The Heavy Nuclei eXplorer (HNX) Small Explorer Mission

A Mission to Measure the Elemental Composition from Carbon (Z=6) to Curium (Z=96) in the Cosmic Radiation

John Krizmanic (NASA/GSFC/CRESST/USRA)
for the **HNX Collaboration**

NASA/GSFC

John Mitchell (PI, CosmicTIGER Lead), Thomas Hams. John Krizmanic, Jason Link, Kenichi Sakai, Makoto Sasaki

Washington University in St. Louis

Bob Binns, Martin Israel, Brian Rauch

California Institute for Technology/JPL

Mark Wiedenback

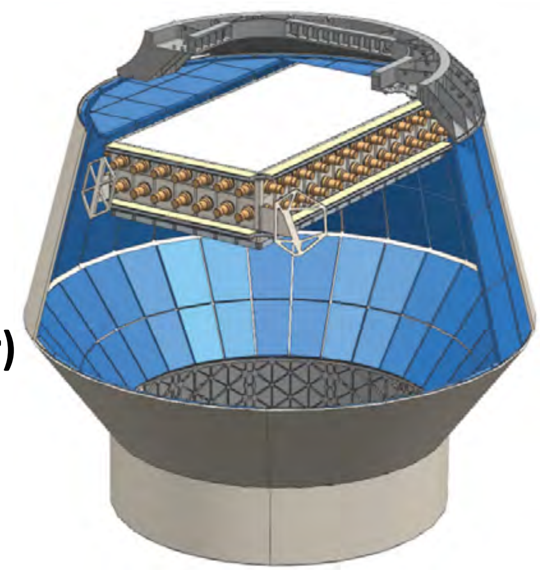
University of California, Berkeley

Andrew Westphal (Deputy PI, ECCO Lead)

The HNX Experiment

HNX uses two complementary instruments to span 6 ≤ Z ≤ 96 (Z > 96 if flux exists) with the needed high exposure factor and charge resolution.

ECCO (Extremely-heavy Cosmic-ray Composition Observer)



- 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 ≥ 70 (Yb) nuclei
- Recovery is required for post-flight processing of glass

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

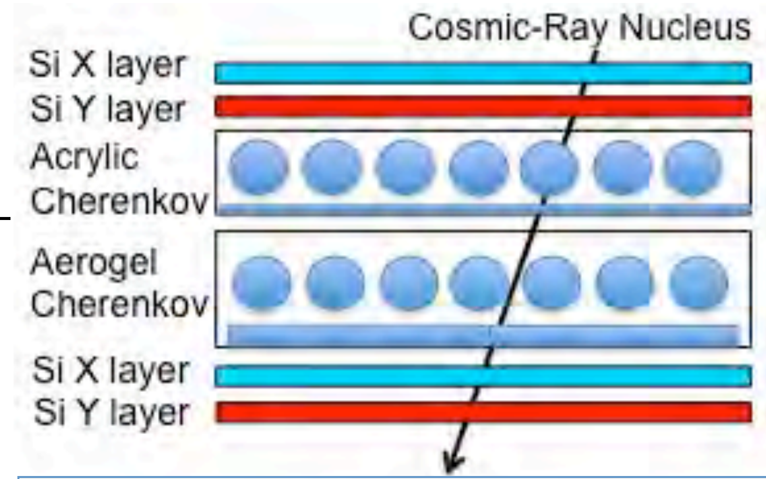
- 2 m^2 electronic instrument using – silicon strip detectors and Cherenkov detectors with acrylic and silica-aerogel radiators in the pressurized DragonLab Capsule

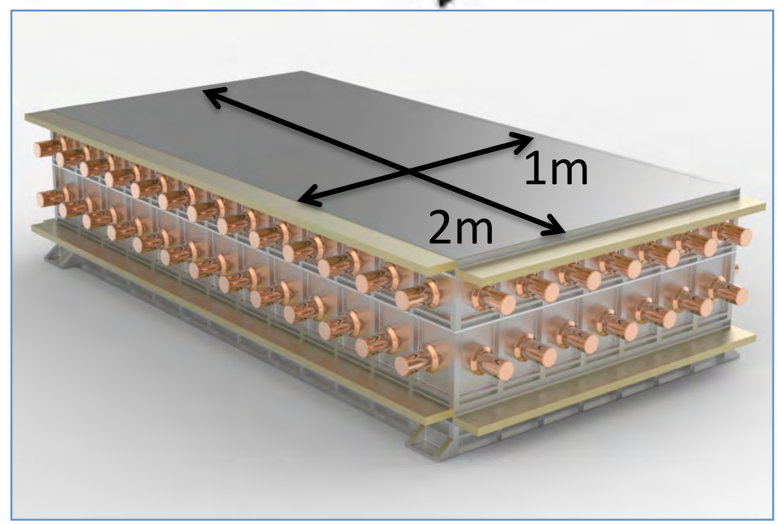
DragonLab Capsule Accommodation

- Pressurization of capsule 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

CosmicTIGER Overview

- Large electronic particle detector system – 2 m^2 active area, $A\Omega = 4.2\ m^2sr$
- Heritage from SuperTIGER, HEAO, Solar Probe Plus
- Measures nuclei $Z \geq 6$ with single element resolution – method proven in accelerator tests, TIGER, and SuperTIGER
- Measurement range extends to the end of the periodic table (adds to ECCO area for $Z \geq 70$)
- Charge measurement employs three detector subsystems in dE/dx vs. Cherenkov and Cherenkov vs. Cherenkov techniques
  - Silicon strip detector (SSD) (x,y) arrays at top and bottom measure ionization energy deposit (dE/dx) and trajectory
  - Cherenkov detector with acrylic radiator (optical index of refraction n=1.5) measures charge and velocity $E_K \geq 325$ MeV/nucleon ($\beta \geq 0.67$)
  - Cherenkov detector with silica aerogel radiator (n=1.04) measures velocity $E_K \geq 2.25$ GeV/nucleon ($\beta \geq 0.96$)





