Ultra-Heavy Galactic Cosmic Rays

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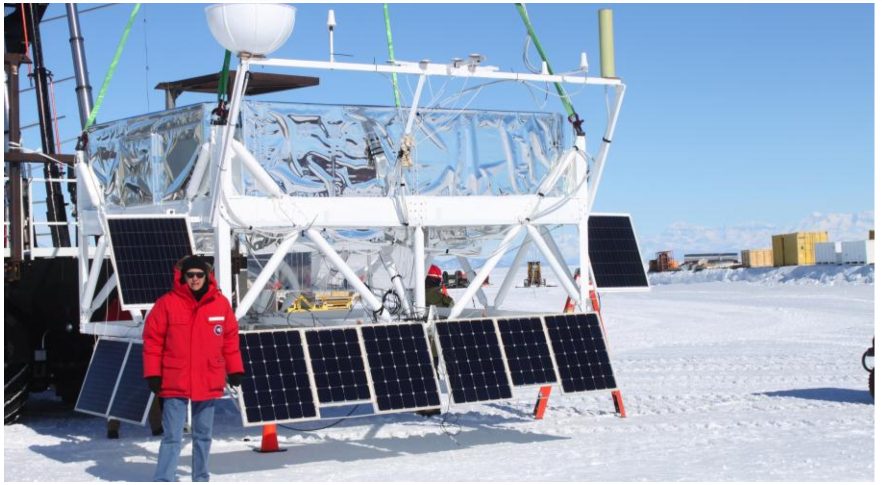
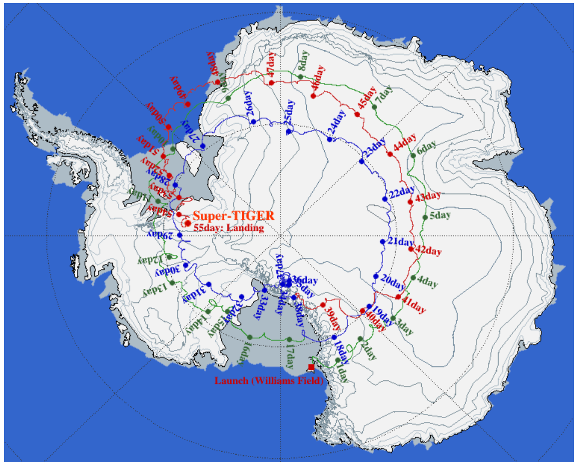
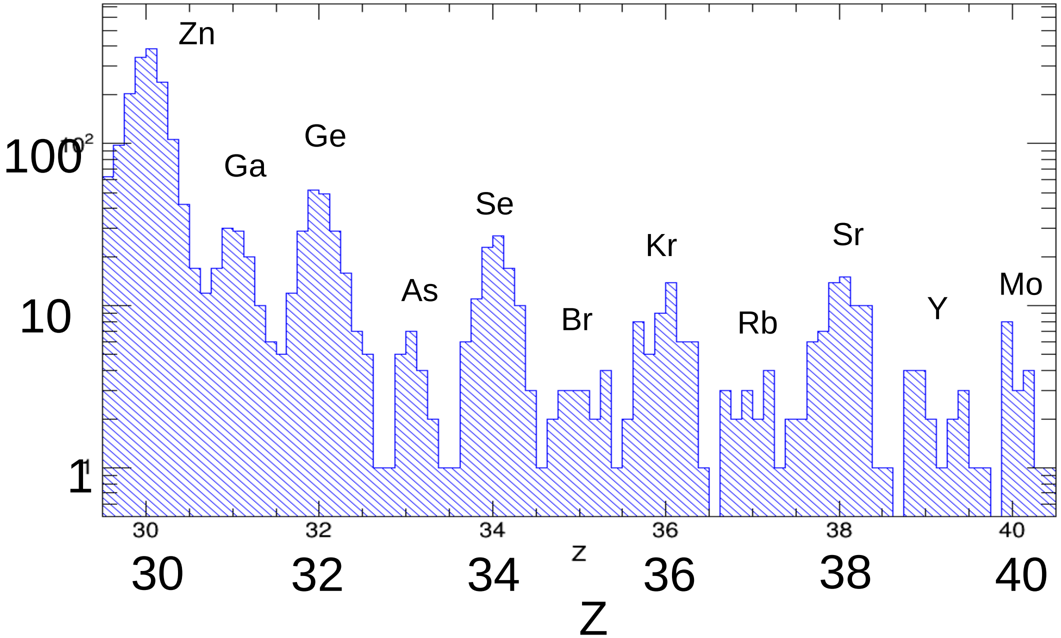
Important Recent Measurements of Ultra-Heavy Galactic Cosmic Rays

