The OASIS Mission

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The Orbiting Astrophysical Observatory in Space (OASIS) is a mission to investigate Galactic Cosmic Rays (GCRs), a major feature of our galaxy. OASIS will use measurements of GCRs to determine the cosmic ray source, where they are accelerated, to investigate local accelerators and to learn what they can tell us about the interstellar medium and the processes that occur in it. OASIS will determine the astrophysical sources of both the material and acceleration of GCRs by measuring the abundances of the rare actinide nuclei and make direct measurements of the spectrum and anisotropy of electrons at energies up to ~10 TeV, well beyond the range of the Fermi and AMS missions. OASIS has two instruments. The Energetic Trans-Iron Composition Experiment (ENTICE) instrument measures elemental composition. It resolves individual elements with atomic number (Z) from 10 to 130 and has a collecting power of $60m^2$.str.yrs, >20 times larger than previous instruments, and with improved resolution. The sample of 10^{10} GCRs collected by ENTICE will include ≥100 well-resolved actinides. The High Energy Particle Calorimeter Telescope (HEPCaT) is an ionization calorimeter that will extend the electron spectrum into the TeV region for the first time. It has 7.5 m^2.str.yrs of collecting power. This talk will describe the scientific objectives of the OASIS mission and its discovery potential. The mission and its two instruments which have been designed to accomplish this investigation will also be described.

The OASIS Mission

Presented by Jim Adams for the OASIS collaboration

ENTICE

(Energetic Trans-Iron Composition Experiment)

Wash. U.

Caltech

JPL

GSFC

U. of Minn.

MSFC

HEPCaT

(High Energy Particle Calorimeter Telescope)

GSFC

LSU

NMSU

MSFC

Three year mission in a sun-synchronous orbit

Author List

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- **The OASIS Mission**

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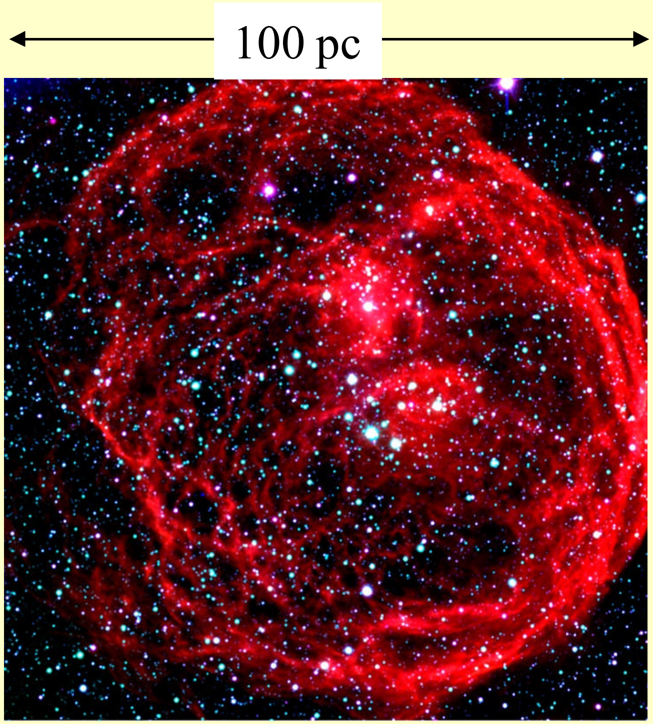
OASIS Objectives

- **OASIS will Answer Key Scientific Questions about Galactic Cosmic Rays (GCRs)**
  - Do GCRs come from OB associations?
  - Where does the GCR electron spectrum end?
    - Does a single local source dominate at the highest energies?
  - What is the physical state of the material injected into the cosmic ray accelerators?
  - Are Z=1 and Z>1 GCRs from different sources?
- **And Produce Other Results**
  - Nucleosynthesis: Determine nucleosynthetic origin of ambiguous elements (e.g., Pb, Bi)
  - Search for superheavy elements
  - Search for evidence of dark matter (Kaluza-Klein particles)

Ultraheavy GCR measurements with ENTICE will:

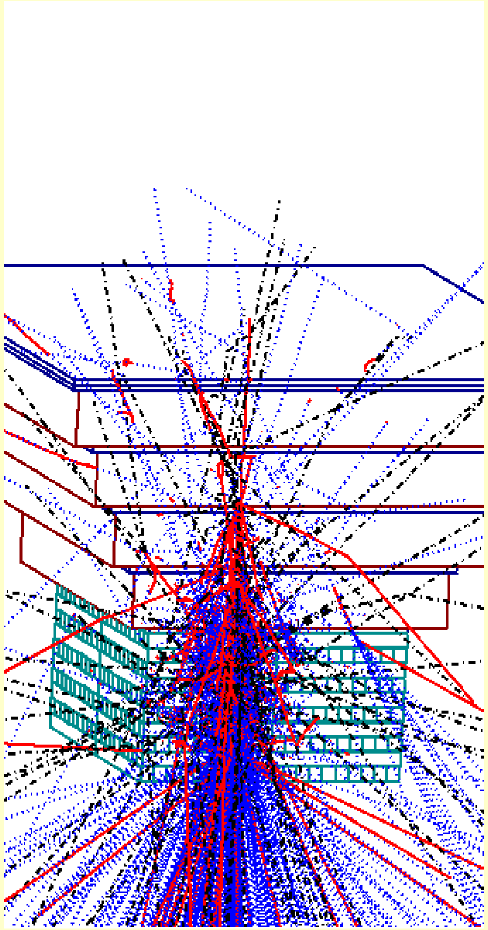
- **Measure the relative abundances of the heaviest cosmic rays**
  - The elemental abundance pattern will identify the site of injection into the accelerator.
    - OB associations?
    - Cold Interstellar Medium (dust and gas)?
    - Warm stellar atmospheres?
- **If freshly synthesized material is found, it would indicate supernova acceleration in OB associations.**
  - SN shocks in superbubbles formed by OB associations are thought to accelerate the local interstellar material from recent SN and stellar winds.
  - This would establish cosmic rays as a sample of the material from which stars are currently being formed.
  - Cosmic Rays would tell us the production ratios of heavy nuclei in supernovae.
- **Bonus Science--Superheavies**
  - Search for superheavy elements



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

HEPCaT will search for:

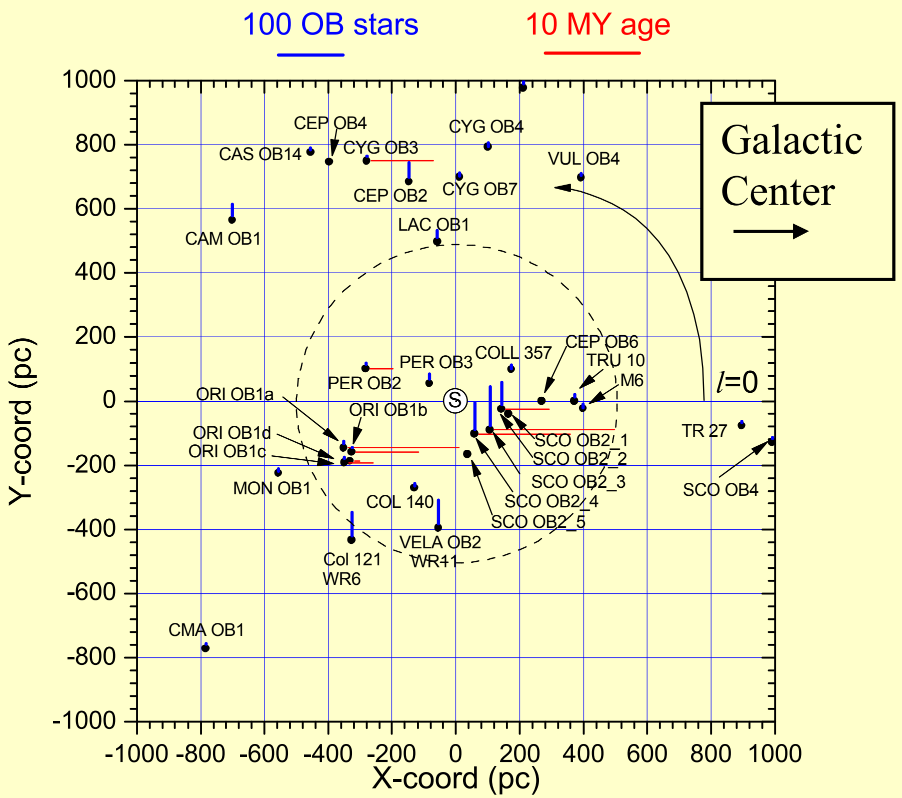
- The end of the electron spectrum where electrons are coming only from the nearest sources
  - To look for structure and to identify these sources
  - If a dominant nearby source can be identified:
    - The CR diffusion coefficient can be measured.
    - This source can be studied as an example of a CR accelerator.
- A signature of the nature of dark matter
- Composition changes at the highest energies (accessible to direct measurement) due to:
  - The growing dominance of more massive stars or
  - Non-standard compositions in young OB associations
- A lower bound to the B/C ratio, indicating the GCR sources are shrouded
- Evidence of GCR re-acceleration



Galactic Cosmic Rays – the Youngest Accessible Sample of Matter

A very fresh (< 10 Myr) sample should be present in galactic cosmic rays (Higdon & Lingenfelter, 2003 ApJ; Binns et al., 2005 ApJ)

- The majority of core collapse SN (80-90%) in our galaxy occur in OB associations
- SN shocks accelerate ambient material in OB association
- Mean time between SN in OB associations is ~1 Myr
- Superbubbles are enriched in freshly-synthesized, rapid neutron capture (r-process) material from SN ejecta (Higdon and Lingenfelter, 2003)



Vertical blue& red bars represent the number of OB stars in the association and the association age (in MY) respectively. l (

