SuperTIGER-2.3: The Third Time’s the Charm

Brian Flint Rauch for the SuperTIGER Collaboration

Wednesday, December 11, 2019
McMurdo Station, Antarctica

SuperTIGER-2 Collaboration

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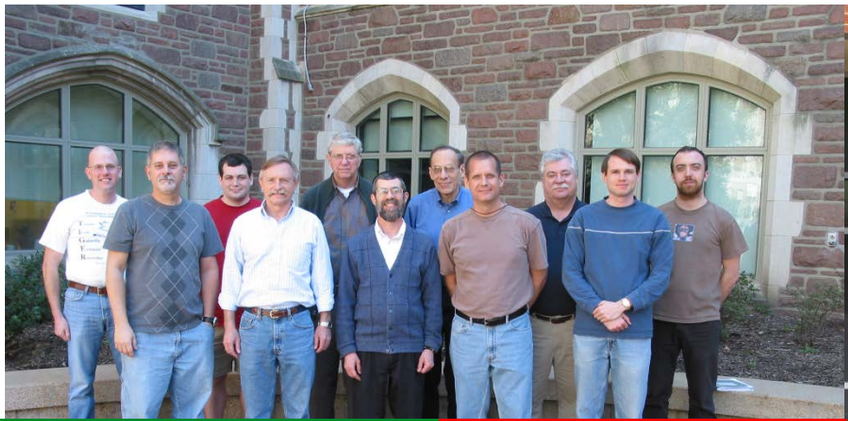
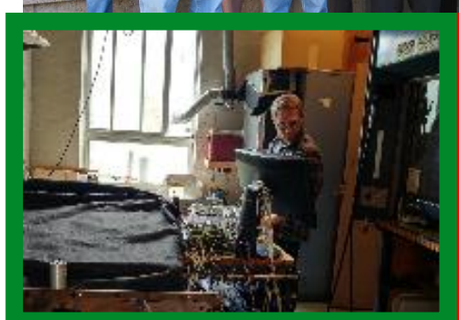
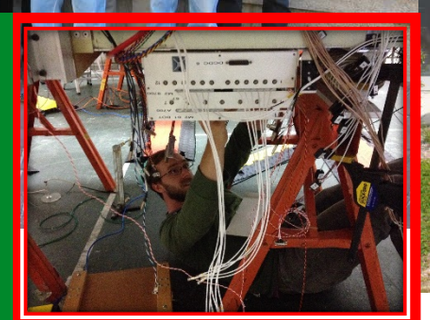
The Super-TIGER Team







Washington University

Science: Bob Binns, Martin Israel, Brian Rauch

Electronics engineers: Richard Bose, Paul Dowkontt

Electronics technician: Garry Simburger

Mechanical/Fiber technician: Dana Braun

Computer programmer: Marty Olevitch

Graduate students: Nathan Walsh, Wolfgang Zober

Undergraduate: David Battel

Machinists: Todd Hardt, Dennis Huelsmann

Goddard Space Flight Center

Science: John Mitchell, Thomas Hams, Theresa Brandt, Jason Link, Kenichi Sakai, Makoto Sasaki

Mechanical design: Devin Hahne, Frank San Sebastian

Gondola design: Mel Donahoo

Stress Analysis: Eduardo Aguayo, Paul Kirchman

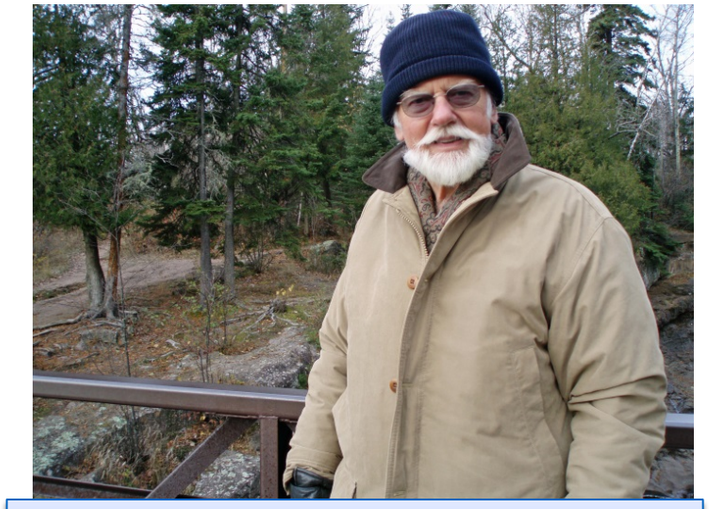
Electronics technicians: Bill Daniels, Ken Simms

Mechanical technician: Sean Fitzsimmons

Caltech/JPL

Science: Ed Stone, Allan Labrador, Dick Mewaldt, Mark Wiedenbeck

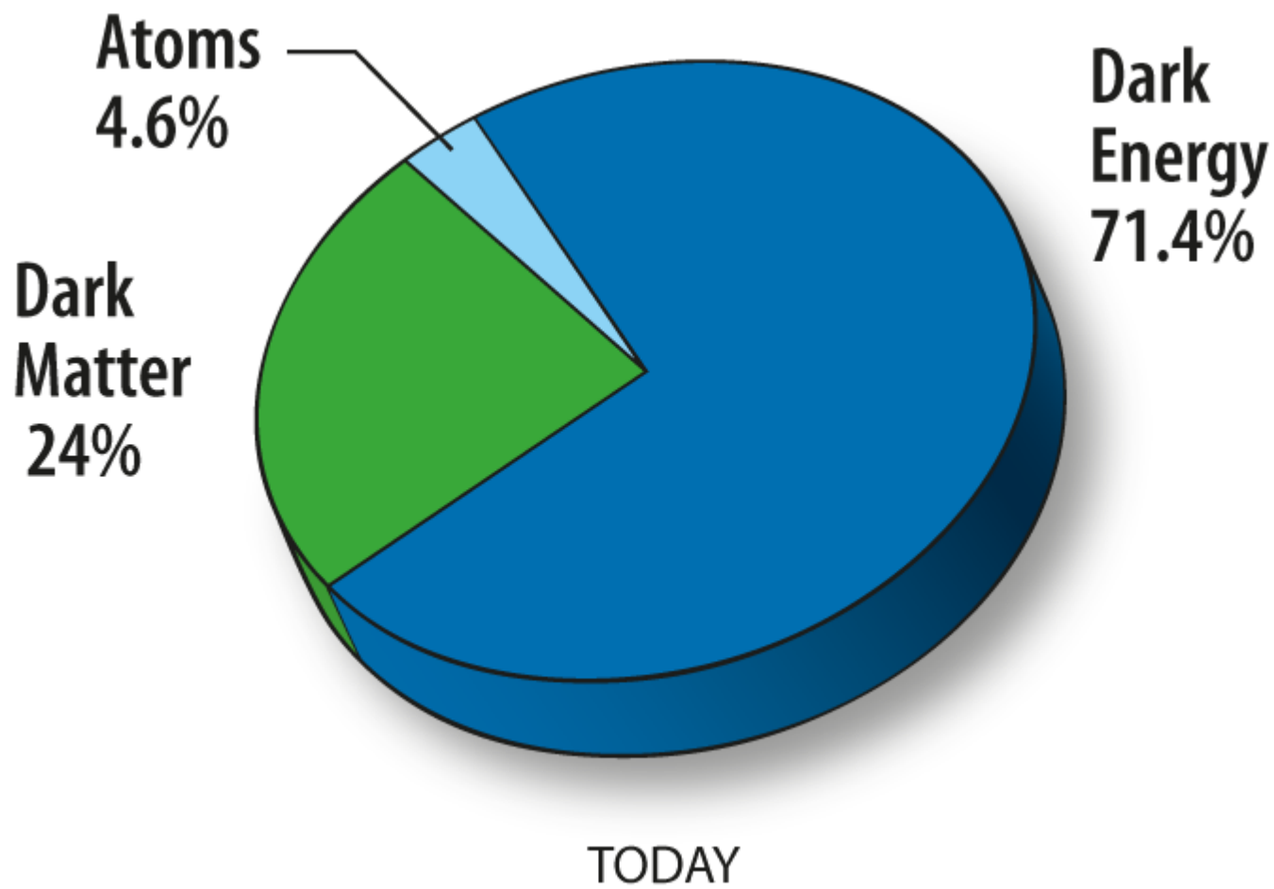
Technician:John Klemic, Marty Crabill



University of Minnesota

Science: Jake Waddington

The Big Picture



WMAP Wilkinson Microwave Anisotropy Probe
https://map.gsfc.nasa.gov/media/121236/index.html

- Universe
  - –71.4% dark energy
  - –24% cold dark matter
  - –4.6% atoms
    - ~4% free $_1$H and $_2$He
    - ~0.5% stars
    - ~0.03% heavy elements (heavier than $_2$He)

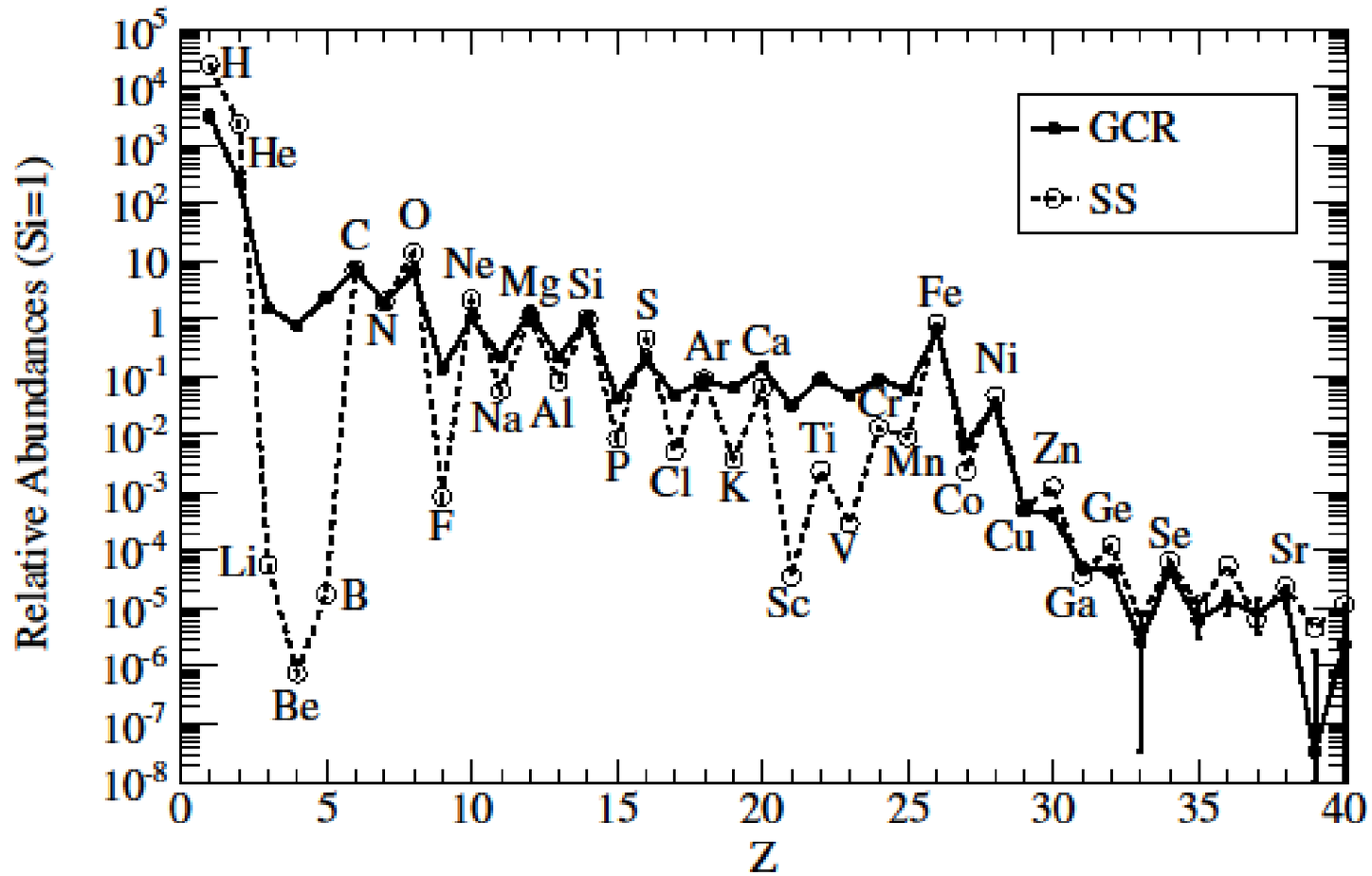
Samples of Regular Matter

On average in the galaxy:

- Interstellar Medium (ISM)
  - –99% gas and 1% dust by mass
  - –91% $_1$H, 8.9% $_2$He & 0.1% heavier by number
  - –1 atom/cm^3
  - –Solar System ~5 billion year old sample of ISM
- Galactic Cosmic Rays (GCR)
  - –99% nuclei and 1% electrons by number
  - –nuclei: ~90% $_1$H, ~9% $_2$He & ~1% heavier
  - –10^{-9} GCR/cm^3
  - –GCR are a few million year old sample of ISM & ?

Comparing Solar System and Galactic Cosmic Ray Abundances

- Solar System (SS)
- Galactic Cosmic Rays (GCR)
- Similar, more less abundant GCR in source filled in by interactions of more abundant GCR

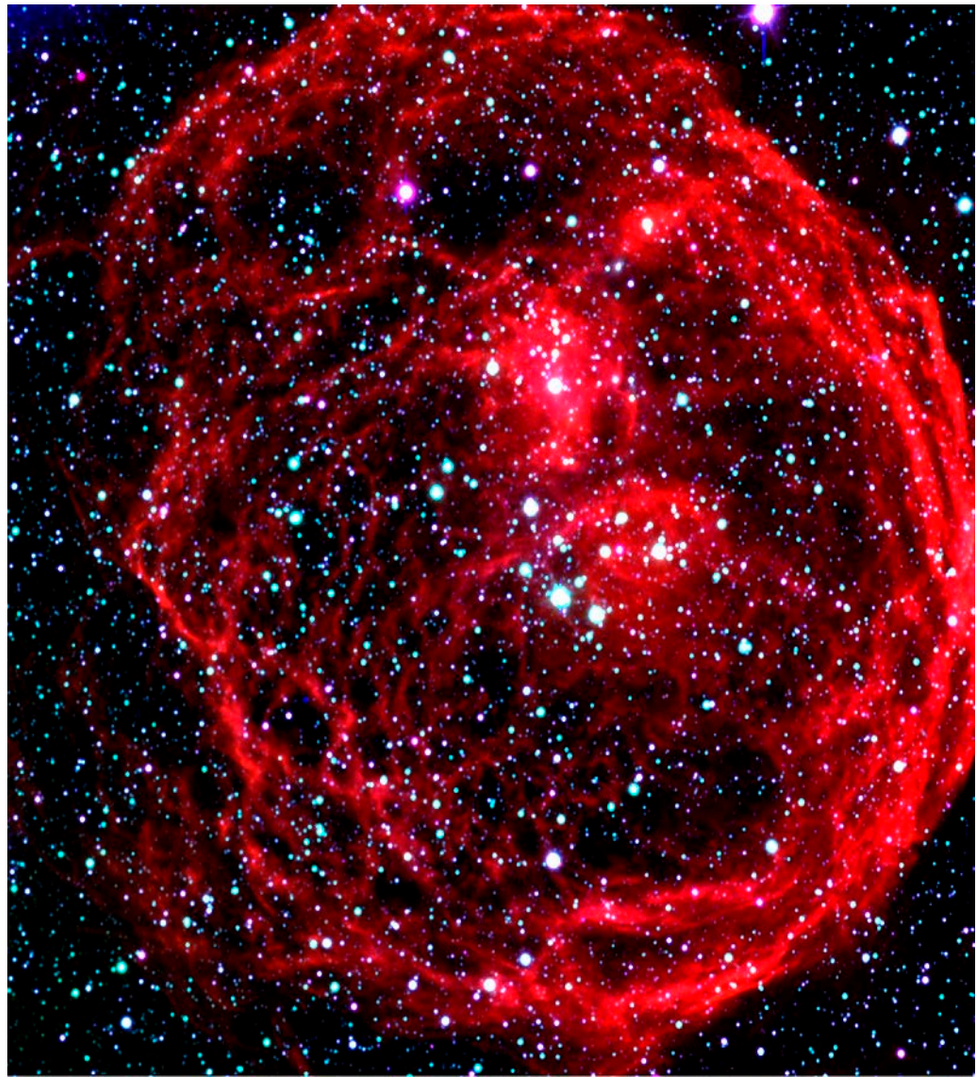


About Galactic Cosmic Rays

- Relativistic (v ~ c) charged particles
  - nuclei, electrons.

$$KE = \frac{1}{2}mv^2 \rightarrow E^2 = p^2c^2 + m_0^2c^4$$

- Isotropic: same flux in all directions – they don't point back to their source
- High energy diffuse media
  - similar in energy to galactic magnetic field and starlight
- Accelerated by Supernovae and other shocks
- All stable elements seen



SuperTIGER-2 Science

- Primary objectives
  - Perform new tests of the origins of galactic cosmic rays
    - Strengthen evidence pointing to OB associations as a major source of cosmic rays
  - To do this
    - Measure composition of cosmic rays $26 \leq Z \leq 40$ with improved statistics and expand our measurements in the $40 \leq Z \leq 56$ range
  - Test mass dependence and refractory/volatile fractionation up to Z=56
- Extending our measurements up to Z=56 enables us to
  - begin to sample the charge range where r-process production resulting from binary neutron star mergers (NSM) may become important
  - Test whether nuclei in the Z=50's charge range are produced and accelerated by the same sources as those in the $Z \leq 40$ range

30 Doradus in LMC

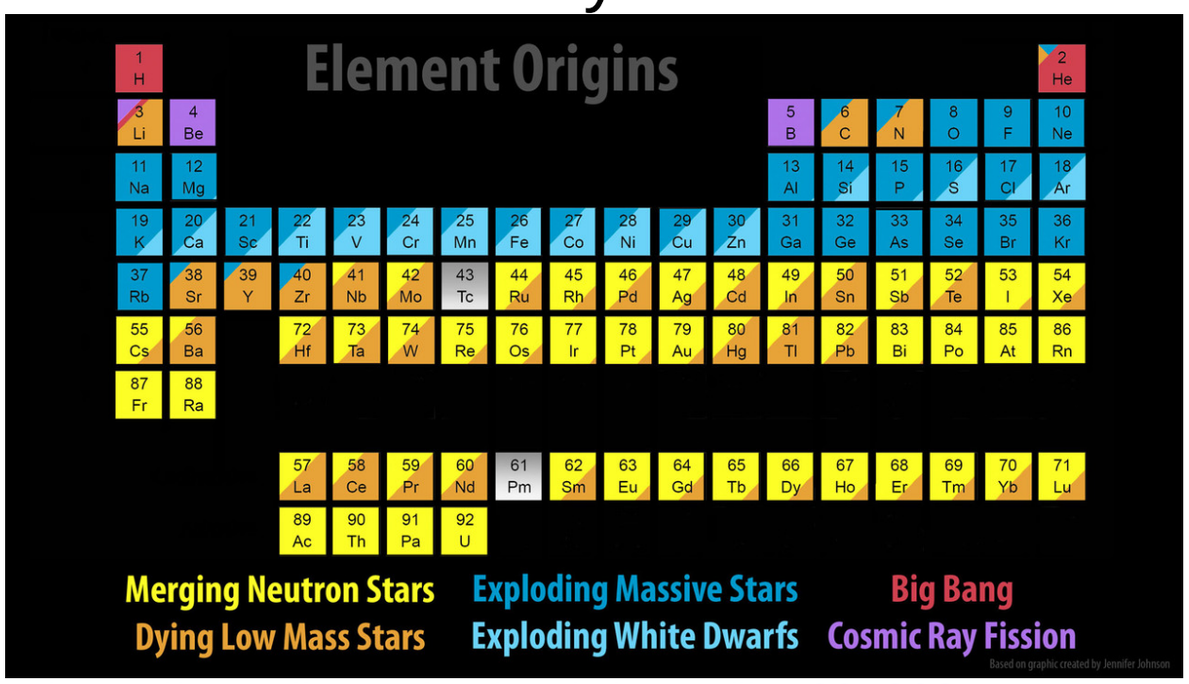
Credit: NASA, ESA,F. Paresce (INAF-IASF), R. O'Connell (U. Virginia), & the HST WFC3HST Science Oversight Com

N44 Superbubble in LMC

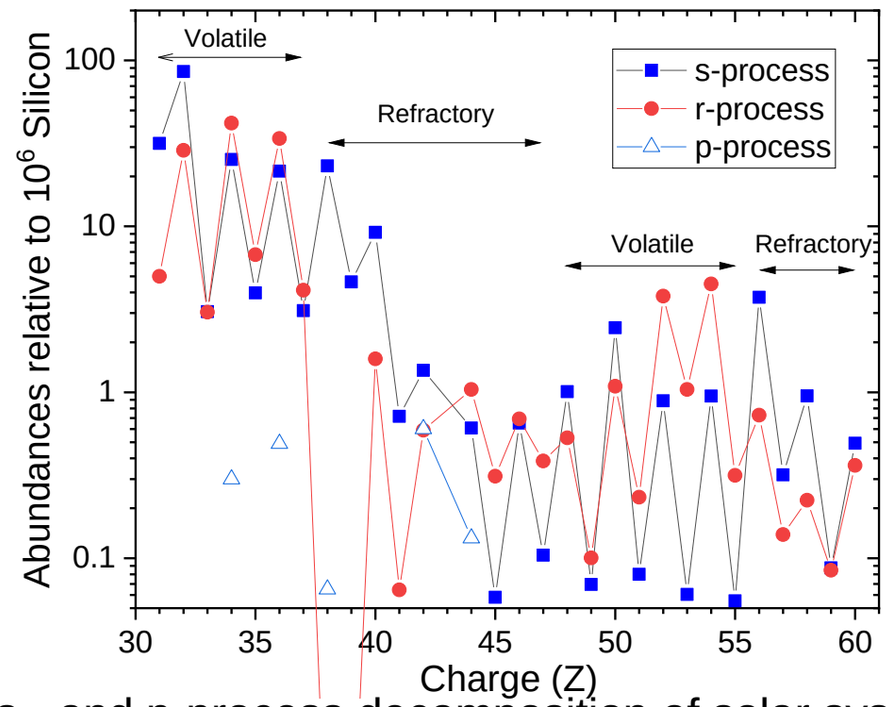
Credit: Gemini Observatory, AURA, NSF

Source Transition Region

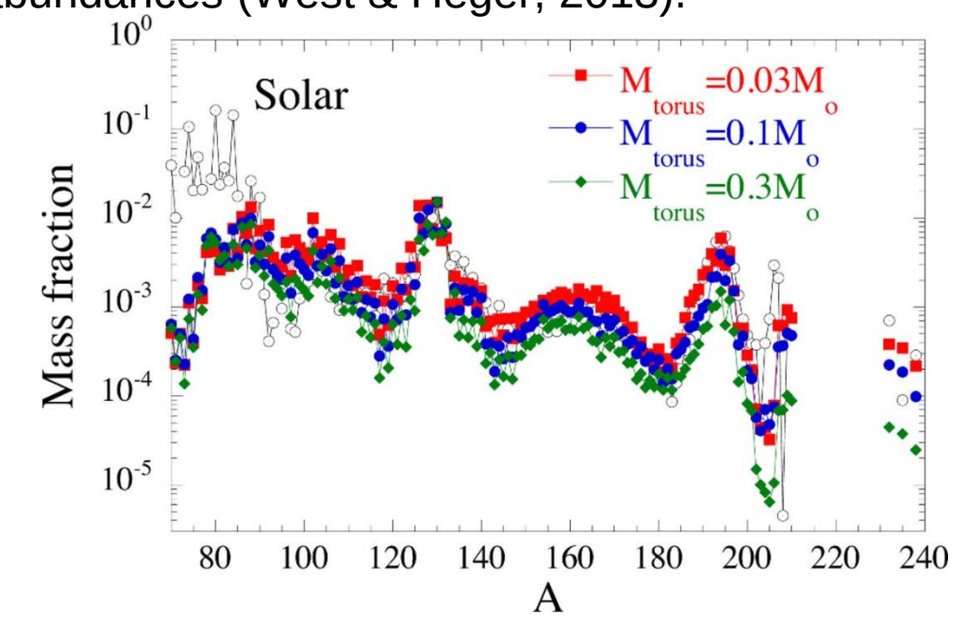
- r-process from massive stars and BNSM
- s-process from massive stars only
- TIGER/ST-1 show:
  - with ACE isotopic measurements (^{22}Ne, ^{56}Fe) GCR enhanced with massive star material
  - refractory elements (dust) preferentially accelerated over volatile (gas)
- Z>40/A>90 GCR measurements can constrain BNSM synthesis models



https://www.ligo.caltech.edu/news/ligo20180817
Figure Credit: Jennifer Johnson/SDSS



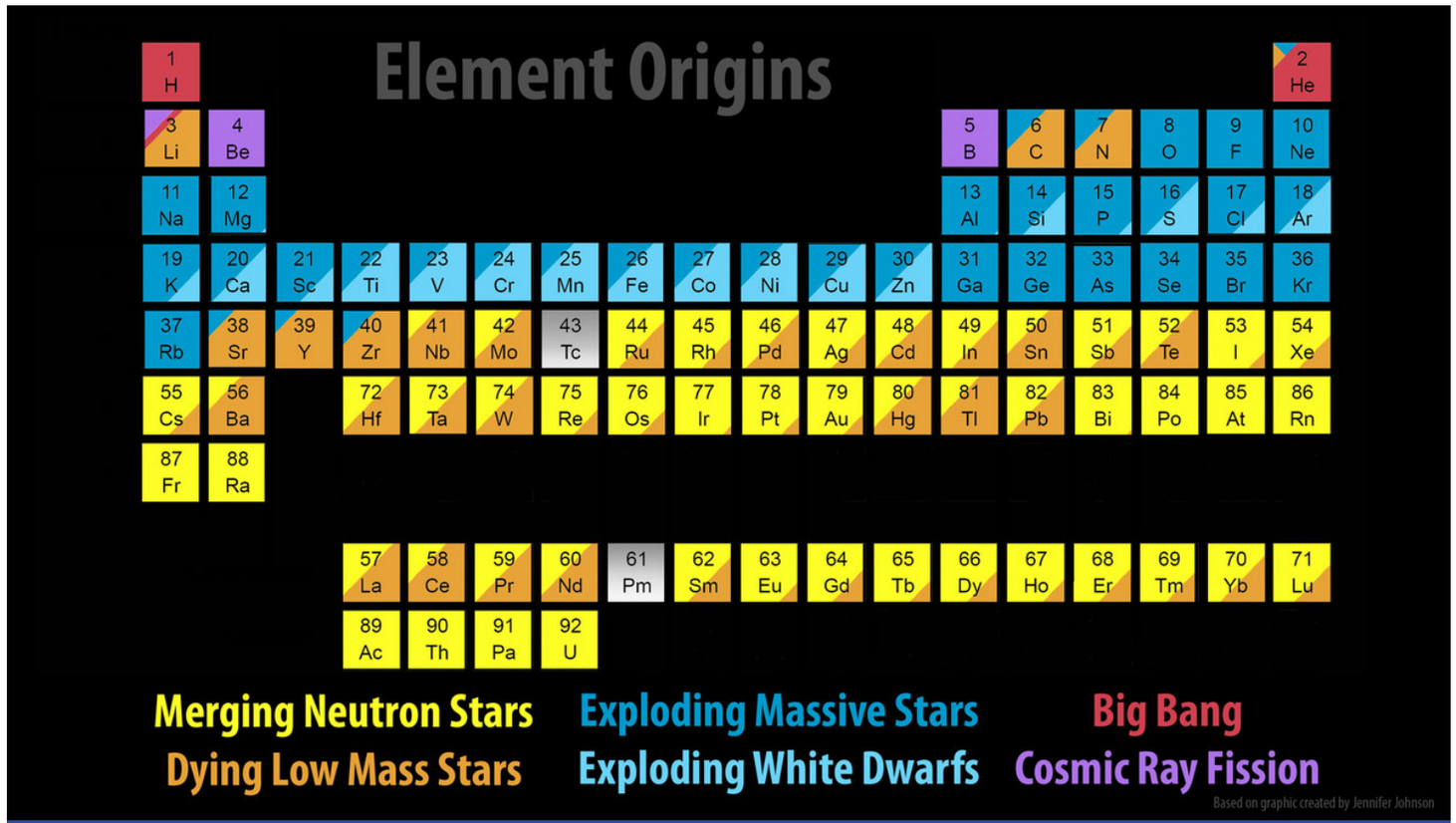
r- ,s-, and p-process decomposition of solar system abundances (West & Heger, 2013).

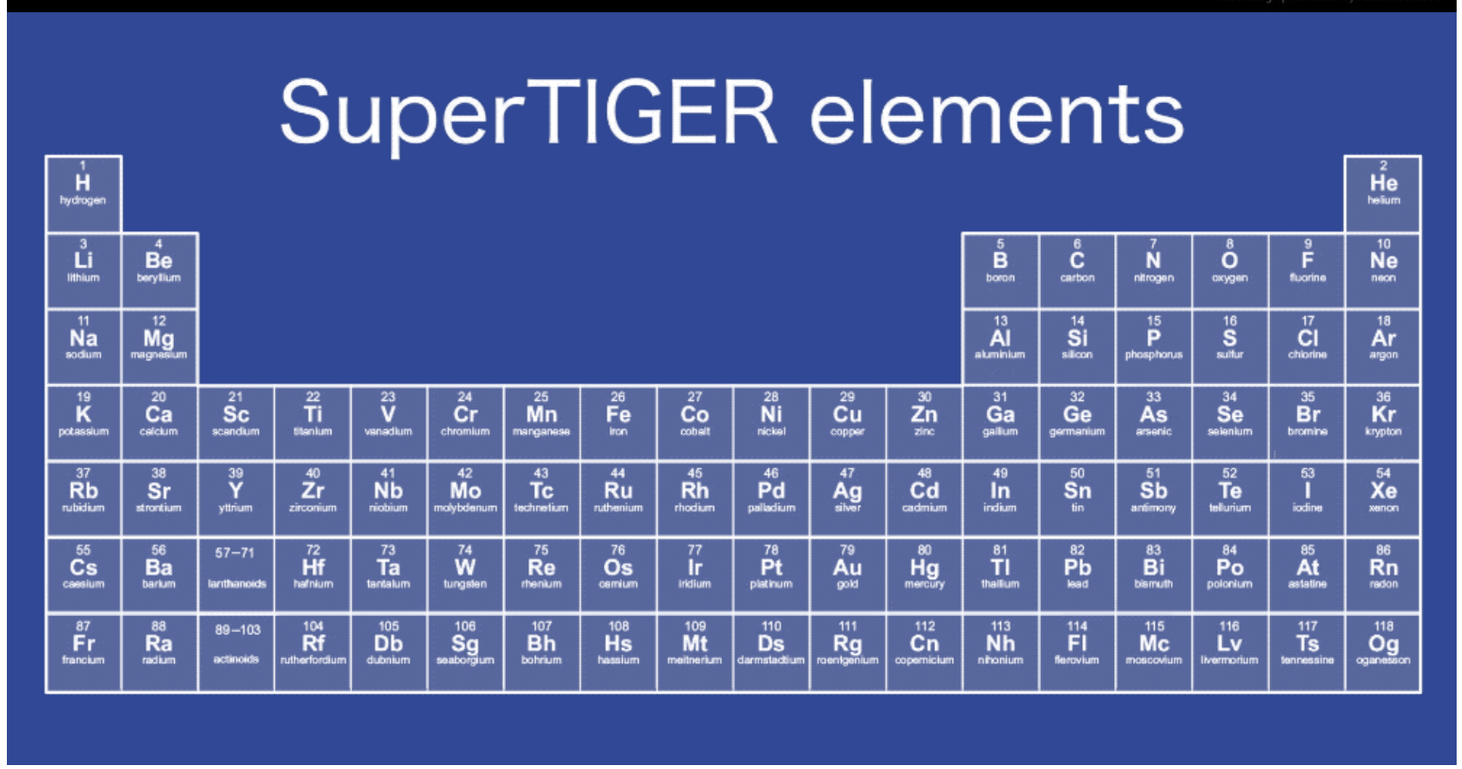


Abundance distributions vs. atomic mass for black hole-torus system for different torus masses (Just et al., 2015).

