Ultra-Heavy Galactic Cosmic Ray Propagation and Atmospheric Corrections for SuperTIGER

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November 20, 2024

Physics of the Cosmos Early Career Workshop

For the SuperTIGER Collaboration

SuperTIGER Collaboration

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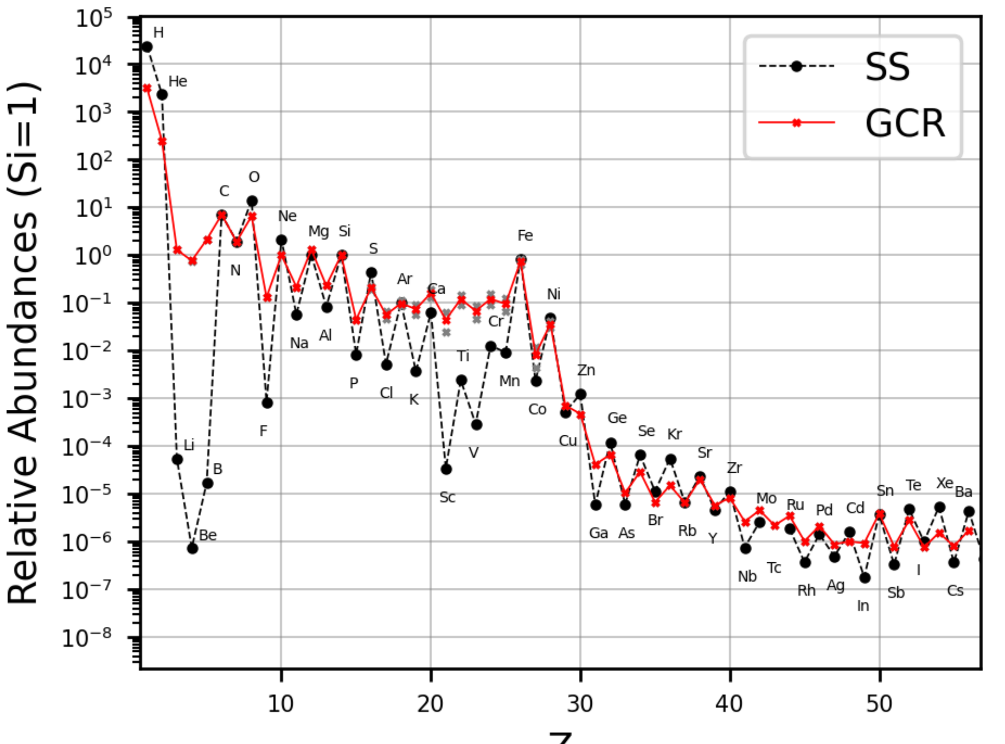
Ultra Heavy Galactic Cosmic Rays

TIGER → SuperTIGER → TIGERISS

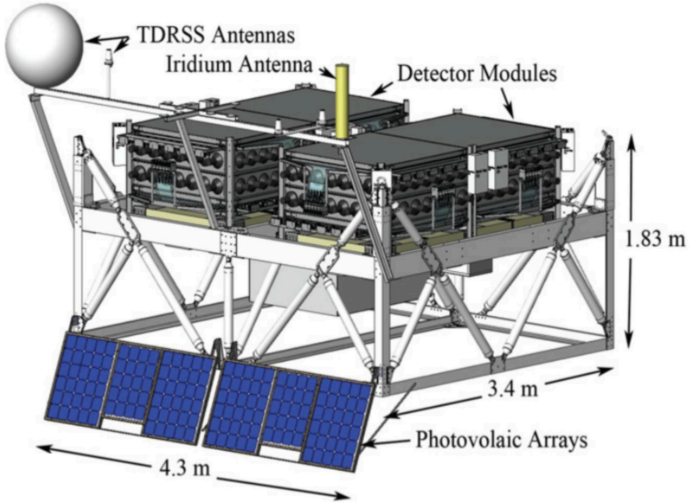
- Ultra-Heavy Galactic Cosmic Rays (UHGCRs)
  - Elemental abundances of cosmic-ray nuclei $Z \geq 30$
- SuperTransIronGalacticElementRecorder
- UHGCR detector: $10 \leq Z \leq (40)56$
  - Balloon-borne, two Antarctic flights
- Energy: 0.8 – 10 GeV/nuc
- TIGERISS: $5 \leq Z \leq 82$
  - ISS payload
  - $5 \leq Z \leq 82$

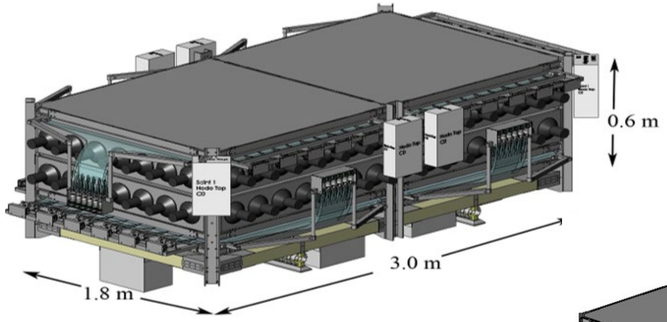


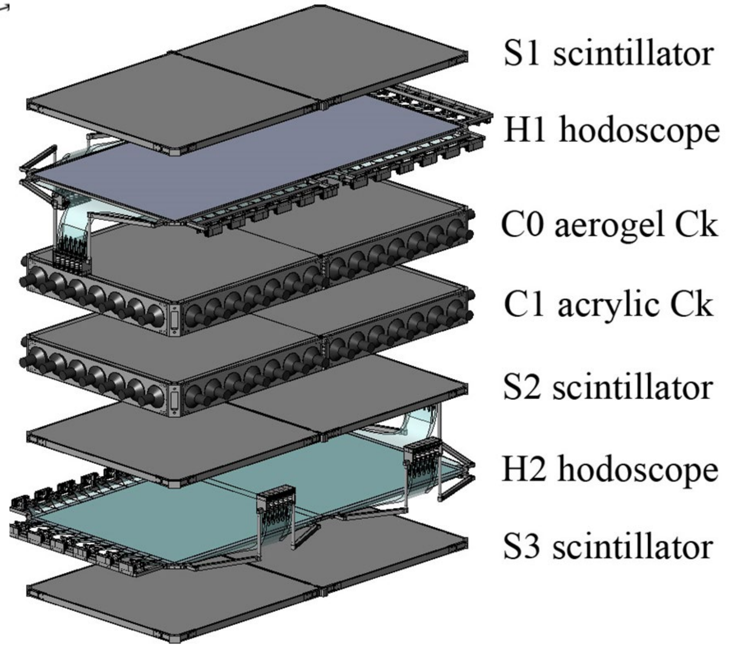
Rauch, Zober, et al. (2024)

