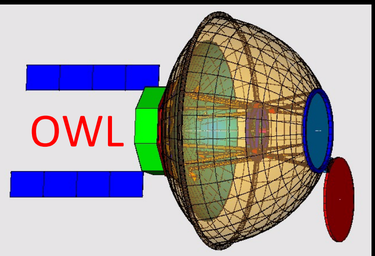
Towards Space Probes of Astrophysical and Cosmogenic Neutrinos

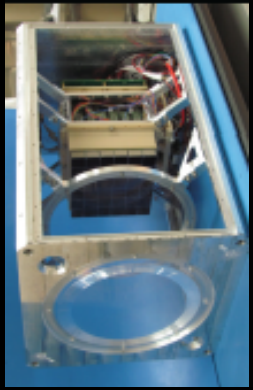


JEM-EUSO

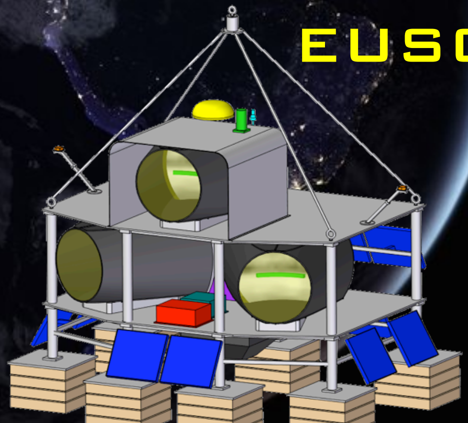
EUSO-SPB1

EUSO-Balloon

Mini-EUSO



EUSO-SPB2

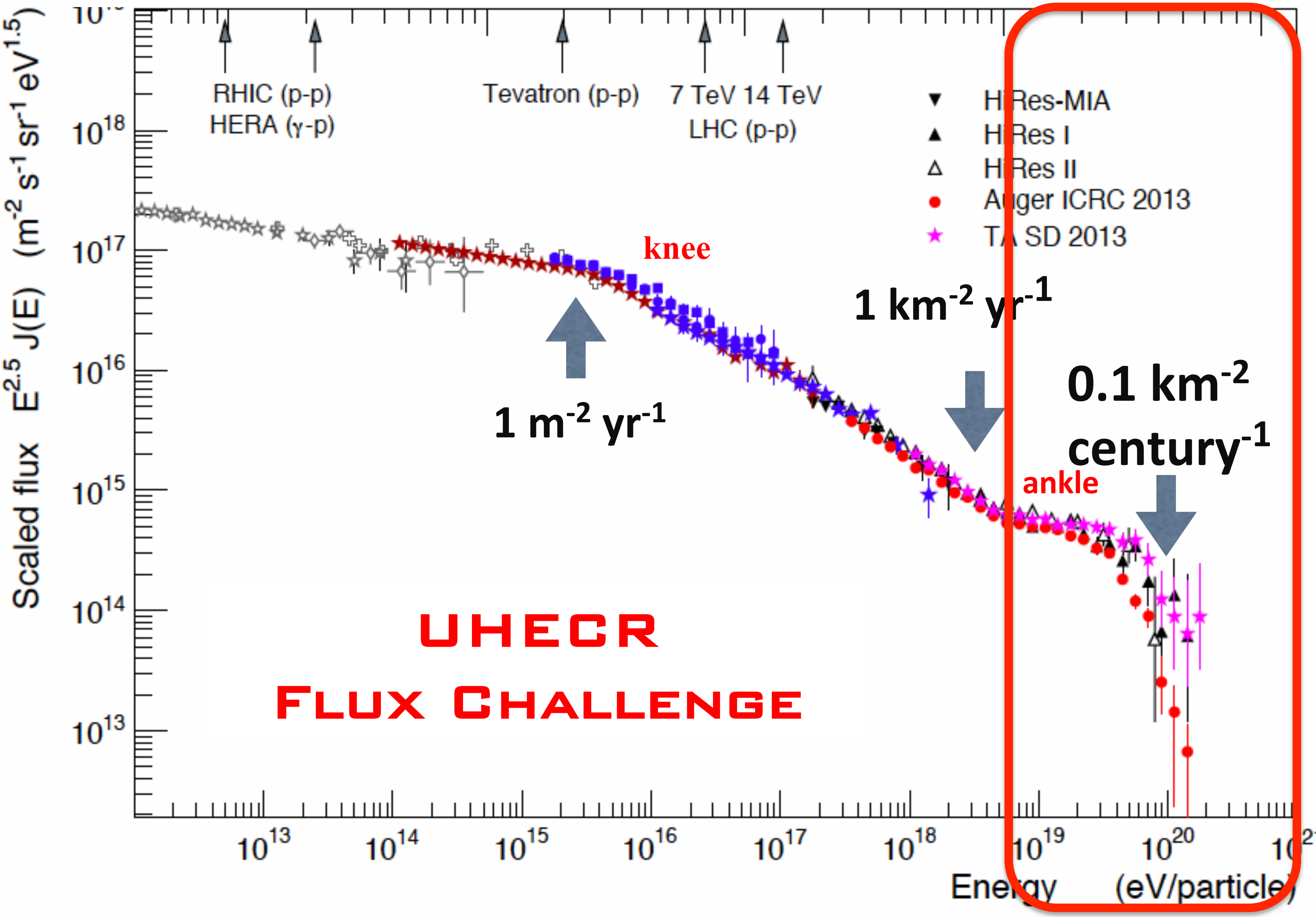


Angela V. Olinto

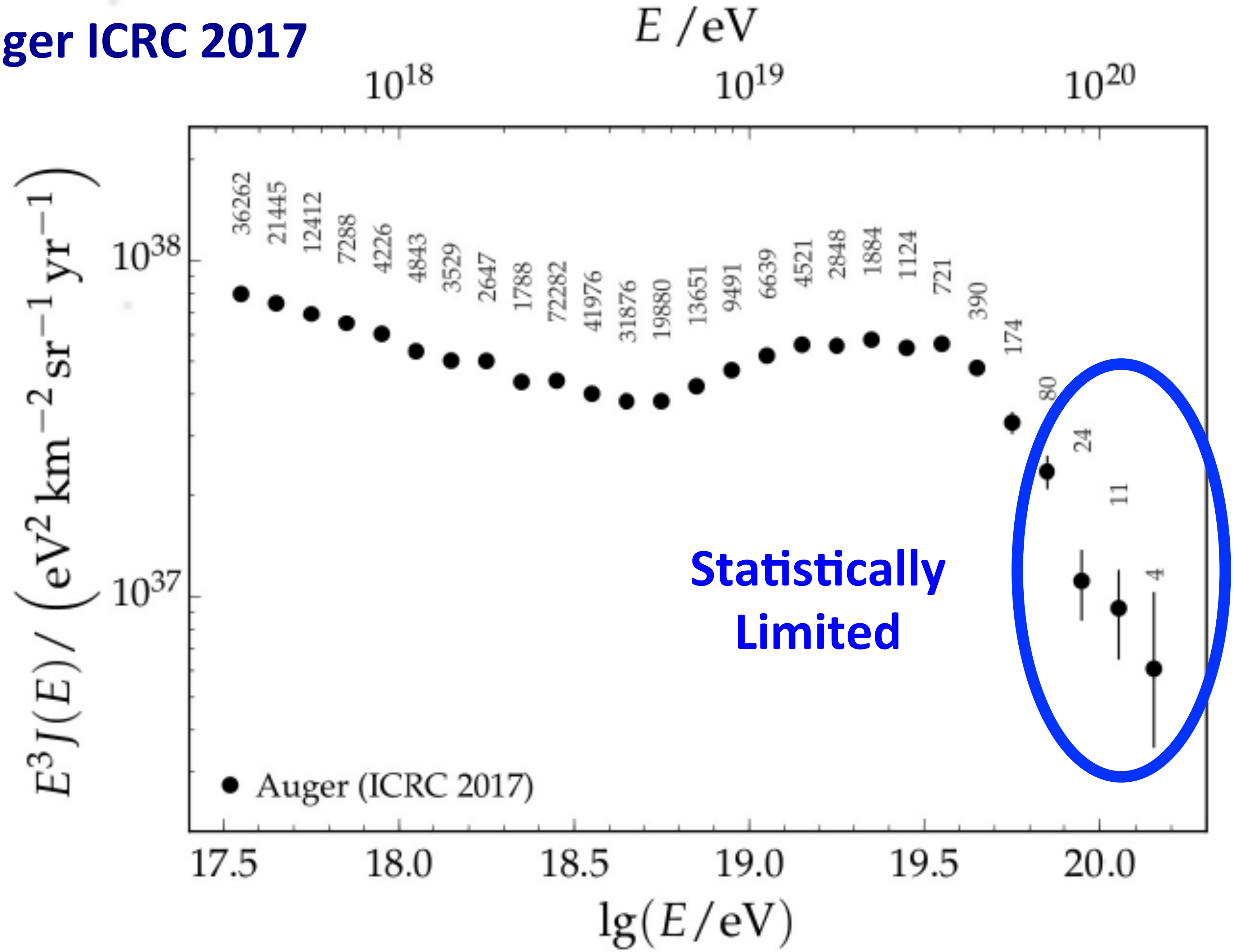
THE UNIVERSITY OF CHICAGO

Space Missions can address the Flux Challenges of UHE CR and Neutrinos by Observing large volumes of Atmosphere

Ultra-High Energy Cosmic Ray Flux

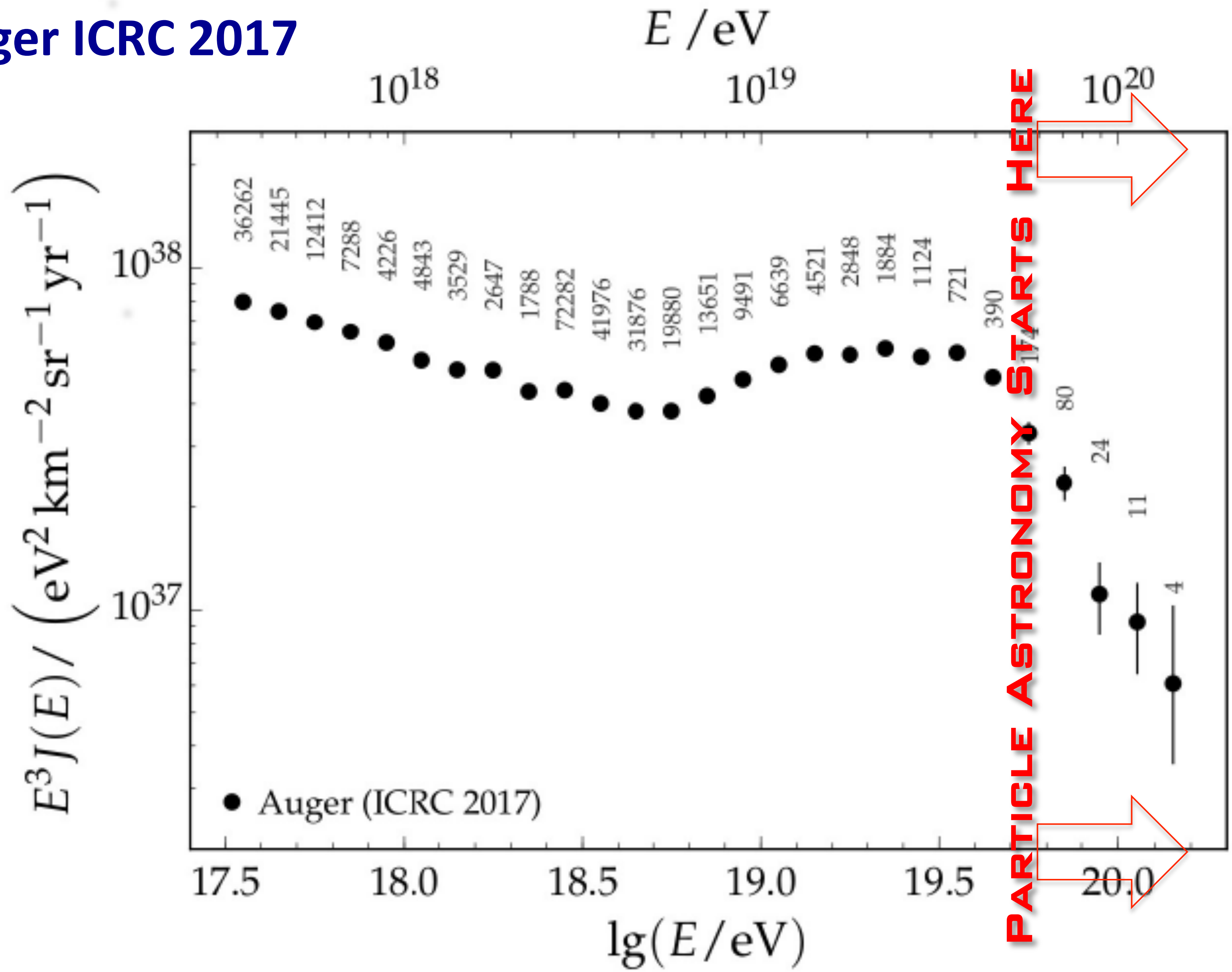


Auger ICRC 2017



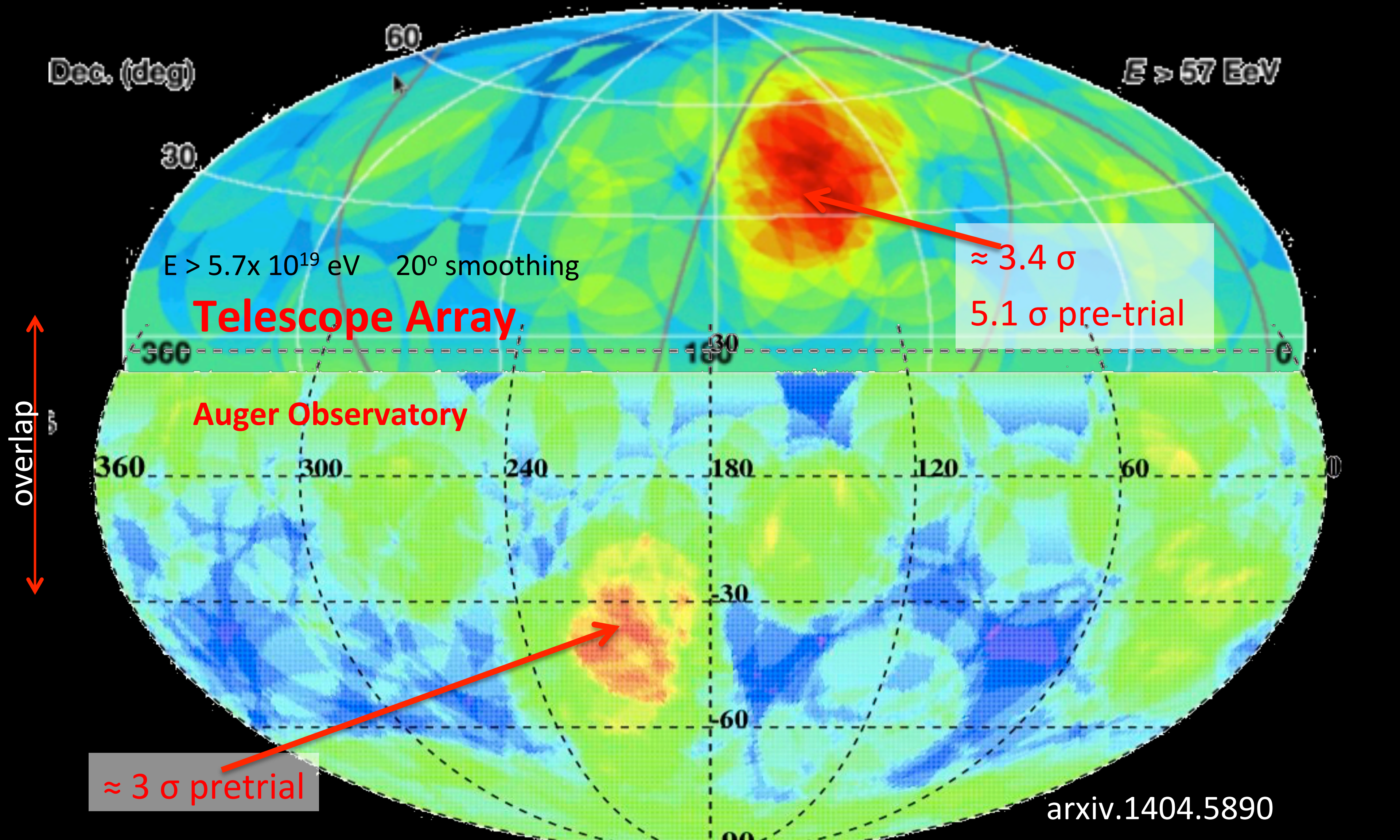
Exposure = 67000 km^2 sr yr

Auger ICRC 2017



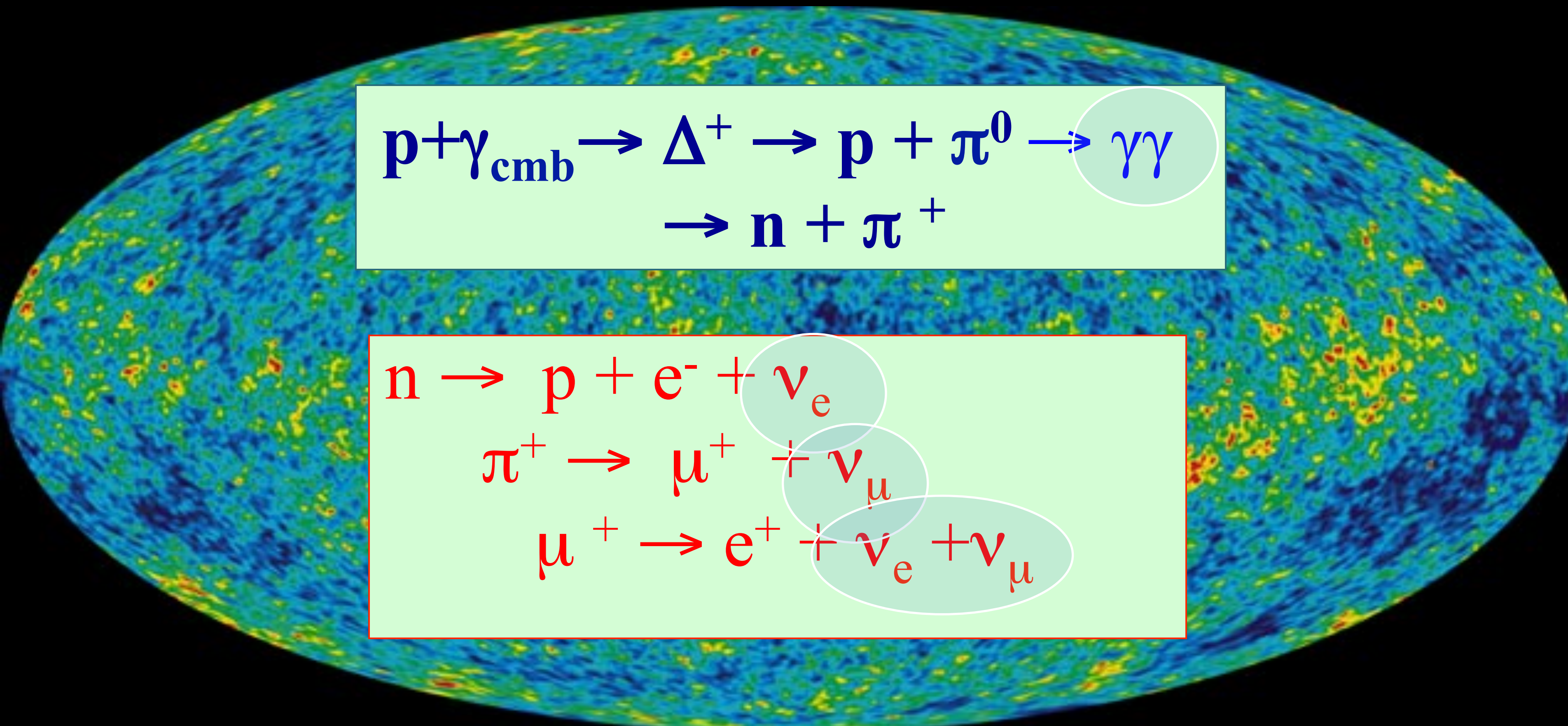
Exposure = 67000 km^2 sr yr

Anisotropy Hints > 60 EeV



arxiv.1404.5890

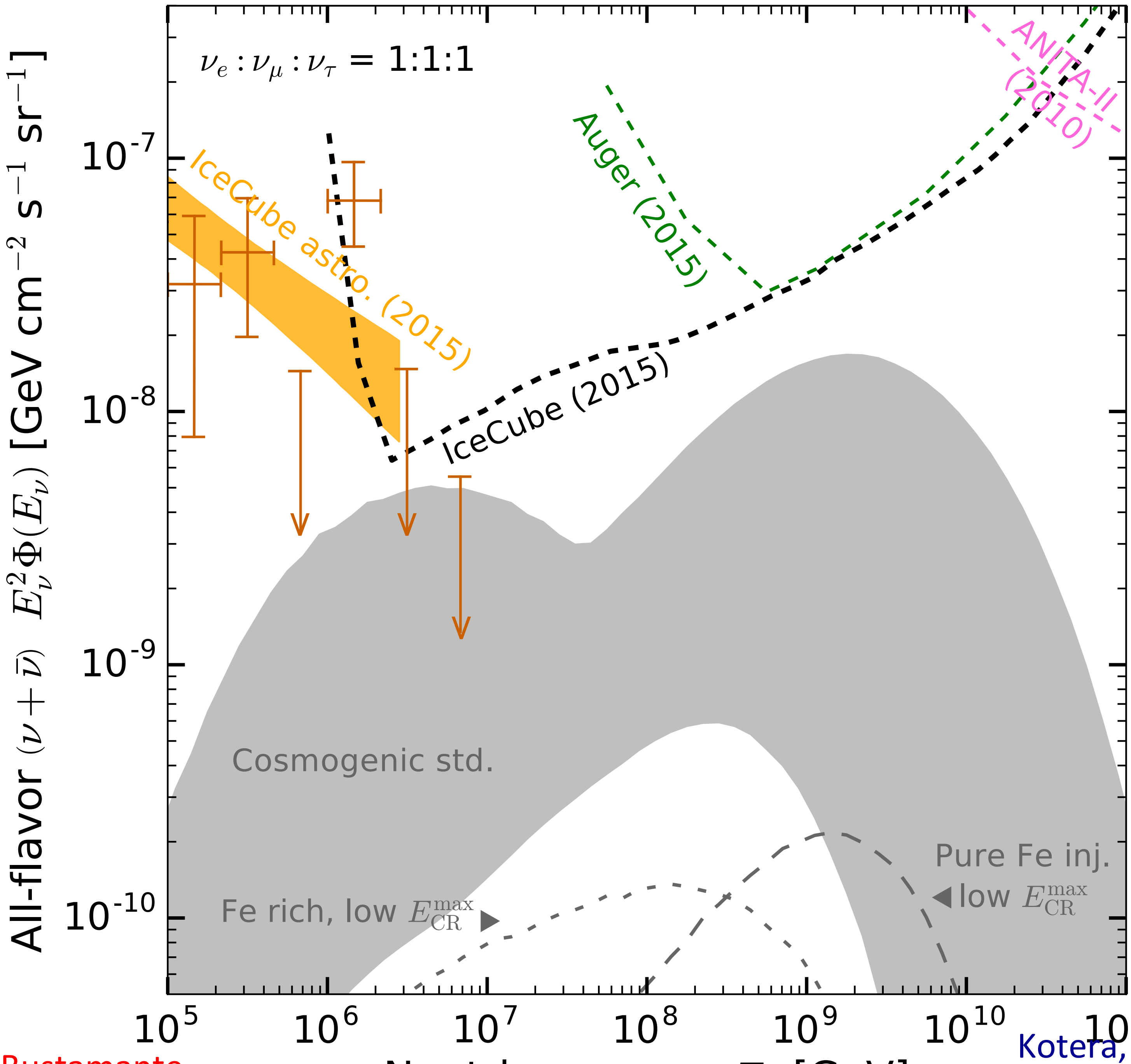
Cosmogenic (GZK, BZ*) Neutrinos & Photons



$$p+\gamma_{cmb} \rightarrow \Delta^{+} \rightarrow p + \pi^{0} \rightarrow \gamma\gamma$$
$$\rightarrow n + \pi^{+}$$