SuperTIGER & Origin Models

- Astrophysical origins:
  - Big Bang $_{1}H$, $_{2}He$ some $_{3}Li$
  - Cosmic ray spallation $_{4}Be$ and $_{5}B$
  - Stars in fusion and neutron capture through $_{40}Zr$
  - Binary neutron star mergers and massive stars for rest
- SuperTIGER has the dynamic range to measure from $_{10}Ne$ to $_{56}Ba$

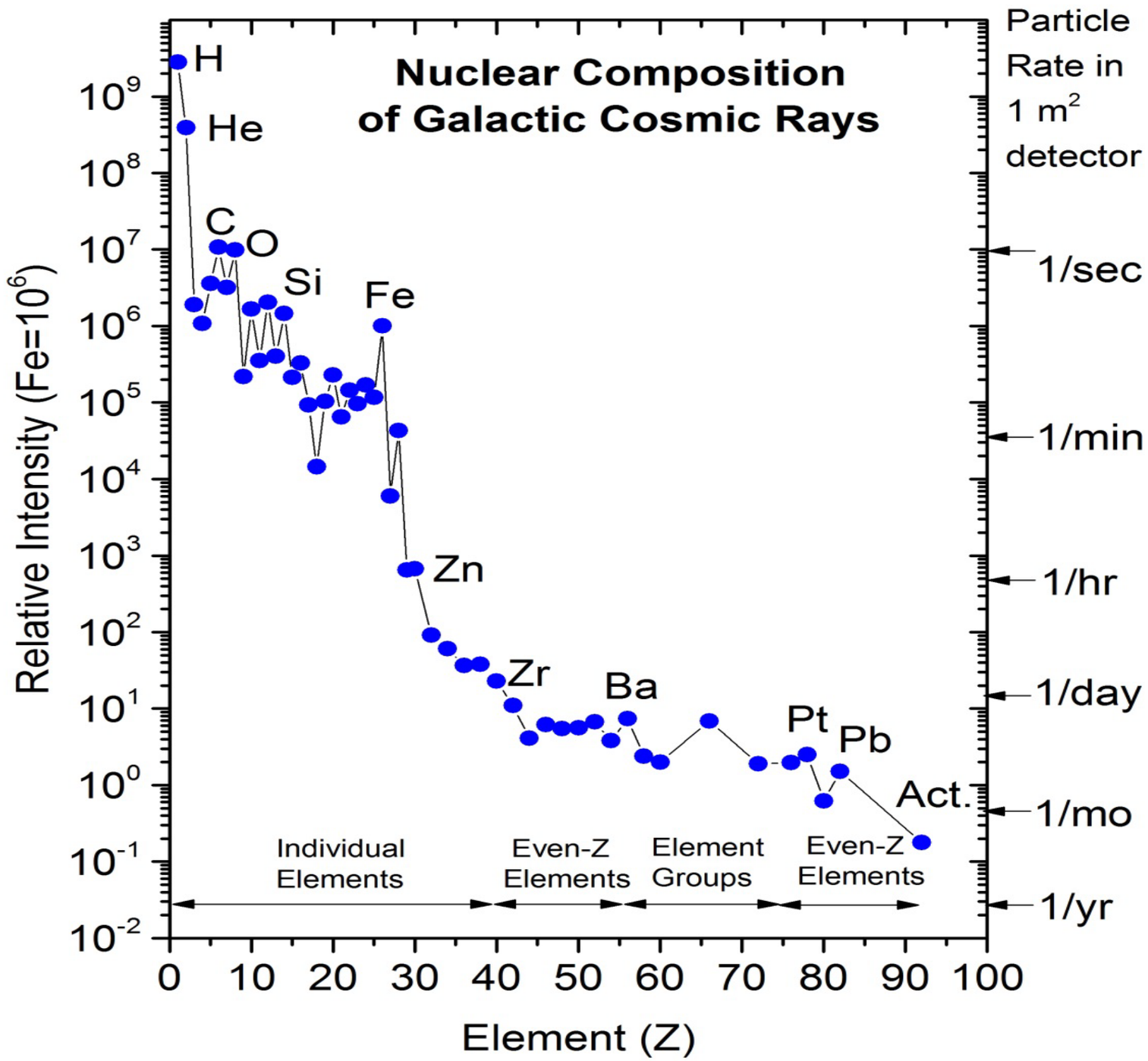




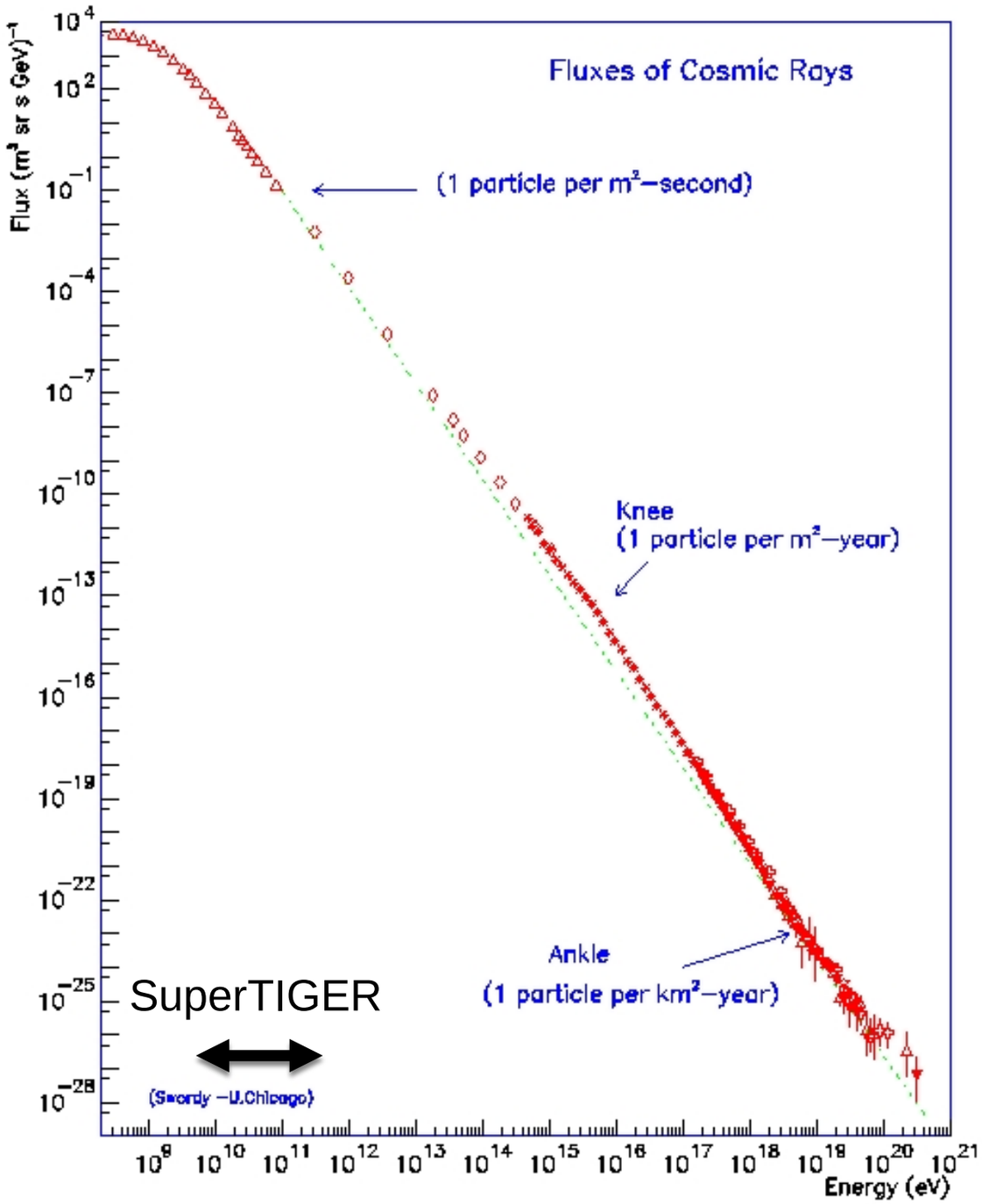
GCR Relative Abundances

Relative abundances depend on nucleosynthetic sources

1. Big Bang: $_1H$ and $_2He$
2. Fusion: up to $_{26}Fe$
3. r- and s-process neutron capture: past $_{26}Fe$



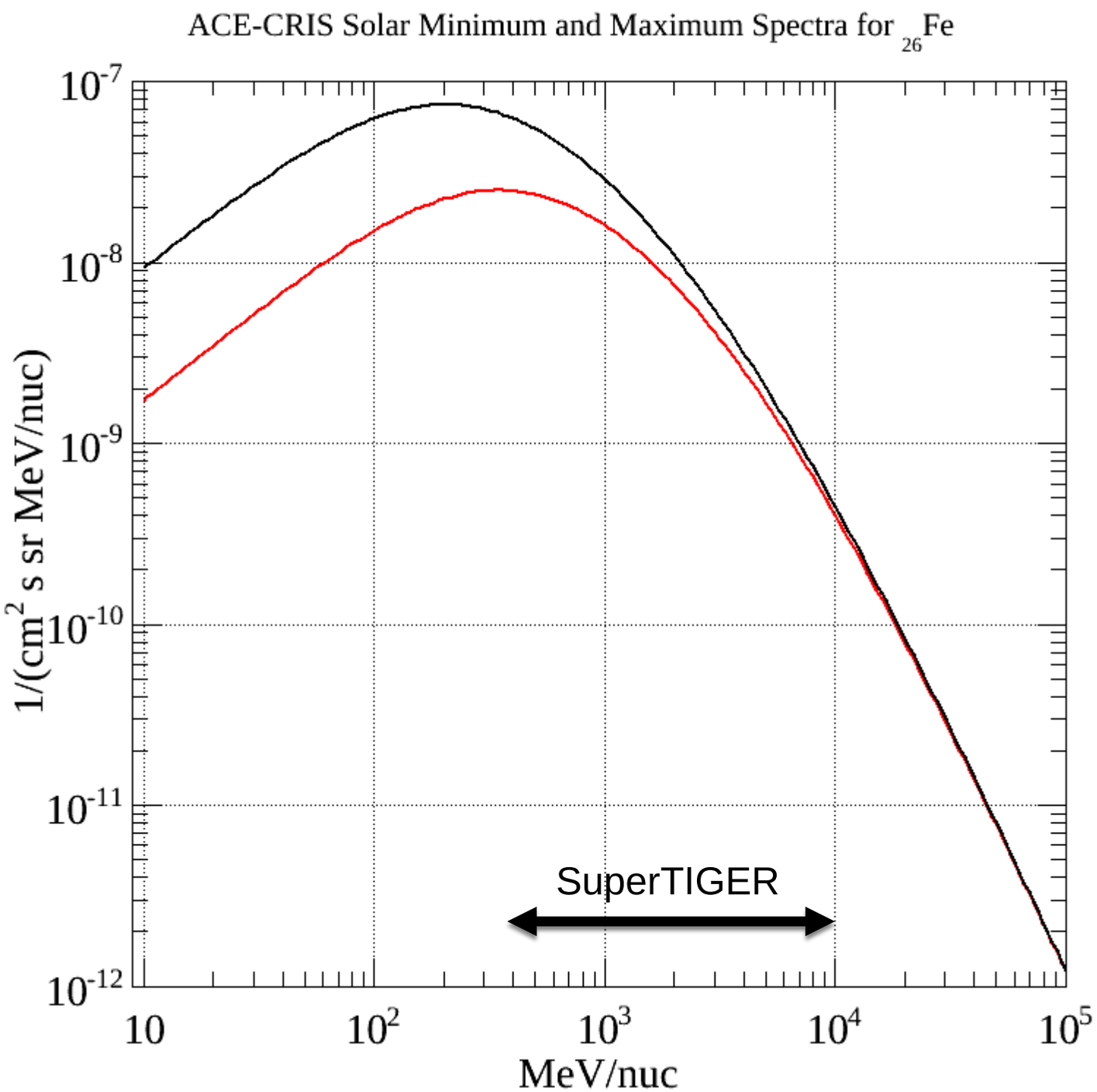
Cosmic Ray Energy Spectrum



- All particle spectrum
- SuperTIGER energy range in instrument roughly 3×10^{8}eV/nuc - 10^{10}eV/nuc
- Highest energy CR likely extragalactic in origin
- Broken power law
- $dN/dE \propto E^{-\alpha}$

http://astroparticle.uchicago.edu/cosmic_ray_spectrum_picture.htm
J. Cronin, T.K. Gaisser, and S.P. Swordy, Sci. Amer. v276, p44 (1997)

Energy Spectrum Modulation

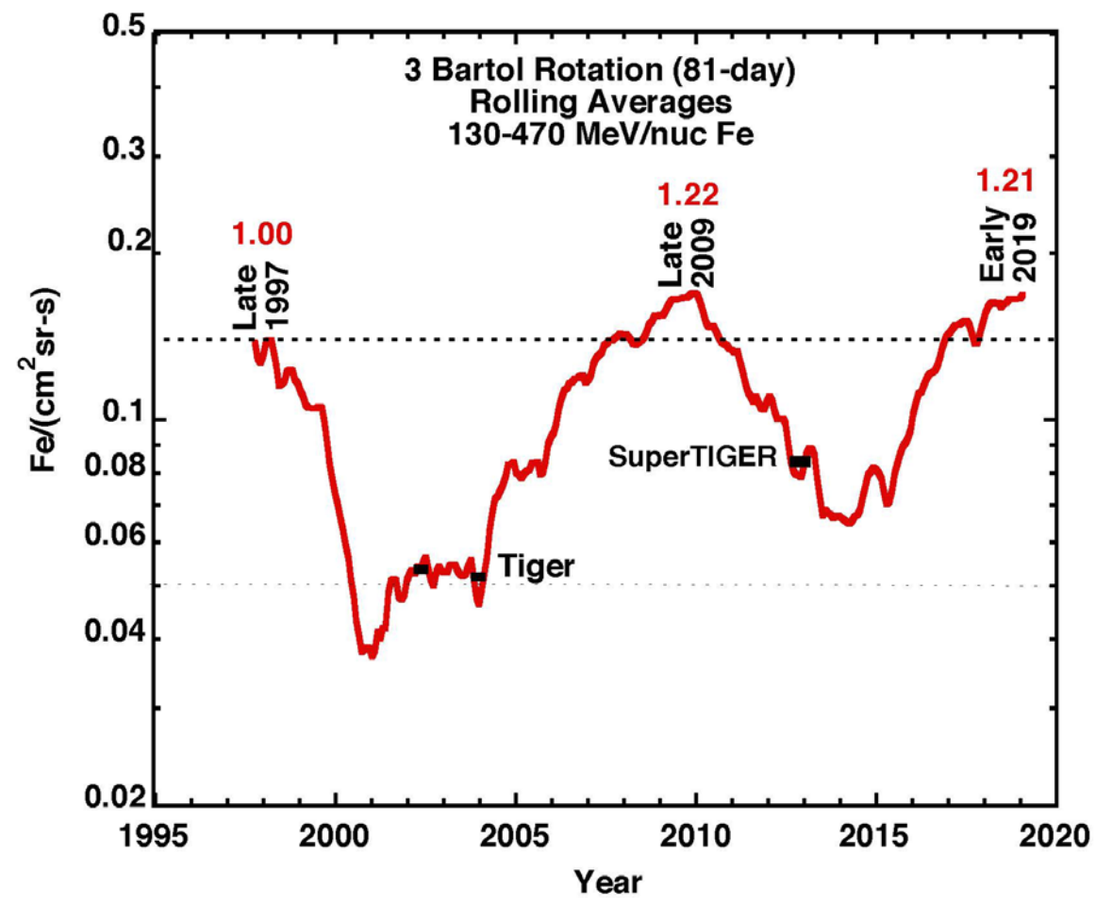


Solar activity impacts GCR fluxes

- Black: Solar Minimum $_{26}$Fe-Spectrum
- Red: Solar Maximum $_{26}$Fe-Spectrum

Favorable Solar Modulation

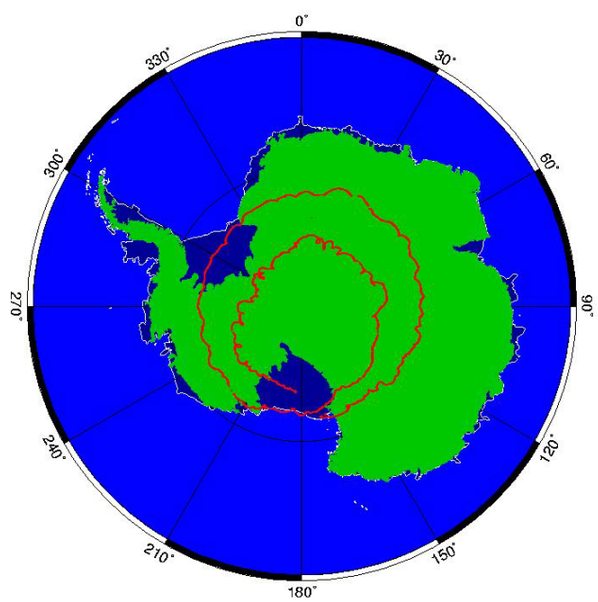
- Recently we have seen the lowest levels of solar activity in the space age
- Reduced solar wind strength allows more of the cosmic ray flux through
- 60 days of ST2 now would be ~1.7x 55 days of ST1
- Cosmic-ray intensity is nearing its cycle maximum
- Now is a very good time to fly SuperTIGER



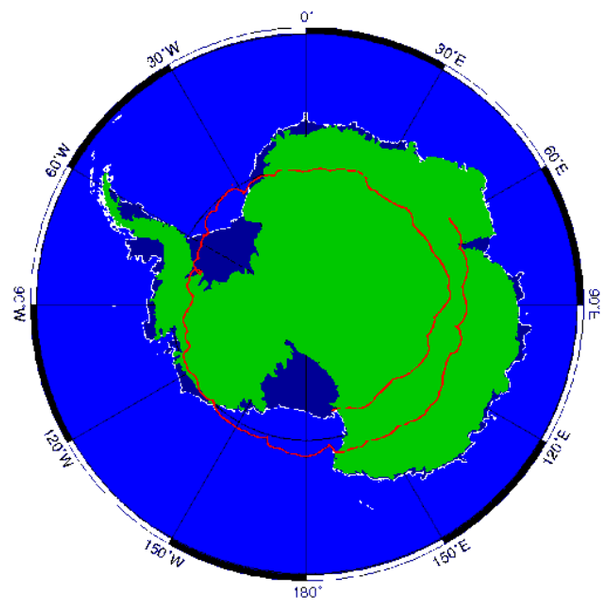
Intensity of cosmic-ray iron nuclei detected by ACE as a function of time. The present solar minimum intensity is essentially equal to that of the space-age historic solar minimum in 2009. Note that the TIGER and SuperTIGER-1 flights occurred at considerably lower intensity levels.

TIGER Instrument & Flights

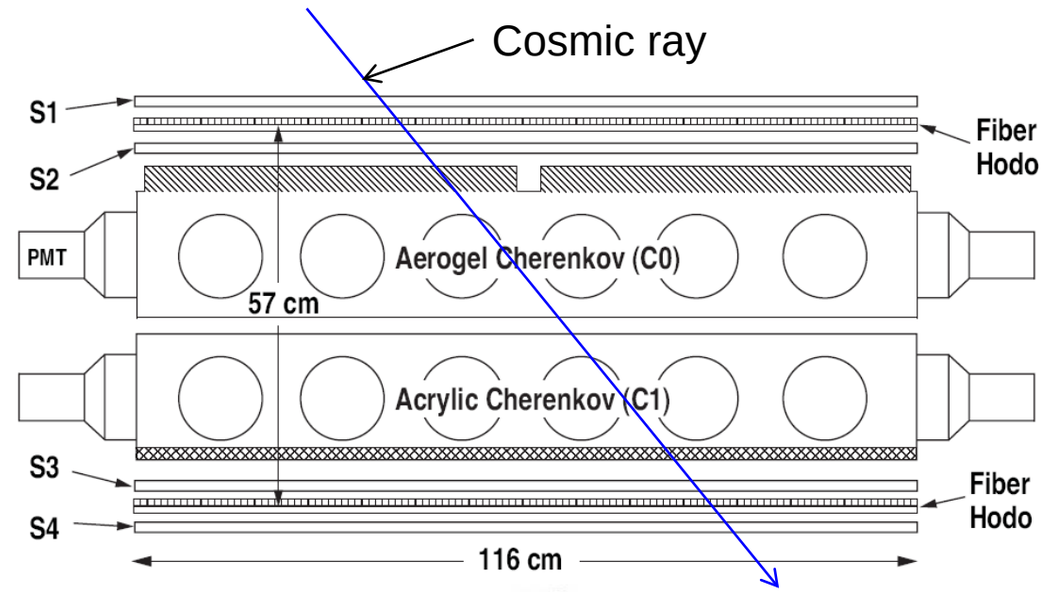
Trans Iron Galactic Element Recorder (TIGER) is the predecessor to SuperTIGER and had 2 very successful Antarctic Balloon flights (2001, 2003) totaling 50 days at float and recording 6.2×10^5 Fe events.



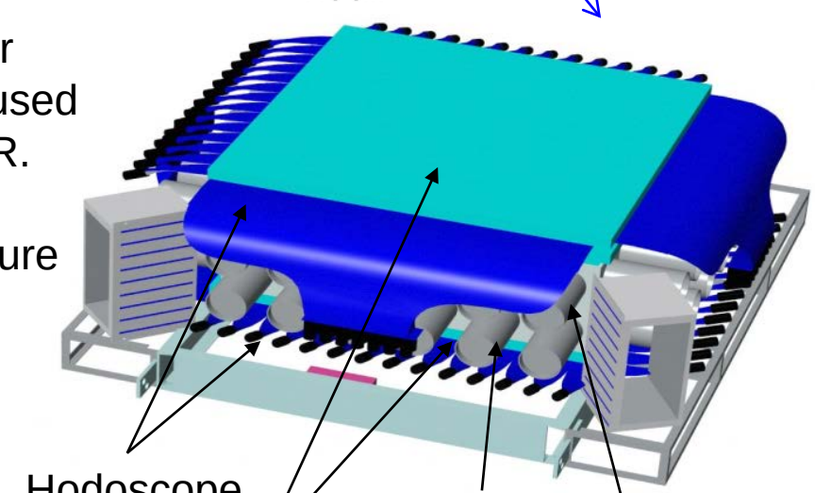
Dec 21, 2001 – Jan 21, 2002
32 days and 3.7×10^5 Fe events



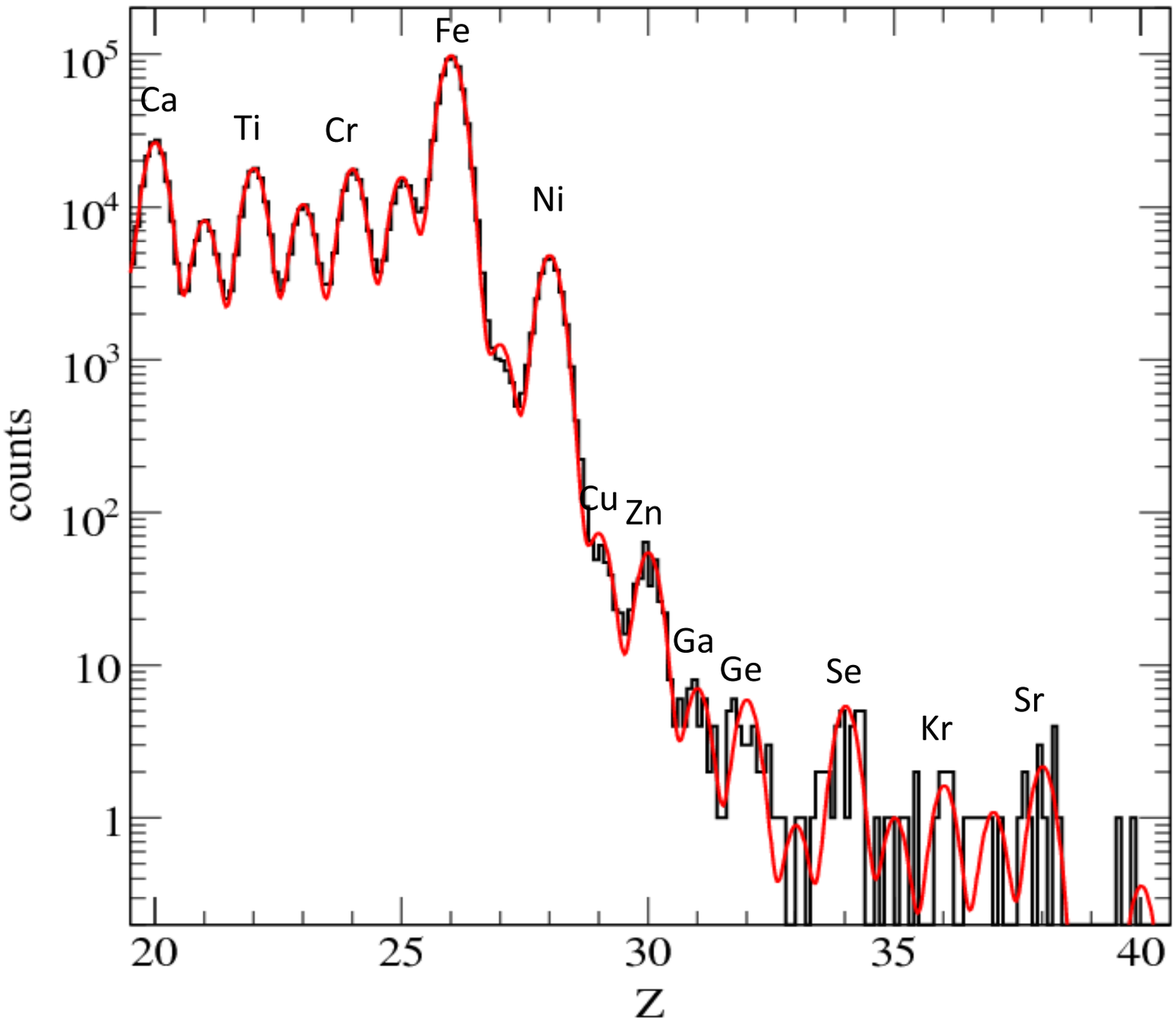
Dec 27, 2003 – Jan 4, 2004
18 days and 2.5×10^5 Fe events



Same Detector configuration used in SuperTIGER. TIGER had an effective aperture of ~0.4 m^2sr



TIGER UH Measurement



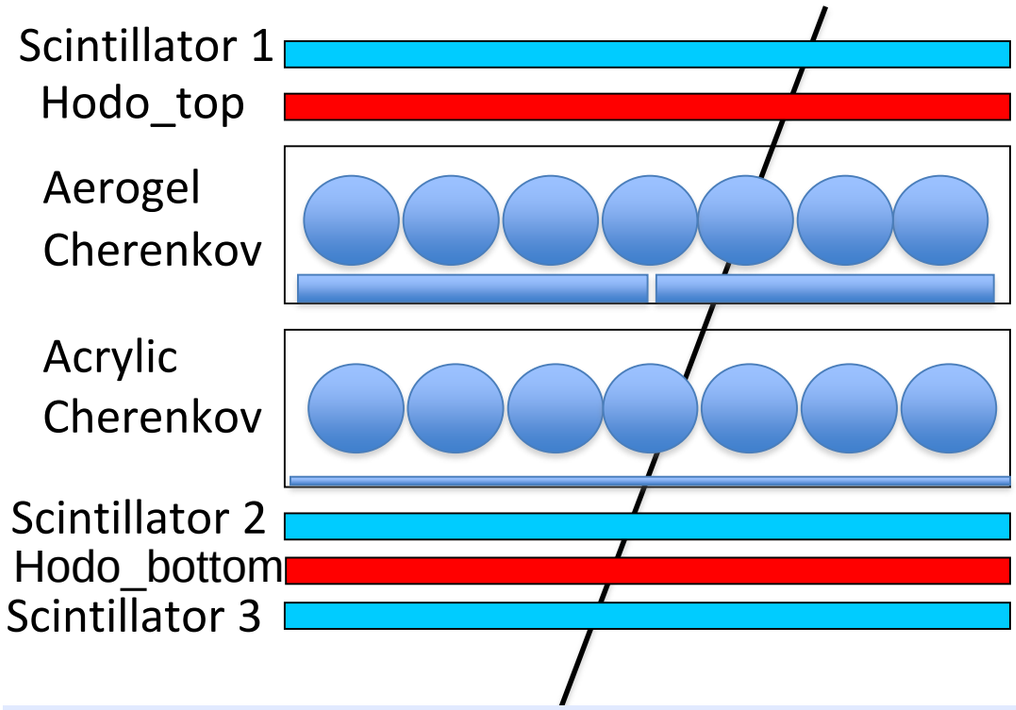
Combined dataset from 50 days of flight over Antarctica in 2001-2002 and 2003-2004.

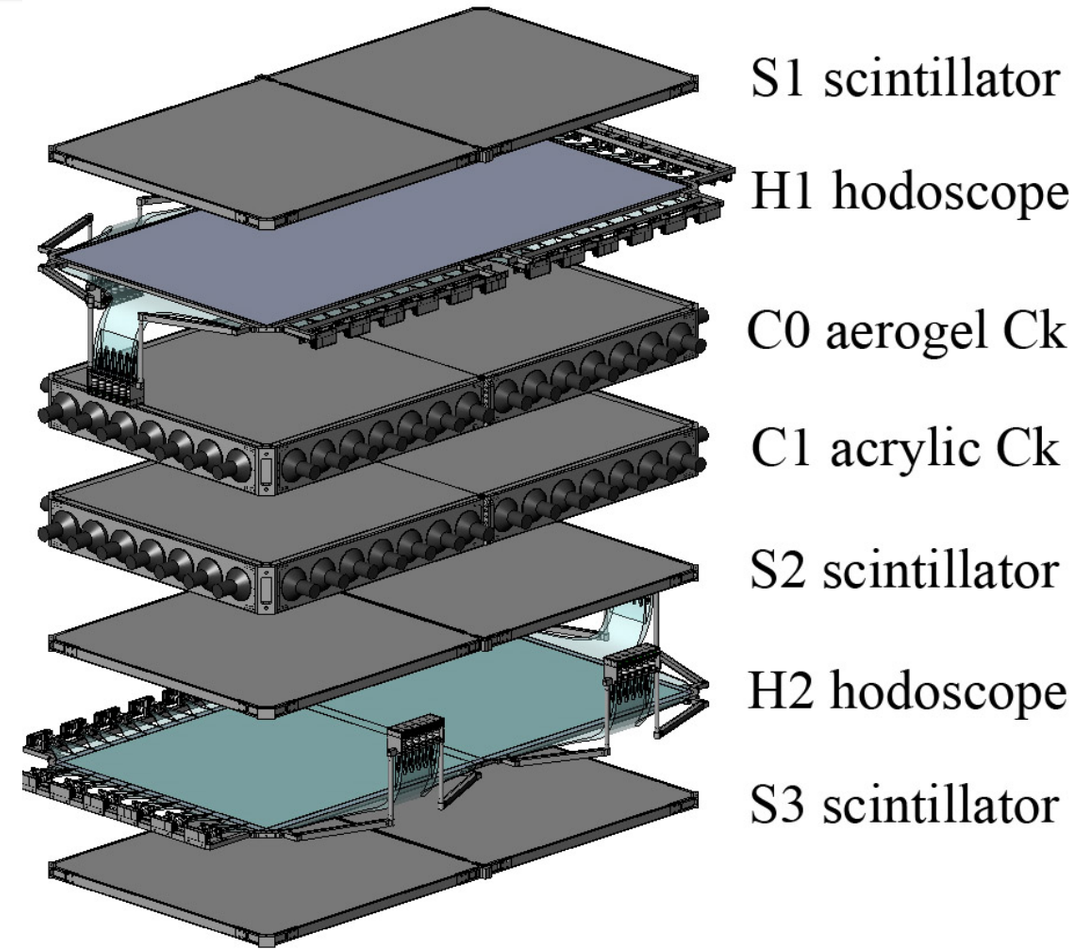
Well defined peaks at $_{31}$Ga, $_{32}$Ge, $_{34}$Se

Limited statistics at higher Z, but hints of $_{36}$Kr and $_{38}$Sr peaks.

Rauch et al., ApJ 697:2083 (2009).

