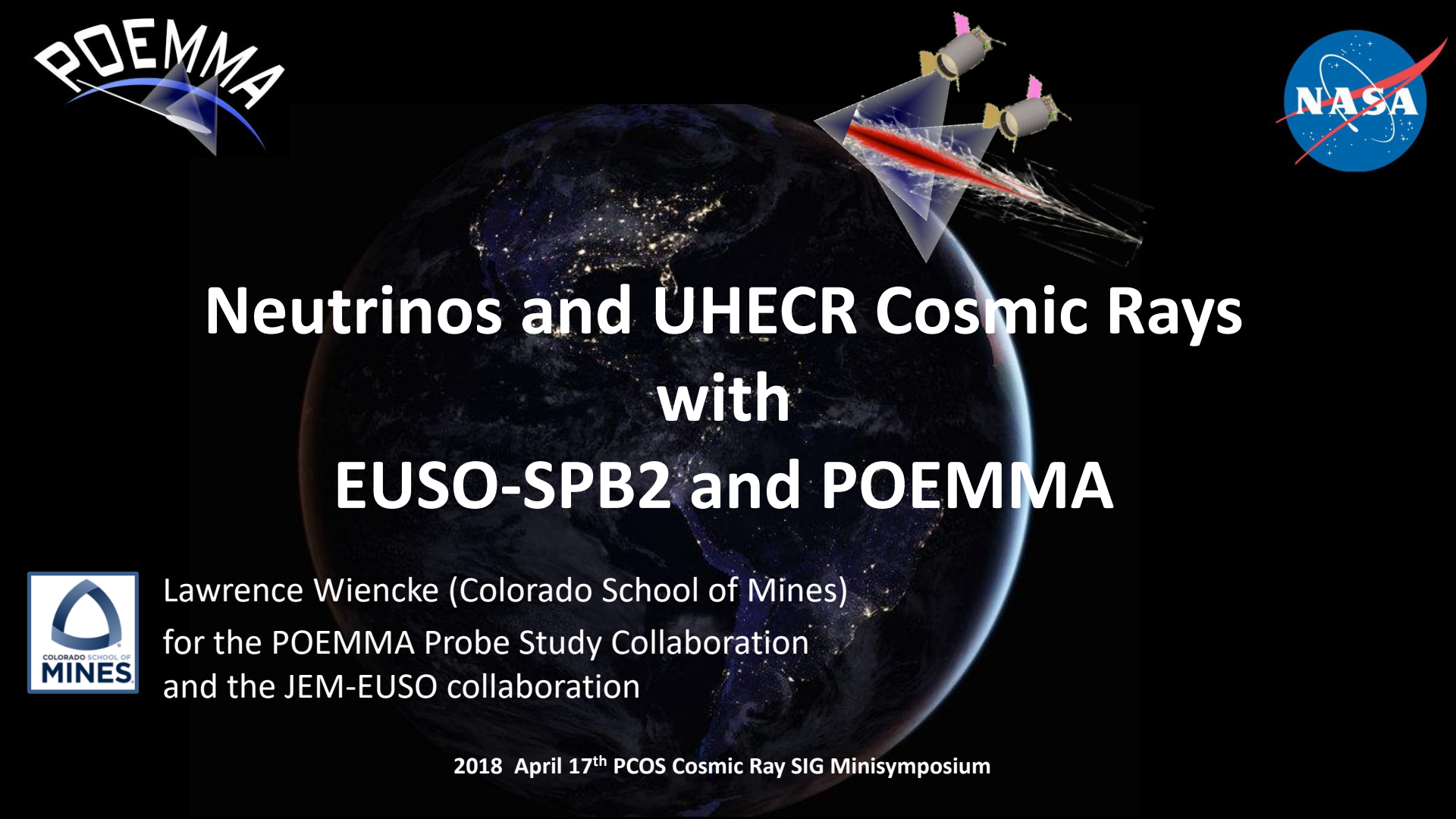


Neutrinos and UHECR Cosmic Rays with EUSO-SPB2 and POEMMA

Lawrence Wiencke (Colorado School of Mines)
for the POEMMA Probe Study Collaboration
and the JEM-EUSO collaboration

2018 April 17th PCOS Cosmic Ray SIG Minisymposium

POEMMA Probe of Extreme MultiMesenger Astrophysics

J. Krizmanic APS April 14th 2018 C15.00003 APS Meeting

also available: arXiv:1708.07599

EUSO-SPB2 Extreme Universe Space Observatory on a Super Pressure Balloon 2

L. Wiencke APS April 14th 2018 C15.00004

also available: white paper arXiv:1703.04513

EUSO-SPB1 (flew 2017, Wanaka NZ)

J. Eser APS April 14th 2018 C15.00005

also available: ICRC 2017 *https://pos.sissa.it/301/1097/pdf*

NASA Astrophysics Probe Mission Concept Studies

***NASA Solicitation NNH16ZDA001N-APROBES* (Scope of Program):**

Announced: 19-Feb-16 Due Date: 15-Nov-16 Selection: 17-Mar-17

NASA has started preparations for the 2020 Astronomy and Astrophysics Decadal Survey (http://science.nasa.gov/astrophysics/2020-decadal-survey-planning/). One of the tasks of the 2020 Decadal Survey Committee will be to recommend a portfolio of astrophysics missions. The Decadal Survey Committee may choose to recommend a portfolio of missions containing a mix of prioritized large- and medium-size mission concepts, or even a program of competed medium-size missions. NASA and the community are interested in providing appropriate input to the 2020 Decadal Survey regarding medium-size mission concepts, also referred to as Astrophysics Probe concepts.

To this end, NASA is soliciting proposals to conduct mission concept studies for Astrophysics Probe missions. Following peer review of the proposed mission concept studies, NASA will select a small number of proposals for 1.5 year (18 month) funded studies. Results of the selected studies will be provided by NASA as input to the 2020 Decadal Survey.

Astrophysics Probes are envisioned to have a total lifecycle (NASA Phases A through E) cost between that of a MIDEX mission (~$400M) and ~$1B. Proposals for concept studies may envision missions that include contributions from other agencies (national or international), industry, and universities.

Should NASA choose to develop a mission that flows from any selected mission concept study, the responsibility for that mission will be assigned by NASA; there is no expectation that the mission concept study team or participating organization.

Specific instructions for mission definition, eg launch date, costing, …
Funded instrument definition, eg IDL, and mission definition, eg MDL, studies FINAL REPORTS DUE SEPTEMBER 2018

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, Robert Streitmatter

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

Gran Sasso Science Institute: Roberto Aloisio

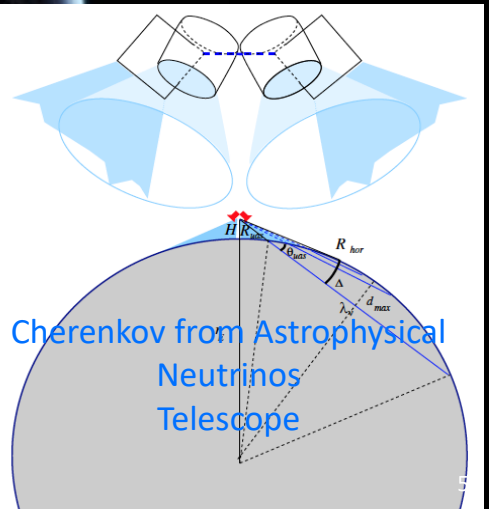
Scientists from 16+ institutions from
OWL, JEM-EUSO, Auger, TA, Veritas, CTA, Fermi, Theory

POEMMA

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

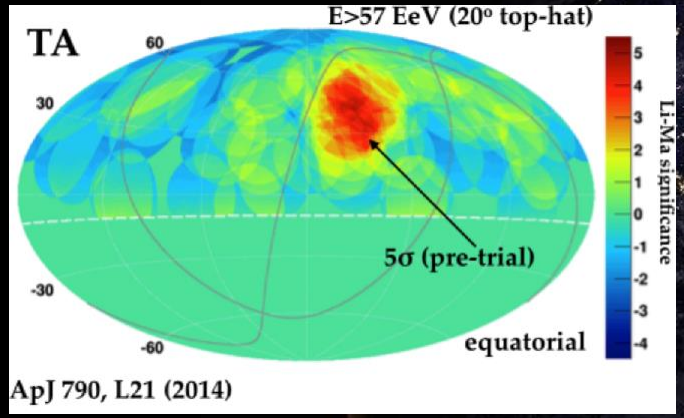
EUSO-SPB1
2017

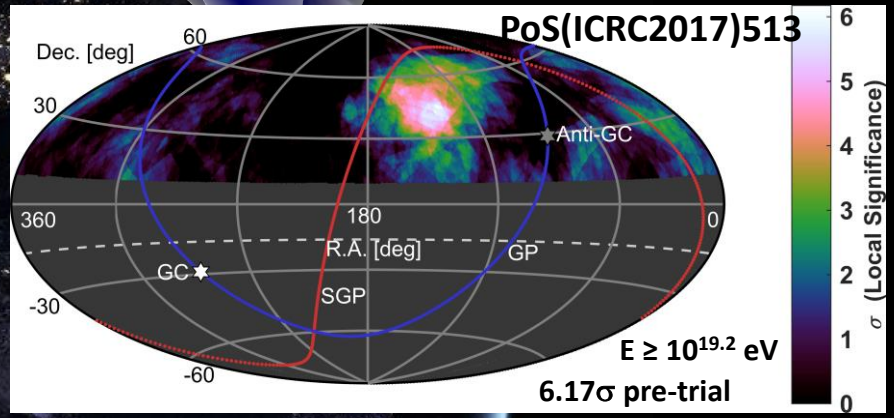
CHANT



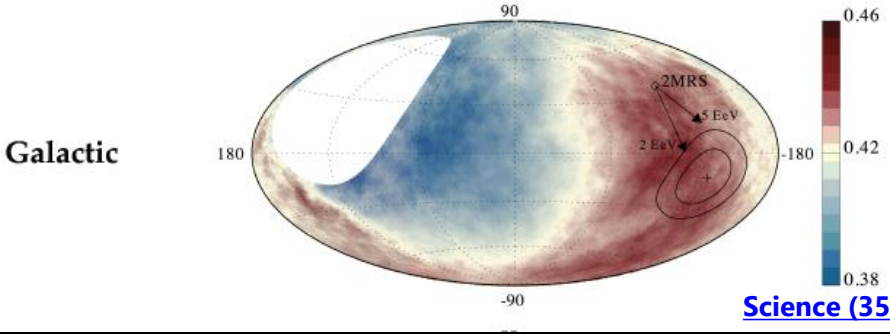
Origin of UHECRs still unknown but have hints

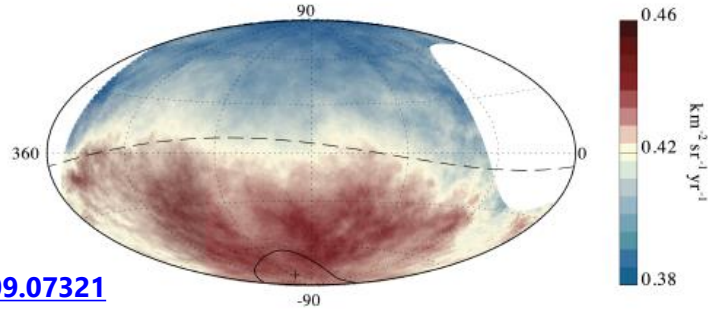
TA Hot Spot: Intermediate-scale Anisotropy





Auger Dipole: Large-scale Anisotropy above 8 EeV (>5.2 σ), direction implies extragalactic origin



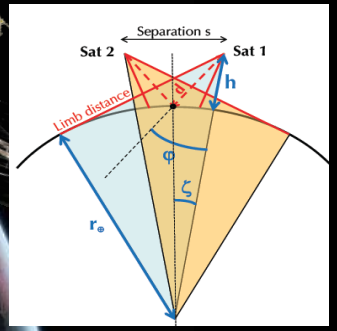


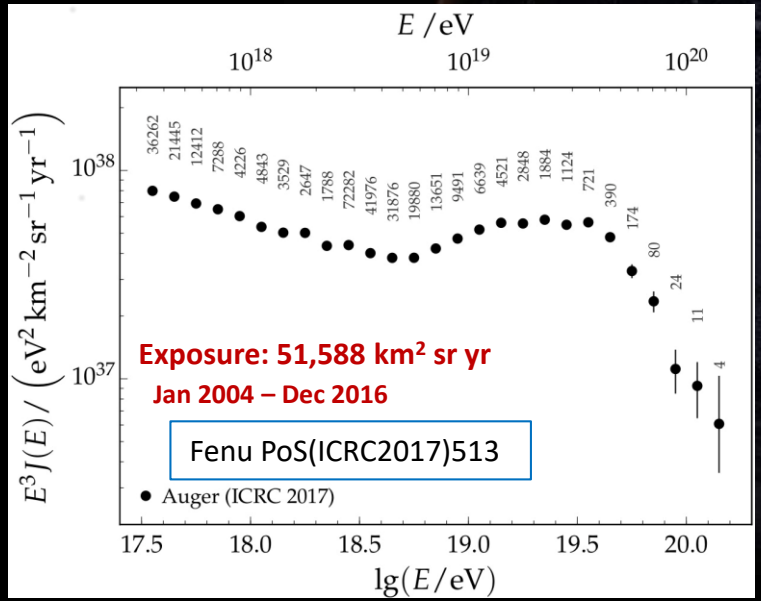
Science (357) 2017, arXiv:1709.07321

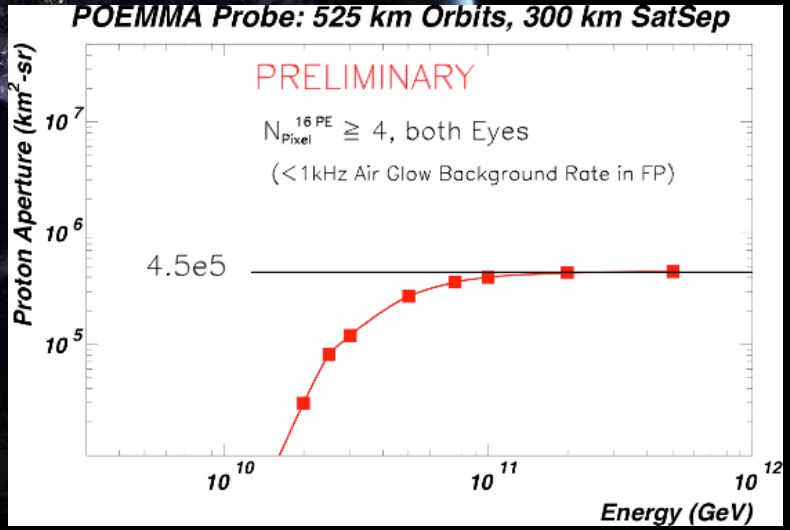
POEMMA UHECRs

Stereo observation of the air fluorescence signal of EASs:

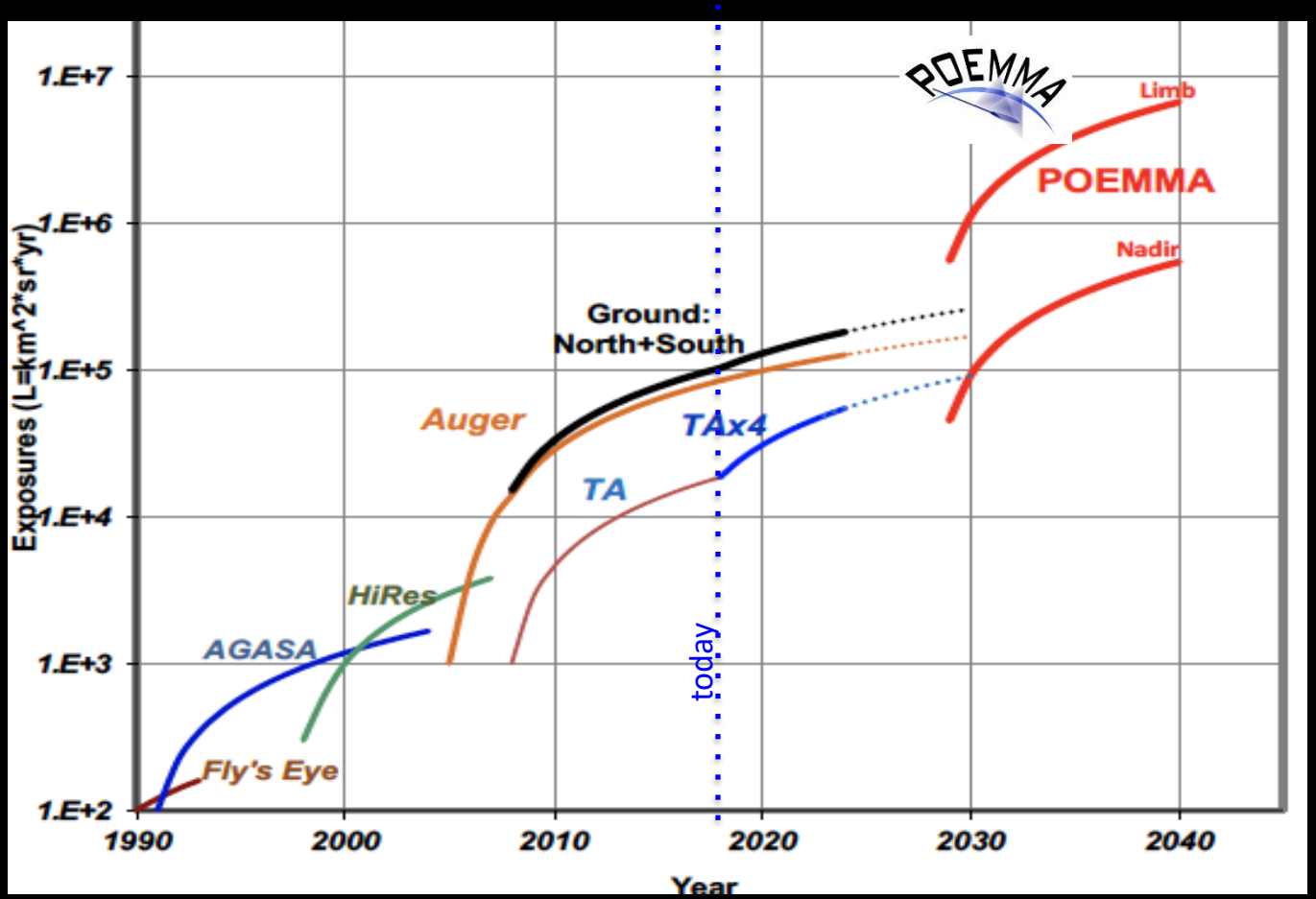
- **Achieve significant increase in exposure via space-based observations (x10 arrays; x100 fluorescence) with full-sky coverage**
- **Achieve good angular and energy resolution**
- **Achieve sufficient X_{MAX} resolution to perform UHECR composition measurements**







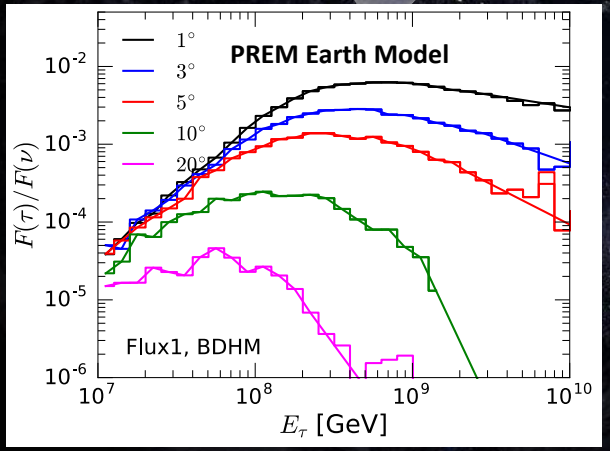
UHECR Exposure History

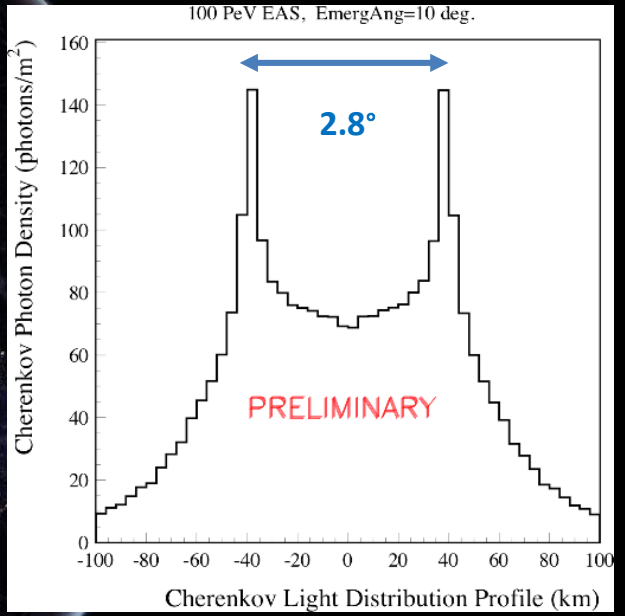


POEMMA Neutrino Detection

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

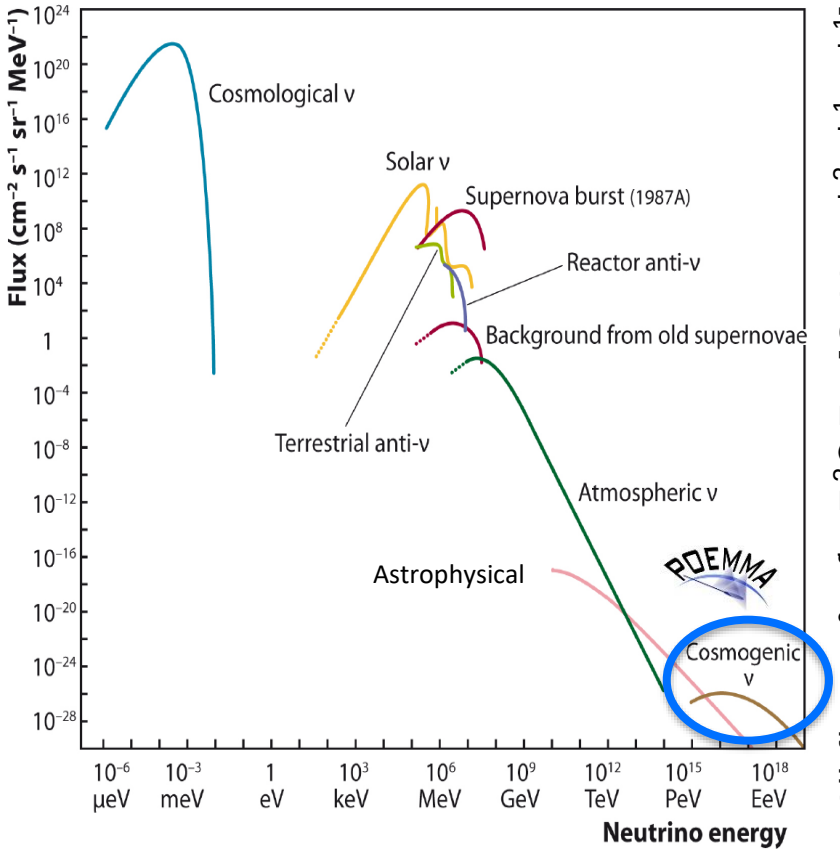
See Hallsie Reno's talk U17.00002 : Tau neutrino signals at POEMMA

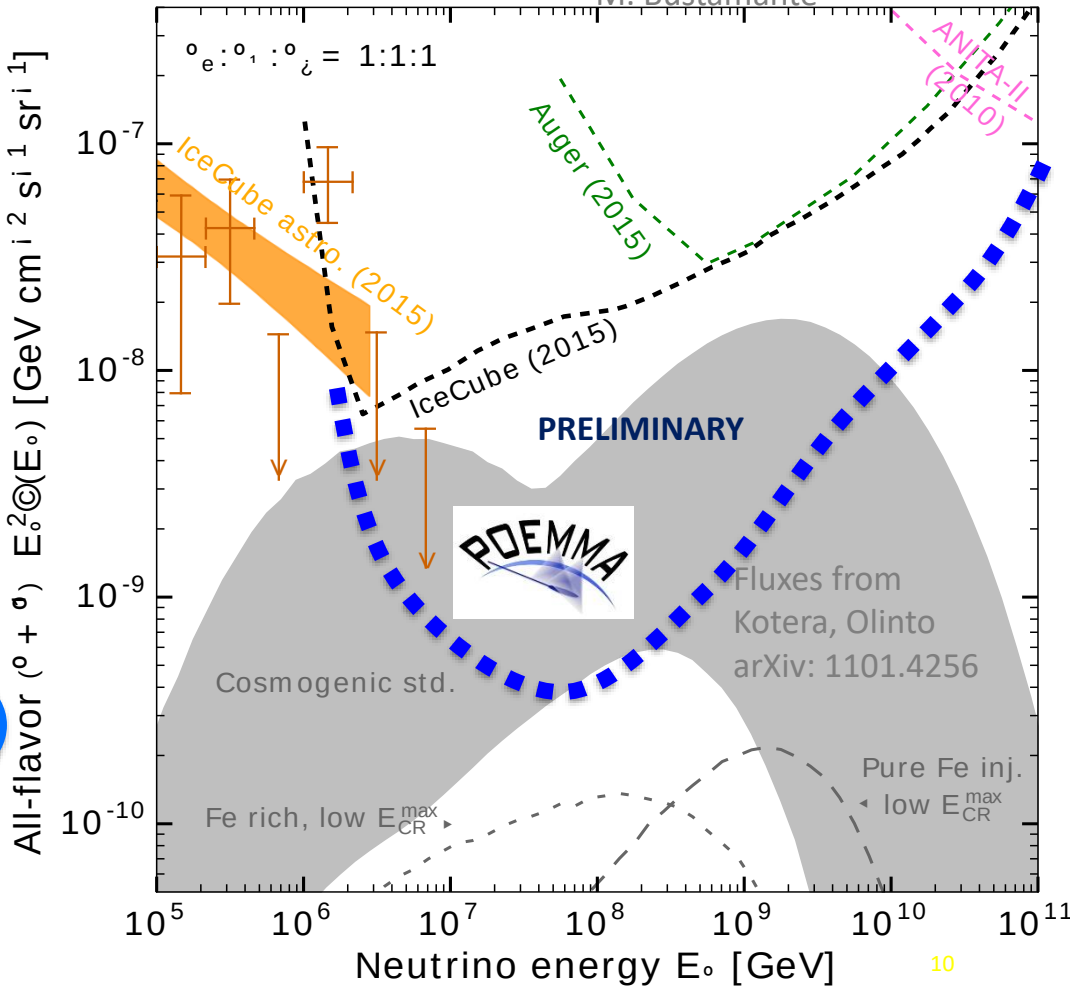




Flux1: Mixed-Composition, Kotera, Allard, Olinto (JCAP 1010:013,2010)