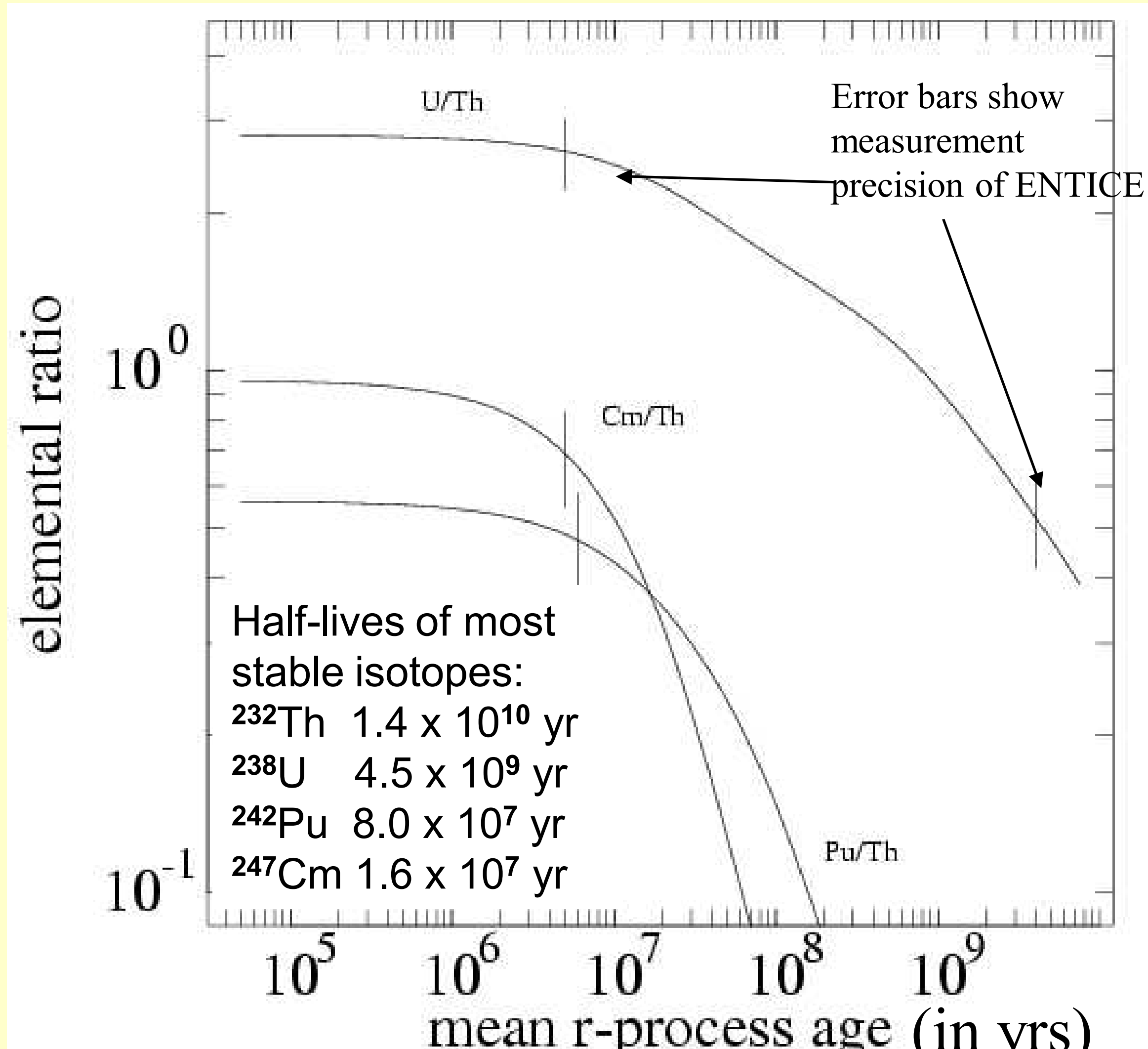
N44 Superbubble

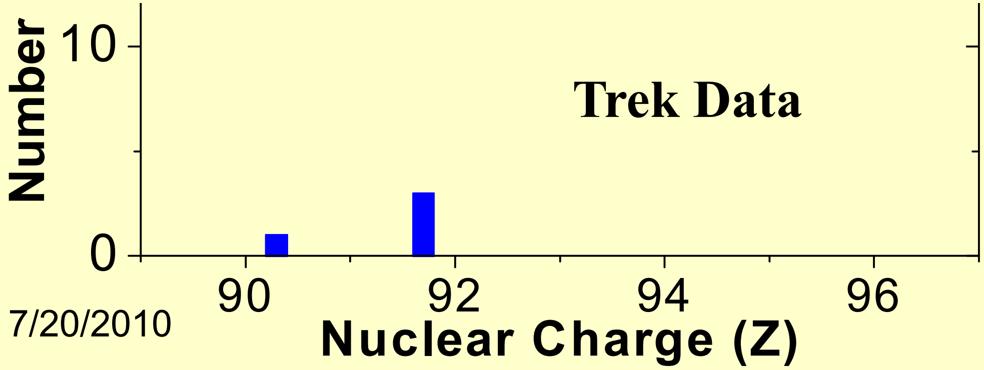
Credit: Gemini Observatory/AURA

What is the Signature of a Fresh Sample?

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

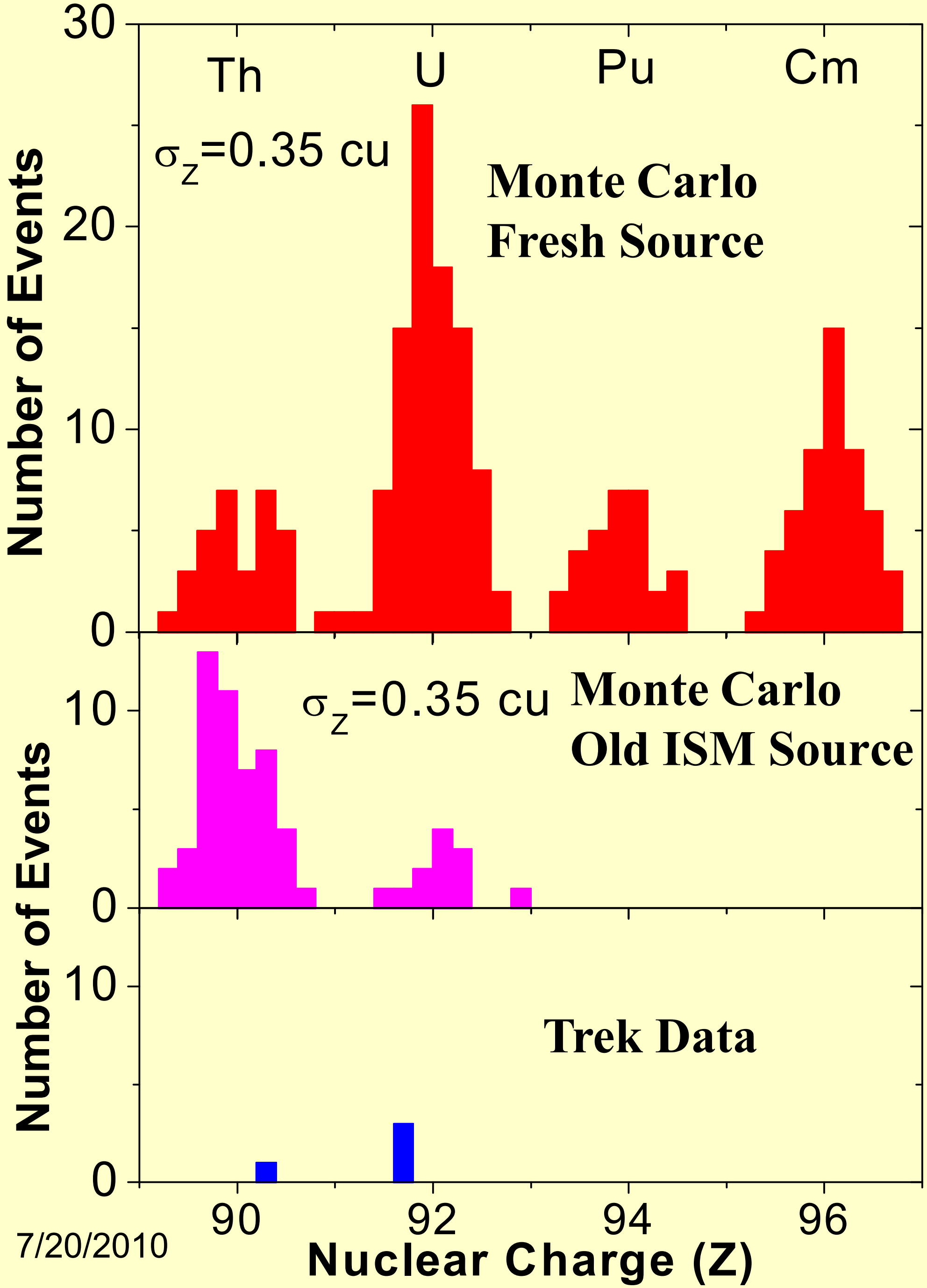
- Pu and Cm are “smoking guns” for fresh nucleosynthesis
- ENTICE is sensitive to as little as a 2% admixture of fresh r-process material (in old interstellar material) at the 3σ level.





To date, only four actinide events have been observed with resolved charges.

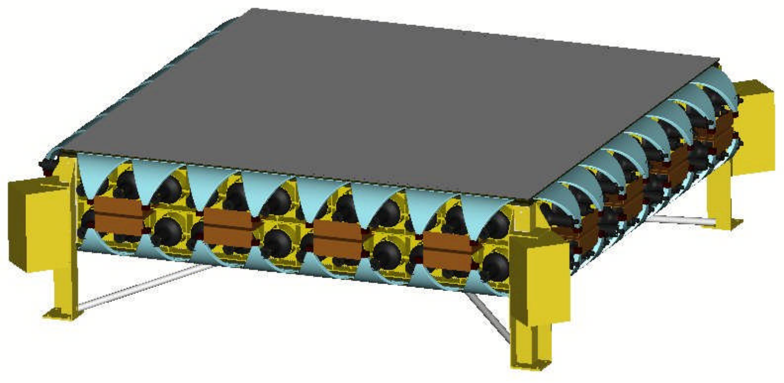
Westphal, et al., *Nature* **396**, 50 (1998)



What could be seen with two years of a large detector in orbit.

To date, only four actinide events have been observed with resolved charges.

Westphal, et al., *Nature* **396**, 50 (1998)



ENTICE Instrument

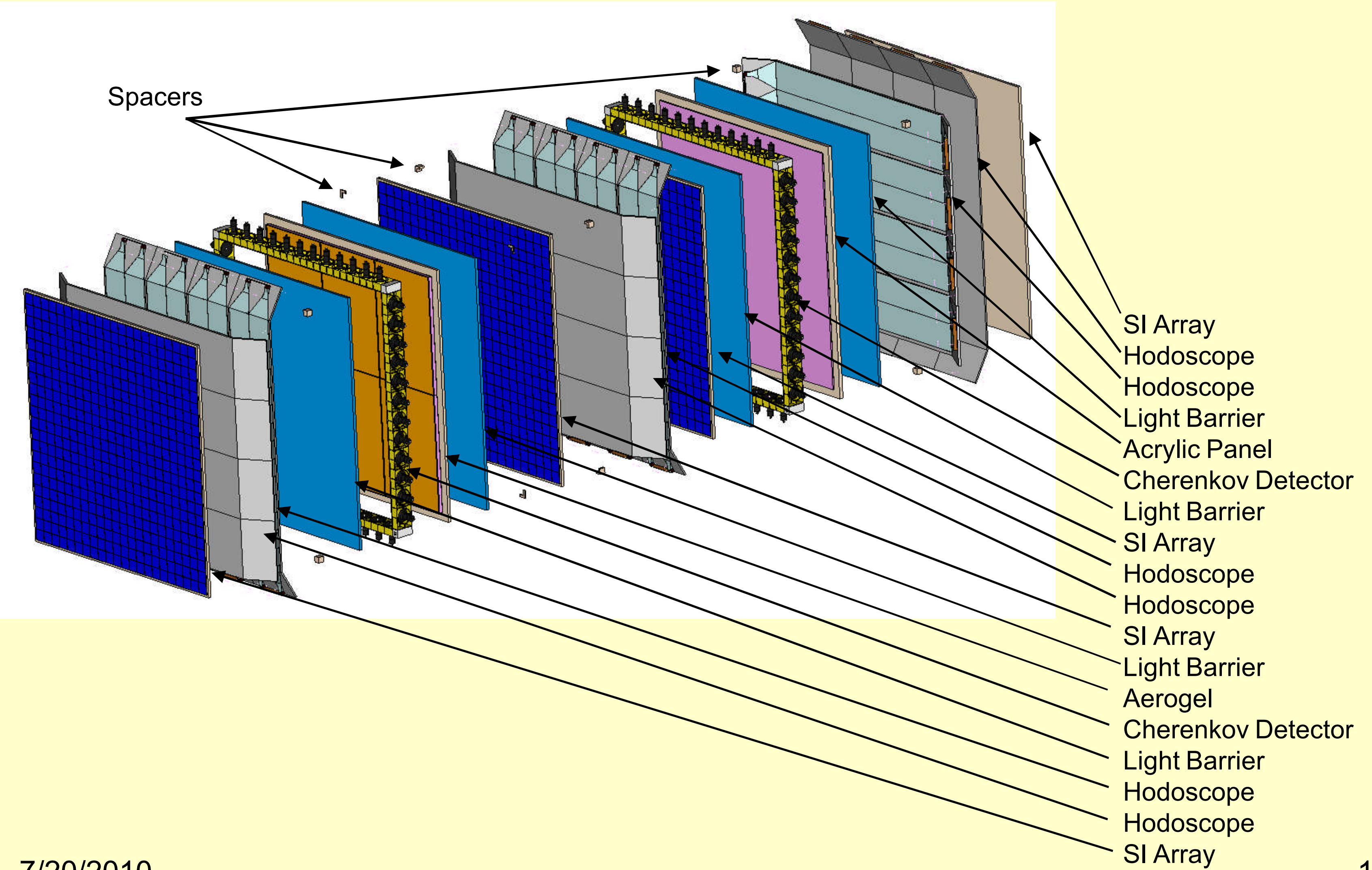
Heritage: HNX Phase A Study and TIGER balloon flights

- **Four identical ENTICE modules**
- **Detector vol. 2m x 2m x 50cm x 4 modules**

  Mass: 2000kg   Power: 310W Bit rate: 40kbps

- **Three kinds of detectors, each with extensive flight heritage.**
  - **800 silicon detectors/module-dE/dx**
    - **Two layers, one top and one bottom**
  - **2 Cherenkov detectors, each 2 m x 2 m**
    - **Each viewed by 48 five-inch photomultipliers**
    - **acrylic rad., n = 1.5; aerogel rad., n=1.04**
  - **Scintillating fiber hodoscope, x,y top & bottom**
    - **0.5-mm fibers, 4-mm segmentation**
    - **Coded readout, eight 16-anode PMTs each side**