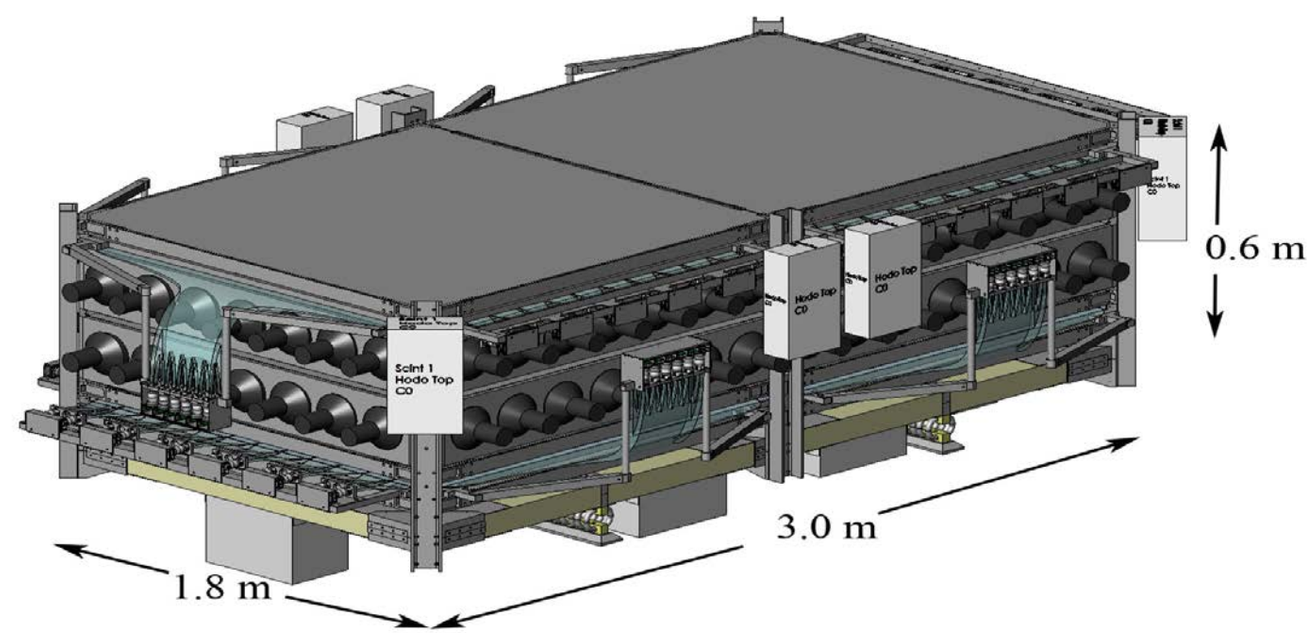
The SuperTIGER Instrument



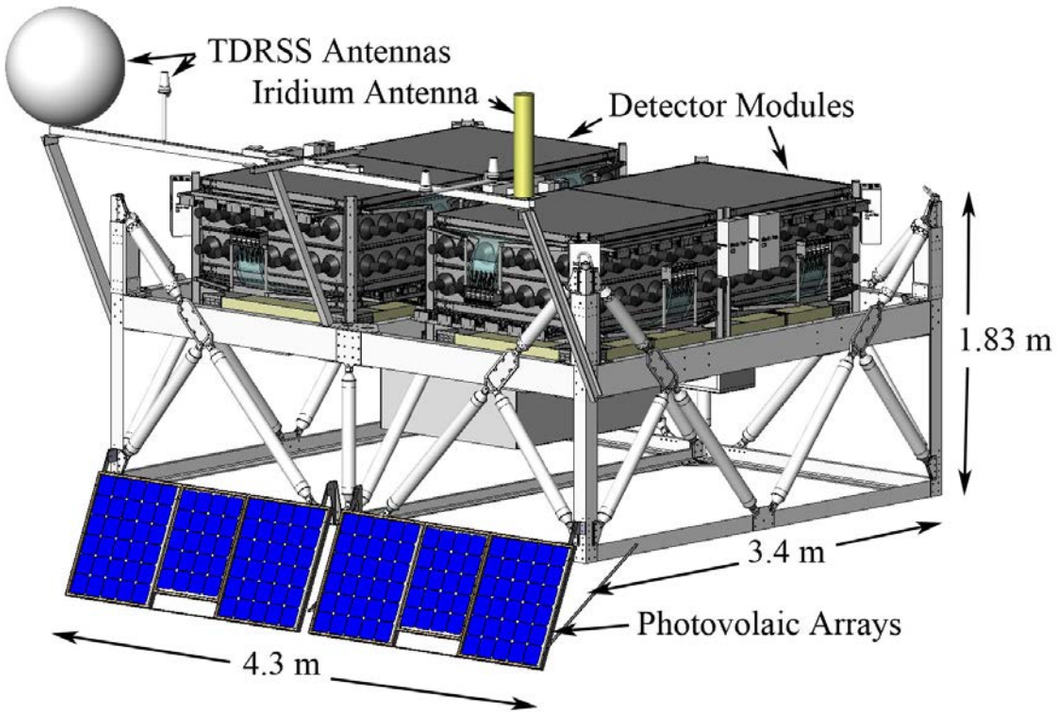


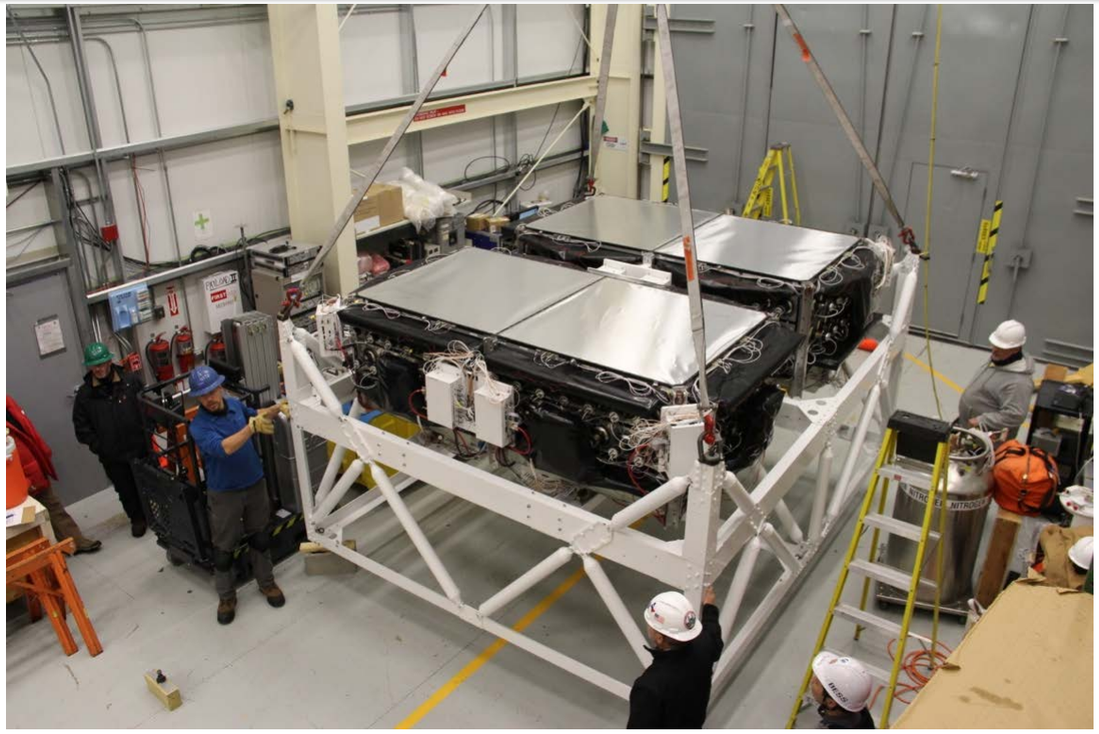
- Stack of 7 detectors
  - 3 Scintillation counters
  - 2 Scintillating Fiber Hodoscopes
  - 2 Cherenkov Detectors
    - Aerogel, n =1.043 or 1.025 (2.5 or 3.3 GeV/nucleon)
    - Acrylic, n = 1.49 (0.3 GeV/nucleon)
- Two nearly identical modules
- Effective area 2.9 m^2sr, 7.2 times that of TIGER.

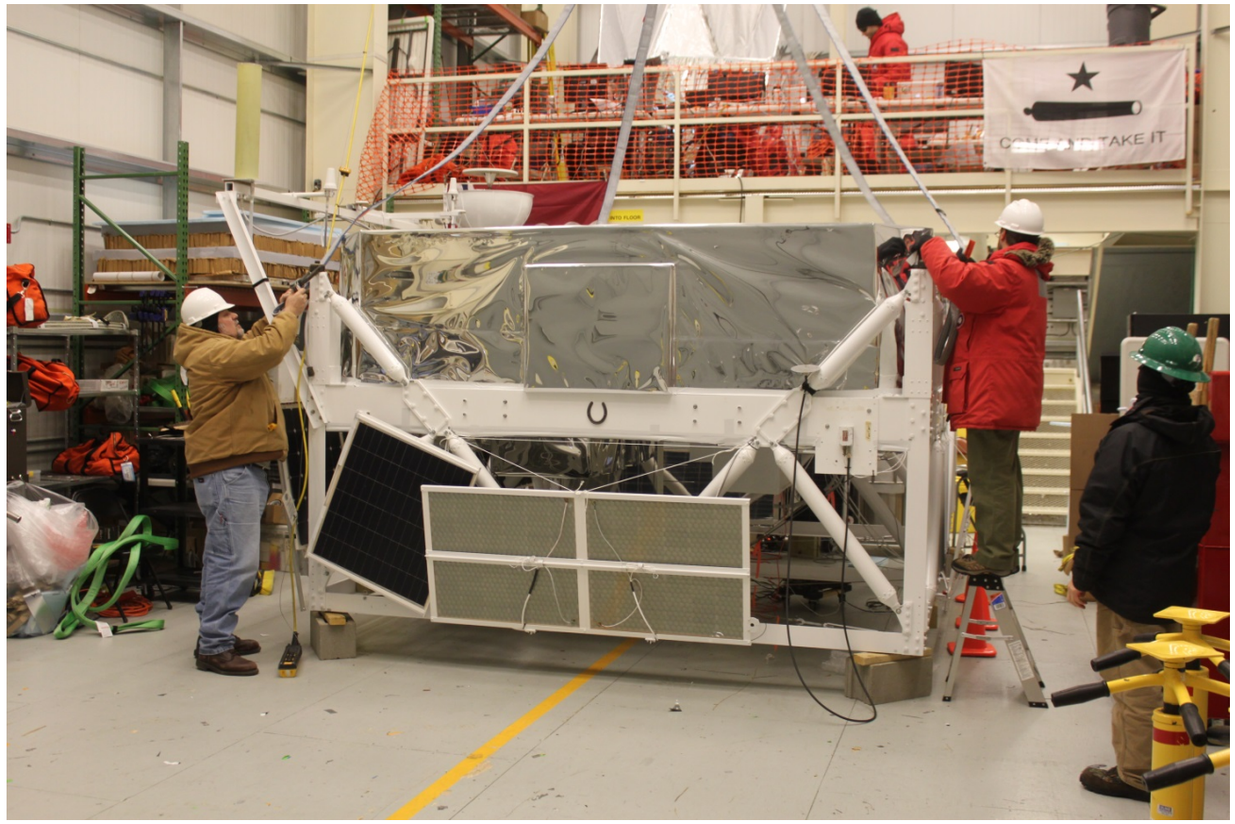
- **See instrument paper: Binns et al. ApJ (2014) 788:18**

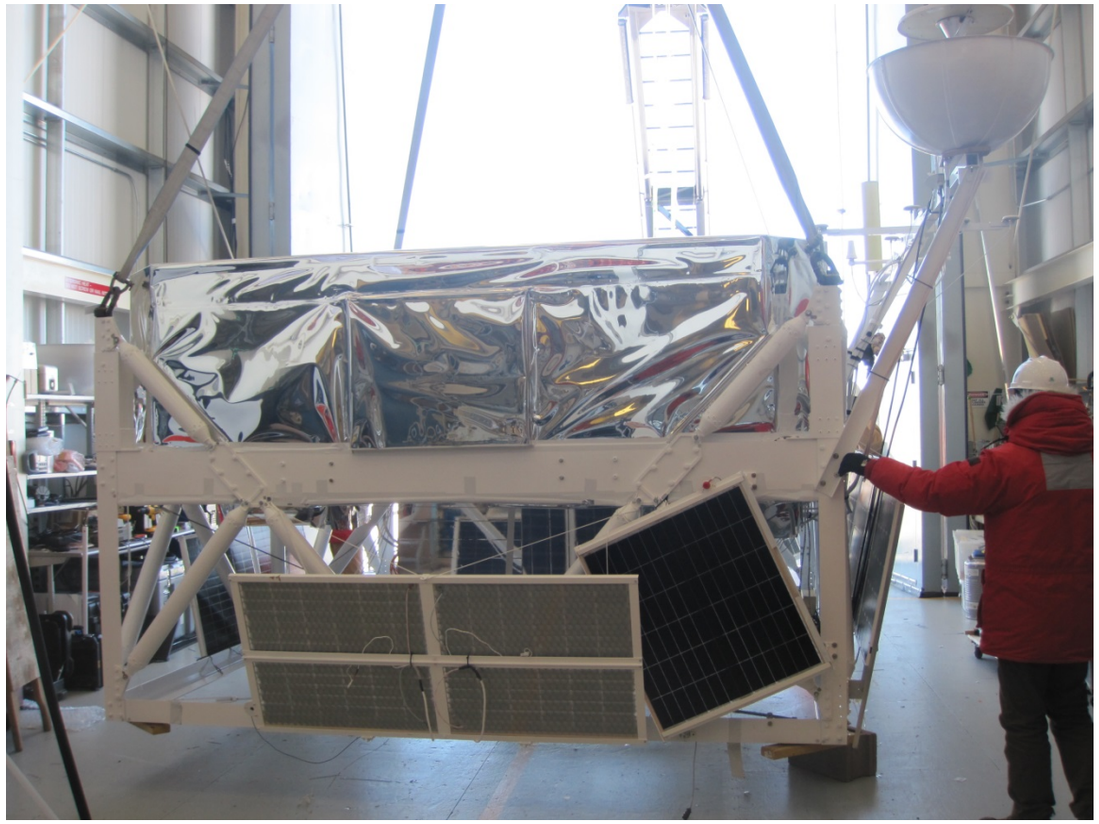


The SuperTIGER-1 Instrument

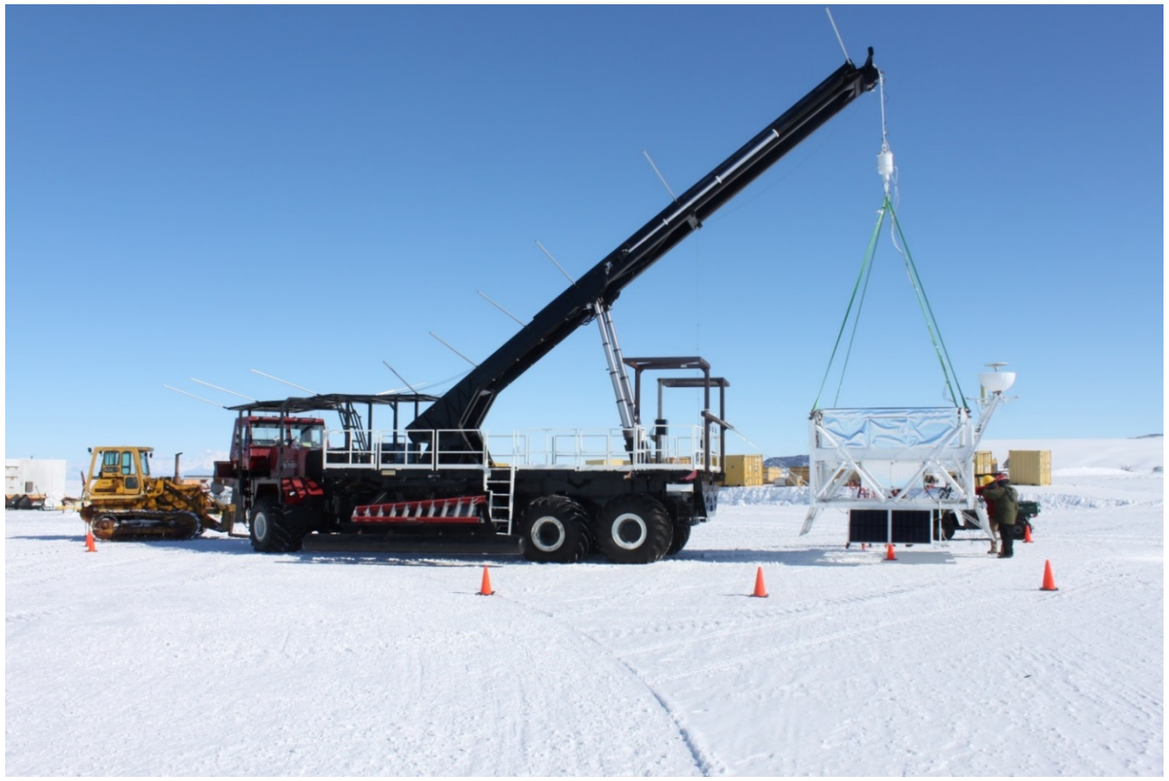




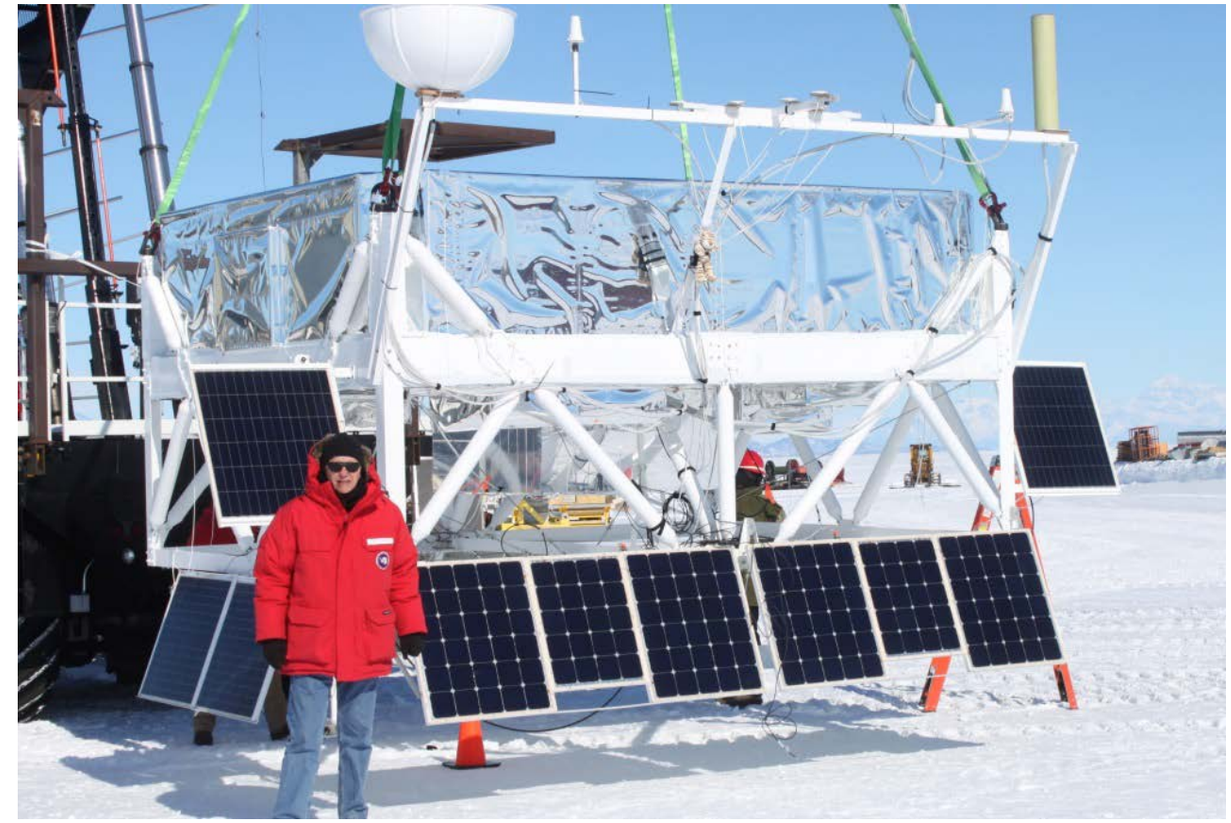




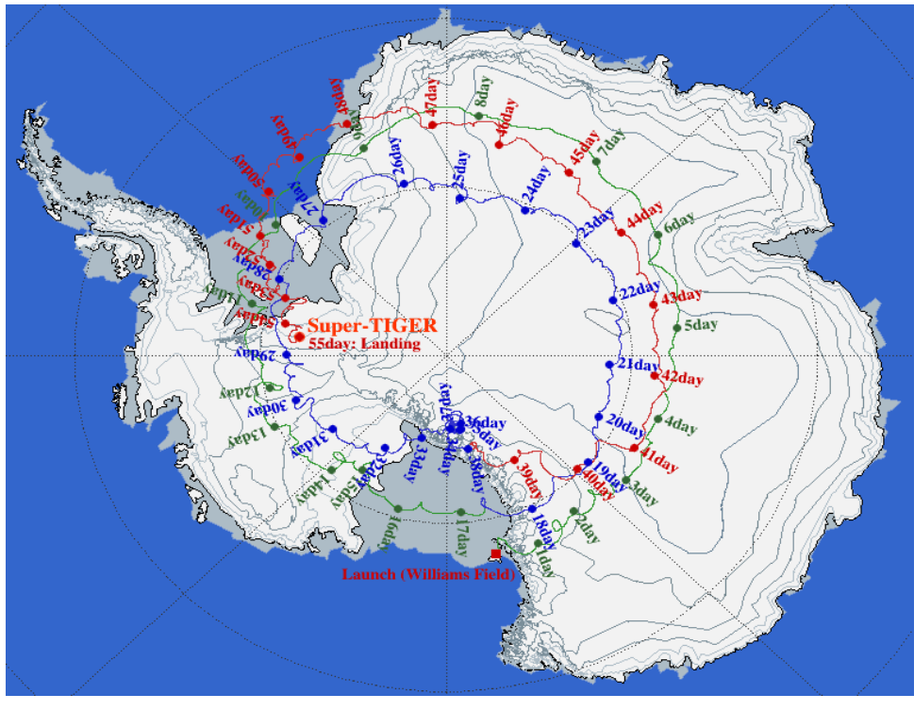
ST-1 Flight – Launch Day



ST-1 Flight, Dec. 8, 2012

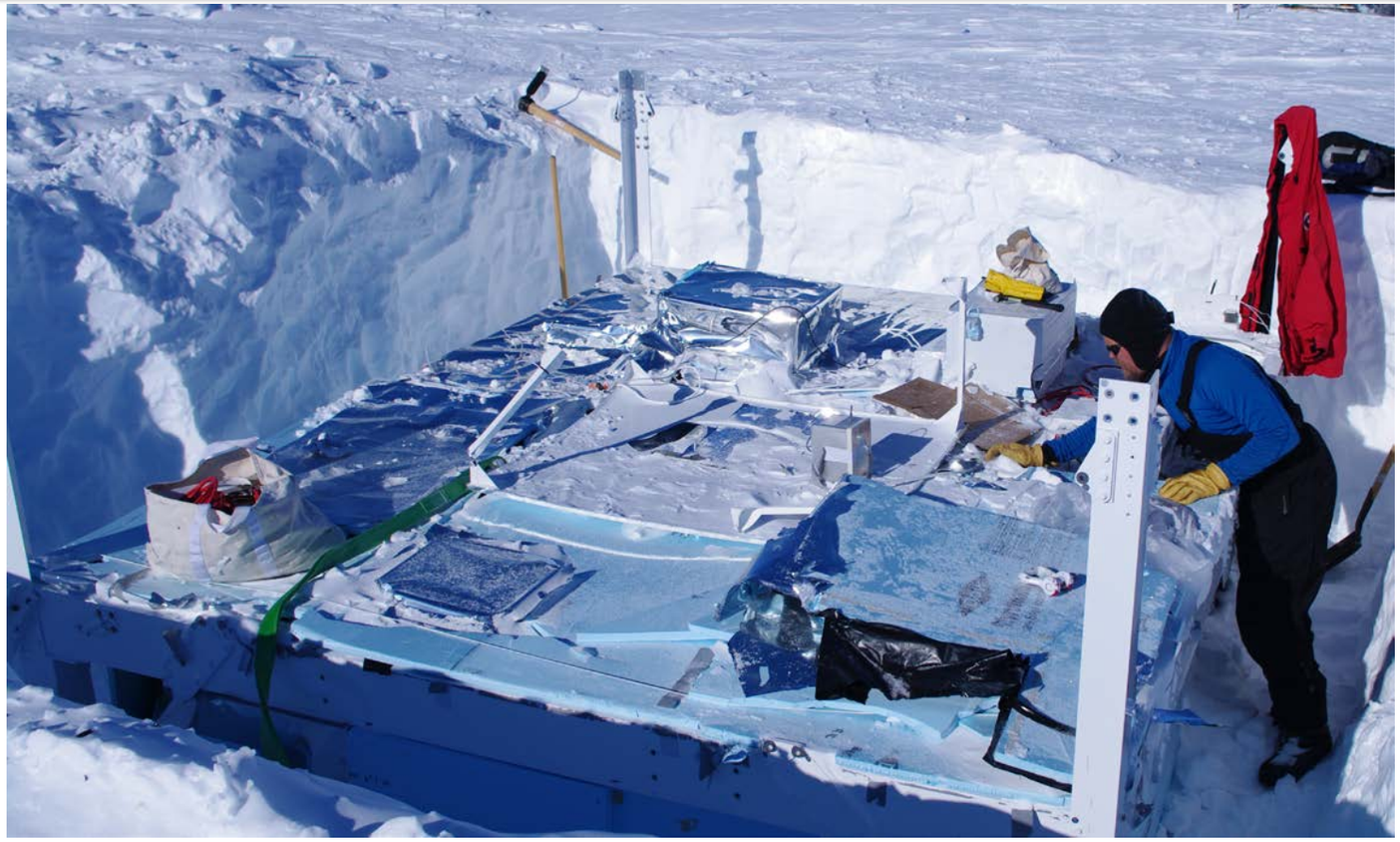


- *Record 55 day flight*
- *~8 times the UHGCR data collected with the two TIGER flights*
- *Best measurement of 30 ≤ Z ≤ 56*

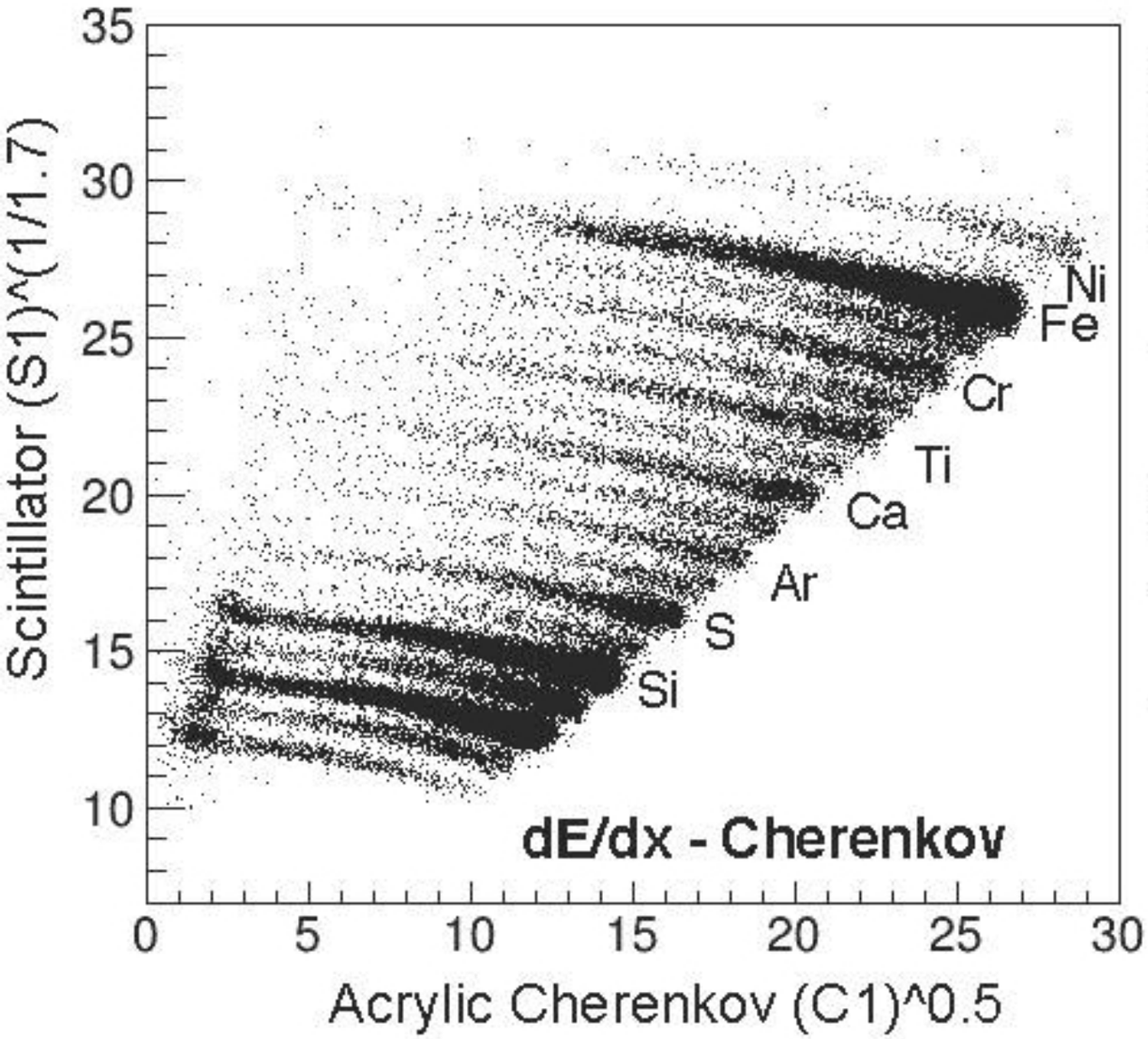


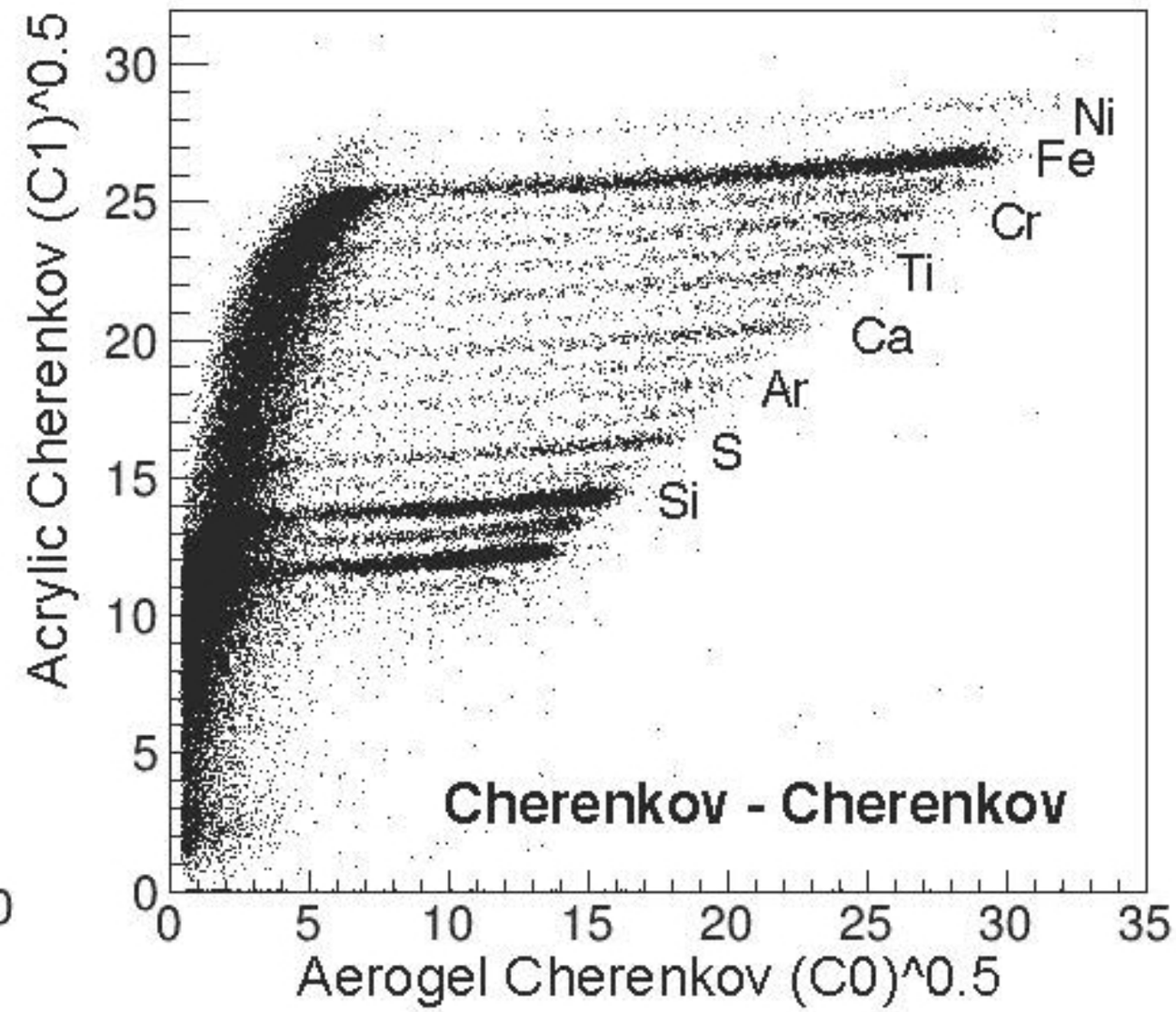
ST-1 2014-2015 Recovery

- Team of 4 camped for 31 days due to airplane scheduling
- Rest of recovery team and Basler arrived January 24, 2015. Took 3 hours to load instrument on Basler
- Completely recovered the full instrument
- Instrument design for minimum damage successful with Basler
- Only significant damage occurred in roll-over upon landing (or later—really don't know)



