Study of cosmic-ray modulation by AMS-02 spectrometer onboard ISS

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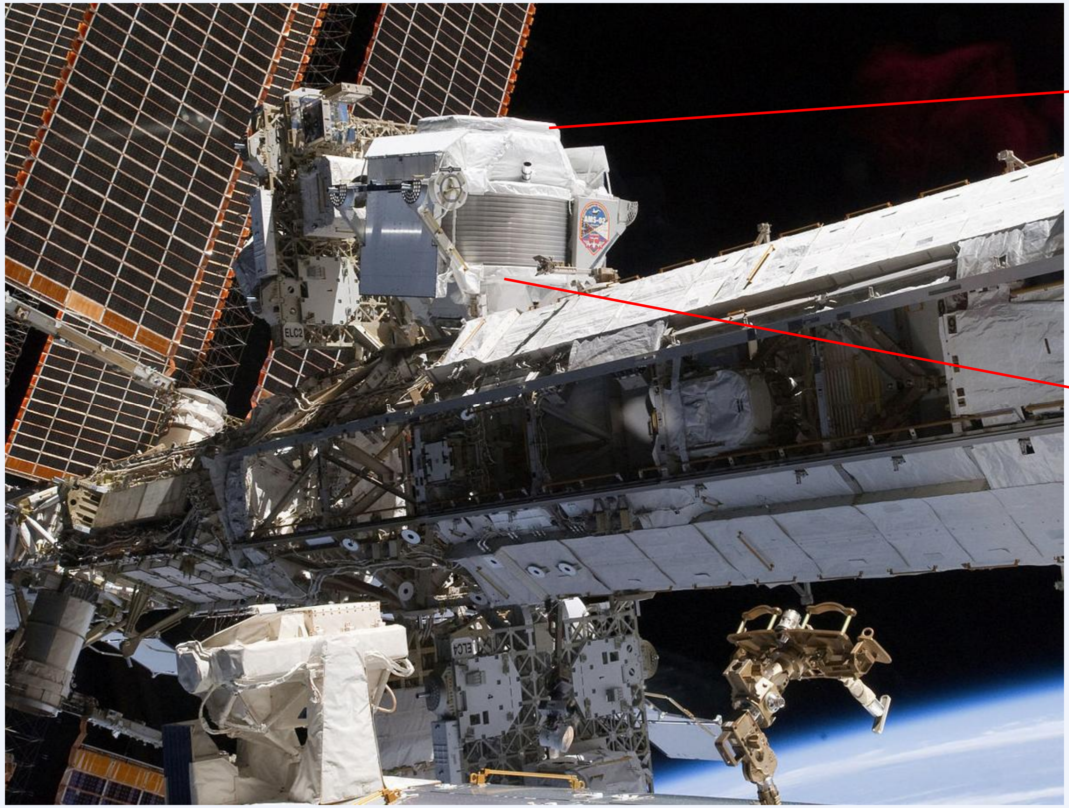
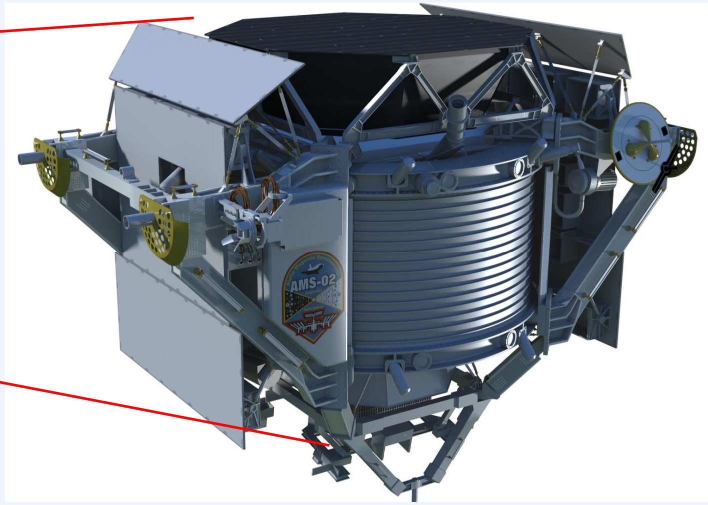
Abstract

