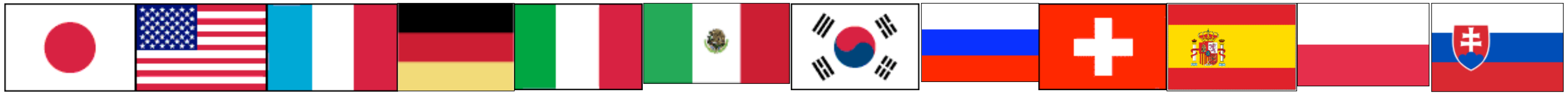
22nd European Cosmic Ray Symposium
3 - 6 August 2010

The Jem-Euso experiment to observe UHECR from the International Space Station

M. Casolino
INFN & University of Rome Tor Vergata
on behalf of the JEM-EUSO collaboration

5/8/2010

JEM-EUSO Collaboration

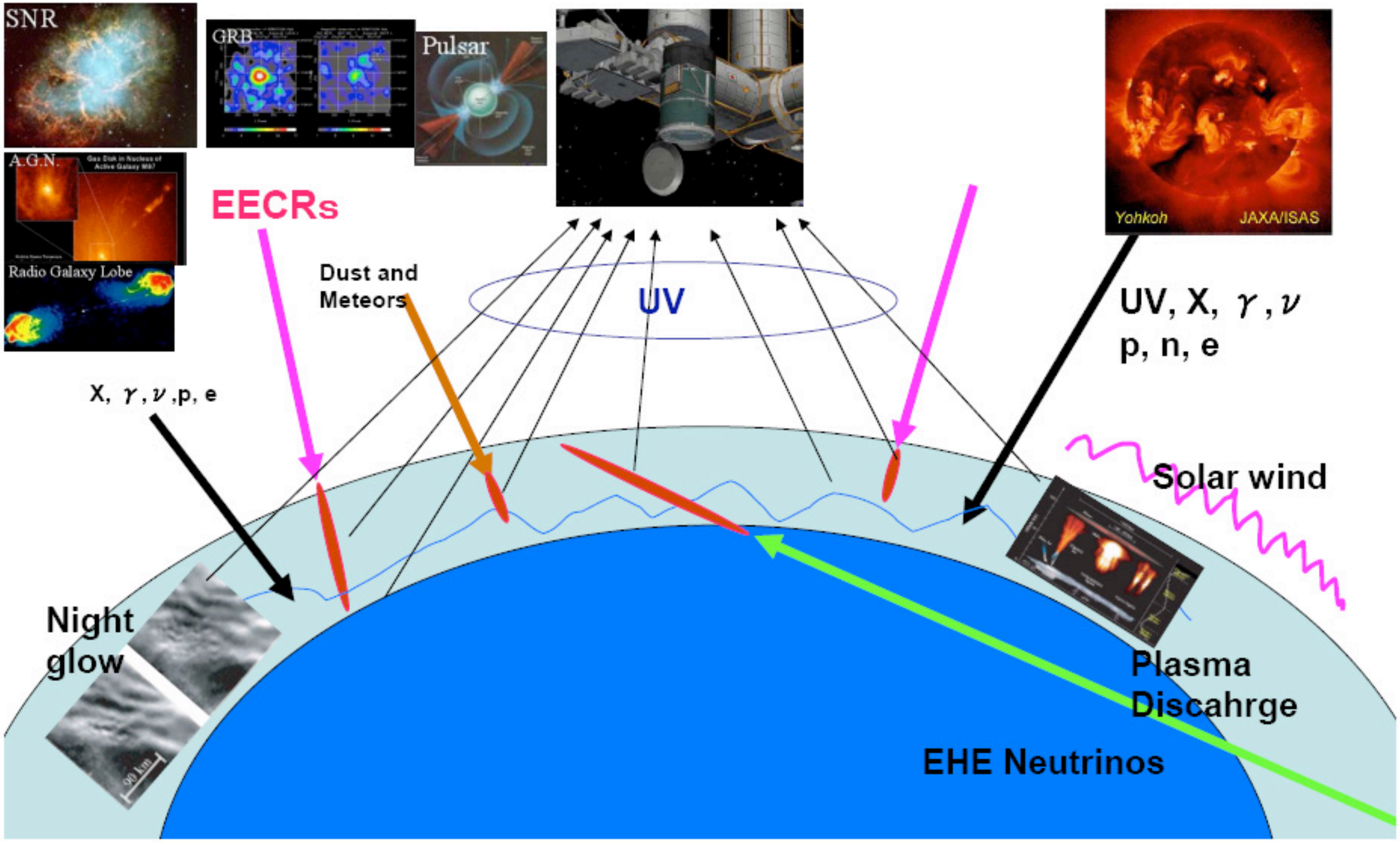


12 countries, 62 institutions, 170 members

- **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** : J-N. Capdevielle, P. Gorodetzky, D. Allard, J. Dolbeau), T. Patzak, J.J. Jaeger, E. Parizot, D. Semikoz, J. Weisbard (*APC,IN2P3,CNRS*), S. Dagoret-Campagne *(LAL,IN2P3,CNRS)*
- **Germany**: M. Teshima, T. Schweizer (*MPI, Munich*), A. Santangelo, E. Kendziorra, F. Fenu (*Univ. Tuebingen*), P. Biermann (*MPI Bonn*), K. Mannheim (*Wuerzburg*), J. Wilms (*Univ. Erlangen*)
- **Italy** : E. Pace, M. Focardi, P. Spillantini (*U. Firenze*) V.Bratina, A. Zuccaro Marchi, L. Gambicorti (*CNR-INOA Firenze*), A. Anzalone, O. Catalano, M.C. Maccarone, P. Scarsi, B. Sacco, G. La Rosa (*IAS-PA/INAF*), G. D'Ali Staiti, D. Tegolo (*U. Palermo*), M. Casolino, M.P. De Pascale, P. Picozza, (*INFN and Univ. Rome "Tor Vergata"*), P. Vallania (*IFSI-INAF Torino*), P. Galeotti, C. Vigorito, M. Bertaina (*U. Torino*), A. Gregorio (*Trieste*), F. Isgro, F.Guario, D. D'urso, D. Supanifsky (*U. "Federico II" di Napoli*), G. Osteria, D. Campana, M. Ambrosio, C. Aramo (*INFN-Nappli*)
- **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.*), T.W. Kim (*Ajou University*), S.W. Kim (*Yonsei University*), K.K. Joo (*Chonnam National University*)
- **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*)
- **Poland**: T. Batsch, B. Szabelska, J. Szabelski, T. Wibig(IPJ), T. Tymieniecka(Podlasie Univ.), Z. Wlodarczyk(Kielce Univ.), G. Siemieniec-Ozieblo(Jagiellonian Univ.)
- **Slovakia**: K. Kudela, R. Bucik, R. Bobik, M. Slivka (Inst. Experimental Physics, KOSICE)

0. Scientific Objectives

JEM-EUSO
=Astronomical Earth Observatory



Science Objectives

- **Main Objective**:

  Astronomy and astrophysics through particle channel with extreme energies

  – Possible identification of the particle and energy sources based on the analysis of the arrival direction

  – Possible identification of the acceleration and radiation mechanisms with the measurement of energy spectrum from individual sources

- **Exploratory objective**:

  – Measurement of extreme energy gamma rays

  – Detection of extreme energy neutrinos

  – Estimation of the structure of galactic magnetic field and its intensity

  – Identification of relativity and quantum gravitational effect

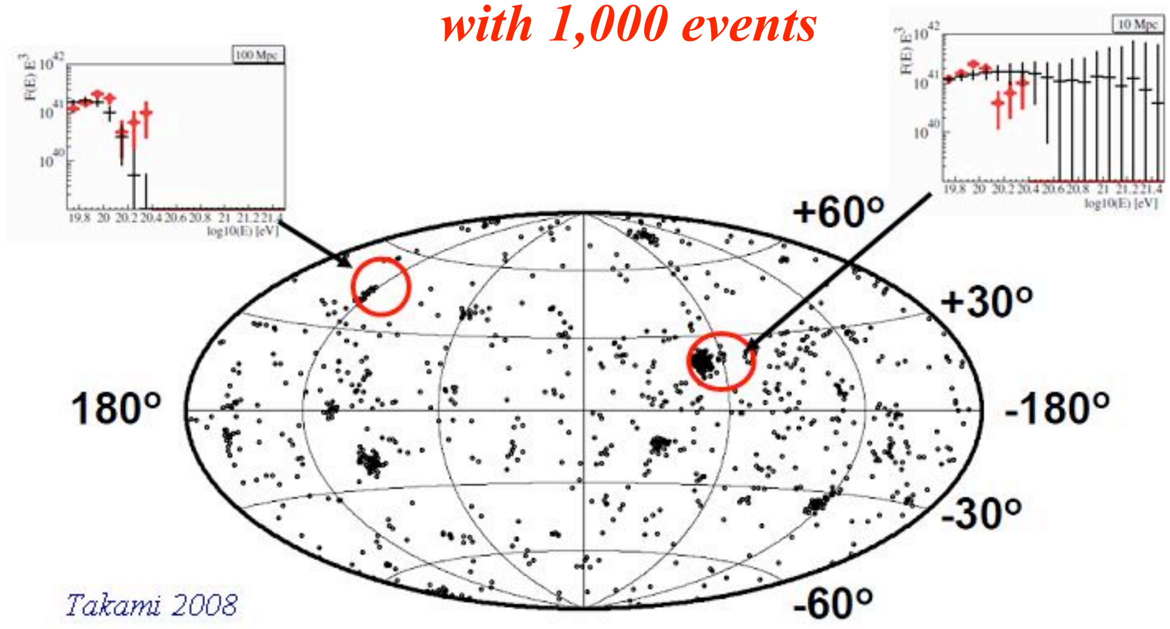
  – Study of atmospheric luminous phenomena

Success criteria

Full success：
detect more than 1000 events with energy higher than 7×10^{19} eV

Minimum success：
500 events
(minimum to identify sources)

JEM-EUSO sky simulated with 1,000 events



Brightness of UHECR∝? X ray（AGN）

Analysis of the arrival direction of particles

- Accuracy of the determination of the arrival direction：less than 2.5 °

Analysis of spectrum

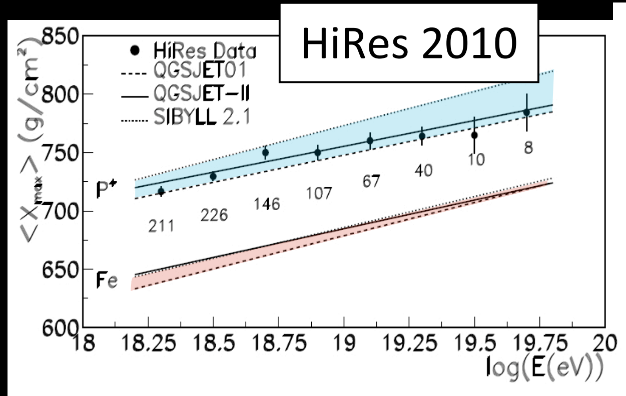
- Accuracy of the energy determination： less than 30%

Identification of Hadron/ photon/ neutrino：

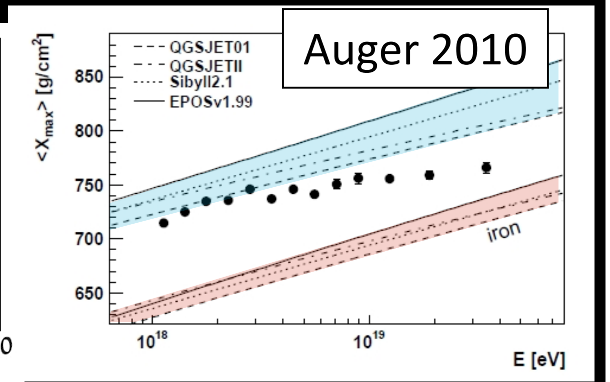
- Accuracy of the Xmax determination: <120 g /cm^2

Open problems:

- What is the nuclear composition of UHECR?

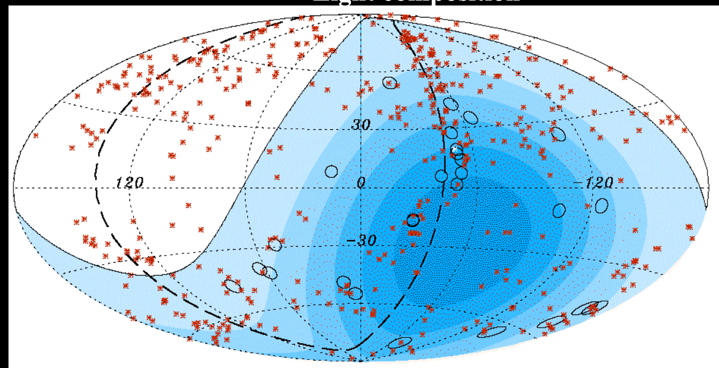


Light composition



Heavier composition above ankle

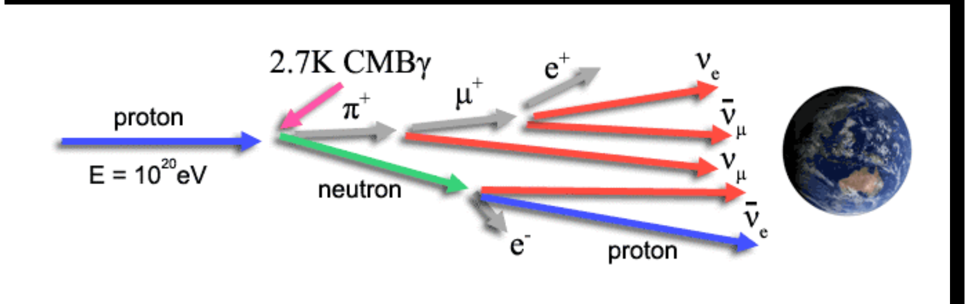
- Are the sources isotropic or not? What is the role of CenA region?



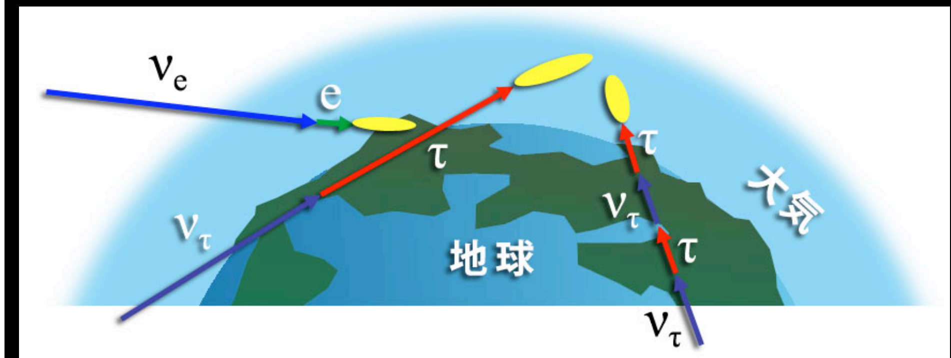
Auger (07,08): excess correlation of UHECR arrival directions with nearby (weak) AGN   99% c.l. rejection of isotropy of arrival directions
HiRes rejects correlation with galaxy and AGN catalogs at 95% cl...

Exploratory Objectives

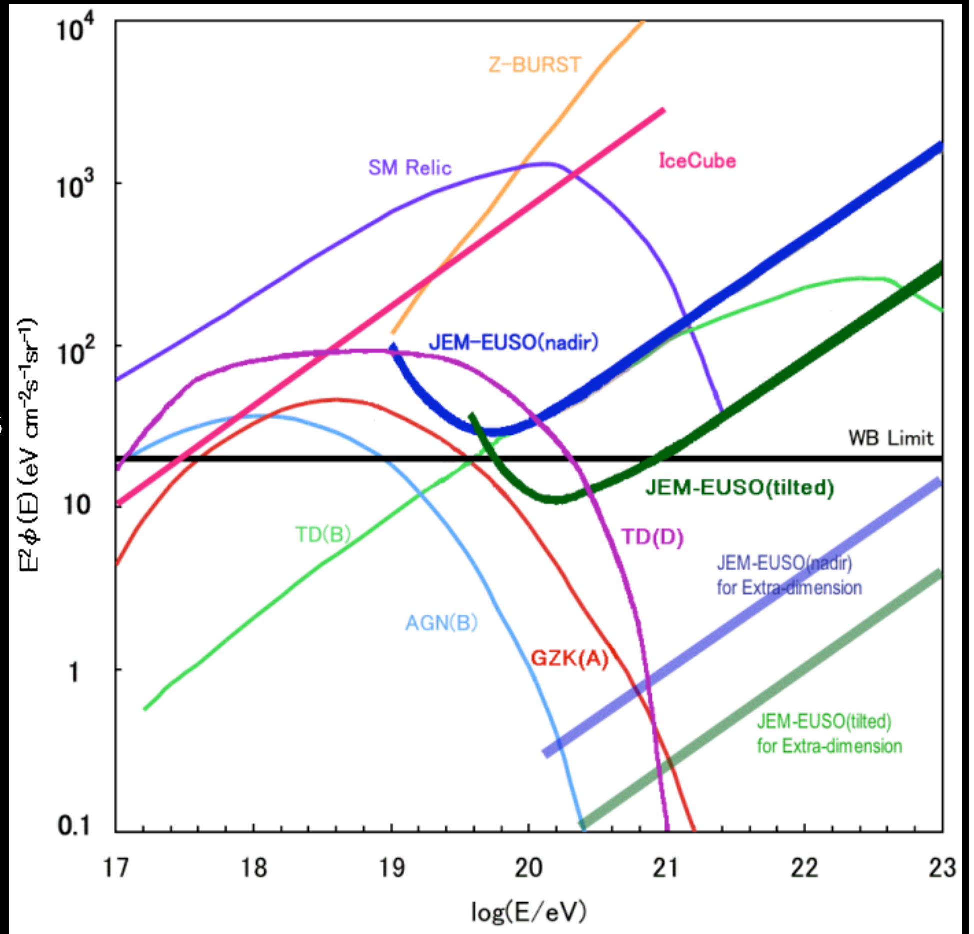
Extreme Energetic Cosmic Neutrinos



Neutrino production by the GZK process



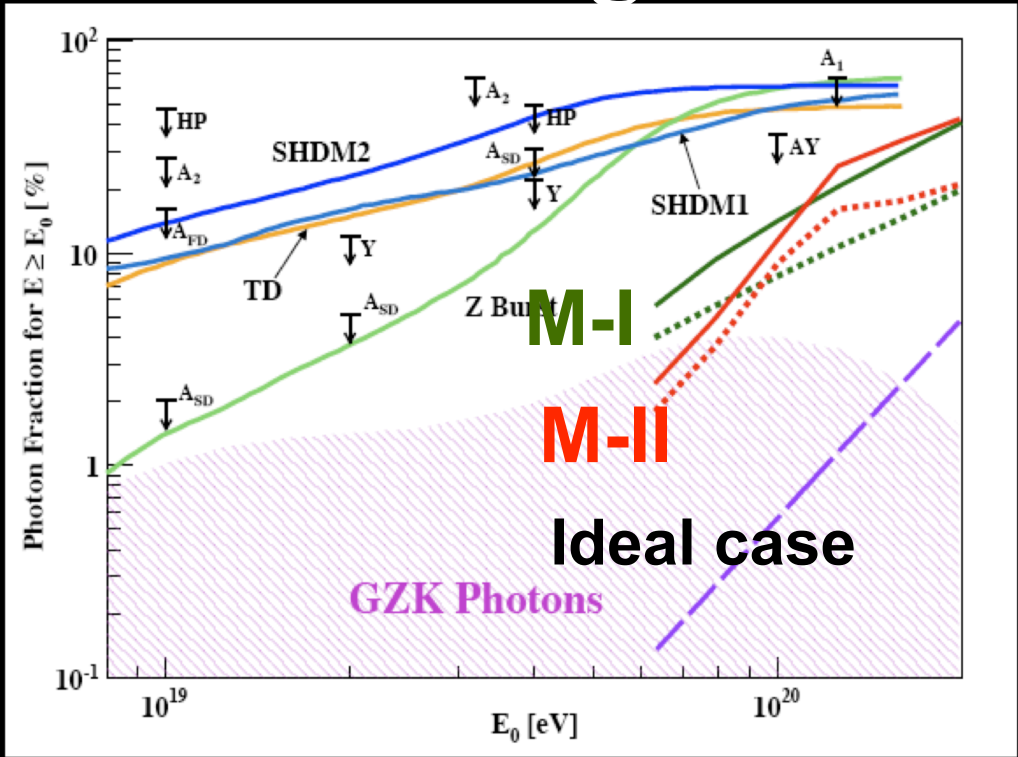
Air showers initiated by different kind of neutrinos



