Unique Properties of Primary Cosmic Rays: Results from the Alpha Magnetic Spectrometer

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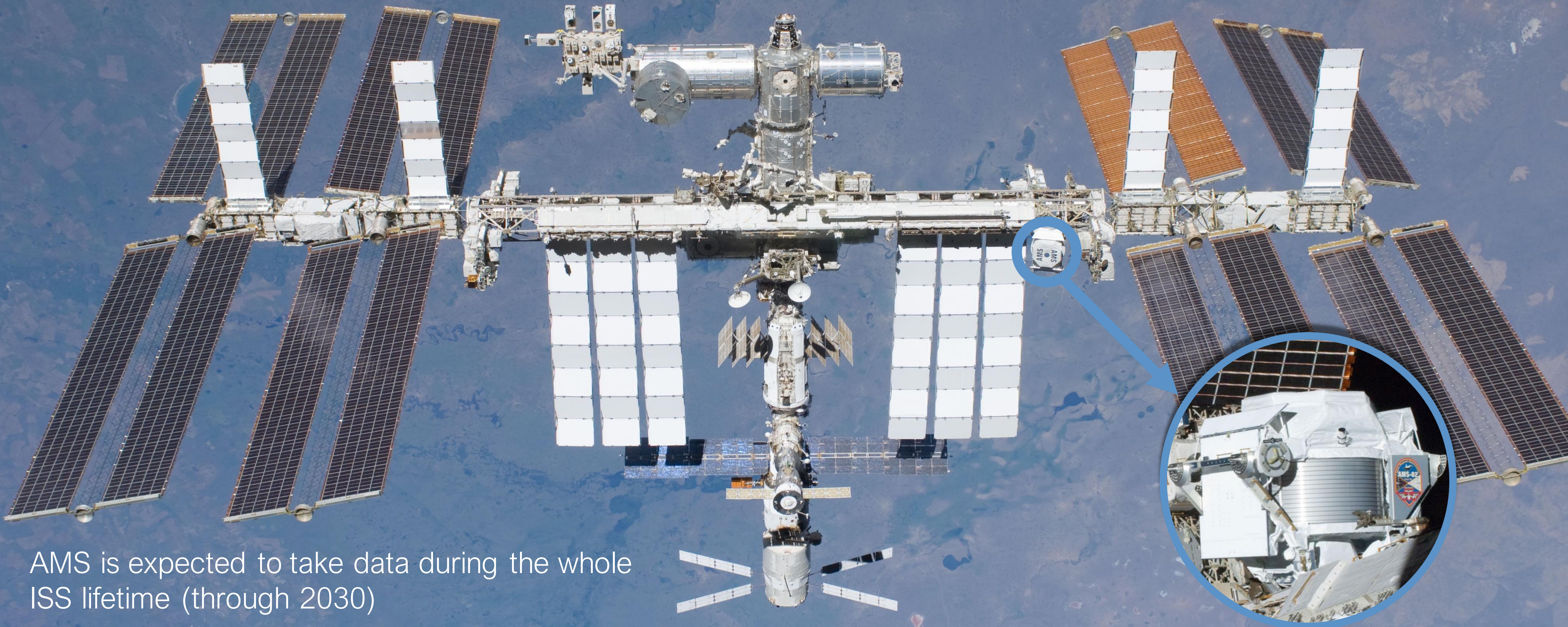
AMS-02 IN ORBIT

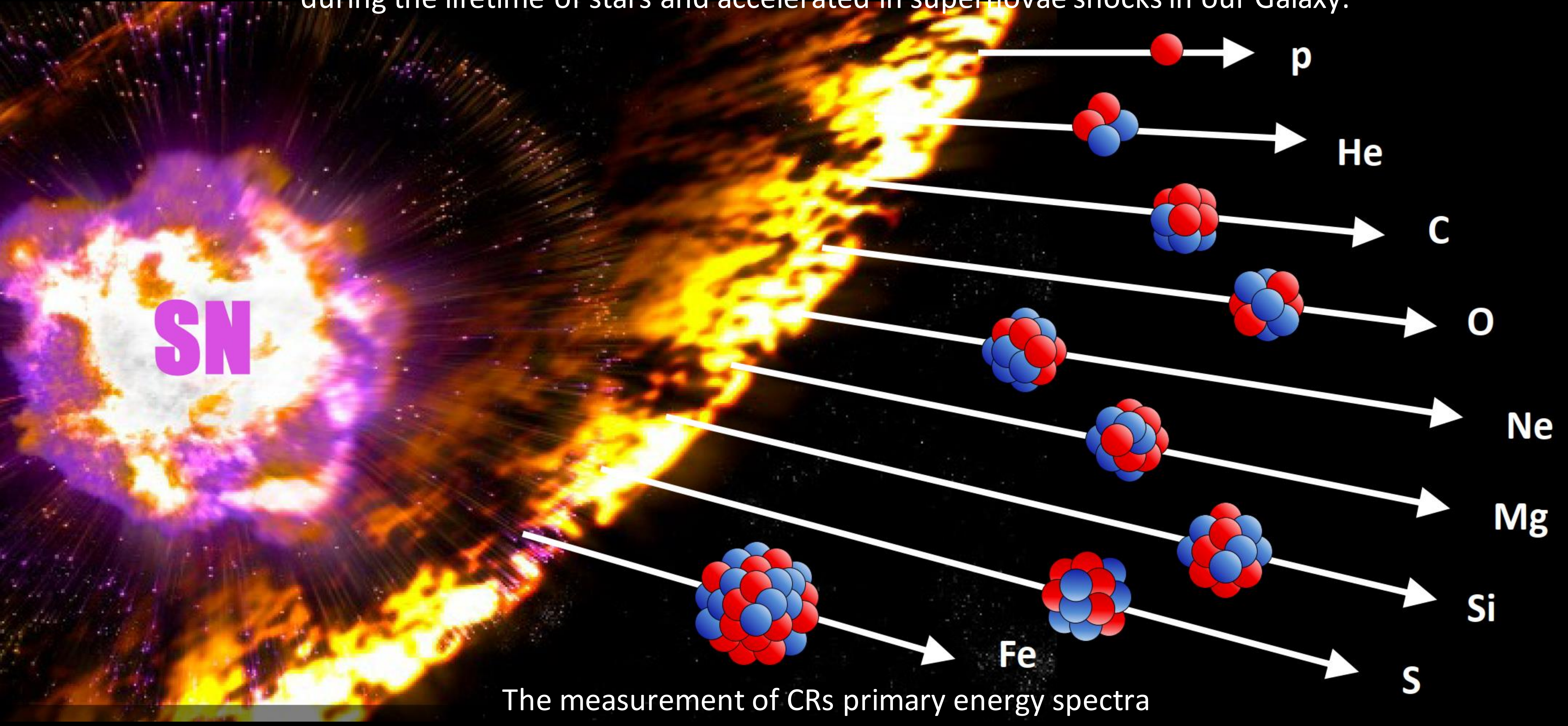
AMS-02 is a large-acceptance high-energy **magnetic spectrometer** capable of measure particles accurately in the **GeV-TeV** energy range. Since **2011** May 19th AMS-02 has been operating on the International Space Station (ISS). AMS recorded **>220 billion CR triggers** in ~12 years of operation.



AMS is expected to take data during the whole ISS lifetime (through 2030)

PRIMARY COSMIC RAYS

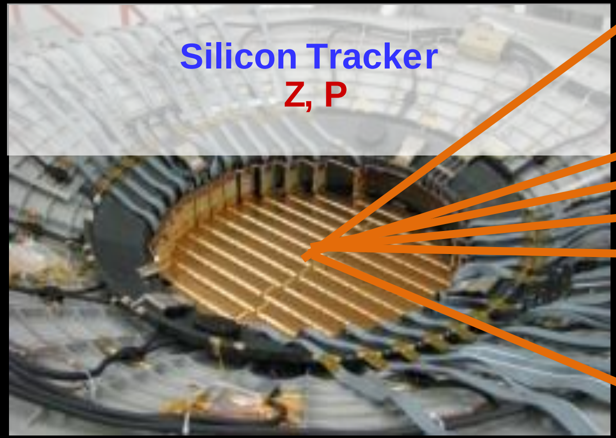
Primary CRs (p, He, C, O, Ne, Mg, Si, ..., Fe) are thought to be mostly produced during the lifetime of stars and accelerated in supernovae shocks in our Galaxy.

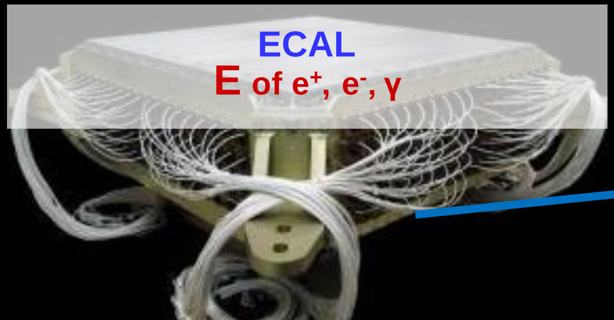


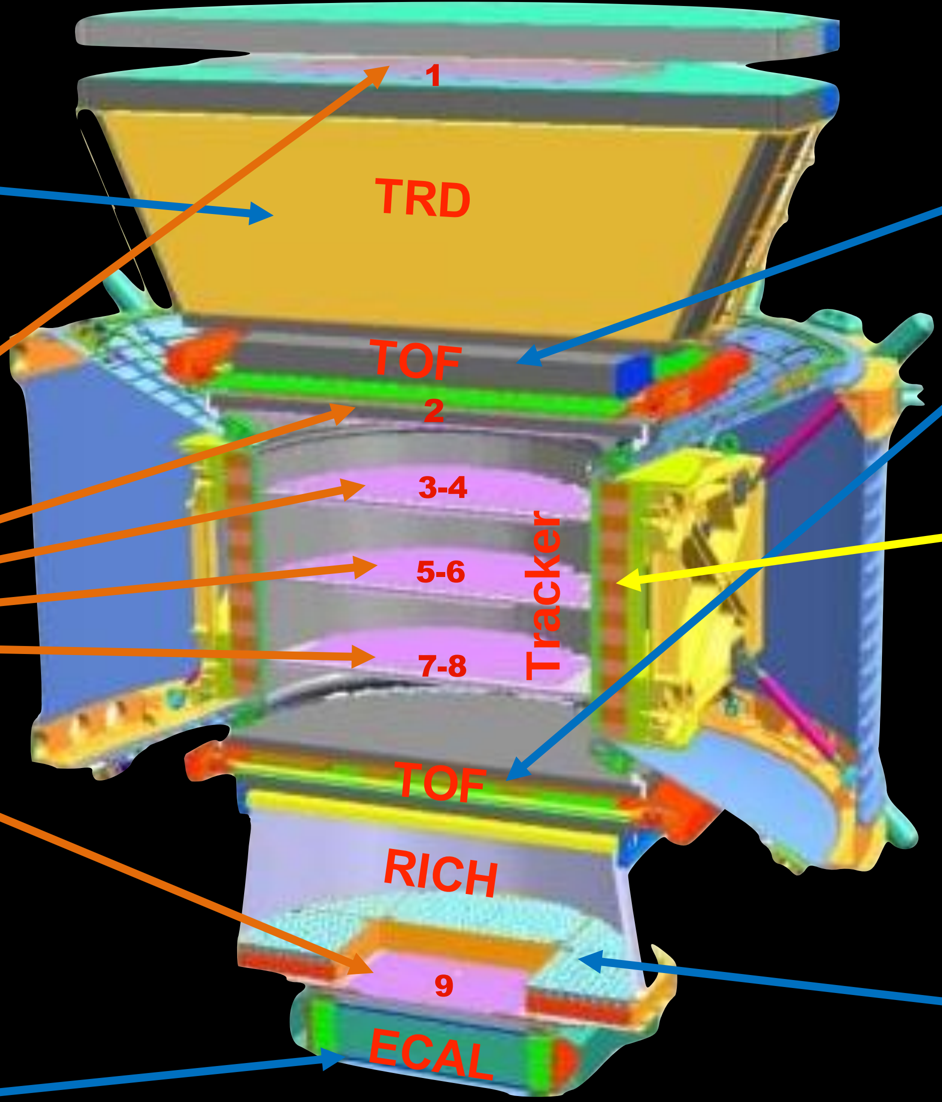
The measurement of CRs primary energy spectra carries information about sources, acceleration and propagation processes.