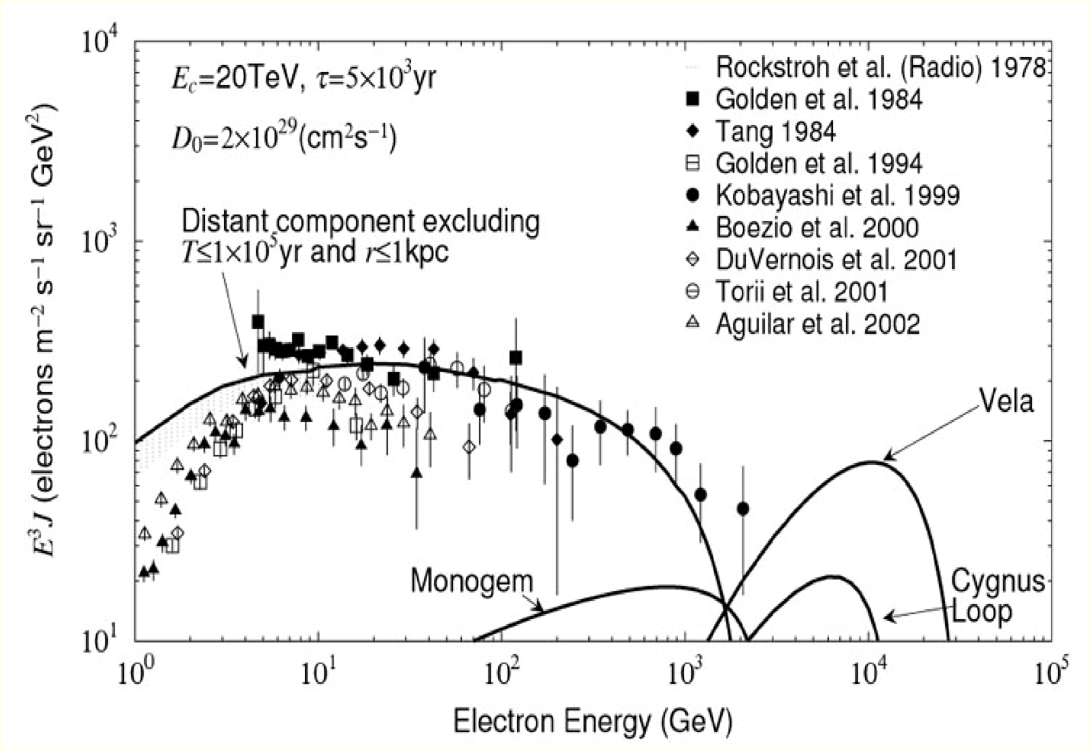
ENTICE Exploded View



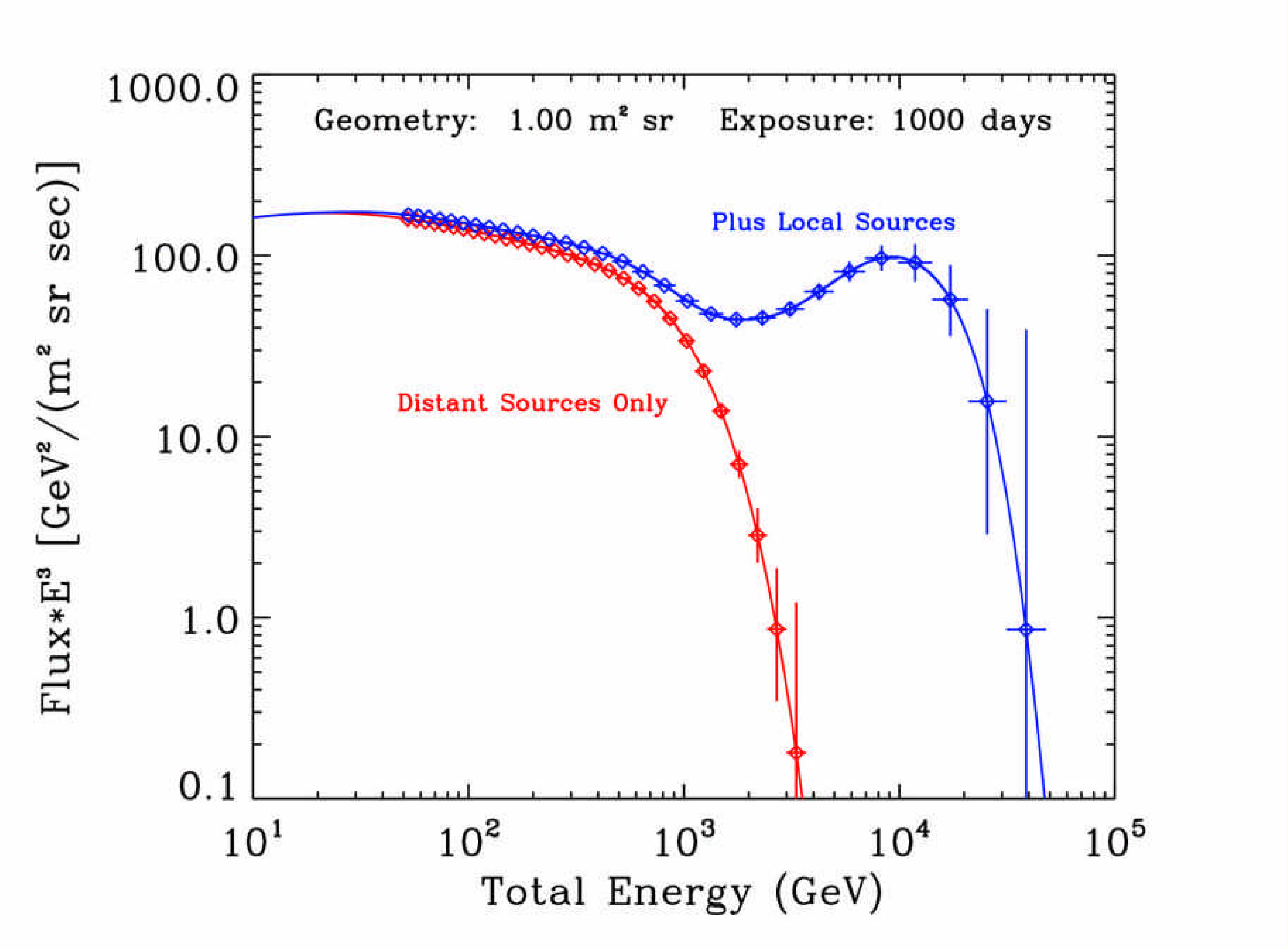
HEPCaT will tell us about local GCR sources

- High energy electrons have a high energy loss rate $\propto E^2$
  - Lifetime of ~10^5 years for >1 TeV electrons
- Transport of GCR through interstellar space is a diffusive process
  - <u>Implies that source of high energy electrons are < 1 kpc away</u>

- Electrons **<u>are</u> accelerated in SNR** (as seen in γ-rays)
- Only a handful of SNR meet the lifetime & distance criteria
- Kobayashi et al (2004) calculations show structure in electron spectrum at high energy
- HEPCaT has the statistics to identify local sources.



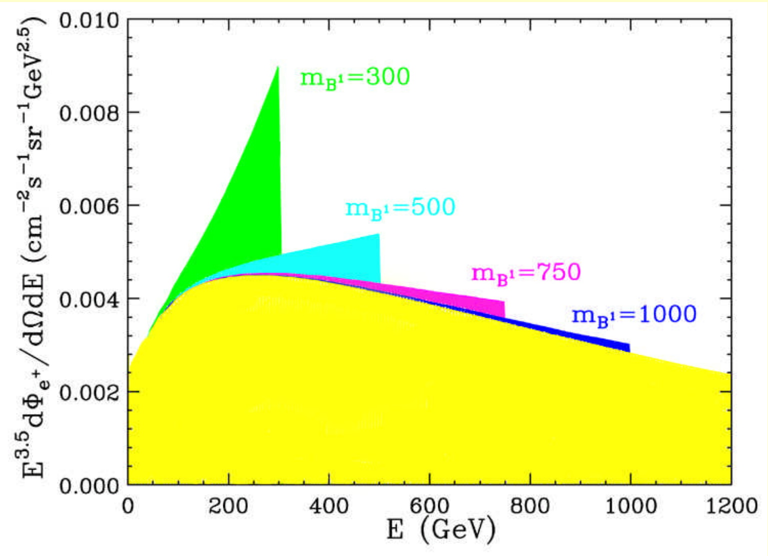
HEPCAT Source Statistics



Electrons may show "signature" of Dark Matter

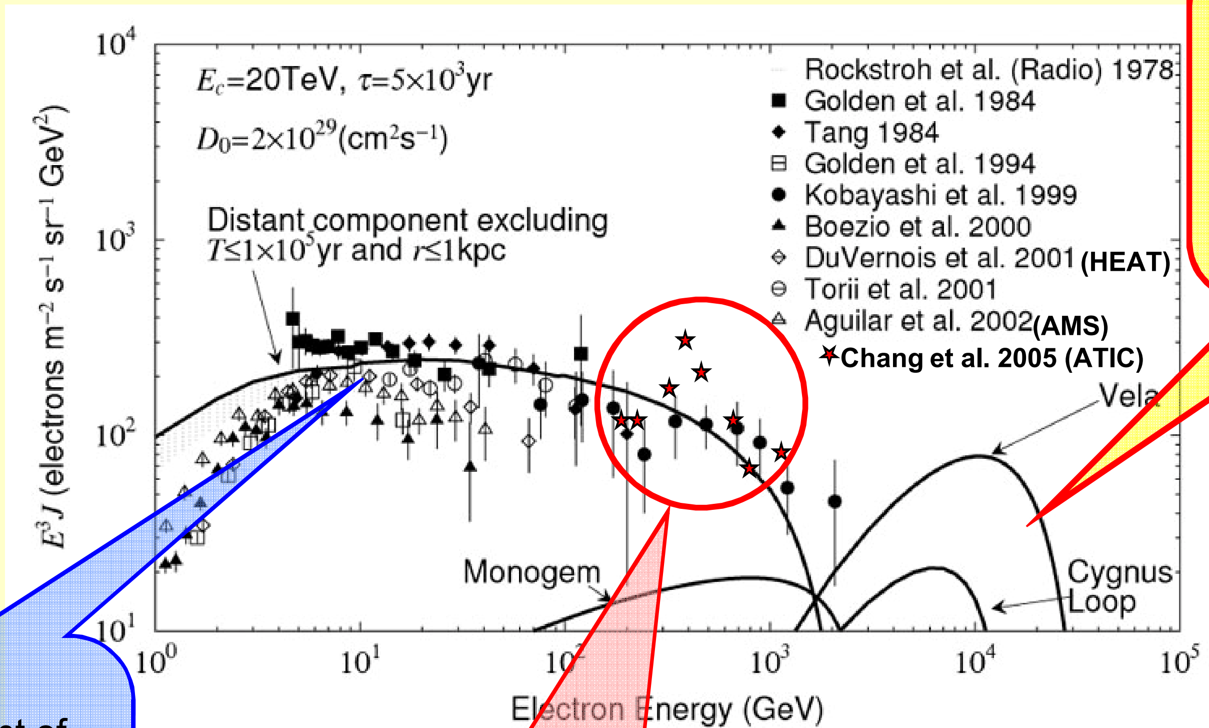
- Existence of dark matter is now widely accepted, but its exact nature remains a major mystery
- Over last several decades all known particles have been eliminated as dark matter candidates.
- Only a few exotic species such as neutralinos and Kaluza-Klein (KK) particles remain as candidates.

- Neutralinos can annihilate to produce e^+, e^- but not at a very high rate.
- Direct annihilation of KK to e , e^- is not suppressed and might produce an observable "feature" in the 150 – 800 GeV electron energy spectrum



Predicted KK annihilation positron signal by Cheng, Feng and Matchev (2002)

SUMMARY: What can be learned from HE electrons (> 10 GeV) ?



Search for the signature of nearby HE electrons sources (believed to be SNR) in the electron spectrum above ~ TeV

Search for anisotropy in HE electron flux (see e.g. Ptuskin & Ormes, 1995 : nearby sources, streaming of local magnetic fields?

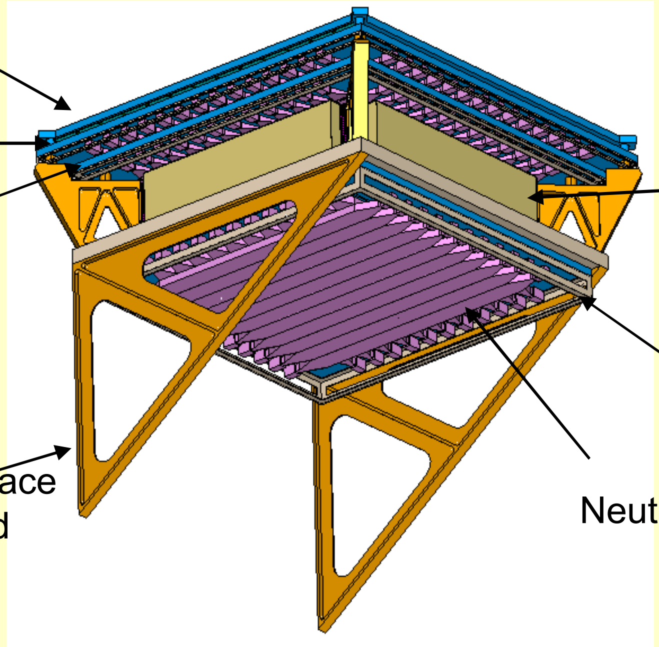
Precise measurement of electron spectrum above 10 GeV (calibration of IC gamma ray flux model, GALPROP)

Search for Dark Matter Signatures (KKDM) – above ~100 GeV (see e.g. Baltz & Hooper, 2004)

What questions can be answered with the elemental composition at high energies?

