The EUSO Balloon Program

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Cosmic Ray International Symposium
Portopalo di Capo Passero, Italy
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2014

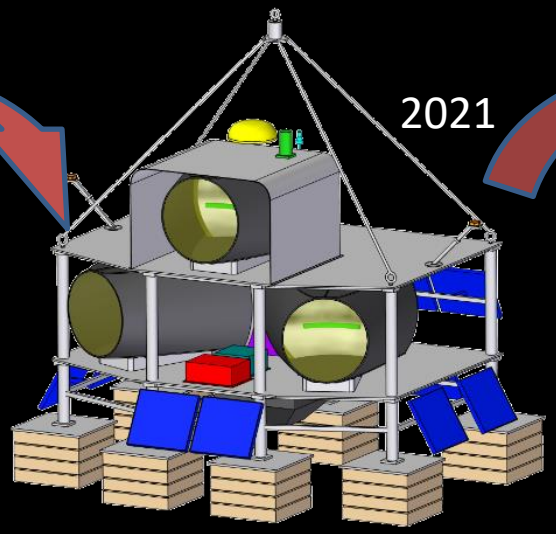
EUSO-Balloon

2017

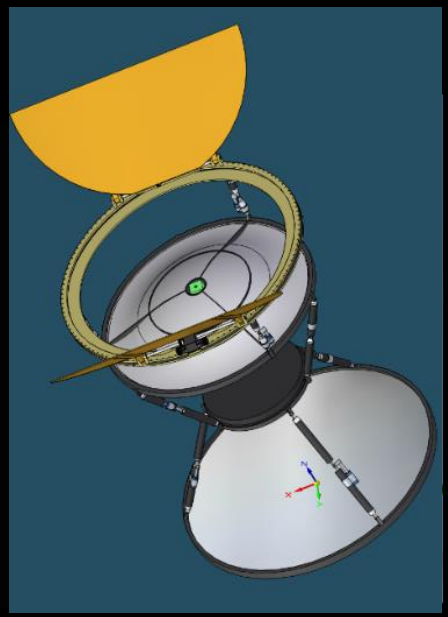
EUSO-SPB1

EUSO-SPB2

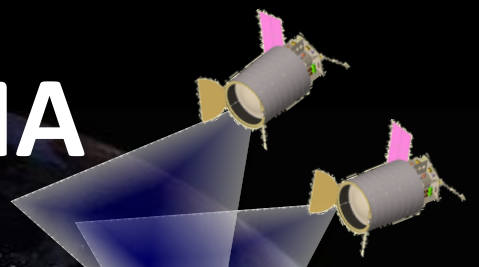
2021



2029



POEMMA

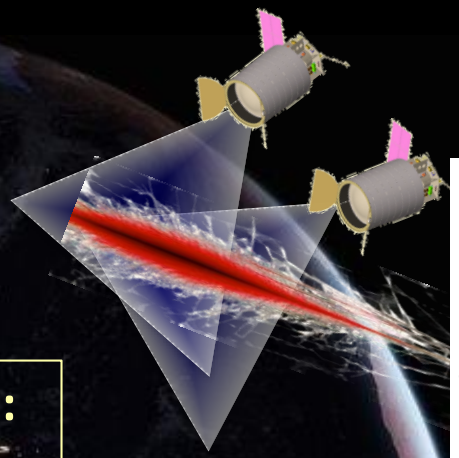


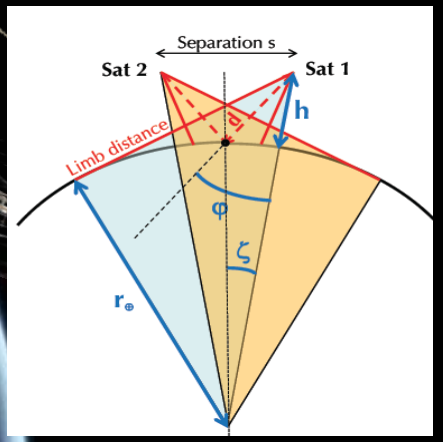
POEMMA will open two new Cosmic Windows:
Neutrinos from astrophysical to cosmogenic (> 10s PeV), and
UHECRs (> 10s EeV) to realize charged-particle astronomy

Space provides order of magnitudes improved sensitivity over a wide range of energies.

POEMMA's goal is to understand the most extreme astrophysical accelerators and explore fundamental physics well above terrestrial accelerator energies.

POEMMA UHECRs

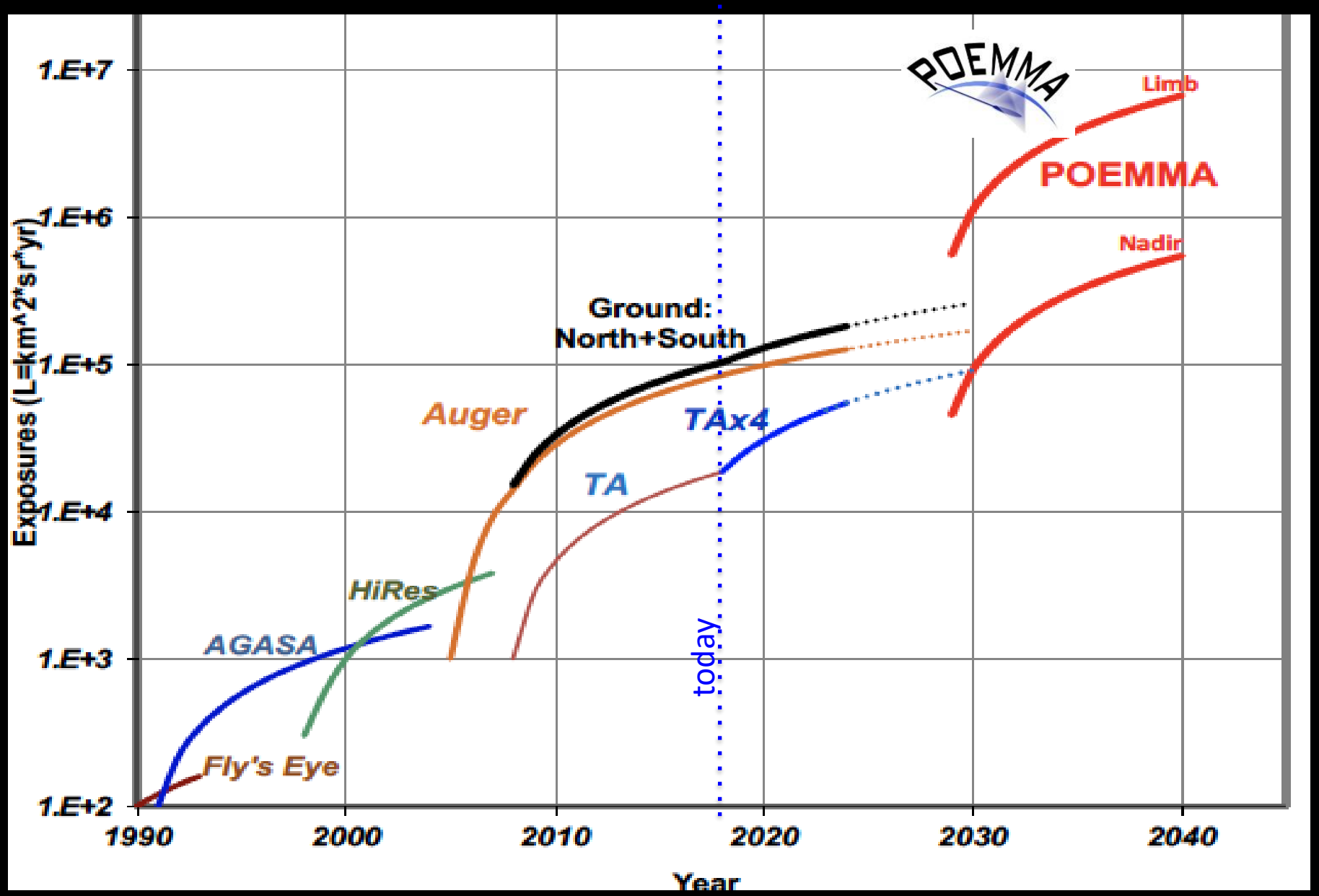




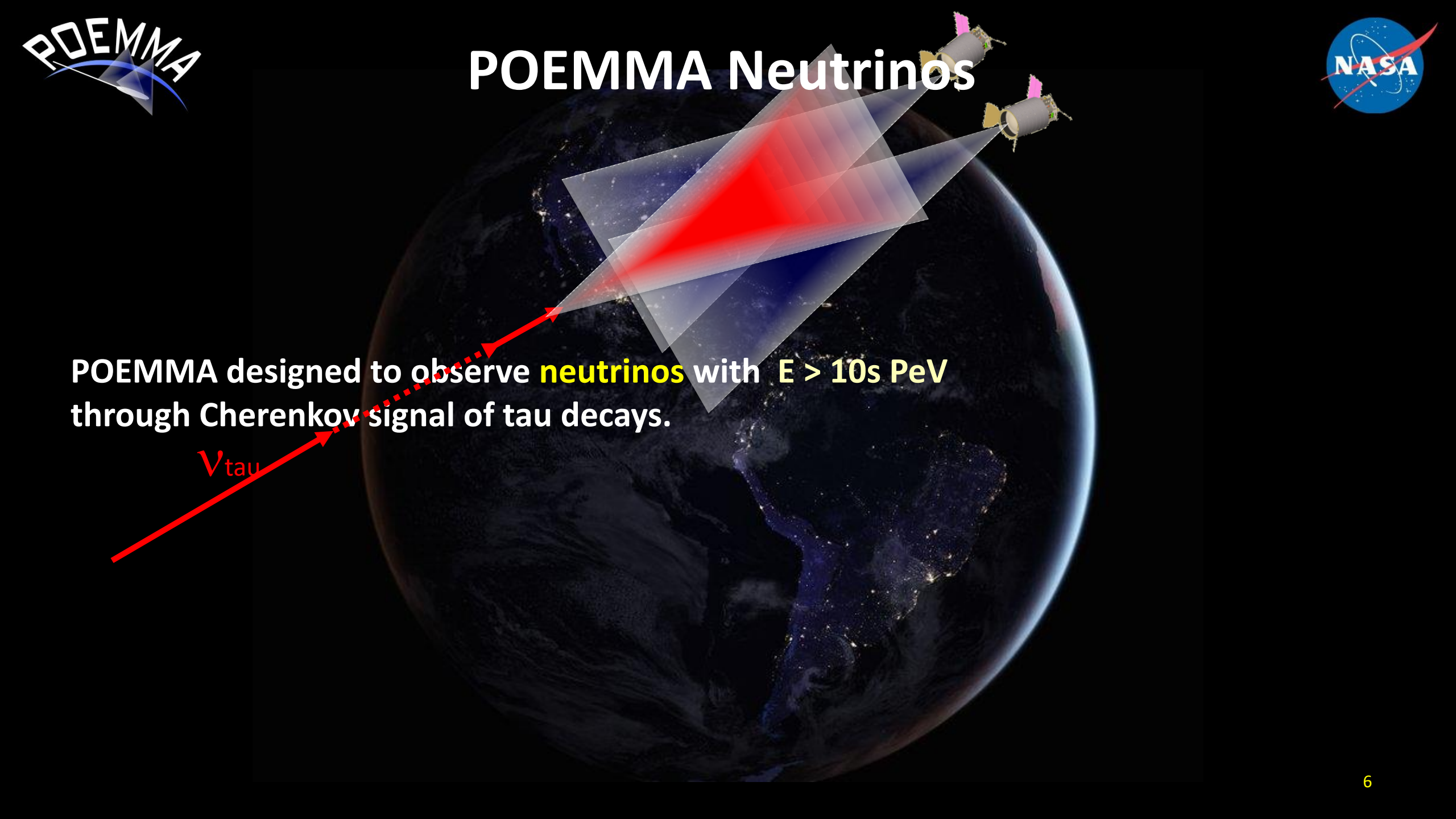
Stereo observation of the air fluorescence signal of EASs:

- Achieve significant increase in exposure via space-based observations (x10 arrays; x100 fluorescence) with full-sky coverage
- Achieve good angular and energy resolution
- Achieve sufficient X_{MAX} resolution to perform UHECR composition measurements

UHECR Exposure History



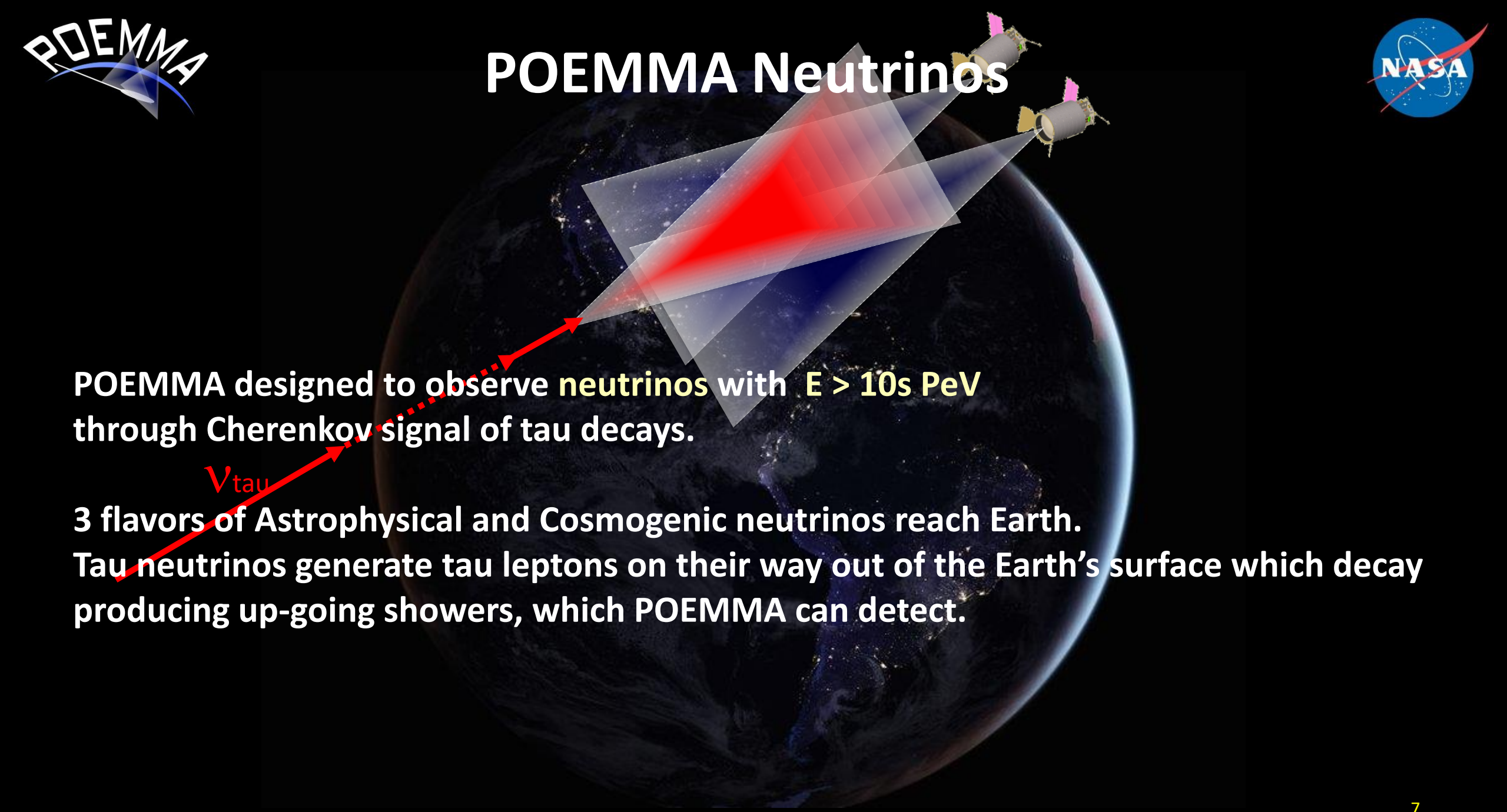
POEMMA Neutrinos



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

ν_{tau}

POEMMA Neutrinos



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

ν_{tau}

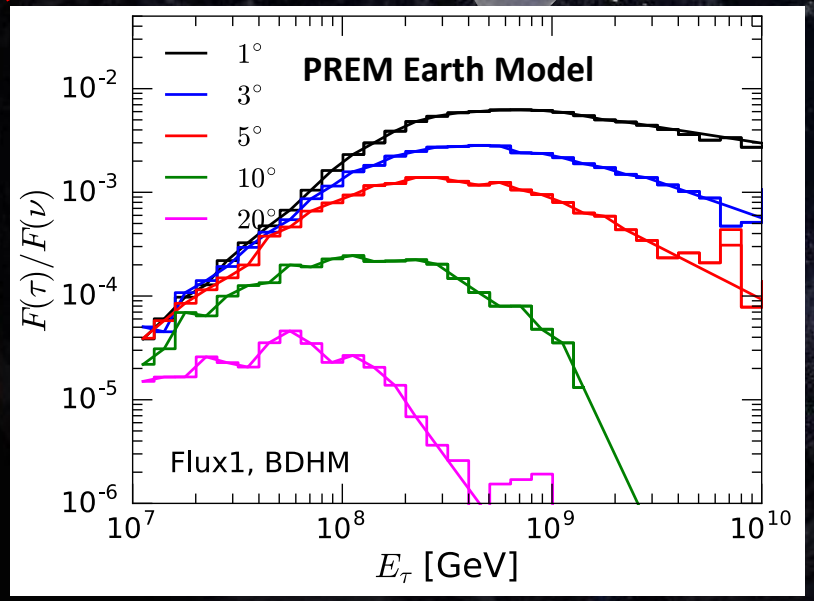
3 flavors of Astrophysical and Cosmogenic neutrinos reach Earth.
Tau neutrinos generate tau leptons on their way out of the Earth's surface which decay producing up-going showers, which POEMMA can detect.

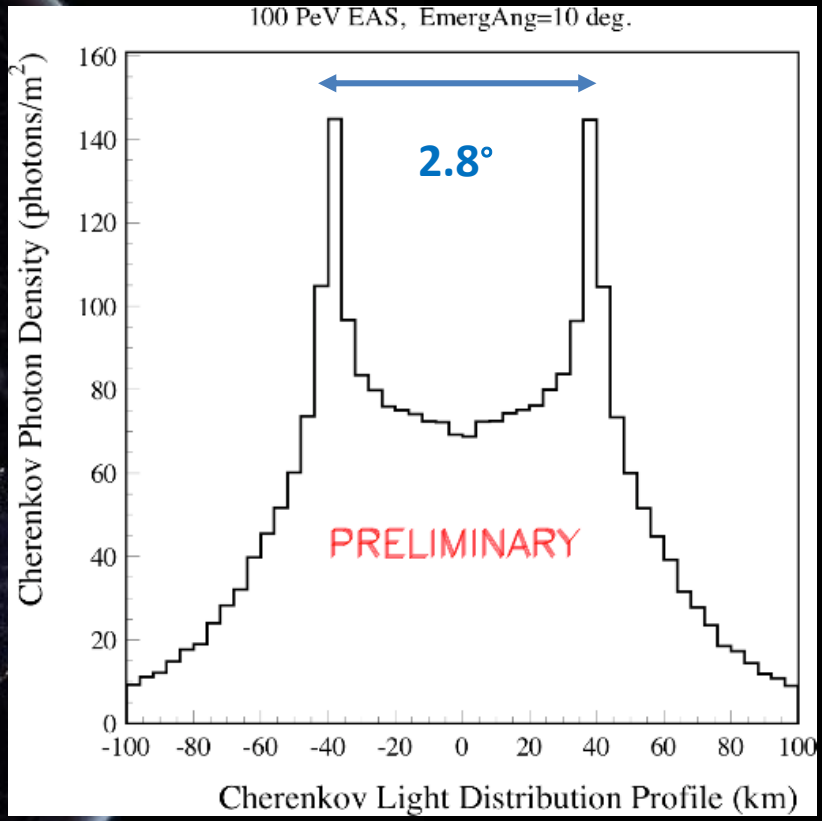
POEMMA Neutrino Detection

POEMMA designed to observe neutrinos with $E_\nu \gtrsim 10$ PeV through the Cherenkov signal from upward-moving EAS induced by tau decays in the atmosphere

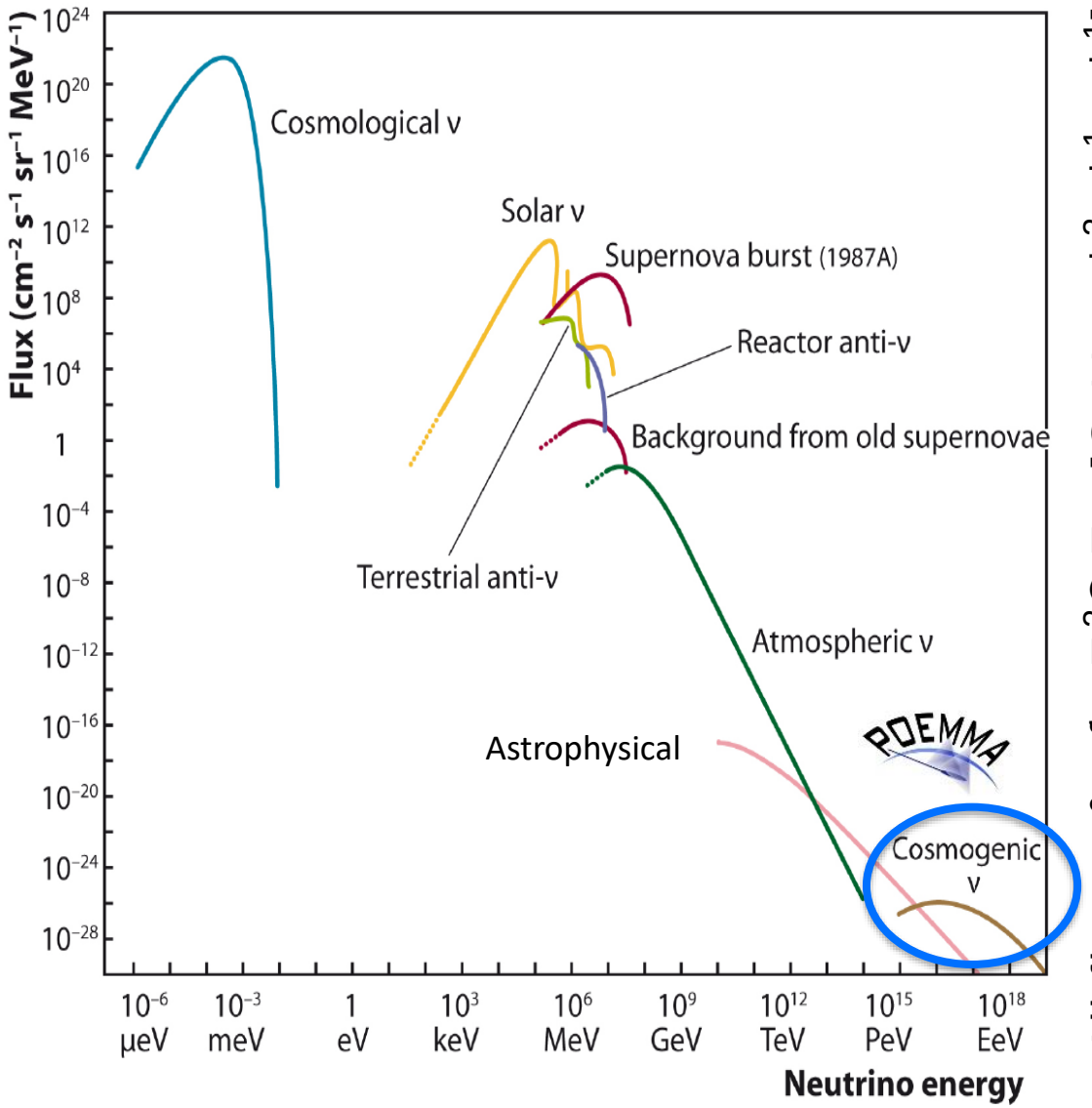
See Hallsie Reno's talk U17.00002 : Tau neutrino signals at POEMMA

