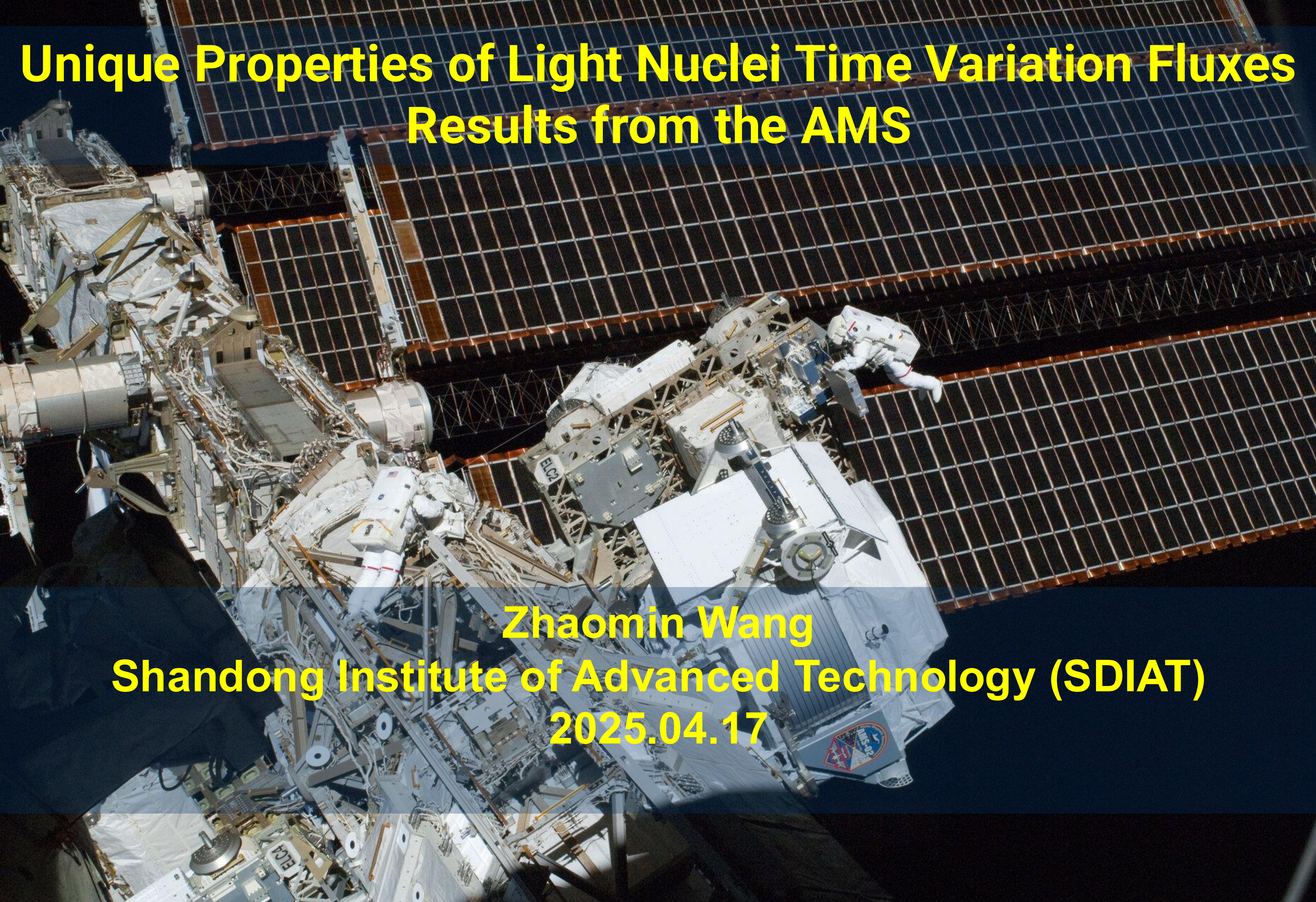

Unique Properties of Light Nuclei Time Variation Fluxes Results from the AMS

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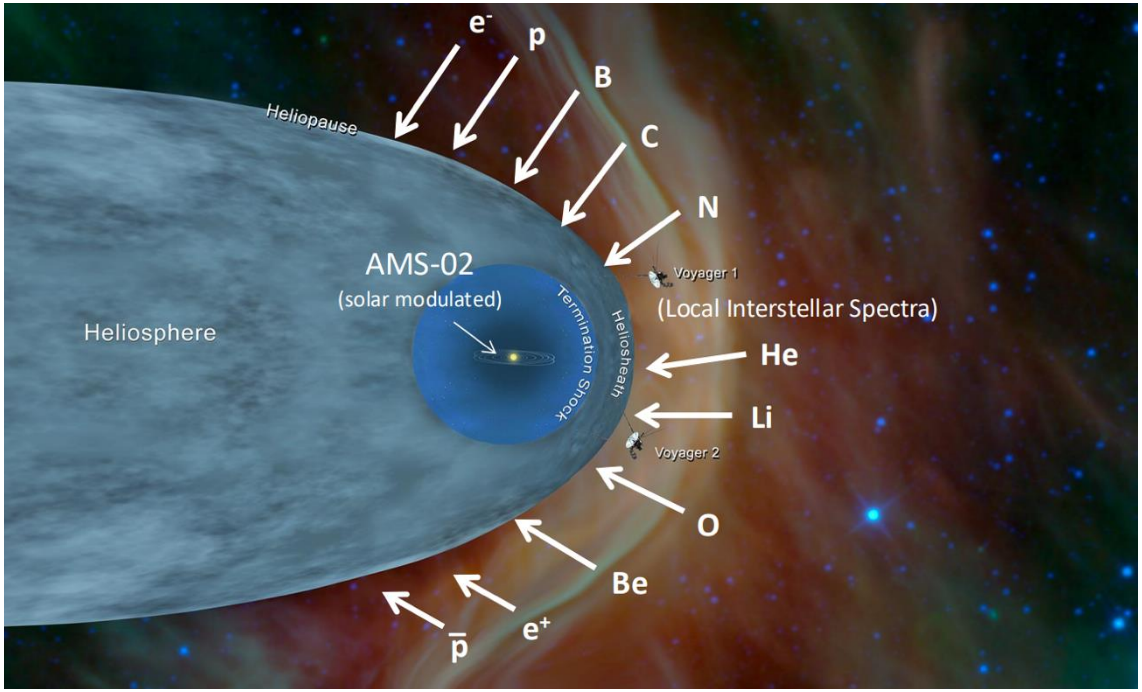
Galactic Cosmic Rays(GCRs) Propagation in the Heliosphere

GRCs entering the heliosphere are subject to diffusion, convection adiabatic energy losses and magnetic drift (described by the Parker's Equation), this is commonly known as solar modulation.



