3 AM, May 13th 2023, Wanaka N.Z.

ASAPP2023
19-23 JUNE 2023 PERUGIA (IT)
Advances in Space AstroParticle Physics
FRONTIER TECHNOLOGIES FOR PARTICLE MEASUREMENTS IN SPACE

EUSO-SPB2: Mission Status and Prospects

Lawrence Wiencke
Colorado School of Mines

ASAPP
June 22nd, 2023
Perugia, Italy

	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
AL	CDTA, CRAAG	M. Traiche (CDTA), M. FOUKA (CRAAG)	Simulations
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
Mx	U. Mexico	G. Medina-Tanco	Thermal Modeling
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

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US	MSFC, Goddard	M. Christl, R. Young, J. Krizmanic, T. Venters	Gondola, SIP Interfacing
US	UAH	P. Reardon, J.Adams, E. Kuznetsov,	Optics Design, Solar Power, CT systems
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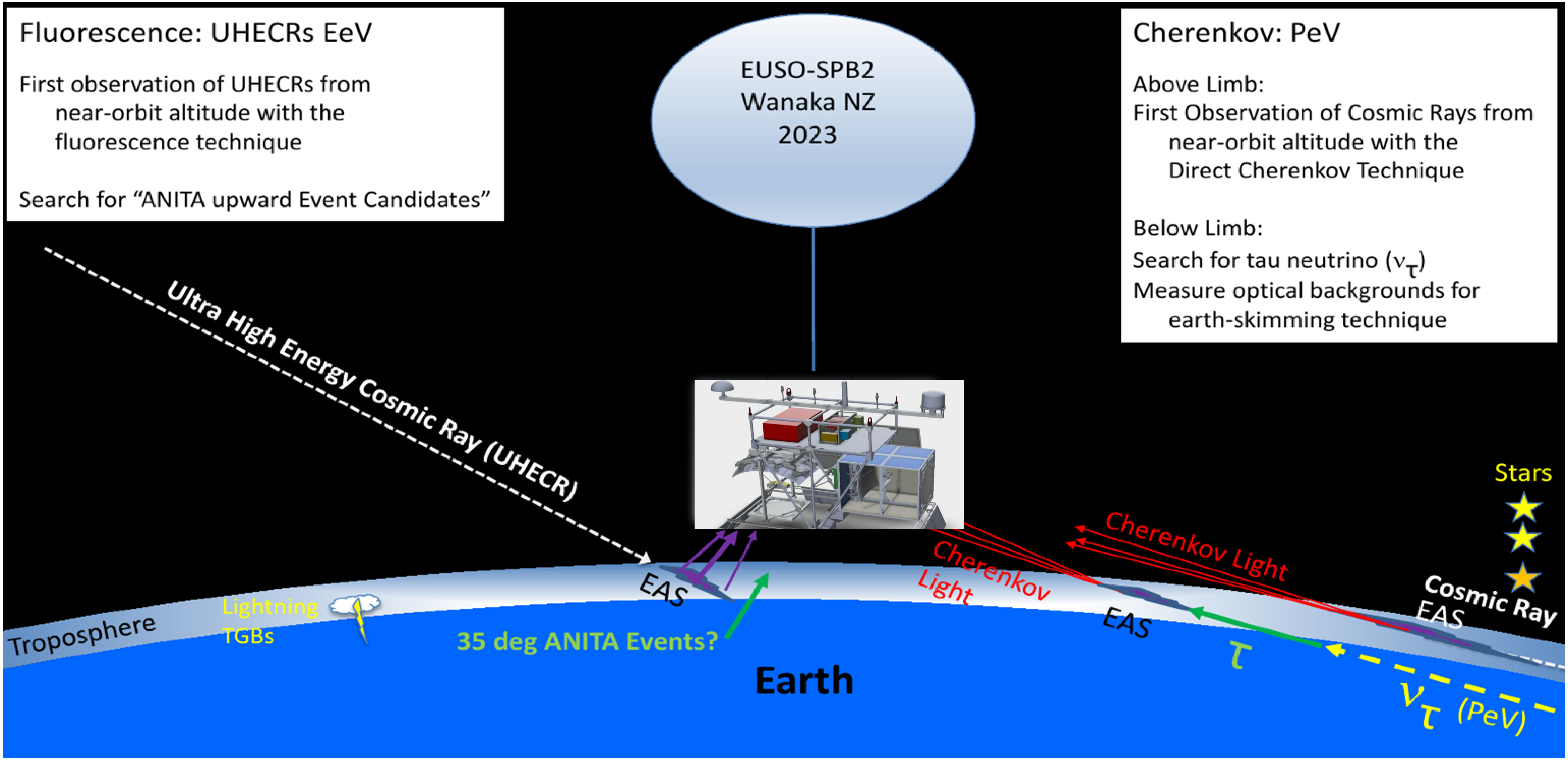
11 Countries participating in EUSO-SPB2

nuSpaceSim Group (Krizmanic et al)

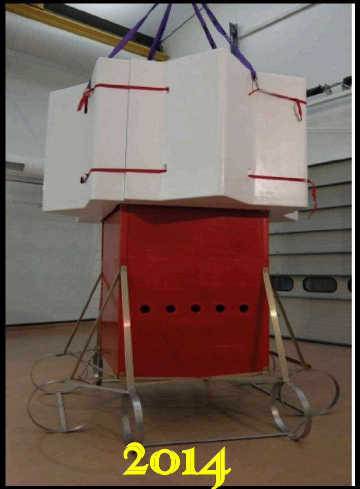
John F. Krizmanic[*1,2,3†], Yosui Akaike[1,2,3], Douglas R. Bergman[4], Johannes Eser[5], Sameer Patel[6], Mary Hall Reno[6], Andrés Romero-Wolf[7], Fred Sarazin[5], Tonia M. Venters[2], Luis Anchordoqui[8], Simon Mackovjak[9], Angela V. Olinto[10], Lawrence Wiencke[5], Stephanie Wissel[11], Alexander Reustle[2,12]


Fluorescence: UHECRs EeV
First observation of UHECRs from near-orbit altitude with the fluorescence technique
Search for “ANITA upward Event Candidates”
EUSO-SPB2
Wanaka NZ
2023
Cherenkov: PeV
Above Limb:
First Observation of Cosmic Rays from near-orbit altitude with the Direct Cherenkov Technique
Below Limb:
Search for tau neutrino (ν_τ)
Measure optical backgrounds for earth-skimming technique
Ultra High Energy Cosmic Ray (UHECR)
Stars
Cherenkov Light
Cherenkov Light
EAS
EAS
Cosmic Ray EAS
Lightning
TGBs
Troposphere
35 deg ANITA Events?
Earth
τ
ν_τ (PeV)

EUSO-SPB2

Telescopes	2	1 Fluorescence (FT)	1 Cherenkov (CT)
Energy Threshold		*~3 EeV*	*~1 PeV*
Sensor Type		MAPMT (Hamamatsu)	SiPM Hamamatsu (S14521-6050CN)
Wavelength Sensitivity		UV 300-420 nm (BG3 filter x QE)	no filter (~300-~900 nm)
Time Bin		1000 ns/bin	10 ns
Pointing (zenith angle)		nadir	+2.2, -15.3 about horizontal
FOV (instrumented)		3x(11x11) deg	6.4x12.8 deg
Number of Pixels		3x2304=6912 (3 48x48 PDMs)	16x32=512 (16 Vert x 32 Horz)
Pixel FOV (& size)		0.2x0.2 deg (2.8x2.8 mm)	0.4x0.4 deg (6.25 x 6.25mm)
Optics (modified Schmidt)	Spherical Mirror Glass, ROC 1659.8 mm	6 segments common focus + camera corrector/filter	4 segments bifocal separation 2 pixels horizontal
Entrance Pupil	1 m diameter	PPMA corrector plate	PPMA corrector plate
Payload Mass (lbs)	~3000 lbs Science (5625 total payload	~850 lbs	~750 lbs
Float Height	110,000 ft (33 km, 7 mbar)		Earth limb 5.8 deg below horz.
Launch Location	Wanaka NZ 2023		
Duration Target	100 days		

EUSO-Balloon



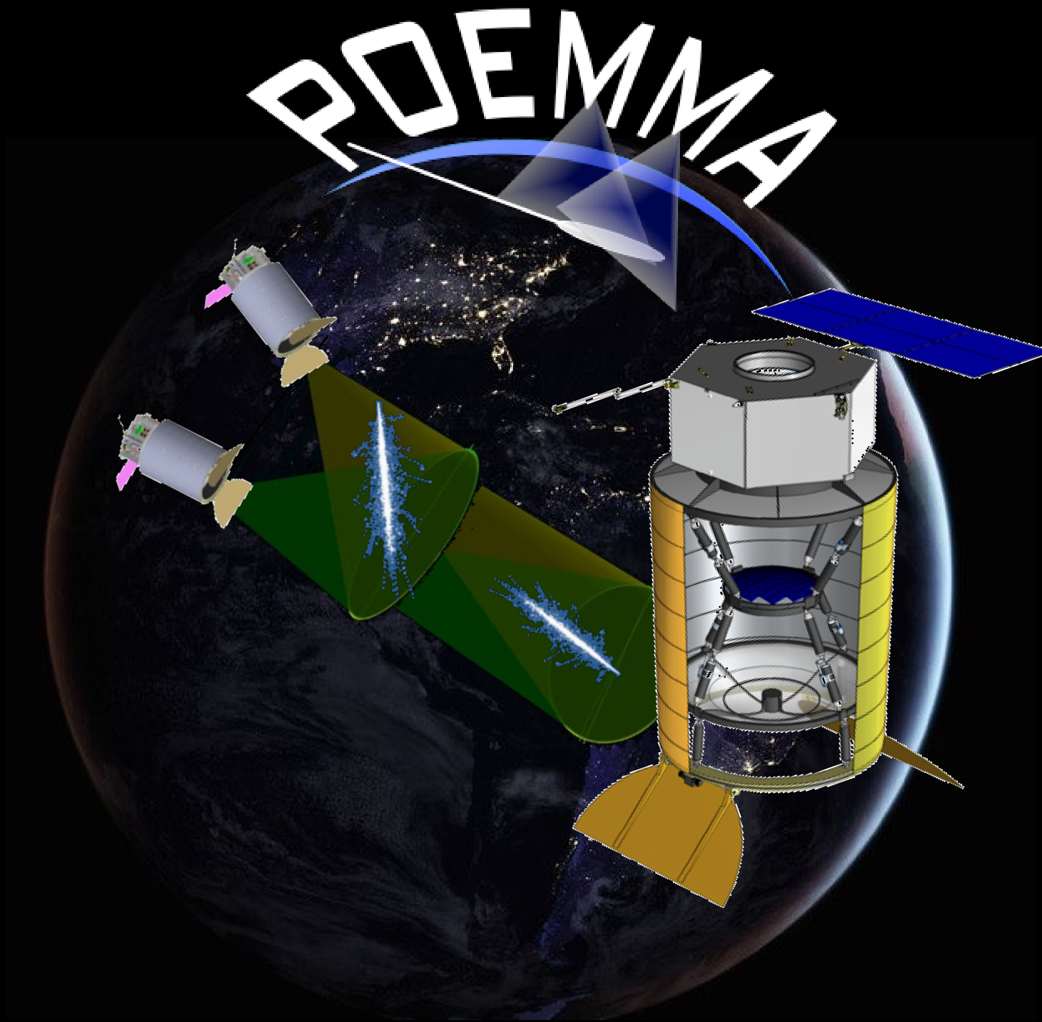
2014

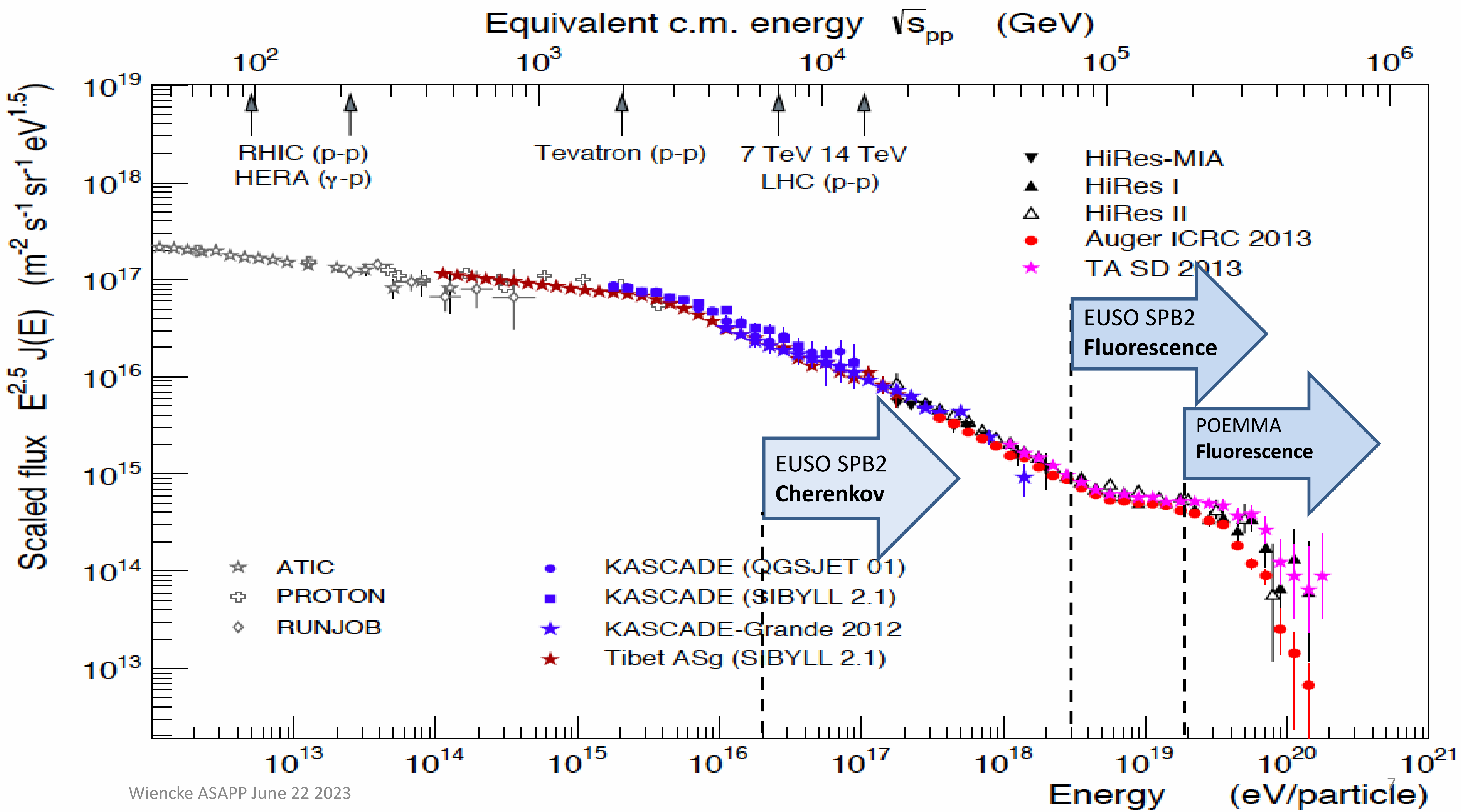
EUSO-SPB1

2017

EUSO-SPB2

2023

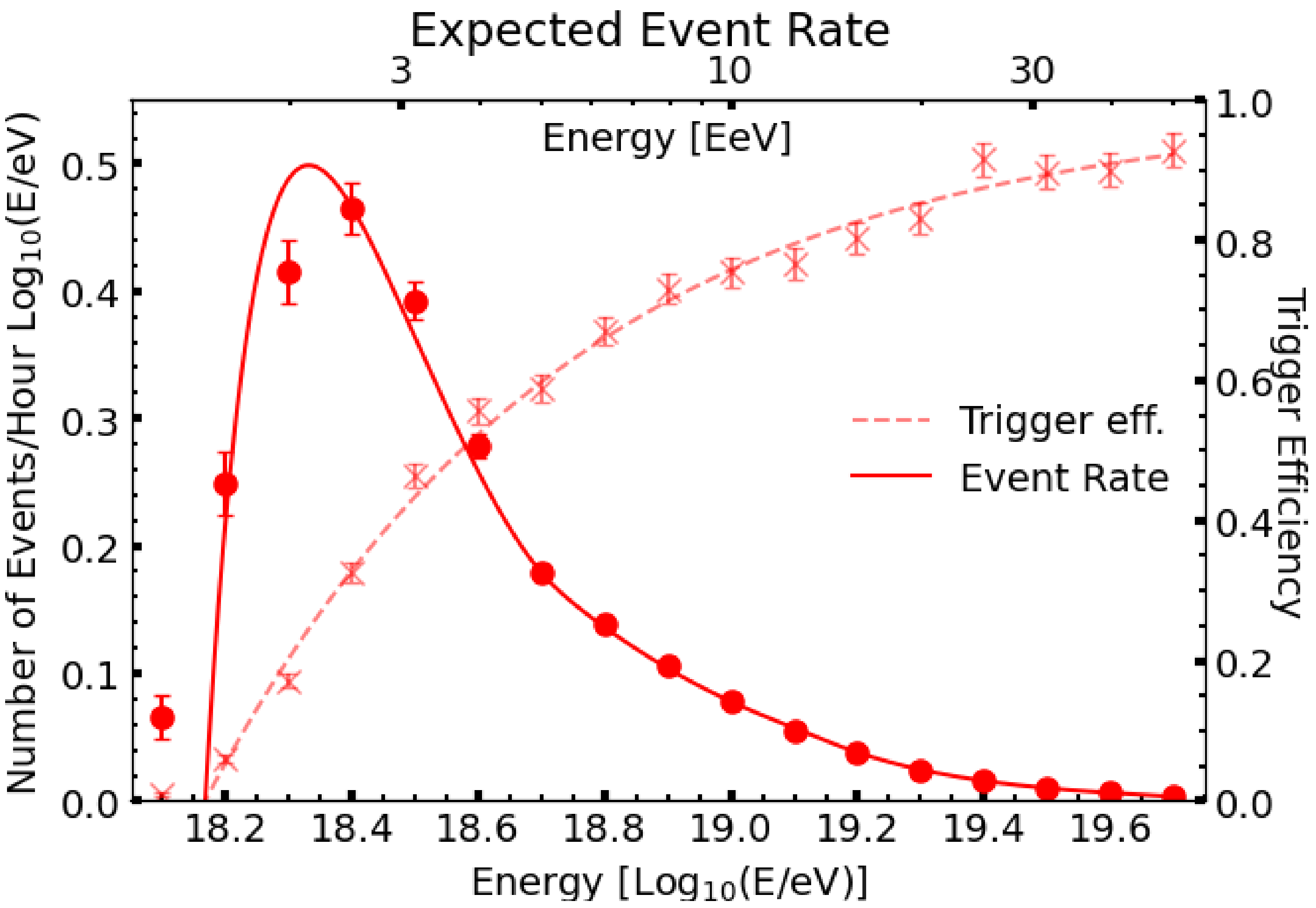




Equivalent c.m. energy $\sqrt{s}_{pp}$ (GeV)
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
EUSO SPB2
Fluorescence
POEMMA
Fluorescence
EUSO SPB2
Cherenkov
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 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 Fluorescence Telescope: Cosmic Ray (Simulation)