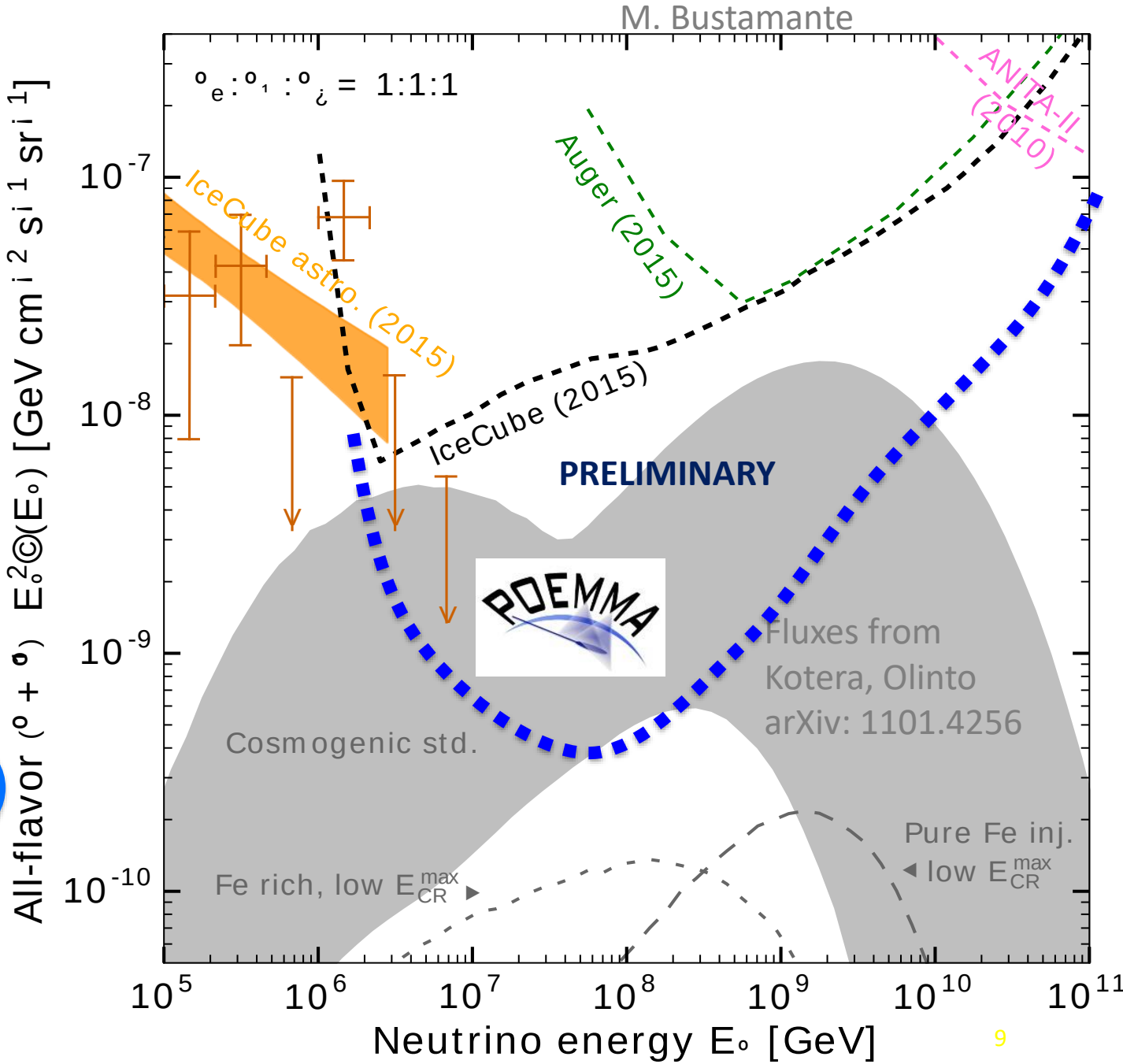
ν_{tau}





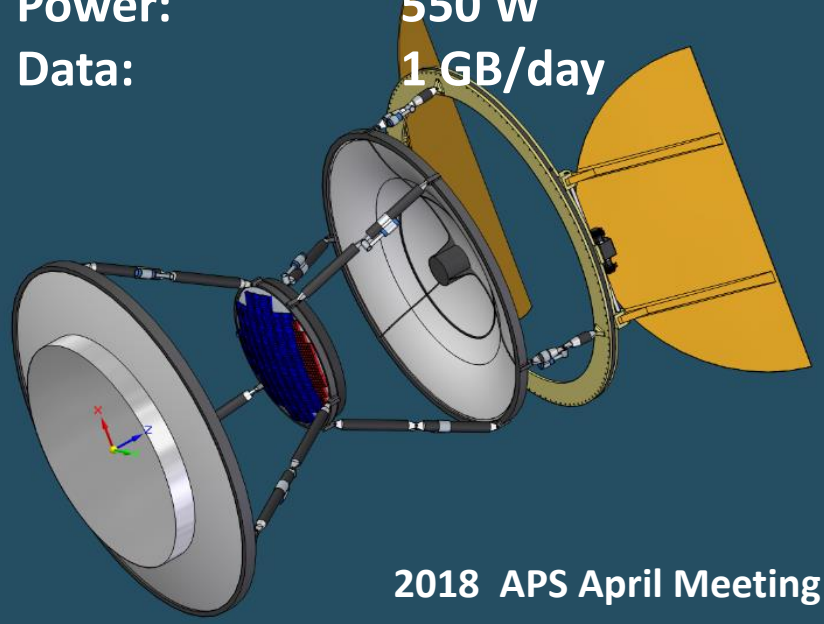
Flux1: Mixed-Composition, Kotera, Allard, Olinto (JCAP 1010:013,2010)


Flux (cm⁻² s⁻¹ sr⁻¹ MeV⁻¹)
Cosmological ν
Solar ν
Supernova burst (1987A)
Reactor anti-ν
Background from old supernovae
Terrestrial anti-ν
Atmospheric ν
Astrophysical
Cosmogenic ν
POEMMA
μeV
meV
eV
keV
MeV
GeV
TeV
PeV
EeV
Neutrino energy

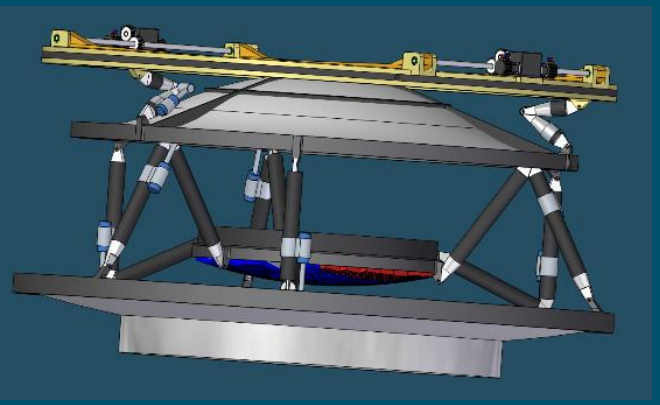

M. Bustamante
$\phi_e : \phi_\mu : \phi_\tau = 1:1:1$
ANITA-II (2010)
Auger (2015)
IceCube astro. (2015)
IceCube (2015)
PRELIMINARY
PUEMMA
Fluxes from Kotera, Olinto arXiv: 1101.4256
Cosmogenic std.
Pure Fe inj.
low E_{CR}^{max}
Fe rich, low E_{CR}^{max}
All-flavor $(\phi + \bar{\phi})$ $E_\nu^2 \Phi(E_\nu)$ [GeV cm⁻² s⁻¹ sr⁻¹]
Neutrino energy E_ν [GeV]

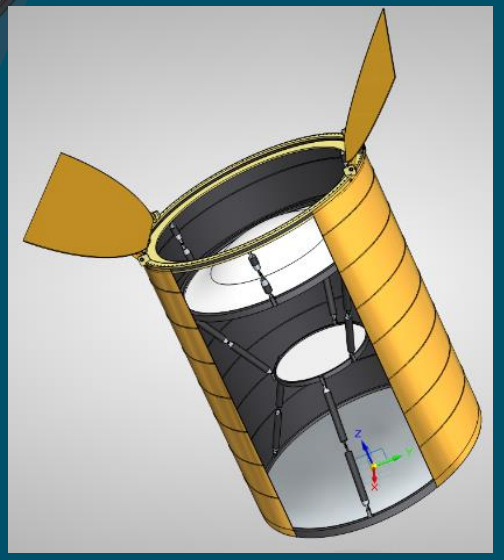
POEMMA INSTRUMENT

Two 4 meter F/0.64 Schmidt telescopes: 45 deg FoV
Hybrid focal surface (MAPMTs and SiPM)
3 mm linear pixel size: 0.084 deg pixel FoV
Instrument Mass: 1,547 kg
Primary Mirror: 4 meter diameter
Corrector Lens: 3.3 meter diameter
Focal Surface: 1.6 meter diameter
Optical Area$_{EFF}$: ~6 to 2 m2
Power: 550 W
Data: 1 GB/day



Stowed Configuration Launch

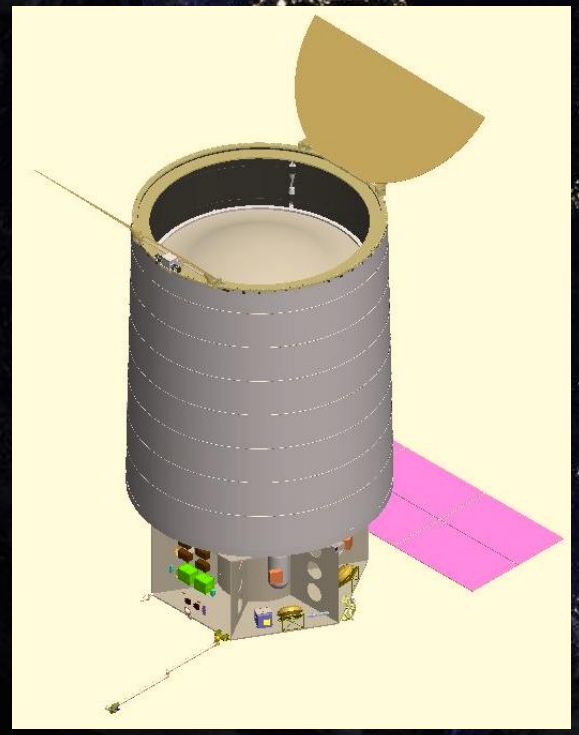


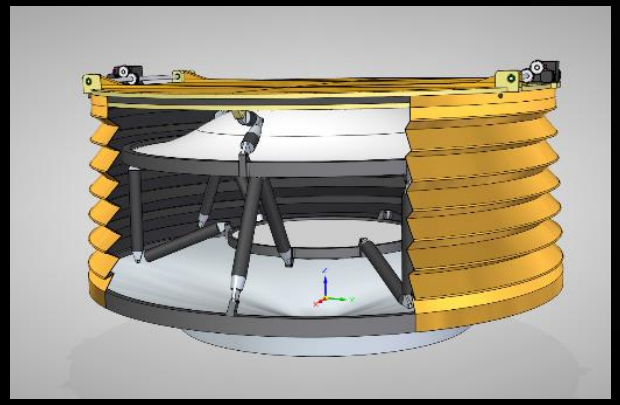


POEMMA MISSION

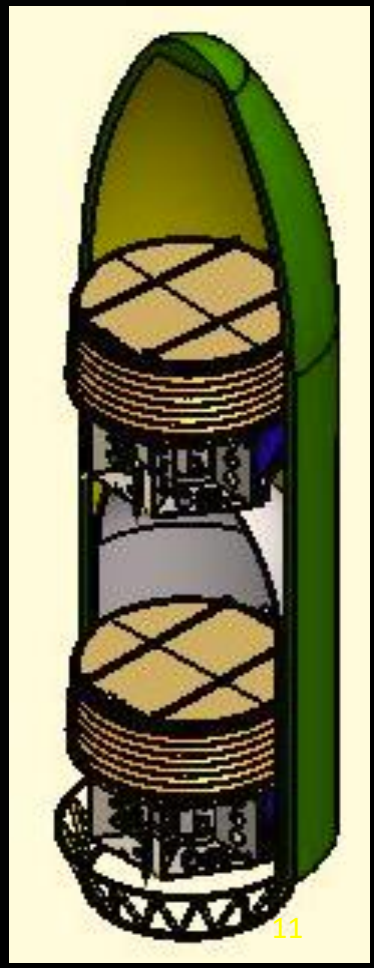
Class B Mission
3-year Prime Mission,
5-year Mission Goal
LEO 525 km, 28.5° inclination
~1500 km to 25 km separation
Controlled re-entry/decommission
Phase A start 10/2023
(NASA HQ guidance)
Launch 11/2029
(MDL forecast)

Spacecraft have ability to slew for transient event follow-up observations





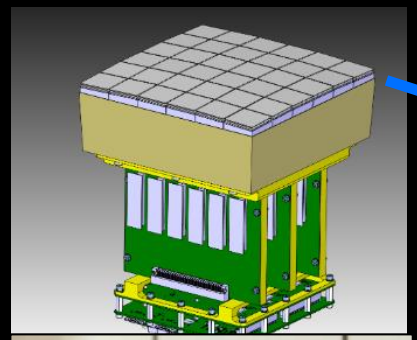
Dual Manifest ATLAS V LPF

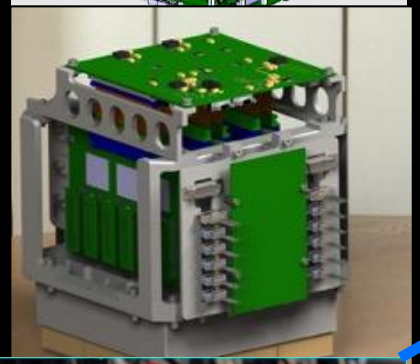


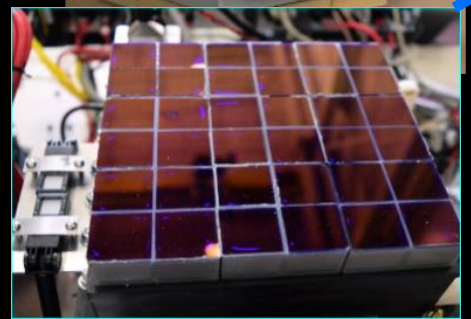
POEMMA
Hybrid MM Focal Surface

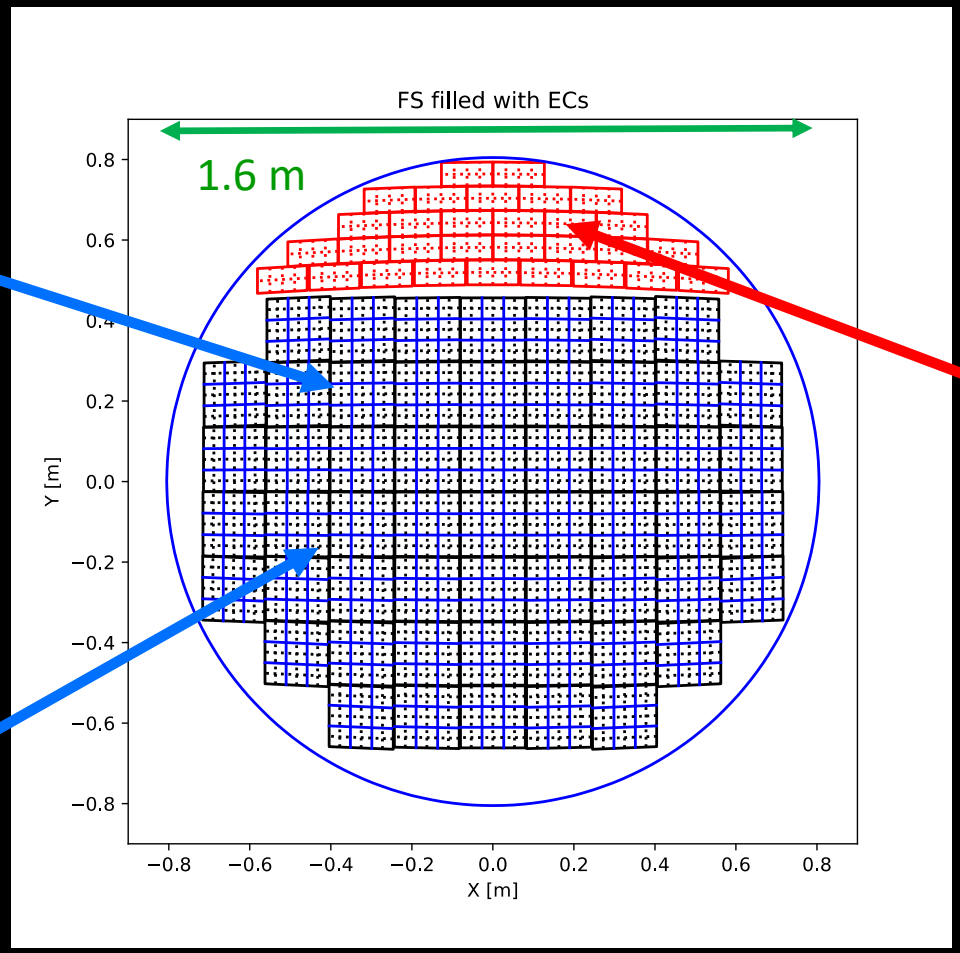
~ 150k 3 mm pixels

UV Fluorescence Detection using MAPMTs with BG3 filter

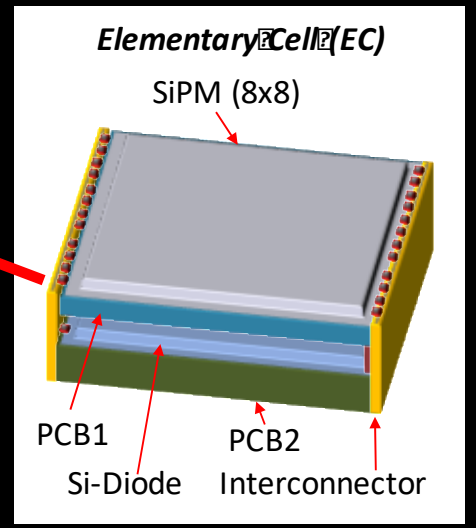








Cherenkov Detection with SiPMs

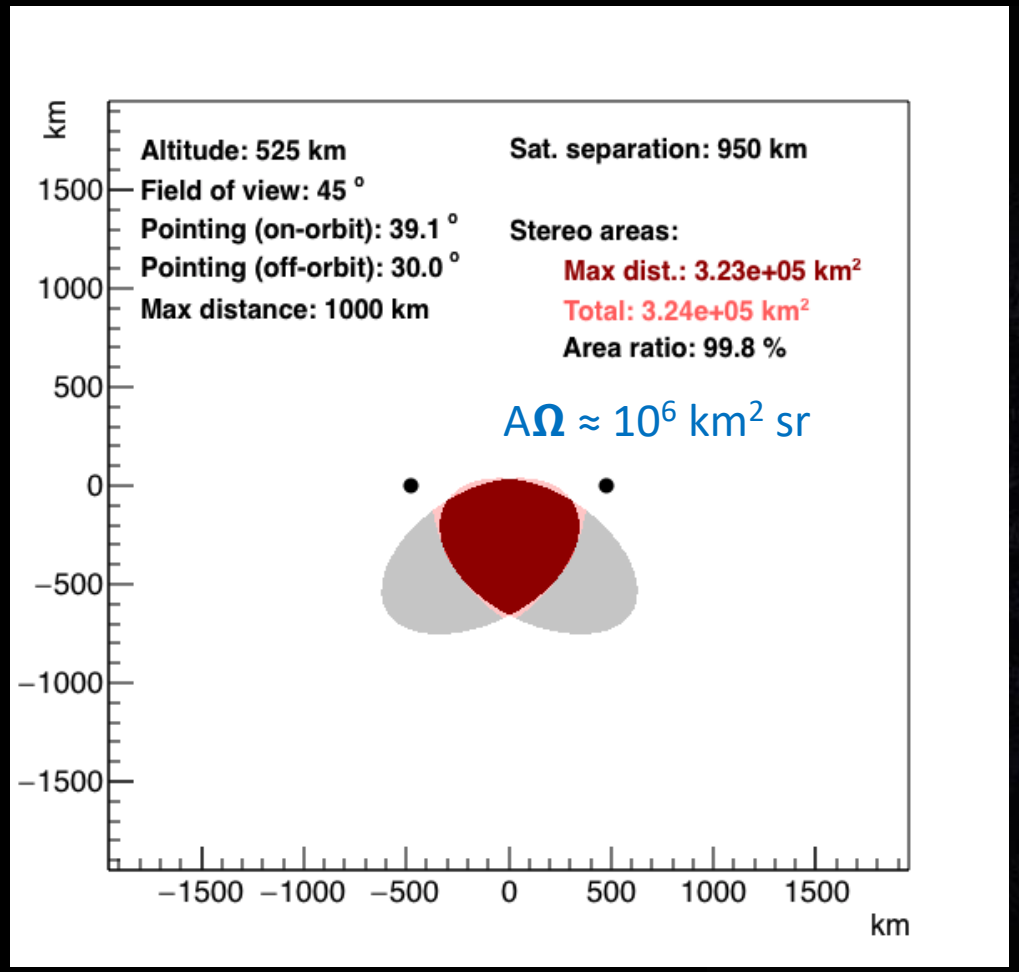


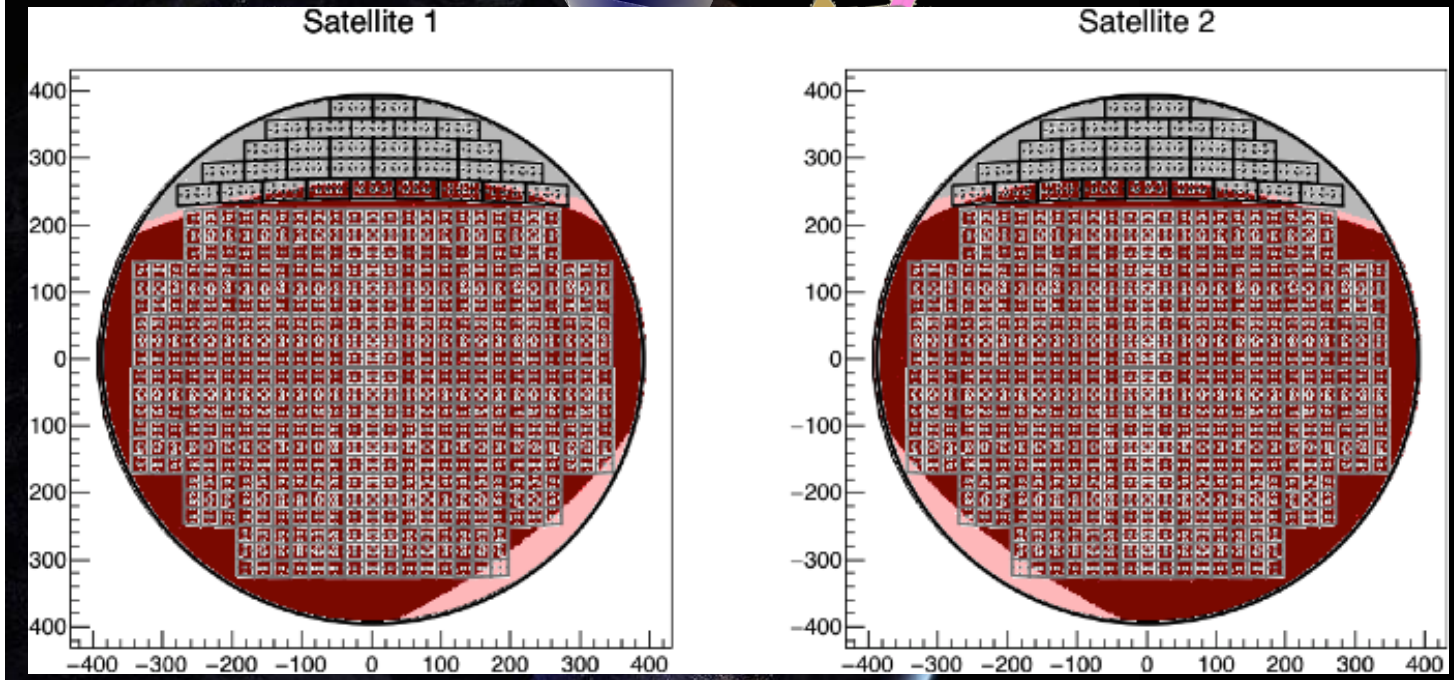
30 SiPM focal surface units
Total 15,360 pixels
512 pixels per FSU (64x4x2)

