Direct Measurements of Cosmic Rays

TeV Particle Astrophysics II - UW Madison 2006

Simon Swordy - U. Chicago (s-swordy@uchicago.edu)

Direct Measurements of Cosmic Rays this Century

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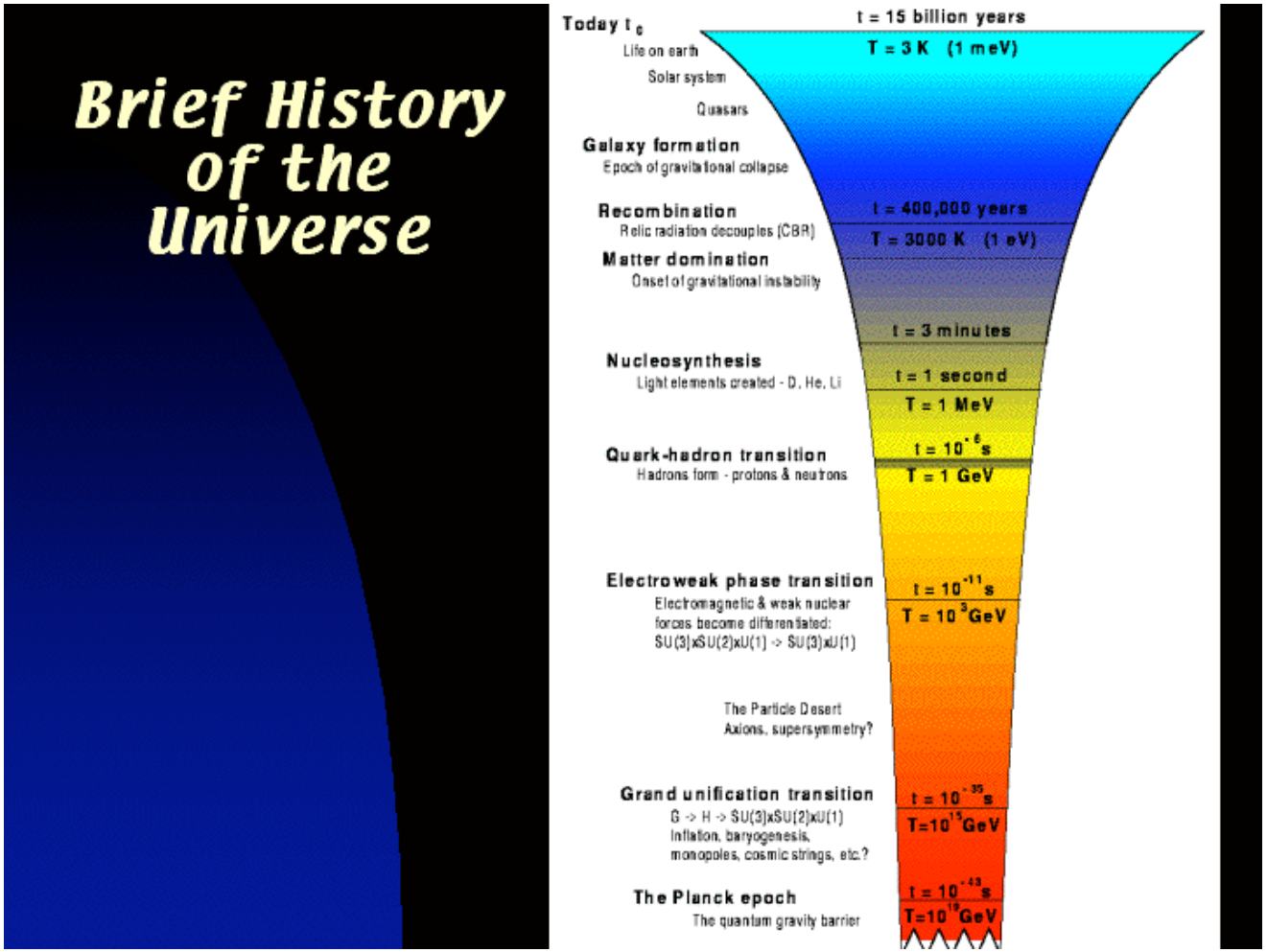
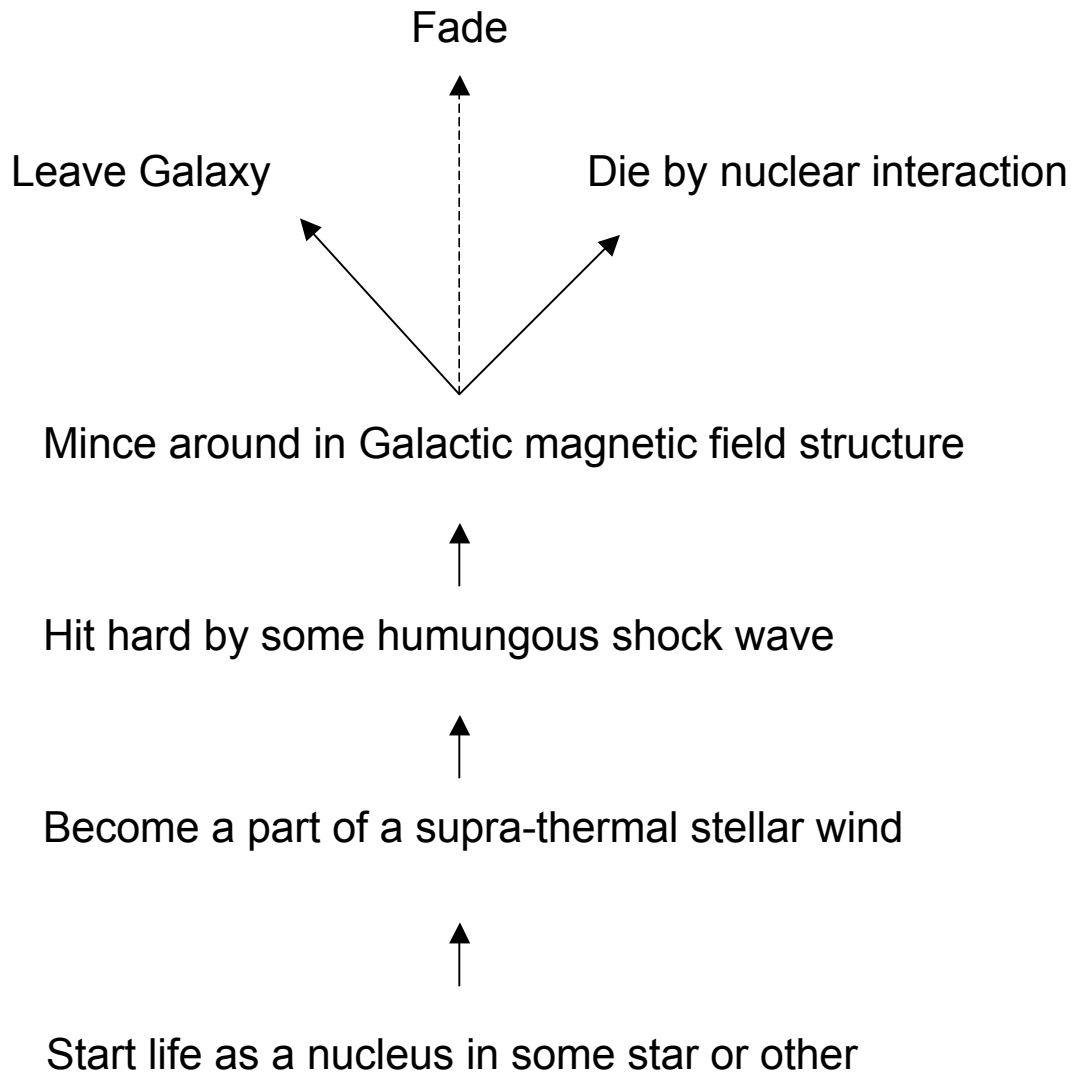
Cosmic Ray Roadmap



