Monthly time variation of light nuclei fluxes

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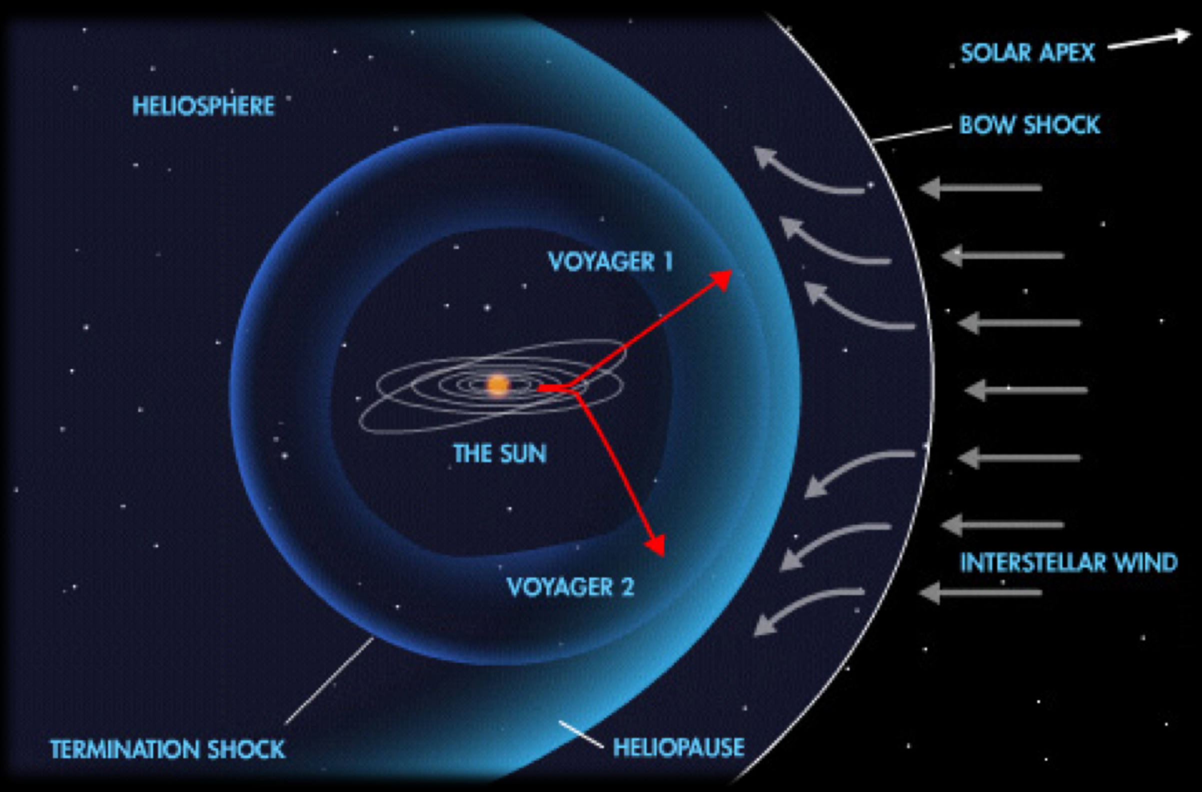
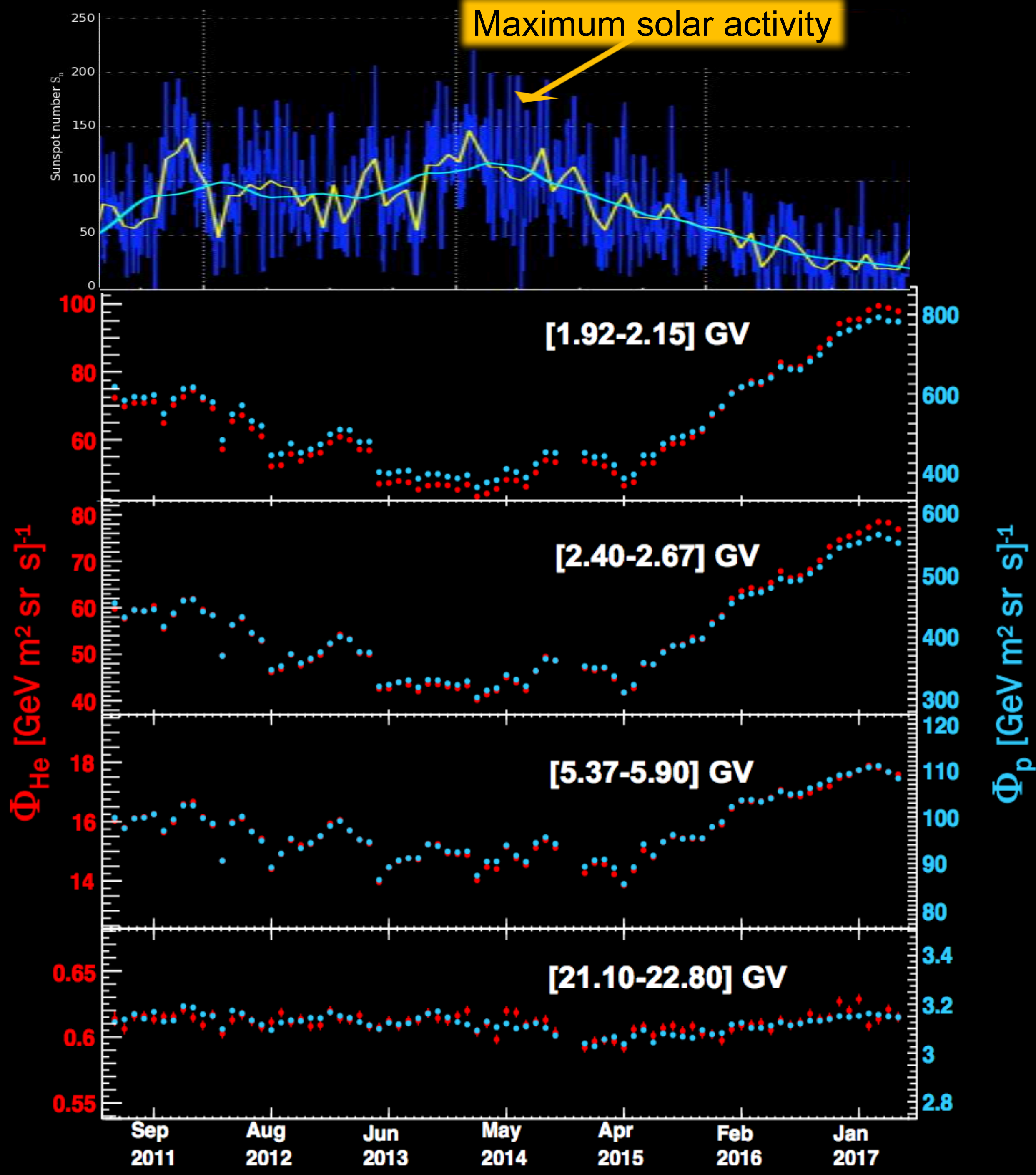
Outline

- ✓Introduction & Motivations
- ✓Our Results in ASI-SSDC
- ✓Comparison with other groups
- ✓AMS draft status
- ✓Conclusion

Galactic CRs arrive in the heliosphere …



- Galactic cosmic rays encounter a turbulent solar wind with an embedded heliospheric magnetic field when entering the heliosphere.
- This leads to significant global and temporal variations in their intensity and in their energy as a function of position inside the heliosphere.
- This process is identified as the **solar modulation** of cosmic rays .