G. Filippatos



Energy threshold: ~1.5EeV with peak sensitivity at 2EeV

~1 event per day (<10% are reconstructible)

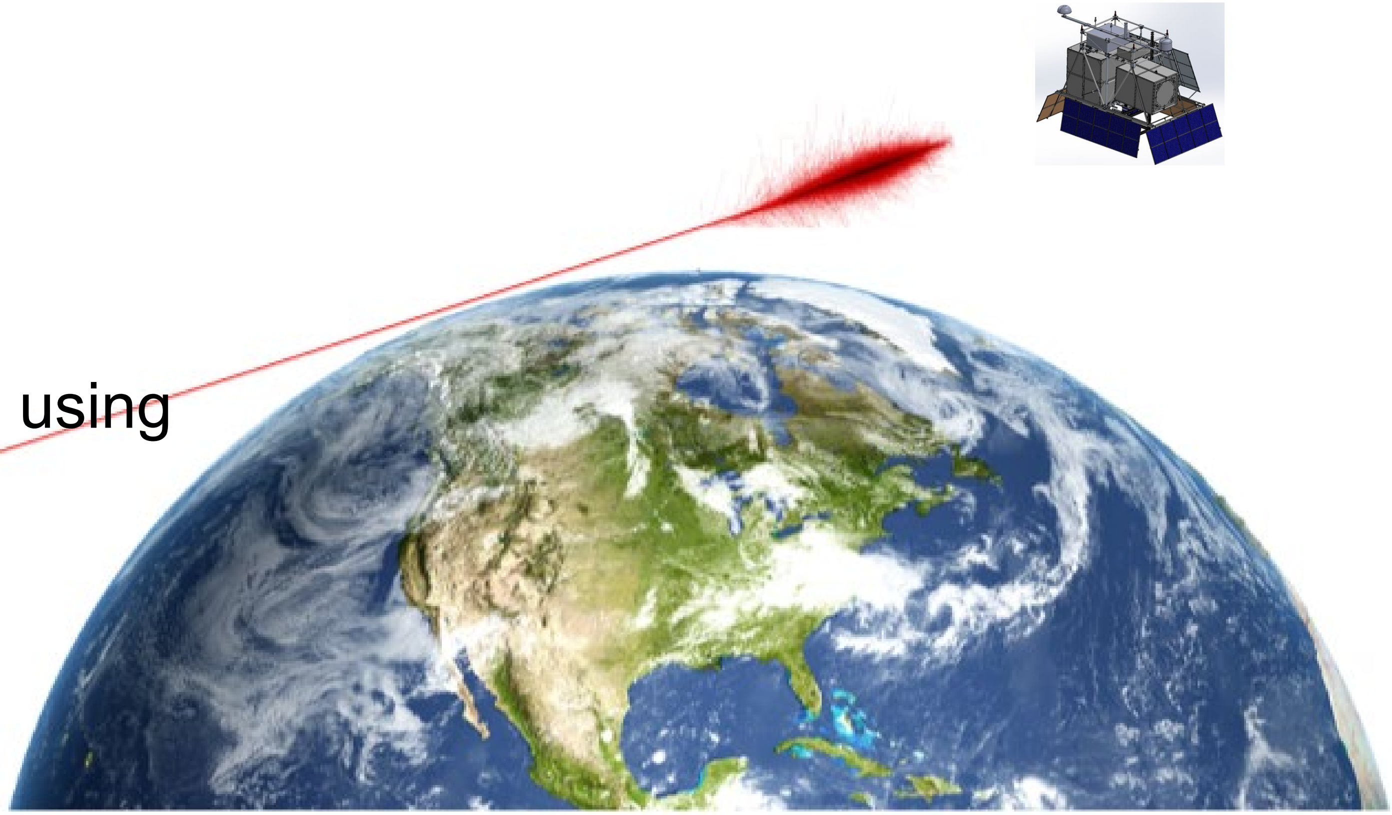
On board pre-selection using Neural Network (~90% accuracy)

Cherenkov Telescope: Direct CR (Method)

- Showers develop at high altitudes
  - 90º zenith: 300g/cm^2

$$E_{thr} = \frac{m}{\sqrt{1 - \frac{1}{n(z)^2}}}$$

- Minimal atmospheric attenuation
  - Aerosols end ~5km
  - Maximal ozone 20-30km
- Full Monte Carlo simulation performed using signals calculated by EASCherSim (Cummings et. al. PRD 2021)

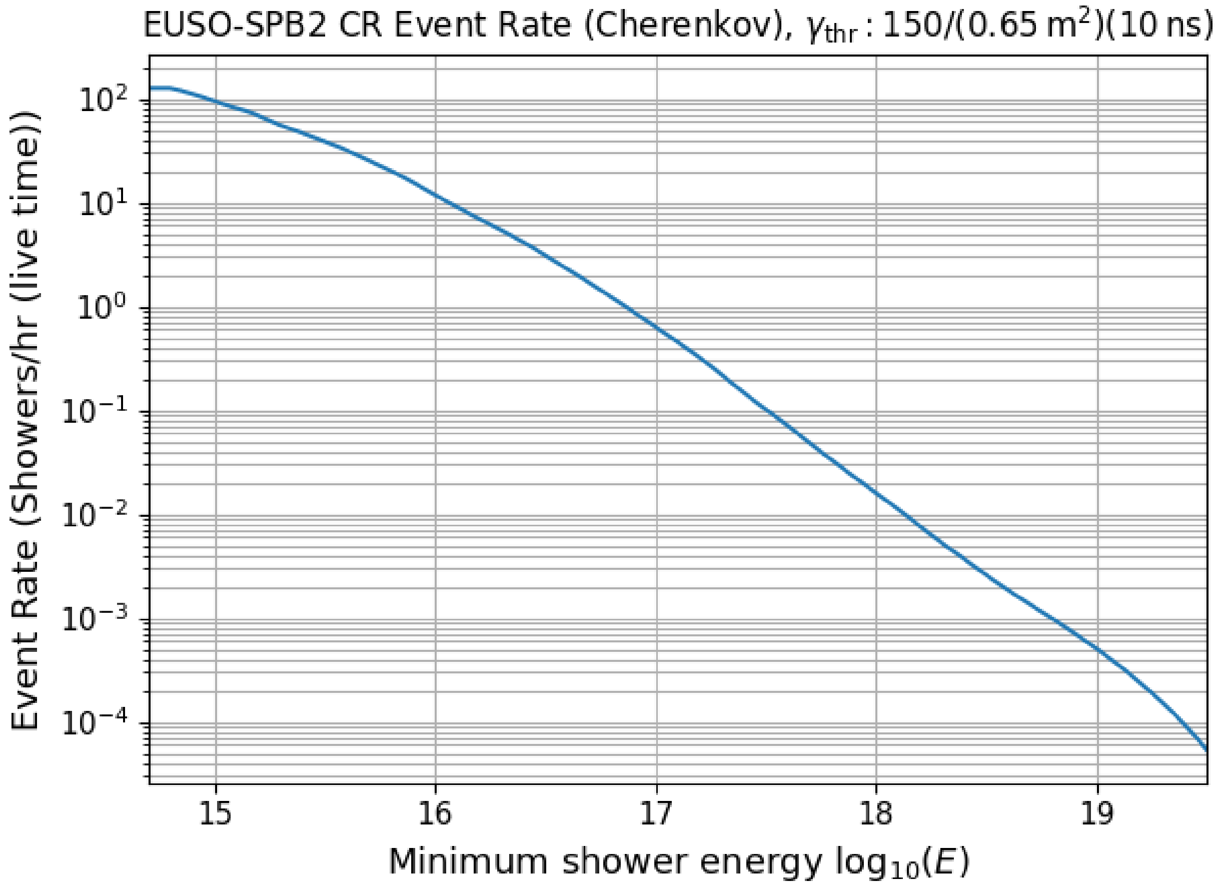


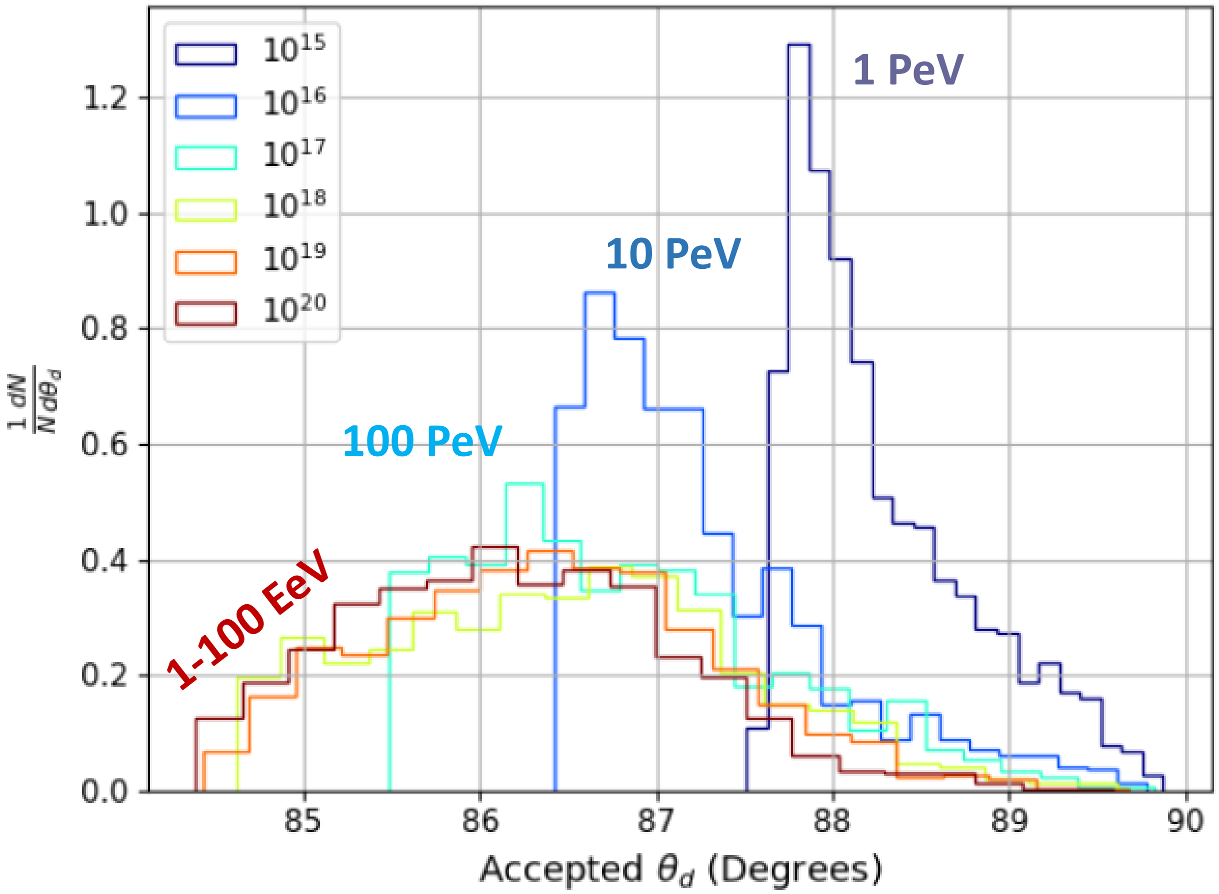
CT Science: Direct CR (Simulation)

- Low energy threshold (~1PeV)
  - Hundreds of events per hour of live time
- Angular acceptance energy dependent
  - High energy events observable near limb

Cummings, Aloiso, Eser, Krizmanic: PRD 104, 063029 (2021)

In situ benchmark for Cherenkov method

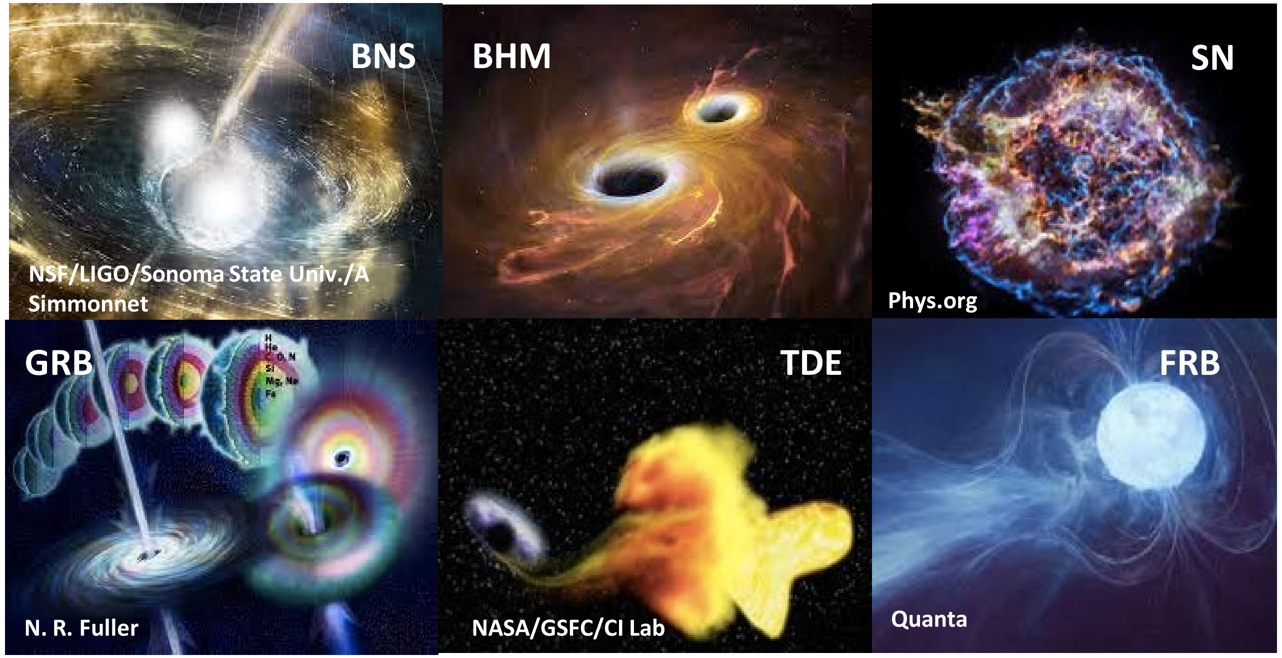




“Below the Limb: the CT measures optical background signals and searches for Cherenkov light from Extensive Air Showers caused by Earth skimming Very-High-Energy (VHE) tau neutrinos (E > 10 PeV) from **transient astrophysical events”**