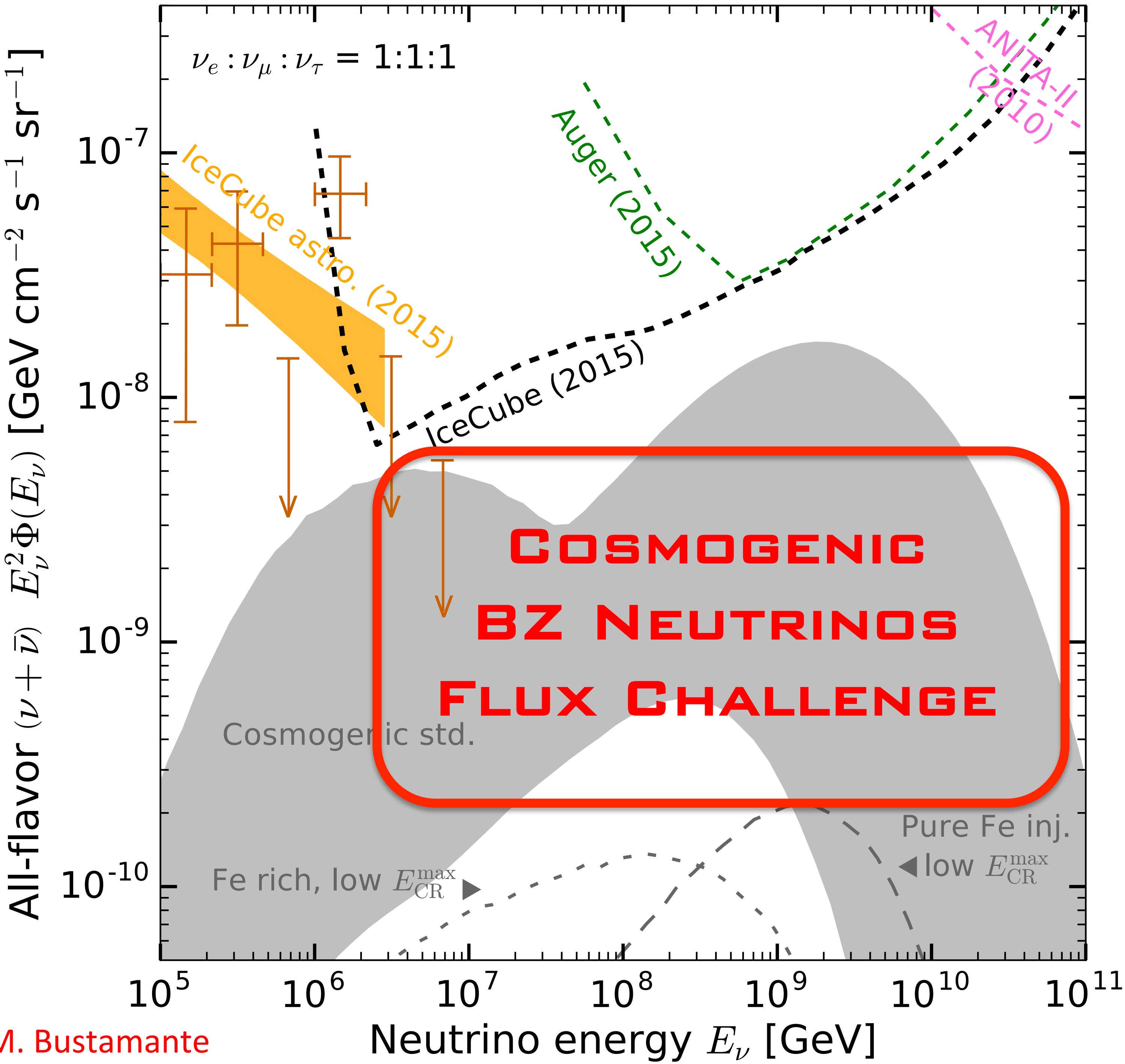
$$n \rightarrow p + e^{-} + \nu_e$$
$$\pi^{+} \rightarrow \mu^{+} + \nu_\mu$$
$$\mu^{+} \rightarrow e^{+} + \nu_e + \nu_\mu$$

*Berezinsky & Zatsepin '69

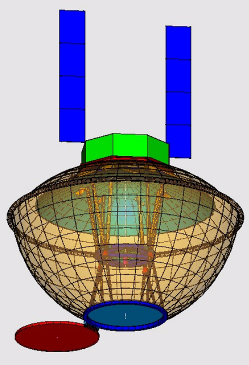


credit M. Bustamante

Kotera, AVO
arXiv: 1101.4256

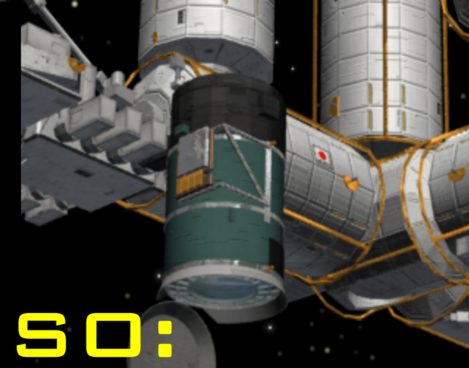


credit M. Bustamante



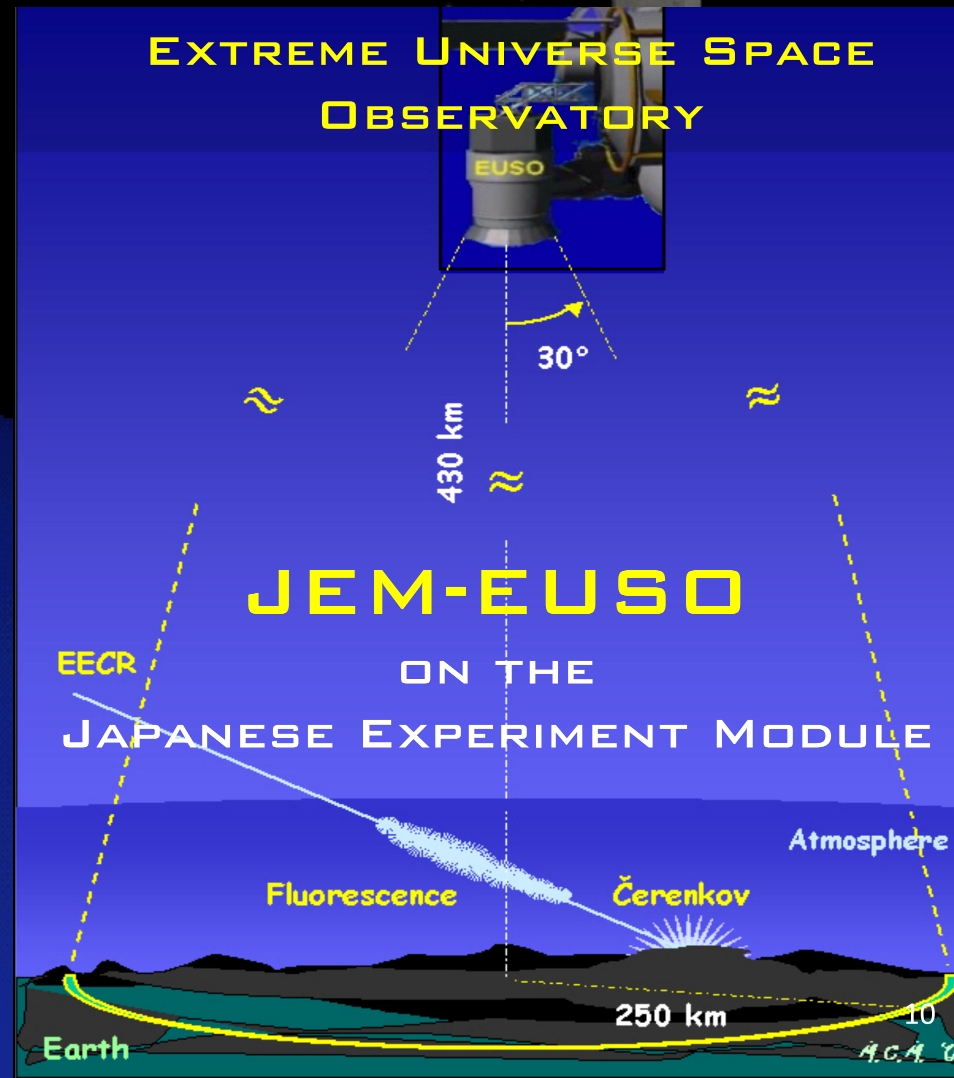
Extensive Air-shower Fluorescence from SPACE

Orbiting Wide-angle Light-collectors

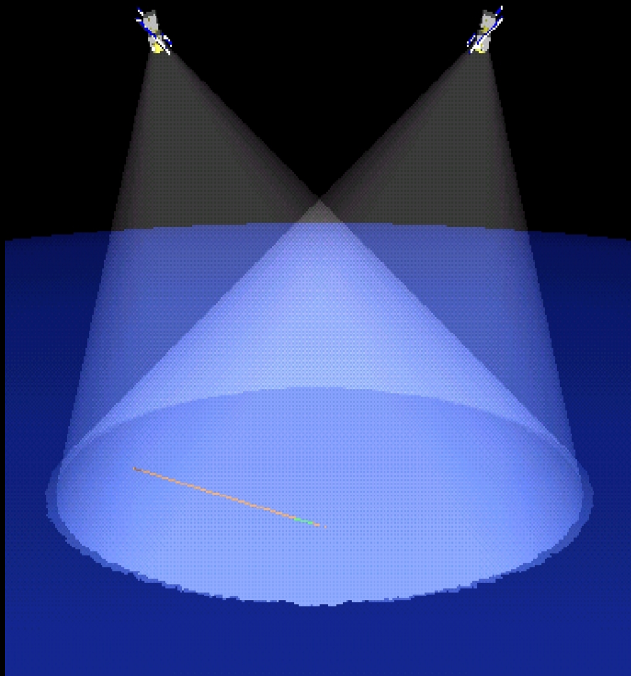


EUSO:

Extreme Universe Space Observatory

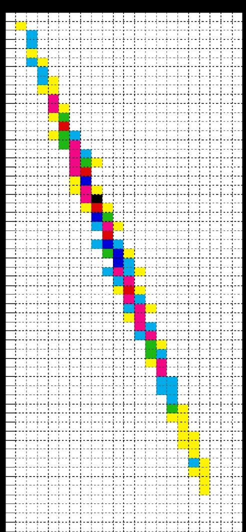


OWL Mission Concept

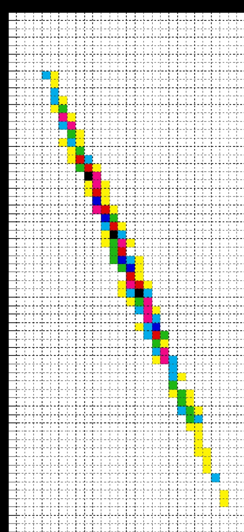


Two Satellites for stereo observations of UHECRs,
each with wide angle 45^{O} FOV
7 meter f/1 reflector Schmidt Telescopes

Low Earth Orbits equatorial (5 - 10^{O}) 1,000km to 550 km
Air Fluorescence (325 –425 nm), 100 ns readout,
Pixels ~ 0.06^{O} (~1 km^2 projected on the ground)
$E_{th} \approx 2\text{-}6 \times 10^{19}$ eV
Exposure 7×10^5 km^2-sr-yr
Upward Neutrino-induced air showers via Cherenkov signal

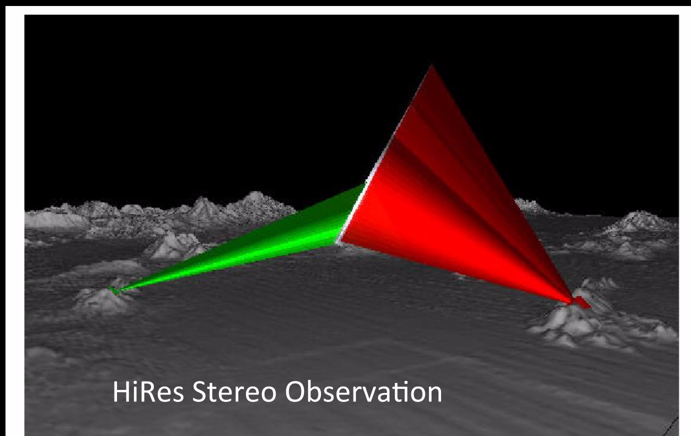


Eye 1



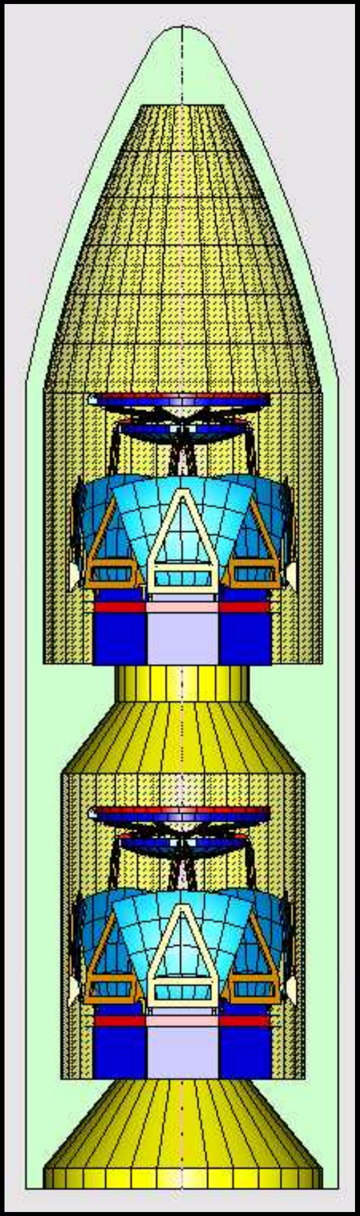
Eye 2

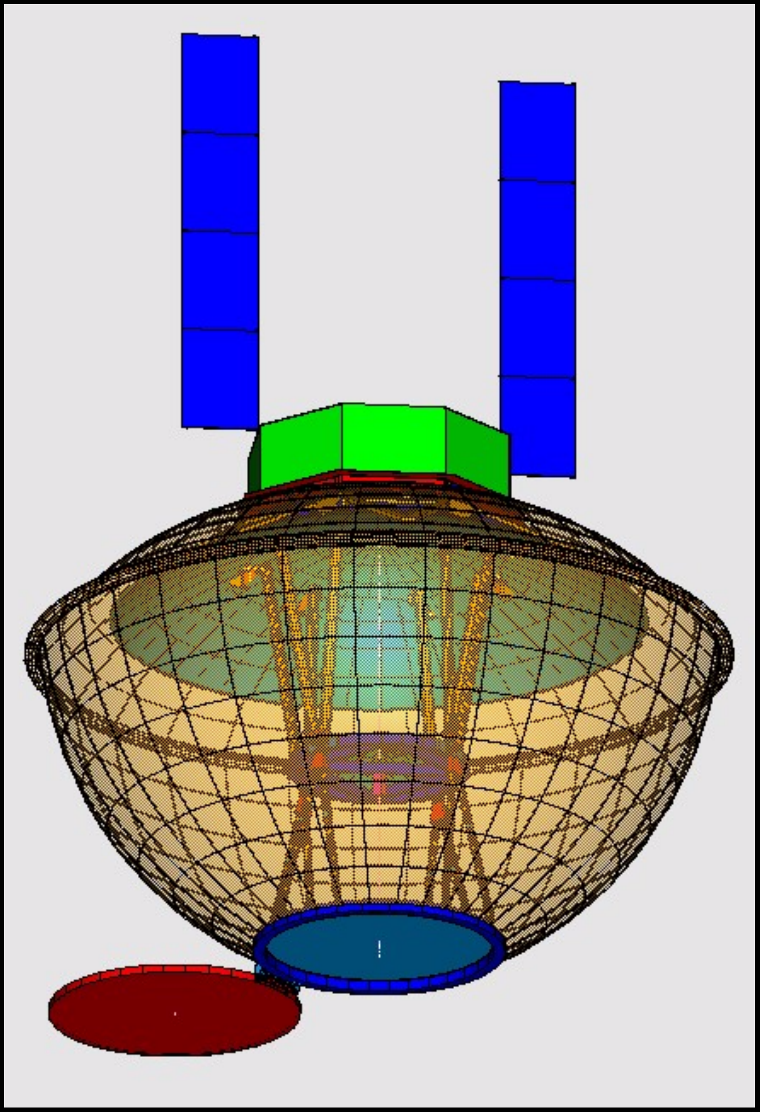
rbiting
ide-angle
ight-collectors

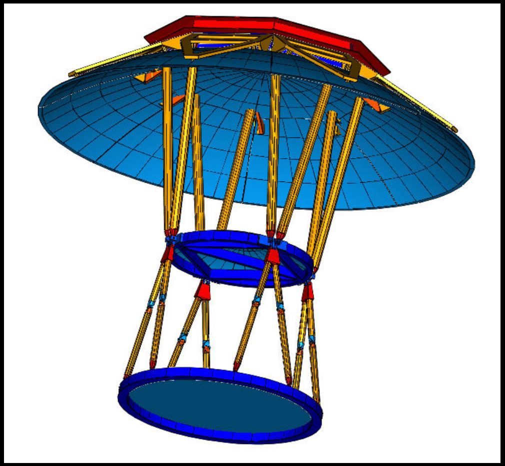


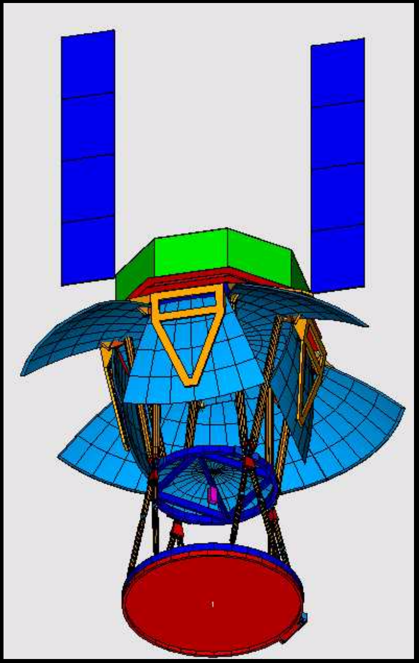
HiRes Stereo Observation

OWL Design 2002









Dual manifest on a heavy launch vehicle

Rodger Farley et al., NASA GSFC

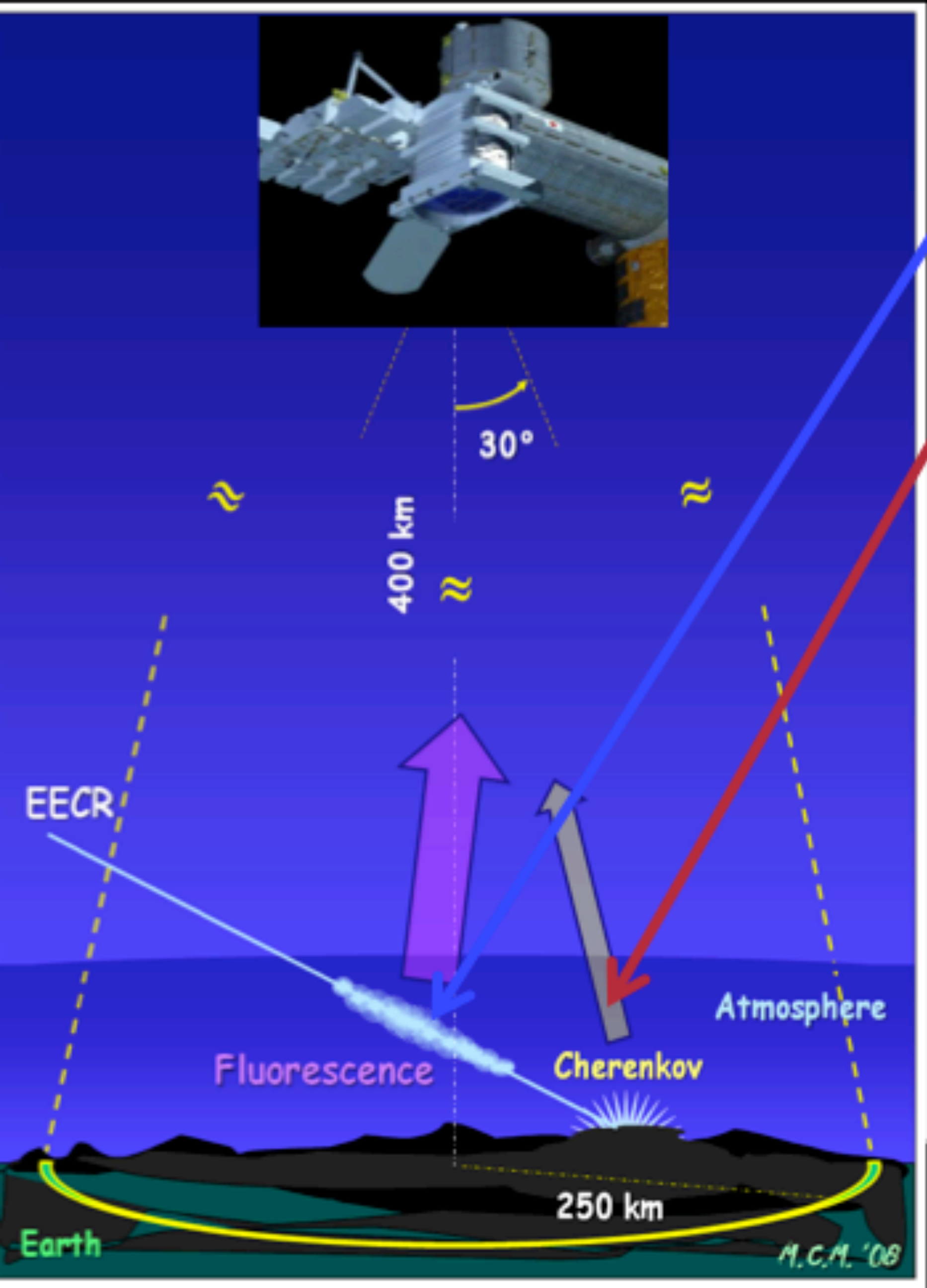
JEM-EUSO

Extreme Universe Space Observatory (EUSO)
in the Japanese Experiment Module (JEM)
of the International Space Station (ISS)

Collaboration: 16 Countries, 95 Institutes, 358 Researchers
Refractor Fresnel Lenses large FOV and large MAPMT camera with 0.3M pixels