Neutrino fluxes for various models and detection capability of JEM-EUSO

Exploratory Objectives

Expected sensitivity on gamma ray fraction

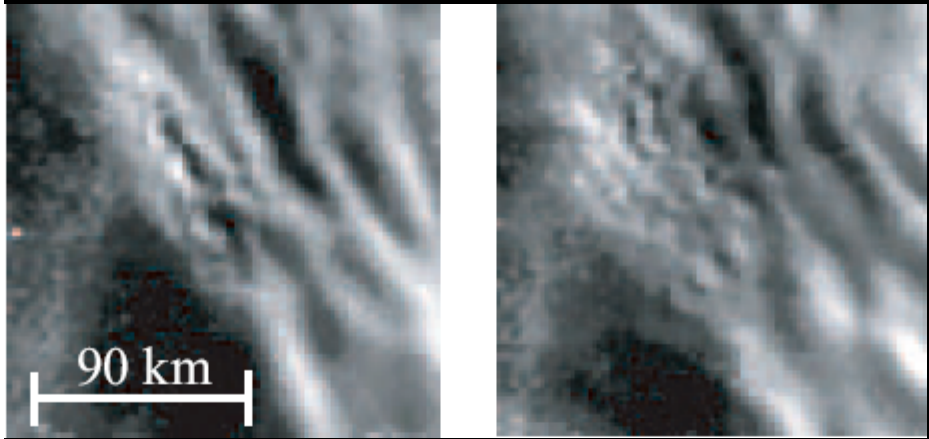


Expected limit by 5 year mission compared with upper limits set by existing experiments (95%CL)

- Ideal case (only statistics): Xmax strong discriminator for gamma ray
- More realistic estimate (assumed experimental errors in *X*max) using 2 different approaches to evaluate flux limit
  → New and stringent limit expected @ the highest energies (~10^{20}eV)
  - Possible detection of GZK photons during the Mission

Exploratory Objectives

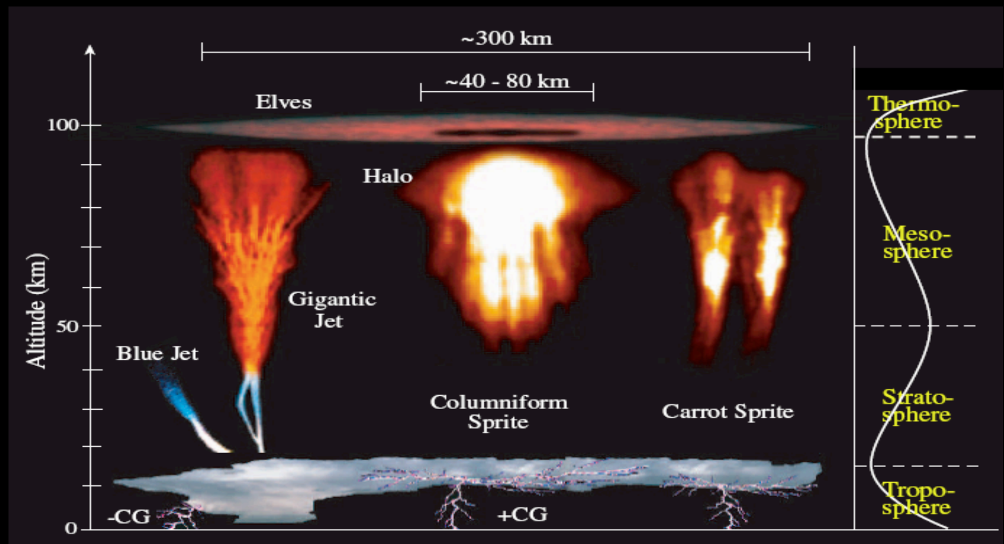
Atmospheric Luminous Phenomena



OH airglow observed from ground

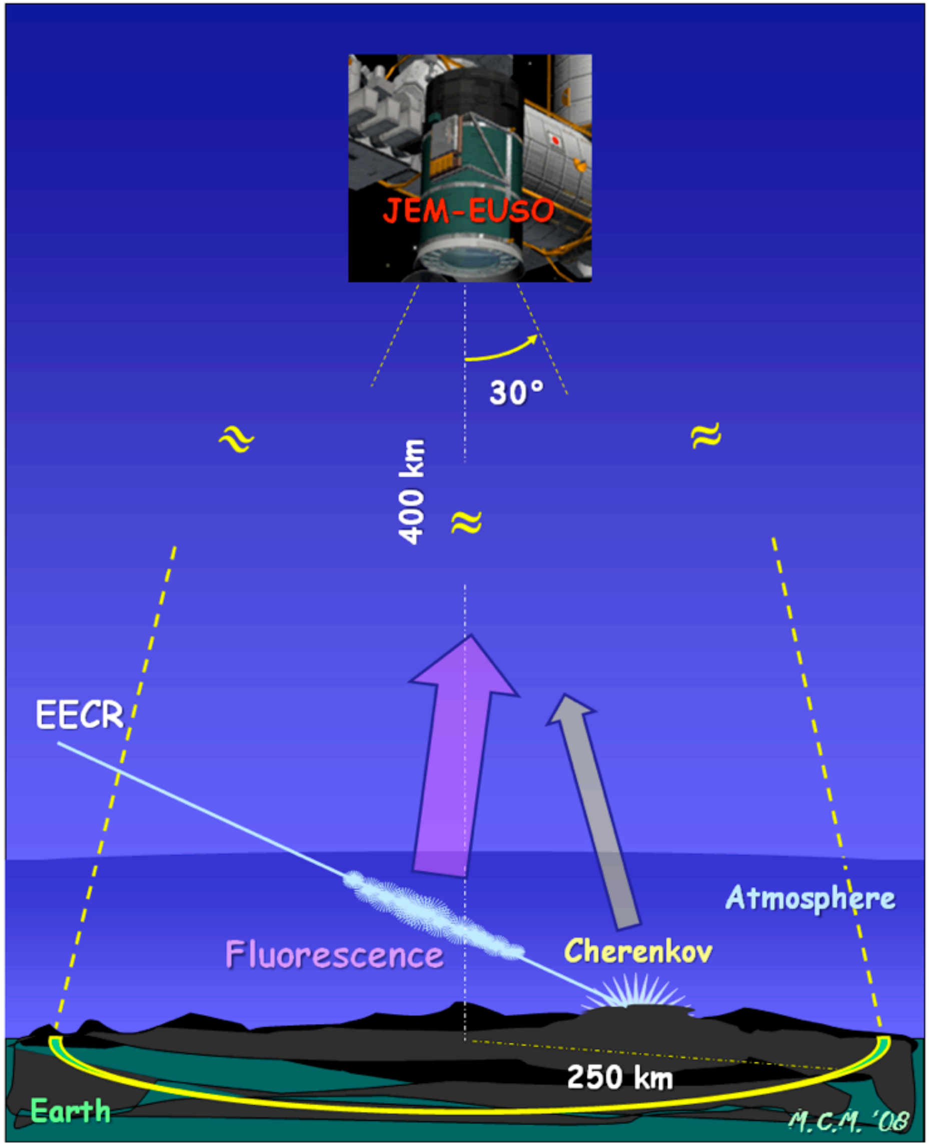
Lightning picture observed from ISS

Leonid meteor swarm in 2001 taken by Hivison camera



Various trangent airglows

1.Principle of observation



Large distance > 400 km

Large FOV [redacted]

[redacted] ≈ [redacted] × [redacted] · [redacted]

η [redacted] ≈ [redacted] ÷ [redacted]

[redacted] ≈ [redacted] ÷ [redacted] × [redacted] · [redacted]

Large Target Mass of the atmosphere

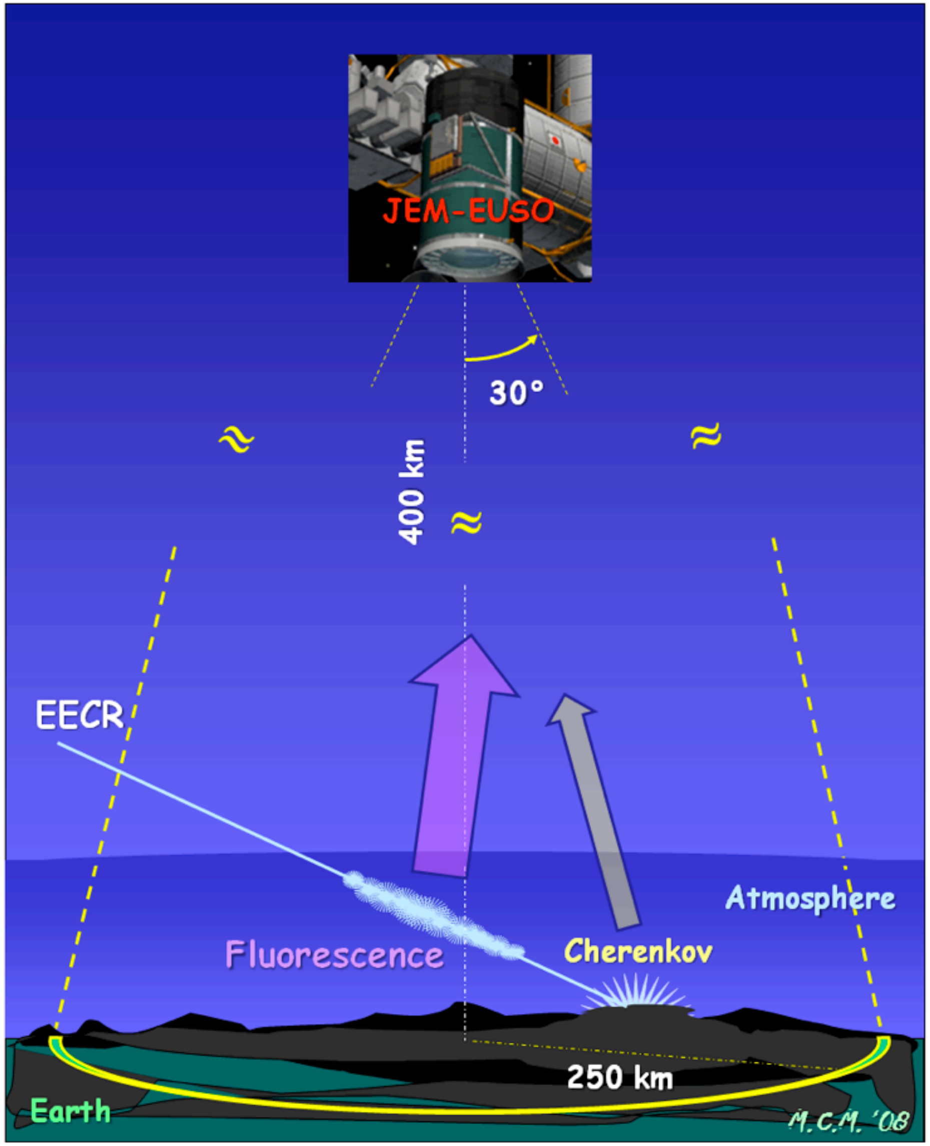
[redacted]

Full sky coverage looking at both North and South sky

[redacted] π [redacted]

Large Distance R but small proximity effect

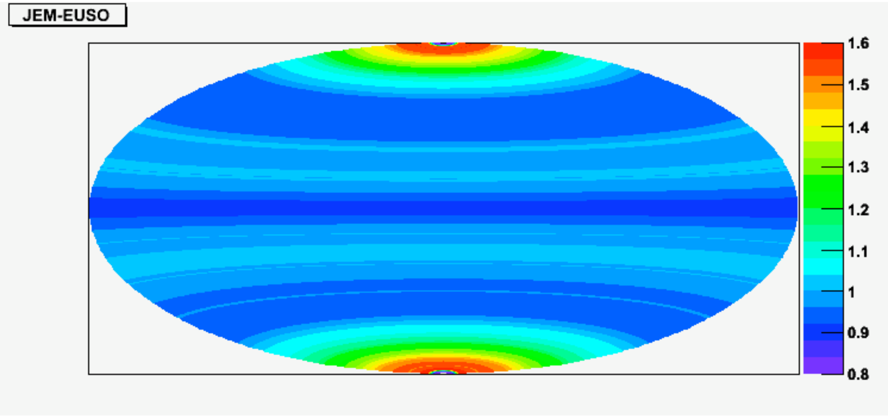
[redacted]

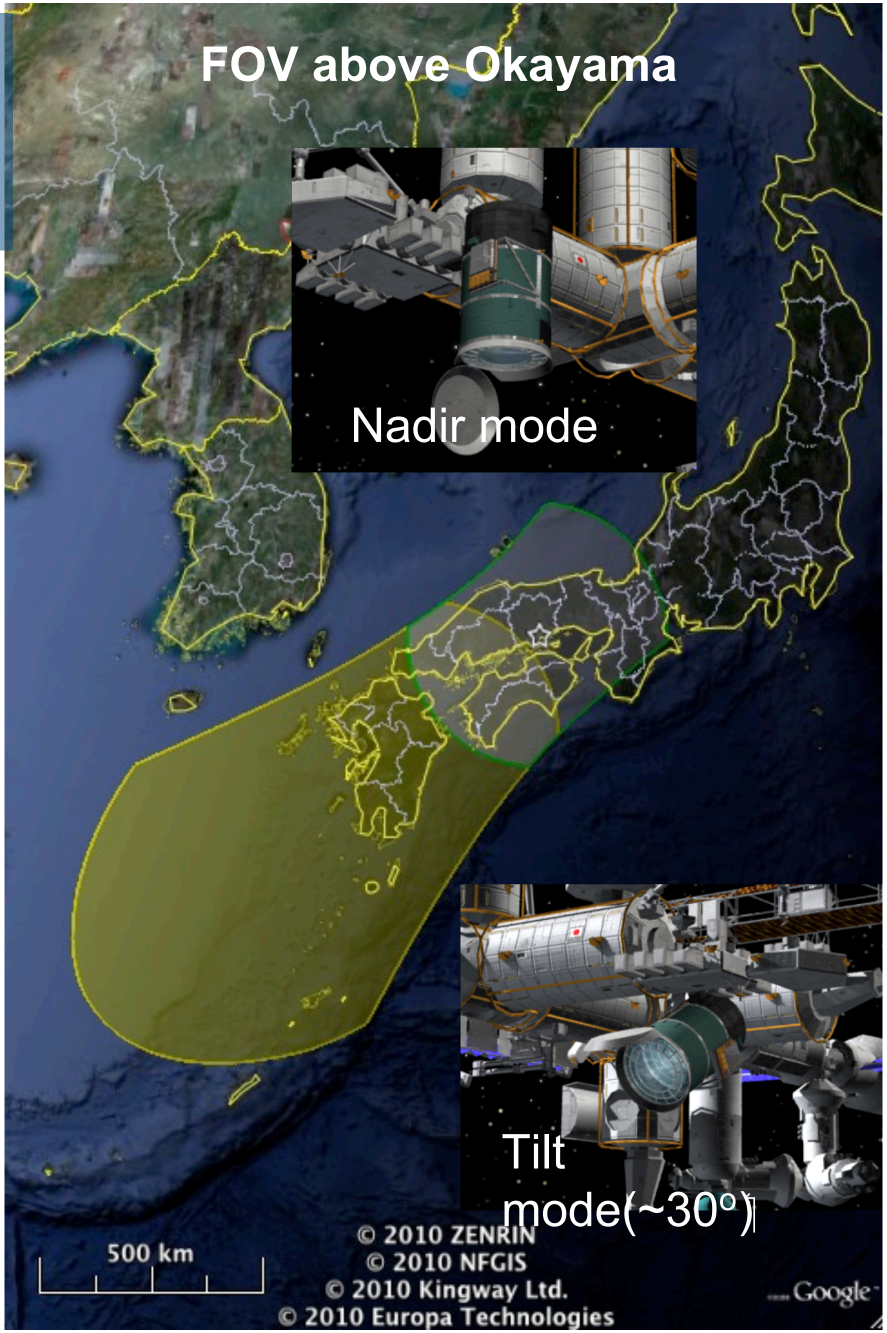


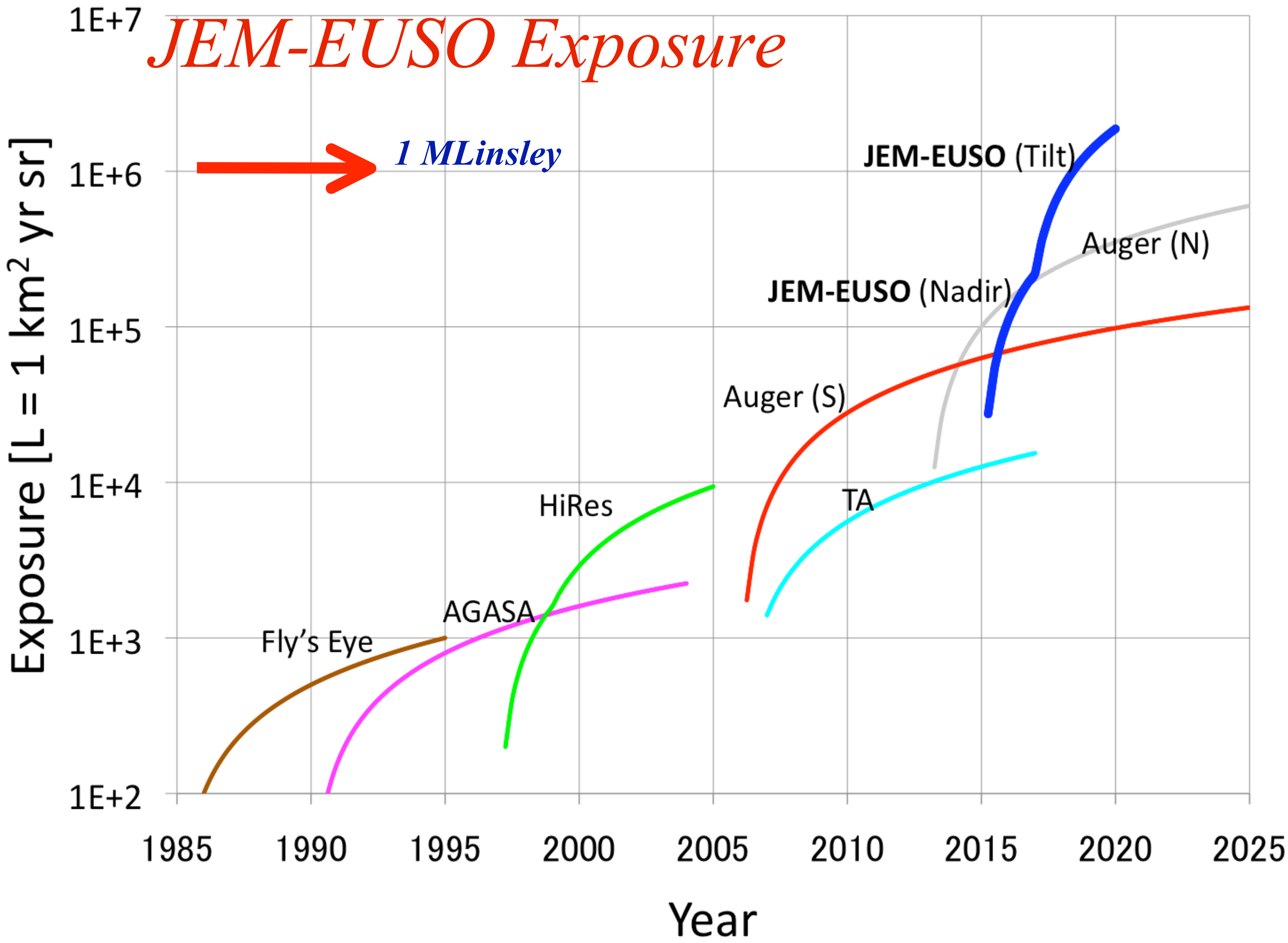
JEM-EUSO Field of view in Nadir and Tilt Mode

- **International Space Station-aboard EECR observatory**
  - Orbiting at ~400 km in ±51.6 degrees latitudes
  - Covers both nordern and southern hemisphere
  - Flight in varying geomagnetic field (~0.6 gauss) around orbit

- Viewing night atmosphere in ~500 x 400 km area (nadir mode)
  - Wide FOV allows to measure entire slowly developing showers
  - Target volume exceeding an order of 10^{12} tons