SuperTIGER Instrument

- Two independent modules
- Events recorded: SSD and TDRSS
- 2 hodoscope layers
  - (x,y) positioning
- 3 Scintillator levels
  - Signal $\propto Z^{1.7}$
- 2 Cherenkov
  - Signal $\propto Z^{2}$
  - C0: n = 1.043,1.025, E_{thr} 2.3, 3.3 = GeV/nuc
  - C1: n = 1.49, E_{thr} = 320 MeV/nuc

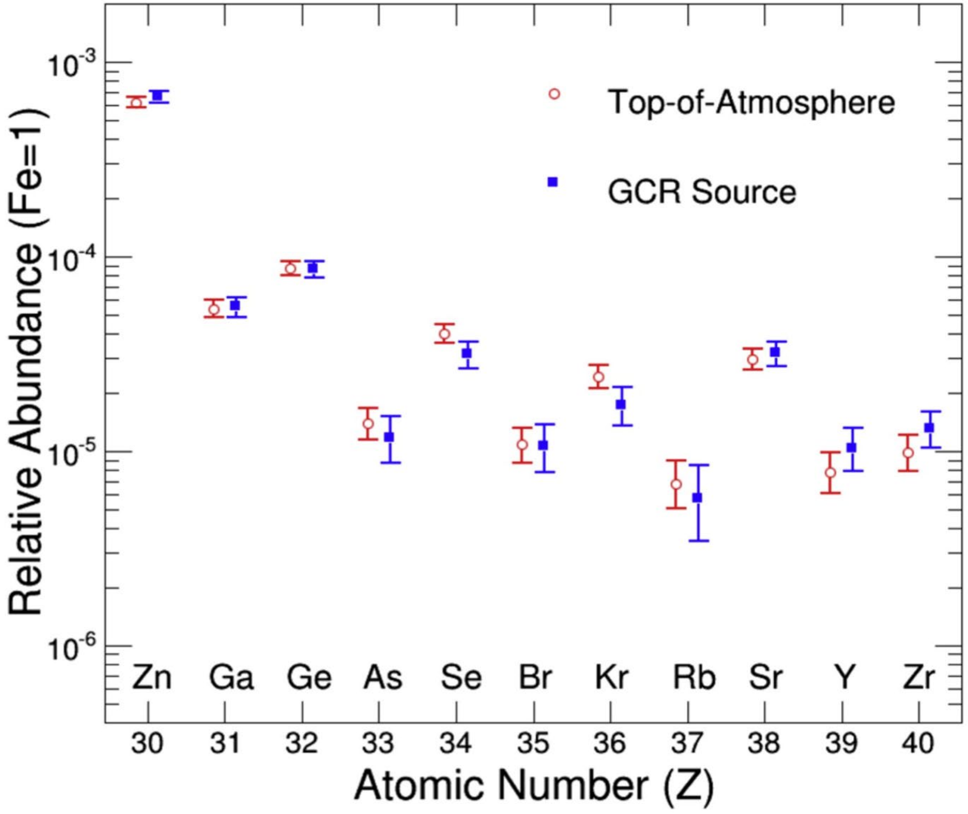




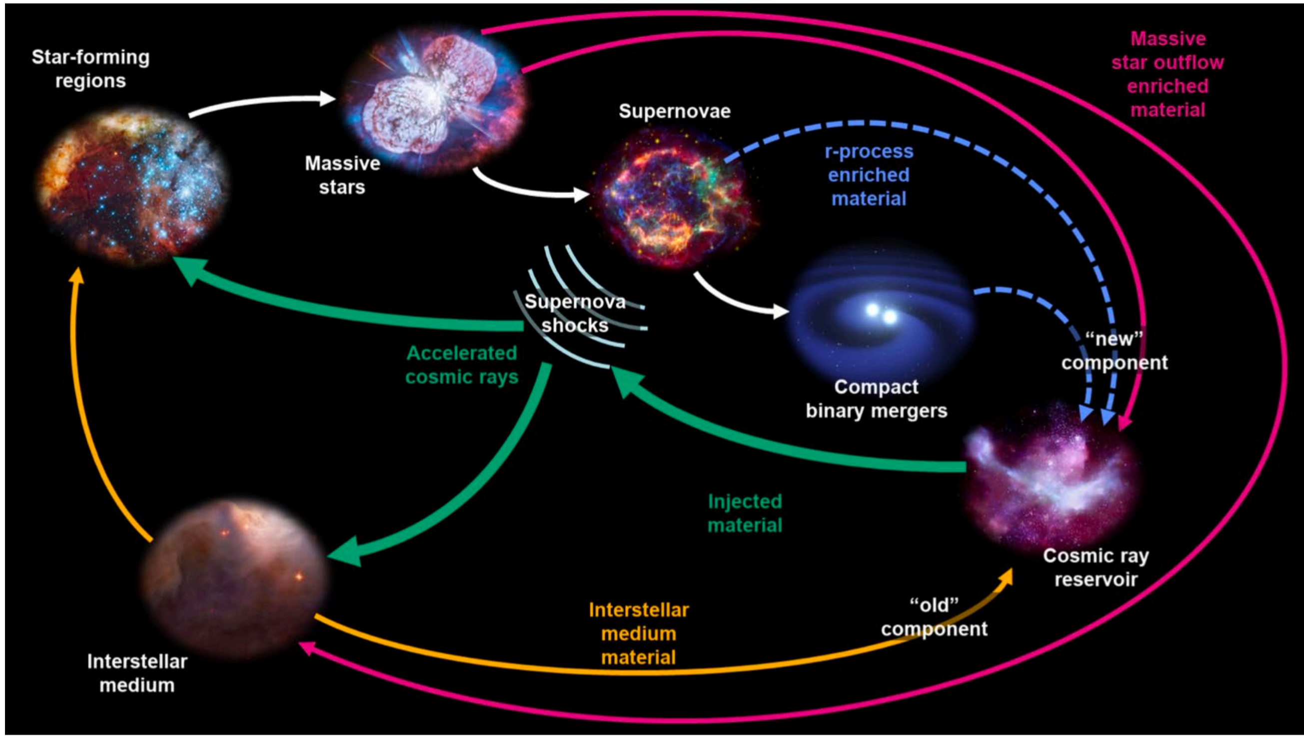


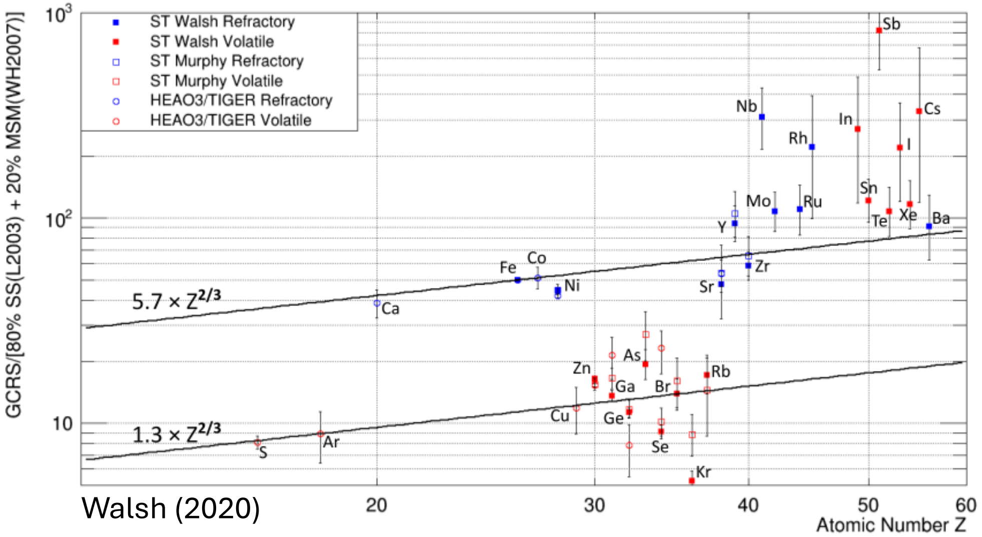
Rauch, Zober for the TIGERISS Collaboration

Galactic Cosmic Ray Source



Murphy et al. (2016)





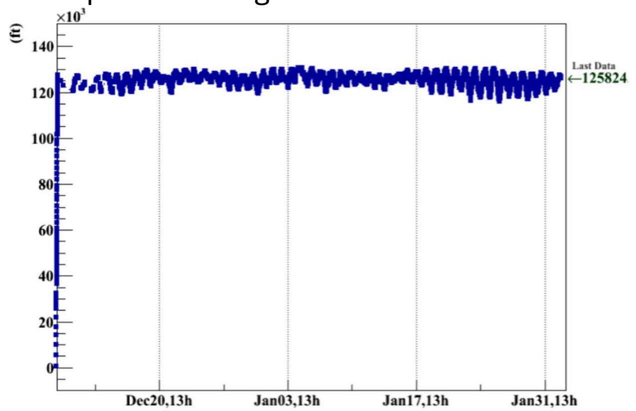
Walsh (2020)

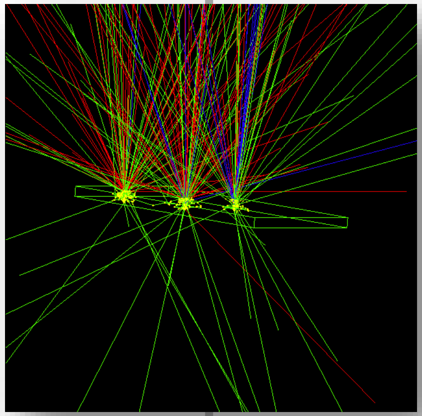
SuperTIGER Atmosphere Corrections with Geant4

- Float altitude: 36 – 40 km
- SuperTIGER-I (2012): 55-day flight
- SuperTIGER-II (2019): 32-day flight
- Average overburden: 5.595 g/cm^2

→Correct for the residual ~0.5% of atmosphere

SuperTIGER Flight I Float Altitudes





- Use interaction products to create response matrix
- Energy loss to find threshold energy for a GCR to make it through the atmosphere
- Define tracking:
  - Event: when track disappears
  - Nuclear interactions, knock-on electrons
- GCR spectrum power law ~ -2.63
- E_{min} = 300 MeV/nuc, E_{max} = 20 GeV/nuc

Using a Response Matrix

Transpose matrix to represent as a colormap

Invert matrix to turn TOI to TOA

Survival fraction*

Z = (10,10) P(10 -> 10)	Z = (11,10) P(11 -> 10)	Z = (12,10) P(11 -> 10)	…
Z = (10,11) P(10 -> 11)	Z = (11,11) P(11 -> 11)	…	
…		…	

