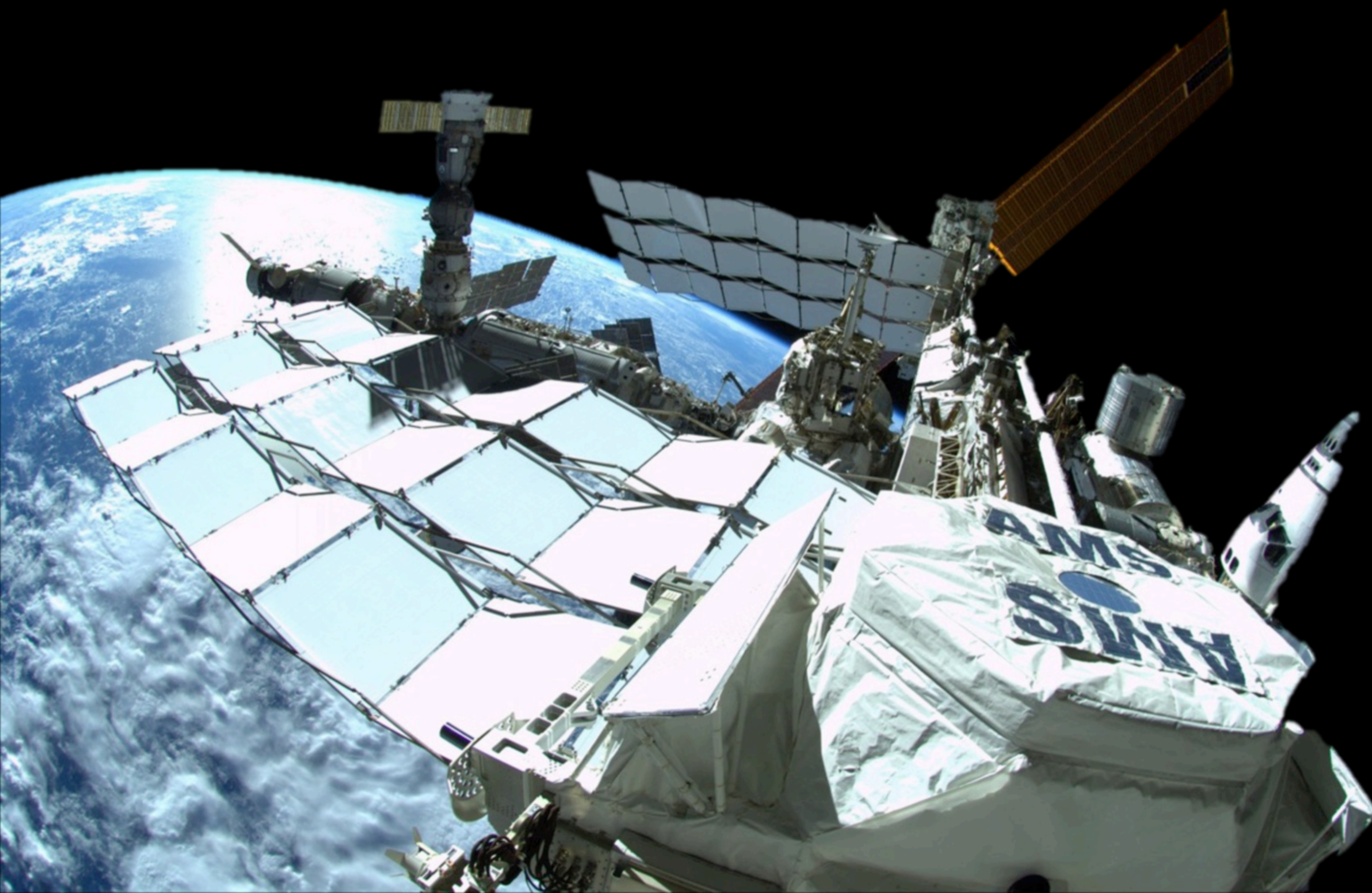
Properties of Secondary Cosmic Rays Lithium, Beryllium and Boron Measured by the Alpha Magnetic Spectrometer

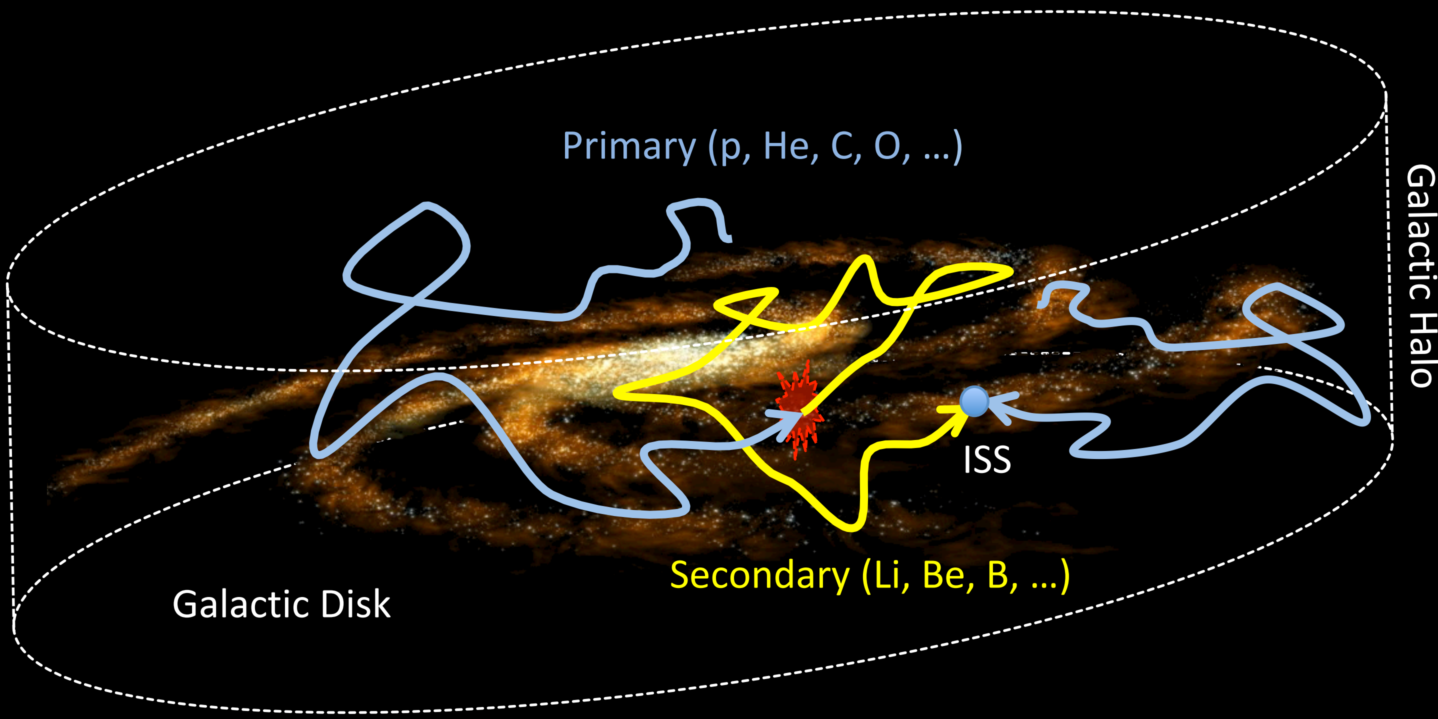
A. Oliva[*] on behalf of the AMS-02 Collaboration.
[*]Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Madrid, Spain



ICRC 2019,
29/07/2019,
Madison (WI), USA

Secondary Cosmic Rays

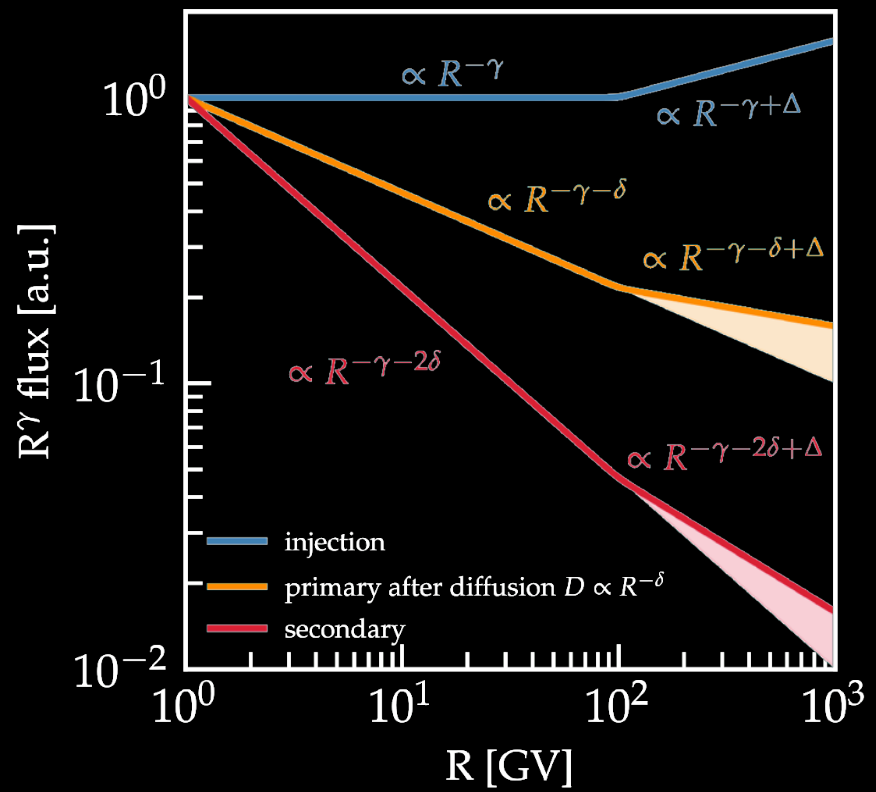
Lithium, Beryllium and Boron are mostly to be produced purely from collision of cosmic rays, such as Carbon and Oxygen, with the interstellar medium (ISM).

