EUSO
(Extreme Universe Space Observatory)

T. Ebisuzaki
RIKEN and
Deputy PI of JEM-EUSO collaboration

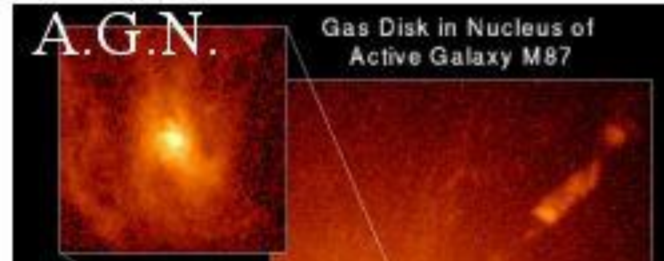
Plan of talk

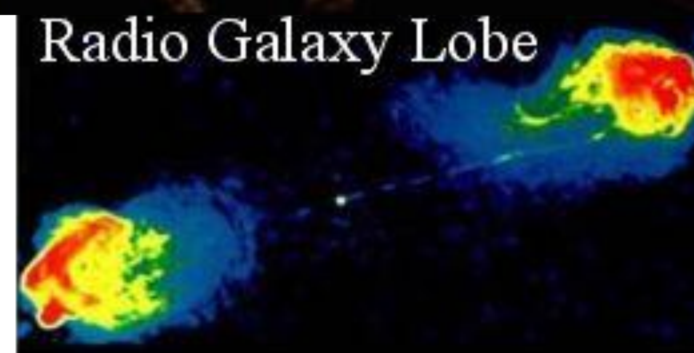
1. Why UHECRs (10^{20} eV)?
2. K-EUSO and beyond
3. Precatory activities
   - TA-EUSO (ground)
   - EUSO balloon (stratosphere h~40 km)
   - Mini-EUSO (ISS h~400 km)

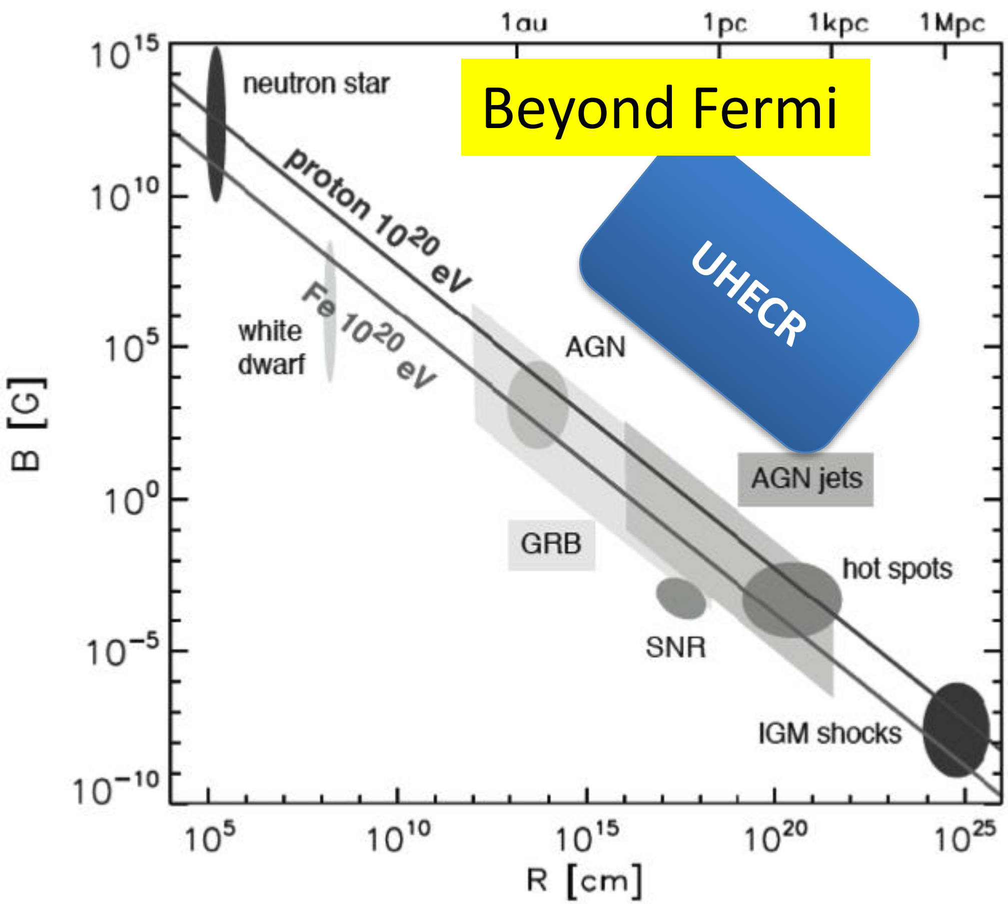
Ultra High Energy Cosmic Rays

- The highest energy particles ever observed
  - 10^{20} eV = 16 J
- What are they?
  - behave as protons and (possibly) heavier nuclei
- Where do they come from?
  - Origin UNKNOWN!
  - The most powerful cosmic accelerators
  - Models range from the formation of compact objects to accretion onto supermassive black-holes and the large-scale structures of the Universe

Hillas plot: Theoretical upper limit < 10^{20} eV

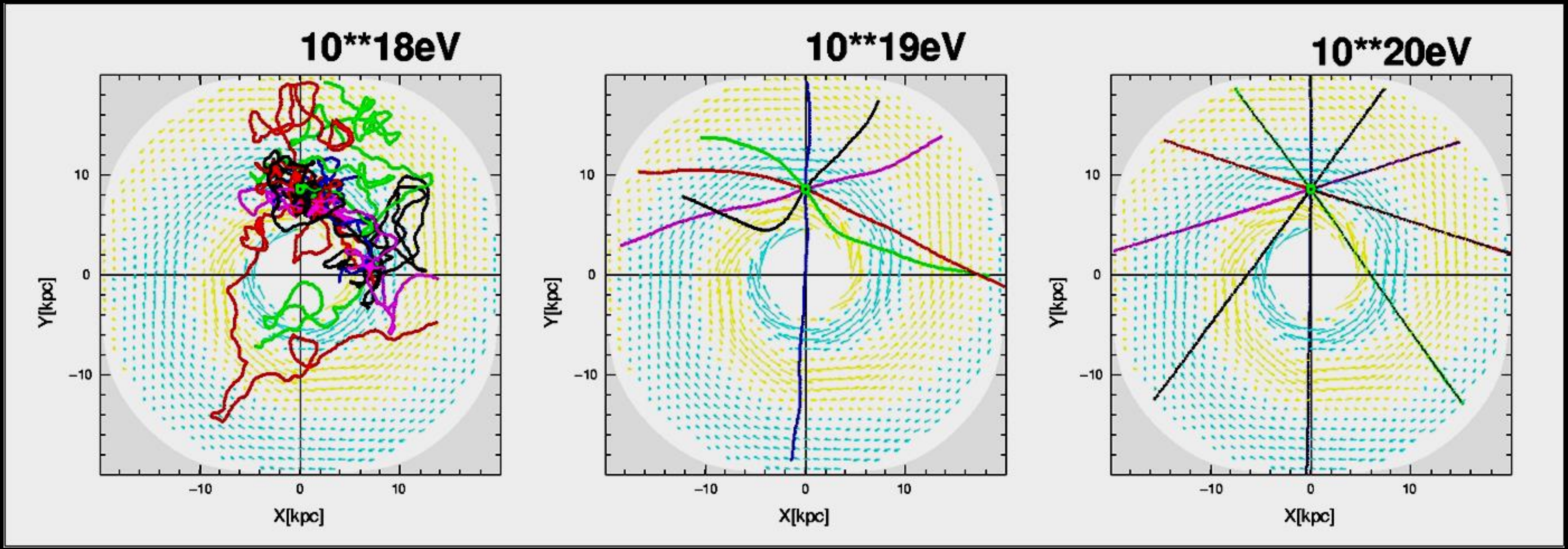






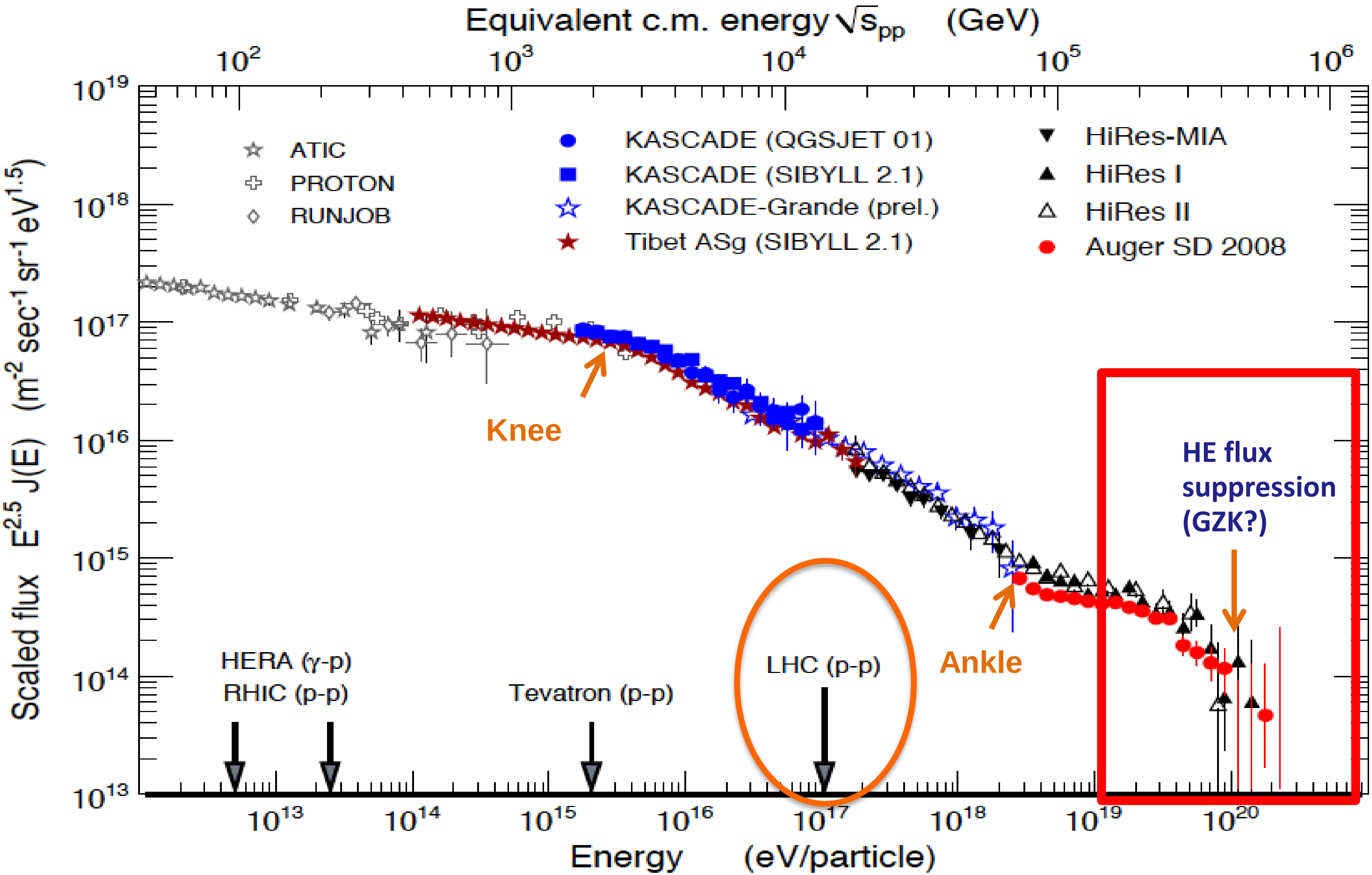
Why UHECRs?

- Particle Astronomy
  - Can discover sources by arrival directions
  - Lower energy CRs do not come directly



Why UHECRs?

- Particle Astronomy
  - Can discover sources by arrival directions
- Center of mass energy >> artificial accelerators
  - Super-LHC energy interactions (300 TeV CM)



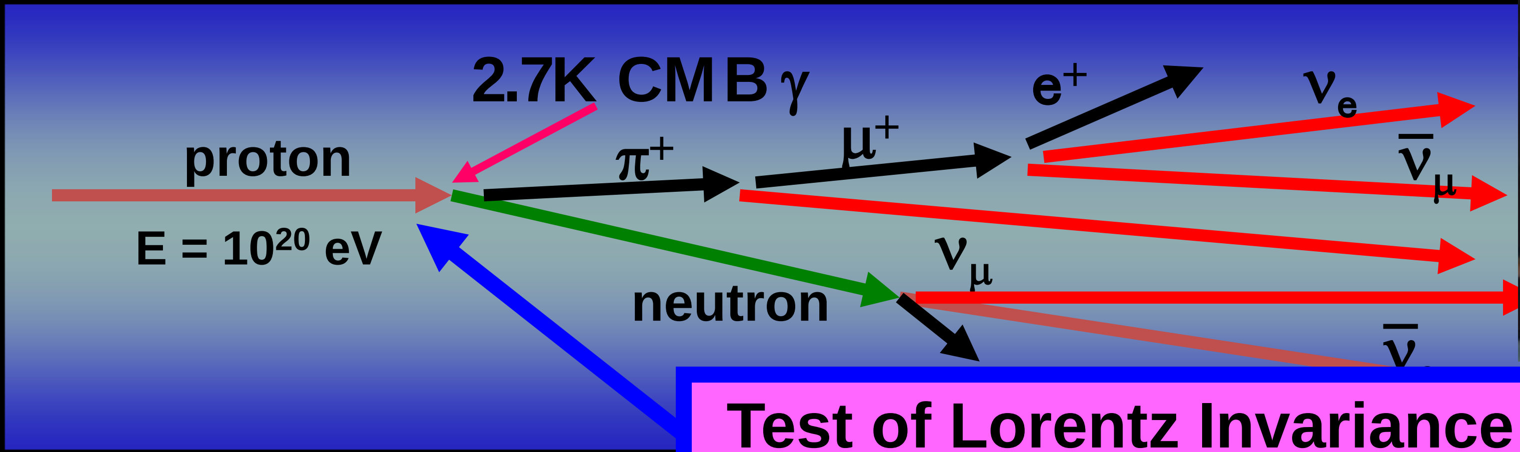
Equivalent c.m. energy $\sqrt{s_{pp}}$ (GeV)
Scaled flux $E^{2.5}$ J(E) (m^{-2} sec^{-1} sr^{-1} $eV^{1.5}$)
Energy (eV/particle)
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande (prel.)
Tibet ASg (SIBYLL 2.1)
HiRes-MIA
HiRes I
HiRes II
Auger SD 2008
Knee
Ankle
HE flux suppression (GZK?)
HERA (γ-p)
RHIC (p-p)
Tevatron (p-p)
LHC (p-p)

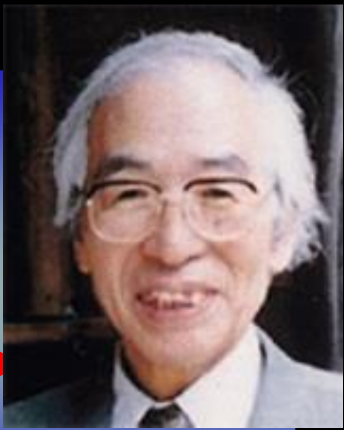
Why UHECRs?

- Particle Astronomy
  - Can discover sources by arrival directions
- Center of mass energy >> artificial accelerator
  - Super-LHC energy interactions (300 TeV CM)
- Verification of Lorentz Invariance