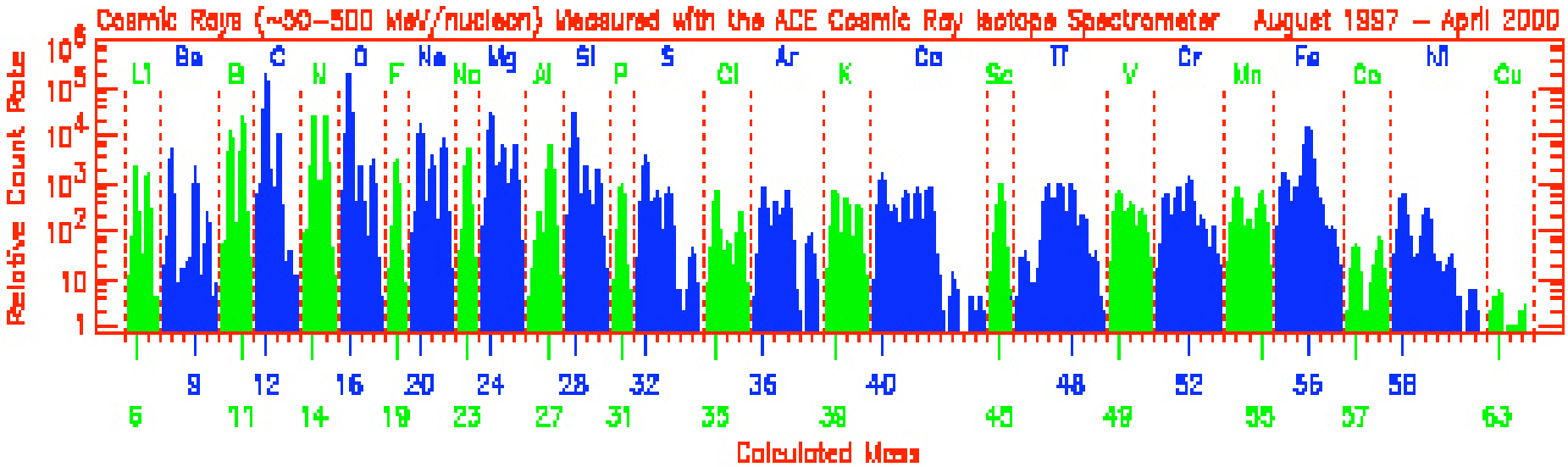
← 99.999999999%
of cosmic ray action

Even Briefer History of Cosmic Rays



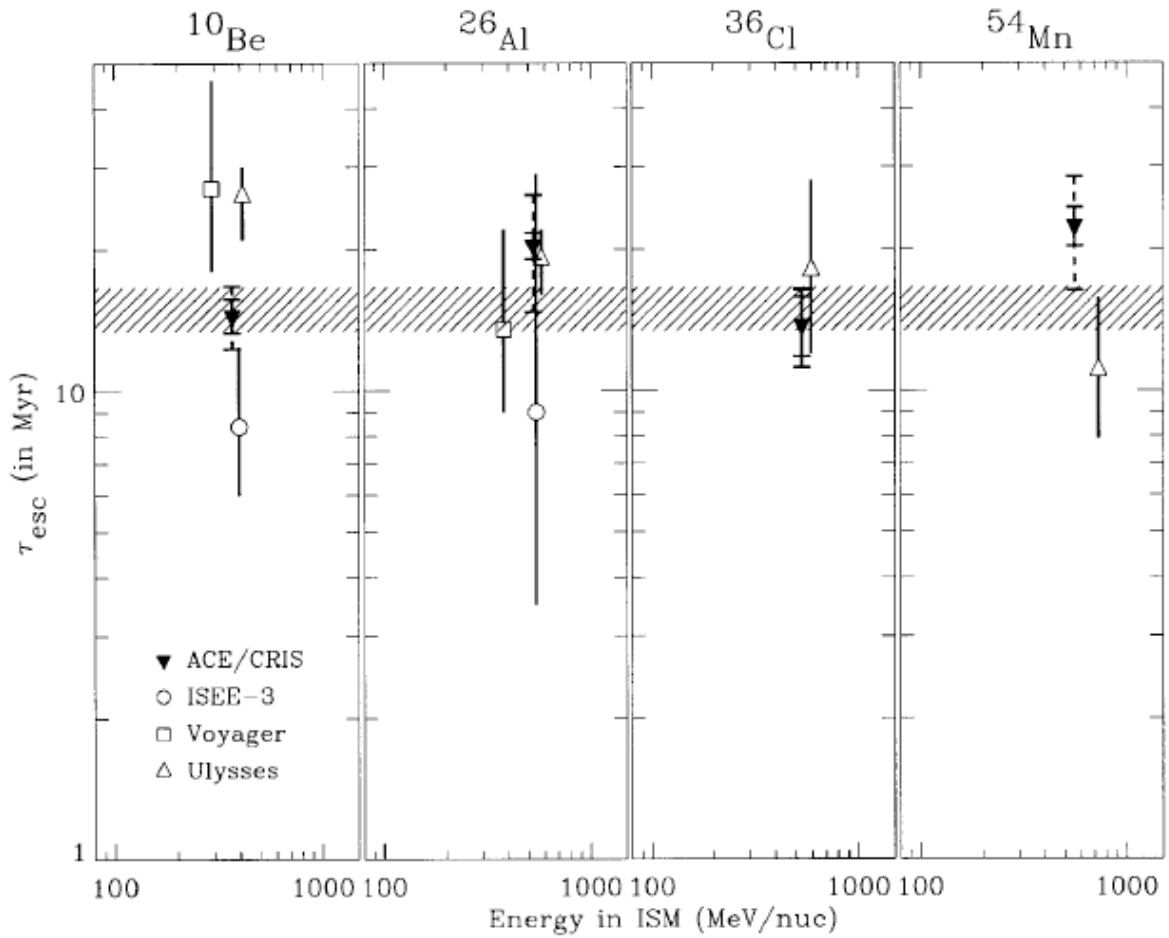
Cosmic Ray Source Material and History?

Best measurements of this come from ACE experiment - NASA/Explorer, 1997-2000
CRIS instrument silicon detectors for Z, A in the ~100MeV range.



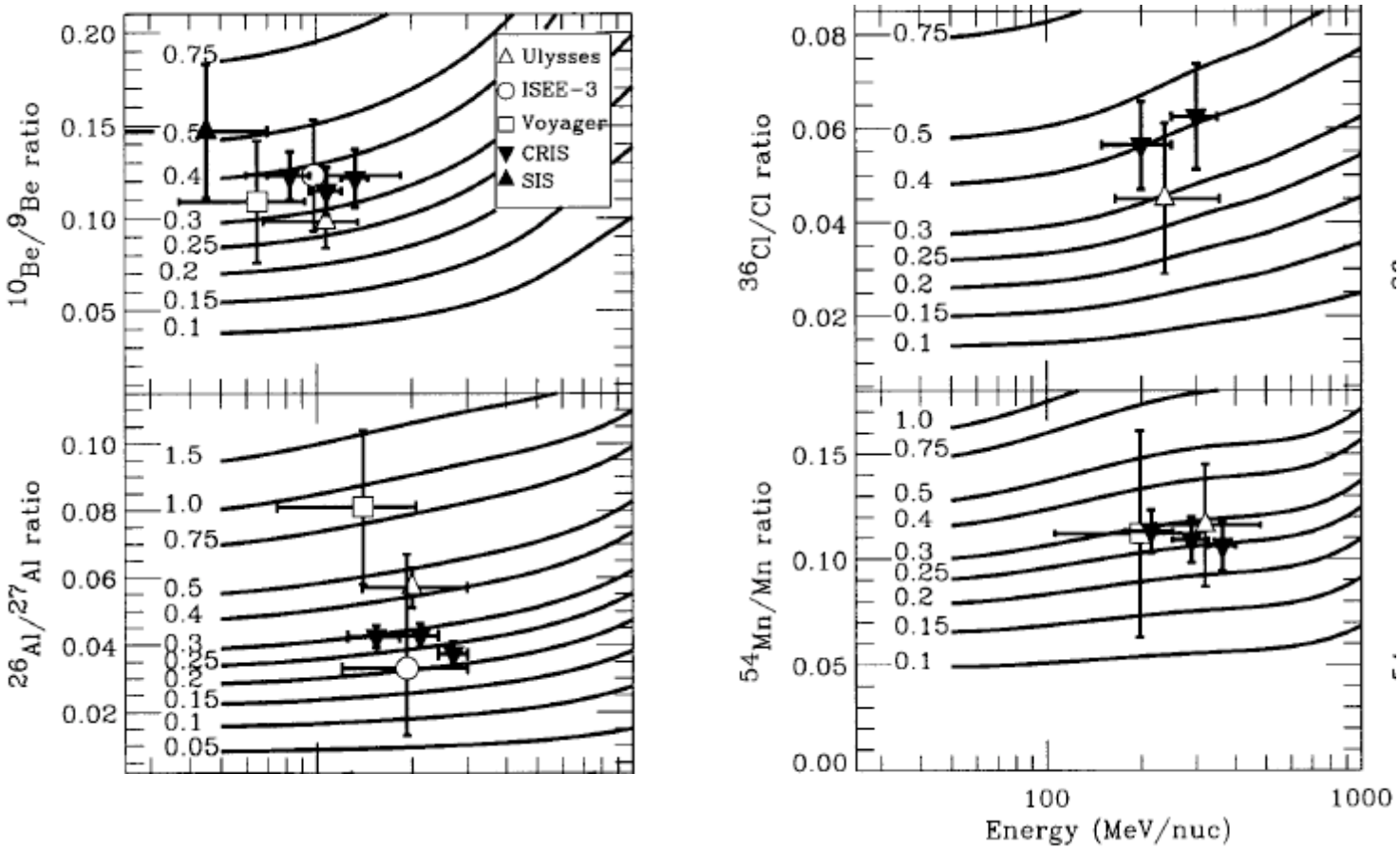
Lifetime of Cosmic Rays from ACE (15±1.6 Myr)

(Secondary radioactive nuclei with comparable half-lives)

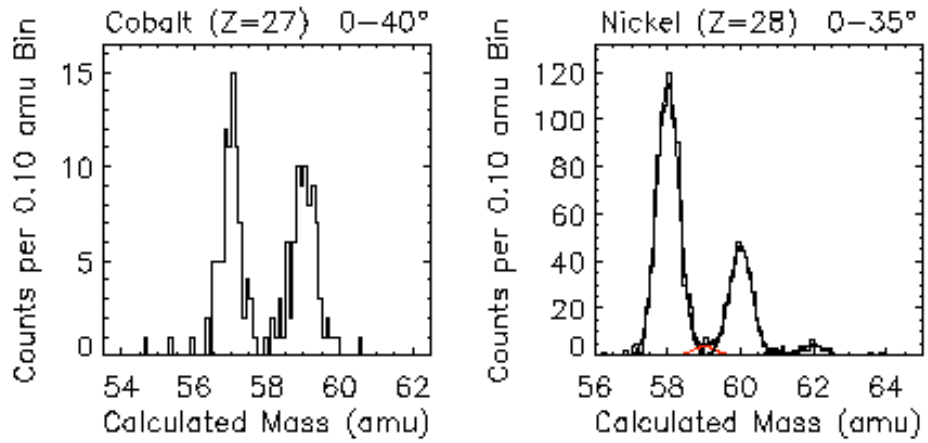


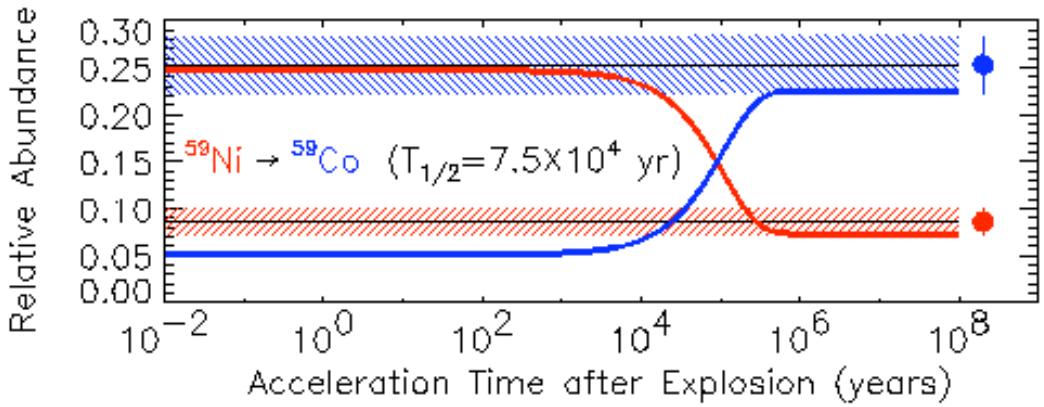
(Yanasak et al. - ApJ 2001, 768)

Also can determine mean density of propagation volume n = 0.34±0.04 atoms per cc
(Because nuclei loss occurs by both fragmentation and decay)



ACE - Time between nucleosynthesis and acceleration >10^5 years
(Absence of electron capture nucleus Ni^{59})





(Wiedenbeck et al., Ap. J. 1999, L61)

