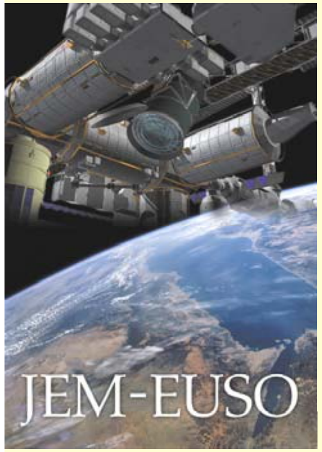



*"Doing astronomy by looking downward"*

# "The JEM-EUSO mission"


## *Andrea Santangelo**

*Advanced Studies Institute, Riken, Wako*

*Kepler Center for Astro and Particle Physics,*

*Eberhard-Karls-Universität , Tübingen*

**** On behalf of the JEM-EUSO Collaboration***

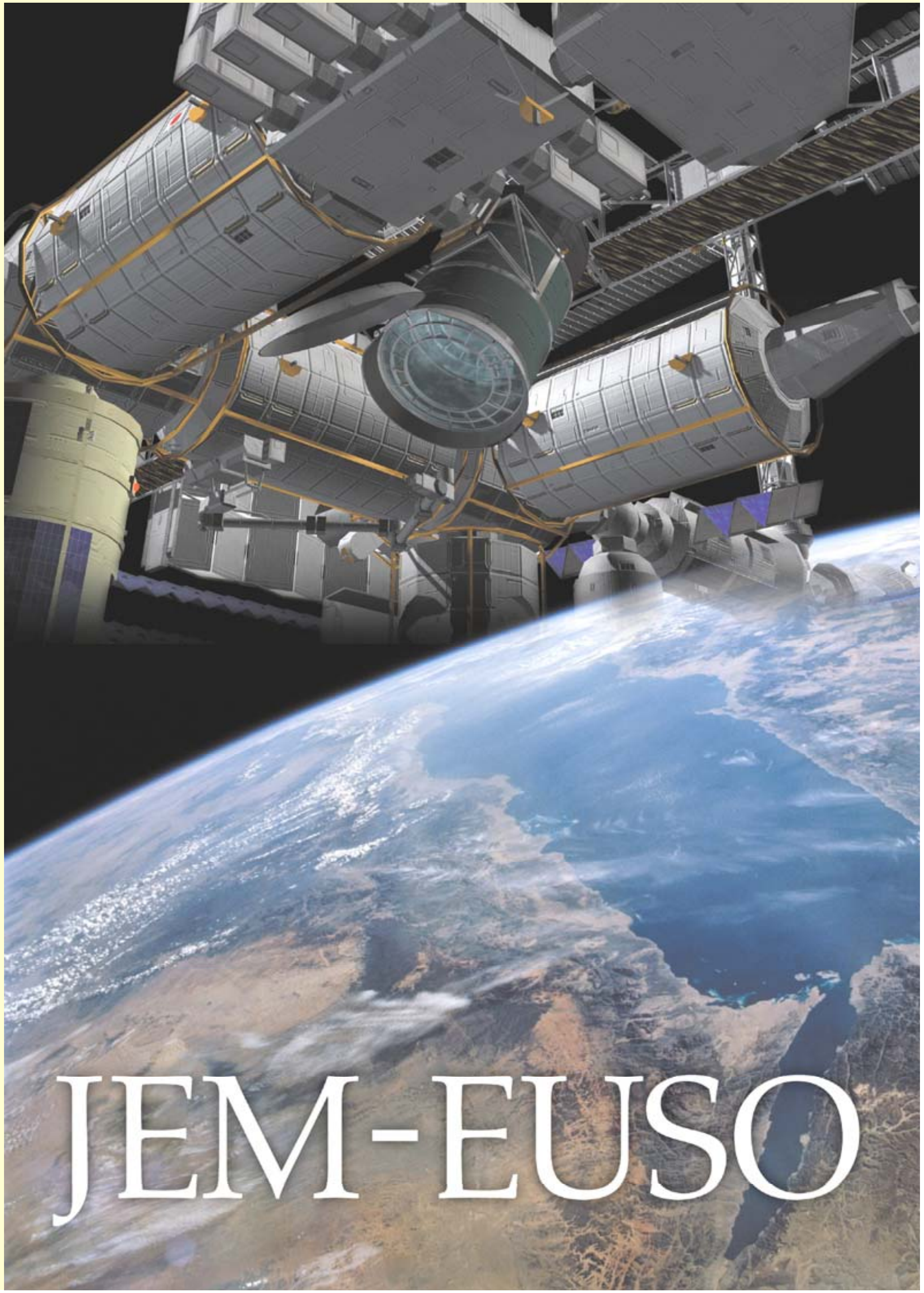
# *I. The JEM-EUSO mission*

*The Extreme Universe Space Observatory on-board the Japan Experiment Module (JEM) of the ISS*

EUSO

*2001- 2004*

*Heritage of the ESA EUSO study*



# *JEM EUSO Collaboration*

- Japan, USA, Korea, Mexico, Russia
- Europe: Bulgaria, France, Germany, Italy, Poland, Slovakia, Spain, Switzerland
- 77 Institutions, more than 250 researchers
- RIKEN: Leading institution

**Andrea Santangelo,**
**Kepler Center-Tü**

# *Main Scientific Objectives (1)*

- Main Objective: Astronomy and Astrophysics through the particle channel
  - *Identification of sources* by high-statistics arrival direction analysis (+multi-wavelength!)
  - *Measurement of the energy spectra* of individual sources (spectral shape, flux, power)

→ *Understand and constrain acceleration and emission mechanisms*

*Physics and Astrophysics at $E>5.\times 10^{19}$eV*

# *Exploratory Scientific Objectives (2)*

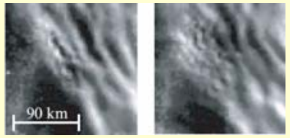
- Exploratory Objectives: new messengers
  - *Discovery of UHE neutrinos* by neutrino discrimination and identification via $X_0$ and $X_{max}$
  - *Discovery of UHE Gammas* by discrimination of $X_{max}$ due to geomagnetic and LPM effect

- Exploratory Objectives: magnetic fields
  - *Constrains on the galactic and local extragalactic fields*

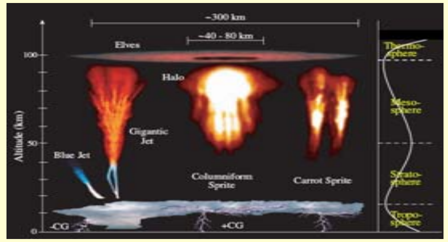
→ *High discovery potential; tests of new physics models*

# *Scientific Objectives 3*

- Exploratory Objectives: Atmospheric science
  - *Nightglow*




  - *Transient luminous events*




  - *Space-atmosphere interactions and climate change*

- Exploratory Objectives: Meteors and meteoroids

→ *A fast UV monitoring of the atmosphere*

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**Kepler Center-Tü**

# *Take home messages:*

## *Physics and Astrophysics at E>5. ×10^19 eV*

*But also… Explore new physics in the energy range E≈1 10^21 eV*

*Highest statistics and therefore largest exposures at extreme energies*

$$E \approx 10^{20-21}\, eV$$

*Lower Energies are important for overlapping with current generation observatories with significant statistics…*

$$E < 5 \times 10^{19}\, eV$$

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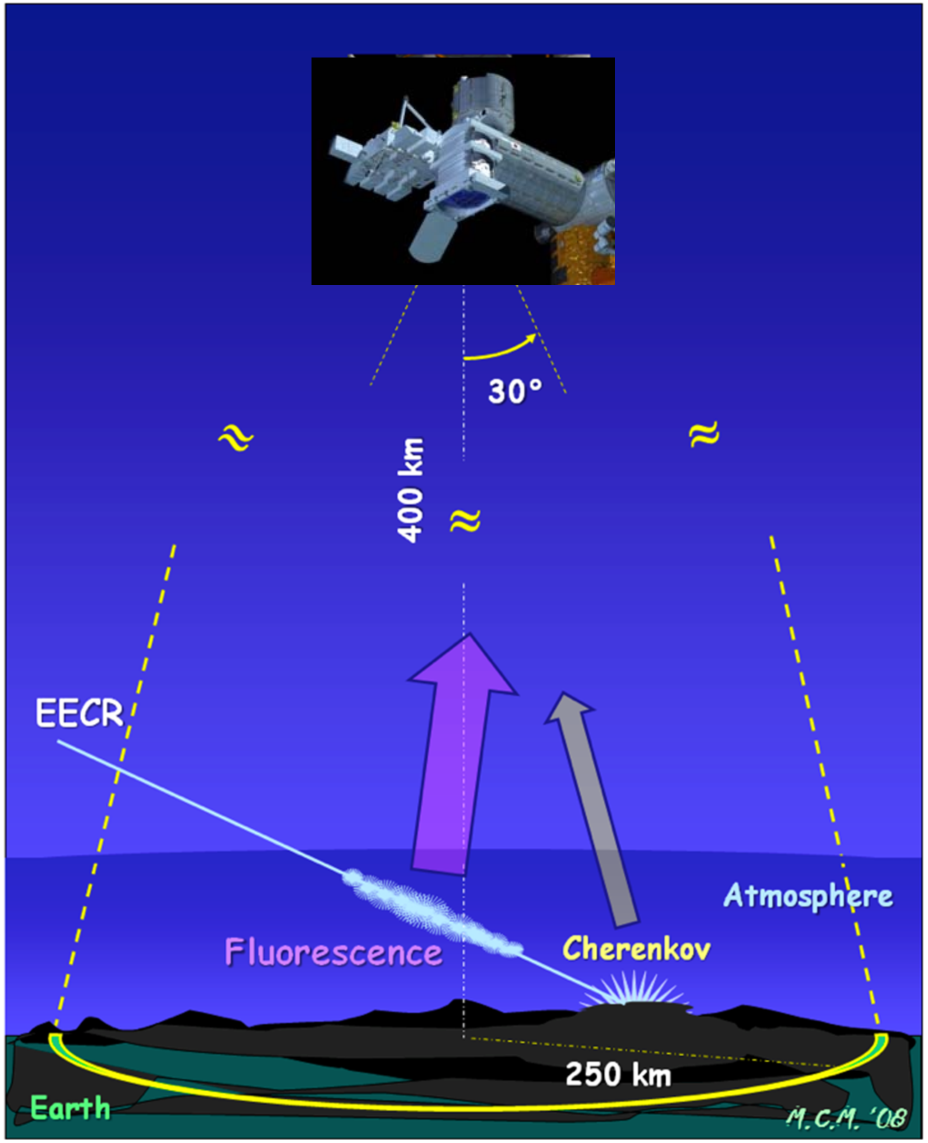
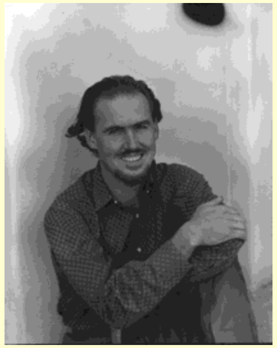
# *Observational Technique: fluorescence from space*



*J. Linsley*

*Y. Takahashi*

*The observation of the UV fluorescence tracks is a well established technique*

330 – 400 *nm*, UV

*Kakimoto et al., 1996 A. Bunner, 1967; Nagano, 2009;*

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

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

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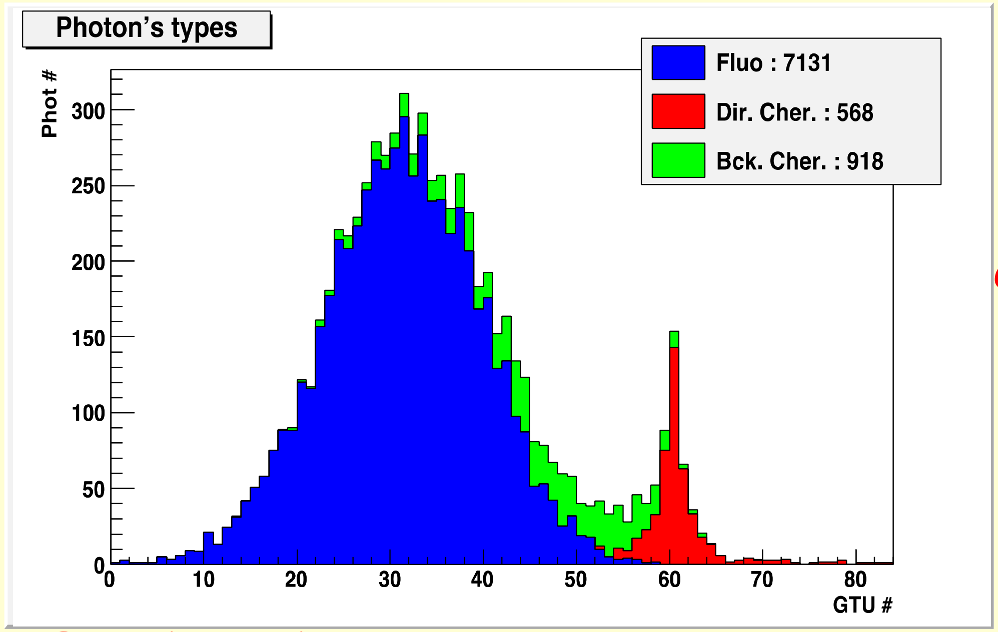
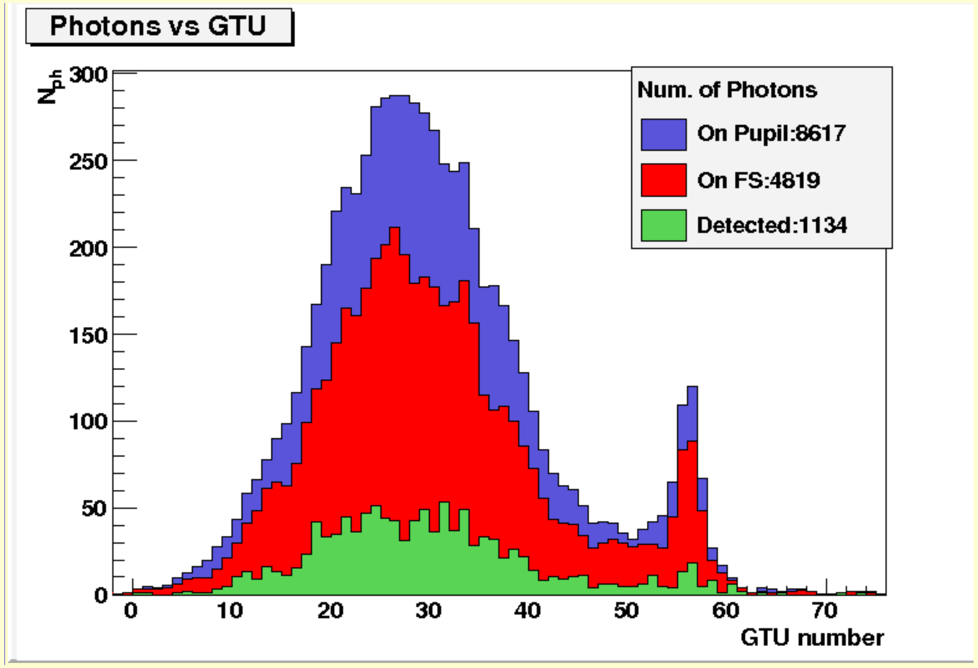



*GTU time units*




***a) Fluorescence***

***b) Scattered Cherenkov***

***c) Direct (diffusively reflected Cherenkov)***

$$1\ GTU = 2.5\ \mu\text{sec}$$

$$Back. = 500 / (\text{m}^2\ \text{sr ns})$$

***FAST SIGNAL***

$$duration \approx 50 - 150\ \mu s$$

*Simulation of the light profile observed at the entrance pupil (above) and throught the instrument using the ESAF code*

**Kepler Center-Tü**

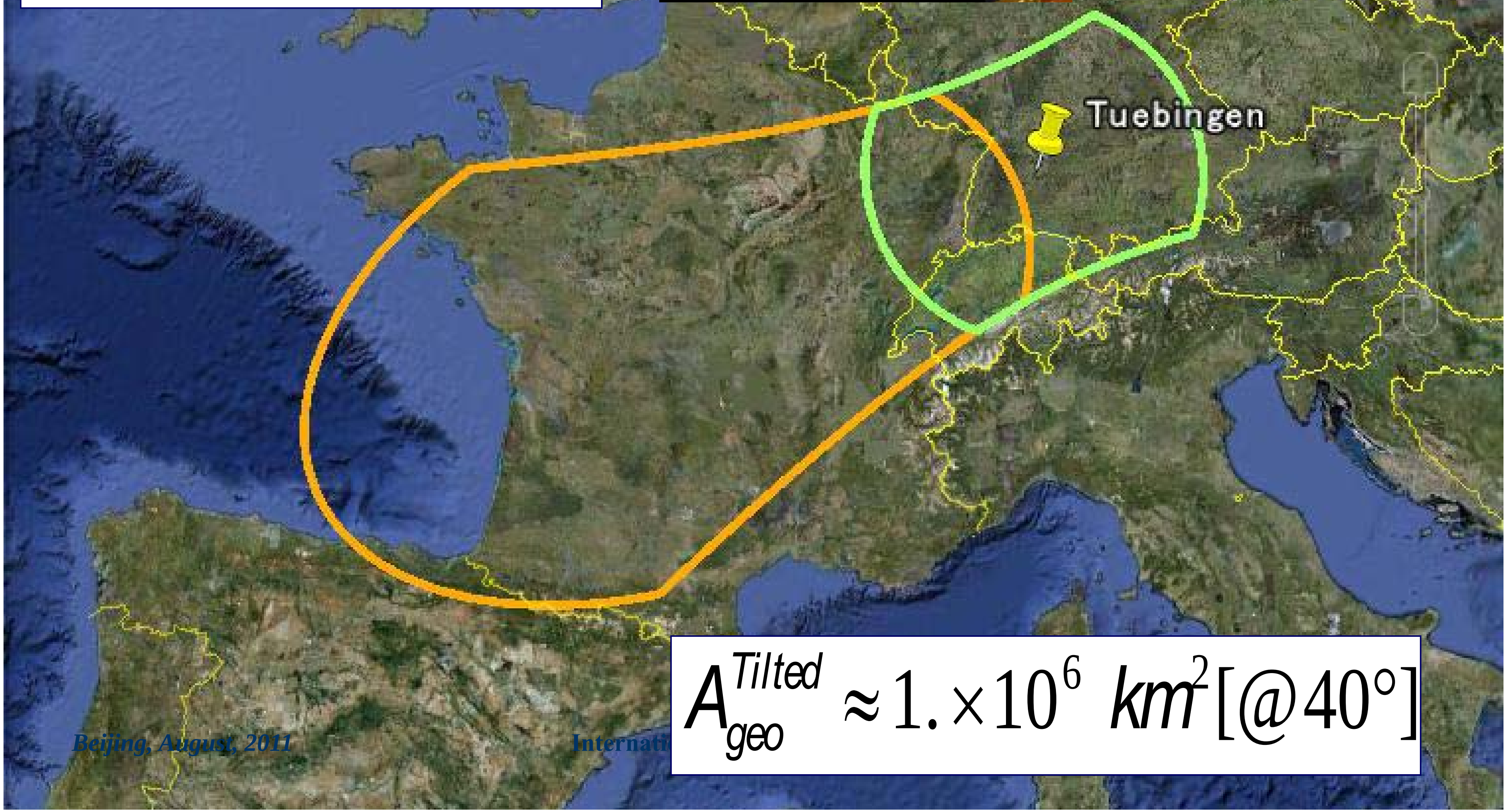
# *Peculiarities from space*

- *Far and almost constant distance* of the shower (no proximity effect)
- Shower is contained in the FOV: *observation of the entire profile*
- Possibility of *observing in cloudy conditions* (in most cases $X_{max}$ above the cloud-top)
- *Less contamination* by Cherenkov
- *Efficient gamma/hadron separation* using different geographical areas
- Measurement of neutrino showers at high altitude *with less LPM effect*

Two advantages:

1. Monitored area

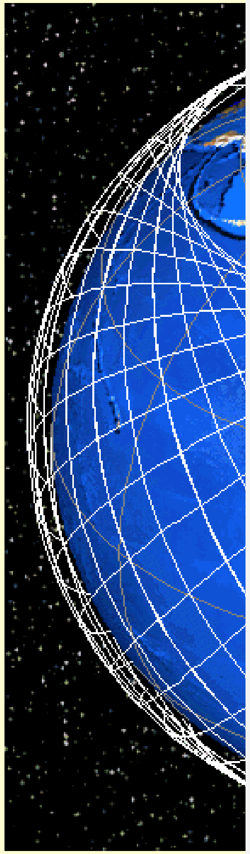
$$A_{geo}^{Nadir} \approx 1.3 \times 10^{5}\ km^{2}$$