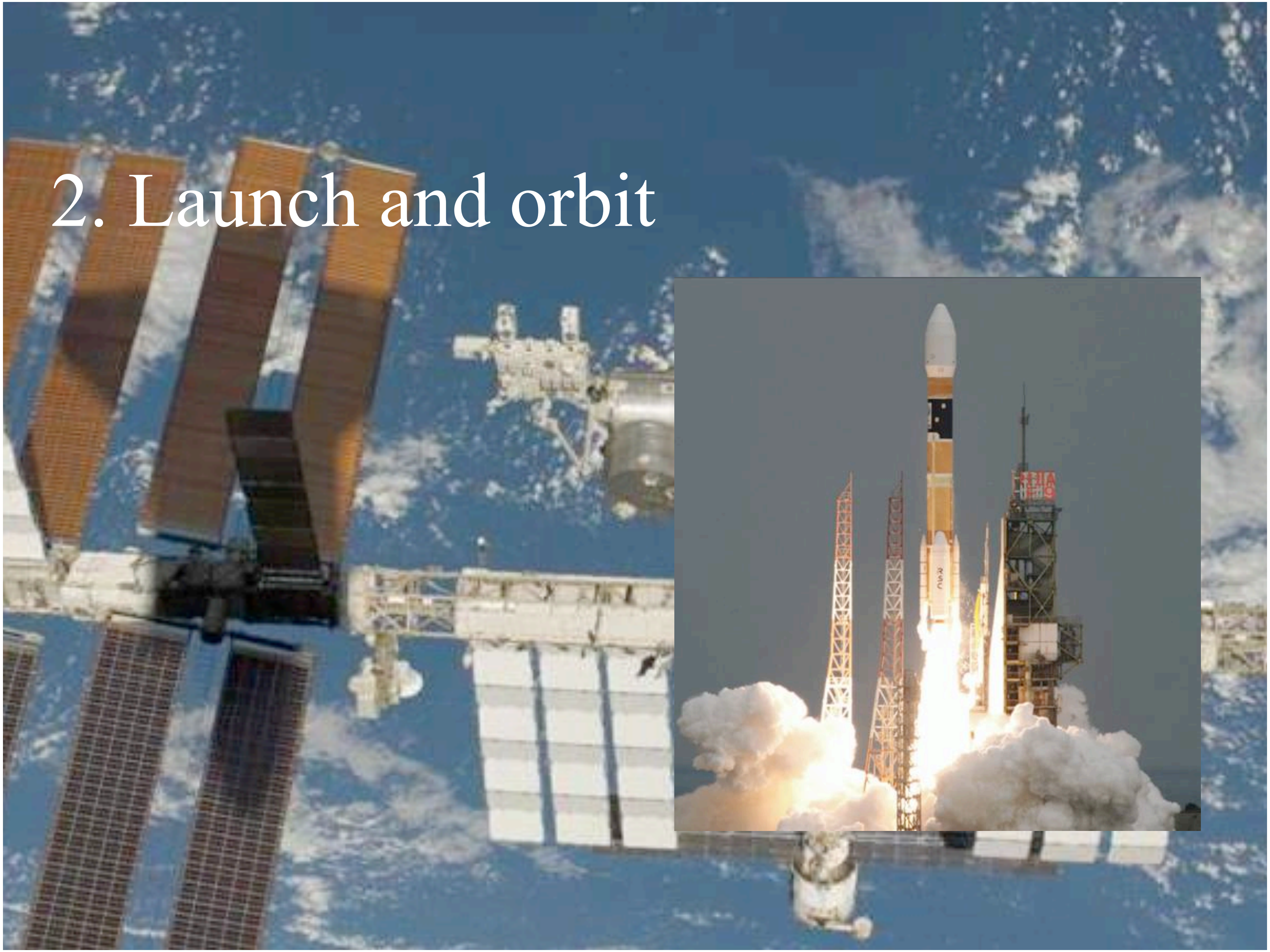






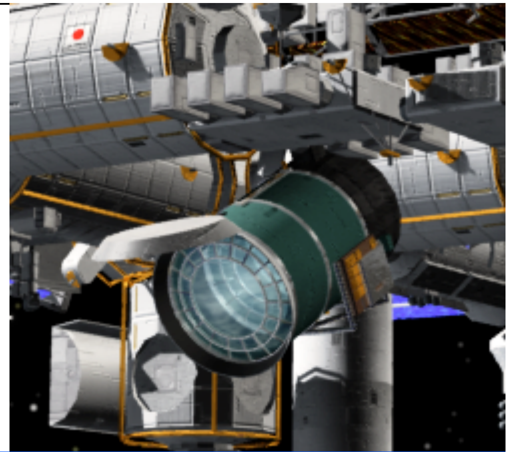
JEM-EUSO Exposure
1 MLinsley
JEM-EUSO (Tilt)
Auger (N)
JEM-EUSO (Nadir)
Auger (S)
TA
HiRes
AGASA
Fly's Eye
1E+7
1E+6
1E+5
1E+4
1E+3
1E+2
Exposure [L = 1 km² yr sr]
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year

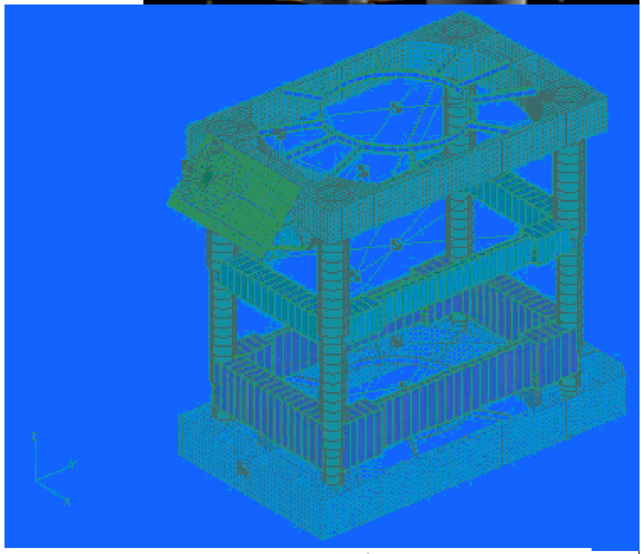
2. Launch and orbit

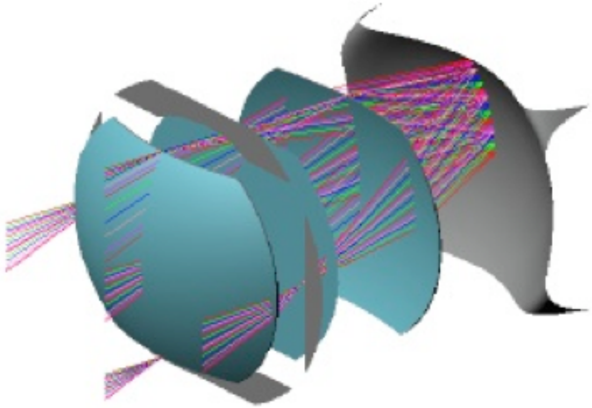


Mission Parameters

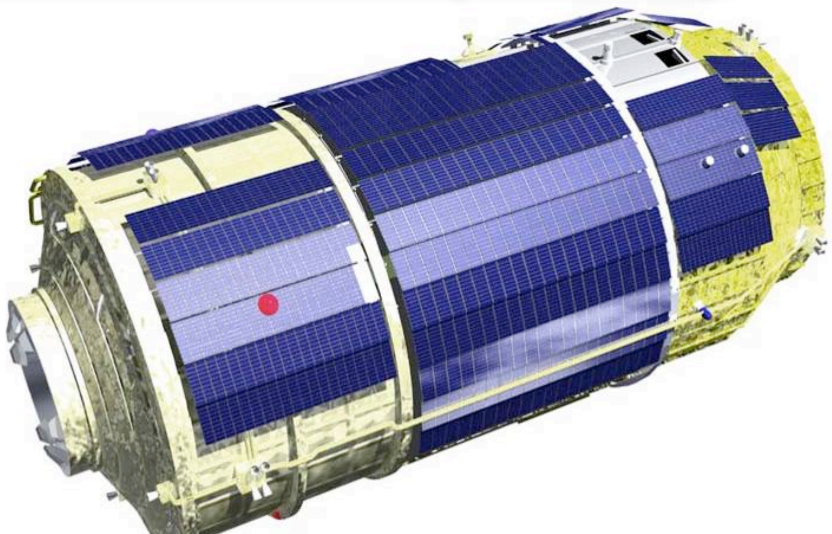
- Time of launch: year 2015
- Operation Period: 3 years (+ 2 years)
- Launching Rocket : H2B
- Transportation to ISS: un-pressurized Carrier of H2 Transfer Vehicle (HTV)
- Site to Attach: Japanese Experiment Module/ Exposure Facility #2
- Height of the Orbit: ~400km
- Inclination of the Orbit: 51.64°
- Mass: 1983 kg
- Power: 926 W (operative), 352 W (non-operative
- Data Transfer Rate: 285 kpbs + on-board storage



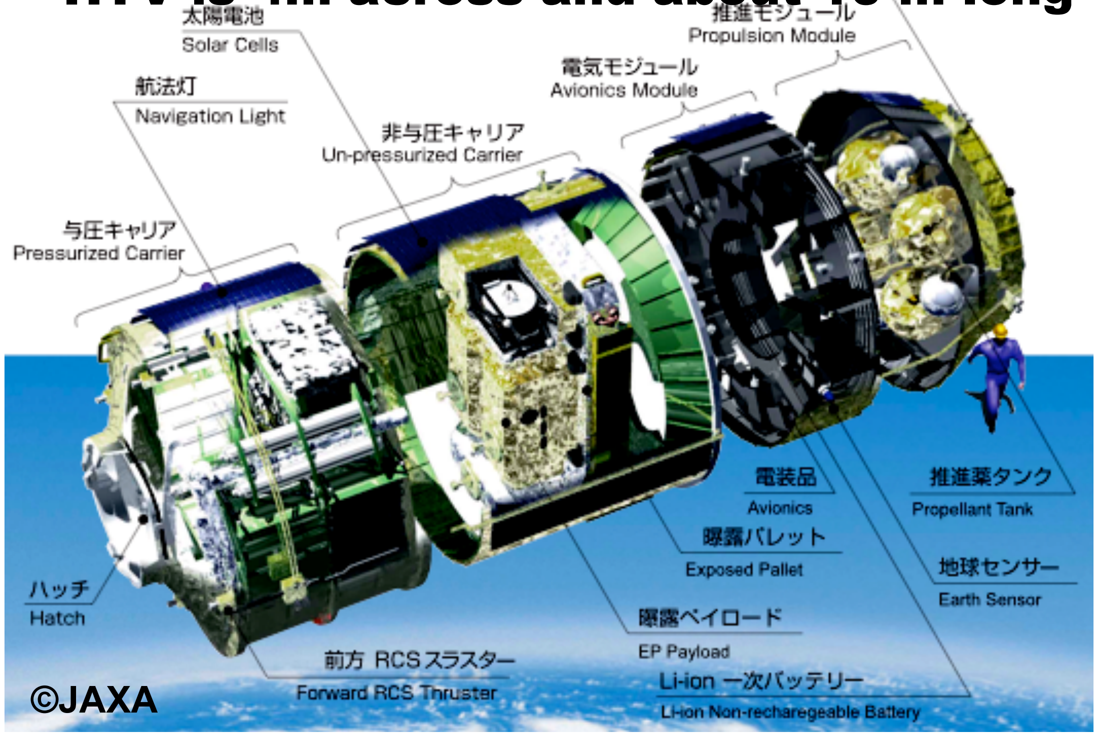


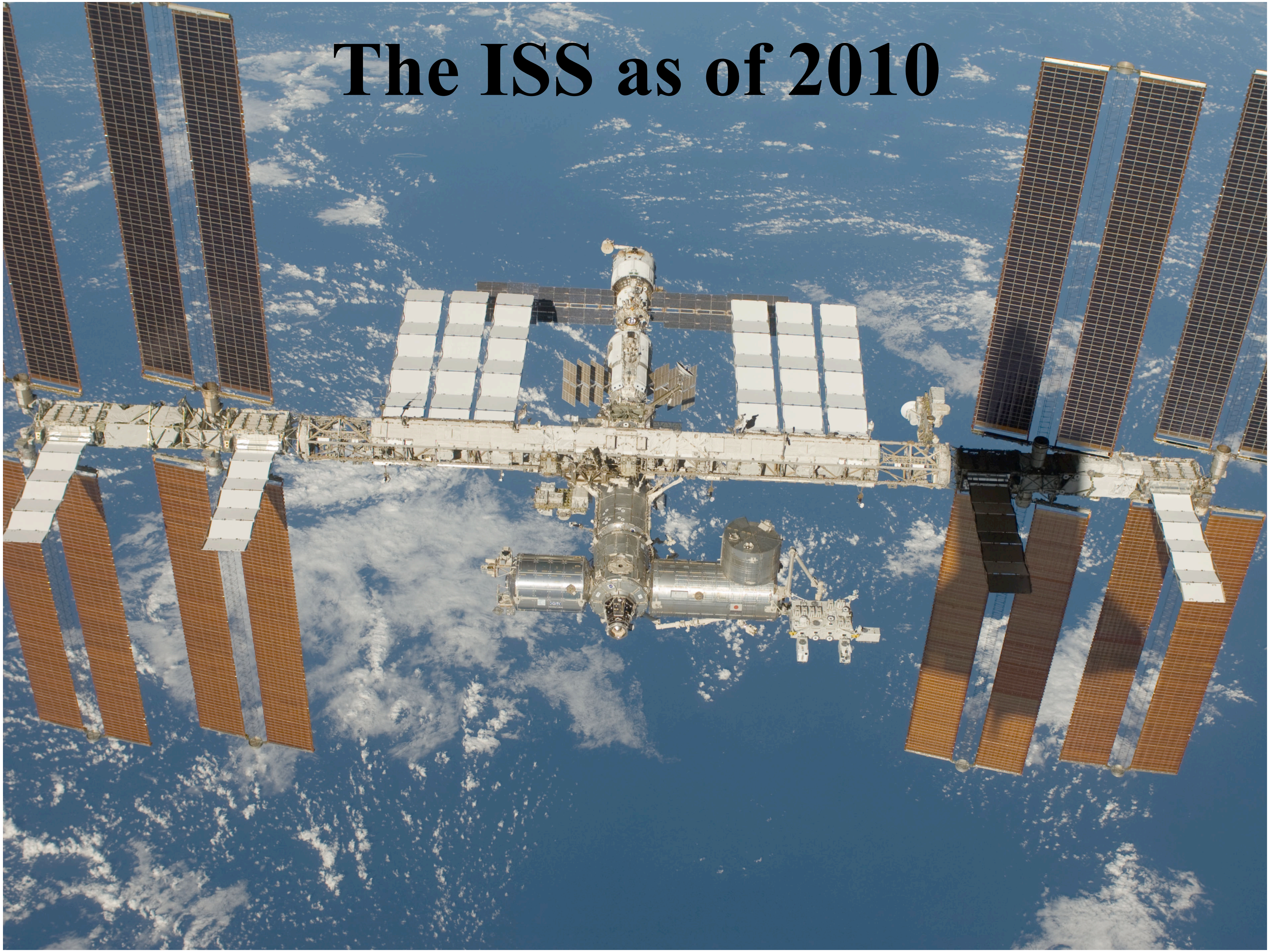


H-II Transfer Vehicle (HTV)