55 Photo Detector Modules (PDMs)= 126,720 pixels

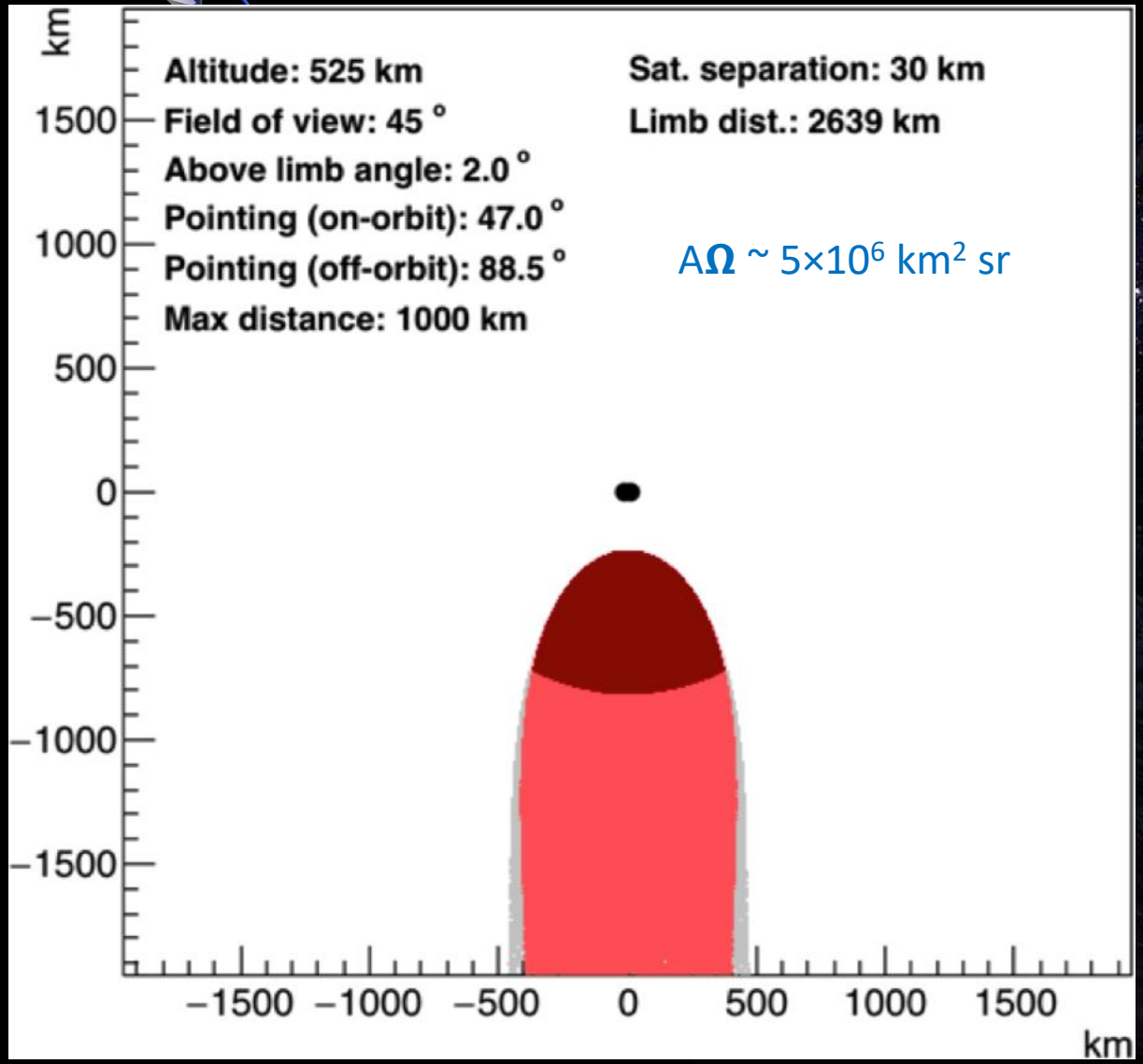
1 PDM = 36 MAPMTs = 2,304 pixels

Example UHECR–mode Configuration

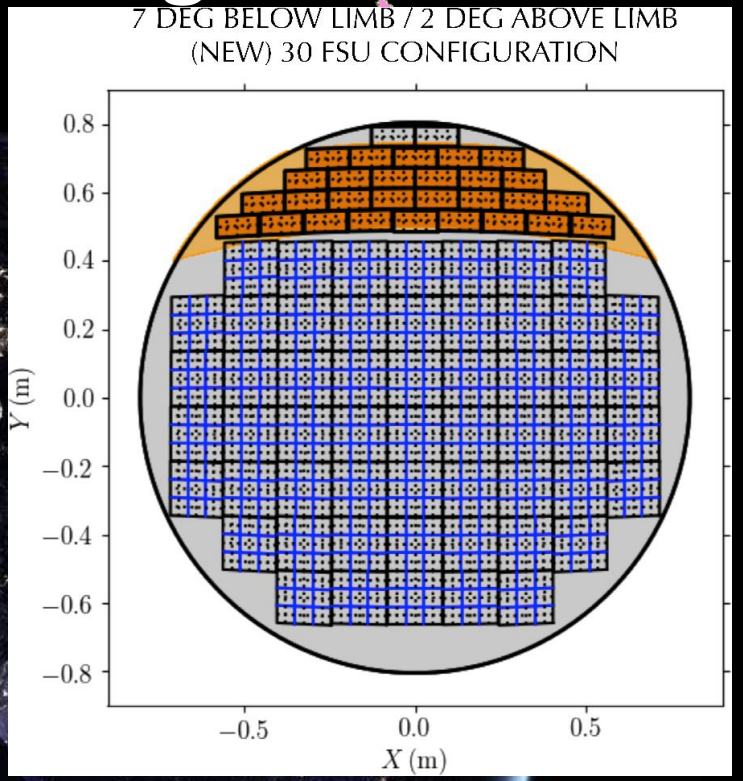


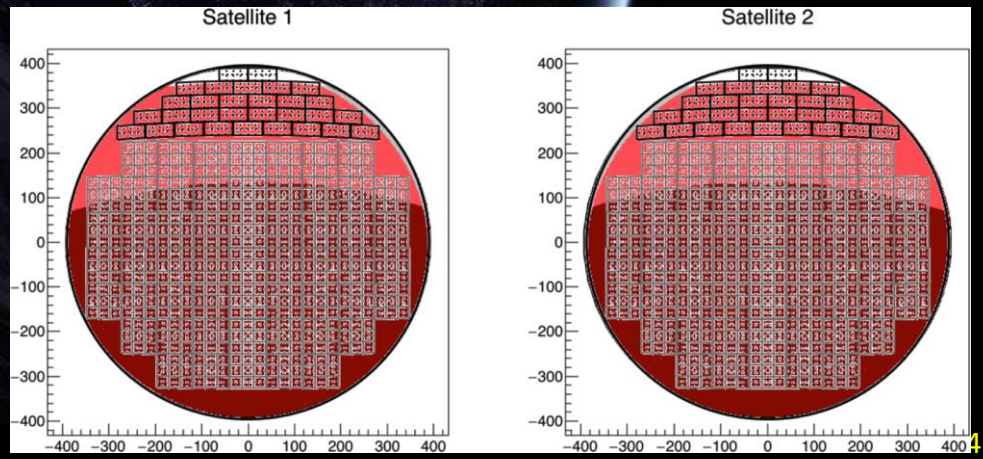


Example Neutrino–mode Configuration



AΩ ~ 5×10^6 km^2 sr

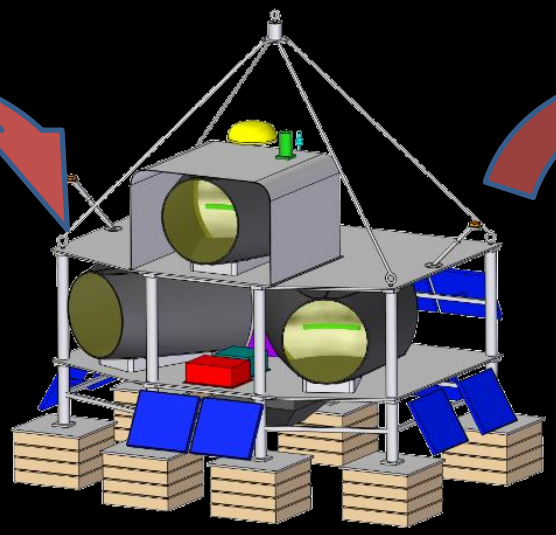


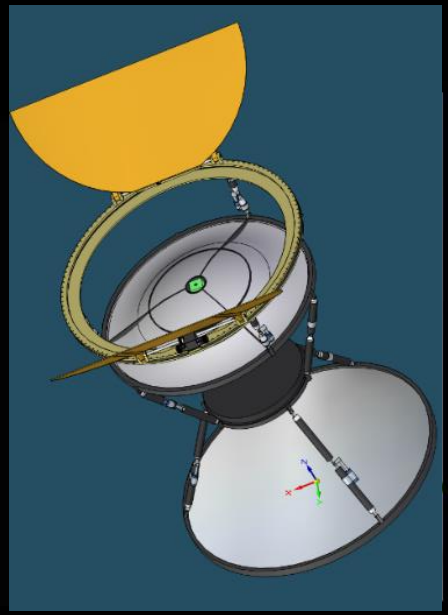


EUSO-SPB2

EUSO-SPB1

EUSO-Balloon

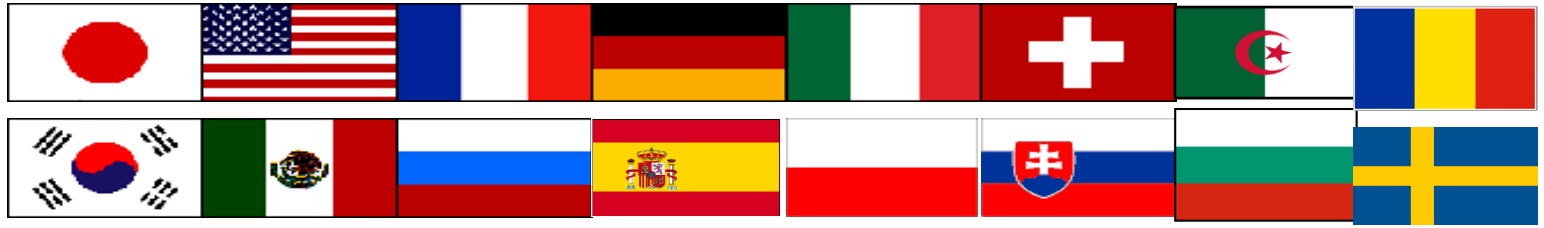




JEM-EUSO Collaboration

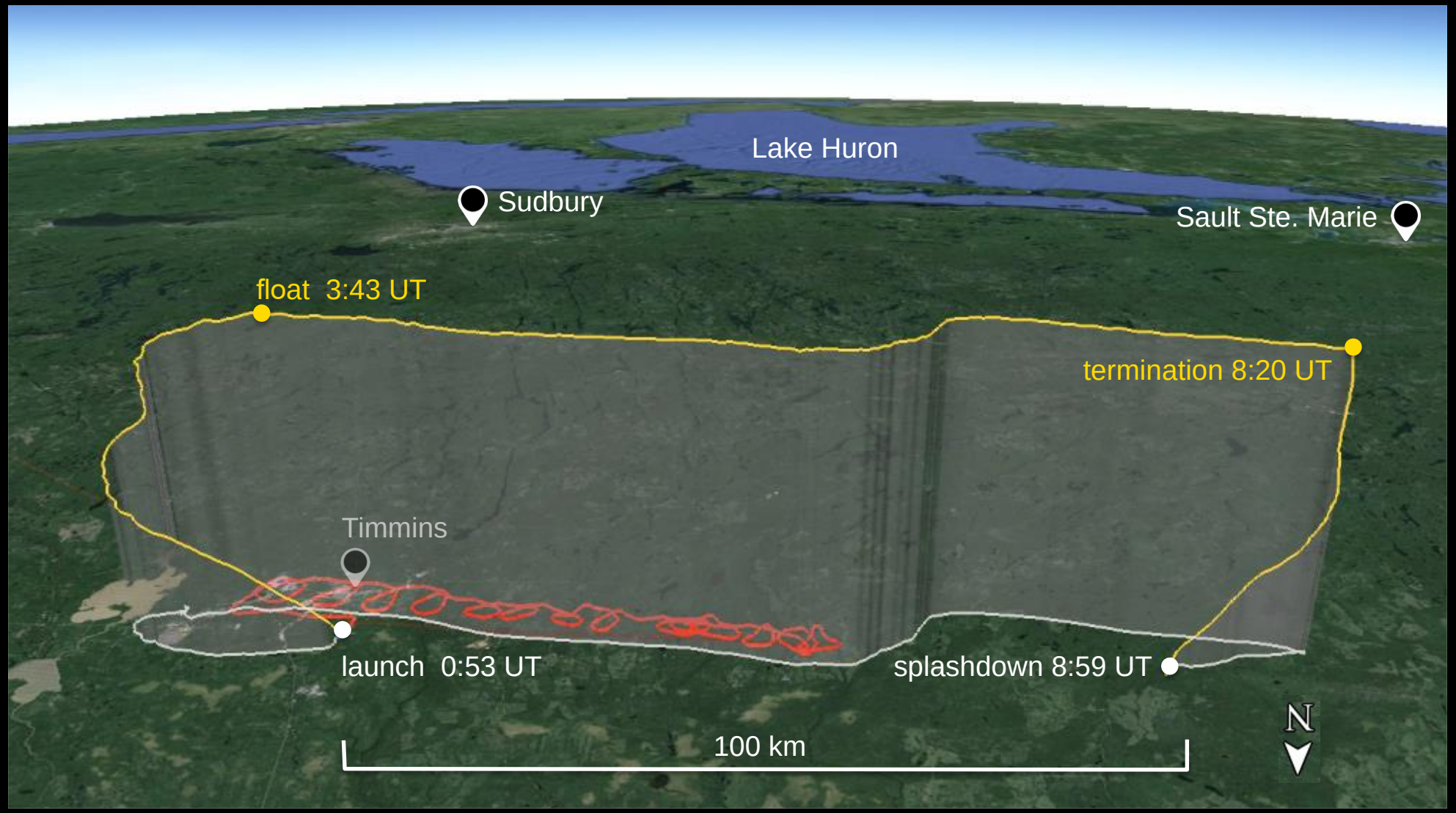
Japan, USA, Korea, Mexico, Russia, Algeria, Bulgaria, France, Germany, Italy, Poland, Romania, Slovakia, Spain, Switzerland, Sweden

16 Countries, 77 Institutions, >300 researchers



EUSO Balloon first flight

EUSO-Balloon: was launched on August, 24 2014 from Timmins, (Canada)



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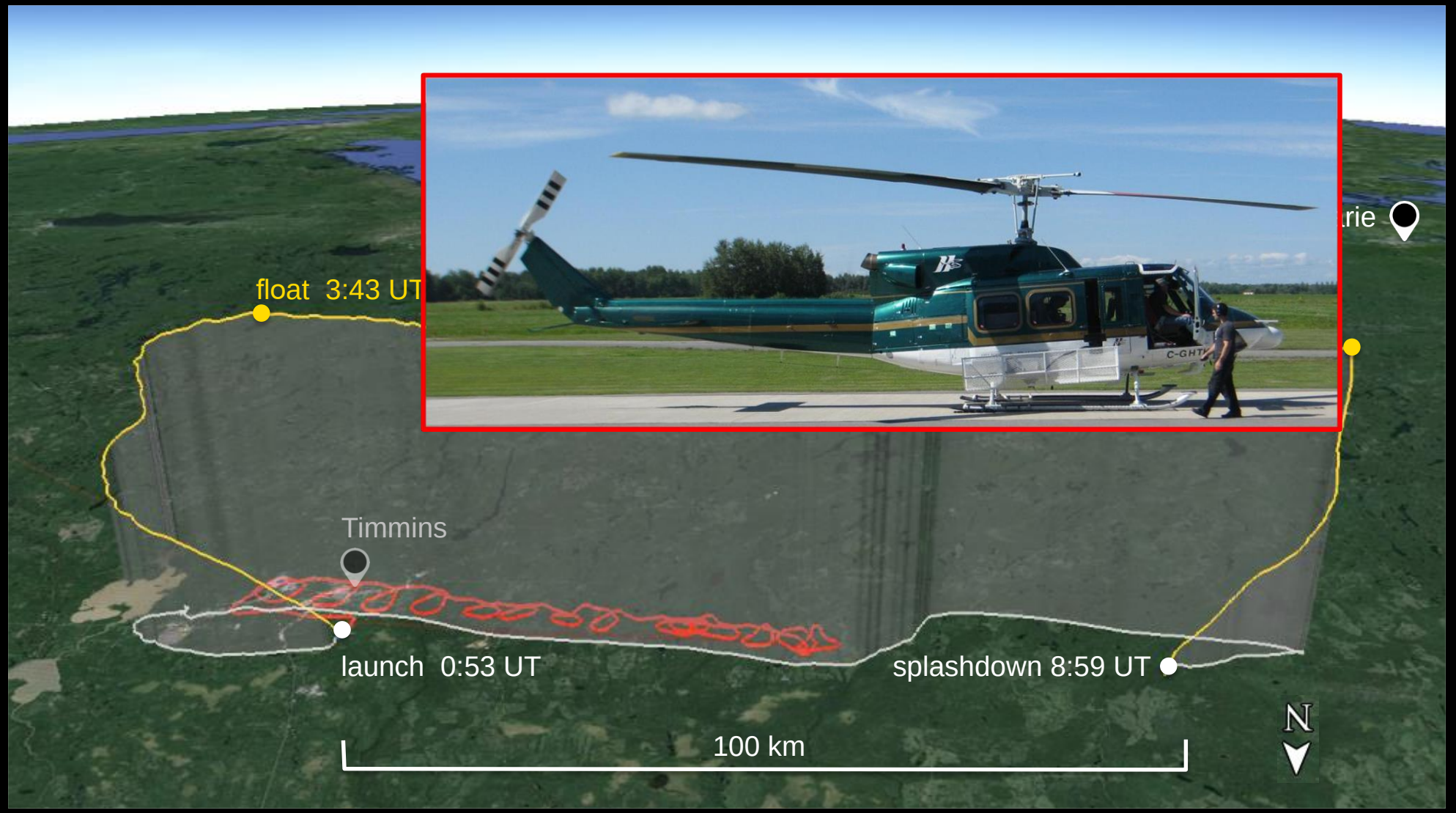
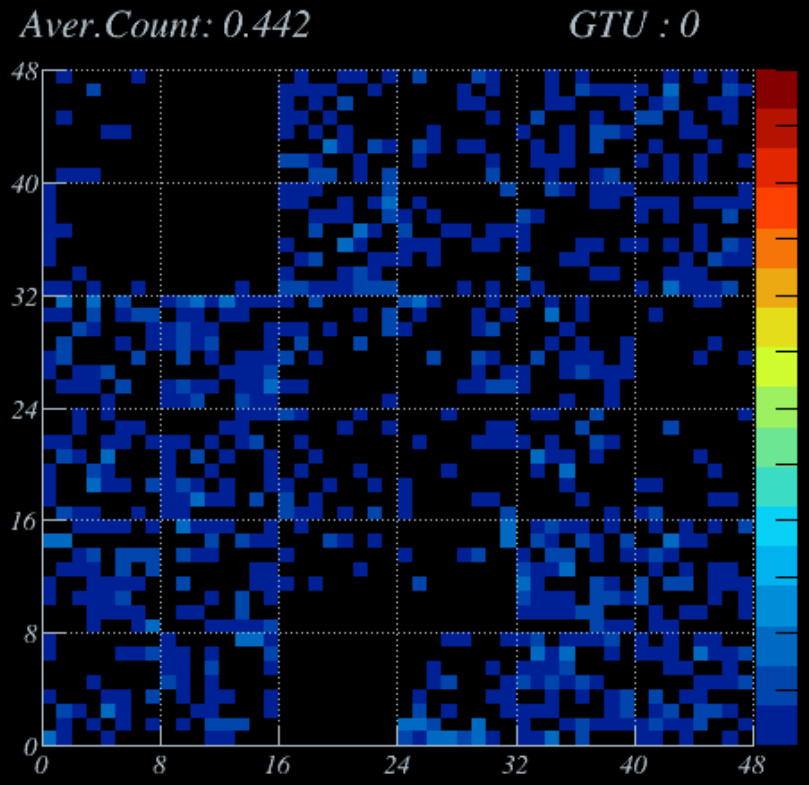
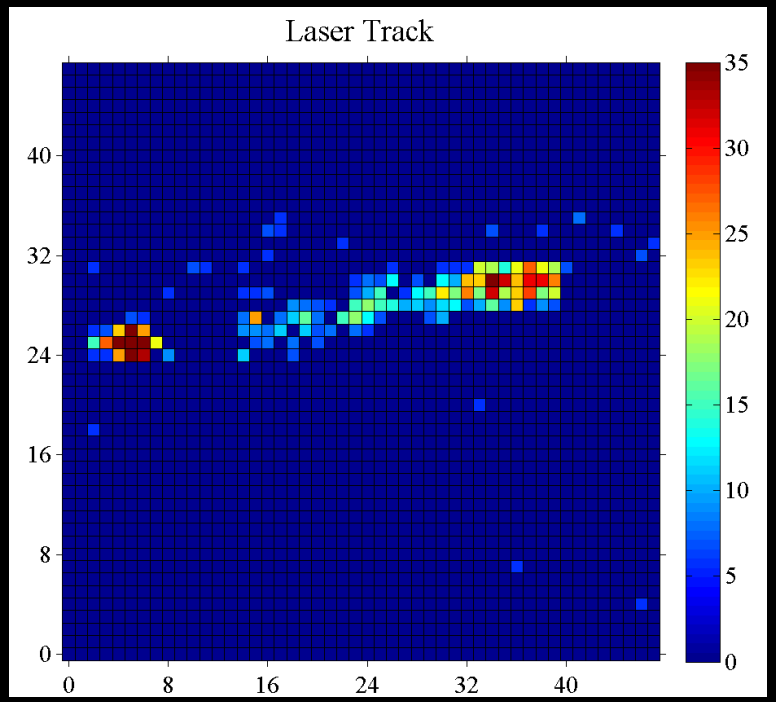


EUSO-Balloon 2014 Timmins Canada
Flasher & Laser events

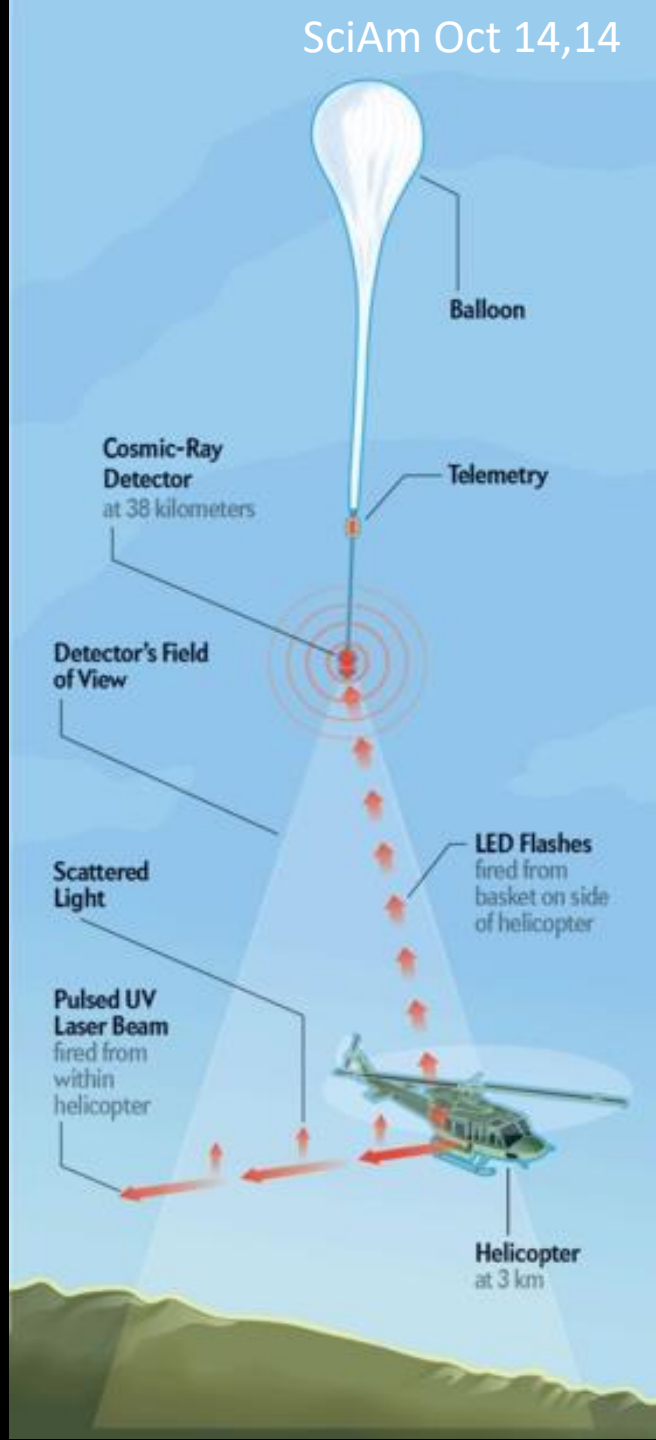




355nm Laser: ~10^{20} eV equivalent brightness

"*First observations* of *speed* of *light* tracks by a fluorescence *detector* looking *down* on the atmosphere",
2018, JINST 13 P05023, The JEM-EUSO collaboration.

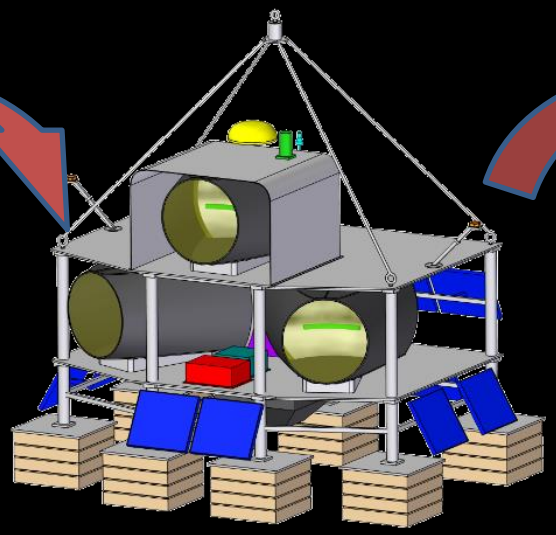
SciAm Oct 14,14

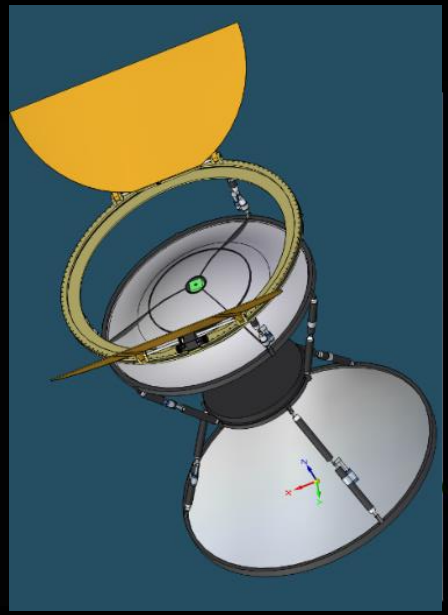


EUSO-SPB2

EUSO-SPB1

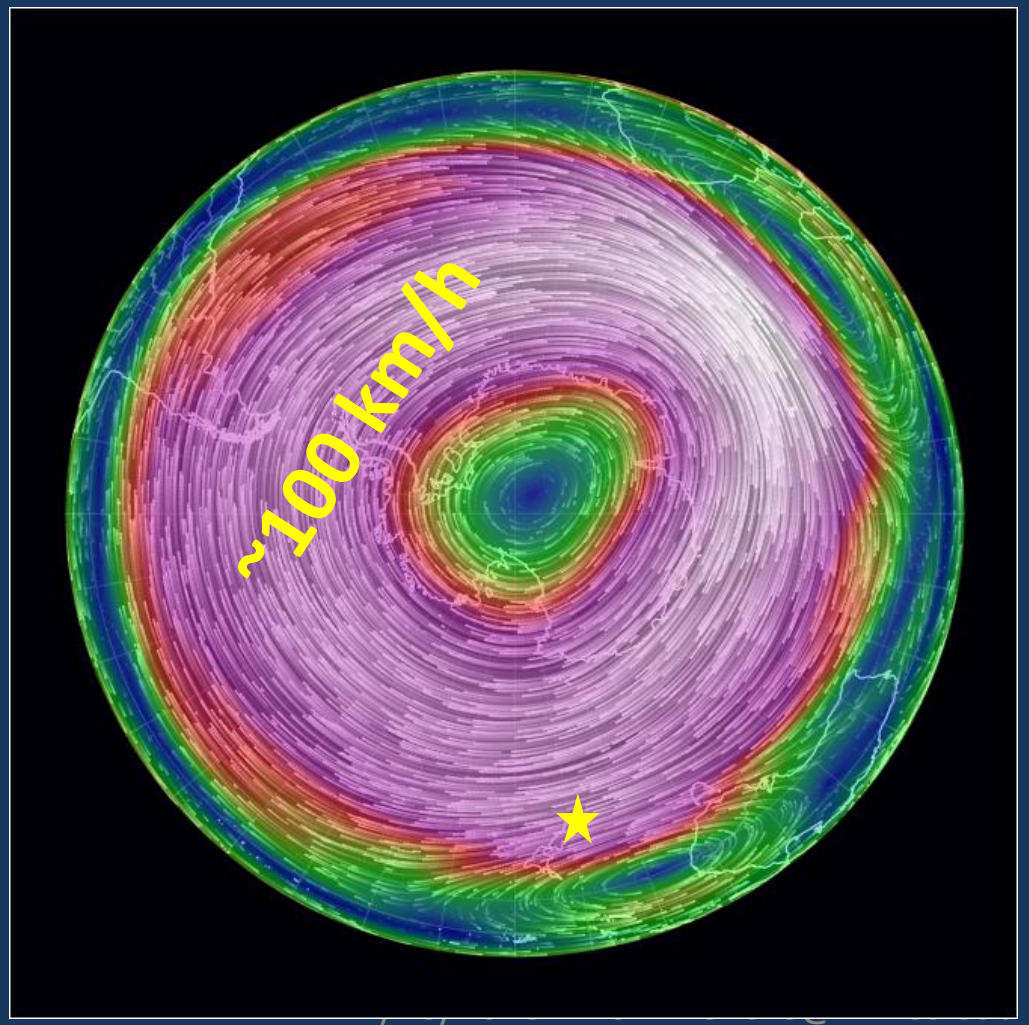
EUSO-Balloon



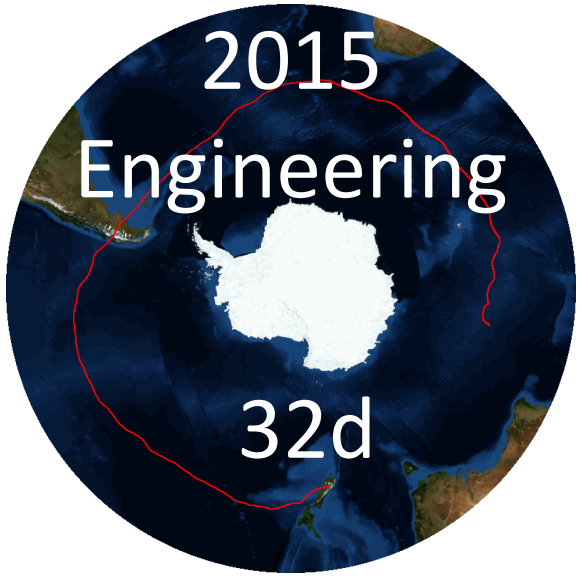


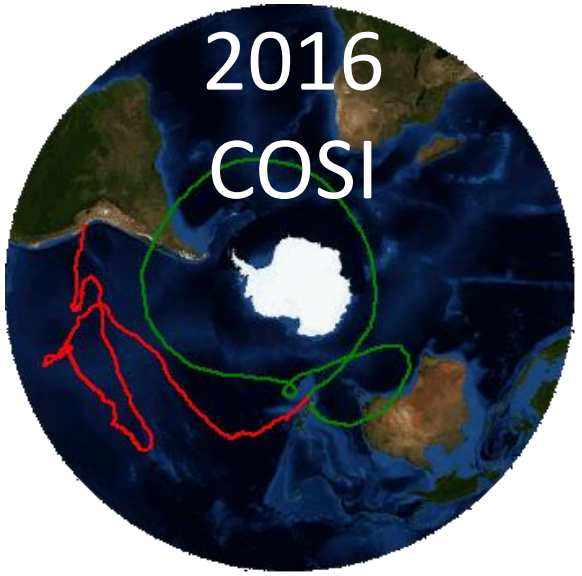
NASA's Long Duration Balloon Program from NZ