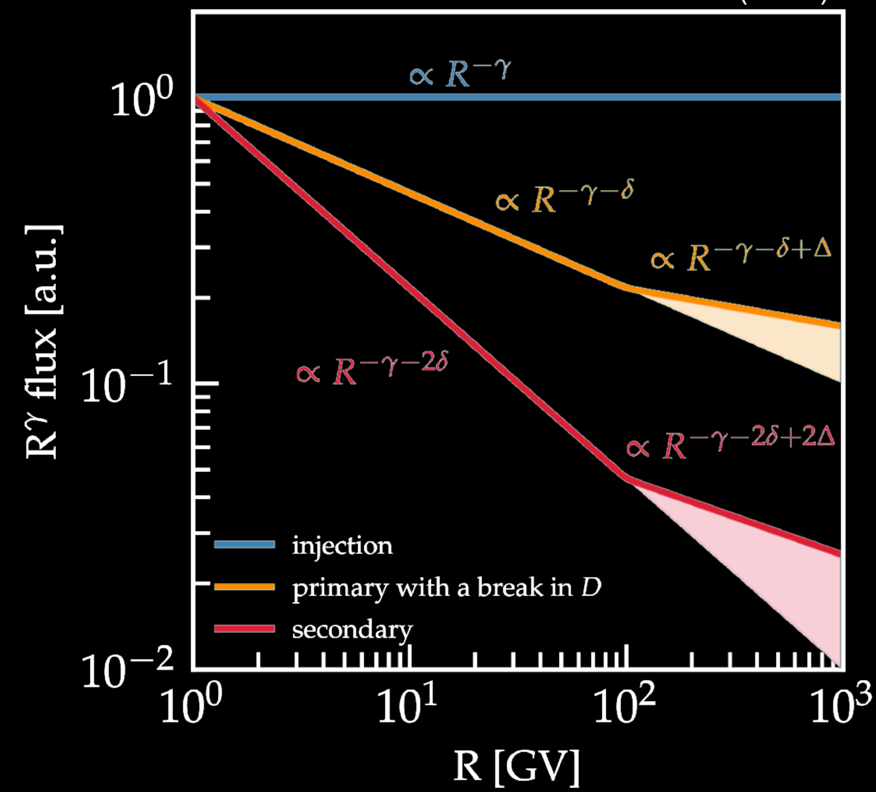


Cosmic rays are commonly modeled as a relativistic gas diffusing into a magnetized plasma. Diffusion models based on different assumptions predict a Sec/Pri ratio asymptotically proportional to $\mathbf{R^{\delta}}$. With Kolmogorov turbulence model a $\boldsymbol{\delta = -1/3}$ is expected, while Kraichnan theory leads to $\boldsymbol{\delta = -1/2}$.

Secondary Cosmic Rays

C. Evoli (2019)





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.

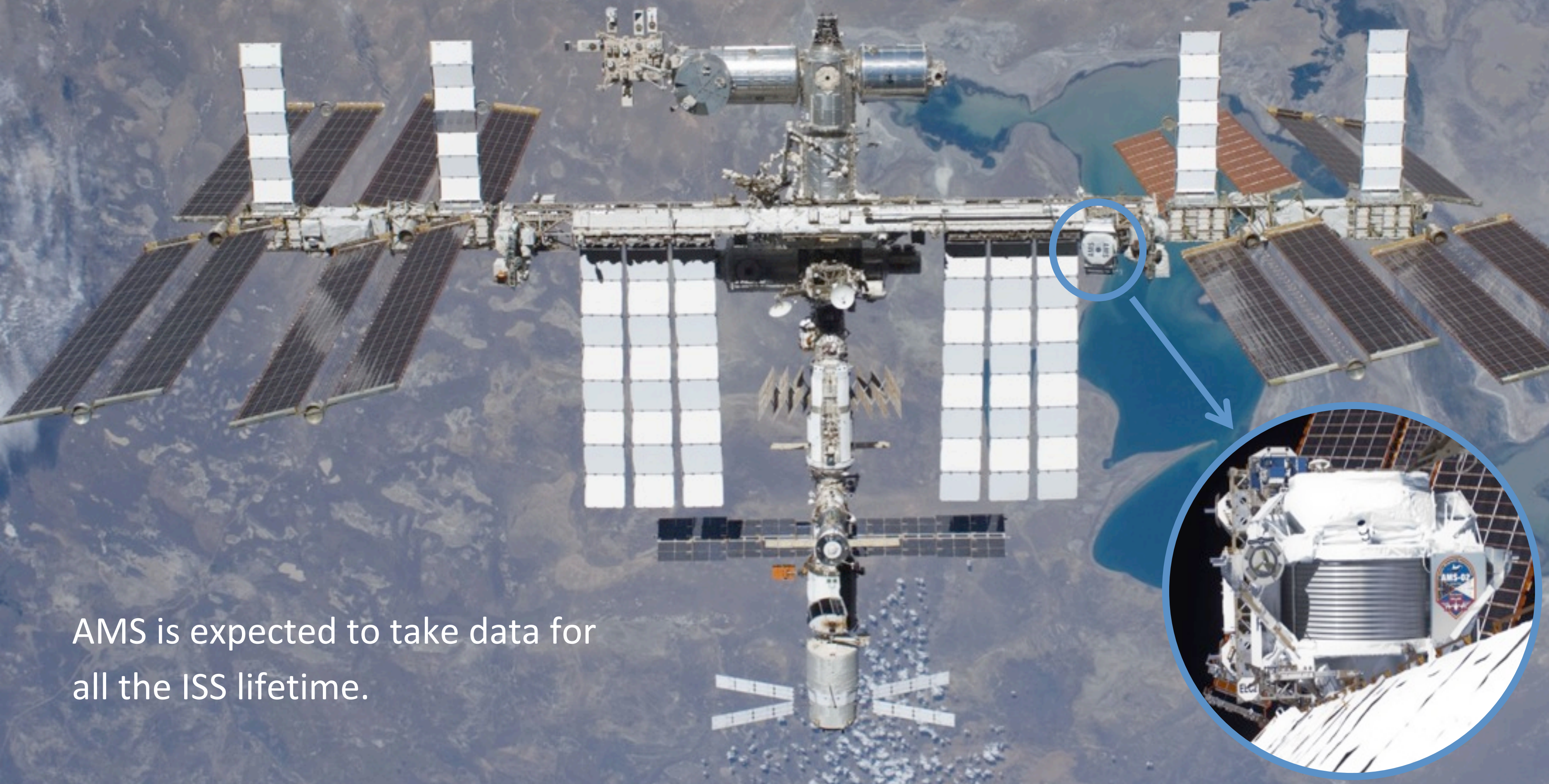
If the hardening is related to **propagation properties** in the Galaxy then a **stronger hardening** is expected for the secondary with respect to the primary cosmic rays.