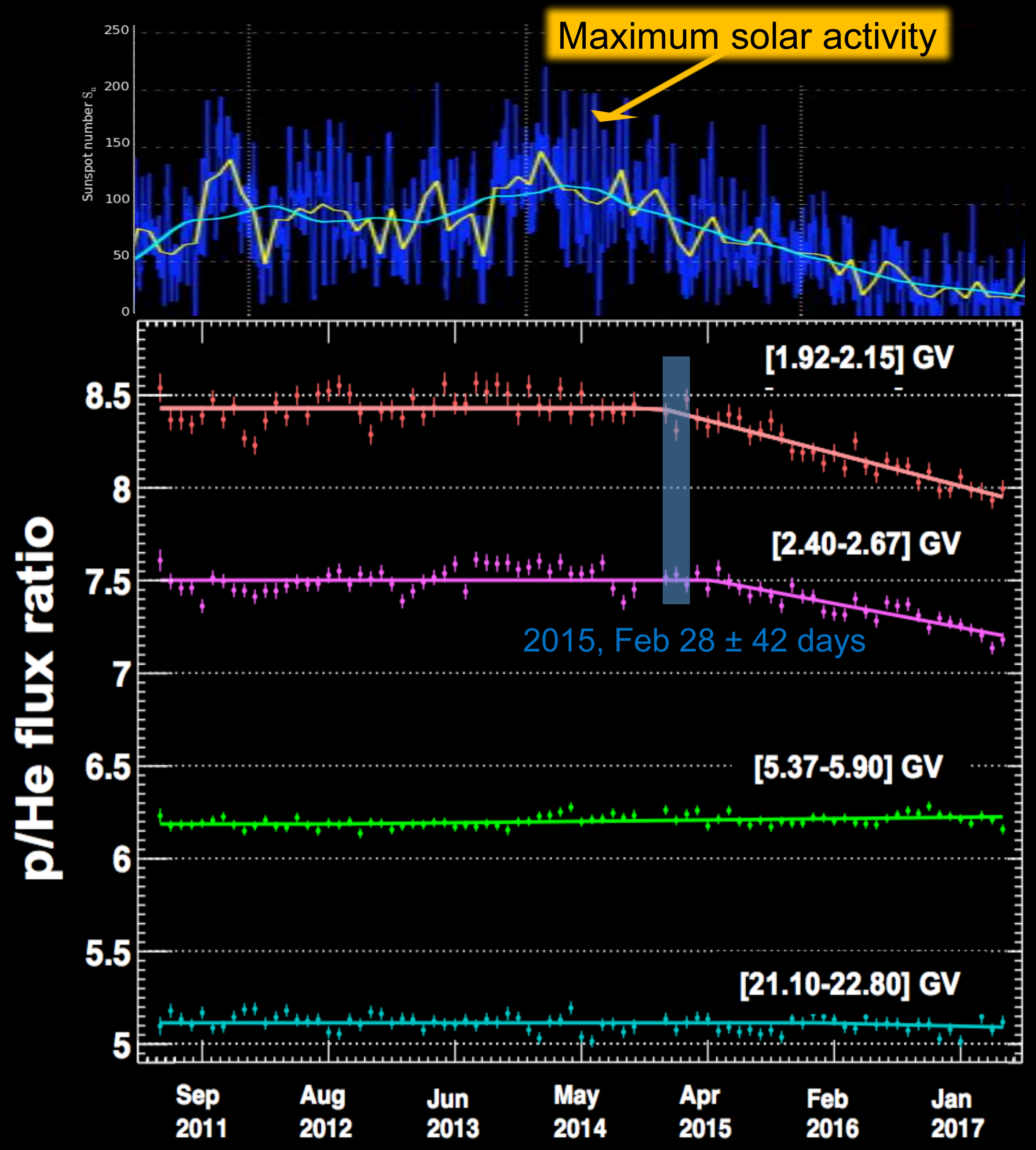


AMS-02 results

Time evolution of the GCR fluxes: P & He

- 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, correlated with the monthly SSN in the solar corona (in low rigidities).

M. Aguilar et al. (AMS-02) Phys. Rev. Lett. 120 (2018) 051101



AMS-02 results

Time- and rigidity- dependence of the p/He ratio

- Nearly constant with time at R > 3 GV
- Long-term structure appearing at R < 3 GV

Multichannel investigation with C/O:

✓ Carbon and Oxygen nuclei are the closest most abundant primary Cosmic rays, they can be used to understand the discrepancies on p and He, improving the knowledge of the nuclei propagation in the heliosphere.

M. Aguilar et al. (AMS-02) Phys. Rev. Lett. 120 (2018) 051101

The Cosmic Rays propagation in the heliosphere is described by Parker equation:

Particle density in phase space

$$\frac{\partial f}{\partial t} = -\vec{V}_{SW} \cdot \vec{\nabla} f + \vec{\nabla} \cdot (\mathrm{K} \cdot \vec{\nabla} f) + \frac{1}{3} \vec{\nabla} \cdot \vec{V}_{SW} \frac{\partial f}{\partial lnR}$$

Solar wind convection | **Diffusion and Drifts** | **Adiabatic energy losses**

- Velocity dependence of the diffusion tensor: $\mathrm{K}(\vec{r}, R) = \beta \mathrm{K}_1(\vec{r})\, \mathrm{K}_2(R)$
  the velocity induces changes in this term for nuclei with different A/Z.

- Difference in spectral shape: the adiabatic energy losses term depends on the spectral shape. If two nuclei have different spectral shape outside the heliosphere (LIS), the last term will be different

- p/He: from numerical model, velocity difference is the main contribution to time dependence.
- C/O: C and O have same velocity (A/Z), so any time dependency comes from spectral shape differences.
- He/C, He/O: very similar velocities, so any time dependence comes from spectral shape differences.

It motivates us to measure the monthly C, O and C/O

Monthly Fluxes

For each ***Bartel Rotation (BR)***, i.e. on a 27-day basis.

starting from May 2011 up to Nov 2019 (8.5 years, 115 Bartels Rotations), the ***Isotropic Differential Flux*** can be calculated by:

Isotropic Differential Flux
$(m^2\ sr\ s\ GV)^{-1}$

$$\Phi_i^{BR} = \frac{N_i^{BR}}{A_i^{BR}\ \varepsilon_i^{BR}\ T_i^{BR}\ \Delta R_i}$$

Number of events in each Bartel rotation

8.5 years of Pass7 Data
Helium: 665M events,
Carbon: 21.1M events,
Oxygen: 18M events

Effective Acceptance

MC B1200.4_00 (Helium)
MC B1215.4_01 (Carbon)
MC B1220.4_02 (Oxygen)

Trigger Efficiency

Exposure Time

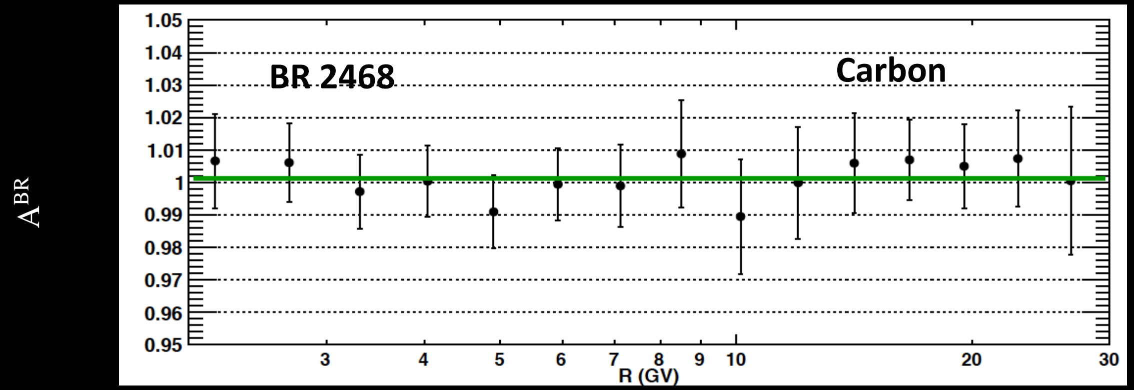
Bin width

bins 1.9 - 60 GV
40 bins

Data/MC Smoothing procedure (Tracking eff.)