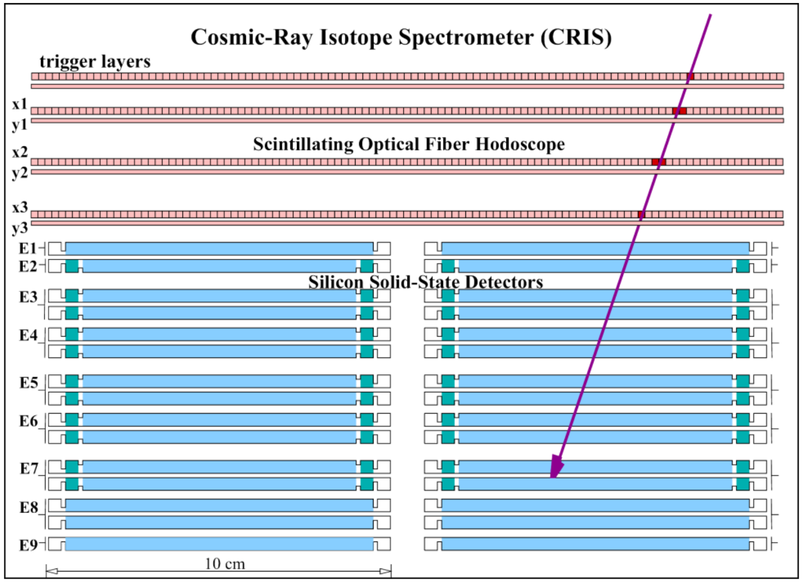
- SuperTIGER
  - Uses dE/dx vs. Cherenkov & Cherenkov-Cherenkov technique to identify elements
- 55-day flight over Antarctica
- For the first time we have measured the abundances of all individual elements in the Z=30-40 range
- Confirms TIGER and ACE data showing that a cosmic-ray source that is a mix of massive star material with old ISM material greatly improves ordering of refractory and volatile elements and points to an OB association origin of GCRs.