- Do cosmic ray protons come from ordinary SNe exploding into the ISM while Z>1 nuclei come from massive stars exploding into their own stellar wind (Biermann et al)?
- Is the composition dominated at high energies by acceleration in young OB associations (Bykov, 2001)?
  - These questions can be answered by measuring the P, He and Fe composition.
- Are cosmic ray sources shrouded by super-bubble shells or dense stellar winds?
- Is there evidence of re-acceleration?
  - Both these points can be investigated by measuring the B/C and other secondary to primary ratios.

HEPCaT Instrument



- **Two identical HEPCaT modules**
  - Each module 1 m^2 ster
  - 1.4 m x 1.4 m x 0.6 m each
  - Total Mass: 4600 Kg, Power 700 W, Telemetry 160 kbps
- **Charge detector**
  - Two layers of Si pixel detectors
  - Near 100% area coverage
- **Trigger**
  - Two XY planes of scintillator strips
- **Calorimeter**
  - 80 x 80 cm^2 active area per module
  - Tungsten and Si strip detectors (SSD) interleaved
  - Successive SSD layers rotated 90°
  - Total depth 40 X_0, 1.7 λI in 38 layers
  - Progressive absorber thickness:
    - 10 layers 0.2 X_0, 4 layers 0.5 X_0, 24 layers 1.5 X_0
- **Neutron Detector**
  - Borated scintillator

Summary

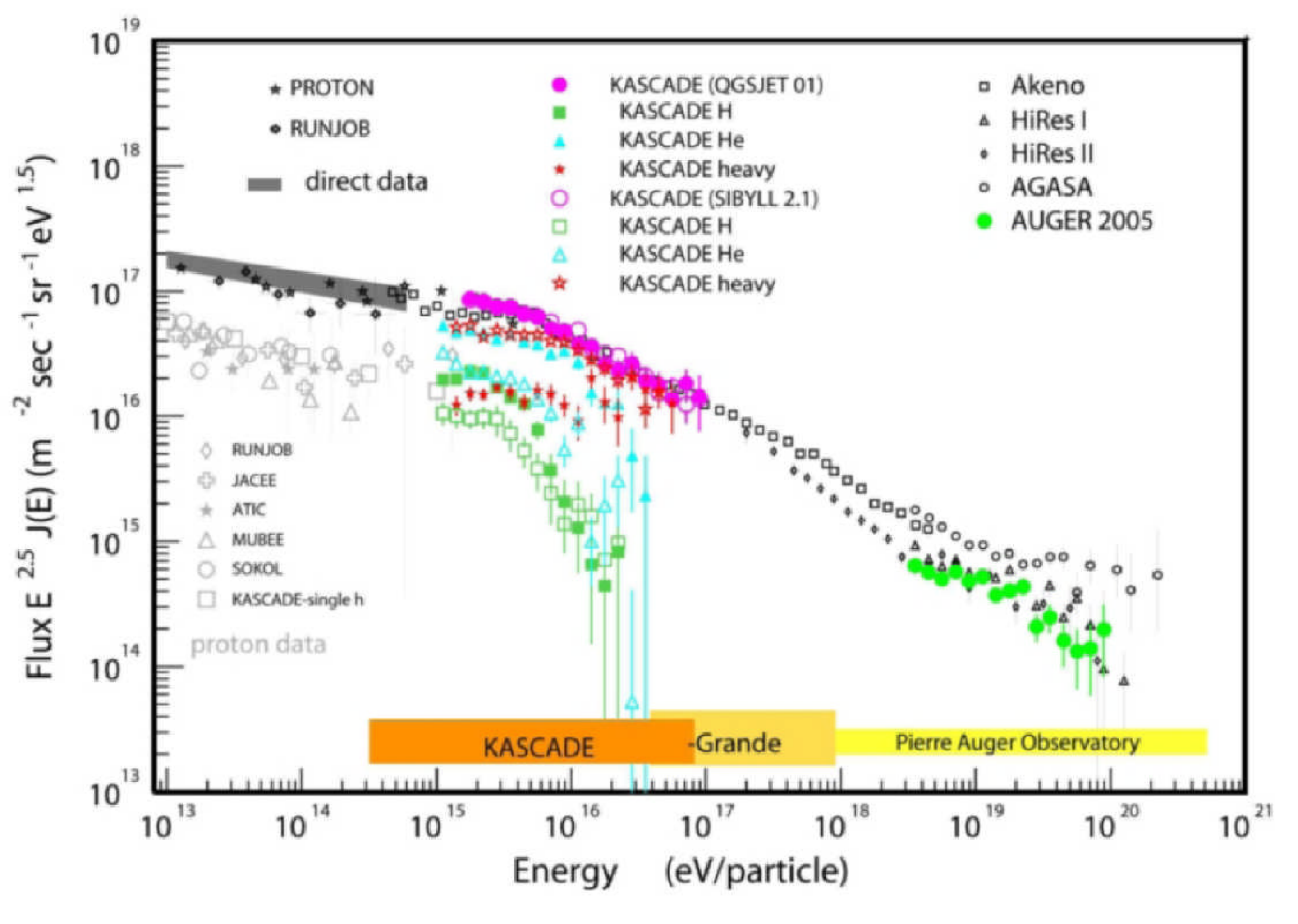
- OASIS will provide definitive answers to important scientific questions in a low risk mission
  - Do GCRs Come from OB associations?
  - Where does the GCR electron end and what will we find there?
  - What is the physical state of the GCR source material?
  - Do protons and heavier nuclei come from different sources?
- The OASIS mission has:
  - Clearly defined goals and requirements
  - Modest spacecraft engineering and mission needs
  - Instruments with balloon-flight heritage and previous Phase A and Mission Concept Studies
  - Spaceflight experience with all detector technologies.
  - Investigators with extensive experience collaborating on balloon and space flights.
  - Phase A–E cost of <$600M (including a 30% reserve)

Thank You

Why not just a large calorimeter?

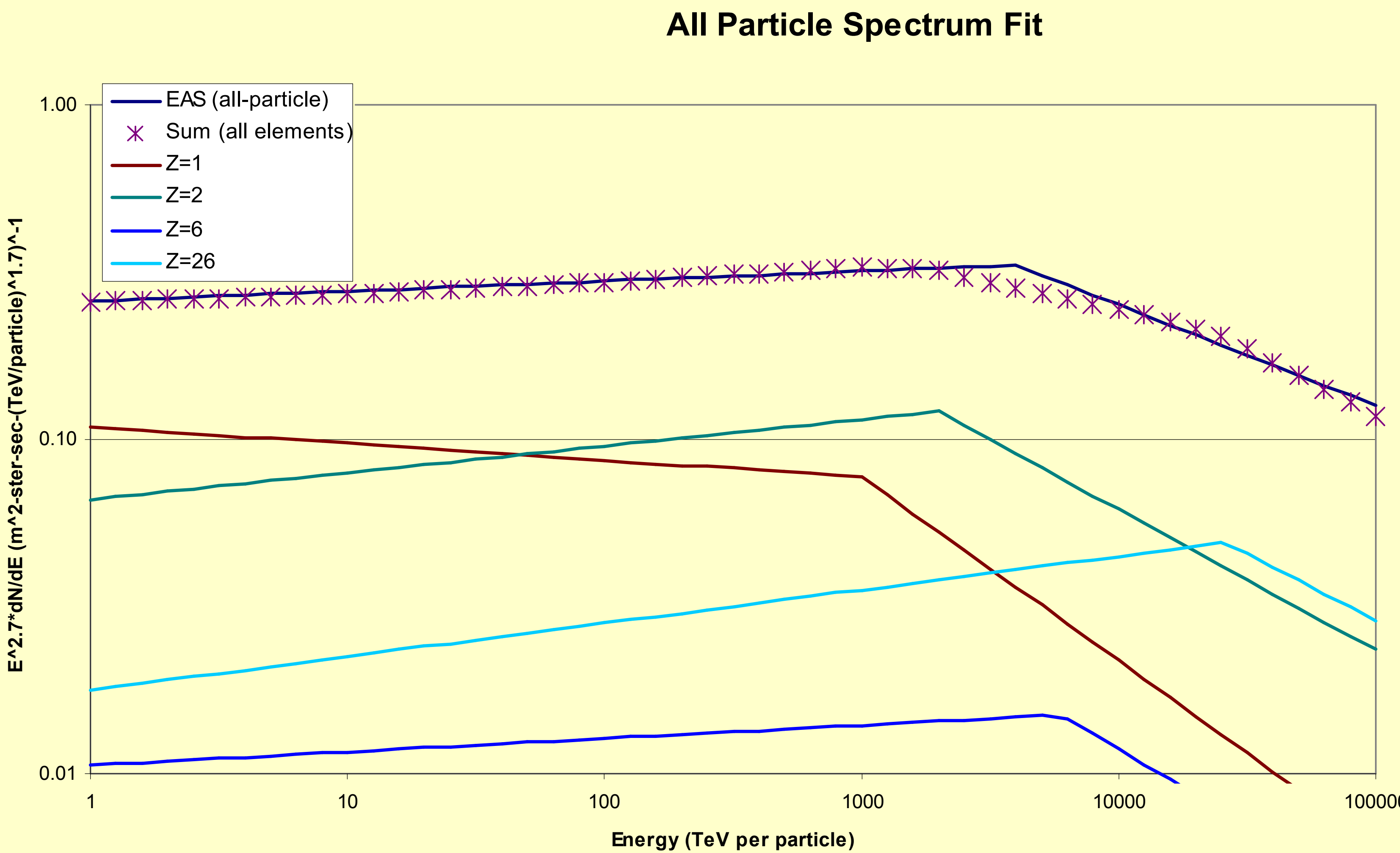
- **We chose not to propose a large calorimeter because:**
  - The largest practical calorimeter cannot detect breaks in elemental spectra that cause the ‘knee’ in the all particle spectrum
  - It is unlikely that such a calorimeter will reveal the cause for the ‘knee’

The GCR All-Particle Spectrum



F. Di Pierro et al, Nuclear Physics B (Proc. Suppl.) 165 (2007) 289–293

The proton 'knee' must be at 10^{15} eV



Calorimeter Capabilities

Question	Calorimeter Size	1m^2 (2m^2-sr)	2m^2 (4m^2-sr)	5m^2 (10 m^2-sr)
In which elements can we measure breaks?	Measure Spectral breaks	P @100 TeV	P, He @100 TeV	P, He >100 TeV
What is the composition at 10^15 (just below EAS knee)?	Composition at 10^15	P,He,Fe	10 of 28 elements	13 of 28 elements
What is the highest energy B/C can be measured?	Secondary ratio B/C	25 TeV	35 TeV	50 TeV
How high in energy can we measure for no break?	No Spectral Break	200 TeV	400 TeV	700 TeV
Can it Compete?	Concept Mission Size/Compete?	Medium/yes	Medium w/o UH/Yes	Large/No

Conditions/assumptions:

- EAS spectral change at 3-4 x10^15 eV
- Directly measure the elemental spectrum 'knees' at Zx100 TeV
- 3 year exposure
- measuring a break (assumed to be 0.3) is more than just testing the null hypothesis
- Note: B/C ratio can be measured to ~3 TeV/nucleon

What would it take to get over the Knee?

- Calorimeter Size: 6x6x0.4m^3
- Calorimeter Thickness 40 rl
- Calorimeter Weight is 97mT
- Geometry factor = 79 m^2-sr
- Mission duration is 3 years
- Launch Vehicle: Ares 5

Acceleration of CR to ~PeV Energies [source(s)]

- Supernovae explosion (SNe), a long-standing hypothesis since the 1930s, is largely based on satisfying the power requirement to sustain the GCR flux

- *SNe exploding into the ISM*: low density, weak *B*-field, acceleration and scattering in a region where the *B*-field is quasi-parallel to shock normal, self-similar (i.e., slow) expansion

- Maximum energy limit from DSA (Lagage & Cesarsky, 1983), 1014 eV, is still an order of magnitude below the 'knee'!

