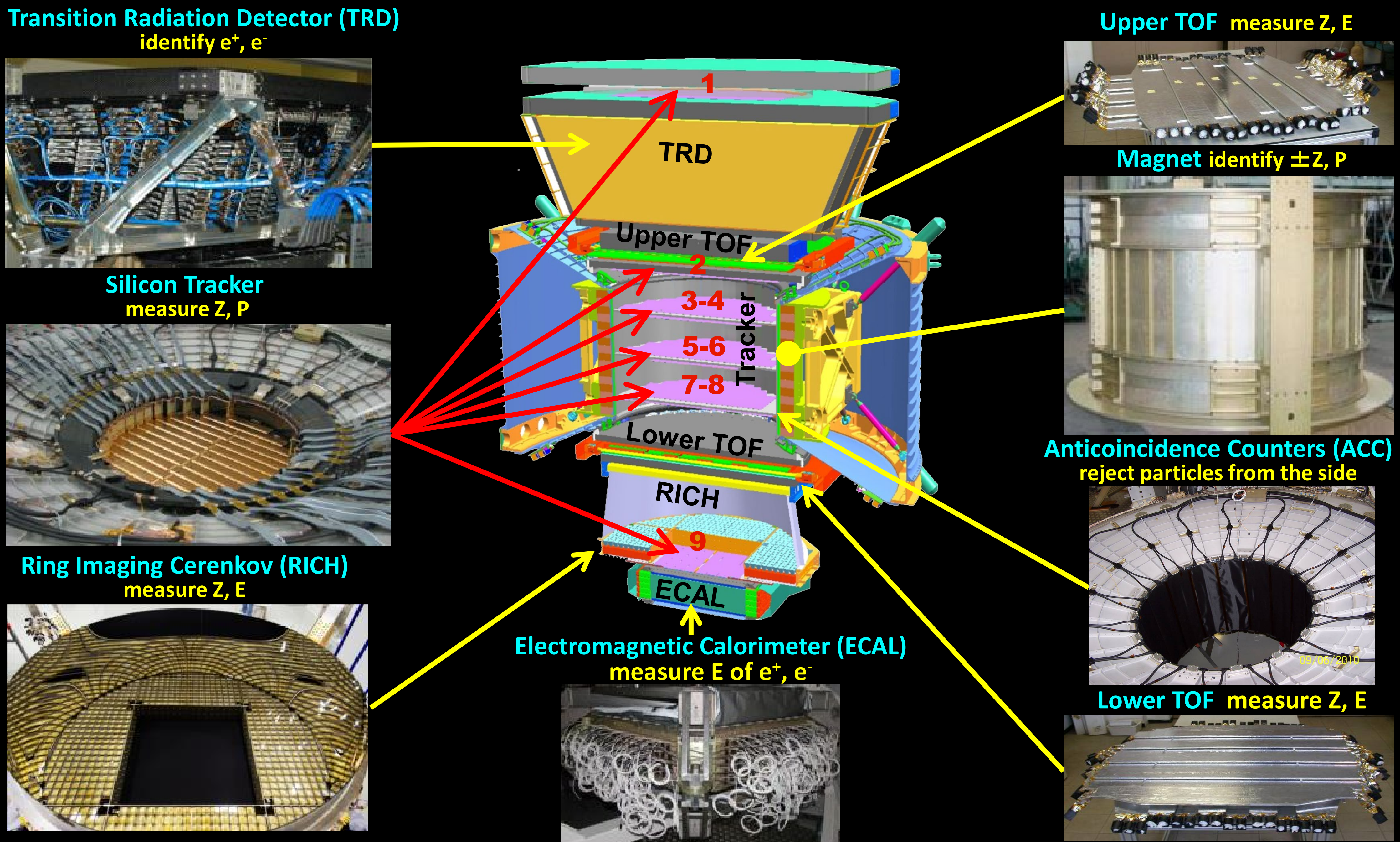
The Latest Time Variation Measurements with AMS

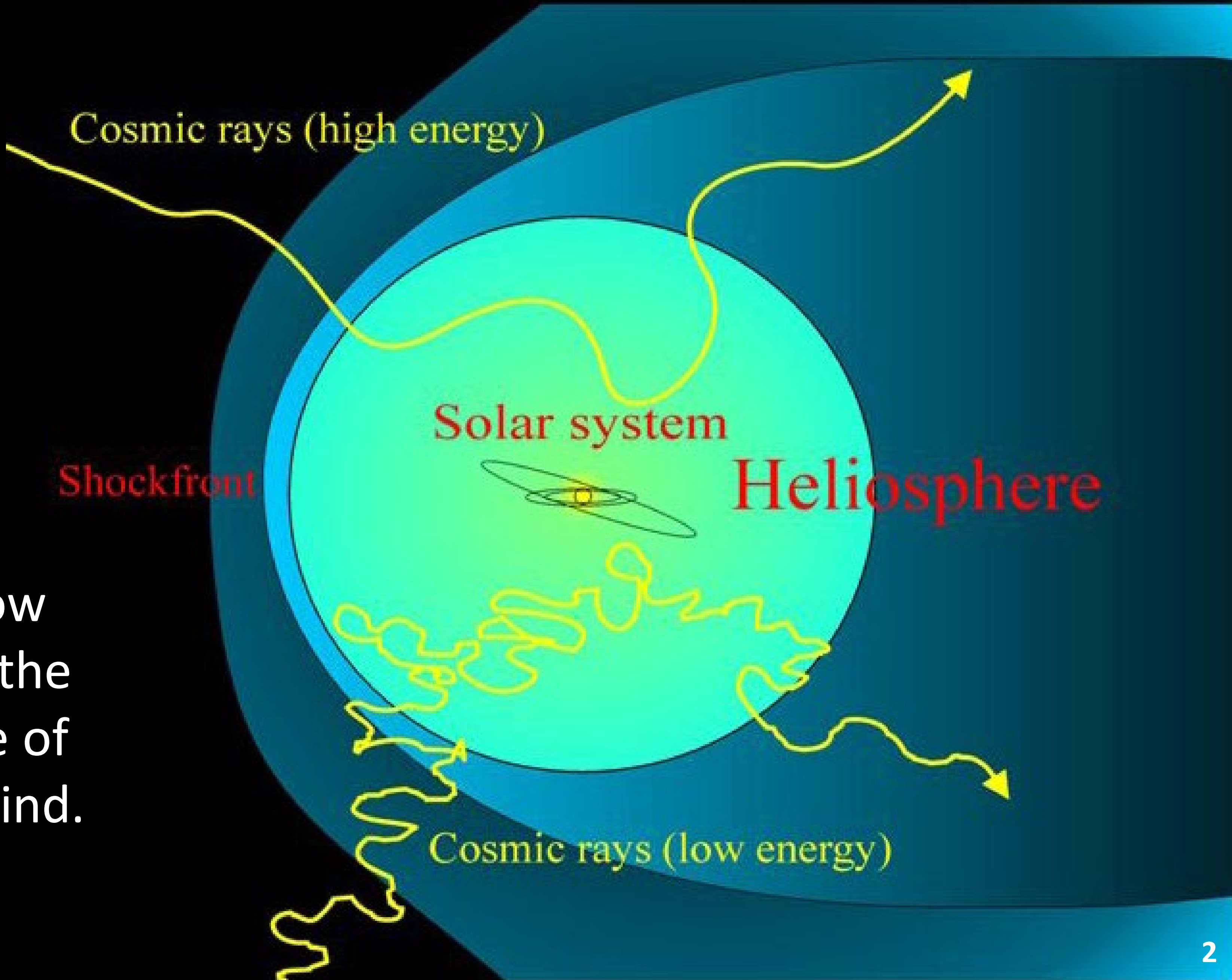
Zetong Sun
Institute of High Energy Physics (IHEP)
on behalf of the AMS collaboration

14th Aug. 2024

AMS is a Space Version of a Precision Detector Used in Accelerators

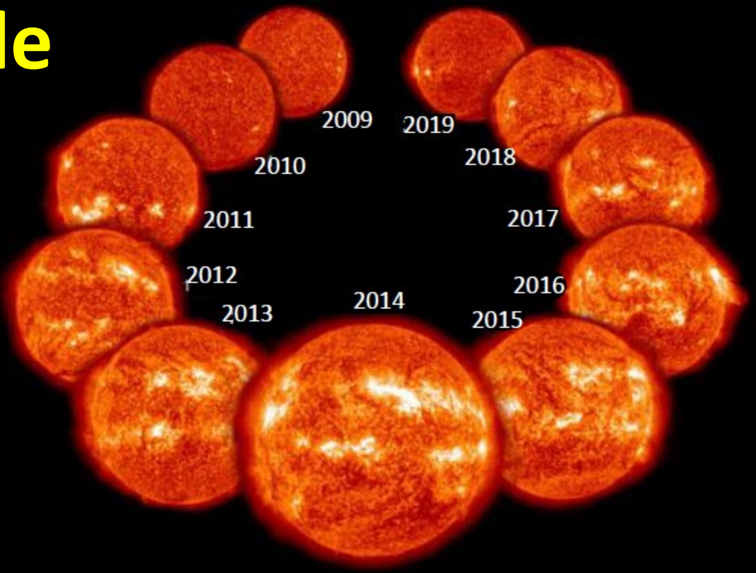


Solar Modulation of Cosmic Rays



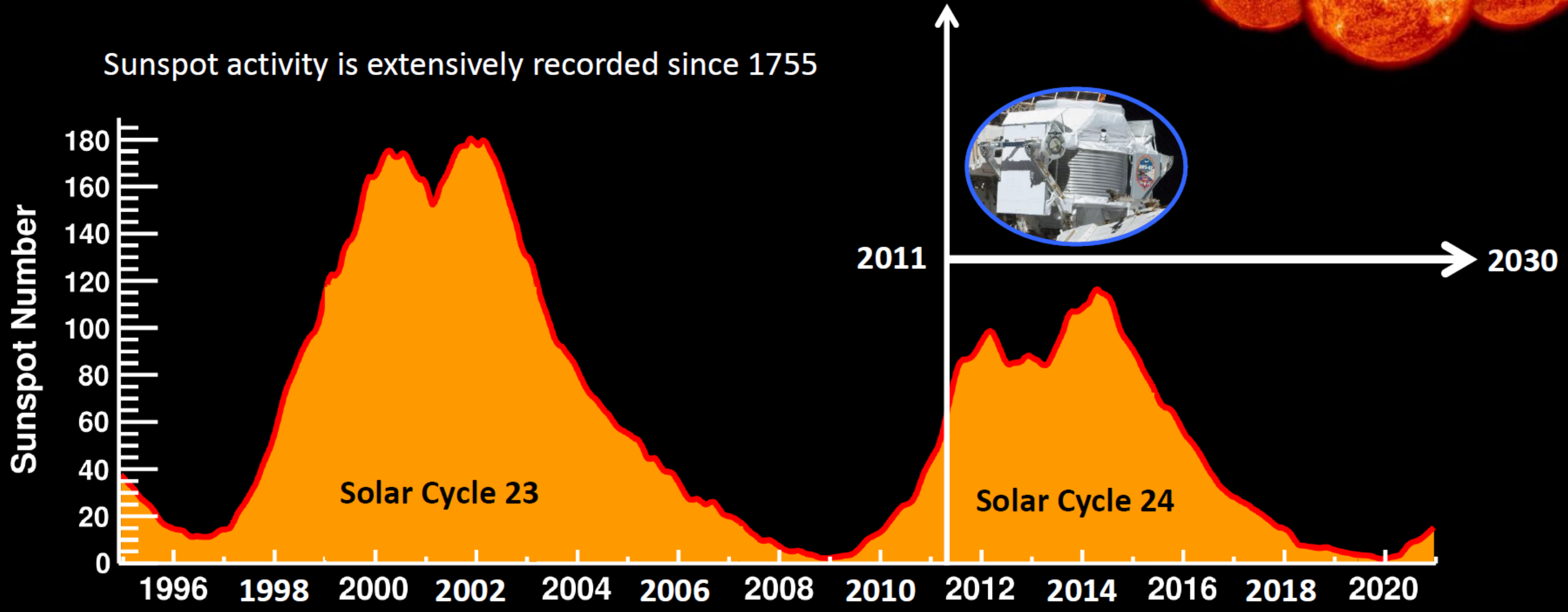
Cosmic ray intensity at low energies is modulated by the Sun through the influence of magnetic field and solar wind.

Long Term Variation: Solar Cycle



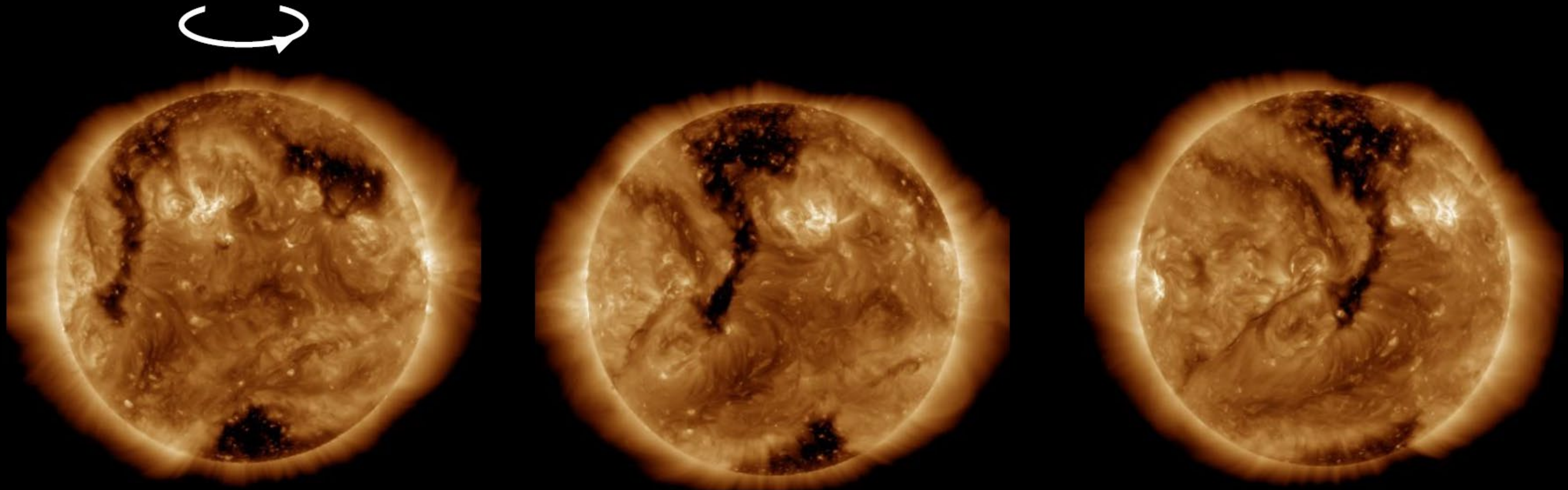
The most significant long-term scale variation of cosmic rays is related to the 11-year solar cycle.

Sunspot activity is extensively recorded since 1755



Cosmic Ray Recurrent Variation in Short Scale

Short scale variation of cosmic rays are related to Sun’s rotation (Bartels Rotation, **BR**: 27days).