AMS-02 On Orbit

From May 19th 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

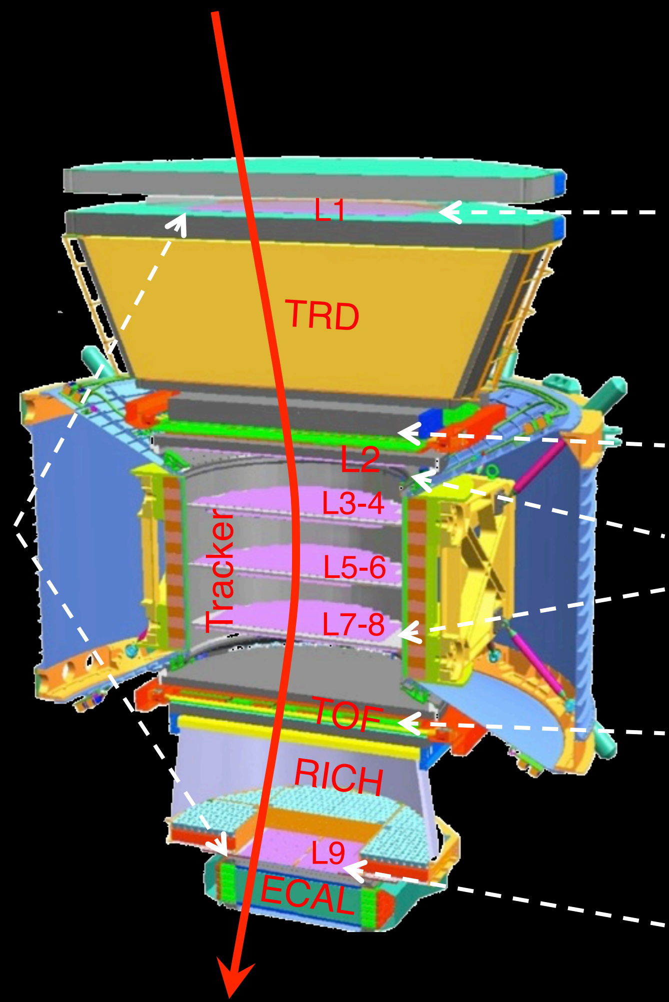
Momentum

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

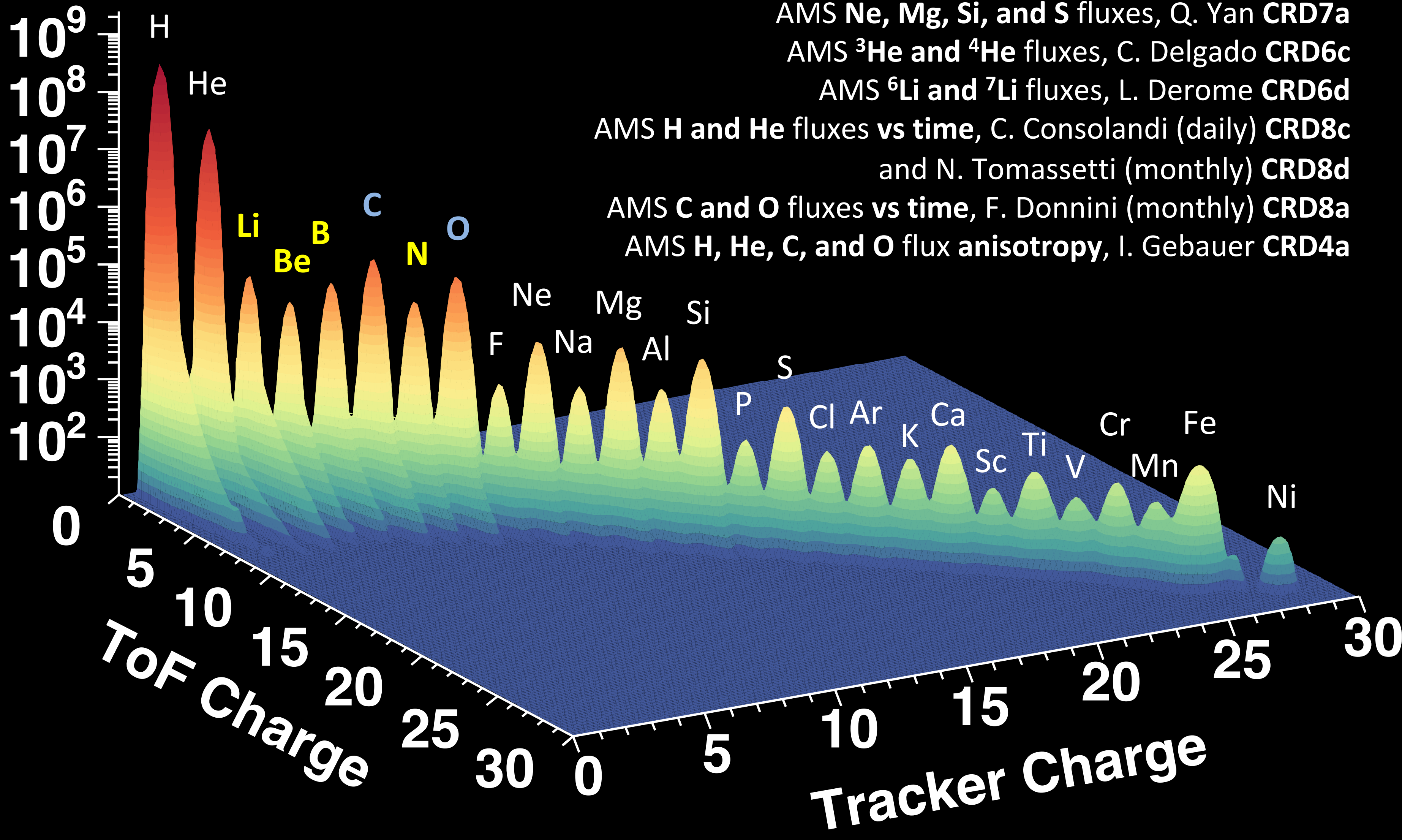


Charge

	ΔZ/Z(3≤Z≤5)
Tracker L1	4–6%
Upper TOF	3.5–5%
Tracker L2-L8	2–3%
Lower TOF	3.5–5%
Tracker L9	4–6%

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
$(\mathrm{m}^2\ \mathrm{sr}\ \mathrm{s}\ \mathrm{GV})^{-1}$

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

$$\Phi_i^Z = \frac{N_i^Z}{A_i^Z\,\epsilon_i^Z\,T_i\,\Delta R_i}$$

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

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

Exposure Time (s)
(1.23×10^8 s, for R > 30 GV)

Bin width (GV)
(depends on the MDR)

Ratio of counts

Ratio of eff. acceptances

Ratio of trigger eff.

$$B/C = \frac{\Phi_i^B}{\Phi_i^C} = \frac{N_i^B}{N_i^C}\cdot\left[\frac{A_i^B}{A_i^C}\cdot\frac{\epsilon_i^B}{\epsilon_i^C}\right]^{-1}$$

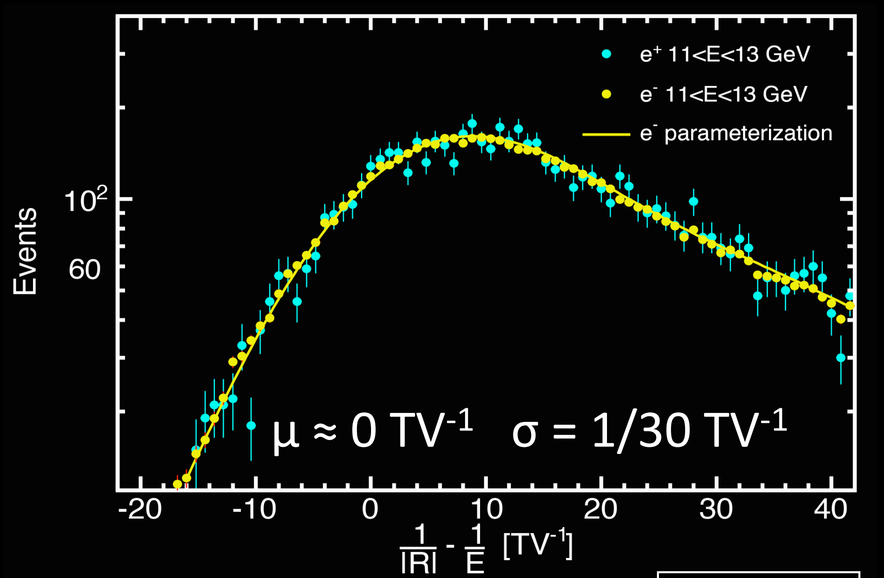
correlations in in systematic errors from uncertainties in nuclear interaction cross sections, bin-to-bin migration and rigidity scale are accounted.

Ratios of species **close in Z** have significantly **lower systematics** than fluxes.

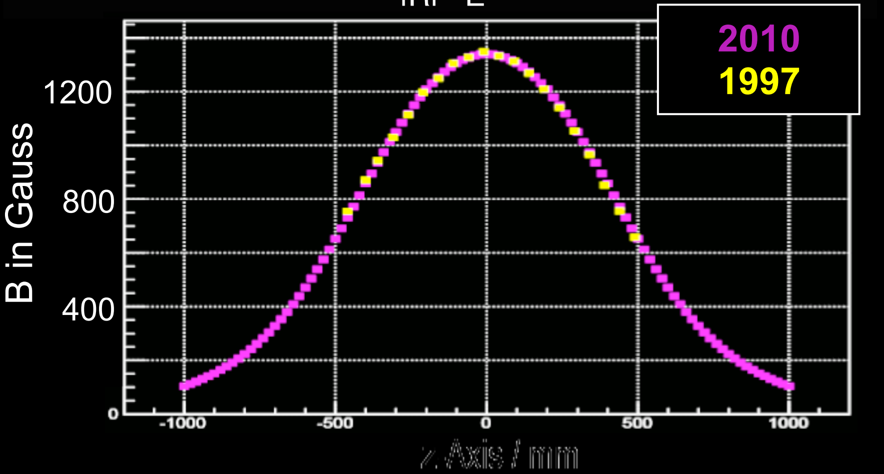
Rigidity Scale Uncertainty

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.



