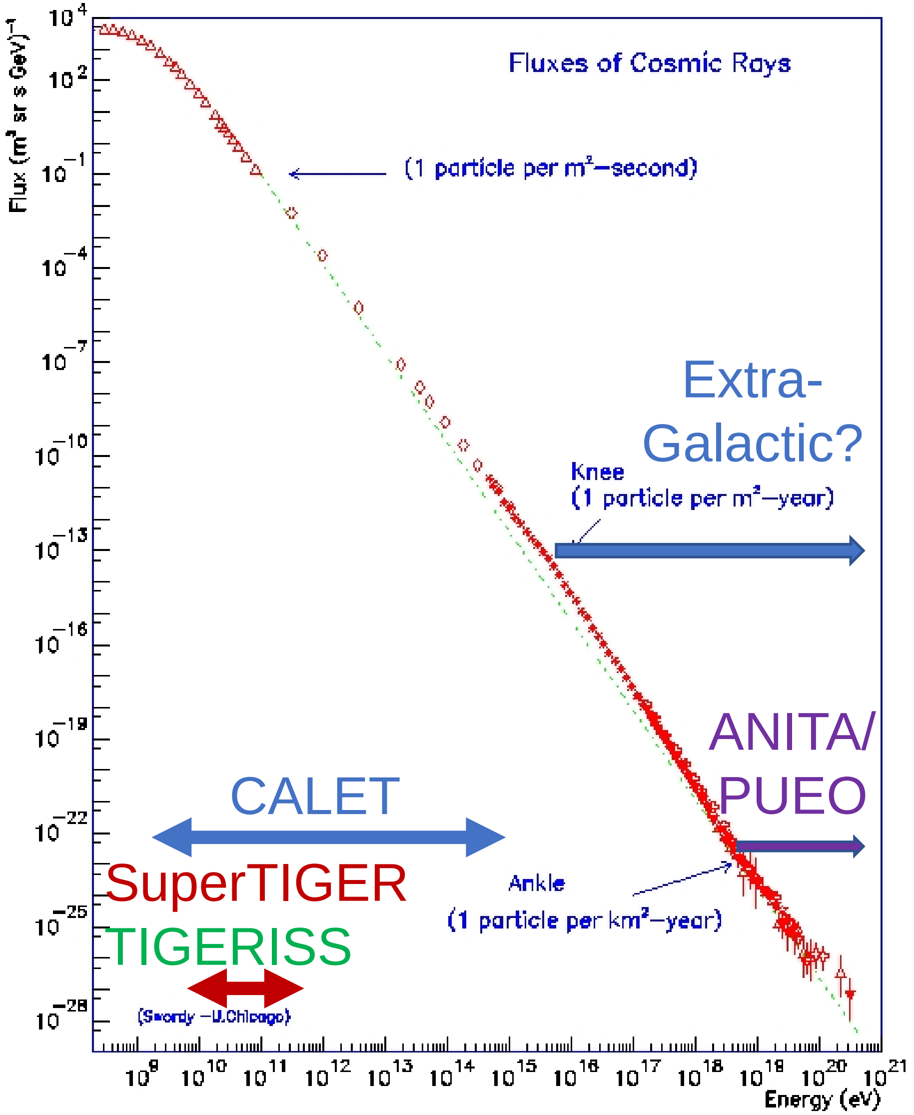
SuperTIGER and TIGERISS mission status and prospects

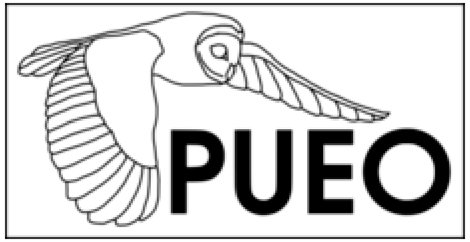
Brian Flint Rauch

Advances in Space AstroParticle Physics ASAPP 2023

Cosmic Rays and Energy

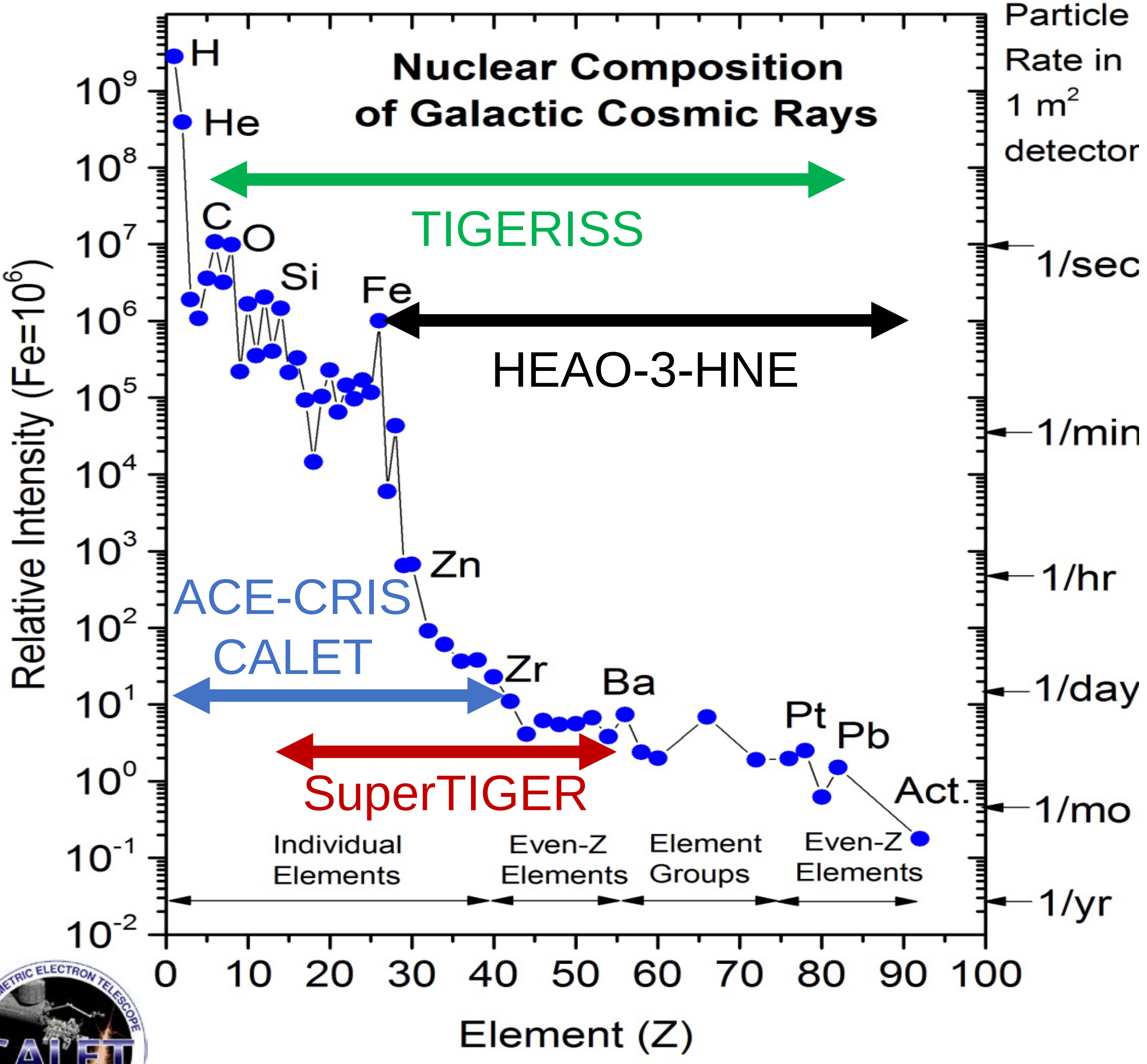


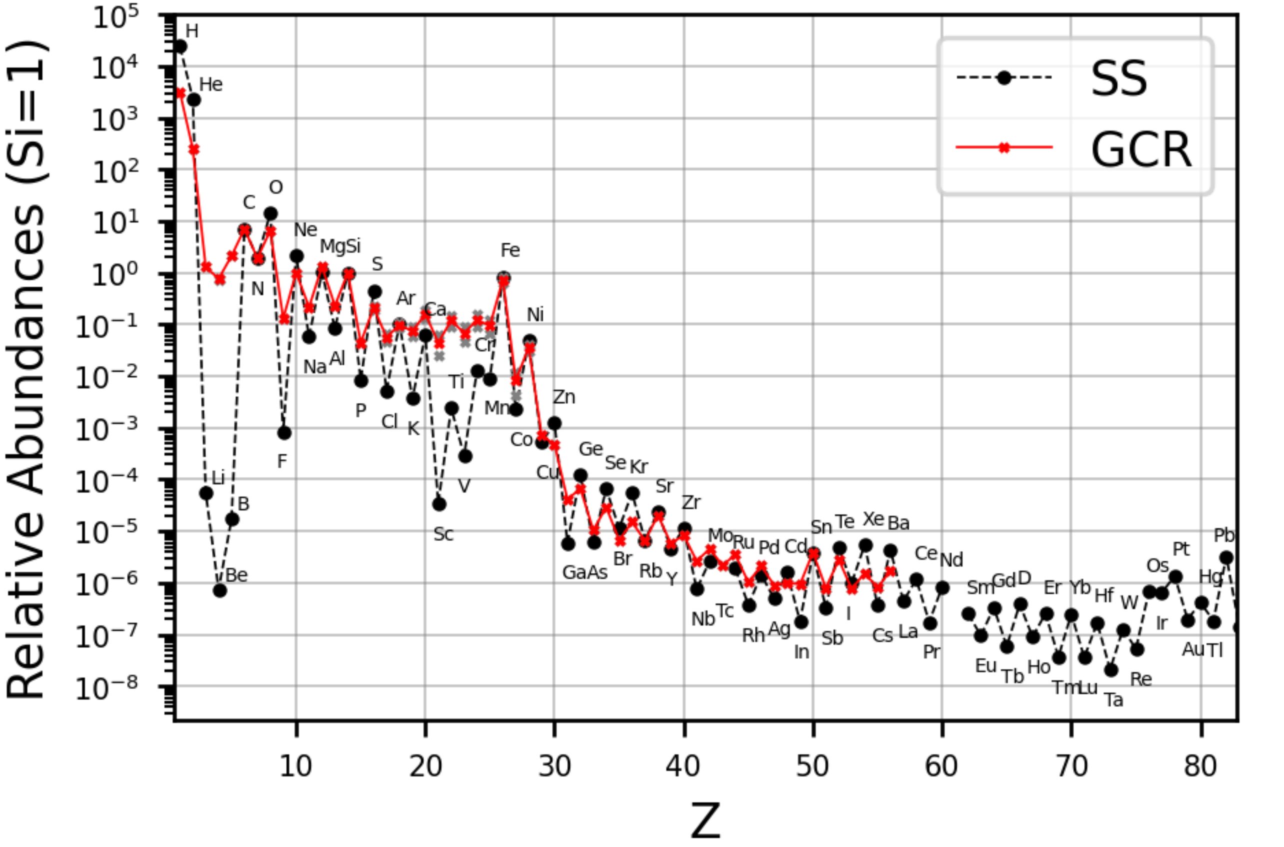
- SuperTIGER/TIGERISS energy range in instrument ~3×10^{8} - 10^{10}eV/nuc
- CALET ~1 – 10^{6} GeV
- Ultraheavy Galactic Cosmic Ray (UHGCR) measured at merely relativistic energies
- Maximize detector area



PUEO is designed to search for the highest energy neutrinos will also observe ultra-high energy cosmic rays

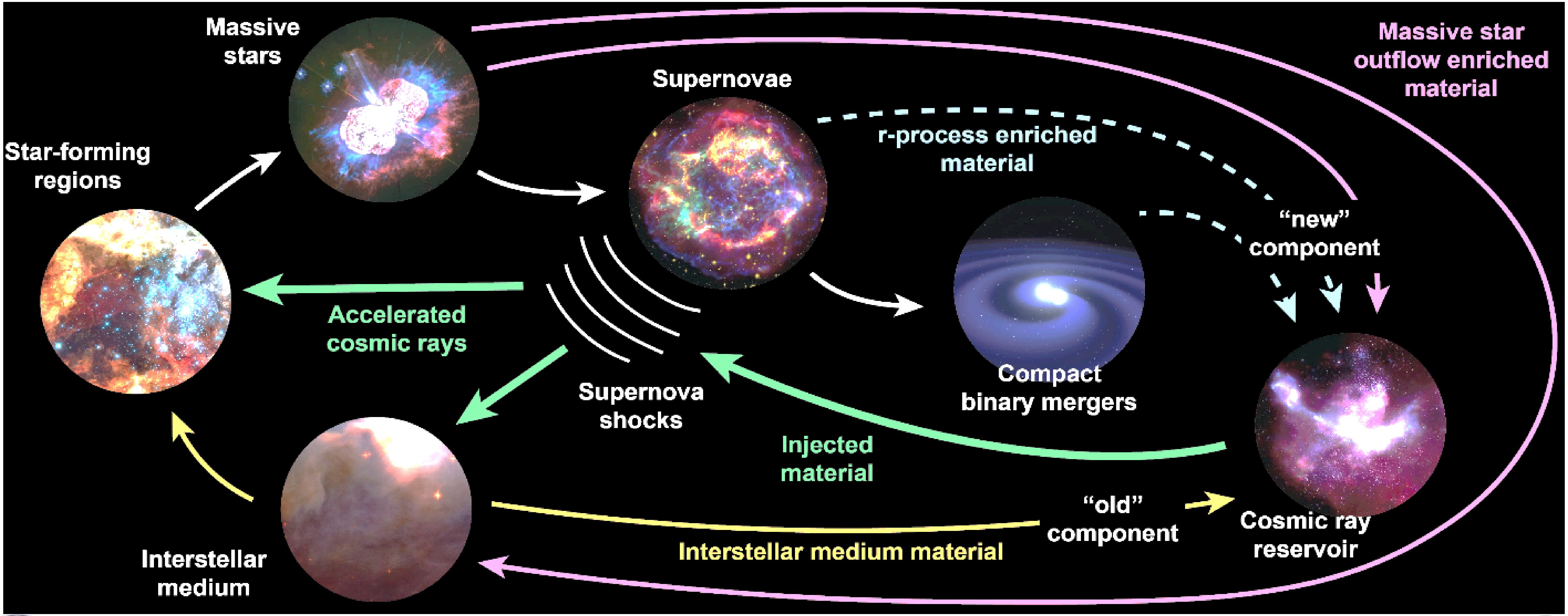
Cosmic Ray Abundance Measurements



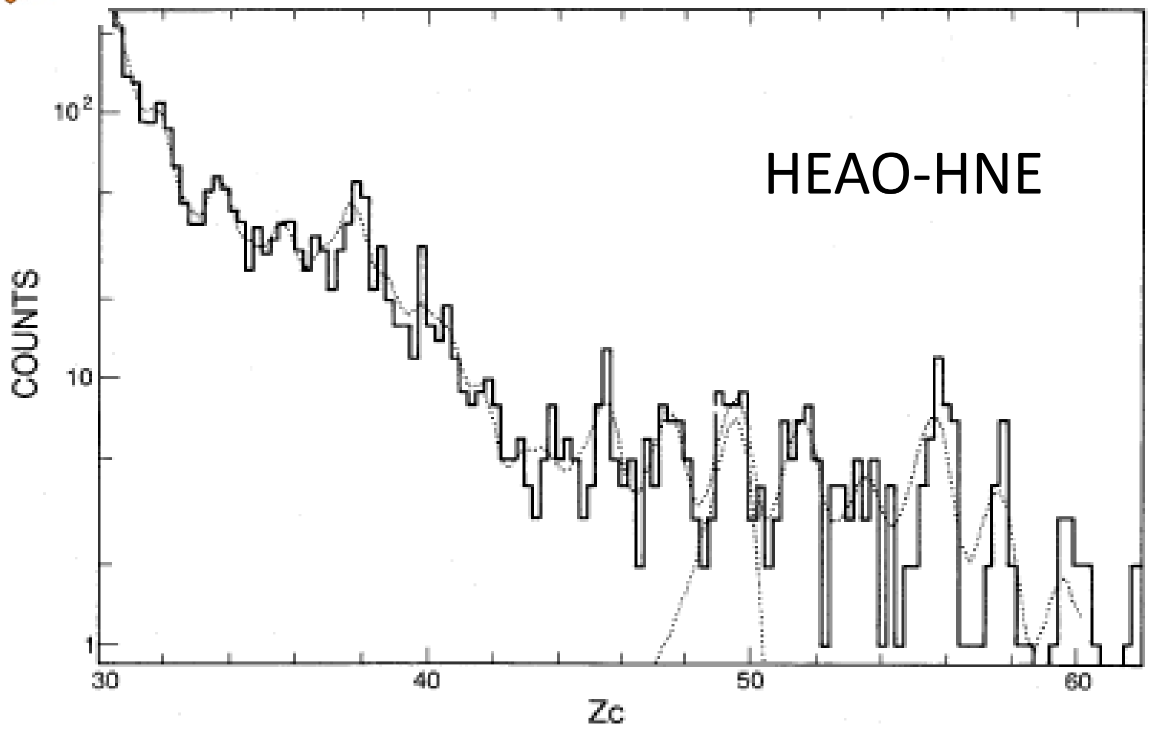


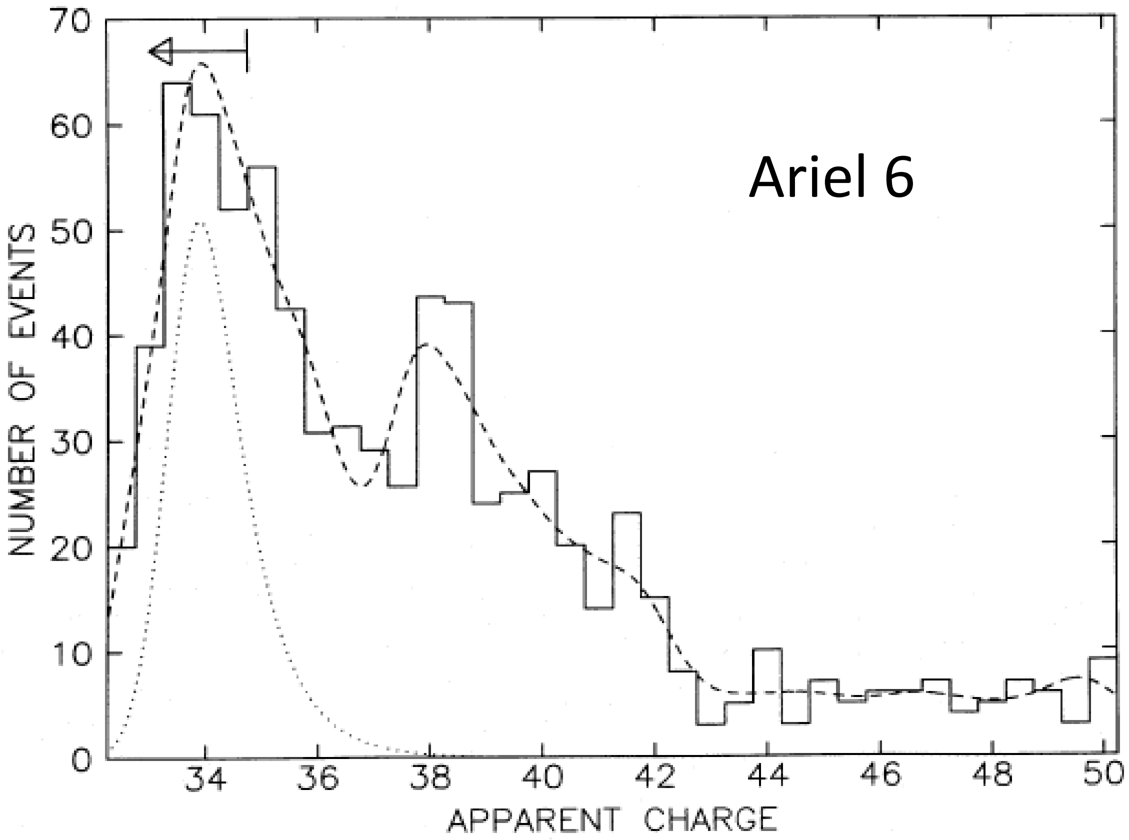
Solar System (SS) Lodders-2003
Galactic Cosmic Rays (GCR) 2 GeV/nuc measurements with single-element resolution

