Overview of the POEMMA mission and the JEM-EUSO sub-missions

Y. Takizawa (RIKEN)

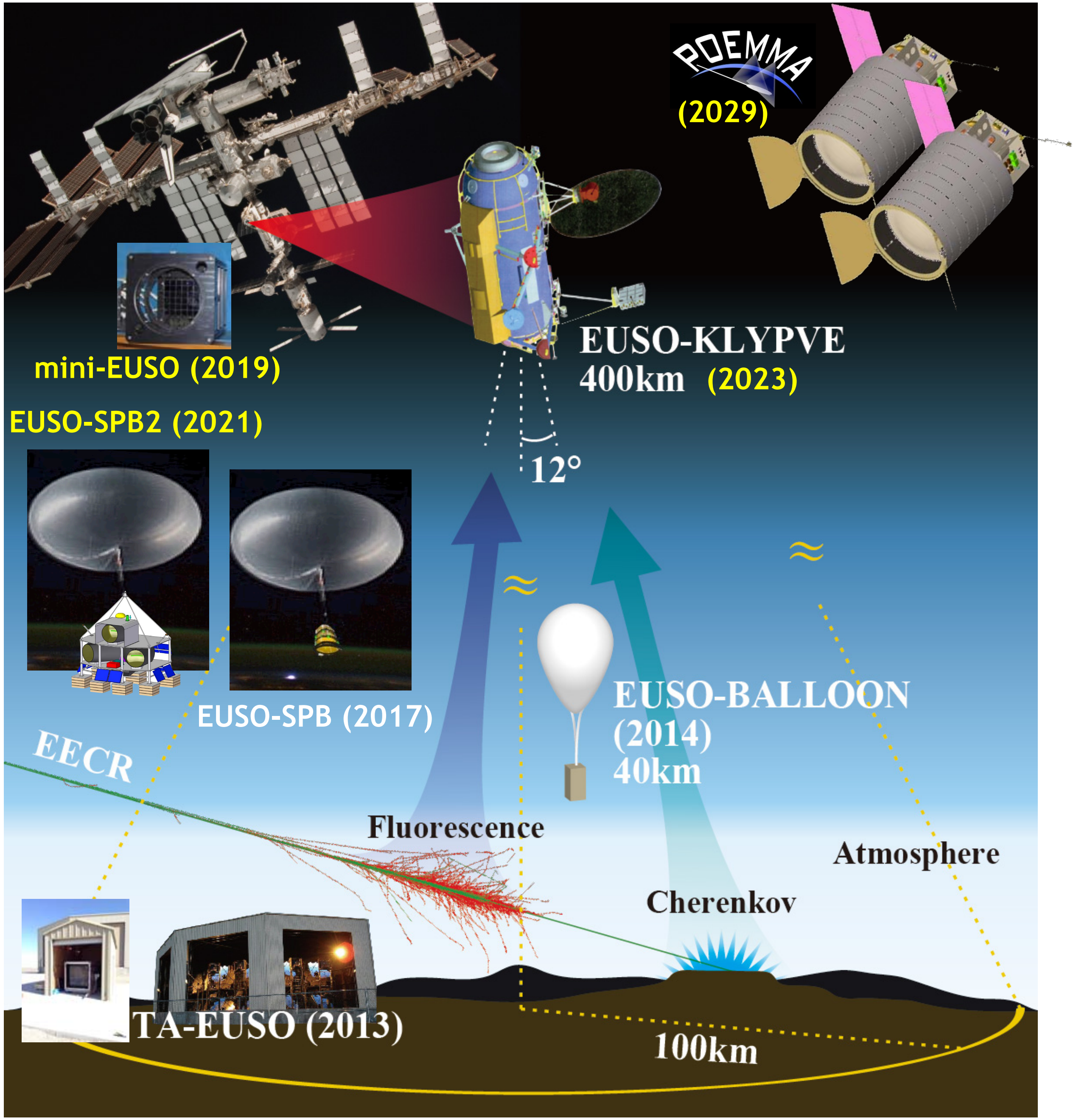
for the JEM-EUSO collaboration

VHEPA2019 (2019.2.19)

The JEM-EUSO program

EUSO-TA (2013-)
EUSO-Balloon (2014)
EUSO-SPB (2017)

Mini-EUSO (2019)
EUSO-SPB2 (2021)
K-EUSO (2023)
POEMMA (2029)



EUSO-TA

(2013 -)

EUSO-TA is an important our test-bench
for developing the EUSO technology.

2013

EUSO-TA was installed in front of the telescope array FD at Black rock mesa.

We are very thankful to the TA group!

EUSO-TA telescope

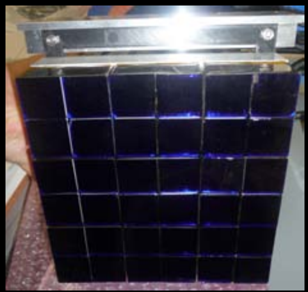
EUSO-TA optics design

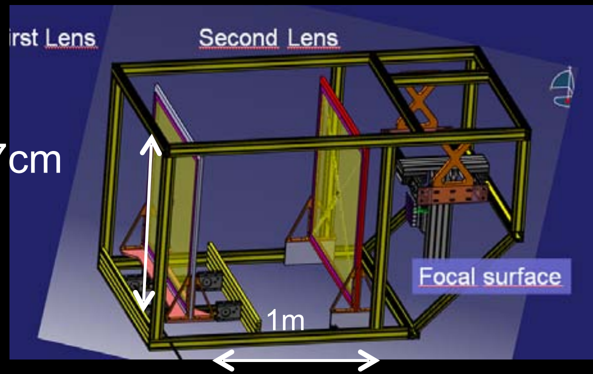
Two Fresnel lenses: 1 sq. m

Focal Surface detector:
Photo Detector Module (PDM): 17*17cm

Field of view: 11*11 degrees
(±5.5 * ±5.5 deg)
Pixel 0.19 deg

Sampling rate 2.5 mus





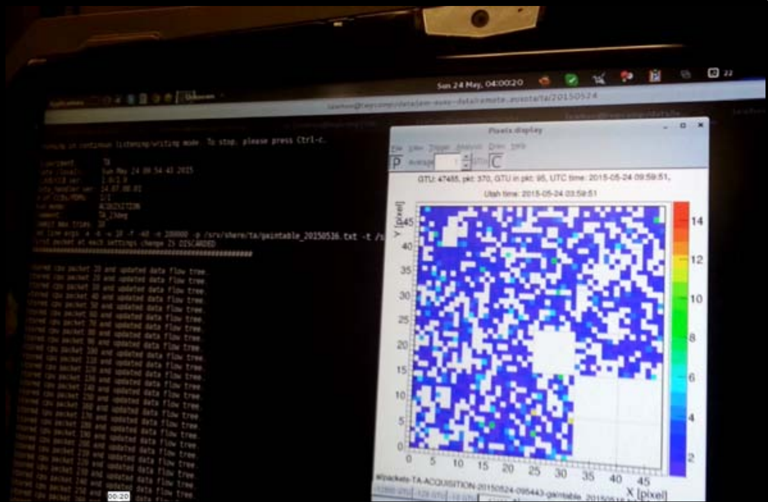
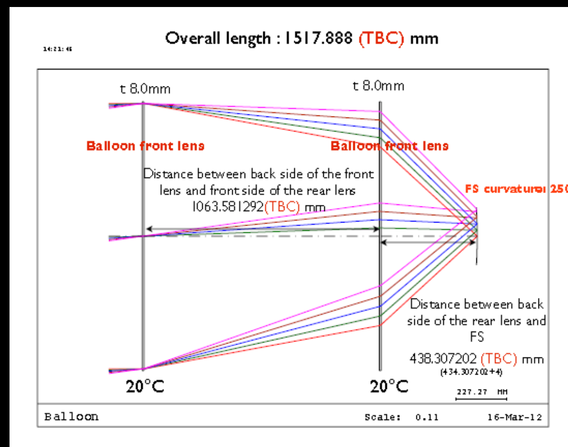
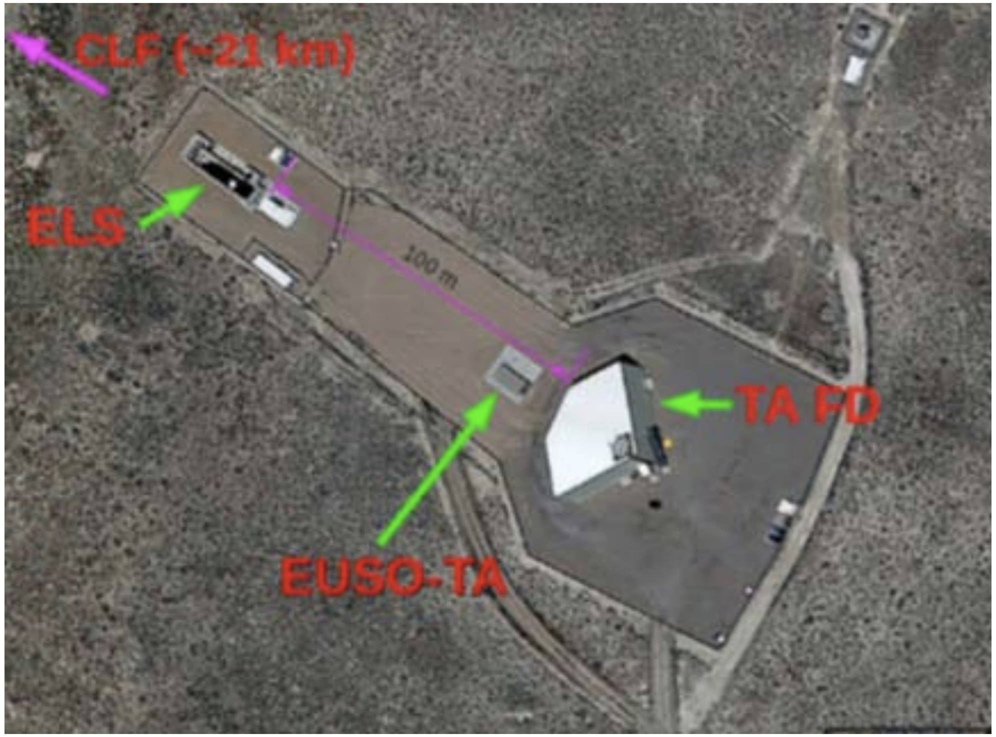
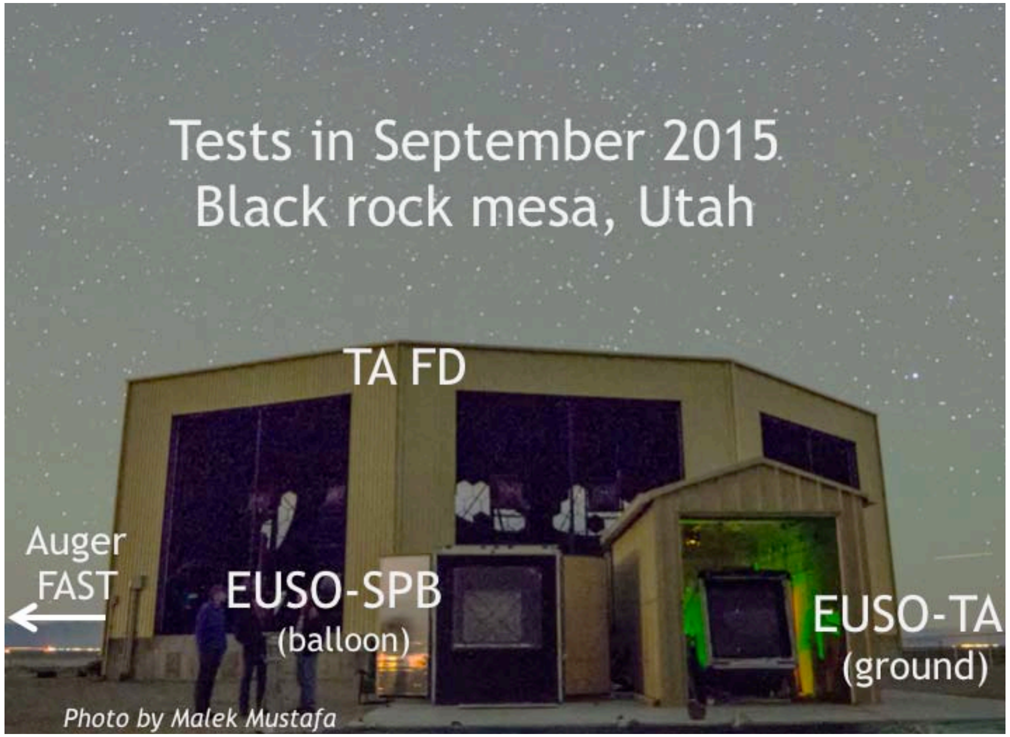


Image is inverted
(Seen from inside)

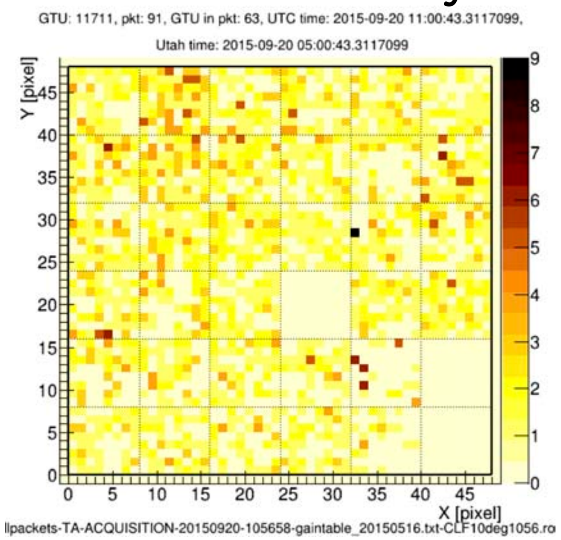


EUSO-TA

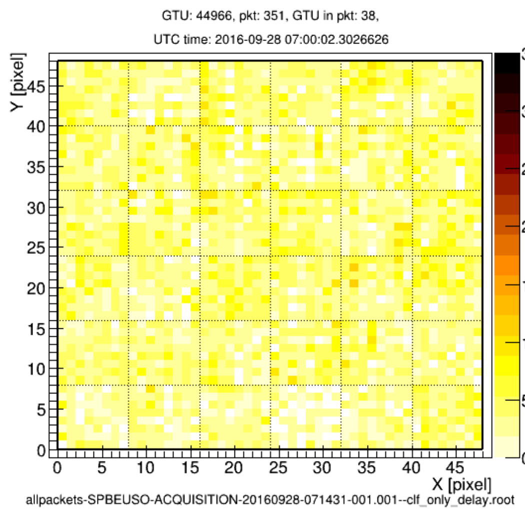




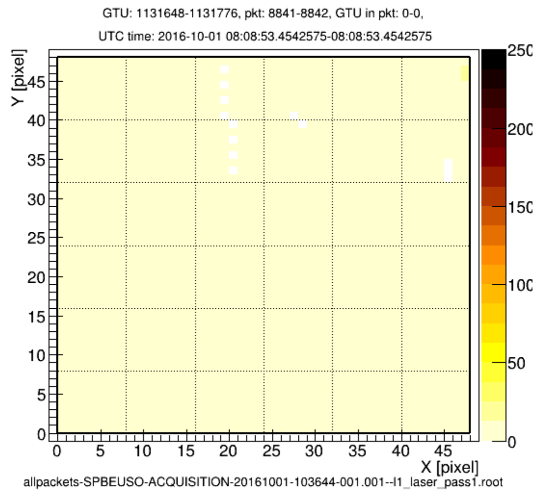
EUSO-TA: Cosmic ray event



EUSO-TA: Laser event

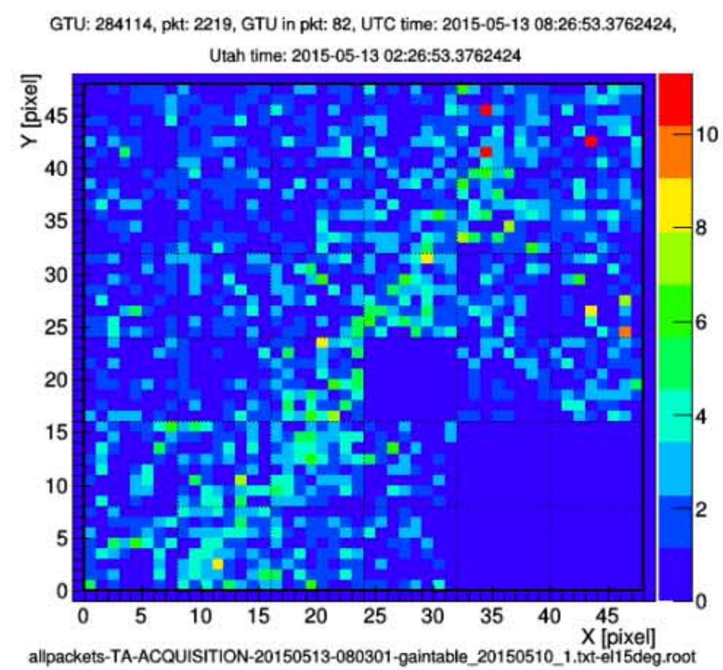


EUSO-TA: Meteo

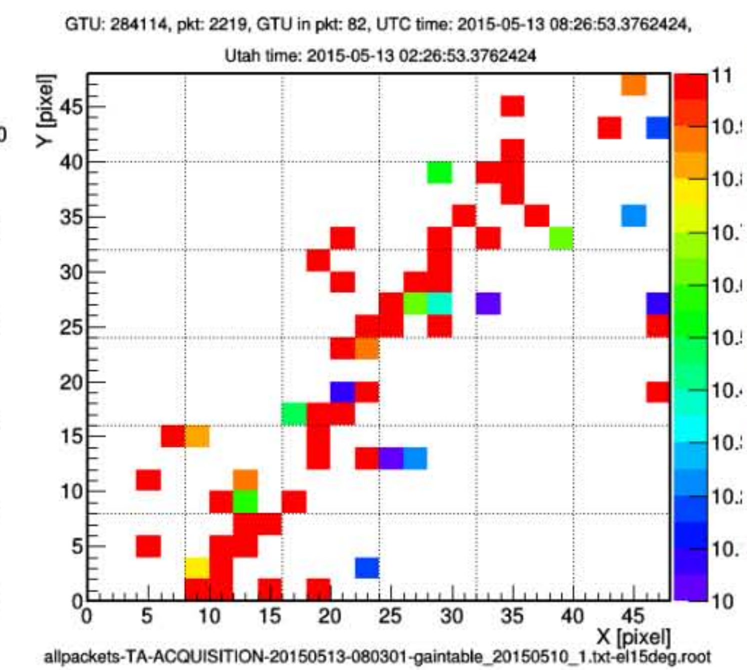


Cosmic ray event, 13/5/2015

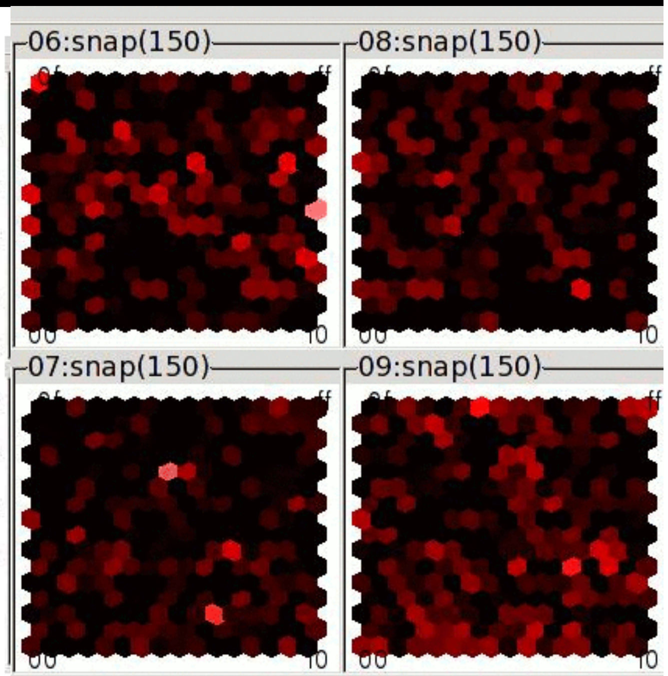
Telescope Array reconstruction
Zenith = 35°
Azimuth = 7° (clockwise from N)
E = 10^18 eV
Rp = 2.5 km
Core = (14.8 km, -10.9 km) respect CLF



EUSO, 1 frame, 2.5micros



EUSO, 2*2



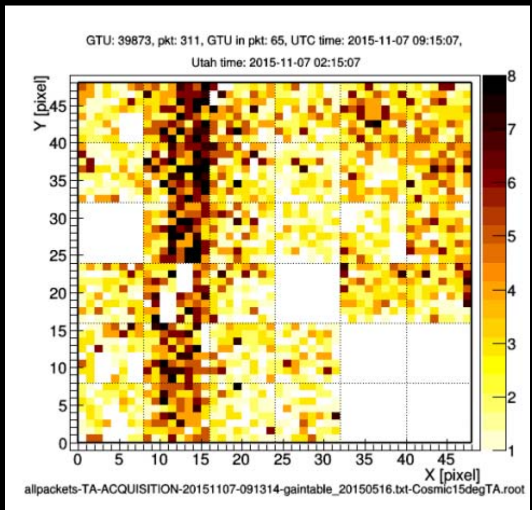
TA signal

EUSO-TA does not look at the shower maximum.