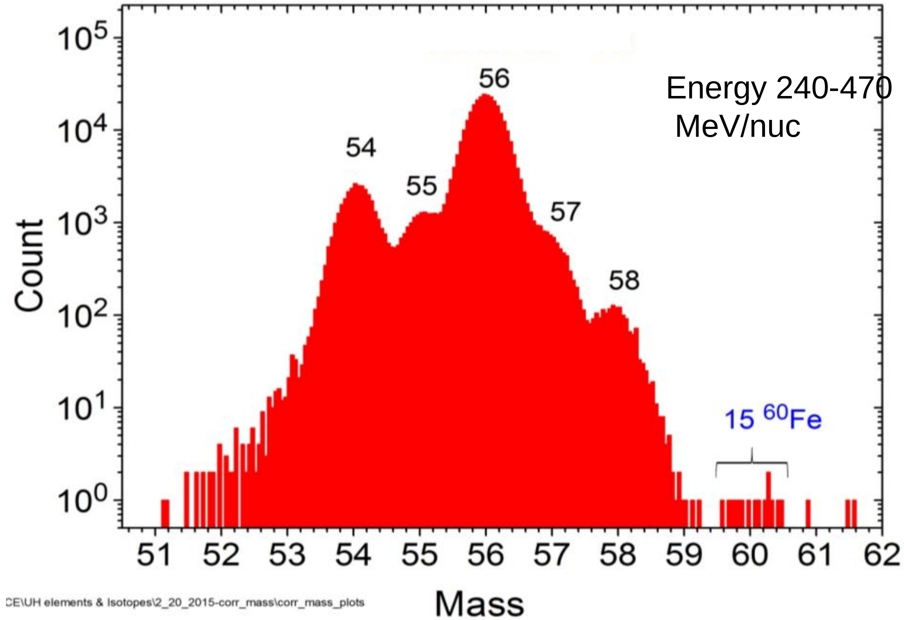






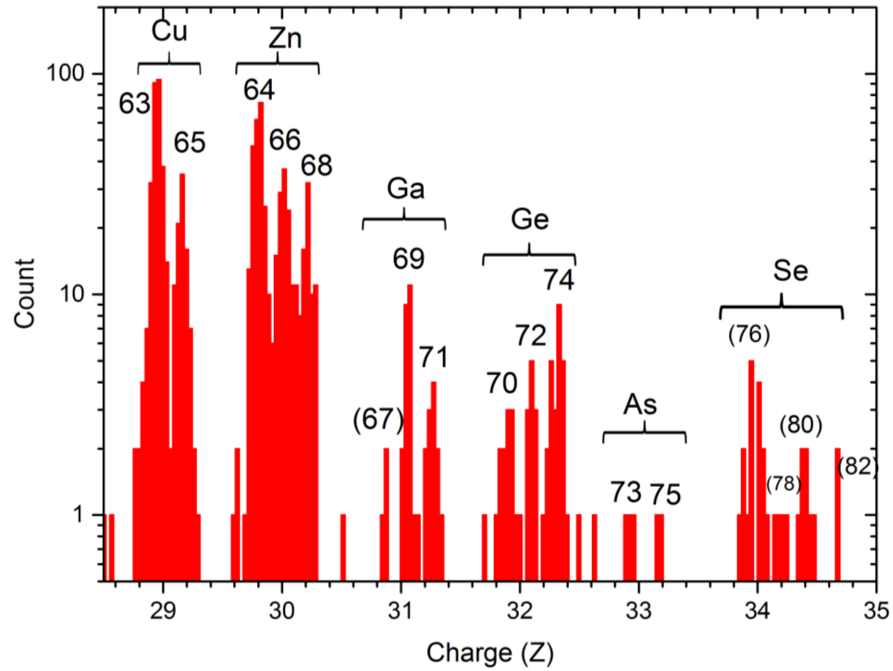
The Cosmic Ray Isotope Spectrometer (CRIS) on the Advanced Composition Explorer (ACE)