Greisen-Zatsepin-Kuz'min Process

Greisen1966; Zatsepin and Kuz'min1966

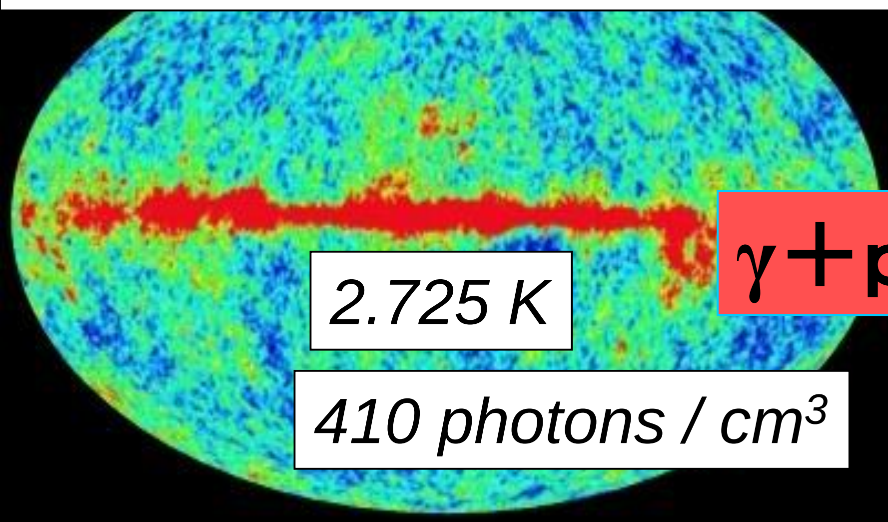


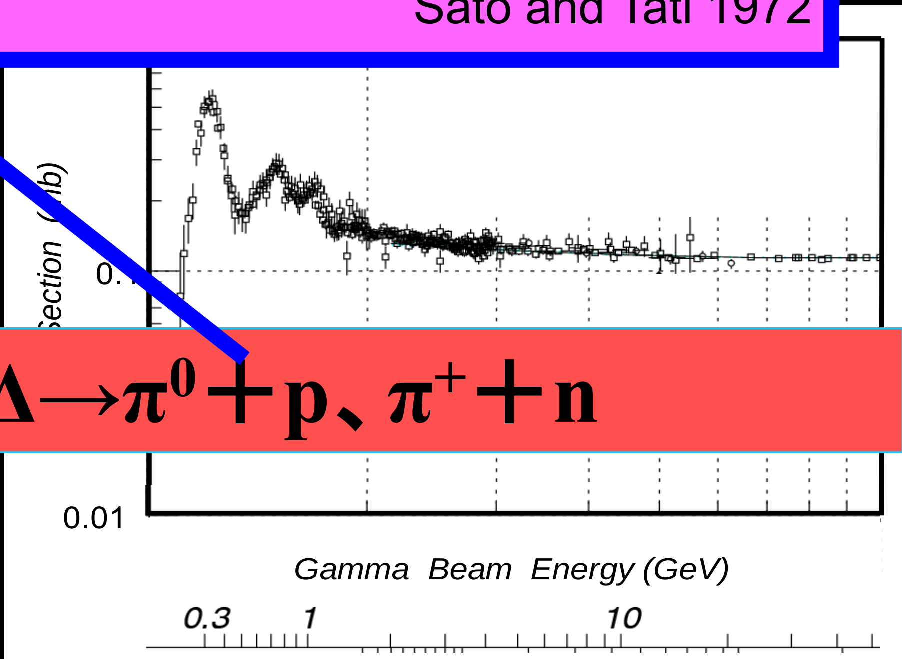


Test of Lorentz Invariance at～10^{11}

Sato and Tati 1972

Microwave Cosmic Background Radiation



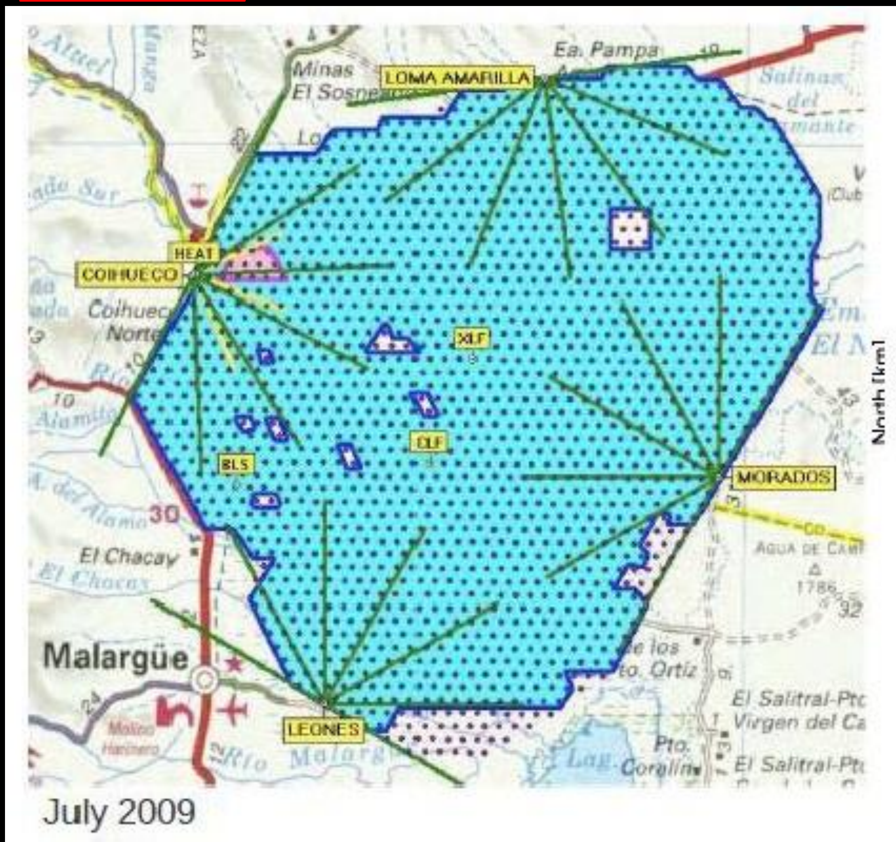


$$\gamma + p \rightarrow \Delta \rightarrow \pi^0 + p、\pi^+ + n$$

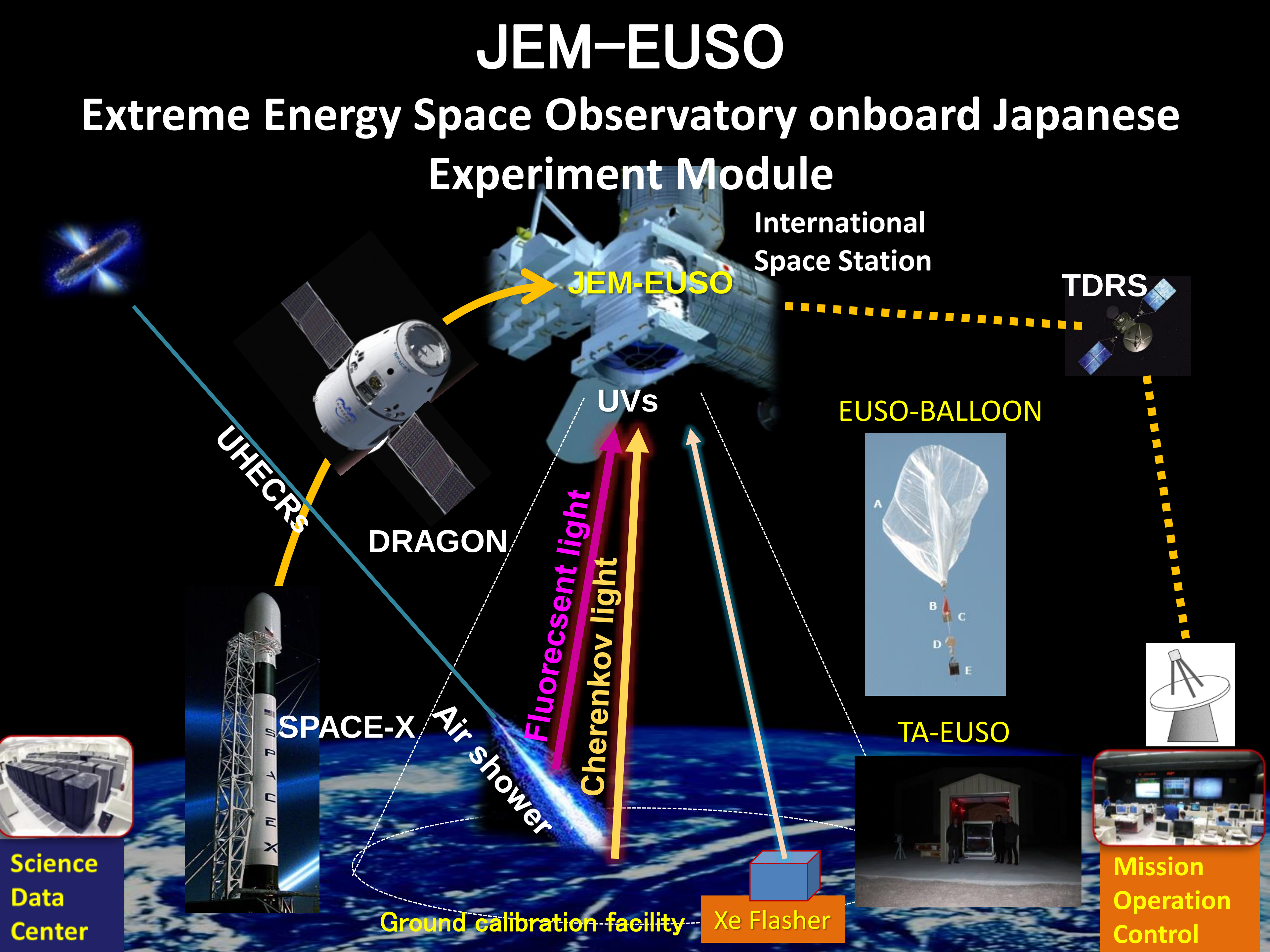
Why we need space ?

Auger

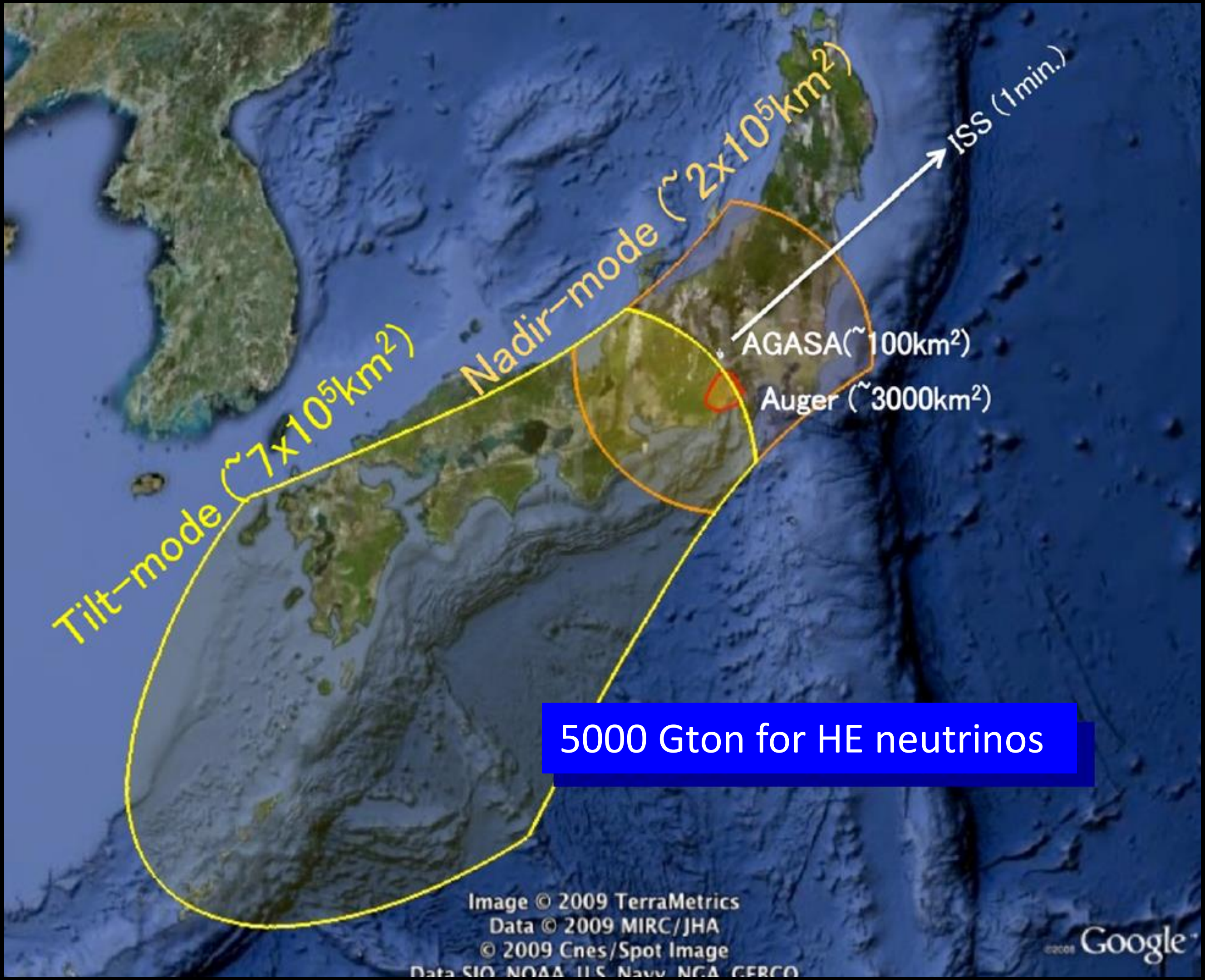
1600 surface detectors
3000 km^2



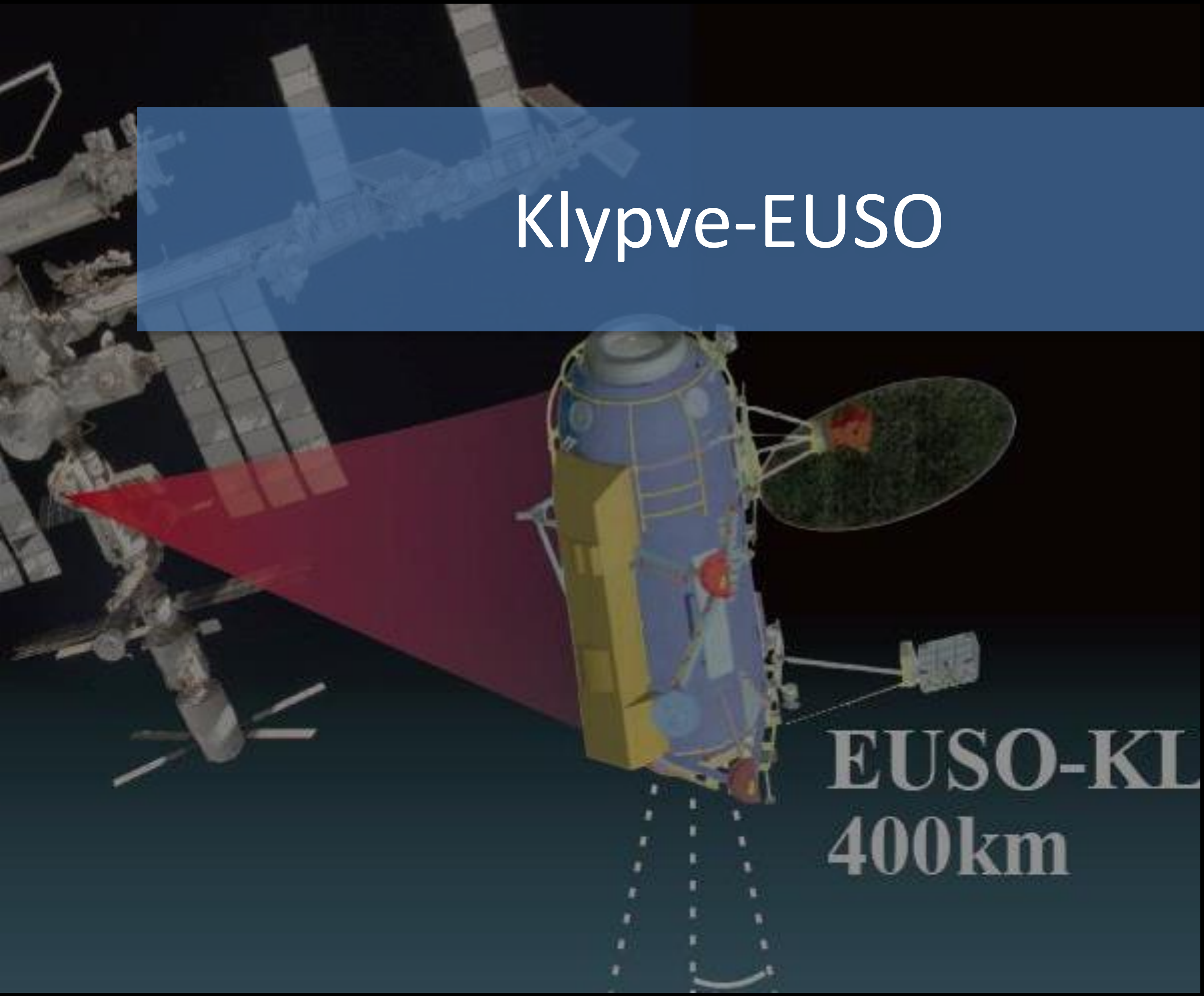
- Ground based detectors are already too huge!
- Need to go space to get statistics large enough

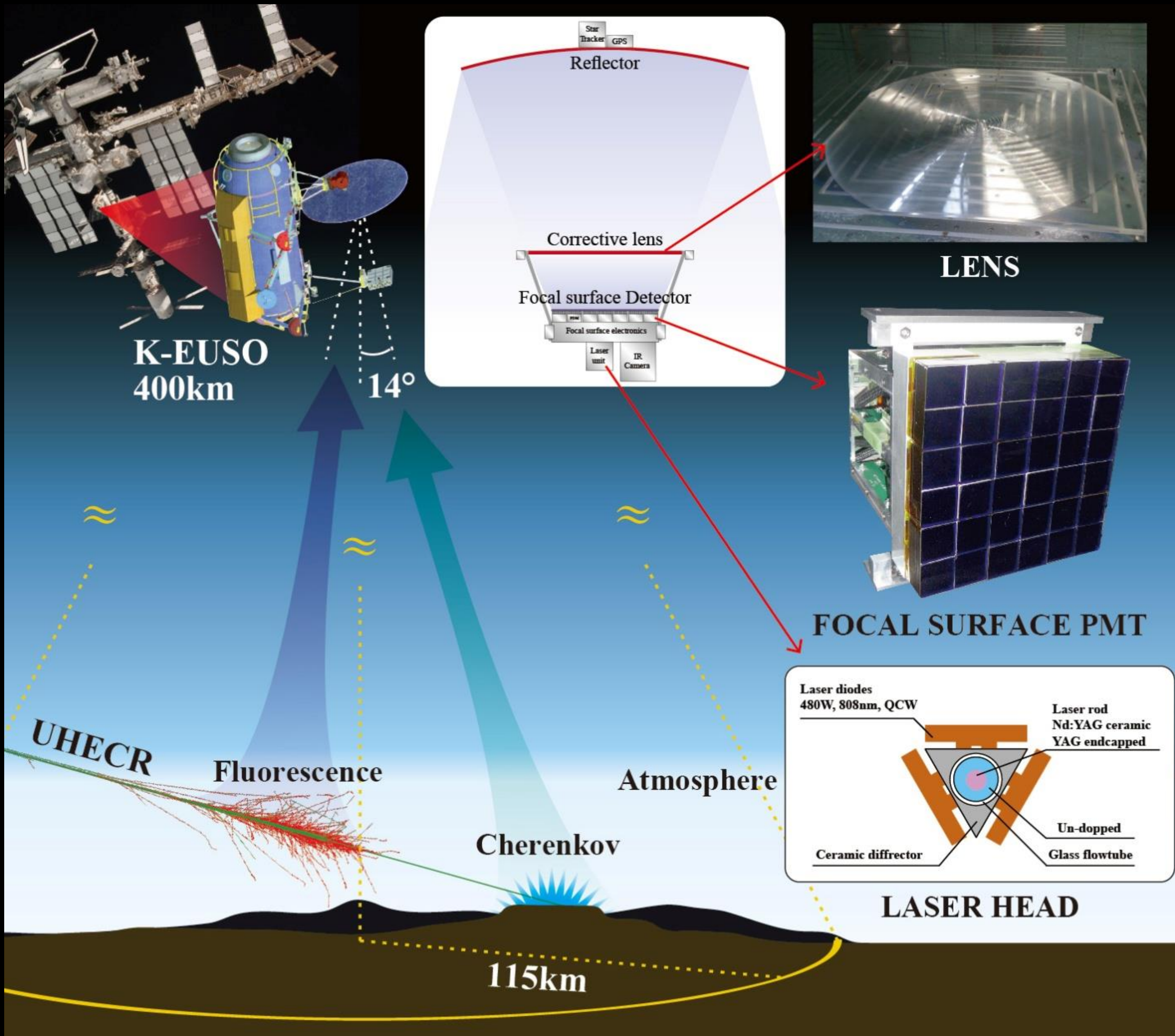

JEM–EUSO
Extreme Energy Space Observatory onboard Japanese Experiment Module
International Space Station
JEM-EUSO
TDRS
UVs
EUSO-BALLOON
UHECRs
DRAGON
Fluorecsent light
Cherenkov light
SPACE-X
Air Shower
TA-EUSO
Science Data Center
Ground calibration facility
Xe Flasher
Mission Operation Control