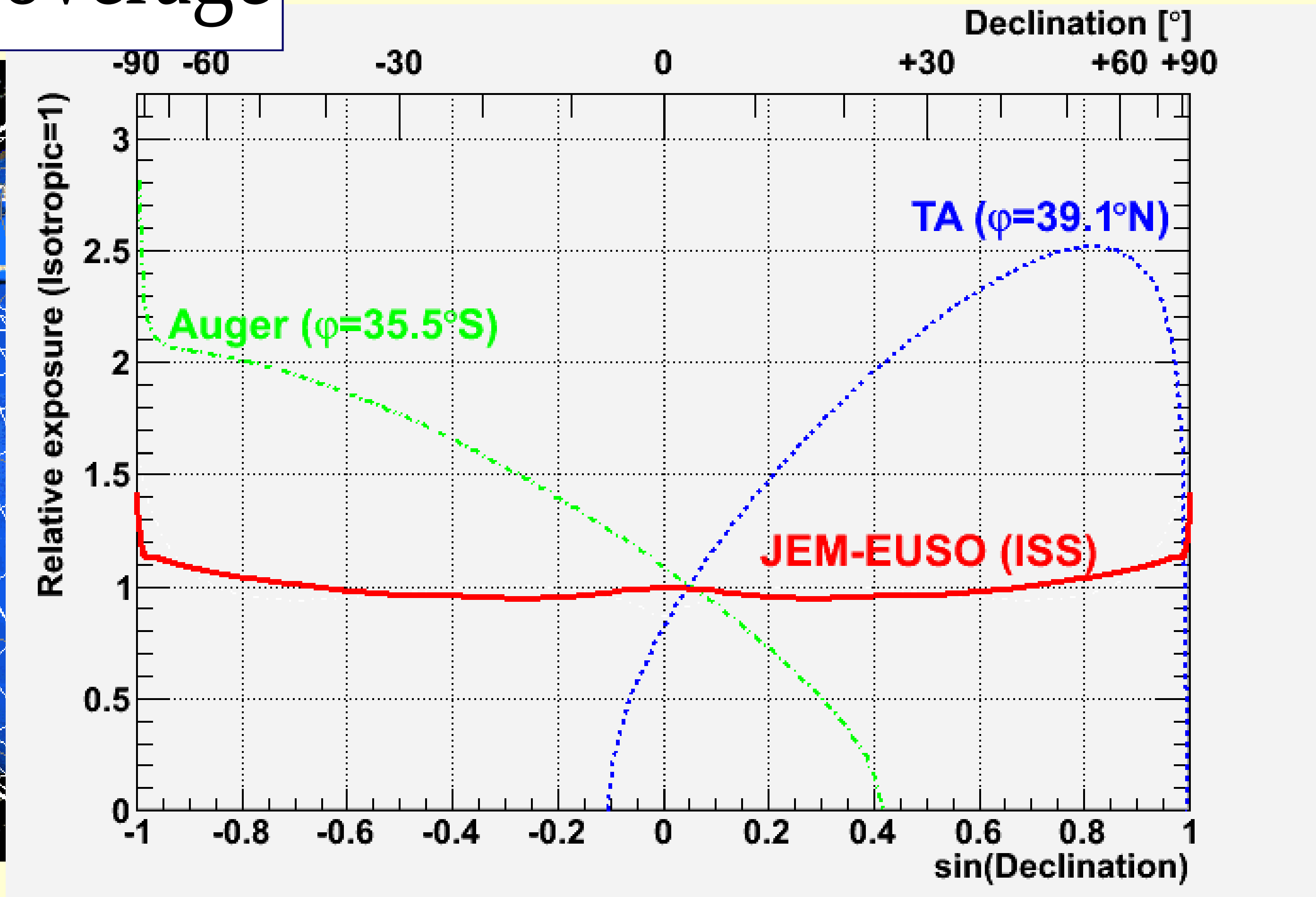


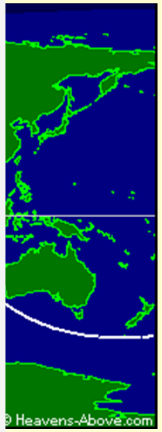

$$A_{geo}^{Tilted} \approx 1. \times 10^{6}\ km^{2} [@40°]$$

# *2. ISS Orbit → Full sky Coverage…*

$4\pi$ coverage



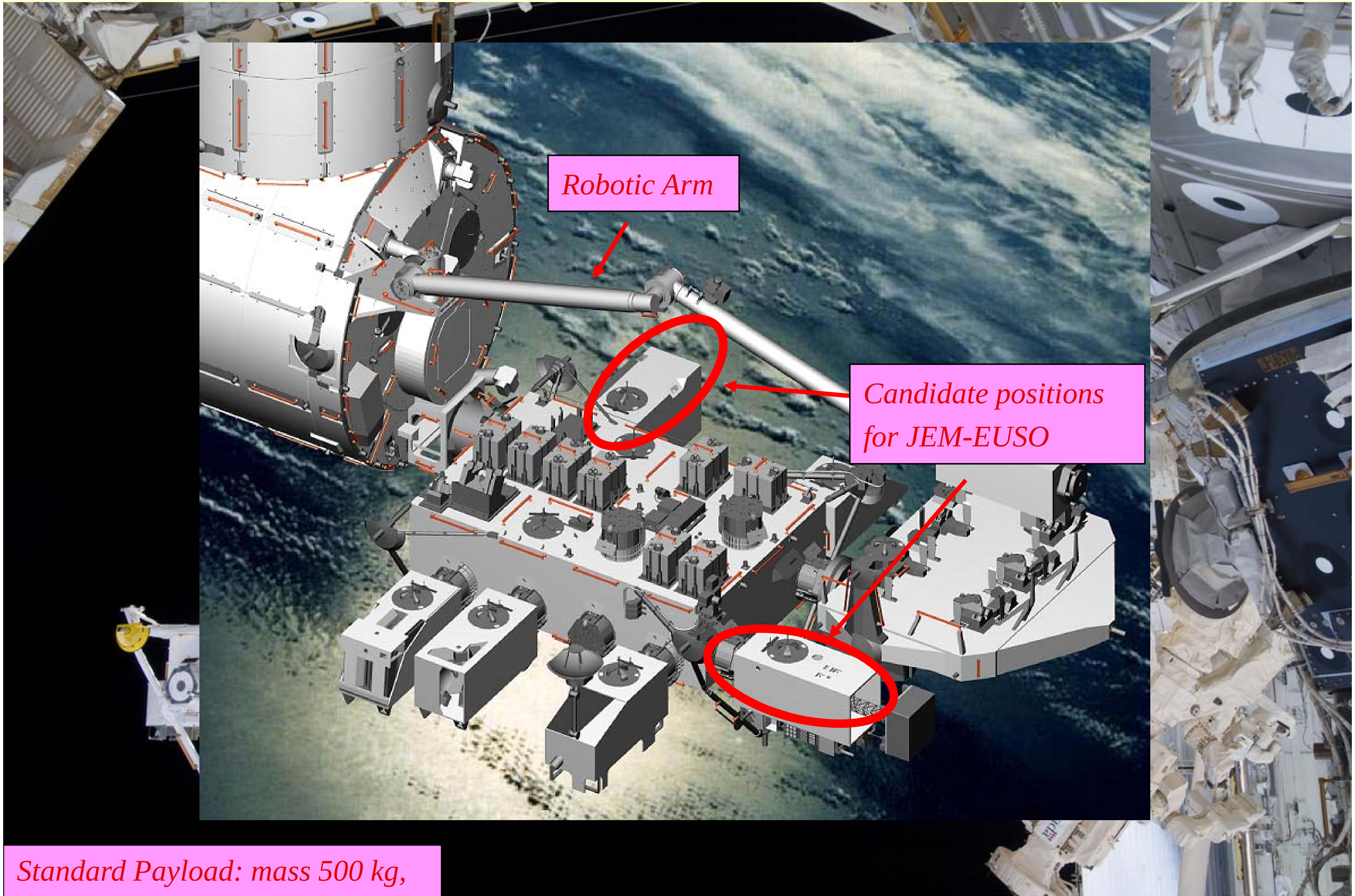



*… and uniform exposure*

# きぼう, Hope

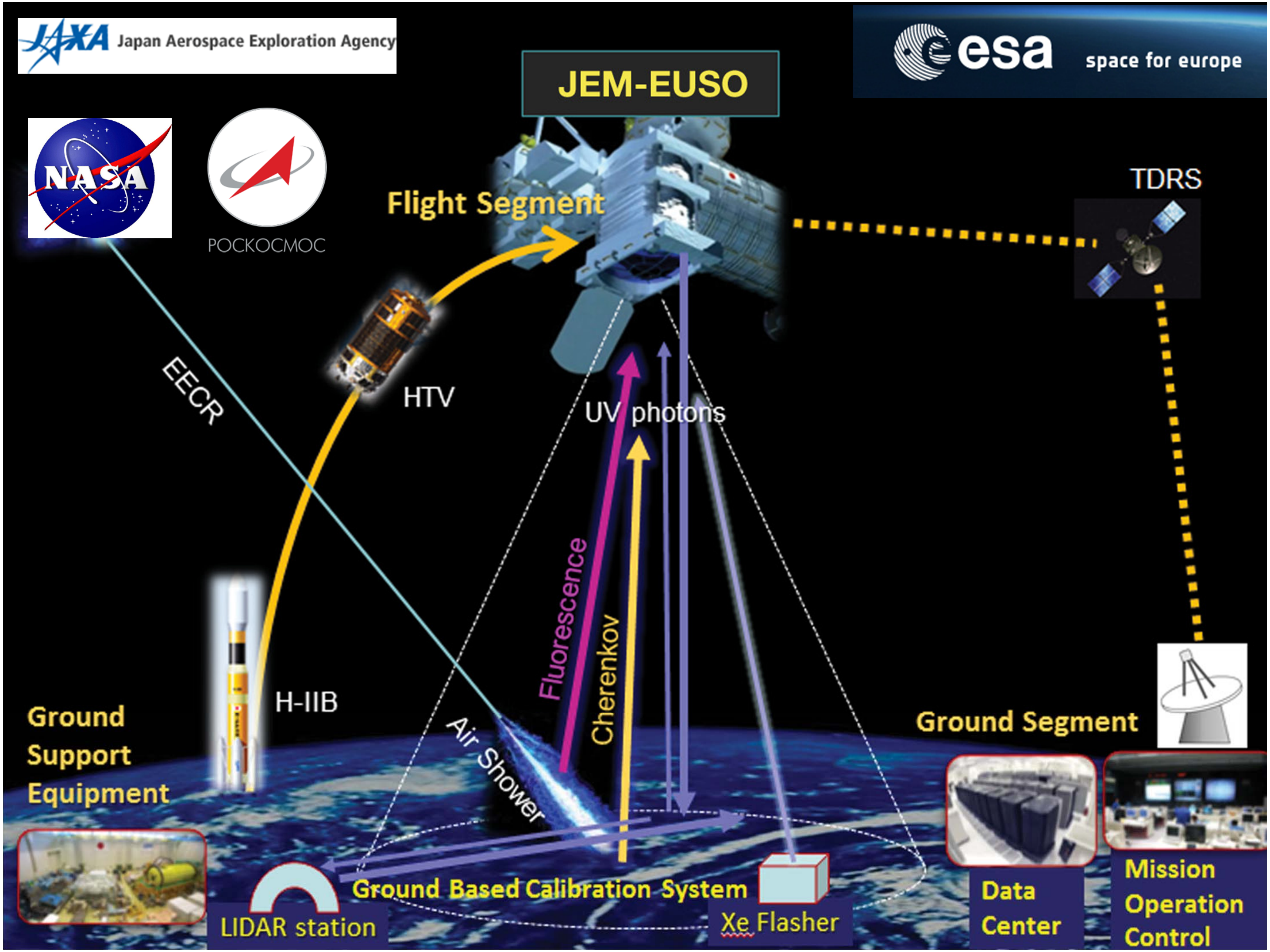
*Japanese Experiment Module*
*“Kibo” July 2009*




*Standard Payload: mass 500 kg, envelope:1.85m ×1.0m ×0.8m*

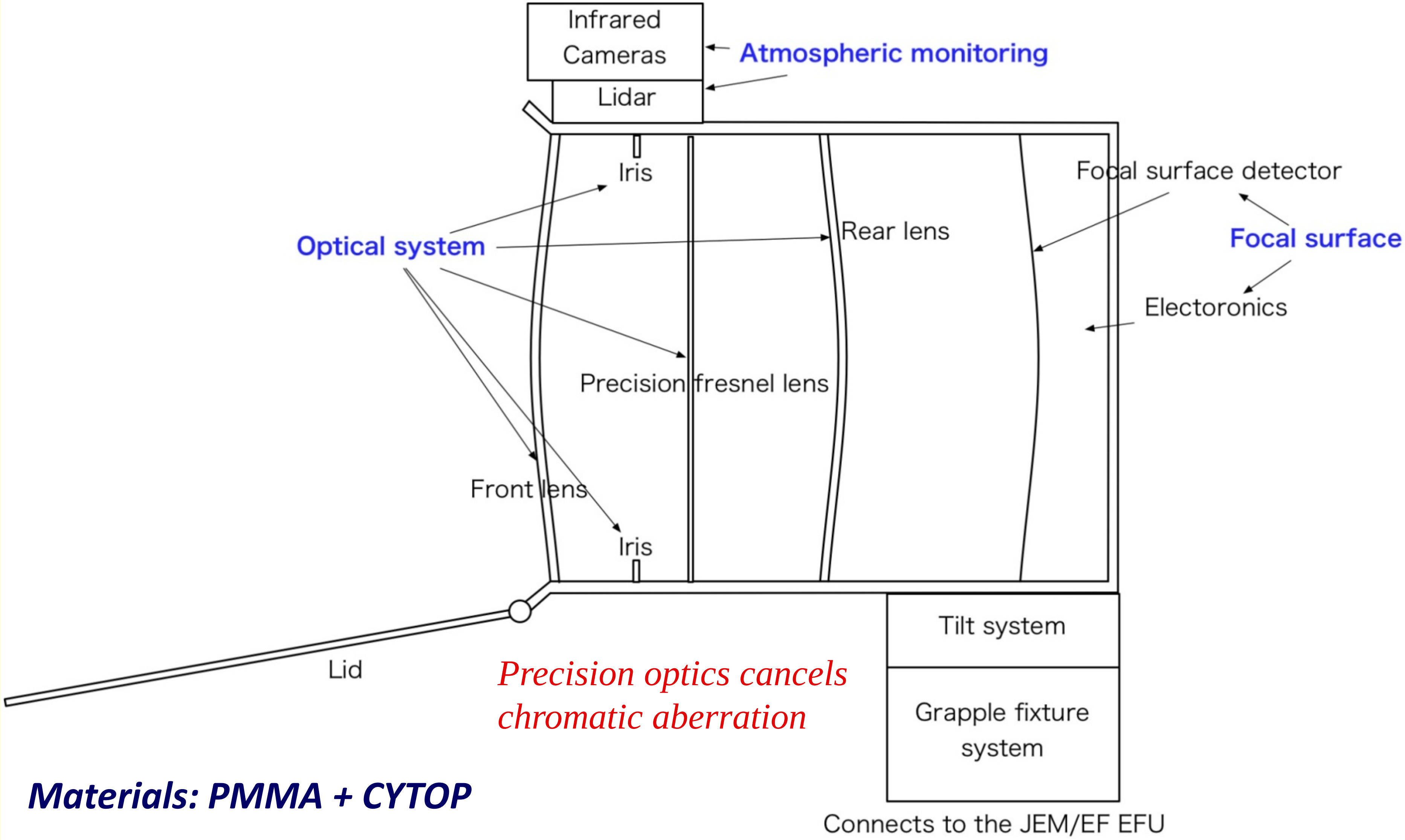
*Mission aspects have been successfully studies by JAXA and RIKEN*

| Parameter | Value |
|---|---|
| Launch date | JFY 2016 |
| Mission Lifetime | 3+2 years |
| Rocket | H2B |
| Transport Vehicle | HTV |
| Accommodation on JEM | EF#2 |
| Mass | 1938 kg |
| Power | 926 W (op.) 352 W (non op.) |
| Data rate | 285 kbps (+ on board storage) |
| Orbit | 400 km |
| Inclination of the Orbit | 51.6° |
| Operation Temperature | -10° to 50° |



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

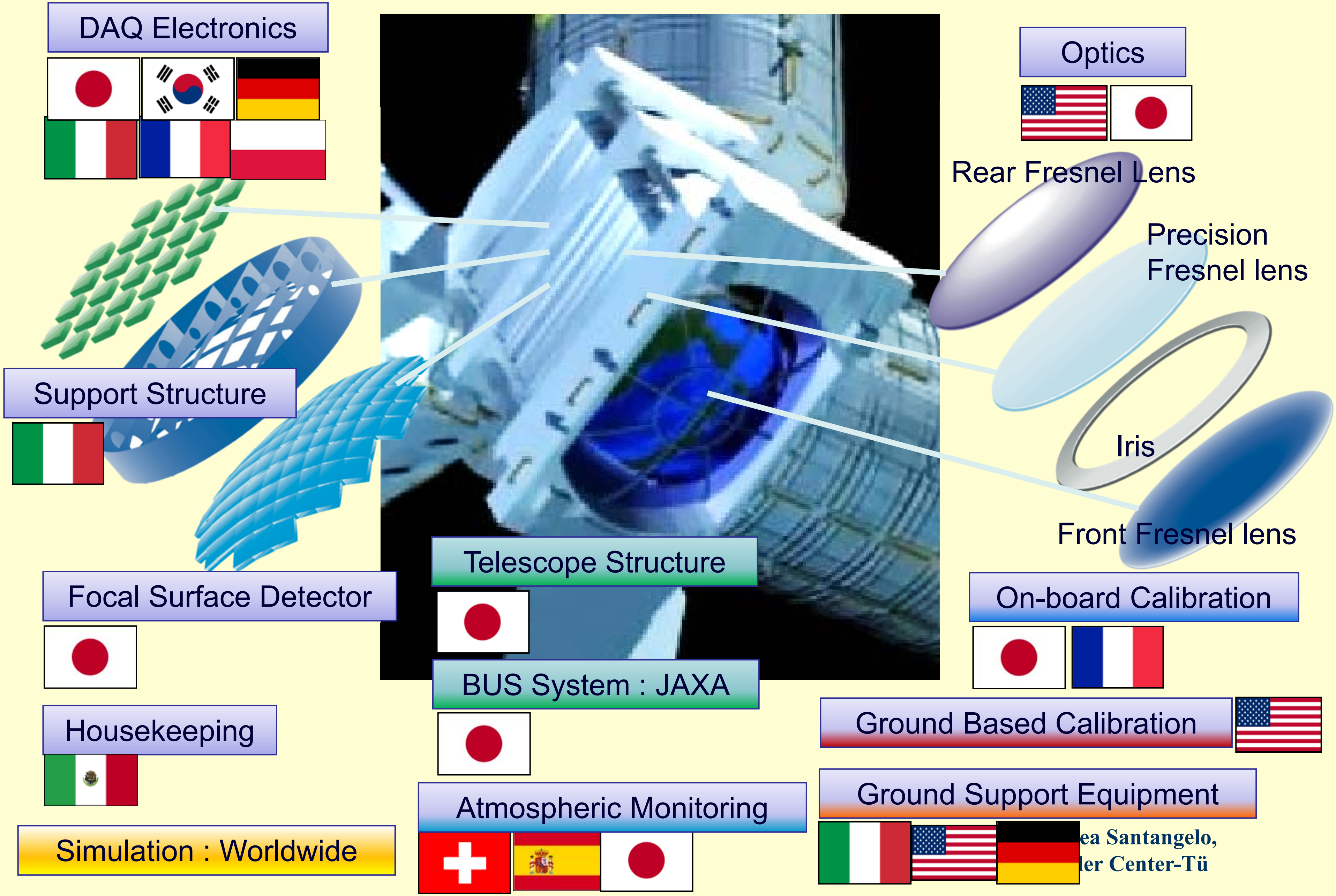
# *Conceptual View of the JEM-EUSO Telescope*




*Precision optics cancels chromatic aberration*

***Materials: PMMA + CYTOP***

# International Role Sharing

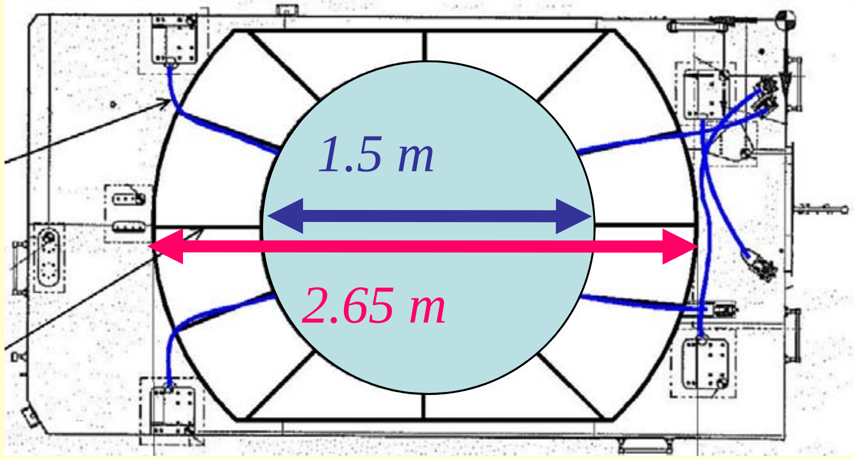


# *The UV Telescope Parameters*

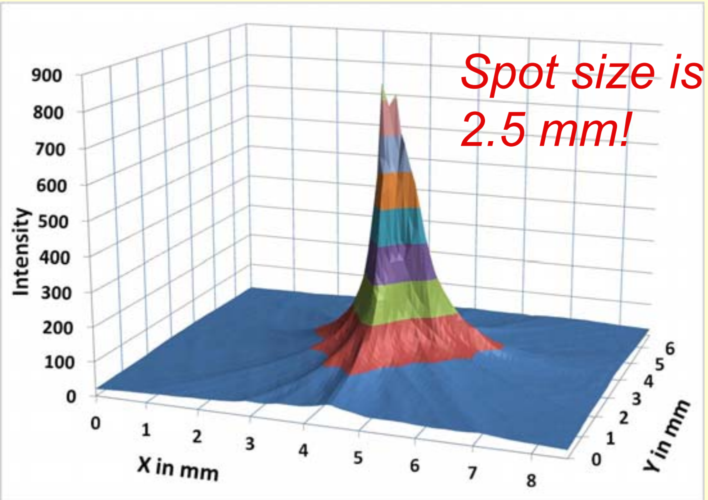
| Parameter | Value |
|---|---|
| Field of View | ±30° |
| Monitored Area | >$1.3\times10^5$km$^2$ |
| Telescope aperture | ≥2.5 m |
| Operational wavelength | 300-400 nm |
| Resolution in angle | 0.075° |
| Focal Plane Area | 4.5 m$^2$ |
| Pixel Size | <3 mm **+** |
| Number of Pixels | ≈$3\times10^5$ |
| Pixel size on ground | ≈560 m |
| Time Resolution | 2.5 μs |
| Dead Time | <3% |
| Detection Efficiency | ≥20% **+** |

**+** *Optics Throughput*

# BBM of the Optics (Protypes)



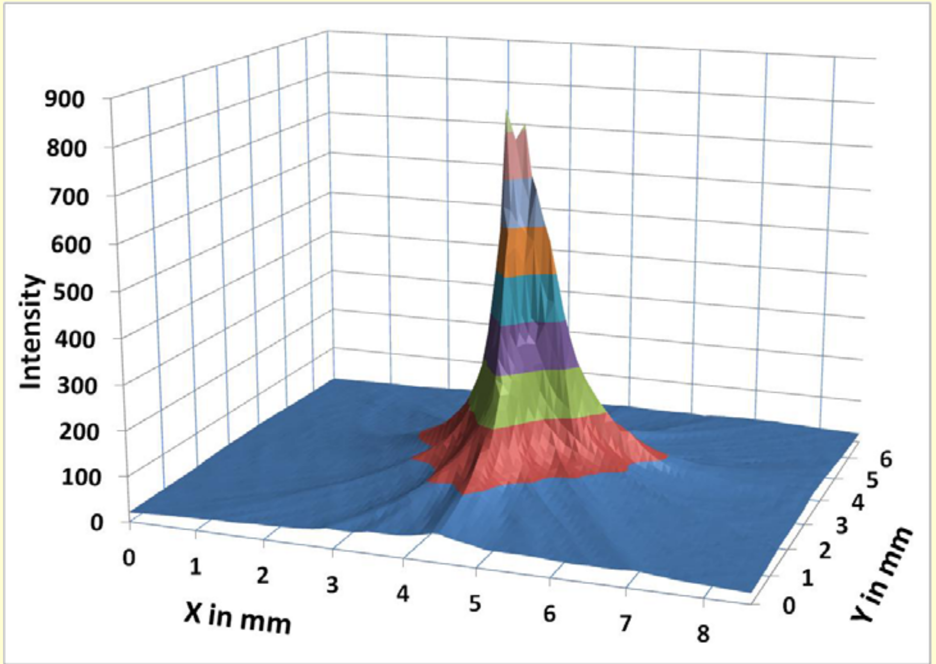

*large diameter Fresnel lenses manufactured in Japan and tested in the US at the University of Alabama (Huntsville) and at MSFC (NASA)*

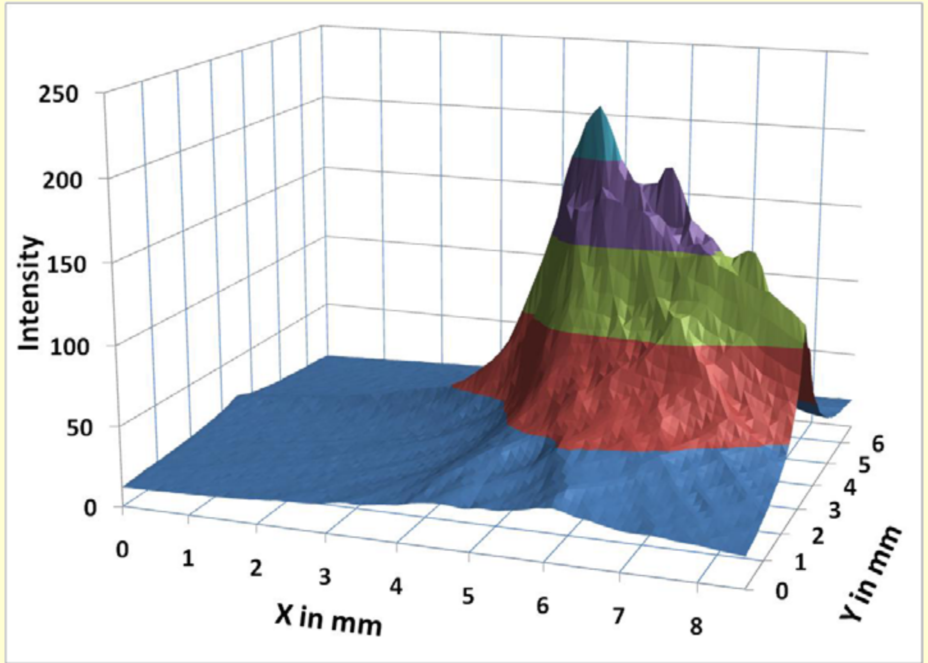



*Tested performances meet already the requirements (or are close to it)*

# *Full aperture tests, Xenon lamp at 40 m*

*Source wavelength range: 300-400 nm , CCD Images of the focal spots - 9x7 mm$^2$*




