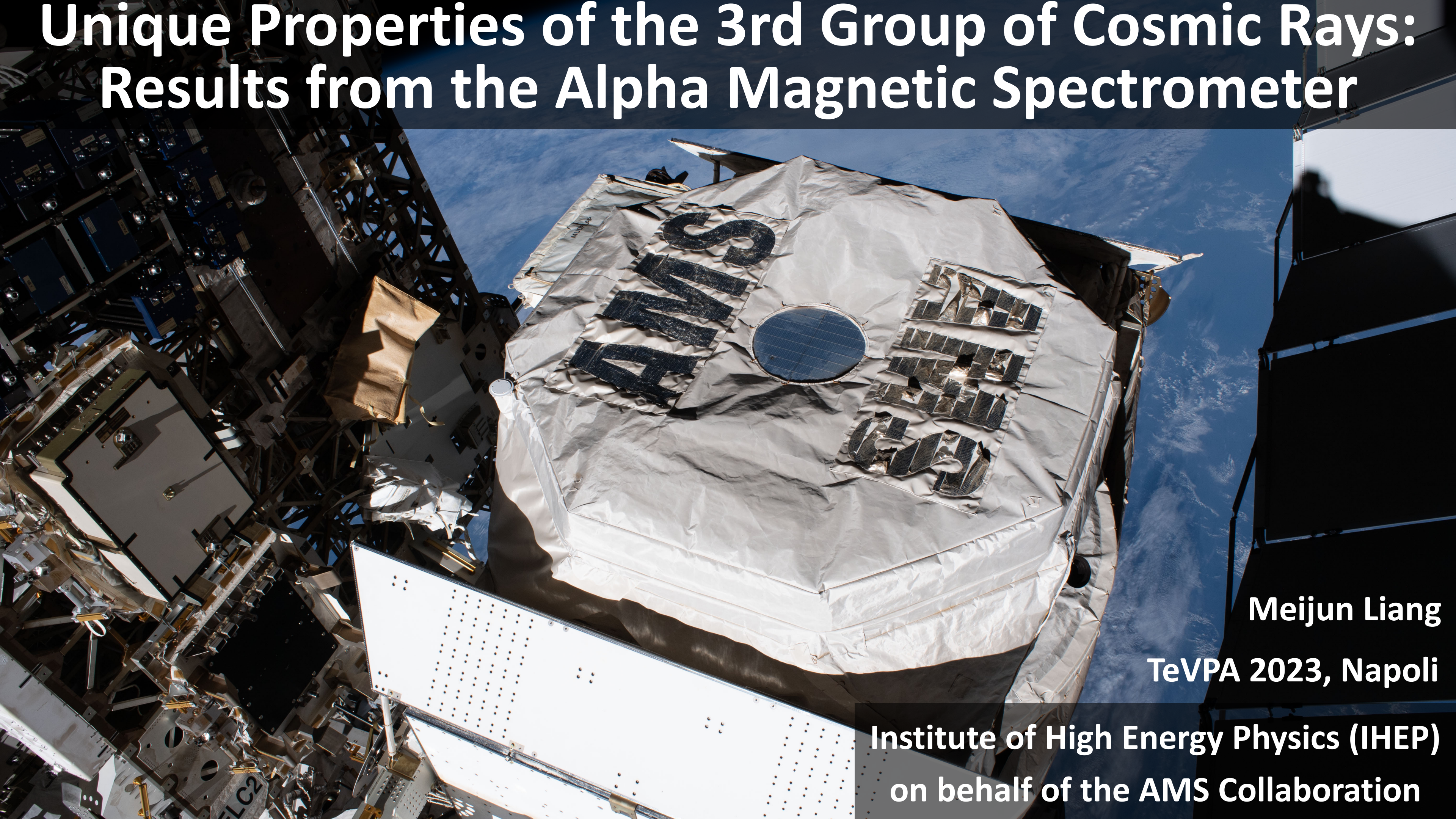
Unique Properties of the 3rd Group of Cosmic Rays: Results from the Alpha Magnetic Spectrometer

