Multi-Messengers from Above: The EUSO-SPB2 Mission

T. Heibges for the JEM-EUSO Collaboration

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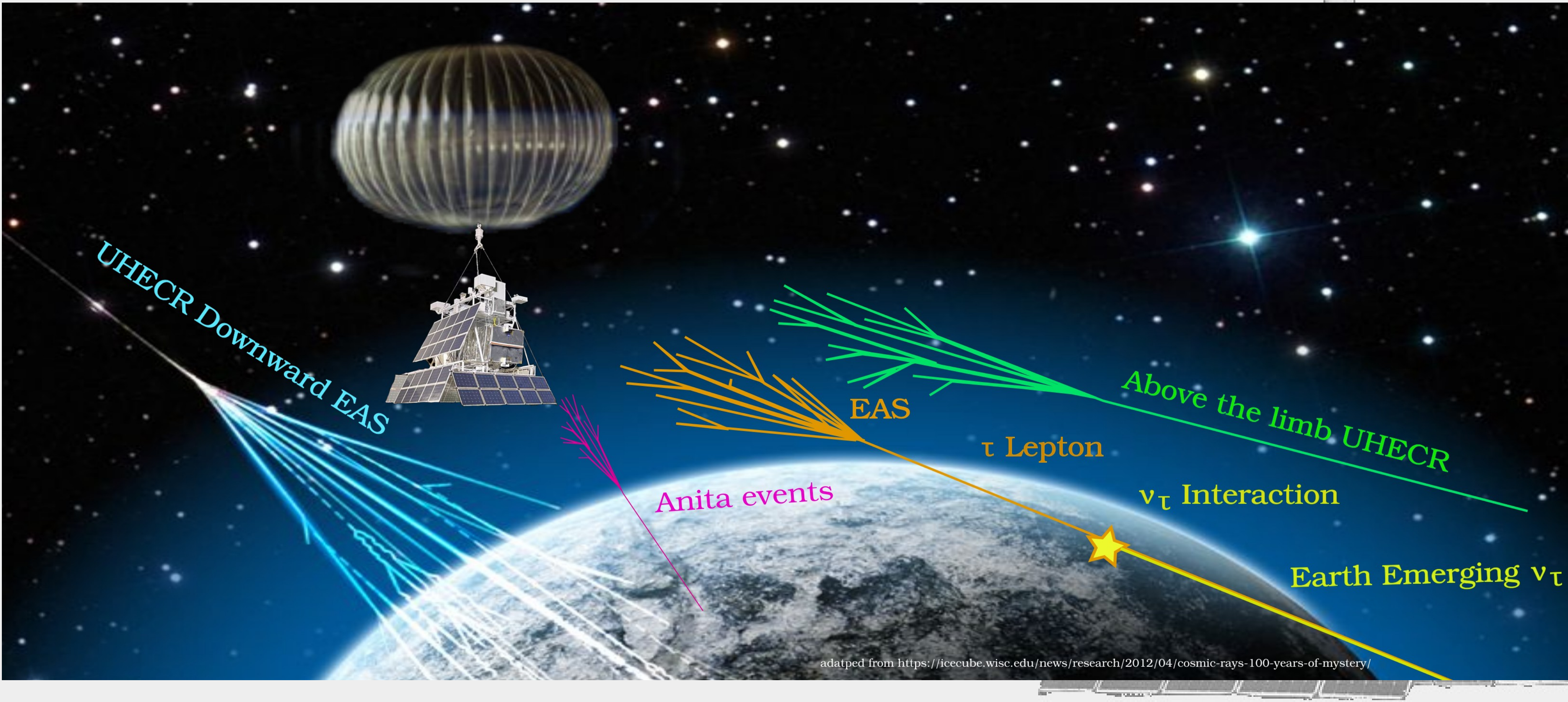
CRIC-MAC 2024

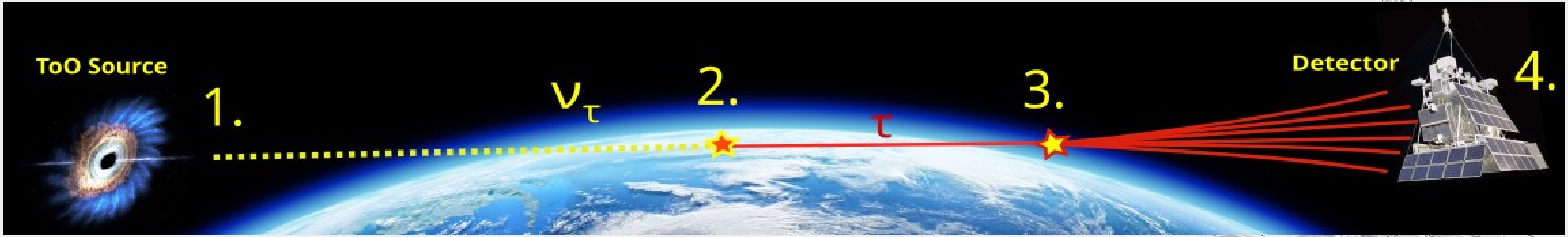
	Institution	EUSO-SPB2 Science Team	Work Packages
US	U. Chicago	A. Olinto (PI), R. Diesing, S. Meyer, J. Eser	IR Camera (UCIRC), Gondola, ST
US	Mines	L. Wiencke (Dep. PI), F. Sarazin, G. Filippatos, V. Kungel, T. Heigbes, H. Wistrand, D. Fuhne	Telescopes:(Mech, Testing, Integ, Calib, Field Testing) Optical Test Stand, ST controller, Simulations
US	Iowa	Y. Onel, M. Reno	CT, FT LED systems, Neutrino ToO
US	MSFC	M. Christl, R. Young, P. Alridge	GCC system
US	UAH	P. Reardon, J.Adams, E. Kuznetsov,	Optics Design, Solar Power, CT subsystems,
US	Lehman U.	L. Anchordoqui, T. Paul	MAPMTs, Simulations
US	Ga Tech	N. Otte, E. Gazda, M. Bagheri, O. Romero	CT SiPM camera development
CZ	U. Olomouc	C Kerny, M. Pech, P. Schovanek	Mirror Segments for CT and FT
FR	APC	G. Prévôt, S. E. Parizot	FT camera Elementary Cells,
FR	OMEGA	S. Blin	Electronics -ASICS
IT	INFN & U. Napoli	G. Osteria, V. Scotti, L. Valore, F. Guarino	CPU, Fluorescence Detector – DAQ, ….
IT	INFN & U. Torino	M. Battisti, M. Bertaina F. Bisconti, F Fenu H. Miamoto K. Shinozaki	Simulations, lab testing, trigger algorithms
IT	INFN & Univ. Bari	F. Cafagna	Flight (telescope) Software, FT Camera Housing
IT	UTIU	C. Fornaro	Fluorescence Telescope DAQ Software
IT	LNF-INFN, Frascati	M.Ricci	Italian coordinator
JA	RIKEN	M. Cassolino, T. Ebisuzaki, Y. Takizawa	Optics(ACP), PMT testing
POL	NCBJ	J. Szabelski, L. Petrowski	FT HV system, simulations
RU	MSU	P. Klimov, A. Belov	FT Camera zynq boards
SE	KTH	C. Fuglesang.	FT Camera structure (prototype)
SK	SAS	S. Mackovjak	UV/Vis Monitors

Science Objectives



Earth Skimming Methodology

https://pos.sissa.it/444/1134



1. Neutrino source crosses through detector FoV

2. A ν_τ interacts and produces a τ

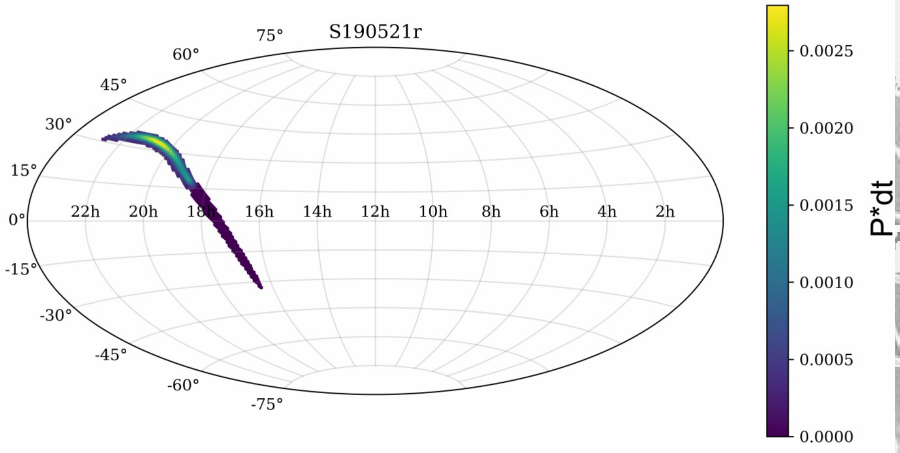
3. The τ decays and produces an EAS.

4. Detector triggers on Cherenkov signal

NUTS (Neutrino Target Scheduler)

- Collects alerts from alert networks
  - **GCN**: GRBs, neutrinos, GW, …
  - **TNS:** SN, TDEs, FRB,…
  - **Atels:** AGN/Balzar Flares, …
- Calculate position of source in sky based on detector location
- Calculate when a source would be in observable band (0°-6.4° from horizon) and require astronomical night
- Select subset of sources based on prioritization scheme
  - Relative distance to source
  - Relative occurrence rate
  - Time source is in FoV

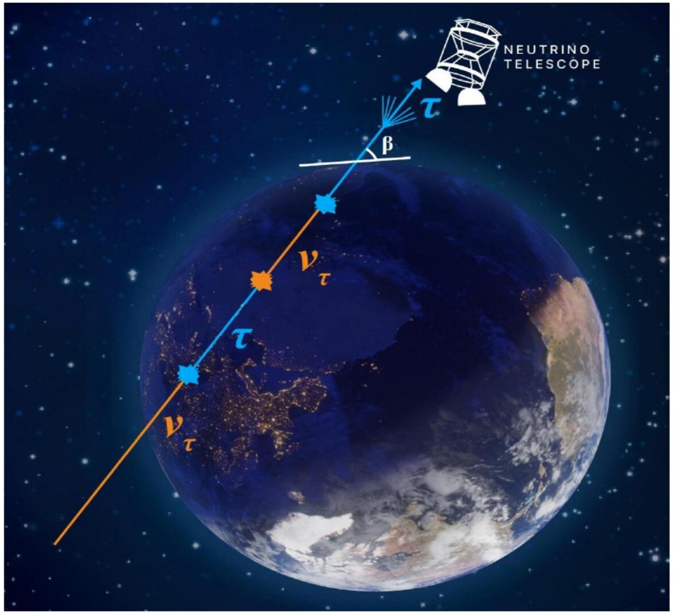
Source Type	Priority
Galactic transient	1
Binary neutron star mergers	2
Tidal disruption events	3
Flaring blazar or active galactic nuclei	4
Gamma-ray bursts	5
Supernovae outside of the galaxy	6
Other transients	7
Steady sources	8

