UNIQUE PROPERTIES OF SECONDARY COSMIC RAYS: RESULTS FROM THE ALPHA MAGNETIC SPECTROMETER

Nikita Belyaev, MIT

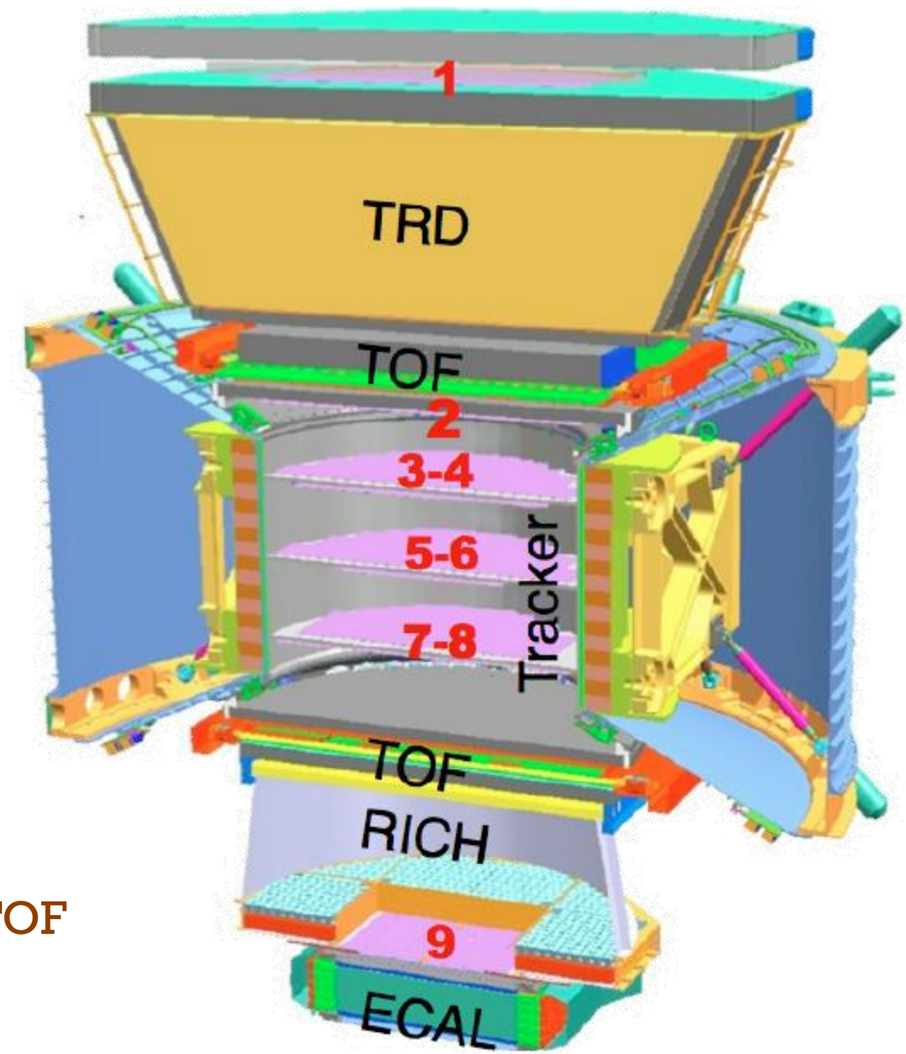
On behalf of the AMS Collaboration

The 17th Marcel Grossmann Meeting, Pescara, Italy, July 2024

THE AMS-02 DETECTOR

Particle identification with the AMS-02:

	e^-	P	Fe	e^+	$\bar{P}$	$\overline{He}$
TRD						
TOF						
Tracker + Magnet						
RICH						
ECAL						
Physics example	Cosmic Ray Physics Strangelets			Dark matter		Antimatter



Measurements of

- Charge: TRD, Tracker, RICH, TOF
- Charge sign: Tracker
- Energy: ECAL
- Momentum: Tracker
- Velocity: TOF, RICH