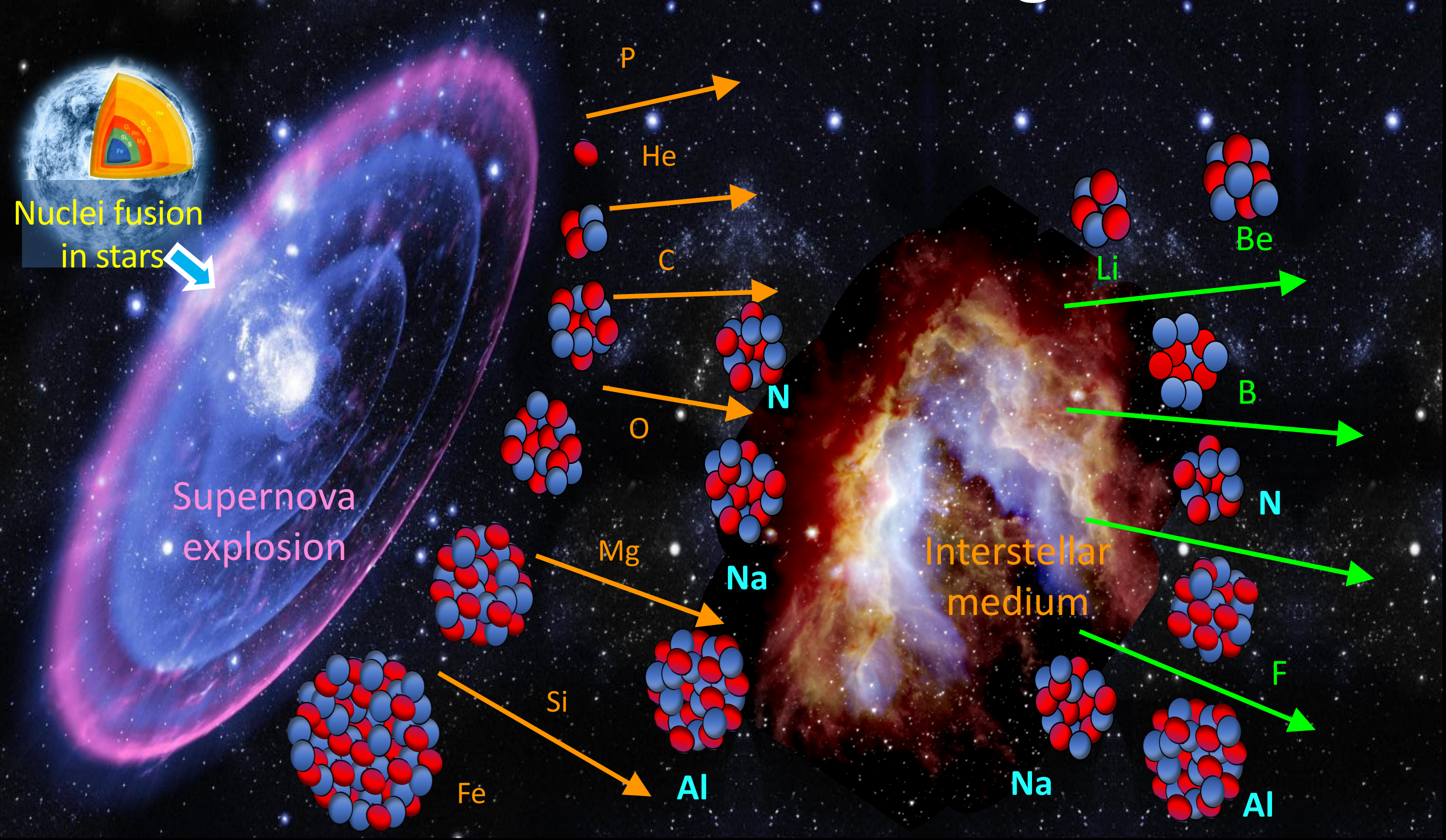


Meijun Liang

TeVPA 2023, Napoli

Institute of High Energy Physics (IHEP)
on behalf of the AMS Collaboration

Three Kinds of Charged Cosmic Rays

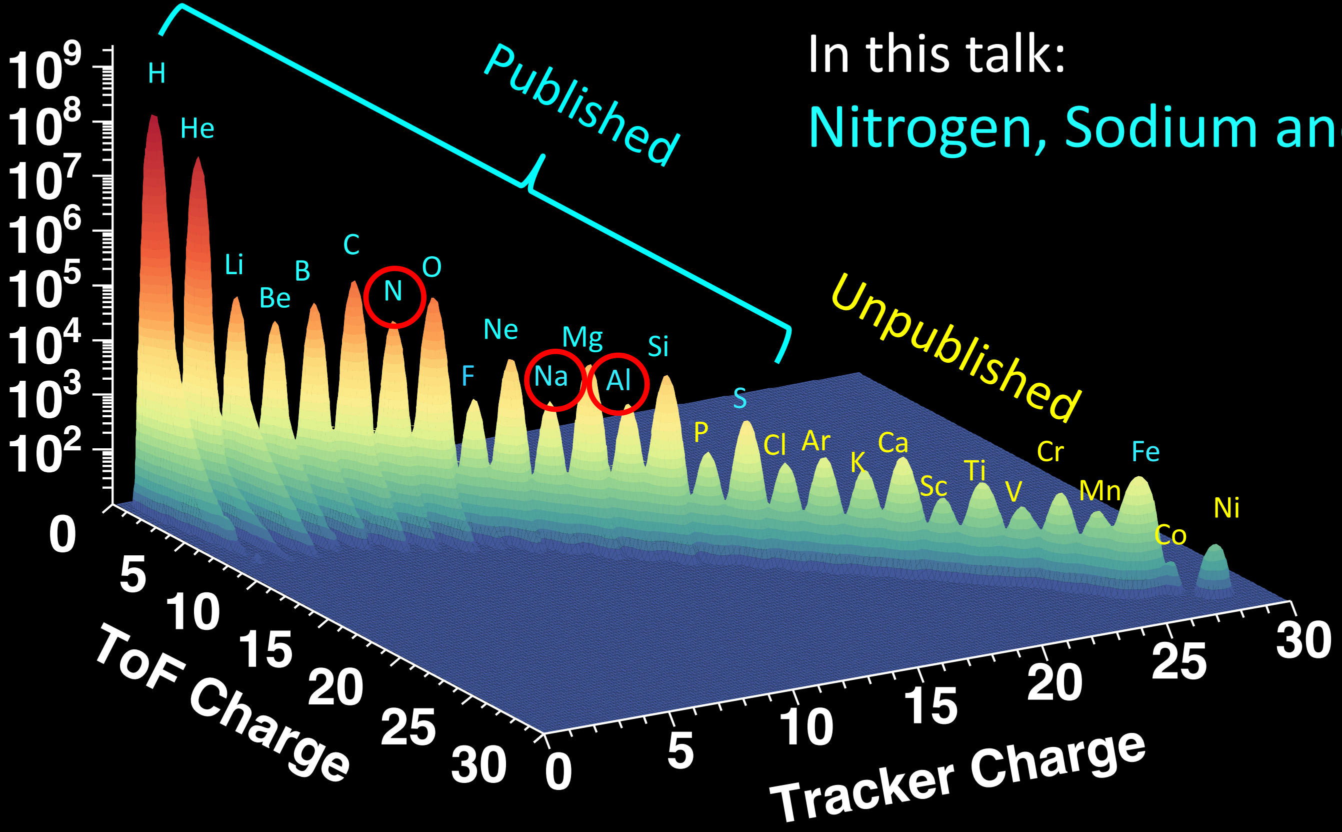


Primary cosmic rays (P, He, C, O, Ne, Mg, Si, …, Fe) are produced and accelerated in supernovae explosions

Secondary cosmic rays (Li, Be, B, F, …) are produced by the collisions of primary cosmic rays and interstellar medium

AMS found the third group of cosmic ray (N, Na, Al, …) are produced both in stars and collisions of primary cosmic rays with the interstellar medium.

Cosmic Ray Nuclei Measurements with AMS

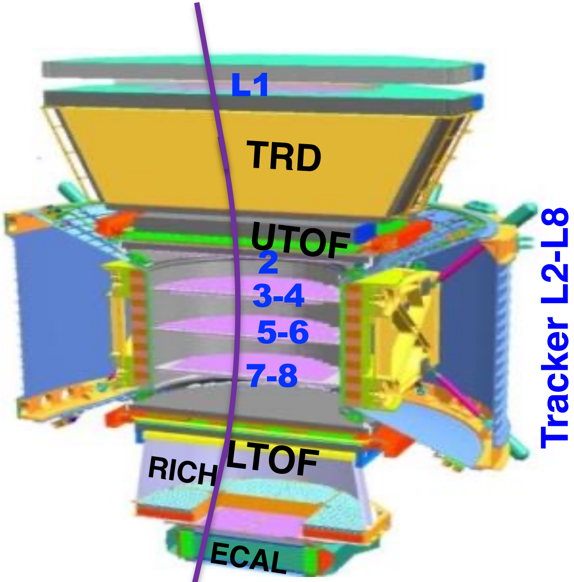


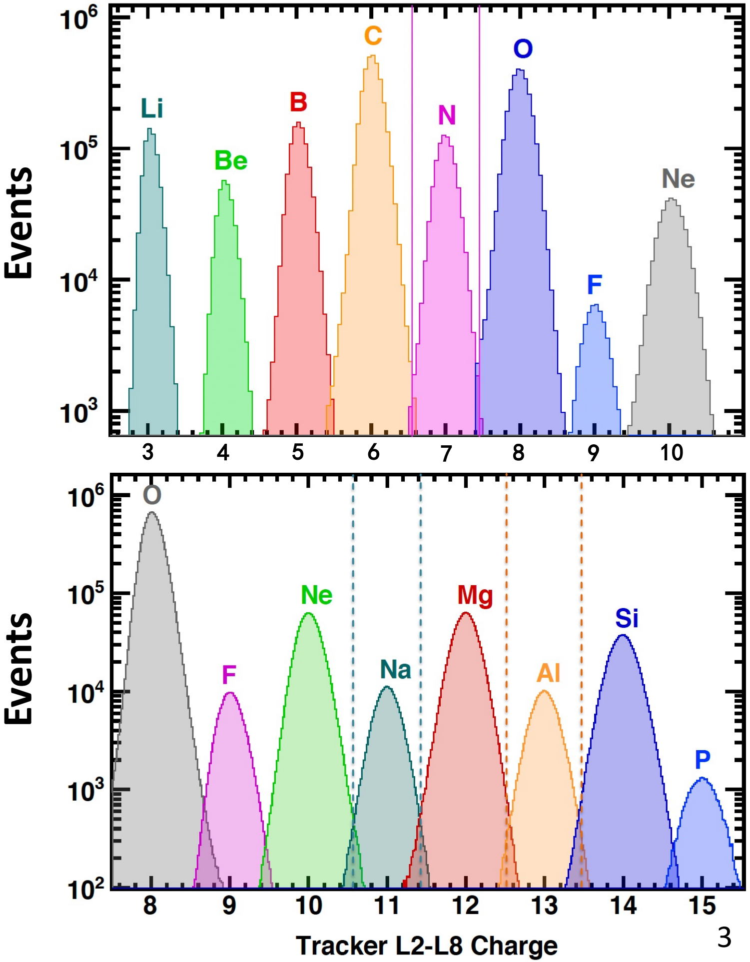
In this talk:

Nitrogen, Sodium and Aluminum

AMS N, Na and Al event selection

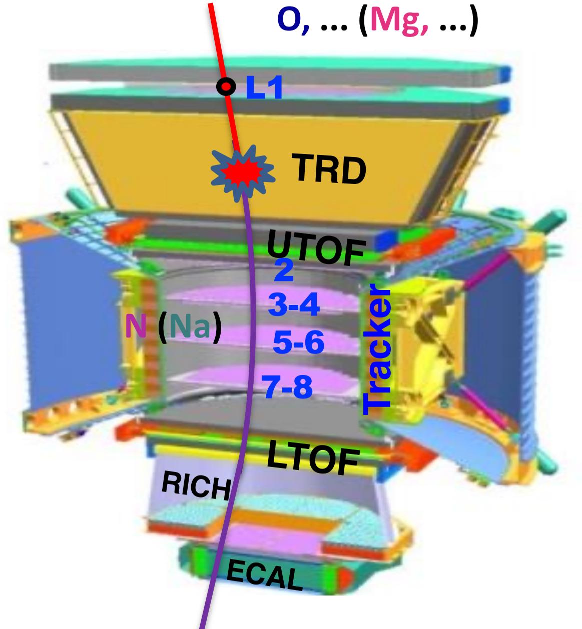
- AMS has a good charge measurement capability. Charge measured by L1, UTOF, tracker L2-L8, LTOF and L9 are required to be consistent along particle trajectory.
- For example, the tracker L2-L8 charge resolution for 3≤ Z≤15 ranges from 0.05 to 0.17 c.u.
- The background due to finite charge resolution is negligible for N, Na and Al, <0.5% over the entire rigidity range.