*Measured with the source on the optical axis.*

*Measured with the source at 10 degrees to the optical axis.*

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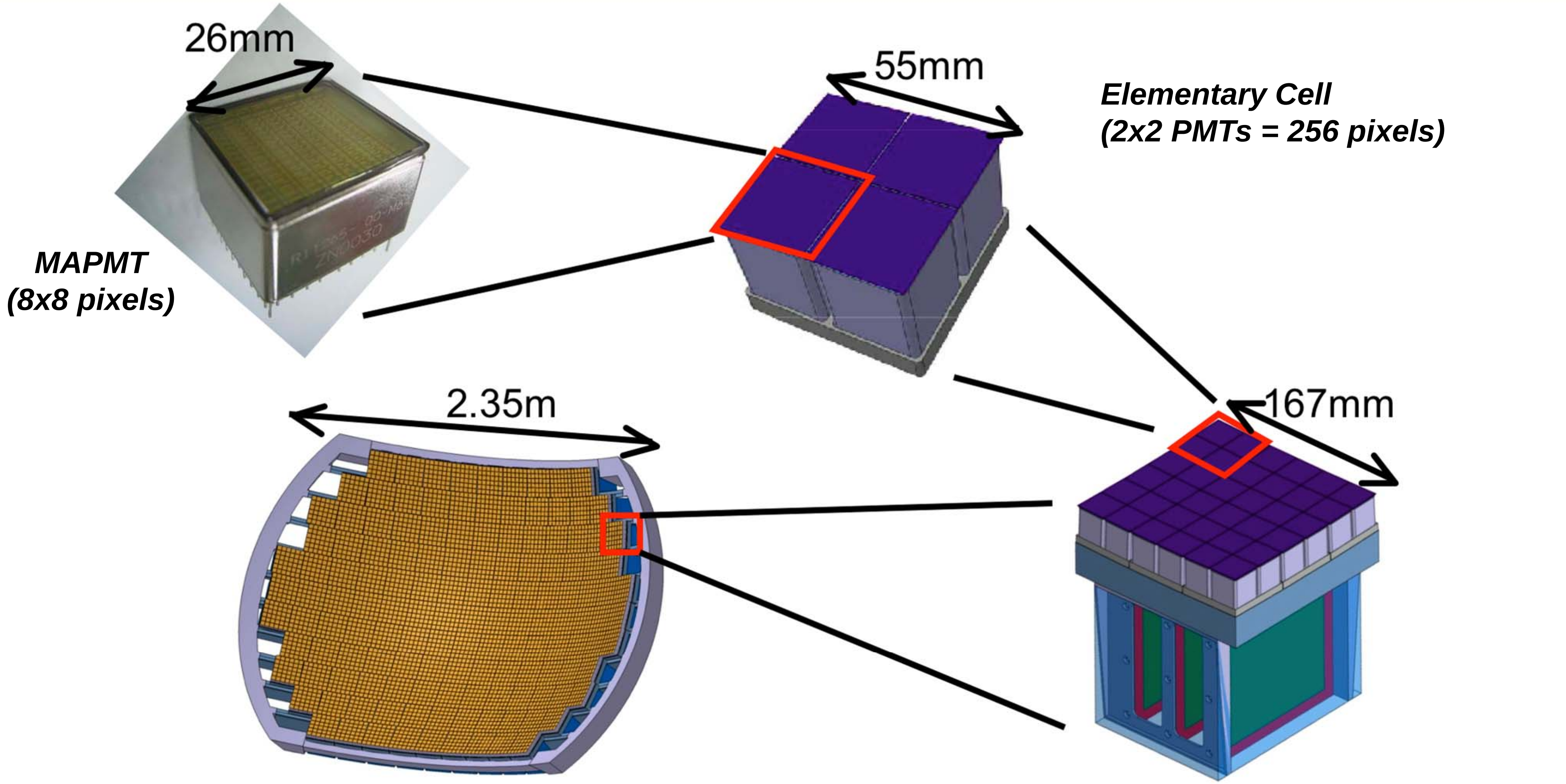
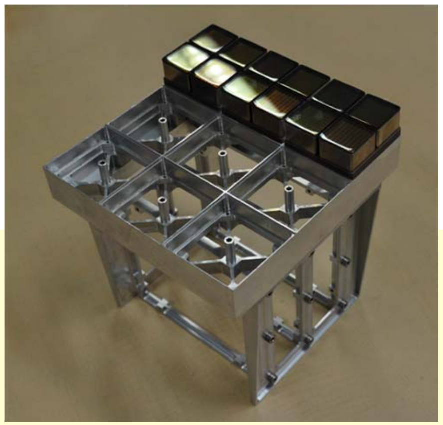
**Kepler Center-Tü**




Focal Surface detector
137 PDMs = 0.3M Pixels

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



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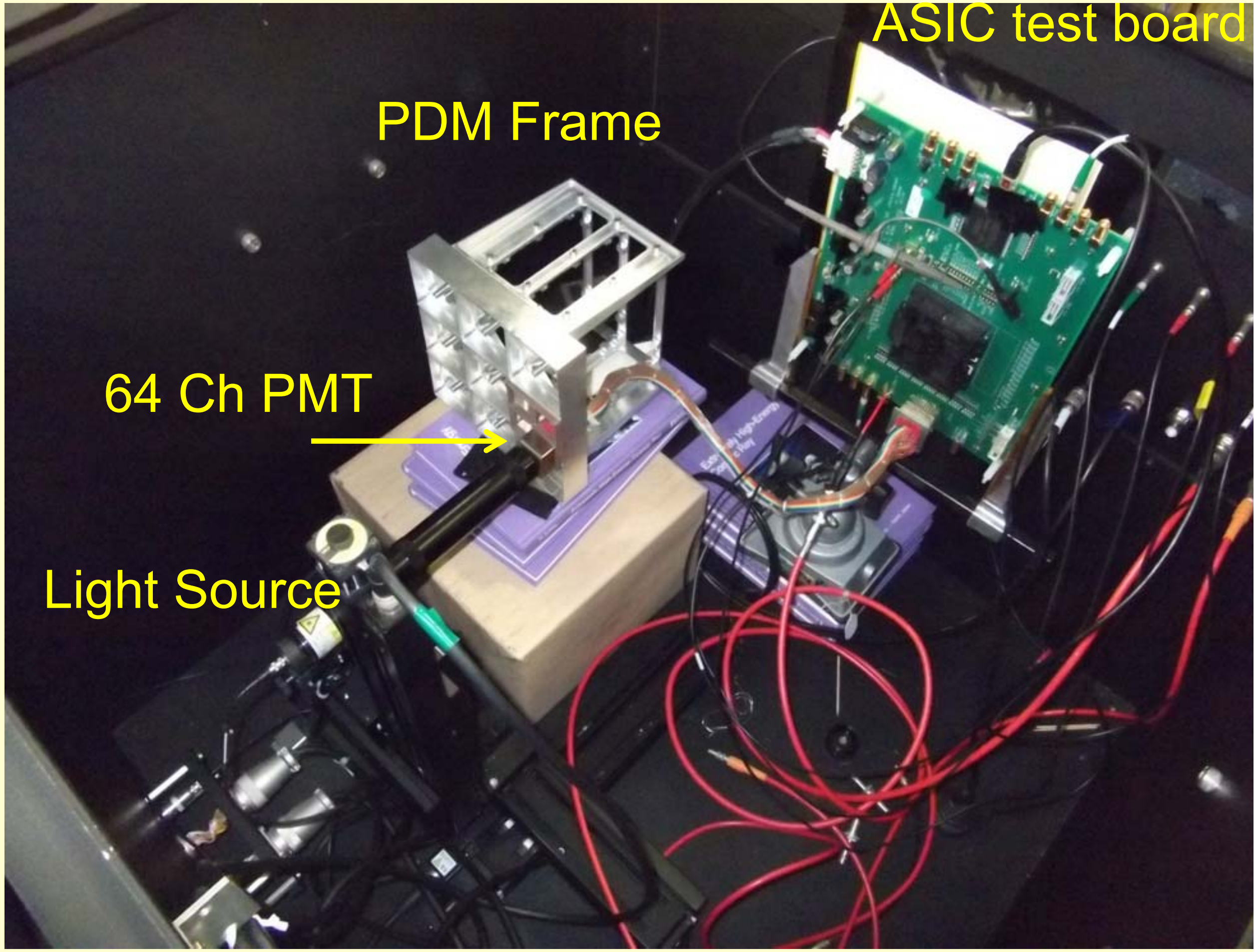
# *Detector and electronics*

- MAPMT-64
- ASIC *Spaciroc*
- *Electronic Cell* Board
- 137 PDM *1st trigger and readout*
- CCB *2nd trigger*




*From 9.6 GB/s to 3 GB/day on the entire FS*

*PDM Bread board model integrated at RIKEN*

# *II. Performances*

# Take home messages:

## Physics and Astrophysics at $E>5\times10^{19}$ eV

But also…
Explore new physics in the energy range $E\approx10^{20}$-$10^{21}$eV

Highest statistics and therefore largest exposures at extreme energies

$$E \approx 10^{20-21} eV$$

But also … lower energies are important for overlapping with ground-based detectors and make a statistically significant comparison!

$$E < 5 \times 10^{19} eV$$

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Kepler Center-Tü

# *Key observation and instrument requirements*

| | |
|---|---|
| Observation area (Nadir) | $\geq 1.3 \times 10^5 (H_{orbit}/400[km])^2\ km^2$ |
| Arrival direction determination accuracy | ≤ 2.5° (at $E=10^{20}$ [eV] and 60° zenith angle) |
| Energy determination accuracy | ≤ 30% ($E=10^{20}$ [eV] and 60° zenith angle) |
| $X_{max}$ determination accuracy | ≤ 120 [g/cm$^2$] ($E=10^{20}$ [eV] and 60° zenith angle) |
| Energy threshold | $\leq 5.5 \times 10^{19}$ [eV] |
| Duty cycle | ≥ 17% |
| Lifetime | > 3 years (goal: > 5 years) |

# *Which is the annual exposure?*

- Of course it depends on the zenith angle and energy…
- It is determined by three factors:

$$TA \times \eta \times \kappa$$

$TA \rightarrow Trigger\ Aperture$ *Determined by the trigger efficiency*

$\eta \rightarrow duty\ cycle$ *Determined by the background (and operation)*

$\kappa \rightarrow cloud\ impact$ *Determined by the cloud coverage*

*P.Bobik et al., 2011*

# *Duty cycle estimation*

*defined as* *<u>the fraction of time in which the nightglow background doesn't hamper EAS observation</u>*

- Based on the *Universitetsky Tatiana satellite*

  *G. K. Garipov et al. 2005a, 2005b*

- Scaling of the UV intensity from Tatiana's to the ISS orbit

The JEM-EUSO duty cycle has been estimated *for a set of Solar Zenith angles* assuming an *UV background < 1500 photons/(m$^2$ ns sr)*

*P.Bobik et al., ID886*

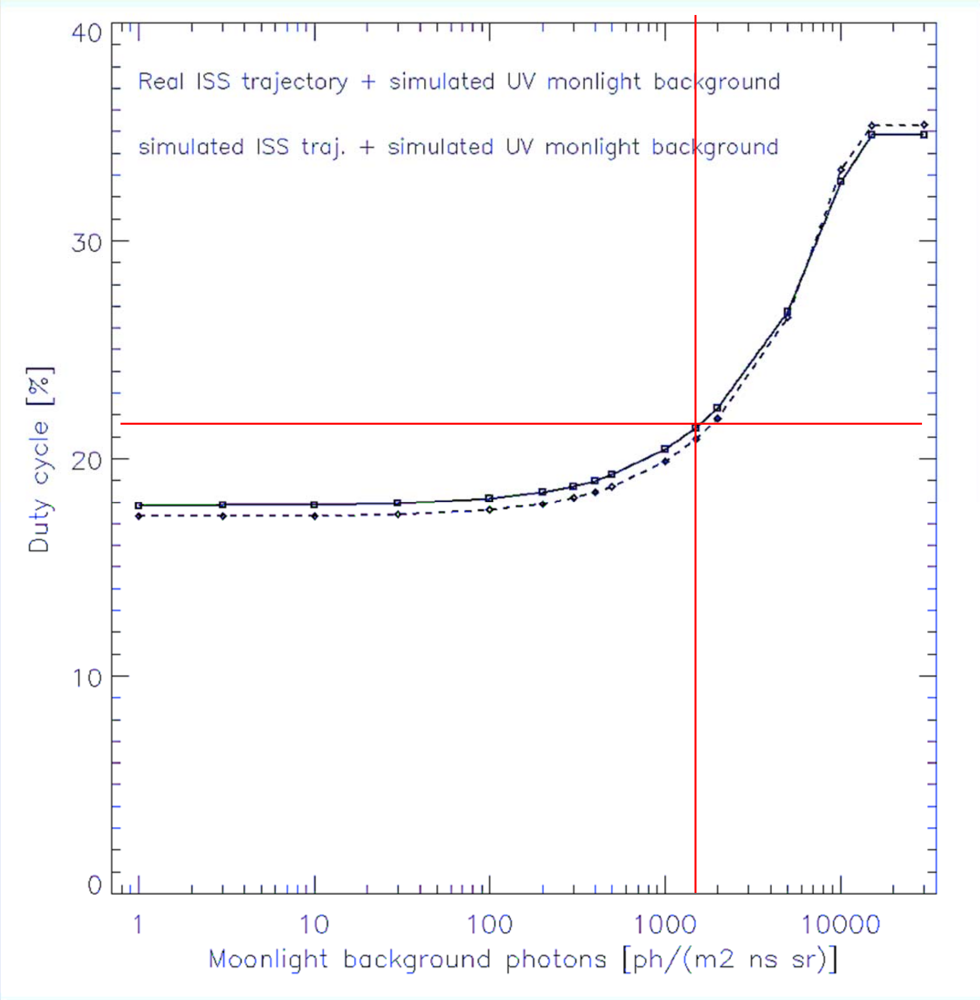
| Solar zenith angle (deg.) | Duty cycle (%) |
|---|---|
| 108 | 22.2 |
| 109 | 22.1 |
| 110 | 21.9 |
| 111 | 21.7 |
| 112 | 21.5 |
| 113 | 21.3 |
| 114 | 21.0 |
| 115 | 20.6 |
| 116 | 20.3 |
| 117 | 19.9 |
| 118 | 19.5 |
| 119 | 19.0 |
| 120 | 18.4 |

# Duty cycle (2)

*Note that:*
*Selecting bckg < 1500 photons/($m^2$ ns sr) with its relative occurrence gives a trigger efficiency curve equivalent to an average bckg of 500 photons/($m^2$ ns sr)*

*We can also operate at higher background rates (higher energies)*

# Duty cycle: EUSO old estimate




*C. Berat et al. 2003*

*F. Montanet et al. 2004*

*Independent estimate*

All these results are in very good agreement with and actually better than *the conservative value* assumed by the JEM-EUSO consortium: *20%*

# Cloud Coverage

*F. Garino et al., 2011*

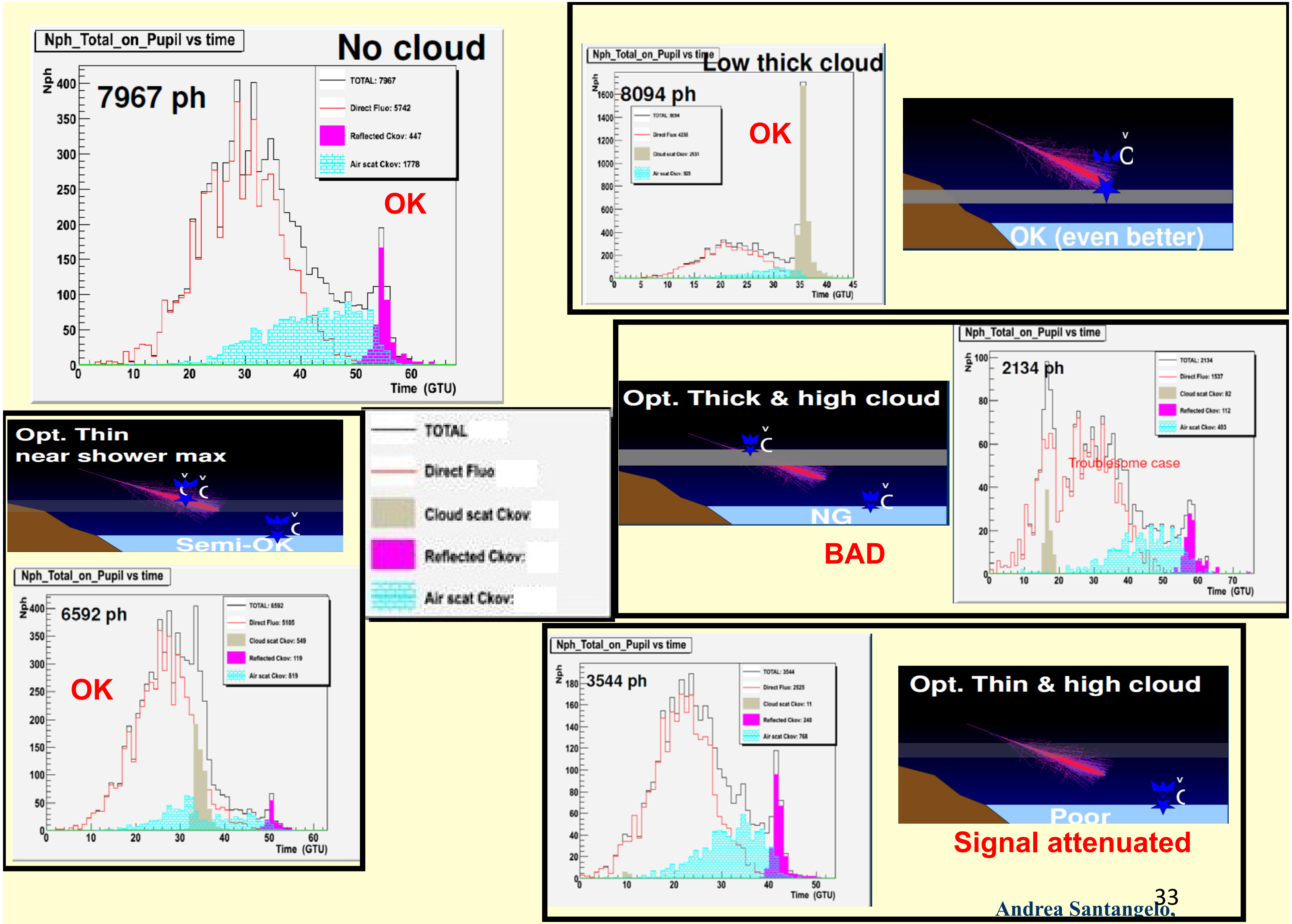
*Cloud top*

*Optical Depth*

| | <3 km | 3-7 km | 7-10 km | >10 km |
|---|---|---|---|---|
| $\tau > 2$ | 17.2 | 5.2 | 6.4 | 6.1 |
| $\tau \approx 1\text{-}2$ | 5.9 | 2.9 | 3.5 | 3.1 |
| $\tau \approx 0.1\text{-}1$ | 6.4 | 2.4 | 3.7 | 6.8 |
| $\tau \approx 0.1$ | 29.2 | <0.1 | <0.1 | 1.2 |

Occurence of clouds (in %) between 50° N and 50° S on TOVS database. The matrix Optical depth vs. Cloud-top altitude is shown.

*Confirmed by ISCCP,CACOLO & MERIS database*




*L. Saez et al., 2011*



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*L. Saez et al., 2011, K. Shinozaki et al. 2011*

# *Cloud-impact to trigger efficiency*

***E>5·10^19^eV***

*Cloud top*

*Optical Depth*

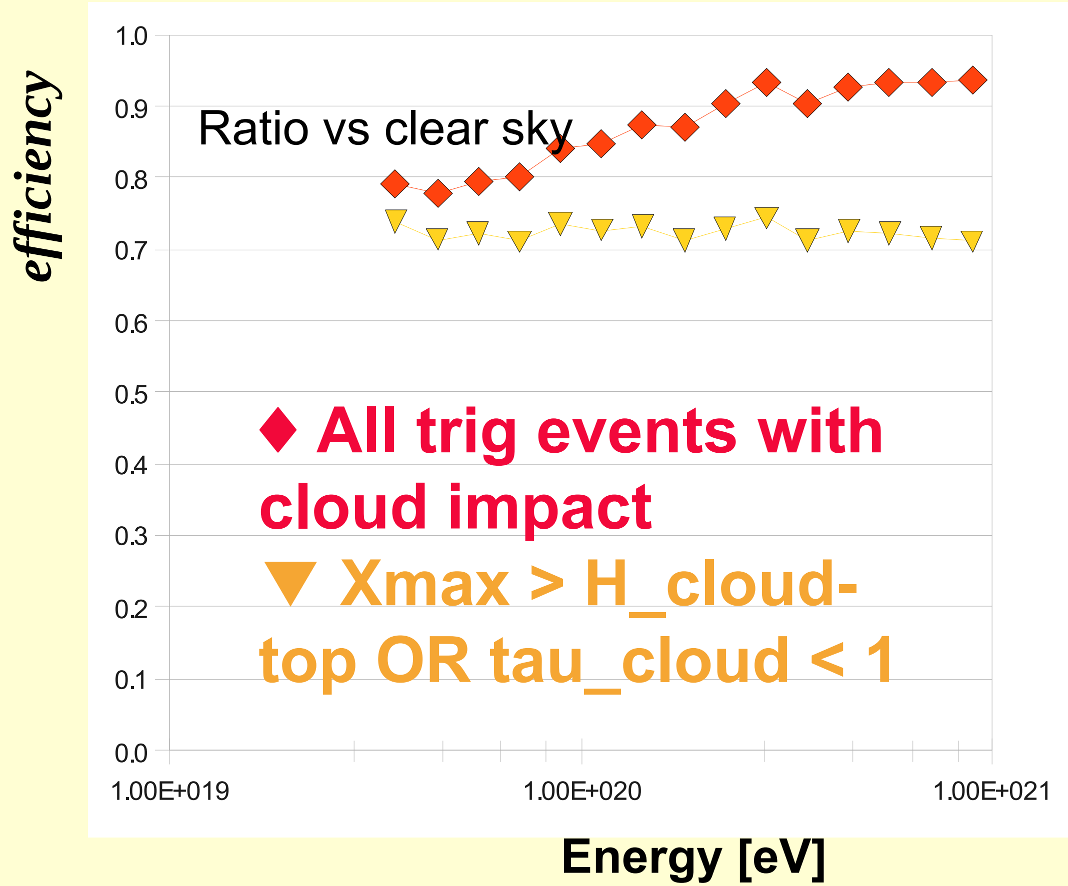
| | <3 km | 3-7 km | 7-10 km | >10 km |
|---|---|---|---|---|
| $\tau > 2$ | 90% | 65% | 35% | 20% |
| $\tau \approx 1\text{-}2$ | 90% | 70% | 45% | 25% |
| $\tau \approx 0.1\text{-}1$ | 90% | 80% | 75% | 70% |
| $\tau \approx 0.1$ | 90% | 90% | 90% | 90% |