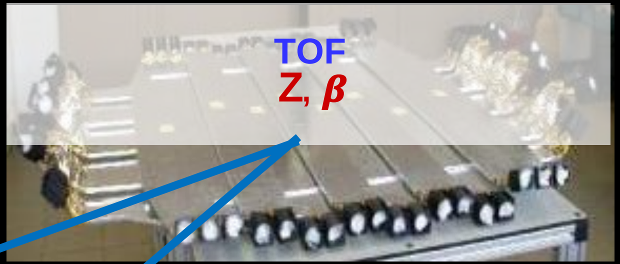
AMS-02 *A TeV multi-purpose spectrometer*

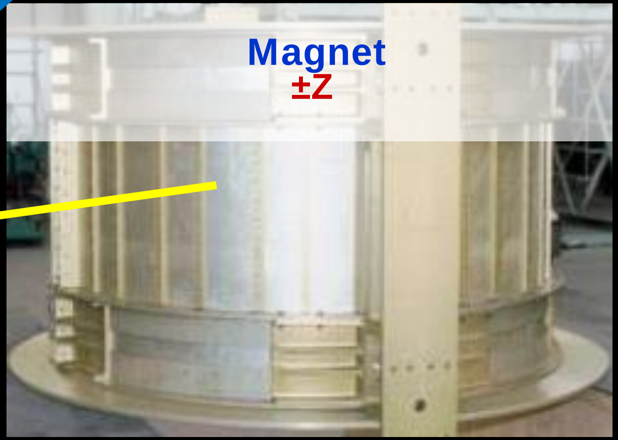
AMS-2 separates hadrons from leptons, matter from anti-matter, chemical and isotopic composition from fraction of GeV to multi-TeV.

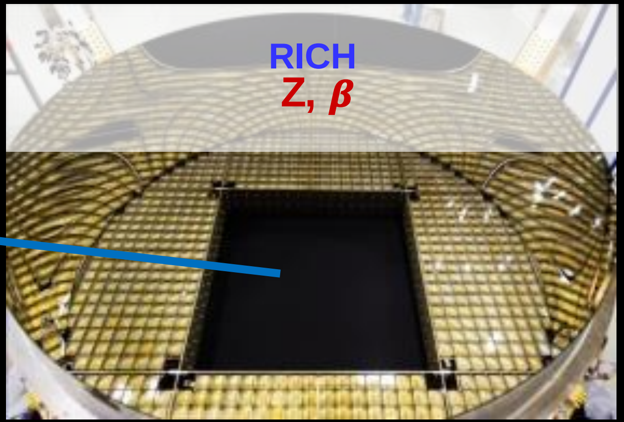






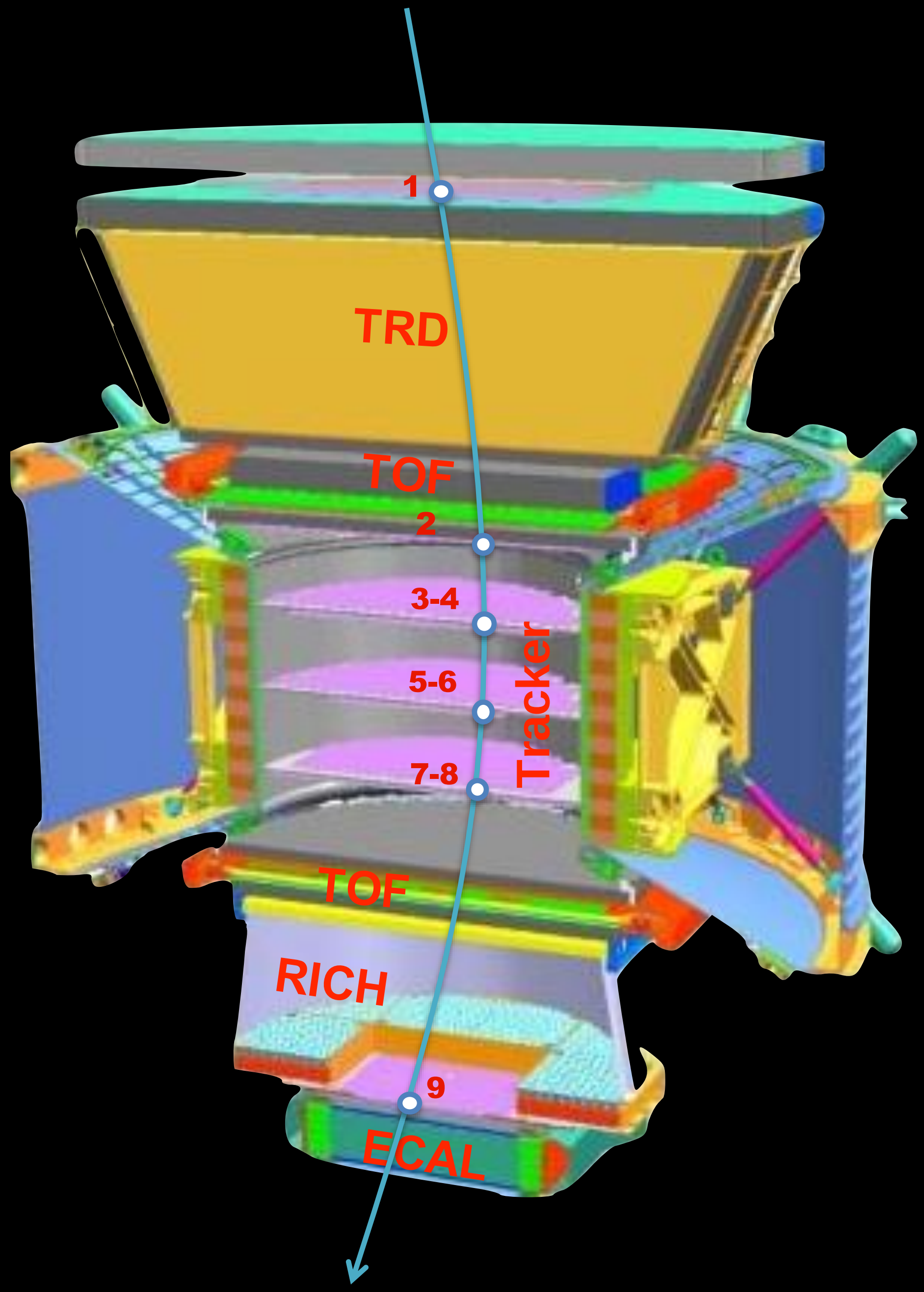






Multiple and/or Independent Measurement of Charge (Z), Energy (β, p, E) and Charge Sign (±).

How AMS measures nuclei



Particle rigidity ($R = p/Z$):

Obtained by measuring trajectory bend in the tracker

	Coordinate resolution	MDR
Z=1	10 µm	2 TV
$2 \leq Z \leq 8$	5-7 µm	3.2-3.7 TV
$9 \leq Z \leq 26$	6-8 µm	3-3.5 TV

G. Ambrosi et al., NIM A 869(2017) 29–37.

Particle ID ($R = p/Z$):

Performed using consistency of charge measured in L1, UTOF, Tracker L2-L8, LTOF and L9

	Tracker L2-L8 Charge Resolution ΔZ/Z
Z=1	4.8%
Z=2	3.4%
$3 \leq Z < 14$	1-2.5%
$Z \geq 14$	≈1%

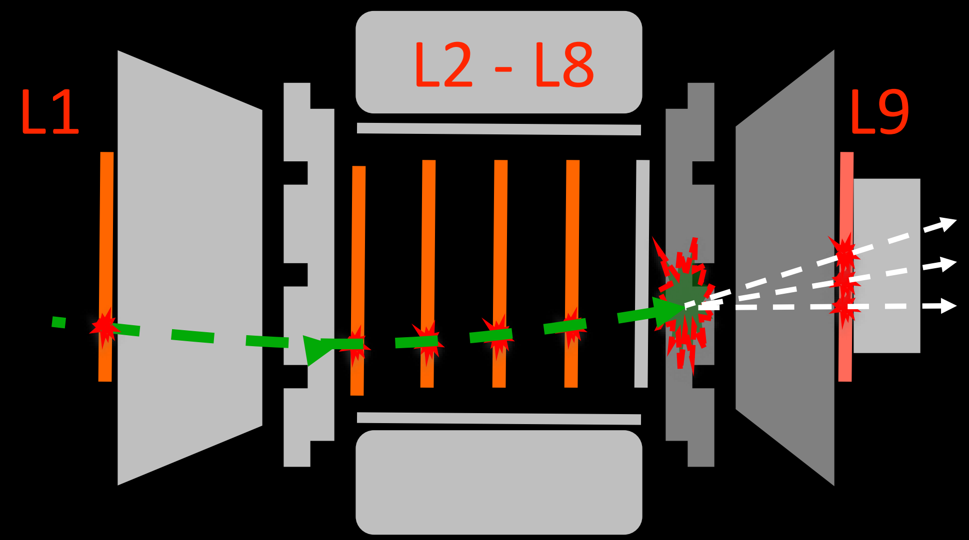
Y. Jia et al., NIM A 972(2020) 164169.

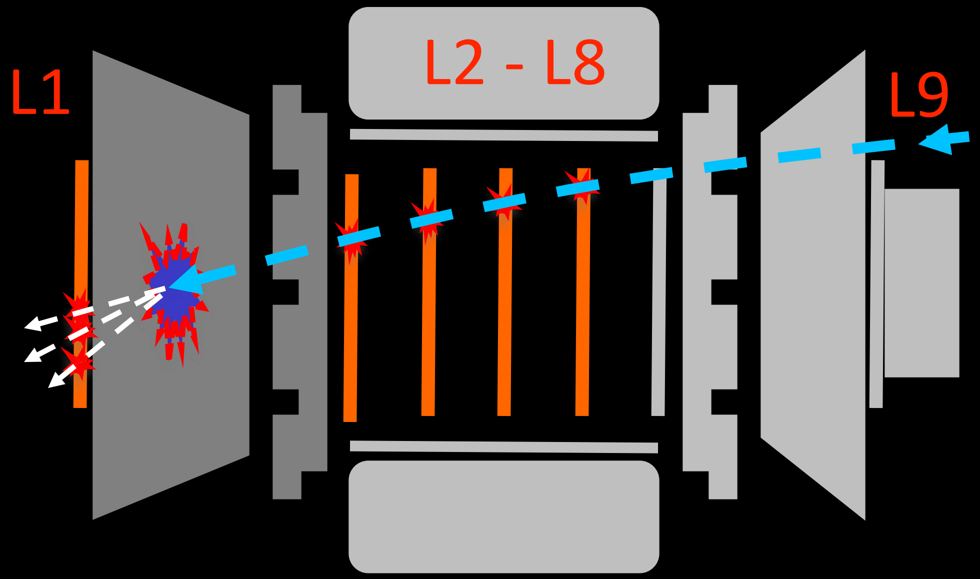
Nuclear Cross Sections with AMS

The absolute value of the cosmic ray fluxes is controlled by the direct measurement of nuclear inelastic cross-section with cosmic rays with AMS material (*C*, *Al*).