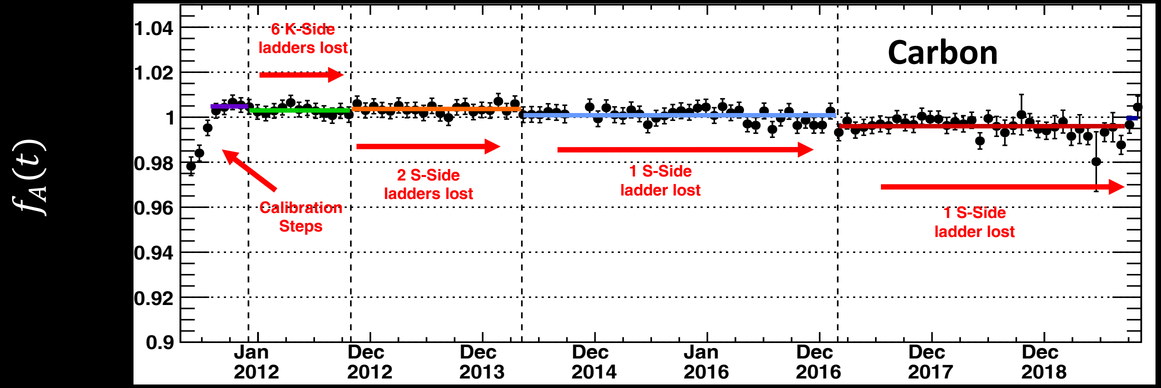
Step1: evaluating in each BR the Amplitude of the Data/MC variation with respect the one in the overall period (8.5 years)

$$A^{BR} = \frac{(\varepsilon_{Data}/\varepsilon_{MC})^{BR}}{(\varepsilon_{Data}/\varepsilon_{MC})_{8.5years}}$$



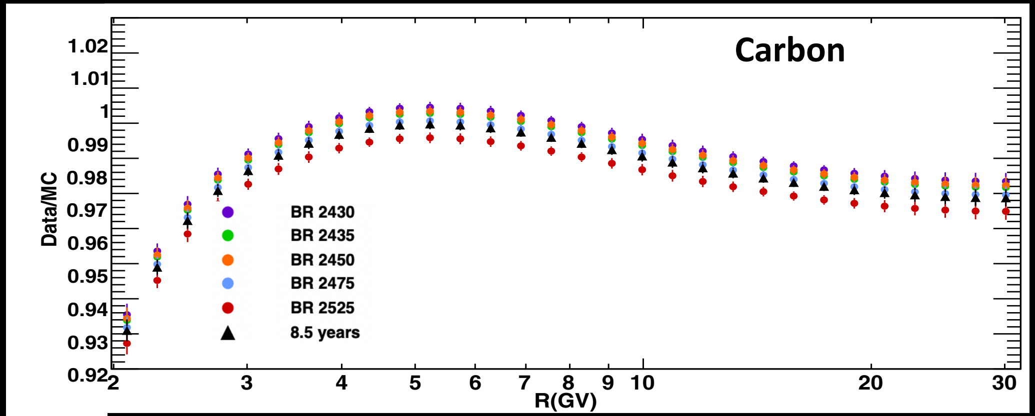
Step2: building the Amplitude as a function of Time to obtain a time dependent correction

$$A^{BR}(t) \rightarrow f_A(t)$$



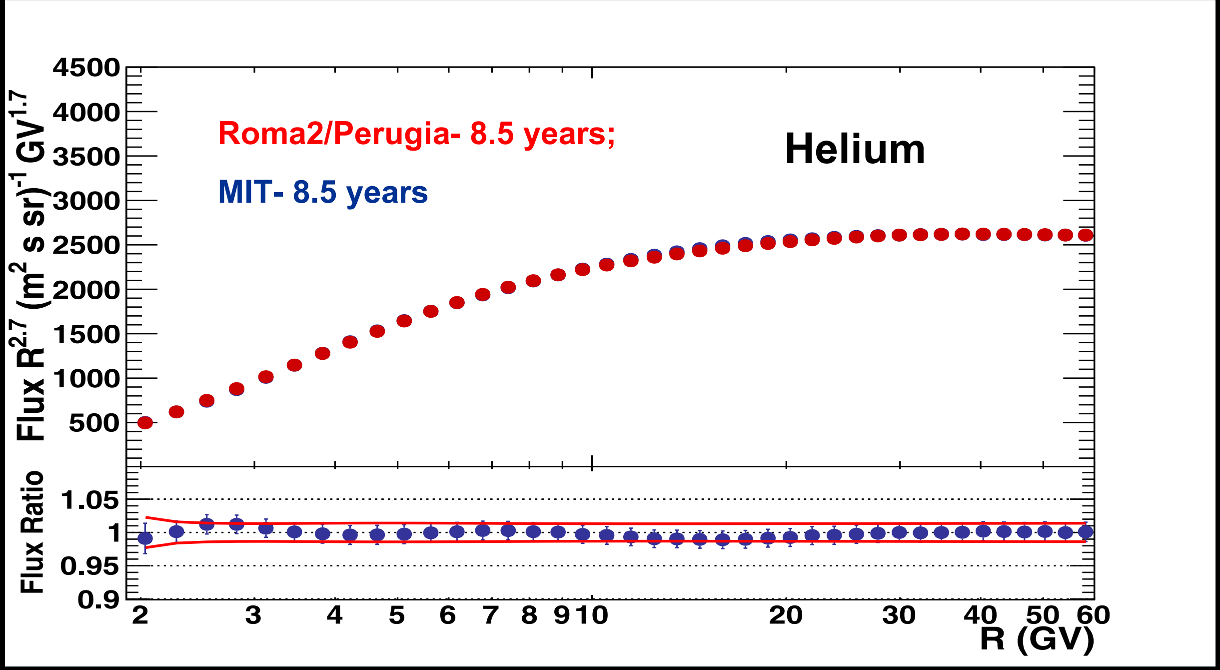
Step3: evaluating the correction for each BR starting from the integrated one