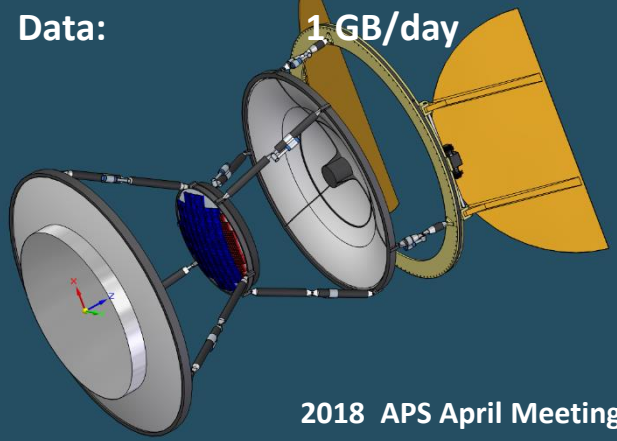
M. Bustamante



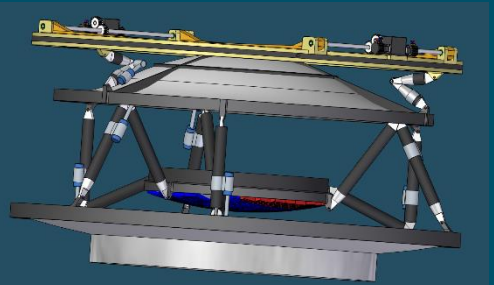


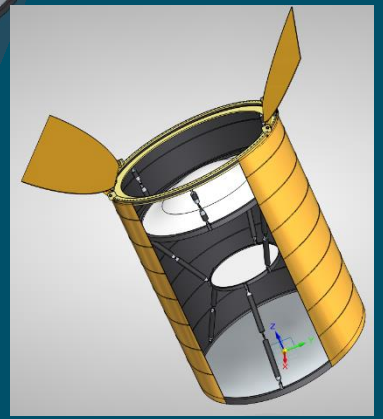
POEMMA INSTRUMENT

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

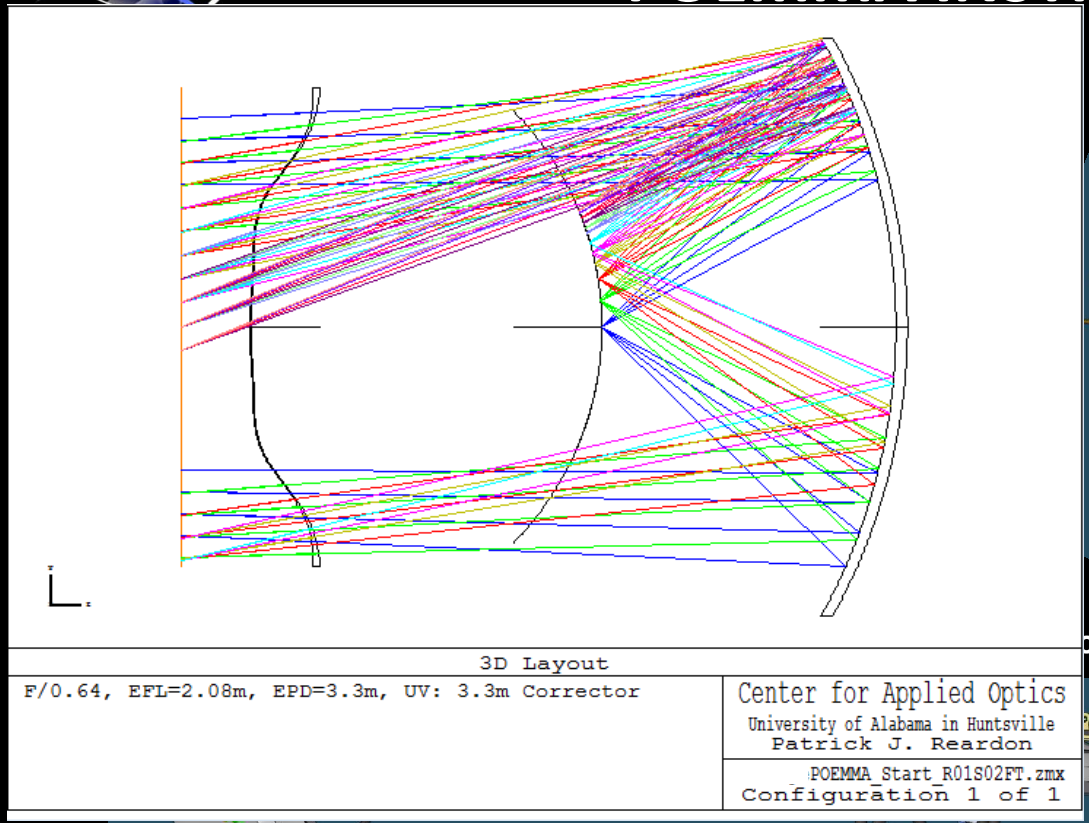


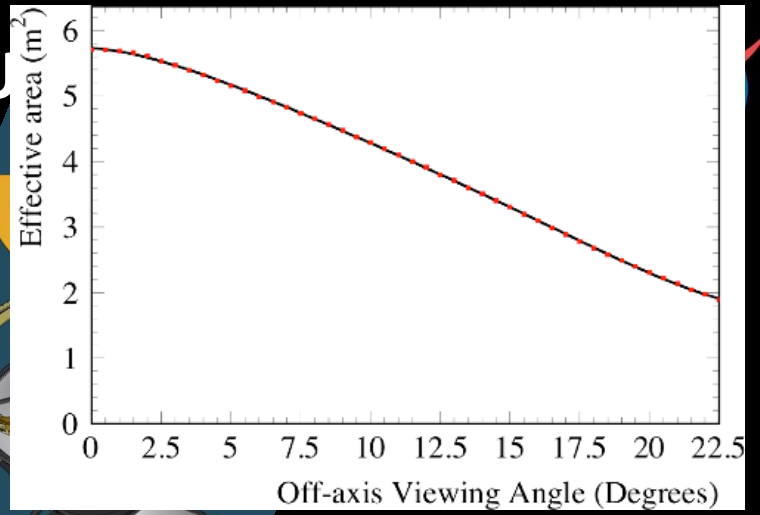
Stowed Configuration Launch

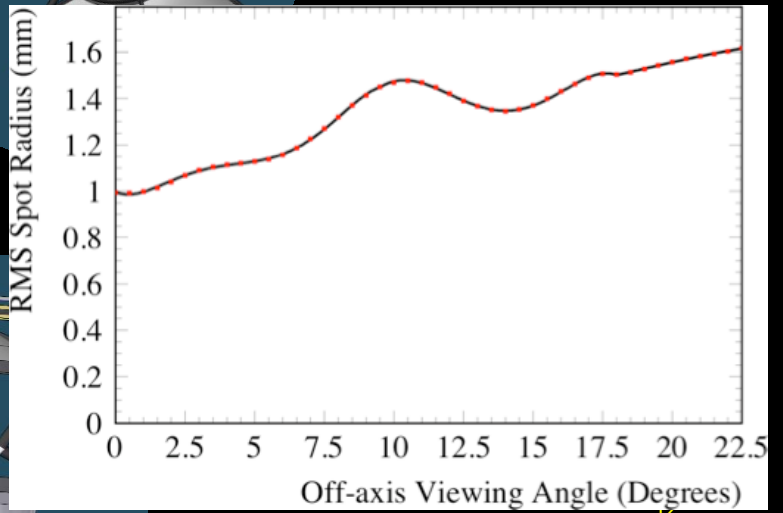




POEMMA INSTRU



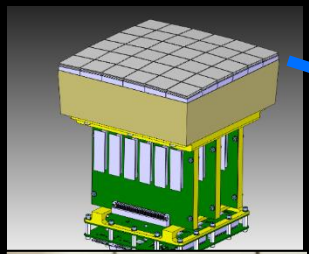


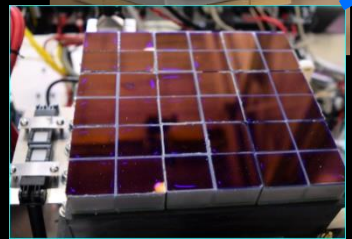


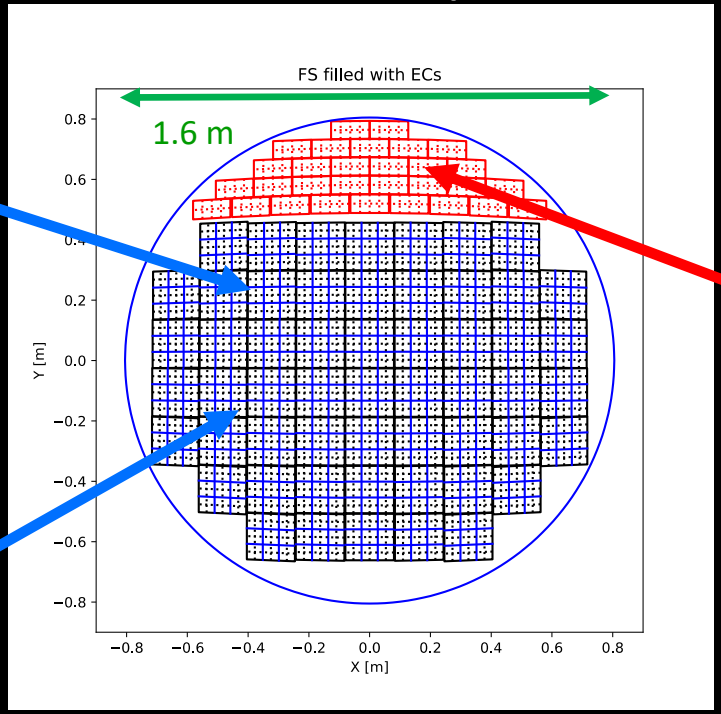
POEMMA
Hybrid MM Focal Surface

~ 150k 3 mm pixels

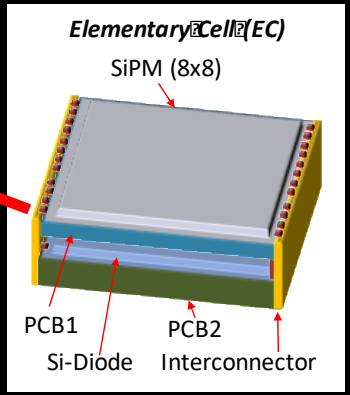
UV Fluorescence Detection using MAPMTs with BG3 filter







Cherenkov Detection with SiPMs



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

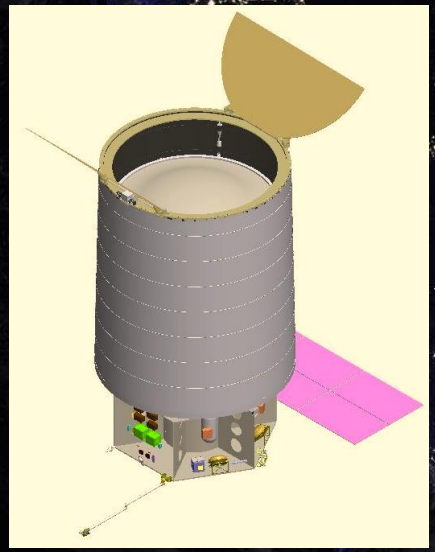
55 Photo Detector Modules (PDMs)= 126,720 pixels

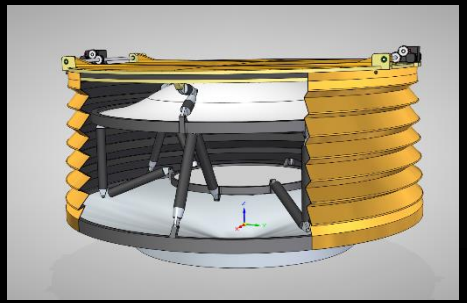
1 PDM = 36 MAPMTs = 2,304 pixels

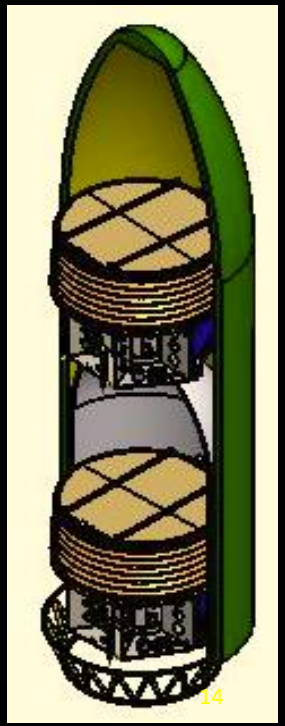
POEMMA MISSION

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

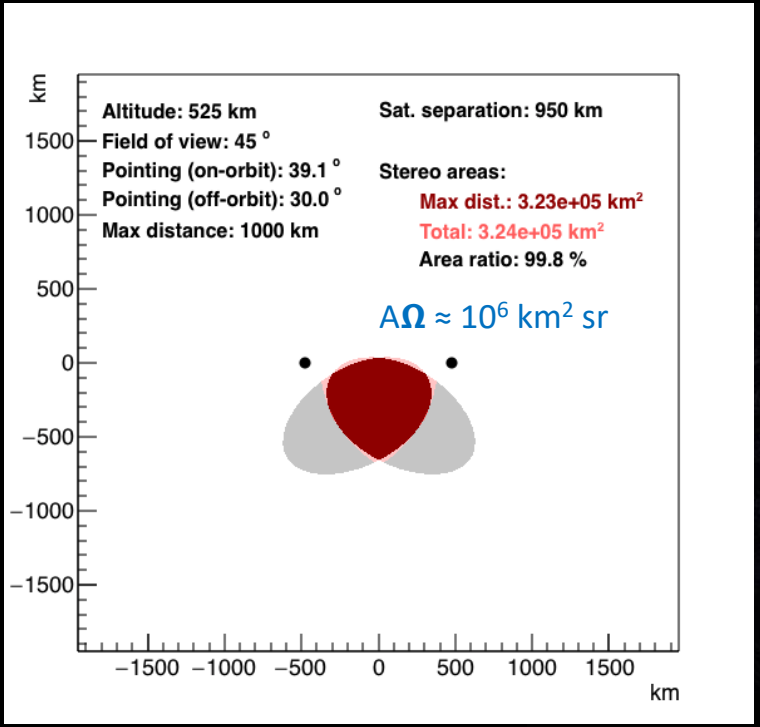


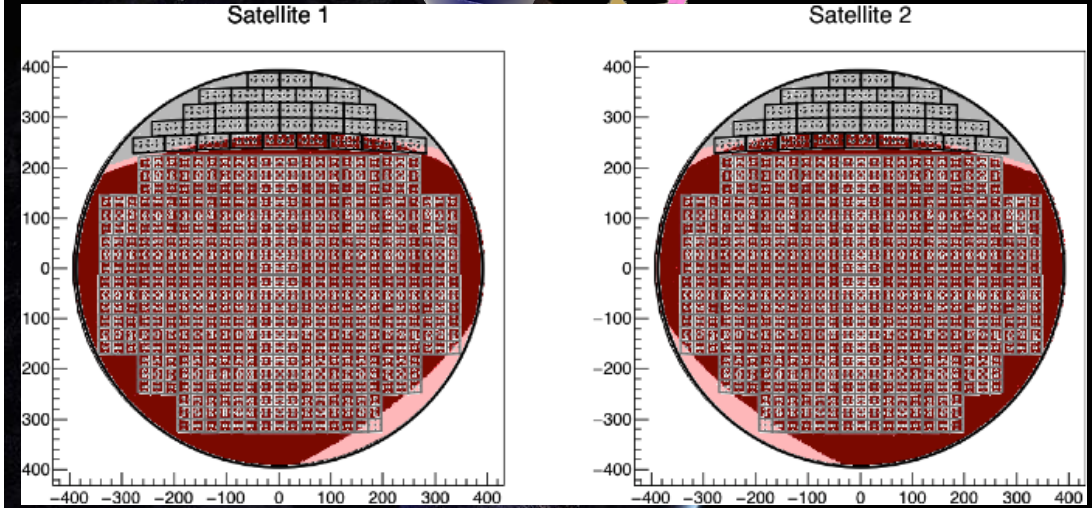




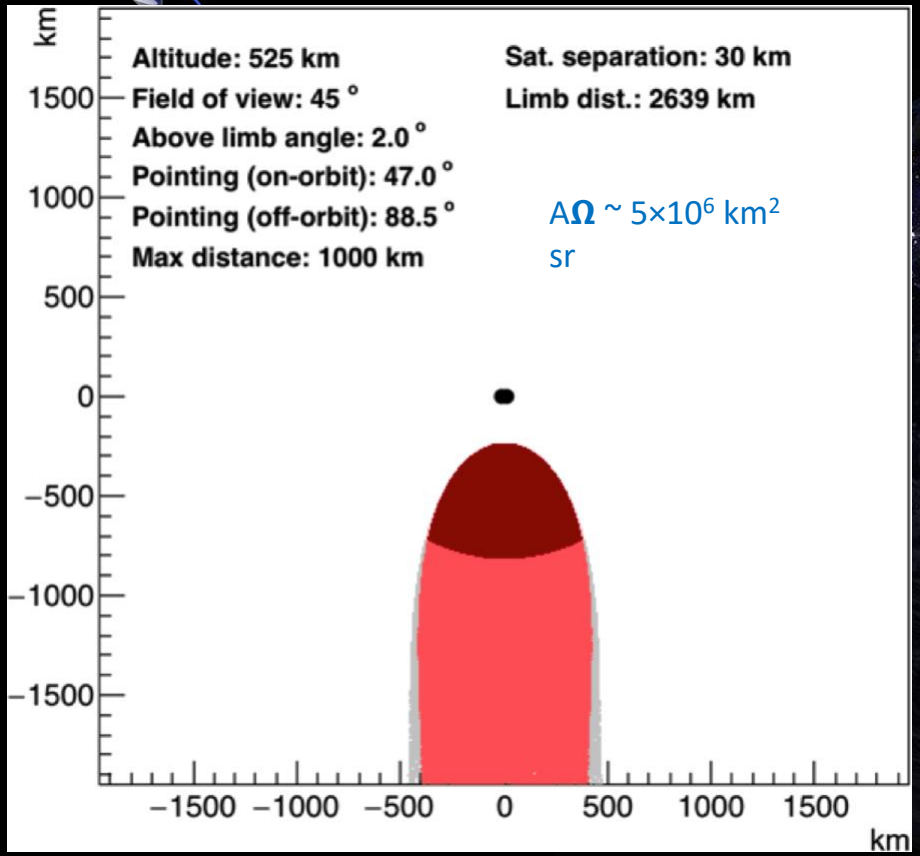
Dual Manifest ATLAS V LPF

Example UHECR–mode Configuration

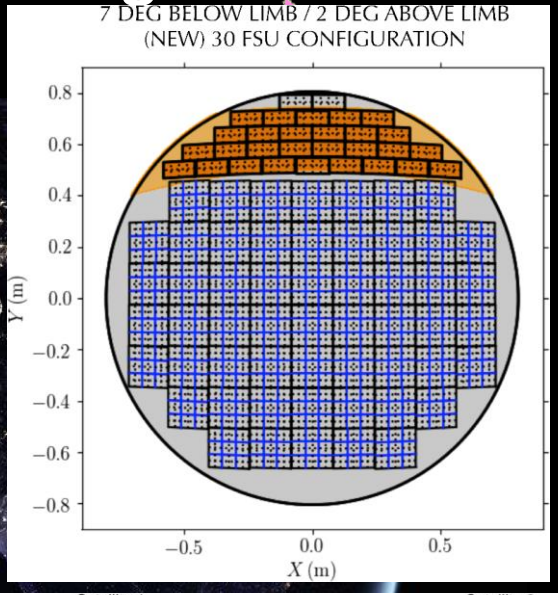


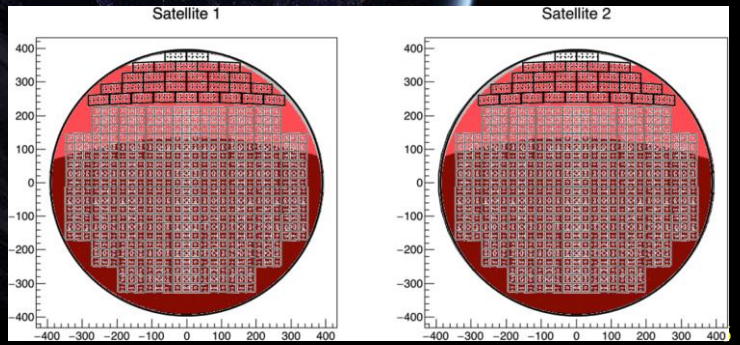


Example Neutrino–mode Configuration



$A\Omega \sim 5\times10^{6}$ km^2 sr





POEMMA

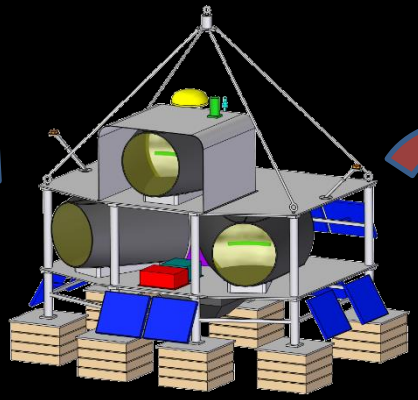
POEMMA will open two new Cosmic Windows:
Neutrinos from astrophysical to cosmogenic (> 10s PeV), and
UHECRs (> 10s EeV) to realize charged-particle astronomy

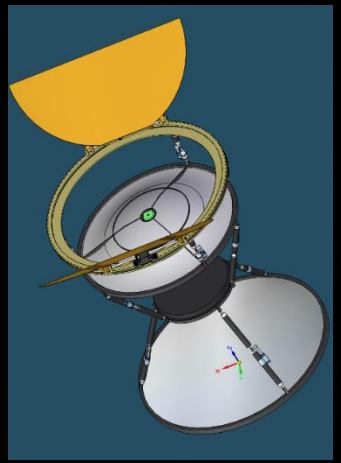
Space provides order of magnitudes improved sensitivity over a wide range of energies.