Alpha Magnetic Spectrometer v.2 (AMS-02) is the largest ever cosmic-ray detector in space (Aguilar et al., 2021a). It was launched in 2011 and is still fully operational onboard the International Space Station (ISS). The primary goal of AMS-02 is to search for exotic and rare signatures of dark matter and anti-matter, but it has collected a uniquely rich set of “ordinary” cosmic-ray data. It includes both energy spectra and temporal variability of cosmic-ray fluxes in the vicinity of Earth. SGO is involved and actively participates in the scientific analysis of AMS-02 data. Here we present the results related to unusual solar modulation of low-energy cosmic rays based on the AMS-02 high-precision data.

AMS-02 spectrometer onboard ISS

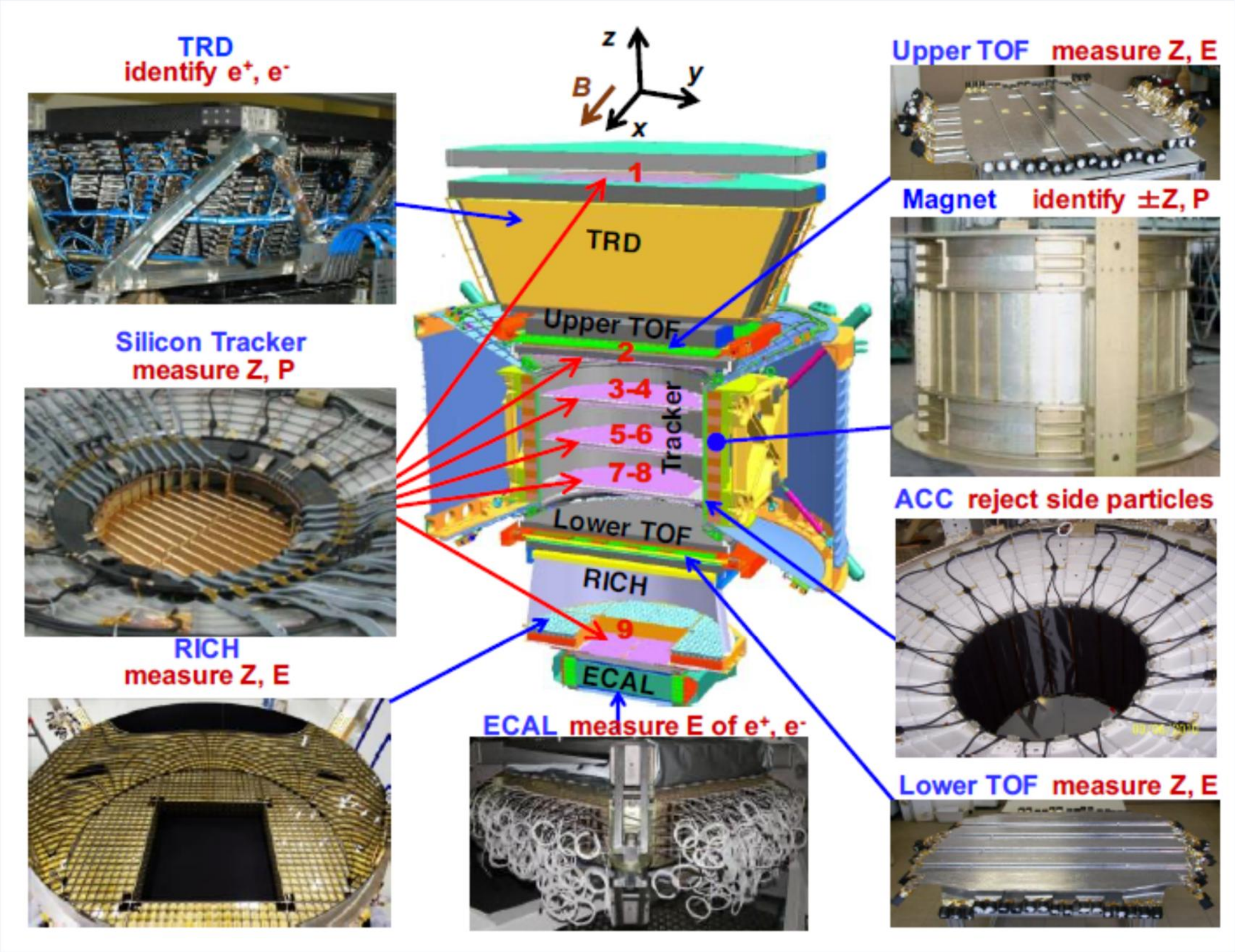




AMS-02: @ISS 05/2011 à …
Mass: ~8.5 tons, power ~2.5 kW, data link 2 Mb/s
MIT&CERN + ~50 organizations from 14 countries

