Unique Properties of Secondary Cosmic Rays: Results from the Alpha Magnetic Spectrometer

A. Oliva[*] on behalf of the AMS-02 Collaboration.
[*]Istituto Nazionale di Fisica Nucleare, Sez. di Bologna

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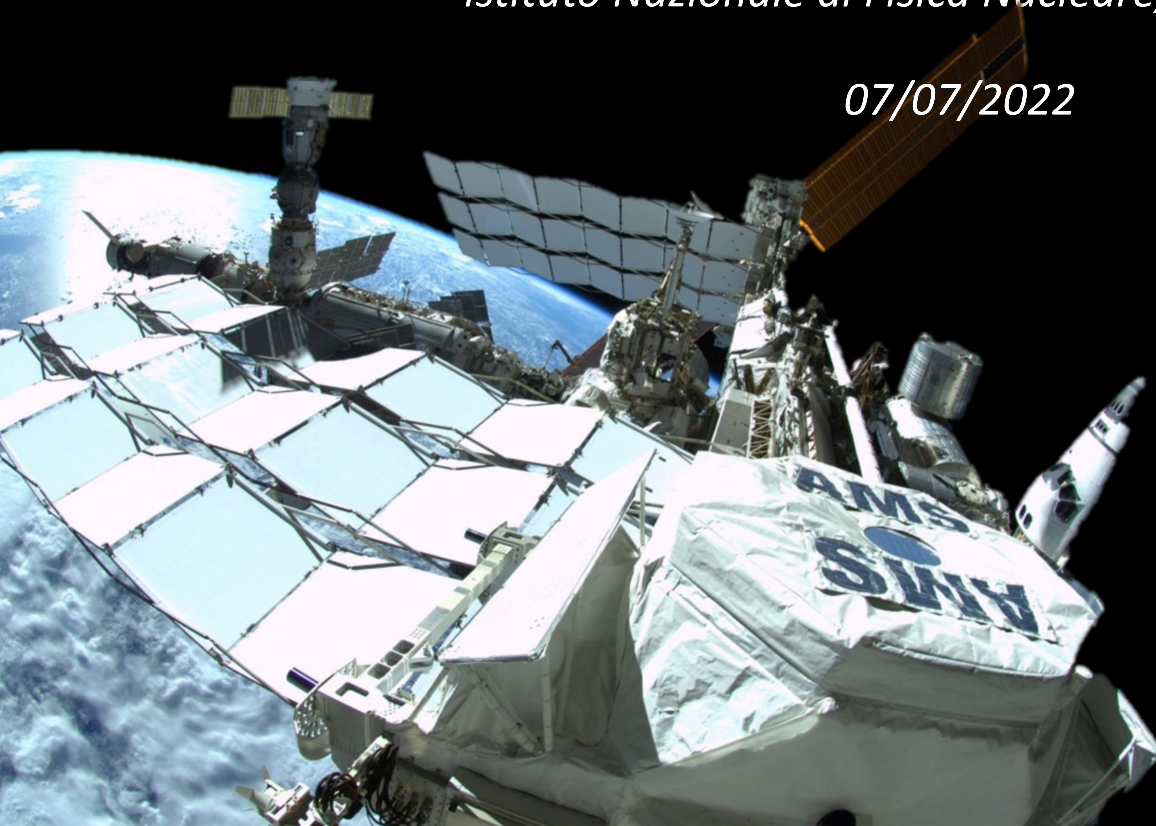

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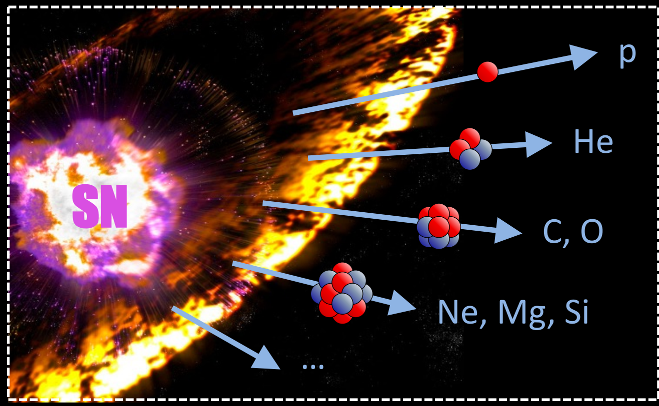
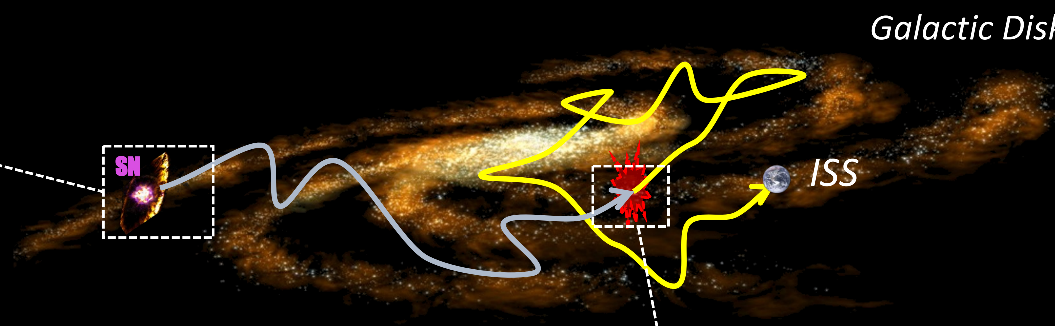
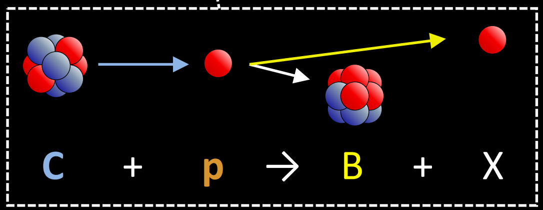
Galactic Cosmic Rays



Primary CRs (p, He, C, O, Ne, Mg, Si, ..., Fe) are thought to be mostly produced during the lifetime of stars and accelerated in supernovae shocks in our Galaxy.