"Ton of science
Target duration:
100 days"



EUSO-SPB1 Goals

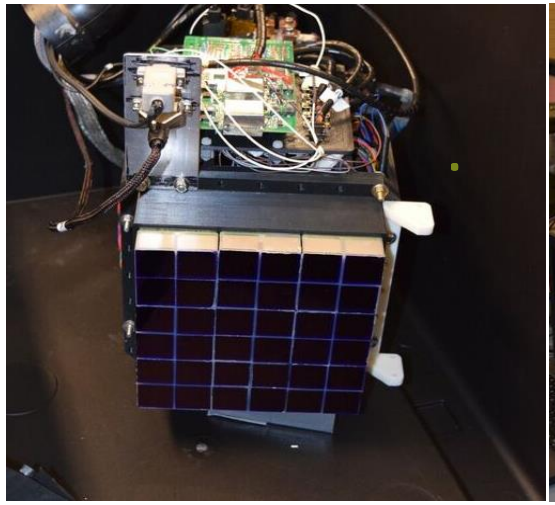




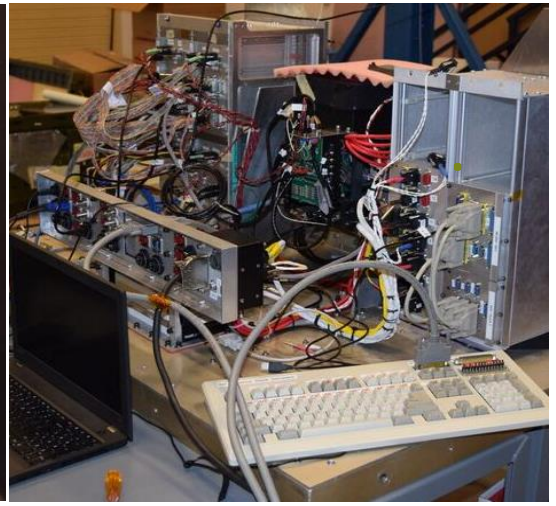
- Objectives:
  - Measure of EAS signals by looking down on the Earth's atmosphere from suborbital space with a fluorescence detector
  - Measure of the UV emission over the ocean and over clouds
  - Search for fast UV pulse-like signatures from other objects

- Flown as NASA **mission of opportunity** from Wanaka,NZ
  - Targeted flight duration: 100 days

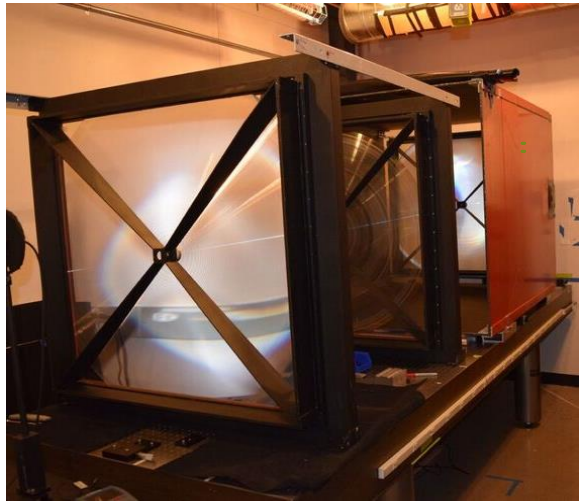
Instrument



Camera



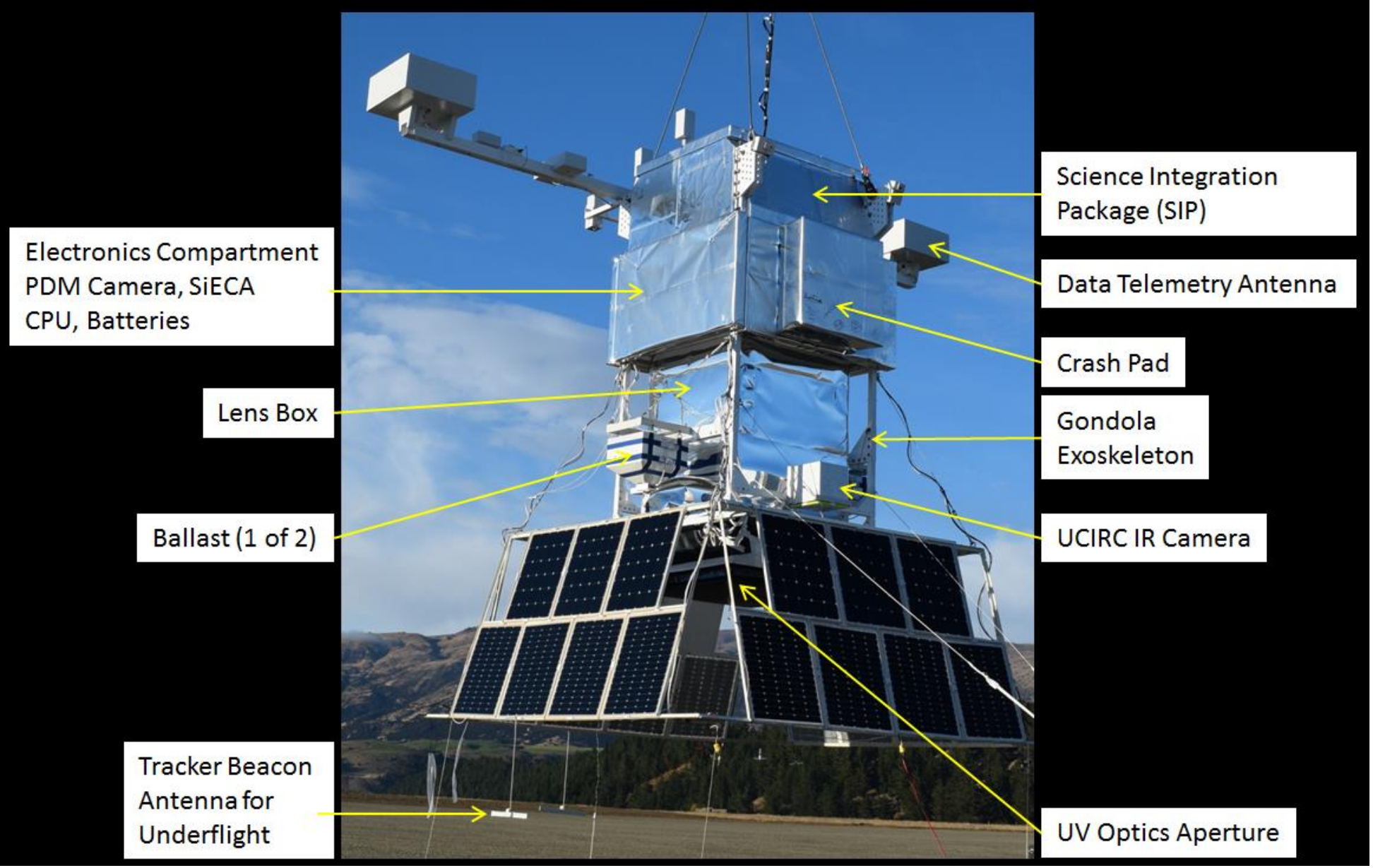
Electronics



Optics

- Upgrade of previous mission (EUSO-Balloon 2014)
- One PDM (Photon Detection Module) = 9 Elementary Cell (EC) = 36 MAPMTs (Multi-Anode PhotoMultiplier Tubes) = 2304 individual pixels
- Single photoelectron counting mode
- Two 1 m² Fresnel lenses to focus UV light

Instrument



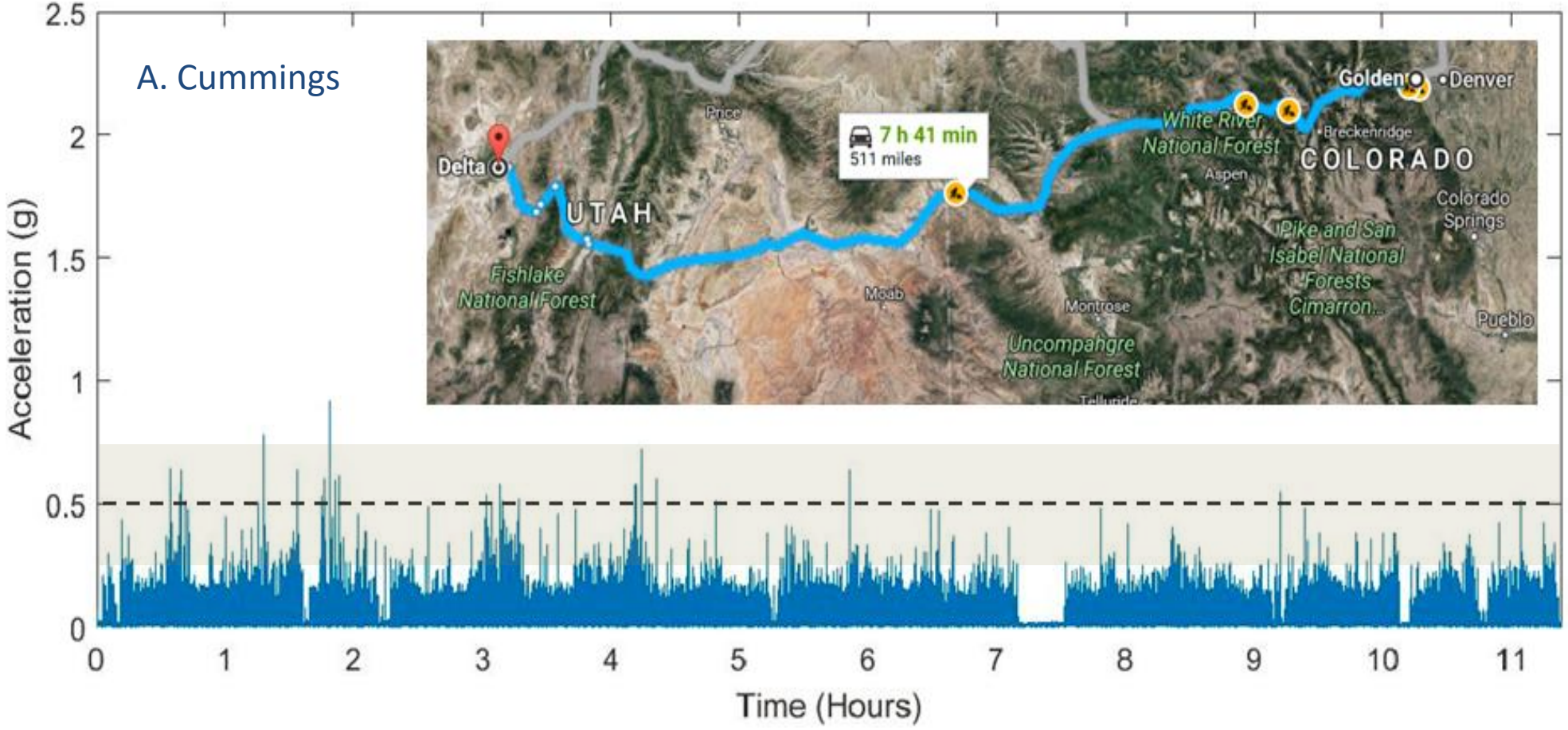
Long duration flight:

- Solar panels
- Ballast hoppers
- Satellite telemetry antennas
- Thermal insulation

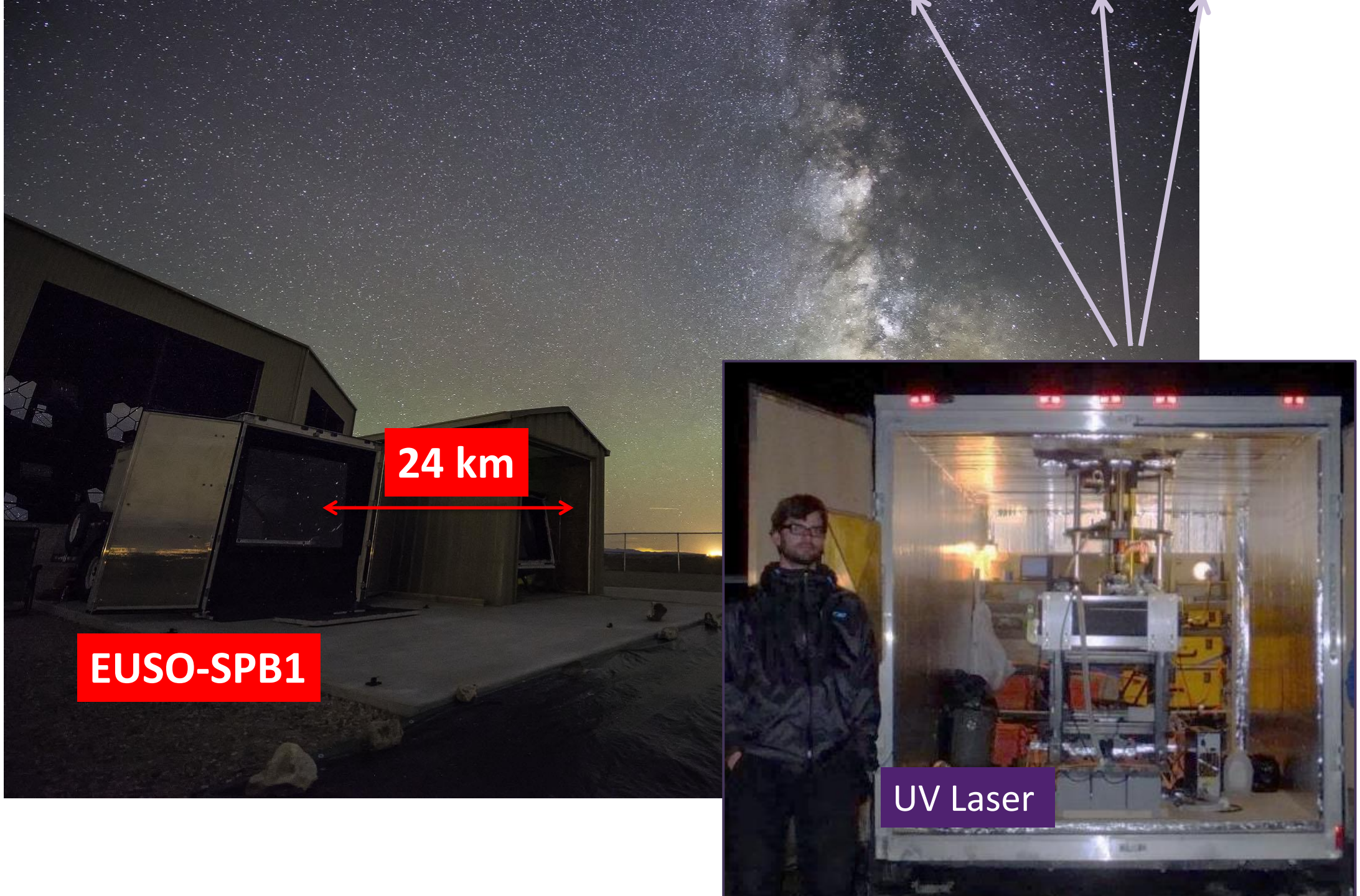
EUSO-SPB Specs

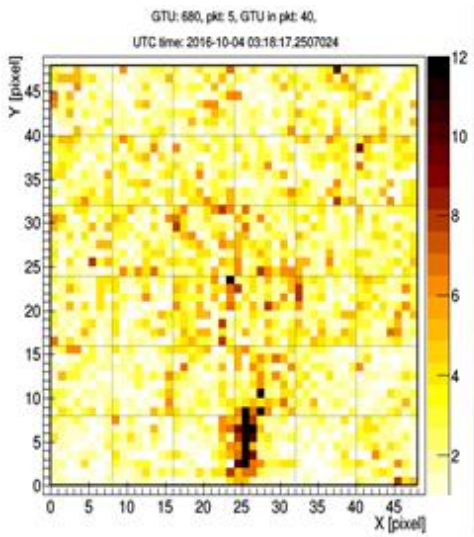
SPB Float Height	110,000 ft = 33.5 km
Weight	
Detector	2250 lbs
Payload	2700 lbs w/ SIP, Antennas, Empty Ballast Hoppers
Dimensions	1.2m x 1.2m x 3m
Power consumption	40 W Day, 70 W Night (assumes 20W PDM heater @ 50%)
Telescope	Refractor with 2 Fresnel lenses
FOV	11. deg (measured w/ stars)
Camera:	2,304 pixels; 36 MAPMTS (Hamamatsu R11265-113-M64-MOD2)
Data volume:	Downlinked ~1-1.5 Gb/day
Recorded	~3 GB/Day w/ 10 hour dark run
	with trigger rate of 0.2 Hz
Energy threshold	for h=33 km ~3 EeV
Ground equivalent Trigger Aperture	
	250 km^2sr @ 3 EeV to ~500 km^2 sr @ 10 EeV

Transported **fully assembled** EUSO-SPB1 telescope
from Golden CO to Utah Desert for field testing 1000 mi round trip

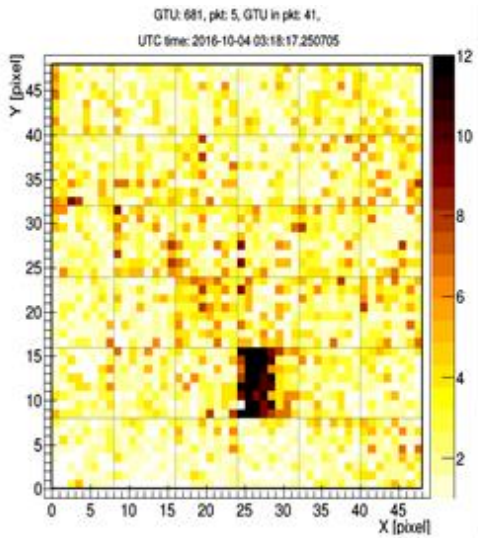


Dashed Line: Flight Ready balloon payloads must be able to tolerate bumps of **about 0.5 g** during transport to launch site (NASA requirement)