$$\delta_{BR}(t) = f_A(t)\ (\varepsilon_{Data}/\varepsilon_{MC})_{8.5years}$$

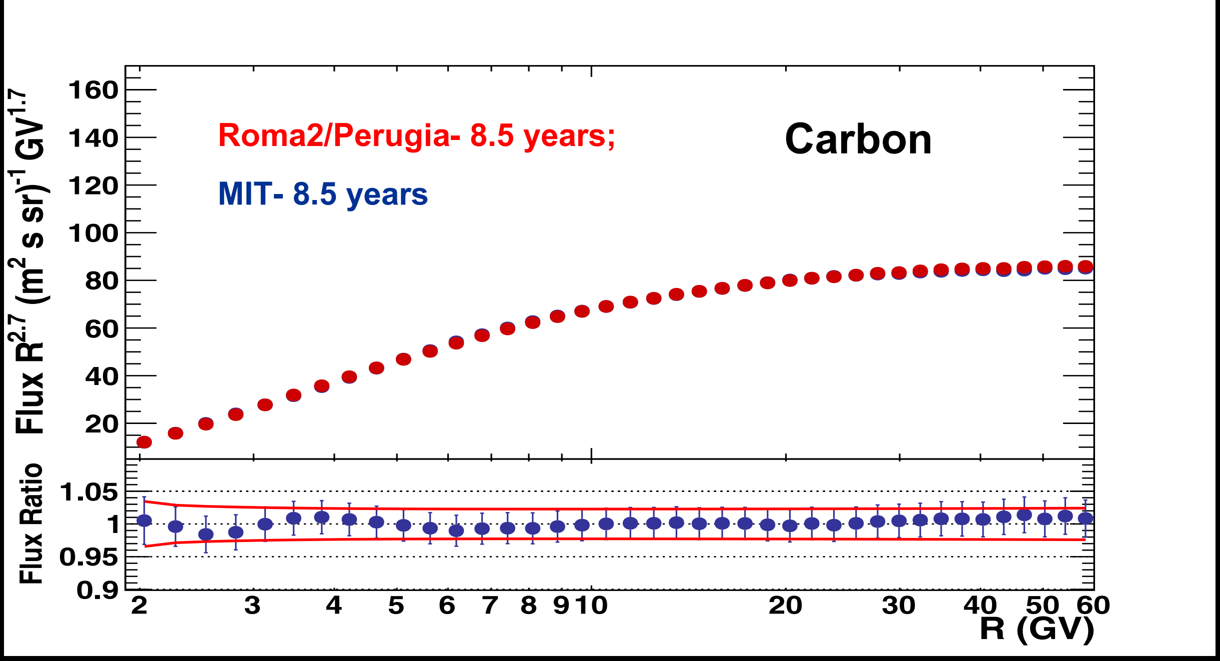


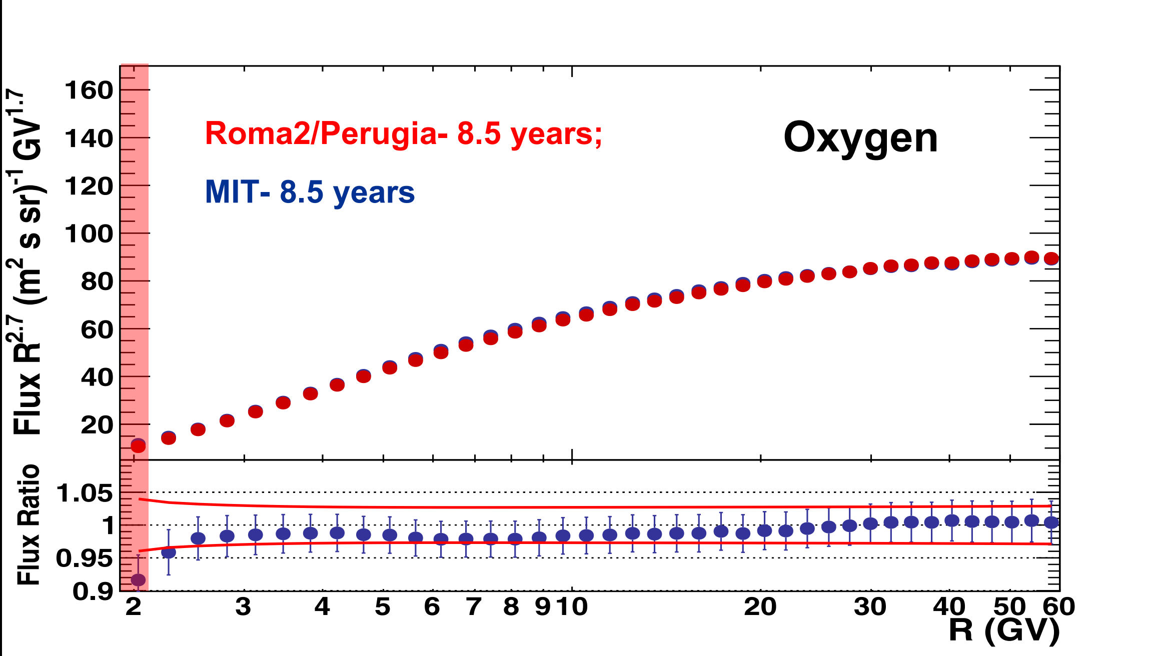
AMS-02 results

Integrated Flux- 8.5 years; May 2011- November 2019



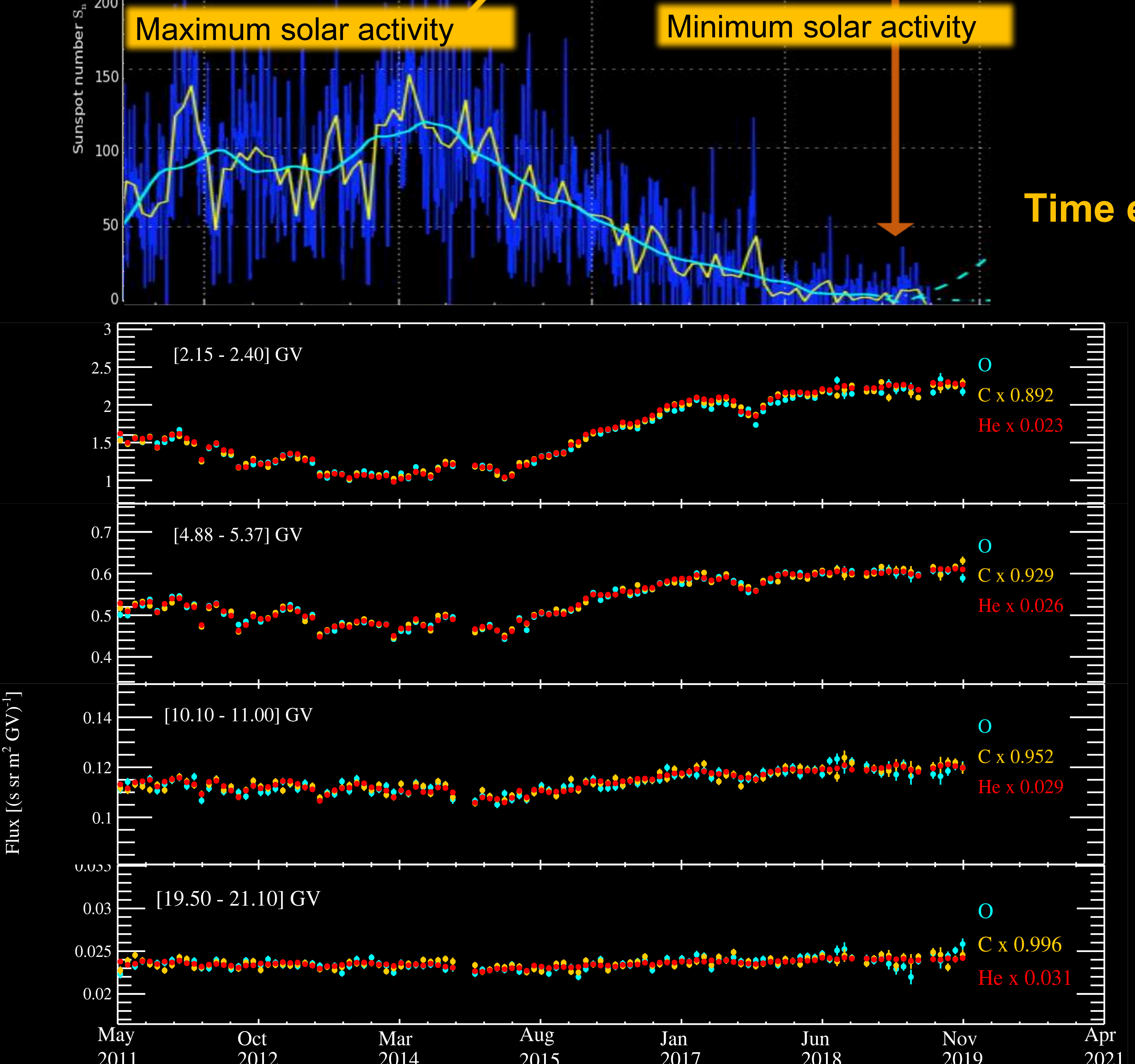
- C, He in agreement with MIT
- O in agreement with MIT above the first bin.