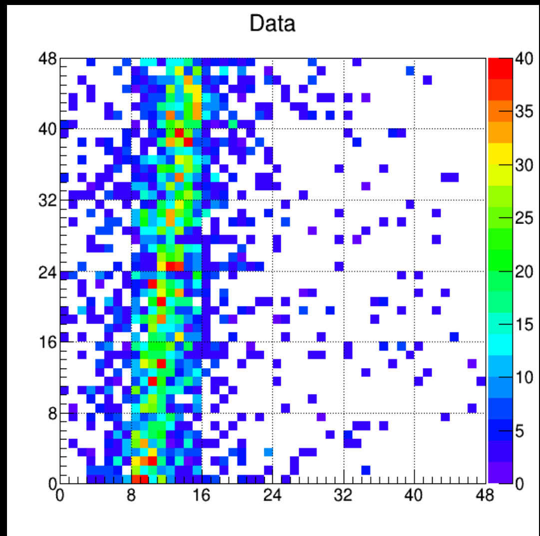
Cosmic ray event 7/11/2015

Telescope Array reconstruction
Zenith = 8°
Azimuth = 82° (Clockwise from N)
E = 10^18.36 eV
Rp = 2.6 km
Core = (14.8 km, -10.6 km) respect CLF

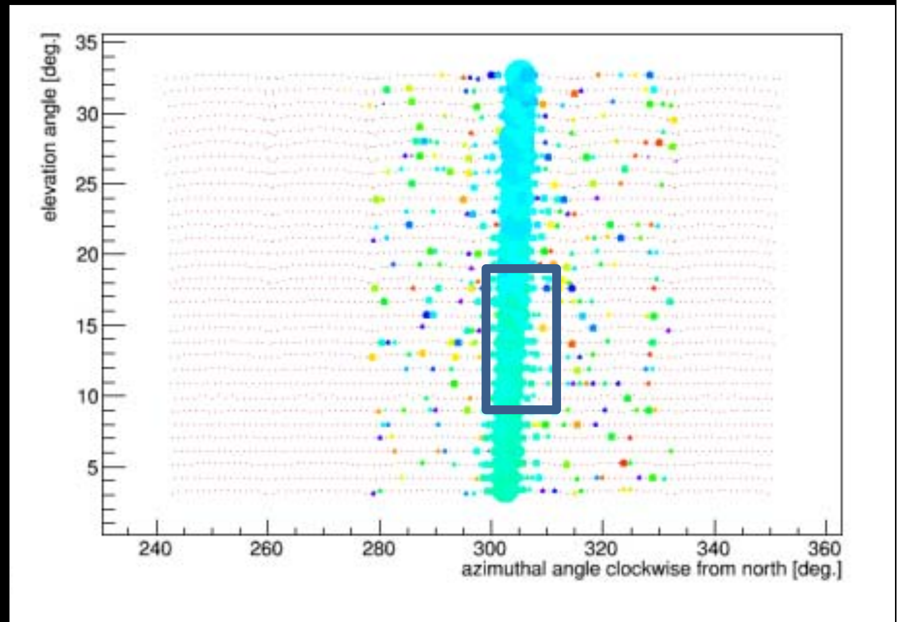
EUSO-TA configuration
EUSO-TA elevation = 15°



EUSO data ,
1 frame, 2.5micros



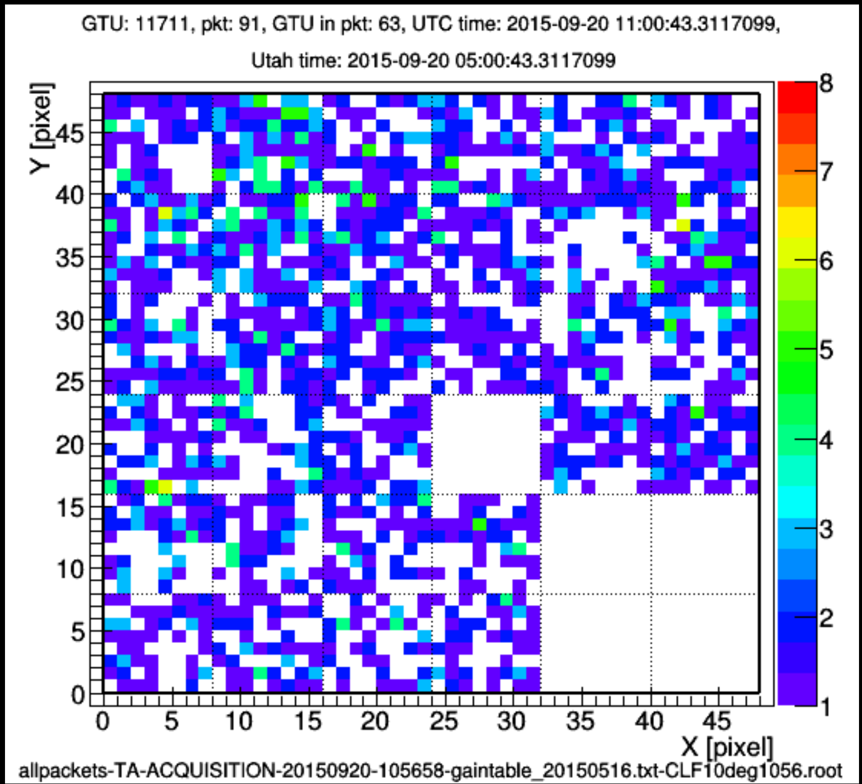
EUSO Simulation ,
1 frame, 2.5micros
F. Bisconti



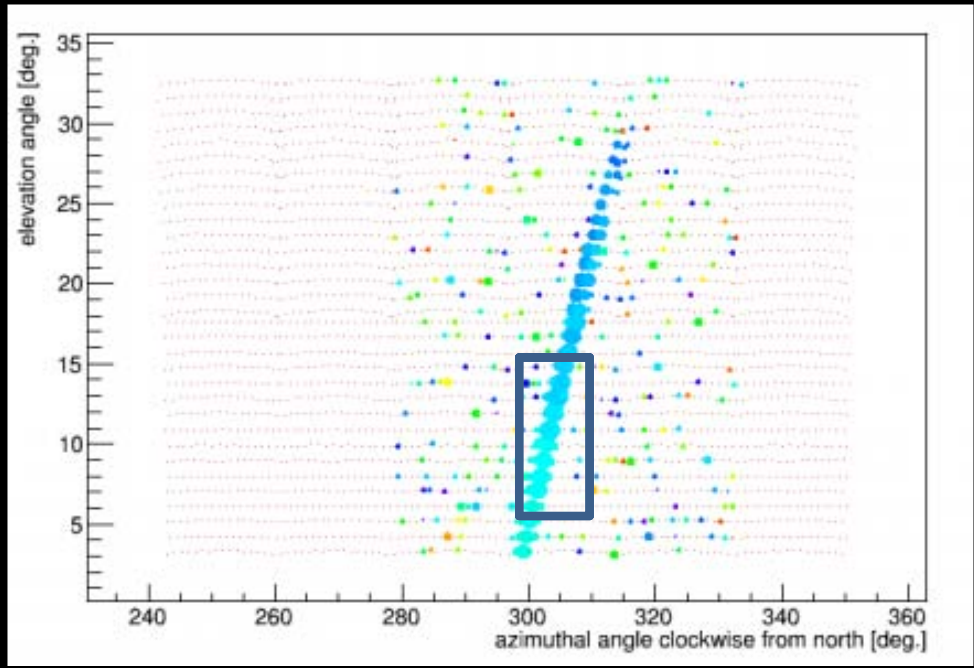
TA signal

EUSO-TA does not look at the shower maximum.

20/9/2015



EUSO, 2 frames, 2.5micros



TA signal from Shin

EUSO-TA does not look at the shower maximum.

EUSO-TA results

2013 - 2017

EUSO-TA campaigns

So far EUSO-TA had 6 observation campaigns:

February/March 2015	• Detector installation • Focusing, initial calibration • Initial CLF and CSOM laser observations
May 2015	• Cosmic ray observations – one UHECR detected • CLF and CSOM laser observations • Flat screen and LED calibration
September 2015	• Cosmic ray observations – analysis ongoing • CLF and CSOM laser observations
October 2015	• Cosmic ray observations – analysis ongoing • Internal trigger tests on **the balloon** PDM board – successful triggering on laser • CLF and CSOM laser observations
November 2015	• Cosmic ray observations • CLF laser observations
September 2017	• Mainly fixing + some observations

Analysis of data

(May, September, October, November 2015 and October 2016)

Days with any observation	58
TAFD external trigger (may contain UHECR)	136.41 h
All good data taken with TAFD trigger	130.29 h, 95.5%
Data taken with other external trigger	21.21 h)
Detected UHECR	9
Meteors	5

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EUSO-TA – First results from a ground-based EUSO telescope

G. Abdellaoui[h], S. Abe[W], J.H. Adams Jr.[b,E], A. Ahriche[e], D. Allard[l], L. Allen[b,C], G. Alonso[a,V], L. Anchordoqui[b,G], A. Anzalone[y,u], Y. Arai[Y], K. Asano[K], R. Attallah[c], H. Attoui[a], M. Ave Pernas[a,U], S. Bacholle[b,D], M. Bakiri[a], P. Baragatti[E,F], P. Barrillon[j], S. Bartocci[E], J. Bayer[q], B. Beldjilali[h], T. Belenguer[a,T], N. Belkhalfa[a], R. Bellotti[r,s], A. Belov[a,P], K. Belov[b,F], J.W. Belz[b,J], K. Benmessai[a], M. Bertaina[B,C], P.L. Biermann[o], S. Biktemerova[a,N], F. Bisconti[o], N. Blanc[a,Y], J. Blecki[a,L], S. Blin-Bondil[k], P. Bobik[a,Q], M. Bogomilov[i], E. Bozzo[a,Z], A. Bruno[s], K.S. Caballero[a,H], F. Cafagna[r], D. Campana[w], J-N. Capdevielle[l], F. Capel[a,X], A. Caramete[a,M], L. Caramete[a,M], P. Carlson[a,X], R. Caruso[t,u], M. Casolino[Z,z], C. Cassardo[B,C], A. Castellina[B,D], O. Catalano[y,u], A. Cellino[B,D], M. Chikawa[I], G. Chiritoi[a,M], M.J. Christl[b,H], V. Connaughton[b,E], L. Conti[E], G. Cordero[a,D], G. Cotto[B,C], H.J. Crawford[b,B], R. Cremonini[C], S. Csorna[b,I], A. Cummings[b,D], S. Dagoret-Campagne[j], C. De Donato[z], C. de la Taille[k], C. De Santis[z], L. del Peral[a,U], M. Di Martino[D], T. Djemil[c], I. Dutan[a,M], A. Ebersoldt[o], T. Ebisuzaki[Z], R. Engel[o], J. Eser[b,D], F. Fenu[B,C], S. Fernández-González[a,S], J. Fernández-Soriano[a,U], S. Ferrarese[B,C], M. Flamini[E], C. Fornaro[E], M. Fouka[b], A. Franceschi[v], S. Franchini[a,V], C. Fuglesang[a,X], T. Fujii[K], J. Fujimoto[Y], M. Fukushima[K], P. Galeotti[B,C], E. García-Ortega[a,S], G. Garipov[a,P], E. Gascón[a,S], J. Genci[a,R], G. Giraudo[B], C. González Alvarado[a,T], P. Gorodetzky[l], R. Greg[b,D], F. Guarino[w,x], A. Guzmán[q], Y. Hachisu[Z], M. Haiduc[a,M], B. Harlov[a,O], A. Haungs[o], J. Hernández Carretero[a,U], W. Hidber Cruz[a,D], D. Ikeda[K], N. Inoue[T], S. Inoue[Z], F. Isgrò[w,E], Y. Itow[Q], T. Jammer[p], S. Jeong[a,C], E. Joven[a,W], E.G. Judd[b,B], A. Jung[l], J. Jochum[p], F. Kajino[L], T. Kajino[O], S. Kalli[f], I. Kaneko[Z], Y. Karadzhov[i], J. Karczmarczyk[a,K], K. Katahira[Z], K. Kawai[Z], Y. Kawasaki[Z], A. Kedadra[a], H. Khales[a], B.A. Khrenov[a,P], Jeong-Sook Kim[a,A], Soon-Wook Kim[a,A], M. Kleifges[o], P.A. Klimov[a,P], D. Kolev[i], H. Krantz[b,D], I. Kreykenbohm[n], K. Kudela[a,Q], Y. Kurihara[Y], A. Kusenko[X,b,F], E. Kuznetsov[b,E], A. La Barbera[y,u], C. Lachaud[l], H. Lahmar[a], F. Lakhdari[g], O. Larsson[a,X], J. Lee[a,C], J. Licandro[a,W], L. López Campano[a,S], M.C. Maccarone[y,u], S. Mackovjak[a,Z], M. Mahdi[a], D. Maravilla[a,D], L. Marcelli[z], J.L. Marcos[a,S], A. Marini[v], W. Marszal[a,K], K. Martens[X], Y. Martín[a,W], O. Martinez[a,F], M. Martucci[v], G. Masciantonio[z], K. Mase[G], M. Mustafa[b,E], R. Matev[i], J.N. Matthews[b,J], N. Mebarki[d], G. Medina-Tanco[a,D], M.A. Mendoza[a,G], A. Menshikov[o], A. Merino[a,S], J. Meseguer[a,V], S.S. Meyer[b,C], J. Mimouni[d], H. Miyamoto[B,C], Y. Mizumoto[O], A. Monaco[r,s], J.A. Morales de los Ríos[a,U], S. Nagataki[Z], S. Naitamor[b], T. Napolitano[v], R. Nava[a,D], A. Neronov[a,Z], K. Nomoto[X], T. Nonaka[K], T. Ogawa[Z], S. Ogio[R], H. Ohmori[Z], A.V. Olinto[b,C], P. Orleański[a,L], G. Osteria[w], A. Pagliaro[y,u], W. Painter[o], M.I. Panasyuk[a,P], B. Panico[w], E. Parizot[l], I.H. Park[a,C], B. Pastircak[a,Q], T. Patzak[l], T. Paul[b,G], I. Pérez-Grande[a,V], F. Perfetto[w,x], T. Peter[b,A], P. Picozza[z,A,Z], S. Pindado[a,V], L.W. Piotrowski[Z,*], S. Piraino[q], L. Placidi[E], Z. Plebaniak[a,K], S. Pliego[a,D], A. Pollini[a,Y], Z. Polonski[b,D], E.M. Popescu[a,M], P. Prat[l], G. Prévôt[l], H. Prieto[a,U], G. Puehlhofer[q], M. Putis[a,Q], J. Rabanal[j], A.A. Radu[a,M], M. Reyes[a,W], M. Rezazadeh[b,C], M. Ricci[v], M.D. Rodríguez Frías[a,U], F. Ronga[v], G. Roudil[m], I. Rusinov[i], M. Rybczyński[a,J], M.D. Sabau[a,T], G. Sáez Cano[a,U], H. Sagawa[K],

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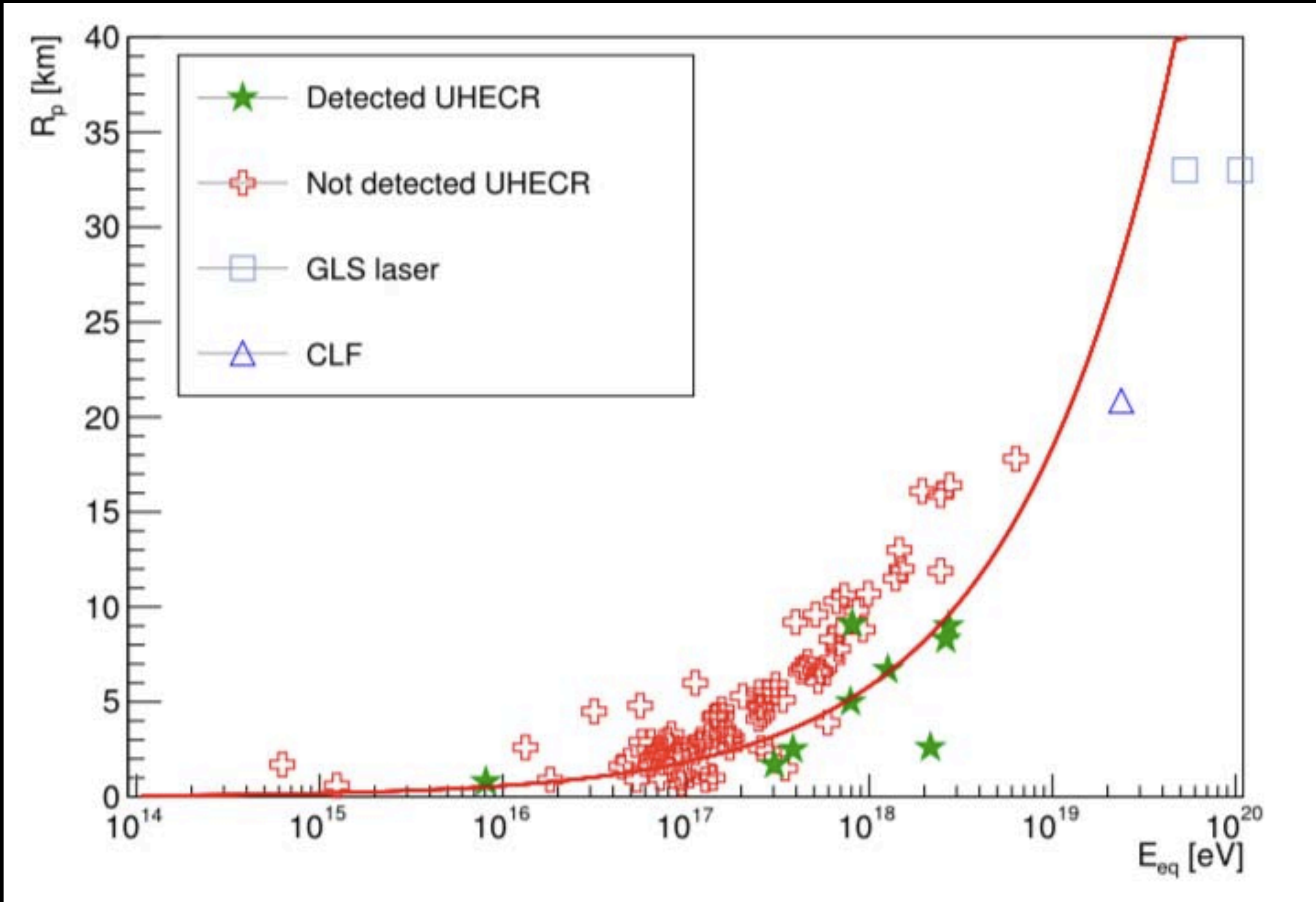
E-mail address: lech.piotrowski@riken.jp (L.W. Piotrowski).

UHECR statistics (using TA FD triggers)



EUSO-TA PDM is improving now using SPB1 and mini-EUSO technologies, such as self-trigger algorithm and high-speed sampling, etc.

It will be installed on March 2019.

Balloon missions

(2014, 2017)

Two 1m x 1m Fresnel lenses optical system
with a photo detector module

Balloon missions

We did two experiments:

EUSO-Balloon (2014, 1 night (8 hours), French team)

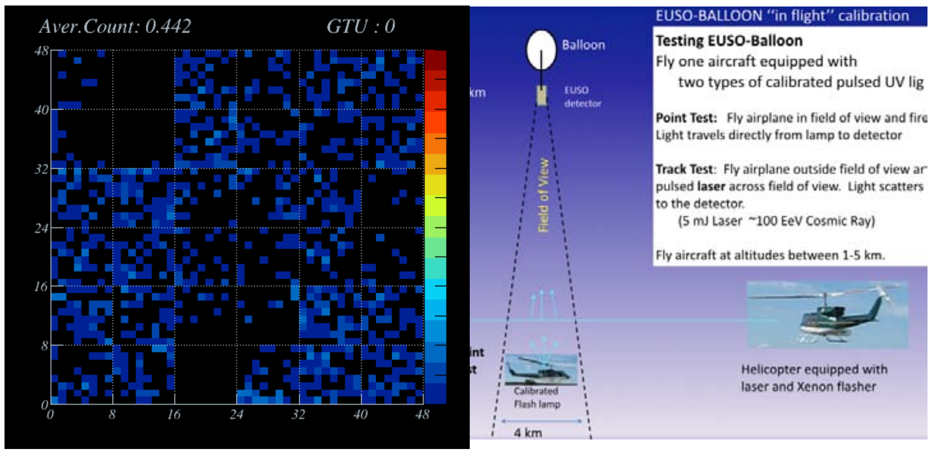
EUSO-SPB (2017, 12 days flight, US team)

Both telescope worked as expected.

We confirmed our remote sensing technology for future space missions.

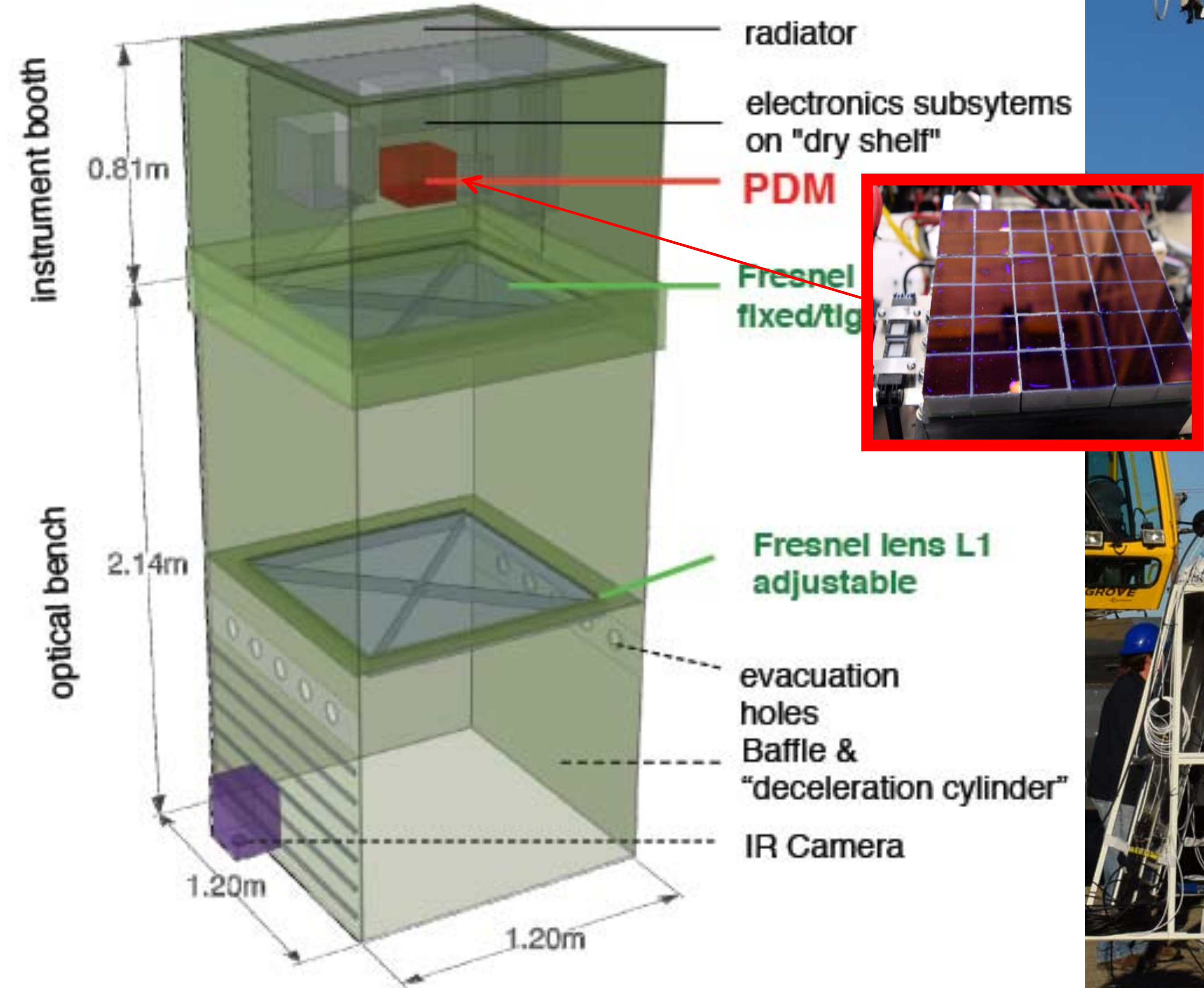
EUSO-Balloon

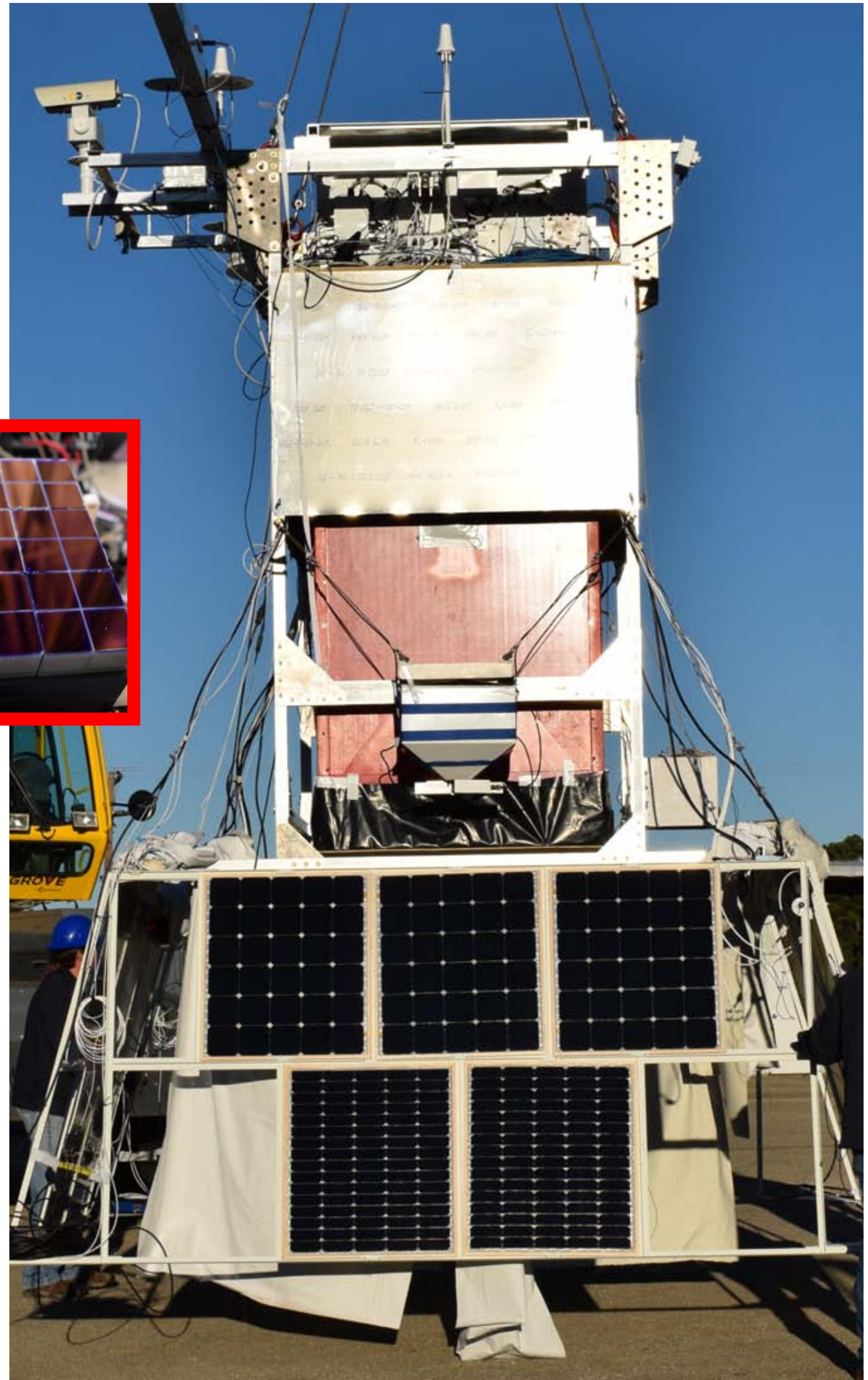
A flasher and Laser events from Helicopter