Cosmic Rays and the Grand Cycle of Matter



Previous Space UHGCR Results

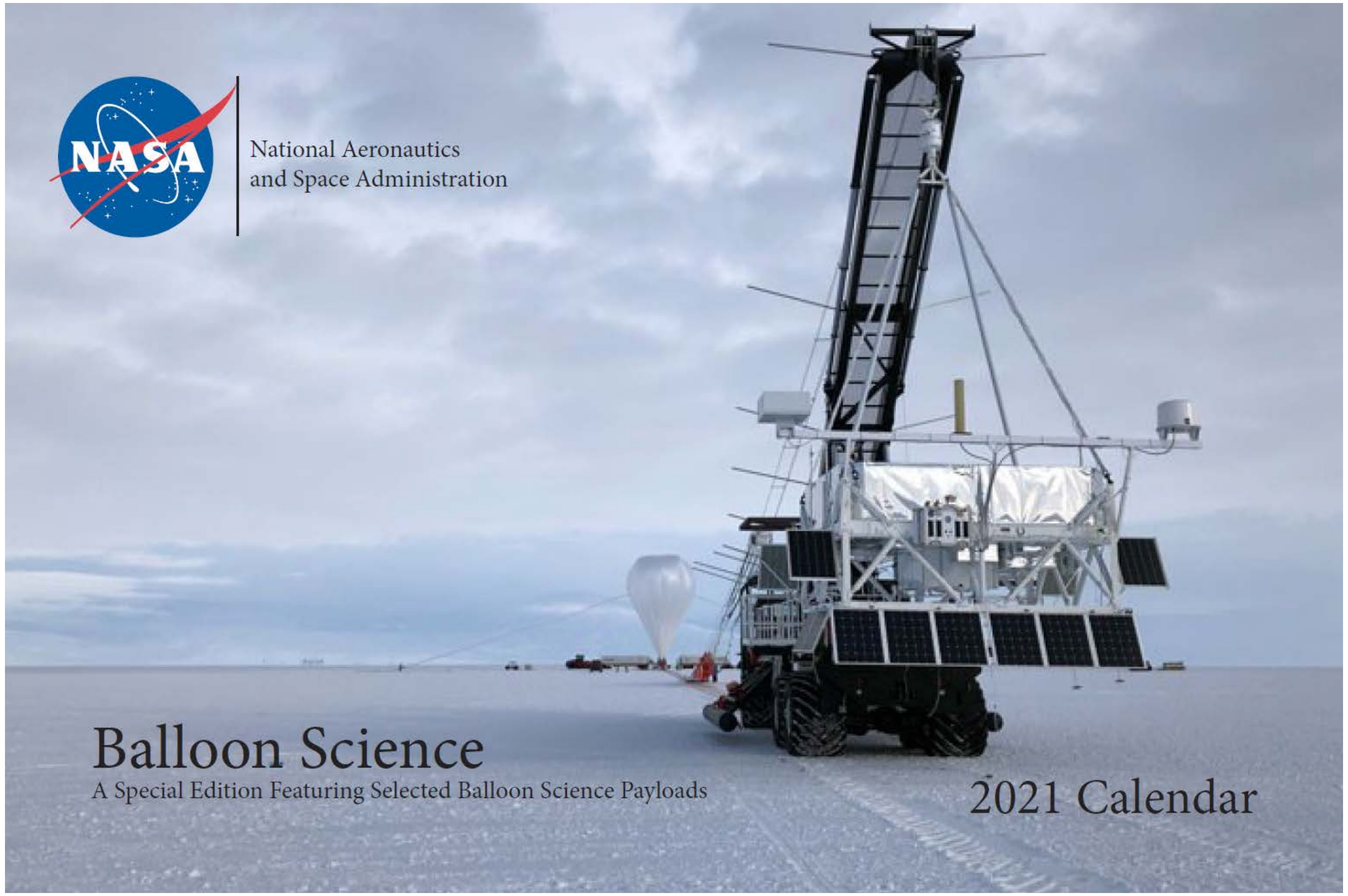




- Left Figure is the chare histogram from HEAO-HNE (Sep. 1979 – Jan. 1981), which resolved only even-odd pairs for Z < 60 (Binns et al. 1983)
- Right Figure is the charge histogram from Ariel 6 (June 1979 - Feb. 1982), which also had limited resolution (Fowler et al. 1987)

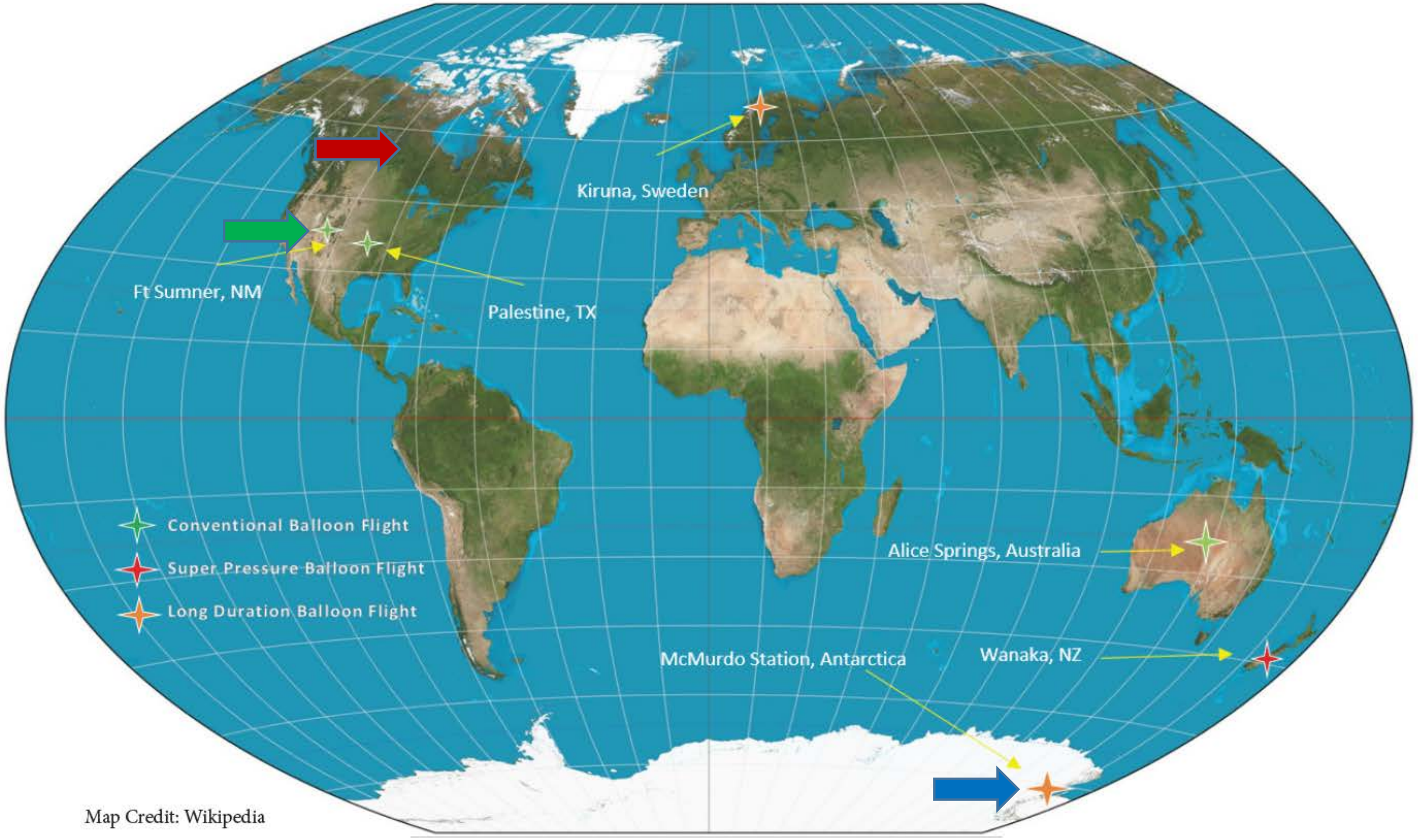
New Measurements Needed
Instrument Development with Balloons

- Stratospheric balloons provide relatively economical access to near space for large payloads up to ~6,000 lbs.
- Balloon payloads can be recovered and flown again, which is advantageous for instrument development and demonstration.
- Balloon projects allow for student involvement that can span the entire project life and include many project roles.

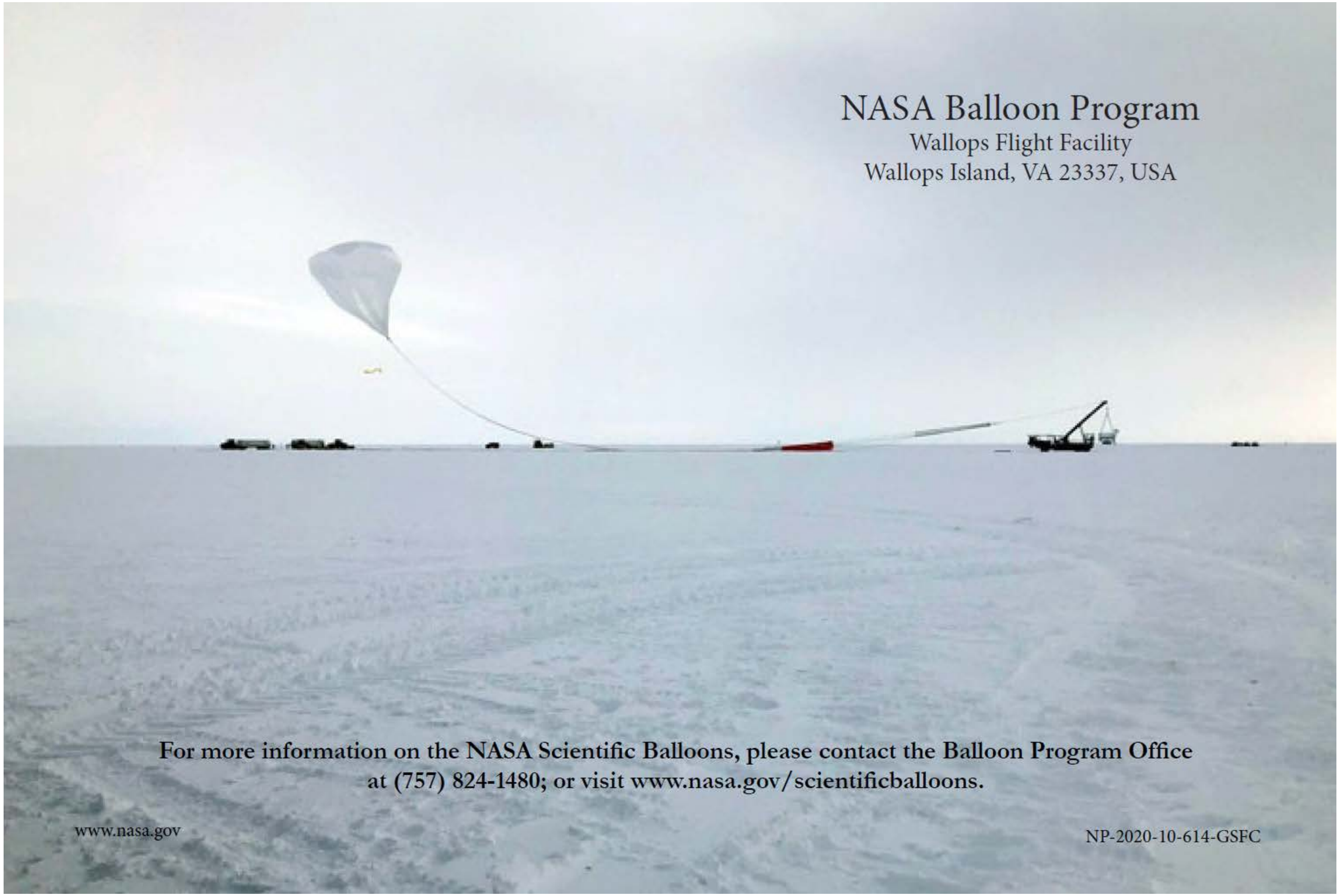


Trans-Iron Galactic Element Recorder (TIGER) Balloon Flights

- The first TIGER payload (1995/1996) flew from Lynn Lake, MB, Canada, not currently in use, indicated by red arrow.
- TIGER 1997 flew from Ft. Sumner, NM.
- TIGER-LDB and SuperTIGER flew from McMurdo Station, Antarctica



Launch Locations Worldwide


NASA Balloon Program
Wallops Flight Facility
Wallops Island, VA 23337, USA
For more information on the NASA Scientific Balloons, please contact the Balloon Program Office
at (757) 824-1480; or visit www.nasa.gov/scientificballoons.
www.nasa.gov
NP-2020-10-614-GSFC

Trans-Iron Galactic Element Recorder Collaboration

1995/1996

Washington University in St. Louis: J.J. Beatty, W.R. Binns, D.J. Crary, D.J. Ficnec, P.L. Hink, J. Klarmann, D.J. Lawrence, B.F. Rauch

Goddard Space Flight Center: L.M. Barbier, E.R. Christian, K.E. Krombel, J.W. Mitchell, R.E. Streitmatter

University of Minnesota: C.J. Waddington

1997

Washington University in St. Louis: W.R. Binns, J.R. Cummings, P.L. Hink, M.H. Israel, S.H. Sposato

California Institute of Technology: G.A. de Nolfo, R.A. Mewaldt, S.M Schindler

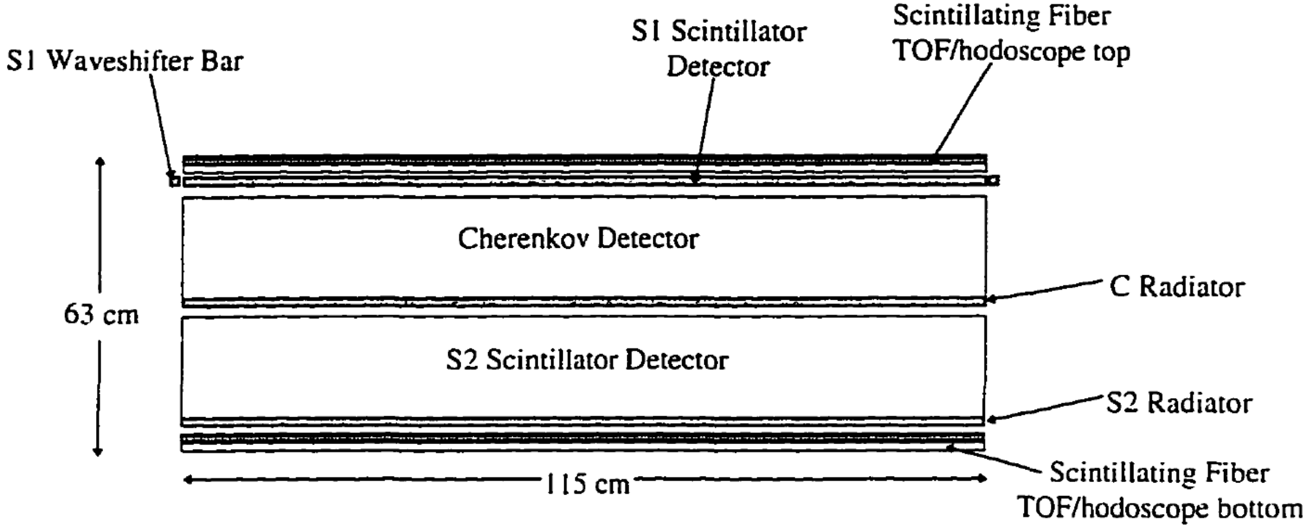
Goddard Space Flight Center: L.M. Barbier, E.R. Christian, J.W. Mitchell, R.E. Streitmatter

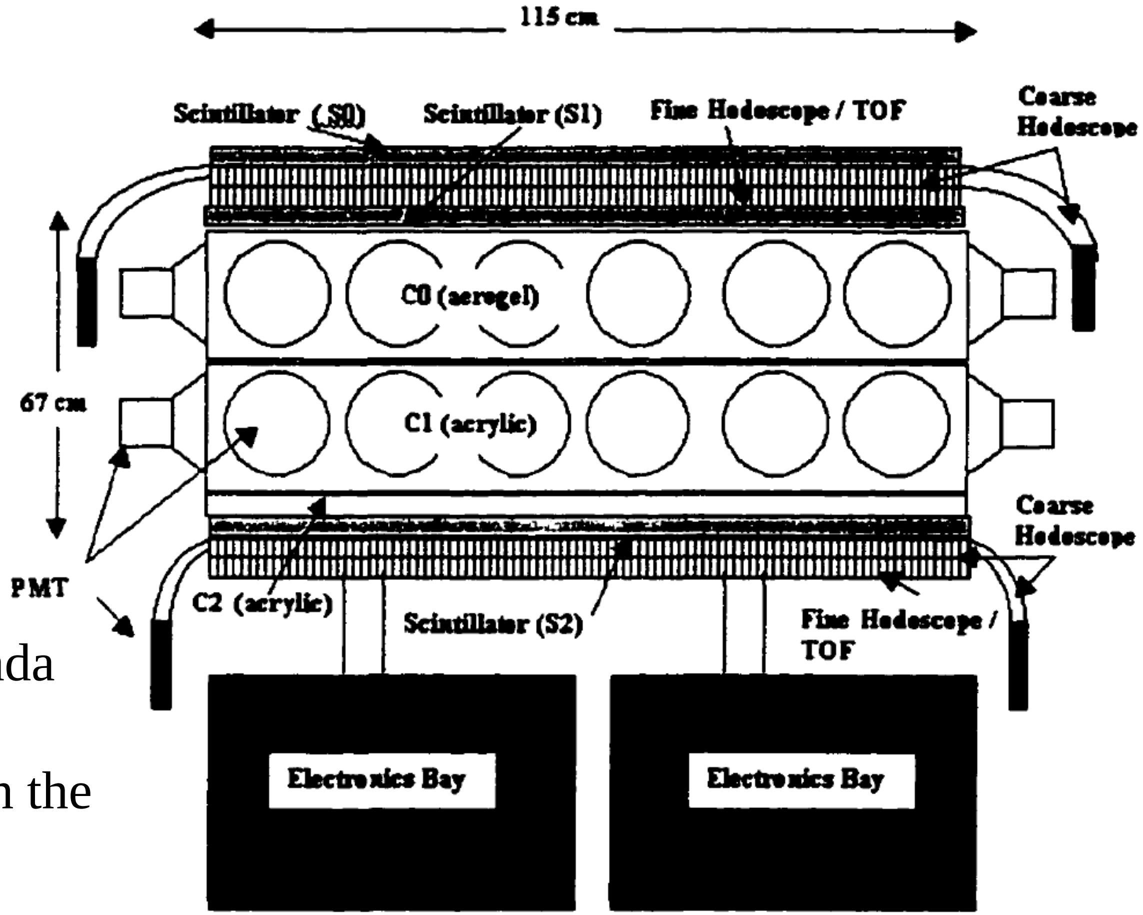
University of Minnesota: C.J. Waddington

This work was supported by NASA grants and the McDonnell Center for the Space Sciences at Washington University

The Trans-Iron Galactic Element Recorder Payloads

1995/1996 1997



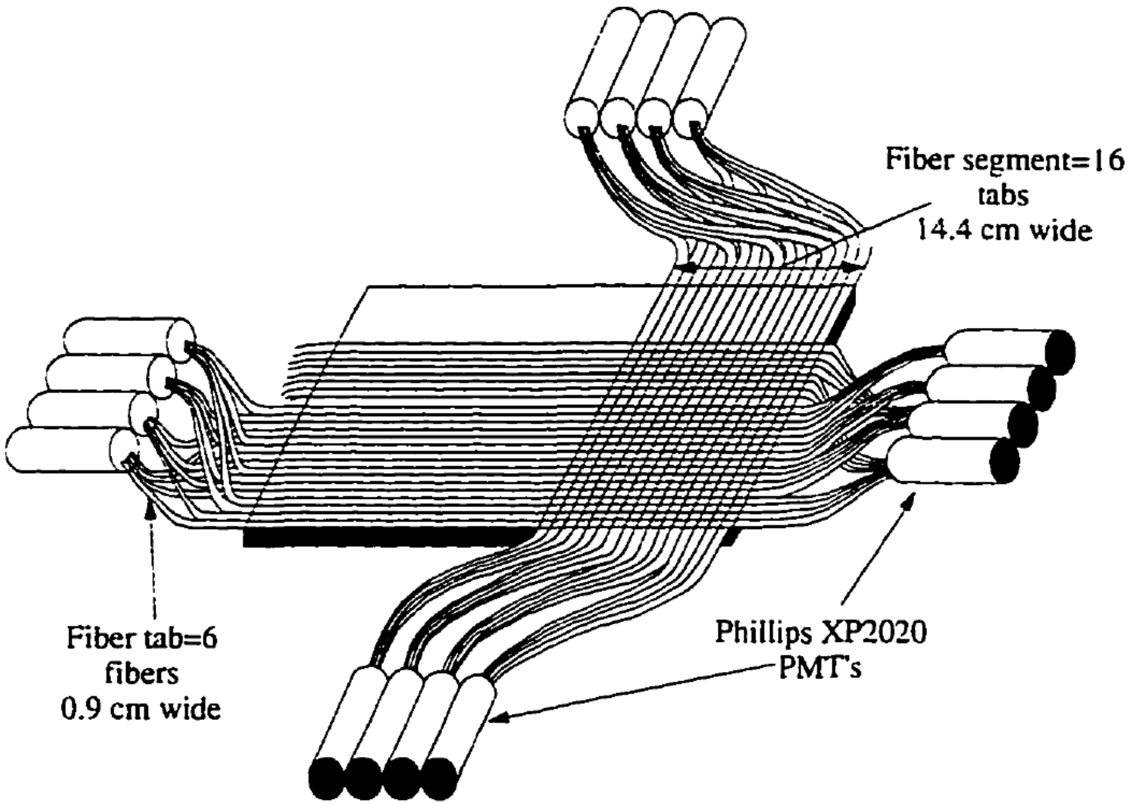


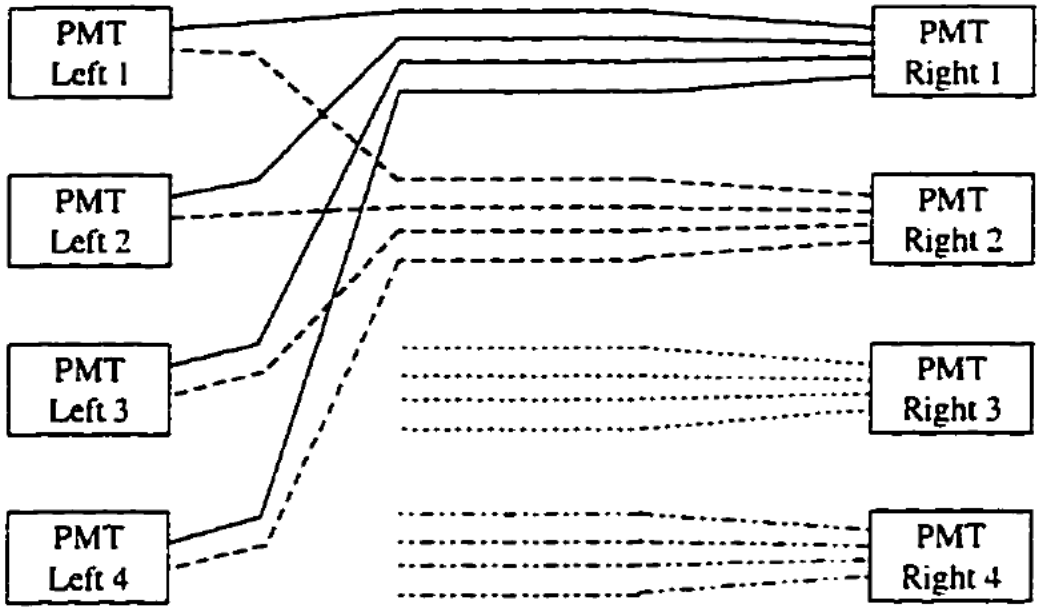
TIGER 1995: 45 minutes at float from Lynn Lake, MB, Canada
- Demonstrated compact scintillator readout worked

TIGER 1996 attempted flight 0 minutes aloft due to a short in the termination package before launch

