Latest results of the Alpha Magnetic Spectrometer on the International Space Station

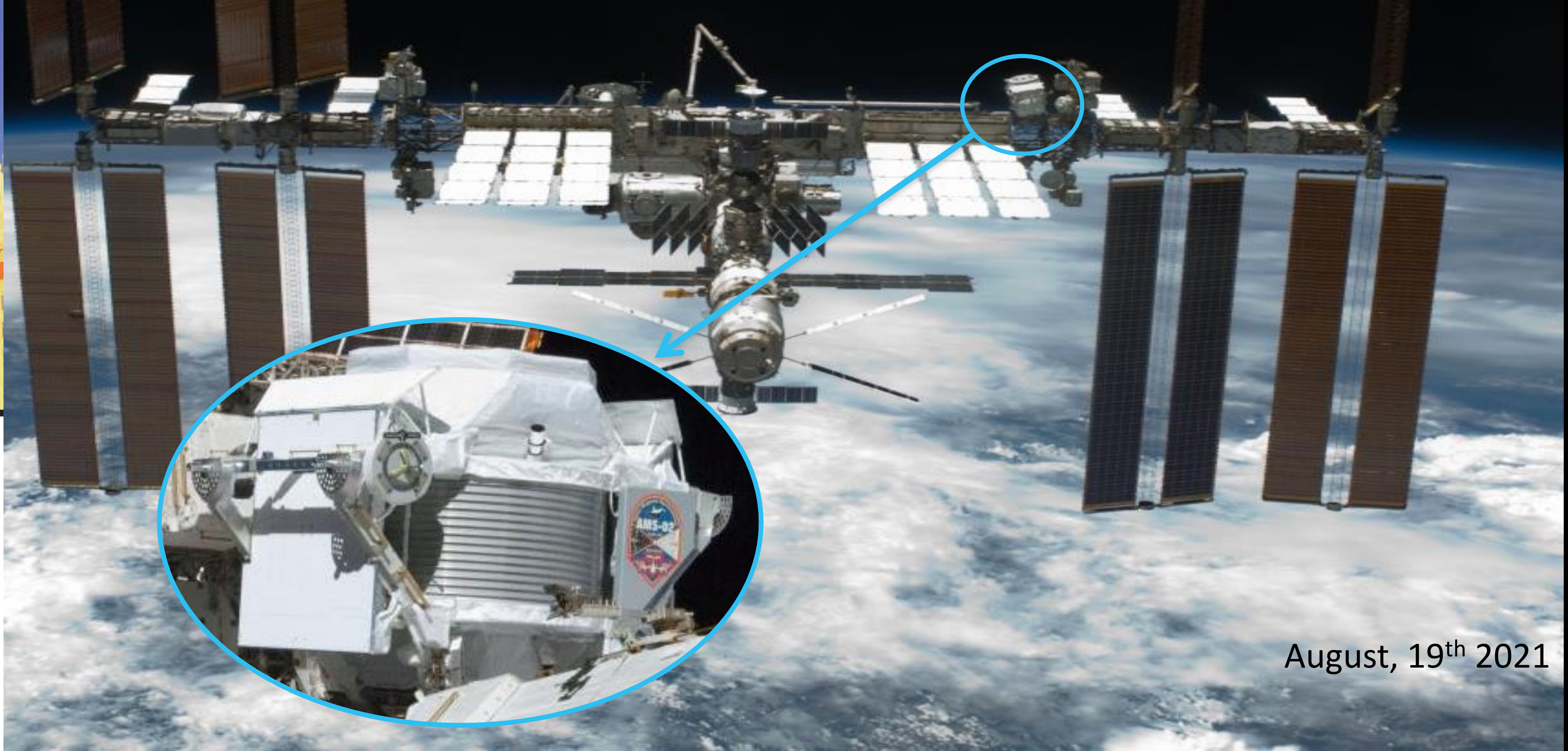
Javier Berdugo (CIEMAT, Madrid)
On behalf of the AMS Collaboration

Dedicated to the Year of Science and Technology

TWENTIETH LOMONOSOV CONFERENCE ON ELEMENTARY PARTICLE PHYSICS

Moscow, August 19 - 25, 2021

Mikhail Lomonosov 1711-1765

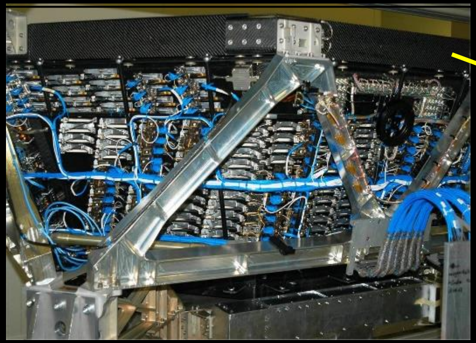


August, 19th 2021

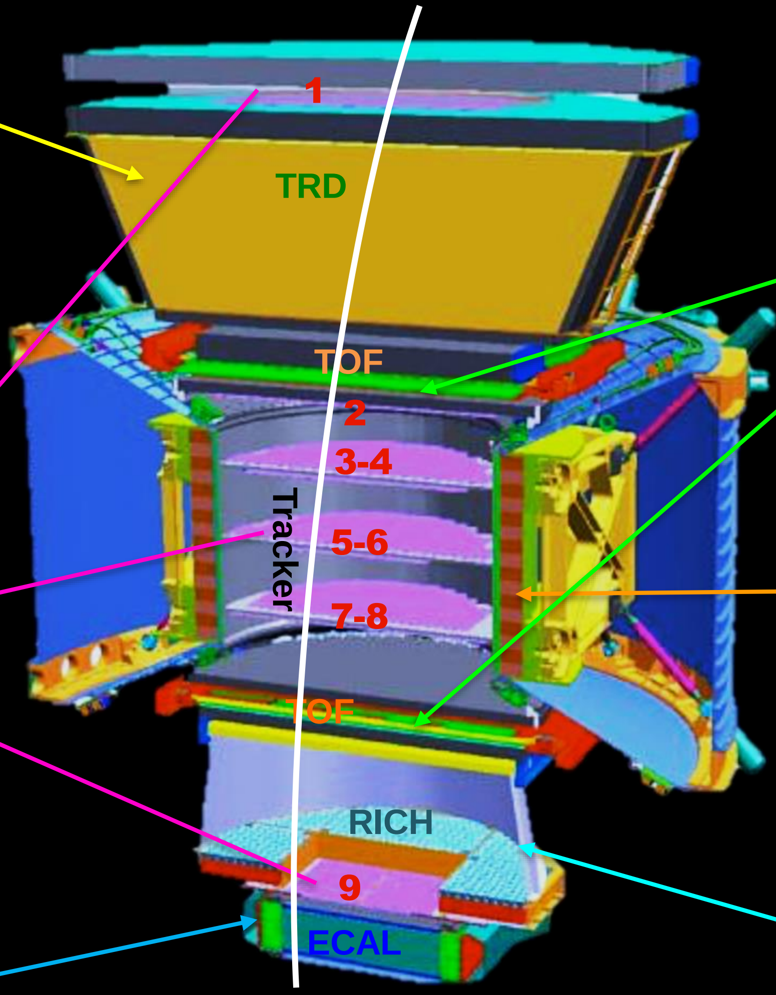
AMS-02: A TeV precision magnetic spectrometer in space

Transition Radiation Detector

Identifies e^+, e^-



Particle (Z, E)

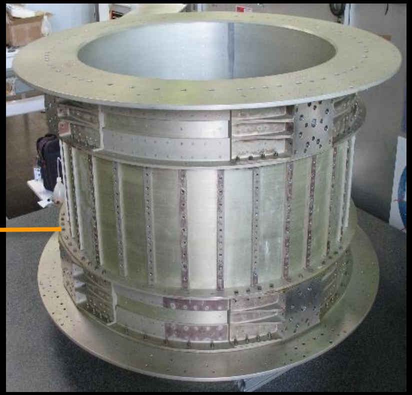


Time Of Flight

β, Z

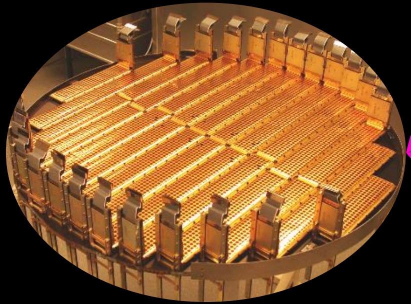
Magnet

B = .15 T



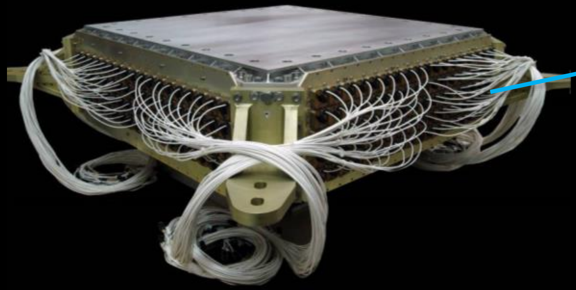
Silicon Detector

Rigidity=p/Ze, ±Z



Electromagnetic Calorimeter

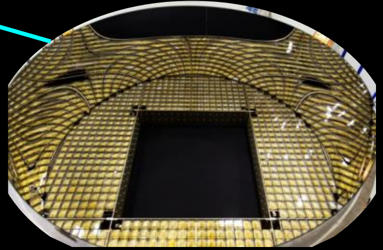
Energy of e^+, e^-



Ring Imaging Cherenkov

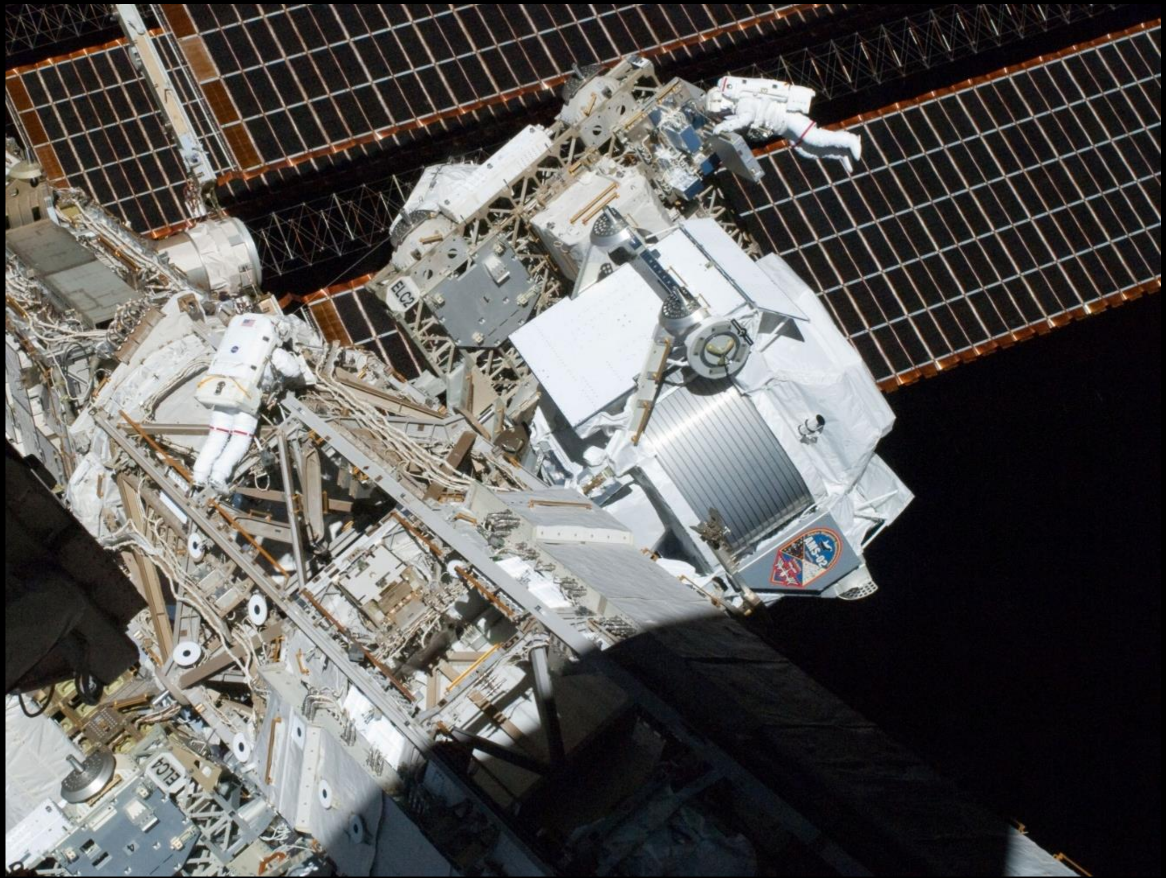
β, Z

Isotopic composition

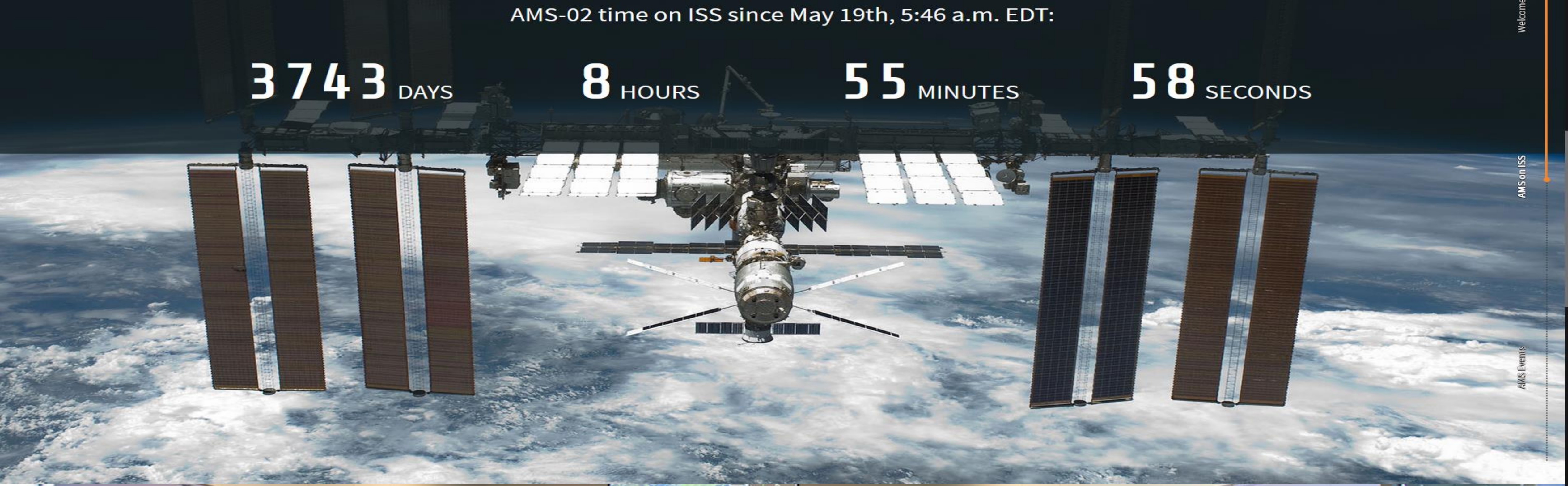


Redundant measurements of Charge (Z) and Energy (E)

Space Shuttle *Endeavour* lift off May 16, 2011, 08:56:28 EDT



AMS installed on the ISS on May 19, 2011


AMS-02 time on ISS since May 19th, 5:46 a.m. EDT:
3743 DAYS
8 HOURS
55 MINUTES
58 SECONDS


AMS has collected
186,148,200,582
cosmic ray events
Last update: August 17, 2021, 6:06 PM

Cosmic rays measurements with AMS

AMS is the first and only instrument providing simultaneous measurements of particles/anti-particles, chemical composition up to Fe in an extended energy range and over a solar cycle

Physical Review Letters

1. *First Result from the AMS on the ISS: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–350 GeV (2013)*
2. *Electron and Positron Fluxes in Primary Cosmic Rays Measured with the AMS on the ISS (2014)*
3. *High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–500 GeV with the AMS on the ISS (2014)*
4. *Precision Measurement of the e+ + e- Flux in Primary Cosmic Rays from 0.5 GeV to 1 TeV with the AMS on the ISS (2014)*
5. *Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the AMS on the ISS (2015)*
6. *Precision Measurement of the He Flux in Primary Cosmic Rays of Rigidities 1.9 GVto 3 TV with the AMS on the ISS (2015)*
7. *Antiproton Flux, Antiproton-to-Proton Flux Ratio, and Properties of Elementary Particle Fluxes in Primary Cosmic Rays Measured with the AMS on the ISS (2016)*
8. *Precision Measurement of the B to C Flux Ratio in Cosmic Rays from 1.9 GV to 2.6 TV with the AMS on the ISS (2016)*
9. *Observation of the Identical Rigidity Dependence of He, C, and O Cosmic Rays at High Rigidities by the AMS on the ISS (2017)*
10. *Observation of New Properties of Secondary Cosmic Rays Lithium, Beryllium, and Boron by the AMS on the ISS (2018)*
11. *Observation of Fine Time Structures in the Cosmic Proton and Helium Fluxes with AMS on the ISS (2018)*
12. *Observation of complex time structures in the cosmic-ray electron and positron fluxes with the AMS on the ISS (2018)*
13. *Precision measurement of cosmic-ray nitrogen and its primary and secondary components with AMS on the ISS (2018)*
14. *Towards Understanding the Origin of Cosmic-Ray Positrons (2019)*
15. *Towards Understanding the Origin of Cosmic-Ray Electrons (2019)*
16. *Properties of Cosmic Helium Isotopes Measured by the Alpha Magnetic Spectrometer (2019)*
17. *Properties of Neon, Magnesium, and Silicon Primary Cosmic Rays Results from the Alpha Magnetic Spectrometer (2020)*
18. *Properties of Iron Primary Cosmic Rays: Results from the Alpha Magnetic Spectrometer (2021)*
19. *Properties of Heavy Secondary Fluorine Cosmic Rays: Results from the Alpha Magnetic Spectrometer (2021)*
20. *Properties of a New Group of Cosmic Nuclei: Results from the Alpha Magnetic Spectrometer on Sodium, Aluminum, and Nitrogen (2021)*