- Requires additional acceleration - perhaps in supernova wind bubbles associated with massive stars (Axford, 1991)

Acceleration of CR to ~PeV Energies [Mechanism(s)]

- Diffusive shock acceleration (DSA) theory is both well developed and appears consistent with data on strong shocks in supernova remnants (SNR)s, even though it falls short of the (~ $3Z \times 10^{15}$ eV) limit.
- For DSA, the two critical quantities are strength and spectral distribution of the fluctuating component of the magnetic field (δB)
- This fluctuating component is assumed to saturate at the strength level of the ambient field $B0$, i.e., $\delta B \sim B0$ (Bohm diffusion limit)
- In this limit, the particle diffusion mfp along the ambient field ≅ its gyro-radius. This leads to the conclusion that it is the ambient, mean field, $B0$, that 'controls' both the acceleration rate and the maximum attainable energy by the particles
- Because of resonant scattering requirement, acceleration beyond the 'knee'
- requires that **δB » B0** or stronger ***B*0** (Uchiyama et al., 2007)

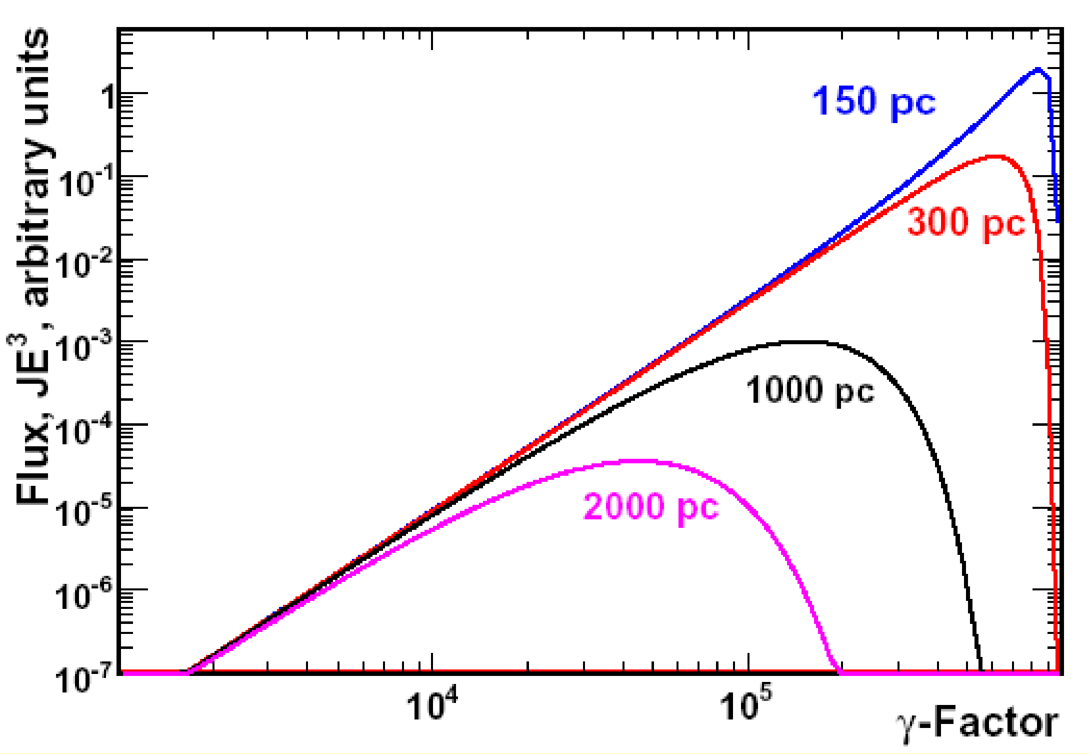
Diffusive Shock Acceleration (DSA)

- Linear DSA predicts E_{max} when the Bohm diffusion limit is reached.
  - Lagage & Cesarsky (1983) predicted E_{max} for protons = 10^{14} eV
    - Based on theoretical estimates of B_{avg} and 10 times too low
  - Uchiyama et al. (2007) measured B_{avg} and concluded E_{max} for protons = 10^{15} eV
- Jokipii (1987) has suggested that that curvature drift acceleration can contribute to GCR acceleration
- Collaborative acceleration within superbubbles (Parizot et al., 2007)
- Magnetic Field Amplification can increase the maximum energy attained by shock acceleration (Ellison, this meeting)
- Non-linear DSA may allow acceleration beyond the Bohm Limit (Malkov and Diamond, 2007 and Malkov and Dury, 2001)
- Therefore E_{max} for protons $\simeq 10^{15}$ eV is possible

Diffusive propagation of the LKP annihilation signal

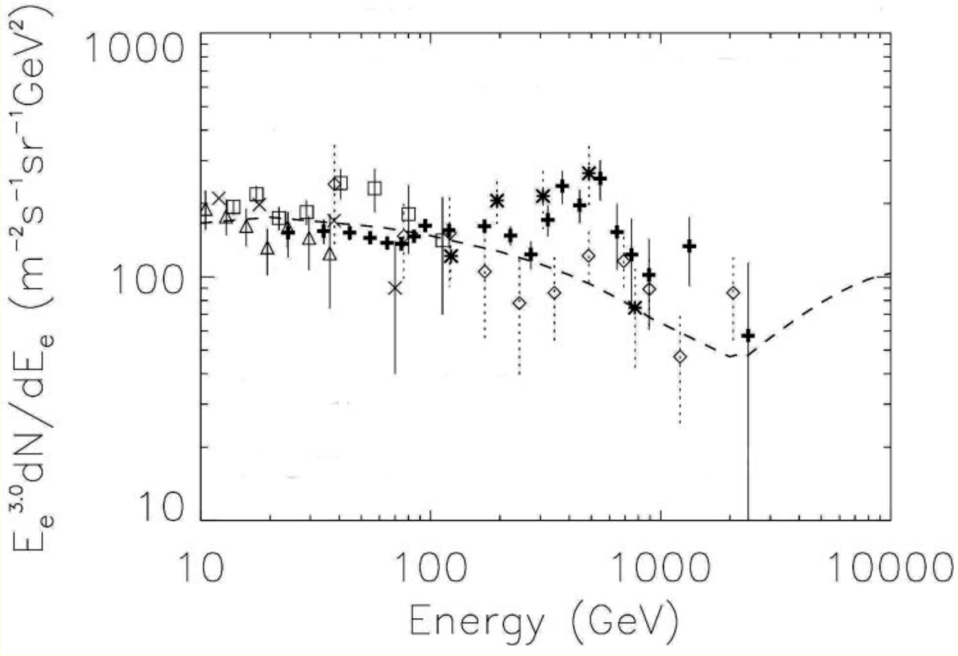
- **Direct annihilation** of the Lightest Kaluza-Klein particle **(LKP) into electron-positron pair** in the Galactic halo *(Baltz and Hooper, JCAP 7, 2007, and references therein)*
- e^- + e^+ yield is estimated to be ~20% per annihilation

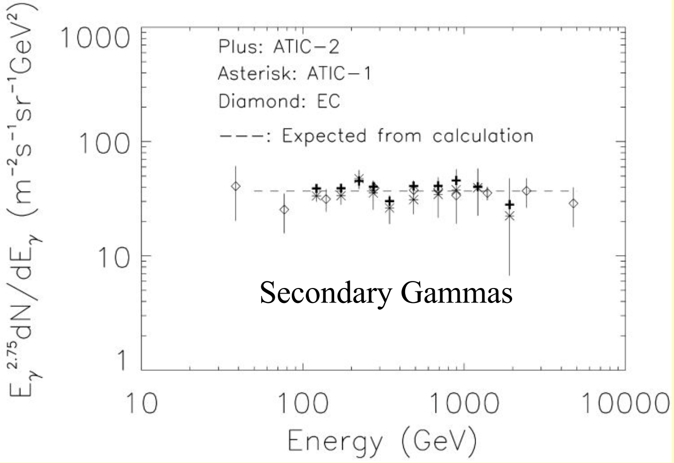
This is an illustration of how the signal from a 500 GeV LKP propagates in the Galaxy from different distances (see Moiseev et al., Frascati Science Series, 2007)



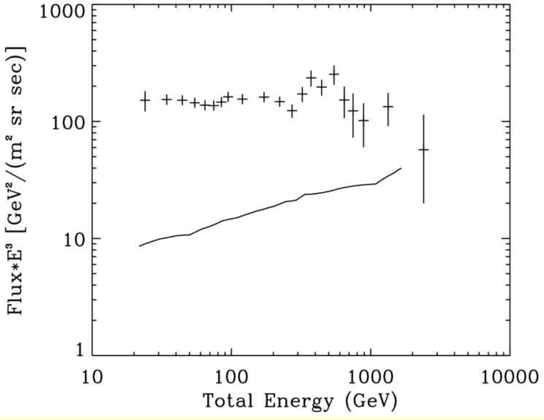
Something interesting in the ATIC & PPB-BETS data

- Possible bump at 300 – 700 GeV seen by both ATIC and PPB-BETS may be a source signature?
- <u>Long duration ATIC flight in 2007 critical to confirming this "feature"</u>

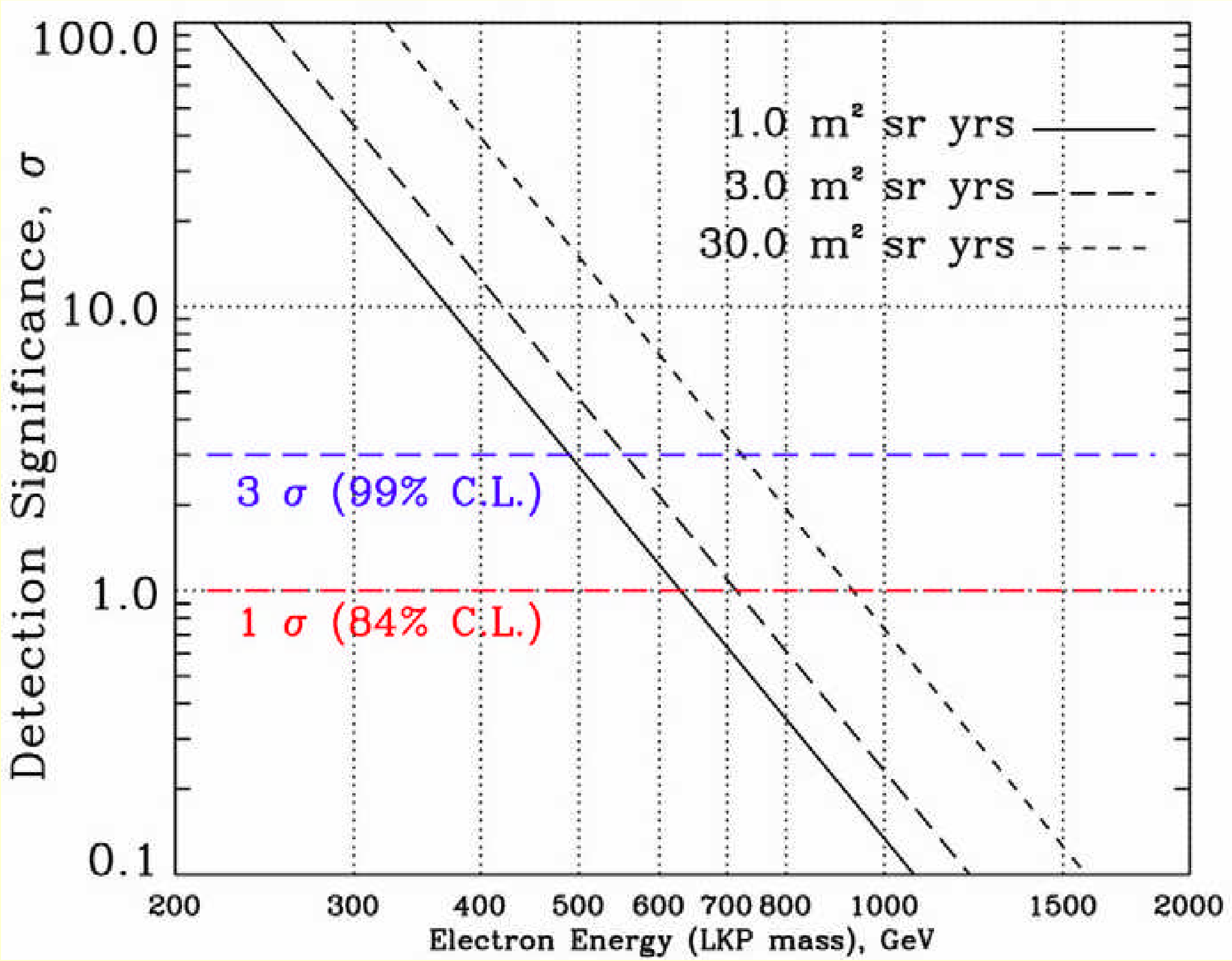




Data from: HEAT (DuVernois et al., 2001); AMS (Aguilar et al., 2002); EC (Kobayashi et al., 1999); BETS (Torii et al., 2001); ATIC (Chang et al., 2005); PPB-BETS (Torii et al., 2006);

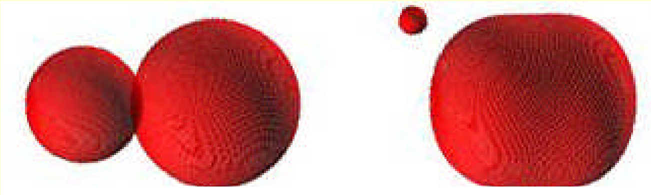


OASIS Measurement of LKP: Detection Significance



It is expected that the dominant background consists of "conventional" electrons with a contamination by hadrons (and gammas) of only a few percent.