EUSO-SPB1

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





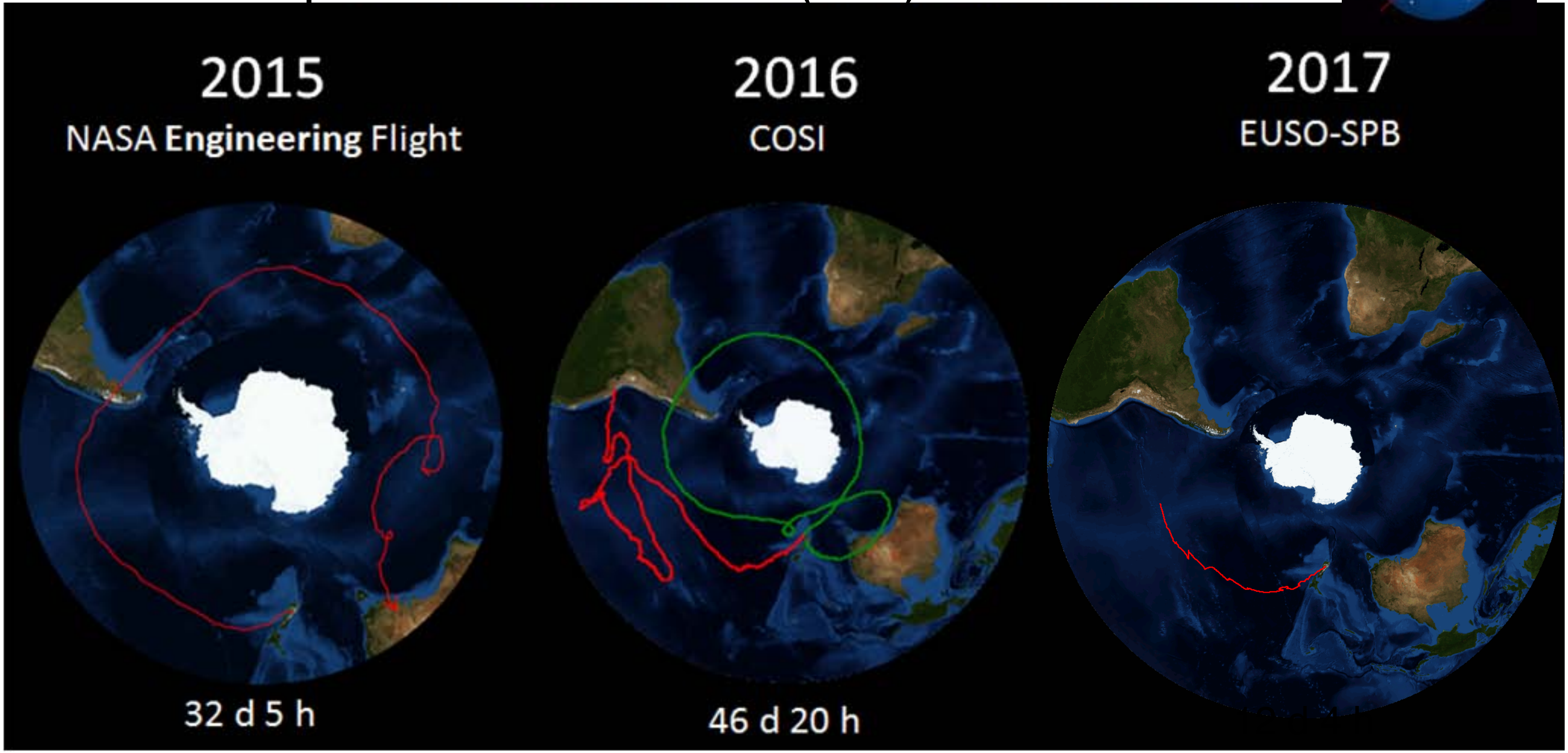
EUSO-SPB

EUSO-SPB was launched on April 24th from the NASA balloon launch site in Wanaka (New Zealand) and landed on the South Pacific Ocean on May 7th.

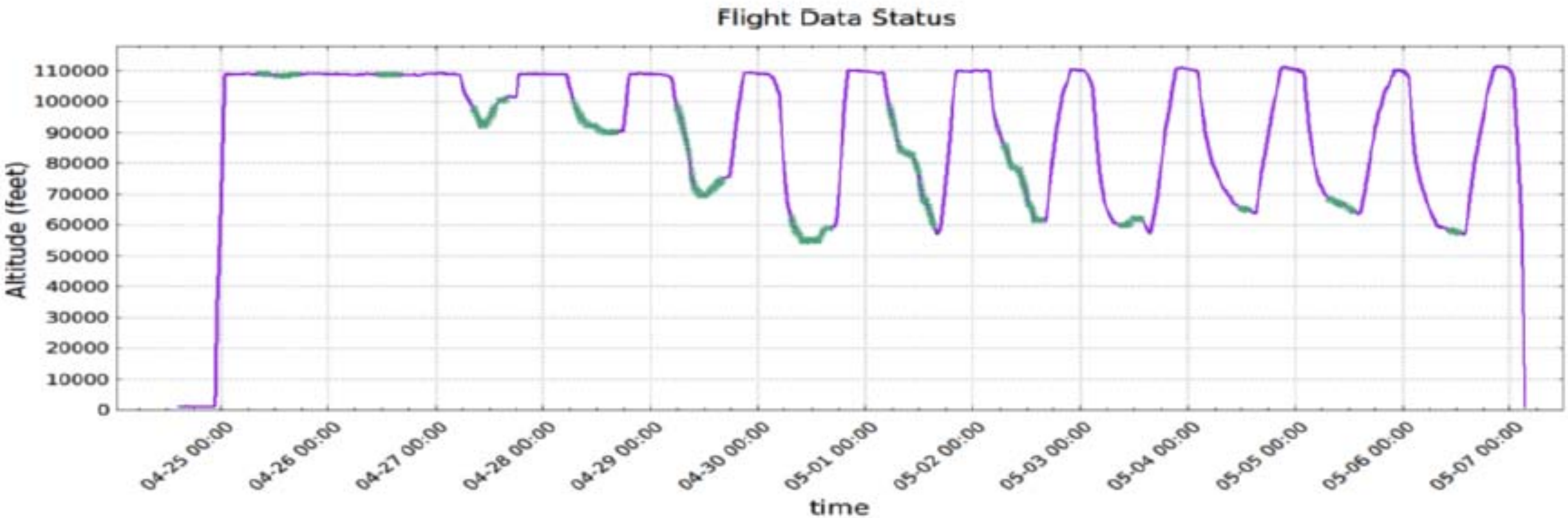

SMITH


EUSO-SPB
LAUNCH,
APRIL 24,
2017
23:51 UTC

WANAKA 2017 Campaign
Super Pressure Balloon (SPB) EUSO mission

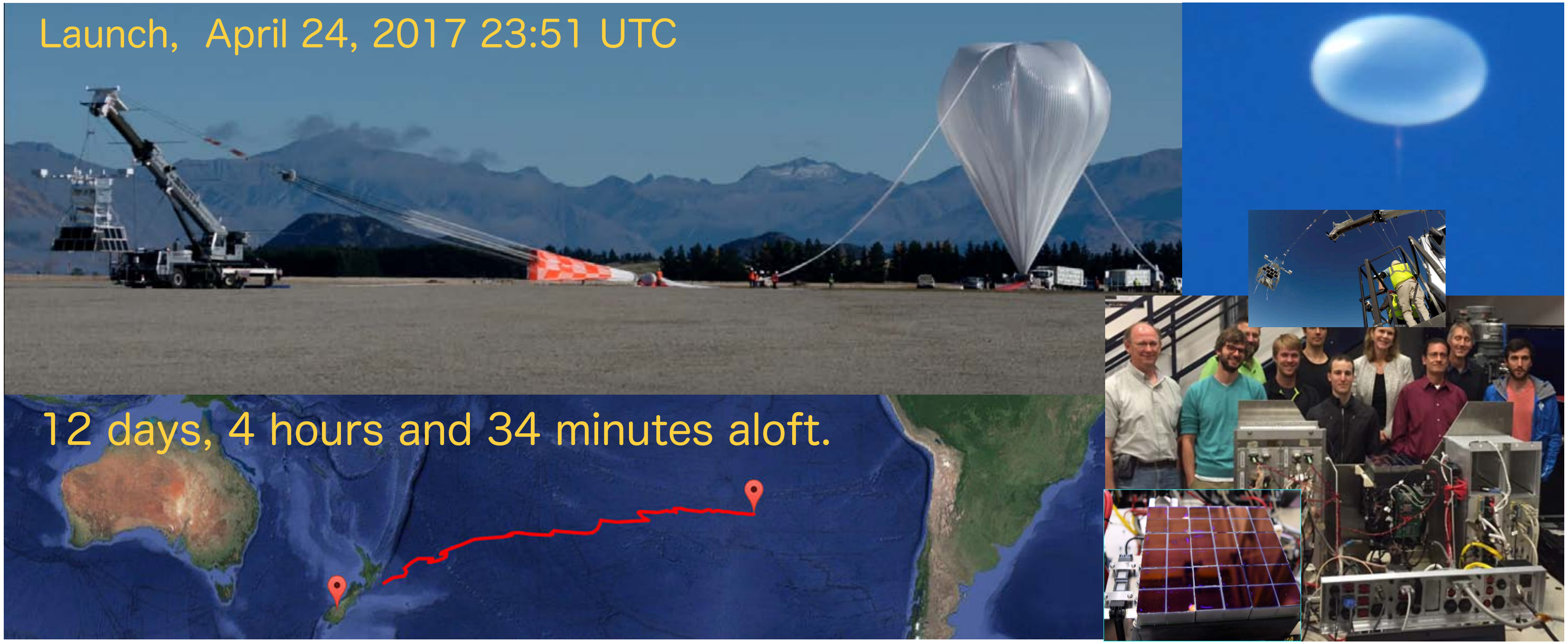


NASA completed its third mid-latitude Super Pressure Balloon (SPB) flight at 11:24 p.m. EDT, Saturday, May 6, after 12 days, 4 hours and 34 minutes aloft.



EUSO-SPB1

Extreme Universe Space Observatory on a Super Pressure Balloon



- SPB1 worked as expected
- We are analyzing data now.
    - We did not find event of UHECR, so far.
    - Expected event number of 12 days is 1.6 by simulation.
        - No detection of UHECR is statistically consistent.

The cause of short flight:

NASA is thinking that

because some debris from the pyrotechnic cutters on the reefing collar had been found to penetrate the 3 mill thick reefing sleeve, it has been assumed by NASA that the balloon (which is thinner) was also penetrated and this started the tear that became a big hole by day 3 of the flight.

Future missions

We will go to space for observing UHECPs.

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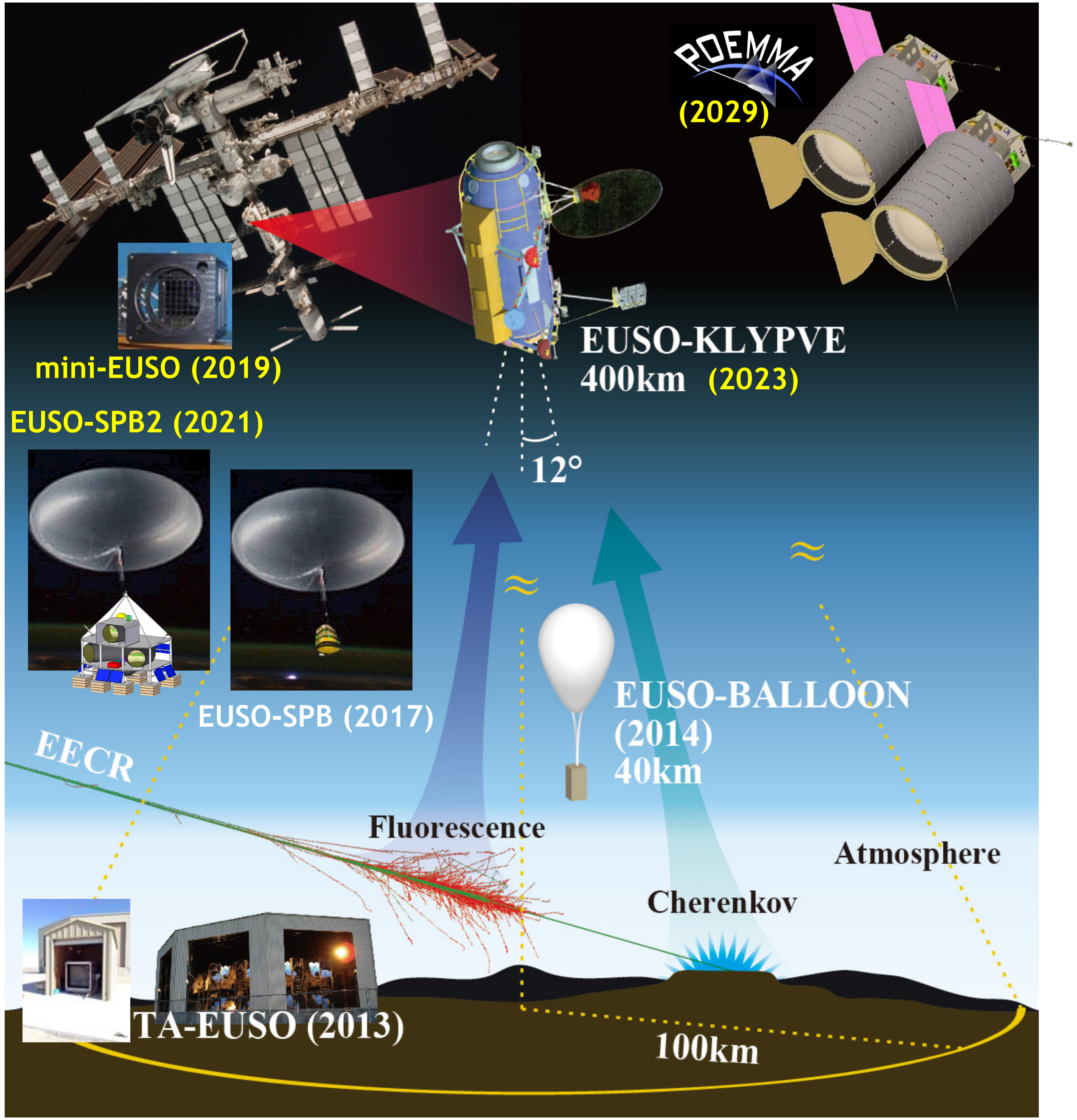


Science of the space missions

- All sky survey with the world's largest exposure
  - Find sources of UHECR.
    - Find new hotspots in the equatorial region of the sky.
      - TA and Auger are low sensitivity in this region.
  - We expected to find new UHECR sources (about ten).
    - If we observed sources, we can study acceleration mechanism by comparison with spectrum of each source.
      - Confirmation of GZK steeping （comparison with each spectrum)
      - Acceleration limit（in case of source distance is in GZK horizon)
        - Possibility of new acceleration mechanism (Japan team)
          - Bow wake field acceleration (T. Ebisuzaki and T. Tajima, 2014a and 2014b)
  - Observation of up-going τ neutrino from space (POEMMA)
    - Pioneer space observations of astrophysical neutrinos and,
    - Discover cosmogenic neutrinos

Mini-EUSO

Mini-EUSO is a Joint mission of Russian and Italian team with the JEM-EUSO corroboration.

Main purpose is measurement of the near UV region background from space for future space missions such as K-EUSO and POEMMA.

Mini-EUSO will be launched in 2019.

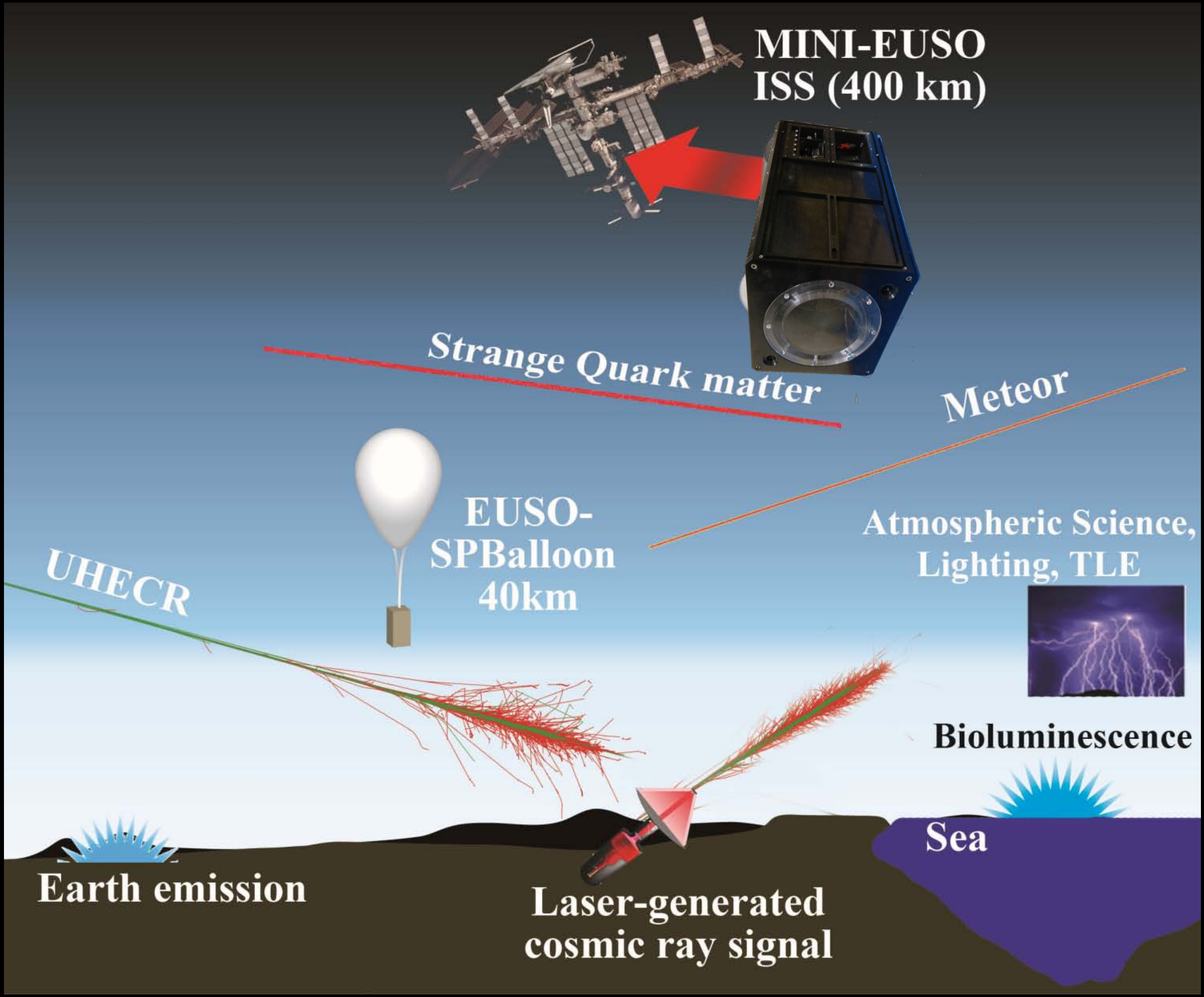
MINI-EUSO

Multi-band, Multi-Wavelength telescope inside ISS

Ultraviolet, with Fresnel lenses
Near Infrared
Visible

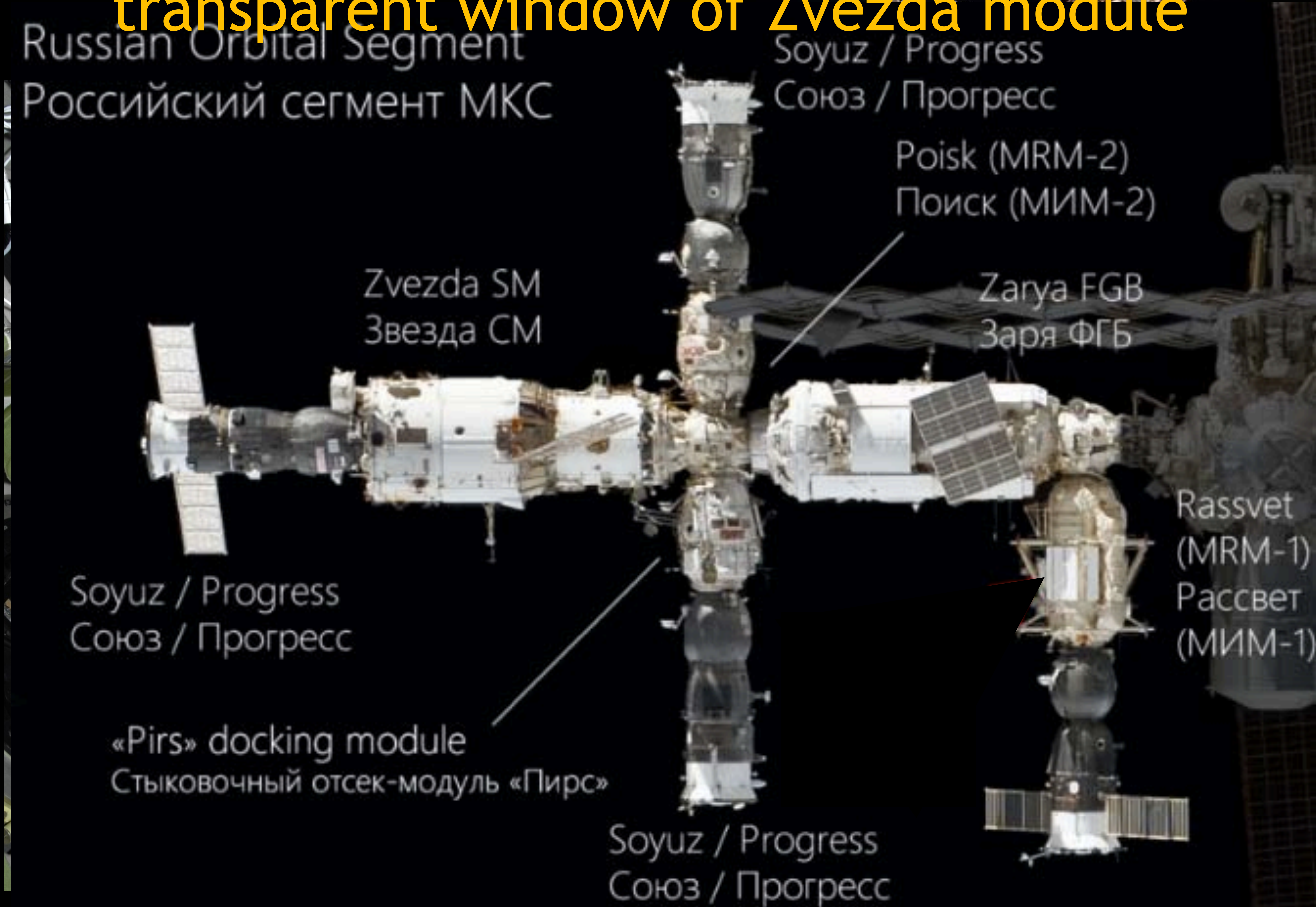
30kg, 60 W
60x37x37 cm

Night observations
From inside UV-transparent window of Zvezda



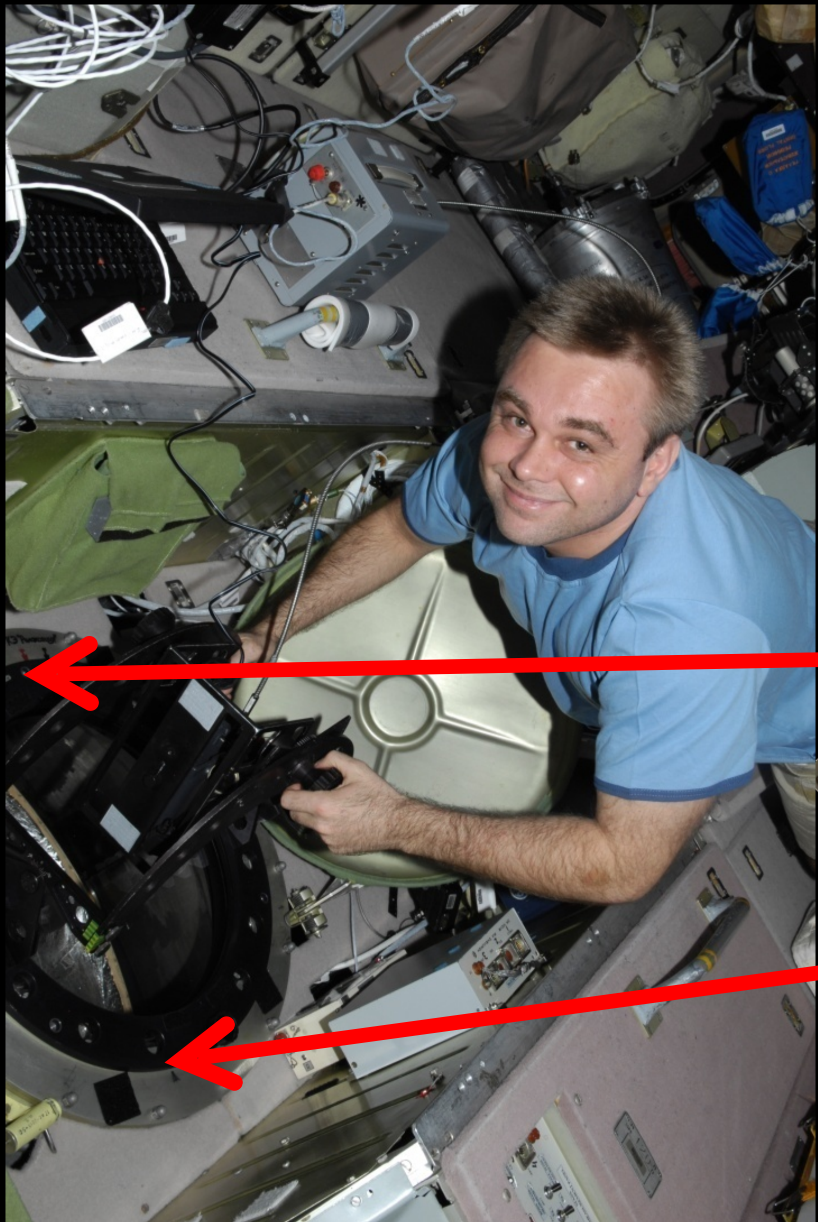
JEM-EUSO collaboration 16 Countries, 93 Institutes, 351 people