Ediitors'Suggestion

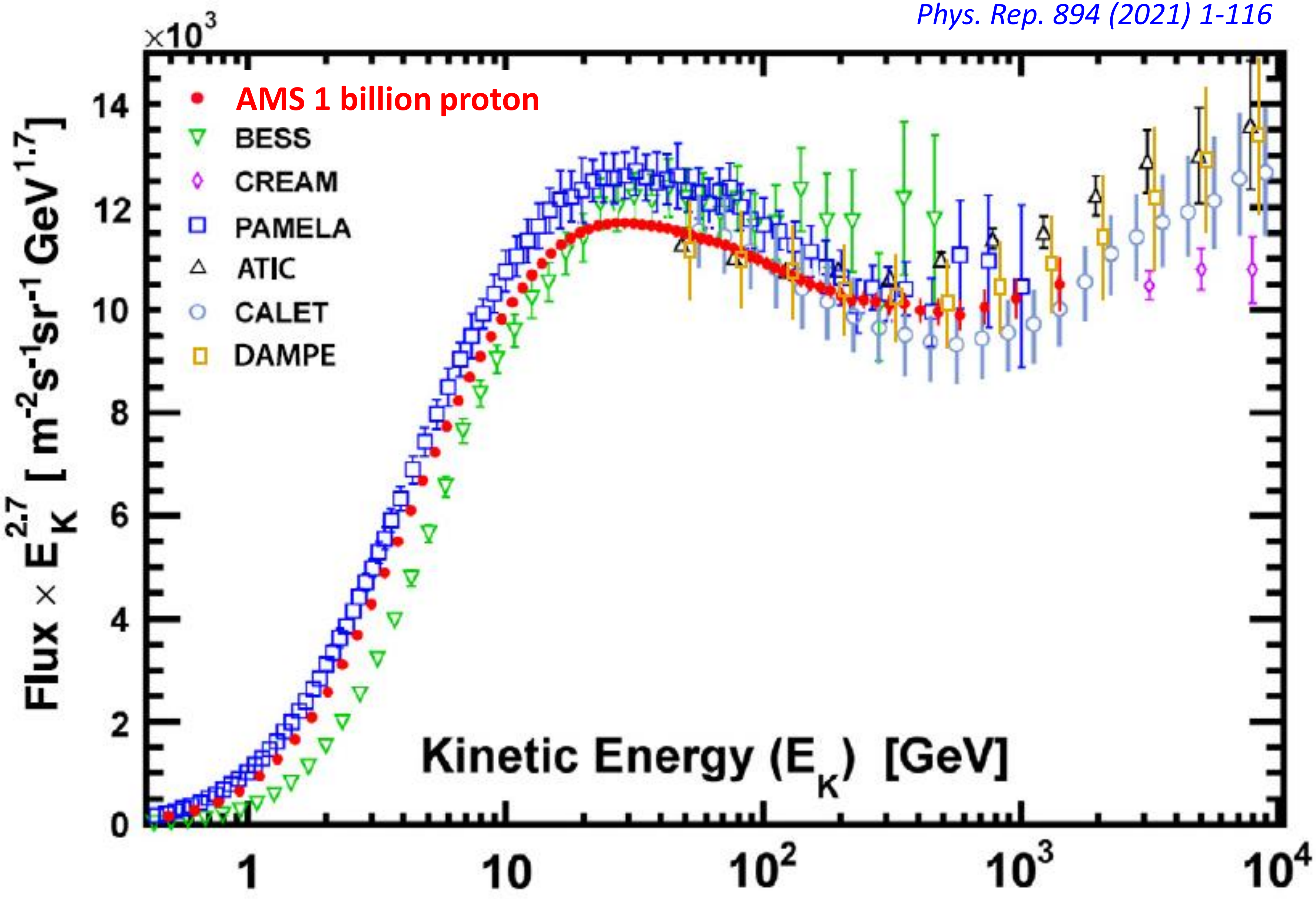
… Periodicities in the Daily Proton Fluxes: Results from the Alpha Magnetic Spectrometer (Submitted)
… Periodicities in the Daily Helium Fluxes: Results from the Alpha Magnetic Spectrometer (in preparation)
… Periodicities in the Daily Electrons and Positrons Fluxes: Results from the Alpha Magnetic Spectrometer (in preparation)

Physics Reports

The Alpha Magnetic Spectrometer (AMS) on the International Space Station: Part II - Results from the First Seven Years (2021)

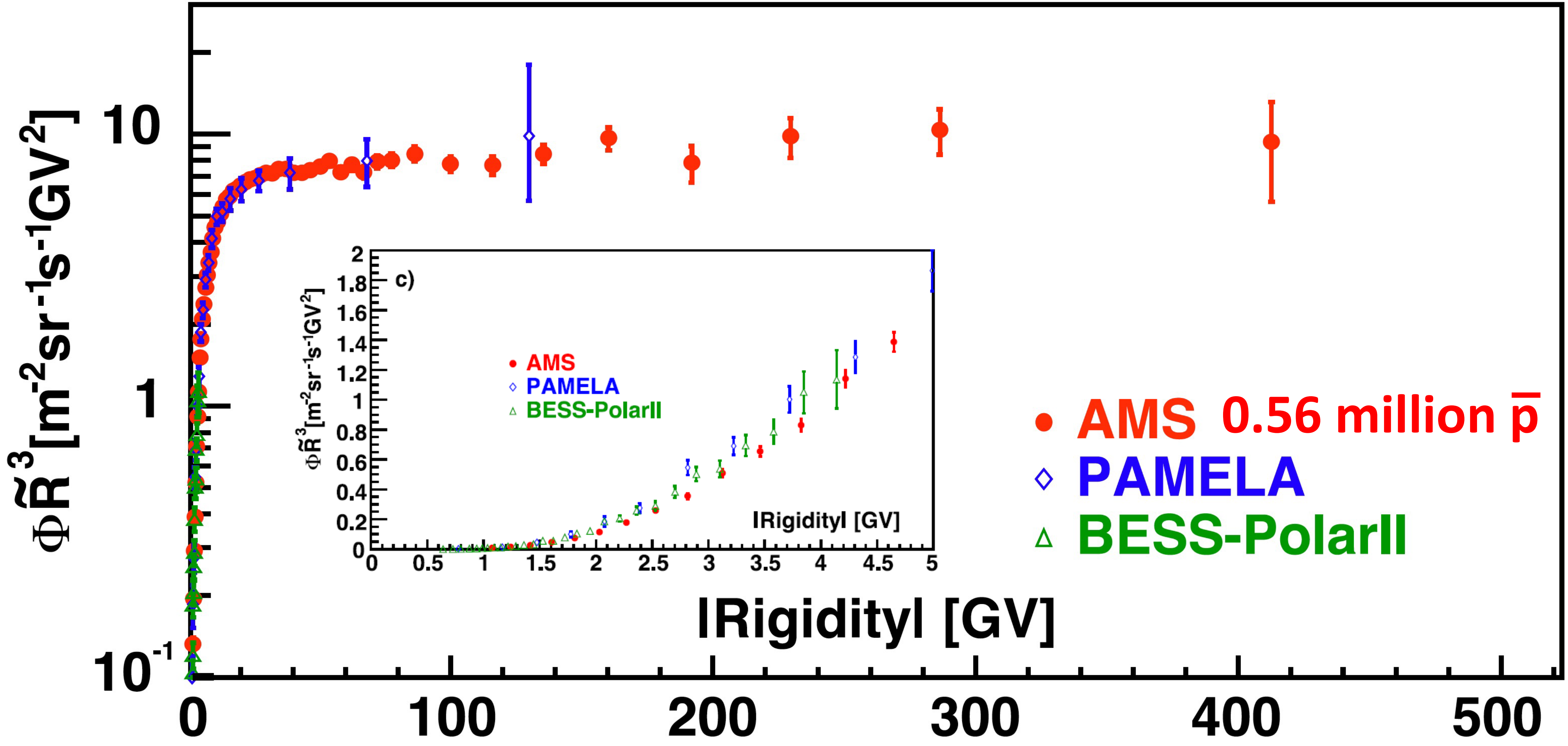
Latest AMS measurement of proton flux in cosmic rays

Phys. Rep. 894 (2021) 1-116



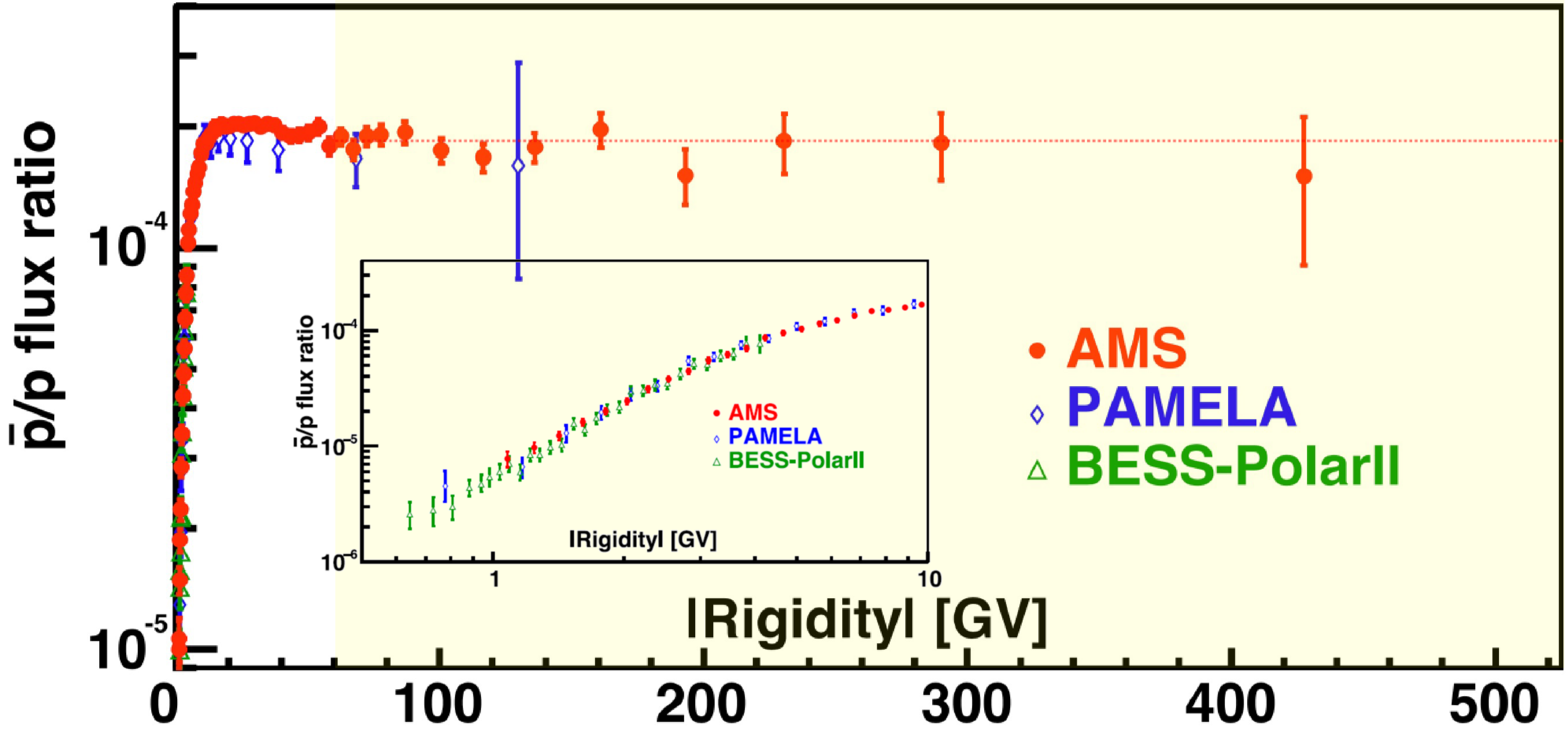
Latest AMS measurement of antiproton flux in cosmic rays

Phys. Rep. 894 (2021) 1-116

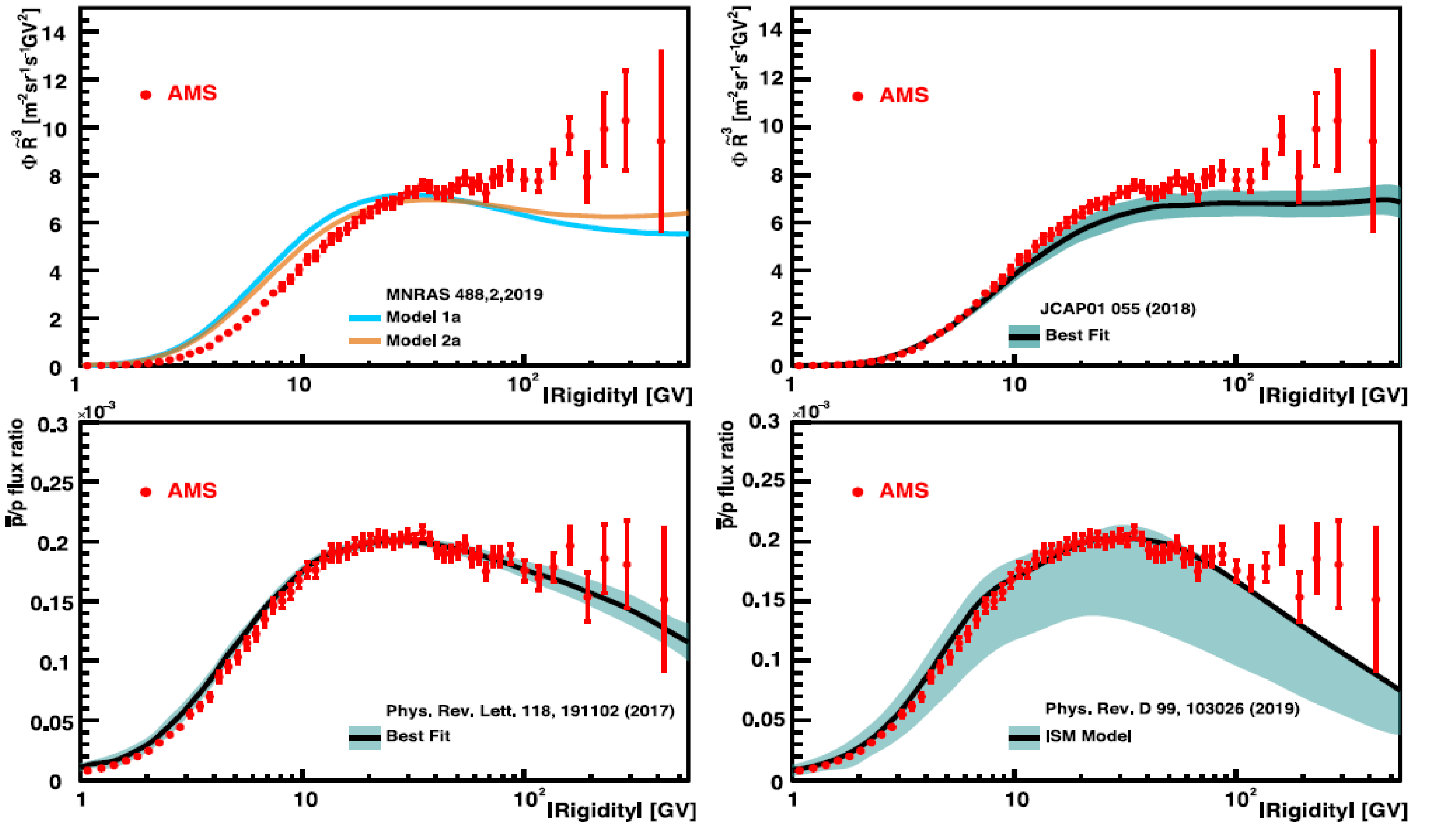


Latest AMS antiproton to proton flux ratio

Phys. Rep. 894 (2021) 1-116



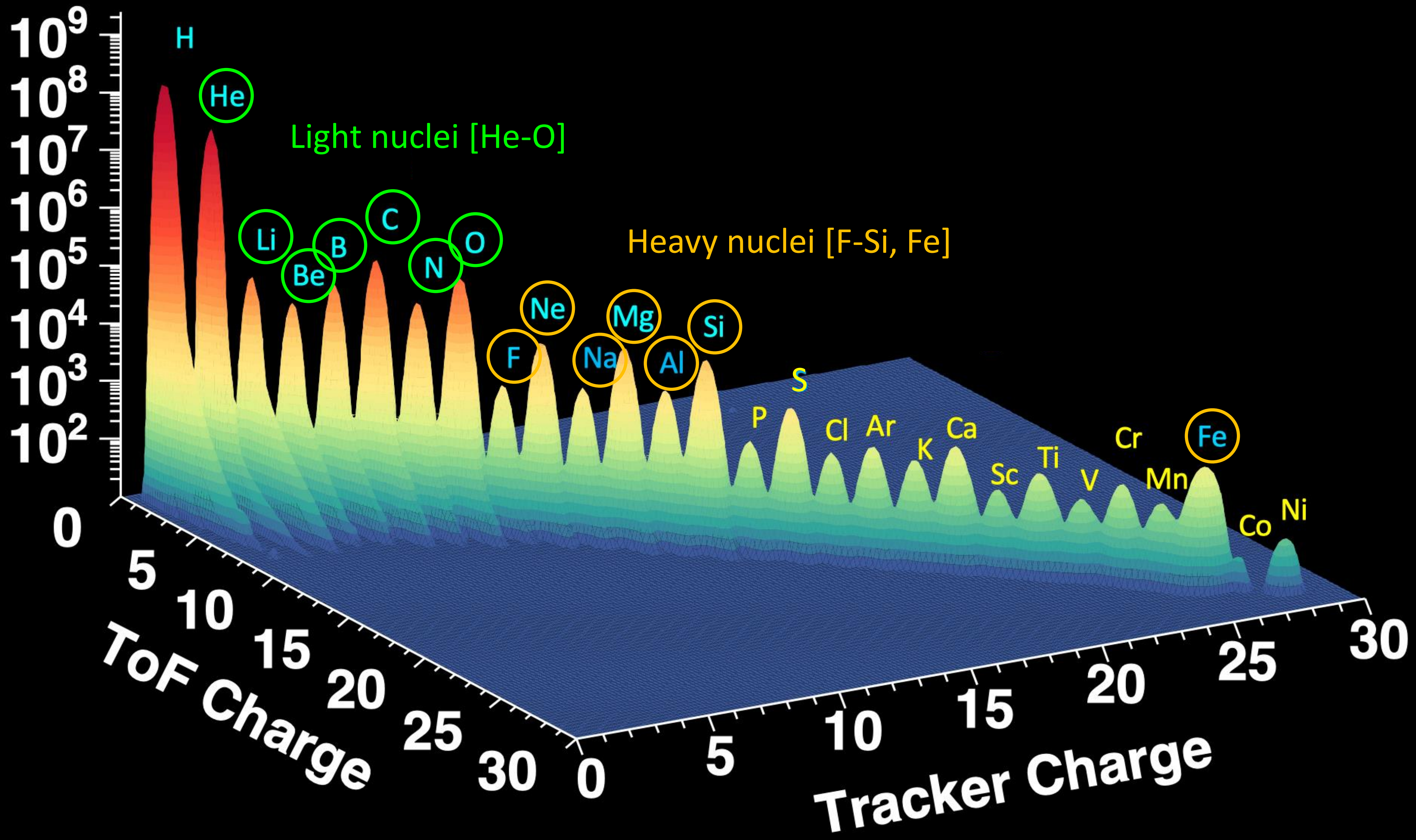
AMS antiproton flux and antiproton-to-proton flux ratio compared with secondary production models



The accuracy of theoretical predictions can be improved with the latest AMS results on the fluxes of primary and secondary cosmic rays and their ratios