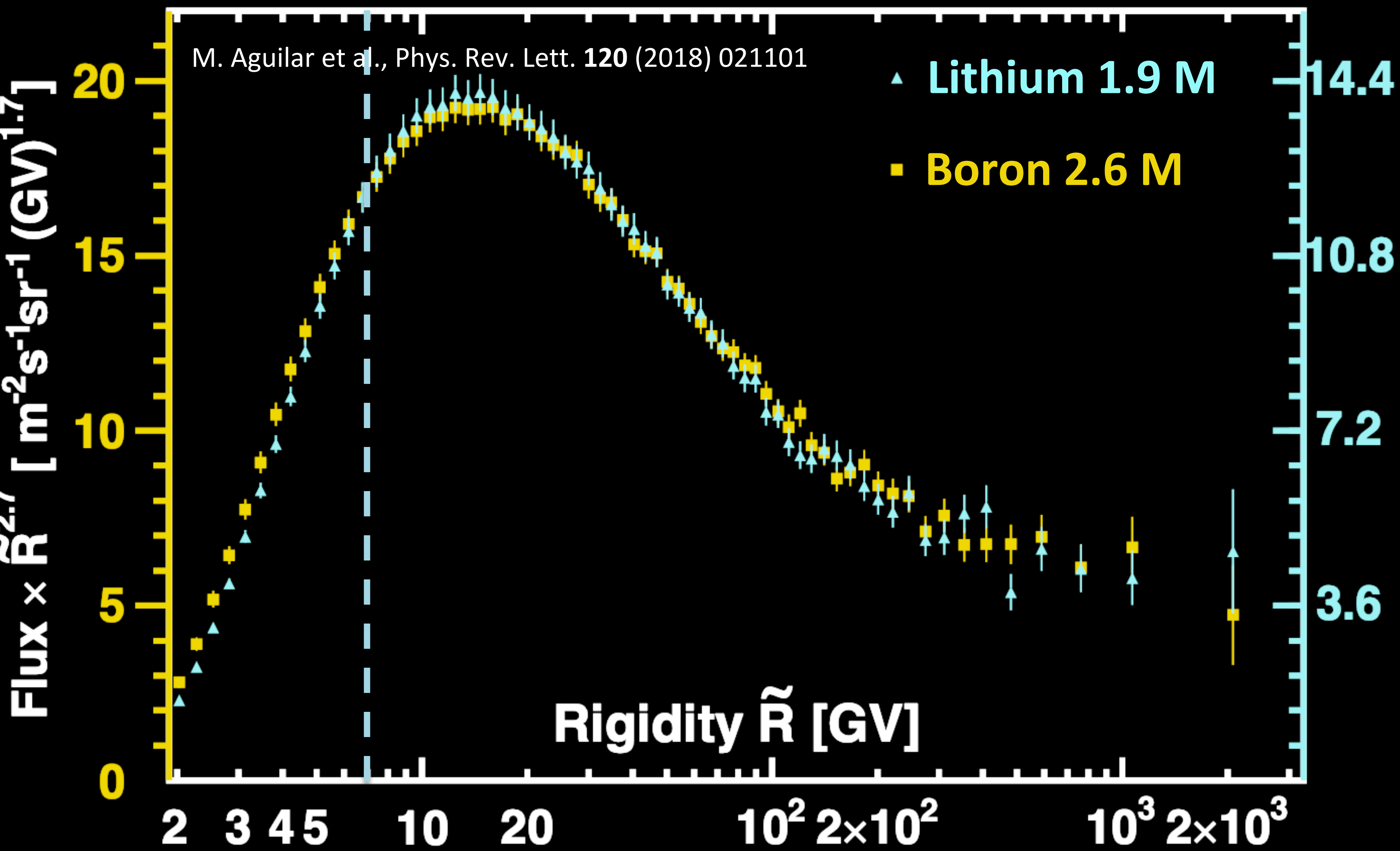
Magnetic field
mapping measurement (0.25%) and temperature corrections (0.1%). Taken in quadrature and weighted by the measured flux rigidity dependence.



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 ~ 1%.

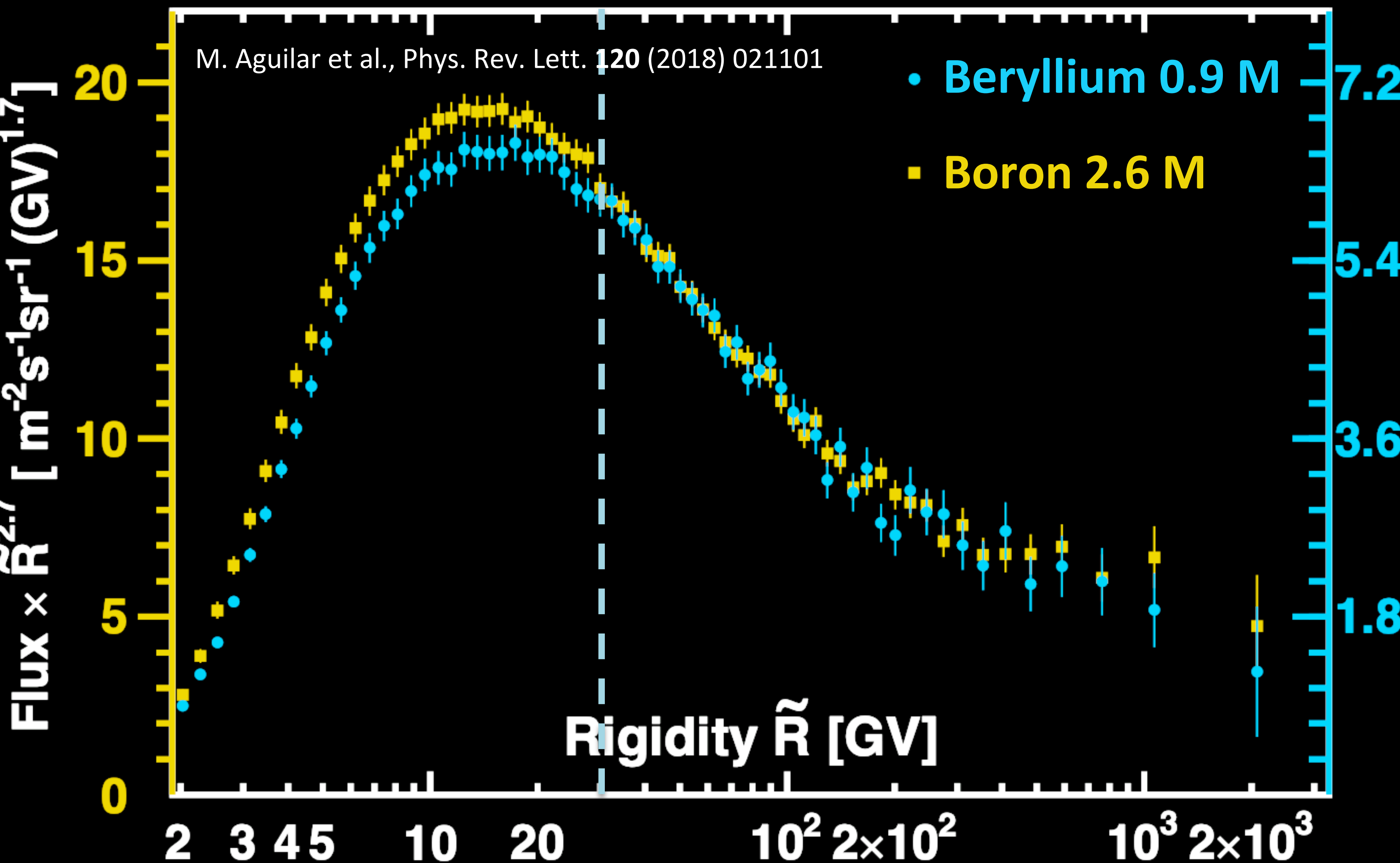
Lithium and Boron Fluxes

Identical above ~ 7 GV.



Beryllium and Boron Fluxes

Identical above ~ 30 GV. Effect of unstable ^{10}Be component.

