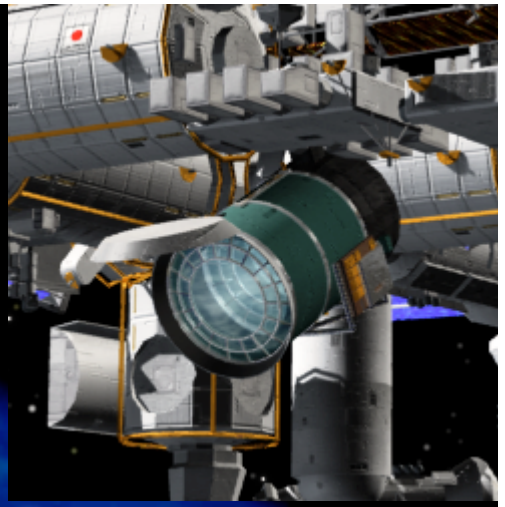
The Extreme Universe Space Observatory on board ISS



JEM-EUSO:Current status and perspectives

Philippe Gorodetzky

APC-Paris 7 — CNRS/Univ

for the JEM-EUSO Collaboration

Colloquium at the Colegio de Espana "Physics of the Standard Model of the Universe: Theory and Observations", Paris June 4 and 5, 2009

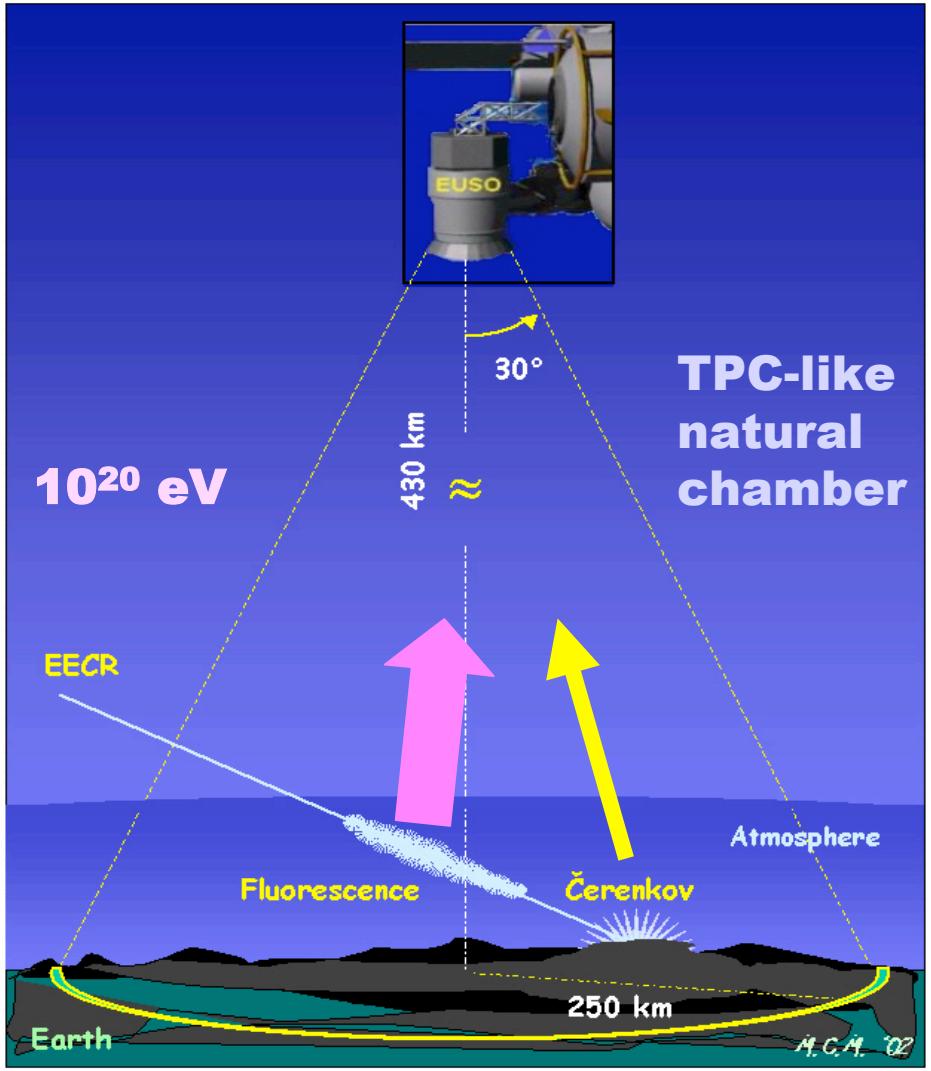
JEM-EUSO Collaboration

10 countries, 56 institutions, 156 members

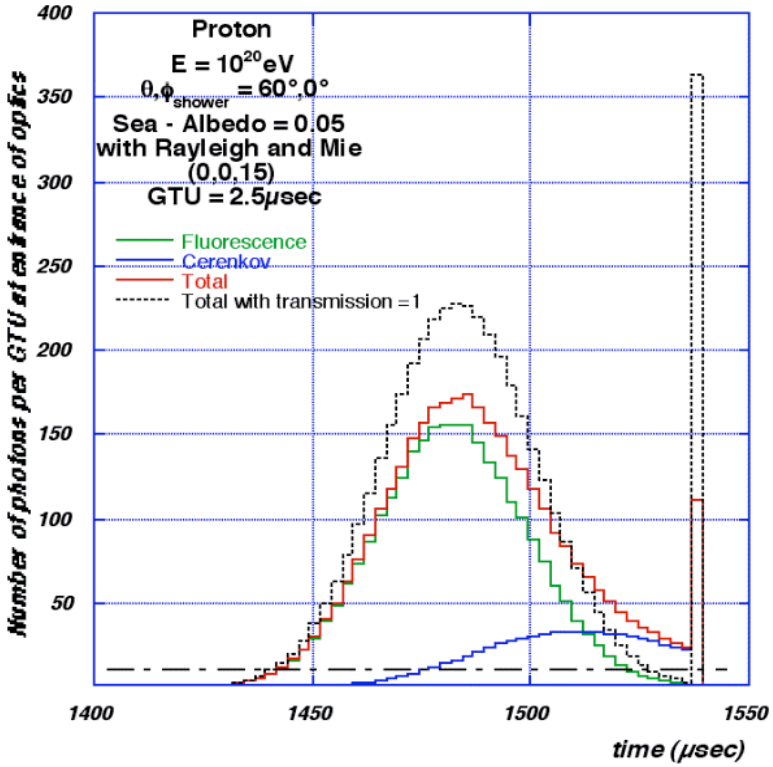
- **Japan** : T. Ebisuzaki, Y. Uehara, H. Ohmori, Y. Kawasaki, M. Sato, Y. Takizawa, K. Katahira, S. Wada, K. Kawai, H. Mase (*RIKEN*), F. Kajino, M. Sakata, H. Sato, Y. Yamamoto, T. Yamamoto, N. Ebizuka, (*Konan Univ.*), M. Nagano, Y. Miyazaki (*Fukui Inst. Tech.*), N. Sakaki, T. Shibata (*Aoyama Gakuin Univ.*), N. Inoue (*Saitama Univ.*), Y. Uchihori (*NIRS*), K. Nomoto (*Univ. of Tokyo*), Y. Takahashi (*Tohoku Univ.*), M. Takeda (*ICRR, Univ. Tokyo*), Y. Arai, Y. Kurihara, H.M. Shimizu, J. Fujimoto (*KEK*), S. Yoshida, K. Mase (*Chiba Univ.*), K. Asano, S. Inoue, Y. Mizumoto, J. Watanabe, T. Kajino (*NAOJ),* H. Ikeda, M. Suzuki, T. Yano (*ISAS, JAXA*), T.Murakami, D. Yonetoku (*Kanazawa Univ.*), T. Sugiyama *(Nagoya*), Y. Ito (*STEL, Nagoya Univ.*), S. Nagataki (*YITP, Kyoto Univ.*), A. Saito(*Kyoto Univ.*), S. Abe, M. Nagata (*Kobe Univ.*), T. Tajima (*KPSI, JAEA*)、M. Chikawa (*Kinki Univ.*), and M. Tajima (*Hiroshima Univ.*)
- **USA** : J. H. Adams Jr., S. Mitchell, M.J. Christl, J. Watts Jr., A. English, R. Young (*NASA/ MSFC*) , Y. Takahashi, D. Gregory, M. Bonamente, P. Readon, V. Connaughton, K. Pitalo, J. Hadaway, J. Geary, R. Lindquist, P. Readon (*Univ. Alabama in Huntsville*), H. Crawford, C. Pennypacker (*LBL, UC Berkeley*), K. Arisaka, D. Cline, J. Kolonko, V. Andreev (*UCLA*), T. Weiler, S. Csorna (*Vanderbilt Univ.*),
- **France** : D. Allard, J-N. Capdevielle, J. Dolbeau, F. Dorigo, P. Gorodetzky, J.J. Jaeger, C. Olivetto, E. Parizot, T. Patzak, D. Semikoz (*APC,CNRS*), J. Waisbard *(IN2P3),* A. Cordier, S. Dagoret, M. Urban *(LAL, CNRS)*
- **Germany**: M. Teshima, T. Schweizer (*Max Planck Munich*), A. Santangelo, E.Kendziorra, F.Fenu (*Univ. Tuebingen*), P. Biermann (*MPI Bonn*), K. Mannheim (*Wuerzburg*), J. Wilms (*Univ. Erlangen*)
- **Italy** : S. Bottai. P. Spillantini, A. Zuccaro (*Firenze*), A. Anzalone, O. Catalano, M.C. Maccarone, P. Scarsi, B. Sacco (*IAS-PA/INAF*), G. D'Ali Saiti (*U. Palermo*), B. Alpat, R. Battiston, B. Bertutti, E. Fiandrini, P. Zuccon (*Perugia*), M. Casolino, M.P. De Pascale, A. Morselli, P. Picozza, R. Sparvoli (*INFN and Univ. Rome "Tor Vergata"*), P. Vallania (*INAF-IFSI Torino*), P. Galleotti, C. Vigorito, M. Bertaina (*Univ. Torino*), A. Gregorio (*Trieste*)
- **Mexico**: G. Medina-Tanco, J.C. D'Olivo, J.F.Valdes (*Mexico UNAM*), H. Salazar, O. Martines (*BUAP*), L. Villasenor (*UMSNH*)
- **Republic of Korea** : S. Nam, I. H. Park, J. Yang (*Ehwa W. Univ.*)
- **Russia**: Garipov G.K., Khrenov, B.A., Klimov P.A. Panasyuk M.I., Yashin I.V. (*SINP MSU*), D. Naumov, Tkachev. L (*Dubna JINR*)
- **Switzerland** : A. Maurissen, V. Mitev (*Neuchatel, Switzerland*) :
- **Spain**: D.Rodriguez-Frias, L.Peral, J.Gutierrez, R.Gomez-Herrero (*Univ. Alcala*)

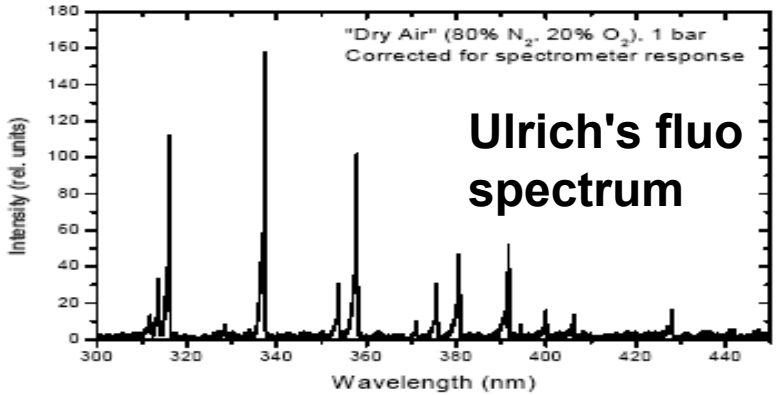
Principle of EUSO

- first *remote-sensing* from space, opening a new window for the highest energy regime



ALL SKY SURVEY

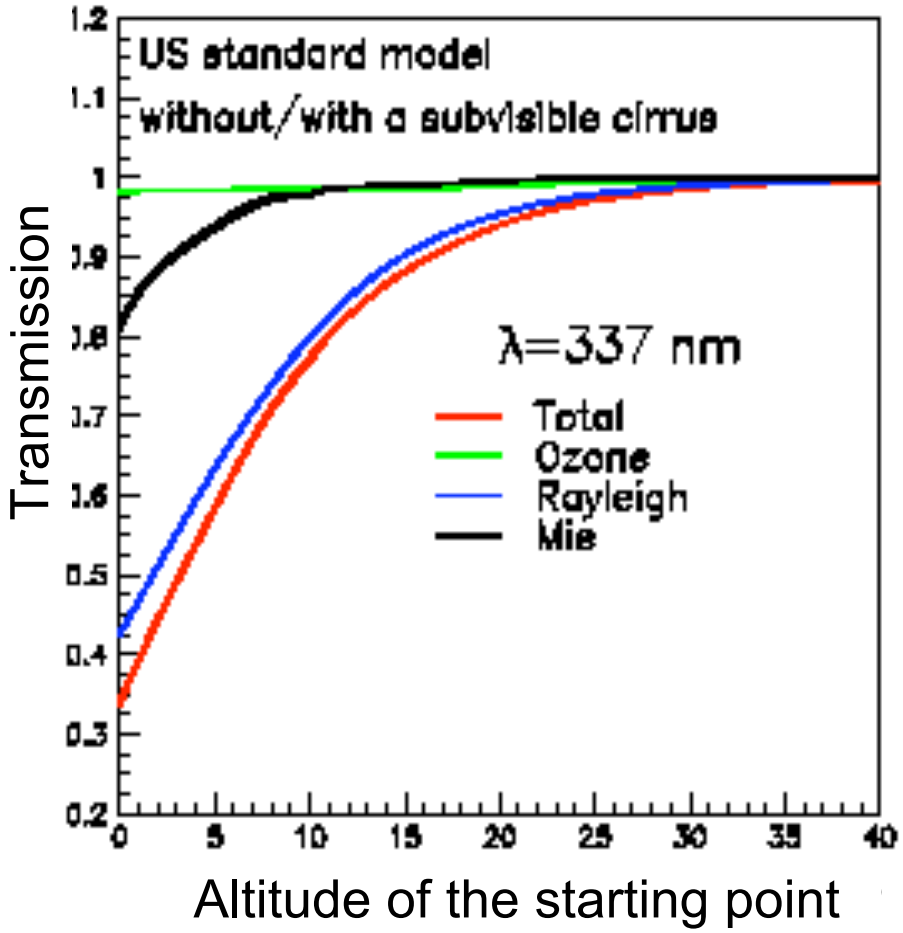




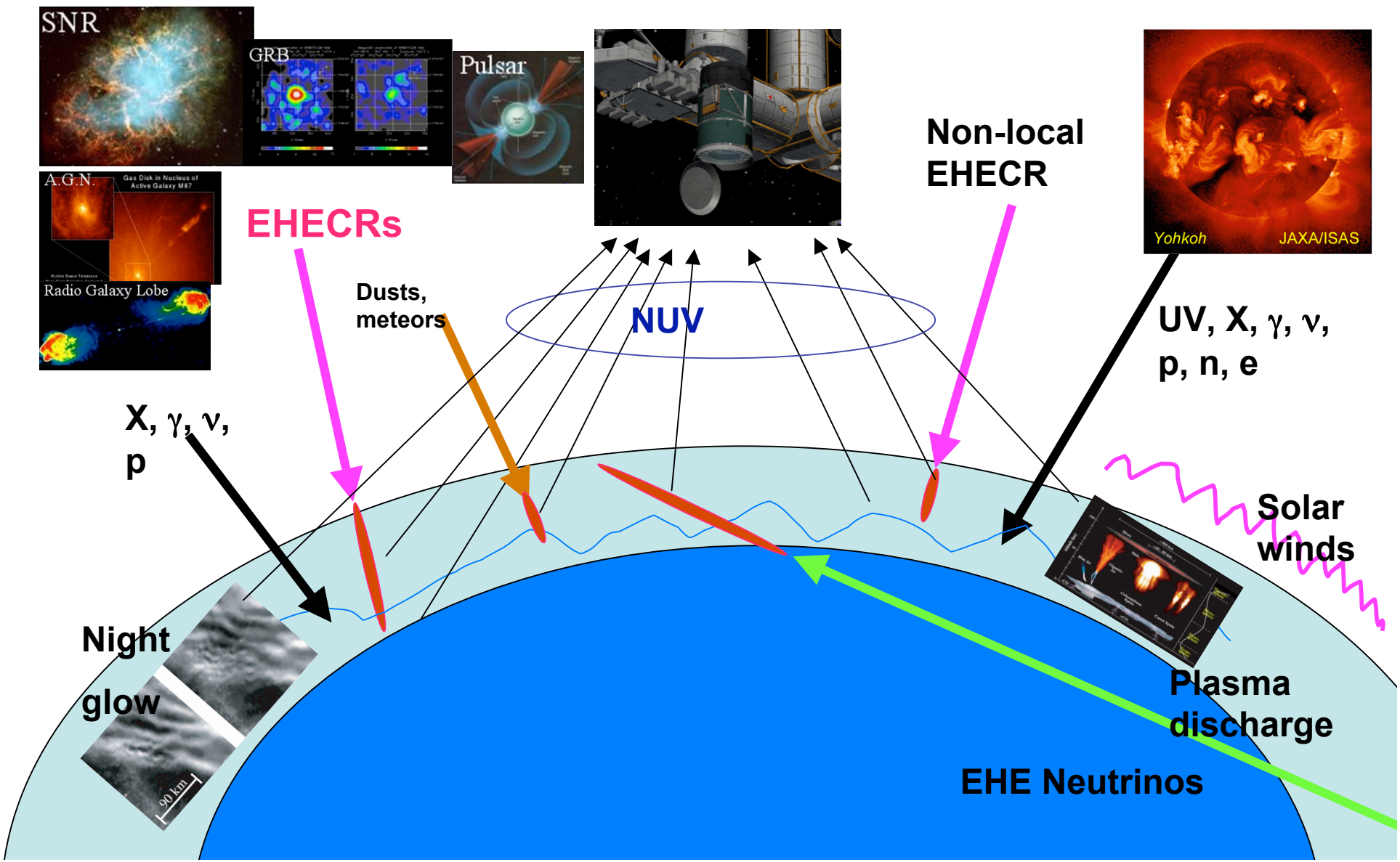
Earth Atmosphere as a Detector

Looking Down from Space is **much better** than Looking up from the Ground; also duty cycle 20-25% instead of 13%.

- Smaller Mie Scattering
  - ~20%
- Low Cloud (2~3km) in night
  - Most of the showers reaches the maximum above the cloud
- Smaller Absorption (loss)
  - ~ 0.3, and uncertainty < 0.05
  - Large absorption/uncertainty (loss) X 10 ~100 for ground fluorescent observatory
- Well determined Distance to a Shower
  - Observation altitude : ~400km
  - Shower altitude : ~10km



JEM-EUSO
= Astronomical Earth Observatory



ESA-EUSO, the shuttle and Columbus

From EUSO to JEM-EUSO

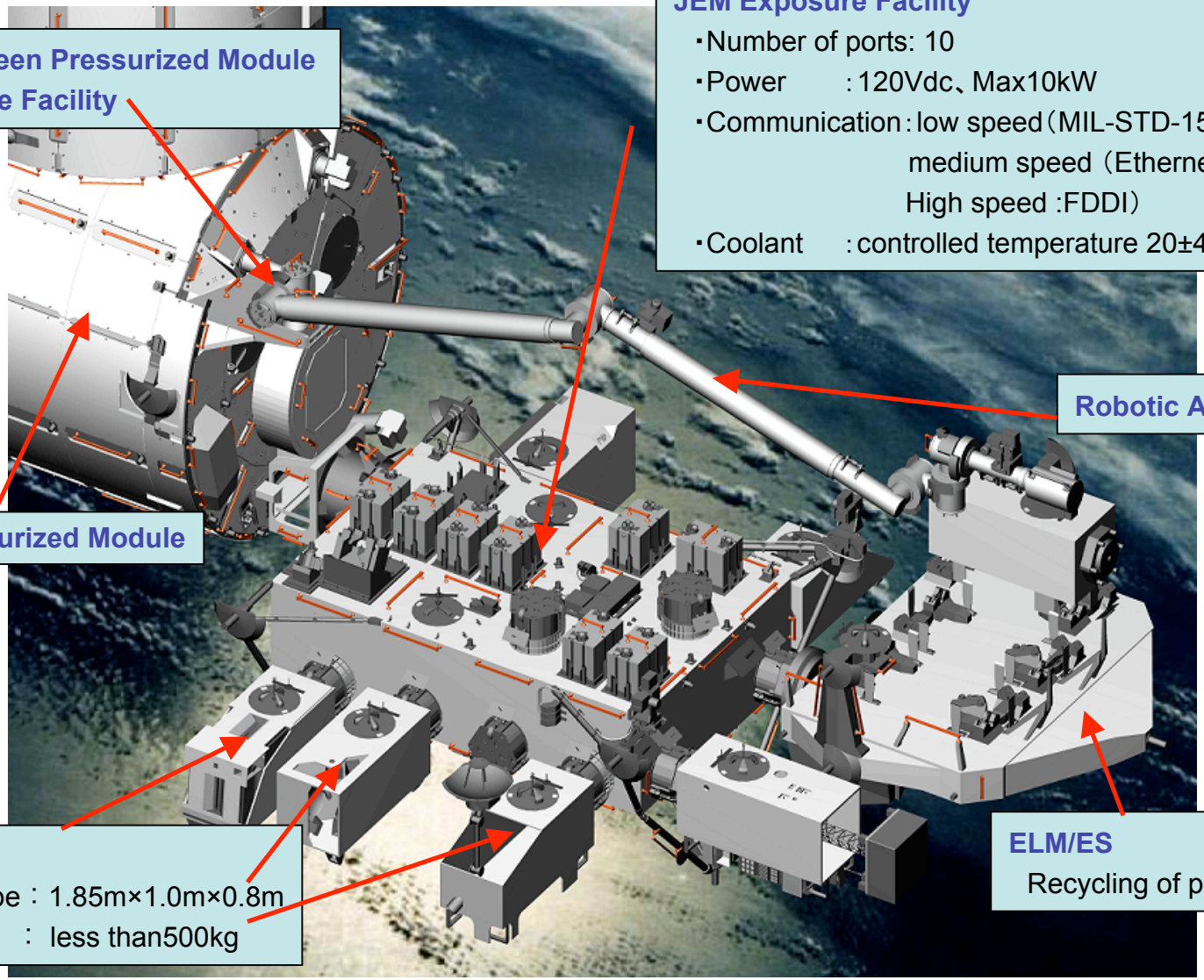
EUSO @ ESA selection 2000 -

- Europe：Phase-A Completed
  »By July 2004
- Japan：JAXA and RIKEN funded concept studies 1998-06
- USA： End-to-End MIDEX $36M

Collaboration:（9 nations）
Italy, France, Switzerland
Germany, (Portugal),
(Spain)
Japan, USA, (Brazil),
Russia, Korea, Mexico

ESA/ESTEC meeting, October 2005,
Plan changed due to large stopping factors:
(i) USA changed the ISS plan and the usage of STS,
(ii) Budgetary troubles at D/S of ESA for Columbus EUSO
ESA D/HME and NASDA worked together to use (JEM EF) and HTV/H2B for EUSO (Phase-A extension 2004).
→ **ESA bankrupt announces Cosmic Vision**
Japan and USA and a part of Europe made JEM-EUSO Working Group. It was authorized by JAXA/ISAS;
Europe re-organized, and Russia/Korea/Mexico joined.