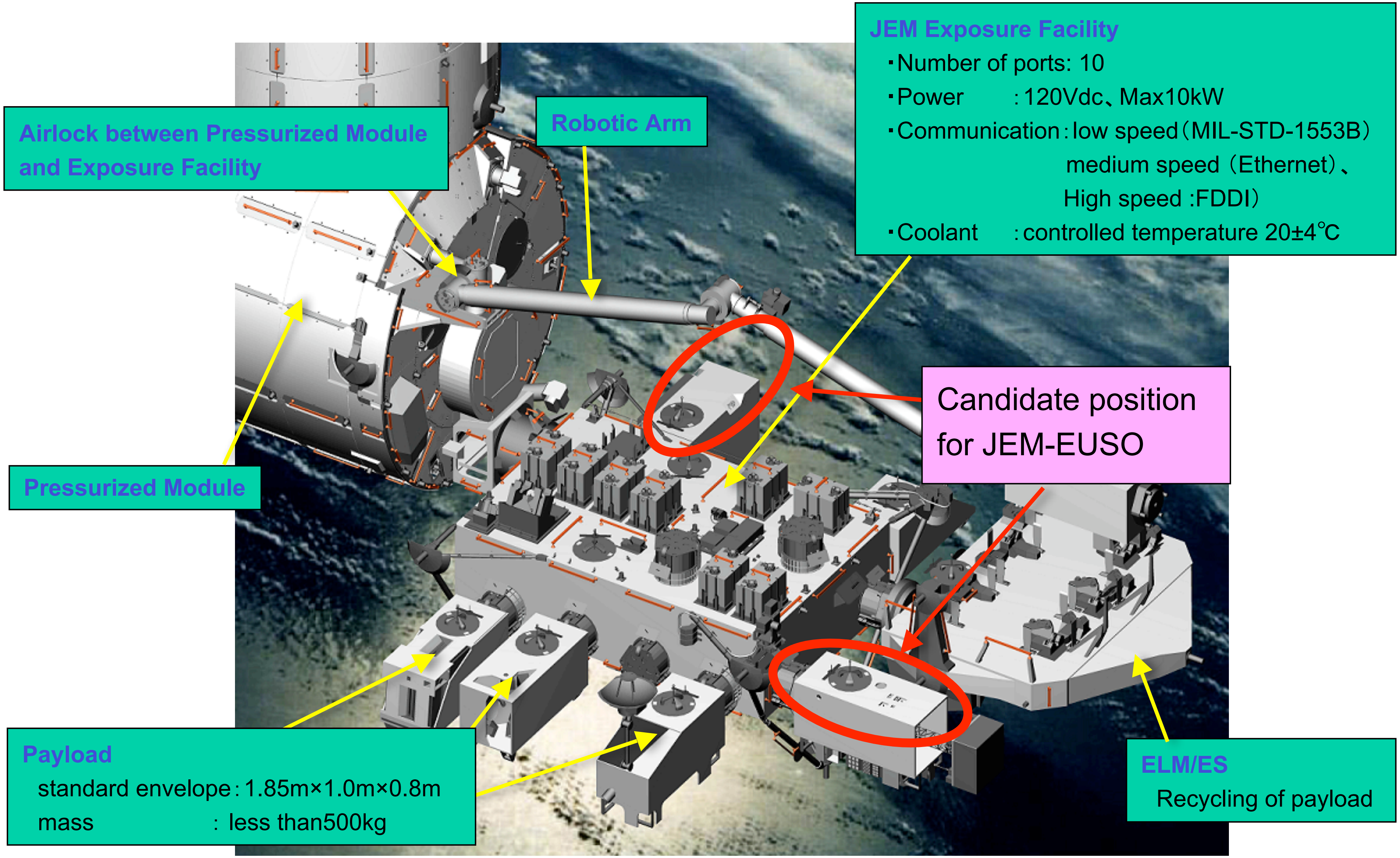


HTV is 4m across and about 10 m long

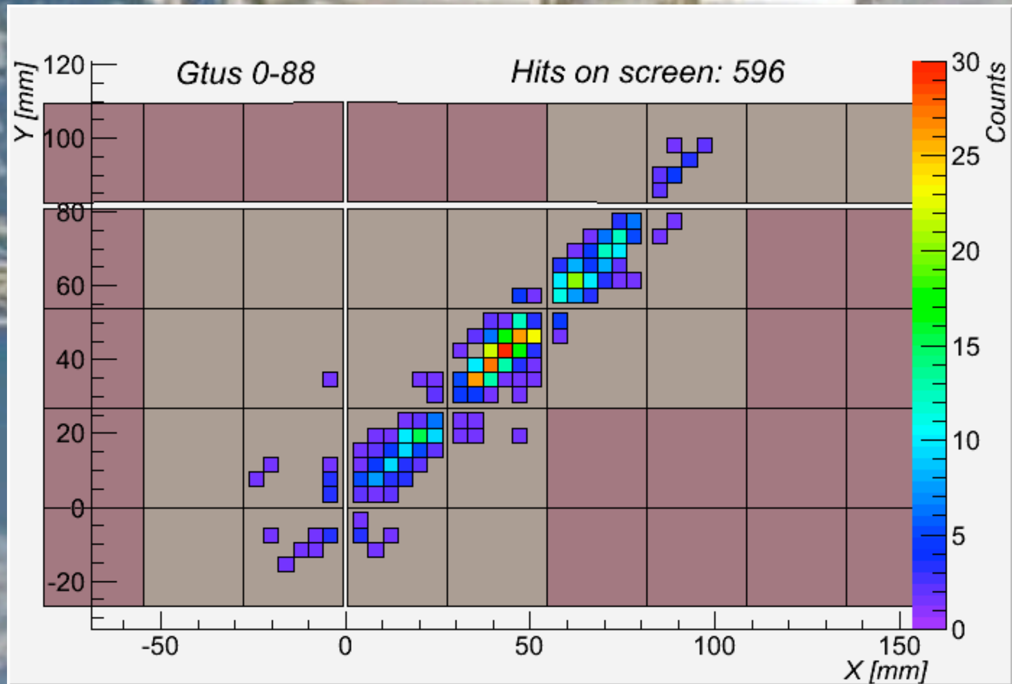



The ISS as of 2010

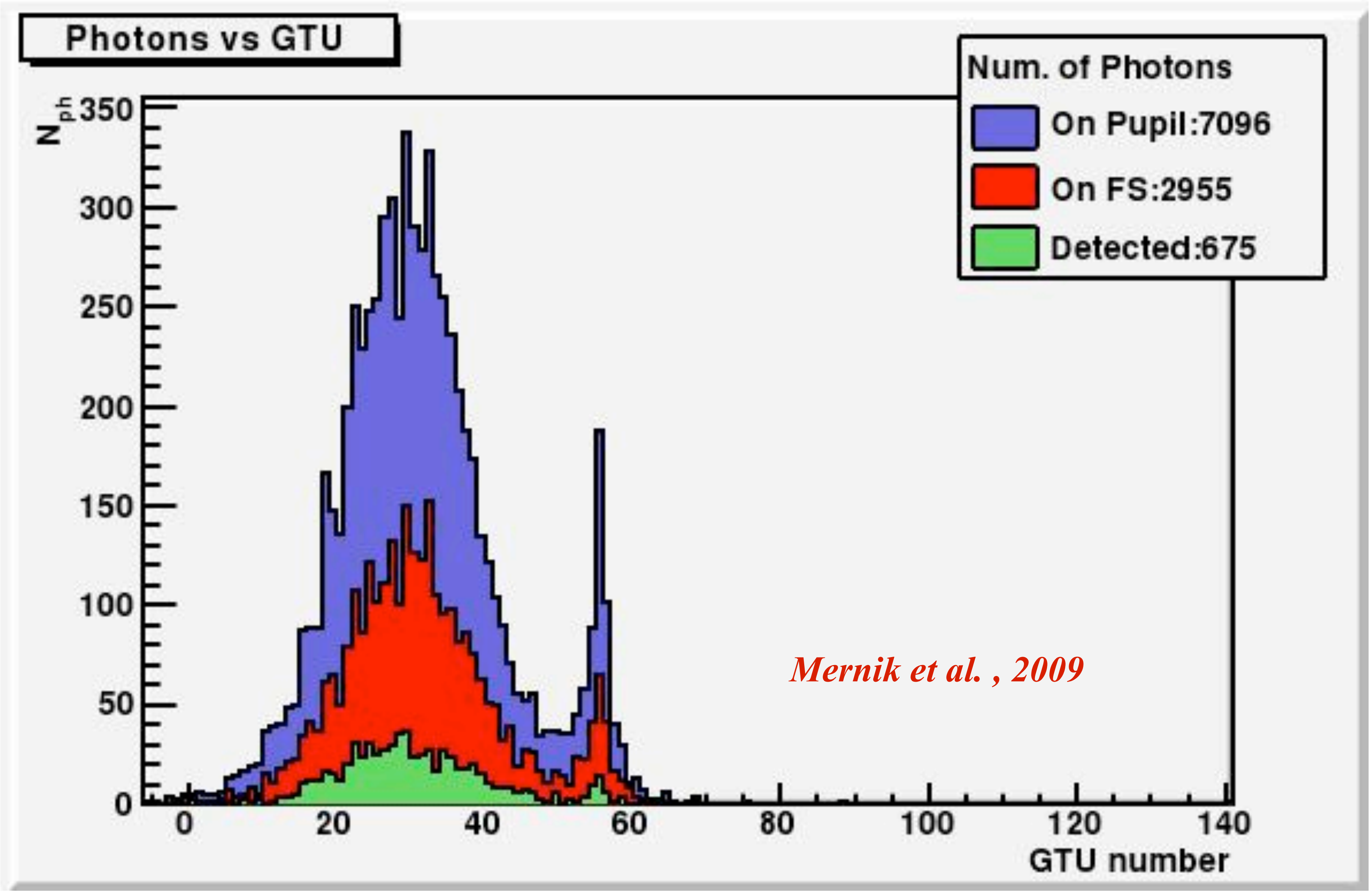
Outline of JEM Exposure Facility



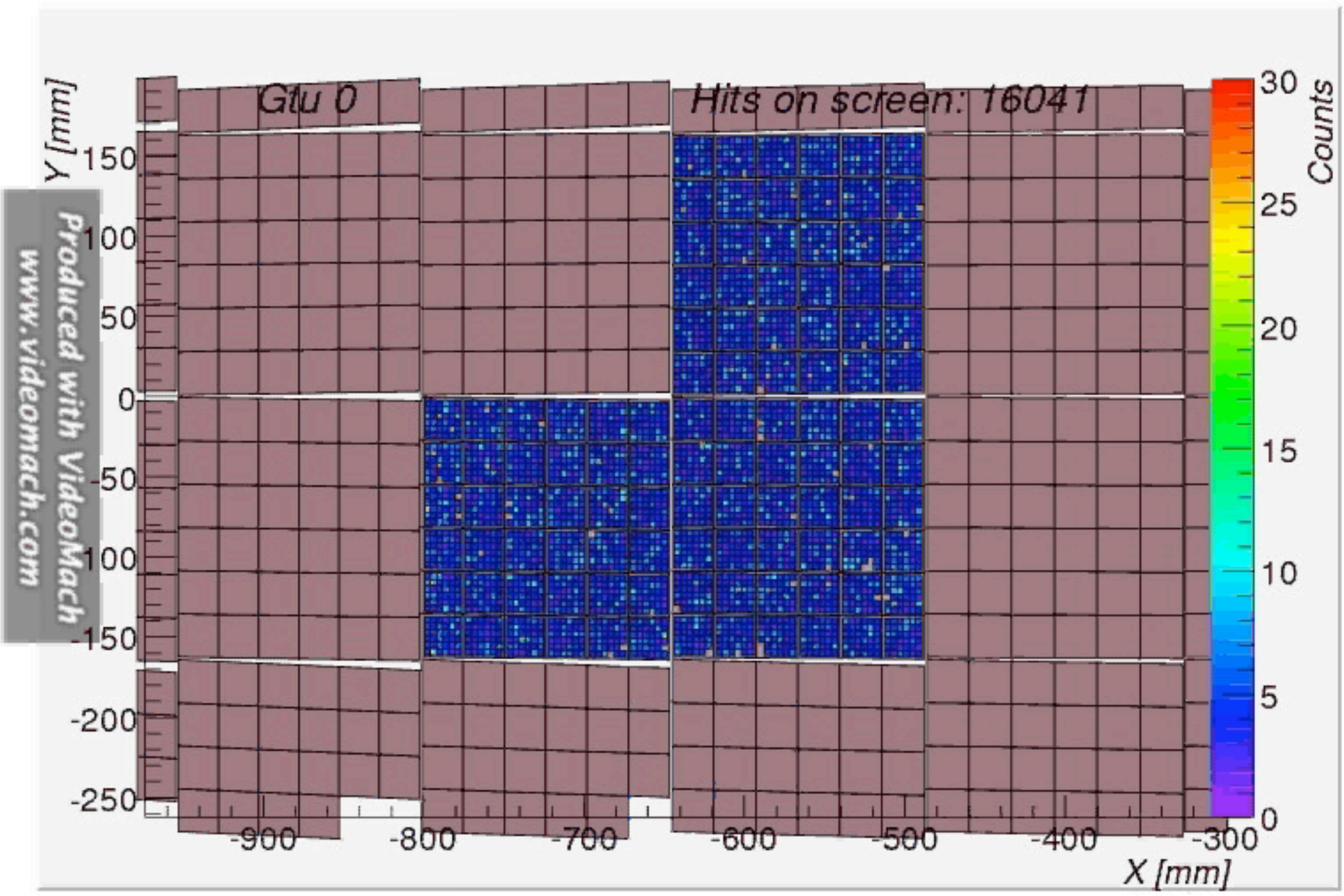
2. Signal & Backround



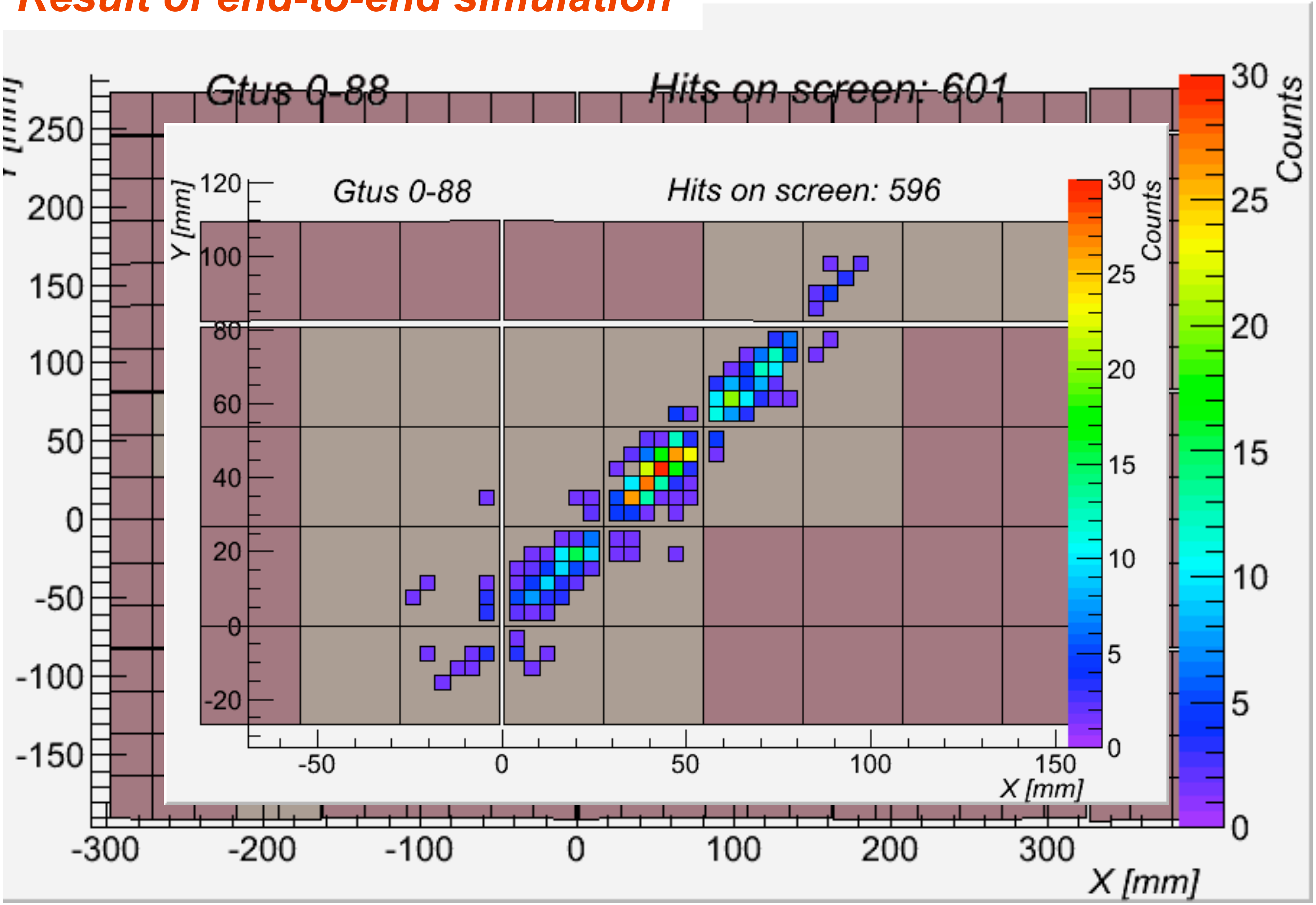
End-to-End Simulations (ESAF): Signal for a p shower (60 deg, 10^{20}eV)



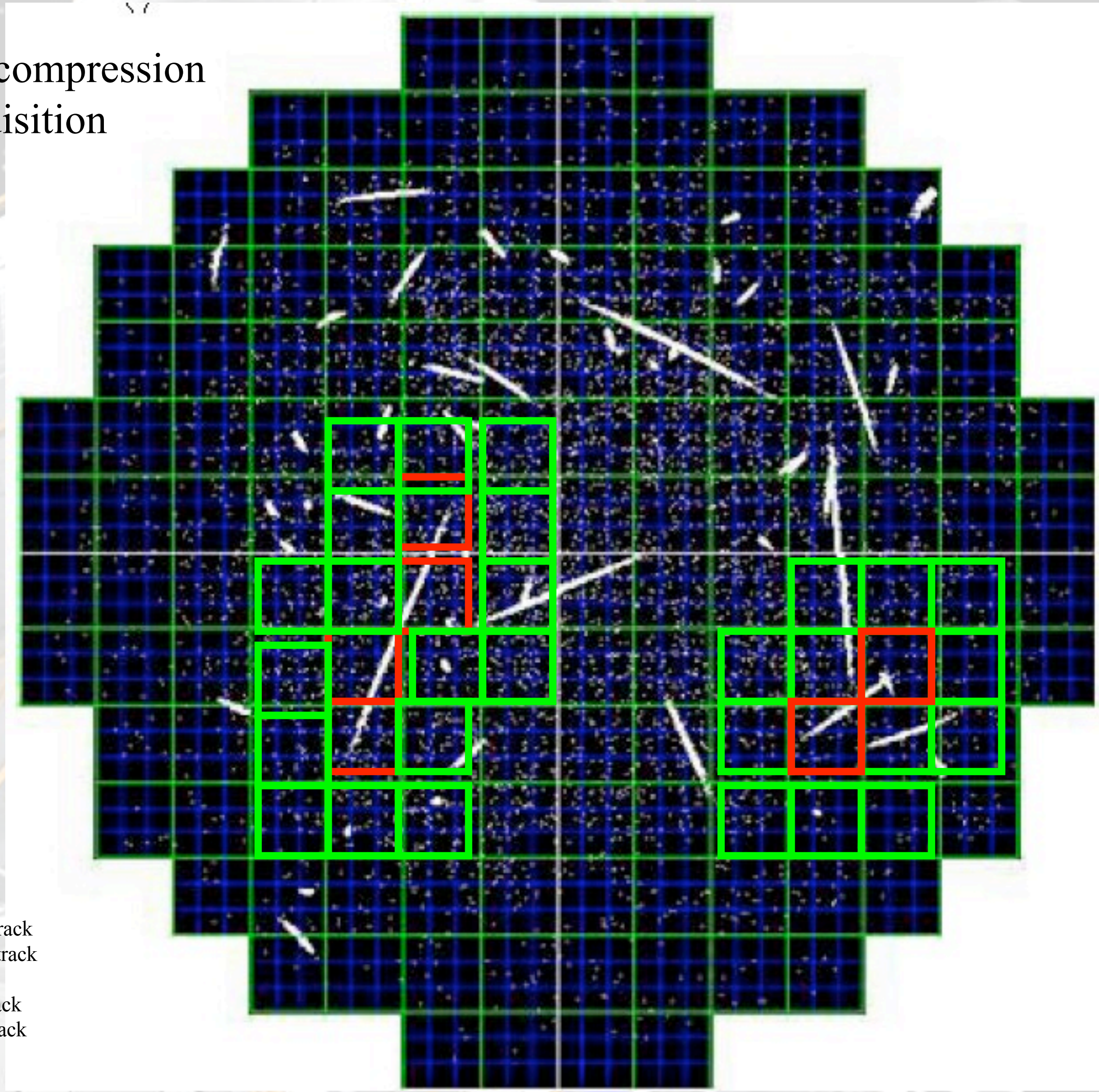
500 counts/ (ns sr m$^{2)}$



Result of end-to-end simulation



- Affects Data compression
- Not data acquisition



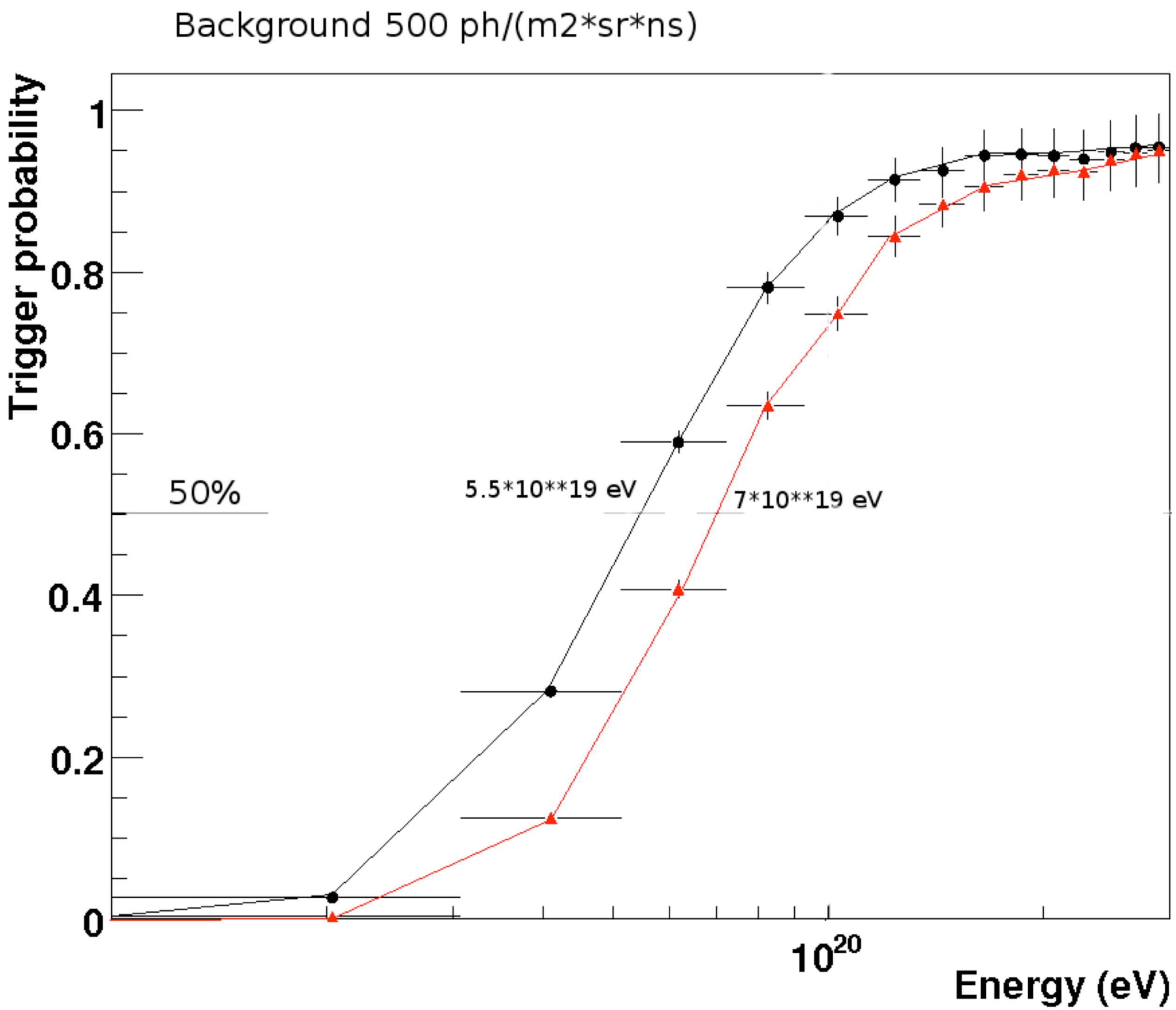
N TRIGGERED

M BOUNDARY

All inclinations
M= 14 for N=4, straight track
M = 21 for N=4 inclined track

M=10 for N=2 straight track
M=13 for N=2 inclined track

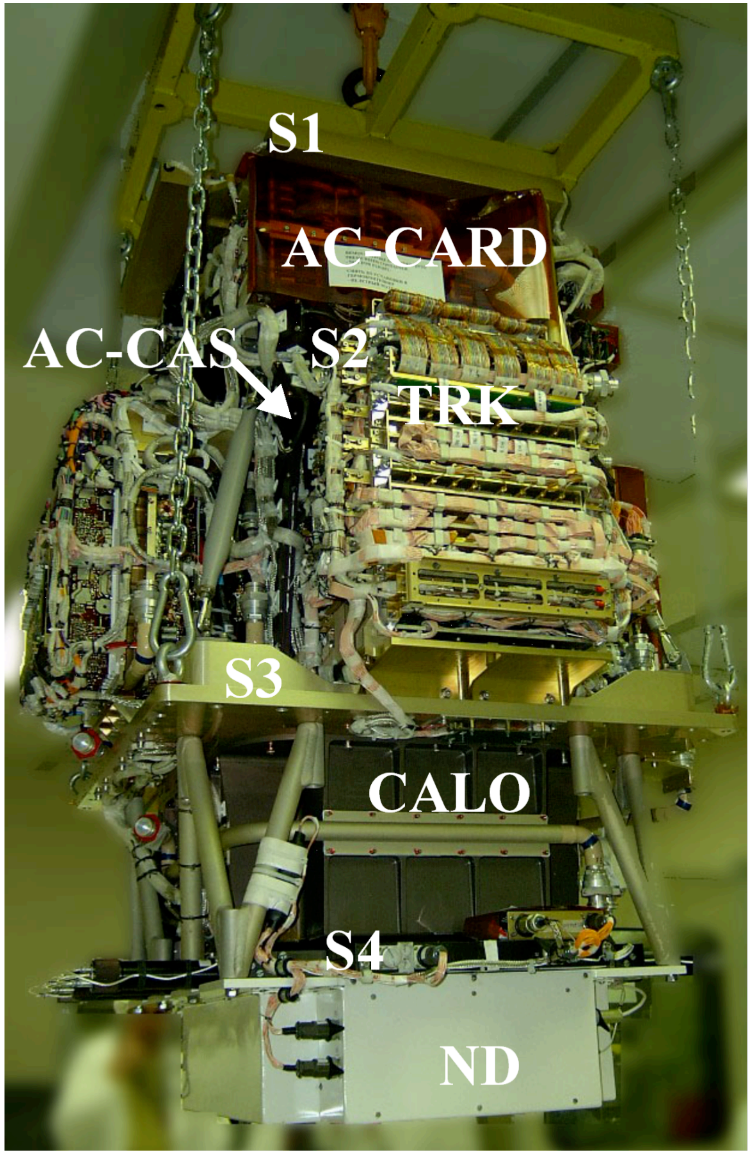
Trigger Efficiency (Dec. 09 baseline)