Even Briefer History of Cosmic Rays Update

Fade

Leave Galaxy

Die by nuclear interaction

~1.5 M years

Mince around in Galactic magnetic field structure

↑

Hit hard by some humungous shock wave

↑

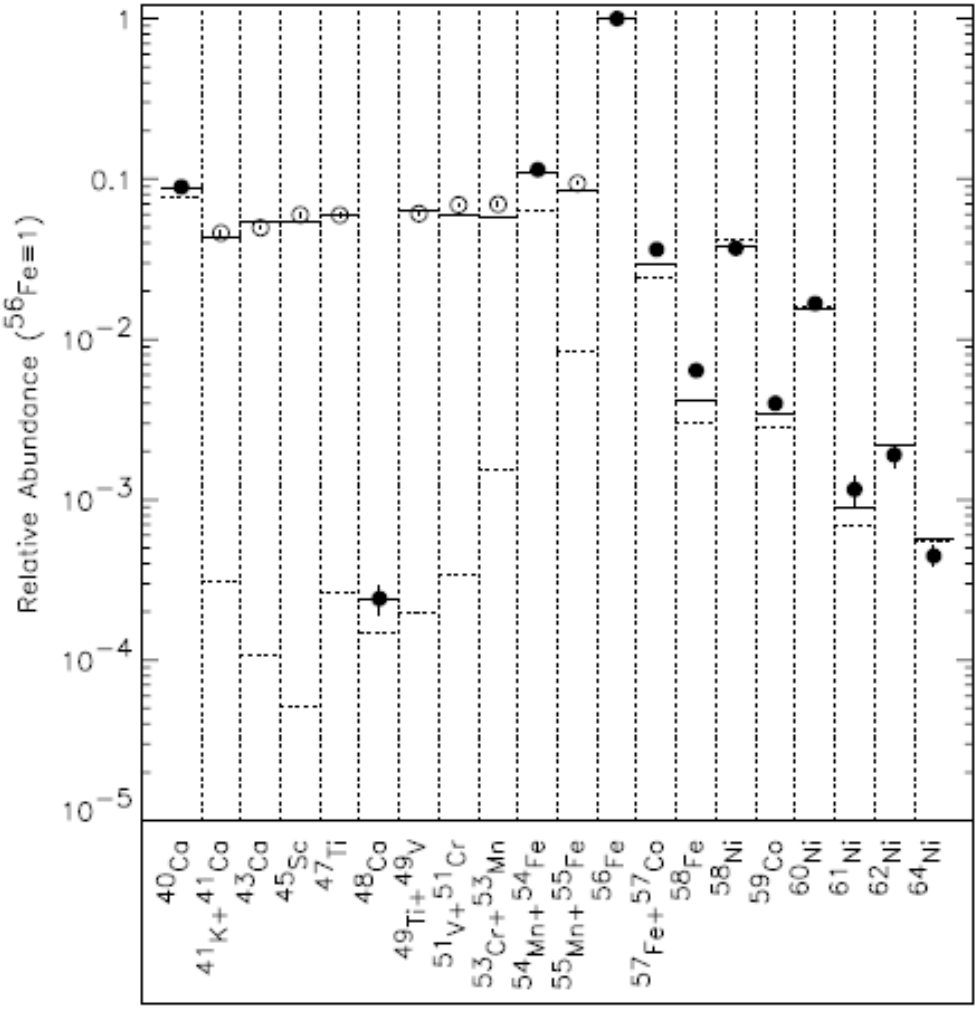
>10,000 years

Become a part of a supra-thermal stellar wind

↑

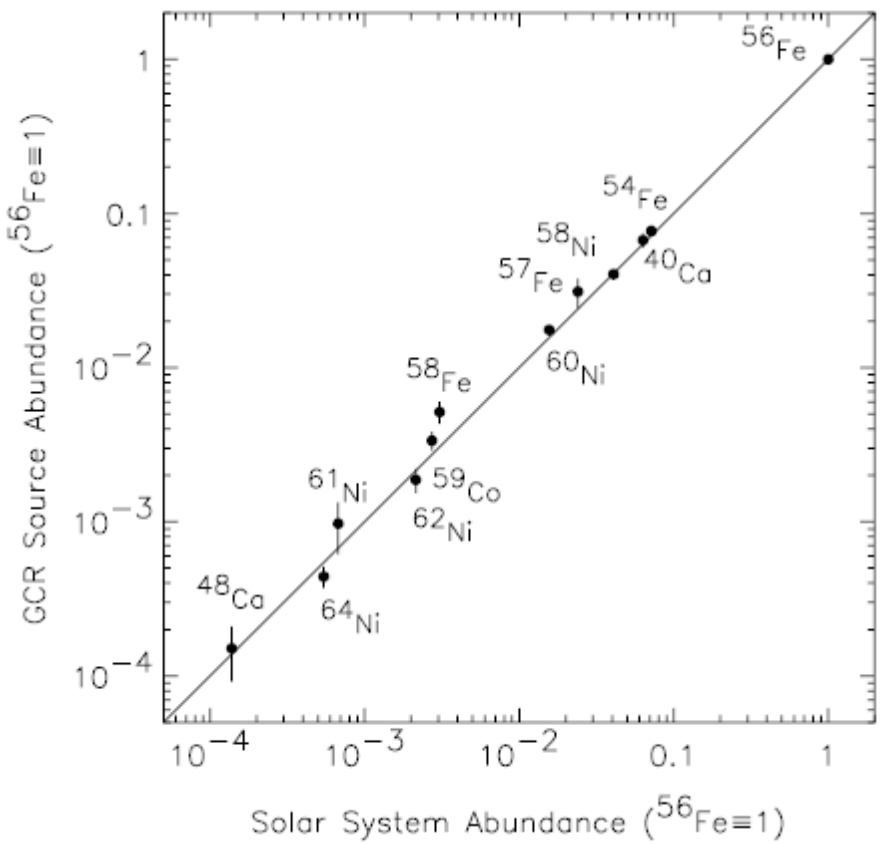
Start life as a nucleus in some star or other

Cosmic Ray Source Isotopic Abundances ~400MeV/N very similar to Solar System (but there are some differences….)



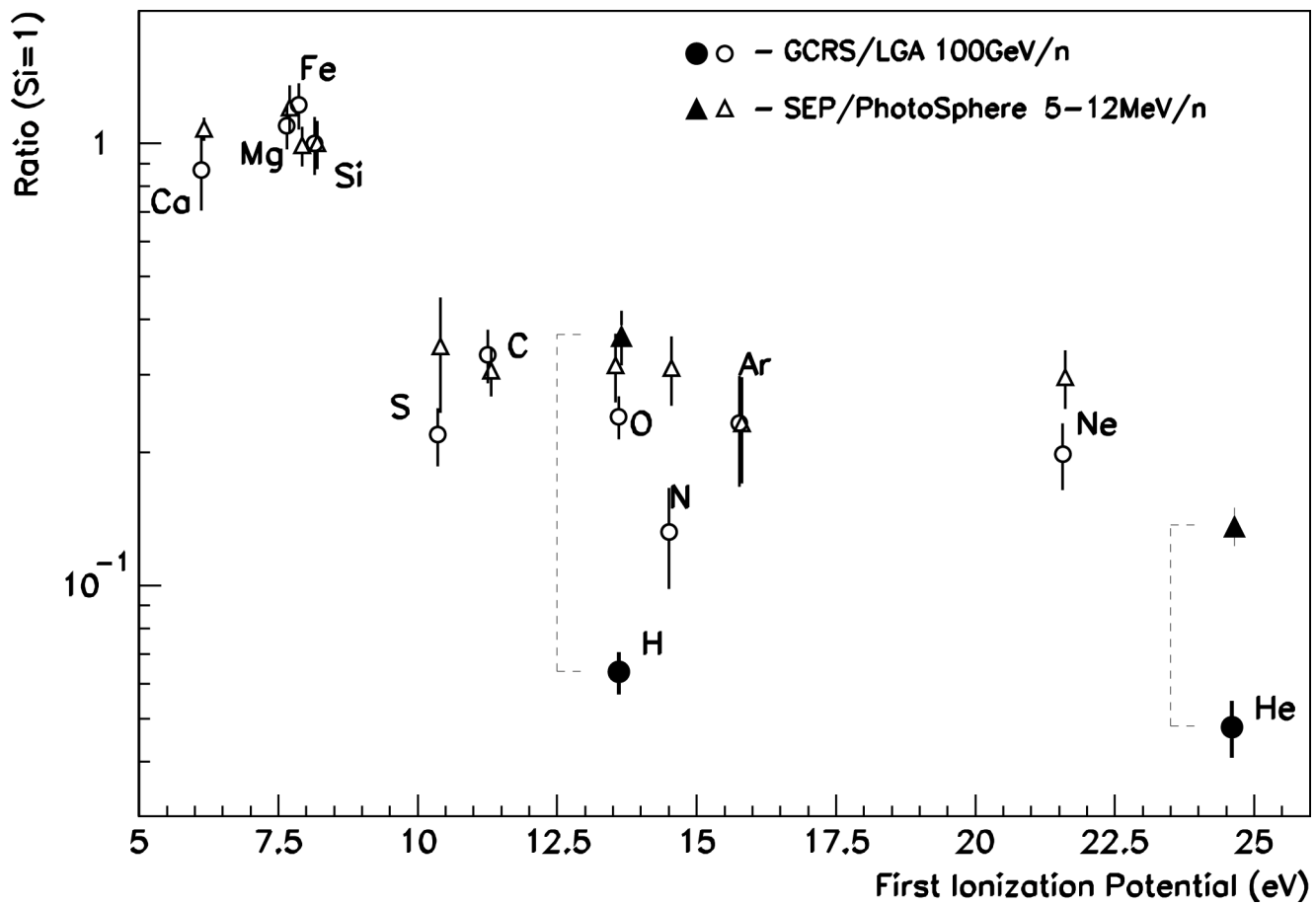
(Wiedenbeck, SpScRev, 2001, 15)

Correlation between CR source Isotopes and Solar System



Correlations of CR/LGA source material at ~100GeV/n with atomic energy level

Also shows up in solar flare composition/photosphere



But, FIP or volatility?

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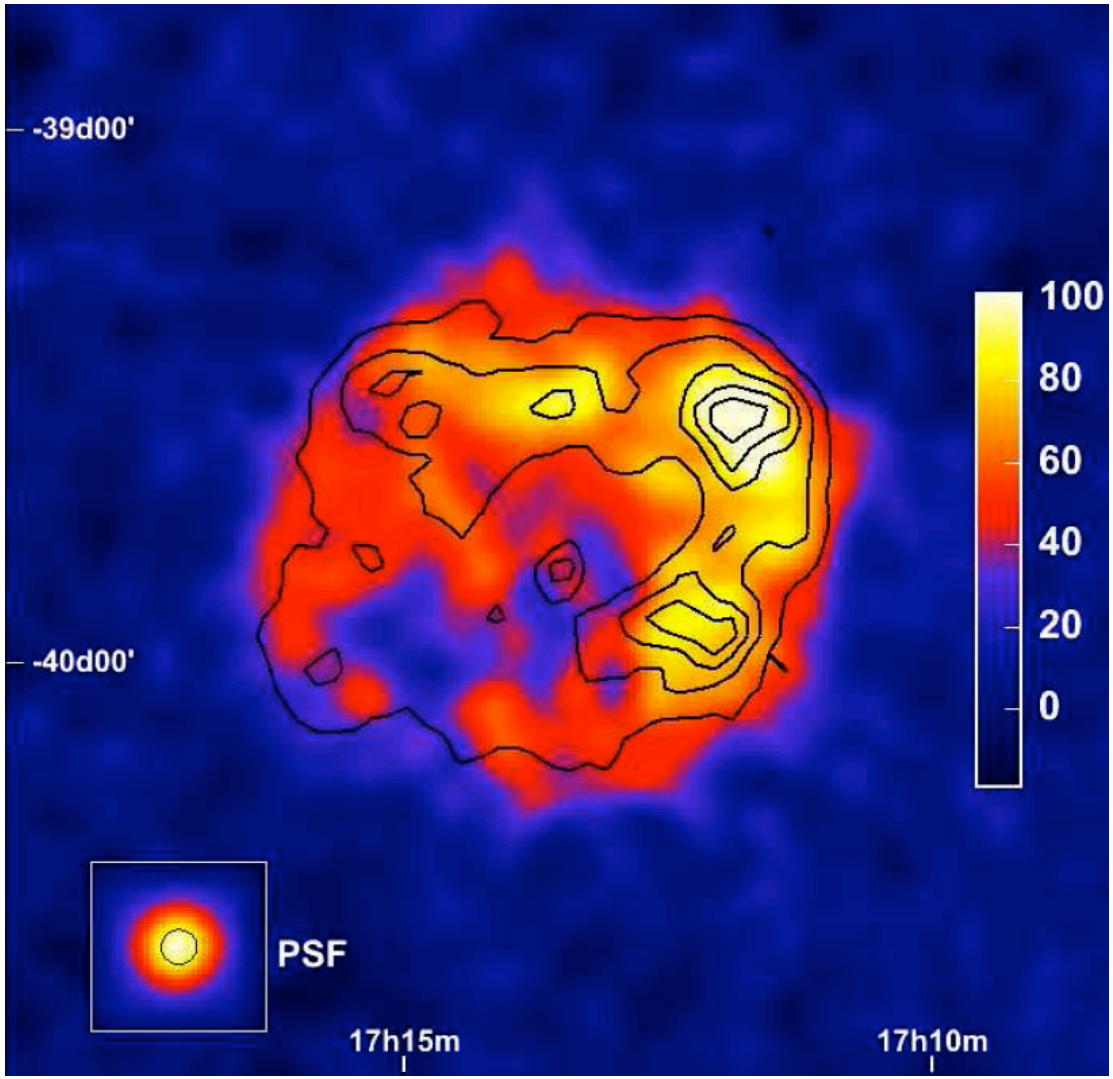
Isotopic similarities with SS and
FIP correlation (but FIP/volatility?)