16 Countries, 95 Institutes, 358 Researchers

Fluorescence from SPACE

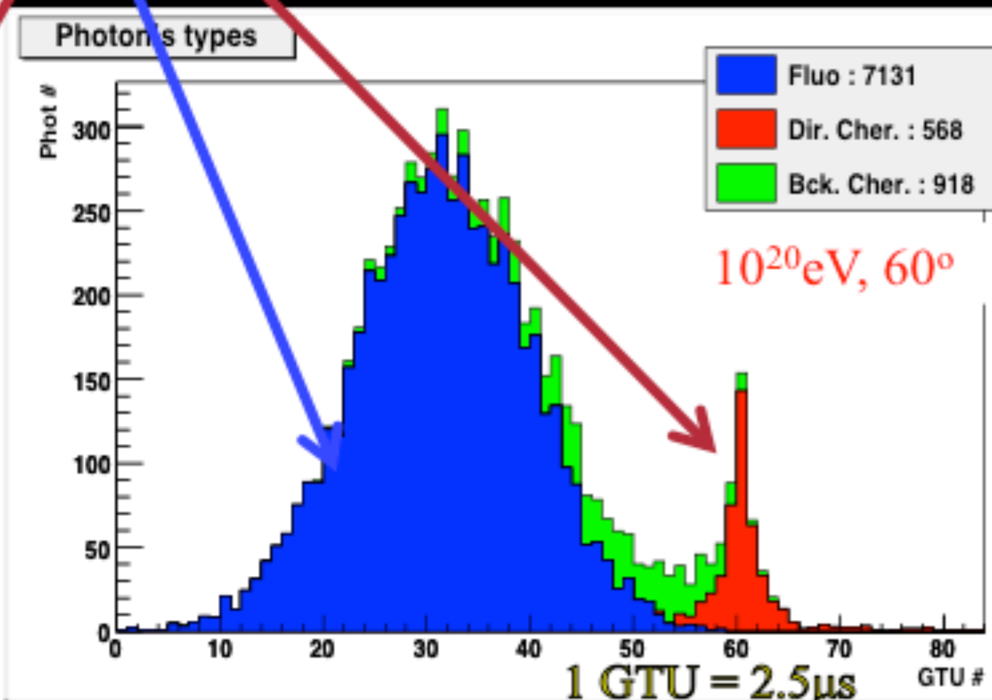


Fast Signal: 50 -150 μs

a) Fluorescence

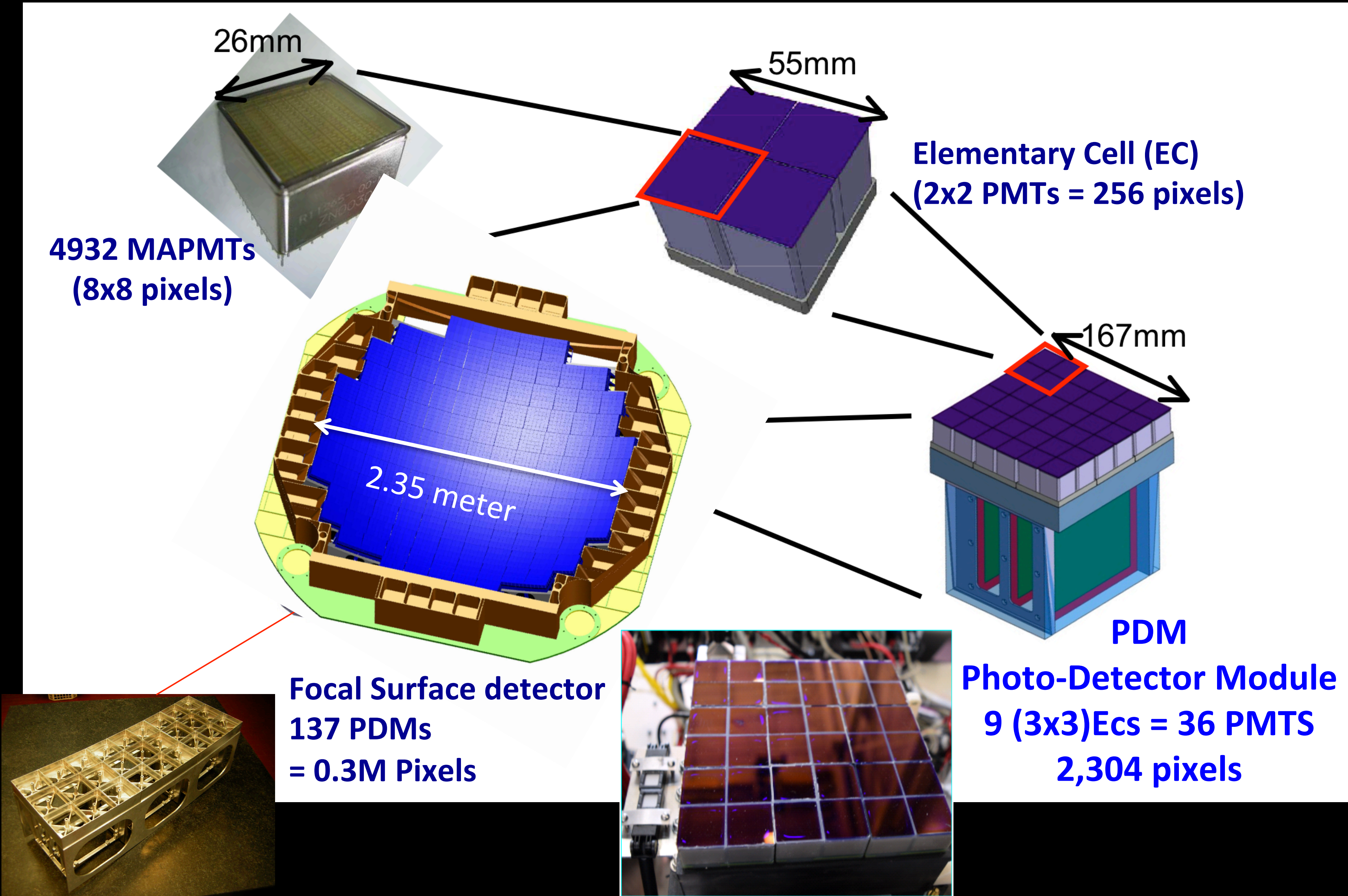
b) Scattered Cherenkov

c) Direct (reflected Cherenkov)



Background: 500 /m^2 sr ns

EUSO Focal Surface



JEM-EUSO program

EUSO-TA (2013-)

EUSO-Balloon (2014)

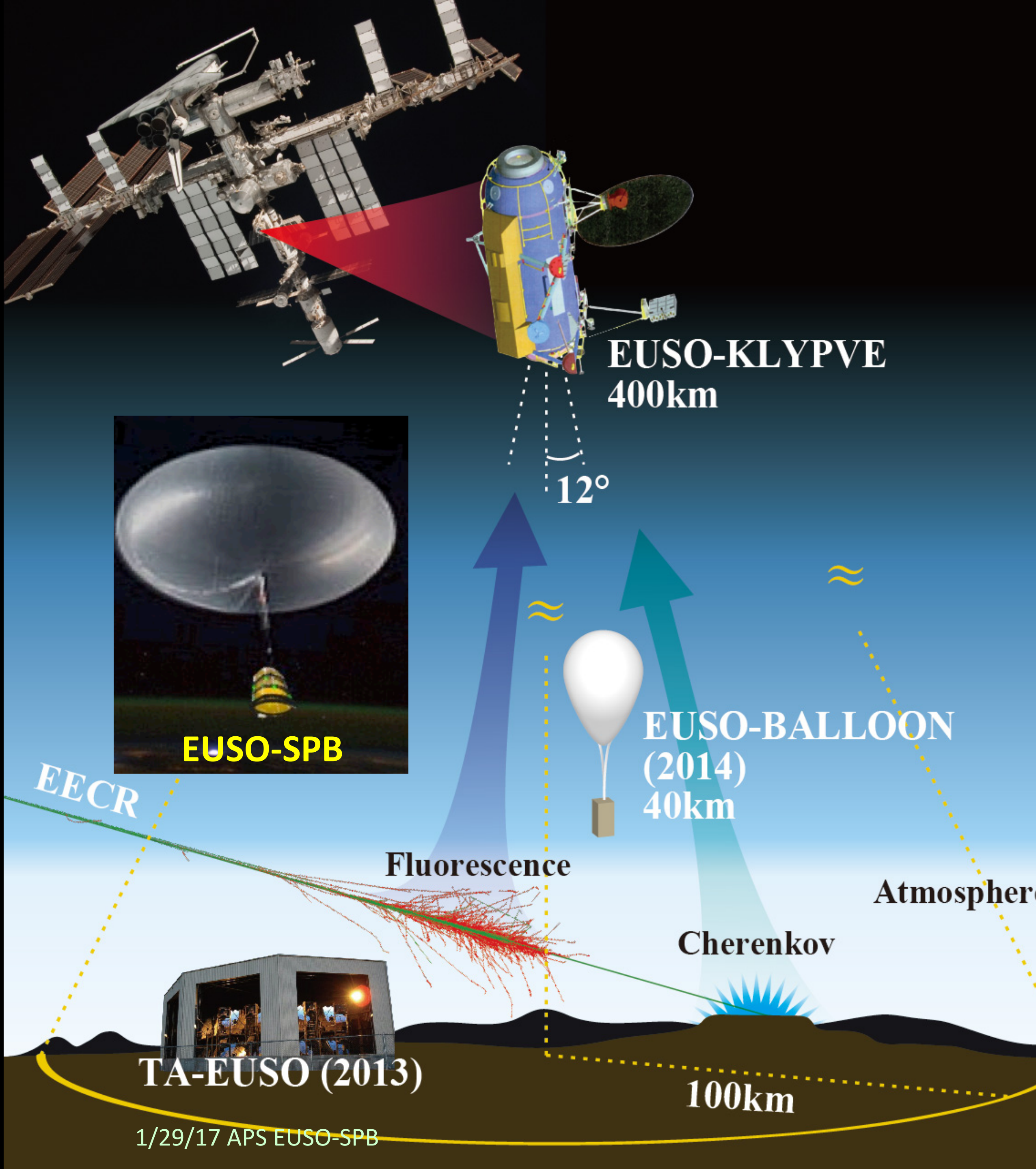
EUSO-SPB (2017)

Mini-EUSO (2018)

EUSO-SPB 2 (2020)

K-EUSO (2023)

POEMMA (2025+)



JEM-EUSO program

EUSO-TA (2013-)

EUSO-Balloon (2014)

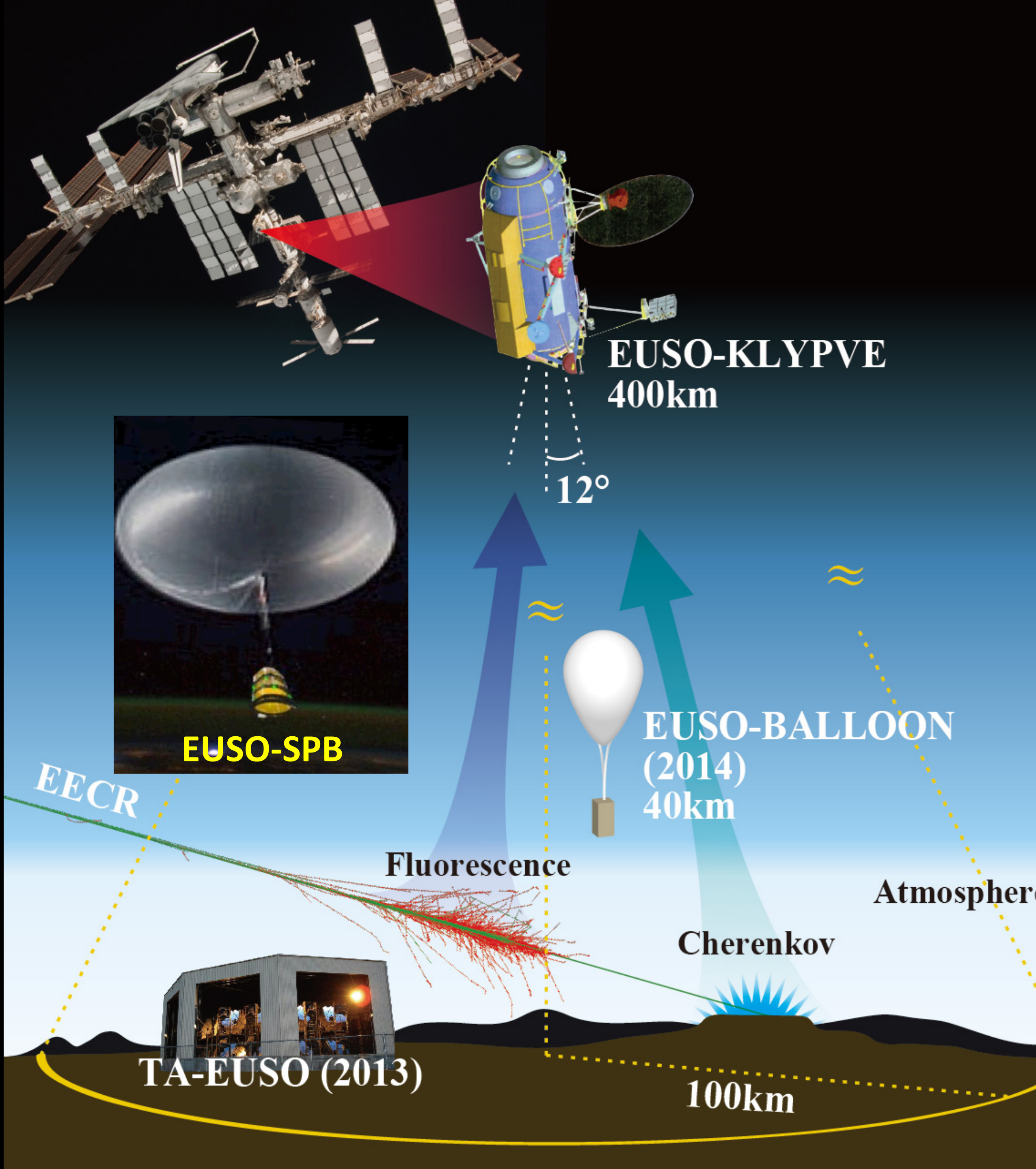
EUSO-SPB (2017)

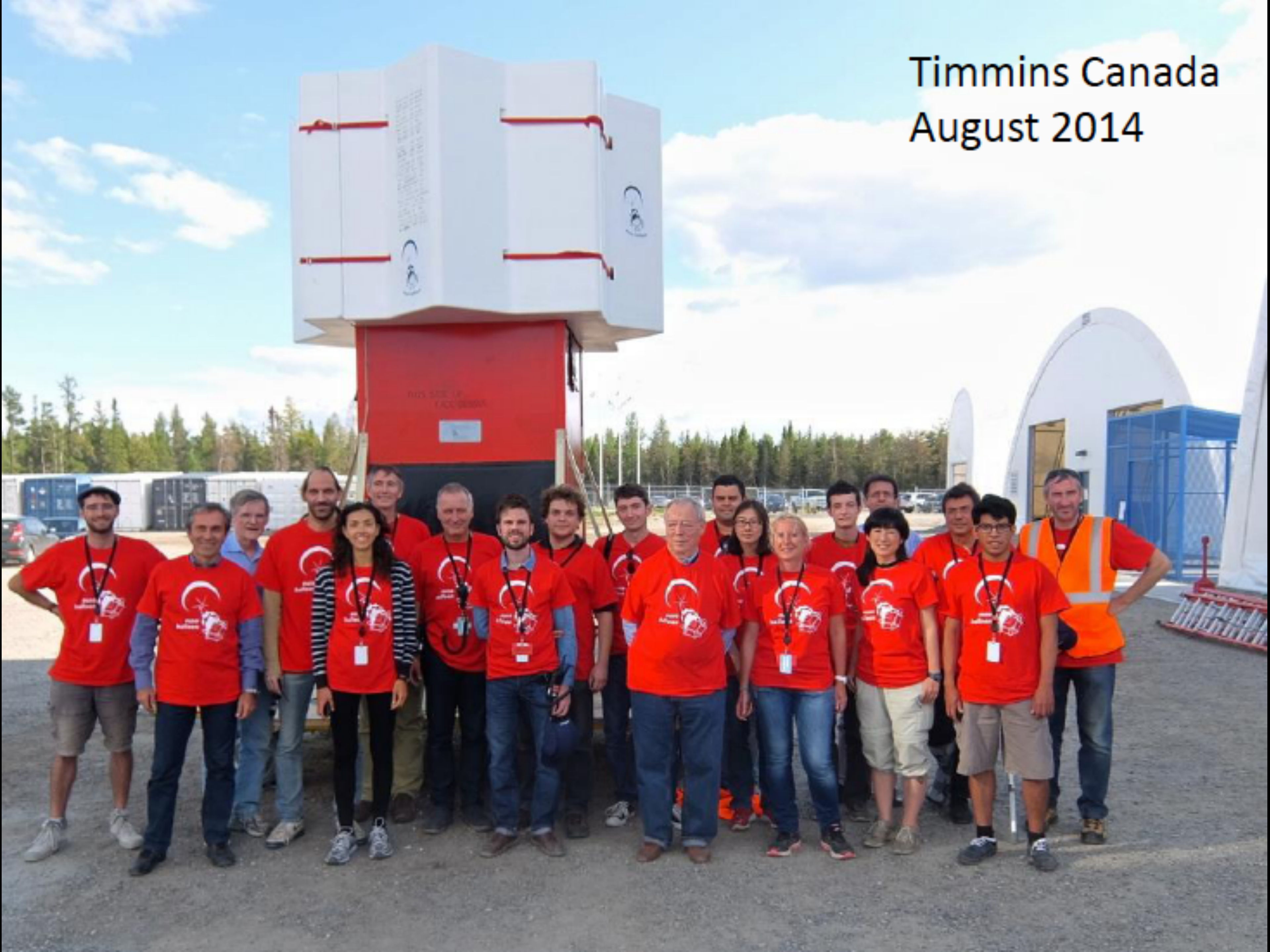
Mini-EUSO (2018)

EUSO-SPB 2 (2020)

K-EUSO (2023)

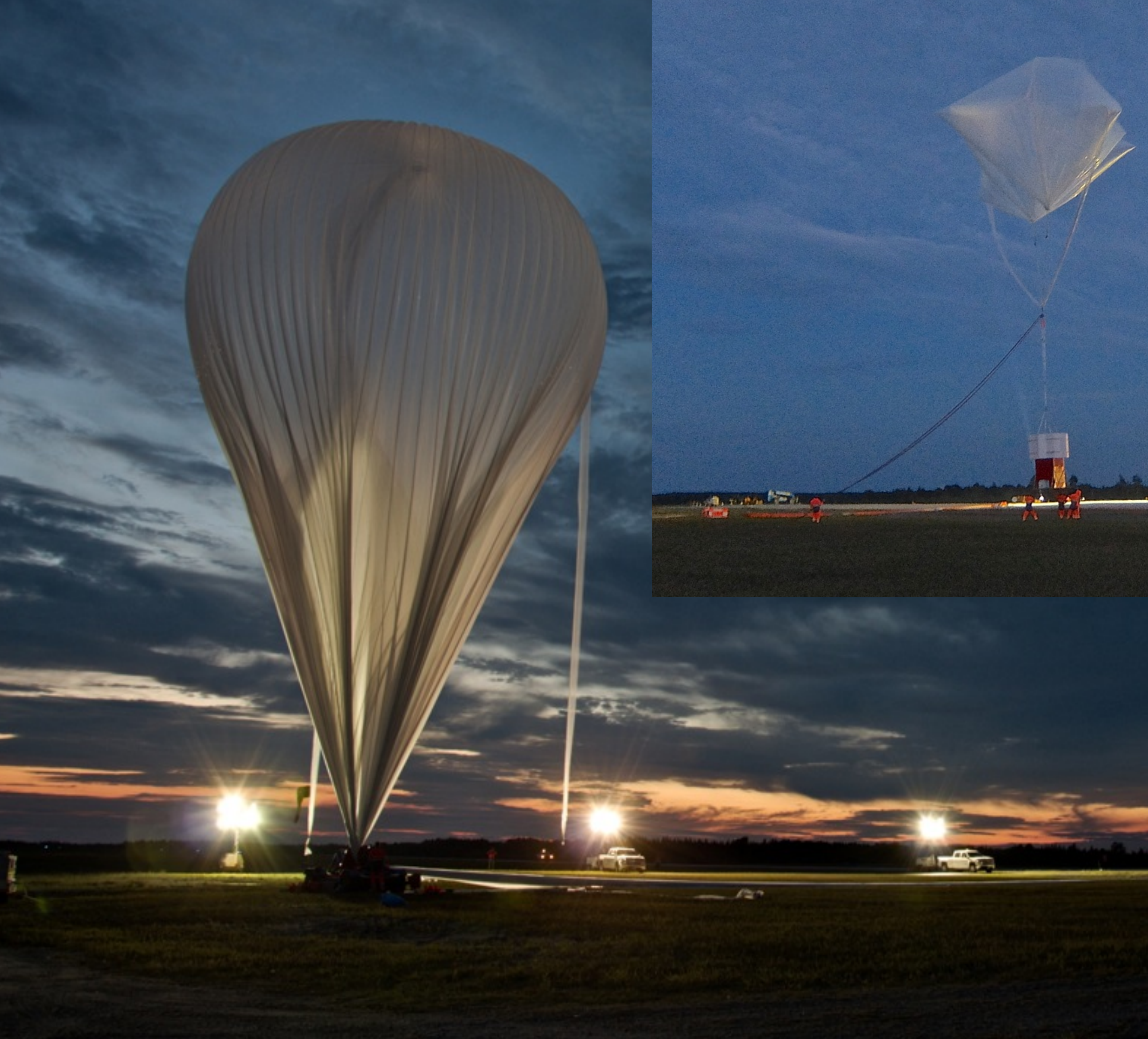
POEMMA (2025+)

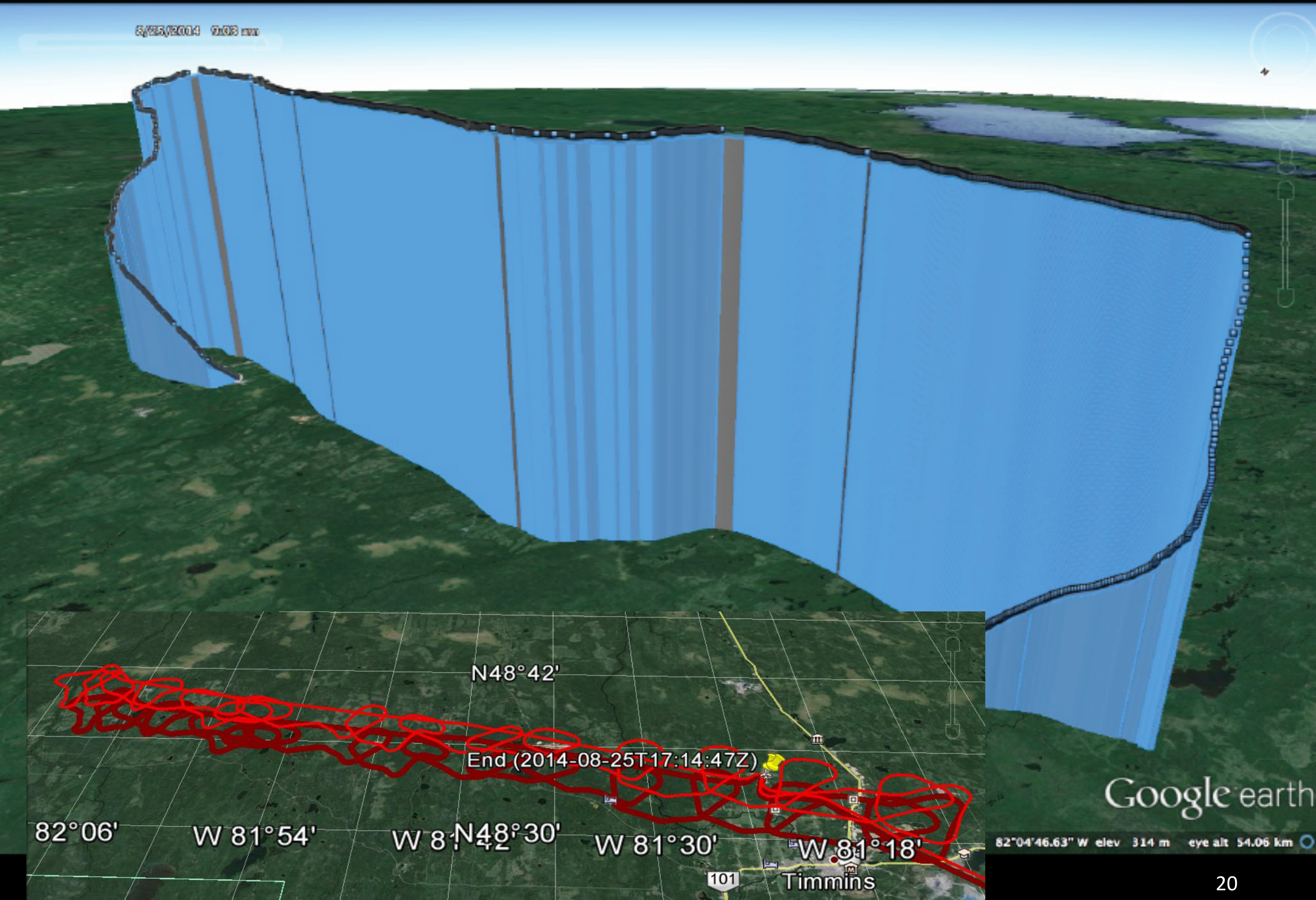


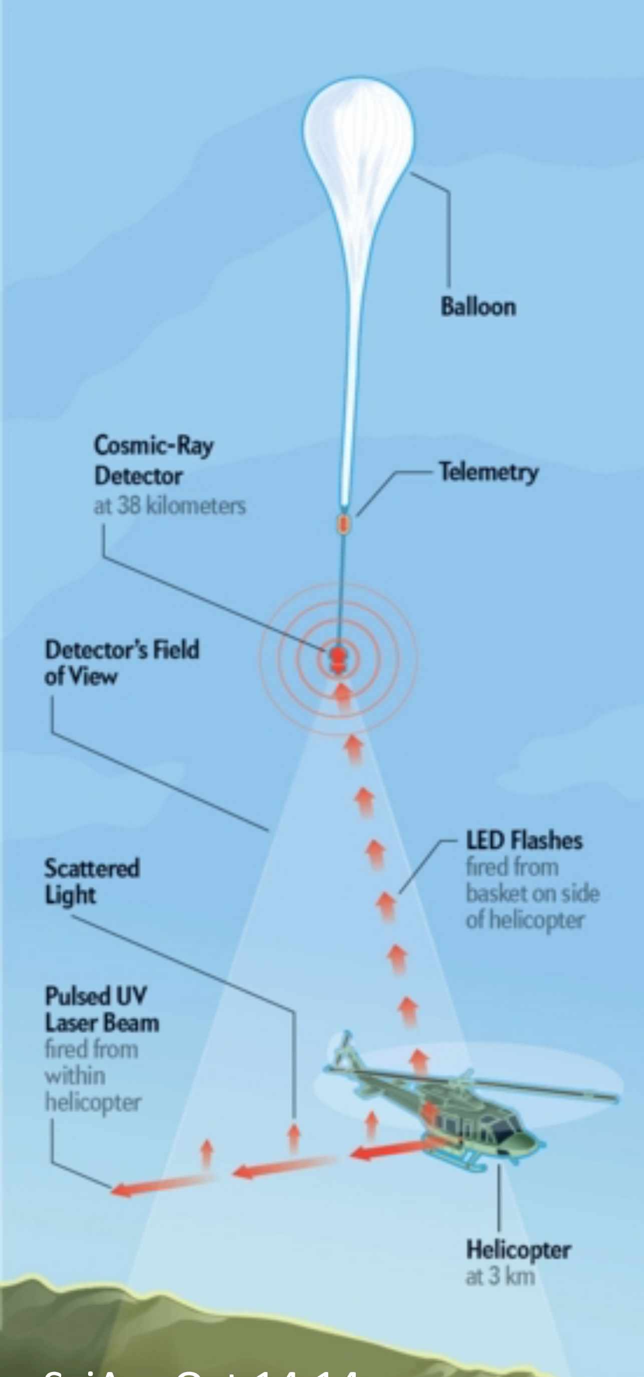

Timmins Canada
August 2014

EUSO Balloon:

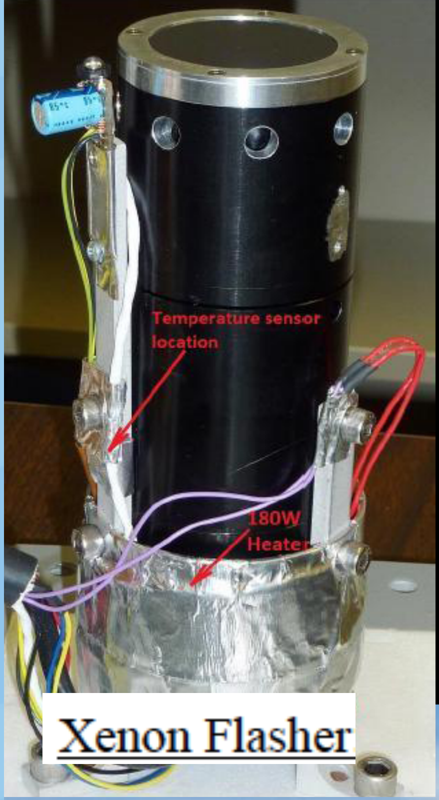
1st flight and first light on 24-25.8.2014



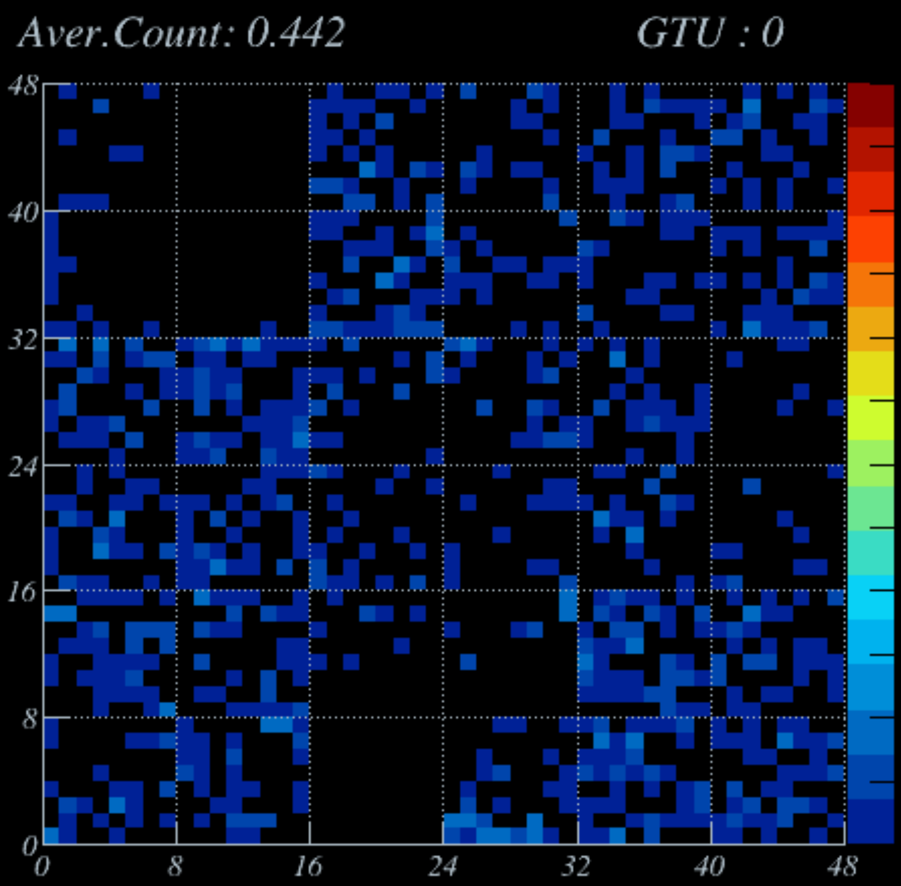

8/25/2014 9:03 am
N48°42'
End (2014-08-25T17:14:47Z)
82°06'
W 81°54'
N48°30'
W 81°30'
W 81°18'
101
Timmins
Google earth
82°04'46.63" W elev 314 m eye alt 54.06 km

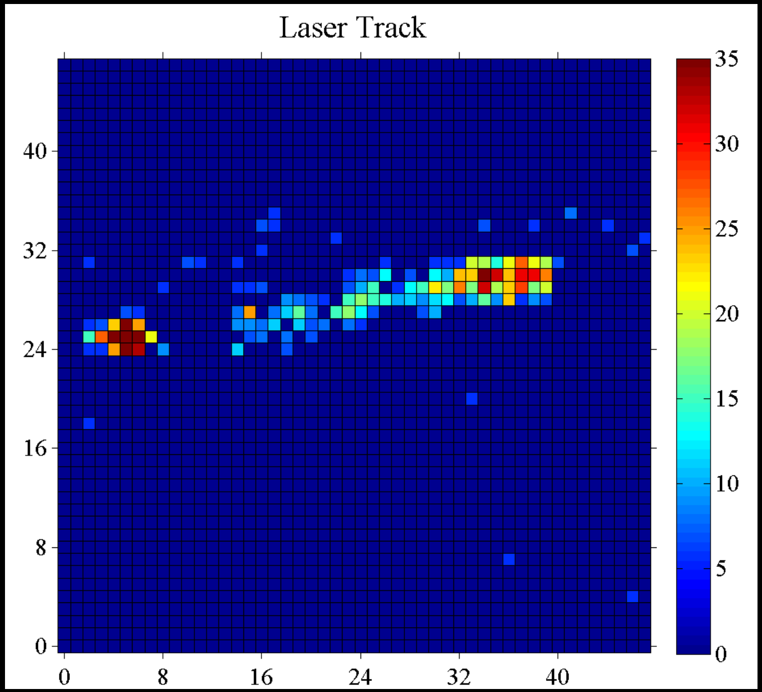


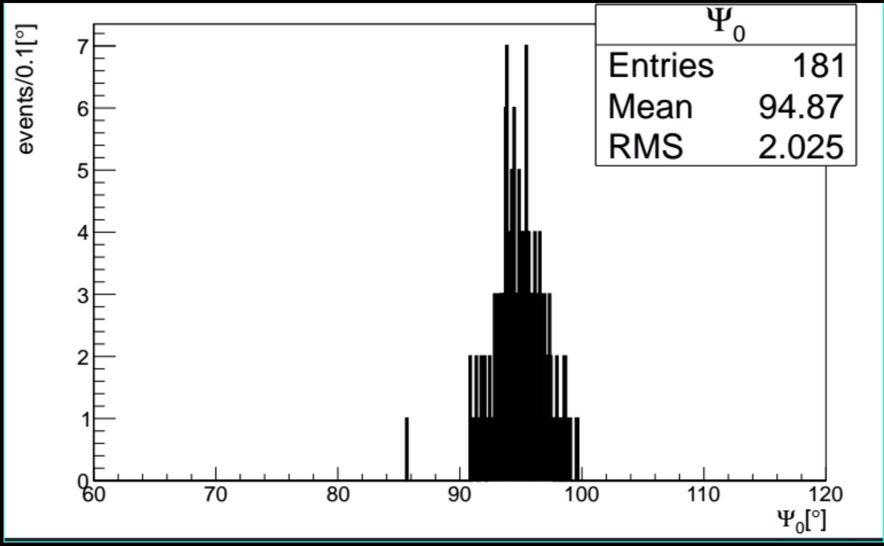
SciAm Oct 14,14



Timmins 2014







Xe Flasher & Laser event

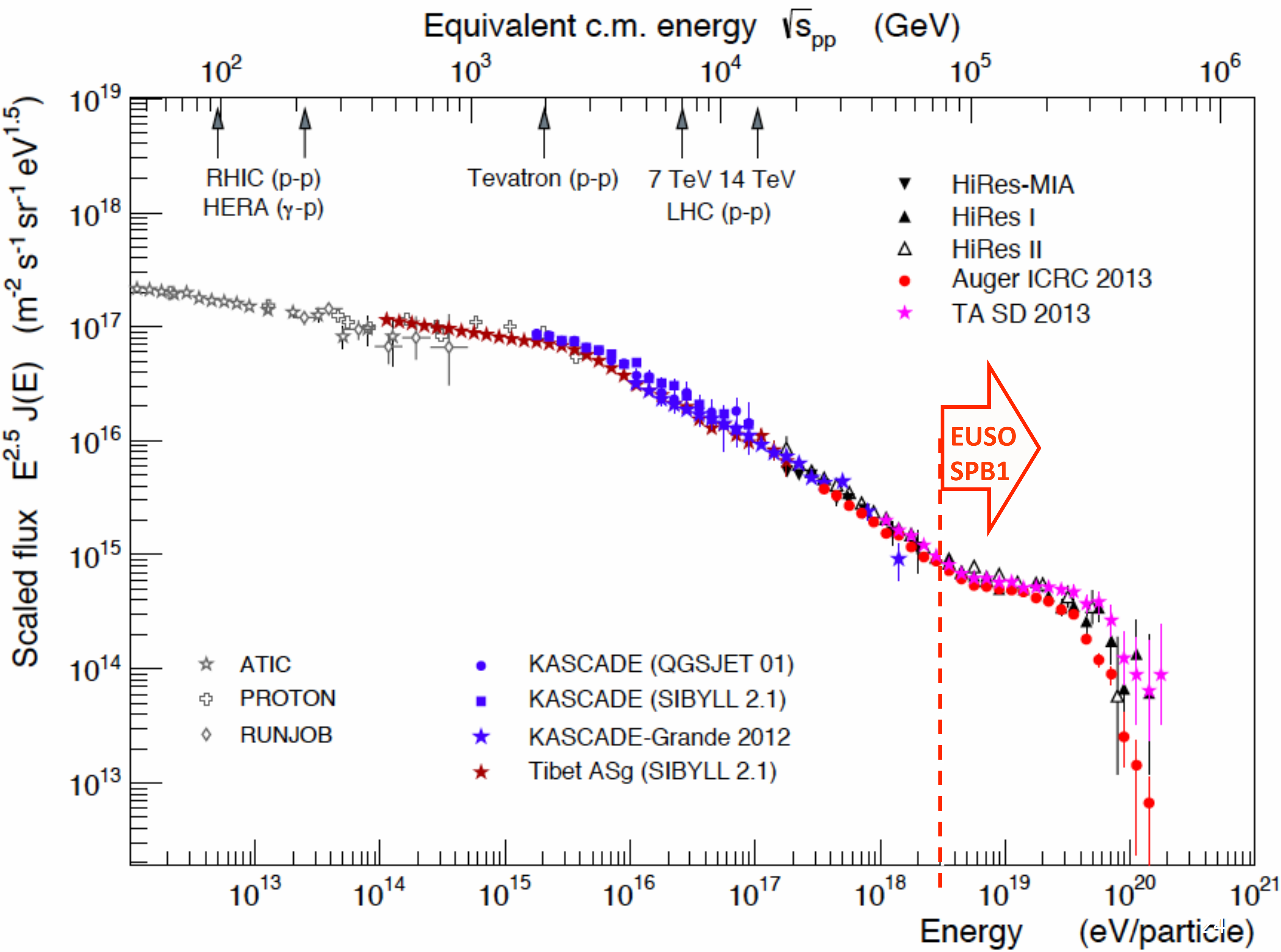
355nm Laser:
~10^{20} eV equivalent brightness

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

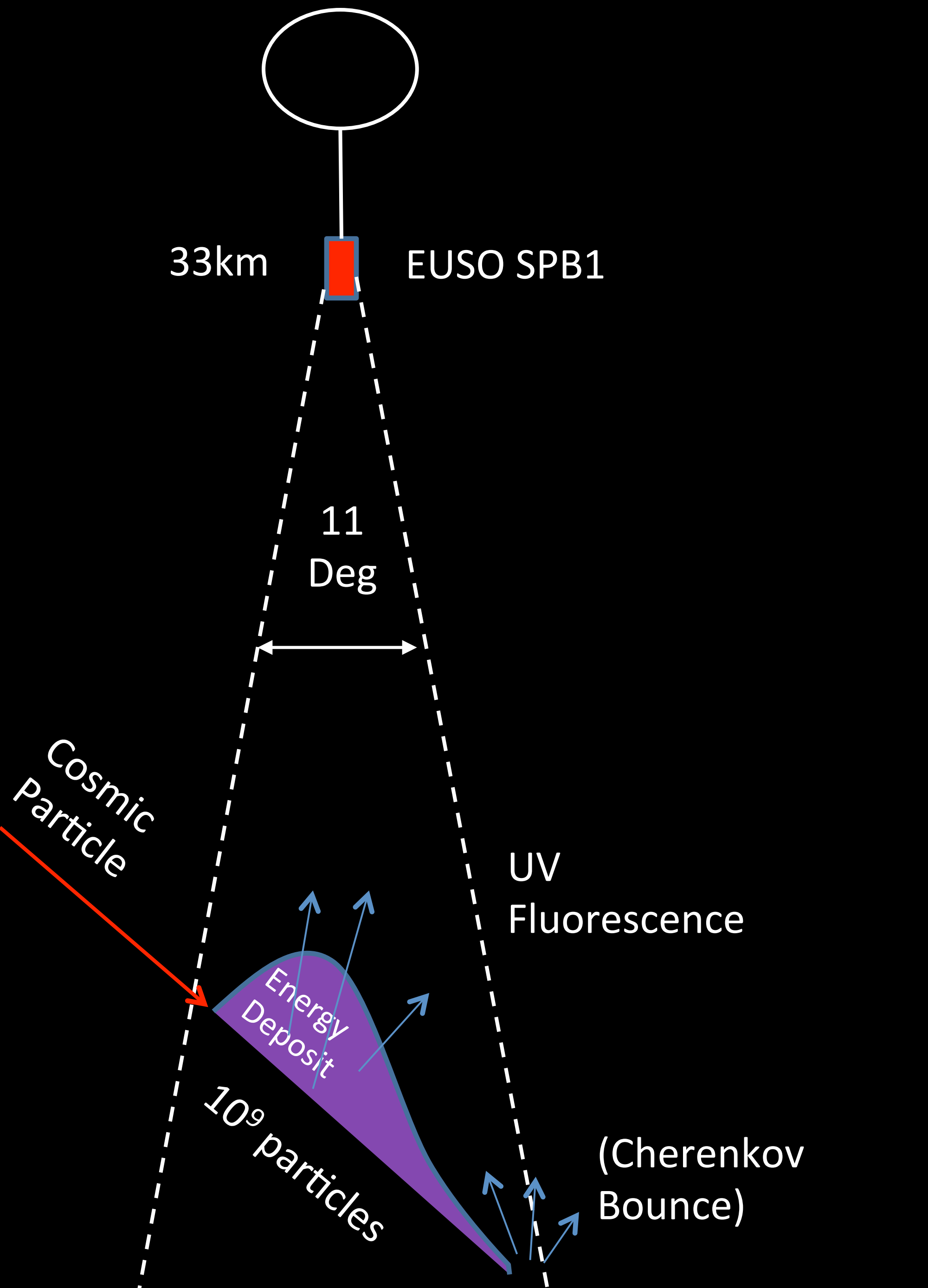
EUSO-SPB: to detect for the **first time UHECRs** using fluorescence from above.

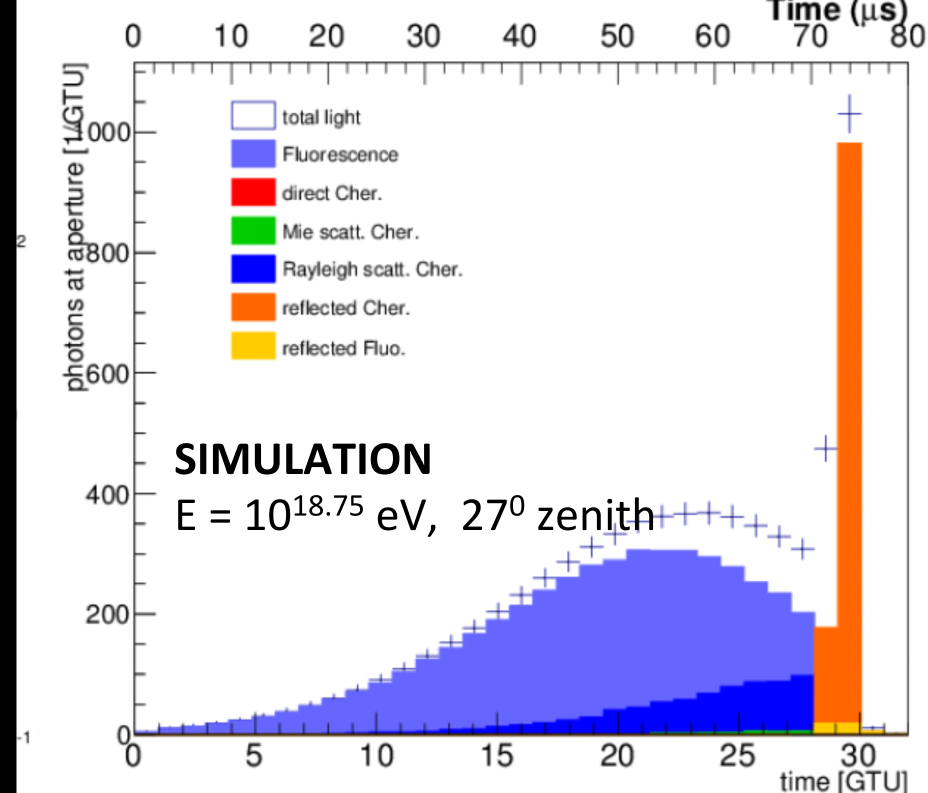
EUSO-SPB: establish the design and technique for POEMMA – Probe Of Extreme Multi-Messenger Astrophysics

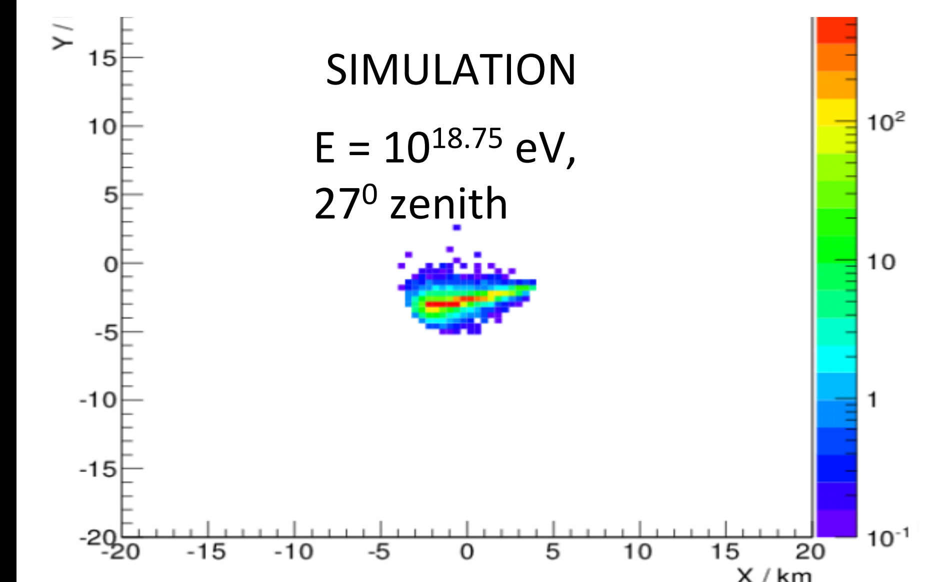
EUSO-SPB: a search for fast UV pulses from other objects: Meteoroids, atmosphere transient luminous events



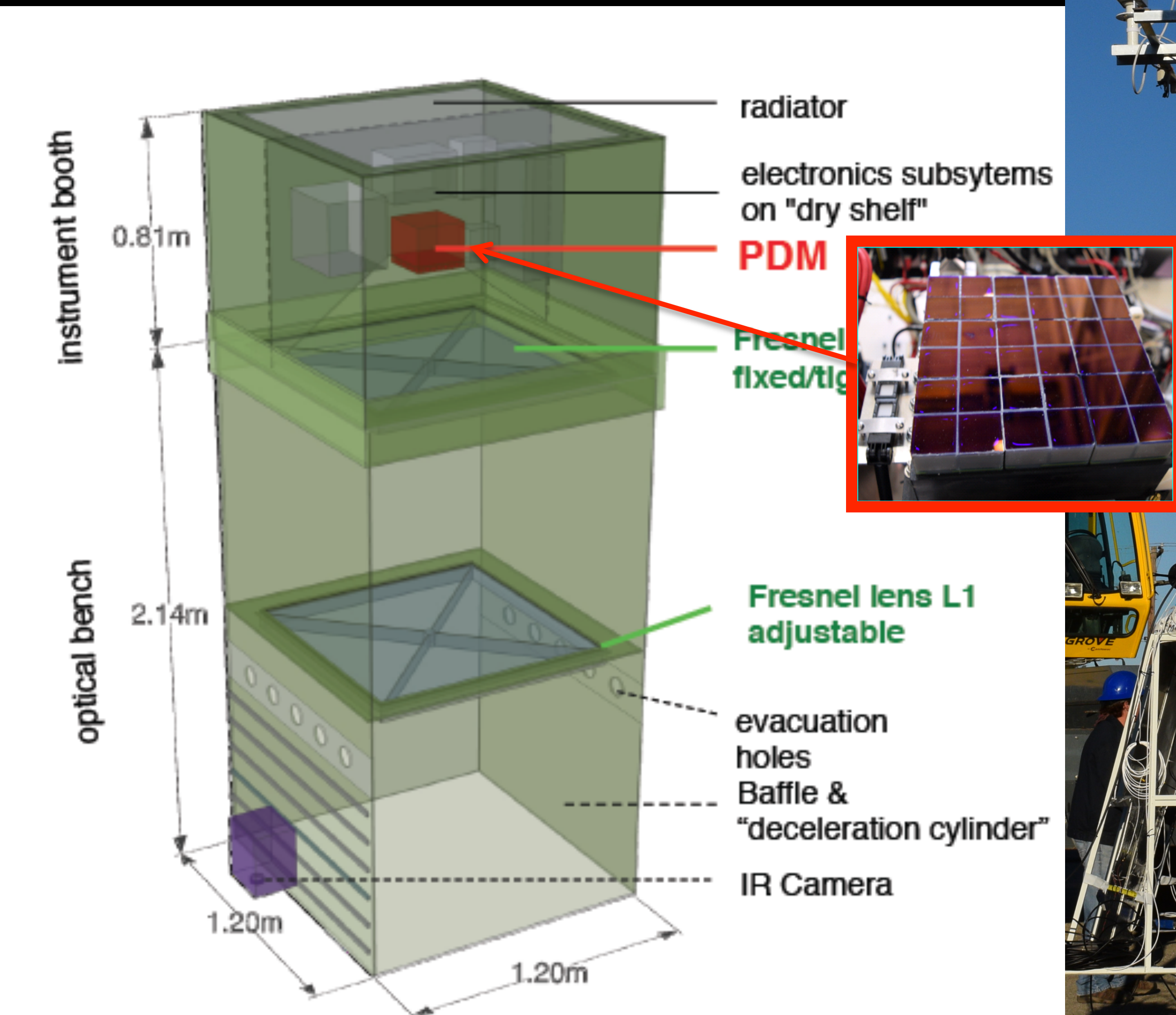
Equivalent c.m. energy $\sqrt{s_{pp}}$ (GeV)
10^2
10^3
10^4
10^5
10^6
Scaled flux $E^{2.5}$ J(E) ($m^{-2}s^{-1}sr^{-1}eV^{1.5}$)
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
EUSO
SPB1
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
Energy (eV/particle)