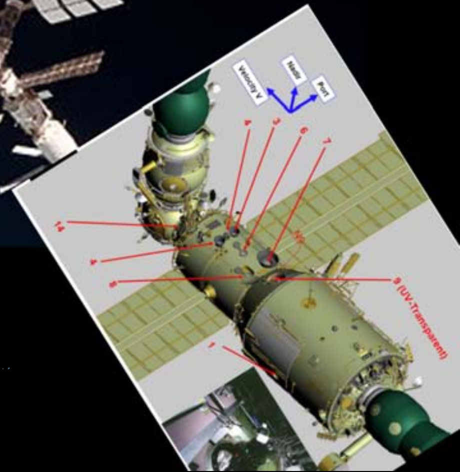
Mini-EUSO observes from inside ISS thorough UV transparent window of Zvezda module

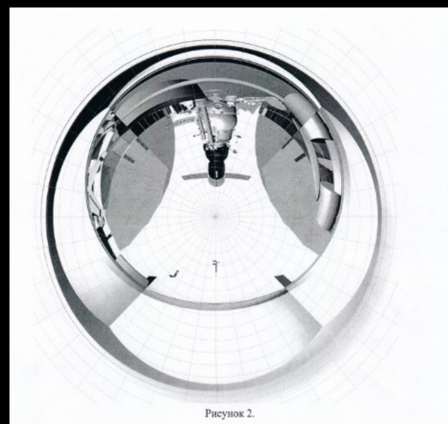


m

Uv transparent window, Zvezda module

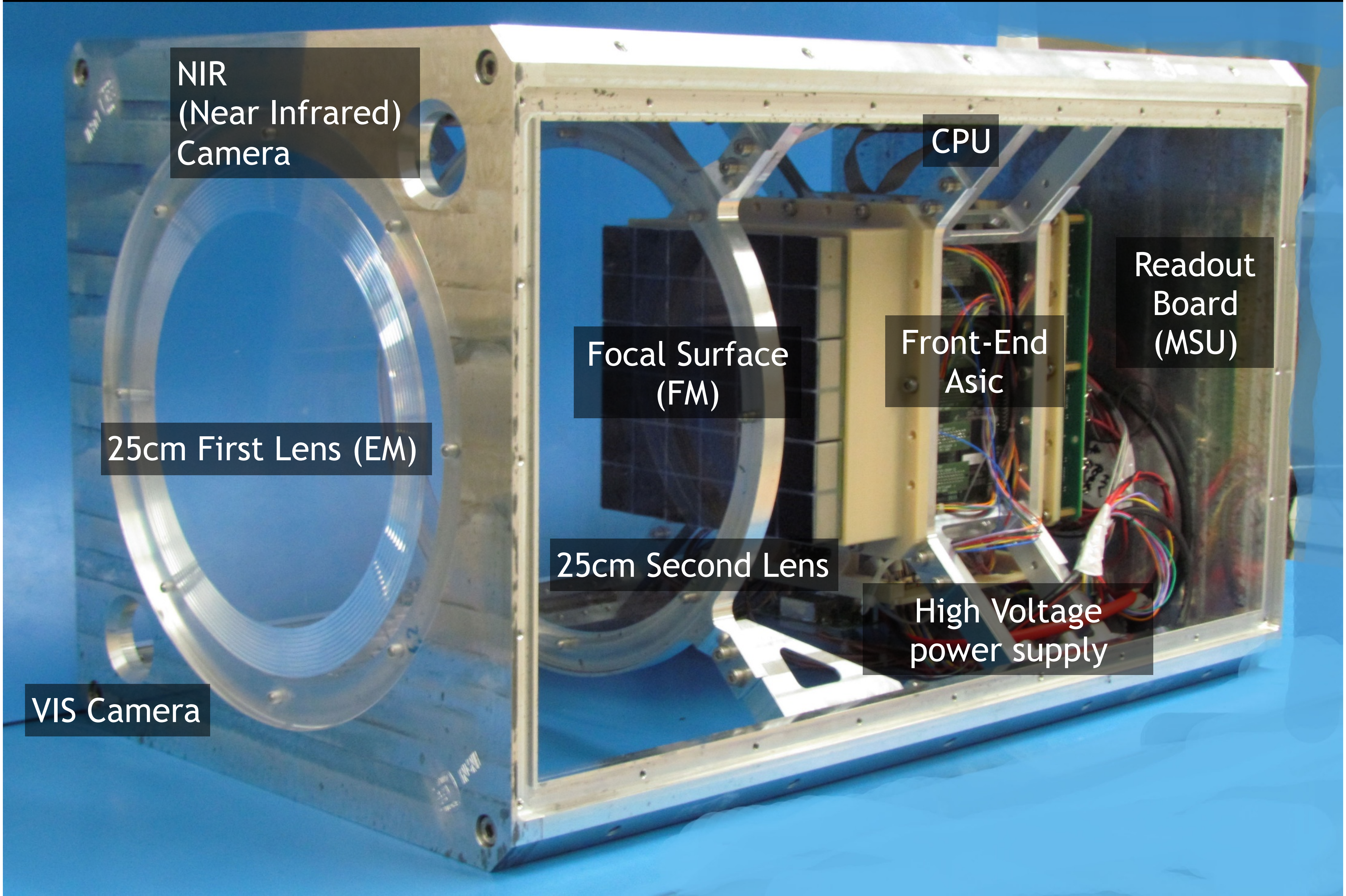






Field of view from window

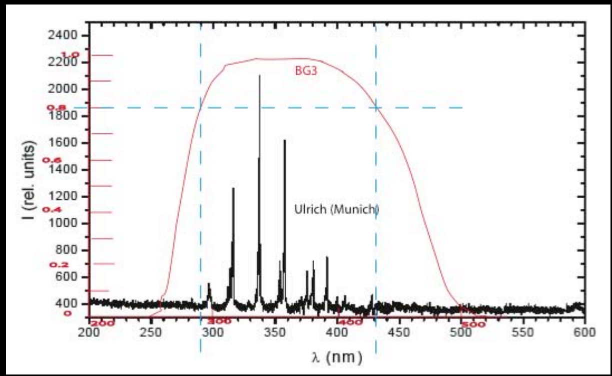
MINI-EUSO EM in clean room

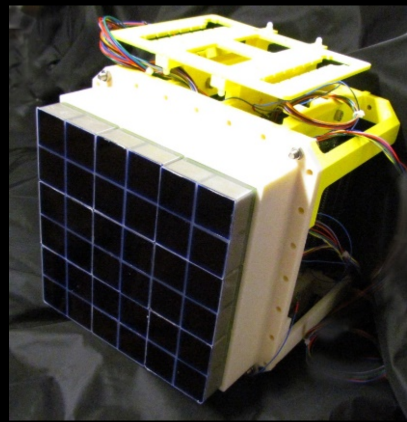


Sensors

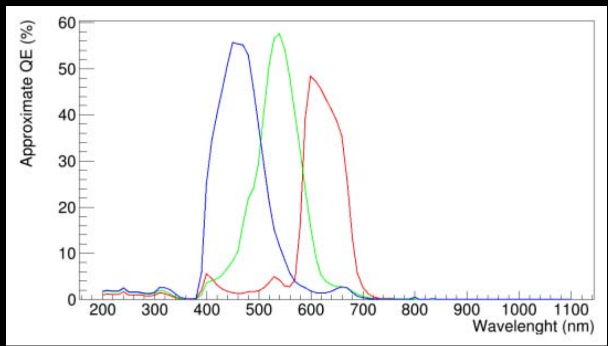
East Japan and Tokyo bay

UV main camera
48*48 pixels
40 deg 243km 5km/pix
2.5mus and above

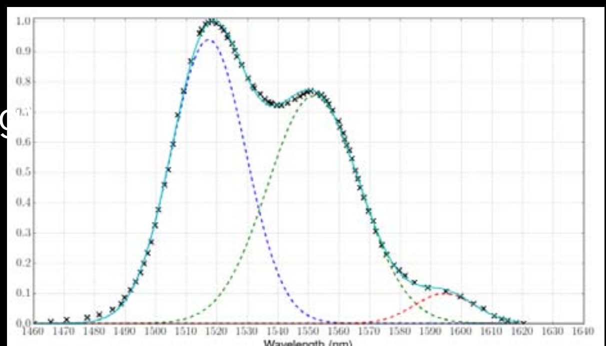




RGB camera
1280*960 pixels
33.2*24.8 degrees
231*174 km 180 m/pixel
1s



NIR camera
(BW with phosphor coating)
1280*960 pixels
33.2*24.8 degrees
231*174 km 180 m/pixel
4s



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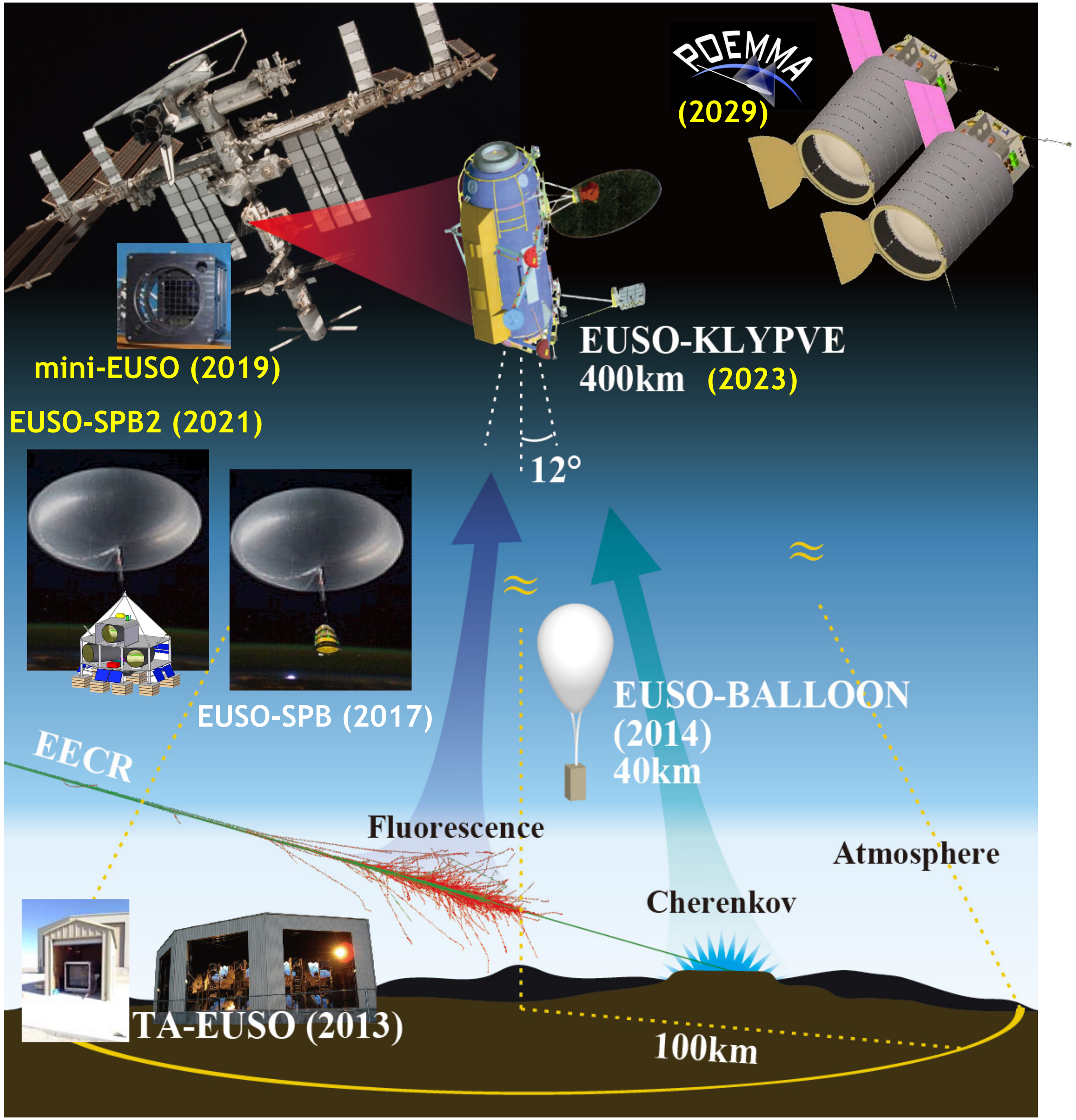
EUSO-SPB2 (2021)
K-EUSO (2023)
POEMMA (2029)

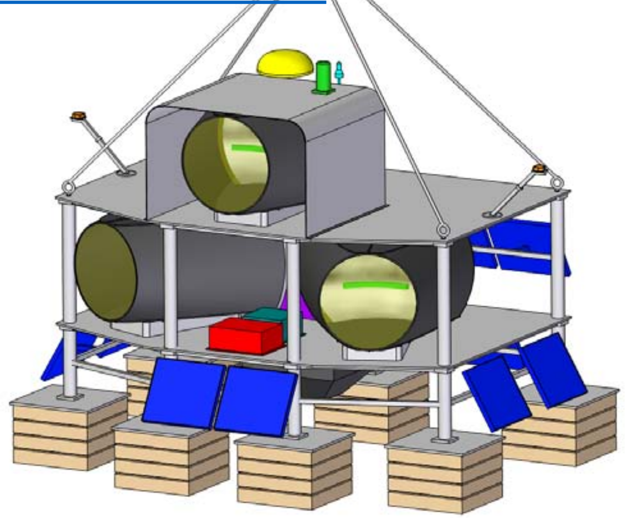


EUSO-SPB2

EUSO-SPB2 will be launched in 2021.

EUSO-SPB2 is a preparation experiment for the POEMMA mission.

arXiv:1703.04513

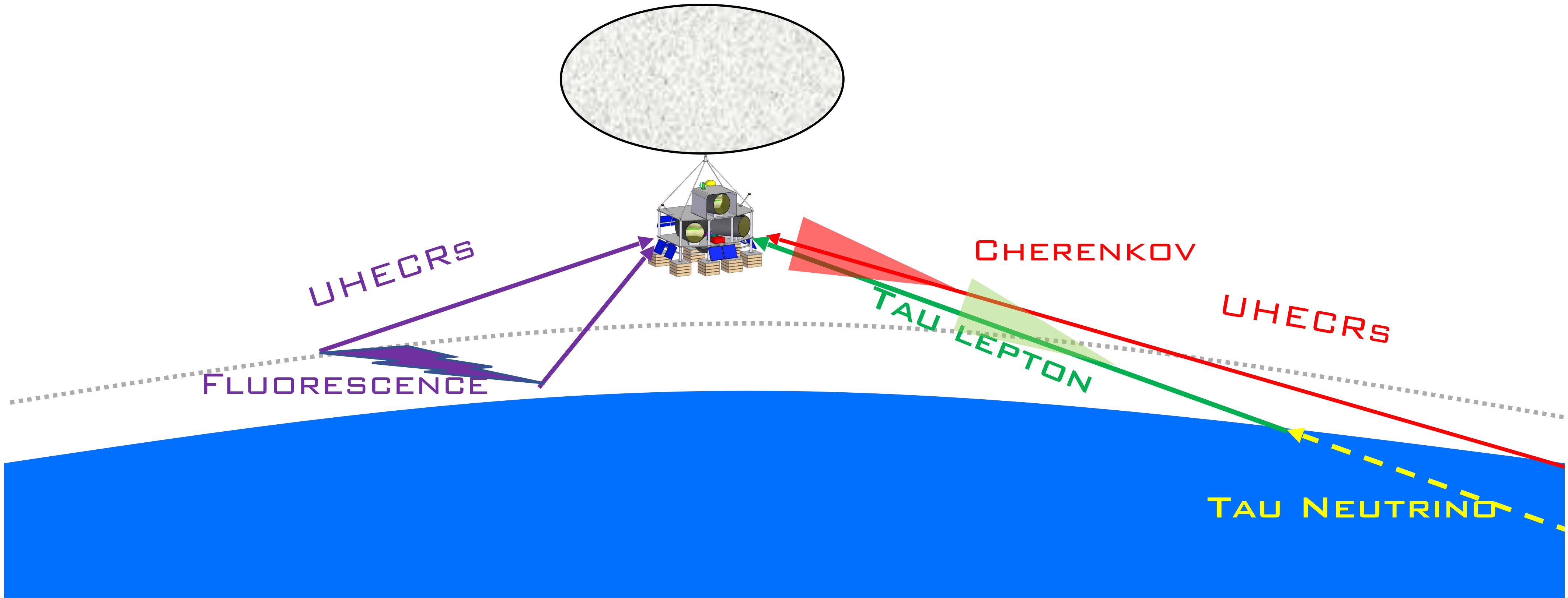


EUSO-SPB2

Cherenkov Emission from UHECRs

Tau Neutrino Background

Fluorescence from UHECRS



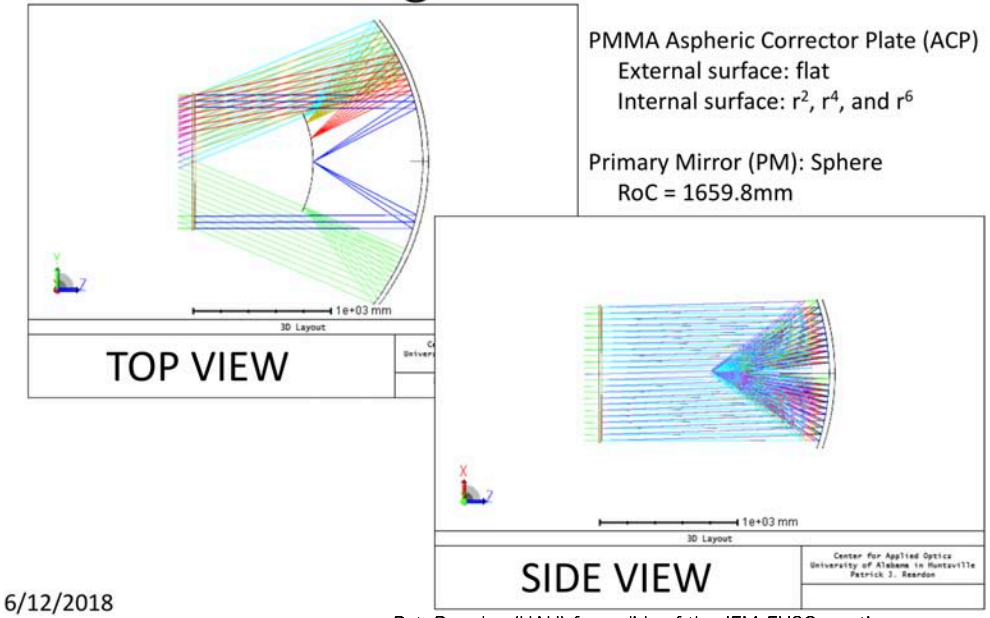
EUSO-SPB2

Schmidt optics
Mirror: 1.8m x 1.1m Spherical (R=1659.8mm)
Corrector lens: 1m diameter, flat+aspherical,
UV transparent PMMA
F# : 0.86
Spot size: 3mm
Angular resolution 0.2°/pixel

Cherenkov telescope: 1 unit、 Bifocal
- 45° horizontal Full-field of view
- 3.2° Vertical Full-field of view
- Expected event rate: 10events/day

Florescence telescope: 1 unit or 2 units
- 28.8° horizontal Full-field of view
- 3.2° Vertical Full-field of view
- Expected event rate: 5events/100 days/unit

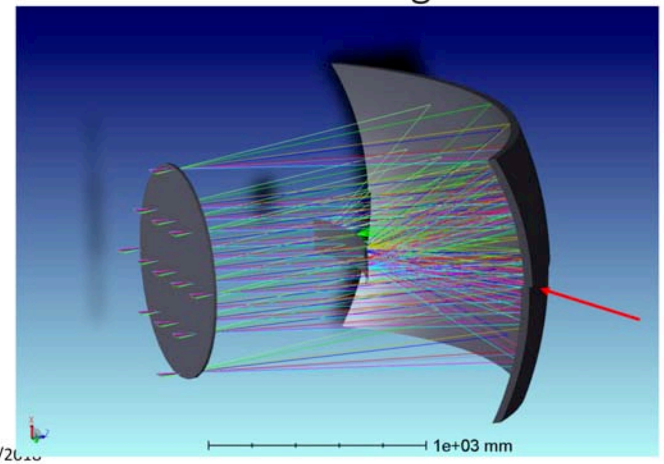
Baseline Design



6/12/2018

Pat. Reardon (UAH) from slide of the JEM-EUSO meeting

Bifocal Design



6/12/2018

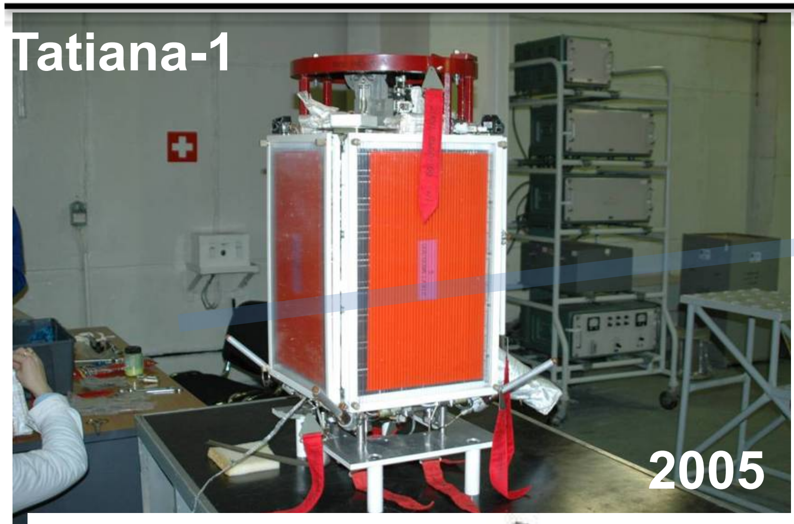
Bifocal mirror system rejects direct hit event on the focal surface.
Mirror is divided by two. each mirror tilts with small angle.
Each mirror makes each image on the focal surface.