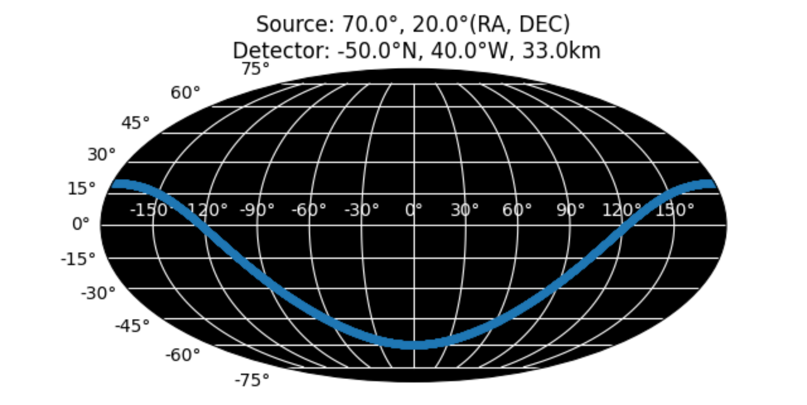


NuSpaceSim

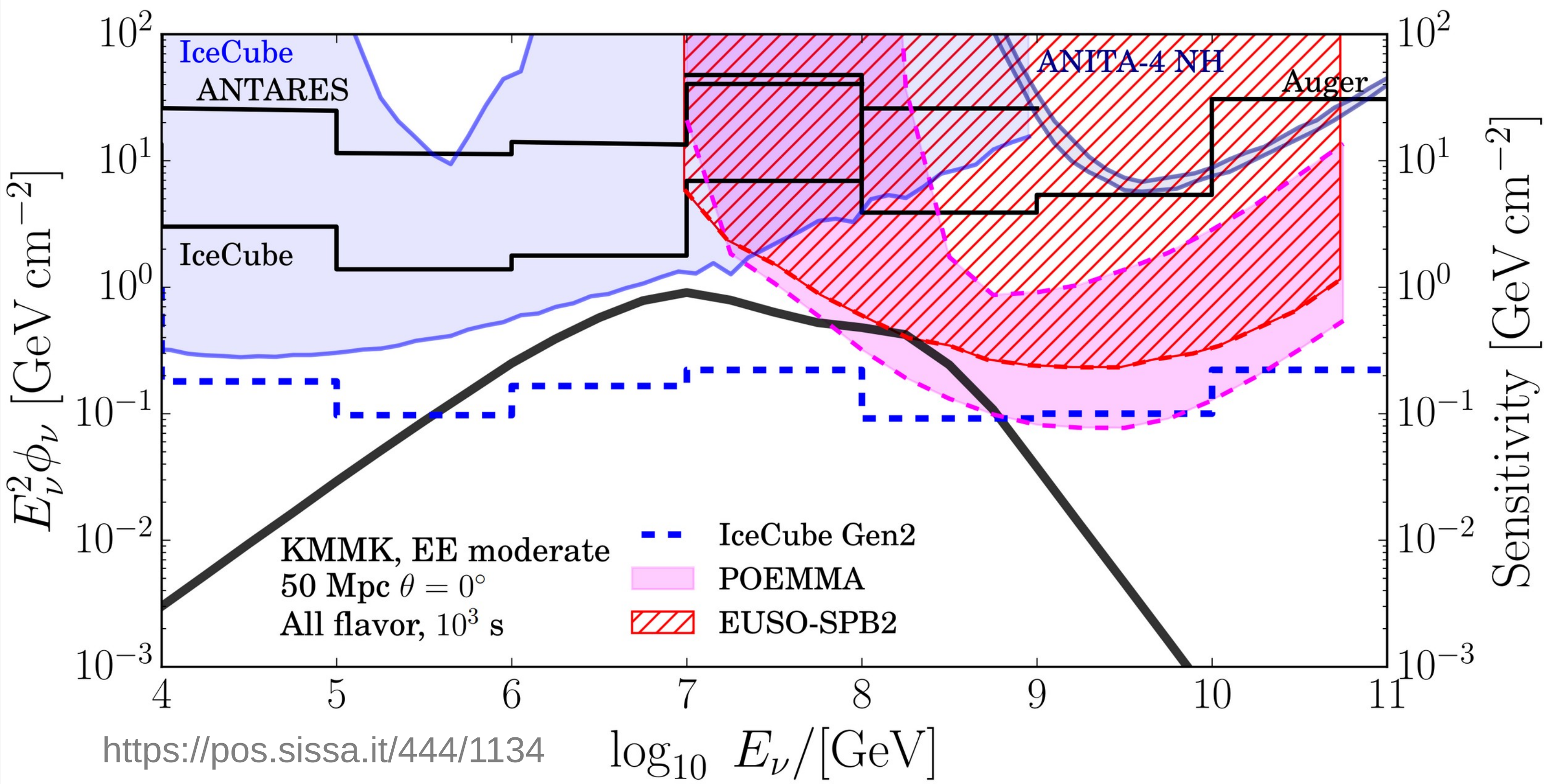
- Monte Carlo Simulation tool for Earth emerging neutrino searches
- Calculates acceptance for diffuse neutrinos
- Special implementation for point-source searches
  - Tracks the source across the FoV of a detector
  - Estimates the aperture toward a source

https://heasarc.gsfc.nasa.gov/docs/nuSpaceSim/



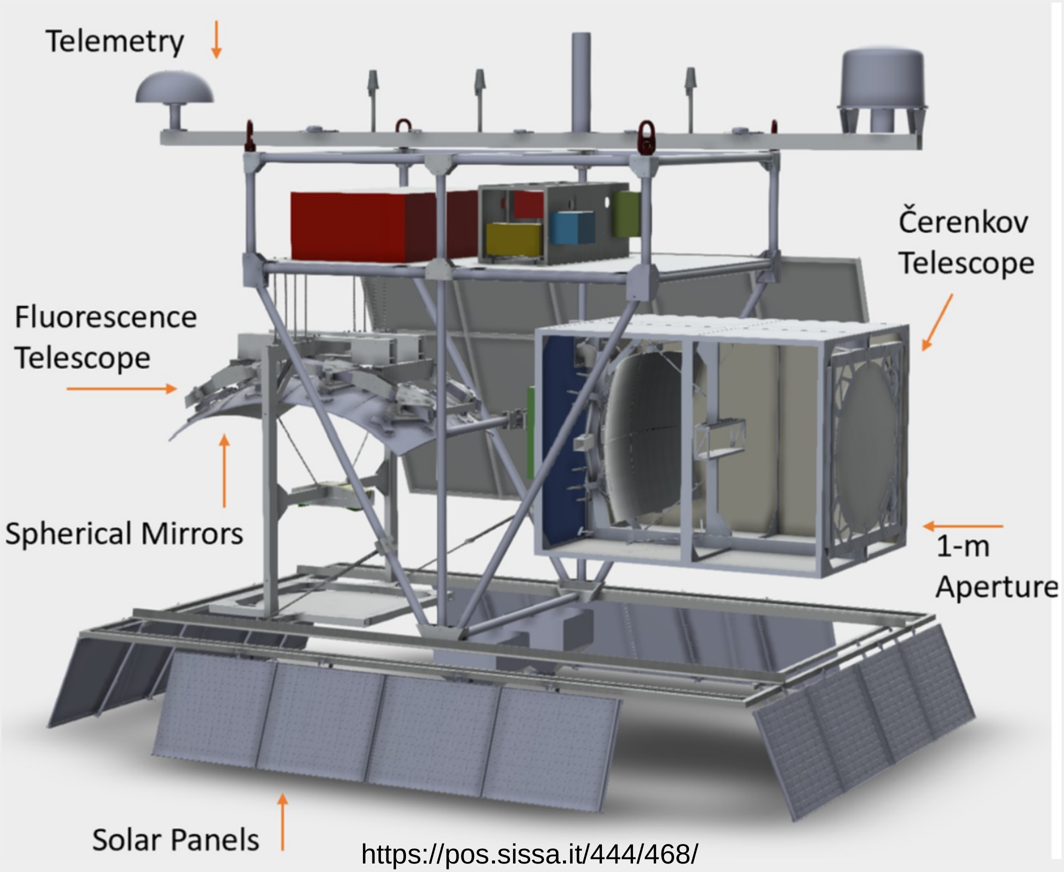


Instantaneous Sensitivity Expectation



Work on updating these numbers using NuSpaceSim ongoing

EUSO-SPB2 Payload

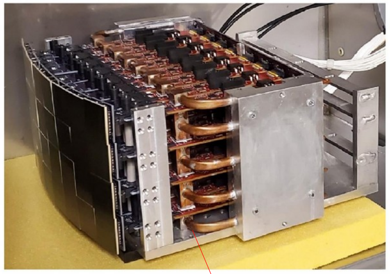


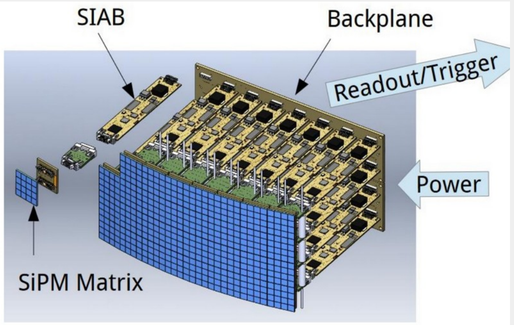
https://pos.sissa.it/444/468/

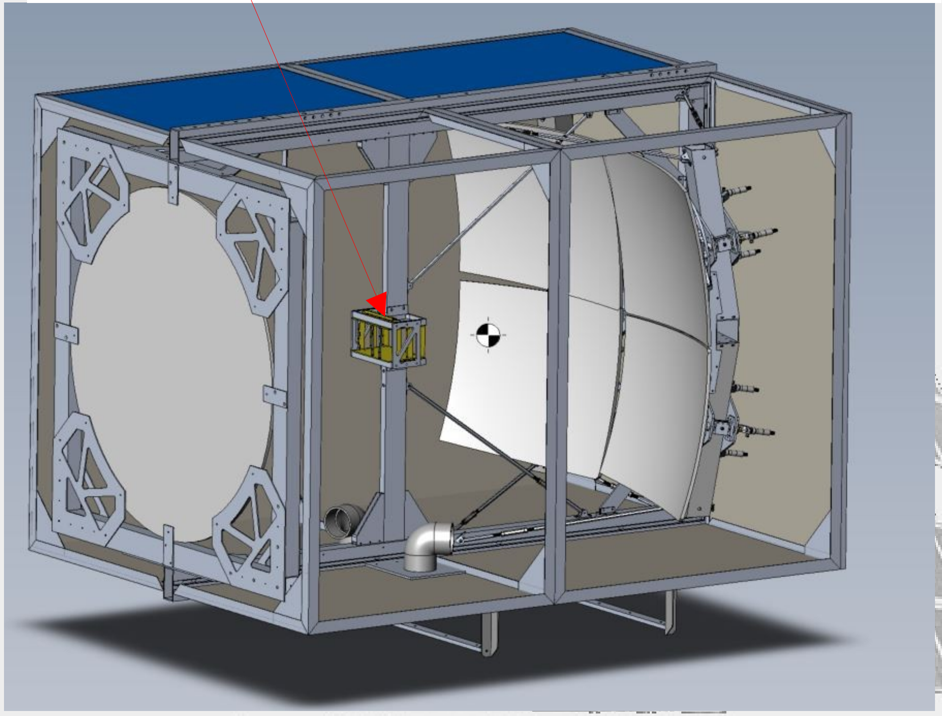
Cherenkov Telescope

- **Camera:**
  - 32 SiPMs with 512 pixels 0.4°x0.4° FoV
  - Each set of 2x4 pixels read out by one music chip
  - 10ns digitization bins
- **Telescope**:
  - FoV: 12.8° x 6.4°
  - **Tilting range**: 3.5° to -13° from horizontal
  - **Azimuth pointing:** 360°
  - Four ~0.5m x 0.4m mirror segments with 1.6m radius of curvature
  - Bi-Focal alignment

https://arxiv.org/abs/2406.08274

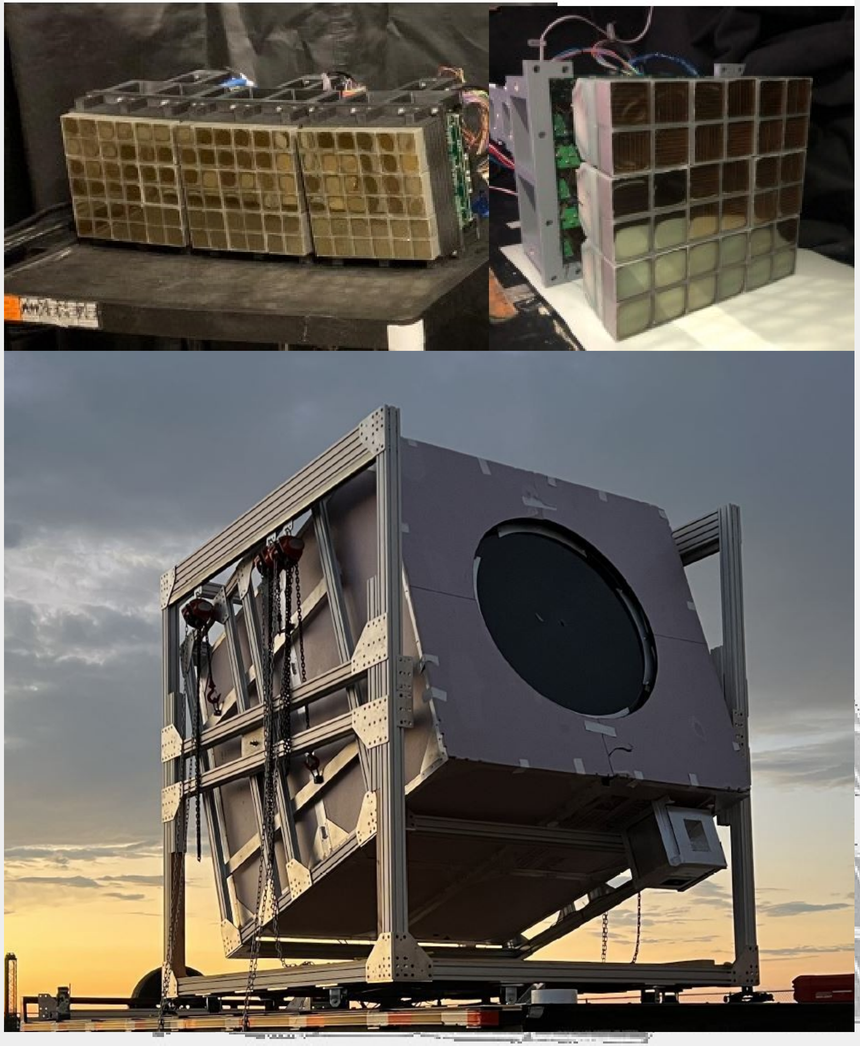






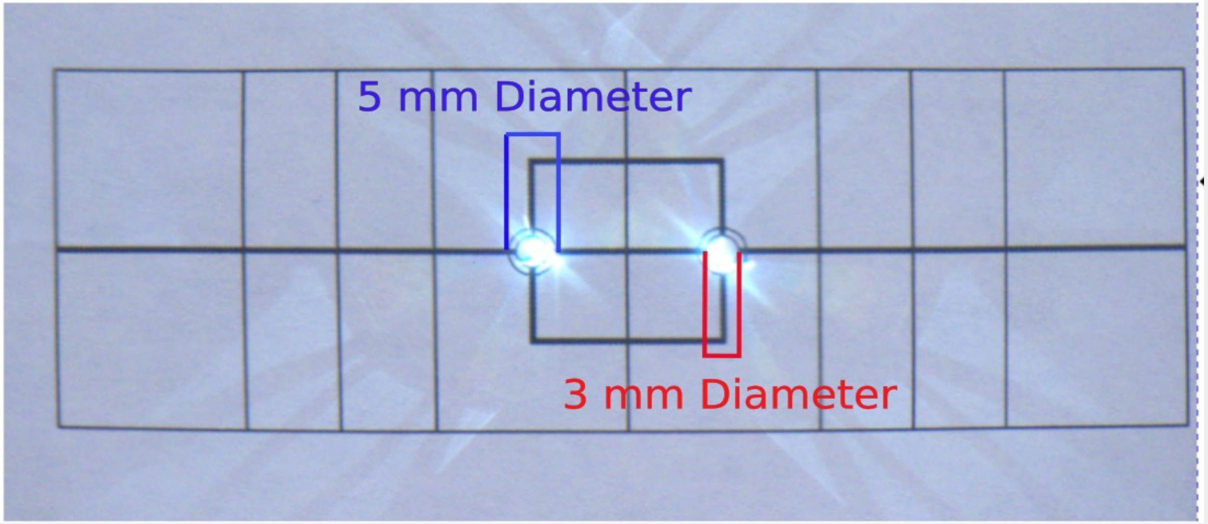
Fluorescence Telescope

- **Camera:**
  - 3 Photo-Detection Modules (PDMs)
  - 36 Multi-Anode Photo-Multiplier Tubes per PDM.
  - 3mm x 3mm pixel size
- **Telescope**:
  - FoV: 36° (h) x 12° (v)
  - Pointing in Nadir
  - Six ~0.5m x 0.4m mirror segments with 1.64m radius of curvature
  - Single focus alignment