Outline of JEM Exposure Facility



JEM Exposure Facility
- Number of ports: 10
- Power : 120Vdc、Max10kW
- Communication : low speed（MIL-STD-1553B）
  medium speed（Ethernet）、
  High speed :FDDI）
- Coolant : controlled temperature 20±4℃

Airlock between Pressurized Module and Exposure Facility

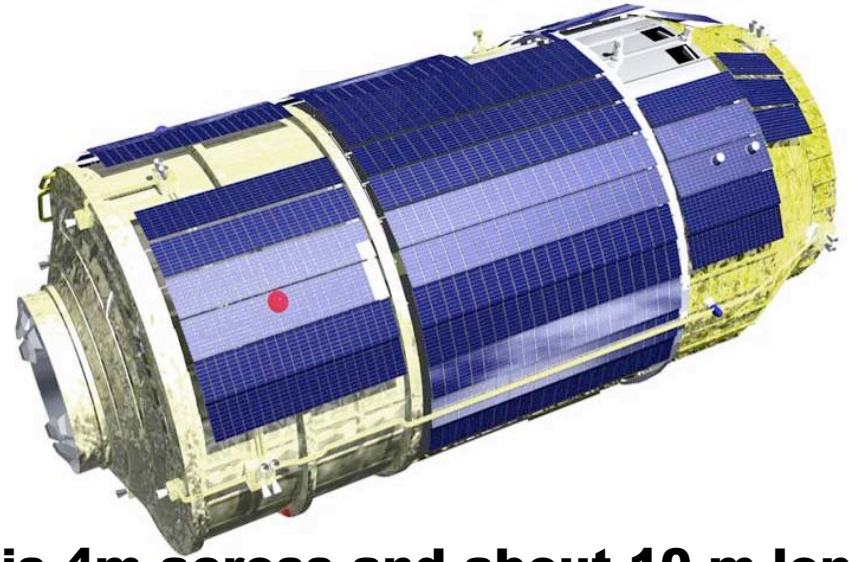
Robotic Arm

Pressurized Module

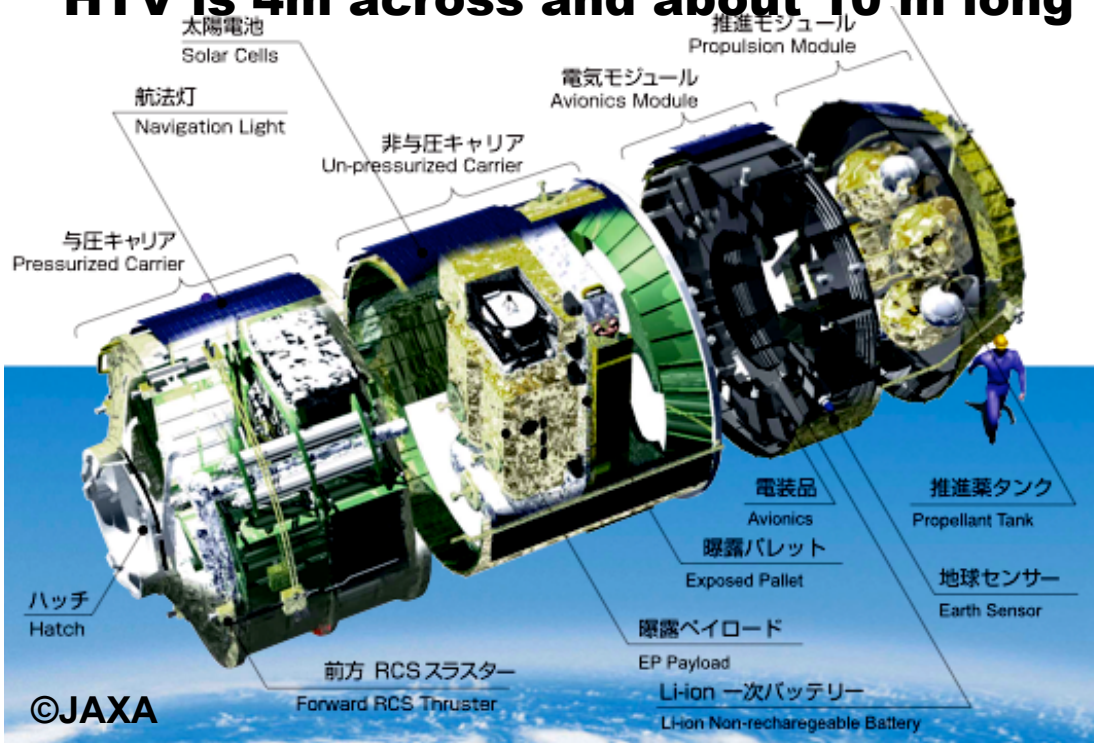
Payload
standard envelope：1.85m×1.0m×0.8m
mass ： less than500kg

ELM/ES
Recycling of payload

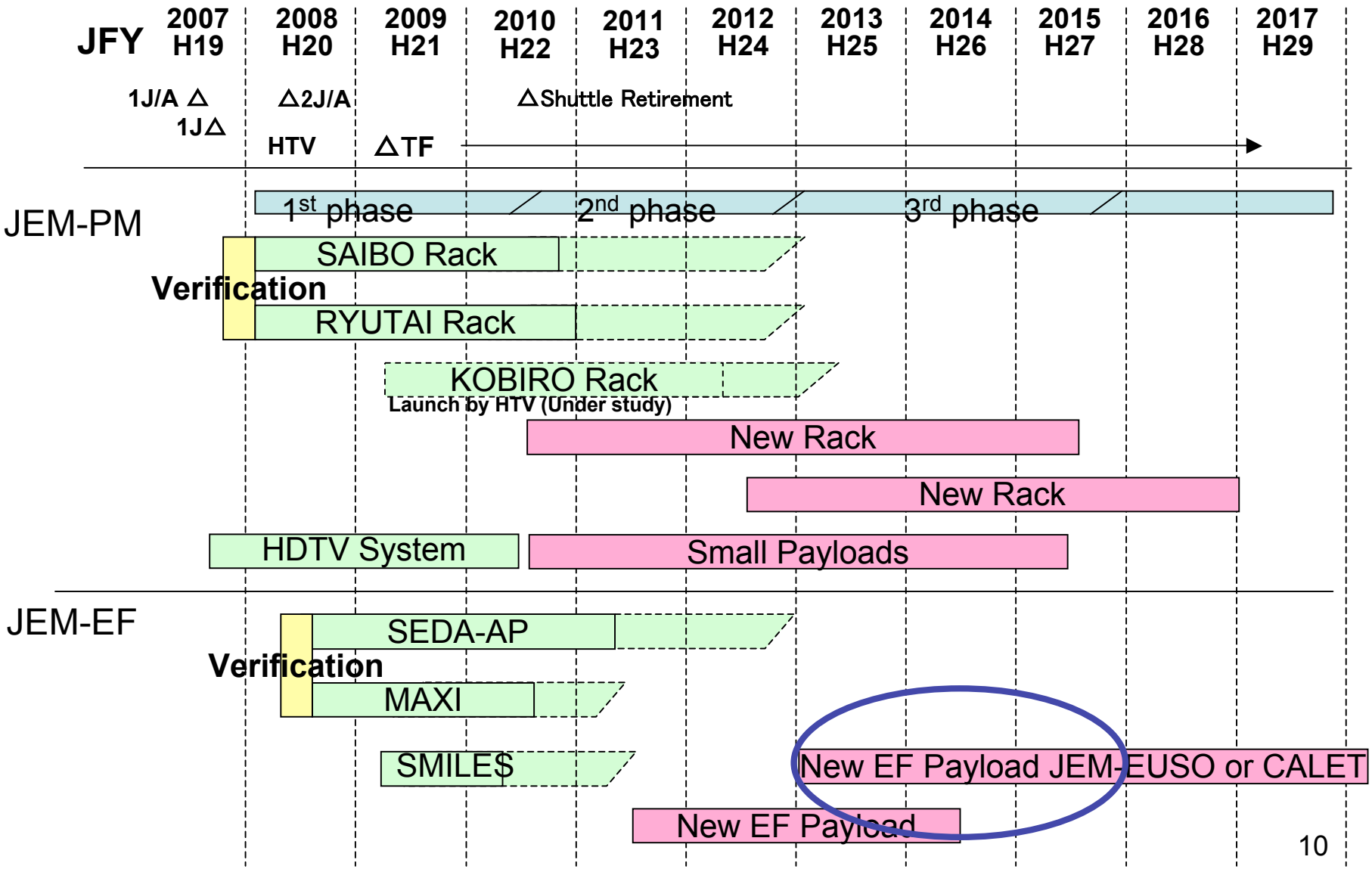
H-II Transfer Vehicle (HTV)



HTV is 4m across and about 10 m long



Resources of the 2nd phase JEM utilization by JAXA (under study)

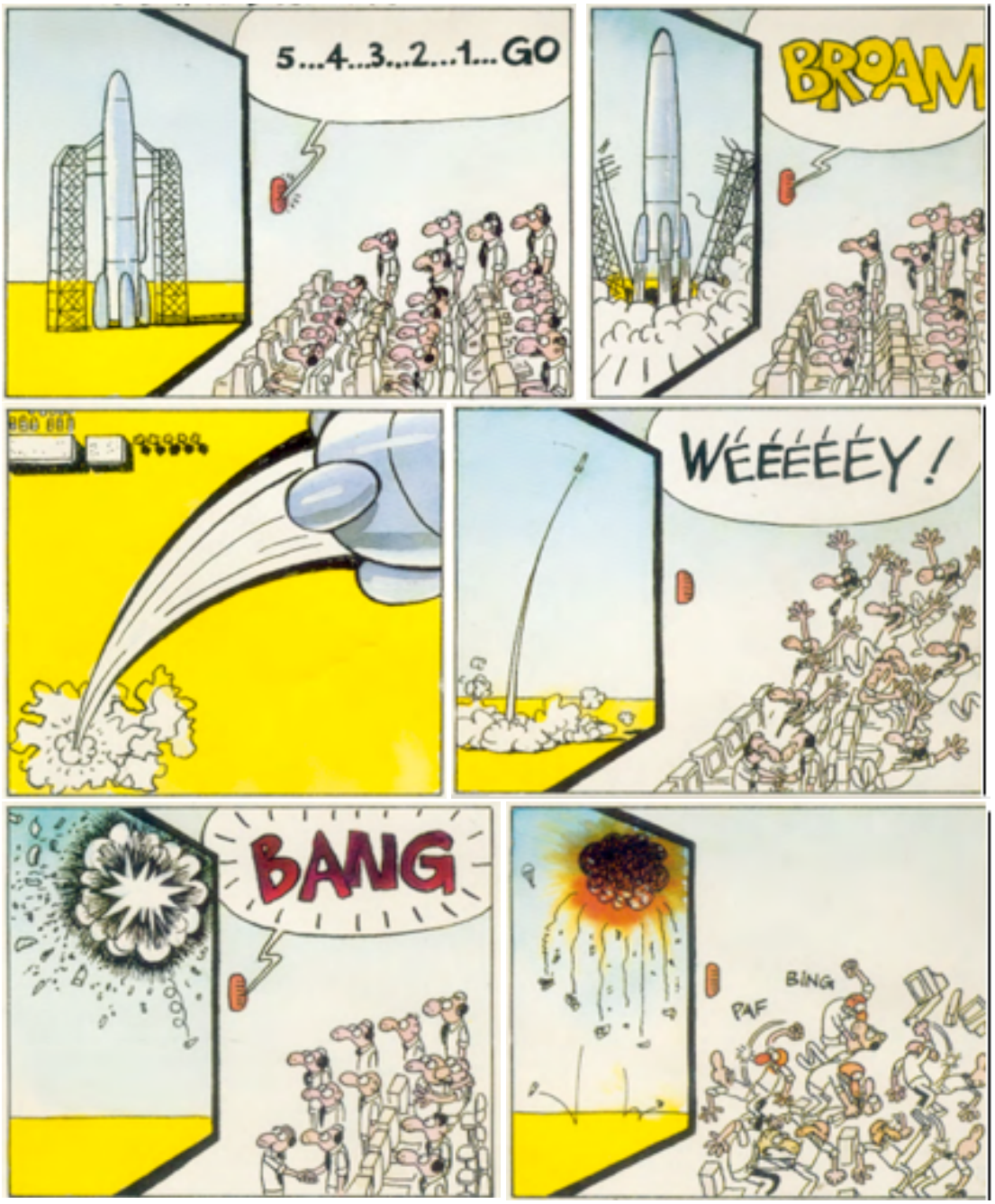


Parameters of Mission

• Time of launch:	year 2013
• Operation Period:	3 years (+ 2 years)
• Launching Rocket :	H2B
• Transportation to ISS:	non pressurized Carrier of H2 Transfer Vehicle (HTV)
• Site to Attach:	Japanese Experiment Module/ Exposure Facility #2
• Height of the Orbit:	~430km
• Inclination of the Orbit:	51.6°
• Mass:	1896 kg
• Power:	998 W (operative), 344 W (non-operative)
• Data Transfer Rate:	297 kpbs

Important calendar (forthcoming)

- August 2009
  - Selection for the Later Phases
- Year 2009-2012
  - Production, Assembly & Verification
- Expected launch by HIIB-HTV in 2013


5...4...3...2...1... GO
BROAM
WÉÉÉÉÉY!
BANG
PAF
BING

1) **No need for stereo: intensity info is stable ($1/r^2$ effect)**

2) **Works as a TPC: x-y given by the 200000 (or more) pixels and z by the time. The time is relative to the Cerenkov flash. If on earth, OK;**
   if on a cloud, 3 methods:
   a) Autonomous
   b) IR Camera
   c) Lidar
   +the slow mode

3) **Very accurate instrument: PMTs efficencies will be known to better than 2% and fluo yield determined to better then 5%**

Science Objectives

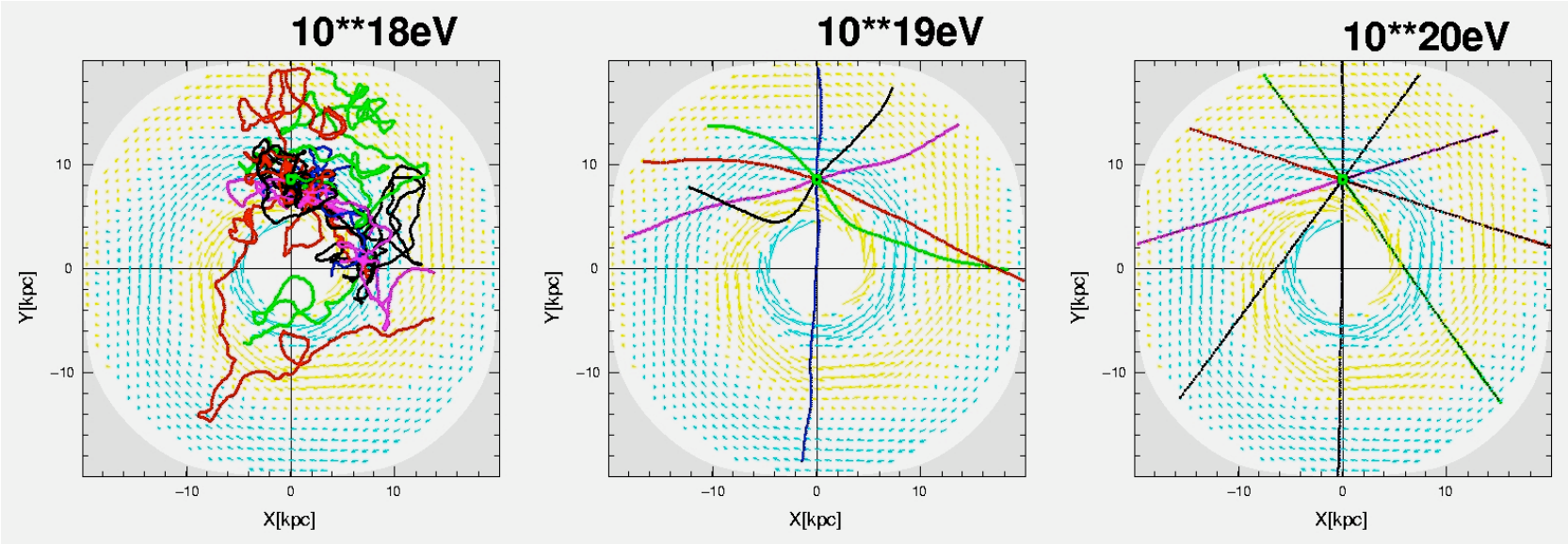
Fundamental Objective:

Extreme energy astronomy by particle channel

Exploratory Objectives

- Detection of extreme energy neutrinos to examine extra dimensions in super-gravity/string theory
- Examination of quantum gravity, dark matter and quantum limit at super-LHC energies to m > 300 TeV/c^2
- Global observations of night-glows, plasma discharges and lightings

$E > 10^{20}$ eV particles are not tilted by Galactic Mag Field

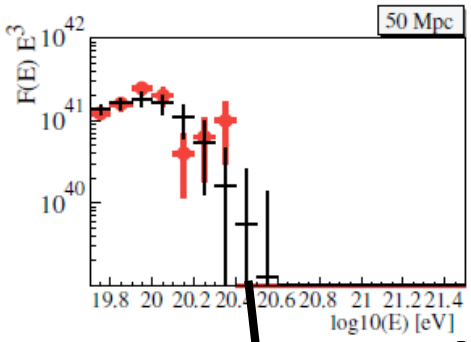


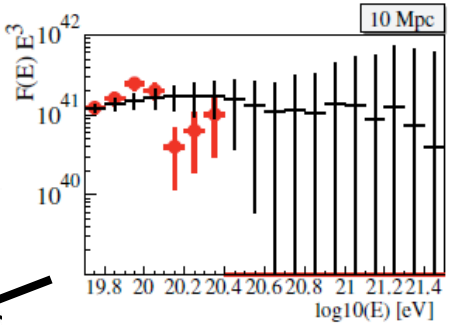
well done **al dente** **not cooked**

Specify origins by the arrival direction:

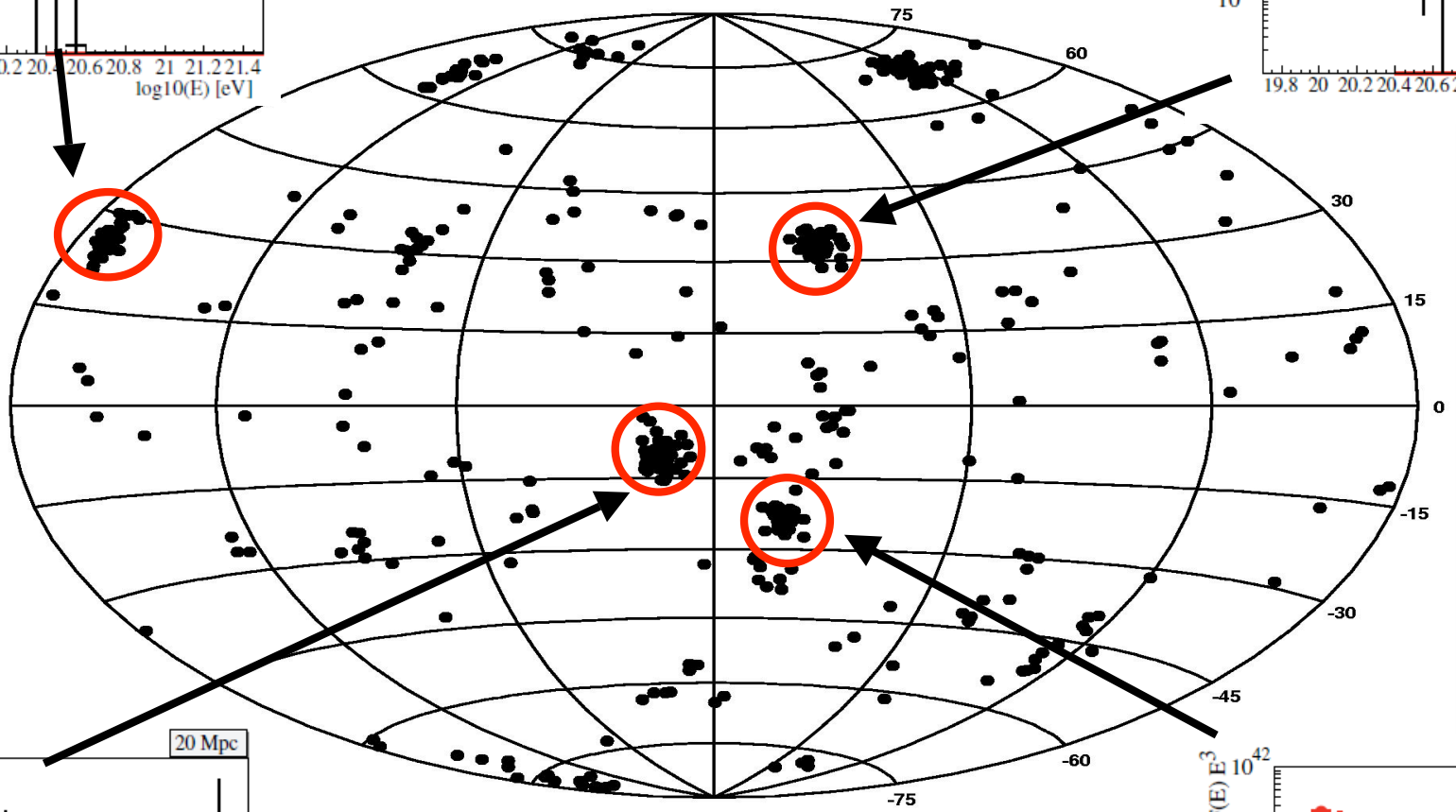
Particle Astronomy

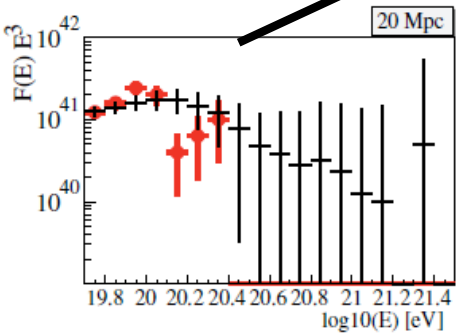
Particle Astronomy Simulation

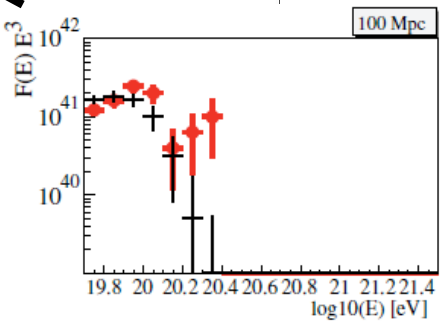




If we get >1,000 events,





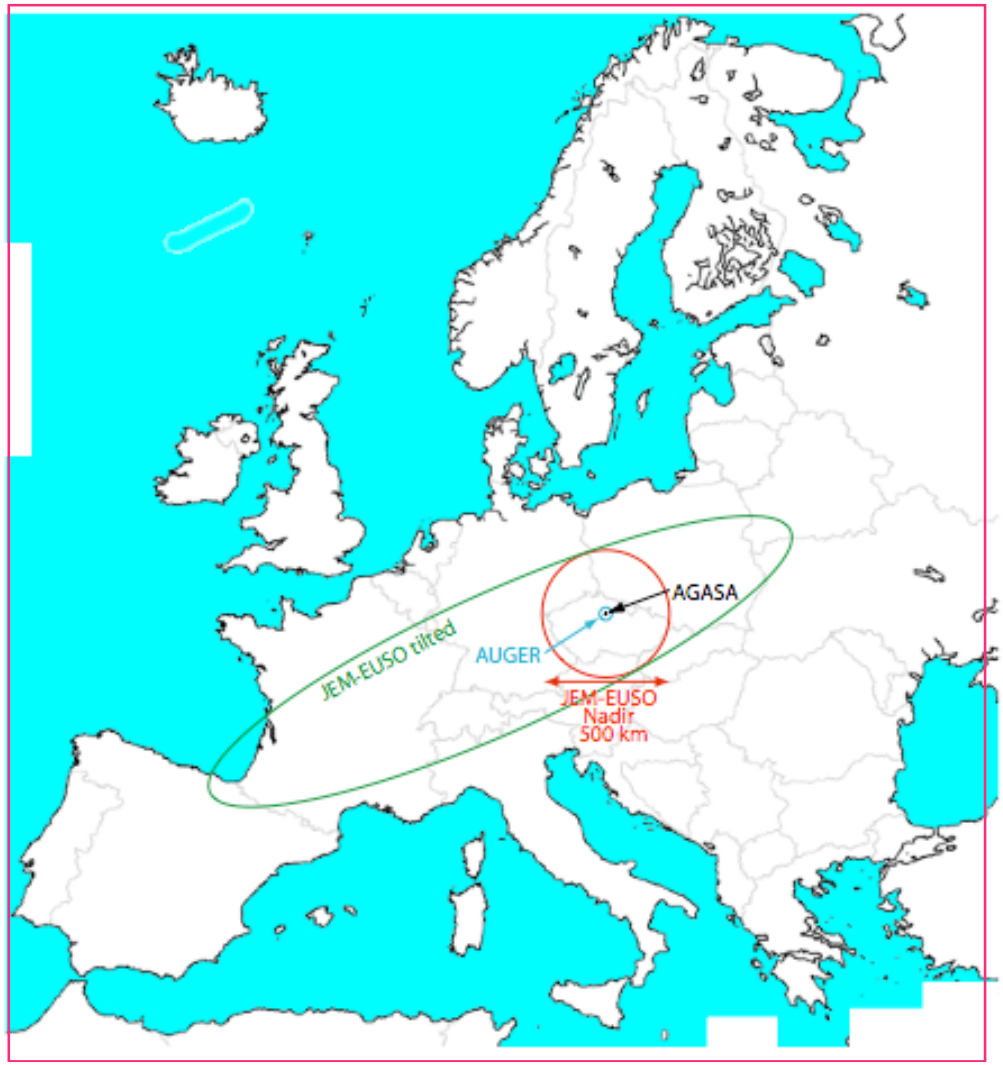


- 1,000 events : E>7x10^{19}eV
- Several dozen clusters are expected
- All sky coverage