SuperTIGER-1 Data





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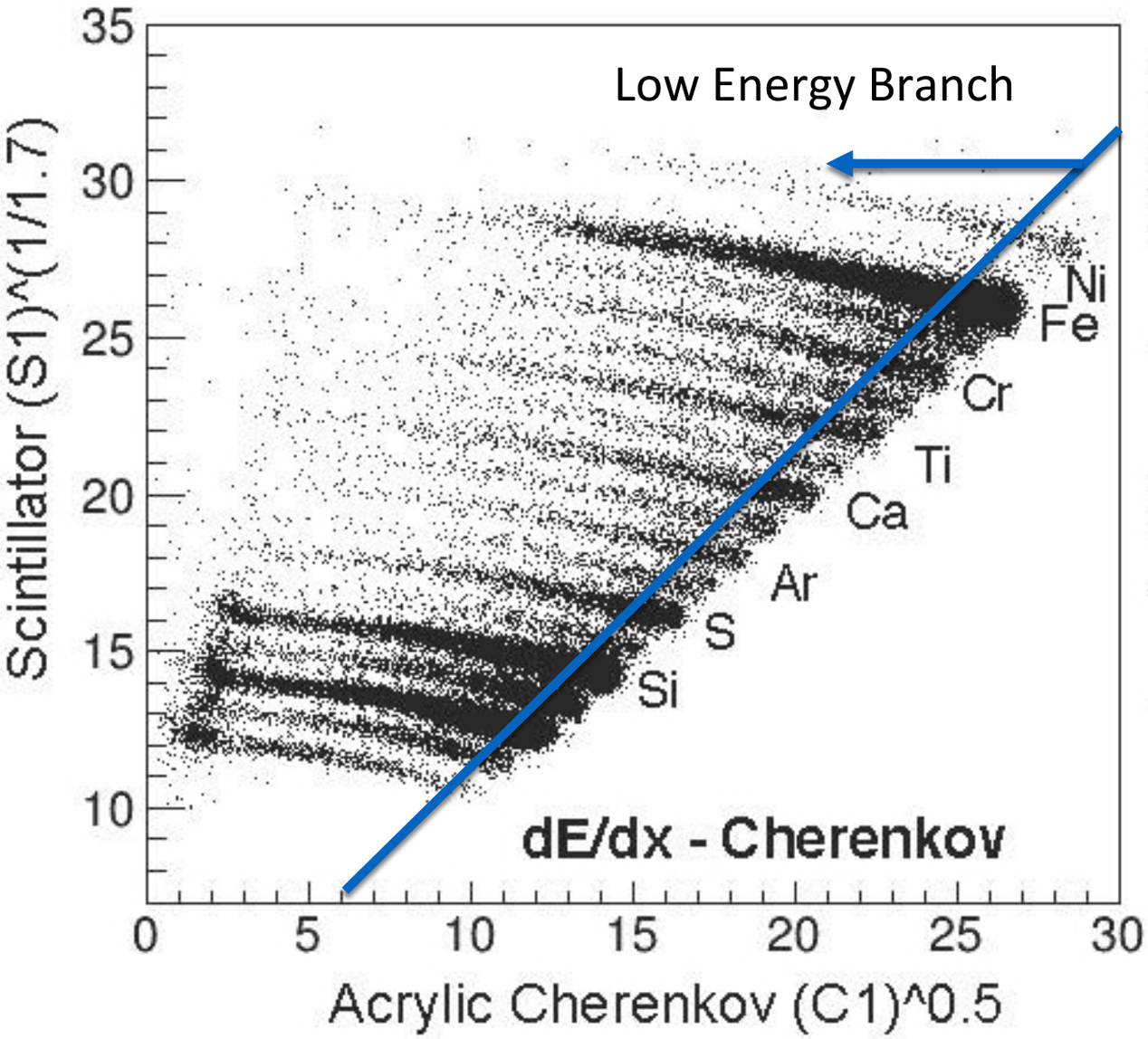
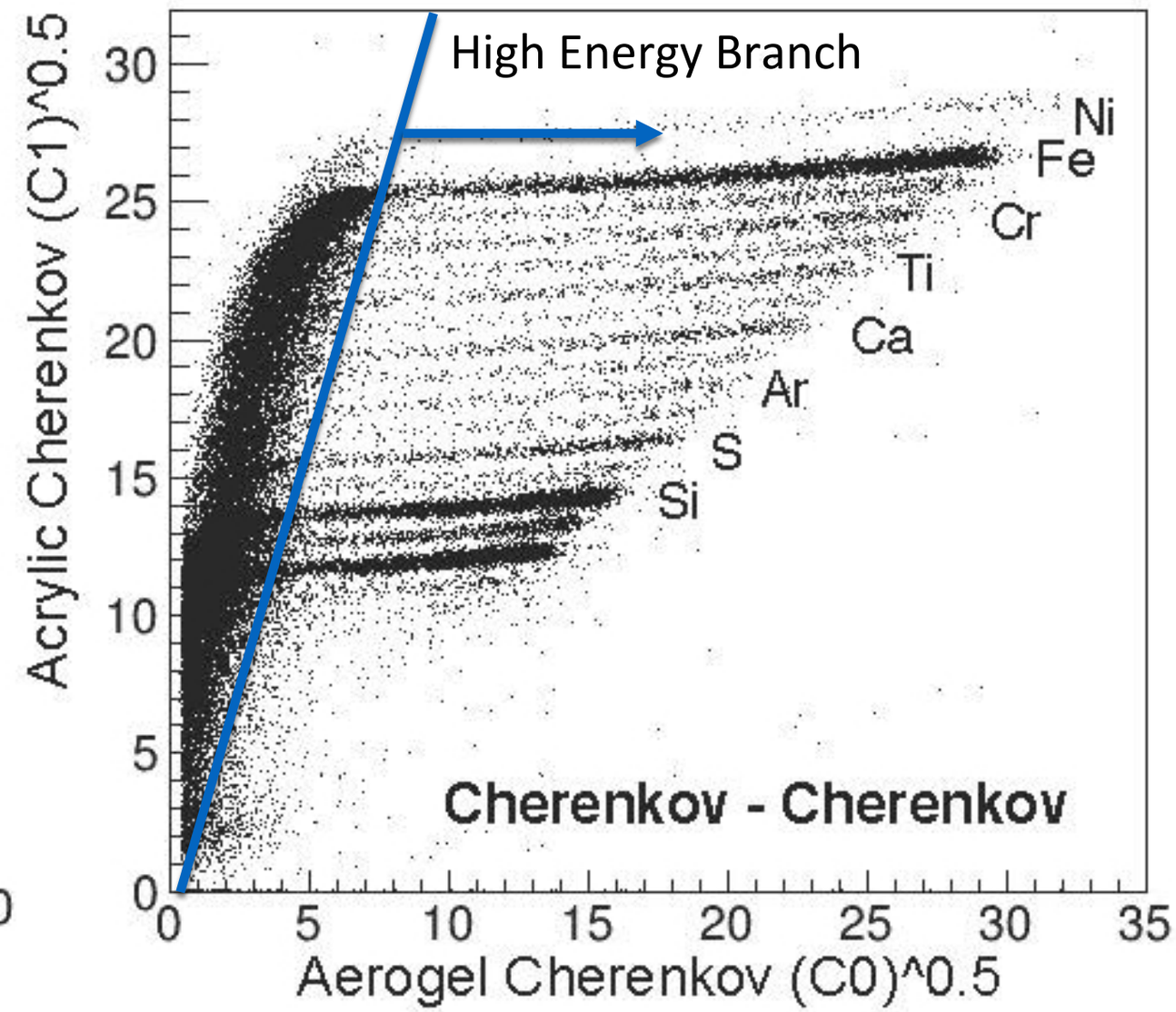
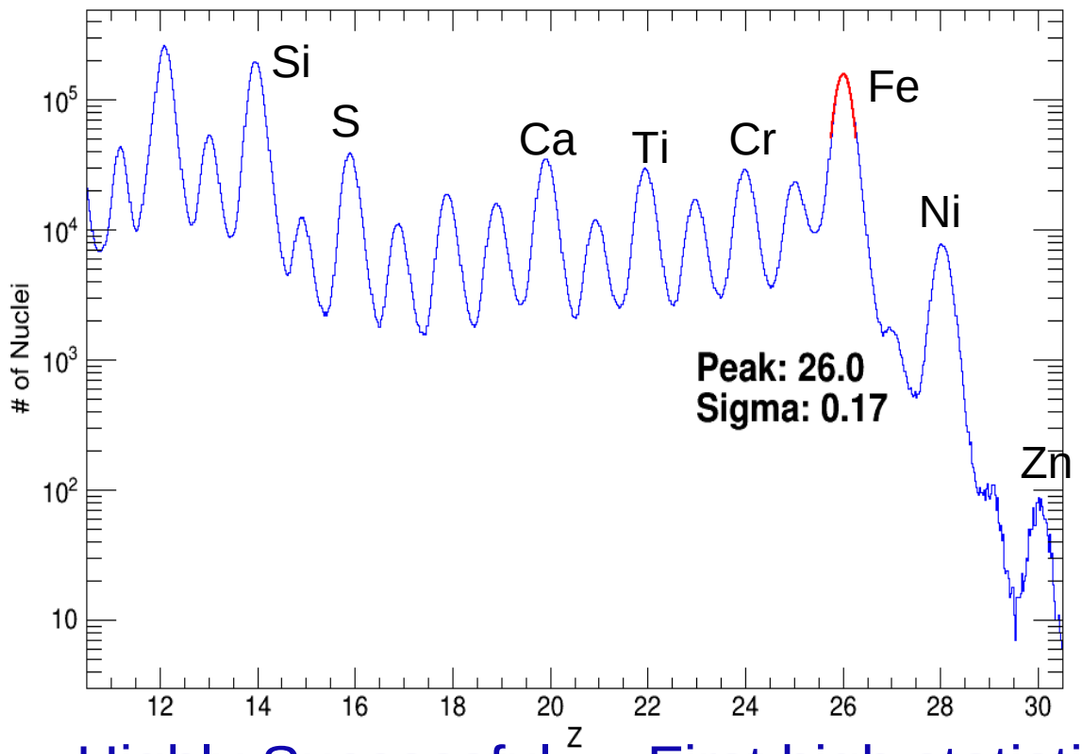
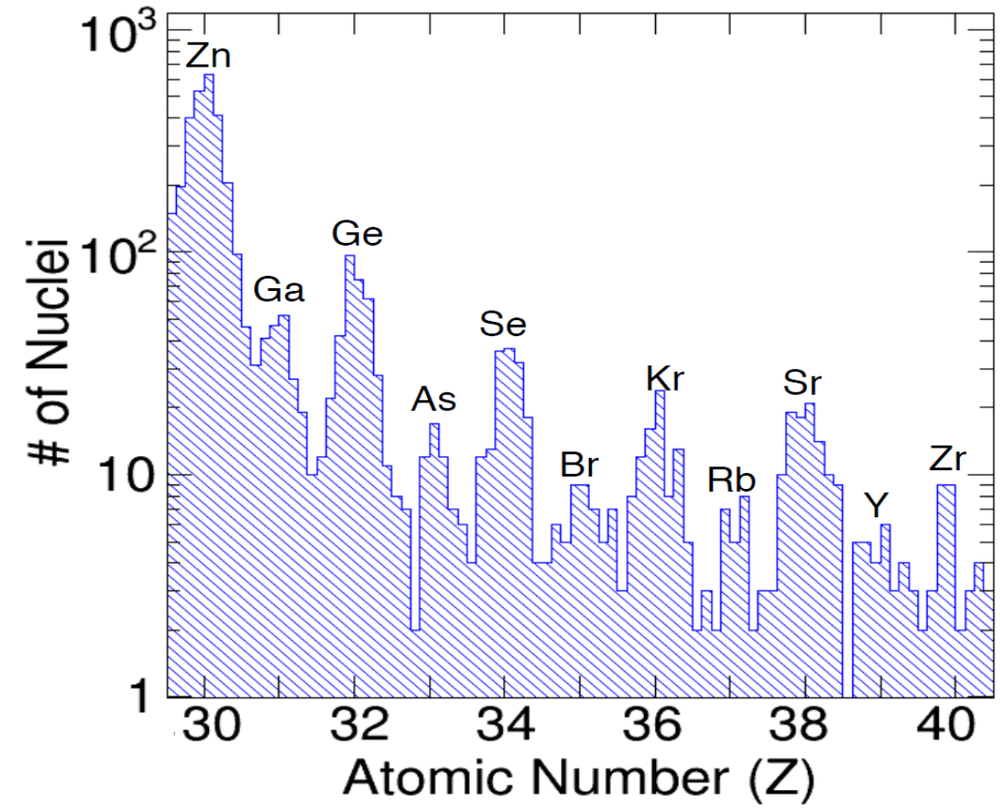


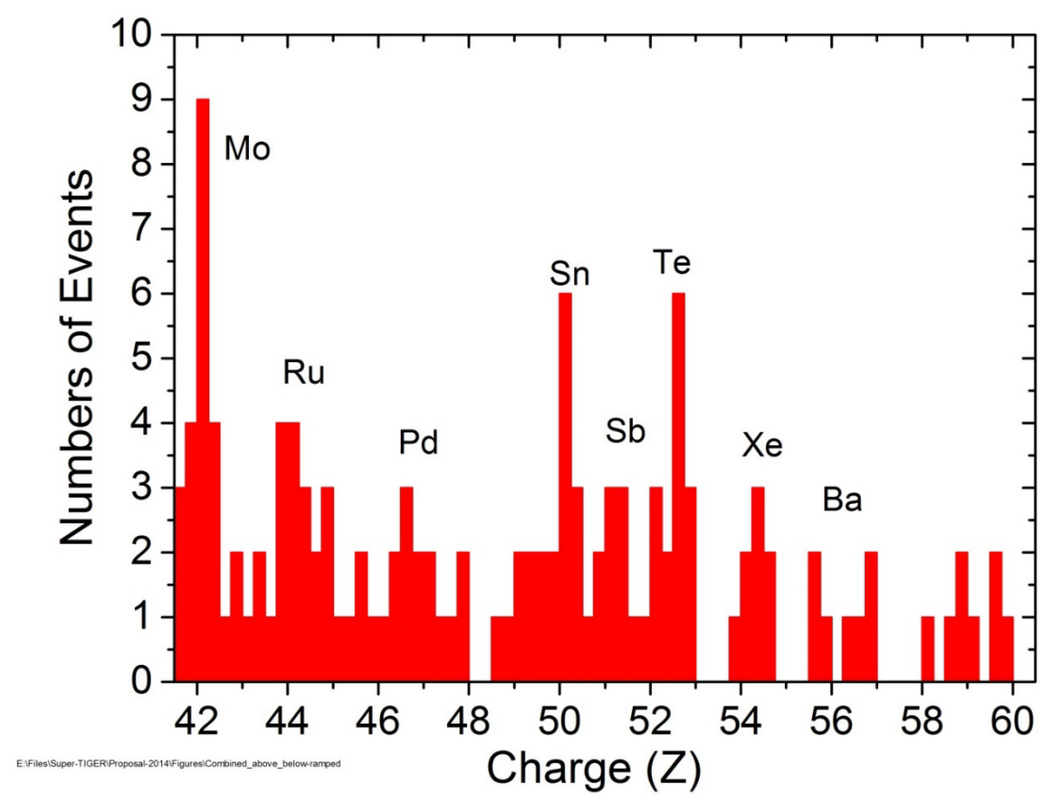


SuperTIGER-1 Data





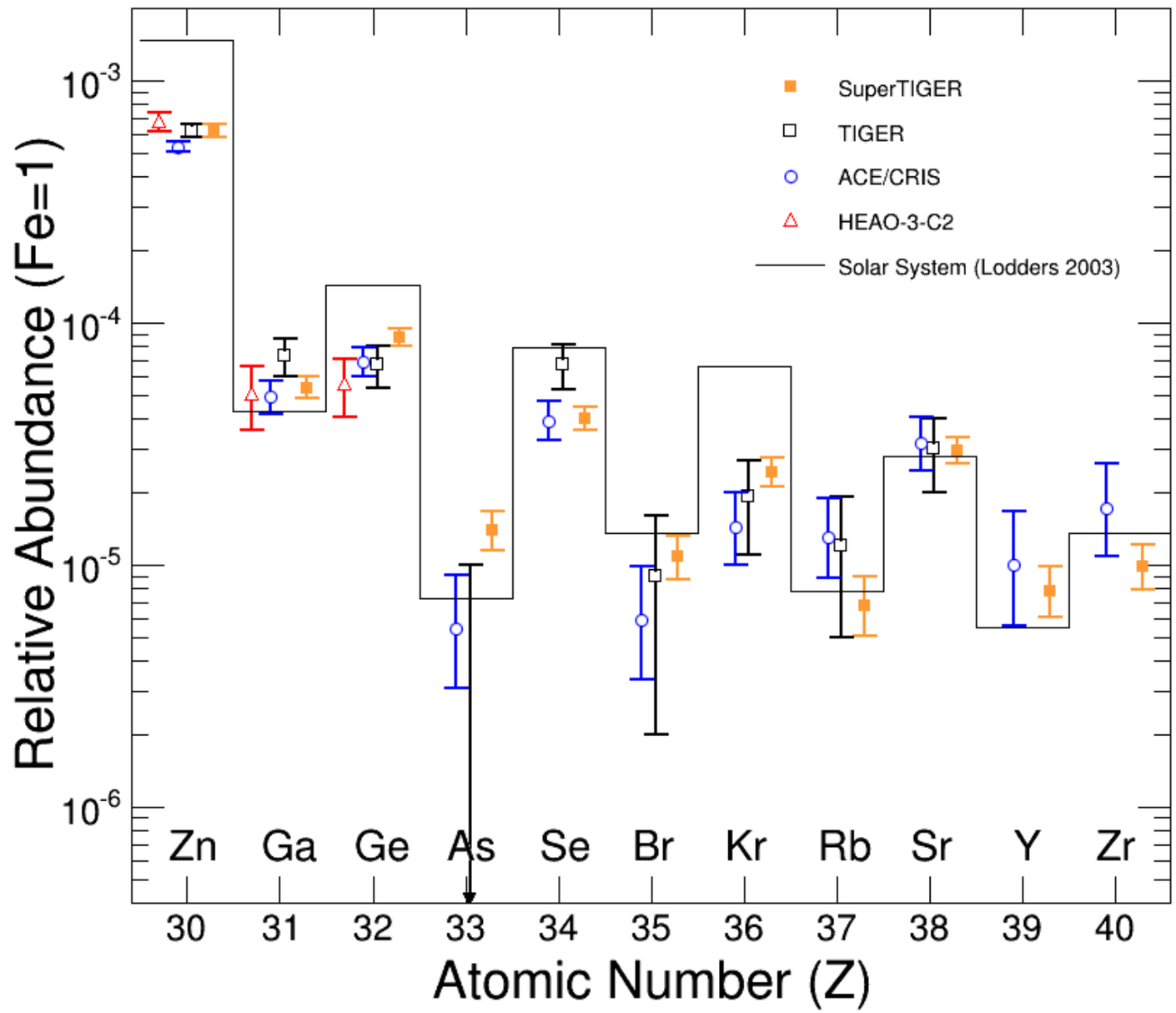
- Highly Successful — First high statistics measurement of abundances of all elements with 30≤Z≤40
- Complementary to ACE measurement taken in space, but ACE has lower numbers of events and lower energy
- Exploratory measurements of Z=40-60 range
- Paper on elemental abundances, Murphy et al., ApJ (2016) 831:148



UH GCR Abundances Relative to SS Abundances

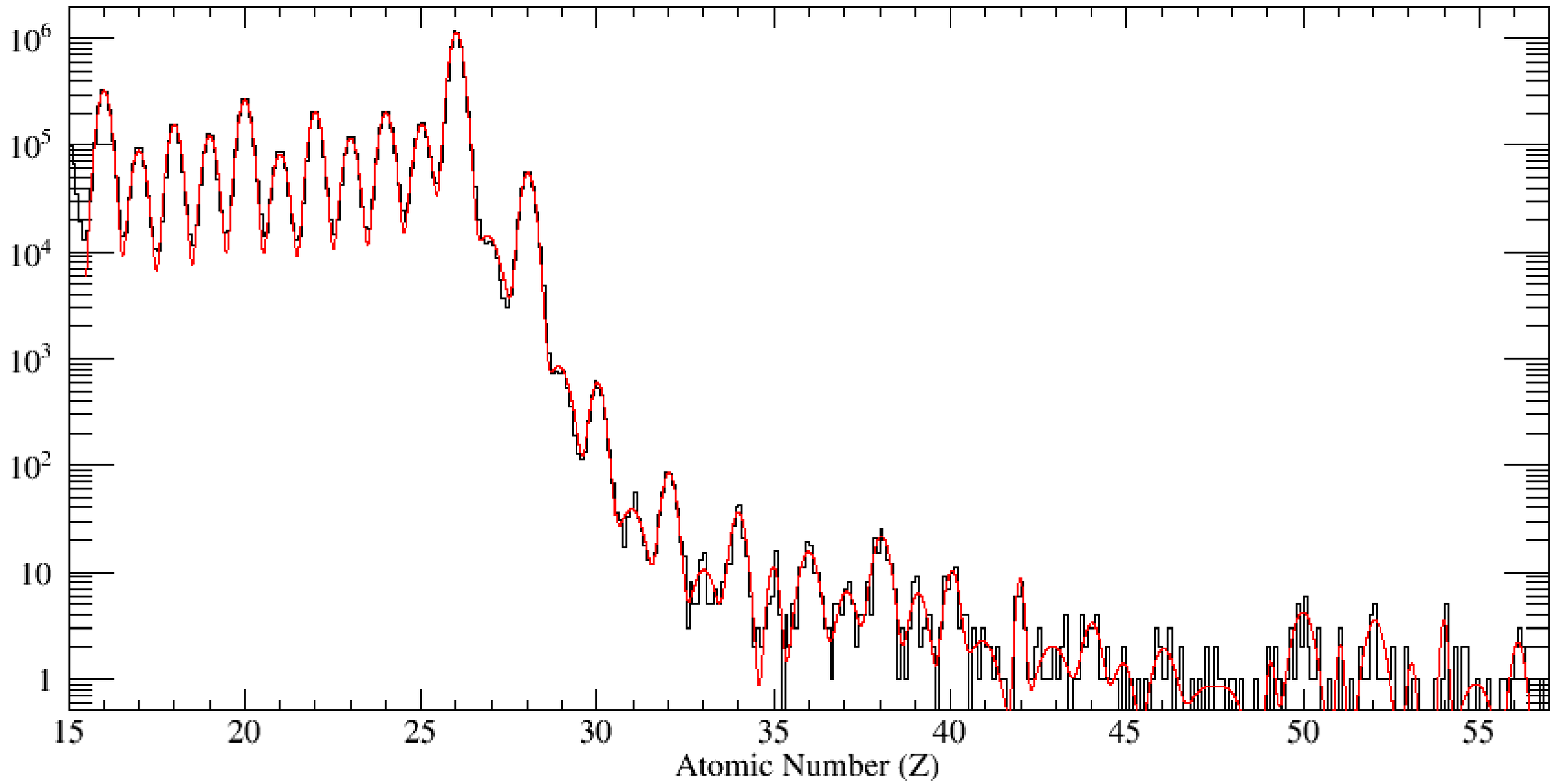
Murphy et al.
ApJ **831** 148 (2016)

ACE-CRIS satellite mission measures elements and isotopes at a lower energy
HEAO-3-C2 earlier satellite missions
Lodders 2003 Solar System Abundances represent ISM



Note here though that Ga abundance about the same as Ge cannot be explained by a source with Solar-System abundances.

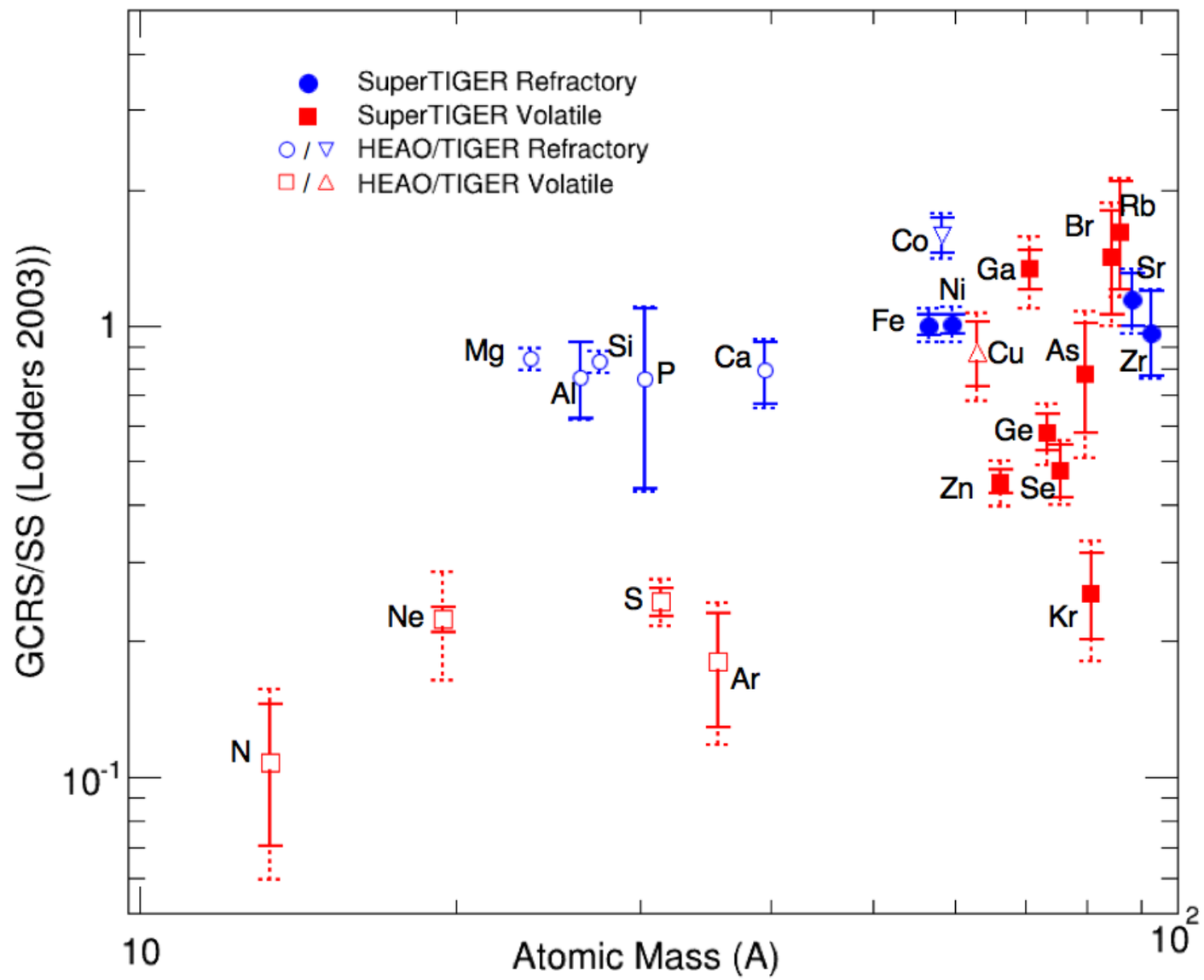
Fitting Abundances to $_{56}$Ba



SuperTIGER-1 data analyzed by Nathan Walsh for dissertation, resolving peaks for elements beyond $_{40}$Zr.

GCRS/SS Abundance Ratio

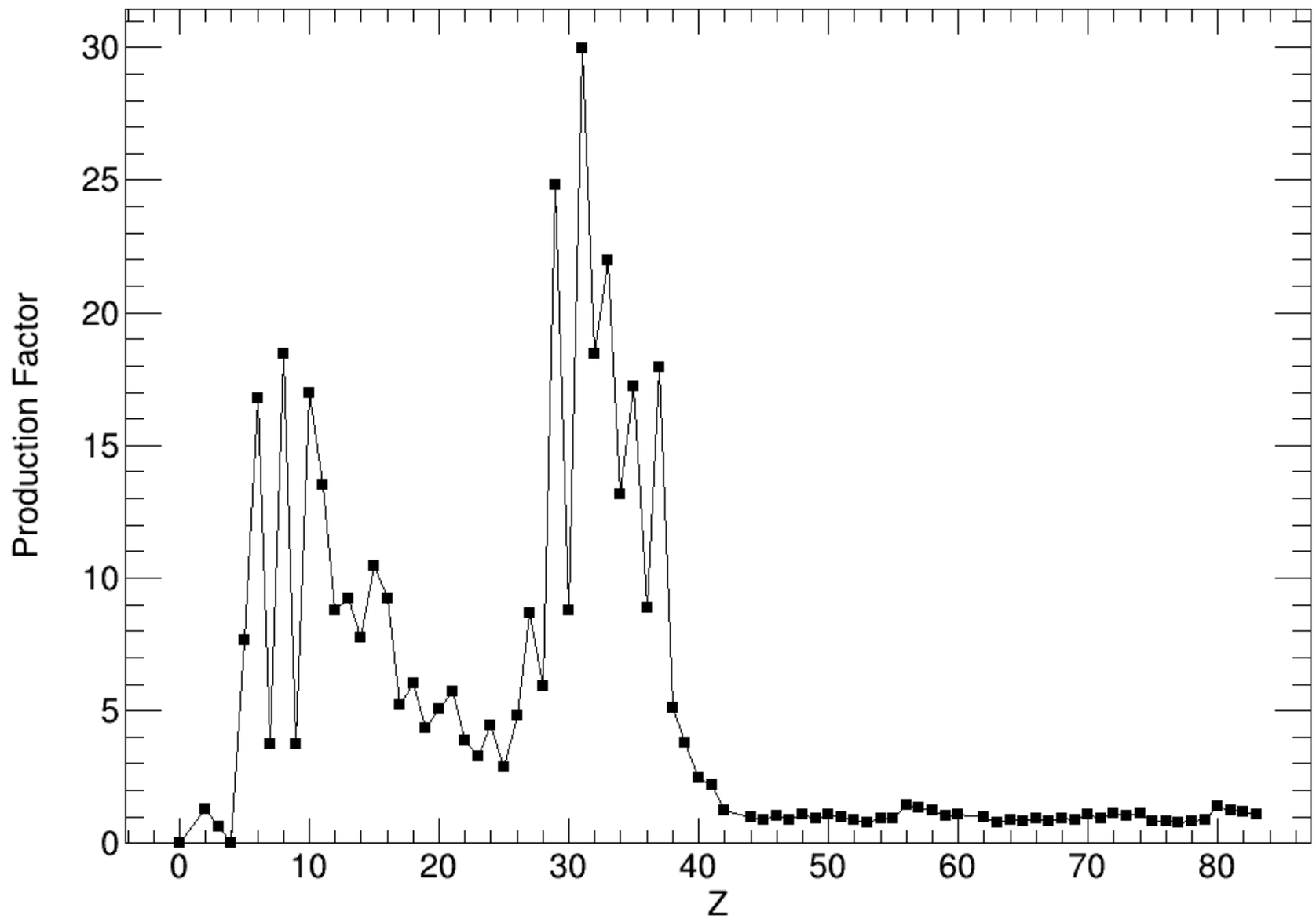
- TOA abundances corrected for propagation to source
- Refractory elements in dust grains preferentially accelerated
- Volatile elements as gas



Massive Star Outflow

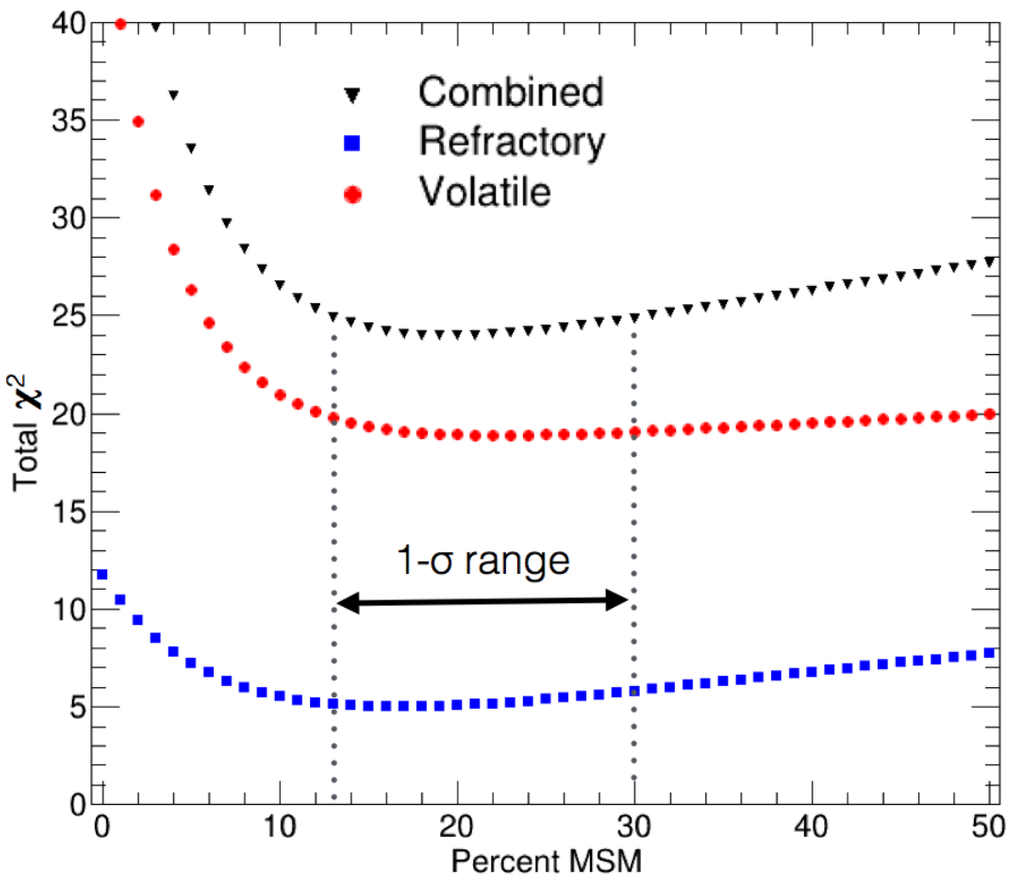
We expect the GCR source to be a mixture of material with Solar System abundances and outflow from massive stars modeled by Woosely and Heger (2007).