Average efficiency* = 82% above 50 EeV

***A spectral distribution $dN/dE \propto E^{-3}$ is assumed***

*L. Saez et al., 2011*

*K.Shinozaki et al. 2011*

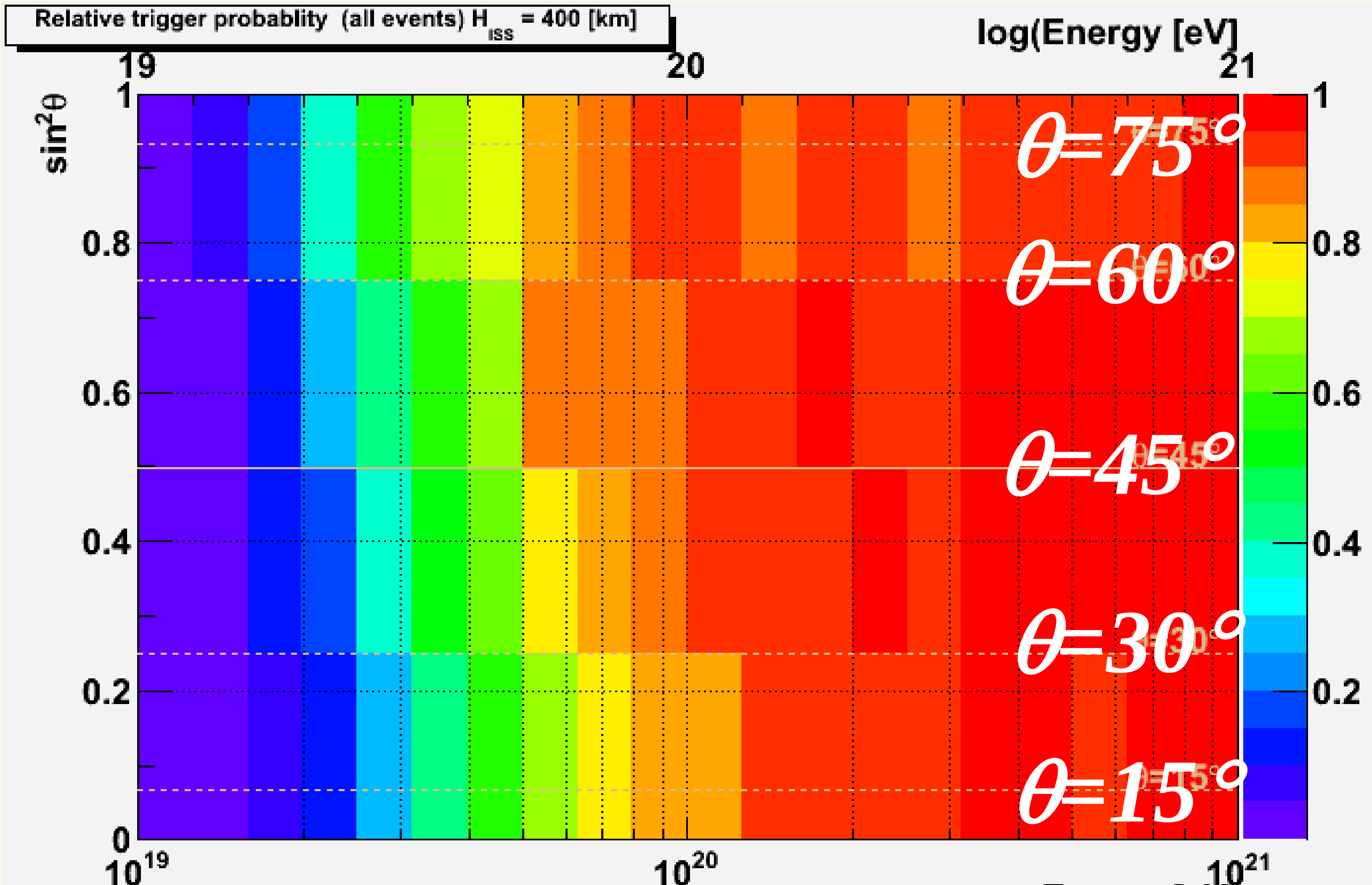



## *Basic conclusion:*

*In more than 70% of the cases the UV track including Xmax is observable*

**Different geometrical conditions for optically thick or optically thin clouds*

# Trigger Probability (Zenith angle vs. Energy)




K.Shinozaki et al., 2011

Full FoV, bckg = 500 ph/$m^2$/ns/sr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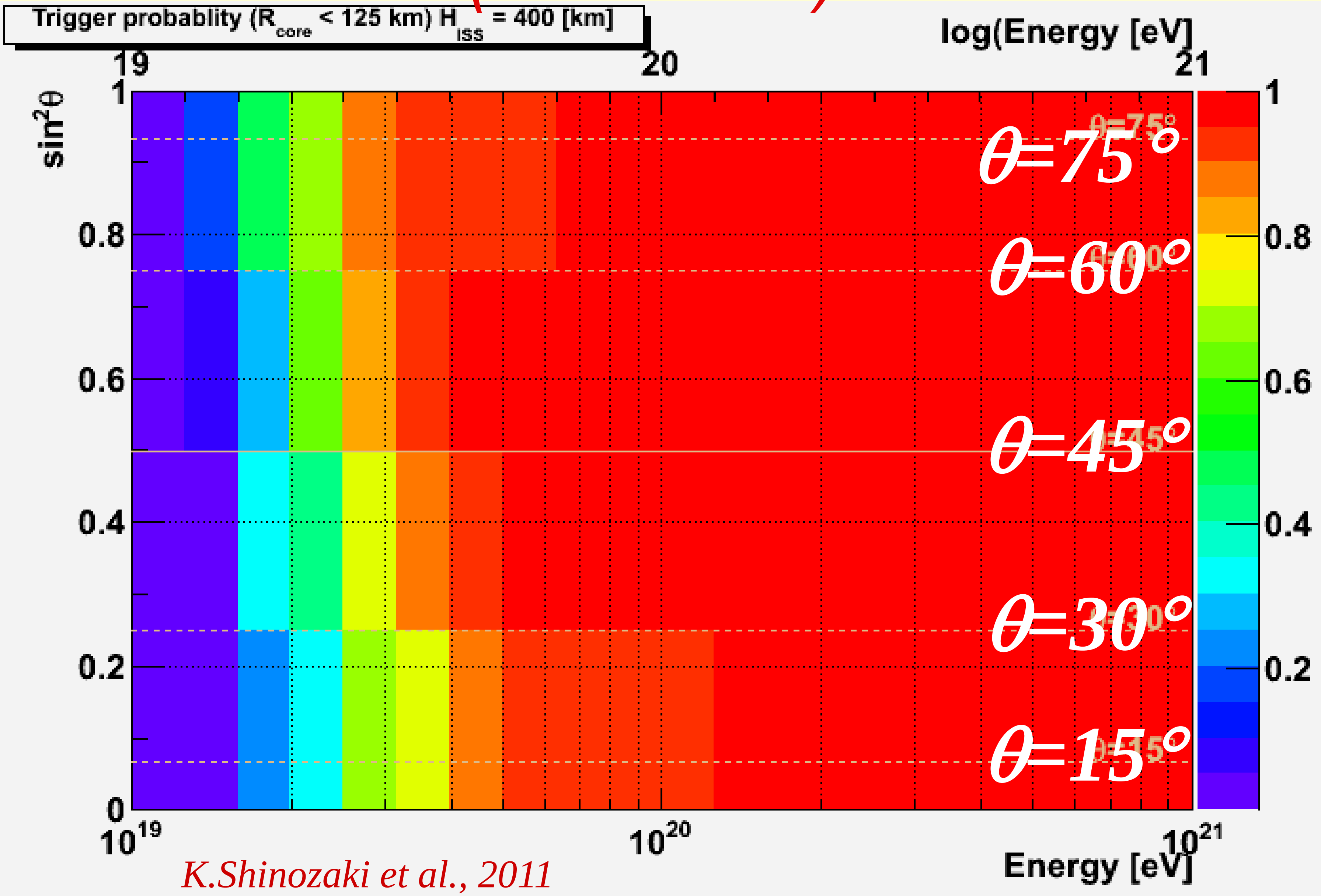
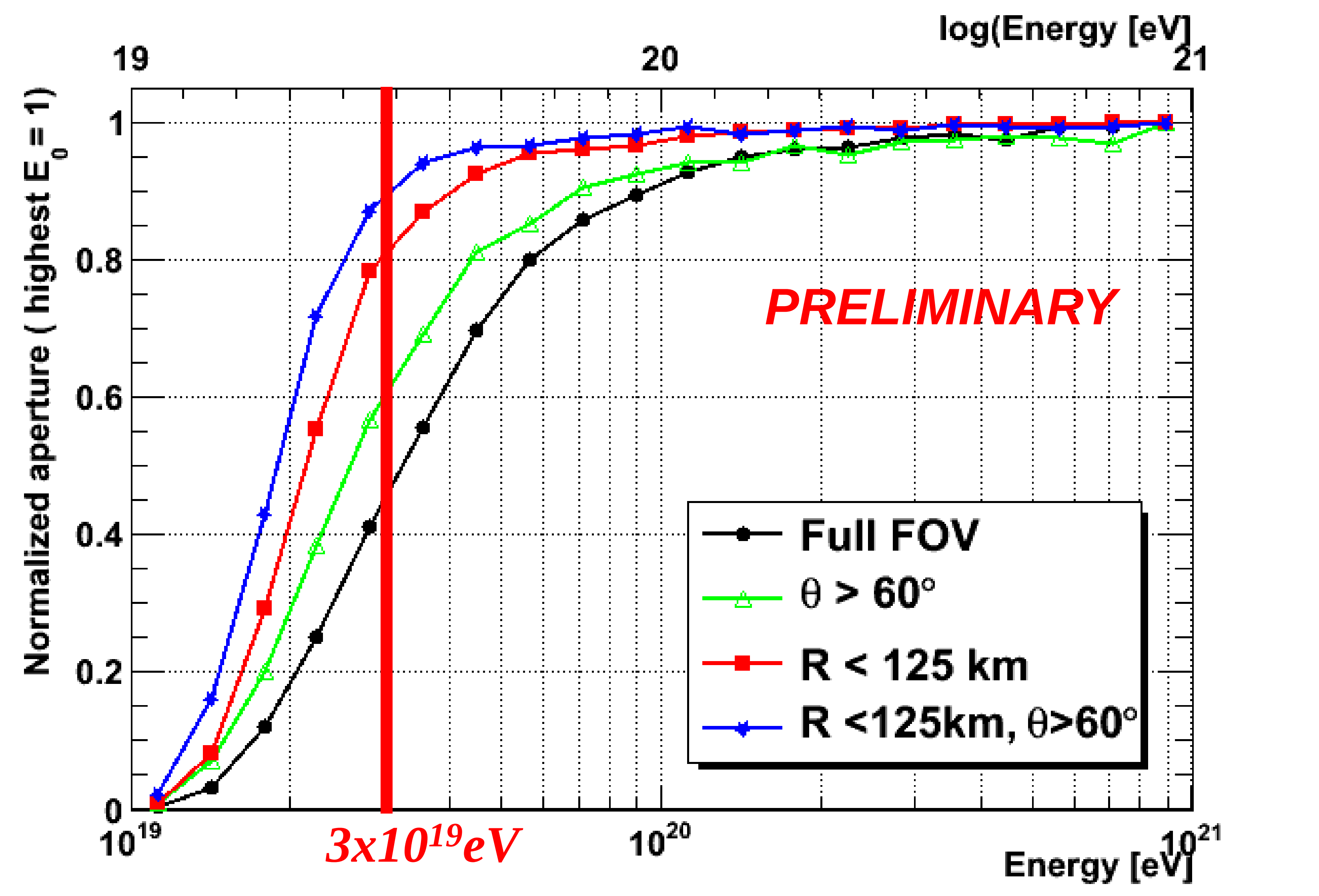
# *Trigger Probability for Central FoV (R<125 km)*

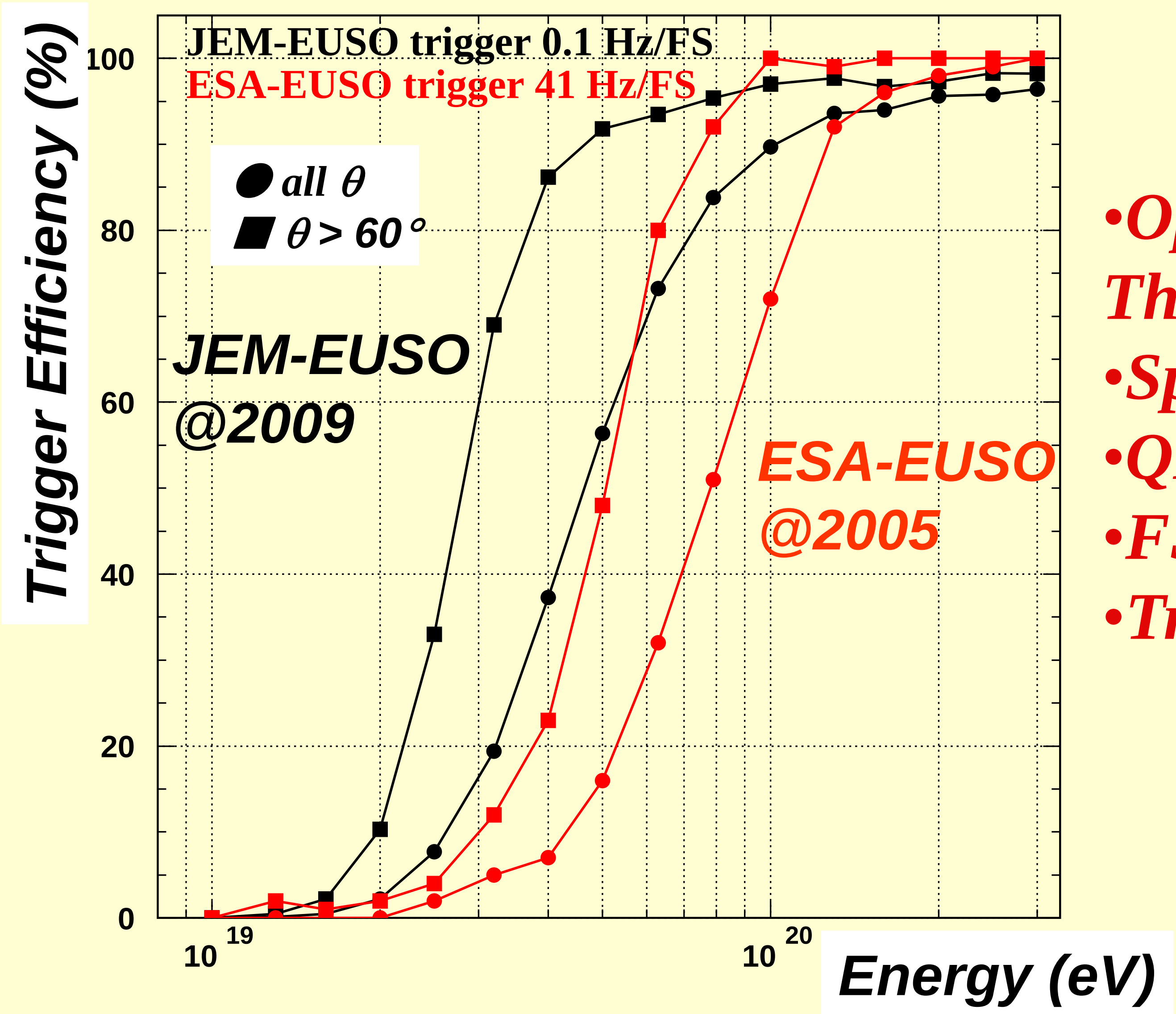



*K.Shinozaki et al., 2011*

# Normalised Aperture: Efficiency



# OVERALL NET IMPROVEMENT




- *Optics Throughput*
- *Spot size*
- *QE PMT*
- *FS layout*
- *Trigger*

***Energy threshold of JEM-EUSO lowered by a factor ~1.8 compared to the old ESA-EUSO***

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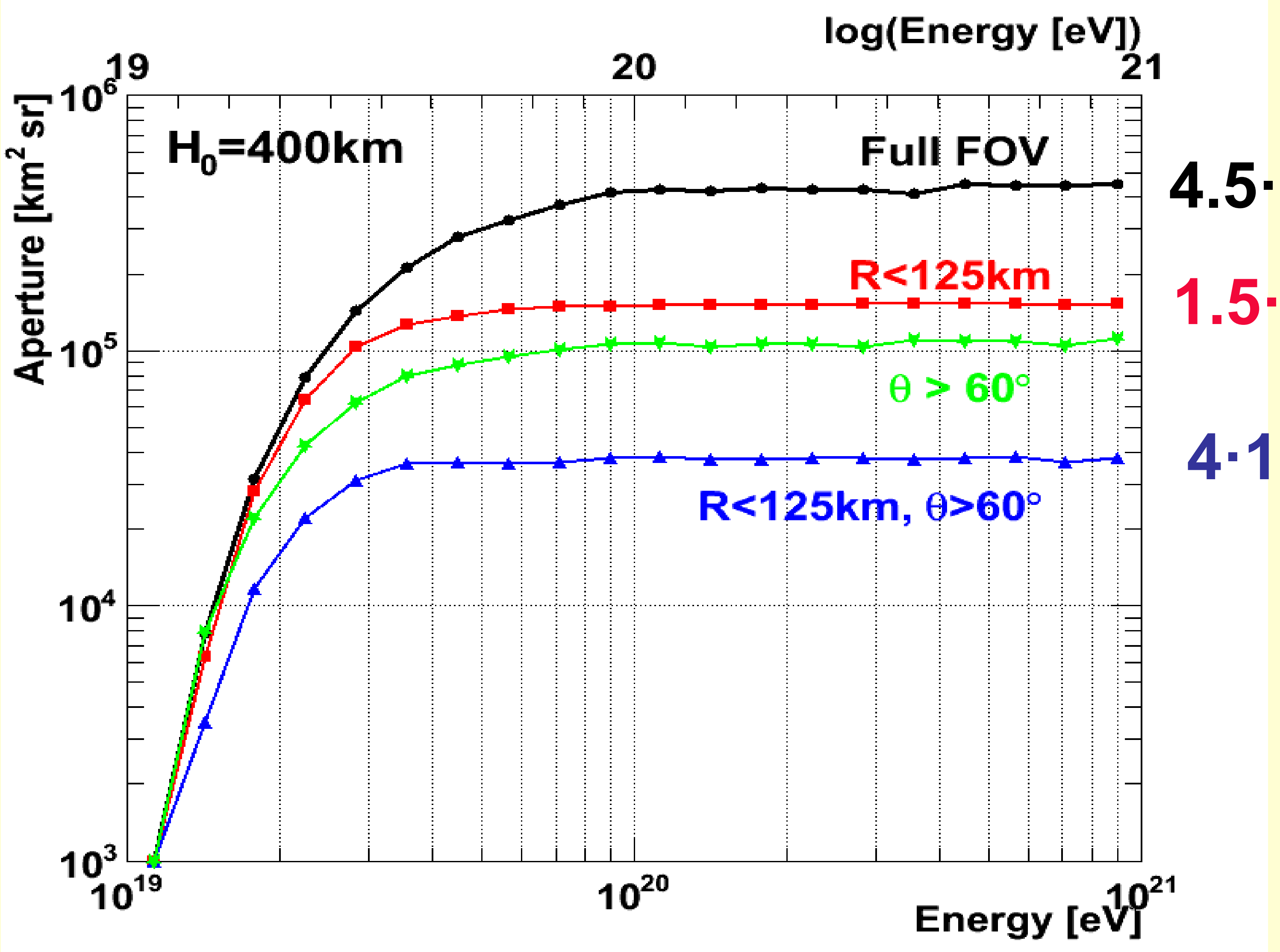
Kepler Center-Tü