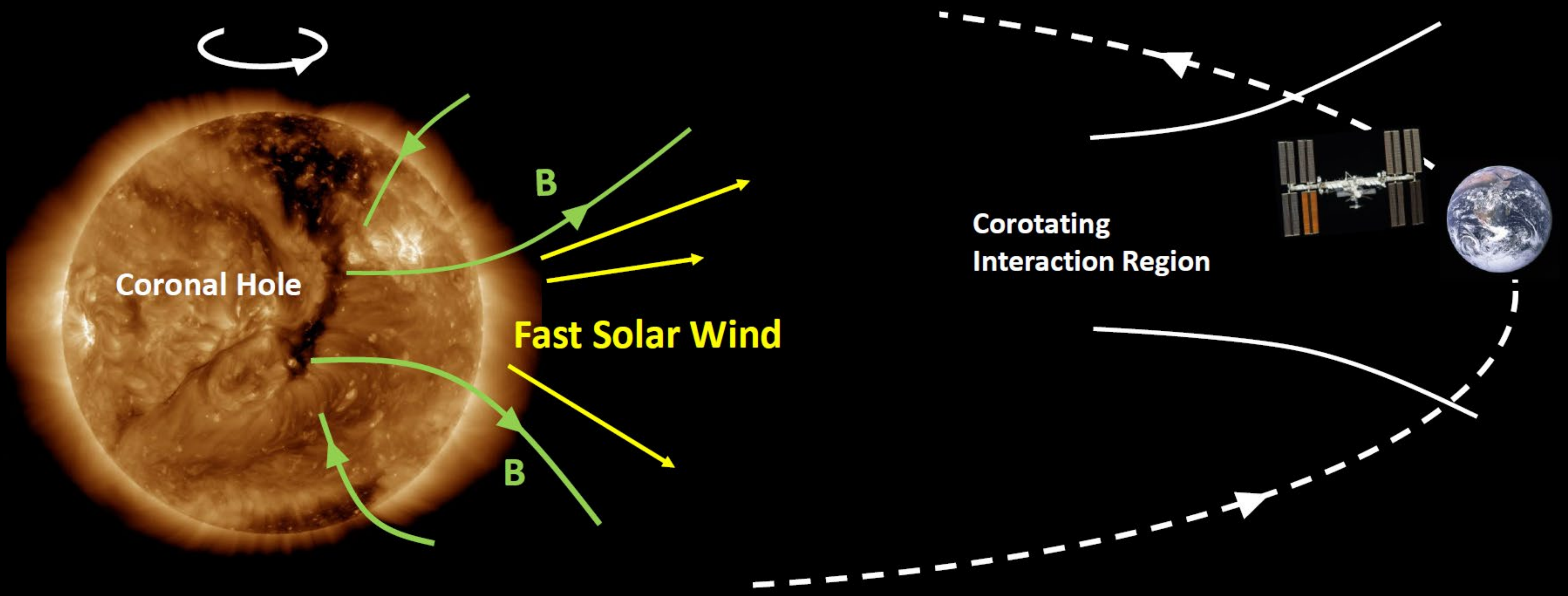
2016-03-22 **2016-03-24** **2016-03-26**

Image taken by Dynamics Observatory (SDO), NASA

Coronal holes are regions where plasma density and temperature are lower, so they appear **darker** in images.

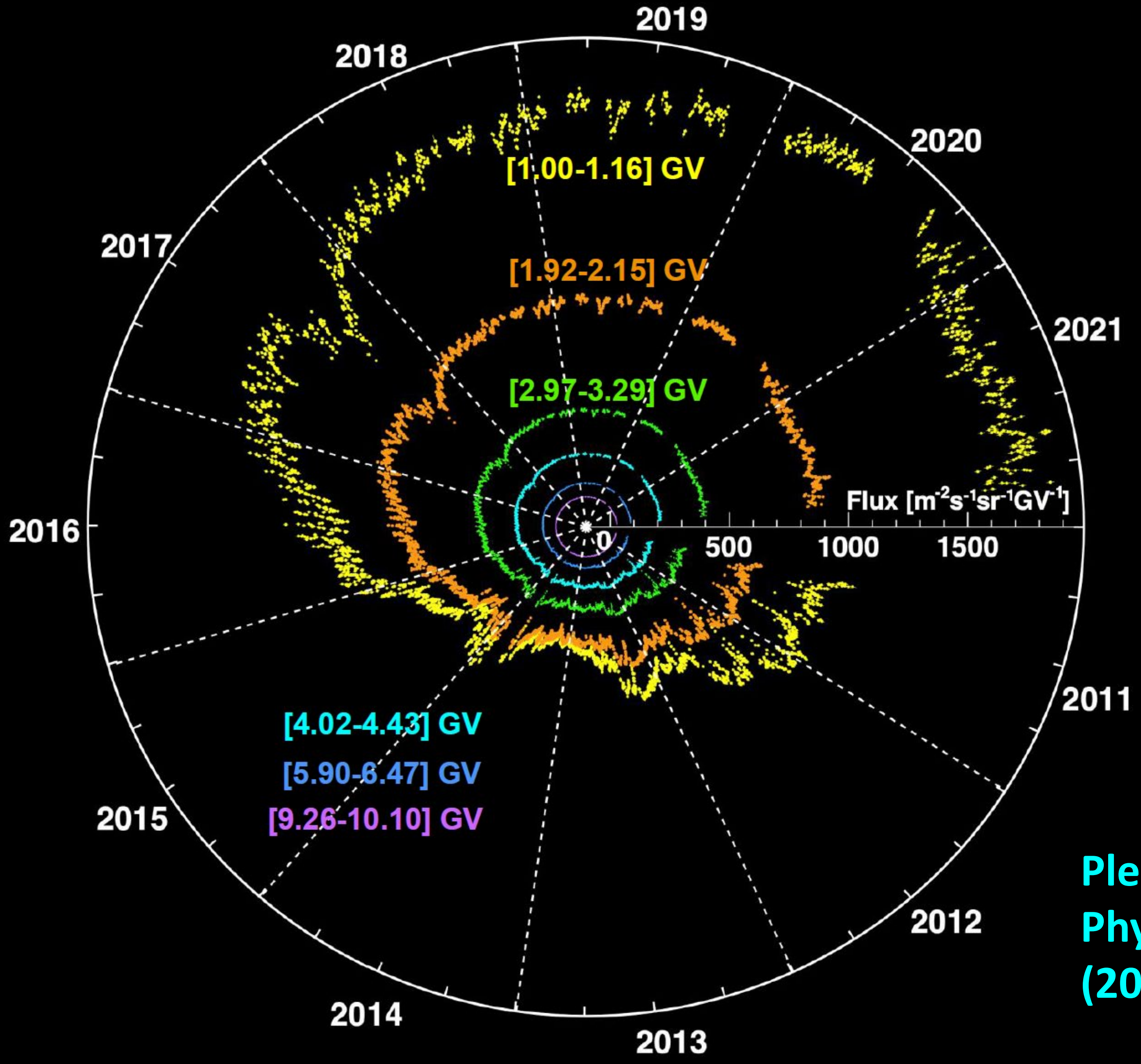
Cosmic Ray Recurrent Variation in Short Scale

Coronal Holes are sources of high speed solar wind affecting the Earth.



Precision measurement of the individual species of cosmic rays in a solar cycle provide unique inputs for the understanding of cosmic rays in the heliosphere.

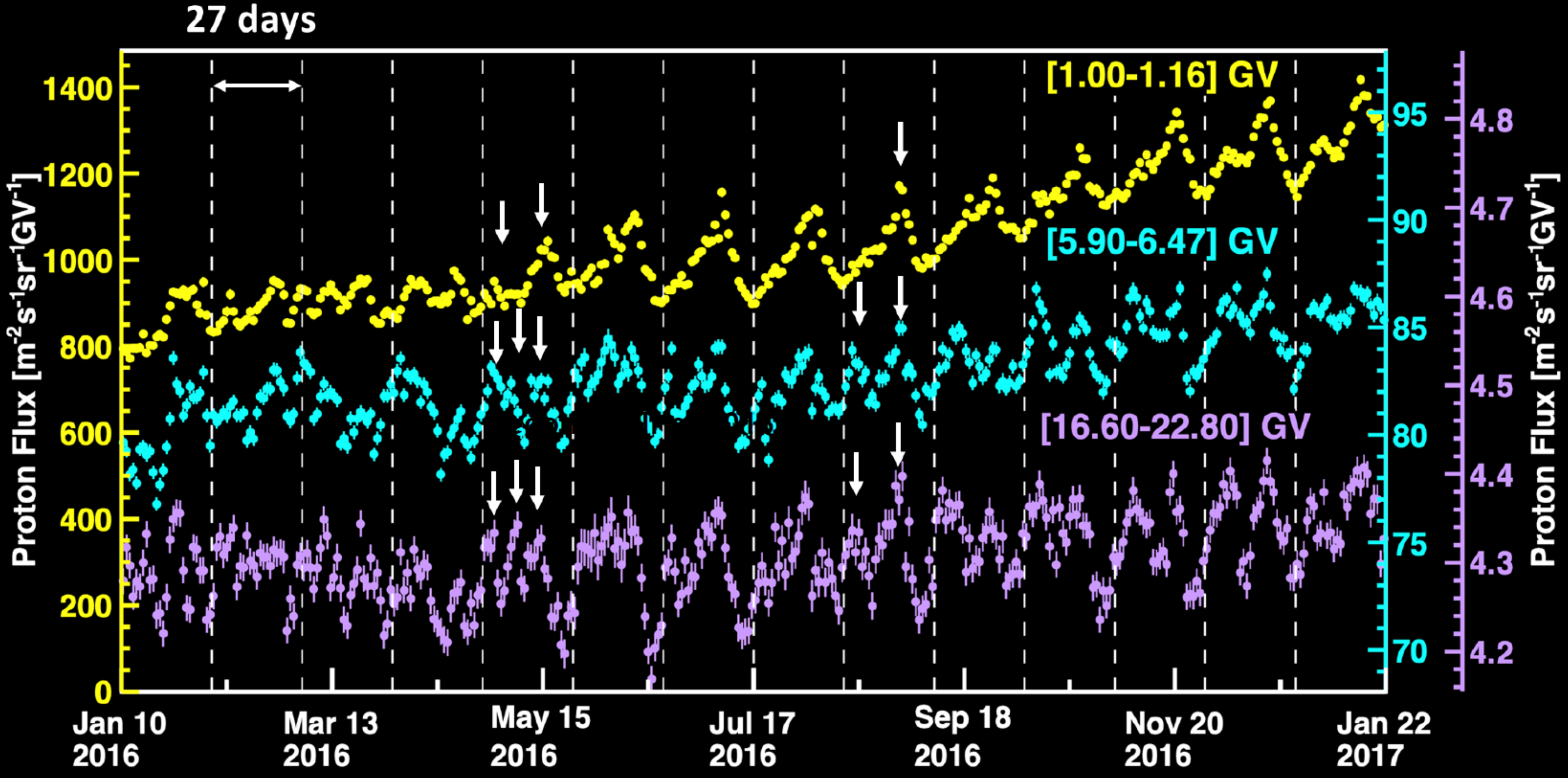
AMS Daily Proton Flux



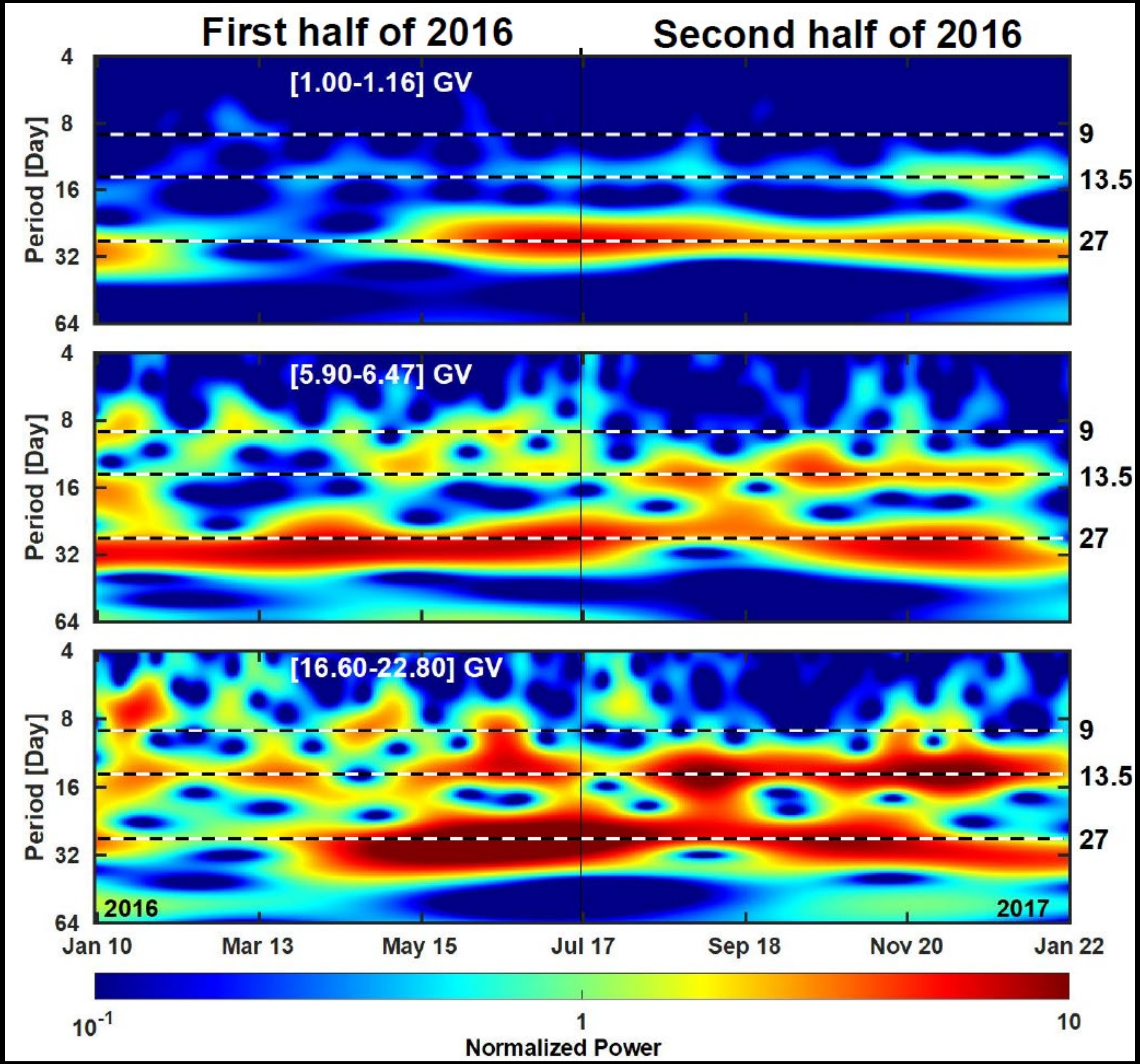
Please refer to
Phys. Rev. Lett. 127, 271102
(2021)

Recurrent Proton Flux Variation in 2016

Double-peak and triple-peak structures are visible in different Bartels rotations.



Wavelet Analysis of Proton Fluxes in 2016



To study the recurrent time variations in the daily proton fluxes, a **wavelet time-frequency** technique was used.

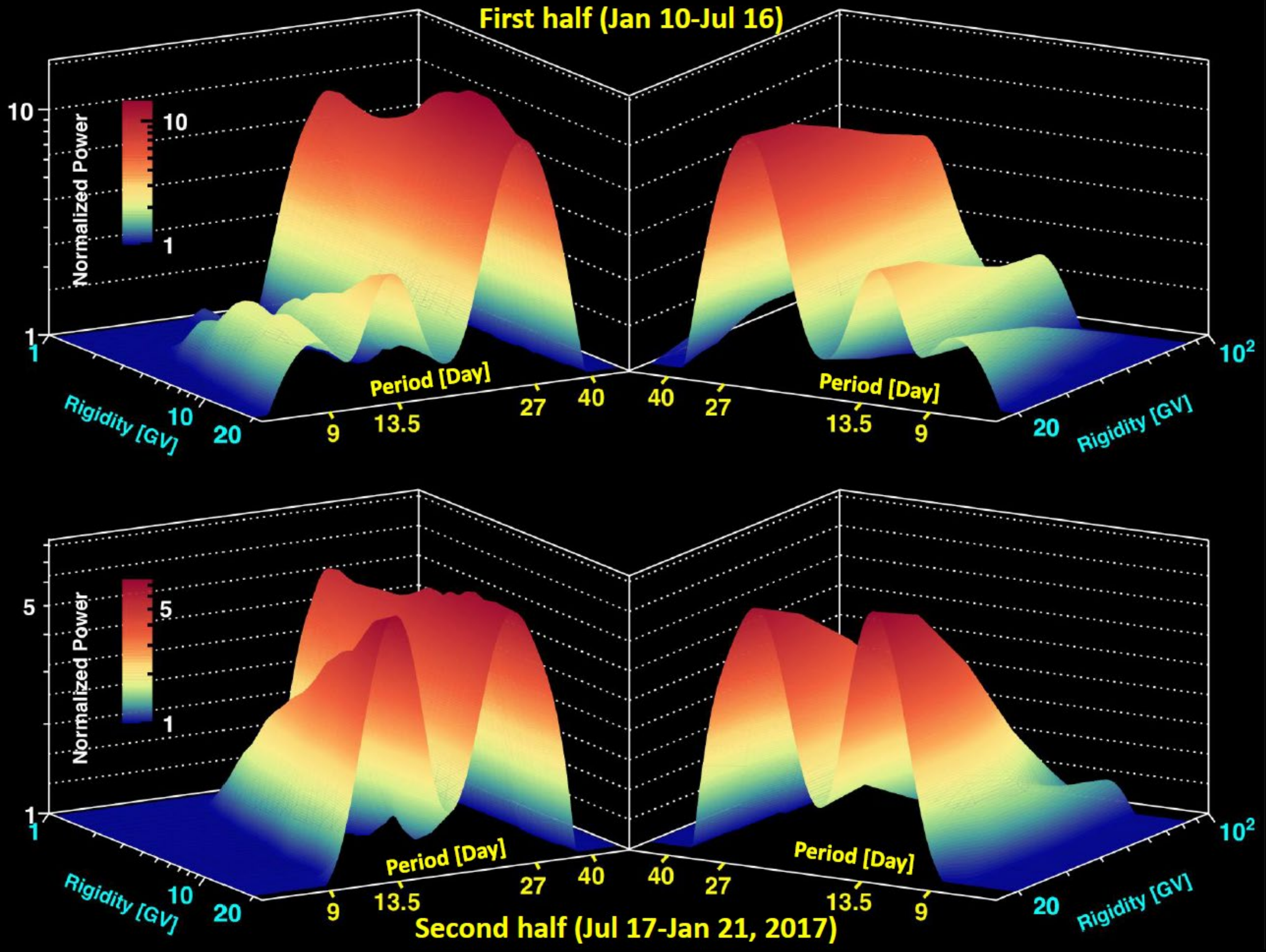
To show the strength of the periodicity, **the normalized power** is defined by the power divided by **the variance** of the time series.