Large effective area

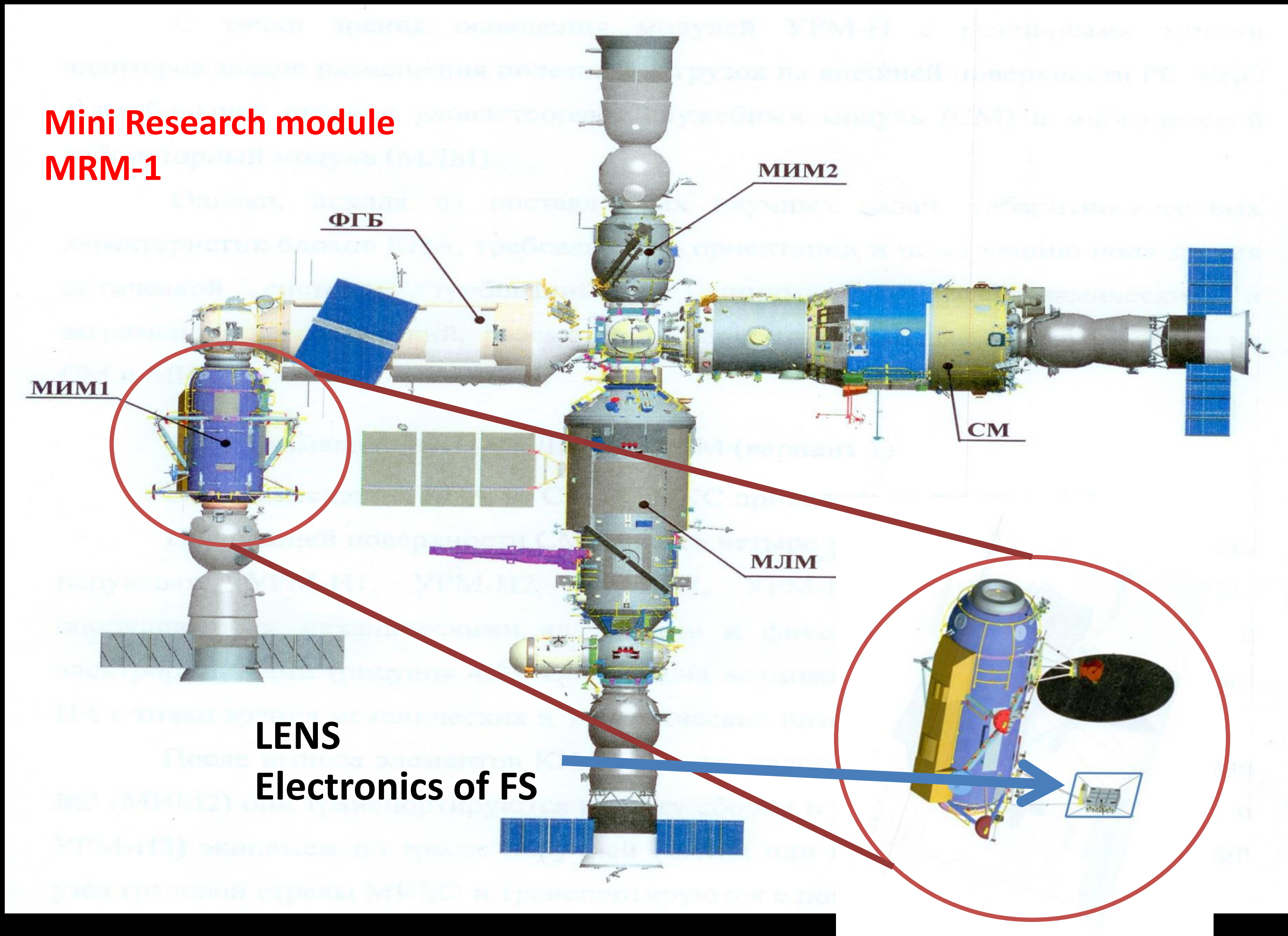


Klypve-EUSO




K-EUSO
400km
14°
Star Tracker
GPS
Reflector
Corrective lens
Focal surface Detector
Focal surface electronics
Laser unit
IR Camera
LENS
FOCAL SURFACE PMT
Laser diodes
480W, 808nm, QCW
Laser rod
Nd:YAG ceramic
YAG endcapped
Un-dopped
Ceramic diffractor
Glass flowtube
LASER HEAD
UHECR
Fluorescence
Atmosphere
Cherenkov
115km

Location on ISS



Deployment module: MRM-1

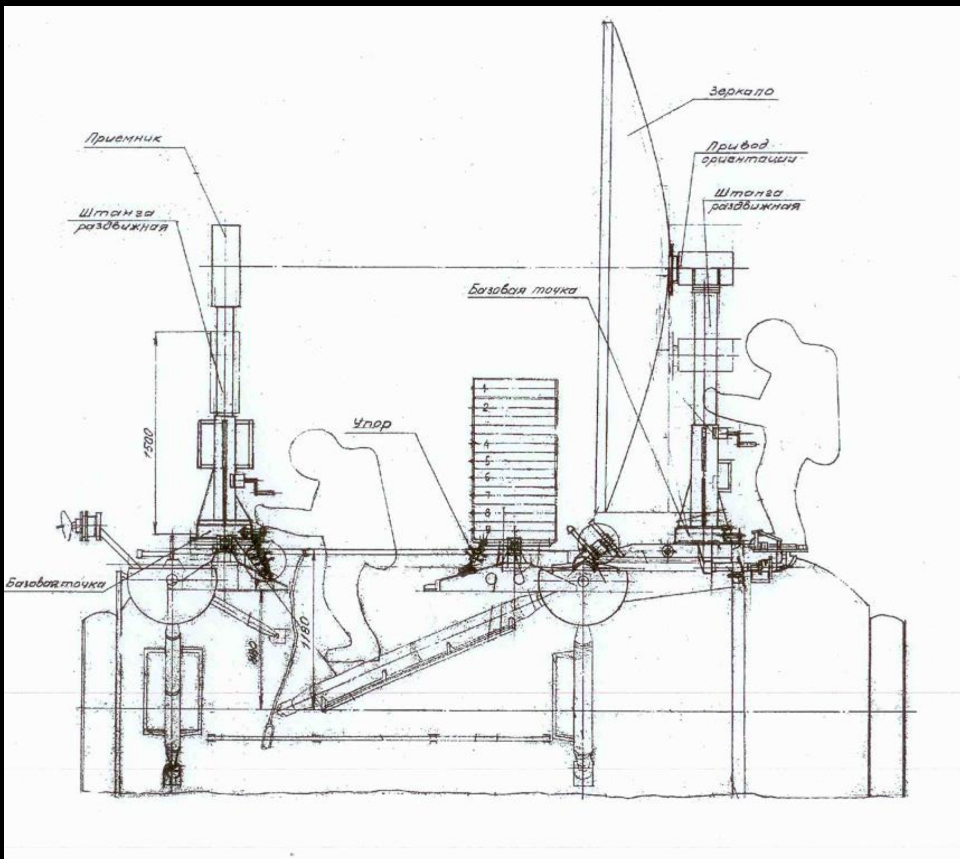
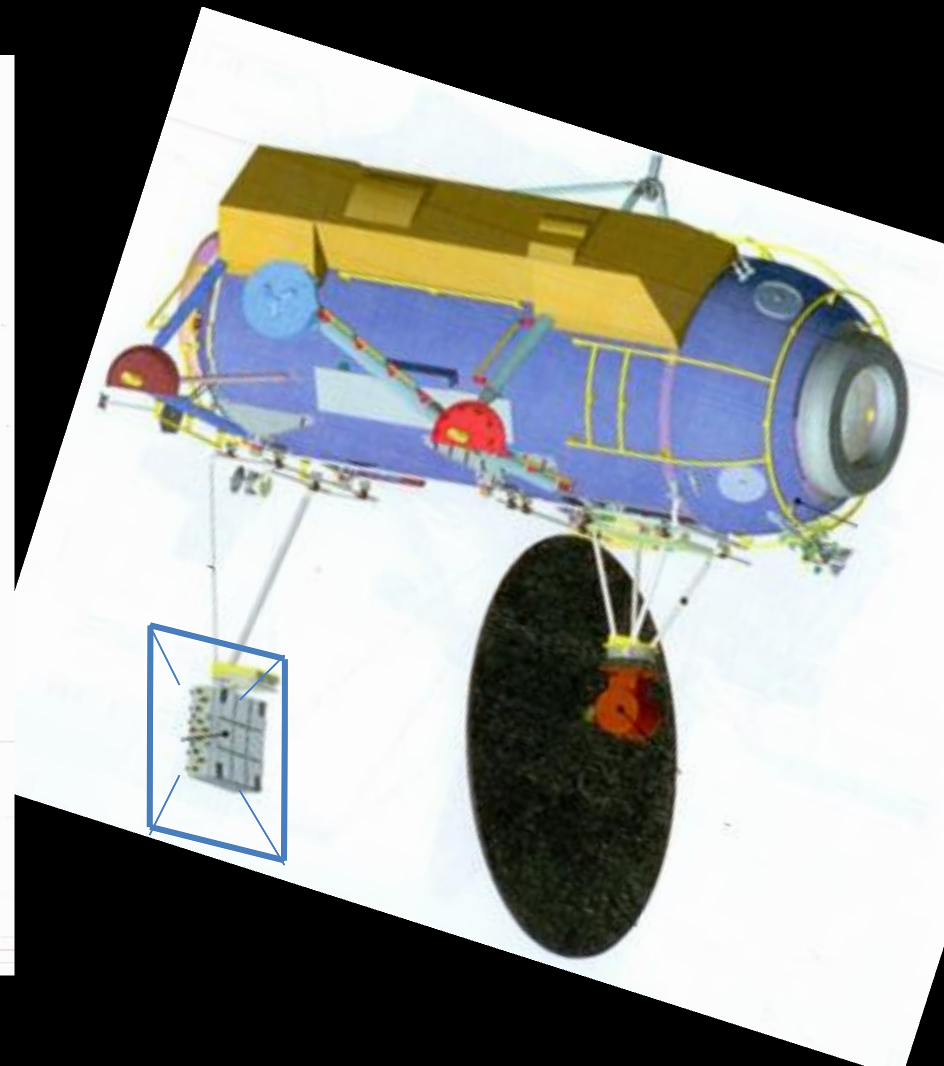
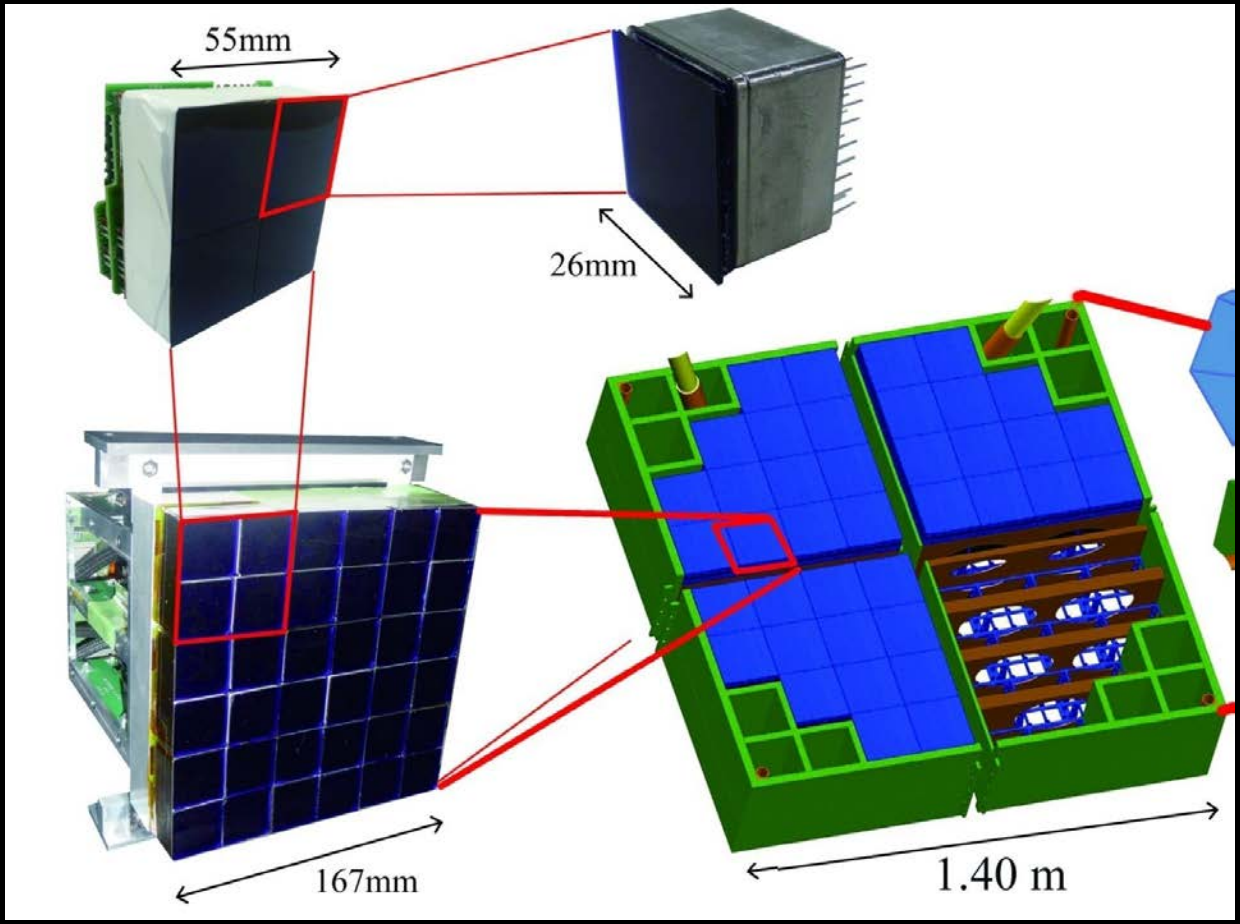


Рисунок 4.13 – Вариант размещения КНА КЛПВЭ на МИМ1



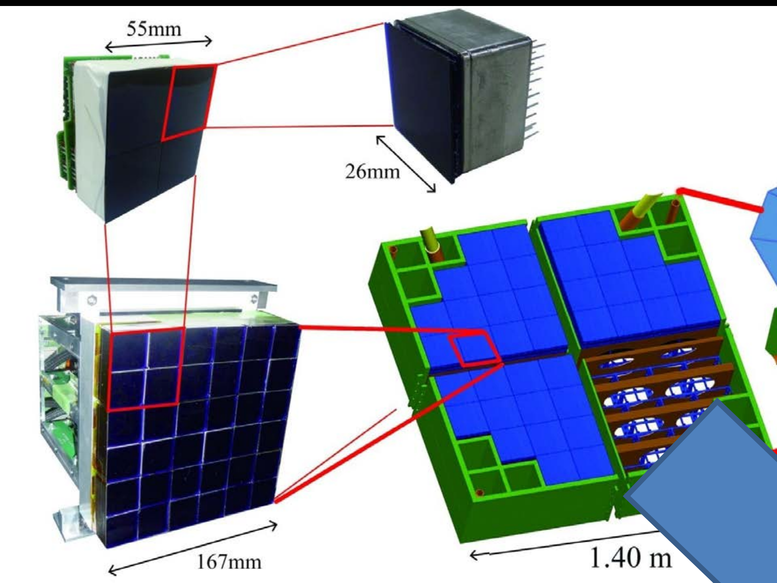
Focal surface: 52*MINI-EUSO Same size also for Schmidt