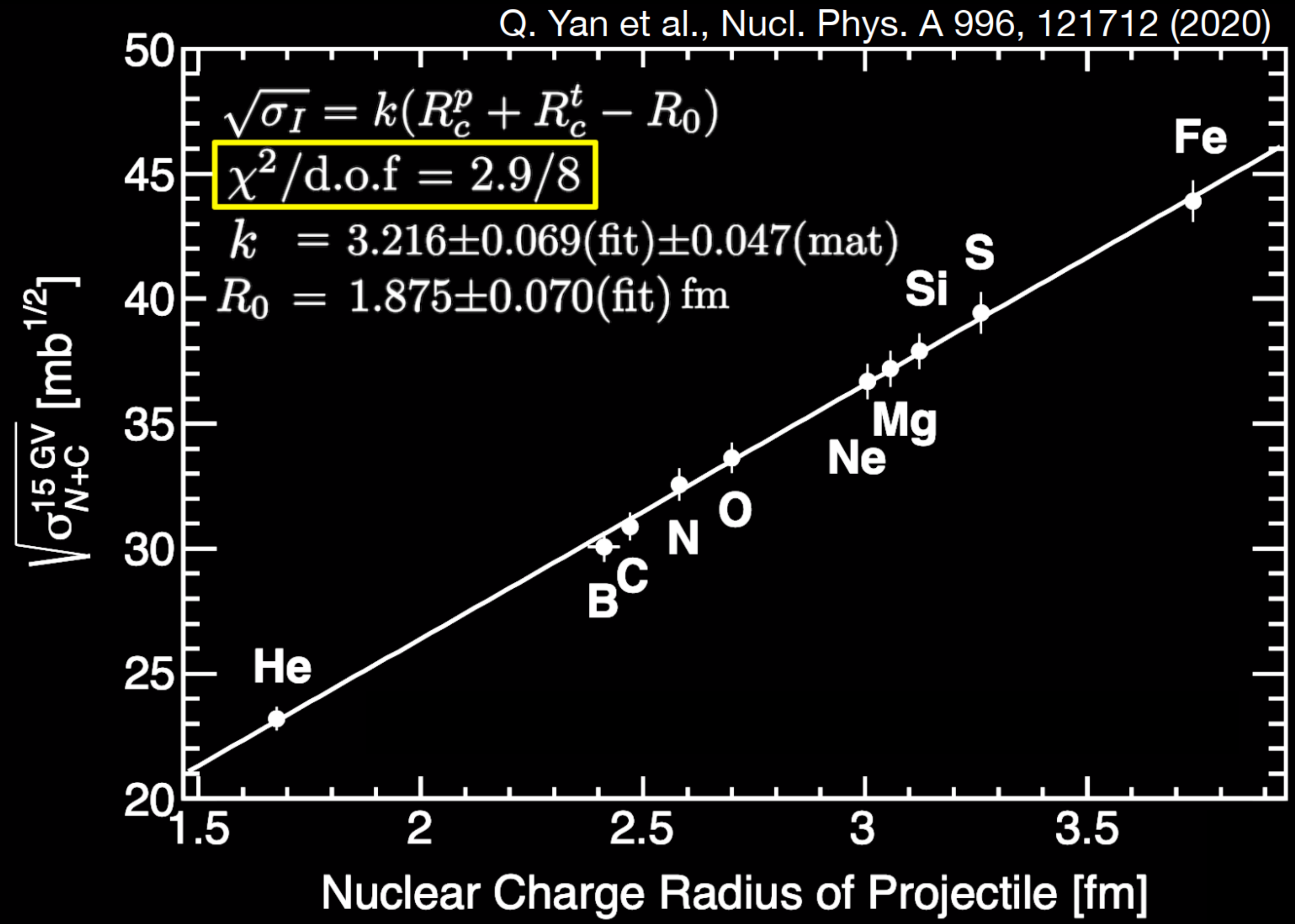
The inelastic cross section is measured by determining the L1-L2 and L8-L9 nuclei survival probabilities.

Measurements are verified using cosmic rays that can enter AMS from both left to right and right to left during the times in which AMS flies "horizontally".



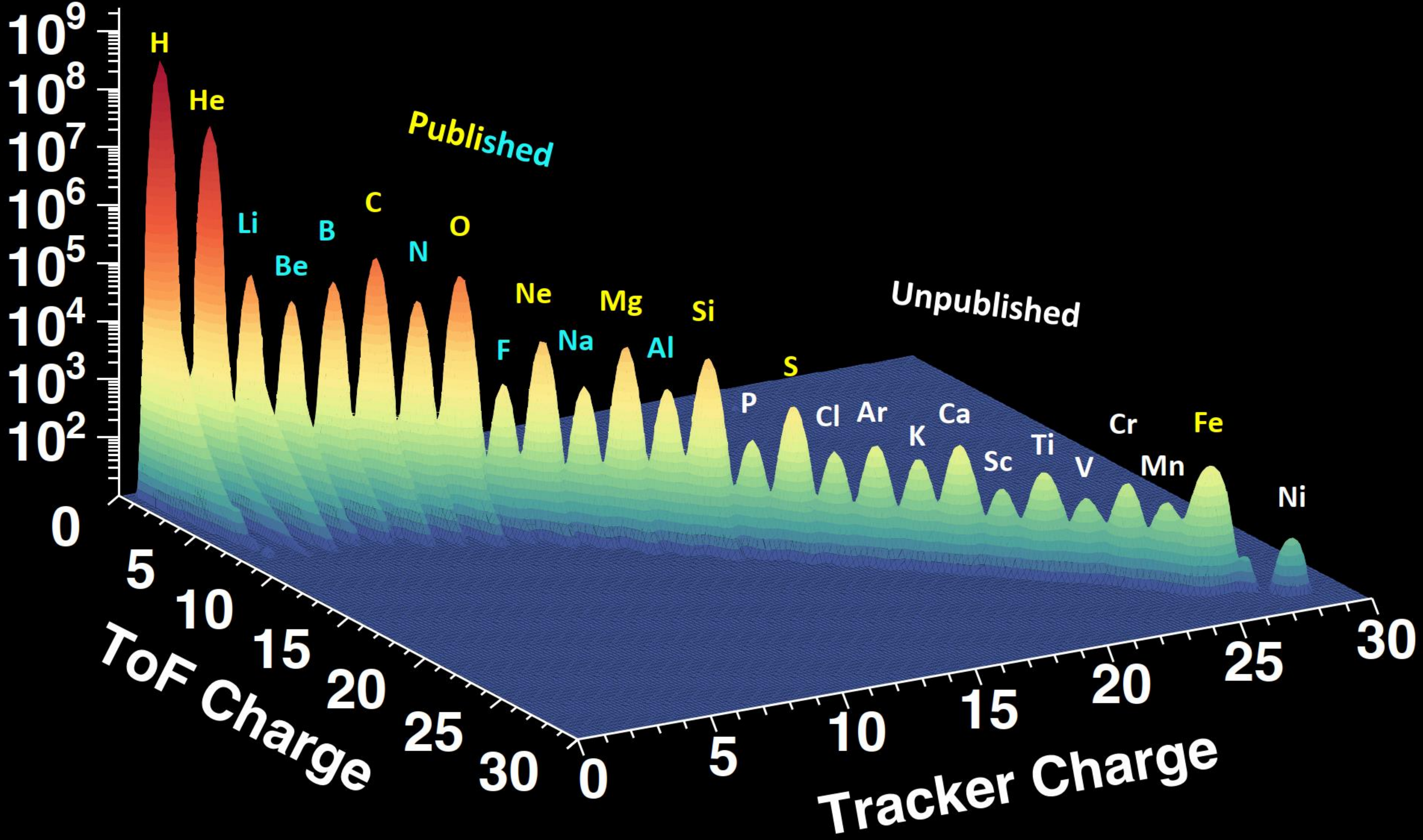


Nuclear Cross Sections with AMS

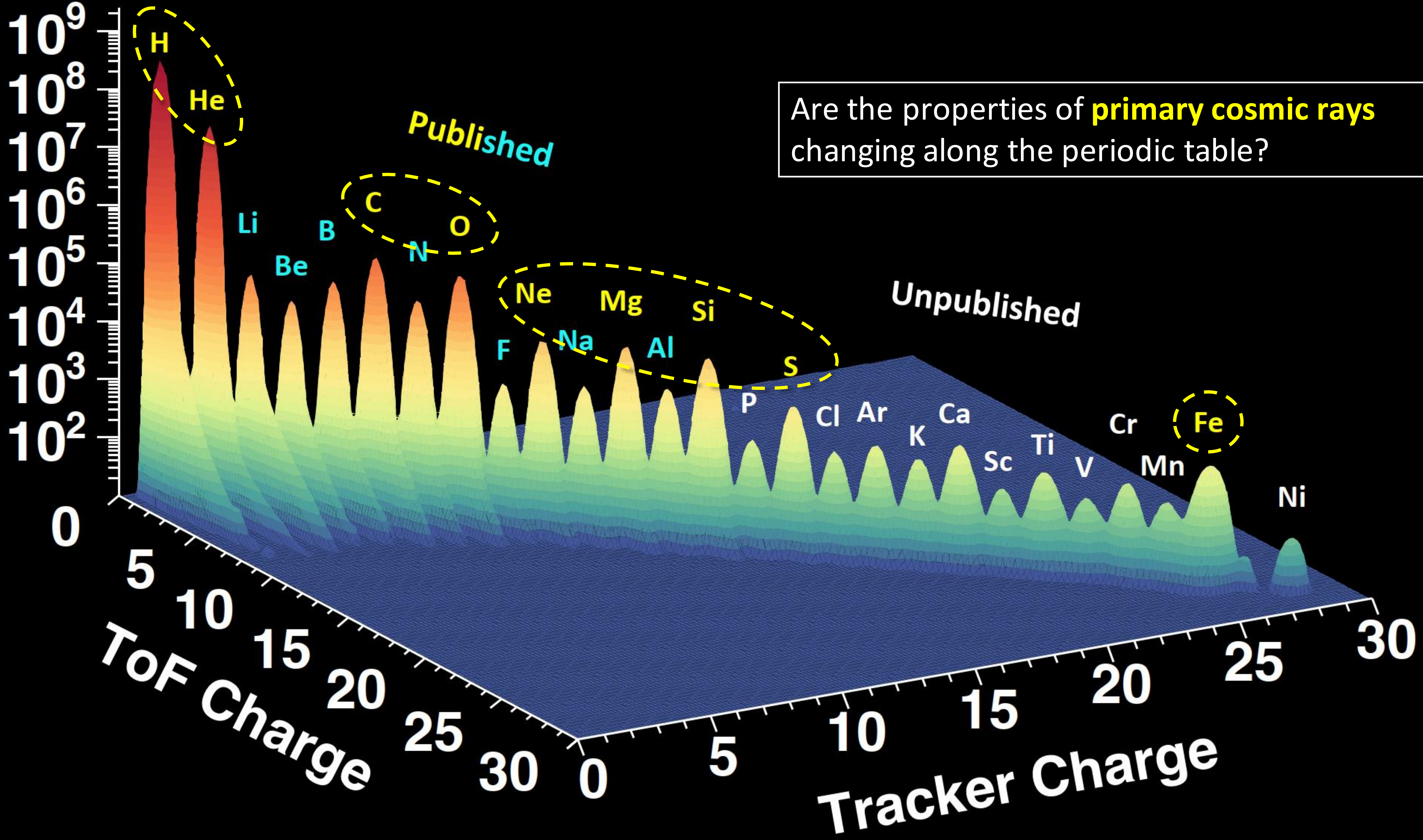


AMS has made nuclei Interaction cross-section measurements in a wide rigidity range (from a few GV to TV) allowing for the precise control of the flux normalization.