AMS-02 results

Time evolution of the GCR fluxes: He, C & O

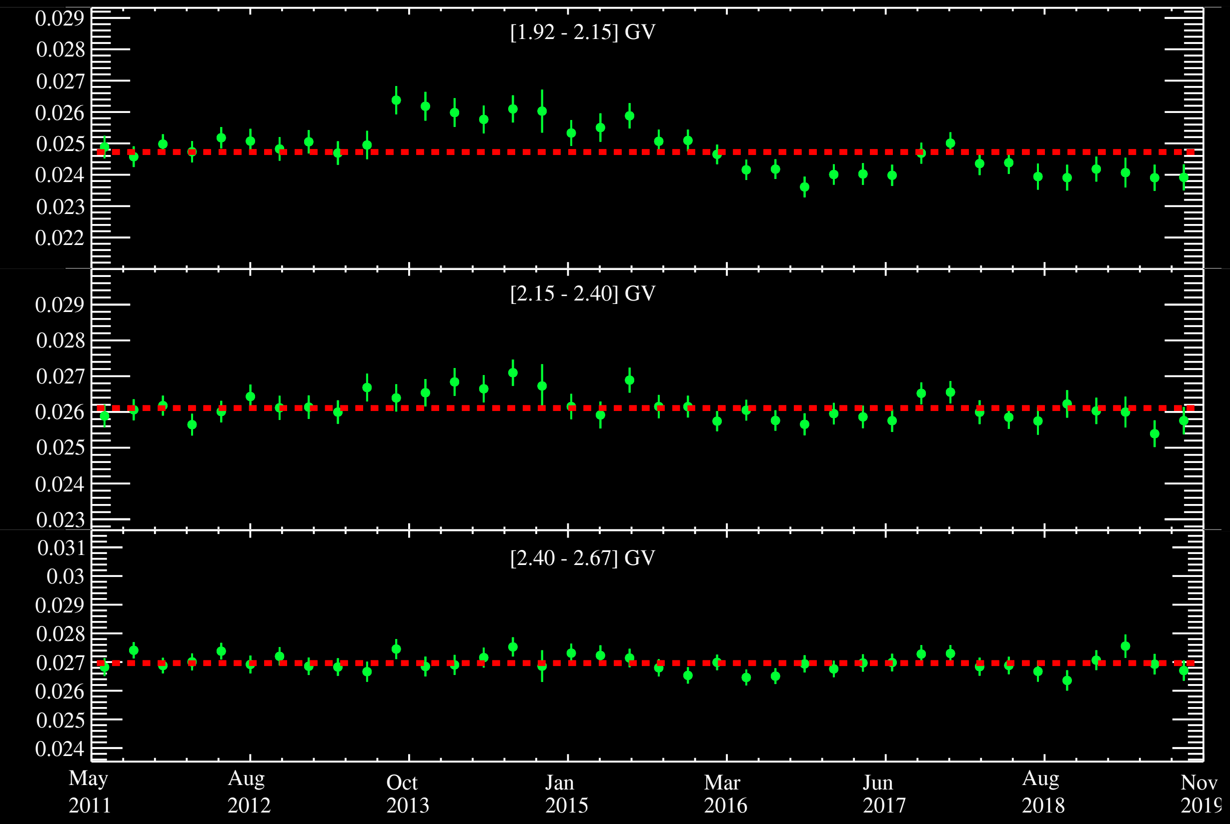


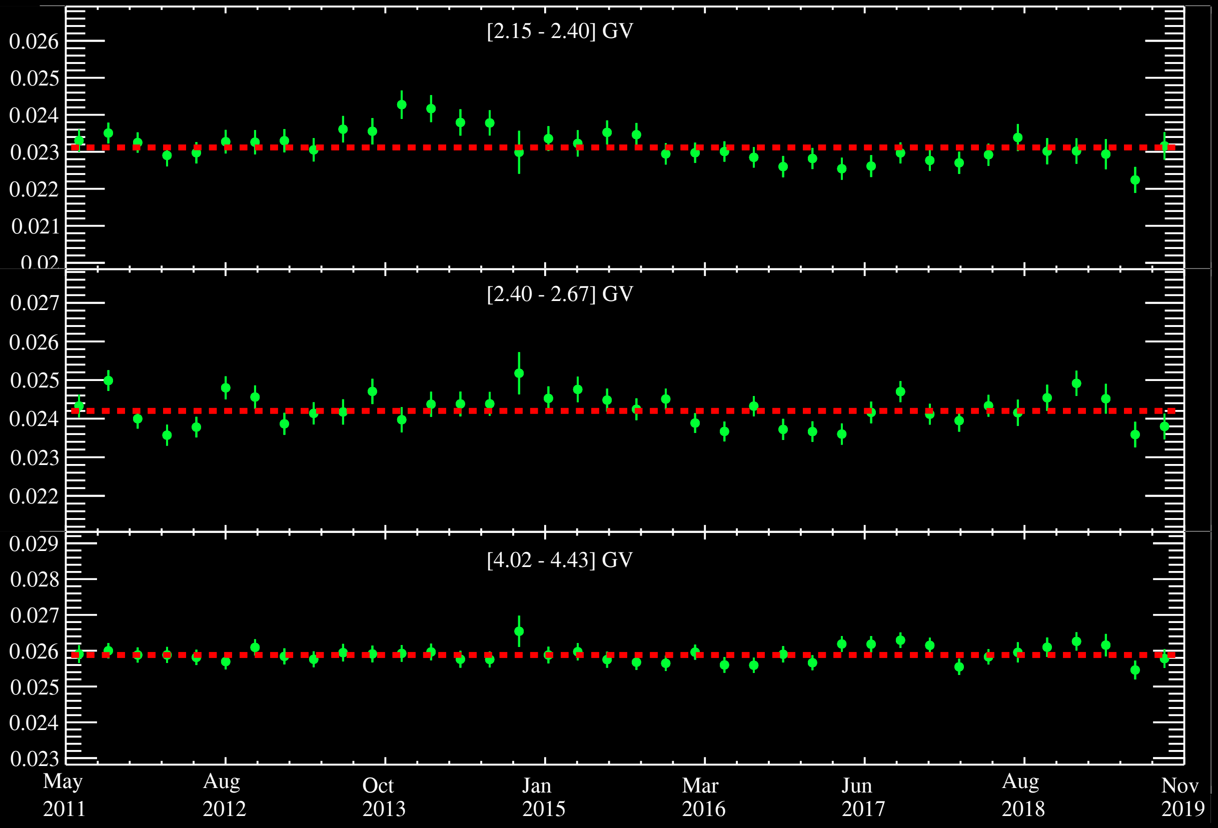
- ✓ Measurements of CR Carbon and Oxygen fluxes for 115 Bartel Rotations (27-days) up to 60 GV.
- ✓ Flux variation behavior at monthly timescales, correlated with the monthly SSN in the solar corona (in low rigidities).

AMS-02 results

Time dependent ratios (C/He & O/He)

C/He Re-binned in time; 3 BRs **O/He**

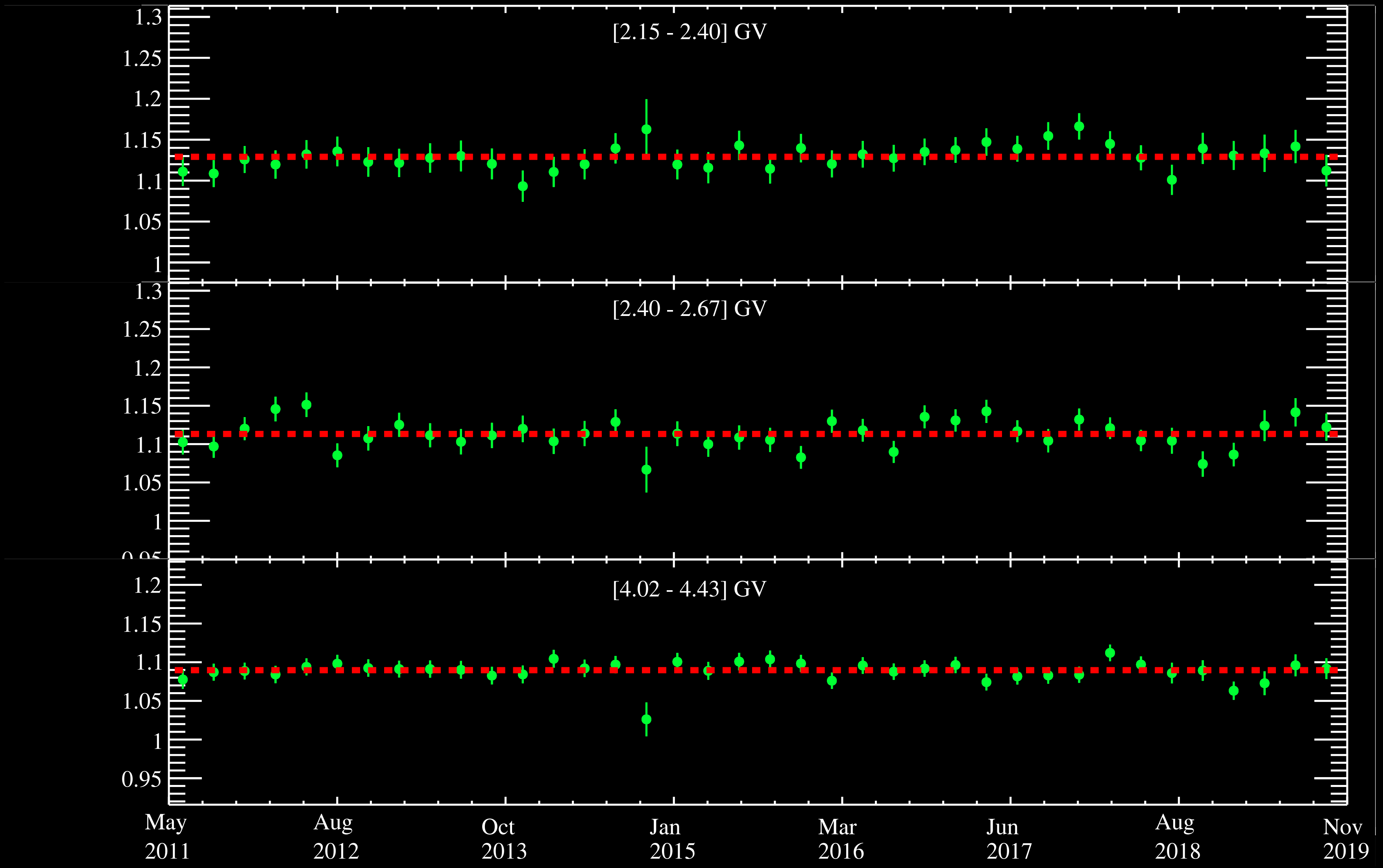




C/He and O/He are not constant in time below ~ 2.4 GV

AMS-02 results

Time dependent ratios (C/O)