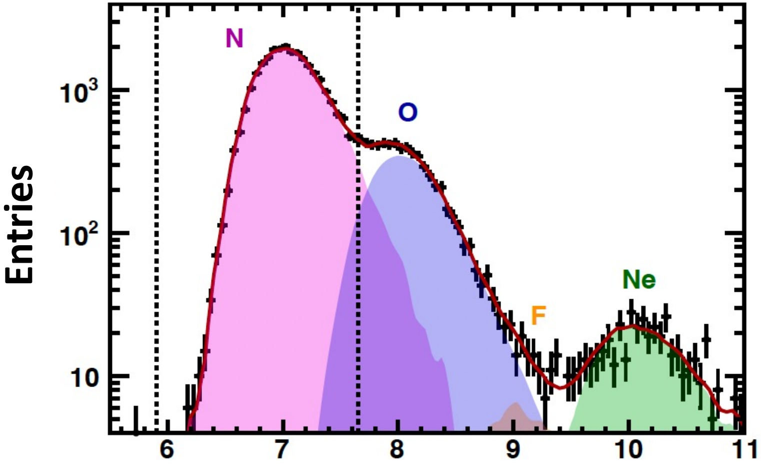


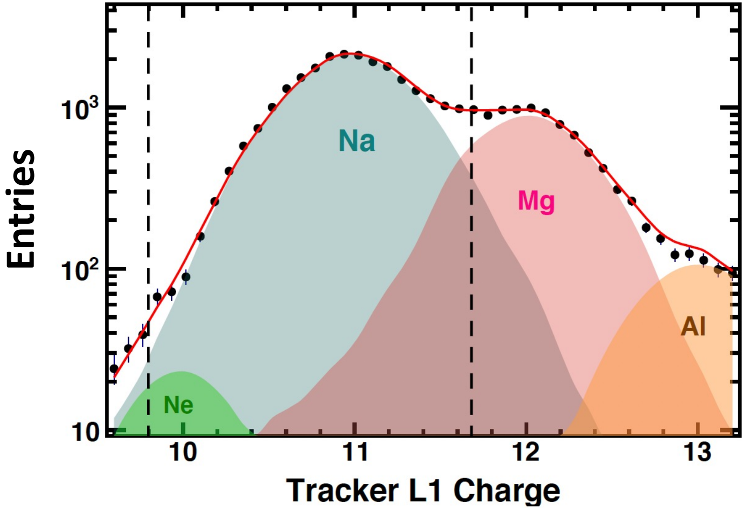


Background from interaction of heavier nuclei

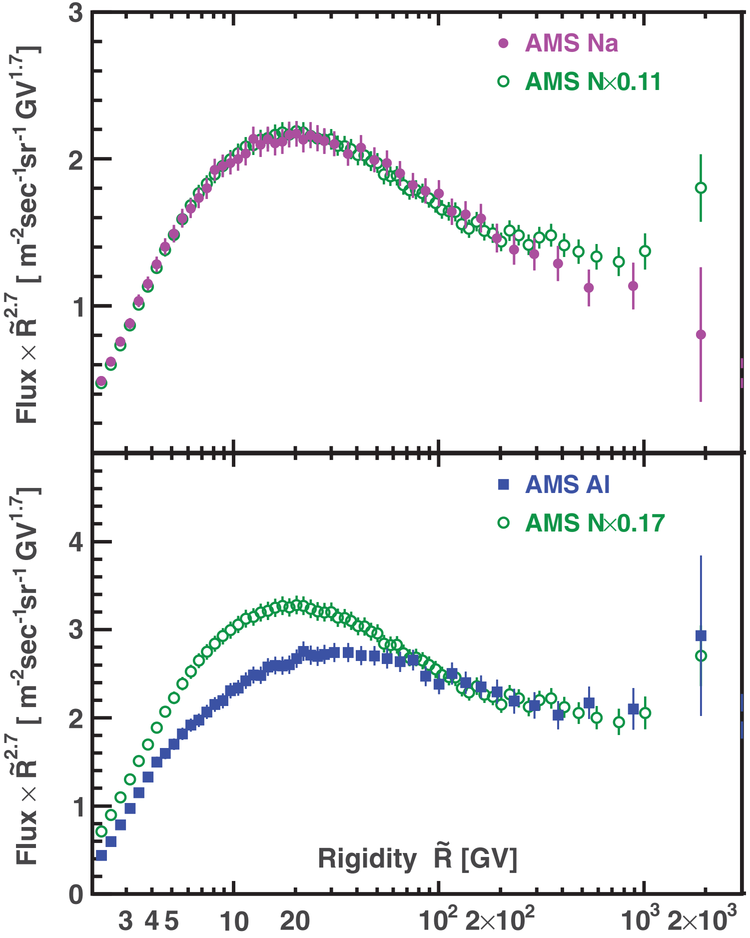
The background from interaction of heavier nuclei in the AMS materials of TRD and UTOF (such as O, …→N or Mg, … → Na), was accurately subtracted using the measured charge from tracker L1, with a typical error of a few percent.







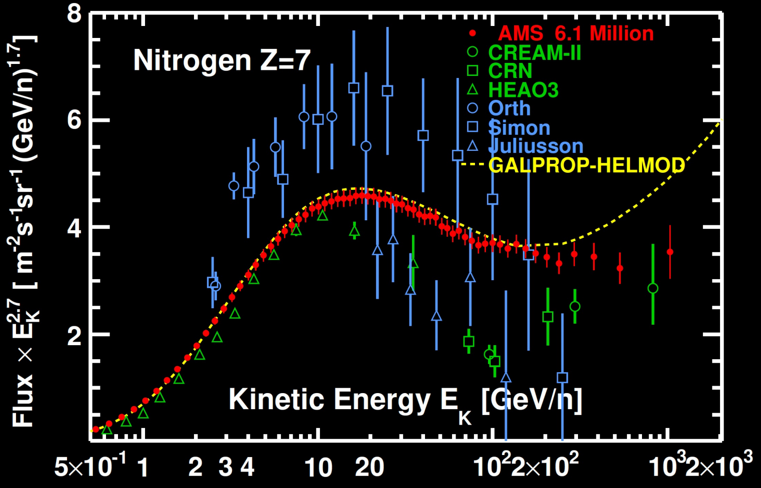
Detailed understanding of the N, Na, Al energy spectrum with AMS



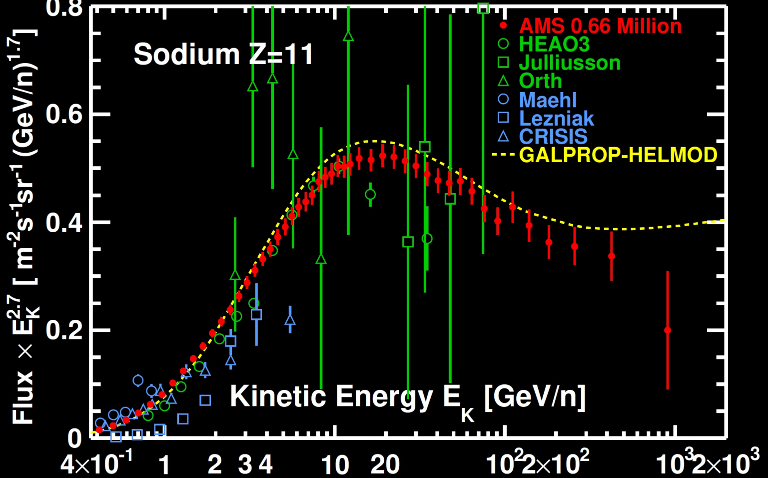
Below 100 GV, the Sodium flux rigidity dependence is similar to the Nitrogen flux rigidity dependence.

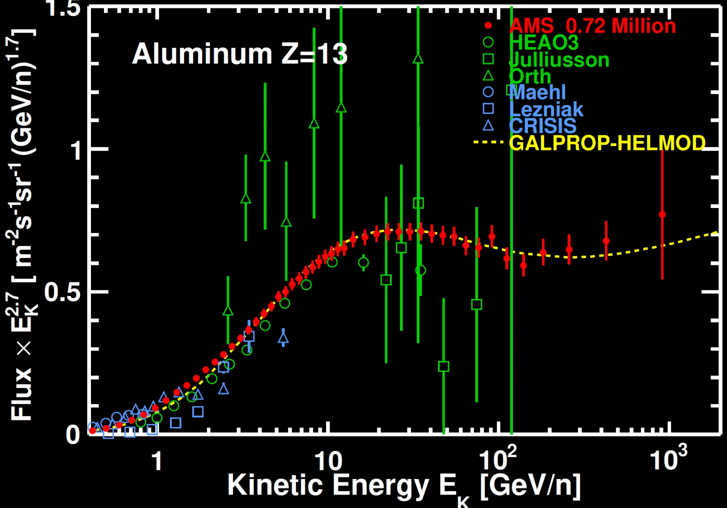
Above 100 GV, the Aluminum flux rigidity dependence is similar to the Nitrogen flux rigidity dependence.