Response Matrix

Z_{TOA} = 10
Z_{TOA} = 11
…

TOA Abundance

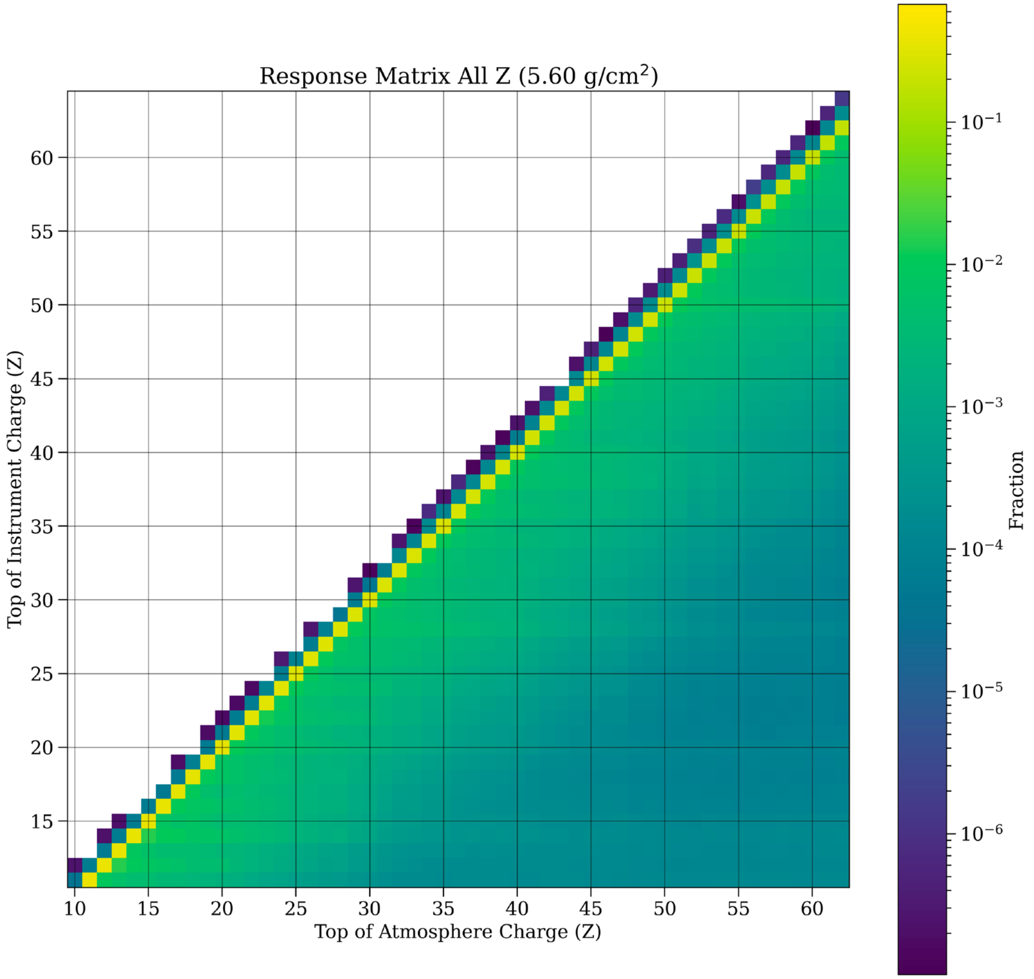
=

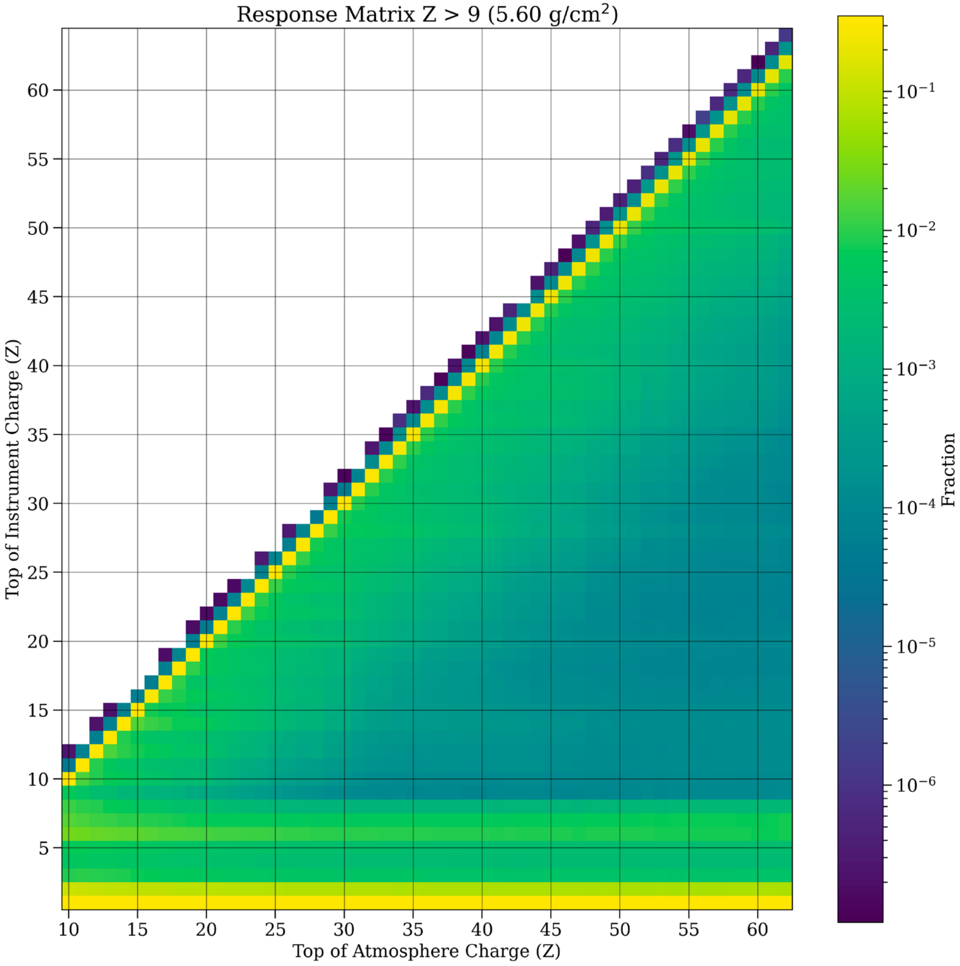
Z_{TOI} = 10
Z_{TOI} = 11
…

TOI Abundance

*Normalized across row

Response Matrices – Average Depth (5.60 g/cm^2)