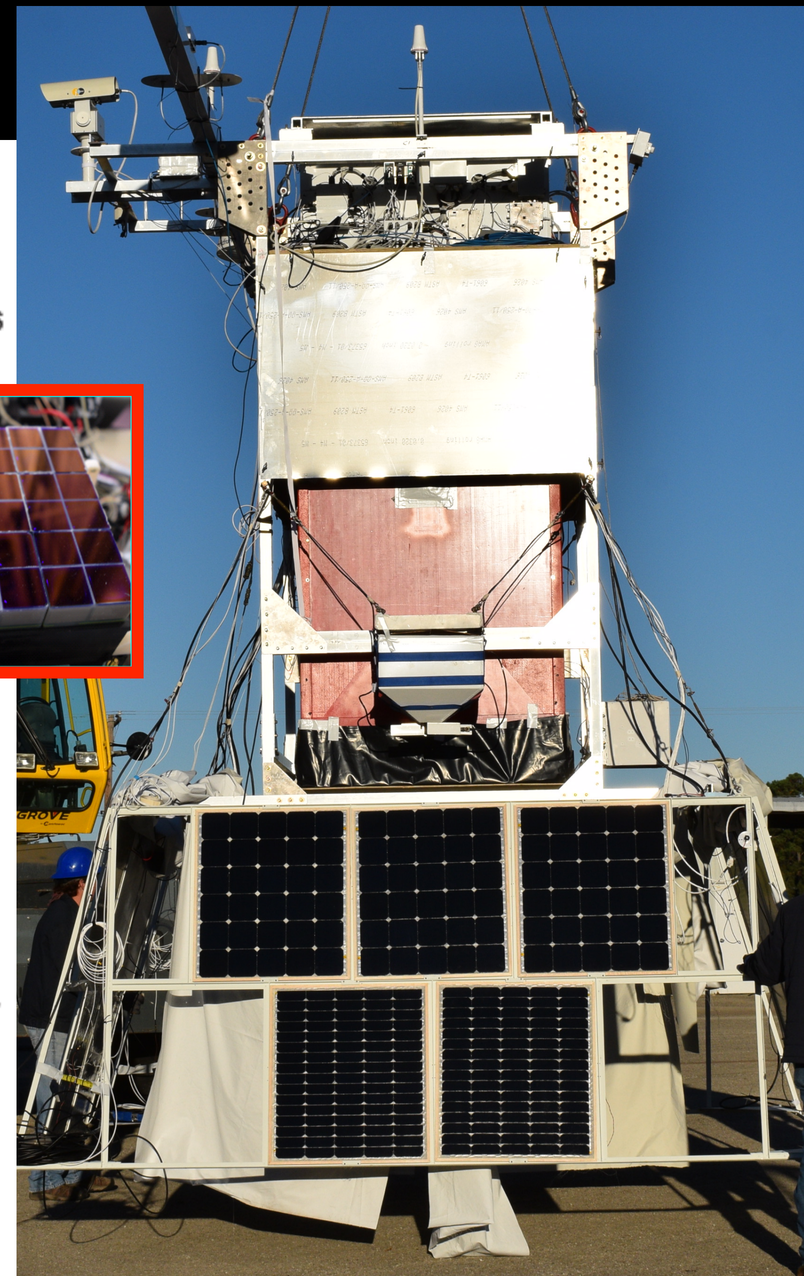

33km
EUSO SPB1
11
Deg
Cosmic
Particle
UV
Fluorescence
Energy
Deposit
10^9 particles
(Cherenkov
Bounce)


Time (μs)
0
10
20
30
40
50
60
70
80
photons at aperture [1/GTU]
total light
Fluorescence
direct Cher.
Mie scatt. Cher.
Rayleigh scatt. Cher.
reflected Cher.
reflected Fluo.
SIMULATION
E = $10^{18.75}$ eV, 27^0 zenith
1000
800
600
400
200
0
5
10
15
20
25
30
time [GTU]

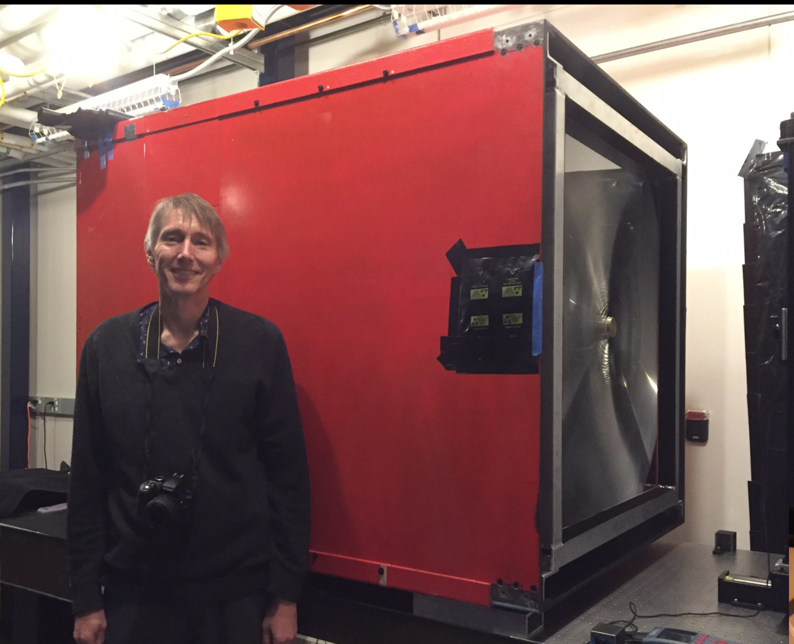

Y /
SIMULATION
E = $10^{18.75}$ eV,
27^0 zenith
15
10
5
0
-5
-10
-15
-20
20
X / km
10^2
10
1
10^{-1}

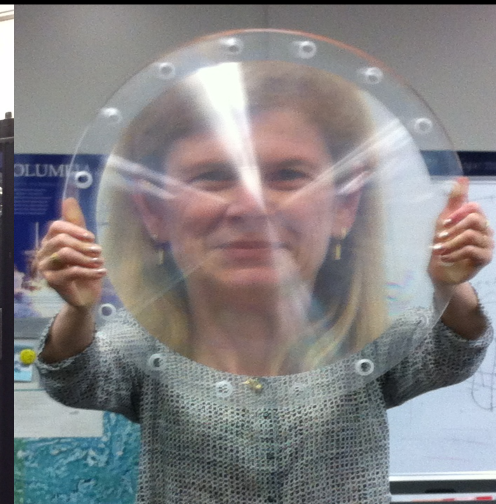
EUSO-SPB Extreme Universe Space Observatory on a Super Pressure Balloon

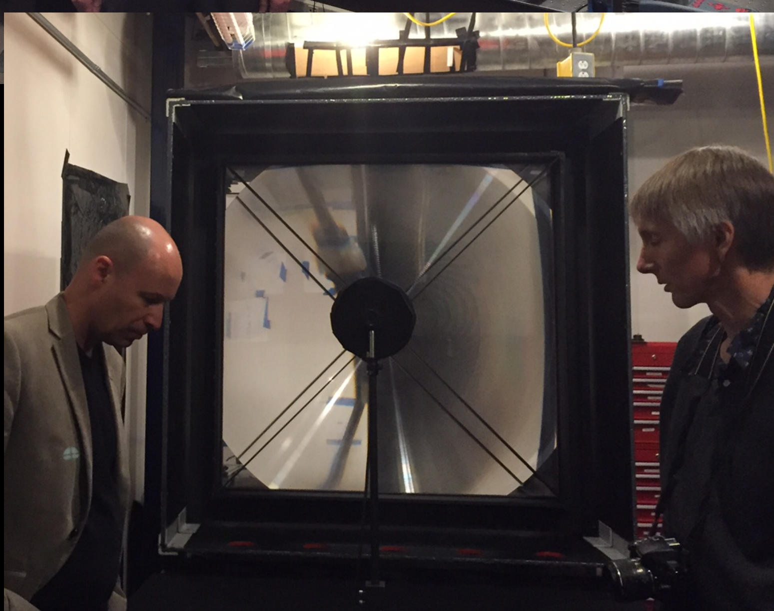




EUSO-SPB Extreme Universe Space Observatory on a Super Pressure Balloon

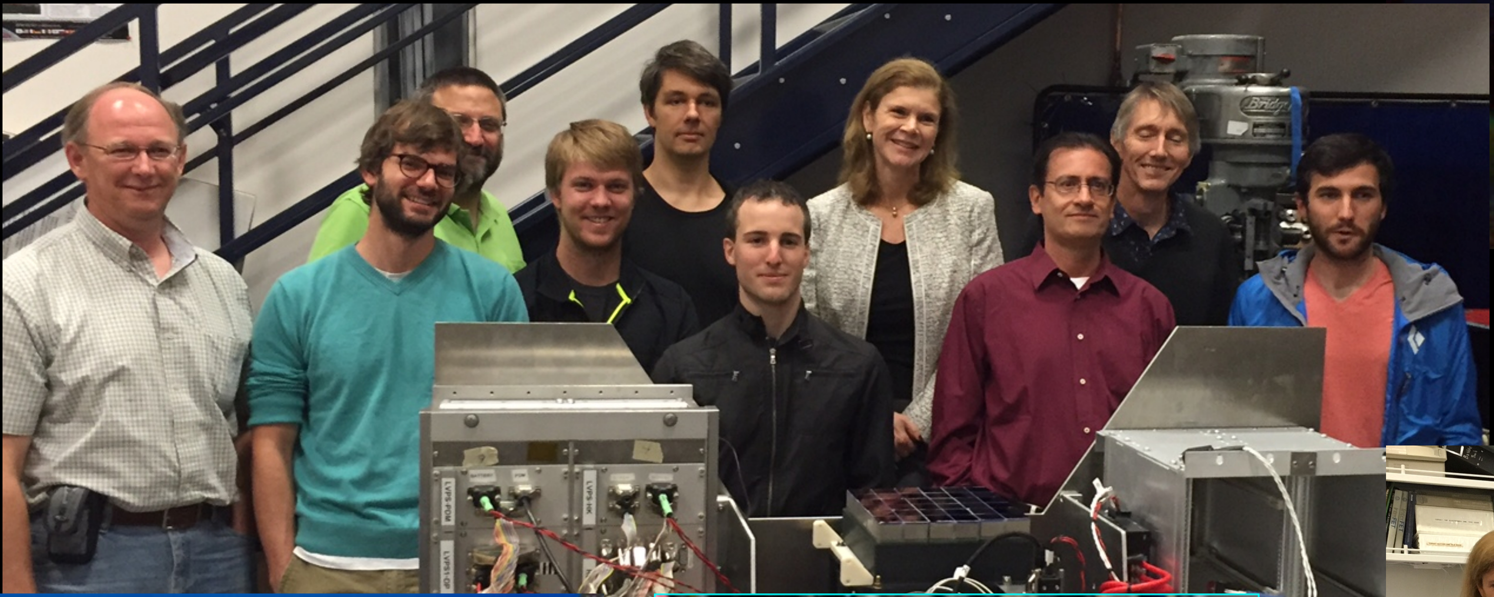


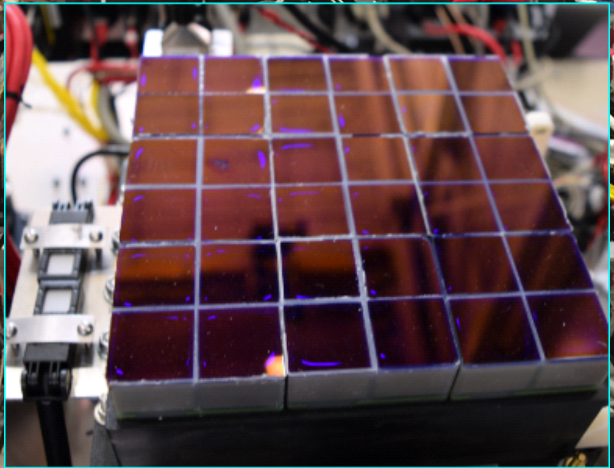


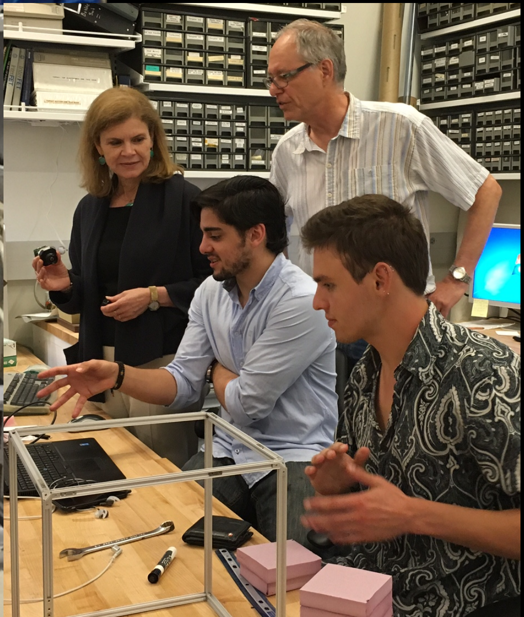


EUSO-SPB Extreme Universe Space Observatory on a Super Pressure Balloon

Ultrafast Camera: Photo-Detector Module (PDM)
(3x3 ECs = 36 MAPMTS ; 2,304 pixels)



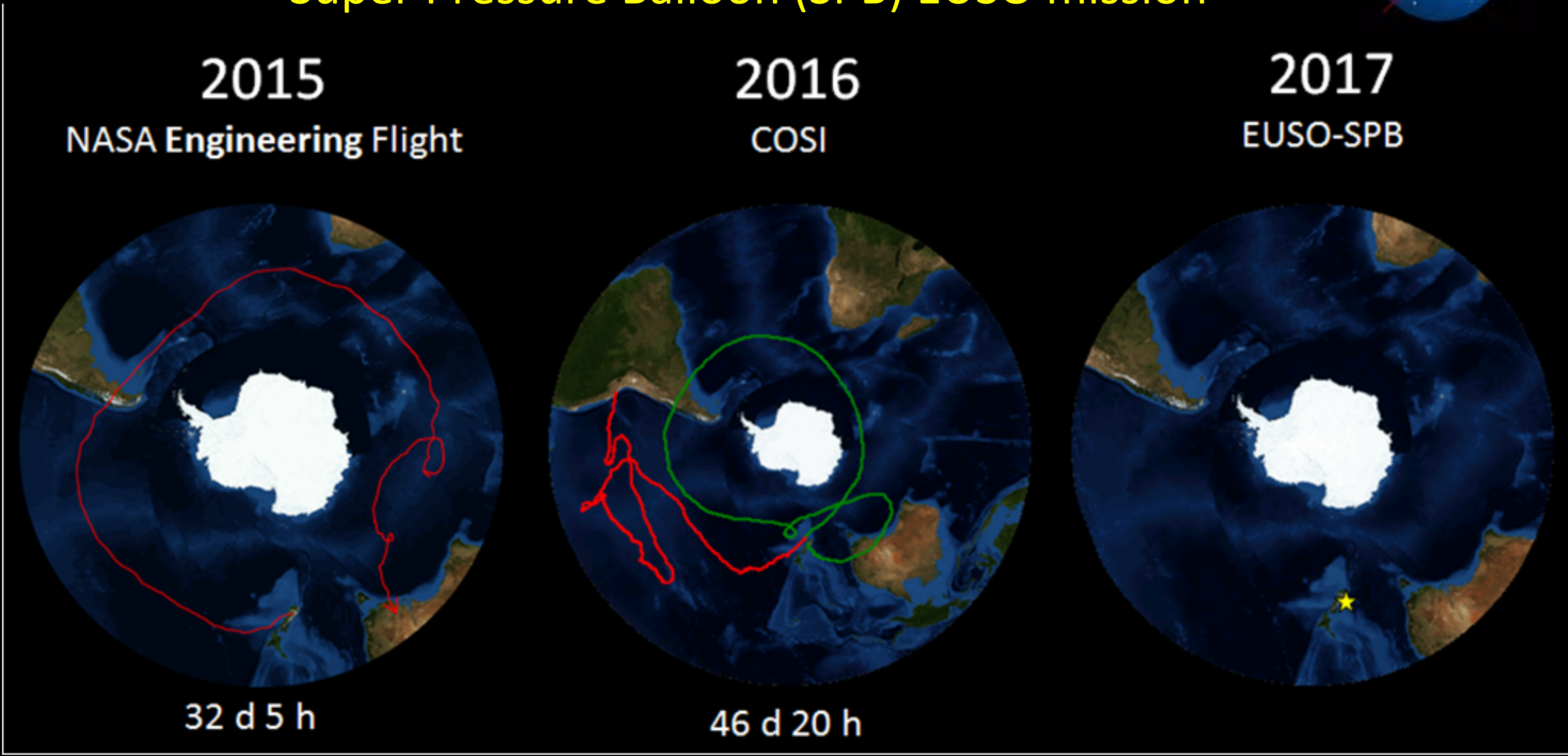





SMITH


SMITH

WANAKA 2017 Campaign
Super Pressure Balloon (SPB) EUSO mission

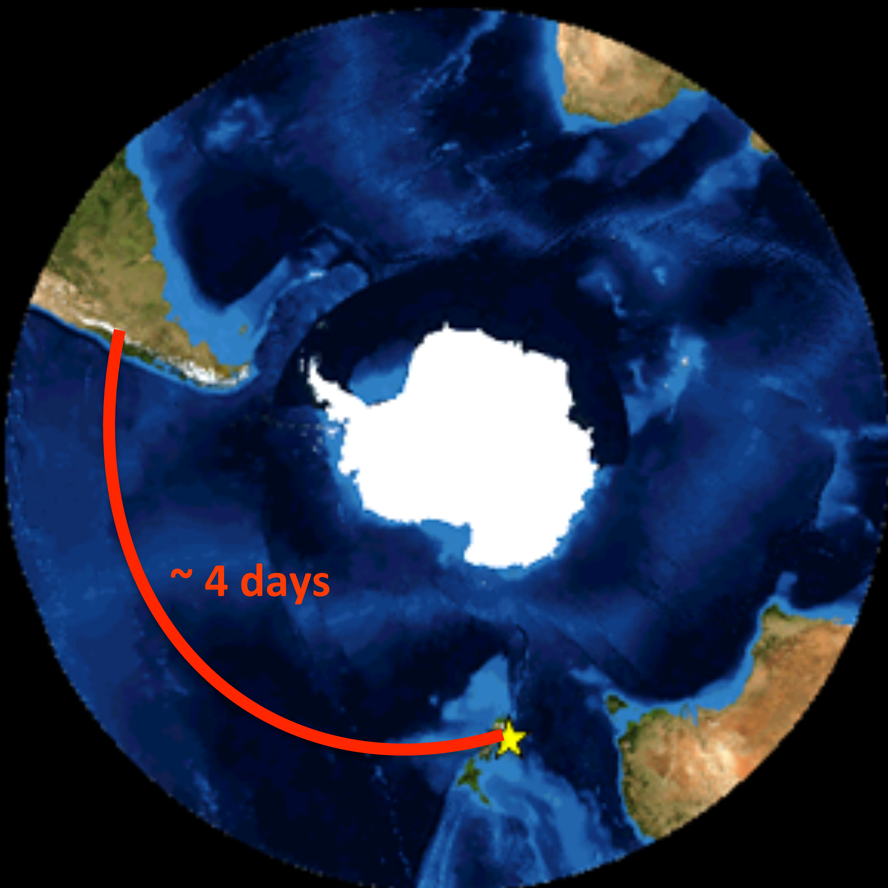


Otago Daily Times

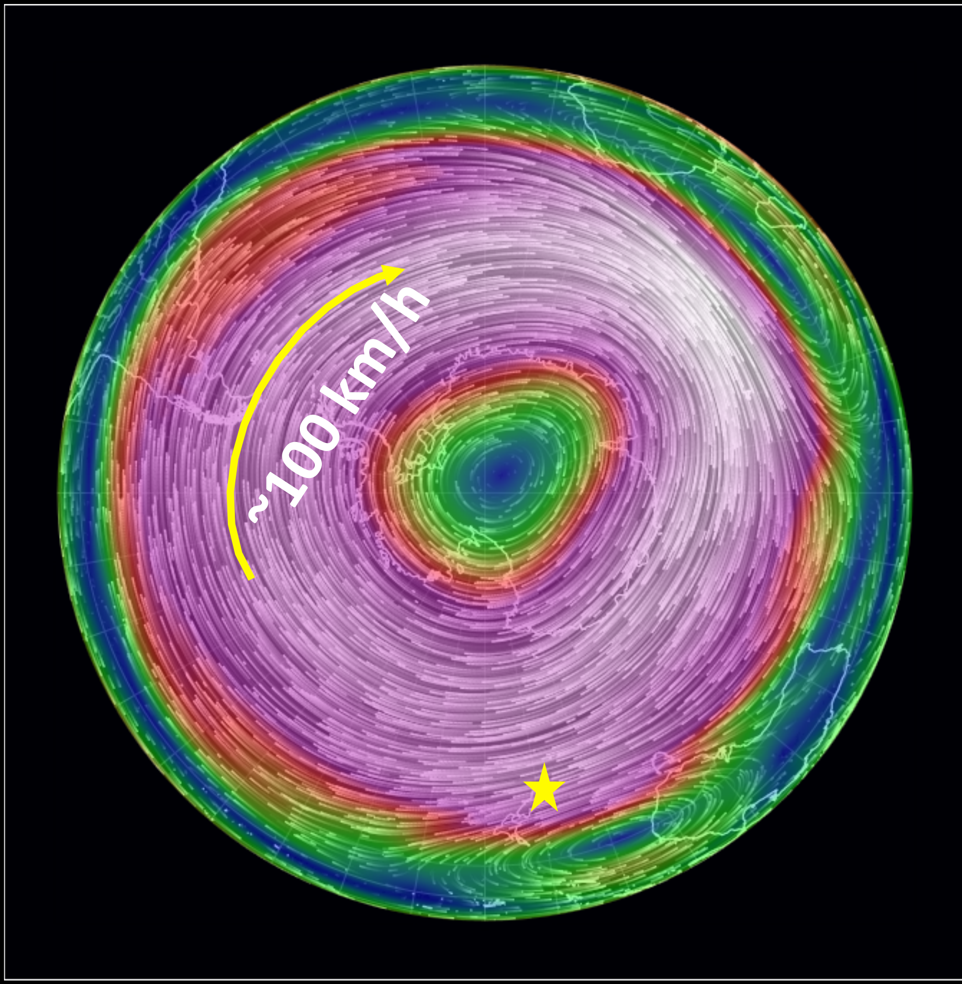
Tuesday, **21 March 2017**

Scientists hoping for record

Why New Zealand?