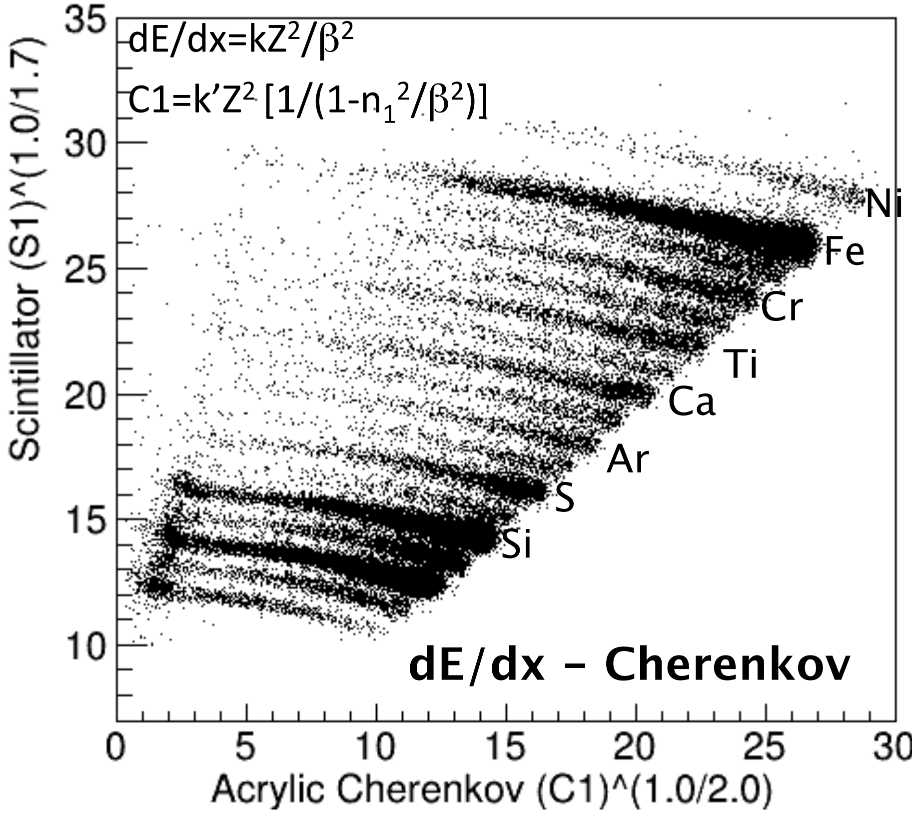
Artist's rendering of CosmicTIGER

Charge Measurement Range: $6 \leq Z \leq 96$ with $\delta Z < 0.25$ cu

CosmicTIGER Charge Identification

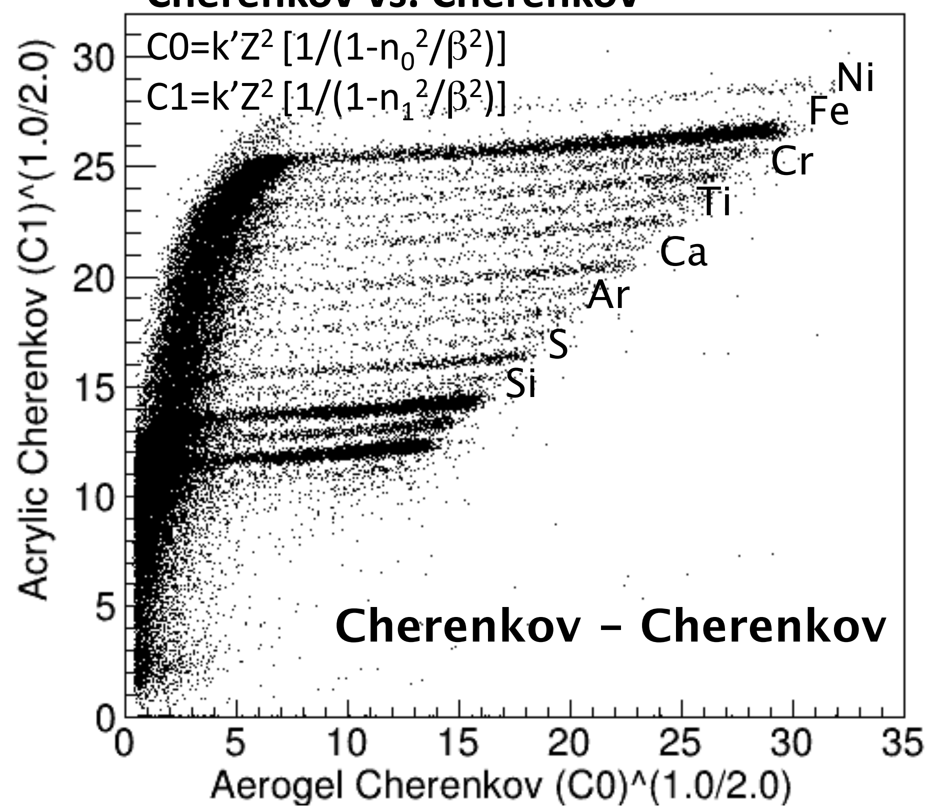
SuperTIGER flight data illustrates the method