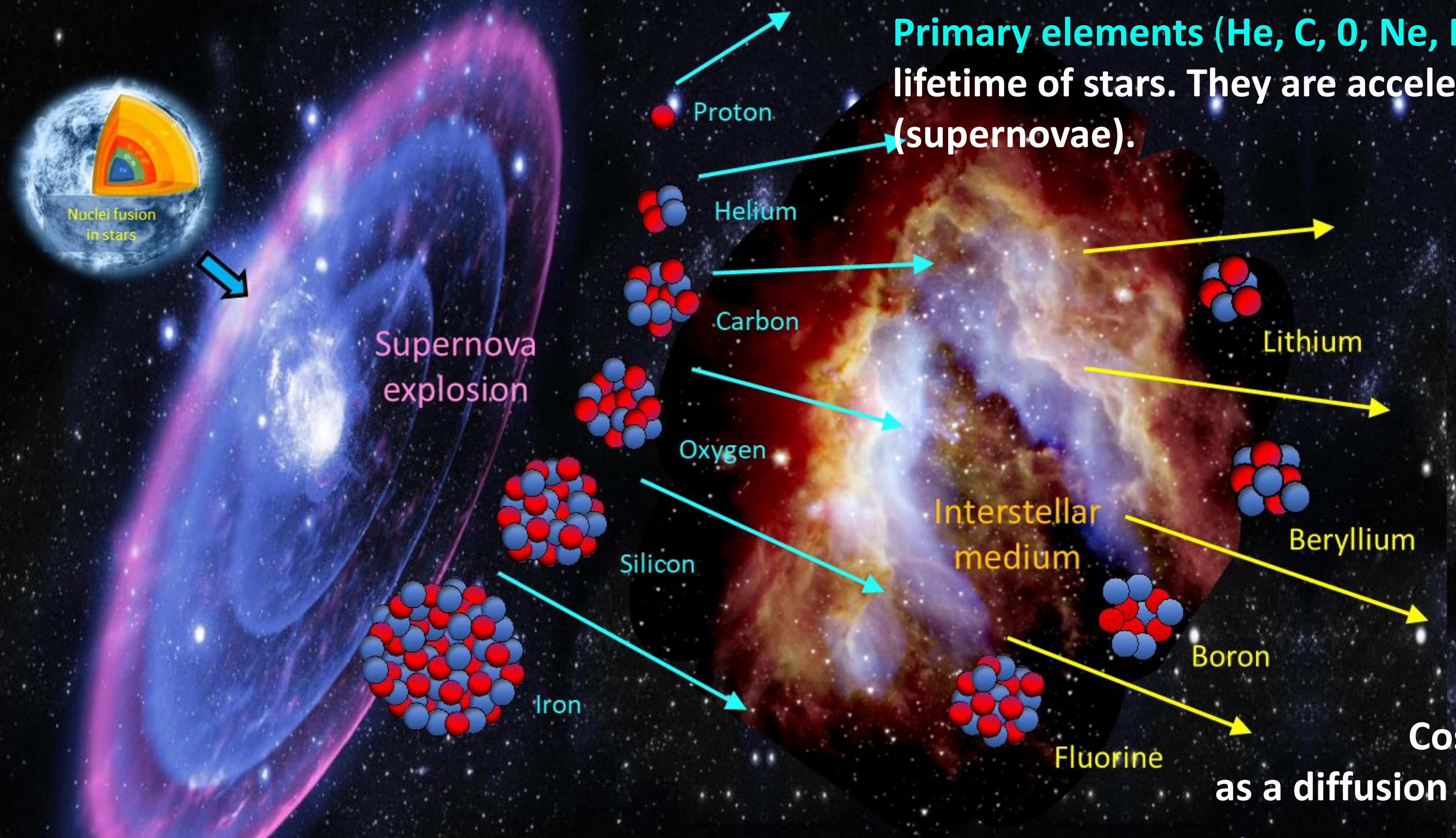
Nuclei cosmic rays detected by AMS

AMS identifies nuclei in cosmic rays from Z=2 to Z=30



Nuclei Cosmic Rays

Primary elements (He, C, 0, Ne, Mg, Si..., Fe) are produced during the lifetime of stars. They are accelerated by the explosion of stars (supernovae).



Secondary Li, Be, B, F, sub-Fe nuclei produced by the collision of primary cosmic rays C, O, Si, ... , Fe with the interstellar medium

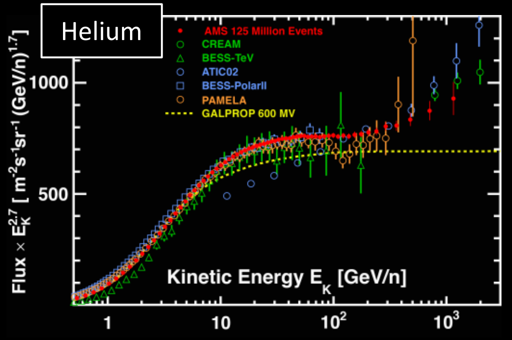
Cosmic ray propagation is commonly modeled as a diffusion process due to the turbulent magnetic field

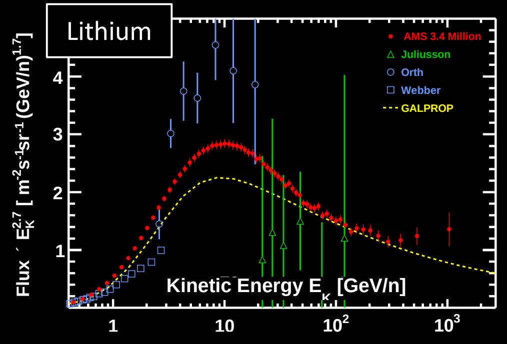
Primary ~ source ($R^{-\alpha}$) x propagation ($R^{-\delta}$) ~ $R^{-(\alpha+\delta)}$

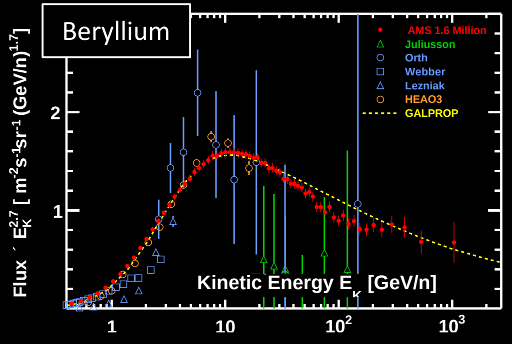
Secondary ~ source ($R^{-(\alpha+\delta)}$) x propagation ($R^{-\delta}$) ~ $R^{-(\alpha+2\delta)}$

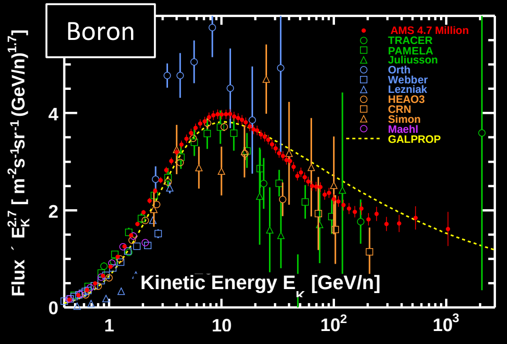
Secondary/Primary ~ $R^{-\delta}$

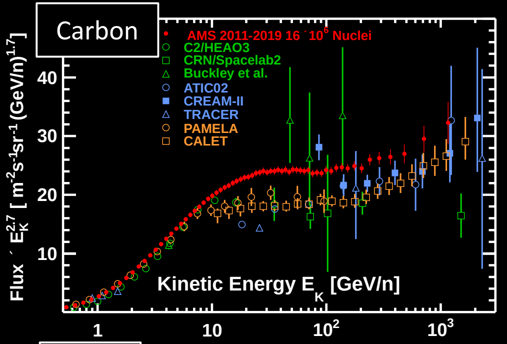
Precise measurements of primary and secondary rigidity dependences provide key information on the source processes and propagation

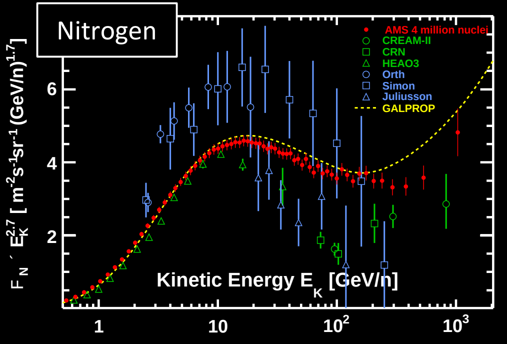


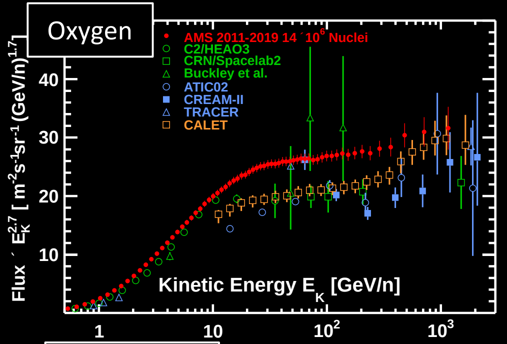


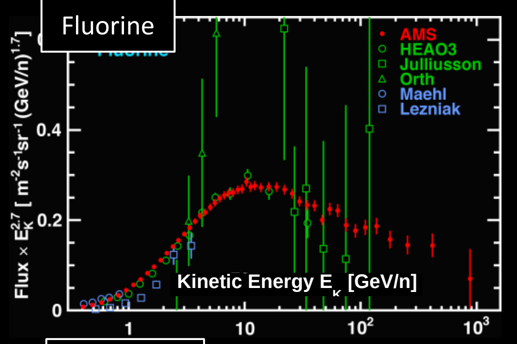


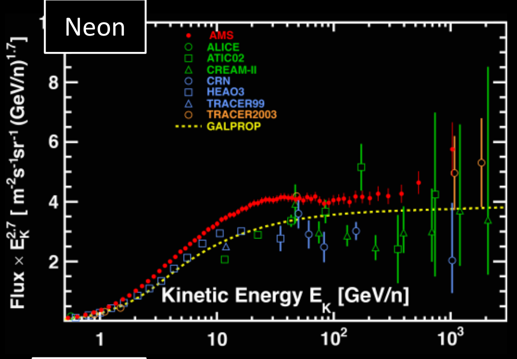


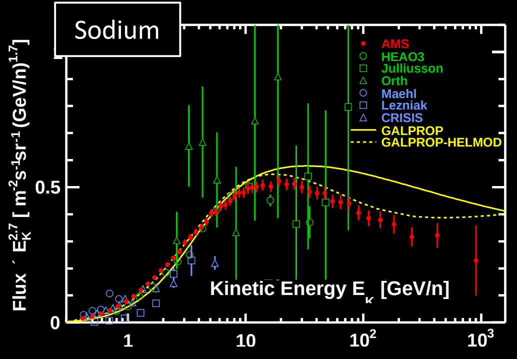


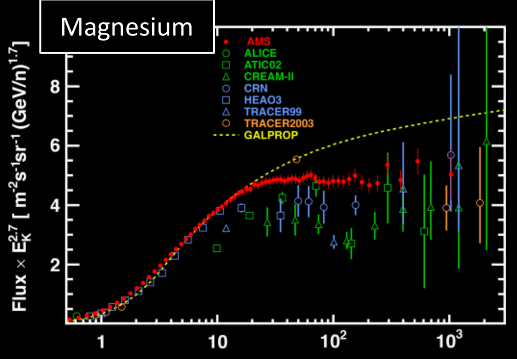


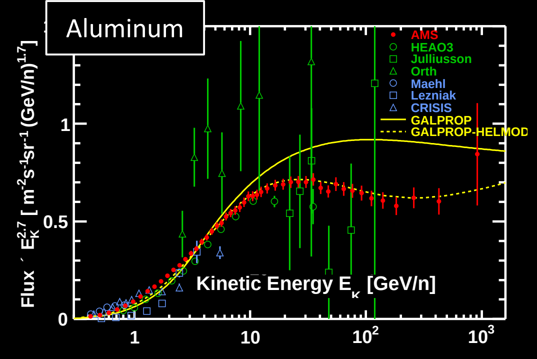


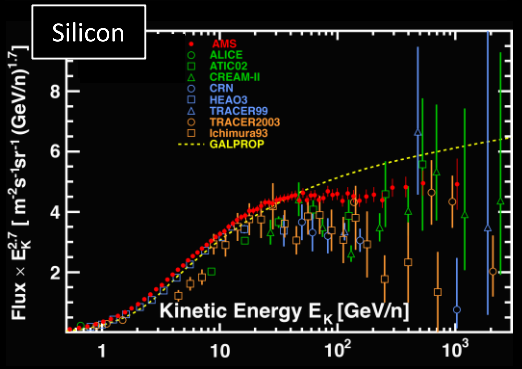




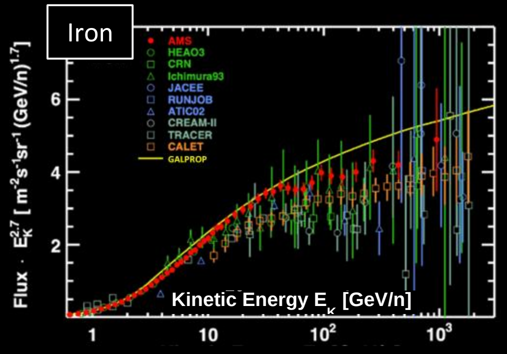






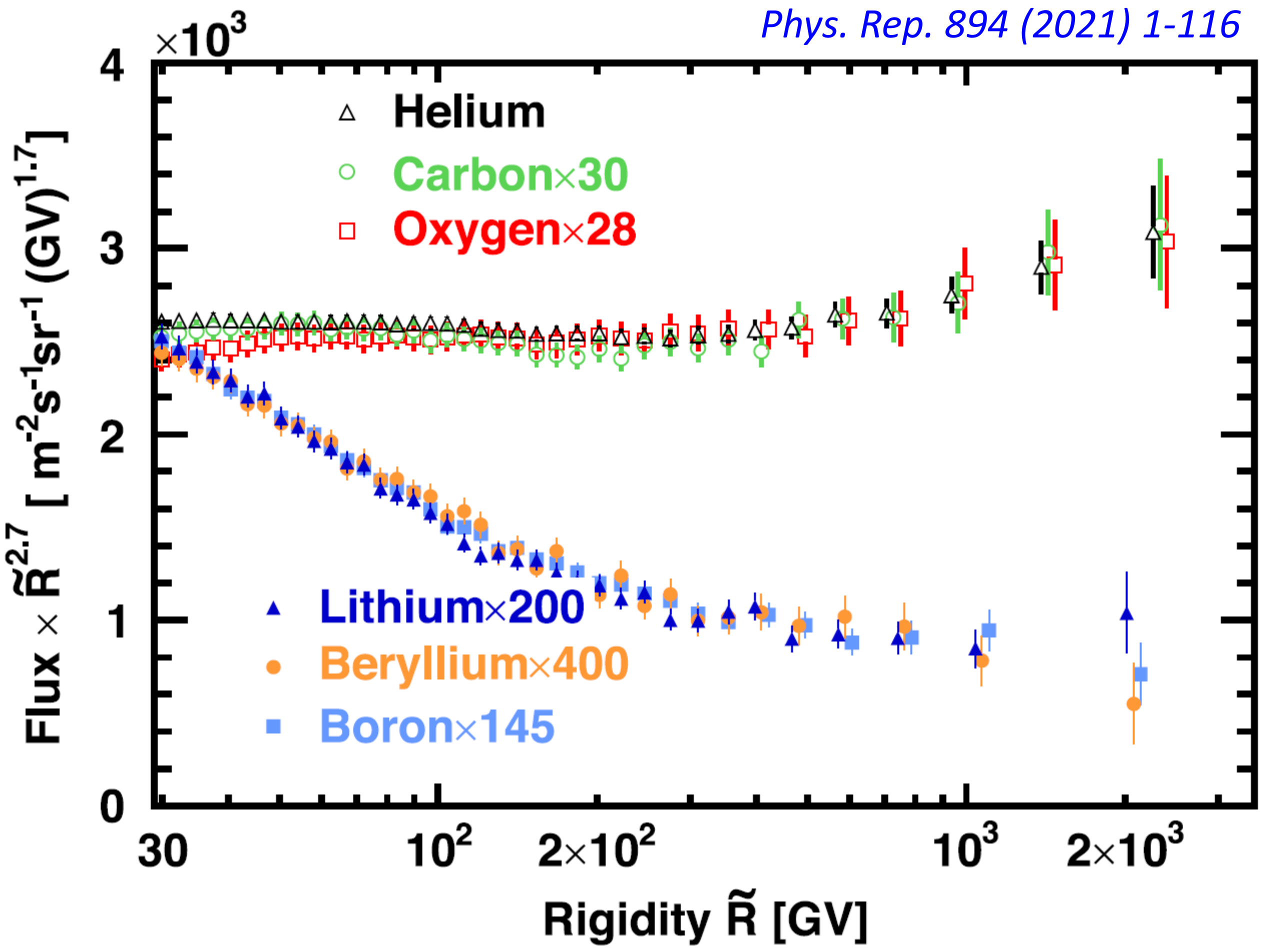


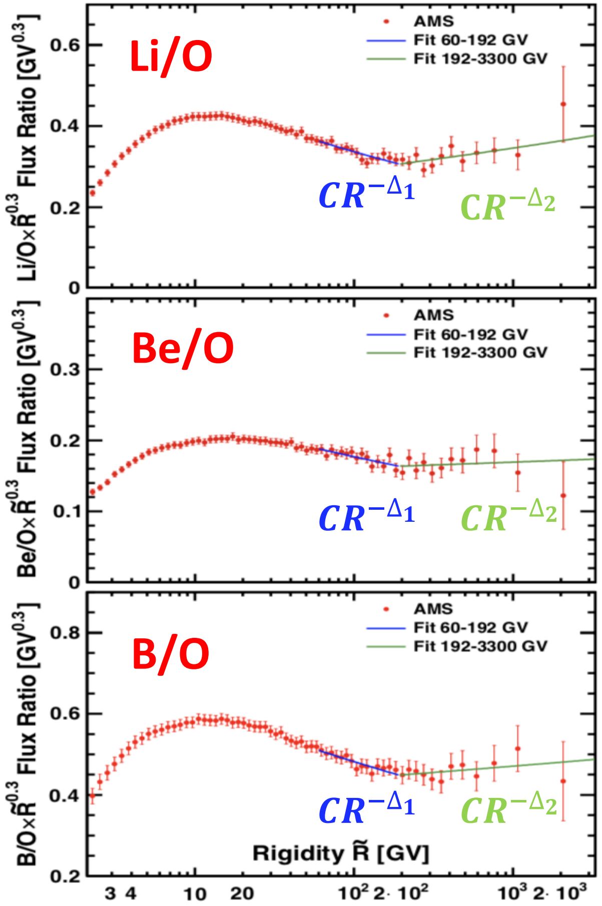
AMS is providing simultaneous measurements of different nuclei cosmic ray fluxes with O(%) accuracy in an extended energy range