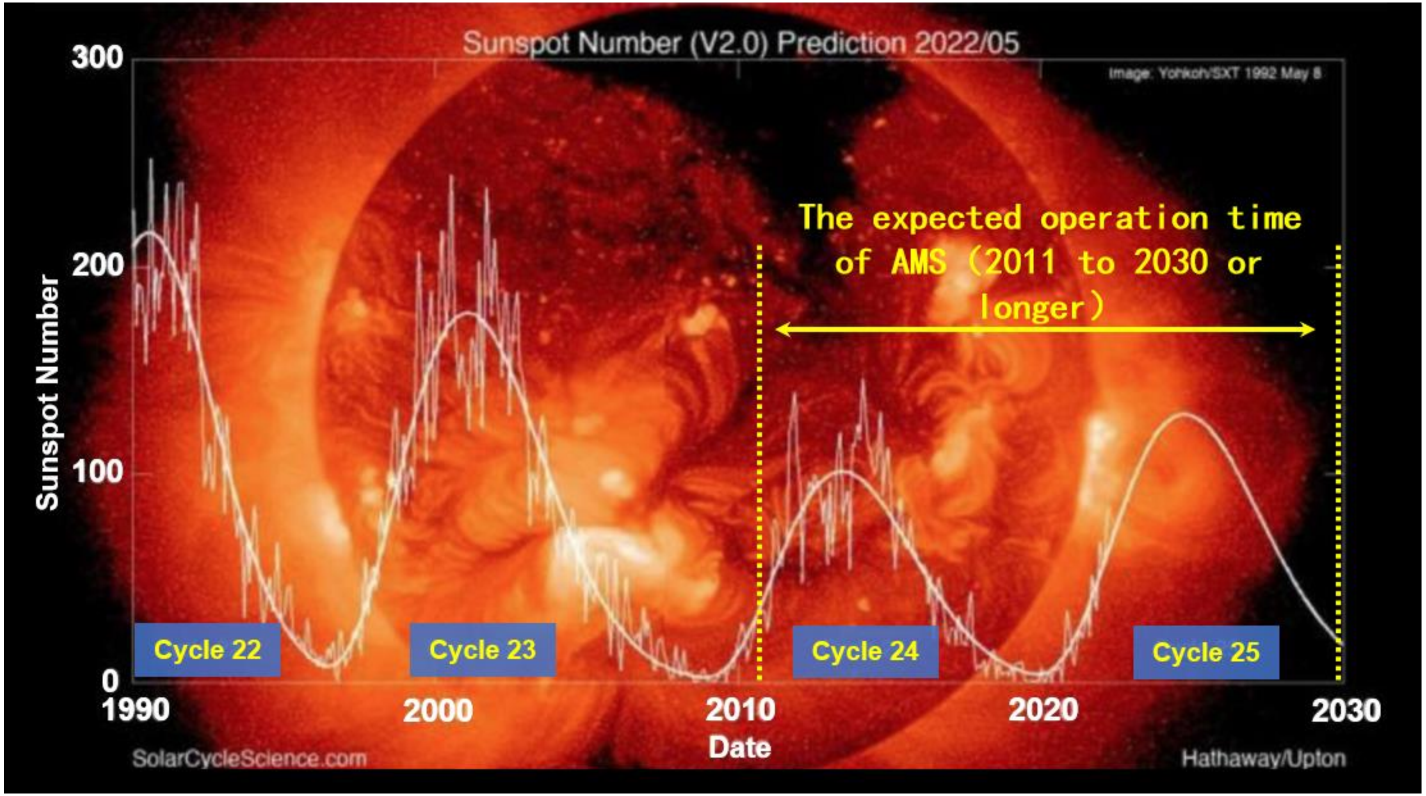
According to the current models, differences in solar modulation among nuclei can be attributed to:

- Differences in the spectral shape of CRs entering the heliosphere
- Differences of the velocities of CR nuclei

Measurement on the time variation fluxes of CR nuclei with different spectral shapes and different A/Z (Mass/Charge) provides important information on understanding the GRCs propagation in the heliosphere and the solar modulation effects

Solar activity and Sunspot Number

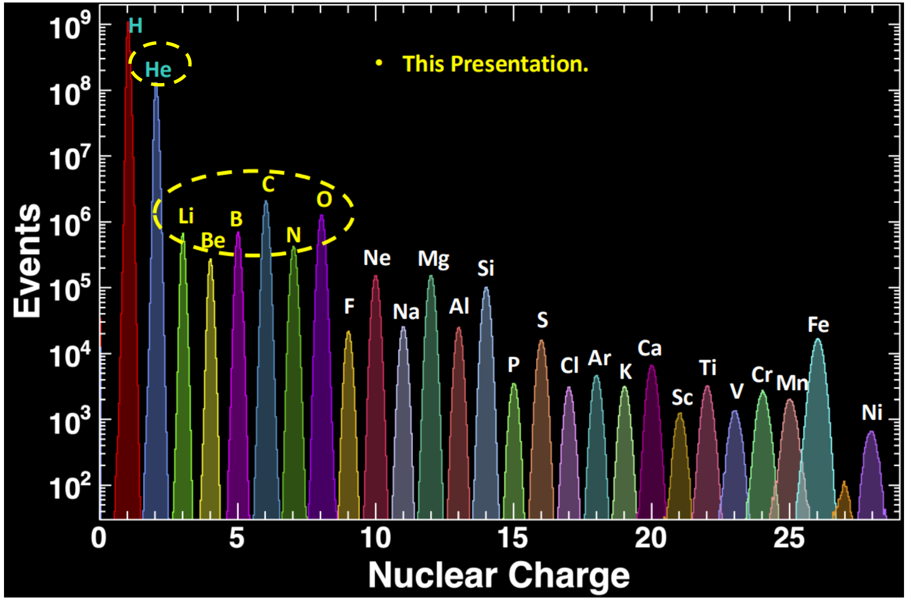
The intensity of solar activity directly affect the flux of CRs at low rigidity region. The sunspot number can be used as an indication of the solar activity level.

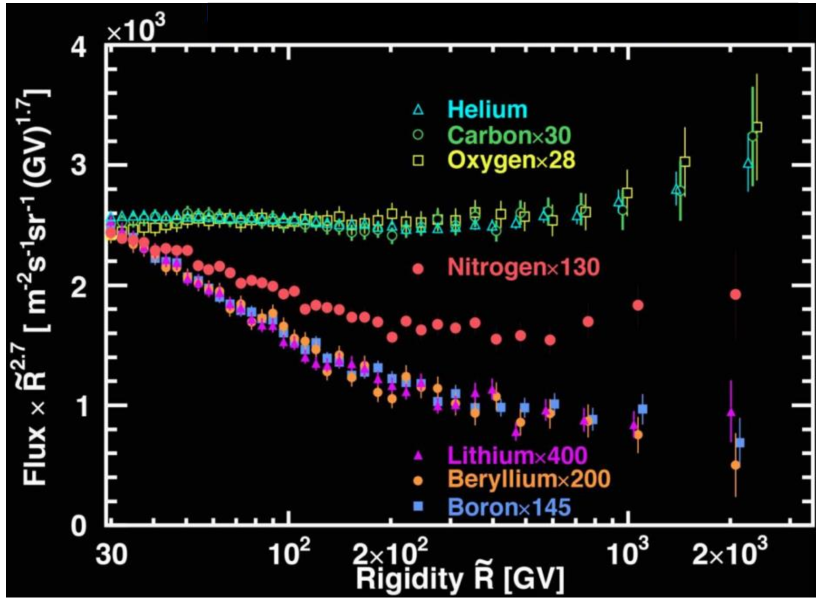


AMS data covers almost the full solar cycle 24, and it will continue take data up to 2030 or longer, which will fully cover the solar cycle 25.