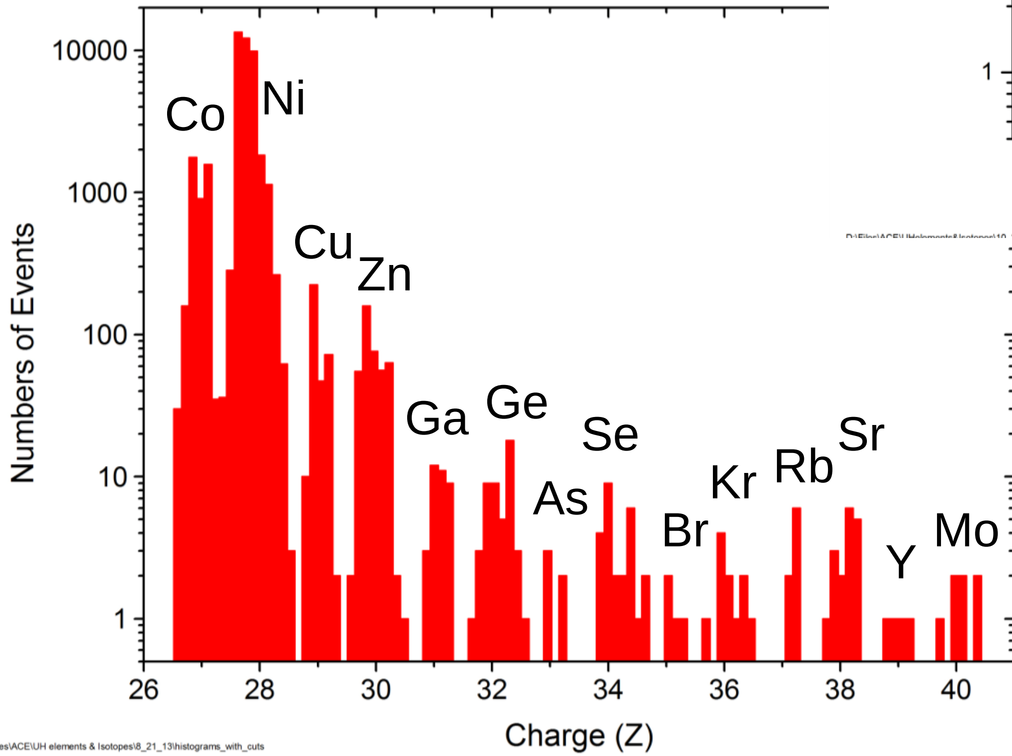




- Measured $^{60}Fe/^{56}Fe$ ratio in GCRs. Ratio=$(4.4 \pm 1.6) \times 10^{-5}$ (reported for the first time at this APS conference).
- ^{60}Fe is radioactive, decaying by beta decay with a half-life of 2.6 Myr.
- Based on this we estimate the maximum time between nucleosynthesis and acceleration to be ~2.5 Myr.
- OB associations appear to be the natural astrophysical setting for this to occur.
- Strong evidence of recent, nearby SNe

ACE-CRIS Elements & Isotopes





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- CRIS has obtained
  - the first measurements of isotopic abundances of nuclei heavier than Nickel
  - The best resolved element abundances for ultra-heavies with 28<Z<40

What's Next?

- SuperTIGER Antarctic flights
  - Obtain measurement of elemental abundances in the Z=40-60 range
- To go beyond that requires a large space instrument such as the Heavy Nuclei Experiment (HNX) capable of measuring all individual elements from Z=50 through the actinides
- HNX was proposed as a SMEX in 2001 and selected for Phase A, but ruled out of scope because it used the Space Shuttle
- New version of HNX proposed to 2014 SMEX AO, now using SpaceX DragonLab