Latest AMS measurements of Light Nuclei in cosmic rays

Above 200 GV, primary and secondary cosmic ray deviate from a single power law





Secondary/Primary flux ratios do not follow a single power law

Above 192 GV secondary cosmic ray harden more than primary

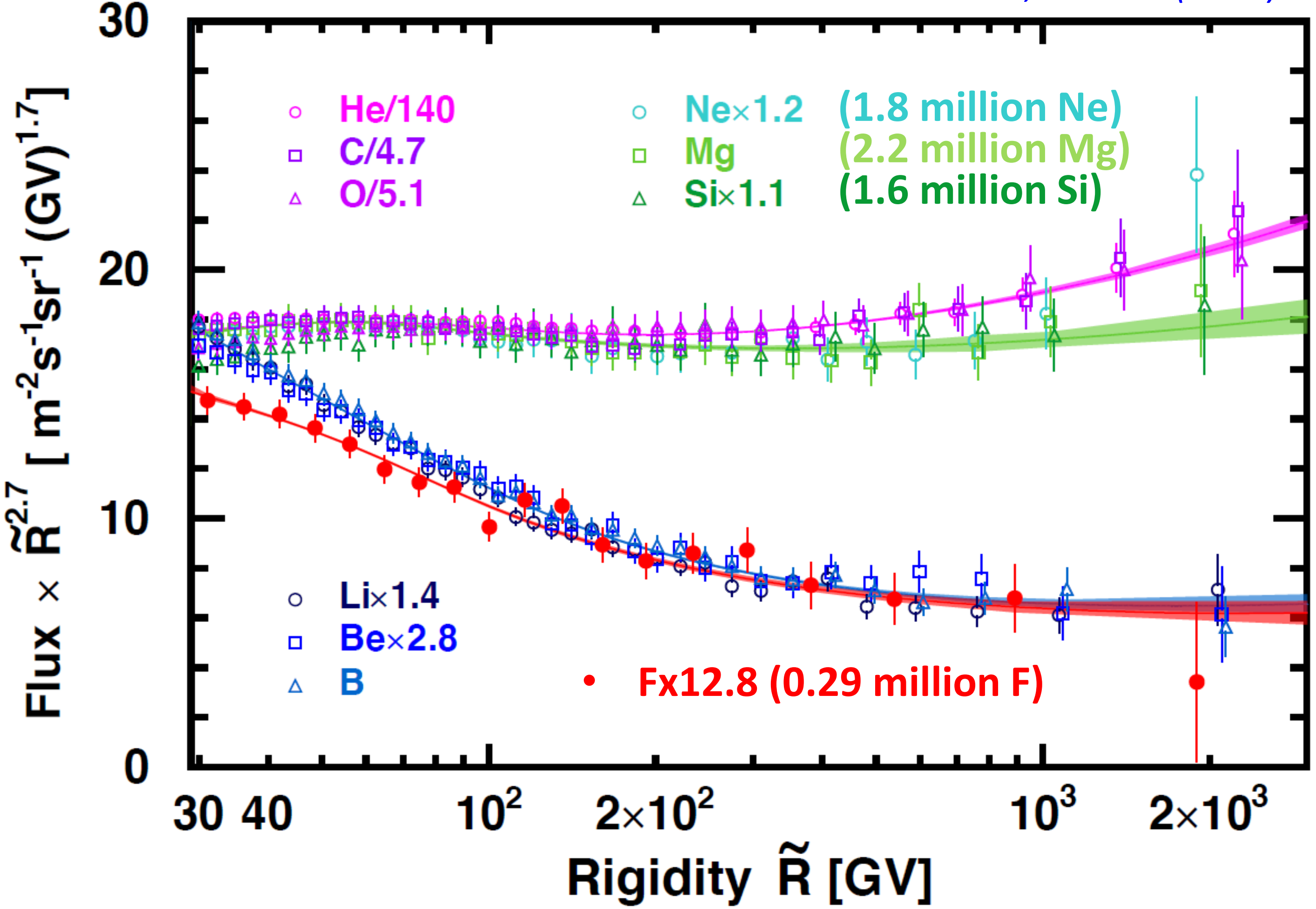
Average hardening $\Delta = \Delta_2 - \Delta_1 = 0.140 \pm 0.025$ (significance 5.6 σ)

New AMS measurements of Heavy Nuclei in cosmic rays

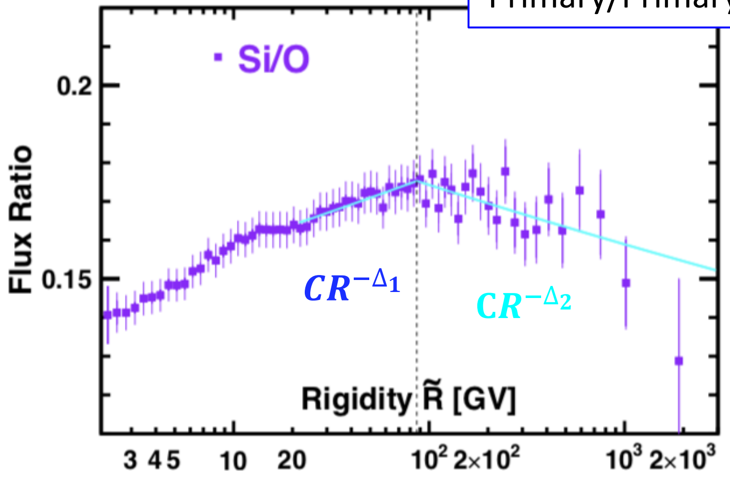
Ne, Mg, Si have distinctly different rigidity behavior from He, C, O

F has distinctly different rigidity dependence from Li, Be, B

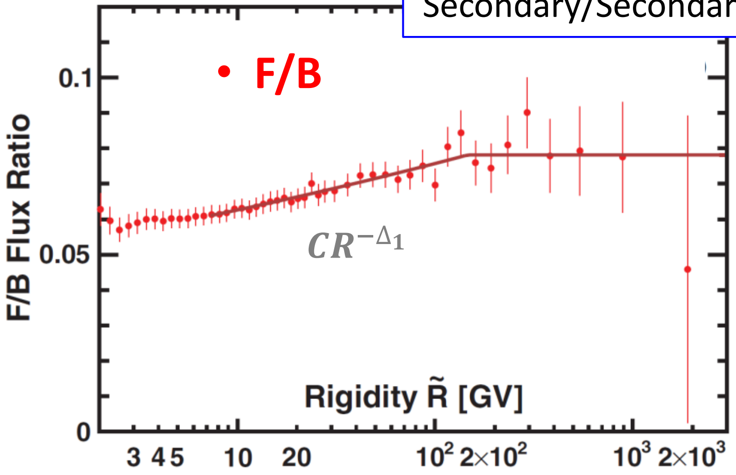
PRL 124, 211102 (2020)
PRL 126, 081102 (2021)



Primary/Primary



Secondary/Secondary

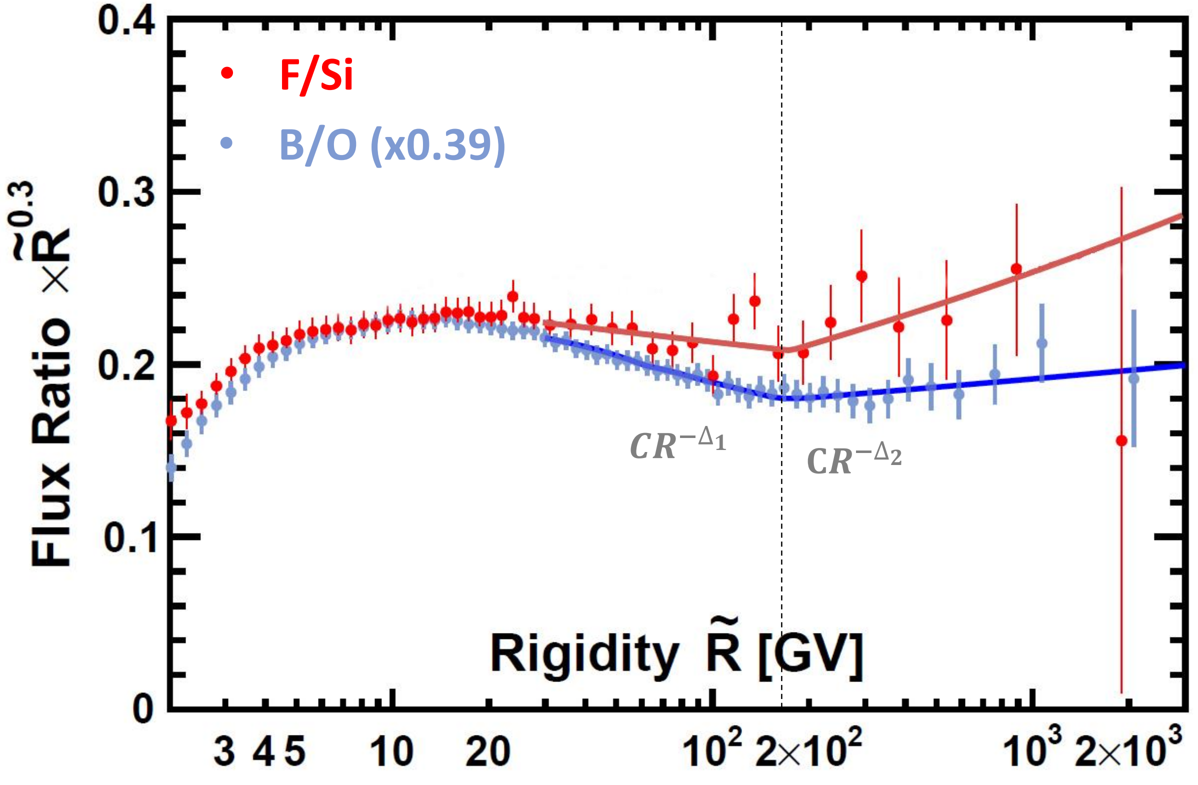


Heavier secondary-to-primary flux ratios (F/Si)

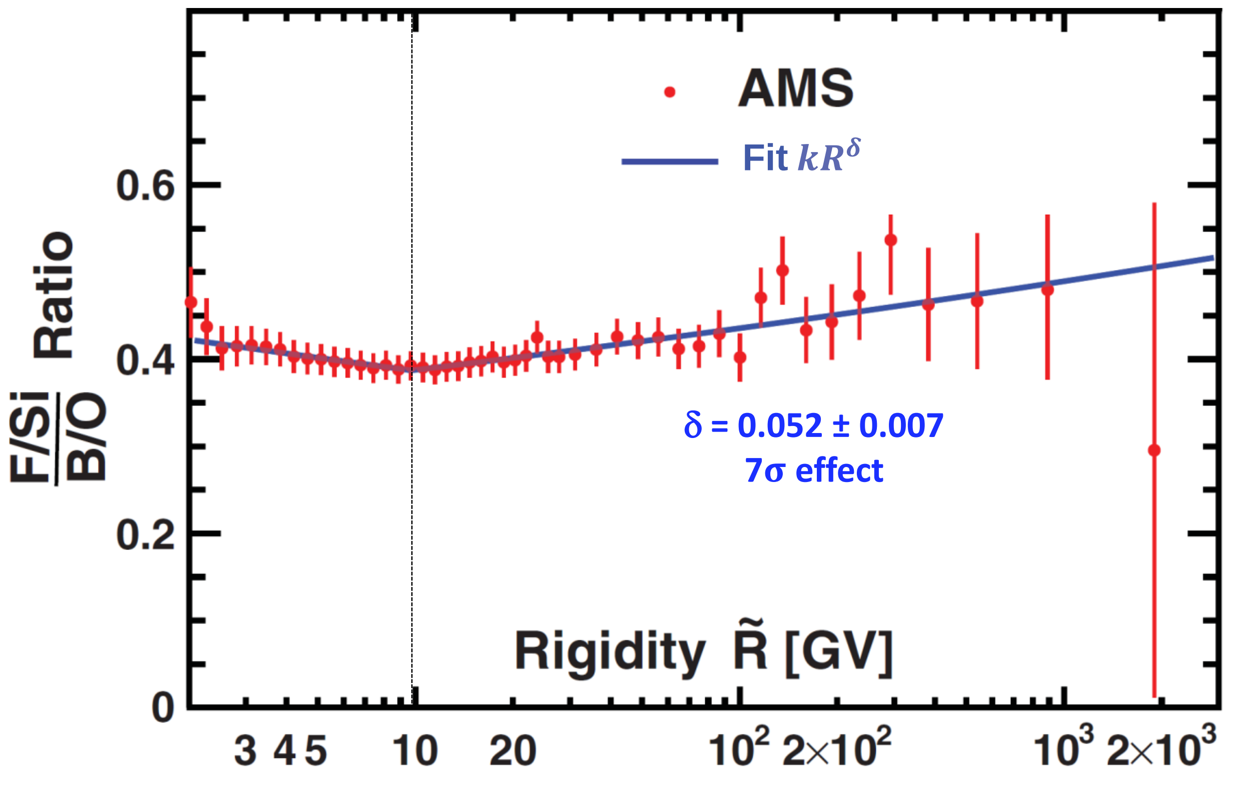
Traditionally the light secondary-to-primary ratio B/O (or B/C) is used to describe the propagation properties of all cosmic rays.

F/Si flux ratio hardens above 175 GV

Average hardening $\Delta = \Delta_2 - \Delta_1$ = 0.15 ± 0.07



Above 10 GV, the (F/Si)/(B/O) ratio can be described by a single power law with δ=0.052±0.007

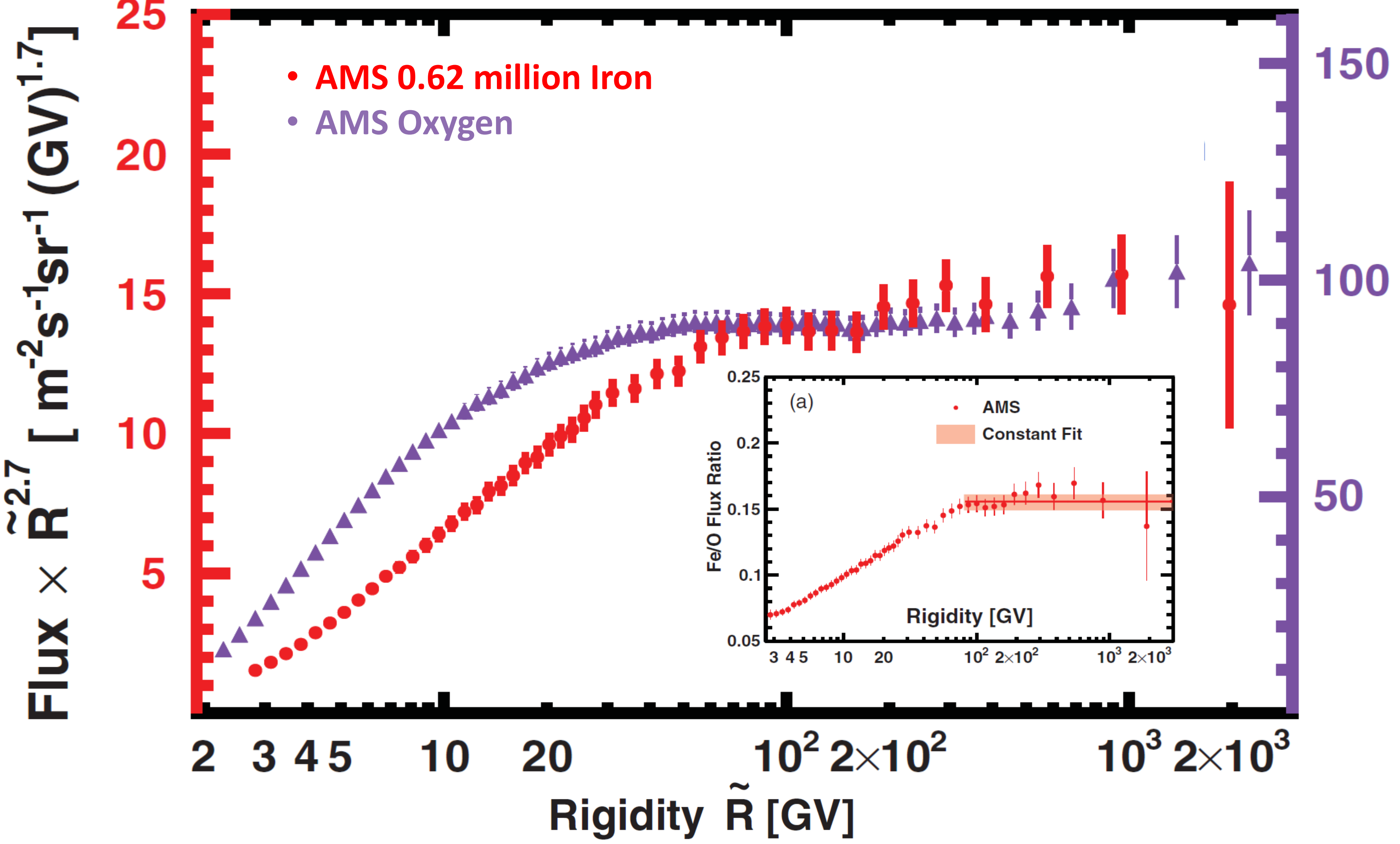


The propagation properties of heavy cosmic rays are different from those of light CRs.