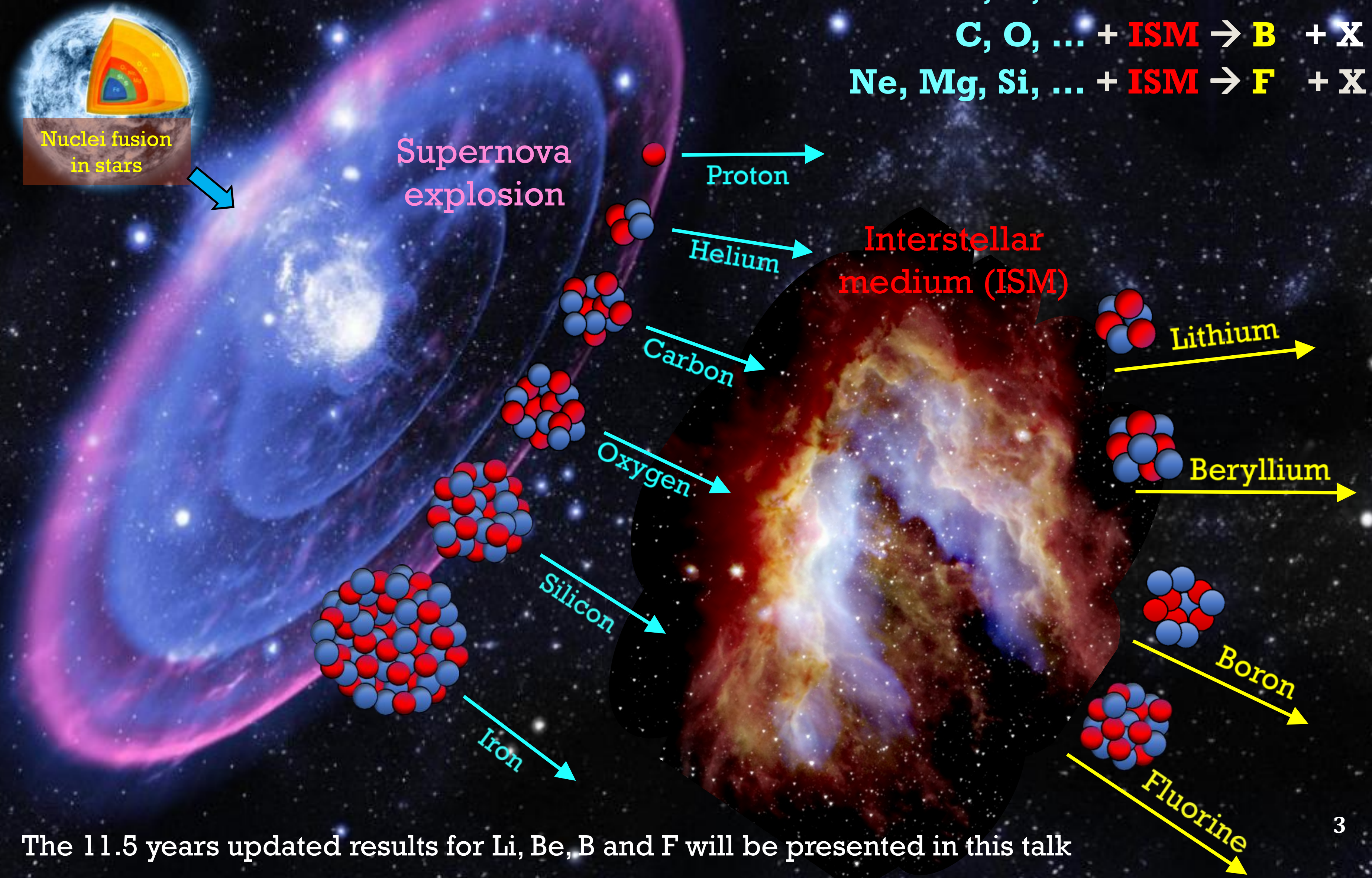
SECONDARY COSMIC RAYS

C, O, … + ISM $\rightarrow$ Li + X

C, O, … + ISM $\rightarrow$ Be + X

C, O, … + ISM $\rightarrow$ B + X

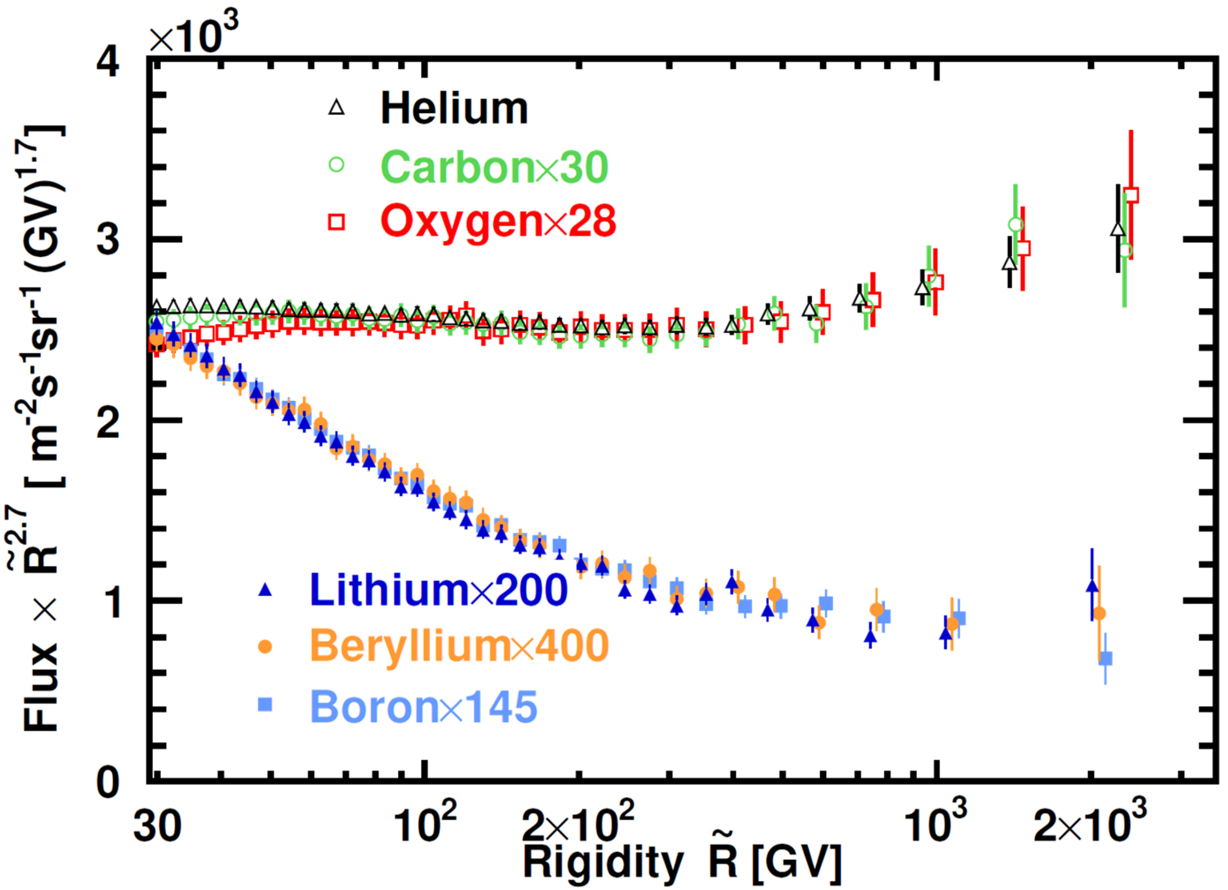
Ne, Mg, Si, … + ISM $\rightarrow$ F + X



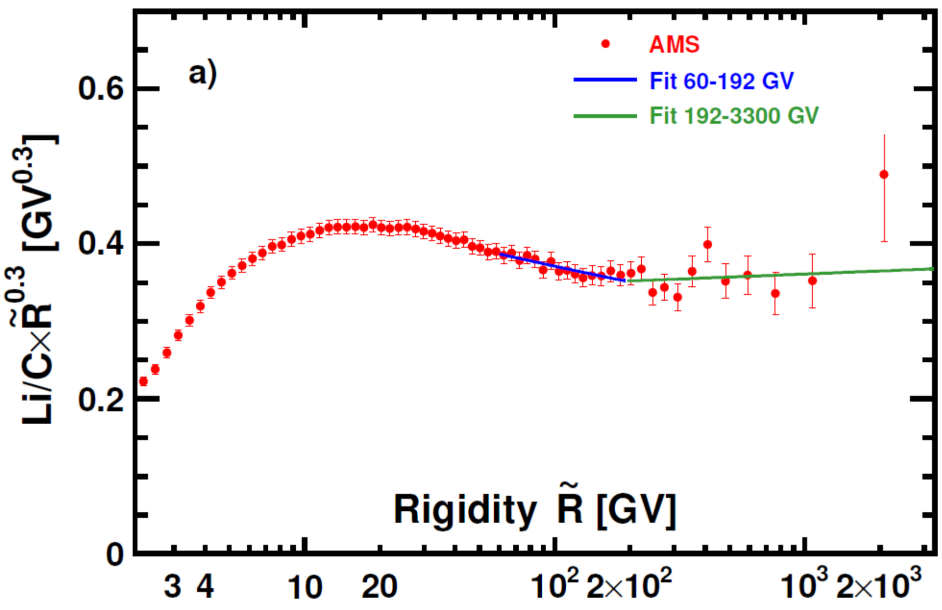
The 11.5 years updated results for Li, Be, B and F will be presented in this talk

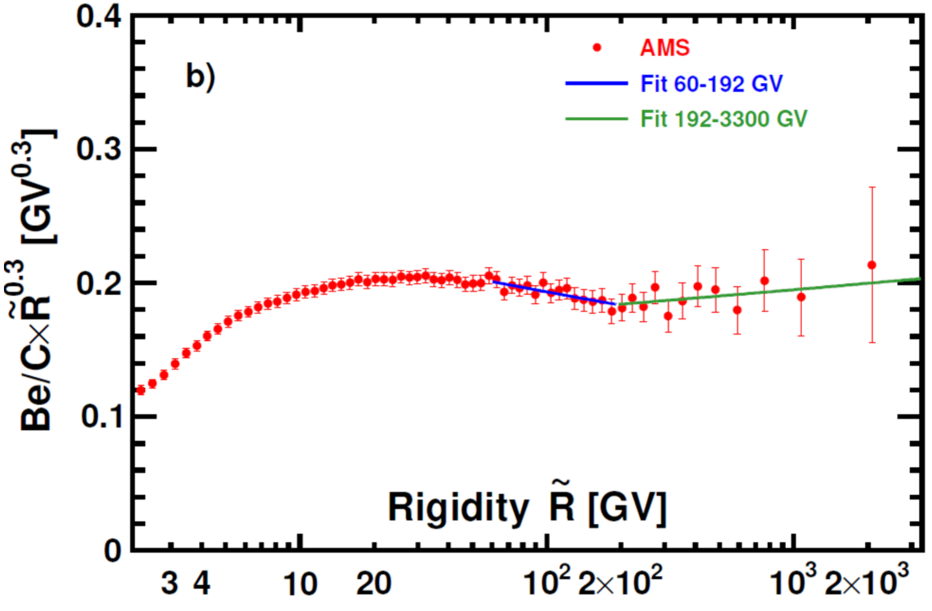
COMPARISON OF THE FLUXES OF LIGHT COSMIC NUCLEI

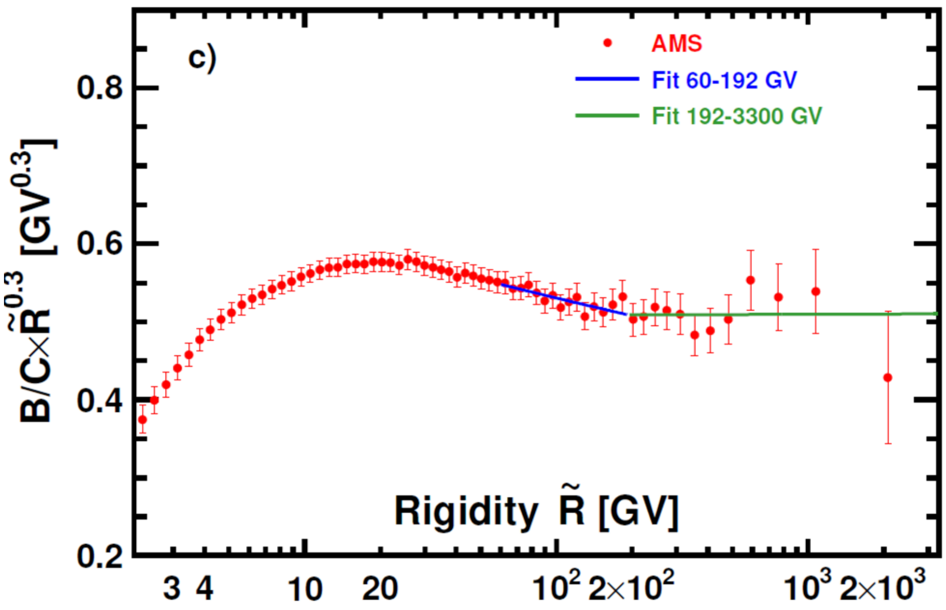
- The rigidity dependencies of primary and secondary cosmic rays are distinctly different.
- The three secondary fluxes (Li, Be, B) have an identical rigidity dependencies above 30 GV, as do the three primary fluxes above 60 GV.
- At lower rigidities, the rigidity dependencies of Li and B fluxes are similar, and the rigidity dependence of Be flux is different due to the ^{10}Be radioactive decay.