AMS 11-Year Results on Nitrogen, Sodium and Aluminum Fluxes

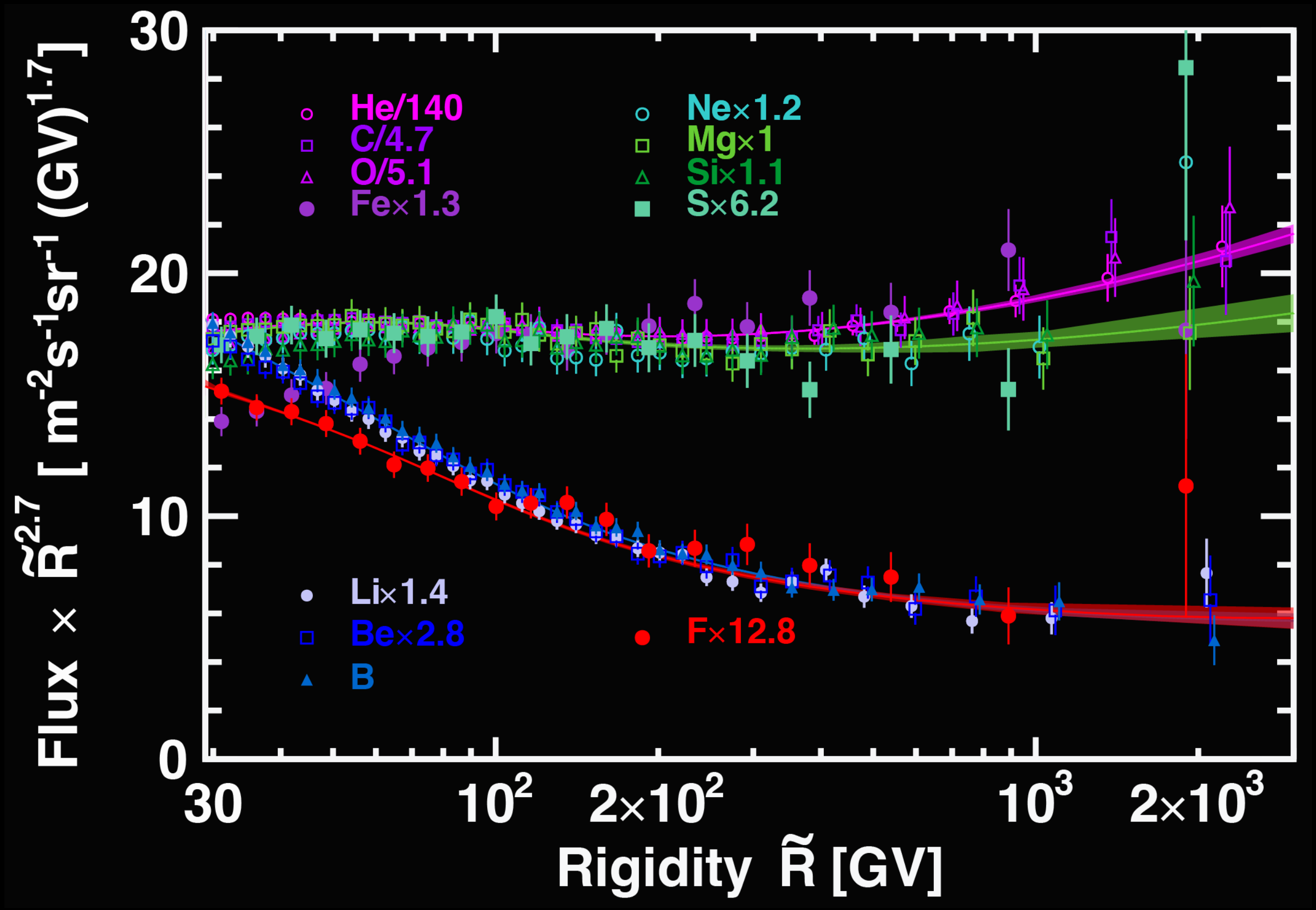


The total errors at ~50 GeV/n are <5% for N, Na and Al





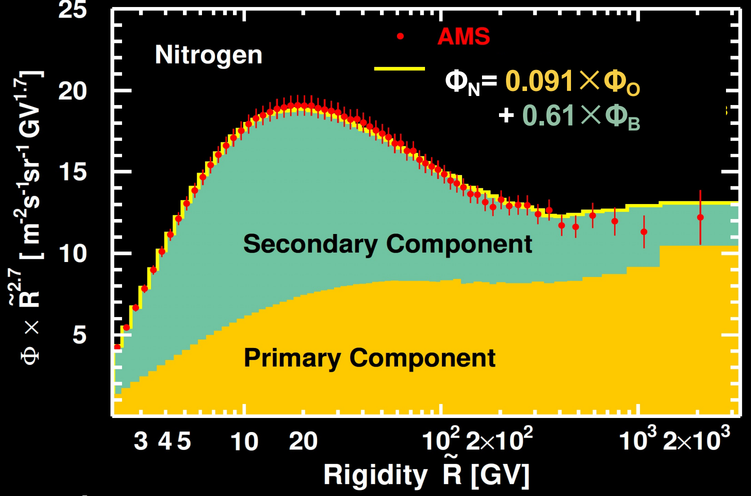
Properties of Primary and Secondary Cosmic Rays Result from AMS



Two classes of primary cosmic rays:
He-C-O-Fe and **Ne-Mg-Si-S**

Two classes of secondary cosmic rays:
Li-Be-B and **F**

Primary and Secondary Components of the N, Na, Al Flux



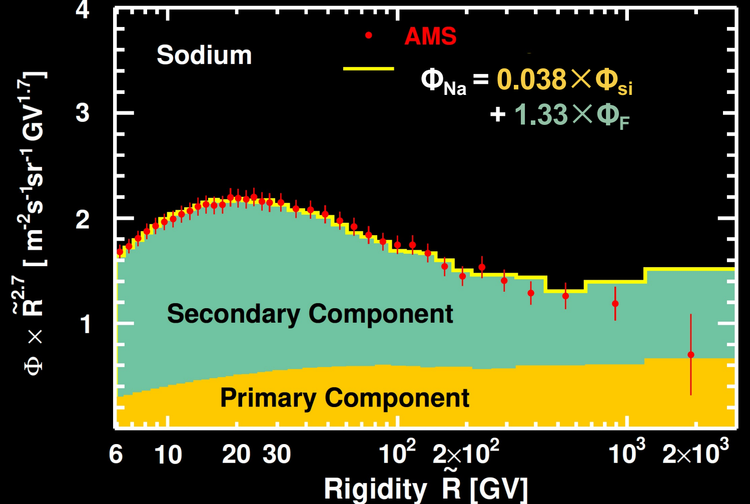
The flux ratios at the source:

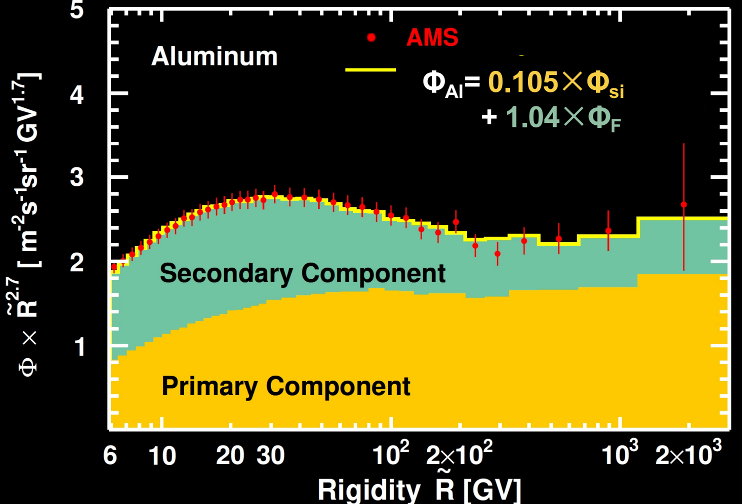
N/O=0.091±0.002,

Na/Si=0.038±0.003,

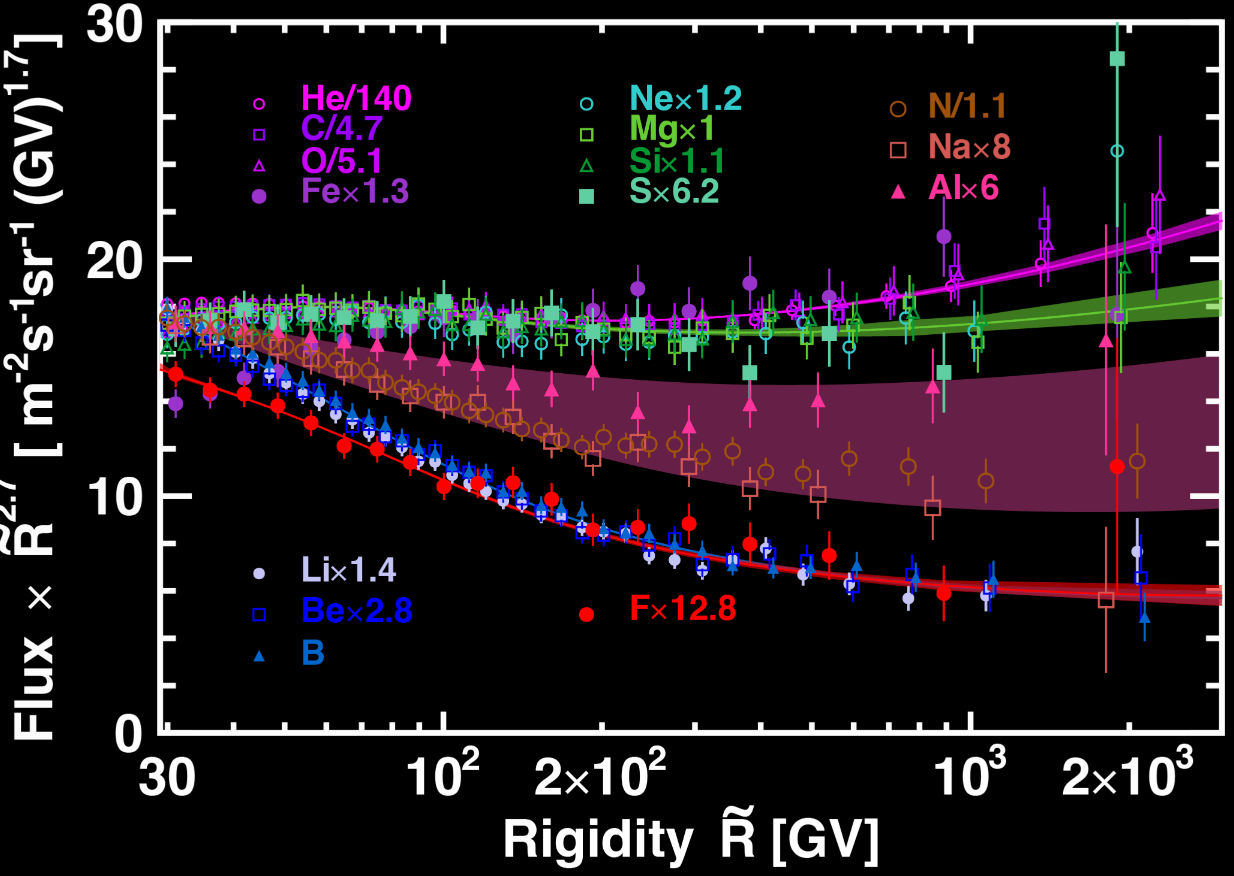
Al/Si=0.105±0.004

are directly determined independent of cosmic ray propagation





Latest AMS Results on Cosmic Ray Nuclei Fluxes (Z>=2)