New AMS measurement of Iron nuclei flux in cosmic rays

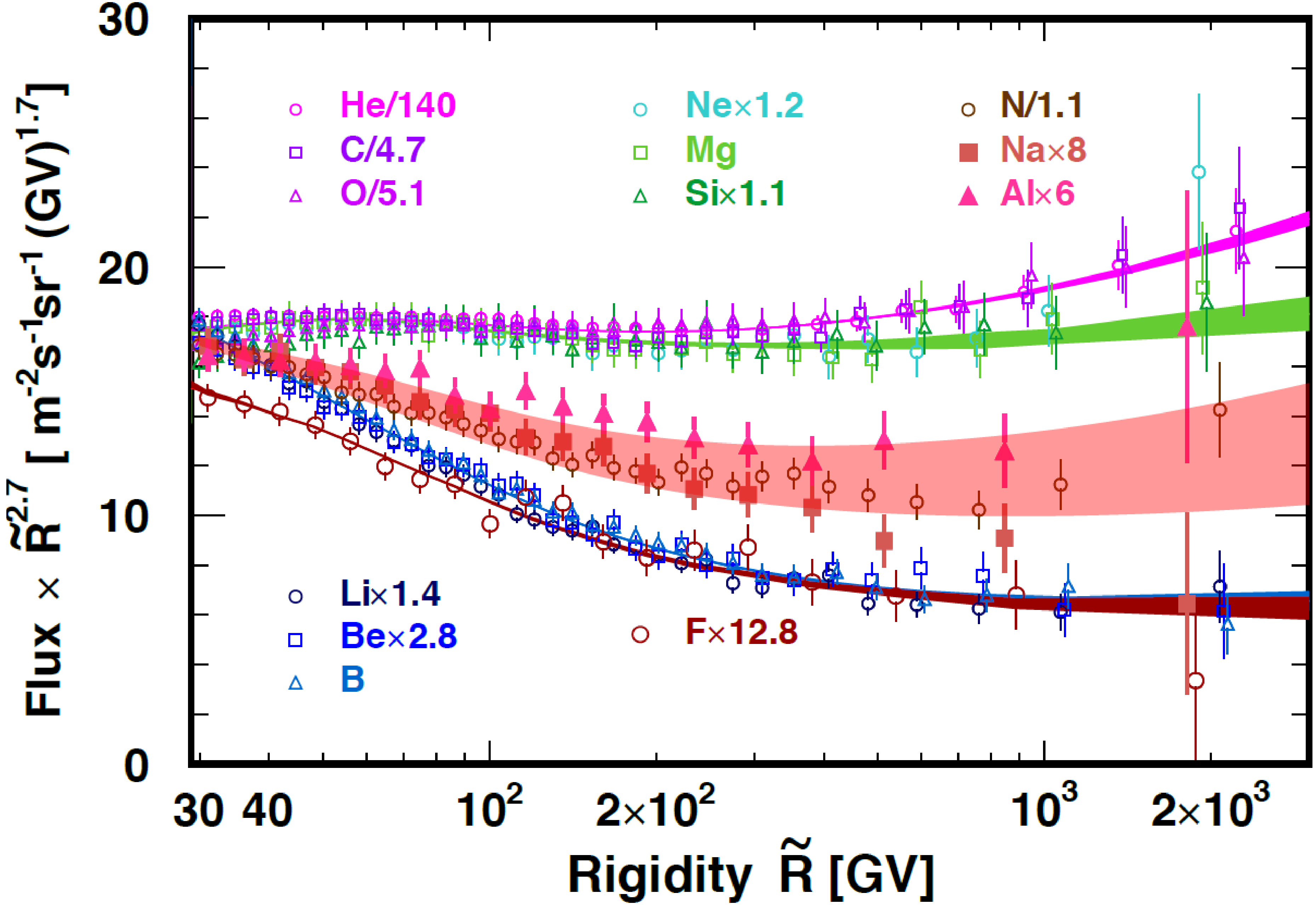
Above 200 GV, Iron flux deviates from a single power law

PRL 126, 041104 (2021)



Iron and Oxygen have identical rigidity dependence above 80.5 GV

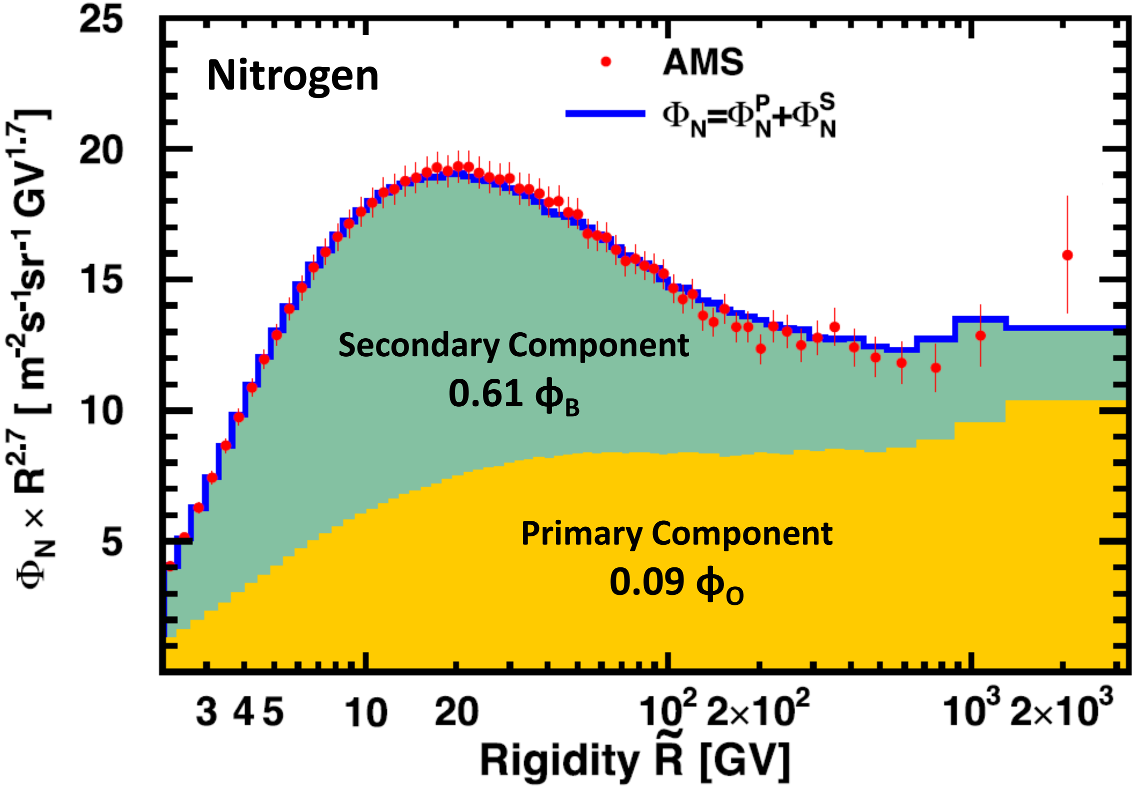
New AMS measurement of N, Na and Al nuclei fluxes in cosmic rays



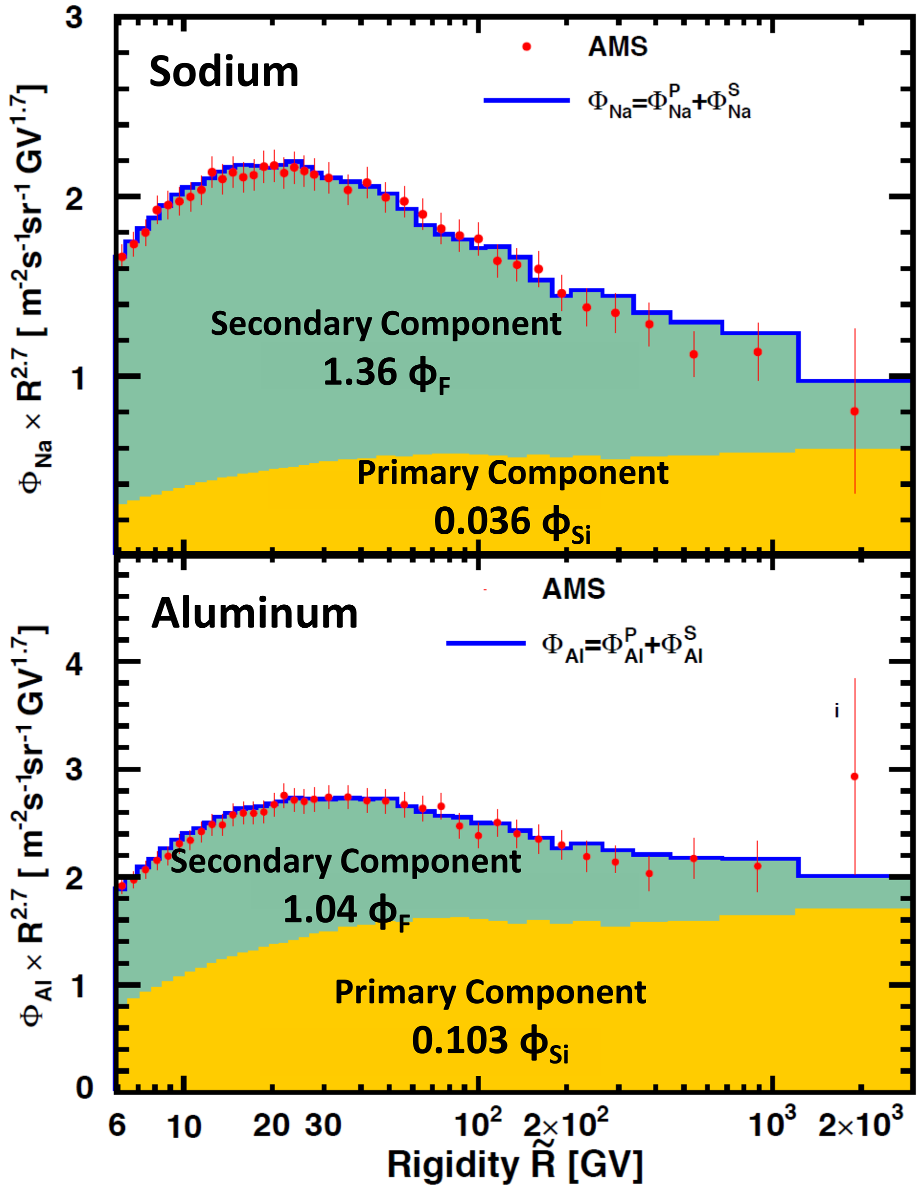
3.9×10^6 Nitrogen
0.46×10^6 Sodium
0.51×10^6 Aluminum

N, Na and Al fluxes expressed as sum of primary and secondary

Phys. Rep. 894 (2021) 1-116



PRL 127, 021101 (2021)

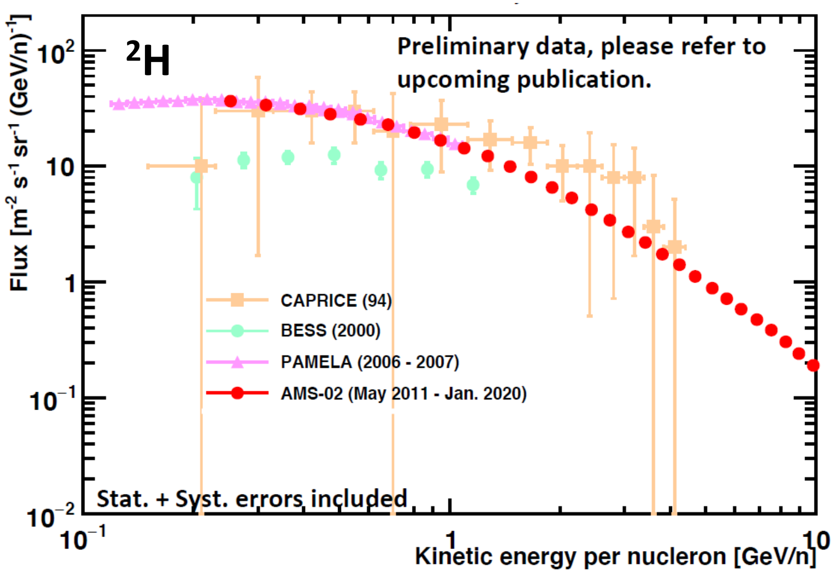


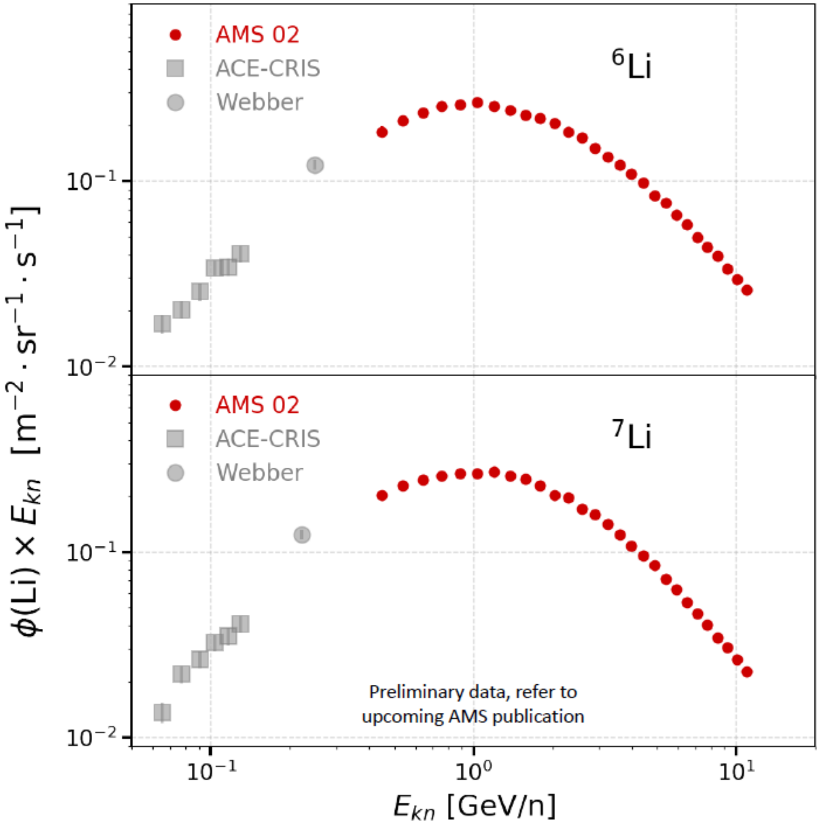
ϕ_N/ϕ_O, ϕ_{Na}/ϕ_{Si}, and ϕ_{Al}/ϕ_{Si} abundance ratios at the source are determined without the need to consider the Galactic propagation of cosmic rays.