We join the collaboration in 2019.
Our contribution: scientific data analysis (solar modulation), data taking shifts;
Our benefits: direct data access, top-end experiment, collaborative publications.

AMS-02 spectrometer

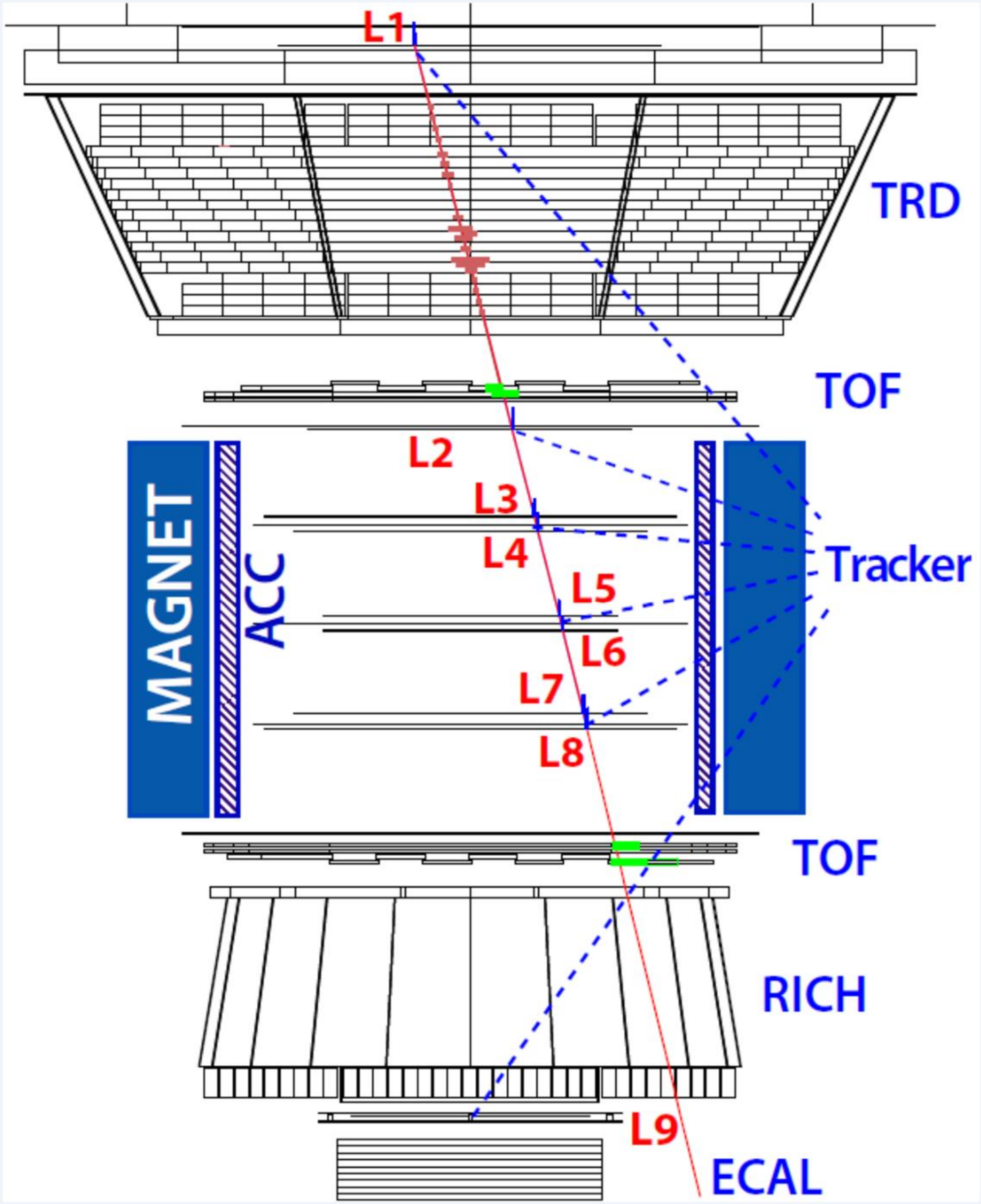


The AMS detector is a TeV precise multipurpose particle physics magnetic spectrometer in space onboard the low-orbiting ISS. Its main part is the big magnet and several detector's subsystems. AMS identifies particles by their charge *Z*, energy *E*, and momentum *P* or rigidity ($R = P/Z$), which are measured independently by the Tracker, Time of flight (TOF), Tranafer-radiation detector (TRD), Ring-image Cherenkov detector (RICH) and calorimeter (ECAL). The anticoincidence (ACC) counters, located in the magnet bore, are used to reject particles entering AMS from the side.

A typical reconstructed events is shown on the next page.

For more detail see Aguilar et al. (2021b)