TIGER 1997: 23.25 hours at float from Fort Sumner, NM
- Demonstrated compact Cherenkov readout did not work
- Demonstrated utility of using 2 types of Cherenkov light collection boxes: acrylic n = 1.5 and silica aerogel n = 1.04

TIGER Scintillating Fiber Hodoscope

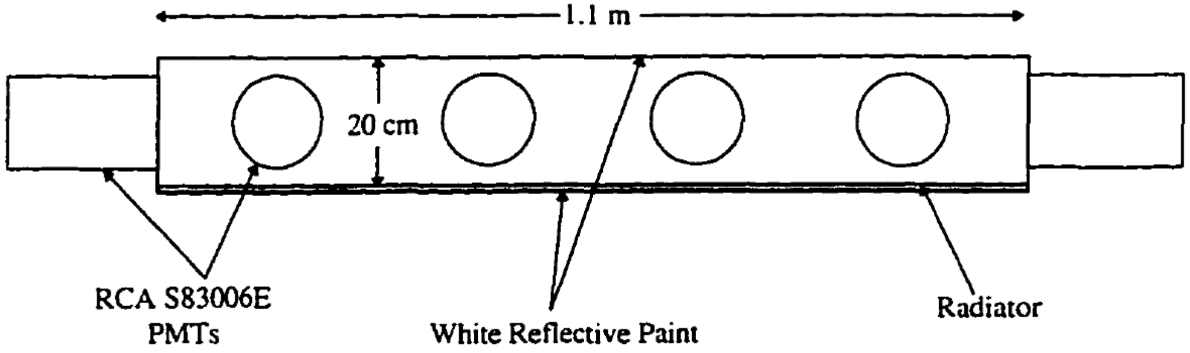


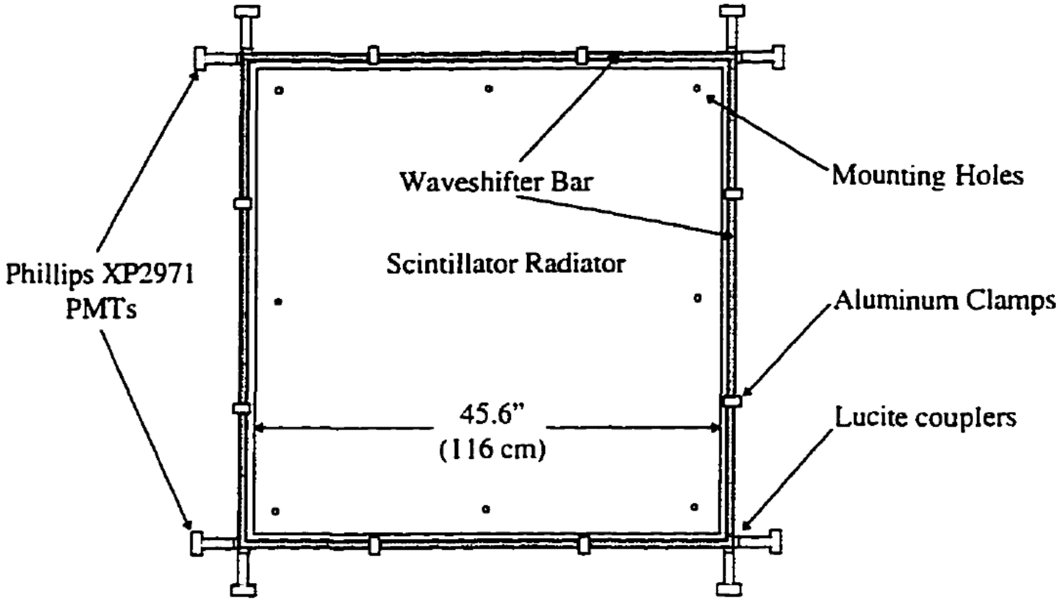


Position determination using scintillating optical fibers with a coded readout.

- Fine side photomultiplier tubes (PMTs) take every 4th tab (groups of 6 1 mm fibers)
- Coarse side PMTs take groups of 4 adjacent tabs
- Each segment is coded to the fine and coarse fibers in the same format

Compact and Light Collection Box Radiator Readouts

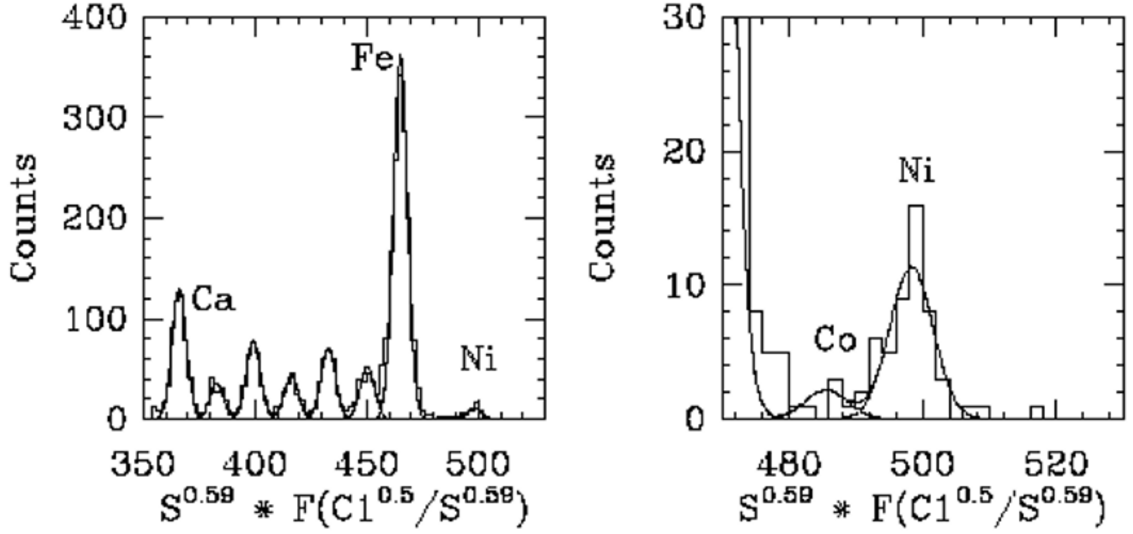


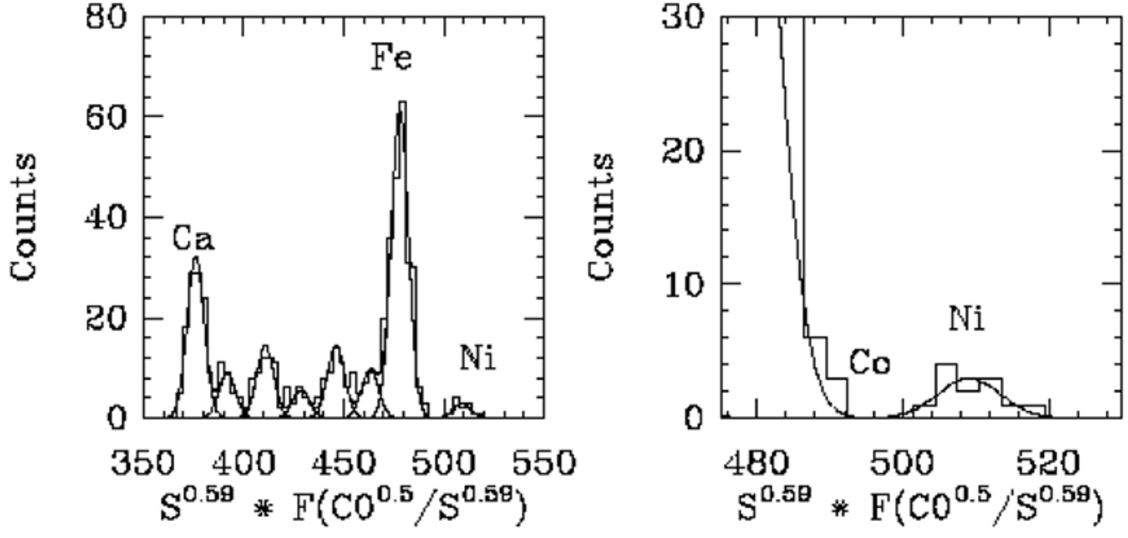


TIGER used two radiator detector readout methods:

- Light collection box (left) with radiators in large white boxes that reflect light generated to be read by large PMTs mounted on all four walls.
- Compact readout (right) that uses wavelength shifter bars along the edges to absorb and reemit light to be piped to the end of the bars and readout by smaller PMTs.

TIGER 1997 Results (Sposato et al. 1999)





- Left Figure is the TIGER-1997 charge histogram of $_{26}$Fe-region data for 0.8 – 2.5 GeV/nucleon.
  - Charges determined using scintillator and acrylic Cherenkov signals.
- Right Figure is the TIGER-1997 charge histogram of $_{26}$Fe-region data for 2.5 – 7.5 GeV/nucleon.
  - Charges determined using scintillator and silica aerogel and acrylic Cherenkov signals.
- Dr. Sposato's PhD dissertation results demonstrated the effectiveness of the TIGER design, paving the way for TIGER-LDB.

TIGER-LDB Collaboration

Trans-Iron Galactic Element Recorder

Washington University in St. Louis
B.F. Rauch, W.R. Binns, J.R. Cummings, M.H. Israel, K. Lodders, L.M. Scott

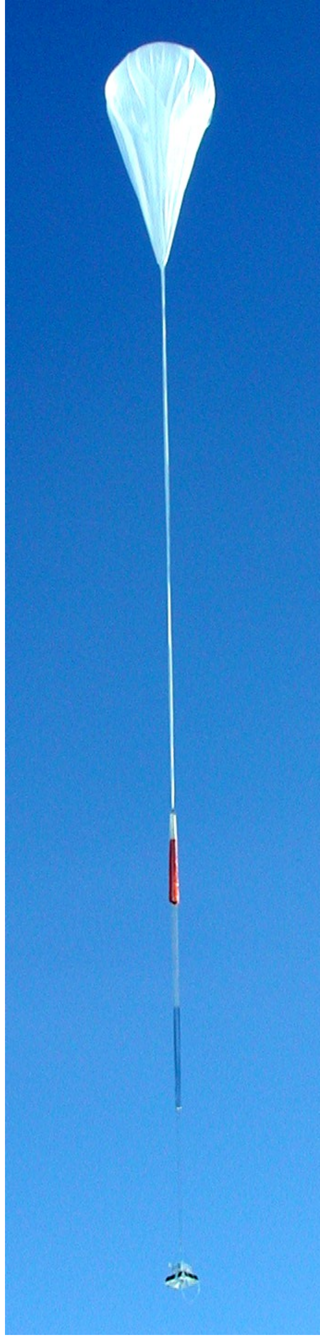
California Institute of Technology
S. Geier, R.A. Mewaldt, S.M Schindler, E.C. Stone

Goddard Space Flight Center
L.M. Barbier, E.R. Christian, J.W. Mitchell, J.T. Link, G.A. de Nolfo, R.E. Streitmatter

Jet Propulsion Laboratory
M.E. Wiedenbeck

University of Minnesota
C.J. Waddington

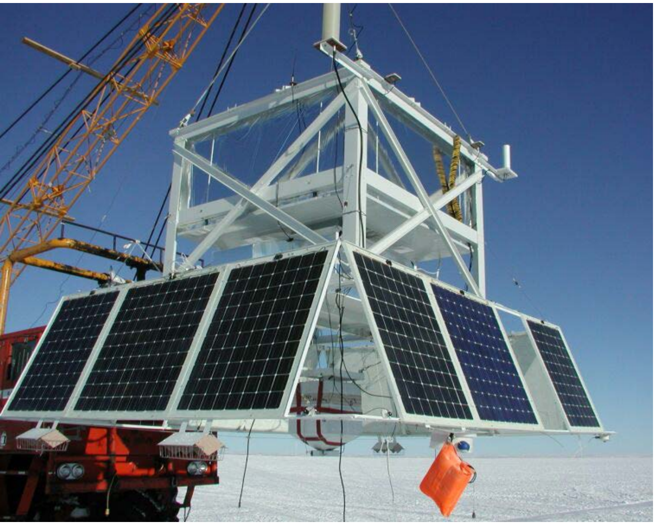
This work was supported by NASA under grant NNG05WC04G, and by the Graduate School of Arts and Sciences at Washington University in St. Louis with a Dean's Dissertation Fellowship.

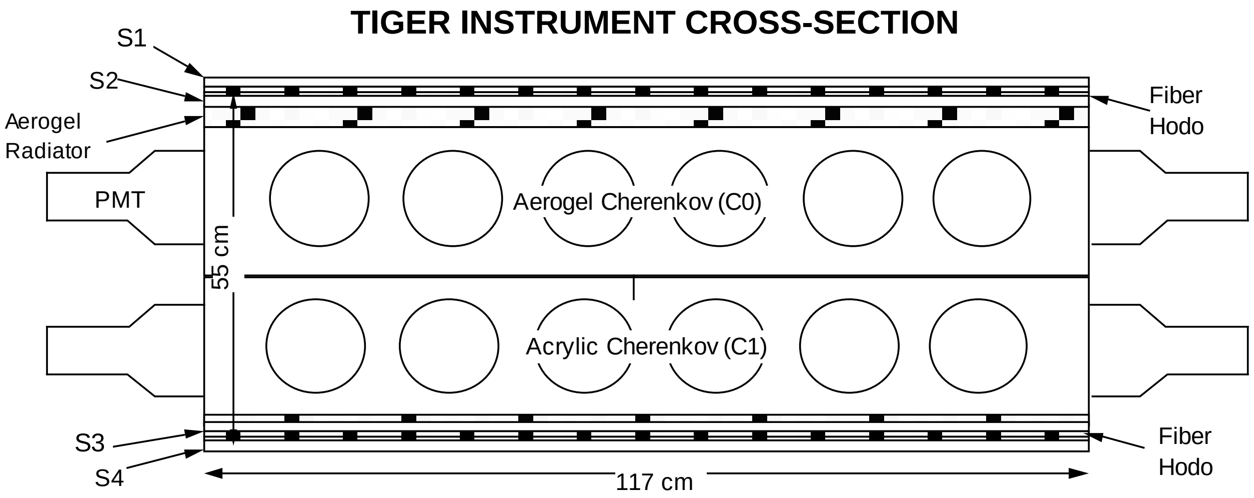


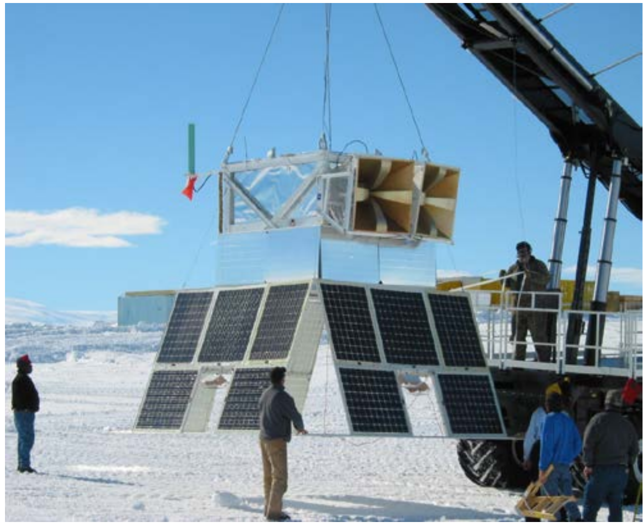
TIGER-LDB Instruments

2001-2002

2003-2004



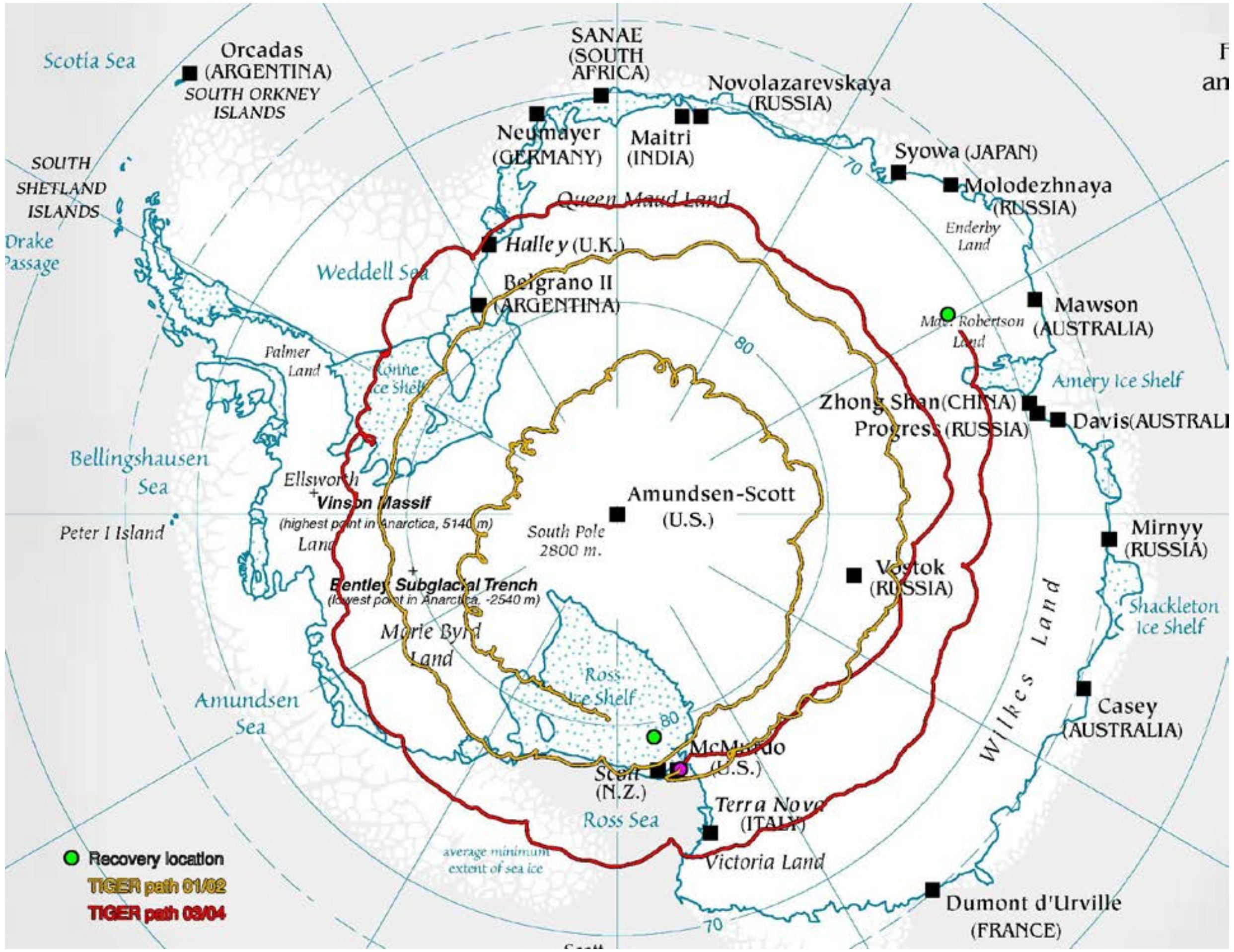




- TIGER-LDB used a suite of detectors demonstrated in the TIGER flights.
- Payload was designed to operate in near vacuum after the Kevlar gondola design they wanted to used failed during another payload’s flight.
  - ➢ Potted high-voltage and all custom-made electronics.
- TIGER-LDB 2003 had the ANITA-Lite piggyback experiment.

TIGER-LDB Antarctic Flights

Dec 21, 2001 – Jan 21, 2002 **Dec 17, 2003 – Jan 4, 2004**



First 32-day flight was the first payload to make two circumnavigations of the south pole, setting a flight-duration record.

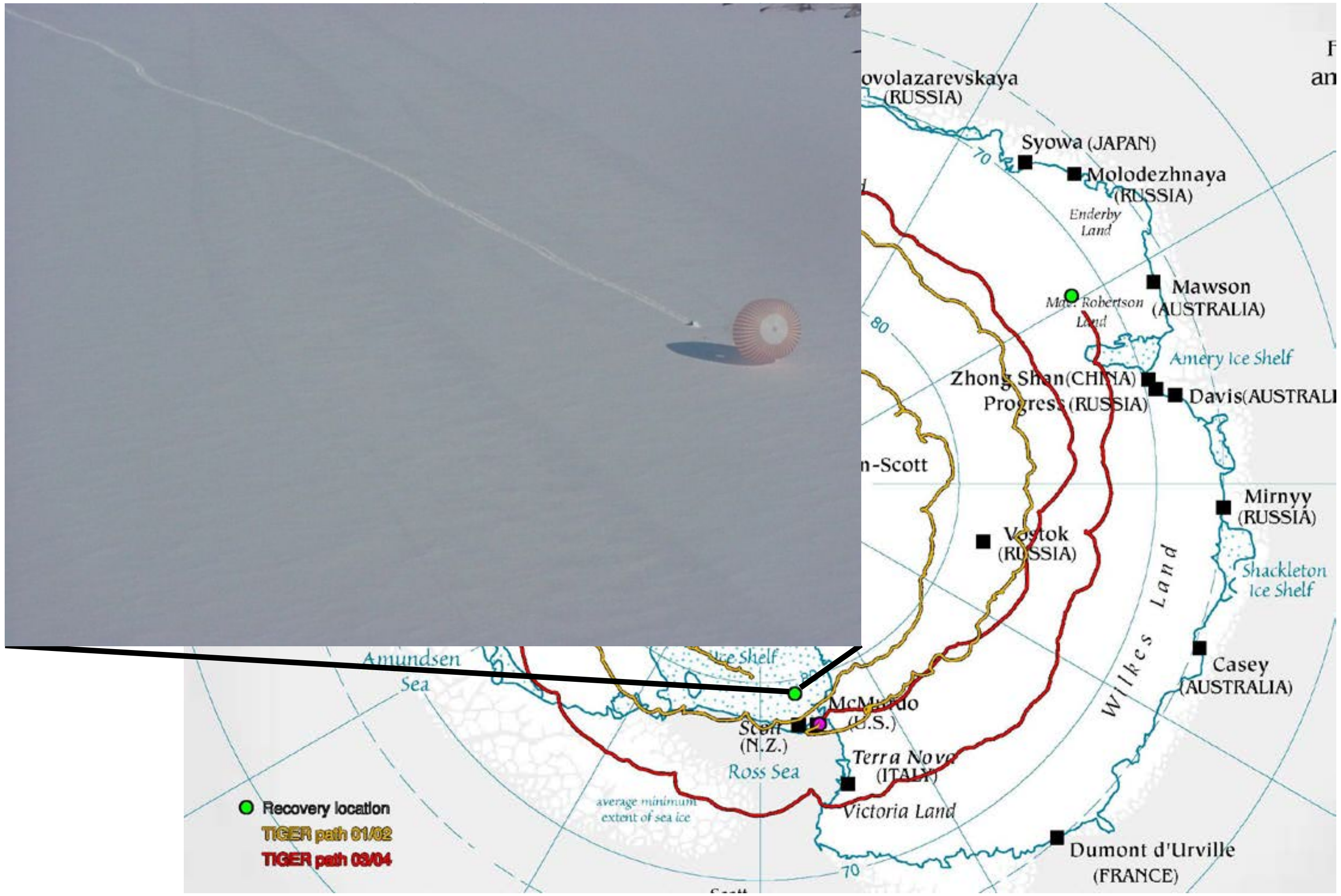
Second 18-day flight was cut short owing to concern that the payload might go off the Antarctic continent.