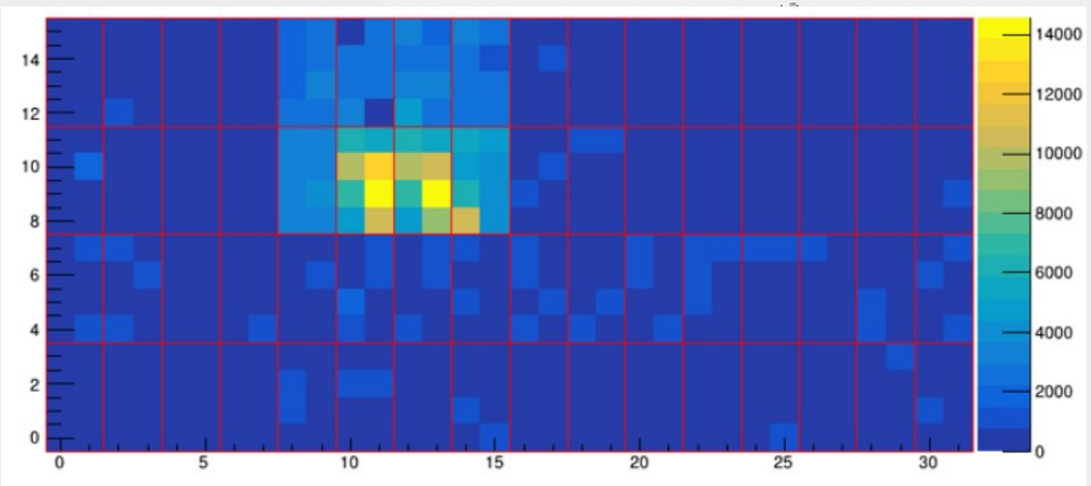
In-Field Alignment

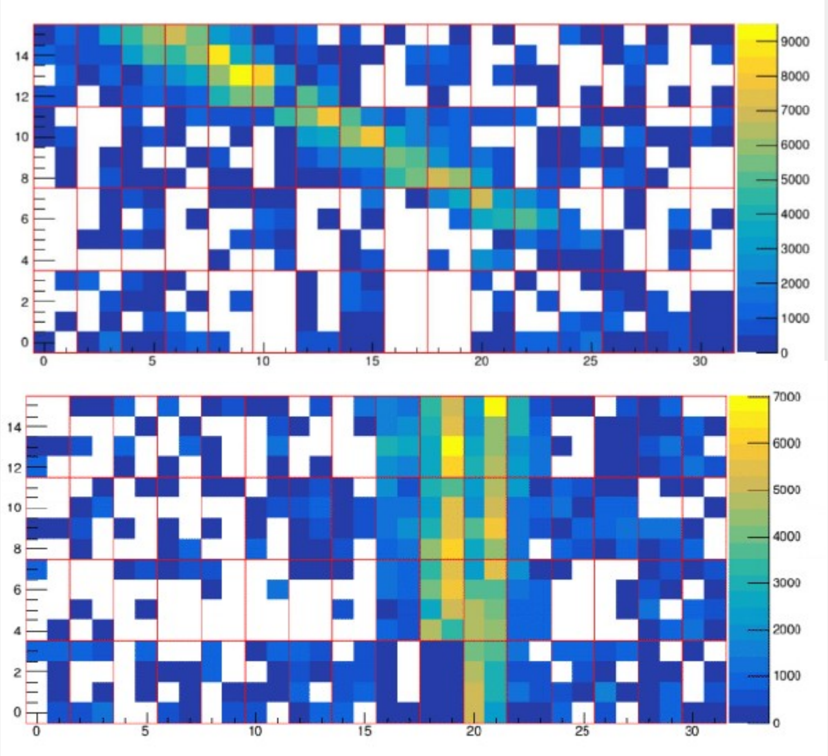
1. Used a Light plant ~5km from detector
2. Used hand held LED ~5km from detector
3. **Achieved a spot size of ~3mm**

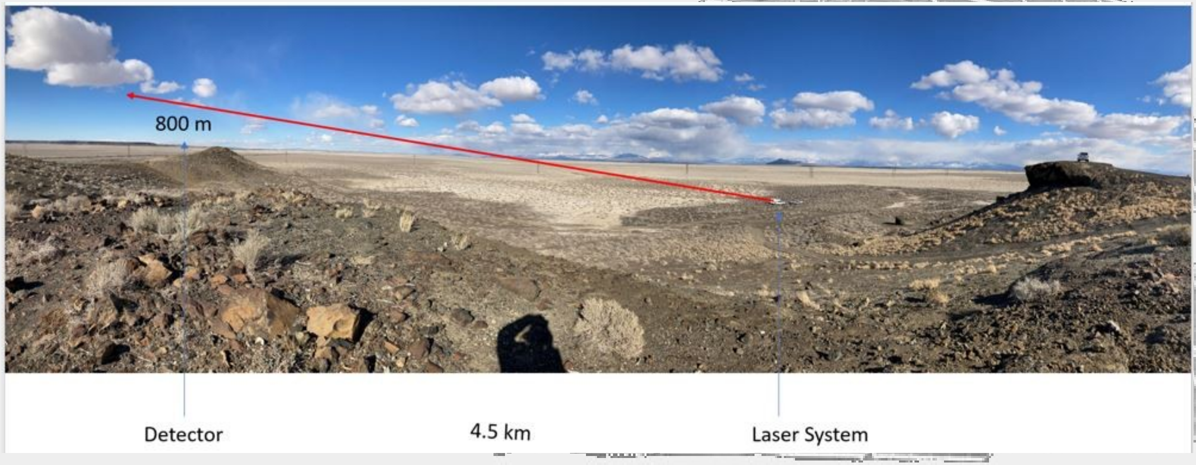


Field Testing the CT

- 3 nights of laser triggers and 6 hours of CR data



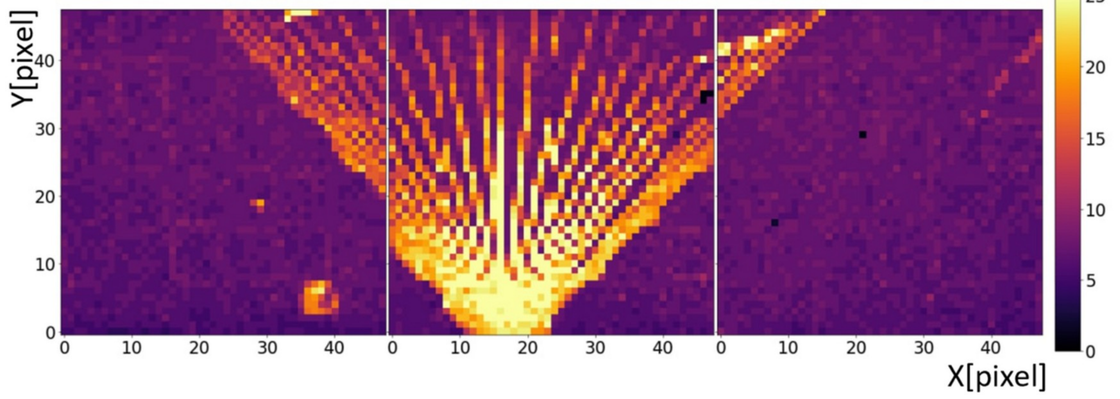


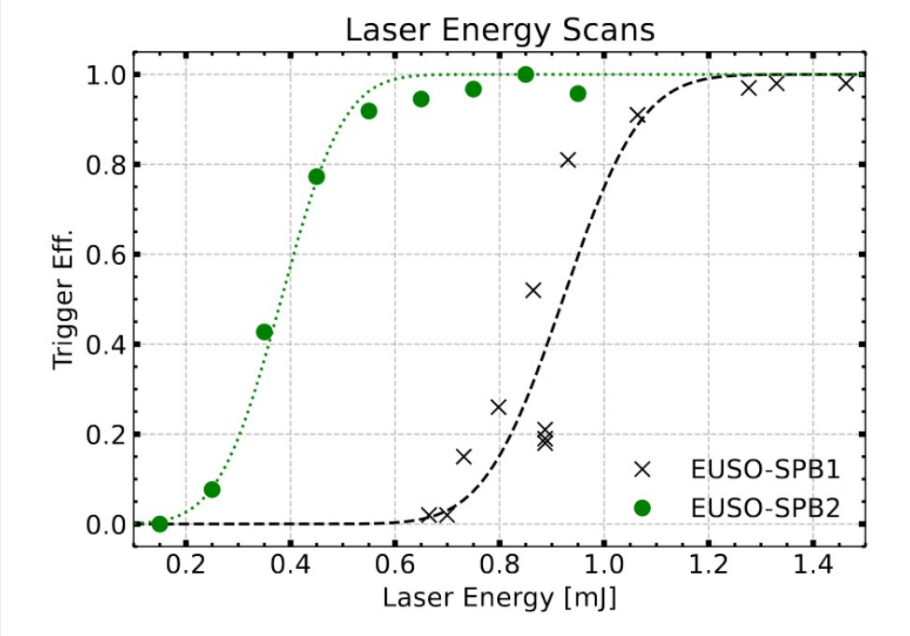


Field testing the FT

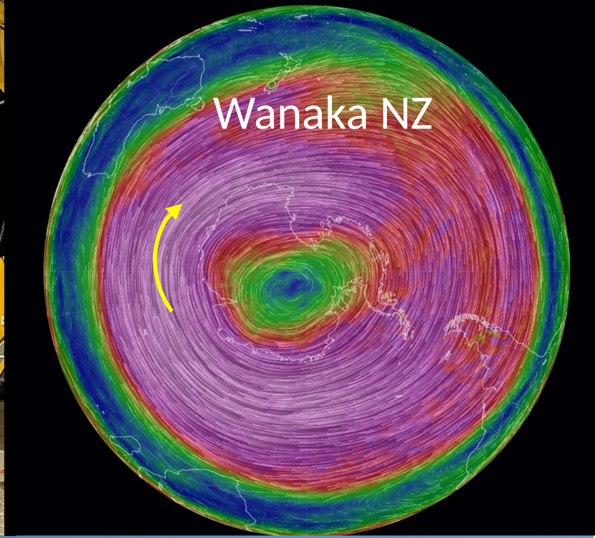
- Spent several nights measuring lasers at about 24 km distance
- About a week searching for UHECR signatures
  - None found
- Observed stars, planes, meteors,…
- Also tested the IR camera