Start life as a nucleus in some star or other

SN shock waves accelerate particles (HESS RXJ…)



(electrons/hadrons?)

Even Briefer History of Cosmic Rays Update

Fade

Leave Galaxy

Die by nuclear interaction

~1.5 M years

Mince around in Galactic magnetic field structure

SN diffusive shock acceleration

Hit hard by some humungous shock wave

>10,000 years

Become a part of a supra-thermal stellar wind

Isotopic similarities with SS and
FIP correlation (but FIP/volatility?)

Start life as a nucleus in some star or other

Pros and Cons of SN diffusive shock acceleration

Pros

- enough power available

- working theory exists which produces power law of particles in magnetic rigidity

- SNR certainly have extensive non-thermal particle populations

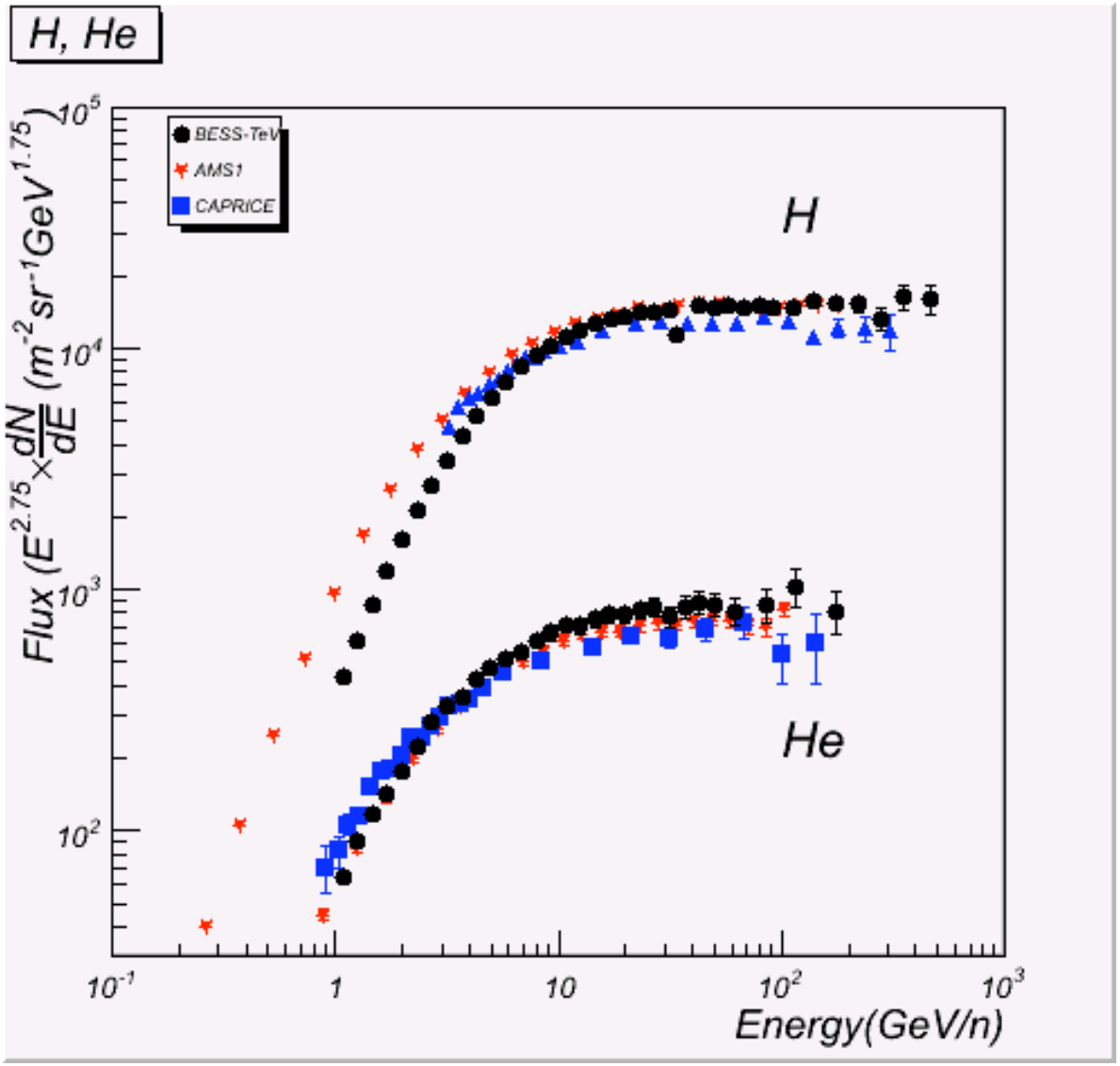
- power law index ~2 close to that observed in CR source (see later) up to ~50GeV

Cons

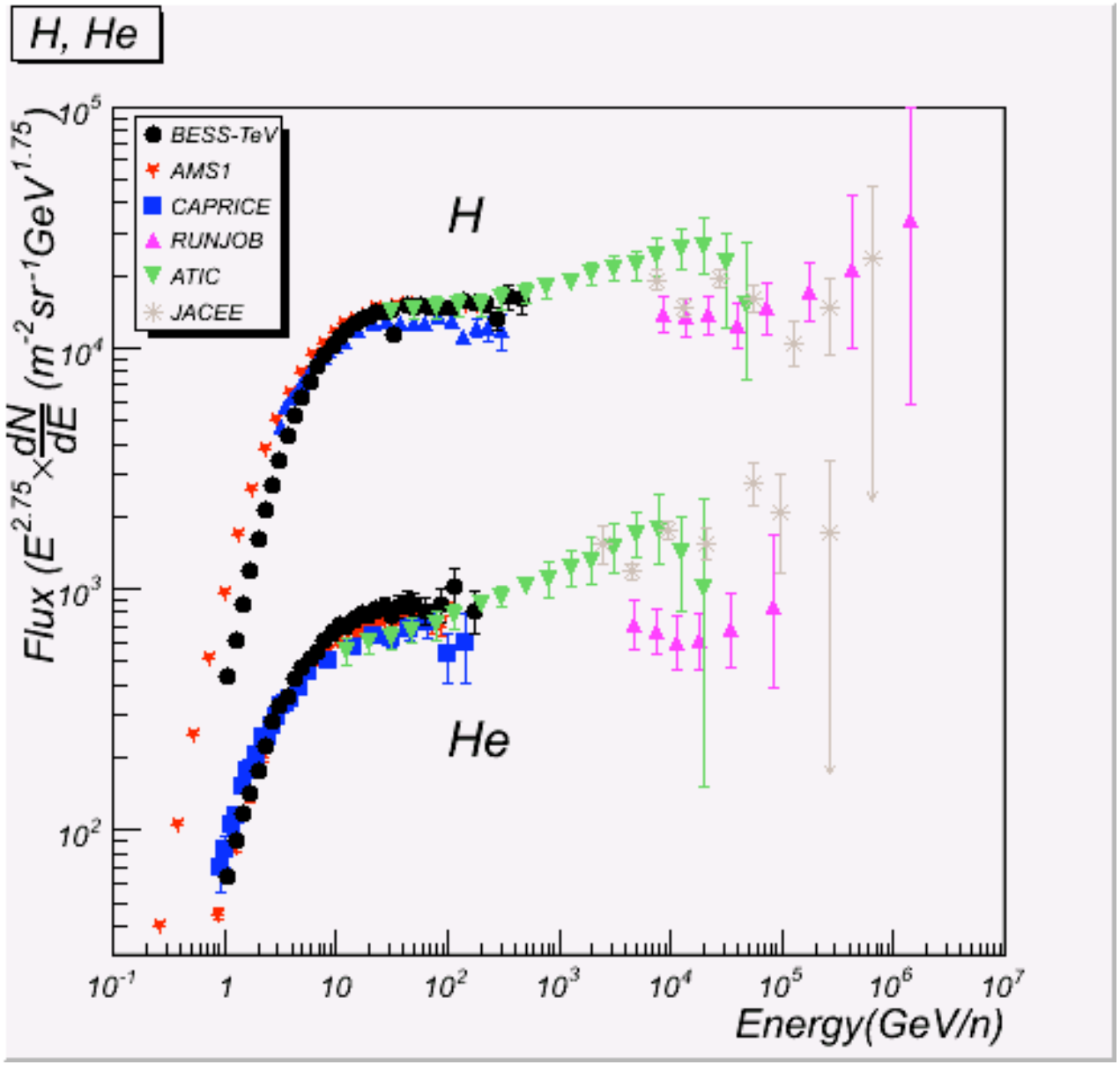
- because of strong shock lifetime, maximum particle energy is limited

- indirectly observed cosmic rays seem to exceed this limit

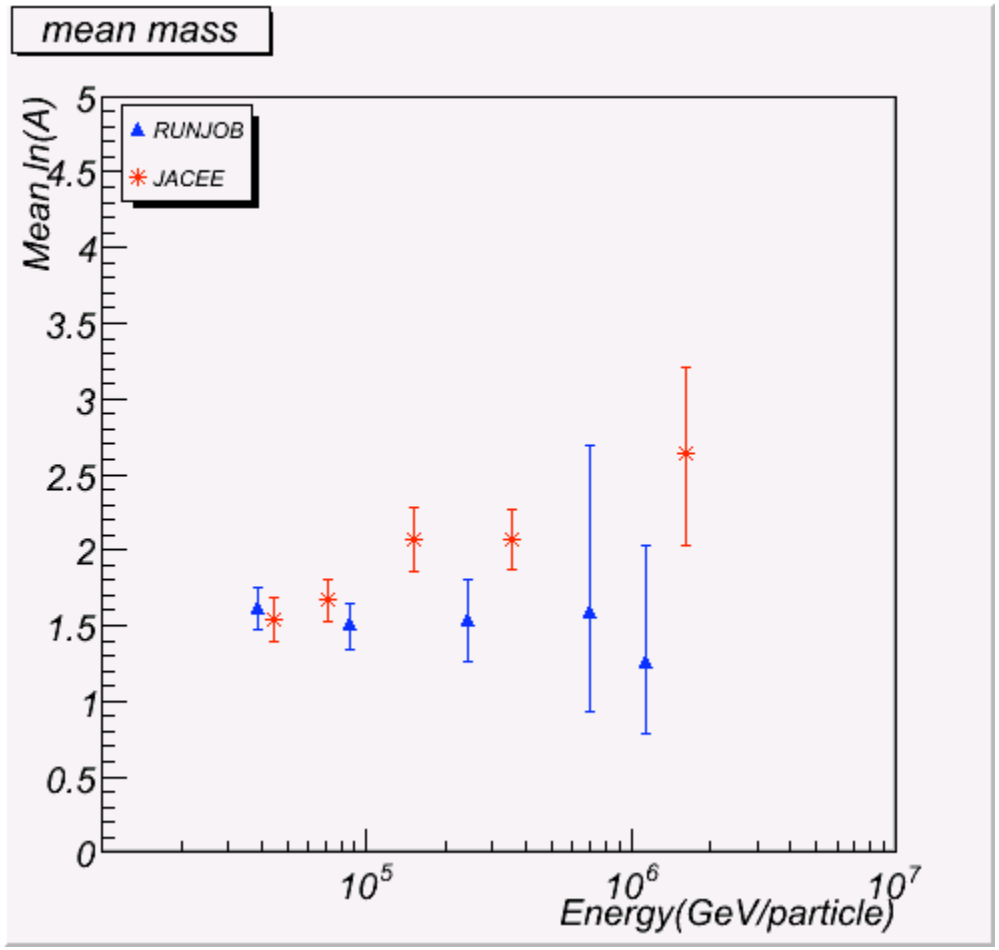
Magnet Spectrometer Data (>2000)
Similar spectra at high energy - same magnetic rigidity spectra
Residual systematic flux uncertainty ~10%