Periods of 9, 13.5 and 27days are observed in 2016.

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.

Periodicities of Daily Proton Fluxes in 2016

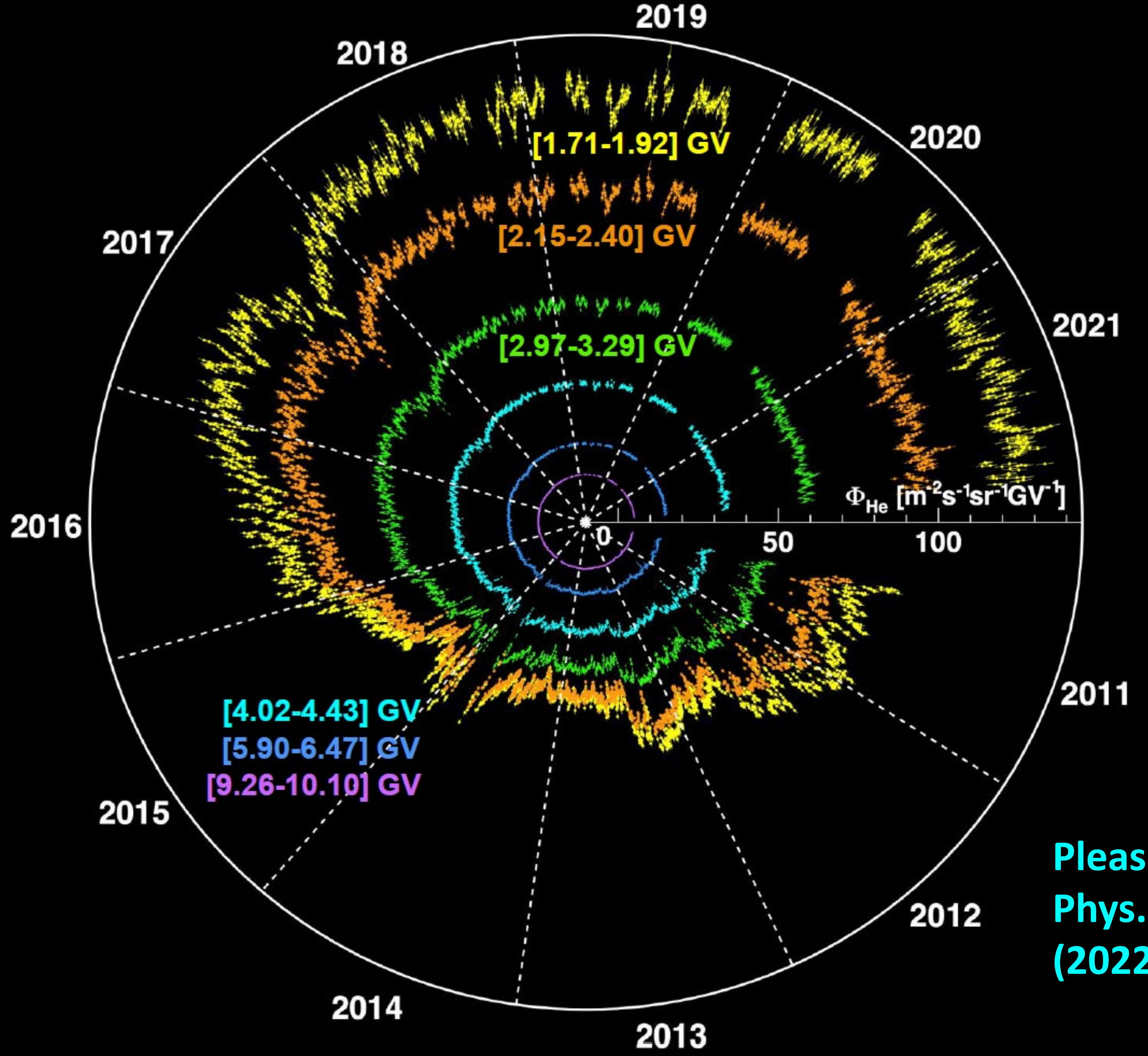


Unexpectedly, the strength of **9-day and 13.5-day periodicities** increases with increasing rigidity up to **~10 GV** and **~20 GV**, respectively. Then the strength decreases with increasing rigidity up to **100 GV**.

Thus, the AMS results do not support the general conclusion that the strength of the periodicities always decreases with increasing rigidity.

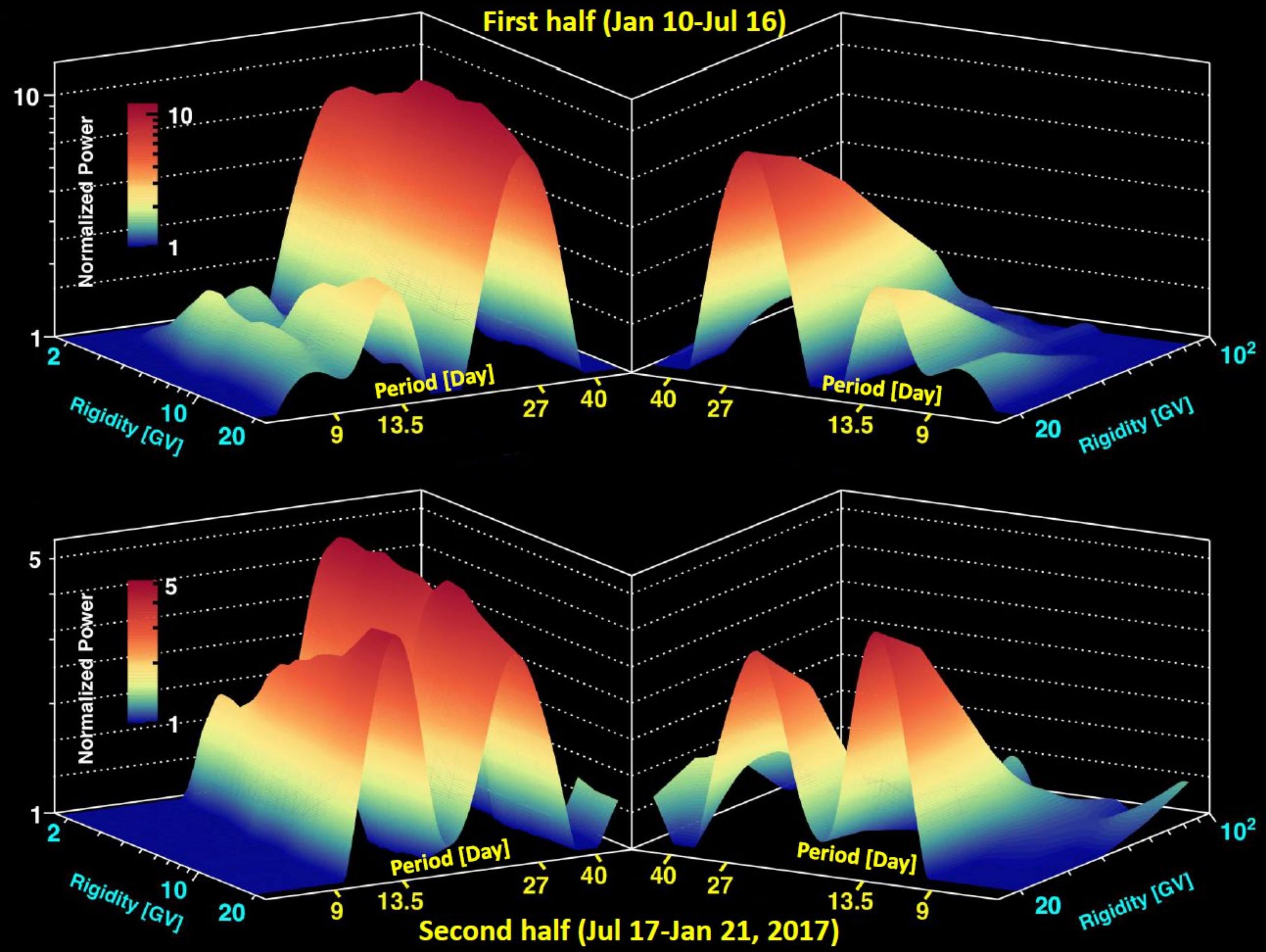
Phys. Rev. Lett. 127, 271102 (2021)

AMS Daily Helium Flux



Please refer to
Phys. Rev. Lett. 128, 231102 (2022)

Periodicities of Daily Helium Fluxes in 2016



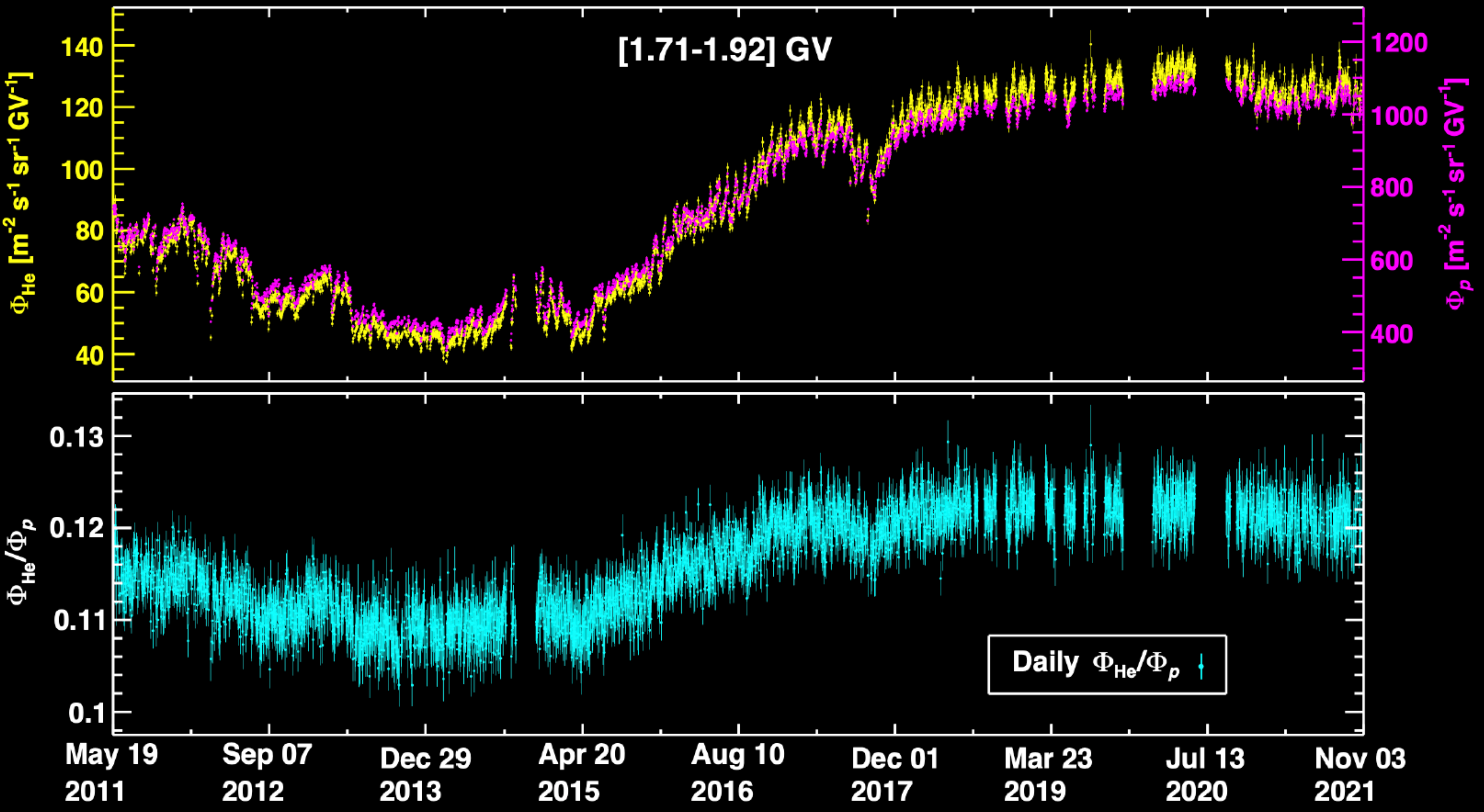
Similar periodic structure are observed for helium.

The AMS results do not support the general conclusion that the strength of the periodicities always decreases with increasing rigidity.

Phys. Rev. Lett. 128, 231102 (2022)