AGASA and AUGER have directions

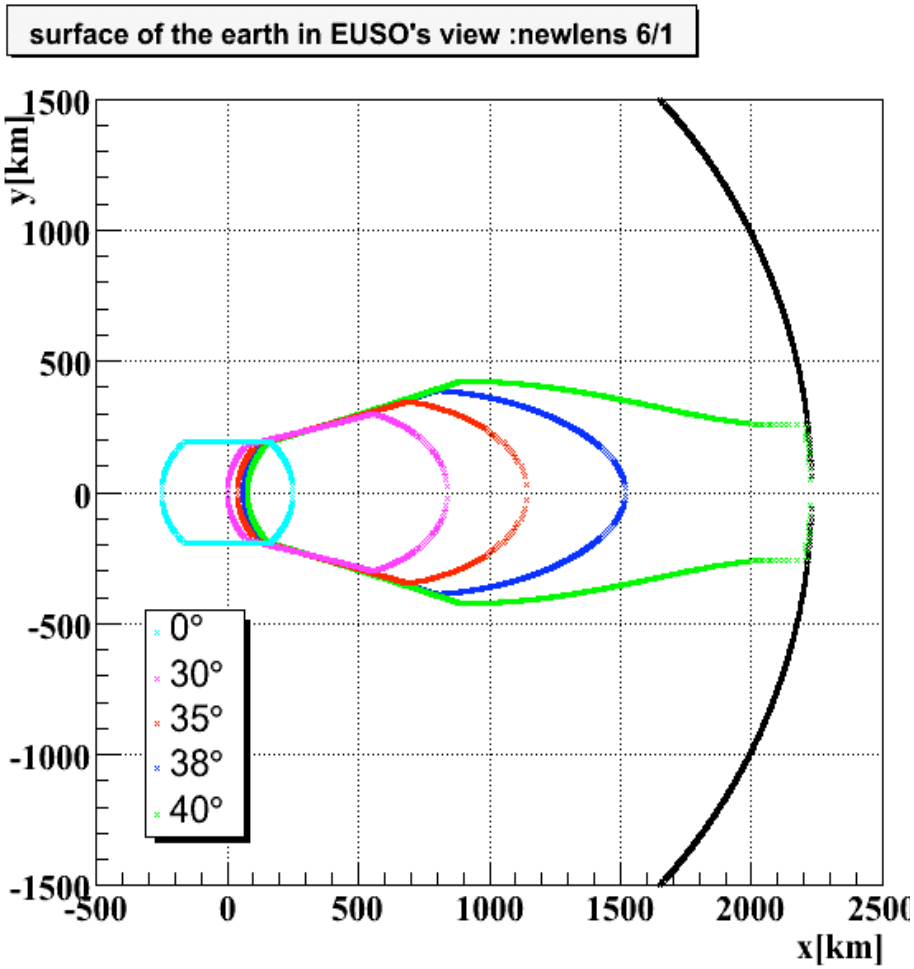
JEM-EUSO FoV

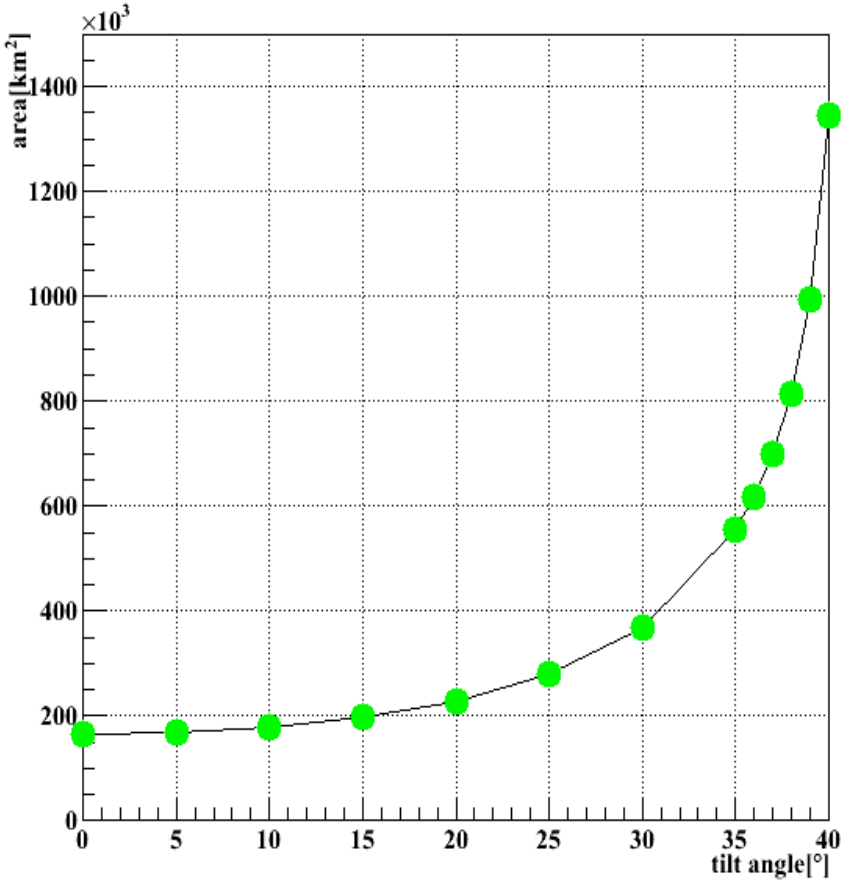
EUSO ~ 1000 x AGASA ~ 30 x Auger
EUSO (Instantaneous) ~ 5000 x AGASA
(nadir mode) ~ 150 x Auger



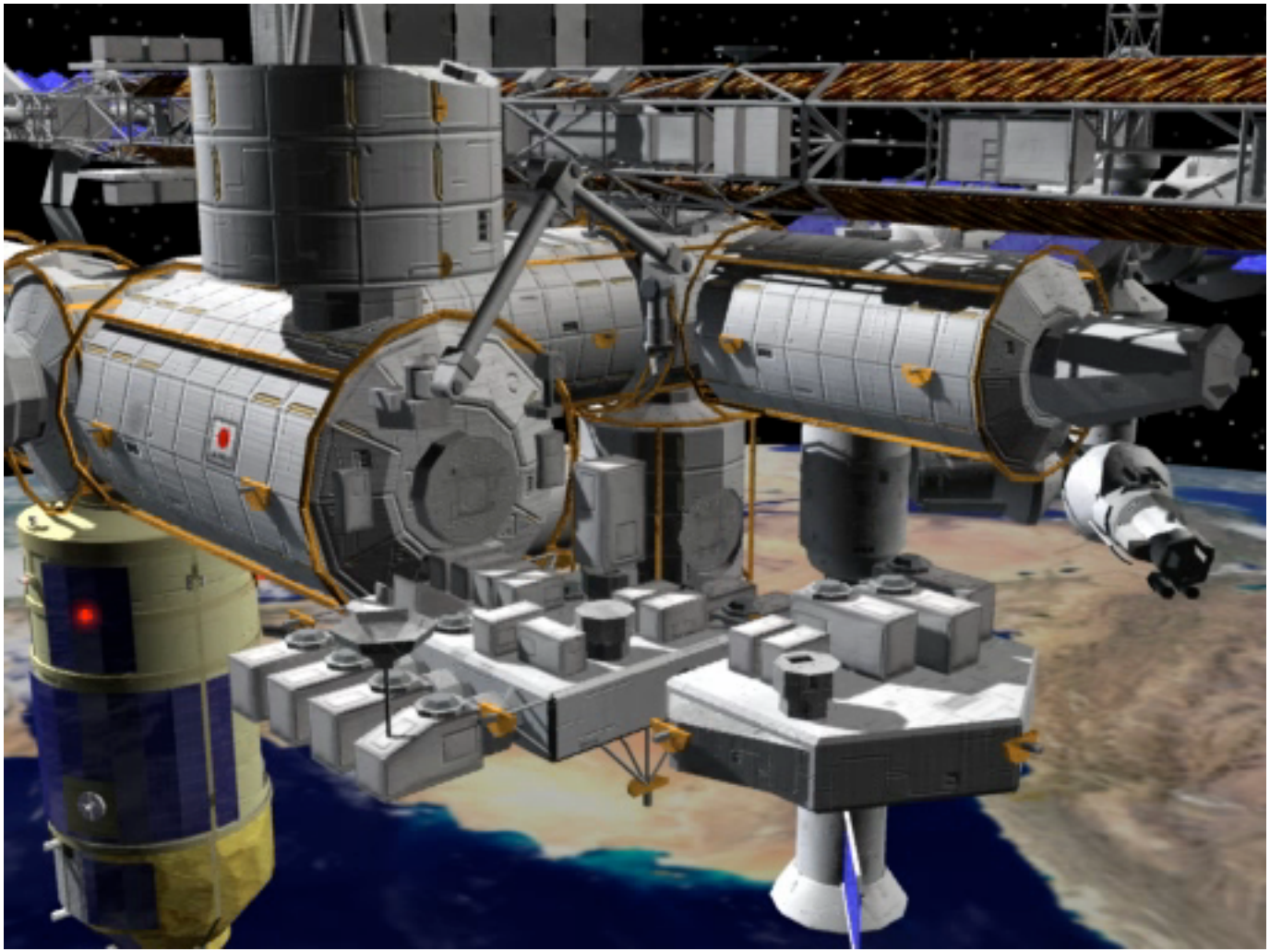
Euso nadir: 2 years
Euso tilted: 3 years

Tilt Mode FOV (3years)





JEM-EUSO, HTV, Kibo



Science Objectives

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Extreme energy astronomy by particle channel

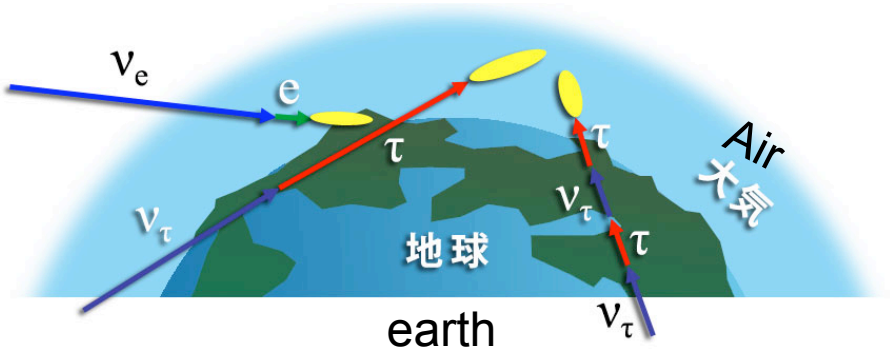
Exploratory Objectives

- Detection of extreme energy neutrinos to examine extra dimensions in super-gravity/string theory
- Examination of quantum gravity, dark matter and quantum limit at super-LHC energies to m > 300 TeV/c^2
- Global observations of night-glows, plasma discharges and lightings

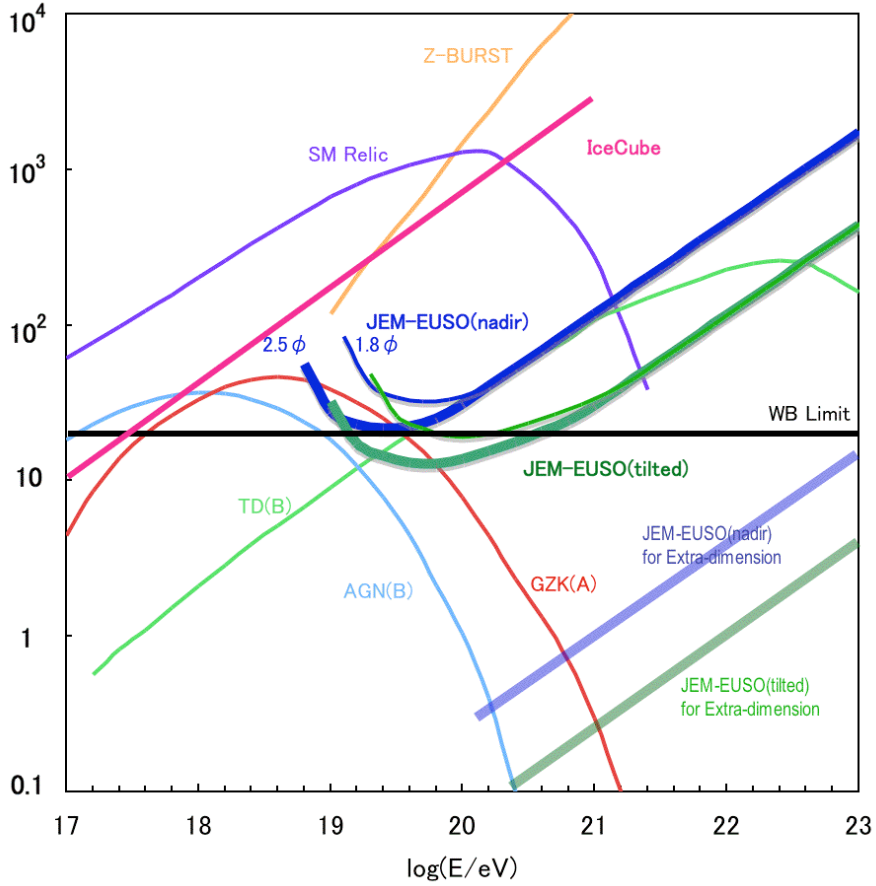
ニュートリノ

Exploratory objective 1:

Sensitivity for neutrino (preliminarv: TBC)



100 times even rate in the case of extra dimension



*Hundreds of neutrino events

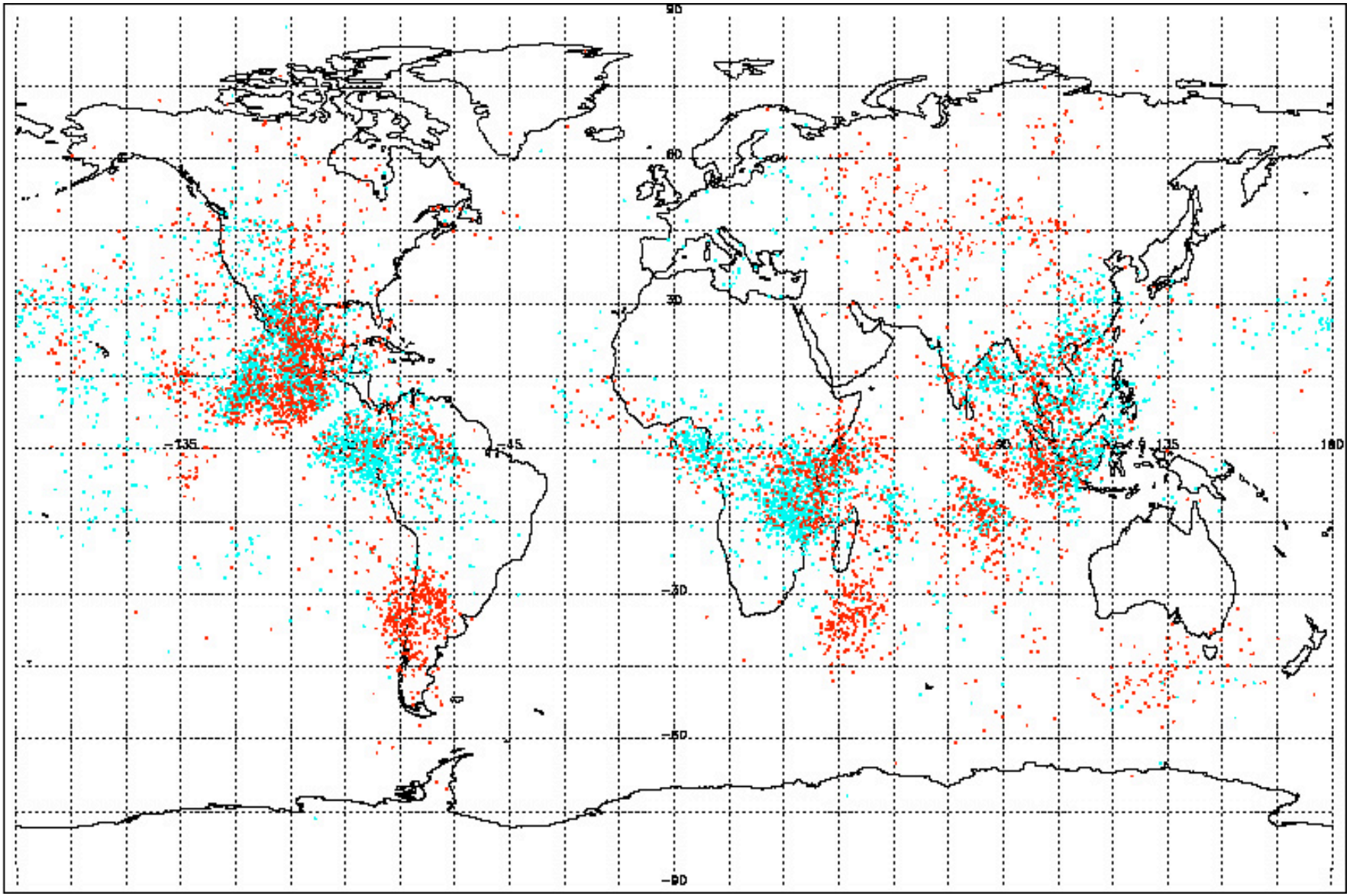
大気圏

Exploratory objective 2:
Atmospheric Sciences

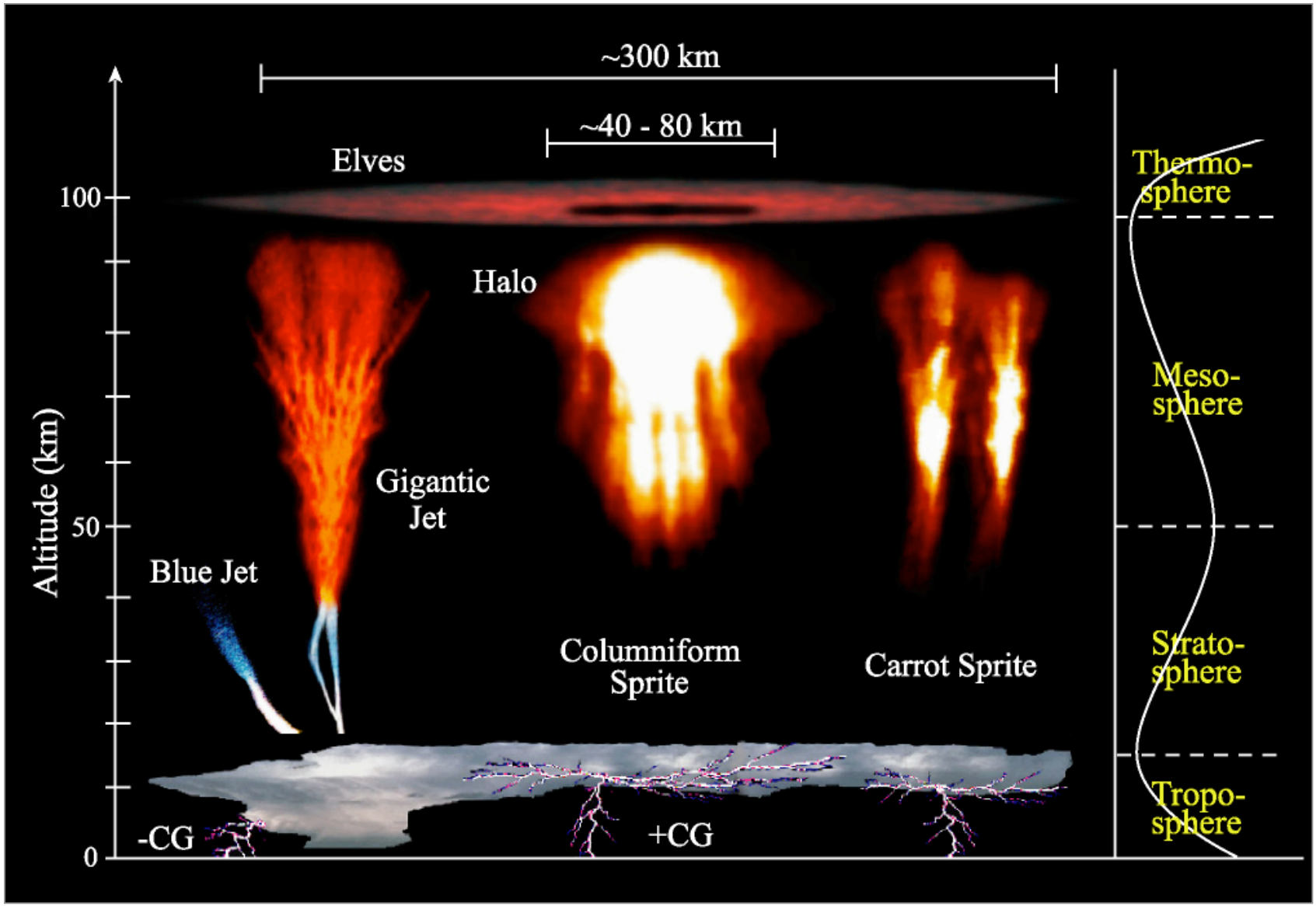
- Lightning, TLEs
  - Nadir Observation of Lightning and TLEs
  - Global Survey of TLEs
  - Correlation with CR
  - New adaptive data acquisition does not saturate ($photons_{AS} = 10^6\ photons_{shower}$)
- Night Glow, Plasma Bubbles
  - Global Imaging of O_2 Hertzburg I night glow
  - Formation Mechanism of Plasma Bubbles
  - Energy, Momentum, and Matter transfers in upper atmosphere
- Clouds
  - Global survey of cloud top hight
- Meteors: ablation studies (slow mode)

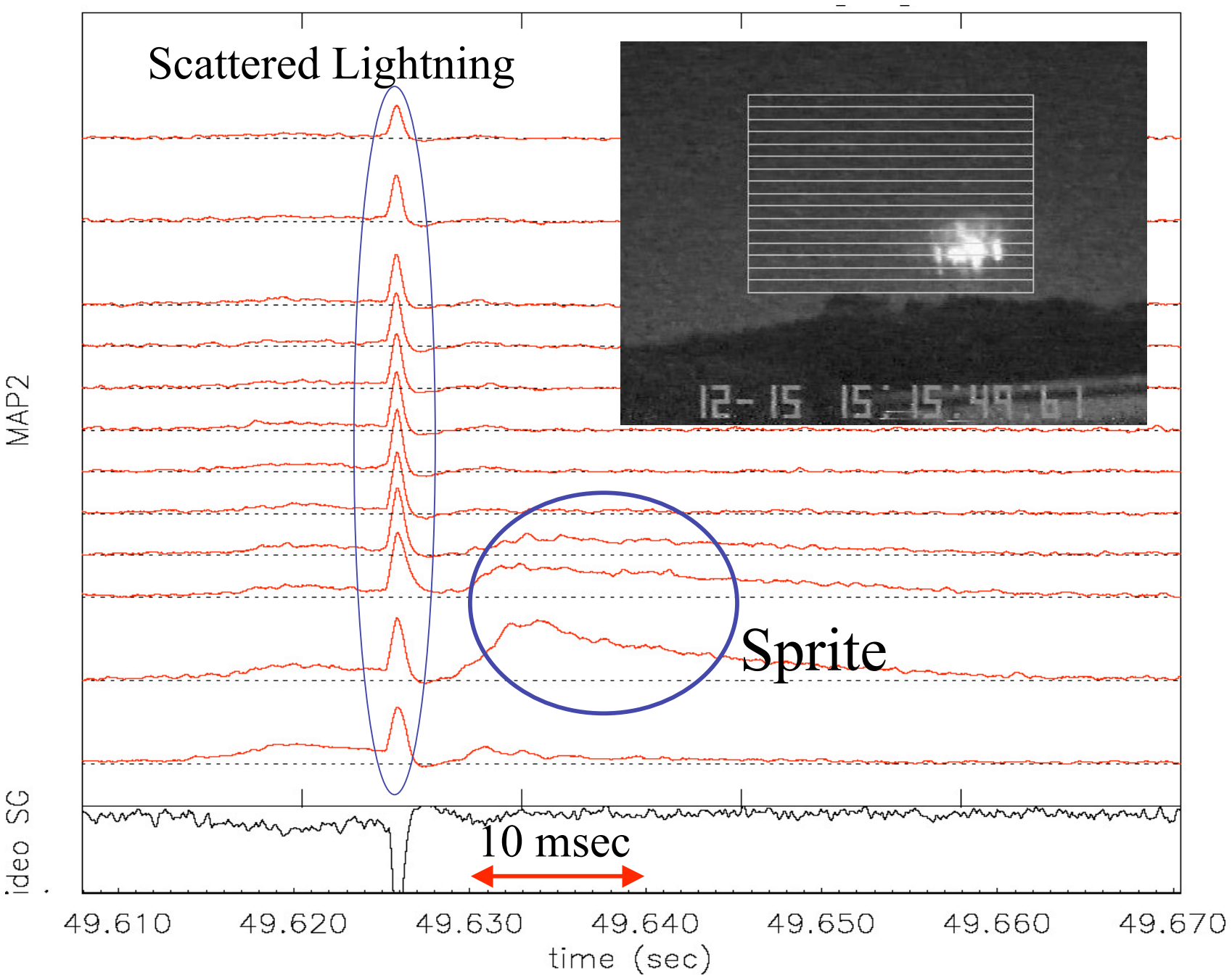
Bright, is not it?