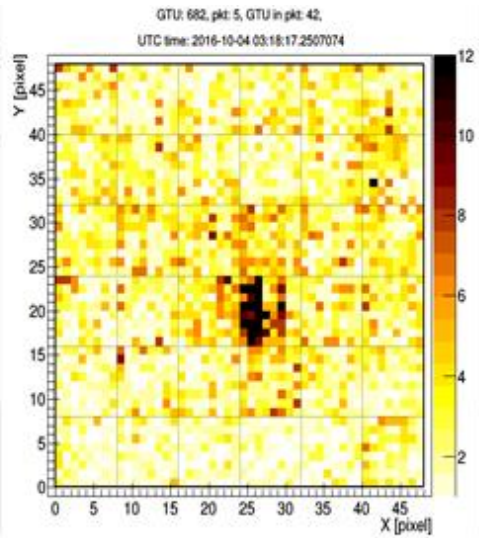

24 km
EUSO-SPB1
UV Laser



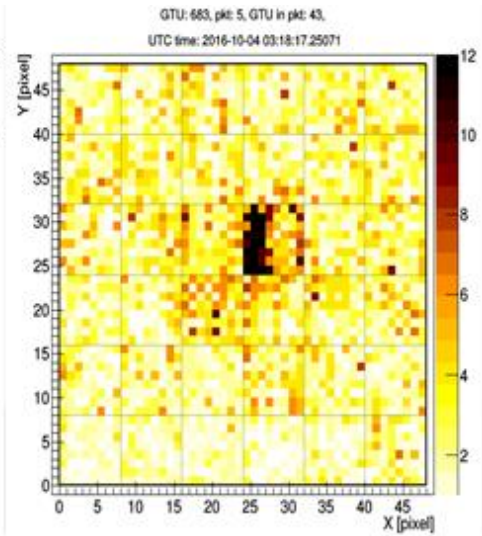
GTU 680



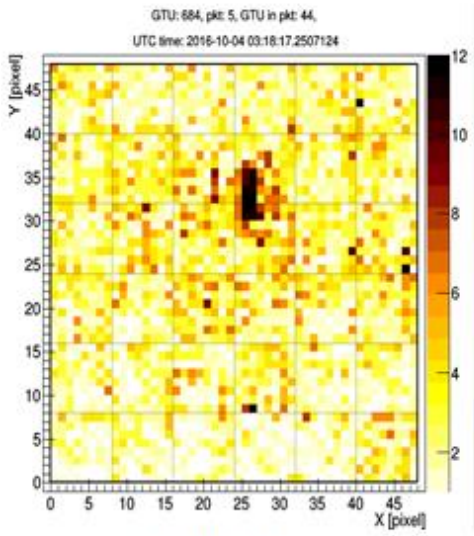
GTU 681



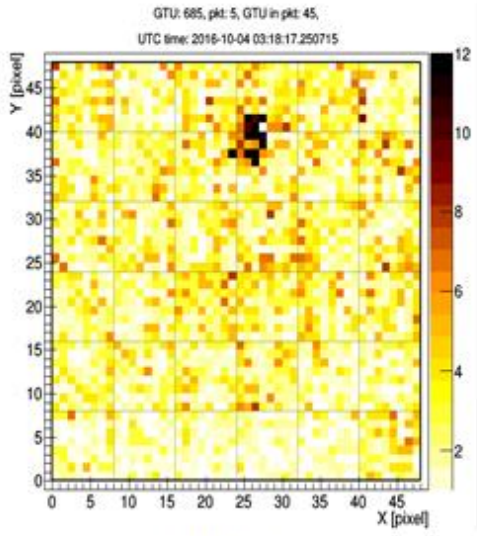
GTU 682



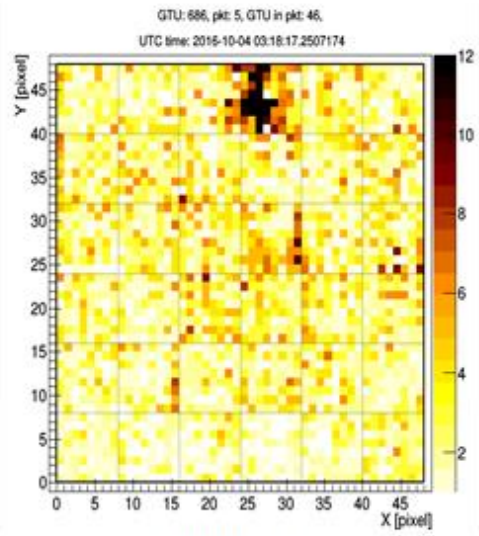
GTU 683



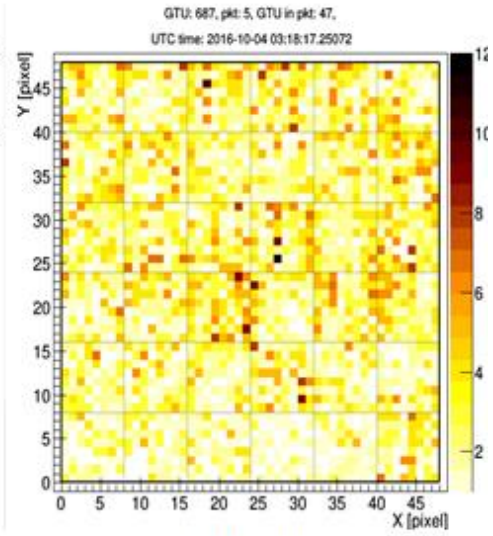
GTU 684



GTU 685

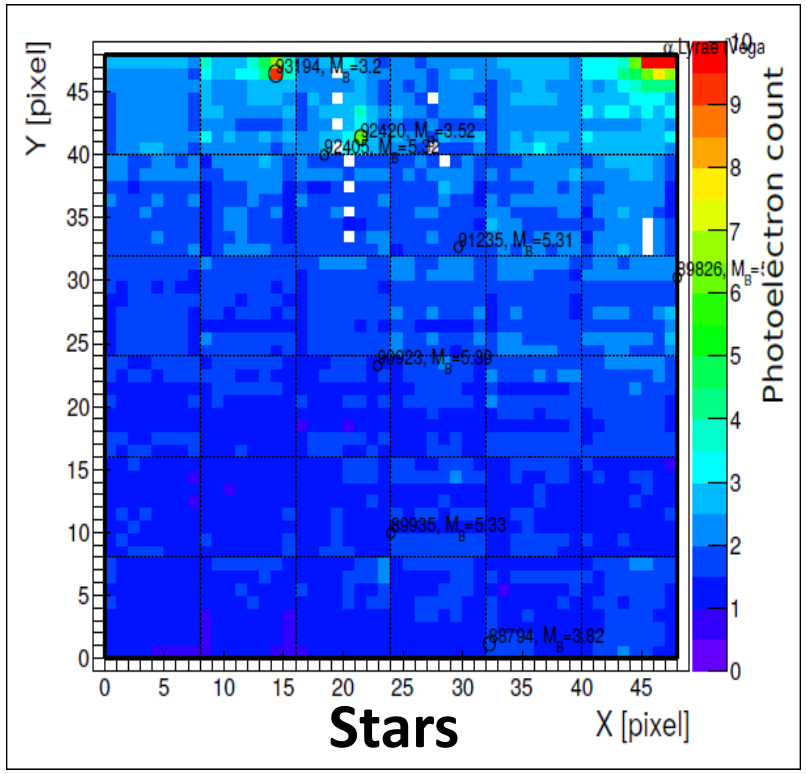


GTU 686

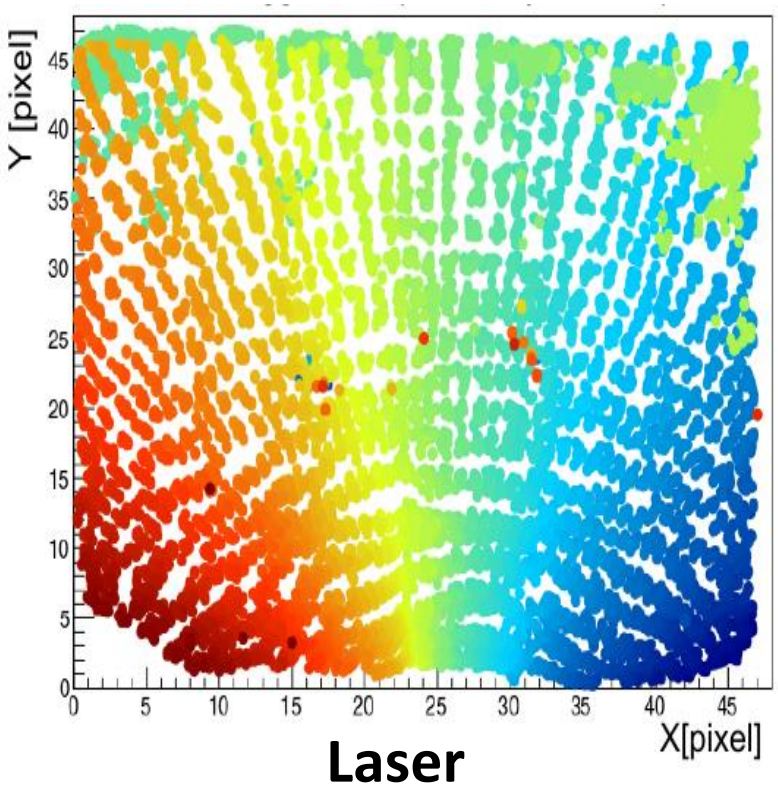


GTU 687

Preflight Tests in the Desert



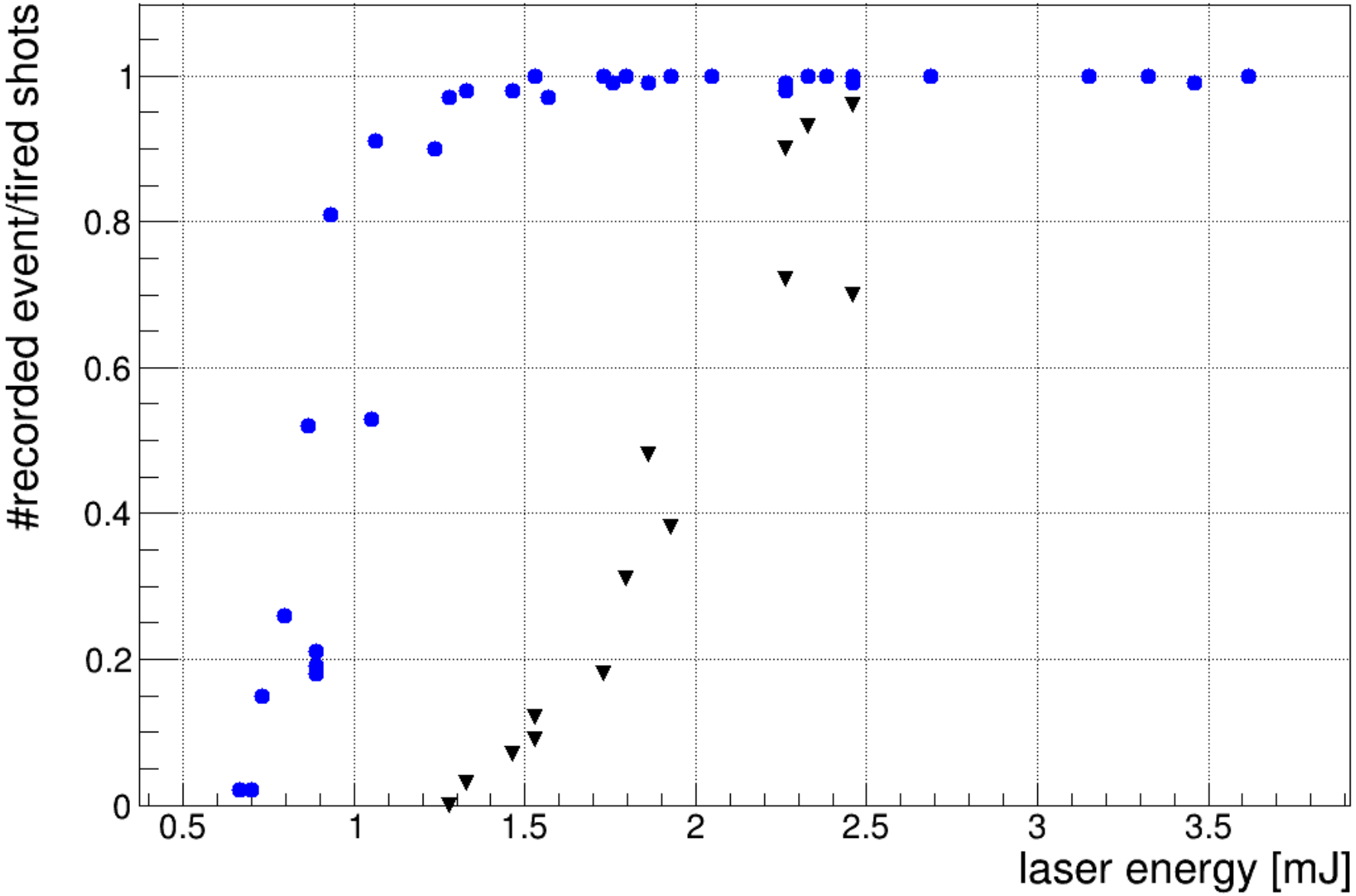
FOV 11.1 +/- 0.15 deg



FOV 11.2 +/- 0.1 deg

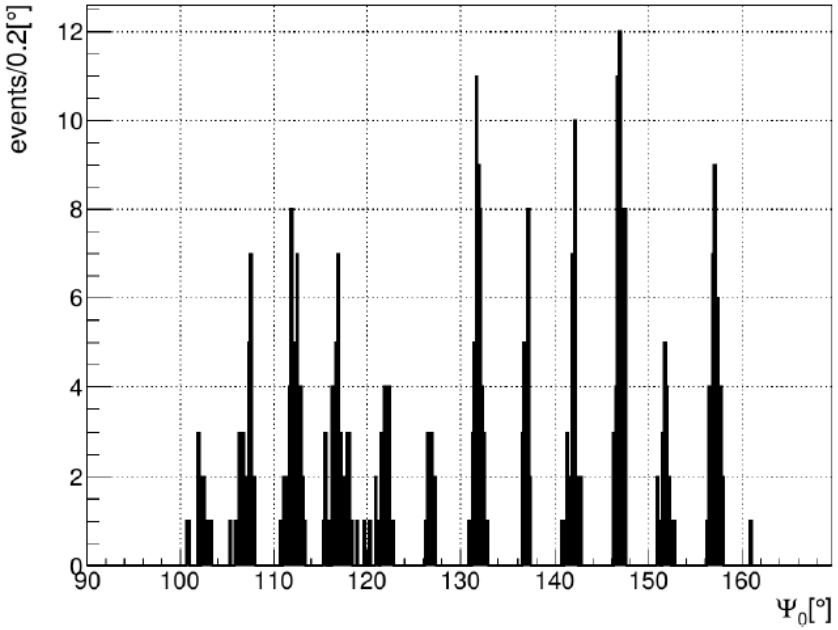
- Field tests: FoV, absolute calibration, detection threshold
  - Setup at Telescope Array site near Delta, UT
  - Using artificial light sources (UV-LED and laser)
  - Thanks to the Telescope Array collaboration (hosting instrument)

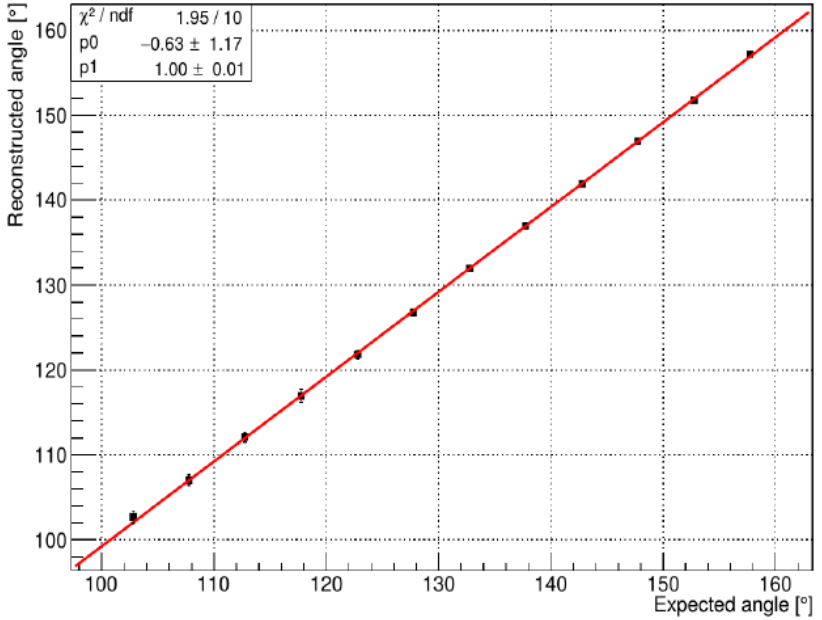
Detection Threshold

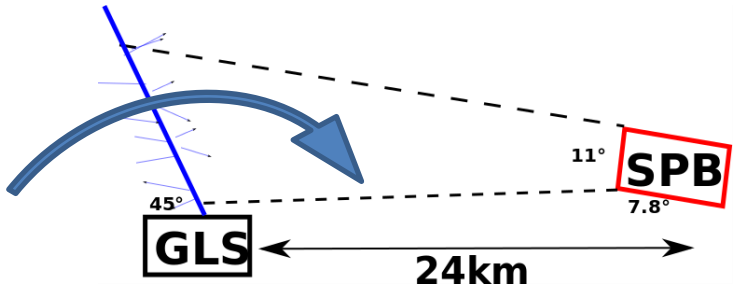


- 2 lens:
  - 943 ± 17 μJ (3.5 EeV equivalent as seen from above)
- 3 lens:
  - 1973 ± 34 μJ (7.4 EeV)

EUSO-SPB1: Reconstruction







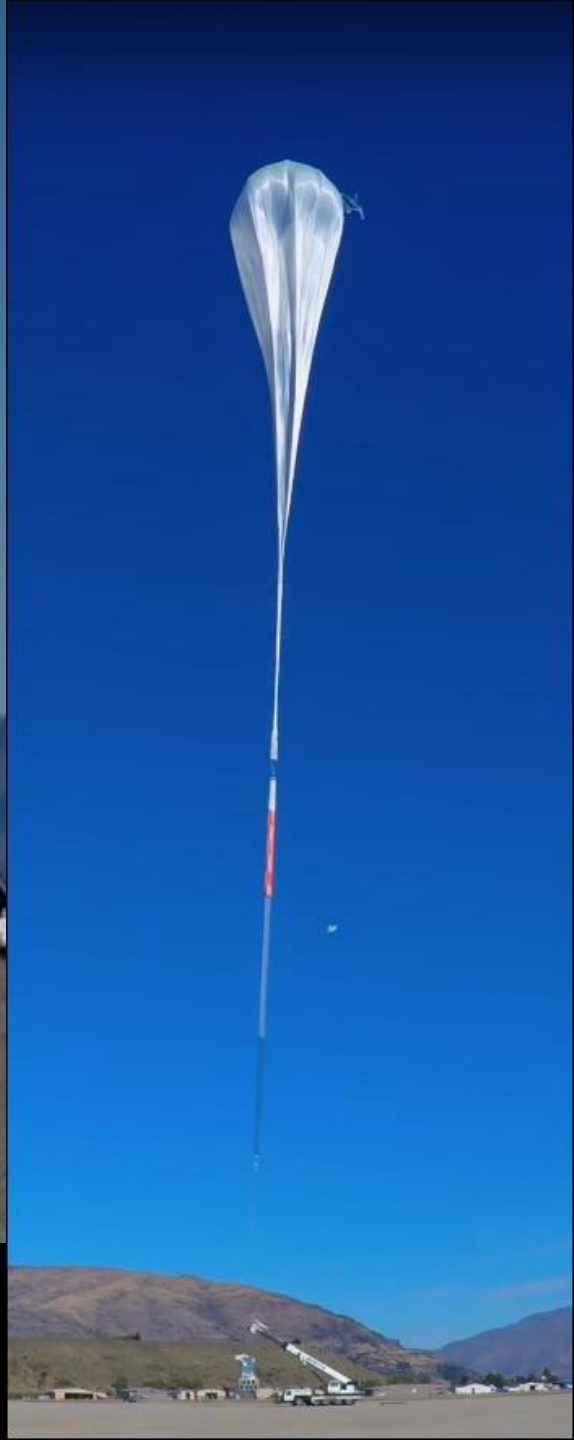
- Different laser zenith angle
- Reconstructed value follows expectational
- Angular resolution increases with longer track
- Angular resolution better than 1°

SPB1
Wanaka NZ February 2017

Launch Ready

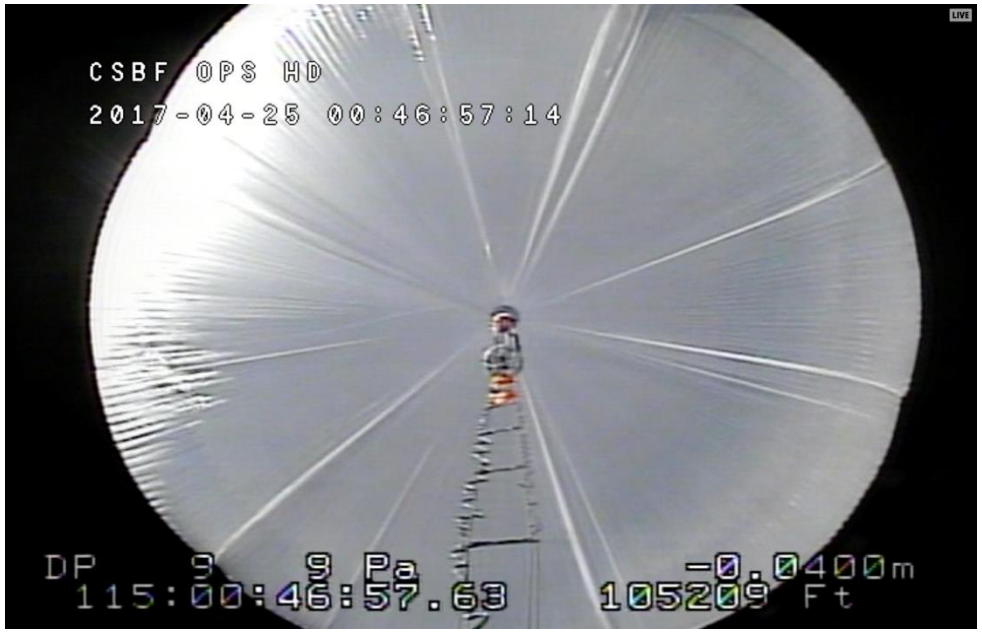
Passed the Launch Readiness Review on 25th of March, 2017