Latest AMS results on CR Light Nuclei Measurements

Previously, AMS observed that nuclei with 2 ≤ Z ≤ 8 in cosmic rays belong to three groups with distinctly different rigidity spectra: the He, C, and O, which are mostly primary; the secondaries Li, Be, and B; and N, which is a combination of primary and secondary components. These three group of nuclei have significant different spectral shapes and also the A/Z ratios.





This presentation will present the 27-days (1 Bartel's Rotation(BR)) fluxes of He, Li, Be, B, C, N, O that are measured by AMS during 2011.05 to 2022.11

CR Light Nuclei Time Variation Fluxes

Cosmic ray flux Φ_i^j in rigidity $[R_i, R_i + \Delta R_i]$ and j-th BR:

Number of events after background subtraction and bin-to-bin migration

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

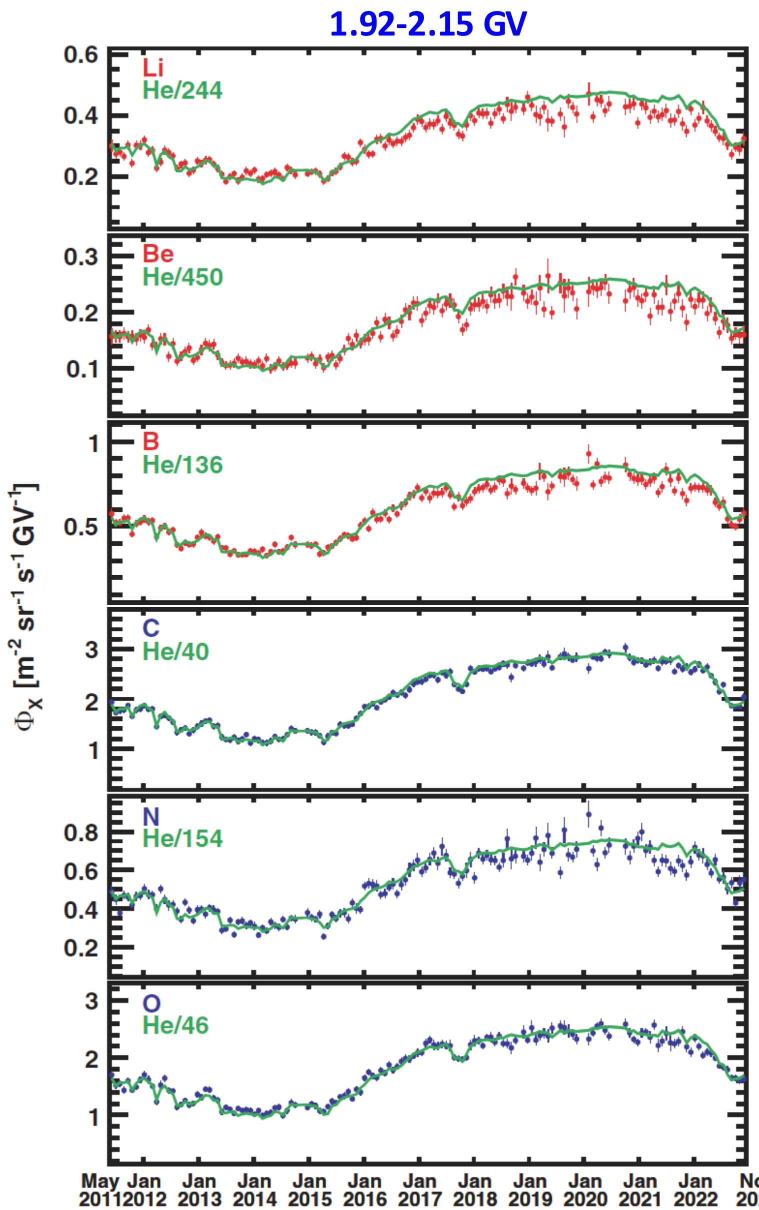
Effective acceptance

Trigger Efficiency

Exposure Time

Rigidity bin width

- The time variation fluxes of light nuclei from 2 GV to 60 GV with 961M He, 5.3M Li, 2.6M Be, 7.8M B, 26.1M C, 6.6M N and 22.1M O are measured.
- All fluxes exhibit similar long-term and short-term time structures
- The Fluxes are anti-correlated with solar activities, being lower during epoch of high solar activity and higher during epoch of low solar activity



Study on Solar Modulation in Light Nuclei

To study the differences in the solar modulation of each nuclei, the relative variations of the fluxes are estimated for the *i*-th rigidity bin as:

$$\frac{\Phi_X^i/\Phi_{He}^i - \langle\Phi_X^i/\Phi_{He}^i\rangle}{\langle\Phi_X^i/\Phi_{He}^i\rangle} = K_{X/He}^i \frac{\Phi_{He}^i - \langle\Phi_{He}^i\rangle}{\langle\Phi_{He}^i\rangle}$$

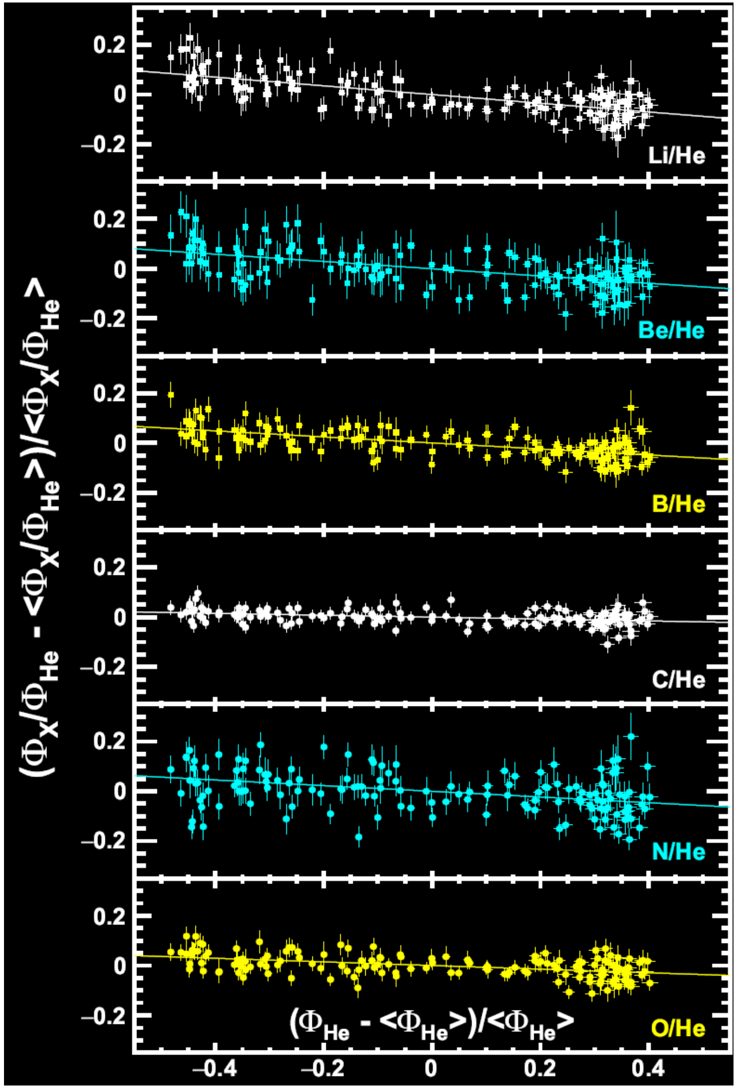
Where "X" is the one of the nuclei between Li and O. Through the *K* value, the relative intensity of the solar modulation between the nuclei and He can be obtained:

K>0: More modulated than He

K=0: Same modulated than He

K<0: Less modulated than He

1.92-2.15 GV



Study on Solar Modulation in Light Nuclei

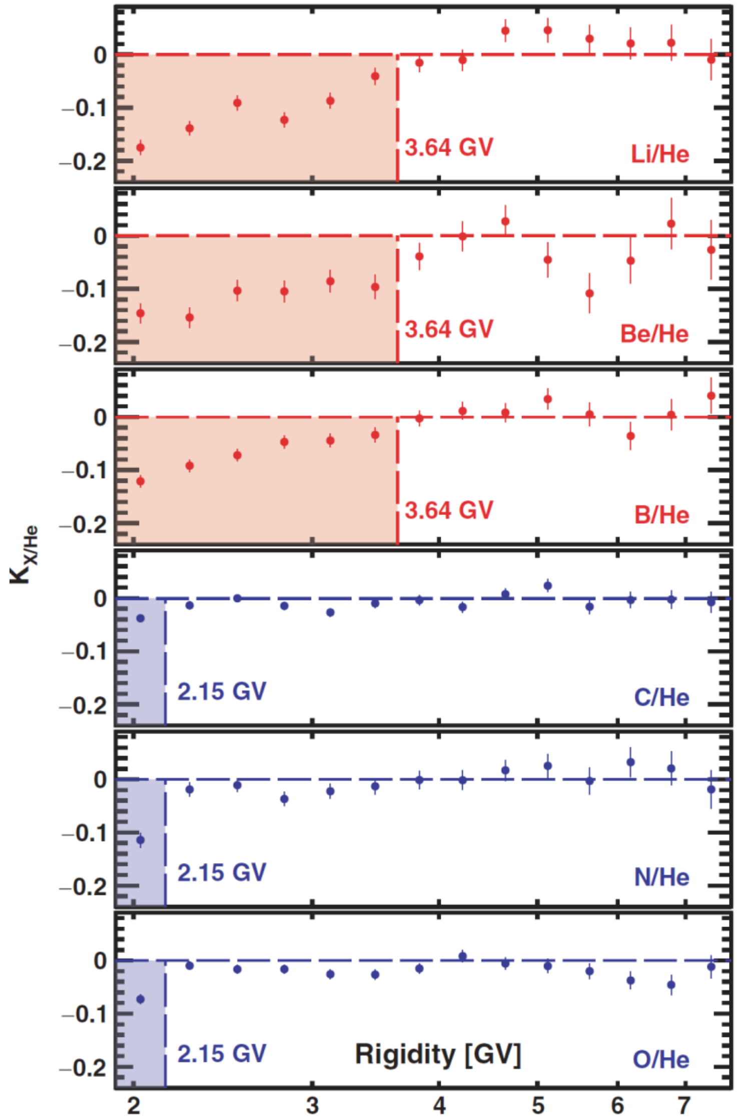
$$\frac{\Phi_X^i/\Phi_{He}^i - \langle \Phi_X^i/\Phi_{He}^i \rangle}{\langle \Phi_X^i/\Phi_{He}^i \rangle} = K_{X/He}^i \frac{\Phi_{He}^i - \langle \Phi_{He}^i \rangle}{\langle \Phi_{He}^i \rangle}$$

K>0: More modulated than He

K=0: Same modulated than He

K<0: Less modulated than He

- Li, Be and B are significantly less modulated than He up to 3.64 GV
- C, N and O are significantly less modulated than He up to 2.15 GV

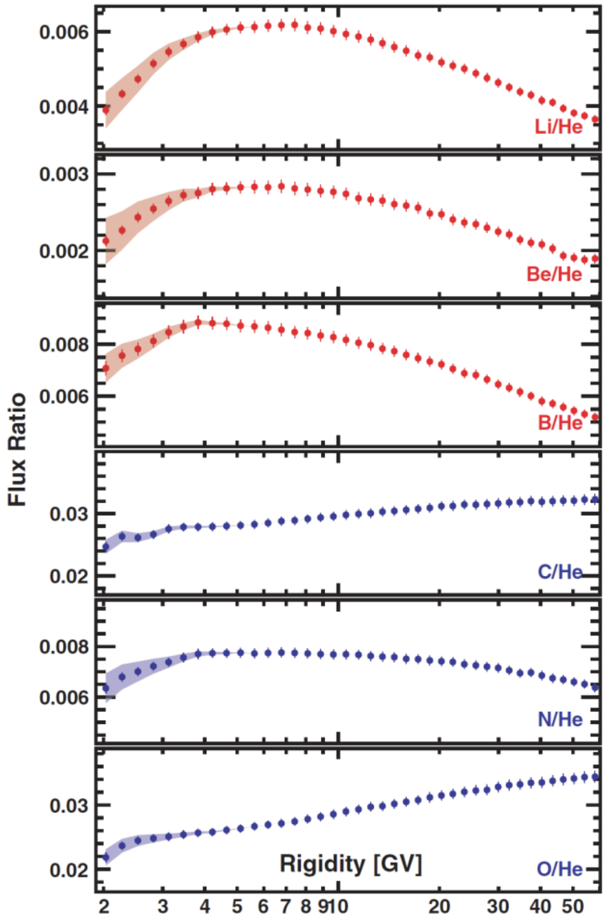


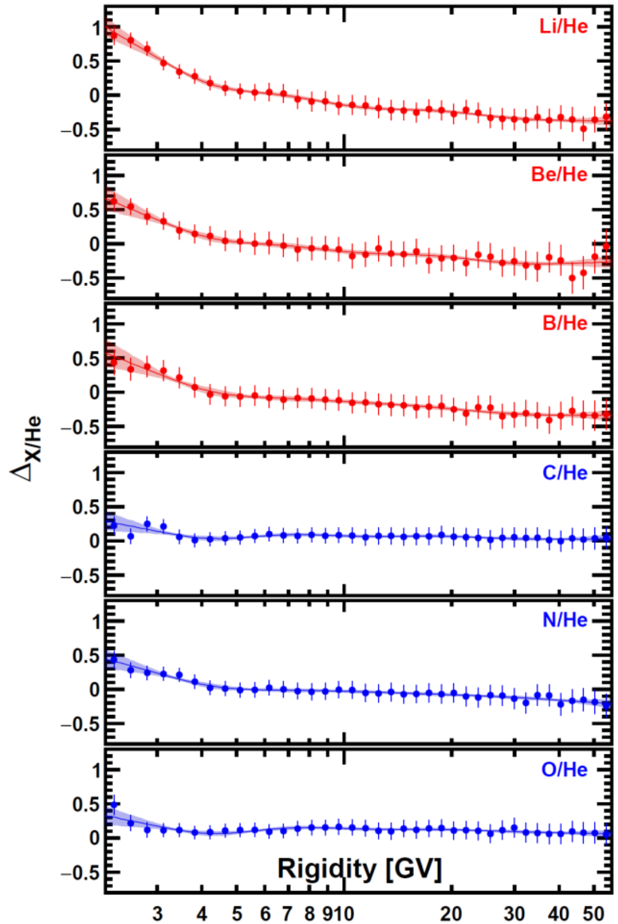
Spectral Shape Contribution to Solar Modulation