# *Instantaneous Aperture*




**$4.5 \cdot 10^5$ km$^2$sr**

**$1.5 \cdot 10^5$ km$^2$sr**

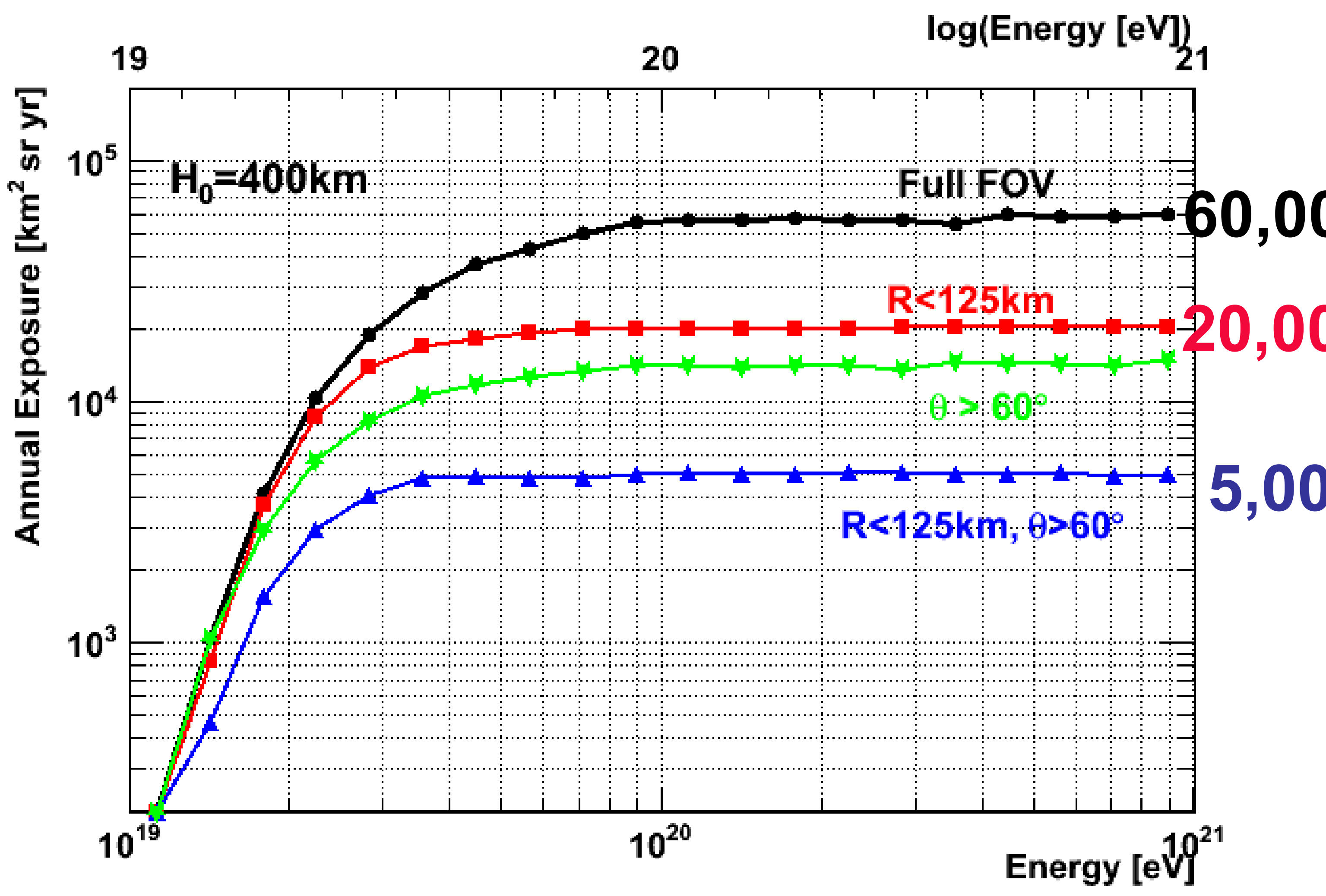
**$4 \cdot 10^4$ km$^2$sr**

*K.Shinozaki et al., 2011*

# *Annual Exposure (…Nadir)*

$TA \times \underline{\eta \times k}$

~14%



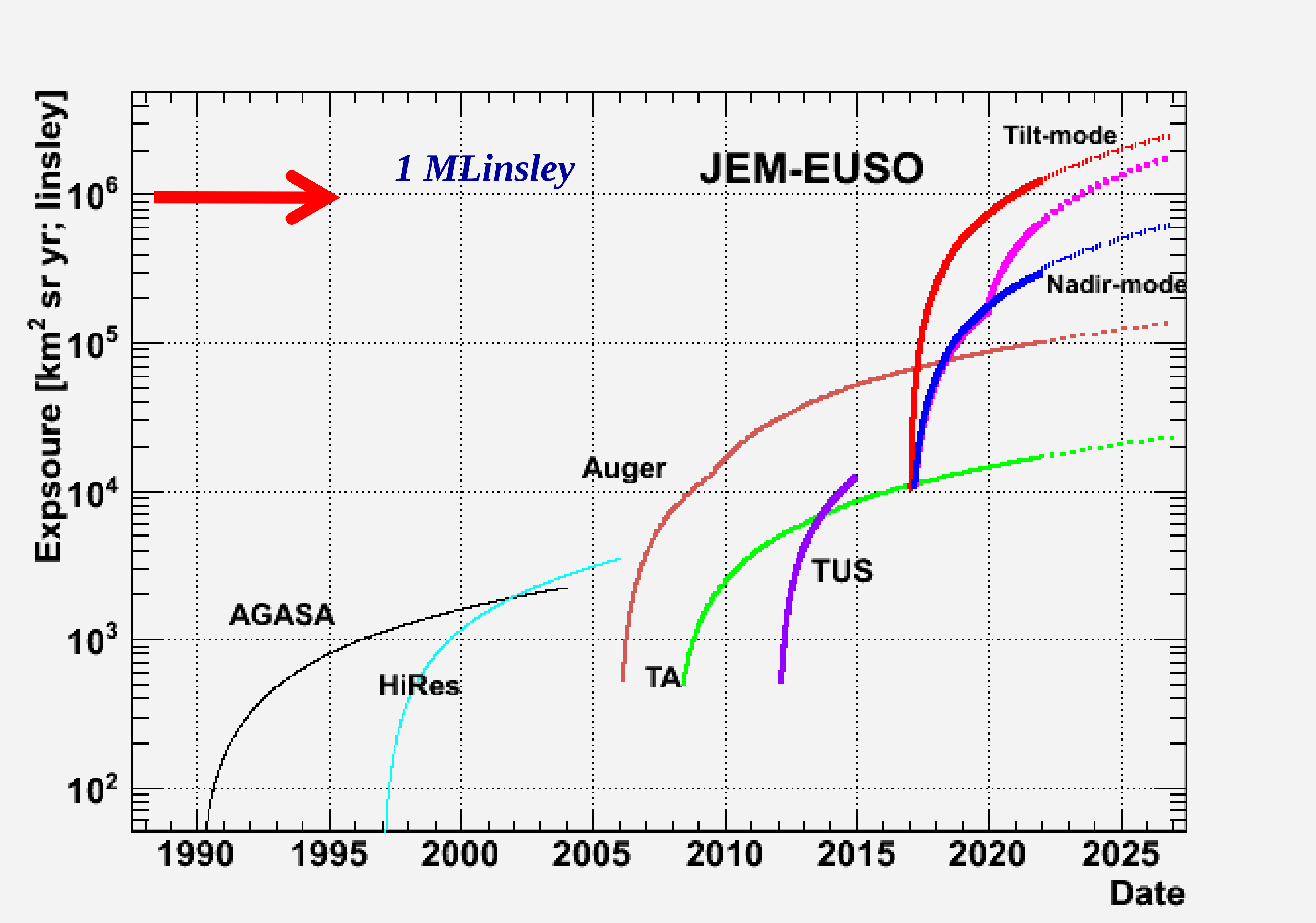

**60,000 km²sr yr**

**20,000 km²sr yr**

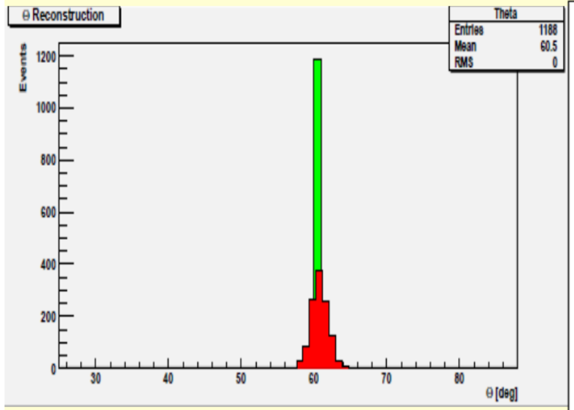
**5,000 km²sr yr**

*K.Shinozaki et al., 2011*

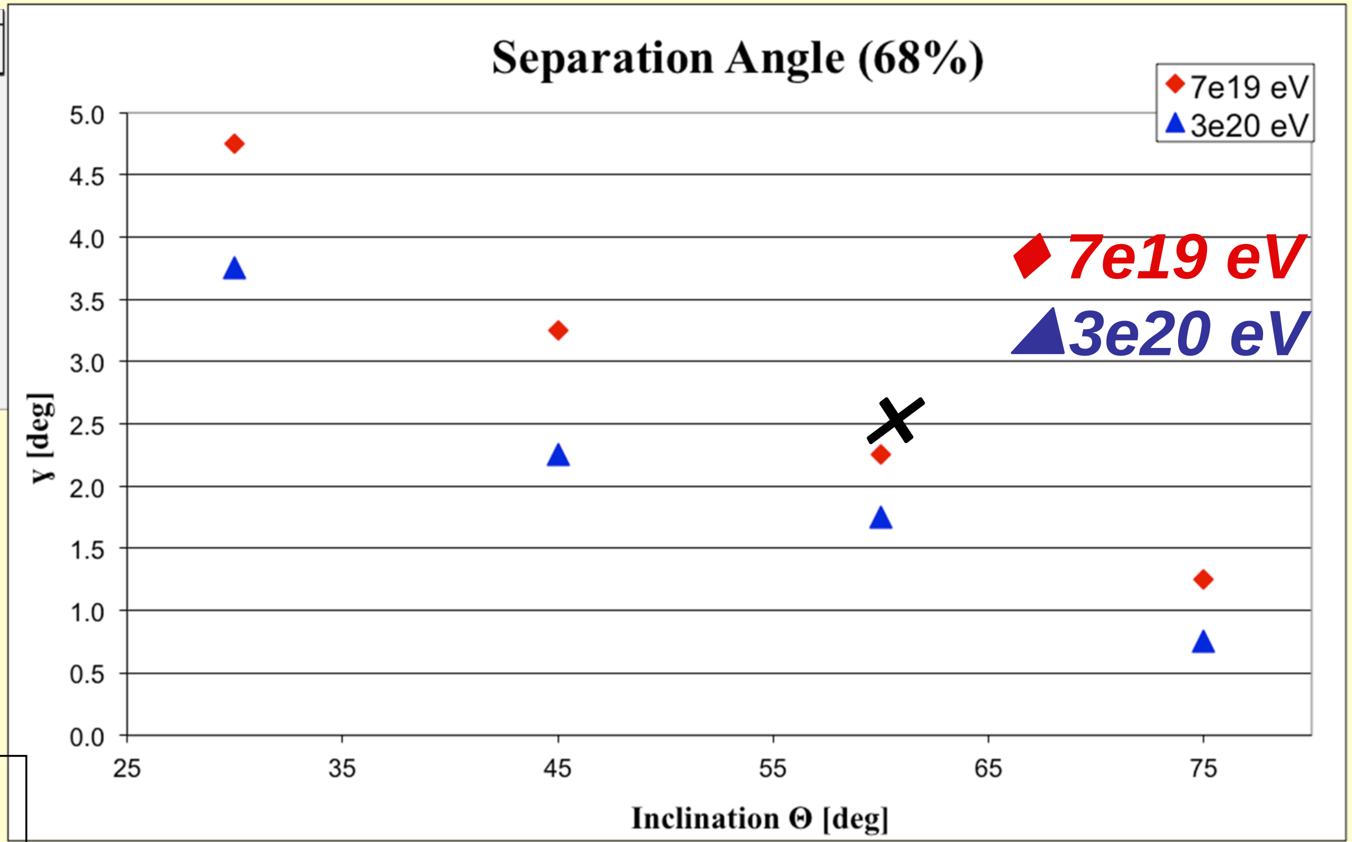
# *Why JEM-EUSO? Large exposure + Full sky coverage*



# *Angular Resolution*




***α(deg)***




***7e19 eV***

***3e20 eV***

**× Requirement**
***α<2.5° @***
***E=$10^{20}$eV, θ=60°***

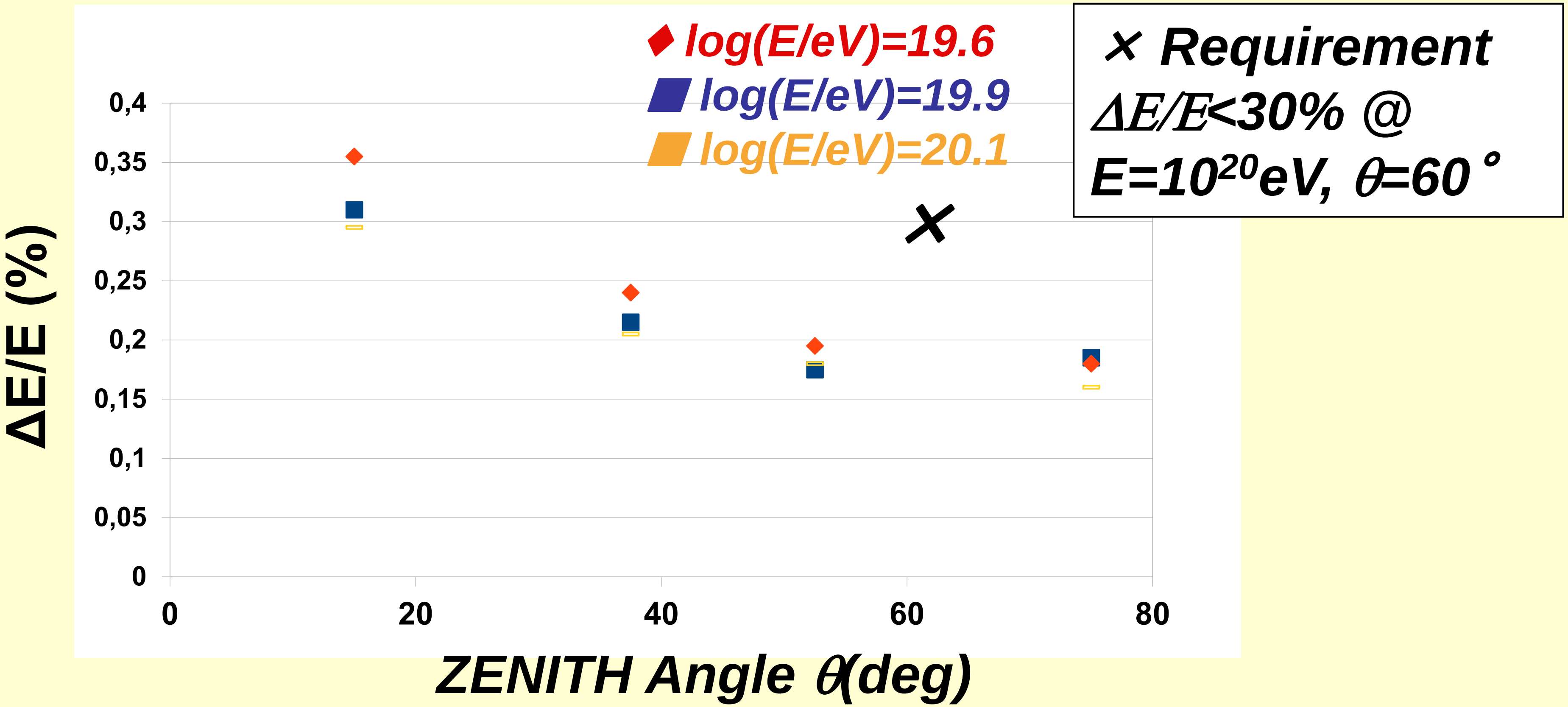
***Zenith Angle θ(deg)***

*End to end simulations show that the requirement is met.*

*T.Mernik et al., 2011*


**Andrea Santangelo,**
**Kepler Center-Tü**

# Energy Resolution




*End to end simulations show that the requirement is met.*

$\Delta X_{max} < 70 gr/cm^2$ (Requirement $\Delta X_{max} < 120 gr/cm^2$) OK

*T.Mernik et al., 2011*

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# Comparison with current observatories

| Observatory | Aperture $km^2$ sr | Status | Start | Lifetime | Duty cycle | Annual Exposure $km^2$ sr yr | Relative to Auger |
|---|---|---|---|---|---|---|---|
| Auger | 7,000 | Operations | 2006 | 4 (16) | 1 | 7000 | 1 |
| TA | 1,200 | Operations | 2008 | 2 (14) | 1 | 1,200 | 0.2 |
| TUS | 30,000 | Developed | 2012 | 5 | 0.14 | 4,200 | 0.6 |
| JEM-EUSO ($E \approx 10^{20}$ eV) | 430,000 | Design | 2017 | 5 | 0.14 | 60,000 | 9 |
| JEM-EUSO (highest energies) Tilted mode 35˚ | 1,500,000 | Design | 2017 | 5 | 0.14 | 200,000 | 28 |

# *Near Term Programmatics*

- Test and calibration of the Optics; integration of the PDM engineering model (Spring 2012);
- Summer 2012 integration of a prototype (optics + PDM EM) and …

in October – December 2012

*Tests of the prototype at the TA site*

**Andrea Santangelo,**
**Kepler Center-Tü**

# *JEM-EUSO Balloon*

– Look down from the balloon with an UV telescope (PDM EM + 3 lenses system)

– Engineering test

– Background test

– Airshower from 40 km altitude

2009 Proposal submitted to CNES

2011/6 Approved by CNES

→ 2013, January, first launch from Kiruna

# *Conclusions*

- *Science:* Evidence for GZK, Indication for Anisotropy, hints of sources but *puzzling scenario* (PAO, HiRes, TA)
  - Current generation of UHE Observatory is too small
  - *We need next generation*
  - *Exploration of the unknown*: UHE neutrinos, photons and new physics
- *Breakthrough can come from space:*
  - Large exposures, uniform exposures of the entire sky
  - JEM-EUSO is the pathfinder with potentially outstanding science output.
- *JEM-EUSO is feasible:*
  - Phase A/B studies of JAXA and of the Collaboration confirms it
  - Prototyping phase has been started. Tests on the key mission elements have been conducted.
- *Launch in 2017*

**Andrea Santangelo,**
**Kepler Center-Tü**

# *Conclusions*

- The JEM-EUSO duty cycle and cloud impact have been thoroughly *estimated to be η≈20% and κ > 70%.*

- JEM-EUSO is designed to have a annual exposure about *9xAuger at $10^{20}$ eV in nadir mode* and *28xAuger* at the highest unexplored energies in tilt mode.

- To reach/approach 1ML integrated exposure it is *necessary to operate the mission also in tilted mode.*

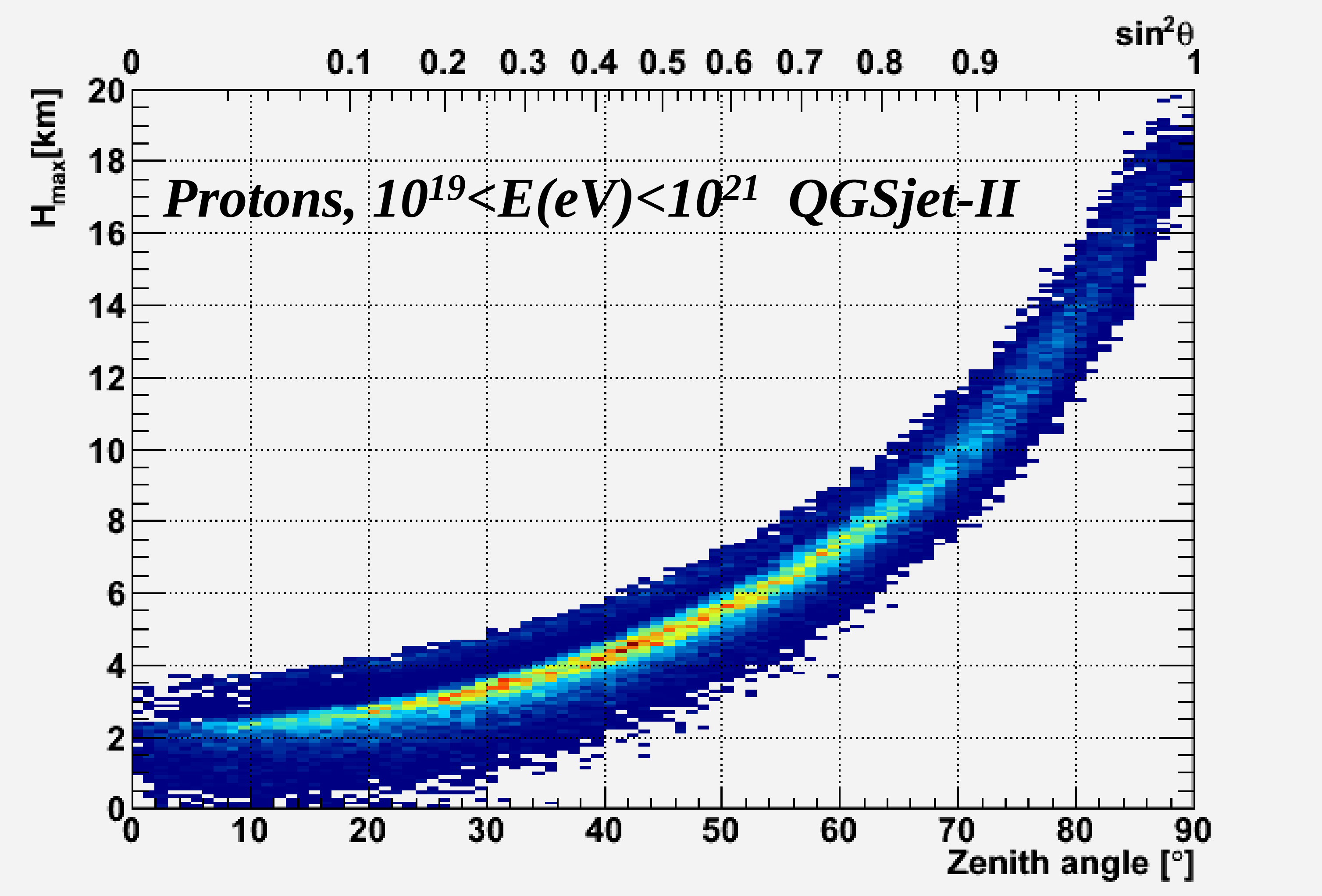
- Simulations in nadir mode shows that the energy, angular and $X_{max}$ resolution meet the requirements.

- JEM-EUSO will have *enough exposure and reconstruction capability at $3x10^{19}$ eV to overlap* with current generation observatory.

- JEM-EUSO is not EUSO! Optics and PMTs QE have been greatly improved and so have been the performances…

**Andrea Santangelo,**
**Kepler Center-Tü**

# $H_{max}$ & ZA dependence



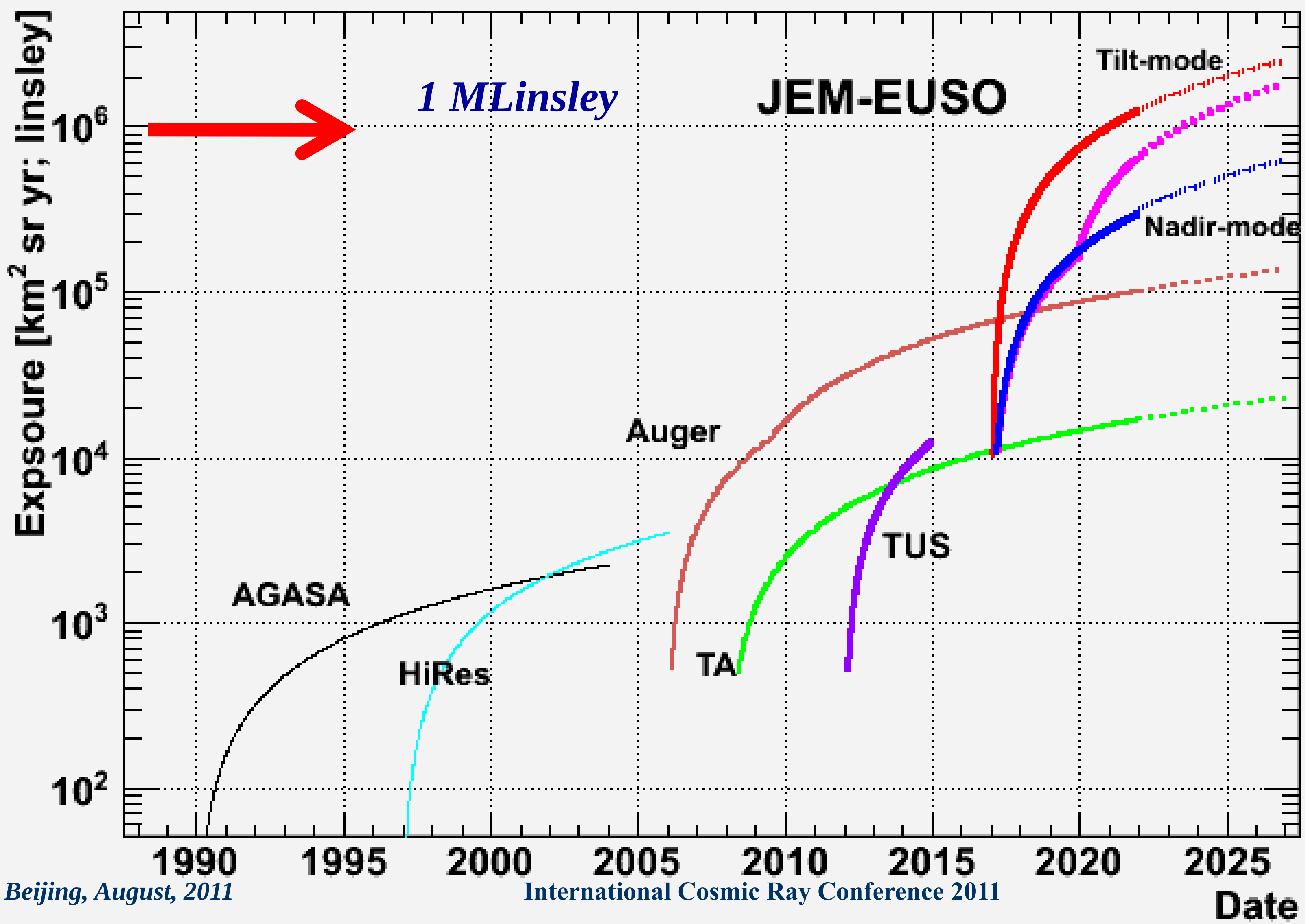

*F.Garino et al., ID398*


**Andrea Santangelo,**
**Kepler Center-Tü**

# *Comparison with current observatories*

| Observatory | Aperture km$^2$ sr | Status | Start | Lifetime | Duty cycle | Annual Exposure km$^2$ sr yr | Relative to Auger |
|---|---|---|---|---|---|---|---|
| Auger | 7,000 | Operations | 2006 | 4 (16) | 1 | 7000 | 1 |
| TA | 1,200 | Operations | 2008 | 2 (14) | 1 | 1,200 | 0.2 |
| TUS | 30,000 | Developed | 2012 | 5 | 0.14 | 4,200 | 0.6 |
| JEM-EUSO (E≈$10^{20}$ eV) | 430,000 | Design | 2017 | 5 | 0.14 | 60,000 | 9 |
| JEM-EUSO (highest energies) Tilted mode 35˚ | 1,500,000 | Design | 2017 | 5 | 0.14 | 200,000 | 28 |

# *Why JEM-EUSO? Large exposure + Full sky coverage*



*Current Status of the Mission?*
*Please ask in the question time...*

# *Conclusions*

- *Science:* Evidence for GZK, Indication for Anisotropy, hints of sources but *puzzling scenario* (PAO, HiRes, TA)
  - Current generation of UHE Observatory is too small
  - *We need next generation*
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- *JEM-EUSO is feasible:*
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  - Prototyping phase has been started. Tests on the key mission elements have been conducted.
- *Launch in 2017*

# *Current Status of the Mission*

- Phase A study jointly conducted by JAXA and the JEM-EUSO consortium (Payload and Mission) is vigorously ongoing...

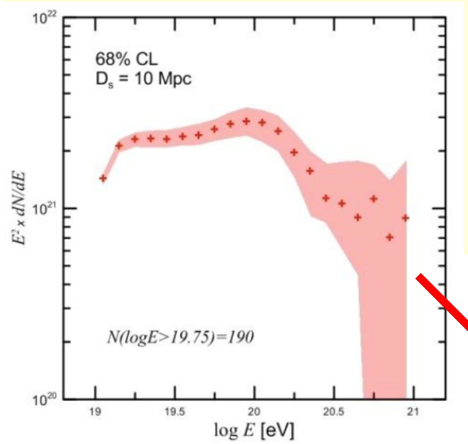
- JEM-EUSO has been included (in 2010) in the ELIPS program of ESA

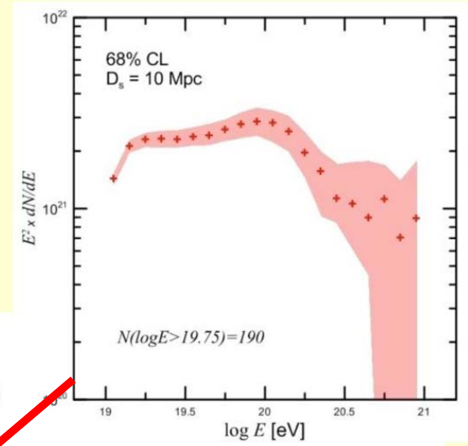
- National contributions have been defined (and in many cases asked and in a few cases already approved!)