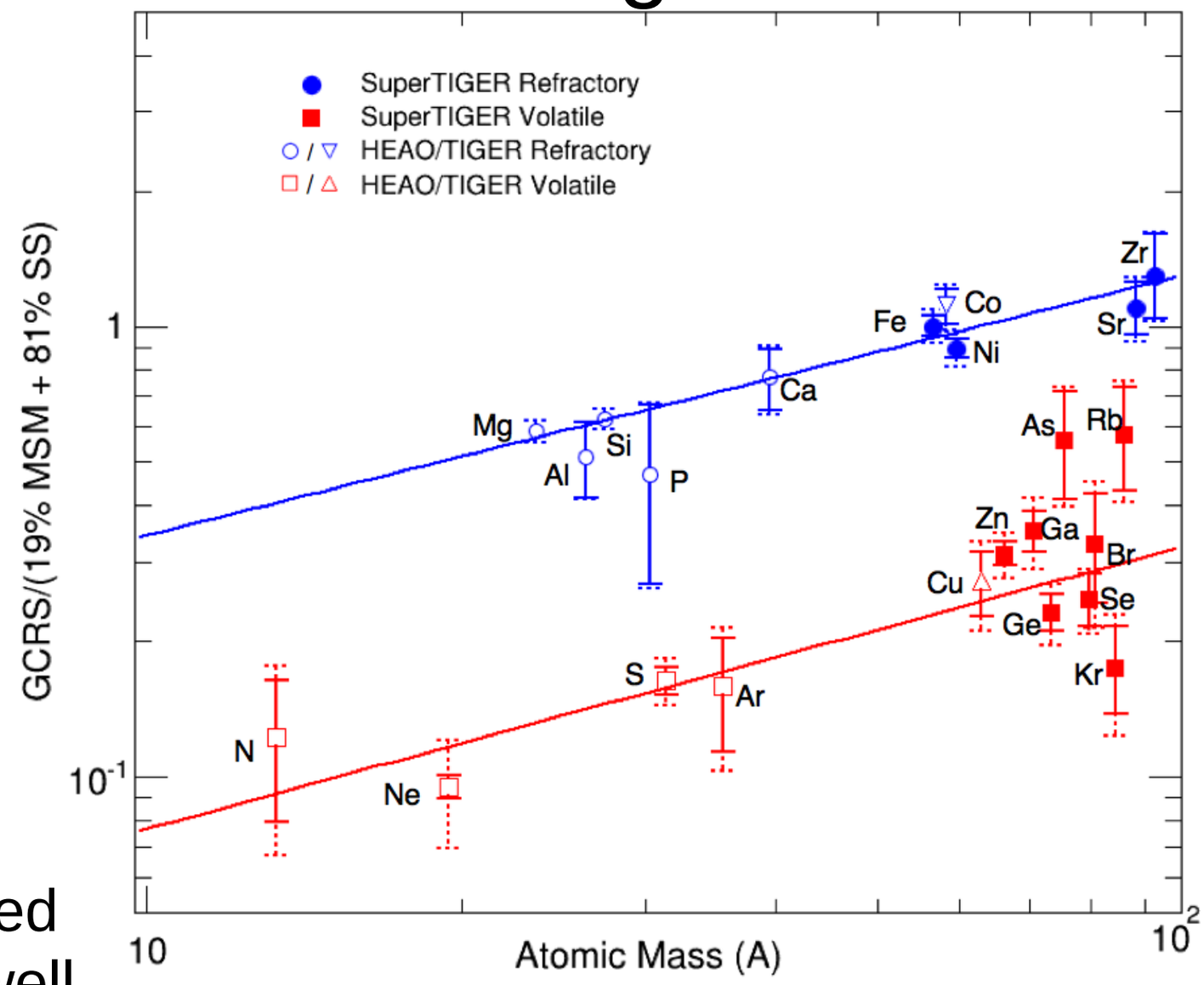
Production factors from Woosley and Heger (2007)



Best Fit Mixture

Comparing GCRS with a mixture of Solar System and massive star material gives order

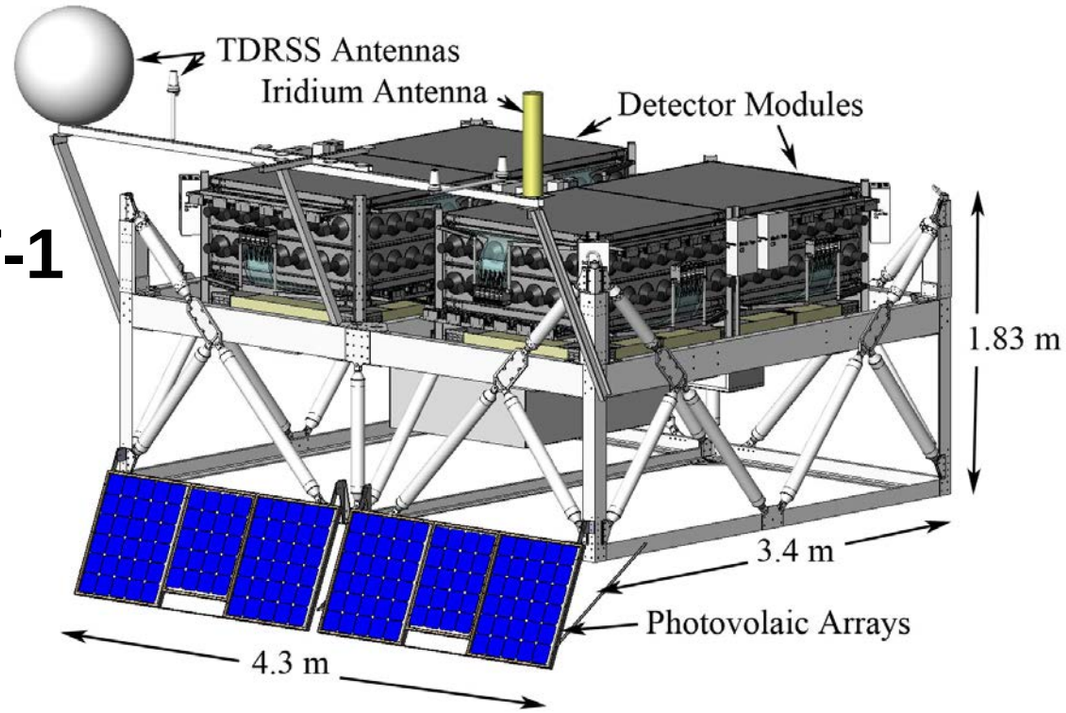




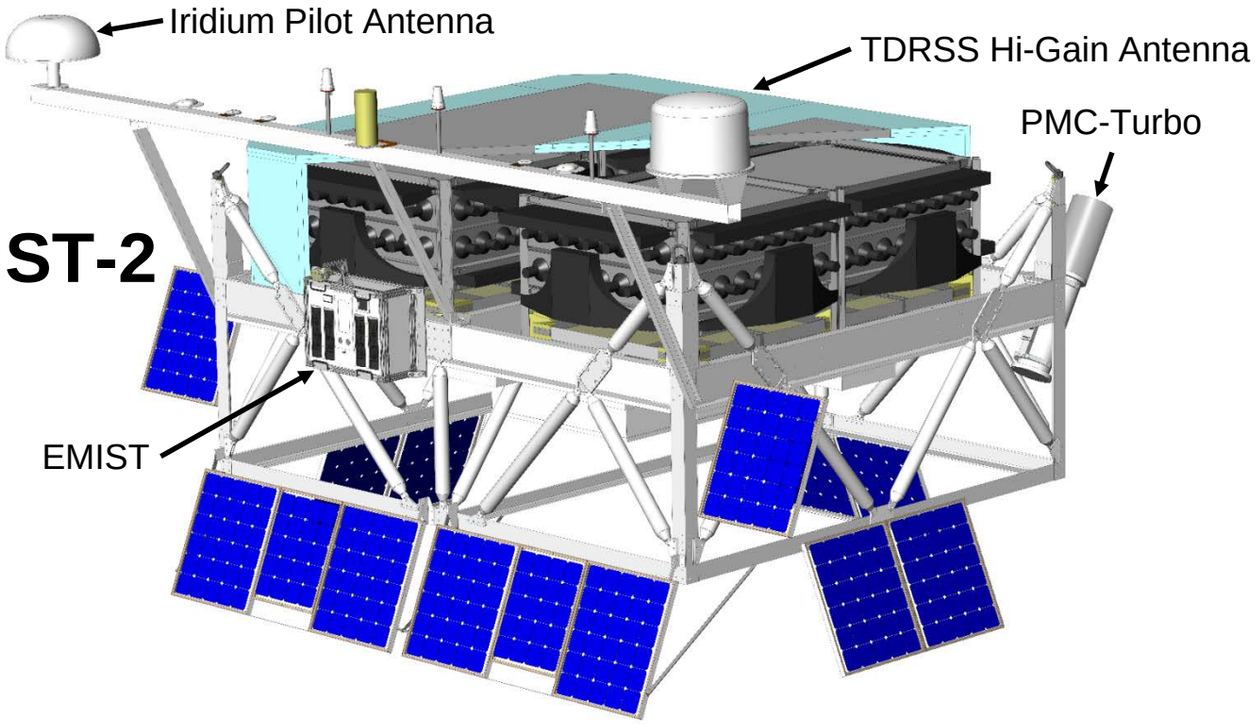
Some massive star material needed in mixture, but the amount is not well constrained

SuperTIGER Instruments

ST-1



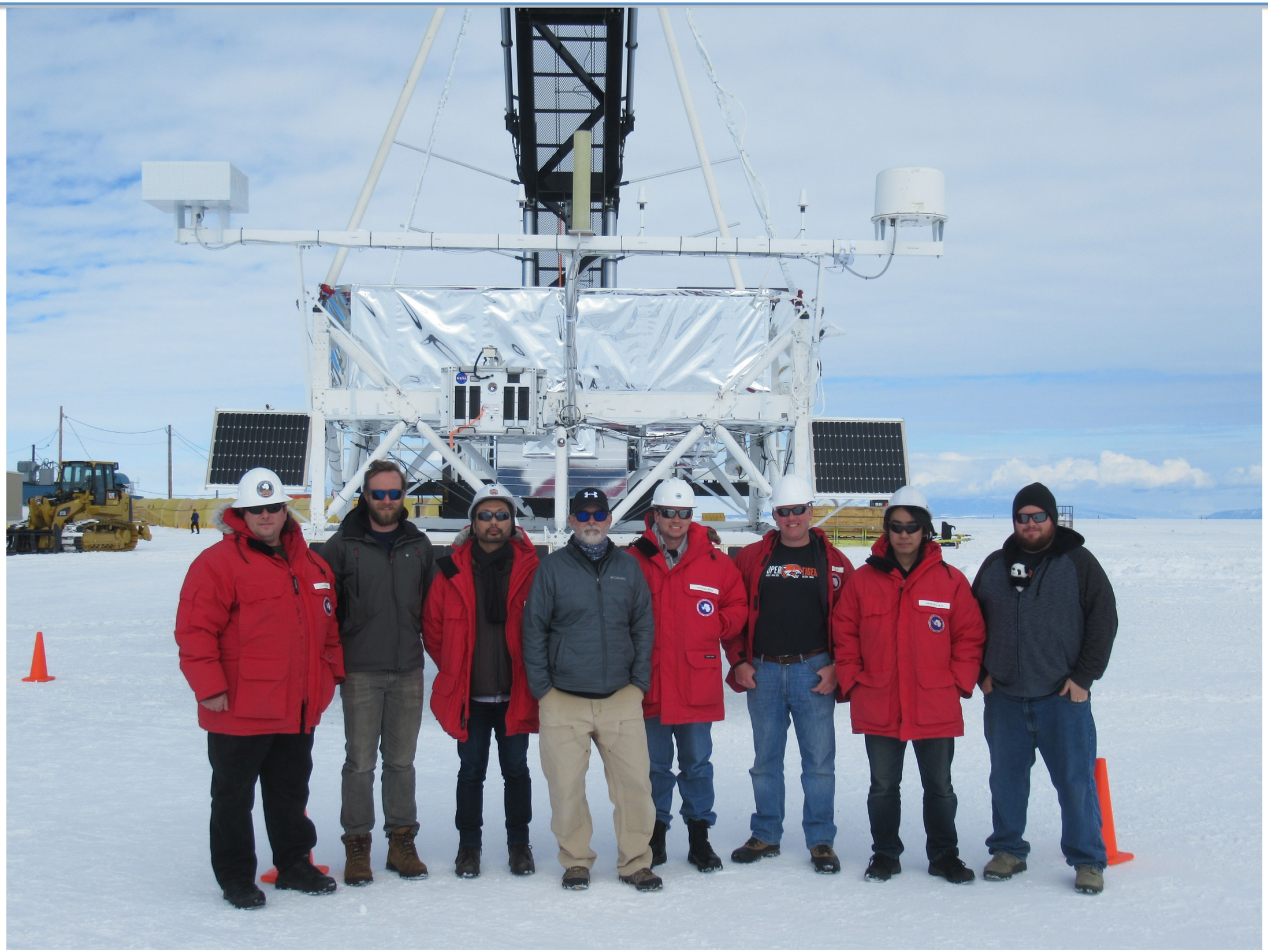
ST-2



ST-2.1 2017-2018
16 Launch Attempts

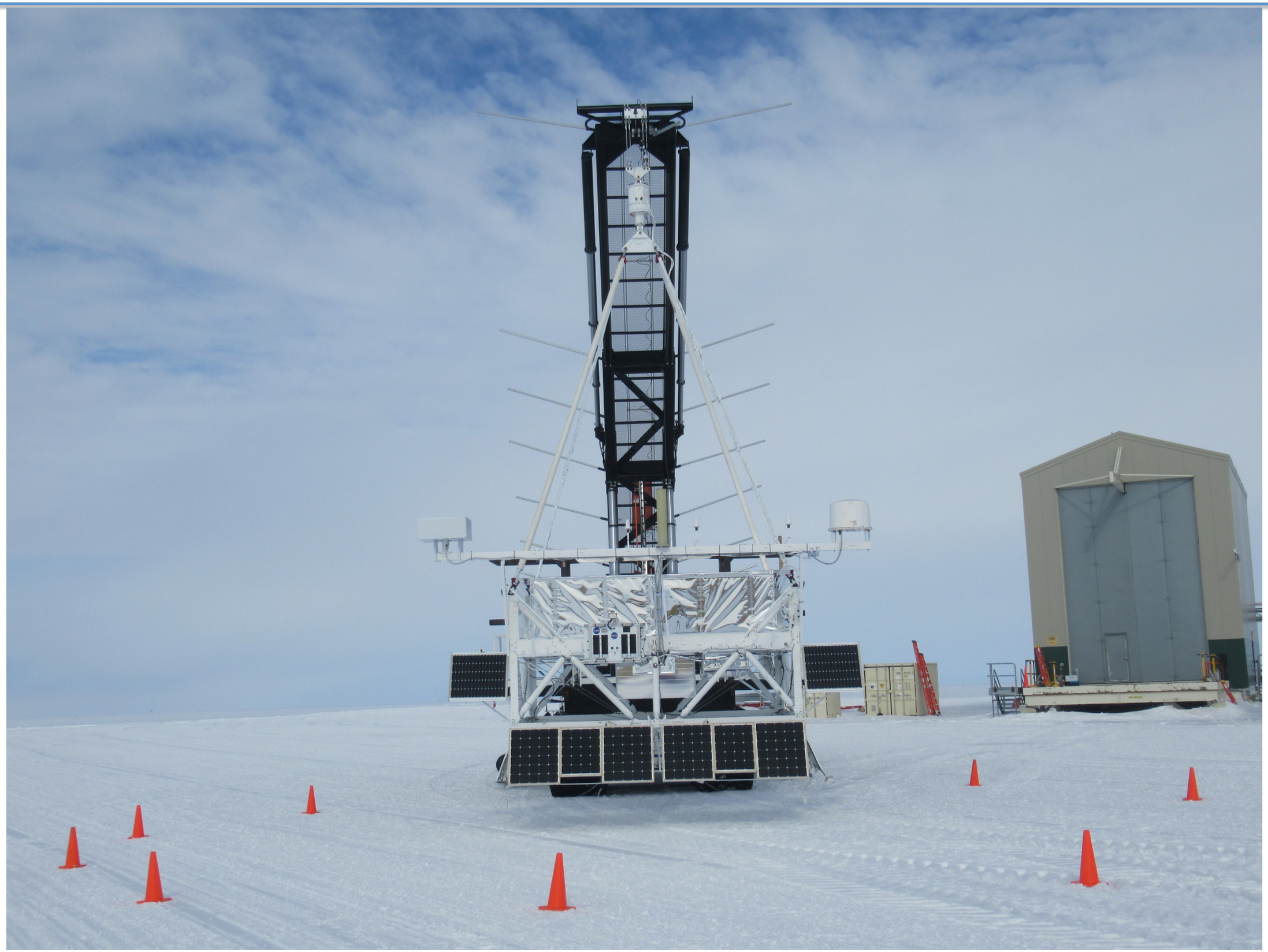
	US Central	
1.	December 8	December 9 2:00 AM - 7: 00 AM NZ
2.	December 13	December 14 2:00 PM - 7:45 PM NZ
3.	December 16	December 16 5:30 PM - December 17 1:00 AM NZ
4.	December 17	December 18 10:00 AM - 9:40 PM NZ - out to launch pad
5.	December 20	December 21 8:00 AM - 8:30 AM NZ - we did not pick up
6.	December 23	December 24 10:00 AM - 3:00 PM NZ
7.	December 24	December 25 3:00 PM - December 26 12:00 AM NZ
8.	December 28	December 28 9:00 PM - December 29 5:30 AM NZ
9.	January 1	January 1 9:00 PM - January 2 1:00 AM NZ
10.	January 1	January 2 12:00 PM - 8:00 PM NZ
11.	January 2	January 3 7:30 AM - 3:00 PM NZ
12.	January 6	January 6 7:30 PM - January 7 5:30 AM NZ
13.	January 7	January 7 7:30 PM - January 8 4:30 AM NZ - out to launch pad
14.	January 9	January 10 7:30 AM - 2:30 PM NZ
15.	January 10	January 11 3:00 AM - 6:00 AM NZ
16.	January 13	January 14 9:00 AM - 4:00 PM NZ