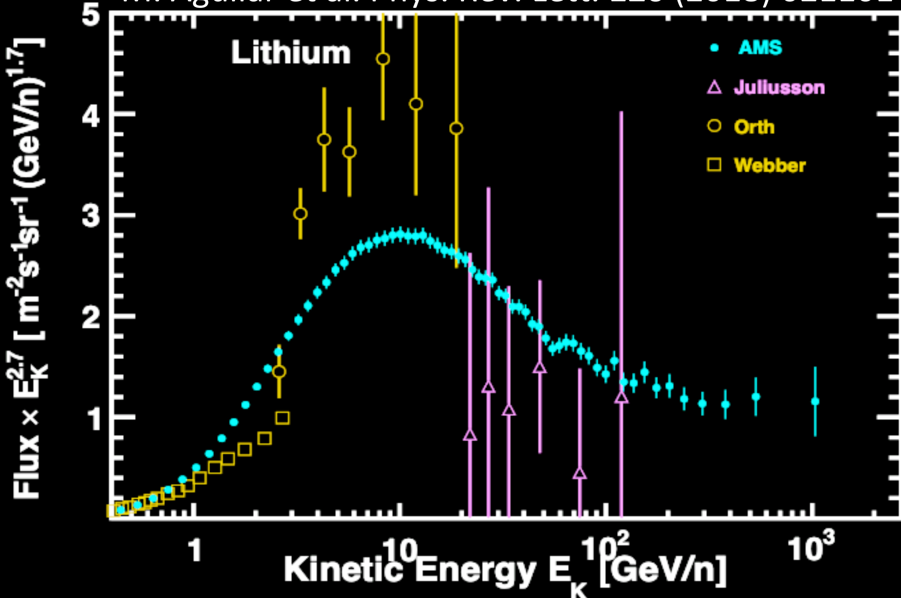


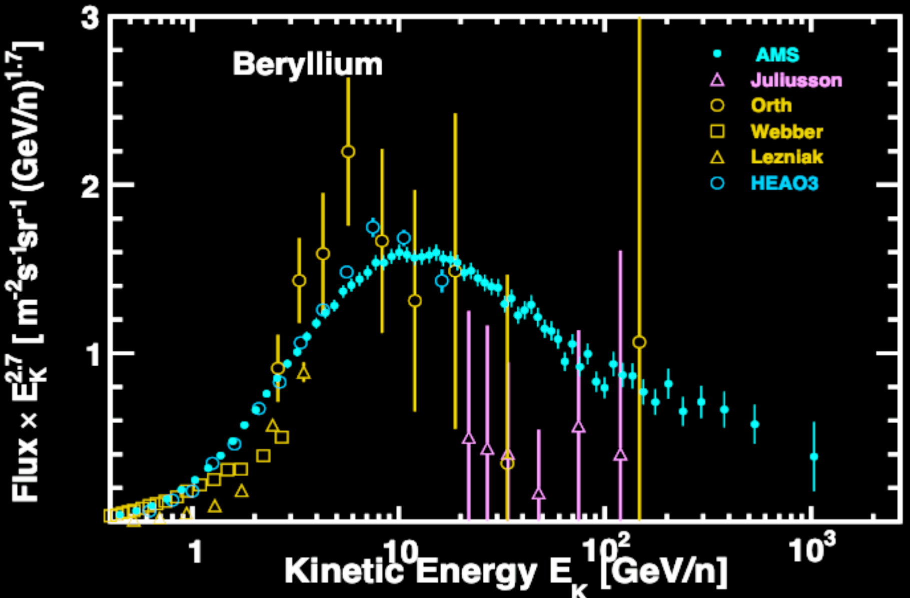
Li, Be and B Fluxes in Kinetic Energy

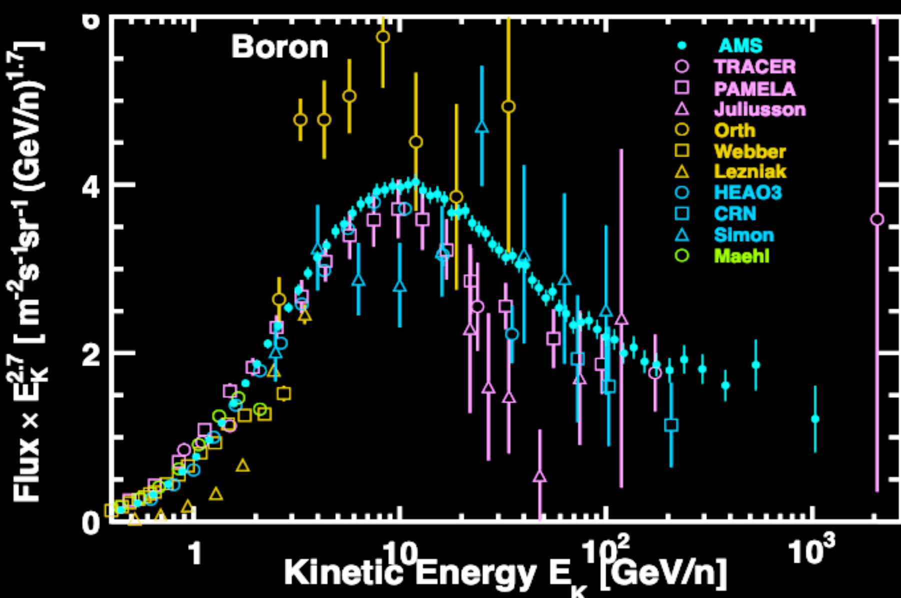
M. Aguilar et al. Phys. Rev. Lett. **120** (2018) 021101

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.

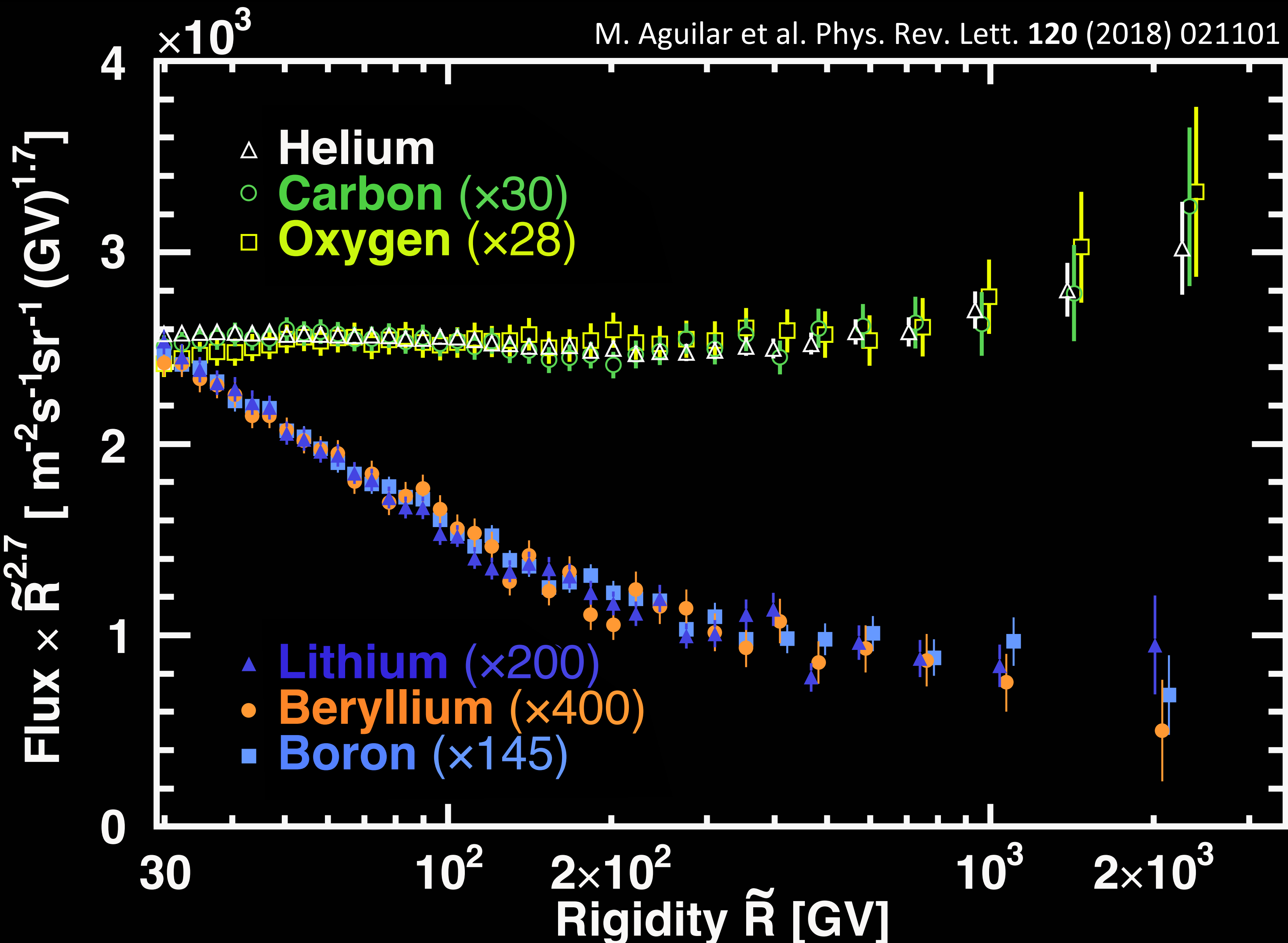
For the B flux, measurements have errors larger than 15% at 50 GeV/n.