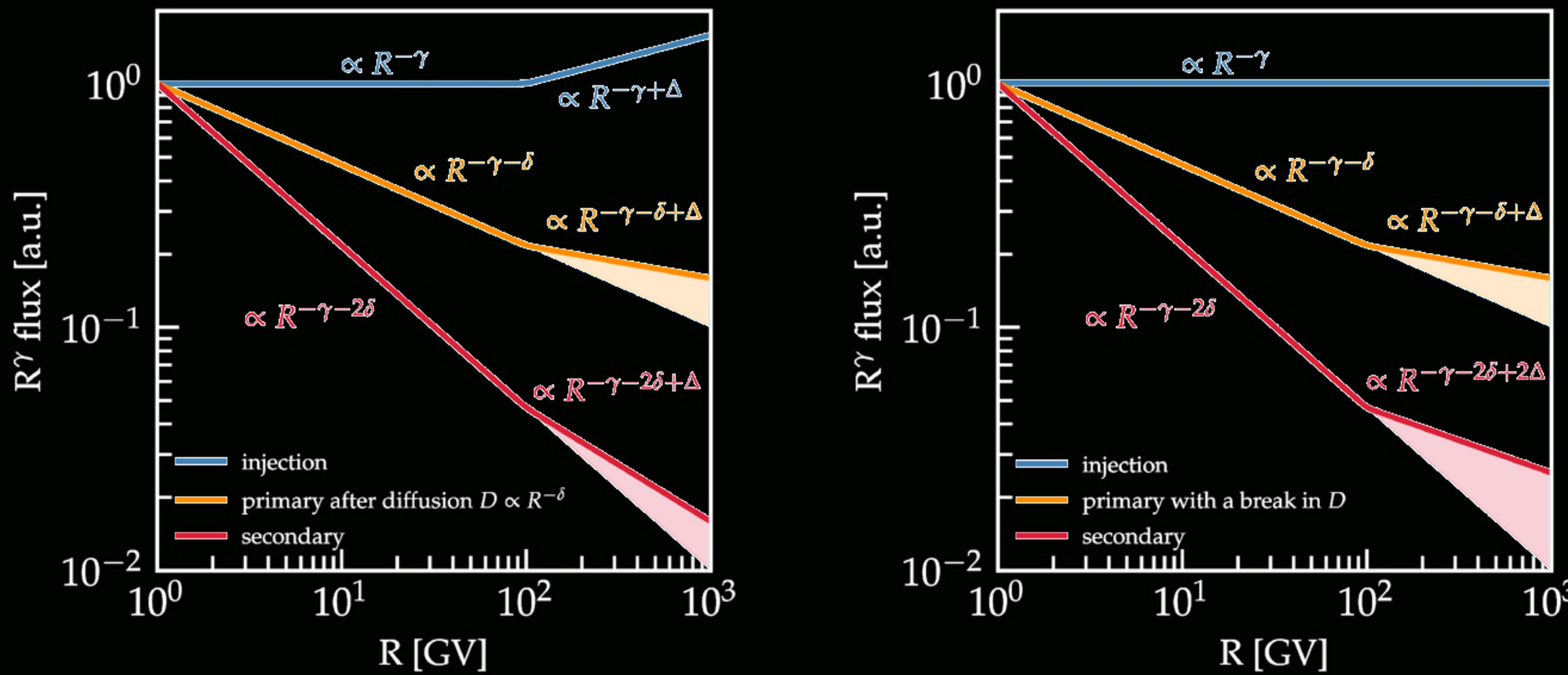
Secondary CRs (Li, Be, B, F, sub-Fe, ...) are mostly produced from collision of primaries with the interstellar medium (mostly p and He).



The measurement of CRs nuclei energy spectra carries information about **sources**, **acceleration** and **propagation** processes of all CRs.

Cosmic Ray Propagation

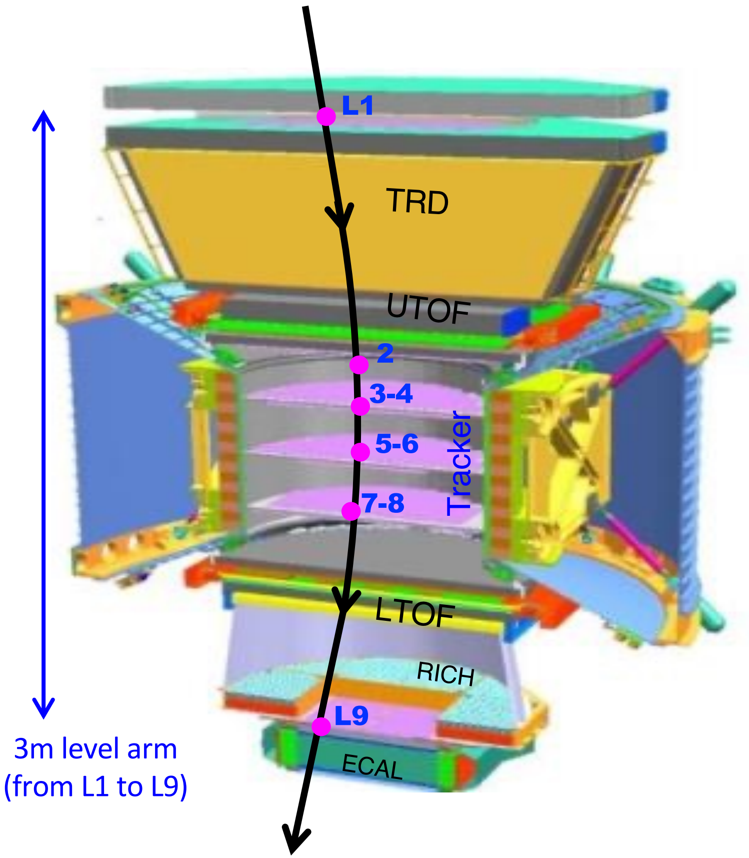
From C. Evoli (2019).



If the hardening in CRs is related to the **injected spectra** at their source, then **similar hardening** is expected both for **secondary** and **primary** cosmic rays.

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.