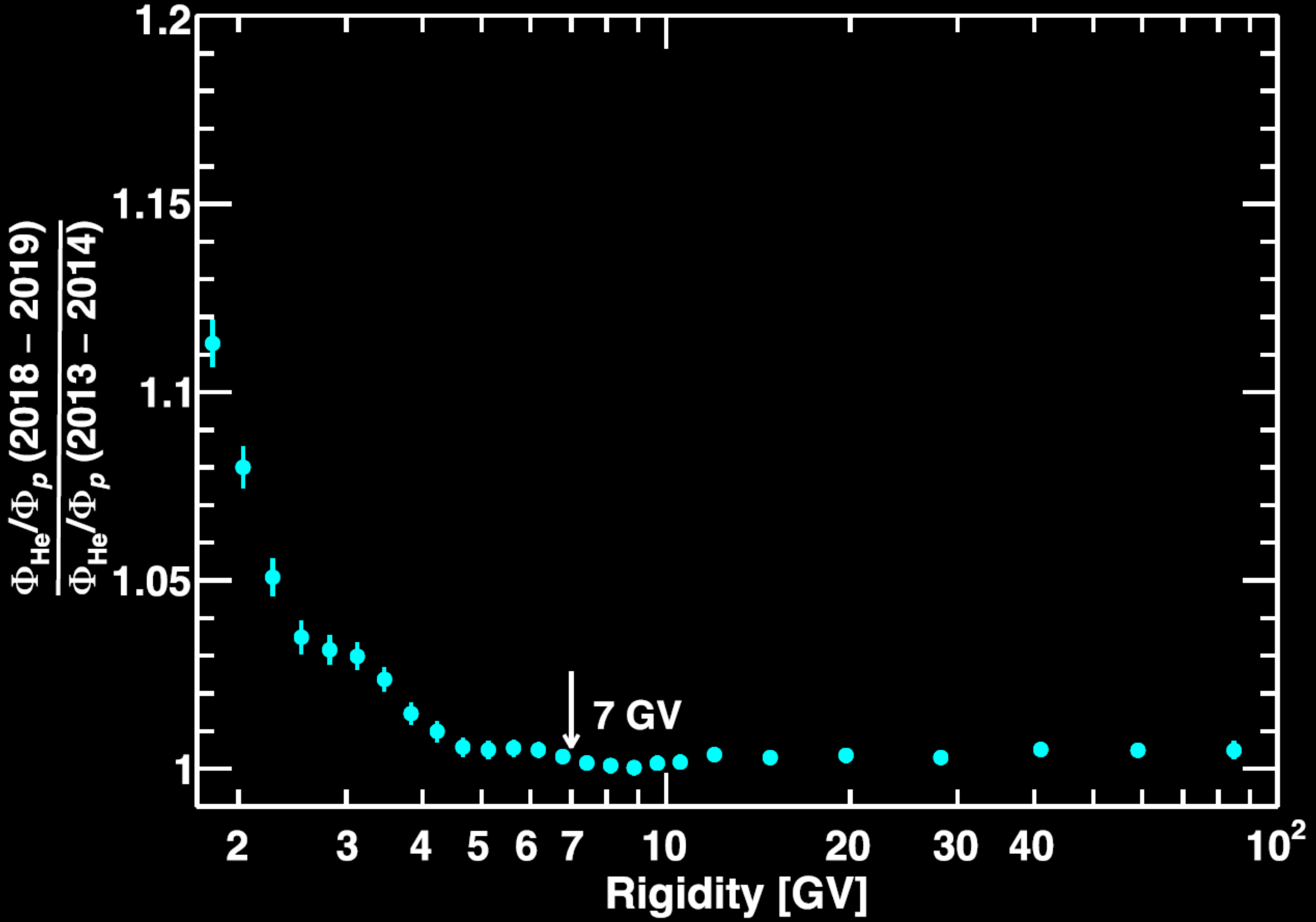
Daily Φ_{He}, Φ_p and Φ_{He}/Φ_p

Φ_{He}/Φ_p exhibits variations on multiple timescales



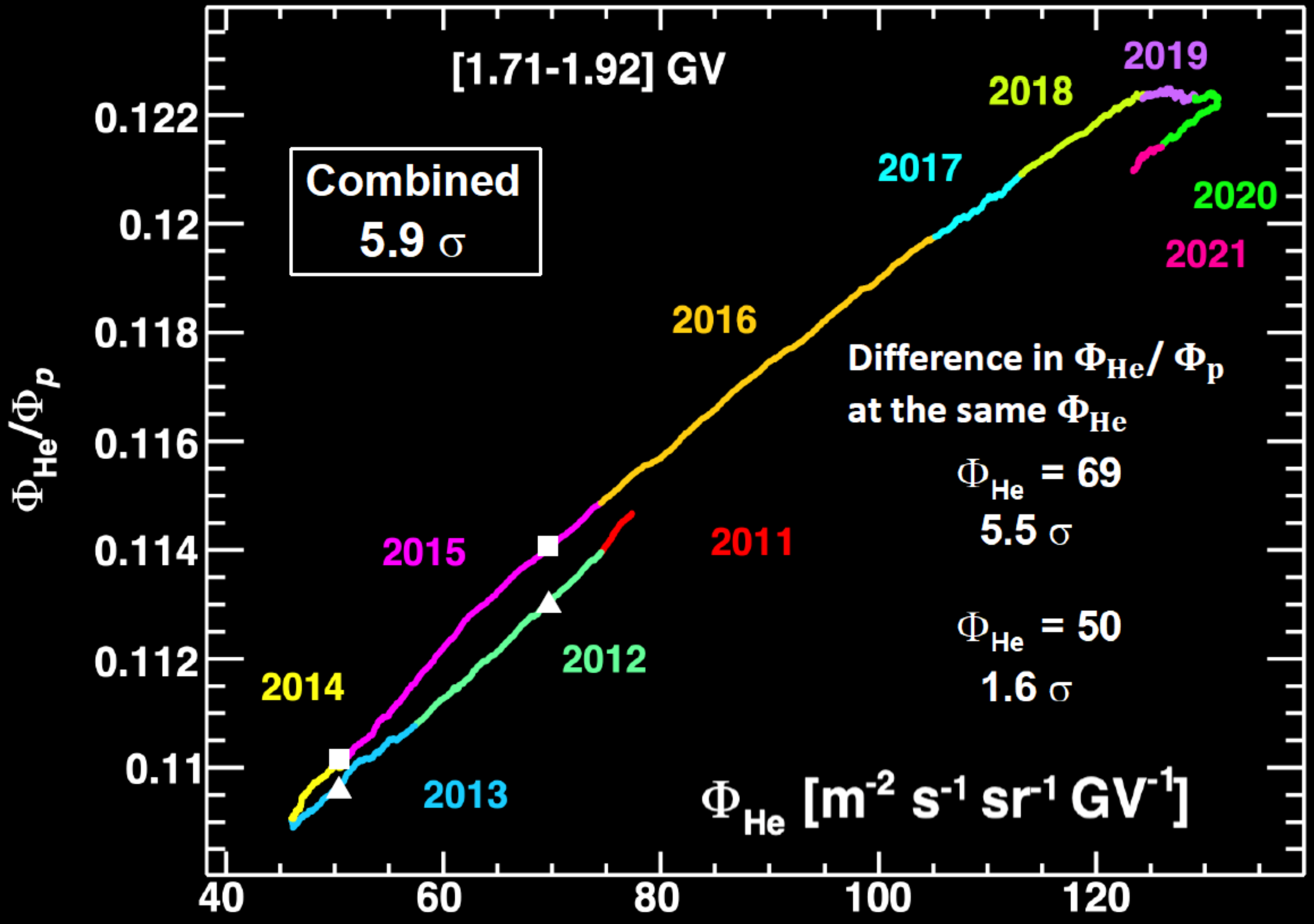
Daily Φ_{He}, Φ_p and Φ_{He}/Φ_p

Below ~7 GV, Φ_{He} exhibits larger time variations than Φ_p



A Hysteresis between Φ_{He}/Φ_p and Φ_{He}

At low rigidity the modulation of the helium to proton flux ratio is different before and after the solar maximum in 2014



We study the significance of the difference of Φ_{He}/Φ_p at the same Φ_{He} but different solar conditions:

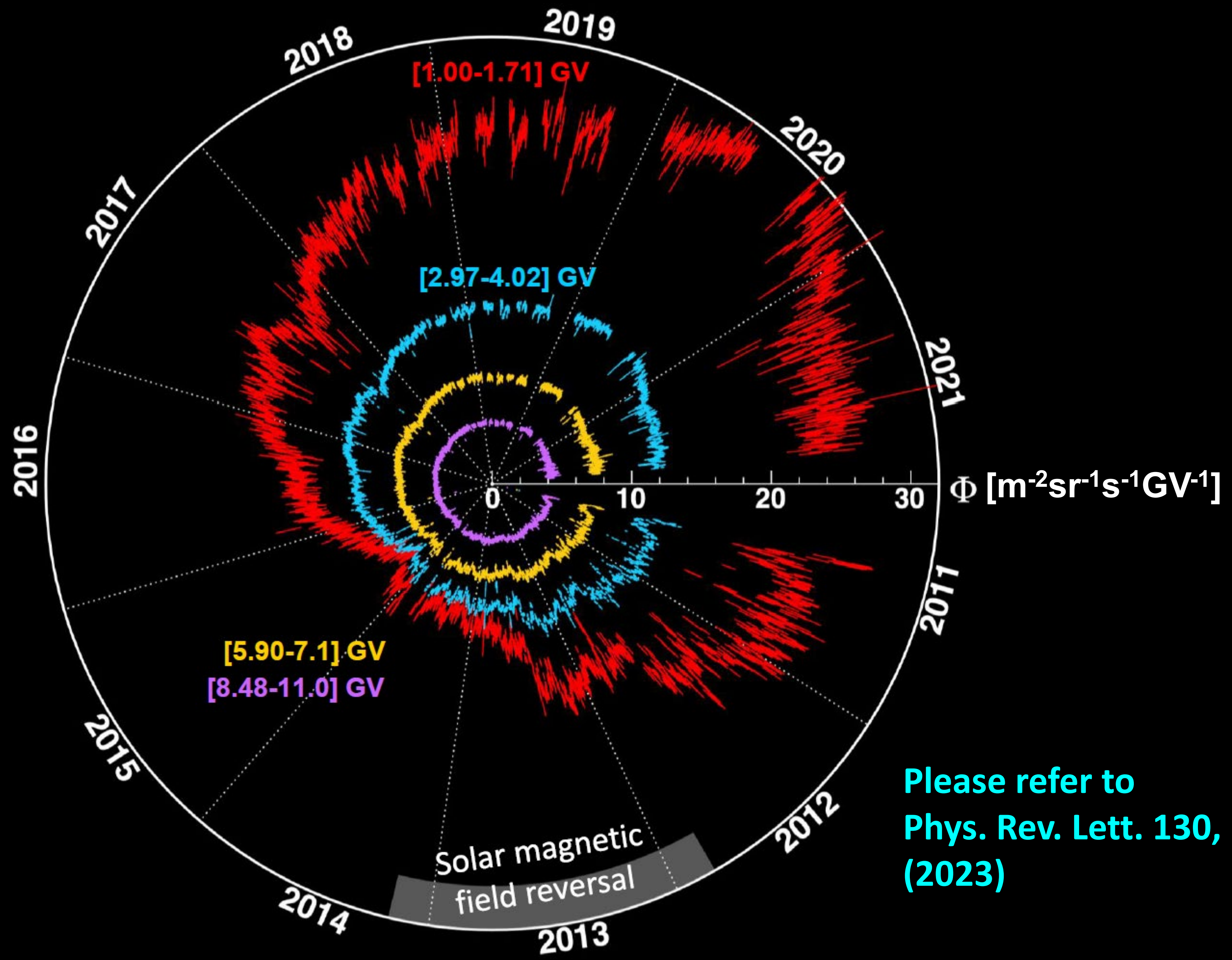
▲ : Φ_{He}/Φ_p before the solar maximum 2014

■ : Φ_{He}/Φ_p after the solar maximum 2014

The hysteresis is observed with an overall significance >7σ below 2.4 GV

Phys. Rev. Lett. 128, 231102 (2022)

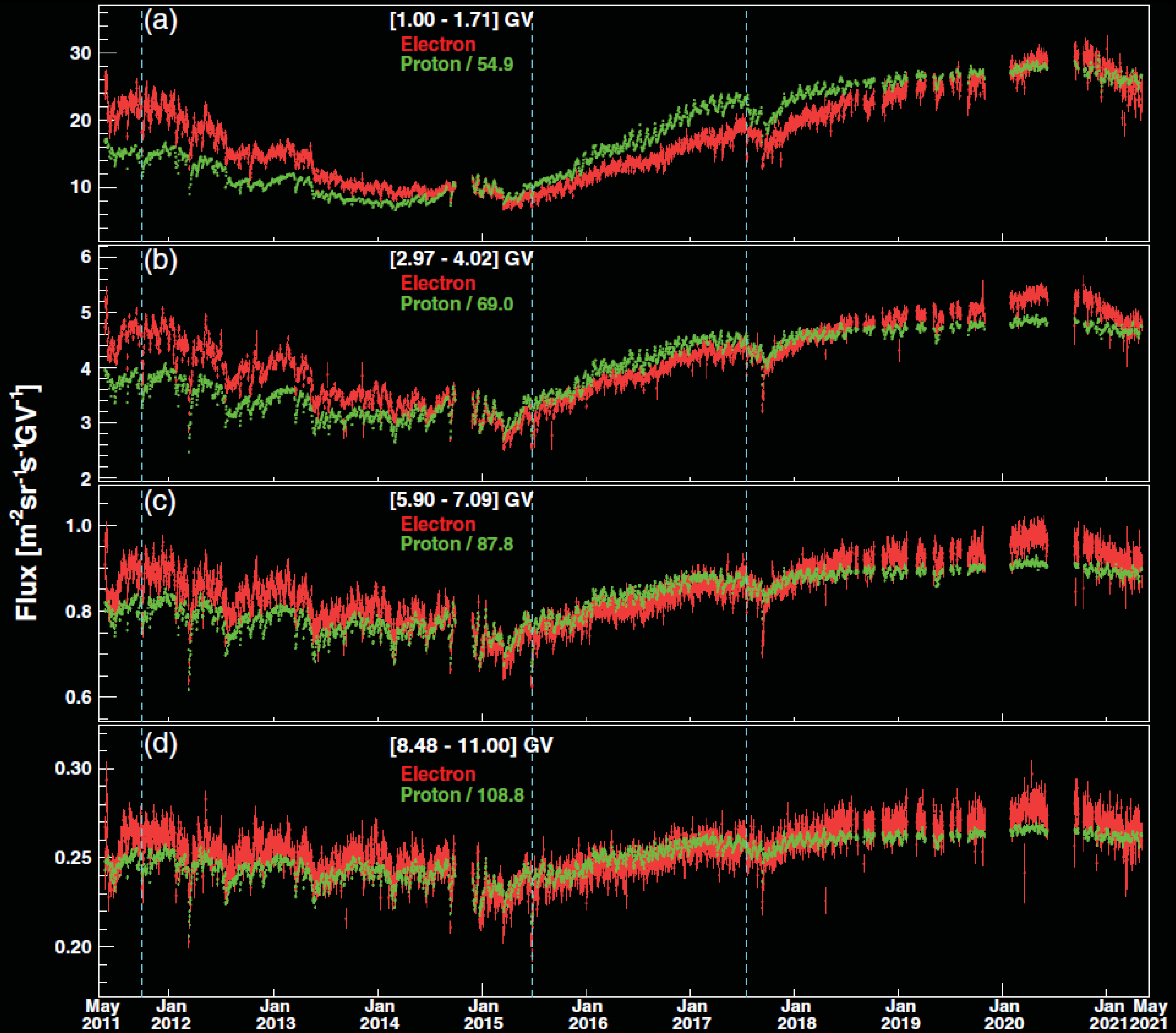
AMS Daily Electron Flux



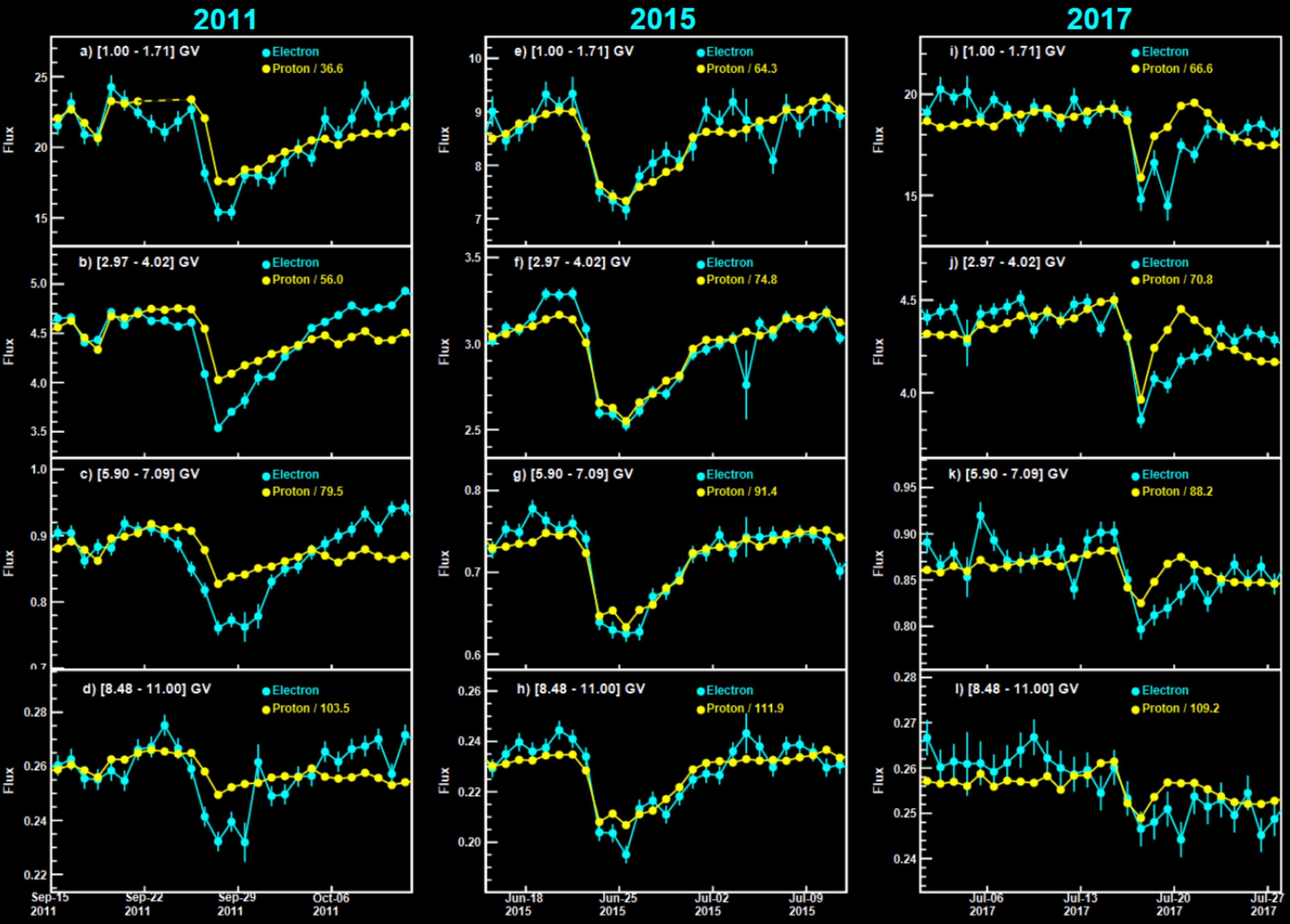
Please refer to
Phys. Rev. Lett. 130, 161001
(2023)