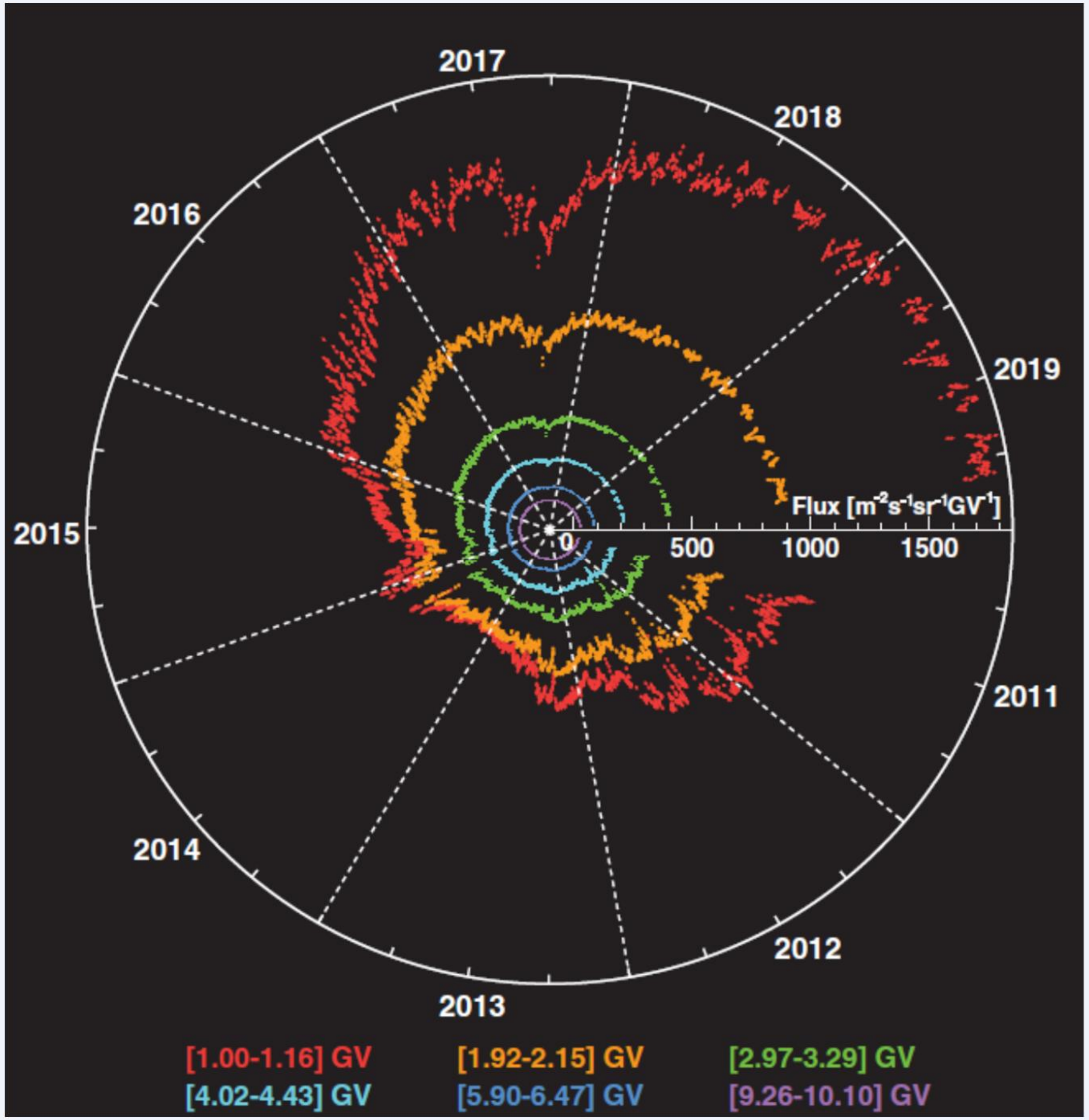
Typical particle track



A proton event display in the bending plane. The red line indicates the reconstructed trajectory using the eight tracker layers. The magenta spread in TRD shows the *dE/dx* measurements in different TRD layers, green areas in upper and lower TOF layers carry the information