Wanaka
South Island
New Zealand



air flow at ~30 km June 9th 2017

https://earth.nullschool.net/#current/wind/isobaric/10hPa/orthographic=180,-90,300

Cameron Beccario

EUSO-SPB1 2017 Wanaka NZ

Date	Outcome	Reason	Notes	Try
April 25	Launch	All GO	YEAH!!!!!!!!!!	8
April 22	Scrubbed	Safety Trajectory	Picked Up	7
April 21	Scrubbed	Wind (surface)	At launch pad w/balloon	6
April 17	Scrubbed	Wind direction	At launch pad (foggy)	5
April 16	Scrubbed	Safety Trajectory	Picked Up	4
April 9th	Scrubbed	Wind	Picked Up	3
April 8th	Scrubbed	Crane	No show	2
April 7th	Scrubbed	Wind/Trajectory	Rolled Out	1
Mar. 25th			Launch Ready	

<u>Launch Attempts</u>

4 Weather

2 Safety-trajectory

1 Crane

1 EUSO-SPB1 launch

7th launch attempt

7:49am MST

8th launch attempt

EUSO-SPB LAUNCH, APRIL 25, 2017

4pm CDT

EUSO-SPB launch, April 25, 2017

4:15pm CDT

5pm CDT

EUSO-SPB

LAUNCH, APRIL 25, 2017

5:50 CDT

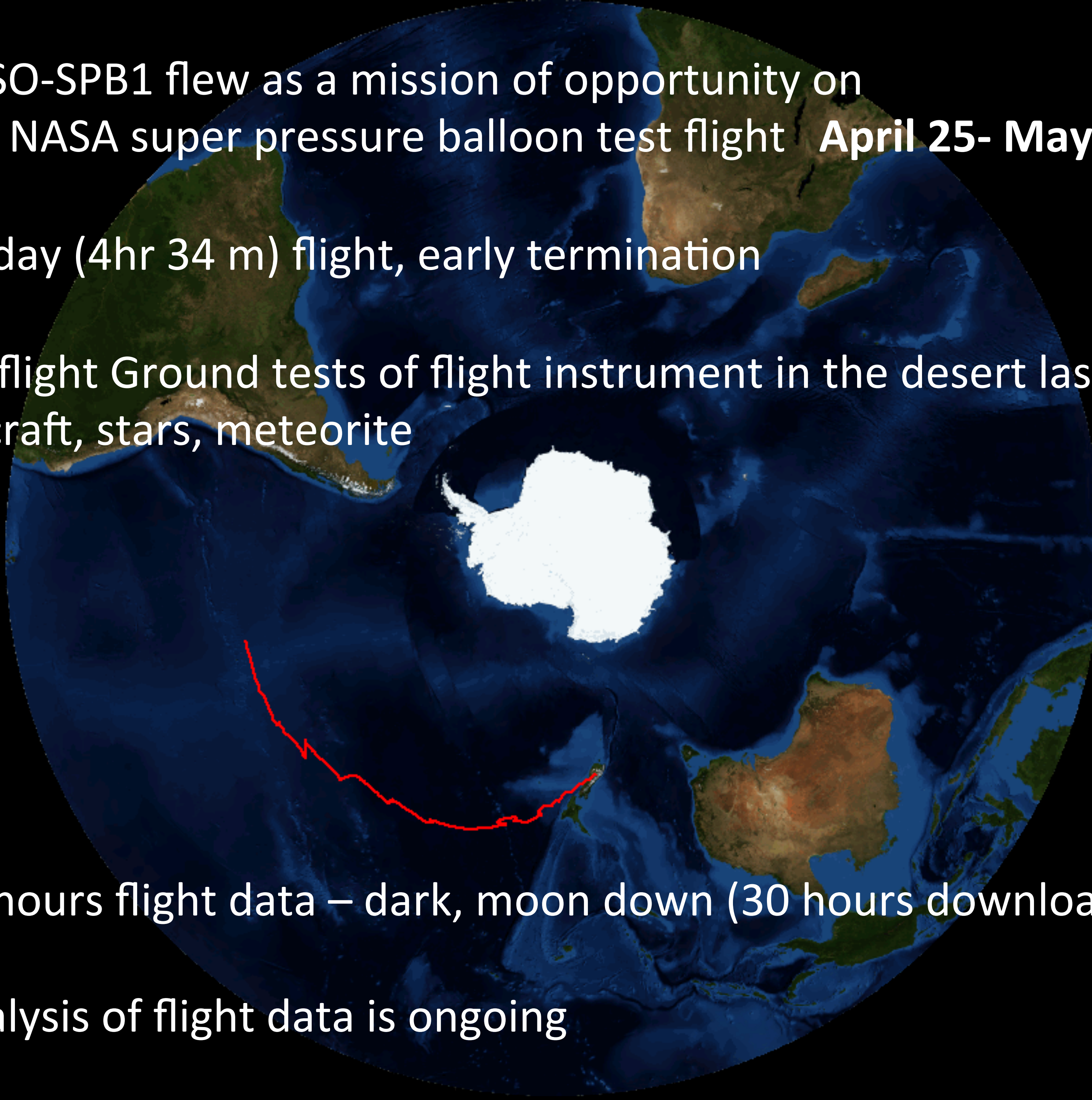

EUSO-SPB
LAUNCH,
APRIL 25,
2017
00:57.27
01:02.93

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 flew as a mission of opportunity on
3rd NASA super pressure balloon test flight **April 25- May 6th 2017**

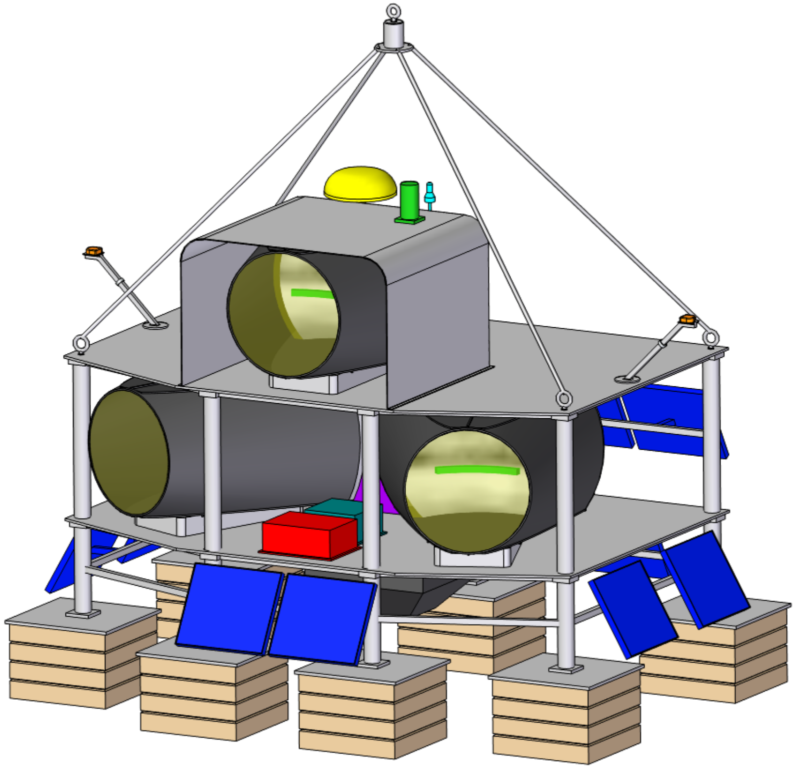
12 day (4hr 34 m) flight, early termination

Preflight Ground tests of flight instrument in the desert lasers, LEDs, aircraft, stars, meteorite



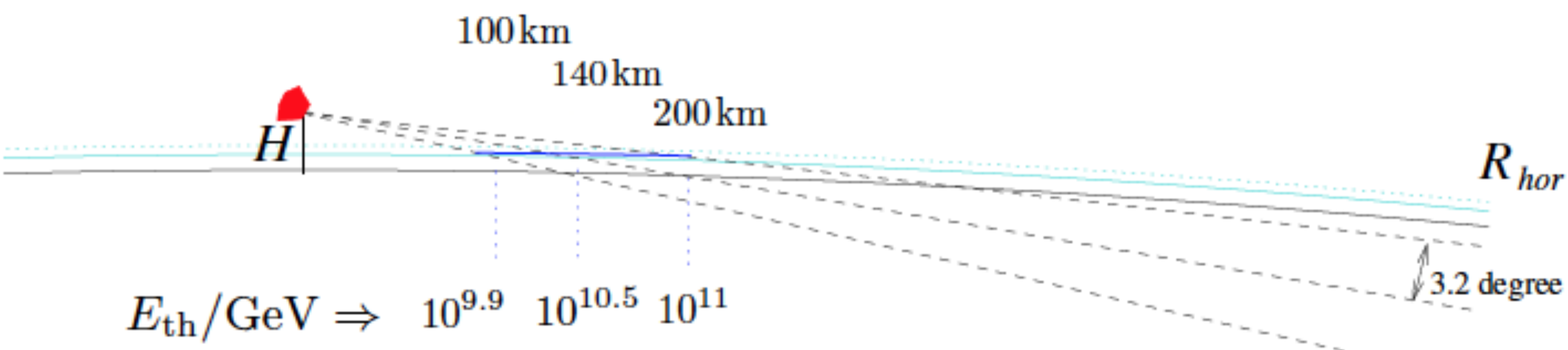
40 hours flight data – dark, moon down (30 hours downloaded)

Analysis of flight data is ongoing



EUSO-SPB2

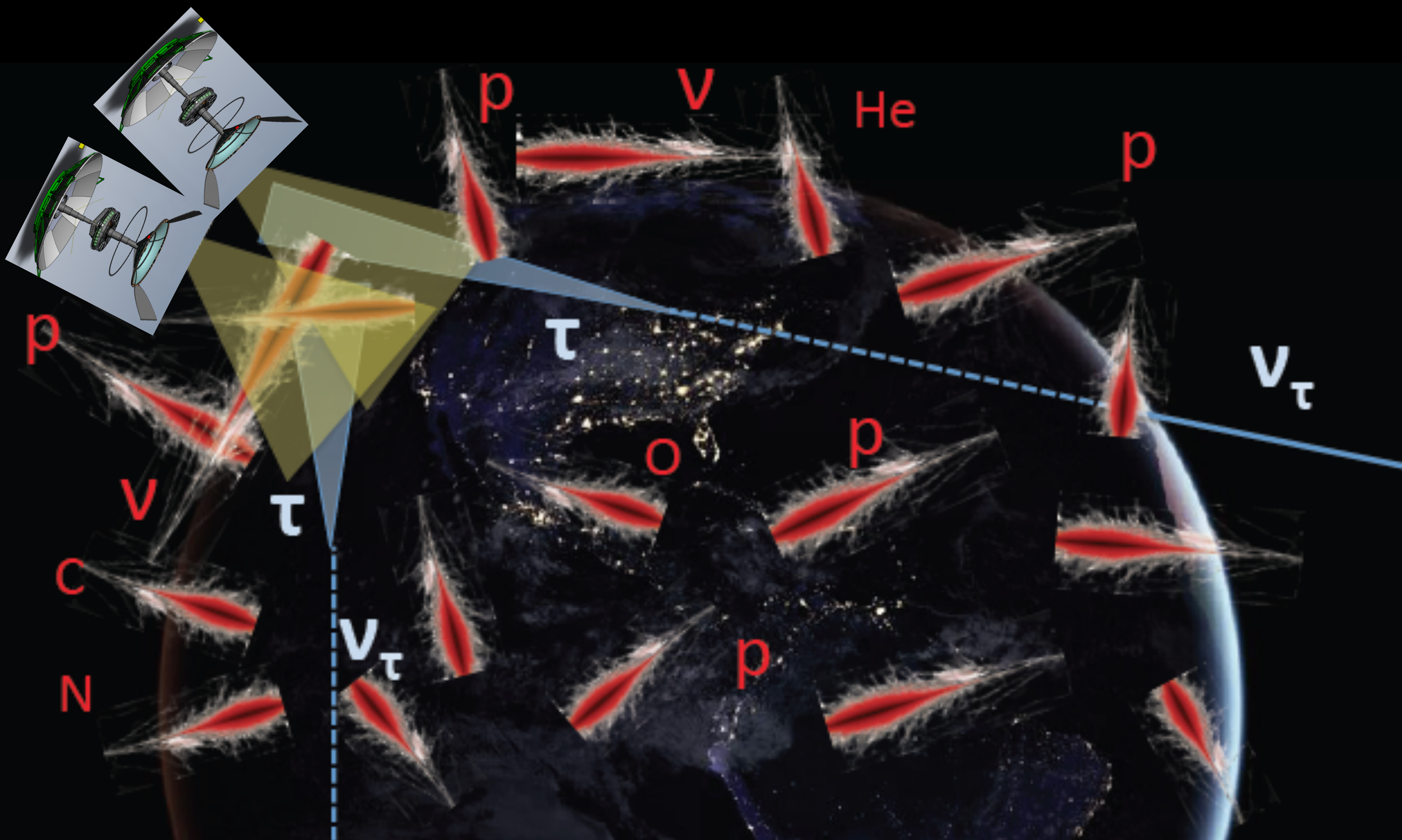
Cherenkov Emission from UHECRs Tau Neutrino background



arXiv:1703.04513

POEMMA

Probe of Extreme Multi-Messenger Astrophysics



NASA Probe Studies for 2020 Decadal Survey

- NASA funding 10 Probe Class (below 1B$) Mission (**18 mos**) Studies in Preparation for the 2020 Decadal Survey
- PI responsible for the final report (due NLT Dec 2018)
- NASA will submit these studies to the Decadal Survey
- Decadal Survey Committee will have the option to prioritize any of these mission concepts, or recommend a competed line of Probes (similar to Explorers)
- Selection based on Science Merit (cost, schedule)

	PI	Affiliation	Short title	Design Lab/Prog Office
	Camp, J.	NASA's GSFC	Transient Astrophysics Probe	IDC/PCOS-COR
	Cooray, A.	Univ. California, Irvine	Cosmic Dawn Intensity Mapper	TeamX/ExEP
	Danchi, W.	GSFC	Cosmic Evolution through UV spectroscopy	IDC/PCOS-COR
	Glenn, J.	Univ. of Colorado	Galaxy Evolution Probe	TeamX/ExEP
	Hanany, S.	Univ. of Minnesota	Inflation Probe Mission Concept Study	TeamX/ExEP
	Mushotzky, R.	Univ. of Maryland	High Spatial Resolution X-ray Probe	IDC/PCOS-COR
POEMMA	Olinto, A.	Univ. of Chicago	Multi-Messenger Astrophysics	IDC/PCOS-COR
	Plavchan, P.	Missouri State Univ.	Precise Radial Velocity Observatory	No design lab funded/HQ grant
	Ray, P.	Naval Research Lab	X-ray Timing and Spectroscopy	IDC/PCOS-COR
	Seager, S.	MIT	Starshade Rendezvous	TeamX/ExEP

POEMMA Study Collaboration

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

NASA/MSFC: Mark J. Christl (deputy PI), Roy M. Young, Peter Bertone

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

University of Utah: Doug Bergman, John Matthews

University of Alabama, Huntsville: James Adams, Patrick Reardon, Evgeny Kuznetsov, Malek Mastafa

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

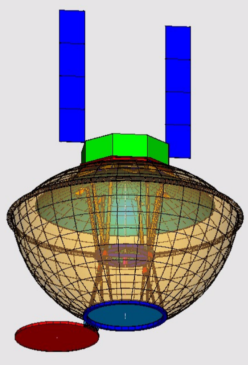
University of Geneva: Andrii Neronov

Gran Sasso Science Institute: Roberto Aloisio

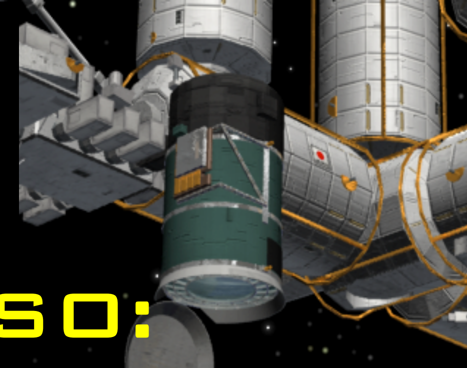
Scientists from16+ institutions from

OWL, JEM-EUSO, Auger, TA, Veritas, CTA, Fermi, Theory

Extensive Air-shower Fluorescence from SPACE

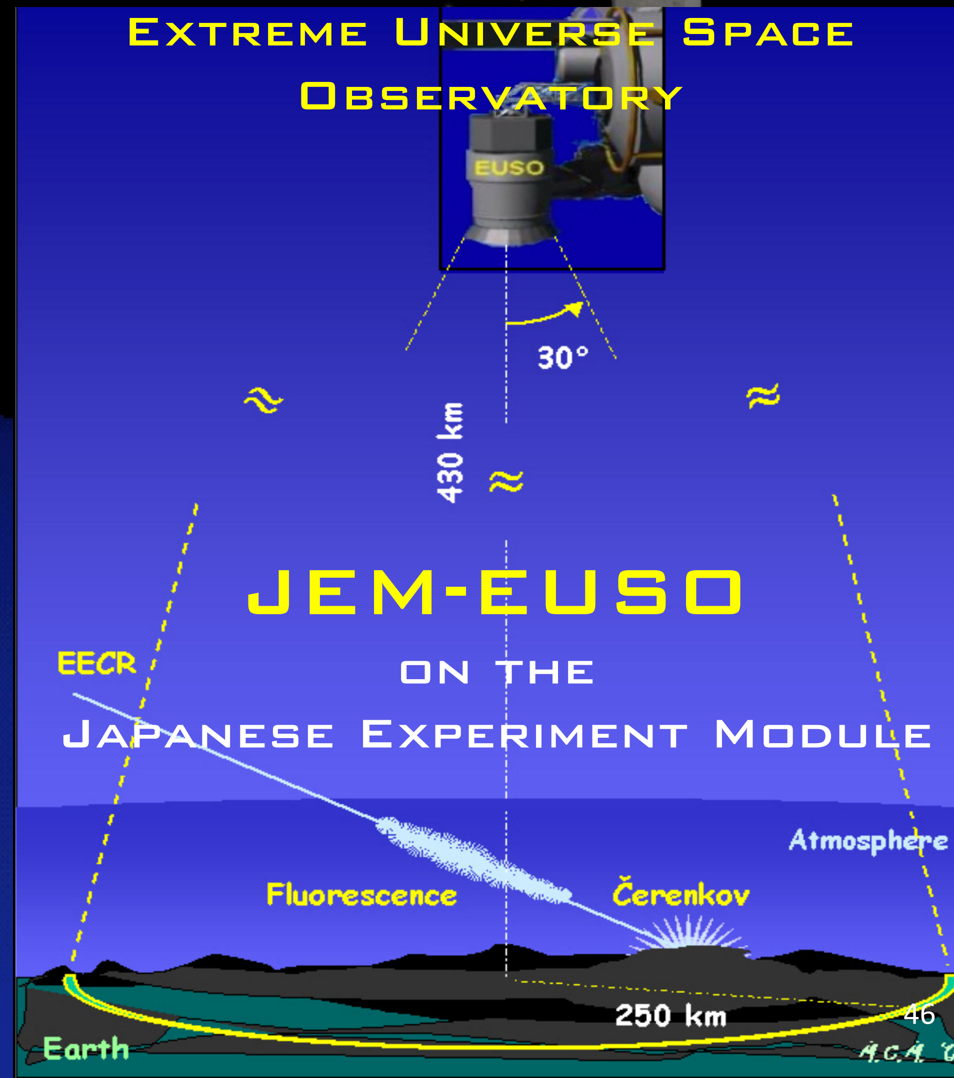


Orbiting Wide-angle Light-collectors



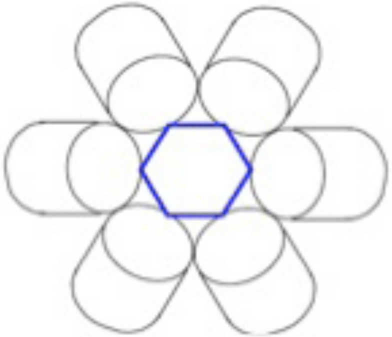
EUSO:

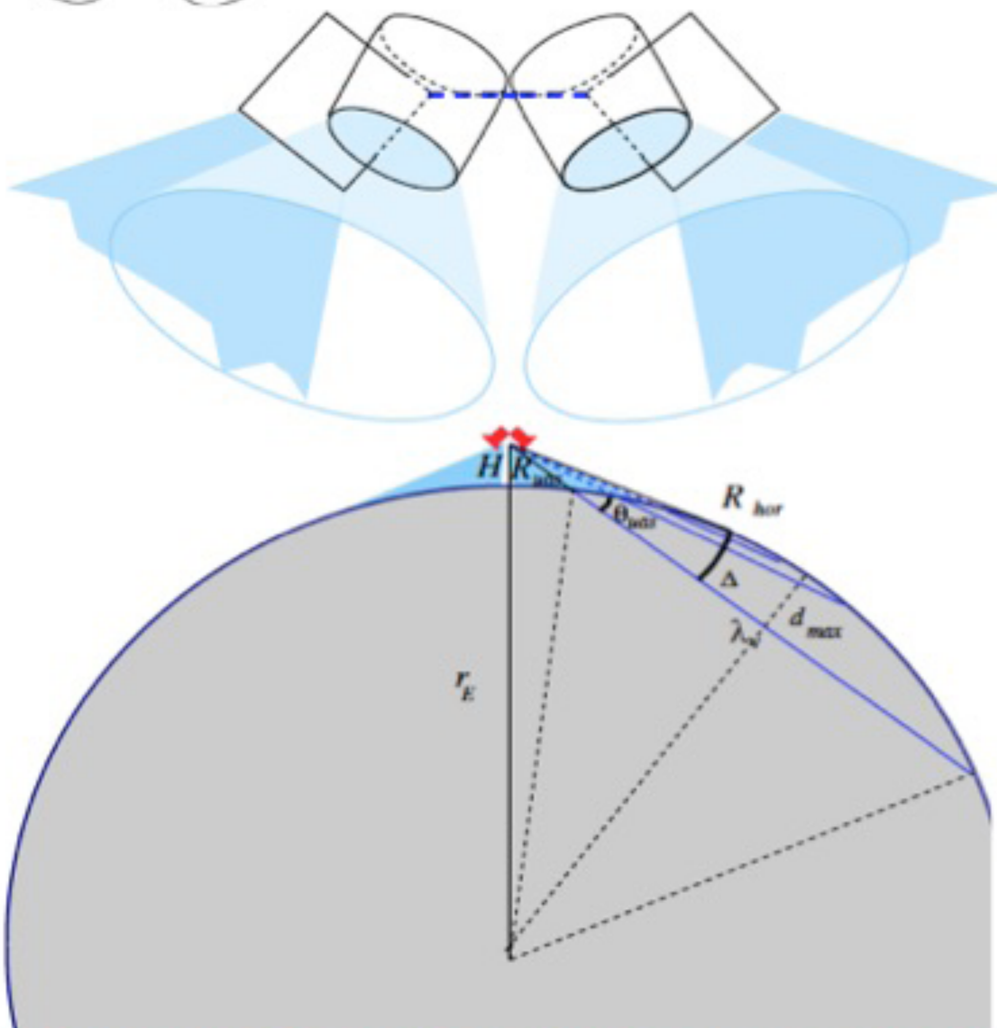
Extreme Universe Space Observatory

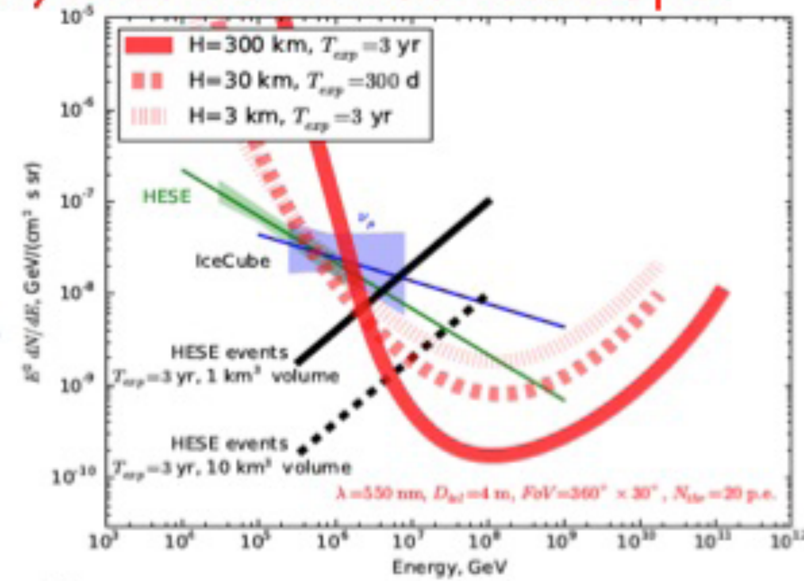


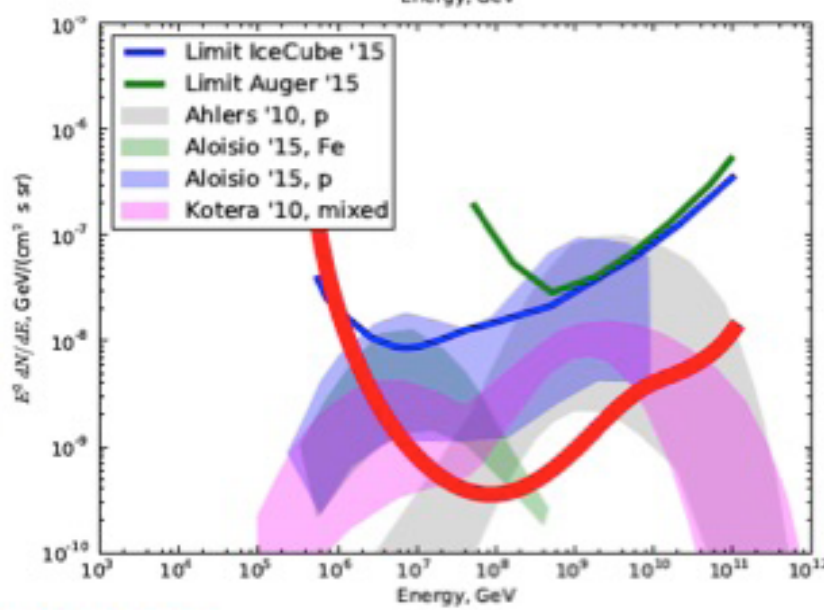
CHANT

Cherenkov from Astrophysical Neutrinos Telescope









A. Neronov, D. Semikoz, L. Anchordoqui, J. Adams, AVO'16

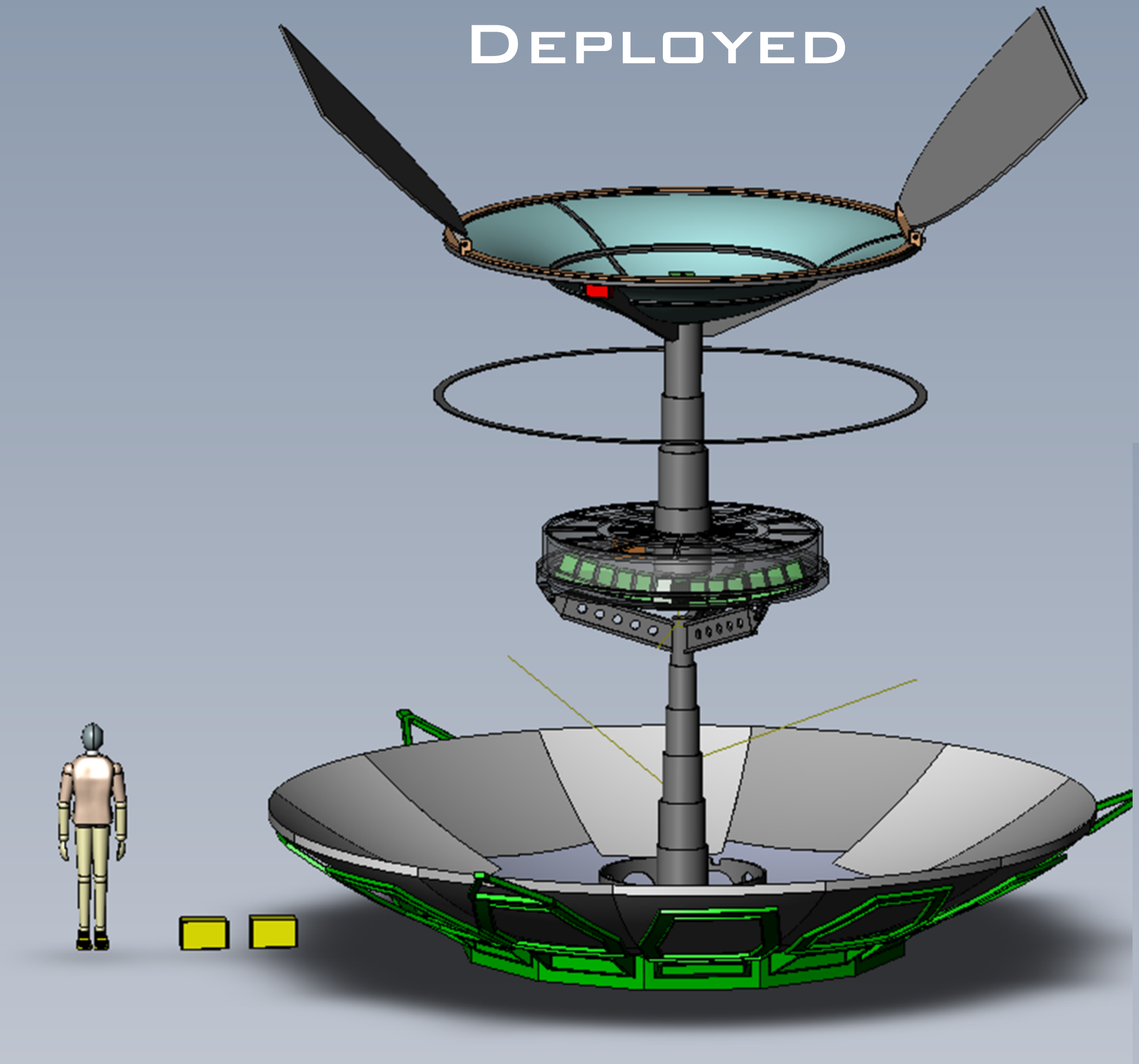
arXiv:1606.03629

POEMMA Conceptual Design
GSFC Instrument Design Lab (IDL)