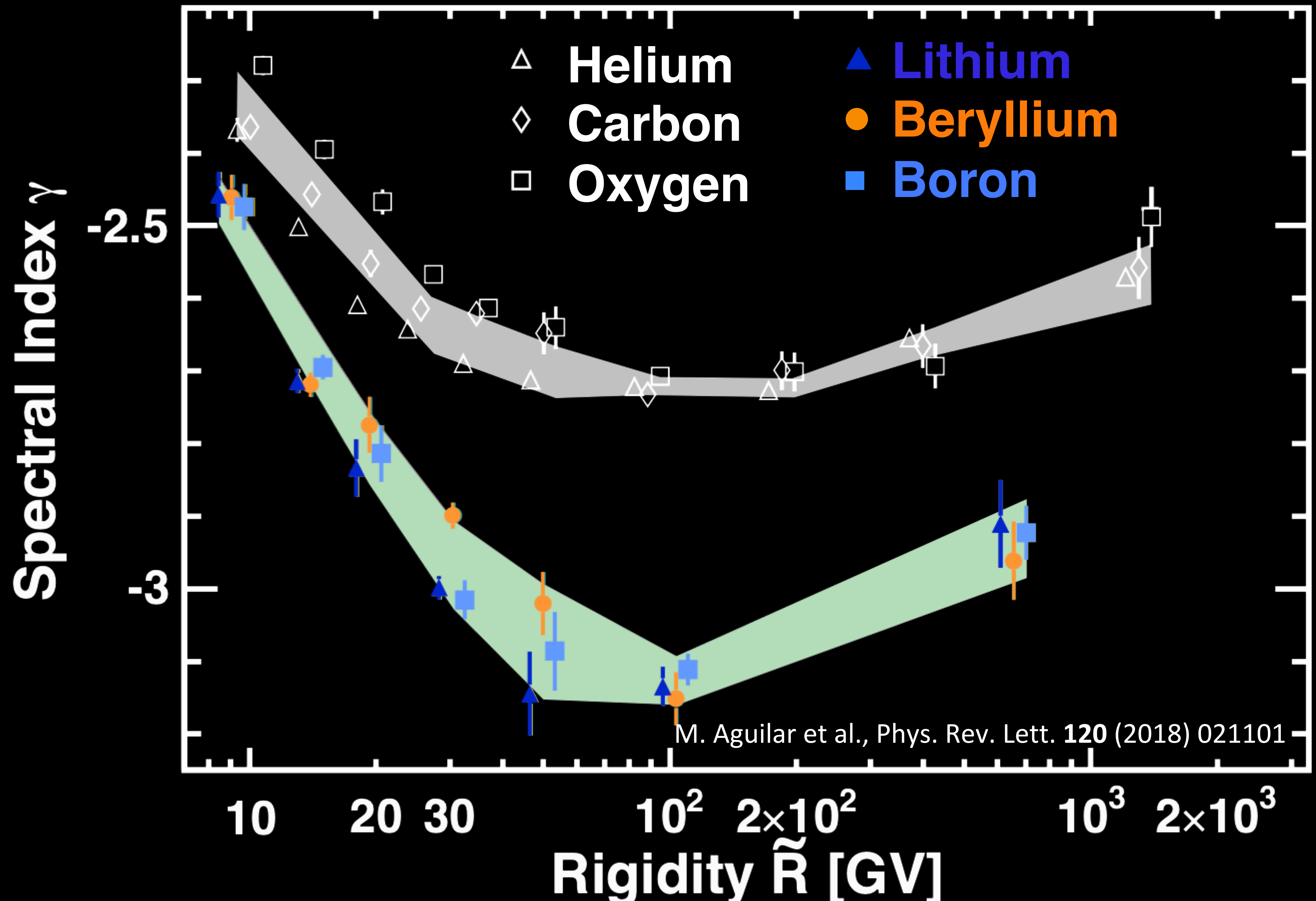


Primary and Secondary Fluxes



Primary and Secondary Spectral Indices

Deviate from single power law above 200 GV. Secondary hardening is stronger.



Secondary/Primary Flux Ratios

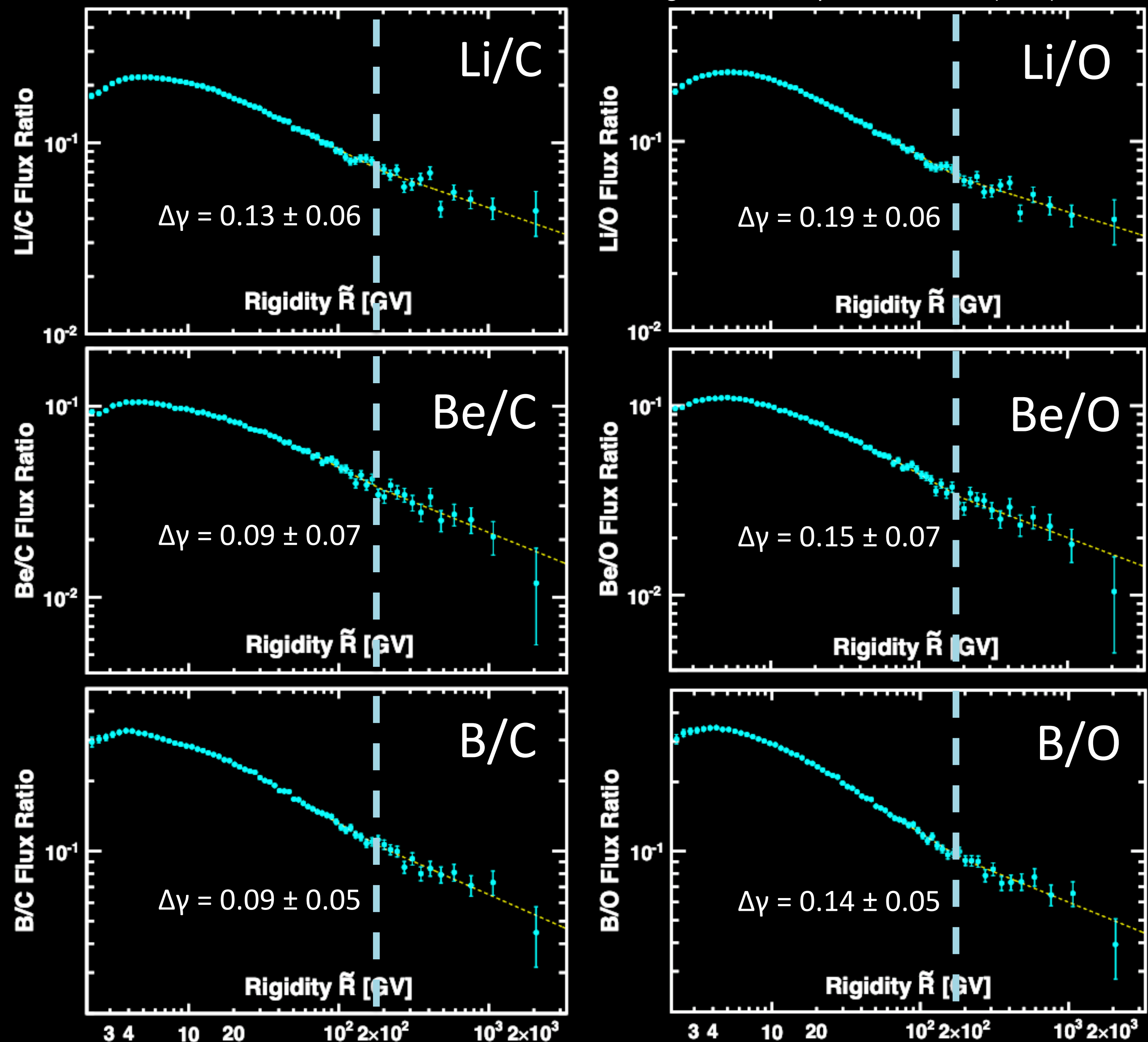
M. Aguilar et al., Phys. Rev. Lett. **120** (2018) 021101

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].

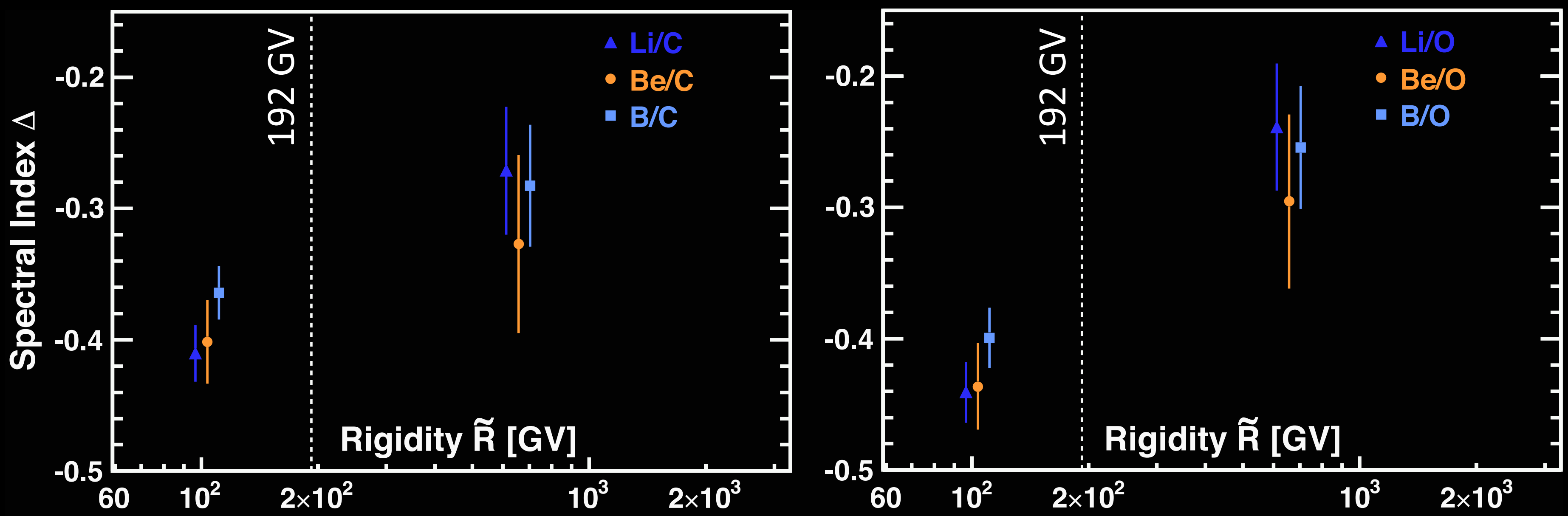
All ratio show a hardening (~ 2σ), i.e. secondaries show a hardening **stronger** than primaries.