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

ANITA's two upward-going 'τ–lepton-like' 0.6 EeV EAS events (arXiv: 1803.05088) may have opened a door …

EUSO-SPB2



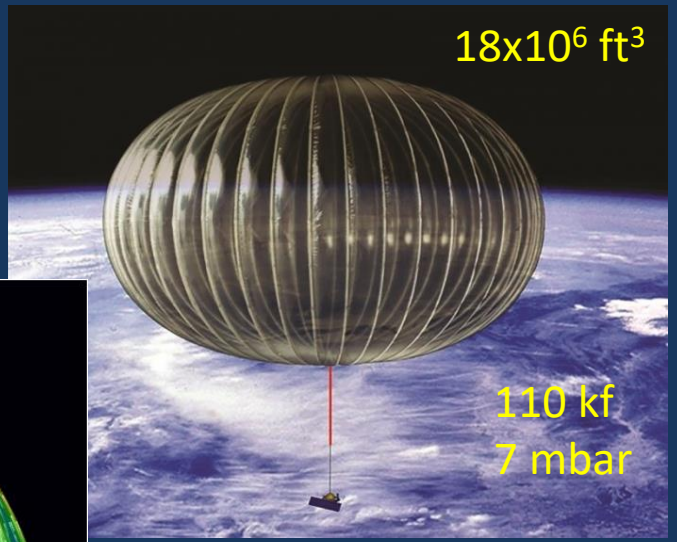


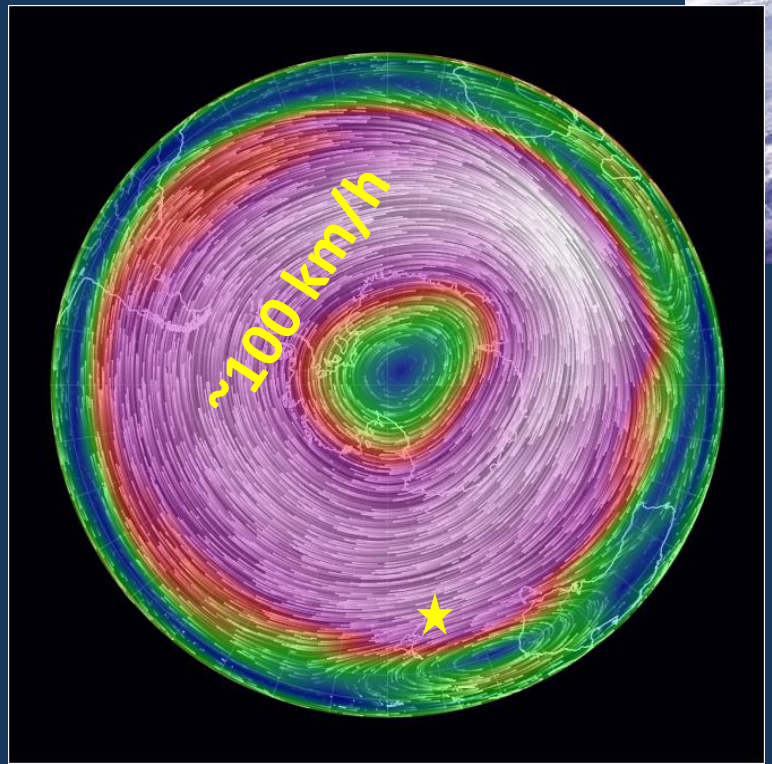
JEM-EUSO Collaboration

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

16 Countries, 77 Institutions, >300 researchers

NASA's Long Duration Balloon Program from NZ



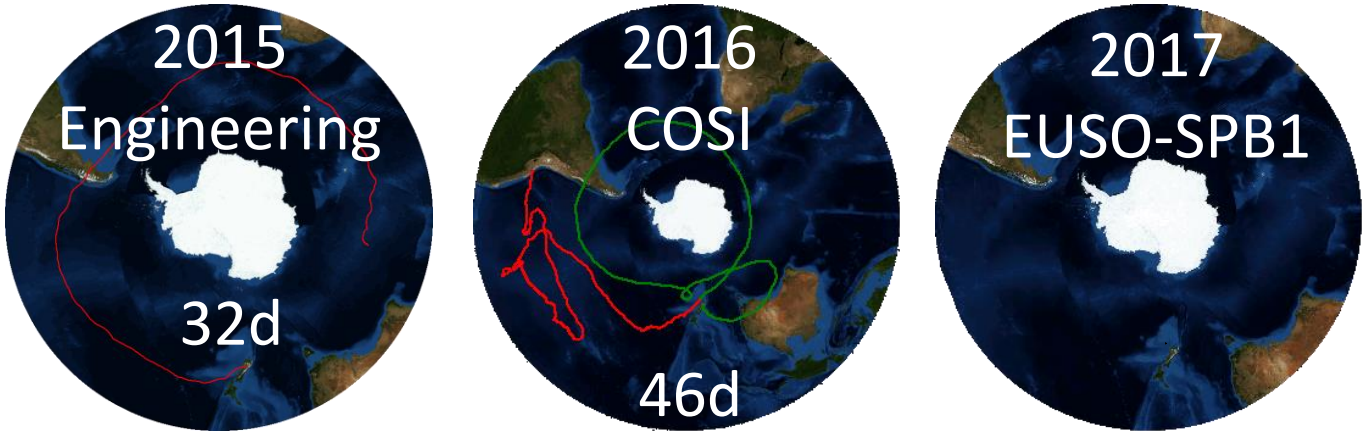


"Ton of science target duration 100 days"

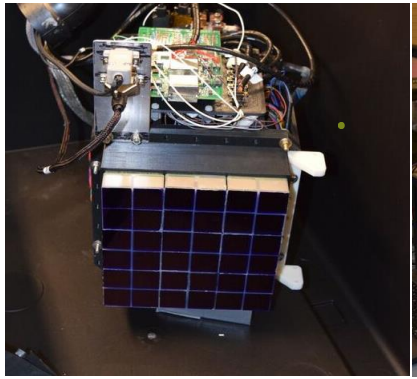
EUSO-SPB1 Goals

- 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

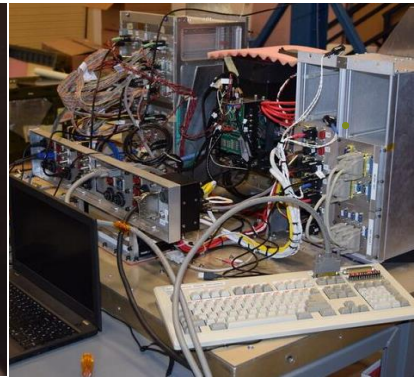
- Flown as NASA mission of opportunity from Wanaka,NZ
  - Targeted flight duration: 100 days



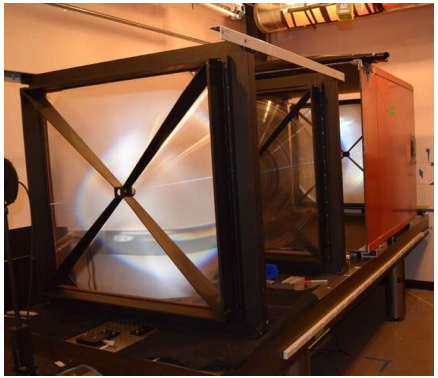
Instrument



Camera



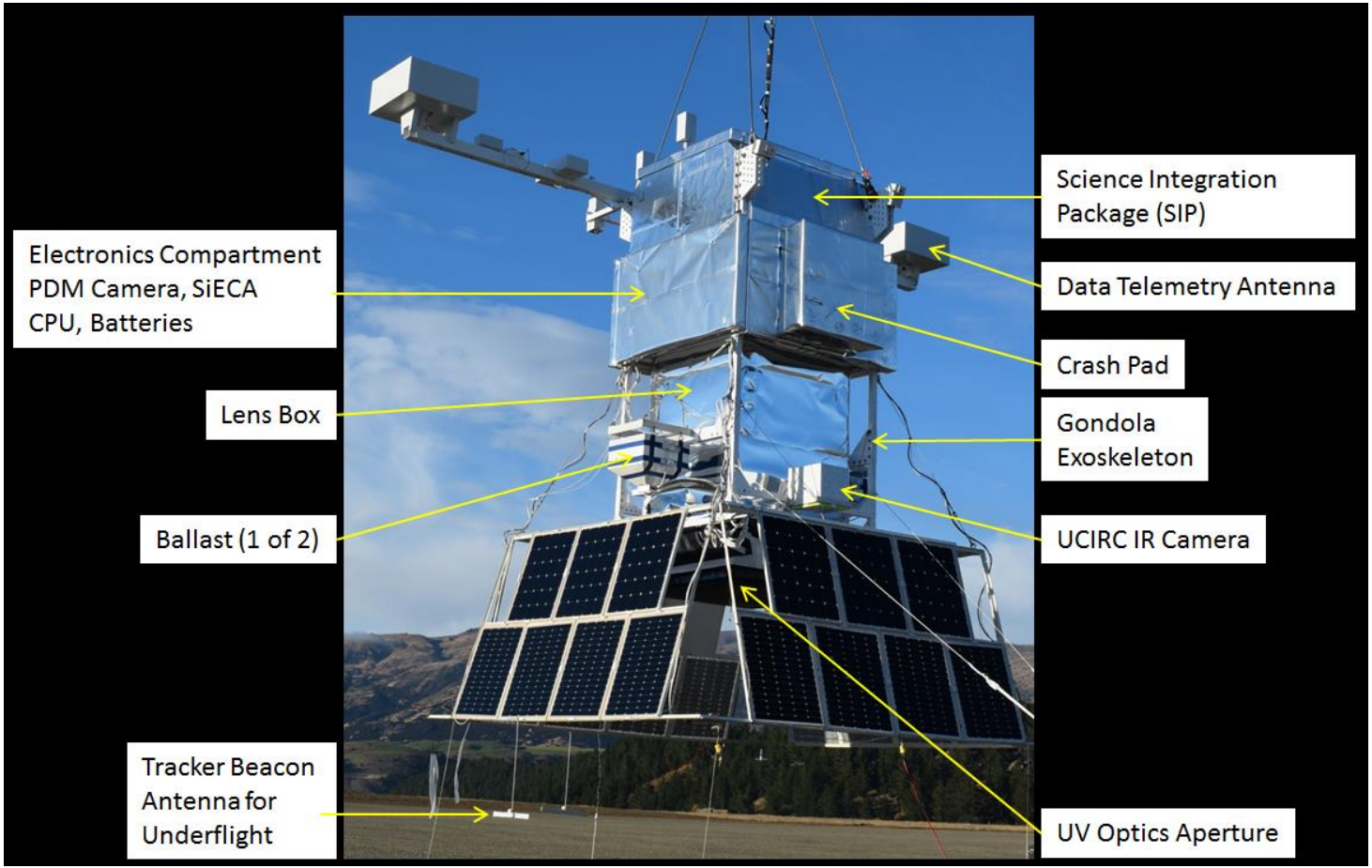
Electronics



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
- Operates in single photoelectron counting mode
- Two 1 m² Fresnel lenses to focus UV light

Instrument



Long duration flight:

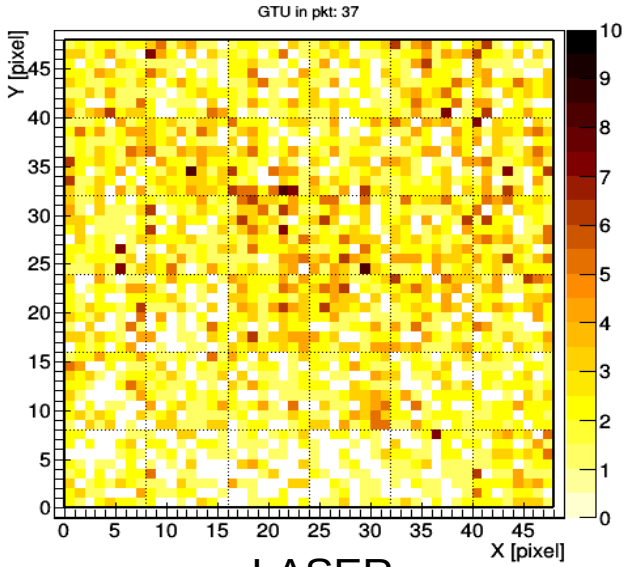
- Solar panels
- Ballast hoppers
- Satellite telemetry antennas
- Thermal insulation

EUSO-SPB Specs

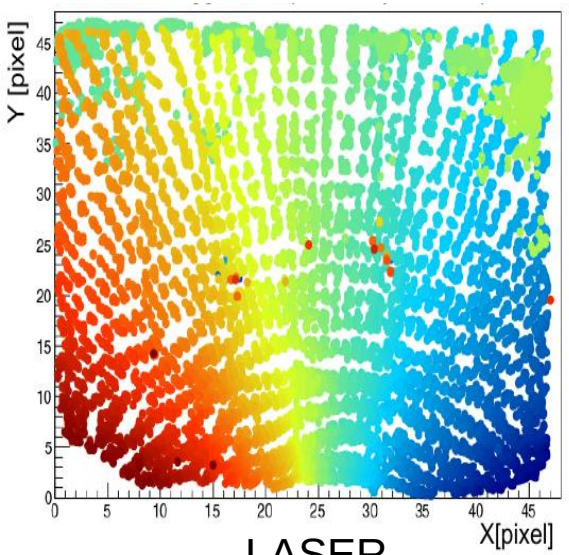
SPB Float Height	110,000 ft = 33.5 km
Weight	
Detector	2250 lbs
Payload	2700 lbs w/ SIP, Antennas, Empty Ballast Hoppers
Dimensions	1.2m x 1.2m x 3m
Power consumption	40 W Day, 70 W Night (assumes 20W PDM heater @ 50%)
Telescope	Refractor with 2 Fresnel lenses
FOV	11. deg (measured w/ stars)
Camera:	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