LITHIUM, BERYLLIUM AND BORON RATIOS TO CARBON







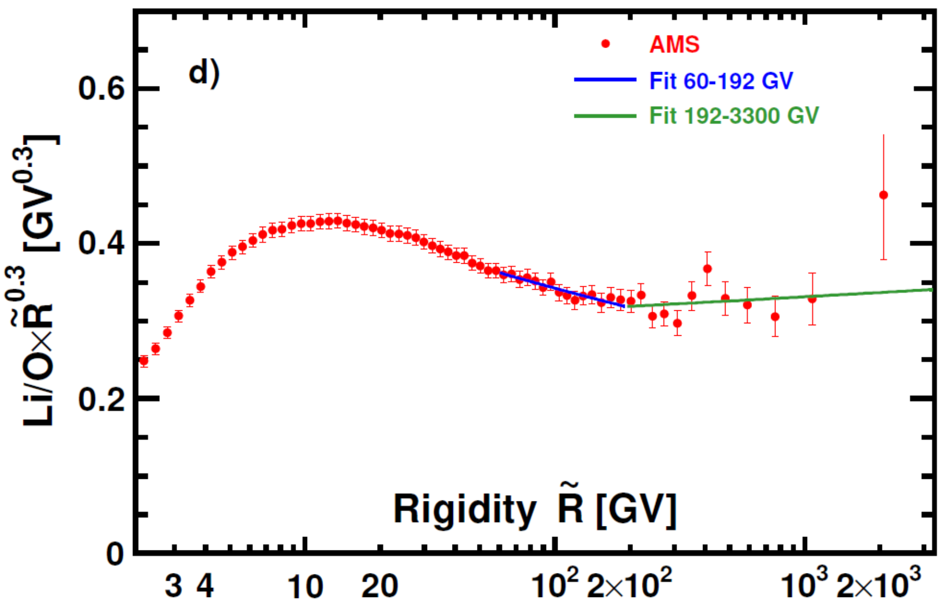
The fitting function (double power law):

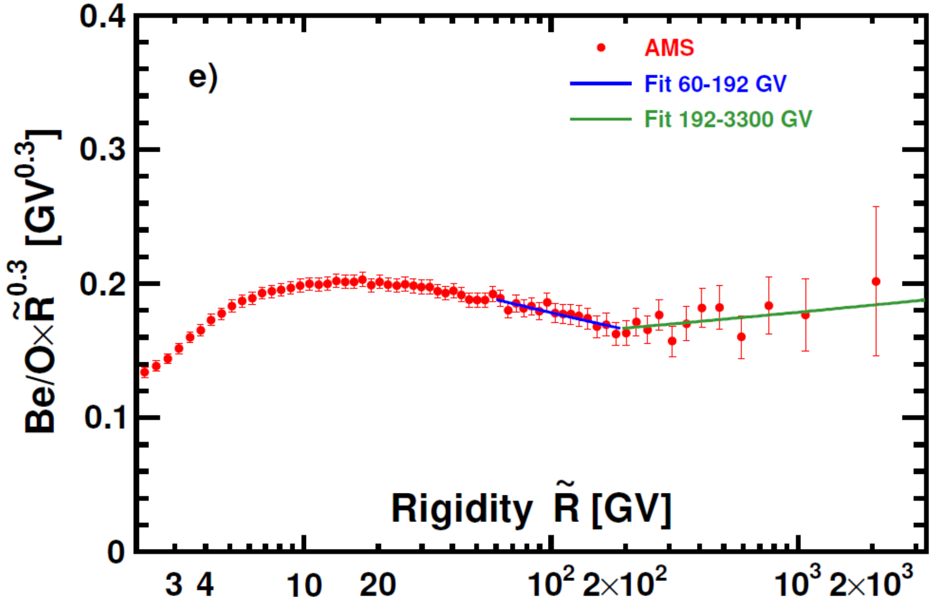
$$\begin{cases} k(R/R_0)^{\Delta_1}, & R \leq R_0 \text{ GV}, \\ k(R/R_0)^{\Delta_2}, & R > R_0 \text{ GV}. \end{cases}$$

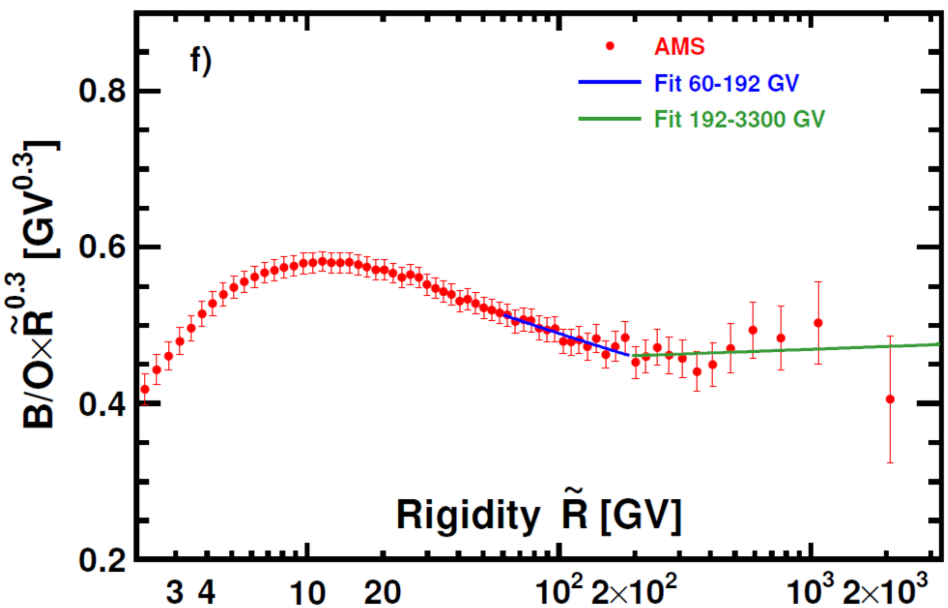
Here, k, Δ_1 and Δ_2 are fit parameters and $R_0 = 192$ GeV.

The fit is performed for $\mathrm{R} > 60$ GeV.

LITHIUM, BERYLLIUM AND BORON RATIOS TO OXYGEN







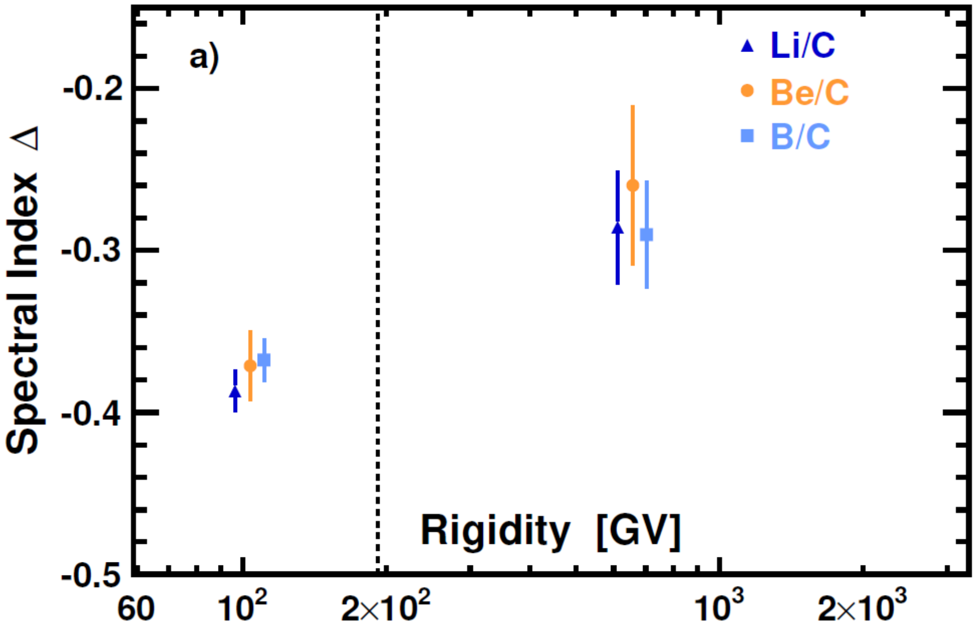
The fitting function (double power law):