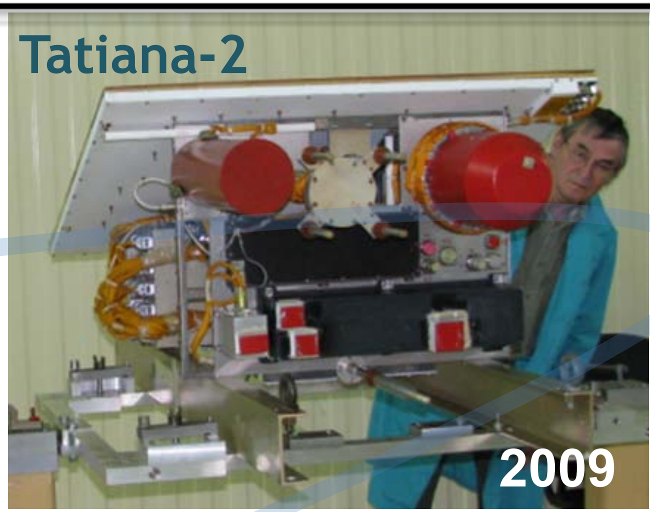
K-EUSO mission

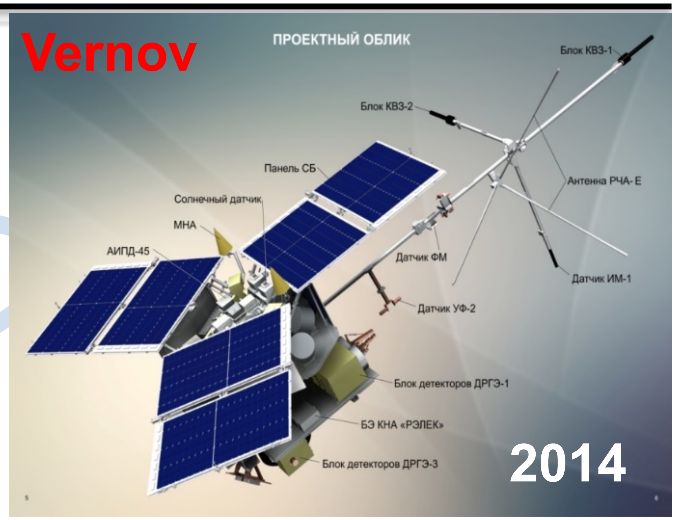
K-EUSO is a Joint mission of Russian and Japanese team with the JEM-EUSO corroboration.

K-EUSO will be launched in 2023.
Phase A study in Russia will be finished by May 2019.

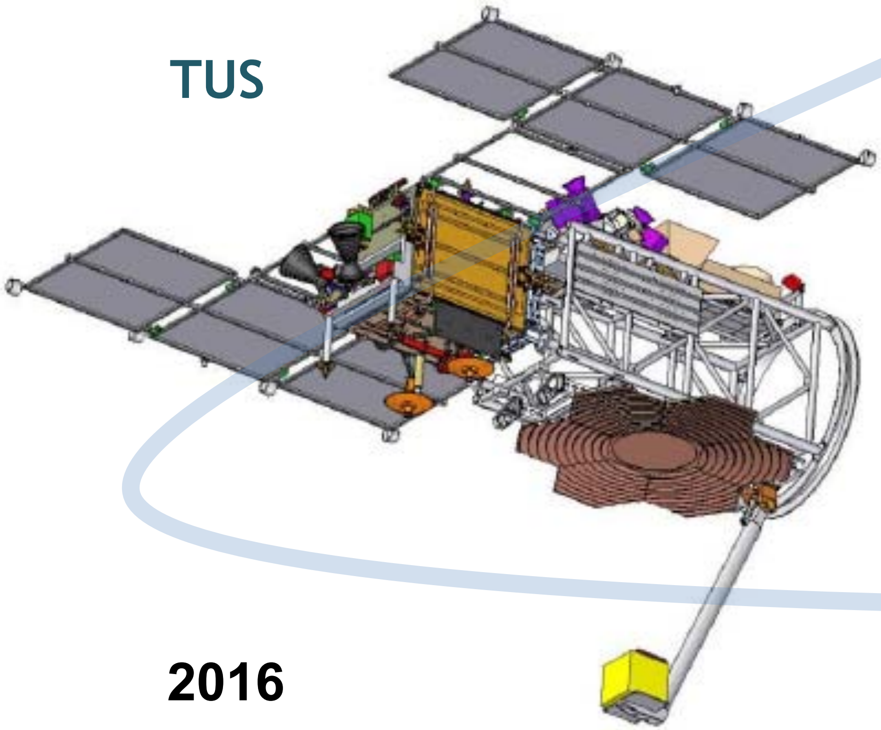
SINP MSU space detectors of UV events in the atmosphere development







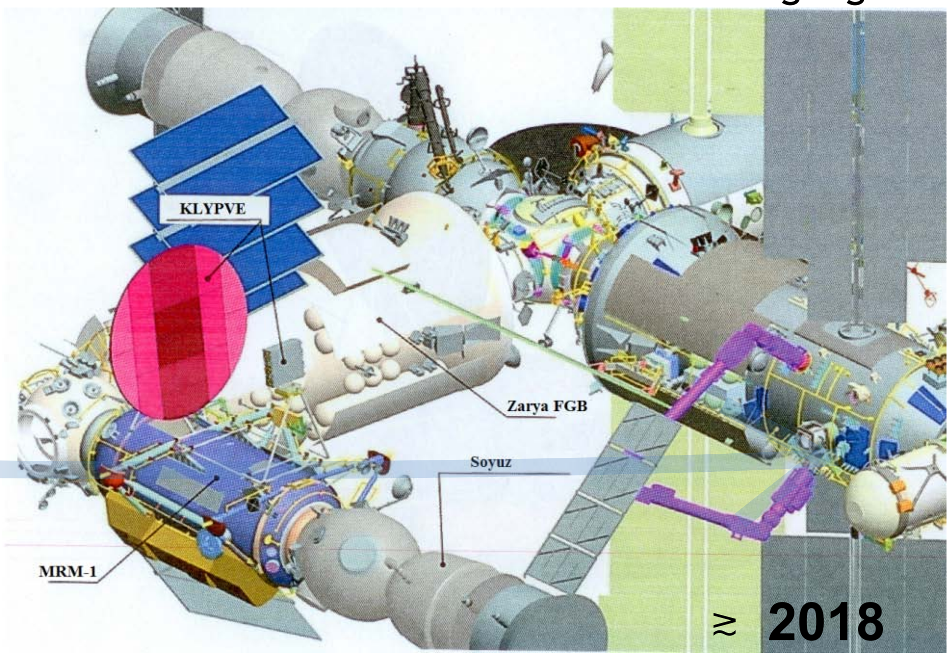
TUS



2016

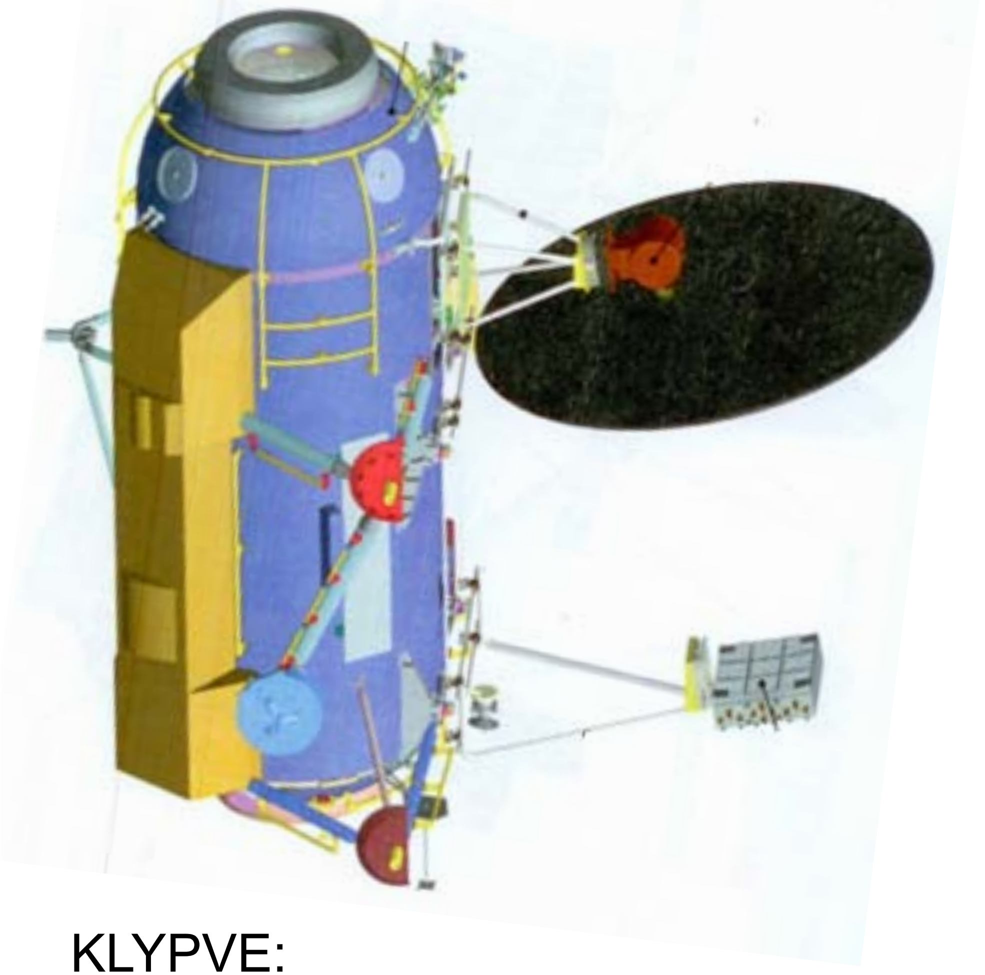
KLYPVE

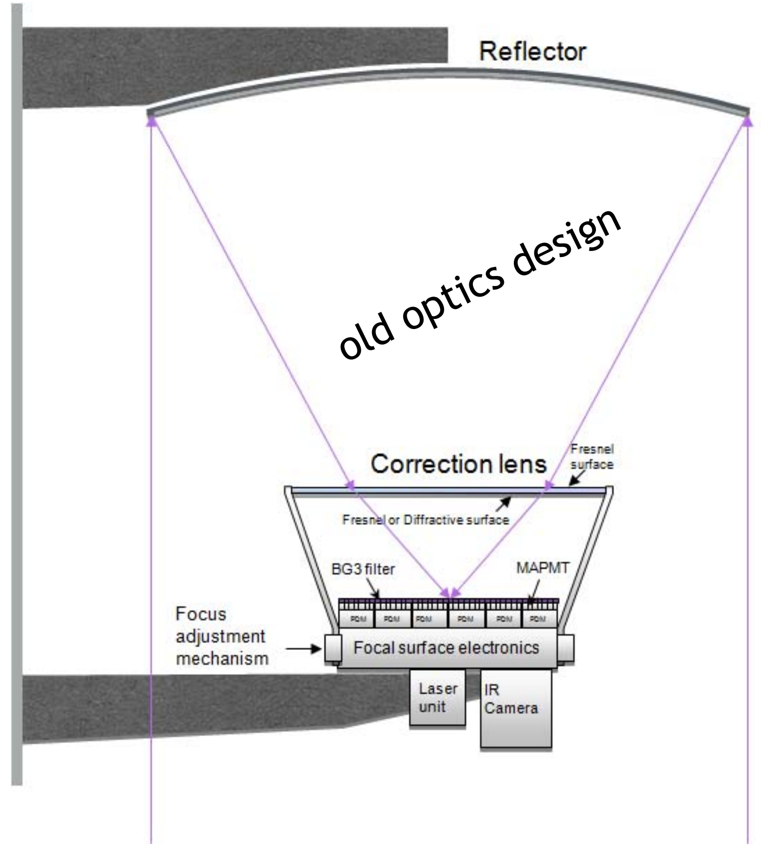
KLYPVE means ‘UHECR’ in Russian language.



KLYPVE -> K-EUSO

KLYPVE updates using the EUSO technology (lens, detector).
K-EUSO is a Joint mission of Russia and Japan with the JEM-EUSO corroboration

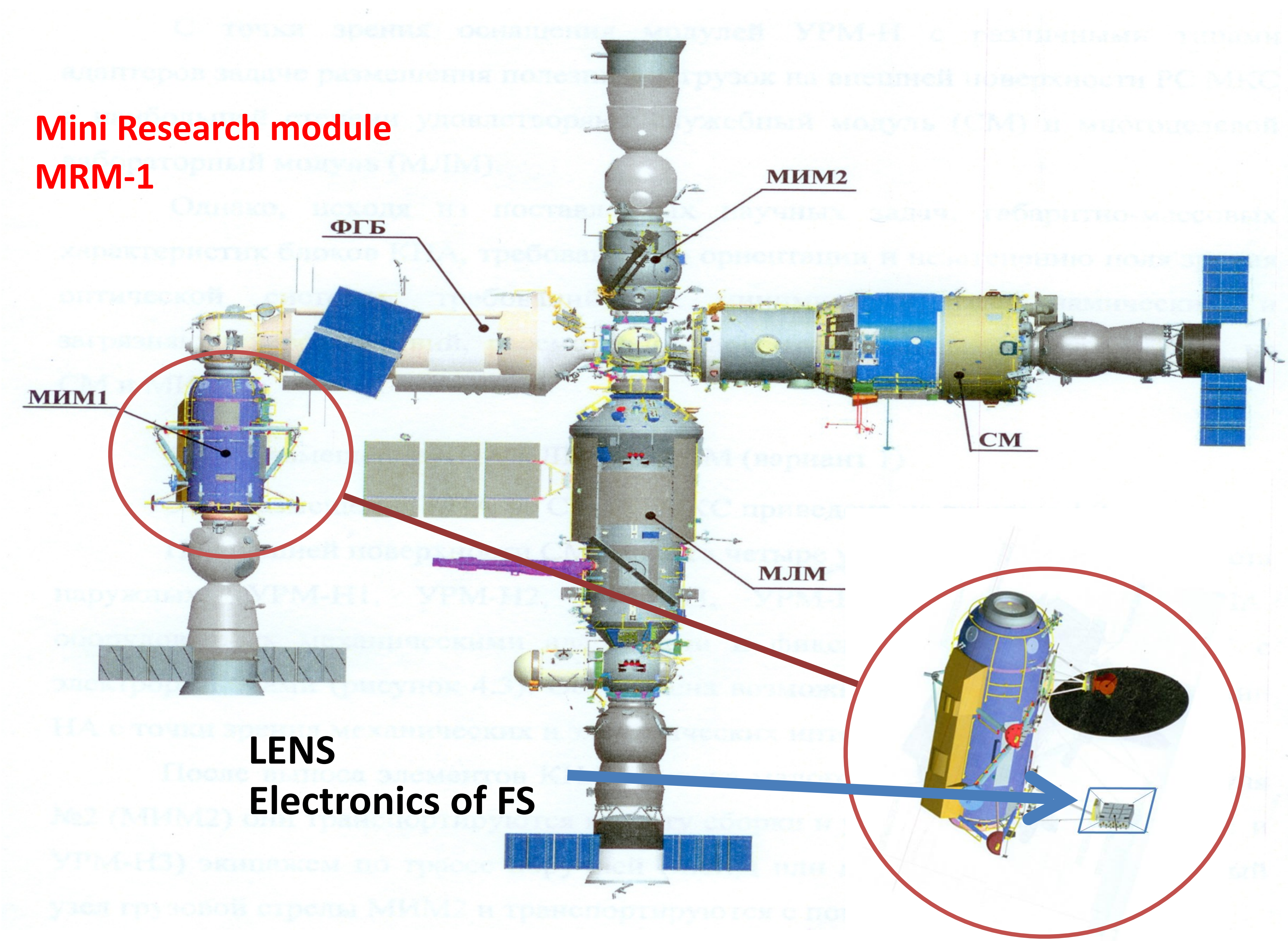




KLYPVE:
FOV ±7°、and 1° angular resolution

K-EUSO:
Additional corrector lens & EUSO detector
→FOV ±14° and 0.1° angular resolution

Mini Research module
MRM-1



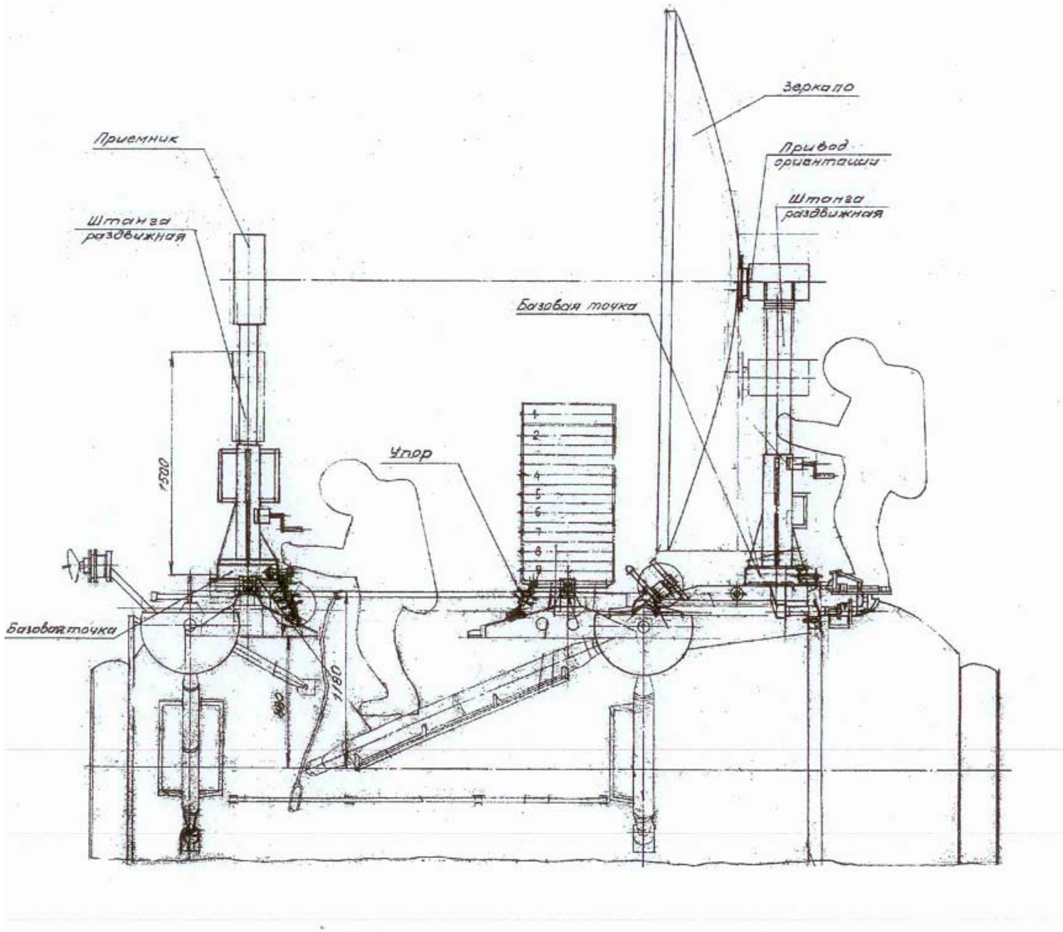
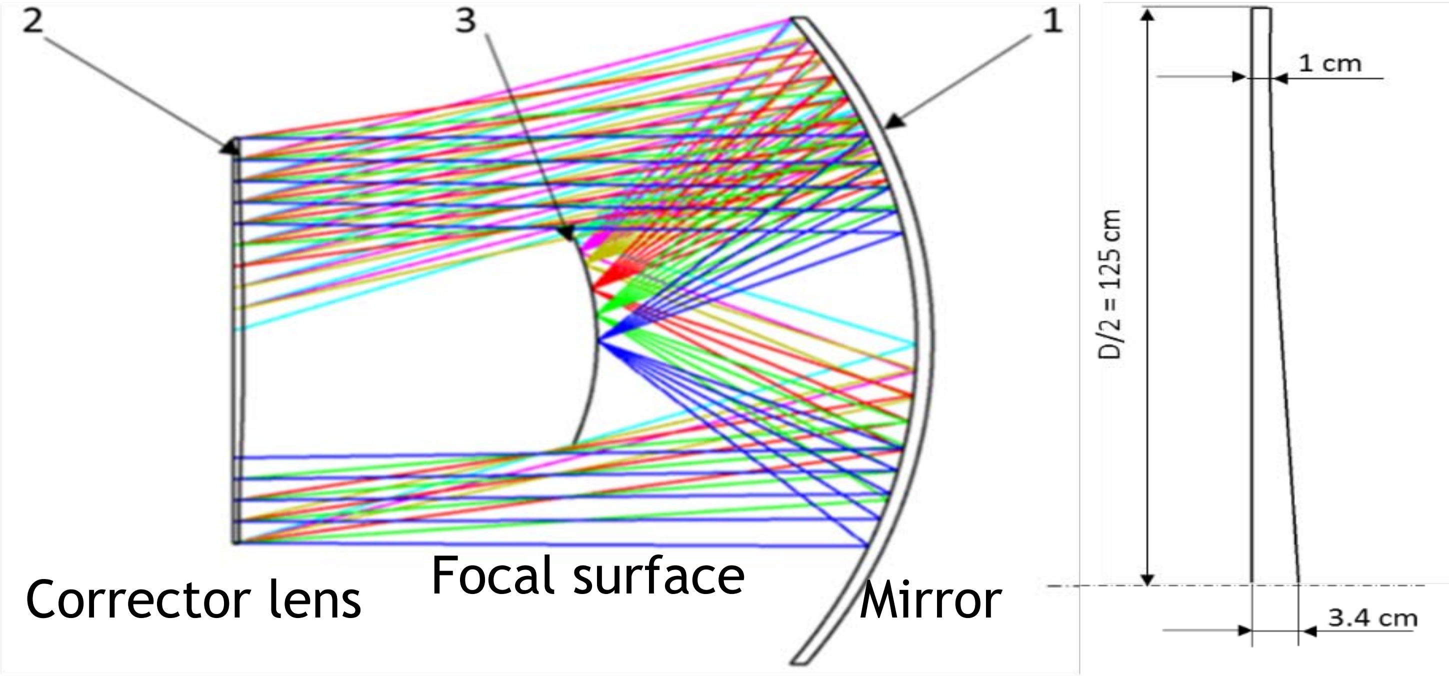


Рисунок 4.13 – Вариант размещения КНА КЛПВЭ на МИМ1

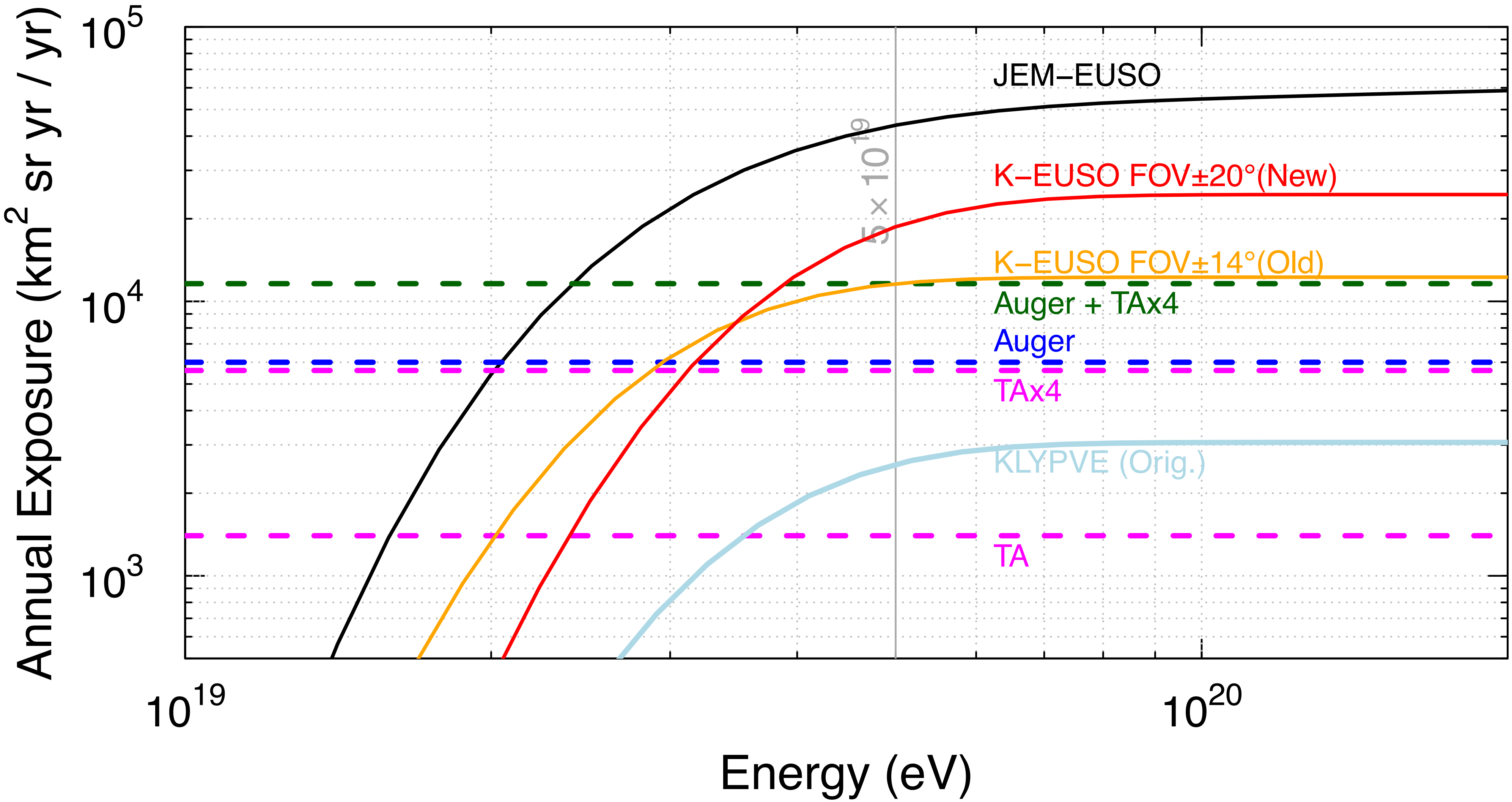
New optics design (Schmidt optics)