CR chemical composition with AMS

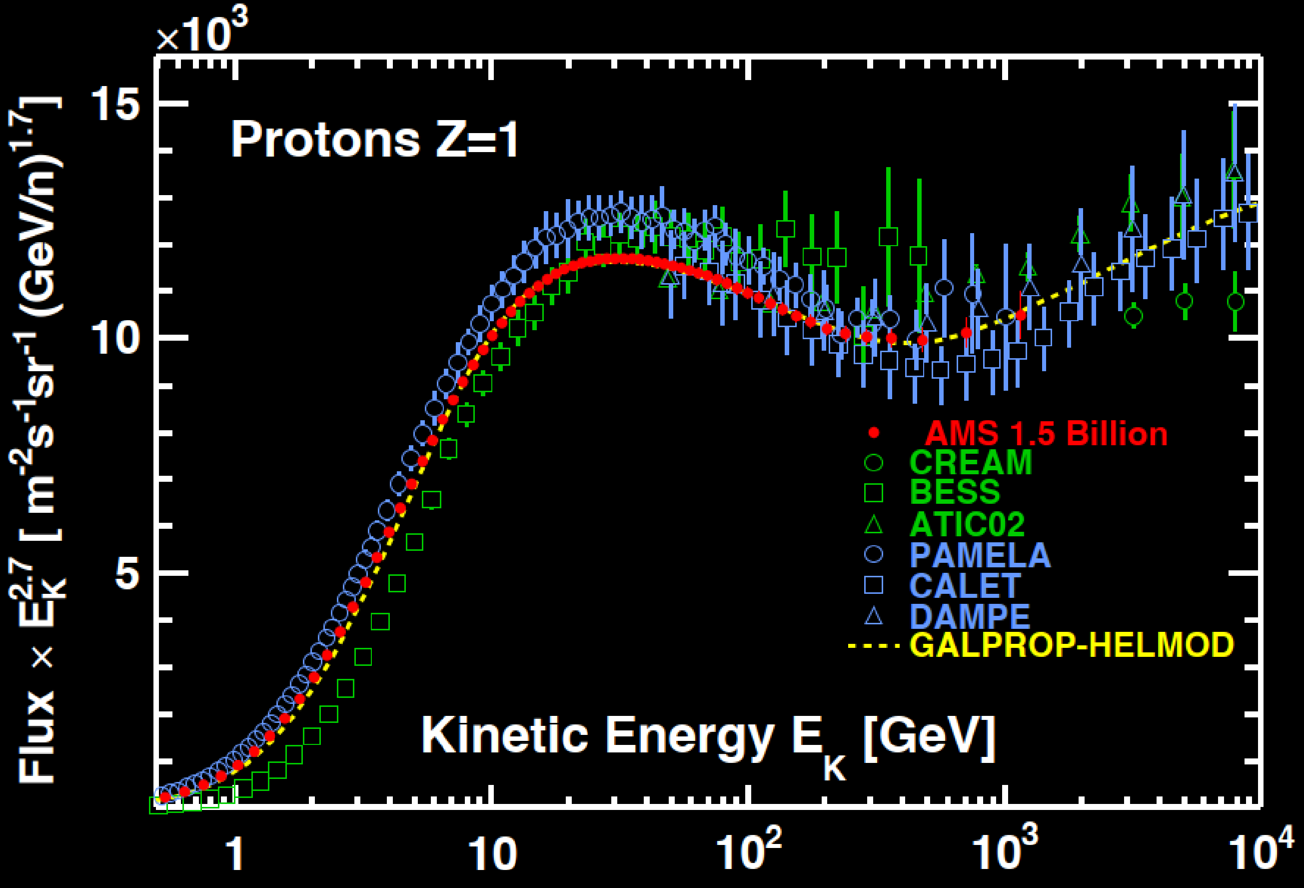


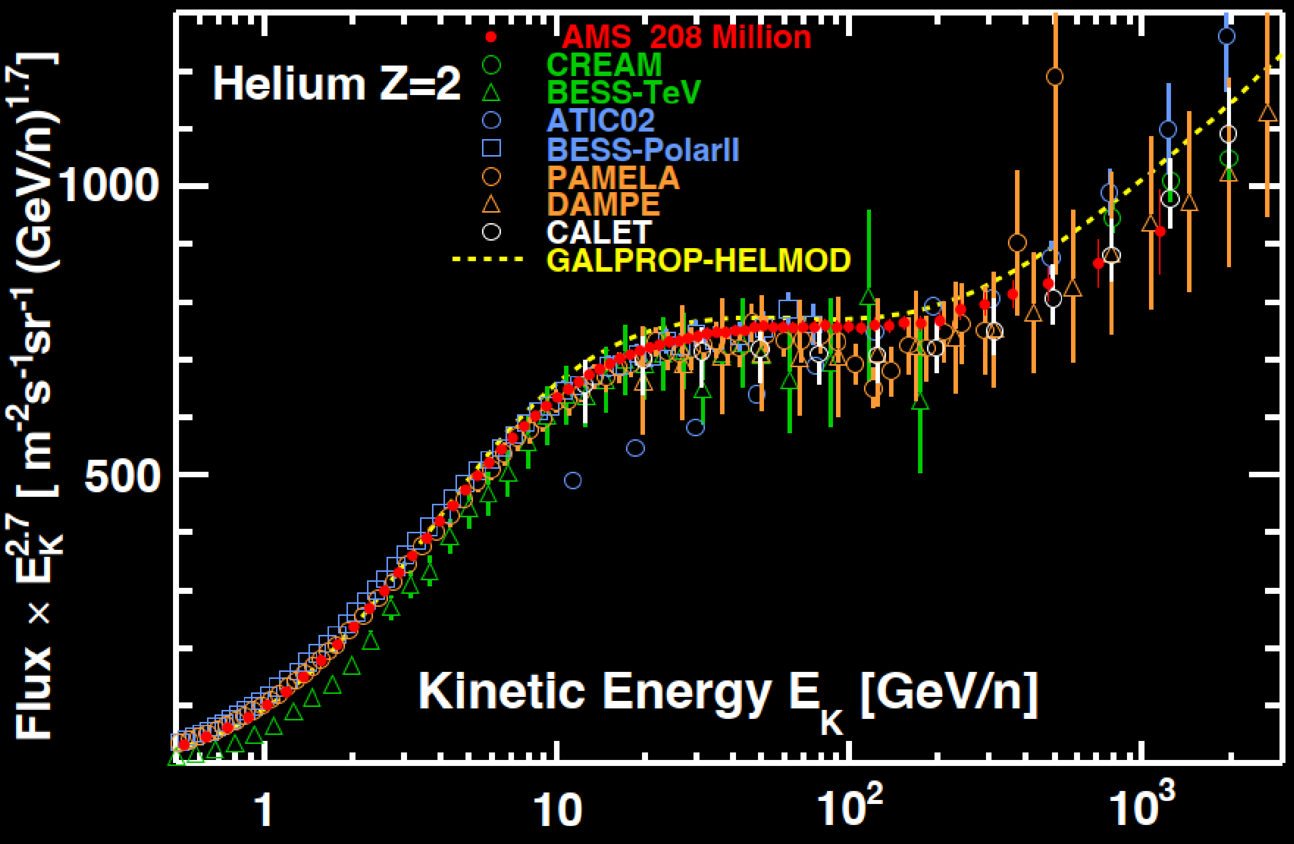
CR chemical composition with AMS



Are the properties of **primary cosmic rays** changing along the periodic table?