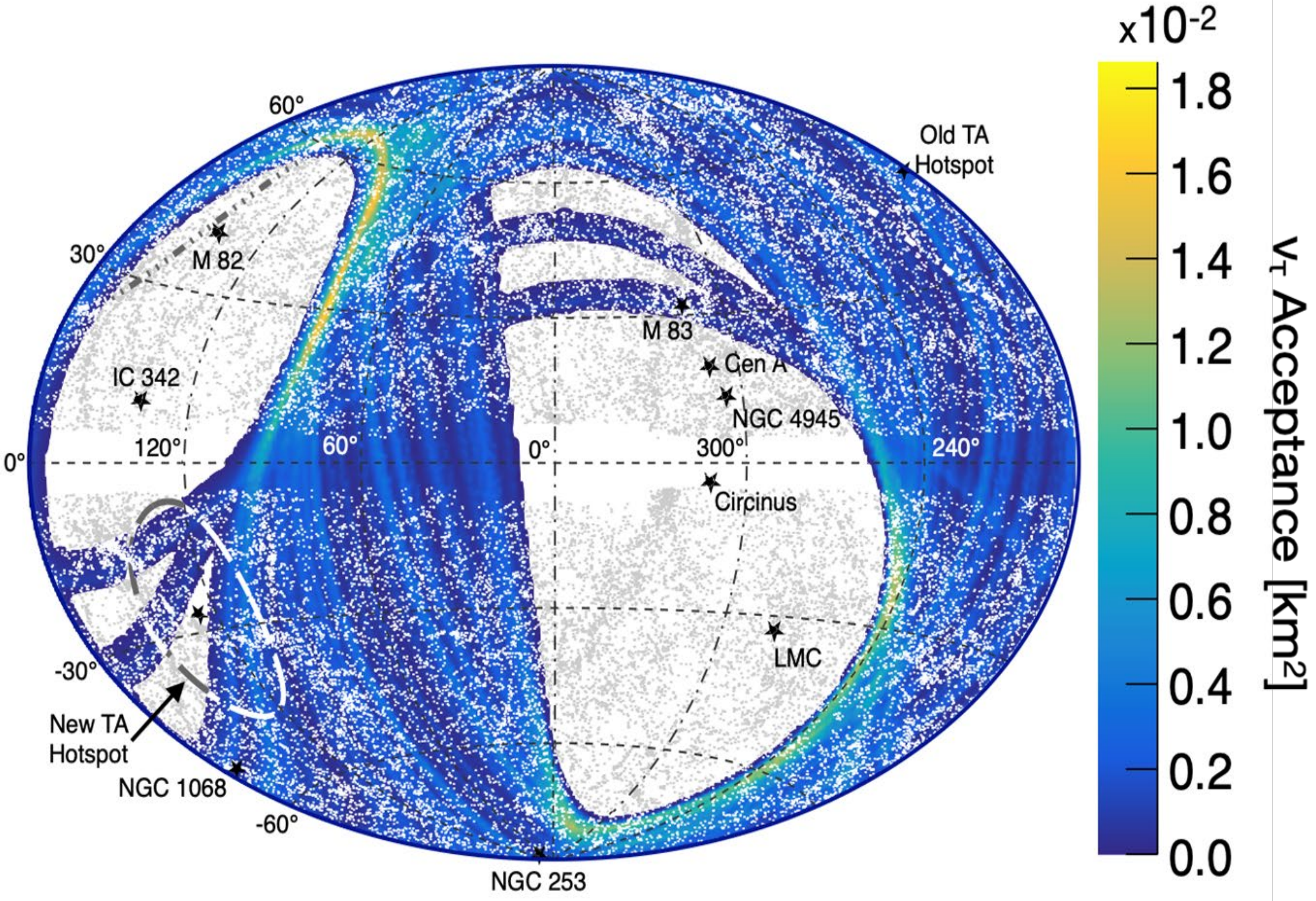
<u>Transient astrophysical events of interest:</u>

- Binary Neutron Star Merger (BNSM)
- Black Hole Merger (BHM)
- Gamma Ray Burst (GRB)
- Tidal Disruption Event (TDE)
- Supernovae
- Blazar Flares
- Fast Radio Bursts (FRB)
- Active Galactic Nuclei



Observing Period O4 for gravitational wave experiments started May 24th, 2023

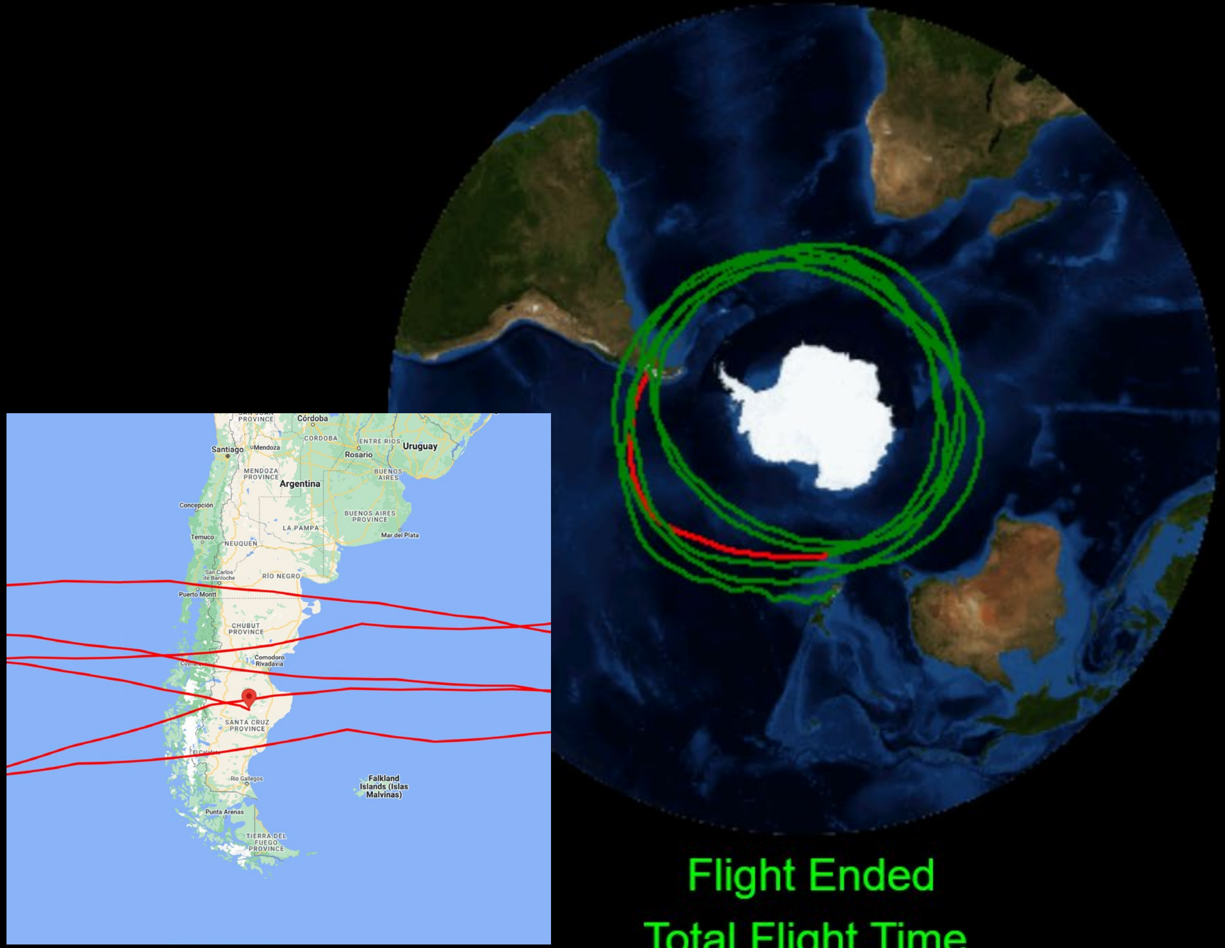
ToO: Acceptance Sky Map (100 day Flight)



May 13th 2023, EUSO-SPB2 Launch, Wanaka NZ

2023 Wanaka, New Zealand
NASA Long Duration Balloon (LDB) Operations

728NT - SN08 - SUPERBIT Balloon Tracking



Flight Ended

Total Flight Time

39 Days 13 hours 35 minutes

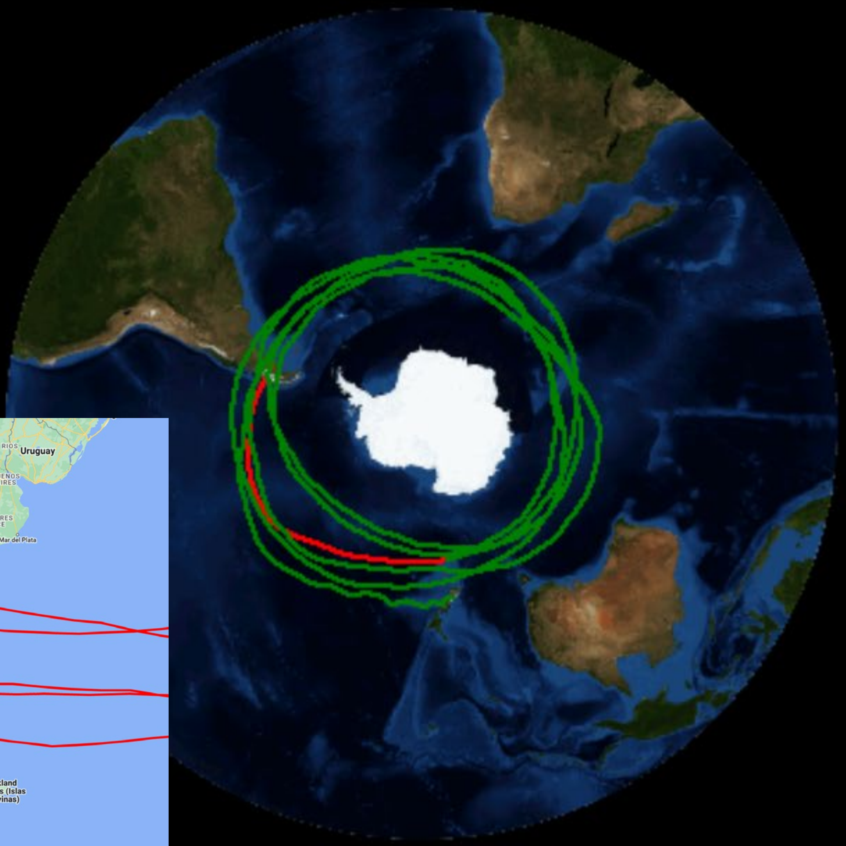
Launched April 15, 2023

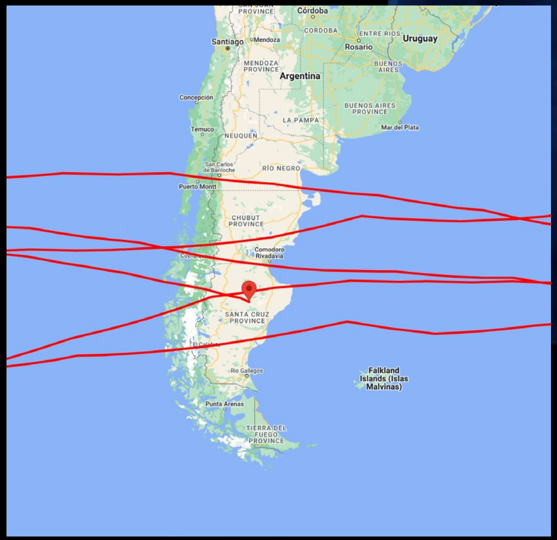
729NT - SN09 - EUSO 2 Balloon Tracking

Launched May 13, 2023

2023 Wanaka, New Zealand
NASA Long Duration Balloon (LDB) Operations

728NT - SN08 - SUPERBIT Balloon Tracking





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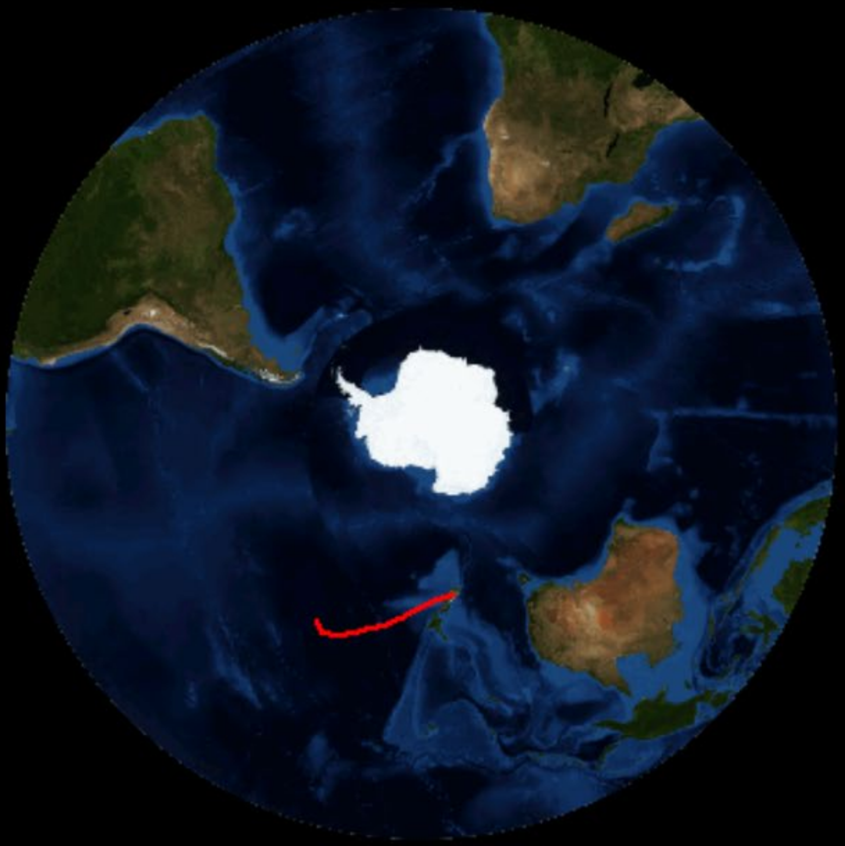


Flight Ended

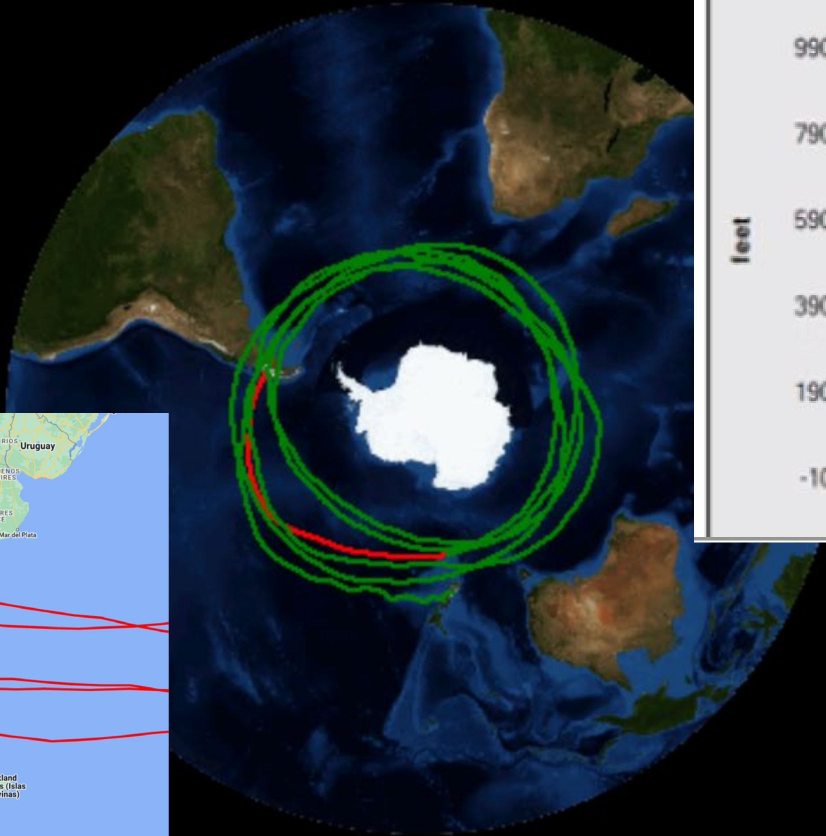
Total Flight Time

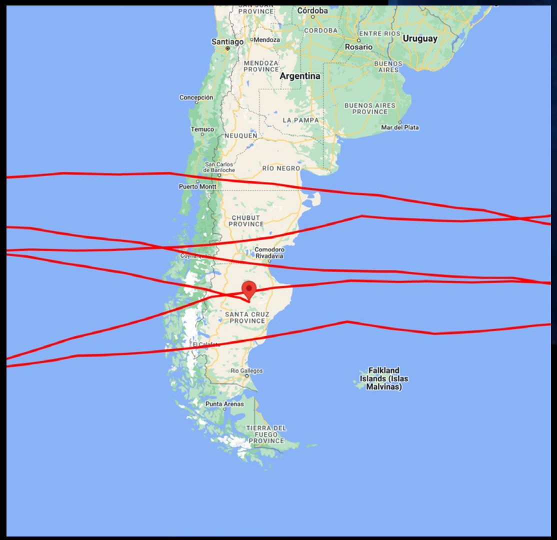
1 day 12 hours 53 minutes

Launched May 13, 2023

2023 Wanaka, New Zealand
NASA Long Duration Balloon (LDB) Operations

728NT - SN08 - SUPERBIT Balloon Tracking





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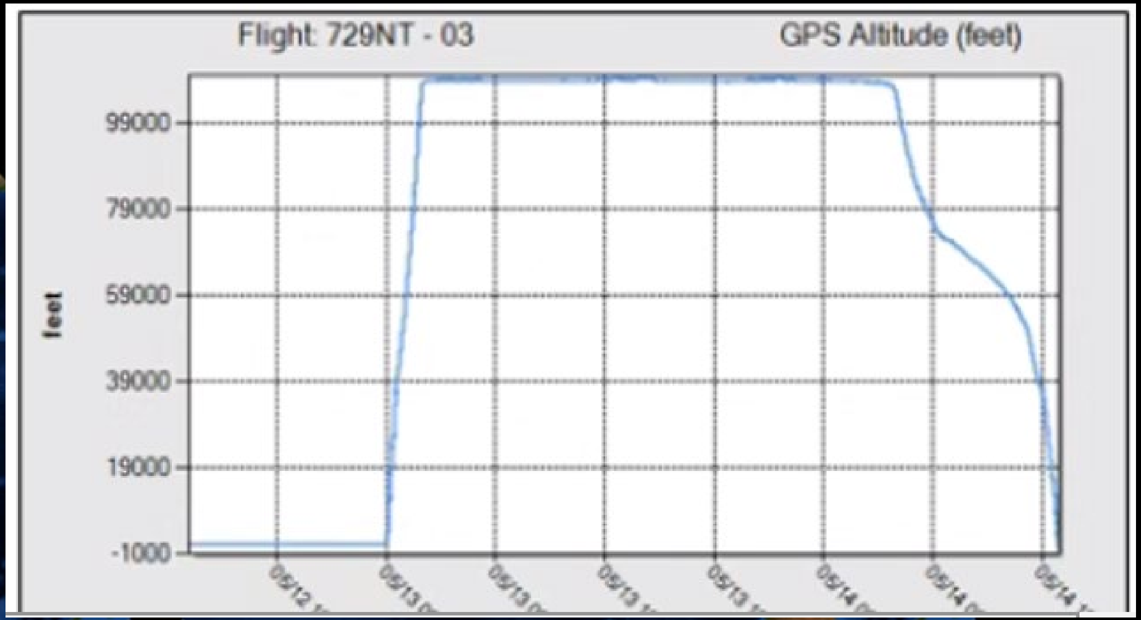

Flight Ended

Total Flight Time

1 day 12 hours 53 minutes

Launched May 13, 2023

However, despite all of this…..