Experiments in space: constraints

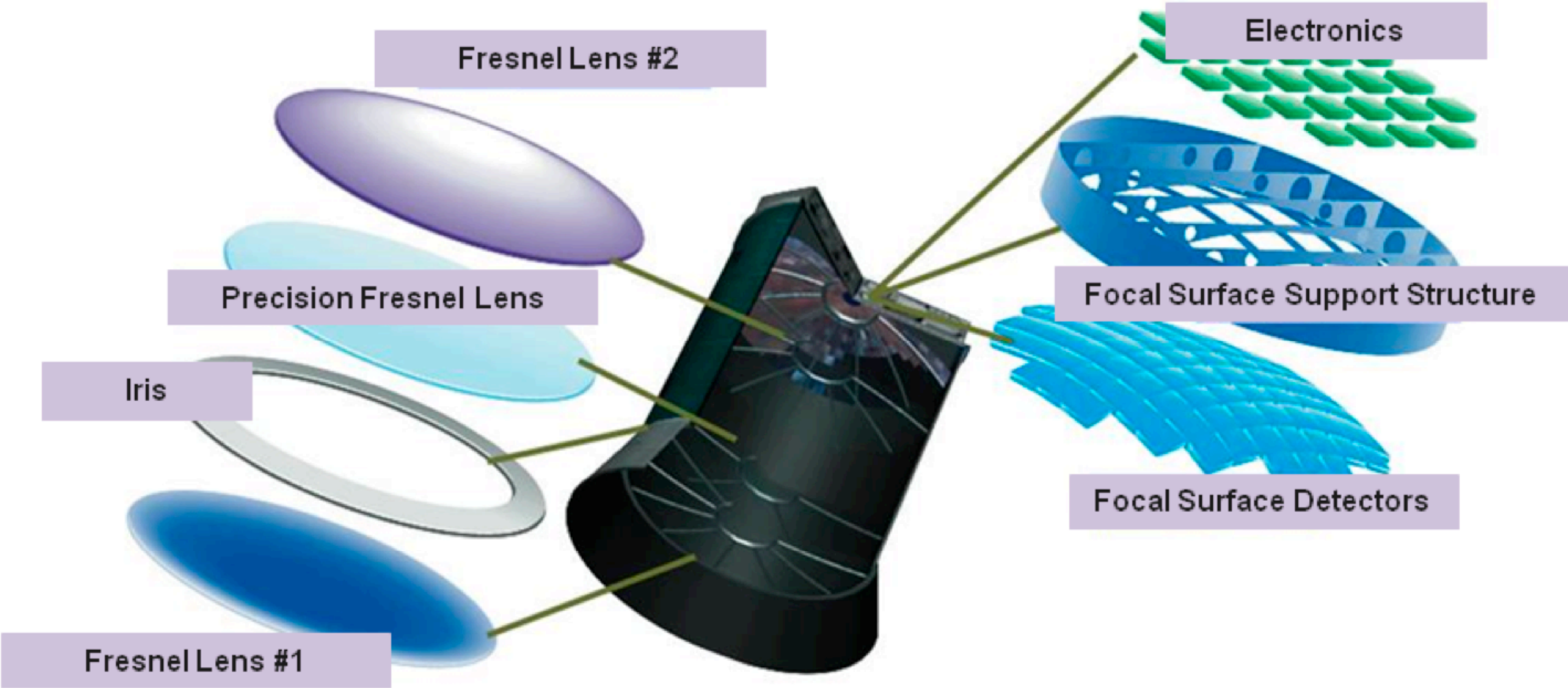
- •Mass / Size
- •Power supply
- •Thermal dissipation
- •Computational power
- •Radiation tolerance
- •Data Storage
- •Downlink to Earth

- •Redundancies
- •Telecommand handling



Pamela antimatter spectrometer on board Russian Resurs DK1 Satellite

The UV Telescope



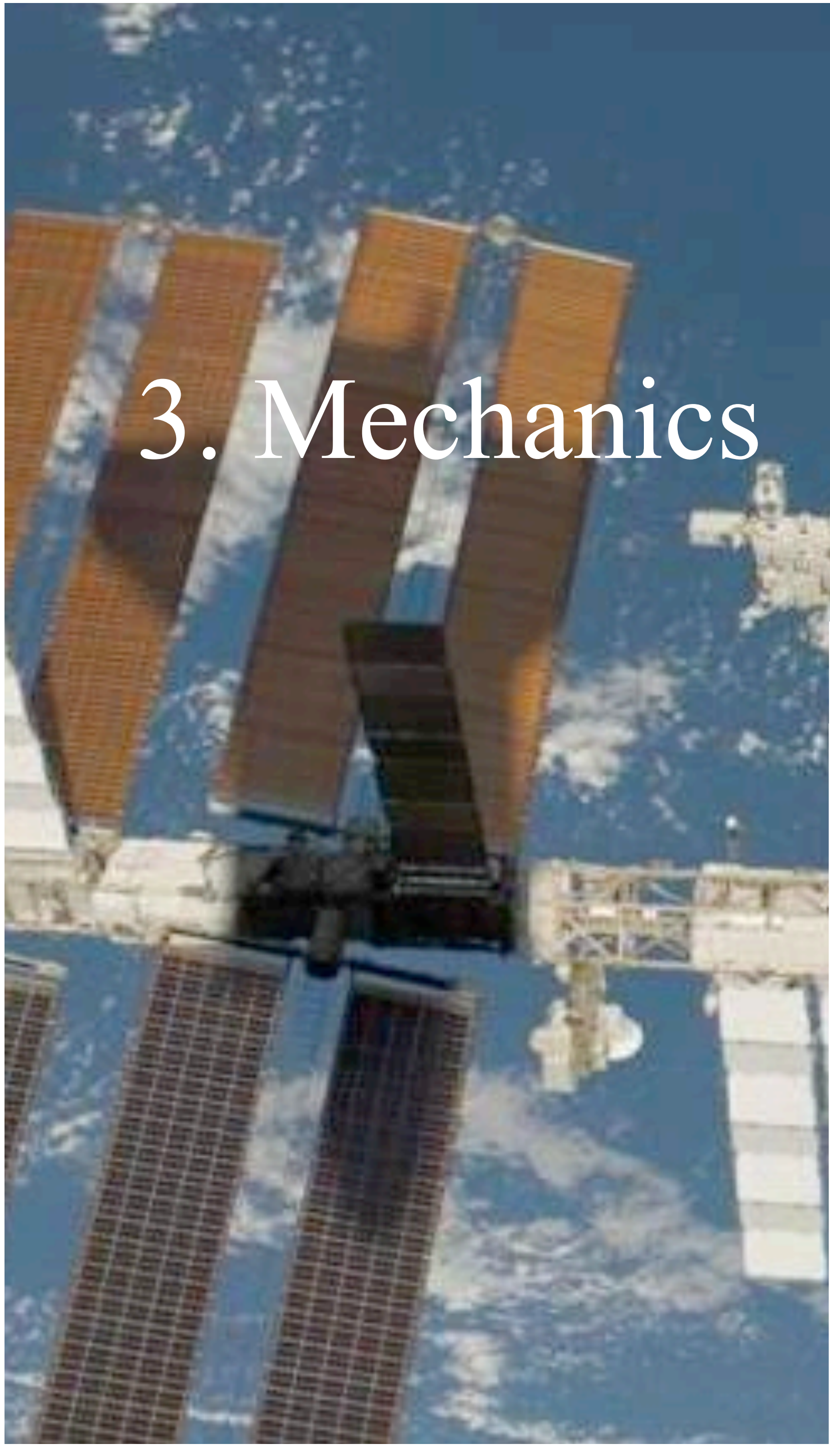
Time of Launch 2015
Operation period 5 years
Launching Rocket H2B
Transportation to ISS Un-pressurized Carrier of H2 Transfer vehicle (HTV)
Site to Attach Japanese Experiment Module/ Exposure Facility EF#2 of ISS
Mass 1983 kg
Power 926 W (op.) 352 W (non-op.)
Data Transfer 285 kilo-bps
Height of the orbit ~430km
Inclination of the Orbit 51.6°

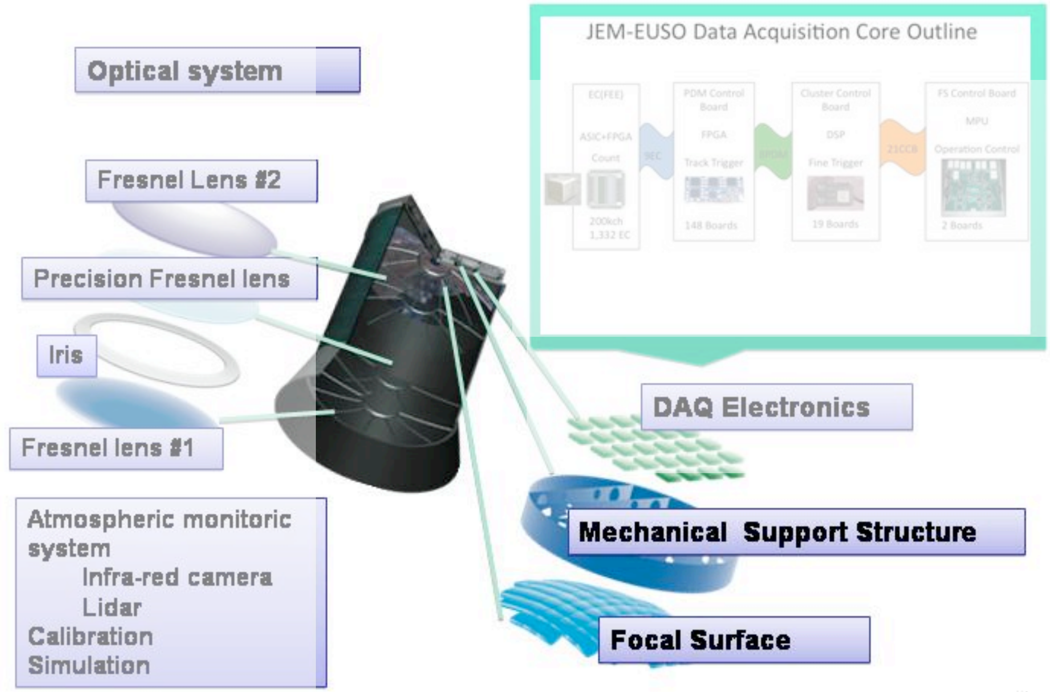
Table 2. *Main parameters of the JEM-EUSO Mission*

Table 1. *Main parameter of the JEM-EUSO instrument*

Field of View	±30°
Aperture Diameter	2.5m
Optical bandwidth	330 - 400nm
Angular granularity	0.1°
Pixel Size	4.5mm
Number of Pixels	$\sim 2.0 \times 10^5$
Pixel Size at the ground	750m
Duty Cycle	~20 - 25%
Observational Area	$\sim 2 \times 10^5$ km^2

3. Mechanics

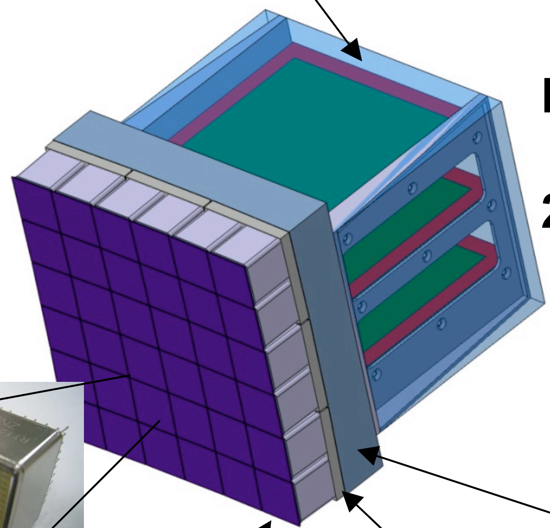




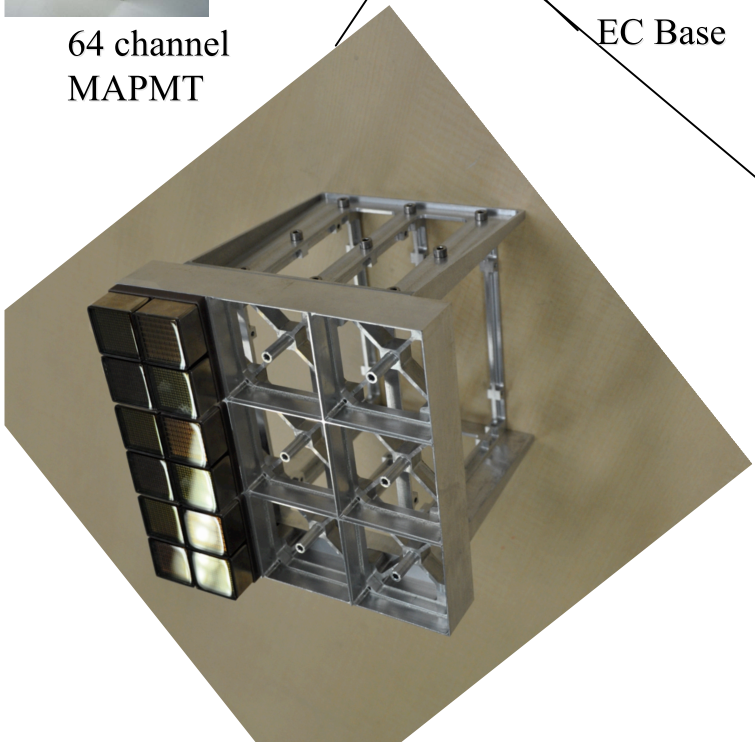
Optical system
Fresnel Lens #2
Precision Fresnel lens
Iris
Fresnel lens #1
Atmospheric monitoric system
Infra-red camera
Lidar
Calibration
Simulation
JEM-EUSO Data Acquisition Core Outline
DAQ Electronics
Mechanical Support Structure
Focal Surface

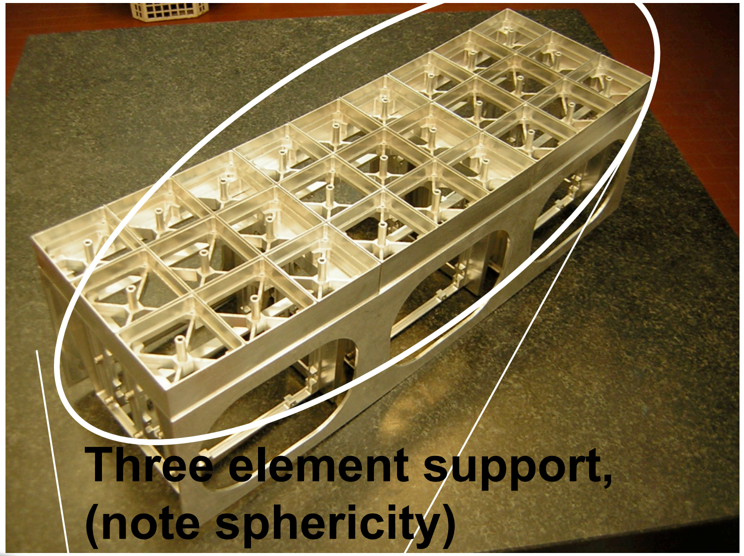
Focal Surface Mechanics

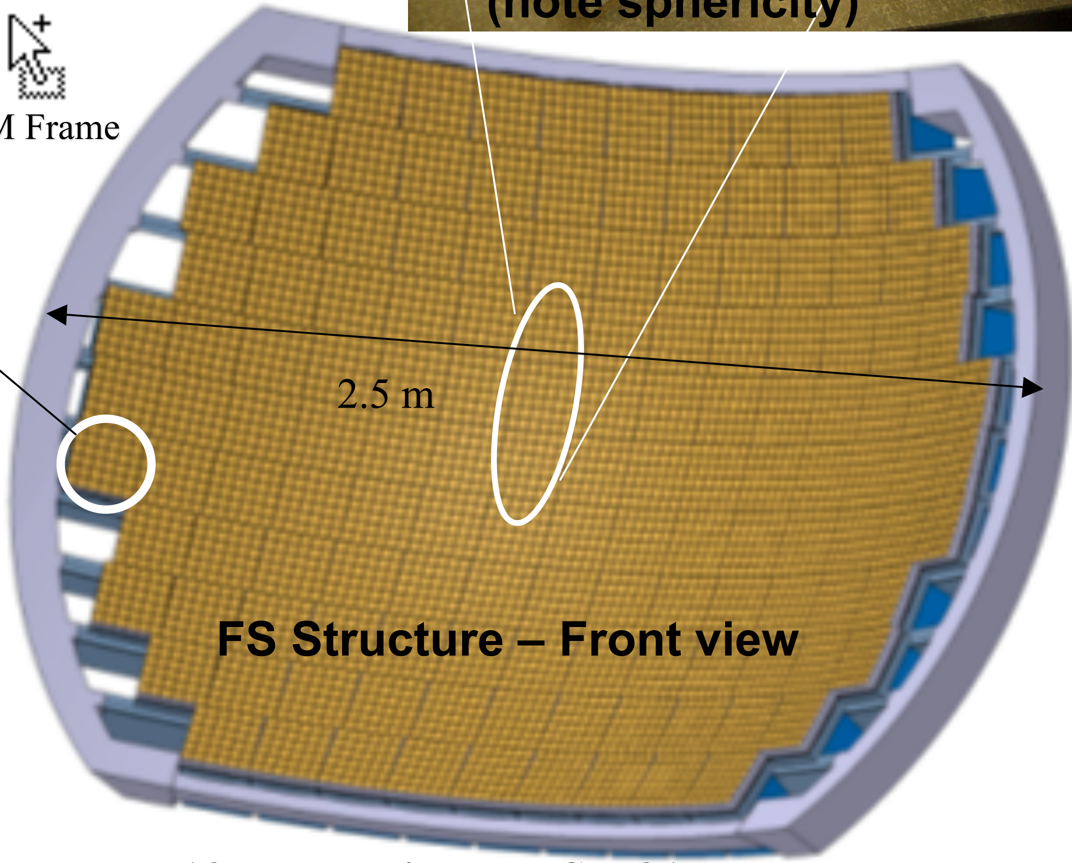
Photo Detector Module
2304 channels



64 channel MAPMT

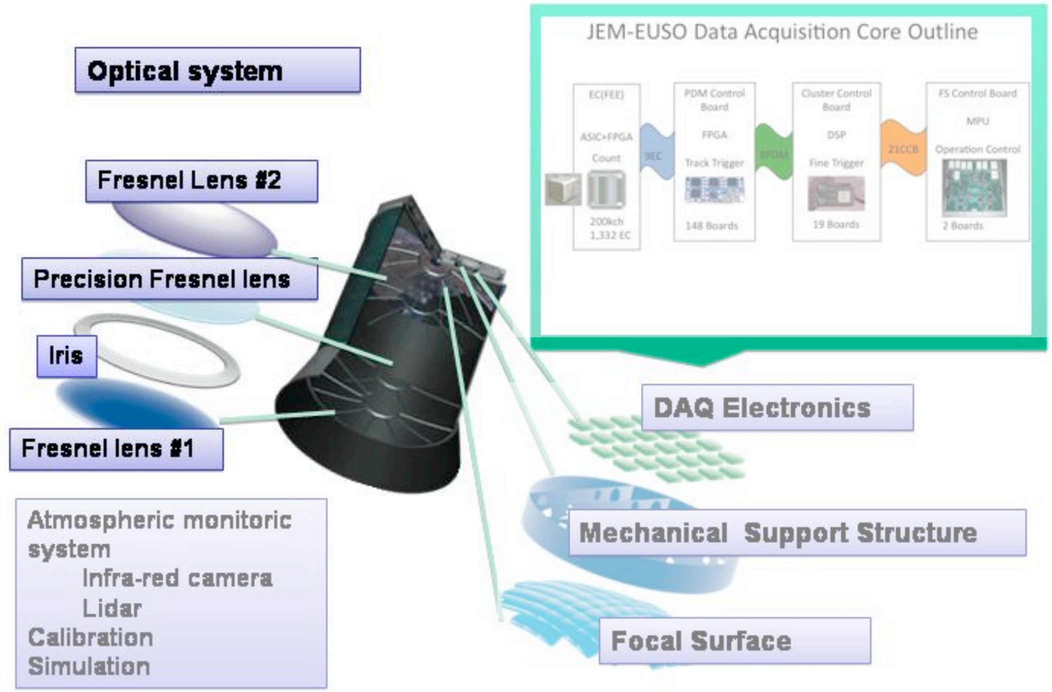






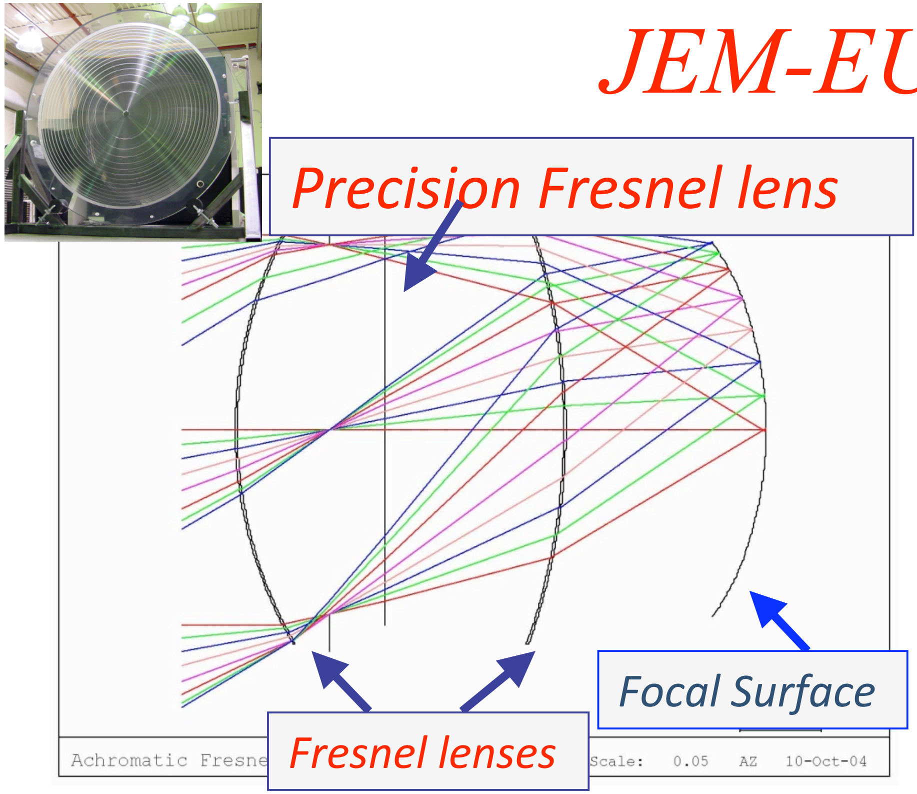
137 PDMs in the FS – 315 kchannels

4. Optics



JEM-EUSO Data Acquisition Core Outline
Optical system
Fresnel Lens #2
Precision Fresnel lens
Iris
Fresnel lens #1
Atmospheric monitoric system
Infra-red camera
Lidar
Calibration
Simulation
DAQ Electronics
Mechanical Support Structure
Focal Surface