Preflight Tests in the Desert

- Laboratory tests: single components, flat fielding
- 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 (support,

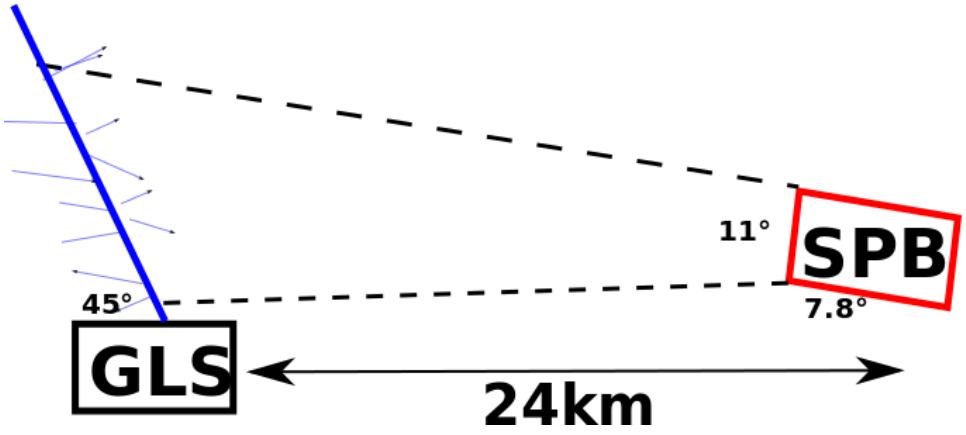


LASER



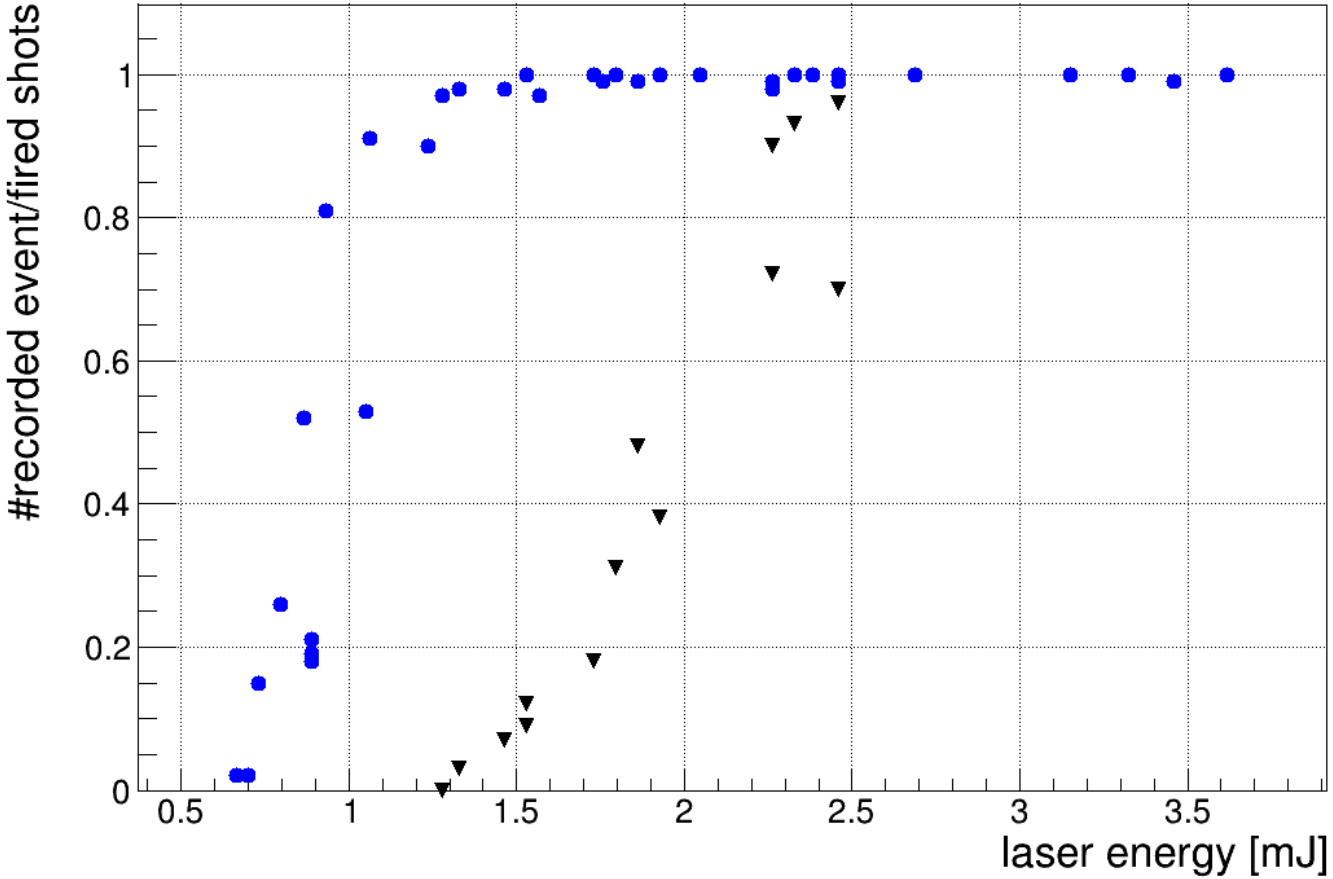
LASER

Detection Threshold Measurement



- 355 nm pulsed UV laser
- Laser elevation angle: 45° away from detector
- Firing 100 shots at different energies
- Energy range from 250 μJ - 4 mJ
- “Noise trigger” correction
- Flat field applied
- Detection threshold at 50% trigger rate

Detection Threshold



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

SPB1 2017
SPB2 Wanaka NZ

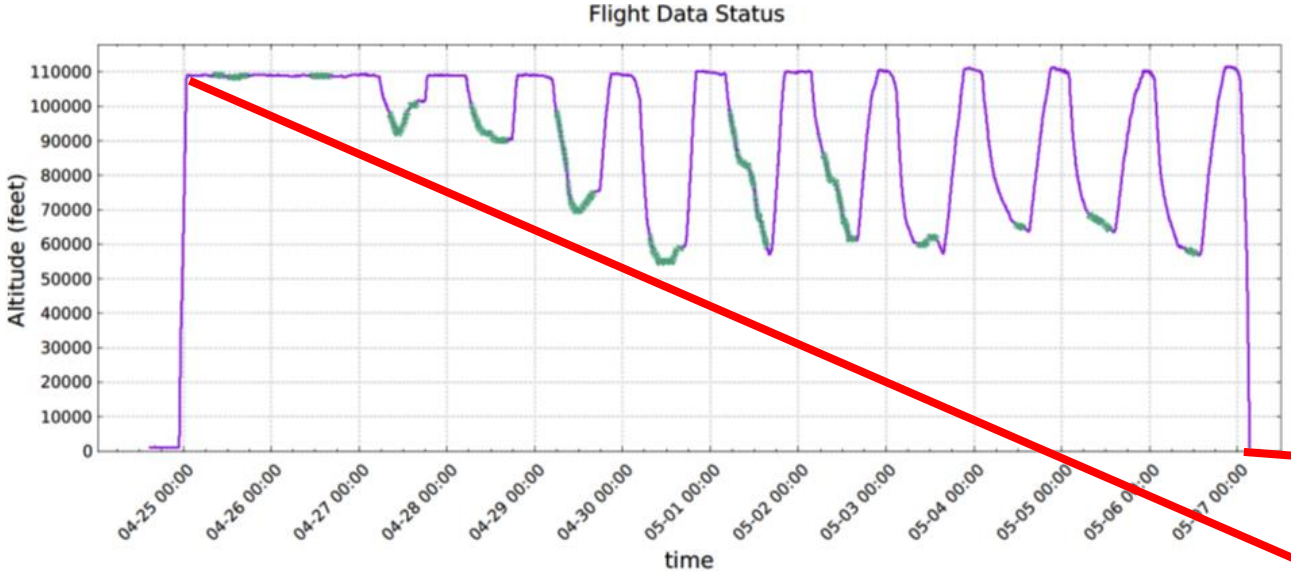
Launch Ready

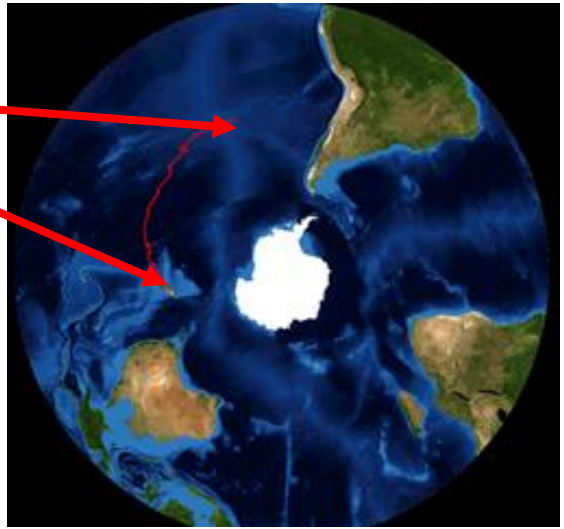
Passed the Launch Readiness Review on 25th of March, 2017

EUSO-SPB1: Launch

- 24/04/2017 23:51 UTC (8th attempt)

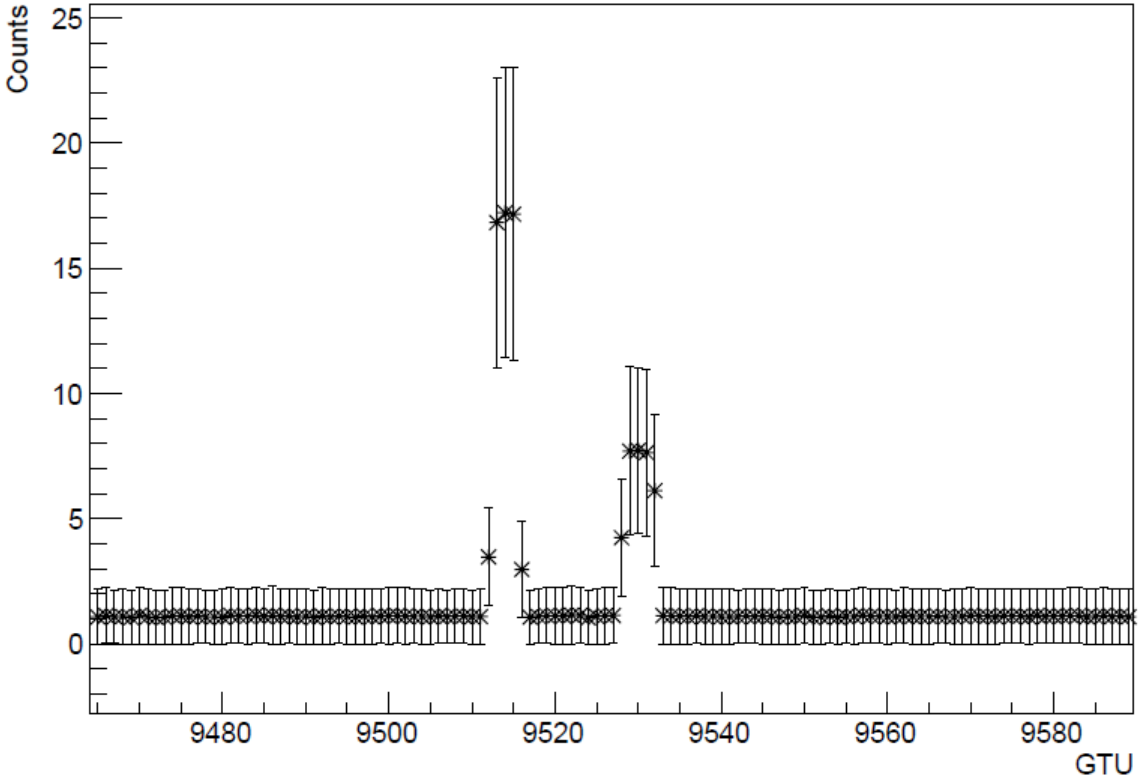
Flight Summary

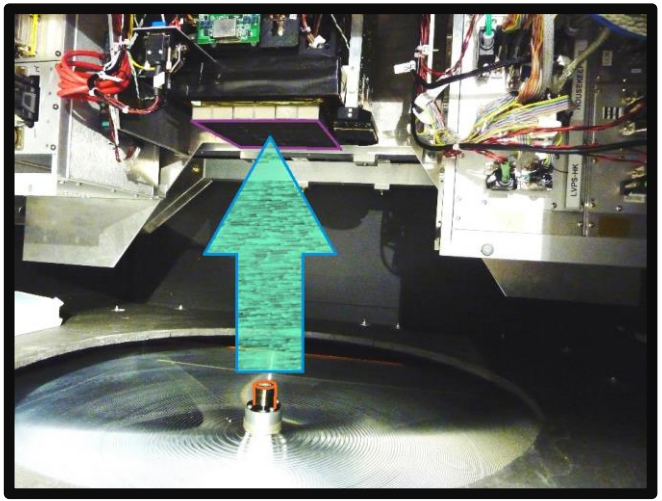




- Flight duration: **12d 4h**
- Terminated 300 km SE of Easter Island
  - Payload lost
- ~30 h (1793 min) of data downloaded