Following 5 years of preparations, science case development, extensive field tests, NASA reviews,
4 stages of payload integration, and hard work, especially by our post-docs, students, technical staff

We delivered an ambitious payload…. on time, on weight, it flew, and it worked

At 5625 lbs, the total mass, including our payload was very close to the 5500 lbs targeted,
we flew 600 lbs ballast as planned (probably gave us a few more hours)
Our solar power system worked at float altitude
Our instruments turned on and worked at float altitude -
Cherenkov Telescope, Fluorescence Telescope, IR Camera, also Shutter/tilt
We collect data with all instruments over two nights with moon down. - 57 GB downloaded

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We were well-prepared to support a long flight and meet our well-developed ambitions science goals
UHECRs, HECRs Backgrounds, Neutrino Searches through Target of Opportunity (ToO)

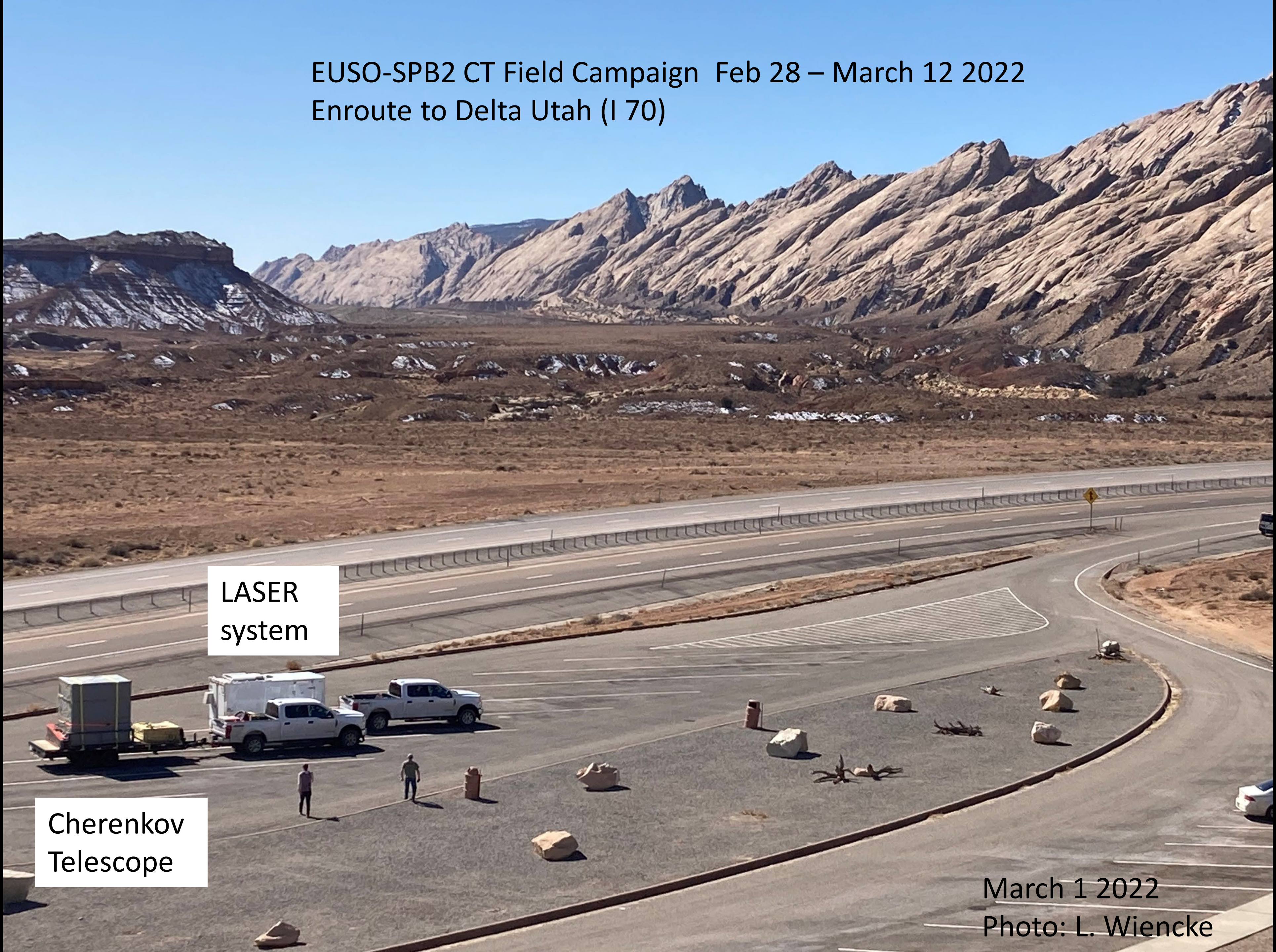
Shifter training performed, documented, shift schedule in place
ToO scheduling in place
System experts had lots of experience with operations
Control/commanding flight software well-tested and working

EUSO-SPB2: 2023 ICRC Presentations

1	oral	Overview and First Results of EUSO-SPB2	Johannes Eser, jeser@uchicago.edu
2	oral	The EUSO-SPB2 Cherenkov Telescope - performance and preliminary results	Eliza Gazda, egazda6@gatech.edu
3	oral	EUSO-SPB2 Fluorescence Telescope in flight performance and preliminary results	George Filippatos, gfilippatos@mines.edu
4	oral	CRs above limb SPB2	Austin Cummings, alc6658@psu.edu
5	poster	Tests and characterisation of the KI trigger: a trigger system for fast events on EUSO-SPB2 Fluorescence Telescope	Hiroko Miyamoto miyamoto@to.infn.it
6	poster	Machine Learning approaches for the EUSO-SPB2 FT	George Filippatos, gfilippatos@mines.edu
7	poster	EUSO-SPB2 Fluorescence Telescope Calibration and Field Tests	Viktoria Kungel, kungel@mines.edu
8	poster	Neutrino Target of Opportunity Sky Coverage and Scheduler for EUSO-SPB2	jonatan-posligua@uiowa.edu
9	poster	Simulating Geomagnetic Effects on Muon-Induced Extensive Air Showers to be measured by the EUSO-SPB2 Mission	Duncan Fuehne, dfuehne@mines.edu
10	poster	Commissioning, Calibration, and Performance of the Cherenkov Telescope on EUSO-SPB2	Oscar Romero, oromero@gatech.edu
11	poster	The Data processor of the SPB2 Fluorescence Telescope: In flight performance	Valentina Scotti, valentina.scotti@na.infn.it
12	poster	ToO Overview	Tobias Heibges, theibges@mines.edu
13	poster	ToO Source Catalog	Hannah Wistrand, hwistrand@mines.edu
14	poster	UCIRC2 IR Camera System	Rebecca Diesing, rrdiesing@uchicago.edu

EUSO-SPB2 Milestones 2022

- Feb/Mar 2022
  - **CT integration at Golden, pack, CT assembly, Field Test @ TA**
- July
  - **Payload integration phase 1** (GCC, Power, FT camera, CT camera, UCIRC)
- Aug/Sept
  - **FT integration at Golden, pack, FT assembly, Field Test @ TA**
- Oct
  - **Payload integration phase 2** with Gondola, full CT, FT, UCIRC, ST
  - **Pack & Load 3 trucks of equipment** for Palestine Tx. NASA's CSBF
- Oct/Nov
  - **Unpack, assemble** telescopes, gondola, Payload at CSBF
  - **Hang tests, Comms & Compatibility Tests, T-Vac (CT camera, ST)**
  - **Take it all apart. Pack for NZ** + export documentation (from hell)
- Dec
  - **3 containers depart from CSBF Palesting Tx for Wanaka Nz**

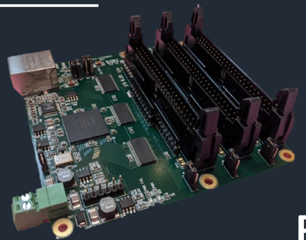


EUSO-SPB2 CT Field Campaign Feb 28 – March 12 2022
Enroute to Delta Utah (I 70)
LASER system
Cherenkov Telescope
March 1 2022
Photo: L. Wiencke