dE/dx vs. Cherenkov



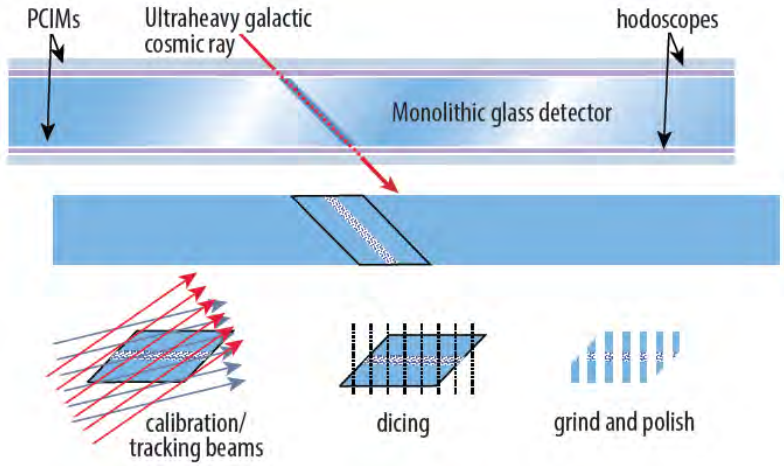
Low Energies: Silicon vs. Acrylic Cherenkov

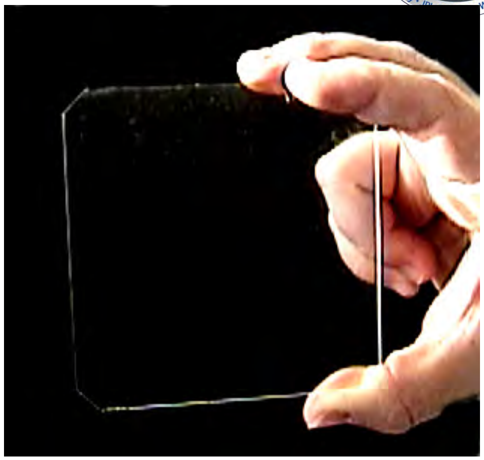
Cherenkov vs. Cherenkov



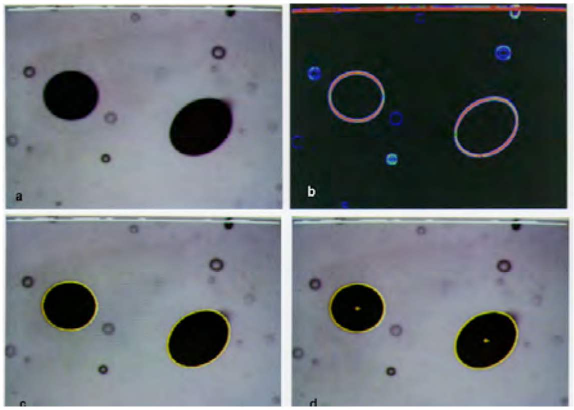
High Energies: Acrylic CK vs. Aerogel CK

ECCO Overview





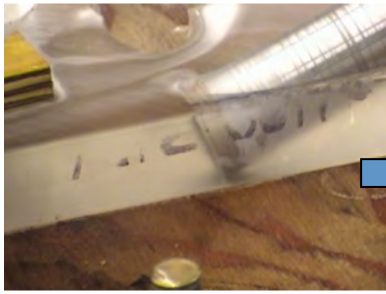
ECCO is simple on orbit…



… all the sophistication is in the laboratory

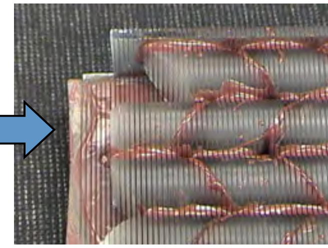
- ECCO based on TREK experiment on MIR
- ECCO BP-1 detector modules cover capsule walls, part of top, and beneath CosmicTIGER
- Active area 21 m^2, $A\Omega$ = 48 m^2sr
- Five layer module made of barium-phosphate BP-1 glass
  - Preliminary Charge Identification Modules (PCIMs – 1 mm): identify charge group
  - Hodoscopes (1.5 mm): initial identification and trajectory determination
  - Monolithic central detector (25 mm): make accurate charge measurements and slow nuclei to measure energy
- Glass is etched to "develop" nuclear tracks
- Tracks are measured using fully automated microscope system with resolution ≤ 50nm