In flight “Health LED” every 16 seconds

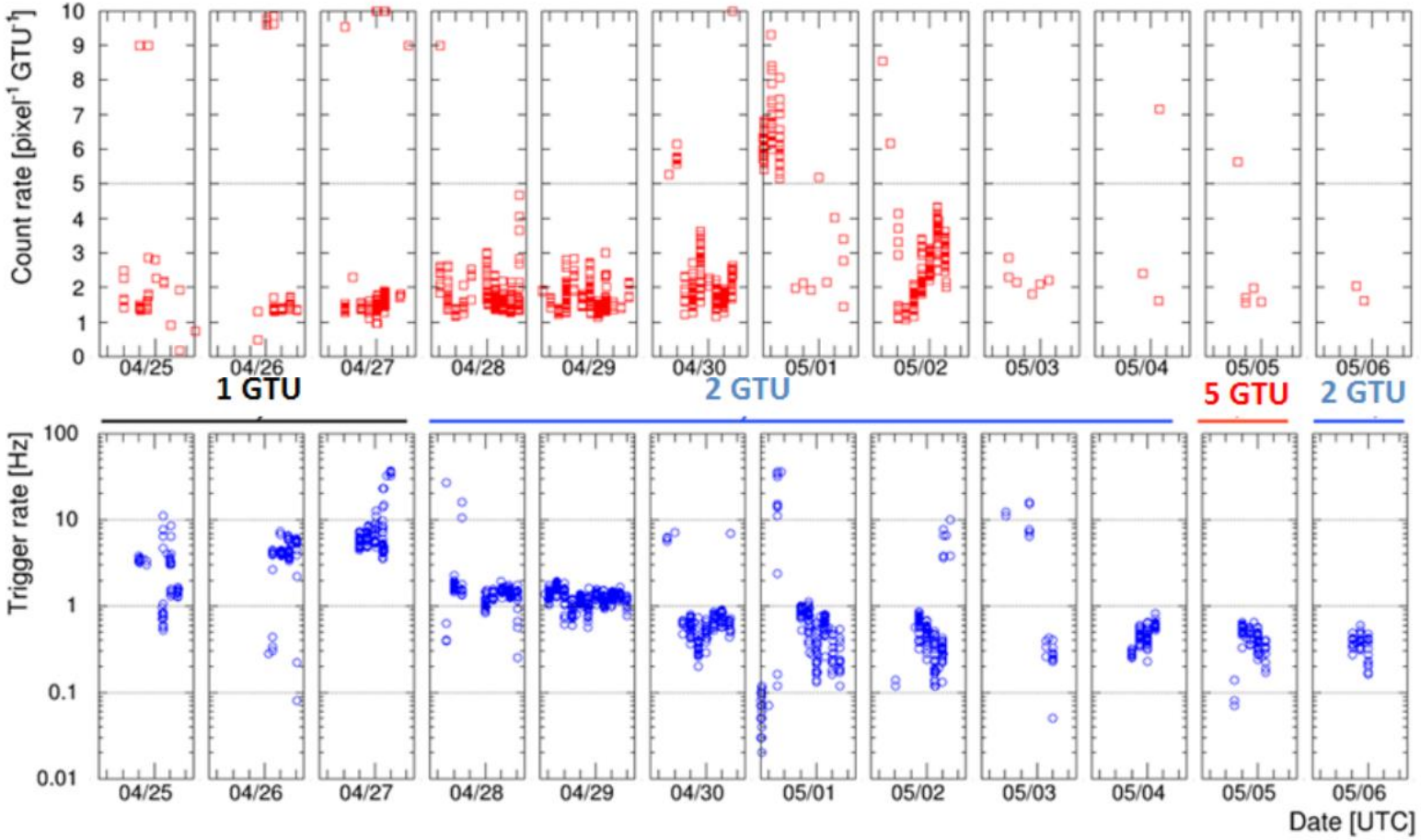




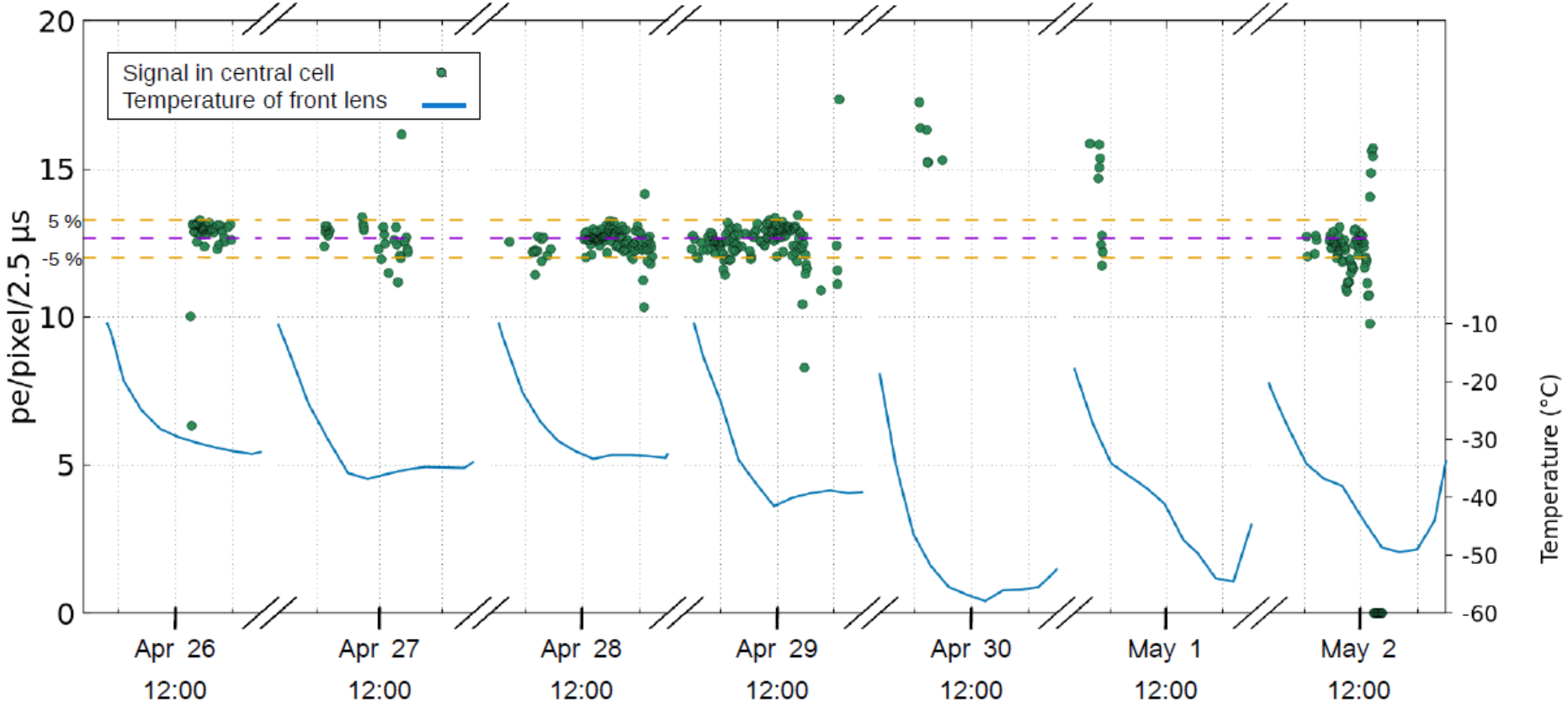
All 9 “elementary cells” in Camera participating at nominal HV (1100V)

1 GTU=2.5 uS

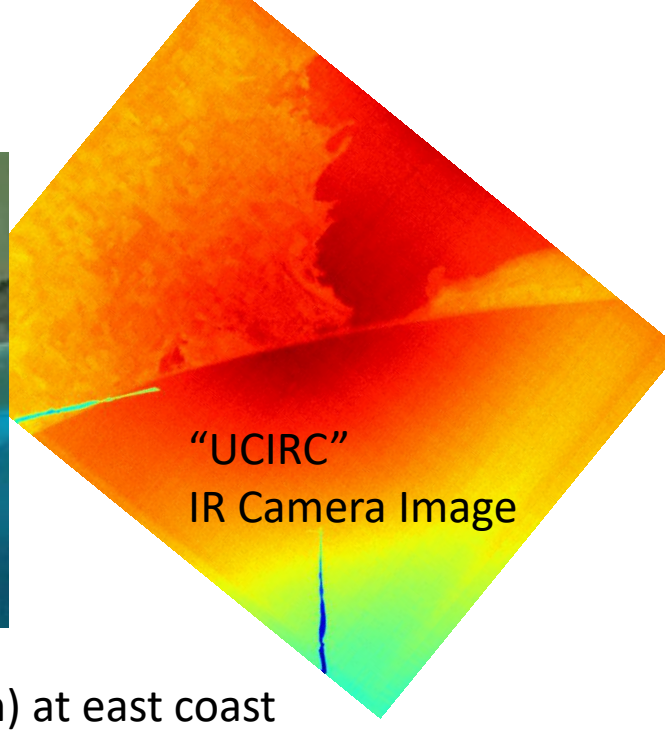
UV-Emission and Trigger Rate



Detector’s Stability during Flight



Ground Source



- Recorded 25/04/2017 at 08:32:34 UTC (hours after launch) at east coast of NZ’s South Island
- 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)

SPB1 Summary

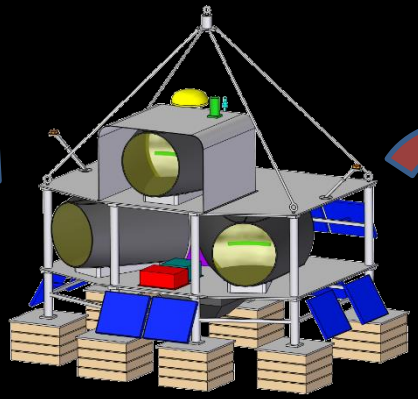
- EUSO-SPB1 was successfully launched end of April 2017
  - Mission of opportunity
- Extensive Preflight Ground tests of flight instrument in the desert
  - lasers, LEDs, aircraft, stars, meteorite

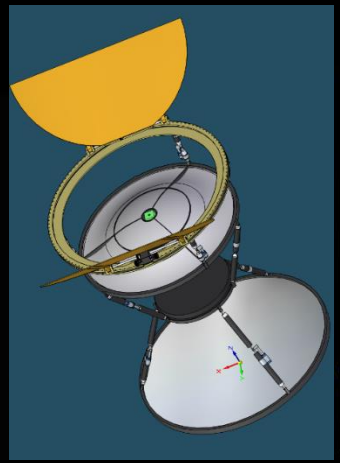
- Stable instrument was flown for 12 days (less time than expected)
- 30 hours of data recorded and downloaded
- Upper limit on expected event rate during flight 1.6 events
- Data analysis still ongoing


Long Live EUSO-SPB1!
LET'S DO LAUNCH
LONG LIVE EUSO-SPB
NEW ZEALAND

EUSO-SPB2

EUSO-SPB1





EUSO-SPB2

Science Goals:

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

New Unexplored Areas:

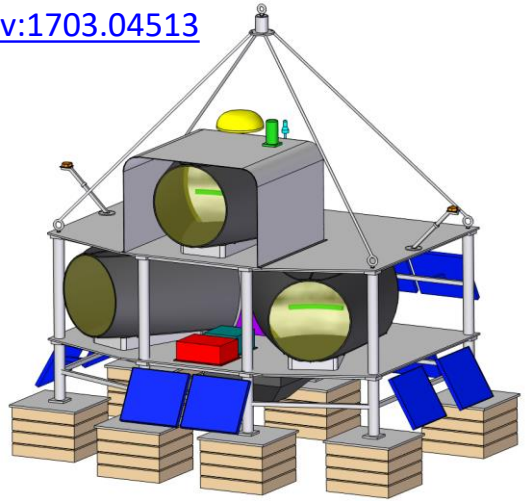
- Detect **Cherenkov from UHECRs from near space**
- Measure the **background of up-going Tau** decays from BZ Neutrinos
- Also thinking about the ANITA-4 tau-like events
- Study Fluorescence from High Altitude Horizontal Showers (HAHAs)

Detect Fluorescence from Above:

- Confirm expectations from ground observations

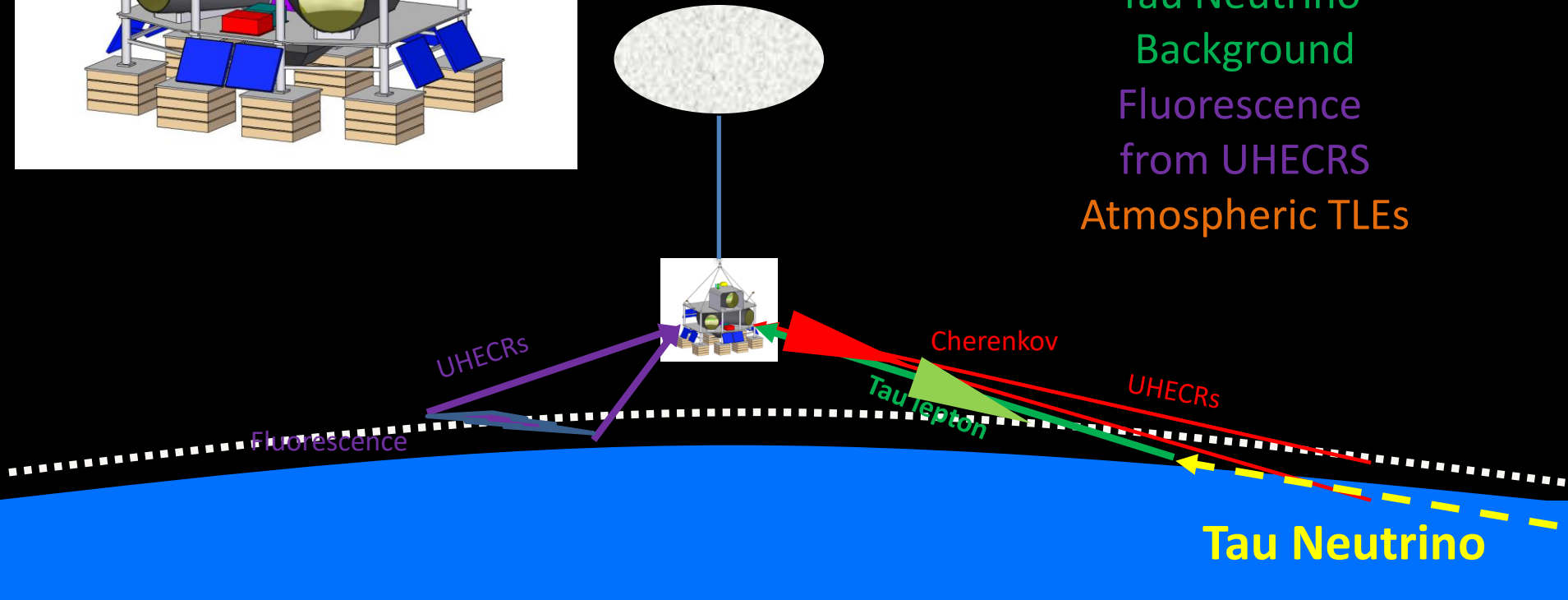
*lower energy threshold and larger acceptance relative to EUSO-SPB1

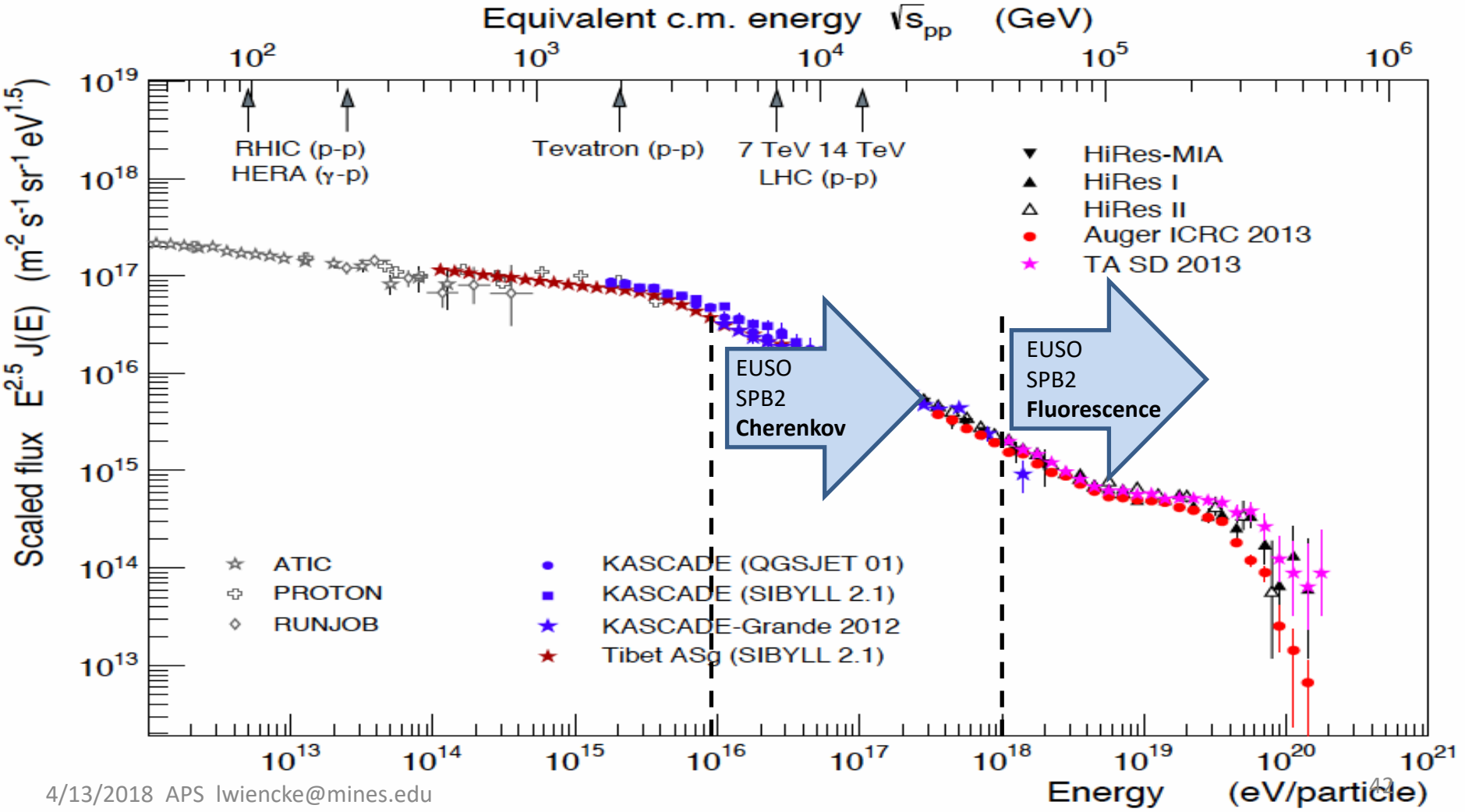
arXiv:1703.04513



EUSO-SPB2

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




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
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
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}
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