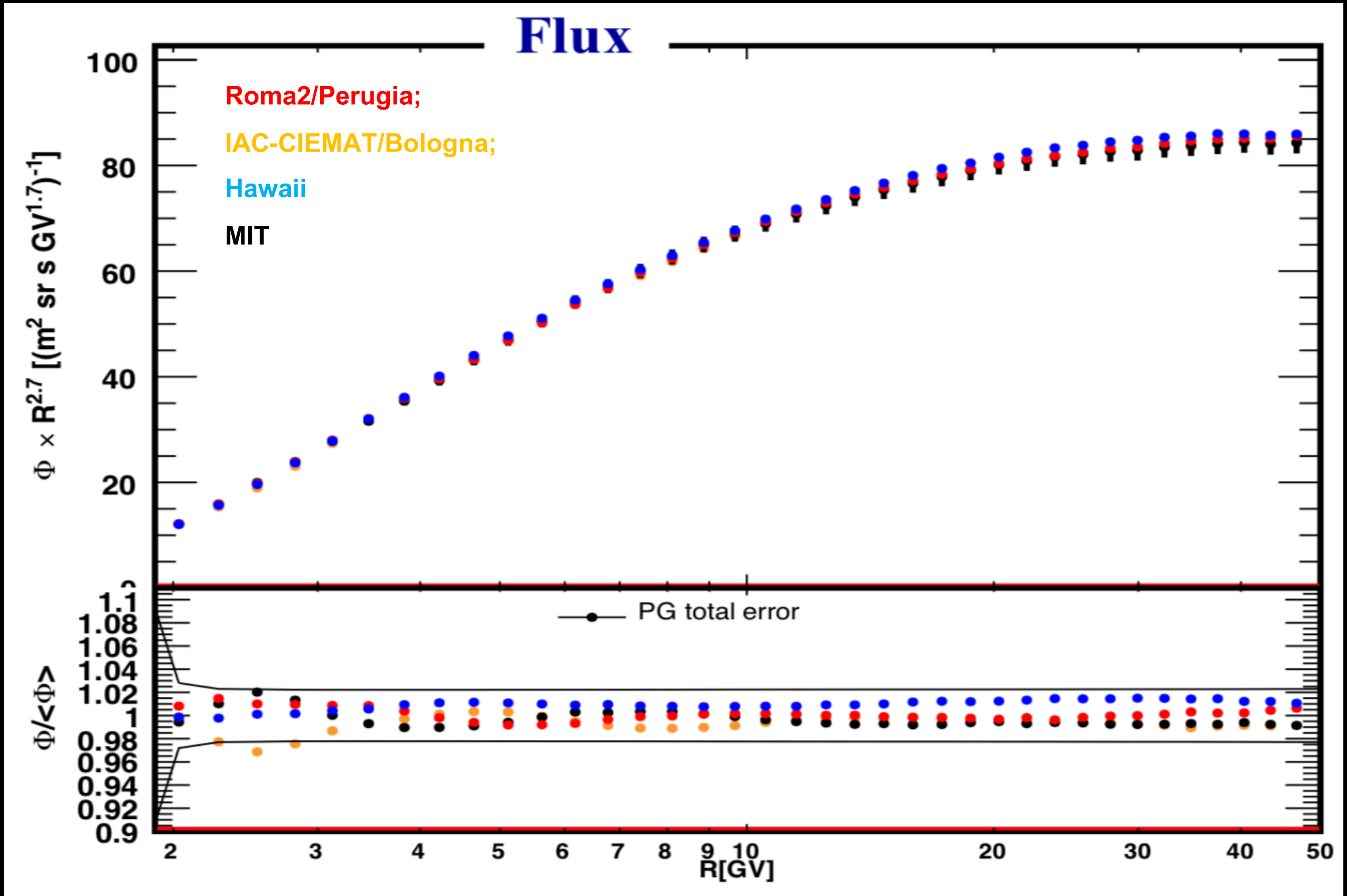
Re-binned in time; 3 BRs

C/O ratio does not show time variation in the whole rigidity range

Comparison with other groups

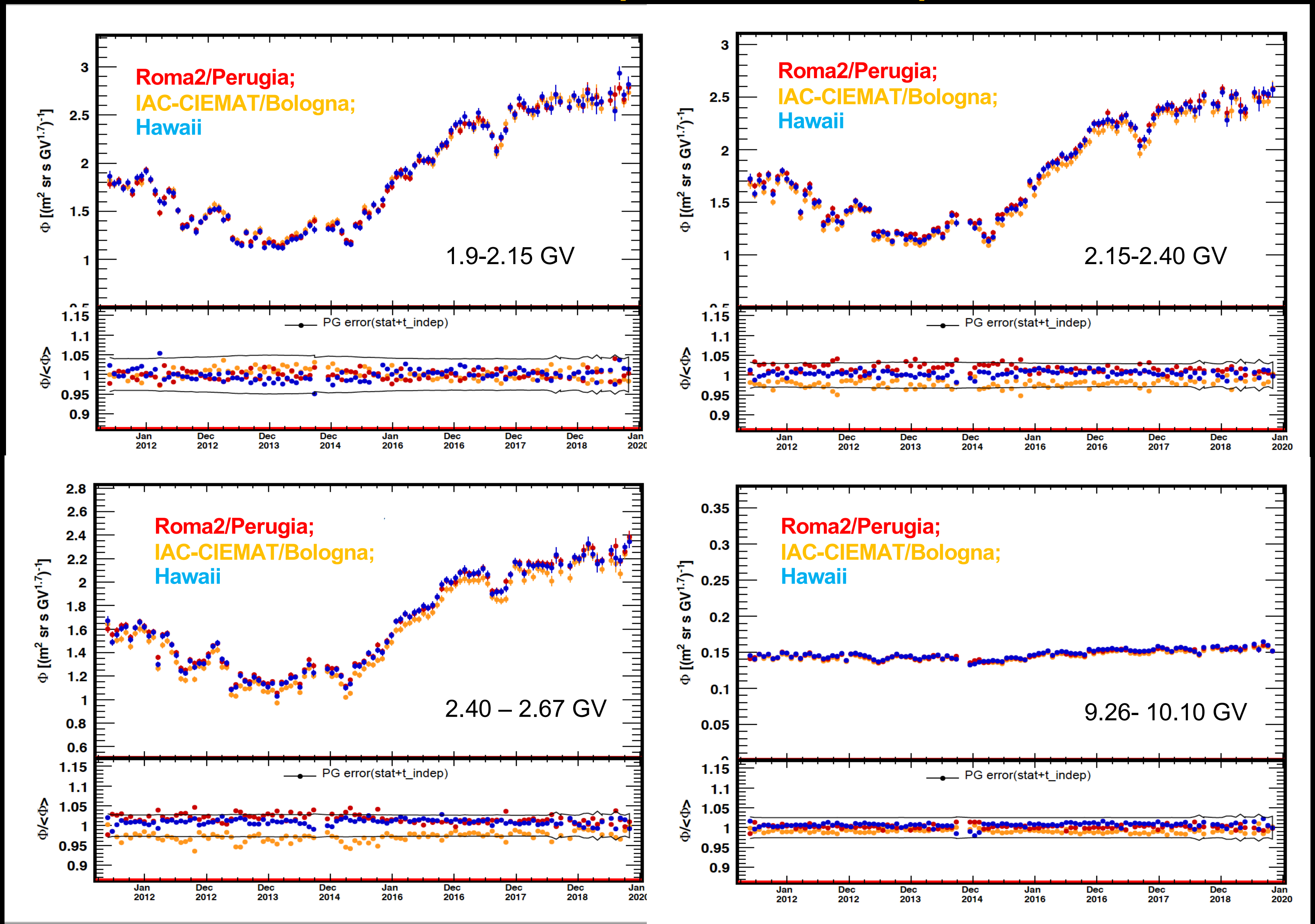
Carbon integrated flux comparison

IAC present differences for the first 3 bins with respect to the other groups.