AMS Daily Electron and Proton Fluxes

The time-dependent behavior of the Φ_{e^-} and Φ_p is distinctly different



Non-recurrent Variation of Electron and Proton Fluxes

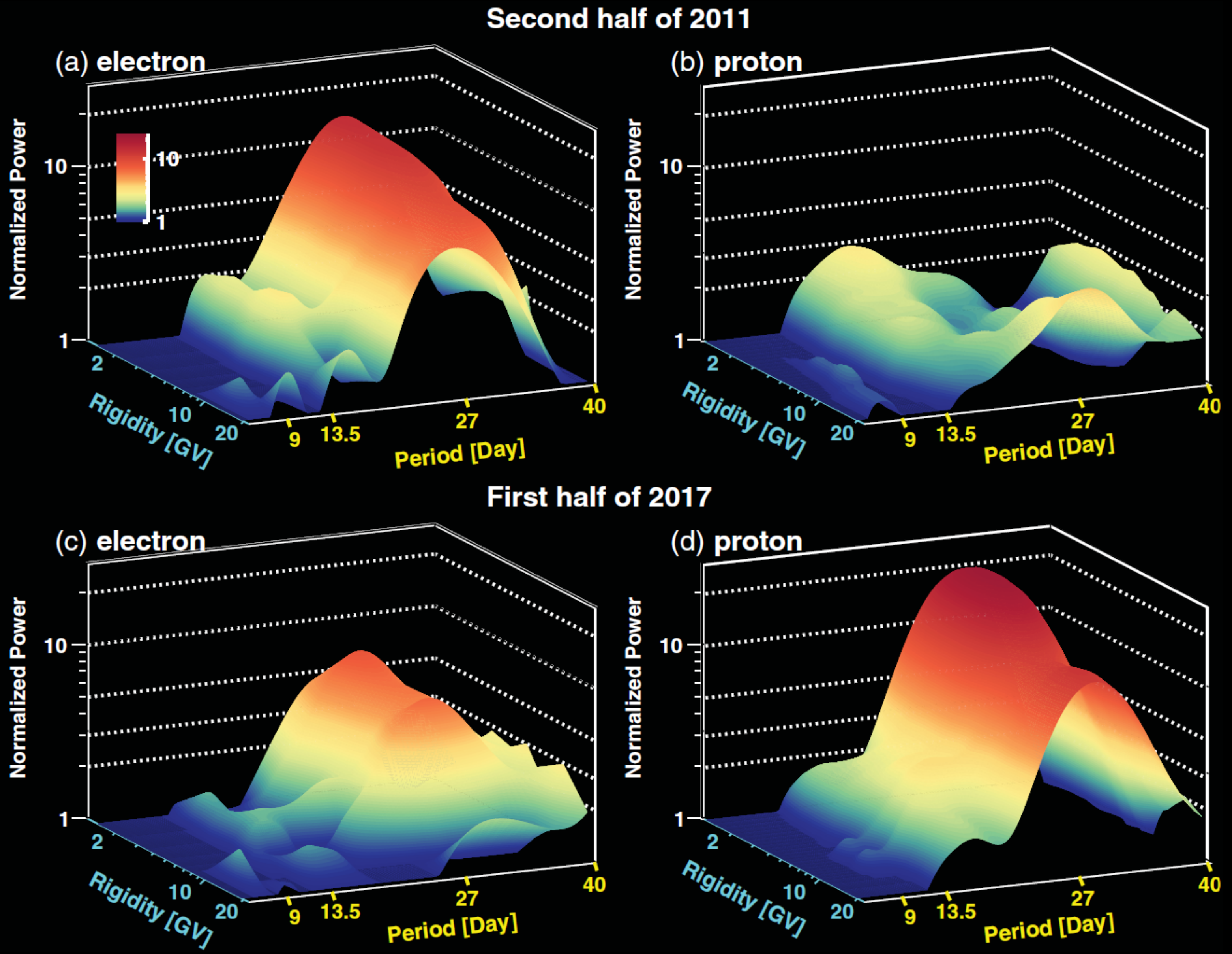


During **lower solar activity** in 2011 and 2017, a **difference between the short-term evolution of electrons and protons** is observed, while during the **solar maximum** in 2015 the **difference vanishes**.

These observations indicate a charge-sign dependence in non-recurrent solar modulation.

Periodicities of Daily Electron Fluxes

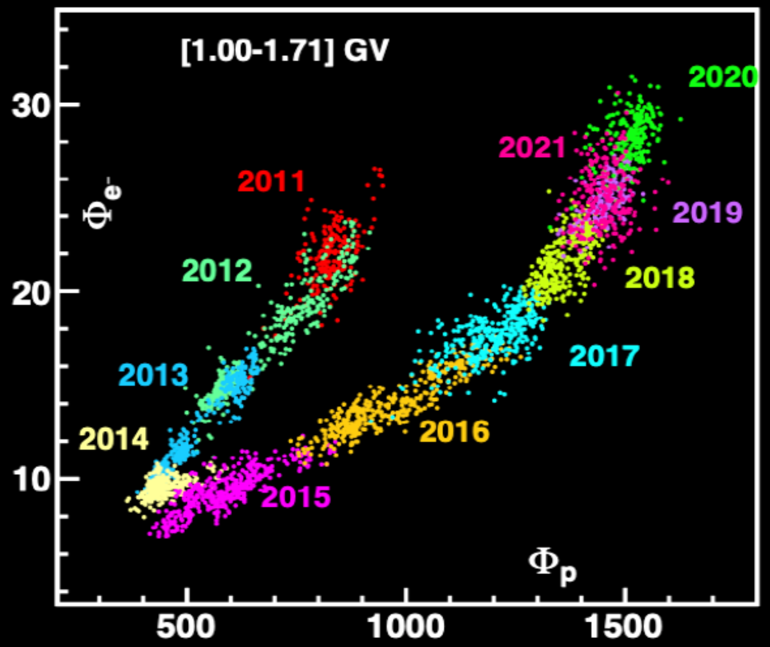
The rigidity dependence of the electron periodicities is different from that of protons

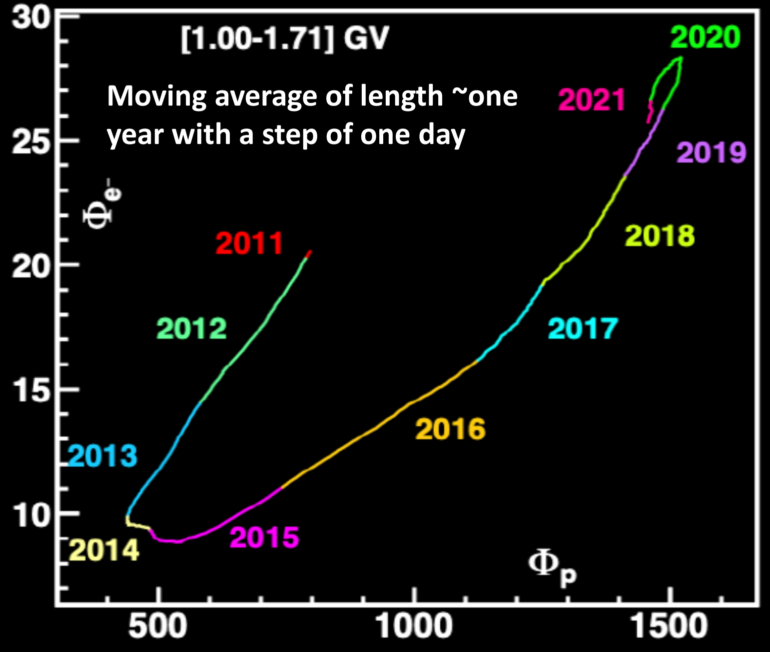


In the second half of 2011 the strength of the 27-day period of electrons is **greater** than that of protons.

In the first half of 2017 the strength of the 27-day period of electrons is **less** than that of protons.

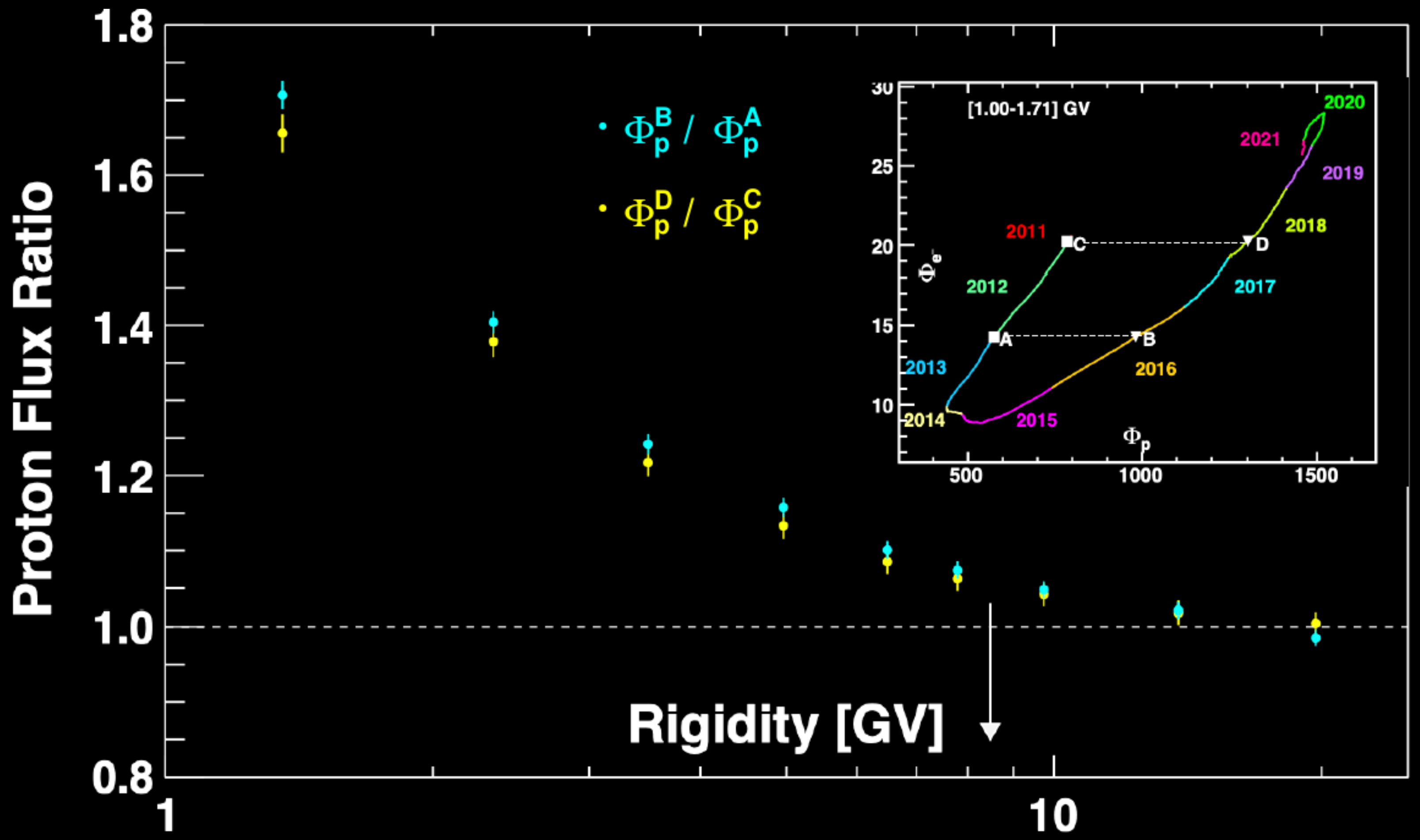
A Hysteresis between Φ_{e^-} and Φ_p





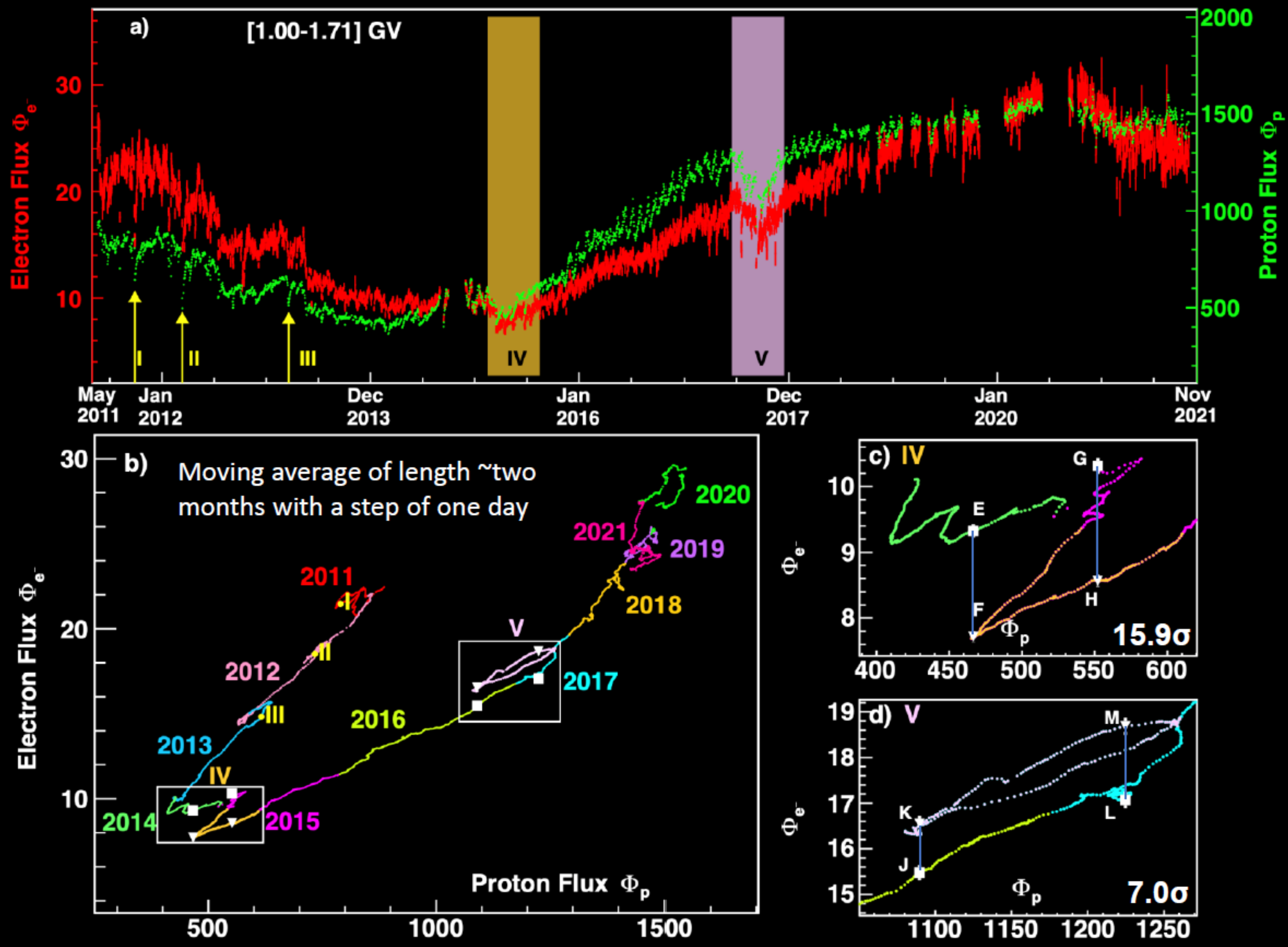
To assess the significance of the hysteresis we study, at different solar conditions, the values of Φ_p at the same Φ_{e^-}.

The hysteresis is observed with a significance > 6σ at rigidities below 8.5 GV.