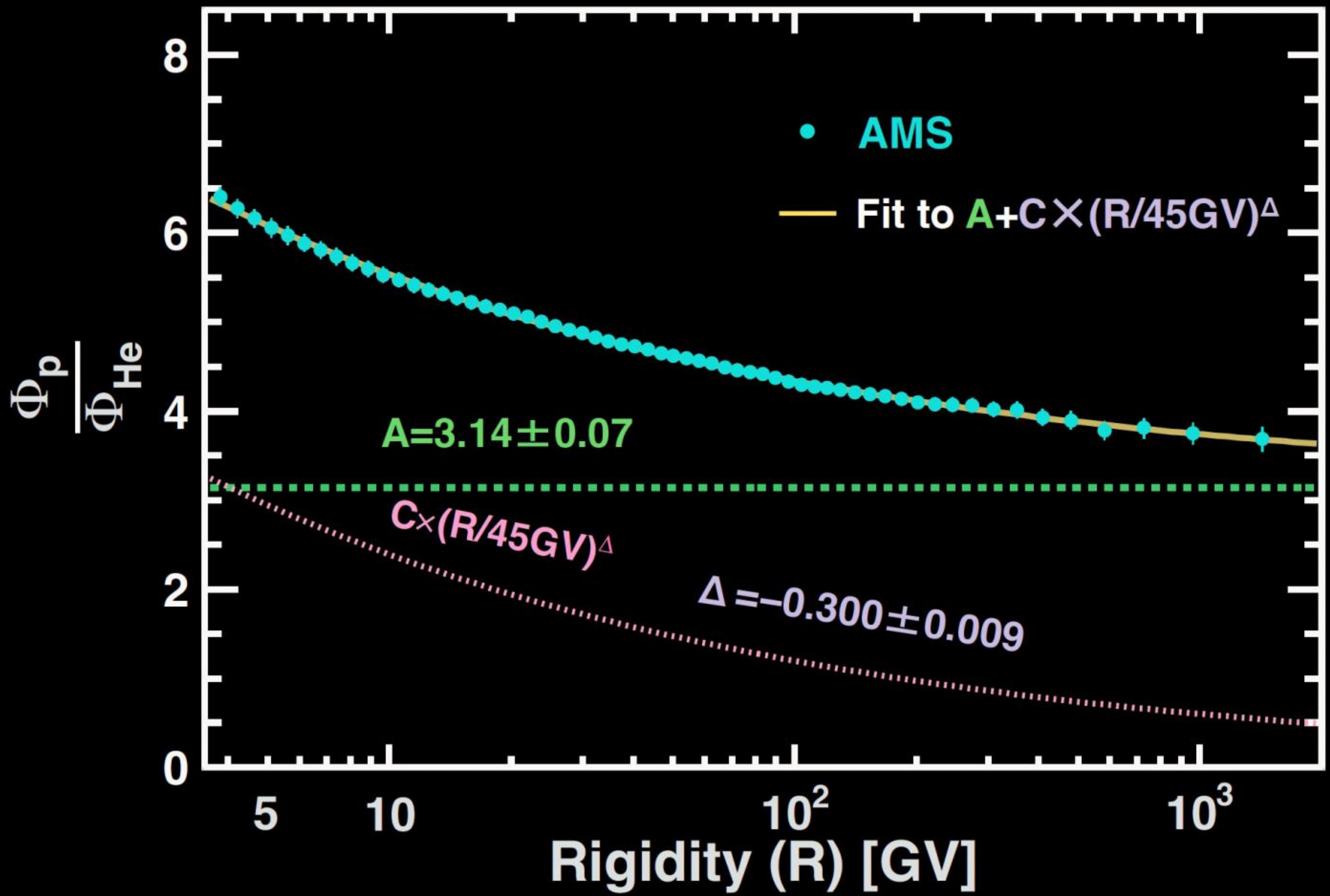
Proton and Helium fluxes





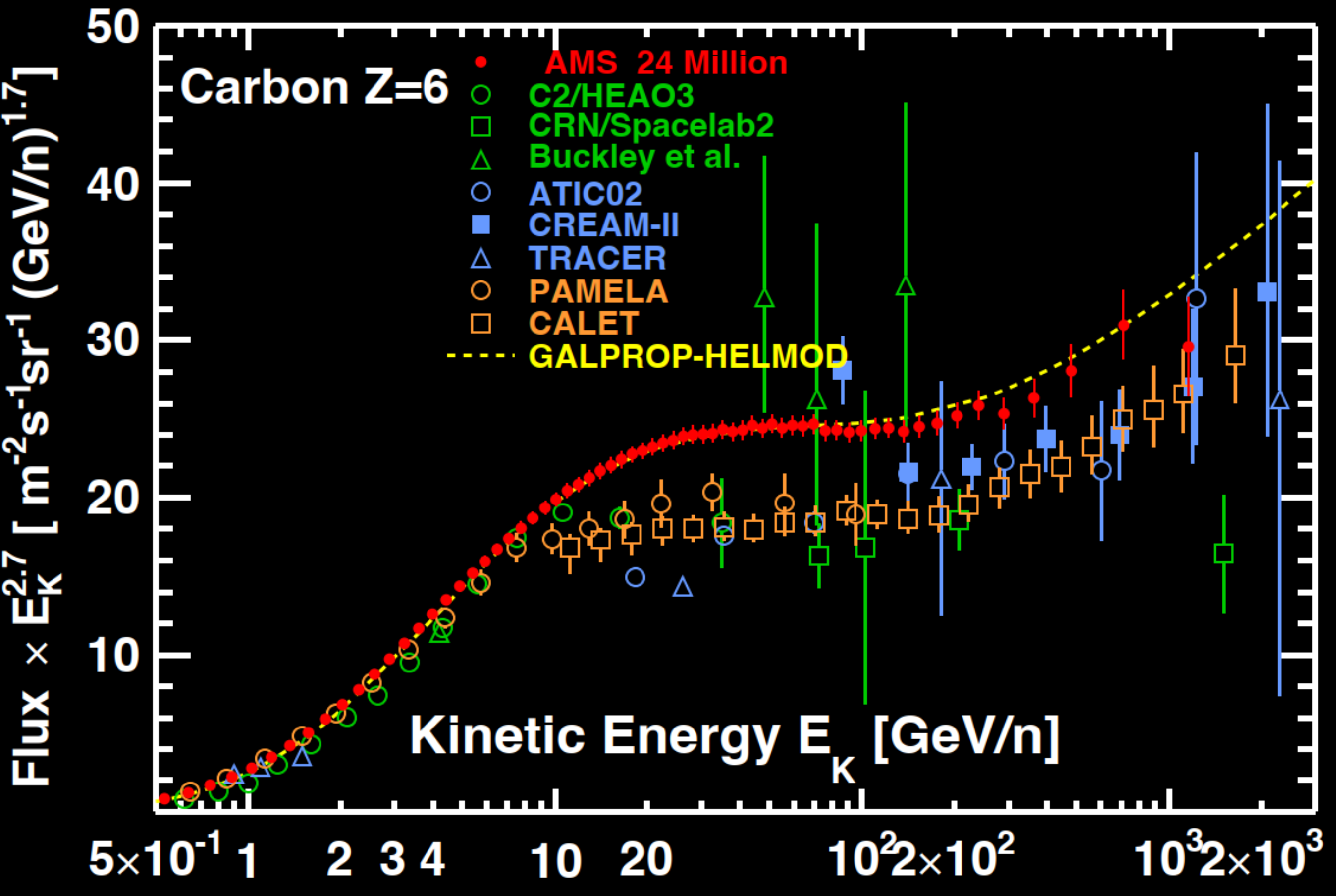
Eleven-year AMS measurements, update of previous measurements.
Most abundant elements in cosmic rays, measured by many experiments.
AMS measures this fluxes with unprecedented statistics.
Both spectra exhibit a significant hardening at a rigidity of about 200 GV.

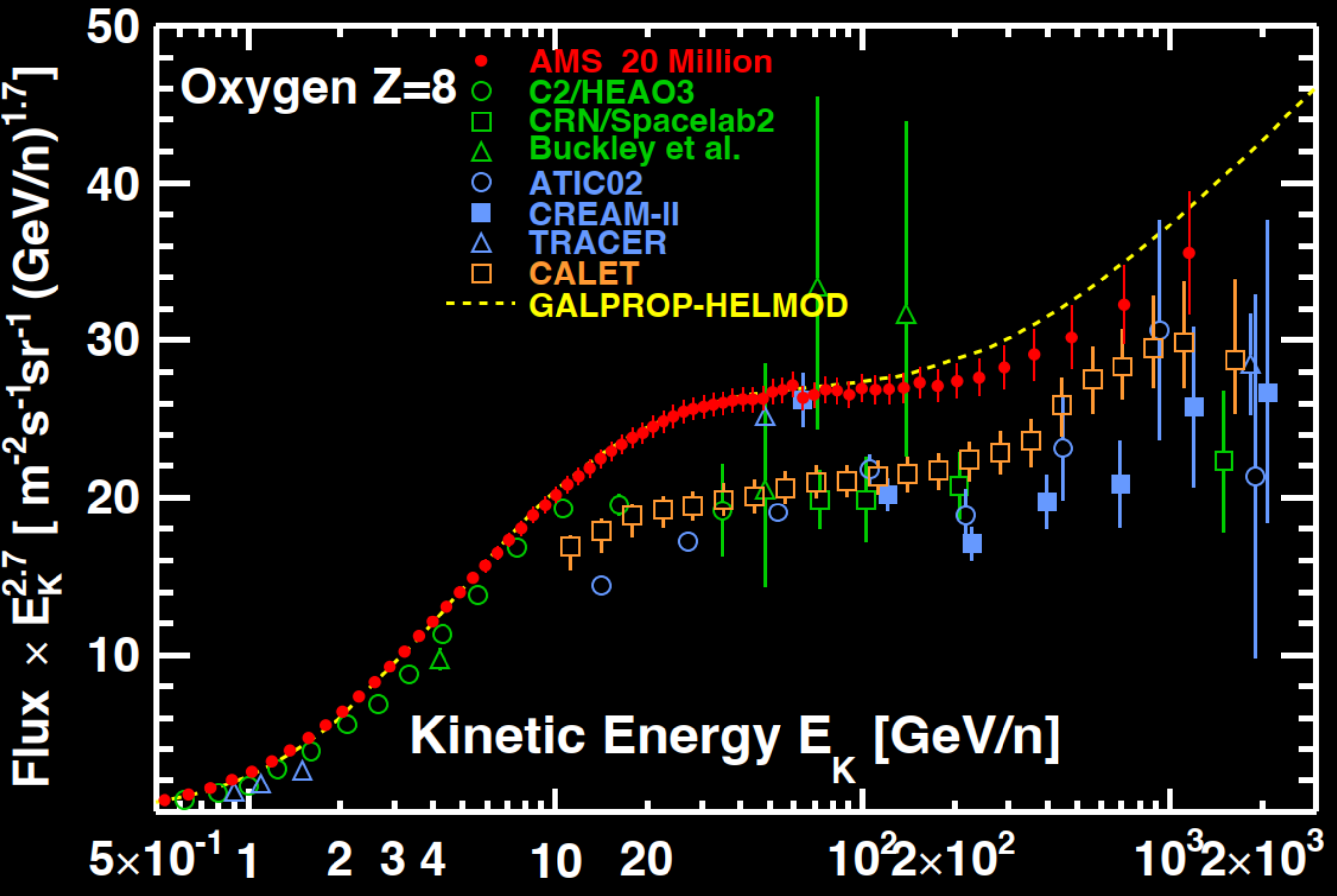
Proton / Helium flux ratio



Proton flux can be described by **helium flux + soft spectrum** with index Δ = -0.300 ± 0.009.
The proton-to-helium flux ratio there has **no spectral feature** around the flux break.