ST-2.1 Hang Test Day

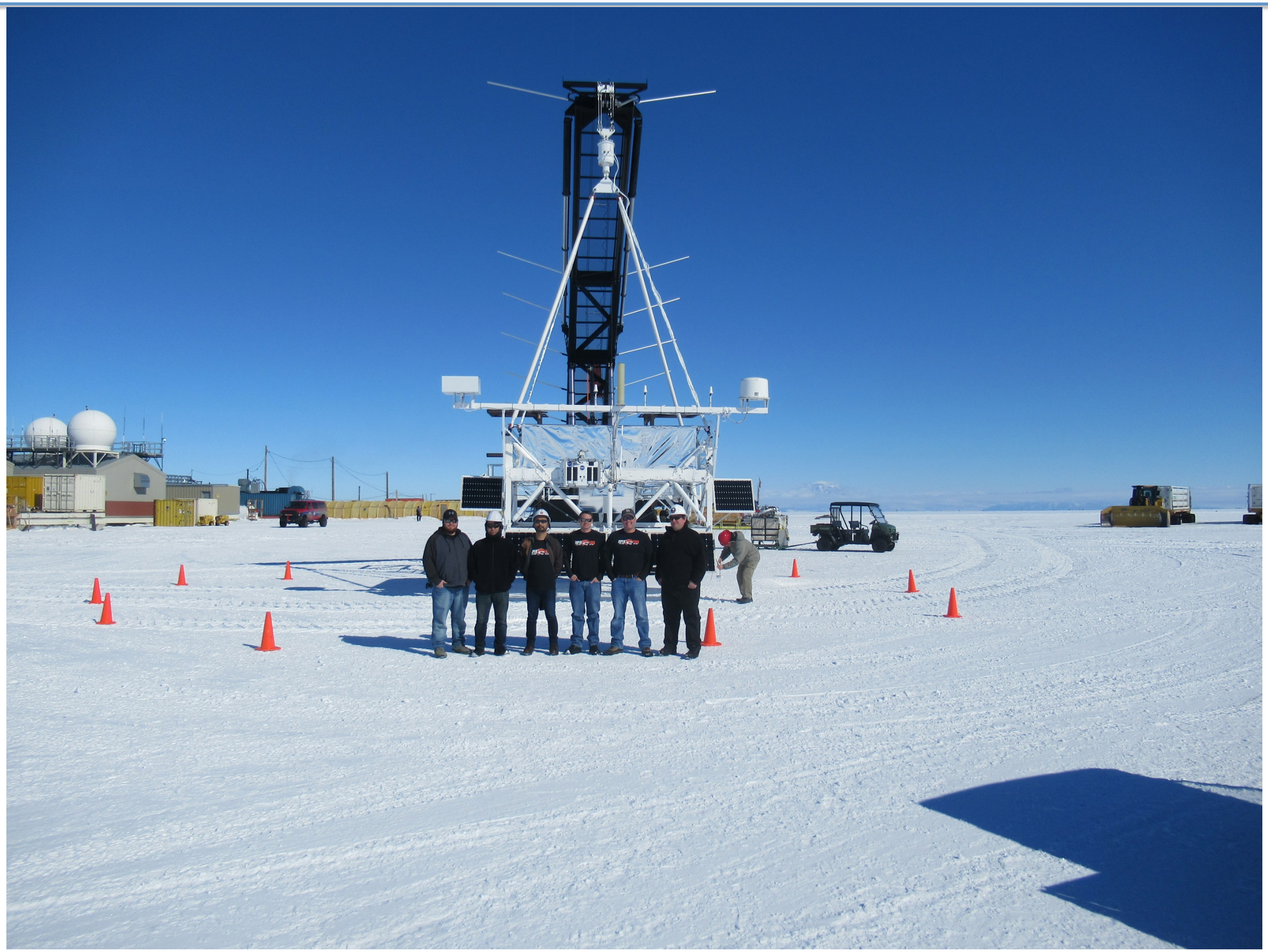


ST-2.1 Attempt #1

ST-2.1 Attempt #2



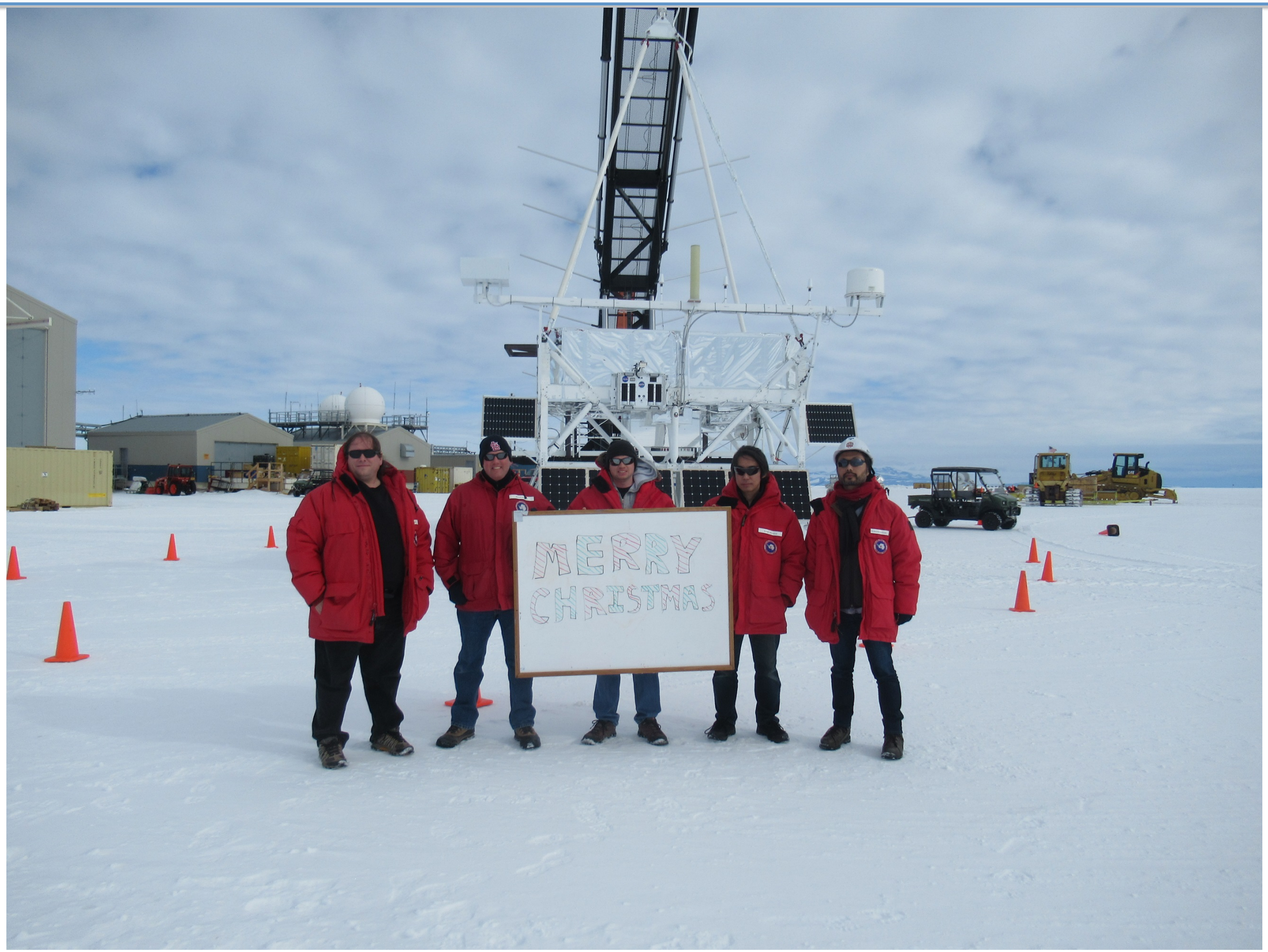
ST-2.1 Attempt #3



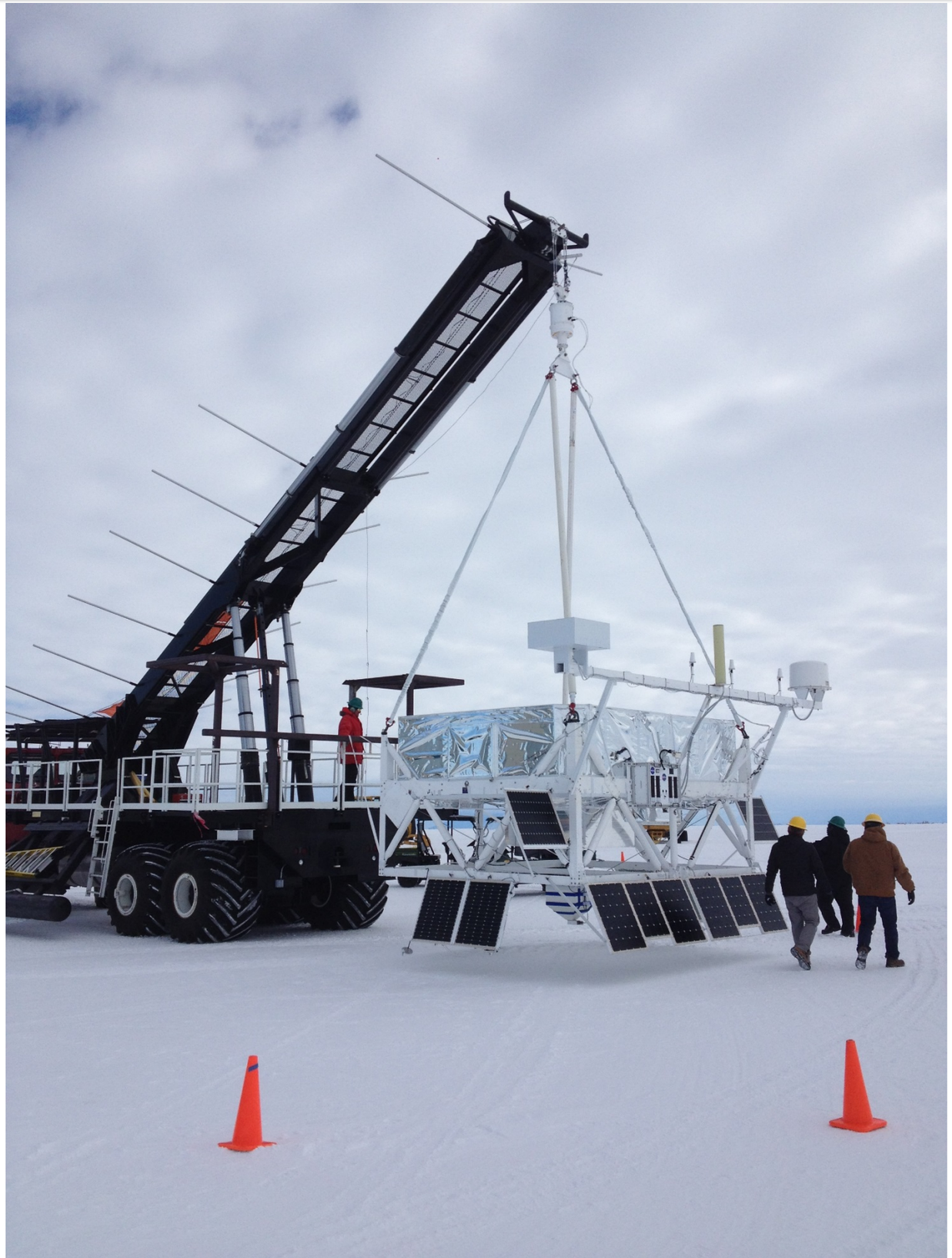
ST-2.1 Attempt #4

ST-2.1 Attempt #5

ST-2.1 Attempt #6

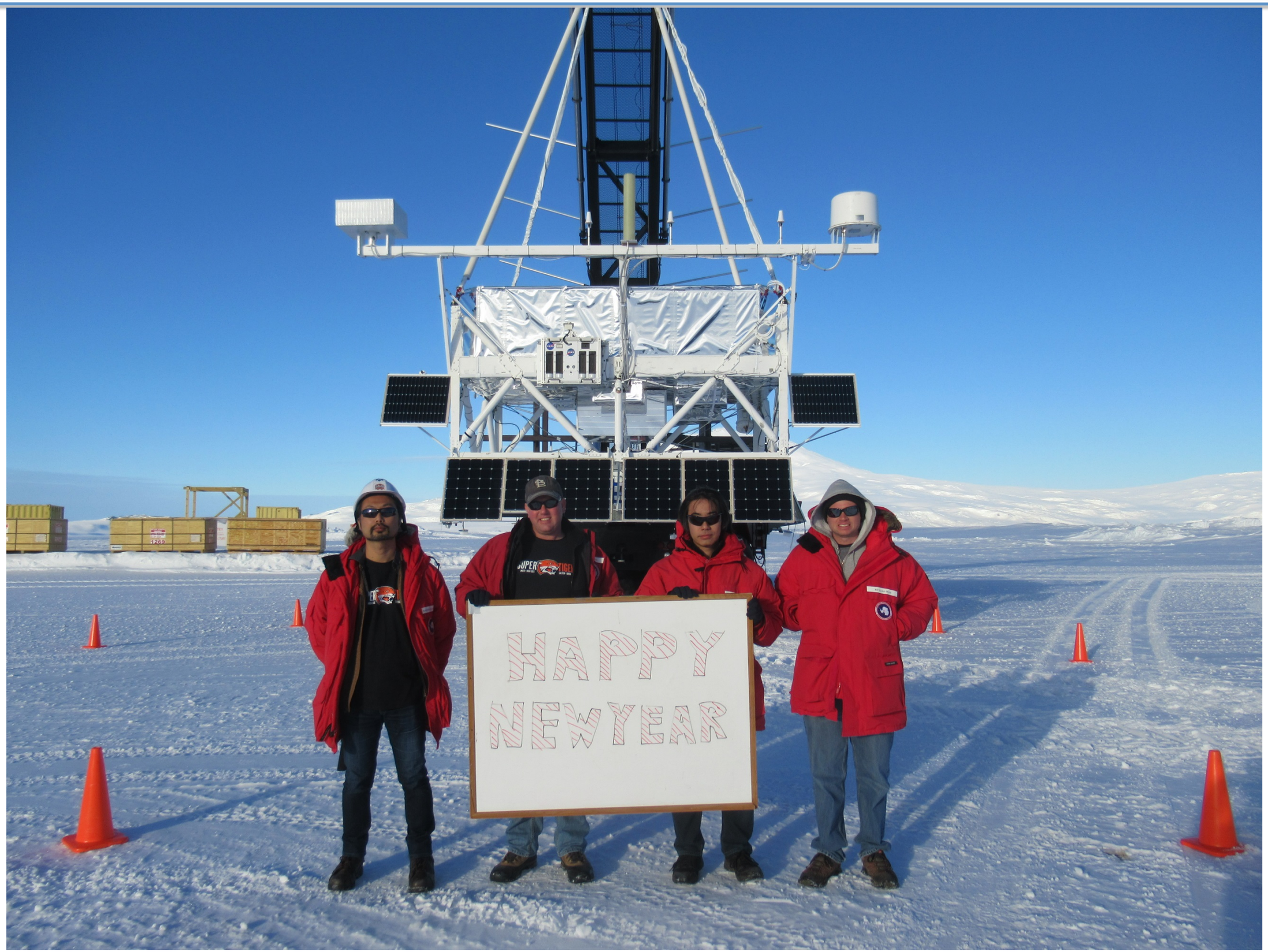


ST-2.1 Attempt #7

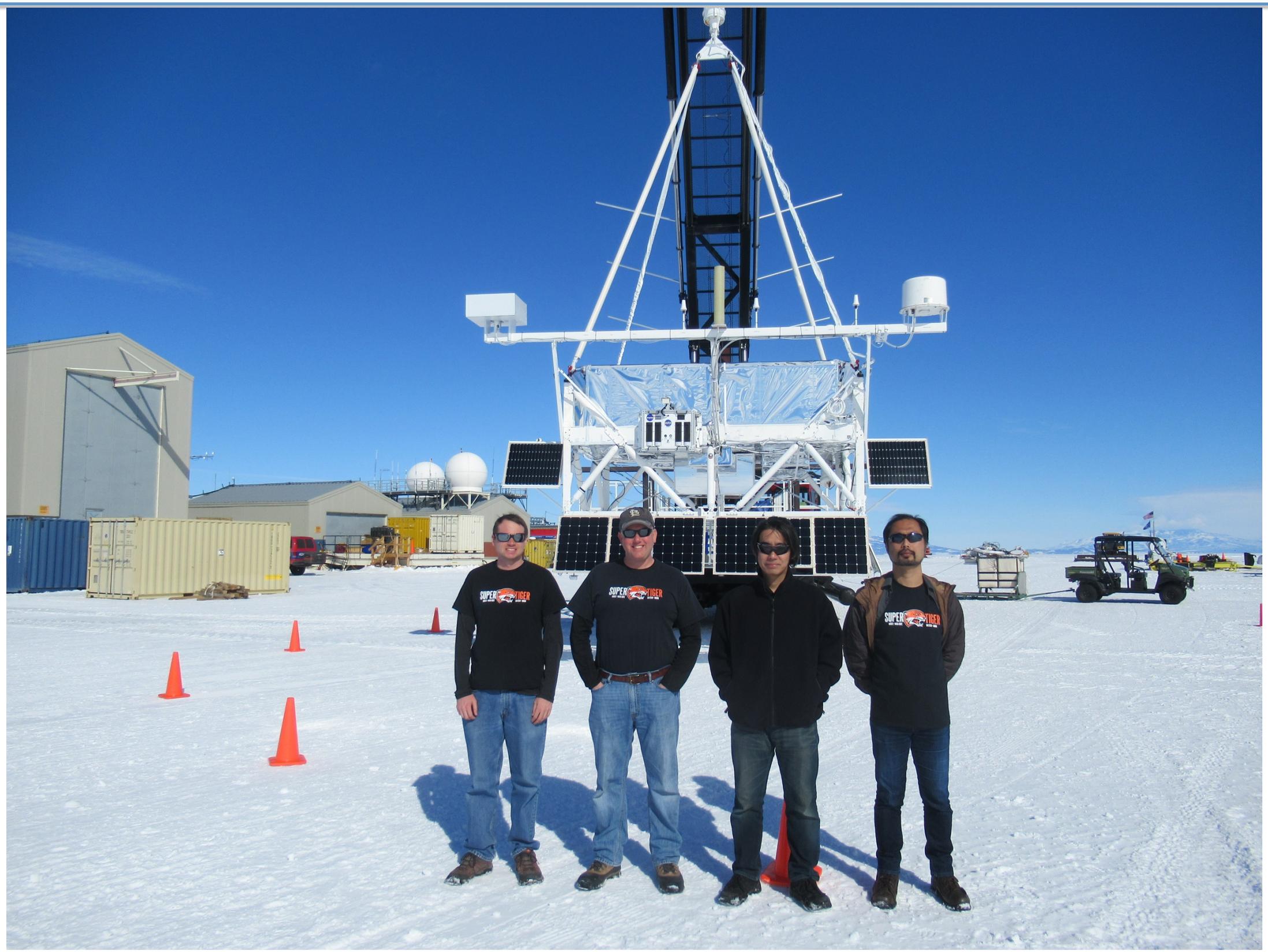


ST-2.1 Attempt #8

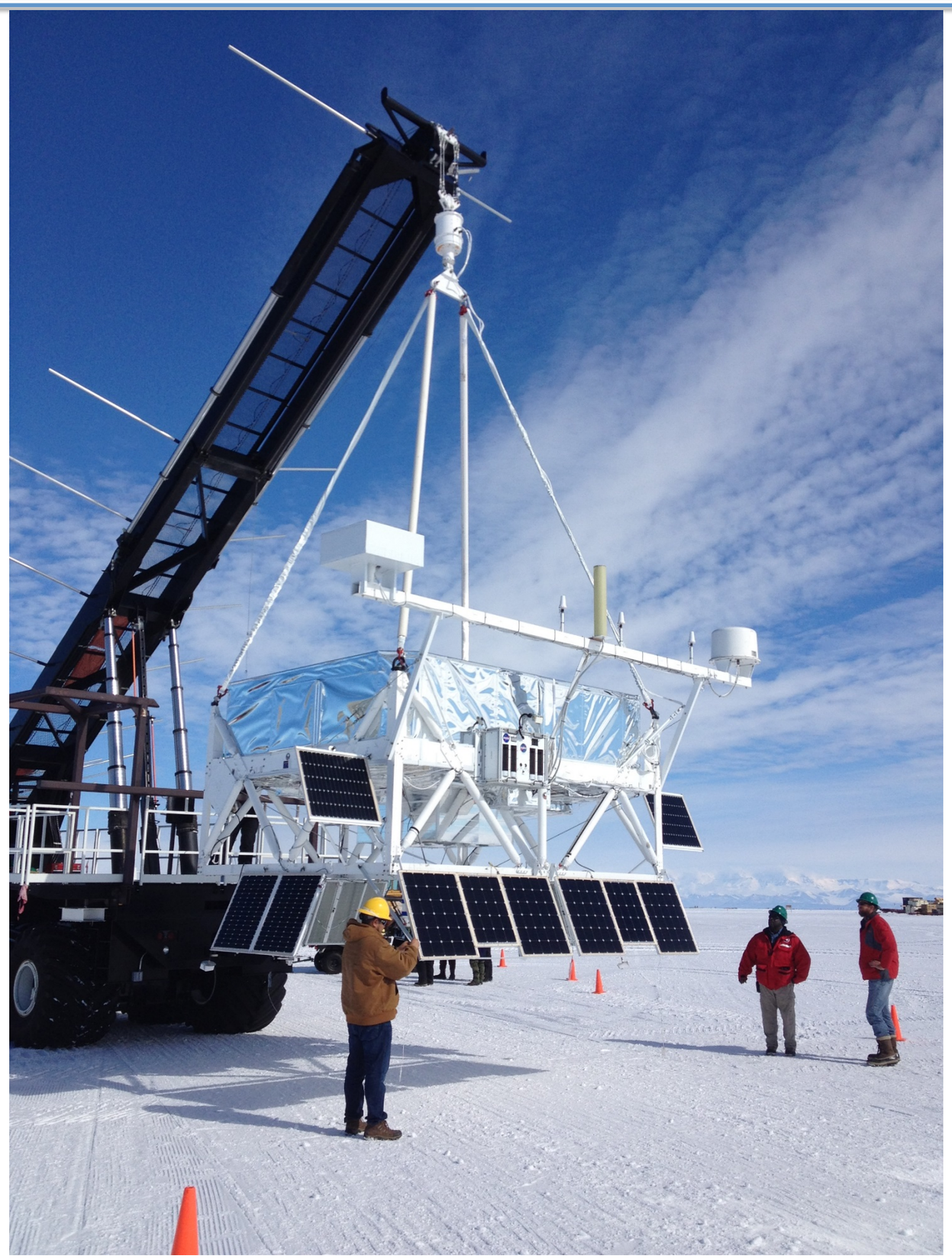
ST-2.1 Attempt #9



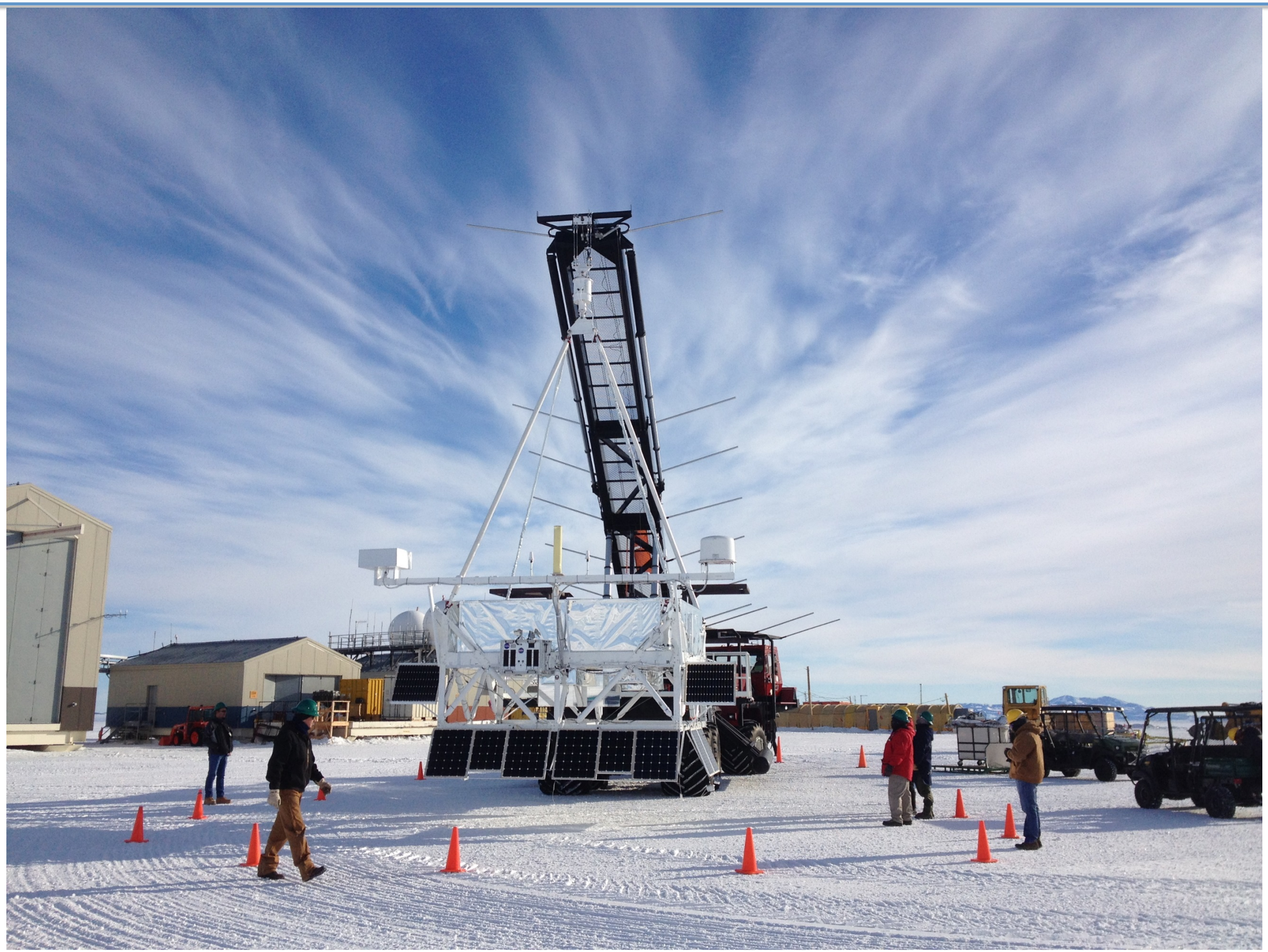
ST-2.1 Attempt #10



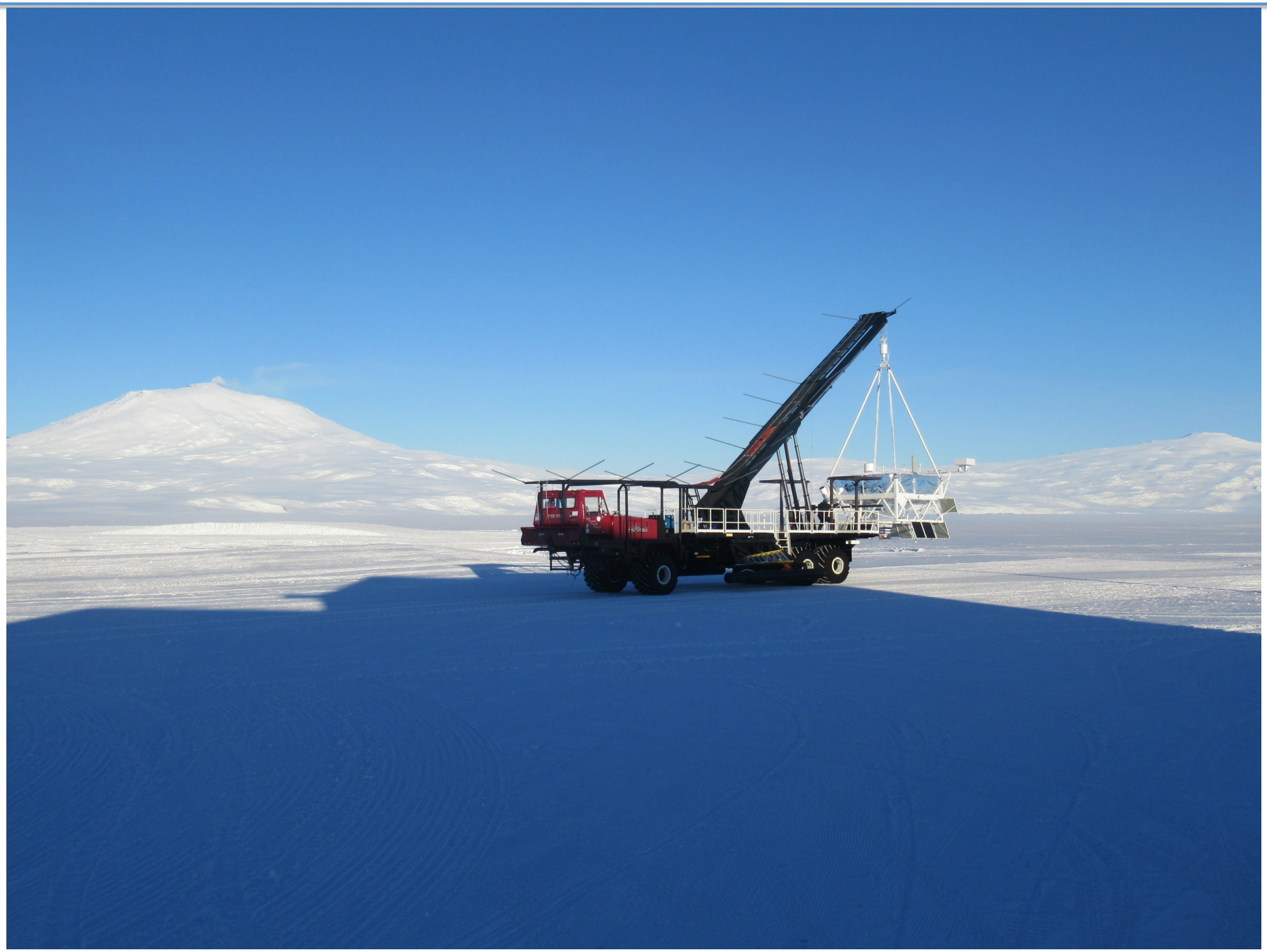
ST-2.1 Attempt #11



ST-2.1 Attempt #12



ST-2.1 Attempt #13

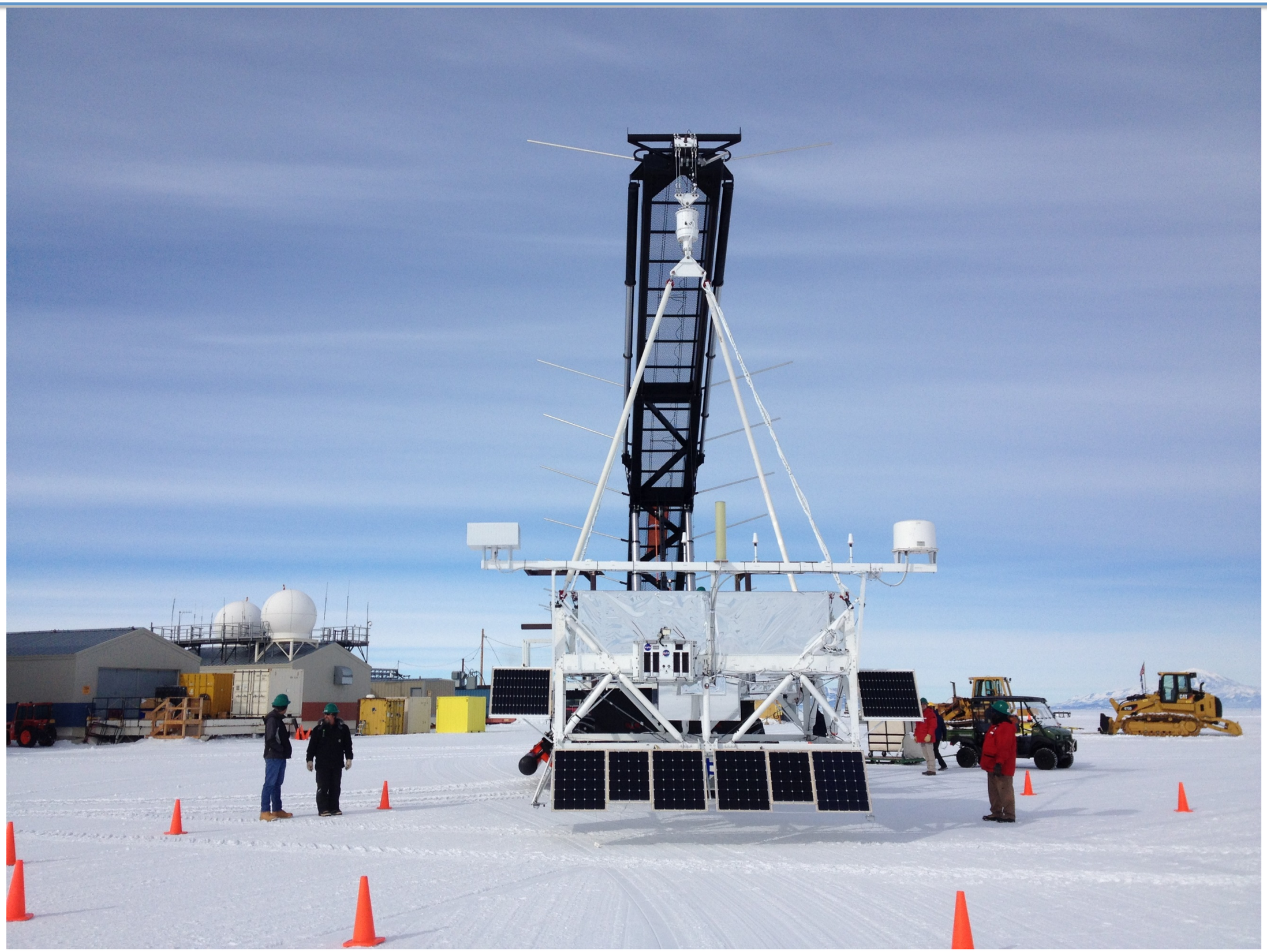


ST-2.1 Attempt #14

ST-2.1 Penguin Invasion

ST-2.1 Attempt #15

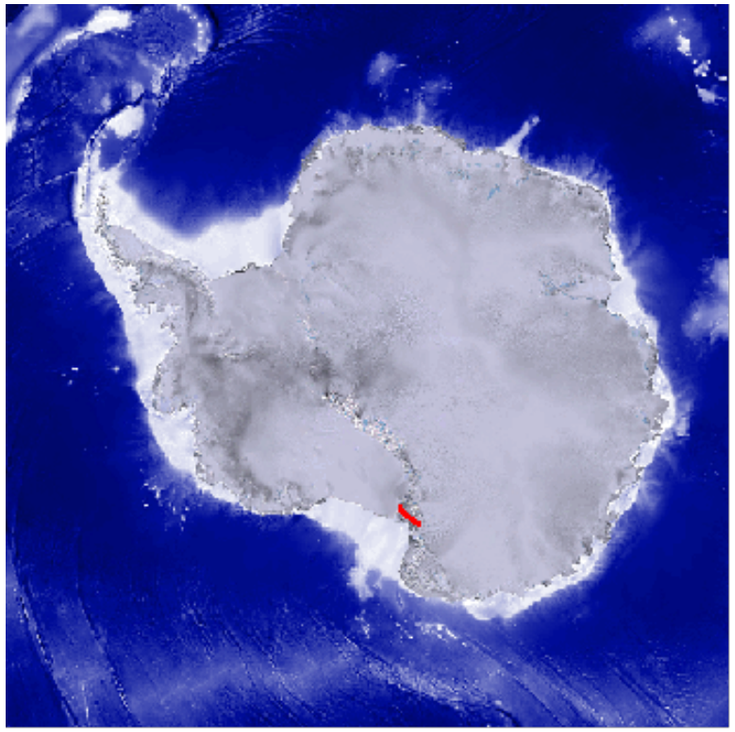
ST-2.1 Attempt #16

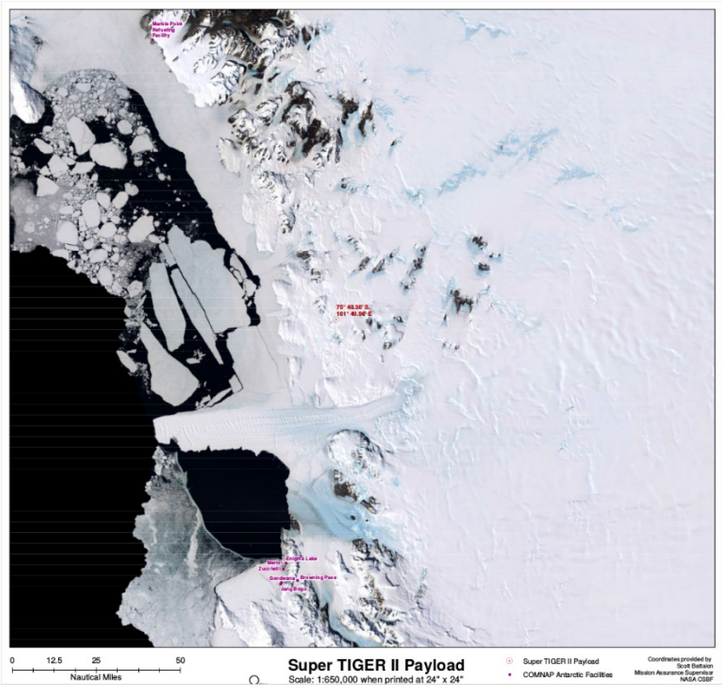


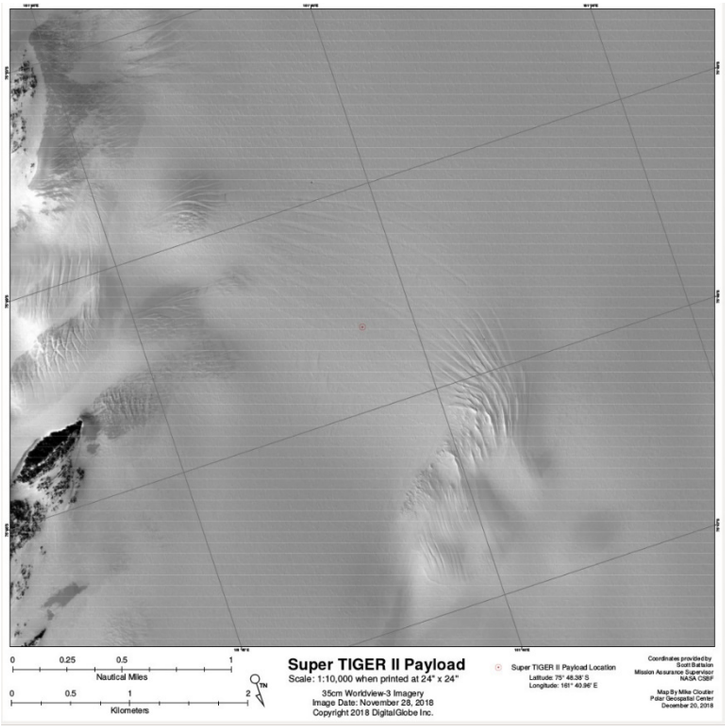
ST-2.1 Packing It In

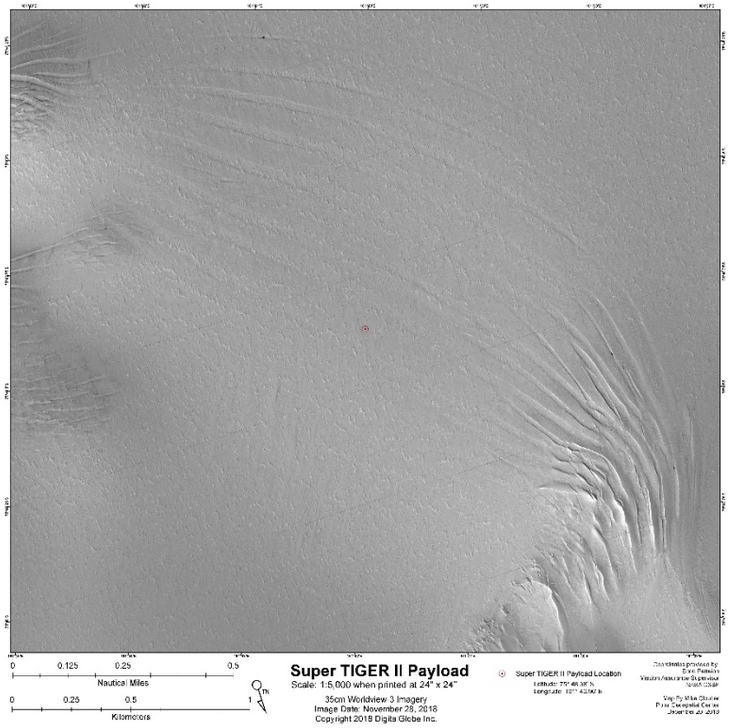
ST-2.2 Flight December 20, 2018

- Flight less than 7 hours
- Maximum altitude ~79,300 ft
- Landed in crevasse field within helicopter range of McMurdo (~150 miles)



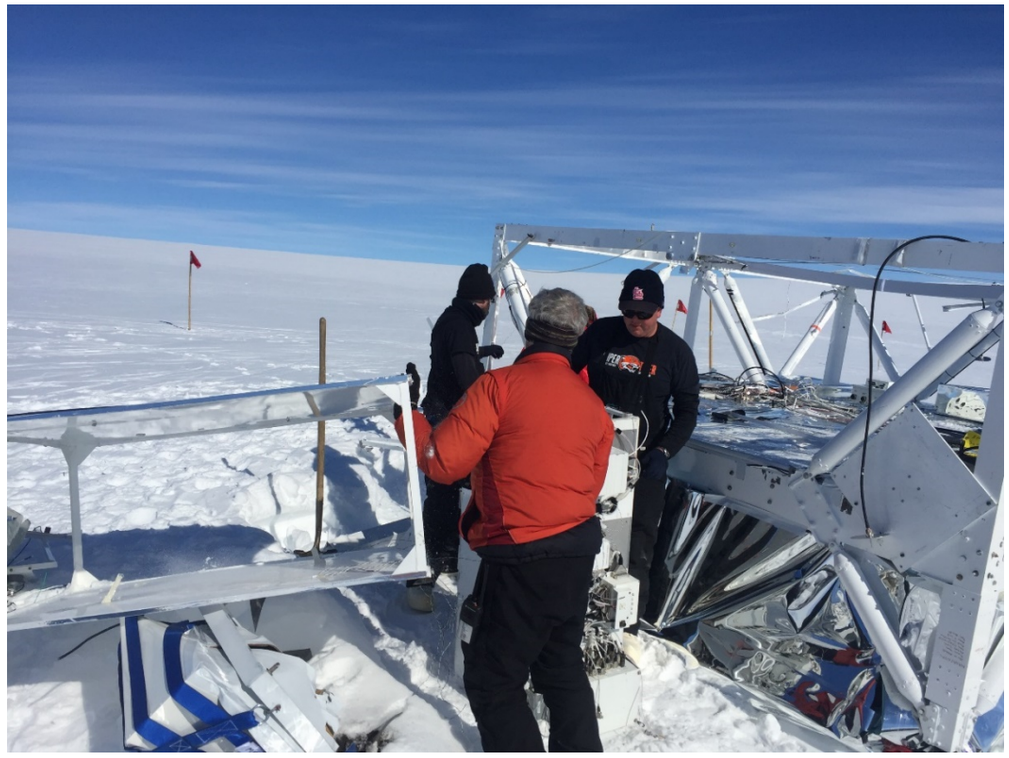






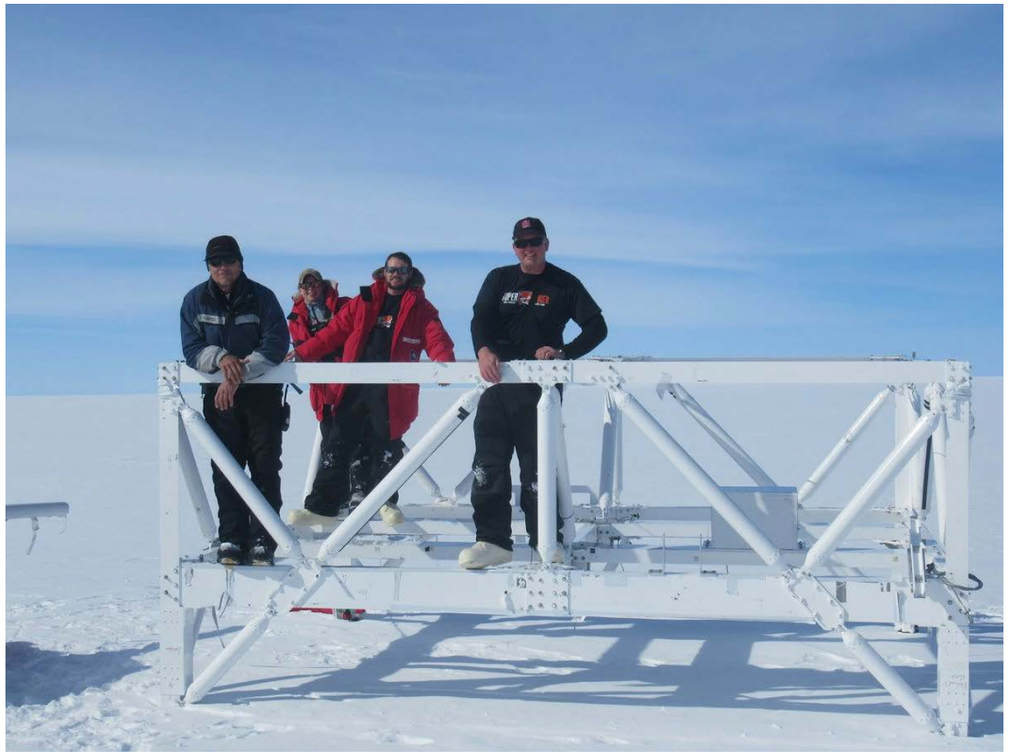
ST-2.2 2019 Recovery

- Payload recovered in 3 days of field operations from McMurdo Station
- Two days with team of 4 supported by 2 Bell 212 helicopters:
  - January 8 perform high priority recovery of attached hardware
  - January 10: gondola and 2 instrument modules slung to Basler site
- January 11 team of 6 supported by a Basler breakdown and recover payload



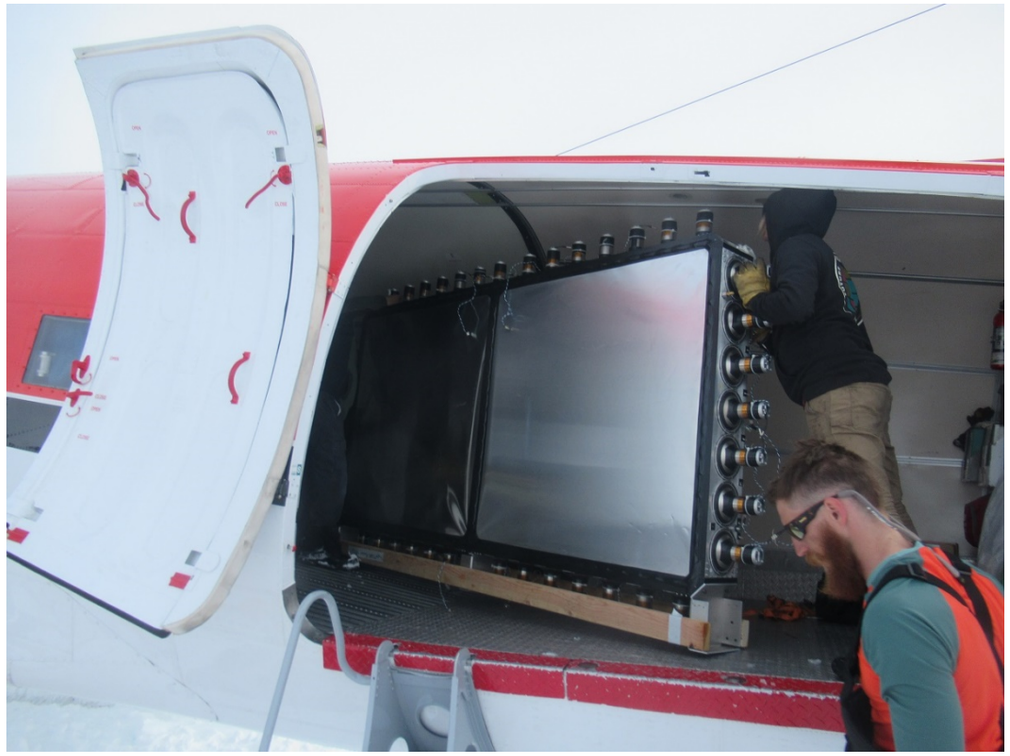
ST-2.2 2019 Recovery Day 2

- Mechanical and wiring connections between the modules and gondola were all disconnected.
- With the payload upside down, the gondola was lifted off of the modules and slung to Basler landing area.
- Modules then slung individually to the Basler landing area – amazing to see.
- Kim Layton stepped in for Kaija Webster.



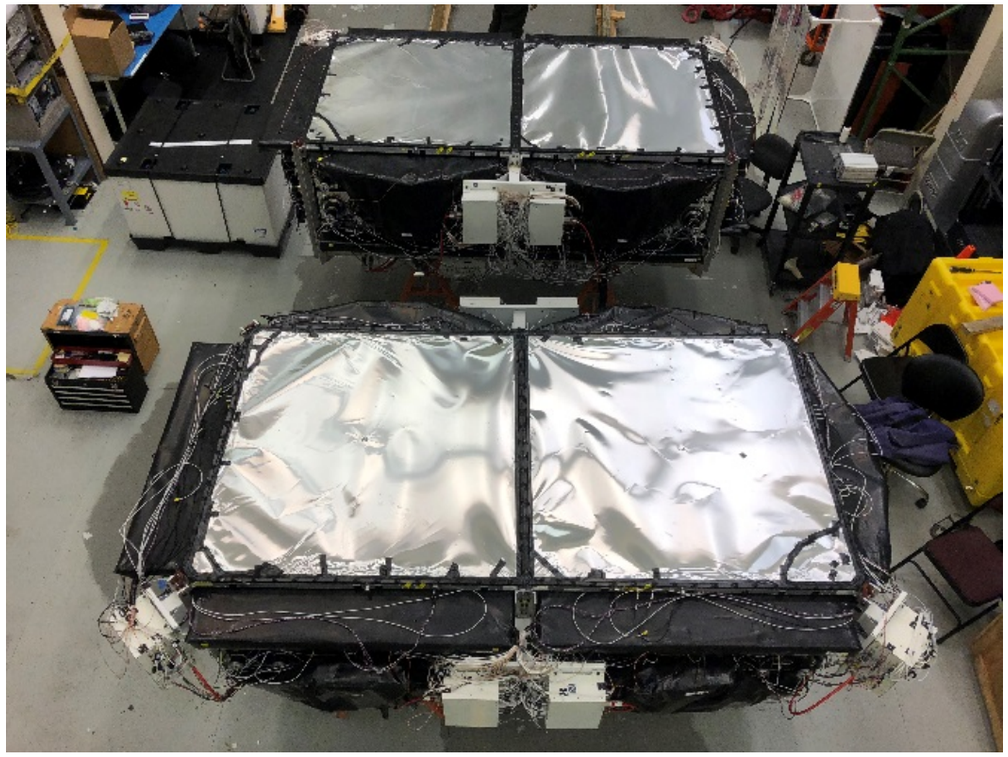
ST-2.2 2019 Recovery Day 3

- Gondola broken down
- Two modules unwired and broken down into individual detectors
- Components loaded on Basler
- Extensive assistance by flight crew
- Team augmented by X-Calibur graduate students Andrew West and Lindsey Lisalda



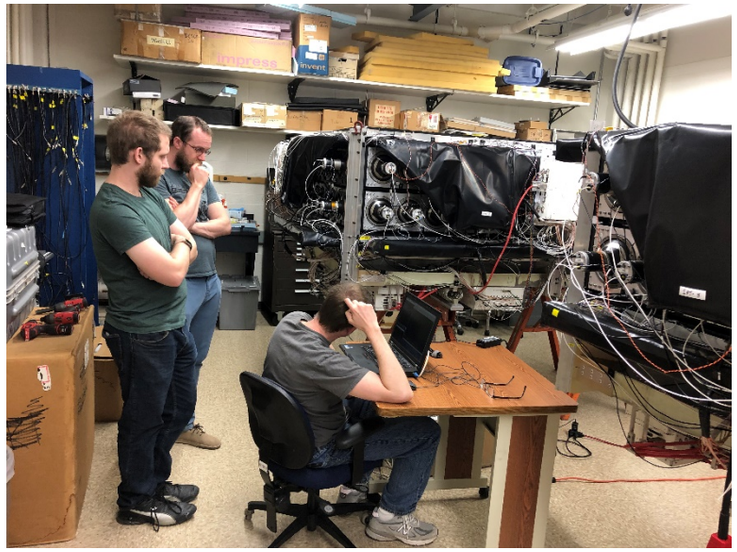
ST-2.2 Back to LDB

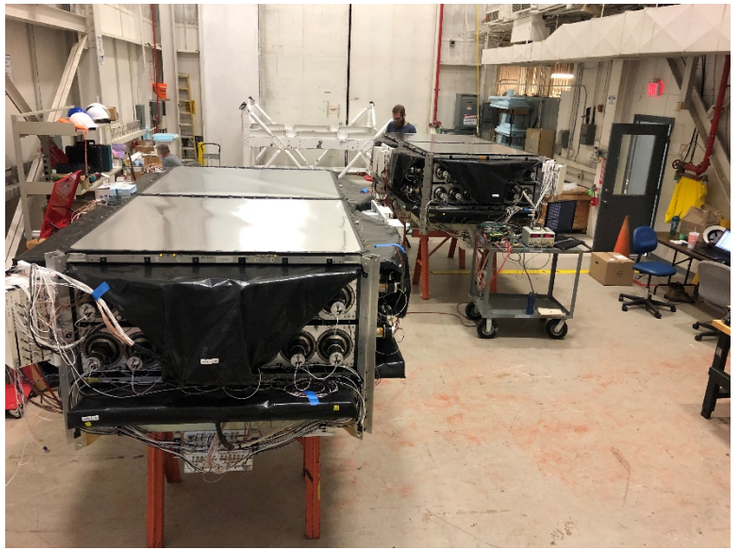
- Basler unloaded and ST-2.2 components returned to LDB.
- Instrument models were stacked, wired up and tested at LDB prior to shipment north.
- All 96% of 552 electronics channels that could be tested worked.