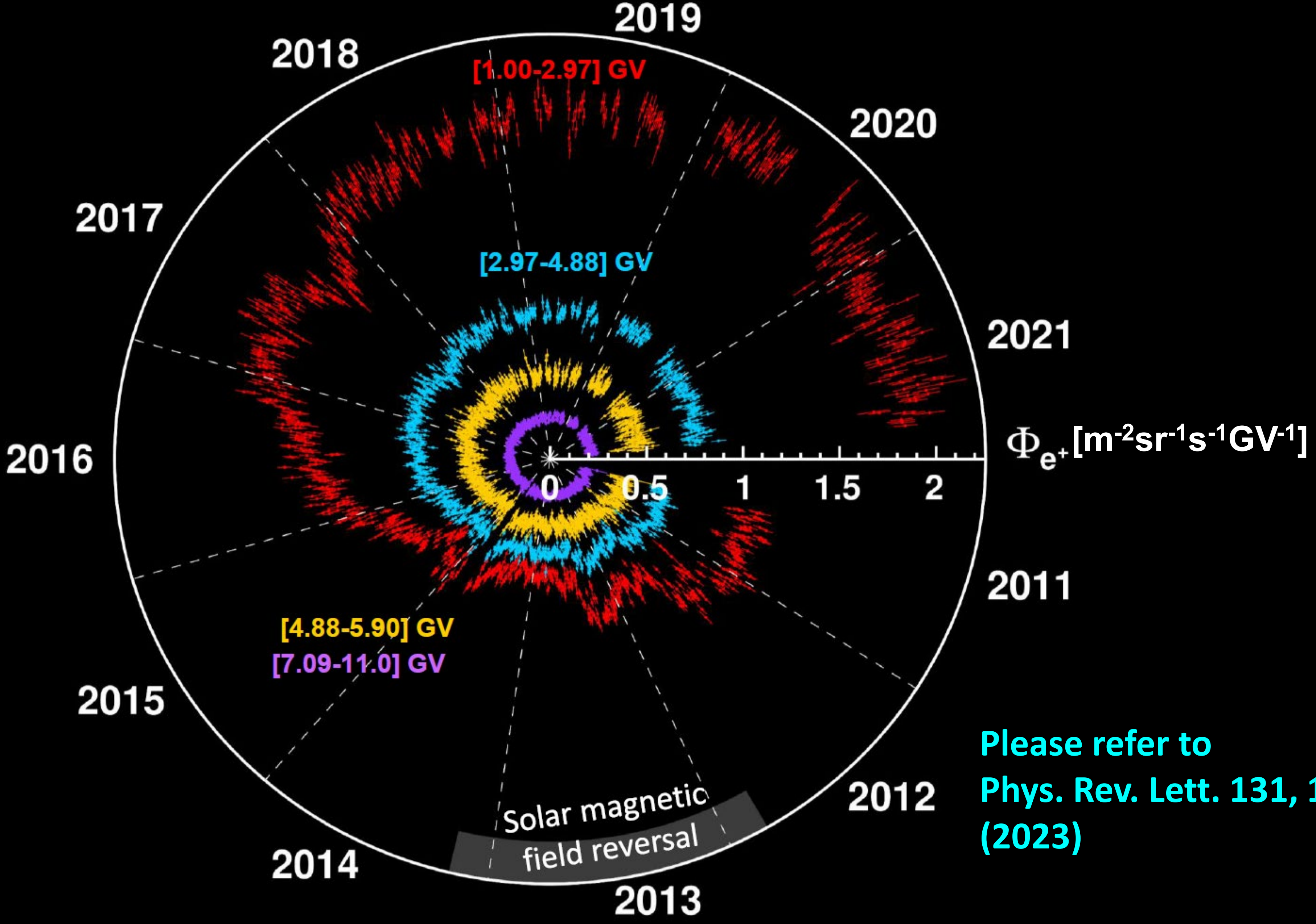


Structures in the Electron-Proton Hysteresis

Significant structures in the electron-proton hysteresis are observed corresponding to sharp variations in the fluxes



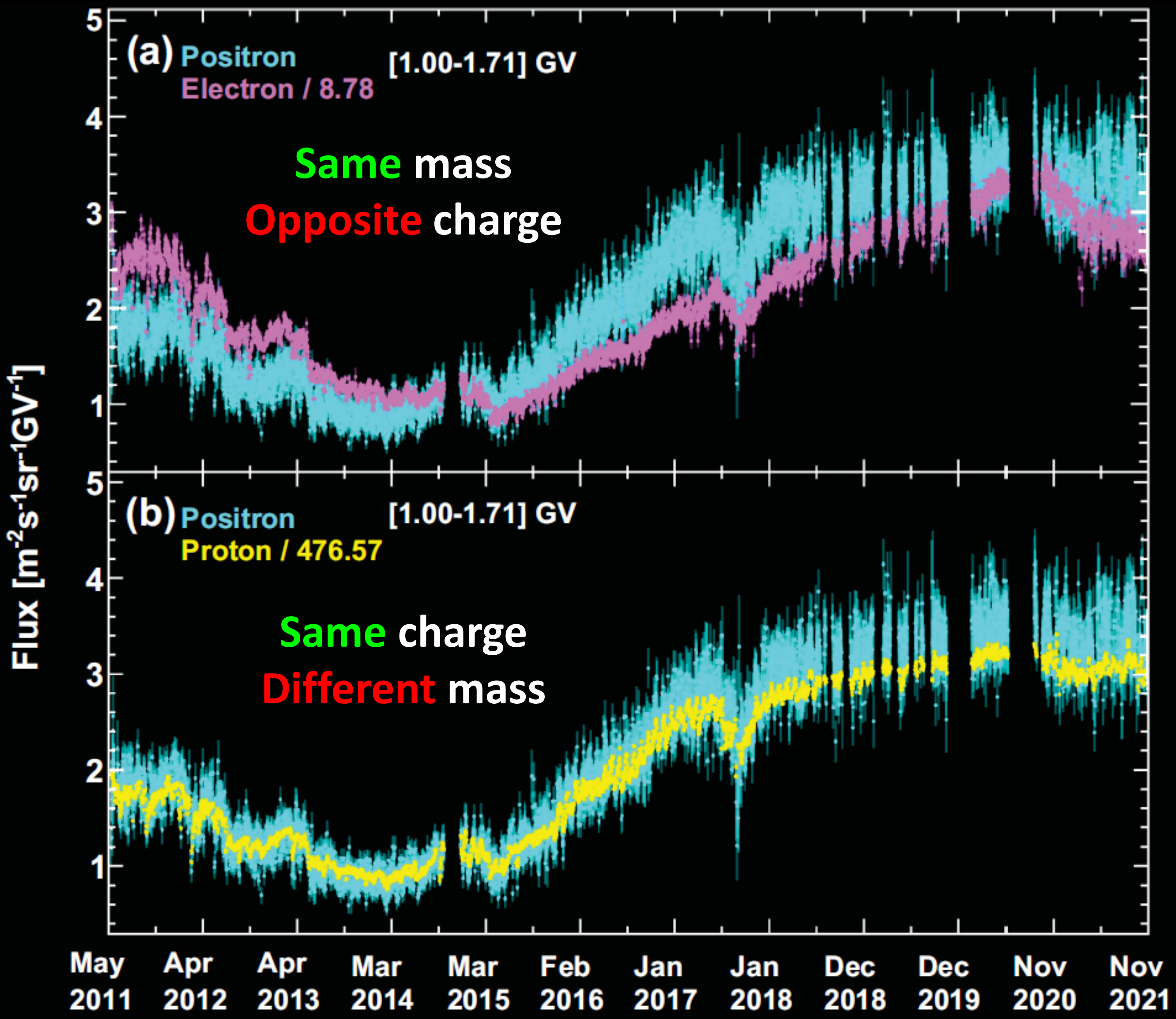
AMS Daily Positron Flux



Please refer to
Phys. Rev. Lett. 131, 151002 (2023)

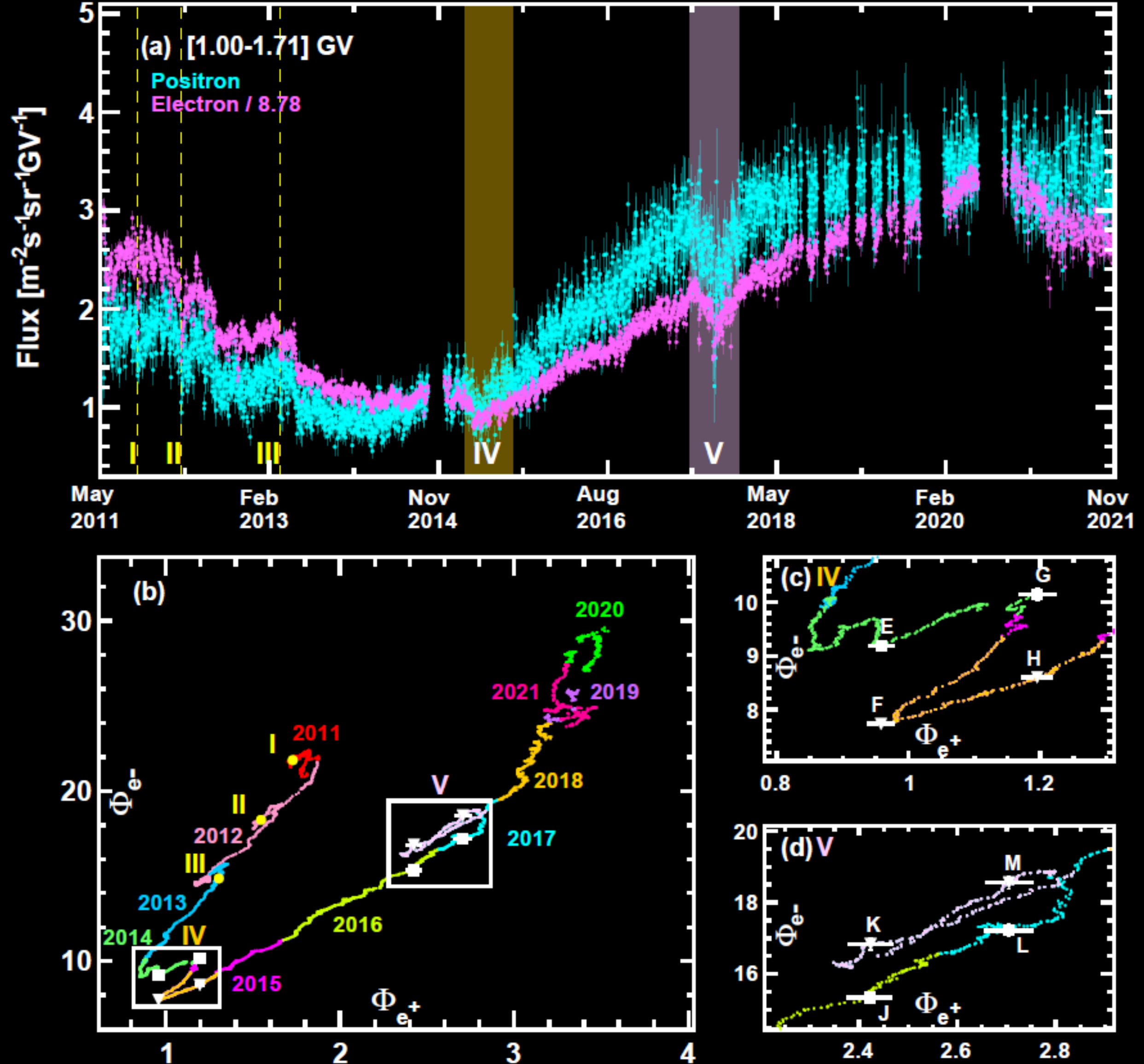
AMS Daily Positron, Electron and Proton Fluxes

The long-term evolution of **positron** and **electron** fluxes is clearly **different**.
On the contrary, **positron** and **proton** fluxes present a **similar** behavior over time.



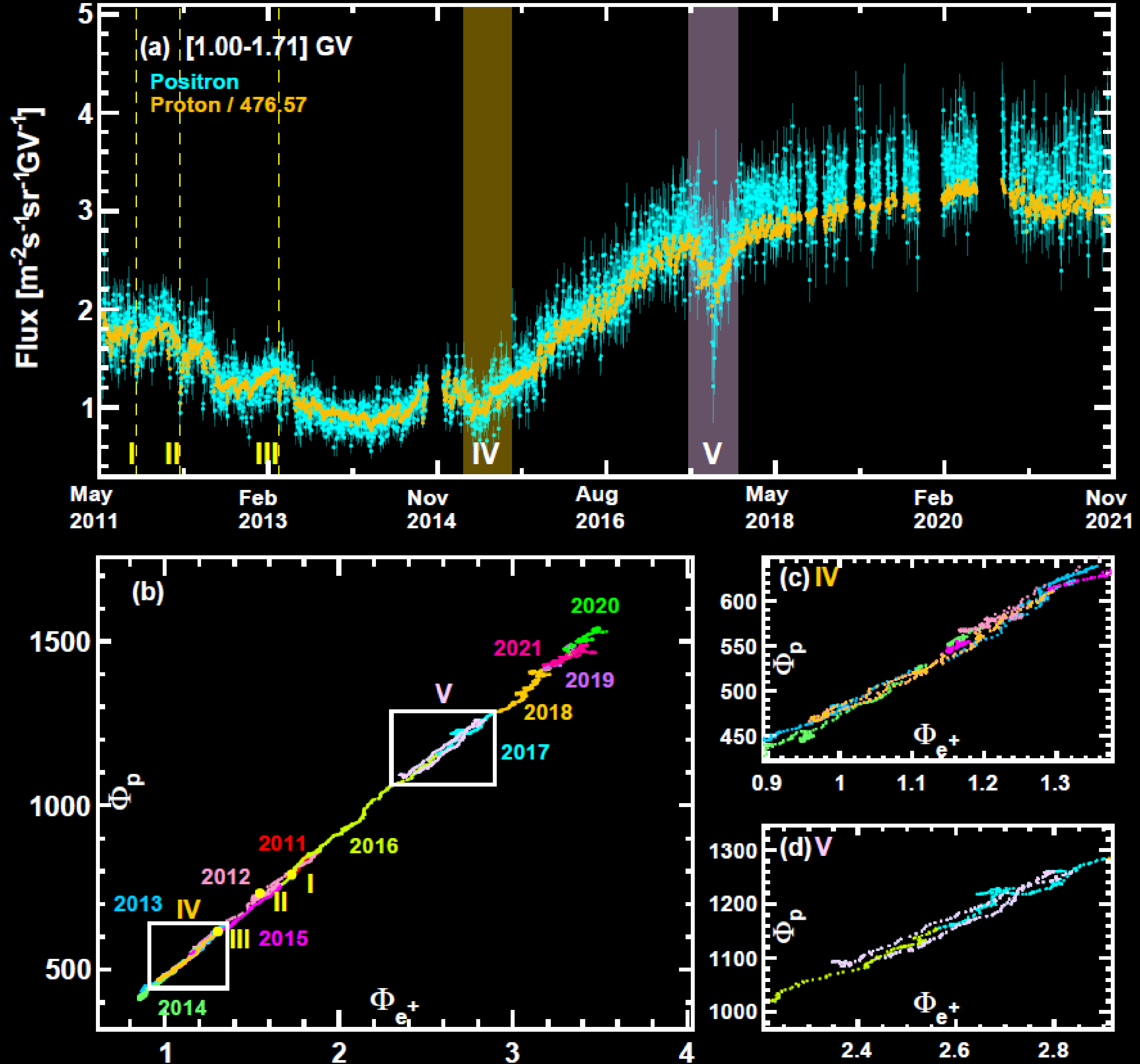
Structures in the Positron-Electron Hysteresis

Significant structures in the positron-electron hysteresis are observed corresponding to sharp variations in the fluxes



No Structures in the Positron-Proton Hysteresis

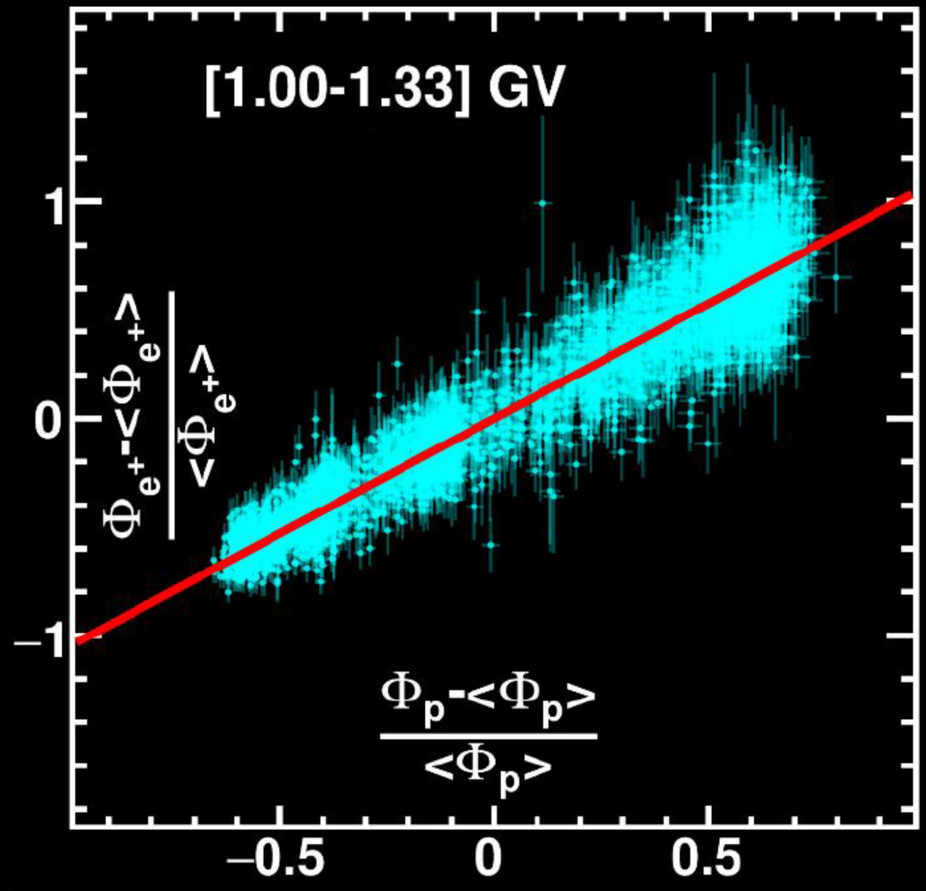
No structures was observed in the positron-proton fluxes