ECCO Charge Identification



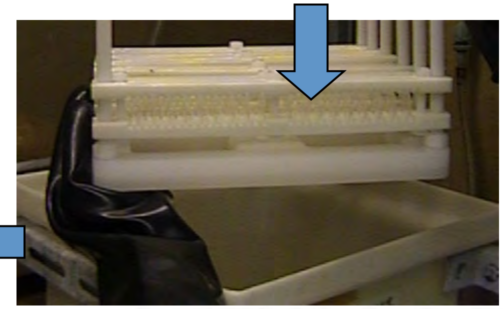
coring

calibration

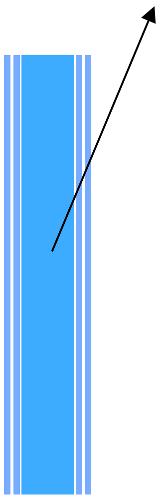


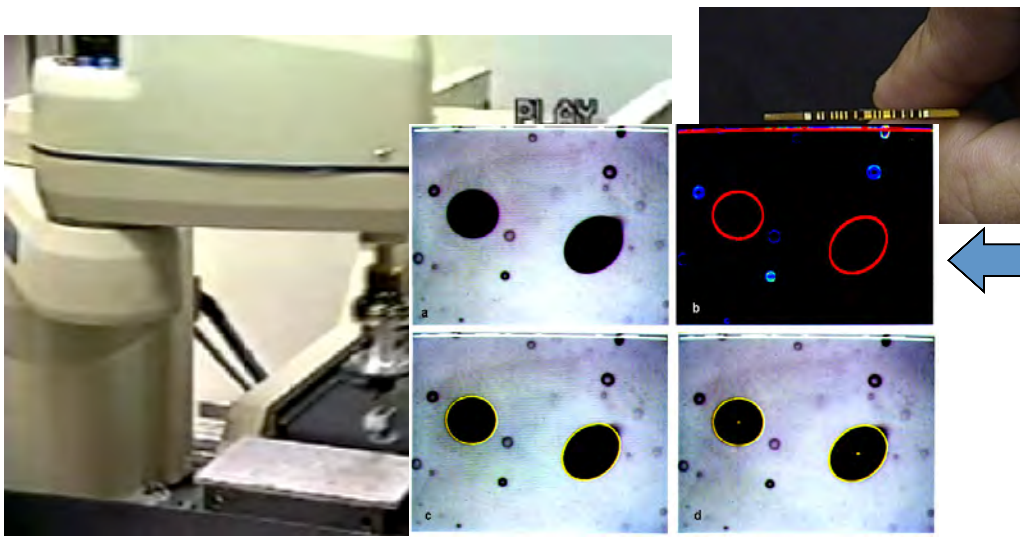
wafering

Grind and polish

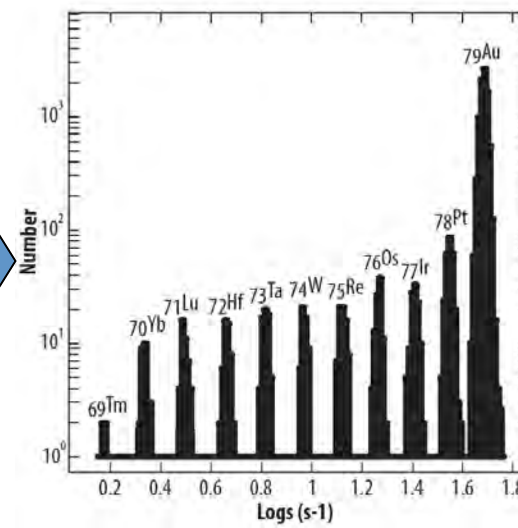


etch



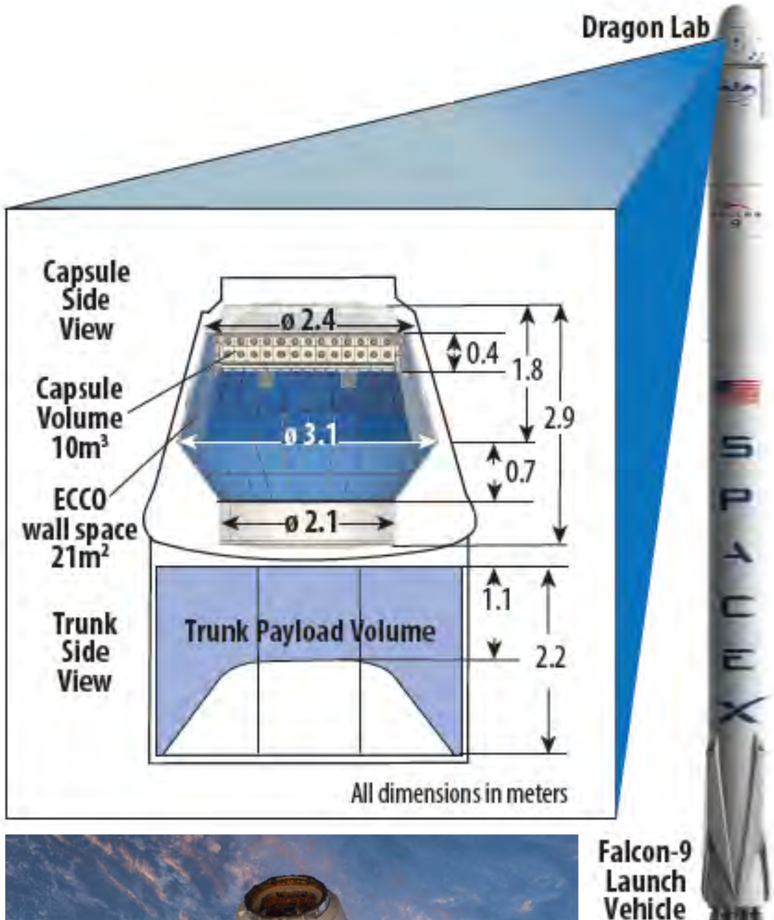


Automated scanning with robotic handling



- Accurate Z measurement – results from Au beam shown
- $\sigma_z \leq 0.35e$ for $Z \geq 70$
- $\sigma_z \leq 0.25e$ for $Z \geq 70$ with reduced statistics

HNX Mission Concept



- **HNX uses the SpaceX DragonLab, launched on the SpaceX Falcon 9**
  - –DragonLab is a free-flying "laboratory" based on the Dragon ISS supply and DragonRider commercial crew spacecraft
  - –Pressurized and temperature controlled capsule and unpressurized "trunk"
  - –Capsule is recoverable, trunk is not
  - –Recovery is required for the ECCO instrument
- **HNX is in the DragonLab capsule flying in a "rideshare" with another payload in trunk**
  - –DragonLab supplies all services including power, telemetry, thermal control
  - –HNX is a perfect match for DragonLab and exceptionally compatible with a wide variety of co-manifested instruments
- **DragonLab will be certified for 2-year flights with safe recovery (possibly 3-4 years)**

Source material for Cosmic Rays

- The current picture is that GCRs mainly originate in OB associations, groups of hot, short-lived, massive stars of spectral types O or B, that form superbubbles by a combination of their stellar winds and SN blast waves.