AMS Nuclei Measurement



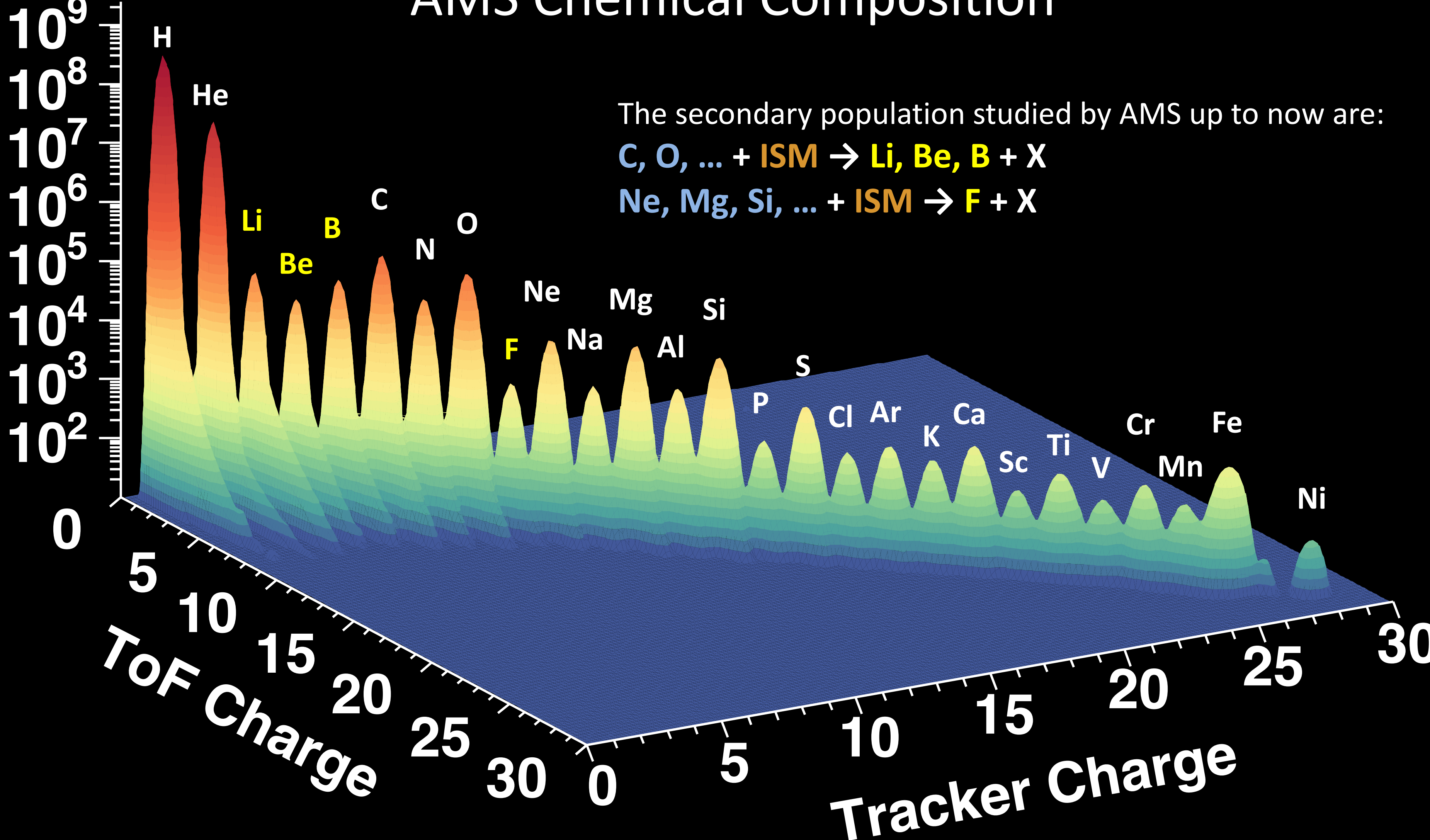
Particle Rigidity (momentum/charge) is measured combining Tracker (9 Layers) + Magnet

	Coordinate Resolution	MDR
Z =1	10 μm	2 TV
$2 \leq Z \leq 8$	5-7 μm	3.2-3.7 TV
$9 \leq Z \leq 14$	6-8 μm	3-3.5 TV

Particle is identified using consistency of charge measured in L1, UTOF, Inner Tracker (L2-L8), LTOF and L9.

	Tracker L2-L8 Charge Resolution (c.u.)
$1 \leq Z \leq 8$	$\Delta Z \approx 0.05\text{-}0.12$
$9 \leq Z \leq 14$	$\Delta Z \approx 0.13\text{-}0.17$

AMS Chemical Composition

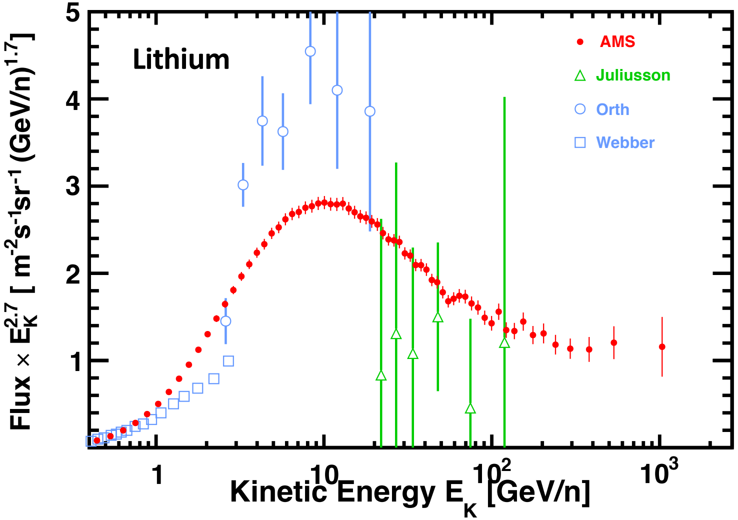


The secondary population studied by AMS up to now are:

C, O, … + ISM → Li, Be, B + X

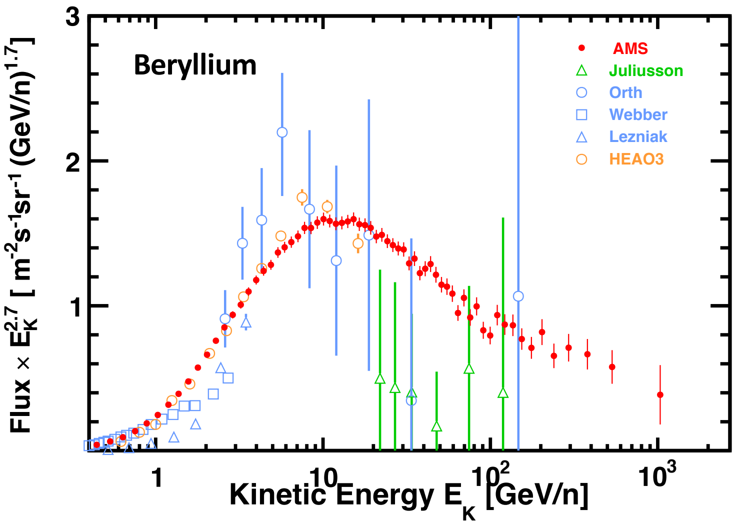
Ne, Mg, Si, … + ISM → F + X

Li, Be, B Fluxes Measured by AMS

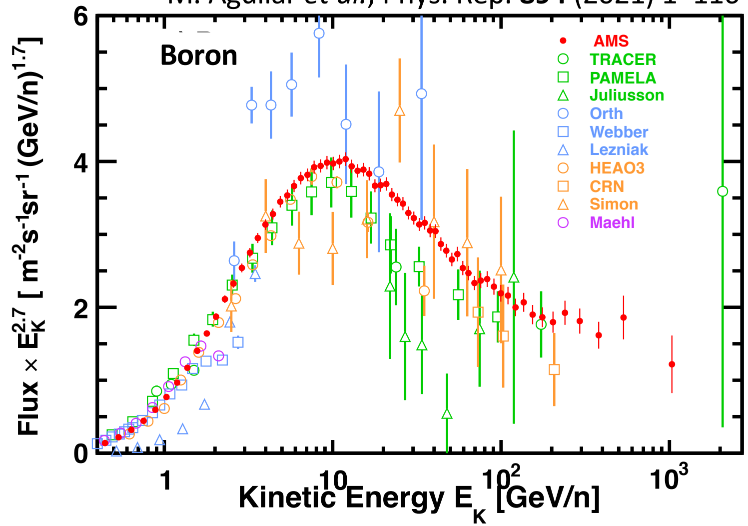


Over the last 50 years, only a few experiments have measured the Li and and Be fluxes above a few GV. Typically, these measurements have errors larger than 50% at 50 GeV/n.

