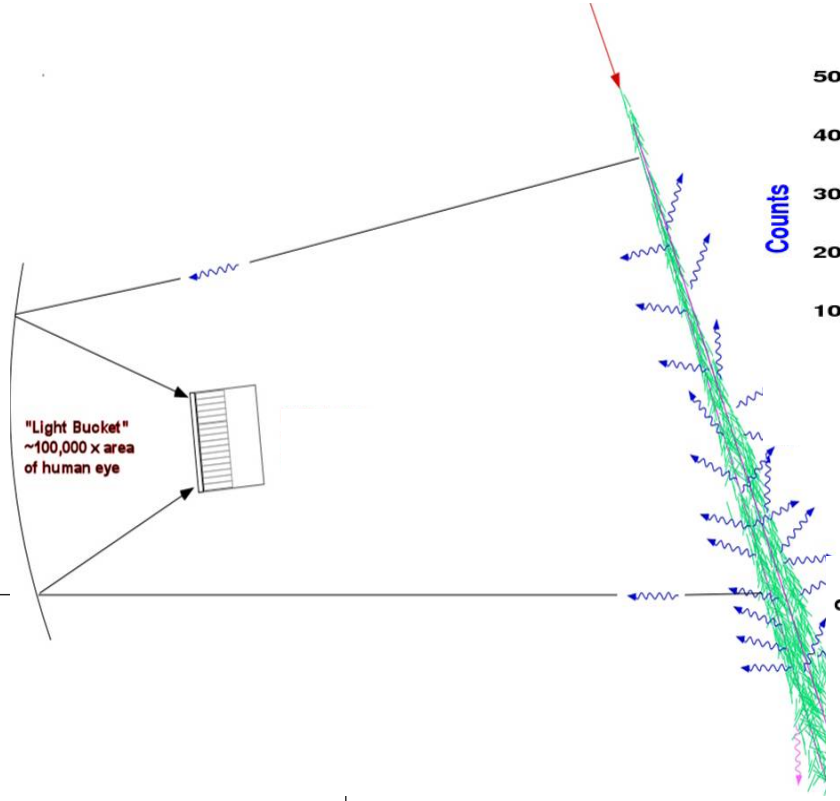
Fluorescence Detector

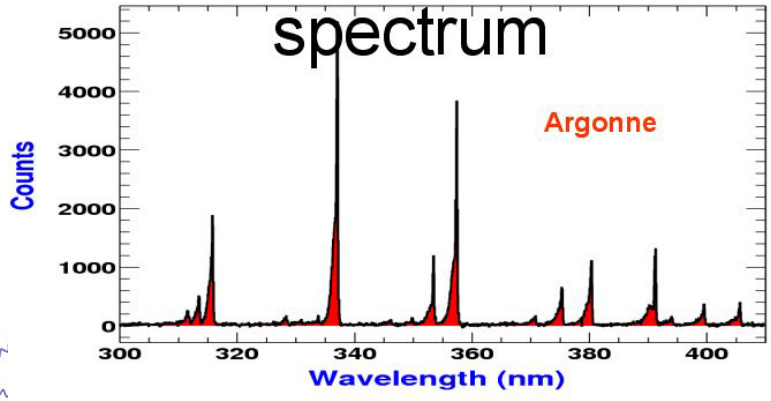


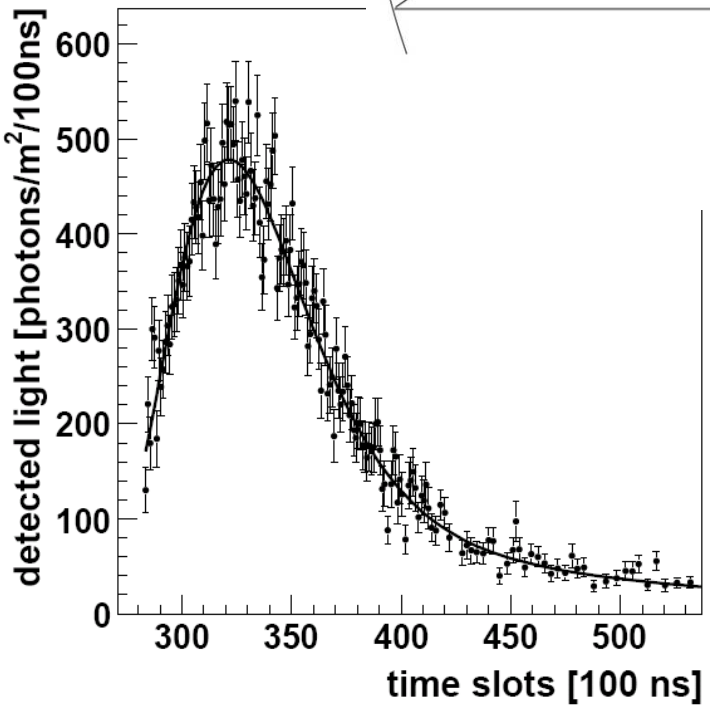
Cherenkov Detector

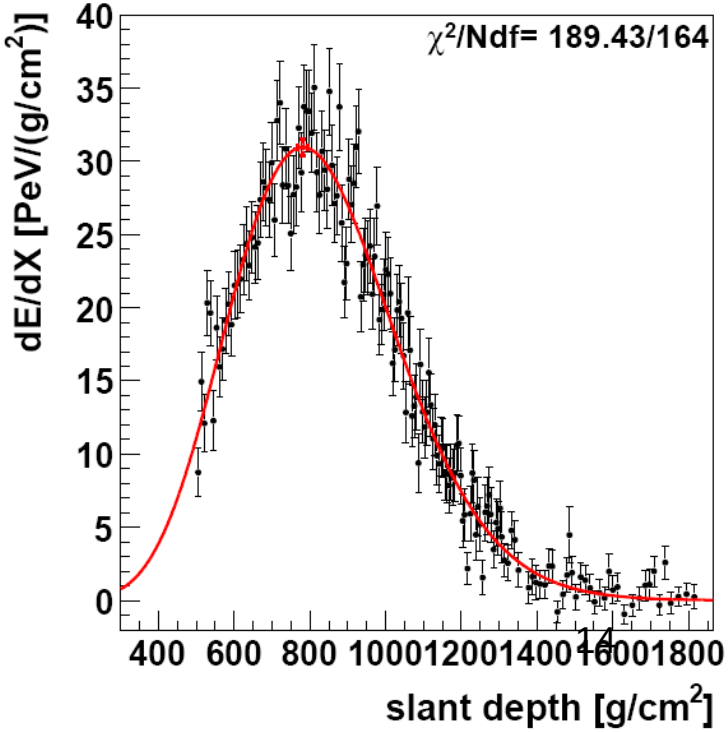
High Energy Extensive Air Shower Fluorescence Technique



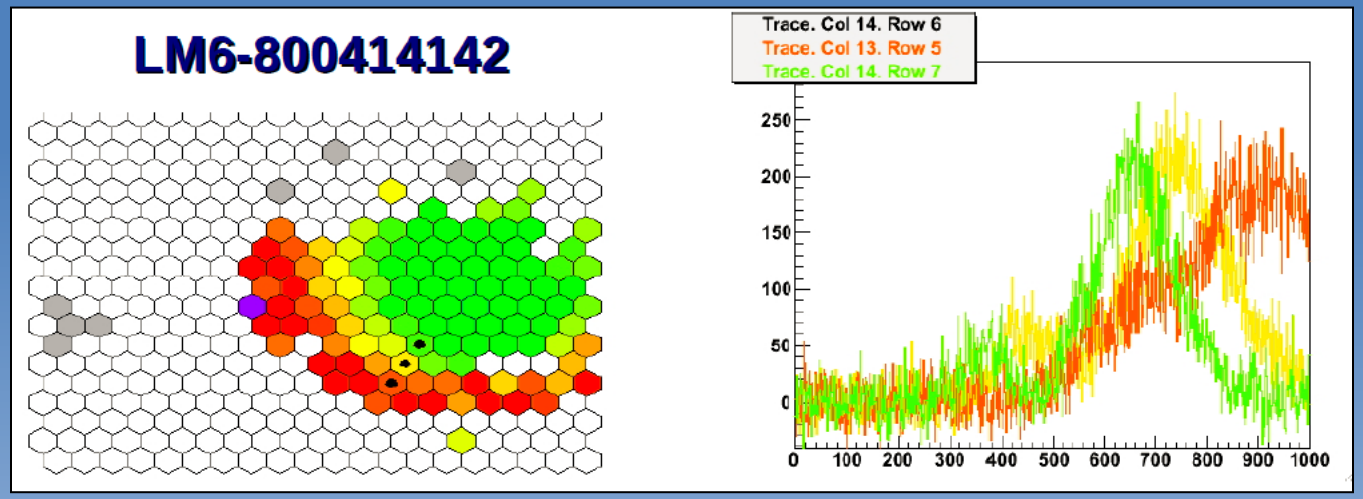




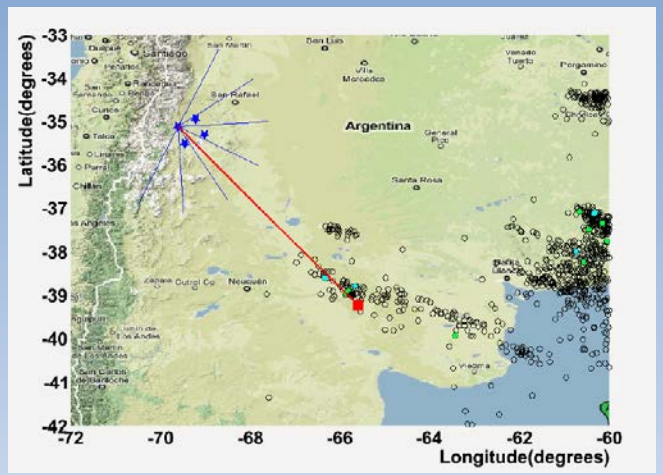




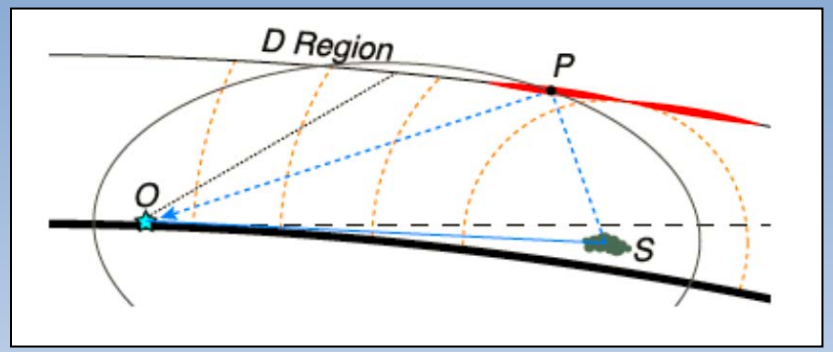
Atmospheric Optical Transients: Observation of "Elves"



Example of an Elve and the timing signal



Location of a distant Elve (red square)
Observed by the observatory (blue squares)

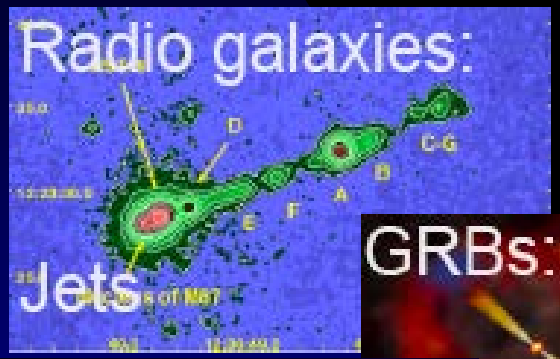


Simple Model of an Elve signature from the source (s) which generates an EMF pulse that causes fluorescence in the ionosphere (P) and the light is observed at (O)

R. Musa for the Pierre Auger Collaboration "Observation of Elves in Auger", EPJ Focus Point on Interdisciplinary Science with Cosmic Rays