Bonus: Are Superheavy Elements Synthesized in Nature?



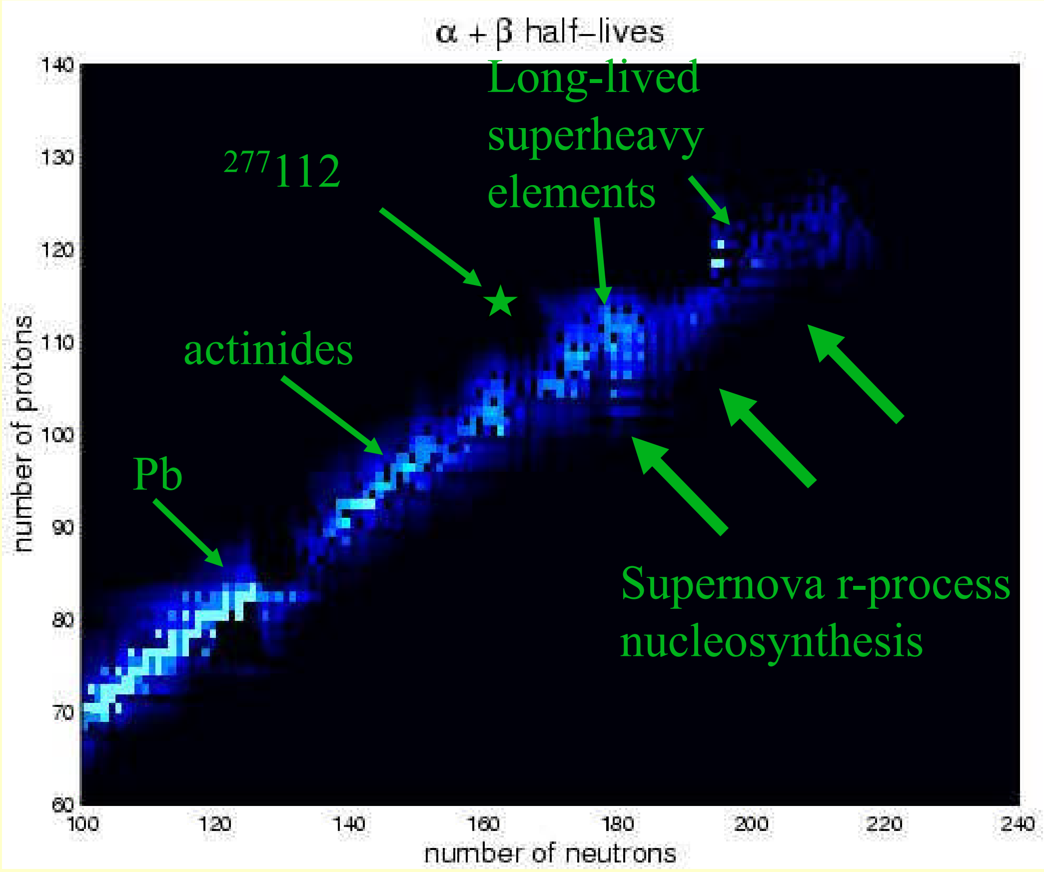
$^{70}Zn + ^{208}Pb \rightarrow ^{1}n + ^{277}112$

$t_{1/2}$ = 30 sec.

The heaviest elements made by accelerators are neutron poor and so are short lived.

But, long lived superheavy elements could be synthesized in the neutron-rich r-process environment in supernovae

ENTICE is sensitive to superheavy (Z>100) nuclei in galactic cosmic rays at the 10^{-14} level



Electrons (Negatrons and Positrons)

- Electrons are both Primary (source produced) and Secondary (produced by interactions in ISM)
- Electrons are accelerated in Supernovae Remnants (SNR)
- Electrons lose energy by Synchrotron Radiation, Compton collisions and Bremstrahlung
- Electron Energy Loss proportional to E^2

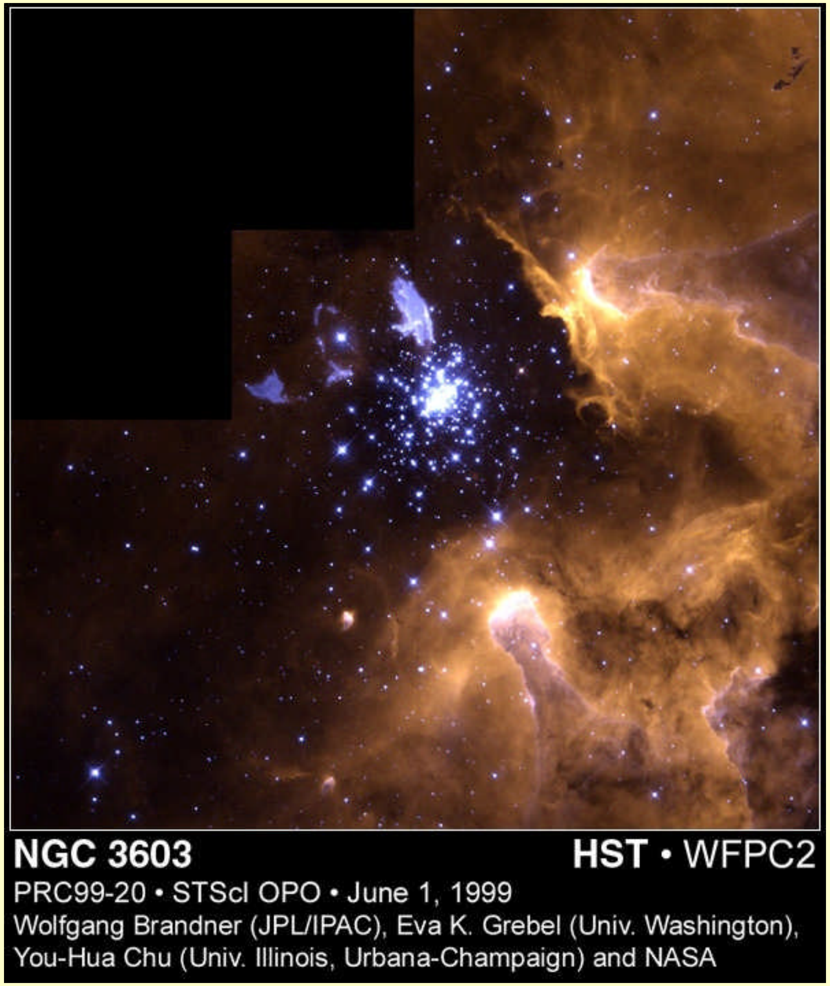
  – Thus, at very high Energy, electrons do not last a long time
    - Cannot get here from very far away (‘local source’)
    - Source (accelerator) must be relatively young

- High energy (TeV) electrons may show nearby SN source(s)

ENTICE will conclusively determine the site of GCR acceleration

By measuring the composition of a statistically significant sample of r-process material OASIS will:

- Conclusively identify the site of nucleosynthesis and acceleration of cosmic rays
- Check the ACE results that suggest an OB association origin of GCRs

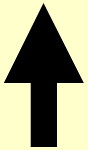


Giant galactic HII region and star forming region NGC 3603

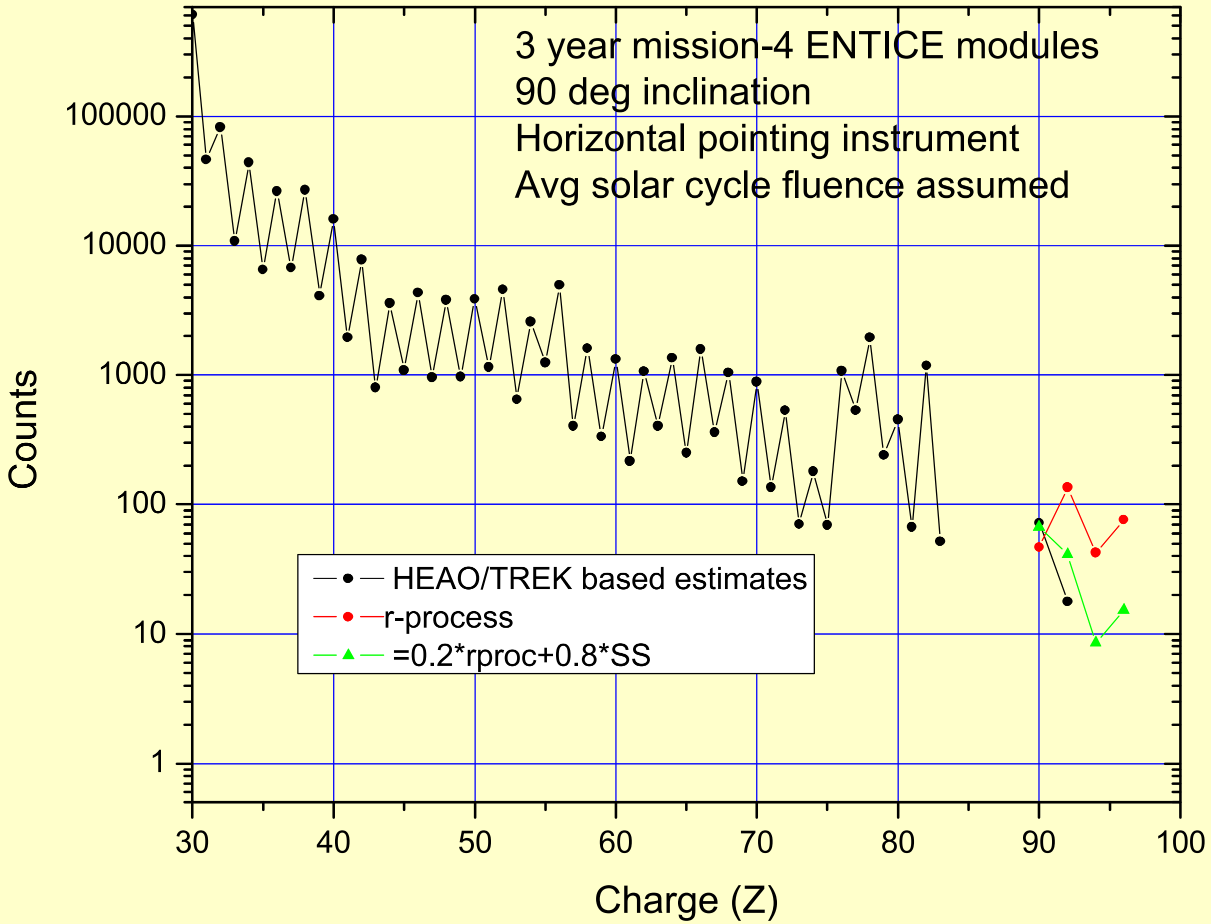
What is the Composition of a Fresh Sample?

Excess r-process material

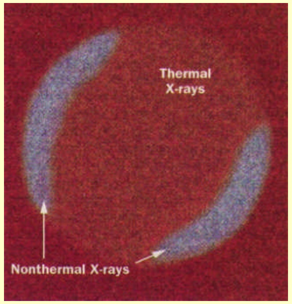
- Low-resolution HEAO data indicated a large r-process enhancement for Z > 60



Solar System material is a mixture of old s- and r-process nuclei



How Are the Most Energetic Particles in Nature Accelerated?