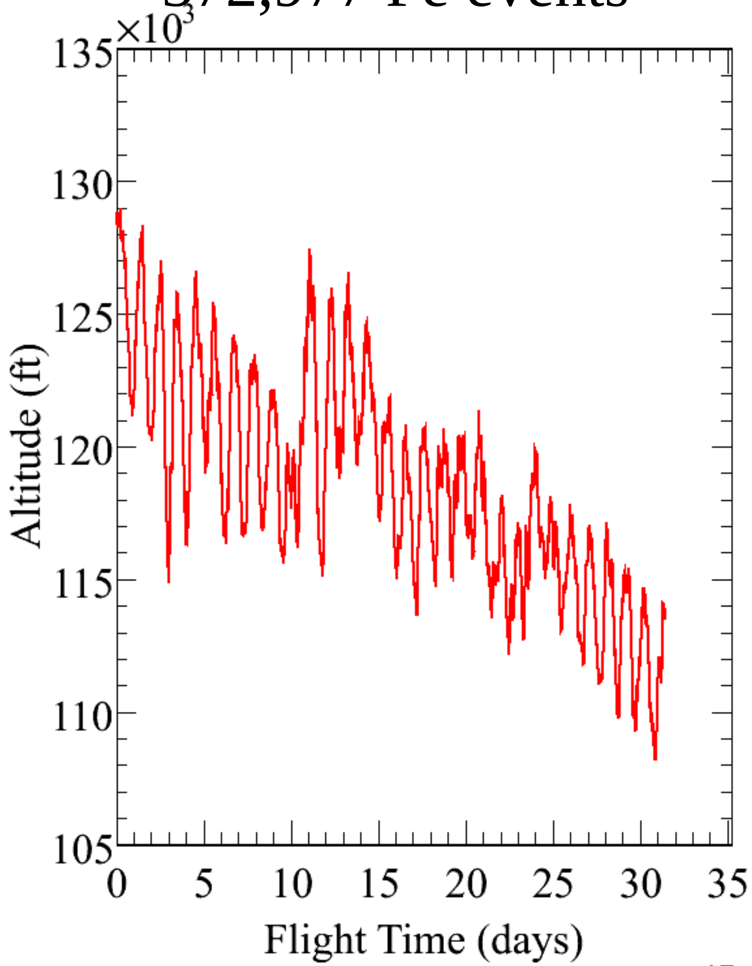
TIGER-LDB Antarctic Flights

TIGER 2001-2004

Dec 21, 2001 – Jan 21, 2002 **Dec 17, 2003 – Jan 4, 2004**

Average: 118,800 ft,
5.5 mb
372,977 Fe events



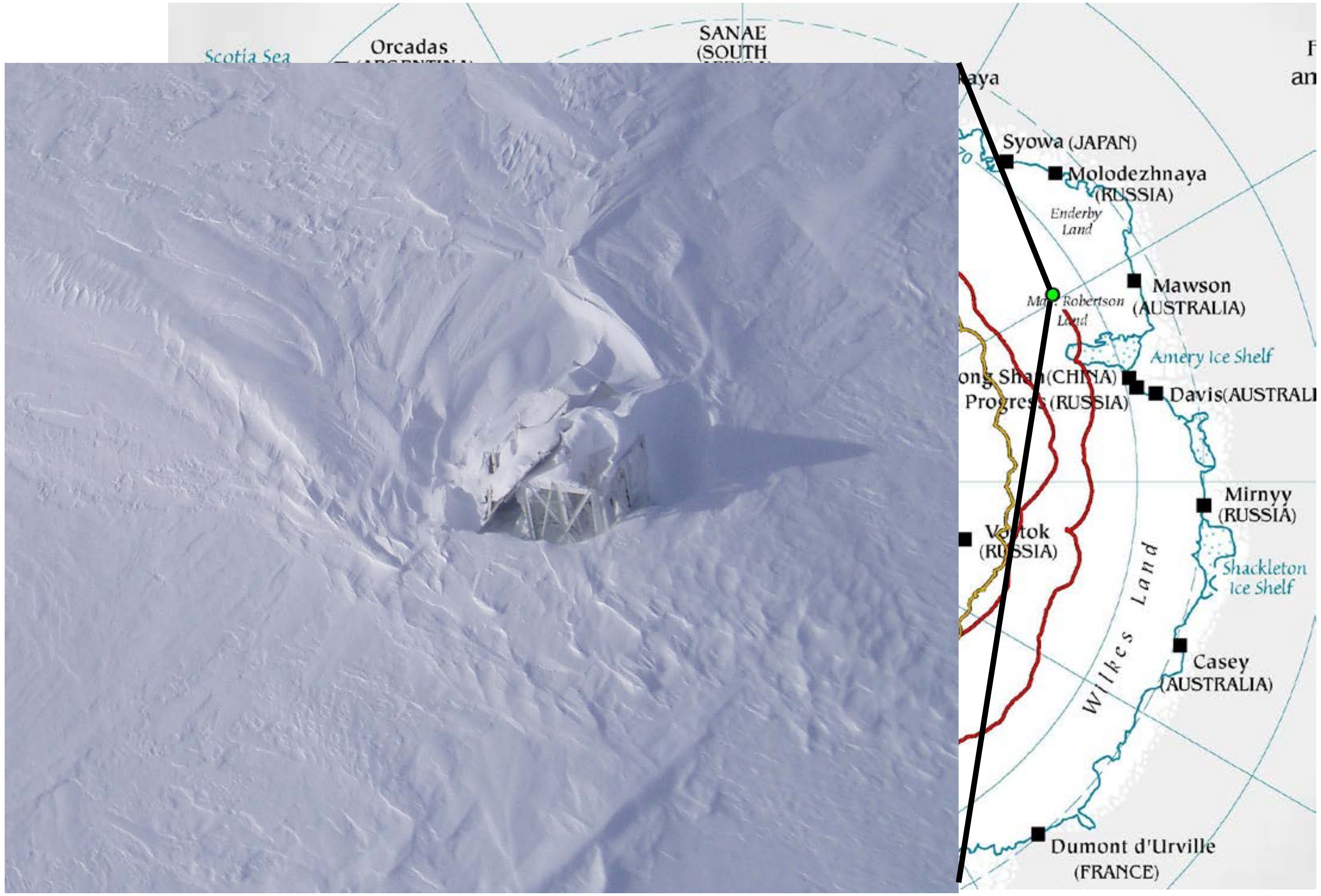


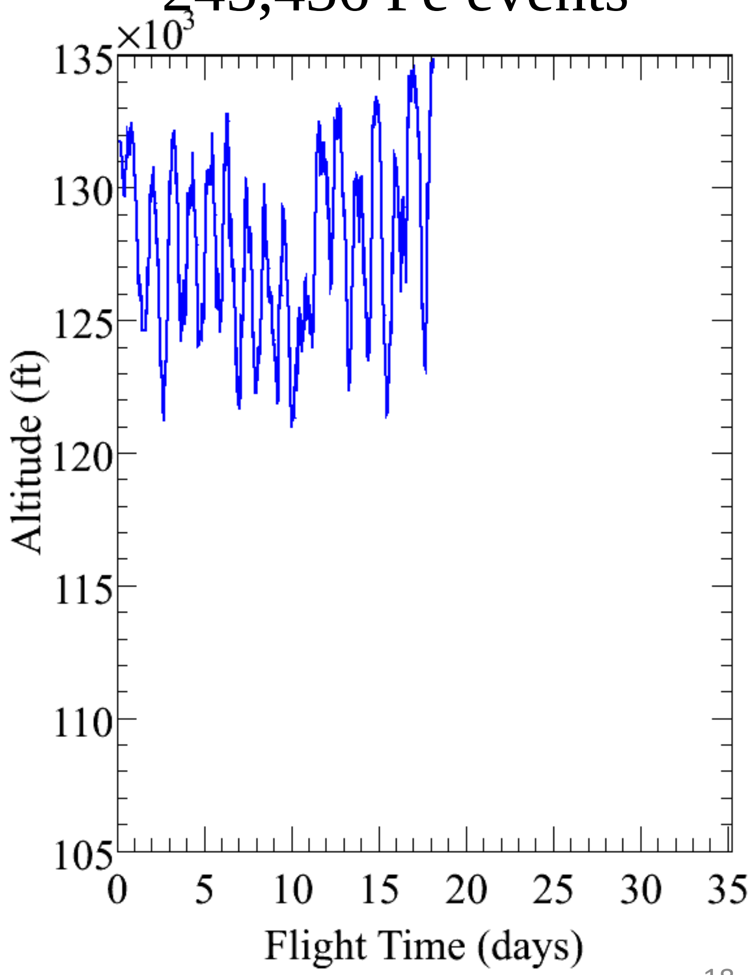
TIGER-LDB Antarctic Flights

Dec 21, 2001 – Jan 21, 2002

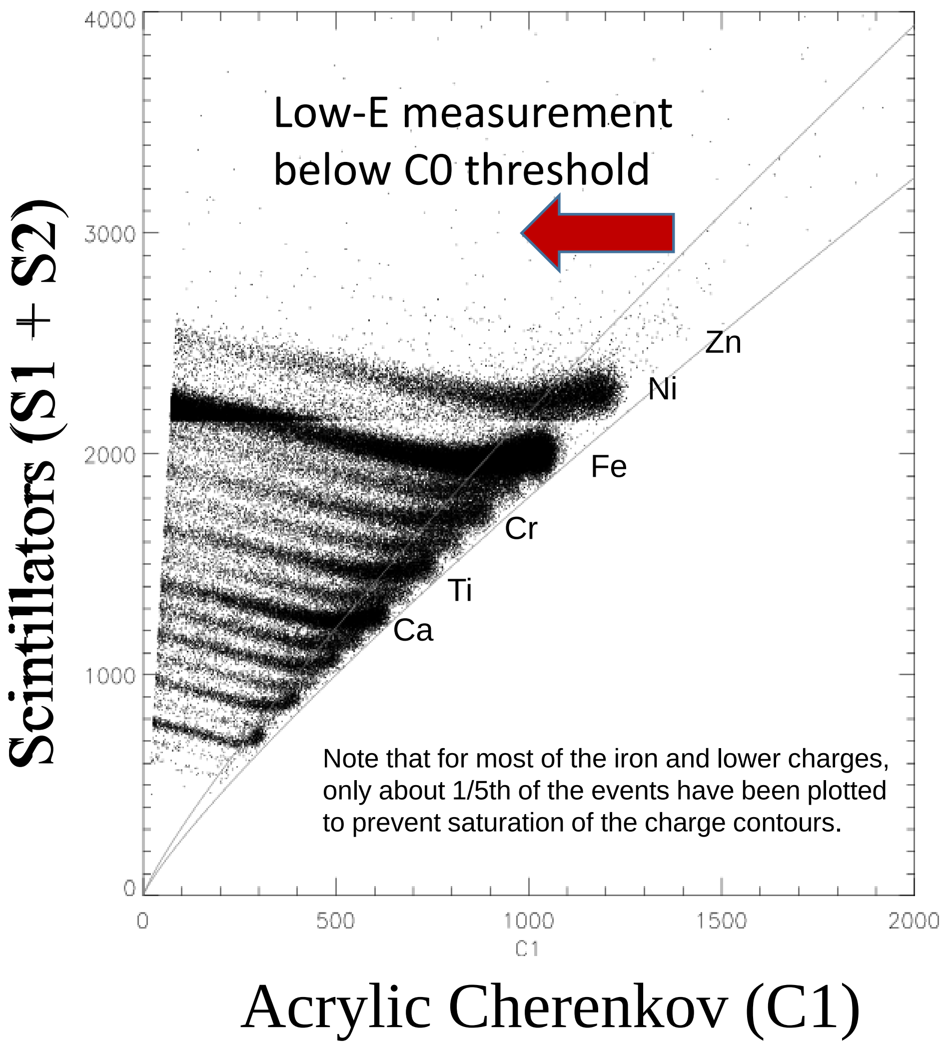
Dec 17, 2003 – Jan 4, 2004

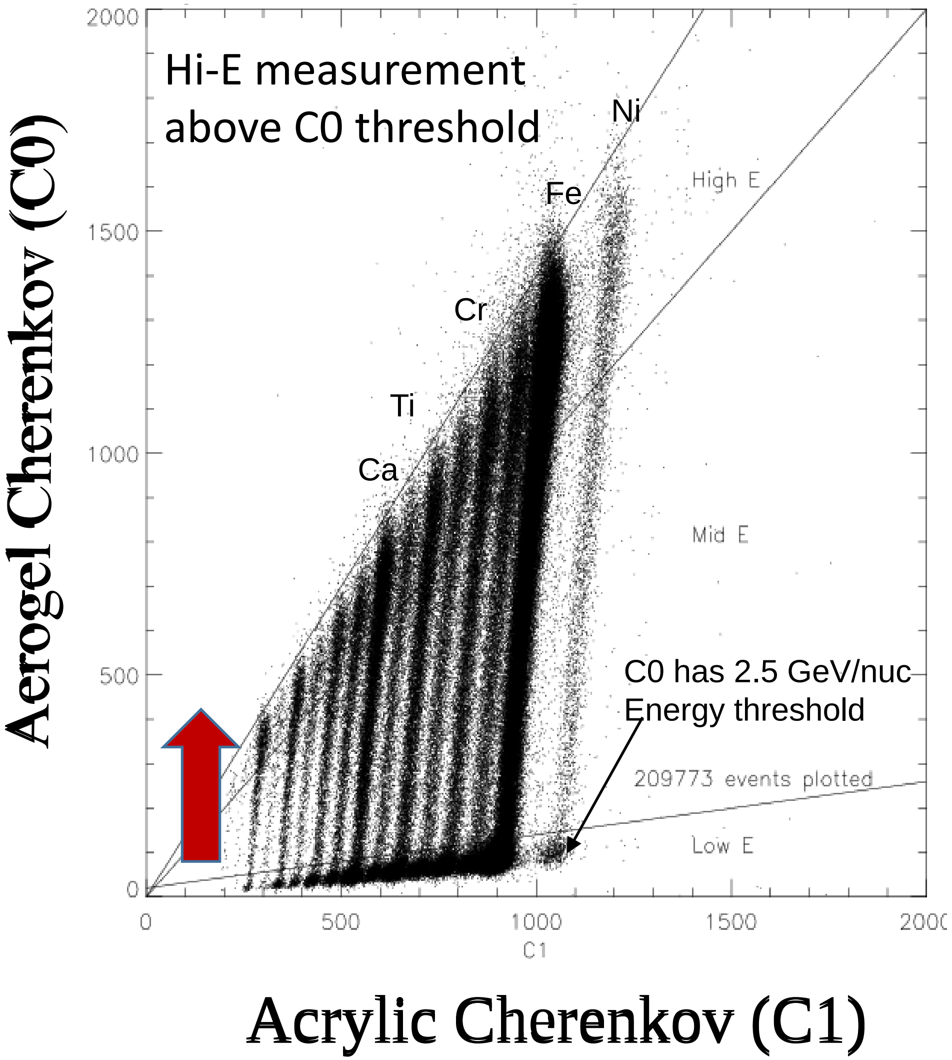
Average: 127,800 ft,
4.1 mb
245,436 Fe events



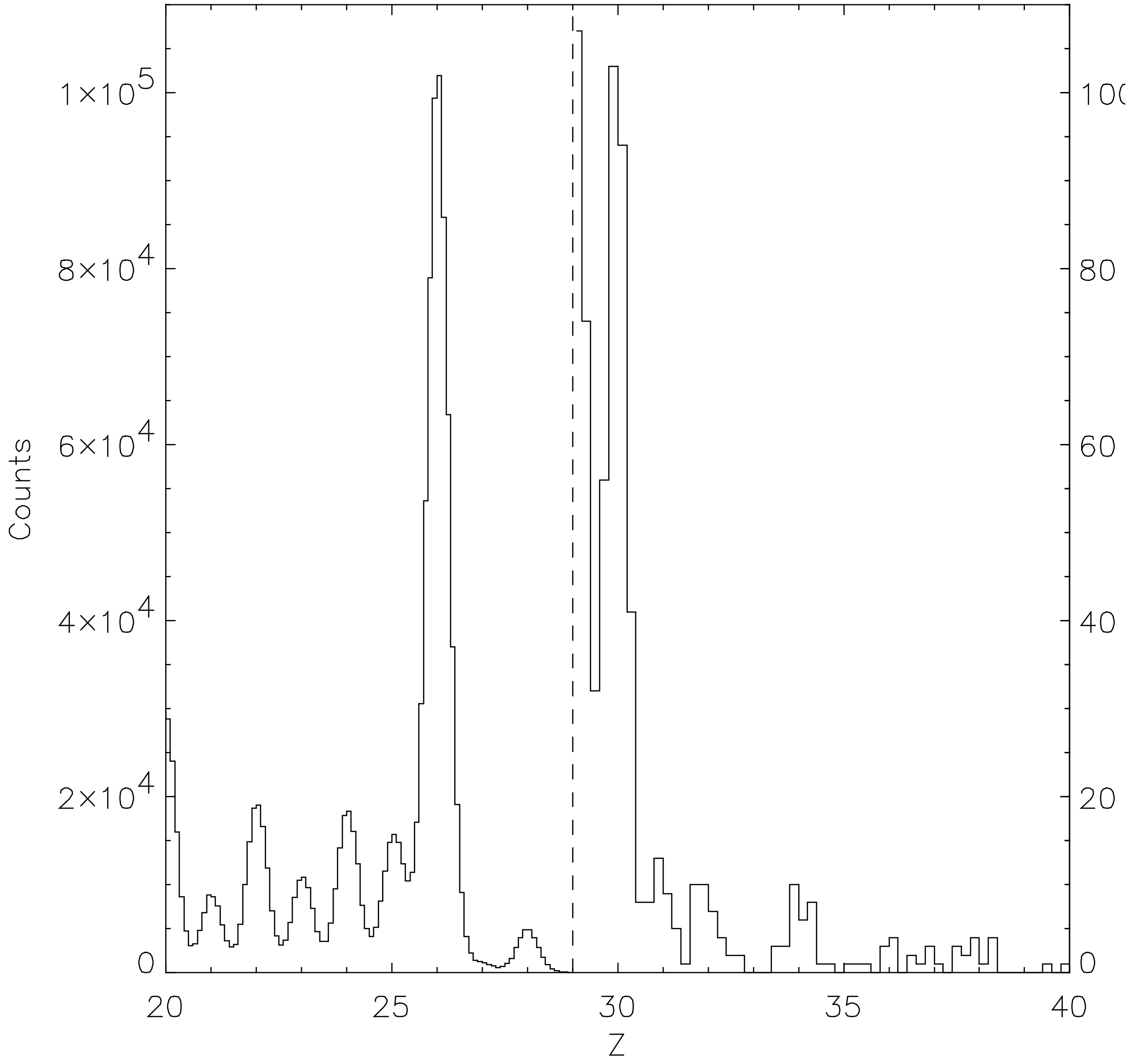


2001 TIGER Data Cross-Plots





Combined 2001 and 2003 Data



- Note change in scale at Z = 29
- The shorter 2003 flight contributed ~2/3 as much ultra-heavy Galactic cosmic ray (UHGCR Z > 30) data as 2001 because it flew higher.
- TIGER science paved the way for SuperTIGER

SuperTIGER

Wolfgang Zober

Super Trans-Iron Galactic Element Recorder (SuperTIGER)
Washington University in Saint Louis, Goddard Space Flight Center and California Institute of Technology

Following on its record setting 55-day flight in 2012-2013, SuperTIGER flew again for 32 days from McMurdo Station, Antarctica on December 15, 2019 to January 17, 2020. It determines cosmic-ray charges and energies using a combination of plastic scintillator dE/dx detectors, acrylic and silica-aerogel Cherenkov counters, and trajectory corrections using a scintillating fiber hodoscope. The 6 m x 4.7 m x 3.7 m tall payload carries two adjacent 1.8 m x 3 m x 1.2 m high detector modules. SuperTIGER probes the origins of galactic cosmic rays and heavy r-process elements by measuring the abundances of nuclei heavier than iron.