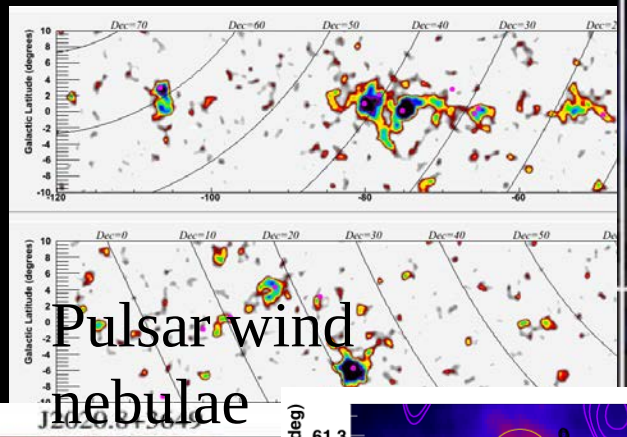
Astrophysical High Energy Accelerators

Extragalactic

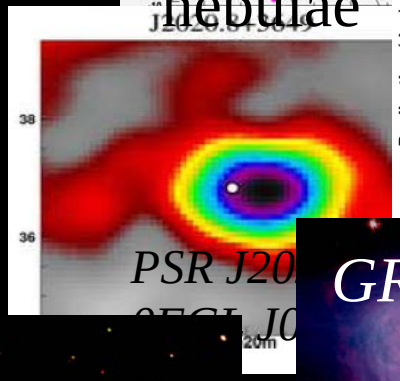


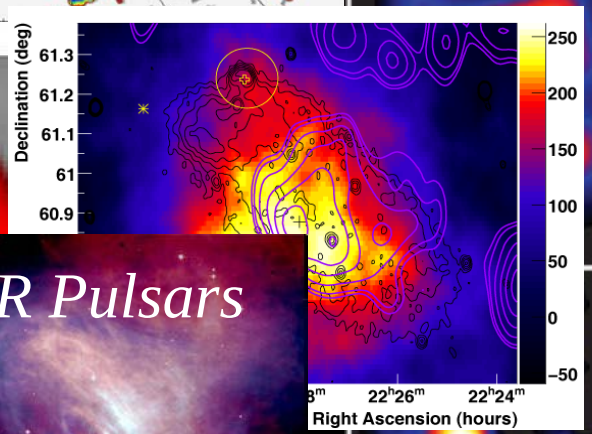
Unidentified γ-ray sources

Galactic



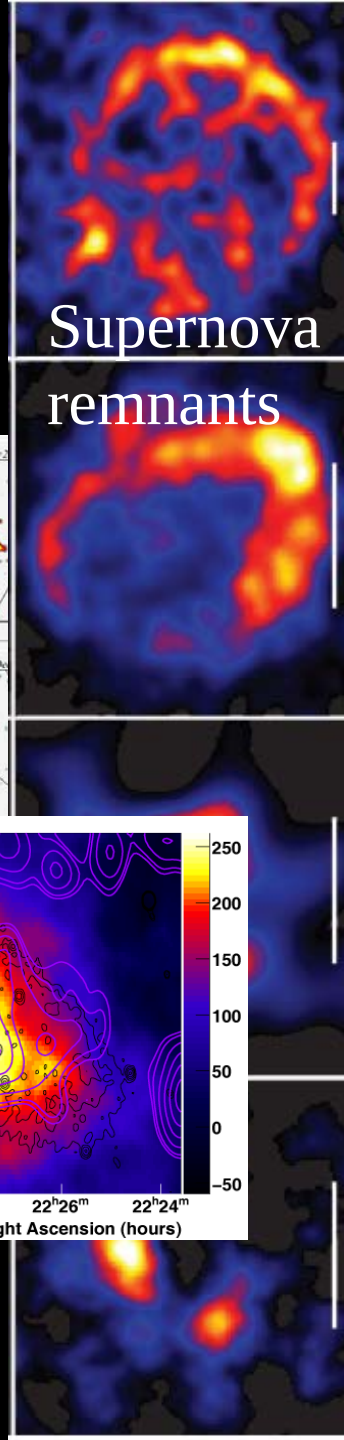
Pulsar wind nebulae





GR Pulsars

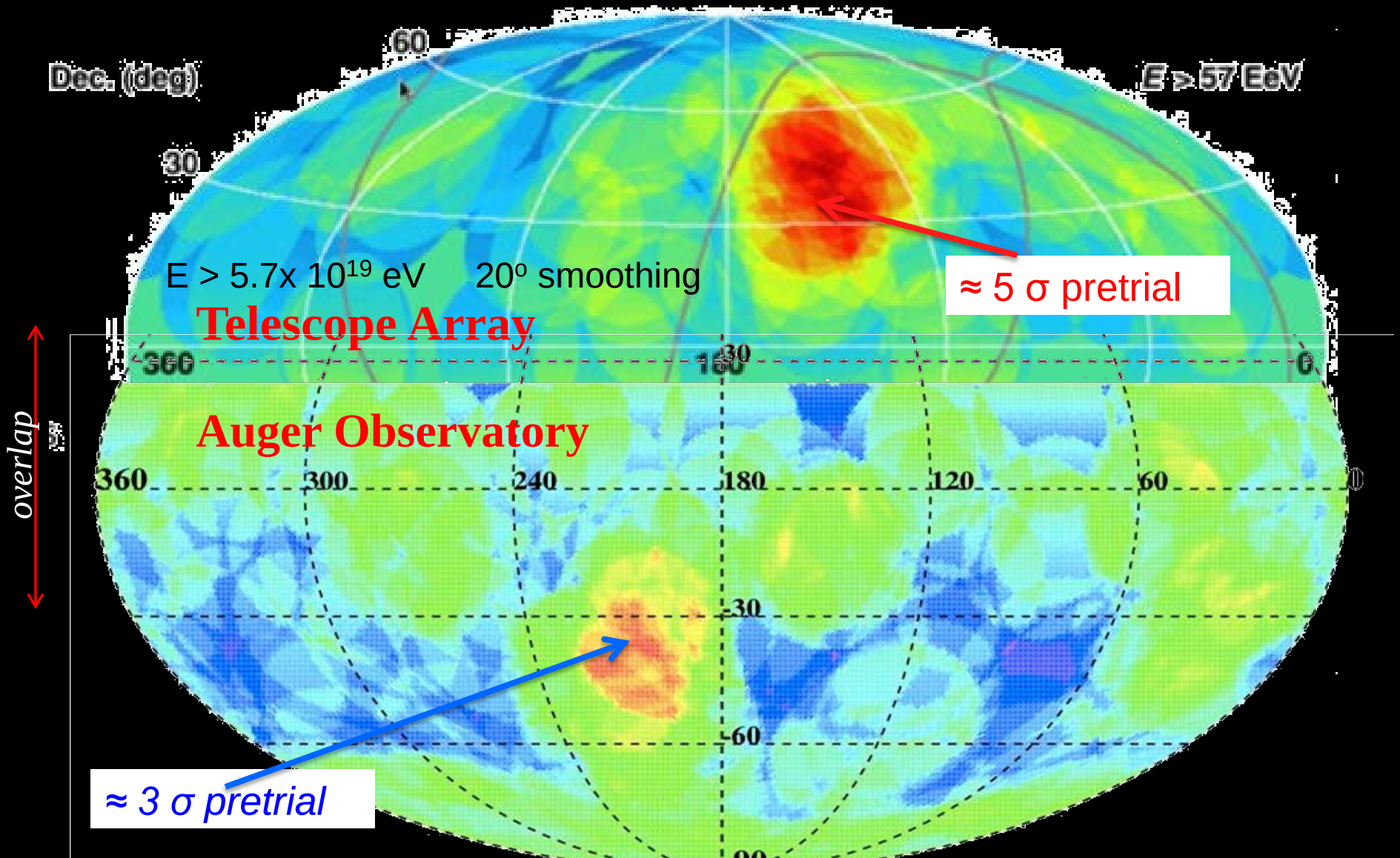
Stellar clusters



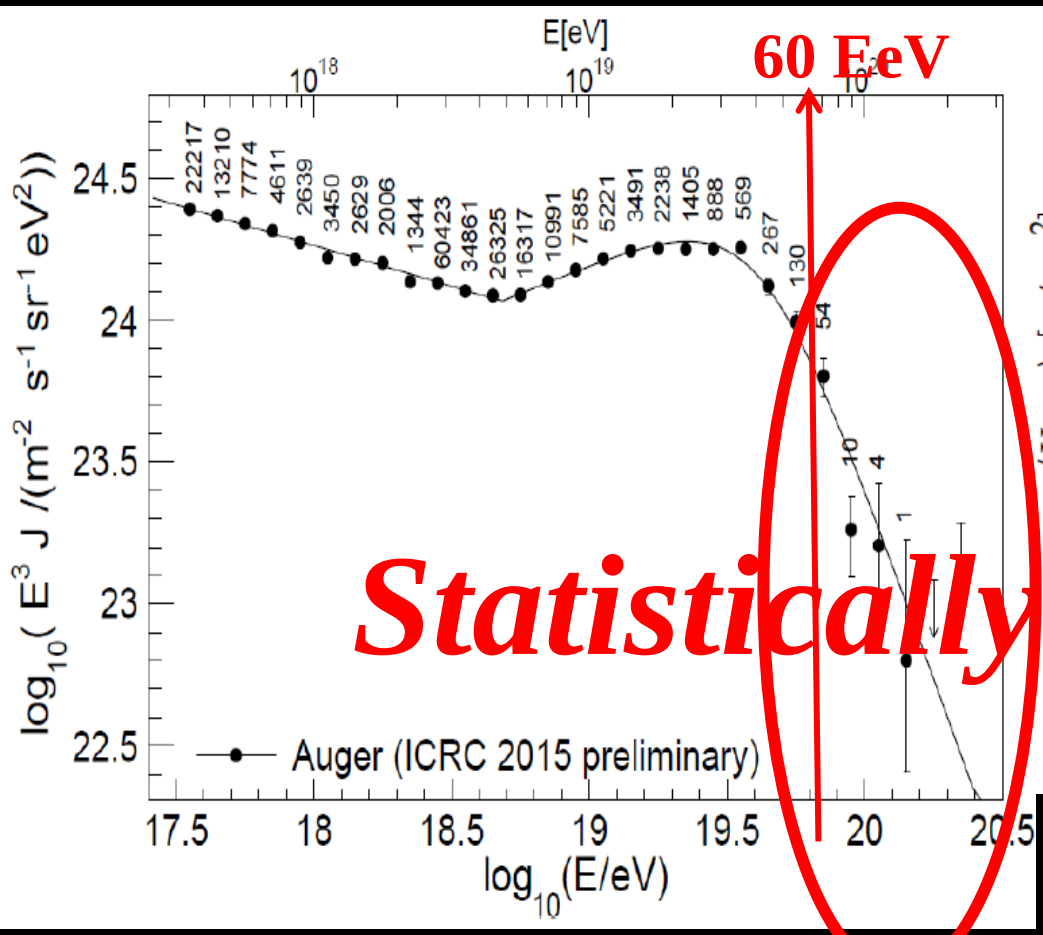
Supernova remnants

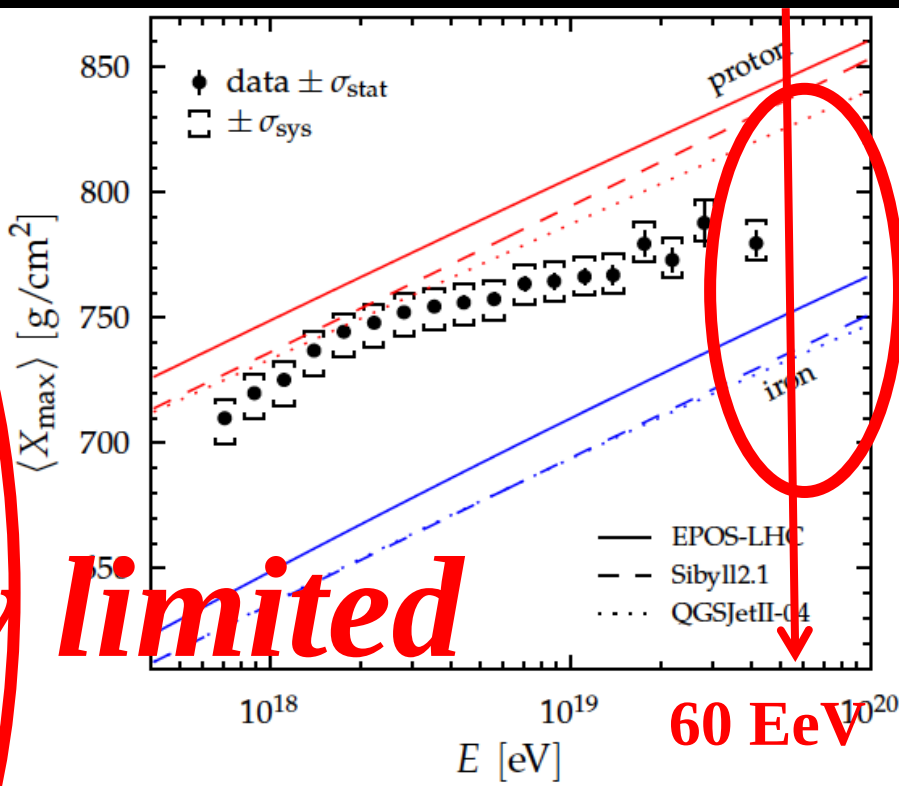
Anisotropy Hints > 60 EeV

Statistically limited



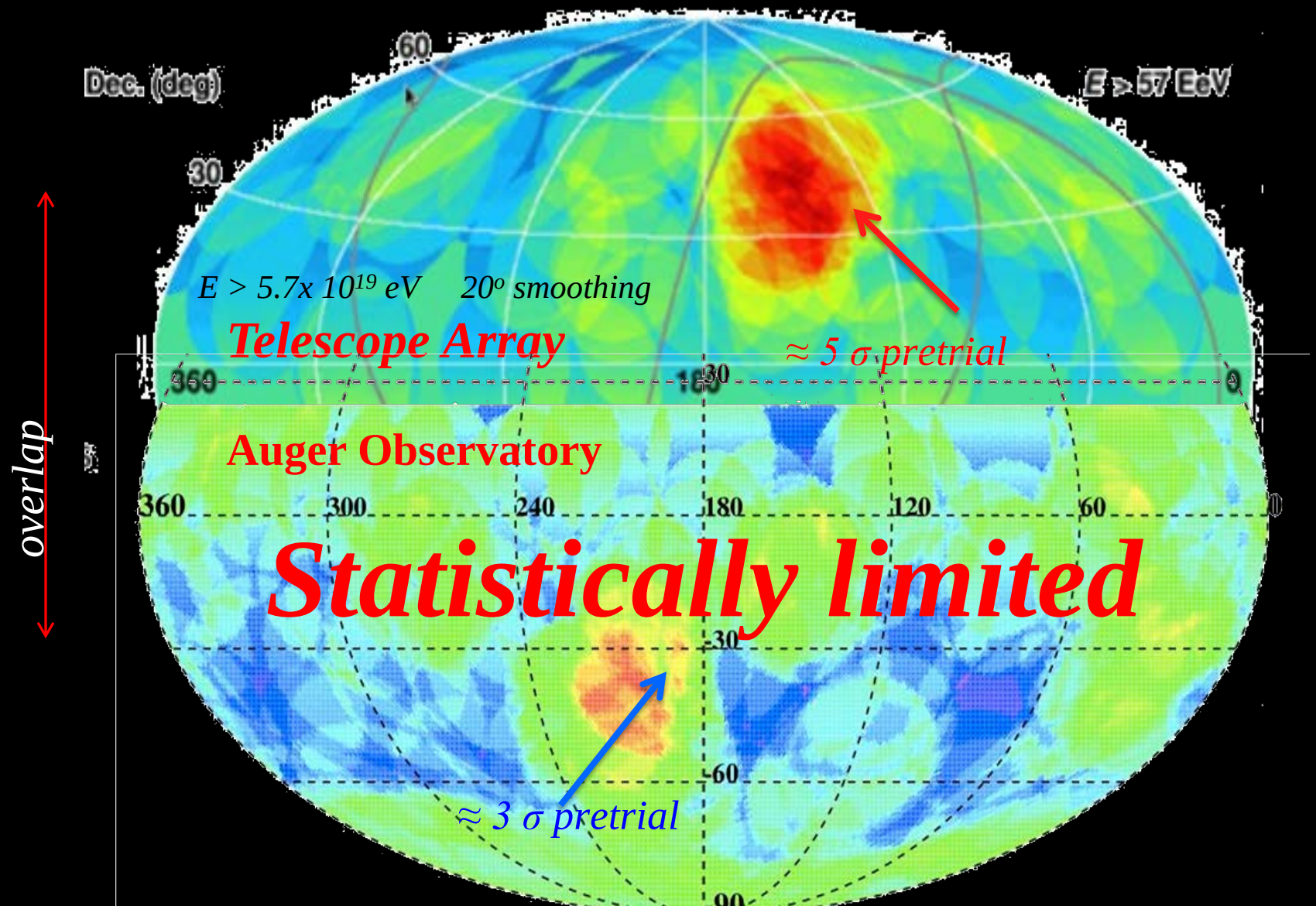
Last Significant Increase in Exposure



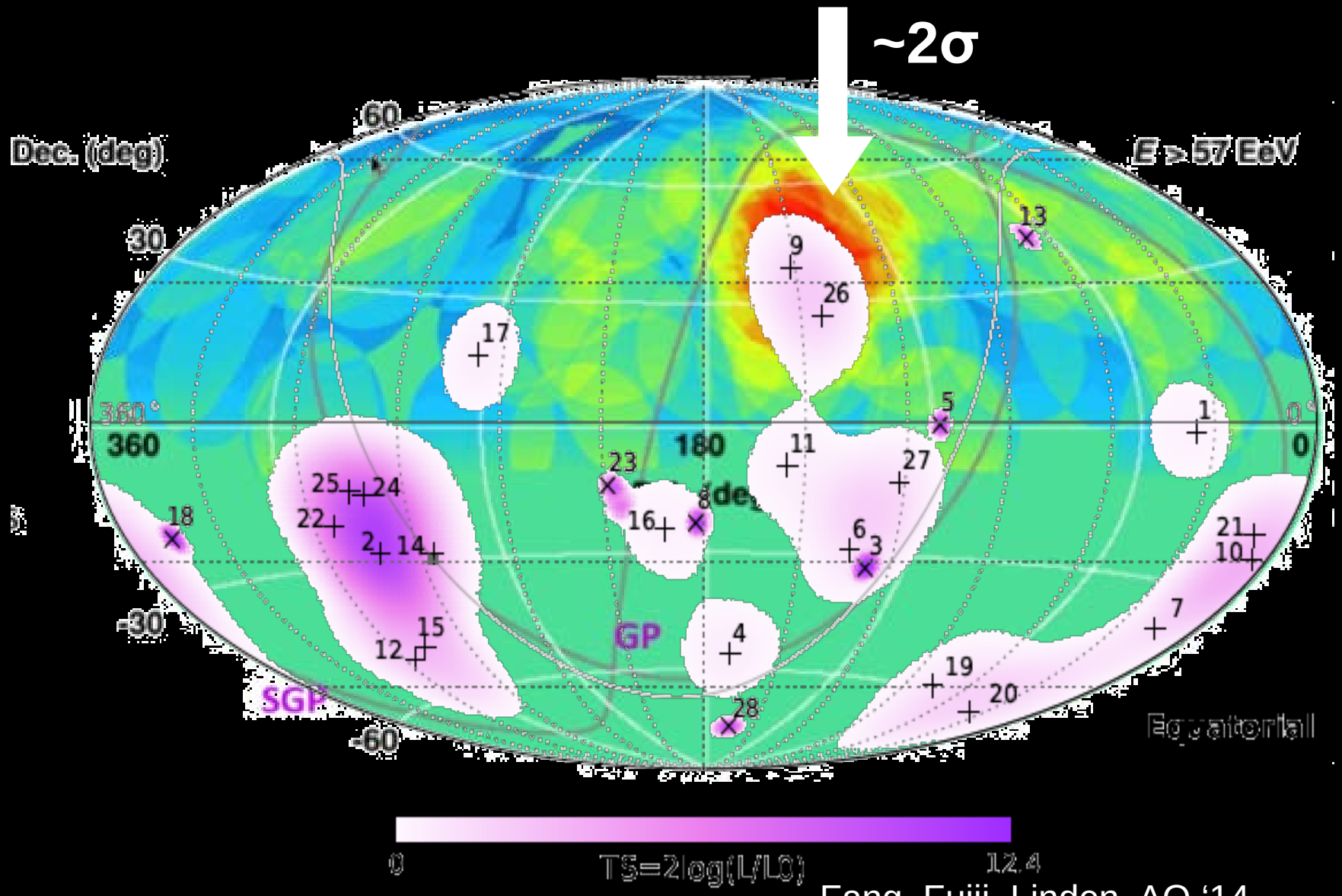


Statistically limited

Anisotropy Hints > 60 EeV



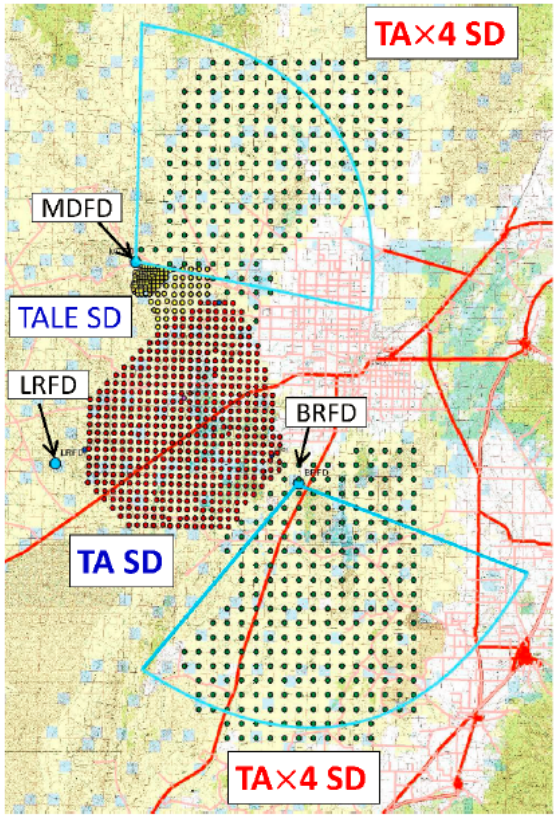
Neutrino & UHECR Coincidence ?



Fang, Fujii, Linden, AO '14

Telescope Array x 4

H.Sagawa, 657



enhance the sensitivity to the hot spot

SD: 507 scintillators
1.2 km - 700 km^2

new 500 SD stations
2.08 km spacing
approved in Japan in Apr 2015

2 new FDs in MD and BRM
submit in US in Oct 2015

3000 km^2
operation
in Dec 2017

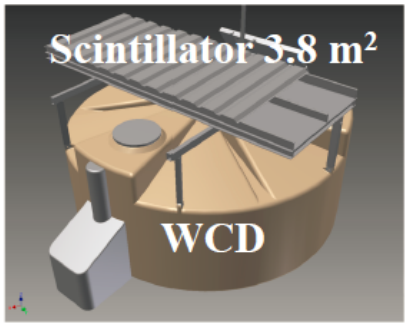
Upgrade of PAO: AugerPrime

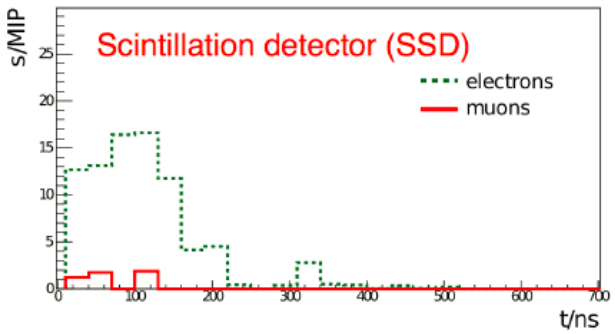
R.Engel, 686

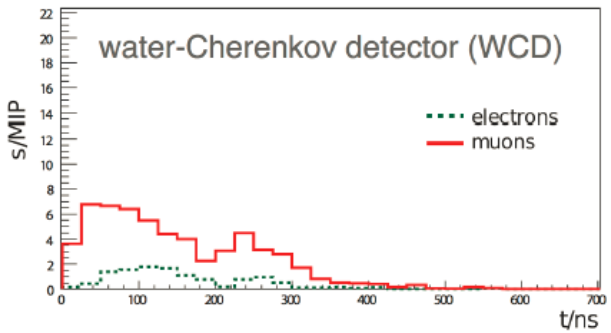
mass sensitivity above the cut-off (no FD ev.)

scintillator
faster electronic (120 MHz)

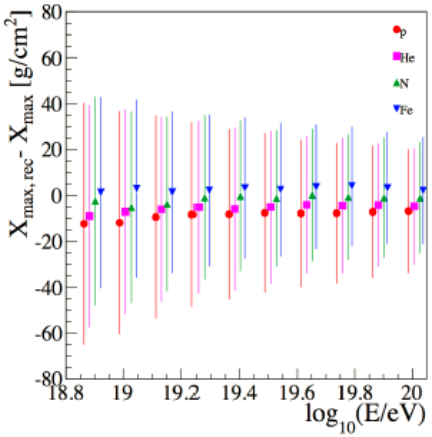
…

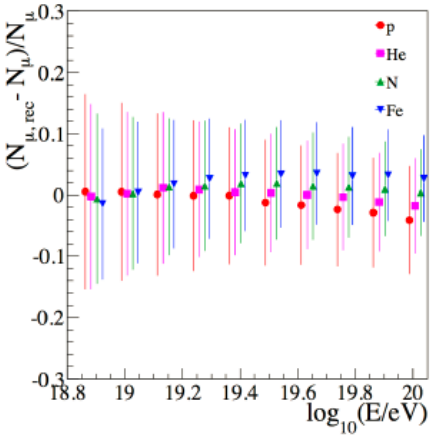






$$S_{\mu,\mathrm{WCD}} = a\,S_{\mathrm{WCD}} + b\,S_{\mathrm{SSD}}$$





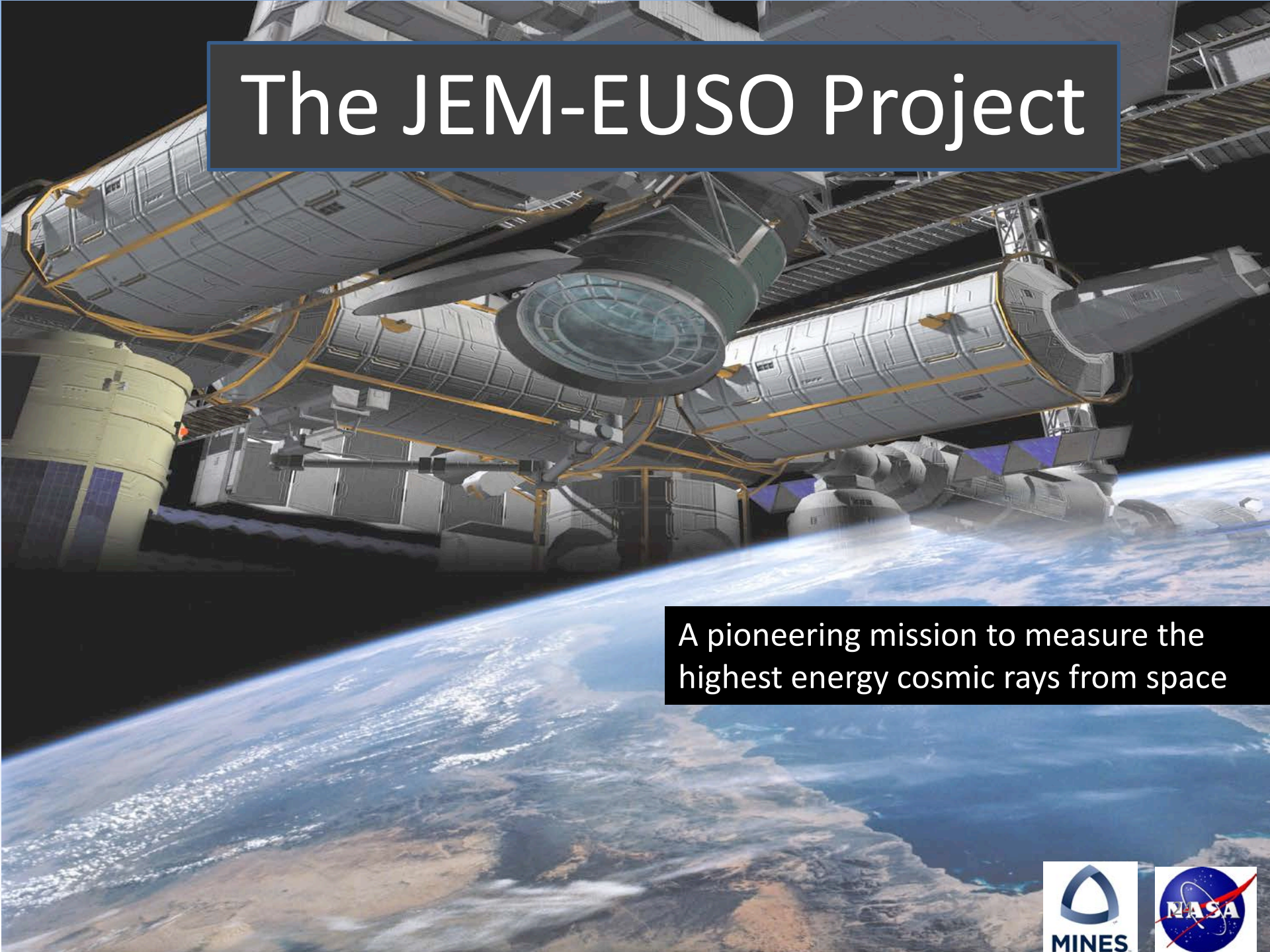
M.Roth, 378

2018-2024 data taking

Really Large Calorimeters

Going to Space

The JEM-EUSO Project



A pioneering mission to measure the highest energy cosmic rays from space

JEM-EUSO Collaboration

- Japan, USA, Korea, Mexico, Russia, Algeria

- Europe: Bulgaria, France, Germany, Italy, Poland, Romania, Slovakia, Spain, Switzerland, Sweden