of the *dE/dx* as well as the coordinate and time measurements. The vertical blue lines in the tracker layers carry the information of coordinates and *dE/dx* or pulse heights. This downward-going event is identified as a proton (Z = 1) with R = 3.90 GV.

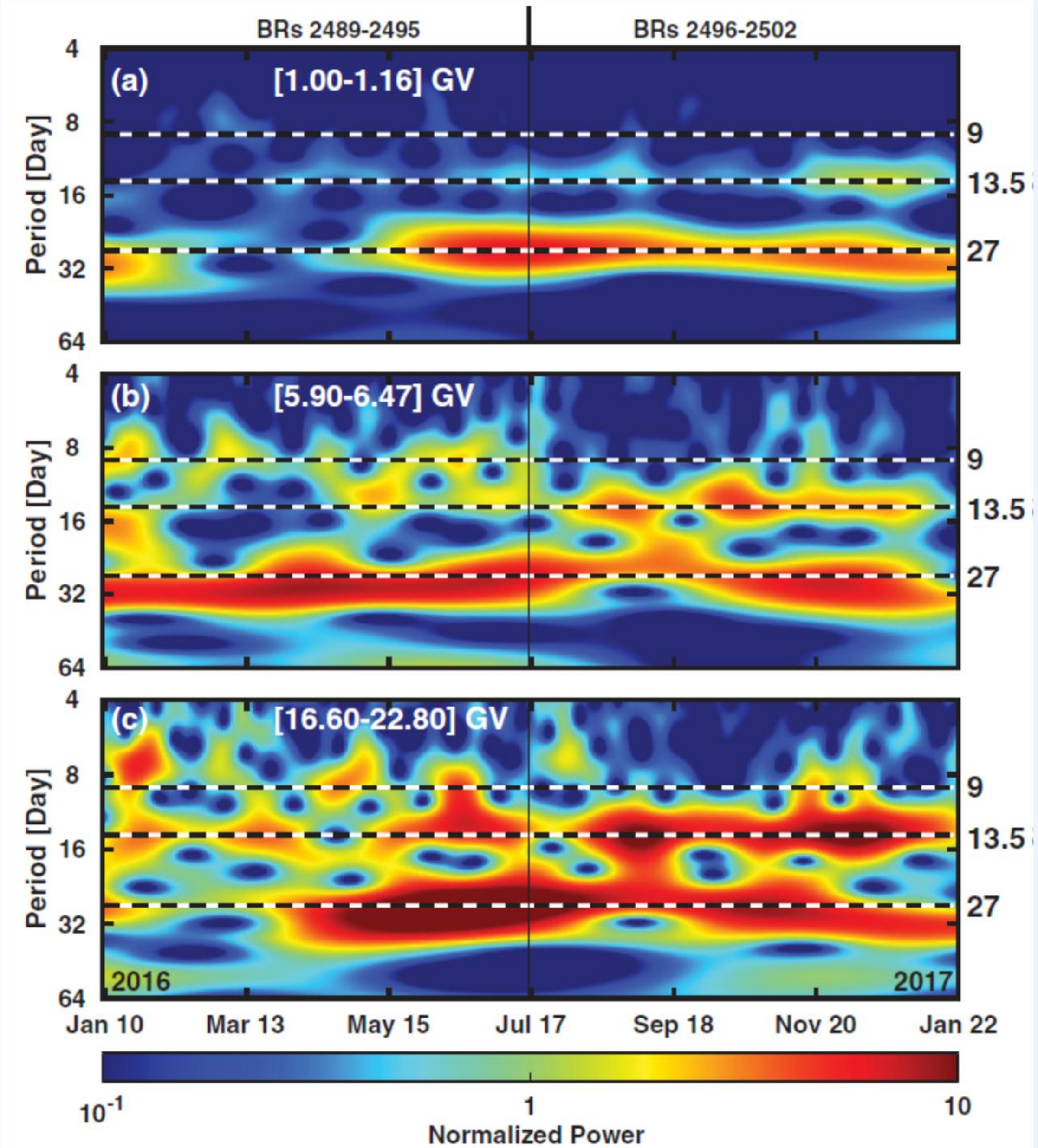
For more detail see Aguilar et al. (2021b)