FOV ±20°
Old design: FOV ±14°

Parameter	Value, m
Entrance Pupil Diameter	2.5
Mirror diameter	4.0
Radius curvature of mirror	3.45
Radius curvature of FS	1.8
Axial length	3.43
Distance from M to FS	1.62

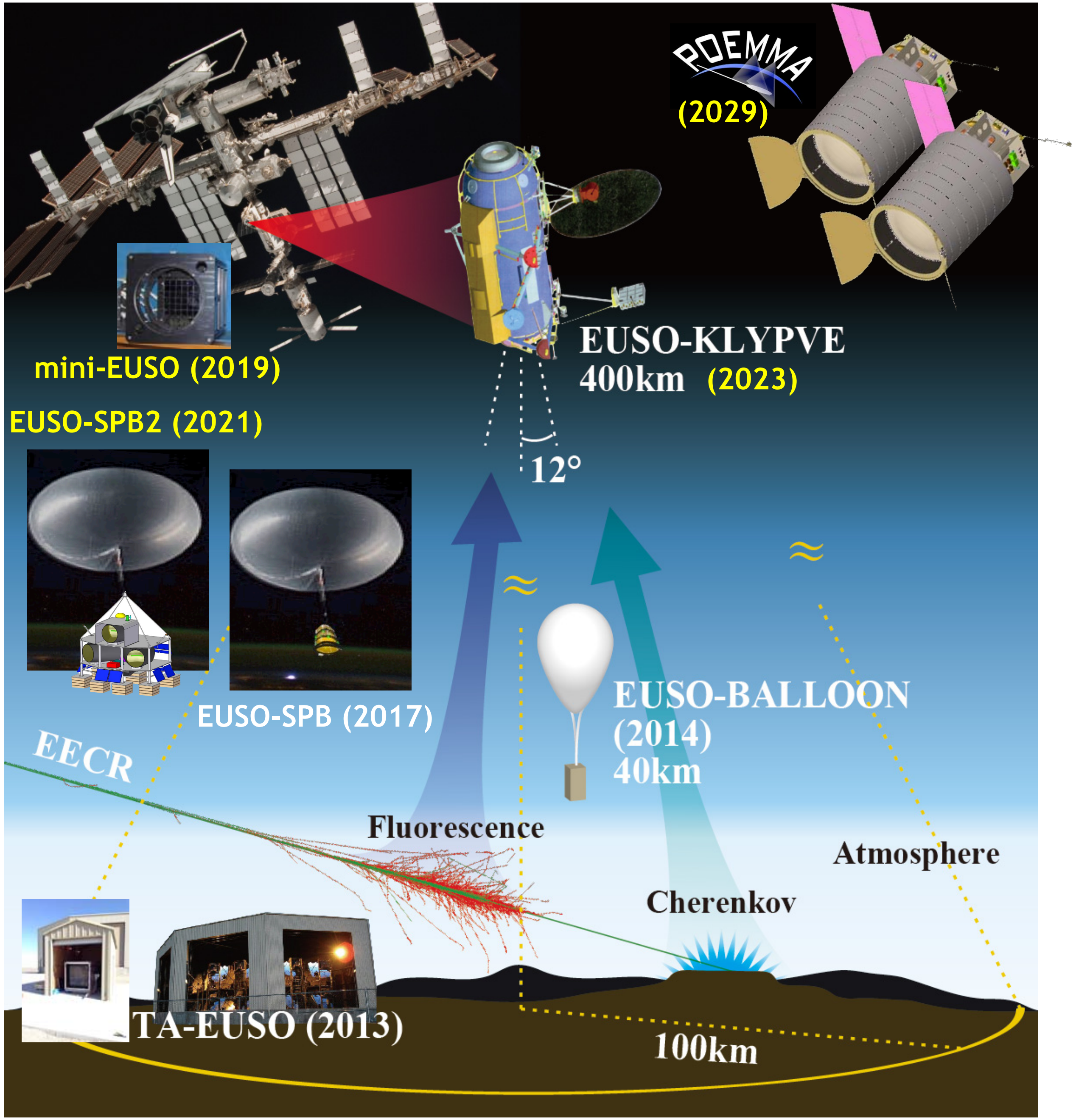
Exposure comparison



The JEM-EUSO program

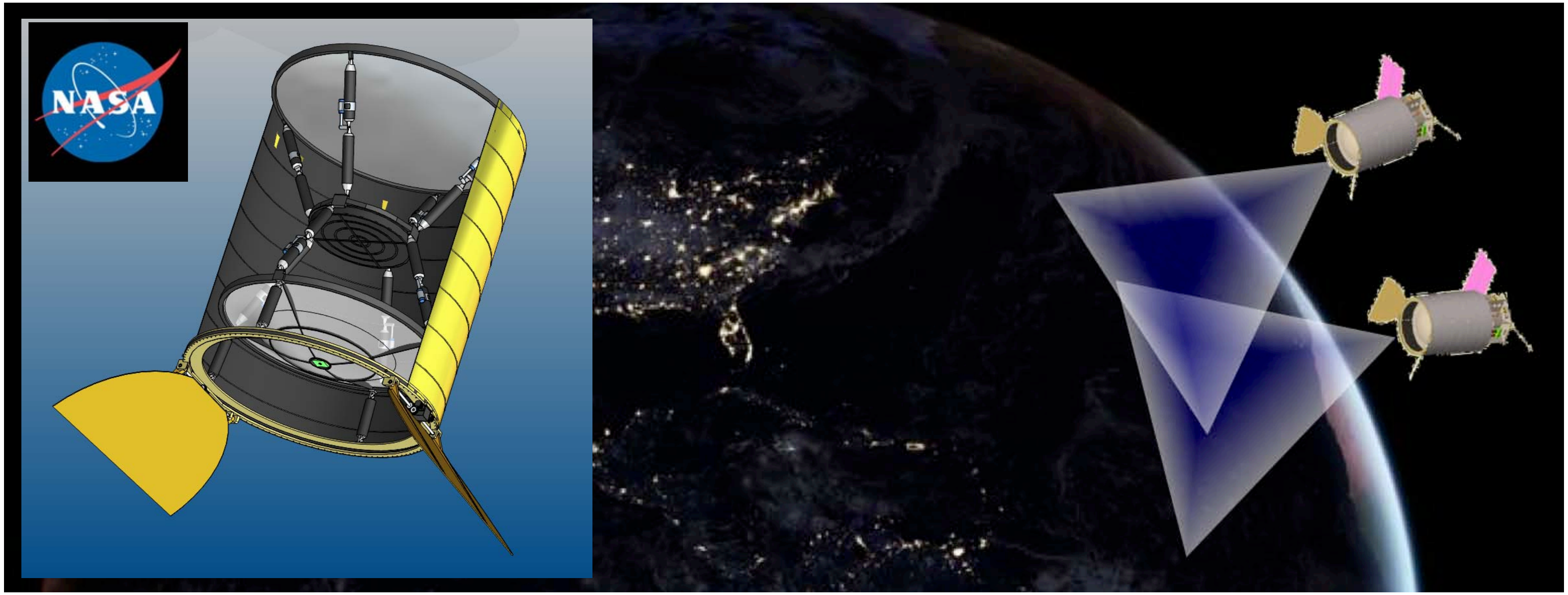
EUSO-TA (2013-)
EUSO-Balloon (2014)
EUSO-SPB (2017)

Mini-EUSO (2019)
EUSO-SPB2 (2021)
K-EUSO (2023)
POEMMA (2029)



POEMMA mission

Stereo observation



POEMMA team is working on a conceptual design for selection of the 2020 Astronomy and Astrophysics Decadal Survey.

POEMMA: STUDY COLLABORATION

University of Chicago: *Angela V. Olinto (PI)*

NASA/MSFC: Mark J. Christl (deputy PI), Roy M. Young, Peter Bertone, Jeff Apple, Gary Thornton, Brent Knight, Kurt Dietz, Mohammad Sabra

University of Alabama, Huntsville: James Adams, Patrick Reardon, Evgeny Kuznetsov, J. Watts Jr., J. Tubbs, M. Mastafa

NASA/GSFC: John W. Mitchell, John Krizmanic, Jeremy S Perkins, Julie McEnery, Elizabeth Hays, Floyd Stecker, Stan Hunter, Jonathan Ormes, Tonia Venters

University of Utah: Doug Bergman, John Matthews

Colorado School of Mines: Lawrence Wiencke, Frederic Sarazin

City University of New York, Lehman College: Luis Anchordoqu, Thomas C. Paul

Georgia Institute of Technology: A. Nepomuk Otte

Space Sciences Laboratory, University of California, Berkeley: Eleanor Judd

University of Iowa: Mary Hall Reno

Jet Propulsion Laboratory: Insoo Jun, L. M. Martinez-Sierra

Vanderbilt University: Steven E Csorna

APC Univerite de Paris 7: Etienne Parizot, Guillaume Prevot

Universita di Torino: Mario Edoardo Bertaina, Francesco Fenu, Kenji Shinozaki

University of Geneva: Andrii Neronov

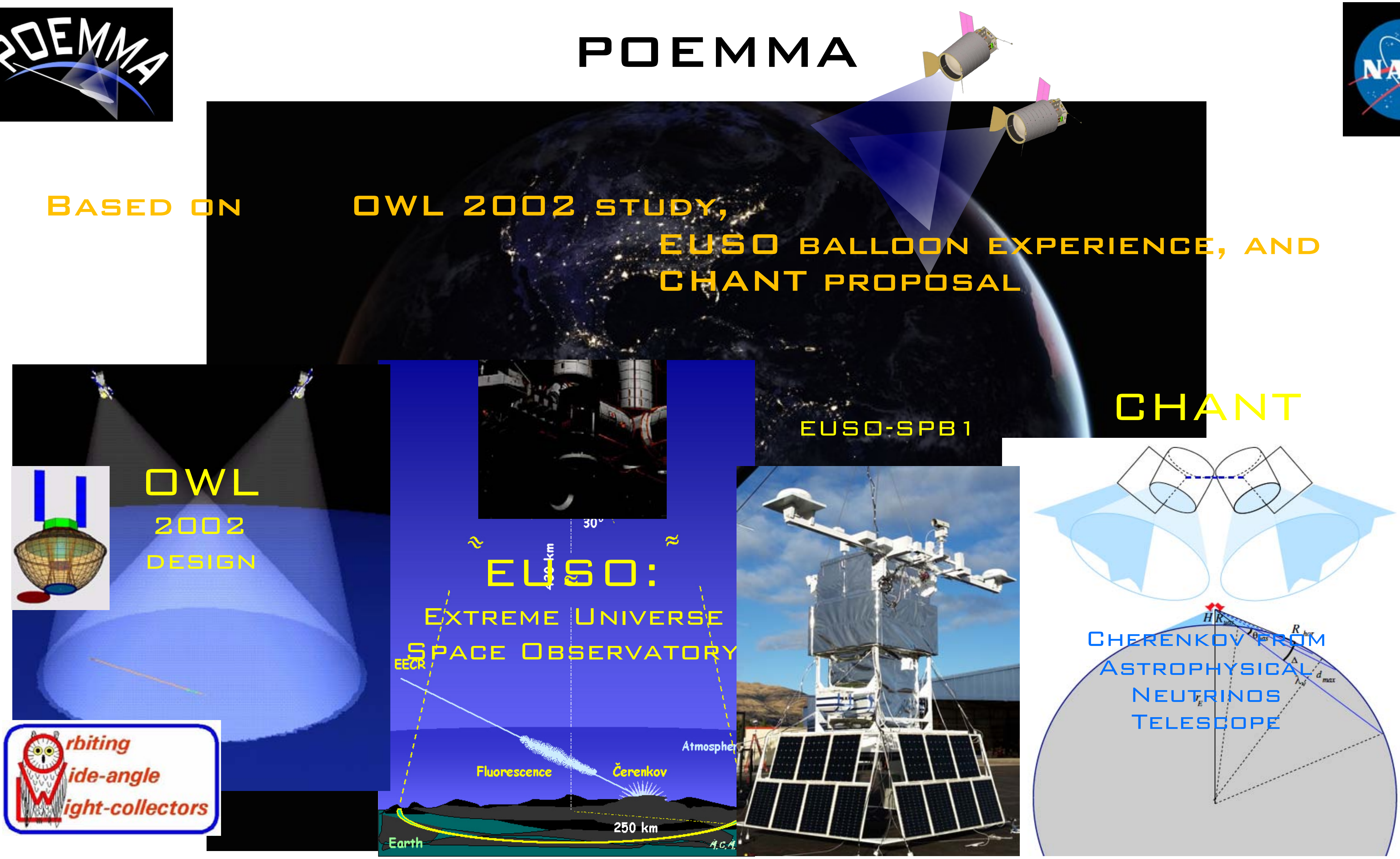
RIKEN: Yoshiyuki TAKIZAWA

Gran Sasso Science Institute: Roberto Aloisio

SCIENTISTS FROM 16+ INSTITUTIONS FROM
OWL, JEM-EUSO, AUGER, TA, VERITAS, CTA, FERMI, THEORY

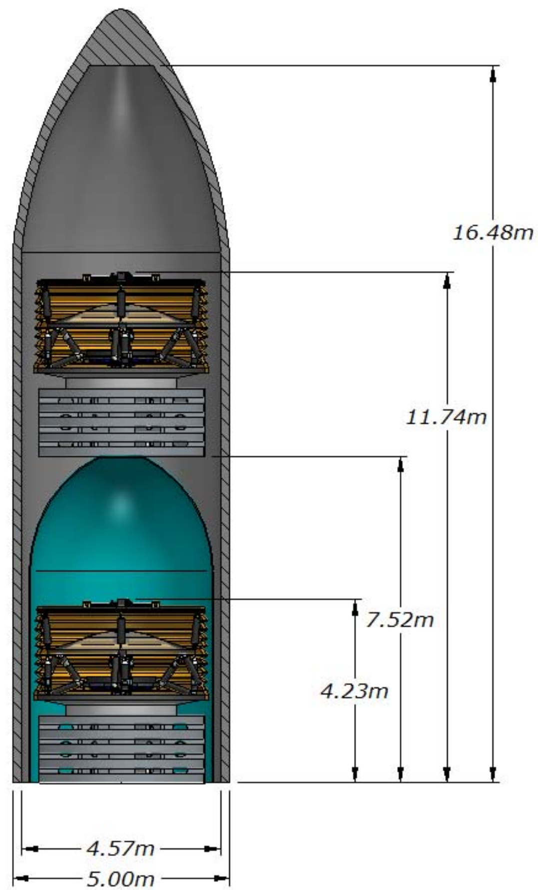
POEMMA

Based on OWL 2002 study, EUSO balloon experience, and CHANT proposal



POEMMA mission

Mission Lifetime:	3 years (5 year goal)
Orbits:	525 km, 28.5° Inc
Orbit Period:	95 min
Satellite Separation:	~25 km – 1000+ km
Satellite Position:	1 m (knowledge)
Pointing Resolution:	0.1°
Pointing Knowledge:	0.01°
Slew Rate:	8 min for 90°
Satellite Wet Mass:	3860 kg
Power:	2030 W
Data:	1 GB/day
Data Storage:	7 days
Communication:	S-band (X-band if needed)
Clock synch (timing):	10 nsec



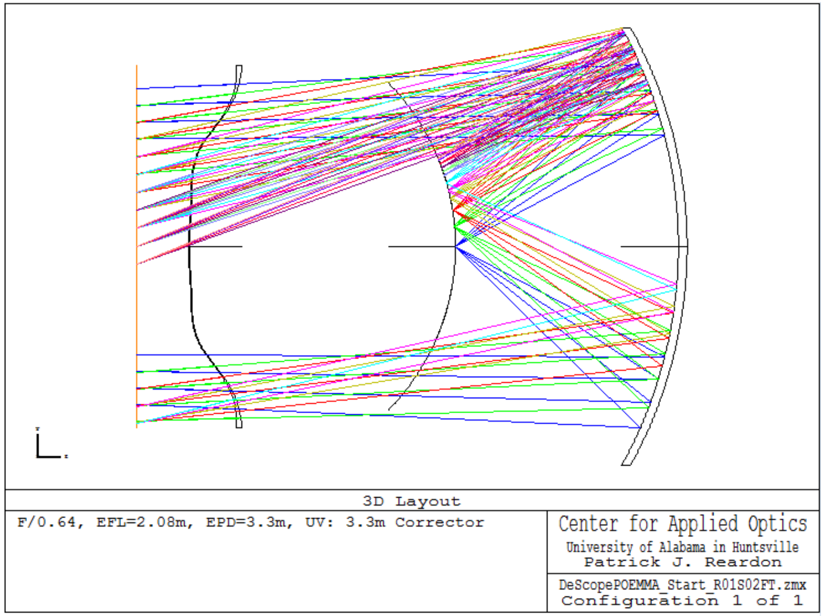
Dual Manifest Atlas V

Operations:

- Each satellite collects data autonomously
- Coincidences analyzed on the ground
- View the Earth at near-moonless nights, charge in day and telemeter data to ground

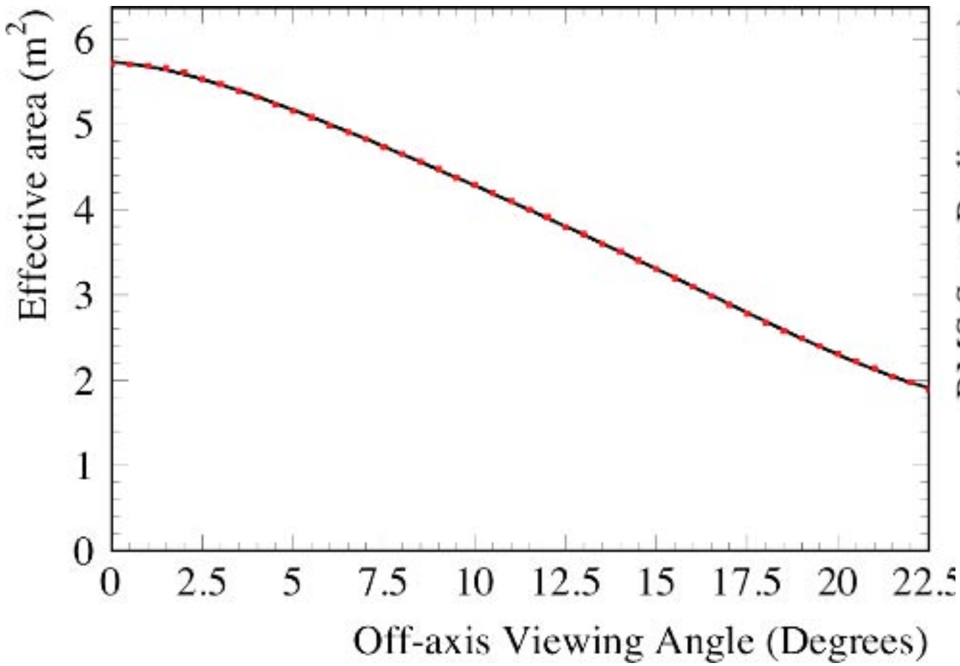
John Krizmanic, UHECR2018

POEMMA optics design

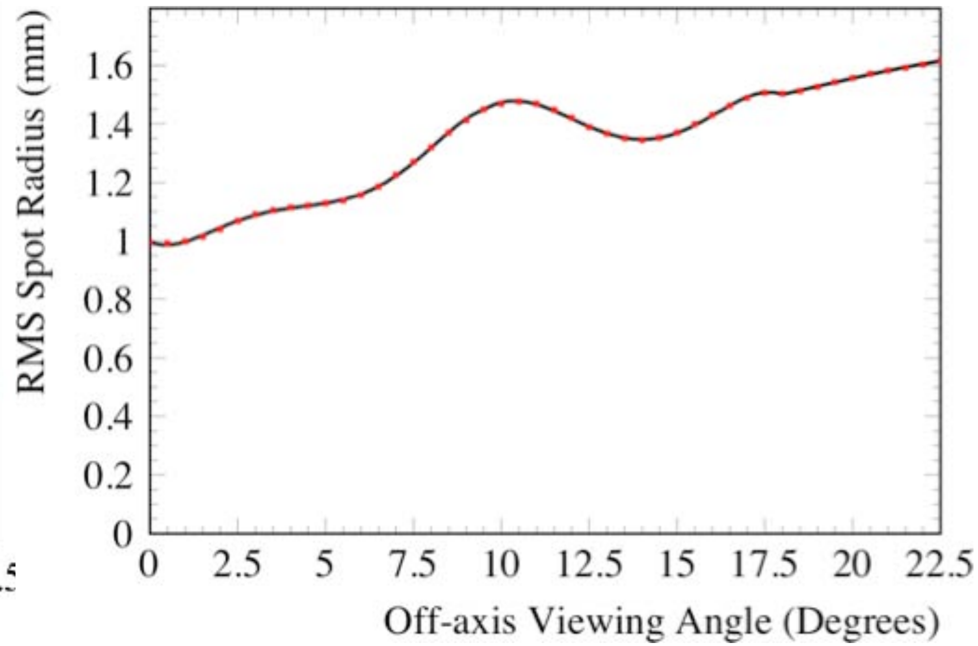


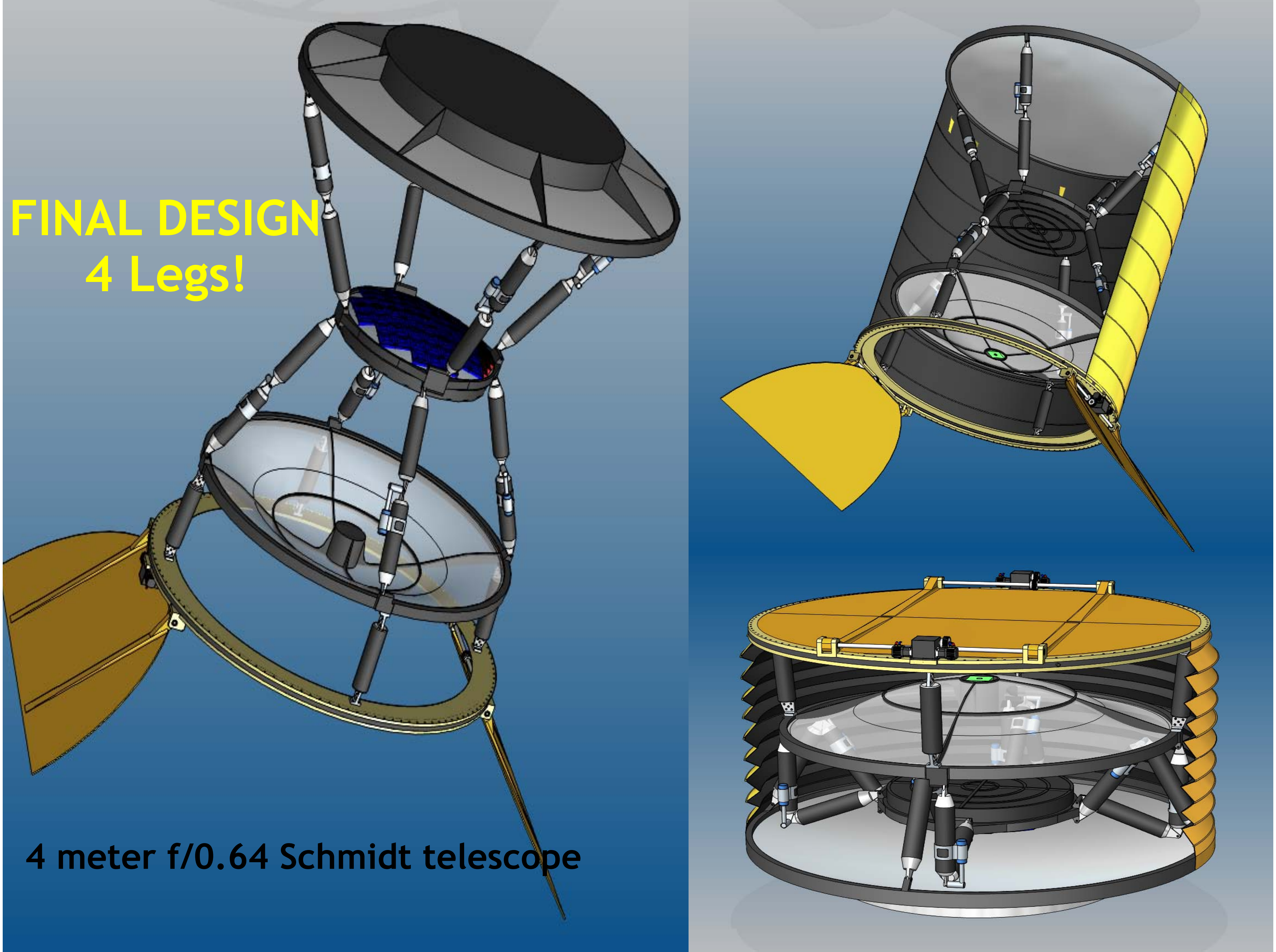
Mirror: 4.0m diameter spherical
Corrector lens: 3.3m, aspherical、UV-PMMA
Forcal surface: 1.6m diameter
FOV: 45°
F# : 0.64
Spot size: ~3mm diameter
Angular resolution： 1°/pixel
Effective area：6~2 m^2 (JEM-EUSO: 2 m^2)
Orbit altitude: 525 km