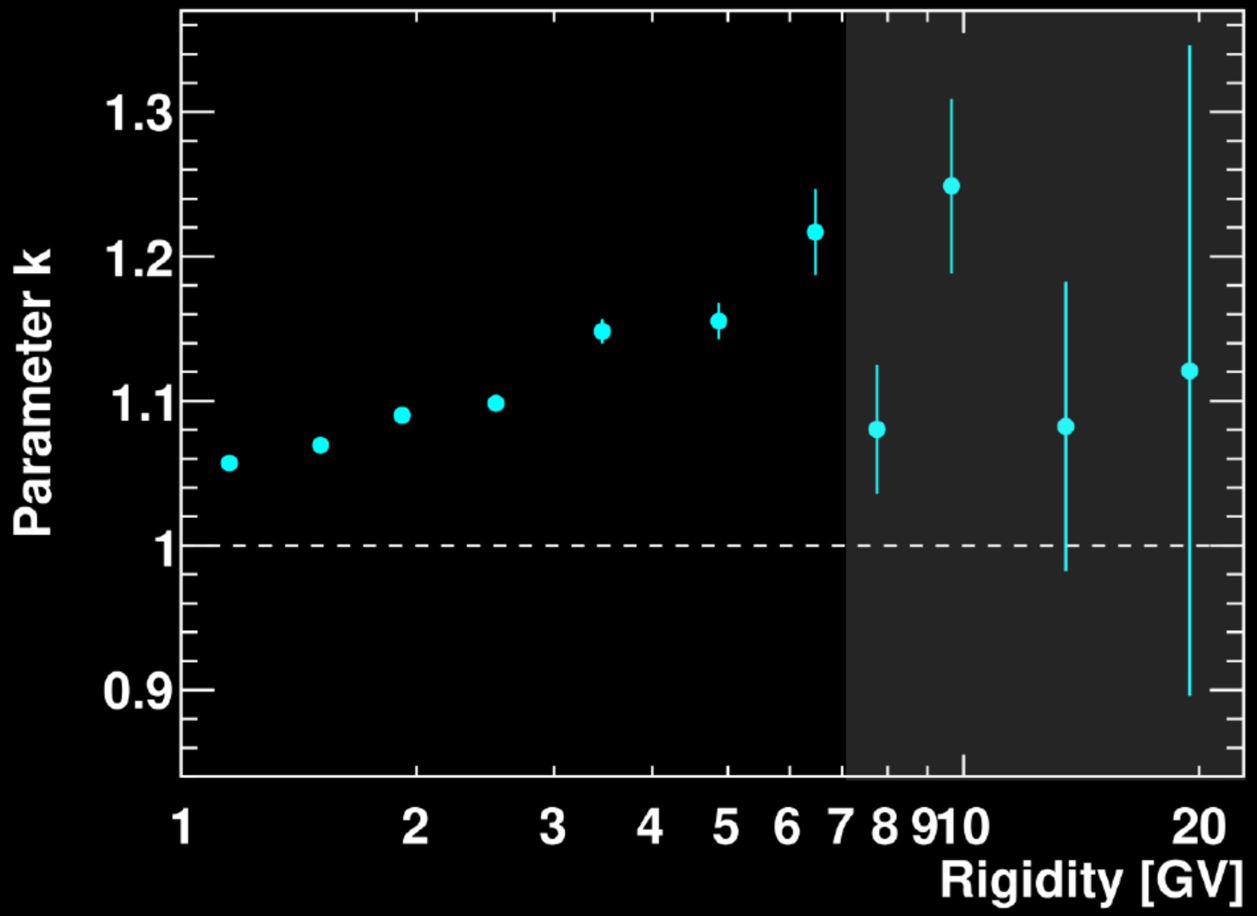


Linear Relation between Φ_{e^+} and Φ_p

To compare the long-term variation of proton and positron fluxes a linear relation between the relative variations of the fluxes is studied: $\frac{\Phi_{e^+} - \langle\Phi_{e^+}\rangle}{\langle\Phi_{e^+}\rangle} = k \frac{\Phi_p - \langle\Phi_p\rangle}{\langle\Phi_p\rangle}$

Below 7 GV, the positron flux is more modulated than the proton flux. (> 5σ)