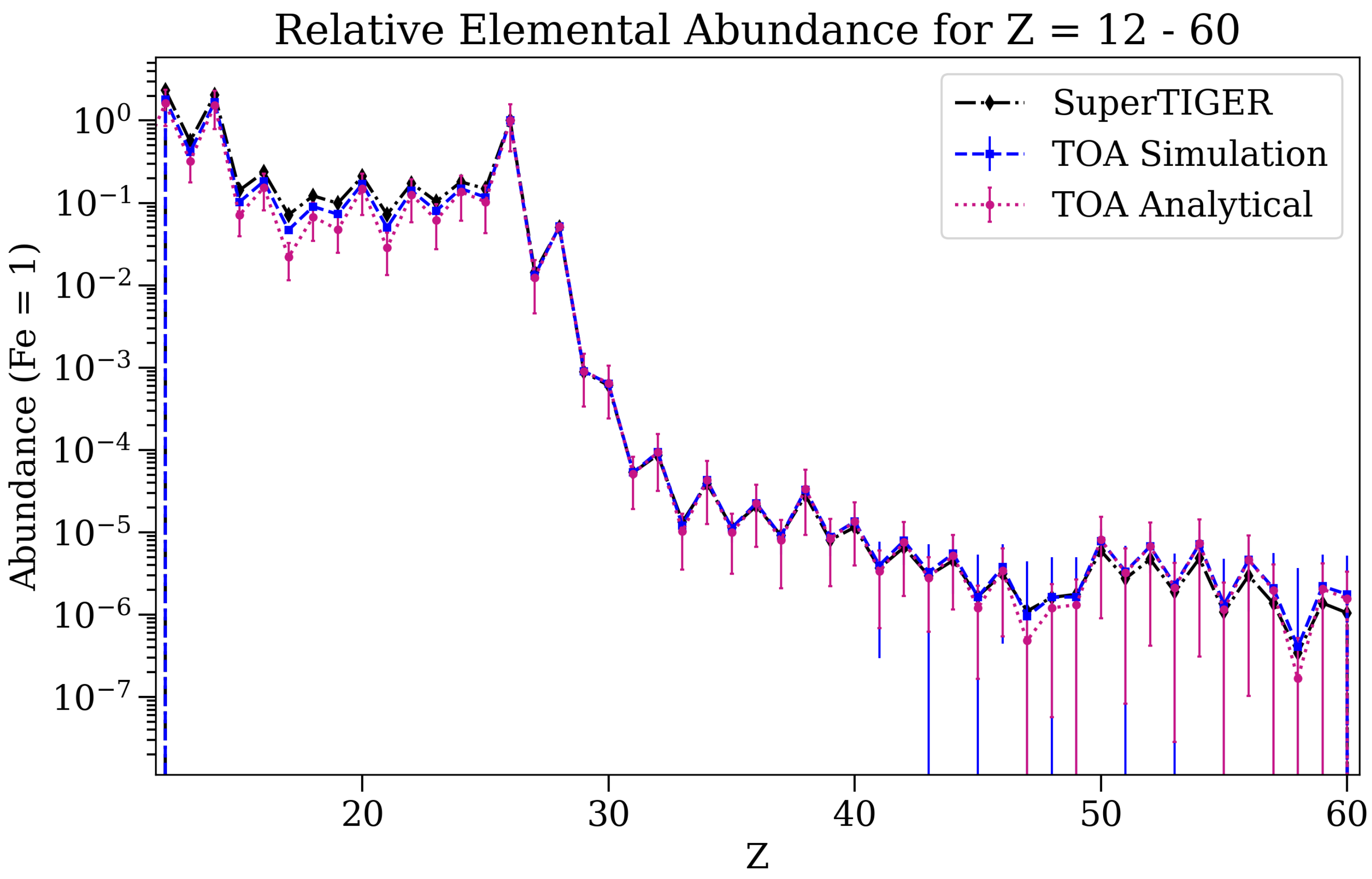
- Bands at low Z (H, He, …)
- Production of heavier elements (above diagonals)

Comparing TOA: Analytical vs Simulation

1. Start with SuperTIGER measured abundances

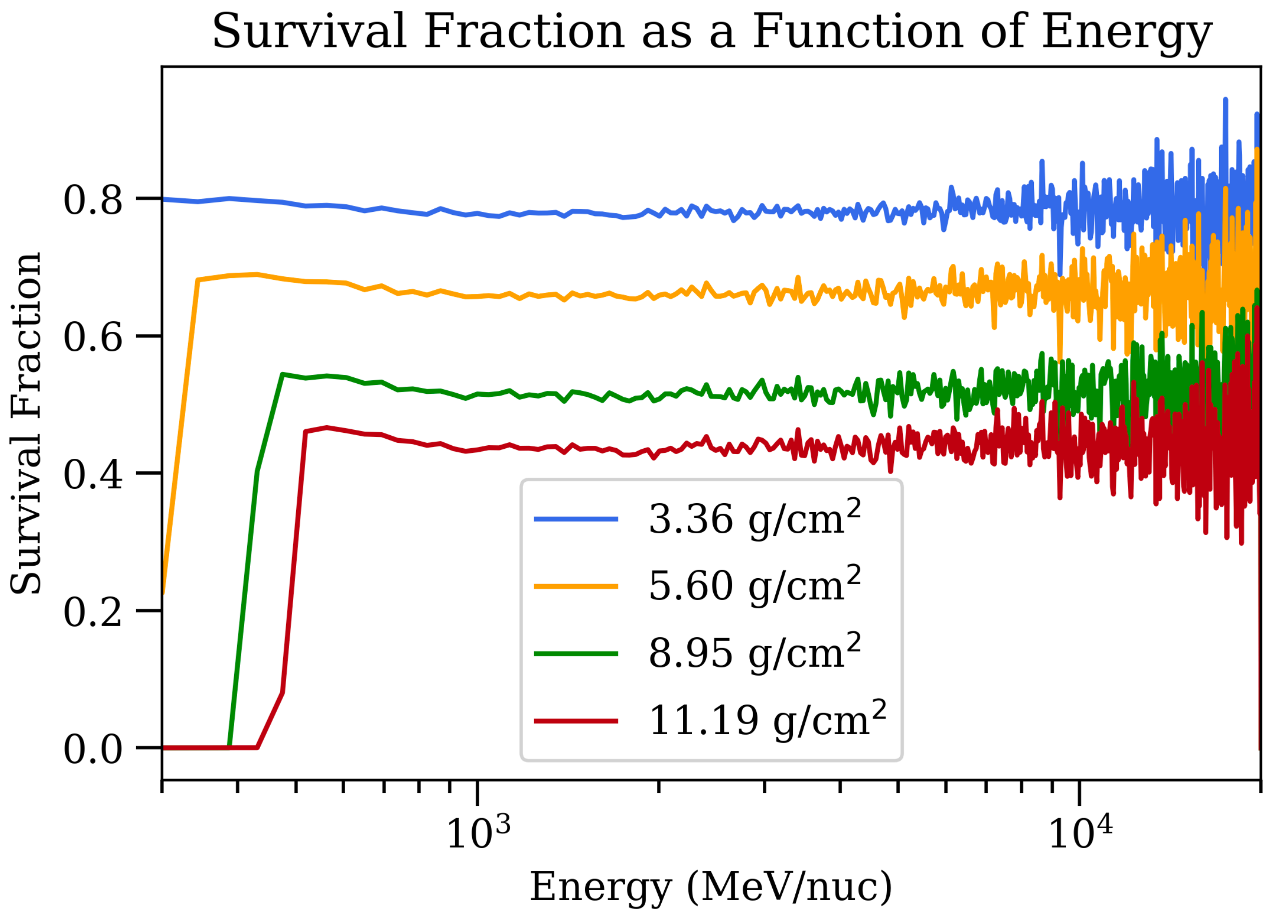
2. Compare analytical model to response matrix from Geant4 simulation

