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Properties of Third Group of Cosmic Nuclei: Results from the Alpha Magnetic Spectrometer

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We report the latest results on the properties of nitrogen (N), sodium (Na), and aluminium (Al) cosmic rays in the rigidity range from 2.15 GV to 3.0 TV based on 6.1 million N, 0.66 million Na and 0.72 million Al nuclei collected by the AMS. We observe all three fluxes are well described by the sums of a primary cosmic ray component and a secondary cosmic ray component. With our measurements, the abundance ratios at the source of N/O, Na/Si, and Al/Si are determined independent of cosmic ray propagation.

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PoS(ICRC2023)096

1. Introduction

Cosmic nuclei nitrogen, sodium and aluminium are thought to be produced both in astrophysical sources and by the collisions of heavier nuclei with the interstellar medium [1]. In this paper, we report the precise measurement of the cosmic ray N, Na and Al fluxes in the rigidity range from 2.15 GV to 3.0 TV based on 6.1 million nitrogen, 0.66 million sodium and 0.72 million aluminium nuclei collected by AMS during the first 11 years (May 19, 2011 to November 11, 2022) of operation aboard the International Space Station.

2. AMS-02 Detector and Analysis

The AMS detector is a large-acceptance magnetic spectrometer, the full description of the detector is presented in [2] and references therein. The key elements used in this measurement are the permanent magnet, the nine layers of silicon tracker, L1-L9, and the four planes of time of flight (TOF) scintillation counters. Together with the permanent magnet, the silicon tracker measures the rigidity of charged cosmic rays.

N, Na and Al events are required to be downward going and to have a reconstructed track in the seven tracker layers placed on the top and inside the magnet. The track is also required to pass through tracker L1, and for the highest rigidity region $R \geq 1.2$ TV, through tracker L9. Charge measurements on tracker L1, the inner tracker (L2-L8), the upper TOF, and, for $R \geq 1.2$ TV, the lower TOF, and tracker L9 are required to be compatible with charge Z=7, 11 and 13 respectively. Details of the N, Na and Al flux analysis procedure and particularly the studies of the systematic errors can be found in [3, 4].

3. Measurement of Nitrogen, Sodium and Aluminium Cosmic Nuclei

The AMS N, Na and Al fluxes as functions of kinetic energy per nucleon E_K are shown in Fig. 1, compared with results from previous experiments [5–10]. The latest GALPROP–HELMOD model [11] prediction based on AMS publication on the two primary cosmic ray classes, He-C-O and Ne-Mg-Si and other AMS data (dashed blue lines) is shown in the same figure.

The N flux Φ_{N} is fitted to the weighted sum of the flux of light primary cosmic ray oxygen Φ_{O} [2], and the flux of light secondary cosmic ray flux boron Φ_{B} [2], to estimate the primary ($\Phi^{\mathrm{P}}_{\mathrm{N}}$) and secondary ($\Phi^{\mathrm{S}}_{\mathrm{N}}$) components of the N flux $\Phi_{\mathrm{N}} = \Phi^{\mathrm{P}}_{\mathrm{N}} + \Phi^{\mathrm{S}}_{\mathrm{N}}$, as shown in Fig. 2.

Following the N flux, we also estimate the primary and secondary components for heavy nuclei Na and Al fluxes by performing fit to weighted sum of fluxes. The Na flux Φ_{Na} is fitted to the weighted sum of the flux of heavy primary cosmic ray silicon Φ_{Si} [2, 15], and the flux of heavy secondary cosmic ray flux fluorine Φ_{F} [2, 16], above 6 GV to estimate the primary ($\Phi^{\mathrm{P}}_{\mathrm{Na}}$) and secondary ($\Phi^{\mathrm{S}}_{\mathrm{Na}}$) components of the Na flux $\Phi_{\mathrm{Na}} = \Phi^{\mathrm{P}}_{\mathrm{Na}} + \Phi^{\mathrm{S}}_{\mathrm{Na}}$. Similarly, the Al flux Φ_{Al} is fitted to the weighted sum of the silicon flux and the fluorine flux above 6 GV, as shown in Fig. 3(b), in order to estimate the primary ($\Phi^{\mathrm{P}}_{\mathrm{Al}}$) and secondary ($\Phi^{\mathrm{S}}_{\mathrm{Al}}$) components in the Al flux $\Phi_{\mathrm{Al}} = \Phi^{\mathrm{P}}_{\mathrm{Al}} + \Phi^{\mathrm{S}}_{\mathrm{Al}}$.