SuperTIGER-2 Collaboration

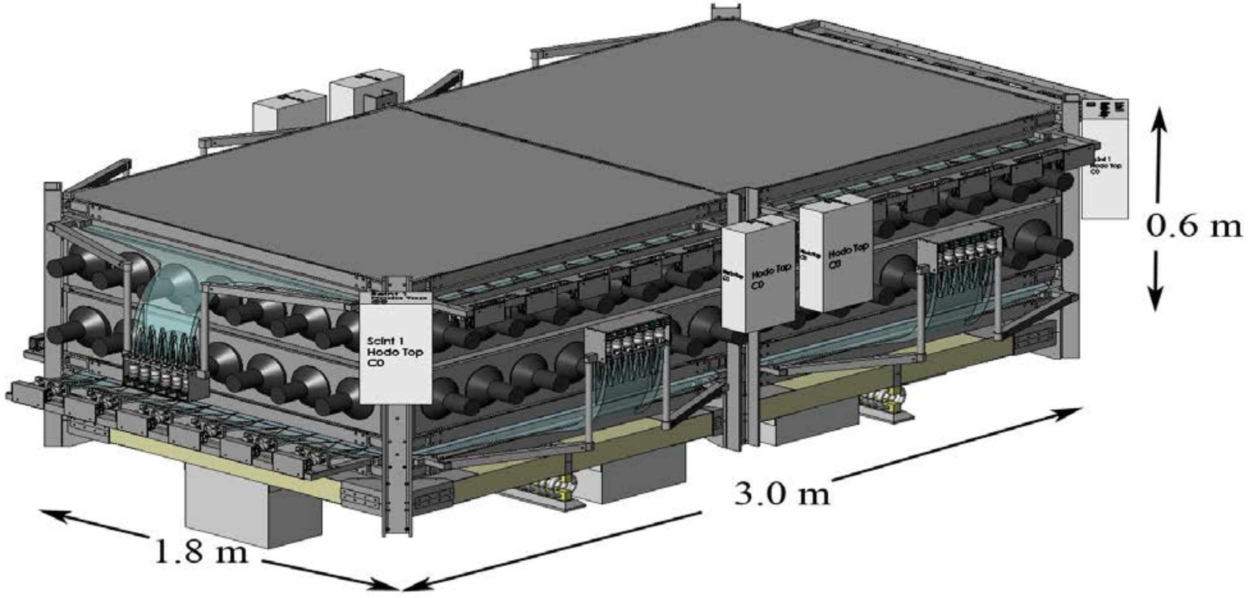
Q. ABARR[1], Y. AKAIKE[2,6], W.R. BINNS[1], R.G. BOSE[1], T.J. BRANDT[2], D.L. BRAUN[1], N. CANNADY[2,6], R.M. CRABILL[3], P.F. DOWKONTT[1], S.P. FITZSIMMONS[2], T. HAMS[2], M.H. ISRAEL[1], J.F. KRIZMANIC[2,6], A.W. LABRADOR[3], J.T. LINK[2,6*], L. LISALDA[1], R.A. MEWALDT[3], J.W. MITCHELL[2], G.A. DE NOLFO[2], M.O. OLEVITCH[1], B.F. RAUCH[1], K. SAKAI[2,6], F. SAN SEBASTIAN[2], M. SASAKI[2,6], G.E. SIMBURGER[1], E.C. STONE[3], T. TATOLI[2], C.J. WADDINGTON[5], N.E. WALSH[1], A.T. WEST[1], M.E. WIEDENBECK[4], W.V. ZOBER[1]

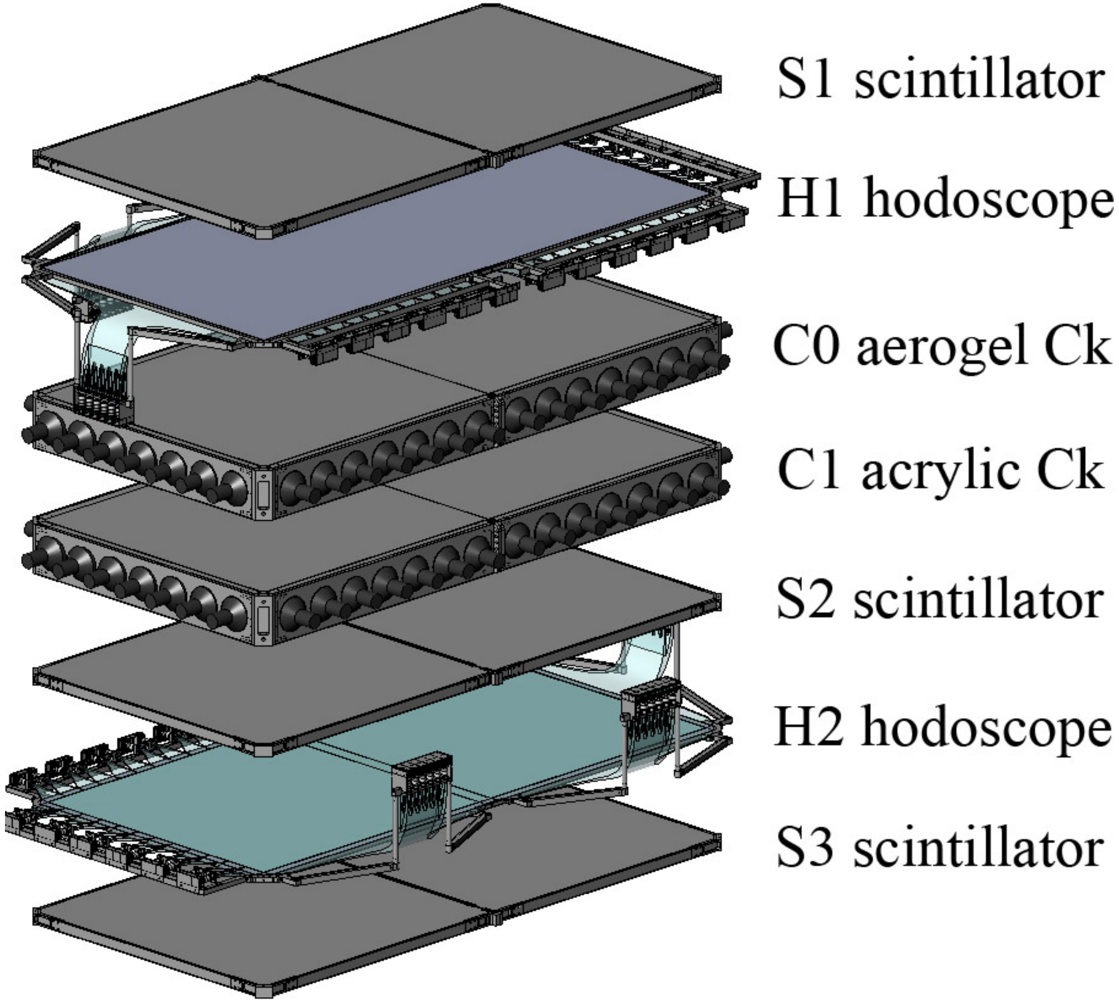
1. Washington University in St. Louis, St. Louis, MO 63130 USA
2. NASA/Goddard Space Flight Center, Greenbelt, MD 2077 USA
3. California Institute of Technology, Pasadena, CA 91125 USA
4. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 USA
5. University of Minnesota, Minneapolis, MN 55455 USA
6. Center for Research and Exploration in Space Science and Technology (CRESST)

* As of May 21, 2021 this person is no longer associated with NASA or CRESST

SuperTIGER Module Configuration (1 of 2)

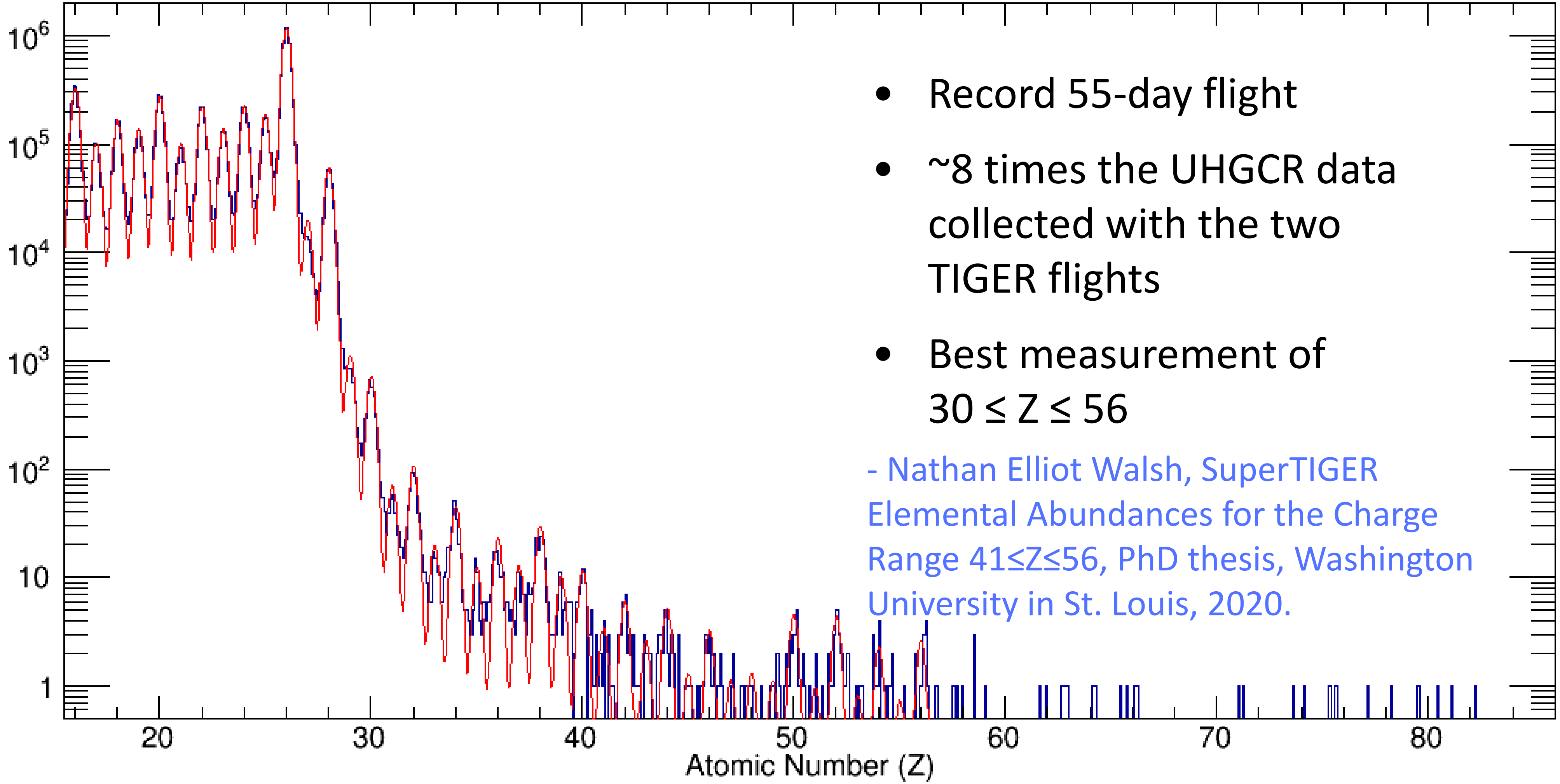
A Supersized (~4x) TIGER





- Stack of 7 detectors
  - 3 Scintillation counters
  - 2 Scintillating Fiber Hodoscopes
  - 2 Cherenkov Detectors
- Aerogel, n =1.043 or 1.025 (2.5 or 3.3 GeV/nucleon)
- Acrylic, n = 1.49 (0.3 GeV/nucleon)
- Effective area 2.9 m2sr, 7.2 times that of TIGER.
- See instrument paper: **Binns et al. ApJ (2014) 788:18**

SuperTIGER Galactic Cosmic Ray Abundances



- Record 55-day flight
- ~8 times the UHGCR data collected with the two TIGER flights
- Best measurement of $30 \leq Z \leq 56$

- Nathan Elliot Walsh, SuperTIGER Elemental Abundances for the Charge Range 41≤Z≤56, PhD thesis, Washington University in St. Louis, 2020.

OB Association Source Model Good Z≤40

Current OB association Galactic cosmic ray source (GCRS) model predictions:

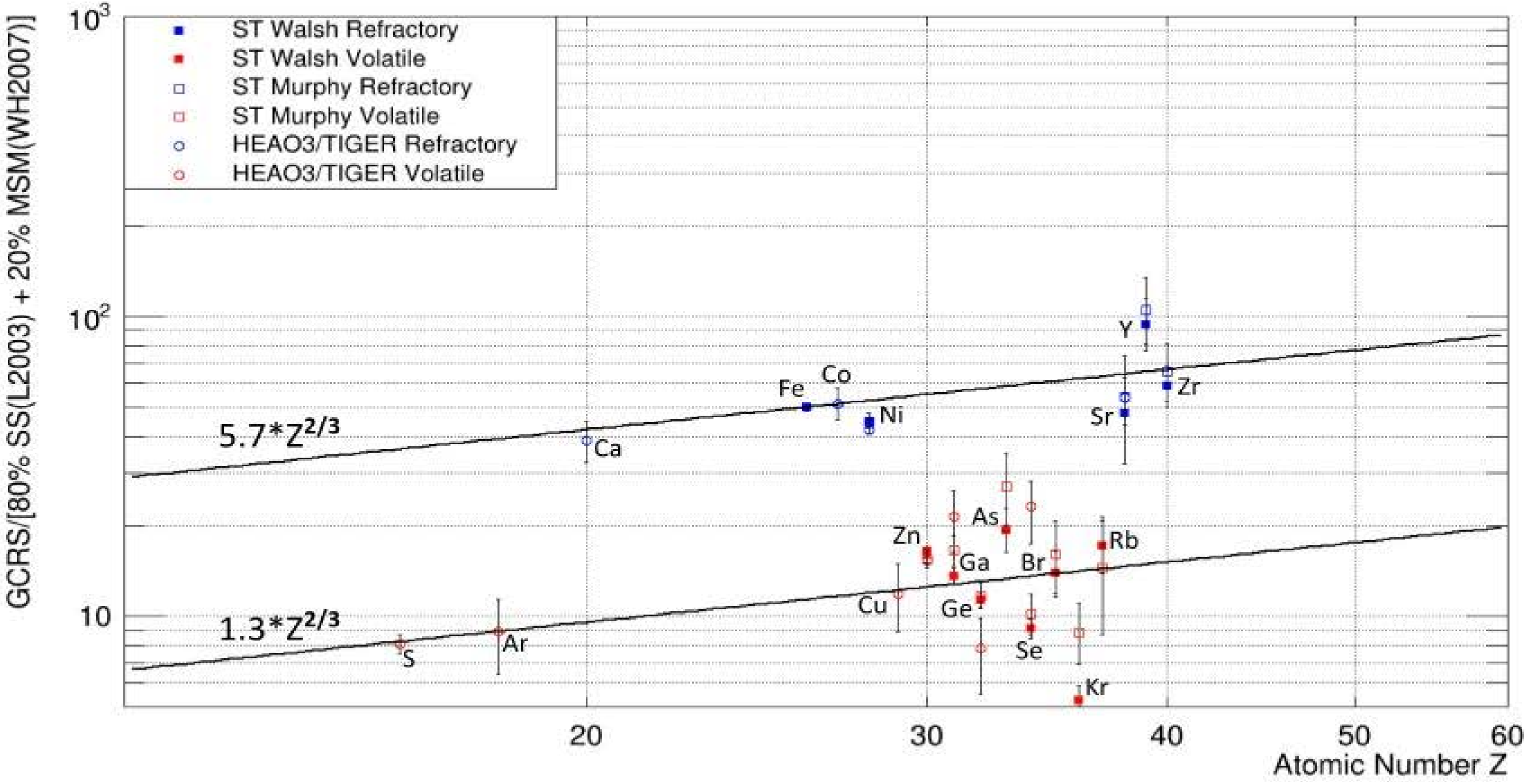
- GCRS = ~80% ISM + ~20% MSM
- interstellar medium (ISM) is similar in composition to Solar System (SS) material
- massive star material (MSM) includes stellar wind outflow and supernova (SN) ejecta

Refractory elements more likely in dust grains than volatiles preferentially injected into the accelerator

$Z^{2/3}$ injection dependence from grain sputtering cross sections seen for both refractories and volatiles

N44 Superbubble in LMC
Credit: Gemini Observatory, AURA, NSF

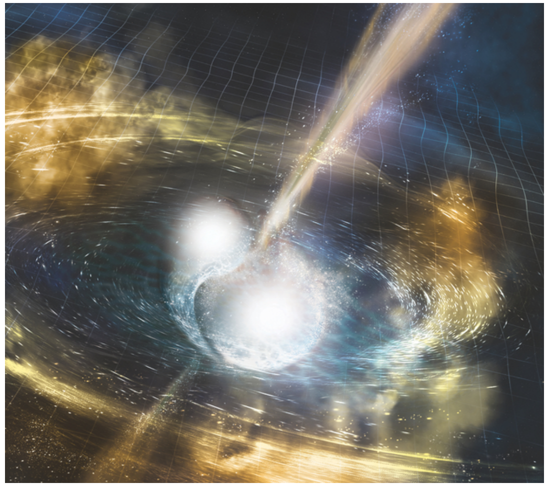
- Nathan Elliot Walsh, SuperTIGER Elemental Abundances for the Charge Range 41≤Z≤56, PhD thesis, Washington University in St. Louis, 2020.
- Rauch et al. 2009
- Murphy et al. 2016



Apparent Model Breakdown for Z>40

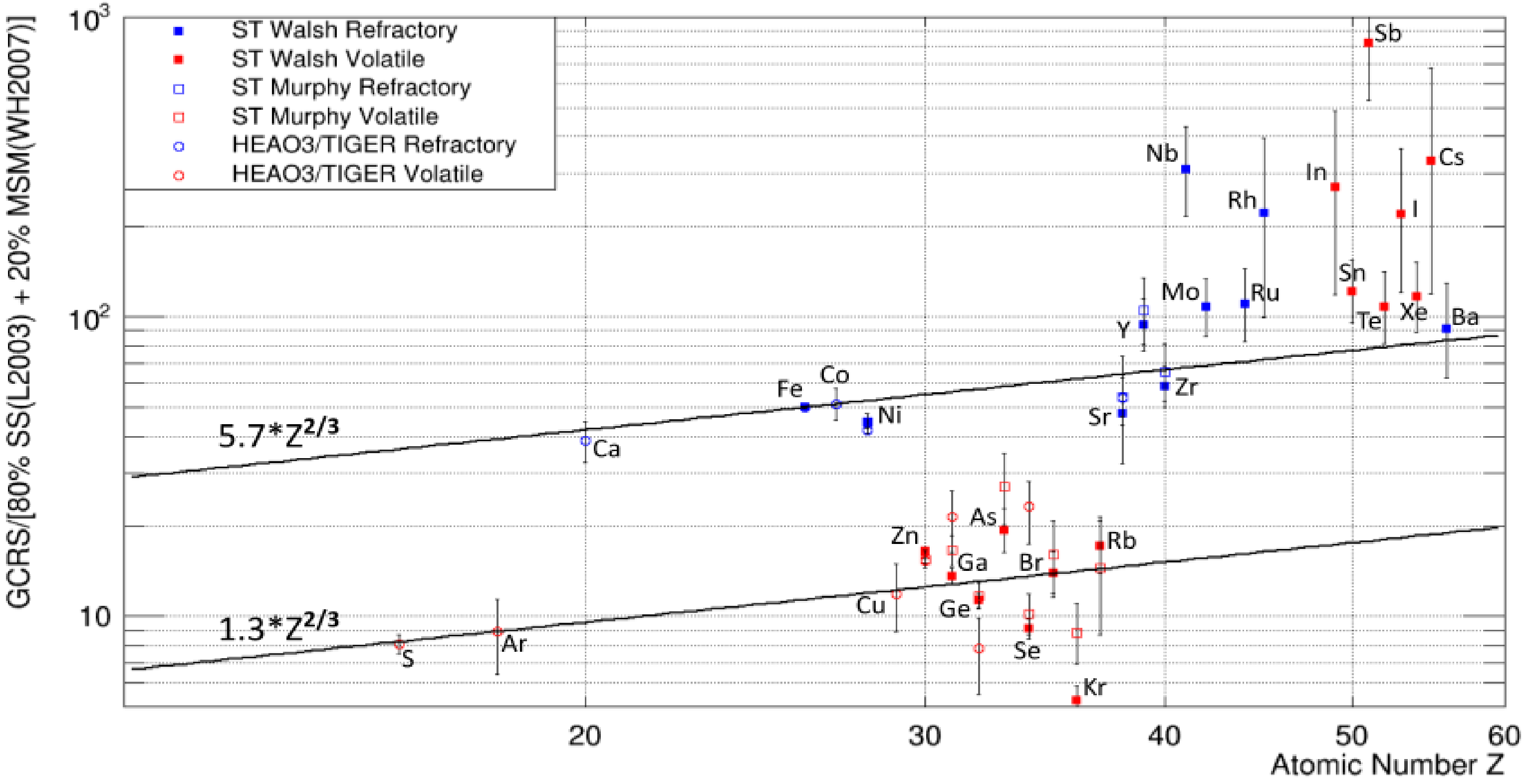
SuperTIGER Z>40 abundances elevated over refractory line: Model is missing something

- Change in acceleration mechanism?
- New source component, e.g., neutron star mergers? (worldwide interest coupled with GW detections). These results paved the way for TIGERISS.



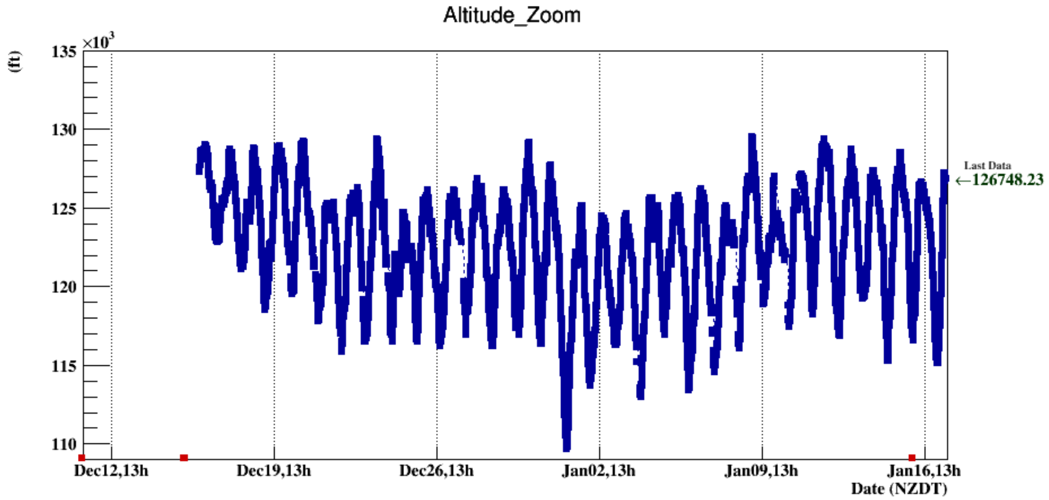
Artist Concept of a BNS such as GW170817

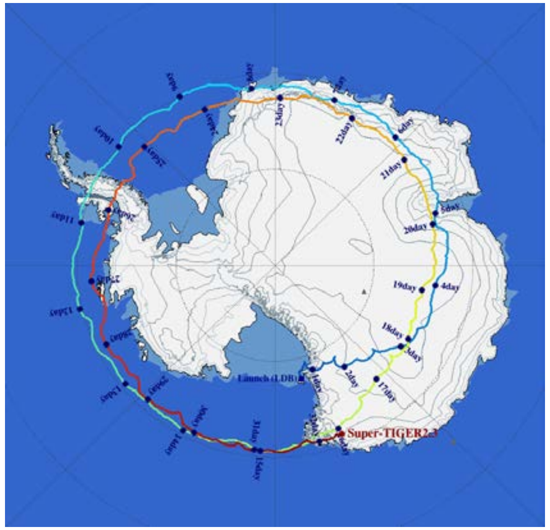
- Nathan Elliot Walsh, SuperTIGER Elemental Abundances for the Charge Range 41≤Z≤56, PhD thesis, Washington University in St. Louis, 2020.