- Simulation error bars: statistical uncertainty
- Analytical error bars: systematic uncertainty



Energy Information

- Geant4 tracking energy
- Obtain energy threshold
- Survival fraction behavior with energy
- ^{56}Fe, survival fraction independent of energy, but step turn on

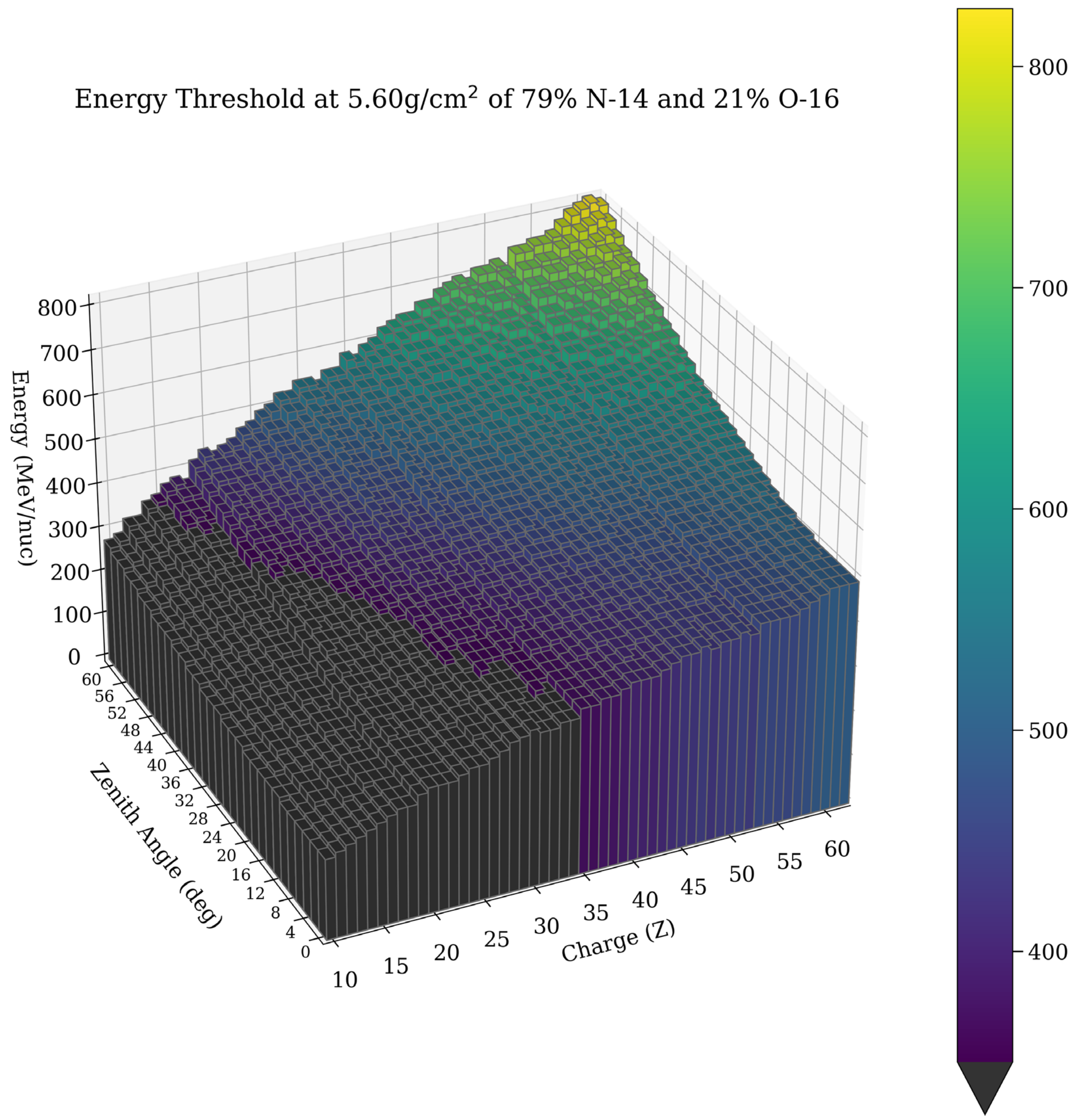


Energy Thresholds

For the atmosphere

Energy required by GCRs to survive through the atmosphere only

- Binned by incidence (zenith) angle, in bins of 2 degrees
- Energy (100 MeV/nuc – 20 GeV/nuc) with 2000 bins



Galactic Cosmic Ray Source Abundances:

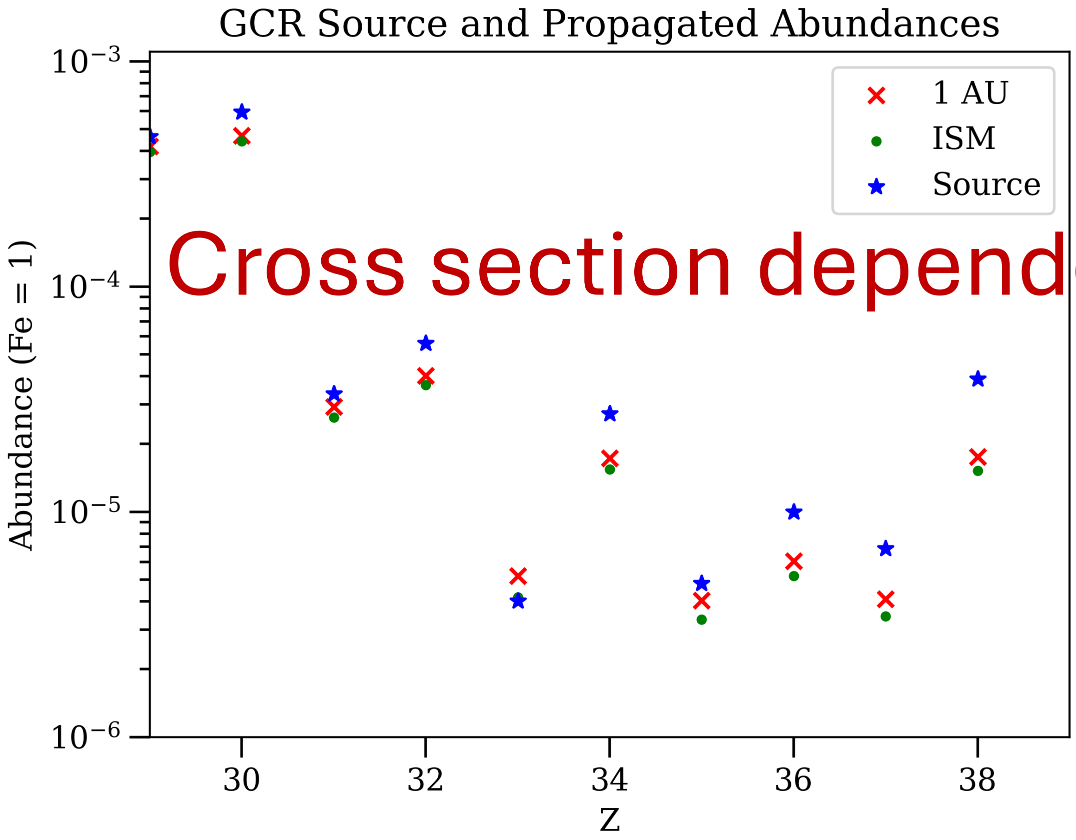
From Leaky-Box Model

- Random walk
- Steady state transport of CR through ISM: $\frac{dN}{dt} = 0$
- Simple leaky-box model
  - Isotropic distribution of cosmic-ray sources in the Galaxy
  - CR accelerated only once at their source – to identical spectra
- Nested leaky-box model
  - GCRS material temporarily stored in reservoirs near their source

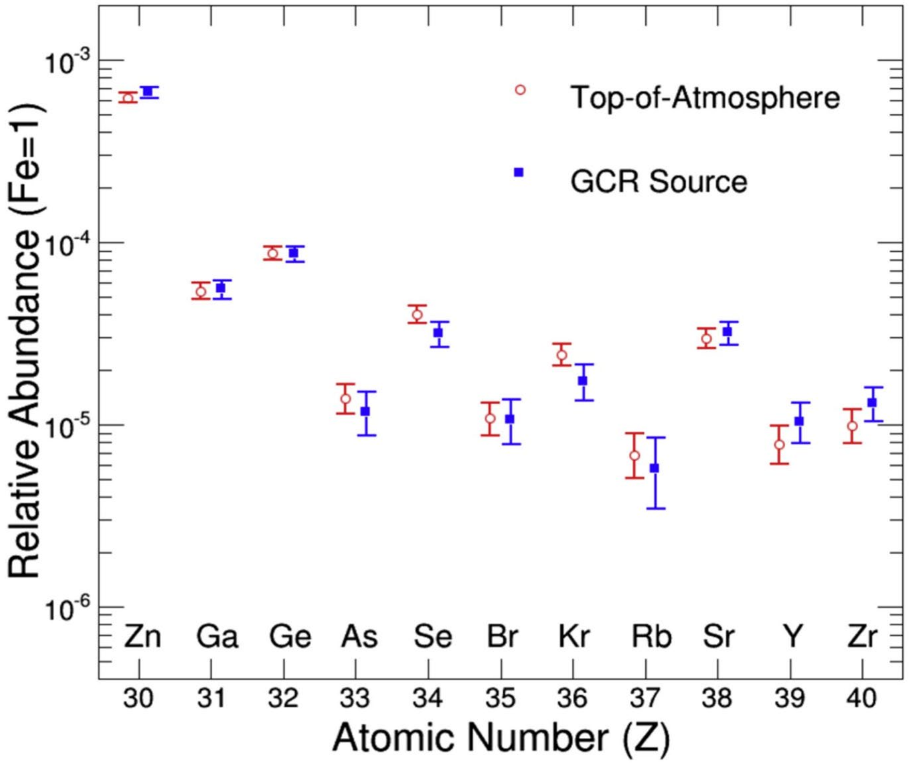
$$\underbrace{Q_i + \sum_j \varphi_j \left(\frac{1}{\Lambda_{ji}^{spall}} + \frac{1}{\Lambda_{ji}^{decay}} \right)}_{\text{Gain}} = \underbrace{\varphi_i \left(\frac{1}{\Lambda_i^{spall}} + \frac{1}{\Lambda_i^{decay}} + \frac{1}{\Lambda_i^{esc}} \right) - \frac{dw_i \varphi_i}{d\varepsilon}}_{\text{Loss}}$$