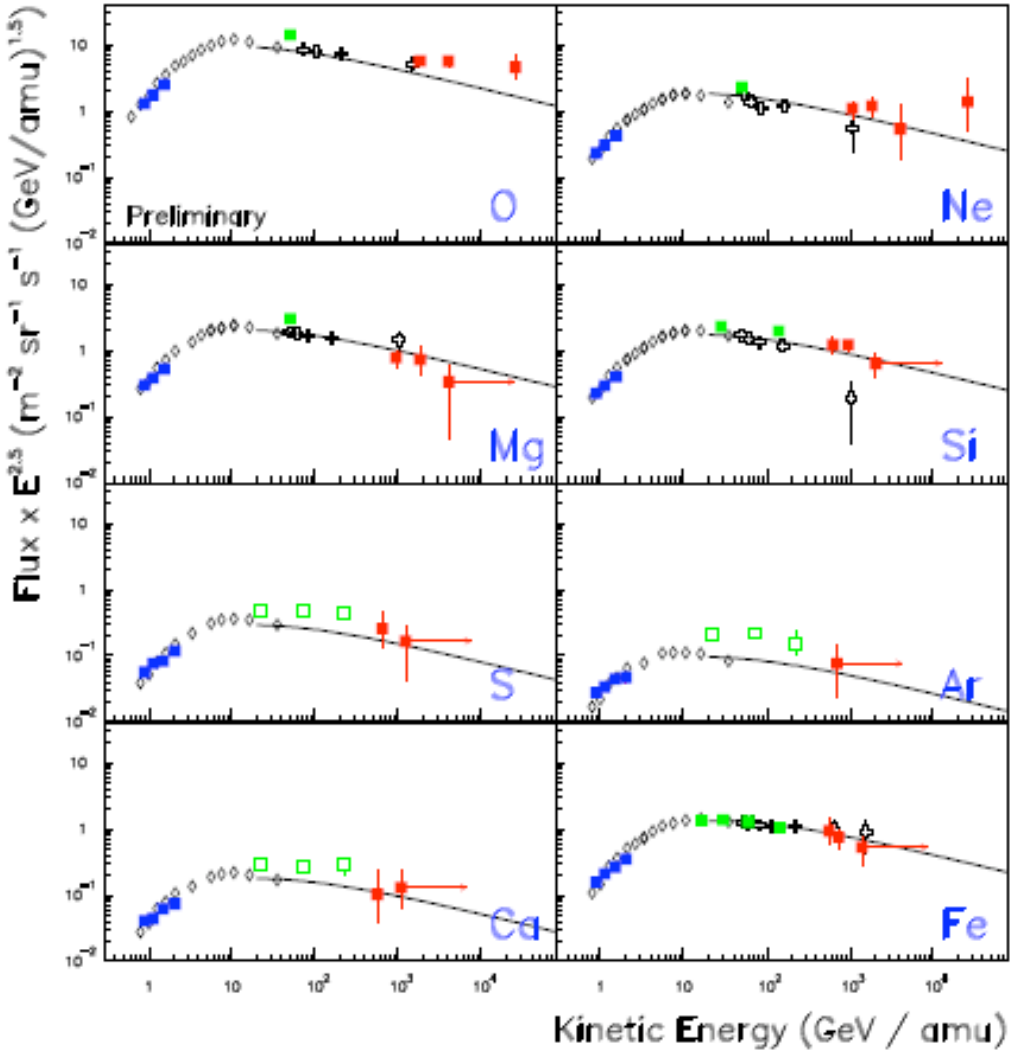
Thin Calorimetry data, passive (JACEE, RUNJOB) and active (ATIC)
Some differences here…..



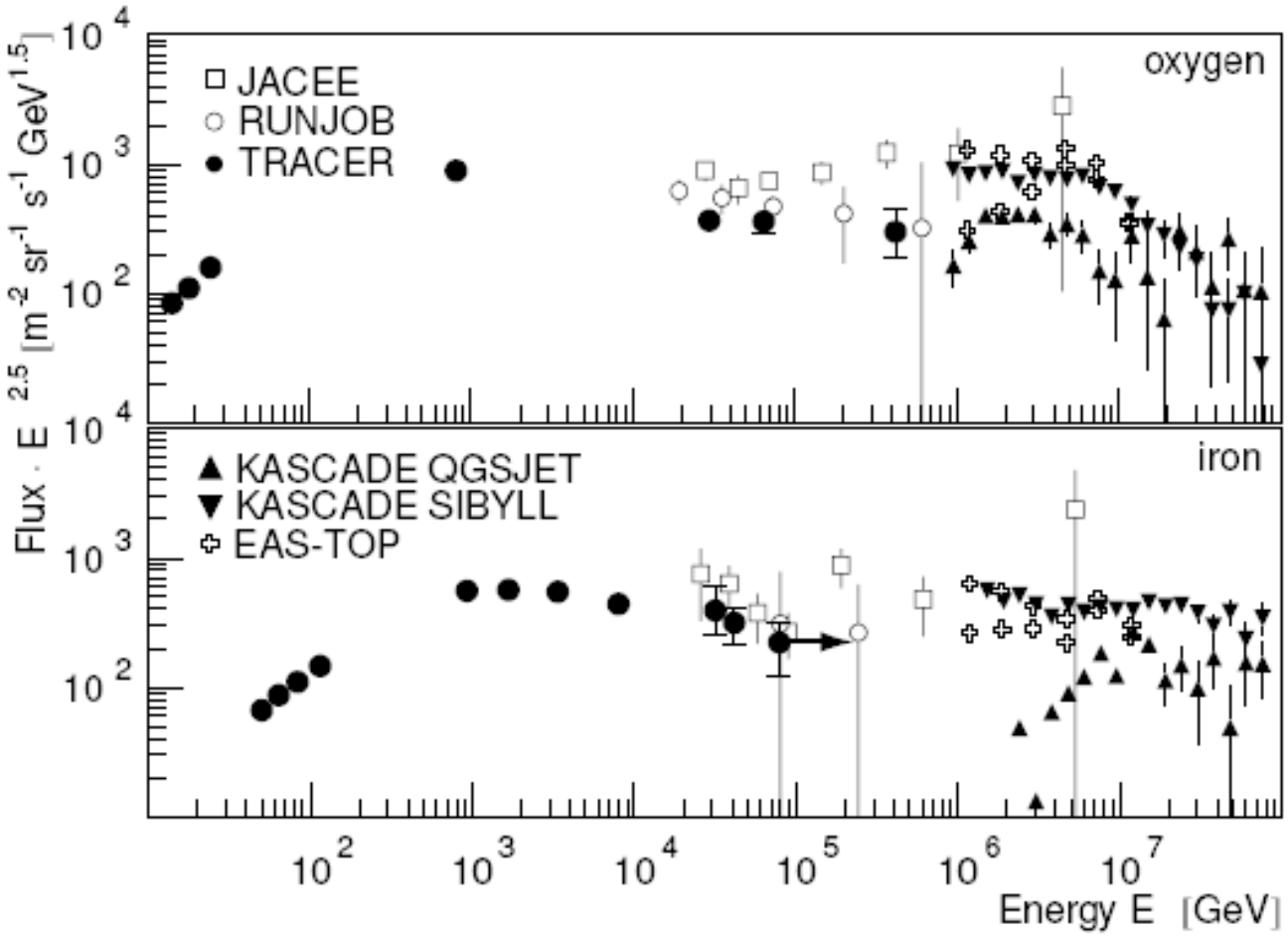
Mean ln(A) versus Energy
- RUNJOB essentially constant into knee region



Heavy Nuclei: TRACER (trd) sees magnetic rigidity spectra, constant slope

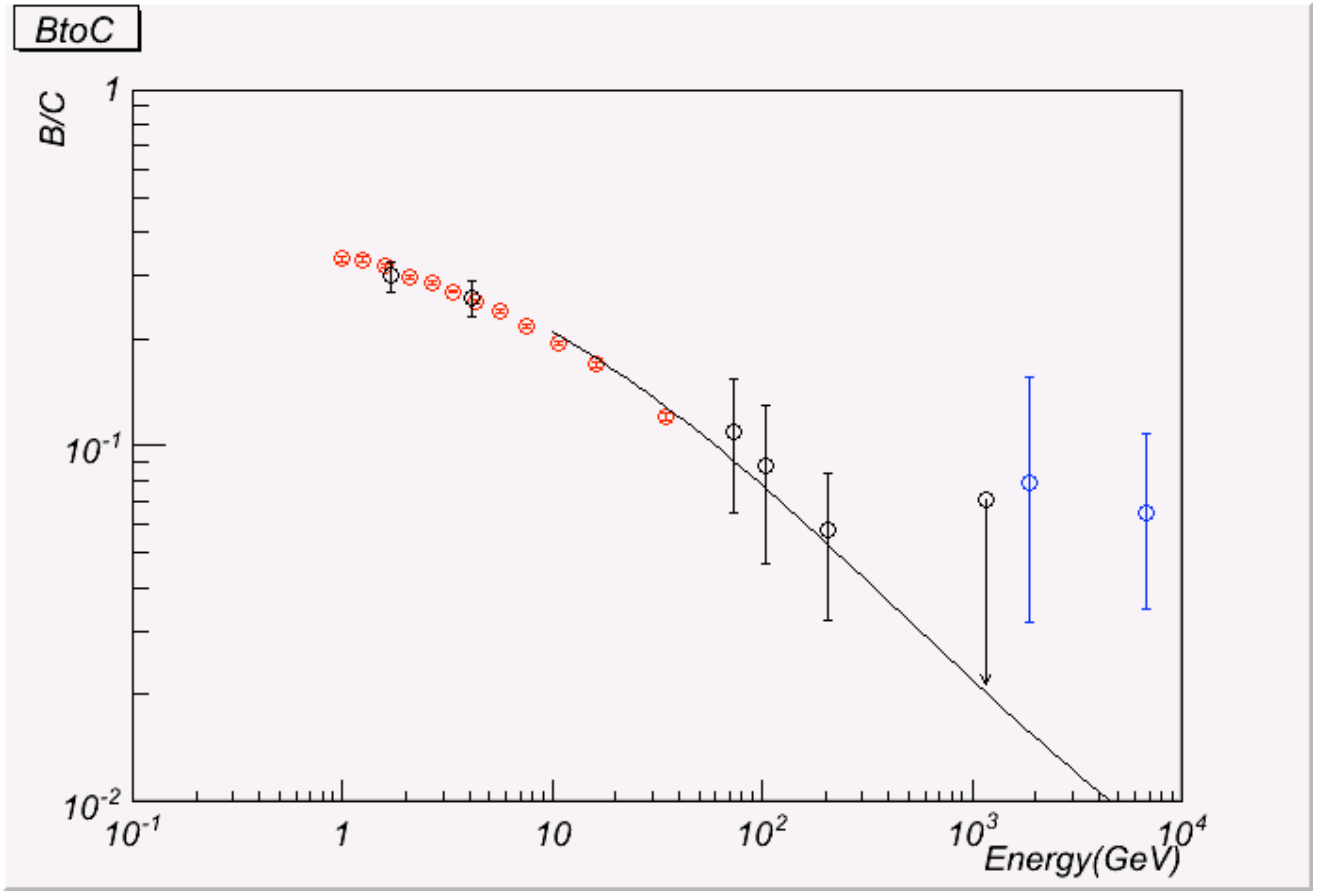


TRACER measurements into knee region
Consistent with RUNJOB



Escape from the Galaxy is energy dependent (secondary/primary ratio decreases with energy, if $E^{-0.6}$ the source is $dN/dE \sim E^{2.1}$