Two classes of primary cosmic rays:

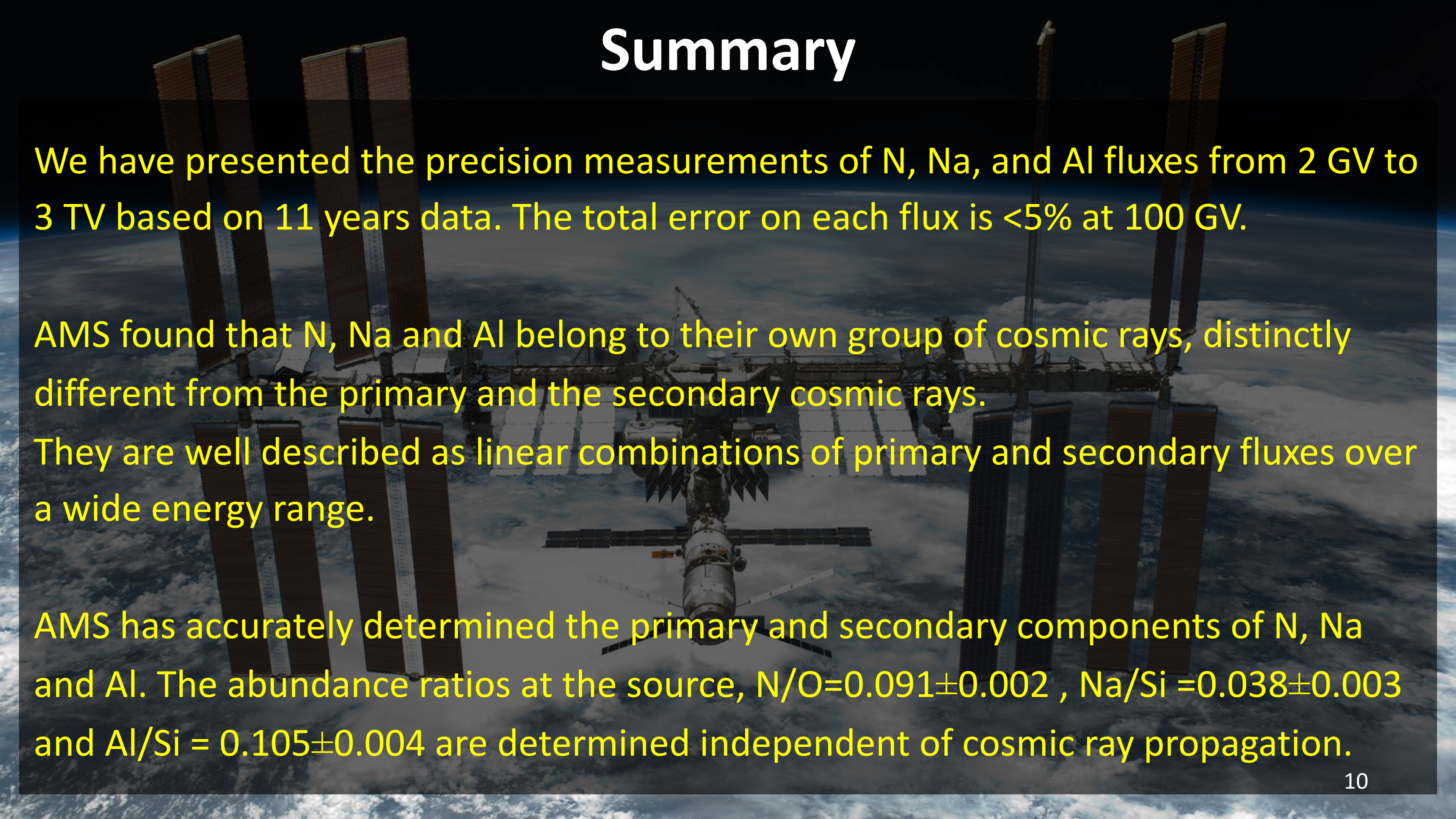
He-C-O-Fe and **Ne-Mg-Si-S**

N, **Na** and **Al**, belong to a distinct group, and are combinations of primary and secondary cosmic rays.

Two classes of secondary cosmic rays:

Li-Be-B and **F**

Summary



We have presented the precision measurements of N, Na, and Al fluxes from 2 GV to 3 TV based on 11 years data. The total error on each flux is <5% at 100 GV.

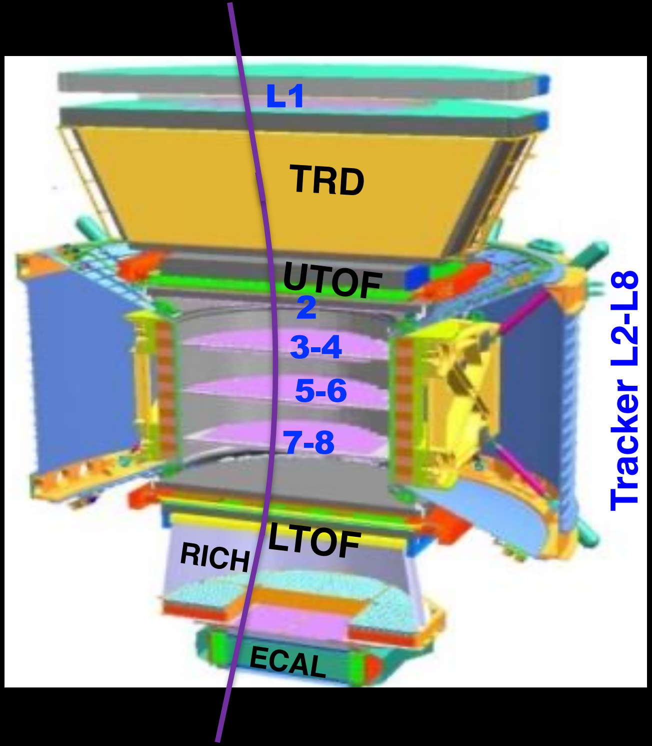
AMS found that N, Na and Al belong to their own group of cosmic rays, distinctly different from the primary and the secondary cosmic rays.
They are well described as linear combinations of primary and secondary fluxes over a wide energy range.

AMS has accurately determined the primary and secondary components of N, Na and Al. The abundance ratios at the source, N/O=0.091±0.002 , Na/Si =0.038±0.003 and Al/Si = 0.105±0.004 are determined independent of cosmic ray propagation.

Back Up

AMS Cosmic Ray Nuclei Measurements

Tracker (9 Layers) + Magnet: Rigidity (Momentum/Charge)
with multi-TV maximal detectable rigidity (MDR)



	Coordinate Resolution	MDR
$Z \geq 2$	5-8 μm	3.0-3.7 TV

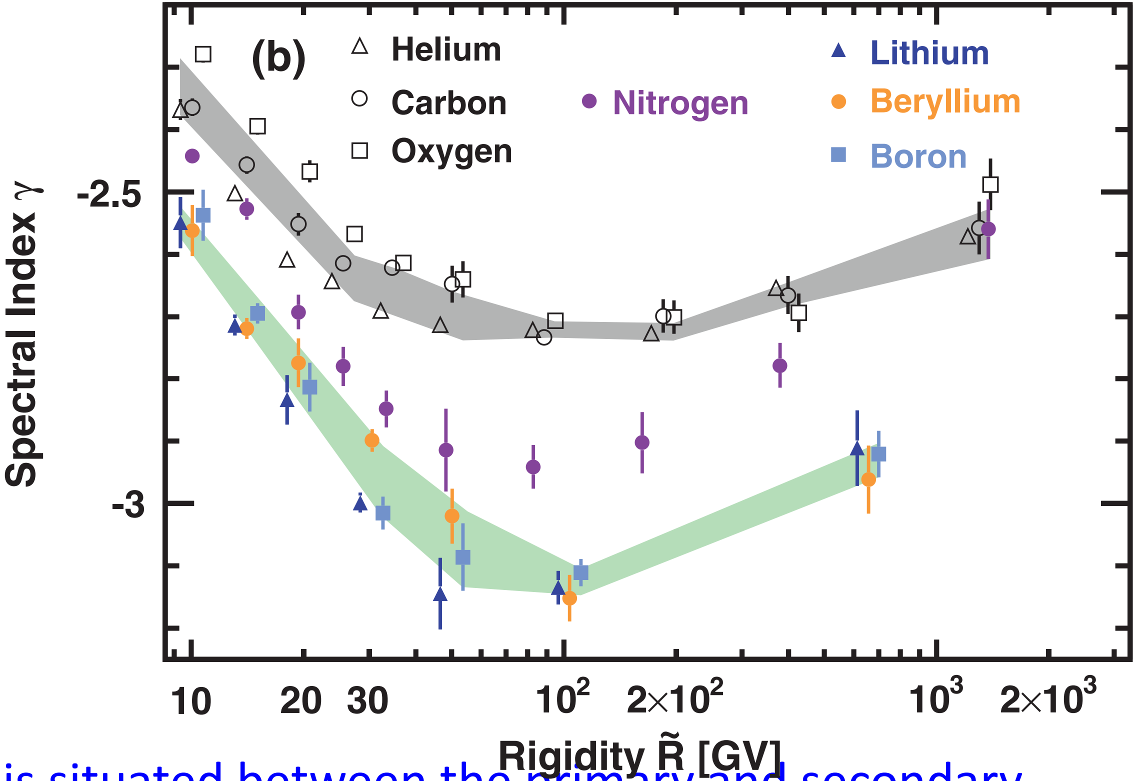
ToF (4 Layers): Velocity and Direction
$\Delta\beta/\beta^2 \approx 1\text{-}2\%$ ($Z \geq 2$)