https://pos.sissa.it/444/468/





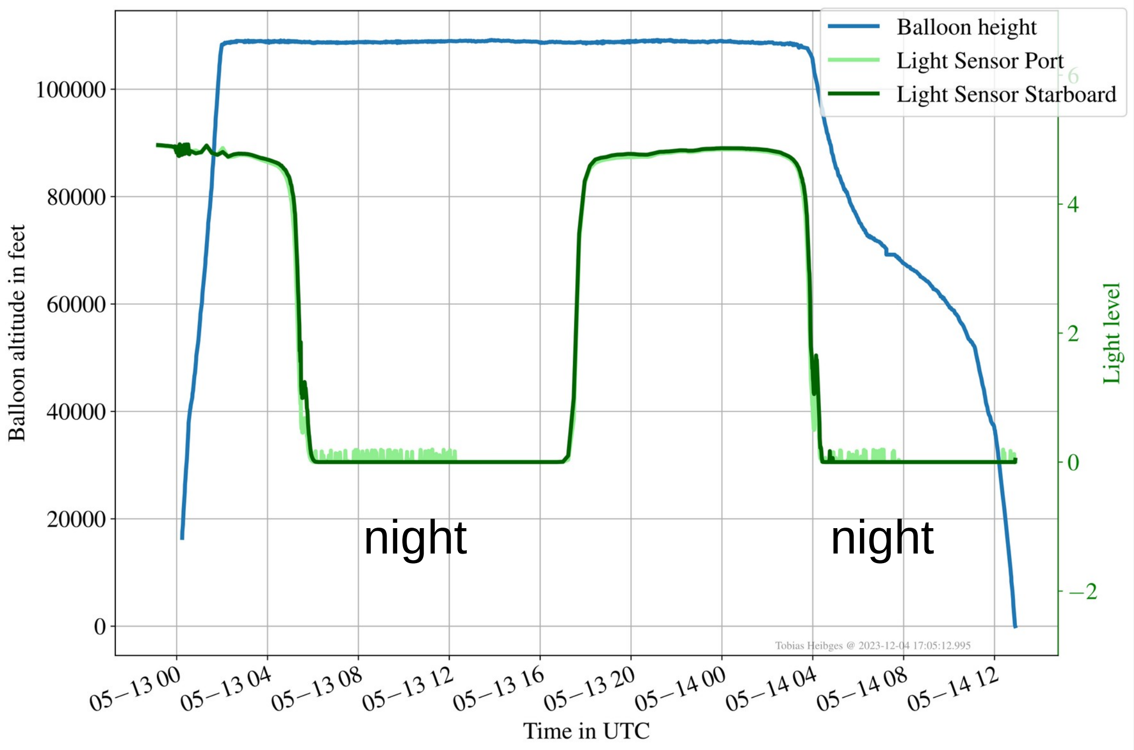
EUSO SPB2 Launch

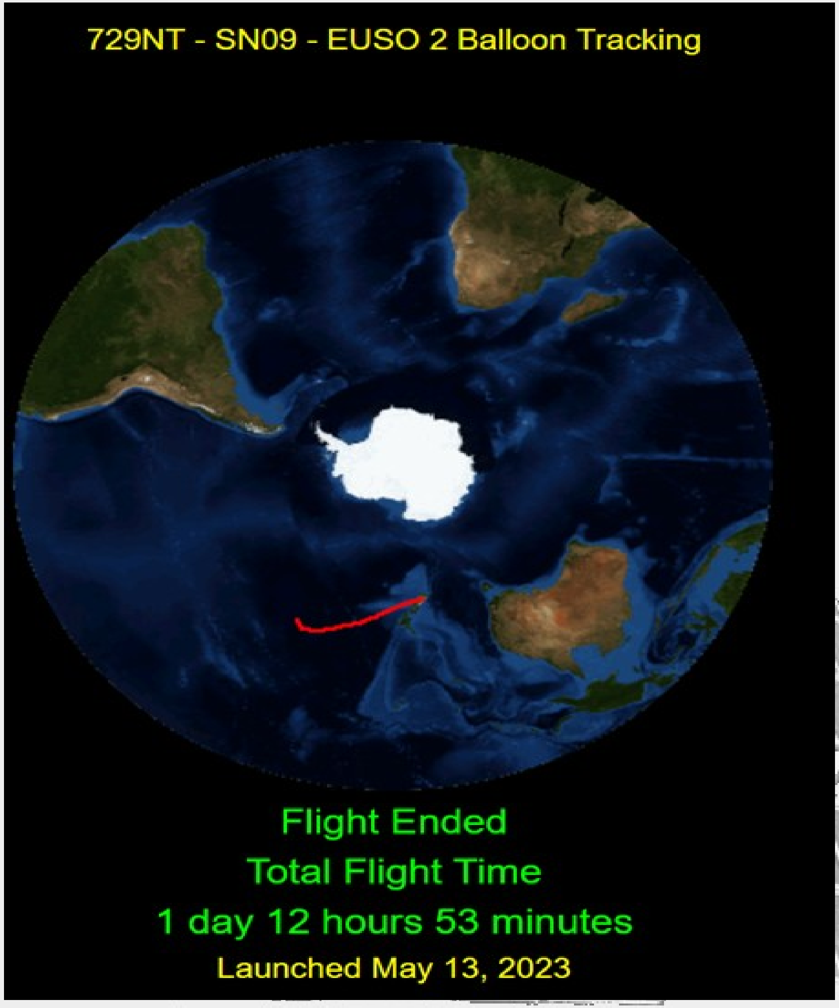


Flight Overview

Total Flight Time: 1 day 12 hours 53 minutes

Total Observation Time: ~12 hours 55 minutes



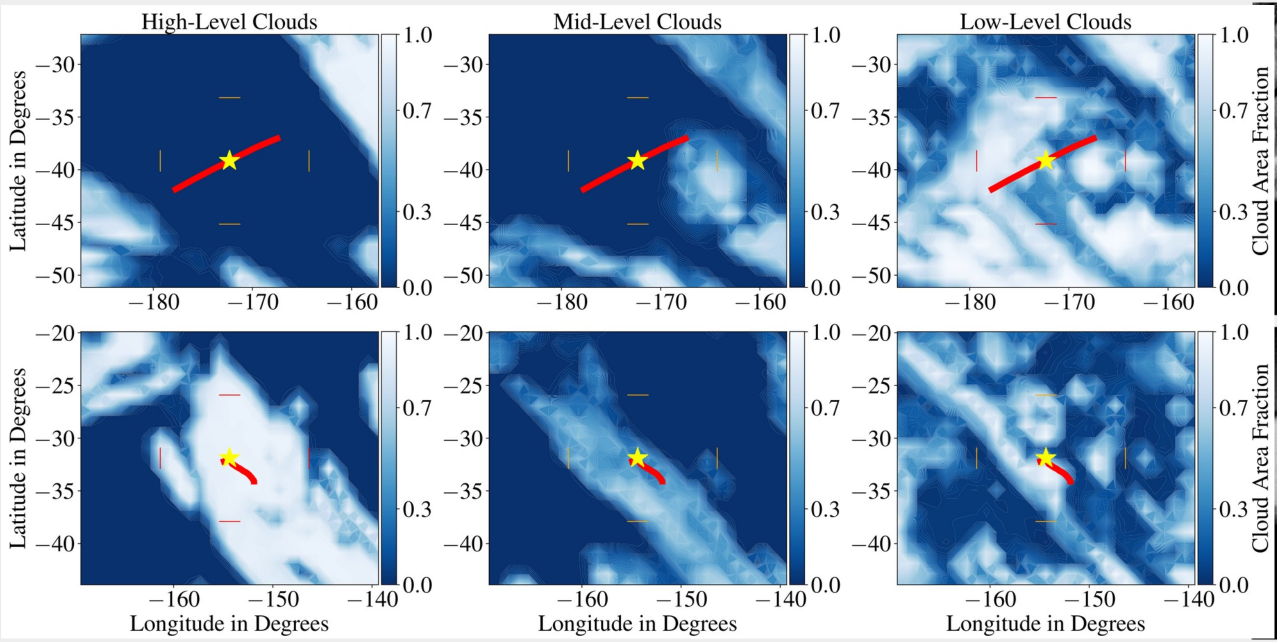


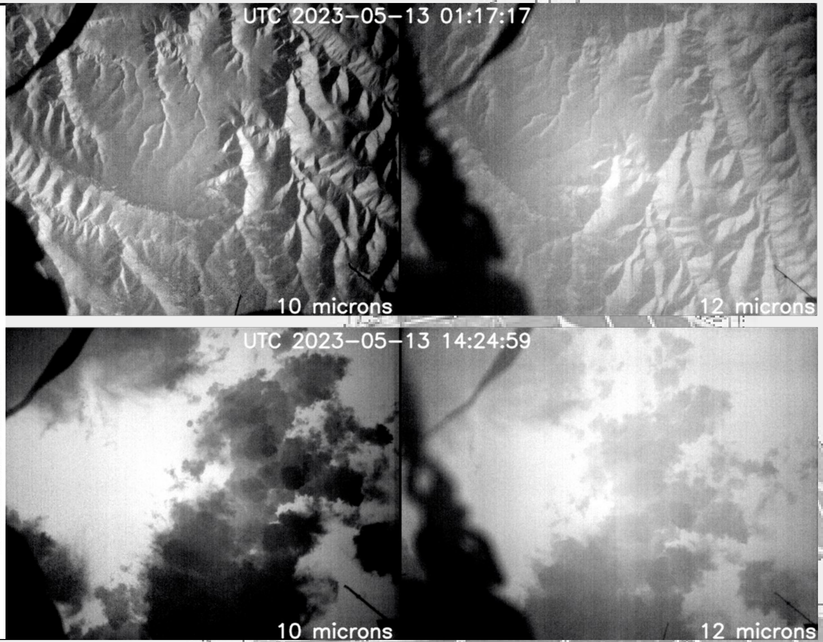
Flight Operations

- Night 1: Commissioning
  - FT needed adjustment of HVPS settings
  - CT comissioning
- Night 2: Observations
  - FT fully operational
  - CT fully operational

Night 1				
Begin Time	**End Time**	**Telescope Status**	**Tilt**	**Pointing**
06:25:00	08:01:00	Commissioning	-	-
08:01:00	08:12:00	Observations	$-5.8°$	$0.0°$
08:12:00	08:23:00	Tilting/Observations	$-5.8°$ to $-9.62°$	$0.0°$
08:15:00	08:35:00	Commissioning	$-9.62°$	$0.0°$
08:38:00	11:24:00	Observations	$-9.62°$	$0.0°$
11:25:00	12:02:00	Observations	$-8.62°$	$0.0°$
12:03:00	12:26:00	Tilting/Observations	$-8.62°$ to $-2.69°$	$0.0°$
12:26:00	12:42:00	Observations	$-2.69°$	$0.0°$
12:43:00	12:55:00	Tilting/Observations	$-2.69°$ to $-9.69°$	$0.0°$
12:55:00	13:39:00	Observations	$-9.69°$	$0.0°$
13:40:00	13:52:00	Observations	$-9.69°$	$315.0°$
13:52:00	-	Shutters Closed	$-5.8°$	$315.0°$
Night 2				
Begin Time	**End Time**	**Telescope Status**	**Tilt**	**Pointing**
05:37:00	05:40:00	Observations	$-8.6°$	$0.0°$
05:40:00	05:58:00	Tilting/Observations	$-8.6°$ to $-1.68°$	$0.0°$
05:58:00	06:46:00	Observations	$-1.68°$	Spinning
06:47:00	07:02:00	Tilting/Observations	$-1.68°$ to $-7.6°$	Spinning
07:02:00	07:10:00	Observations	$-7.6°$	Spinning
07:10:00	09:24:00	Troubleshooting	$-7.6°$	Spinning
09:10:00	12:40:00	Observations	$-7.6°$	Spinning
12:40:00	-	Shutters Closed	$-7.6°$	Spinning