JEM-EUSO Optics

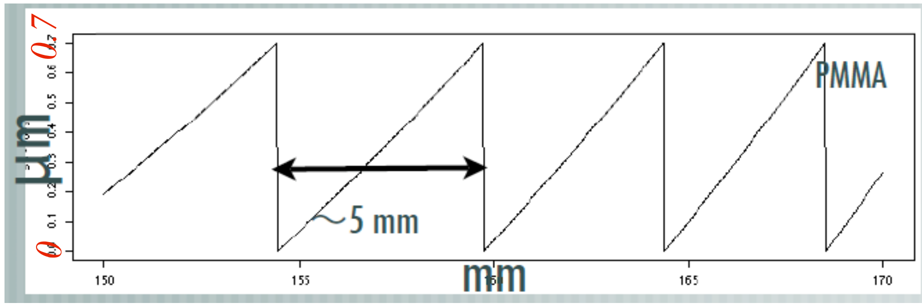


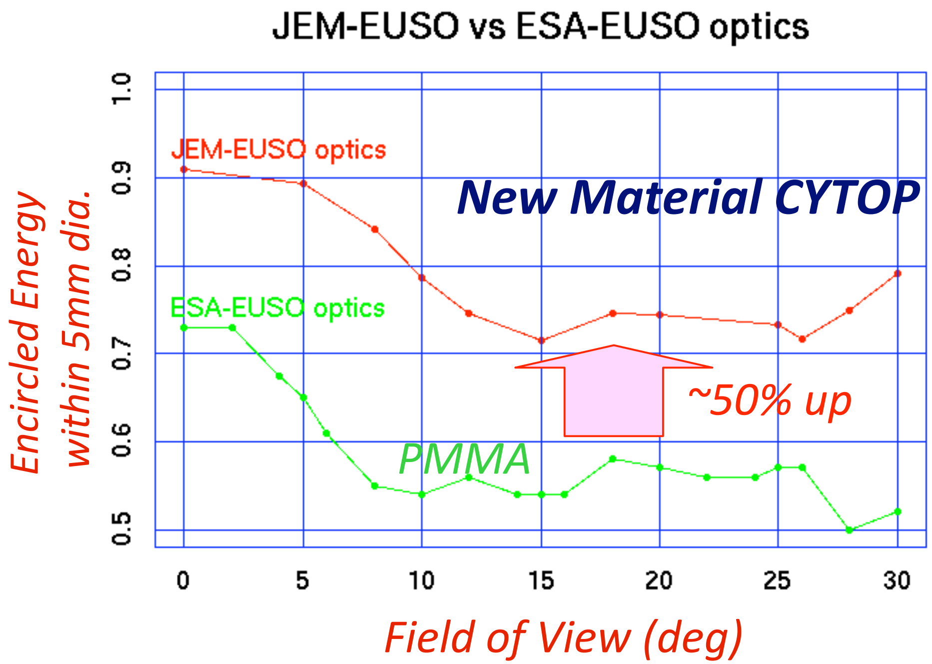
Optics Requirements

- *FoV ± 30°*
- *Pupil entrance pupil ≥ 2 m*
- *F/# ≤ 1.0*
- *Spot dimension ~0.1 ° (5mmΦ)*
- *Spectral range 330-400 nm*

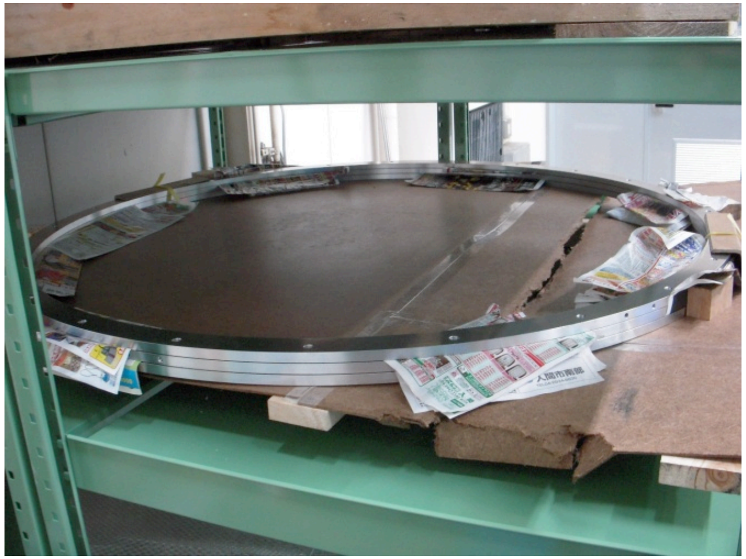
Precision optics cancels chromatic aberration

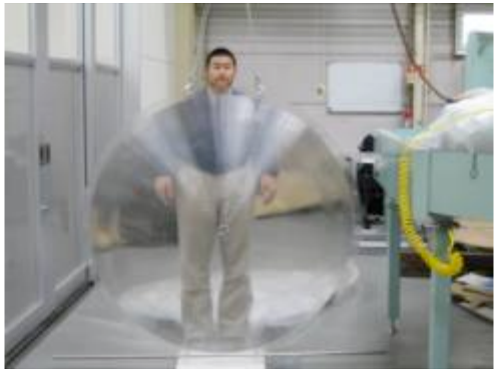
Surface of the Precision Fresnel lens

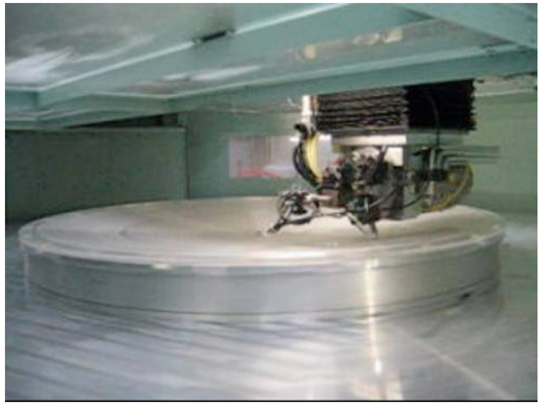


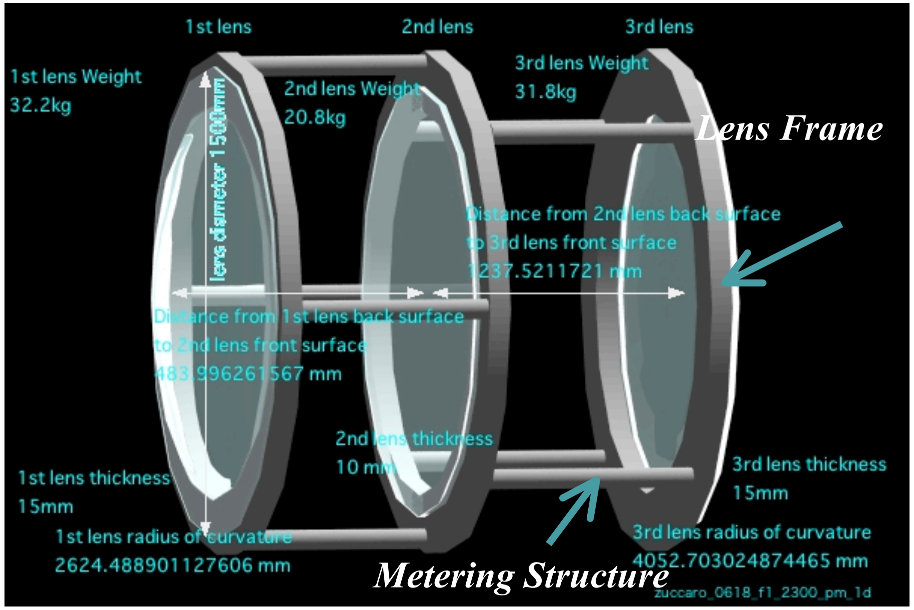


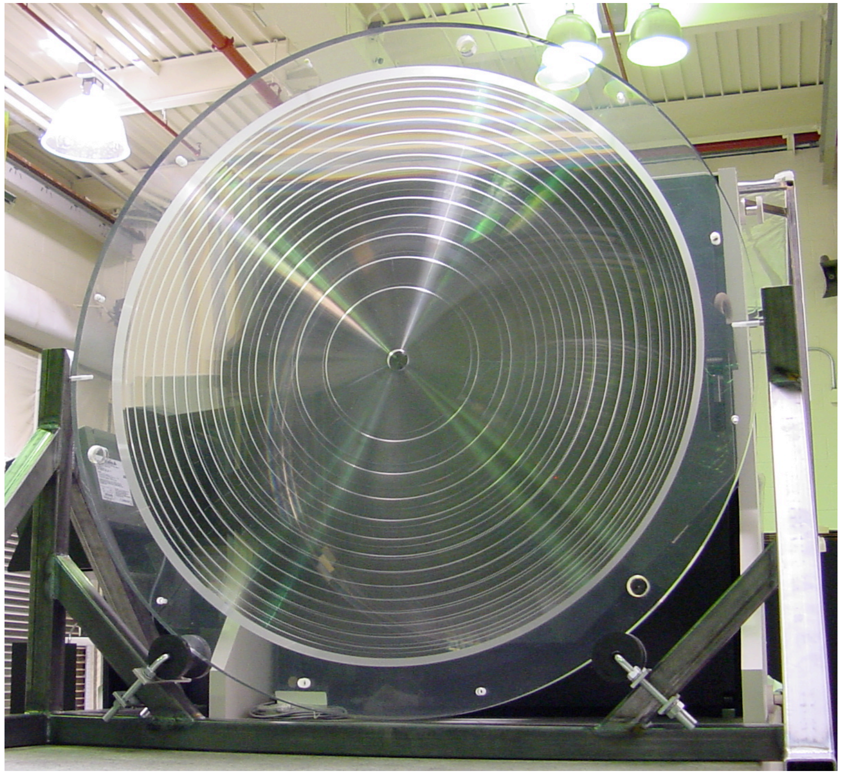
Prototypes: Structure, 1.5m Bread Board Model





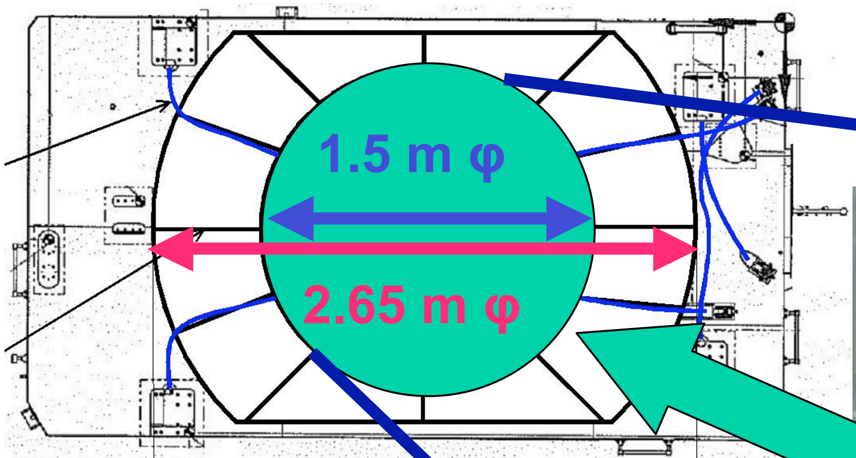


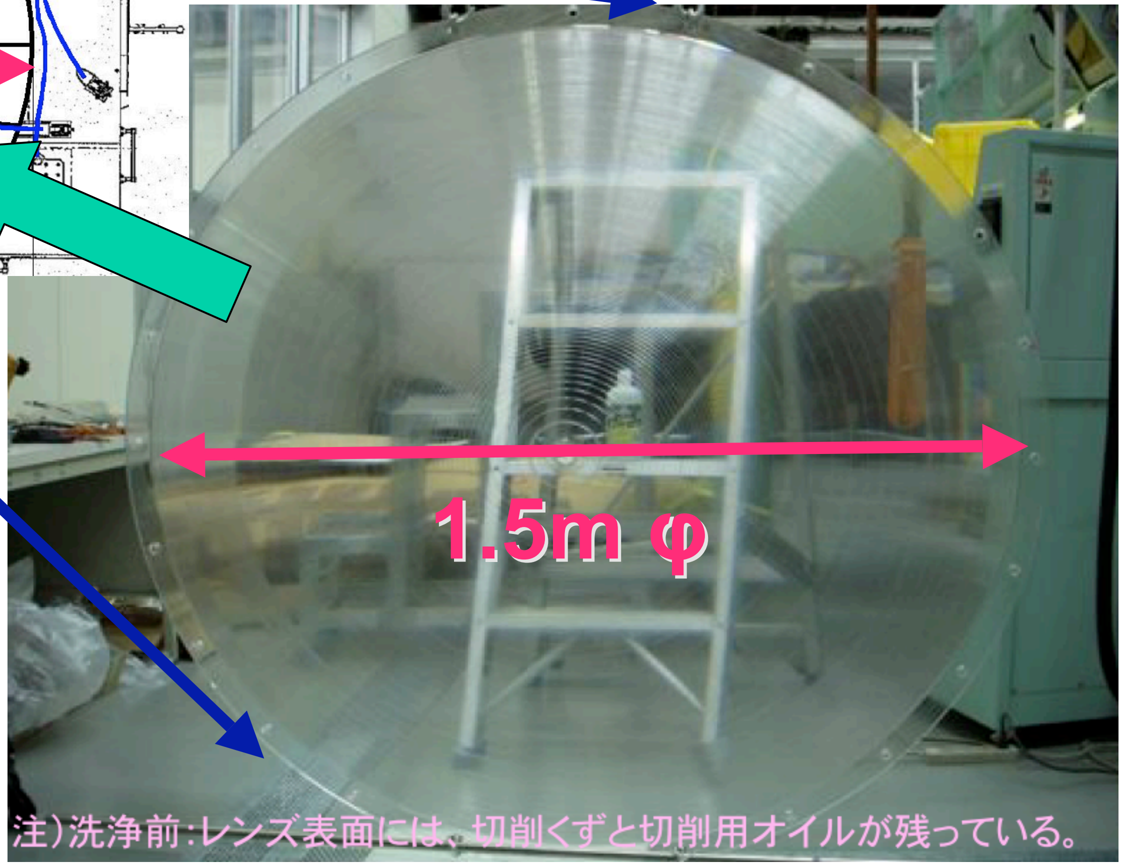




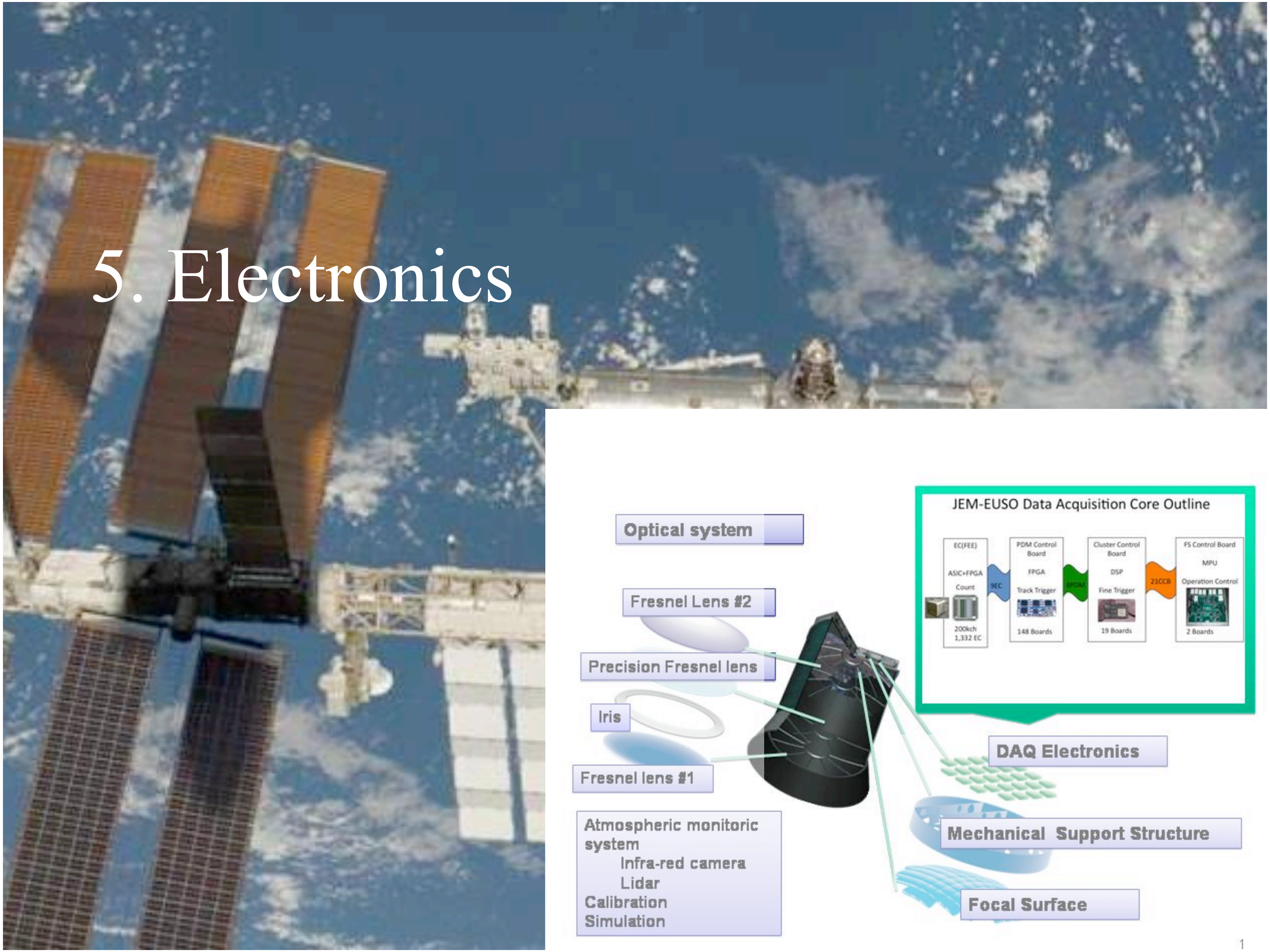
Lens manufacturing

Cutting machine with a 3.4m diameter turn table to make a 2.65m dia. Fresnel Lens.