ST-2.3 Refurbishment and Testing

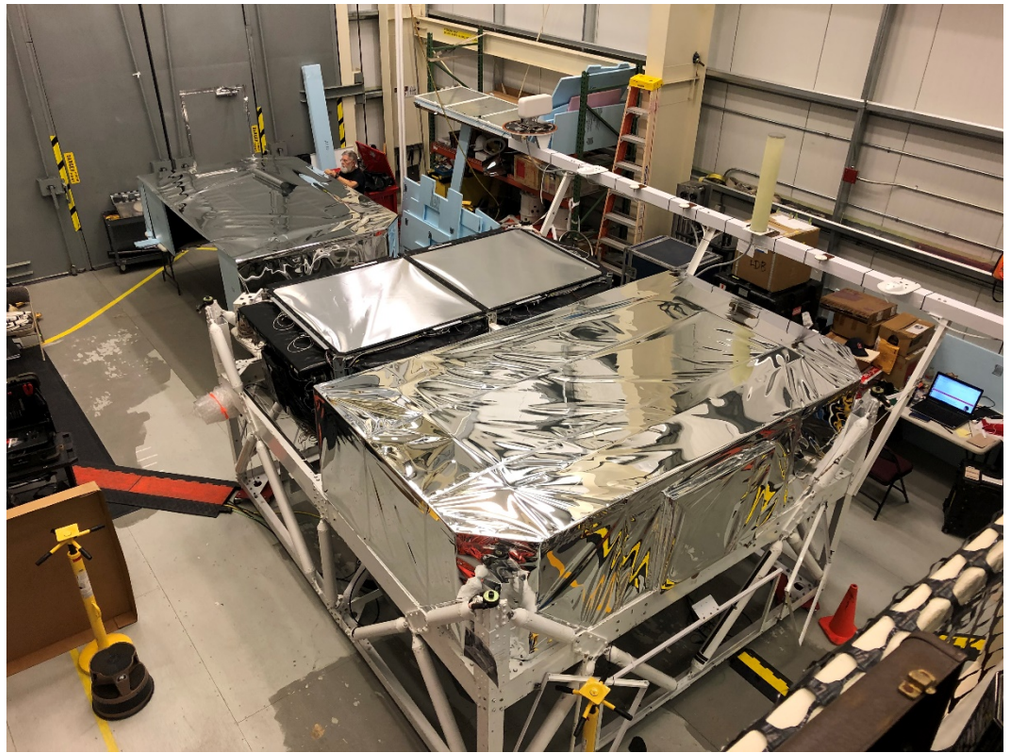
- SuperTIGER-2 testing and refurbished at Washington University.
- Most of the work was on top scintillator detectors the payload ended up on.
- ST-2.3 integrated and tested at NASA/CSBF for 2019-2020 Antarctic campaign.

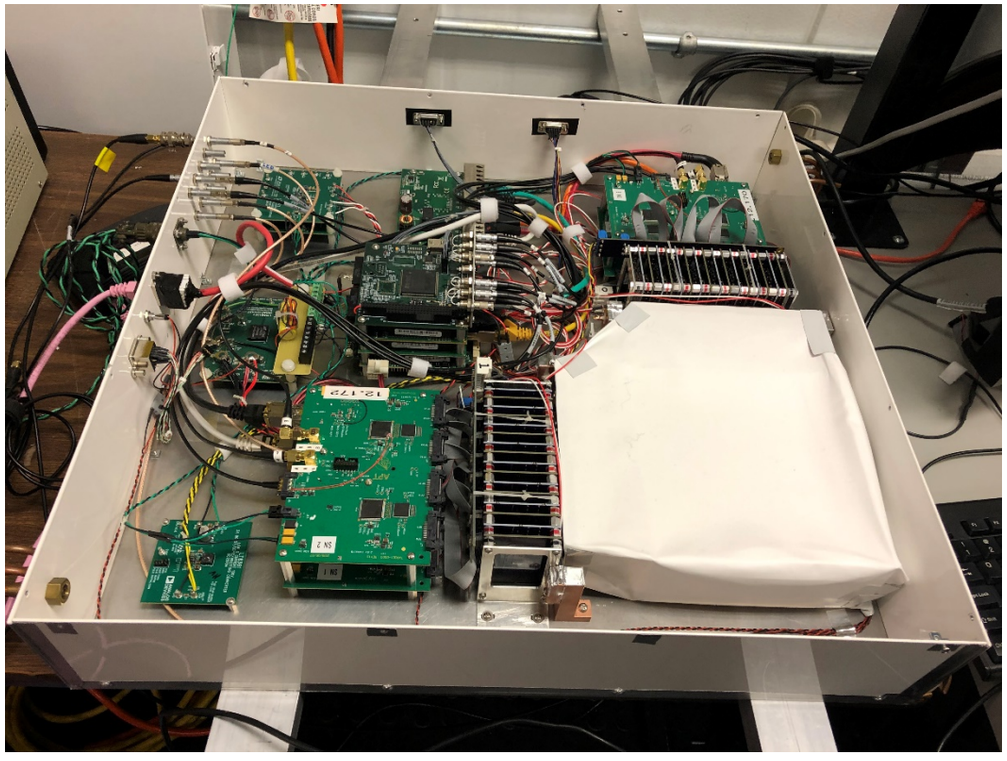




SuperTIGER-2.3 Ready

- APT-Lite piggyback experiment integrated.
- SuperTIGER-2.3 passed its compatibility test this morning





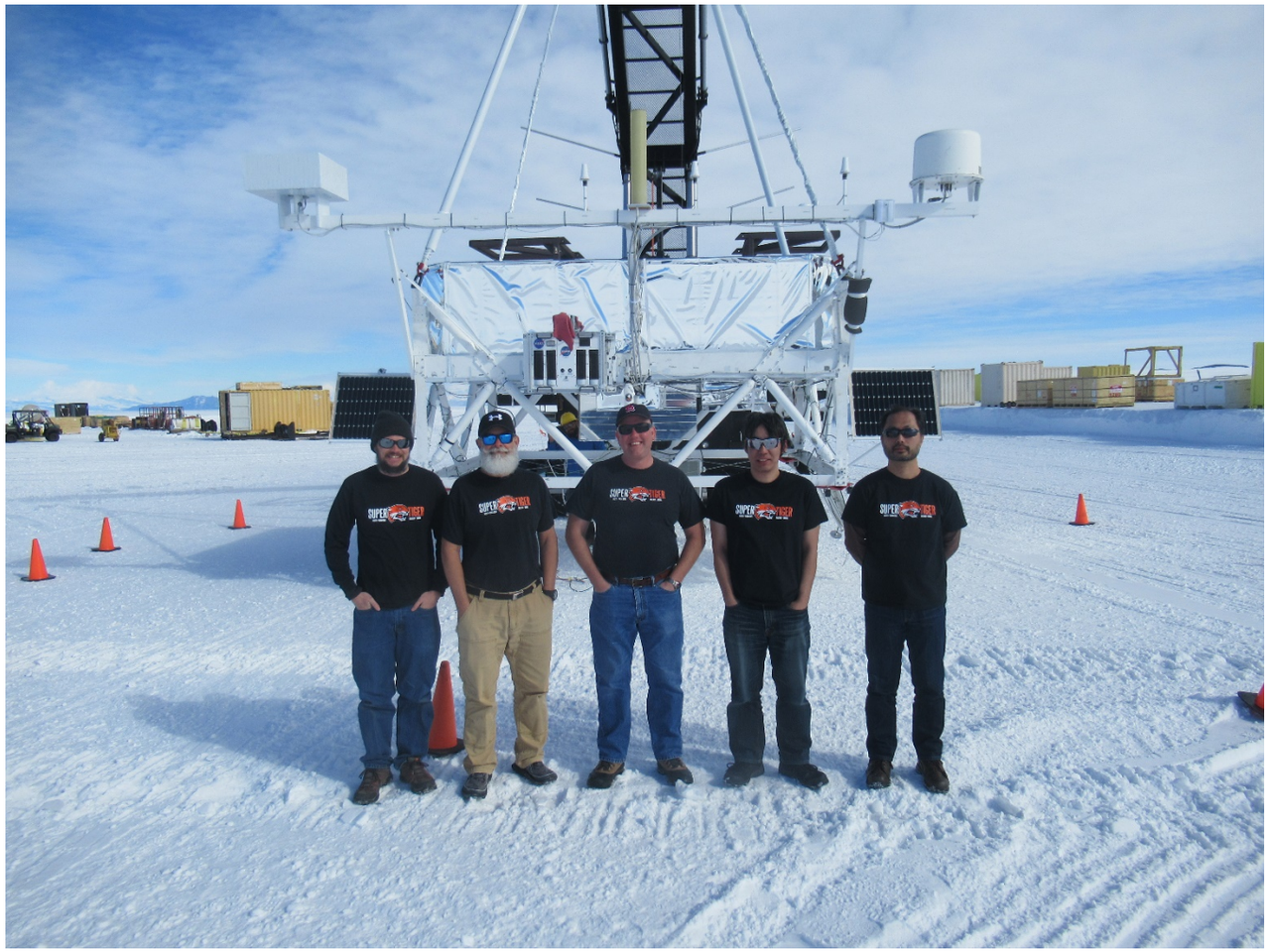
ST-2.1 Ice Team 2017-2018

- Washington University
  - Brian Rauch (Co-Leader)—Science
  - Richard Bose—Electronics & software
  - Dana Braun—Mechanical
  - Garry Simburger—Electronics
  - Nathan Walsh—Grad Student—Science & hodoscope

- Goddard Space Flight Center
  - Makoto Sasaki (Co-Leader)—Science & S-counters
  - Kenichi Sakai (Co-I)—Science & Cherenkov
  - Jason Link (CoI)—Science & S-counters
  - Sean Fitzsimmons—Mechanical

ST-2.2 Ice Team 2018-2019

- Washington University
  - Brian Rauch (Co-Leader)—PI, Science
  - Richard Bose—Electronics & software
  - Dana Braun—Mechanical
- Goddard Space Flight Center
  - Makoto Sasaki (Co-Leader)—Science & S-counters
  - Kenichi Sakai (Co-I)—Science & Cherenkov
  - Sean Fitzsimmons—Recovery



ST-2.3 Ice Team 2019-2020

- Washington University
  - Brian Rauch—PI, Science, Recovery
  - Richard Bose—Electronics & software
  - James Buckley —Science & APT-Lite
  - Dana Braun—Mechanical
  - Zachary Hughes —Grad Student—APT-Lite
  - Garry Simburger —Electronics
  - Andrew West —Grad Student—Assembly
  - Wolfgang Zober —Grad Student—Assembly & recovery
- Goddard Space Flight Center
  - Yosui Akaike —Science & monitoring
- California Institute of Technology
  - Robert Crabill —Recovery

Acknowledgements

- This research was supported by NASA under grants NNX09AC17G and NNX14AB25G, by the McDonnell Center for the Space Sciences at Washington University, and by the Peggy and Steve Fossett Foundation.
- We thank the NASA Columbia Scientific Balloon Facility, the NASA Balloon Program Office, and the NSF United States Antarctic Program for the excellent and highly professional efforts that resulted in the record long-duration balloon flight for SuperTIGER-1 and the successful recovery efforts.
- Special thanks to those who supported the in-season SuperTIGER-2.2!

McDonnell Center for the Space Sciences

facebook.com/thesupertiger

Twitter: @SuperTIGERLDB

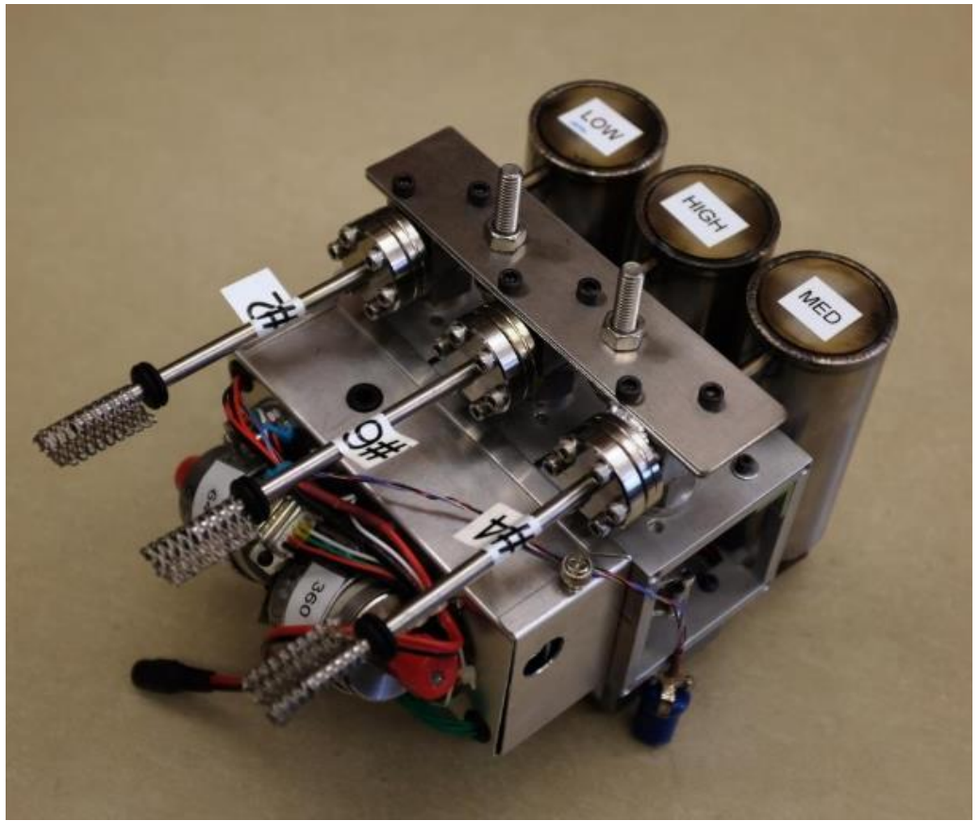
Website: http://supertiger.wustl.edu/

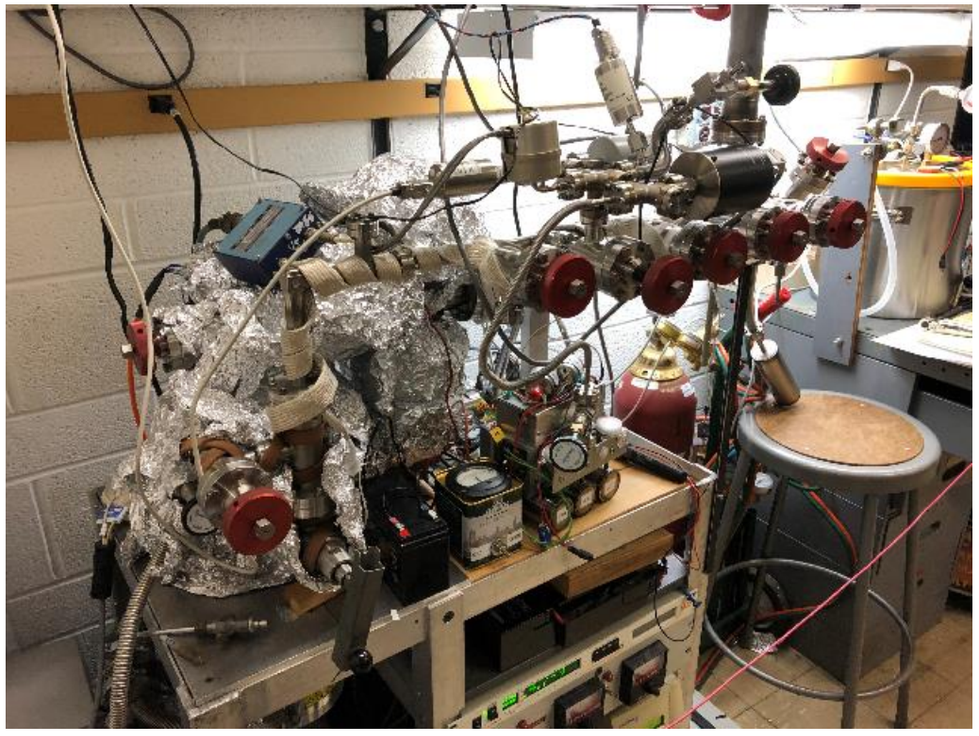
Youtube: SuperTIGERLDB

Backup Slides

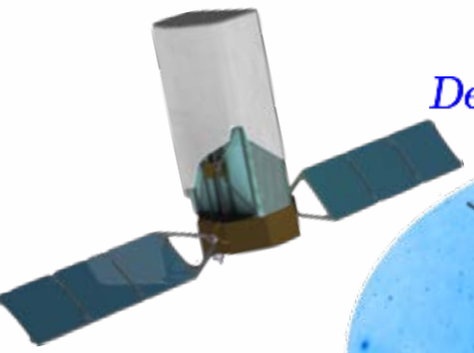
BAS Piggyback

- Balloon Air Sampler (BAS)
- –Capture and return atmospheric samples at various altitudes
- –Perform laboratory measurements of the atmospheric $_{2}He$, $_{36}Kr$, and $_{54}Xe$ (and other gases) content as a function of altitude.
- 3 flight cylinders and one ground level reference
- –Weight <20 lbs
- –Power 8 Watts for 2 minutes each valve on balloon ascent

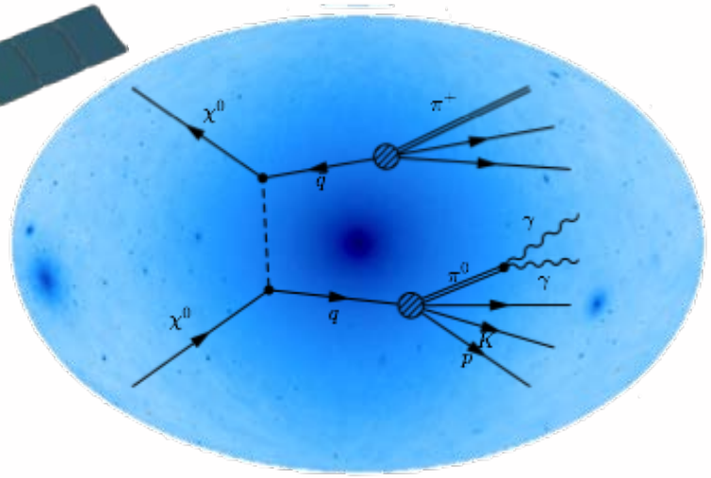


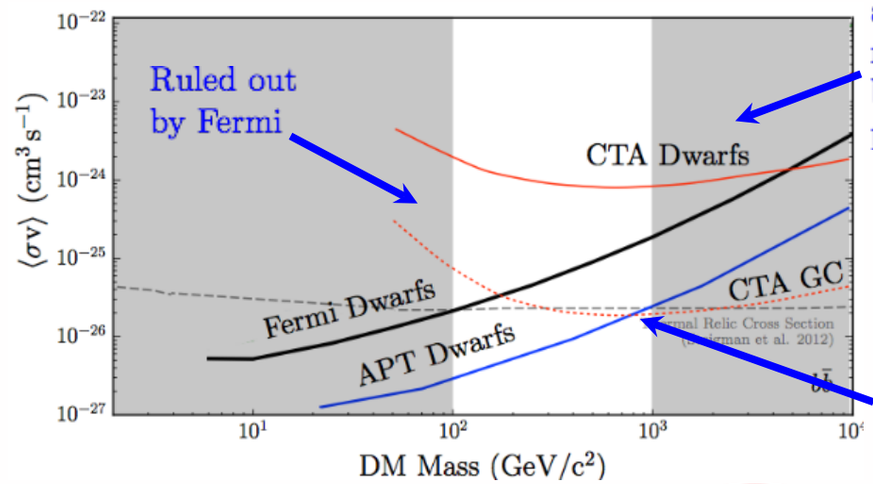


Science with APT



Detect or rule out WIMP dark matter over entire natural parameter space

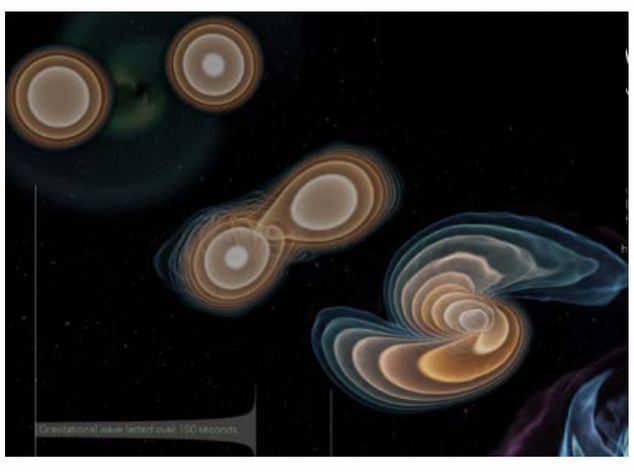


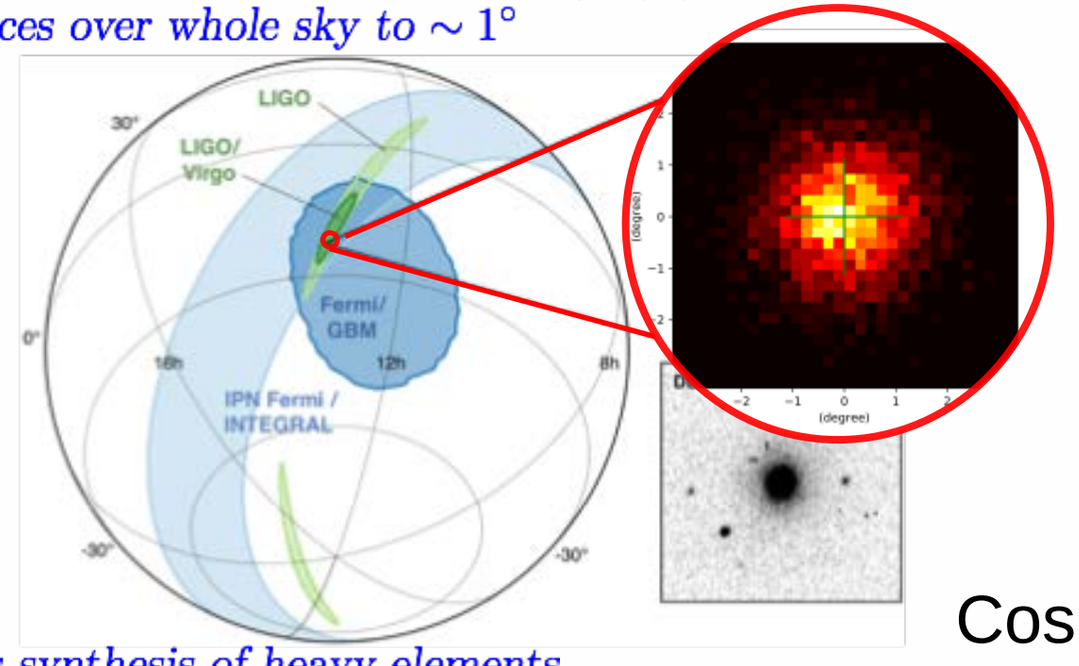


These masses above natural range motivated by hierarchy problem!

Ground-based (CTA) GC constraints are better

Localize n-star mergers/GW sources over whole sky to $\sim 1°$





Descriminate n-star and r-process synthesis of heavy elements

Cosmic rays too.

APT Concept

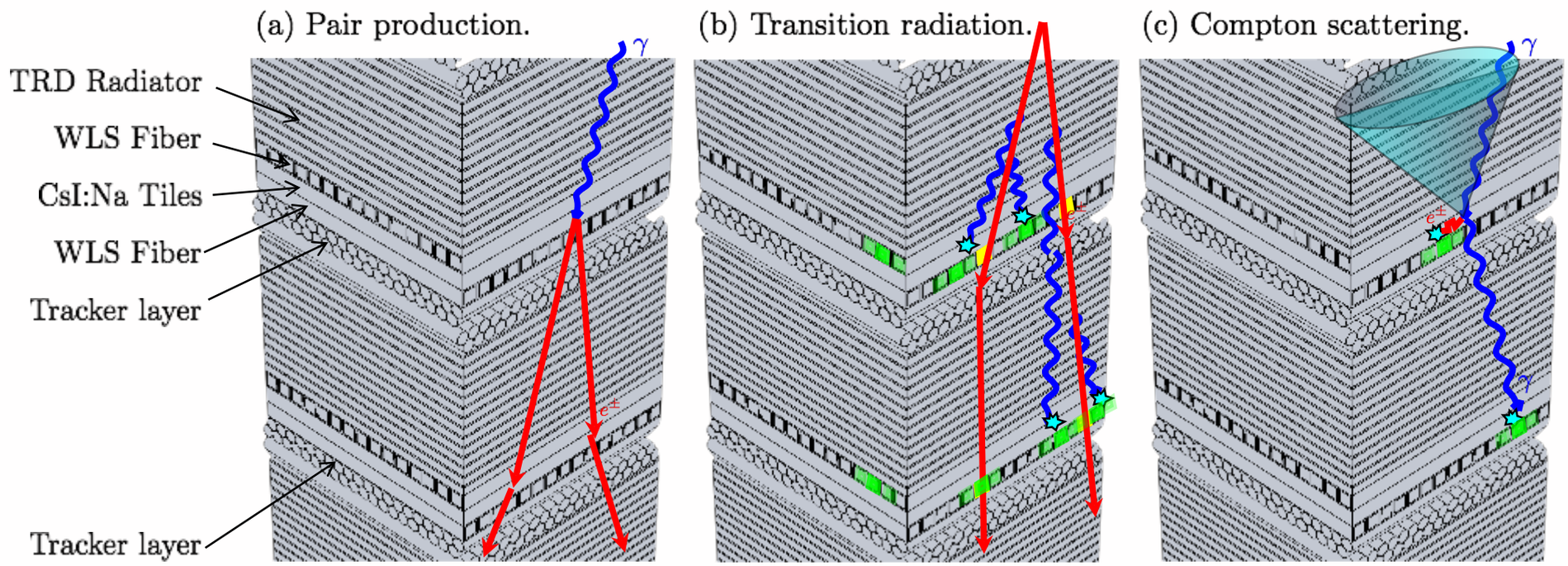
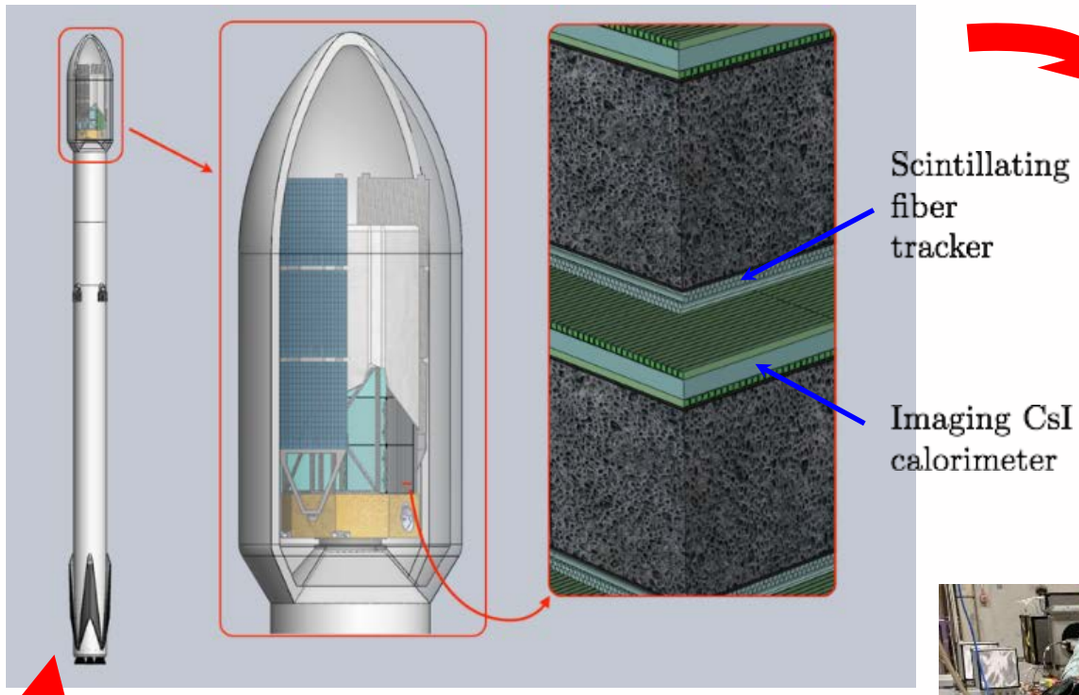
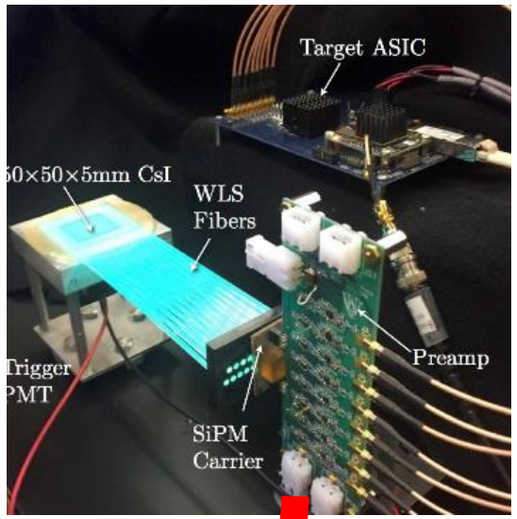


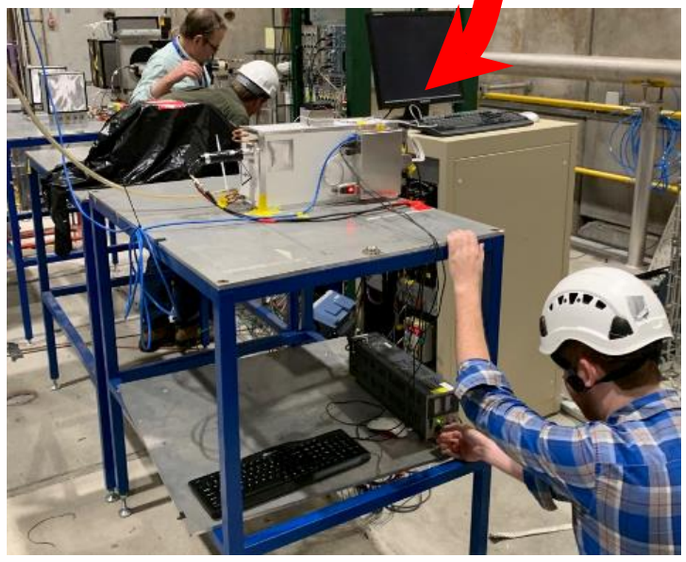
Figure 4: (a) Pair event; (b) transition radiation from e^-/e^+ pair (c) Compton scatter event. X-rays and γ-rays are blue, e^-/e^+ are red, blue stars indicate energy deposition in the CsI, and green indicates light collected by the WLS fibers. The blue cone in figure (c) represents the reconstructed arrival direction for a Compton scatter.