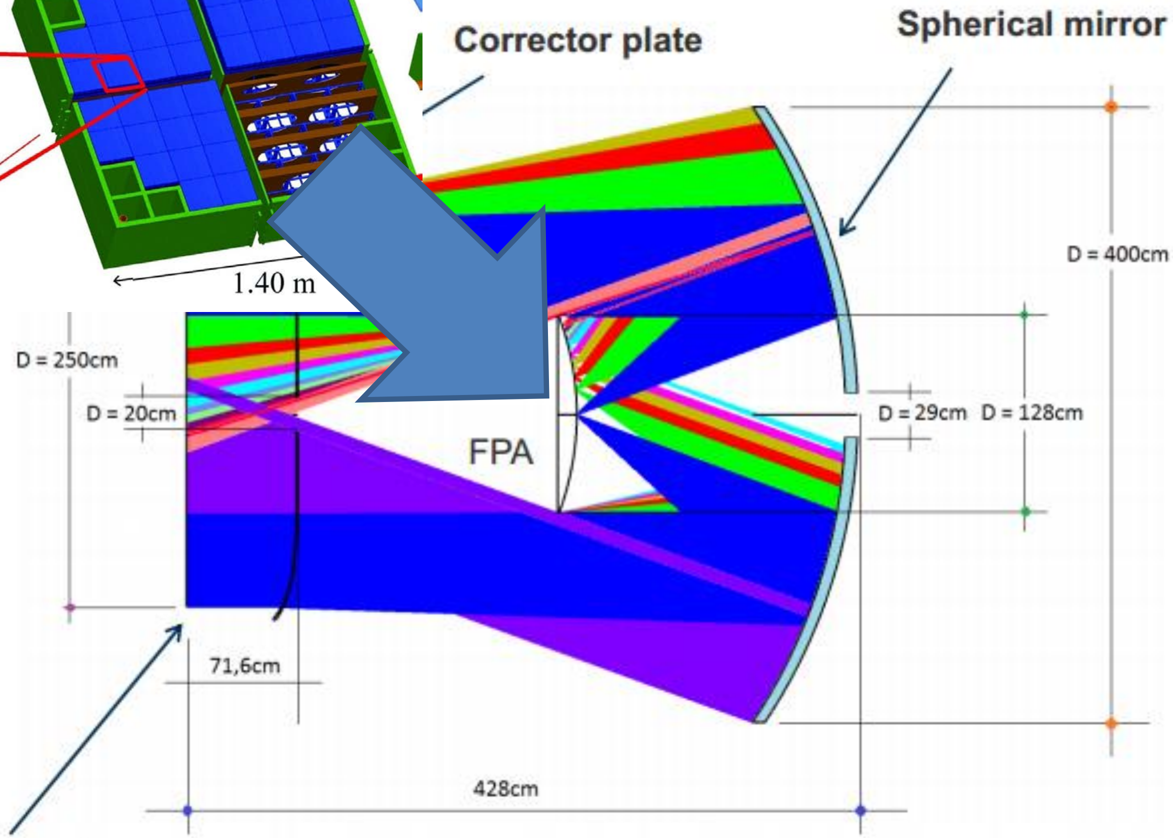
PDM 60 @
100keuro each
6MEuro



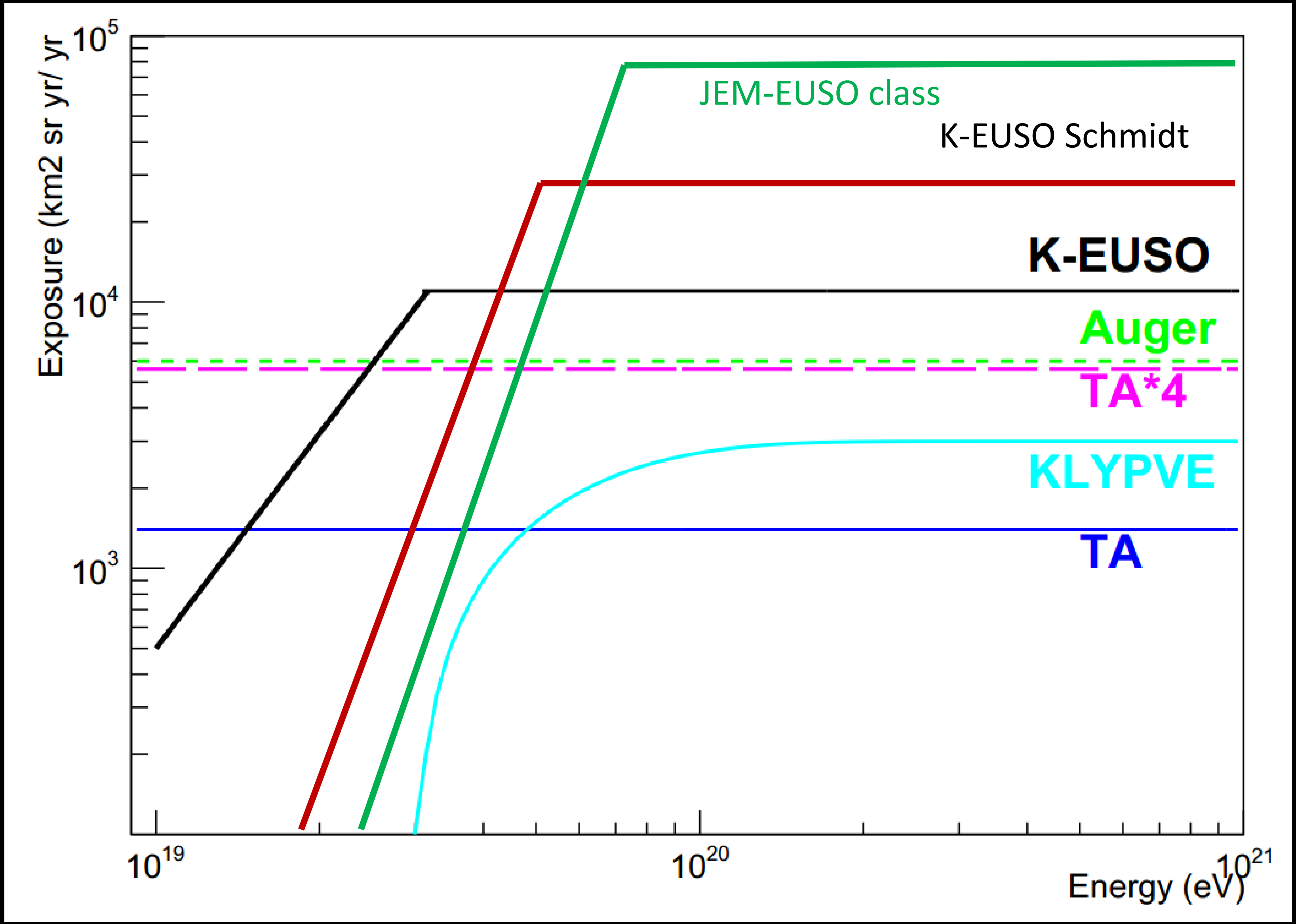
INO-CNR
Istituto Nazionale di Ottica

OHB
CGS



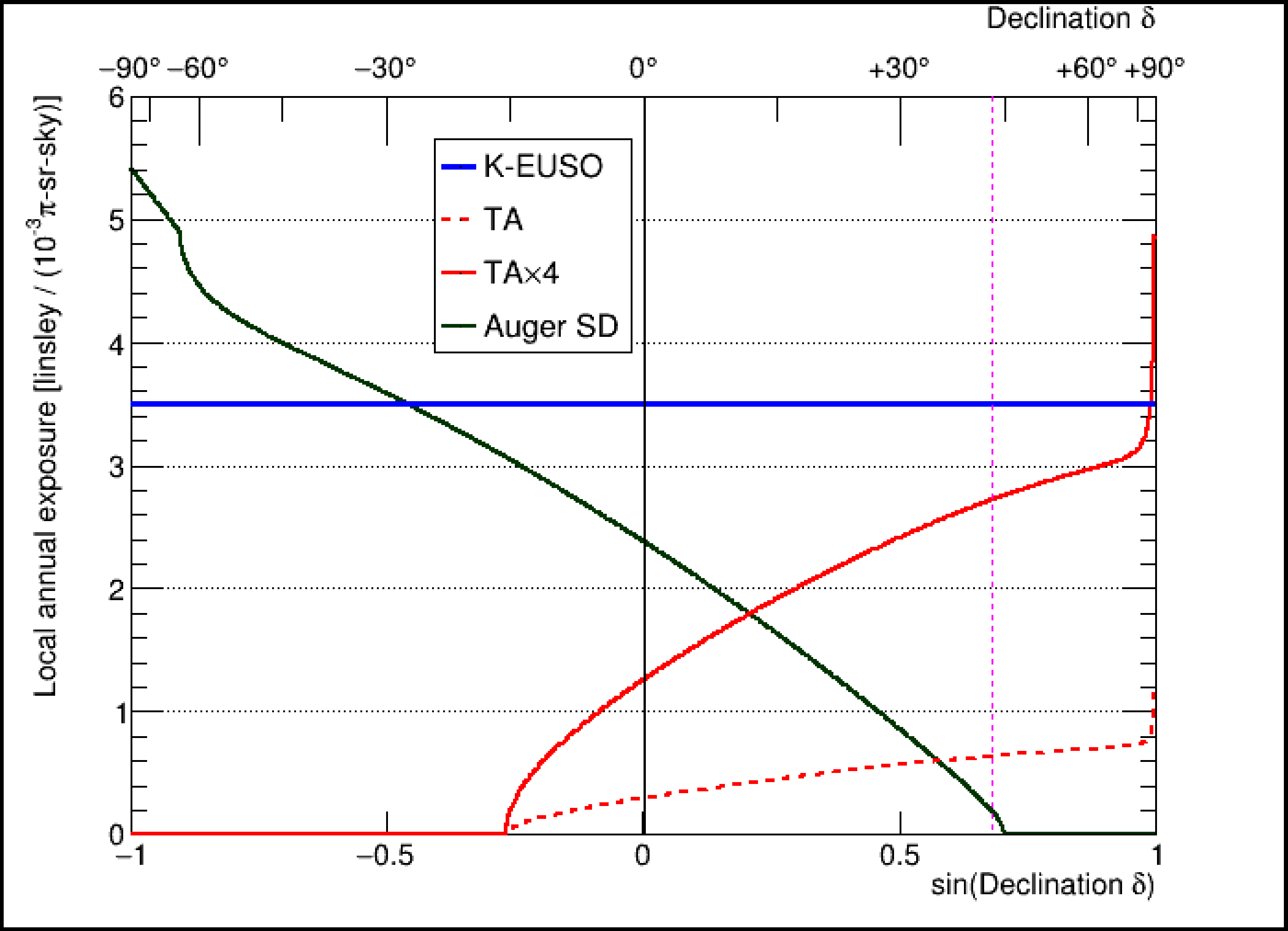


K-EUSO and Schmidt exposure

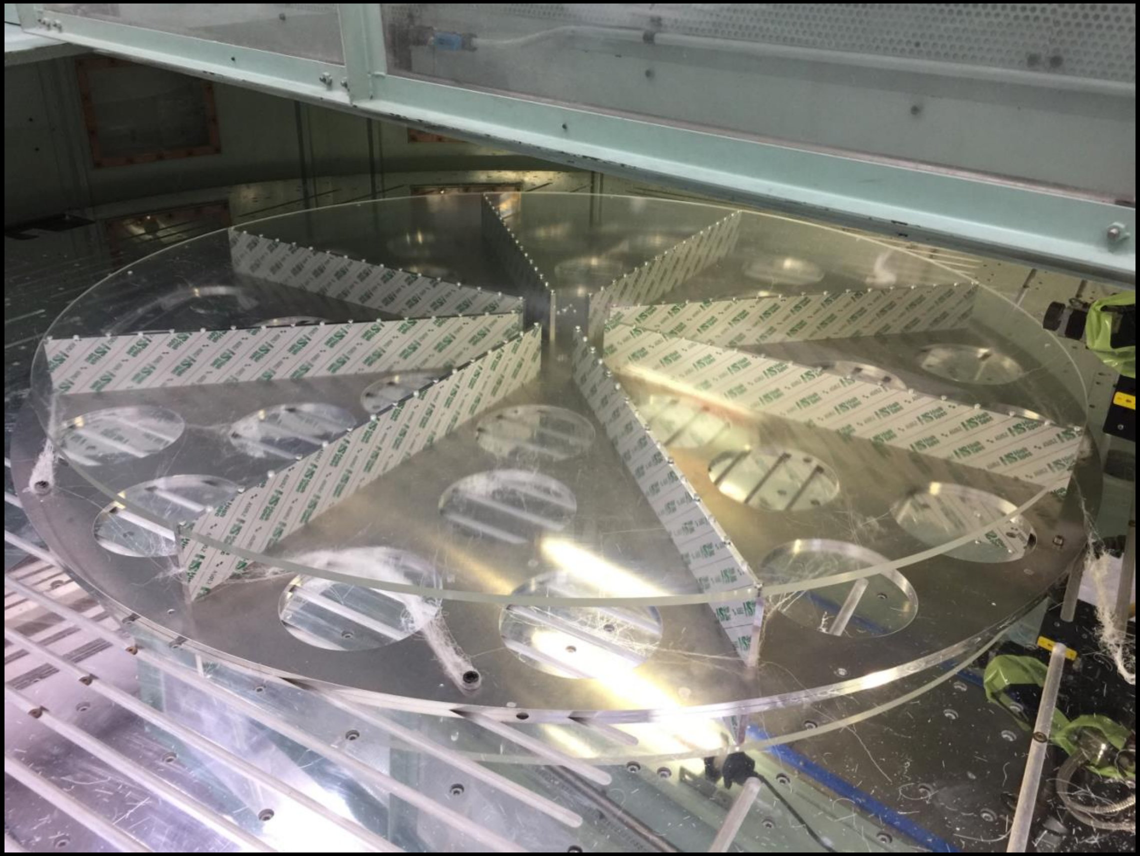


Uniform response over both hemispheres

Some (5%) disuniformity due to clouds, continents and moon phase

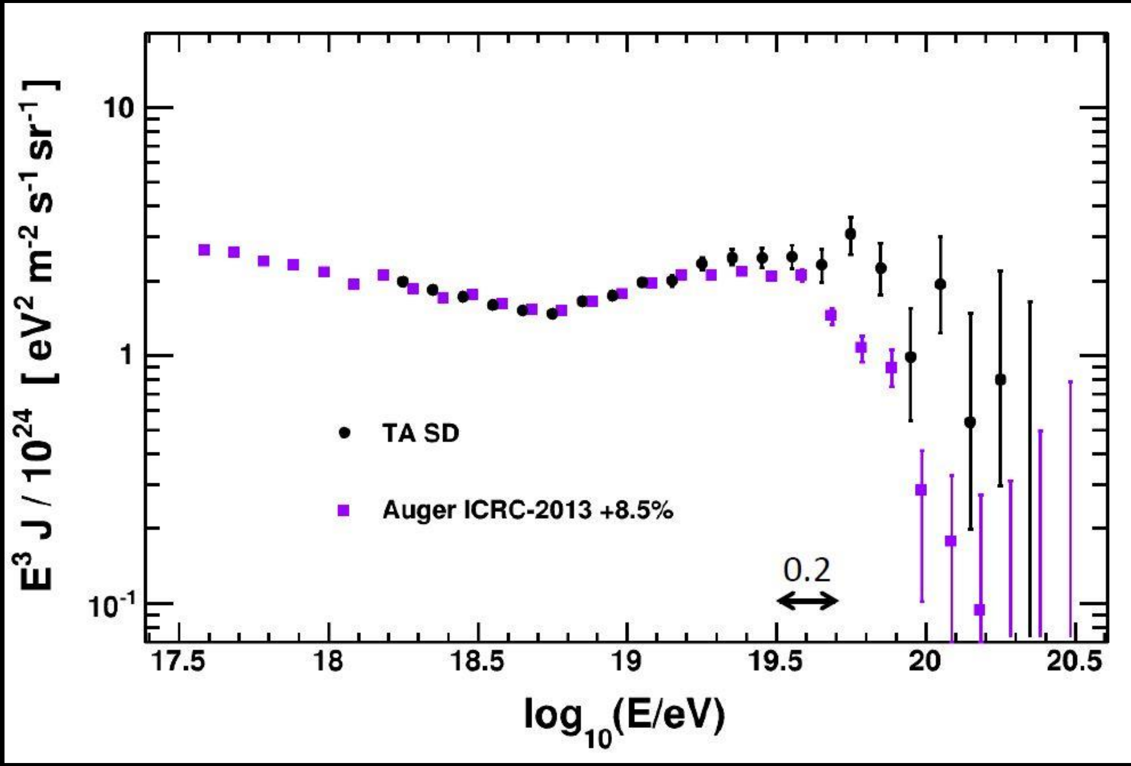


K-EUSO Lens EM being manufactured, Japan



Science of K-EUSO

KLYPVE detector goes from technological demonstrator to instrument capable of:



1. Study of UHECR fux from space with uniform response

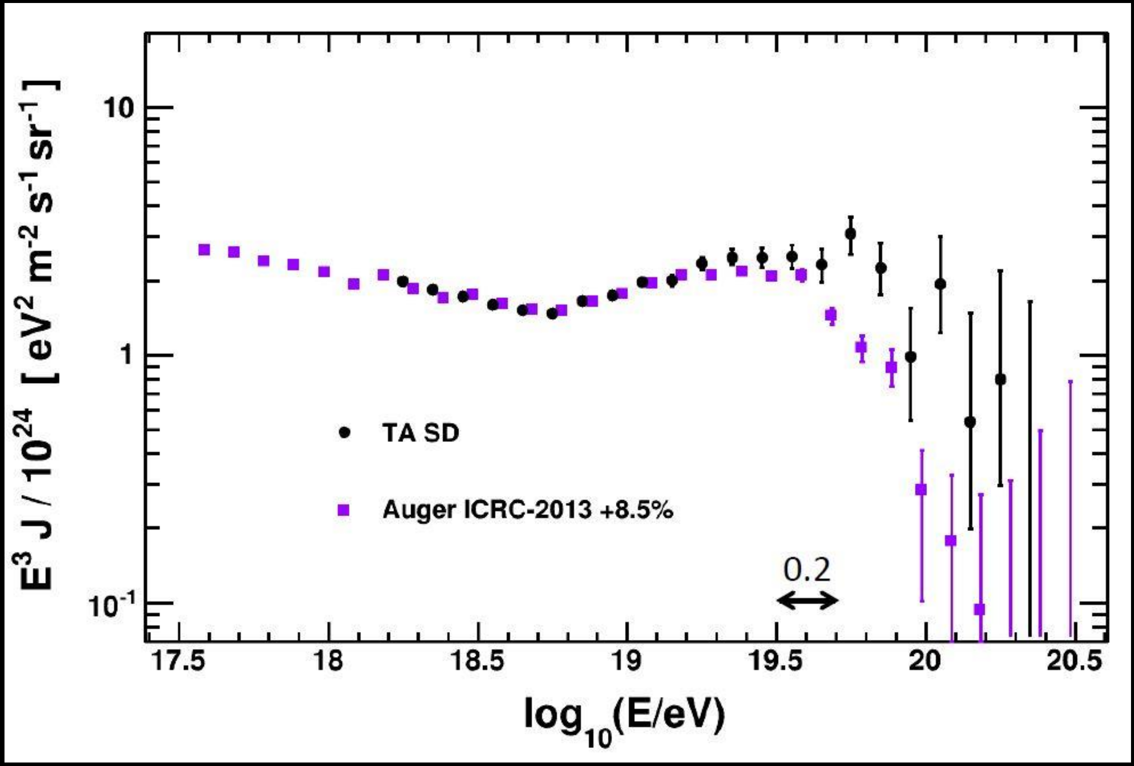
2. Are the North and South fluxes different or not?

4. Anysotropy, Hotspot

Unique physics of UHECR of Klypve: 1. N-S spectral difference

Auger and TA spectra

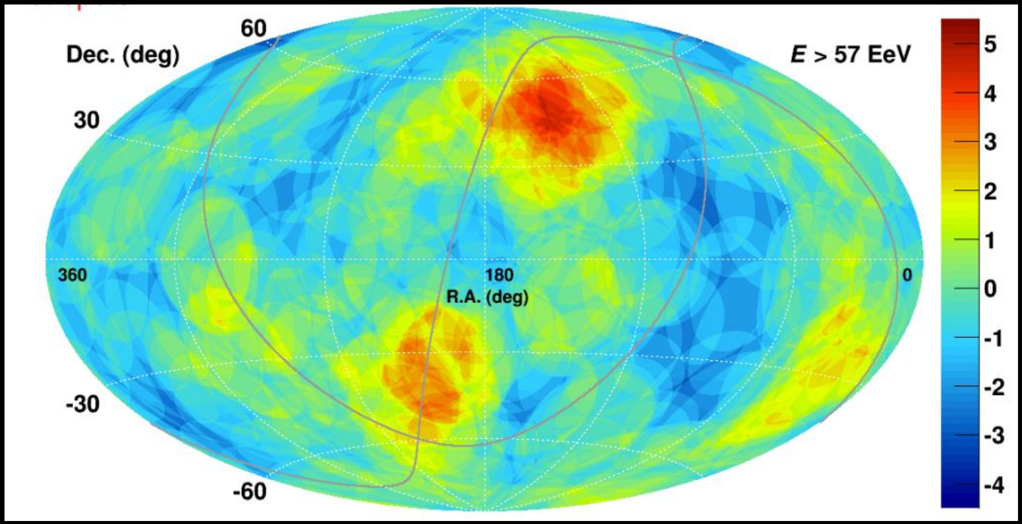
Need to rescale.
Is it correct?
Is it physics?
At GZK are they different+
Composition?