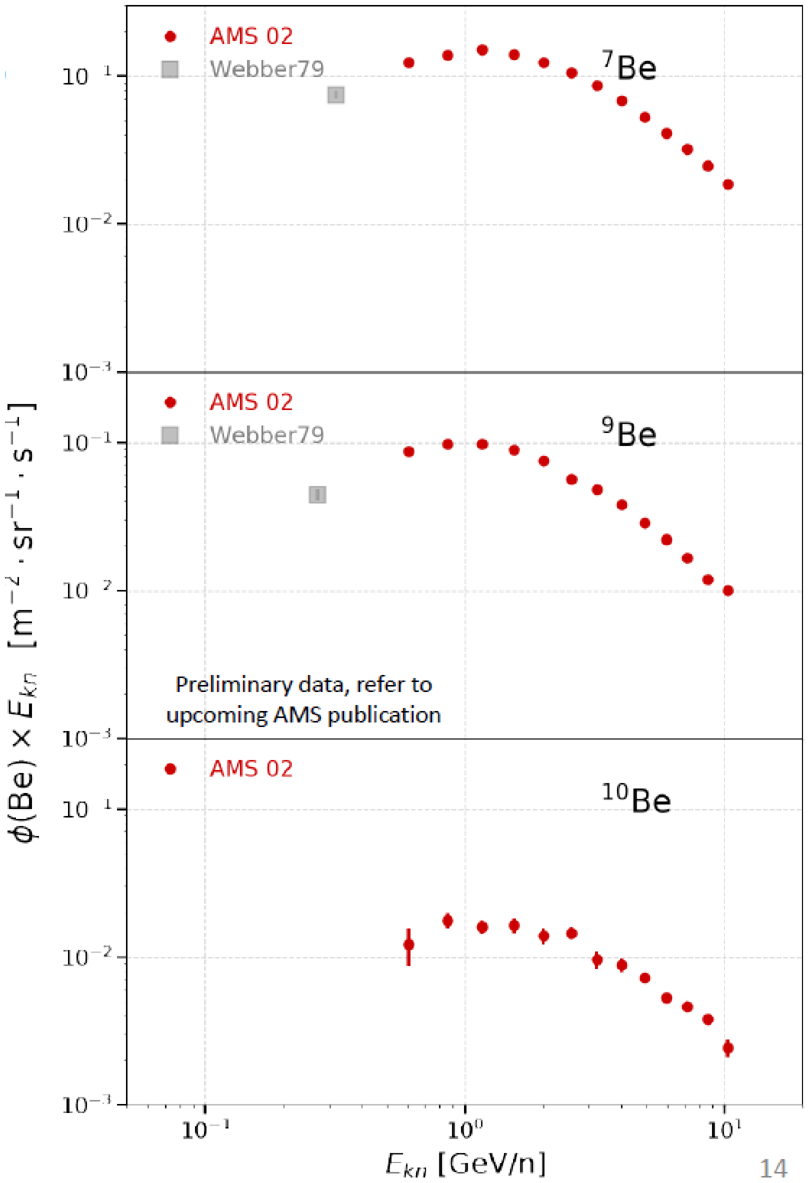
Measurement of Isotopes with AMS 02

Preliminary data, refer to upcoming AMS publication

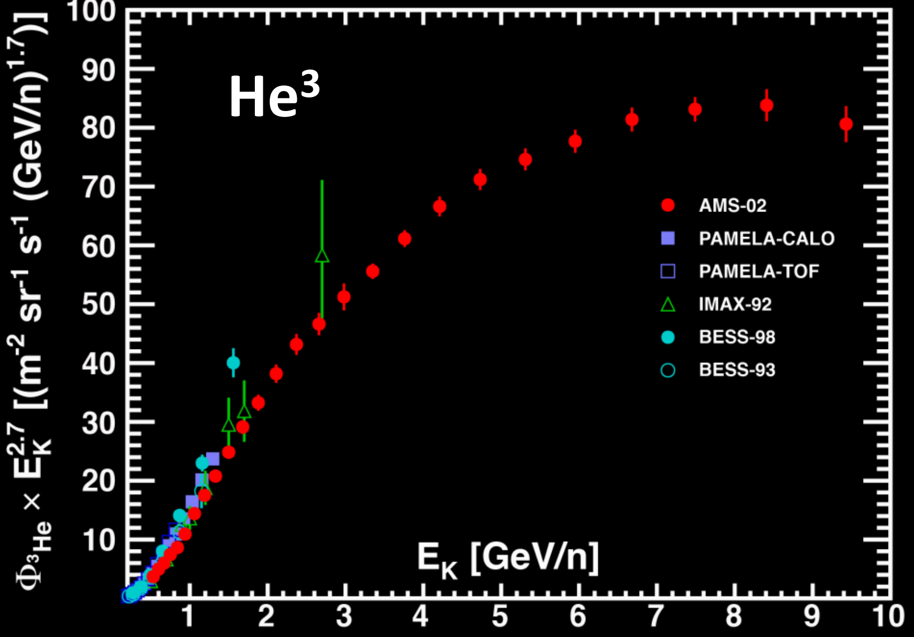
Extend the measurement up to 10 GeV/n

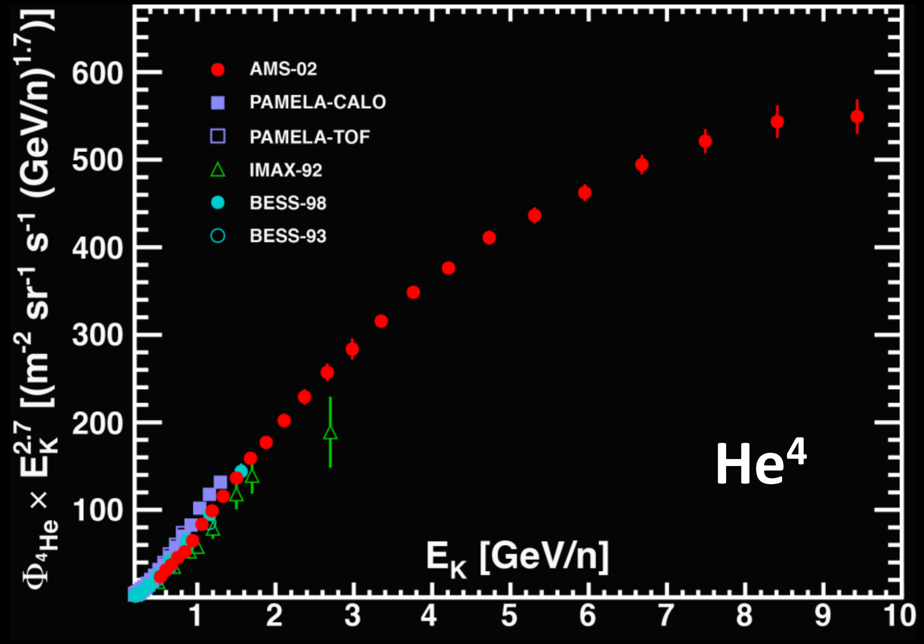


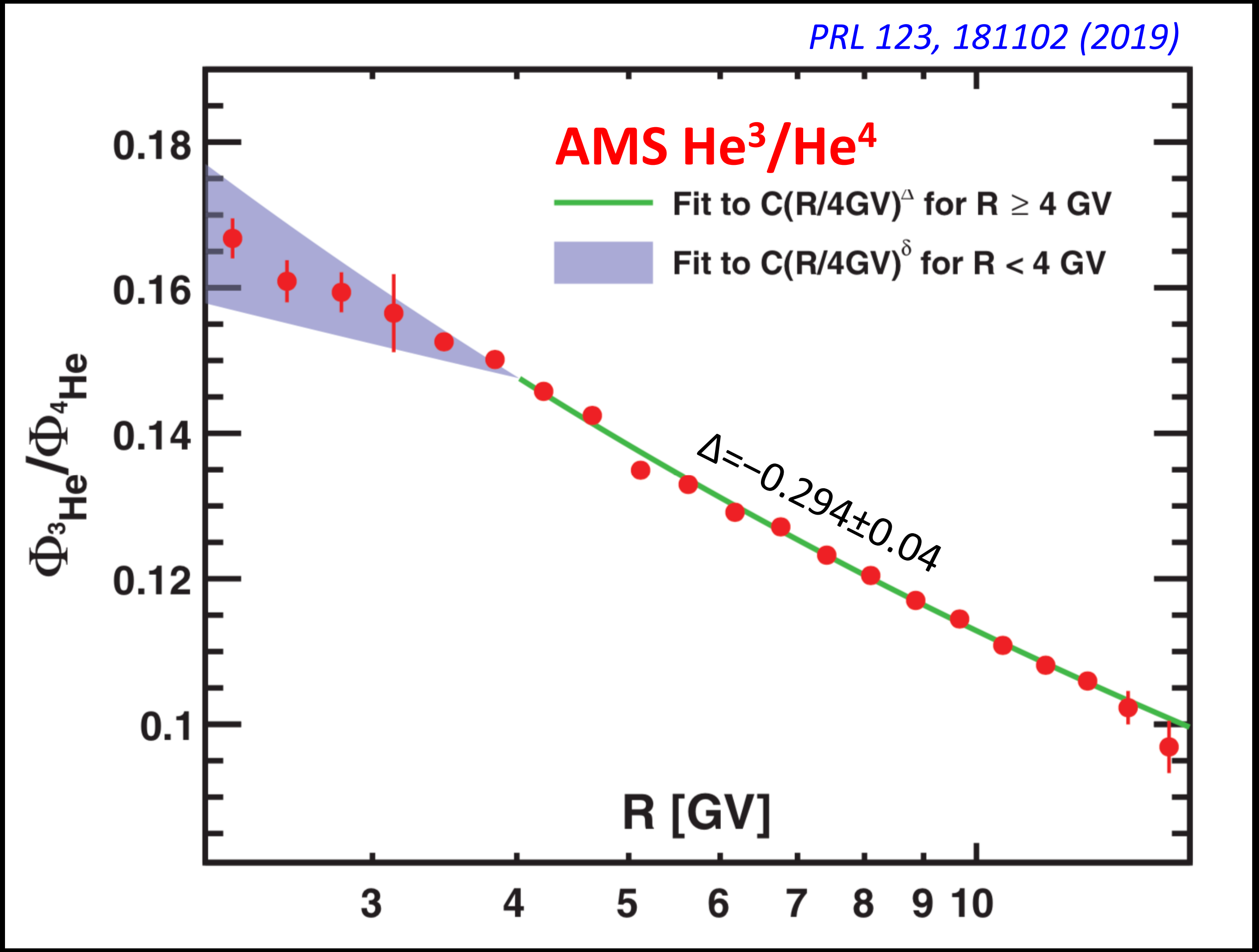




Measurement of Isotopes with AMS 02

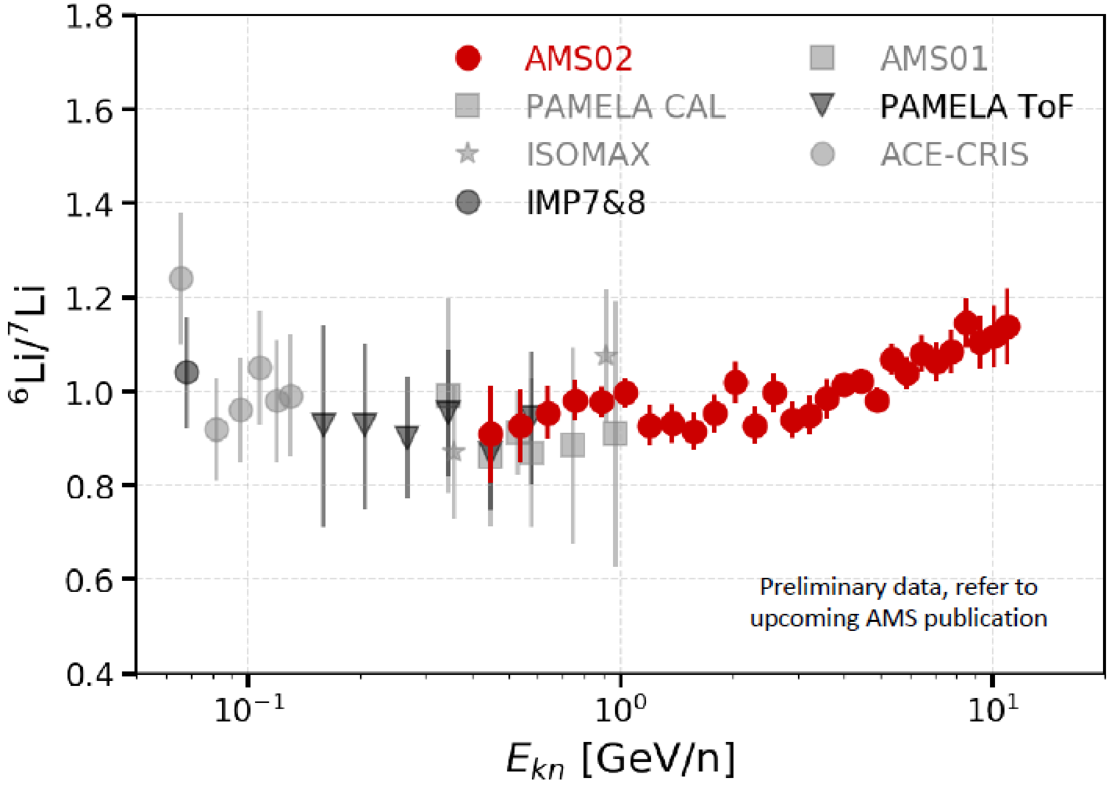


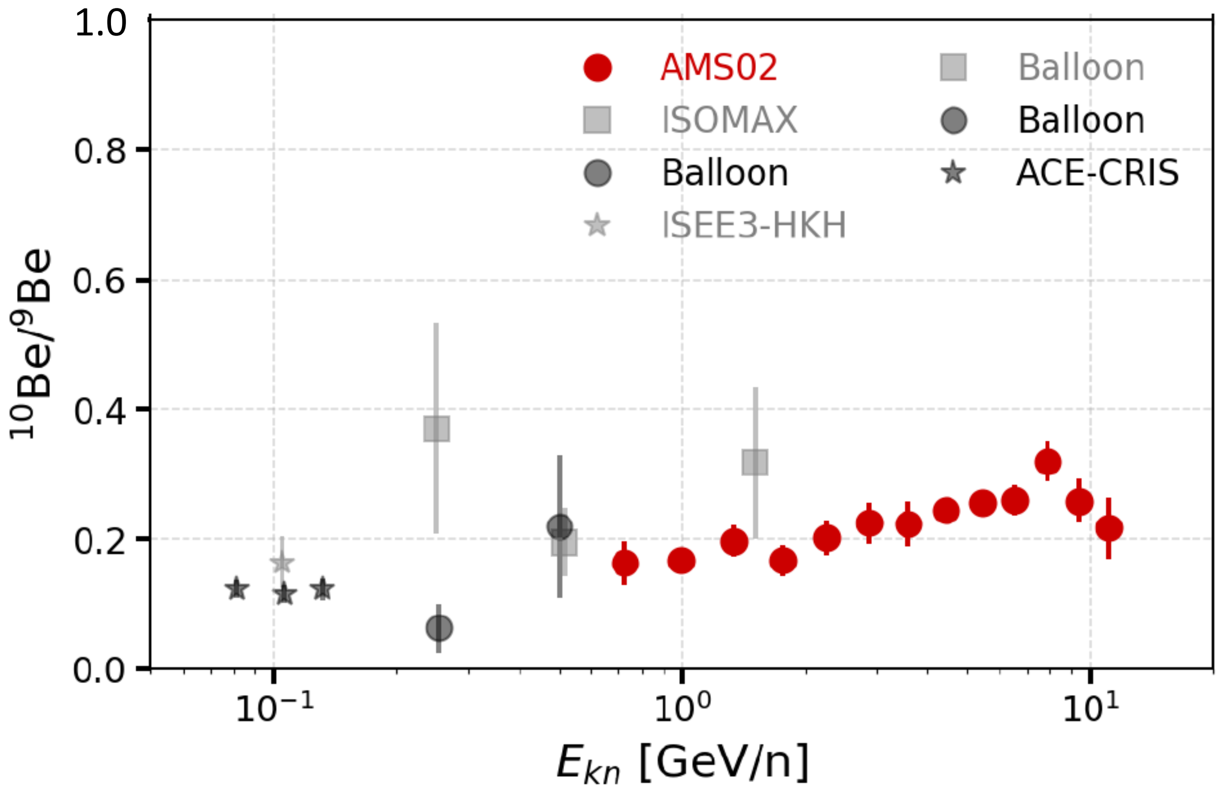




Measurement of $^{6}Li/^{7}Li$ fluxes and $^{10}Be/^{9}Be$ with AMS 02

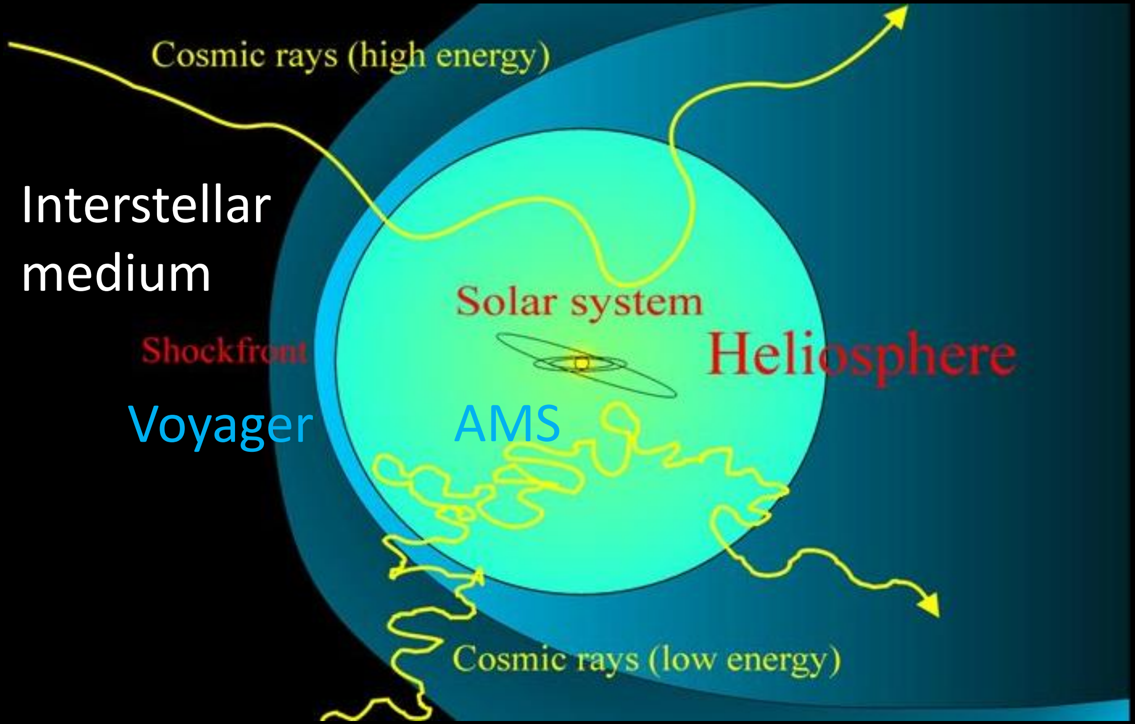
Preliminary data, refer to upcoming AMS publication

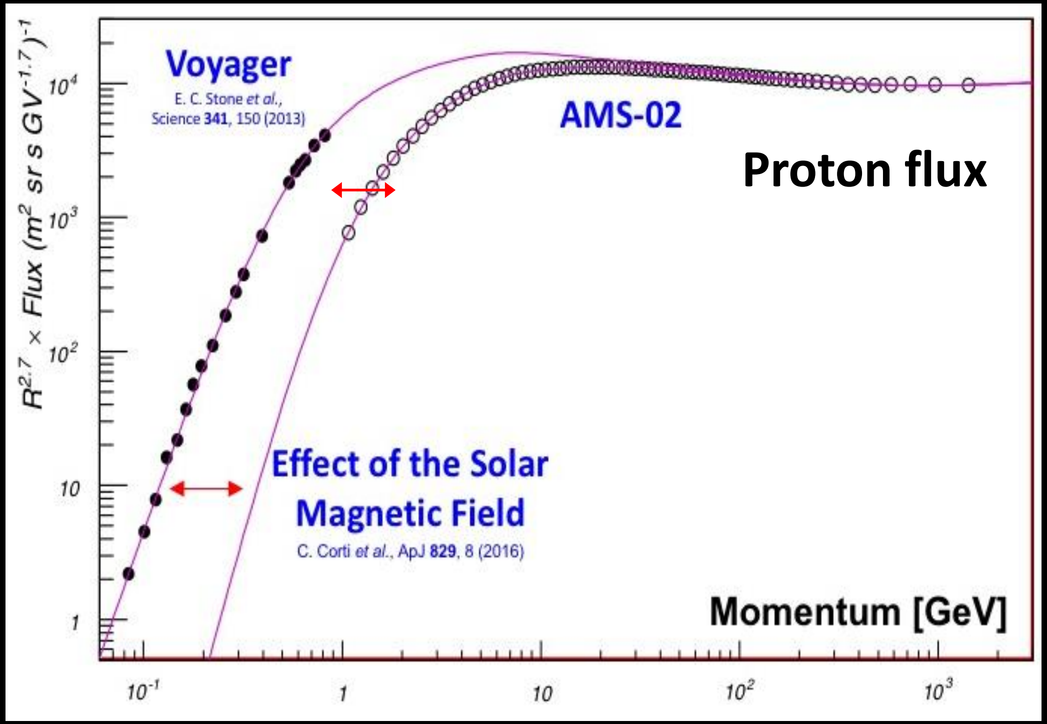




Cosmic ray spectra and Solar Physics

Cosmic rays from the interstellar medium are "screened" by the heliosphere
This is particularly visible at low energies





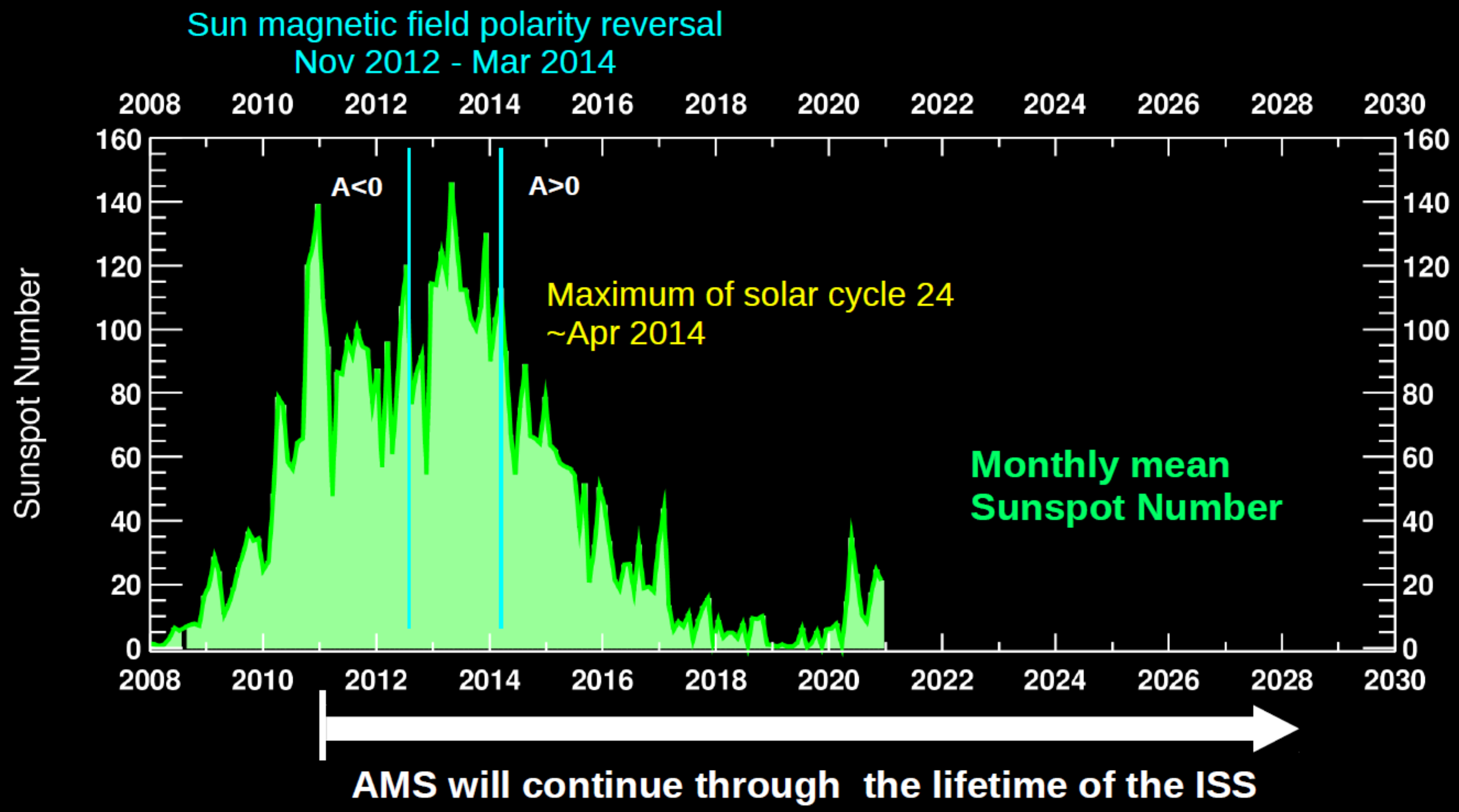
The temporal evolution of the interplanetary space environment causes disturbances in the cosmic-ray fluxes that correlate with solar activity

Measurements of time evolution of cosmic ray fluxes of different particles over an extended period of time is very valuable input

AMS period of observation

Cosmic ray flux variations correlate with solar activity at different time scales

The most significant long-term scale variation is the 11-year solar cycle
during which the number of sunspots changes from minimum to maximum and then back to a minimum

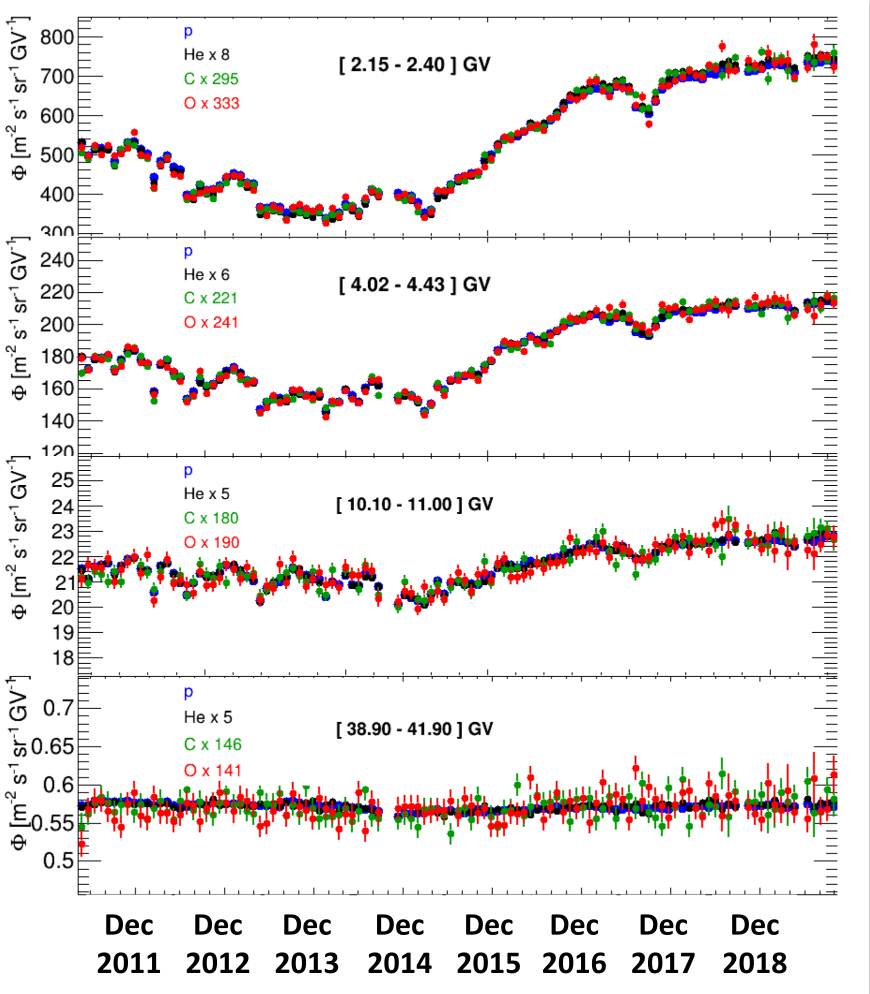


Latest AMS results on the time evolution of cosmic ray fluxes

Previously, AMS has reported the time evolution of the monthly (Bartels rotation) proton, helium, electrons and positrons fluxes measured during the first 7 years of data taking.