- 16 Countries, 77 Institutions, more than 300 researchers

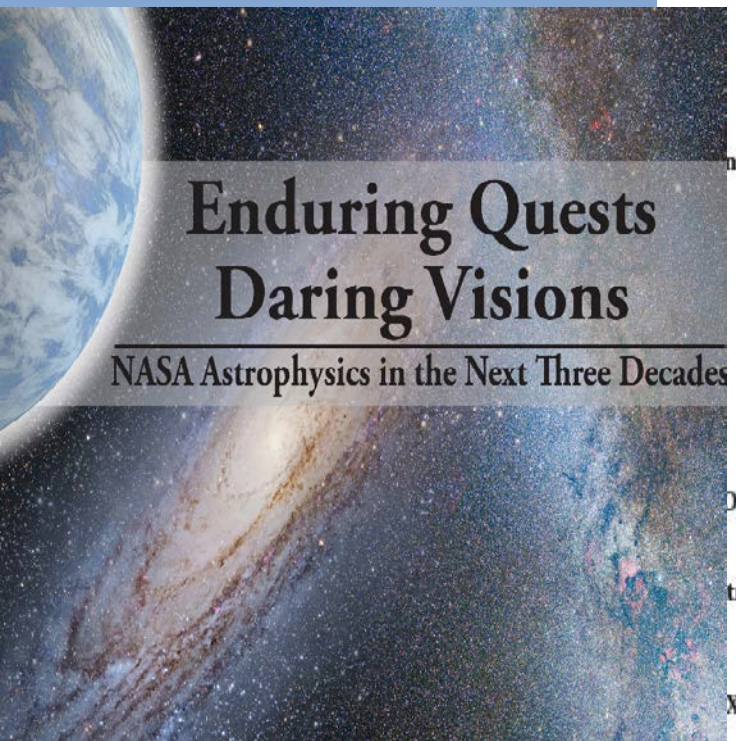
JEM-EUSO in USA

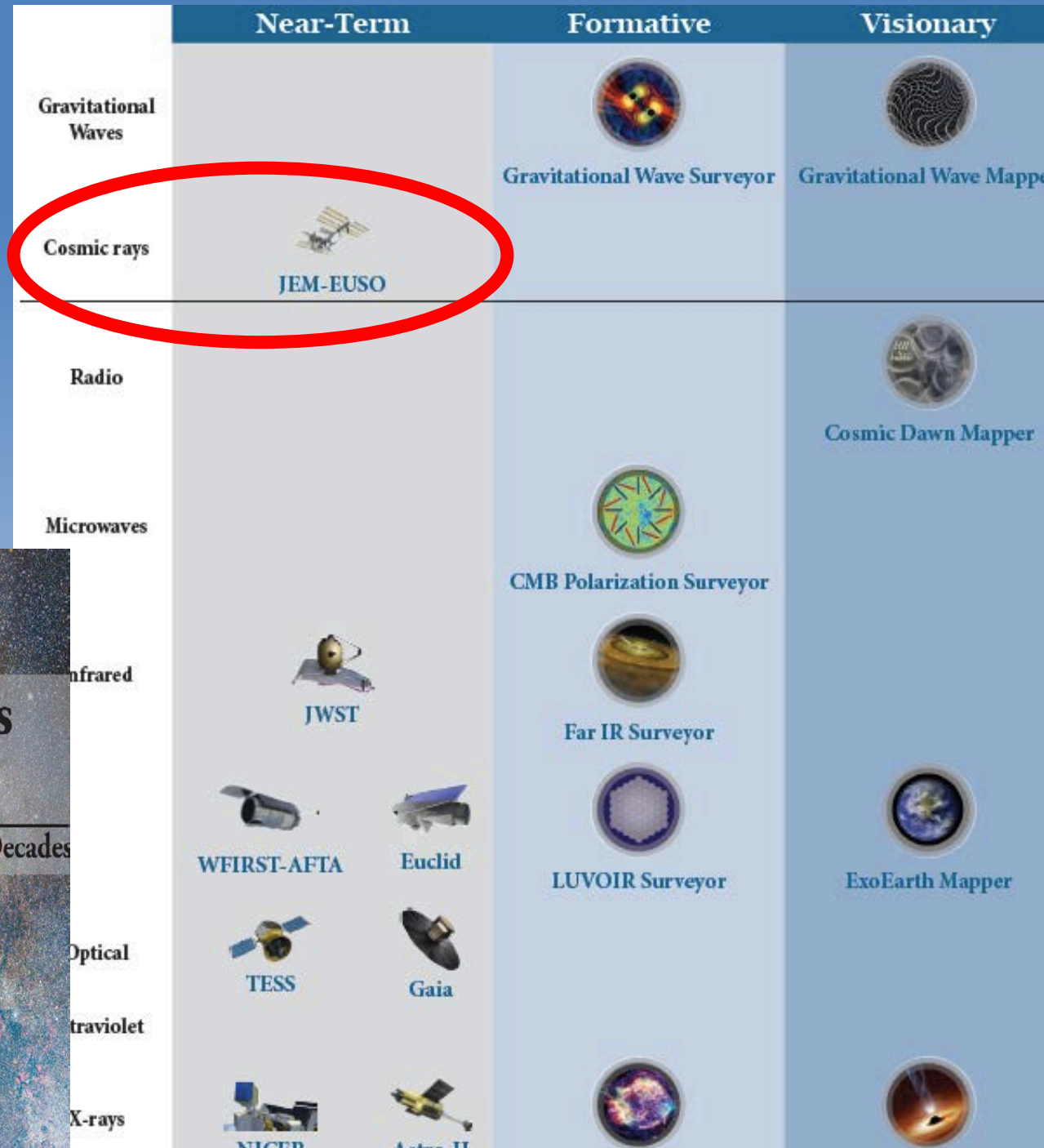
Institutions on NASA APRA

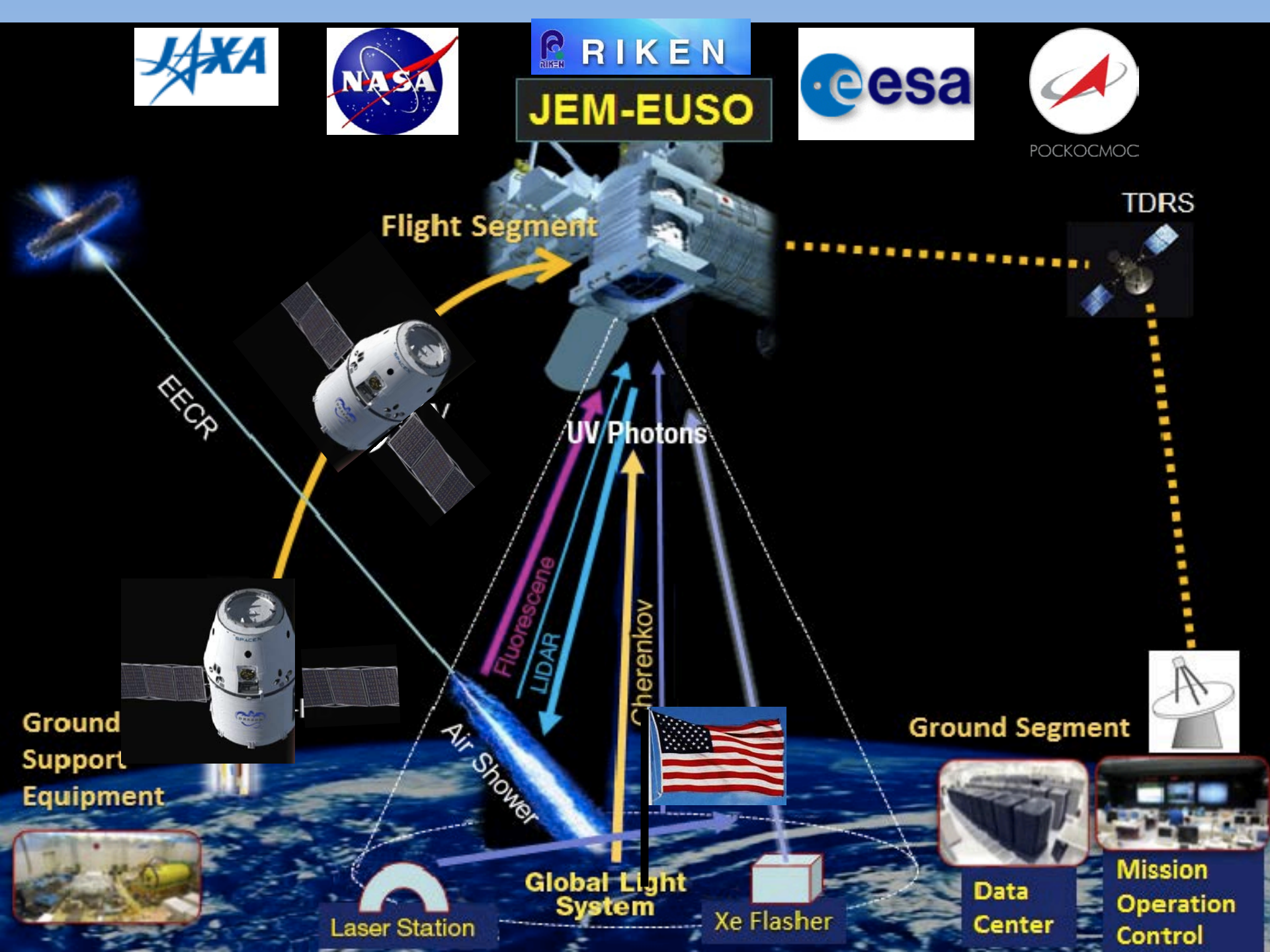
University of Chicago, PI Institution
University of Alabama in Huntsville
Marshall Space Flight Center
University of Wisconsin-Milwaukee
Colorado School of Mines
Vanderbilt University

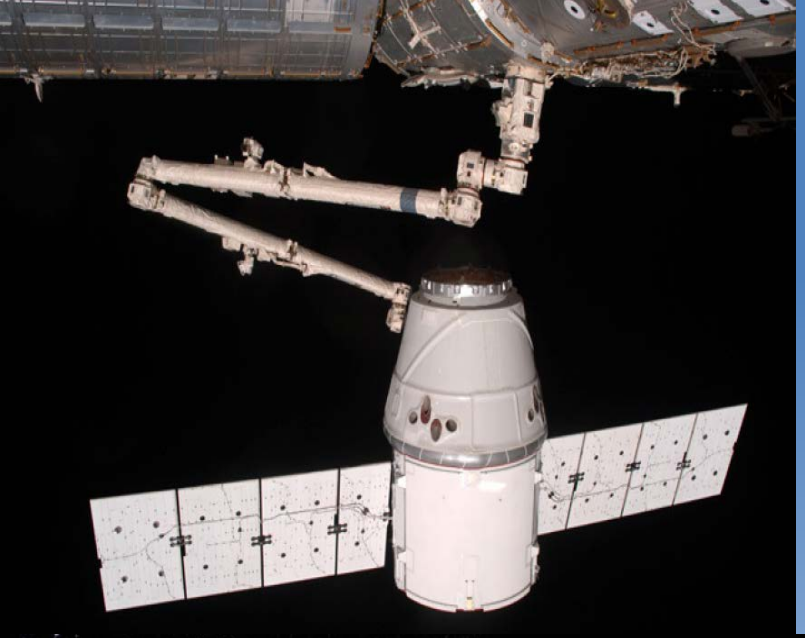
Other US Institutions in the Collaboration
University of California, Berkeley
University of California, Los Angeles
Fermilab
University of Kansas, Wichita
others interested in joining

NASA Astrophysics Roadmap 2014



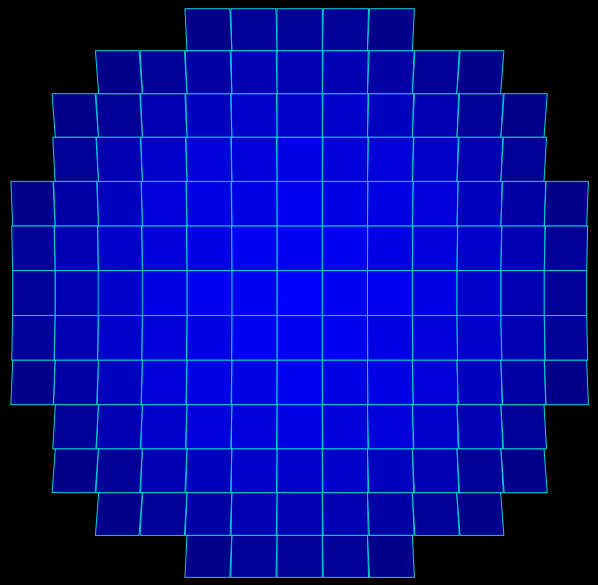


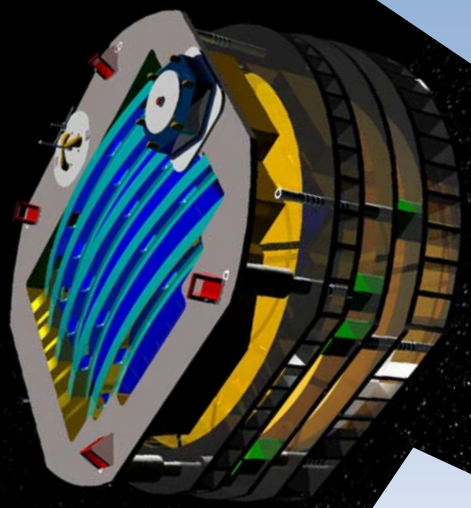

JAXA
NASA
RIKEN
JEM-EUSO
esa
POCKOCMOC
TDRS
Flight Segment
EECR
UV Photons
Fluorescene
LIDAR
Cherenkov
Air Shower
Ground Support Equipment
Ground Segment
Laser Station
Global Light System
Xe Flasher
Data Center
Mission Operation Control

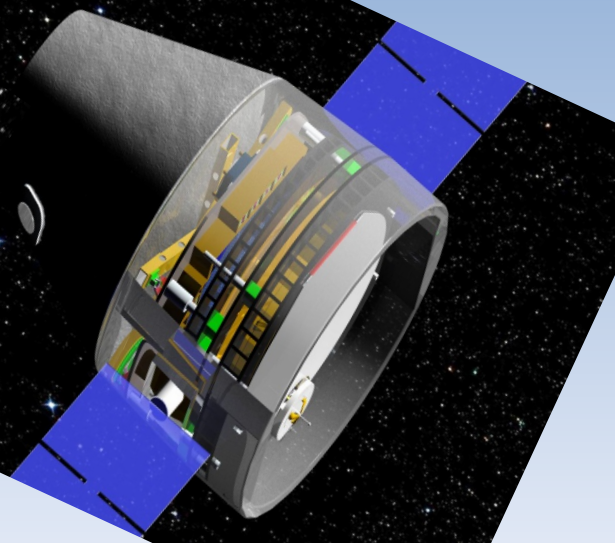


Improved
Energy resolution:
Requirements:
30% for E > 80 EeV
Central region
20% for E > 50 EeV;
5 to 10% for E > 300 EeV

X_{max} resolution
Requirements: 120 g/cm^2 for 200 EeV
Central region
100 g/cm^2 for E> 50 EeV;
50 g/cm^2 for E > 300 EeV







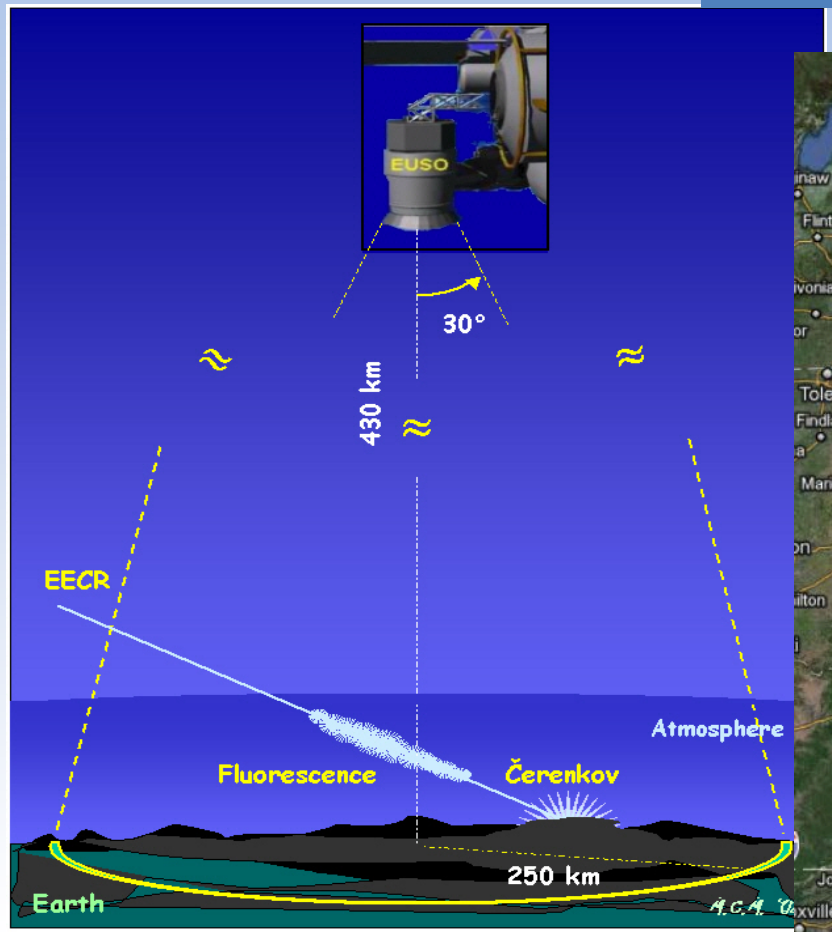
Nadir (2 yrs)

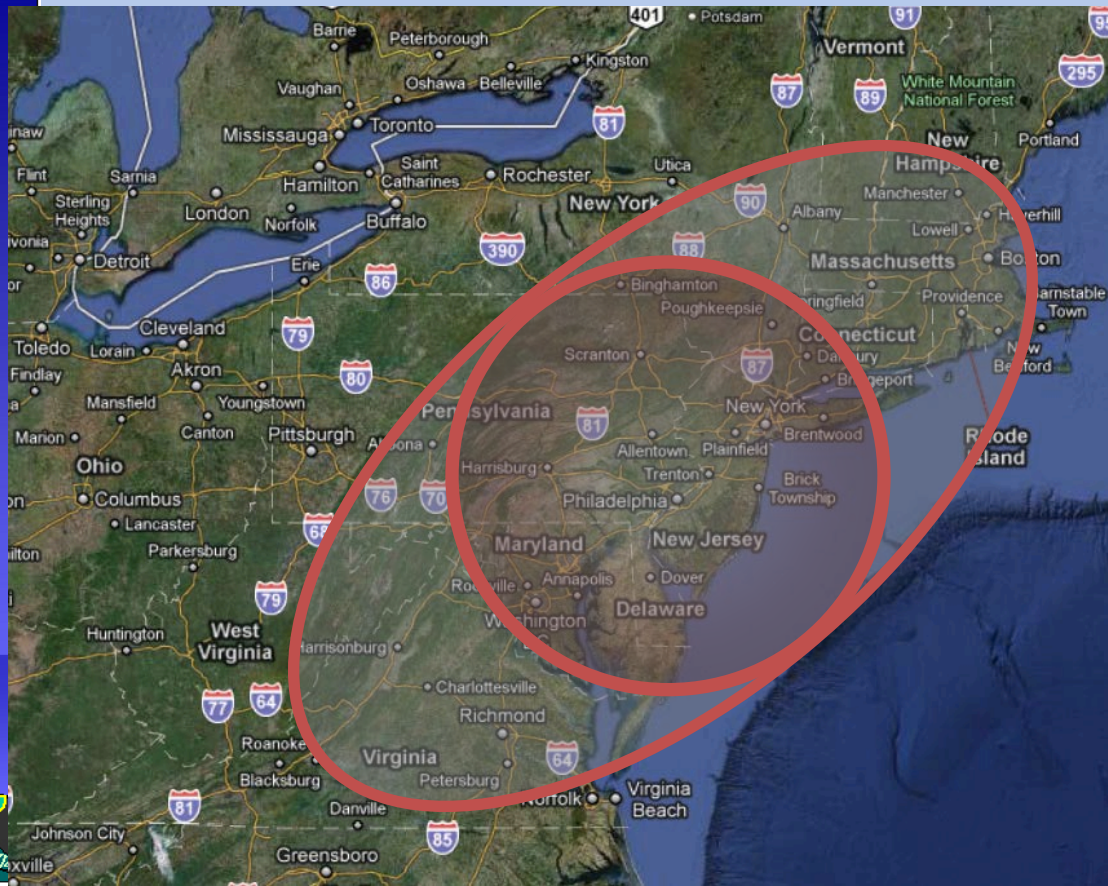
35° tilt (3 yrs)