- The leading model of the cosmic-ray source asserts that it is a mixture of *old* ISM material, similar to the that of the Solar System (SS), with *new* material from massive stars (including Wolf-Rayet stars and their precursors) and ejecta from core-collapse supernovae, which occur mostly in OB associations.

- Both isotopic and elemental abundance measurements point to a cosmic-ray source with ~80% by mass old material similar to our SS, and ~20% new massive star production (MSP) material. Based on ACE CRIS results: excess ^{22}Ne and ^{58}Fe explained as outflow from WR stars Binns, et al. *ApJ*, **634**, 351 (2005).

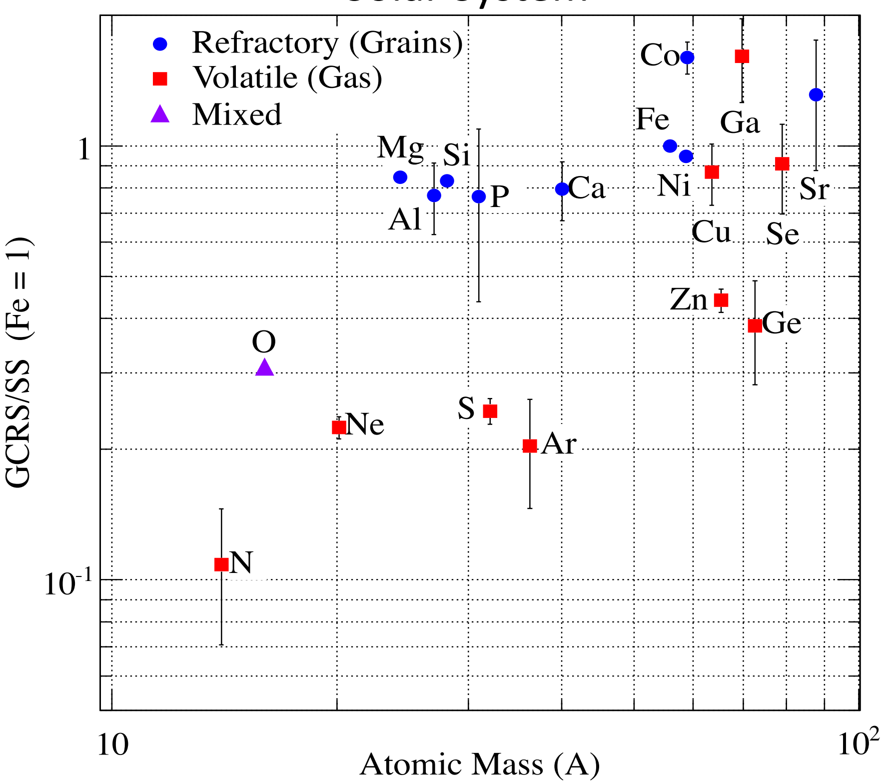
- However, the supporting data suffer from both limited charge range and limited statistics.

- Measurements of the rare UHGCR elements thus allow us to probe these regions for enrichments expected from nucleosynthesis in massive stars.

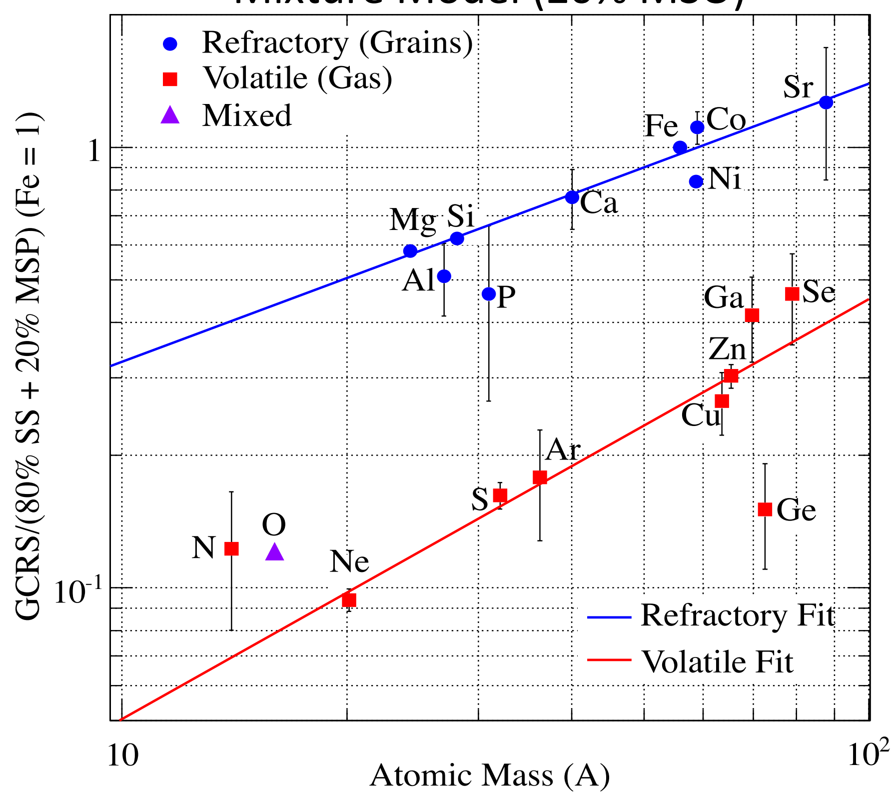
TIGER UHGCR Results vs Source Material

- Refractory elements are significantly more abundant than volatile elements
- Refractory depend on mass as ~$A^{2/3}$ (initially accelerated as grains). Volatiles depend on mass as A^{1}.