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



M. Aguilar *et al.*, Phys. Rep. **894** (2021) 1–116



Li, Be, B Fluxes Measured by AMS

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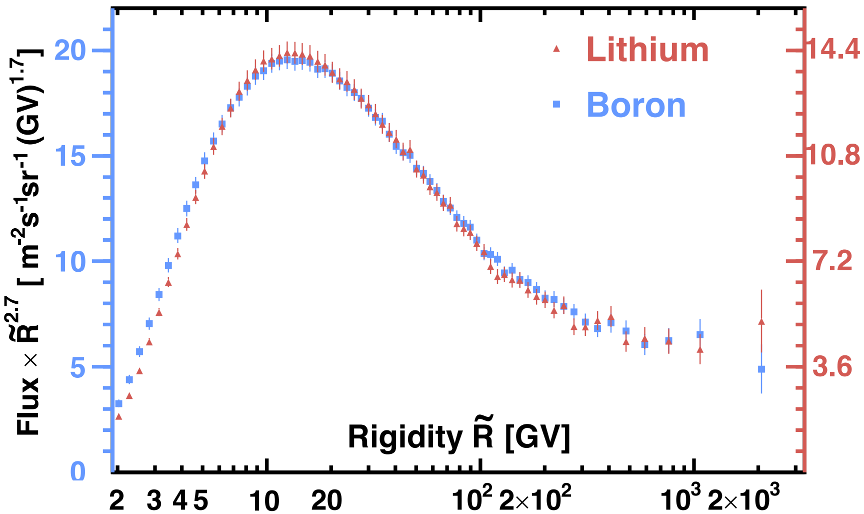
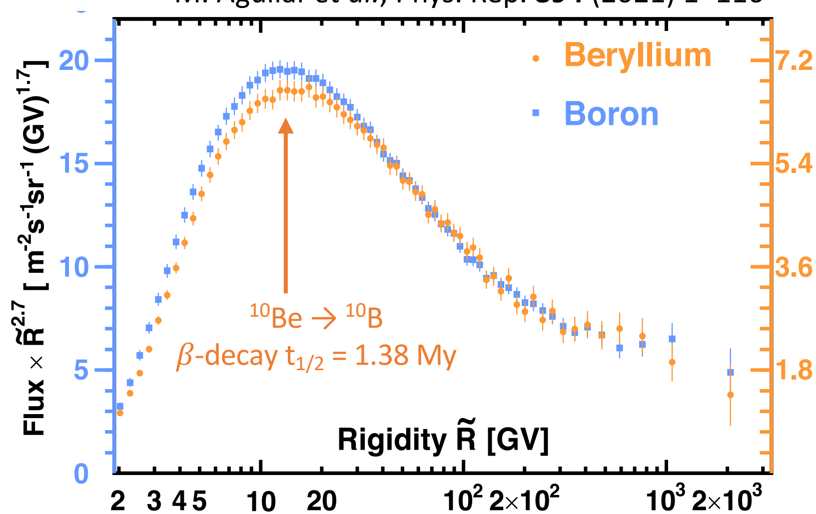
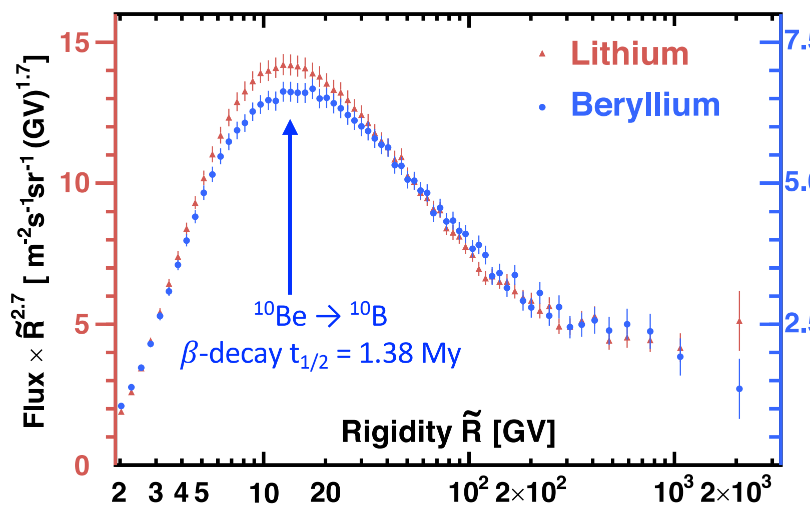