Effective area



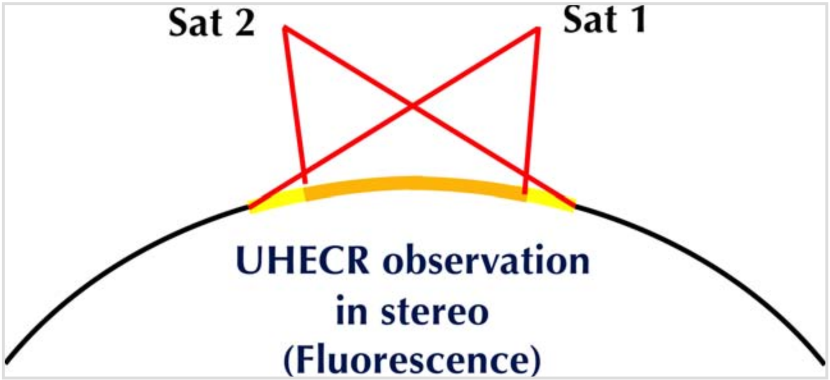
Spot size（radius, mm)



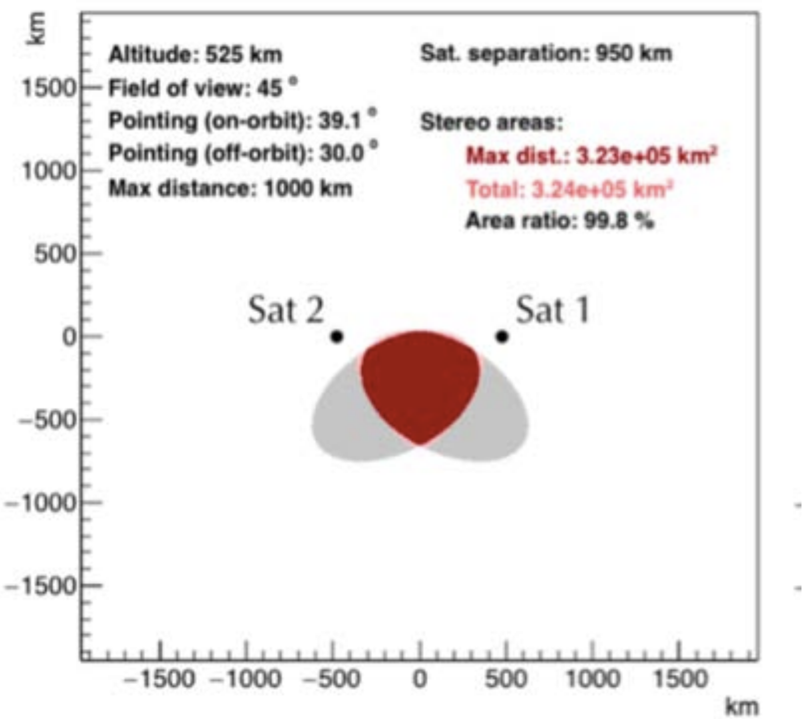

FINAL DESIGN
4 Legs!
4 meter f/0.64 Schmidt telescope

POEMMA observation modes

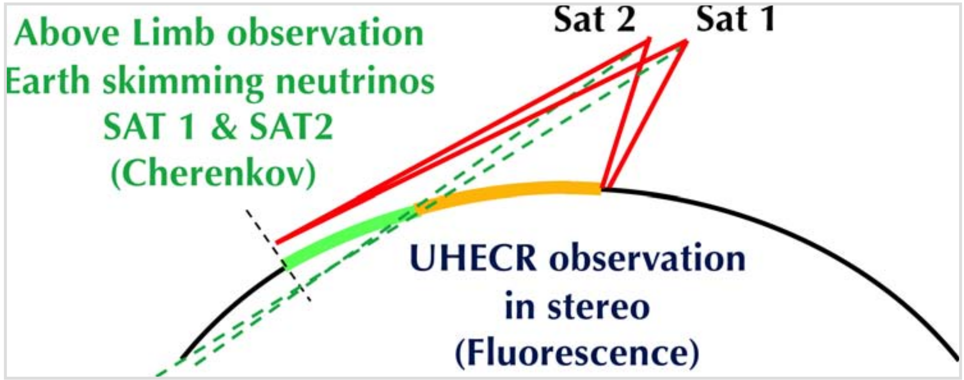
Nadir mode (UHECR)



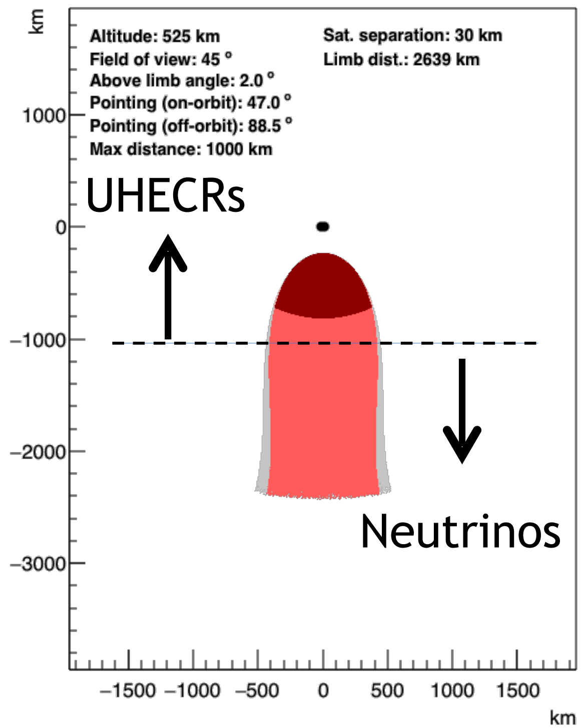
Satellite Separation ~300 km



Limb-viewing mode (UHECR + neutrino)



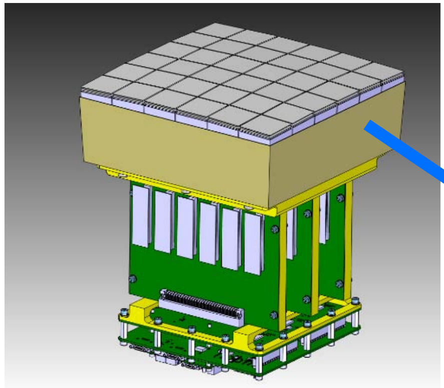
Satellite Separation ~30 km

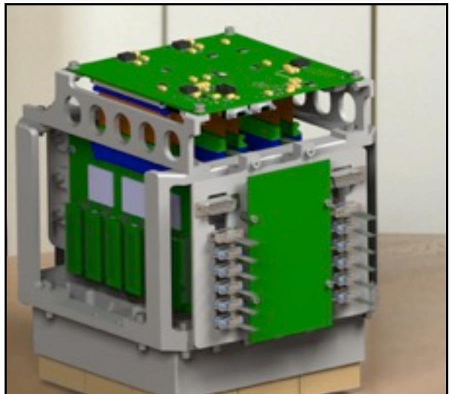


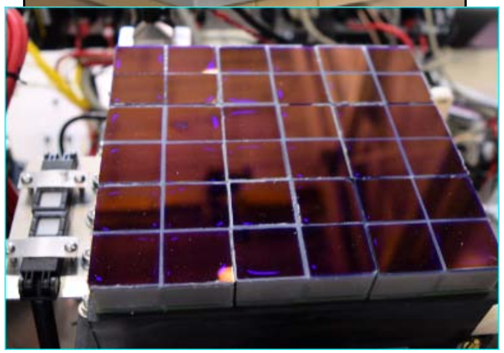
Hybrid focal surface detector

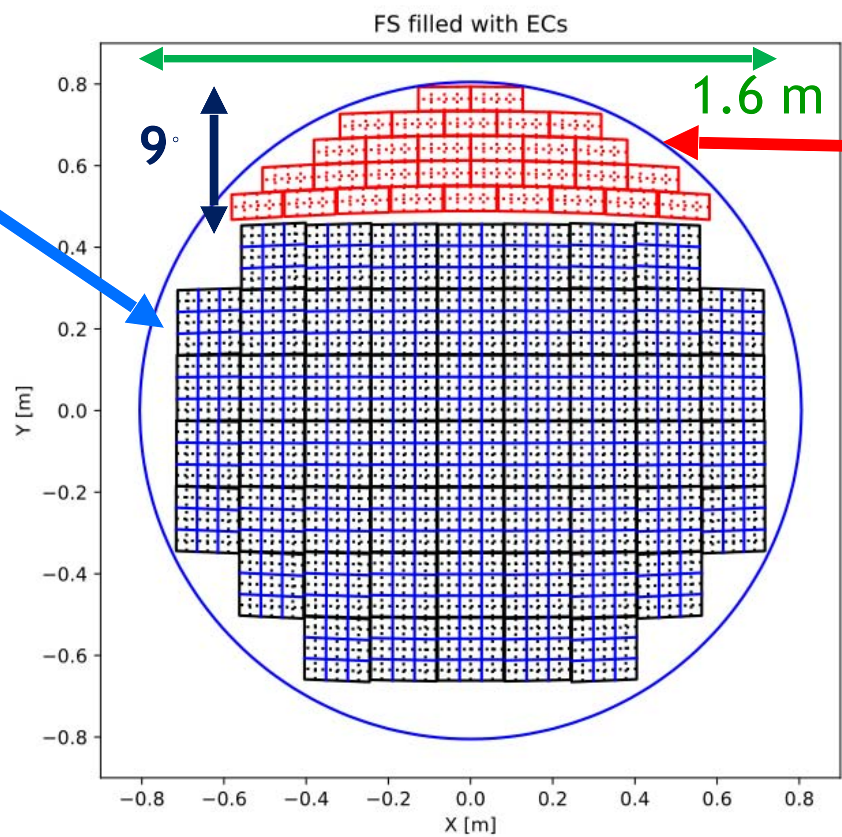
UV Fluorescence Detection using MAPMTs with UV filter: developed by JEM-EUSO: 1 usec sampling

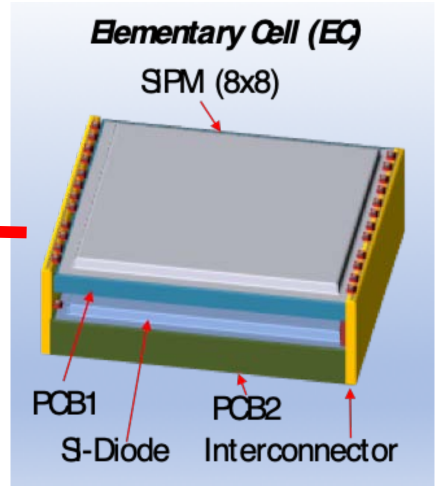
Cherenkov Detection using SiPMs:
20 nsec sampling





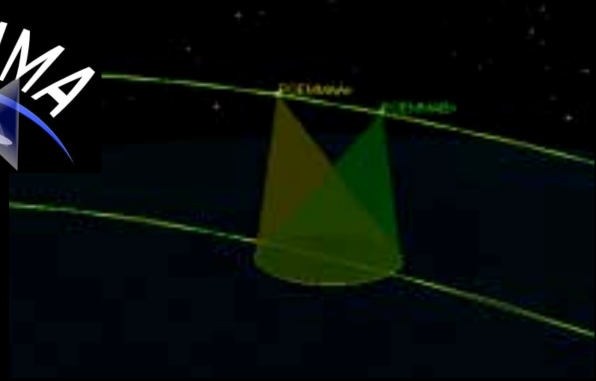




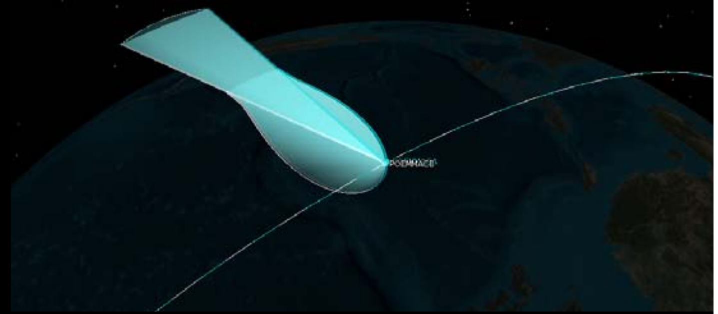


30 SiPM focal surface units
Total 15,360 pixels
512 pixels per FSU (64x4x2)

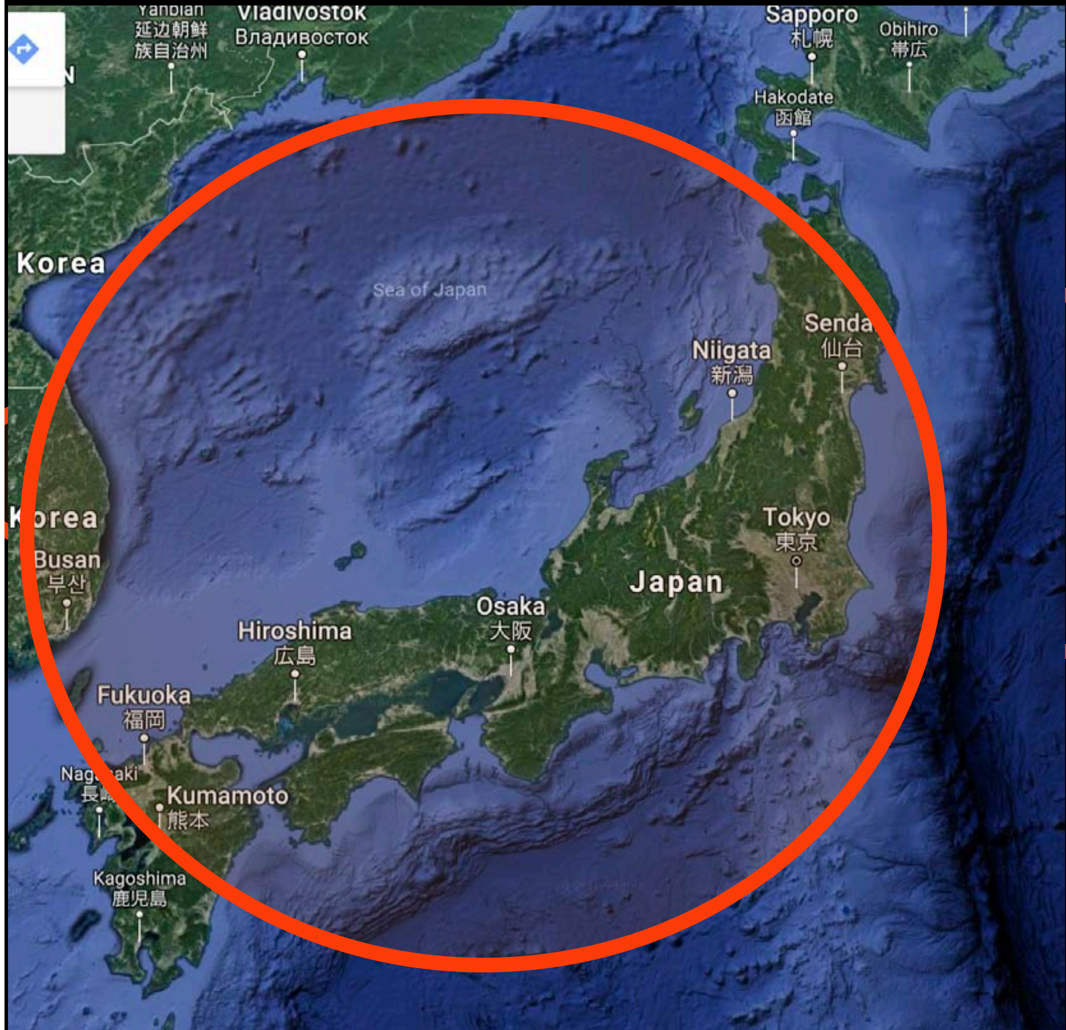
55 Photo Detector Modules (PDMs)= 126,720 pixels
1 PDM = 36 MAPMTs = 2,304 pixels



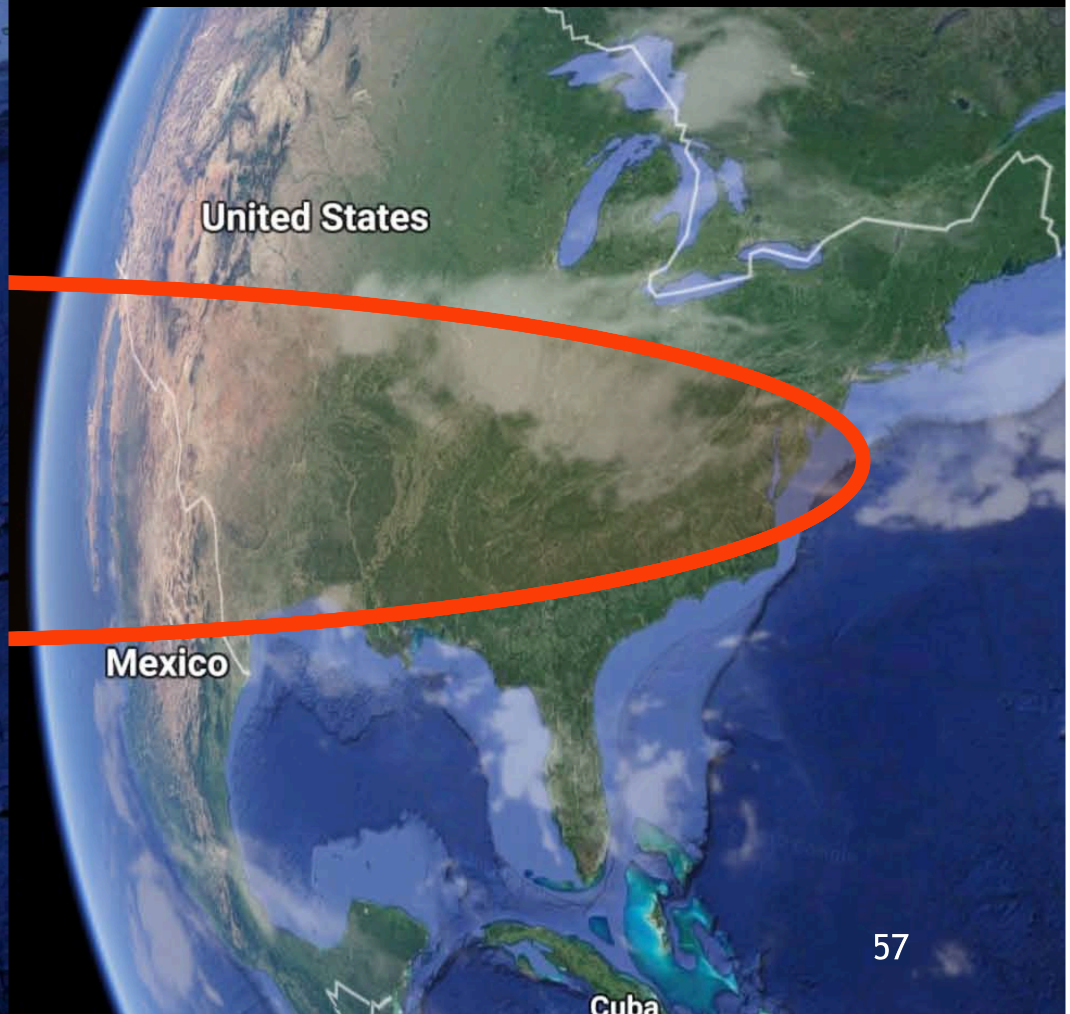
POEMMA



Nadir for UHECR:
Radius 200-400 km

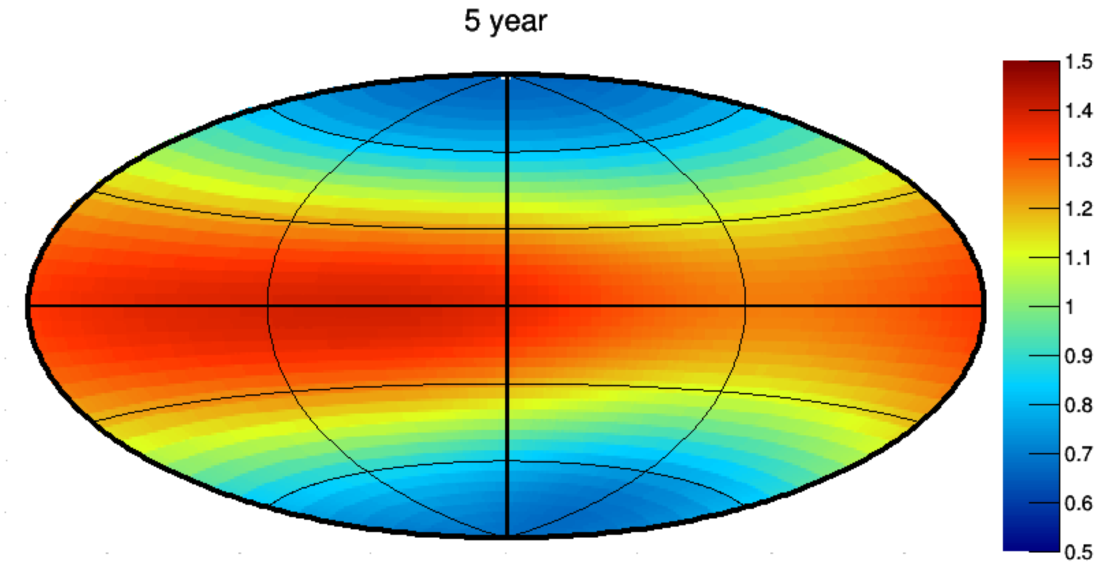


Limb for Neutrinos:
Radius 2.6-3.7 10^3 km



Sky Coverage

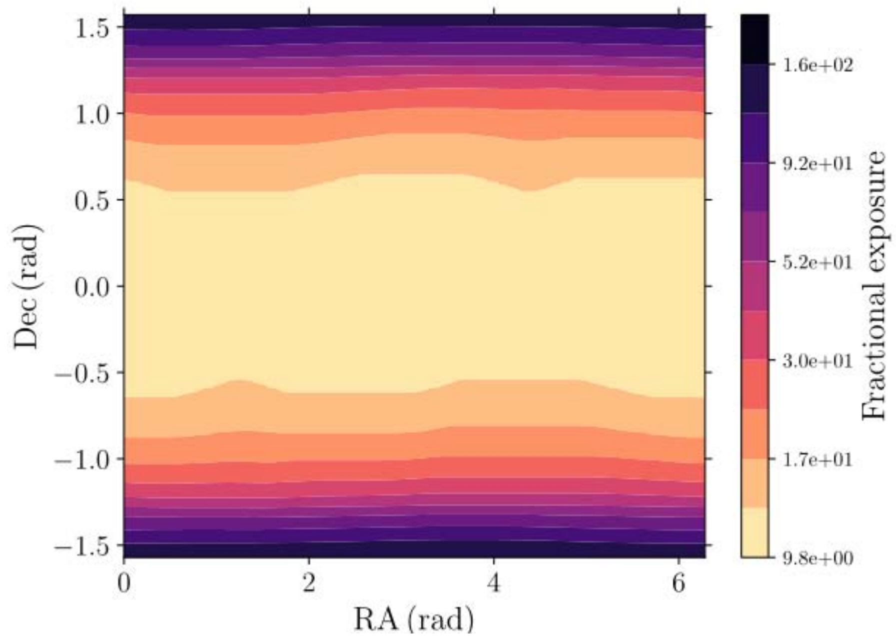
Nadir mode (UHECR)