Fig. 2 and Fig. 3 show that all the N, Na and Al fluxes are well fitted as the linear combinations of primary and secondary fluxes over a large rigidity range. It determines directly the N/O, Na/Si

PoS(ICRC2023)096

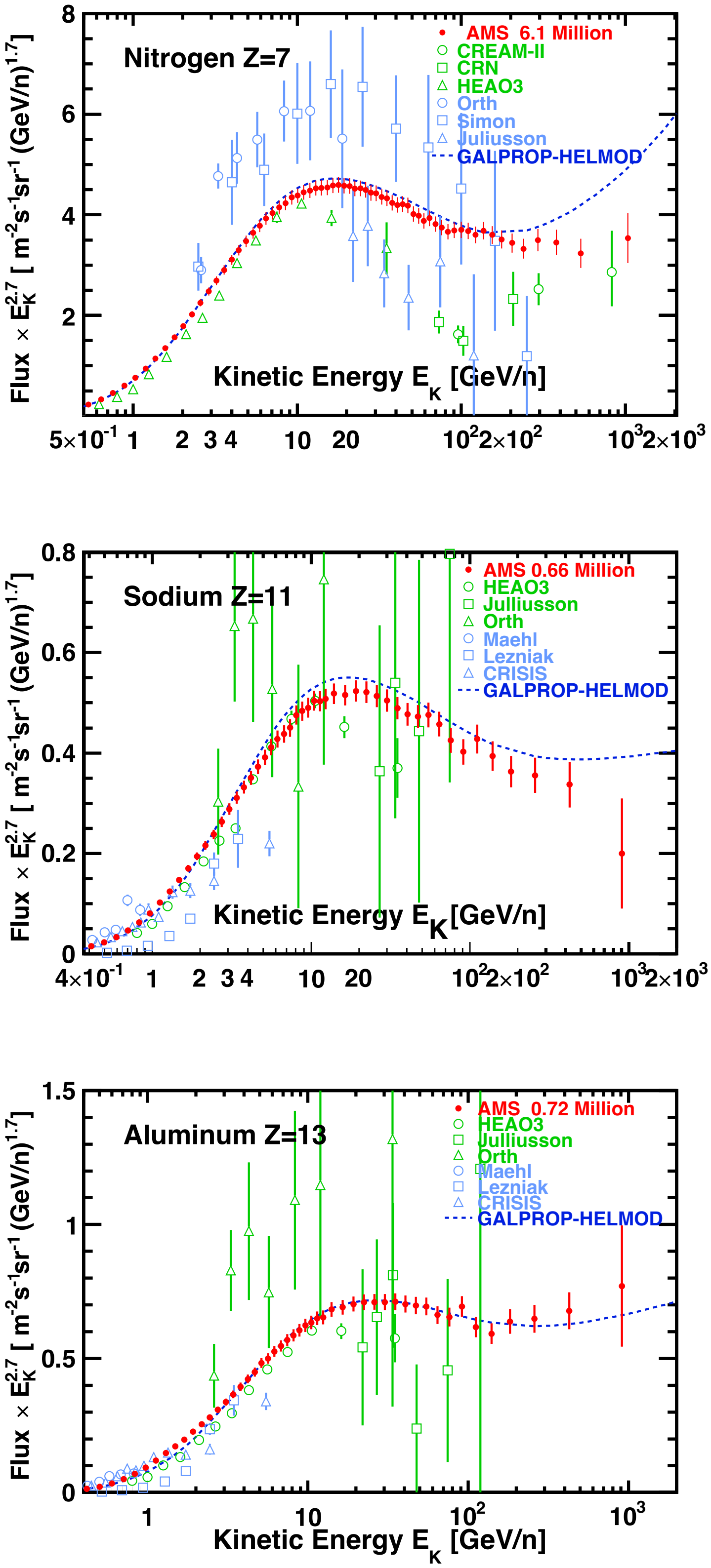

Figure 1: The 11 years AMS (a) N flux Φ_N, (b) Na flux Φ_{Na} and (c) Al flux Φ_{Al} multiplied by $E_K^{2.7}$ compared with results from earlier experiments [5–10] as functions of kinetic energy per nucleon E_K. For the AMS measurement E_K is calculated as in [4] and results from earlier experiments are taken from [12].