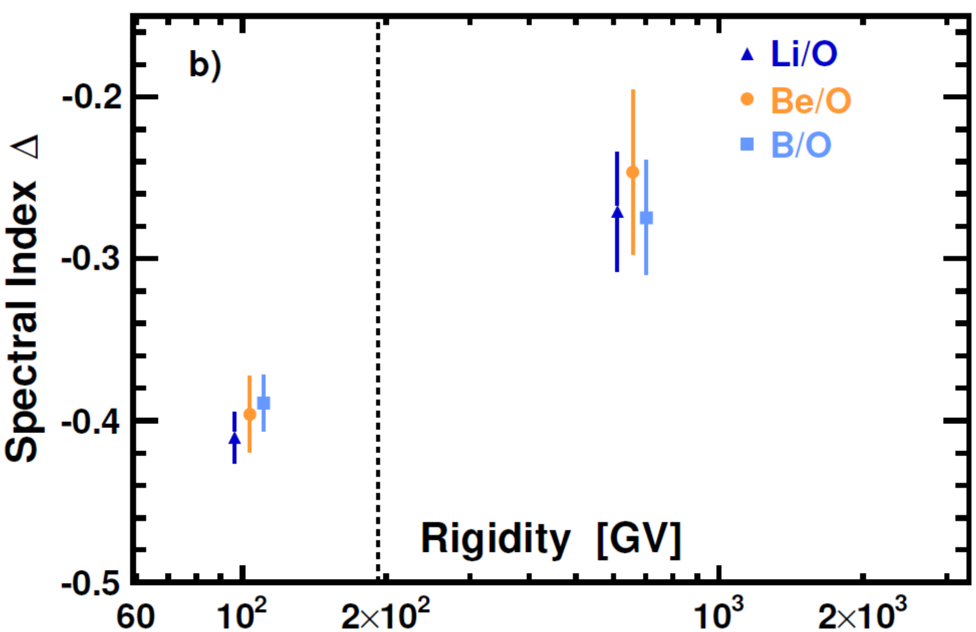
$$\begin{cases} k(R/R_0)^{\Delta_1}, & R \leq R_0 \text{ GV}, \\ k(R/R_0)^{\Delta_2}, & R > R_0 \text{ GV}. \end{cases}$$

Here, k, Δ_1 and Δ_2 are fit parameters and $R_0 = 192$ GeV.

The fit is performed for $\mathrm{R} > 60$ GeV.

SECONDARY TO PRIMARY FLUX RATIOS SPECTRAL INDICES





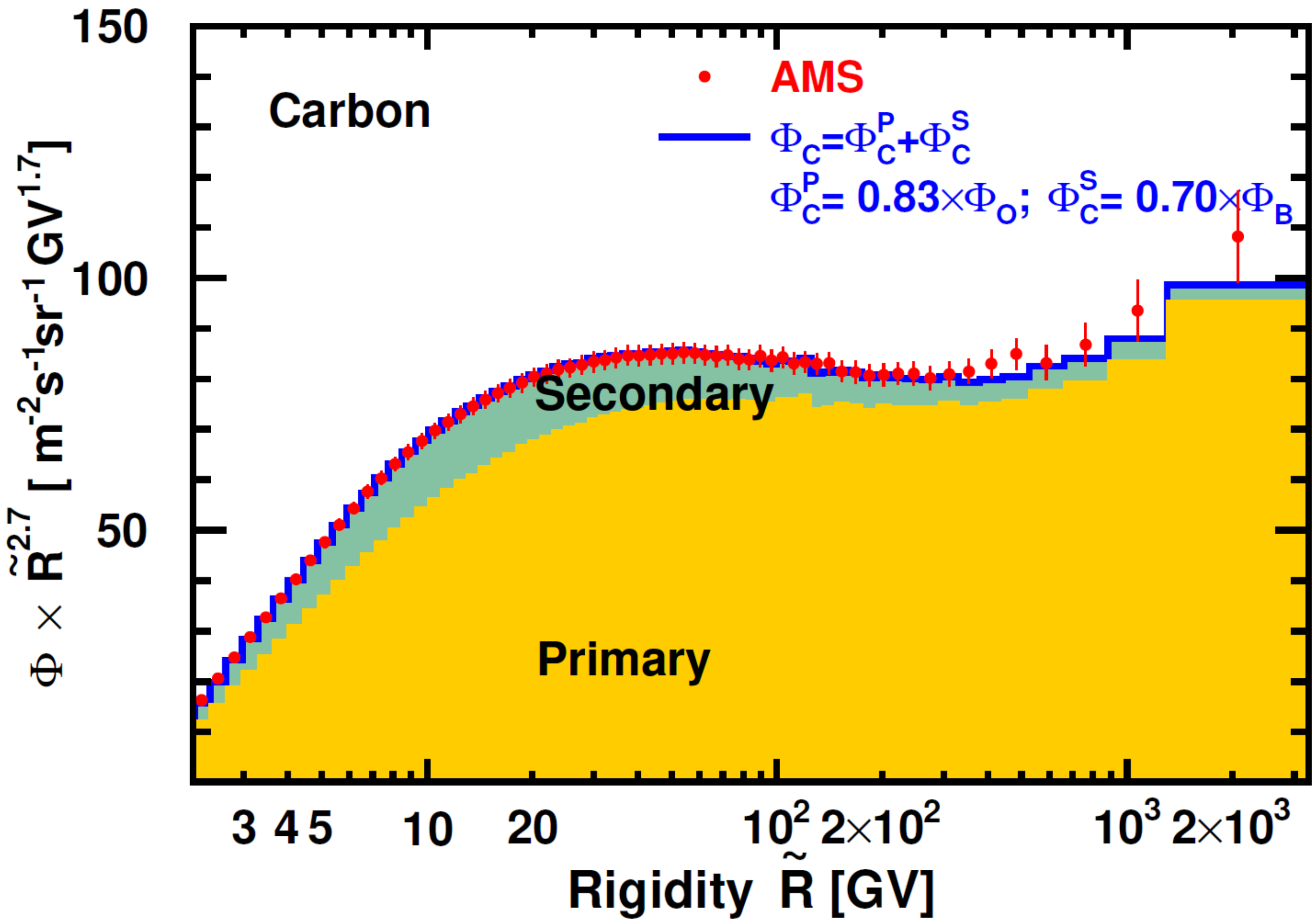
- The spectral indices of Li/C, Be/C and B/C above $R_0 = 192$ GV exhibit a hardening of $\Delta_2 - \Delta_1 = 0.094 \pm 0.022$.
- The spectral indices of Li/O, Be/O and B/O above $R_0 = 192$ GV exhibit a hardening of $\Delta_2 - \Delta_1 = 0.133 \pm 0.025$.

$$\begin{cases} k(R/R_0)^{\Delta_1}, & R \leq R_0 \text{ GV}, \\ k(R/R_0)^{\Delta_2}, & R > R_0 \text{ GV}. \end{cases}$$

- The difference in hardening between the two cases arises from the different natures of carbon and oxygen fluxes.

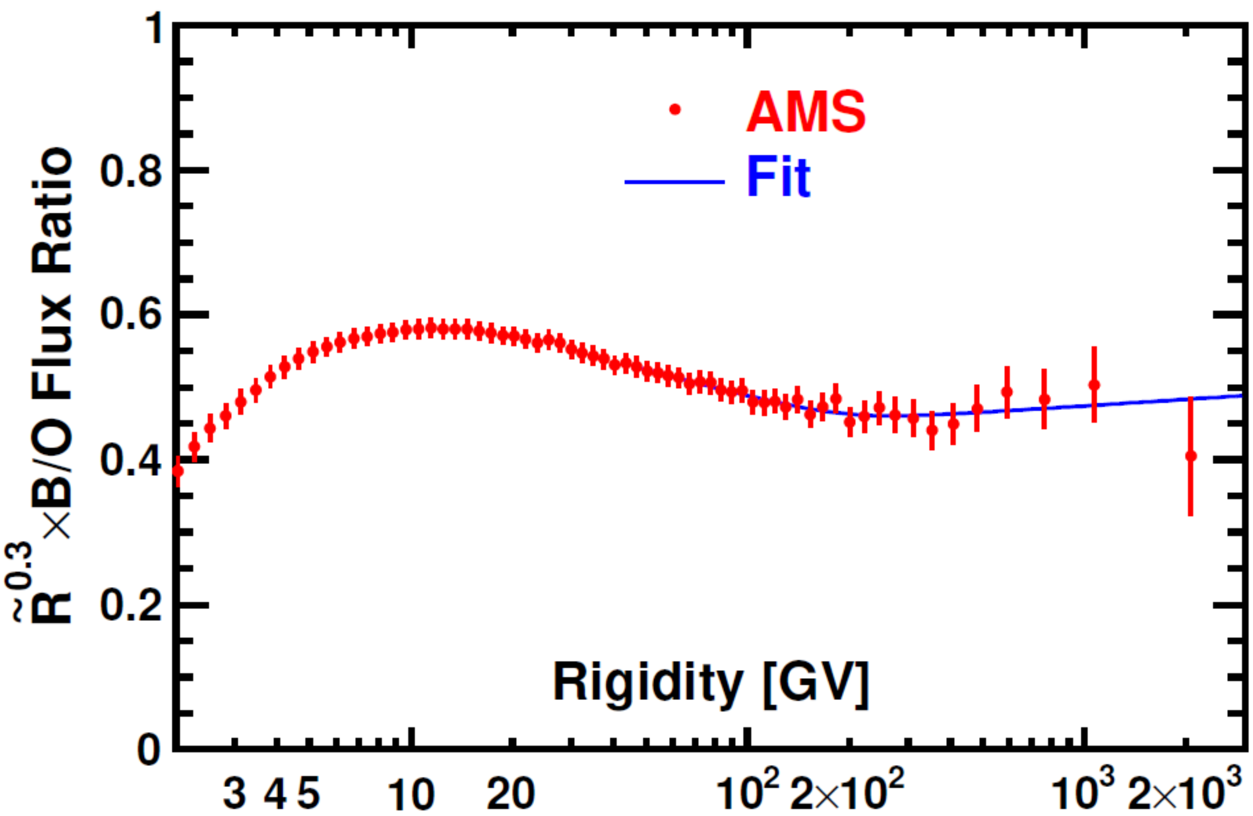
THE NATURE OF THE CARBON FLUX

- The carbon flux is expected to have a non-zero secondary component.
- To precisely determine the primary and secondary components of C flux, we have fitted them as linear combinations of characteristic primary (O) and secondary (B) fluxes.