Science of K-EUSO

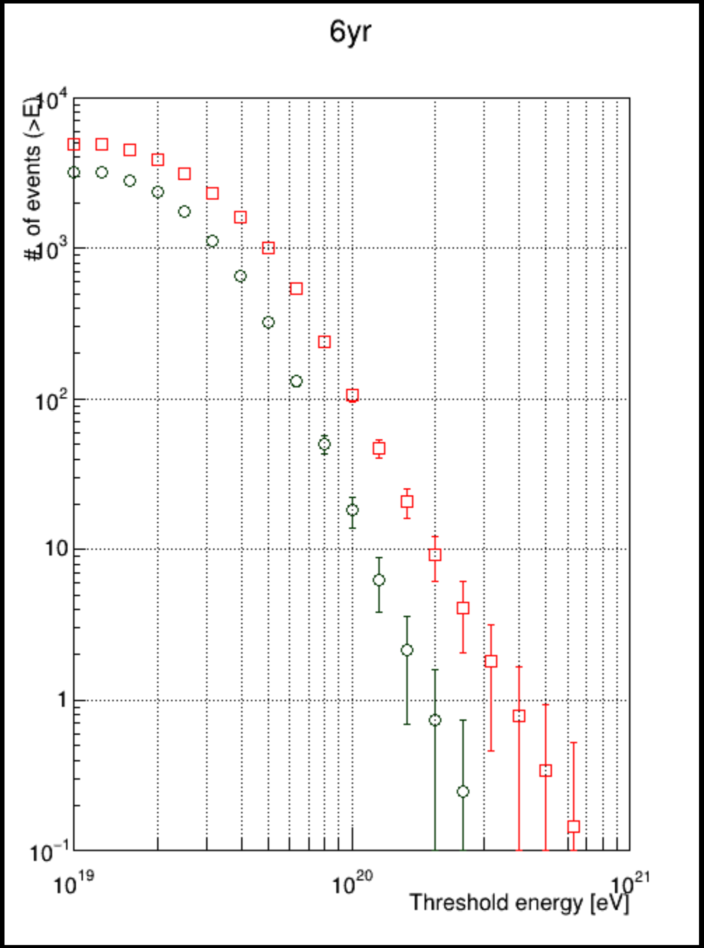
Anysotropy, Hotspots

Earth observations



Unique physics of UHECR of Klypve: 1. N-S spectral difference

After three years (with Schmidt)

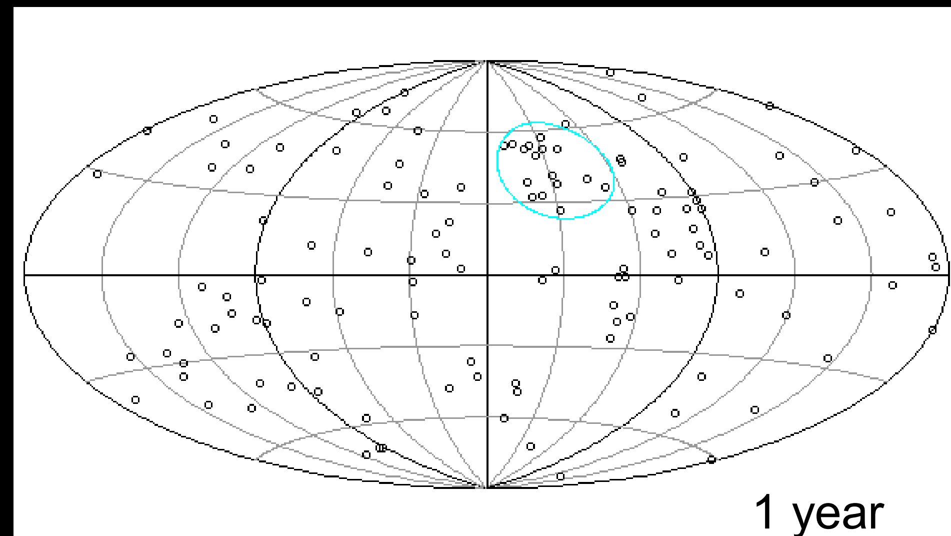


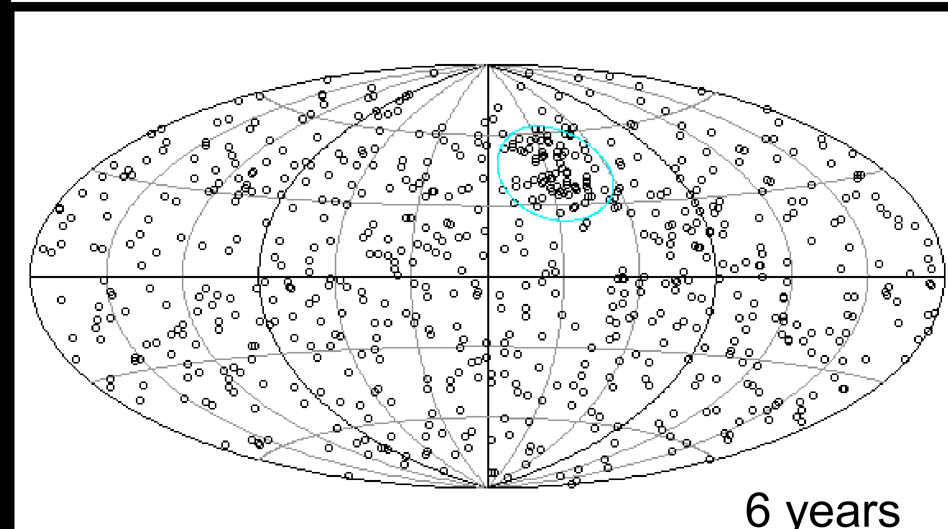
N_events E>5.7e19 eV 700

Used Auger and TA spectra 2015 in each hemisphere

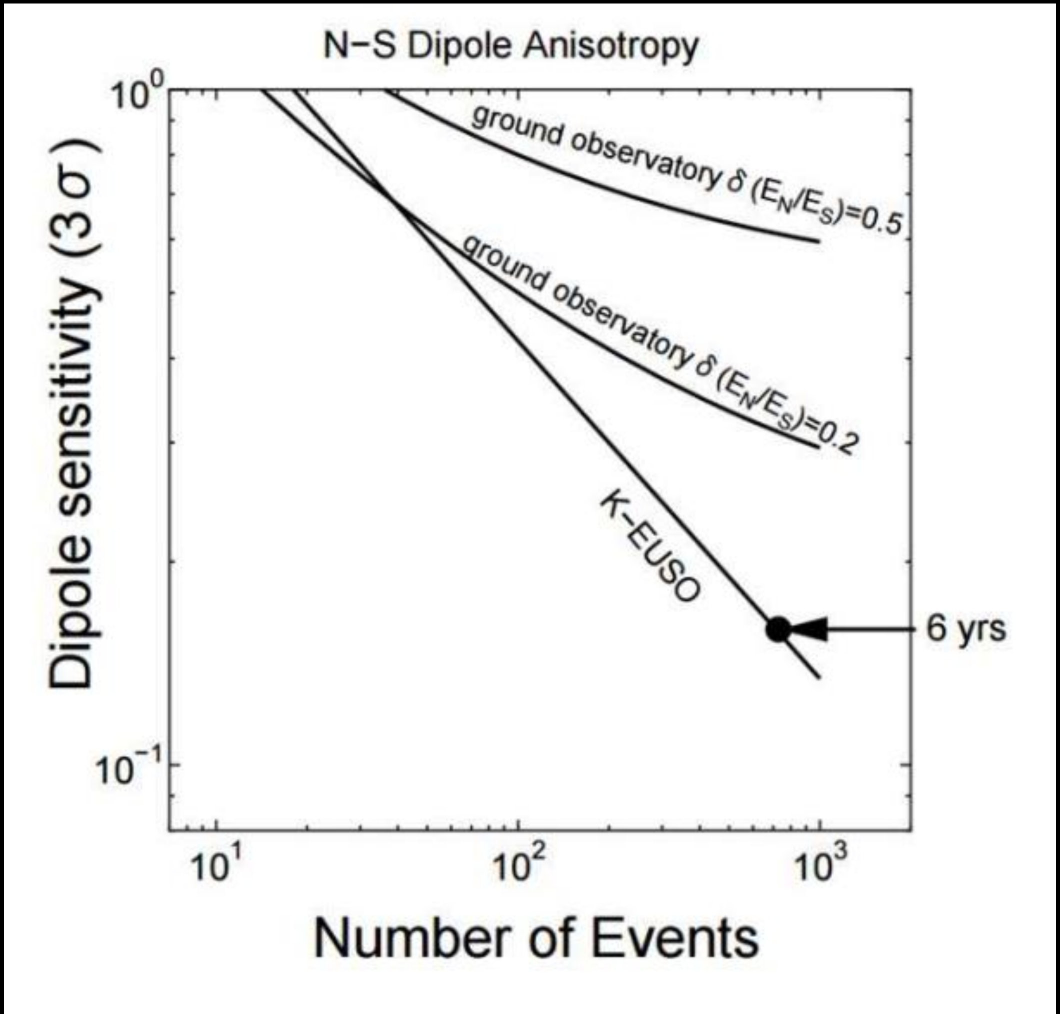
Unique physics of UHECR of Klypve: 2. anisotropy and hotspots

	N_hot	N_BG	Significance sigma	# of events
1yr	16.2	3.8	2.5 with LEE 3.9 w/o LEE	117.3
6yr	97.4	22.9	7.5 with LEE 9.49 w/o LEE	704.0



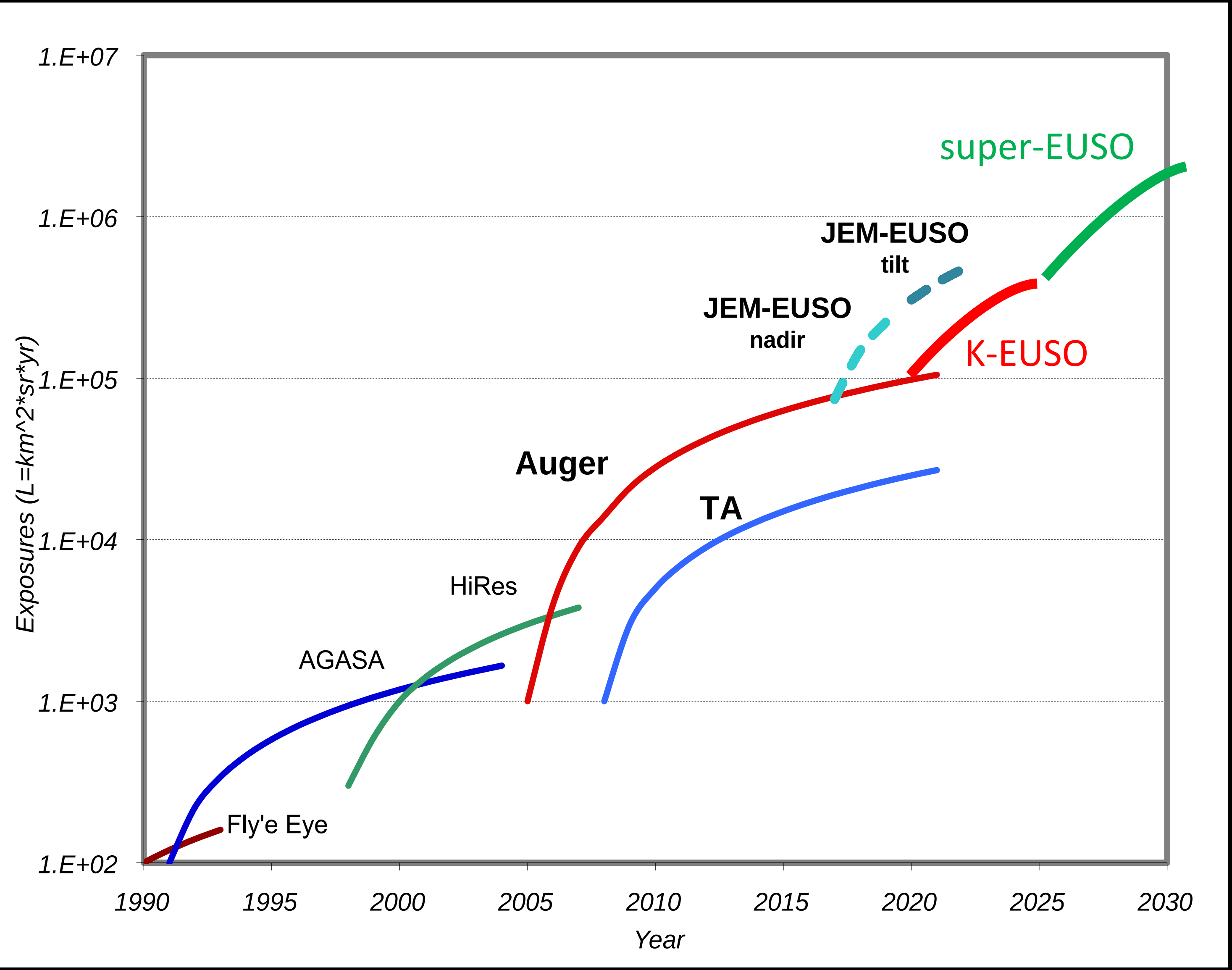


Unique physics of UHECR of Klypve: 3. No dipole component?



Klypve and beyound

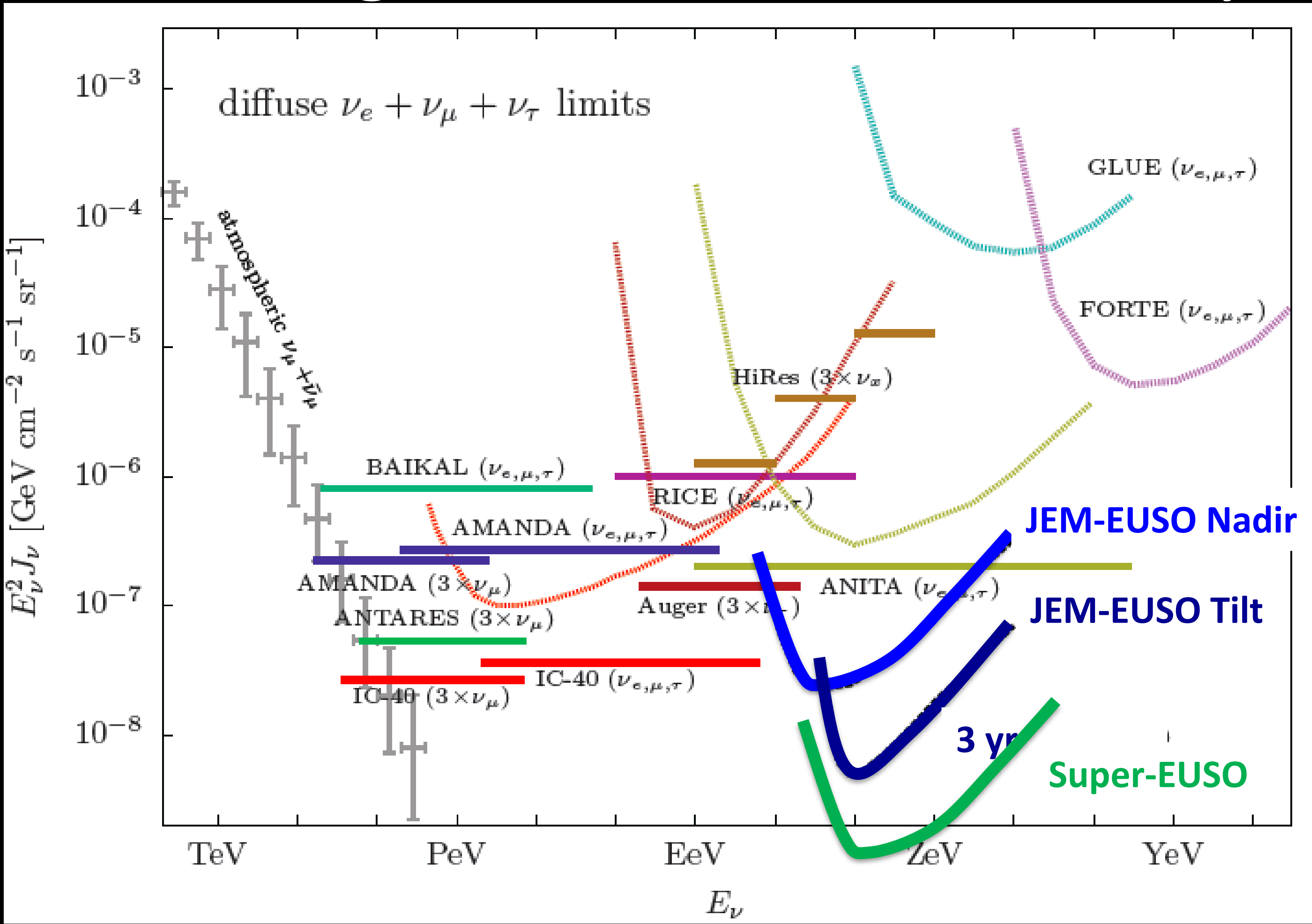
- Next step: JEM-EUSO class mission
  - Charged particle Astronomy:
    - Several independent sources
      - Comparisons among them: M82/M87/background
  - HE neutrinos ~(10^{20} eV)
- Super EUSOs
  - Geo-schinchronus orbit above pacific ocean

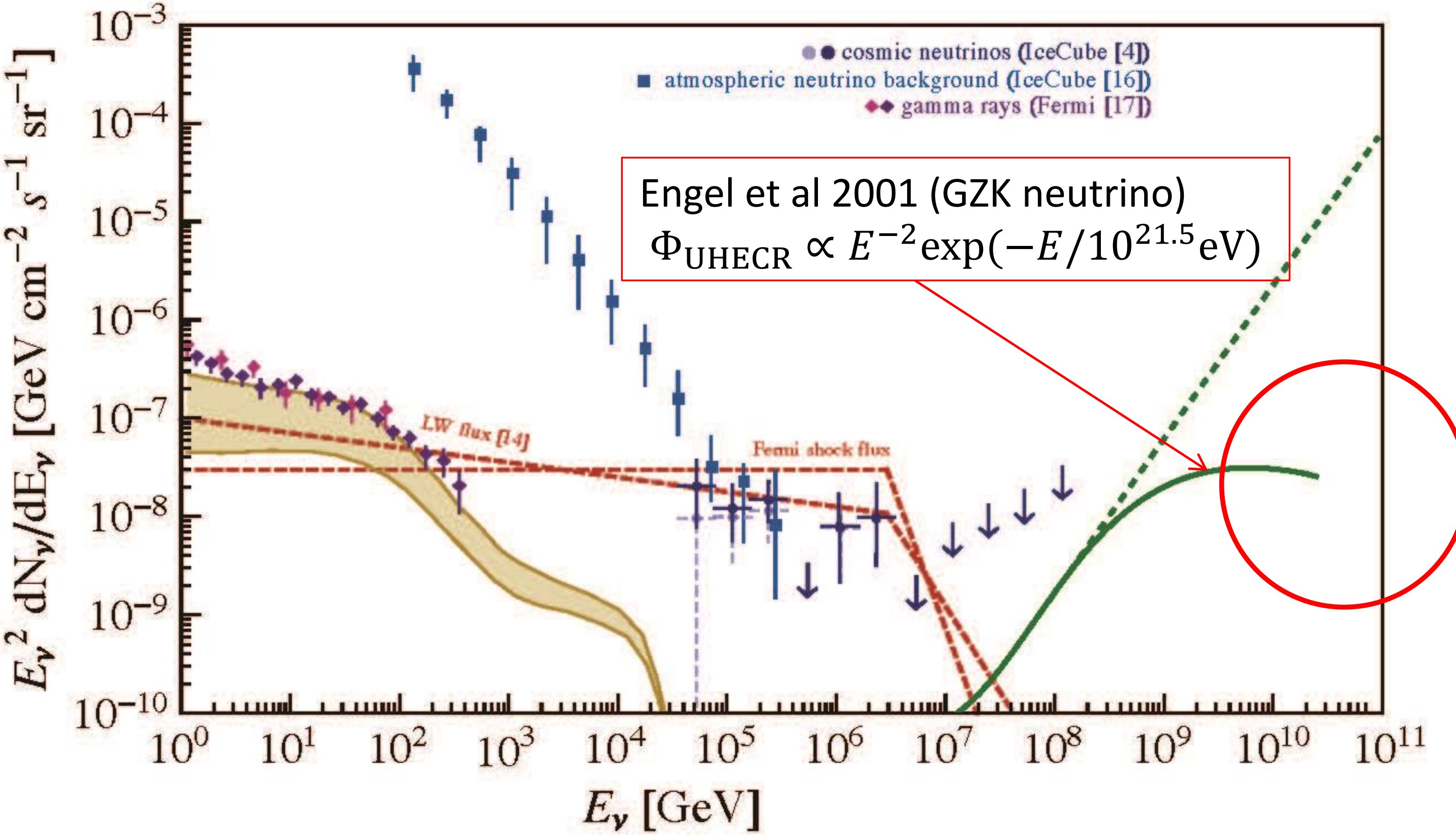

1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
Exposures (L=km^2*sr*yr)
1990
1995
2000
2005
2010
2015
2020
2025
2030
Year
super-EUSO
JEM-EUSO
tilt
JEM-EUSO
nadir
K-EUSO
Auger
TA
HiRes
AGASA
Fly'e Eye


