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

Brief History of the Universe

99.999999999% of cosmic ray action
Even Briefer History of Cosmic Rays

Start life as a nucleus in some star or other

Become a part of a supra-thermal stellar wind

Hit hard by some humungous shock wave

Mince around in Galactic magnetic field structure

Die by nuclear interaction

Leave Galaxy

Fade
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)

Also can determine mean density of propagation volume $n = 0.34 \pm 0.04$ 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$^{59}$)

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      - Leave Galaxy
        - Mince around in Galactic magnetic field structure
          - Start life as a nucleus in some star or other
            - 
              - >10,000 years
                - ~1.5 M years
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 \( \sim 100 \text{GeV/n} \) with atomic energy level

Also shows up in solar flare composition/photosphere

But, FIP or volatility?
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~1.5 M years

>10,000 years

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?)
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- SN diffusive shock acceleration
- Isotopic similarities with SS and FIP correlation (but FIP/volatility?)
- >10,000 years
- ~1.5 M years
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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 $\sim 2$ close to that observed in CR source (see later) up to $\sim 50\text{GeV}$

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

Flux ($m^2 \cdot s \cdot sr \cdot GeV^{-1}$)

Total Particle Energy (eV)

Preliminary

HEAO

CRN

CREAM Cerenkov

CREAM TRD
CREAM HiZ Carbon Spectrum

Flux (m² s sr GeV)^{-1}

Total Particle Energy (eV)

HEAO

CRN

CREAM Cerenkov
CREAM TRD

Preliminary
Electrons at high energy lose 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