Two days in August



Luminescence phenomena associated with lightning




Scattered Lightning
Sprite
10 msec
MAP2
ideo SG
49.610
49.620
49.630
49.640
49.650
49.660
49.670
time (sec)

Exploratory objectives: meteors

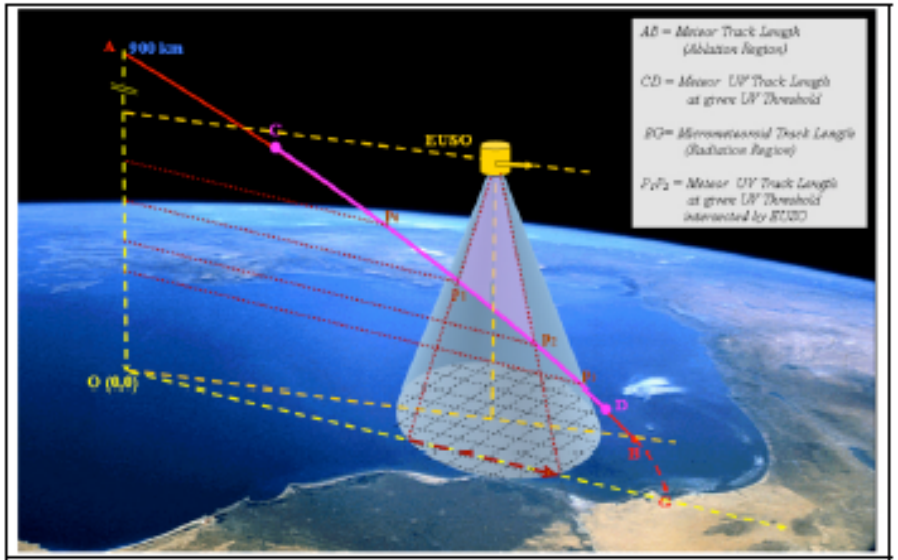


Figure 6.5.8-2 *The path of a meteor in the EUSO field-of-view*

τ ~ seconds

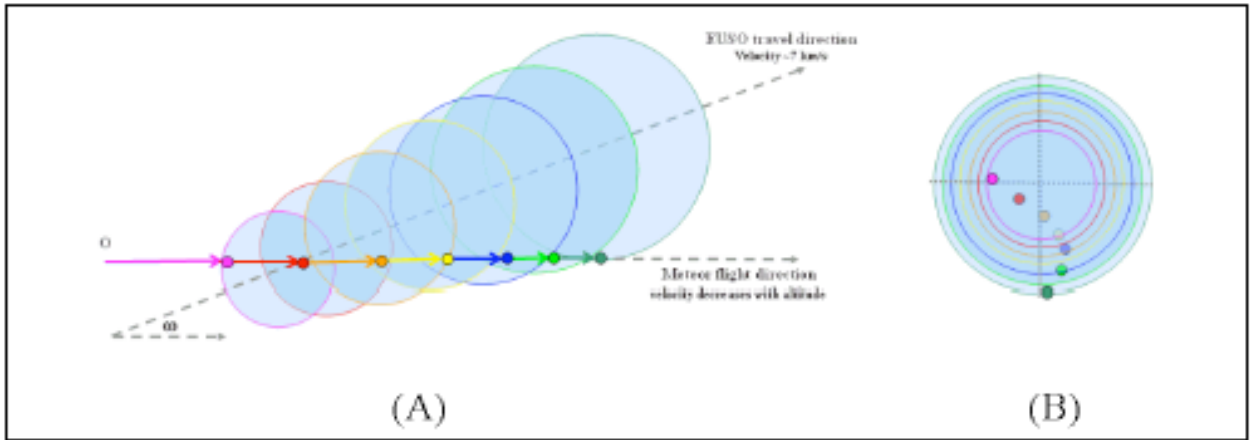
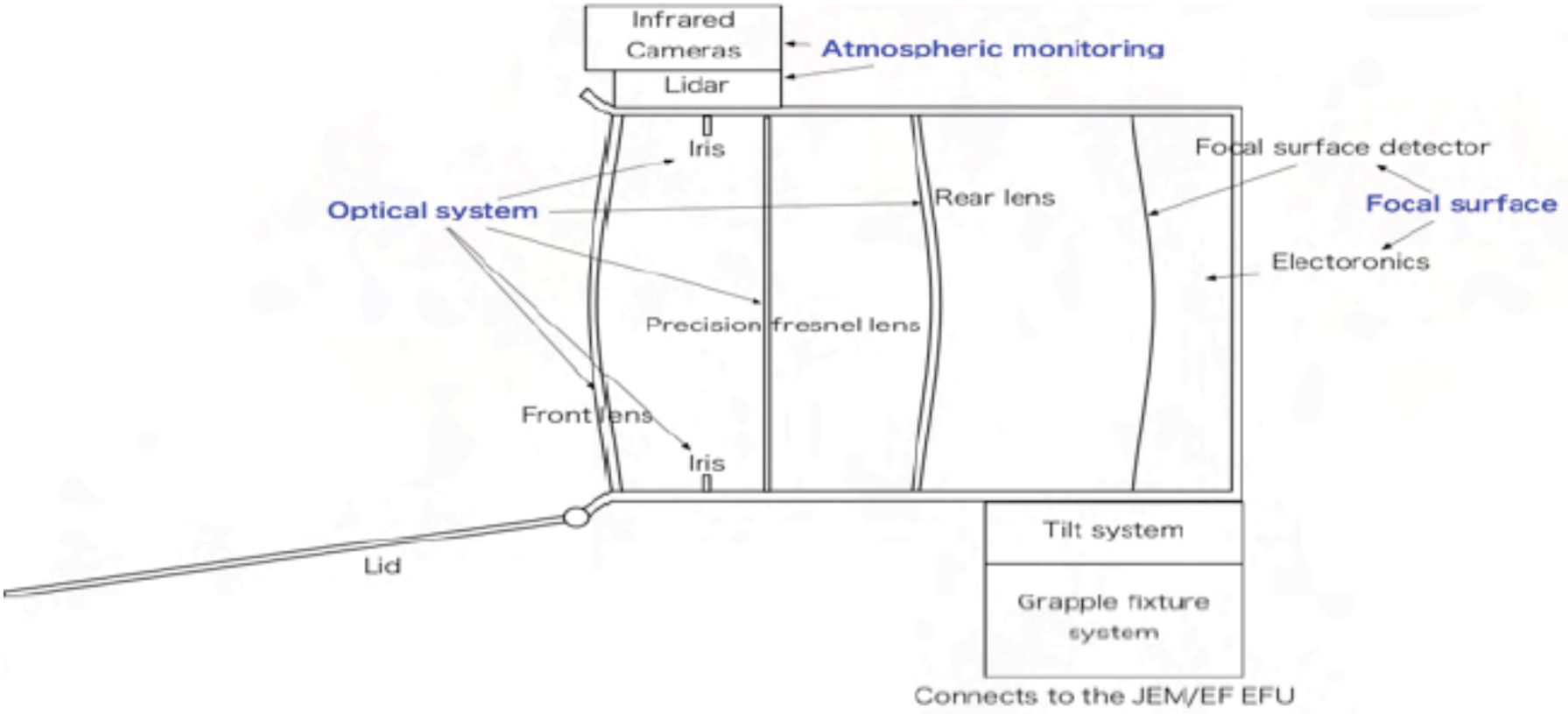
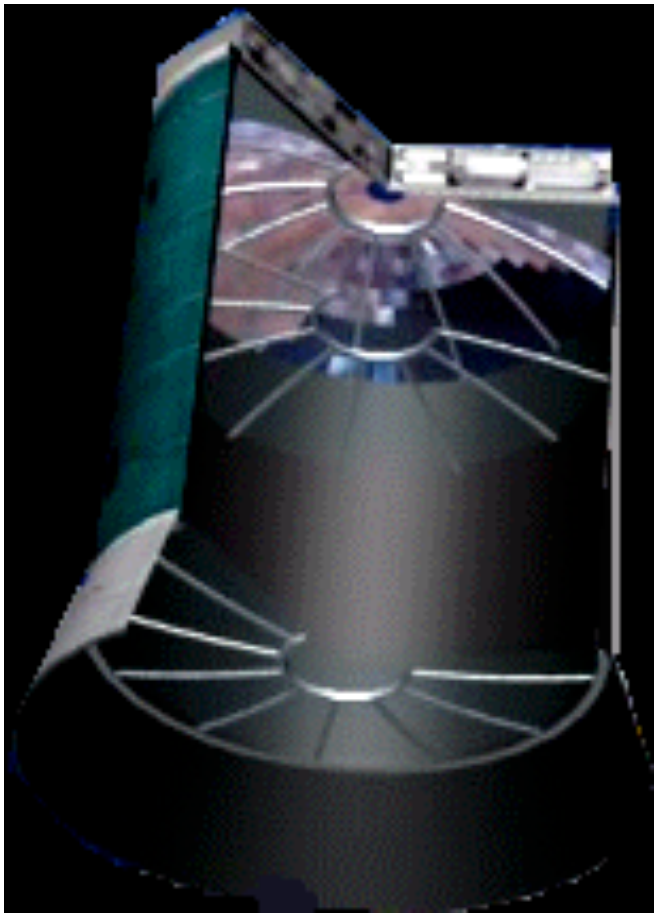
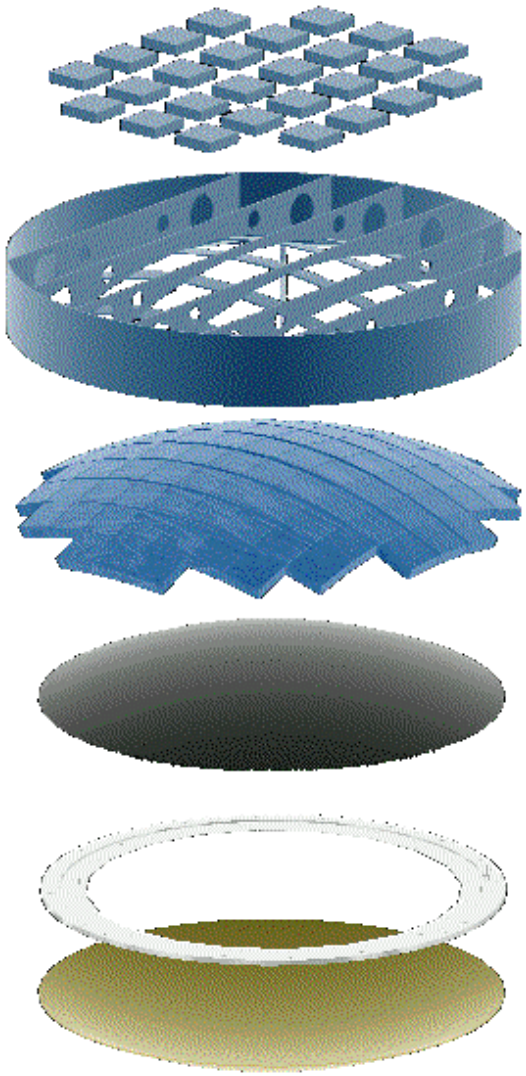


Figure 6.5.8-3 *EUSO meteor observation. (A) - Different frames are taken at constant time steps Δt and are represented by sections of the "cone" with different colors (first frame is pink, last is green). The sections move along the EUSO travel direction and are equally spaced because of the constant velocity (~7 km/s). The sections increase their diameter with time because they refer to progressively lower "cone"-meteor intersection altitude. Meteors velocities at each time are represented by colored vectors whose module decrease with time (altitude). The meteor "spots" moves with curved trajectories on the "observation cone" projection shown in the (B) panel.*


Infrared Cameras
Atmospheric monitoring
Lidar
Iris
Focal surface detector
Optical system
Rear lens
Focal surface
Electoronics
Precision fresnel lens
Front lens
Iris
Tilt system
Lid
Grapple fixture system
Connects to the JEM/EF EFU

JEM-EUSO Telescope Structure





Electronics : LAL + JAXA + Konan

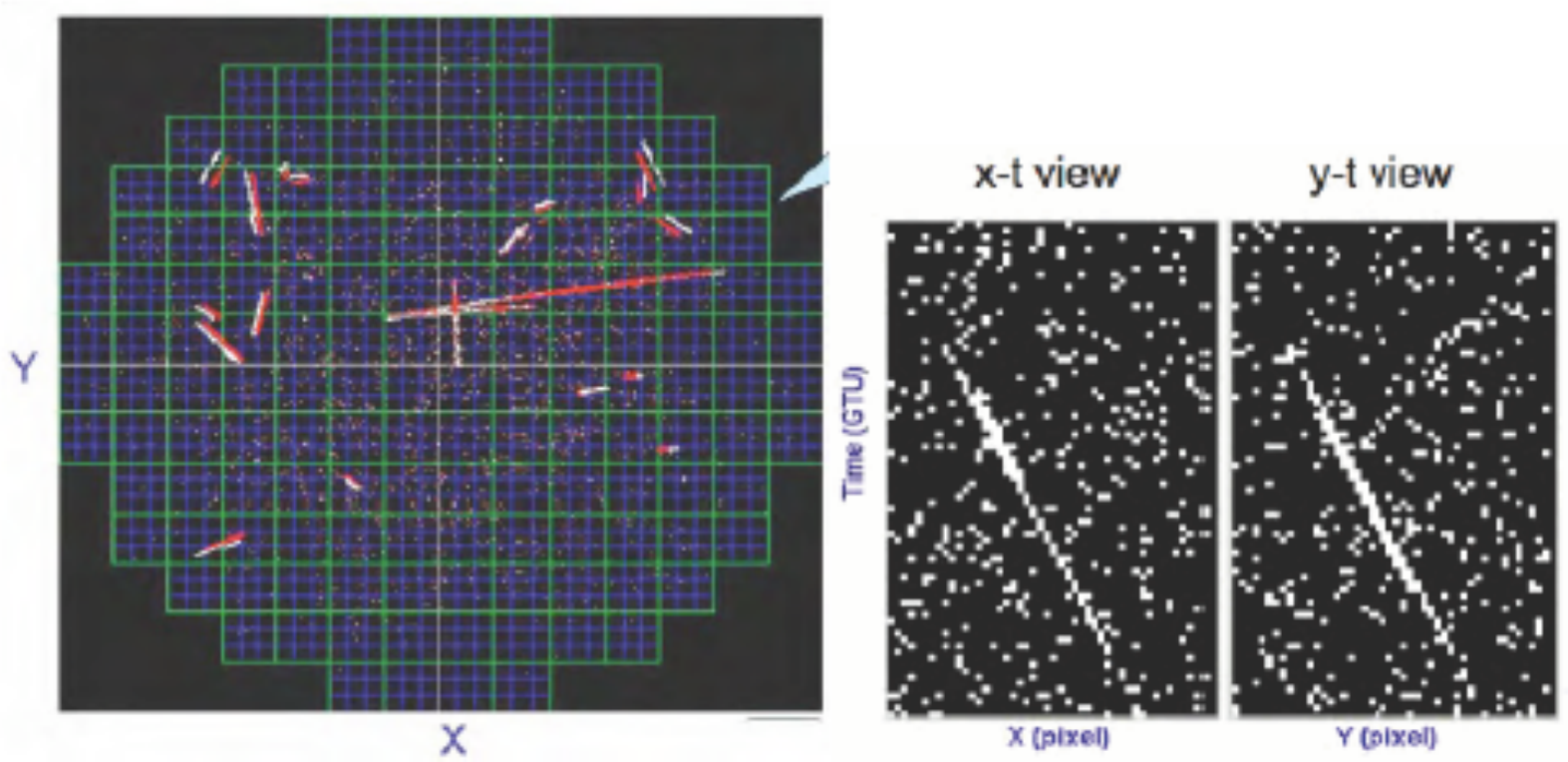
Structure : Riken + Frascati

Focal Surface : Riken + (Munich?)

Optics : USA + Riken

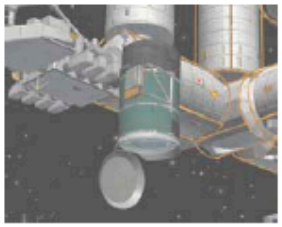
Simulation : Saitama U. + France + Tuebingen

Calibration : APC + Aoyama U.

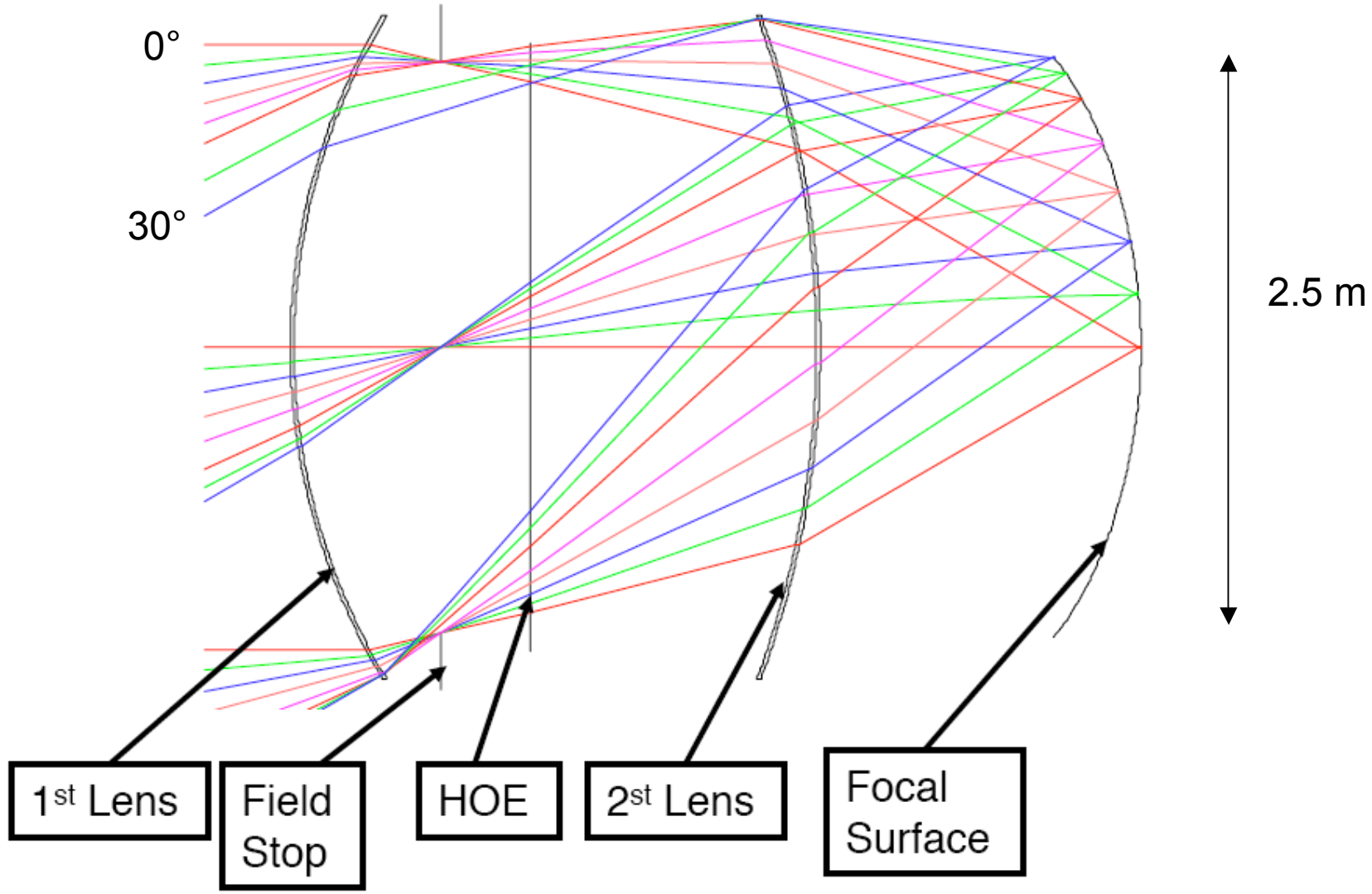

Y
X
x-t view
y-t view
Time (GTU)
X (pixel)
Y (pixel)

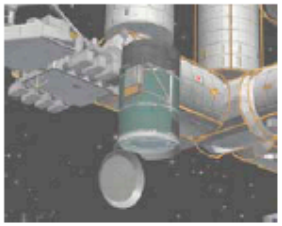
European Countries

France	Calibration, (IR camera), Detector, Calibration, Simulations, Theory
Germany	Detectors
Italy	Third Trigger Board, MPU, System Software
Switzerland	Lidar system, Atmospheric Monitoring
Spain	Ground segments, Interface software, Analysis software

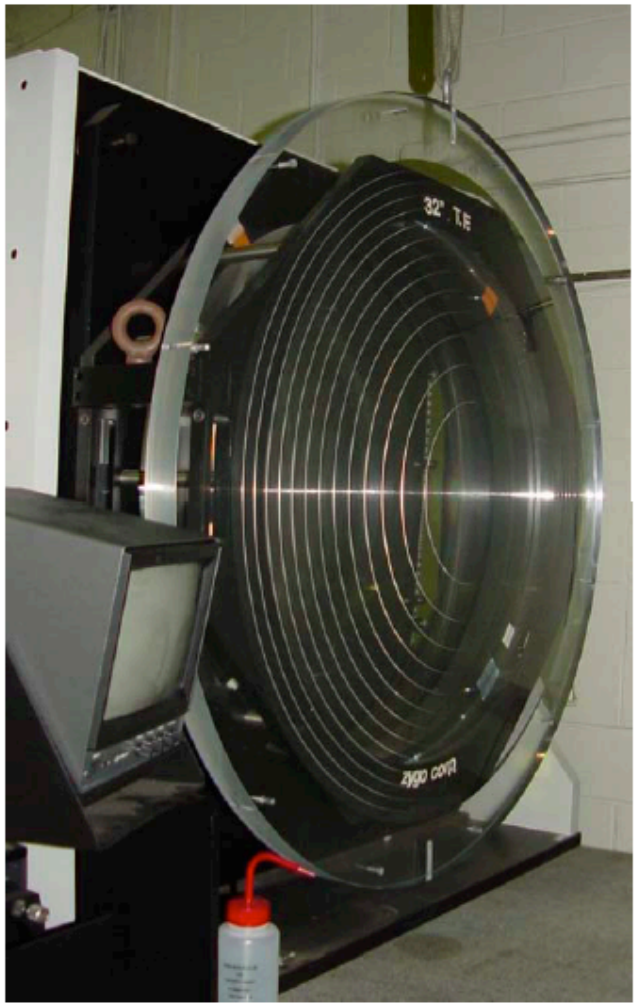


60° Design with CYTOP

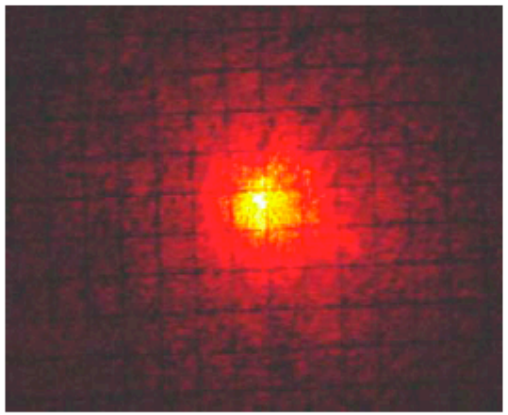




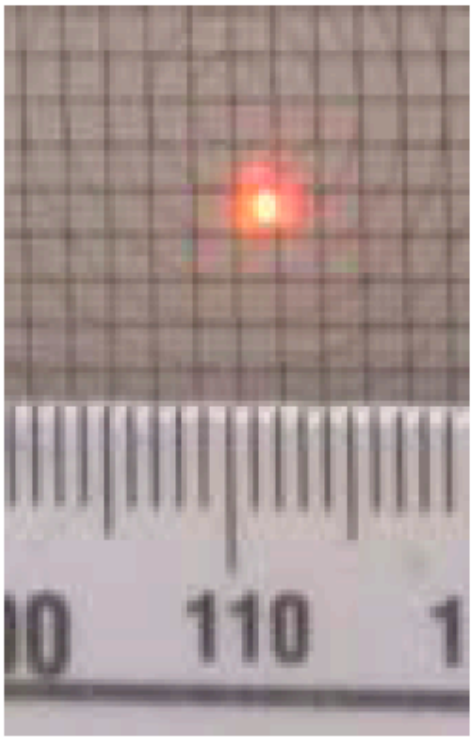
Diamond Turning and Polishing Fresnel Lenses



Phase A lens on 32 inch Zygo



Before
(PMMA)

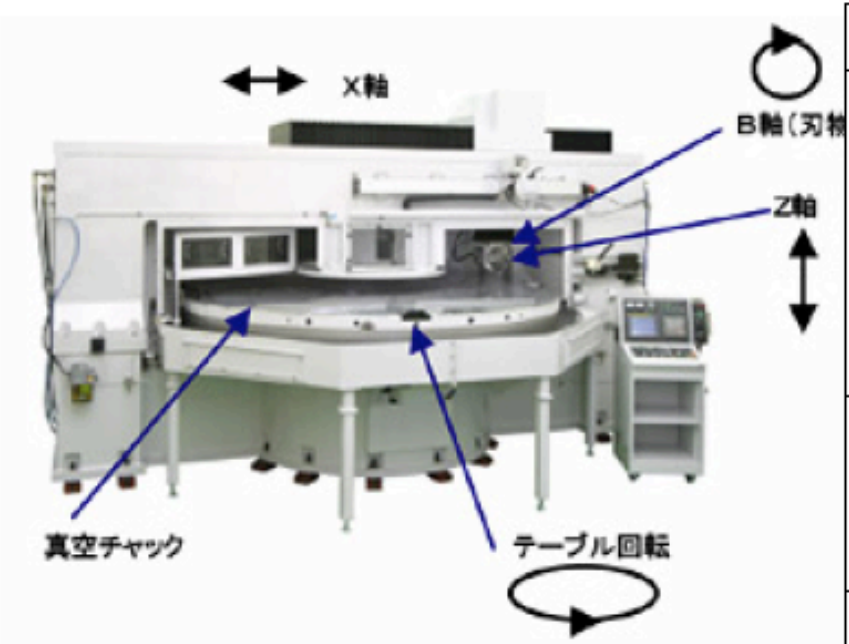


After
(CYTOP)