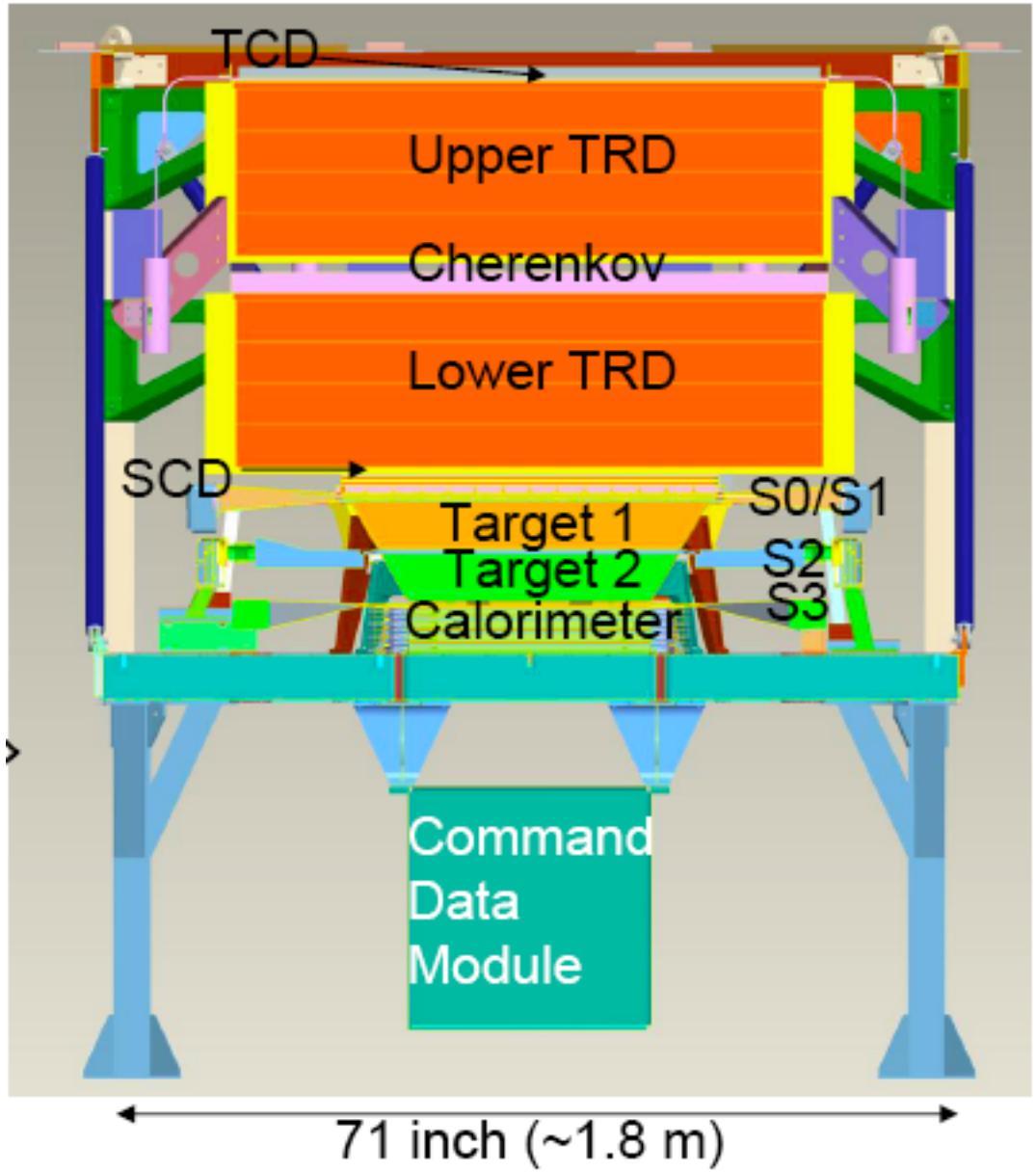
New measurements on B/C from RUNJOB (blue) seem high (red -HEAO, Black-CRN)



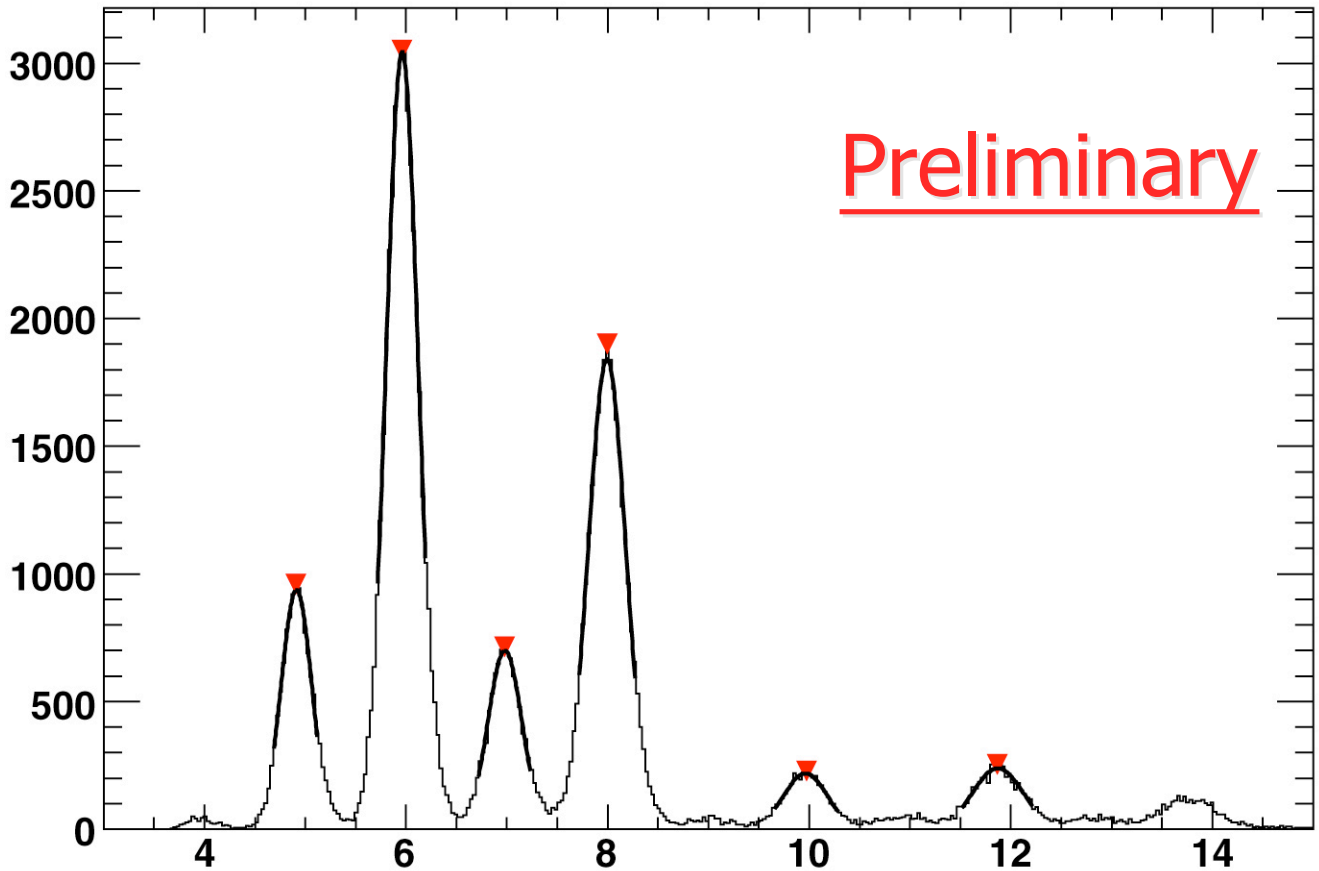
CREAM -I 2004-2005
(42 days)
Cosmic Ray Energetics
And Mass

Maryland, Penn State,
Chicago, Ohio St., INFN
Italy, Korea

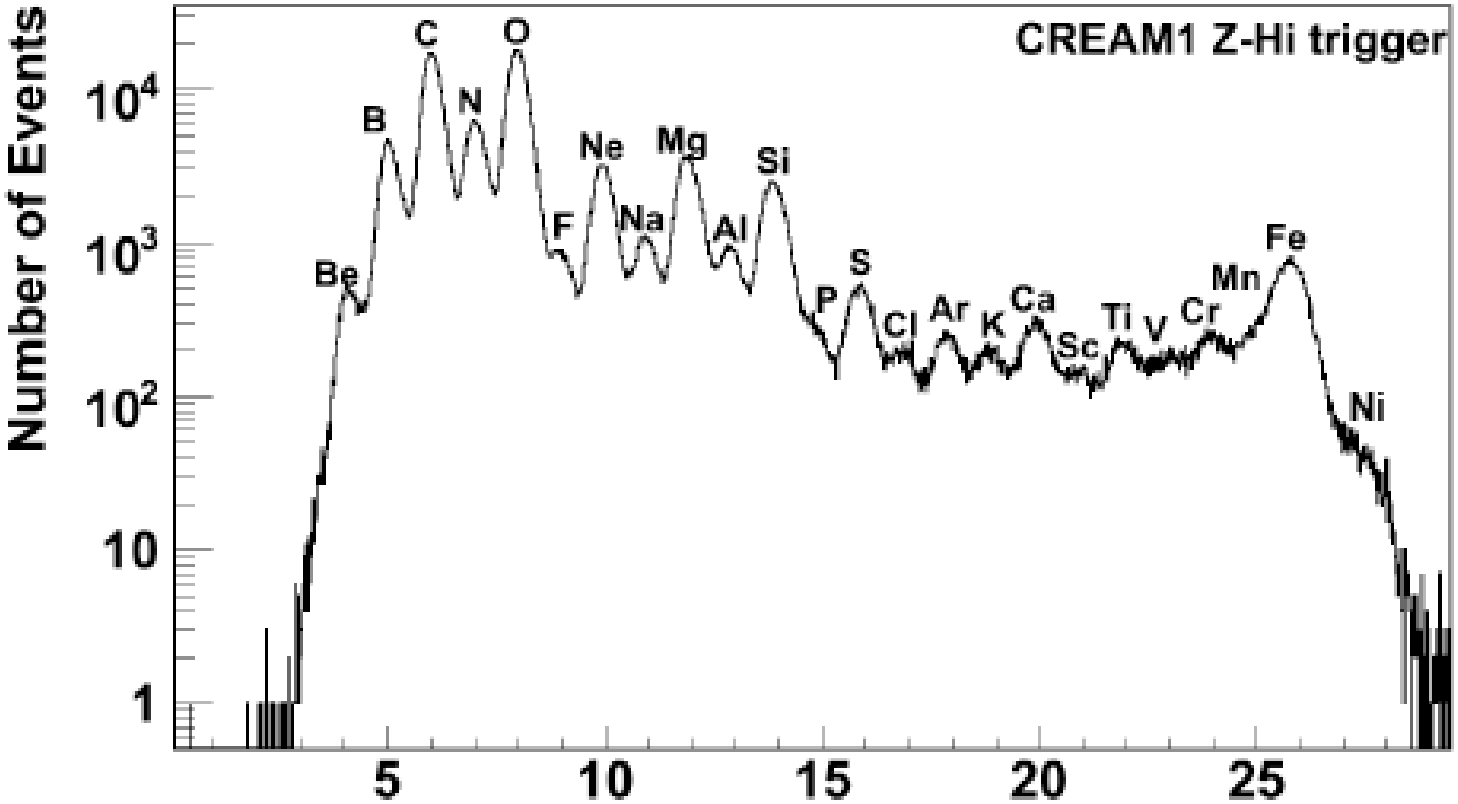
Also CREAM-II 2005-
2006 (28 days)