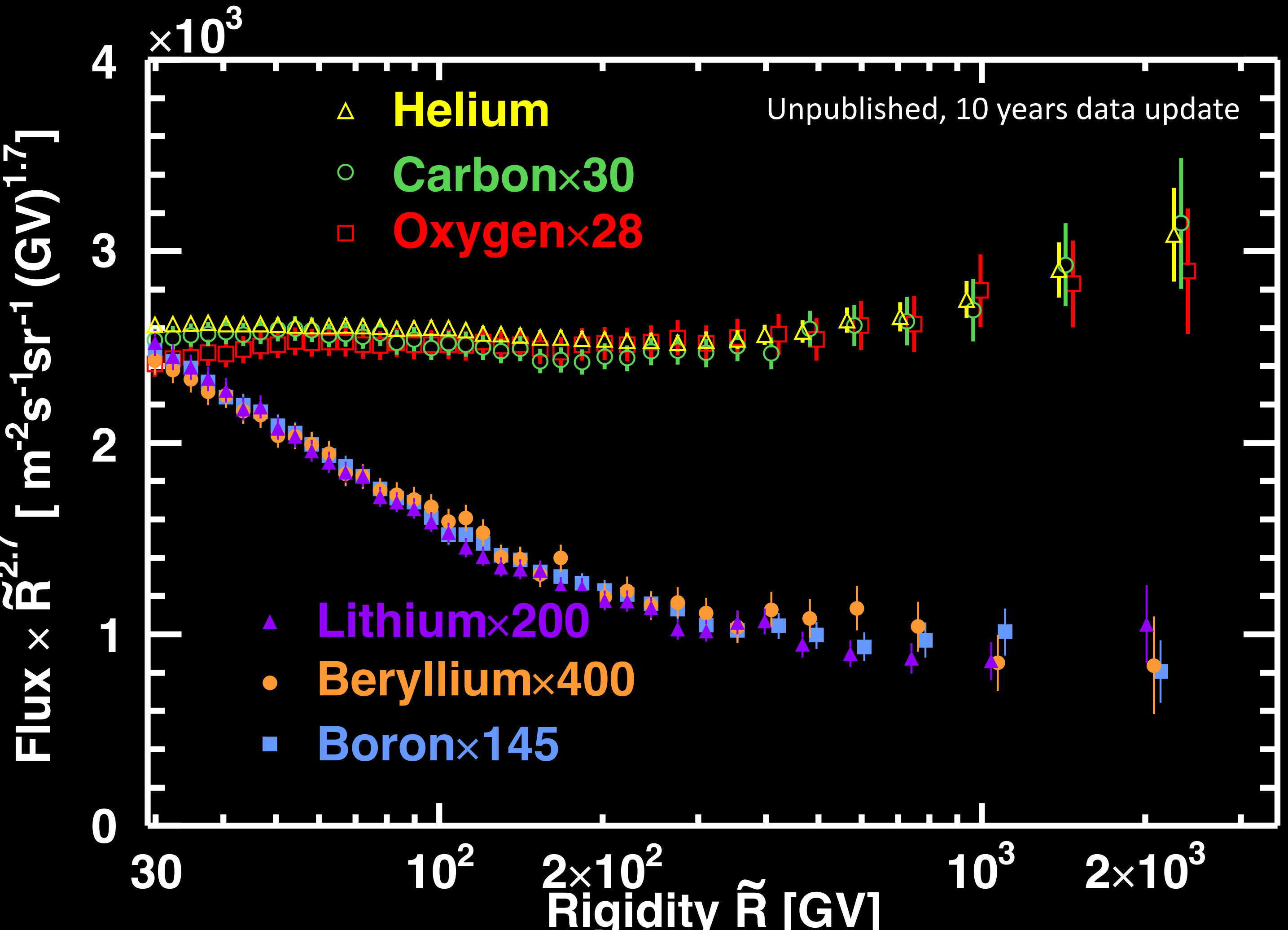




The Li and B fluxes have an identical rigidity dependence above 7 GV.

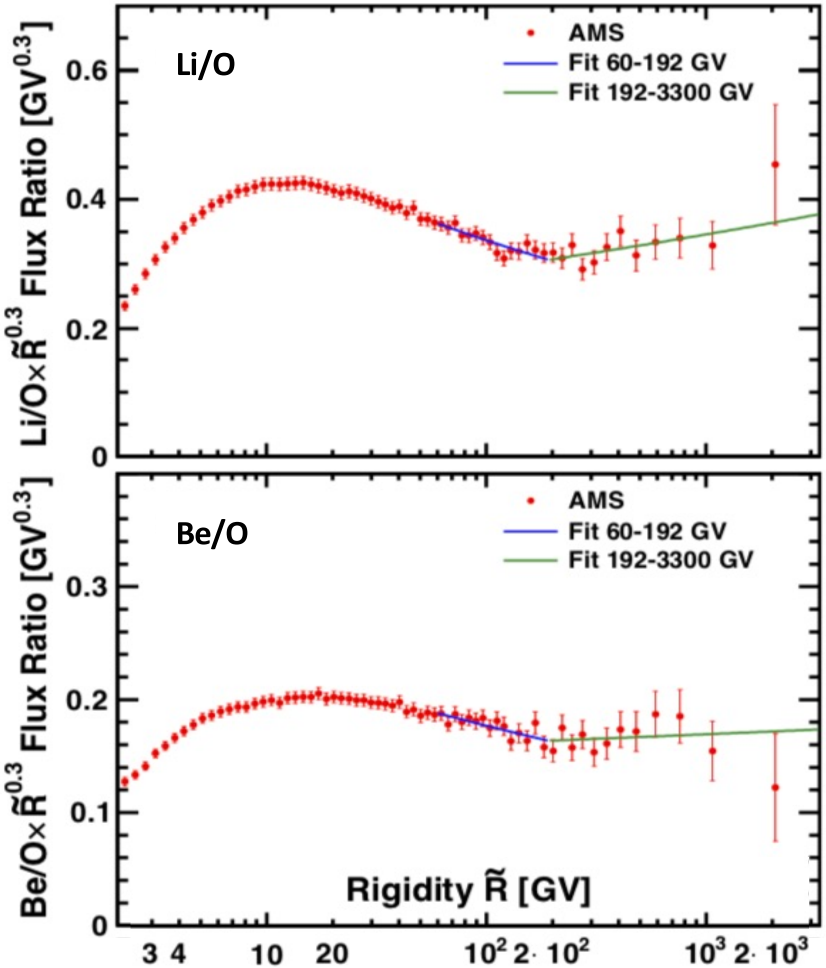
All three fluxes have an identical rigidity dependence above 30 GV.

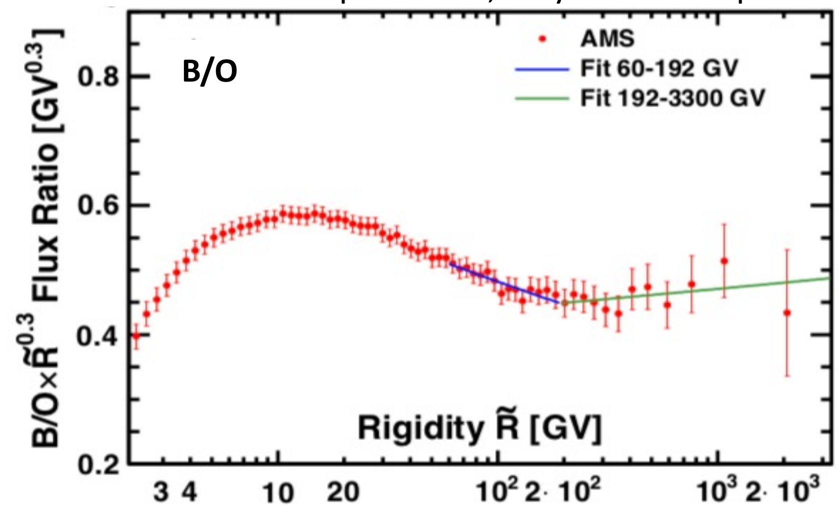
Light Ions Primary and Secondary Fluxes



Secondary-to-Primary Ratios

Unpublished, 10 years data update





The Li/O, Be/O, and B/O flux ratios were fitted to:

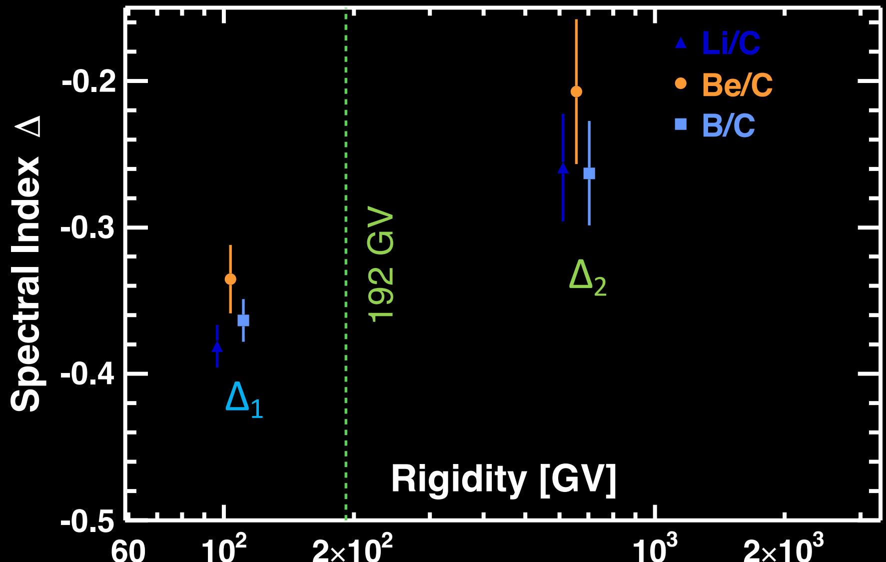
$$\begin{cases} C\,(R/192\ \mathrm{GV})^{\Delta_1}, & R \leq 192\ \mathrm{GV}, \\ C\,(R/192\ \mathrm{GV})^{\Delta_2}, & R > 192\ \mathrm{GV}. \end{cases}$$

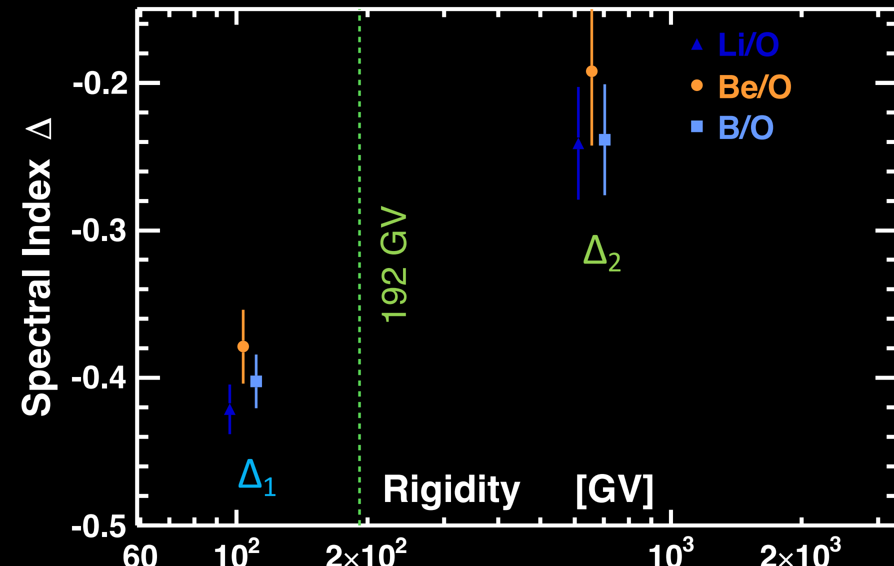
Above 192 GV, the secondary-to-primary flux ratios exhibit an additional hardening, or the secondary cosmic rays hardens more than the primary.

Secondary-to-Primary Ratio Spectral Indices

Above 192 GV all six secondary-to-primary flux ratios harden.

Unpublished, 10 years data update



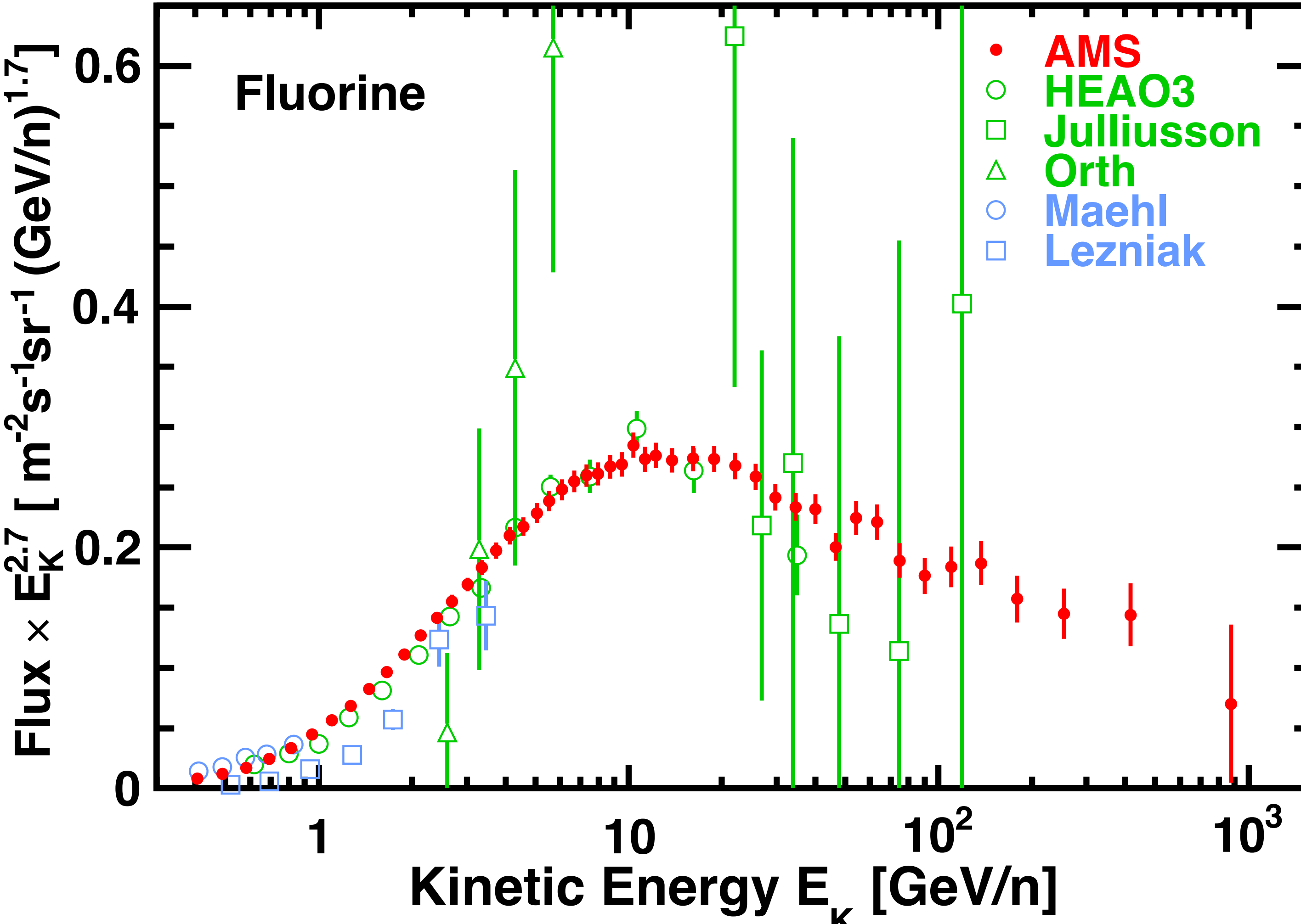


Average **hardening** $\Delta = \Delta_2 - \Delta_1 = 0.145 \pm 0.022$, significance: $\mathbf{6.5\sigma}$