Globally, an hardening at 192 GV of **0.13 ± 0.03** is observed.



Secondary/Primary Spectral Indices

M. Aguilar et al., Phys. Rev. Lett. **120** (2018) 021101

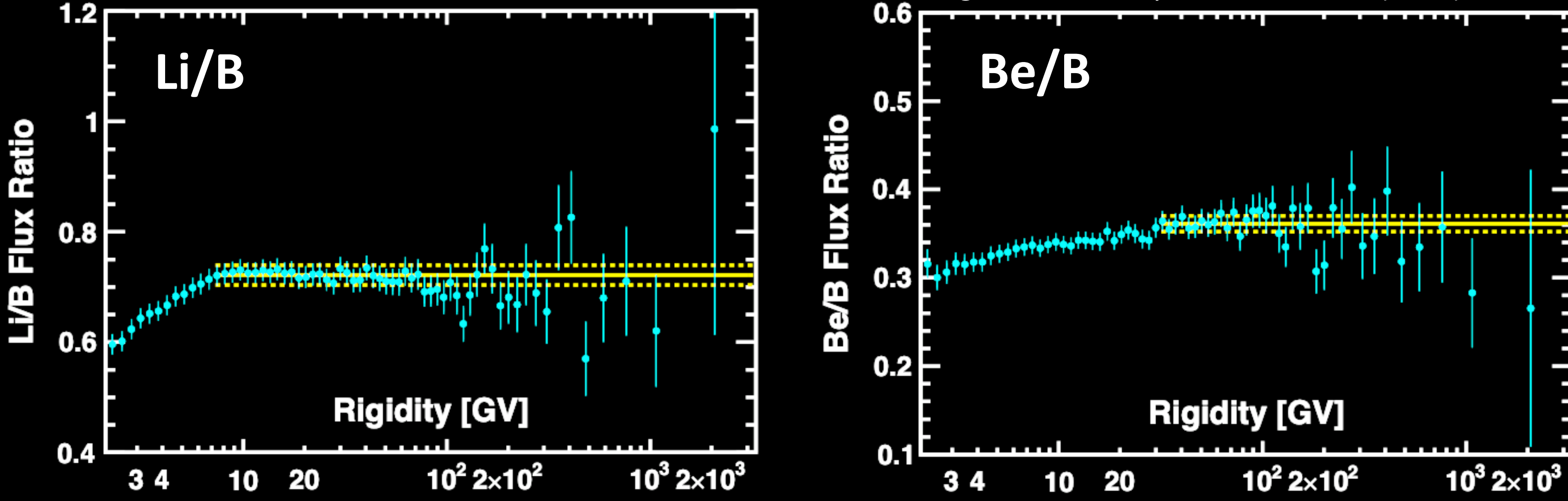


Combining the six secondary/primary ratios an hardening at 192 GV of **0.13 ± 0.03** is observed. This observation favors the hypothesis that the flux hardening is an **universal propagation effect**.

A. E. Vladimirov et al., Astroph. J. **752** (2012) 68
P. Blasi et al., Phys. Rev. Lett. **109** (2012) 061101
N. Tomassetti, Phys. Rev. D **92** (2015) 081301(R)
…

Secondary/Secondary Spectral Indices

M. Aguilar et al., Phys. Rev. Lett. **120** (2018) 021101

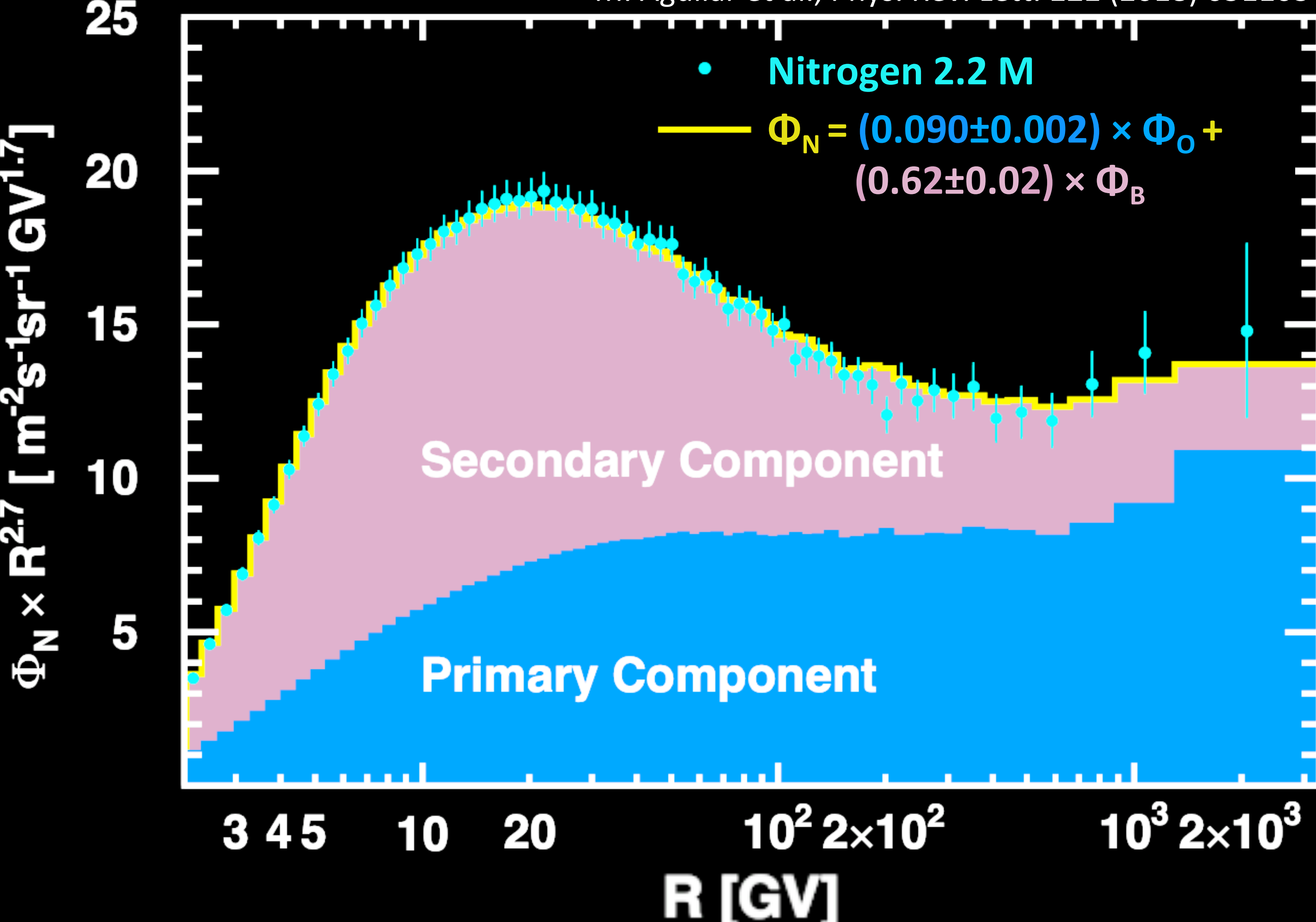


They all have the same behavior above 30 GV.
Li/B have the same behavior above 7 GV.