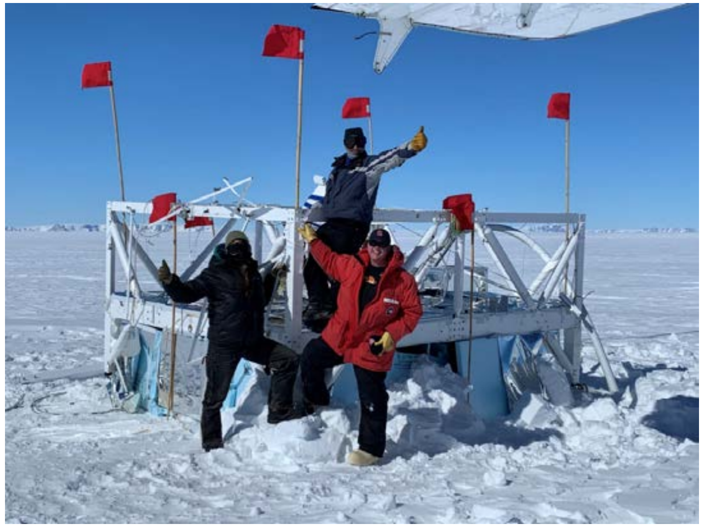


ST-2.3 Northerly 32 Day Flight

12-15-2019 -01-17-2020: 32 days

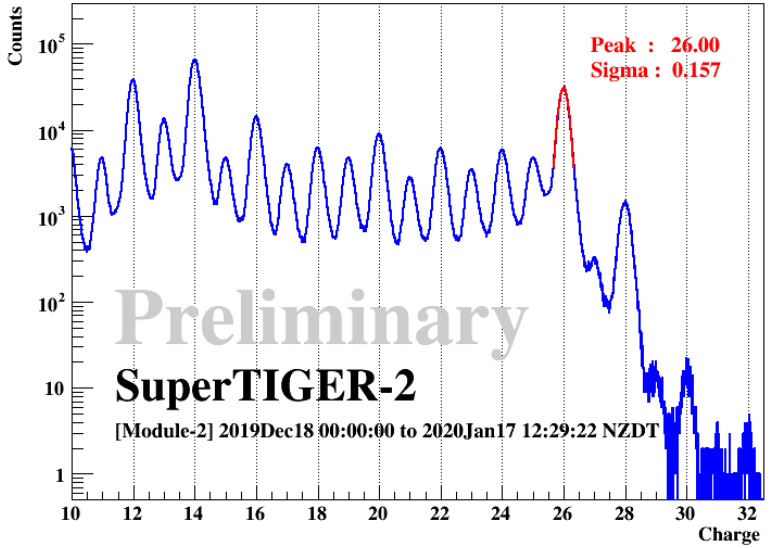


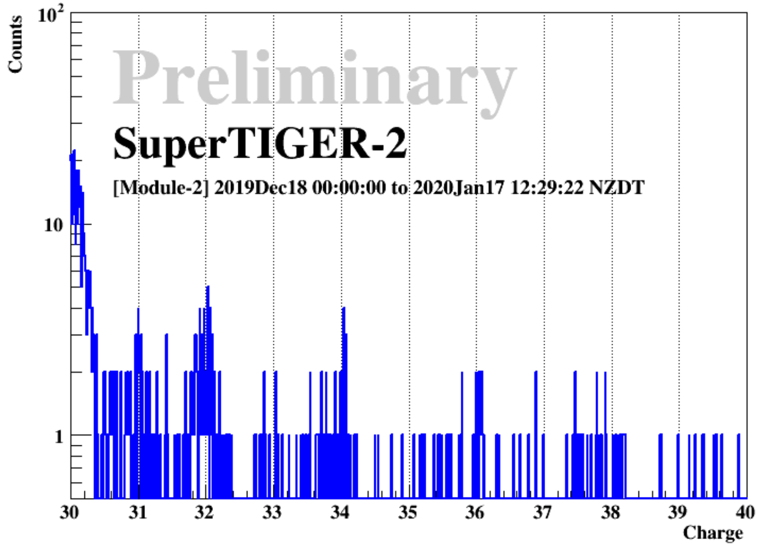




Module 1 computer failed after 3 days, only got ~1/3 as much data as ST-1.

01-22-2020 11-05-2021





ST-2.3 Status: Recovery - Perhaps

SuperTIGER-2.3 02-04-2023

CALET Collaboration as of April 2020

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30) University of Tokyo, Japan
31) Waseda University, Japan
32) Washington University-St. Louis, USA
33) Yokohama National University, Japan
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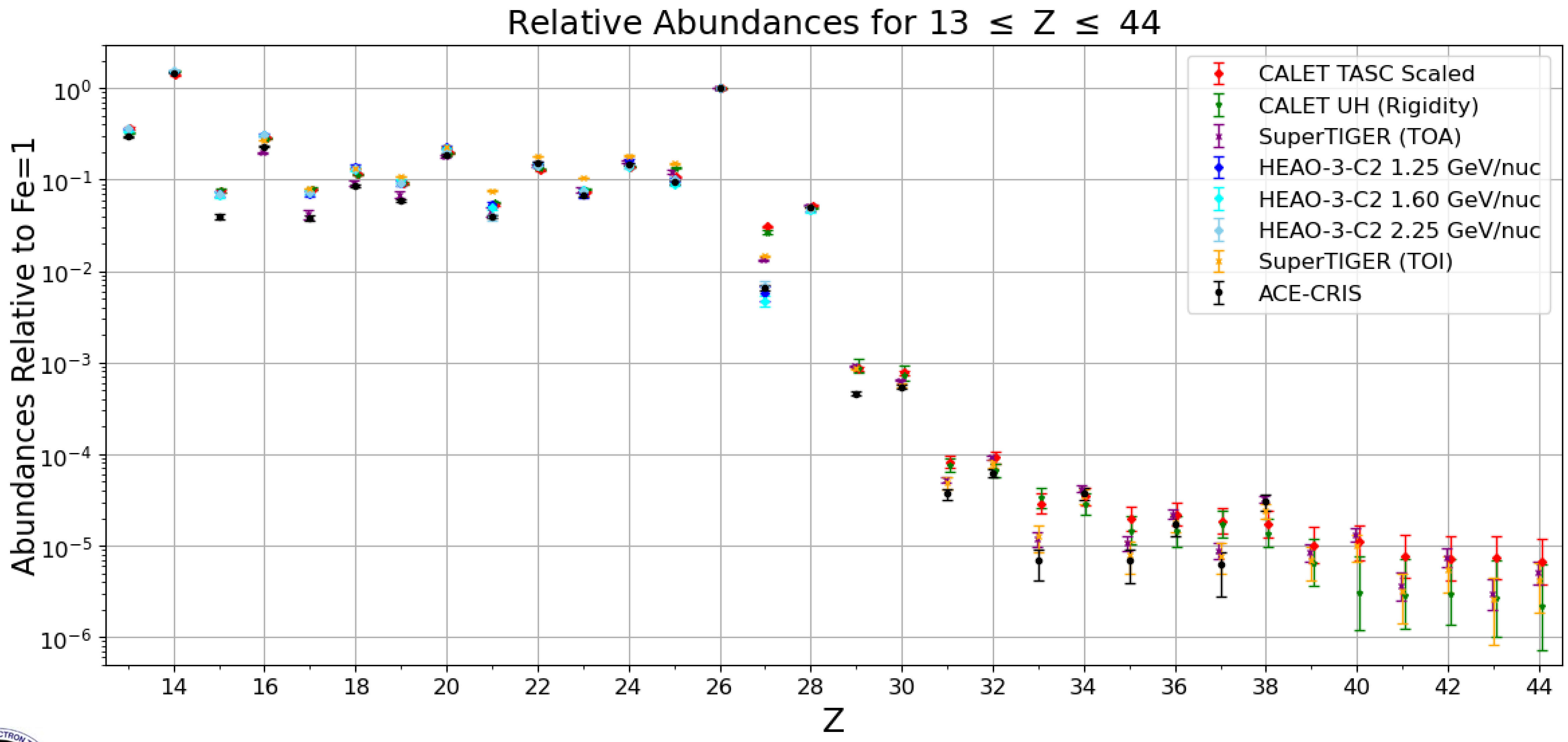
TIGERISS team members with CALET experience.

CALET Ultra-Heavy Galactic Cosmic Rays



The Trans-Iron Galactic Element Recorder for the International Space Station (TIGERISS)

Selected in Second NASA Astrophysics Pioneers Solicitation

Brian Rauch WUSTL– PI

John Krizmanic GSFC – Deputy PI

TIGERISS Collaboration

Washington University in St. Louis

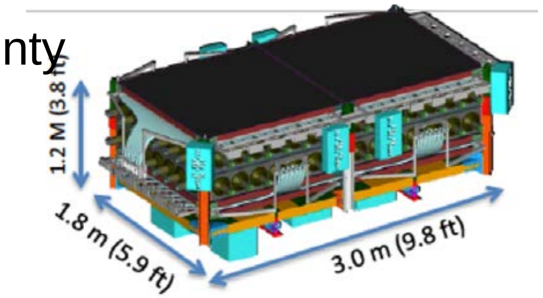
NASA Goddard Space Flight Center

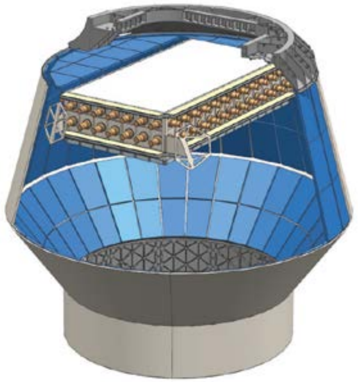
University of Maryland, Baltimore County

Howard University

Pennsylvania State University

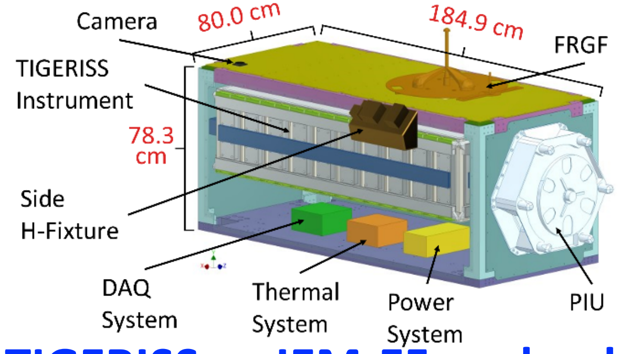
Northern Kentucky University





TIGERISS - Heritage

Instrument: 1.5 m × 0.6 m × 0.42 m



TIGERISS as JEM-EF payload

TIGERISS Collaboration

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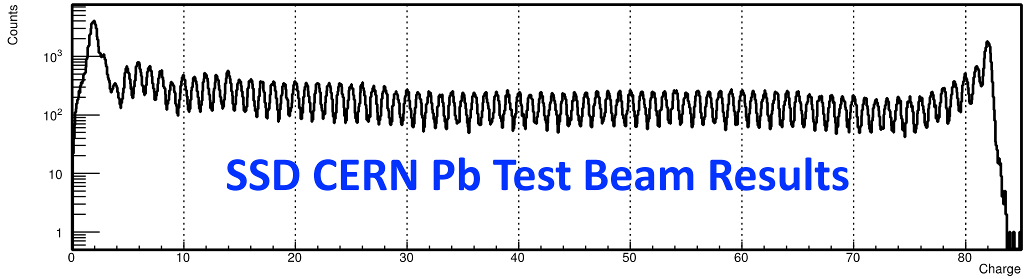
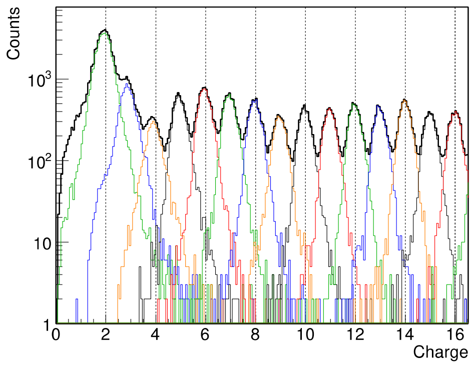
10. Stinger Ghaffarian Technologies, Washington, DC 20002, USA

TIGERISS Instrument

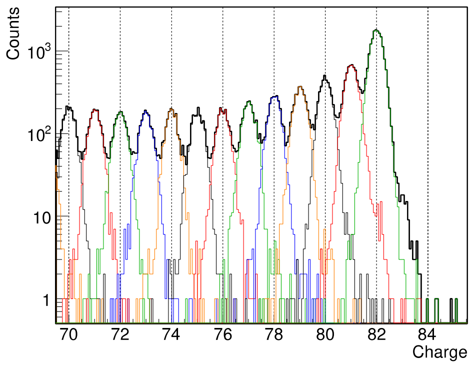
Silicon strip detector (SSD) for precision charge measurement 5 ≲ Z ≤ 82 and SiPM Cherenkov detector readout based on CERN testing.



(a) $Z = 2 - 82$



(b) $Z = 2 - 16$



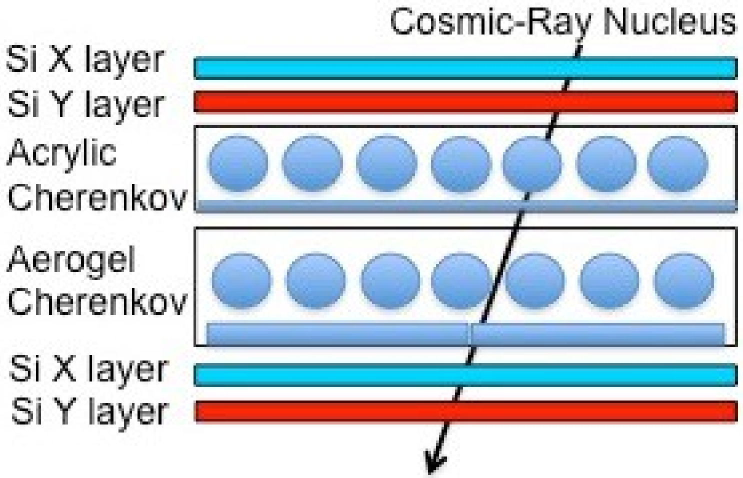
(c) $Z = 70 - 82$

$\sigma_Q < 0.24e$ for 5 ≲ Z ≤ 82

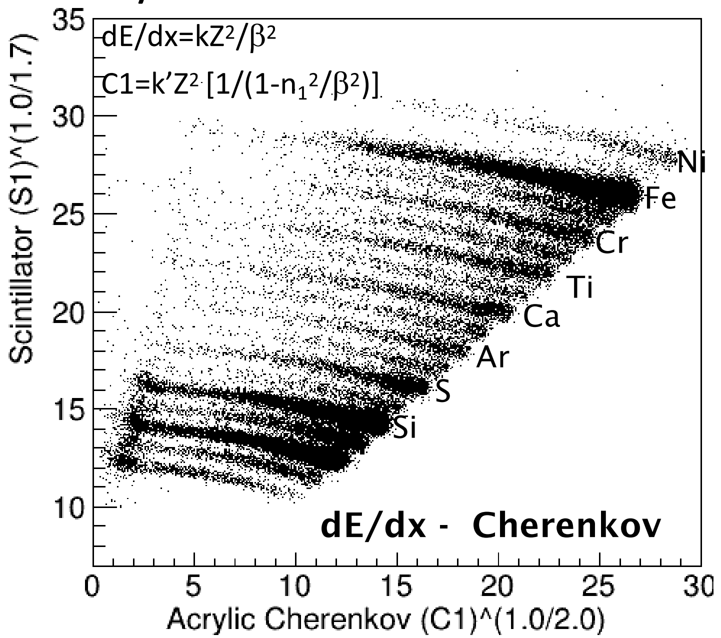
- Large electronic particle detector system – 1.1 m^2 active area, AΩ > 1.1 m^2 sr (JEM-EF version)

Charge measurement:

- dE/dx vs. Cherenkov
- Cherenkov vs. Cherenkov techniques:

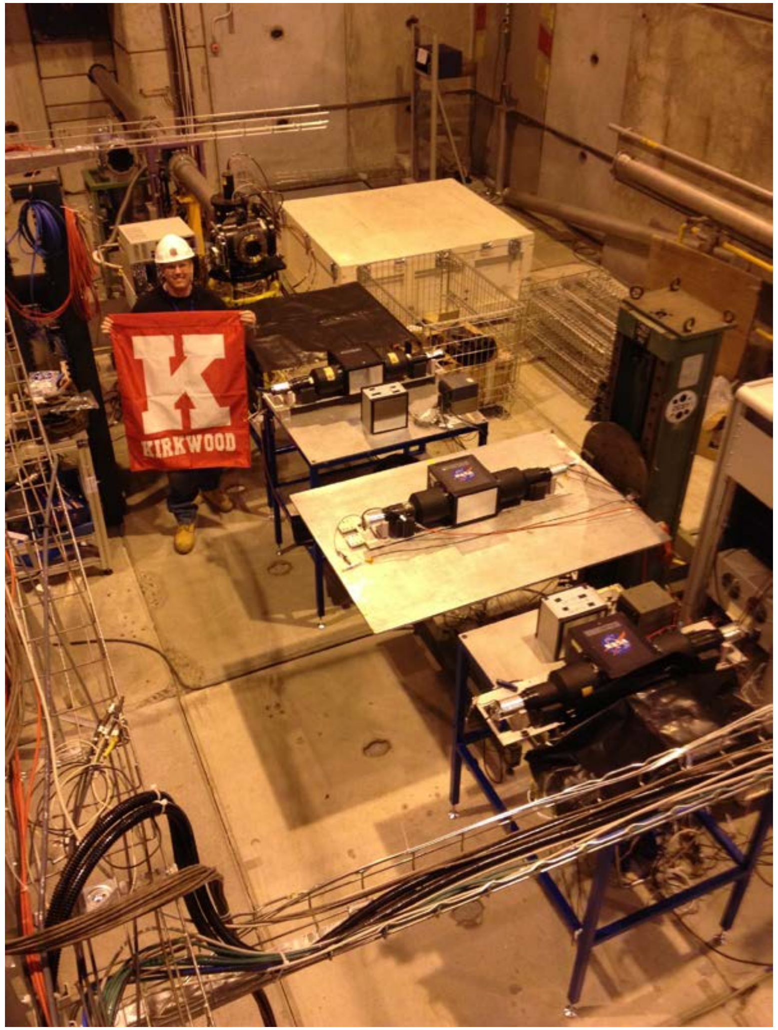


dE/dx vs. Cherenkov



Low Energies: Silicon vs. Acrylic Cherenkov

Beam Tests Comparing SuperTIGER Scintillators with Silicon Strip Detectors



- TIGERISS will use Silicon Strip Detectors (SSDs) that have far better signal saturation properties than the scintillators previously used, as demonstrated at CERN beam tests.
- SSDs will provide both position and charge information, replacing scintillating fiber hodoscope and scintillator detectors.
- TIGERISS will use silicon photomultipliers (SiPMs) that operate at ~50 V also tested at CERN beam runs.