The Cherenkov Camera

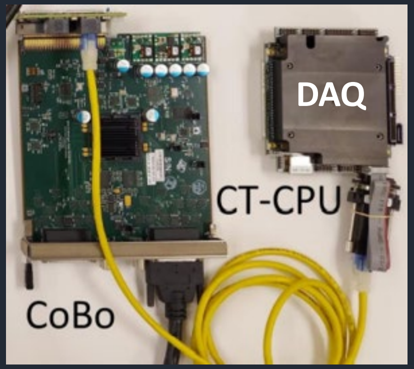
Read-out Electronics

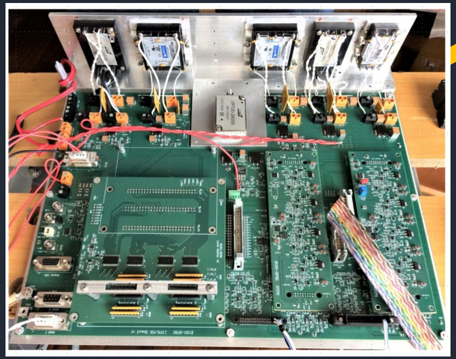
Trigger Board

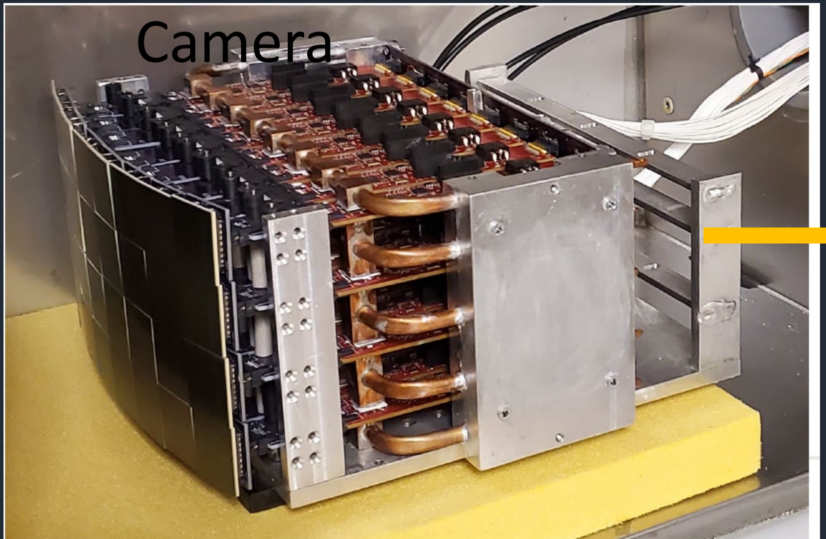


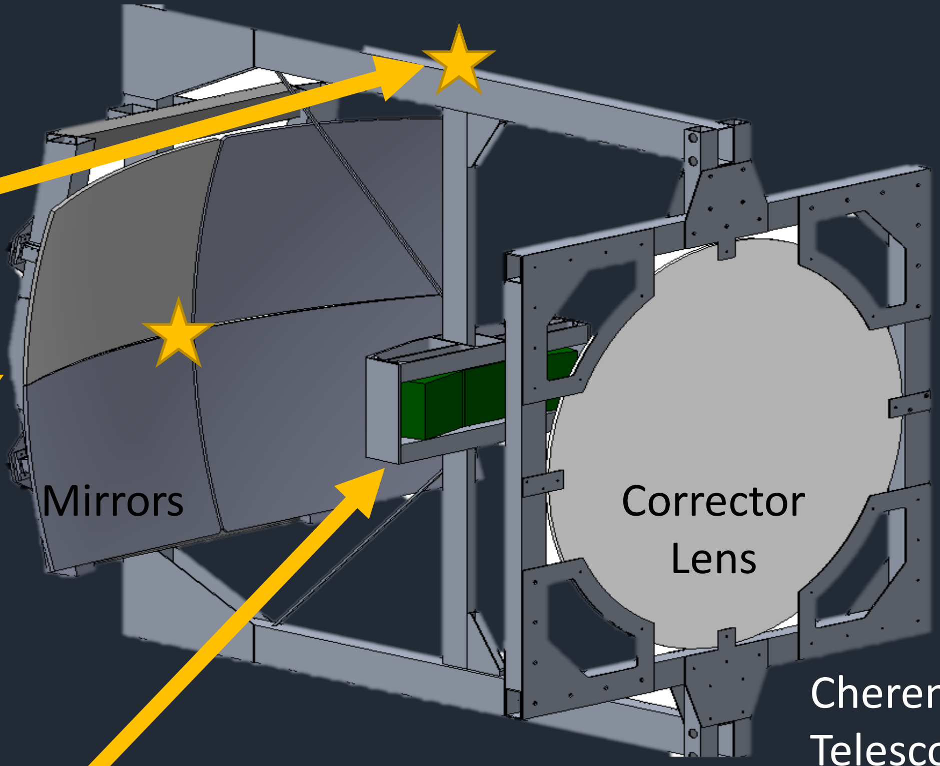
Digitizer Board

Power Module

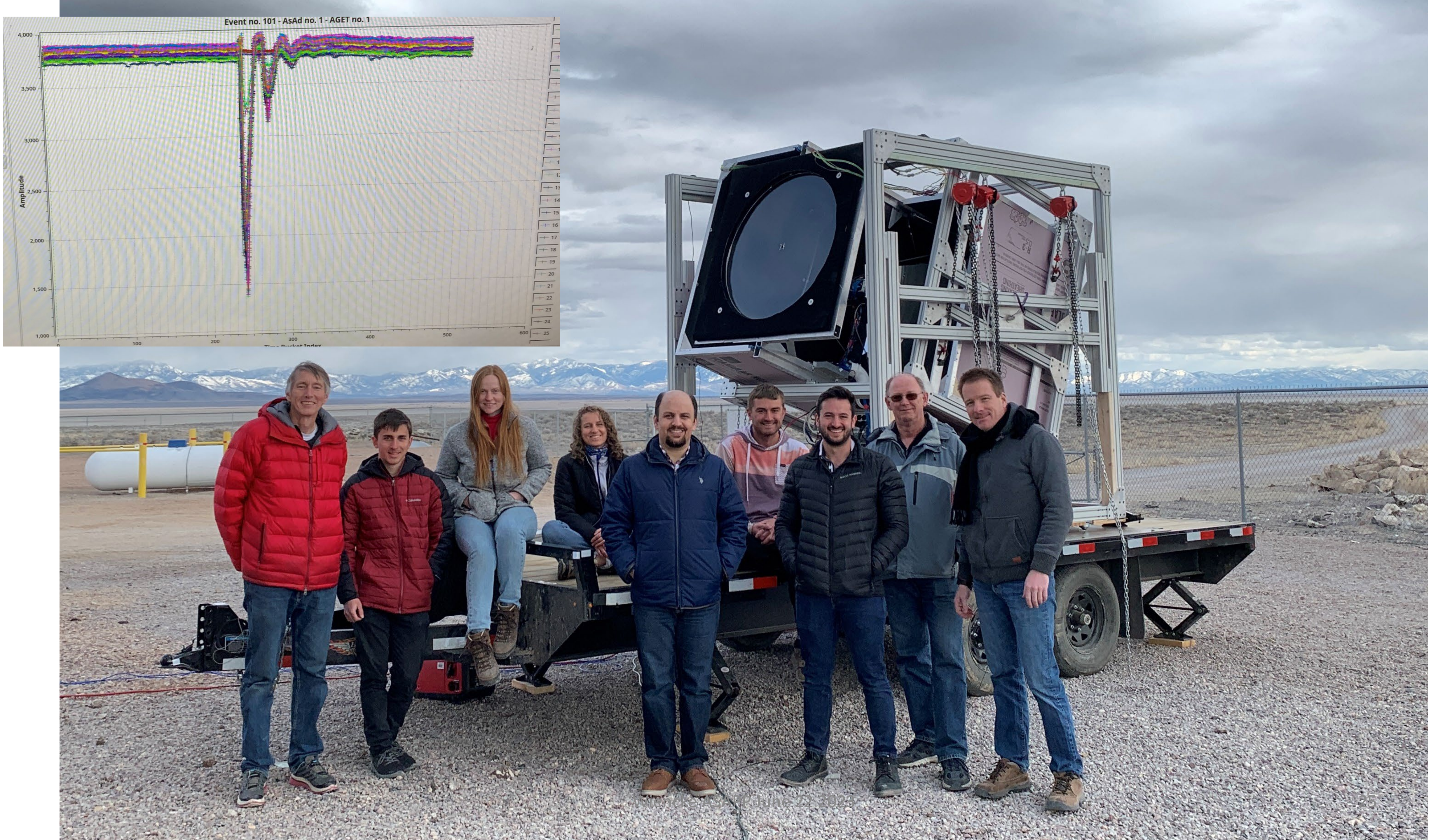




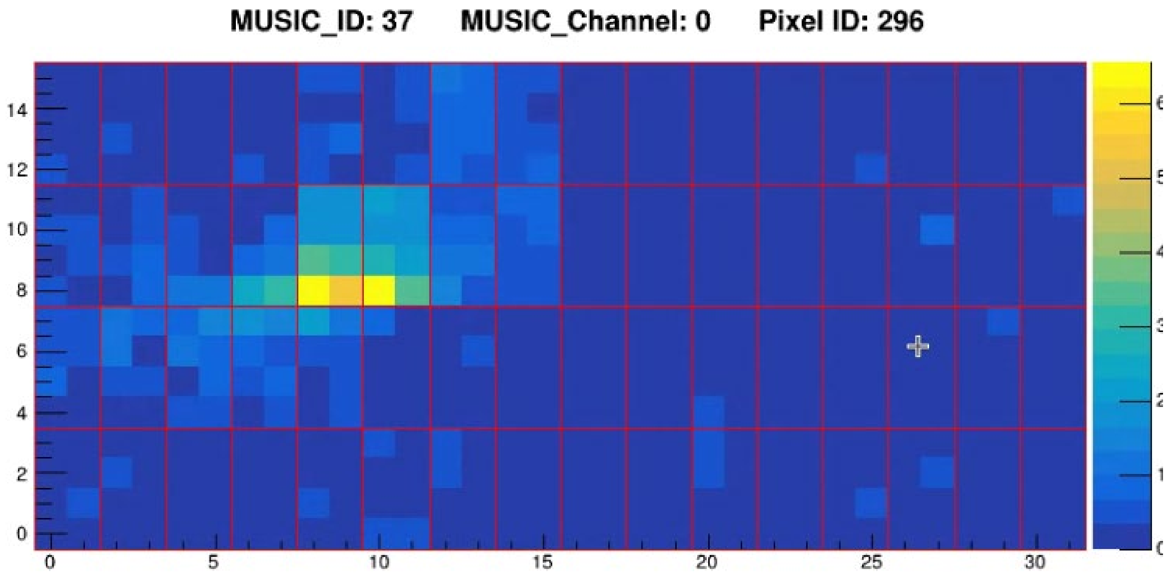


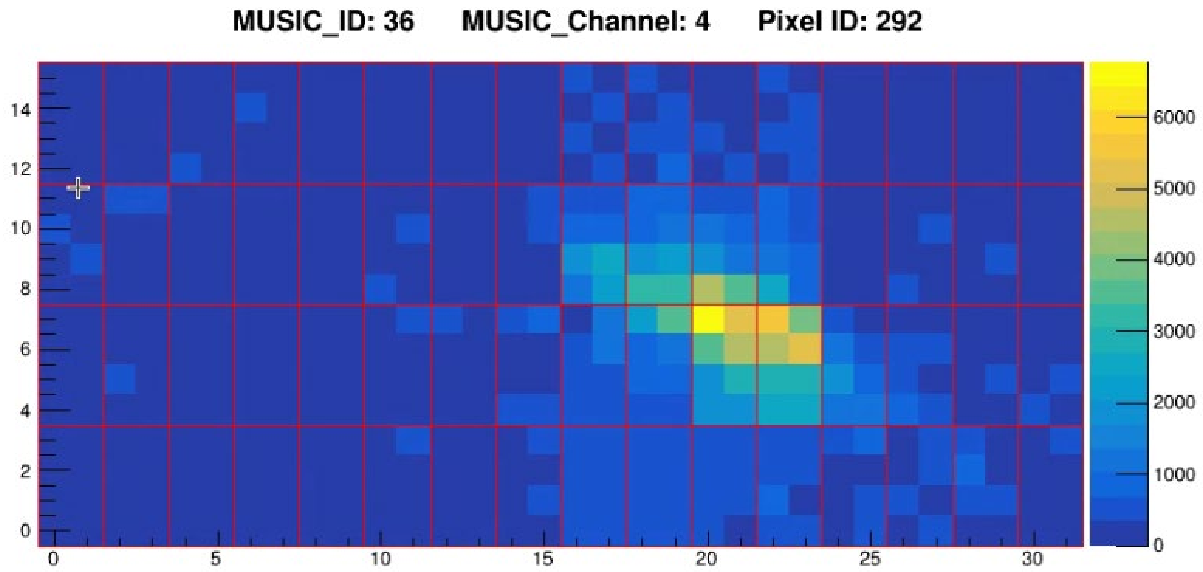


Cherenkov Telescope


Event no. 101 - AsAd no. 1 - AGET no. 1
Amplitude
4,000
3,500
3,000
2,500
2,000
1,500
1,000
100
200
300
400
500
600

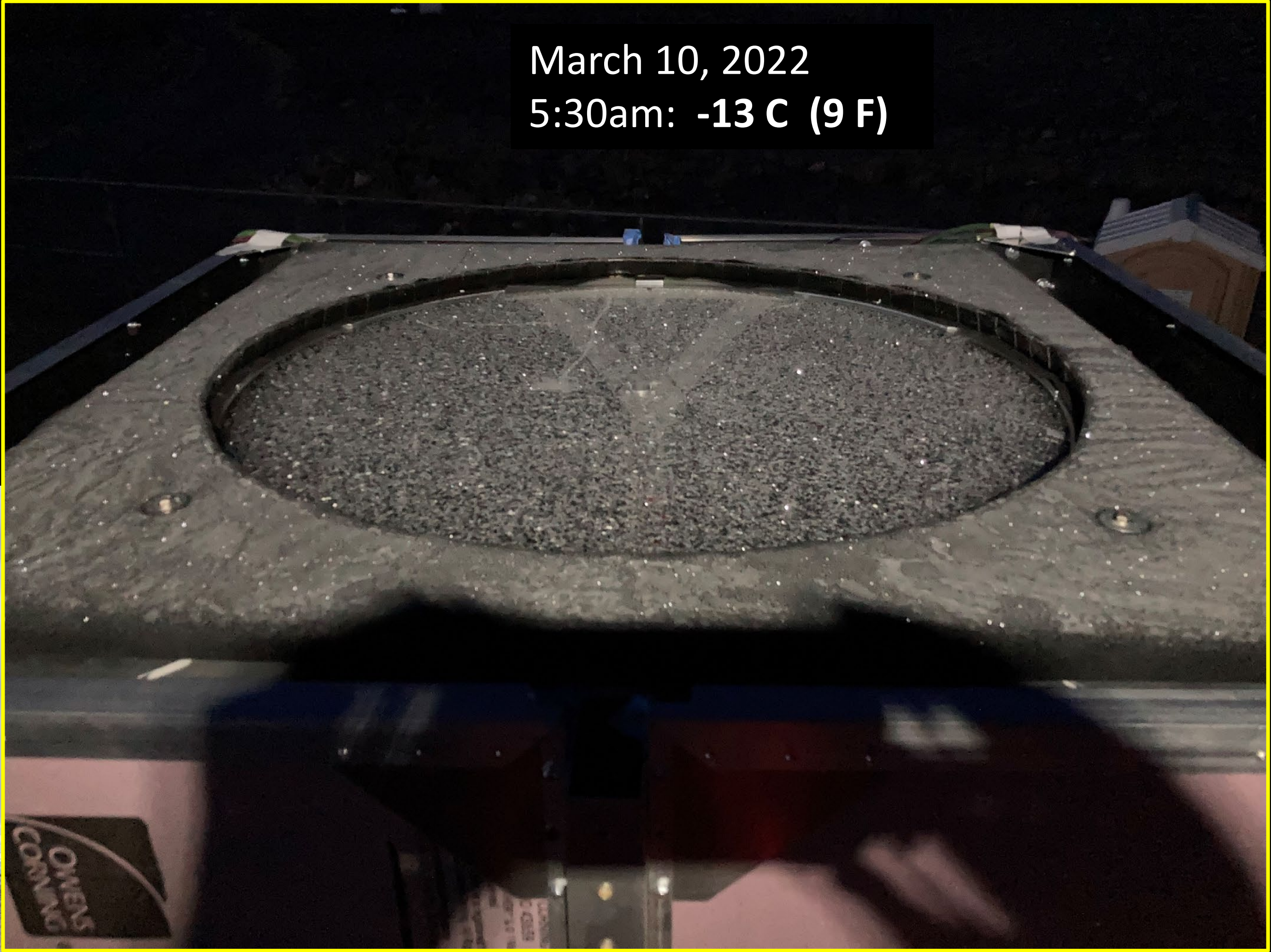
EUSO-SPB2 Field Test March 2022:
2 example **cosmic ray events**: TeV-ish Energy Scale





Yes, there really is frost in the desert.

Real-time data analysis would have caught this.



A clear and very cold night.
We were still seeing some cosmic ray events through the frost.

Lots of data from other nights with no frost.

March 10th 2022 6 am 10F

Detector disassembly and packing

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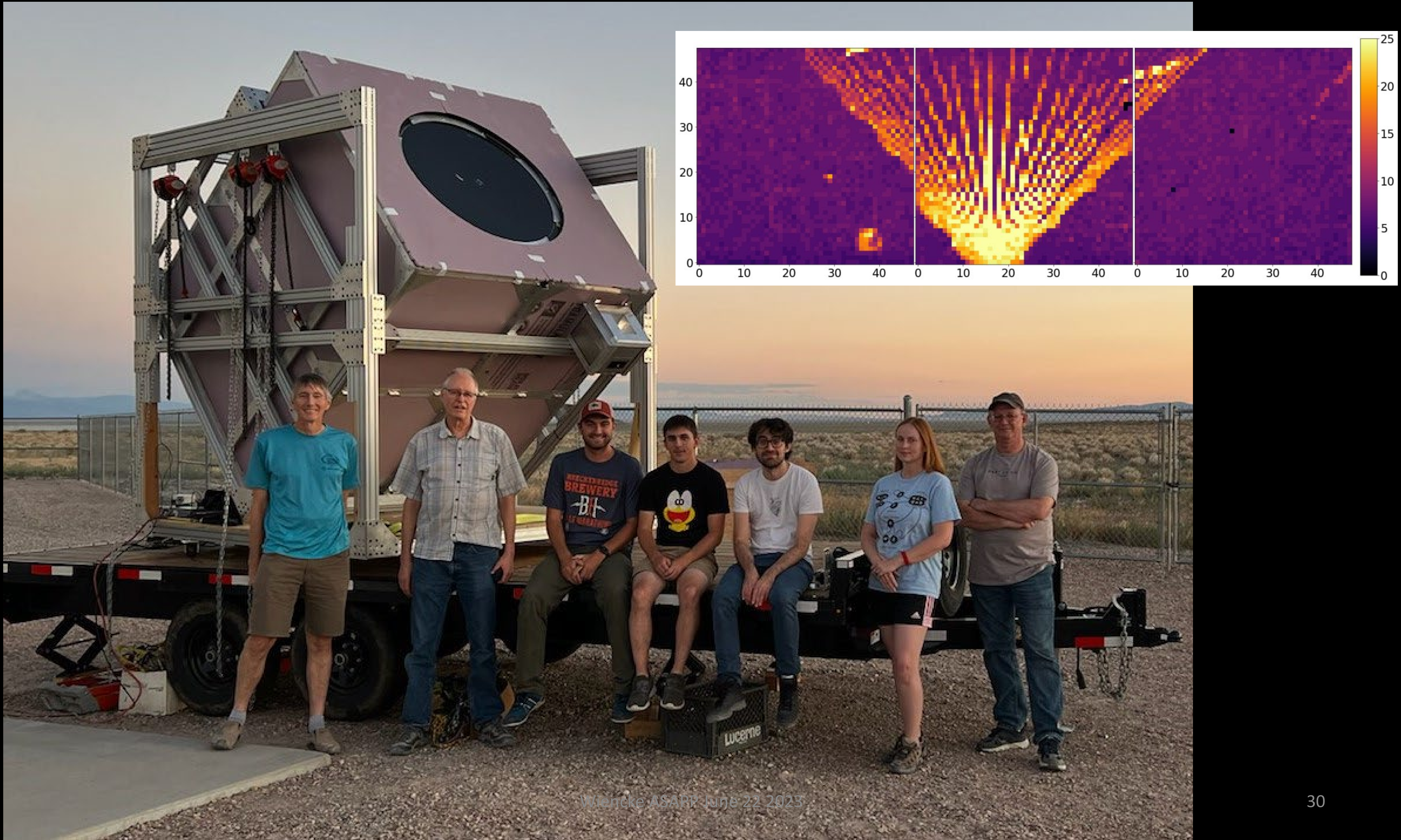
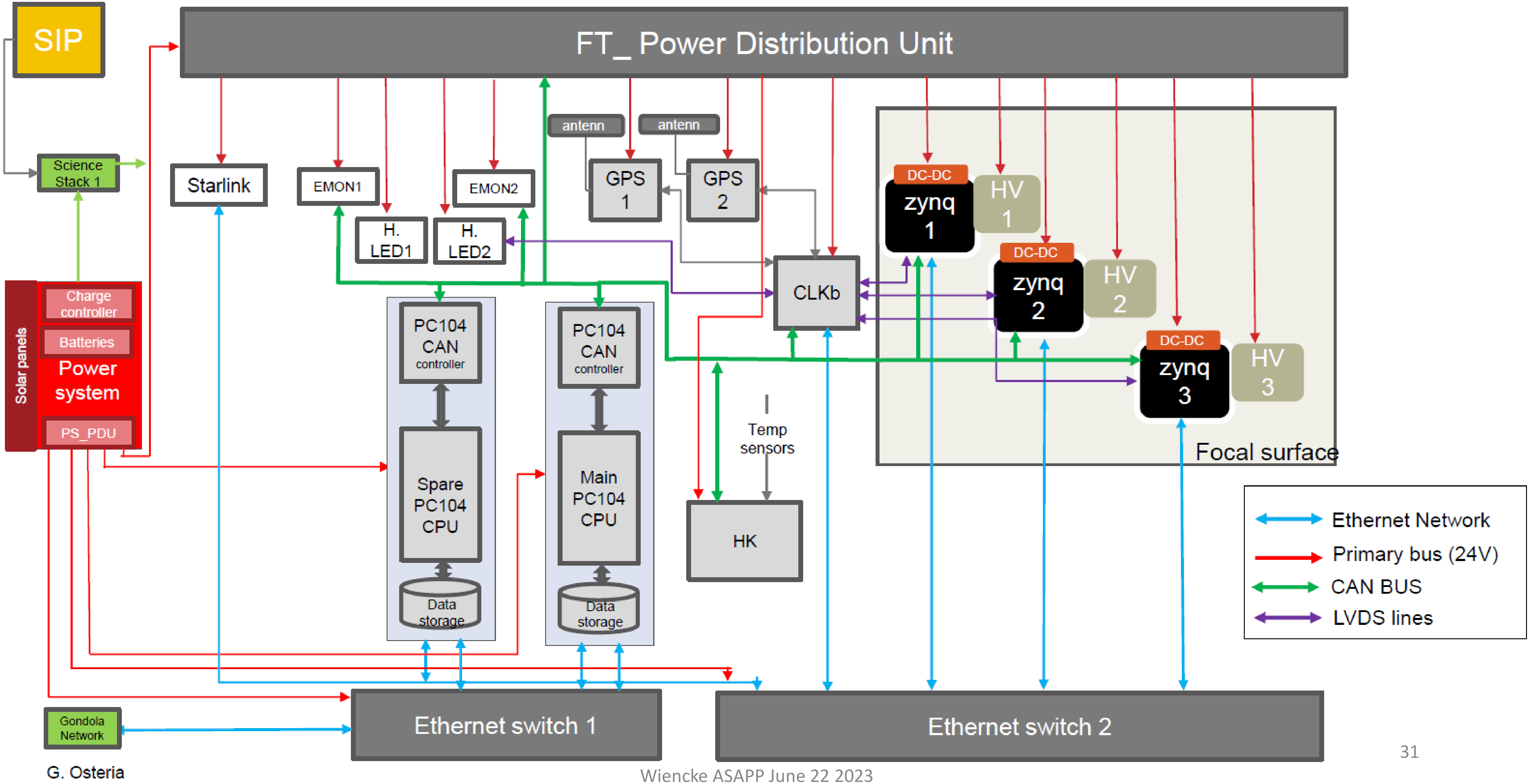
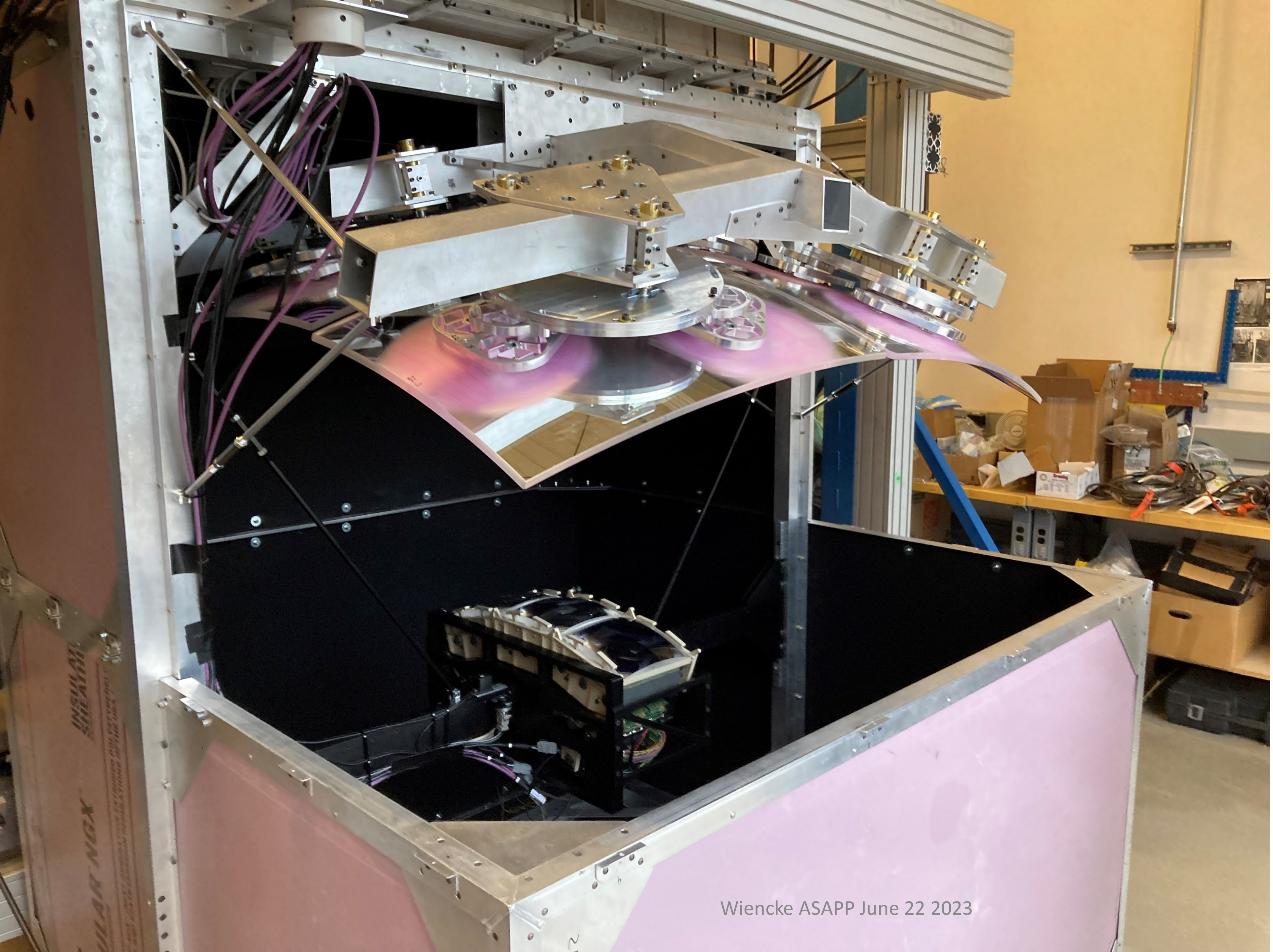