This new observation strongly favors the hypothesis that **the observed spectral hardening** is due to a **propagation effect**

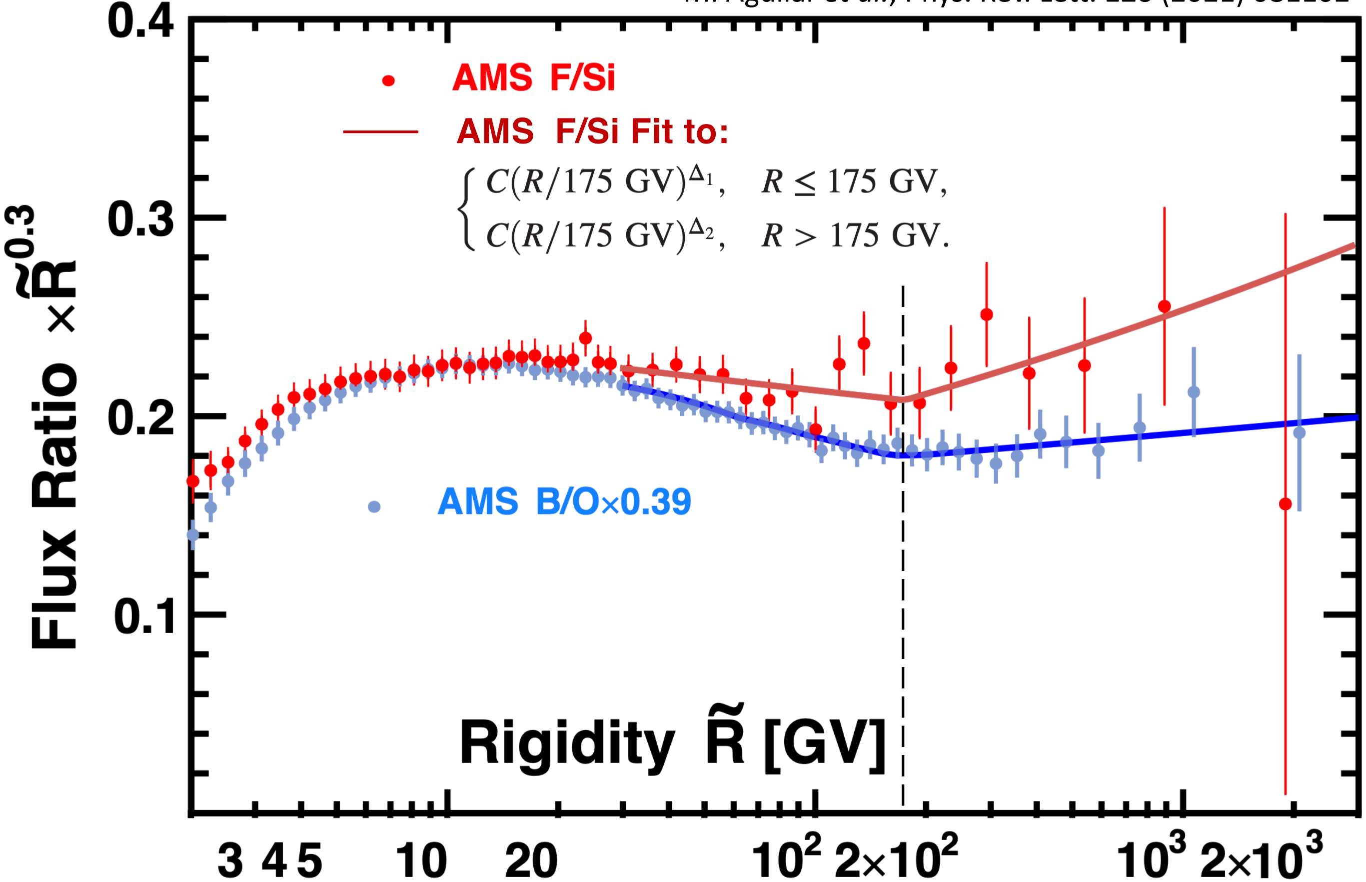
Fluorine Flux Measured by AMS

M. Aguilar *et al.*, Phys. Rev. Lett. **126** (2021) 081102



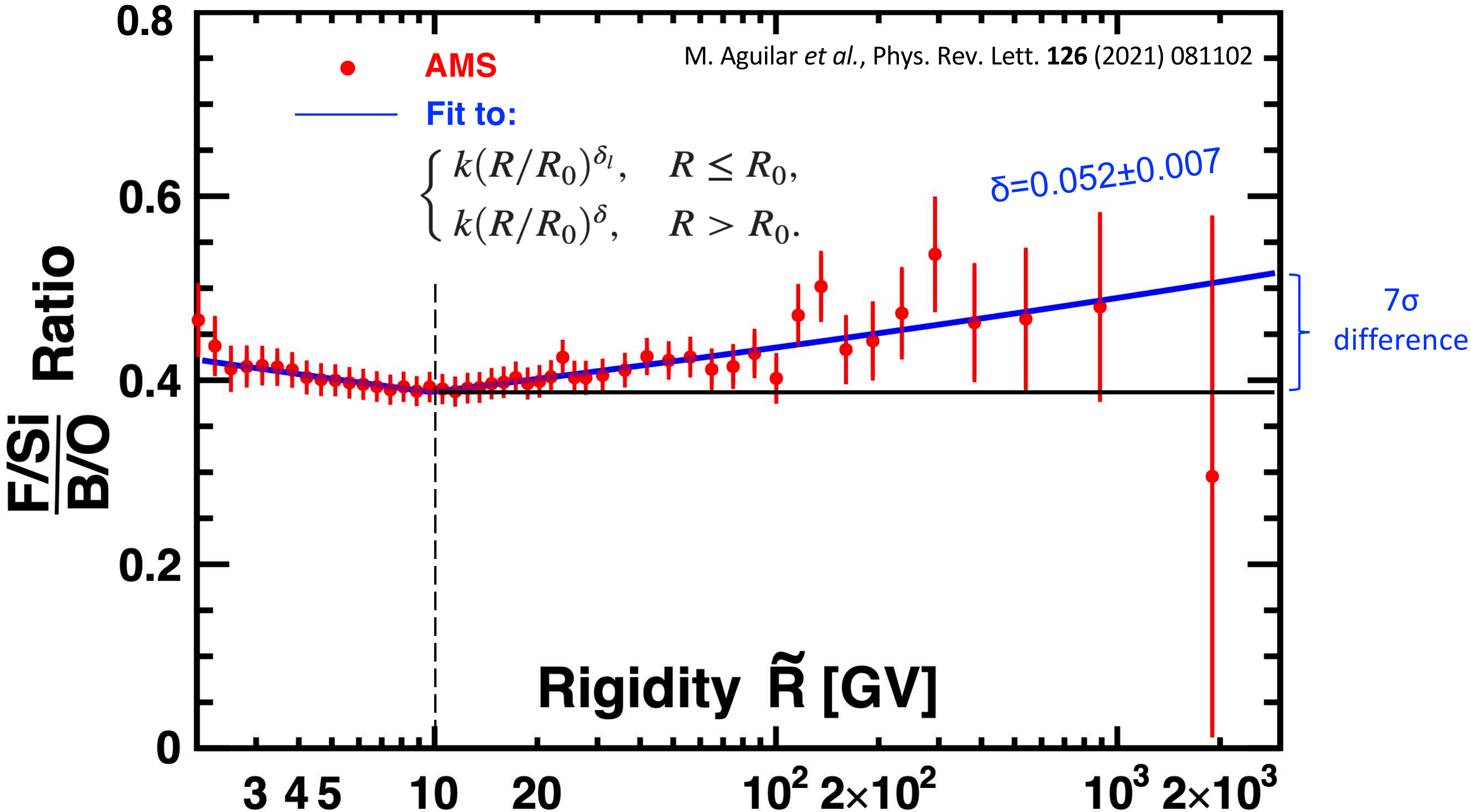
Heavy (F/SI) and Light (B/O) Primary-to-Secondary Ratios