Cosmic-ray variability



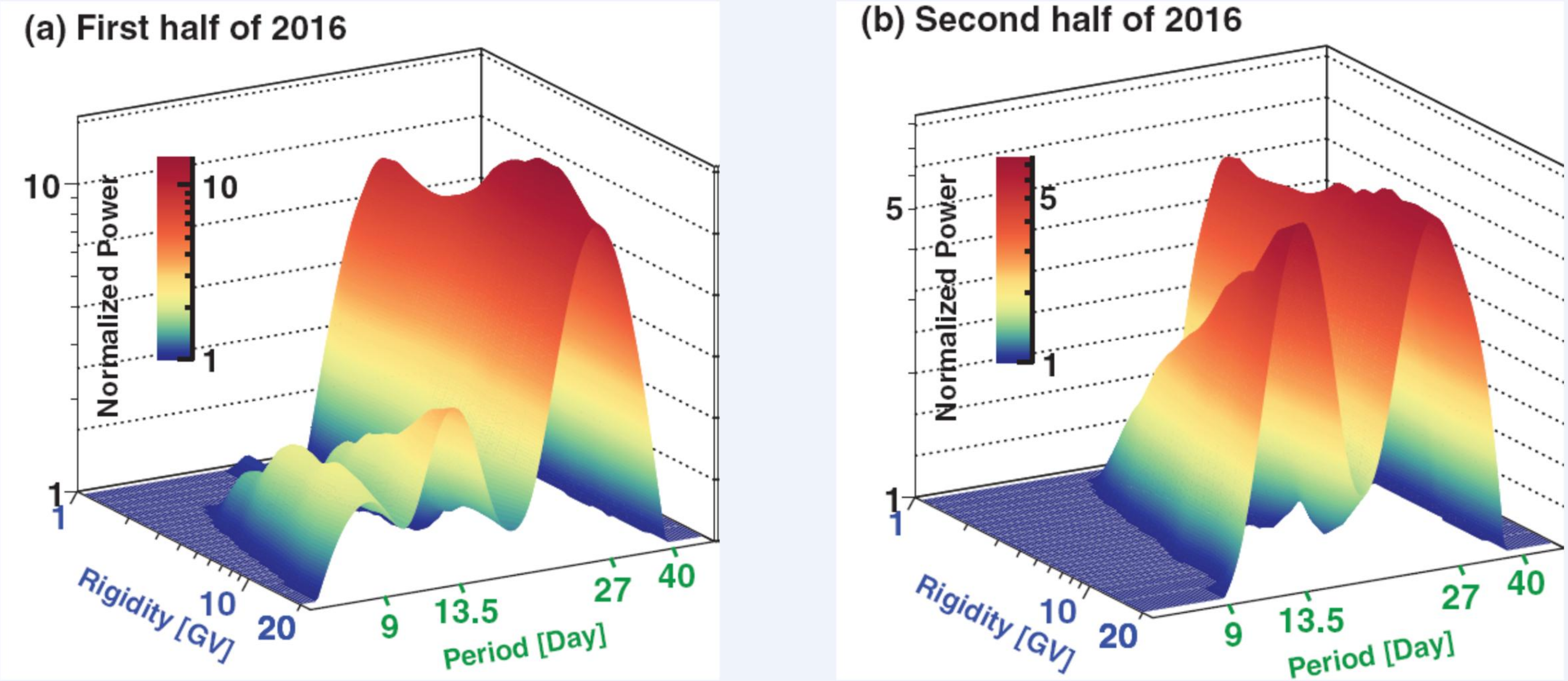
This figure shows time variability of daily proton fluxes measured by AMS for six typical rigidity bins from 1 to 10 GV measured from May 2011 to Oct 2019 which covers a major portion of solar cycle 24 including the ascending, maximum, and descending phases. This dataset includes 5.5E+9 individual protons identified by AMS. Days with solar energetic particle (SEP) events are removed for the two lowest rigidity bins. The gaps in the fluxes are due to detector studies and upgrades. As seen, the proton fluxes exhibit large variations with time, and the relative magnitude of these variations decreases with increasing rigidity. The dip the second half of 2017 is caused by a burst of solar activity in July-Sep 2017 culminated with the GLE # 72 on 10-Sep-2017 (e.g., Mishev et al., 2018).