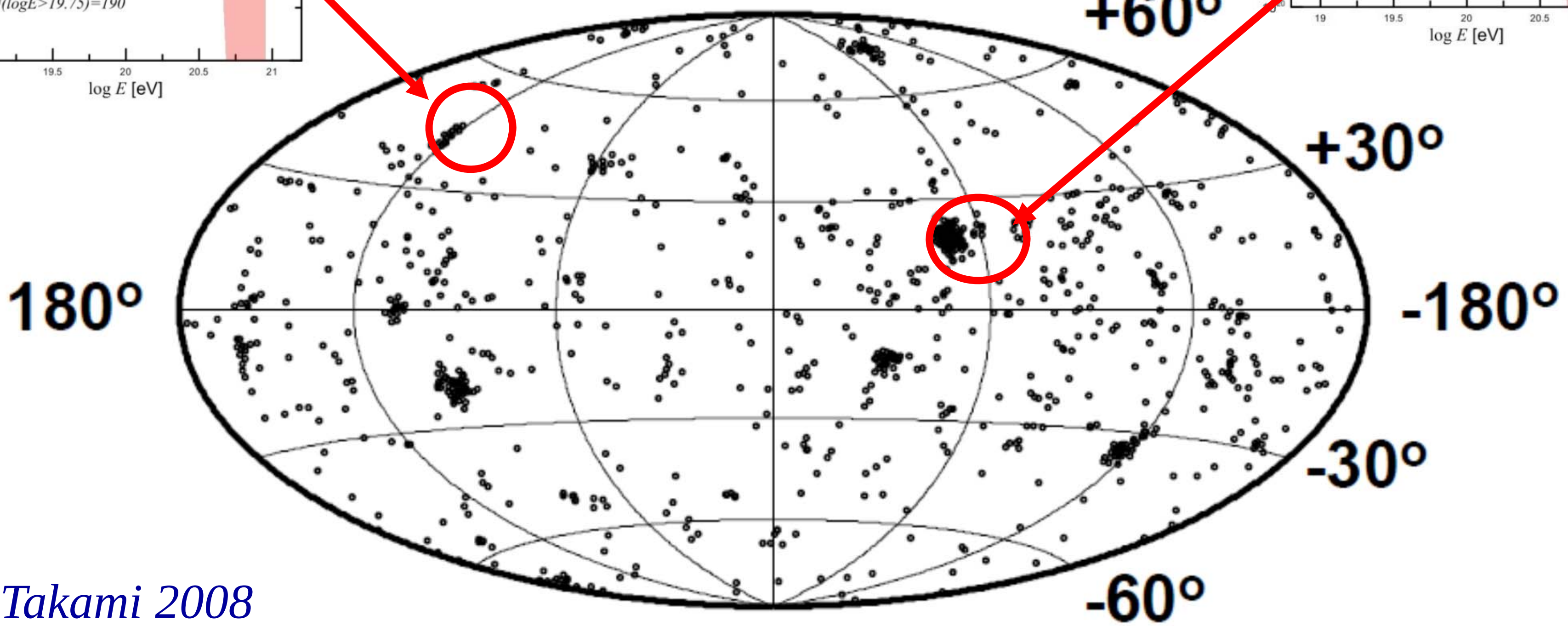
- US JEM-EUSO MO proposal (Explorer Call) is being reviewed by NASA (September 2011)

# *JEM-EUSO sky*

***Forecast in case of 1,000 events***
***Brightness proportional to AGN***




*Takami 2008*

***Brightness of particles ∝ X ray（AGN）***

- *We expect to discover several tens of clusters*
- *Can observe the whole sky*

**Andrea Santangelo,**
**Kepler Center-Tü**

# Atmospheric Monitoring System

- **IR Camera**

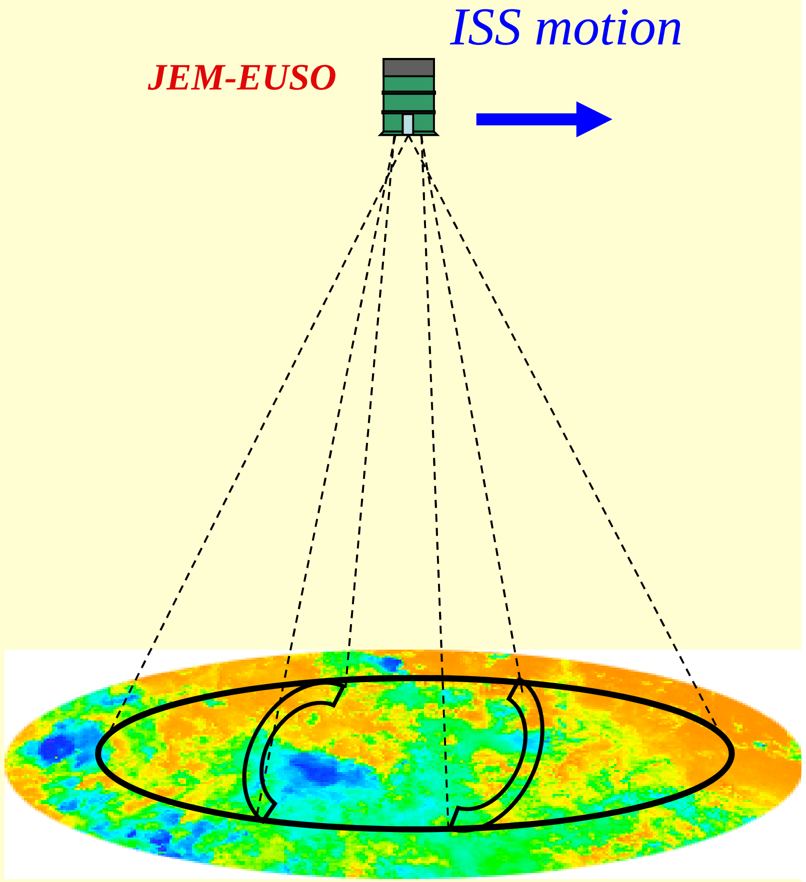
  *Imaging observation of cloud temperature inside FOV of JEM-EUSO*

- **Lidar**

  *Ranging observation using UV laser*

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

  *Continuous background photon counting*




| | |
|---|---|
| ▪ Cloud amount, cloud top altitude: | (IR cam., Lidar, slow-data) |
| ▪ Airglow : | (slow-data) |
| ▪ Calibration of telescope : | (Lidar) |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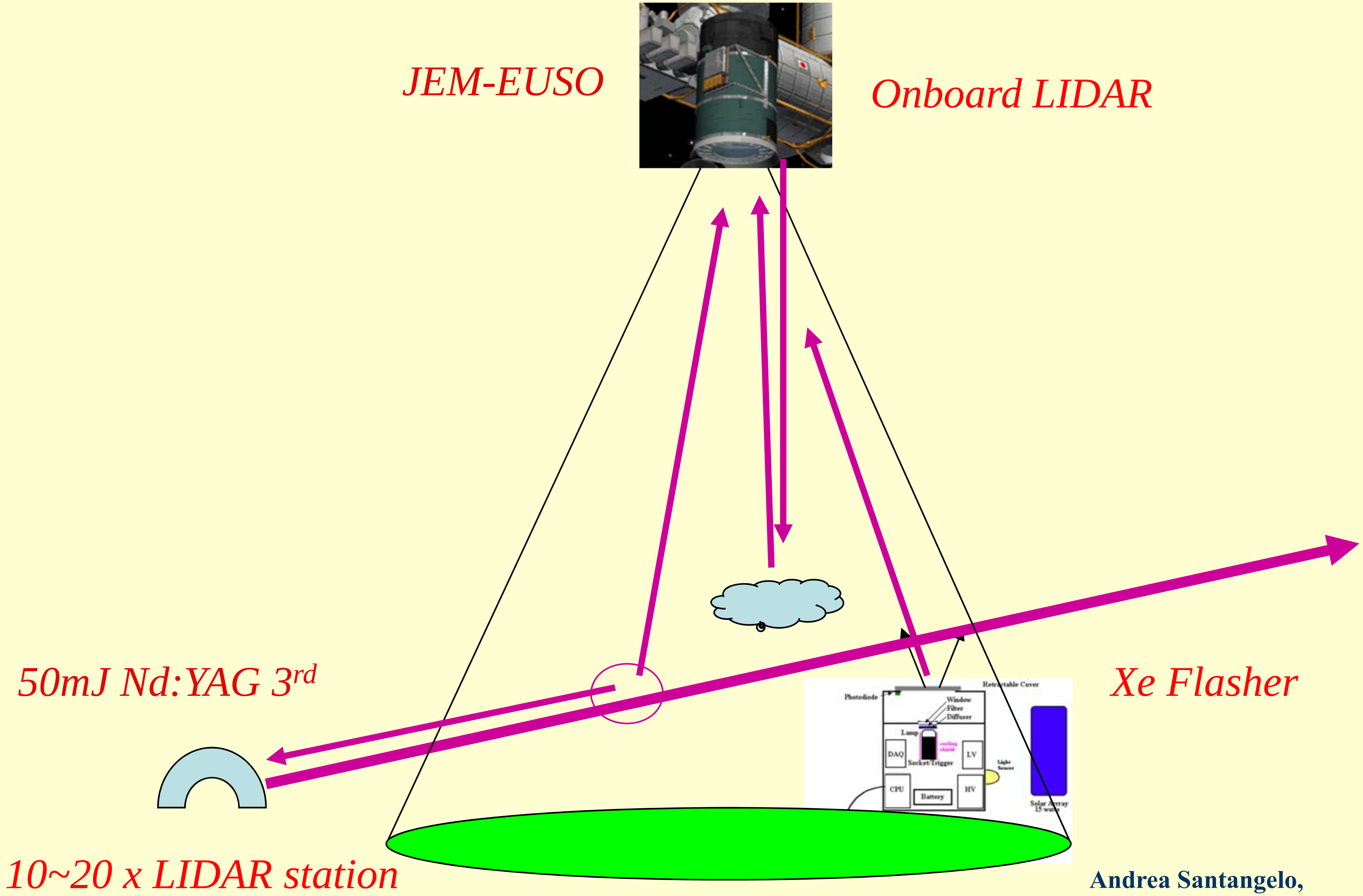
# Calibration and Monitor by Onboard LIDAR, Ground LIDAR & Xe flasher

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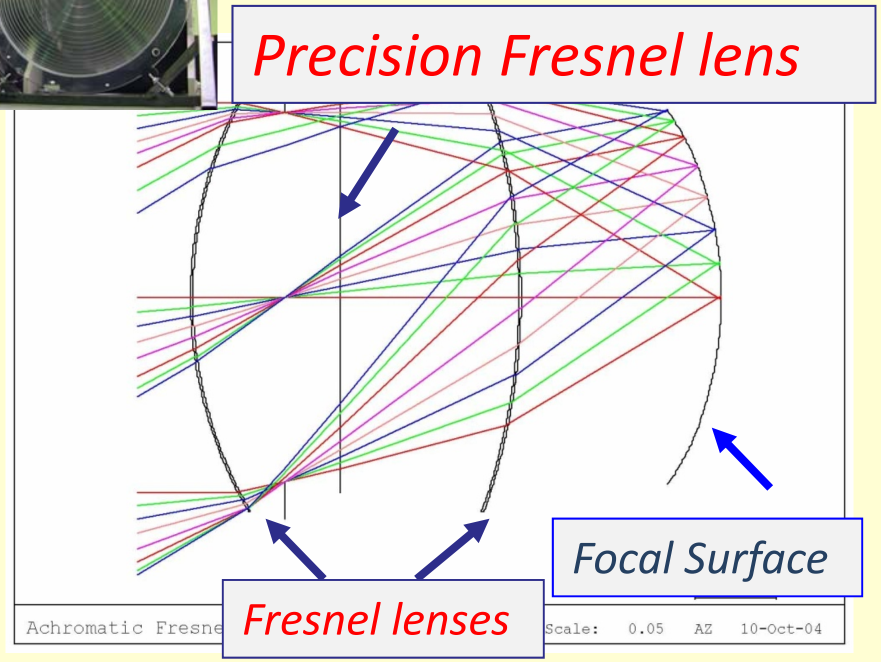
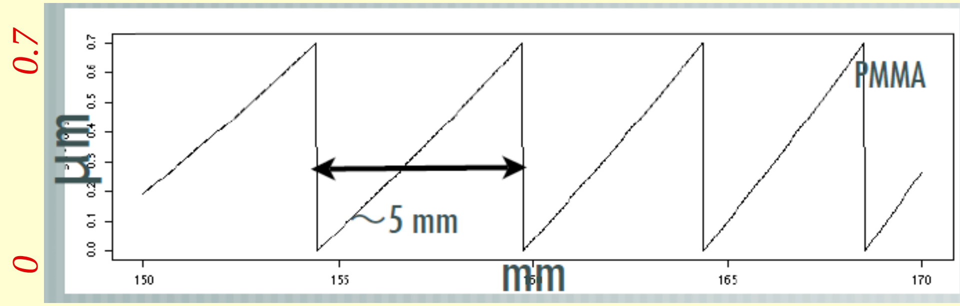
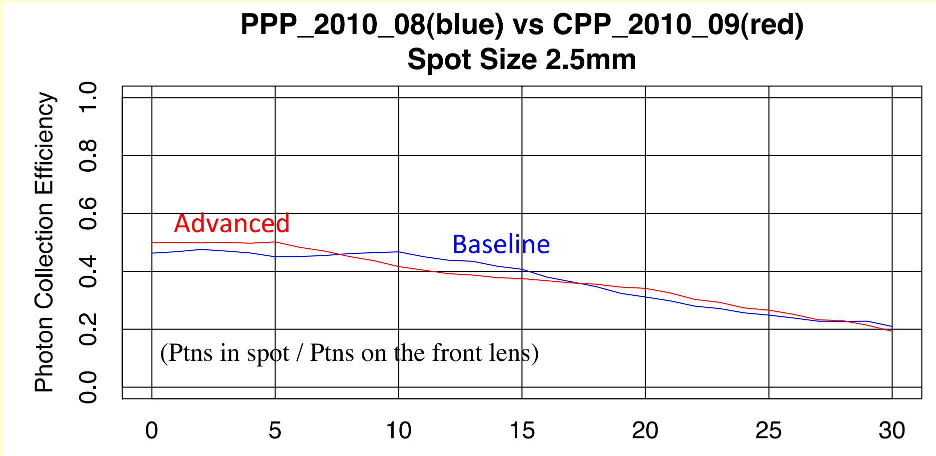
# JEM-EUSO Optics

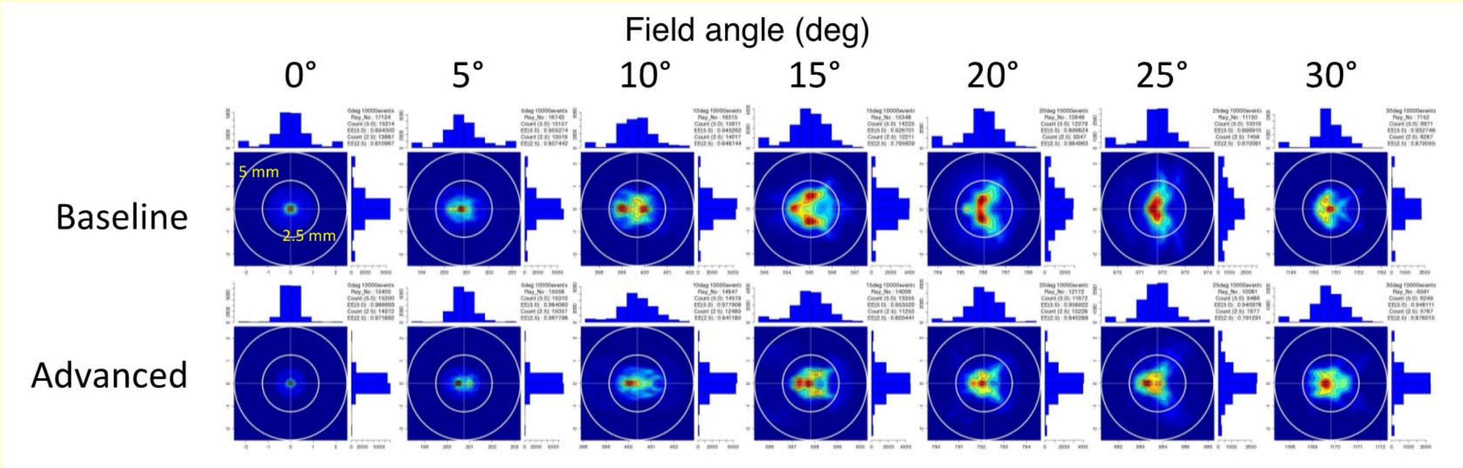



*Surface of the Precision Fresnel lens*




*Precision optics cancels chromatic aberration*




*Spot size is 2.5 mm*

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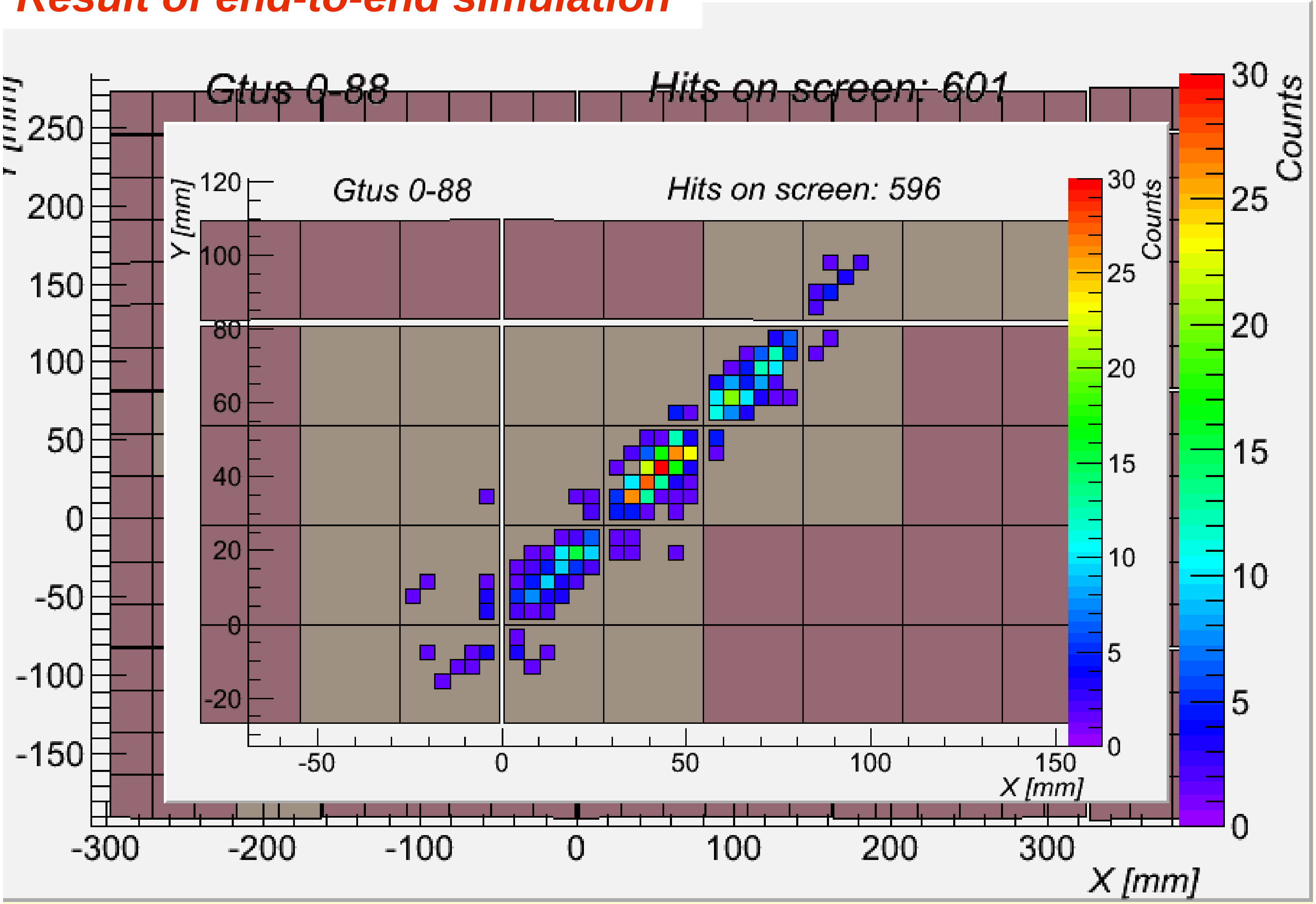
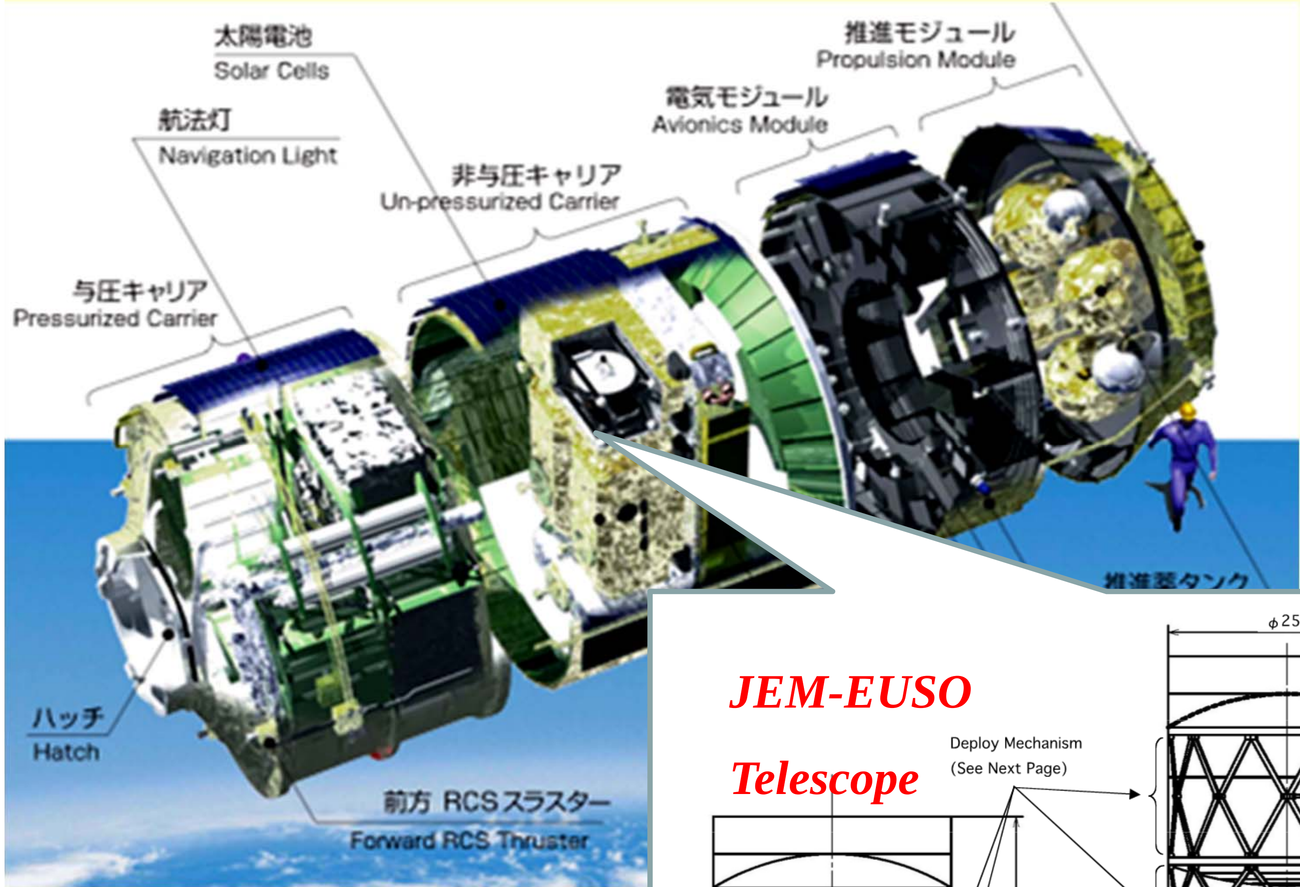
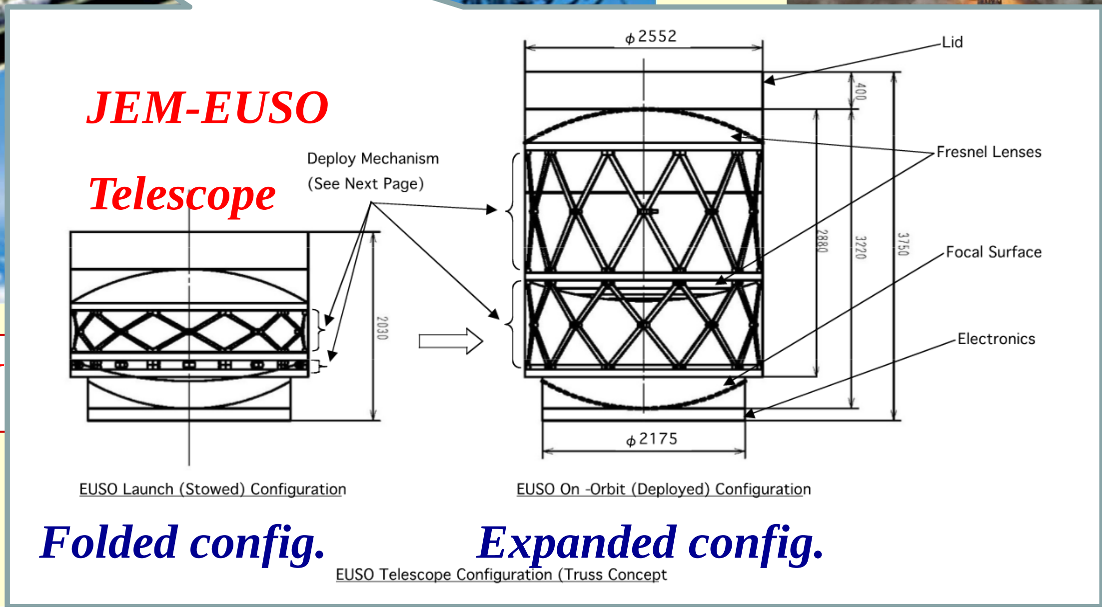
# Result of end-to-end simulation