M. Aguilar *et al.*, Phys. Rev. Lett. **126** (2021) 081102



Above 175 GV, the F/Si ratio exhibits a hardening ($\Delta_2^{F/Si} - \Delta_1^{F/Si}$) of 0.15 ± 0.07 compatible with the AMS result on the hardening of the Li/O, Be/O, and B/O flux ratios.

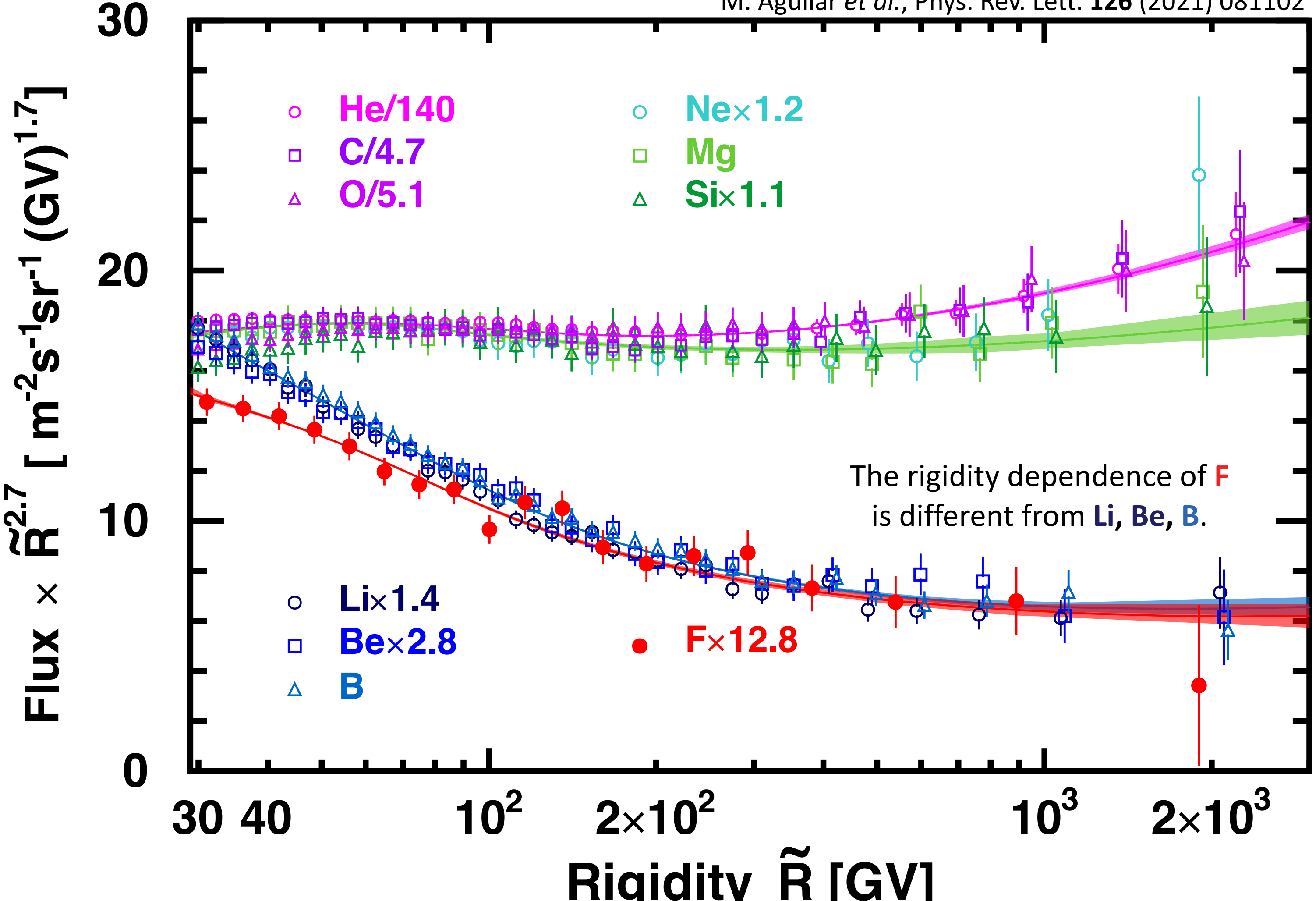
The (F/Si)/(B/O) Ratio



Above 10 GV, the (F/Si)/(B/O) ratio can be described by a single power law with **δ = 0.052 ± 0.007**.
The propagation properties of heavy cosmic rays (F–Si), are different from those of light cosmic rays (He–O).

Light Ions Primary and Secondary Fluxes from He to Si

M. Aguilar *et al.*, Phys. Rev. Lett. **126** (2021) 081102



Conclusions

- The latest AMS results on the secondary cosmic ray **Li, Be, B,** and **F** fluxes from 2 GV to 3 TV were presented.

- The spectra of secondary cosmic ray Li, Be, B all deviate from single power law above 200 GV. The **spectral hardening of the secondary cosmic rays is larger than primary** cosmic ray (He, C, O) by more than 5σ. The F flux, and the F/Si ratio, show that this additional hardening is also present in the heavier secondary cosmic rays.

- Unexpectedly, the heavier secondary-to-primary F/Si flux ratio rigidity dependence is distinctly different from the lighter B/O ratio by more than 7σ. This reveals that the propagation properties of **heavy cosmic rays**, from F to Si ($9 \le Z \le 14$), are **different** from those of **light cosmic rays**, from He to O ($2 \le Z \le 8$).

- Future high precision AMS measurements of all heavy secondary cosmic nuclei ($Z>14$), such as Sub-Fe, will provide **unique insights** into the understanding of the cosmic rays.