USA - JAPAN

instrument

2.UTD-3400
-Specifications-

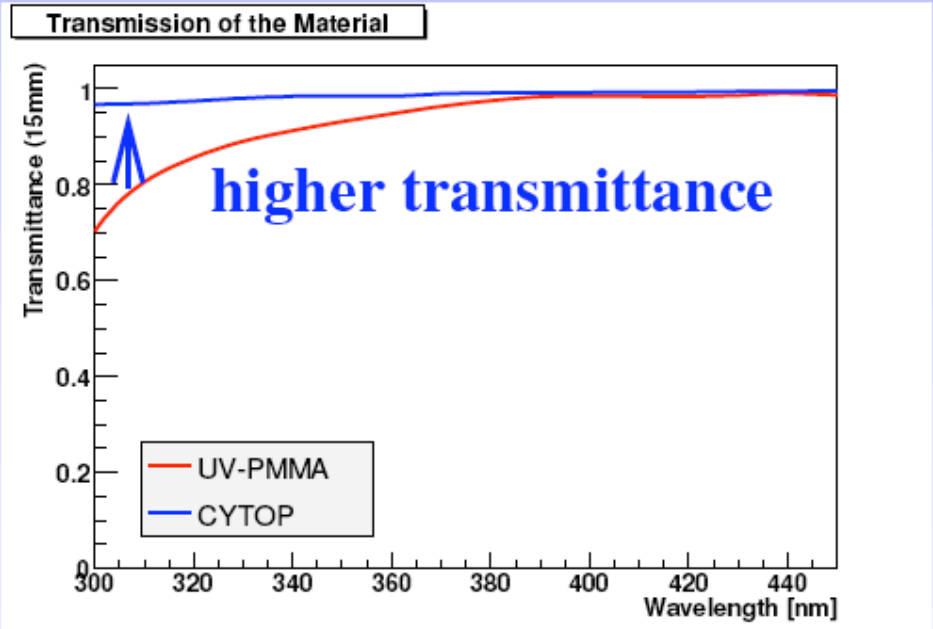


Toshiba lathe

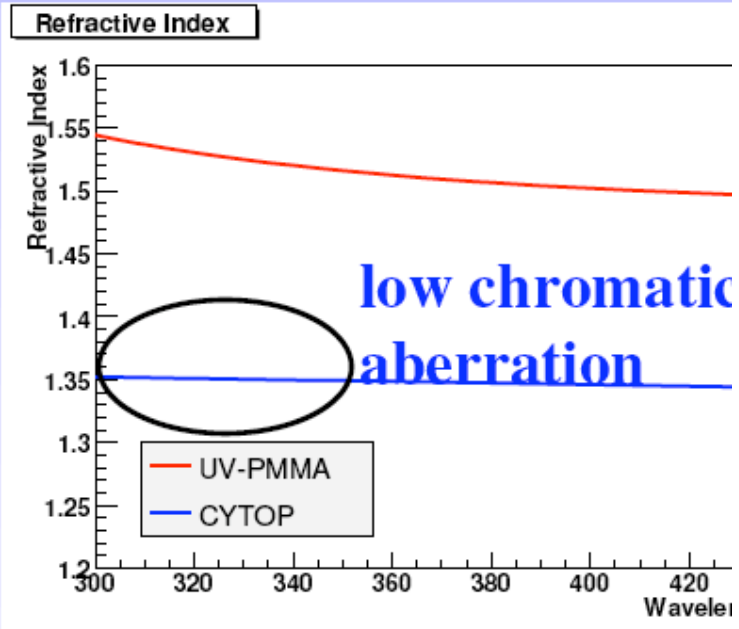
Major Specifications		
rotation Table	diameter (mm)	3400
	loadable mass(kg)	2000
	Rotation velocity (min^{-1})	10–80
	Largest prcessable diameter (mm)	3400
	oil sustained shaft	
Linear axis	Horizontal motion (X)(mm)	1850
	Vertical motion (Z) (mm)	240
	Super precision V-V roler guide	
Rotation axis	Angle range (B axis) (deg)	±360
	Air sustained shaft	
Least settable unit最小設定単位		X, Z: 0.01 μ m, B: 0.00001 deg
mass (kg)		38000

UV PMMA vs. CYTOP

Transmission



Refractive Index



Advanced Design

- Re-design of Optics(Cytop)
  - Spot size→1/2

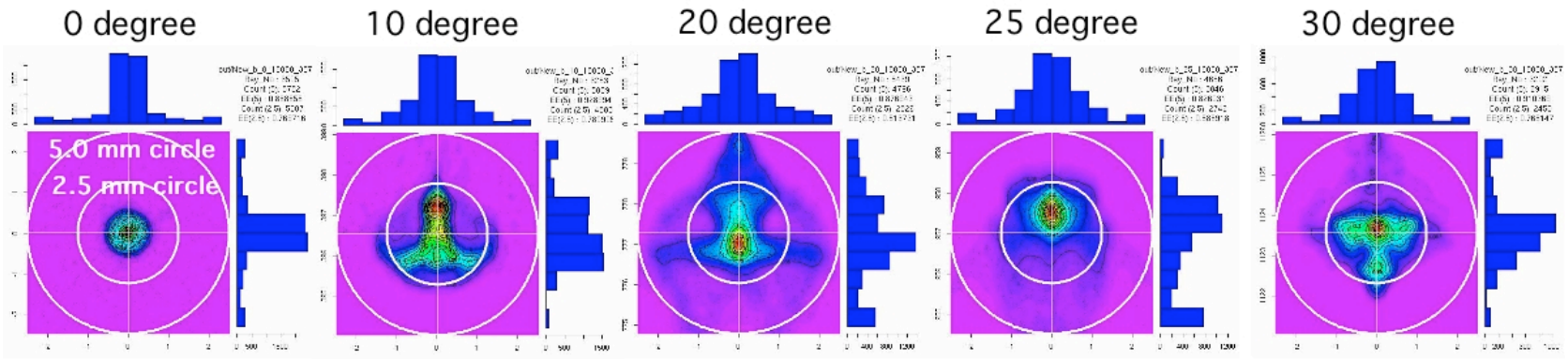
•Interferometer filter

– Lower backgroundx0.5

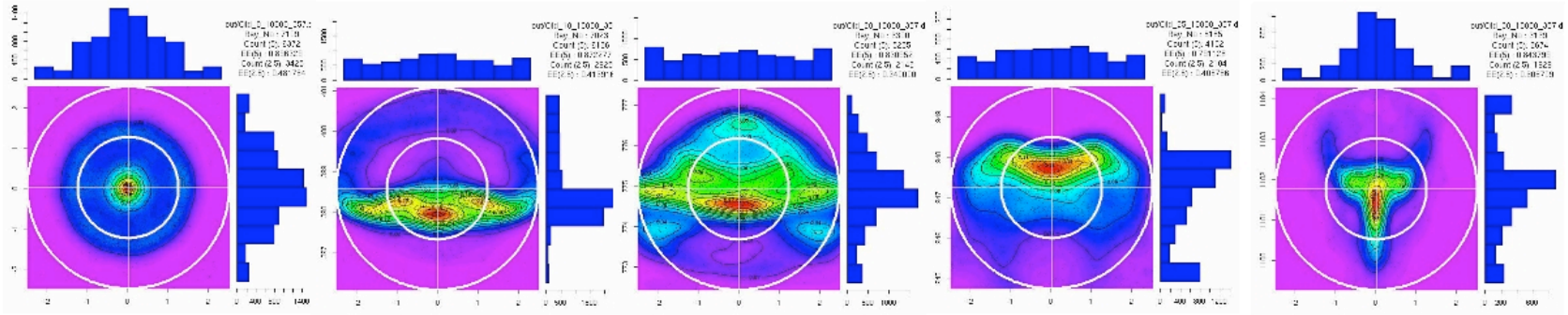
•Smaller pixel size

–4.4mm→3.3mm、2.5mm (2 minutes arc)

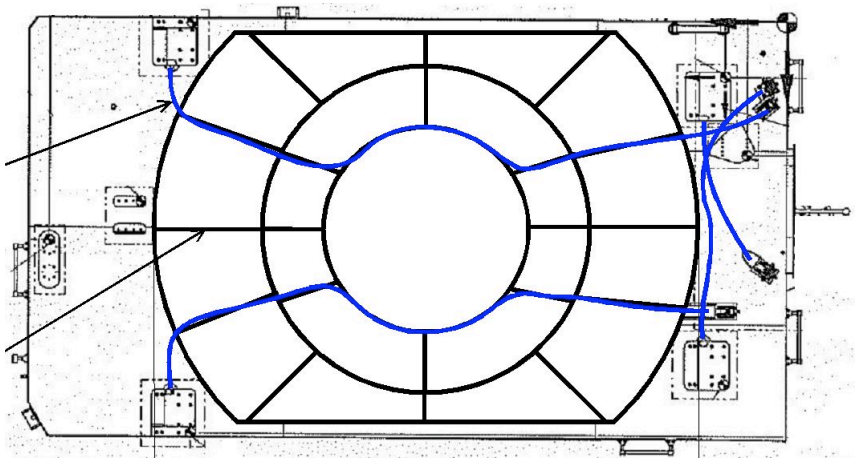
New Optics

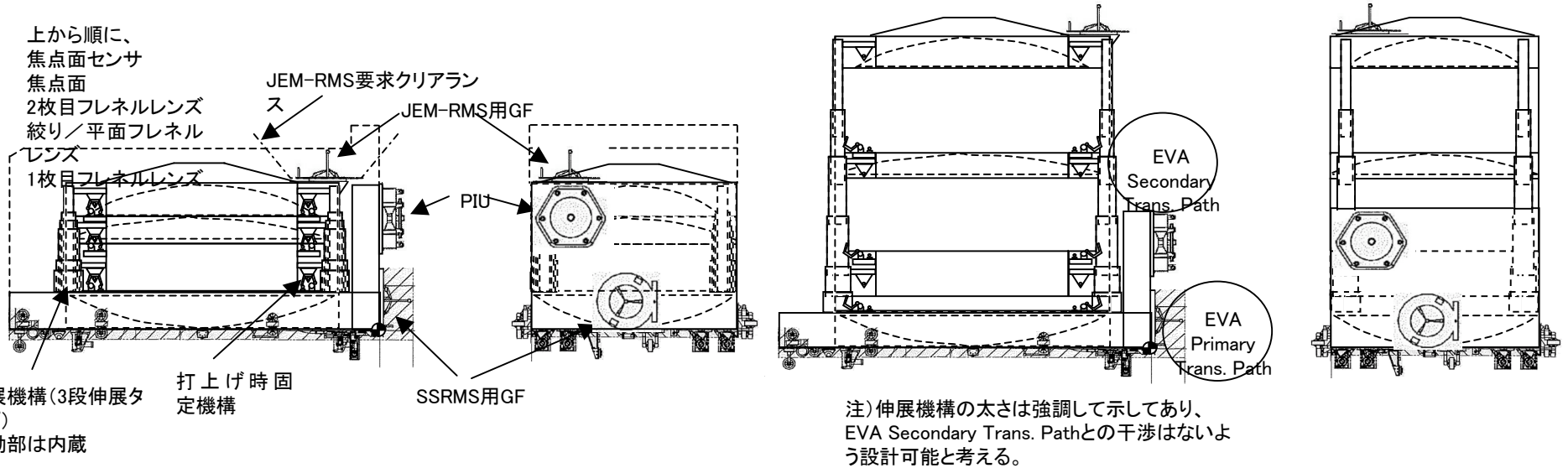


Baseline Optics

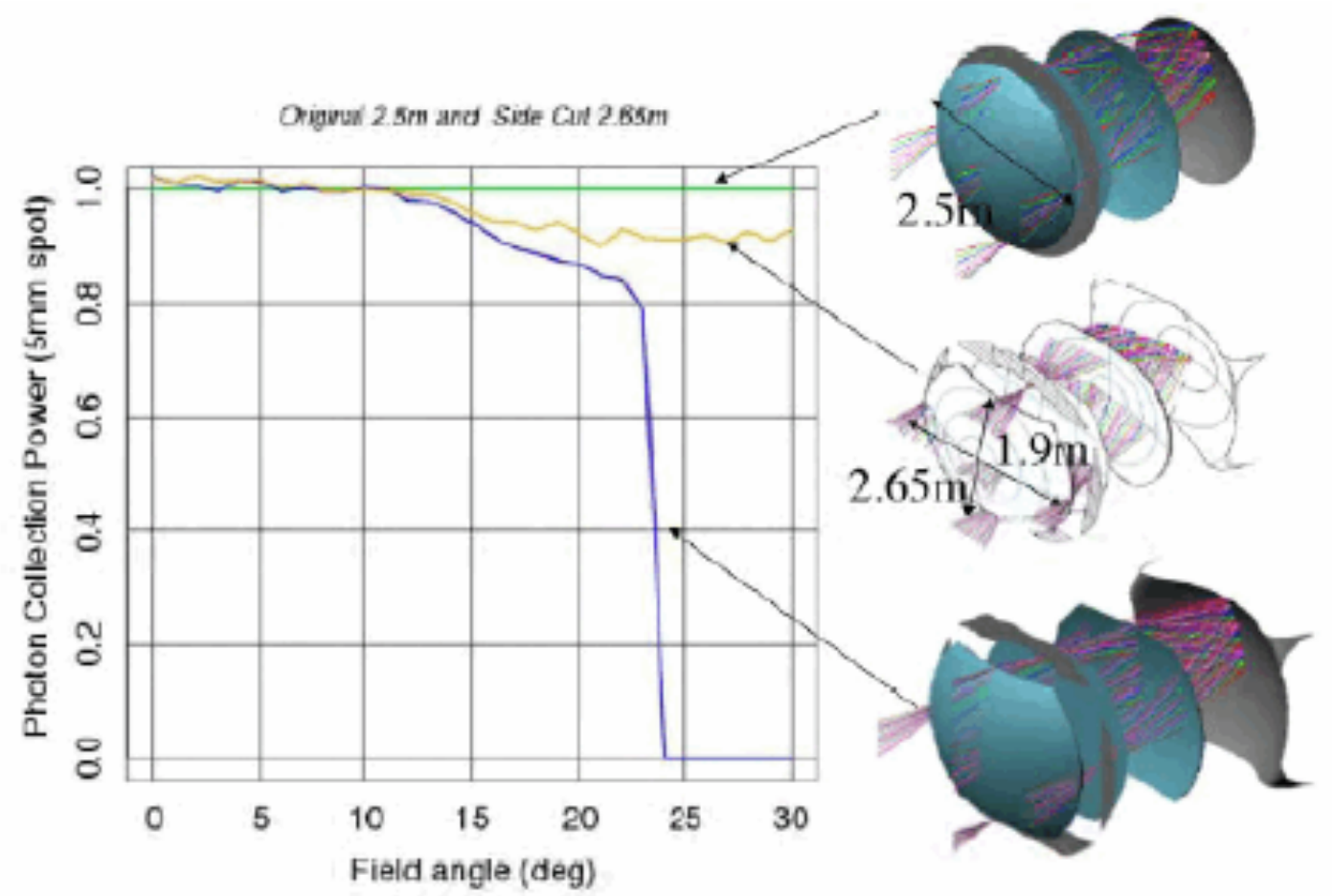


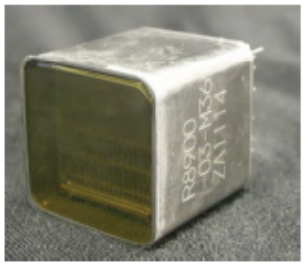
Accommodation to HTV：Case-C

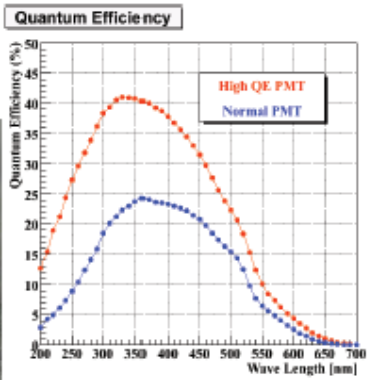


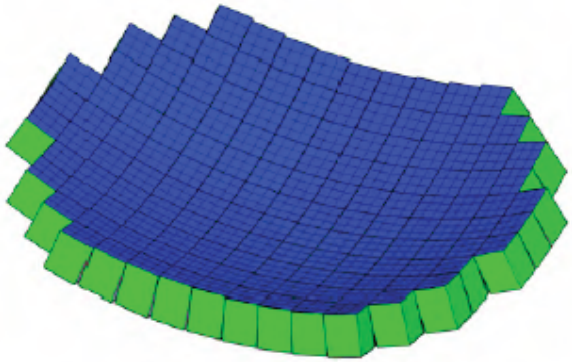


注）伸展機構の太さは強調して示してあり、
EVA Secondary Trans. Pathとの干渉はないよう設計可能と考える。

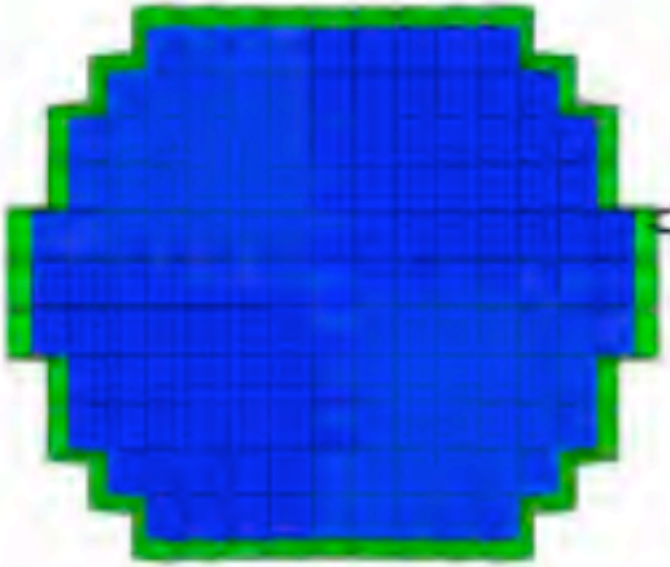

Original 2.5m and Side Cut 2.65m
Photon Collection Power (5mm spot)
0.0
0.2
0.4
0.6
0.8
1.0
0
5
10
15
20
25
30
Field angle (deg)
2.5m
1.9m
2.65m







Focal Surface detector



Elementary Cell

(2x2 PMTs = 144 pixels)

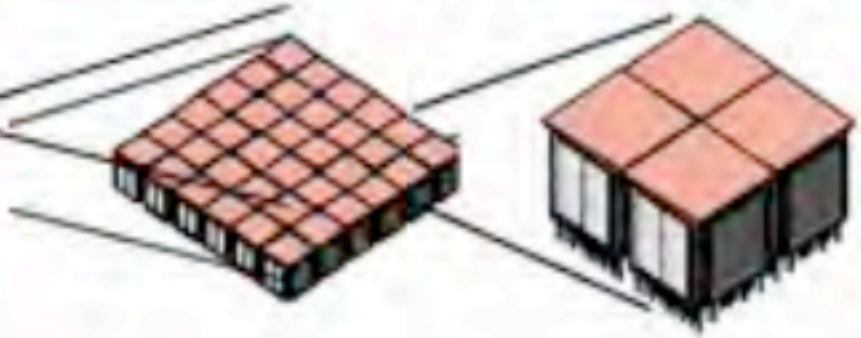
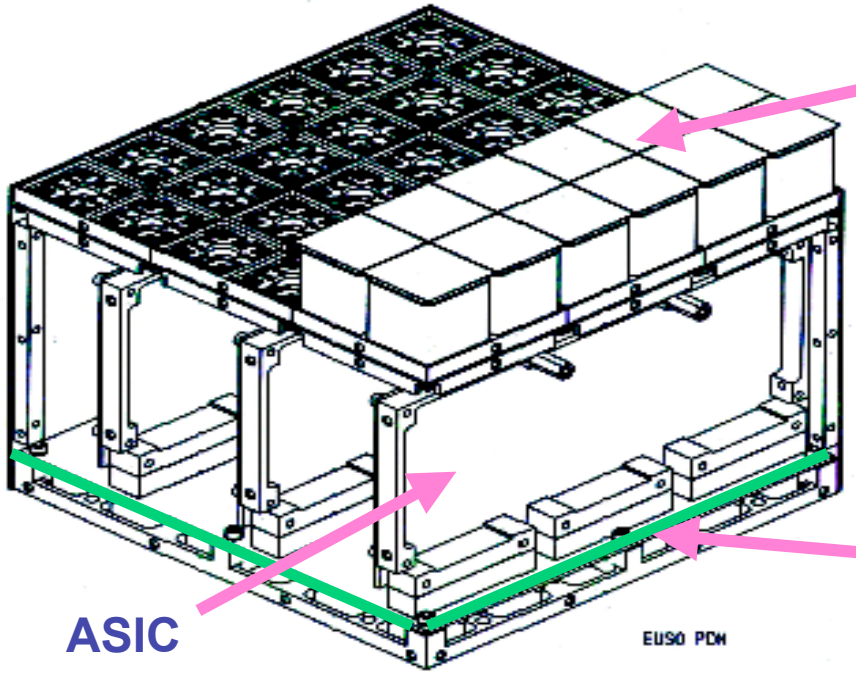


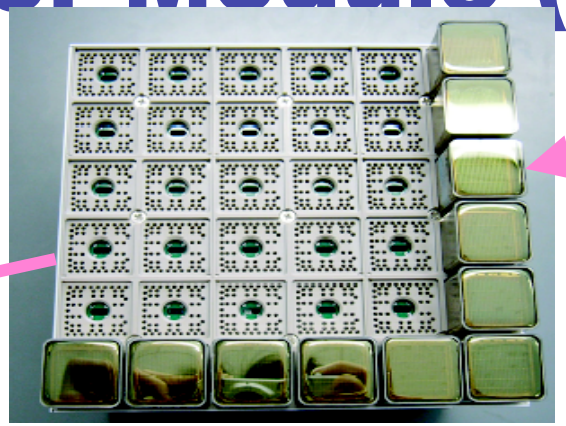
Photo-Detector Module

(3x3 ECs = 1296 pixels)

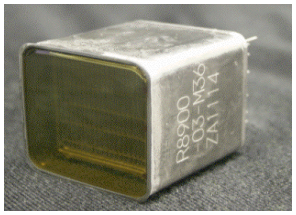
Photo Detector Module (PDM)

