Precision Measurement of the Monthly Proton and Helium Fluxes in Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station

Nicola Tomassetti
Perugia University & INFN

International Cosmic Ray Conference, 36th ICRC – 2019, 24 July – 02 August, Madison, USA

Presented on behalf of the AMS Collaboration
In collaboration with ASI under agreement ASI-UniPG 2019-2-HH.0
Sunspot number and the Solar Cycle

The Sun’s activity governs the magnetic flux, plasma wind, and CR radiation in heliosphere creating hazardous space weather
Sunspot number and the Solar Cycle

The Sun’s activity governs the magnetic flux, plasma wind, and CR radiation in heliosphere creating hazardous space weather.

Influence on the CR flux:
- Time – dependent
- Space – dependent
- Particle – dependent
- Energy – dependent
Sunspot number and the Solar Cycle

The Sun’s activity governs the magnetic flux, plasma wind, and CR radiation in heliosphere creating hazardous space weather

MAX
MIN
11-year Solar Cycle
Solar modulation of GCR: a golden age

The effect is time-, space-, energy-, and particle-dependent ⇒ need for multichannel, time-resolved & E-resolved GCR data

Time-resolved proton data

Data from interstellar space

Voyager

Time dependence of antimatter

2.31 - 2.65 GeV

AMS-02

Time dependence of Z>1 CR nuclei

Flux [GV/\text{s}^{1}\text{sr}^{-1}\text{m}^{2}]
Solar modulation of GCR: a golden age

The effect is time-, space-, energy-, and particle-dependent ➔ need for multichannel, time-resolved & E-resolved GCR data

Time-resolved proton data

Data from interstellar space

Voyager V1 V2

Time dependence of antimatter

2.31 - 2.65 GeV

AMS-02

Time dependence of Z>1 CR nuclei
The Alpha Magnetic Spectrometer

- LEO: on the ISS at ~400 km altitude
- Active since May 19th, 2011
- Continuous operation 7/24
- Average trigger rate ~ 700 Hz
- 141+ giga-particles collected
- High acceptance
- Complete particle ID (mass, charge, sign)
- Redundant energy measurements

- Particle-resolved
- Time-resolved
- Energy-resolved
- Space resolved
AMS has collected 142,262,238,906 cosmic ray events

Last update: July 23, 2019, 10:17 AM
AMS-02 results: time evolution of the GCR fluxes

Measurements of CR proton and helium fluxes for 79 Bartel Rotations (27-days), at rigidity R from 1 GV to 50 GV.

Flux variation behavior at monthly timescales, apparently correlated with the monthly SSN in the solar corona.

M. Aguilar et al. (AMS-02)
AMS-02 results: time- and rigidity- dependence of the p-He fluxes

![Graphs showing the time and rigidity dependence of proton and helium fluxes.](image-url)
AMS-02 results: time- and rigidity- dependence of the p-He fluxes
AMS-02 results: time- and rigidity- dependence of the p-He fluxes
AMS-02 results: time- and rigidity- dependence of the p-He fluxes
AMS-02 results: time- and rigidity- dependence of the p-He fluxes

![Graph showing proton and helium fluxes over time and rigidity](image)

(a) Proton (b) Helium
AMS-02 results: time- and rigidity- dependence of the p-He fluxes
AMS-02 results: time- and rigidity- dependence of the p-He fluxes
AMS-02 results: time- and rigidity- dependence of the p-He fluxes

** AMS Proton**

- Relative variations of proton and helium fluxes at the same rigidity

- Time and rigidity dependence of the p-He fluxes
AMS-02 results: time- and rigidity- dependence of the p-He fluxes

variations of proton and helium fluxes at the same rigidity are not identical
AMS-02 results: time- and rigidity- dependence of the p/He ratio

p/He ratio
✓ Nearly constant with time at R > 3 GV
✓ Long-term structure appearing at R < 3 GV

Parameteric description
\[ r_i(t) = \begin{cases} 
  a_i & t < t_i \\
  a_i + b_i(t - t_i) & t \geq t_i, 
\end{cases} \]

Brocken-line model. Ti= 2015 Feb 28 ± 42 days.