- 3 x area

$E_{th} \sim 10^{20}$ eV

Fluorescence only
~ 20% duty cycle





JEM-EUSO

Fresnel Lens Refractor

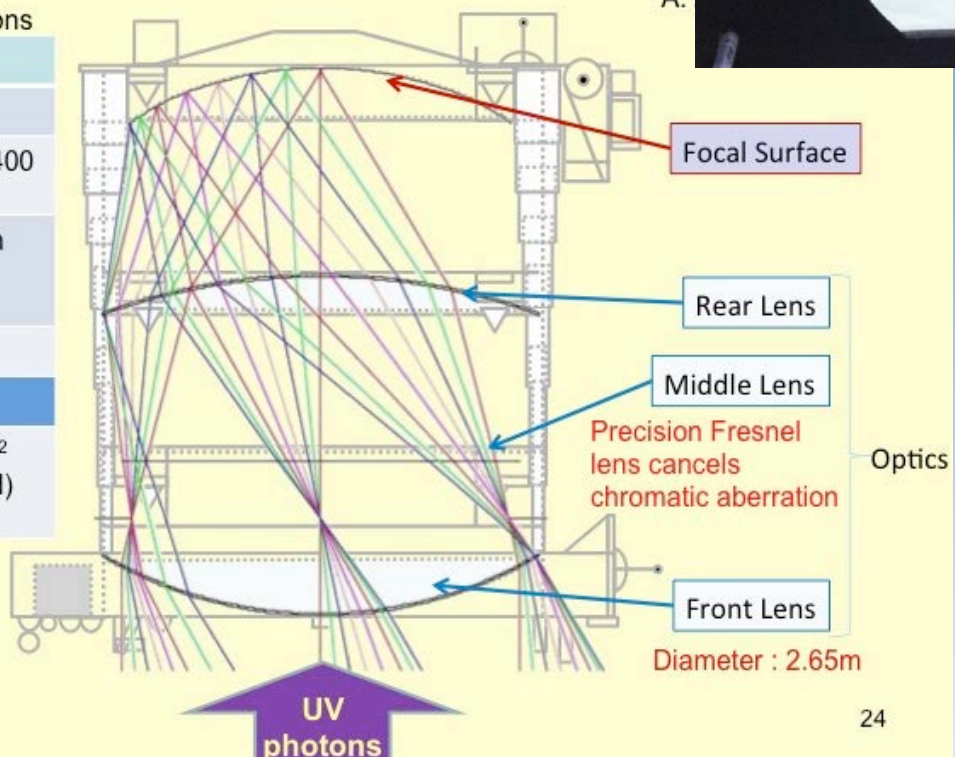
60 deg FOV

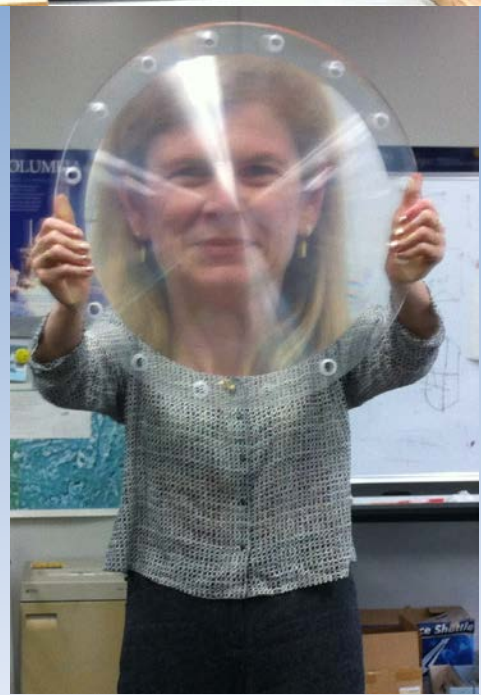
Optics design by ray tracin

A.

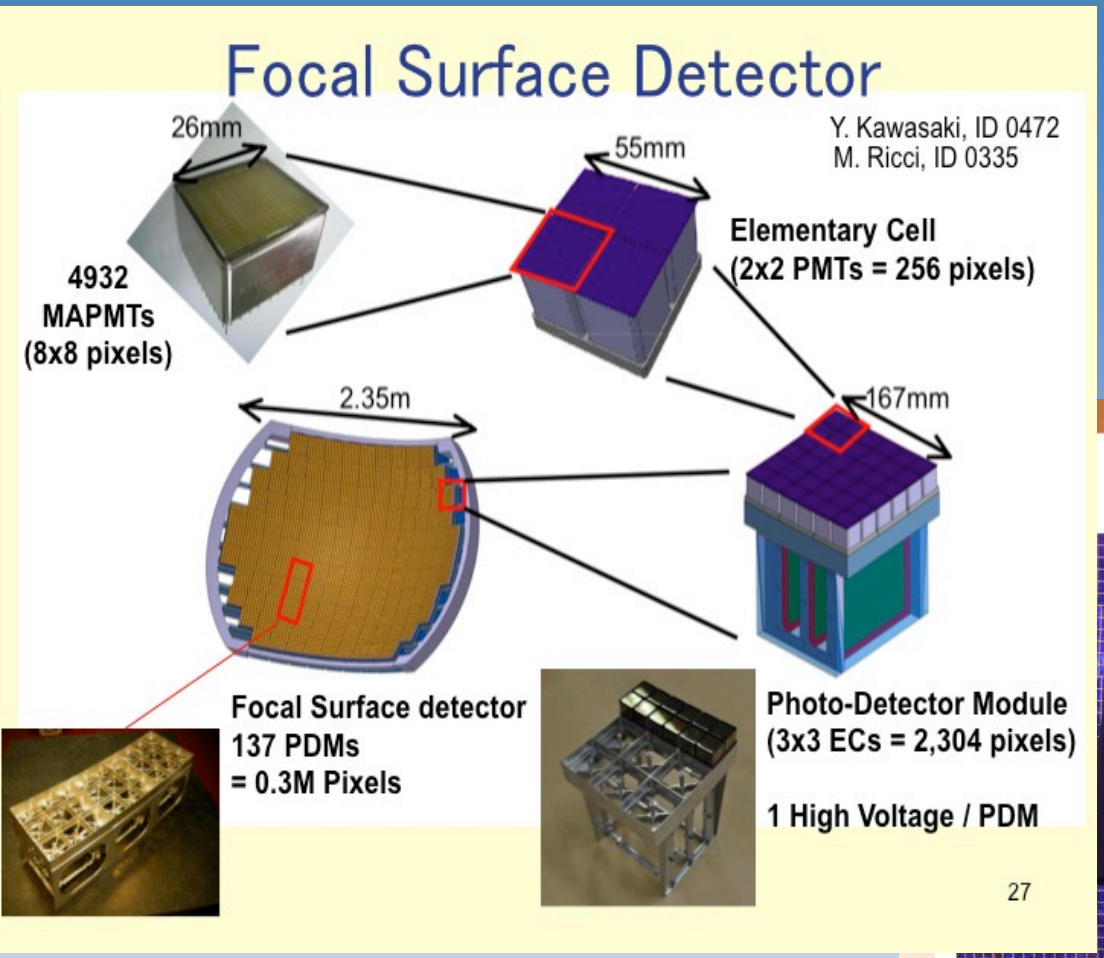
Simulation conditions

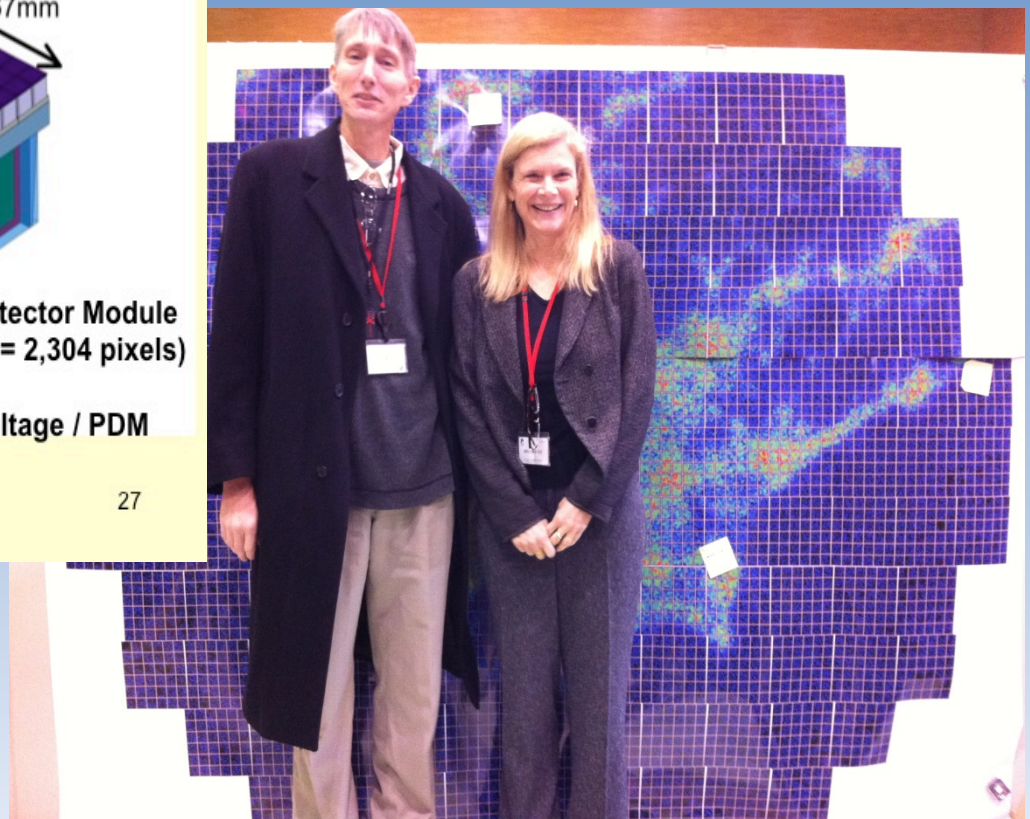
Optics	
FOV	±30
Optical bandwidth	330 ÷ 400 nm
Entrance Pupil Diameter	≥ 2.3 m
F/number	≤1
Focal surface	
Focal surface area	~4.5 m² (curved)

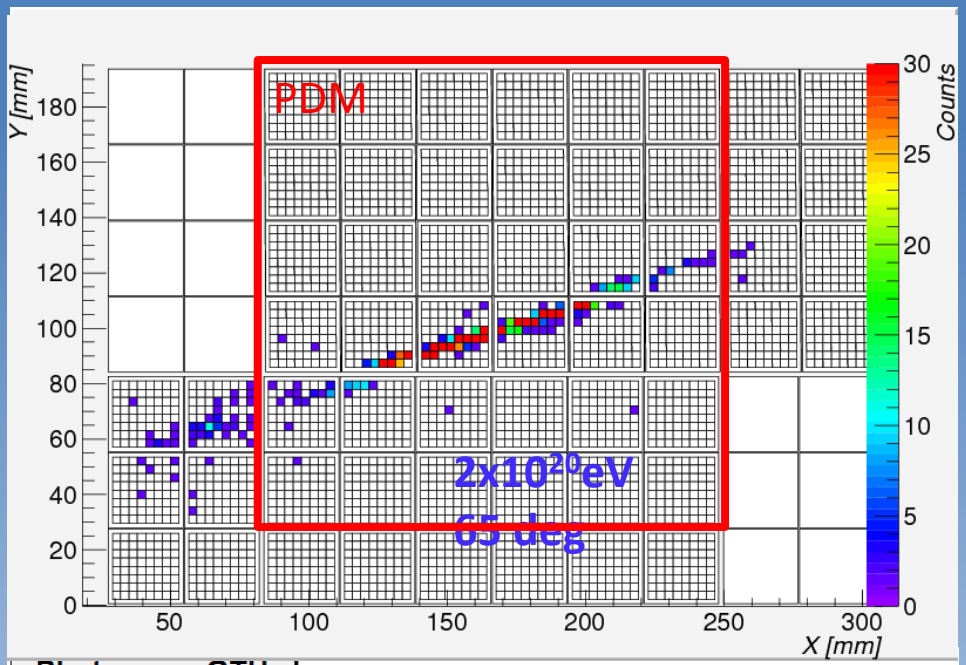




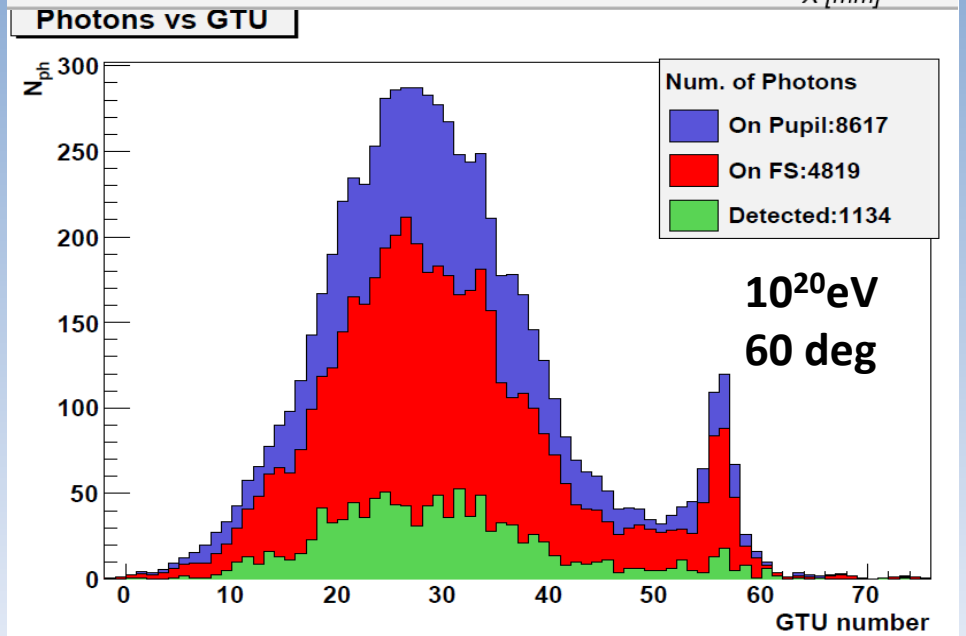
JEM-EUSO
0.3M pixel MAPMT ultrafast camera



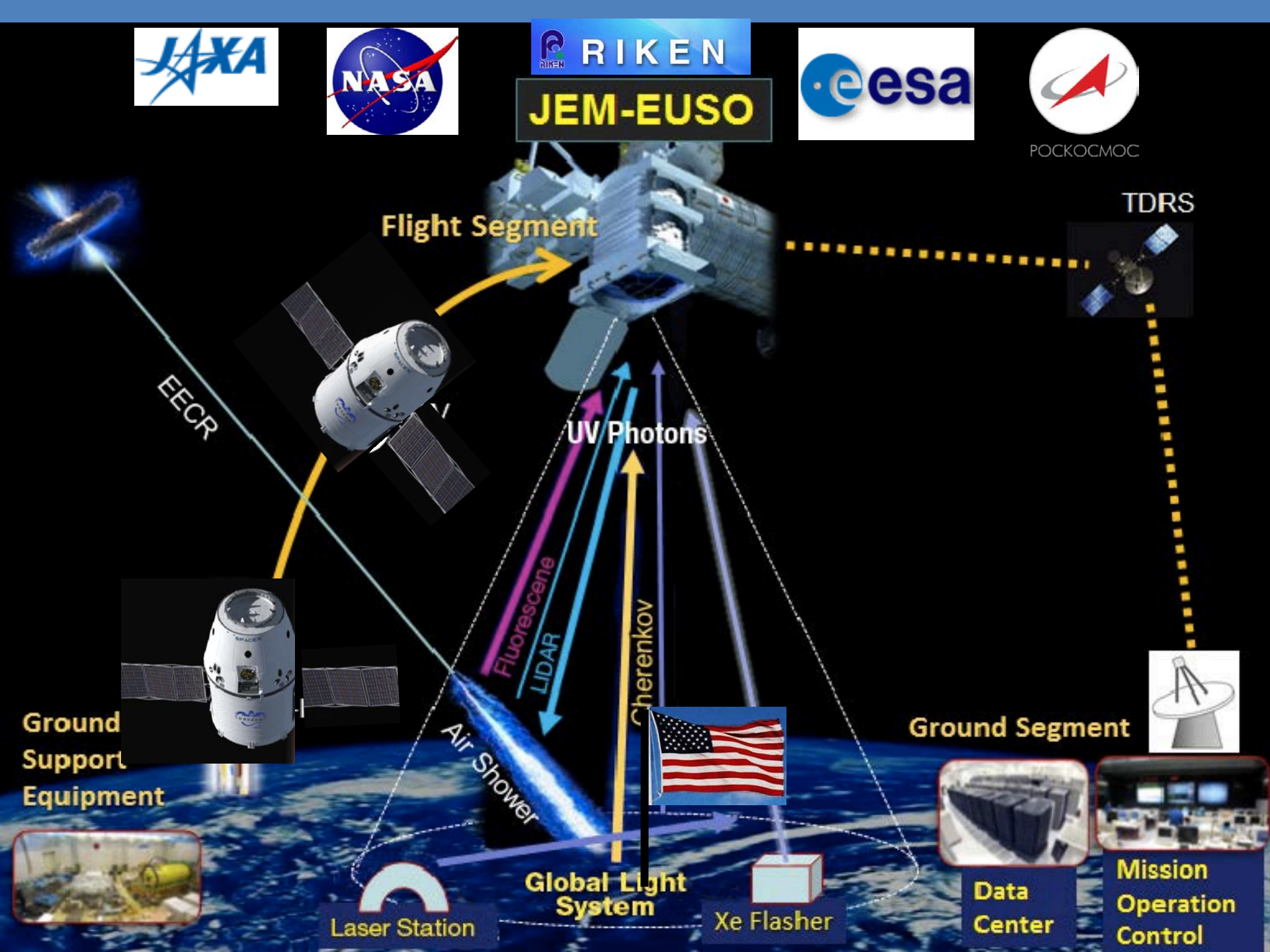




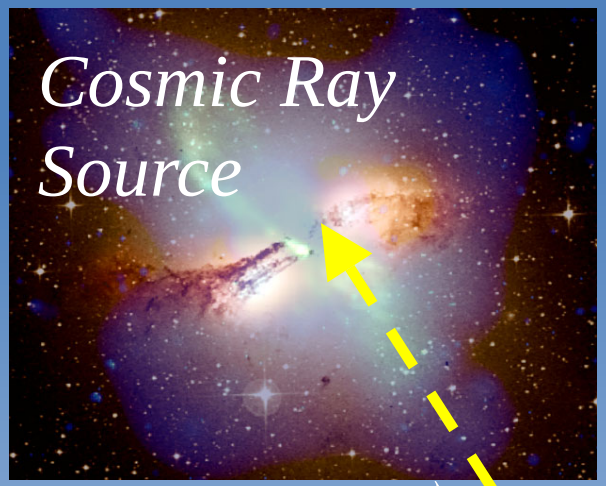
Simulated air shower image on the focal surface detector.



