Properties of Secondary Cosmic Rays Lithium, Beryllium and Boron Measured by the Alpha Magnetic Spectrometer

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Lithium, Beryllium and Boron are mostly to be produced purely from collision of cosmic rays, such as Carbon and Oxygen, with the interstellar medium (ISM).

Cosmic rays are commonly modeled as a relativistic gas diffusing into a magnetized plasma. Diffusion models based on different assumptions predict a Sec/Pri ratio asymptotically proportional to $R^\delta$. With Kolmogorov turbulence model a $\delta = -1/3$ is expected, while Kraichnan theory leads to $\delta = -1/2$. 
If the hardening is related to propagation properties in the Galaxy then a stronger hardening is expected for the secondary with respect to the primary cosmic rays.

If the hardening in CRs is related to the injected spectra at their source, then similar hardening is expected both for secondaries and primary cosmic rays.
AMS-02 On Orbit

From May 19\textsuperscript{th} 2011 active on ISS, operating continuously since then.
AMS has collected > 142 billion cosmic rays up to today.
With such a statistics the most rare components of the cosmic rays are visible.

AMS is expected to take data for all the ISS lifetime.
AMS CRs Nuclei Measurement

Tracker L1-L9
Δy(3≤Z≤5) ≈ 5–6 μm
R = p/Z, ΔR/R(MDR) = 1
MDR(3≤Z≤5) ≈ 3.5–3.7 TV

Upper TOF
ΔZ/Z(3≤Z≤5) 4–6%

Tracker L1

Tracker L2-L8
3.5–5%

Lower TOF
2–3%

Tracker L9

Tracker L1-L9
Δy(3≤Z≤5) ≈ 5–6 μm

Tracker
R = p/Z, ΔR/R(MDR) = 1
MDR(3≤Z≤5) ≈ 3.5–3.7 TV

TOF

RICH

ECAL

Charge

Momentum

AMS

CRs

Nuclei

Measurement
AMS CRs Chemical Composition

AMS H, He, C, and O fluxes, Q. Yan CRD8b
AMS Ne, Mg, Si, and S fluxes, Q. Yan CRD7a
AMS $^3$He and $^4$He fluxes, C. Delgado CRD6c
AMS $^6$Li and $^7$Li fluxes, L. Derome CRD6d
AMS H and He fluxes vs time, C. Consolandi (daily) CRD8c
and N. Tomassetti (monthly) CRD8d
AMS C and O fluxes vs time, F. Donnini (monthly) CRD8a
AMS H, He, C, and O flux anisotropy, I. Gebauer CRD4a
Measurement of Flux and Ratio

Isotropic differential flux \((m^2 \text{ sr s GV})^{-1}\)

\[
\Phi^Z_i = \frac{N^Z_i}{A^Z_i \epsilon^Z_i T_i \Delta R_i}
\]

Number of particles (subtracted for backgrounds and corrected for rigidity migrations)

Exposure Time (s)
(1.23\times10^8 s, for \(R > 30\) GV)

Trigger Efficiency
(very high, \(\varepsilon > 98\%\) at all \(R\))

Effective acceptance (m\(^2\) sr)
(from MC, verified with data)

Bin width (GV)
(depending on the MDR)

Ratio of counts

Ratio of trig. eff.

Ratio of eff. acceptances

\[
B/C = \frac{\Phi^B_i}{\Phi^C_i} = \frac{N^B_i}{N^C_i} \cdot \left[ \frac{A^B_i}{A^C_i} \cdot \frac{\epsilon^B_i}{\epsilon^C_i} \right]^{-1}
\]

correlations in in systematic errors from uncertainties in nuclear interaction cross sections, bin-to-bin migration and rigidity scale are accounted.

Ratios of species close in \(Z\) have significantly lower systematics than fluxes.
Rigidity Scale Uncertainty

Two contributions to this uncertainty:

**Residual tracker misalignment**
checked with $E_{ECAL}/R_{Tracker}$ ratio for electrons and positrons, limited by the high energy positron statistics.