BRECKENRIDGE BREWERY
Lucerne
0 10 20 30 40
0 10 20 30 40
0 10 20 30 40
0 10 20 30 40
0 5 10 15 20 25

FT ARCHITECTURE AND DP





EUSO-SPB2 Fluorescence Telescope Field Test Analysis for Flat-Fielding

Patrick Sternberg, Advisors: Dr. Lawrence Wiencke, George Filippatos, and Dr. Viktoria Kungel

COLORADOSCHOOLOFMINES

Objective

Instruments aboard the Extreme Universe Space Observatory on a Super Pressure Balloon 2 (EUSO-SPB2) search for signatures from ultra-high energy cosmic rays (UHECRs) and tau neutrinos. Interaction between the Earth's atmosphere and UHECRs produce faint light sources that are detected using a fluorescence telescope. A field test in the Utah desert studied limitations of this instrument and the impacts of known light sources. This analysis focuses on the data collected when the telescope was orientated vertically upwards and rotated in azimuth while a laser pulsed overhead, Fig. 1. A virtual flat field characterized and removed events to study instrument limitations.

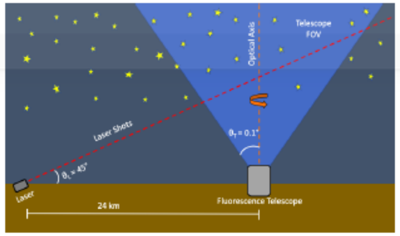


Figure 1: Sketch of the September 1st field test geometry. A full rotation would ensure laser light across the entire focal surface.

Data Structure and Triggering Events

The ROOT data analysis framework recorded and stored events. When an event triggers the telescope, it records 64 frames, or gate time units (GTU), before and after the event. The field test data contained 2094 events. To remove triggering events, the center twenty GTU were removed.

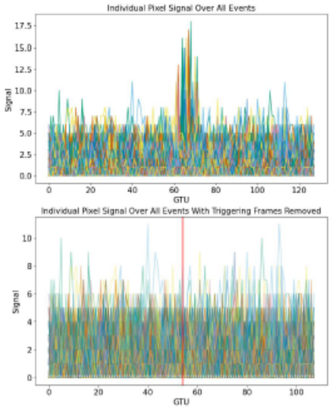


Figure 2: An individual pixel that observed a laser pulse showed that the laser events occurred in the center of the 128 GTU. Removing the center 20 frames deleted the triggering events by accounting for data structure variations.

Results

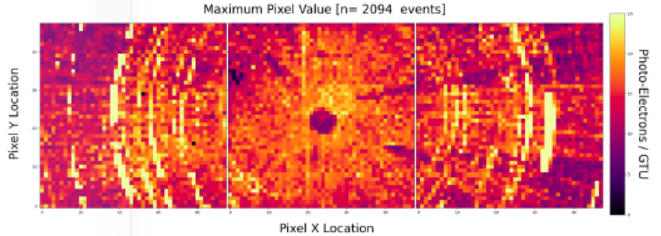


Figure 3: Maximum pixel value observed over a full rotation. Star light caused the brightest pixel values while laser light covered most of the field of view.

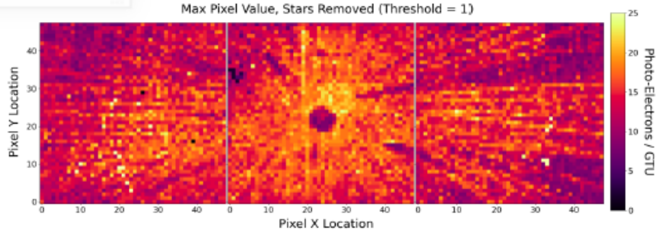


Figure 4: The star deletion code swept over each pixel for consistently high signals. The most success occurred with a scanning threshold of 1 photo-electron/GTU.

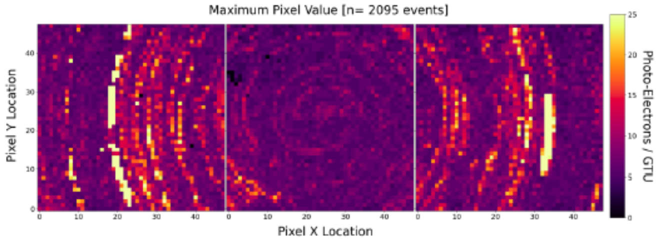


Figure 5: The center 20 frames containing triggering events were removed to observe stars clearly.

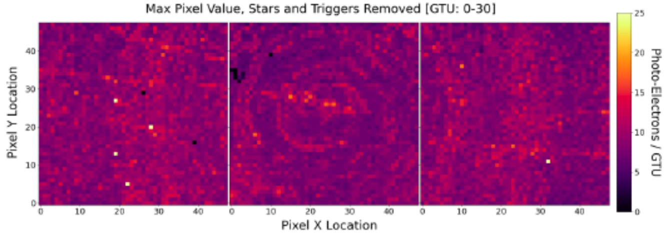


Figure 6: In the virtual flat-field, distant star light and a few remaining laser shots are still visible. Only the first 30 GTU of the data set were considered to reduce data structure complexity.

Flat-Fielding

The mean and standard deviation without stars or laser tracks present provided information on pixel behavior in the absence of light sources. For each event, only the first 30 GTU were included.

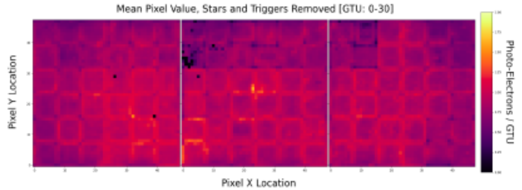


Figure 7: Mean plot with triggering events and stars removed. Note the visibility of the photomultiplier tube geometry.

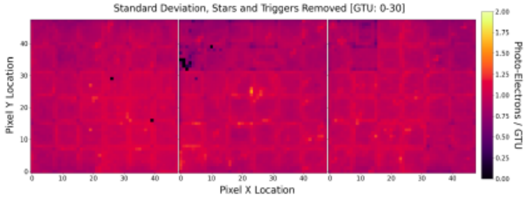


Figure 8: Standard deviation with triggering events and stars removed. Low variability in photon count data was observed.

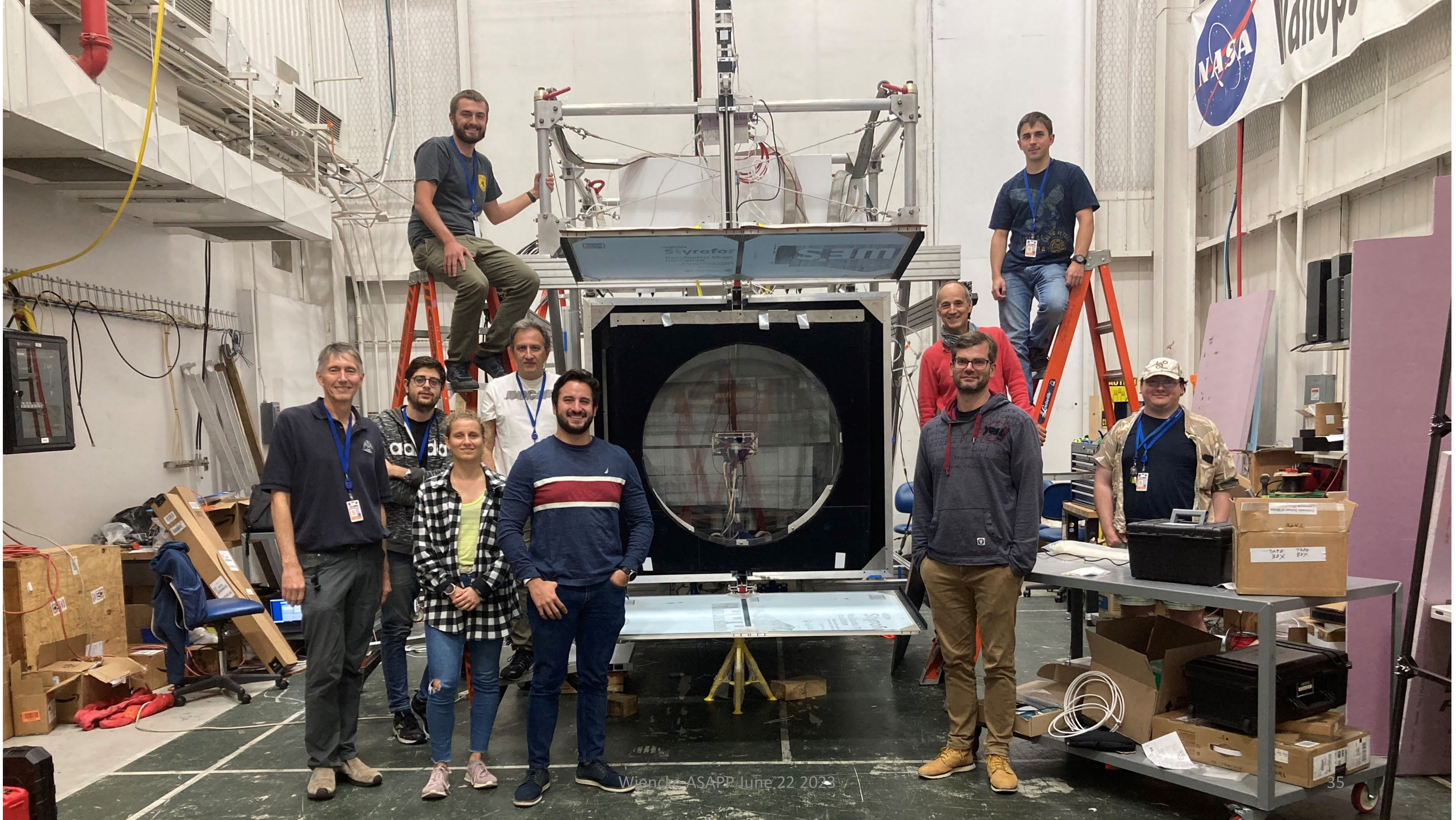
Conclusion

The virtual flat fielding techniques were effective in removing laser events and distant star light. The top third of the telescope's field of view appeared consistently darker which implied wiring or electronic differences. Individual photomultiplier geometry was observed when plotting pixel mean, Fig. 7, and standard deviation, Fig. 8. These highlighted differences in photo-electrons/GTU values across pixels. Known variations and the ability to remove consistently bright light sources aids in understanding UHECR events during EUSO-SPB2's flight. Future analysis of flight data will utilize virtual flat-fielding techniques to single out and study UHECR events.

Figure 9: EUSO-SPB2 payload assembled in Wanaka, New Zealand prior to its launch in Spring, 2023.