L1, UTOF, Inner Tracker (L2-L8), LTOF and L9
Consistent Charge Along Particle Trajectory
Inner Tracker Charge Resolution:
$\Delta Z = 0.05 - 0.35$ ($1 \leq Z \leq 28$)

Detailed understanding of the N energy spectrum with AMS

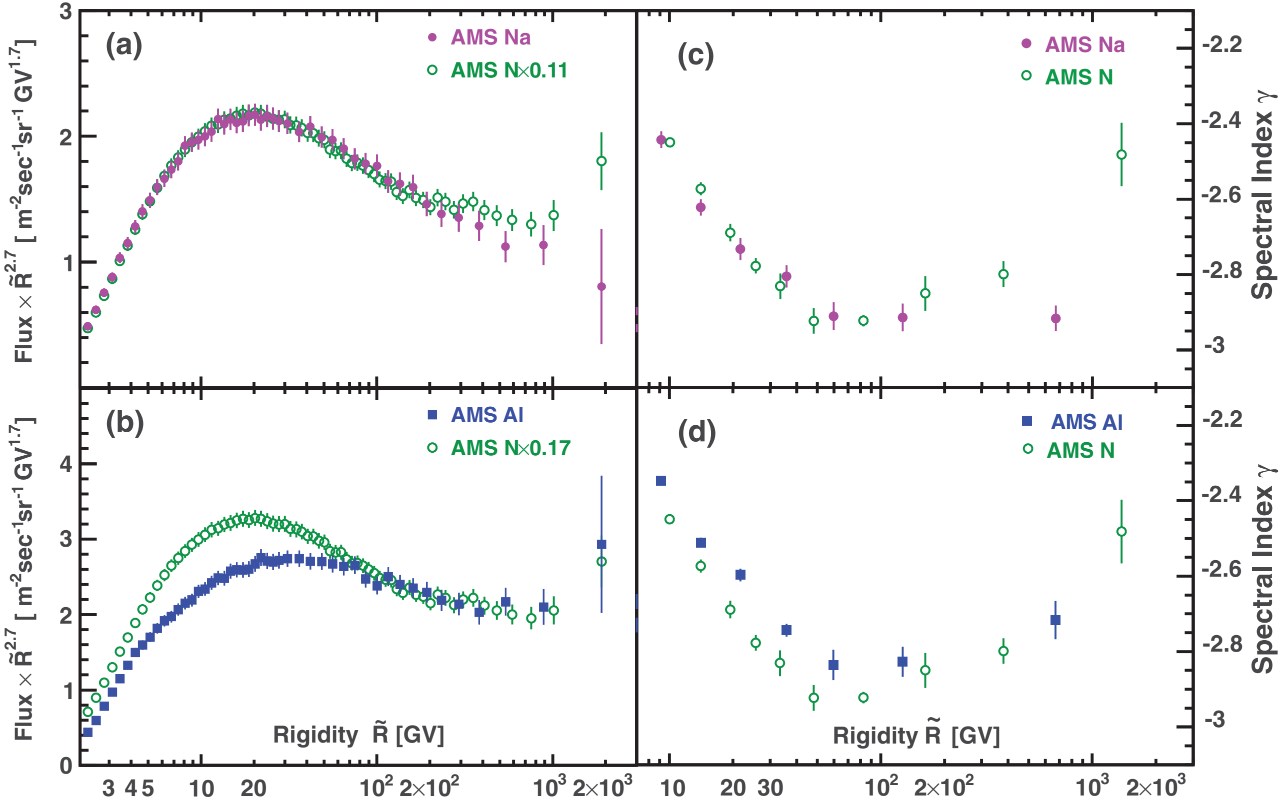
$N(E) \propto E^{-\gamma}$

- When γ is close to 1, it indicates that the number of high-energy cosmic rays decreases relatively slowly with increasing energy.
- When γ is significantly greater than 1, it indicates a steeper decrease in the number of high-energy cosmic rays.
- When γ is less than 1, it suggests that there are more high-energy cosmic rays compared to lower-energy ones.



The Nitrogen spectral index is situated between the primary and secondary cosmic ray spectral index

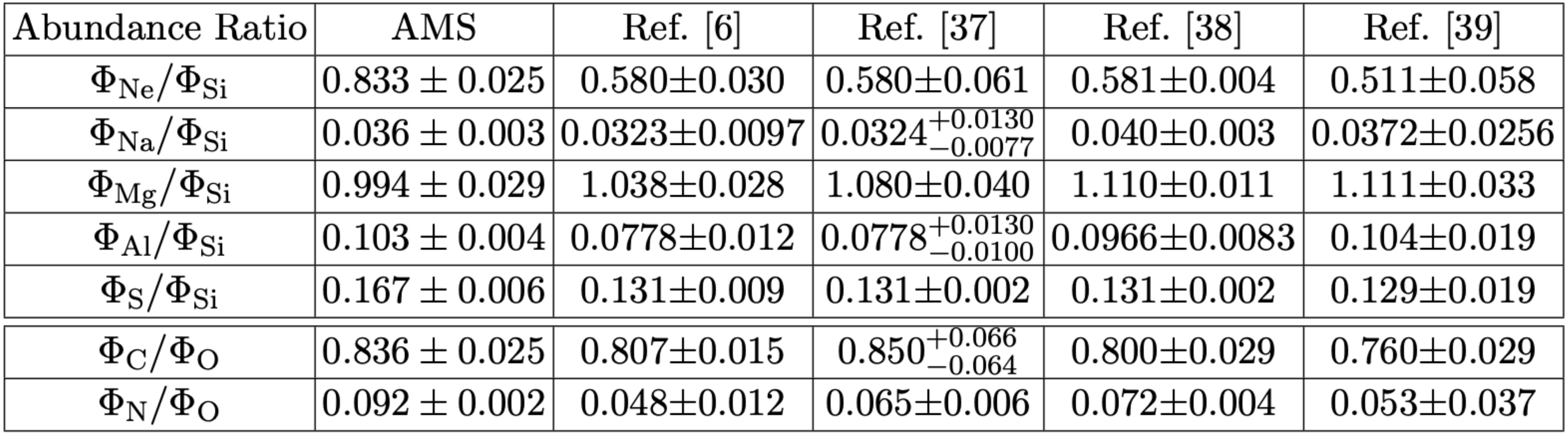
Detailed understanding of the N, Na, Al energy spectrum with AMS



Below 100 GV, the Sodium flux rigidity dependence are similar to the Nitrogen flux rigidity dependence.

Above 100 GV, the Aluminum flux rigidity dependence are similar to the Nitrogen flux rigidity dependence.

The fluxes ratio compare with other experiments



Abundance Ratio	AMS	Ref. [6]	Ref. [37]	Ref. [38]	Ref. [39]
$\Phi_{\mathrm{Ne}}/\Phi_{\mathrm{Si}}$	0.833 ± 0.025	0.580 ± 0.030	0.580 ± 0.061	0.581 ± 0.004	0.511 ± 0.058
$\Phi_{\mathrm{Na}}/\Phi_{\mathrm{Si}}$	0.036 ± 0.003	0.0323 ± 0.0097	$0.0324^{+0.0130}_{-0.0077}$	0.040 ± 0.003	0.0372 ± 0.0256
$\Phi_{\mathrm{Mg}}/\Phi_{\mathrm{Si}}$	0.994 ± 0.029	1.038 ± 0.028	1.080 ± 0.040	1.110 ± 0.011	1.111 ± 0.033
$\Phi_{\mathrm{Al}}/\Phi_{\mathrm{Si}}$	0.103 ± 0.004	0.0778 ± 0.012	$0.0778^{+0.0130}_{-0.0100}$	0.0966 ± 0.0083	0.104 ± 0.019
$\Phi_{\mathrm{S}}/\Phi_{\mathrm{Si}}$	0.167 ± 0.006	0.131 ± 0.009	0.131 ± 0.002	0.131 ± 0.002	0.129 ± 0.019
$\Phi_{\mathrm{C}}/\Phi_{\mathrm{O}}$	0.836 ± 0.025	0.807 ± 0.015	$0.850^{+0.066}_{-0.064}$	0.800 ± 0.029	0.760 ± 0.029
$\Phi_{\mathrm{N}}/\Phi_{\mathrm{O}}$	0.092 ± 0.002	0.048 ± 0.012	0.065 ± 0.006	0.072 ± 0.004	0.053 ± 0.037