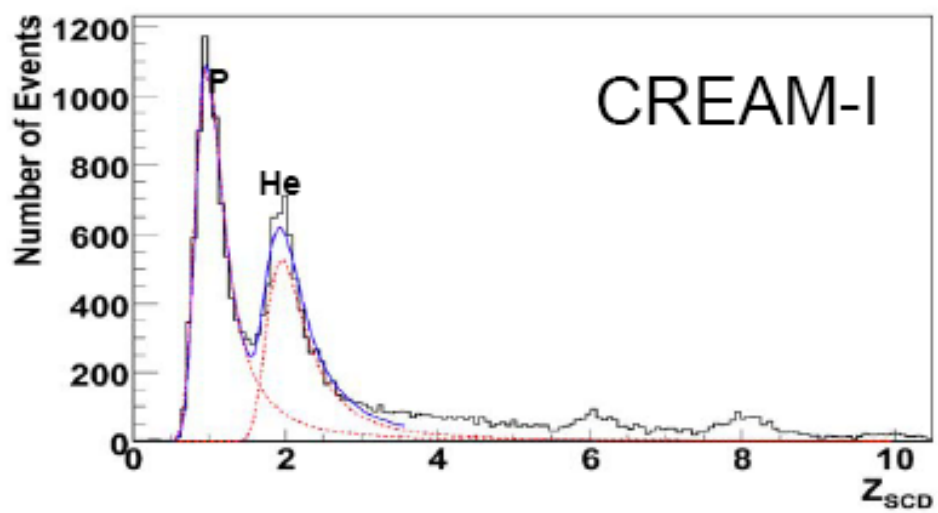
Charge Resolution from TRD/Cerenkov in CREAM-I



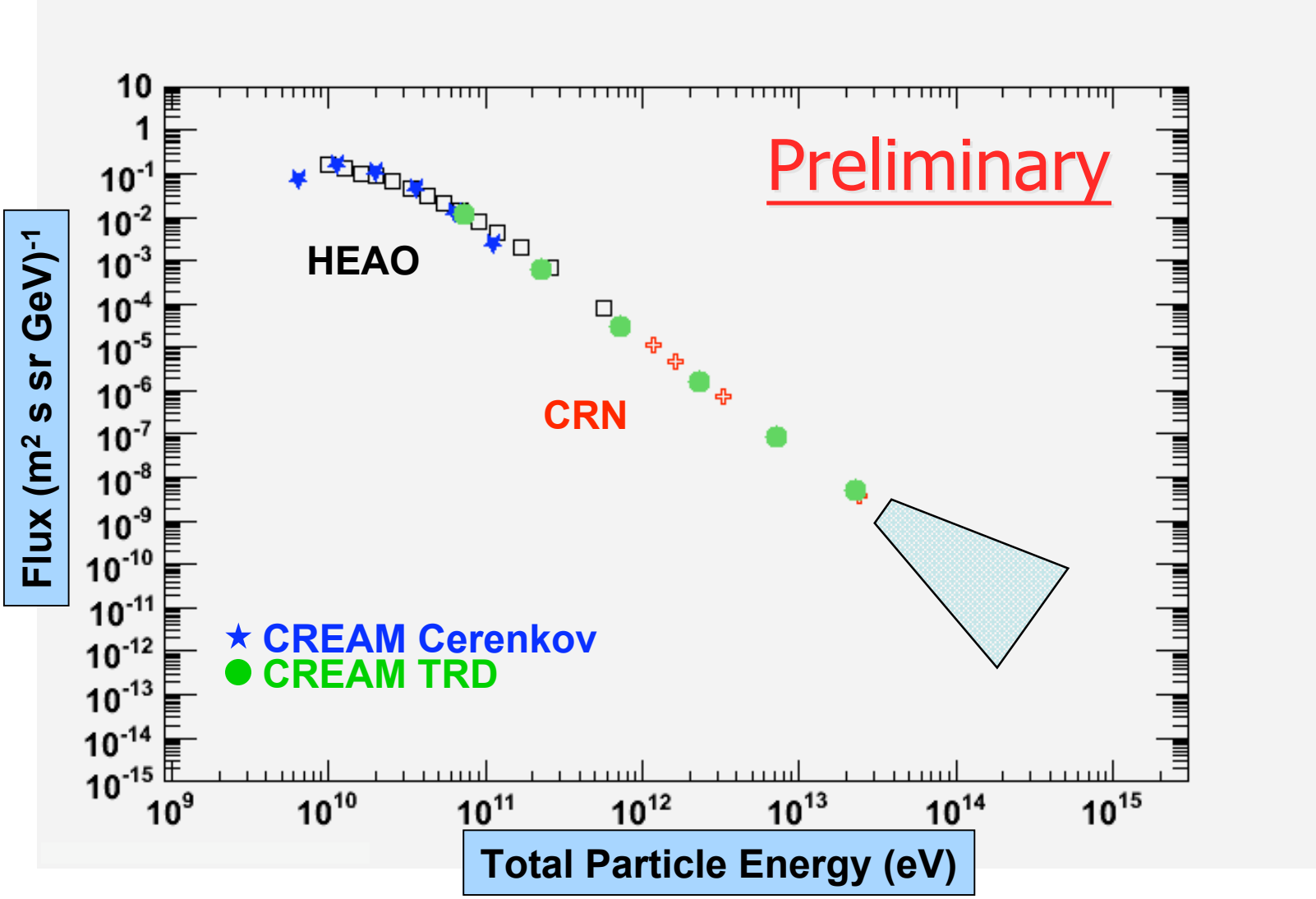
CREAM-I, Hi-Z with Silicon, TCD and Cerenkov