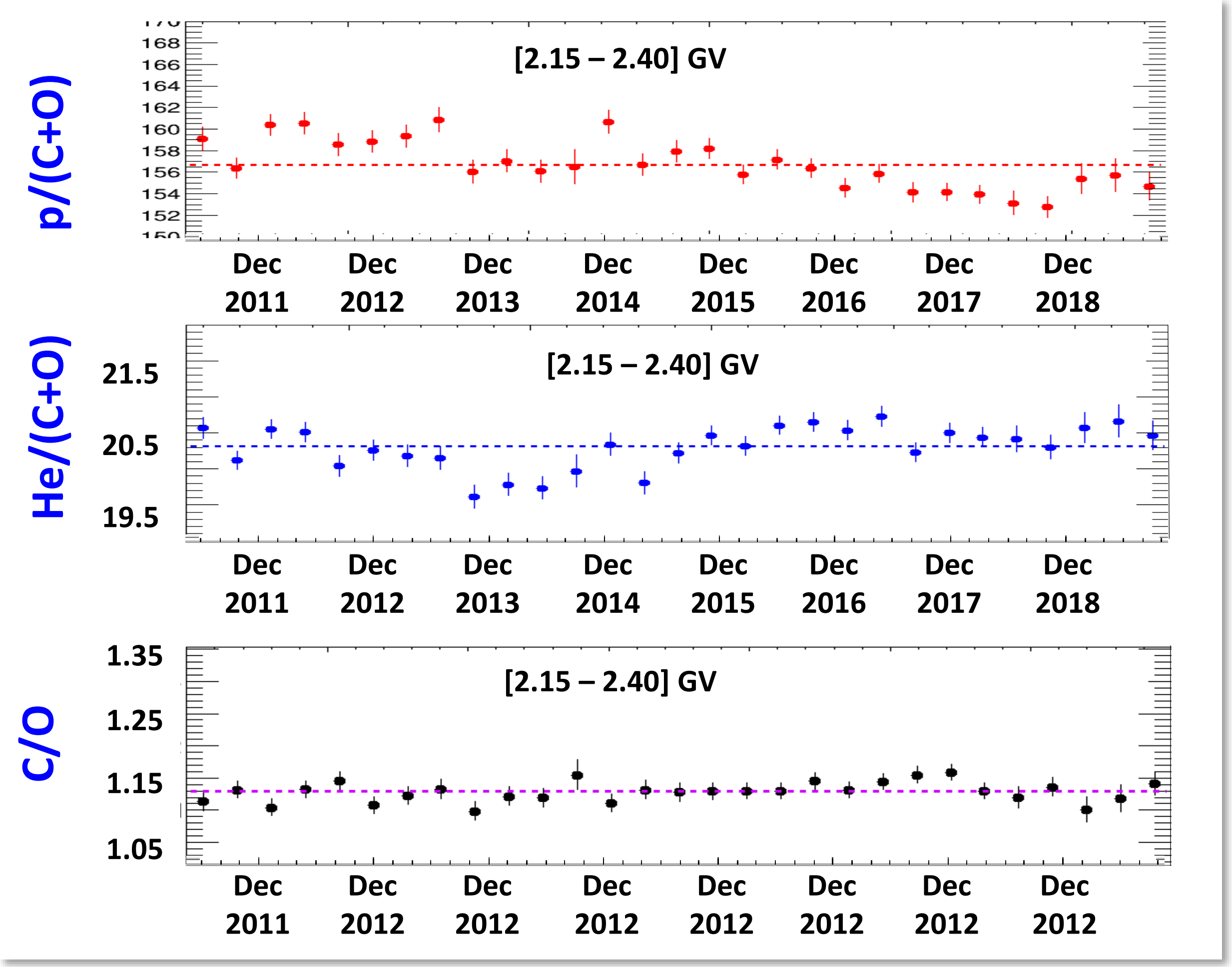
Time evolution of p, He, C and O

Data from May 2011 to Oct. 2019



20th Lomonosov Conference (24 August, Tuesday)

V. Formato (INFN, Rome Tor Vergata) *Observation of Fine Time Structures in the primary cosmic rays light nuclei fluxes*



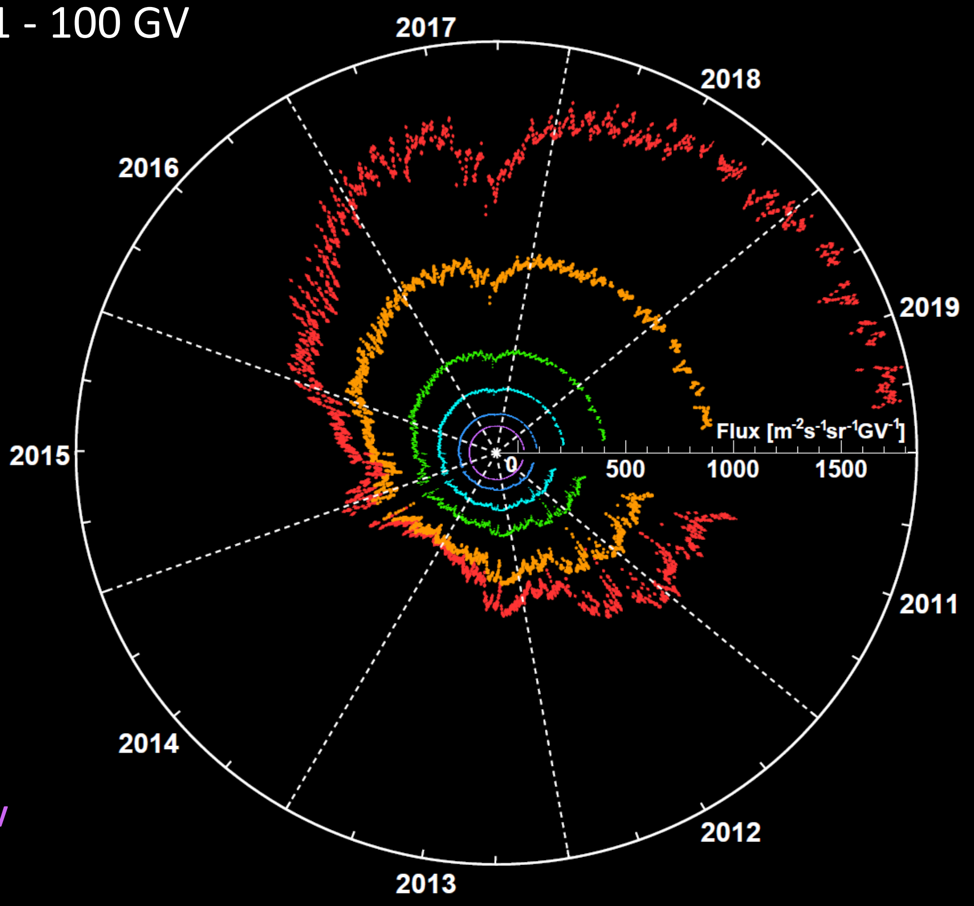
AMS Daily Proton and Helium Fluxes

Preliminary data, refer to upcoming AMS publication

Data collected from May 20, 2011 to October 29, 2019 (2824 days or 114 Bartels rotations)

5.5 billion protons
Rigidity: 1 - 100 GV

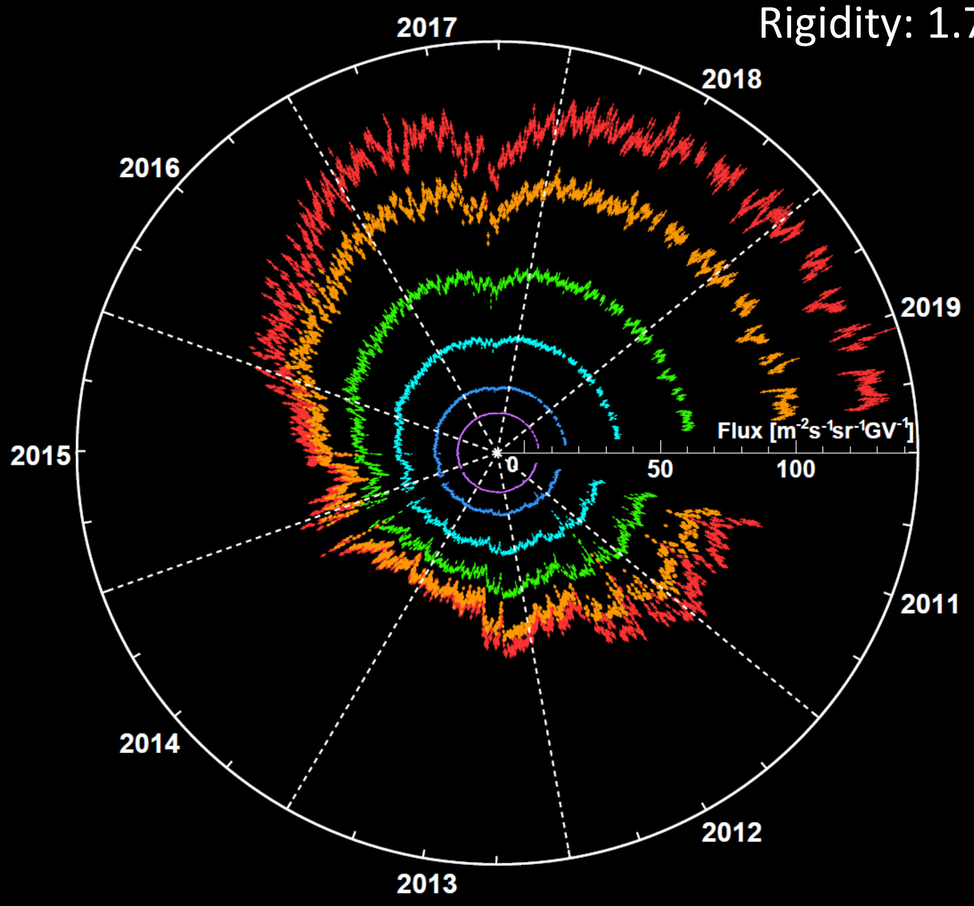
Daily proton flux



[1.00-1.16] GV
[1.92-2.15] GV
[2.97-3.29] GV
[4.02-4.43] GV
[5.90-6.47] GV
[9.26-10.10] GV

Daily helium flux

0.76 billion helium
Rigidity: 1.71 - 100 GV



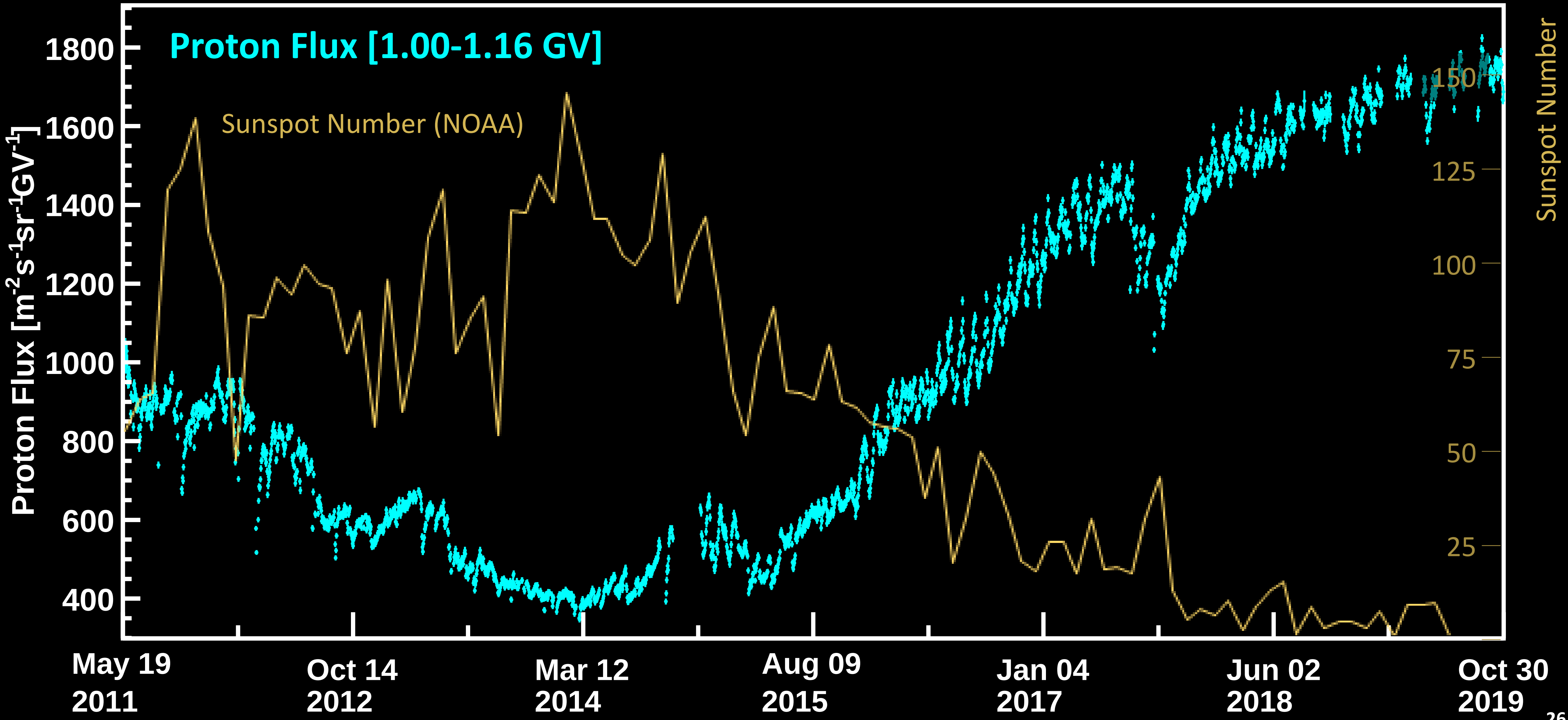
[1.71-1.92] GV
[2.15-2.40] GV
[2.97-3.29] GV
[4.02-4.43] GV
[5.90-6.47] GV
[9.26-10.10] GV

Both fluxes exhibit variations on different time scales, from days to years
The relative magnitude of these variations decreases with increasing rigidity.