# Transfer to the ISS:
# H-IIB Transfer Vehicle (HTV)

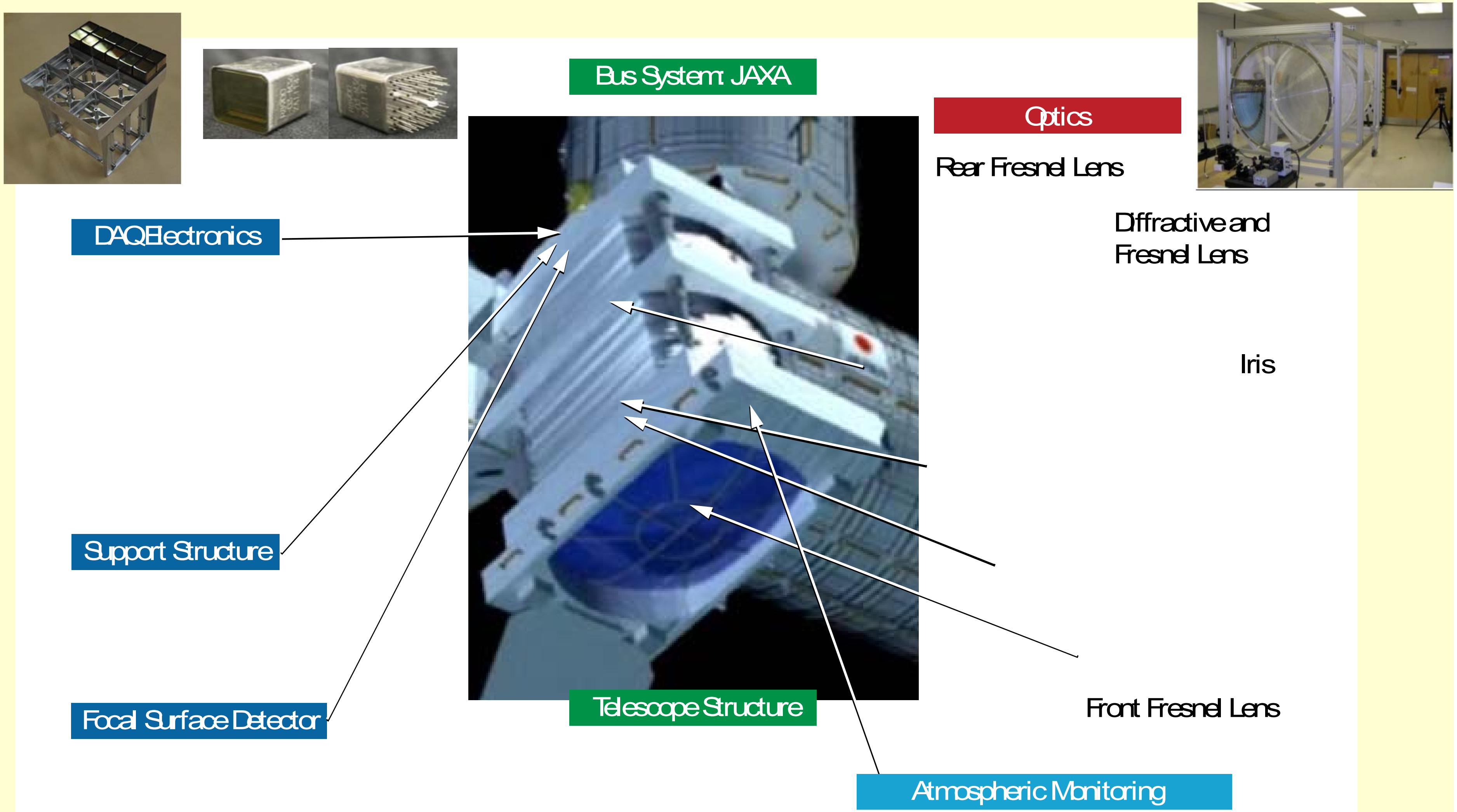



*Successfull Launch of H*

*4 m across, 10 m long*

# Science Instrument:
# UV Telescope + Atmospheric Monitoring





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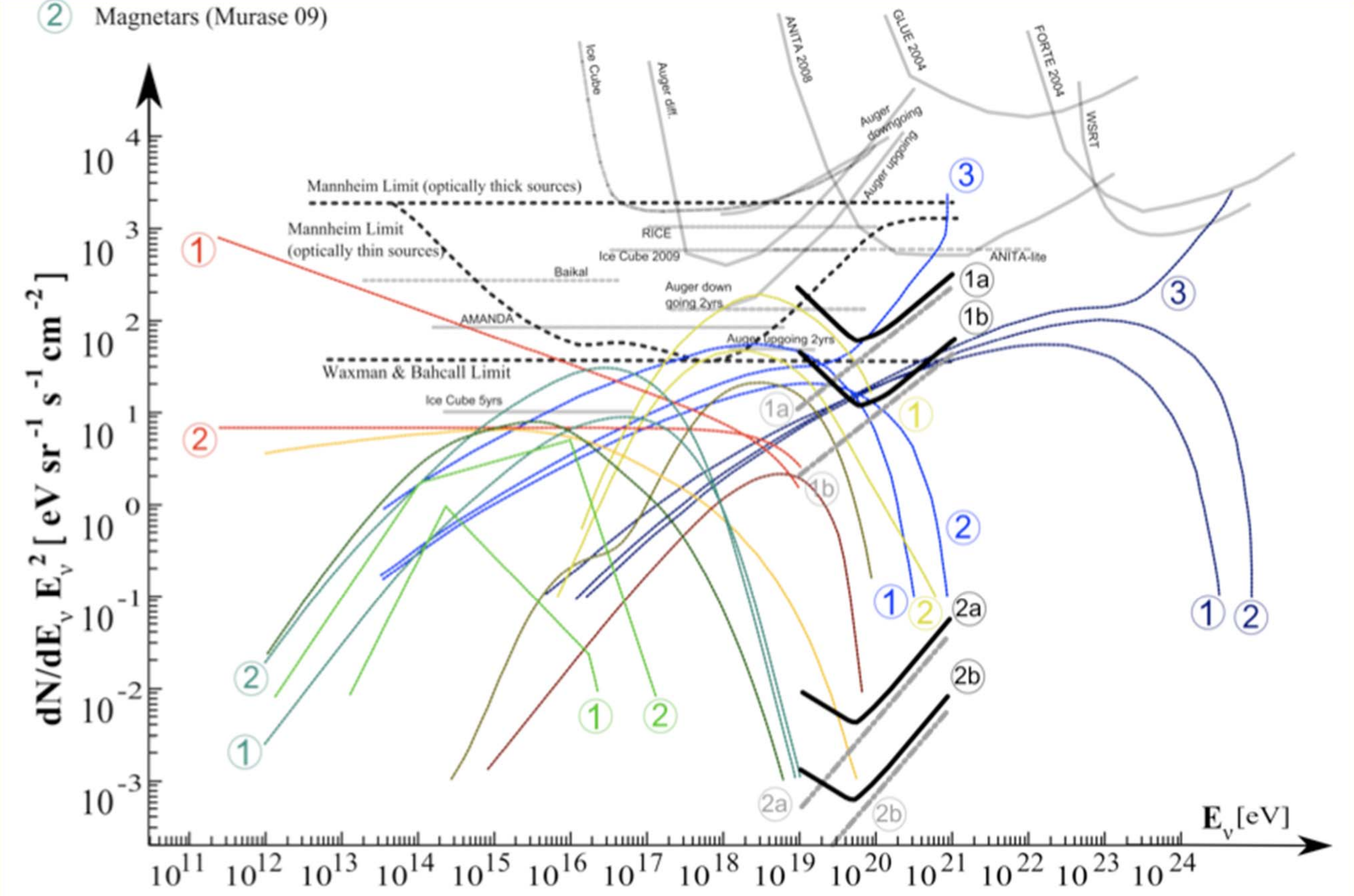
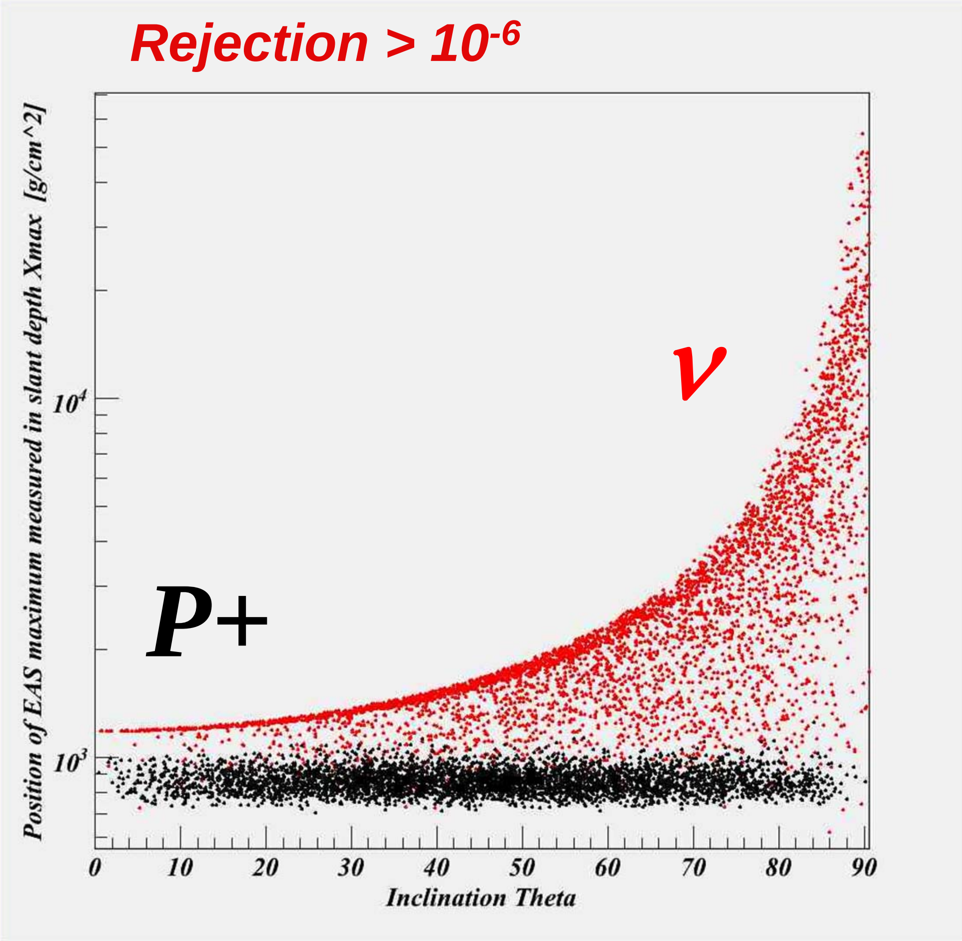
**Kepler Center-Tü**

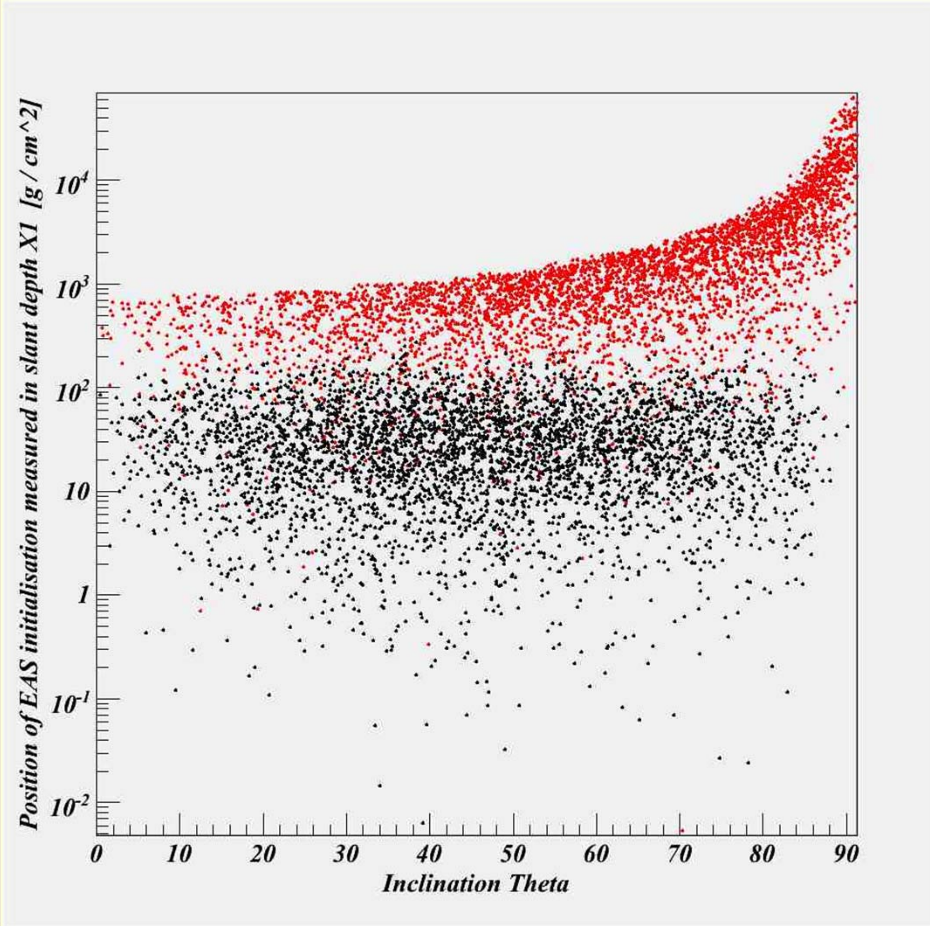
*Bittermann, 2010*

# *The Zoo of neutrino models*



# *Discrimination of Neutrinos vs Protons*

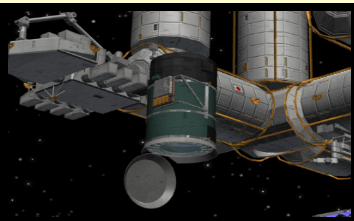



**Xmax**

**X1 initial point**

# *Neutrino shower simulation*



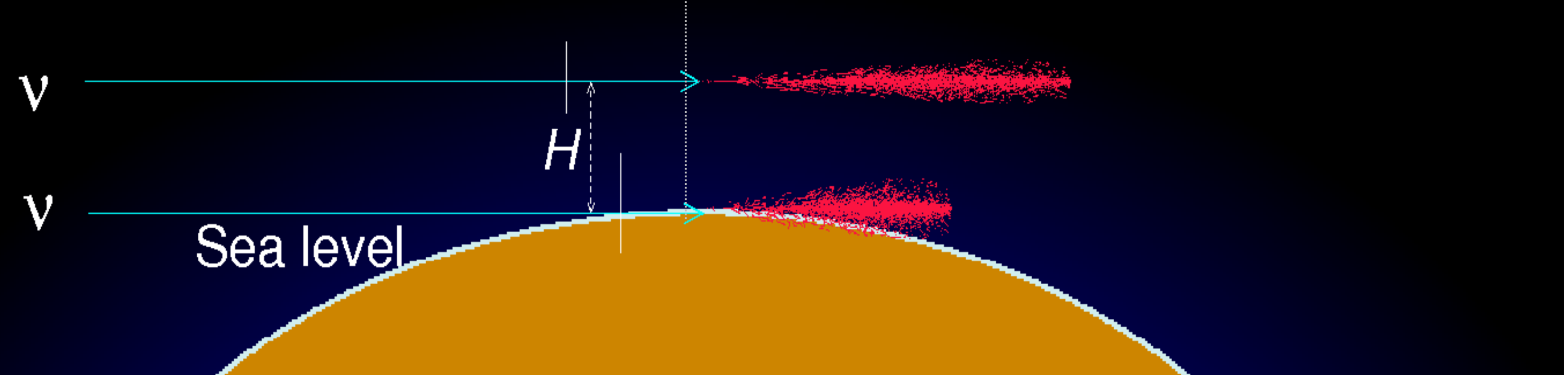
*Horizontally incident neutrinos*

*Survival prob. to come in FOV*

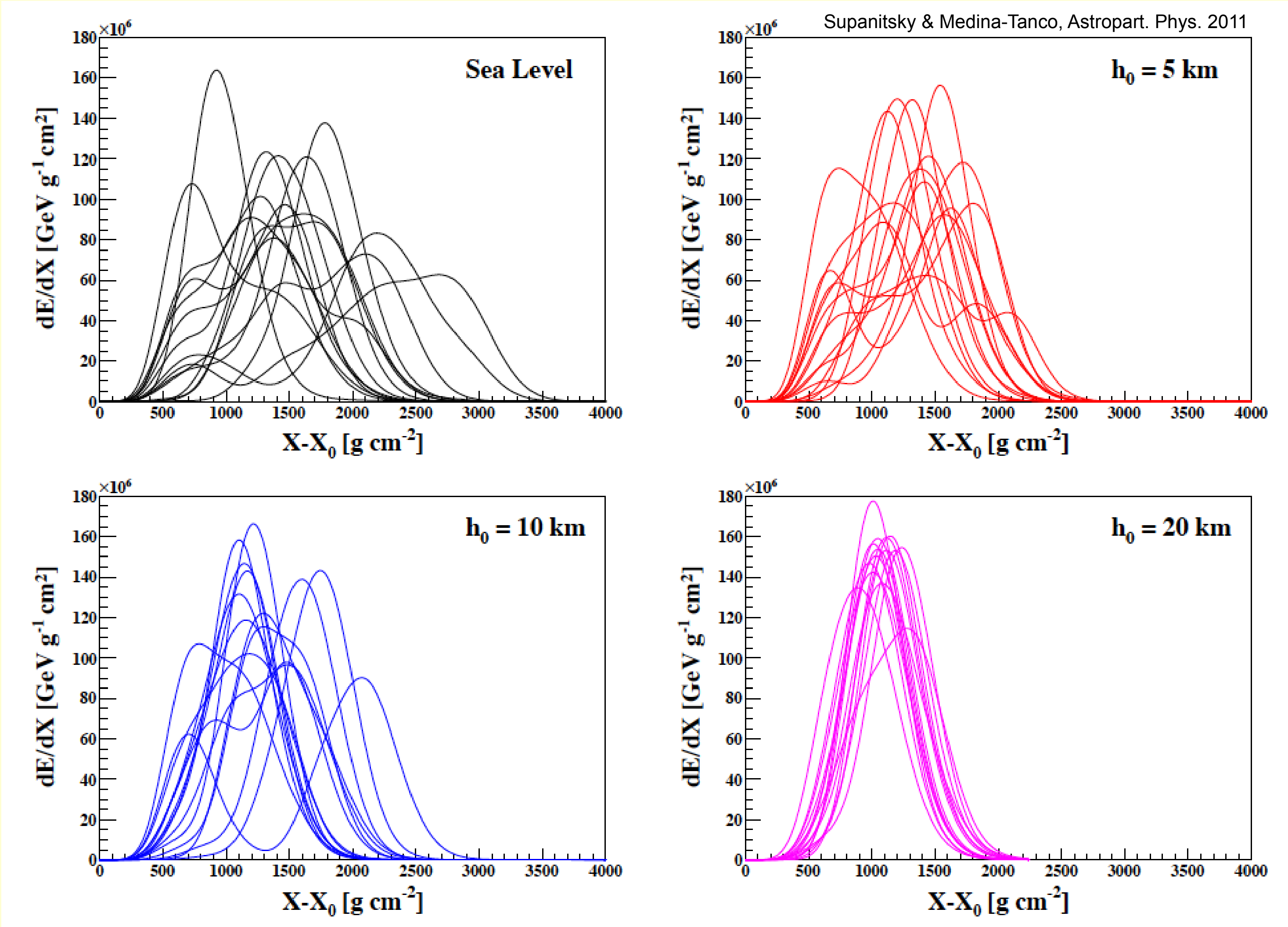
*Neutrino: ~exp(-0.001)*

*Proton: ~exp(-1000) for $10^{20}$ eV*

*CONEX code used for shower simulation in atmosphere*



# *Profile of neutrino induced showers*




- First peak resulted from hadronic part of shower
- Second and following peaks from electromagnetic part
  - LPM effect more significant at lower altitudes

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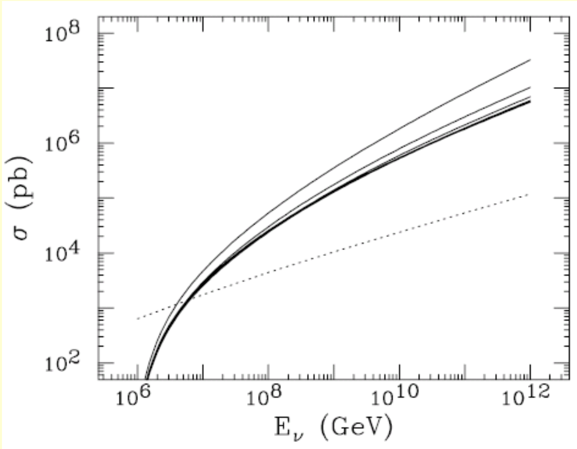
**Kepler Center-Tü**