Cloud coverage during flight

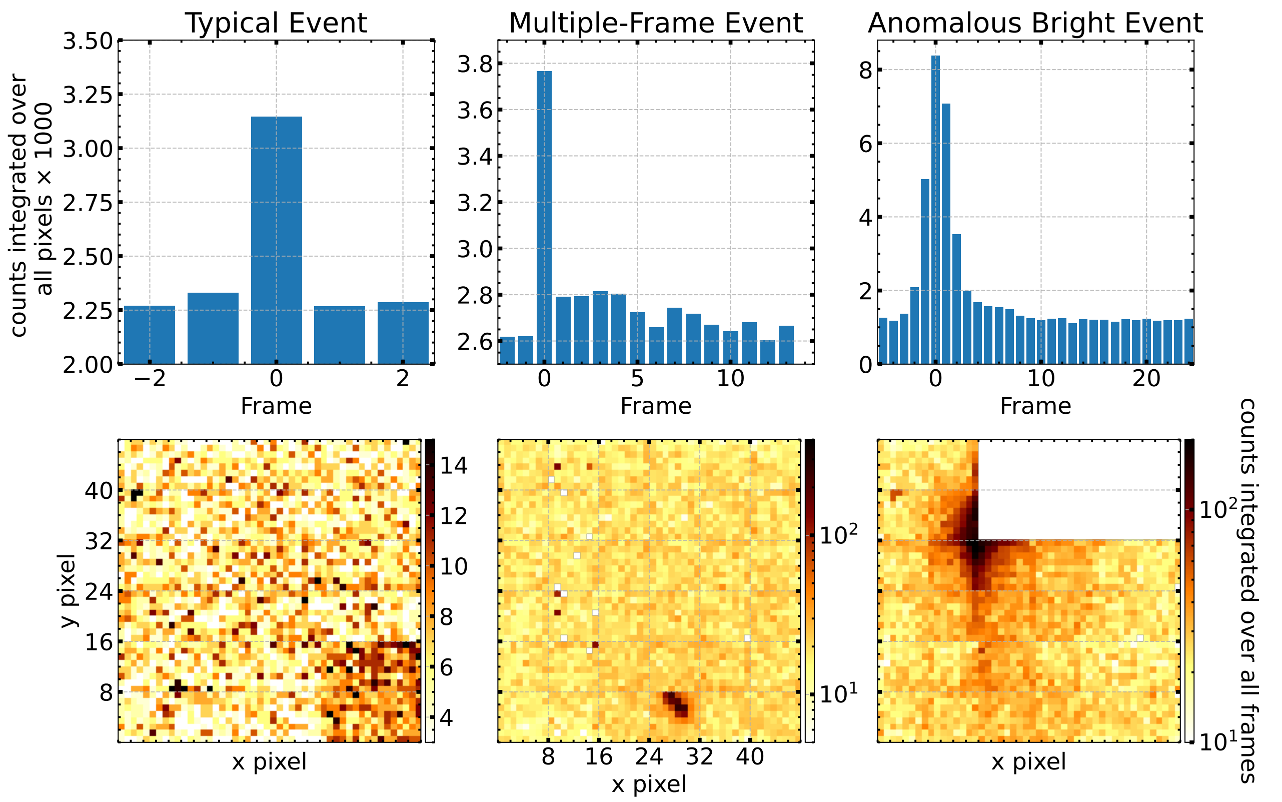




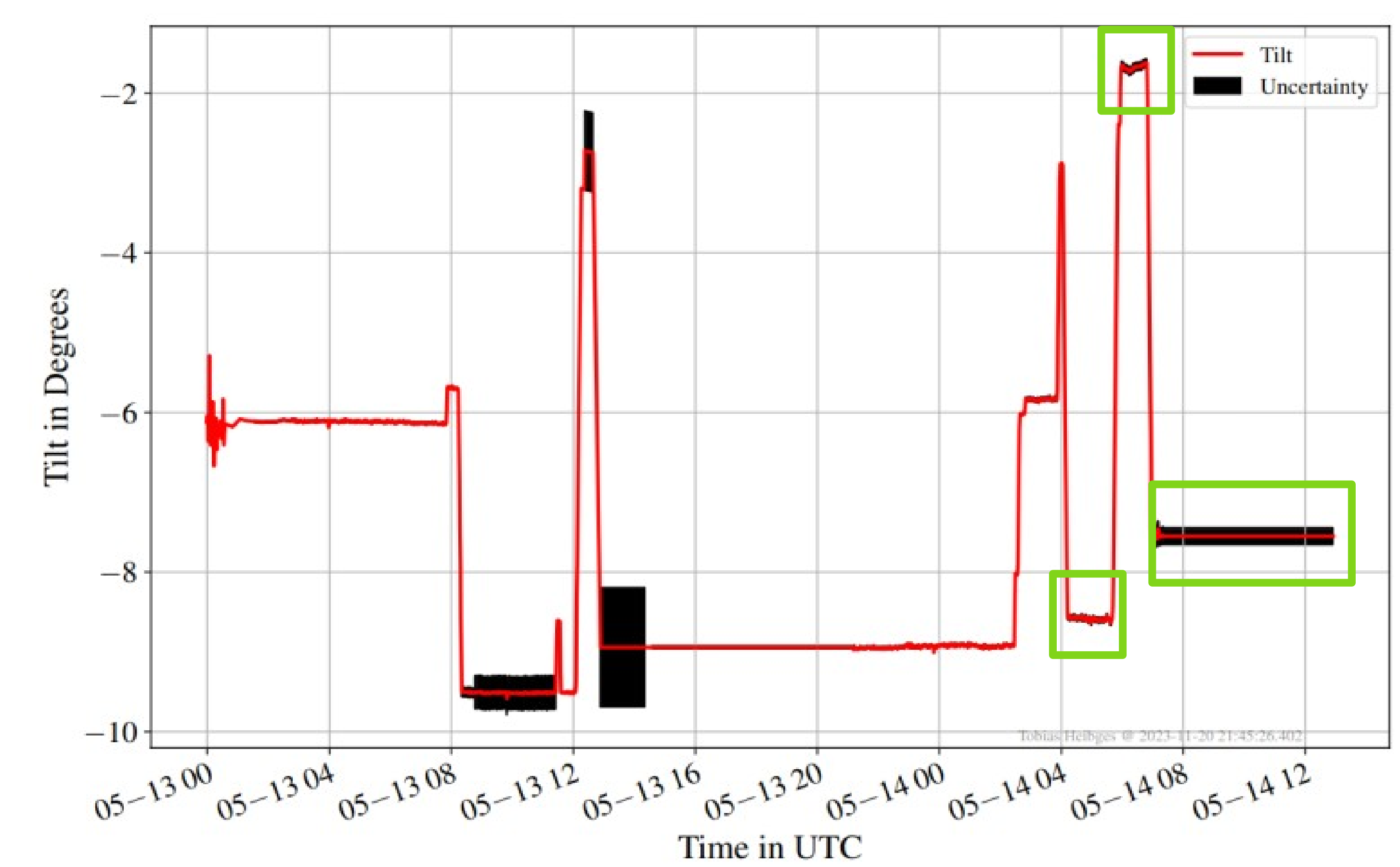
https://pos.sissa.it/444/450/

FT First Results

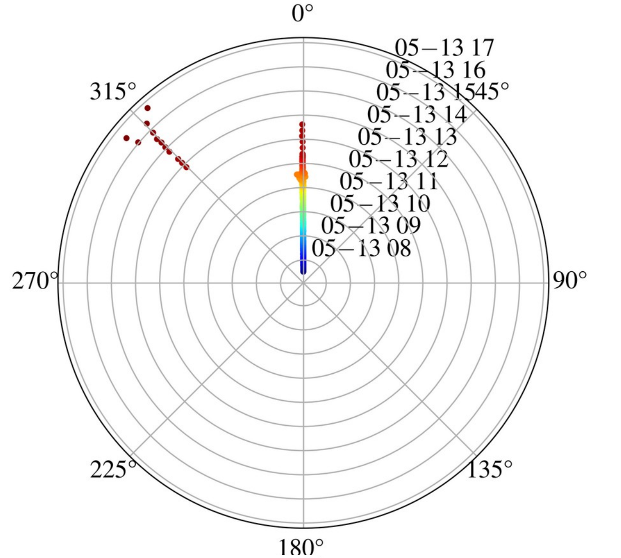
- Expected 1.24 UHECR events throughout the flight
  - None have been found
- Over 99.000 events downloaded
- Most events are single EC flashes
- Multiple-Frame Events associated with charged particle hits
- Anomalous Bright Events likely discharge in the camera on descent



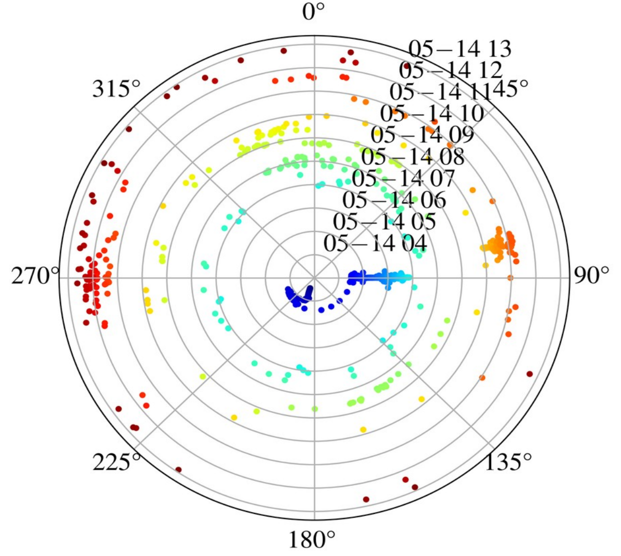
CT Pointing



Tilt
Uncertainty
Tilt in Degrees
−2
−4
−6
−8
−10
05−13 00
05−13 04
05−13 08
05−13 12
05−13 16
05−13 20
05−14 00
05−14 04
05−14 08
05−14 12
Time in UTC



0°
45°
90°
135°
180°
225°
270°
315°
05−13 17
05−13 16
05−13 15
05−13 14
05−13 13
05−13 12
05−13 11
05−13 10
05−13 09
05−13 08

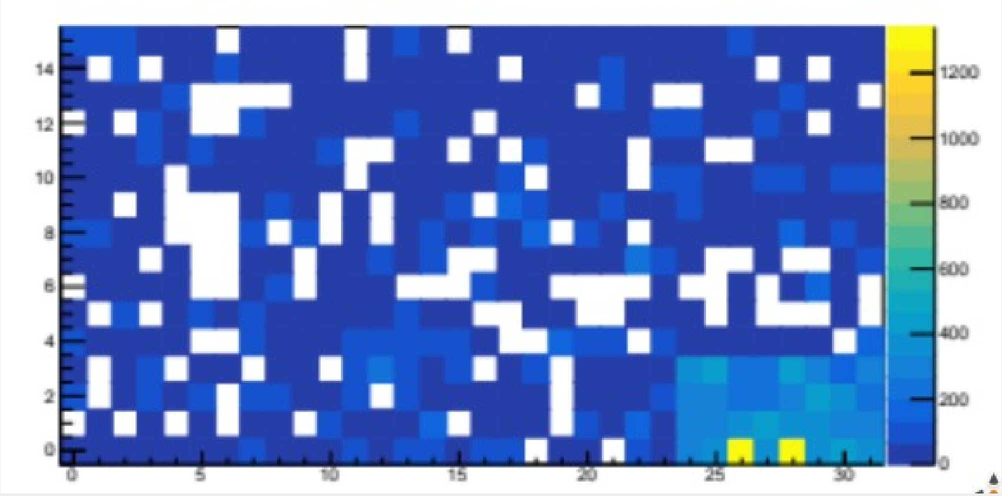


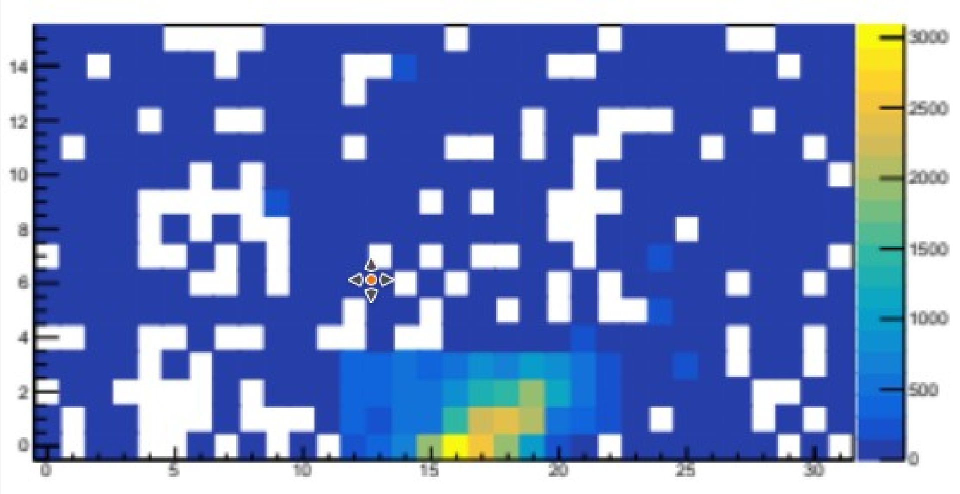
0°
45°
90°
135°
180°
225°
270°
315°
05−14 13
05−14 12
05−14 11
05−14 10
05−14 09
05−14 08
05−14 07
05−14 06
05−14 05
05−14 04

CT: Above the Horizon Cosmic Rays

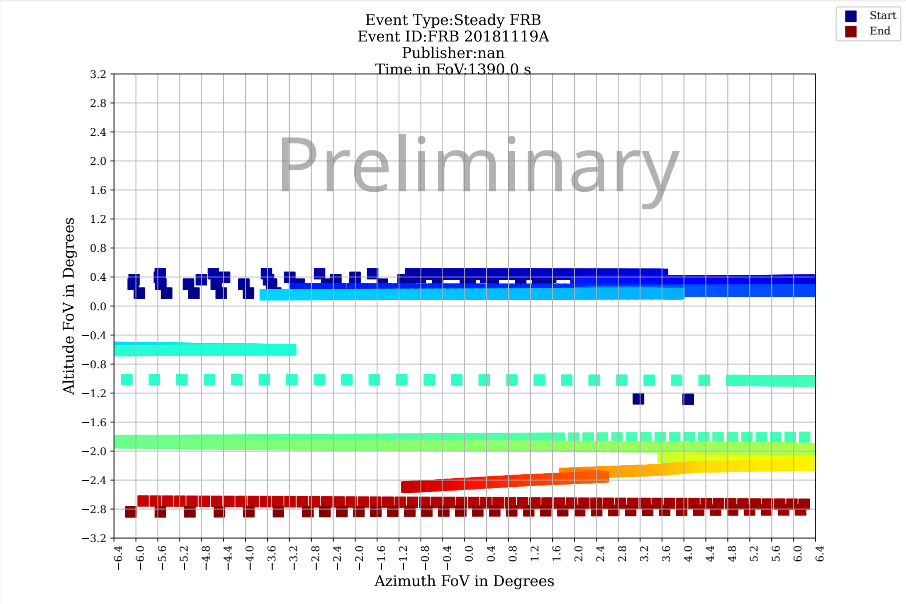
First pass at signal searches:

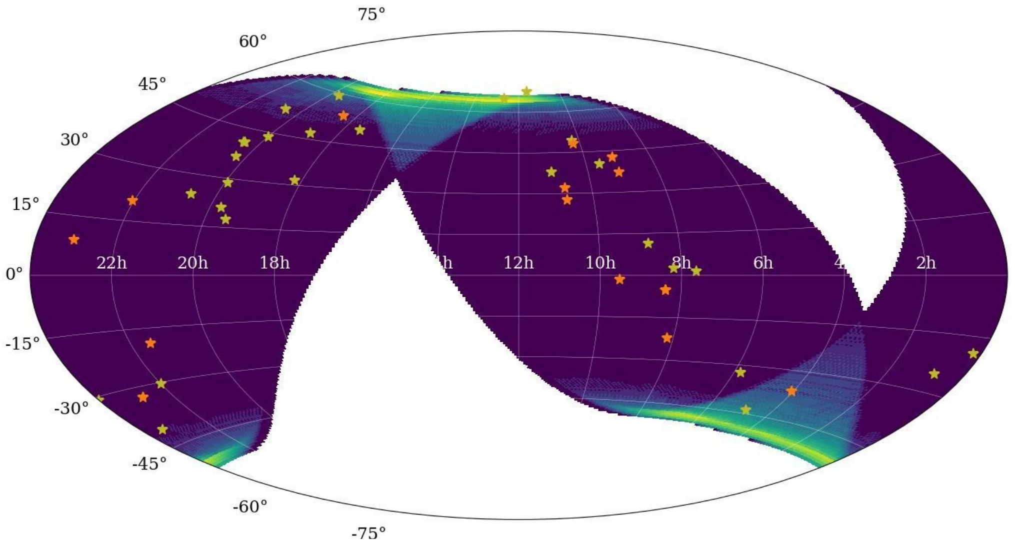
- Only high amplitude events
- Several CR candidates while looking above the horizon
- Some unidentified signals