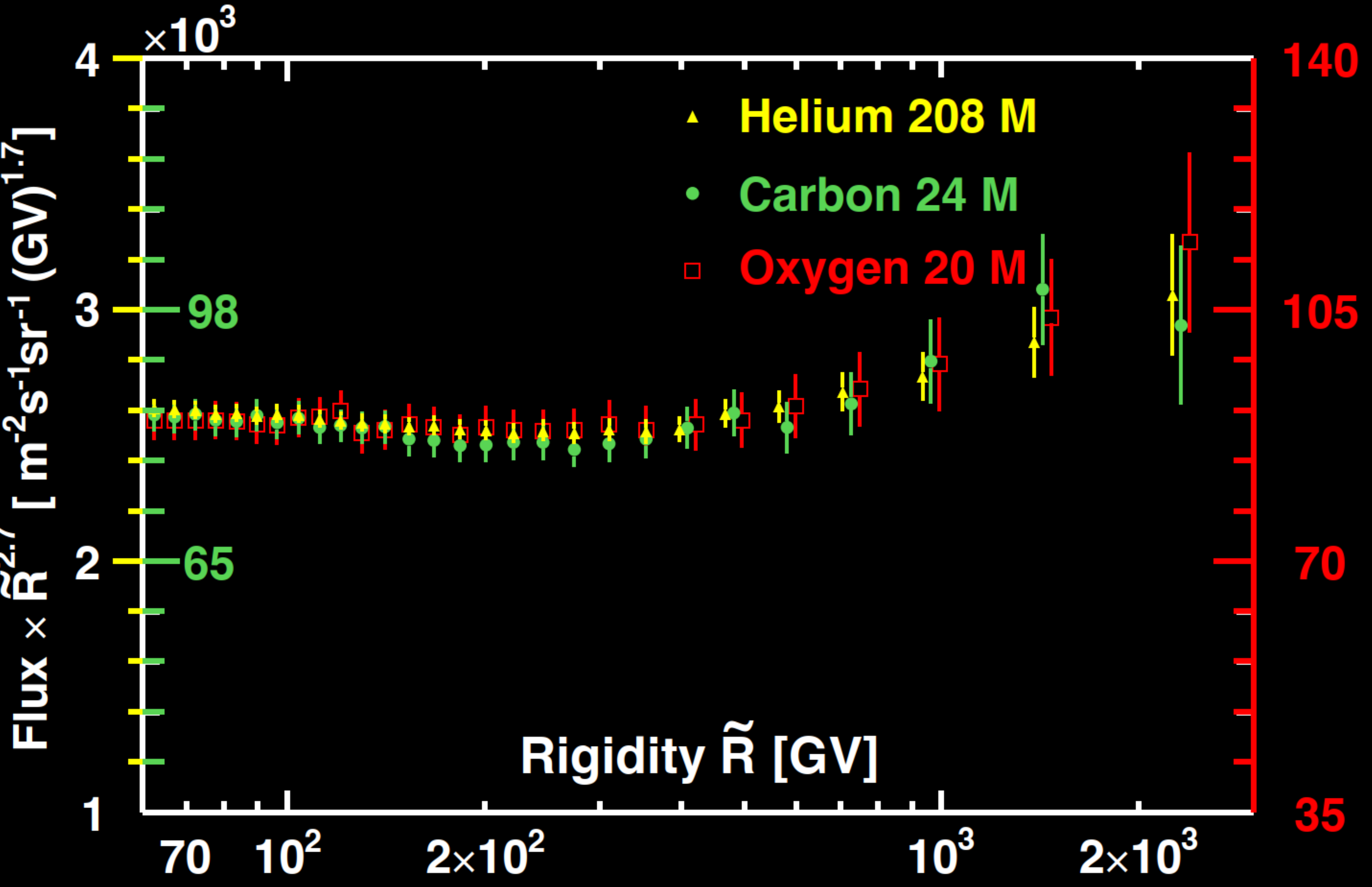
Carbon and Oxygen fluxes





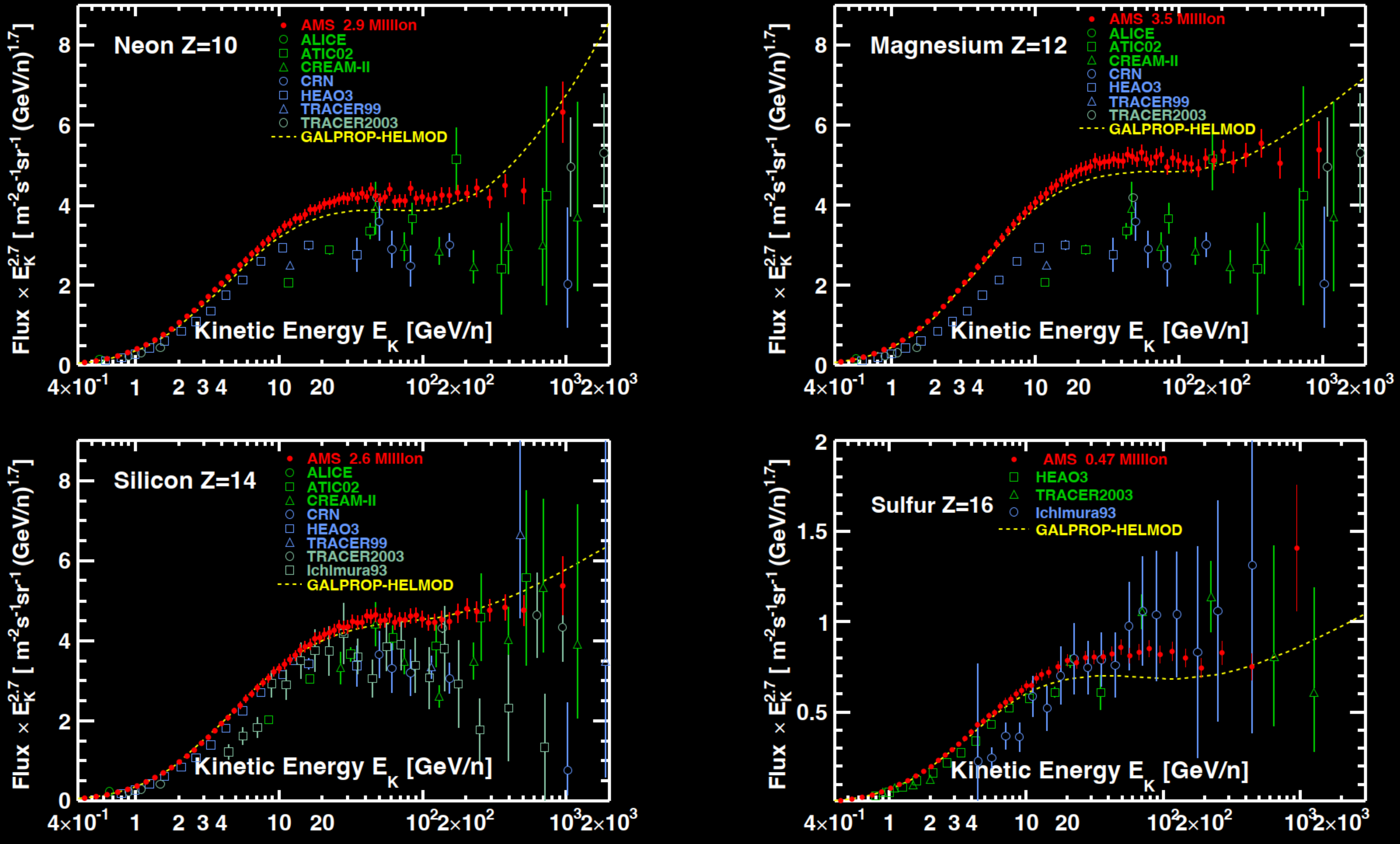
Carbon and Oxygen spectra exhibit a break in the flux at about 200 GV.

Helium, Carbon and Oxygen



He, C and O spectra have an identical rigidity dependence above 60 GV.
Above 200 GV, they all deviate from a single power law and harden in an identical way.

Neon, Magnesium, Silicon and Sulfur fluxes

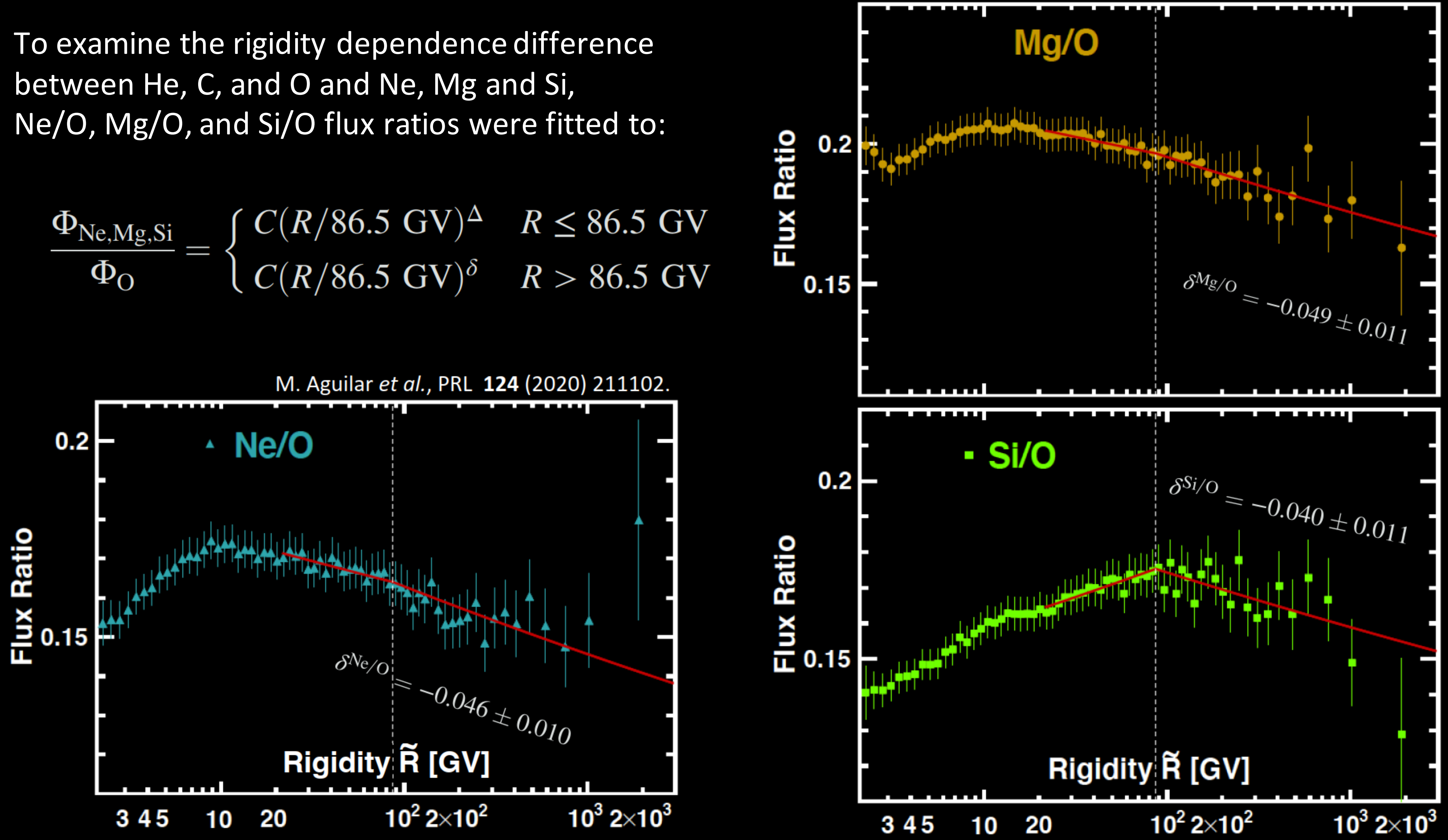


Neon, Magnesium, Silicon ratios to Oxygen

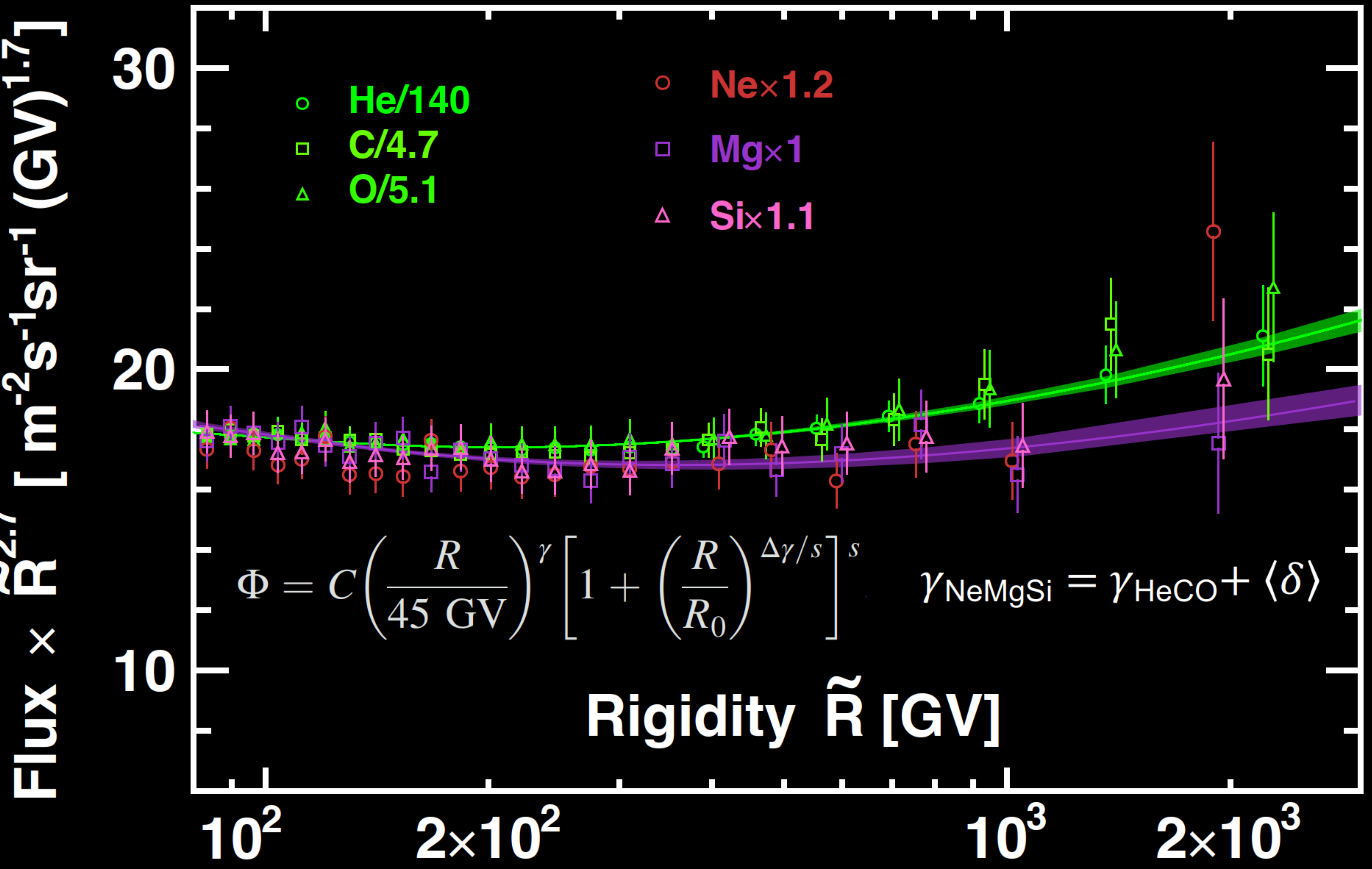
To examine the rigidity dependence difference between He, C, and O and Ne, Mg and Si, Ne/O, Mg/O, and Si/O flux ratios were fitted to:

$$\frac{\Phi_{\mathrm{Ne,Mg,Si}}}{\Phi_{\mathrm{O}}} = \begin{cases} C(R/86.5\ \mathrm{GV})^{\Delta} & R \leq 86.5\ \mathrm{GV} \\ C(R/86.5\ \mathrm{GV})^{\delta} & R > 86.5\ \mathrm{GV} \end{cases}$$