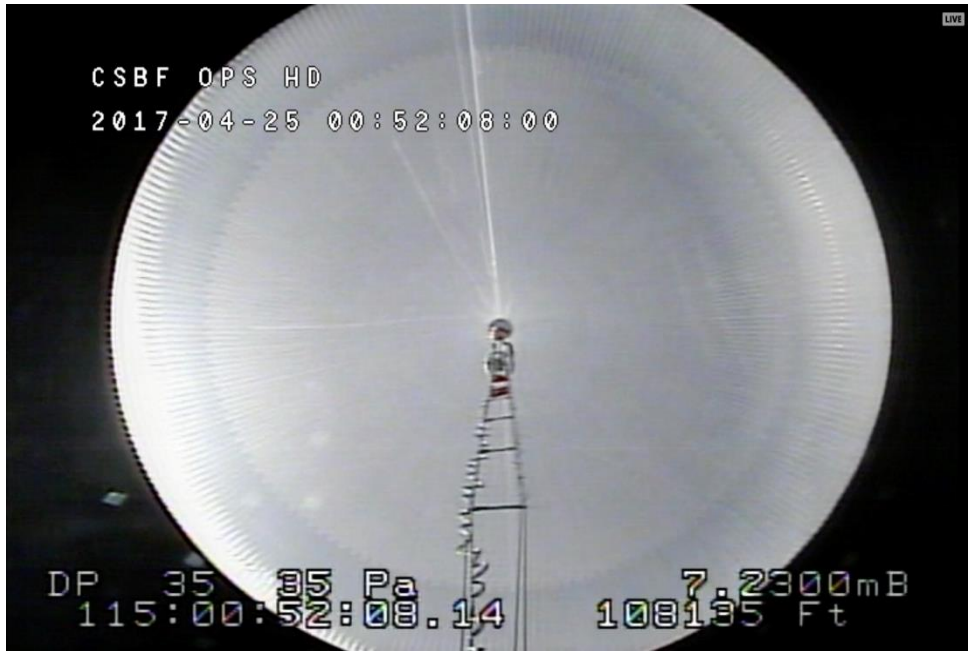
EUSO-SPB1: Launch



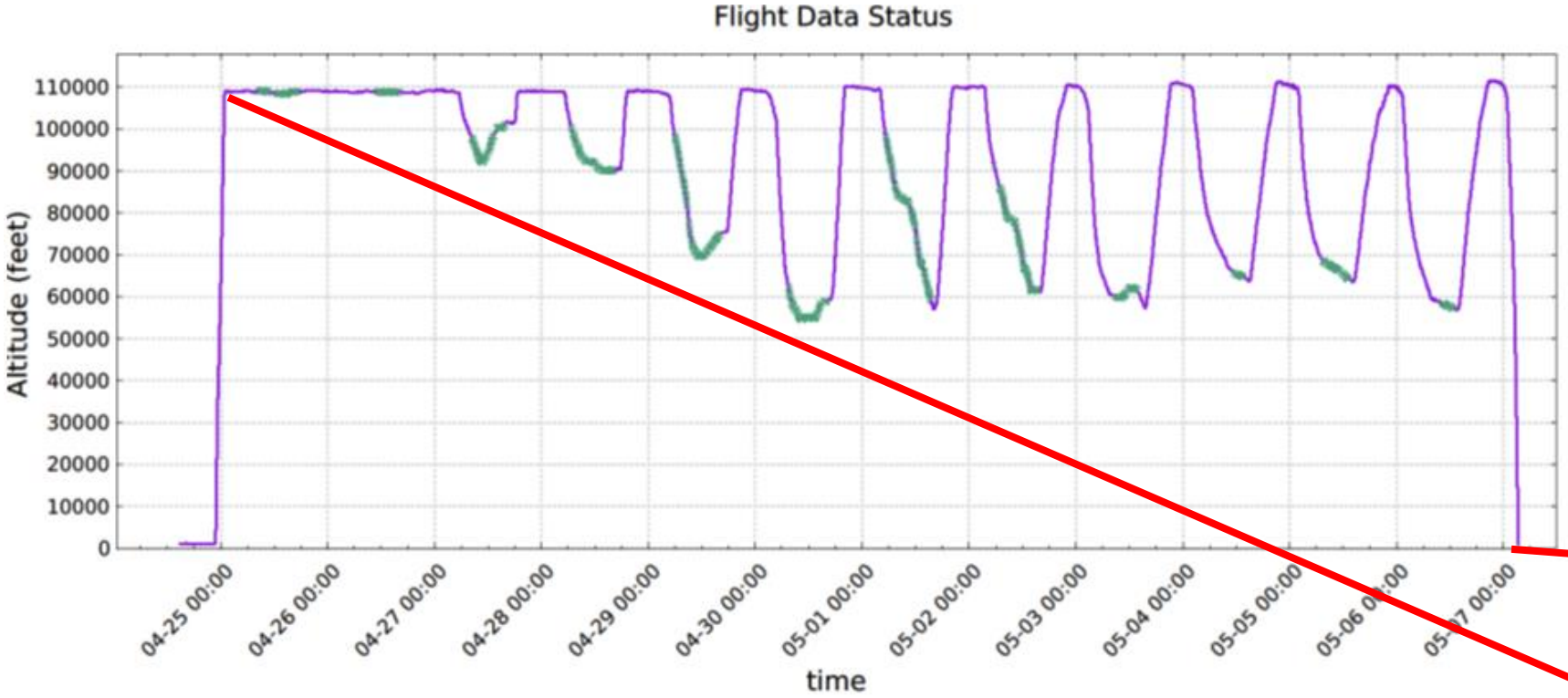
- 24/04/2017 23:51 UTC

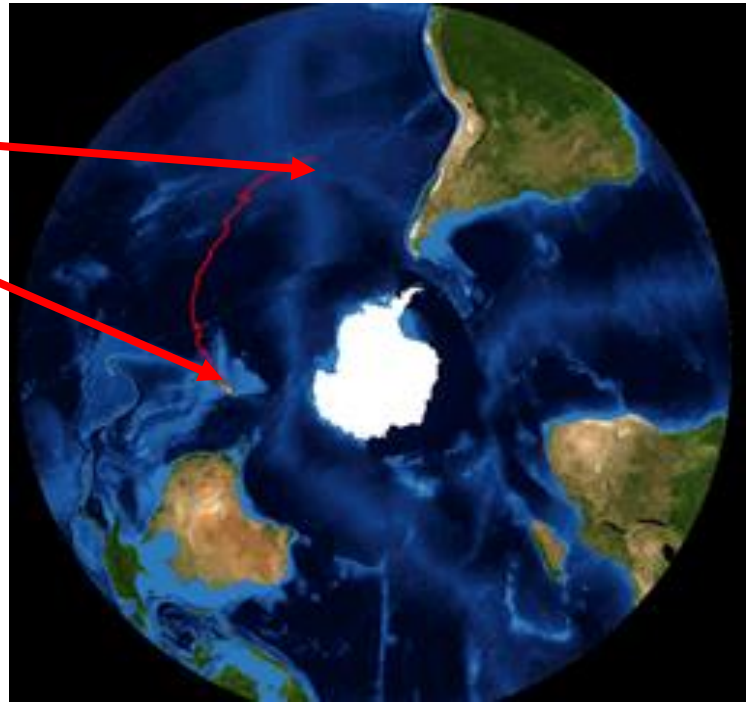
Pressurization





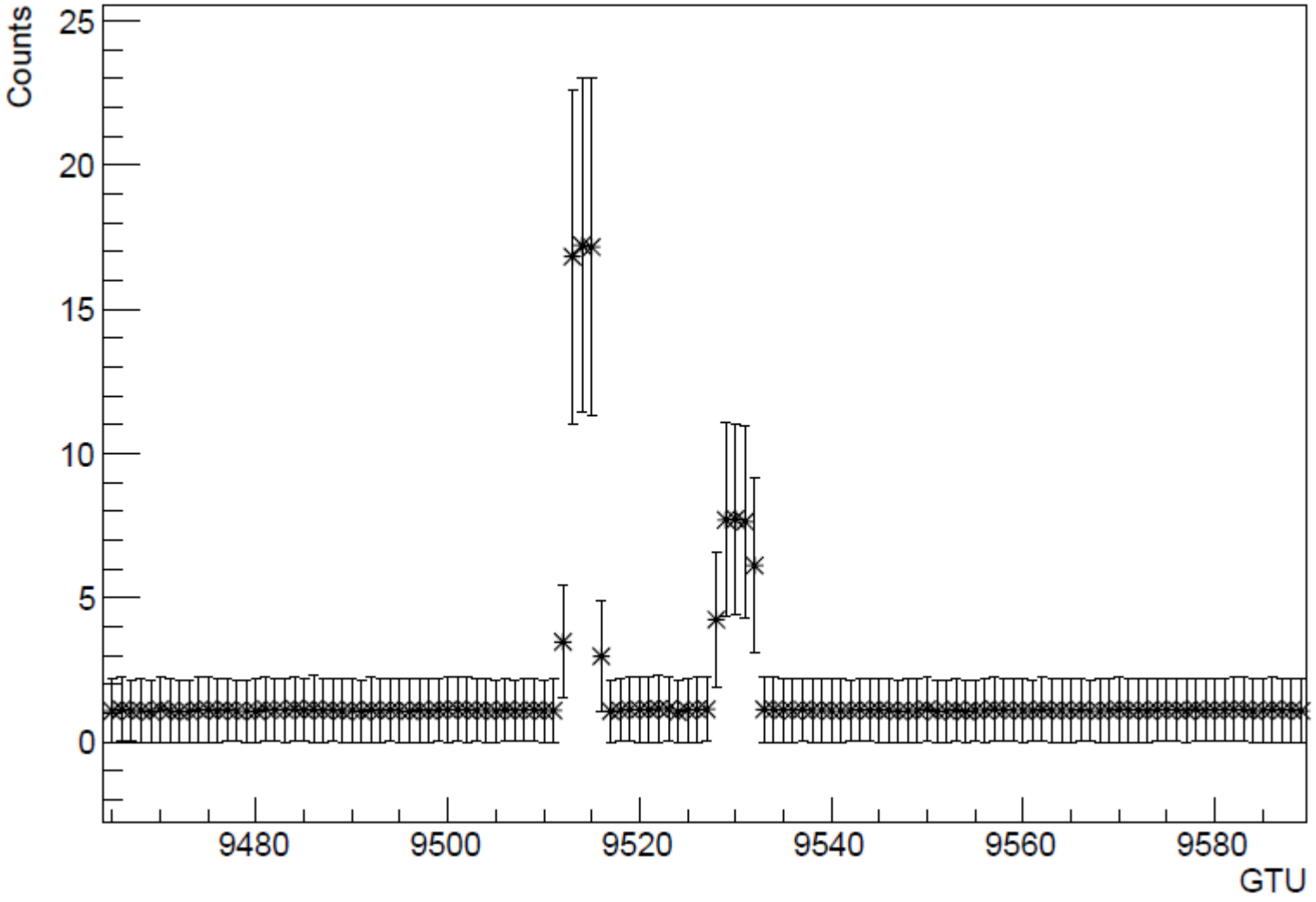
Flight Summary

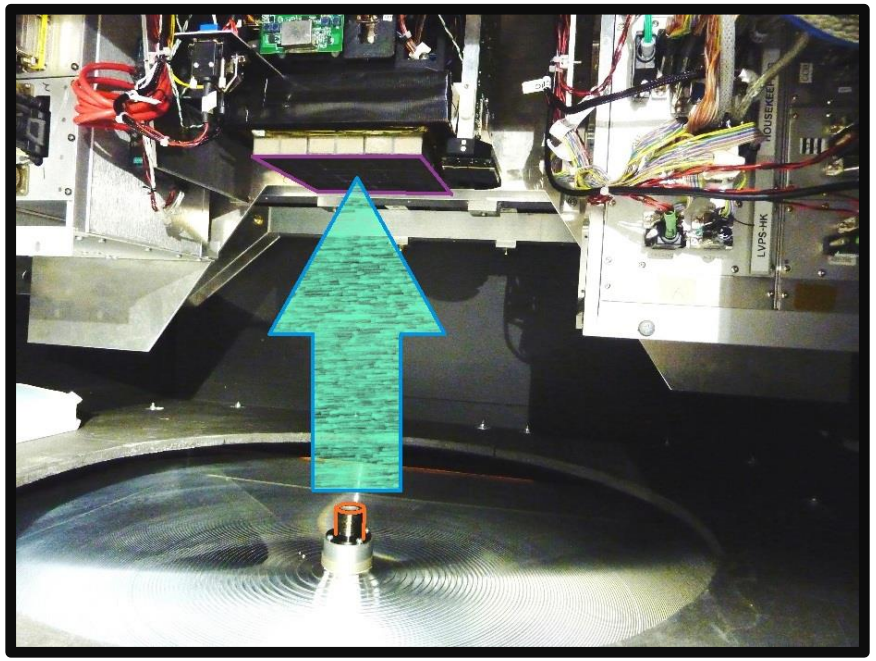




- Flight duration: **12d 4h**
- Terminated 300 km SE of Easter Island
  - Payload lost
- ~30 h (1793 min) of data downloaded

In flight “Health LED” every 16 seconds

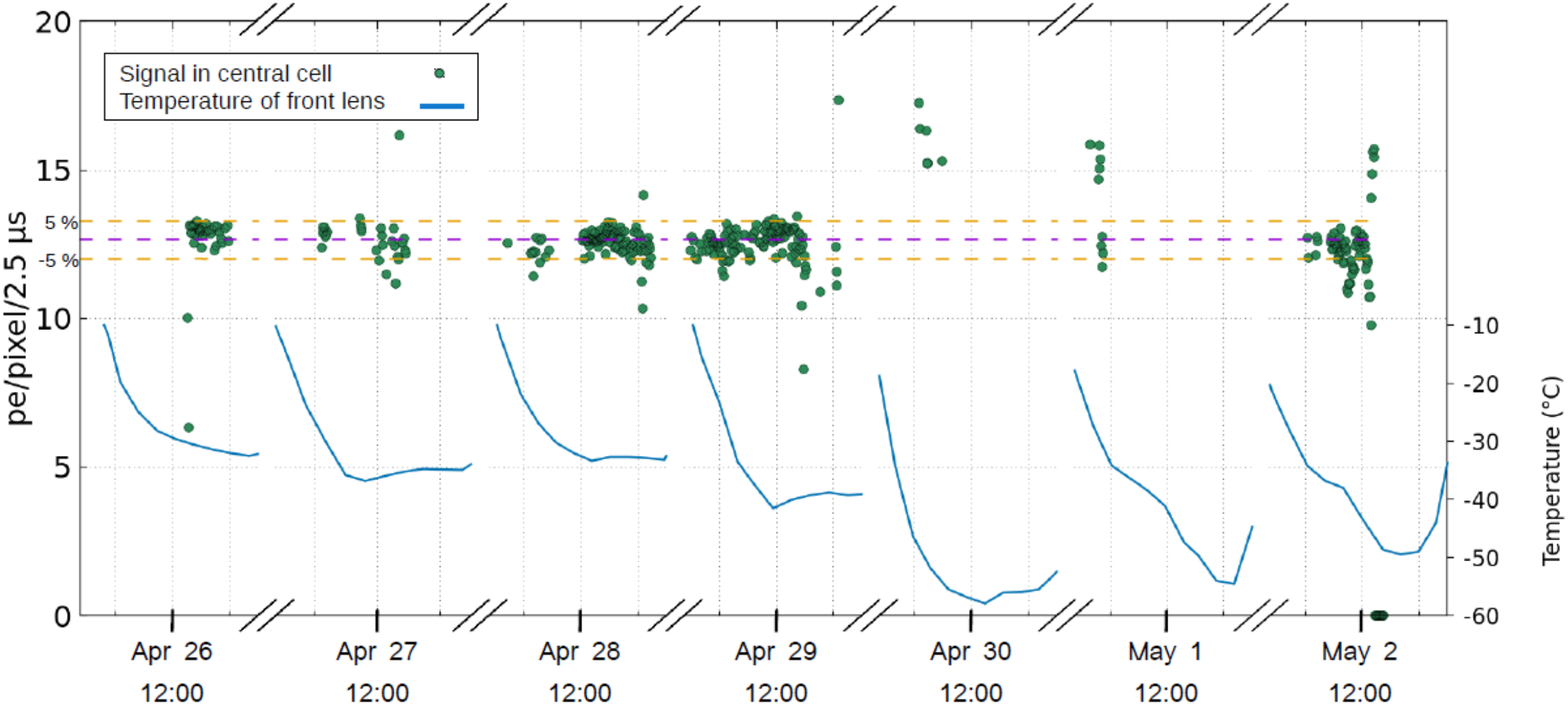




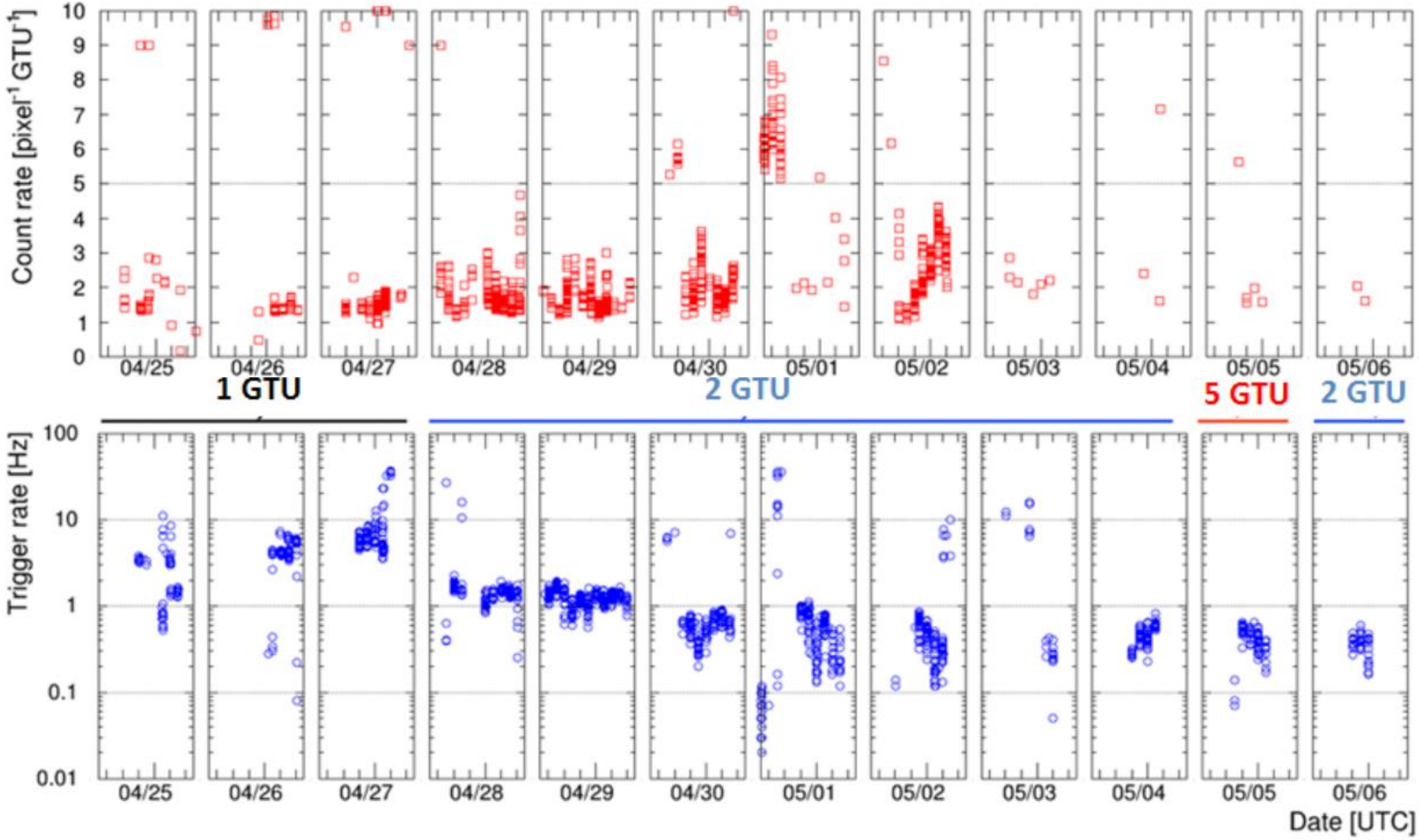
All 9 “elementary cells” in Camera participating at nominal HV (1100V)

1 GTU=2.5 uS

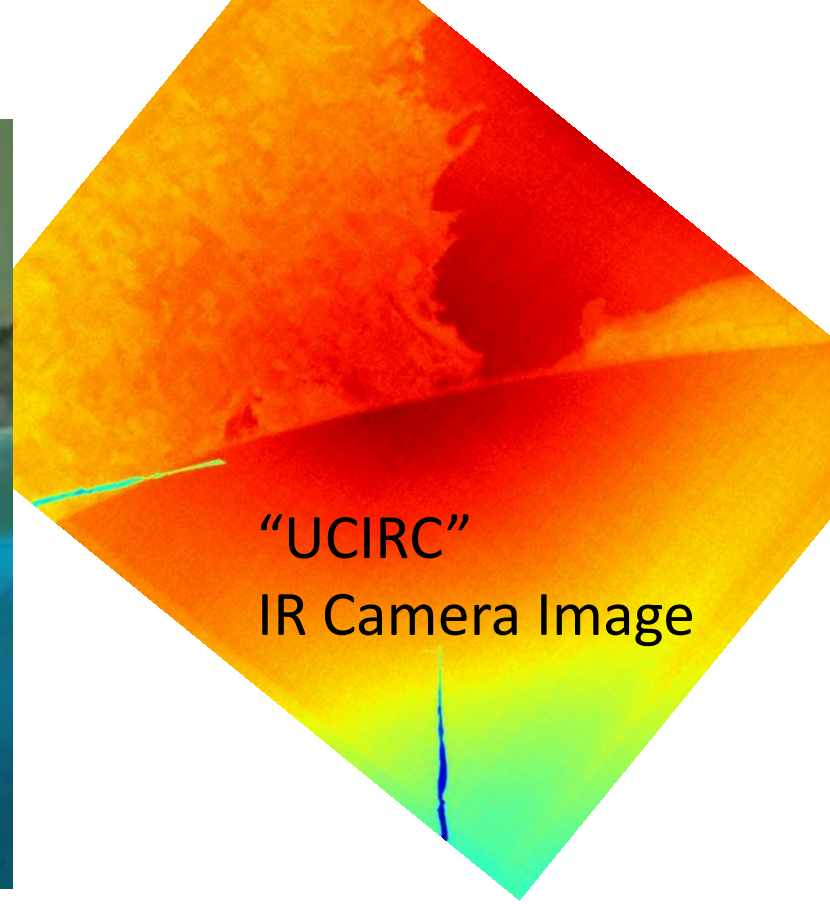
Detector’s Stability during Flight



UV-Emission and Trigger Rate



Ground Source

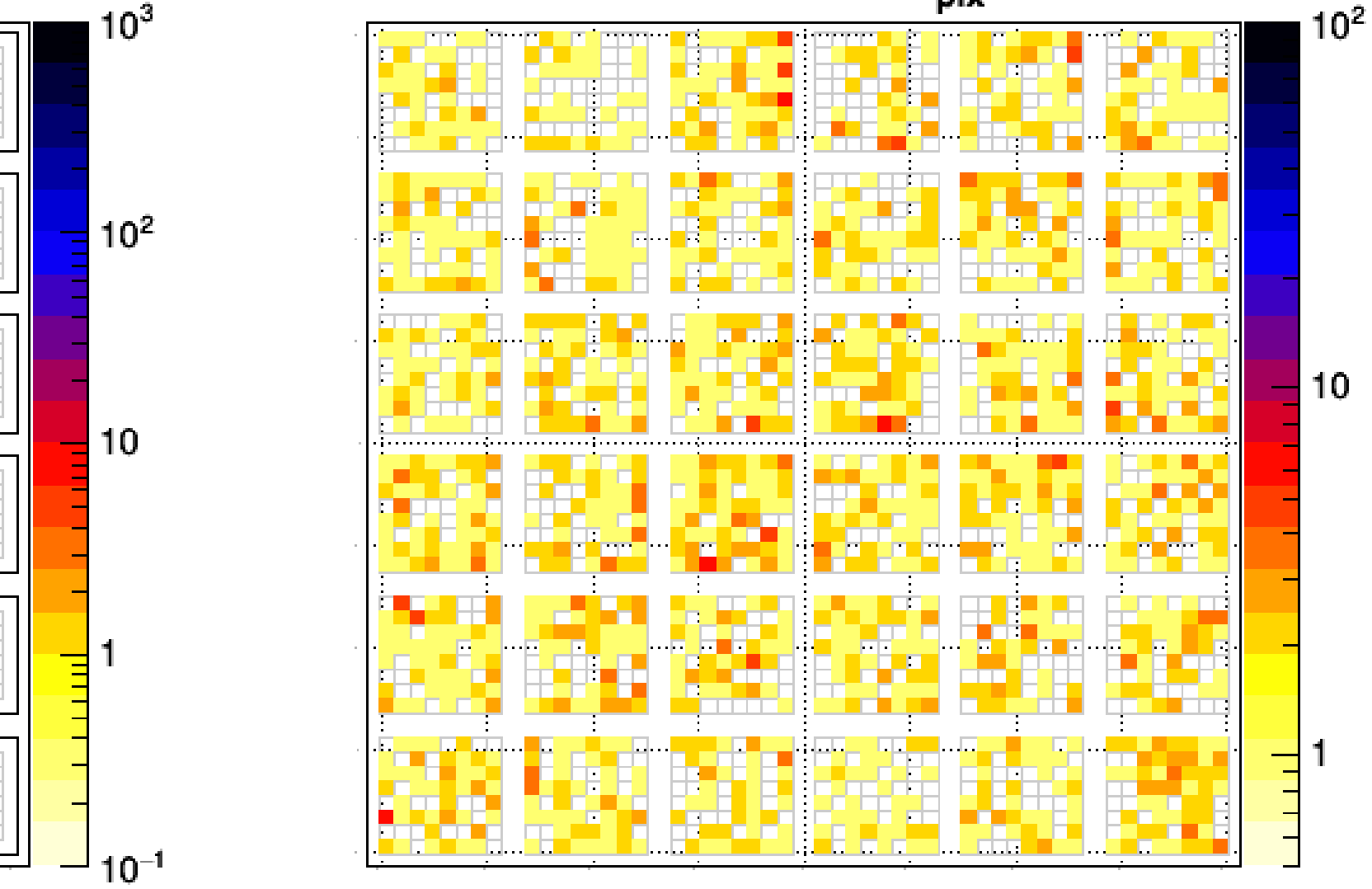


- Recorded 25/04/2017 at 08:32:34 UTC (hours after launch)
- Velocity of source similar to speed of balloon (30km/h)
- Frequency of the source is 100Hz (AC frequency in NZ is 50Hz)
- Signal spread equal to instrument PSF (point source)

38

$\sum_{pix} n = 2480 \langle n \rangle = 1.076$

$\sigma / \langle n \rangle = 98.17\%$ $\#hit_{pix} = 1512$



Low Energy Direct CR passing through camera

SPB1 Summary

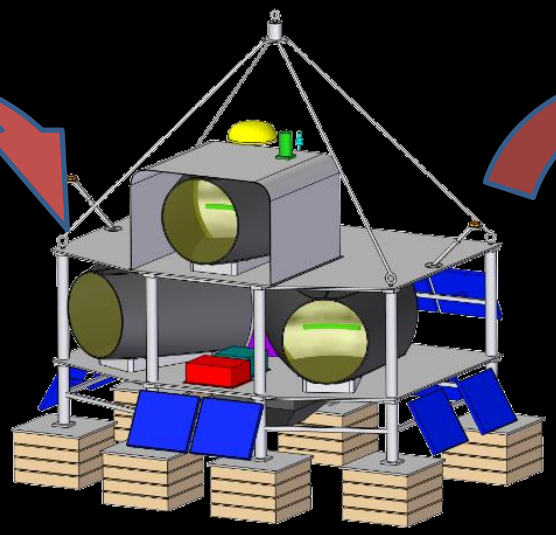
- EUSO-SPB1 was successfully launched end of April 2017
  - Mission of opportunity
- Extensive Preflight Ground tests of flight instrument in the desert
  - lasers, LEDs, aircraft, stars, meteorite

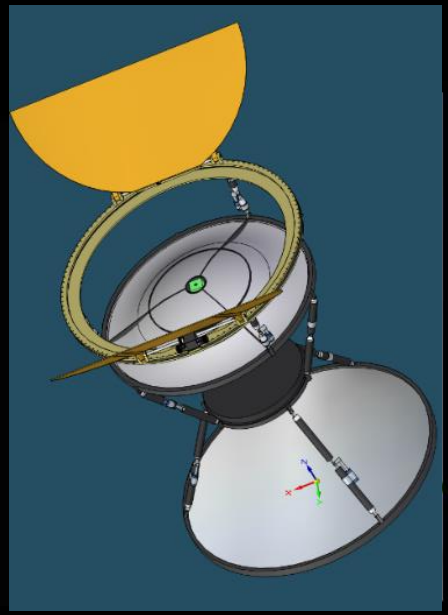
- Stable instrument was flown for 12 days (less time than expected)
- 30 hours of data recorded and downloaded
- Upper limit on expected event rate during flight ~1.2 events
- No Extensive Air Shower Events found

EUSO-SPB2

EUSO-SPB1

EUSO-Balloon





	Institution	EUSO-SPB2 Science Team	Current Activities
AL	CDTA	M. Traiche	Simulations
FR	APC	G. Prévôt, P. Gorodetzky, S. E. Parizot	Photon Detection Module (PDM)
FR	LAL	S. Dagoret	Electronics
FR	OMEGA	S. Blin	Electronics -ASICS
GER	KIT	A. Haungs, W. Painter	SiPM prototype from SPB1
IT	INFN & U. Napoli	G. Osteria, V. Scotti,	CPU, Fluorescence Detector (DAQ)
IT	INFN & U. Torino	M. Bertaina F Fenu K. Shinozaki	Trigger Algorithms, Simulations, lab testing
IT	INFN & Univ. Bari	F. Cafagna	Flight Software. Opps Center
IT	UTIU	C. Fornaro	DAQ Software
IT	LNF-INFN, Frascati	M.Ricci	Italian coordinator
JA	RIKEN	M. Cassolino, T. Ebisuzaki, Y. Takizawa, L. Piotrowski,	Optics, PMT testing Opps Center
MX	UNAM	G. Medina-Tanco	Thermal Modeling
POL	NCBJ	J. Szabelski	Fluorescence Detector Embedded HV system
RUS	MSU	P. Klimov	PDM prototype + ZYNQ (K-EUSO)
US	U. Chicago	**A. Olinto (PI),** S. Meyer,	IR Camera (UCIRC)
US	CSM	**L. Wiencke (Dep. PI),** F. Sarazin, J. Eser	Telescopes – Mechanical, Testing, Integration Calibration, Simulations
US	MSFC	M. Christl, R. Young	Gondola, SIP Interfacing
US	UAH	P. Reardon, J.Adams, E. Kuznetsov,	Optics Design, Solar Power
US	Lehman U.	L. Anchordoqui	MAPMTs

EUSO-SPB2

Science Goals:

Build upon the EUSO-SPB1 experience (and EUSO-Balloon)
to pave the way towards the POEMMA mission

New Unexplored Areas:

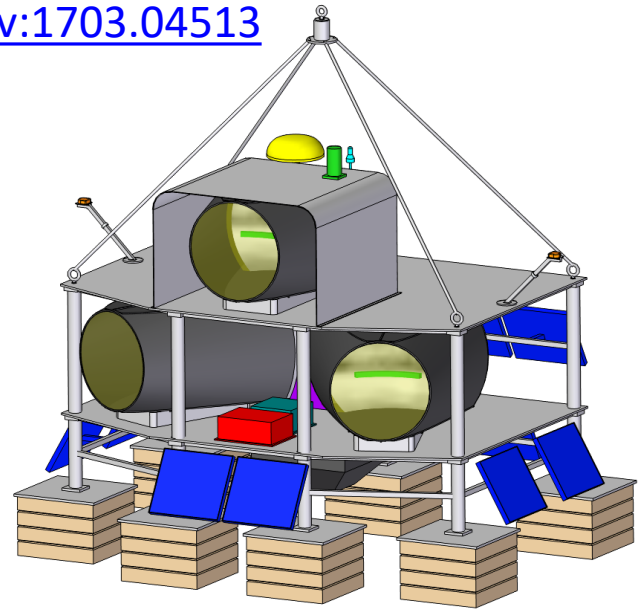
- Detect **Cherenkov from UHECRs from near space**
- Measure the **background of up-going Tau** decays from BZ Neutrinos
- Also thinking about the ANITA-4 tau-like events
- Study Fluorescence from High Altitude Horizontal Showers (HAHAs)

Detect Fluorescence from Above:

- Confirm expectations from ground observations

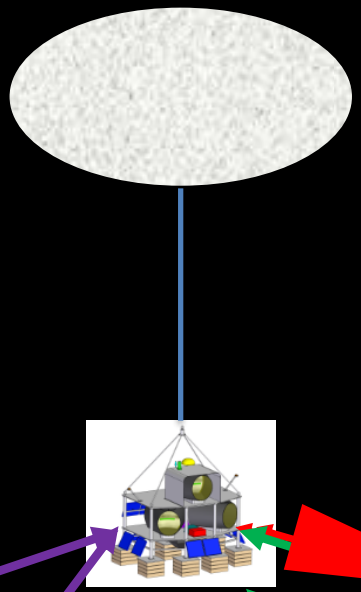
*lower energy threshold and larger acceptance relative to EUSO-SPB1

arXiv:1703.04513



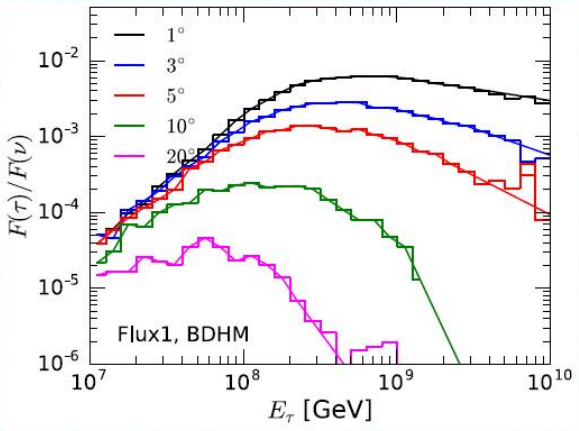
EUSO-SPB2

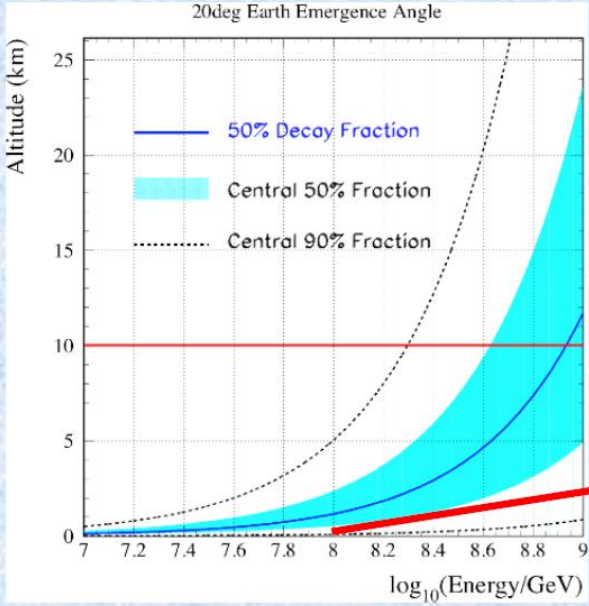
Cherenkov Emission
from UHECRs
Tau Neutrino
Background
Fluorescence
from UHECRS
Atmospheric TLEs