Y. Takahashi 1999
Great observatory made &
deployed from the renewed ISS
heading for its own orbit


N
US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2012 Europa Technologies
© 2012 Google
Google earth

Leading ZeV neutrino sensitivity




cosmic neutrinos (IceCube [4])
atmospheric neutrino background (IceCube [16])
gamma rays (Fermi [17])
Engel et al 2001 (GZK neutrino)
$\Phi_{\mathrm{UHECR}} \propto E^{-2}\exp(-E/10^{21.5}\mathrm{eV})$
LW flux [14]
Fermi shock flux
$E_\nu^2\, dN_\nu/dE_\nu$ [GeV cm^{-2} s^{-1} sr^{-1}]
E_ν [GeV]
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11}

Preparatory activities

- TA EUSO (1m square)
- EUSO balloon (1m square)
  - 2014 flight by CNES
  - 2017 SPB flight by NASA (coming soon)
- Mini-EUSO (25 cm Φ)
  - Russian module at ISS
  - Launch in 2017

1. EUSO-TA

EUSO-TA

2013: Installation, building, lenses

2014: for Auger/Fast tests

2015:

February/March

- Detector installation
- Focusing, initial calibration
- Initial CLF and CSOM laser observations

May

- Cosmic ray observations – one UHECR detected
- CLF and CSOM laser observations
- Flat screen and LED calibration

September

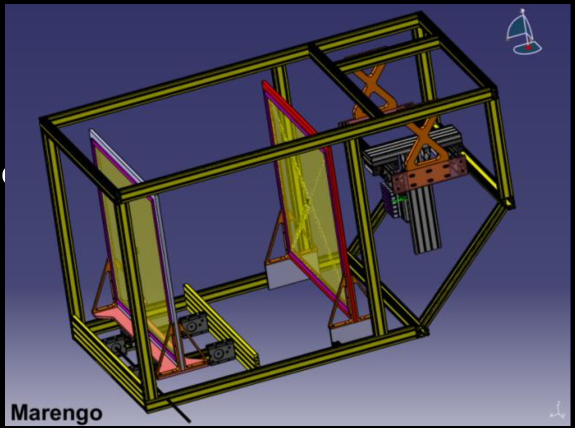
- Cosmic ray observations – analysis ongoing
- CLF and CSOM laser observations

October

- Cosmic ray observations – analysis ongoing
- Internal trigger tests on the balloon PDM board – successful triggering laser
- CLF and CSOM laser observations

November

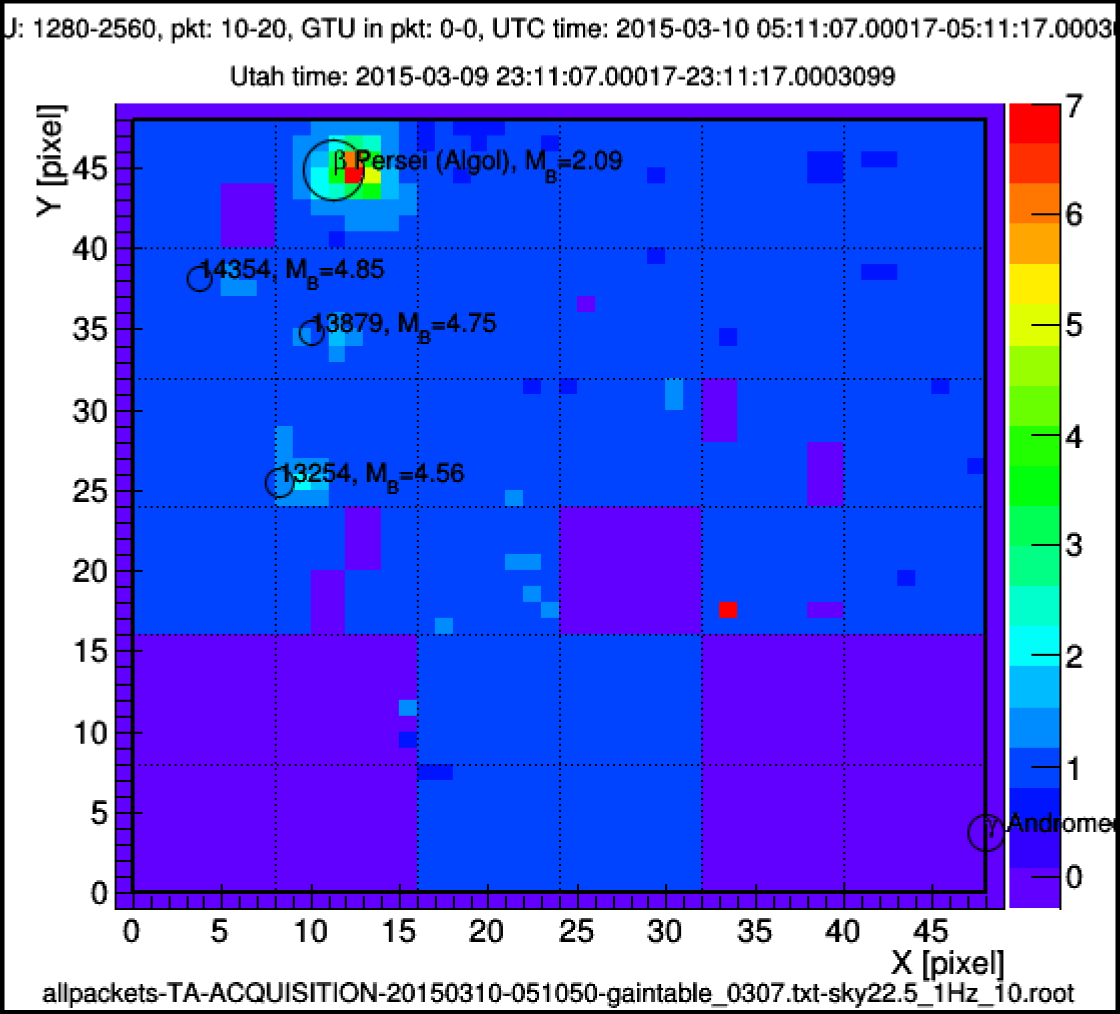
- Cosmic ray observations
- CLF laser observations



2016: refurbishment of focal surface, joint tests with super pressure balloon

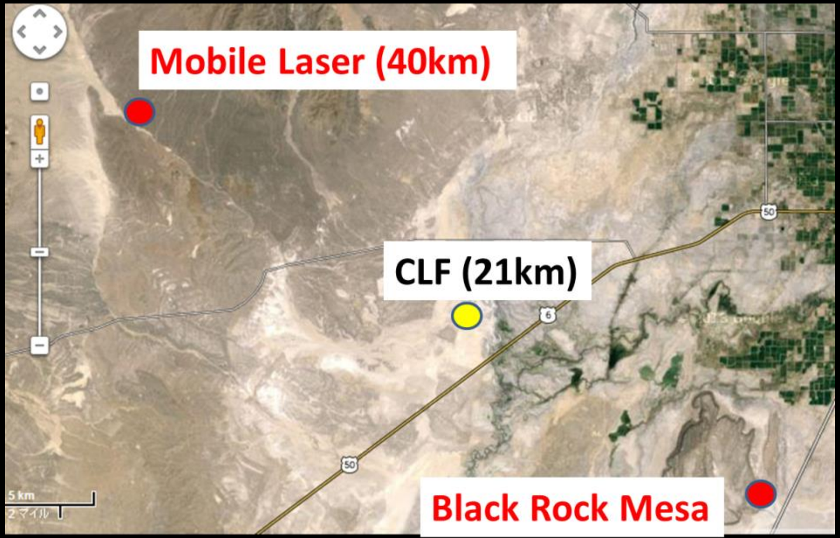
Stars Imaging

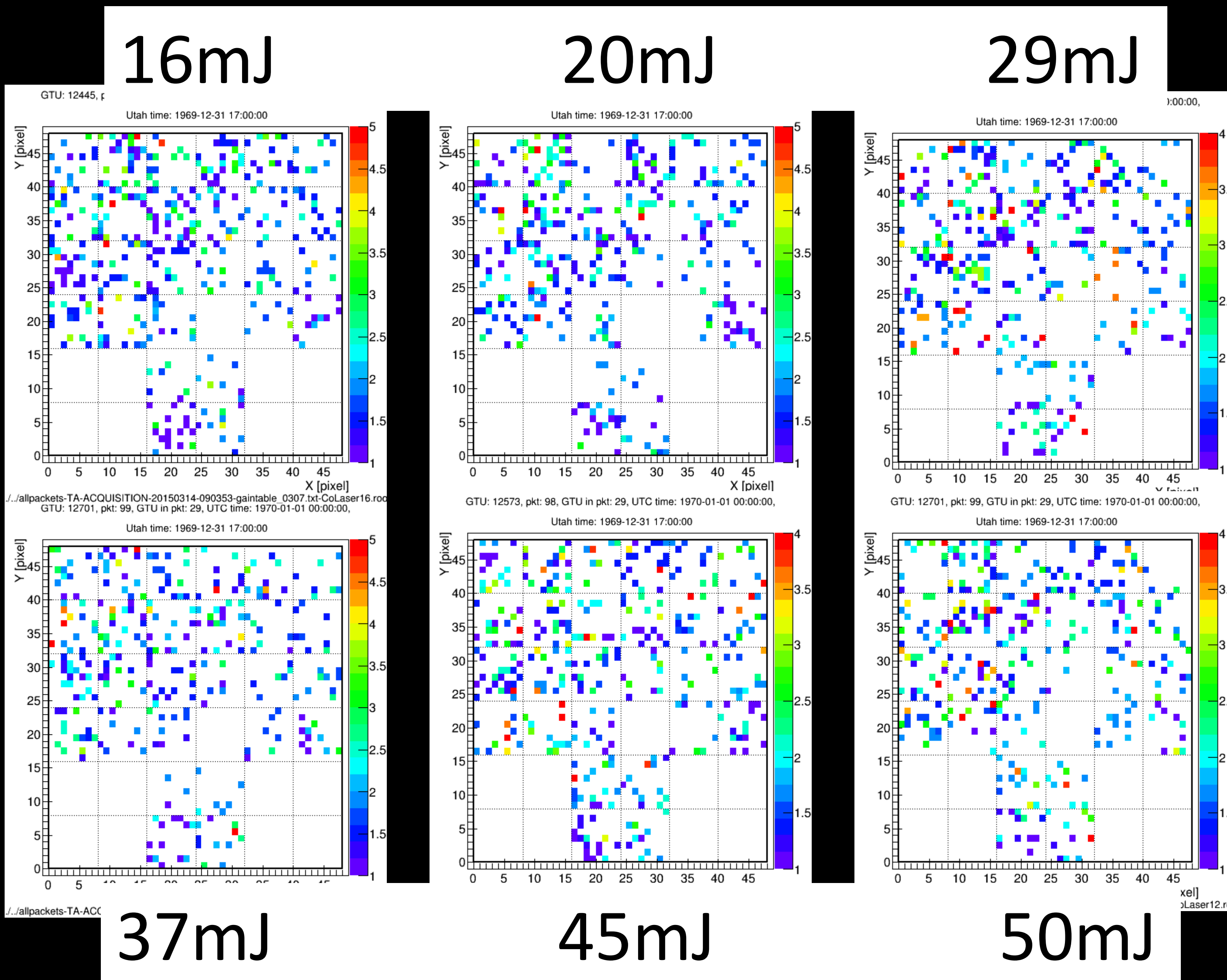
May be used for calibration Hypparcos catalogue



Colorado school of mines movable laser

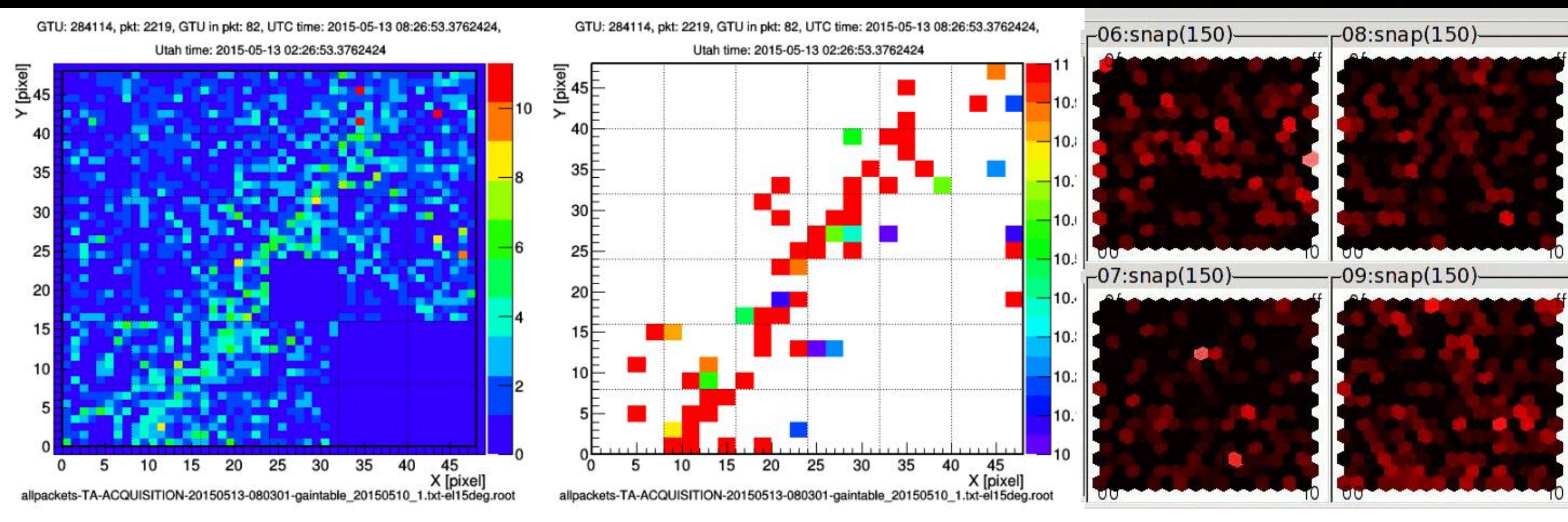
Total of 17 nights
Distances of 24, 34, 40, 60, 100 km
Power 0.5mJ up to 90mJ
Several inclination




16mJ
20mJ
29mJ
37mJ
45mJ
50mJ
GTU: 12445,
Utah time: 1969-12-31 17:00:00
Y [pixel]
X [pixel]
../../allpackets-TA-ACQUISITION-20150314-090353-gaintable_0307.txt-CoLaser16.roo
GTU: 12701, pkt: 99, GTU in pkt: 29, UTC time: 1970-01-01 00:00:00,
GTU: 12573, pkt: 98, GTU in pkt: 29, UTC time: 1970-01-01 00:00:00,
GTU: 12701, pkt: 99, GTU in pkt: 29, UTC time: 1970-01-01 00:00:00,

Cosmic ray event, 13/5/2015

Telescope Array reconstruction
Zenith = 35°
Azimuth = 7° (clockwise from N)
E = 10^18 eV
Rp = 2.5 km
Core = (14.8 km, -10.9 km) respec



EUSO, 1 frame, 2.5micros

EUSO, 2*2

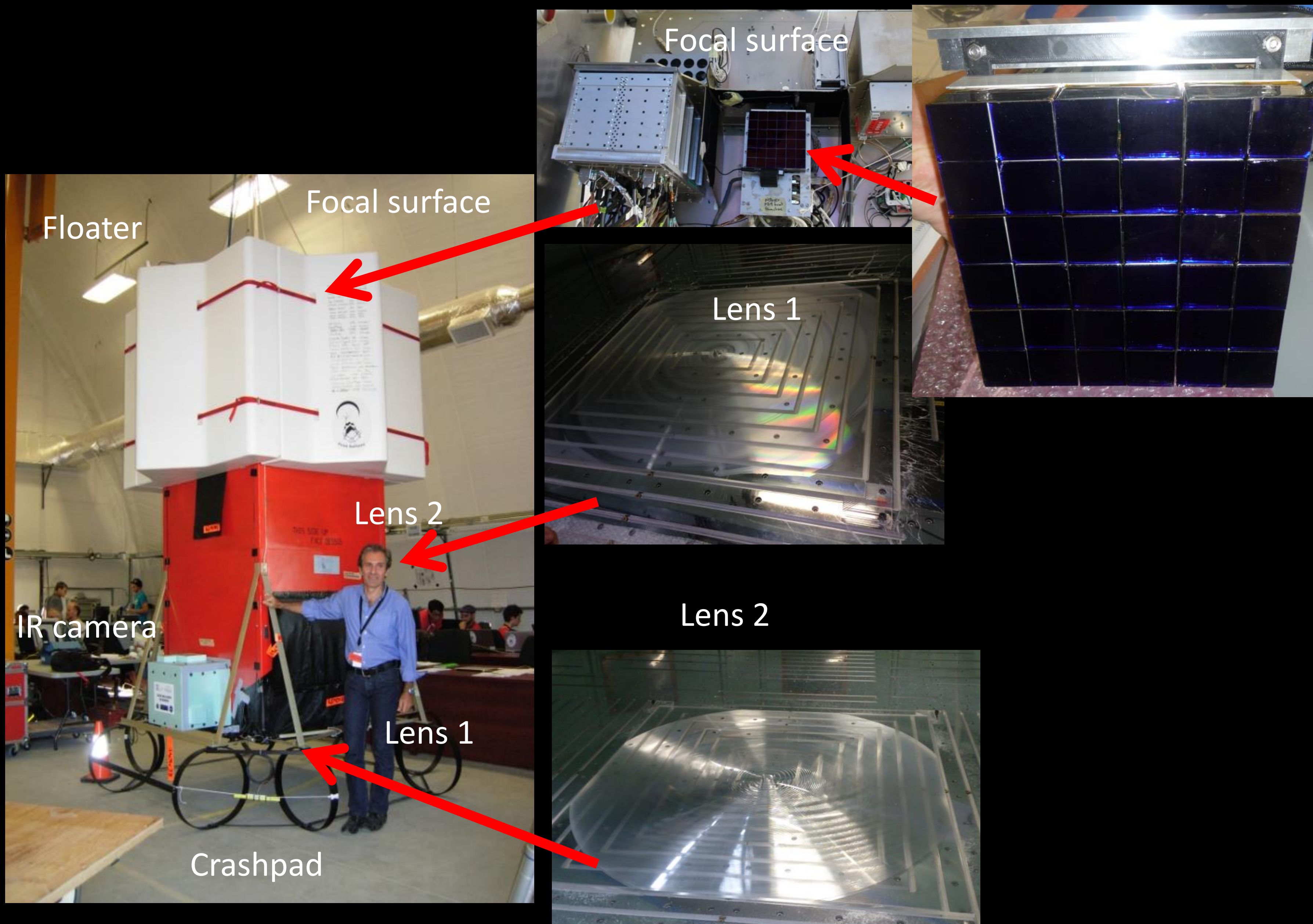
TA signal

2. EUSO-Balloon flights

1[st] flight, Aug 2014
Timmins (CA)