Schmidt Optics

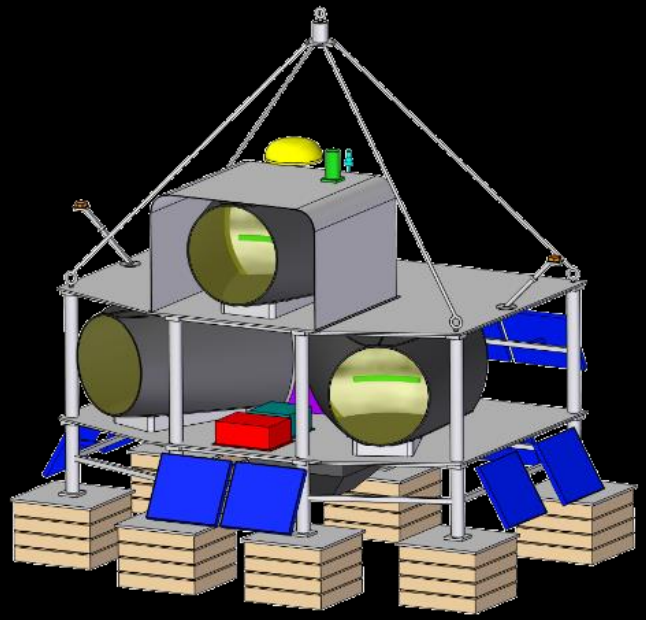
Multiple (3) Telescopes
- 2 Cherenkov ~10 ns
- 1 Fluorescence 1 uS

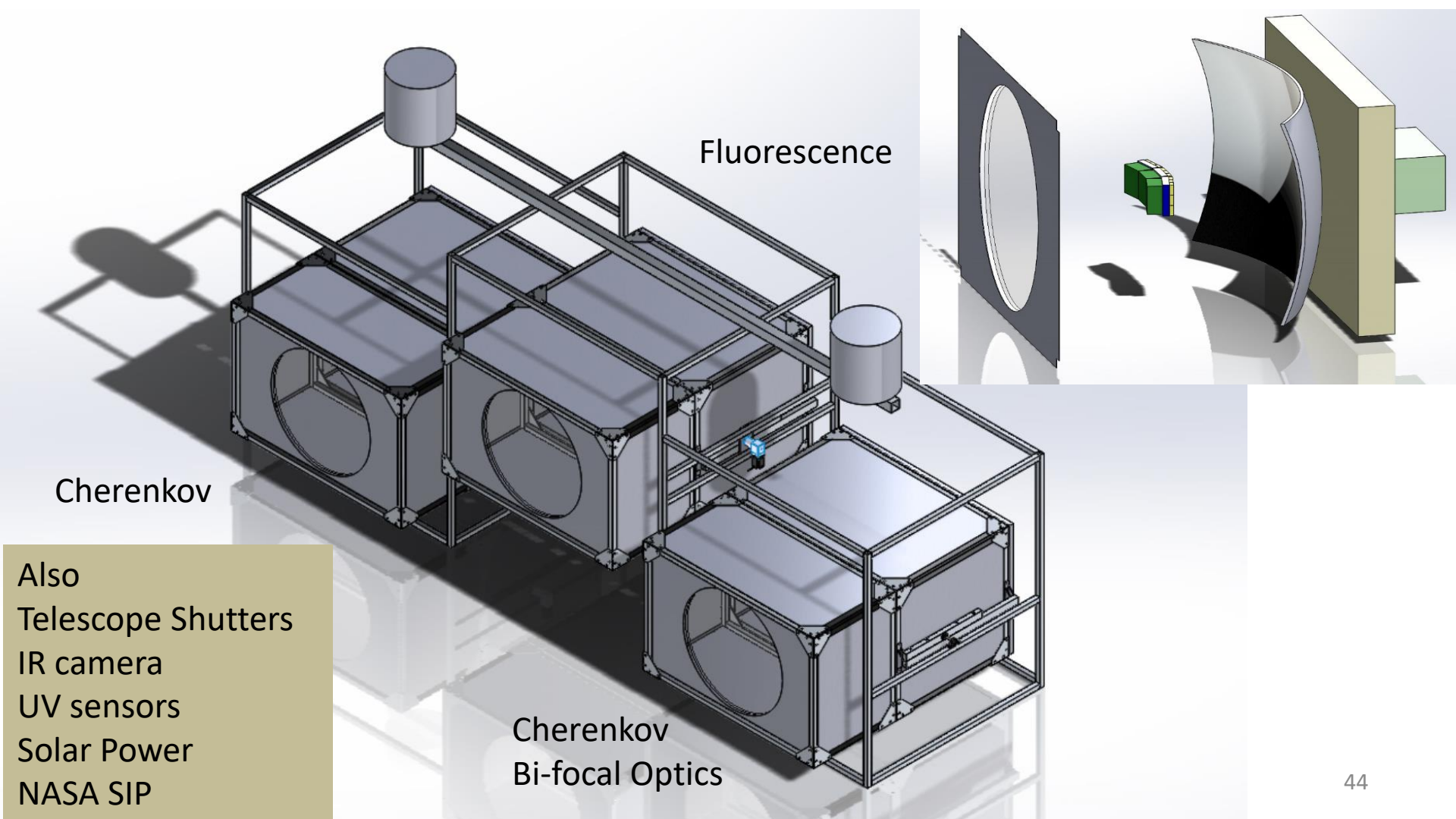
Tilting, perhaps to NADIR

SiPMs qualification for POEMMA

In flight calibration with Stars

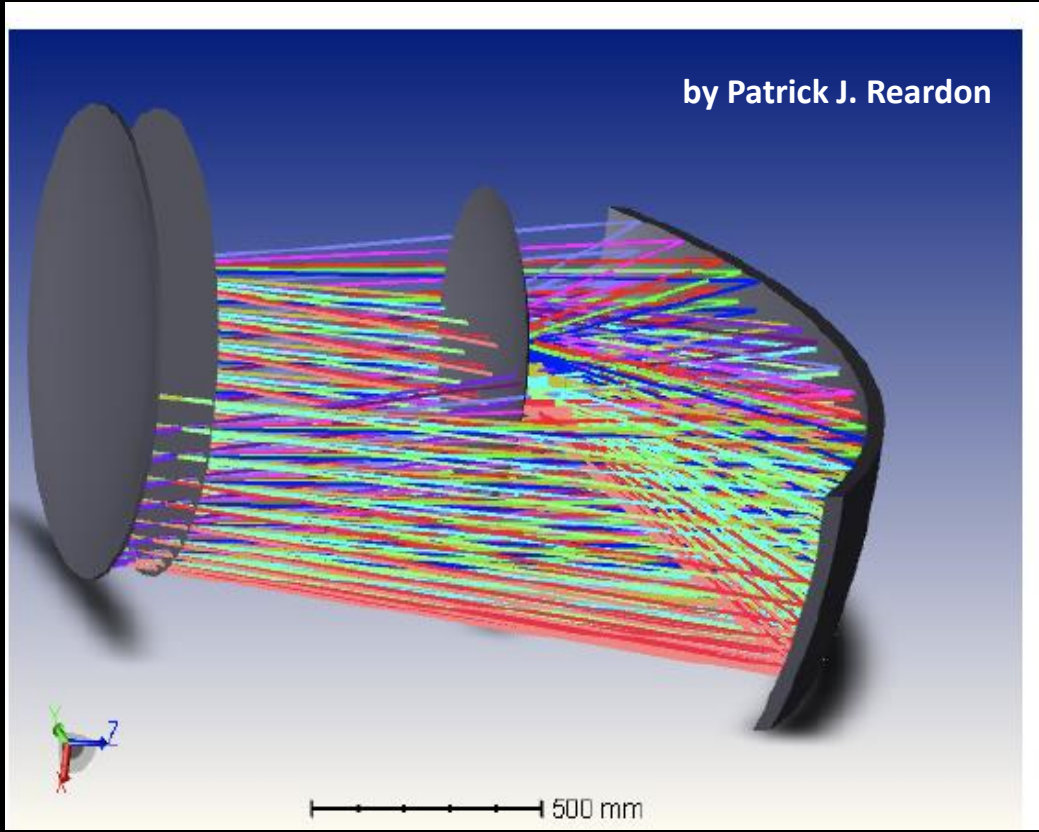
Preflight ground tests - US: Desert, Mountain, Wanaka





Also
Telescope Shutters
IR camera
UV sensors
Solar Power
NASA SIP

Schmidt Optics for SPB2



Cherenkov Telescopes

FoV 5◦ X 45◦ bi-focal mirror

FoV 5◦ X 45◦ normal mirror

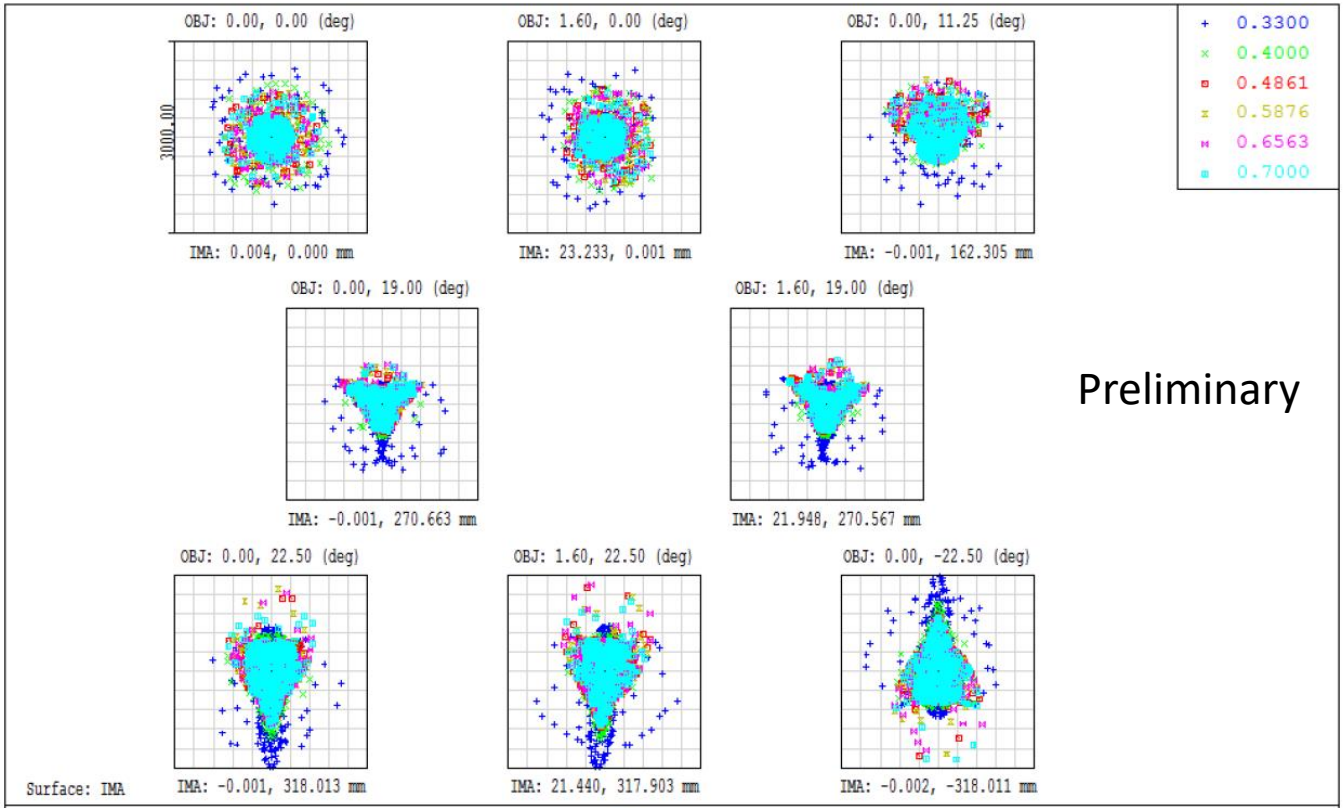
Fluorescence Telescope

FoV 15◦ X 45◦ normal mirror

Corrector Plate: 1m2

Image resolution: ~ few mm

Pixel size: ~3mm square



Preliminary

Spot Diagram

Units are µm. Airy Radius: 0.6166 µm

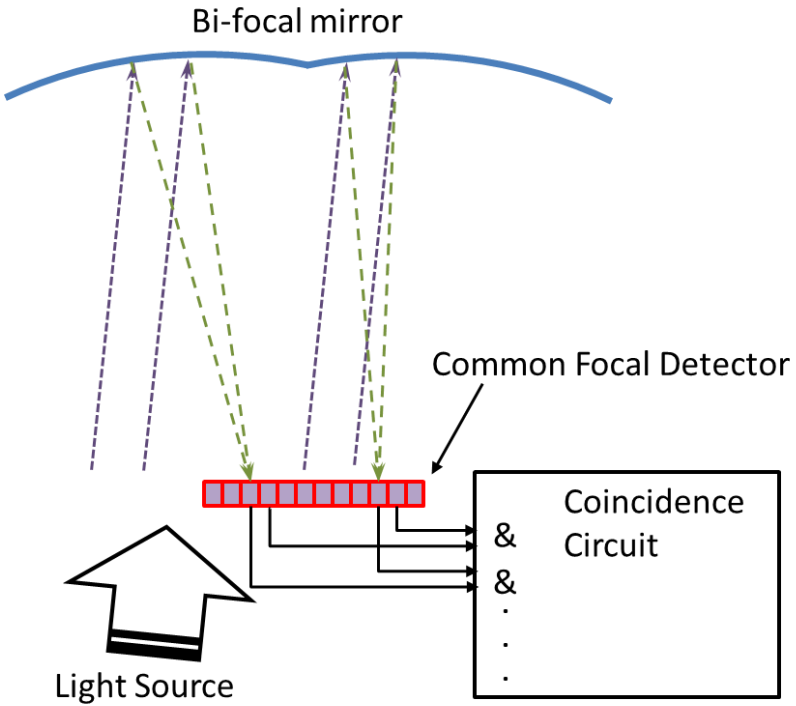
Field	1	2	3	4	5	6	7	8
RMS radius :	306.206	296.112	343.894	314.575	312.477	447.967	453.794	449.934
GEO radius :	1154.15	1146.93	1074.45	1202.88	1129.80	1491.86	1492.55	1490.18