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


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

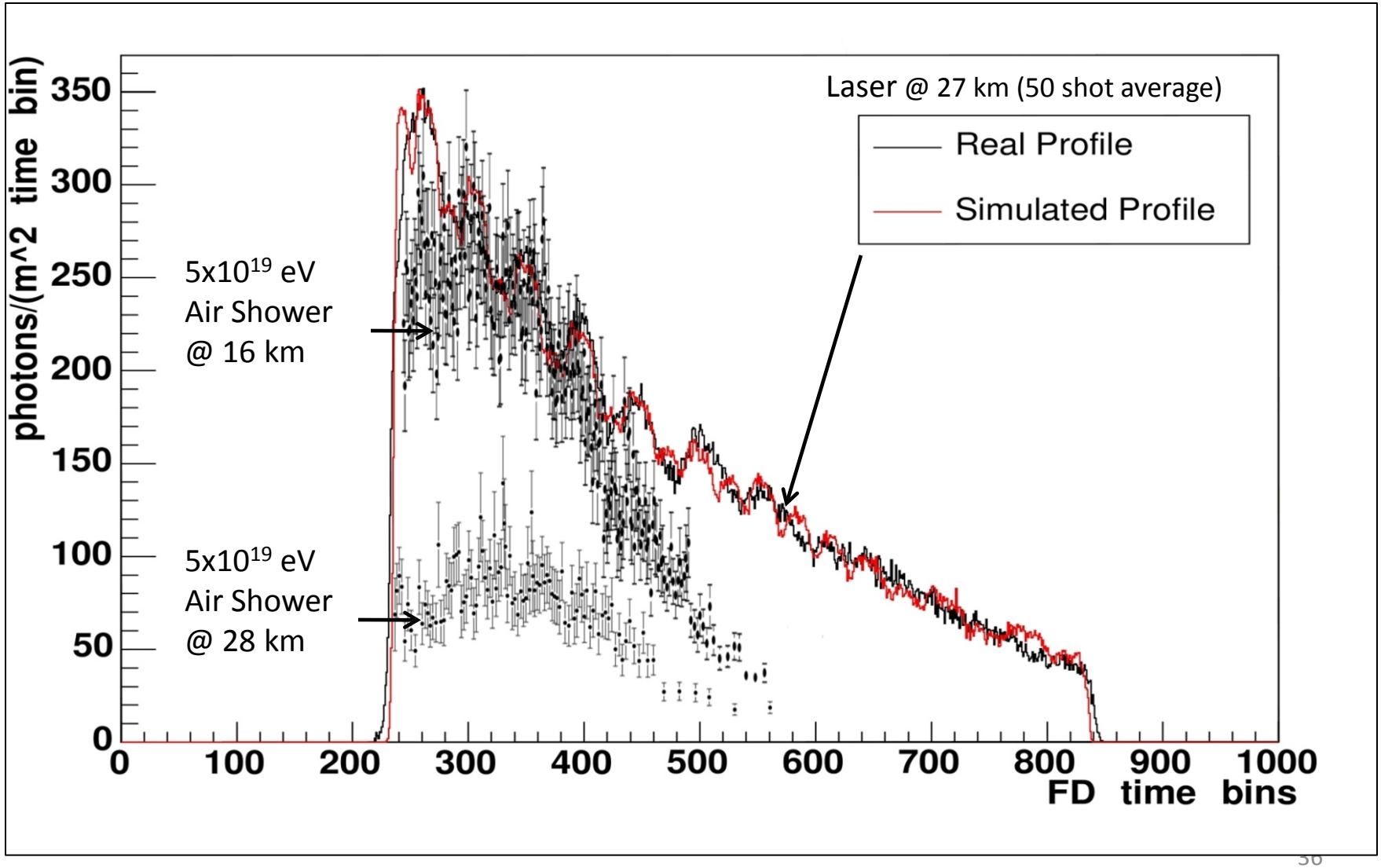
Global Light System



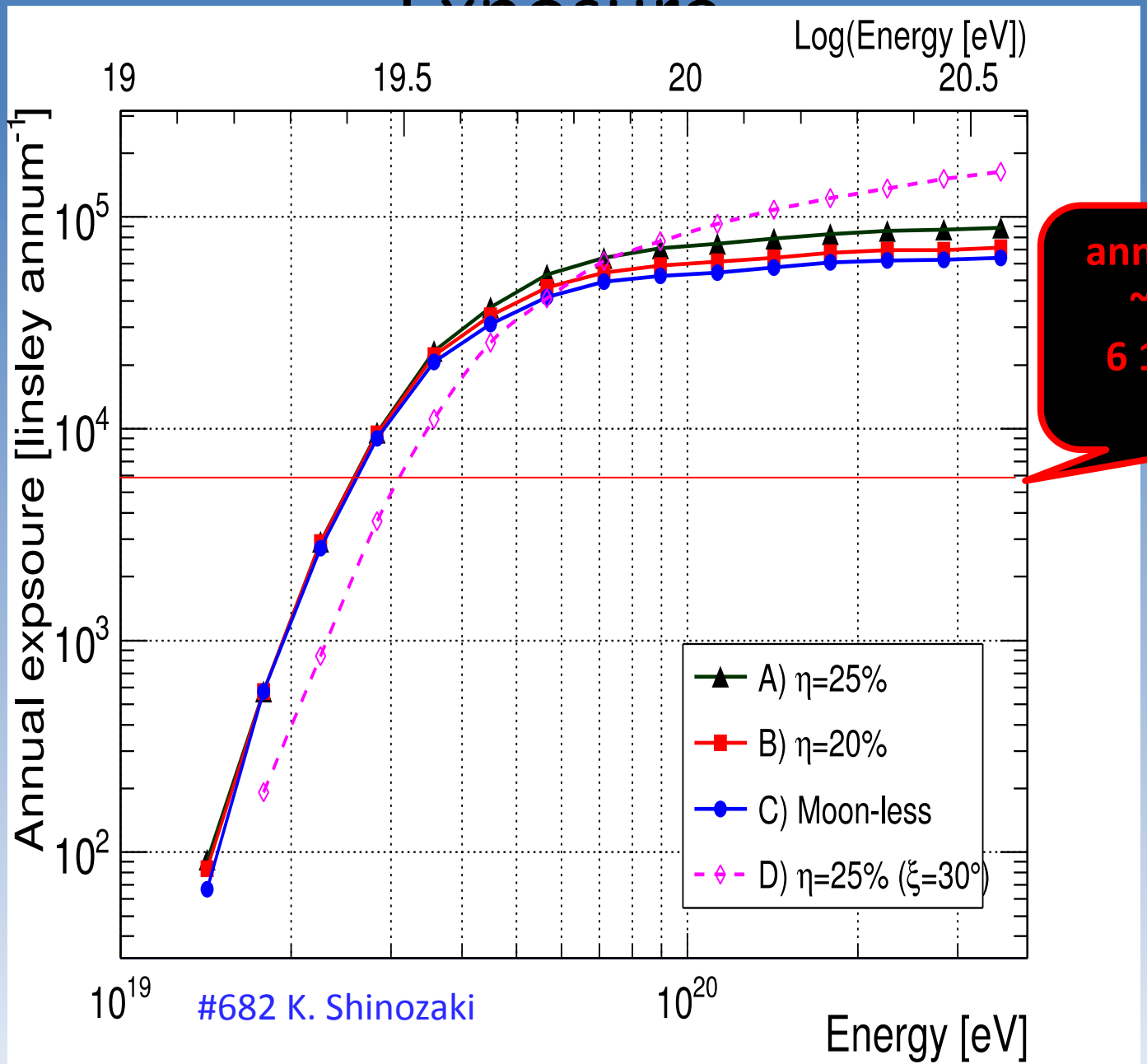
JEM-EUSO detector

Laser Beam

Laser – Air Shower Equivalence

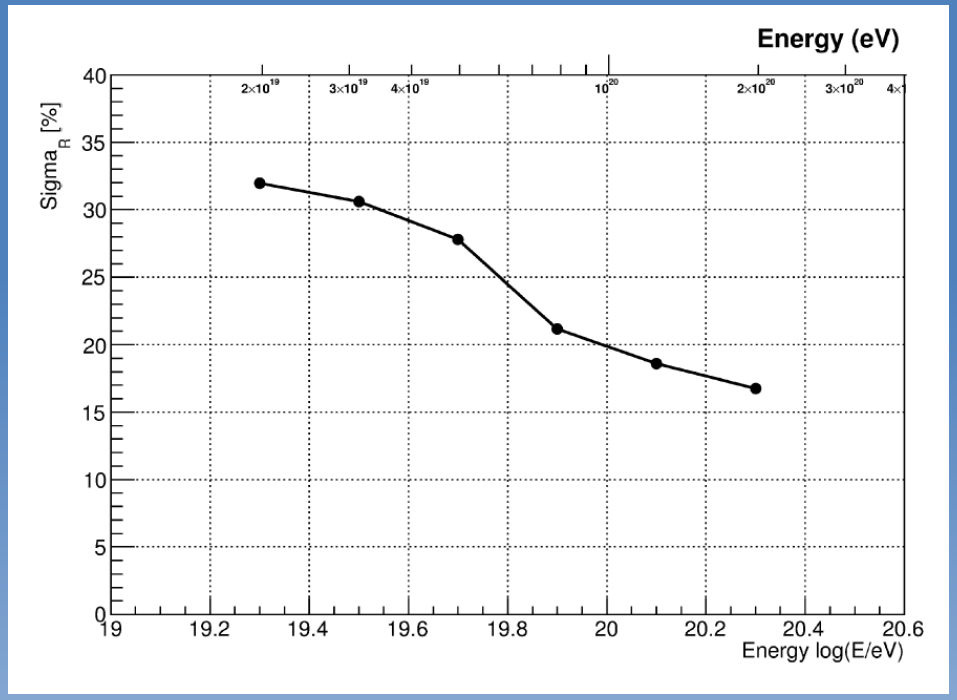


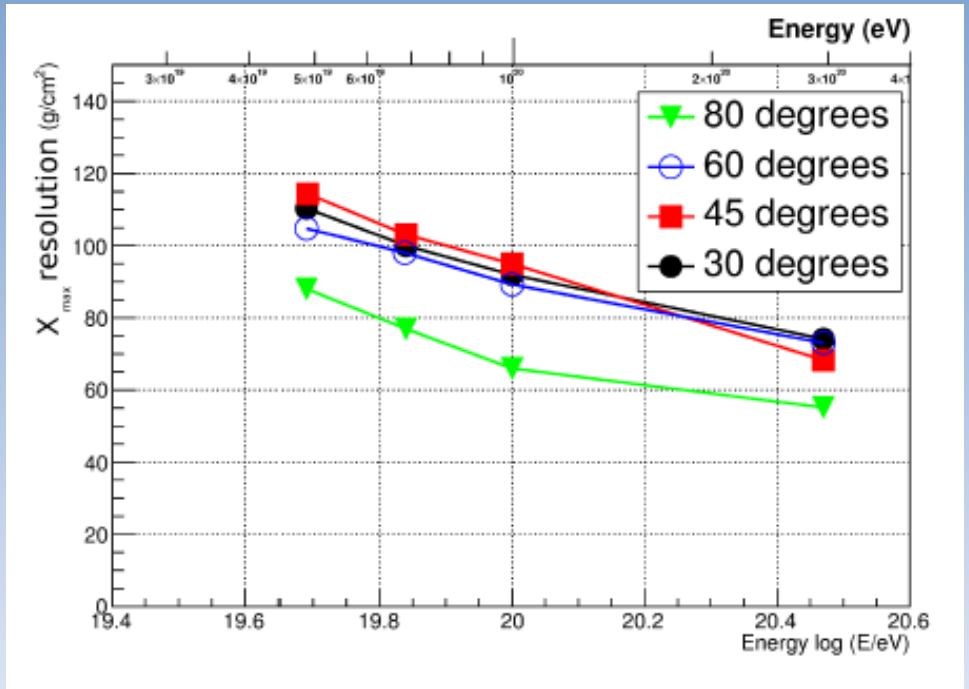
JEM-EUSO Annual Exposure



#682 K. Shinozaki

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





Fenu et al. ICRC 2015

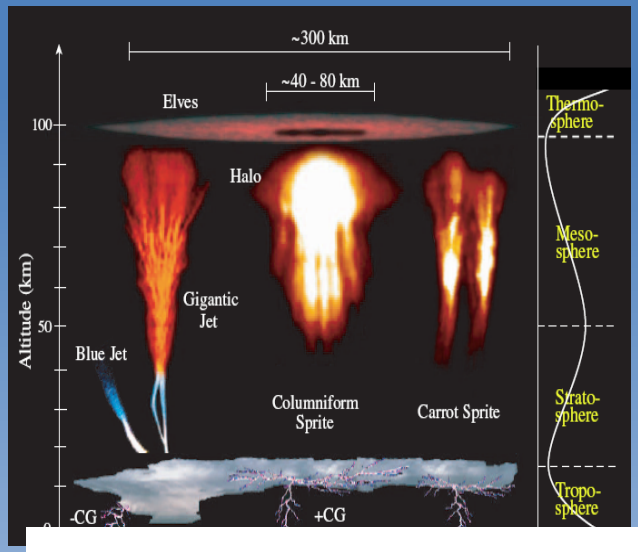
JEM-EUSO Science objectives

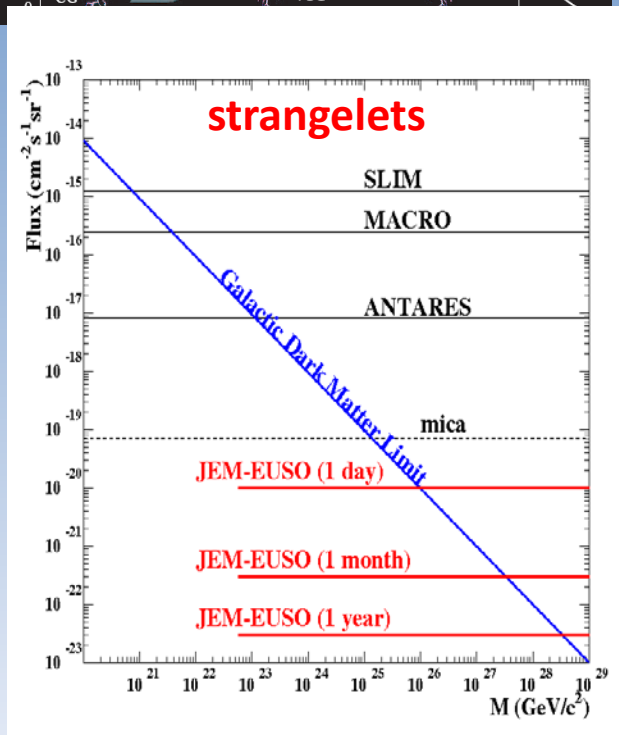
- **Study of Cosmic Particles at the Highest Energies**

- Main Science Objectives:
- Identify **UHE sources**
- Measure energy spectra of individual sources
- Measure the trans-GZK spectrum

- Exploratory objectives:
- Discover UHE Gamma-rays
- Discover UHE neutrinos
- Study Galactic and Extragal. Magnetic Fields
- Discover Relics from the Early Universe
- (e.g., SHDM)

- Atmospheric Science
- Nightglow
- Transient luminous events (TLE)
- Meteors and meteoroids