Calcs & plots by K. Shinozaki

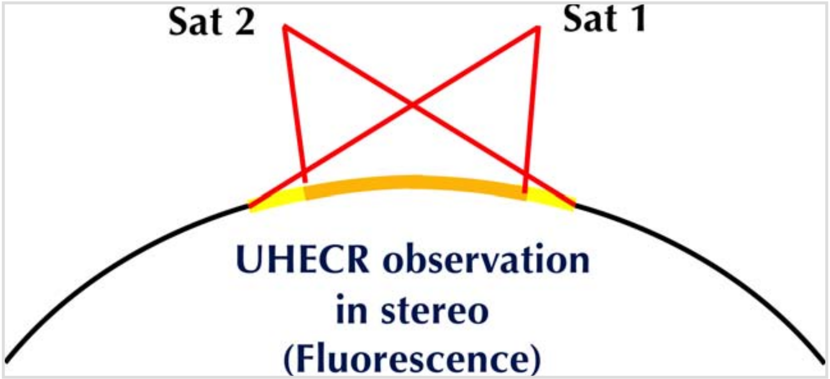
Limb-viewing mode (neutrino+UHECR)

One year with re-orientations



Calcs & plots by C. Guépin & F. Sarazin

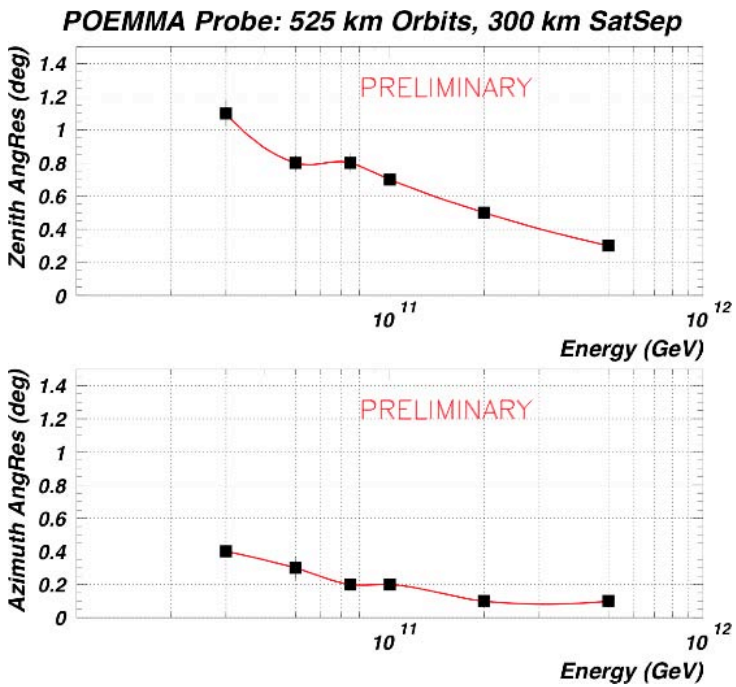
UHECR observation (Nadir)



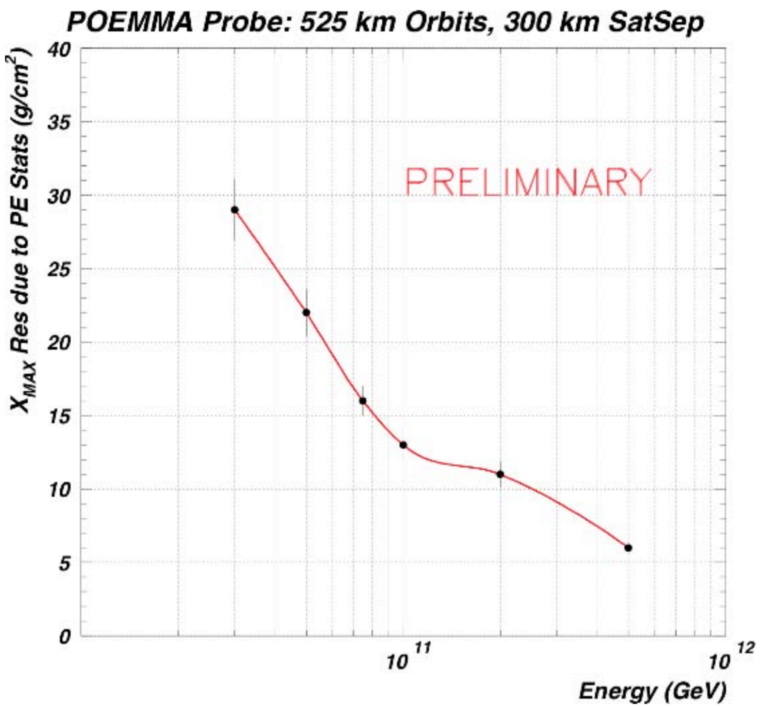
Satellite Separation ~300 km

Energy resolution: ～20%
JEM-EUSO requirement < 30%

Angular resolution



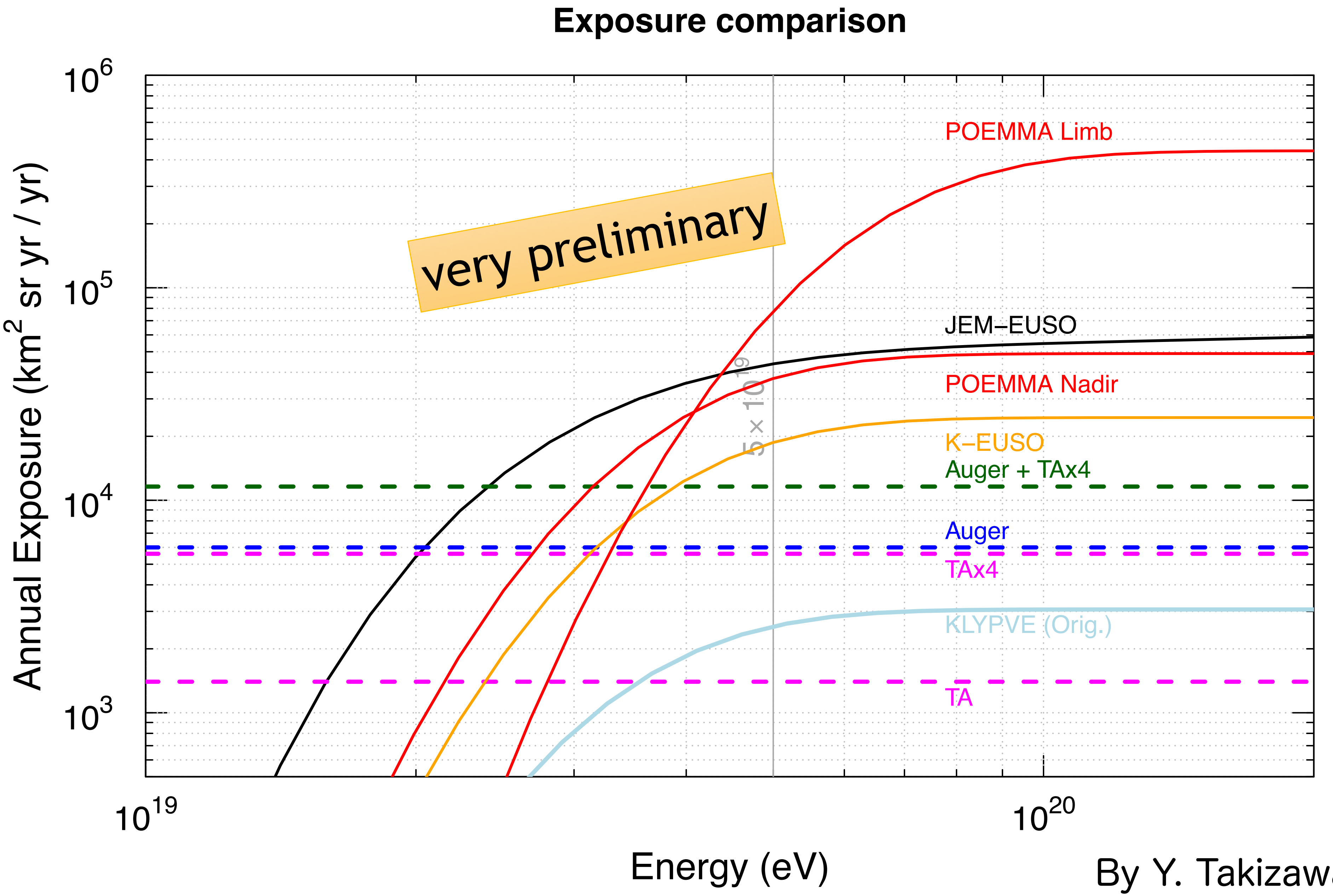
Xmax determination error



JEM-EUSO requirement : < 2.5°

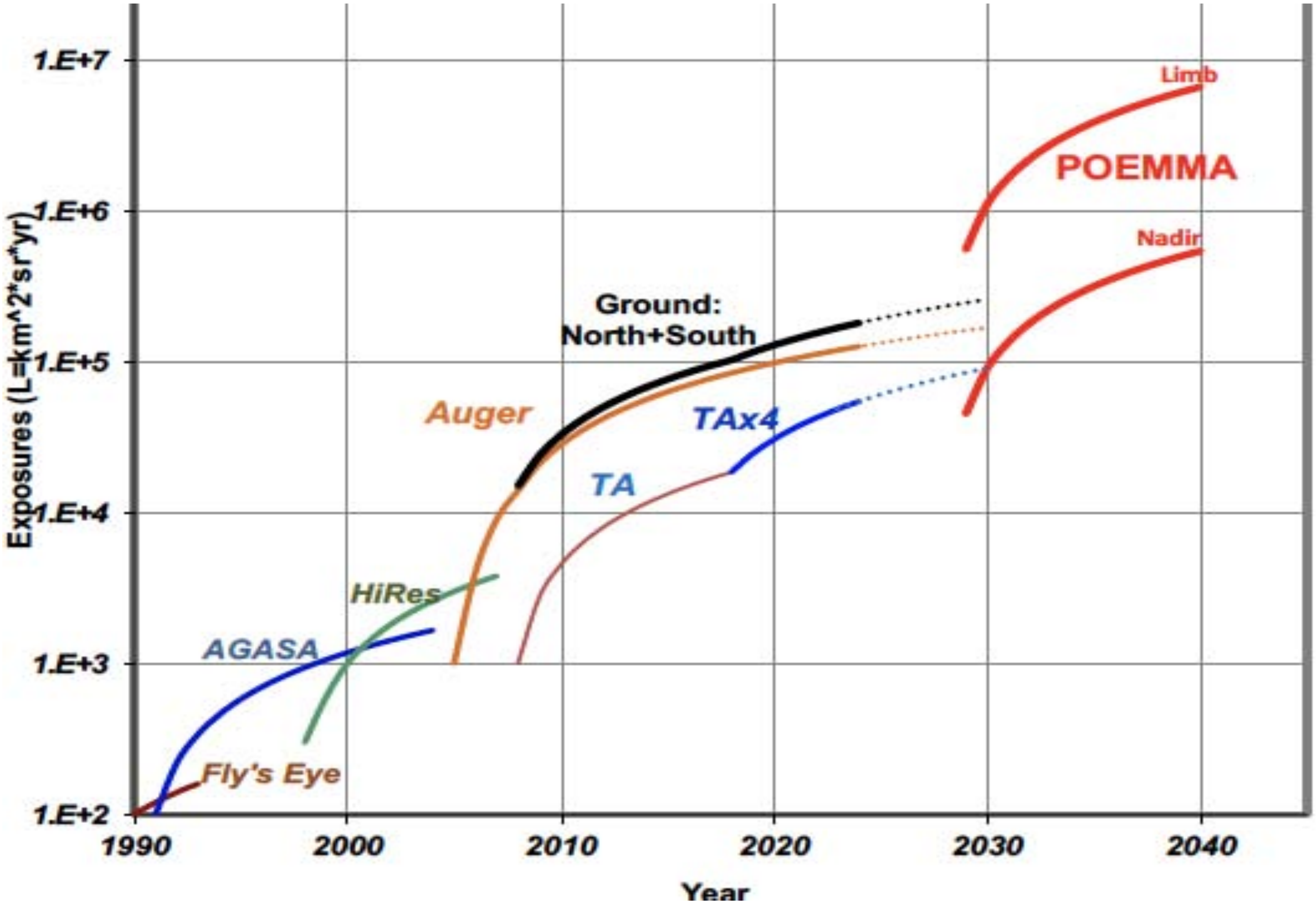
JEM-EUSO requirement : < 120 g/cm²

Anuual exposure comparison



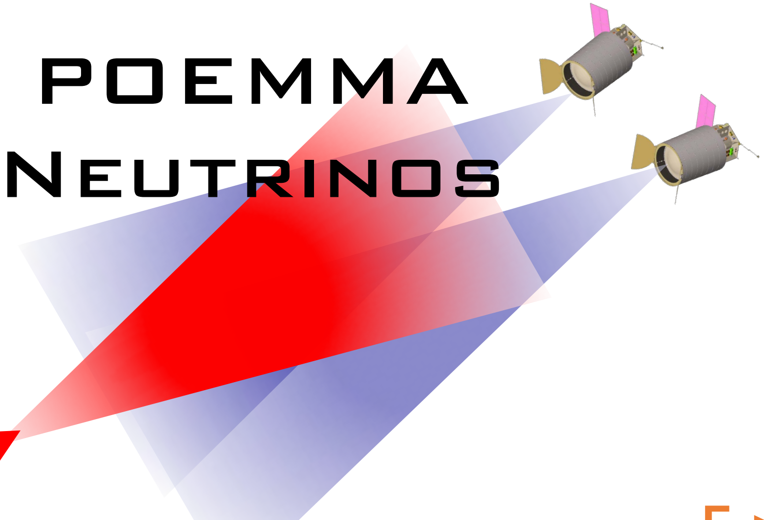
By Y. Takizawa

Integral exposure



John Krizmanic, UHECR2018

POEMMA
Neutrinos



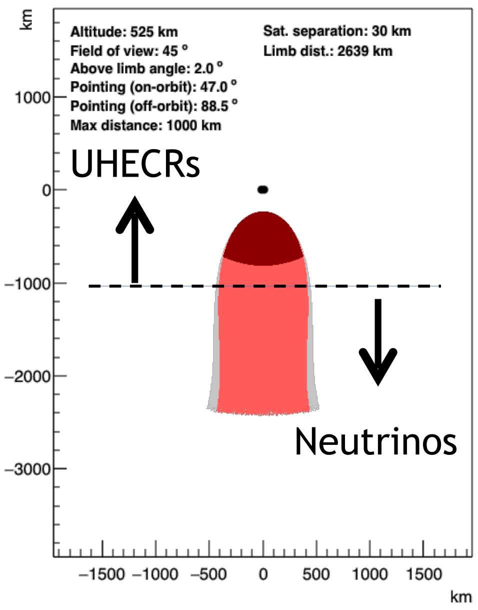
POEMMA designed to observe neutrinos with E > 10s PeV through Cherenkov signal of tau decays.

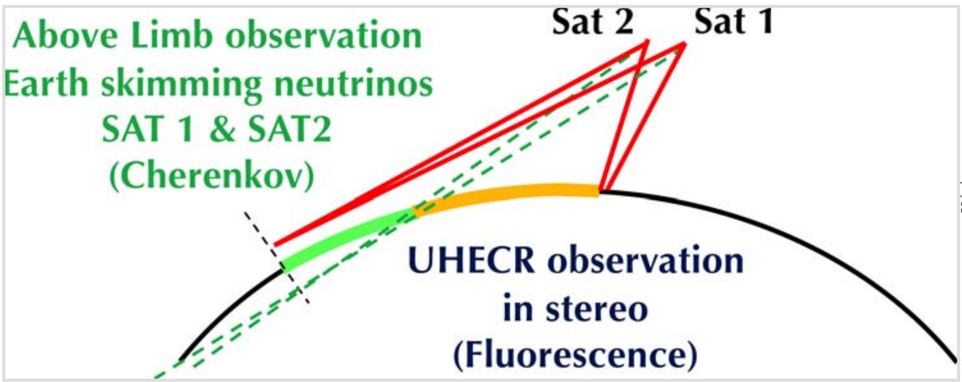
3 flavors of Astrophysical and Cosmogenic neutrinos reach Earth.

Tau neutrinos generate tau leptons on their way out of the Earth's surface which decay producing up-going showers, which POEMMA can detect.

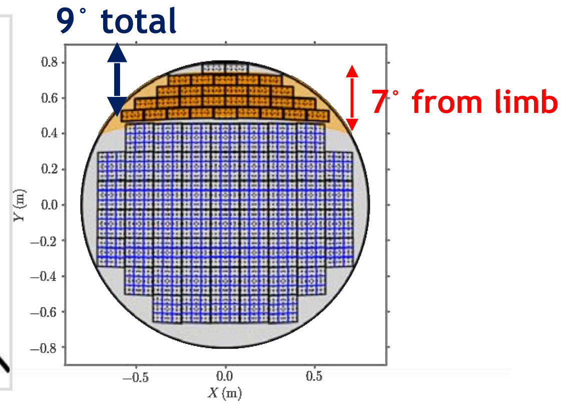
Up-going τ neutrino observation

Limb-viewing mode (UHECR + neutrino)

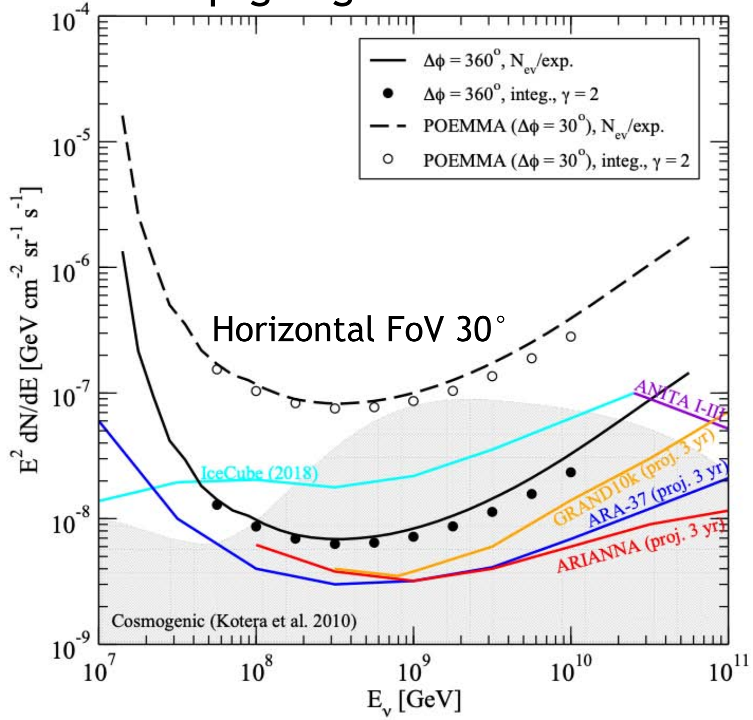




Satellite Separation ~30 km



POEMMA up-going tau neutrino sensitivity

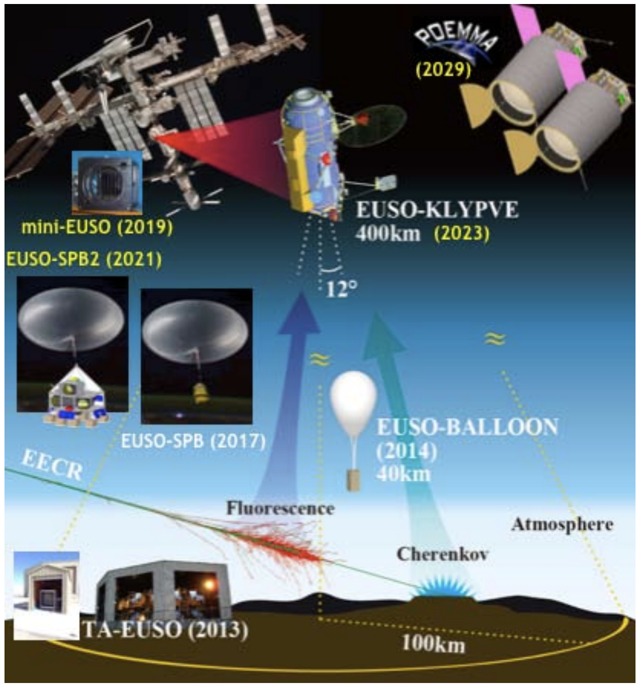


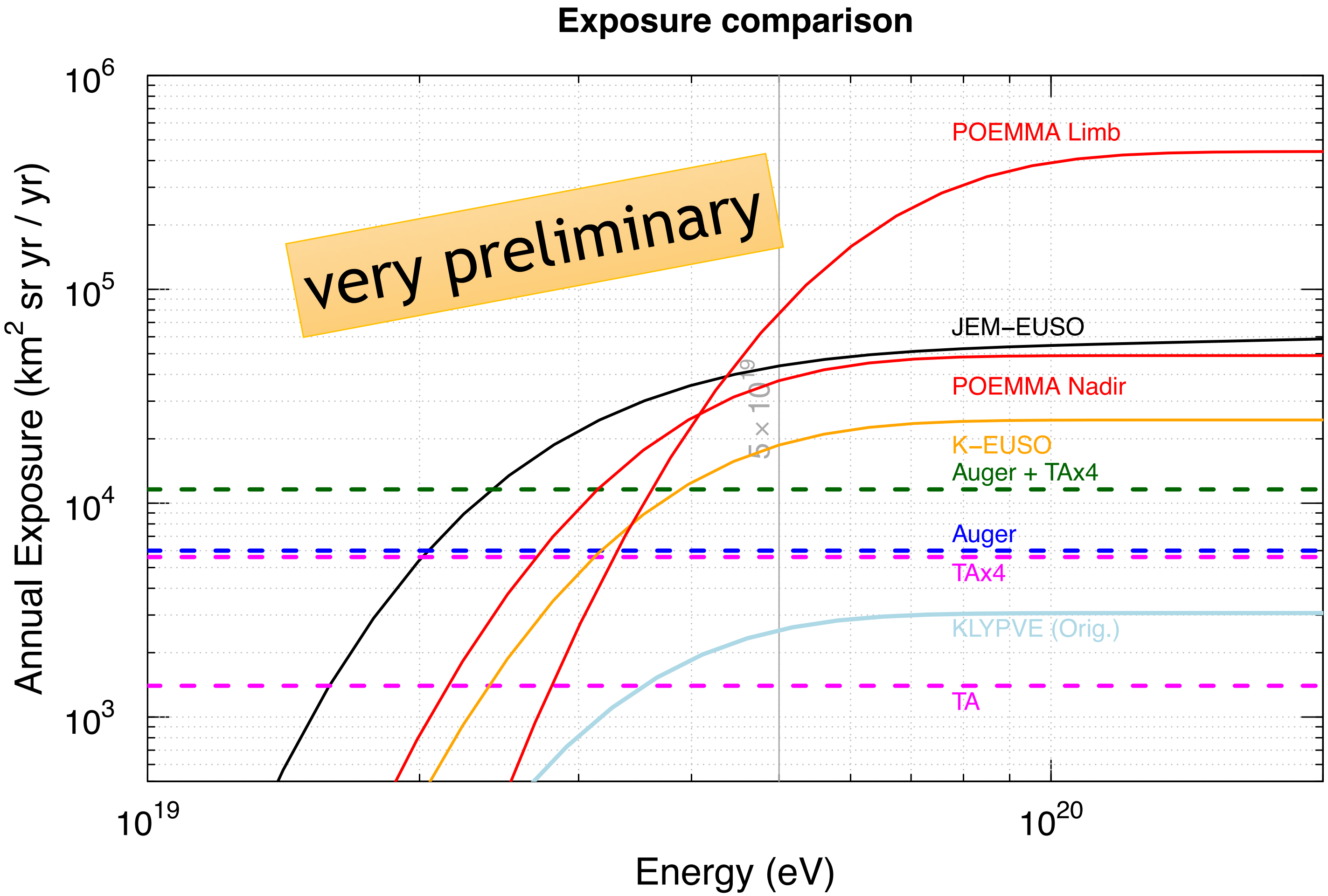
- 20% duty cycle
- 10 PE threshold with time coincidence to reduce air glow background 'false positives'
- Viewing to 7° away from Limb

We are improving the optics design to increase detection sensitivity.

Summary

We will start space missions from 2019.
mini-EUSO(2019), K-EUSO(2023), POEMMA(2029)





Thank you