ToO Observations



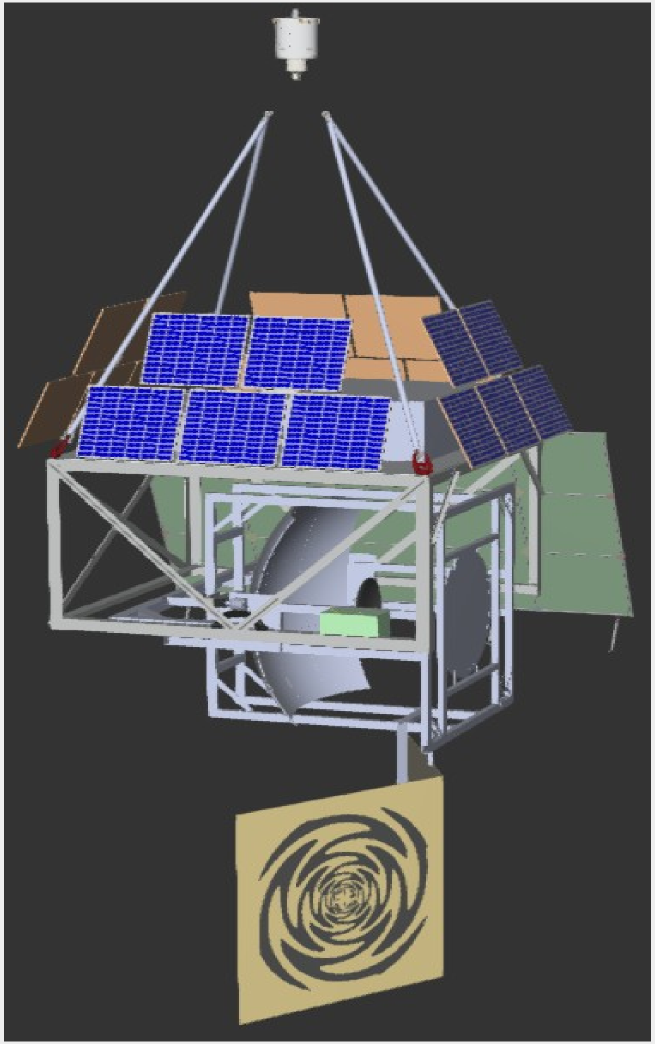


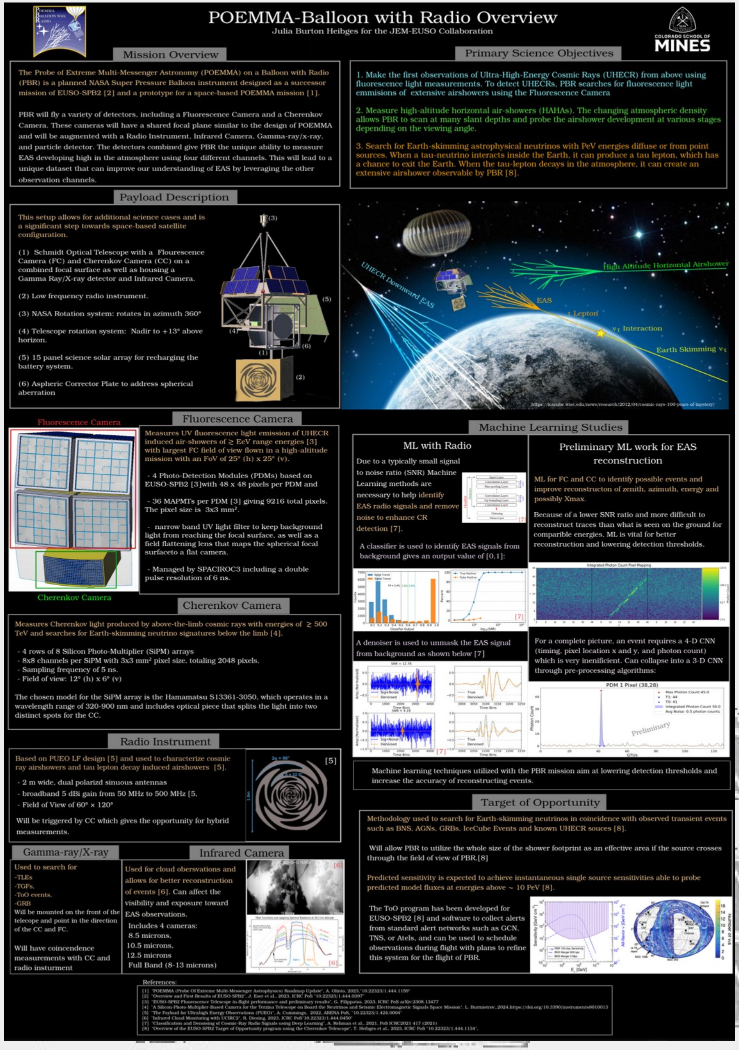
Event Type	Event ID	Publisher	Observation Start Time	Observation End Time
AGN	4FGL J0910.0+4257	ATels	2023-05-14T08:30:00.000	[illegible]
blazar	PKS 0402-362	ATels	2023-05-14T07:30:00.000	[illegible]
blazar	PKS 0402-362	ATels	2023-05-14T07:30:00.000	[illegible]
blazar	S4 0954+65	ATels	2023-05-14T05:30:00.000	[illegible]
FSRQ	S40954+658	ATels	[illegible]	[illegible]
GRB	None	Swift-XRT Position	[illegible]	[illegible]
SN II	SN 2023gjg	TNS	[illegible]	2023-05-14T09:30:00.000
Steady hotspot	Old TA Hotspot	None	[illegible]	2023-05-14T09:50:00.000
Steady HBL	PKS 0548-322	TeVCat	[illegible]	2023-05-14T09:50:00.000
Steady HBL	1ES 1011+496	TeVCat	[illegible]	2023-05-14T09:50:00.000
Steady HBL	1ES 0806+524	TeVCat	[illegible]	2023-05-14T07:40:00.000
Steady HBL	PKS 0447-439	[illegible]	[illegible]	2023-05-14T11:10:00.000
Steady HBL	RBS 0723	[illegible]	2023-05-14T09:40:00.000	2023-05-14T10:10:00.000
Steady HBL	1ES 0647+250	[illegible]	2023-05-14T07:10:00.000	2023-05-14T07:50:00.000
Steady HBL	[illegible]	[illegible]	2023-05-14T05:30:00.000	2023-05-14T08:50:00.000
Steady HBL	[illegible]	[illegible]	2023-05-14T09:30:00.000	2023-05-14T10:00:00.000
Steady FSRQ	[illegible]	TeVCat	2023-05-14T09:00:00.000	2023-05-14T09:30:00.000
Steady FSRQ	PKS 0346-27	TeVCat	2023-05-14T06:40:00.000	2023-05-14T07:20:00.000
Steady FRB	FRB 20181119A	None	2023-05-14T05:30:00.000	2023-05-14T10:20:00.000
Steady FRB	FRB 20180301A	None	2023-05-14T07:30:00.000	2023-05-14T08:00:00.000

PRELIMINARY

- First pass Identifying sources that crossed the FoV during flight
- Efforts to simulate fluence limits ongoing

What is next?





POEMMA-Balloon with Radio Overview

Julia Burton Heibges for the JEM-EUSO Collaboration

COLORADO SCHOOL OF MINES

Mission Overview

The Probe of Extreme Multi-Messenger Astronomy (POEMMA) on a Balloon with Radio (PBR) is a planned NASA Super Pressure Balloon instrument designed as a successor mission of EUSO-SPB2 [2] and a prototype for a space-based POEMMA mission [1].

PBR will fly a variety of detectors, including a Fluorescence Camera and a Cherenkov Camera. These cameras will have a shared focal plane similar to the design of POEMMA and will be augmented with a Radio Instrument, Infrared Camera, Gamma-ray/x-ray, and particle detector. The detectors combined give PBR the unique ability to measure EAS developing high in the atmosphere using four different channels. This will lead to a unique dataset that can improve our understanding of EAS by leveraging the other observation channels.

Primary Science Objectives

1. Make the first observations of Ultra-High-Energy Cosmic Rays (UHECR) from above using fluorescence light measurements. To detect UHECRs, PBR searches for fluorescence light emmisions of extensive airshowers using the Fluorescence Camera

2. Measure high-altitude horizontal air-showers (HAHAs). The changing atmospheric density allows PBR to scan at many slant depths and probe the airshower development at various stages depending on the viewing angle.

3. Search for Earth-skimming astrophysical neutrinos with PeV energies diffuse or from point sources. When a tau-neutrino interacts inside the Earth, it can produce a tau lepton, which has a chance to exit the Earth. When the tau-lepton decays in the atmosphere, it can create an extensive airshower observable by PBR [8].

Payload Description

This setup allows for additional science cases and is a significant step towards space-based satellite configuration.

(1) Schmidt Optical Telescope with a Flourescence Camera (FC) and Cherenkov Camera (CC) on a combined focal surface as well as housing a Gamma Ray/X-ray detector and Infrared Camera.

(2) Low frequency radio instrument.

(3) NASA Rotation system: rotates in azimuth 360°

(4) Telescope rotation system: Nadir to +13° above horizon.

(5) 15 panel science solar array for recharging the battery system.

(6) Aspheric Corrector Plate to address spherical aberration

UHECR Downward EAS
High Altitude Horizontal Airshower
EAS
τ Lepton
ν_τ Interaction
Earth Skimming ν_τ

https://icecube.wisc.edu/news/research/2012/04/cosmic-rays-100-years-of-mystery/

Fluorescence Camera

Fluorescence Camera
Cherenkov Camera

Measures UV fluorescence light emission of UHECR induced air-showers of ≳ EeV range energies [3] with largest FC field of view flown in a high-altitude mission with an FoV of 25° (h) x 25° (v).

- 4 Photo-Detection Modules (PDMs) based on EUSO-SPB2 [3]with 48 x 48 pixels per PDM and
- 36 MAPMTs per PDM [3] giving 9216 total pixels. The pixel size is 3x3 mm².
- narrow band UV light filter to keep background light from reaching the focal surface, as well as a field flattening lens that maps the spherical focal surfaceto a flat camera.
- Managed by SPACIROC3 including a double pulse resolution of 6 ns.

Cherenkov Camera

Measures Cherenkov light produced by above-the-limb cosmic rays with energies of ≳ 500 TeV and searches for Earth-skimming neutrino signatures below the limb [4].

- 4 rows of 8 Silicon Photo-Multiplier (SiPM) arrays
- 8x8 channels per SiPM with 3x3 mm² pixel size, totaling 2048 pixels.
- Sampling frequency of 5 ns.
- Field of view: 12° (h) x 6° (v)

The chosen model for the SiPM array is the Hamamatsu S13361-3050, which operates in a wavelength range of 320-900 nm and includes optical piece that splits the light into two distinct spots for the CC.

Radio Instrument

Based on PUEO LF design [5] and used to characterize cosmic ray airshowers and tau lepton decay induced airshowers [5].

- 2 m wide, dual polarizd sinuous antennas
- broadband 5 dBi gain from 50 MHz to 500 MHz [5.
- Field of View of 60° × 120°

Will be triggered by CC which gives the opportunity for hybrid measurements.

[5]

Gamma-ray/X-ray

Used to search for
-TLEs
-TGFs,
-ToO events,
-GRB
Will be mounted on the front of the telecope and point in the direction of the CC and FC.

Will have coincendence measurements with CC and radio insturment

Infrared Camera

Used for cloud obersvations and allows for better reconstruction of events [6]. Can affect the visibility and exposure toward EAS observations.

Includes 4 cameras:
8.5 microns,
10.5 microns,
12.5 microns
Full Band (8-13 microns)

[6]

Machine Learning Studies

ML with Radio

Due to a typically small signal to noise ratio (SNR) Machine Learning methods are necessary to help identify EAS radio signals and remove noise to enhance CR detection [7].

A classifier is used to identify EAS signals from background gives an output value of [0,1]:

A denoiser is used to unmask the EAS signal from background as shown below [7]

Preliminary ML work for EAS reconstruction

ML for FC and CC to identify possible events and improve reconstructon of zenith, azimuth, energy and possibly Xmax.

Because of a lower SNR ratio and more difficult to reconstruct traces than what is seen on the ground for comparible energies, ML is vital for better reconstruction and lowering detection thresholds.

Integrated Photon Count Pixel Mapping

For a complete picture, an event requires a 4-D CNN (timing, pixel location x and y, and photon count) which is very inenificient. Can collapse into a 3-D CNN through pre-processing algorithms:

PDM 1 Pixel (38,28)
Max Photon Count:45.0
T1: 44
T0: 41
Integrated Photon Count 50.0
Avg Noise: 0.5 photon counts
Preliminary

Machine learning techniques utilized with the PBR mission aim at lowering detection thresholds and increase the accuracy of reconstructing events.

Target of Opportunity

Methodology used to search for Earth-skimming neutrinos in coincidence with observed transient events such as BNS, AGNs, GRBs, IceCube Events and known UHECR souces [8].

Will allow PBR to utilize the whole size of the shower footprint as an effective area if the source crosses through the field of view of PBR.[8]

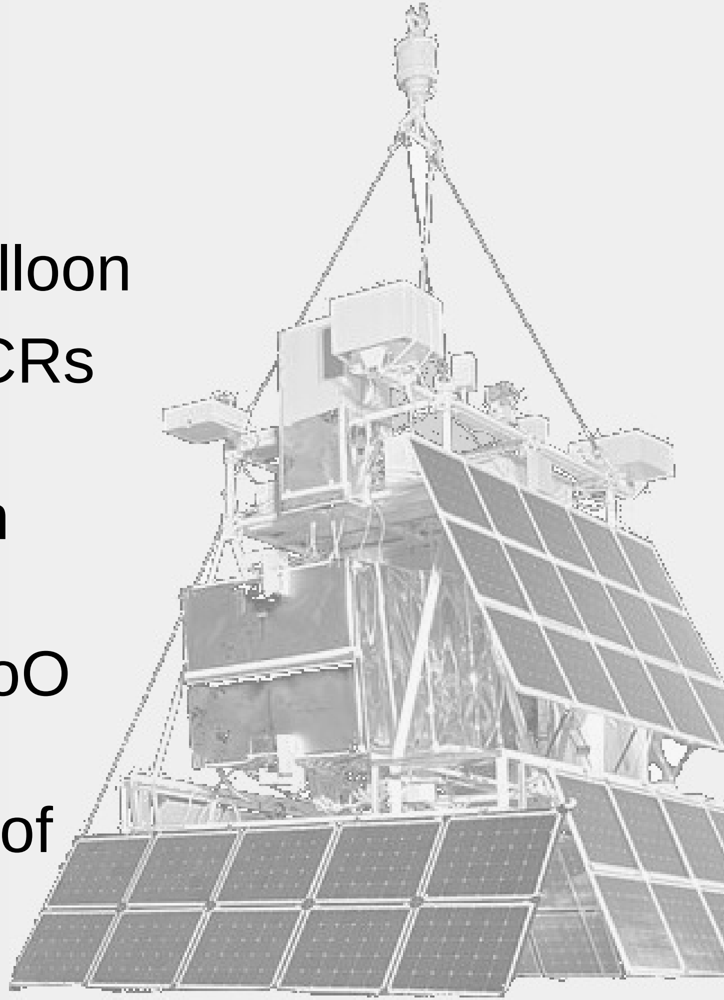
Predicted sensitivity is expected to achieve instantaneous single source sensitivities able to probe predicted model fluxes at energies above ~ 10 PeV [8].