APT Research & Development

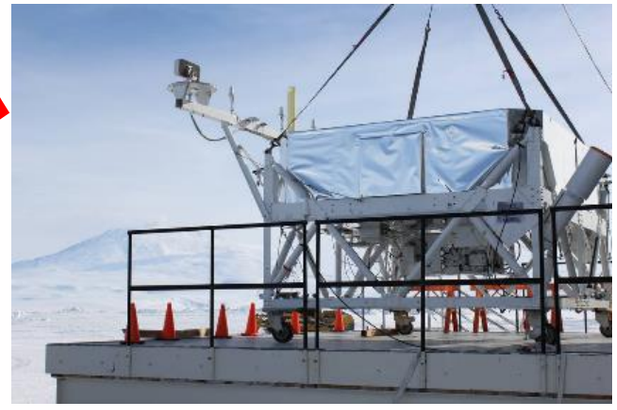
APRA - Detector and electronics development





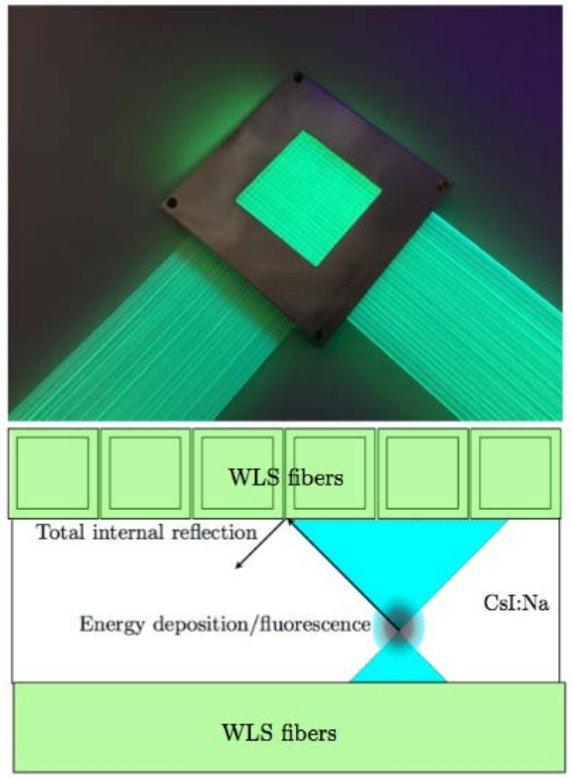


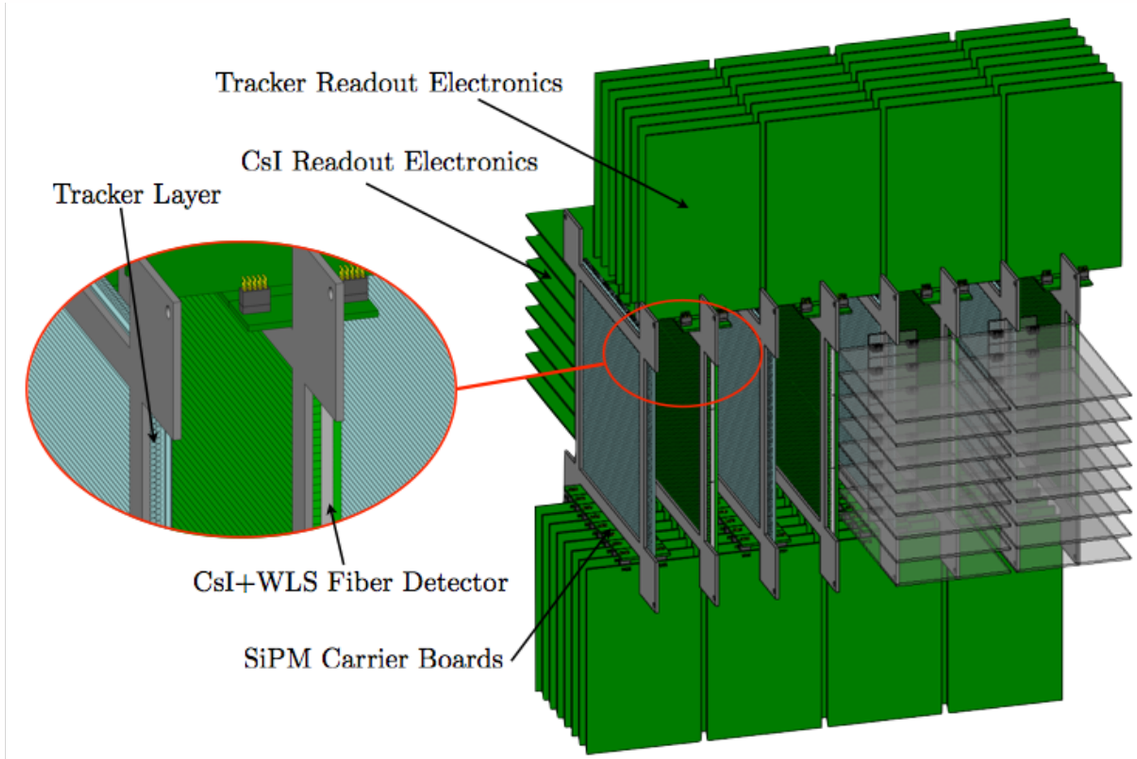
Accelerator beam tests



Piggy-back flight on SuperTiger

Beam Test/APTLite



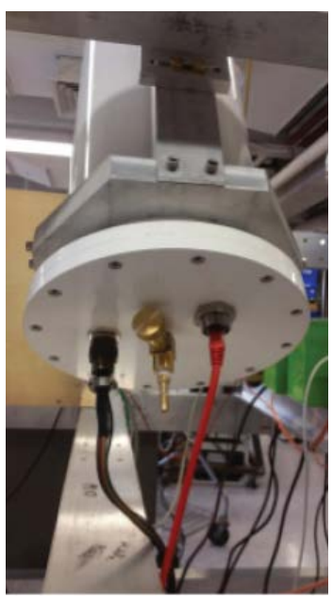


- Beam test instrument will have 4 layers of 150mm x 150mm CsI detectors and trackers
- Balloon flight instrument have one 150mmx150mm CsI:Na detector, with two (crossed) planes of 75 2mm WLS fibers. 64 channels will be read-out with SiPMs, custom preamps, bias voltage boards and 4 16 channel Target C waveform digitizer ASICs.
- Trigger, power and <1kbps ethernet from SuperTiger instrument
- We predict about 1500 Iron group cosmic rays with ST. Will validate charge resolution and suitability for a balloon flight payload.

PMC-Turbo Piggyback Payload

- Upper atmosphere studies
  - Polar Mesospheric Clouds
  - Turbulence
- PMC-Turbo Sweden flight had higher than expected light contamination
  - Study effectiveness of new light baffle

Pressure vessel with mounting cradle. The total weight in this configuration is 40 lbs.



Baffle survived flight

Old cylindrical baffle

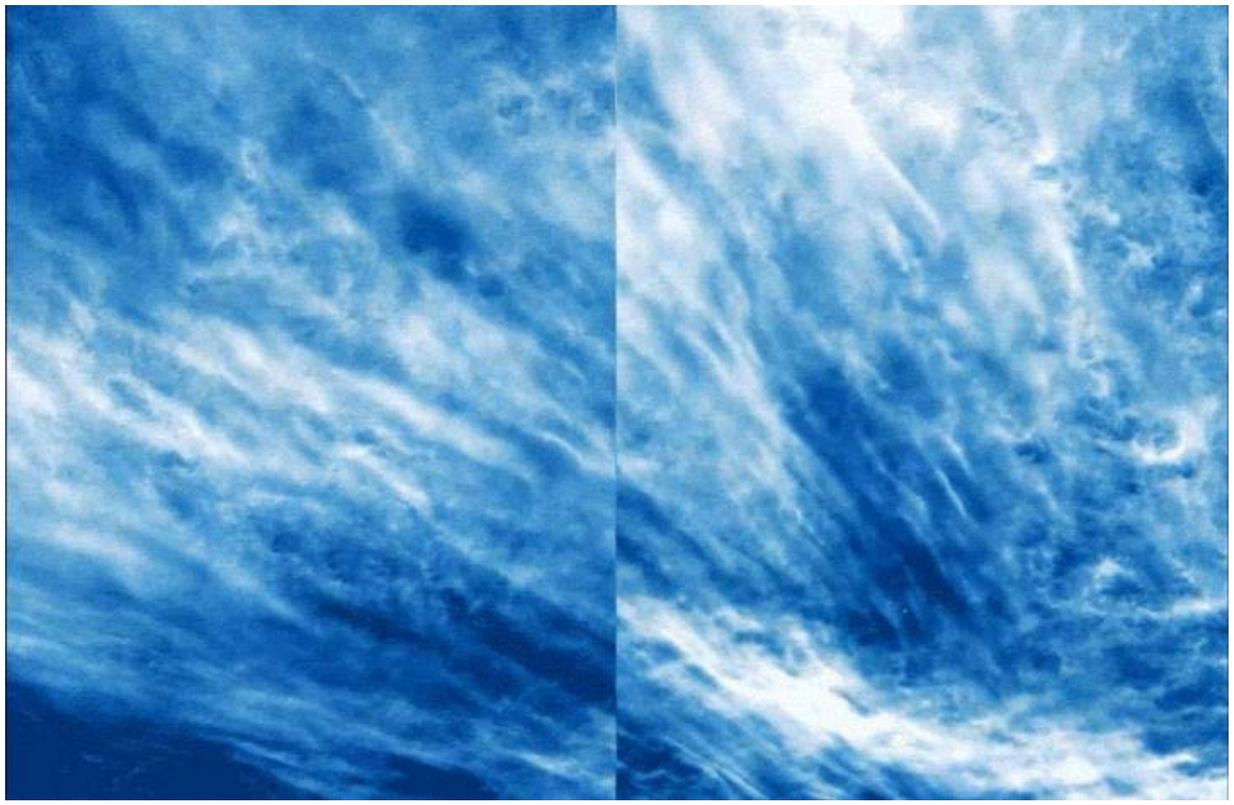
New baffle design

- Size—cylinder 34 inches long & 11 inches diam.
- Weight — ~50 lbs
- Power—steady state 60 W, startup 110 W for ~30 seconds
- Telemetry—5kbs Openport

PMC-Turbo Science

Noctilucent clouds (also known as Polar Mesospheric Clouds, or PMCs, when viewed from space) are the highest clouds observed on Earth, typically forming at altitudes near 83km in the summertime at high latitudes in both hemispheres. They are of particular interest as their presence is believed to be a “miner’s canary” for climate change at high altitudes.

https://projectpossum.org/2019/01/15/pmc-turbo-camera-flies-over-antarctica-to-image-noctilucent-cloud-dynamics/



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E-MIST: FY20 SIP Planning Meeting

May 21, 2019

David J. Smith, NASA Ames
David.J.Smith-3@nasa.gov

Event # A-454-M

Piggyback Payload on ST2

E-MIST Team Members

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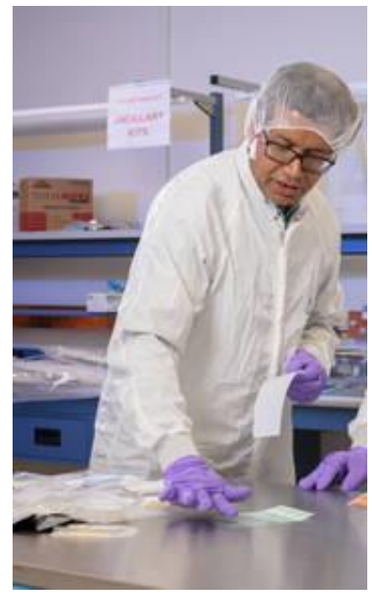
E-MIST Principal Investigator

Dr. Jon Glazka
NASA Ames Research Center
E-MIST Co-Investigator

Dr. Samantha Waters
NASA Ames Research Center
E-MIST Co-Investigator



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E-MIST Engineer

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E-MIST Engineer

Exposing Microorganisms in the Stratosphere (E-MIST)

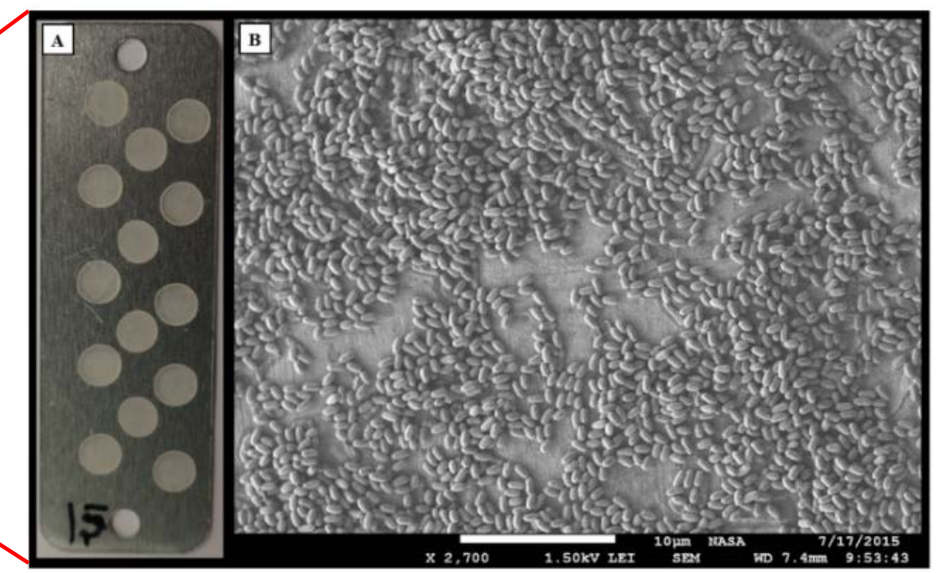
NASA Planetary Protection Office Grant for FY17-FY20:

Survival and -Omics Outcomes from Exposing Microorganisms in the Stratosphere on Long Duration Balloon Flights around Antarctica

We know microbes will travel to Mars on spacecraft.

Will they survive and how will they change when exposed to Mars-like conditions?

Earth's polar stratosphere allows us to examine these important exploration questions.



http://www.nasa.gov/ames/research/space-biosciences/e-mist-2015

2017

E-MIST Payload

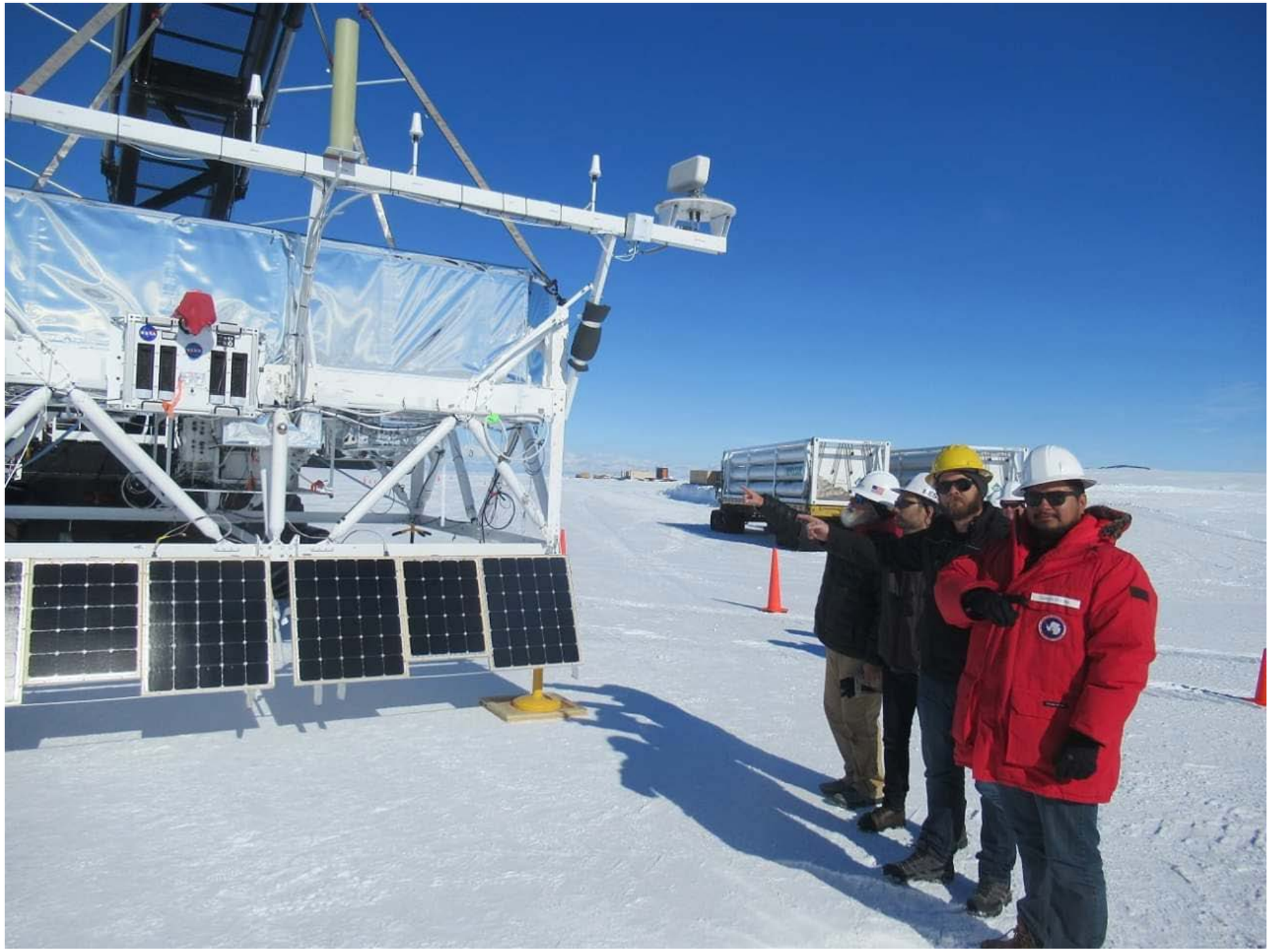
21” x 33” x 10”

80 lbs

15-30 W power draw

No telemetry

2018



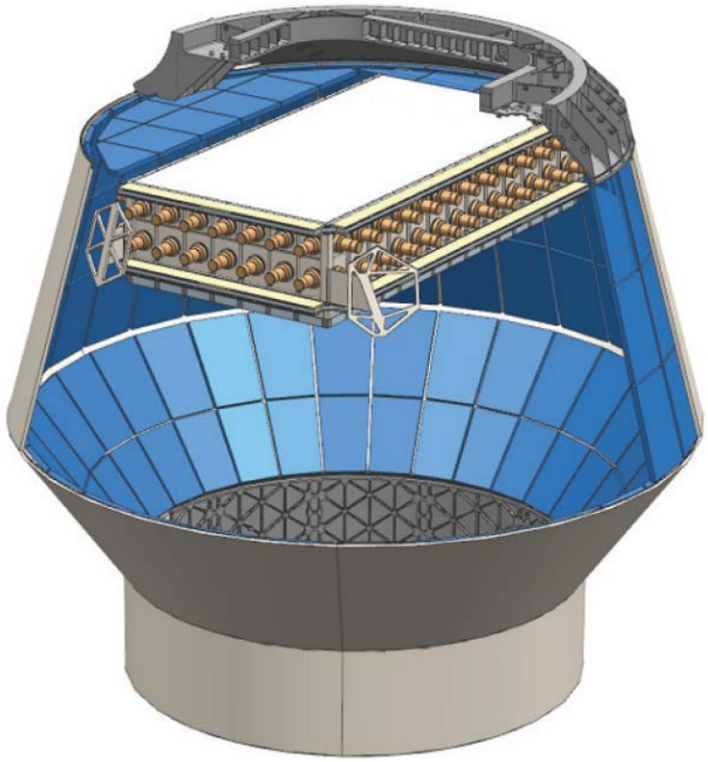

UVA/B
UVC
DOSIMETER
NASA
NASA

HNX – Heavy Nuclei Explorer

HNX is a proposed SMEX payload that uses two complementary instruments to span $6 \leq Z \leq 96$ ($Z > 96$ if flux exists) with the needed high exposure factor and charge resolution.

ECCO (Extremely-heavy Cosmic-ray Composition Observery)

- Uses ~21 m^2 of Barium Phosphate (BP-1) glass tiles covering the walls and part of the top of the DragonLab Capsule to measure $Z \geq 70$ (Yb) nuclei
- Recovery is required for post-flight processing of glass



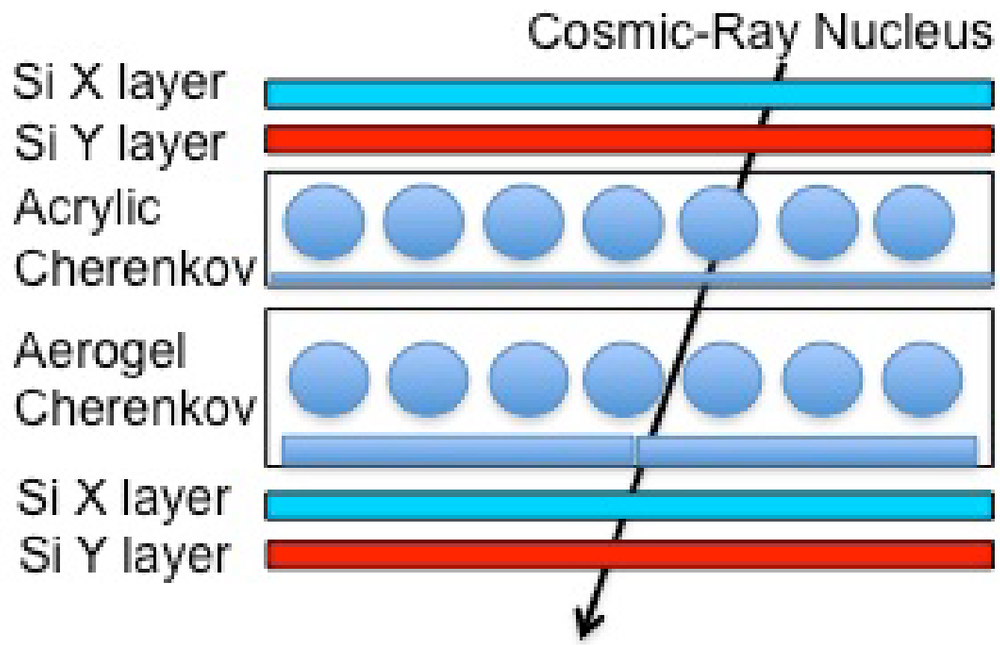
CosmicTIGER (Cosmic-ray Trans-Iron Galactic Element Recorder)

- 2 m^2 electronic instrument using – silicon strip detectors and Cherenkov detectors with acrylic and silica-aerogel radiators.

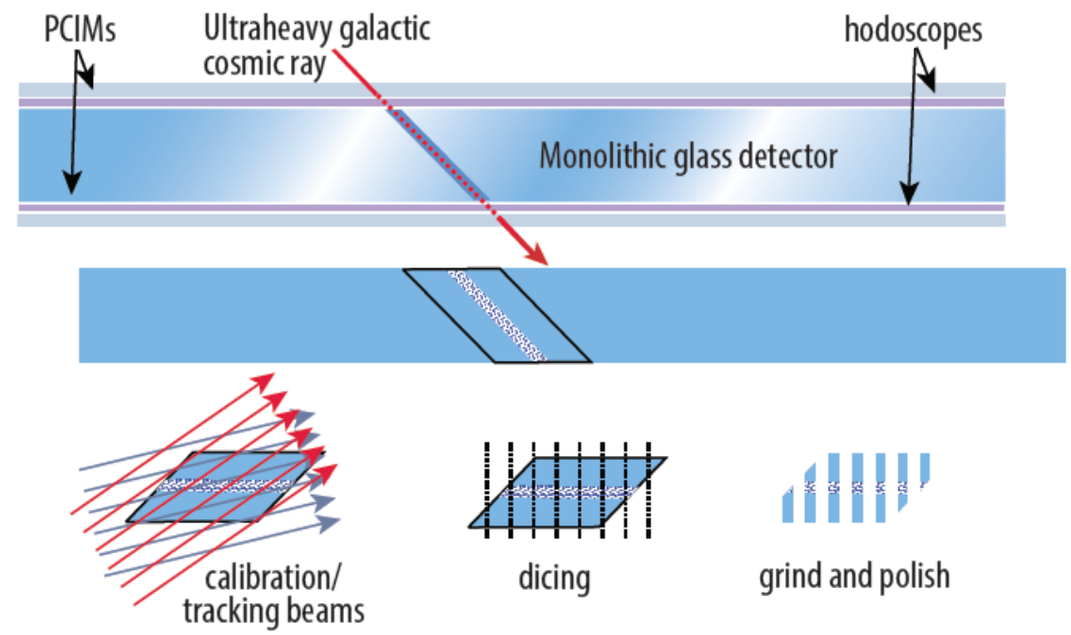
HNX accommodation inside DragonLab capsule is straight forward

- Pressurization reduces complexity of CosmicTIGER – no high-voltage potting, convective/forced air cooling and Temperature Stability for ECCO
- Mission duration baseline is 2 years, can be extended since there are no consumables

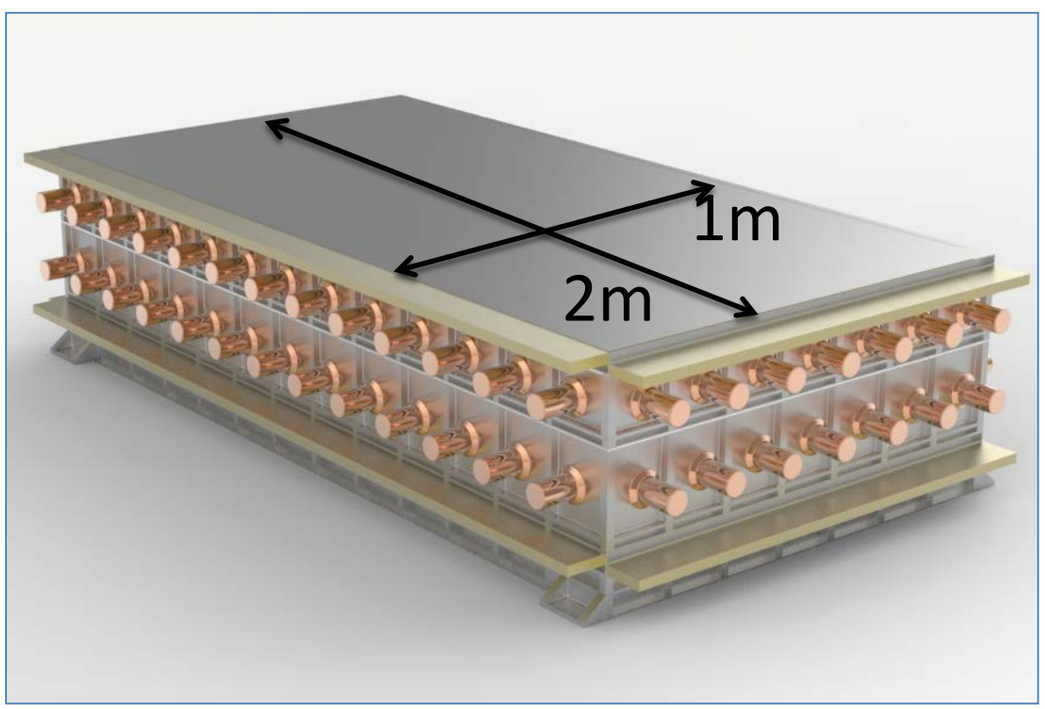
HNX – Detectors

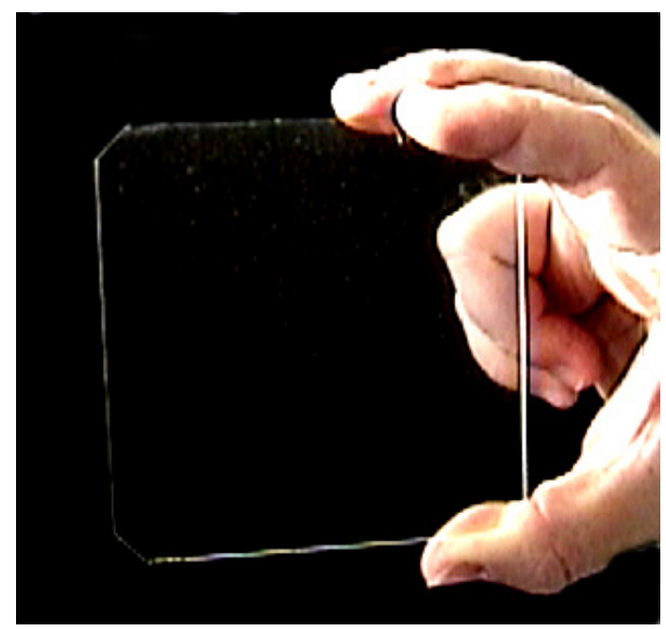


DRAGON-TIGER

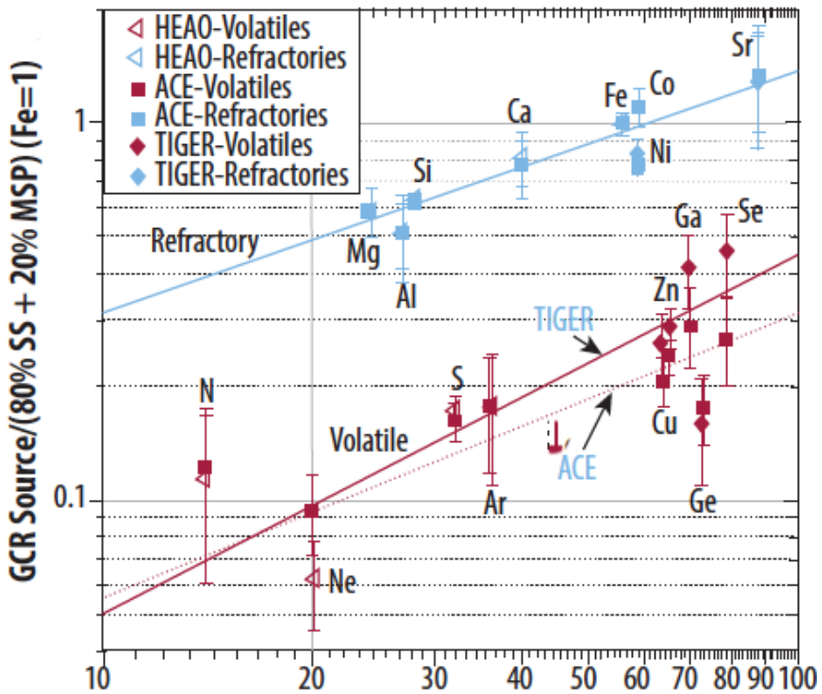


ECCO

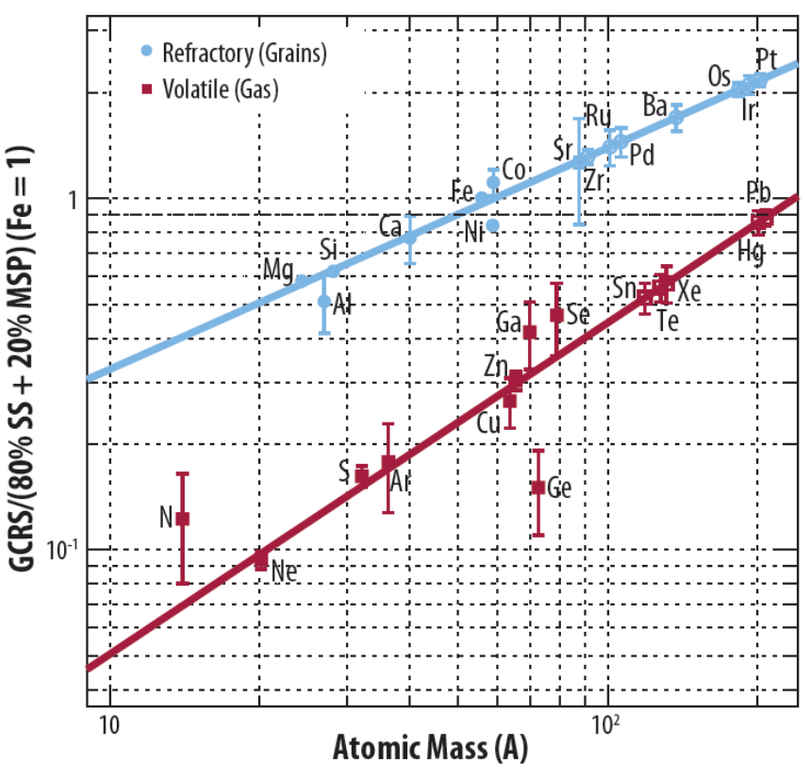




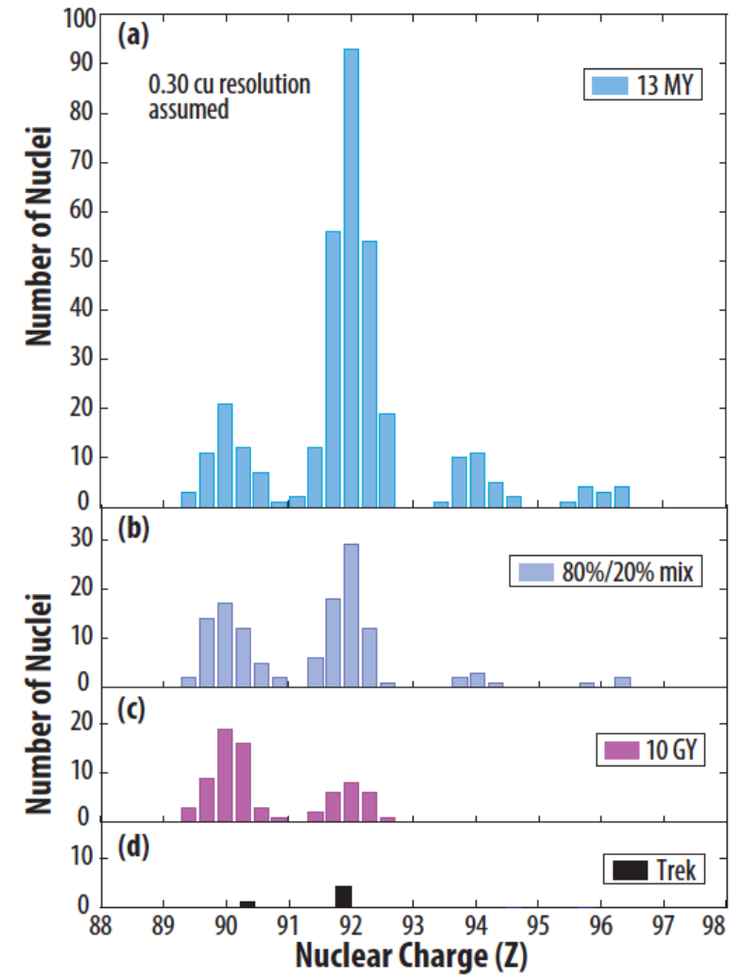
HNX – Expected Results



Combined TIGER, ACE, and HEAO element abundances Rauch et al., ApJ 697:2083 (2009).



HNX will greatly improve old/new value and accurately determine mass dependence



Possible actinide abundances from 2 years of HNX data compared to Trek (Mir) measurements. LDEF UHCR experiment has high statistics but limited resolution.