M. Aguilar *et al.*, PRL **124** (2020) 211102.

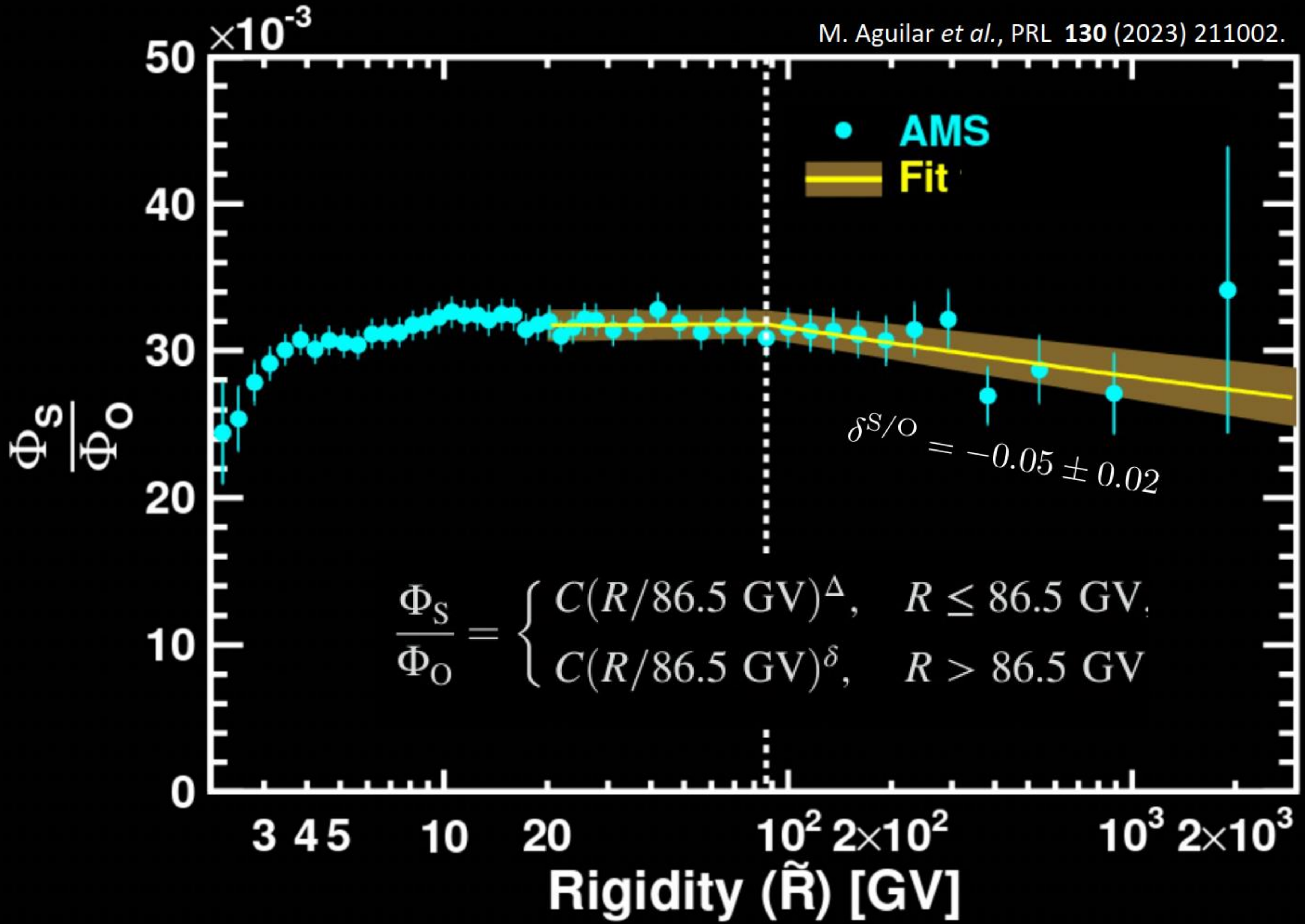


Properties of Ne, Mg, and Si



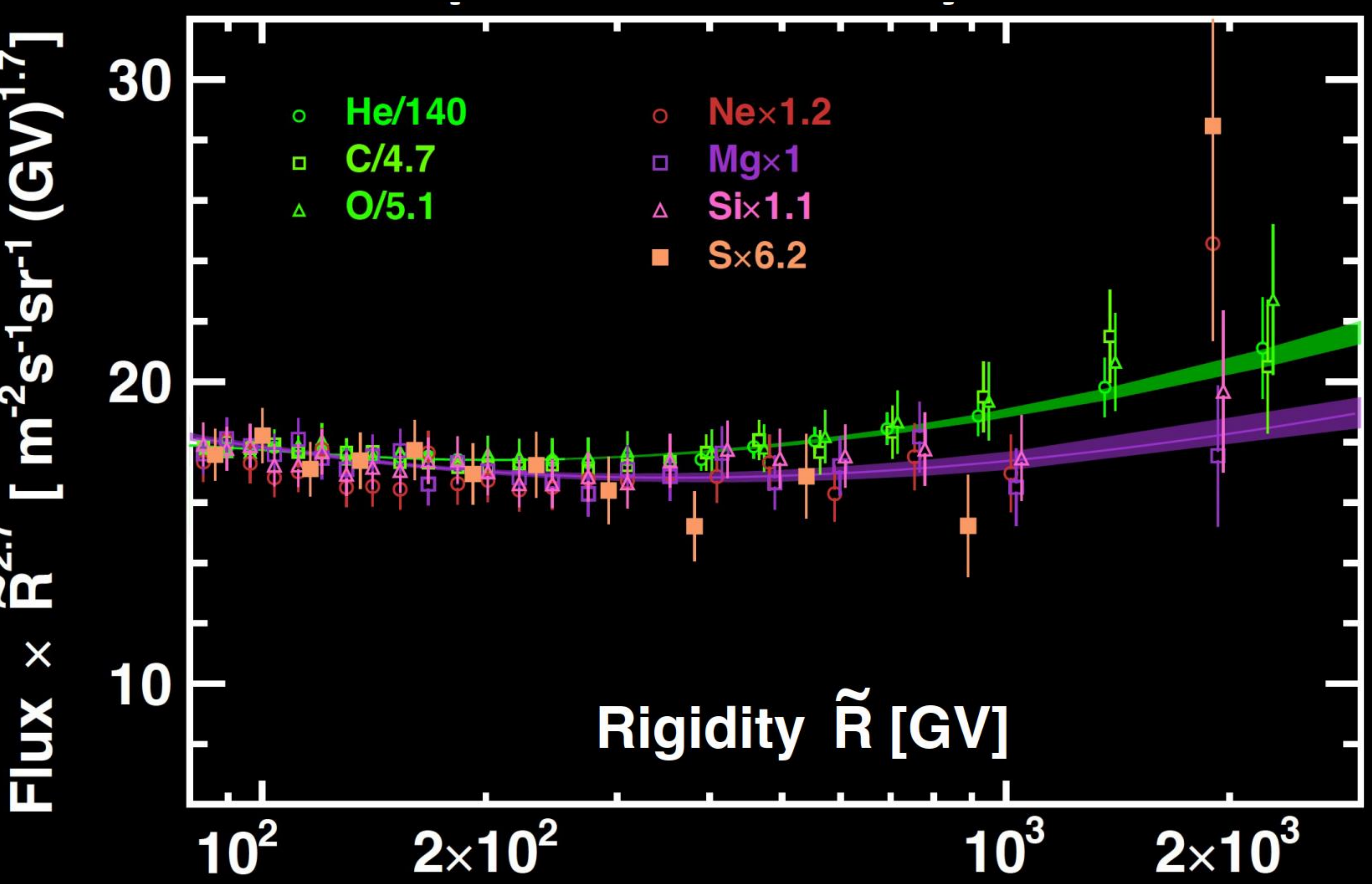
Above 86.5 GV, the rigidity dependence of heavy CRs Ne, Mg, and Si spectra is different from light CRs He, C, and O. This shows that primary cosmic rays have at least two distinct classes.

Properties of Heavy CRs: Sulfur



Sulfur belongs to the same class of Neon, Magnesium and Silicon.

Properties of Heavy CRs



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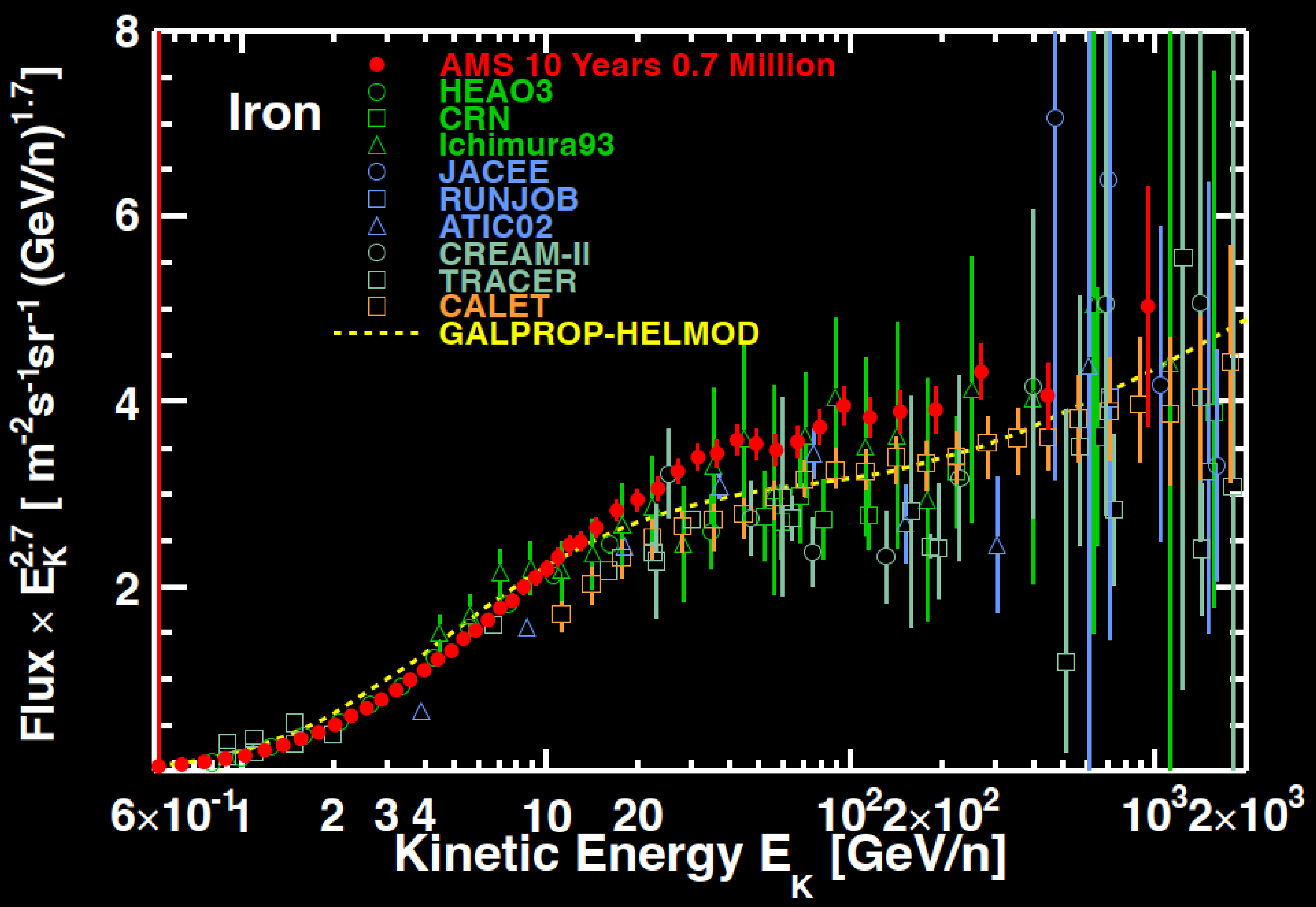
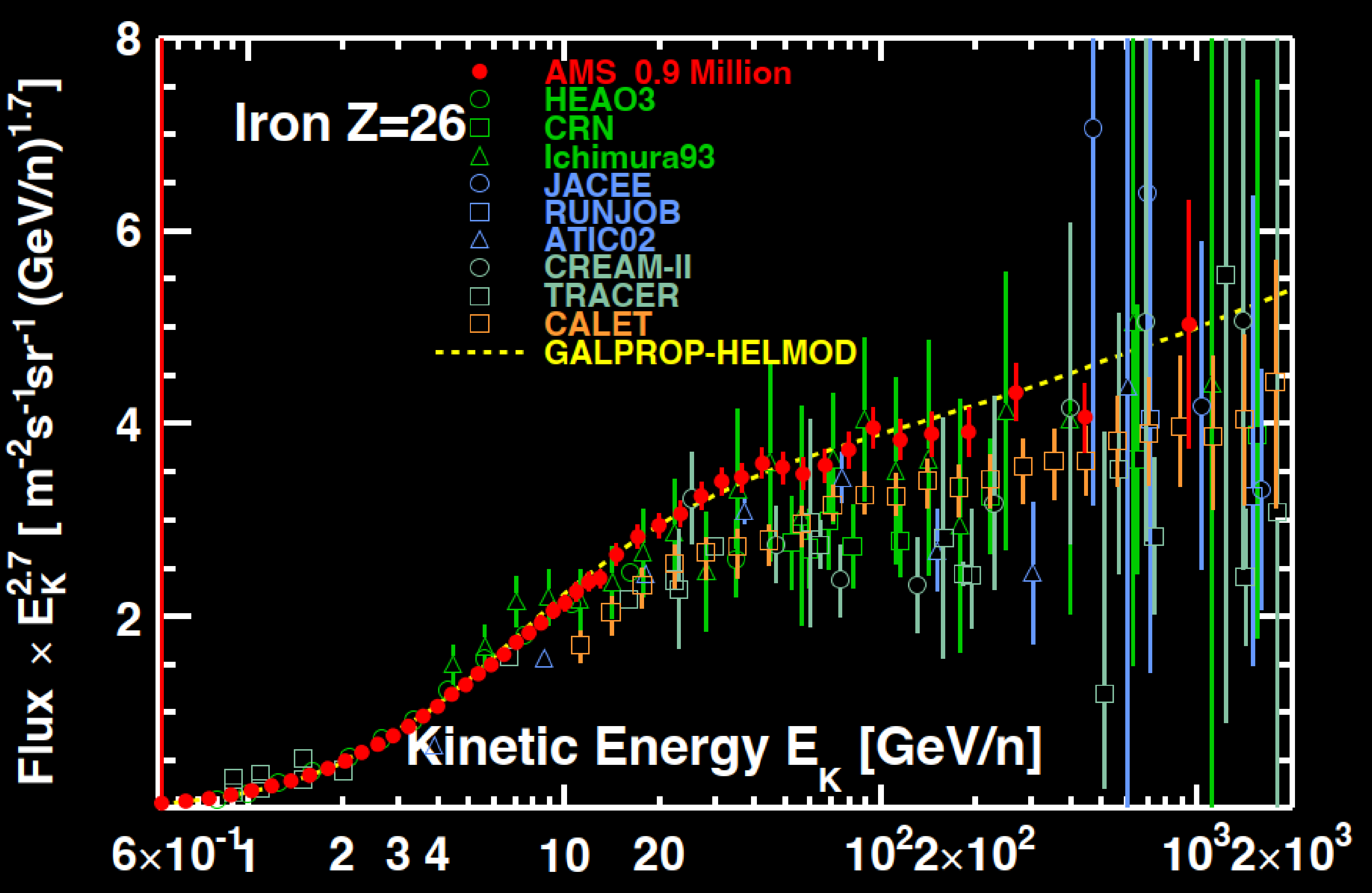
Iron flux