RIGIDITY DEPENDENCE OF THE SECONDARY COSMIC RAYS

- The AMS result shows that above 192 GV the secondary cosmic rays harden nearly twice as much as the primary cosmic rays. This favors the hypothesis that the hardening is related to propagation properties in the Galaxy.
- To verify this result, the fit of flux ratio of characteristic secondary flux B to characteristic primary flux O with Eq. (1) was performed above 45 GV.



The fitting function:

$$\Phi = C\left(\frac{R}{45\ \mathrm{GV}}\right)^{\gamma}\left[1+\left(\frac{R}{R_0}\right)^{\Delta\gamma/s}\right]^{s} \quad (1)$$

Fit results:

$\gamma_{\mathrm{B/O}} = 0.40 \pm 0.01;$

$\Delta\gamma_{\mathrm{B/O}} = 0.13 \pm 0.06;$

$s = 0.05 \pm 0.04;$

$R_0 = 200 \pm 88\ \mathrm{GV};$

$\chi^2/\mathrm{ndf} = 21/29.$

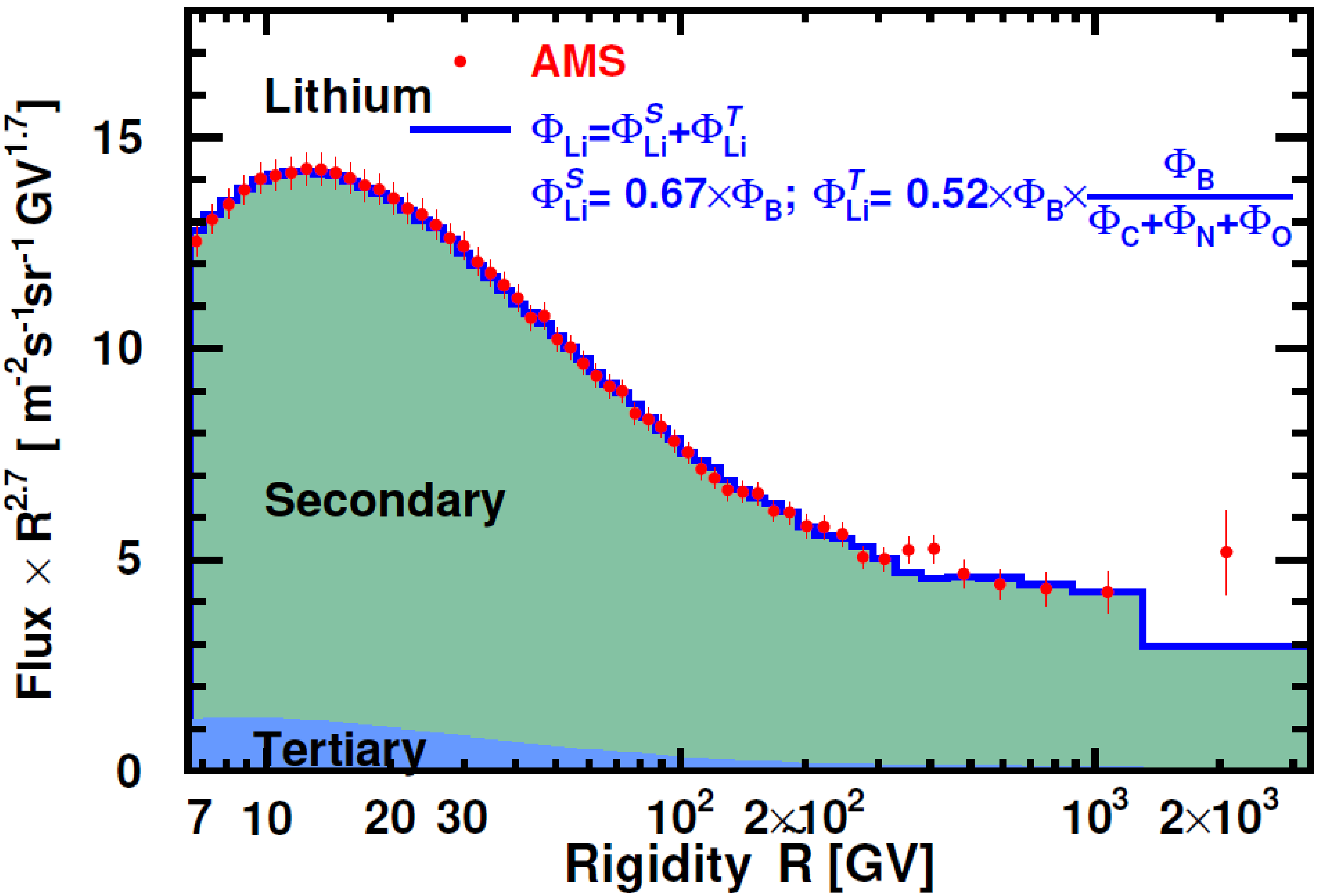
Good agreement with the oxygen results

(see Dr. Zuberi's talk)

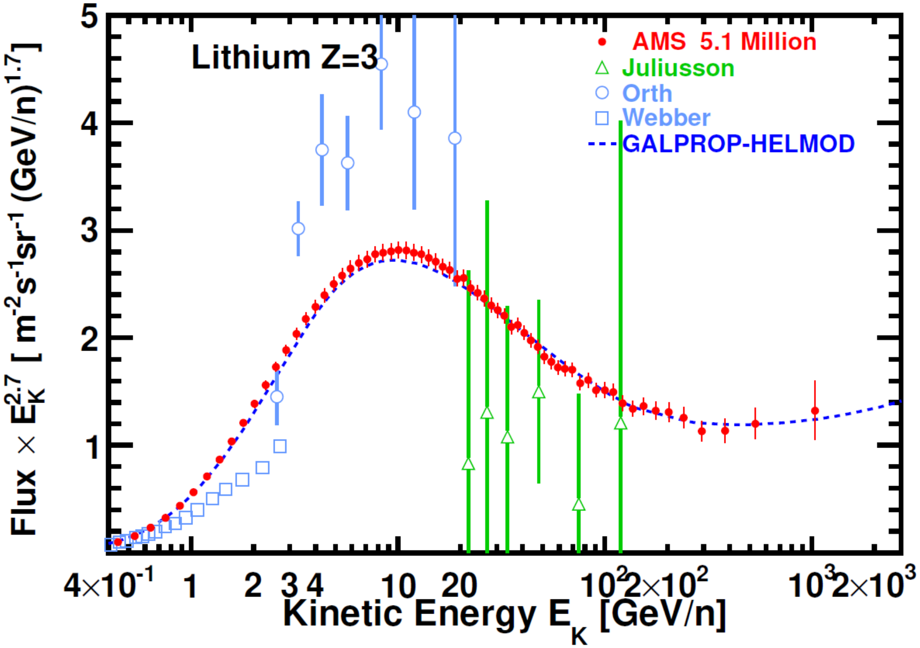
$\Delta\gamma_{\mathrm{O}} = 0.16 \pm 0.03$