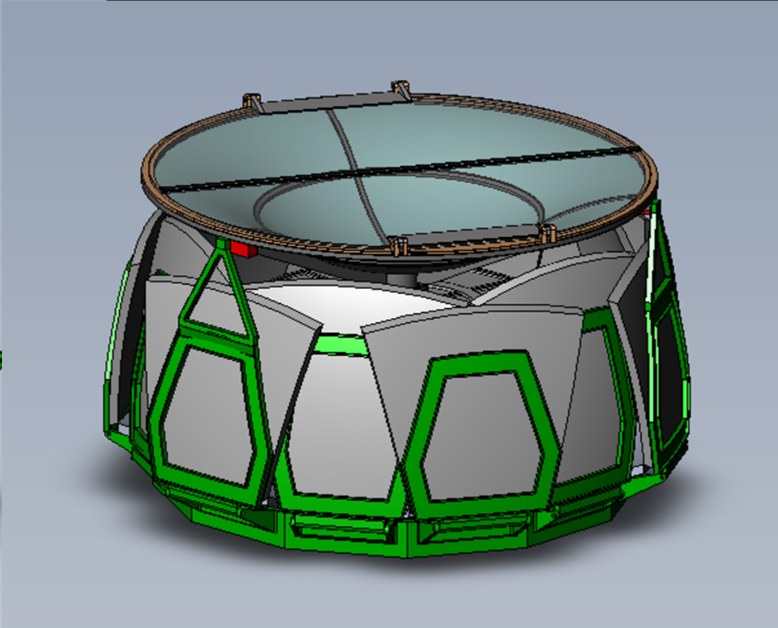
Integrated Design Center
(previously ISAL)

IDL design

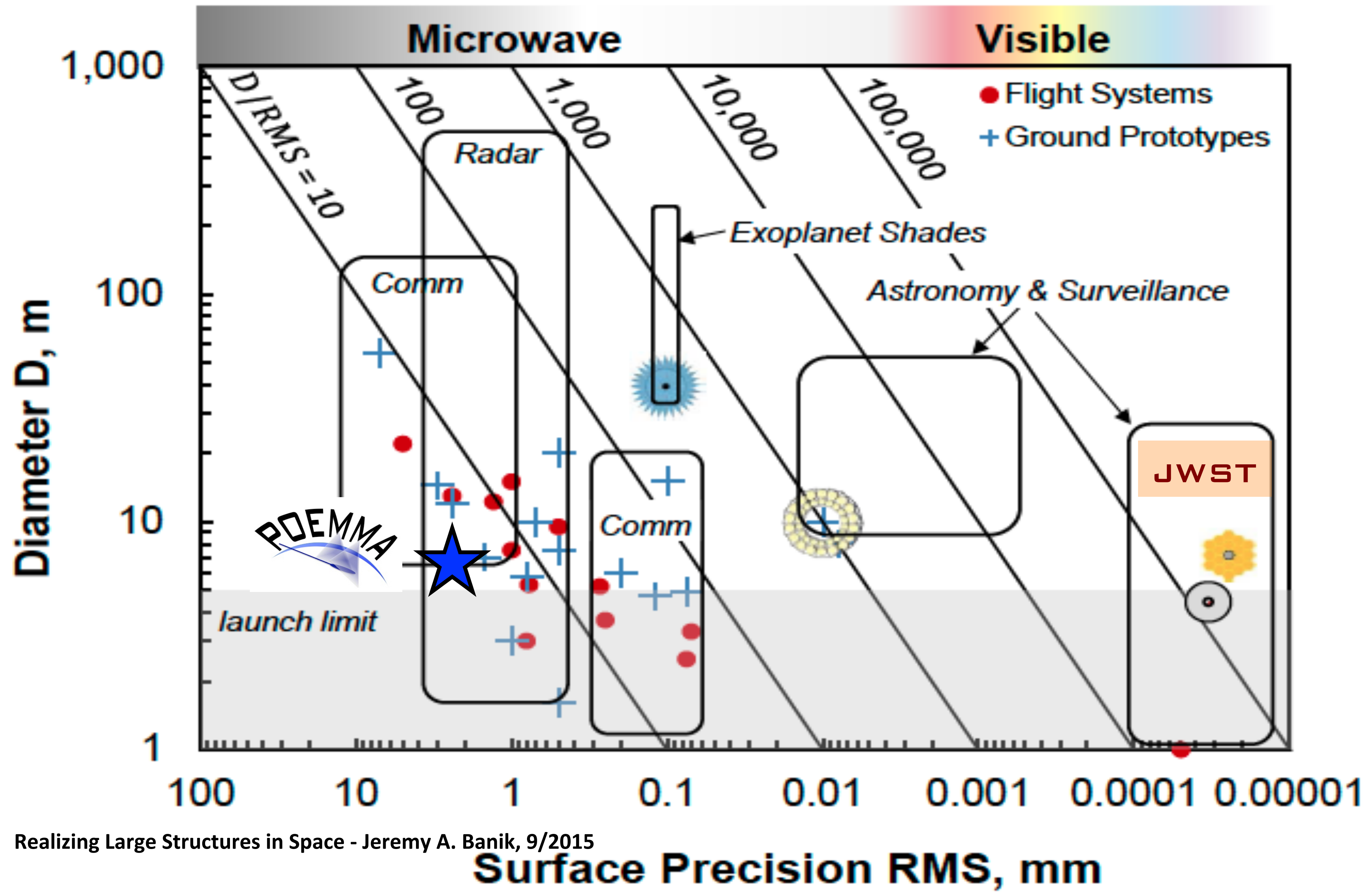
Deployed



Stowed

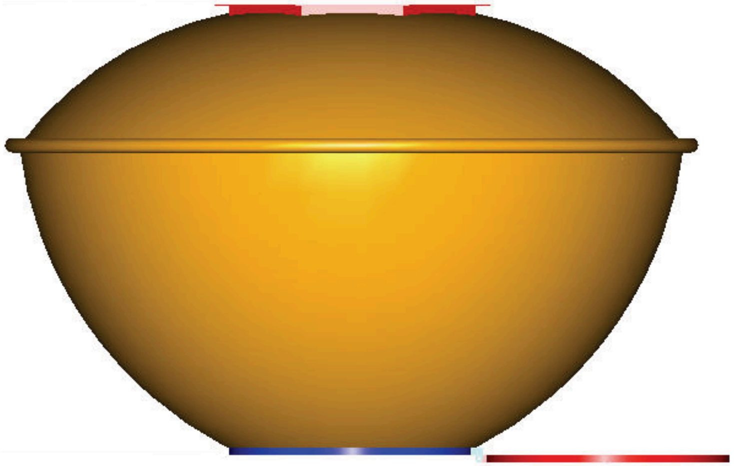


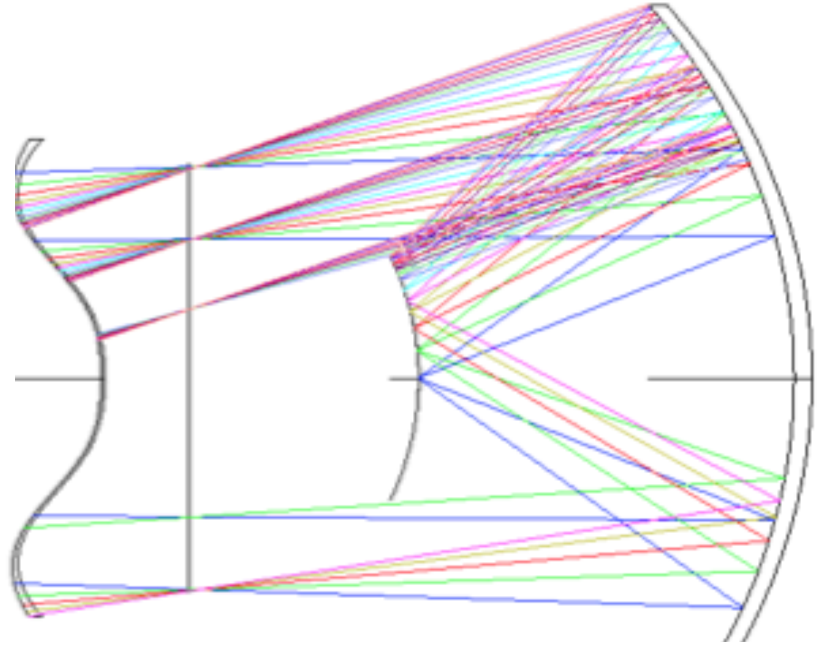
Large Reflectors

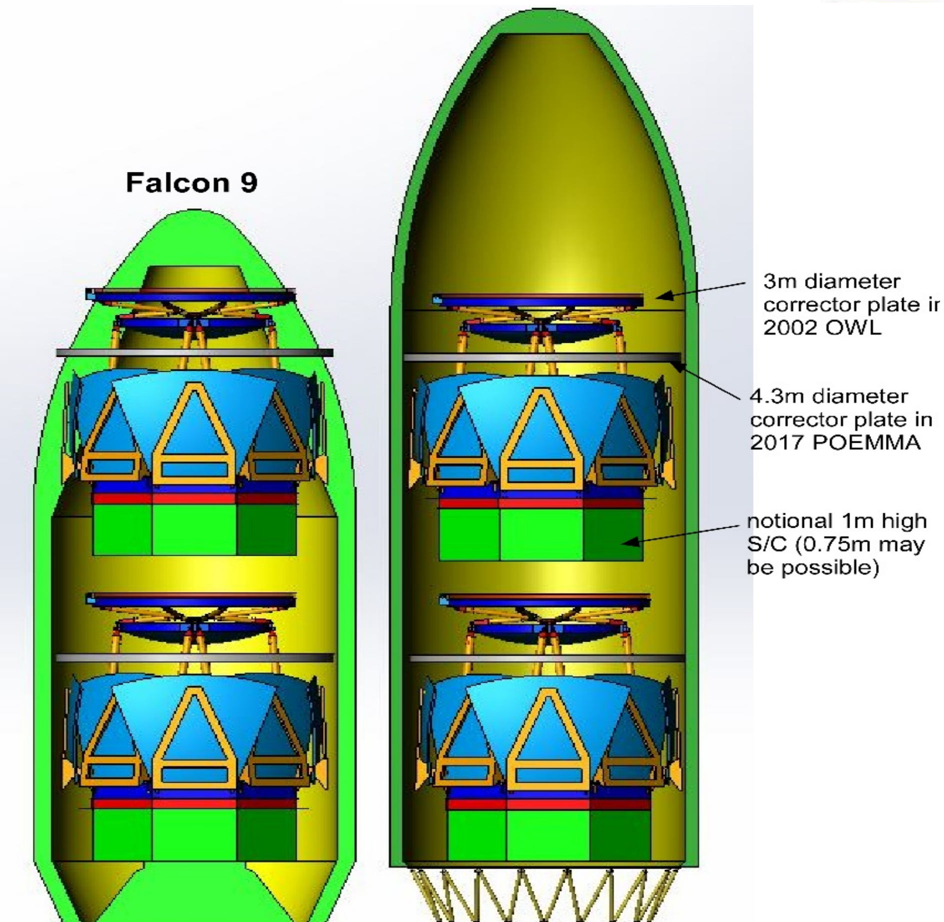


Realizing Large Structures in Space - Jeremy A. Banik, 9/2015

POEMMA

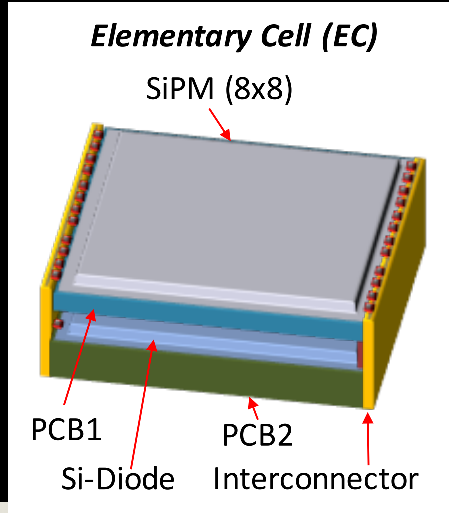




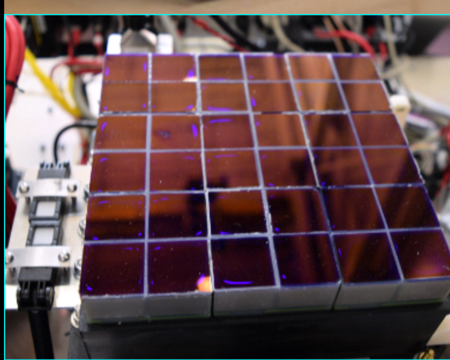


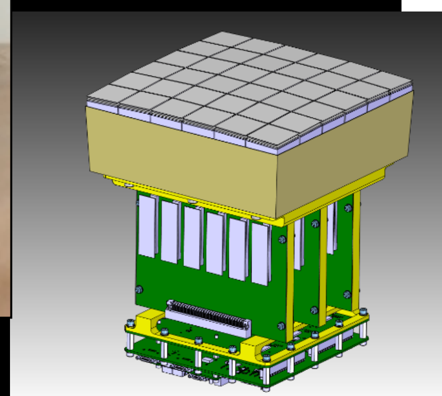
Falcon 9
3m diameter
corrector plate ir
2002 OWL
4.3m diameter
corrector plate in
2017 POEMMA
notional 1m high
S/C (0.75m may
be possible)

Hybrid Focal Surface

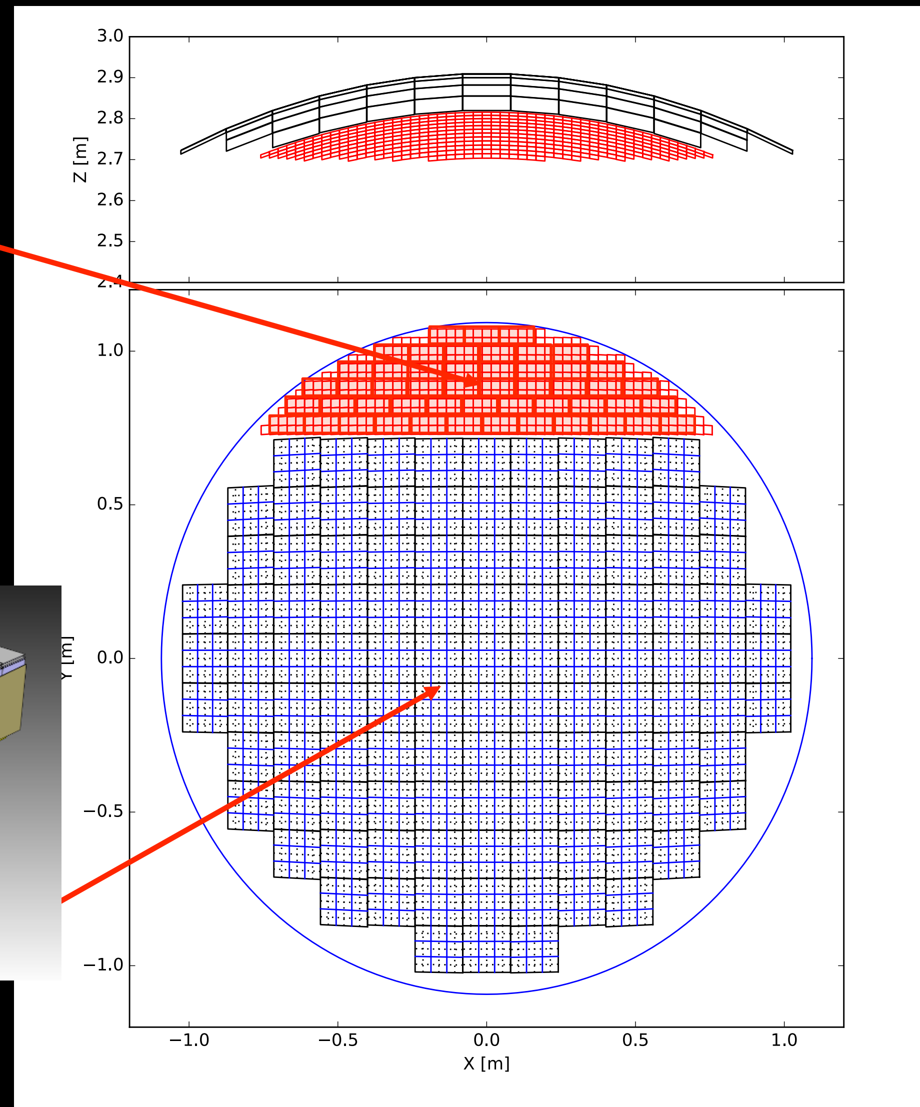


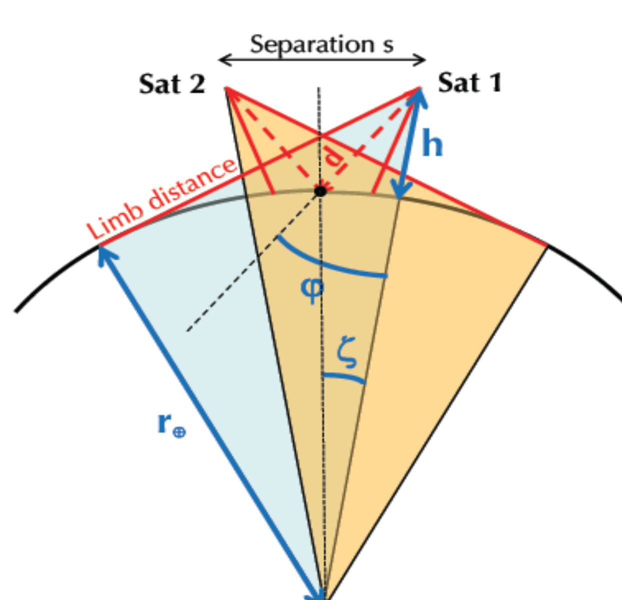
50 FSU
focal surface
units





111 PDMs

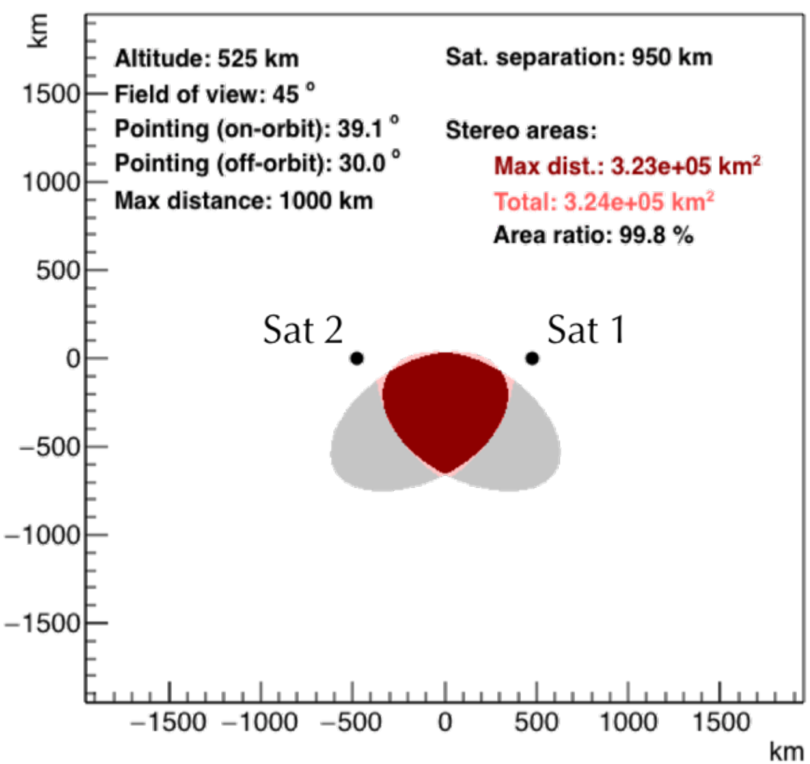




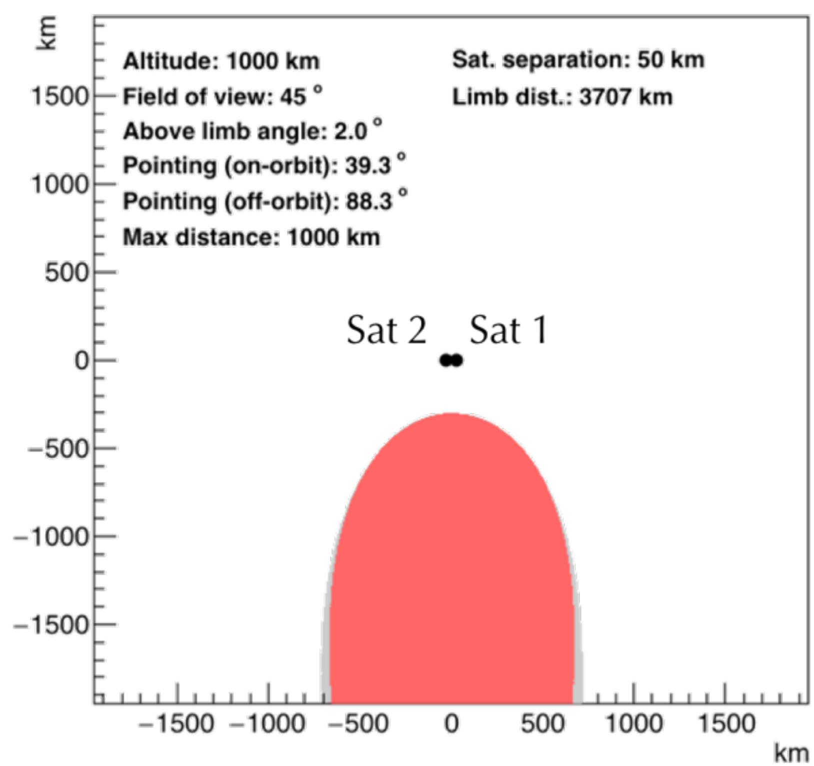
POEMMA Mission Design to optimize Science priorities