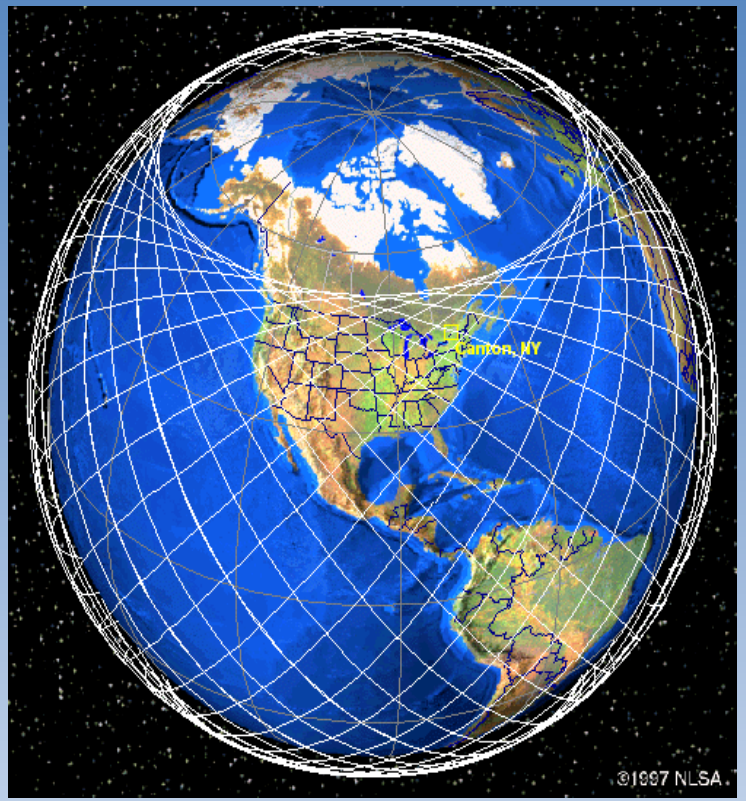




JEM-EUSO Full Sky Coverage

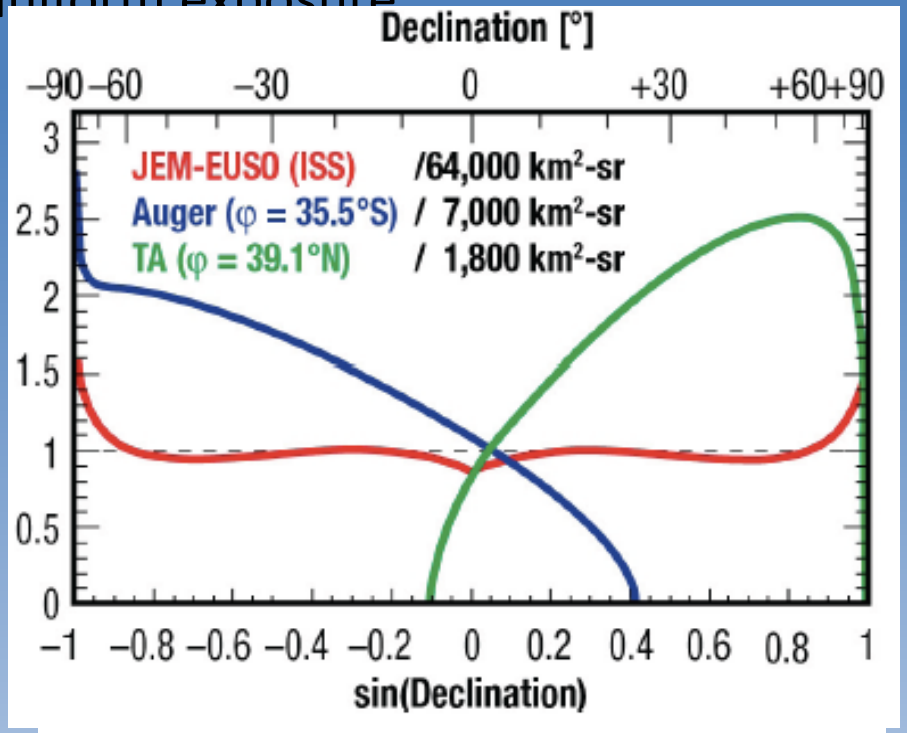
with nearly uniform exposure

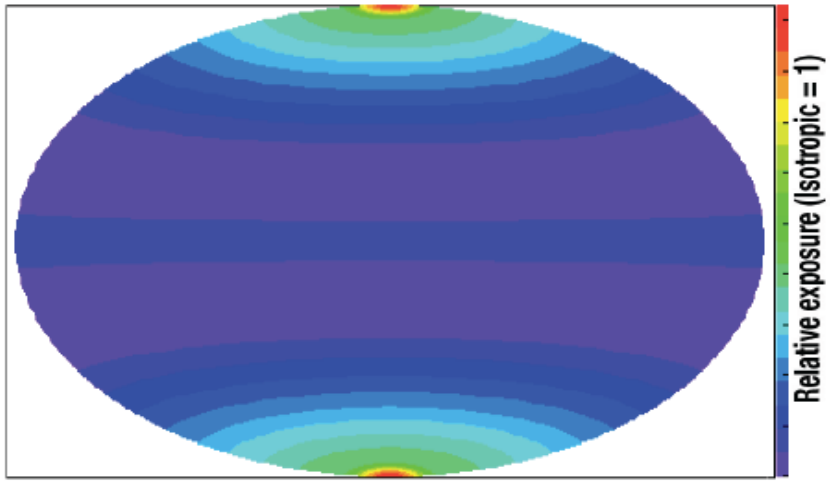
The ISS ORBIT



http://www.nlsa.com/

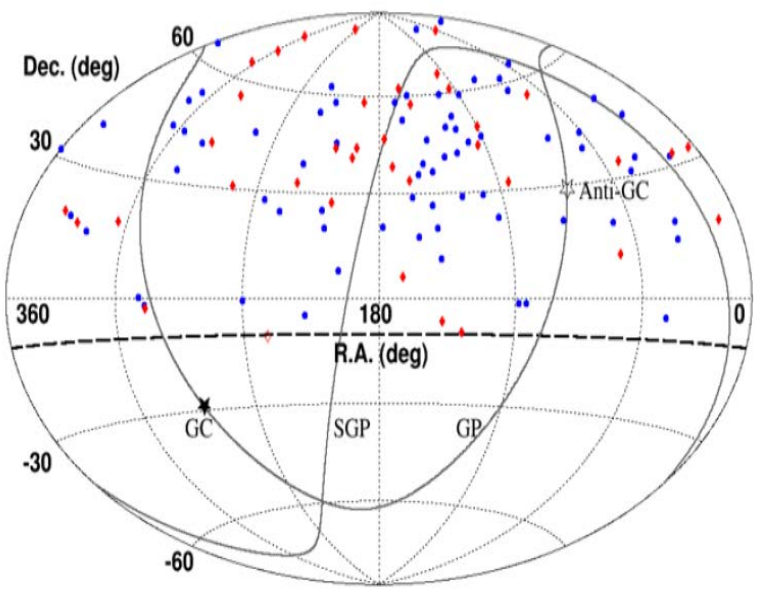
Inclination: 51.6°
Height: ~400km

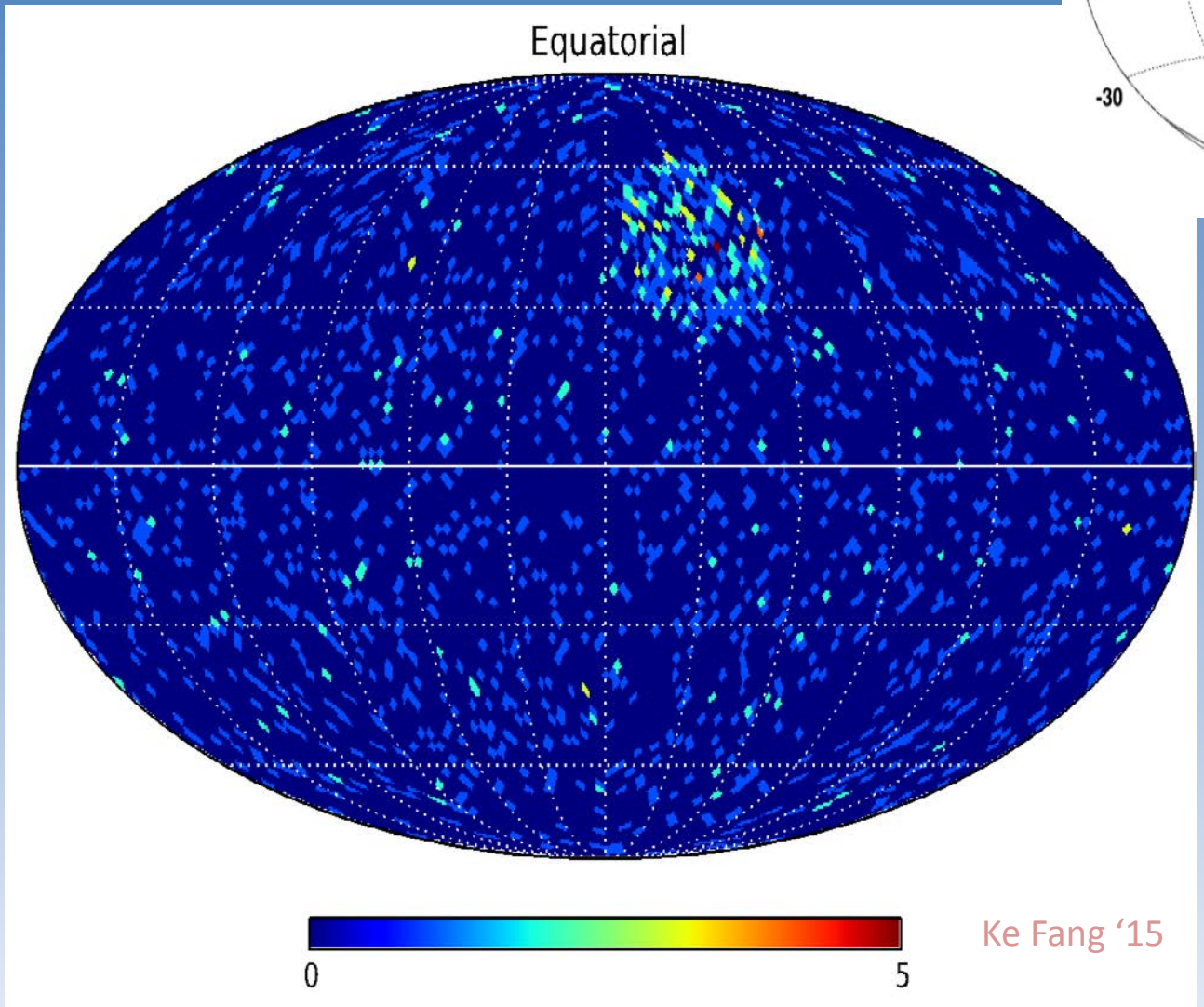




JEM-EUSO Source Identification

2620 events > 57 EeV over the entire sky
240 events > 57 EeV from HotSpot



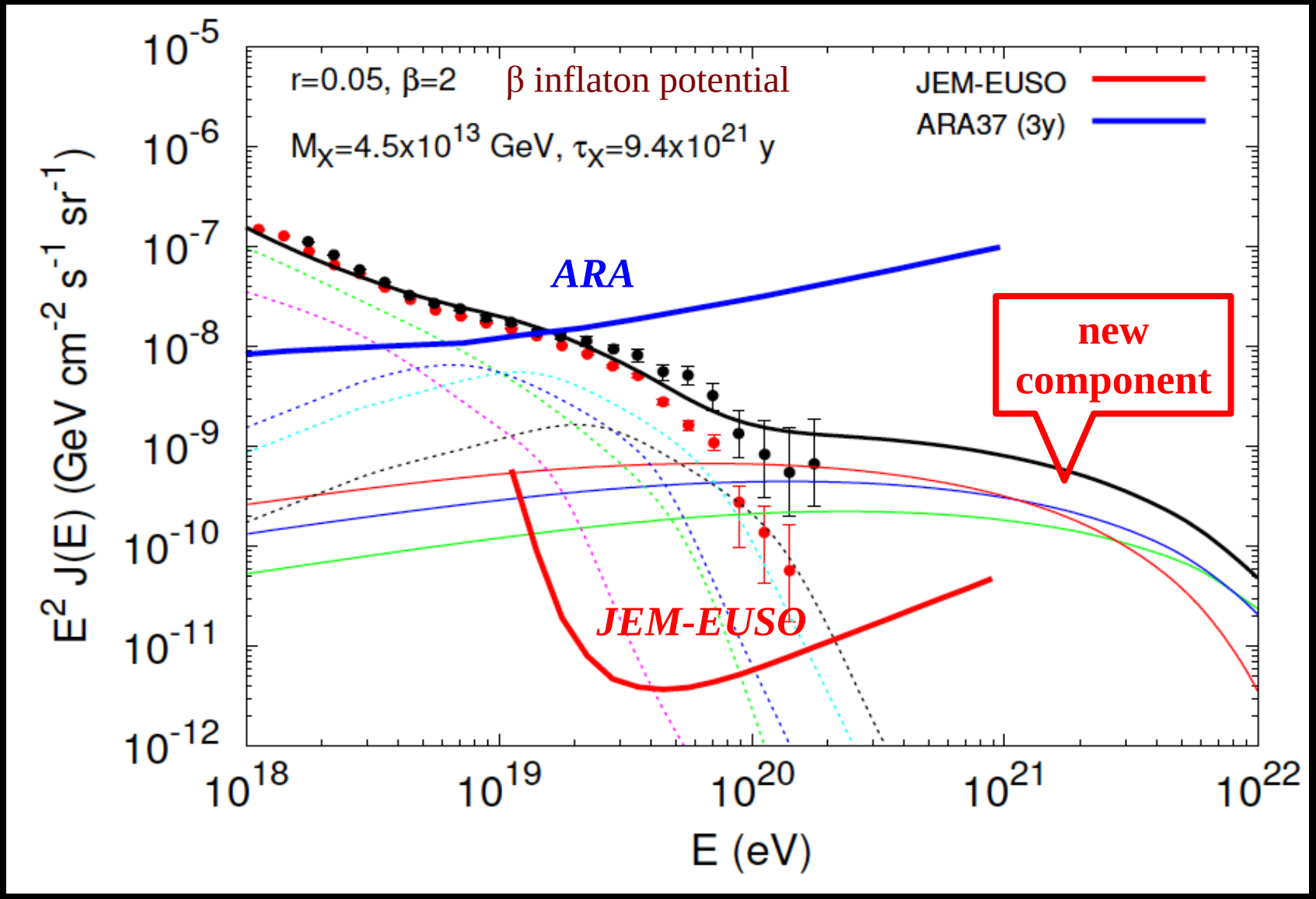


Ke Fang '15

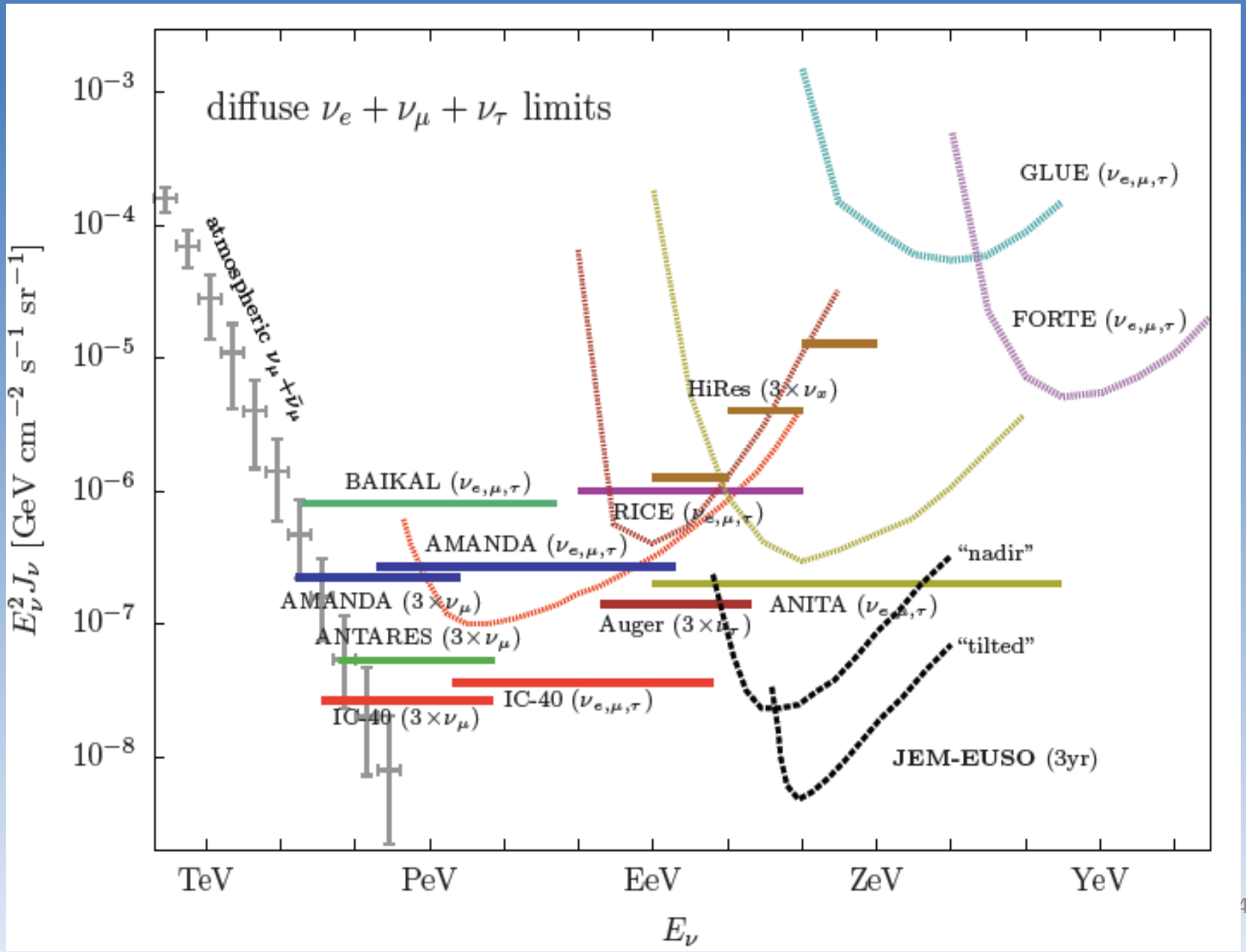
5 yr Mission
using TA 7yr numbers
(1 JE yr = 40 TA yr
= 10 TAx4 yr)

Super Heavy Dark Matter

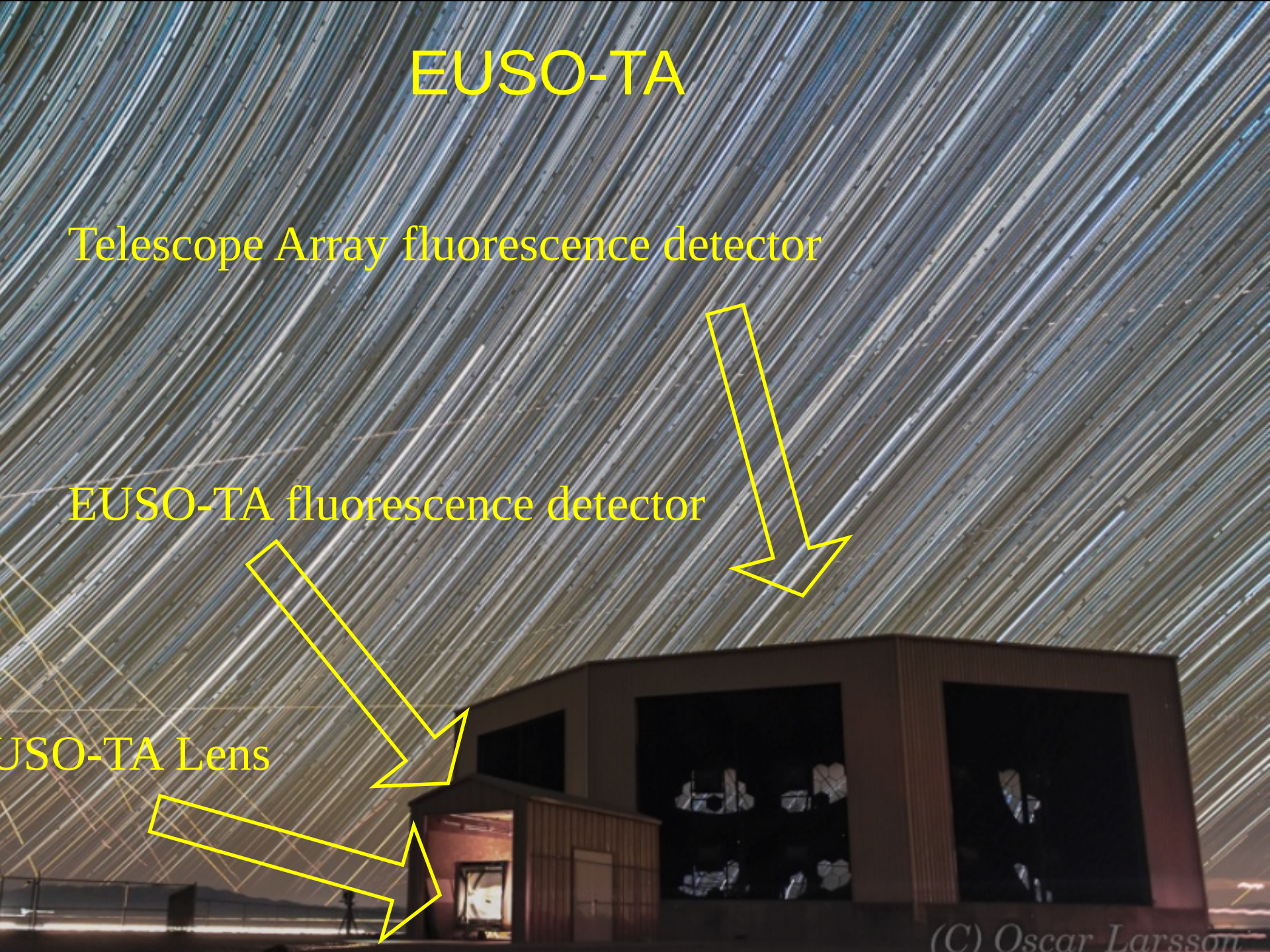
Aloisio, Matarrese, AO '15

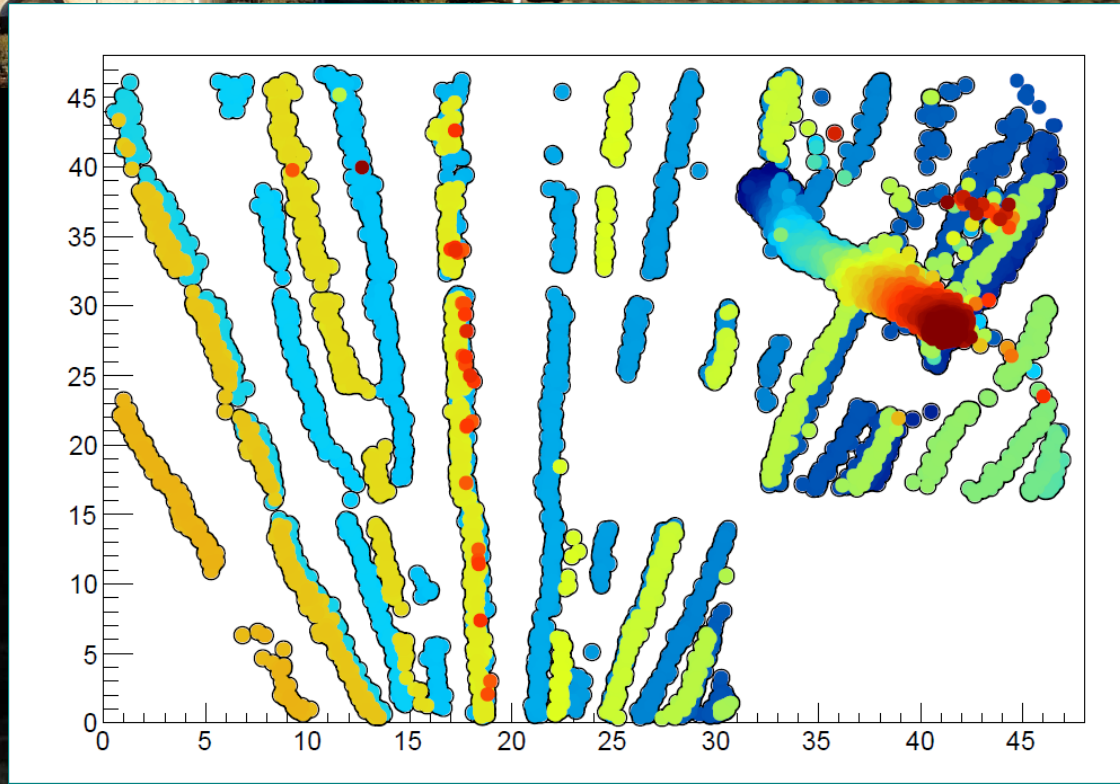


ZeV neutrinos?