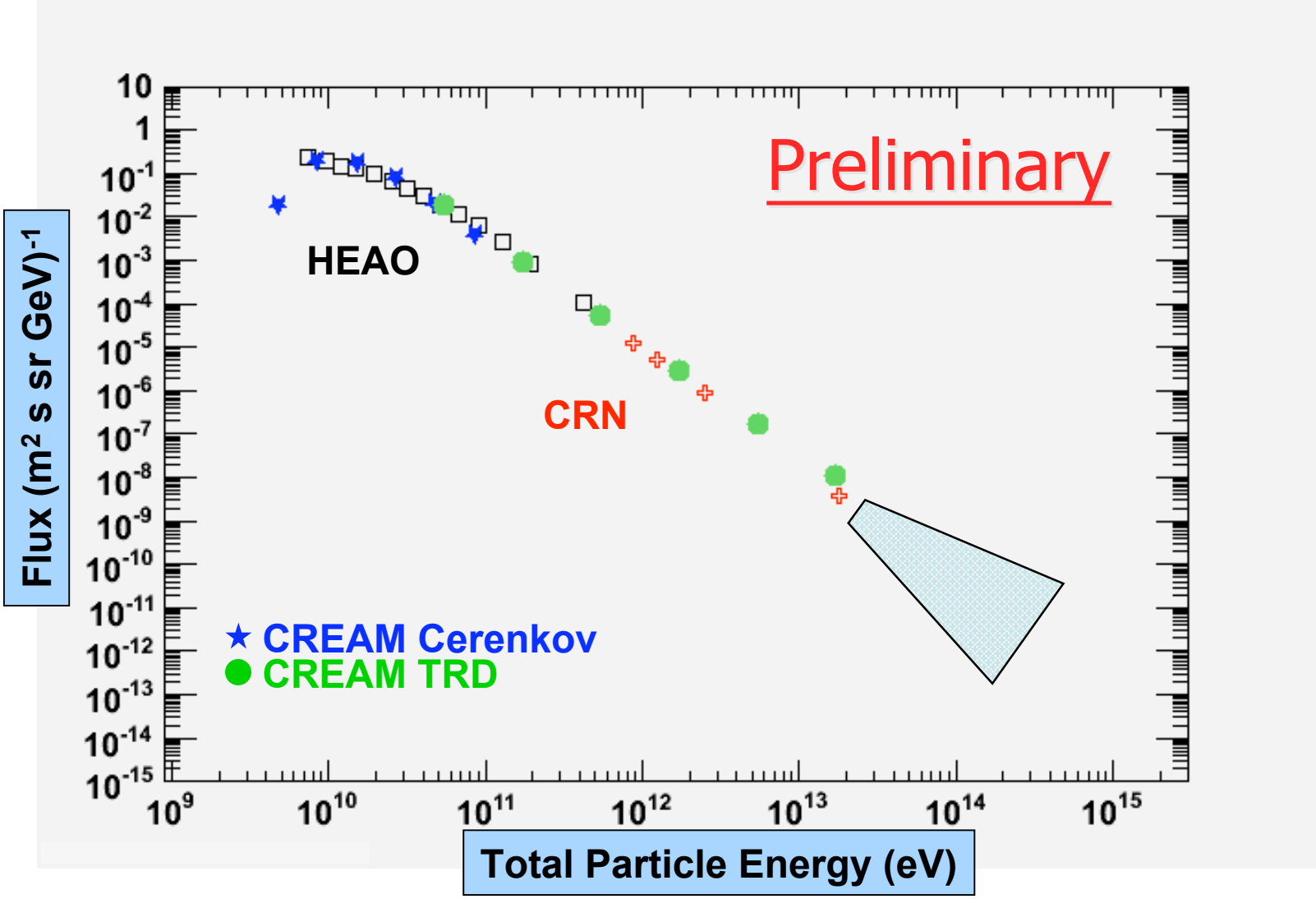
CREAM-I, Lo-Z trig



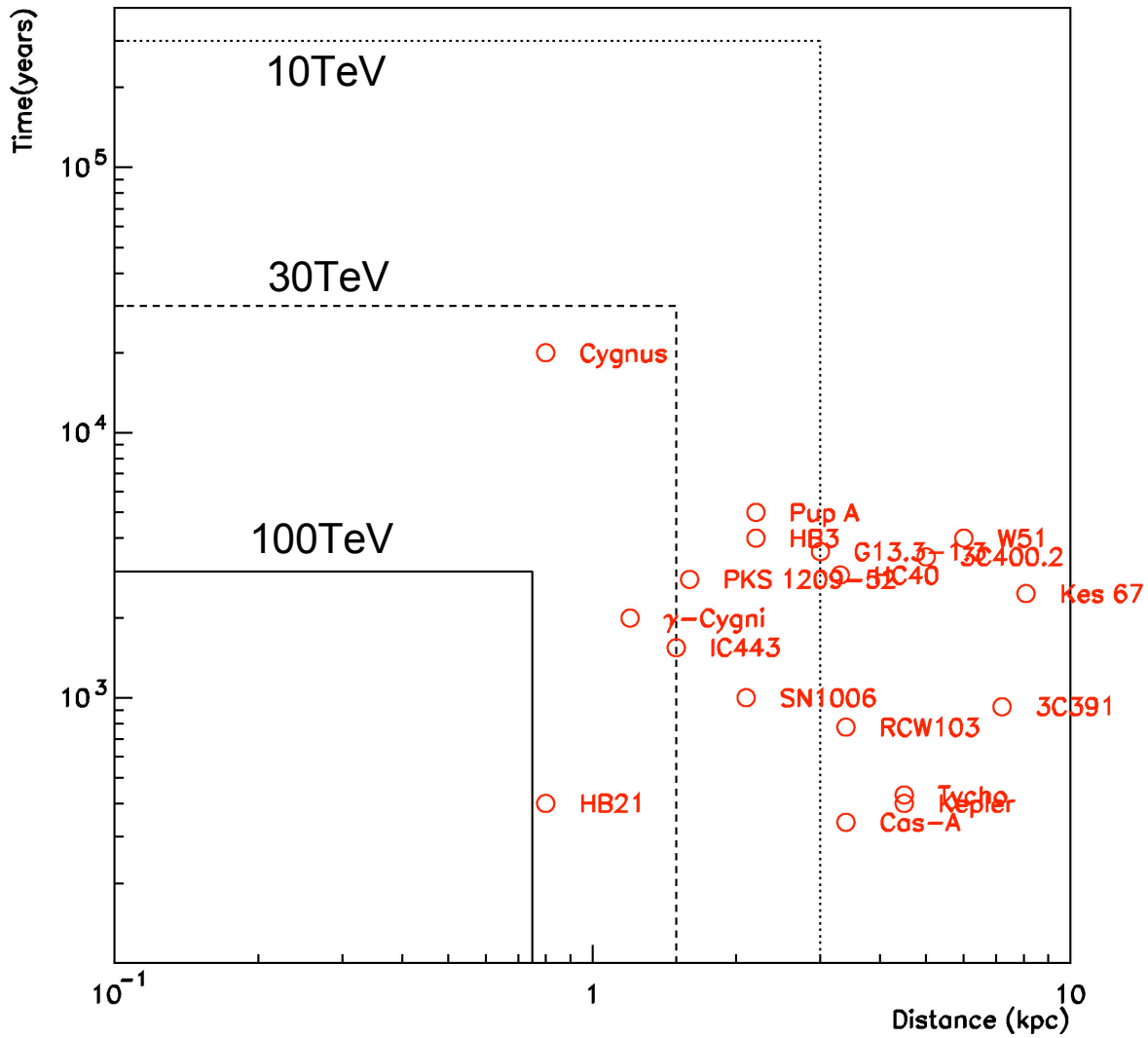
CREAM HiZ Oxygen Spectrum



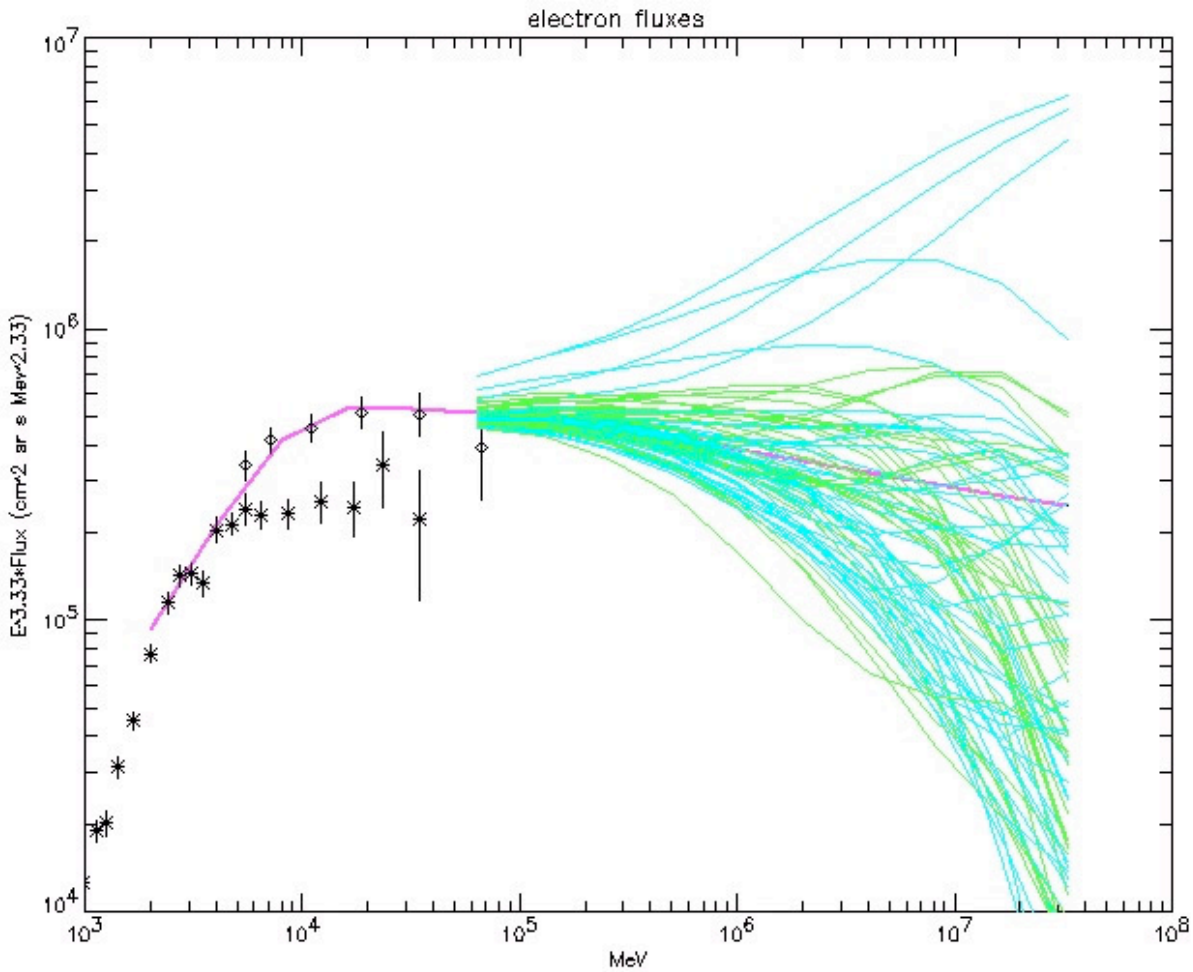
CREAM HiZ Carbon Spectrum



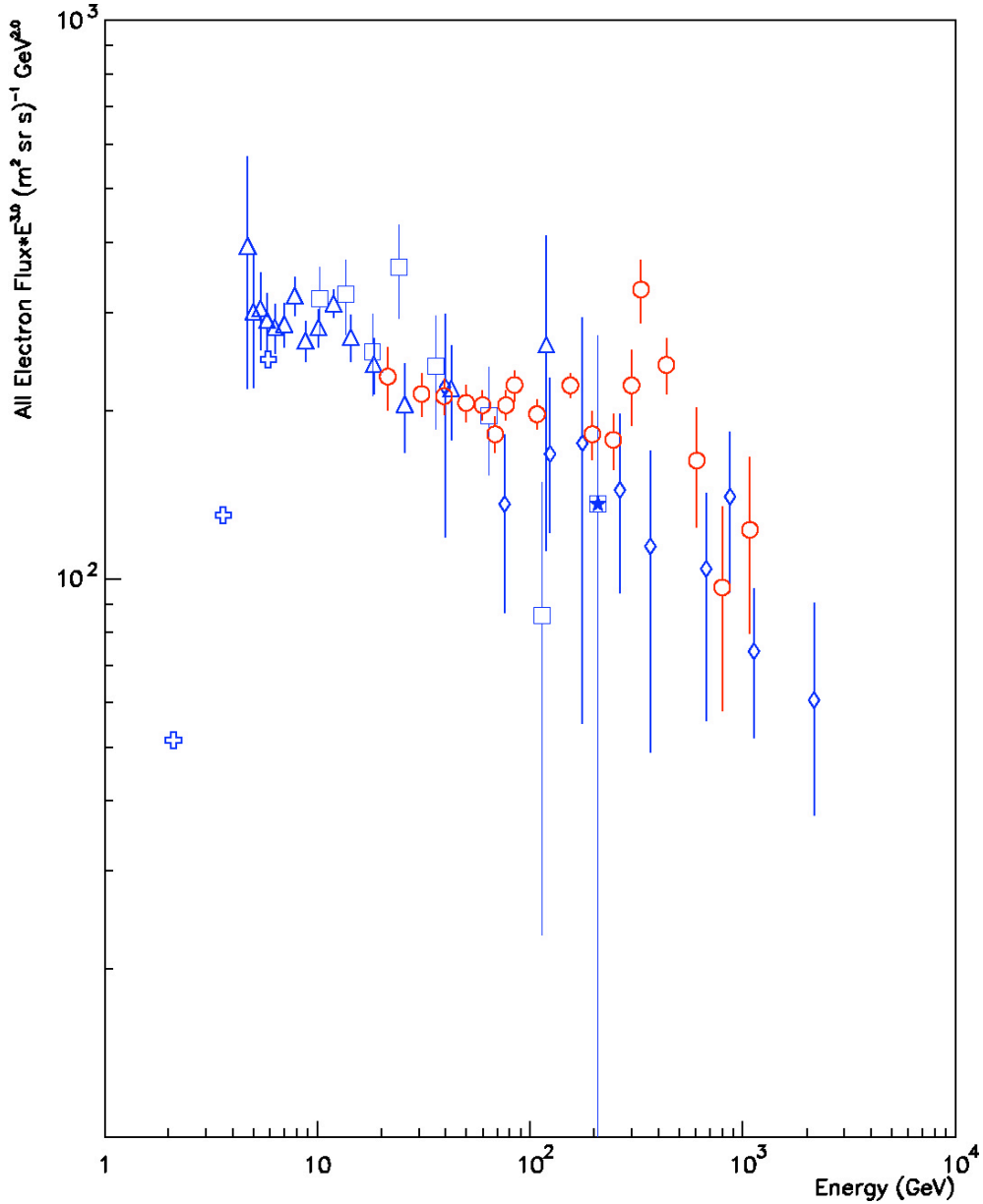
Electrons at high energy loose energy mostly by synchrotron
Places limits on the distance and age of source



Electron Models with stochastic SN (Galprop -Strong and Moskalenko)



New electron measurements from ATIC - 2005 -> Feature?



Conclusions:

- SNR shock acceleration of most of the cosmic rays seems to be in good shape.

- Nuclei spectra are power laws in rigidity

- Source spectra have power law index 2.1-2.3

- Newer measurements (RUNJOB, TRACER) show mean mass at the knee may be lighter than previously thought

- Electrons at high energy could be very interesting