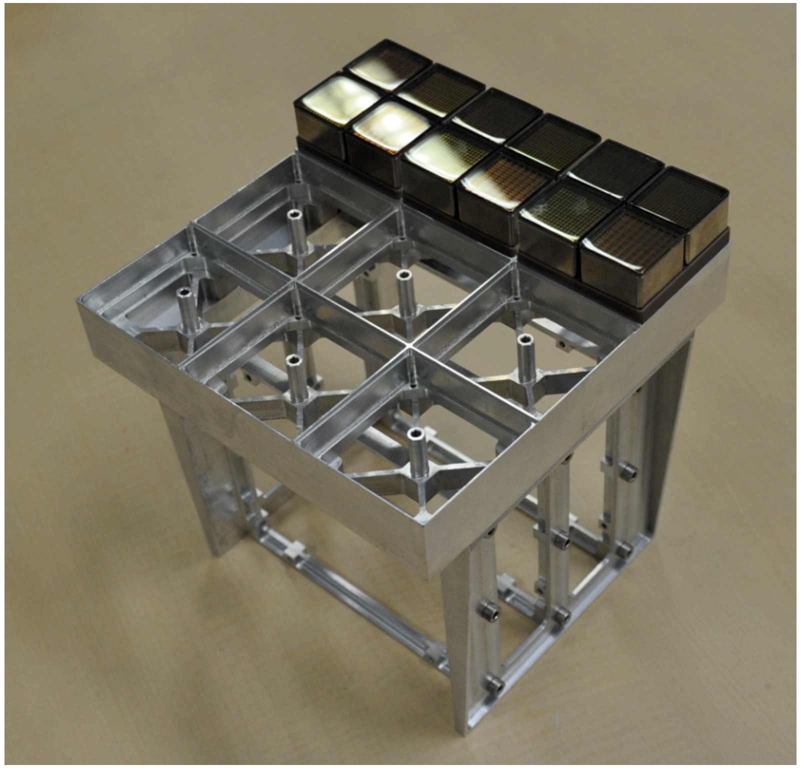


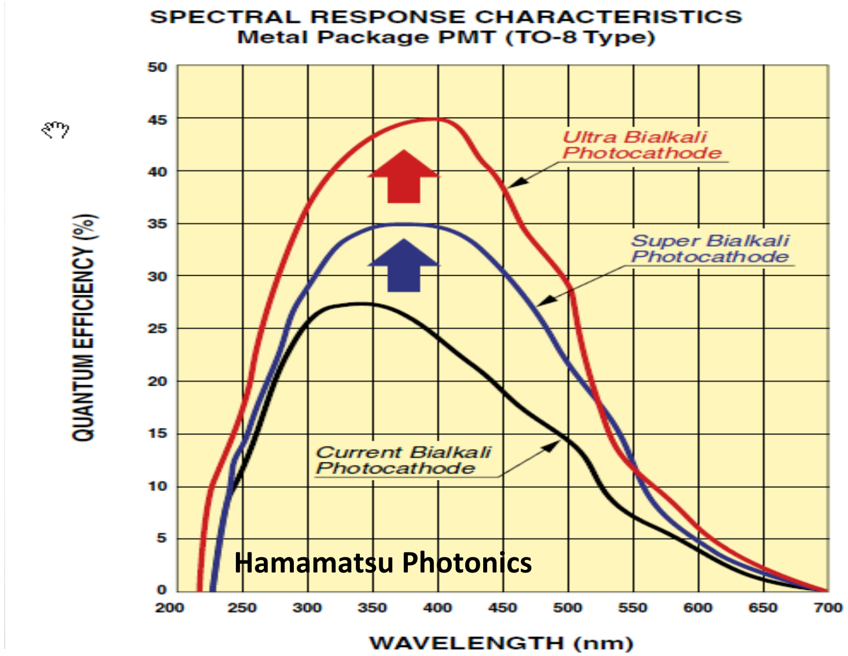


5. Electronics

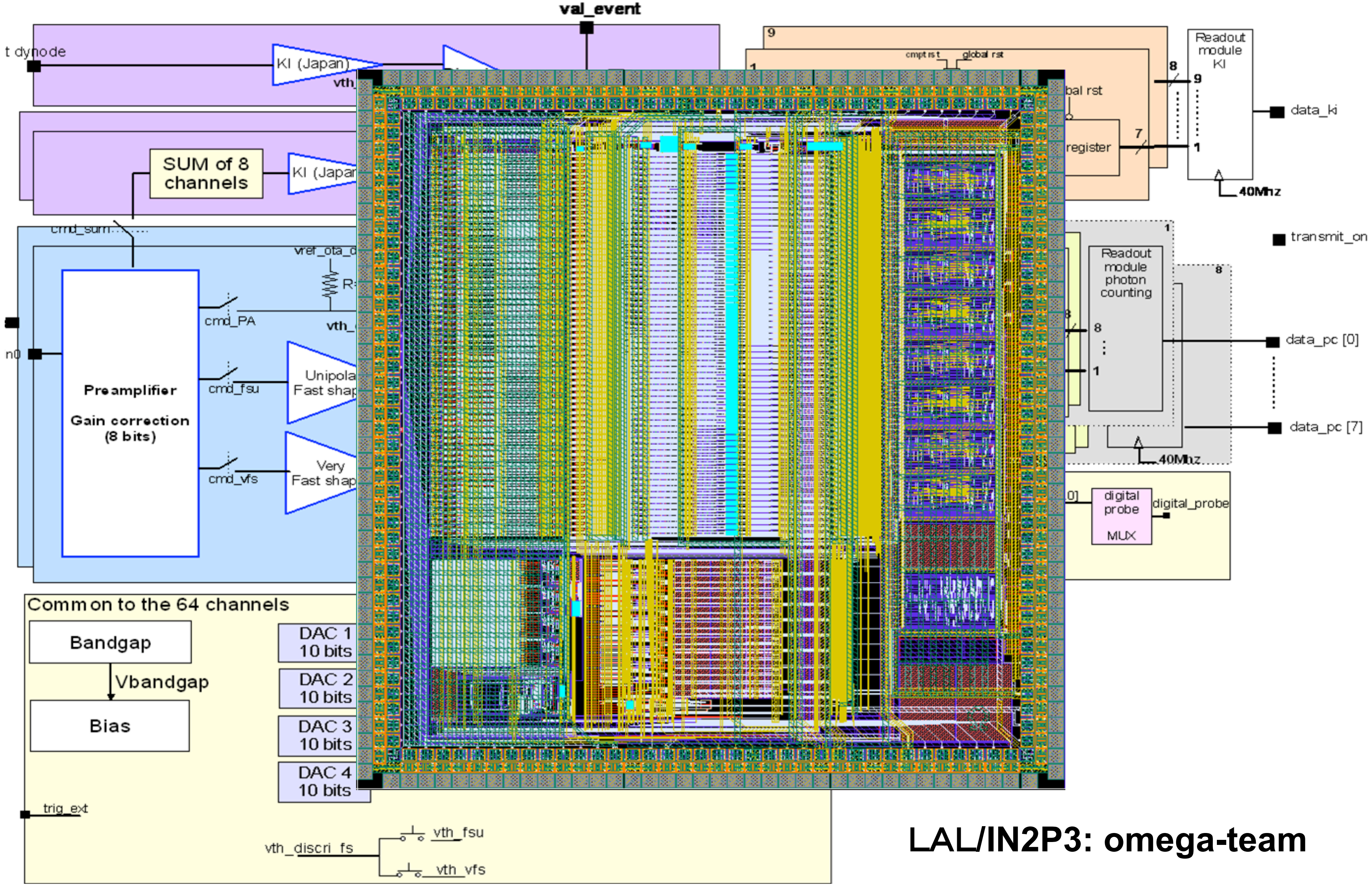


Hamamatsu
Ultra Bialkali high efficiency
MAPMT M64
64 channels in 8*8 grid
Arranged in 6*6 in PDM structure

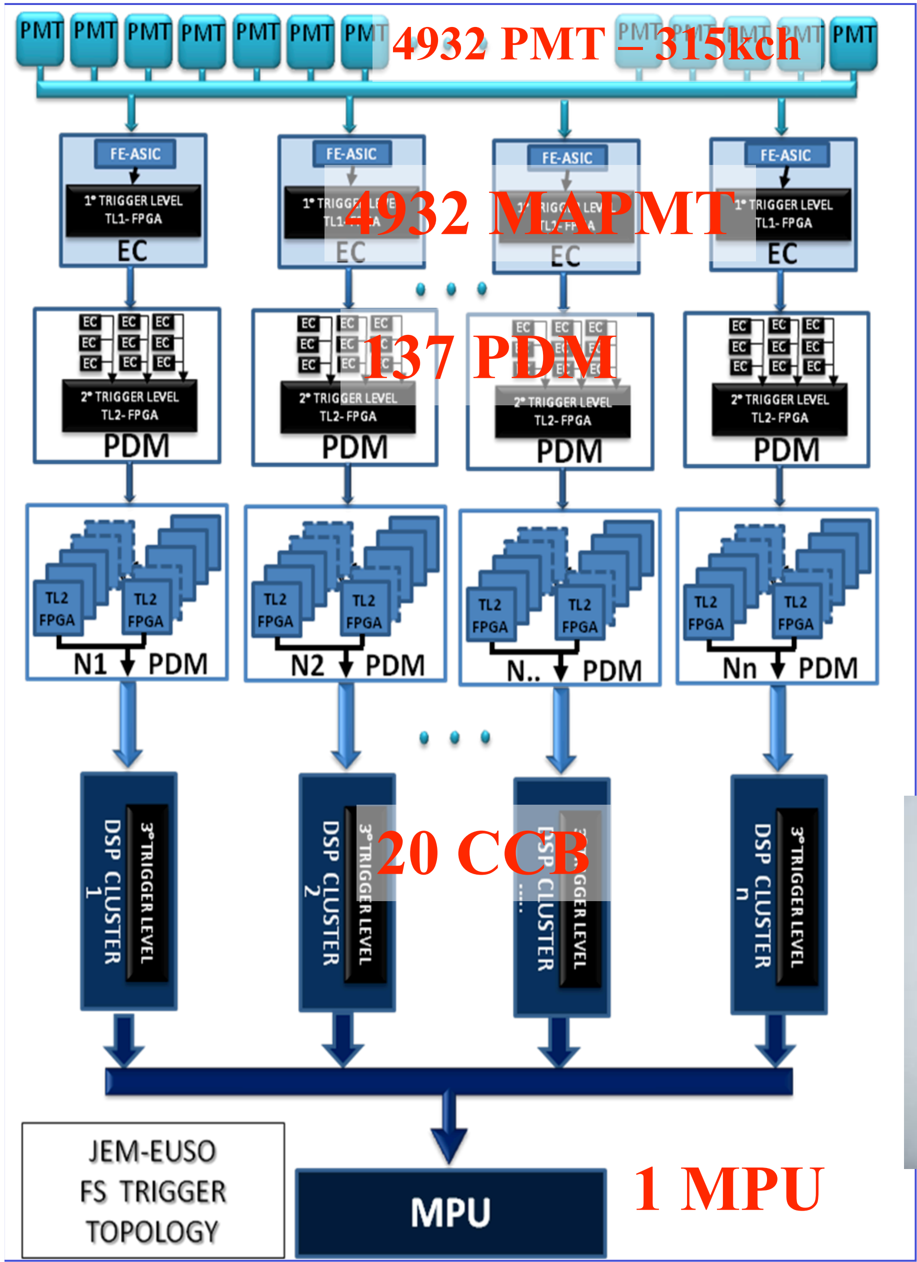


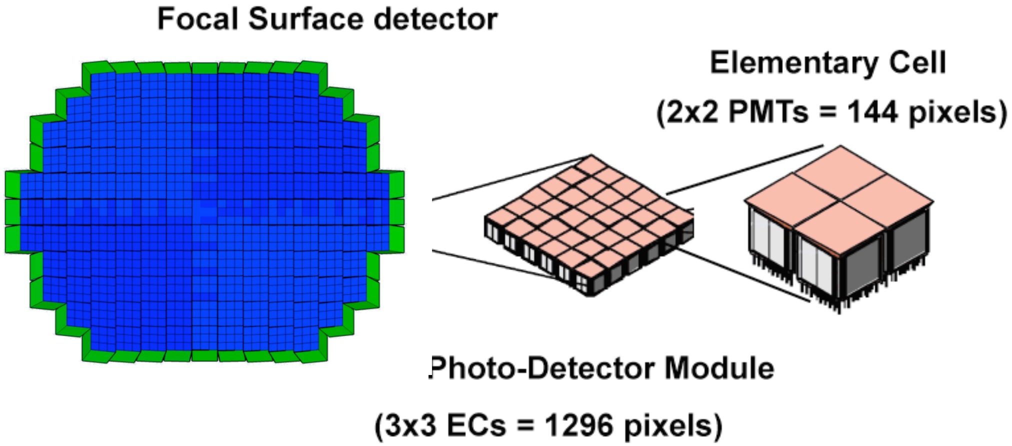


PMT Read-out ASIC : SPACIROC

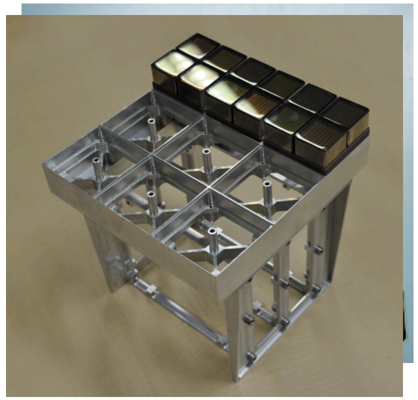


LAL/IN2P3: omega-team



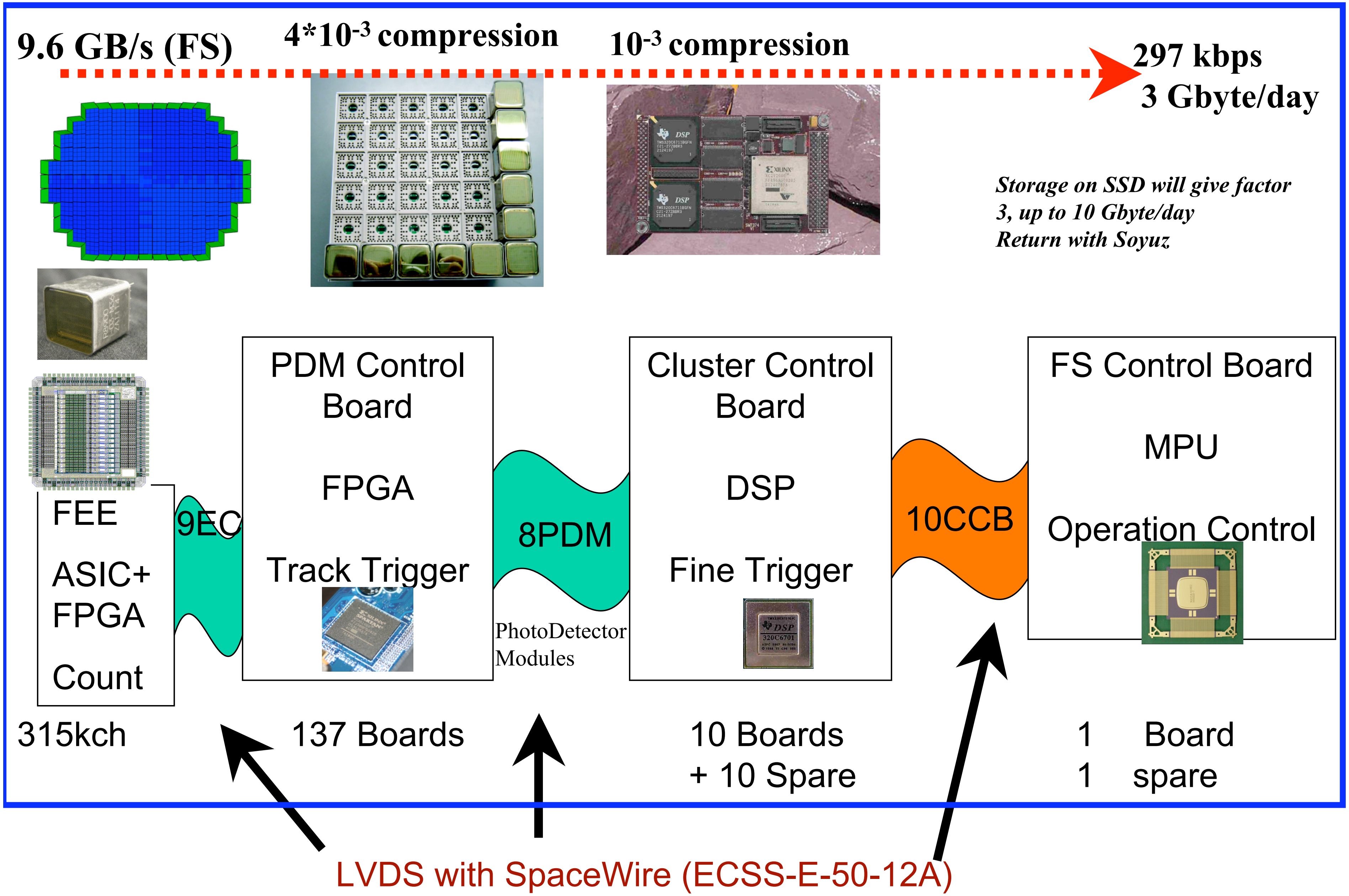


- 315 Kchannels
- Strongly parallel and hyerarchical structure
- Intrinsic redundancy

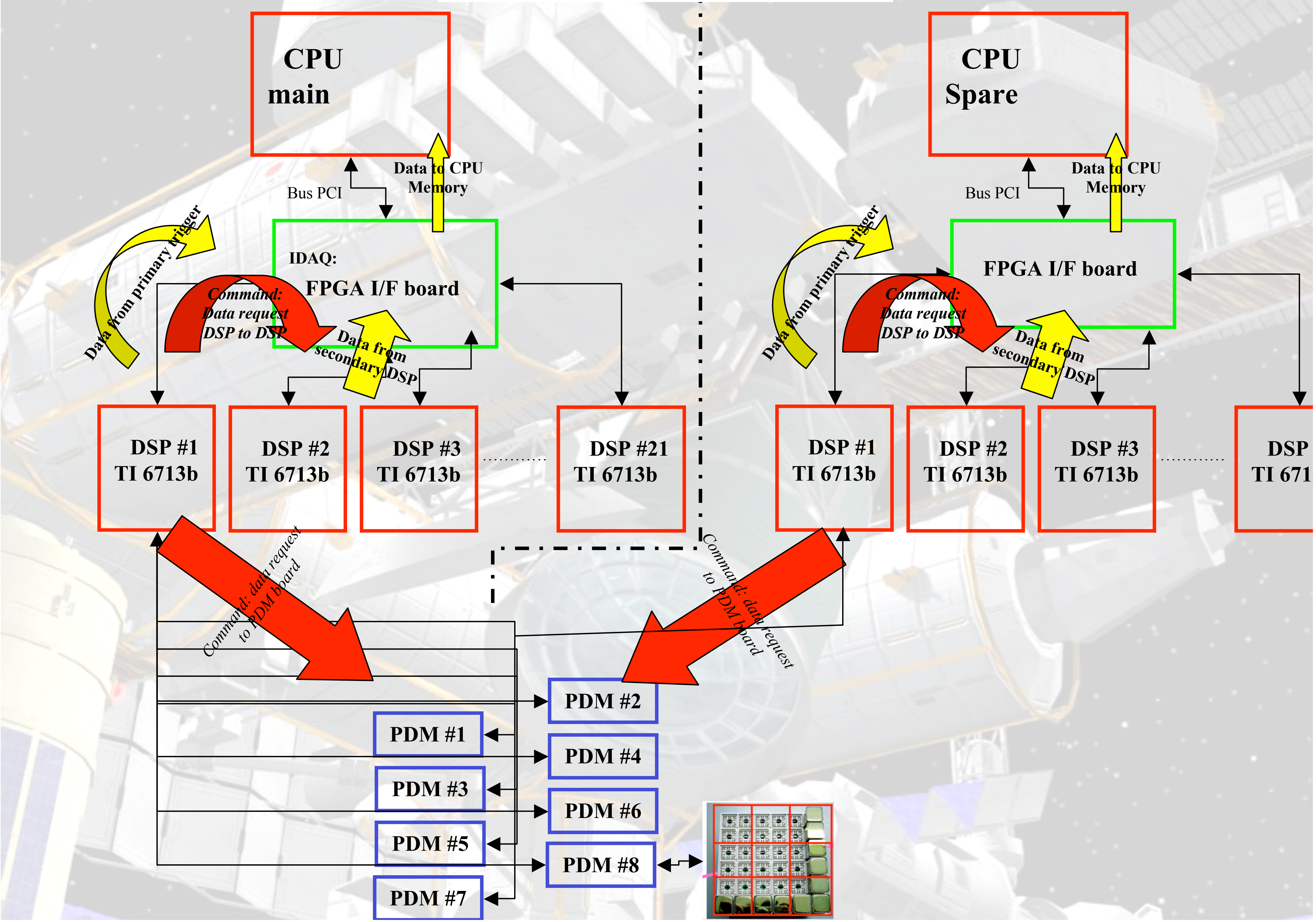


64 channel UBA PMT - PDM: 36 PMTs

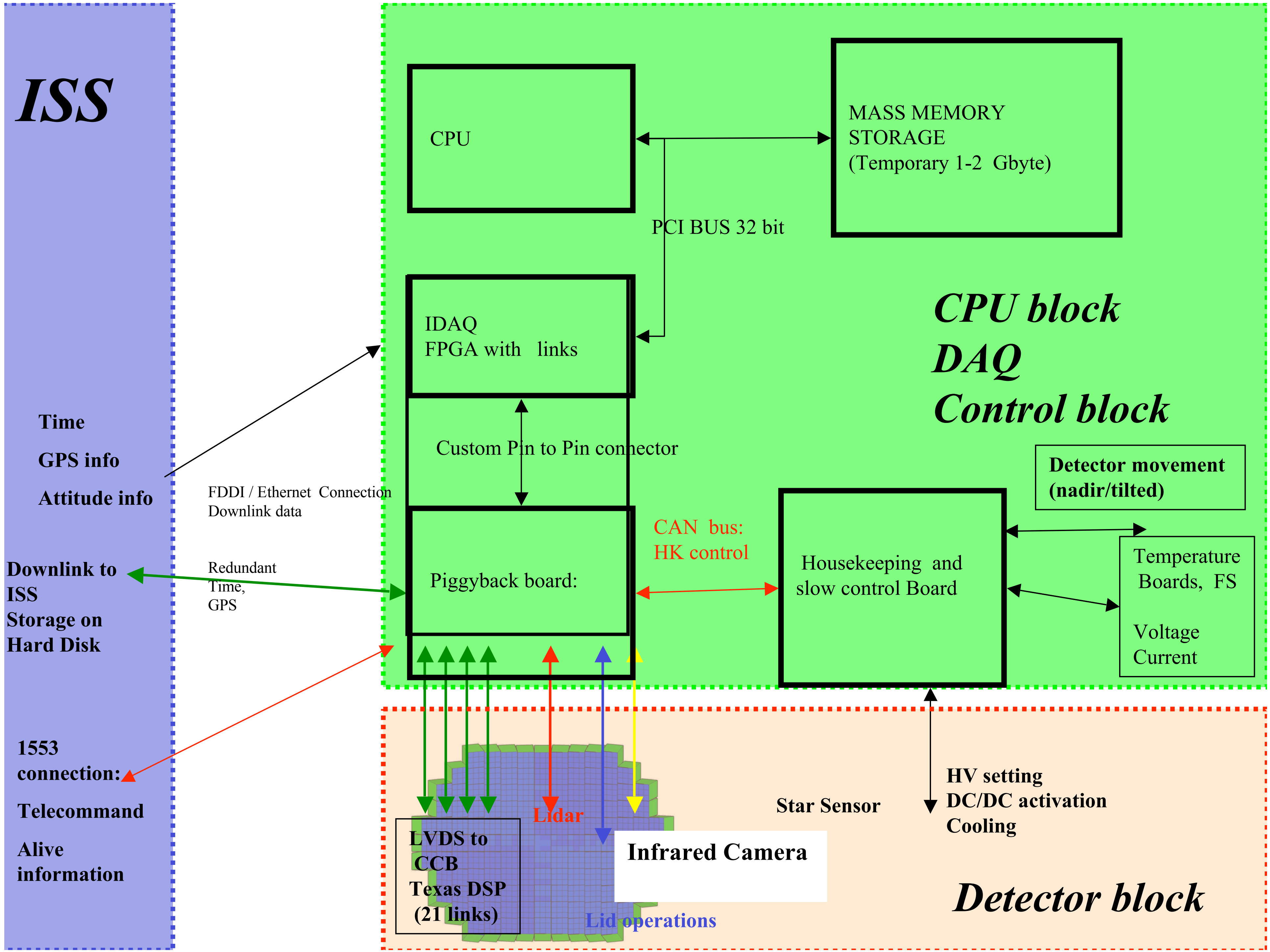
JEM-EUSO DAQ – Data reduction block scheme