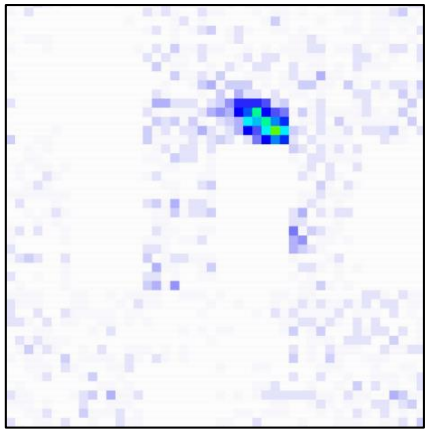
Box width : 3000 Reference : Centroid

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

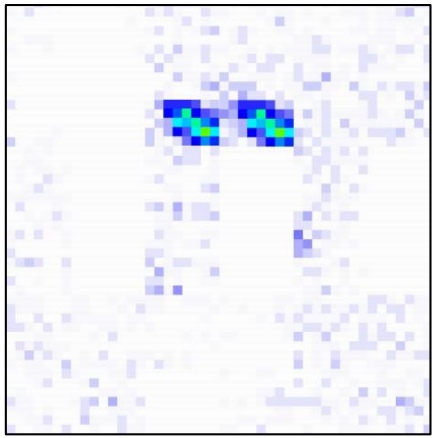
EUSO-SPB2_Chr.zmx
Configuration 1 of 1

Bi-focal Mirror Concept (Cherenkov Telescope)



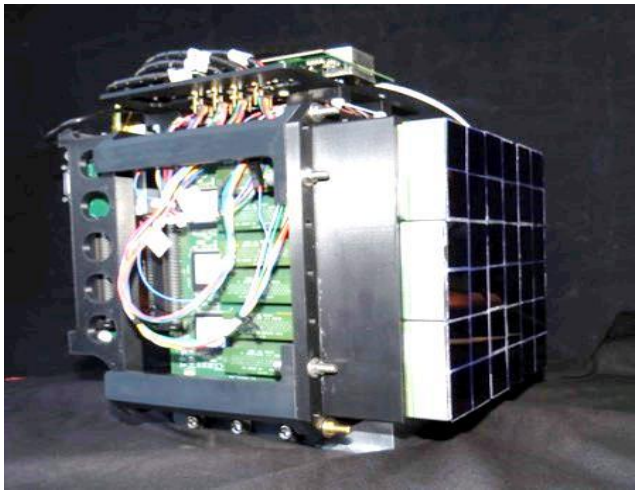


Std. mirror



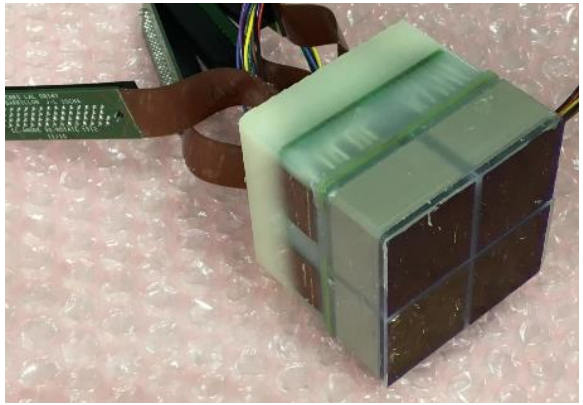
Bi-focal mirror

FD Focal Surface



SPB1 Photo Detector Module (PDM)
9 Elementary Cells

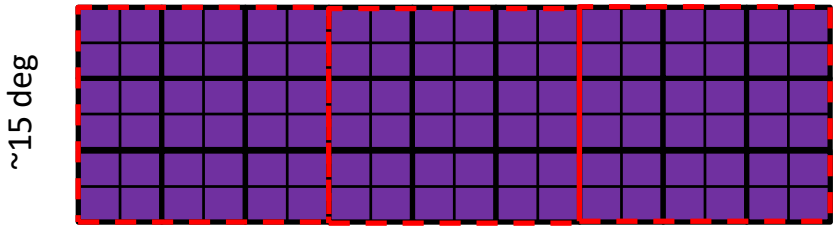
48x48=2304 pixels
Single Photoelectron Counting
1.0 μS time bins (fluorescence)
1 “video clip” = 128 time bins
~15 watts



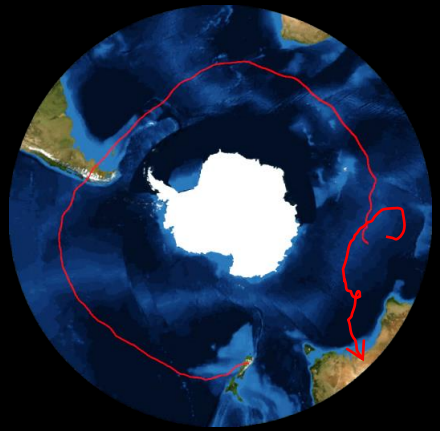
SPB1 Elementary Cell (EC)
2x2 64 Channel Hammatsu Multi-annode PMTs
Base, HV (+ digitization for SPB2)

SPB2

FD Baseline Design is 3x9 ECs (3 PDMs)

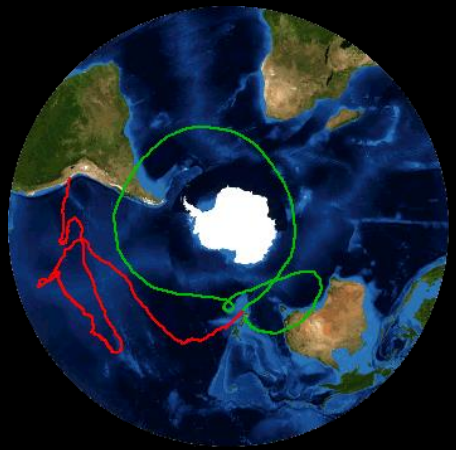


2015: 32 d 5 h



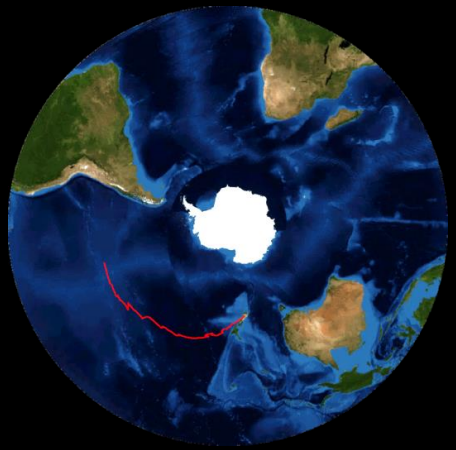
Engineering Flight

2016: 46 d 20 h



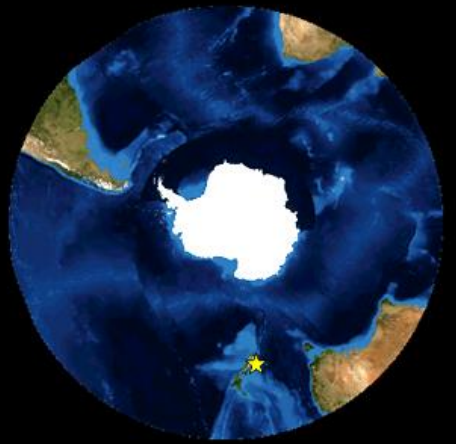
COSI

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..

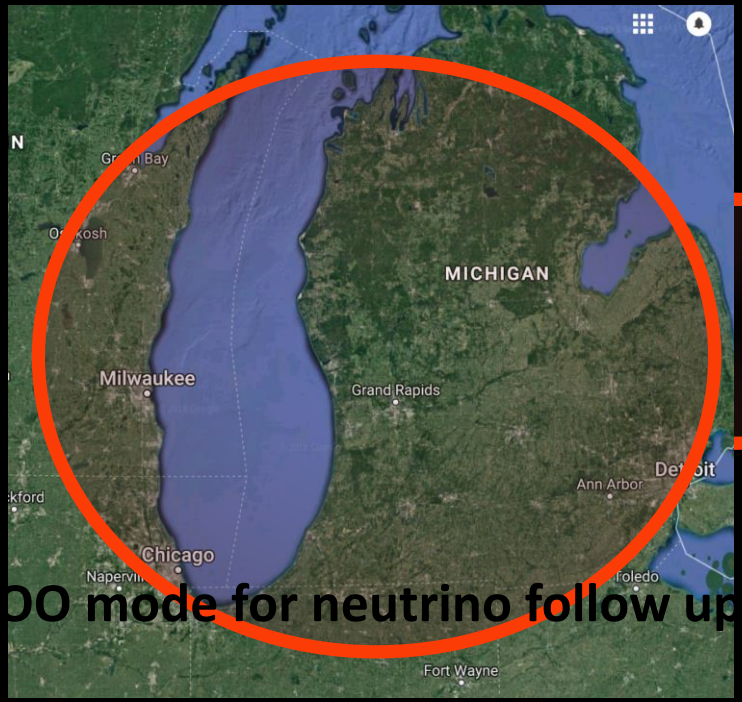
EUSO-SPB2 Improved Multi-Telescope Instrument, builds on SPB1 experience
Add unexplored areas
Cherenkov, Neutrino Backgrounds, High Altitude EASs
Scientific and Technical Pathway toward POEMMA

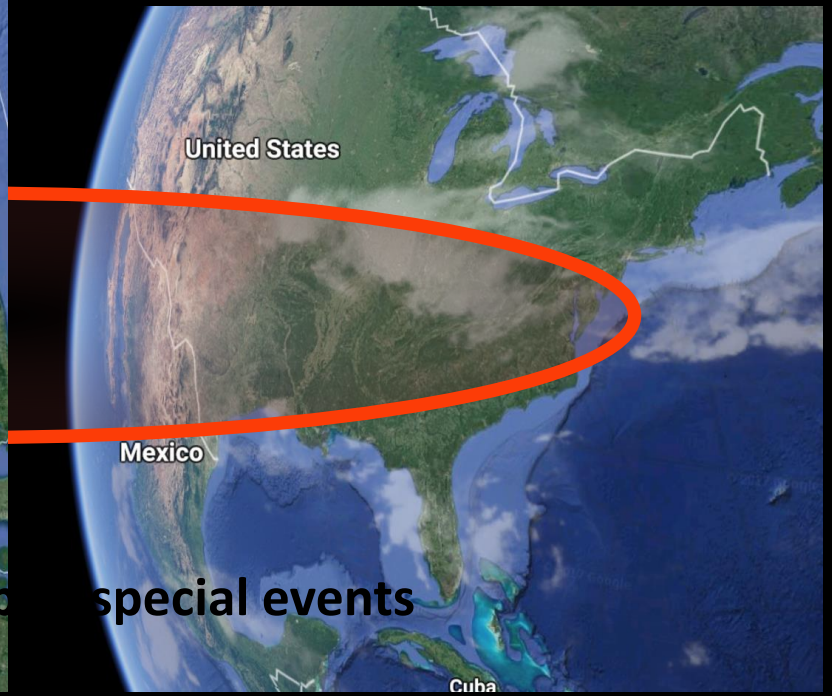
POEMMA will open two new Cosmic Windows:
neutrinos from astrophysical to cosmogenic, and
extreme energy cosmic ray (> 10s EeV)

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

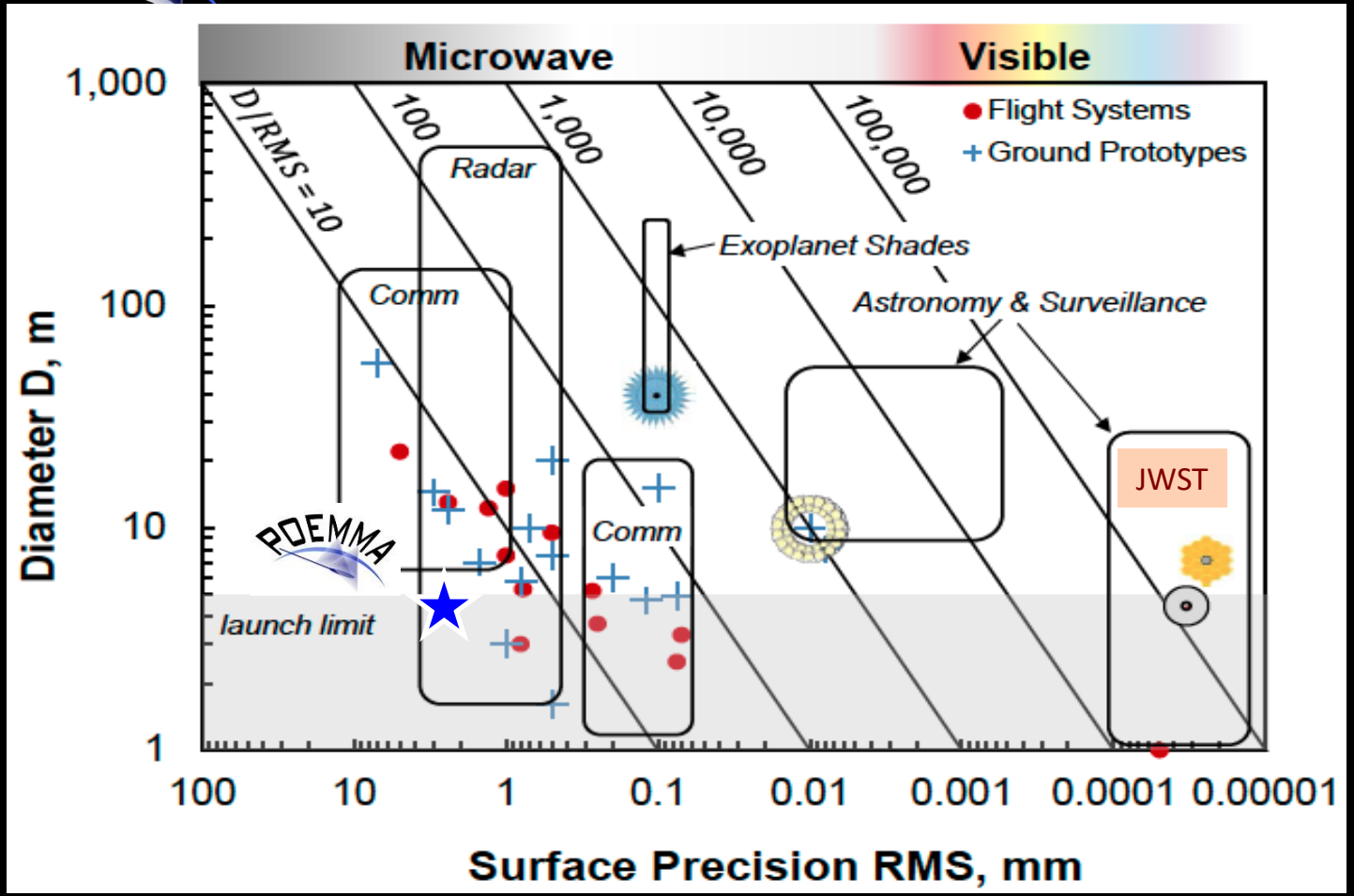
Backup Slides

POEMMA





OO mode for neutrino follow up special events


Microwave
Visible
Flight Systems
Ground Prototypes
D/RMS = 10
100
1,000
10,000
100,000
Radar
Comm
Exoplanet Shades
Astronomy & Surveillance
JWST
Comm
launch limit
1,000
100
10
1
Diameter D, m
100
10
1
0.1
0.01
0.001
0.0001
0.00001
Surface Precision RMS, mm