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Observation of Z>2 trapped nuclei by AMS on ISS

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The Alpha Magnetic Spectrometer (AMS-02) is a high energy particle physics experiment operating continuously aboard the International Space Station (ISS) since the 19th of May of 2011. A component of trapped $Z>2$ ions located in the South Atlantic Anomaly (SAA) has been detected traversing the instrument both in down-going and up-going directions.

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The Alpha Magnetic Spectrometer (AMS-02) particle detector, launched in 2011 and installed as a module in the International Space Station (ISS), has the potential of precisely measuring cosmic ray fluxes and composition, including ions up to Z=26. Since the beginning of its operation, AMS-02 has collected over 150 billion events. In this paper we report the observation of a Z>2 trapped nuclei population, detected near the equator inside the SAA, in 8.5 years of data collection.

1. Data Sample

The selection considers the widest field of view of the detector, up to 45 degrees with respect to vertical, and includes events traversing AMS in both, down-going and up-going directions. A layout of the detector is presented in [1-2]. Events are required to have a good track reconstruction in the Inner Tracker and satisfy good quality criteria on velocity and charge reconstruction. Charge measurements in the Inner Tracker and Time of Flight (TOF) are selected to be in accordance with Z>2 ions and conditions to reject interacting events inside the detector have been implemented as well. This study focuses in the equatorial region with $|\Theta_M|<0.3$ and velocity $|\beta|<0.86$.

2. Backtracing Procedure

The procedure of backtracing a charged particle's trajectory to ascertain its origin, consists on propagating the particle with inverted sign an arrival direction in the Earth's magnetic field. In this study, we have applied a backtracing routine that implements the IGRF-13 geomagnetic field model [3]. The outcome of the procedure classifies events in the following possible categories [4]:

- **Cosmic:** when the particle trajectory escapes a limit of 25 Earth's radii.
- **Quasi Trapped (QT):** if the particle reaches a boundary set at 40 km from the Earth's surface.
- **Stable Trapped (ST):** if after 50 s of propagation, the backtracing outcome is neither cosmic nor quasi trapped.

However, it is important to consider two effects that could introduce a difference in the particle classification when the backtracing is performed once. Firstly, the existence of the so-called penumbra region, where small variations of the initial conditions could lead to a change of the procedure's outcome. Secondly, uncertainties in the backtracing parameters, such as the rigidity determination, the ISS orbit location and AMS direction could also modify the particle categorization. Therefore, in order to account for these effects, the backtracing routine was conducted several times, varying the particle arrival direction (±0.2°) and space station position in time (±50 ms). Finally, the previously described procedure allows a conservative classification of our data sample and the selection of those particles with QT and ST trajectories is certainly achieved.

3. Results

Succeeding our sample selection and backtracing procedure, a population of trapped ions has been identified in the equatorial region inside the SAA, as shown in Fig.1. Both, down-going and up-going events are included in the observation and these two populations present similar relative

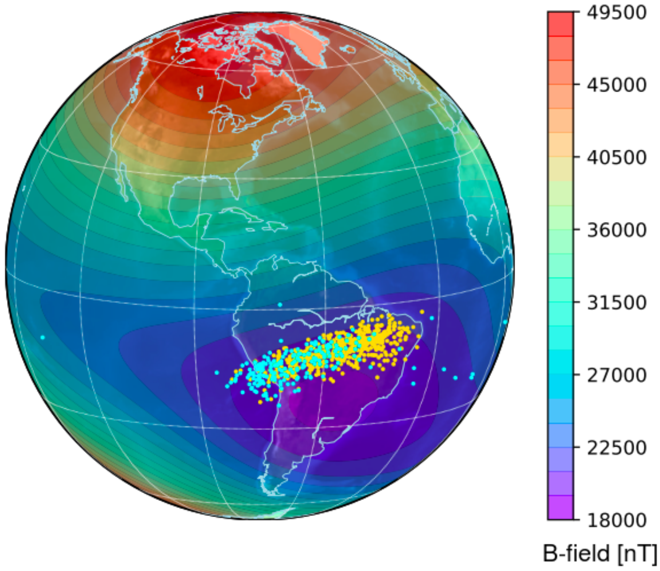

Figure 1: Trapped nuclei events detection location. Down-going and up-going particles are displayed in cyan and yellow respectively, on top of the total Earth's magnetic field map [nT].

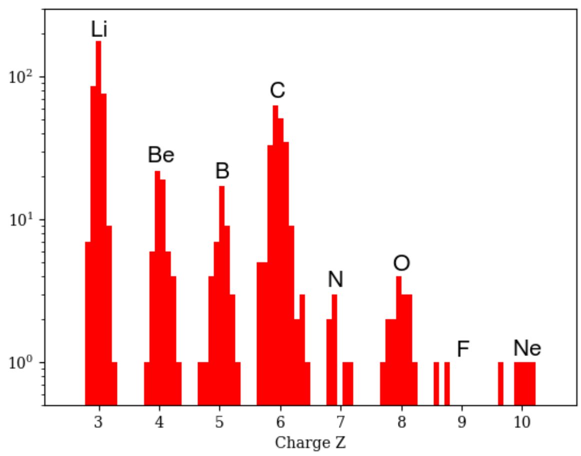

Figure 2: Charge distribution of Z>2 trapped ions. Both, down-going and up-going events are included.

abundances. The charge distribution of trapped ions is depicted in Fig.2, where an overabundance of Lithium and Carbon is noticeable. In addition, the Li/C and C/O ratios for this trapped population are remarkably different from those observed in galactic cosmic rays (where Li/C ~ 0.1 and C/O ~1).

4. Conclusions

A search of trapped nuclei with Z>2 has been carried out with 8.5 years of AMS data collection. By means of a backtracing procedure, the classification of events as trapped has been conservatively achieved. Hence, we report the observation of a population of $Z>2$ trapped nuclei, near the equator inside the SAA, including events entering AMS from down-going and up-going directions. Our results show that the relative abundances of the trapped particles are distinctly different from the galactic cosmic rays. This study represents the first observation of $Z>2$ trapped ions above 1 GV.

References

[1] Battiston, R., The antimatter spectrometer (AMS-02): A particle physics detector in space, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors, and Associated Equipment, Vol. 588, (2008).

[2] Kounine. A. The Alpha Magnetic Spectrometer on the International Space Station, International Journal of Modern Physics, E 21.08 (2012).

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

[4] Fiandrini, E. et al., Protons with kinetic energy E>70 MeV trapped in the Earth's radiations belts, Journal of Geophysical Research, 109, (2014).

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