Properties of Heavy Nuclei in South Atlantic Anomaly with AMS-02

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The Instrument

The Alpha Magnetic Spectrometer (AMS) is a high-energy particle physics experiment onboard the International Space Station (ISS), that has collected more than 200 billion events since the beginning of its operation in May of 2011.

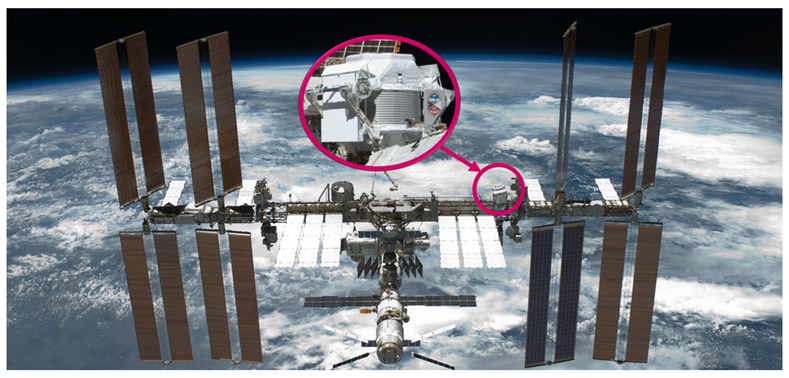

Figure 1: AMS-02 onboard of the ISS.

Data Sample

In this study, we select $Z>2$ ions using the Inner Tracker and the Time of Flight (TOF) charge measurements, along with quality criteria on particle's track, velocity and charge reconstruction. This selection allows events entering AMS in a large field of view, up to $\mathbf{45}^\circ$ to the vertical, from down-going and up-going incoming directions (see Fig.2). To further reduce the down-going sample, we require rigidity to be conservatively below the minimum local cutoff in the field of view ($R < \mathbf{2}$ GV near the poles and $R < \mathbf{10}$ GV around the equator). Globally we selected 80 million events in the down-going direction and 3 million for up-going.

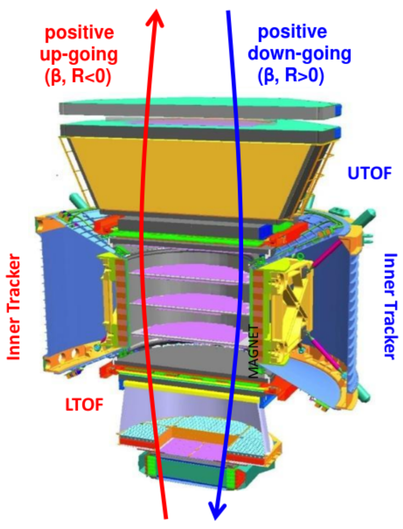

Figure 2: Down-going (blue) and up-going (red) events traversing AMS.

Backtracing Procedure

To ascertain the origin of selected events, we apply a tracing procedure that propagates a charged particle in the Earth's magnetic field (modelled with IGRF-13 **[1]**), backward in time. Particles are classified in the following categories (see Fig.3):

- Primary: if the particle's trajectory intersects a spherical boundary at 50 Earth's radii. These particles have cosmic origin.
- Secondary: when the trajectory intersects a spherical a boundary at 100 km from the Earth's surface. These particles are produced by interaction of cosmic rays with the atmosphere.
- Stably Trapped (ST): Particle is neither primary nor secondary. These particles are bounded in trajectories around the Earth.

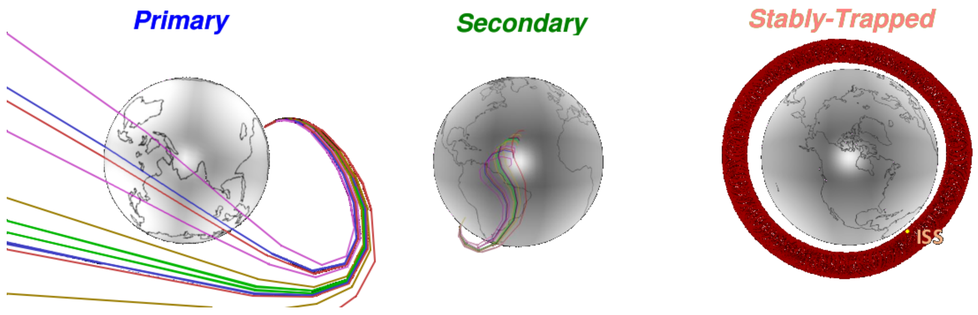

Figure 3: Backtracing outcome trajectories examples for primaries (left), secondaries (middle) and stably-trapped (right).

To account for systematic uncertainties in the AMS measurement of particle's arrival direction and rigidity estimation, and systematics due to the trajectory reconstruction, the backtracing was performed several times varying the particle's arrival direction ($\mathbf{\Delta\theta = 2^\circ}$), rigidity ($\mathbf{\Delta R/R = 10\%}$) and ISS orbit coordinates on time ($\mathbf{\Delta t = 50}ms$). Hence, the backtracing procedure was applied extensively to the data sample, allowing to select a well-defined stably-trapped ion population.

Results

We identify a ST heavy nuclei ($Z>2$) population, detected in the South Atlantic Anomaly (SAA), and traversing the instrument in both, down-going and up-going directions. As shown in Fig.4b, the ST rigidity spectra extends from 1 to 5 GV, below the geomagnetic cutoff.