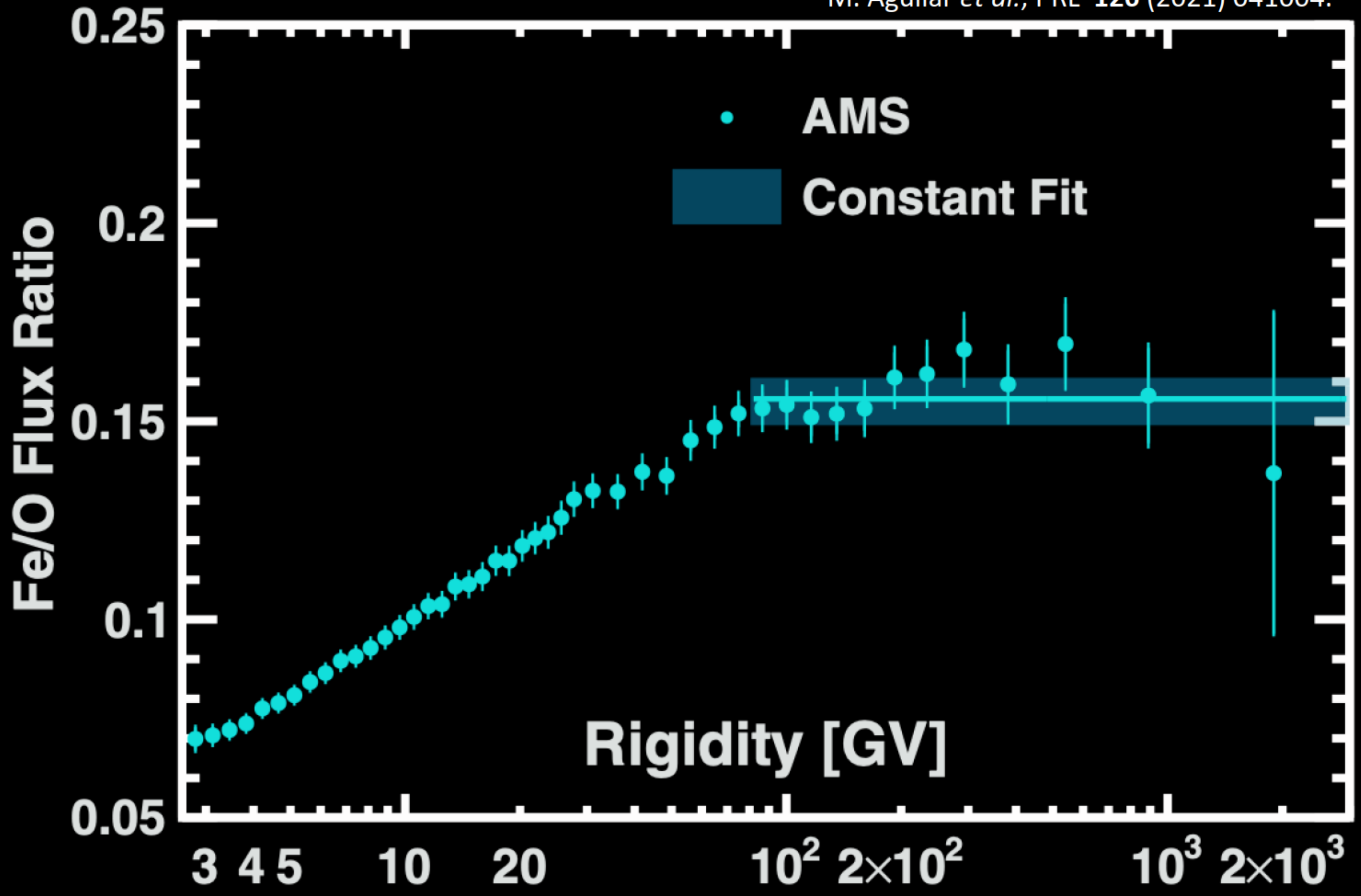
Model with AMS data but without Fe
M. J. Boschini et al., ApJS 250 (2020) 27



Model with AMS data with Fe data
M. J. Boschini et al., ApJS 213 (2021) 5

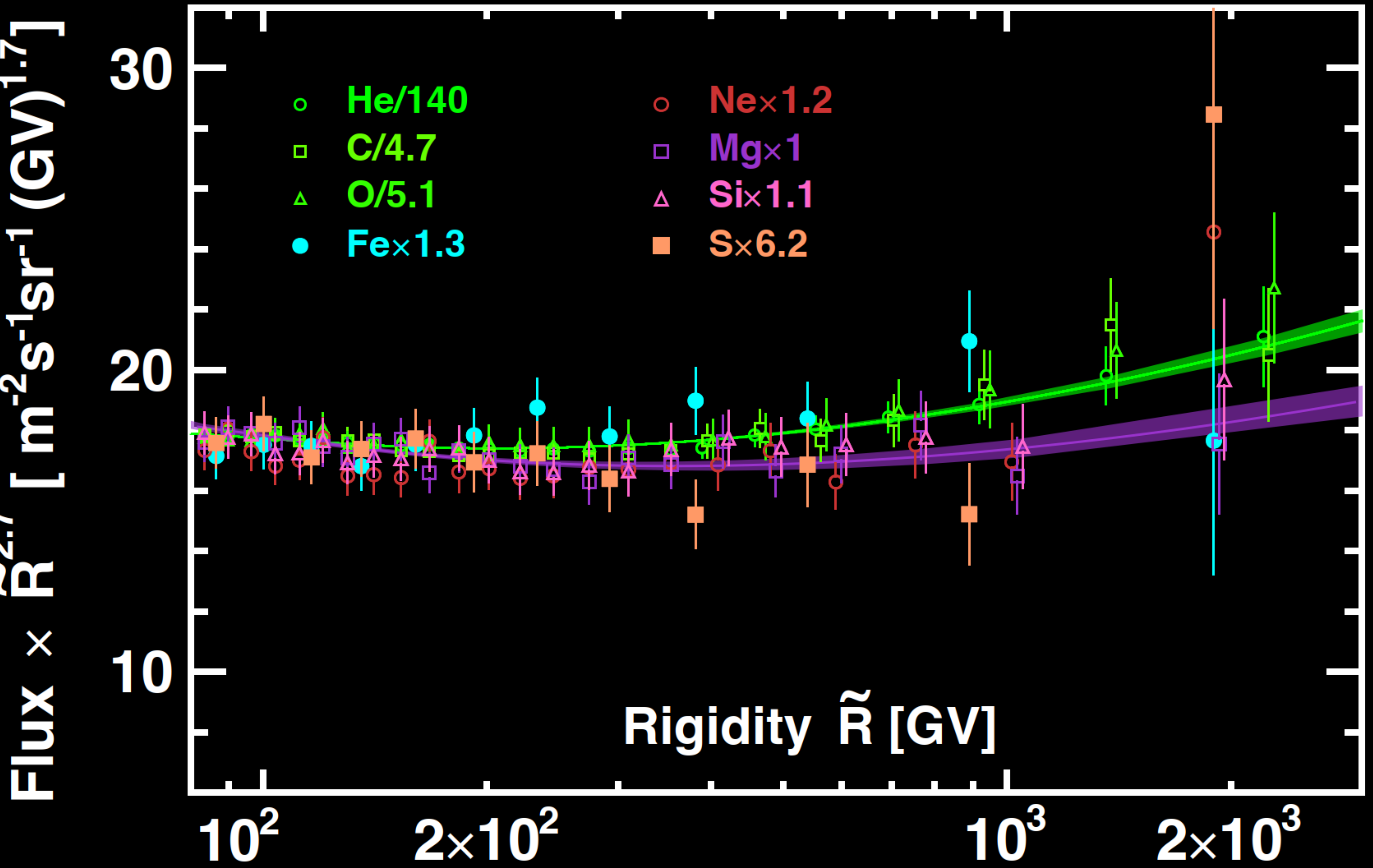
Iron/Oxygen flux ratio

M. Aguilar *et al.*, PRL **126** (2021) 041004.



Iron belongs to the primary class of Helium, Carbon and Oxygen.

Properties of Iron flux



Conclusion

In the first 11 years of operations AMS has collected more than 200 billion cosmic rays and measured with unprecedented precision primary cosmic rays p, He, C, O, Ne, Mg, Si S, Fe from 2 GV to 3 TV revealing new unexpected properties.

Future high-precision AMS data on all cosmic-ray data will continue to provide unique insights into the understanding of cosmic rays.