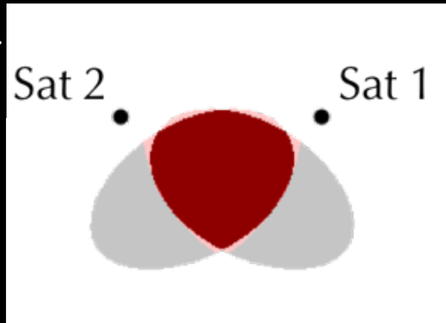
- Orbits from 525 to 1000 km altitude, inclin 28.5°
- UHECR cross-calibration with ground
- UHECR sky map, composition above 10 EeV
- UHECR flux at 100 EeV
- Below limb: Tau decay search
- Above limb: horizontal showers

UHECR stereo observation mode

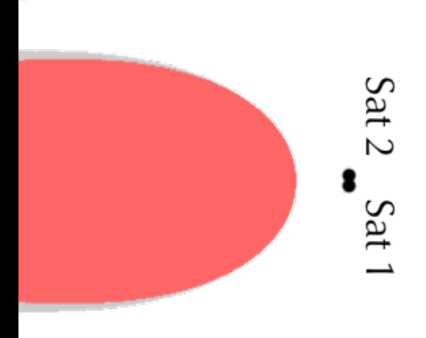


Neutrino stereo observation mode



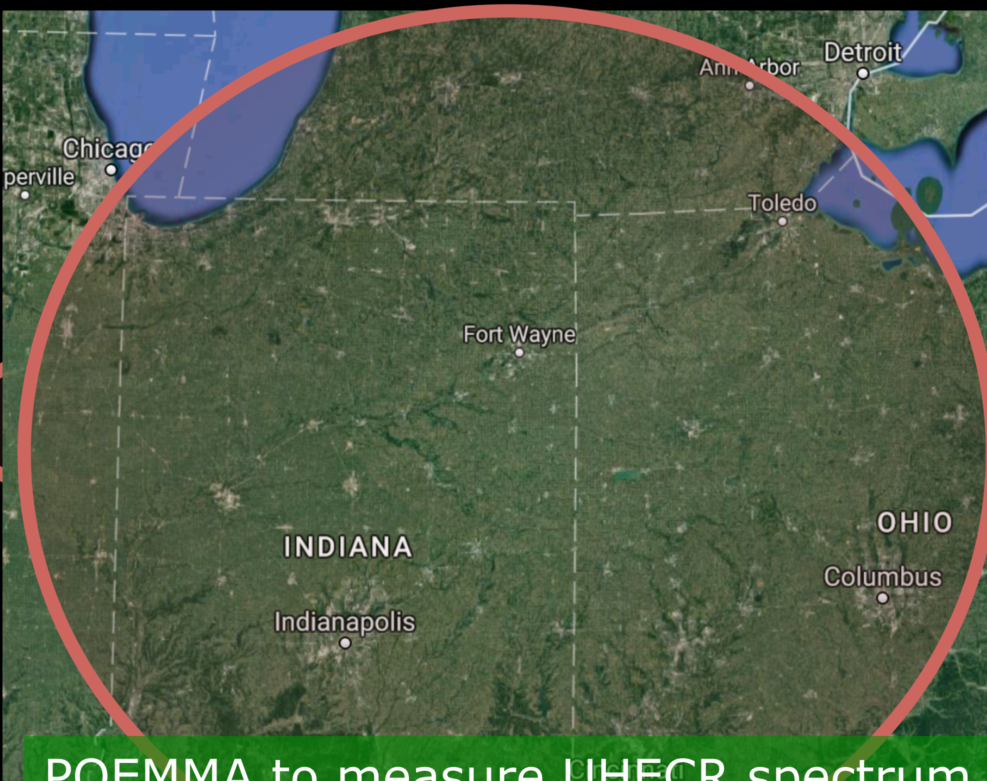


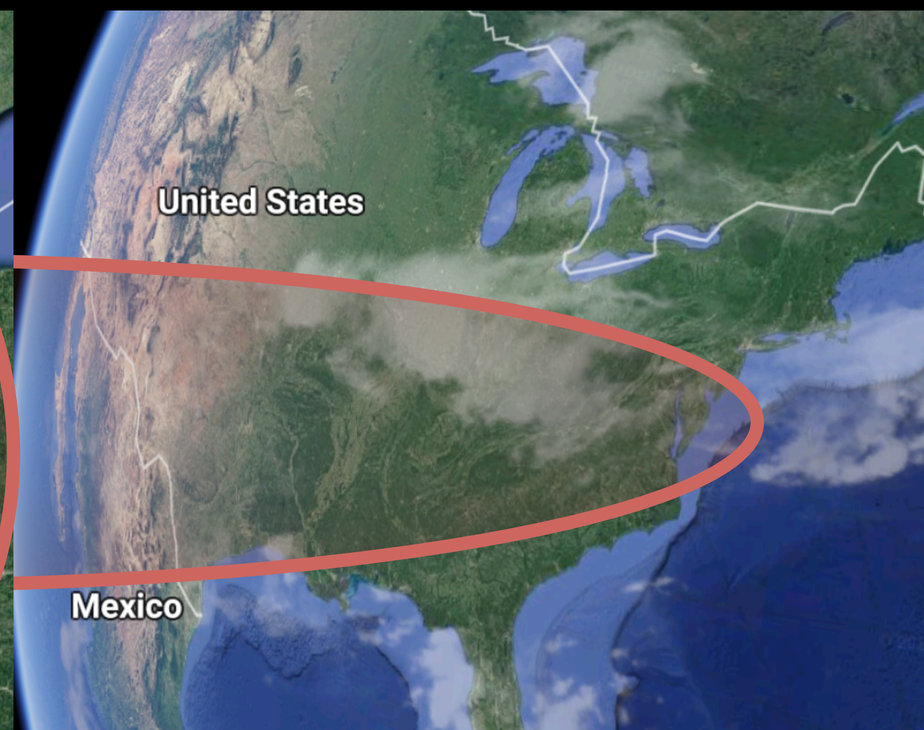
POEMMA



Nadir for UHECR:
Radius 200-400 km

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





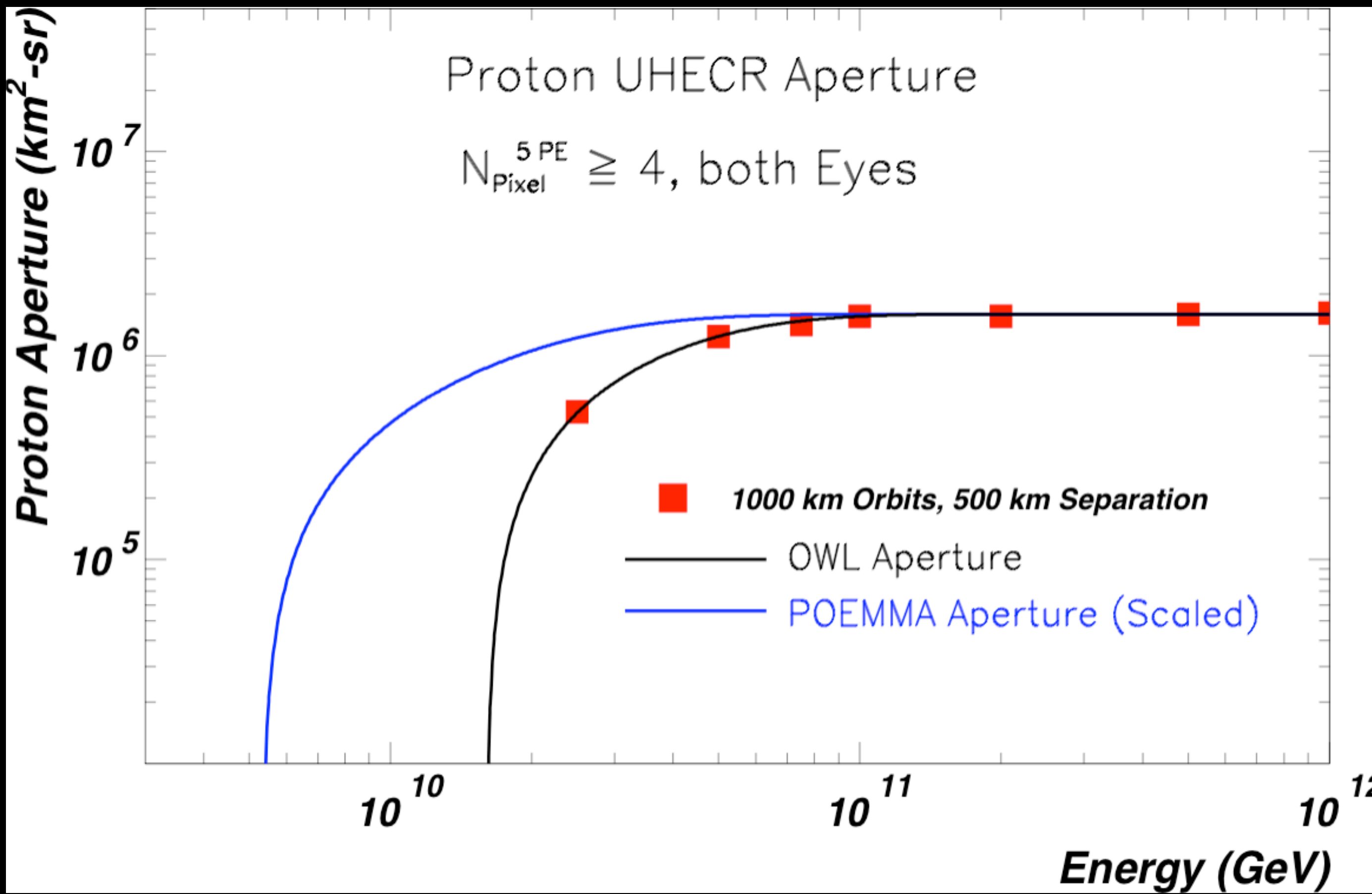
POEMMA to measure UHECR spectrum, composition at the highest energies (to understand the source mechanisms), find significant anisotropies (to identify the sources), and search for cosmogenic neutrinos .

OWL: 5 year mission should achieve 7×10^5 km^2-sr-yr (assuming 10% Duty Cycle)

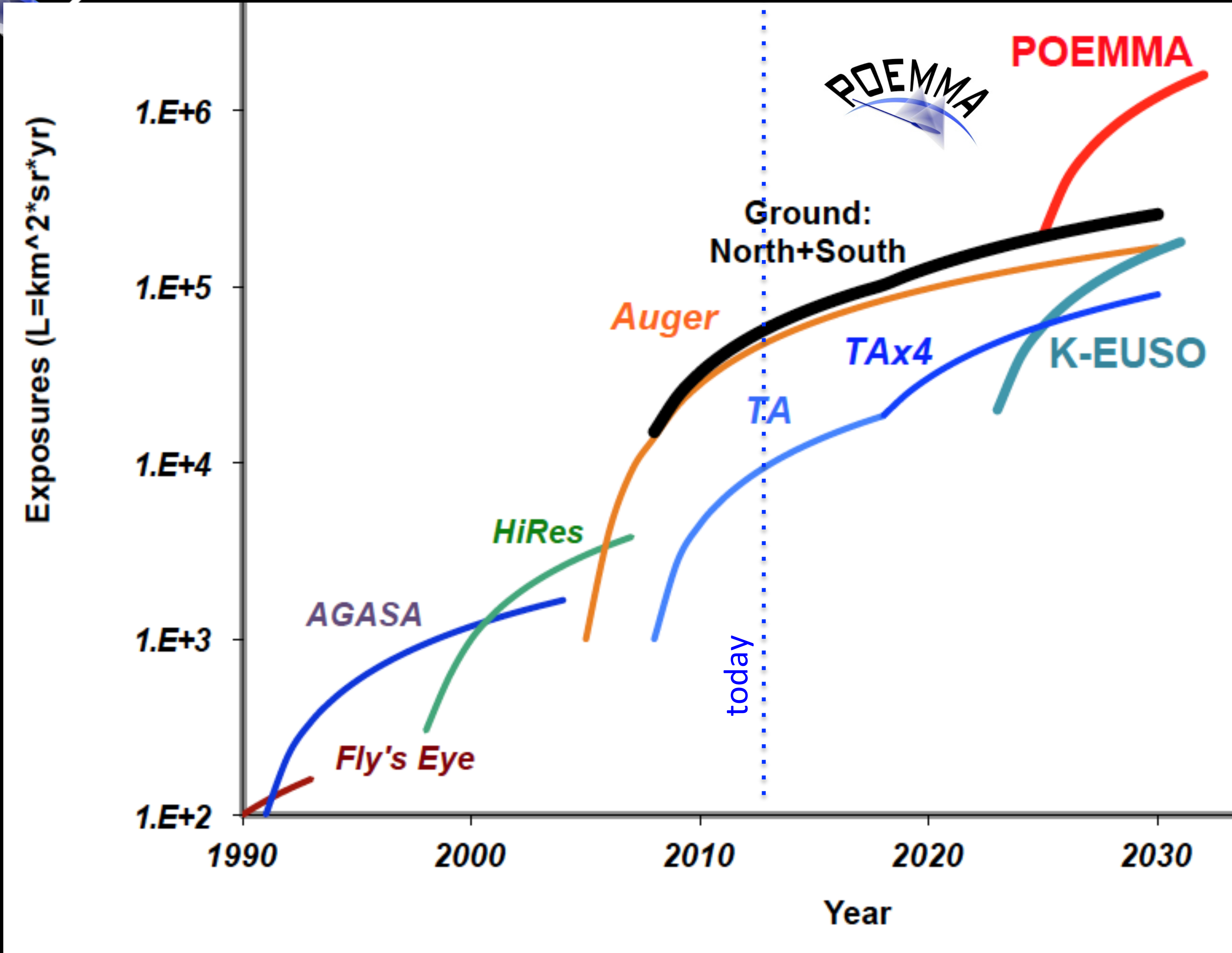
~1° angular resolution

~15% energy resolution around 10^{20} eV.

POEMMA proposed for × 2 improvement in light collection vs OWL, and higher QE of current focal plane detector technology leads to an additional 30% increase.

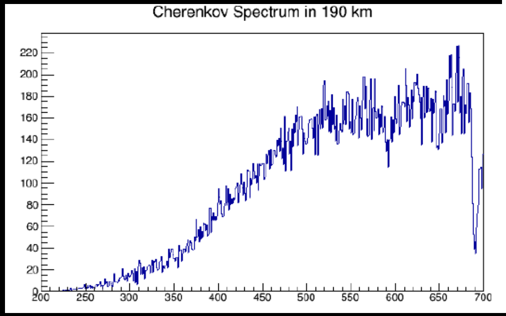


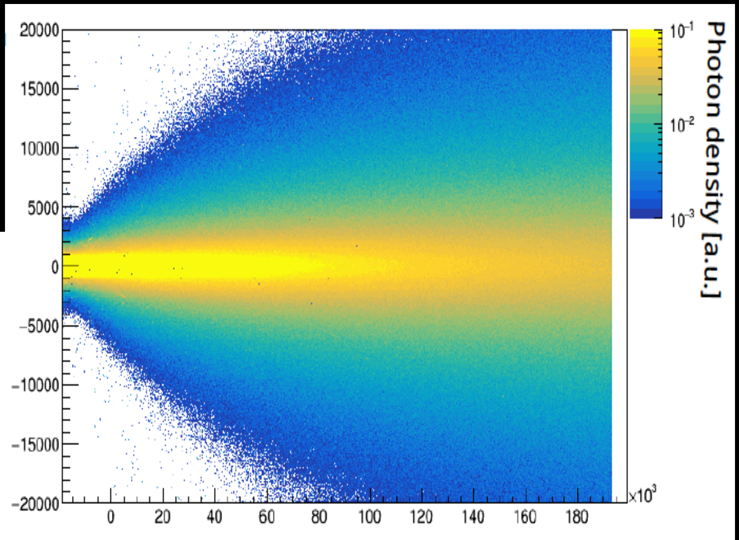
UHECR Exposure History



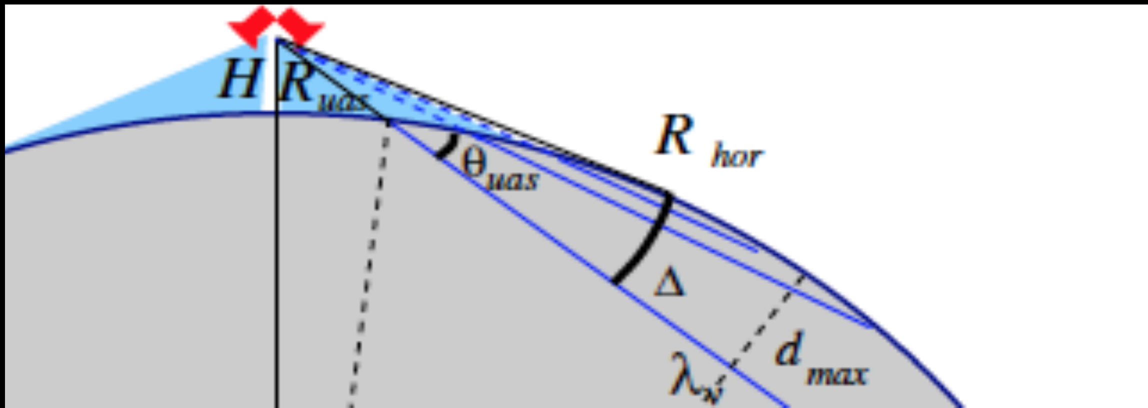
POEMMA Science

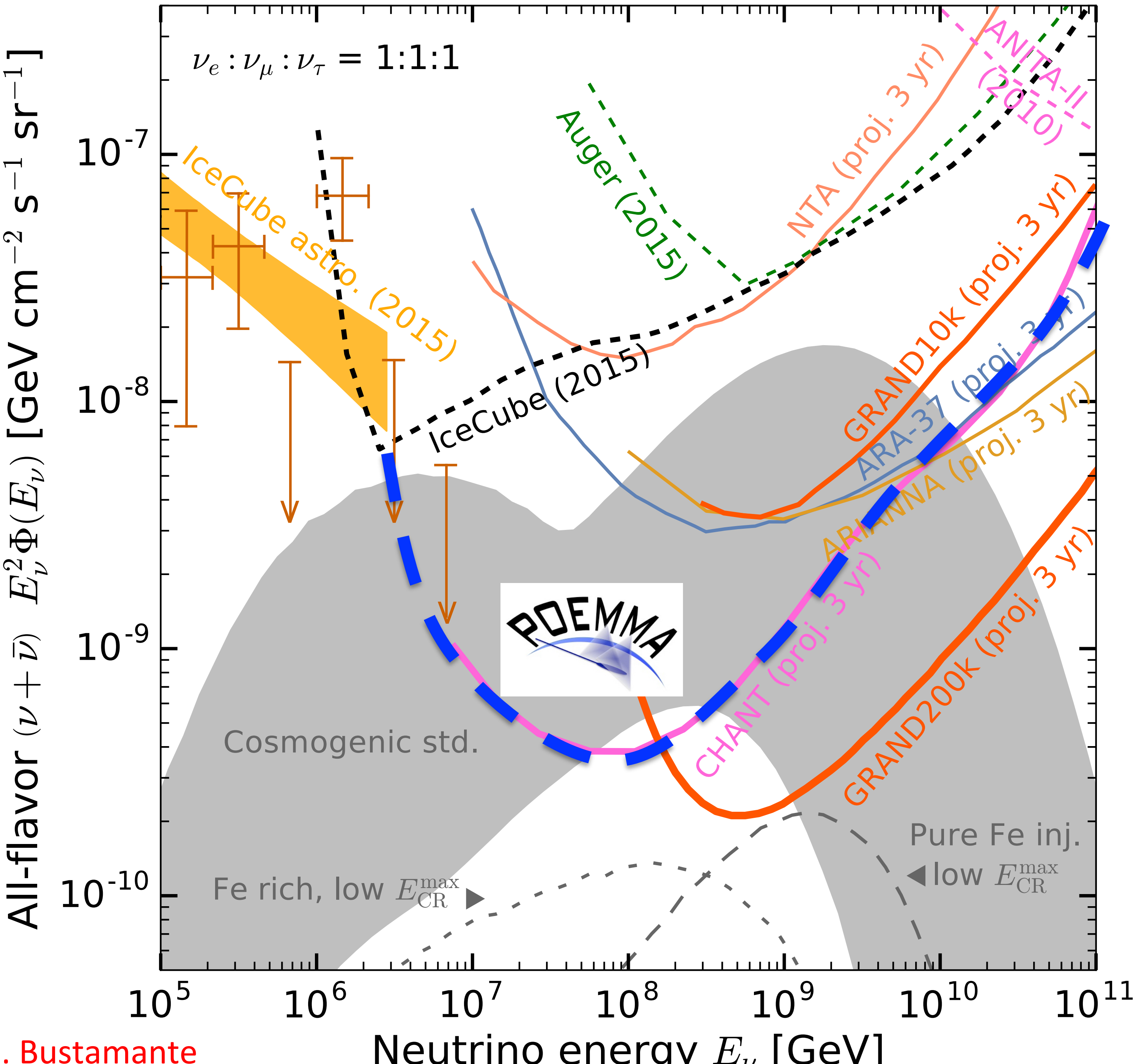
Extensive Air-showers also produces forward moving Cherenkov radiation peaks in the optical range (500 – 700 nm).





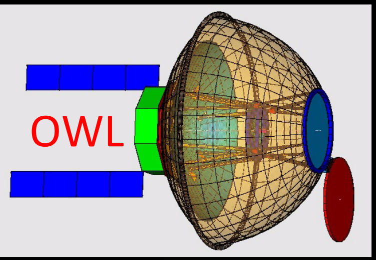
POEMMA will search for the Cherenkov emission from upward going EAS. Up from ground can only be produced by tau-lepton decays generated by UHE tau-neutrinos that crossed the Earth before producing a tau-lepton. These unique events are even rarer than UHECR showers. The strategy in POEMMA is to observe large volumes of Atmosphere towards the limb of the Earth for these rare grazing events.





credit M. Bustamante

Towards Space Probes of Astrophysical and Cosmogenic Neutrinos

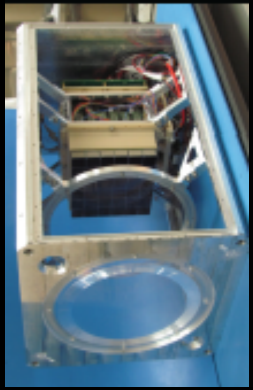


JEM-EUSO

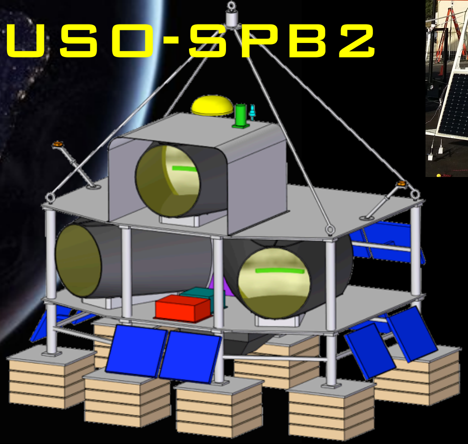
EUSO-SPB1

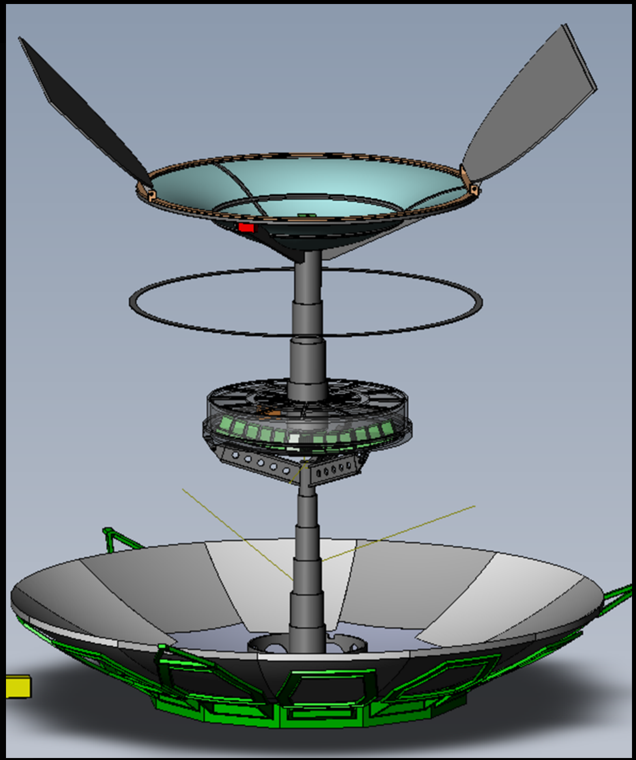
EUSO-Balloon

Mini-EUSO



EUSO-SPB2





POEMMA:

TO Explore the Extreme Multi-Messenger Universe