GCRS Compared to Solar System



GCRS Compared to OB Association Mixture Model (20% MSO)

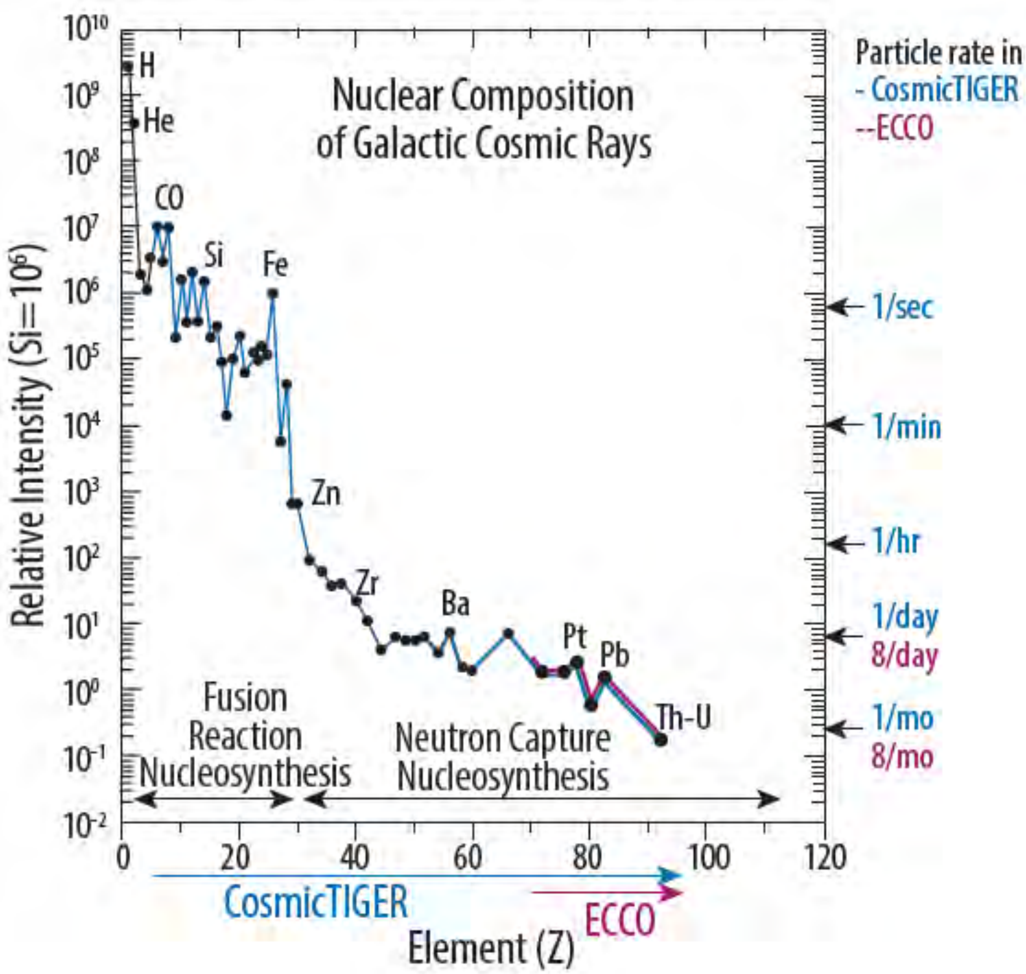


For Z>26, data from TIGER Rauch et al. *ApJ* **697**, 2083 (2009)
For Z<26, data from HEAO-C2 Englemann et al. *A&A* **233,** 96 (1990)
For SS, data from Lodders *ApJ* **591**, 1220 (2003)