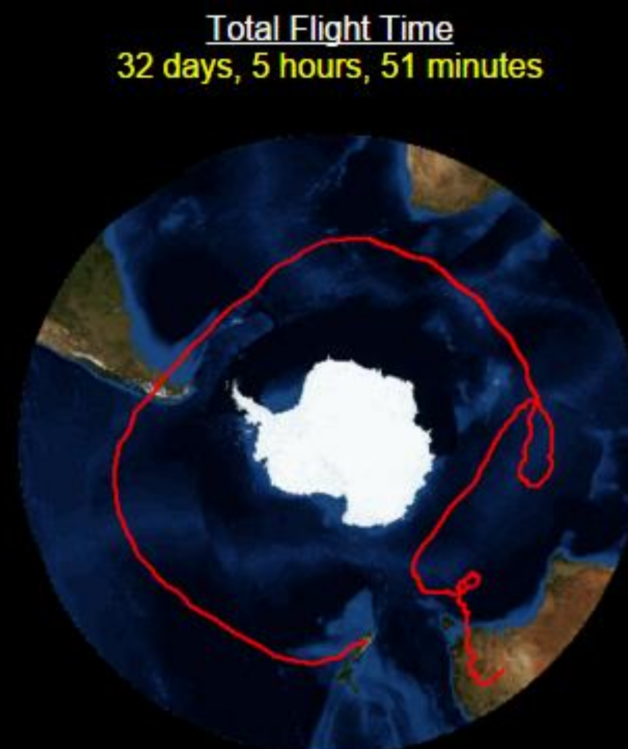
Payload built by JEM-EUSO collaboration
CNES (French Space Agency) mission

Timmins Balloon payload



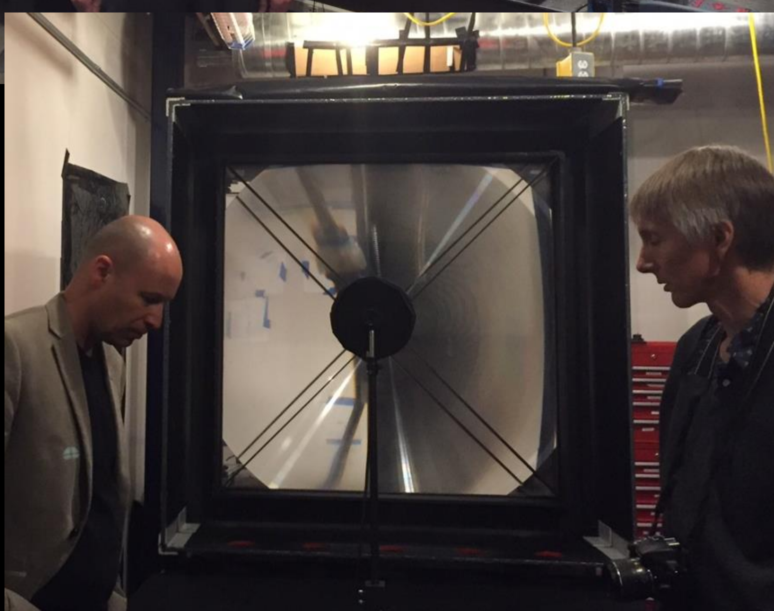
Xe flasher and Laser events from NASA helicopter

EUSO-Balloon 2nd flight, March 2017
Wanaka, New Zealand



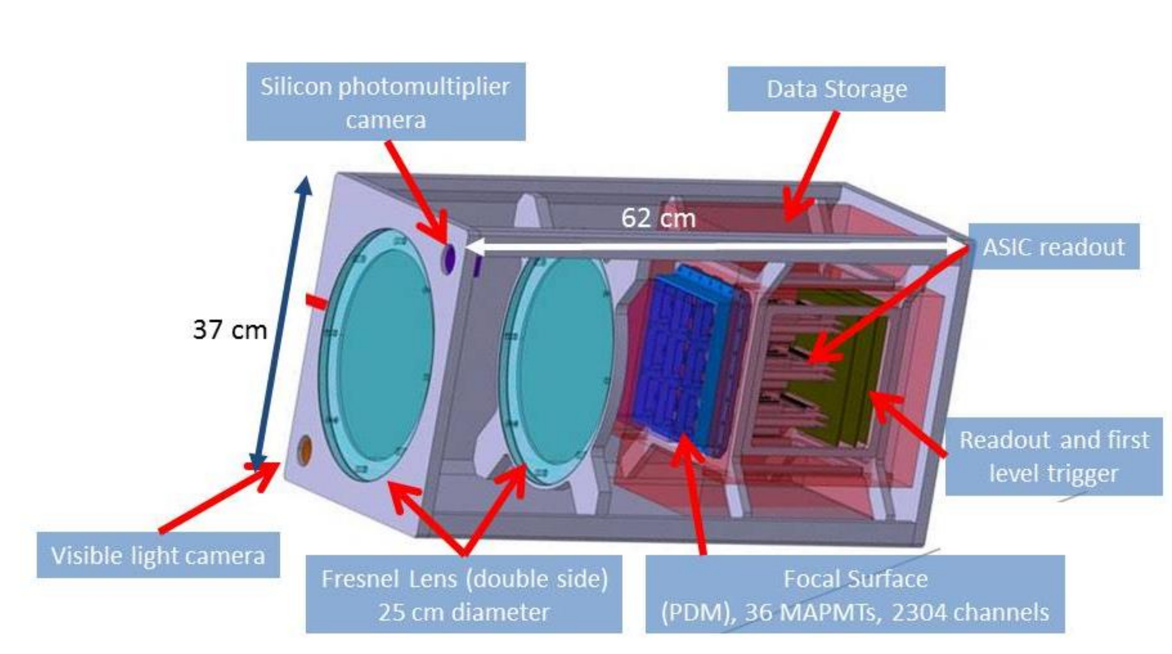
NASA Mission. 2nd
Payload built by JEM-EUSO collaboration
New lenses, Focal Surface,
Improved Electronics
More than 30 days
Goal: First UV UHECR shower observation from above

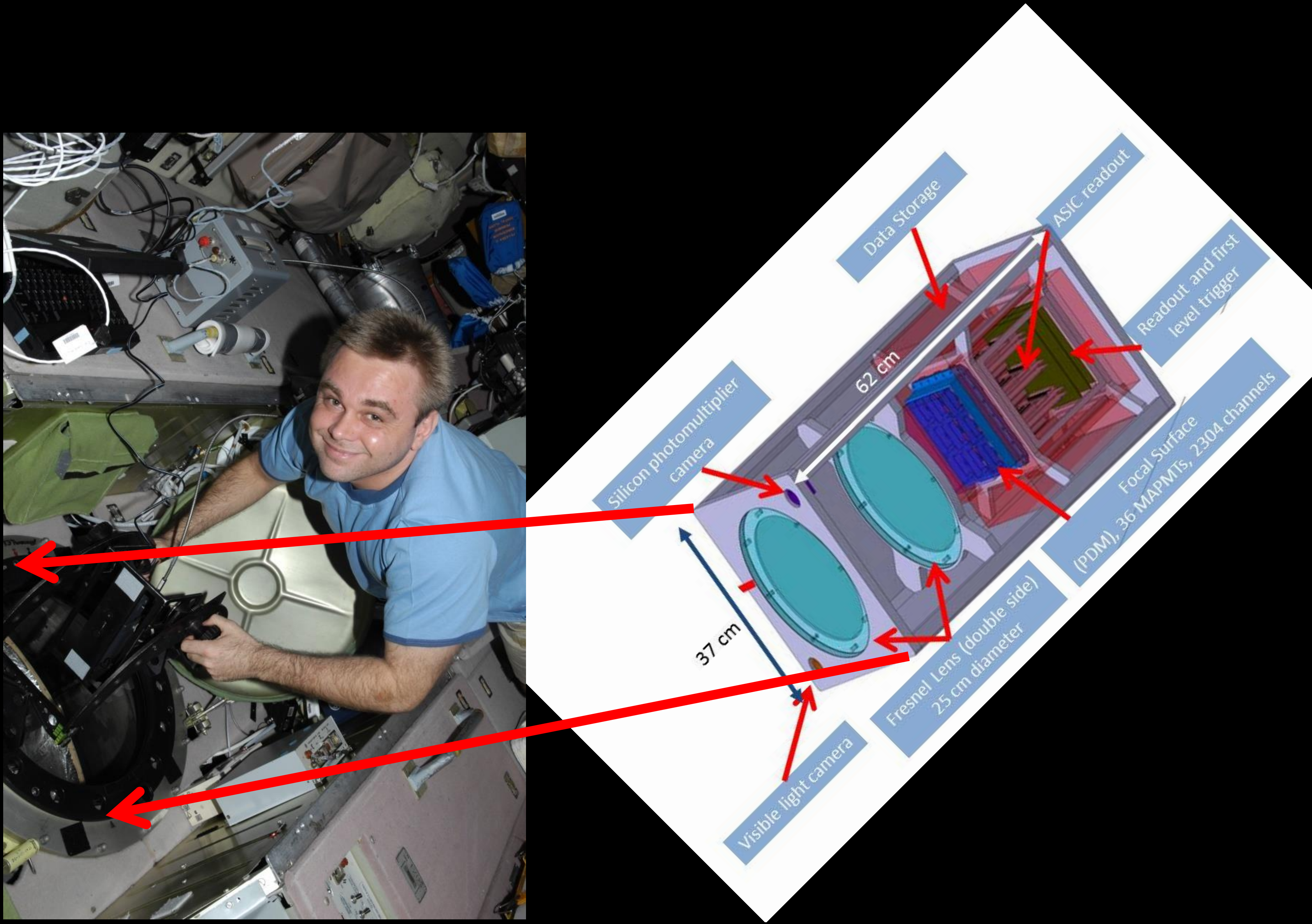
EUSO-SPB Extreme Universe Space Observatory on a Super Pressure Balloon



3. MINI-EUSO

- Approved & financed by Italian Space Agency
- Approved & financed by Russian Space Agency
- Inside the ISS
- 2 Fresnel lenses and one PDM
- 60W @ 27V
- 30kg not incl SSD





Data Storage
ASIC readout
Readout and first level trigger
Silicon photomultiplier camera
62 cm
37 cm
Focal Surface (PDM), 36 MAPMTs, 2304 channels
Fresnel Lens (double side) 25 cm diameter
Visible light camera

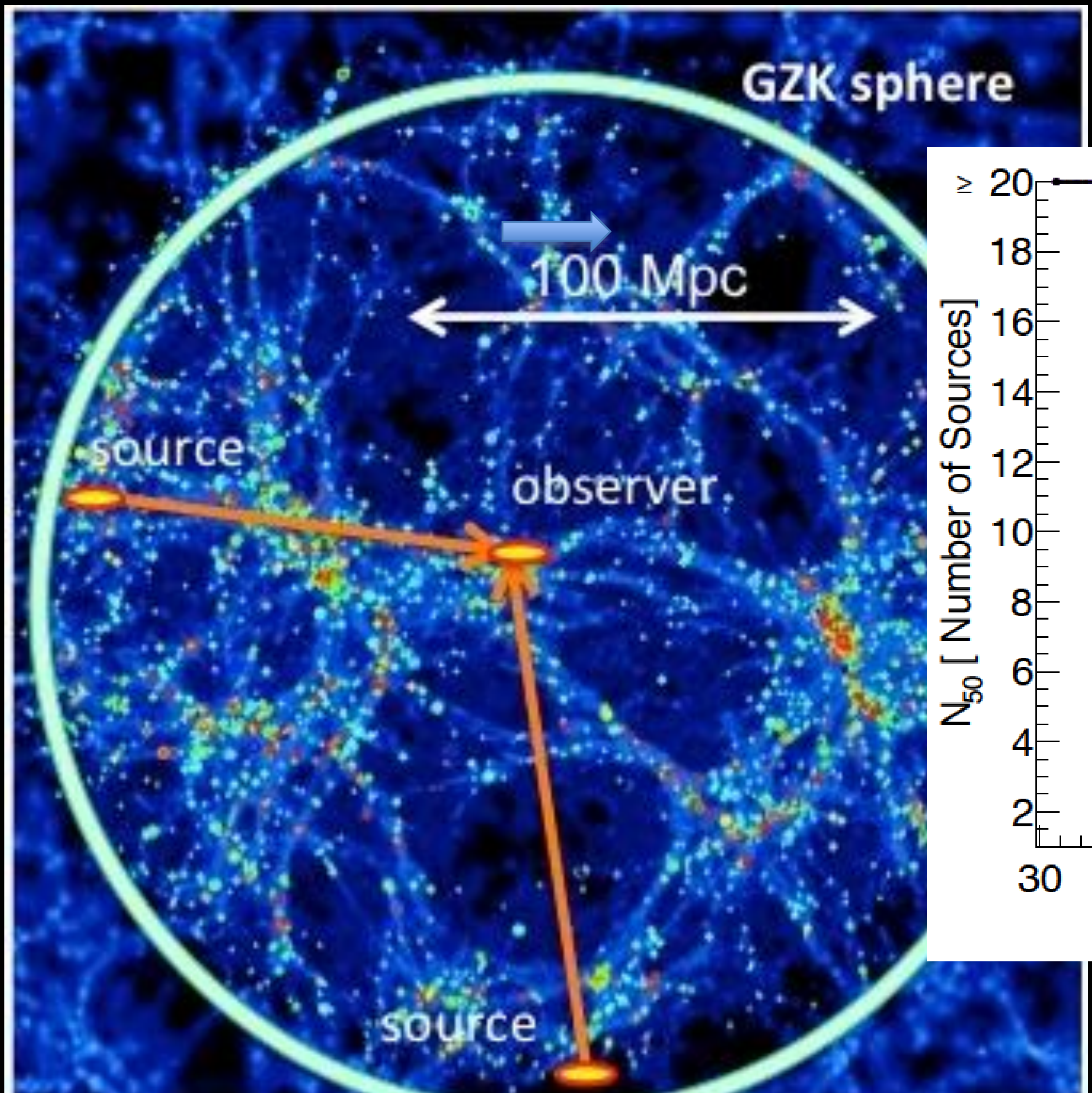

MINI-EUSO
Multiwavelength Imaging New Instrument
Extreme Universe Space Observatory
agenzia spaziale italiana
MINI-EUSO
Multiwavelength Imaging New Instrument
Extreme Universe Space Observatory
RIKEN
MINI-EUSO
Multiwavelength Imaging New Instrument
Extreme Universe Space Observatory
JEM-EUSO collaboration
PDM structure