Overview of HNX Objectives

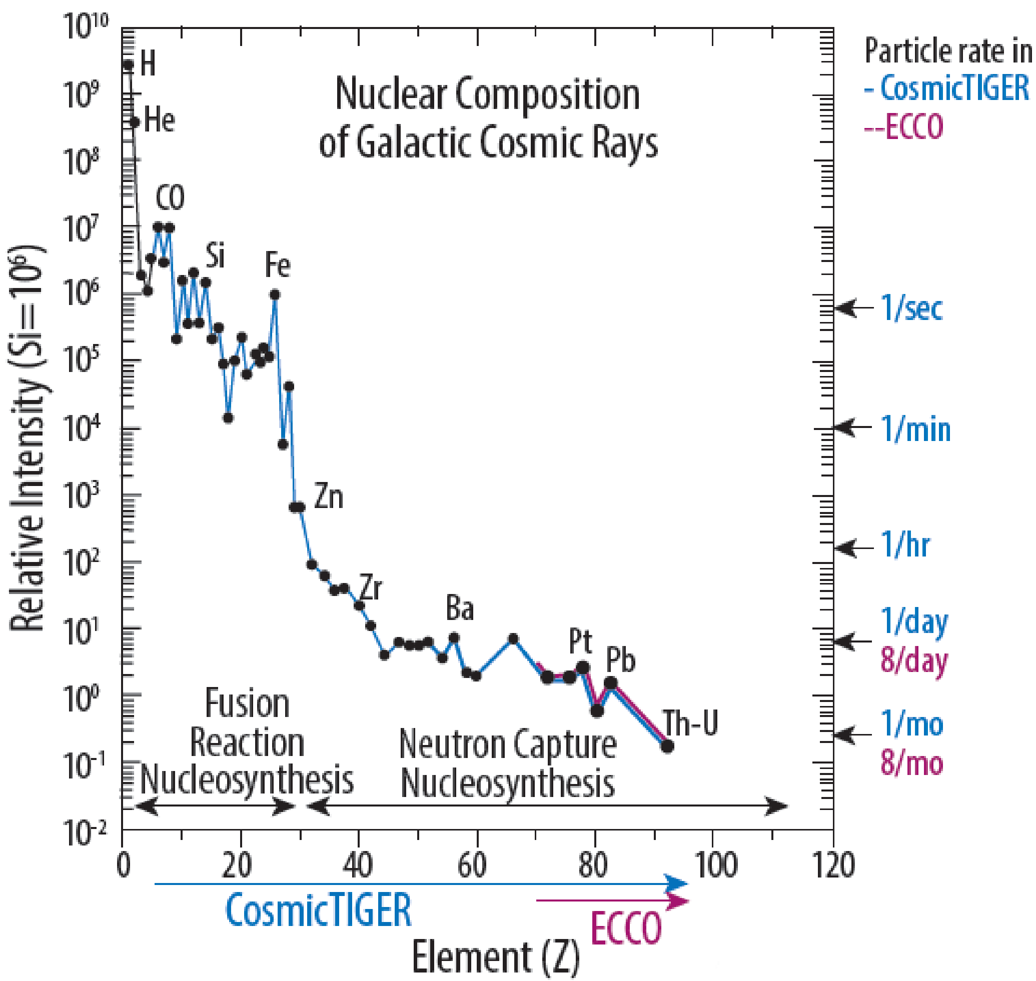
- **Obtain a direct sample of matter from the birthplace of heavy nuclei**
  - SN shocks in superbubbles formed by OB associations accelerate material from recent SN and stellar winds.
  - HNX is a " sample return" mission of nuclei that almost certainly contain recently synthesized material from OB associations.
  - This is a young sample (several Myr since acceleration); it can tell us the production ratios of heavy nuclei.
- **Determine how cosmic accelerators work**
  - The presence of fresh material in the heaviest cosmic rays strongly suggests supernova/superbubble acceleration.
  - Pattern of element abundances carries
    - the signature of the site of injection into the accelerator.
    - The r-, s-process mix in the GCR source.
- **Bonus Science--Superheavies**
  - Search for superheavy elements and exotic particles with mass as much as 5 orders of magnitude heavier than Uranium.

Superbubble (N 70) in the Large Magellanic Cloud
(ESO Very Large Telescope Image)

HNX Science Design

•**HNX Explores to the end of the periodic table**

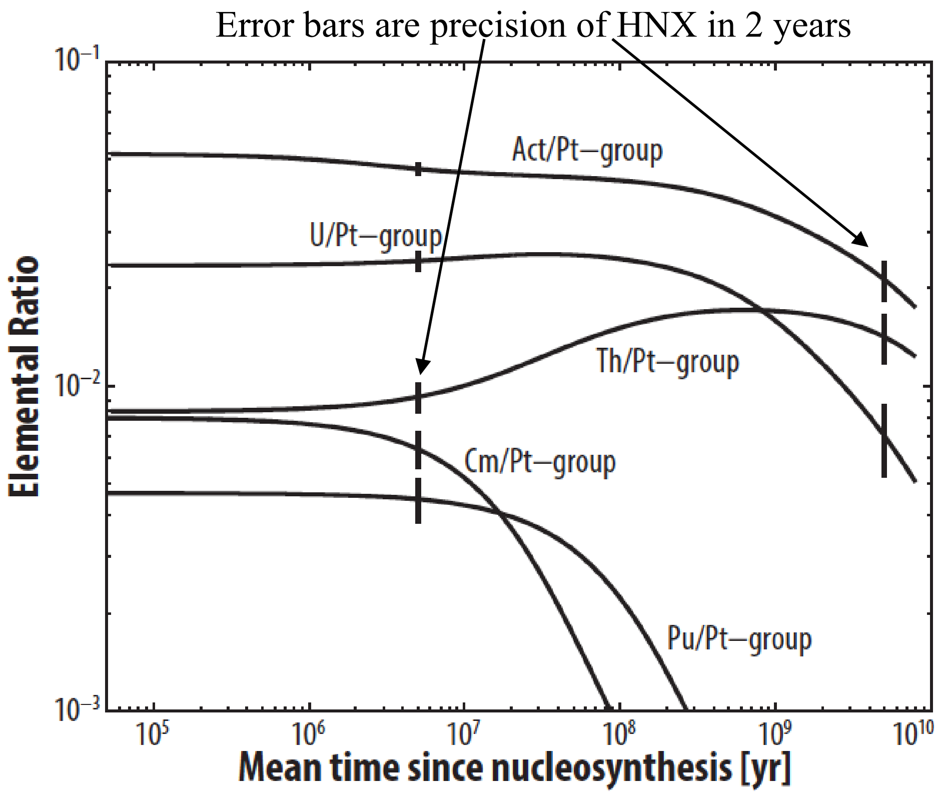
- Elements in the upper 2/3rds are extremely rare