ASCA x-ray image of SNR 1006

Supernova shocks as accelerator of galactic cosmic ray nuclei

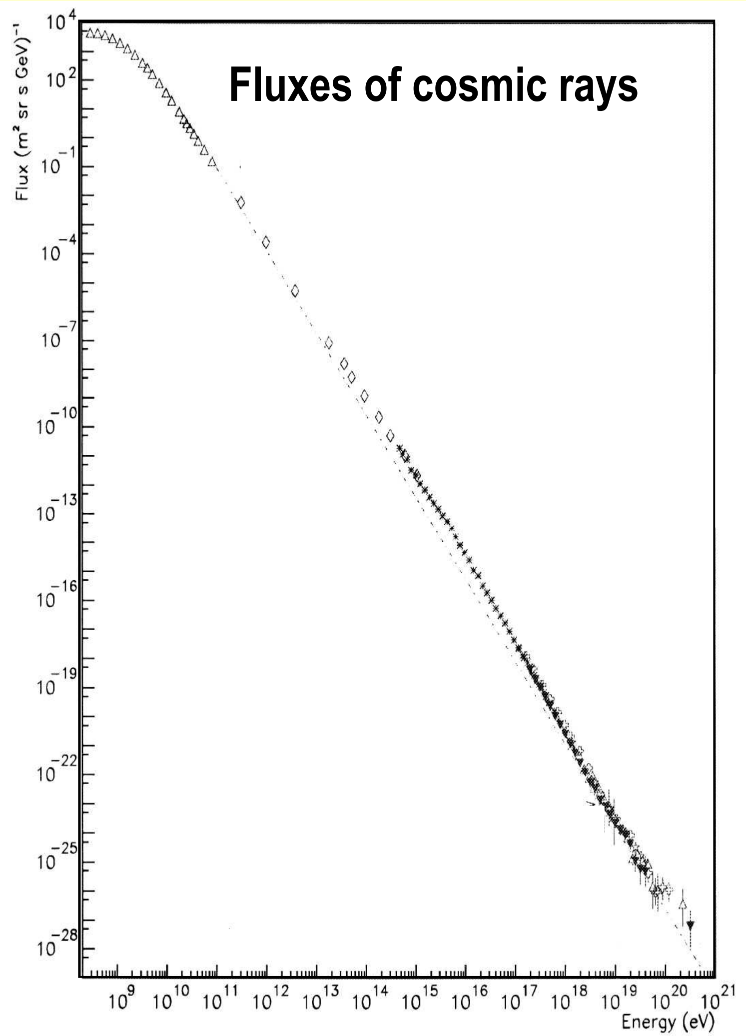
- Only known engine with sufficient power
- Acceleration mechanism understood theoretically

Isolated supernova energy limit is ~$10^{14\text{-}15}$ eV but the GCR spectrum extends continuously and almost featurelessly up to >10^{19} eV

However, recent models indicate that collaborative acceleration within OB associations could accelerate particles to >>10^{15} eV

OASIS will answer the fundamental question:

- **Is the site of galactic cosmic ray acceleration clusters of supernovae in OB associations?**
- *Absence of a fresh component could lead to an "energy crisis" for the SN acceleration hypothesis*



ENTICE Implementation – Silicon Detectors

- 2 layers, each a 20 x 20 detector array
  - All detectors 9.6 x 9.6 cm^2
  - Tested prototypes from two vendors
    - rms thickness uniformity better than 0.5%
    - Passed vacuum tests
    - No failures in 140+day test at 40°C
- Extensive heritage
  - Team experience with many designs, on ACE, SAMPEX, Galileo, ISEE-3, Voyager, IMP-7&8
  - Large-area arrays have flown in space on AMS, on balloons in ATIC and WiZard/Caprice, will soon be flown on GLAST

BNL-AGS Data
10.6 GeV/nuc Au frags.
0.20 cu resol.

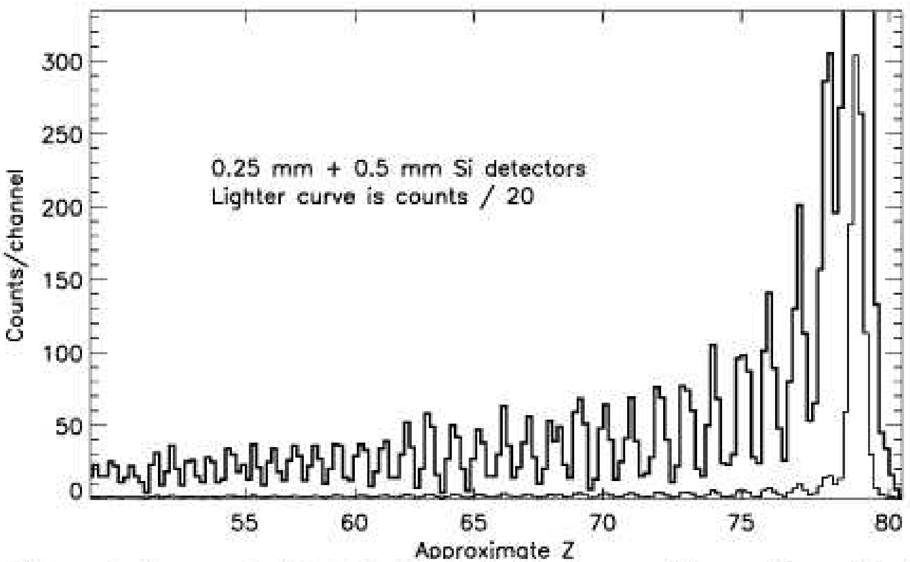


Figure 4. Fragmented 10.6GeV/n Au incident on prototype silicon detectors at the BNL-AGS. The sum of signals from a 0.25mm and 0.5mm thick detector are plotted, and is representative of the anticipated ENTICE performance.

ENTICE Implementation – Cherenkov

- Both Cherenkov detectors have identical configuration except for radiators.
- Acrylic: single sheet 1-cm thick. Aerogel: mosaic 3 cm thick
- Light-collection box with diffuse white walls
- 48 PMTs on each box. PMTs flew on HEXTE.
- Extensive heritage
  - TIGER balloon flight 1-m^2 Acrylic and Aerogel
  - HEAO C-3 Acrylic Cherenkov 1.6 m x 1.3 m
  - HEAO C-2 two Aerogel Cherenkov 0.6 m diameter
  - Prototypes in 10.6 GeV/nucleon gold beam at
  - Muon tests with prototypes demonstrate
    - ~3 pe/mip from Aerogel (1.8 pe/mip required)
    - ~16 pe/mip from Acrylic (8 pe/mip required)

BNL-AGS Data
10.6 GeV/nuc Au frags.
0.22 cu resol.

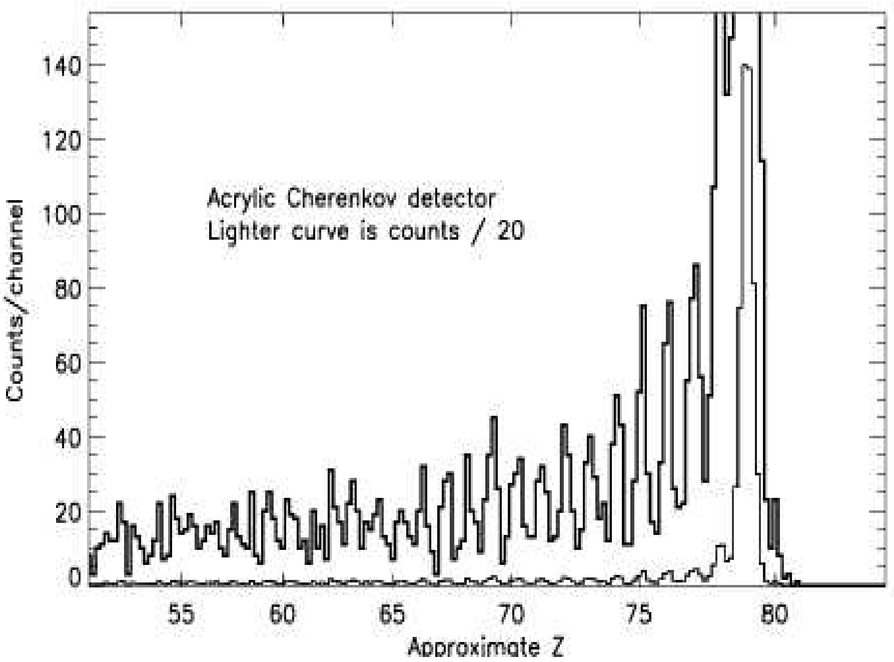
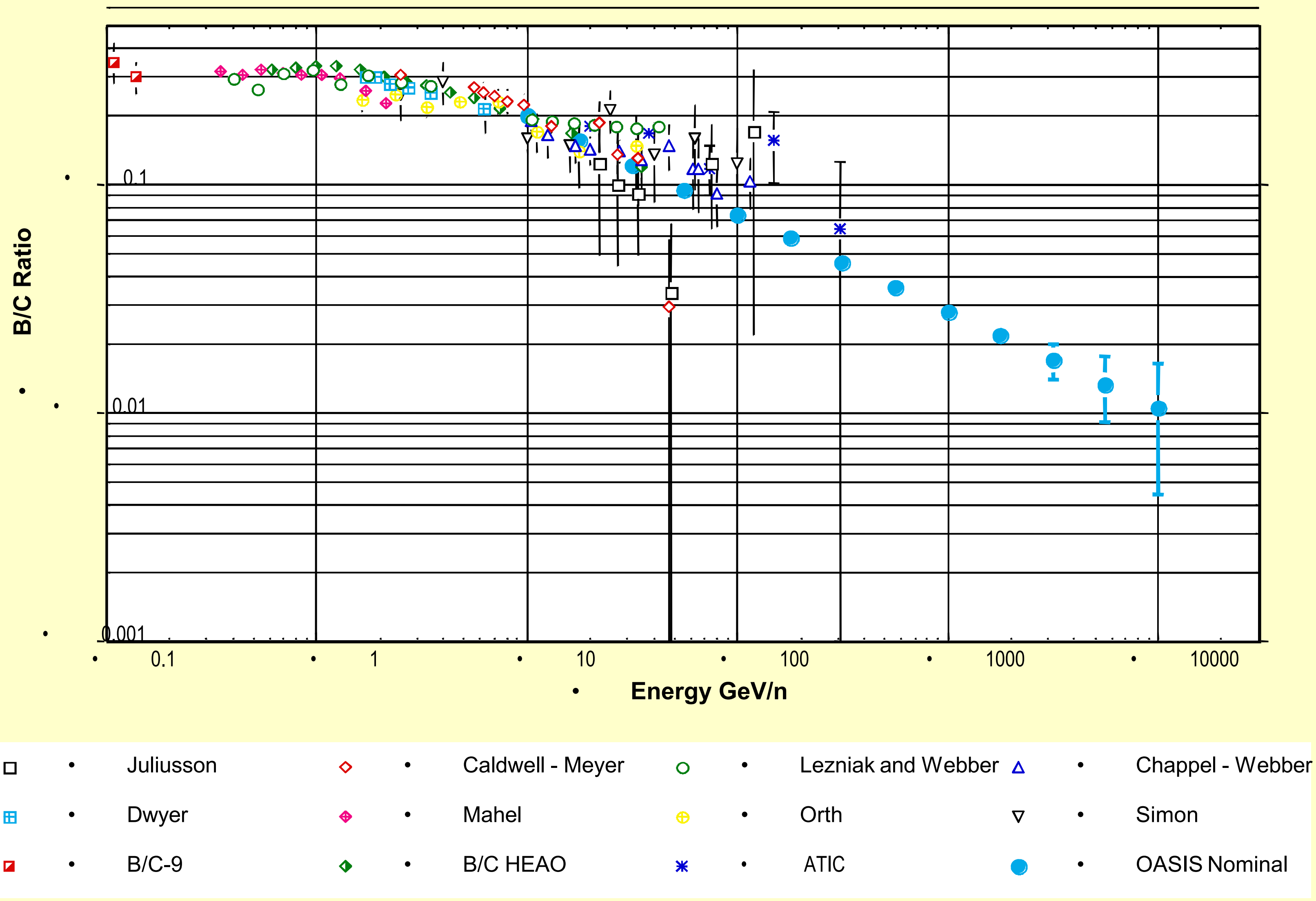


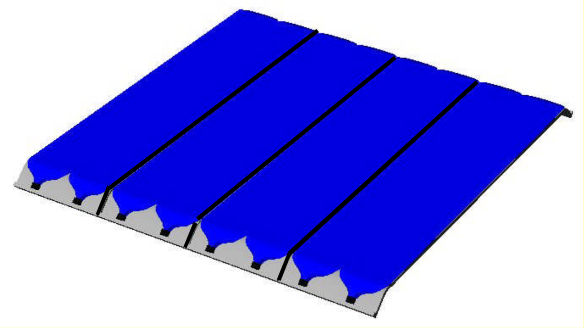
Figure 5. Fragmented 10.6GeV/n Au incident on prototype Acrylic Cherenkov counter at the BNL-AGS.