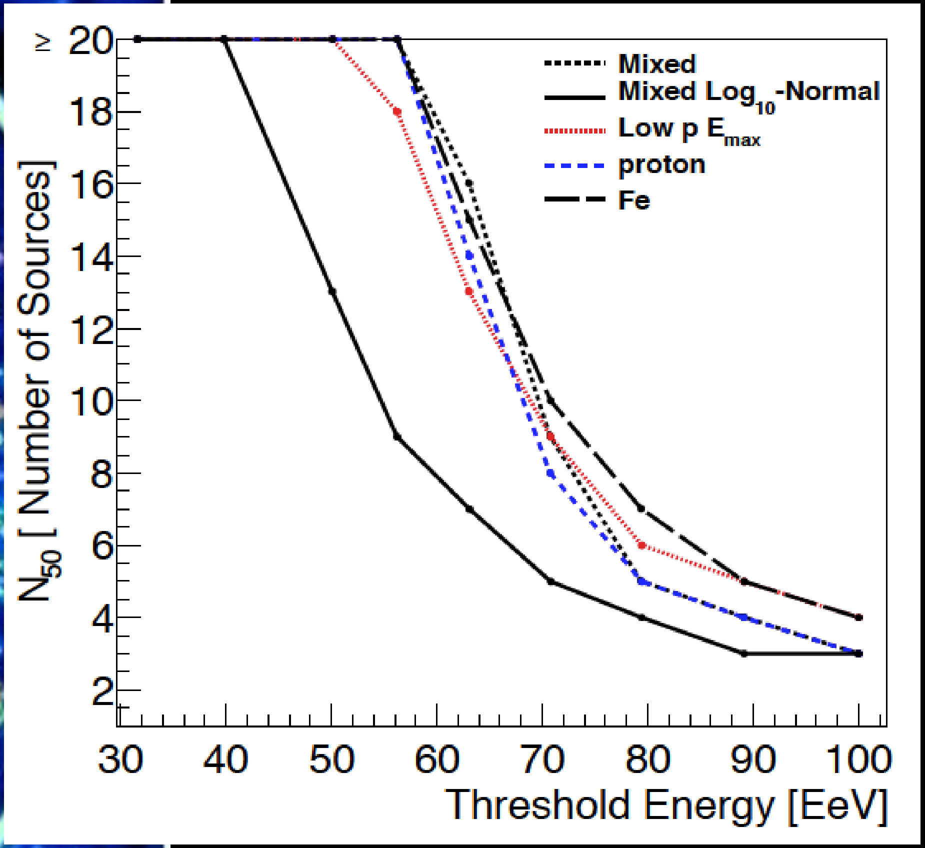
Conclusions

- EUSO: space observatory looking down
  - UHECR (~10^{20} eV) observation
    - Beyond Fermi, LHC, and Lorentz
  - Super Wide Optics with Large Fresnel Lens
    - Debris detection and deorbit from space
    - Earth Observation
- Precatory activities are going on
  - TA-EUSO (TA site Utah: 2013-2017)
  - EUSO balloon
    - 2014 Flight
    - 2917 flight: First science mission with NASA SPB program
  - Mini-EUSO (ISS Russian module 2017)

backup

GZK effect implies Fewer Sources at higher Energies easier to identify

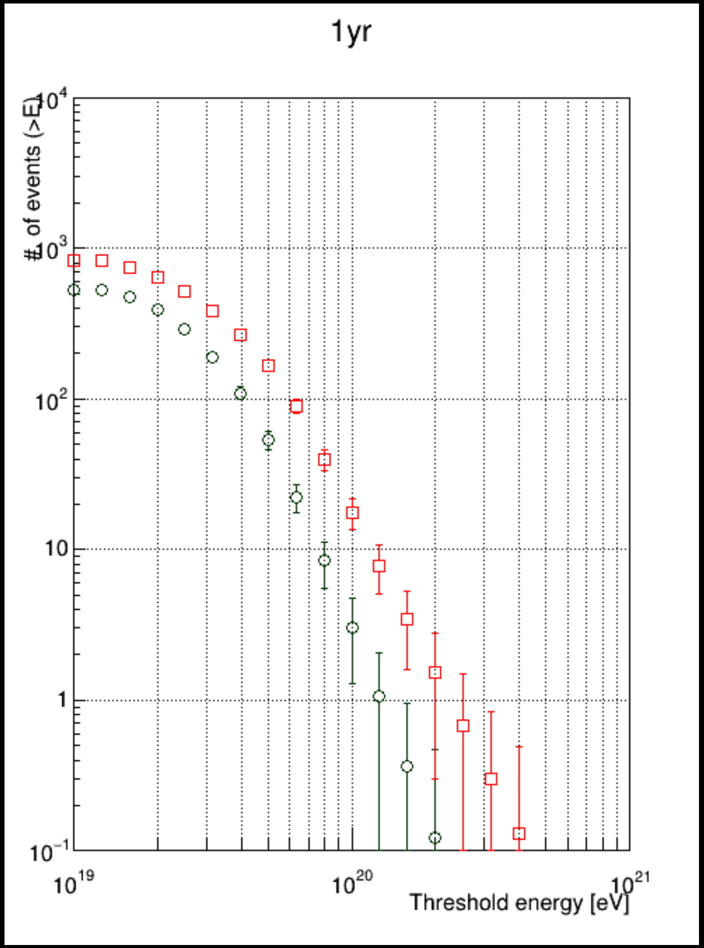




Unique physics of UHECR of Klypve: 1. N-S spectral difference

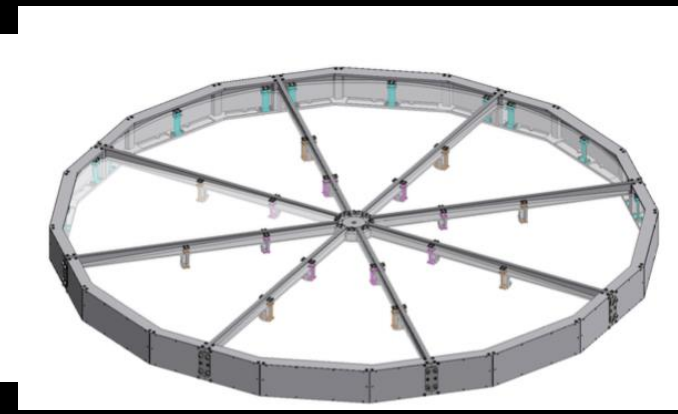
After 1 year
We can answer question on the difference of the two hemispheres

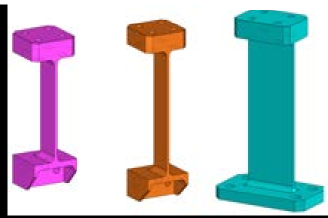
With Schmidt 6months

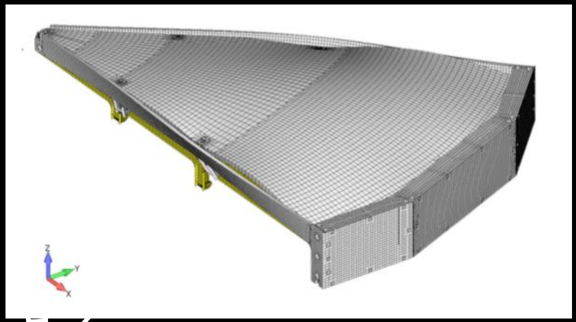


N_events E>5.7e19 eV 120
Used Auger and TA spectra 2015 in each hemisphere

Lens Frame





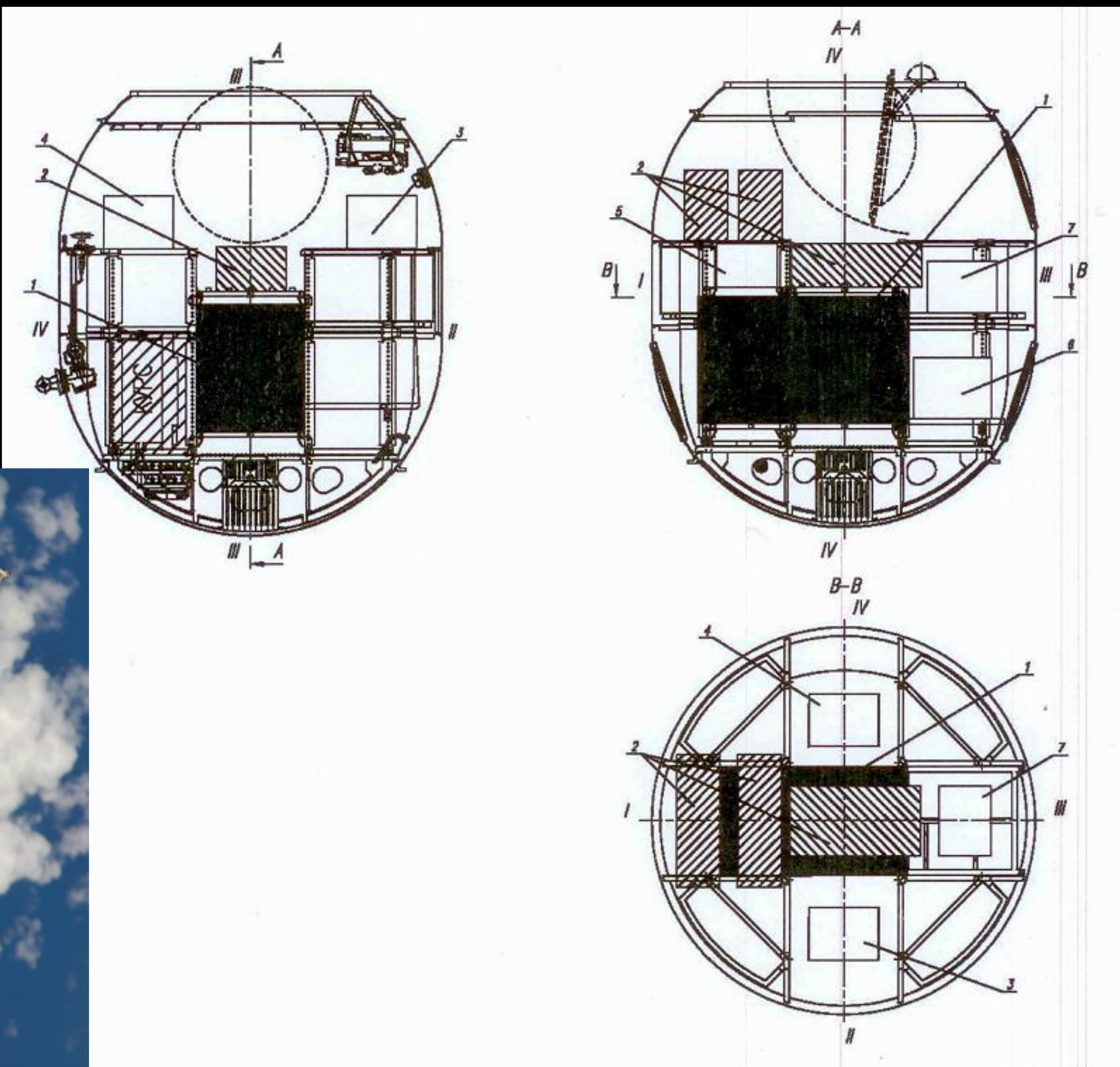


Kinematic mount
温度変化によるレンズの収縮・膨張による
ストレスを吸収する。

1次振動モード : 44 Hz

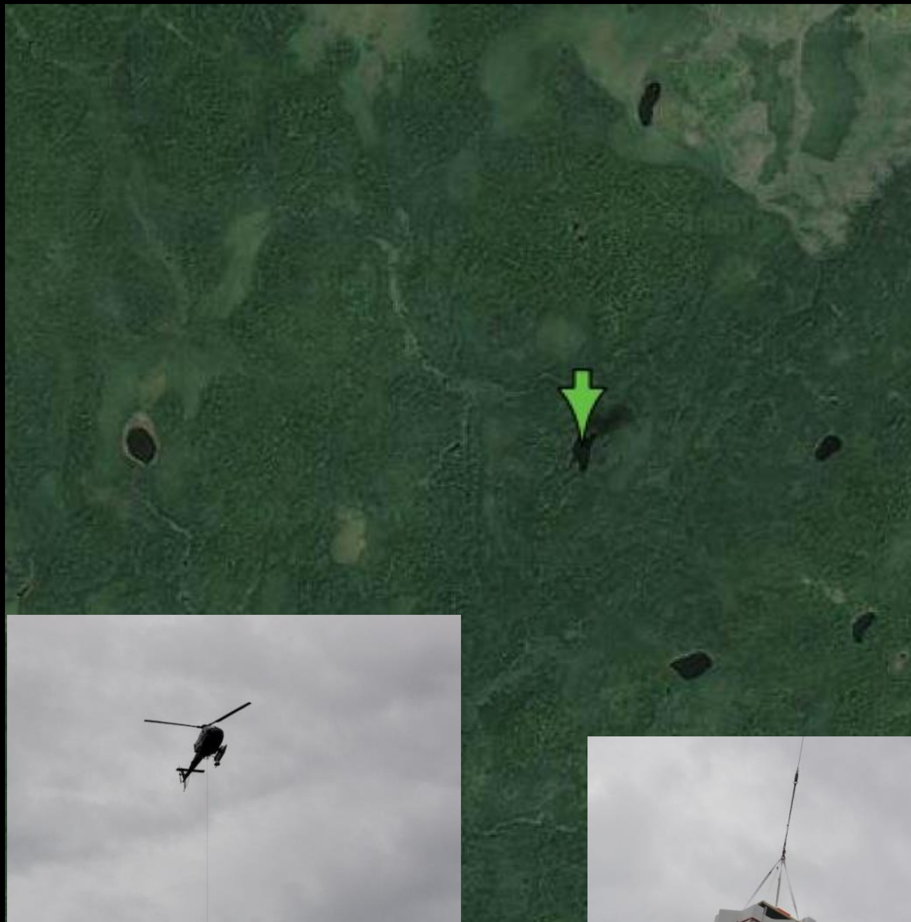
Allocation within Progress

- Segmentation in 120*70 *70 blocks

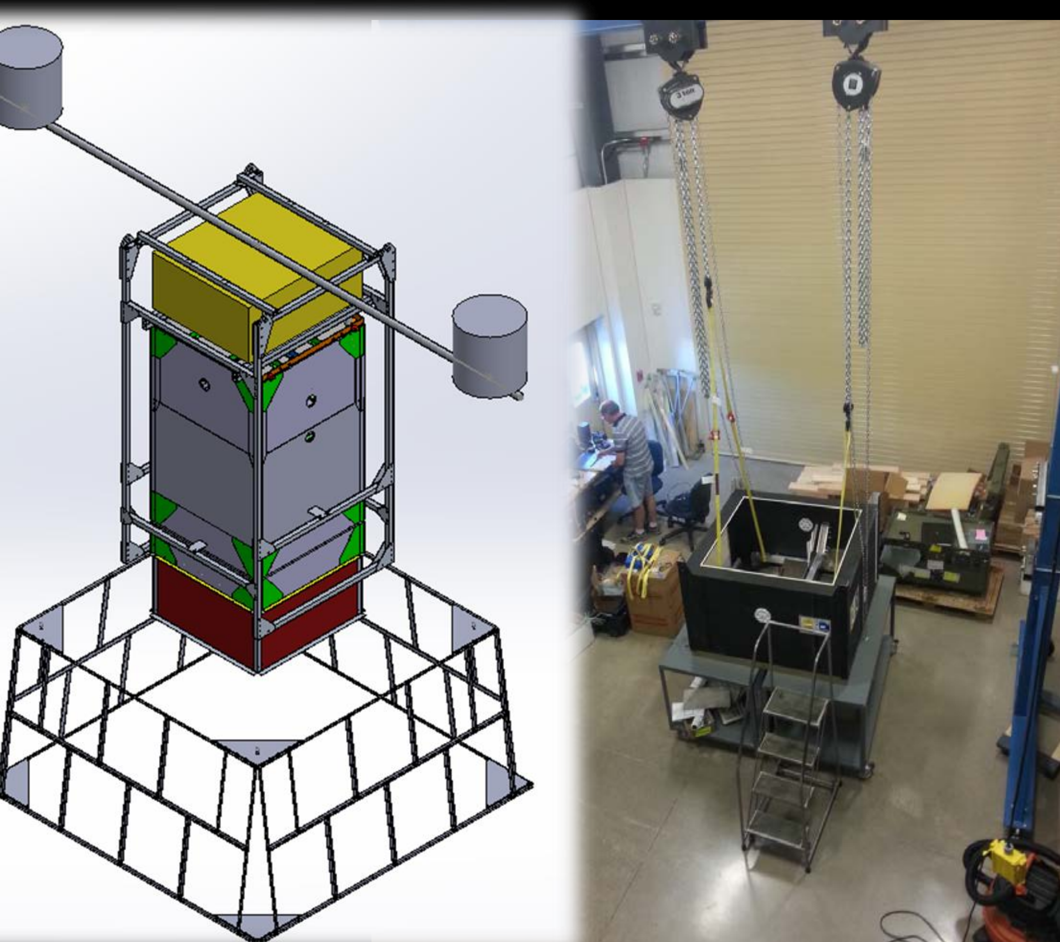


- K-EUSO is a crucial detector for UHECR physics
- Crucial step to larger missions
- Only from space we can answer anisotropy questions.
- Conjuction with ground arrays
- Just 2 Auger equivalent is needed, more is better
- Technology and cost is the leading part

Landing and recovery



Super Pressure Ballon Integration in Colorado



New structure, solar panels, telemetry

New 1sp m lens system

New focal surface and electroncis

Conclusions

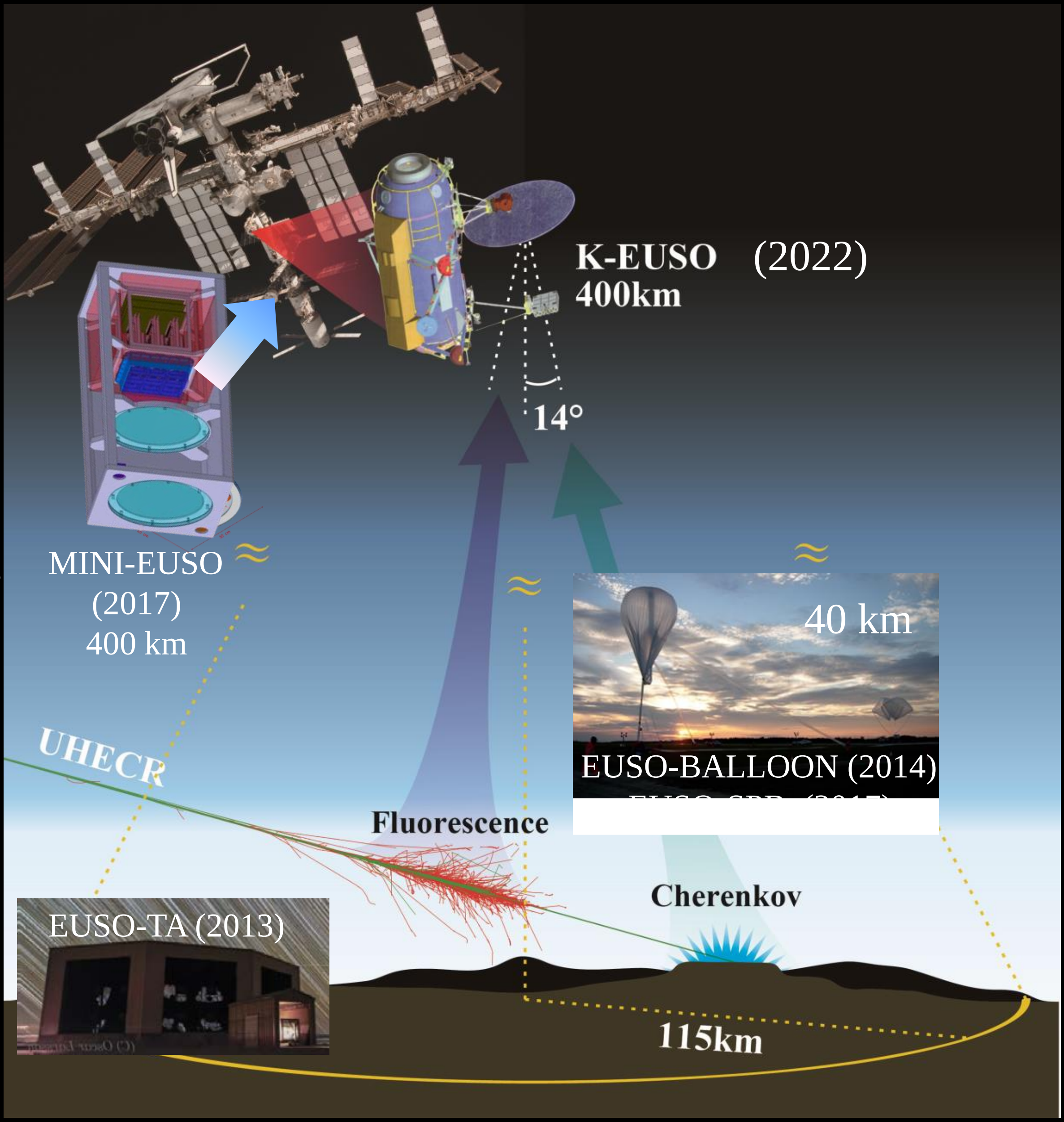
Roadmap to space

Detector development

2017 Long term missions

K-Euso is a concrete mission of opportunity fraction of the cost of JEM-EUSO

In one year Address several fundamental physics issues, N/S spectra, hotspot .



EUSO-TA (2013-)