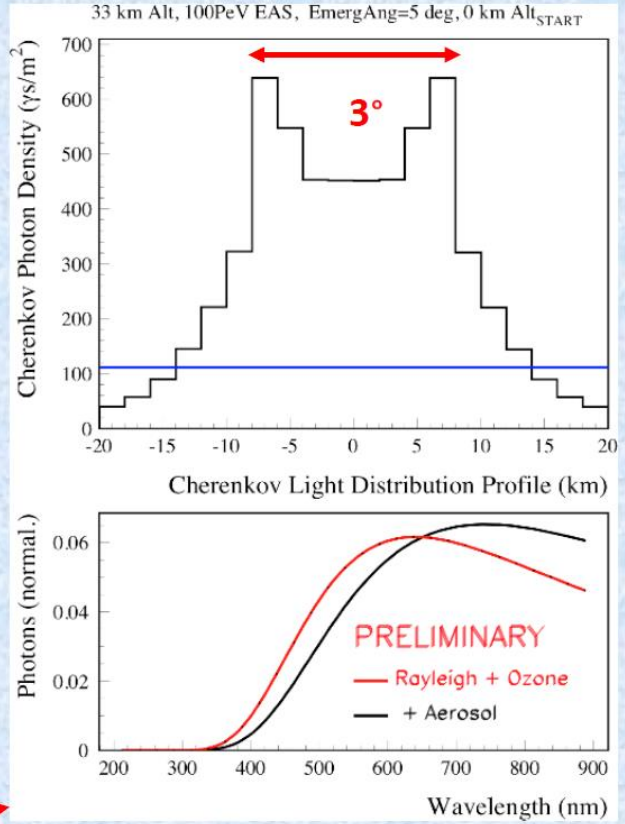
UHECRs
Fluorescence
500 PeV
EAS
35 deg
Anita "taus"?
Tau lepton
Cherenkov
UHECRs
Tau Neutrino

Simulation Results 33km altitude observation (SPB2): $\beta_E = 5°$



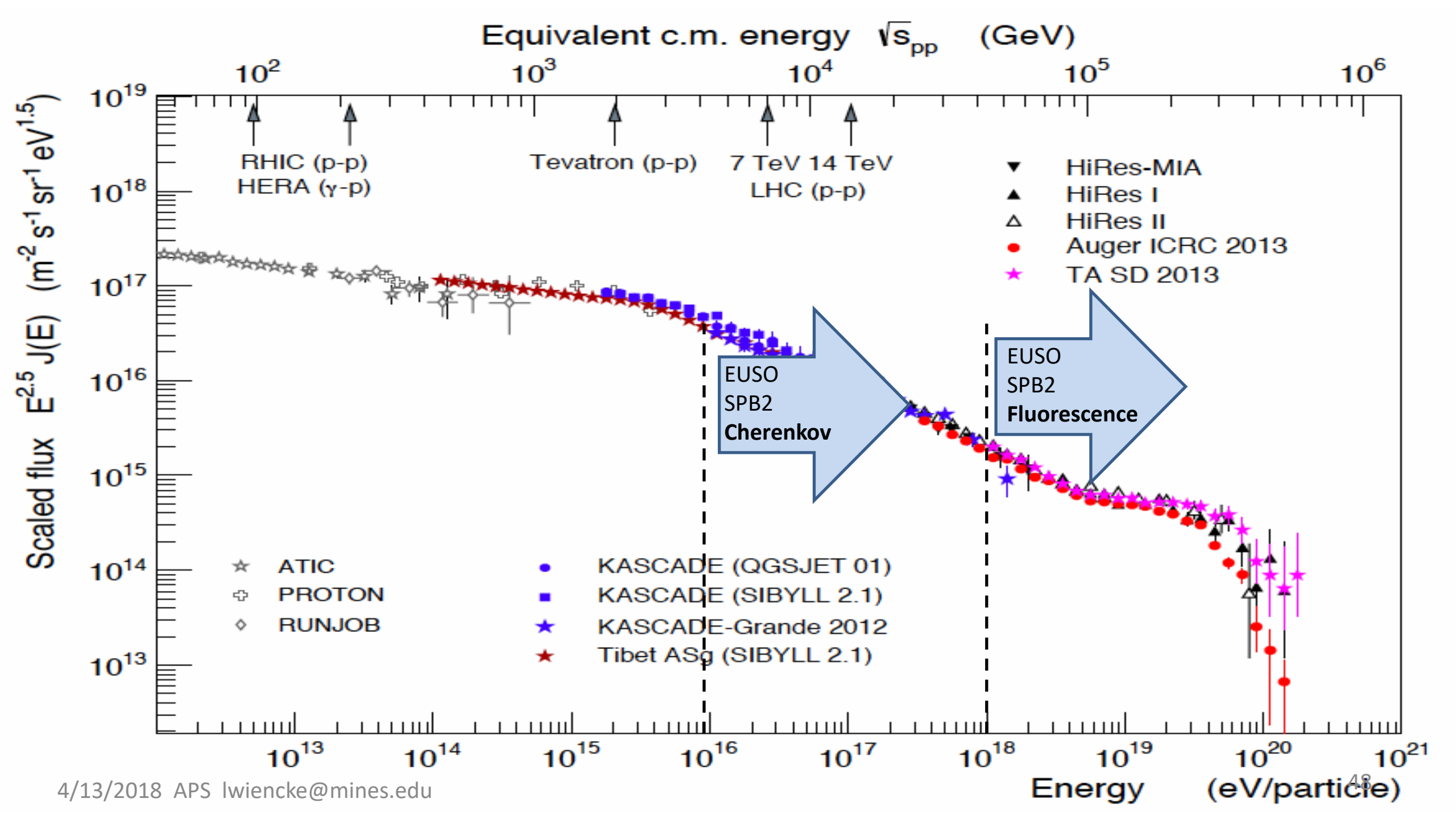


33 km, 100 PeV EAS, sea level start



$\Delta\alpha$	β_E(33 km)	β_E(525 km)	β_E(1000 km)
1	3.6	7.0	8.2
2	5.2	10.0	11.7
3	6.6	12.3	14.5
4	7.9	14.4	16.9
5	9.1	16.2	19.0
6	10.3	18.0	21.0
7	11.4	19.6	22.8
8	12.6	21.2	24.6

POEMMA
Simulations Team
Krizmanic et al


Equivalent c.m. energy $\sqrt{s_{pp}}$ (GeV)
10^2
10^3
10^4
10^5
10^6
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
SPB2
Cherenkov
EUSO
SPB2
Fluorescence
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}
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)

EUSO-SPB2

Technical Goals:

Test instrumentation and methods for POEMMA

Many (3) Telescopes

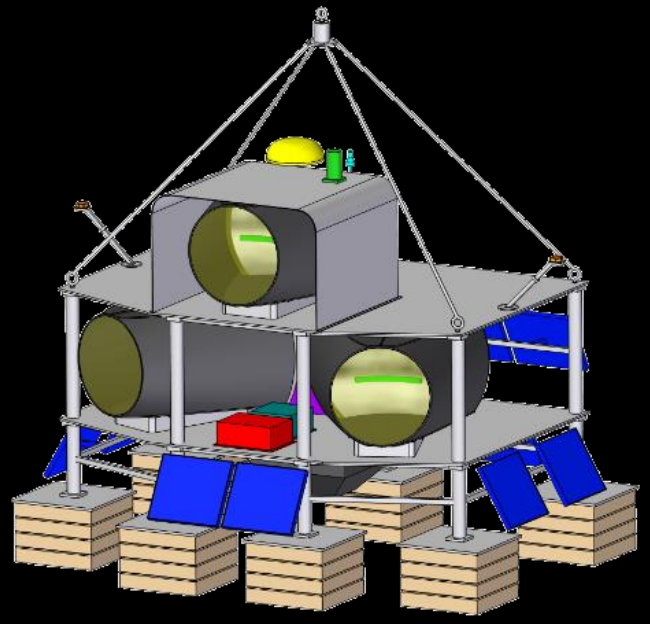
2	Cherenkov	~10 ns	PeV Scale
1	Fluorescence	1 us	EeV Scale

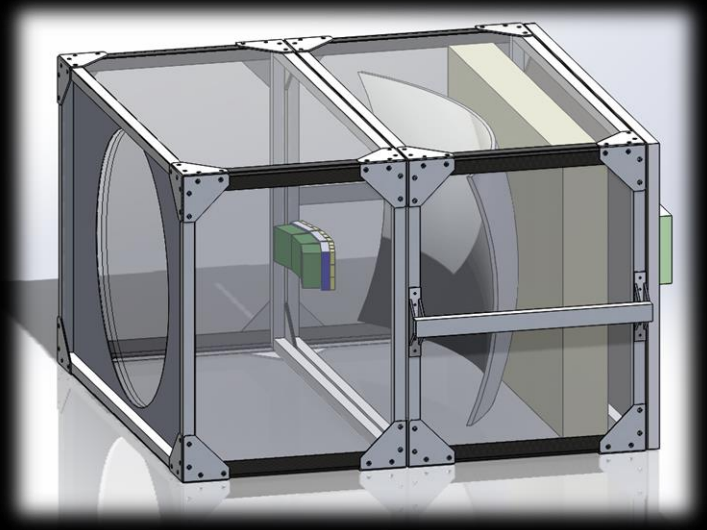
Schmidt Optics, same for all telescopes
Bi-Focal alignment for Cherenkov

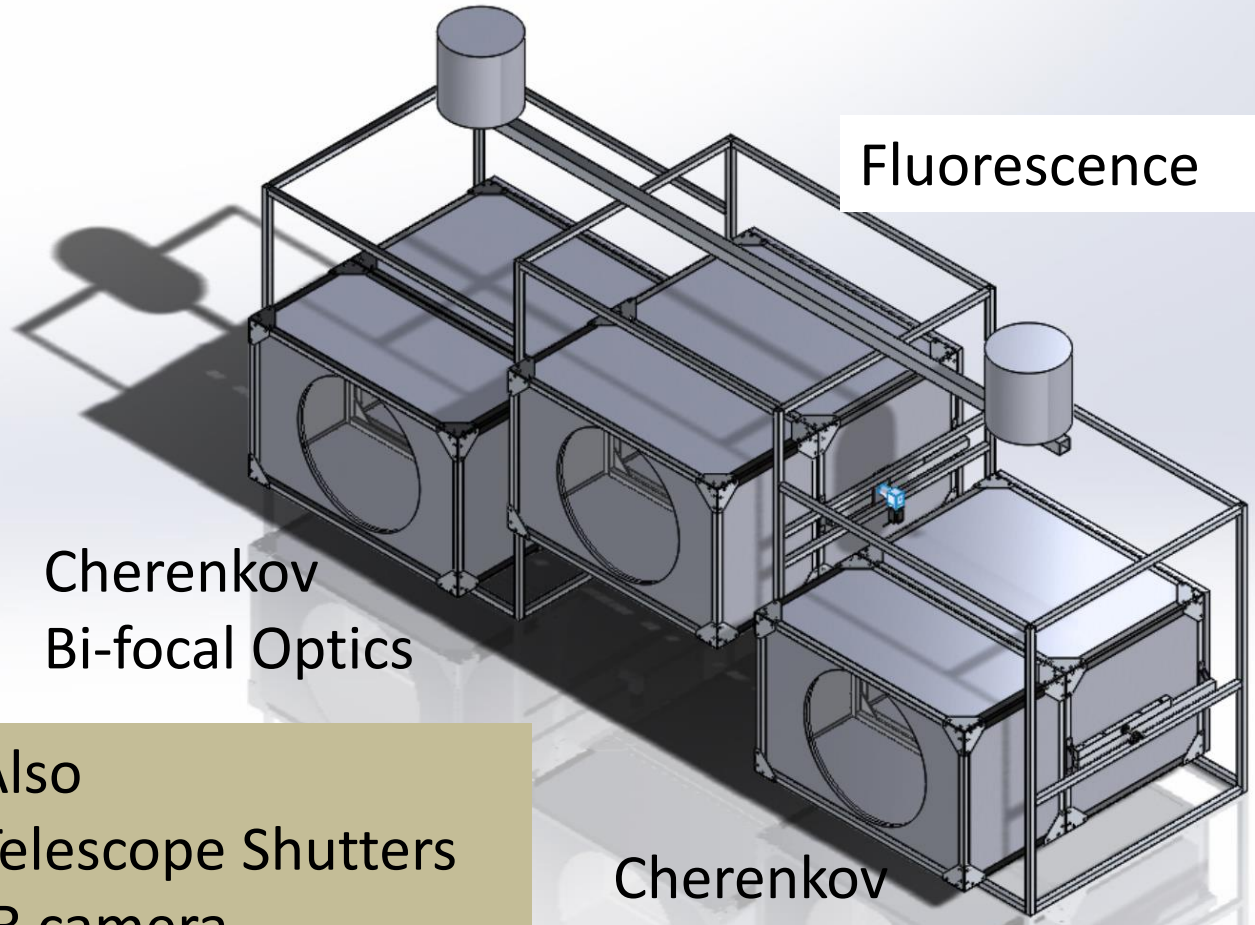
Tilting, perhaps to NADIR (fluorescence)

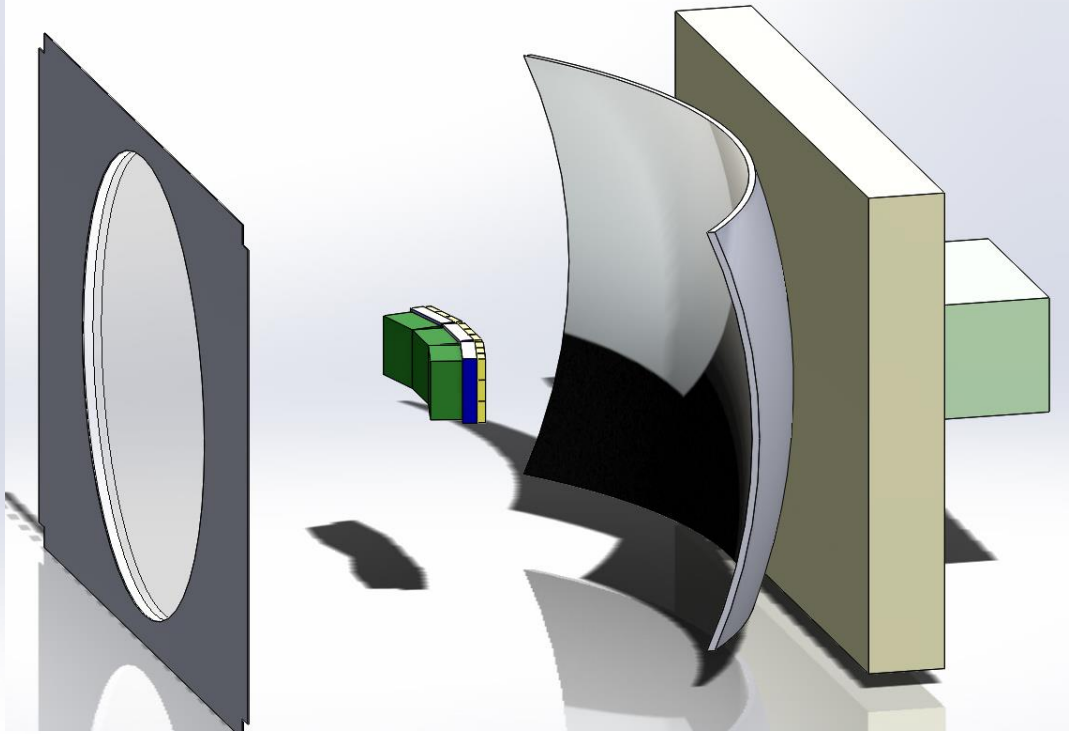
SiPMs qualification for POEMMA
Ancillary Devices (IR camera, AMON, (LIDAR?)
In flight calibration with Stars (in POEMMA mission design)
Preflight field tests - US: Desert, Mountain

Long Stratospheric Flight 100 day target





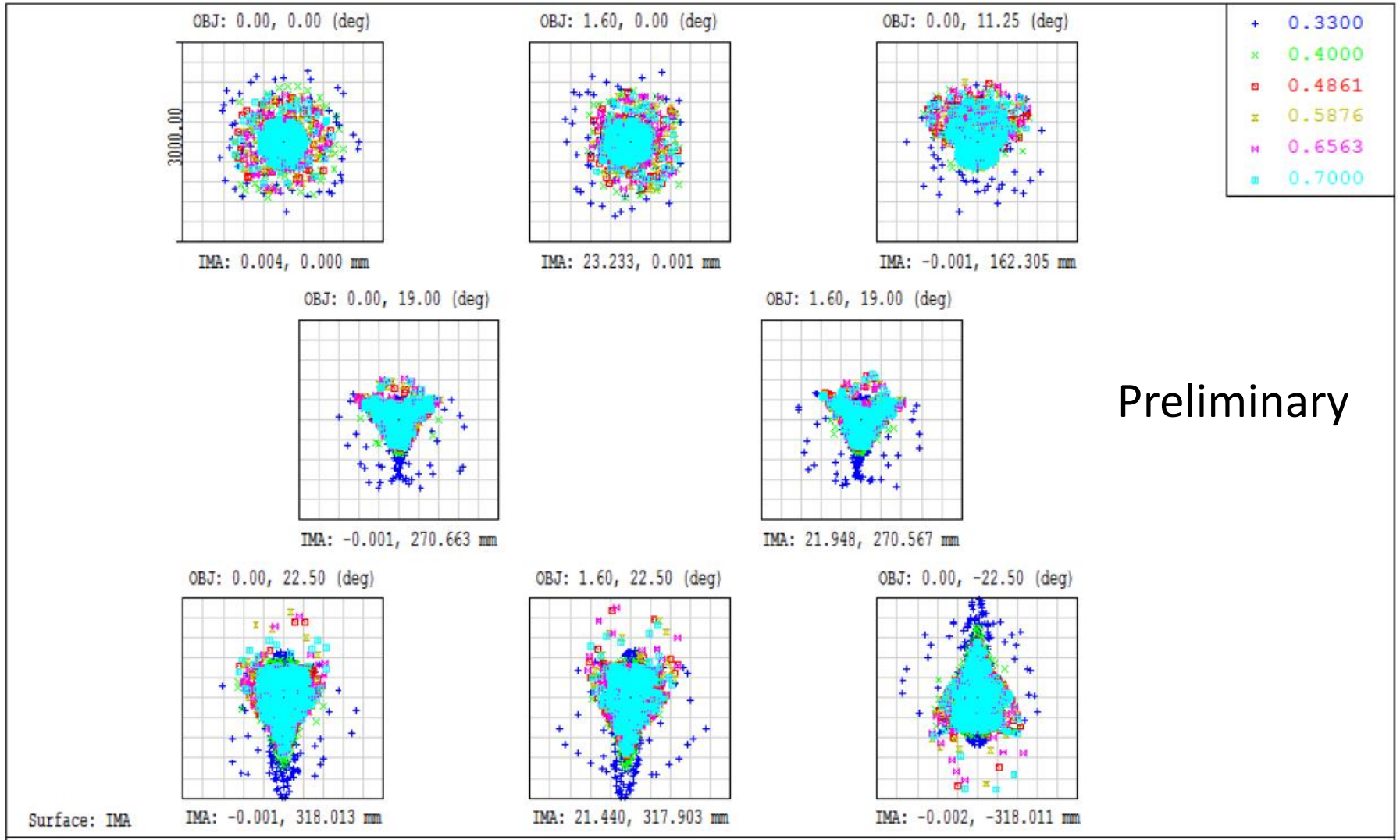




Also
Telescope Shutters
IR camera
UV sensors
Solar Power
NASA SIP

Cherenkov Telescopes
FoV 5◦ X 45◦ bi-focal mirror
FoV 5◦ X 45◦ normal mirror
Fluorescence Telescope
FoV 15◦ X 45◦ normal mirror

Corrector Plate: $1m^2$
Image resolution: ~ few mm
Pixel size: ~3mm square



Preliminary

Spot Diagram

Units are µm.
Airy Radius: 0.6166 µm

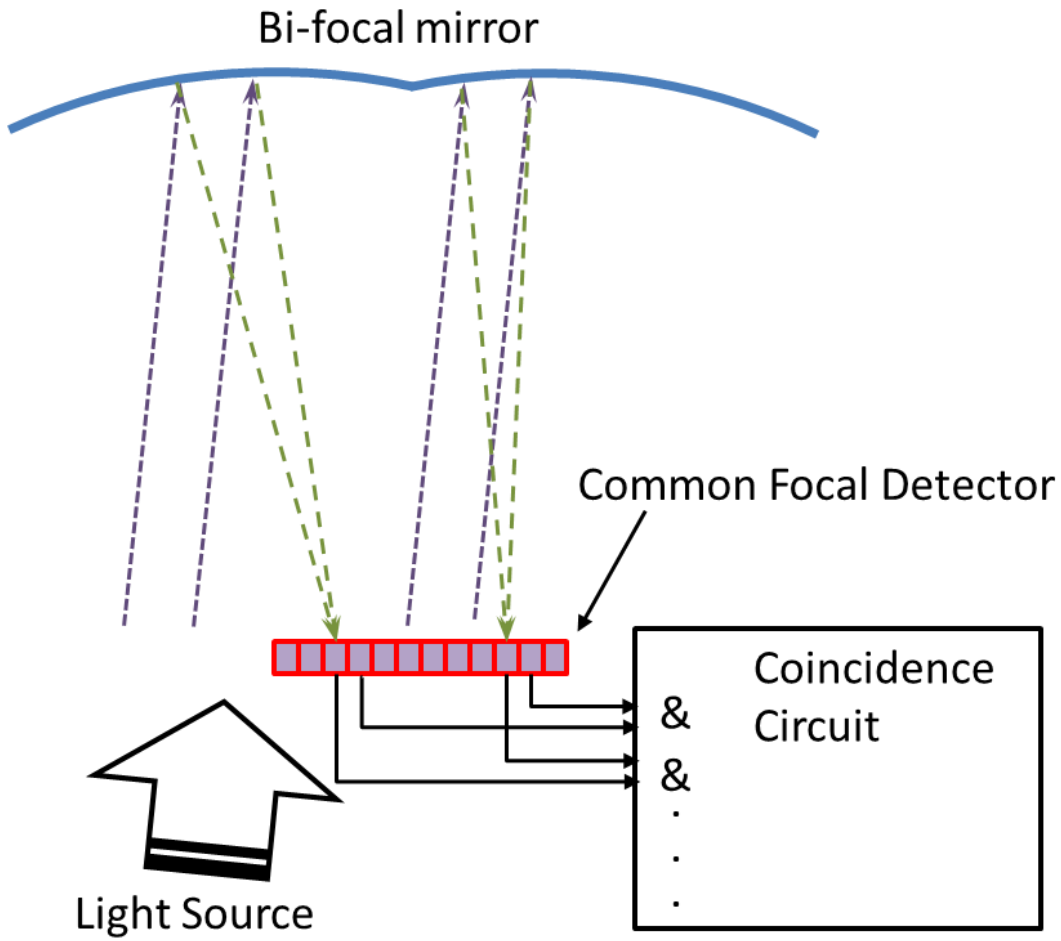
Field	1	2	3	4	5	6	7	8
RMS radius :	306.206	296.112	343.894	314.575	312.477	447.967	453.794	449.934
GEO radius :	1154.15	1146.93	1074.45	1202.88	1129.80	1491.86	1492.55	1490.18

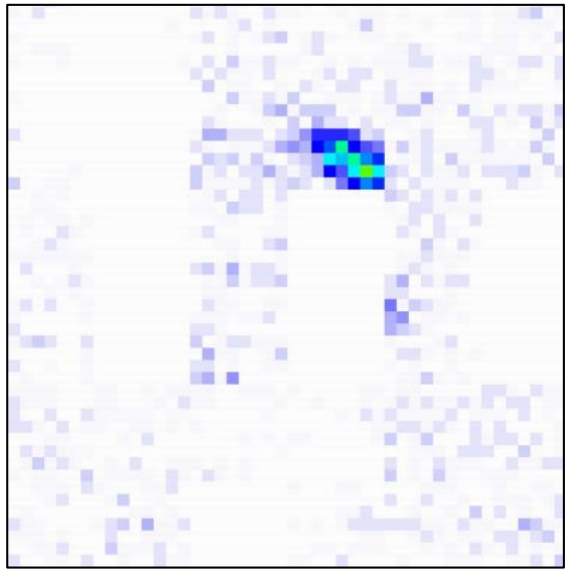
Box width : 3000
Reference : Centroid

Center for Applied Optics
University of Alabama in Huntsville
Patrick J. Reardon

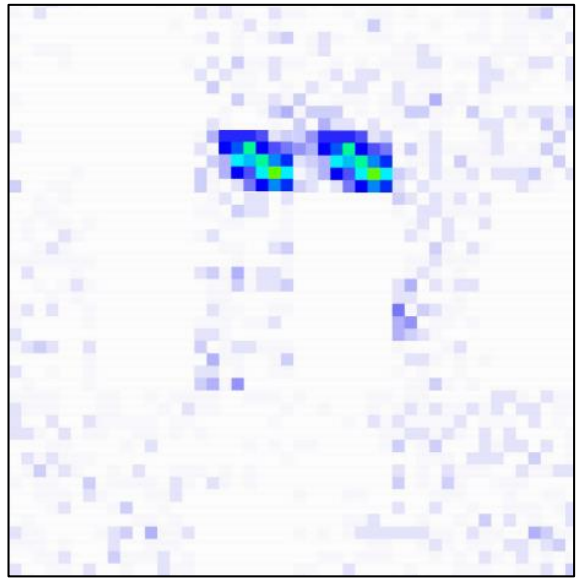
EUSO-SPB2_Chr.zmx
Configuration 1 of 1

Bi-focal Mirror Concept (Cherenkov Telescope)