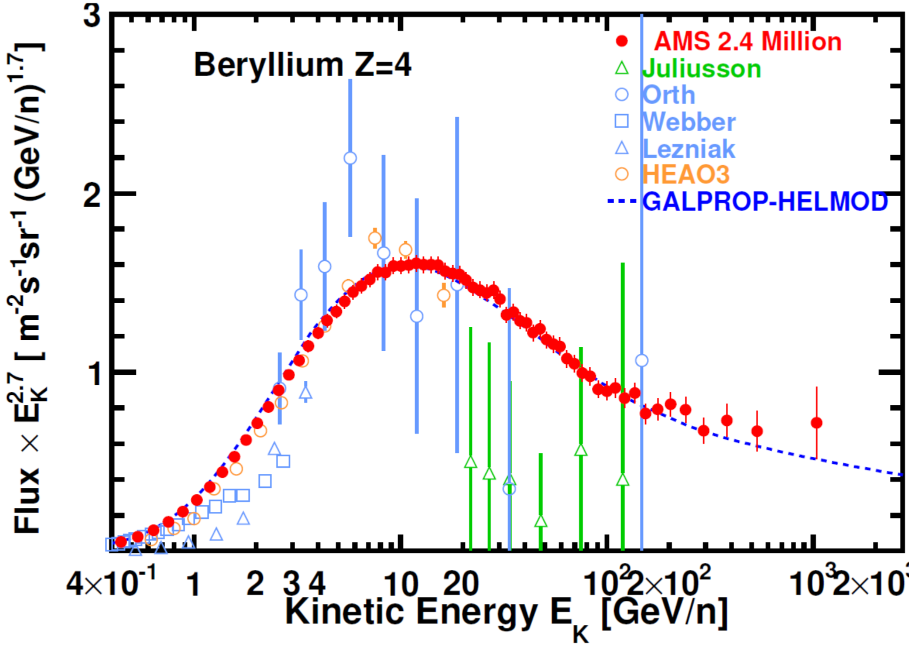
THE NATURE OF THE LITHIUM FLUX

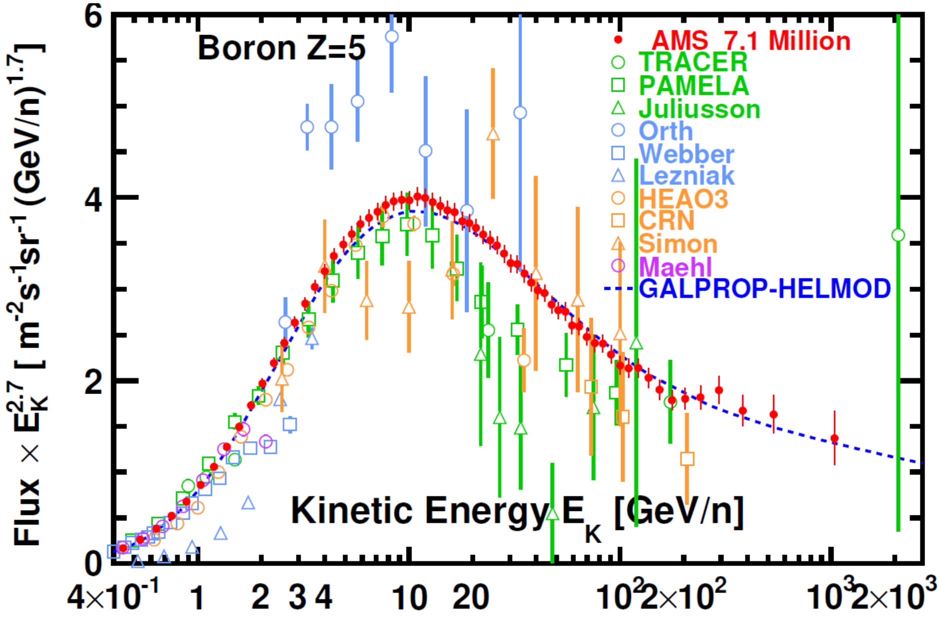
- Since Li is the lightest pure secondary cosmic rays, one can expect that some part of Li flux has a tertiary nature, i.e. produced by the interaction of Be and B with interstellar medium.
- With more statistics, we can now study the nature of Li flux at low rigidities using the same method we used for carbon.



THE AMS RESULTS TOGETHER WITH OTHER EXPERIMENTS AND PREDICTION OF THE GALPROP COSMIC RAY MODEL BASED ON THE AMS DATA







PROPERTIES OF THE FLUORINE FLUX

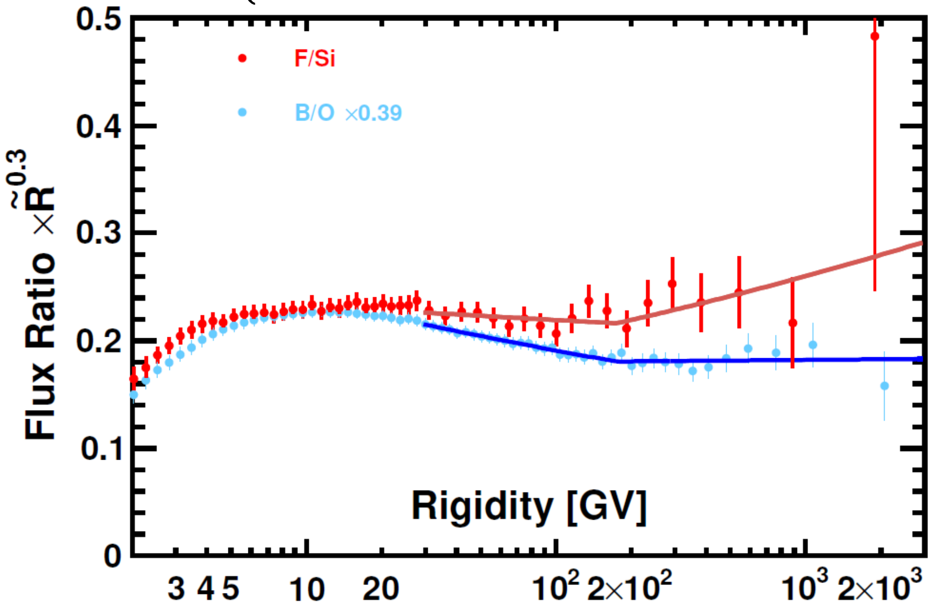
- The AMS results show that the heavier secondary-to-primary F/Si flux ratio rigidity dependence is distinctly different from the lighter B/O rigidity dependence.
- For the higher rigidity range $R > R_0 = 175\,\mathrm{GV}$, the spectral index of F/Si $\Delta_2^{F/Si} = -0.19 \pm 0.06$, while for the B/O ratio $\Delta_2^{B/O} = -0.28 \pm 0.02$.

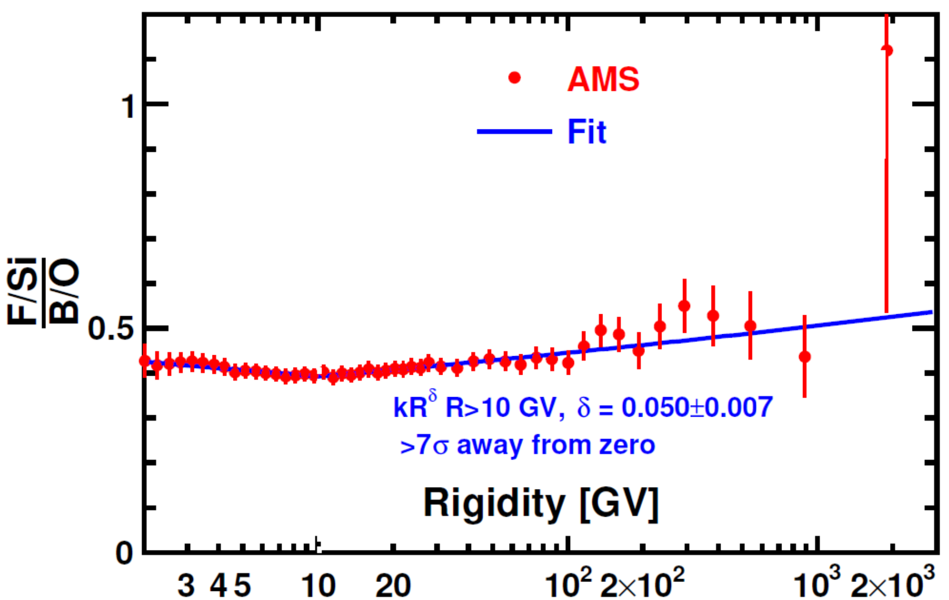
Double power law fits:

$$\begin{cases} k(R/R_0)^{\Delta_1}, & R \le R_0\ \mathrm{GV}, \\ k(R/R_0)^{\Delta_2}, & R > R_0\ \mathrm{GV}. \end{cases}$$

Single power law fit:

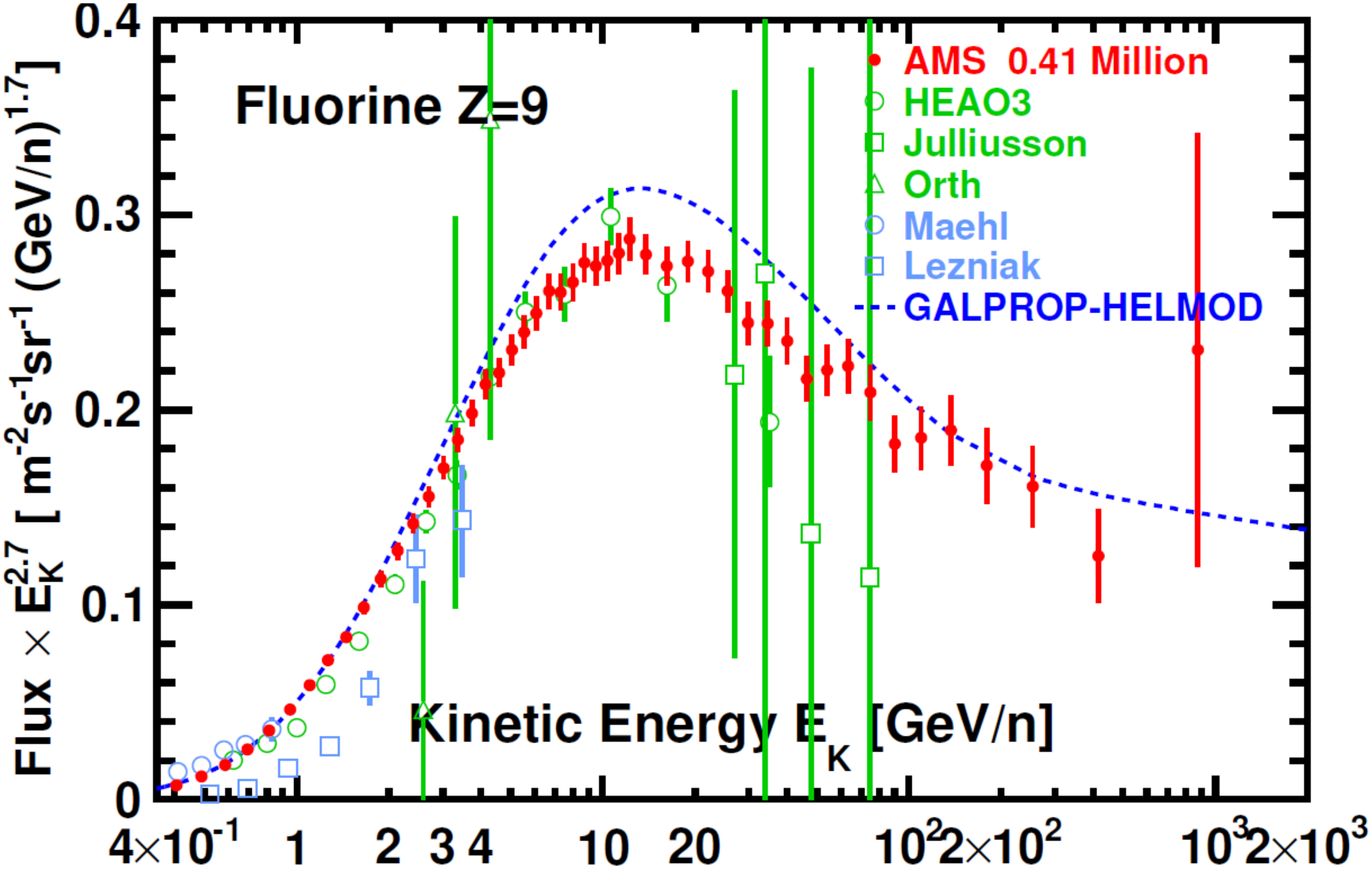
$$kR^{\delta}$$



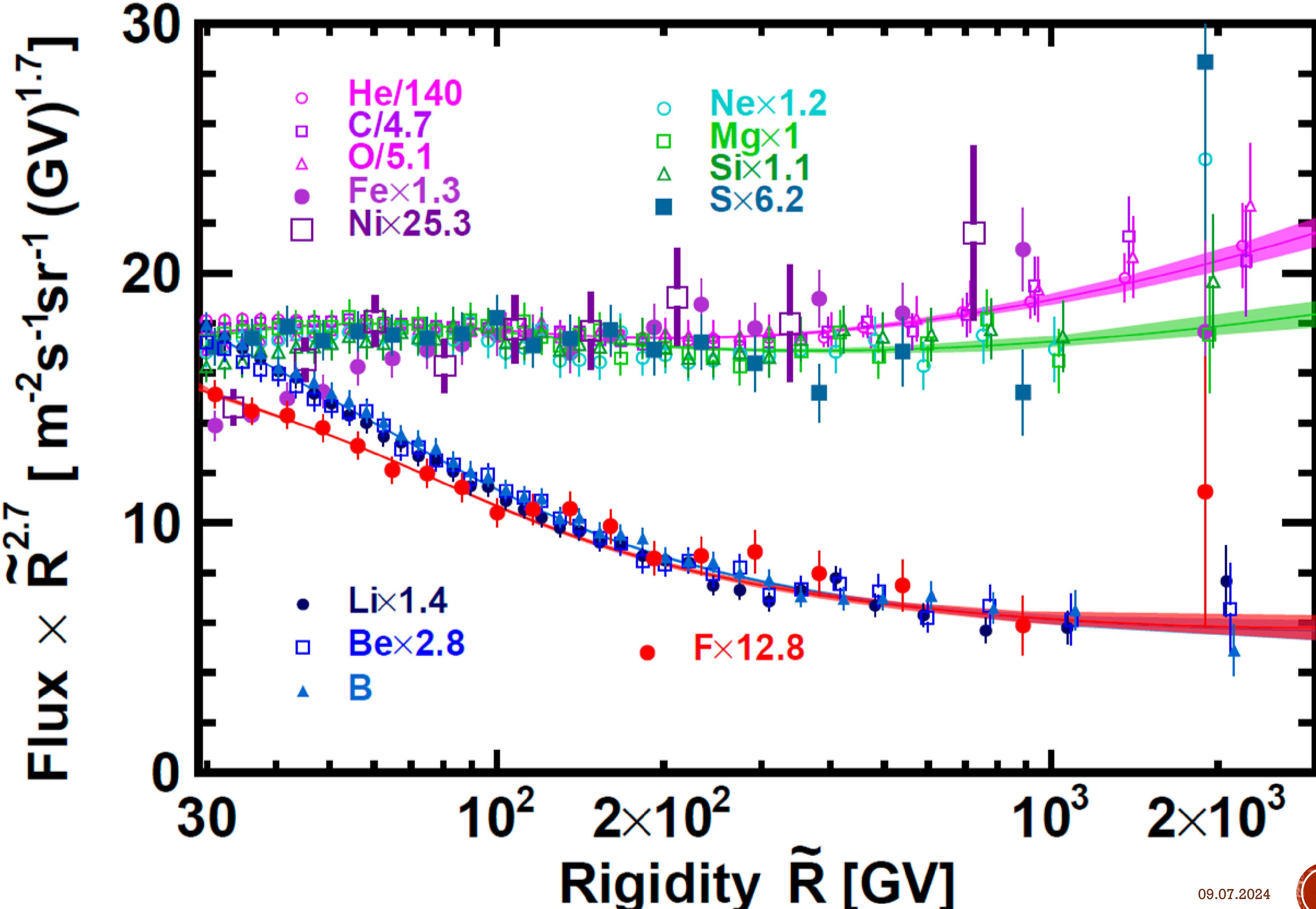


THE AMS RESULTS TOGETHER WITH OTHER EXPERIMENTS AND PREDICTION OF THE GALPROP COSMIC RAY MODEL

- The AMS results demonstrate unexpected spectral shape compared to the GALPROP cosmic ray model predictions for Fluorine secondary cosmic rays.
- Further development of the theoretical models is necessary to explain the observed unexpected phenomena.