Short-term variability



To study short-term recurrent variability of CR fluxes, a wavelet time-frequency power spectrum analysis of daily proton fluxes was performed from 10-Jan-2016 to 21-Jan-2017 for three rigidity bins (a) [1-1.16] GV, (b) [5.9-6.47] GV, and (c) [16.6-22.8] GV. The color code indicates the normalized power. The solar synodic rotation period of 27 days is clearly observed as well as its harmonics at 13.5 and 9 days as indicated by the dashed lines). The strength of all three periodicities changes with time and rigidity. In particular, shorter periods of 9 and 13.5 days, when present, are more visible at 6 GV and 20 GV compared to 1 GV, which is contrary to the theoretically expected results that the strength of the variability decreases with energy/rigidity of particles.

Short-term variability



The normalized power of recurrent proton-flux variability as a function of rigidity (blue axis) and period (green axis) for (a) the first and (b) the second half of 2016 for protons with rigidity from 1 to 20 GV. As seen, the strength of 9-day, 13.5-day, and 27-day periodicities is rigidity dependent. In particular, while the strength of 27-day periodicity is nearly constant, the strengths of 9-day and 13.5-day periodicities increase with increasing rigidity up to ~10 GV and ~20 GV, respectively.

Conclusions

In conclusion, precise measurements of the daily proton fluxes in cosmic rays from 1 GV to 100 GV have been performed by AMS-02 onboard the ISS for the period between May 2011 and October 2019 with 5.5×10^9 measured protons.

The proton fluxes exhibit variations on different timescales, from days to several years. From 2014 to 2018, recurrent flux variations with a period of 27 days (the synodic solar rotation period) was observed. Shorter harmonic periods of 9 days and 13.5 days were significantly observed in 2016. The strength of all three periodicities changes with both time and rigidity.

Unexpectedly, while the strength of the 27-day periodicity in cosmic rays was found to be almost independent of the particle's rigidity, the strength of 9-day and 13.5-day periodicities increases with increasing rigidities up to $\sim$10 GV and $\sim$20 GV respectively. The origin of this phenomenon is not known and it needs further investigation.

References

- Aguilar, M. et al. (AMS collaboration), The Alpha Magnetic Spectrometer (AMS) on the international space station: Part II - Results from the first seven years, *Phys. Rep*., 894, 1-116 (2021a) doi: 10.1016/j.physrep.2020.09.003

- Aguilar, M. et al. (AMS collaboration), Periodicities in the Daily Proton Fluxes from 2011 to 2019 Measured by the Alpha Magnetic Spectrometer on the International Space Station from 1 to 100 GV, *Phys. Rev. Lett*., 127, 271102 (2021b), doi: 10.1103/PhysRevLett.127.271102.

- Mishev, A., I. Usoskin, O. Raukunen, M. Paassilta, E. Valtonen, L. Kocharov, R. Vainio, First Analysis of Ground-Level Enhancement (GLE) 72 on 10 September 2017: Spectral and Anisotropy Characteristics, *Solar Phys*., 293, 136 (2018) doi: 10.1007/s11207-018-1354-x