Source Abundances

- Repeat leaky-box propagation until source abundances give TOA

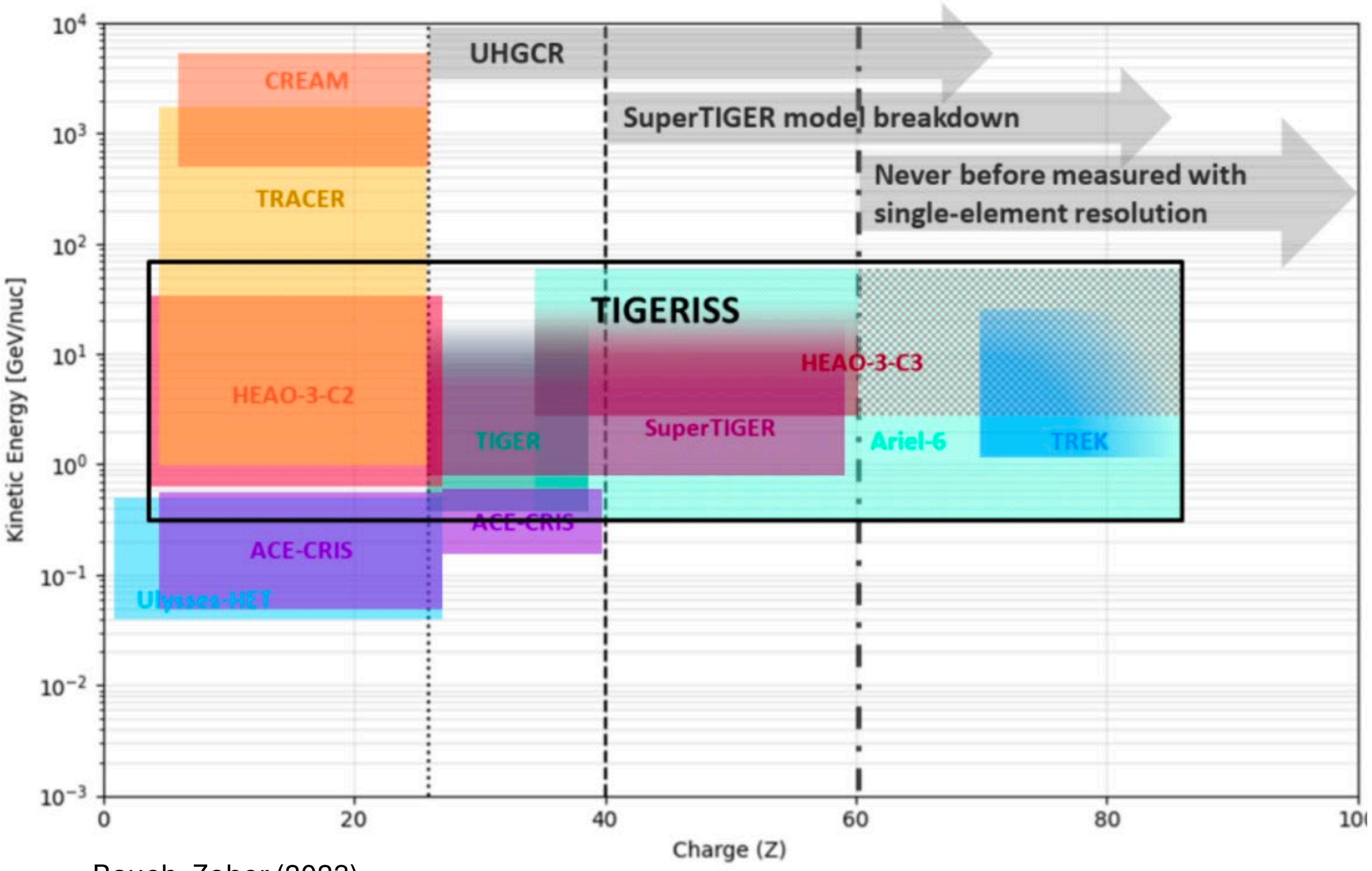


Cross section dependent



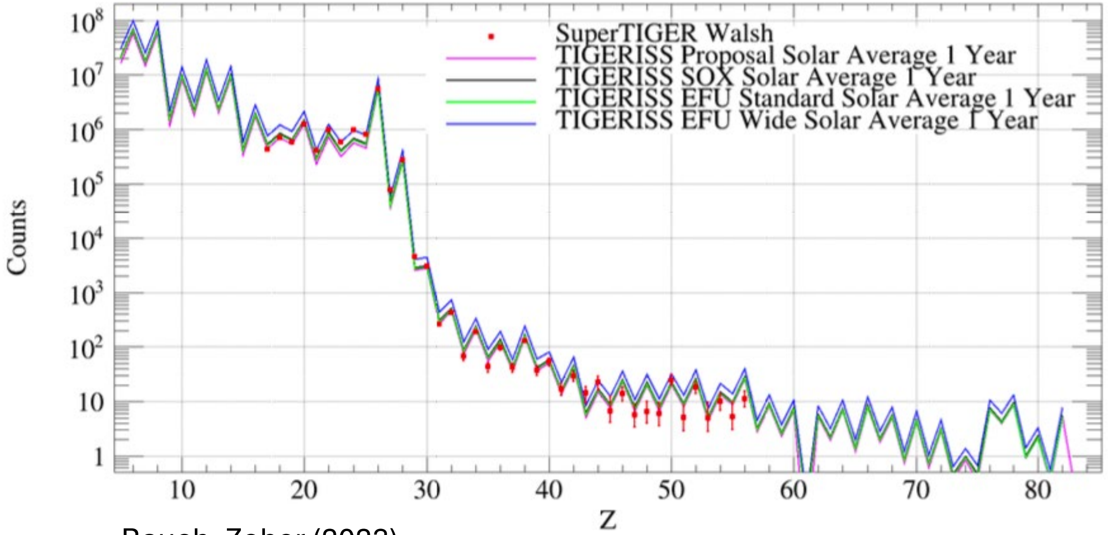
Murphy et al. (2016)

To the Future: SuperTIGER → TIGERISS



Rauch, Zober (2023)

- Galactic propagation for ST → pipeline for TIGERISS analysis



Rauch, Zober (2023)

Thank You

SuperTIGER under grants NNX09AC17G and NNX09AC18G, NNX15AGC23, 80NSSC20K0405 and 80NSSC23K0055. TIGERISS is supported under NASA cooperative agreement 80NSSC22M0299.
This work was also supported 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 and the successful recovery effort.