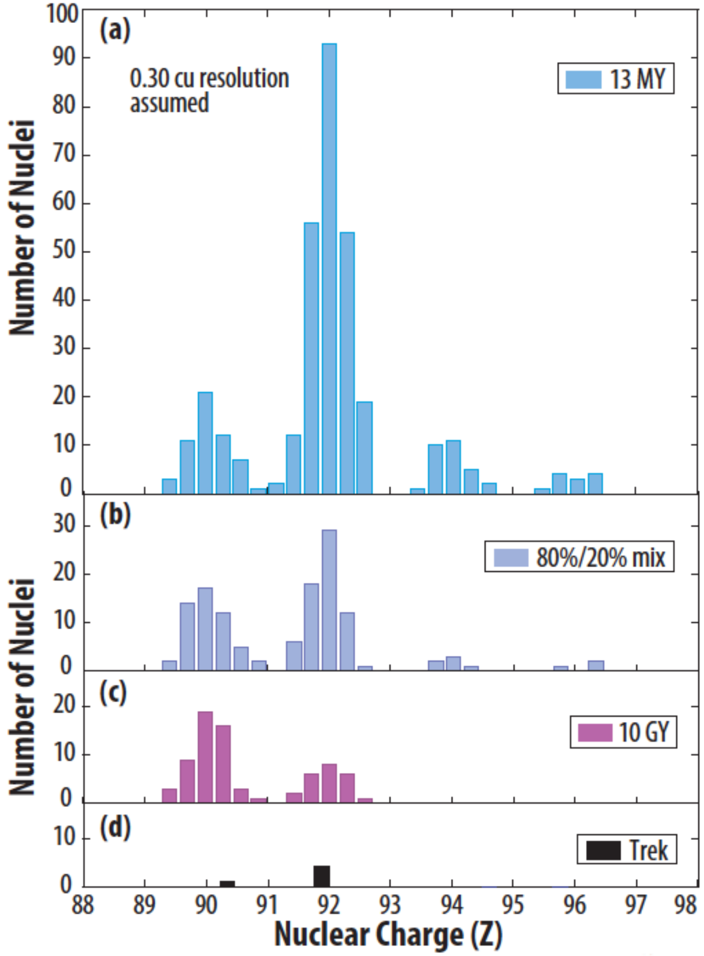


- **Requires a very large instrument with long exposure in space!**
- *HNX uses complementary active (CosmicTIGER) and passive (ECCO) detectors to give the required ~ 40 m^{2}sr geometric factor*
- ECCO uses BP-1 (barium phosphate) glass detectors
  - Trek experiment on Mir used BP-1 to record the only cosmic-ray actinides (4 nuclei) reported
  - Require return to Earth for processing ➔SpaceX DragonLab
- CosmicTIGER electronic instrument is based on TIGER and SuperTIGER balloon instruments and HEAO and Solar Probe Plus space instruments

What is the Signature of a Fresh Sample?