PoS(ICRC2023)096

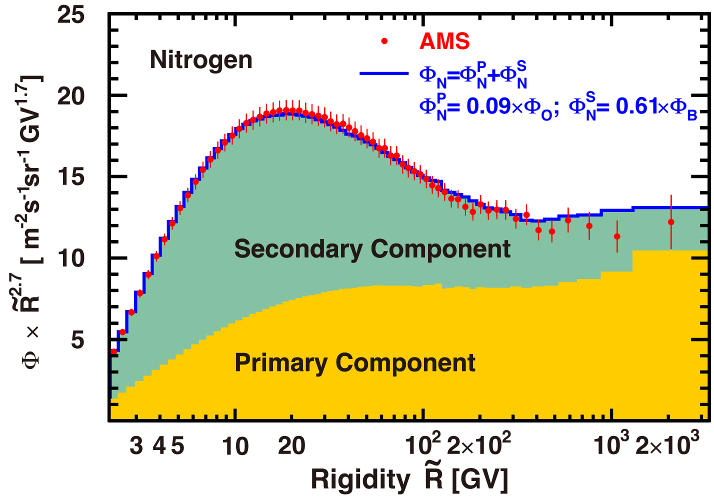

Figure 2: The AMS N flux $\Phi_N = \Phi_N^P + \Phi_N^S$ with the fit result to the weighted sum of the O flux Φ_O and th eB flux Φ_B. The result gives $\Phi_N^P = (0.091 \pm 0.002) \times \Phi_O$ and $\Phi_N^S = (0.61 \pm 0.02) \times \Phi_B$.

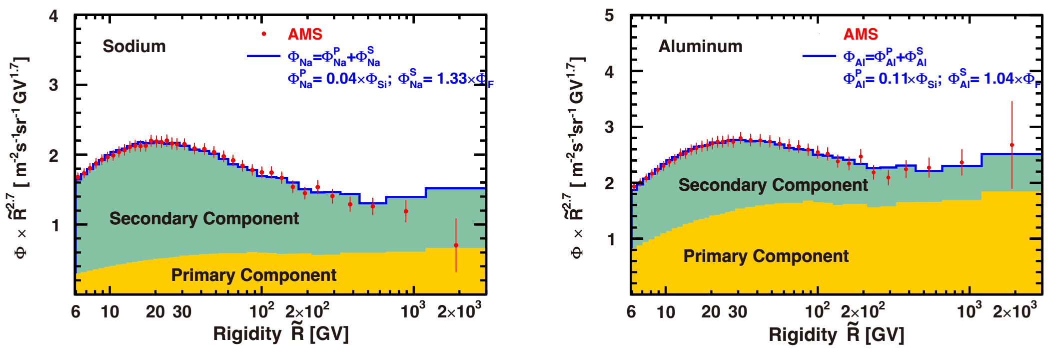

Figure 3: (a) The AMS Na flux $\Phi_{Na} = \Phi_{Na}^P + \Phi_{Na}^S$ with the fit result to the weighted sum of the Si flux Φ_{Si} and the F flux Φ_F above 6 GV. The result gives $\Phi_{Na}^P = (0.038 \pm 0.003) \times \Phi_{Si}$ and $\Phi_{Na}^S = (1.33 \pm 0.04) \times \Phi_F$. (b) The AMS Al flux $\Phi_{Al} = \Phi_{Al}^P + \Phi_{Al}^S$ with the fit result to the weighted sum of the Si flux Φ_{Si} and the F flux Φ_F above 6 GV. The result gives $\Phi_{Al}^P = (0.105 \pm 0.004) \times \Phi_{Si}$ and $\Phi_{Na}^S = (1.04 \pm 0.03) \times \Phi_F$. The primary and secondary component contributions are shown by the yellow and green shading respectively in (a) and (b). As seen, the sodium and aluminum fluxes have decreasing secondary component and increasing primary component with increasing rigidity.

and Al/Si ratios at the source without the need of considering the propagation of cosmic rays in the Galaxy, with 0.091 ± 0.002 for N/O, 0.038 ± 0.003 for Na/Si and 0.105 ± 0.004 for Al/Si.