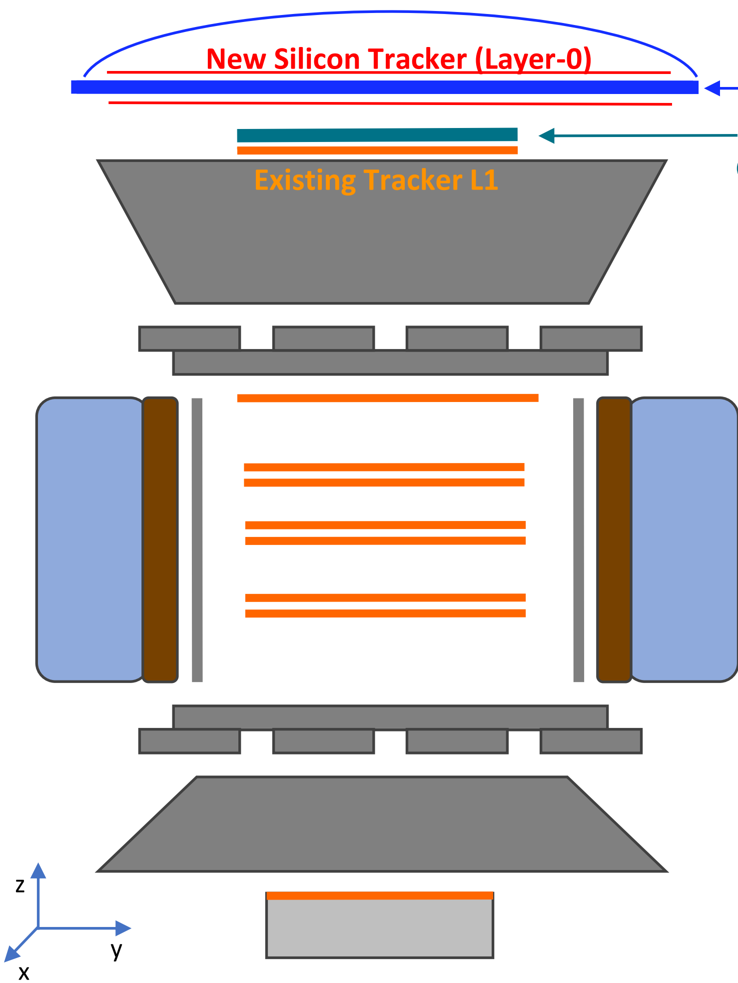


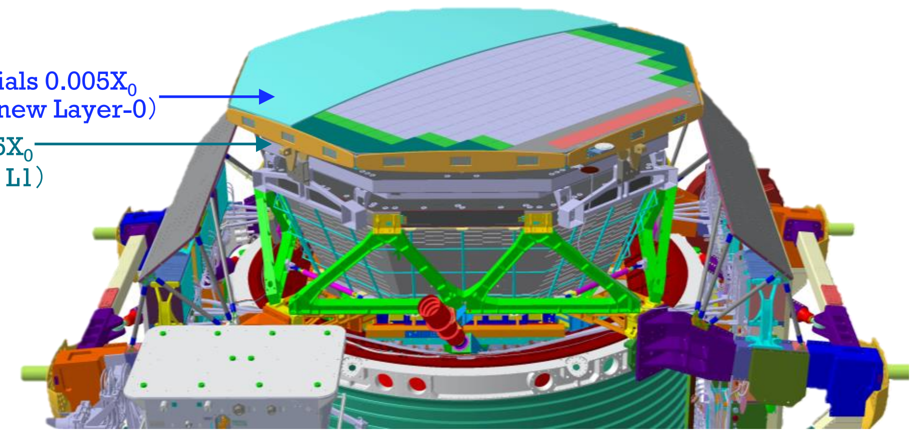
COSMIC NUCLEI FLUXES SUMMARY

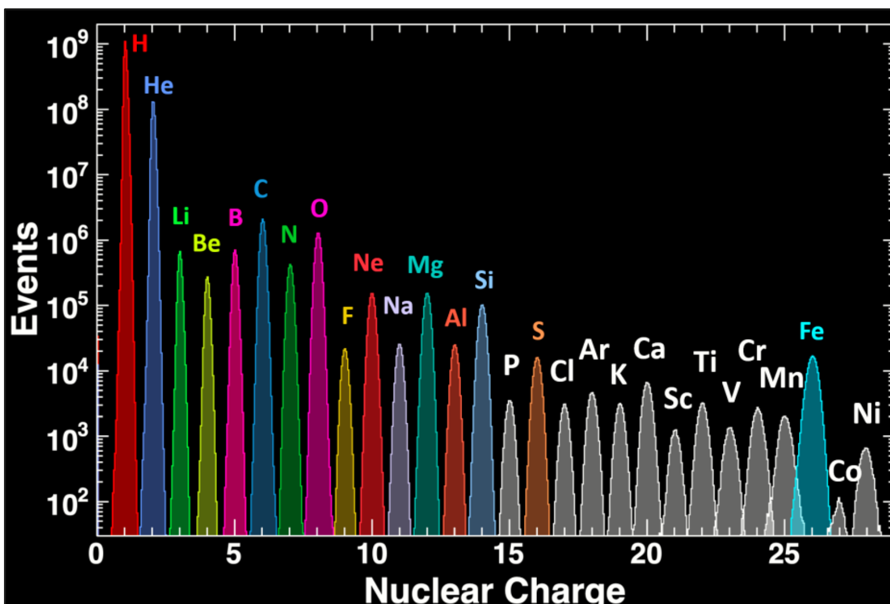


THE AMS UPGRADE (2026)

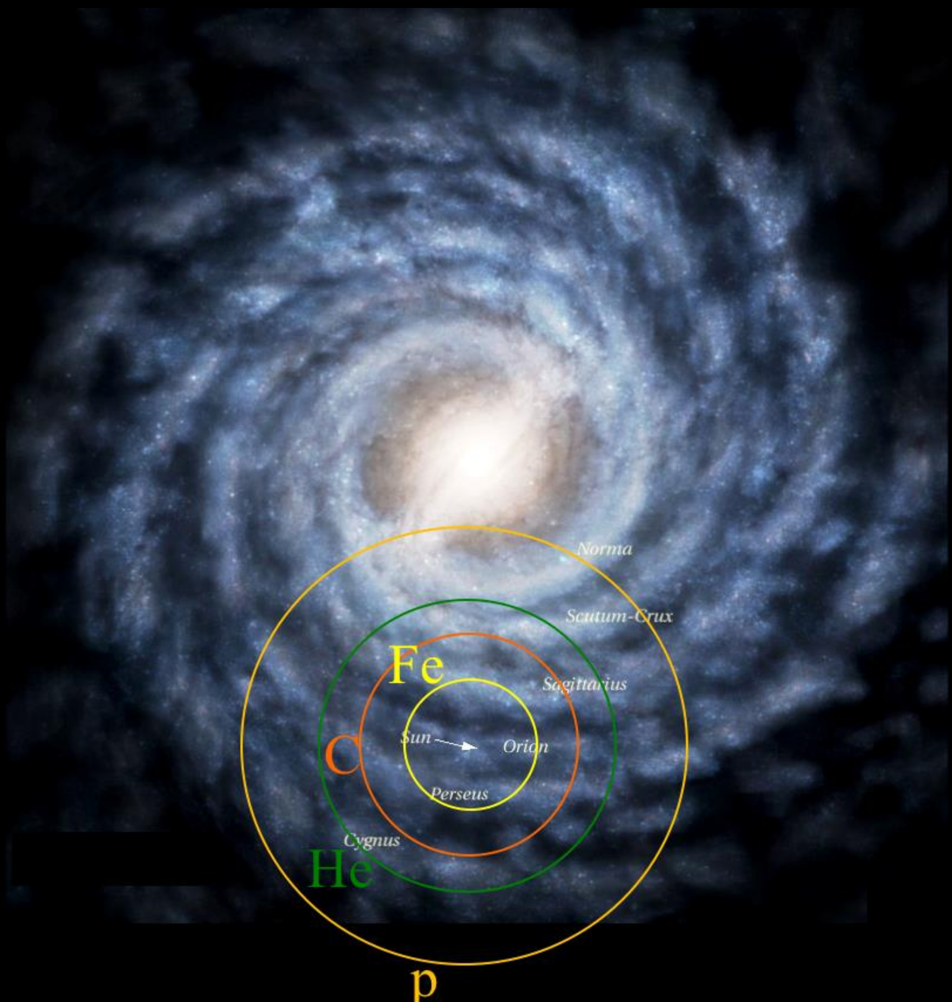
- With the completion of the AMS Upgrade, the acceptance will increase by 300% with minimal materials above the Layer-0.







FUTURE STUDY OF COSMIC RAY PROPAGATION IN HEAVY COSMIC RAYS



The effective propagation distances for p, He, C, and Fe for 1 GV rigidity

- Measurements of the heavy secondary cosmic ray nuclei with $Z > 20$ will allow AMS to study propagation properties in the Galaxy at different distances.
- The precision AMS data will provide the most comprehensive information on the cosmic ray propagation model.

CONCLUSIONS

- The properties of secondary cosmic rays Li, Be, B and F have been presented based on 11.5 years of the AMS data.
- We found that the secondary cosmic rays Li-Be-B and F form two different classes of cosmic rays.
- The rigidity dependences of the secondary cosmic rays and the primary cosmic rays are distinctly different. In particular, above ~ 200 GV the secondary cosmic rays harden twice as much as the primary cosmic rays.
- The AMS, as the unique magnetic spectrometer in space, will continue to unveil the secrets of the Galaxy and provide unique measurements of cosmic rays.

BACKUP

SECONDARY COSMIC RAYS

- Secondary cosmic rays Li, Be, B, F, P, sub-Fe nuclei are produced by the collision of primary cosmic rays, C, O, Si, … , Fe with the interstellar medium.