Cosmic ray isotopes measured by AMS-02

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on behalf of the AMS-02 collaboration

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AMS: a unique TeV precision, accelerator-type spectrometer in space

AMS was installed on ISS in May 2011. It will continue through the lifetime of ISS.

To date, it collected more than 140 billions of charged particles: $e^+$, $e^-$, $p$, $p\bar{p}$, nuclei...
AMS Physics Goals

- **Searches for primordial antimatter:**
  - Anti-nuclei: AntiHe, ...
- **Dark Matter searches:**
  - e+ , AntiD , ...
- **Measuring CR spectra – refining propagation models;**
  - Nuclei spectra from p, He -> Fe
- **Study effects of solar modulation on CR spectra over 11 year solar cycle**
- ...
Secondary CR are produced from collisions of primary CR with the interstellar medium (ISM).

- They carry information on the history of the travel and properties of ISM.
- Most abundant species: Li, Be, B and light isotopes ($^3$He, $^6$Li and D).

The fluxes of the secondary species are very important for the understanding of the origin and propagation of cosmic rays.
Secondary CR Flux before AMS

Lithium

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Light isotopes in cosmic rays

- B/C probes mostly “local” propagation
- \( p, \bar{p}, D \) and \( p \)-bar come from much further
- light secondary like \( D, \) \( 3He \) and \( Li \) constrain better the \( p \)-bar secondary prod.

\[ \frac{^6Li}{^7Li} \]: Both from C,N,O fragmentation

\[ \frac{^3He}{^4He} \]: sec/primary

\[ \frac{D}{p} \]: sec/primary, D-bar searches
AMS: Identification of isotopes

Isotopes: Identified from the concurrent measurement of Rigidity \((p/Z)\) and Velocity

\[
M = \frac{RZ}{\gamma \beta} \Rightarrow \frac{\Delta M}{M} = \sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\frac{\gamma^2 \Delta \beta}{\beta}\right)^2}
\]

- **Z measurement:**
  L1->UTof->(L1-L8)Tracker->LTof: negligible charge confusion

- **R measurement:**
  (L1-L8) Tracker

- **Velocity measurement:**
  - ToF: 4 Layers, \(\Delta \beta/\beta \sim 1-2\%\)
  - RICH NaF: \(\Delta \beta/\beta \sim 0.3\%, \beta > 0.75\)
  - RICH Agl: \(\Delta \beta/\beta \sim 0.1\%, \beta > 0.95\)
AMS: Identification of isotopes

D mass resolution

\[ M = \frac{RZ}{\gamma \beta} \Rightarrow \frac{\Delta M}{M} = \sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\gamma^2 \frac{\Delta \beta}{\beta}\right)^2} \]

-> Template fit of mass distributions
Templates for the mass distributions

\( ^6\text{Li}/^7\text{Li} \) and \( ^3\text{He}/^4\text{He} \):

- Template reconstructed from \( \beta \) and \( R \) resolution models obtained from MC
- Systematic in the mass template shapes: varying the \( \beta \) resolution and \( R \) resolution models (shift, width and tails)

ToF mass templates: \( E_{\text{kin}} = [0.40-0.45] \text{ GeV/n} \)

**D/p:**

- Collection of mass templates from MC of D and p: Fine tuning of MC \( \beta \) resolution
- Best fitting template is chosen
- Systematic in the mass template fit from spread of results

1 template for each isotope, each energy bin, each analysis.
Measurement of the Isotope abundances

- Isotope abundances fitted on the mass distributions on data by weighting isotope mass templates:

- Errors on abundances include statistical error and systematic error from the mass template shapes.
Reconstruction of fluxes

Isotopic fluxes:

- Computed from abundances, effective acceptances and exposure time.
- Corrected for contamination from fragmentation of heavier nuclei.
- Unfolded to correct energy migration due to finite $\beta$ resolution.

Preliminary data, refer to upcoming AMS PRL publication
Isotope fluxes vs kinetic energy per nucleon

- **Ekin per n**: Comparison with previous experiments
- First measurement of $^6$Li and $^7$Li fluxes above 0.3 GeV/n.
- First precision measurement of D above 1 GeV/n

![Graph 1: $^6$Li flux vs Ekin](image1)

![Graph 2: D flux vs Ekin](image2)

![Graph 3: $^7$Li flux vs Ekin](image3)
Isotope fluxes vs Rigidity

- Use of different binning vs $E_{k/n}$ to get the same rigidity bins (accounting for En. loss)
- Full isotopic analysis done for the two binning
- $E_{k/n} \rightarrow R$ conversion for each Isotope.

First isotopic measurements in the 1-20 GV rigidity range

Preliminary data, refer to upcoming AMS PRL publication
Isotope flux ratios vs E\textsubscript{kin}/n

- **E\textsubscript{kin} per n**: Comparison with previous experiments
- First measurement of $^{4}\text{He}/^{4}\text{He}$ above 3 GeV/n
- First measurement of $^{6}\text{Li}/^{7}\text{Li}$ above 1 GeV/n
- First precision measurement of D above 1 GeV/n

![Graph of $^{3}\text{He}/^{4}\text{He}$ vs E\textsubscript{kin}/n]

![Graph of Preliminary data, refer to upcoming AMS PRL publication]

![Graph of $^{6}\text{Li}/^{7}\text{Li}$ vs E\textsubscript{kin}/n]

![Graph of Preliminary data, refer to upcoming AMS PRL publication]
Isotope flux ratios vs R

- **R:** ~ time independent (Interaction with variable solar wind is R-dependent)
- First measurement of $^{6}\text{Li}/^{7}\text{Li}$ against rigidity above 6 GV

- **Above 4 GV:** compatible with single power law
- **Below 4 GV:** AMS02 discovered a low energy time dependence of the $^{3}\text{He}/^{4}\text{He}$ ratio
In general, CR flux is **anticorrelated** with solar activity.

AMS-02 scanned the complete 24th cycle.

Time dep. of $^{3}\text{He}/^{4}\text{He}$ ratio modeled with:

$$r_i(t) = \begin{cases} a_i & t < t_i \\ a_i + b_i(t - t_i) & t \geq t_i \end{cases}$$

$t_i = \text{February 25th, 2015}$
D/p flux ratio time dependence

- $\Delta T = 1$ Bartel rot. (27 days): D show same time structures as p

- $\Delta T = 4$ Bartel rot.: First hints of low energy D flux time dependence

- Same break at 2015, 25th February, correlated with polarity flip of solar magnetic field

Preliminary data, refer to upcoming AMS PRL publication

$$r_i(t) = \begin{cases} a_i & t < t_i \\ a_i + b_i(t - t_i) & t \geq t_i, \end{cases}$$

$1.35 \text{ GV}$

$3.50 \text{ GV}$

$7.80 \text{ GV}$

$4.4 \times 10^3 \text{ yrs}^{-1}$
Conclusions

- Isotopic composition of light nuclei in cosmic rays is a key measurement to understand cosmic rays origin and propagation.
- First measurement of $^6$Li and $^7$Li fluxes above 0.3 GeV/n.
- First precision measurement of D flux above 1 GeV/n.
- First measurement of $^3$He/$^4$He ratio above 2 GeV/n.
- Measurements in rigidity from 1 to 20 GV.
- AMS02 discovered a time dependence in the low energy (R < 4GV) $^3$He/$^4$He ratio.
- Similar time dependence from the measurement of D/p ratio.
Thanks for your attention