To explore the spectral dependency of the solar modulation in a model-independent way, the spectral index $\Delta_{X/\mathrm{He}}$ of the flux ratio is calculated using:

$$\Delta_{X/\mathrm{He}} = \frac{d[\log\langle \Phi_X^i / \Phi_{\mathrm{He}}^i \rangle]}{d[\log(R)]}$$

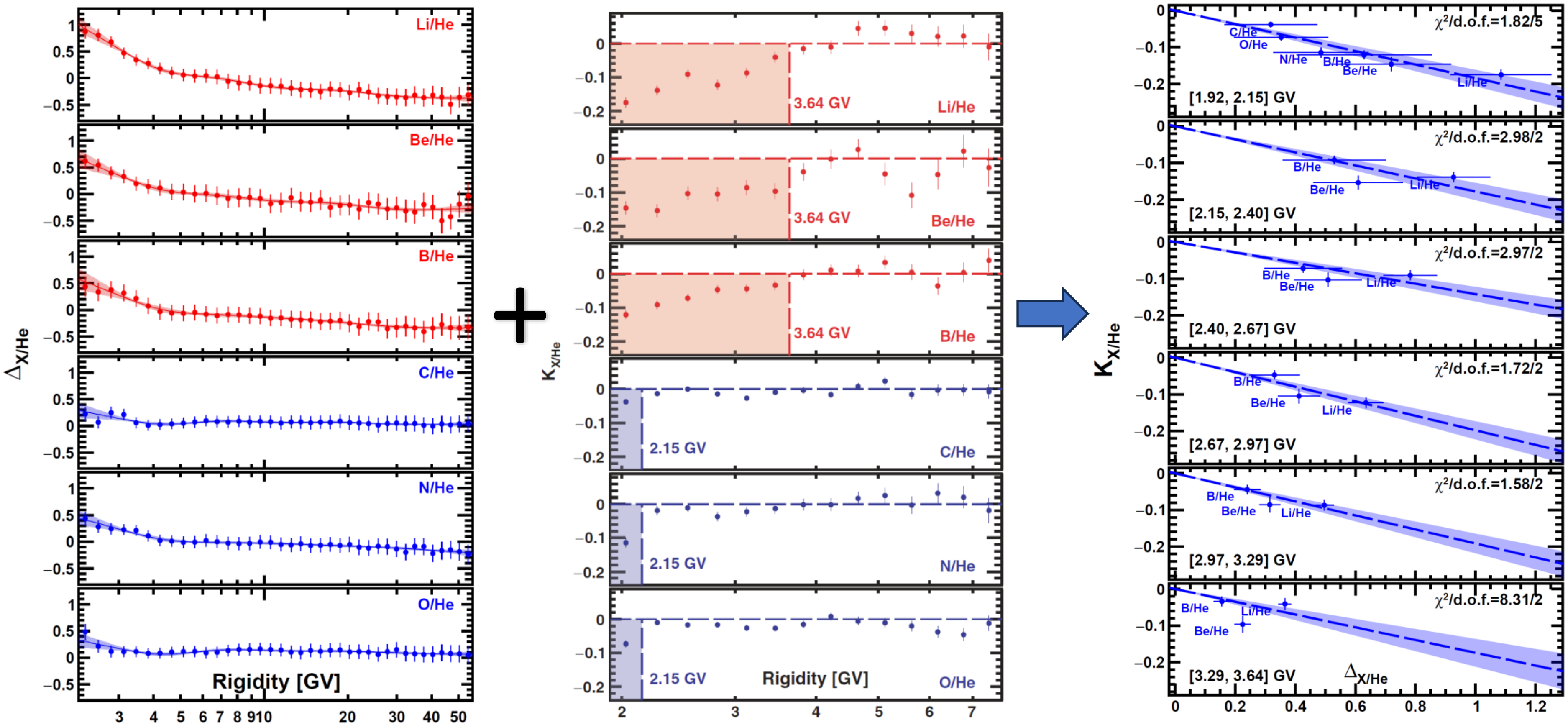
in a sliding window with three consecutive rigidity bins.





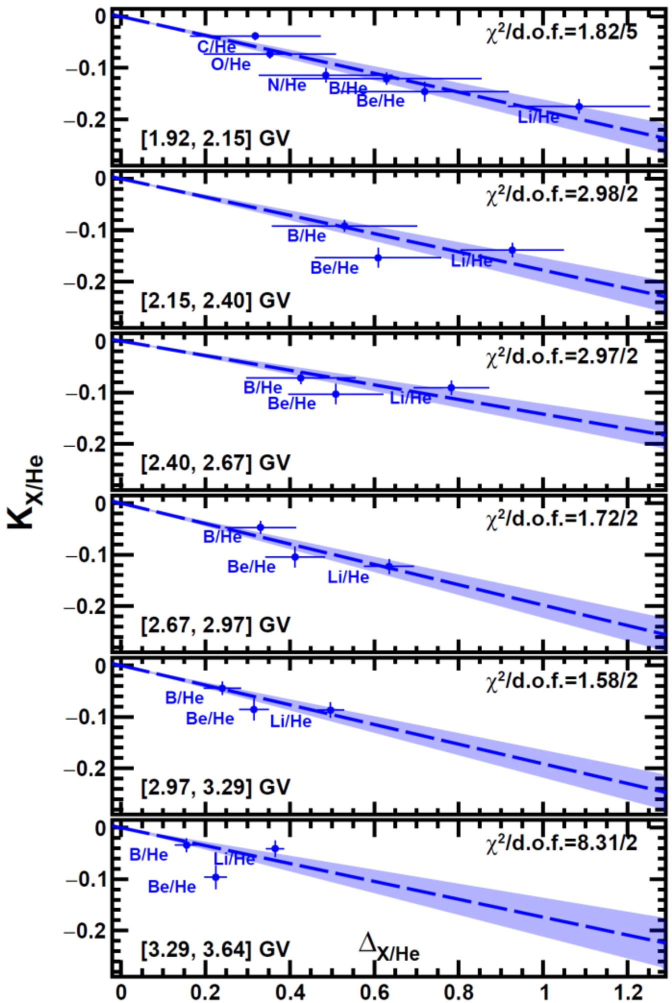
The values of $\Delta_{X/\mathrm{He}}$ show that below 3.64 GV, the spectral indices of Li/He, Be/He, and B/He flux ratios and, below 2.15 GV, the spectral indices of C/He, N/He, and O/He flux ratios are greater than zero, showing that He flux rigidity dependence is steeper (i.e., decreasing more quickly) than that of Li, Be, B, C, N, and O fluxes in these rigidity ranges

Spectral Shape Contribution to Solar Modulation



We build up the $K_{X/\mathrm{He}}$ as function of $\Delta_{X/\mathrm{He}}$ in different rigidity bins where the $K_{X/\mathrm{He}}$ is not 0, and found that the relationship can be described by a liner function.