Comparison with other groups

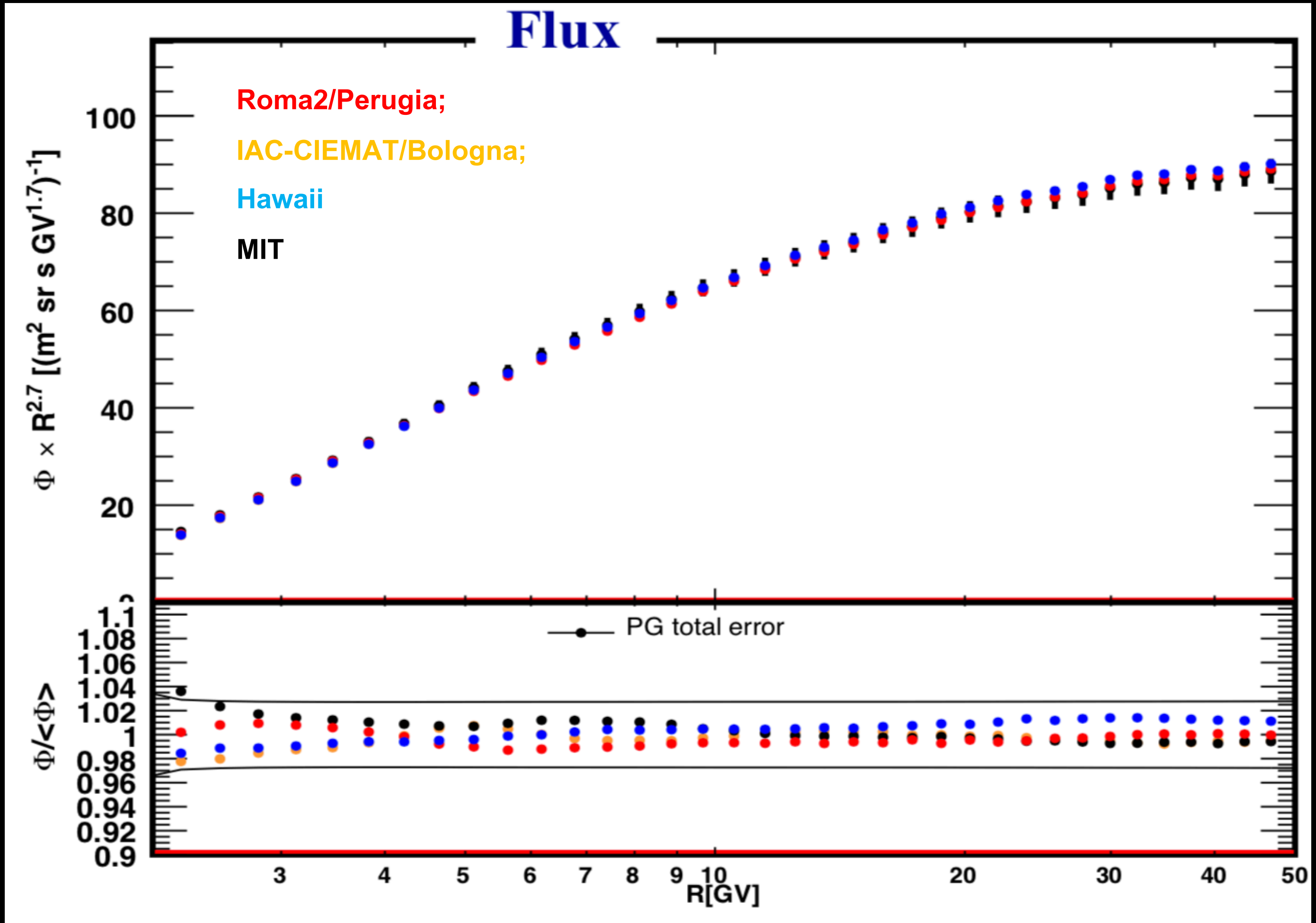
Carbon Time-dependent flux comparison



Comparison with other groups

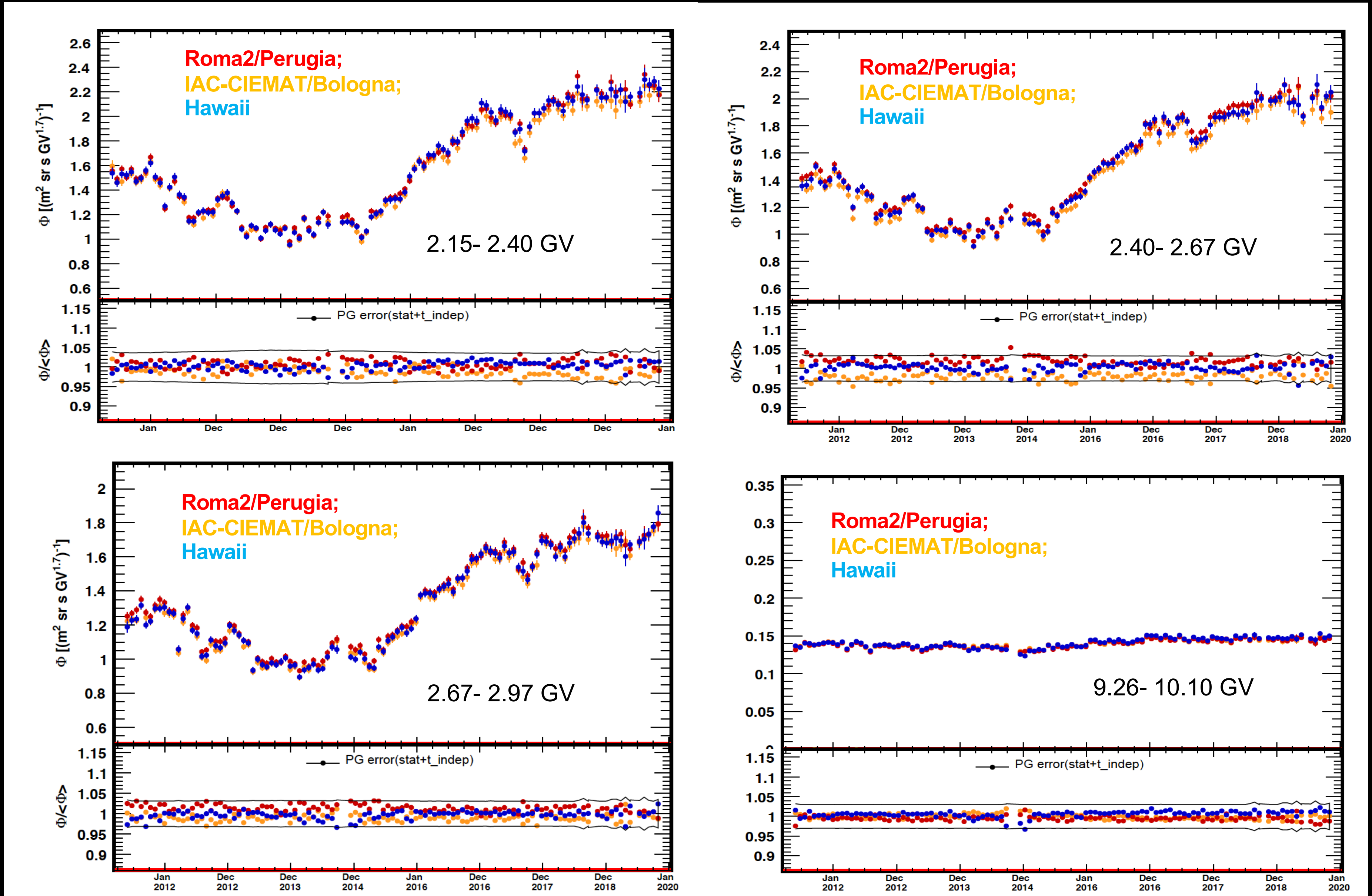
Oxygen integrated flux comparison

IAC/PG-RM/Hawaii are in a good agreement but there are differences with respect to MIT, peaking at ~4% for the first bin (2.03-2.27GV).



Comparison with other groups

Oxygen Time-dependent flux comparison



Paper draft on time dependent light nuclei fluxes

Time Structures in Proton, Helium, Carbon, Oxygen Cosmic Rays Measured by the Alpha Magnetic Spectrometer

Abstract

We present the precision measurement of time structures in 8.5 years, from Bartels rotation 2426 to 2540, of the proton, helium, carbon, and oxygen fluxes at rigidities from 1 to 60 GV based on 6.3×10^9 nuclei collected with the Alpha Magnetic Spectrometer aboard the International Space Station. We observe that the proton, helium, carbon, and oxygen fluxes show similar time variations. The flux ratio of He/(C+O), p/(C+O), and p/He are time dependent. The magnitude of these time variations decreases with increasing rigidity. The C/O flux ratio is time independent. In addition, these results allow the derivation of cosmic ray spectra outside the heliosphere in a unexplored rigidity range.

Paper draft on time dependent light nuclei fluxes

Content of the paper

- Measurement performed with data up to Nov 2019
- First time measurement of C and O fluxes vs time from 1.92 GV and 2.15 GV up to 60 GV.

Paper draft on time dependent light nuclei fluxes

Content of the paper

- Measurement performed with data up to Nov 2019
- First time measurement of C and O fluxes vs time from 1.92 GV and 2.15 GV up to 60 GV.
- Updated measurement of p and He fluxes vs time with higher statistics.