Source: Rauch_et_al_COSPAR_2012

UHGRC Science Drives HNX Design

HNX's goal is to take UHGCR measurements to the end of the periodic table

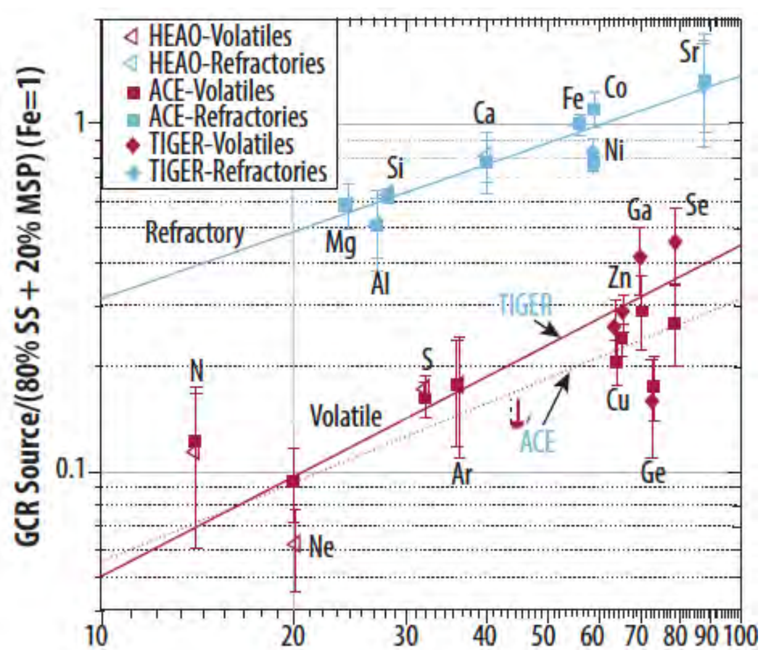


- **Requires a very large instrument with a long exposure in space:**
- *HNX uses complementary active (CosmicTIGER) and passive (ECCO) detectors to give the required ~ 50 m^2sr geometric factor*
- ECCO uses BP-1 (barium phosphate) glass detectors
  - Trek experiment on Mir used BP-1 to record the only cosmic-ray actinides (4 nuclei) reported
  - Requires return to Earth for processing
    ➔ SpaceX DragonLab Capsule
- CosmicTIGER electronic instrument is based on TIGER and SuperTIGER balloon instruments as well as HEAO and Solar Probe Plus space instruments

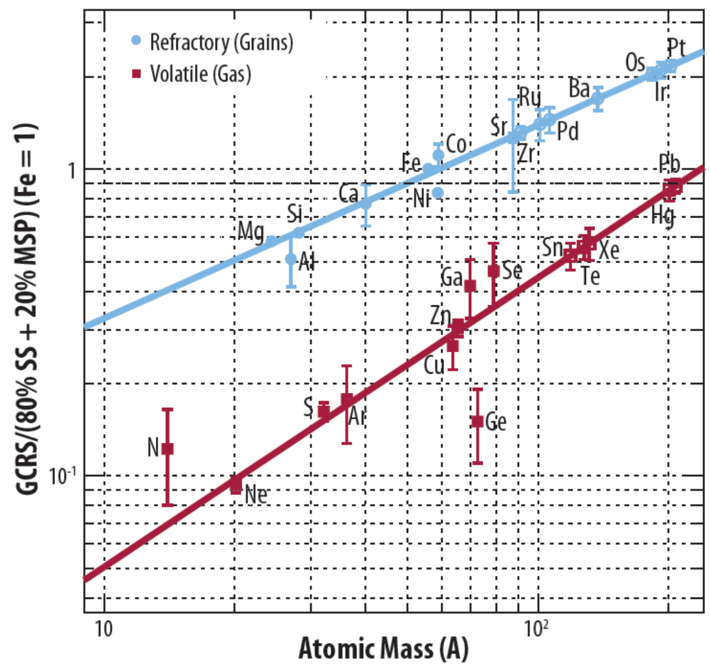
Extending the UHGCR measurements to Z=83

HNX's large exposure allows for >1800 nuclei 38 ≤ Z ≤ 83 to be measured with < 0.25 charge unit resolution, testing our current knowledge:

That the element abundances are best represented by source material that is ~20% massive star production (wind + SN ejecta) and 80% normal ISM



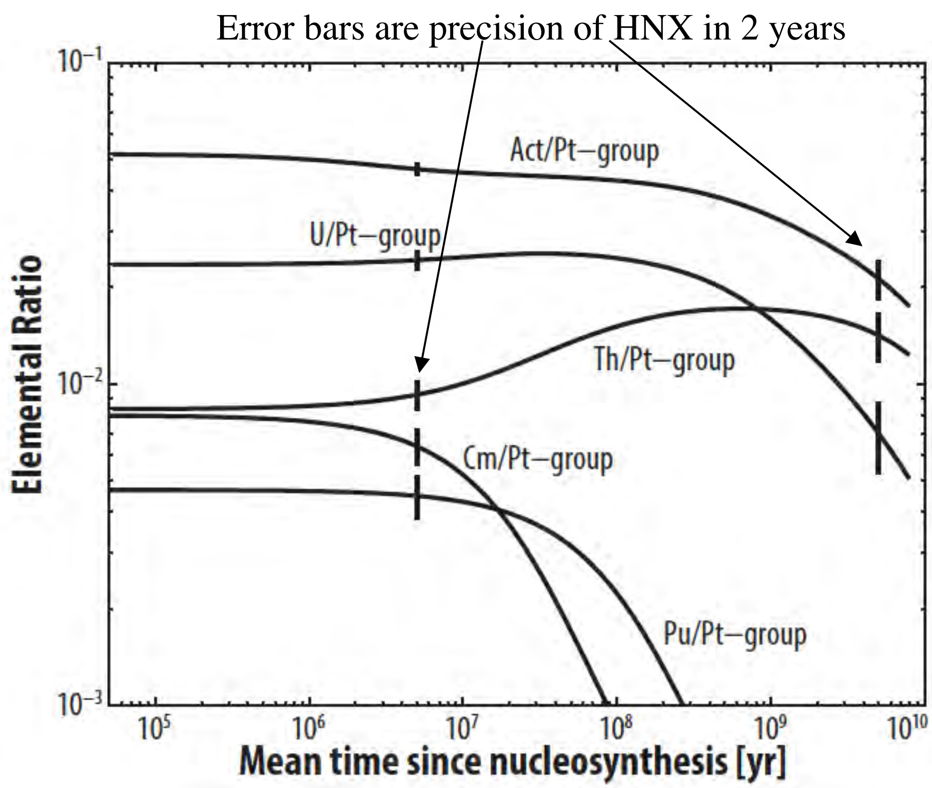
Combined TIGER, ACE, and HEAO element abundances Rauch et al., ApJ 697:2083 (2009).