The ToO program has been developed for EUSO-SPB2 [8] and software to collect alerts from standard alert networks such as GCN, TNS, or Atels, and can be used to schedule observations during flight with plans to refine this system for the flight of PBR.

References:

[1] "POEMMA (Probe Of Extreme Multi-Messenger Astrophysics) Roadmap Update", A. Olinto, 2023,"10.22323/1.444.1159"
[2] "Overview and First Results of EUSO-SPB2", J. Eser et al., 2023, ICRC PoS "10.22323/1.444.0397"
[3] "EUSO-SPB2 Fluorescence Telescope in-flight performance and preliminary results", G. Filippatos, 2023, ICRC PoS arXiv:2308.13477
[4] "A Silicon-Photo-Multiplier-Based Camera for the Terzina Telescope on Board the Neutrinos and Seismic Electromagnetic Signals Space Mission", L. Burmistrov, 2024 https://doi.org/10.3390/instruments8010013
[5] "The Payload for Ultrahigh Energy Observations (PUEO)", A. Cummings, 2022, ARENA PoS, "10.22323/1.424.0004"
[6] "Infrared Cloud Monitoring with UCIRC2", R. Diesing, 2023, ICRC PoS"10.22323/1.444.0450"
[7] "Classification and Denoising of Cosmic-Ray Radio Signals using Deep Learning", A. Rehman et al., 2021, PoS ICRC2021 417 (2021)
[8] "Overview of the EUSO-SPB2 Target of Opportunity program using the Cherenkov Telescope", T. Heibges et al., 2023, ICRC PoS "10.22323/1.444.1134".

Summary



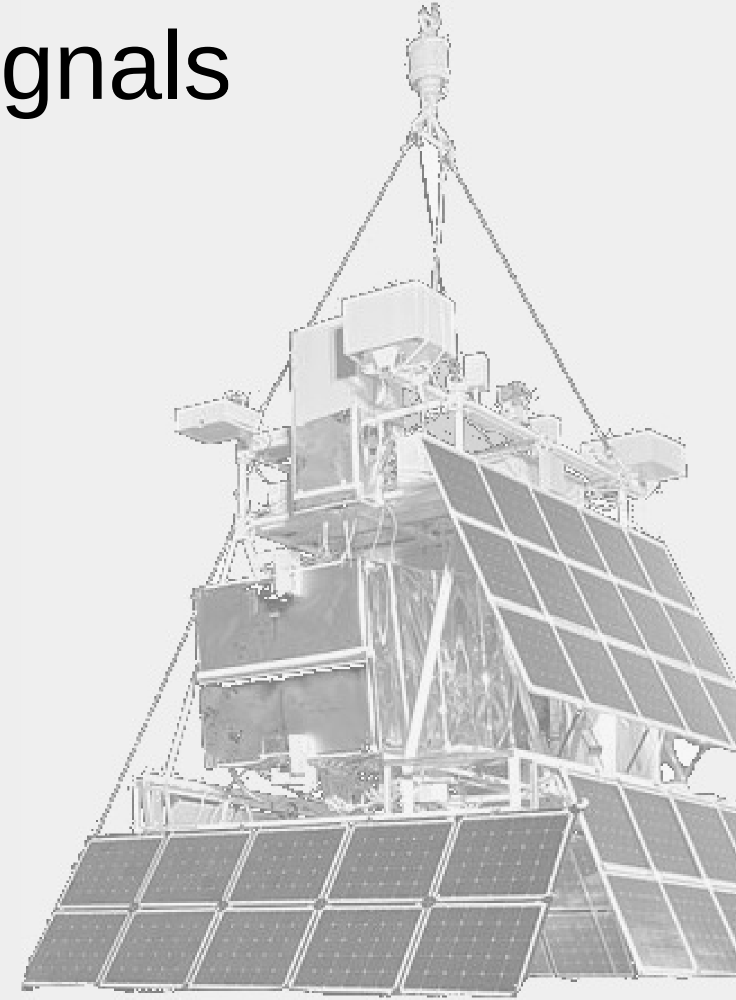
We built, tested and flew EUSO-SPB2

- Flight was cut short due to a leak in the balloon
- Demonstrated the CT's ability to observe CRs above the Horizon
- Demonstrated the FT's ability to function in near-space environments
- Spinning during descent makes planned ToO follow-ups impossible
- Some ToO sources have crossed the field of view

Questions?

Building Cuts – Background signals

- Diffuse Neutrino background
- Reflected EAS
- Refracted EAS
- Deflected Muons
- Direct CR hits



Building Cuts – Background signals

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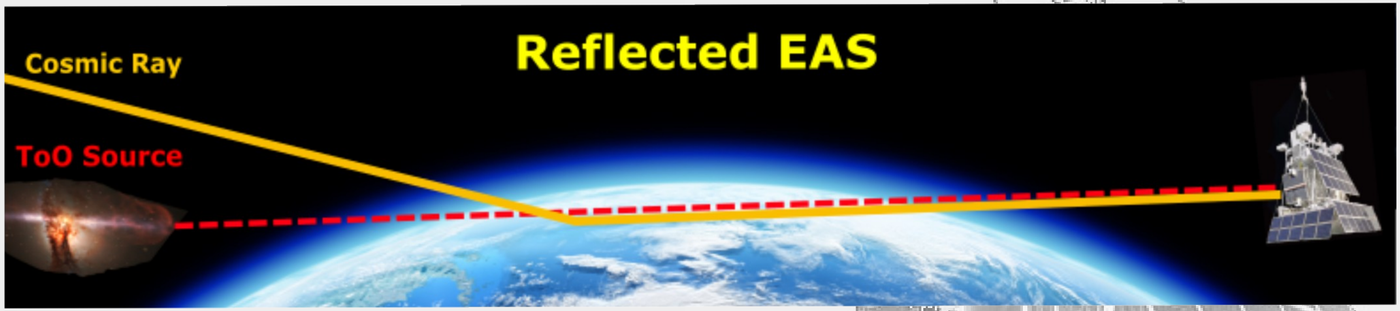
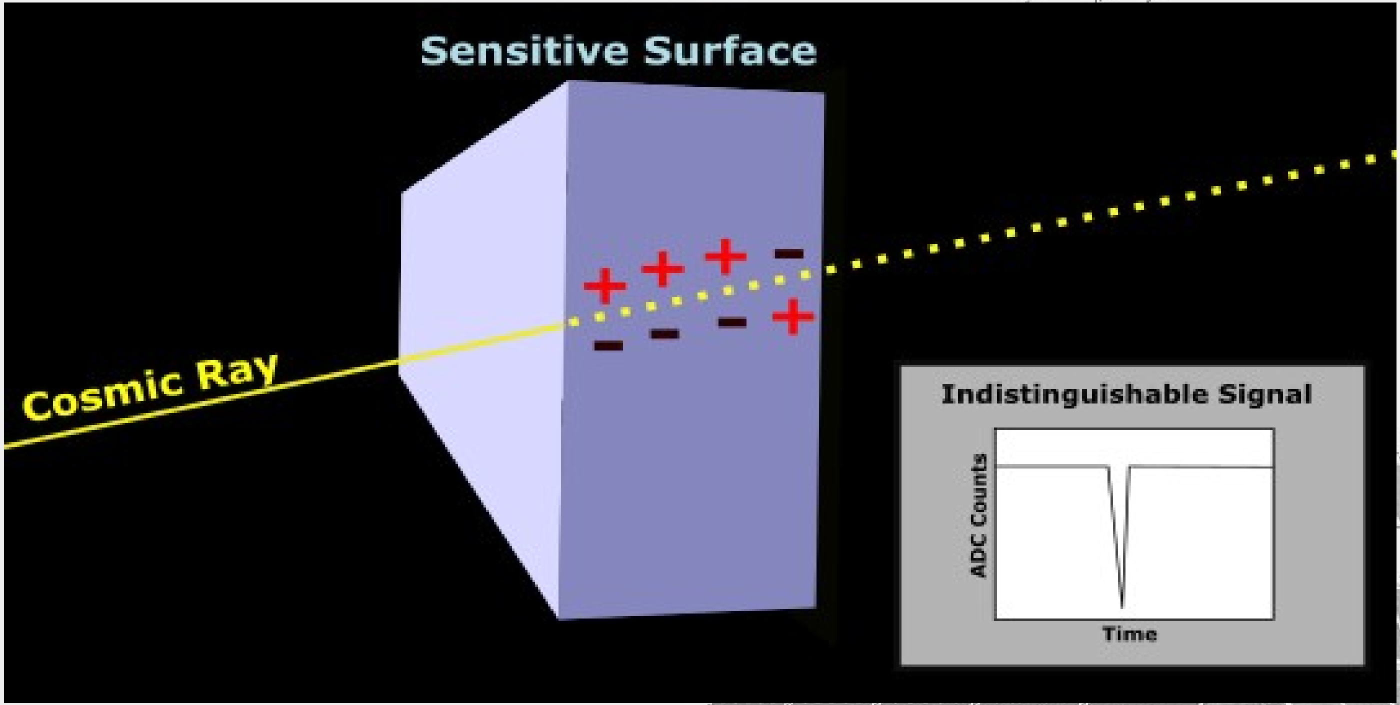


Building Cuts – Background signals

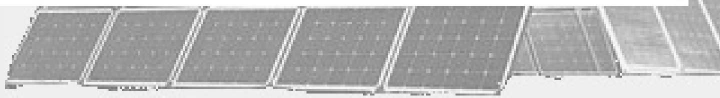
- Diffuse Neutrino background
- Reflected EAS
- Refracted EAS
- **Deflected Muons**
- Direct CR hits

Building Cuts – Background signals

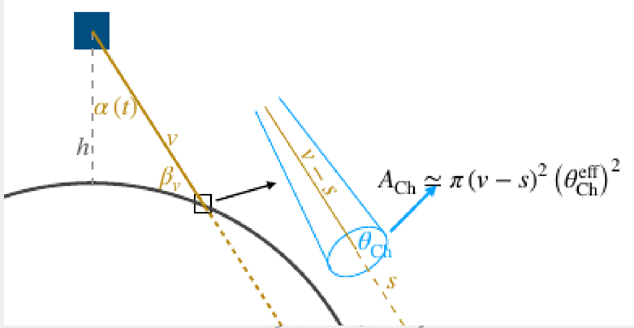
- Diffuse Neutrino background
- Reflected EAS
- Refracted EAS
- Deflected Muons
- **Direct CR hits**



Balloon	0.5×10^6 m^3 (18×10^6 ft^3)	Helium
Nominal float height	33.5 km (110000 ft)	
Telemetry (data)	≈200 Mbits s^{-1}	1 Starlink (maritime unit)
	≈75 kbits s^{-1}	1 TDRSS
	≈75 kbits s^{-1}	1 Iridium OpenPort
Telemetry (comms)	≈1.2 kbits s^{-1} (255 bit bursts)	2 Iridium Pilots
Power consumption	200 W (day), 420 W (night)	w/ battery heater at night
Batteries	6× 24 A·h Lithium-Ion	Valence U27-24XP
Solar panels	15×100 W	SunCat Solar
Detector weight	1223 kg (2250 lb)	Without SIP, antennas, and ballast
Releasable ballast	272 kg (600 lb)	≤0 lb remaining at termination
Total weight	2557 kg (5625 lb)	Everything below balloon
Flight start	2023 May 13 00:02 UT	44.7218°S 169.2540°E
Flight end	2023 May14 12:54 UT	34.0831°S 151.8768°W
Flight duration	36 hr 52 mn	Leaky Balloon



Sensitivity Calculation



The sensitivity is given by:

$$\mathcal{F}_{\rangle} = \frac{2.44}{\ln(10) \cdot E_{\nu_i} \cdot \mathcal{A}(E_{\nu_i})}$$

Where the effective area is:

$$\mathcal{A}(E_{\nu_\tau}) = \frac{1}{T} \int_{t_0}^{t_0+T} dt \mathcal{A}(t, E_{\nu_\tau})$$

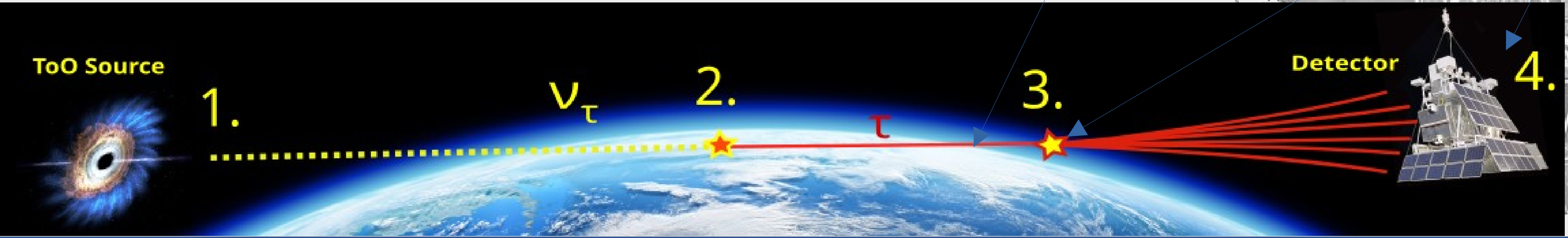
And changes as the source moves in the sky

The effective area is given by this:

$$\mathcal{A}(t, E_{\nu_\tau}) = \int ds \quad P_{\text{obs}}(t, E_{\nu_\tau}, \beta, s) A_{cc}(s).$$

And the probability of observation is:

$$P_{\text{obs}} = \int dE_\tau \quad p_{\text{exit}}(E_\tau | E_{\nu_\tau}, \beta) p_{\text{decay}}(s, E_\tau) p_{\text{detect}}$$



