Observation of the New Properties of the Secondary Cosmic Rays Lithium, Beryllium and Boron with AMS on ISS

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Secondary Nuclei in Cosmic Rays

Lithium, Beryllium and Boron are produced from collisions of cosmic rays with the interstellar medium (ISM), they are called secondary cosmic rays.

The fluxes of the secondary species are very important for the understanding of the origin and propagation of cosmic rays, e.g. the hardening of primary cosmic rays above ~200GV (see the talk from Dr. F. Donnini).

We thank Professor Igor Moskalenko for many helpful discussions.
Lithium, Beryllium and Boron Flux before AMS

- Lithium
- Beryllium
- Boron
Nuclei Flux Measurement

**Momentum**

Tracker + Magnet, $R = p/Z$
Spatial resolution ($Z=5$) $\approx 5.3$ um
Full Span (L1-L9) MDR ($Z=5$) $\approx 3.7$ TV

**Charge**

$\Delta Z$ ($Z=5$)

- Tracker L1: 0.30
- Tracker L2-L8: 0.12
- Tracker L9: 0.30
- Upper TOF: 0.16
- Lower TOF: 0.16
- RICH: 0.32

$\Delta \beta/\beta^2$ ($Z=5$) $\approx 0.01$
Event Selection

misidentification from non-interacting nuclei is negligible.

Tracker L2-L8 charge distribution from Z=2 to Z=6 are selected with ToF charge and Tracker L1 charge. Vertical lines are the selections on tracker L2-L8 charge for Li, Be and B.
Background due to heavier nuclei interactions below L1 was computed with data. Estimated background <3% for B, <0.5% for Li and Be in the entire rigidity range.

Events are selected as boron by inner (L2-L8) tracker charge measurement. The charge template are derived from data by selecting non-interacting events. Vertical lines show the selections on L1 charge.
Background from Interactions (II)

Background due to heavier nuclei interactions above tracker L1 is calculated by using MC samples (from nuclei Z=3 to Z=8) generated according to AMS flux measurements.

This background is very important, MC interaction channels have been verified with data. Systematic error due to this background estimation is < 1.5% in the entire rigidity range.
Measurement Verification

Ratio of flux measured by using events passing through **L1-L9** over the one measured by using events passing through **L1-L8**

The observed agreement verifies:
(i) **acceptance**: the amount of material traversed is different
(ii) **unfolding**: bin-to-bin migration is different due to different resolution
Lithium and Boron Fluxes

Above 7 GV Li and B have identical rigidity dependence


![Graph showing the comparison between Lithium and Boron fluxes above 7 GV. The graph indicates that Lithium has 1.9 million events and Boron has 2.6 million events.]
Lithium and Beryllium Fluxes

Above 30 GV Li and Be have identical rigidity dependence. The fluxes are different by a factor of 2.
Secondary Cosmic Rays Fluxes

have identical rigidity dependence above 30GV

\[ \text{Flux} \propto \tilde{R}^{2.7} \left( \text{m}^2 \text{s}^{-1} \text{sr}^{-1} \text{GV}^{-1.7} \right) \]

\[ \tilde{R} \sim 10^3 \times 10^3 \]

- Lithium×200
- Beryllium×400
- Boron×145
Primary and Secondary Cosmic Ray Fluxes

Primaries and secondaries have distinctively different rigidity dependence.

![Graph showing primary and secondary cosmic ray fluxes.](image-url)
Primary and Secondary Spectral Indices

$Flux \Phi = C R^{\gamma}$

Fluxes deviate from single power law above $\sim 200$ GV

$\Phi \propto R^{\gamma}$

-2.5

-3

Spectral Index $\gamma$

Rigidity $\tilde{R}$ [GV]

10 20 30

10^2 2\times10^2

10^3 2\times10^3

Helium

Carbon

Oxygen

Lithium

Beryllium

Boron

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Combining the six ratios, the secondary/primary ratio (B/C,...) deviates from a single power law above 200GV by 0.13±0.03

\[ \Delta[200-3300\text{GV}] - \Delta[60-200\text{GV}] = 0.13\pm0.03 \]

This observation favors the hypothesis that the hardening above \(~200\text{GV}\) is related to propagation properties in the galaxy.
In Progress
Conclusions

• Lithium, Beryllium and Boron Fluxes in the rigidity range from 1.9 GV to 3.3 TV with a total of 5.4 Million nuclei measured by AMS based on the first 5 years of operation have been presented.

• The Li and B fluxes have identical rigidity dependence above 7 GV and all three fluxes have identical rigidity dependence above 30 GV with the Li/Be flux ratio of 2.0 ± 0.1.

• The Li, Be and B fluxes deviate from a single power law above 200 GV in an identical way. But their rigidity dependences are distinctly different from the primary cosmic rays. In particular, above 200 GV, the secondary cosmic rays harden more than the primary cosmic rays.
backup
Rigidity Migration

The bin-to-bin migration of events was corrected using the unfolding procedure using the MC rigidity resolution functions. One of the many performed verification of the accuracy of this function is given by the comparison of the tracker spatial resolution.

![Graphs showing comparison of data and simulation for Li, Be, and B data with R > 50 GV.](image)

Systematic errors arising from the understanding of the resolution matrix and the bin-to-bin migration unfolding procedures account for <1.5% below 200GV and 8-10% at 3.3 TV.
Inelastic Interactions of Nuclei in the AMS Materials

Inelastic XS of Light Nuclei on AMS materials (C+Al) are known with large uncertainties only below 10 GV and represent a large source of errors for the flux determination.

We developed a method to verify the effect of interactions on AMS acceptance using data acquired when AMS pointing in horizontal direction (~10^5 sec exposure), in which cosmic rays can enter AMS both left to right and right to left.

The systematic errors due to uncertainties of inelastic cross sections are < 2%–3% up to 100 GV and <3%-4% at 3.3 TV.
Inelastic Interactions

Probability of detecting non-interacting event on L9 depends on the inelastic interactions in the materials between L8 and L9 ("1/3" of the AMS material). Direct measurement of this "survival probability" allows the control of flux normalization.

Systematic errors associated to inelastic interaction is < 2% up to 100 GV and 3-4% up to 3.3 TV.
Secondary/Primary Flux Ratios

Data were fit with a broken power law with break at 192 GV.

All ratio show a hardening (at the level of 2σ), consequence of the fact that secondary show a hardening stronger than primaries.

Globally an average hardening of $0.13 \pm 0.03$ is observed.

Secondary Nuclei Flux with Previous Measurements

Lithium

Beryllium

Boron