**Magnetic field**
mapping measurement (0.25%) and temperature corrections (0.1%). Taken in quadrature and weighted by the measured flux rigidity dependence.

The rigidity scale is the dominating systematics in the flux evaluation at 3 TV. On the B/C ratio the effect is **largely cancelled** and rigidity scale error is $\sim 1\%$. 
Lithium and Boron Fluxes

Identical above $\sim 7$ GV.


\[ \text{Flux} \times R^{2.7} \quad [\text{m}^{-2}\text{s}^{-1}\text{sr}^{-1} (\text{GV})^{1.7}] \]

[Rigidity $\tilde{R}$ [GV]]
Identical above ~ 30 GV. Effect of unstable $^{10}$Be component.


- Beryllium 0.9 M
- Boron 2.6 M
Over the last 50 years, only a few experiments have measured the Li and Be fluxes above a few GV. Typically, these measurements have errors larger than 50% at 50 GeV/n.

For the B flux, measurements have errors larger than 15% at 50 GeV/n.
Primary and Secondary Fluxes


Flux $\times \tilde{R}^{2.7}$ [m$^2$ s$^{-1}$ sr$^{-1}$ (GV)$^{-1.7}$]

- **Helium**
- **Carbon** ($\times 30$)
- **Oxygen** ($\times 28$)

- **Lithium** ($\times 200$)
- **Beryllium** ($\times 400$)
- **Boron** ($\times 145$)
Deviate from single power law above 200 GV. Secondary hardening is stronger.

AMS published high precision data of: Li/C, Be/C, B/C, Li/O, Be/O, and B/O.

Data were fit with power laws in the rigidity intervals [60.3 GV – 192 GV] and [192 GV – 3300 GV].

All ratio show a hardening (~2σ), i.e. secondaries show a hardening stronger than primaries.

Globally, an hardening at 192 GV of $0.13 \pm 0.03$ is observed.
Combining the six secondary/primary ratios an hardening at 192 GV of $0.13 \pm 0.03$ is observed. This observation favors the hypothesis that the flux hardening is an universal propagation effect.

A. E. Vladimirov et al., Astroph. J. 752 (2012) 68
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They all have the same behavior above 30 GV.
Li/B have the same behavior above 7 GV.

The behavior of Be/B below 30 GV can be related to the $^{10}\text{Be}$ component, that beta-decays with $t_{1/2} = 1.4$ My through $^{10}\text{Be} \rightarrow ^{10}\text{B} + e^- + \bar{\nu}$, and can be related to the cosmic rays confinement time.
\[ \Phi_N = (0.090 \pm 0.002) \times \Phi_O + (0.62 \pm 0.02) \times \Phi_B \]
In The Future

B/C

Preliminary AMS 7 years data. Please refer to the AMS forthcoming publication in PRL.
In The Future
Conclusions

Lithium, Beryllium and Boron fluxes have been measured from 1.9 GV to 3.3 TV, with 1.9M, 0.9M and 2.6M nuclei respectively with a typical accuracy of 3-4% at 100 GV. The three fluxes deviate from a single power law above 200 GV in an identical way. This hardening is larger than the one observed for primary species (He, C, O).

The secondary/primary flux ratios Li/C, Be/C, B/C, Li/O, Be/O, and B/O were measured taking into account correlations on systematic errors. The secondary/primary flux ratio show an average hardening of 0.13 ± 0.03.

These observations favor the hypothesis that the flux hardening is an universal propagation effect.

The Be/B ratio show a low energy dependence that can be due to the $^{10}$Be decay.

Nitrogen spectrum have been measured from 2.2 GV to 3.3 TV, with 2.2M events. The flux is described by the sum of a primary (Oxygen) and a secondary (Boron) component. The model independent N/O ratio at source of 0.09 ± 0.02 is derived.

The accuracy of the secondary cosmic ray nuclei fluxes will be significantly improved, in particular at the highest rigidities, during the lifetime of the ISS.

Heavier nuclei secondary fluxes will be measured, probing origin and propagation of cosmic rays at high mass and charge.