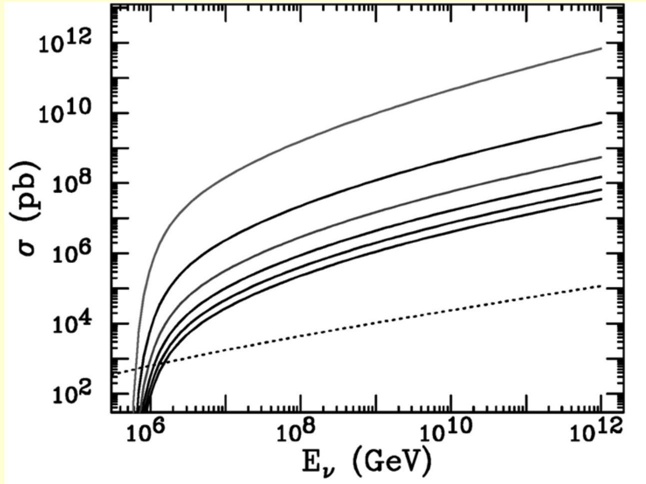
# Neutrino cross sections

## Black Hole production



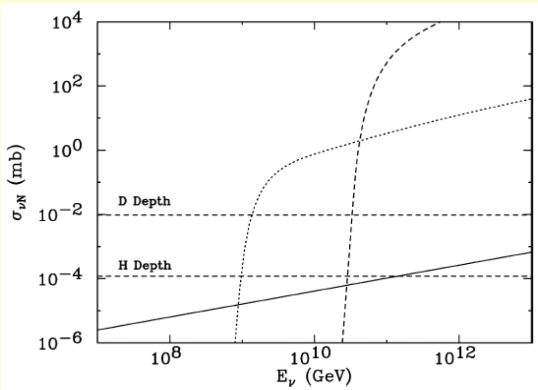

*Feng & Shapere, 2002*

## p-brane production




*Anchordoqui, Feng and Goldberg, 2002*

## EW instanton effects

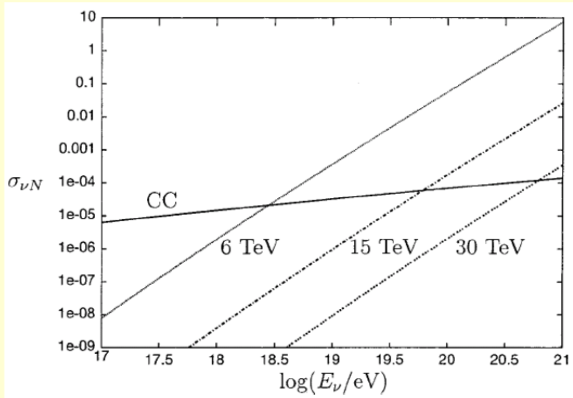



*Han & Hooper, 2004*

*Bezrukov et al., 2003a, 2003b*

*Ringwald, 2003*

## Exchange of KK modes




*Kachelriess & Plümacher, 2000*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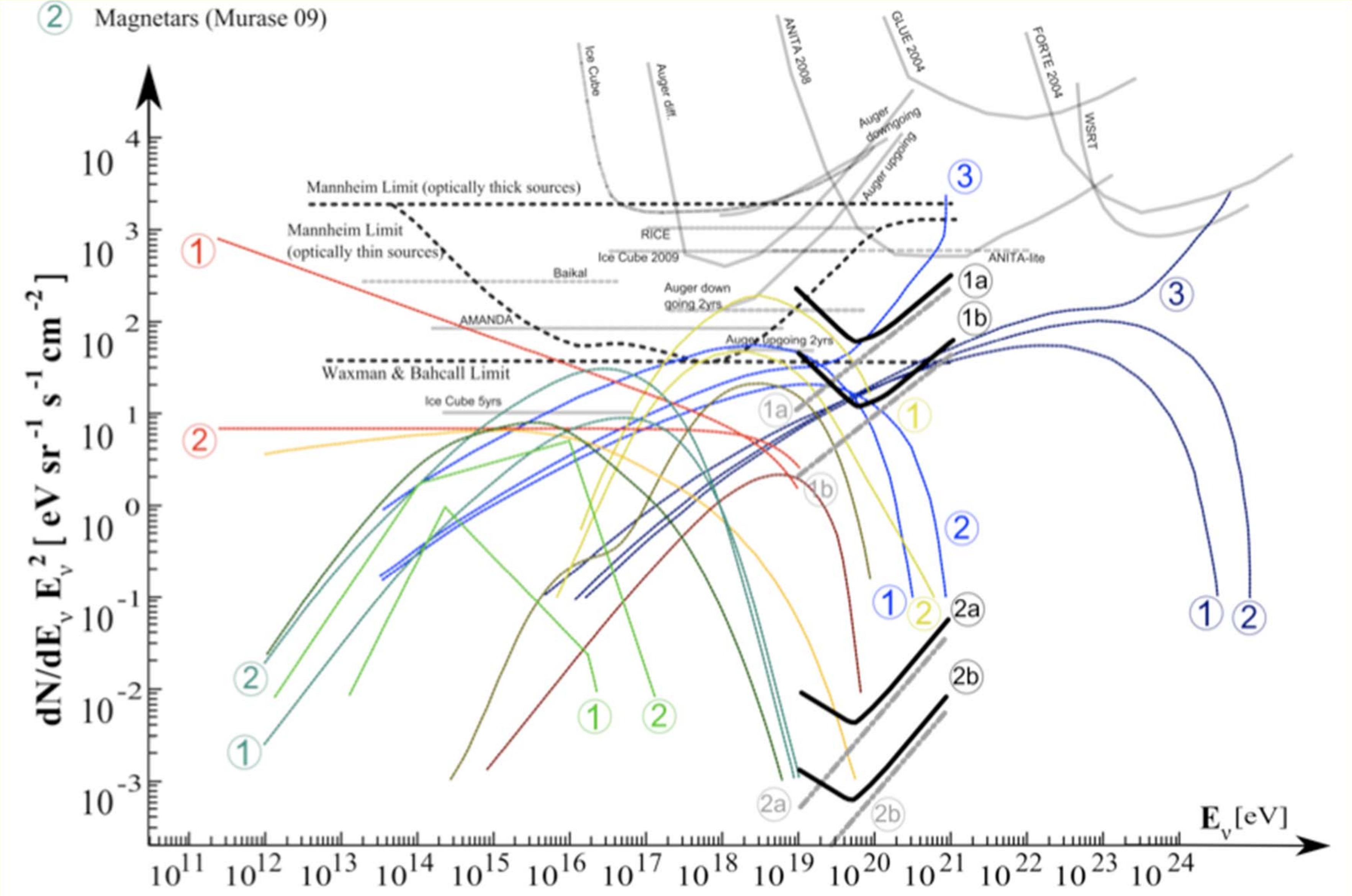
**Kepler Center-Tü**

*Bittermann, 2010*

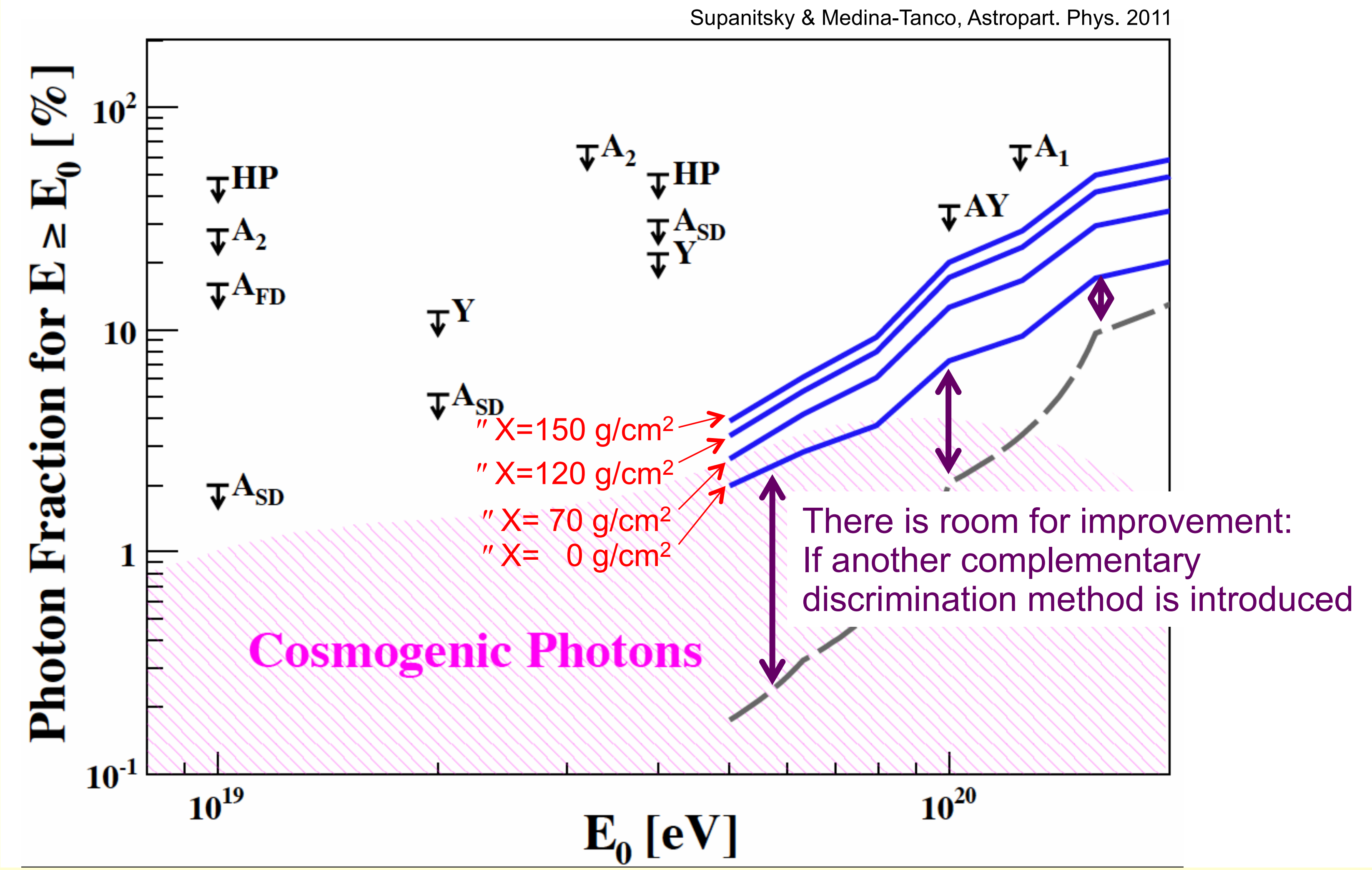
# *The Zoo of neutrino models*



# *Constrains from Auger*

*Auger Collaboration, 2009*

**Top-down models *are strongly constrained by the absence of identified photon candidates* in the Auger data**



# *Transient Luminous events*

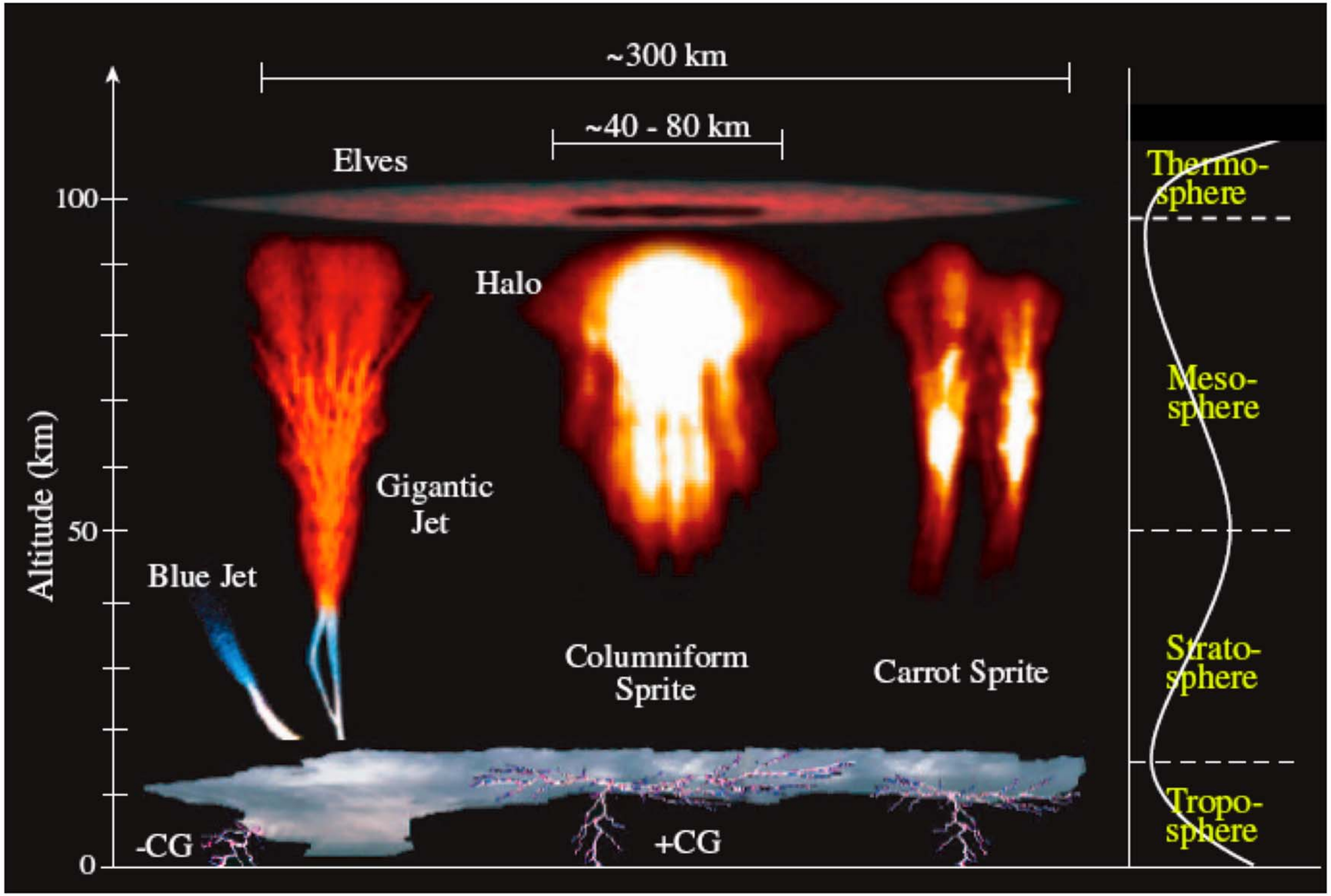
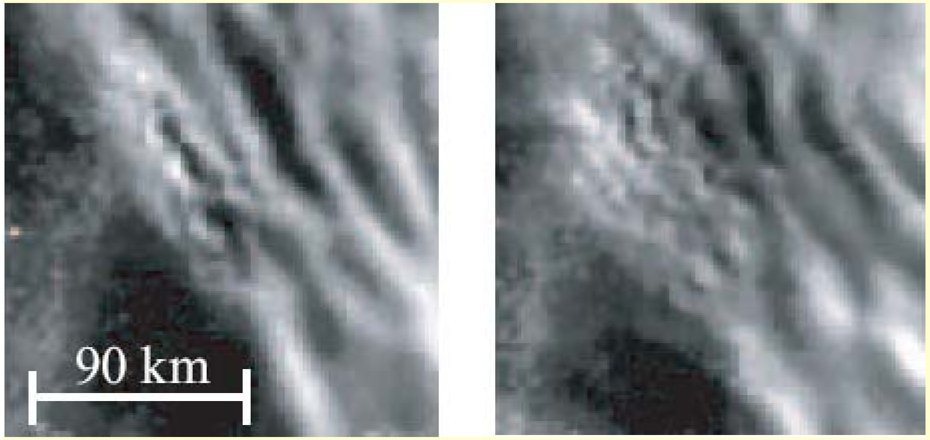


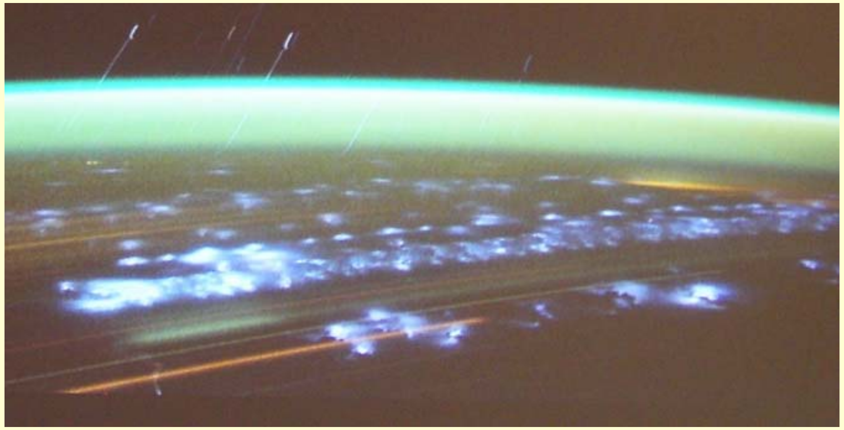

**Figure 2.2.5-2.** *Various transient luminous events associated with lightning.*

*From the JEM-EUSO phase A report*

# *Atmospheric Luminous Phenomena*

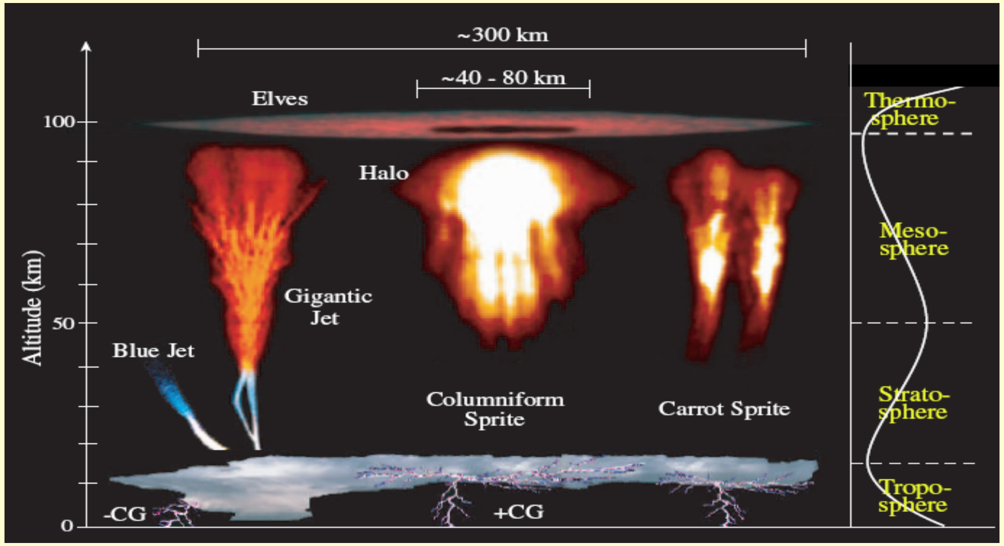



***OH airglow observed from ground***



***Lightning picture observed from ISS***

***Leonid meteor swarm in 2001 taken by Hivison camera***




***Various transient events***

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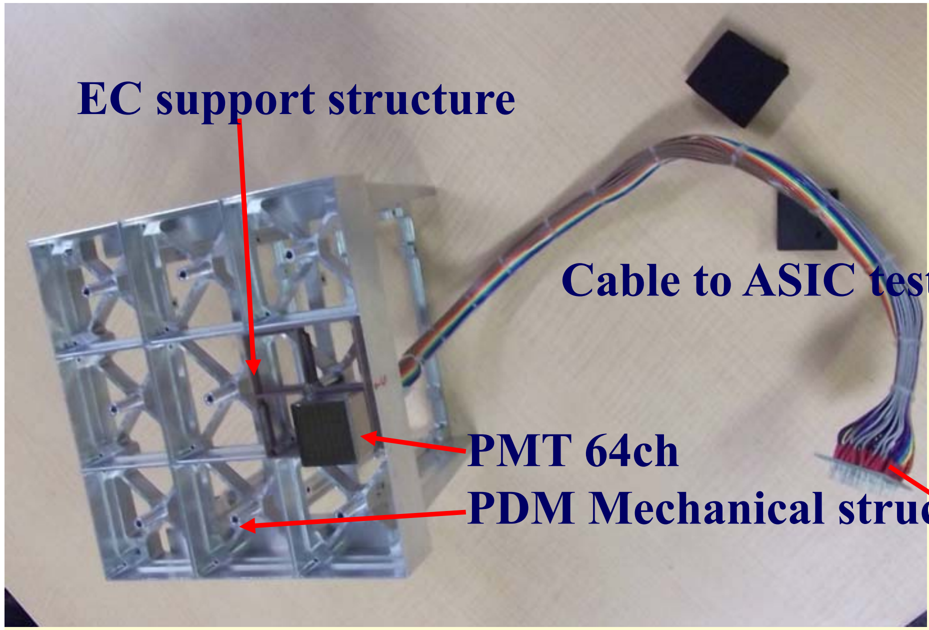
**Kepler Center-Tü**

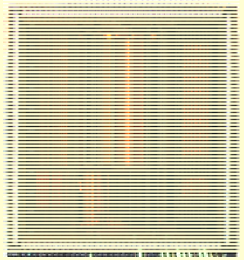
EC support structure

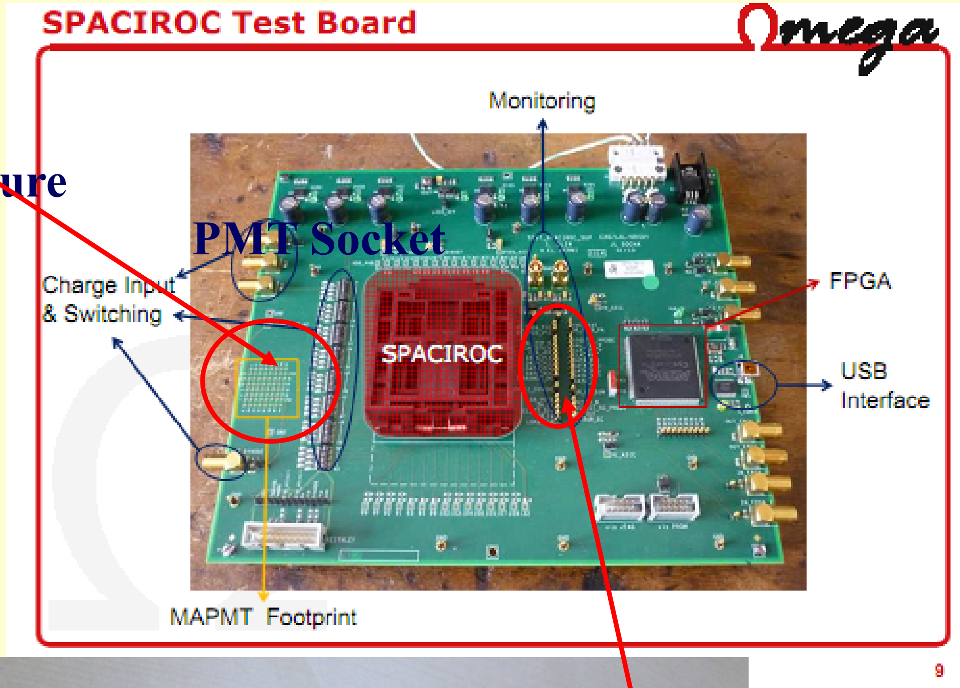


Cable to ASIC test board (in stead of ECboard)

PMT 64ch

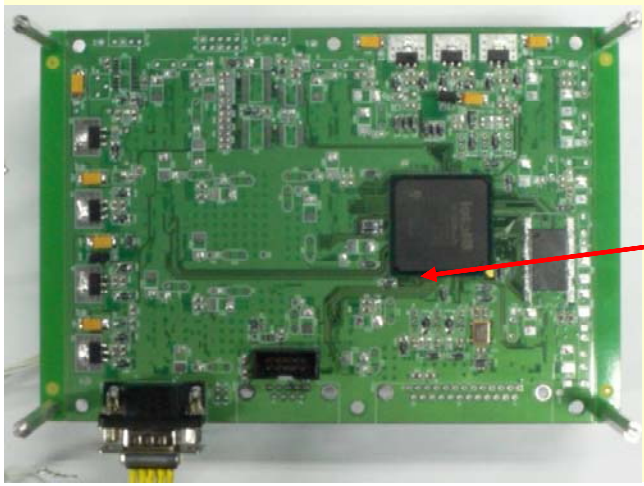
PDM Mechanical structure

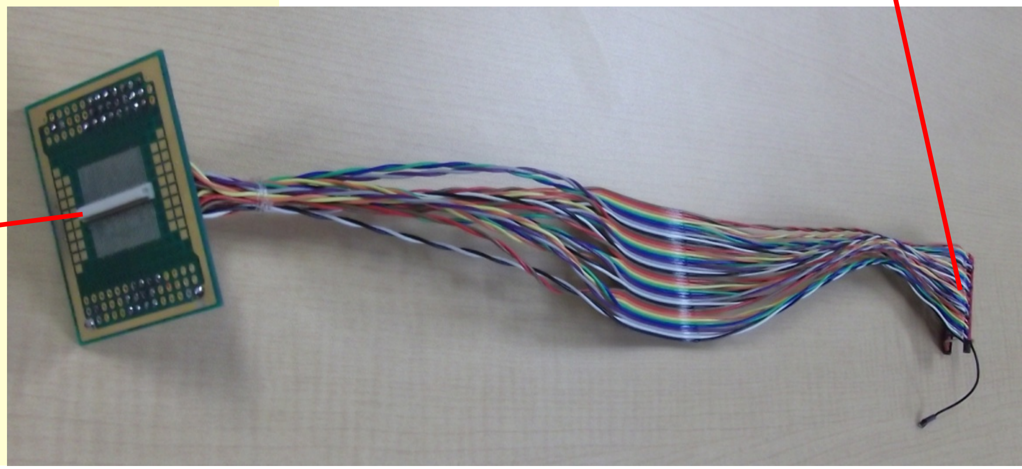





PMT Socket

PDM (Korea) FPGA (Actel) board





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# JEM-EUSO DAQ – Data reduction block scheme