Mandated to Consider All ISS Attachment Points

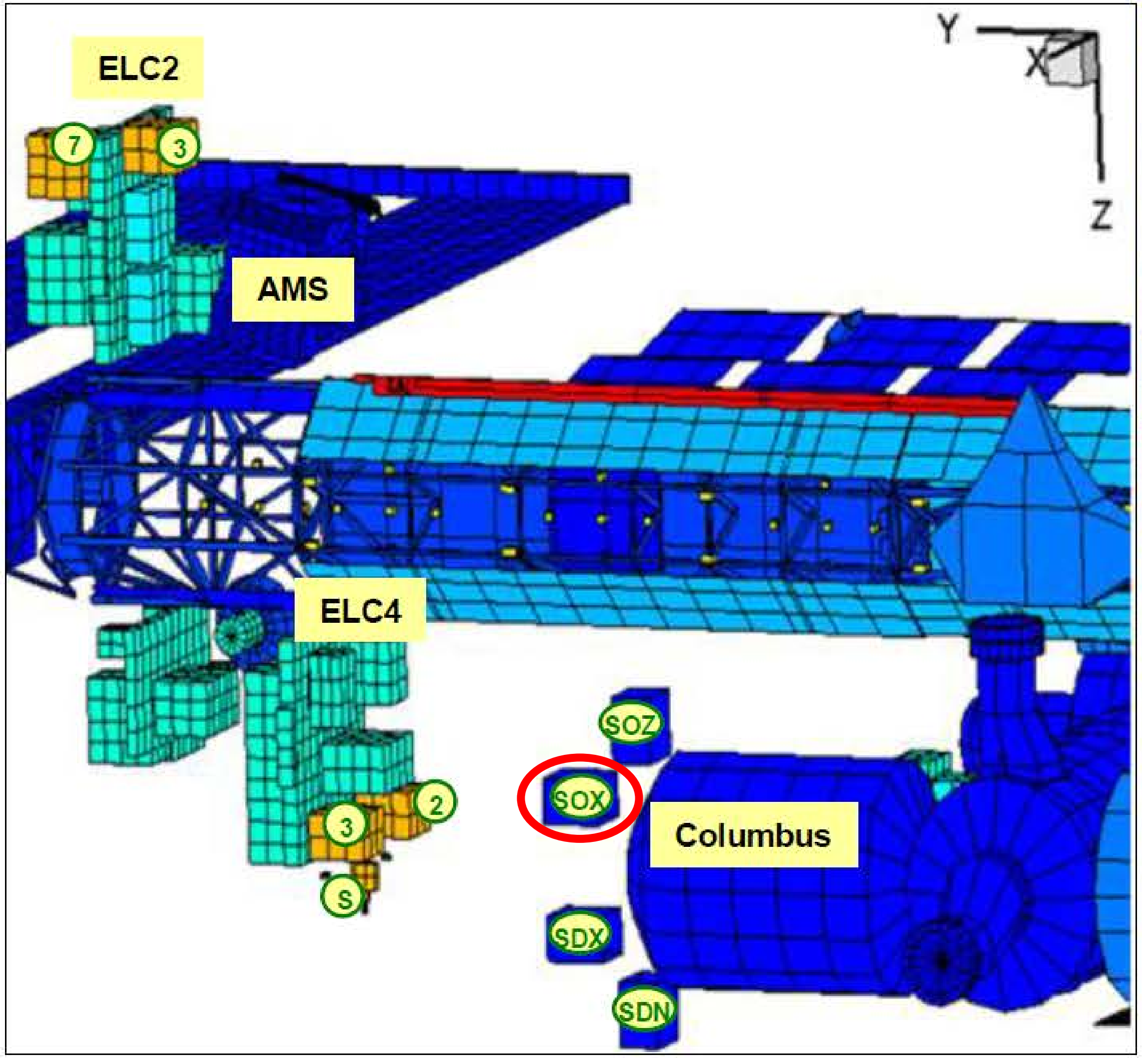
TABLE 4.0-1 ISS EXTERNAL CAPABILITIES COMPARISON, pg. 4-2, SSP 51071

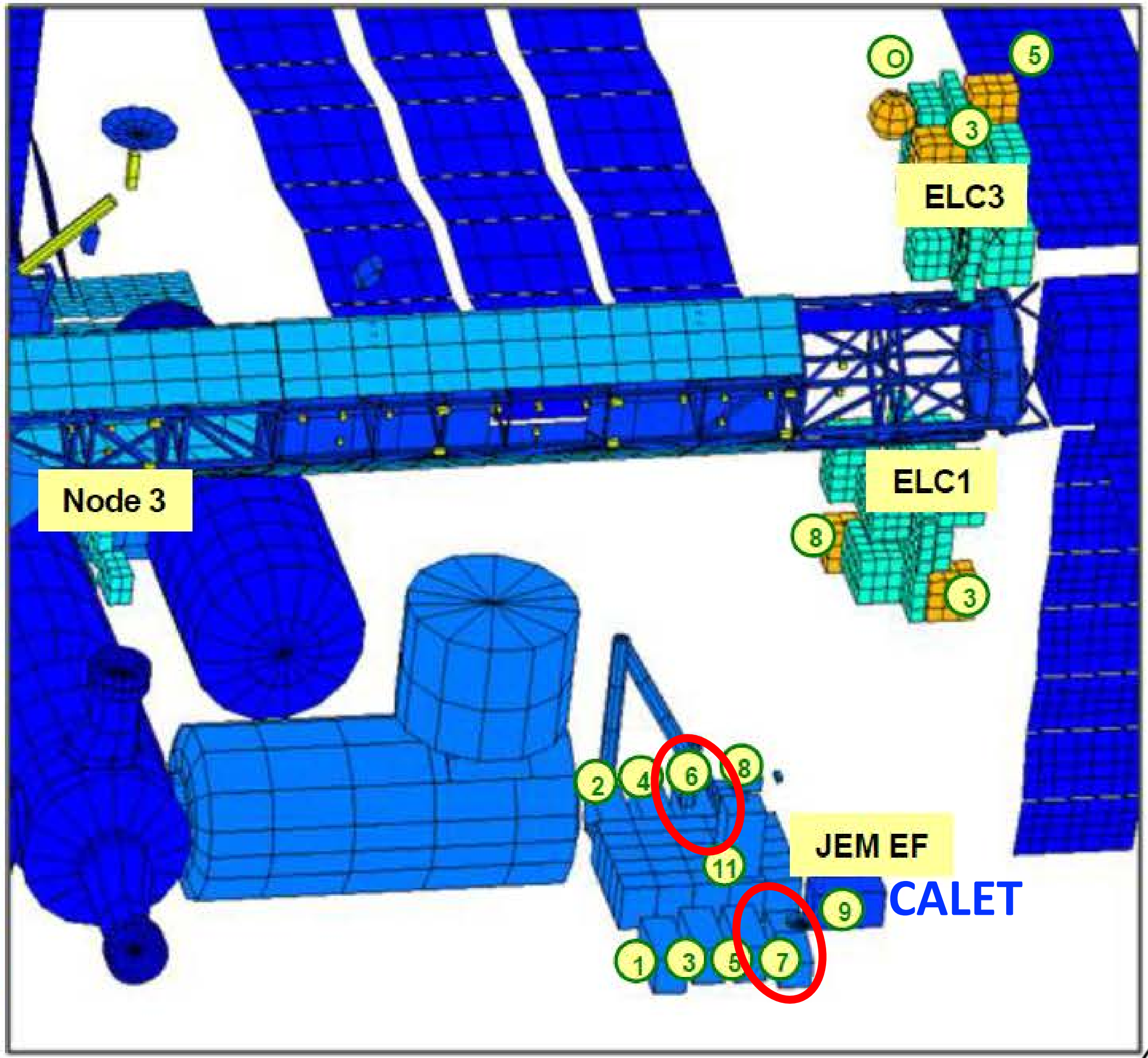
Service/Location	ELC/ExPRESS Payload Adapter (ExPA)	JEM-EF	Columbus-EPF
Payload Mass lbs [kg]	500 [226.8]	1100 [500] @ standard payload locations 5500 [2500] @ heavy payload locations	500 [230]
Payload Volume	34×46×49 (H, in.) or 1 m^3	72.83×31.5×39.37 (H, in.) or 1.5 m^3	34×46×49 (H, in.) or 1 m^3
Thermal	Passive cooling, active heating (using PD-provided heating elements)	Active Cooling 3 kW @ standard-power locations, 6 kW @ high-power locations	Passive cooling, active heating (using PD-provided heating elements)
Power			
Operational Power (W)	750 @ 113-126 Vdc 500 @ 28 Vdc per ExPA (adapter)	3-6 kW, 113-126 Vdc*	2.5 kW total (shared) 113-126V between 2 feeds*
Survival Power watts	Primary/Secondary of 300 @ 106.5 to 126.5 Vdc each	120 W @ 110.5 to 126 Vdc Heater Power	1.2 kW @ 120±7 Vdc shared between the payload compliment
Command & Data Handling			
Ethernet	One-way Ethernet (10 BASE T) link for downlinking ELC cargo science data.	Refer to MRDL	Refer to MRDL
Low-Rate Data Link (LRDL)	20 kbps (typical) telemetry downlink using MIL-STD-1553B[14]	20-kbps (typical) telemetry downlink using MIL-STD-1553B[14]	20-kbps (typical) telemetry downlink using MIL-STD-1553B[14]
High-Rate Data Link (HRDL)	N/A	User data rate determined by parsing the 100-Mbps encoded signaling rate with Sync symbols. One-way downlink only via optical interface.	32 Mbps maximum shared data rate in 32-kbps increments. Data rate determined by parsing the 100-Mbps encoded signaling rate with Sync symbols. One-way downlink only via optical interface.
Medium-Rate Data Link (Wired)	N/A	Wired Ethernet (10/100 BASE T) for downlink and two-way Ku-band communication	Wired Ethernet (10/100 BASE T) for downlink and two-way Ku-band communication
Wireless Data	10–50 Mbps per External Wireless Communication (EWC) Access Point (AP)	10–50 Mbps per EWC Access Point	10–50 Mbps per EWC AP
Sites for External Payloads	Four ELC providing eight sites for payloads (2 sites per ELC)	Five available to NASA	Two available to NASA

* Note: Denotes resources are shared among payloads at that site (JEM-EF, Columbus)

ISS External Attachment Options

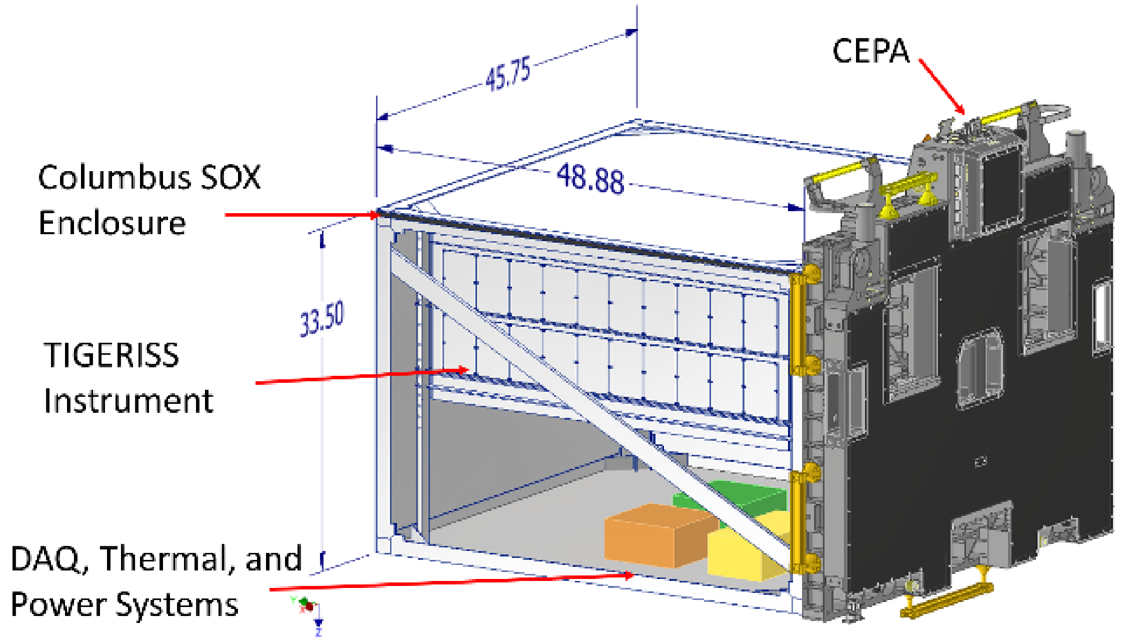
FIGURE 3.2.8-1 PAYLOAD MAPPING SITES (ELCS 1-4), pg. 3-32, SSP 51071



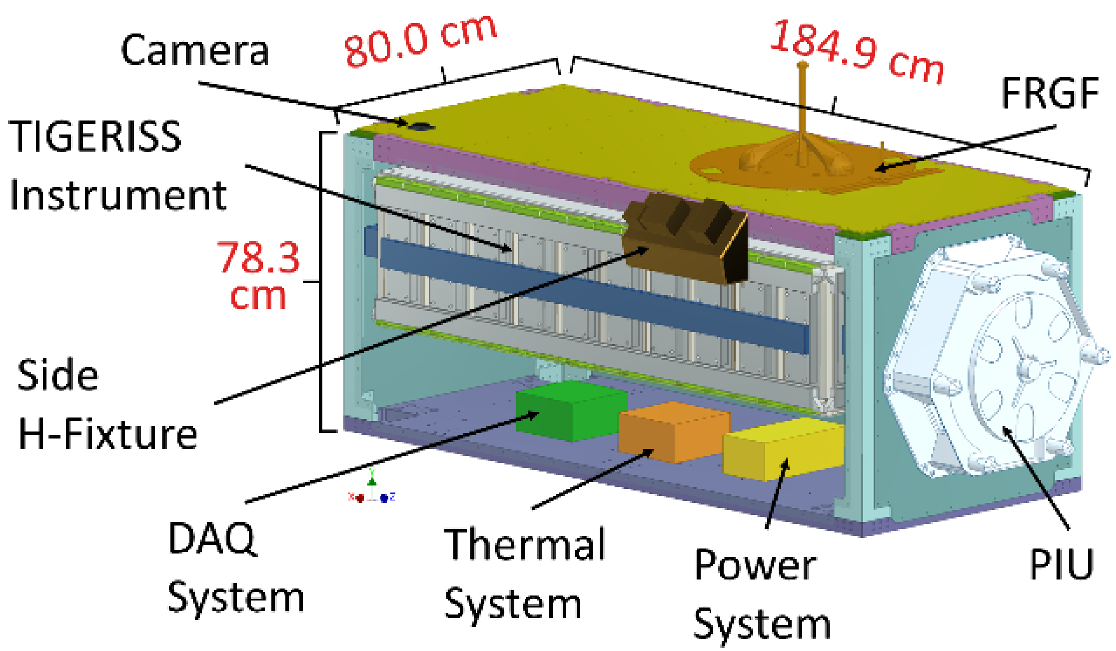


TIGERISS Instrument Configurations

Columbus-SOX

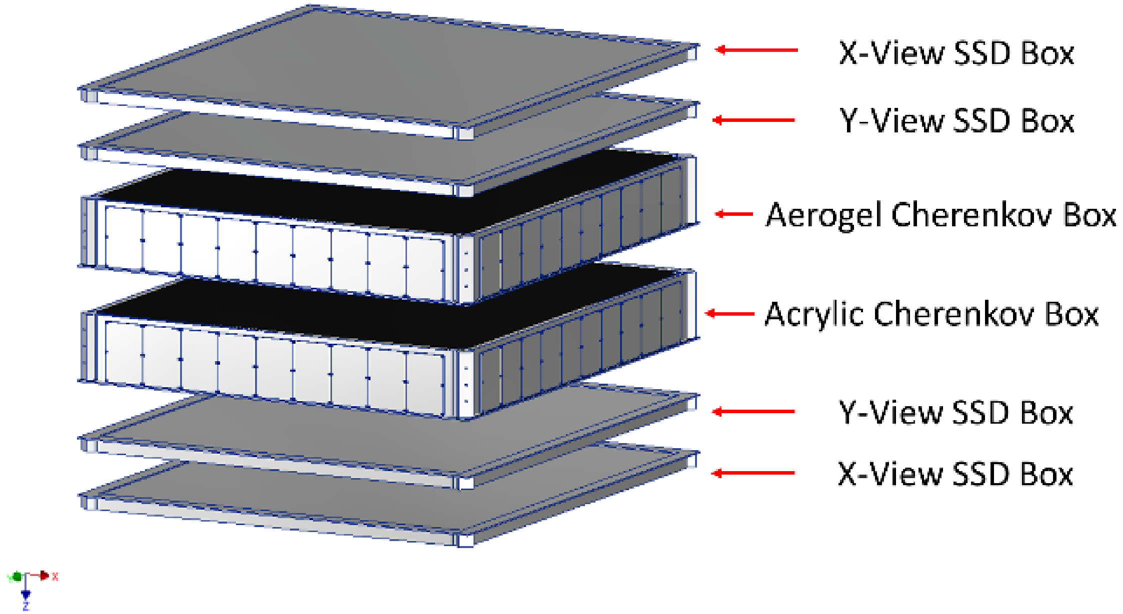


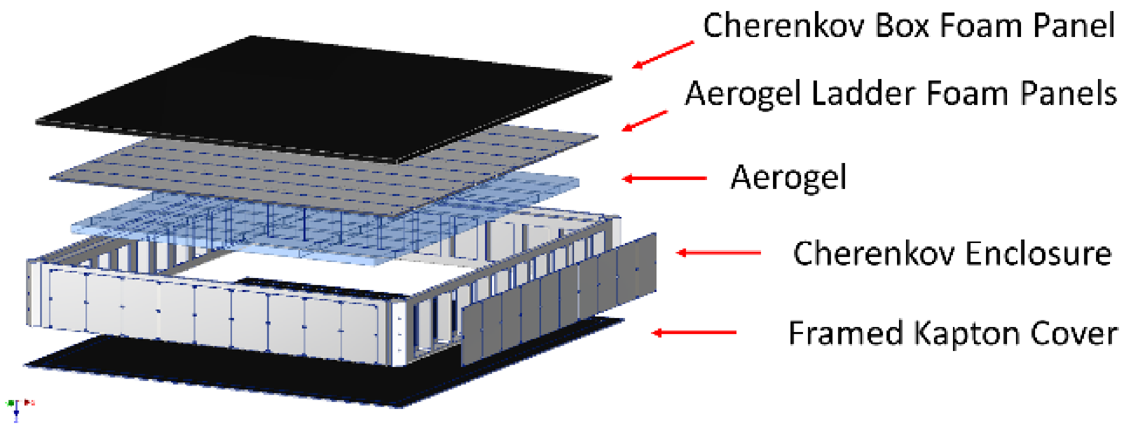
JEM-EF

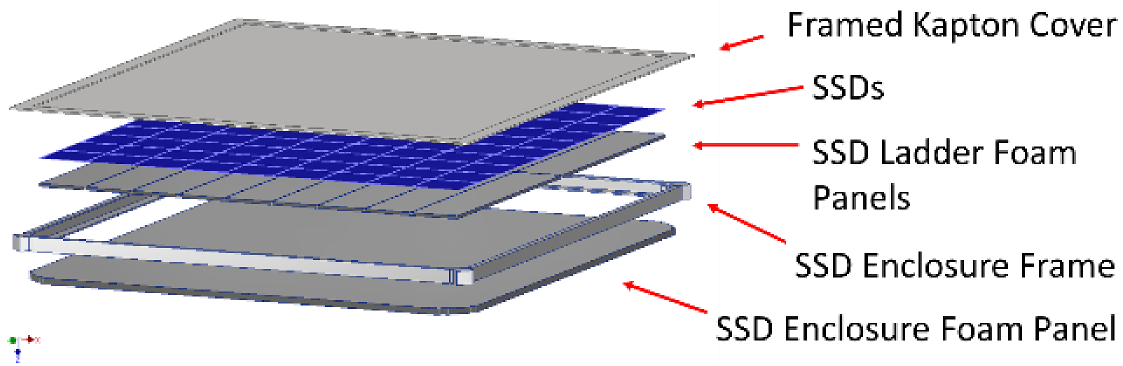


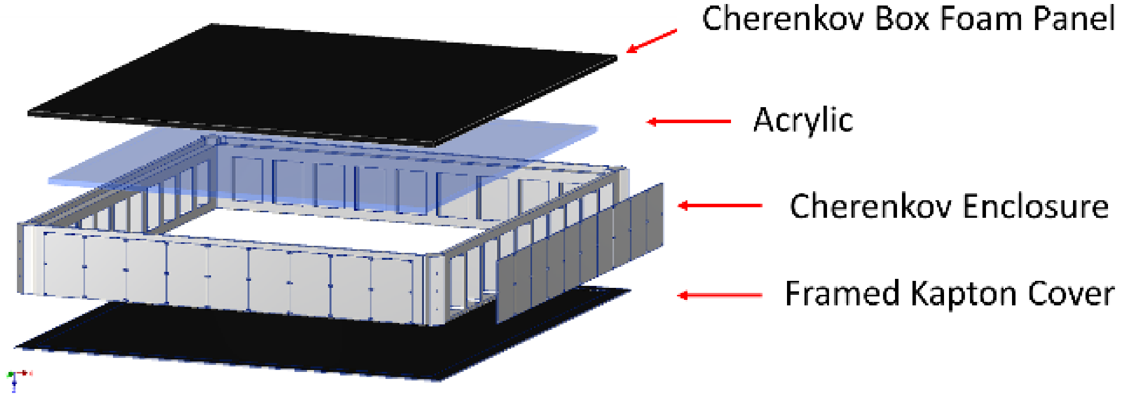
- ELC expected to be occupied at TIGERISS planned launch in 2026.
- Standard JEM-EF payload width 0.8 m.
- Considering a 1.0 m wide JEM-EF version subject to JAXA waiver.