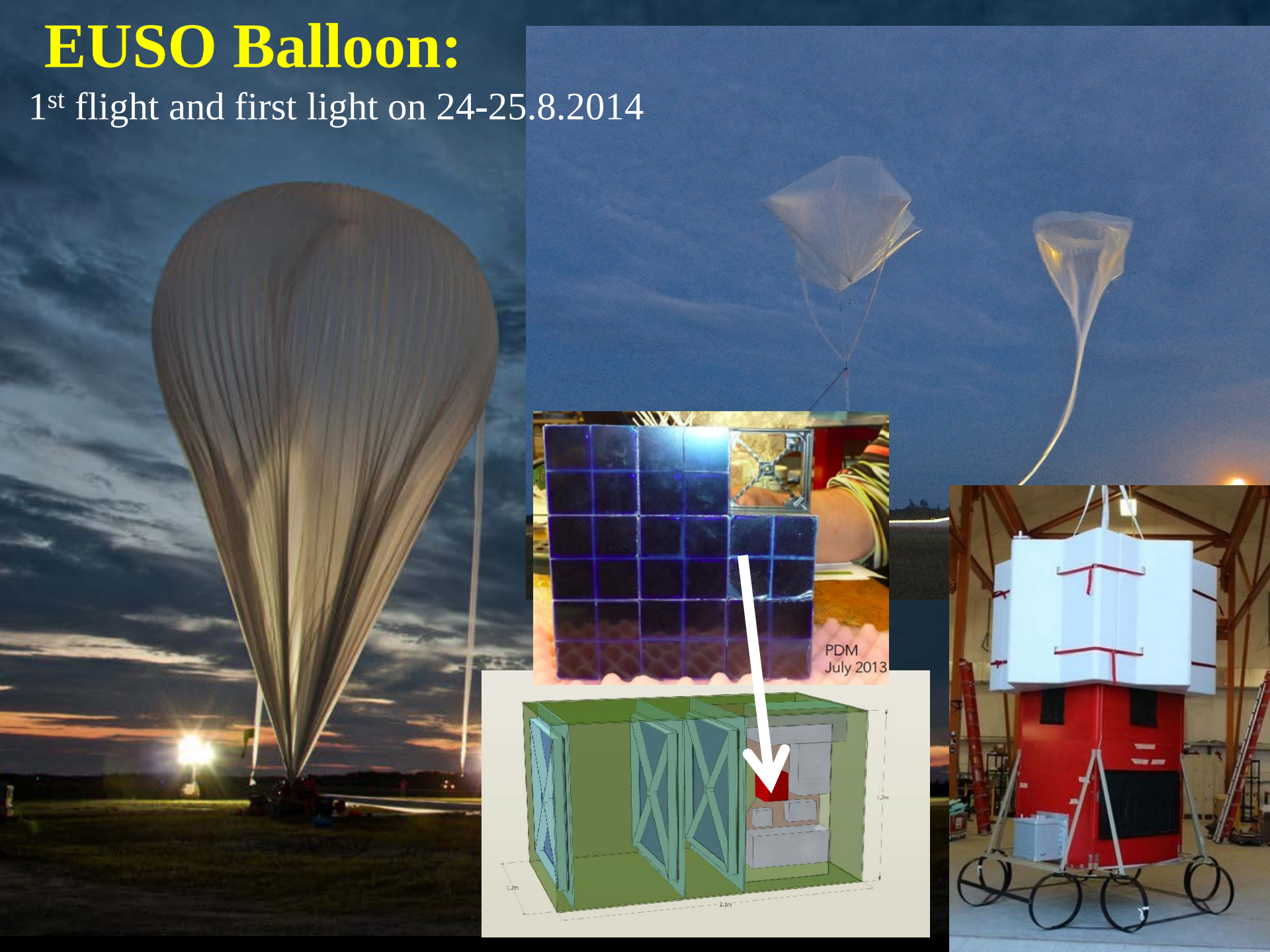
EUSO-TA

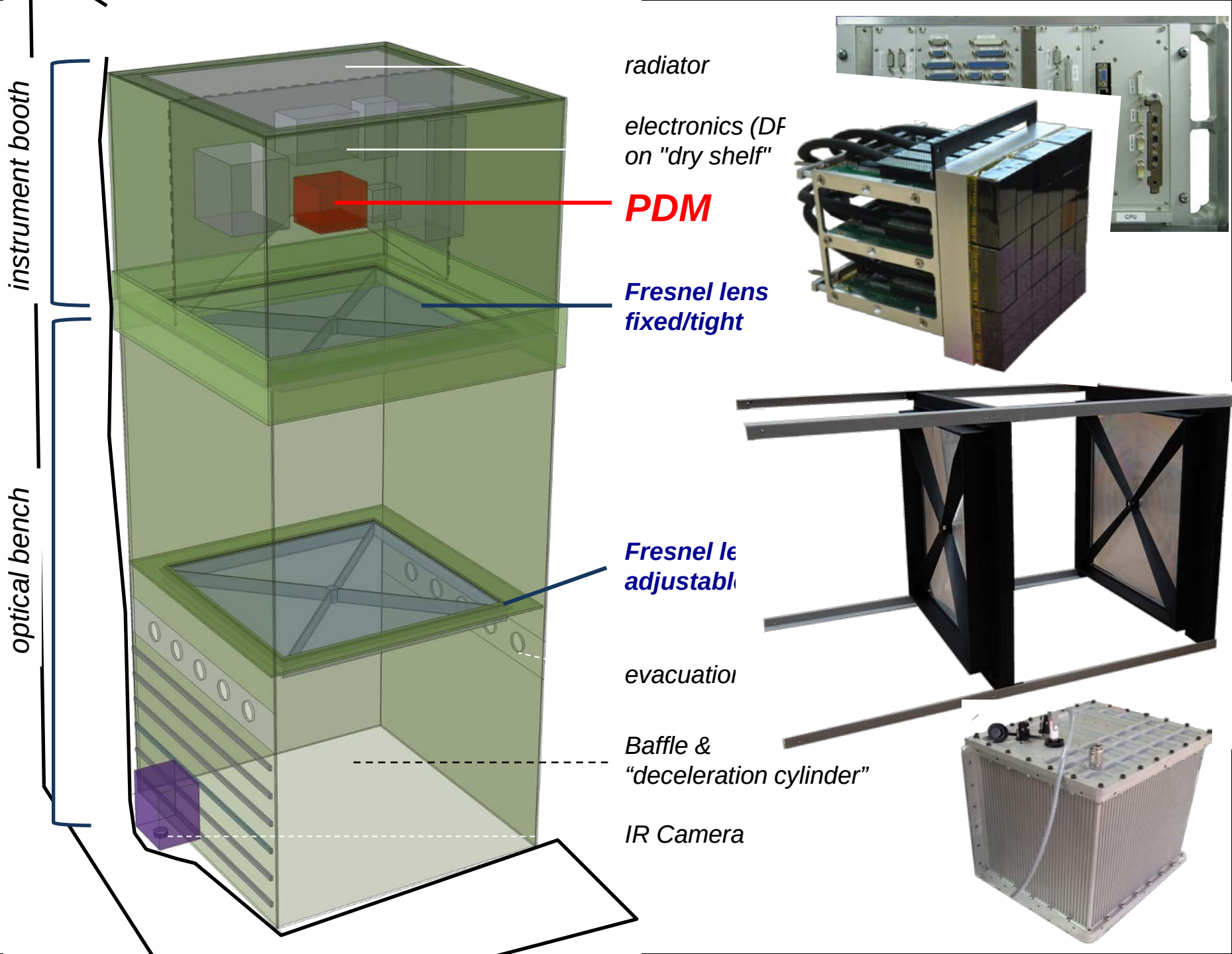

Telescope Array fluorescence detector
EUSO-TA fluorescence detector
USO-TA Lens
(C) Oscar Larsson

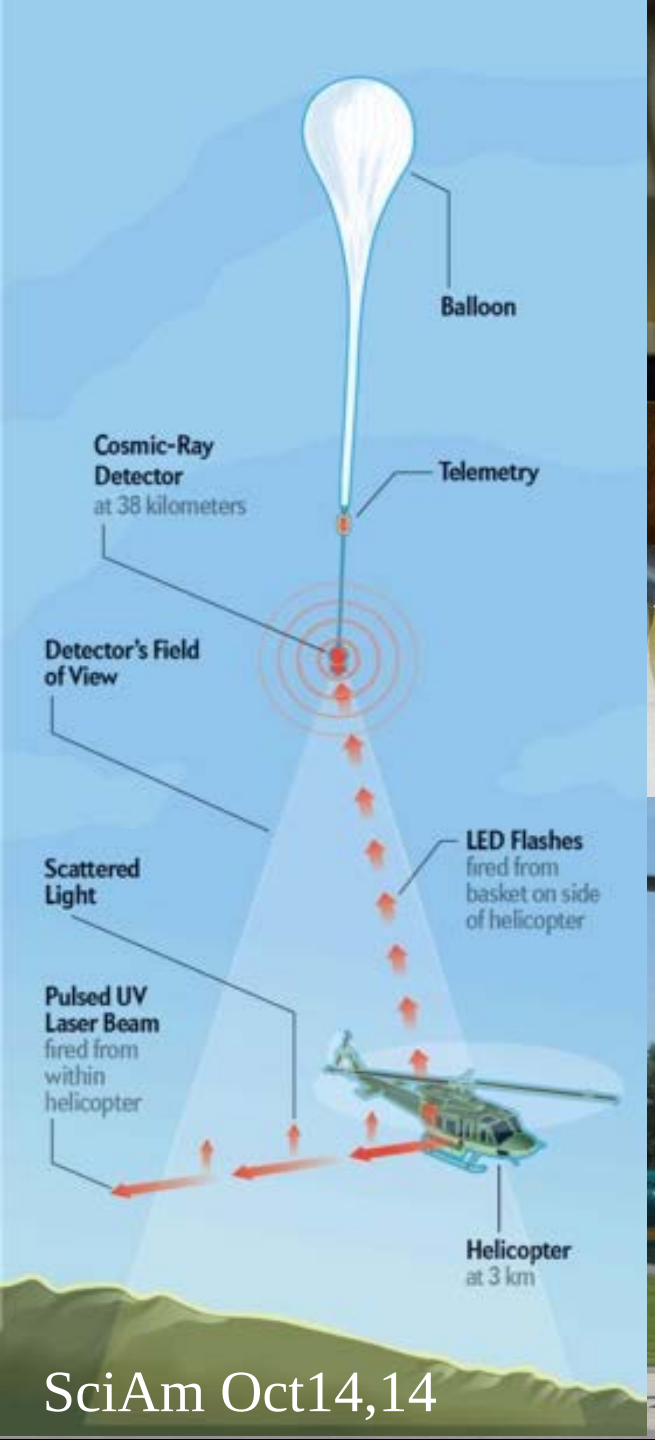

0
5
10
15
20
25
30
35
40
45

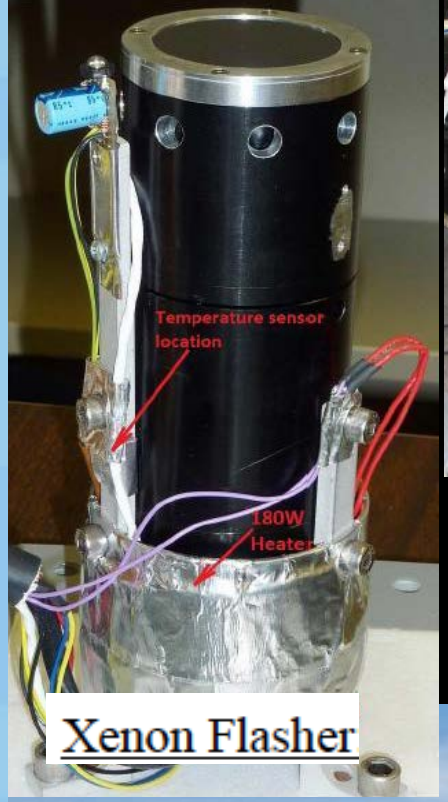
EUSO Balloon:

1st flight and first light on 24-25.8.2014



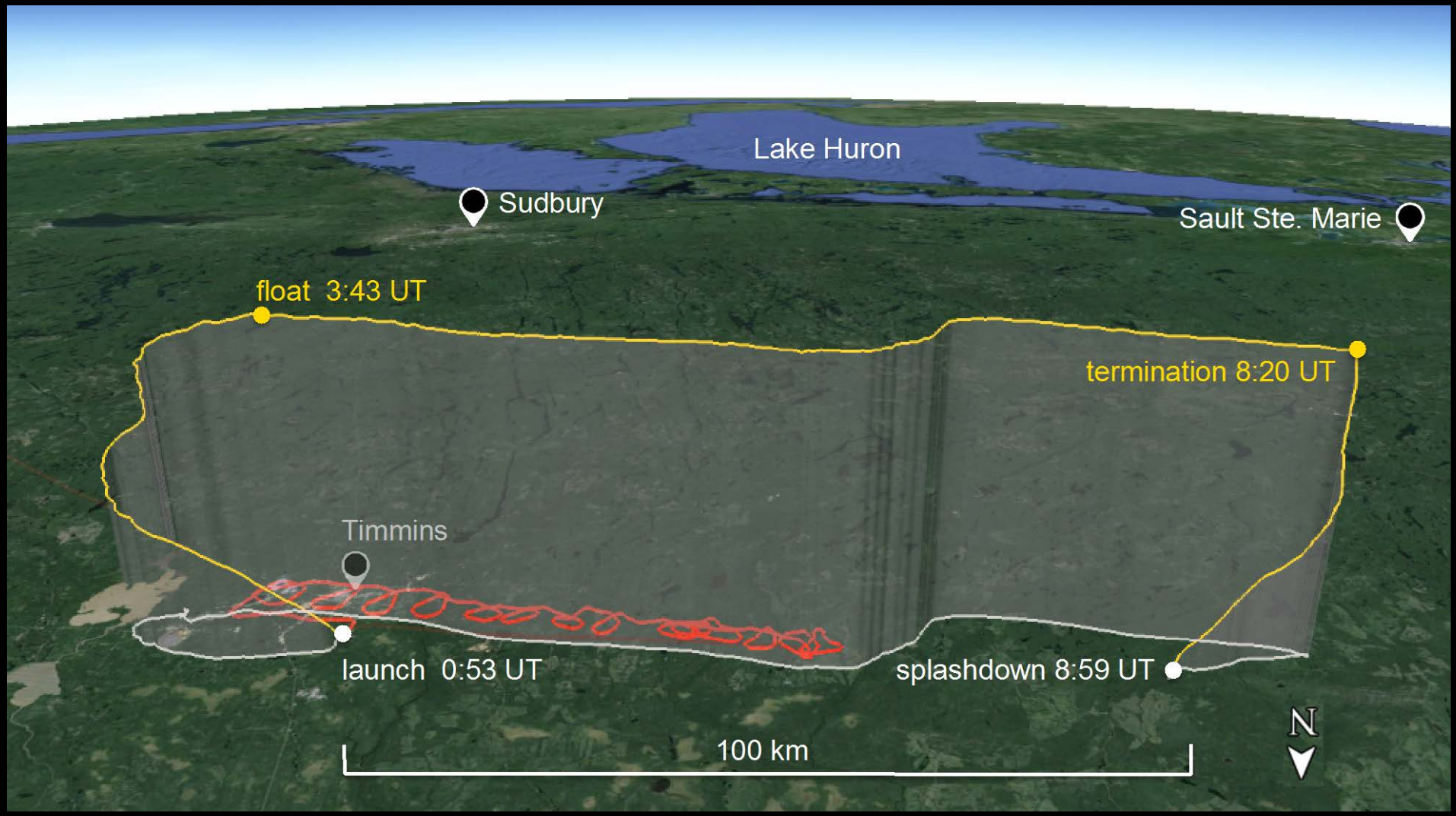

instrument booth
optical bench
radiator
electronics (DF
on "dry shelf"
PDM
Fresnel lens
fixed/tight
Fresnel le
adjustabl
evacuatio
Baffle &
“deceleration cylinder”
IR Camera





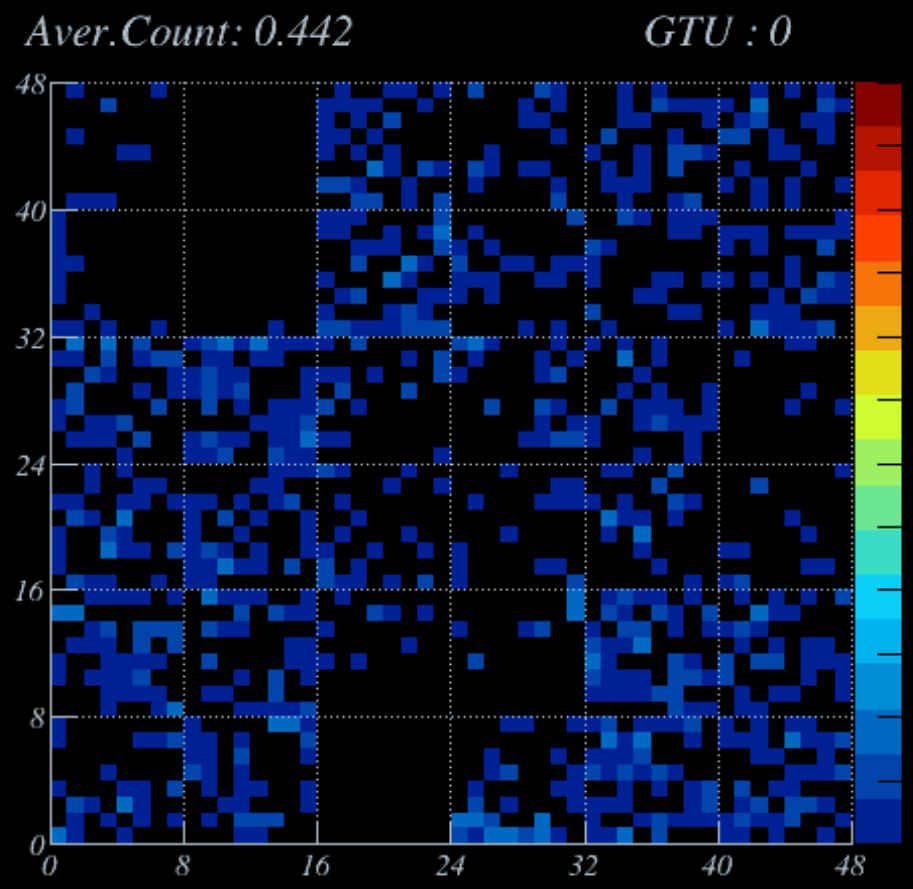
SciAm Oct14,14

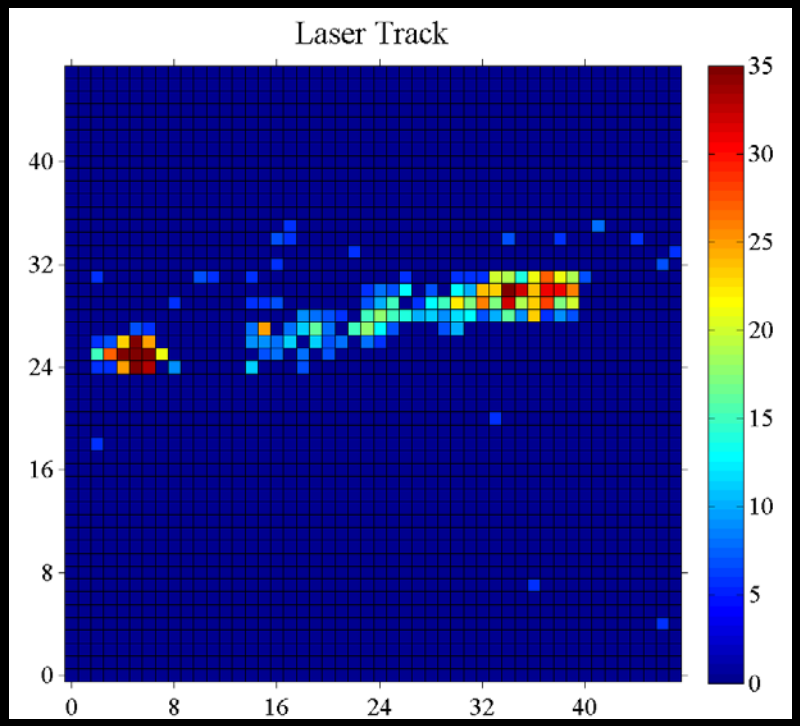
EUSO Balloon first flight



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

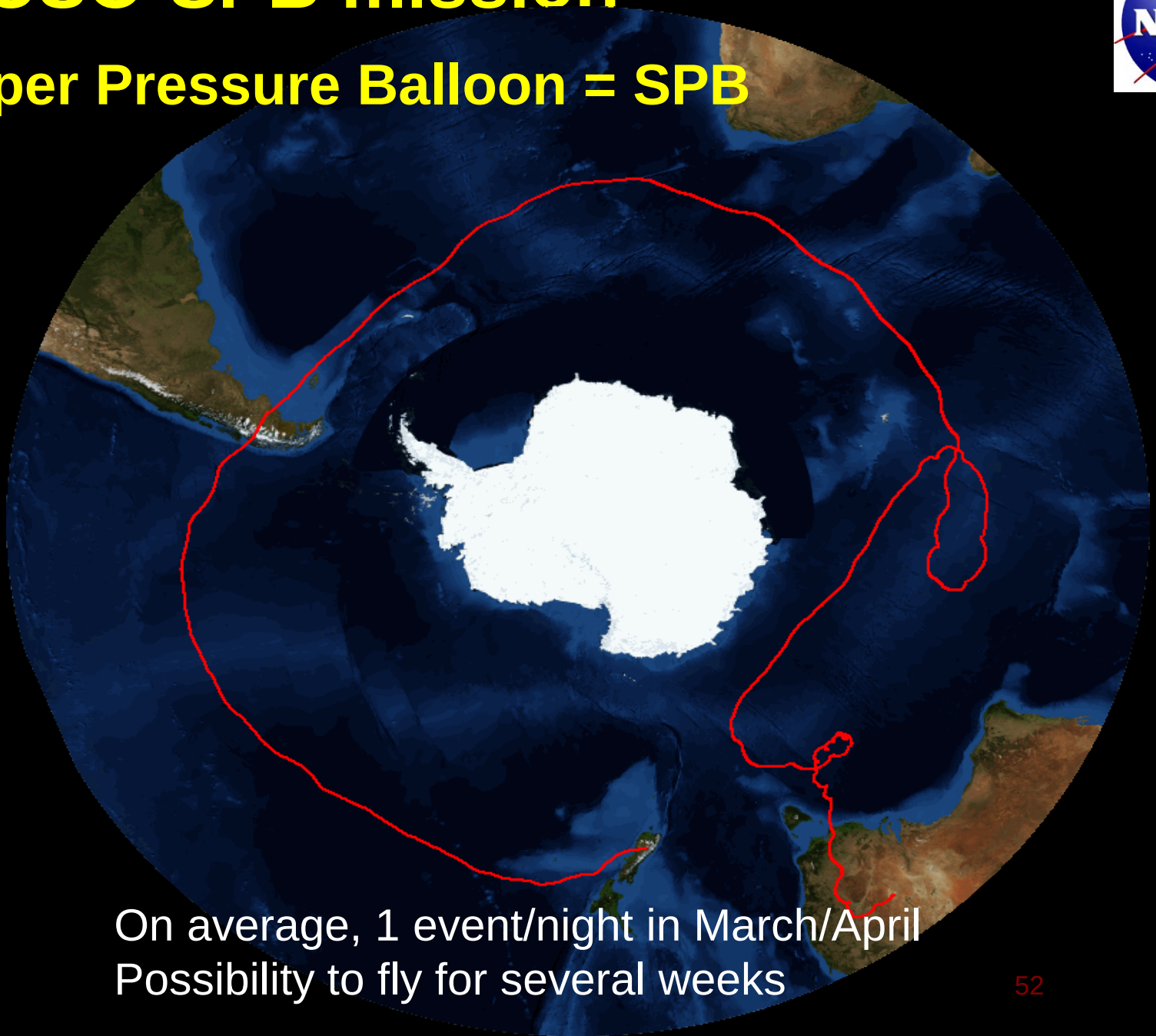
Flasher & Laser shot





EUSO-SPB mission

Super Pressure Balloon = SPB



On average, 1 event/night in March/April
Possibility to fly for several weeks

EUSO-SPB

Super Pressure Balloon (SPB)
Ultra Long Duration flight
2017 Spring Campaign

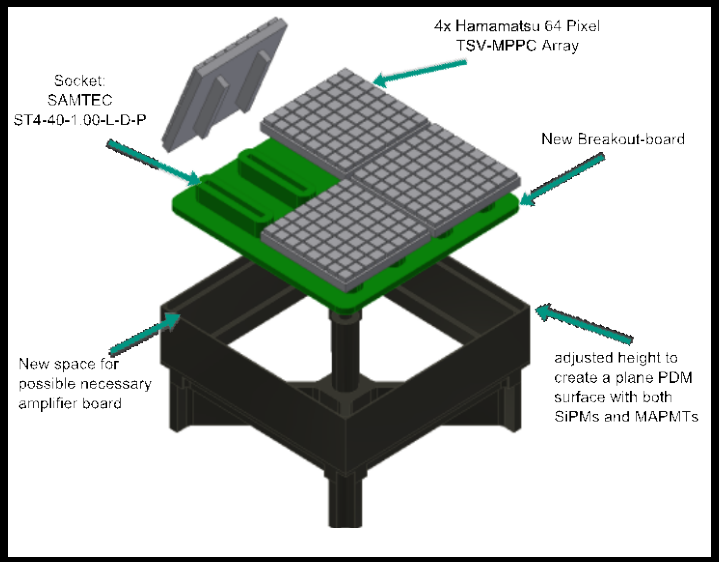
First observations of UHECRs from near space:
50 nights (2 dark periods)