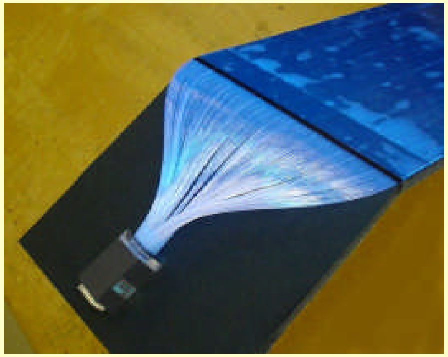
OASIS Measurement of Boron/Carbon



ENTICE Implementation -- Hodoscope

- Four layers: x y top, x y bottom
- Each layer, 4 panels 0.5m x 2m
  - 0.5-mm square scintillating optical fibers
  - bonded to 0.6-cm Aluminum honeycomb
- Multi-anode PMT read out both ends
  - R5900-016 Hamamatsu multi-anode PMTs
  - Passed vib & T/V testing for fiberGLAST
  - Single-anode version flew on AMS
- Coded readout identifies 4-mm tabs
  - Using eight 16-anode PMTs at each end.
- 1 x 1 m^2 TIGER balloon-flight prototype
  - Worked well throughout two flights totaling 50 days at float
  - Proves >99.9% detection efficiency for Fe
- ACE/CRIS 26 x 26 cm^2 fiber hodoscope
  - Working well in space for 10+ years

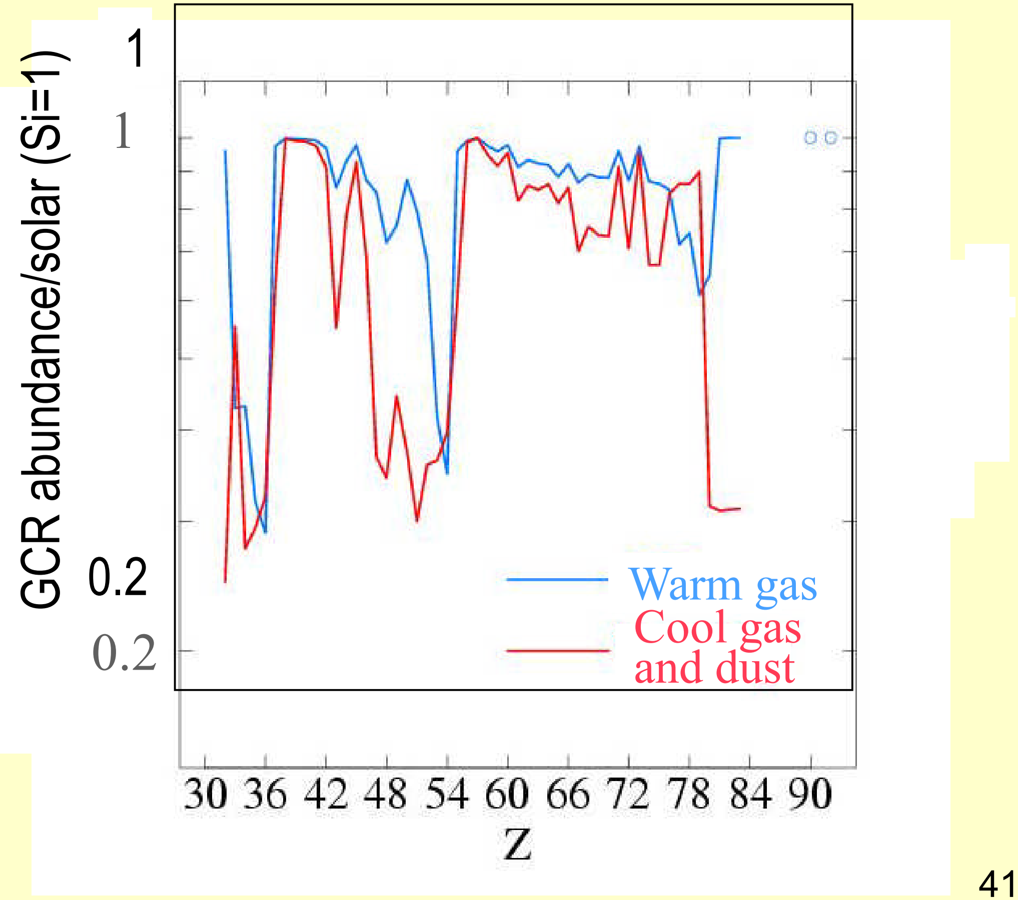


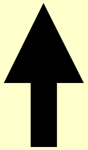


What are Cosmic Accelerators Accelerating?

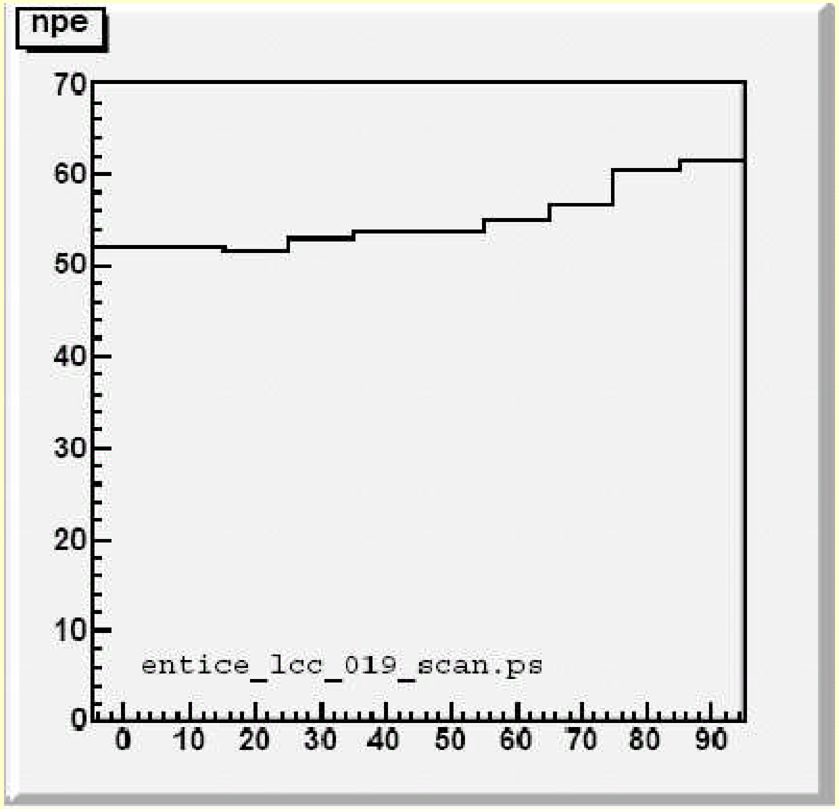
HNX will characterize the physical state (warm gas or cool dust+gas) of the injector for the GCR accelerator

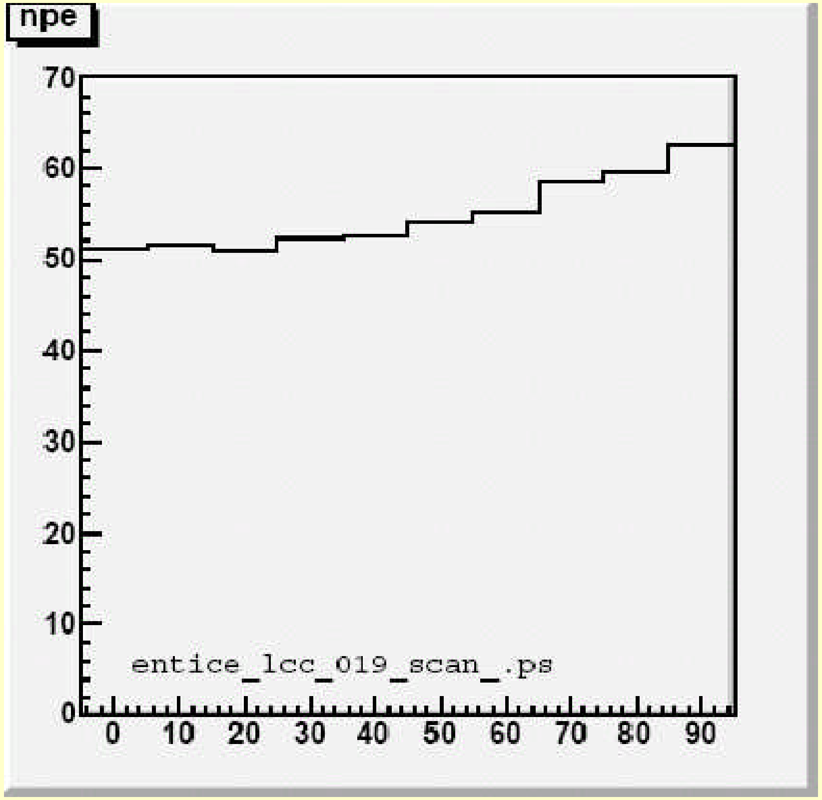
Comprehensive elemental abundance pattern is a fingerprint of GCR origin





Acrylic Cherenkov Detector Uniformity

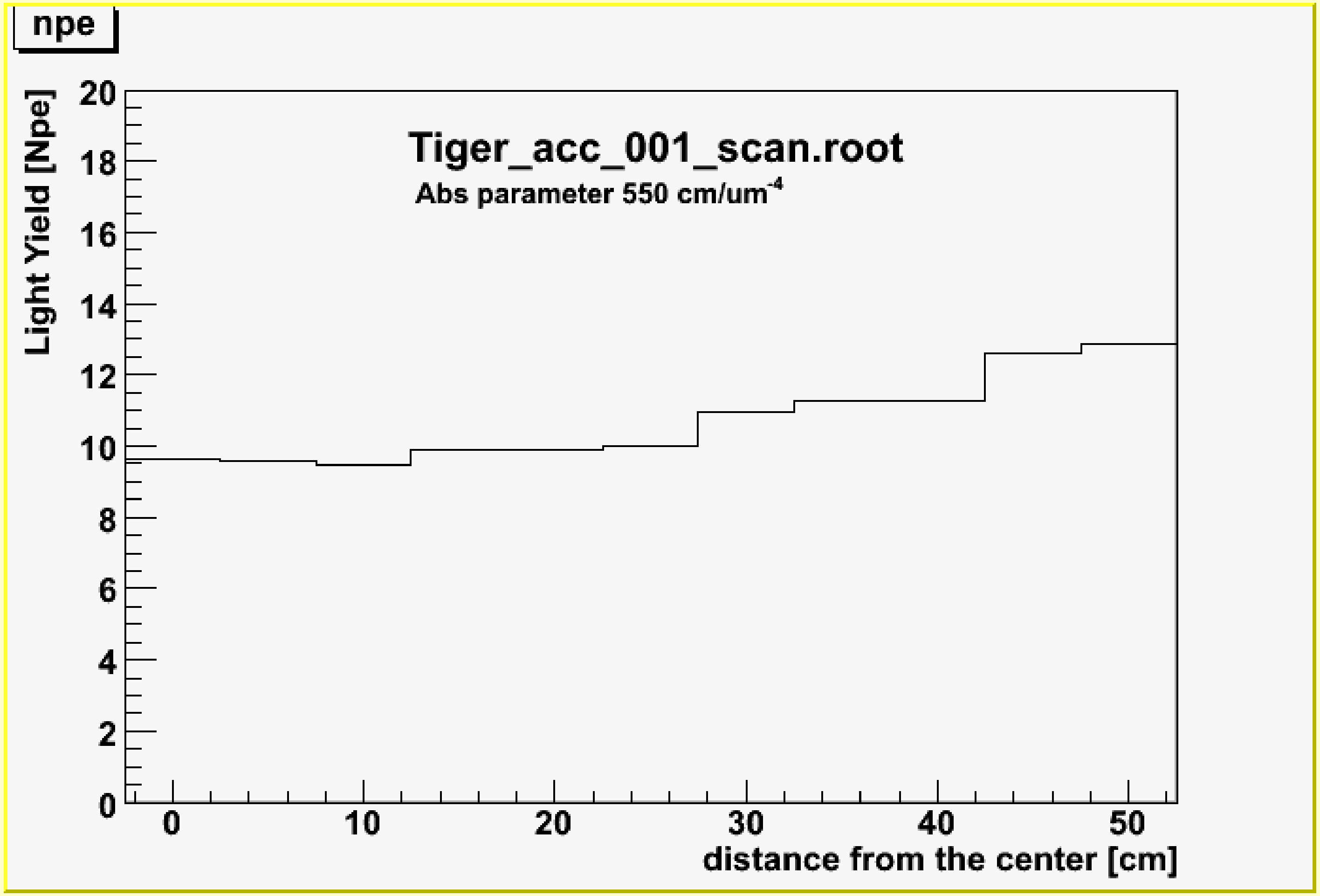


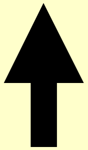


Signal versus distance from the center of the detector for downward-moving particles

Signal versus distance from the center of the detector for upward-moving particles

Aerogel Cherenkov Detector Uniformity





Signal versus distance from the center of the detector