TIGERISS Columbus SOX Instrument

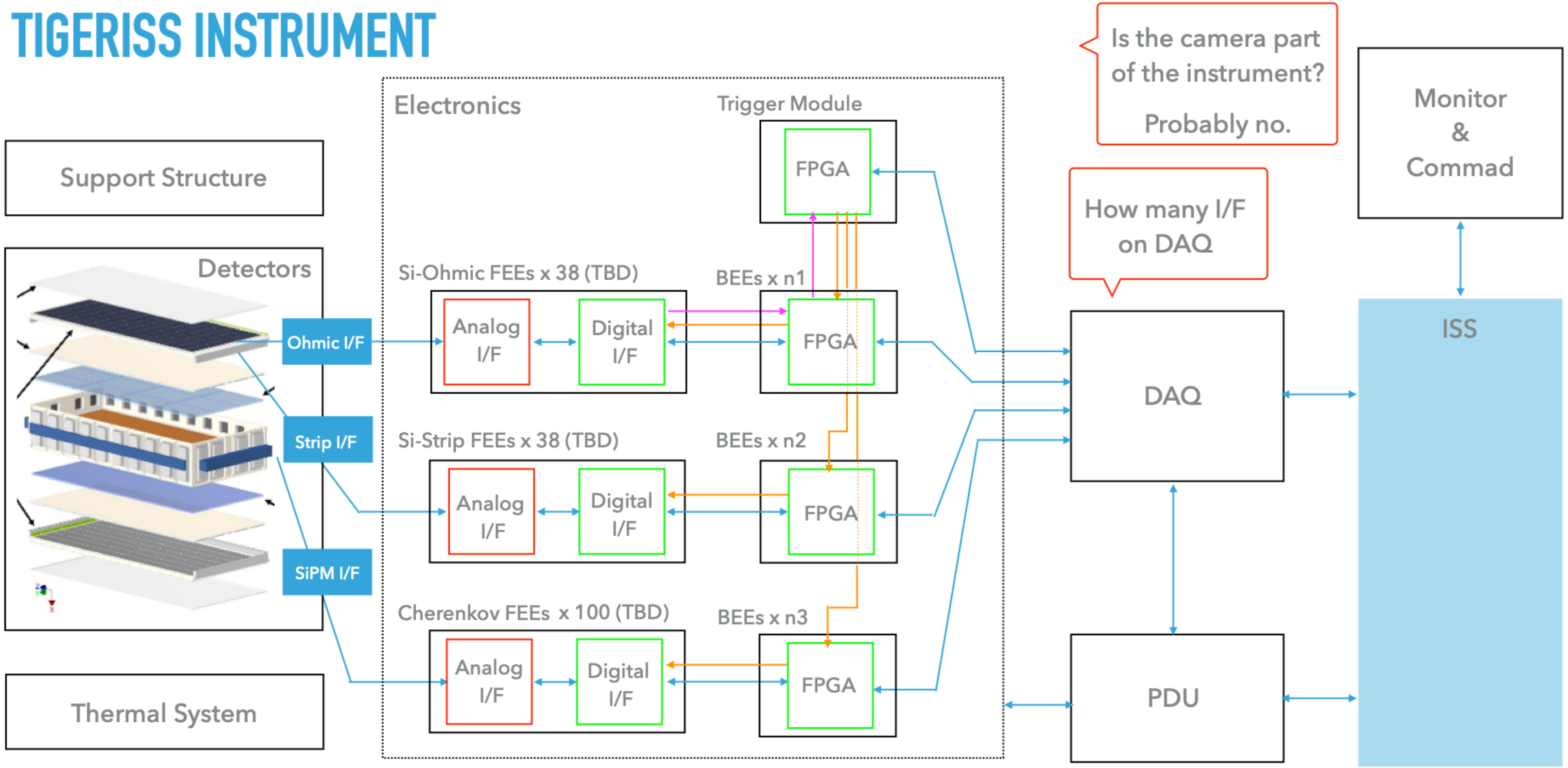




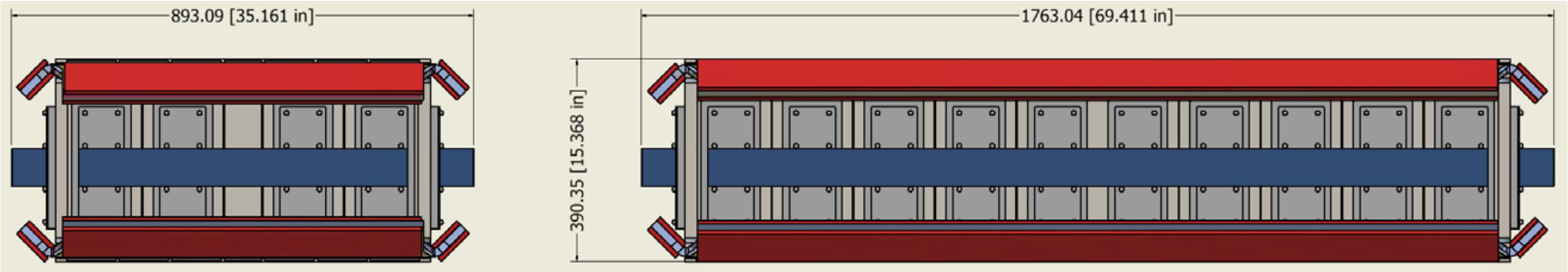


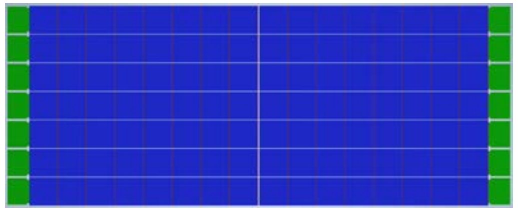


TIGERISS Instrument Block Diagram

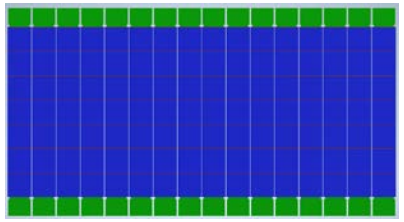


TIGERISS Silicon Strip Detectors (SSDs)

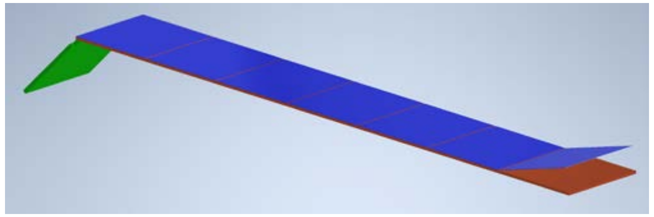




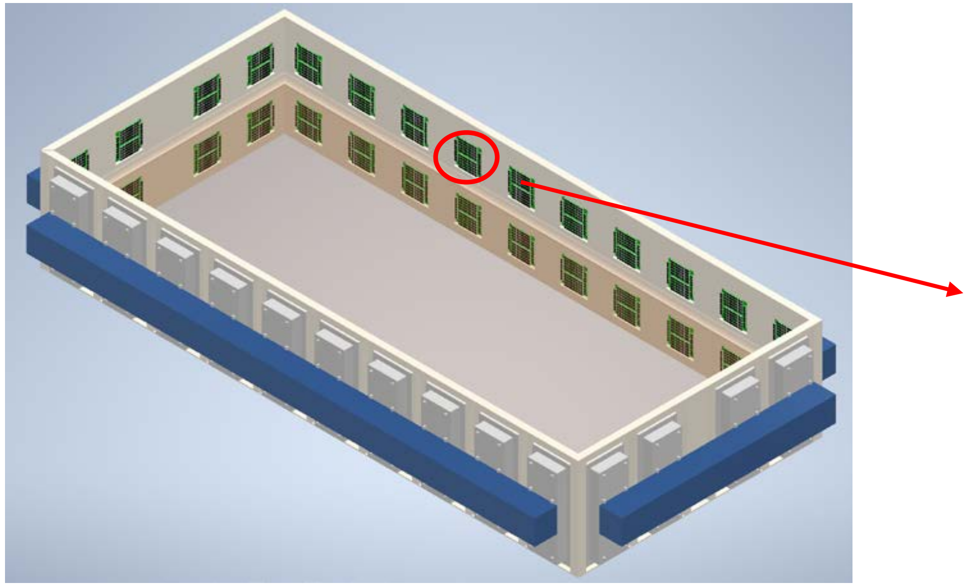
X-axis
Aligned

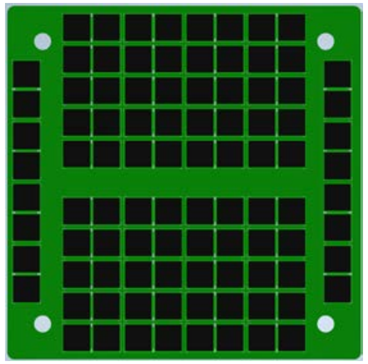


Y-axis
Aligned



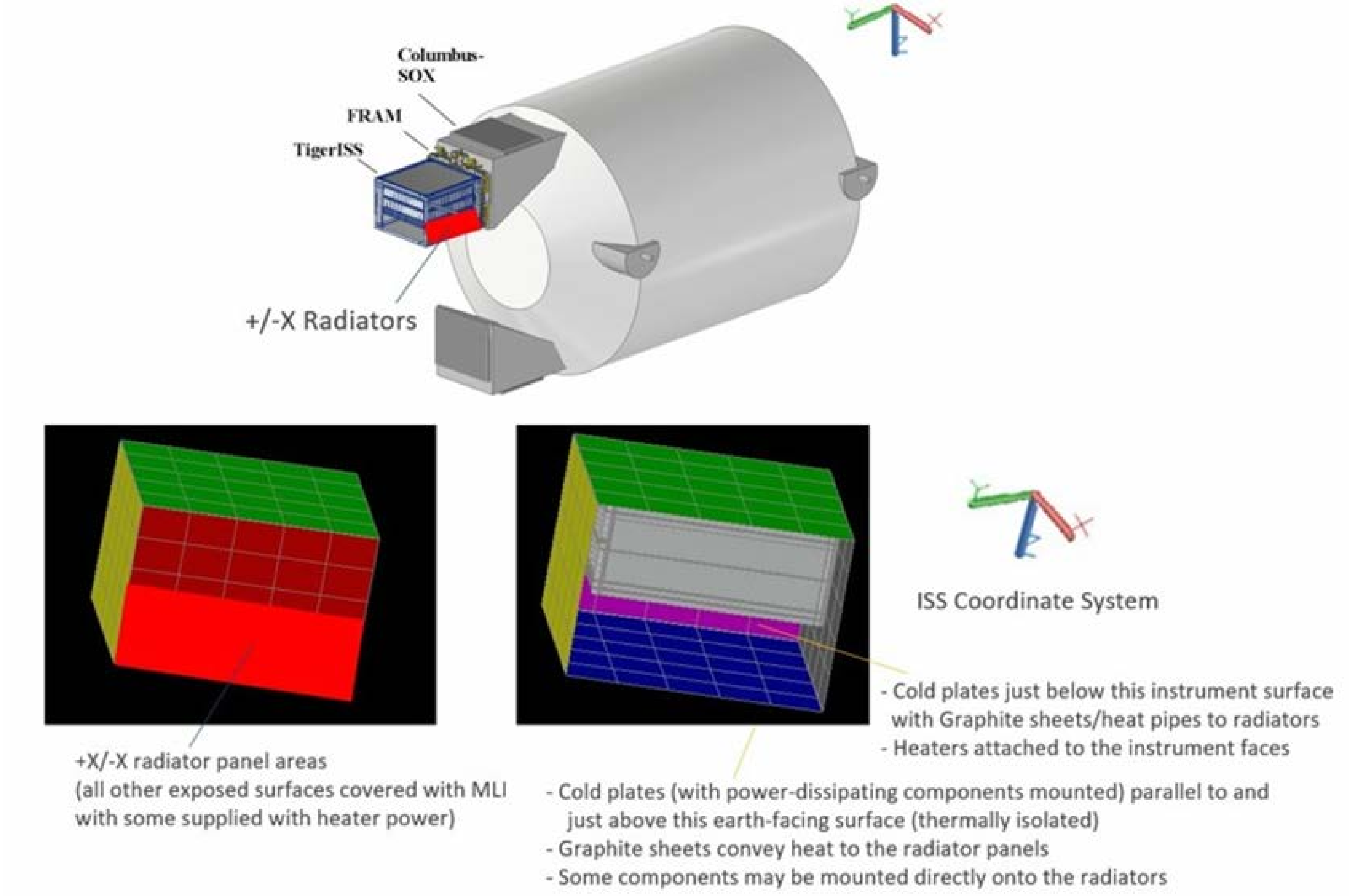
Aerogel and Acrylic Cherenkov Box
(radiators not shown)



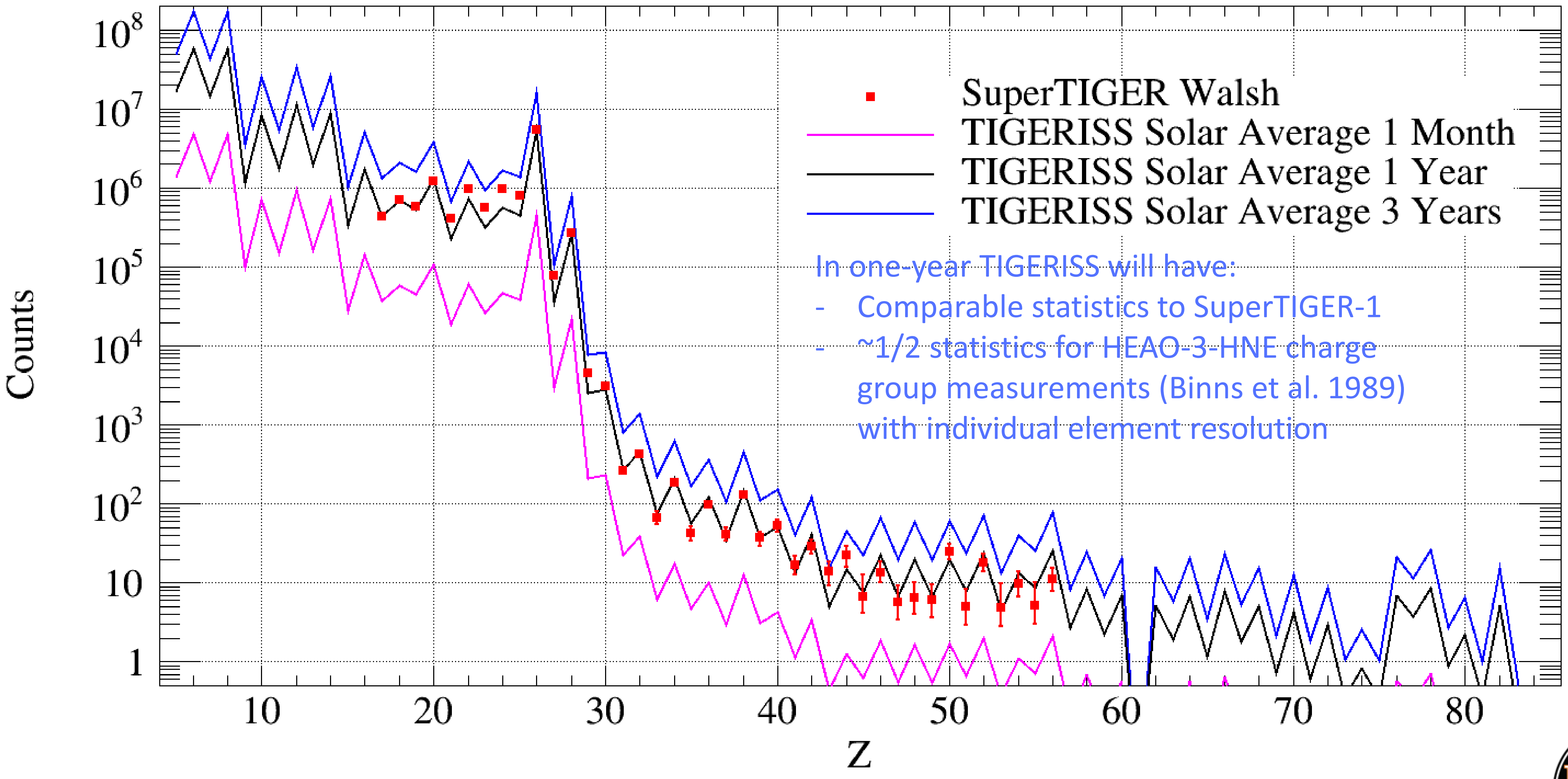


- Micron Silicon Strip Detector (SSD) in ladders
- SiPMs Hamamatsu S13360-6025 – provide high performance compact readout of light box

TIGERISS Columbus SOX Thermal System



Predicted TIGERISS Measurements



In one-year TIGERISS will have:
- Comparable statistics to SuperTIGER-1
- ~1/2 statistics for HEAO-3-HNE charge group measurements (Binns et al. 1989) with individual element resolution

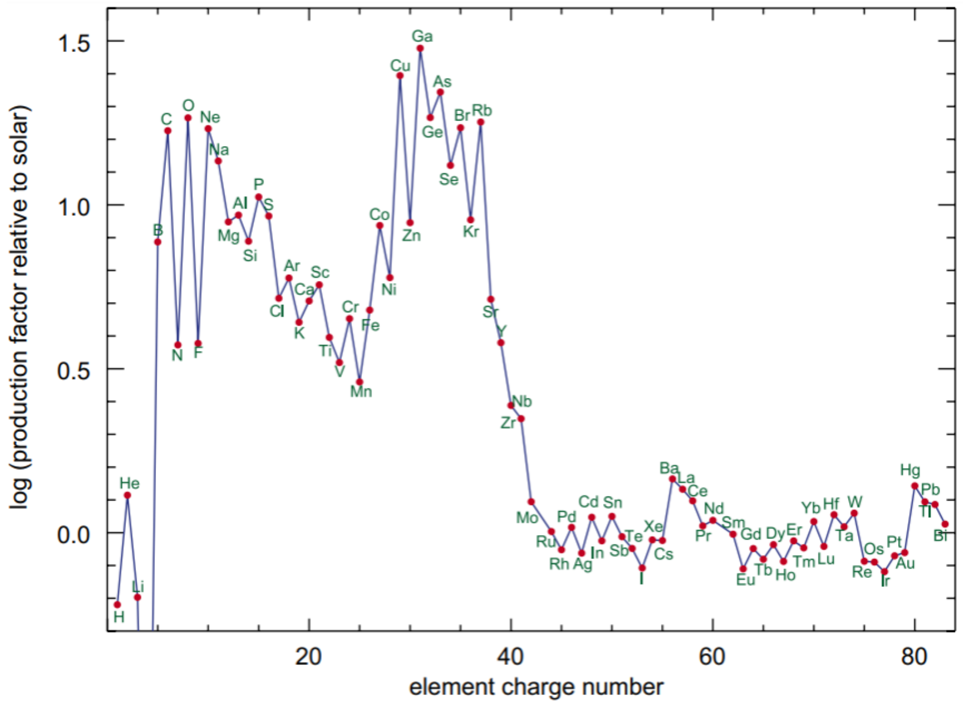
Heavy Element Production Models

How and where are the heaviest elements created?

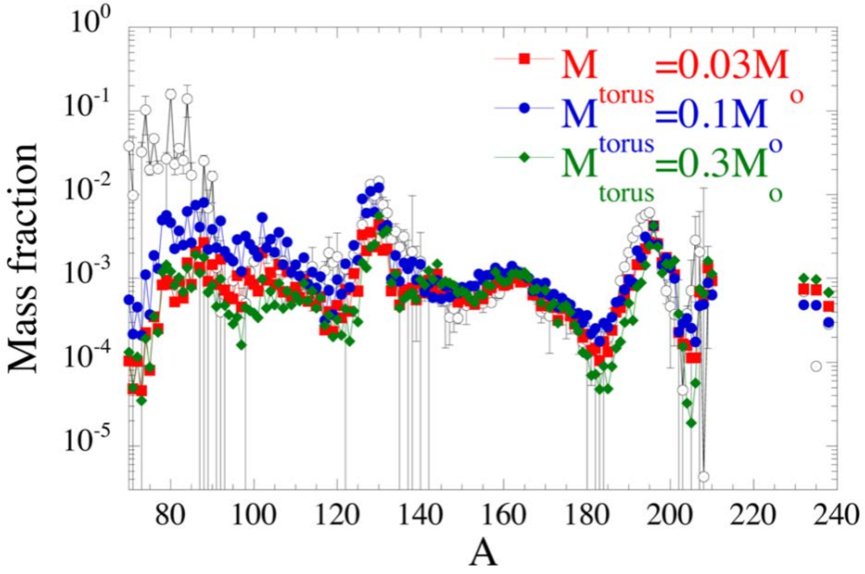
•TIGERISS's absolute and relative abundances of r- & s-process elements will probe NSM physics and contributions to GCRs

•TIGERISS will observe transition region between SN and NSM production at Z~40 (A~90)

•In an extended mission (5yr), TIGERISS will reach Pt-Pb region and constrain NSM production models

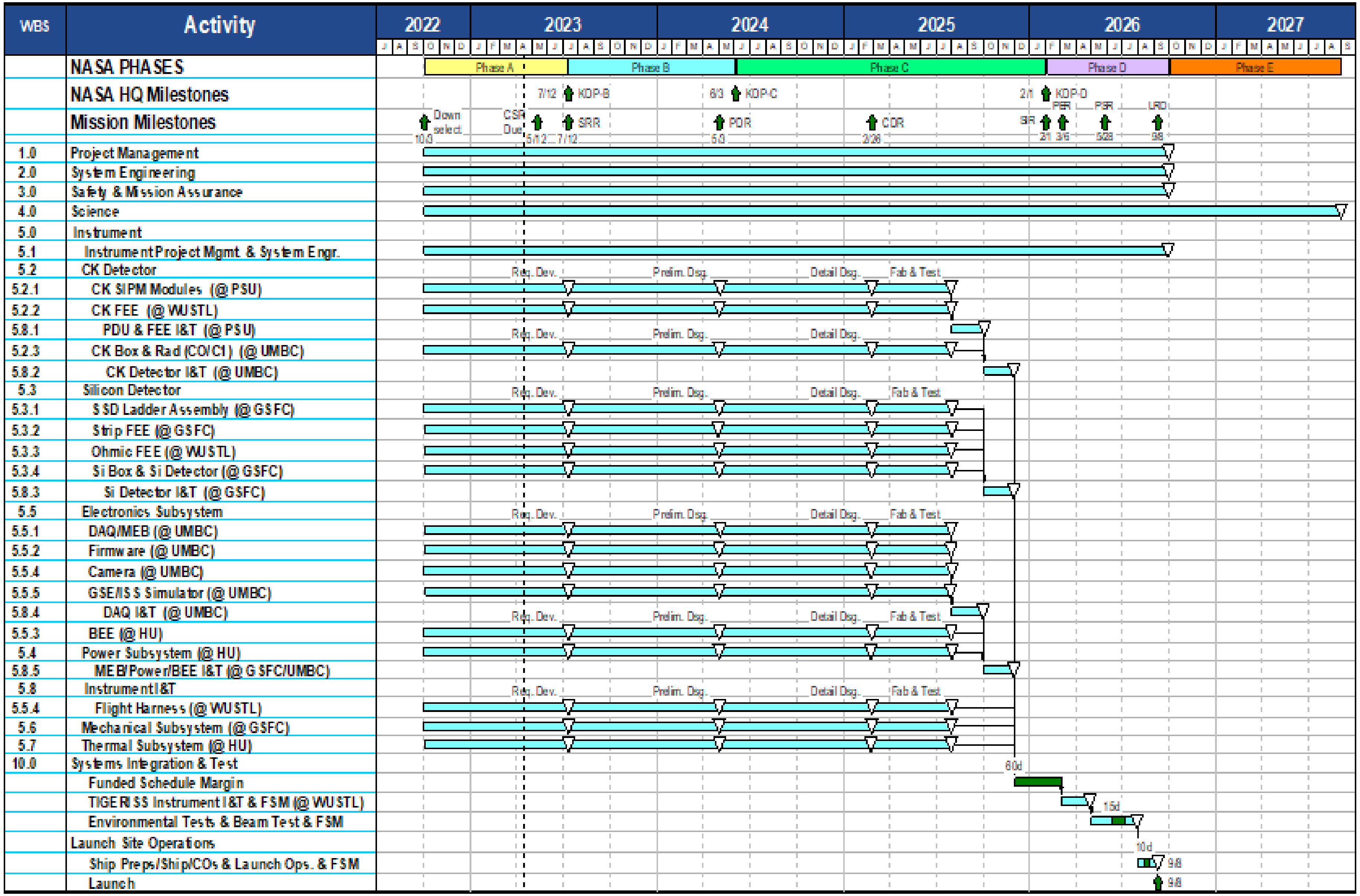


Supernova (SN) production relative to solar composition (Woosley & Heger, 2007, PhysRev 442, 269-283)



Neutron star merger (NSM) production model compared to solar composition (open circles) (Just et al., 2015, MNRAS 448, 541-567)

TIGERISS Term Schedule



Acknowledgements

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- We thank the NASA Columbia Scientific Balloon Facility, the NASA Balloon Program Office, and the NSF United States Antarctic Program for the record long-duration balloon flight for SuperTIGER-1, the successful recovery efforts, and the 32-day SuperTIGER-2.3 flight providing scientific and technical background for TIGERISS.

McDonnell Center for the Space Sciences

Peggy and Steve Fossett Foundation