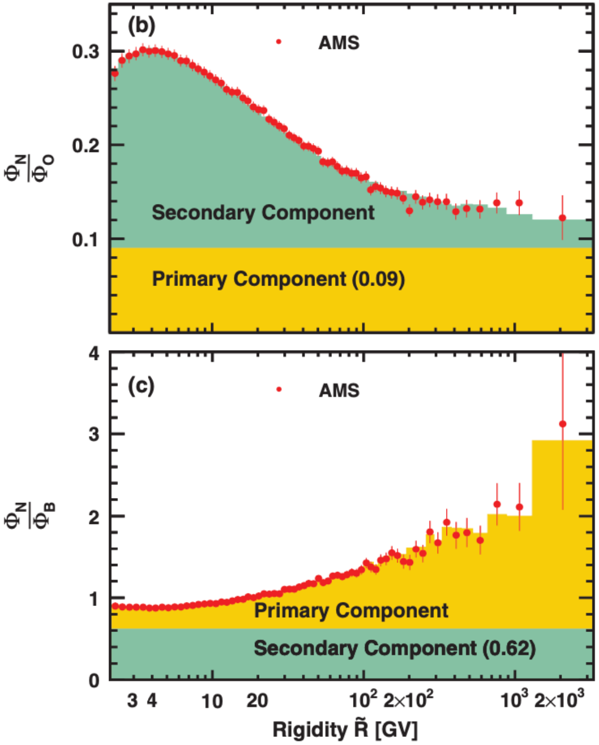
Ref.[6]: HEAO-3-C2

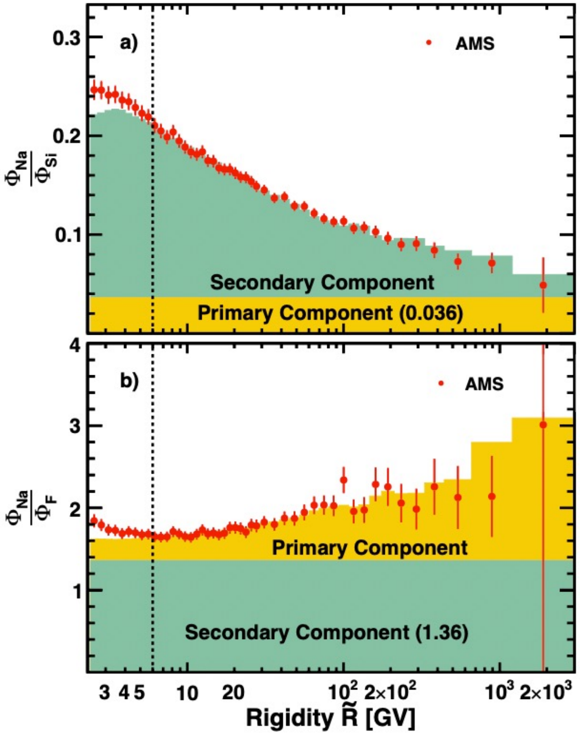
Ref.[37]: Ulysses

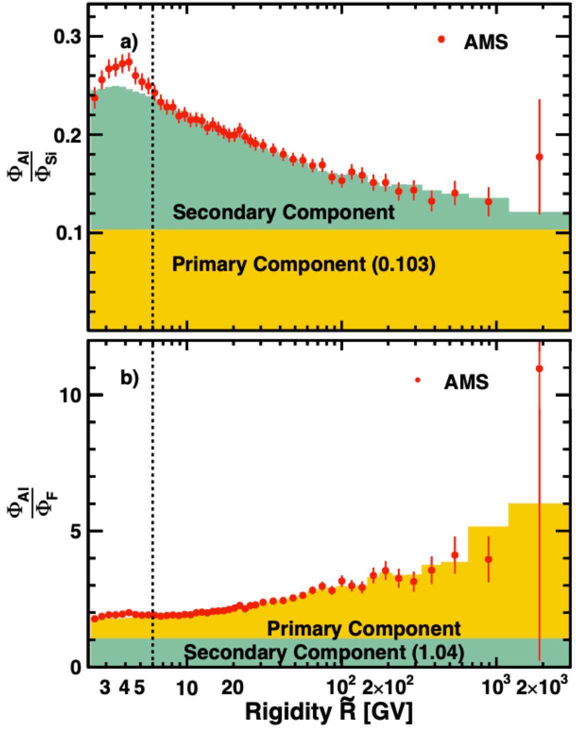
Ref.[38]: Voyager

Ref.[39]: ACE-CRIS

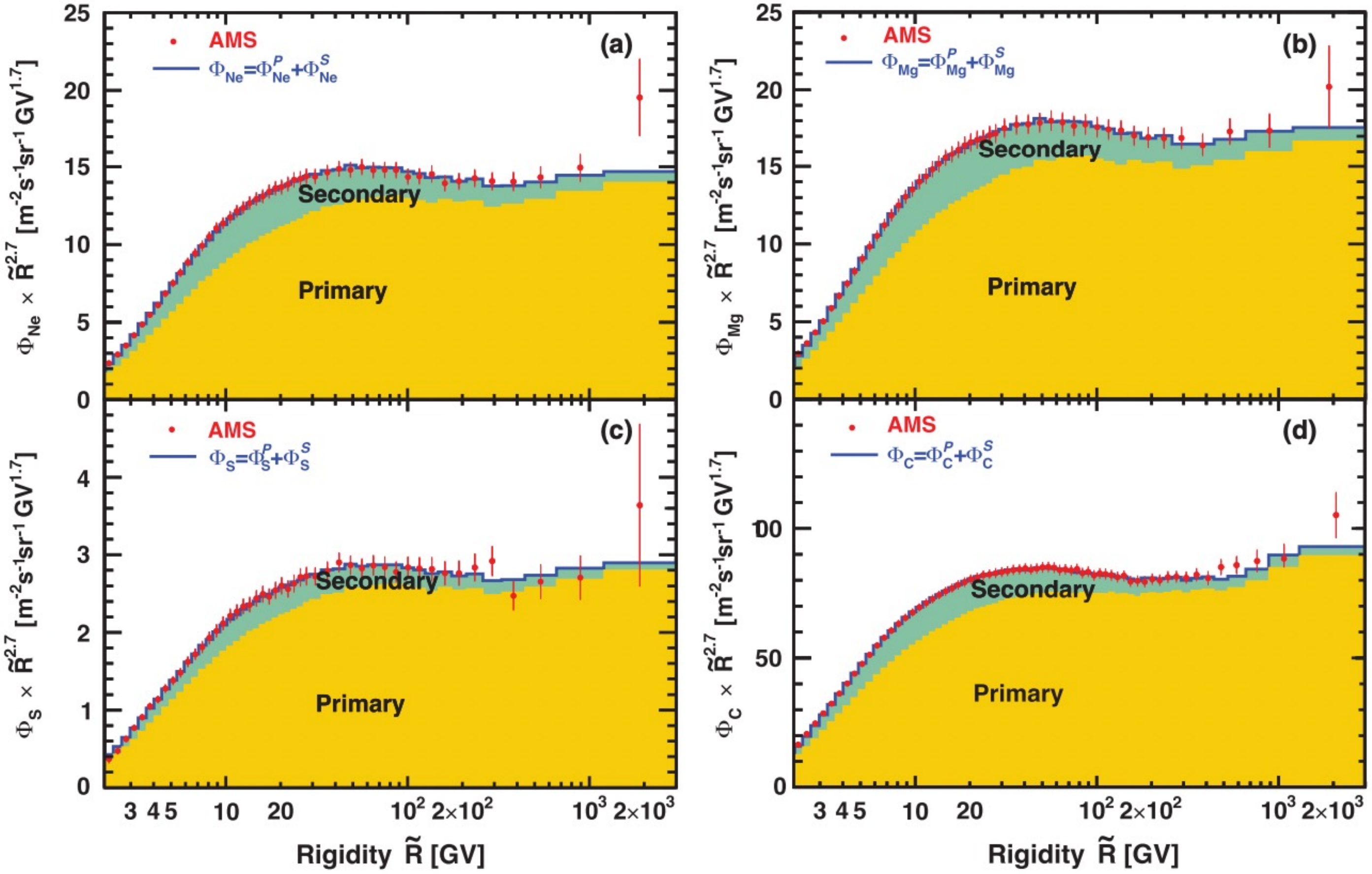
Primary and Secondary Components of the Ni, Na and Al Flux