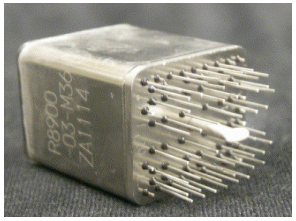


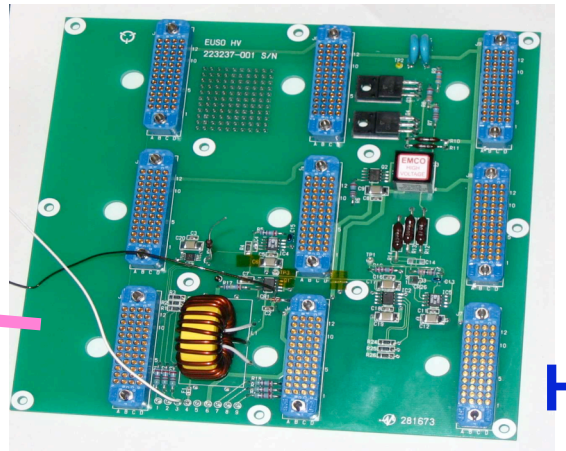
ASIC



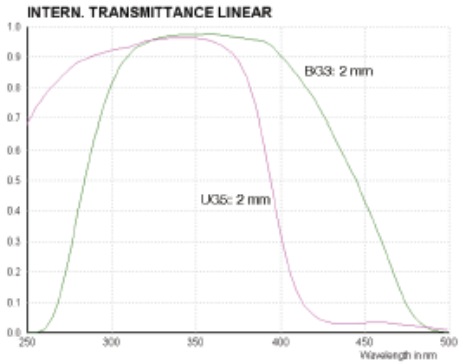
MAPMT 36PMT
x36 or 64 pixels

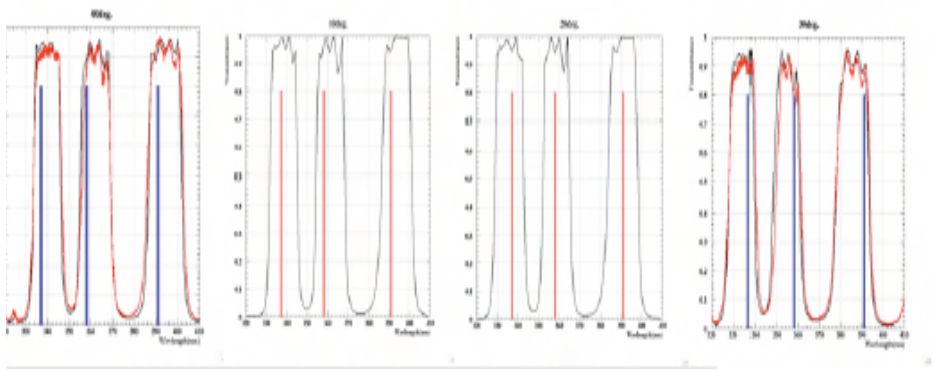


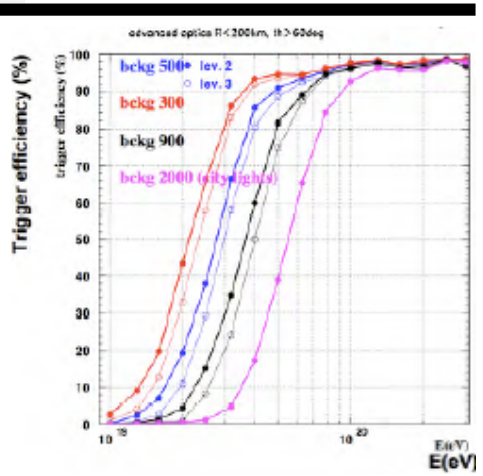




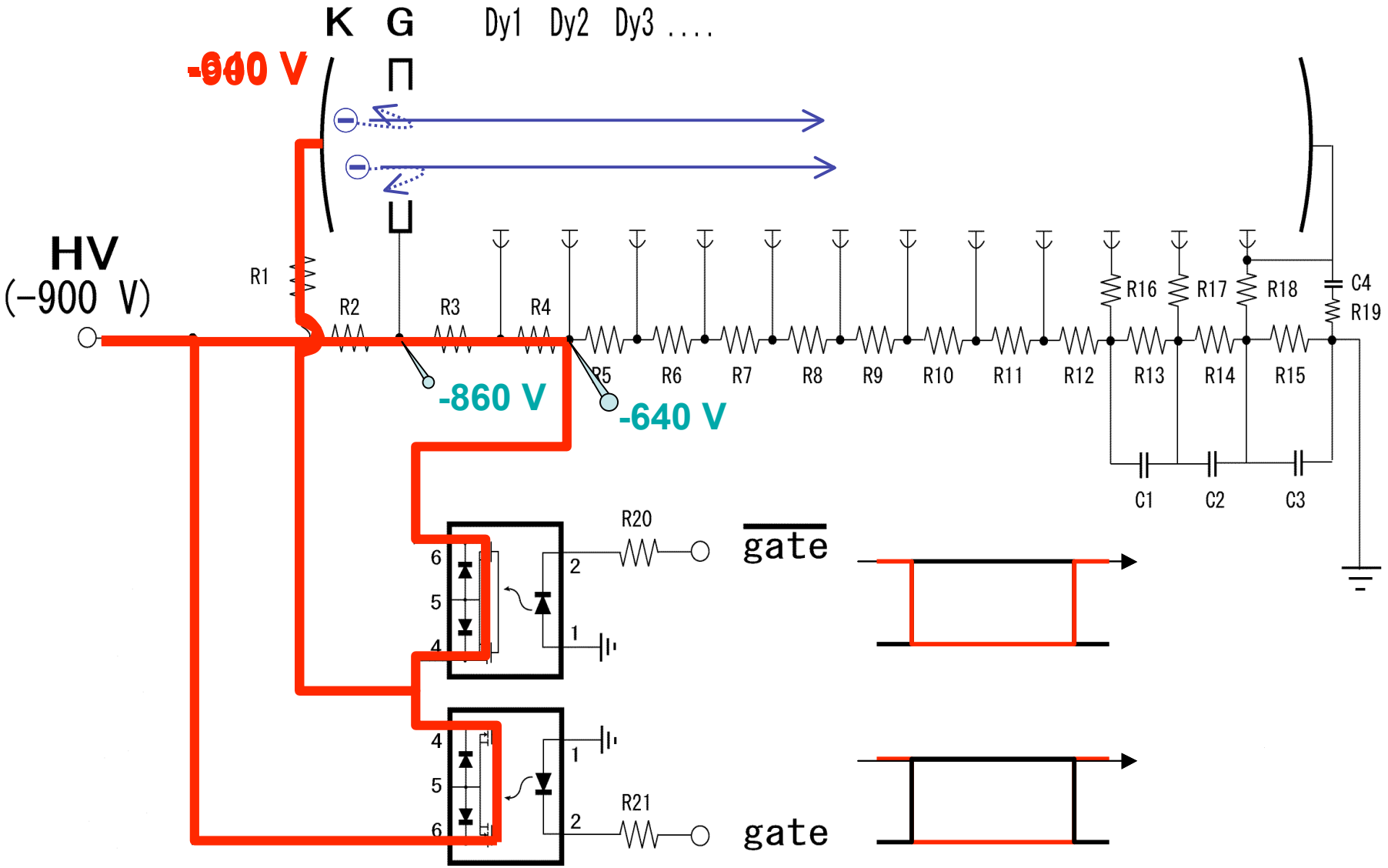
HV board







MAPMT Gain Control

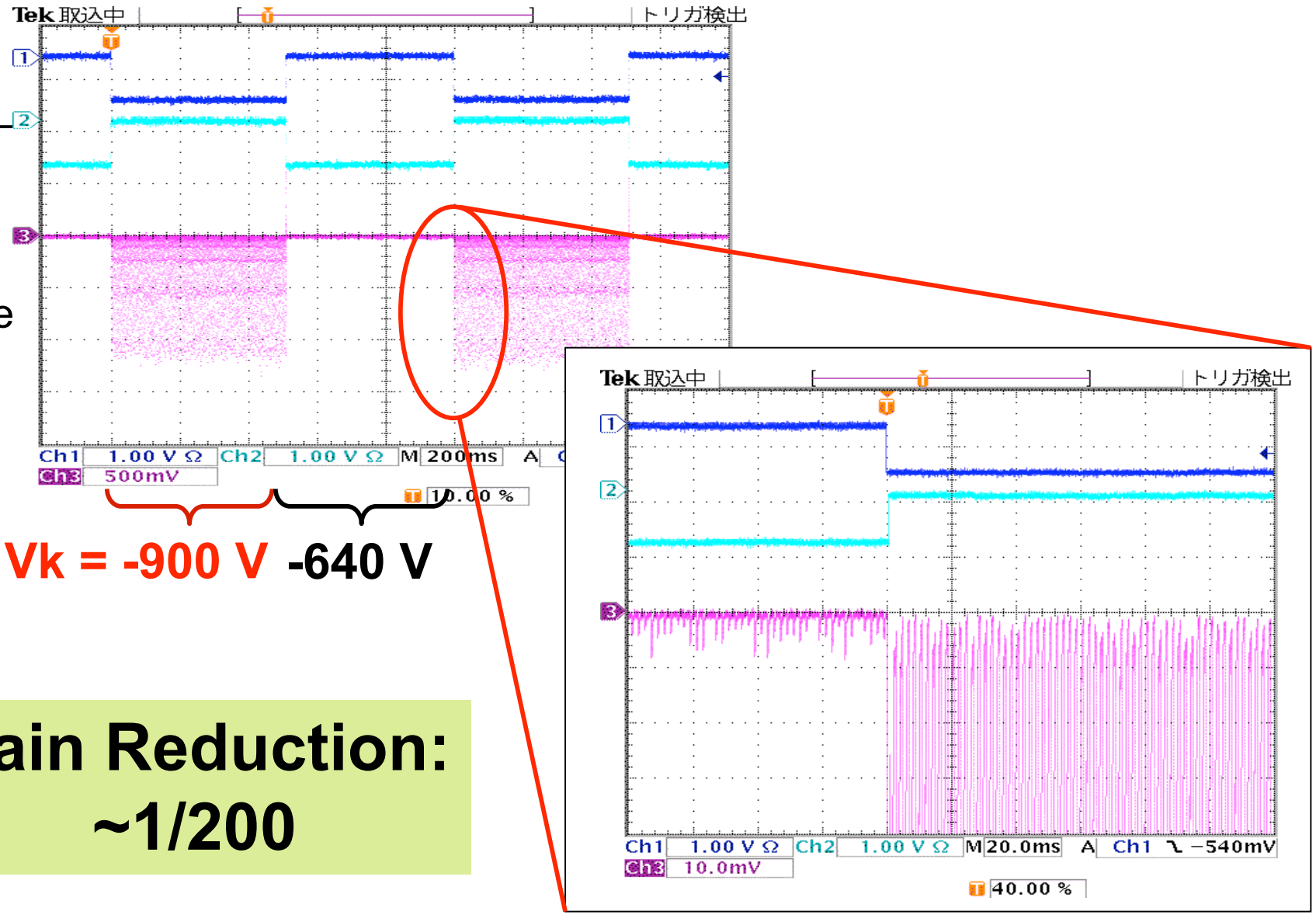


MAPMT Gain Control

gate

gate

anode sig.



Vk = -900 V -640 V

Gain Reduction: ~1/200

Atmospheric Monitoring System

- IR Camera

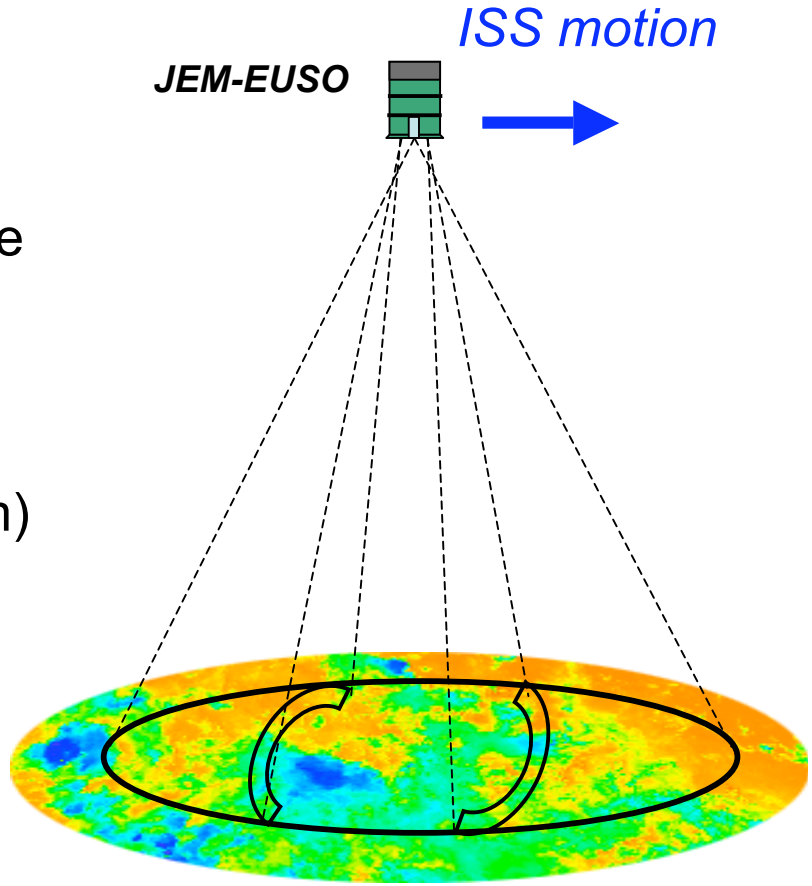
  Imaging observation of cloud temperature inside FOV of JEM-EUSO (200 m)

- Lidar

  Ranging observation using UV laser (8 m)

- JEM-EUSO "slow-data"

  Continuous background photon counting with some selected PMTs (stereo)



- *Cloud amount, cloud top altitude*: (IR cam., Lidar, slow-data)
- *Airglow*: (slow-data)
- *Calibration of telescope*: (Lidar)

FRANCE

1) Calibration (APC)
   A. *Before flight*
      - PMTs (10000)
      - PDMs (we make the apparatus and ship it to Japan)

   B. *In flight*
      - Focal Surface
      - Lenses

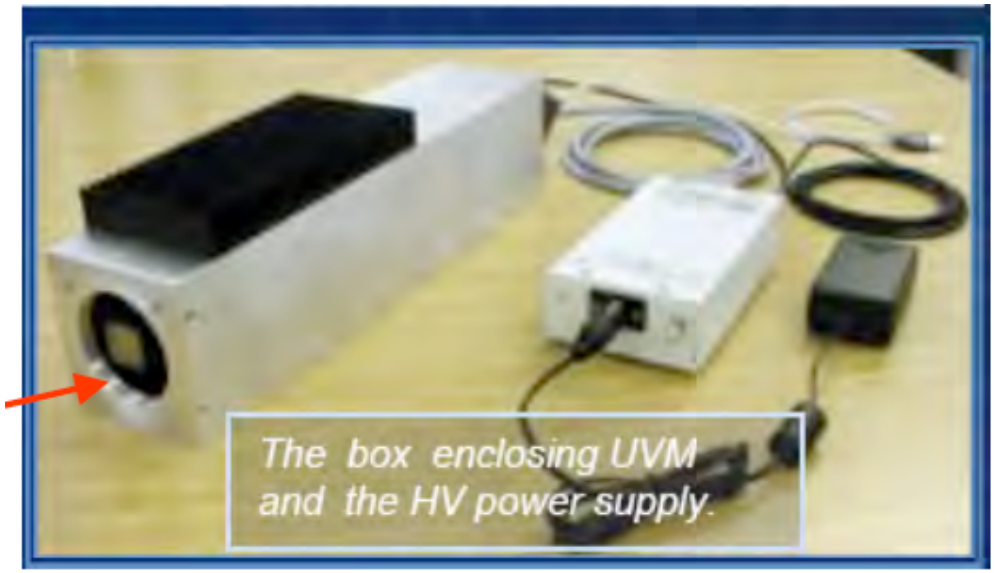
2) Fluorescence yield of individual lines (APC + LAL)

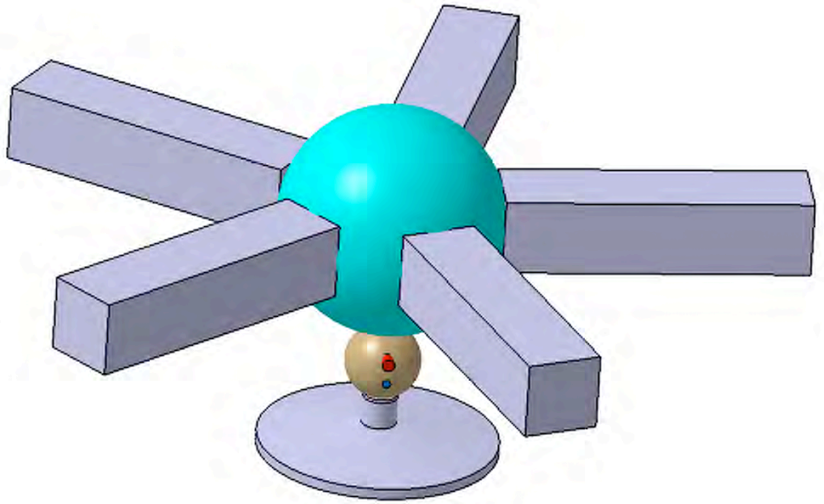
3) Front End Electronics (LAL: Maroc)

4) High Voltage for PMTs (APC)

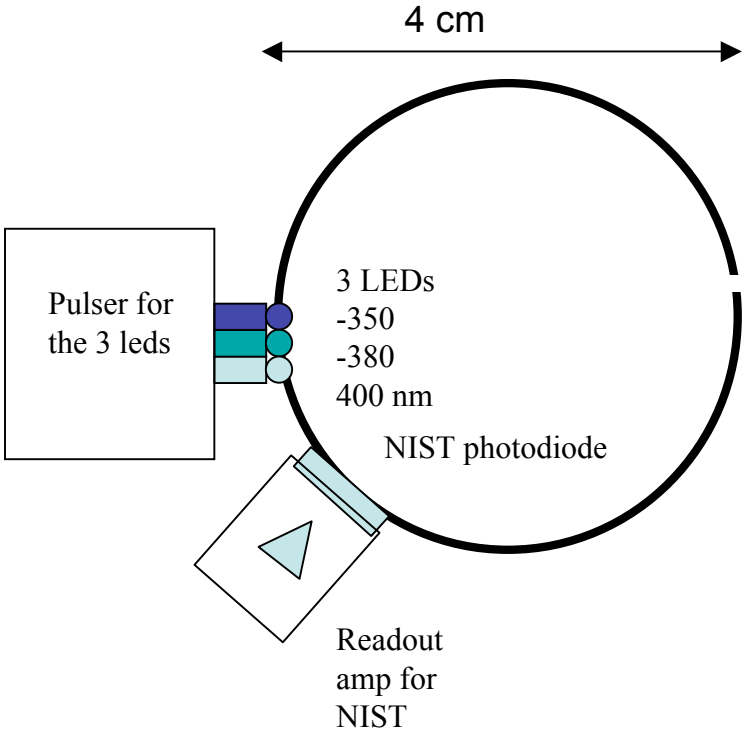
5) (Infra-red Camera)

Calibration of 10000 PMTs (Paris)

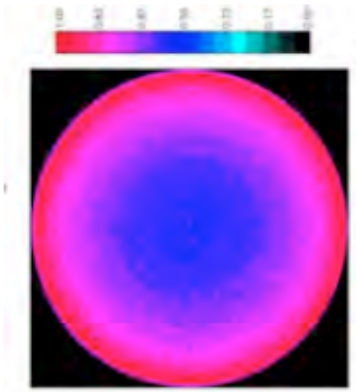


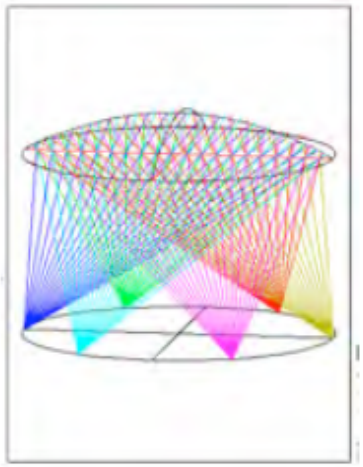


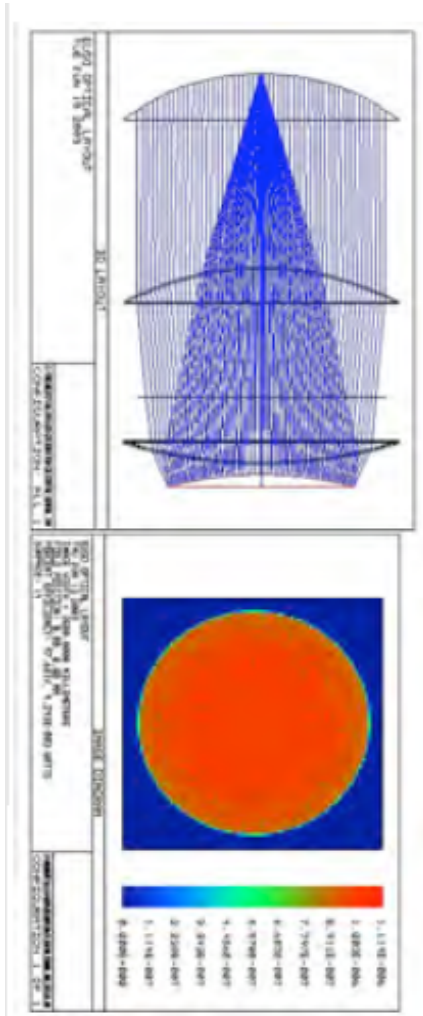
On board calibration (Paris)



Small (1 mm) hole to let the light go out

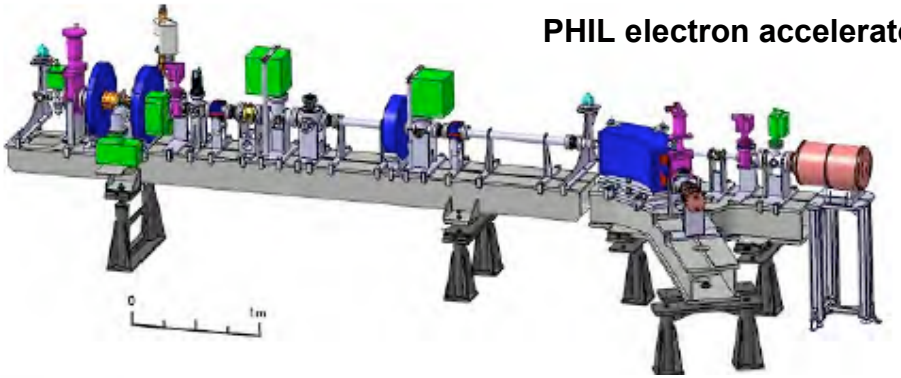






Space qualification!

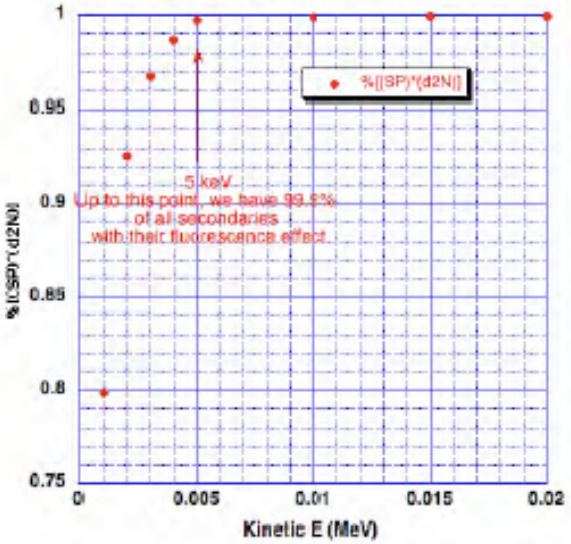
PHIL electron accelerator

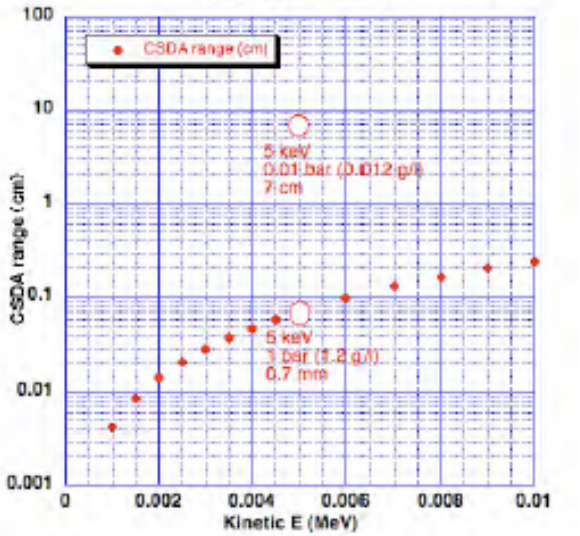


Fluorescence yield measurement

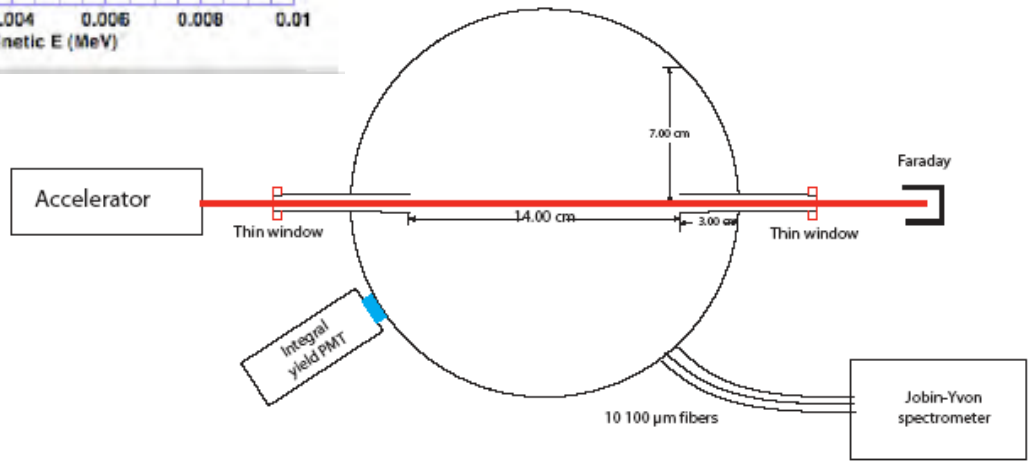
(APC & LAL & Madrid)

Goal: 5% precision



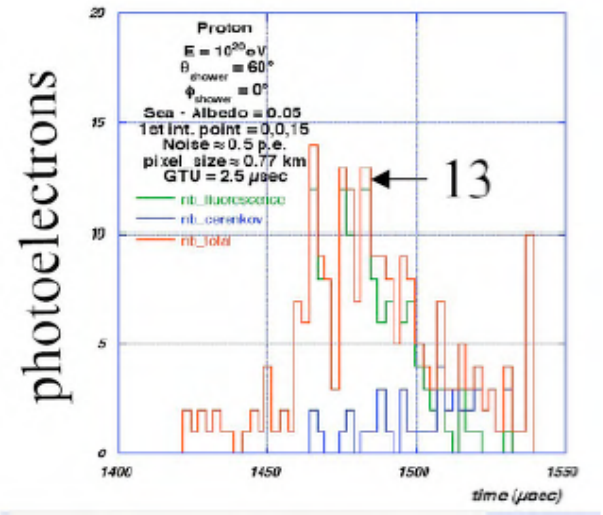


Measurement at atmospheric pressure only with a 5% precision: *"Absolute measurement of the nitrogen fluorescence yield in air between 300 and 430 nm"* G. Lefeuvre et al. NIM A 578 (2007)78