AMS Daily Proton Flux

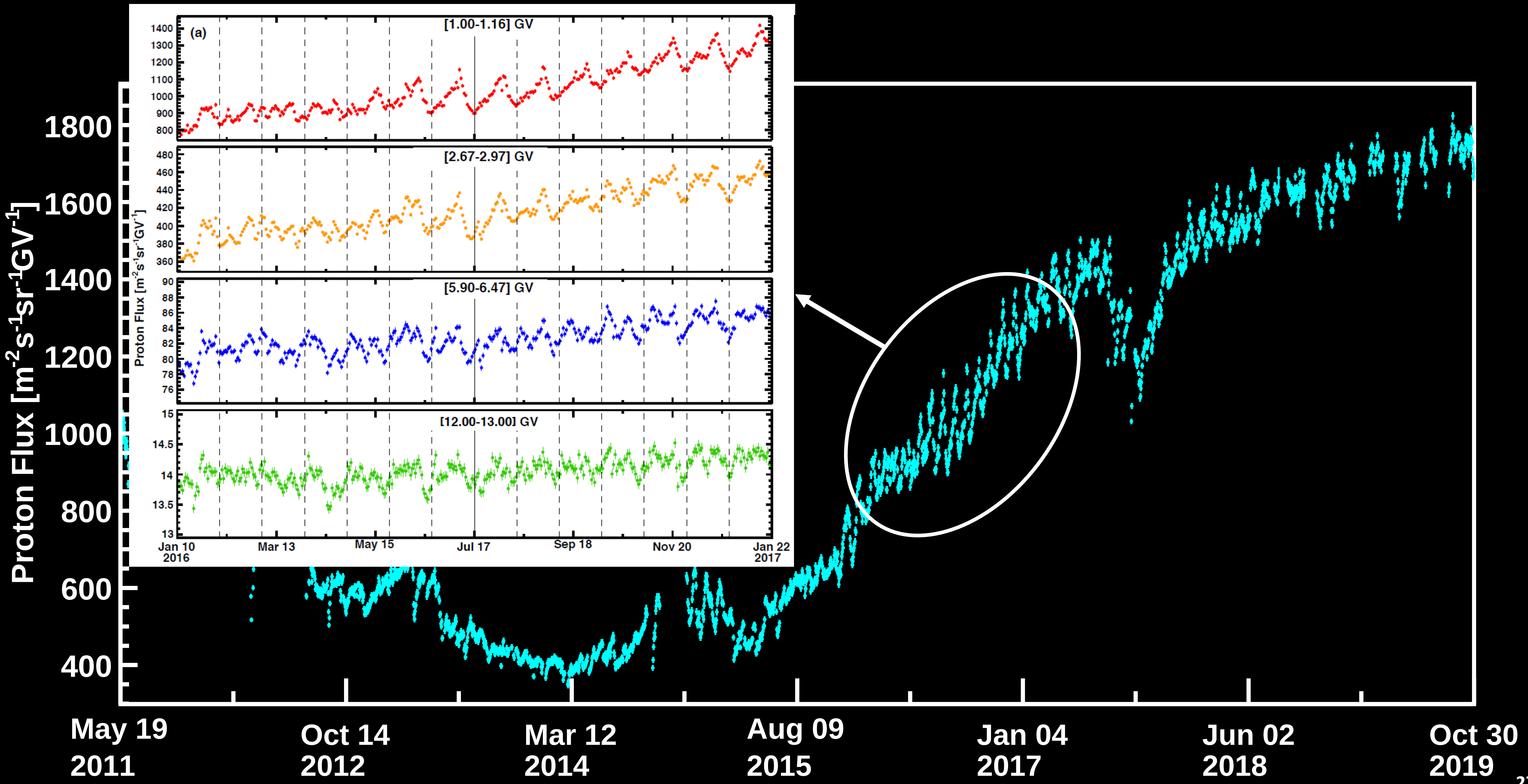
Preliminary data, refer to upcoming AMS publication

Long-term variation related to the 11-year solar cycle



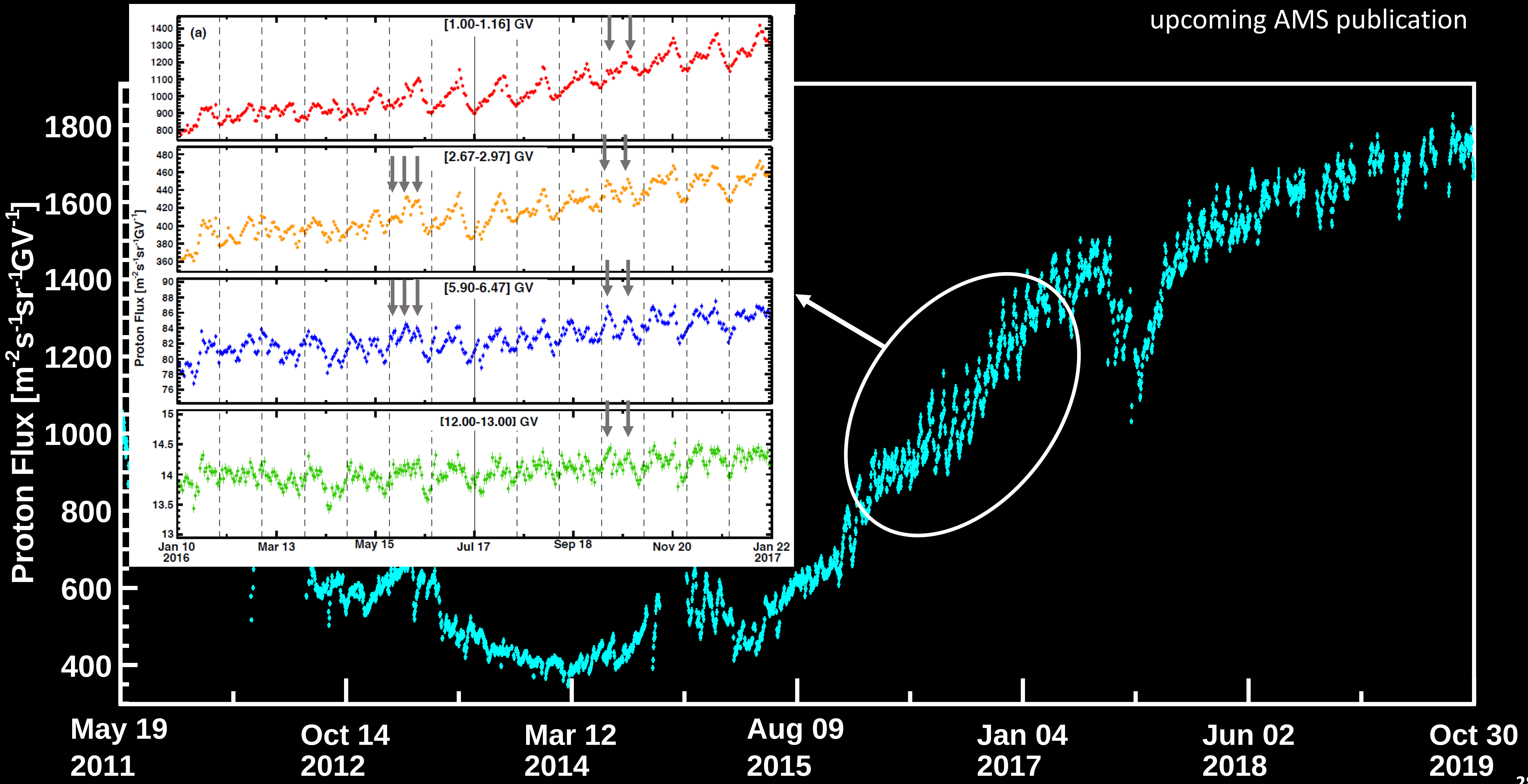
Periodicities in the Daily Proton Fluxes

Preliminary data, refer to upcoming AMS publication



Periodicities in the Daily Proton Fluxes

Preliminary data, refer to upcoming AMS publication

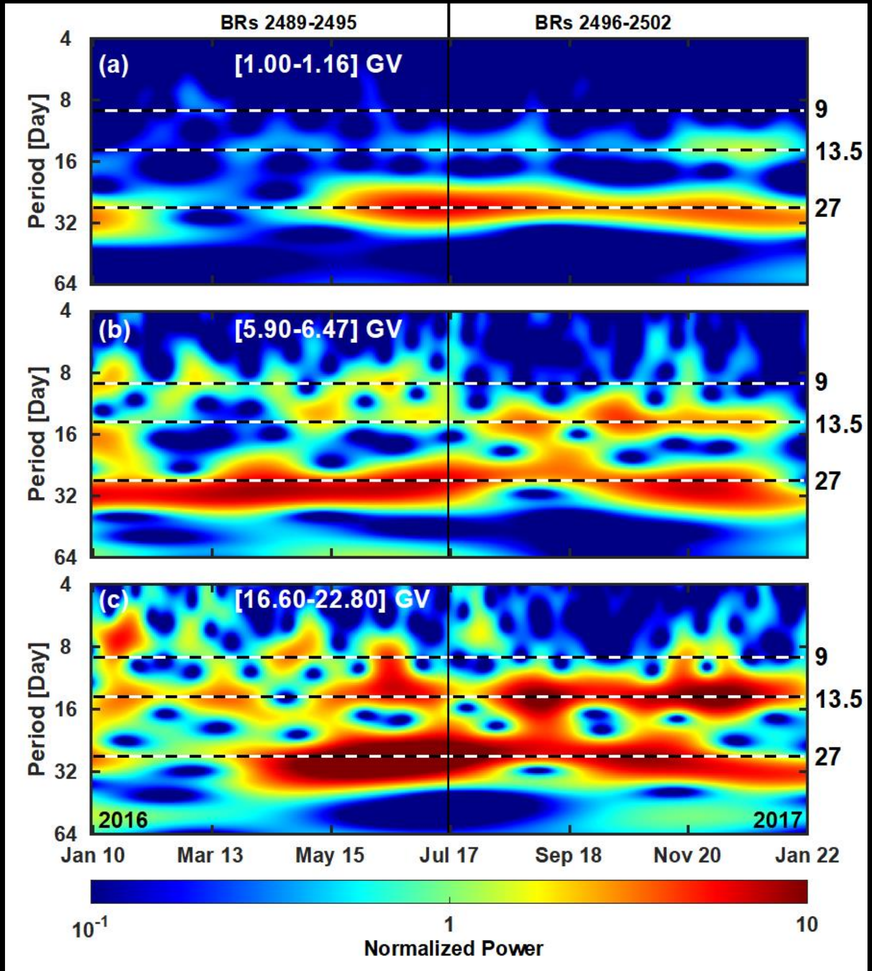


Periodicities in the Daily Proton Fluxes

Preliminary data, refer to upcoming AMS publication

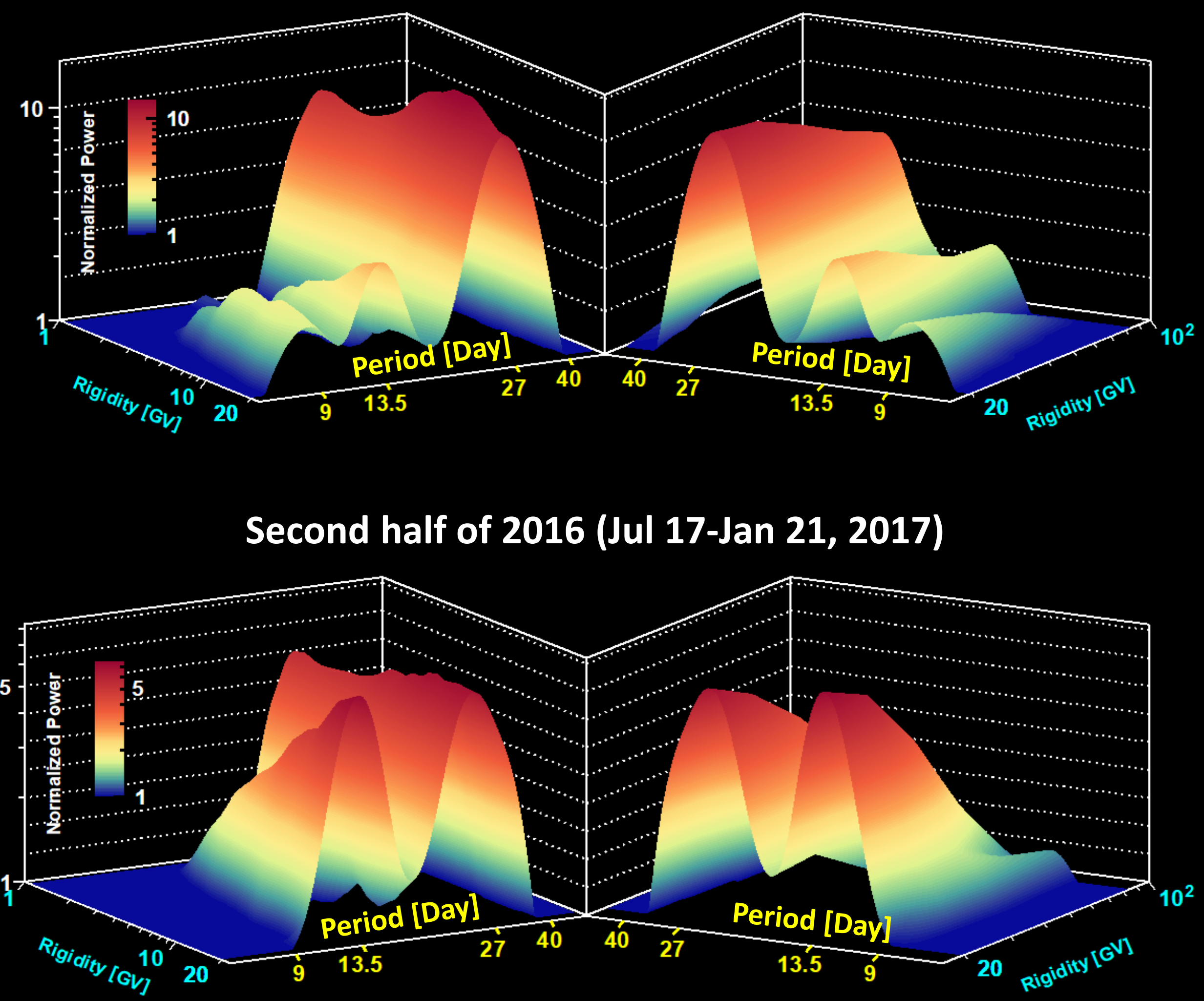
Wavelet time-frequency analysis to identify when periodic structures are significant

2016



First half of 2016 (Jan 10-Jul 16)

Second half of 2016 (Jul 17-Jan 21, 2017)



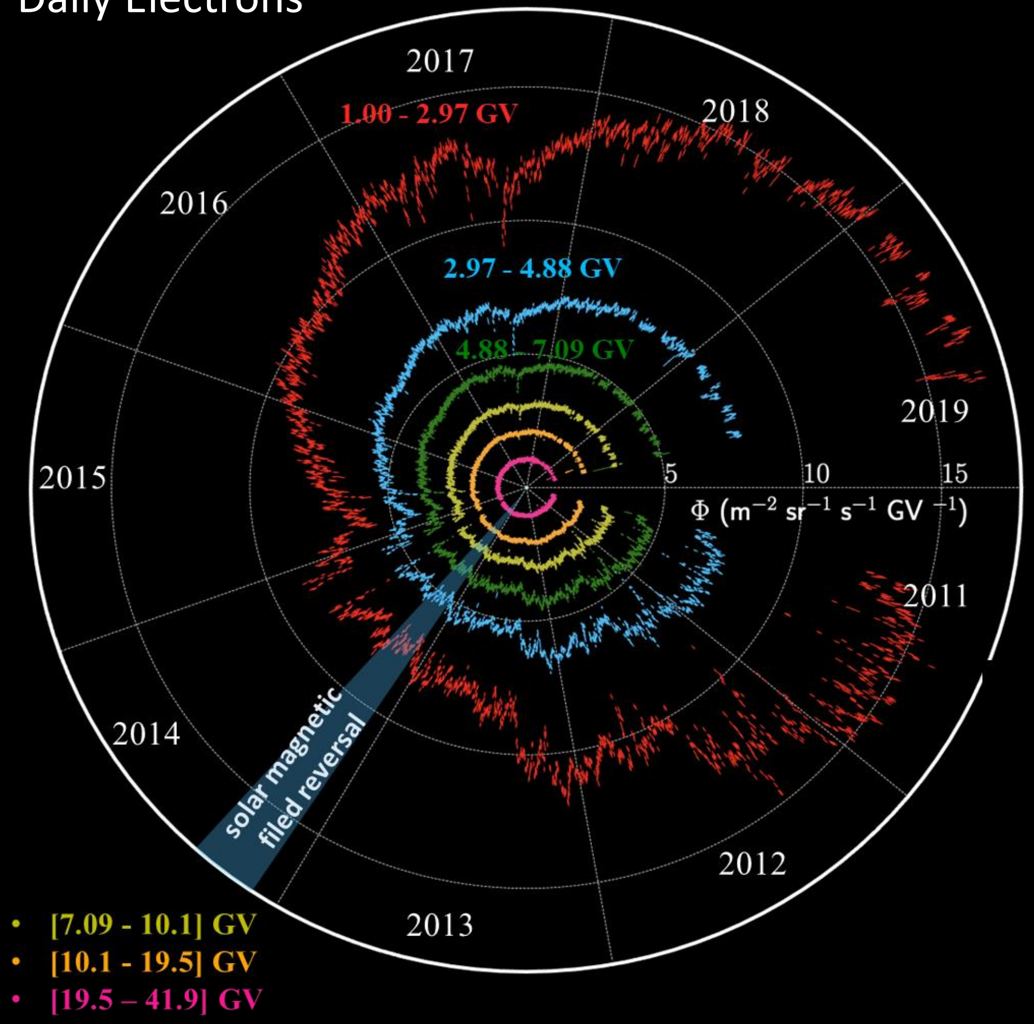
Power is normalized by the variance of flux in the corresponding time interval to show the strength of the periodicities.

AMS Daily Electron and Positron Fluxes

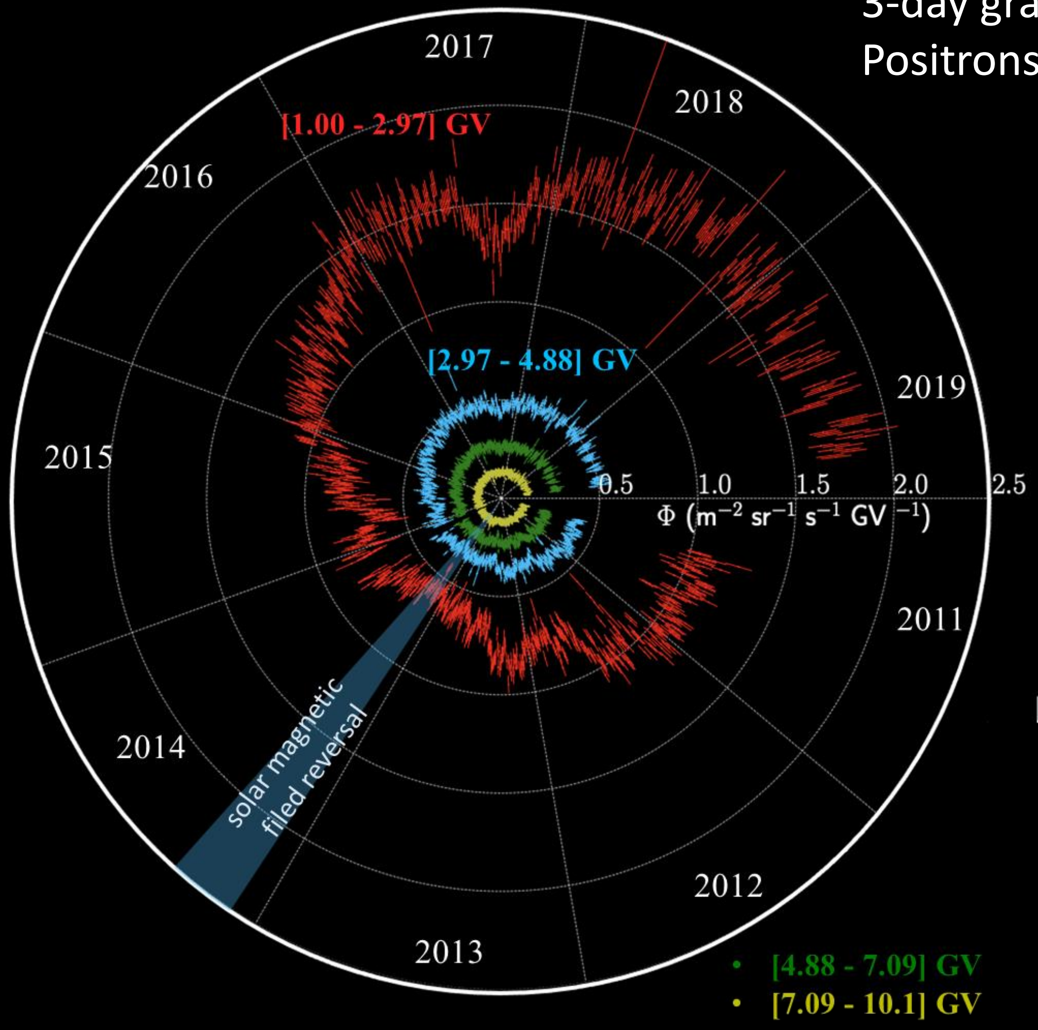
Preliminary data, refer to upcoming AMS publication

Simultaneous measurements of particle and anti-particle over a complete solar activity cycle represent a unique input to study charge-sign dependent heliosphere effects

Daily Electrons



3-day granularity Positrons



Conclusions

In ten years on the ISS, AMS has recorded more than 180 billion cosmic rays.

AMS is providing simultaneous measurements of particles/anti-particles, chemical composition up to Fe in an extended energy range and over a solar cycle

The new features measured by AMS on high and low energy cosmic rays are new phenomena.

AMS will continue to collect and analyze data for the lifetime of the Space Station