Recent models for the p/He evolution
- Tomassetti et al. PRL 121, 251104 (2018)
- Gieseler et al. JGR 122, 10964 (2017)
Origin of long-term structure in the p/He ratio

- Mass/charge dependence of CR diffusion appearing at low-rigidity
- Differences in the interstellar spectra of proton and helium
- Role of 3He and 4He isotopic composition effects

- Improved models of CR modulation are being developed
- Multichannel investigation w/ other data: 3He/4He, C/O

Tomassetti et al. PRL 121, 251104 (2018)
Gieseler et al. JGR 122, 10964 (2017)
Conclusions

- Precision CR data provide substantial advance in understanding Solar Modulation.

- We have presented the monthly fluxes of proton and helium in CRs measured by AMS during ascending phase of Cycle 24, through its maximum, and toward its minimum.

- The high precision of these data enables us to observe fine time structures in the fluxes, at monthly and yearly time scale phenomena.

- Prominent time structures are observed in proton and helium up to 40 GV of rigidity.

- In the p/He ratio, the short-term structures of the fluxes largely cancel out. At R> 3 GV, the p/He ratio is remarkably constant. Below 3 GV, it shows a clear long-term behavior.

- The long-term behavior of the ratio gives information on CR diffusion in heliosphere, but there are other effects. Modeling challenge: how to make sense of all nuclear data.
backup
Energy spectra
Proton and helium energy spectra for 16 (out of 79) time periods
Quantitative inspection of proton and helium fluxes by making a comparison between:

- AMS data collected in low-Earth-orbit.
- Voyager-1 data collected in the interstellar space.

Calculations of local interstellar spectra are shown, in order to smoothly connect the Voyager-1 data (interstellar) with AMS data at high-energy (where solar modulation is negligible).

The green band represents the envelope of the AMS time-series.

For the p/He ratio, the band appears tight: The LIS model connects well the AMS and Voyager-1 data. No variation?
Explanation for the long-term $p/He$ behavior

- Different $p$-$He$ LIS and their uncertainties accounted
- Isotopic composition accounted.
- Tested various diffusion coefficients with numerical models

$K(R) = (v/3)\lambda(R)$ parallel diffusion coefficient

$\lambda(R) =$ universal \textit{composition-blind} mean free path

\[ K(R, t) = \frac{\beta c}{3} \lambda(R, t) \equiv k_0(t) \times \beta(R) \times f(R) \]

- **Time dependence**
- **Rigidity dependence**

Rigidity and $M/Z$ dependence:

\[ \beta(R) = \frac{R}{\sqrt{R^2 + (M/Z)^2}} \]

At the same value of rigidity $R$:
- Protons are faster than He ($4He$ or $3He$)
- Diffusion coefficient of protons is larger

\[ \frac{p}{He} \]

\[ 2012 \quad 2012 \quad 2013 \quad 2014 \quad 2016 \quad 2016 \]

Jan,01  Dec,31  Dec,31  Dec,31  Jan,01  Dec,31

Model $K \propto \beta R$  Model $K \propto R$  AMS-02

NT+ PRL 121, 251104 (2018) [1811.08909]
NT+ Adv Space Res. (2019)[1906.11477]
Explanation for the long-term p/He behavior

✓ The p/He time-dependence is predicted from a proton-driven model
✓ The p/He structure is expected to disappear at relativistic rigidities

The p/He long-term structure is a signature of the universality of the CR mean free paths $\lambda(R)$.
Precision Measurement of the Monthly Proton and Helium Fluxes in Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station

Nicola Tomassetti
Perugia University & INFN

International Cosmic Ray Conference, 36th ICRC
24 July – 02 August 2019, Madison, USA

Presented on behalf of the AMS Collaboration