EUSO-SPB2 Milestones 2022

- Feb/Mar 2022
  - **CT integration at Golden, pack, CT assembly, Field Test @ TA**
- July
  - **Payload integration phase 1** (GCC, Power, FT camera, CT camera, UCIRC)
- Aug/Sept
  - **FT integration at Golden, pack, FT assembly, Field Test @ TA**
- Oct
  - **Payload integration phase 2** with Gondola, full CT, FT, UCIRC, ST
  - **Pack & Load 3 trucks of equipment** for Palestine Tx. NASA's CSBF
- Oct/Nov
  - **Unpack, assemble** telescopes, gondola, Payload at CSBF
  - **Hang tests, Comms & Compatibility Tests, T-Vac (CT camera, ST)**
  - **Take it all apart. Pack for NZ** + export documentation (from hell)
- Dec
  - **3 containers depart from CSBF Palesting Tx for Wanaka Nz**


NASA
Styrofoam

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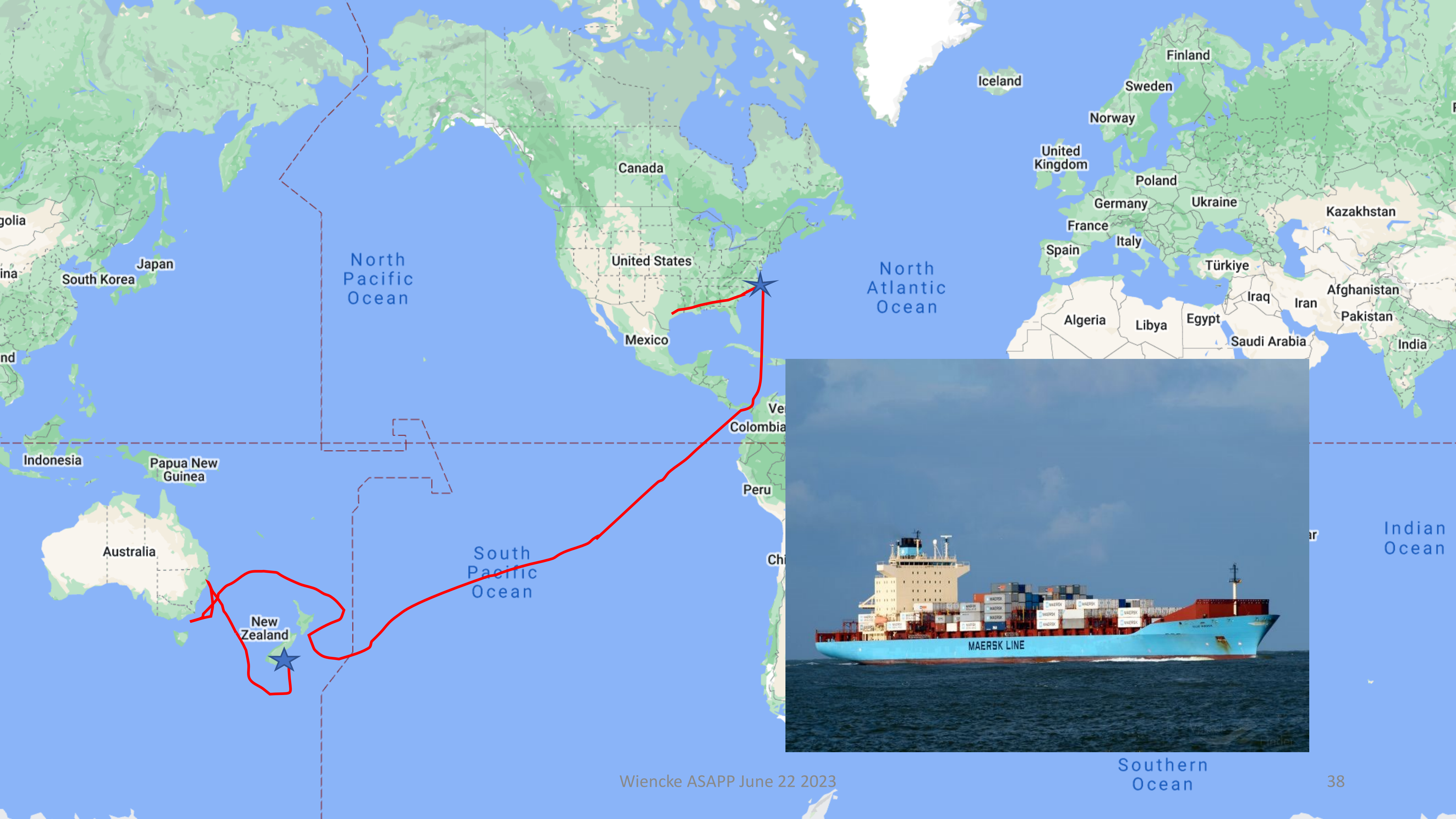
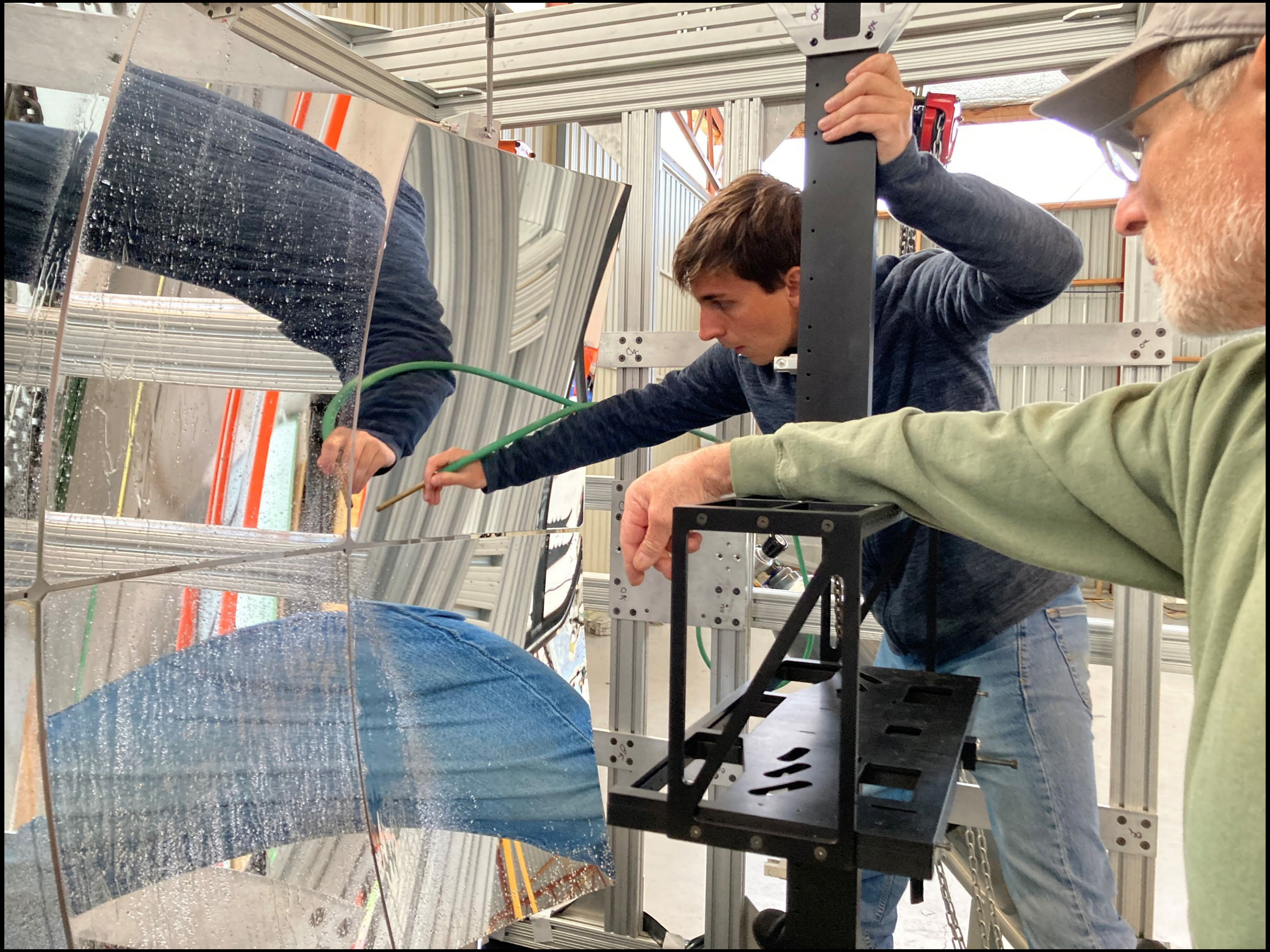
EUSO-SPB2 Shipping Containers (packed)
Columbia Scientific Balloon Facility, Palestine Tx, Nov 20 2022


Finland
Iceland
Sweden
Norway
United Kingdom
Poland
Canada
Germany
Ukraine
Kazakhstan
France
Italy
Spain
Türkiye
golia
Japan
South Korea
North Pacific Ocean
United States
North Atlantic Ocean
Iraq
Iran
Afghanistan
Pakistan
Algeria
Libya
Egypt
Saudi Arabia
India
Mexico
Colombia
Indonesia
Papua New Guinea
Peru
Australia
South Pacific Ocean
New Zealand
Indian Ocean
Southern Ocean
MAERSK LINE

EUSO-SPB2 Milestones

- Feb 12
  - **Containers reach Wanaka NZ**
- Feb, March,
  - Reassemble Gondola and gound support mechanical
  - Clean optics, reassemble Telescope opto-mechanical
  - March 18th
    - Visit by NASA Administrator Bill Nelson
  - Data collected with FT and CT outside hanger and pointed same direction
- April
  - April 2nd Telescopes installed in Gondola
  - April 3rd V. Kungel defends PhD Thesis –First for EUSO-SPB2
  - Payload declared flight ready, following flight readiness review (April 29th)
- May 13th 2023 Launch
  - 3rd attempt, limited by trajectory safety analysis numbers

EUSO-SPB2 Wanaka NZ




THIS SIDE UP FRAGILE
HUSKY
003
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Wiencke ASAPP June 22 2023

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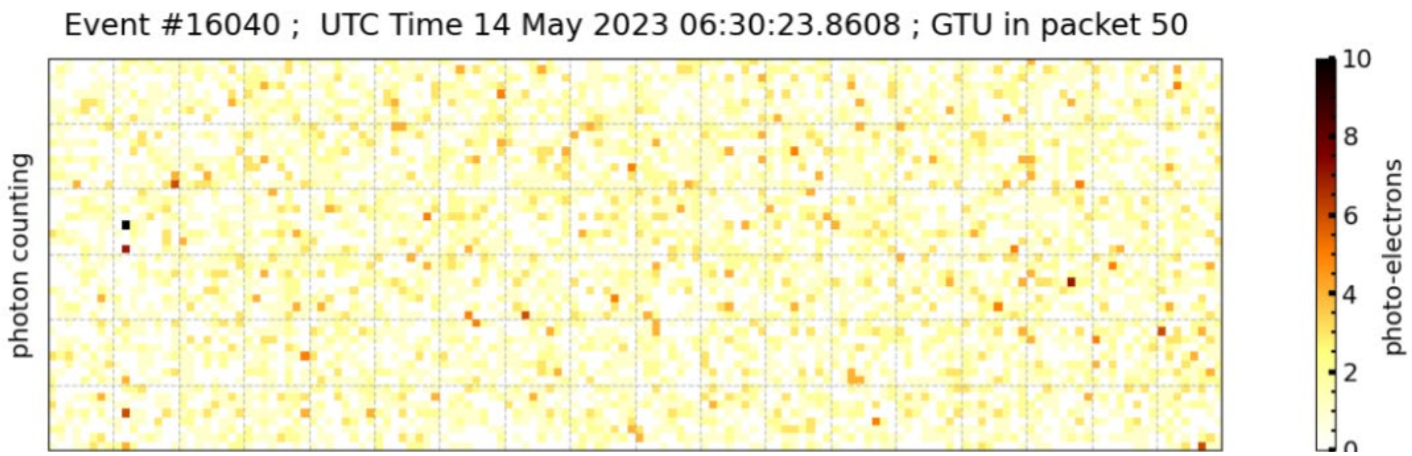
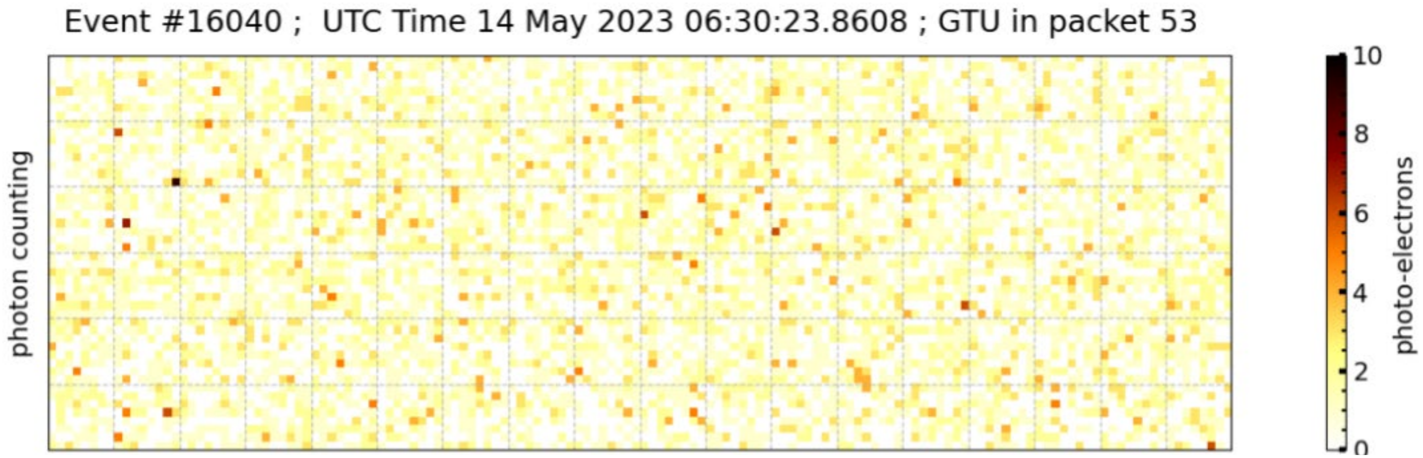
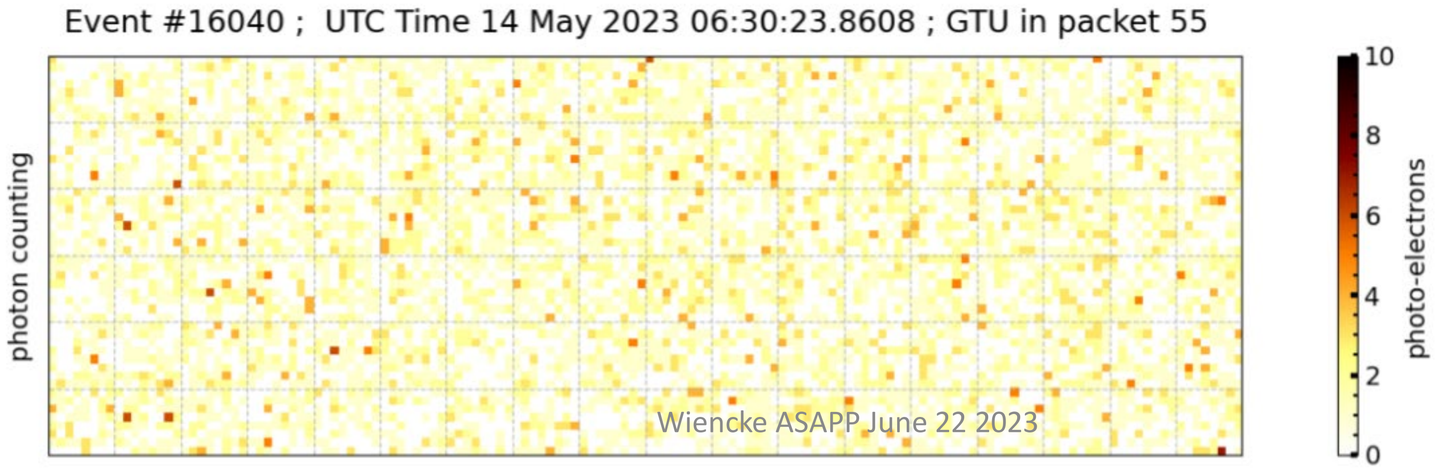
2am May 12 2023,
Wanaka NZ