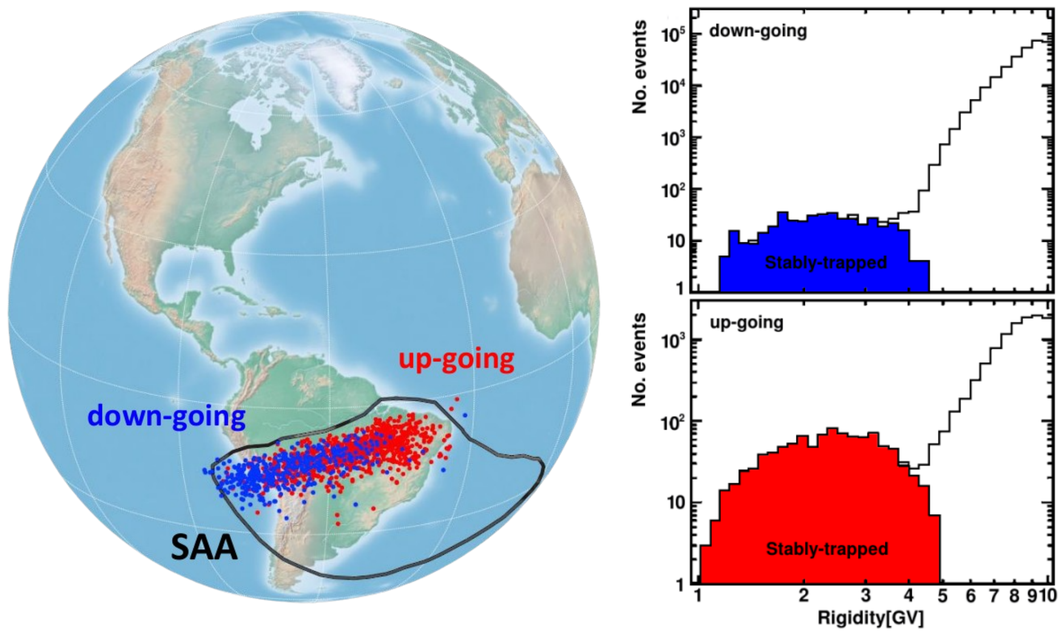

Figure 4: a) down-going (blue) and up-going (red) selected events geographic location. b) ST rigidity distribution for down-going (blue) and up-going (red), in the north of SAA ($\mathbf{-20^\circ < \theta_M < 10^\circ, -10^\circ < \phi_M < 50^\circ}$).

The charge distribution of the ST component is displayed in Fig.5a, it is noticeable that both populations, down-going and up-going exhibit similar relative abundances. ST events have a different charge distribution with respect to Galactic Cosmic Rays (GCRs), as shown in Fig.5b (where Li/C $\sim$ 0.1 and C/O $\sim$ 1).

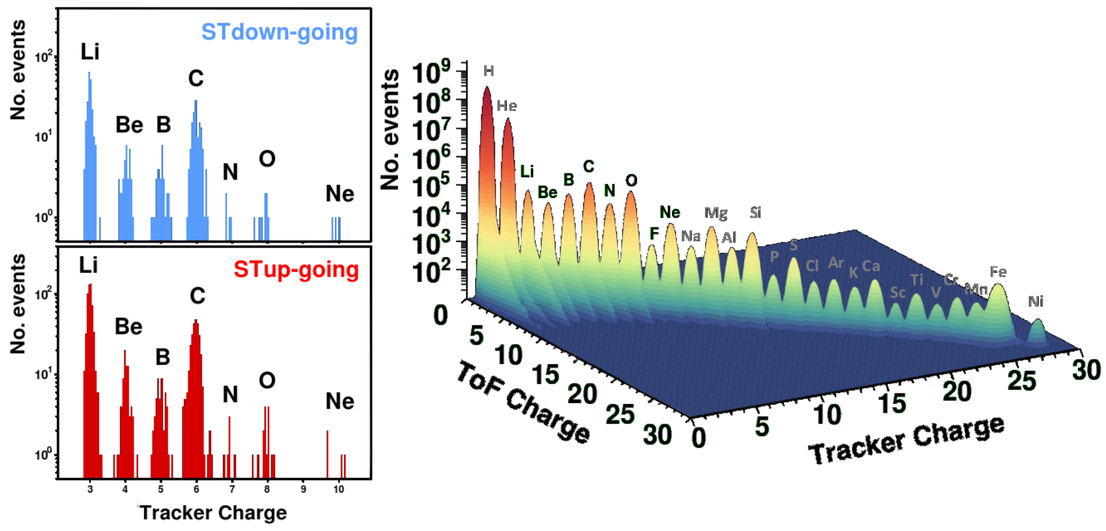

Figure 5: a) Charge distribution for down-going (up-blue) and up-going (down-red) populations of ST ions. b) Charge distribution of Galactic Cosmic Rays measured by AMS-02 **[2]**.

In addition, all stably-trapped events have a pitch angle (i.e. angle between the magnetic field and the particle's velocity) of about $\mathbf{90}^\circ$.

Conclusions

- A component of $Z>2$ ions, well-identified as stably-trapped, has been detected inside the SAA and traversing AMS in both, down-going and up-going directions.
- The stably-trapped population properties, as rigidity, charge and arrival direction, differ from those known for GCRs.
- This represents the first time observation of a high-Z population of ions with rigidities up to 5 GV.

References

[1] Thébault, E. et al., *International geomagnetic reference field: the 12th generation*, Earth, Planets and Space, 67(1), (2015).

[2] Aguilar, M., Cavasonza, L. A., Ambrosi, G., Arruda, L., Attig, N., Barao, F., ... Pashnin, A. (2021). *The Alpha Magnetic Spectrometer (AMS) on the international space station: Part II — Results from the first seven years.*, Physics reports, 894, 1-116.