Hyerarchical structure

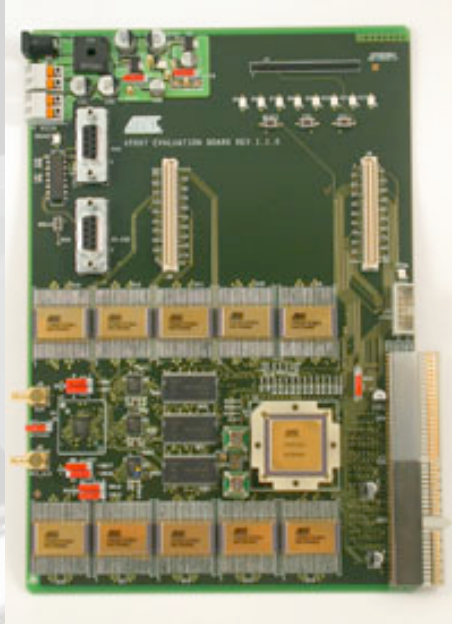


6. System level architecture



ISS
Time
GPS info
Attitude info
Downlink to ISS
Storage on Hard Disk
1553 connection:
Telecommand
Alive information
FDDI / Ethernet Connection
Downlink data
Redundant
Time,
GPS
CPU
MASS MEMORY STORAGE
(Temporary 1-2 Gbyte)
PCI BUS 32 bit
IDAQ
FPGA with links
Custom Pin to Pin connector
Piggyback board:
CAN bus:
HK control
Housekeeping and slow control Board
CPU block
DAQ
Control block
Detector movement (nadir/tilted)
Temperature Boards, FS
Voltage
Current
HV setting
DC/DC activation
Cooling
Star Sensor
Lidar
LVDS to CCB
Texas DSP
(21 links)
Infrared Camera
Lid operations
Detector block

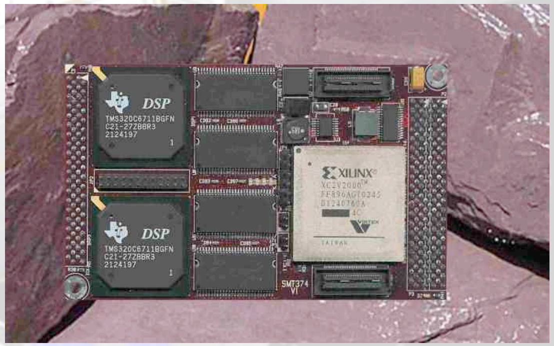
General Architecture Requirements



Main CPU

- Low computational power (100-200 MIPs)
- Flexible
- Redundable
- Variable connections
- Modifiable if detector structure and distribution changes during development
  (e.g. 2.5 μs → 1 μs GTU, PMT36-> PMT64)
- Main/spare cold redundancy
- Atmel AT697E, HIREC HR5000

DSP – Cluster control board



- high computational power (1000+ MIPs)
- Main/spare redundancy; Intrinsic redundance
- High level trigger
- TI6713b

CPU Tasks

- Event readout
  1. Cosmic rays (PMT readout) after data processing
  2. Calibration
  3. Slow control & Housekeeping
  4. full acquisition events
  5. Atmospheric phenomena: special triggers, metereoids, lightning ecc
  6. spurious trigger which require special rejection techniques
  7. Housekeeping and ancillary data for each event

- Telemetry & Telecommand
- Data storage

- Operations
  1. HV and operation parameters, discrimination settings, calibration commands
  2. Lidar operations & Acquisition
  3. IR Camera operations & Acquisition
  4. ISS position & Attitude (from ISS Housekeeping)
  5. Lid operations
  6. Refocusing
  7. Tilt operation movement (frequent and housekeeping)
  8. Reshrink (open / close) detector

CPU principle

(Low) data processing capabilites, high degree of flexibility and autonomous decisions

Alarm and contingency automatic

1. Power
2. Safe mode (→usually switch off)

Telecommands from ground to overrule :

- Observation parameters
- Calibration
- Data flow
- Operations in reduced data connection
- HV regulations
- etc…

Trigger at PDM level (Third Level):

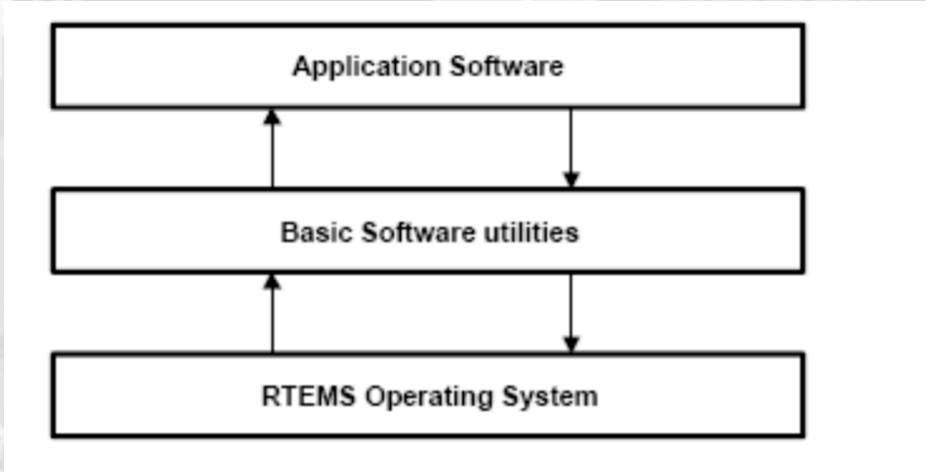
1. Stop acquisition
2. Stop live time
3. Transfer to CPU
4. Request information to secondary PDM
5. Process info of secondary PDM
   *look at red pixel
   *reprocess data with different threshold
6. Get secondary PDM data
7. Compress secondary PDM data
8. Pack and store to ISS

Note that large events will trigger more than one PDM, probably trigger will come from more than one PDM with small offset due to propagation of track.

However delays/overheads in data transmission will be higher.

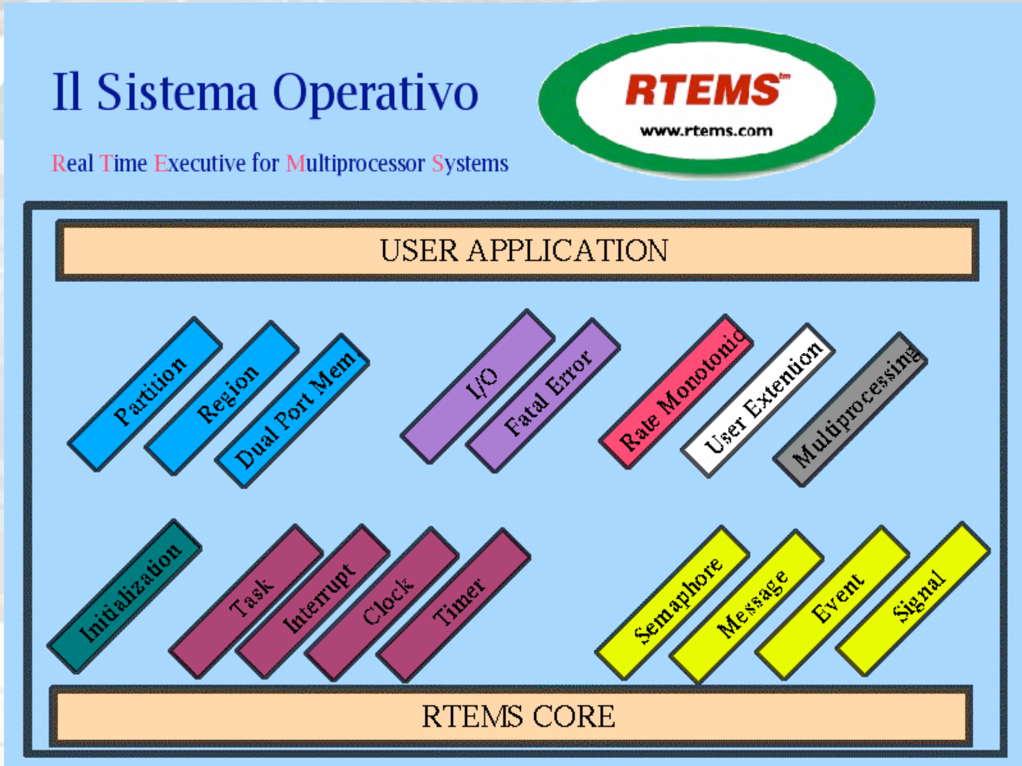
6. Software

RTEMS Real Time Operating System



- •Used By Pamela, Aurora…
- •ESA development
- •Open source
- •Supports Leon V.5
- •Multitasking
- •Real time
- •Task priority
- •Ease of development/debugging

- •Special techniques for reprogramming
  - •In full
  - •In part (double subroutine call)



Thanks to F. Sebastiani
http://www.bzimage.it/linuxday2003/slides_noframe/linuxday2003-sparc-rtems-erc32.html

7. Development plan – EGSE

Development scheme

1. Software test boards

   (commercial board – algorithm
   implementation & tuning)

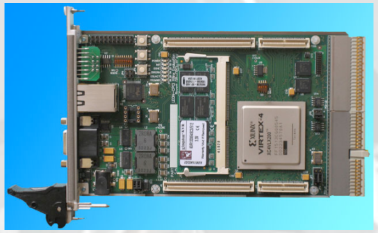
2. Hardware development boards

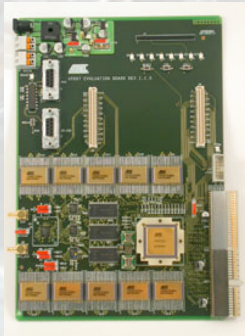
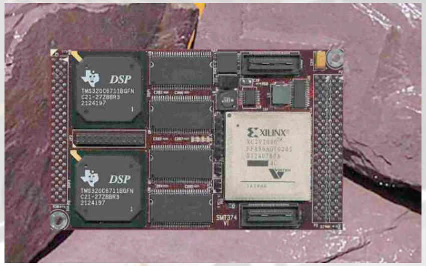
   (Test link, interfaces etc)

3. Prototype boards (E.M.)

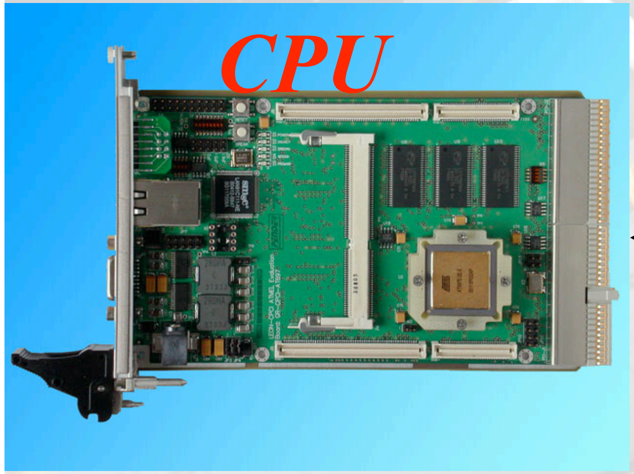
4. Flight configuration

5. EGSE – Electronic Ground Support Equipmend / Simulator



Development configuration / board breakdown



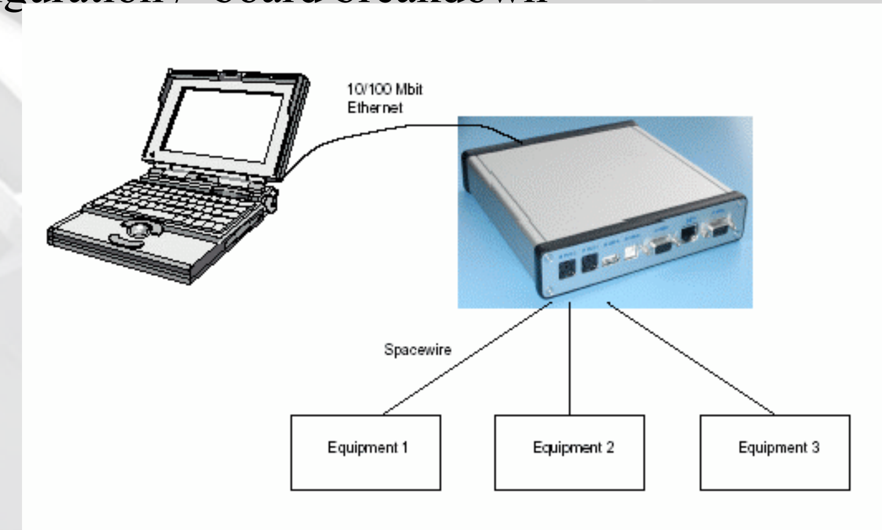
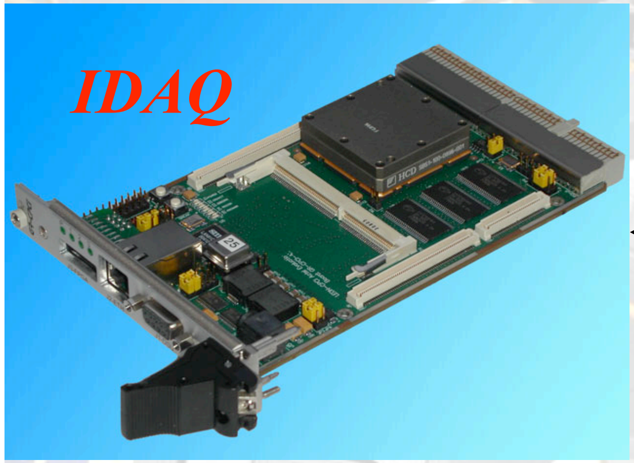
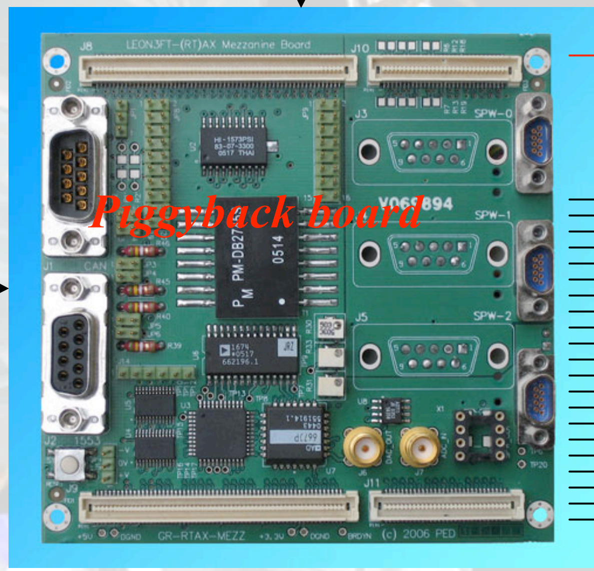


Figure 1. GRESB system diagram

BUS PCI

1553 / spacewire / CAN bus





HK board CAN BUS

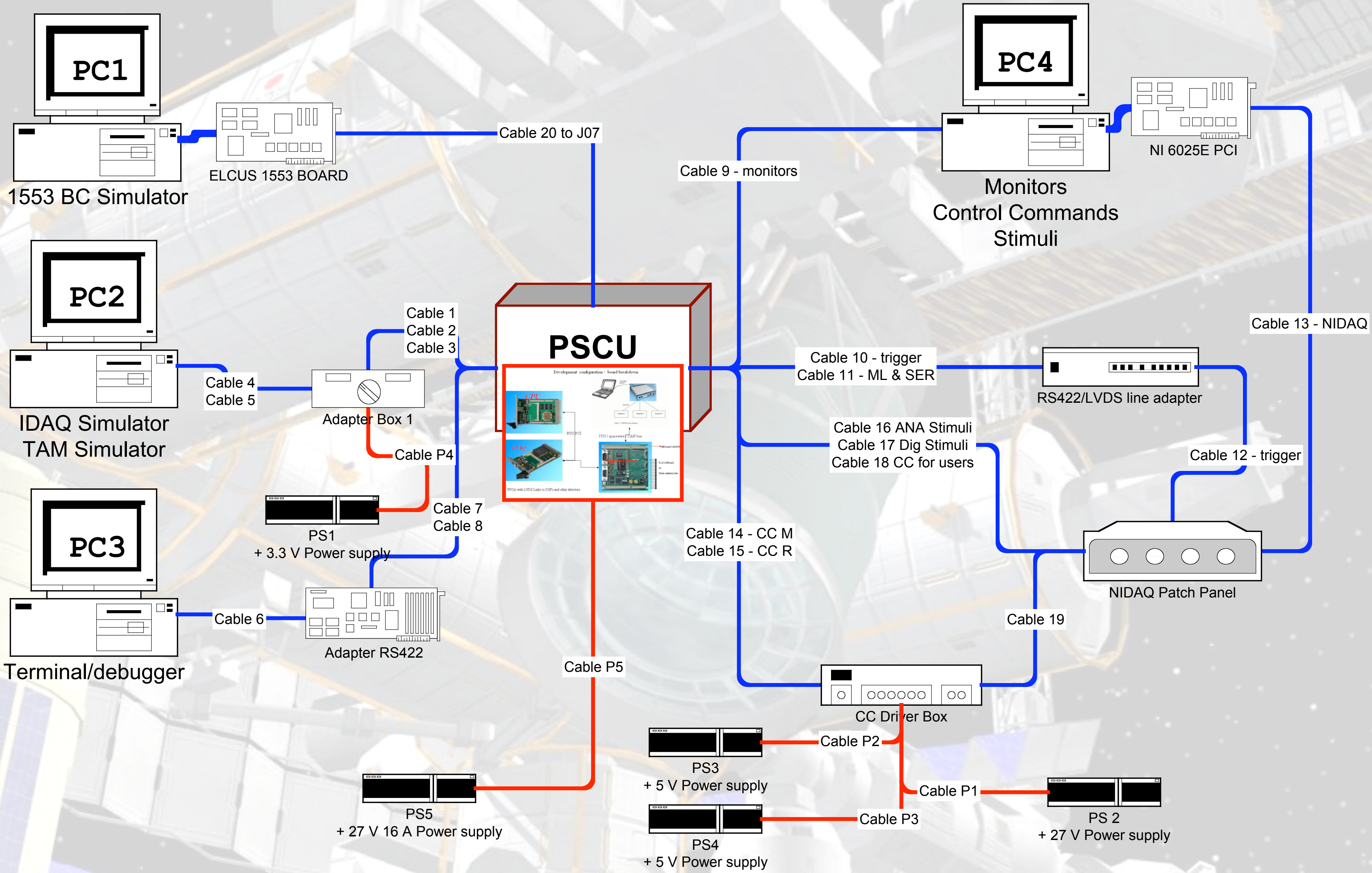
To 21 DSPboard

Or

Chain communicction

FPGA with LVDS Links to DSPs and other detectors

EGSE/ Simulator



8. Conclusions

Jem-Euso has completed phase A/B with JAXA
Ready to proceed to phase B/C
Proposal to national funding agencies and institutes have been submitted and accepted or under evaluation

ESA:

Positive Recommendation in Fundamental Physics Roadmap and Astronomy WG of ESA

Approved in the research pool of ELIPSE program by Human Spaceflight Div. ESA

Launch foreseen in 2015

Dedicated to

Prof. Yoshiyuki Takahashi

(1947 - 2010)