Spectral Shape Contribution to Solar Modulation



The relationship of the $\Delta_{X/\mathrm{He}}$ and $K_{X/\mathrm{He}}$ is fitted with

$$K_{X/\mathrm{He}} = \xi \Delta_{X/\mathrm{He}},$$

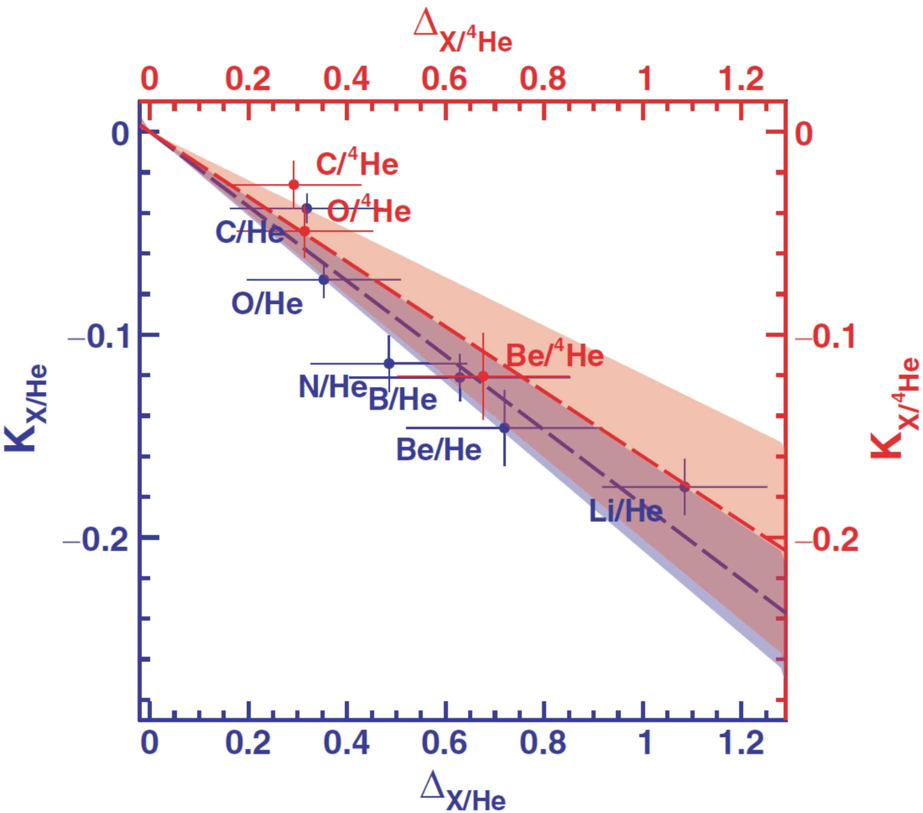
which yields:

R (GV)	ξ
1.92–2.15	-0.18 ± 0.02
2.15–2.40	-0.18 ± 0.02
2.40–2.67	-0.14 ± 0.02
2.67–2.97	-0.20 ± 0.02
2.97–3.29	-0.19 ± 0.03
3.29–3.64	-0.17 ± 0.04

All ξs are consistent with a rigidity-independent average value of −0.175 $\pm$ 0.010. A negative ξ means fluxes are more modulated for nuclei with steeper spectra.

Study on the Velocity Dependence of Solar Modulation

To estimate the magnitude of the velocity effect in a model-independent way, we compared the time variations of Be, C, and O fluxes with that of the ^{4}He. As all the four nuclei are supposed to have similar velocity for the same rigidity(same A/Z), the solar modulation velocity effect is negligible.



- **The $K_{Be/^4He}$, $K_{C/^4He}$ and $K_{O/^4He}$ are compatible with $K_{Be/He}$, $K_{C/He}$ and $K_{O/He}$**
- **The liner relationship of $K_{X/^4He} = \xi' \Delta_{X/^4He}$ give the ξ' also compatible with ξ**
- **The velocity effect on solar modulation is small compared to the spectral shape**

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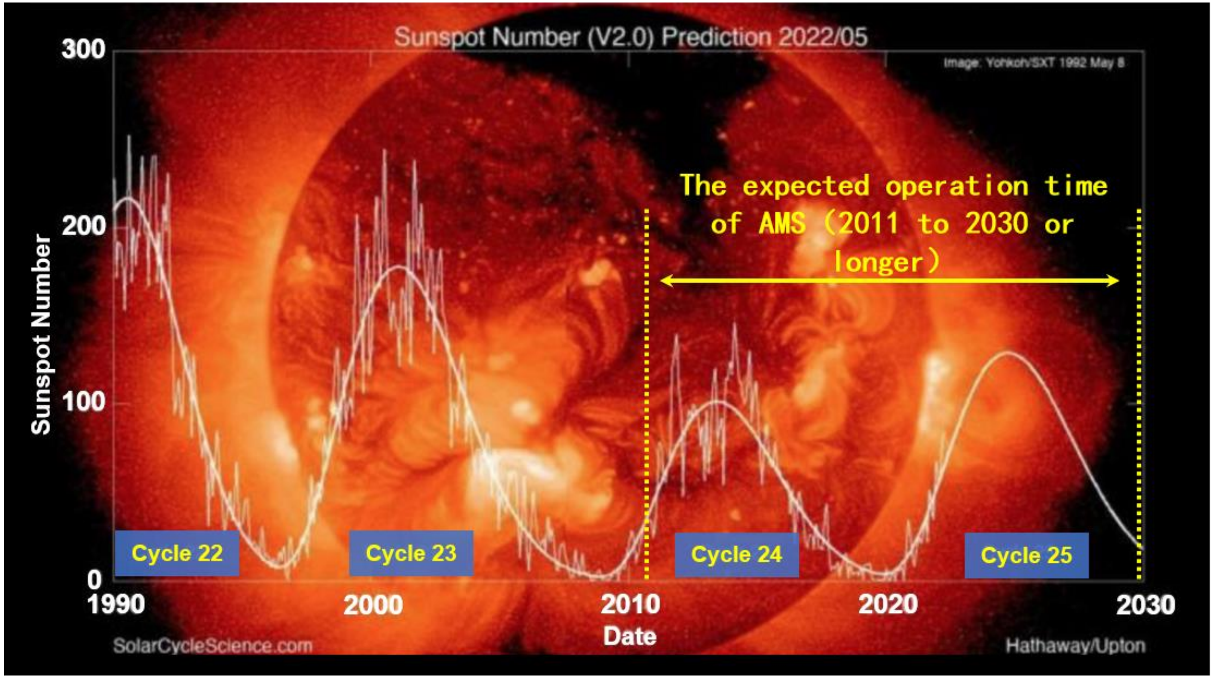
Solar Modulation of Cosmic Nuclei over a Solar Cycle: Results from the Alpha Magnetic Spectrometer

Conclusion

- The measurements of AMS on He, Li, Be, B, C, N, and O time variation fluxes in 147 Bartels rotations from May 2011 to November 2022 in the rigidity range from 1.92 to 60.3 GV have been presented.
- The 7 nuclei fluxes show similar but not identical time variations with amplitudes decreasing with increasing rigidity.
- below 3.64 GV, the Li, Be, and B fluxes, and, below 2.15 GV, the C, N, and O fluxes, are significantly less affected by solar modulation than the He flux.
- We observe that these differences in solar modulation are linearly correlated with the differences in the spectral indices of the nuclei fluxes. This shows, in a model-independent way, that solar modulation of galactic cosmic nuclei depends on their spectral shape.
- Solar modulation differences due to nuclei velocity dependence on the mass-to-charge ratio (A=Z) are not observed.