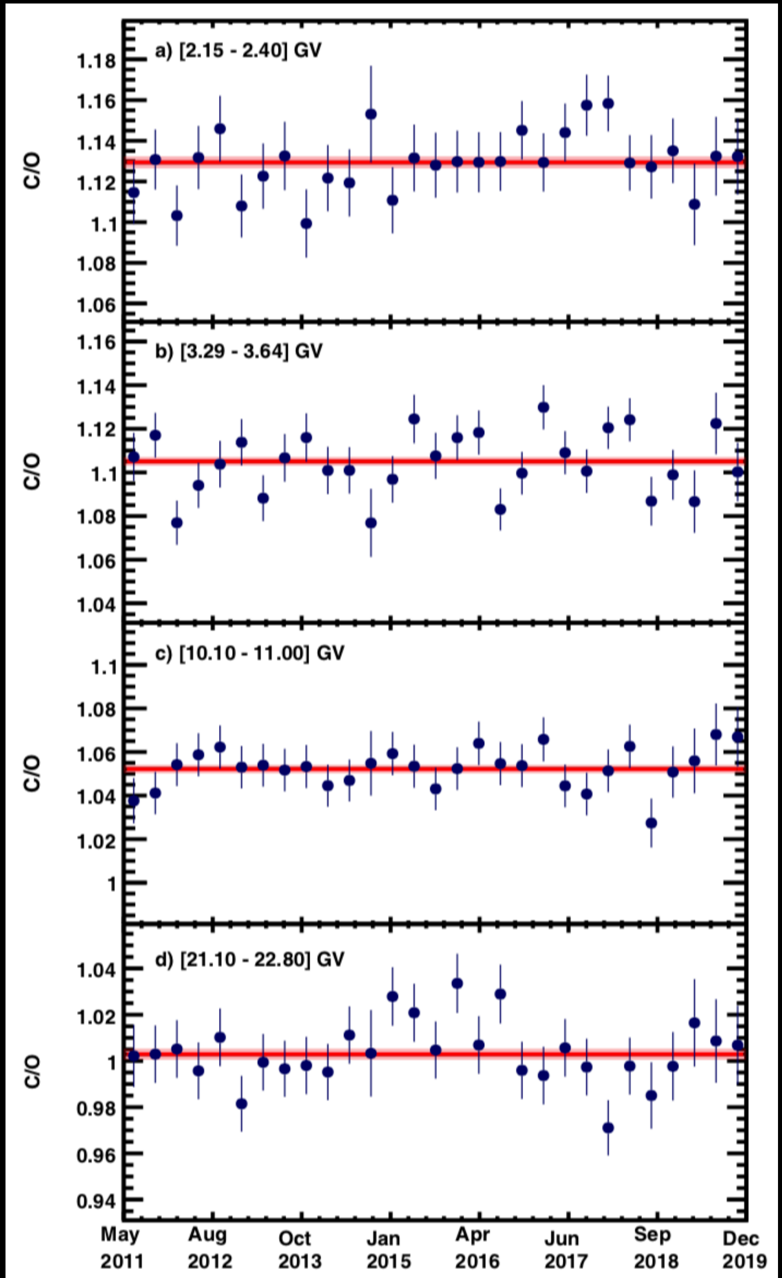
Observations:

- All fluxes exhibit similar long-term and short-term time variation.

Paper draft on time dependent light nuclei fluxes

Content of the paper

- Measurement performed with data up to Nov 2019
- First time measurement of C and O fluxes vs time from 1.92 GV and 2.15 GV up to 60 GV.
- Updated measurement of p and He fluxes vs time with higher statistics.
- Study of the time dependence of interesting flux ratios: C/O



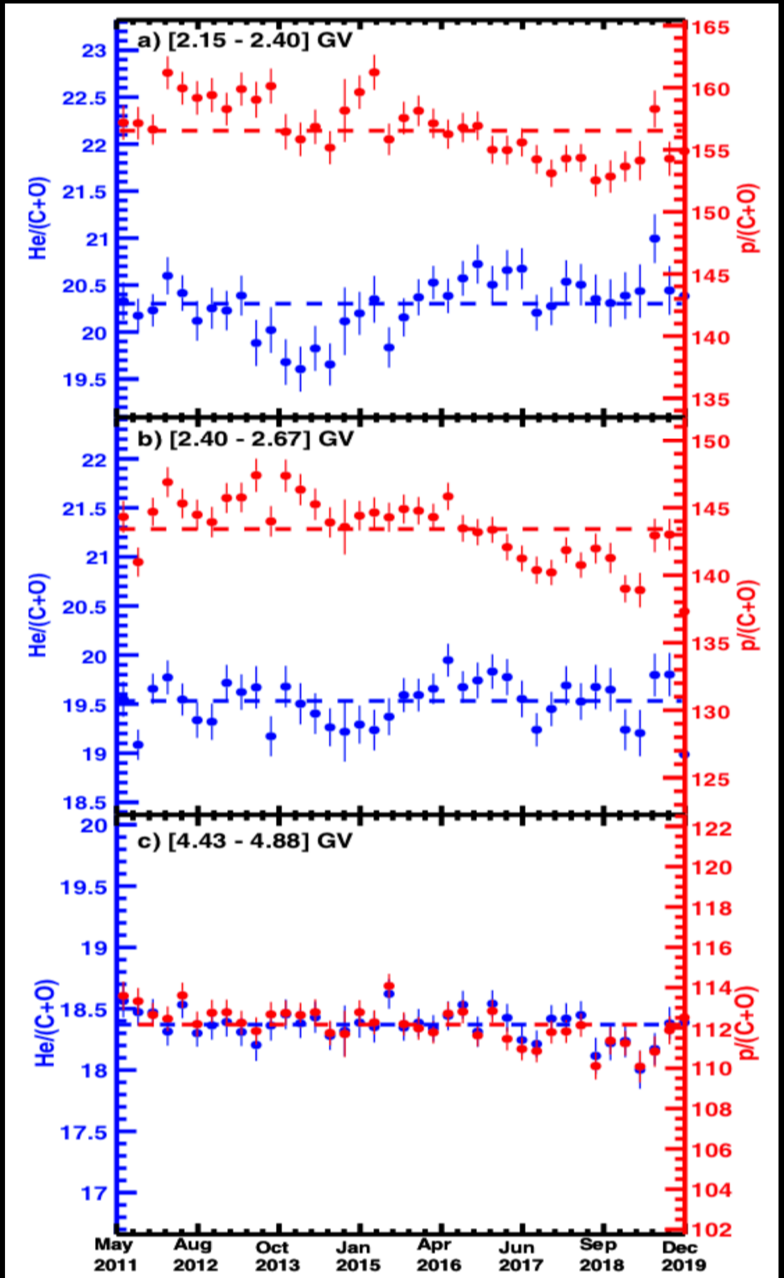
✓ **C/O is constant in time at all rigidities**

✓ C and O have similar mass-to-charge ratios, the observation that the C/O flux ratio is constant in time implies that the C and O LIS have a very similar rigidity dependence above 2 GV

Paper draft on time dependent light nuclei fluxes

Content of the paper

- Measurement performed with data up to Nov 2019
- First time measurement of C and O fluxes vs time from 1.92 GV and 2.15 GV up to 60 GV.
- Updated measurement of p and He fluxes vs time with higher statistics.
- Study of the time dependence of interesting flux ratios: C/O
- Study of the time dependence of interesting flux ratios: p/(C+O), He/(C+O)



✓ **He/(C+O) and p/(C+O) show long-term time dependence below 2.4, and 4.43 GV**

✓ He, C and O have similar mass-to-charge ratios, while the observation that the He/(C+O)flux ratio is not constant in time implies that the He and (C,O) LIS have different rigidity dependences above 2 GV.

Conclusions

- ✓ Precise measurement of helium, carbon, and oxygen time dependence fluxes and their ratios (May 2011 and Nov 2019 over rigidities from 2 GV to 60 GV).
- ✓ Carbon and oxygen fluxes are the first measurements as a function of time in this rigidity range
- ✓ Helium spectrum have been measured with a factor 5 larger statistics and over an extended time interval with respect to previous AMS publication.
- ✓ The amplitude of the time variations of the fluxes decreases with increasing rigidity.
- ✓ The C/O flux ratio is constant in time, 2- 60 GV.
- ✓ The He/(C+O) ratio shows significant time variations with decreasing amplitudes while rigidity increases.