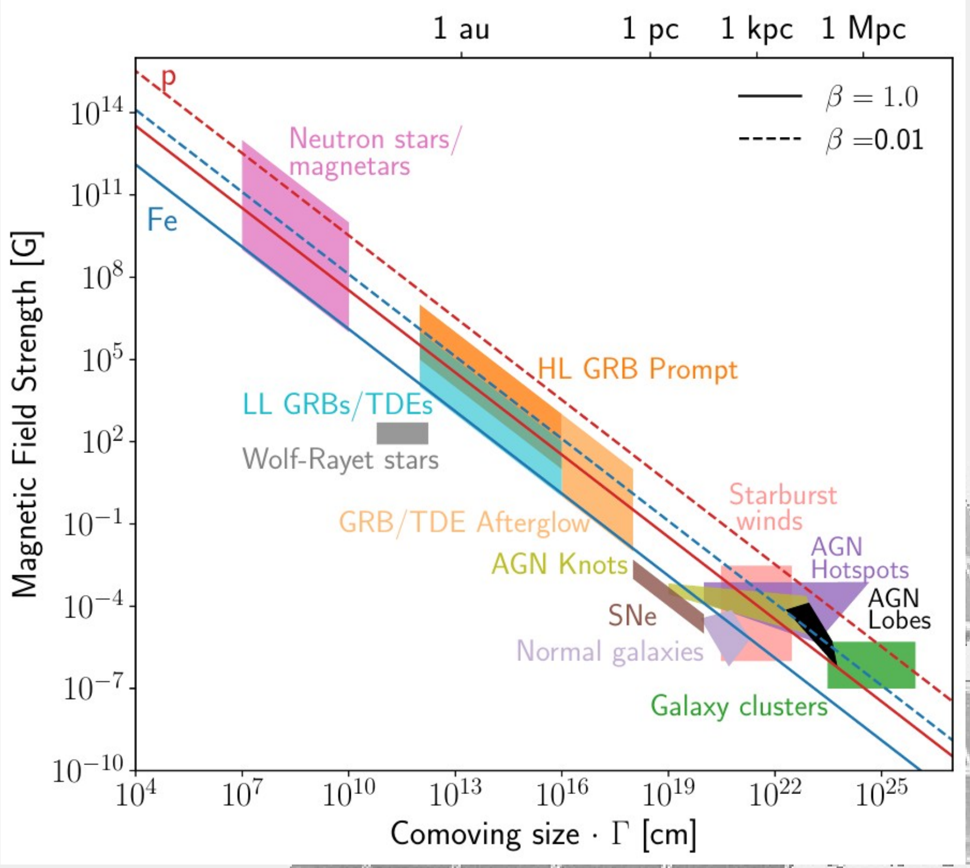
What are source candidates for CRs?

Open Questions in Cosmic-Ray Research at Ultrahigh Energies, Frontiers in Astronomy and Space Sciences, Batista et al. [3]

- Most models predict gradual acceleration
  - Need to confine particles in acceleration region

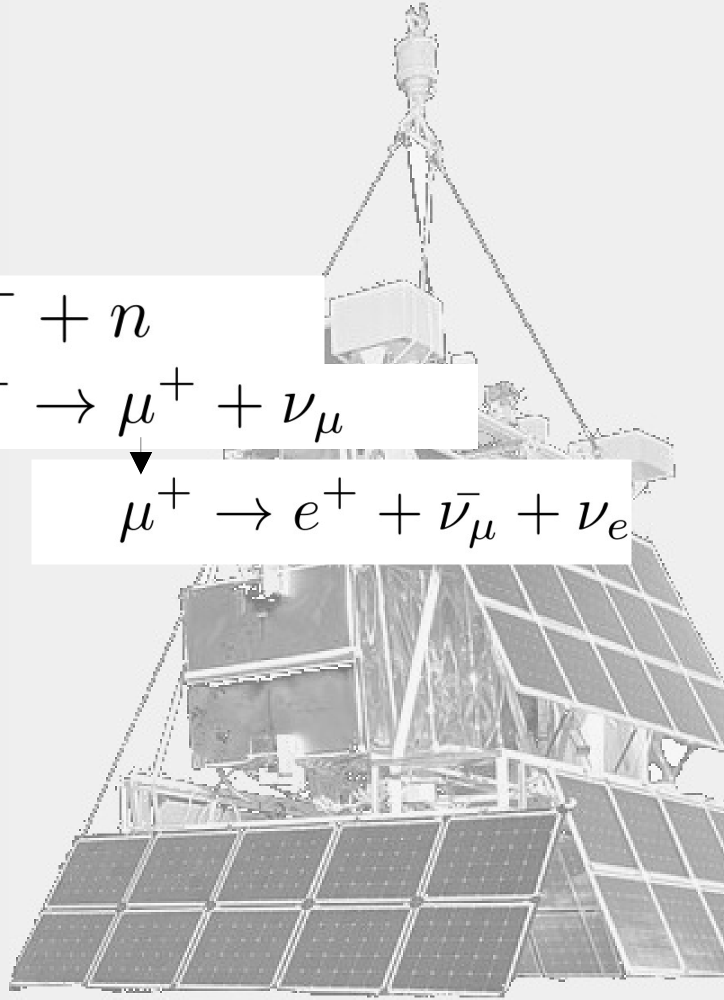
$$r_L = \frac{\gamma m v_\perp}{|q|B} = \frac{E v_\perp}{|q|Bc^2}$$

- Source candidates range from ~km - ~kPc in size
  - Usually small sources don't exist very long and are associated with violent events
    - GRB, BNS, SN…
  - Also Larger sources can produce flaring behavior
- These are the sources we look for with ToO
- We don't find sources ourselves but rely on observations in light, neutrino or GW



Cosmic ray interactions

- CRs can interact with matter or photons
  - Most interactions will produce pions
  - Interactions products include:
    - Gamma rays
    - Neutrinos
      - Flavor ratio ($1\nu_e:2\nu_\mu:0\nu_\tau$ at production)
      - Flavor ratio ($1\nu_e:1\nu_\mu:1\nu_\tau$ at Earth after oscillation)
    - Muons
    - Other Hadrons
- Interactions occur:
  - In the source
  - In transit (e.g. with the CMB)
  - In CR interactions with the atmosphere



$$p + \gamma \rightarrow \pi^+ + n$$

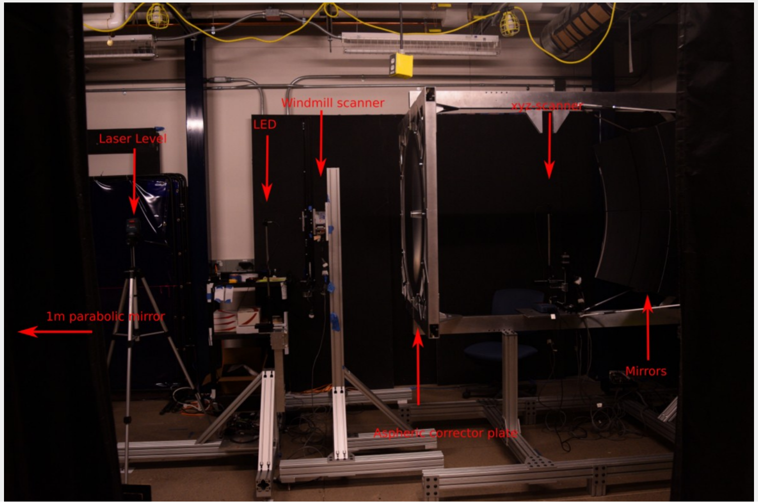
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

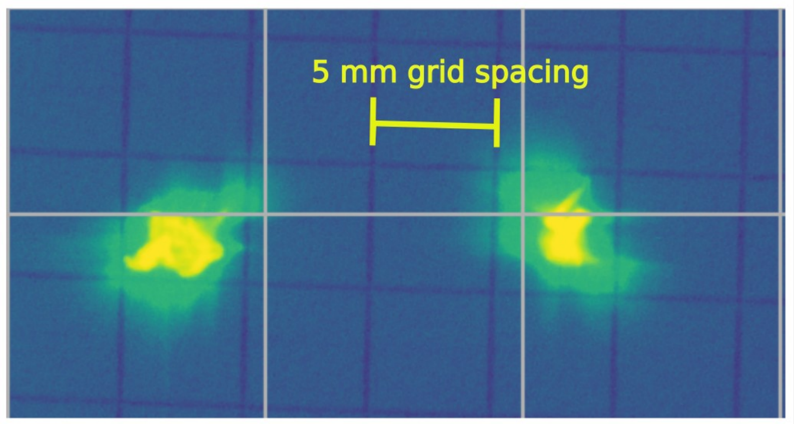
$$\mu^+ \rightarrow e^+ + \bar{\nu_\mu} + \nu_e$$

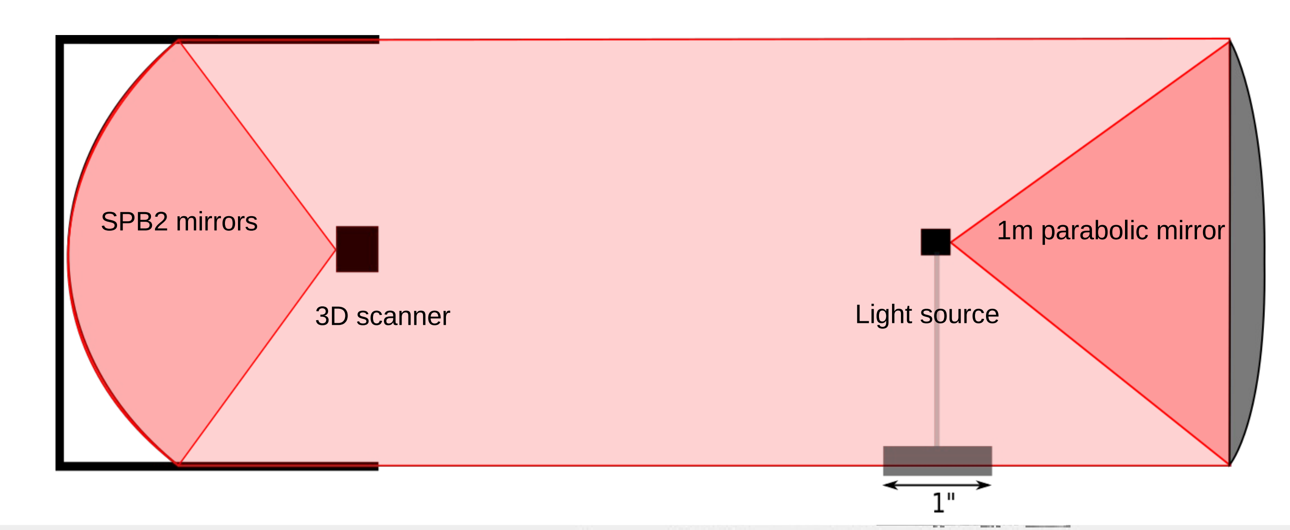
Optical Testing and Alignment

- Optical test setup in the GRLA including:
  - 1m parallel light beam
  - 3D psf (windmill) scanner
  - LED light source

- **Best spotsize 3mm 90% containment**







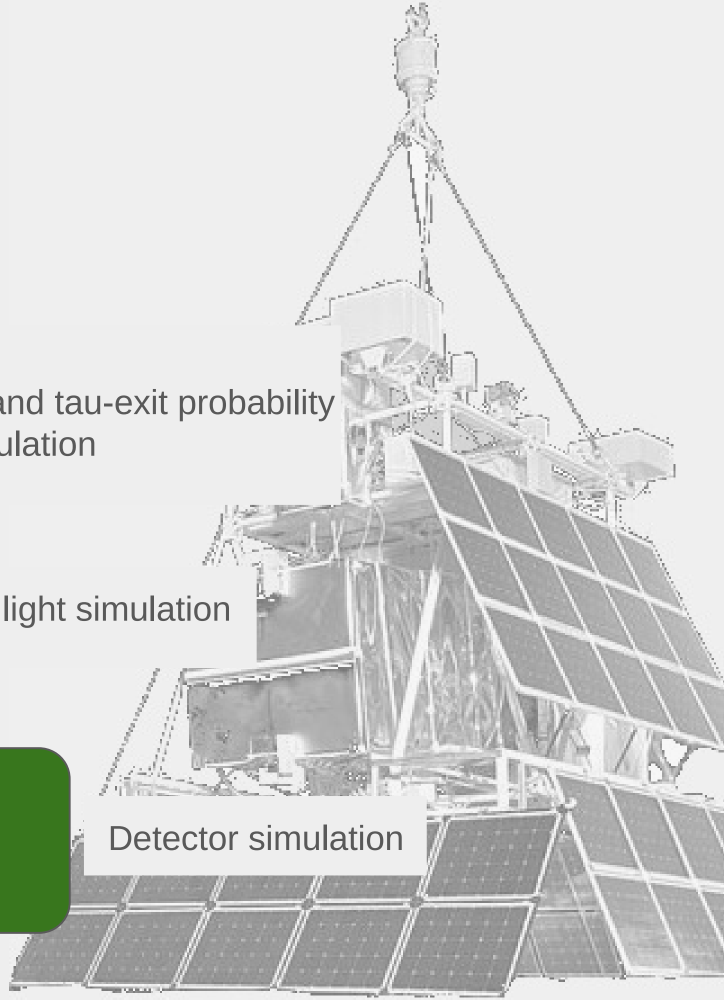
Cherenkov light simulation chain

NUTS — Determine which sources could be observable for balloon in motion

NuSpaceSim — Calculate neutrino interaction and tau-exit probability and longitudinal airshower simulation

EASCherSim/ CHASM — Cherenkov light simulation

OffLine — Detector simulation



Detector Response - Trigger

- Hardware Trigger
  - Coincident signal between two neighboring music chips within 50ns.
  - Does not mean a bifocal pair...
- Software Trigger
  - Requires that two triggering pixels are a bifocal pair.