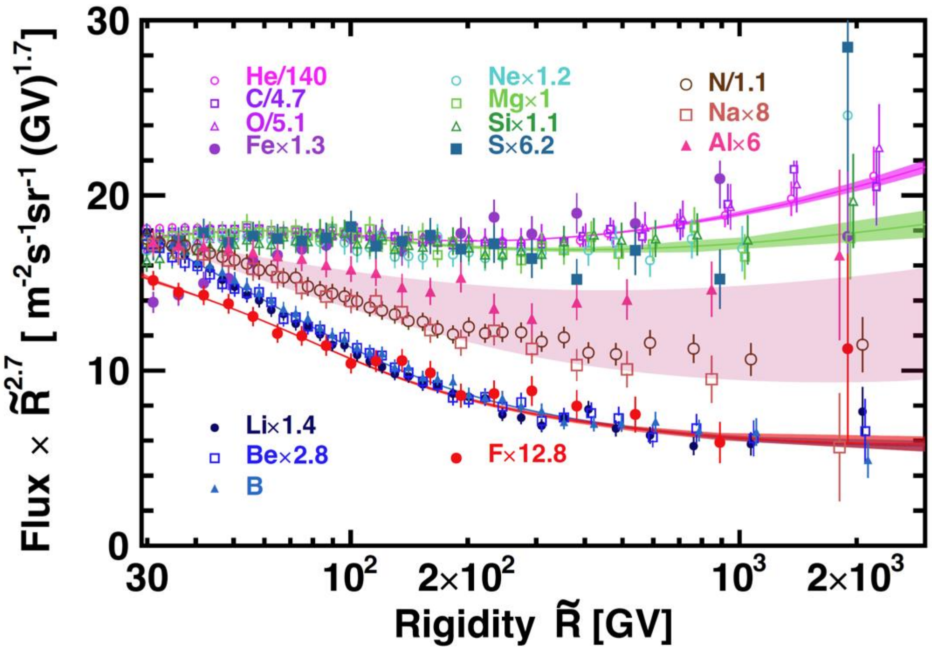
Future Works

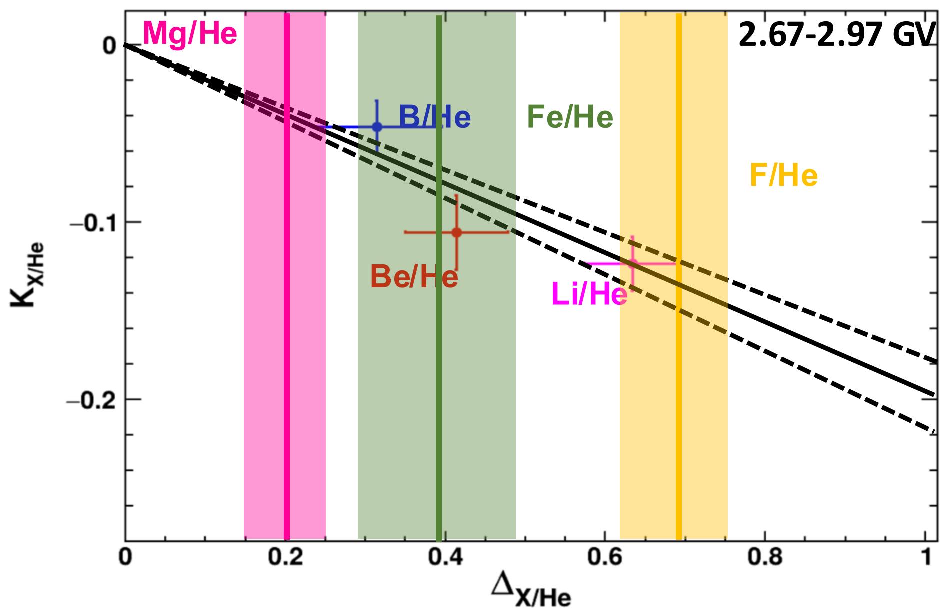


AMS will operate in space up to 2030 or longer, during the very long observation window the sunspot number will undergo double cycle variation(minimum-maximum-minimum-maximum-minimum), meanwhile the solar magnetic poles will complete a polarity reversal cycle.

Continuous observations of cosmic ray time variation patterns will, for the first time, reveal distinct behavioral differences in nuclei fluxes before and after major solar activity events. These findings will significantly deepen our understanding of the mechanisms through which solar activity modulates cosmic rays.

Future Works





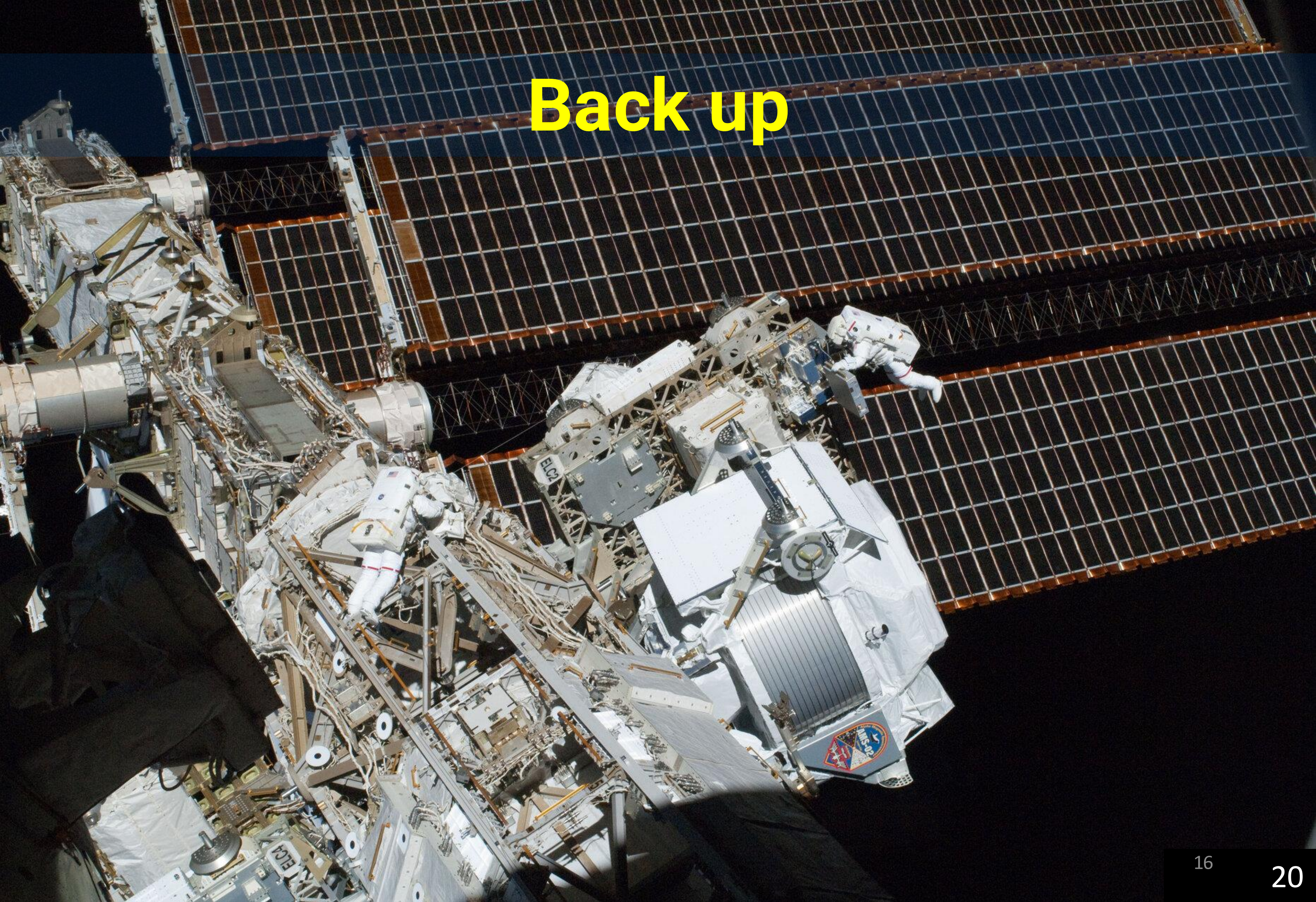
AMS have measured CR nuclei fluxes with charge Z=1-14, 16, 26. Based on the rigidity dependence of the spectra, they can be separated into several groups:

- 2 groups of primary CRs: He-C-O-Fe and Ne-Mg-Si-S
- 2 groups of secondary CRs: Li-Be-B and F
- 1groups of primary + secondary CRs: N-Na-Al

Currently, AMS only finish the light nuclei(Z=1-8) time variation fluxes, what about the situation on heavier nuclei?

Thank you

Back up

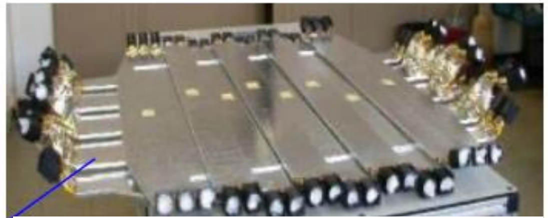


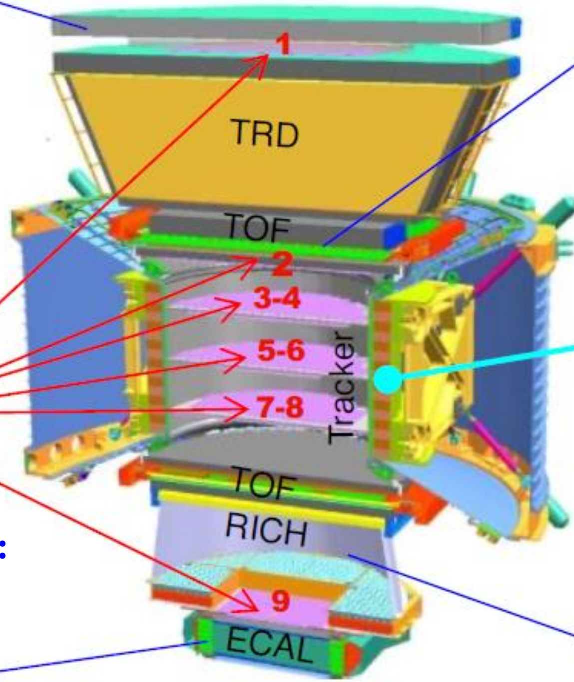
Alpha Magnetic Spectrometer (AMS)

Transition Radiation Detector (TRD):
$e^{\pm}/p$ identification, charge measurement

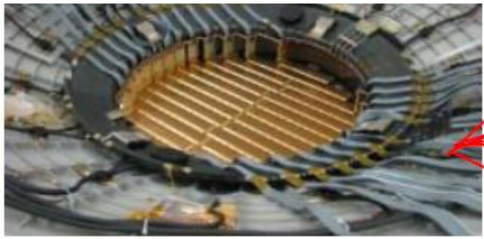
The charge, energy and rigidity(momentum/charge) of cosmic rays carry the key information

Time Of Flight (TOF):
velocity, charge measurement

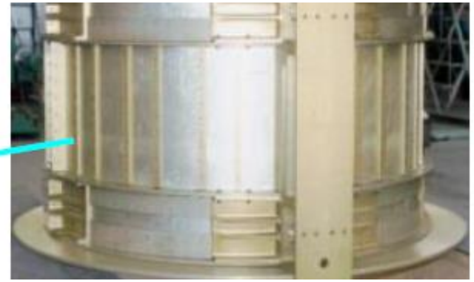




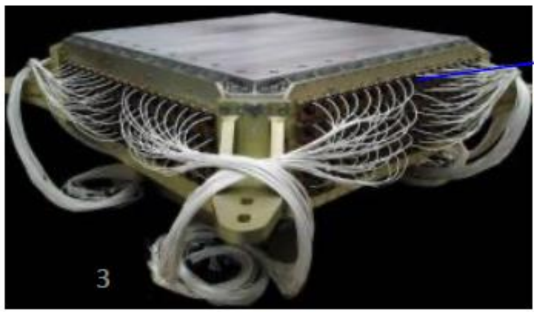
Silicon Tracker:
momentum, position, charge measurement



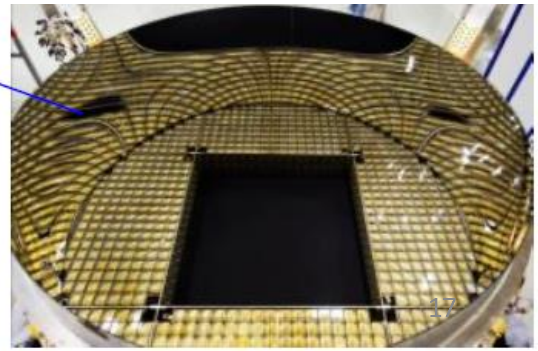
Permanent Magnet:
Anti-particle identification, momentum measurement



Electromagnetic Calorimeter (ECAL):
energy measurement



Ring Imaging Cherenkov (RICH):
velocity, charge measurement



AMS can measure the charge, energy and rigidity of a particle multi-times independently on its trajectory inside the detector

Parker's Equation

GCRs entering the heliosphere are subject to diffusion, convection, adiabatic energy losses and magnetic drift.
This is commonly known as Solar Modulation.

$$\frac{\partial \varphi}{\partial t} = \boxed{\nabla \cdot (\mathbf{k} \nabla \varphi)} - (\boxed{\mathbf{V}} + \boxed{\langle \mathbf{v}_d \rangle}) \cdot \nabla \varphi + \boxed{\frac{1}{3}(\nabla \cdot \mathbf{V}) \frac{\partial \varphi}{\partial \log p}}$$

Similar to the galactic transport equation (in part, similar underlying physics), describes CR diffusion in the heliosphere

Magnetic diffusion on field perturbations

Convection due to solar wind

Drift due to magnetic field gradients

$$\langle \mathbf{v}_d \rangle = \nabla \times \left(K_d \frac{\mathbf{B}}{|\mathbf{B}|} \right)$$
$$K_d = K_0 \frac{\boxed{\beta} R}{3|\mathbf{B}|}$$

Adiabatic energy losses due to expanding sloar wind

Explicit dependence on spectral shape