Front-end ASIC (LAL)

- Shower measurement: single electron mode. Best results: photon counting (existed in "old" MAROC chip at LAL)



- Most other measurements involve more light: counting saturates. Pulse charge integration (existed in "old" japanese chip)

- Best of both worlds: the two circuits on the same ASIC at LAL

- Power reduced to 0.5 mW / pixel (175 W total)

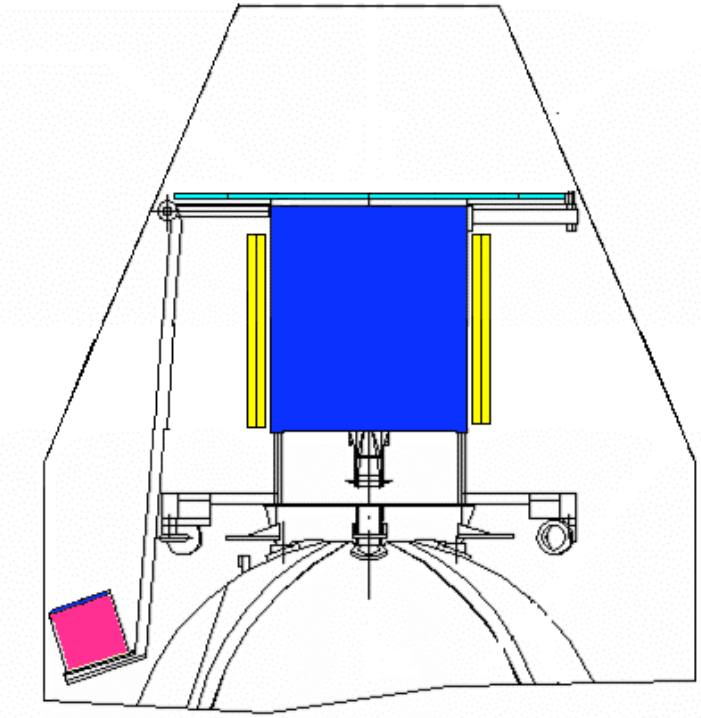
TUS : Path finder mission

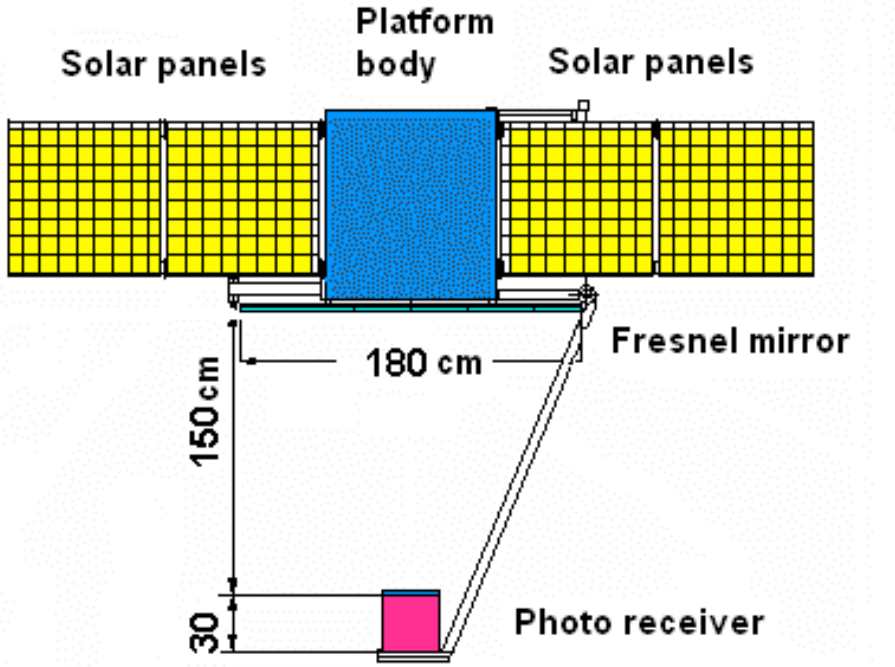
After Tatiana which measured the background from the stars reflected on earth, the TUS detector will be launched on a new platform separated from the main body of the “Foton” satellite (RosCosmos project, Samara enterprise, launching in 2009-2010).

Satellite limits for the scientific instrument are:

mass 60 kg, electric power 60 W, orientation to nadir ±3^{o} .

Preliminary TUS design: 1- in the transportation mode, 2 – in operation.





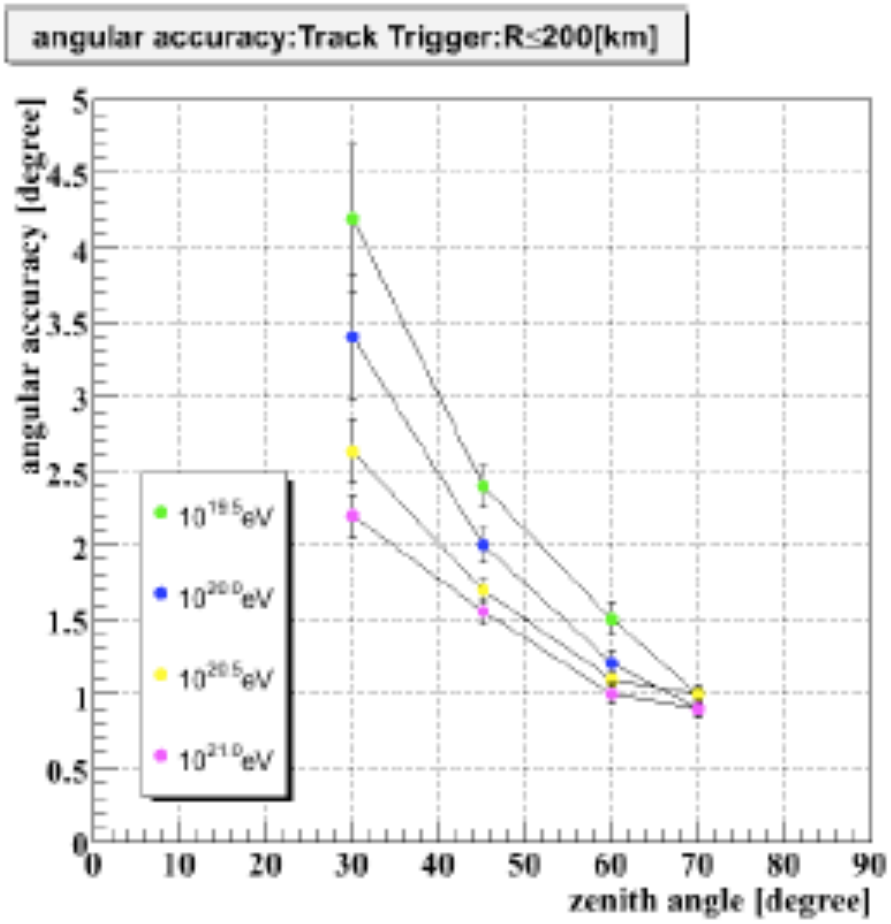
Mirror area 1.5 m^2 , pixels cover 4000 km^2 of the atmosphere (orbit height 400 km).

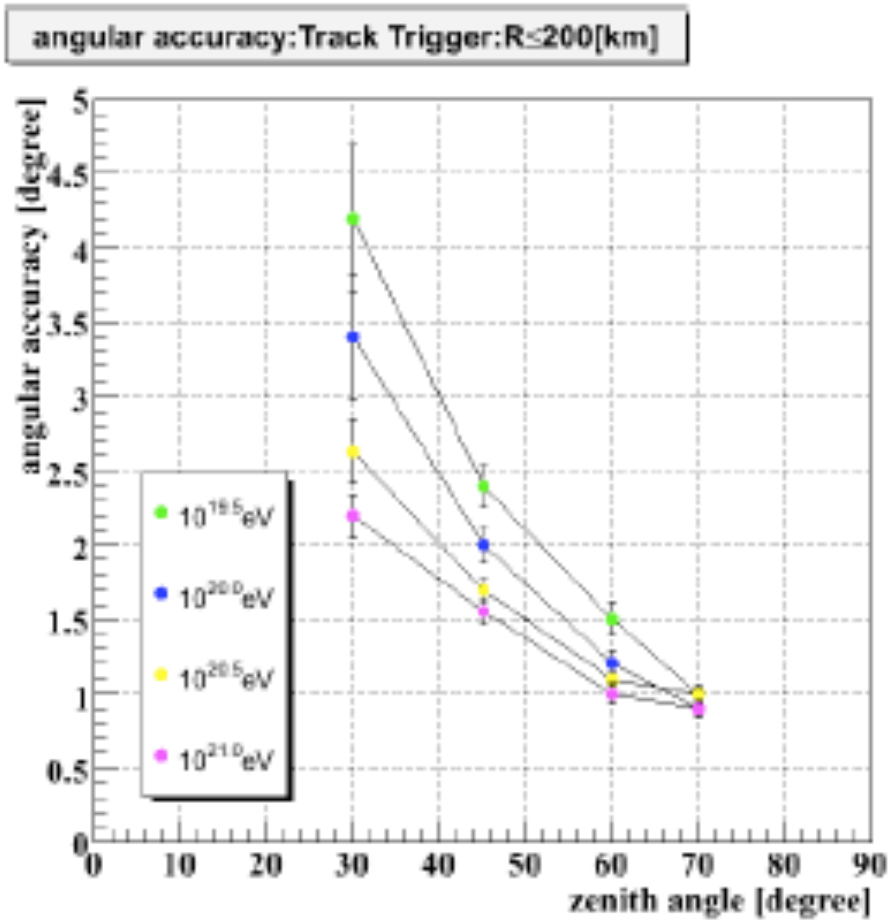
Perspectives

Large aperture ==> high statistics

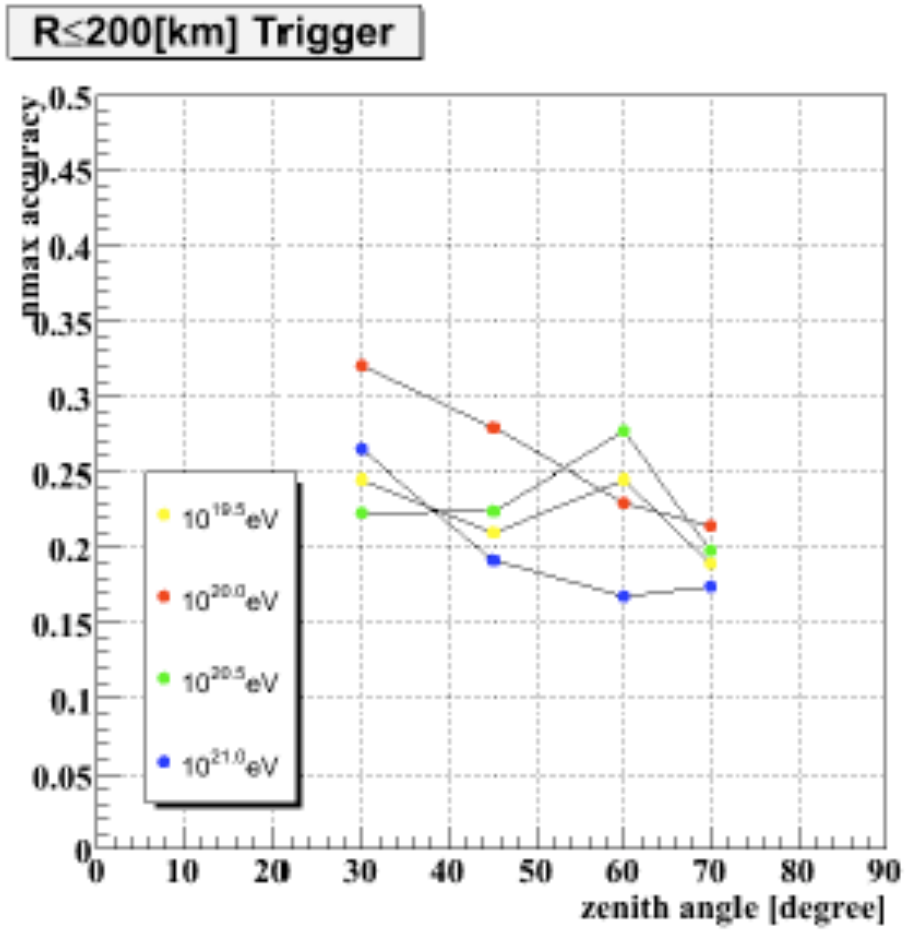
Precise instrument ==> high quality data

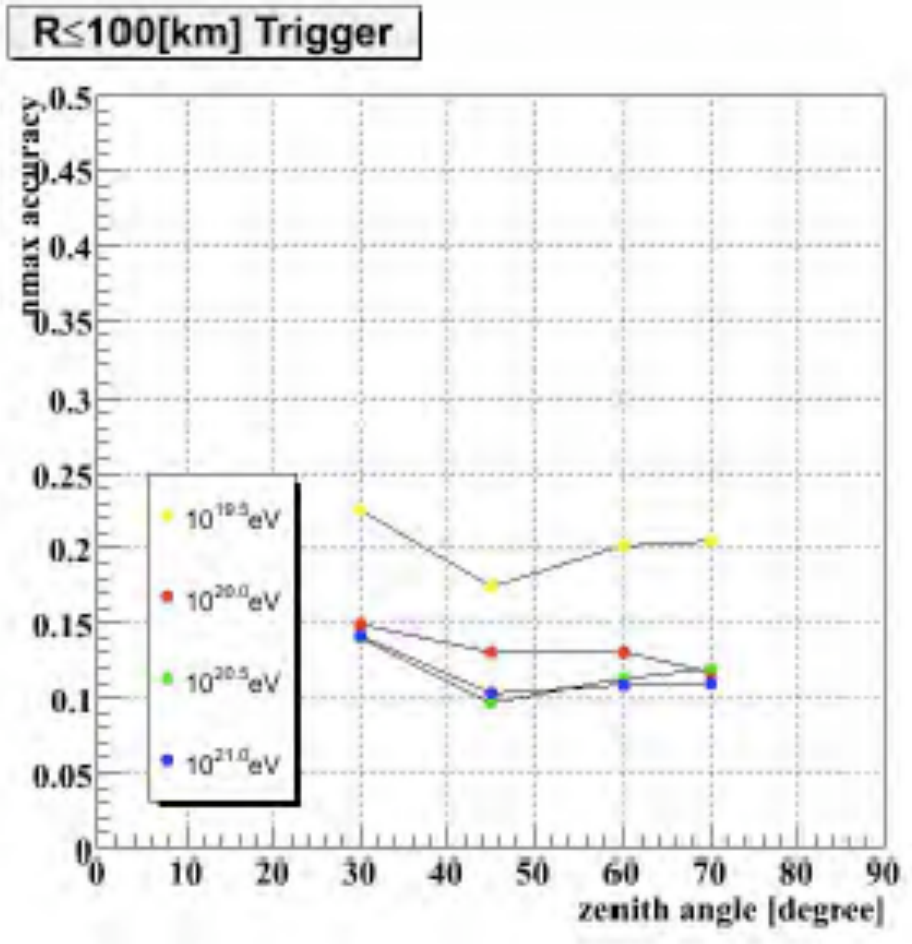
θ


angular accuracy:Track Trigger:R≤200[km]
angular accuracy [degree]
zenith angle [degree]
$10^{19.5}$eV
$10^{20.0}$eV
$10^{20.5}$eV
$10^{21.0}$eV

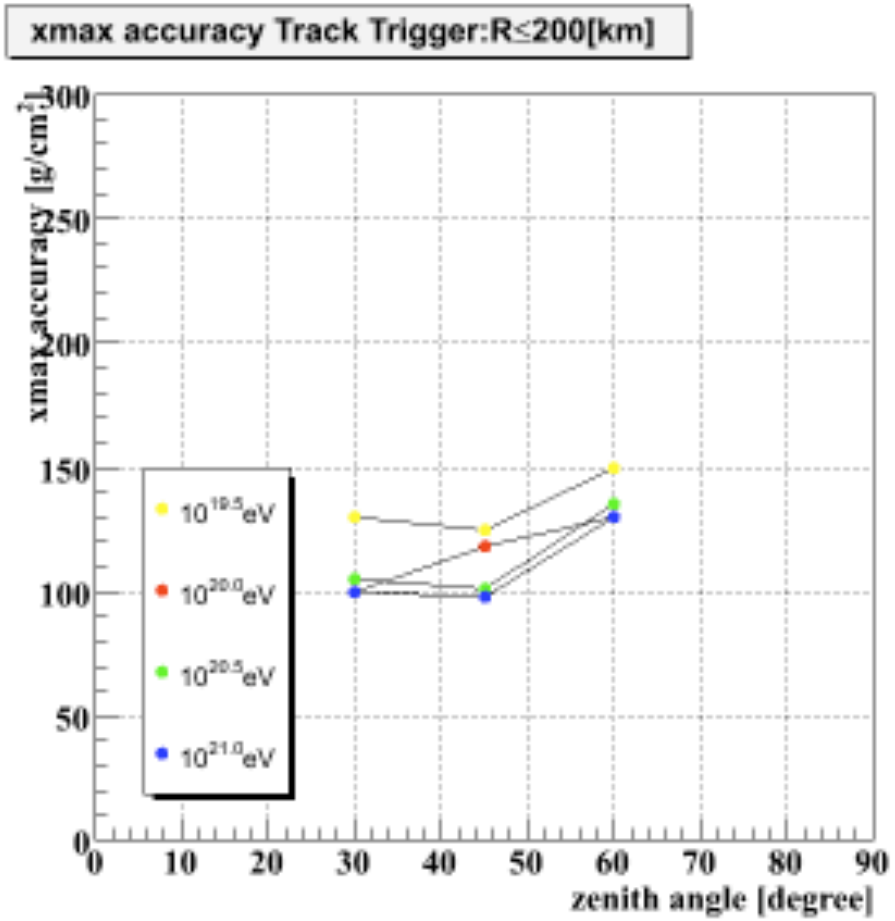

angular accuracy:Track Trigger:R≤200[km]
angular accuracy [degree]
zenith angle [degree]
$10^{19.5}$eV
$10^{20.0}$eV
$10^{20.5}$eV
$10^{21.0}$eV

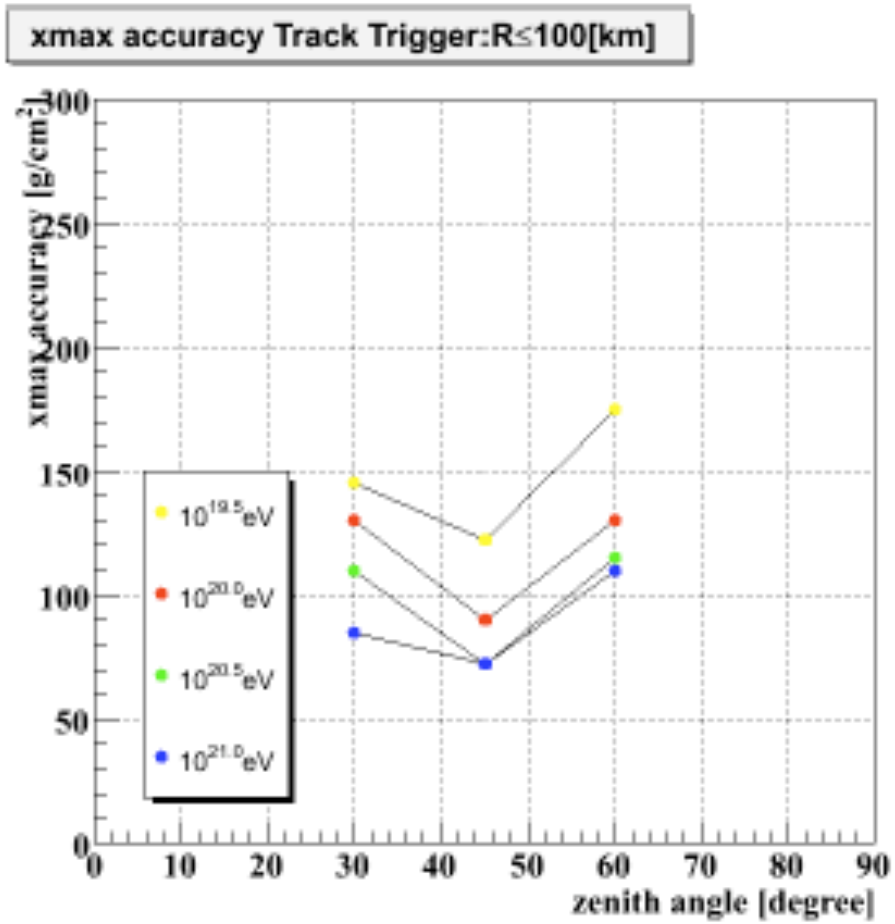
E


R≤200[km] Trigger
nmax accuracy
zenith angle [degree]
$10^{19.5}$eV
$10^{20.0}$eV
$10^{20.5}$eV
$10^{21.0}$eV

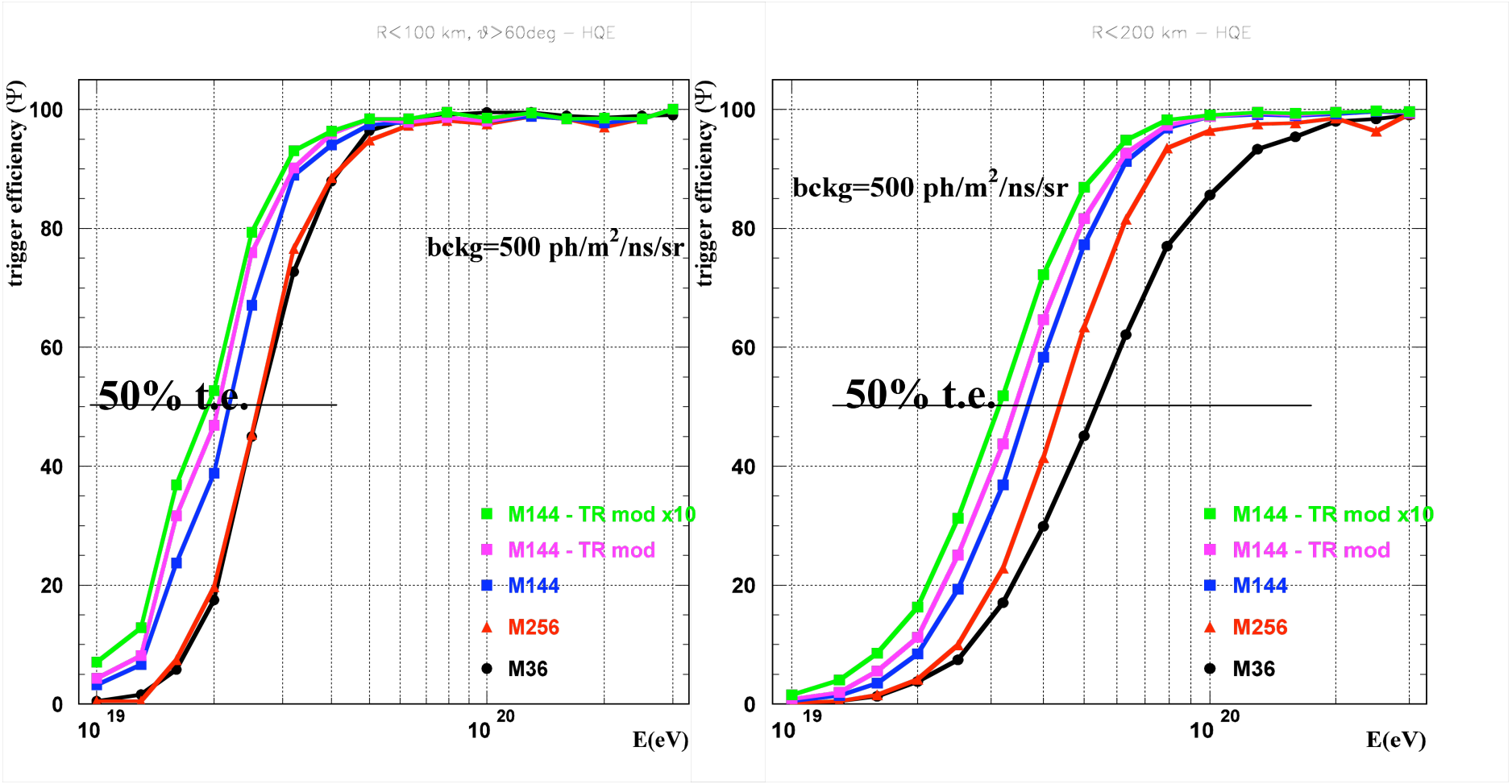

R≤100[km] Trigger
nmax accuracy
zenith angle [degree]
$10^{19.5}$eV
$10^{20.0}$eV
$10^{20.5}$eV
$10^{21.0}$eV

X_{max}


xmax accuracy Track Trigger:R≤200[km]
xmax accuracy [g/cm²]
zenith angle [degree]
10^19.5eV
10^20.0eV
10^20.5eV
10^21.0eV


xmax accuracy Track Trigger:R≤100[km]
xmax accuracy [g/cm²]
zenith angle [degree]
10^19.5eV
10^20.0eV
10^20.5eV
10^21.0eV