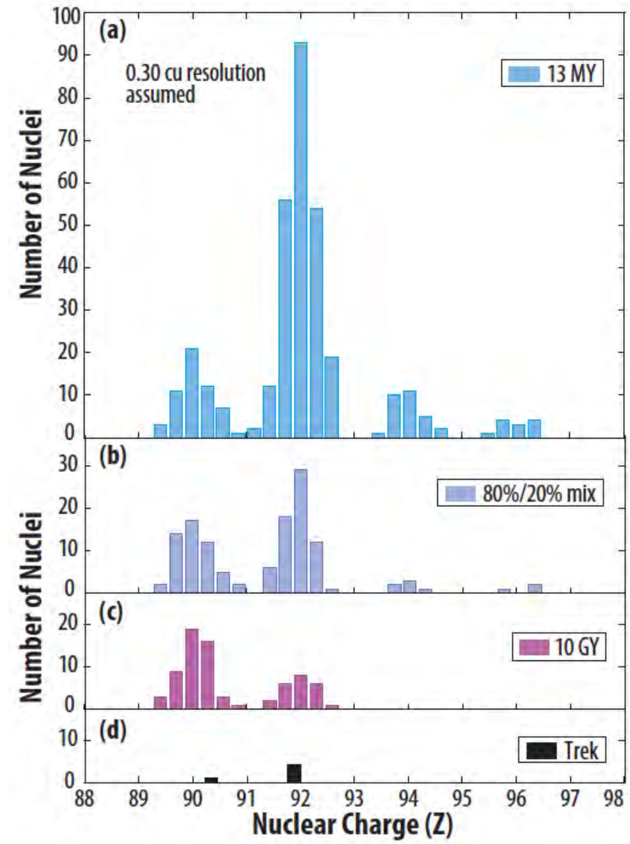


HNX will greatly improve old/new value and accurately determine mass dependence

Actinides as a clock of UHGCR

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





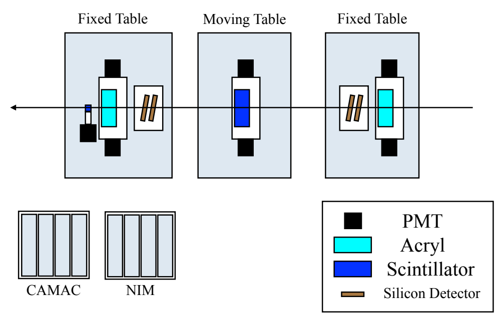
- −Half-lives span the timescales for galactic chemical evolution
- −Relative abundances strongly depend on the age of the GCR source material
- −Ratios of daughter/parent nuclei important: Th/U, (Th,U, Pu)/ Cm
- −**HNX will measure ~50 actinides to probe the UHGCR age**

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

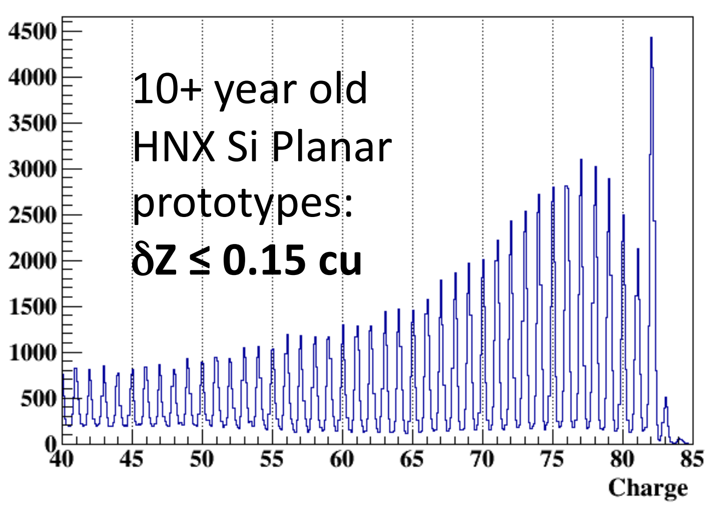
Silicon Detector Development

Results from 2015 CERN Lead test beam run:
HNX planar silicon detectors with discrete CSA electronics

Beam Test Setup



Charge Resolution



Current HNX Detector Development

- We have initiated an order for 5 HNX prototype silicon strip detectors:
    - 10 cm × 10 cm × 500 um
    - single-sided, DC coupled
    - 32 channels
    - 3 mm strip pitch
- We have a PHASIC test board from our CalTech collaborators.
- We will assess the performance of the HNX strip detectors with the PHASIC in the laboratory at GSFC and at a CERN Lead test beam run scheduled for late 2016.

Summary

- The Heavy Nuclei eXplorer (HNX) mission has been developed to investigate two aspects of how the Galaxy generates and distributes matter:
  - determine the nature of the astrophysical reservoirs of nuclei at the cosmic-ray sources
  - determine the mechanisms by which nuclei are removed from these reservoirs and injected into the cosmic accelerators. Comparison to ACE results:
    - lack of ^{59}Ni (has decayed into ^{59}Co) demonstrates that **cosmic-ray acceleration occurs at least ~10^5 years after nucleosynthesis** of ^{59}Ni.
    - detection of primary ^{60}Fe puts a **conservative estimate that acceleration occurred in ~10^7 years**.
  - search for anomalously heavy particles in the cosmic radiation
- HNX will measure the composition of the ultra-heavy cosmic rays with single element resolution from $_6$C to $_{96}$Cm
- HNX builds on heritage from Trek (Mir), HEAO, TIGER, SuperTIGER, and Solar Probe Plus as well as the HNX-Shuttle Phase A study (2001)
- HNX was proposed to NASA in response to the 2014 Small Explorer Announcement of Opportunity, but unfortunately not selected. Developing for next SMEX AO.