Fig. 4 presents cosmic nuclei fluxes measured by AMS as a function of rigidity from Z=2 to Z=14 together with Z=16 and Z=26. It shows that there are two classes of primary cosmic rays, He-C-O-Fe and Ne-Mg-Si-S, and two classes of secondary cosmic rays, Li-Be-B and F. As seen from Fig. 4, N, Na, and Al belong to a distinct group and are the combinations of primary and secondary cosmic rays.

PoS(ICRC2023)096

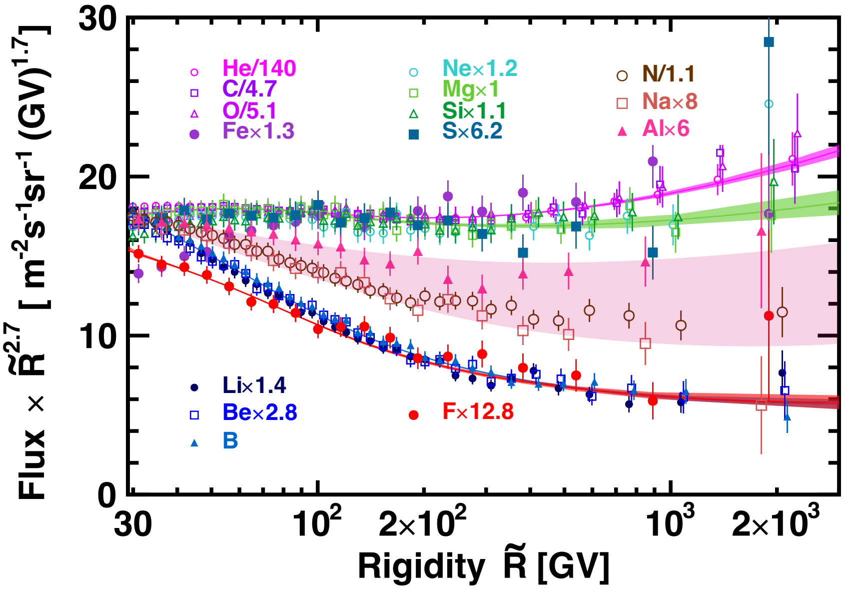

Figure 4: The fluxes of cosmic nuclei measured by AMS as a function of rigidity from Z=2 to Z=14 together with Z=16 and Z=26 above 30 GV. As seen, there are two classes of primary cosmic rays, He-C-O-Fe and Ne-Mg-Si-S, and two classes of secondary cosmic rays, Li-Be-B and F. Nitrogen (N), sodium (Na), and aluminium (Al), belong to a distinct group and are the combinations of primary and secondary cosmic rays. For clarity, data points above 400 GV are displaced horizontally. For display purposes only, fluxes were rescaled as indicated. The shaded tan band on N, Na, and Al is to guide the eye.

4. Conclusion

In conclusion, we have presented the precision measurement of the N, Na and Al fluxes as functions of rigidity from 2.15 GV to 3.0 TV, with detailed studies of the systematic errors. We found that Na and Al, together with N, belong to a distinct cosmic ray group and are the combinations of primary and secondary cosmic rays. Similar to the N flux, which is well described by the sum of a primary cosmic ray component (proportional to the oxygen flux) and a secondary cosmic ray component (proportional to the boron flux), both the Na and Al fluxes are well described by the sums of a primary cosmic ray component (proportional to the silicon flux) and a secondary cosmic ray component (proportional to the fluorine flux). The fraction of the primary component increases with rigidity for the N, Na, and Al fluxes and becomes dominant at the highest rigidities. The abundance ratios at the source of N/O (0.091 ± 0.002), Na/Si (0.038 ± 0.003) and Al/Si (0.105 ± 0.004) are determined directly without the consideration of cosmic ray propagation in the Galaxy. These are new and unexpected properties of cosmic rays.

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PoS(ICRC2023)096

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PoS(ICRC2023)096