Trigger efficiency by simulation



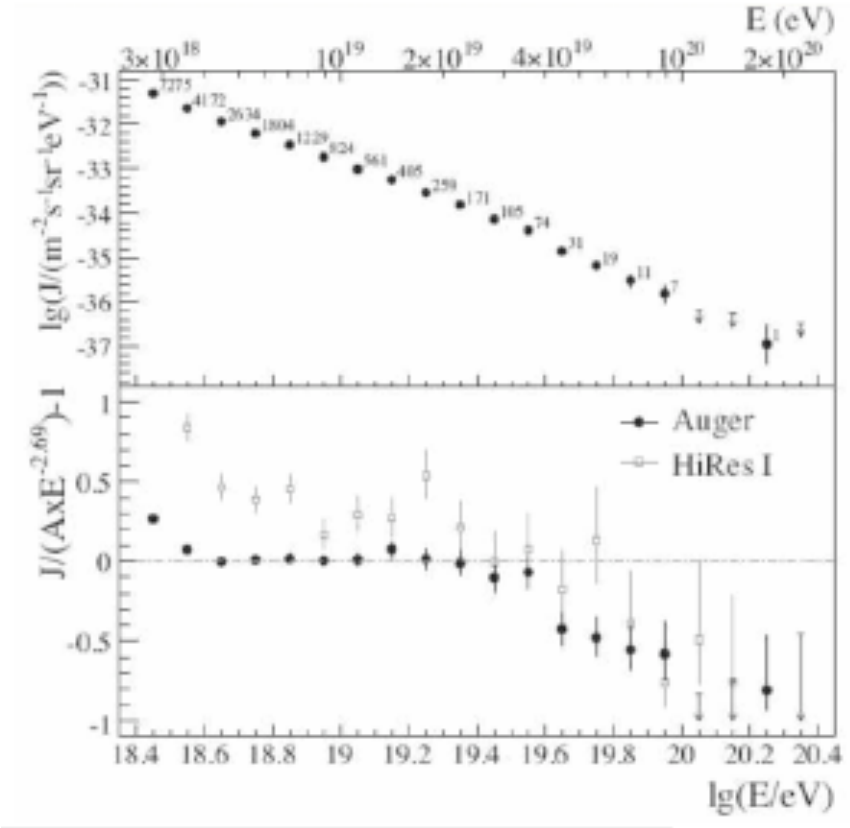
Success Criteria

- **Full Success:**
  Number of Events >1000
  (above 7×10^{19} eV)
- **Minimum Success:**
  Number of Events > 500 ← **Critical number to clarify the origin of EECRS**
- **Extra Success**
  Achieve one or all of three exploratory objectives

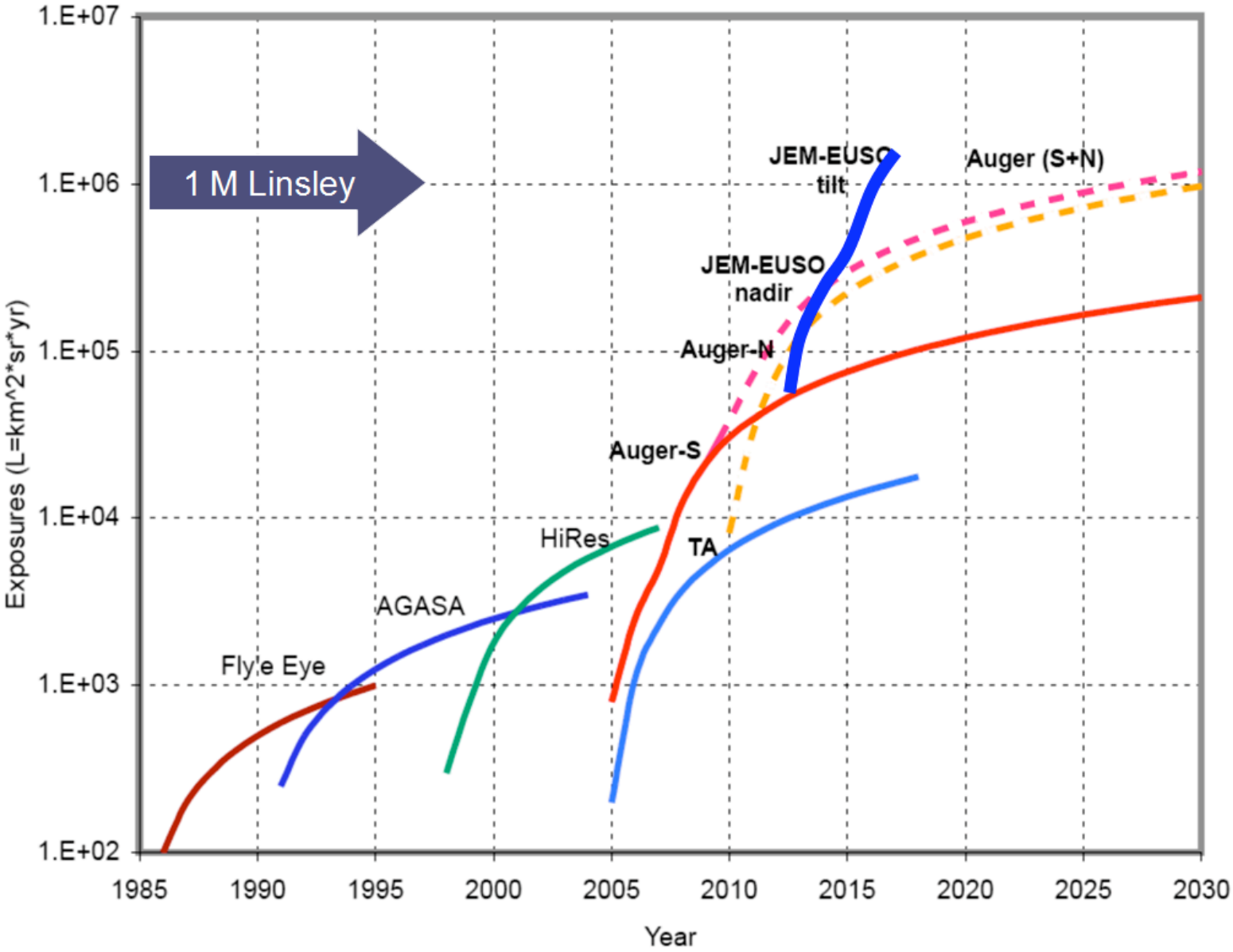
- Arrival direction
  - < 2 degrees
- Energy resolution
  - < 30%
- Hadron/Photon/neutrino:
  - $\Delta X_{max} <$ 120 g / cm^2

Expected Number of Events
5 years

	$>7\times10^{19}$ eV	$>1\times10^{20}$eV
2.6 m dia. side cut Case-C	2170	530
Advanced Design (more smaller pixels) Case-D	3820	769

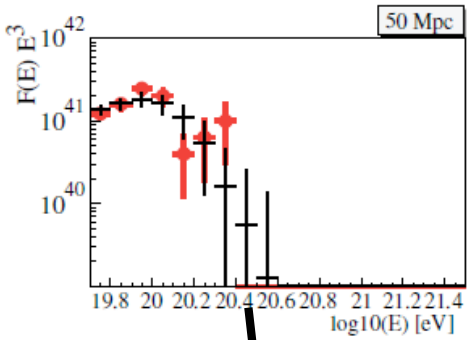


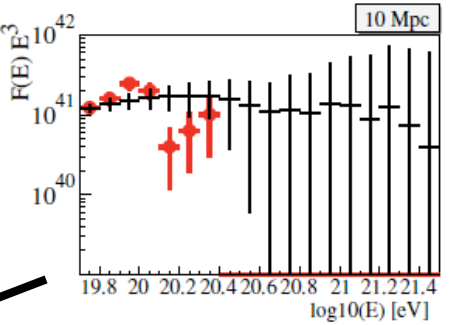
Exposure

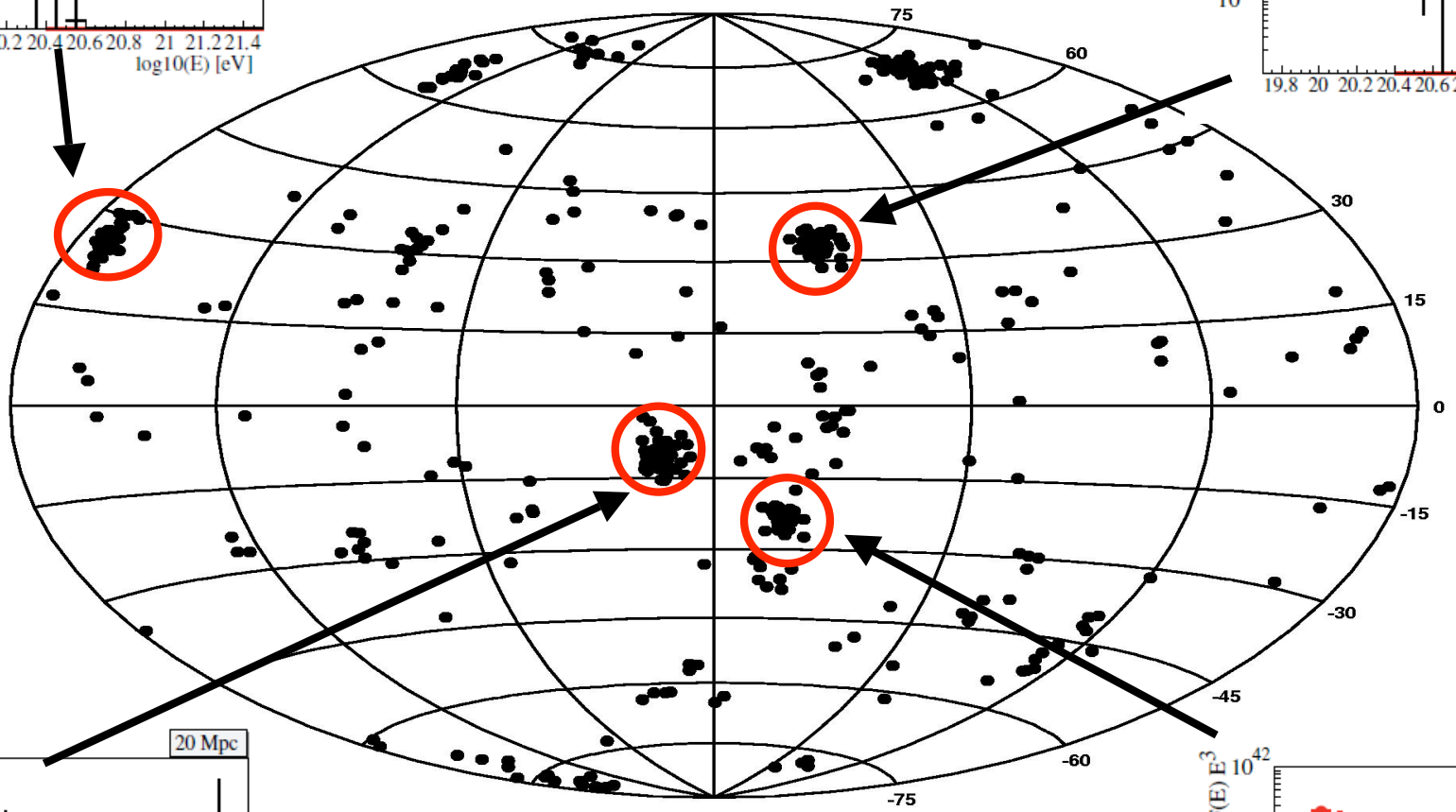

1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
Exposures (L=km^2*sr*yr)
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Year
1 M Linsley
JEM-EUSO tilt
Auger (S+N)
JEM-EUSO nadir
Auger-N
Auger-S
HiRes
TA
AGASA
Fly'e Eye

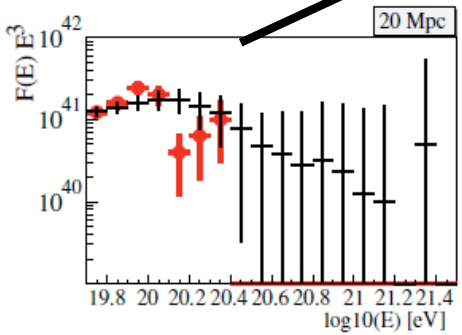
Particle Astronomy

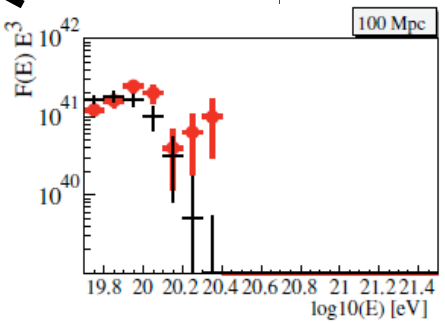
If we get >1,000 events,



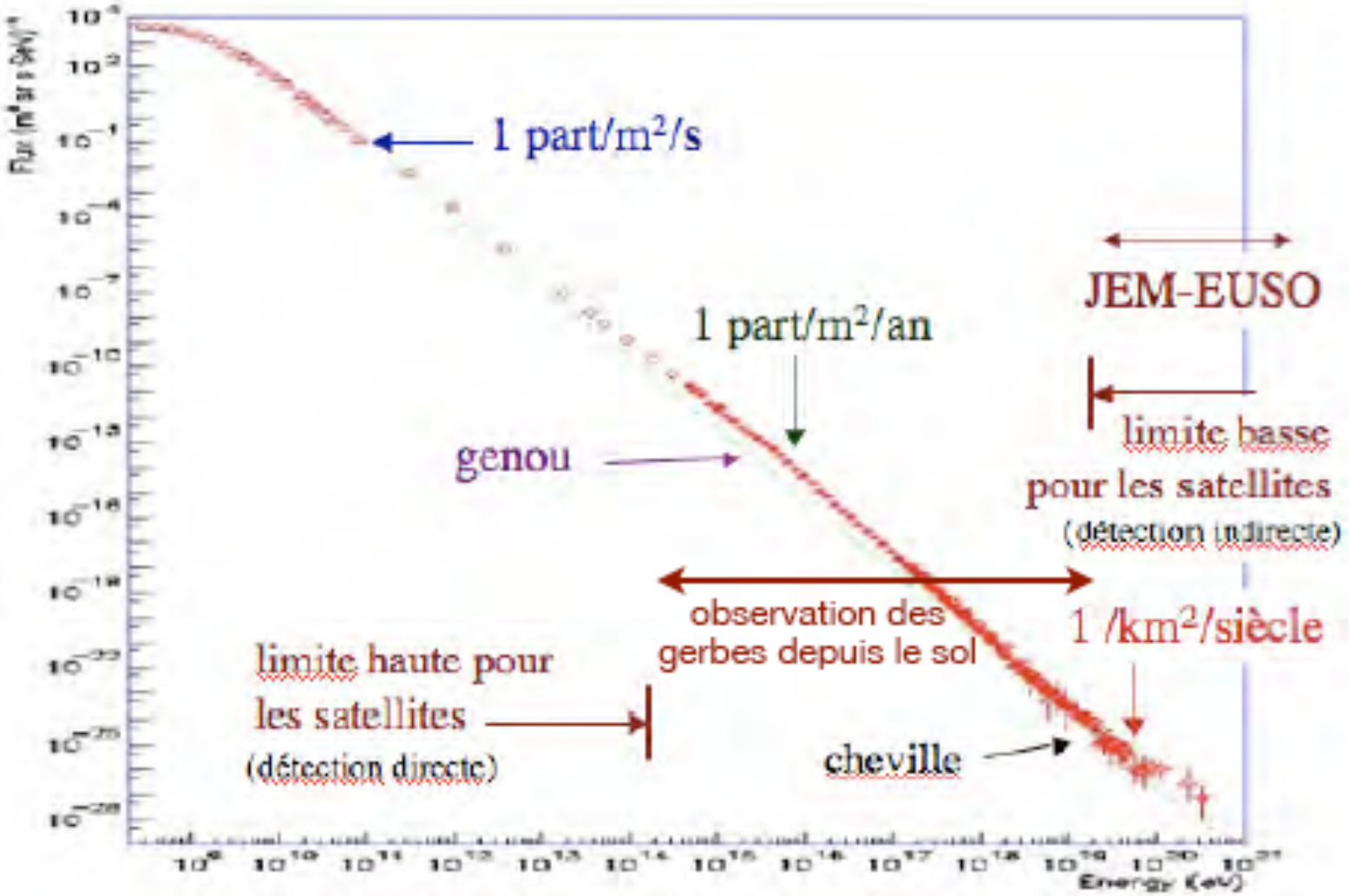






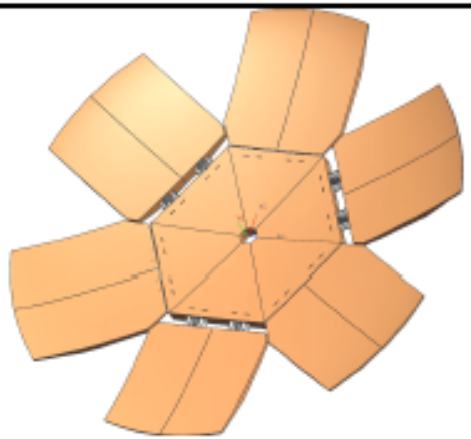


- 1,000 events : $E>7\times10^{19}$eV
- Several dozen clusters are expected
- All sky coverage

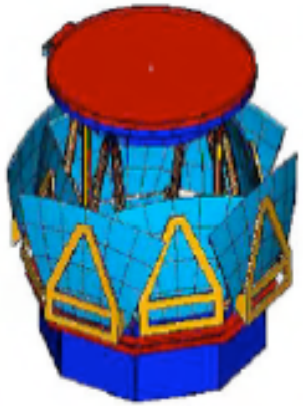

1 part/m²/s
1 part/m²/an
genou
JEM-EUSO
limite basse
pour les satellites
(détection indirecte)
observation des
gerbes depuis le sol
1 /km²/siècle
limite haute pour
les satellites
(détection directe)
cheville
Energy (eV)

ESA's Cosmic Vision: S-EUSO

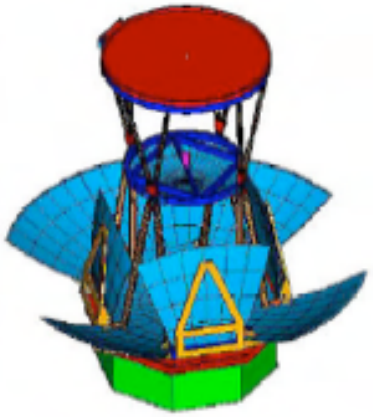
2020 - 2025



• Figure 2 – Concept scheme of the optics deployment (Carlo Gavazzi Space).



• Figure 3 – The folded structure (from the OWL concept study, NASA, [10]).



• Figure 4 - The un-folded structure (from the OWL concept study, NASA, [10]).

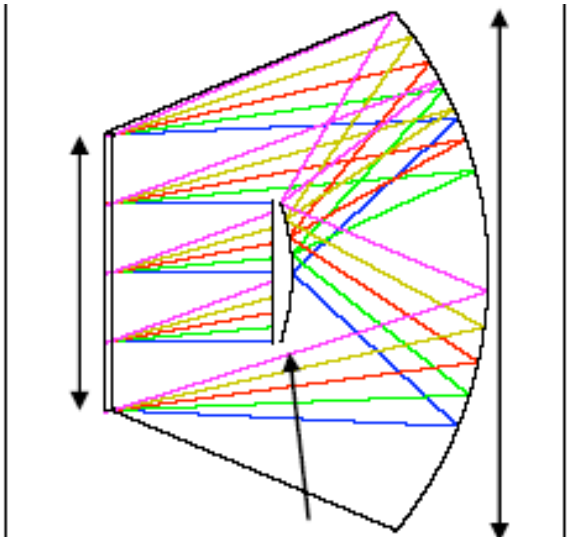
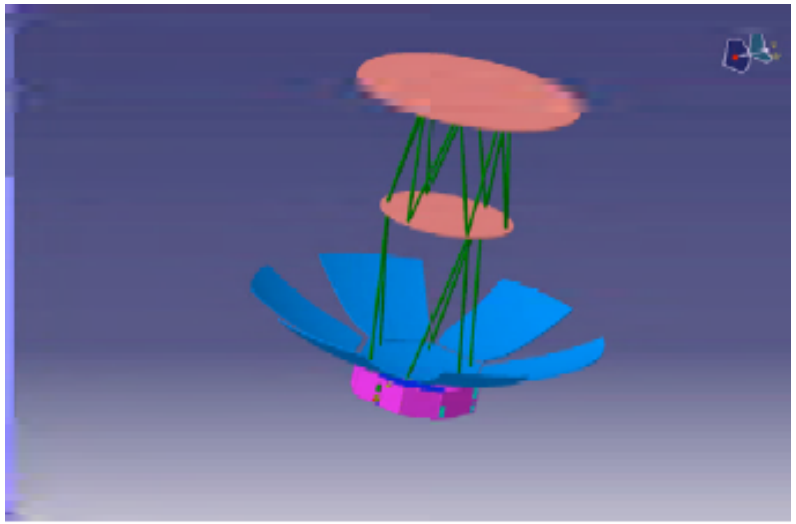


Figure 1 – Optical scheme.

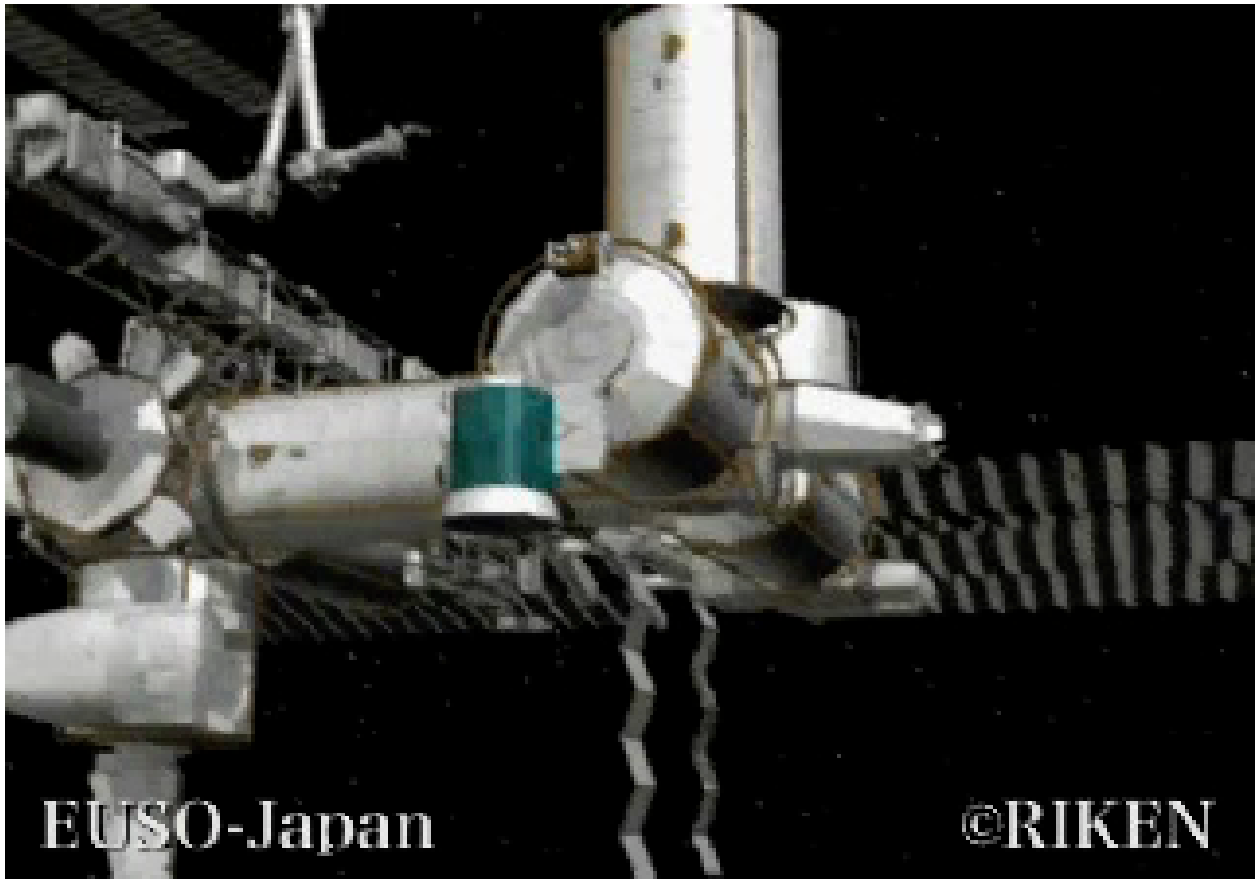


• Figure 11 – In-flight configuration.

Summary

- EUSO completed Phase-A from 2000 to 2004 in the ESA program and NASA MIDEX program
- JEM-EUSO has been selected by JAXA as a mission candidate for the second-phase utilization of JEM/EF on ISS for launch in 2013

  for 5-yrs (or longer) exposure.
- Phase-A Study under JAXA began
- JEM-EUSO has exposure (with tilt) > 10^6 km^2 sr yr
  - First Observatory of EECR from space


EUSO-Japan
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