Actinides (Th, U, Pu, Cm) are clocks that measure absolute age of the UHGCR





- Pu and Cm are "smoking guns" for fresh nucleosynthesis
- ^{247}Cm would be in a fresh sample and would be the heaviest element ever found in nature

Possible actinide abundances from 2 years of HNX data

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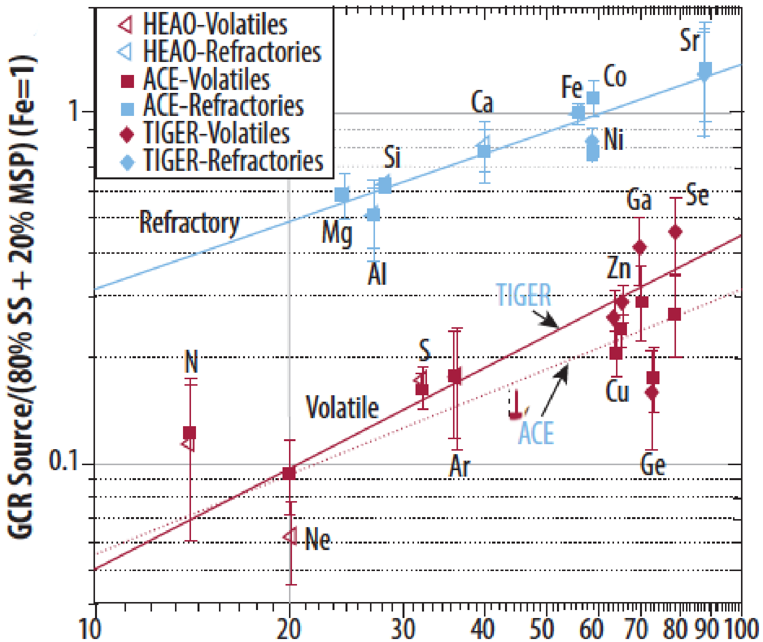
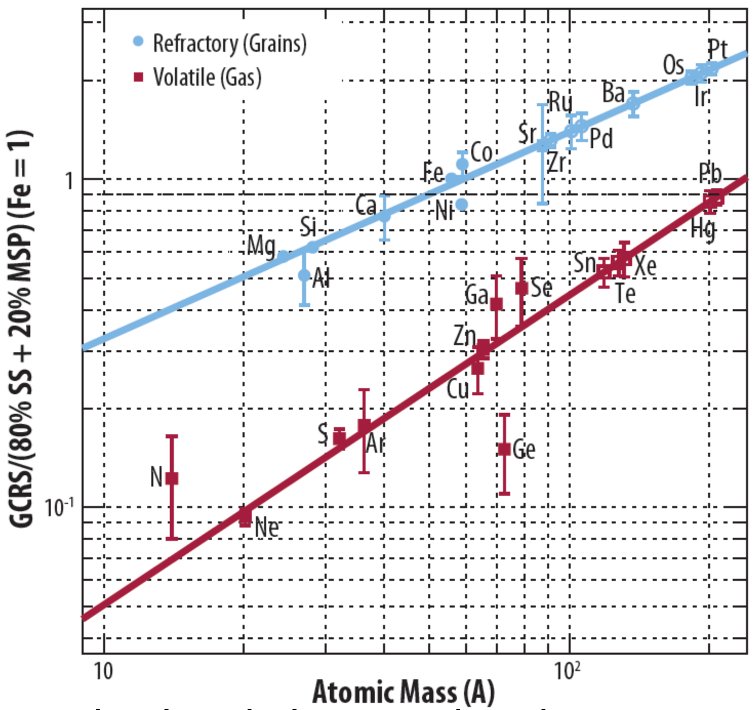
What Mix of Processes are Responsible for the UHGCR?

- Are GCR are accelerated from newly synthesized material, old material, or a combination?
- What mix of nucleosynthesis processes are responsible for the heavy nuclei?
- How are UHGCR elements preferentially selected for acceleration?
- What is the integrated pathlength of UHGCRs between the time they are initially accelerated and the time we observe them?



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



Simulated element abundances to Pt from 2 years of HNX data

Conclusions

- Results over the last 10 years from TIGER, SuperTIGER, and ACE are exciting.
- There is a lot more exciting science to be had by extending our present measurements of low energy UHCRs throughout the periodic chart of the elements to the heaviest nuclei.
- To do this we require a space mission.