Primary and Secondary Components of the C, Mg, Ne, S Flux



Primary and Secondary Components of the C, Mg, Ne, S Flux

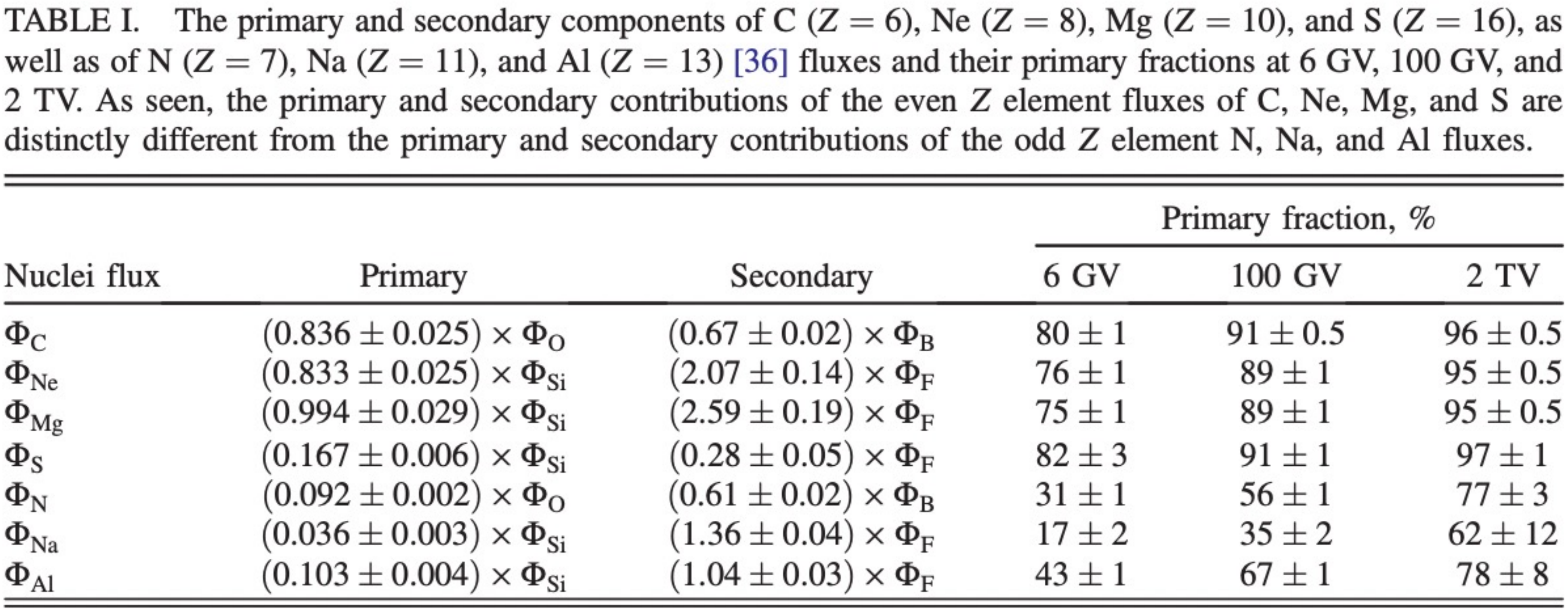


TABLE I. The primary and secondary components of C ($Z = 6$), Ne ($Z = 8$), Mg ($Z = 10$), and S ($Z = 16$), as well as of N ($Z = 7$), Na ($Z = 11$), and Al ($Z = 13$) [36] fluxes and their primary fractions at 6 GV, 100 GV, and 2 TV. As seen, the primary and secondary contributions of the even Z element fluxes of C, Ne, Mg, and S are distinctly different from the primary and secondary contributions of the odd Z element N, Na, and Al fluxes.

			Primary fraction, %		
Nuclei flux	Primary	Secondary	6 GV	100 GV	2 TV
Φ_C	$(0.836 \pm 0.025) \times \Phi_O$	$(0.67 \pm 0.02) \times \Phi_B$	80 ± 1	91 ± 0.5	96 ± 0.5
Φ_{Ne}	$(0.833 \pm 0.025) \times \Phi_{Si}$	$(2.07 \pm 0.14) \times \Phi_F$	76 ± 1	89 ± 1	95 ± 0.5
Φ_{Mg}	$(0.994 \pm 0.029) \times \Phi_{Si}$	$(2.59 \pm 0.19) \times \Phi_F$	75 ± 1	89 ± 1	95 ± 0.5
Φ_S	$(0.167 \pm 0.006) \times \Phi_{Si}$	$(0.28 \pm 0.05) \times \Phi_F$	82 ± 3	91 ± 1	97 ± 1
Φ_N	$(0.092 \pm 0.002) \times \Phi_O$	$(0.61 \pm 0.02) \times \Phi_B$	31 ± 1	56 ± 1	77 ± 3
Φ_{Na}	$(0.036 \pm 0.003) \times \Phi_{Si}$	$(1.36 \pm 0.04) \times \Phi_F$	17 ± 2	35 ± 2	62 ± 12
Φ_{Al}	$(0.103 \pm 0.004) \times \Phi_{Si}$	$(1.04 \pm 0.03) \times \Phi_F$	43 ± 1	67 ± 1	78 ± 8

Primary and Secondary Components in Cosmic Rays

Nuclei Flux	Primary	Secondary
Φ_C	$(0.83 \pm 0.02) \times \Phi_O$	$(0.70 \pm 0.02) \times \Phi_B$
Φ_{Ne}	$(0.83 \pm 0.02) \times \Phi_{Si}$	$(1.99 \pm 0.14) \times \Phi_F$
Φ_{Mg}	$(1.01 \pm 0.03) \times \Phi_{Si}$	$(2.39 \pm 0.17) \times \Phi_F$
Φ_S	$(0.162 \pm 0.005) \times \Phi_{Si}$	$(0.33 \pm 0.04) \times \Phi_F$
Φ_N	$(0.091 \pm 0.002) \times \Phi_O$	$(0.61 \pm 0.02) \times \Phi_B$
Φ_{Na}	$(0.038 \pm 0.003) \times \Phi_{Si}$	$(1.33 \pm 0.04) \times \Phi_F$
Φ_{Al}	$(0.105 \pm 0.004) \times \Phi_{Si}$	$(1.04 \pm 0.03) \times \Phi_F$

AMS Iron Flux

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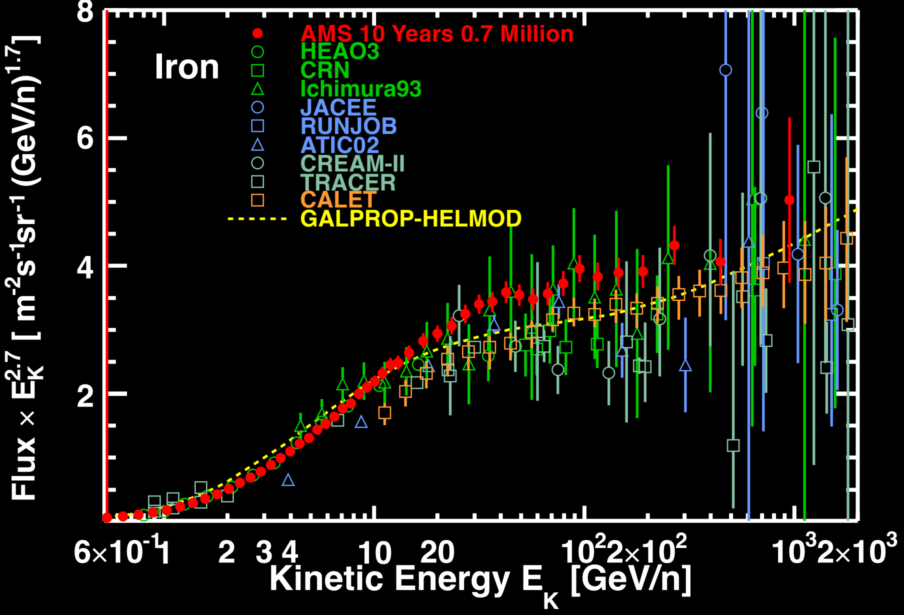

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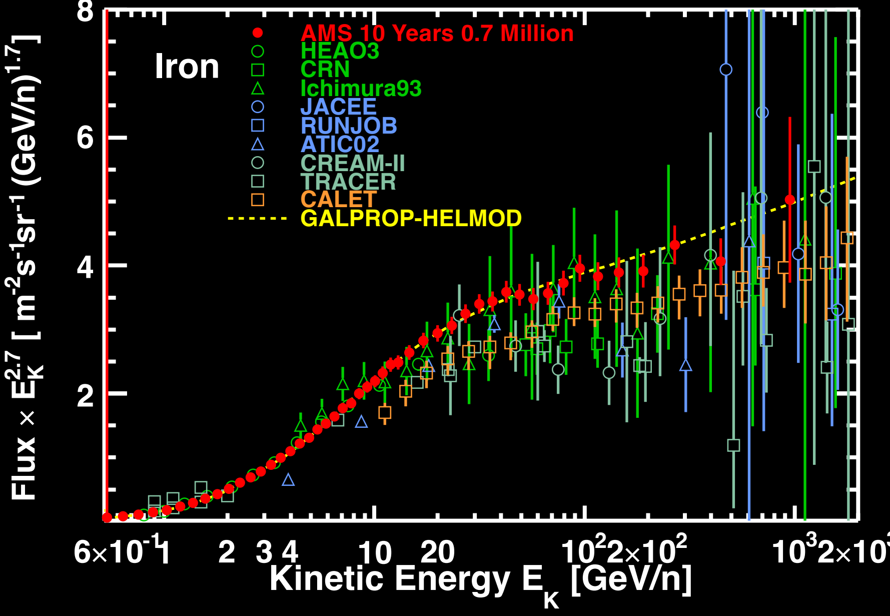

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