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

$$A_{Exp.} \approx 10^3 km^2 sr$$

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

SPB Flight under NASA leadership (2017)



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

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

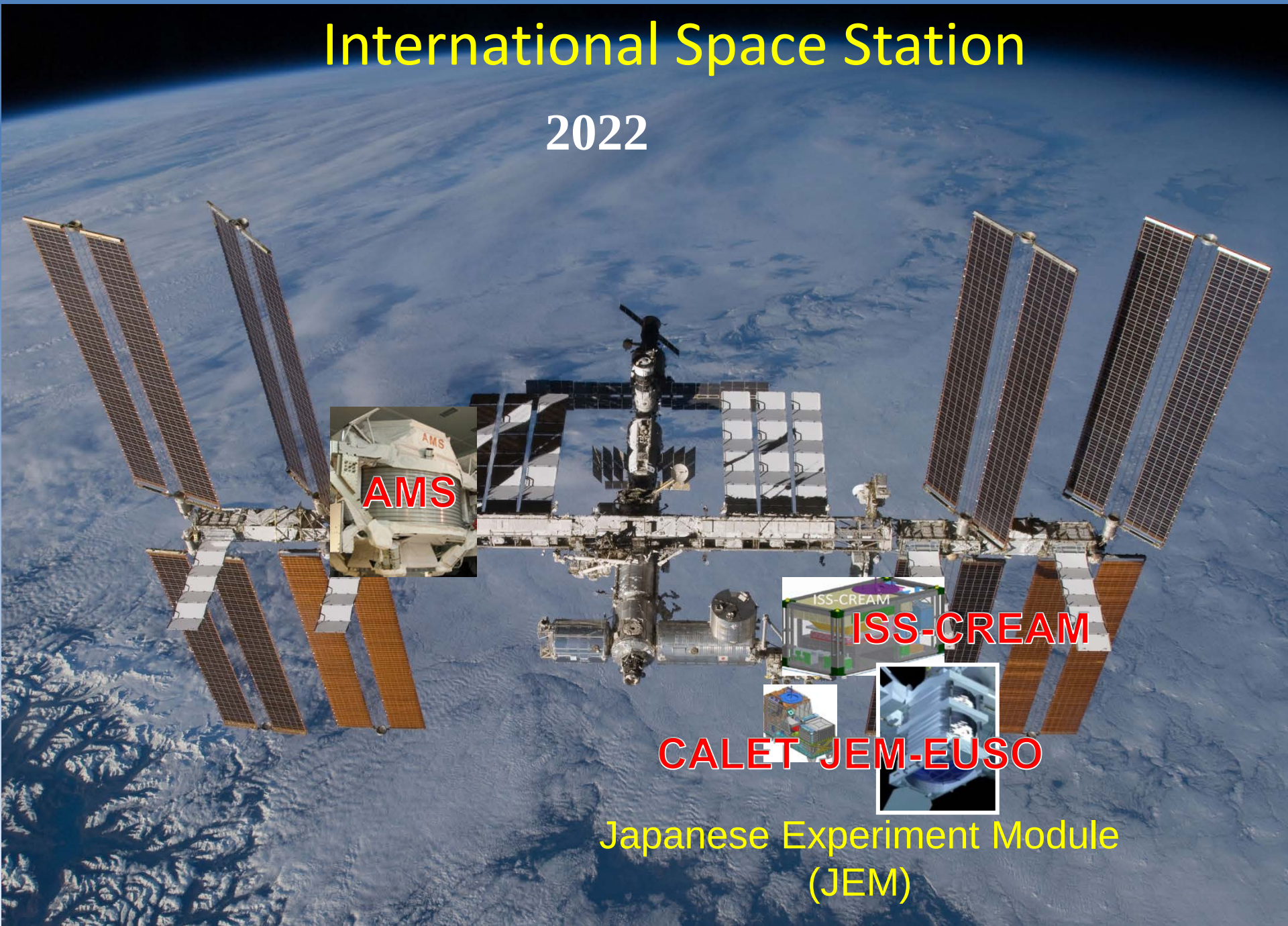
A key development of the JEM-EUSO program

$$A_{Exp.} \approx 10^3 km^2 sr$$

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

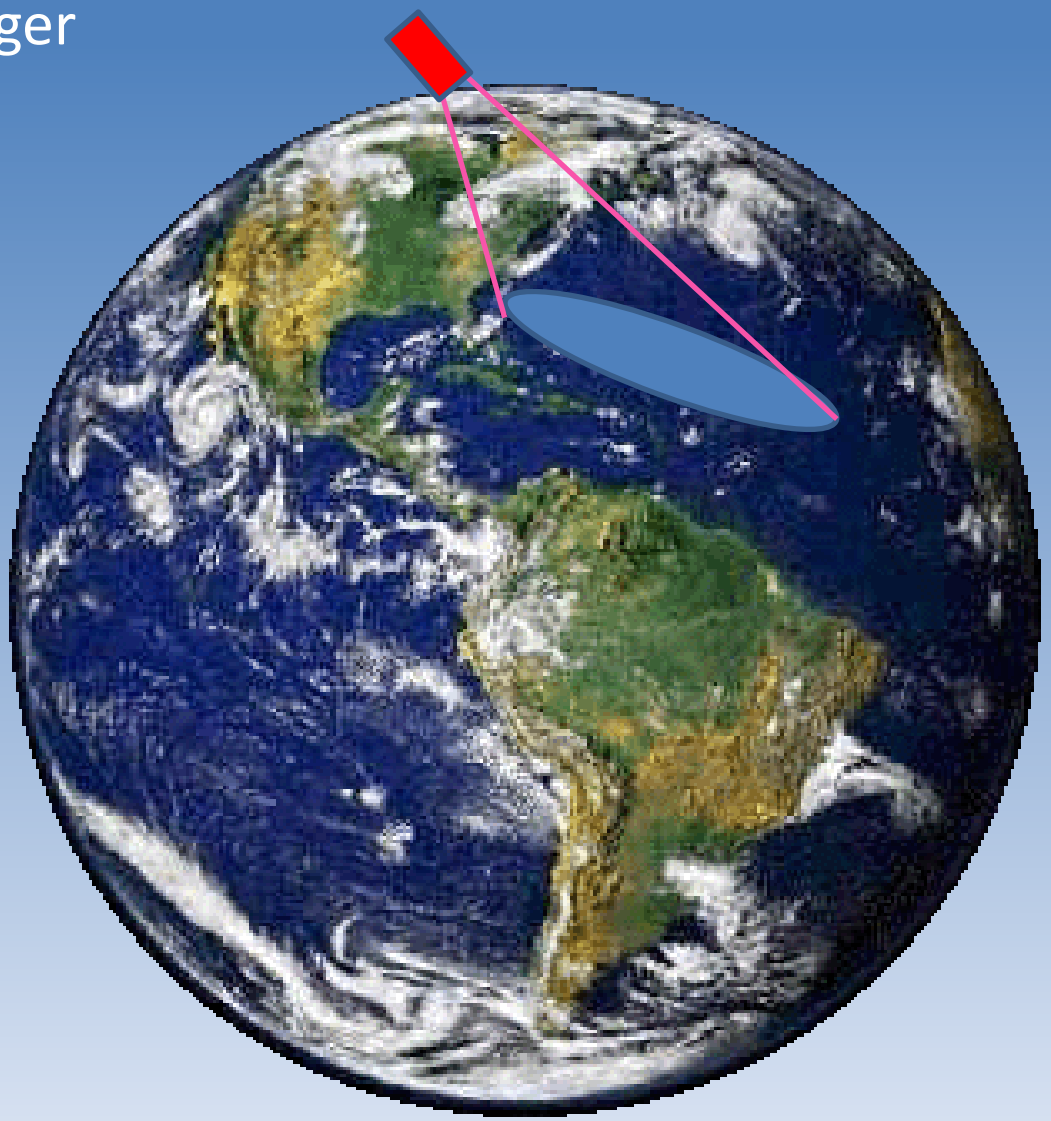
International Space Station

2022

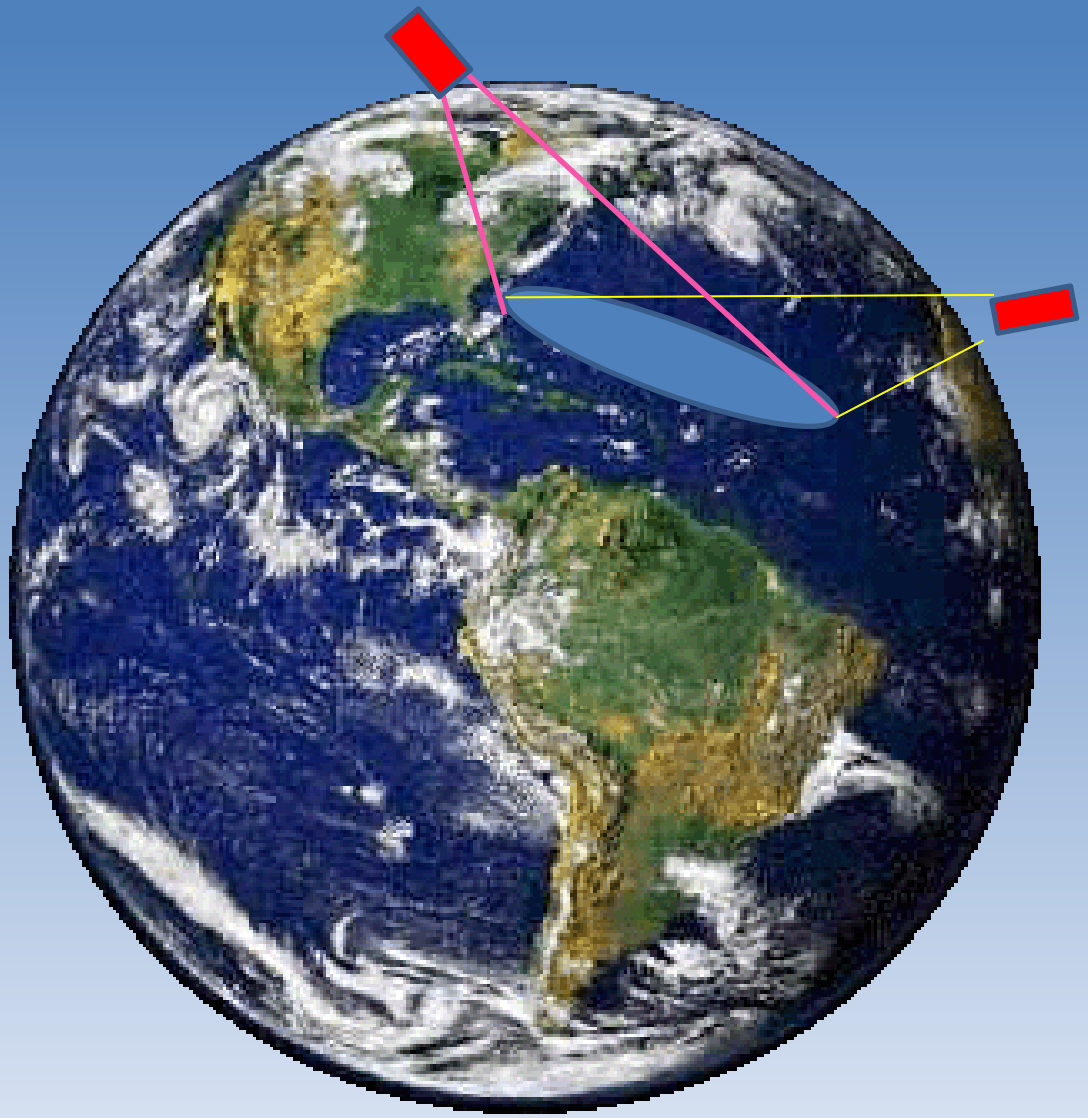


Japanese Experiment Module
(JEM)

In 20 years?
Free Flyer with variable orbit (energy threshold)
(100) X Auger



Stereo?



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

Earth - surface ~ $5\ 10^8$ km^2

~$3.4\ 10^6$ events/yr

4 Orders of Magnitude to Go!!

Technology Wish List/ Conclusion

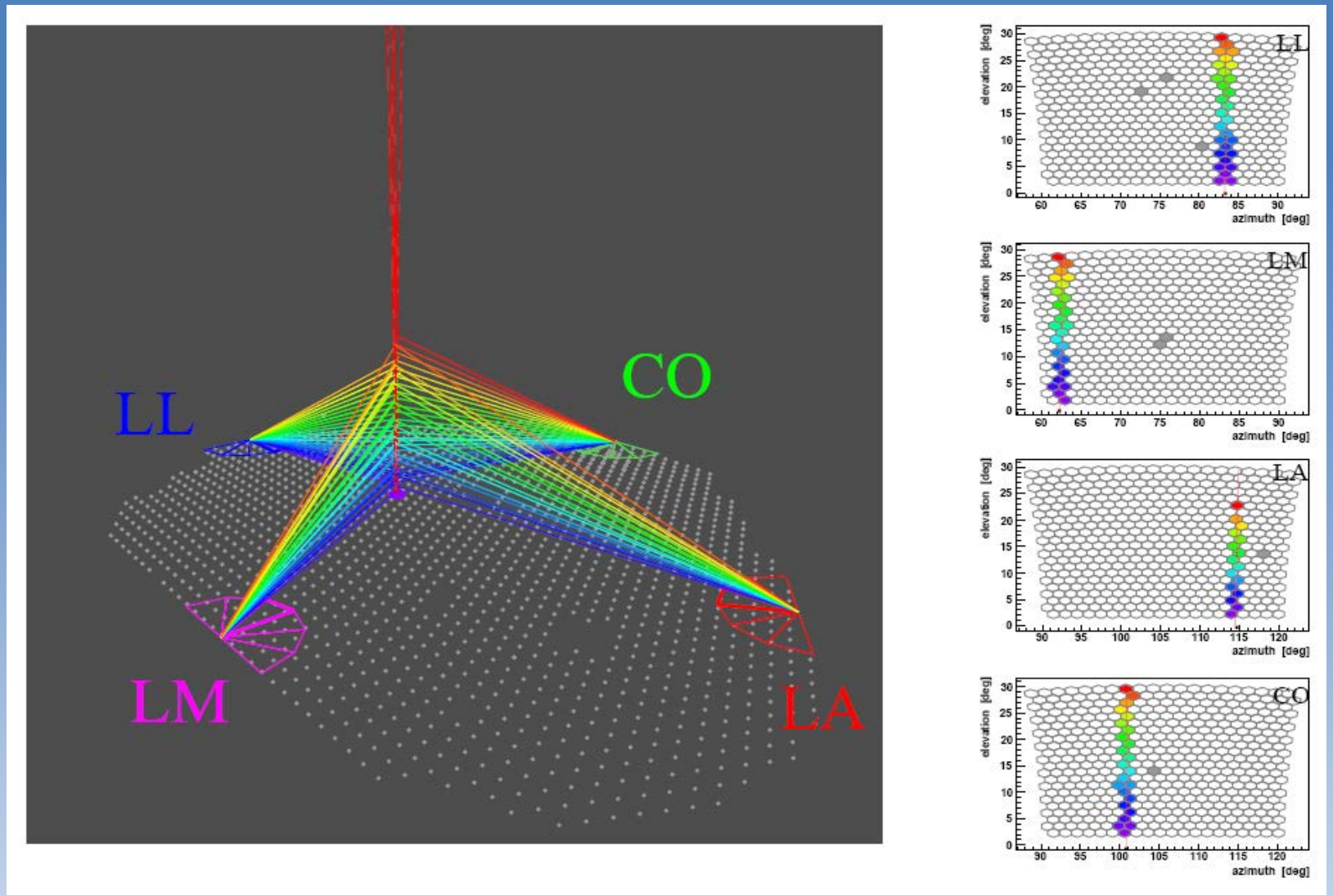
More efficient photon detection (A Holy Grail)
Silicon PM focal surface for UHECR space based detector
Wide FOV lightweight refractive optics
Absolute photometric calibration methods
Tunable Lasers 300-400 nm @ 5-50 mJ/pulse (EAS $5x10^{19}$-$5x10^{20}$ optical equivalent)

Triggerless DAQ – write out the entire sky?

Higher rate telemetry down-links and innovative ways to recover large data samples

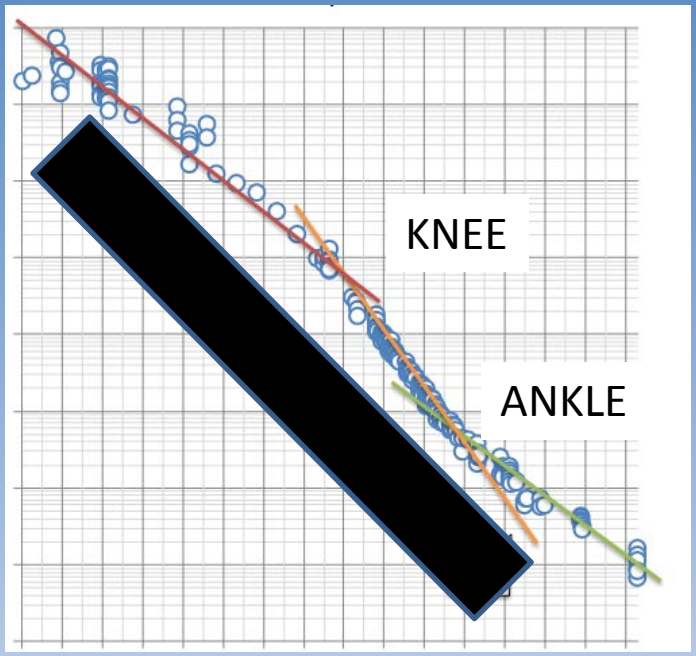
Extra Slides

The Pierre Auger Observatory: A Quad-Quasi-Static LIDAR system

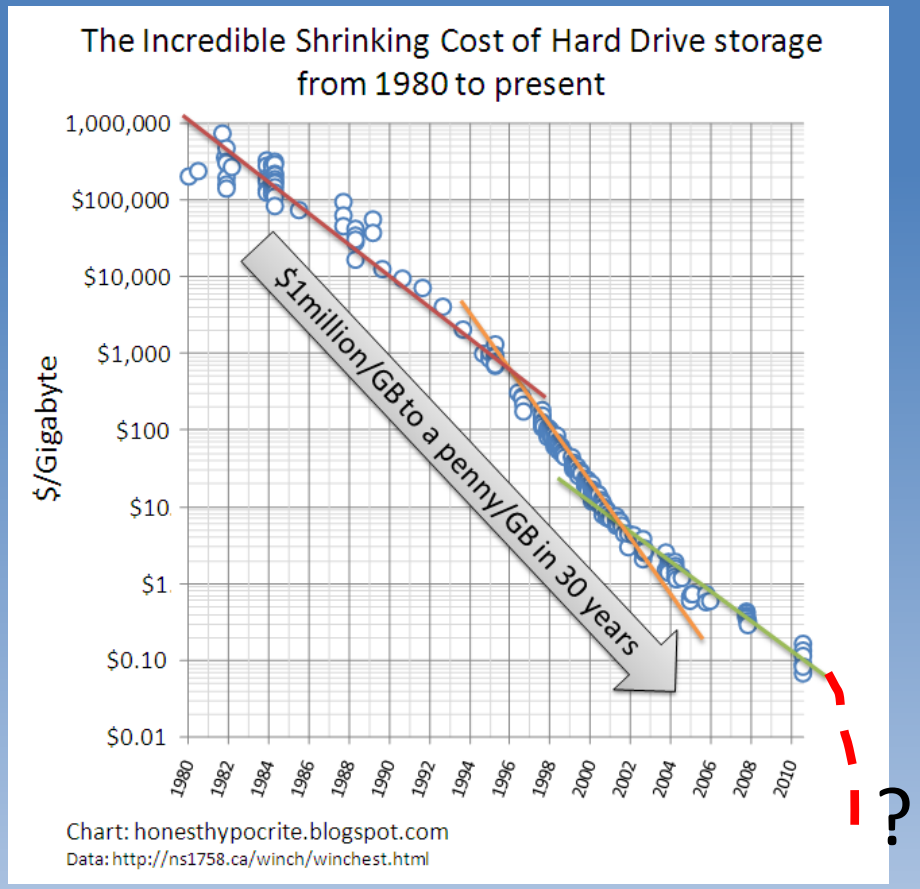


A vertical laser pulse directed upward from the Central Laser Facility is observed by the four eyes of the Auger fluorescence detector under exceptionally clear conditions. The triggered pixels in the four eyes are shown on the right. The eyes are 26 to 40 km distant

A plot with a familiar shape



Cost of Hard Drive Storage (1980-2010)



?

Instead of dropping science, drop the trigger?

Write out the entire sky

This crazy idea gets a bit little less crazy every year.

Sensible option for Auger Post-2015?

- Would make detector unique.
- Increase science scope