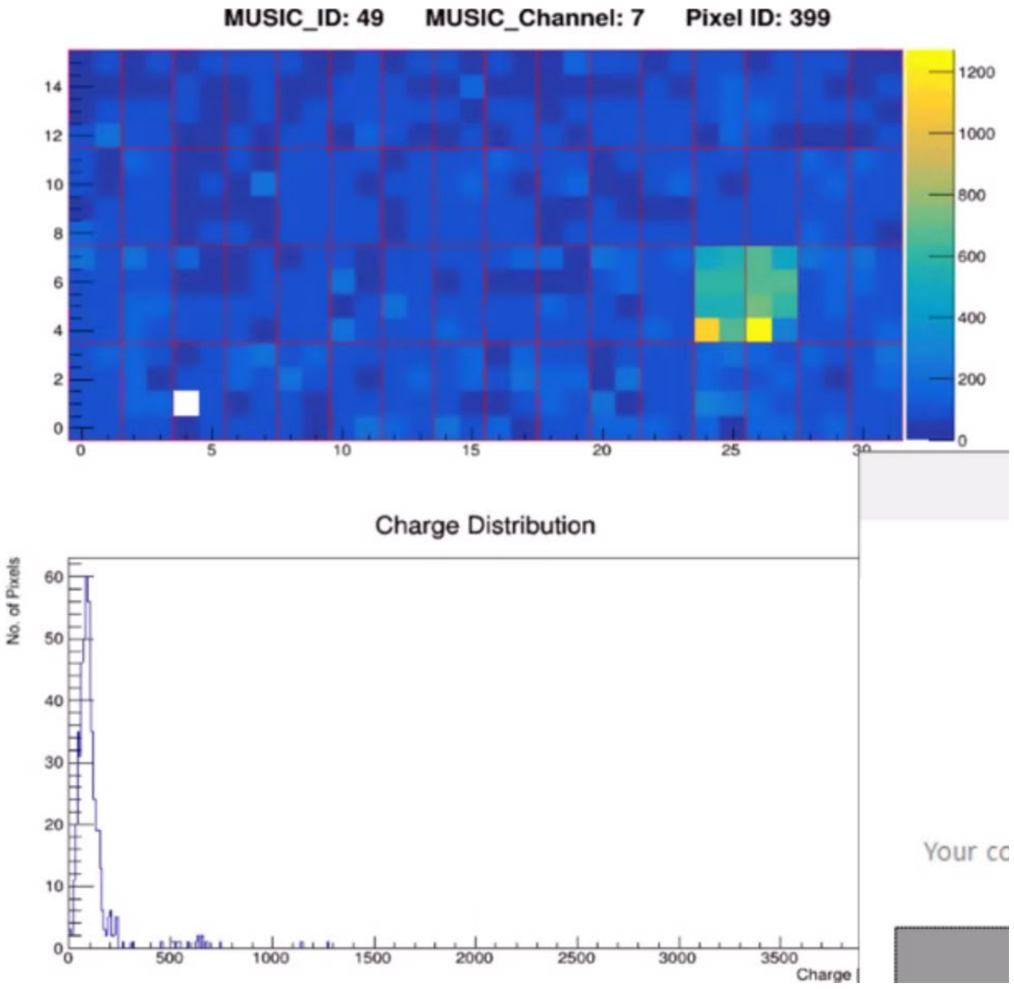


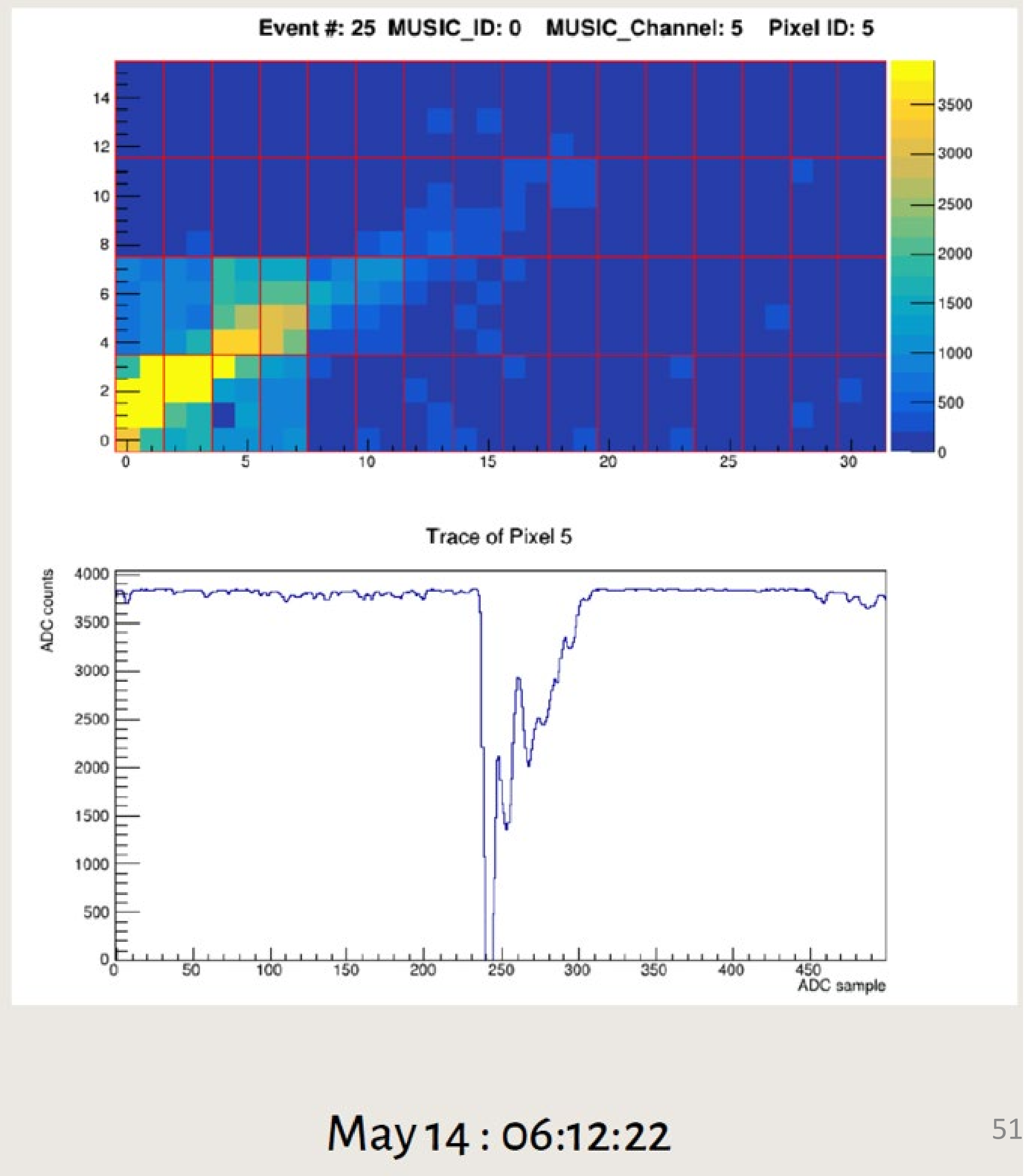
FT example data

6912 photon-counting channels working

Searches for EeV cosmic ray events in progress

PeV Cosmic Ray Candidate Triggers
Recorded by the Cherenkov Telescope looking above the limb

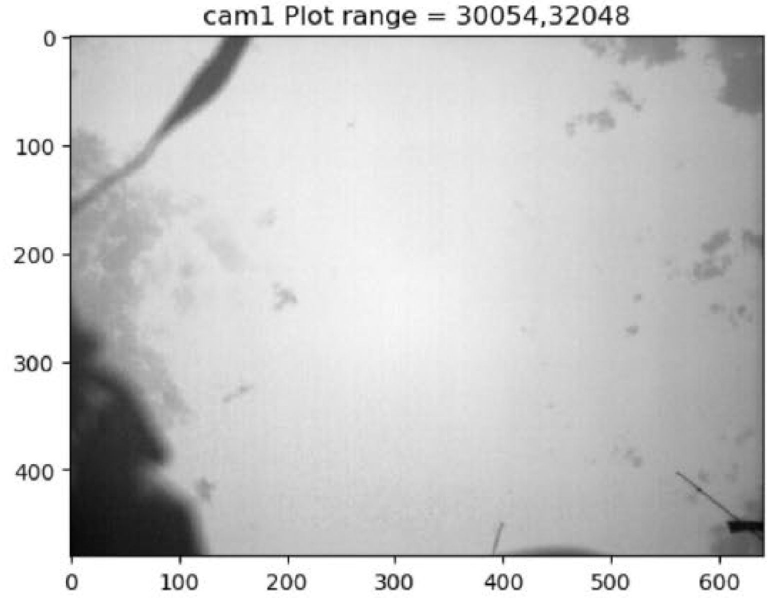


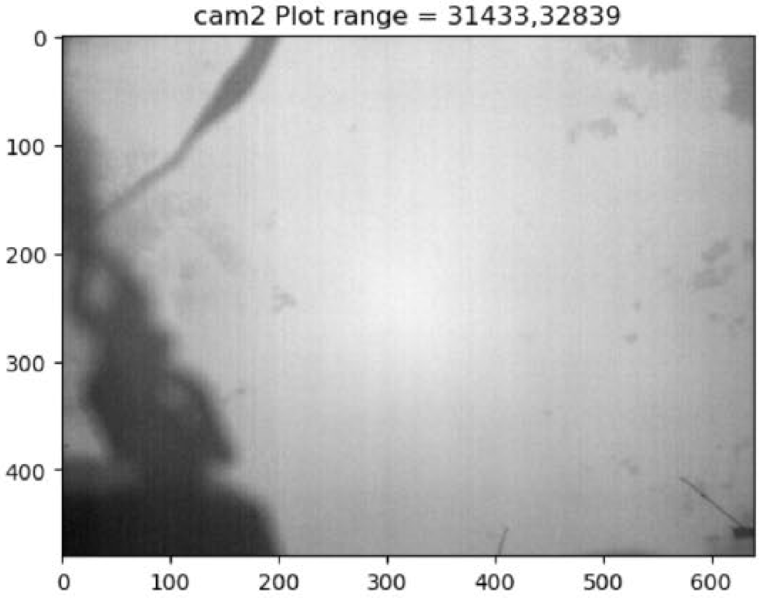


Example Data from our IR Camera System
Points Nadir to measure cloud top height

Camera 1 Camera 2

Raw image



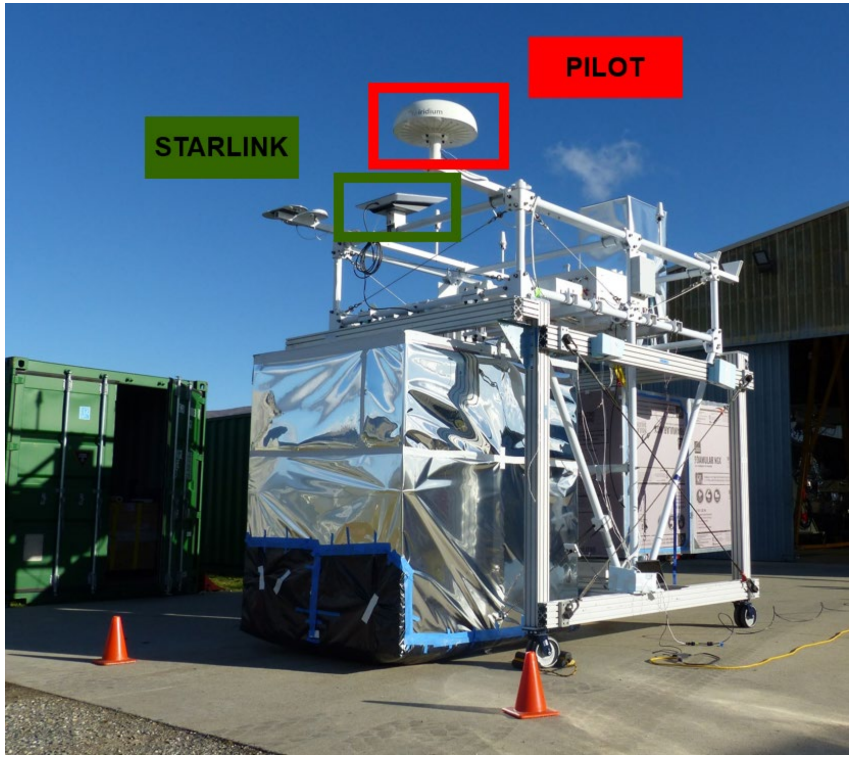


For balloon experiments, Starlink will likely be transformational

EUSO-SPB2 Data Downloaded
May 13,14 2023

TDRSS:	**StarLink:**
CT: 168	CT: 16,506
FT: 302	FT: 40,441
IR: 61	IR: 450
Total: 531MB	Total: 57,397MB

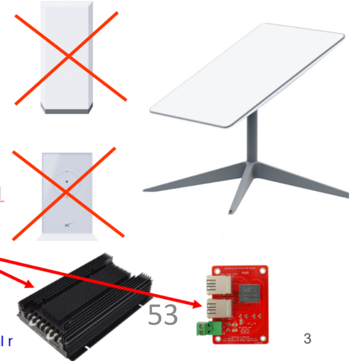
EUSO and SuperBIT each received a unit in Wanaka as a test



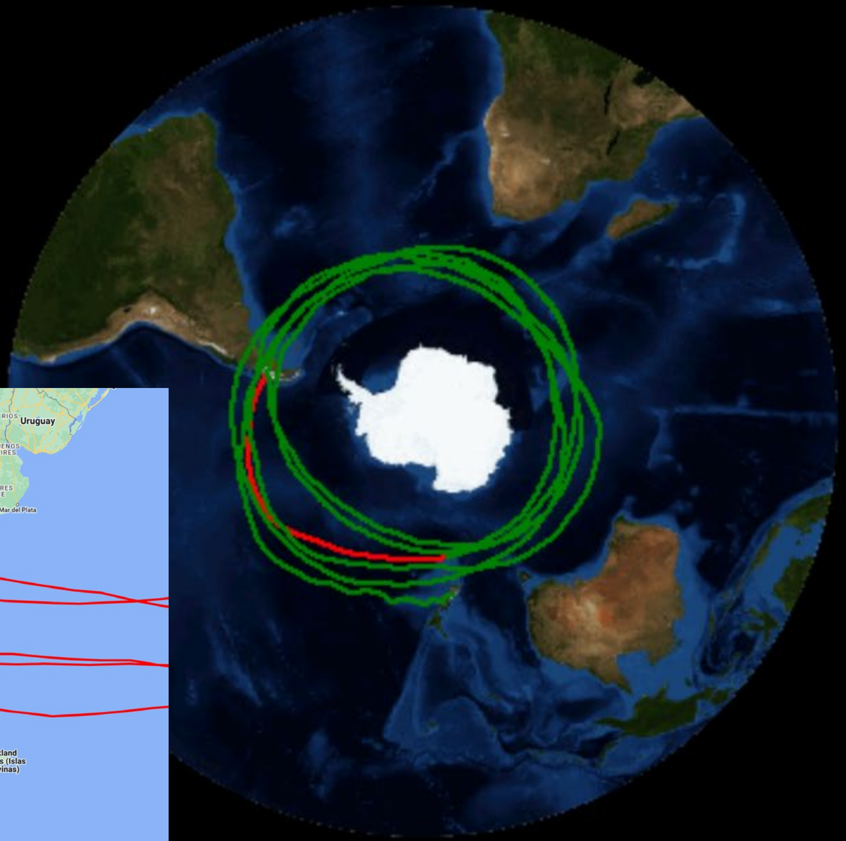
Francesco Cafagna (U. Bari, Italy)

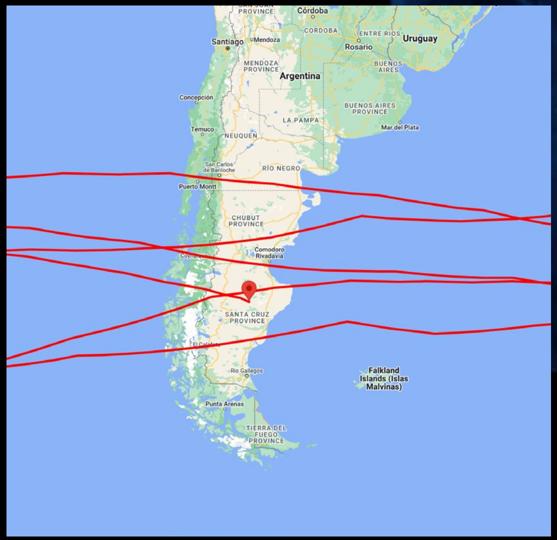
Starlink

- The standard kit includes an antenna, a power supply (featuring PoE – Power Over Ethernet) and a Wi-Fi router.
- Both power supply and router were substituted by a DC-DC converter and a passive PoE adaptor.
- CSBF requested a complete isolation between the Starlink and the SIP networks.



728NT - SN08 - SUPERBIT Balloon Tracking





Flight Ended

Total Flight Time

39 Days 13 hours 35 minutes

Launched April 15, 2023

729NT - SN09 - EUSO 2 Balloon Tracking

Space can be really hard

Flight Ended

Total Flight Time

1 day 12 hours 53 minutes

Launched May 13, 2023

We delivered an ambitious payload on time, flew it, and it worked

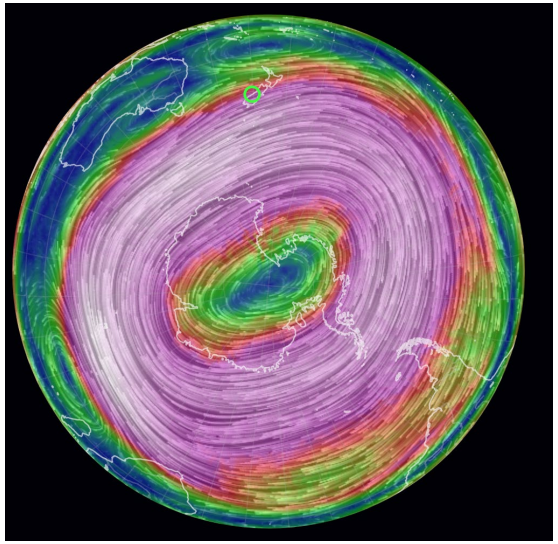
At 5625 lbs, the total mass, including our payload was very close to the 5500 lbs targeted,
we flew 600 lbs ballast (gave us another few hours)
Our solar power system worked at float altitude
Our instruments turned on and worked at float altitude -
Cherenkov Telescope, Fluorescence Telescope, IR Camera, also Shutter/tilt
We collect data with all instruments over two nights with moon down. - 57 GB downloaded

We were well-prepared to support a long flight and meet our science goals
UHECRs, HECRs Neutrino Searches through Target of Opportunity (ToO)

Shifter training performed, documented, shift schedule in place
ToO scheduling in place
System experts had lots of experience with operations
Control/commanding flight software well-tested and working

Also… gravitational-wave detectors started O4 on May 24th [link]
11 days after EUSO-SPB2 May 13th launch, and 4 days after new moon,

Stratospheric circulation remains strong



10 mbar, June 11 2023

Backup Slides

What went wrong with the balloon?

Leak at or near the top of the balloon.

That's why the ballast had little/no effect.

What caused the leak?

Unknown at present

Some possible causes include a manufacturing defect, handling, something in the launch process

How is NASA investigating?

Collected witness statements and photos from launch

Formed two GSFC Review Boards

- QRB (Quality review board) to investigate manufacturing defects
- ARB (Anomaly review board) to investigate launch prep and sequence
- (5/31/23) letters delivered to QRB and ARB with charges from NASA/WFF head
- Final reports due 11/1/23

April 9th 2023 SN08 Balloon (Super Bit)

Take home message

May14th_a

(04h40 UTC)

We were so beautiful!