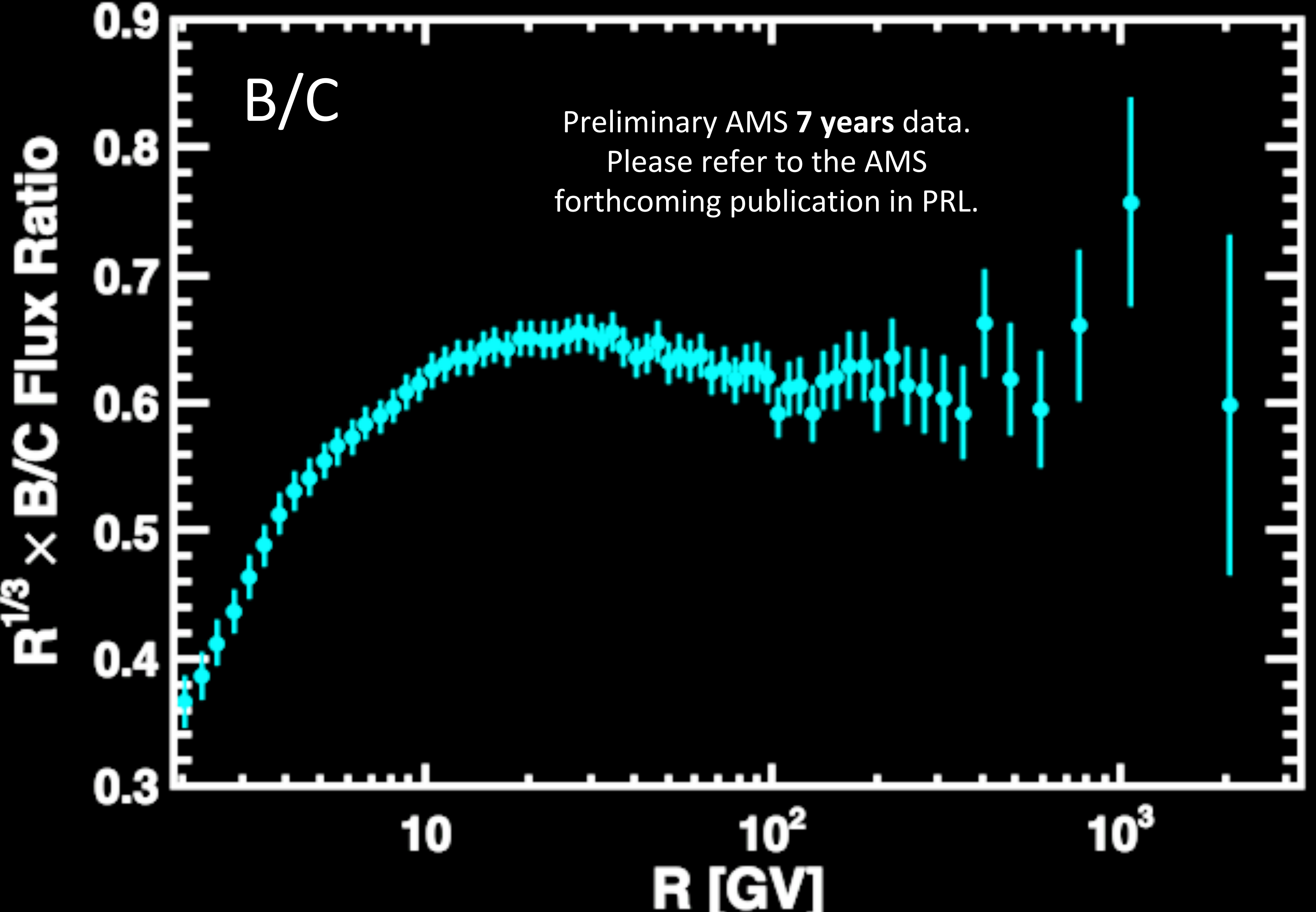
The behavior of Be/B below 30 GV can be related to the ^{10}Be component, that beta-decays with $t_{1/2}$ = 1.4 My through $^{10}\mathrm{Be} \rightarrow {}^{10}\mathrm{B} + e^- + \bar{\nu}$, and can be related to the **cosmic rays confinement time**.

Nitrogen Flux

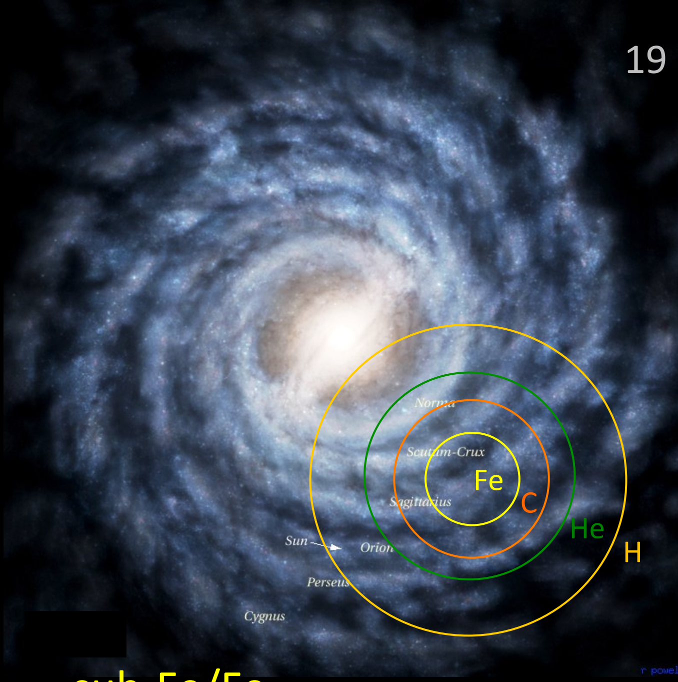
M. Aguilar et al., Phys. Rev. Lett. **121** (2018) 051103

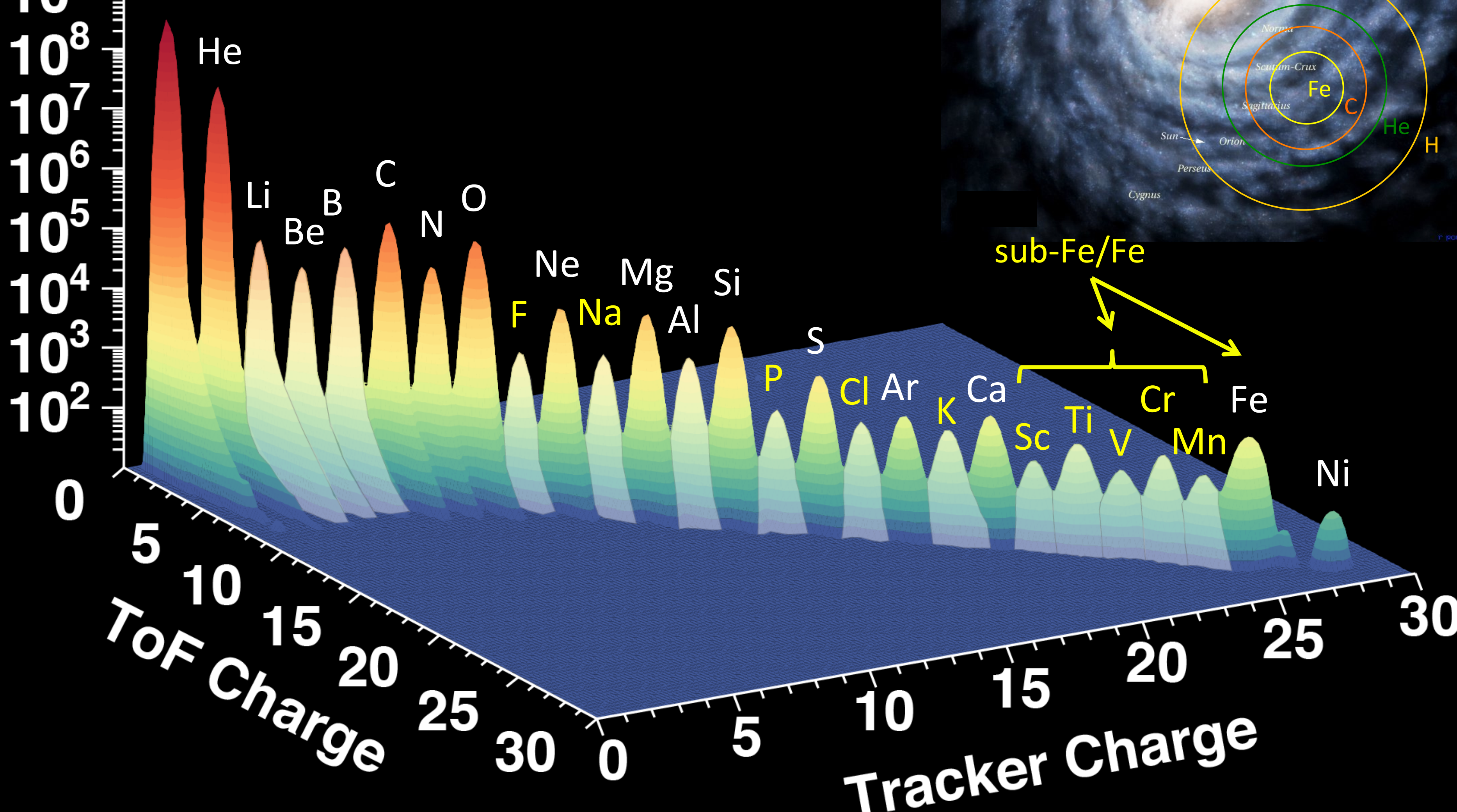


In The Future



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.