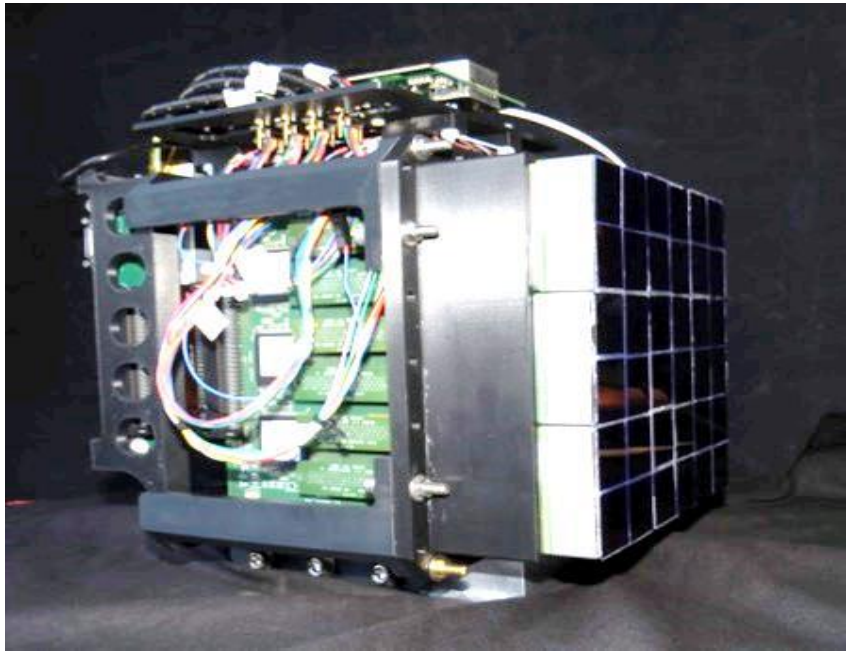


Std. mirror

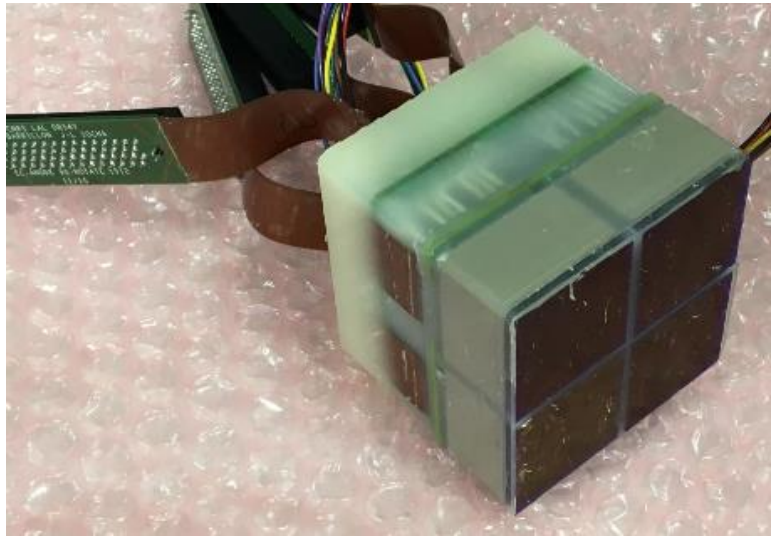


Bi-focal mirror

FD Focal Surface

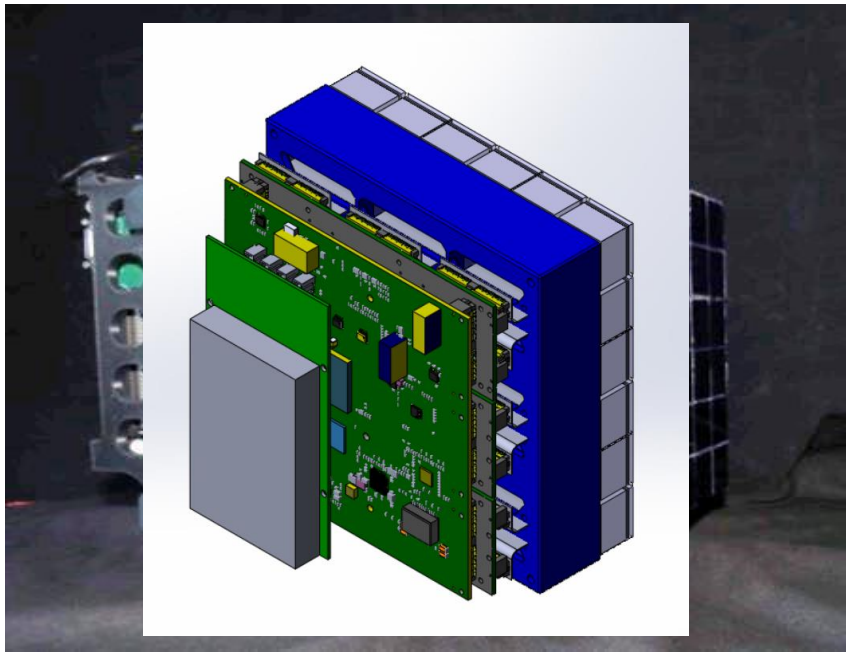


SPB1 Photo Detector Module (PDM)
9 Elementary Cells

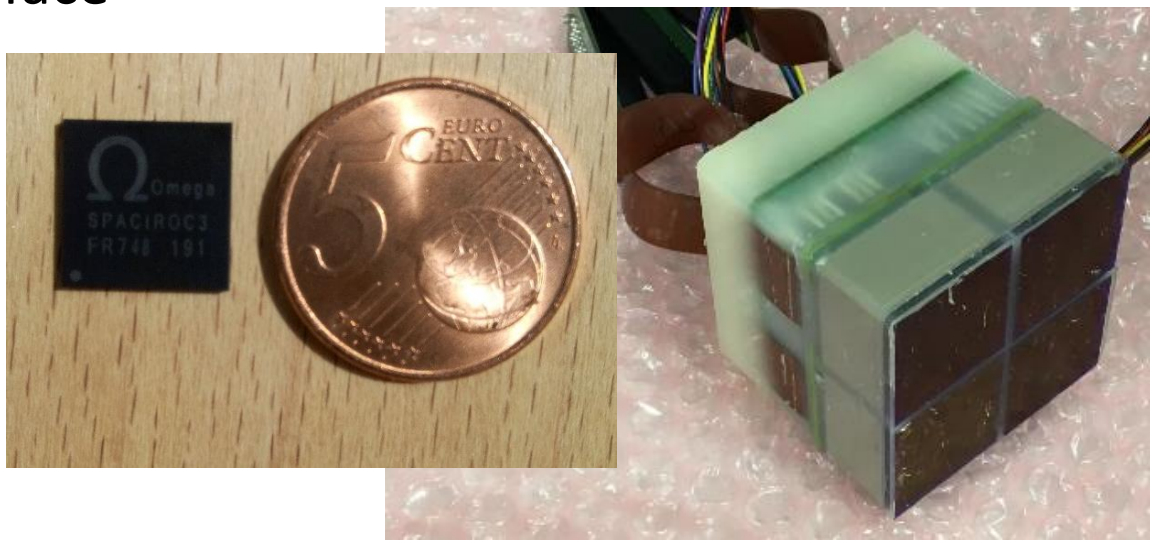


SPB1 Elementary Cell (EC)
2x2 64 Channel Hammatsu Multi-annode PMTs
Base, HV (+ digitization for SPB2)

Fluorescence Detector Focal Surface



SPB1 Photo Detector Module (PDM)
9 Elementary Cells

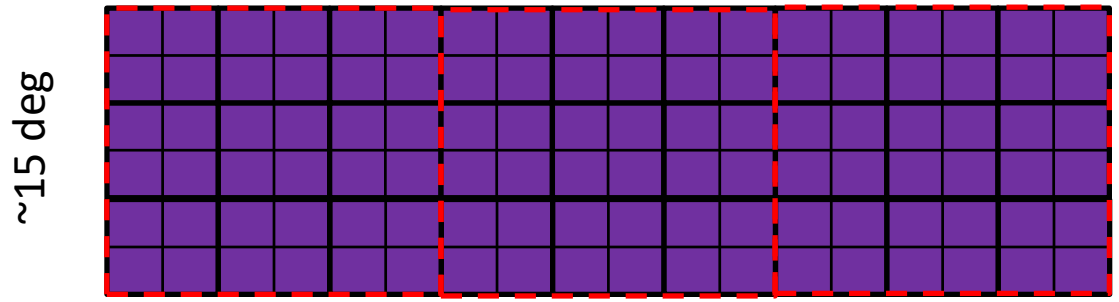


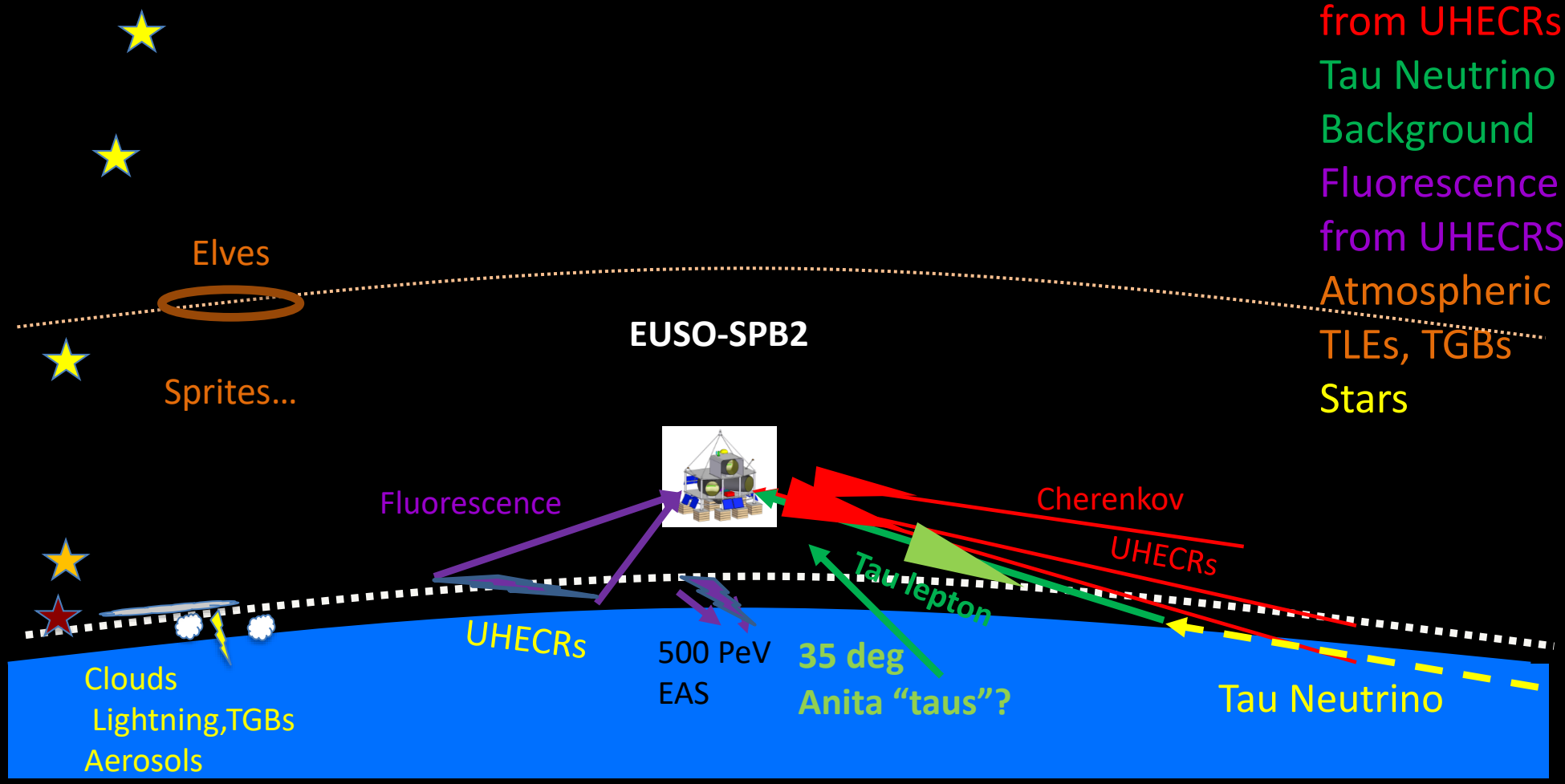
SPB1 Elementary Cell (EC)
2x2 64 Channel Hammatsu Multi-annode PMTs
Base, HV (+ digitization for SPB2)

48x48=2304 pixels
Single Photoelectron Counting
1.0 μS time bins (fluorescence)
1 “video clip” = 128 time bins
~15 watts

SPB2

FD Baseline Design is 3x9 ECs (3 PDMs)





Cherenkov Emission
from UHECRs
Tau Neutrino
Background
Fluorescence
from UHECRS
Atmospheric
TLEs, TGBs
Stars

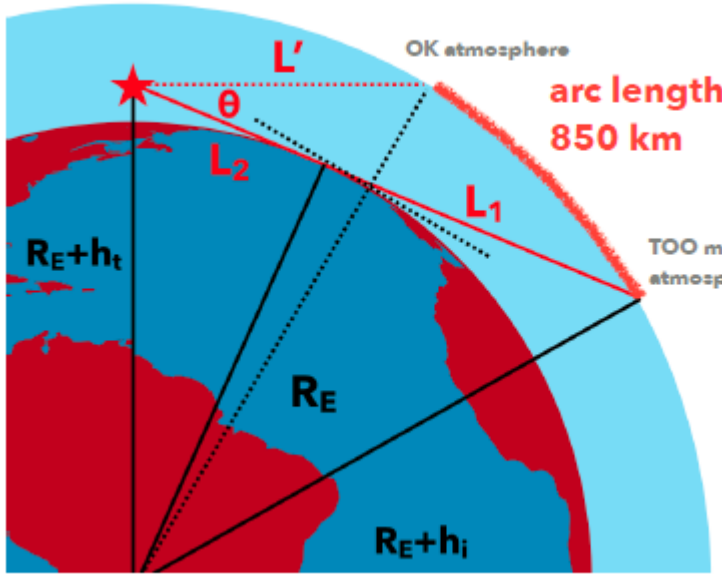
EUSO-SPB2 OBSERVABLE REGION FOR ELVES

$$L = L_1 + L_2 = \sqrt{(R_E + h_i)^2 - R_E^2} + \sqrt{(R_E + h_t)^2 - R_E^2} \approx 1000 + 600 = 1600 \text{ km} \quad (1)$$

$$L' = \sqrt{(R_E + h_i)^2 - (R_E + h_t)^2} \approx 800 \text{ km} \quad (2)$$

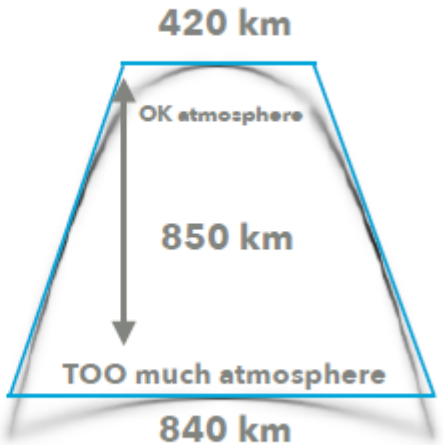
$$\theta = \frac{\pi}{2} - \cos^{-1}\frac{L_2}{R_E + h_t} \approx 5.6 \text{ degrees} \quad (3)$$

with $R_E = 6370$ km, $h_i = 80$ km, $h_t = 30$ km.

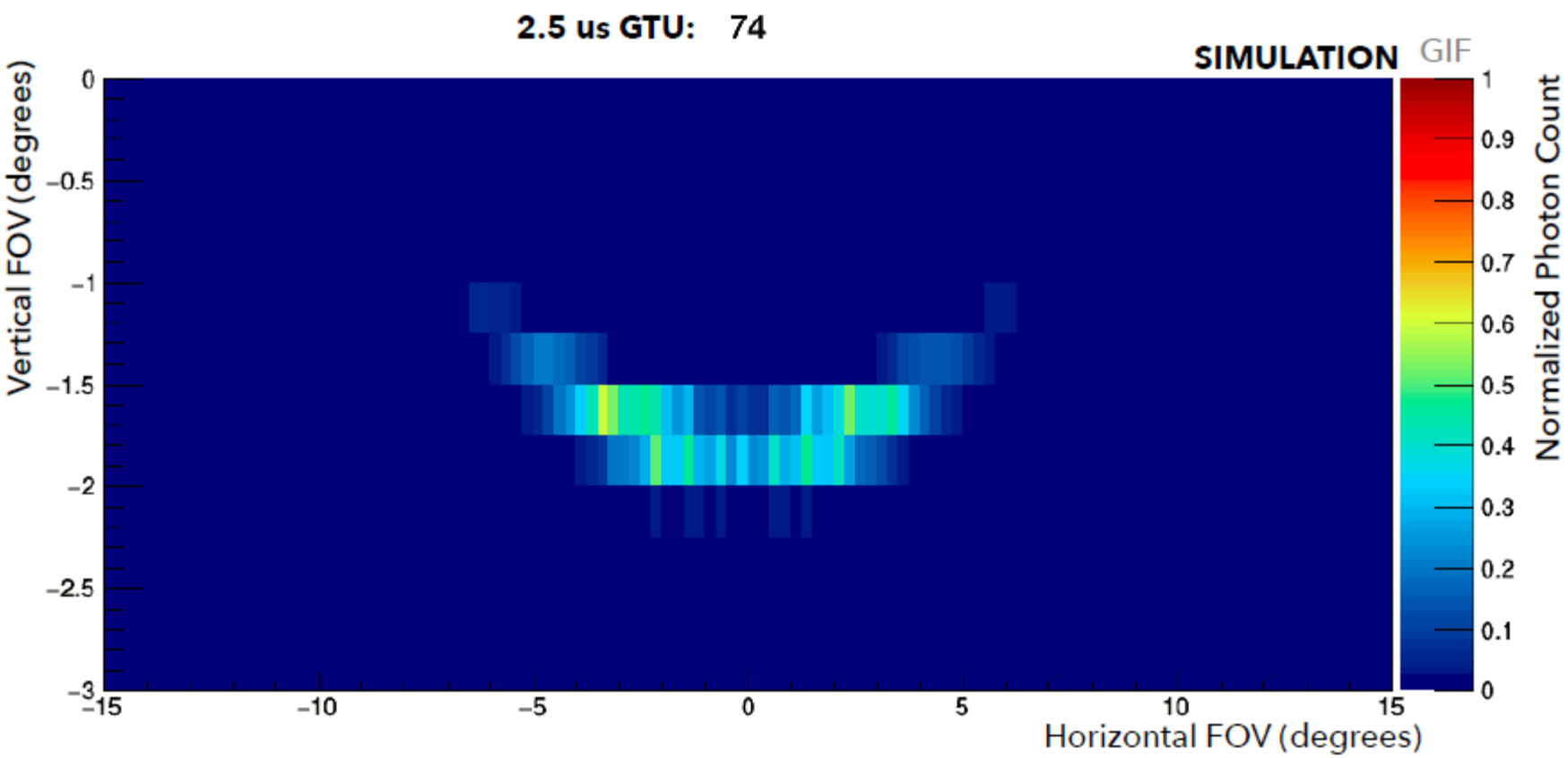


Possible telescope FOV in detector coordinate system:

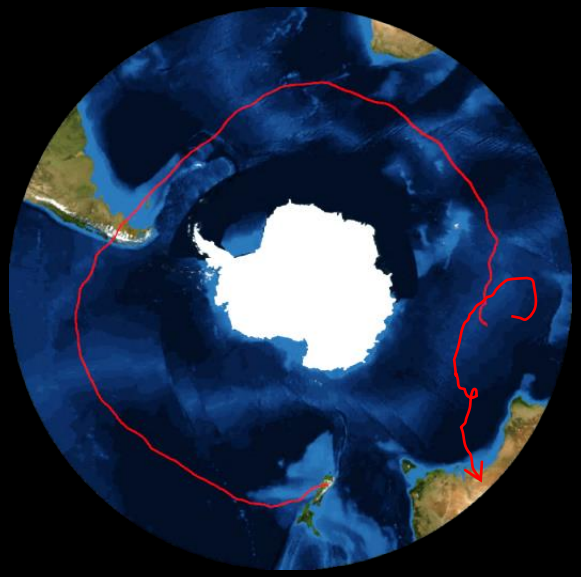
Possible telescope FOV projected to the ionosphere:



ELVES are typically < 250 km in radius!

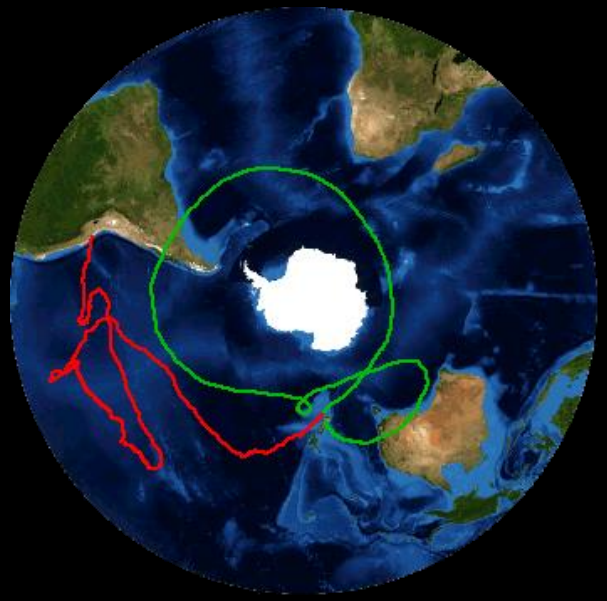

2.5 us GTU: 74
SIMULATION
GIF
Vertical FOV (degrees)
0
−0.5
−1
−1.5
−2
−2.5
−3
−15
−10
−5
0
5
10
15
Horizontal FOV (degrees)
Normalized Photon Count
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

2015: 32 d 5 h



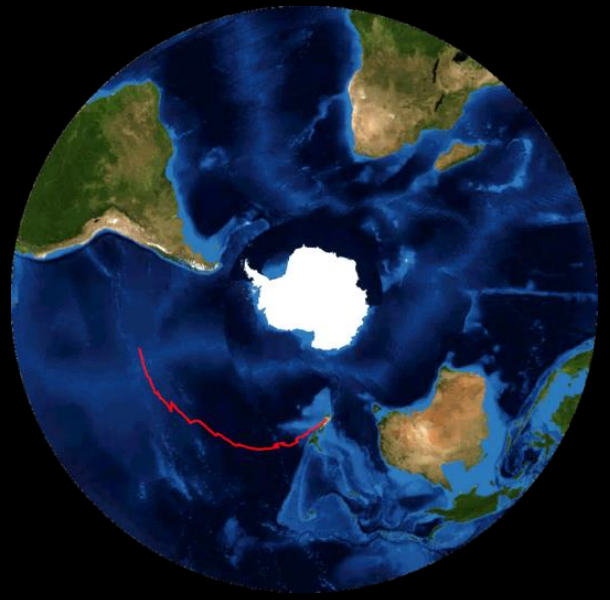
Engineering Flight

2016: 46 d 20 h



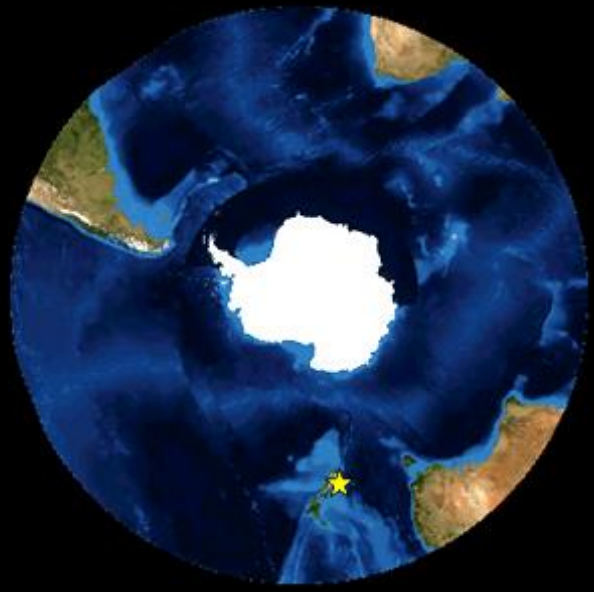
COSI

2017: 12 d 4 h



EUSO-SPB1

2022: 100 d ?



EUSO-SPB2

Summary

EUSO-SPB1 Successful Launch, 12 Day flight 2017
Most Data Downloaded (loss of half of telemetry, premature termination)
Detector performed well. Stable, measure UV emission, direct CRs..

EUSO-SPB2 Improved Multi-Telescope Instrument, builds on SPB1 experience
Add unexplored areas
Cherenkov, Neutrino Backgrounds, High Altitude EASs
Scientific and Technical Pathway toward POEMMA

POEMMA will open two new Cosmic Windows:
neutrinos from astrophysical to cosmogenic, and
extreme energy cosmic ray (> 10s EeV)

Space provides order of magnitudes improved sensitivity over a wide range of energies.