Relation between Positron, Electron and Proton Fluxes

Electron-Positron: hysteresis

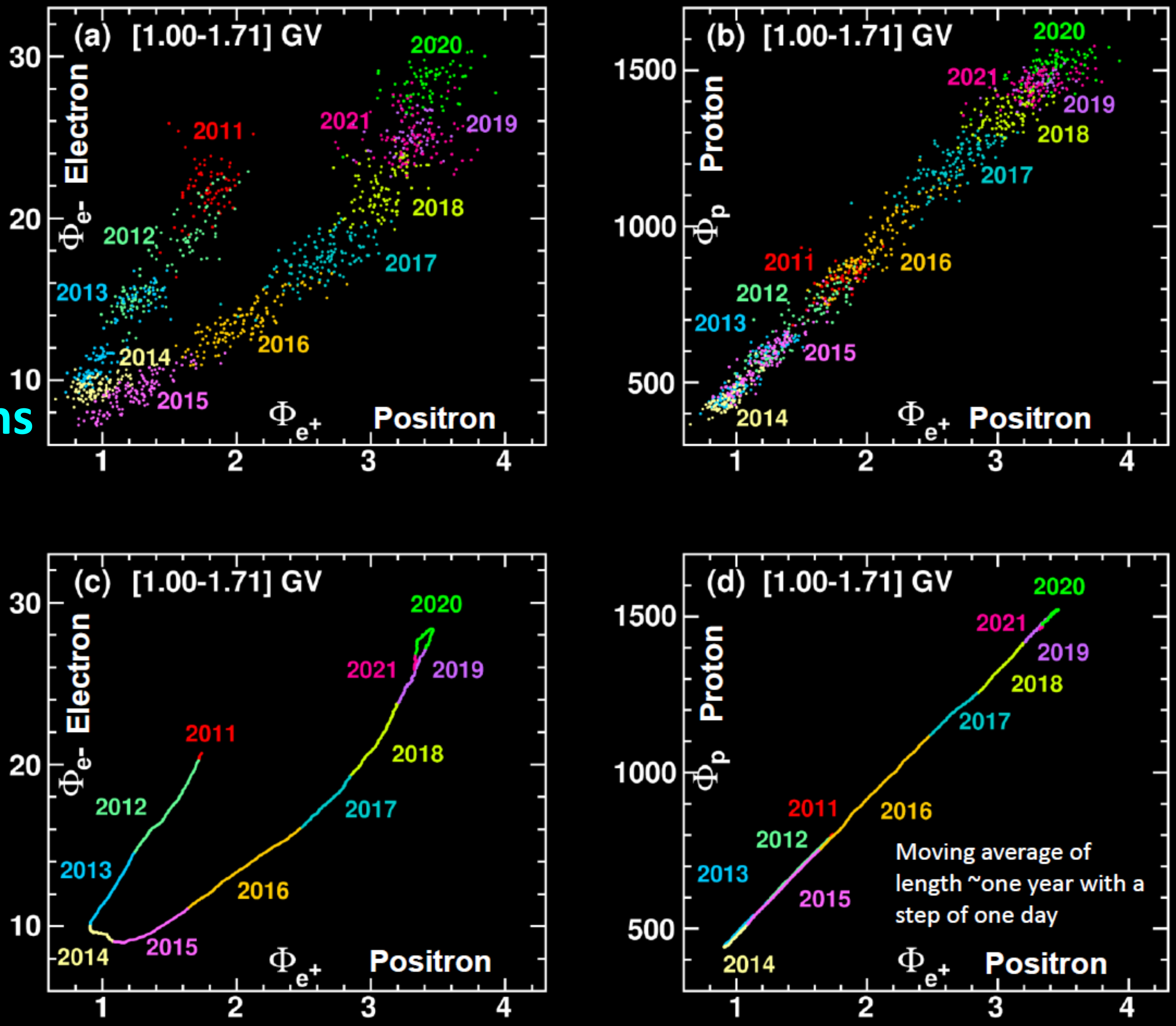
Proton-Positron: linear relation

Electrons vs Positrons

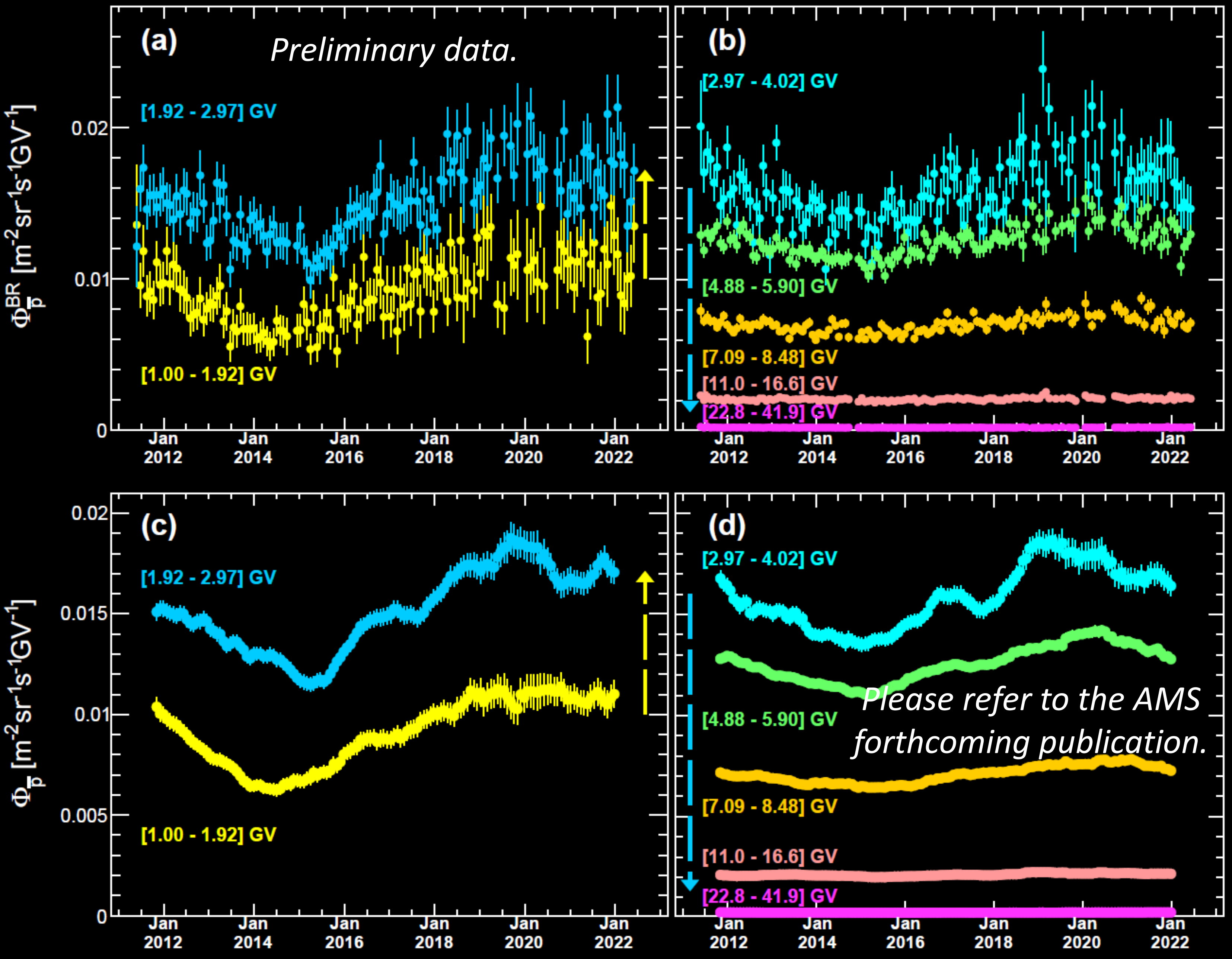
Protons vs Positrons

Same mass
Opposite charge

Different mass
Same charge



AMS Monthly Antiproton Flux

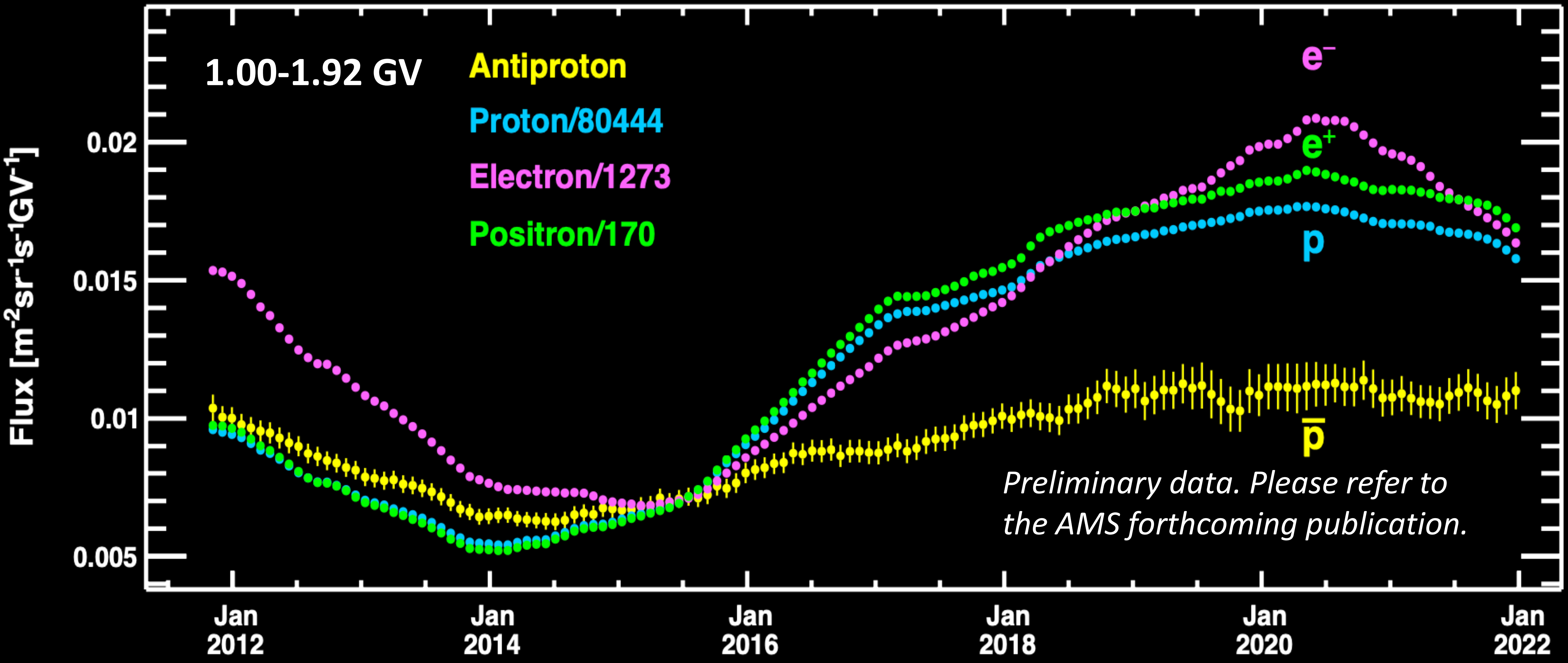


Temporal evolution of antiproton fluxes by 1 Bartels rotation

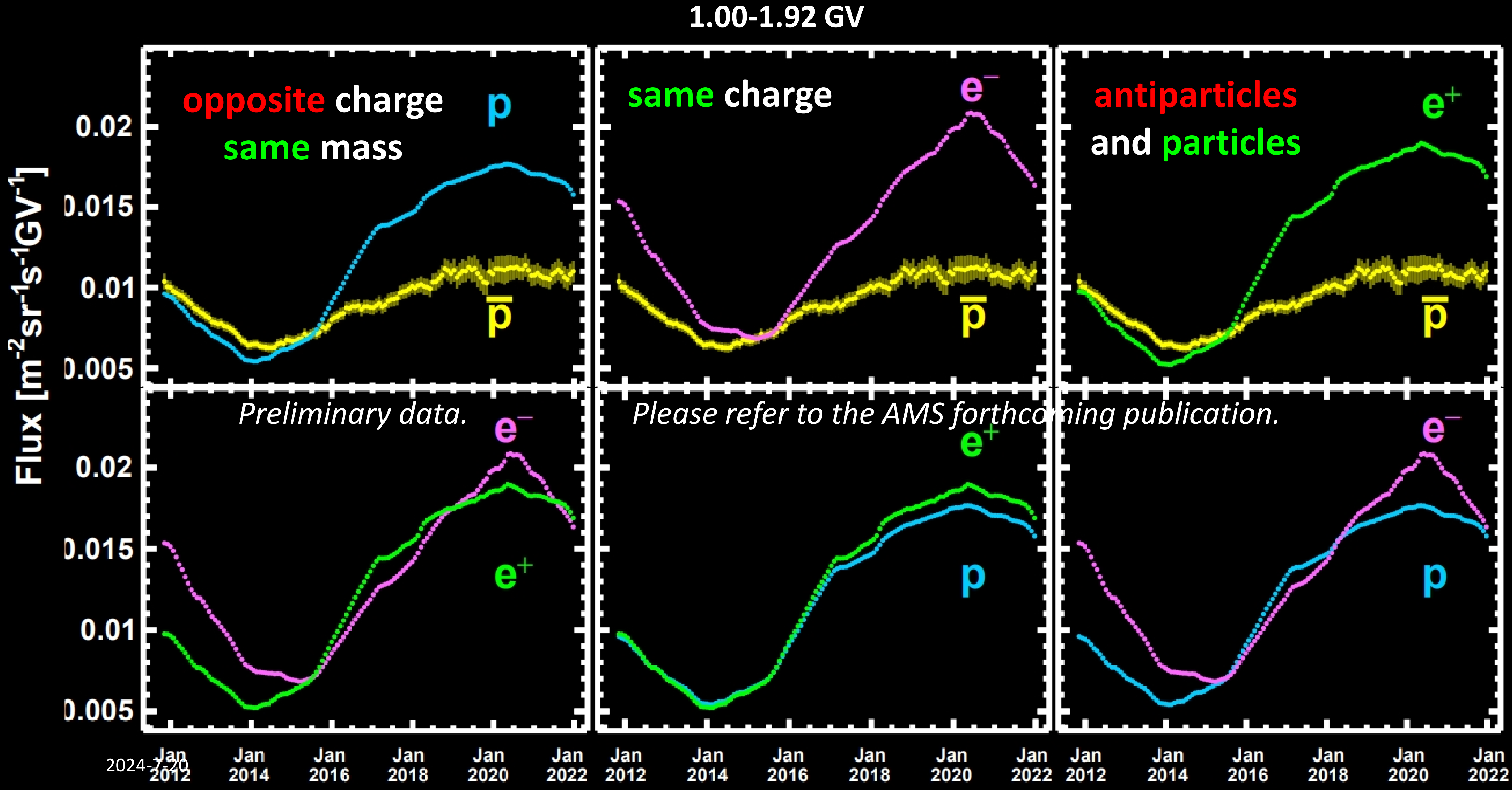
13-BR moving average values. The data point for each Bartels rotation period is calculated from a time window of 13 BR centered around that period.

Temporal Structures of the Elementary Particle Fluxes

Antiproton flux is distinct to other particles

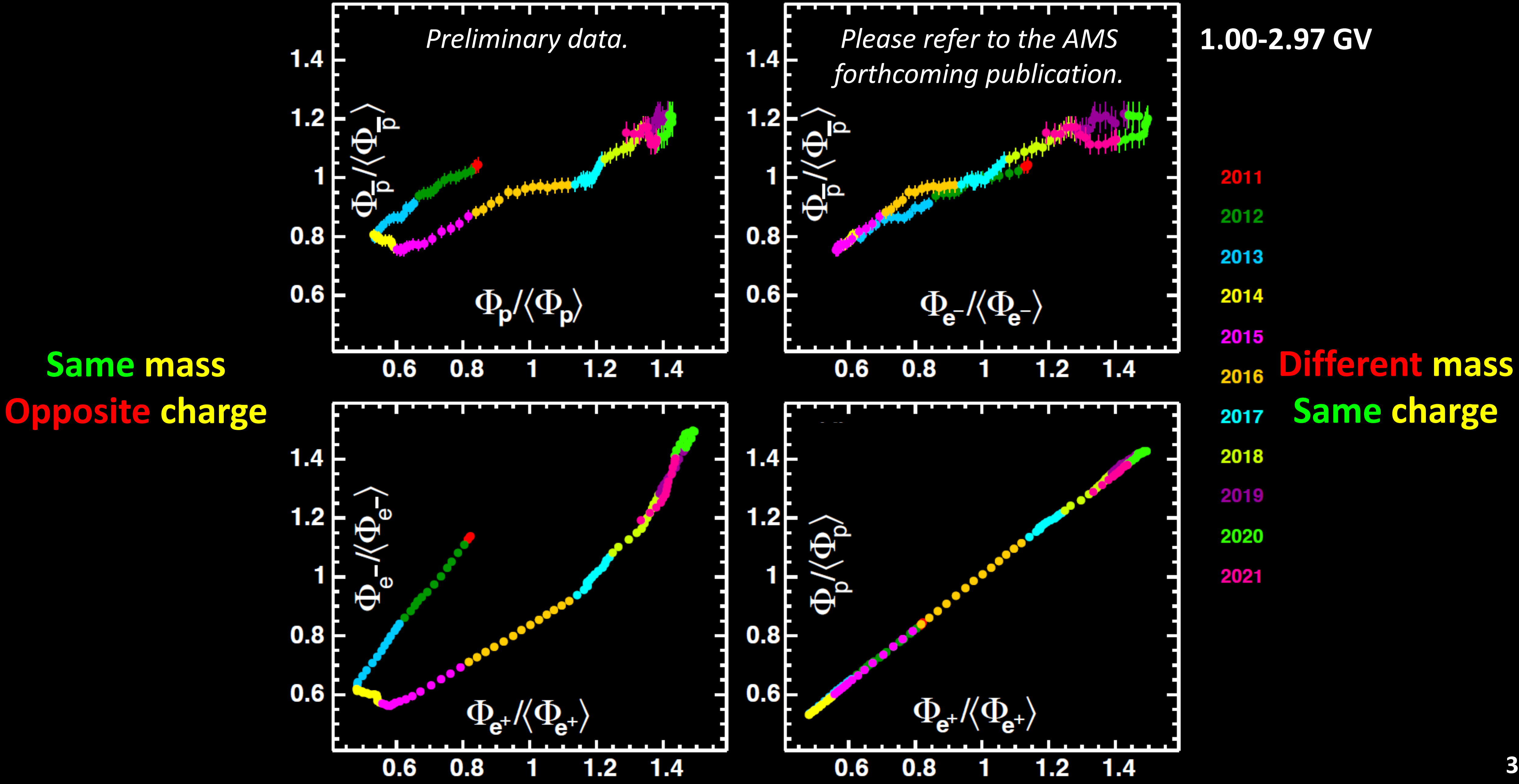


Temporal Structures of the Elementary Particle Fluxes



2024-7-20

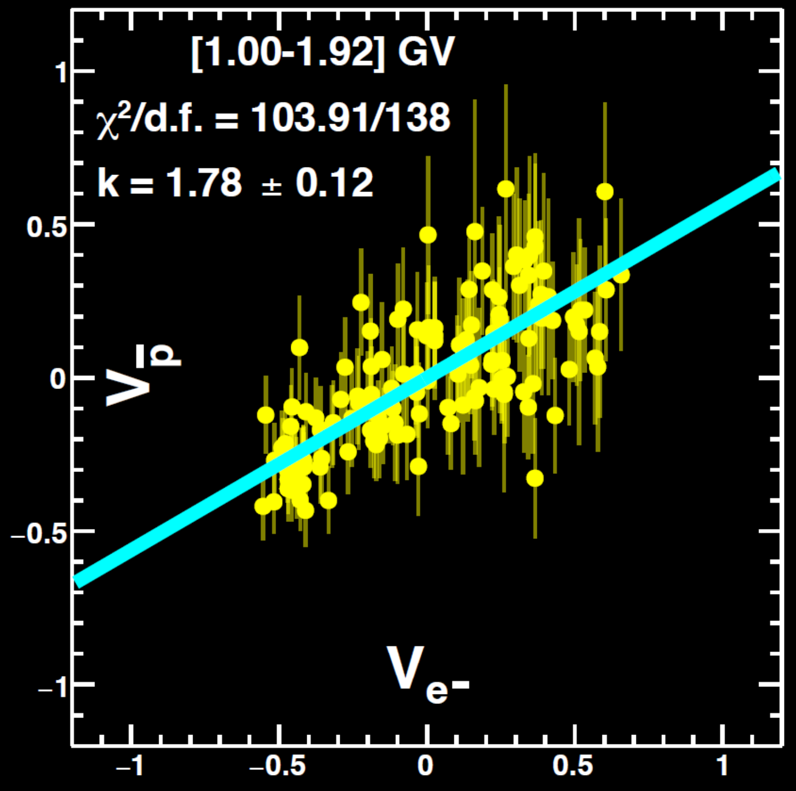
Hysteresis of Elementary Particles

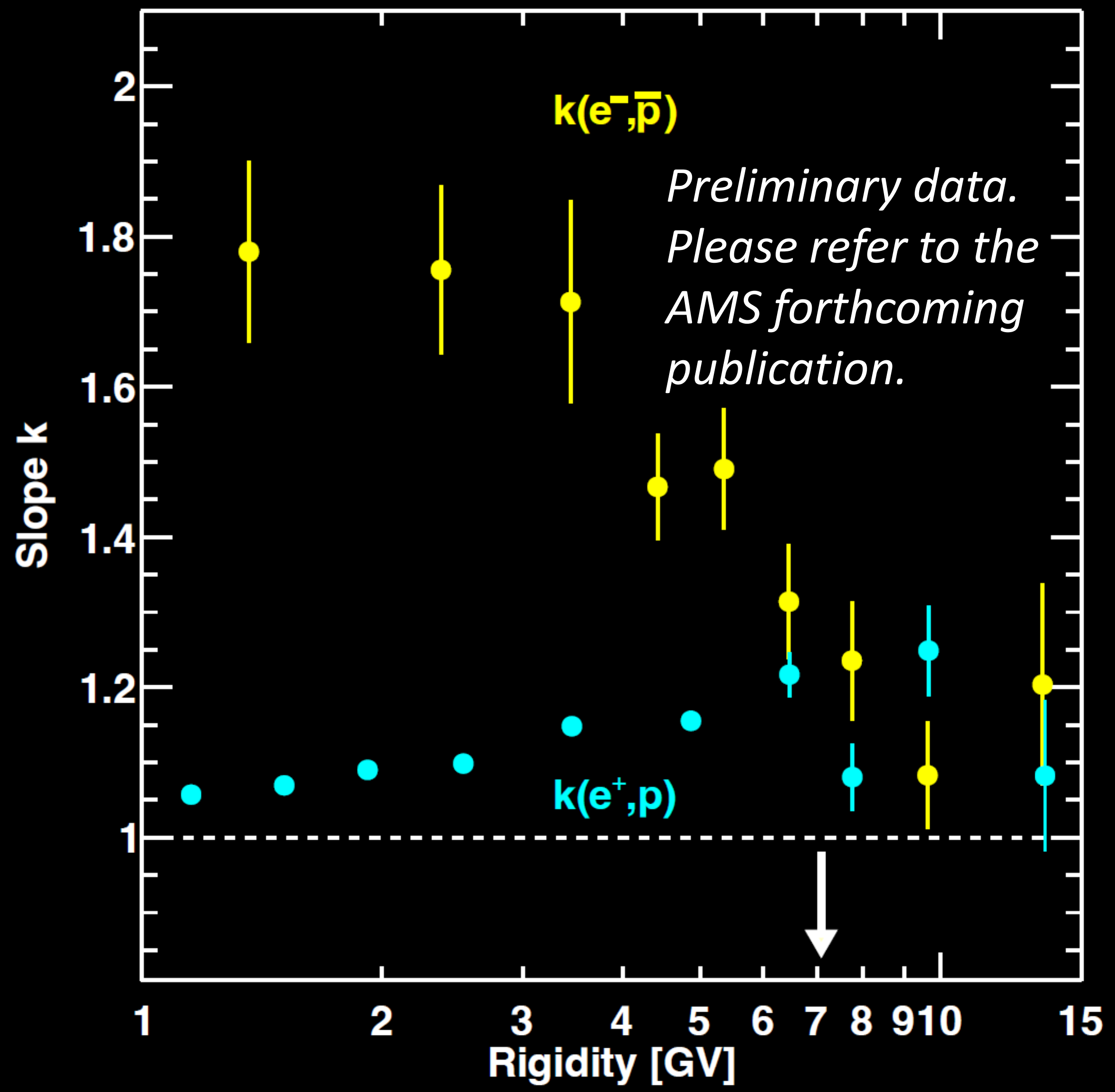


Linear Relation between $\Phi_{\bar{p}}$ and Φ_{e^-}

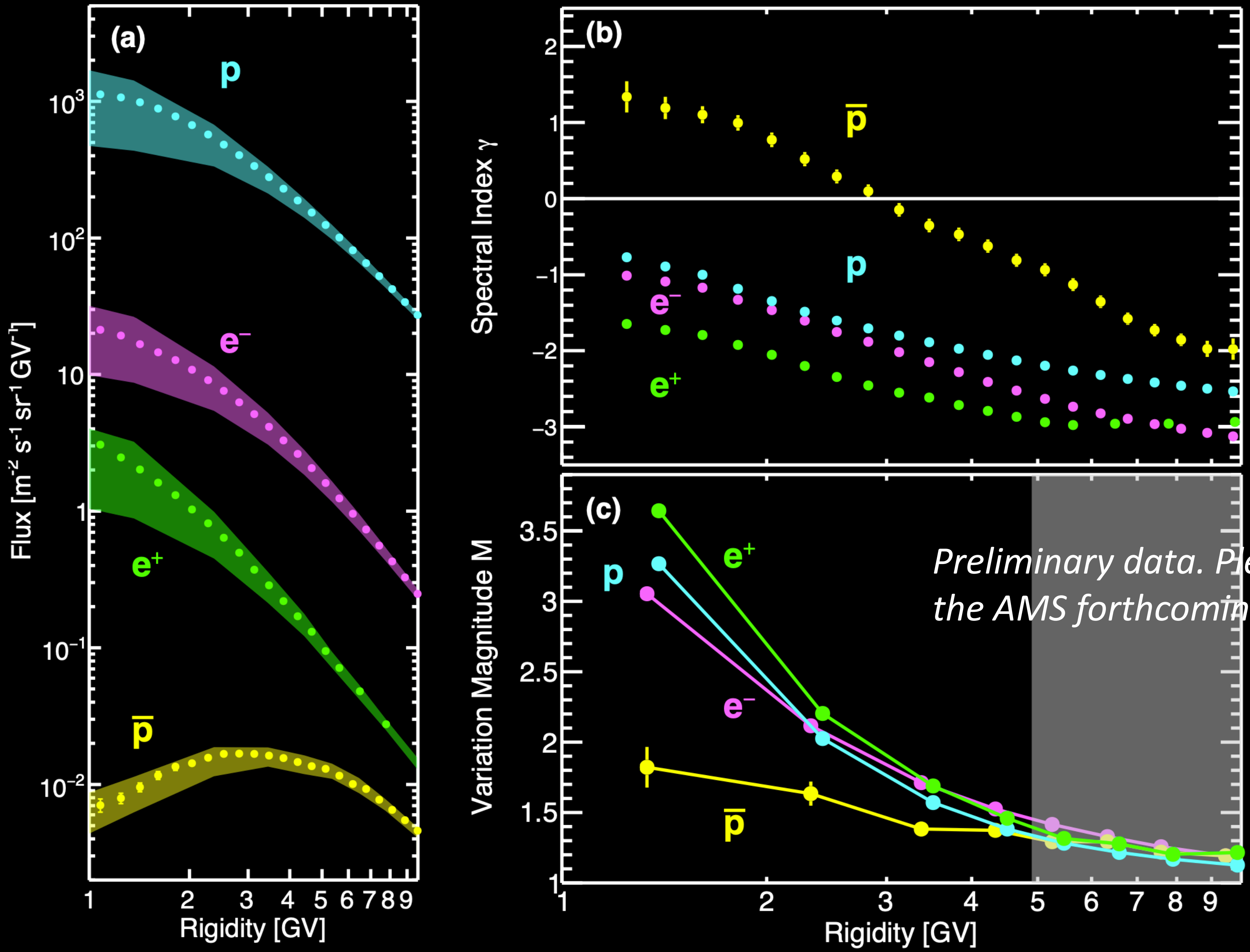
Using the same method in Φ_{e^+} and Φ_p , to study the linear relation of the long-term variation of $\Phi_{\bar{p}}$ and Φ_{e^-}

$k(e^-, \bar{p})$ is different from $k(e^+, p)$



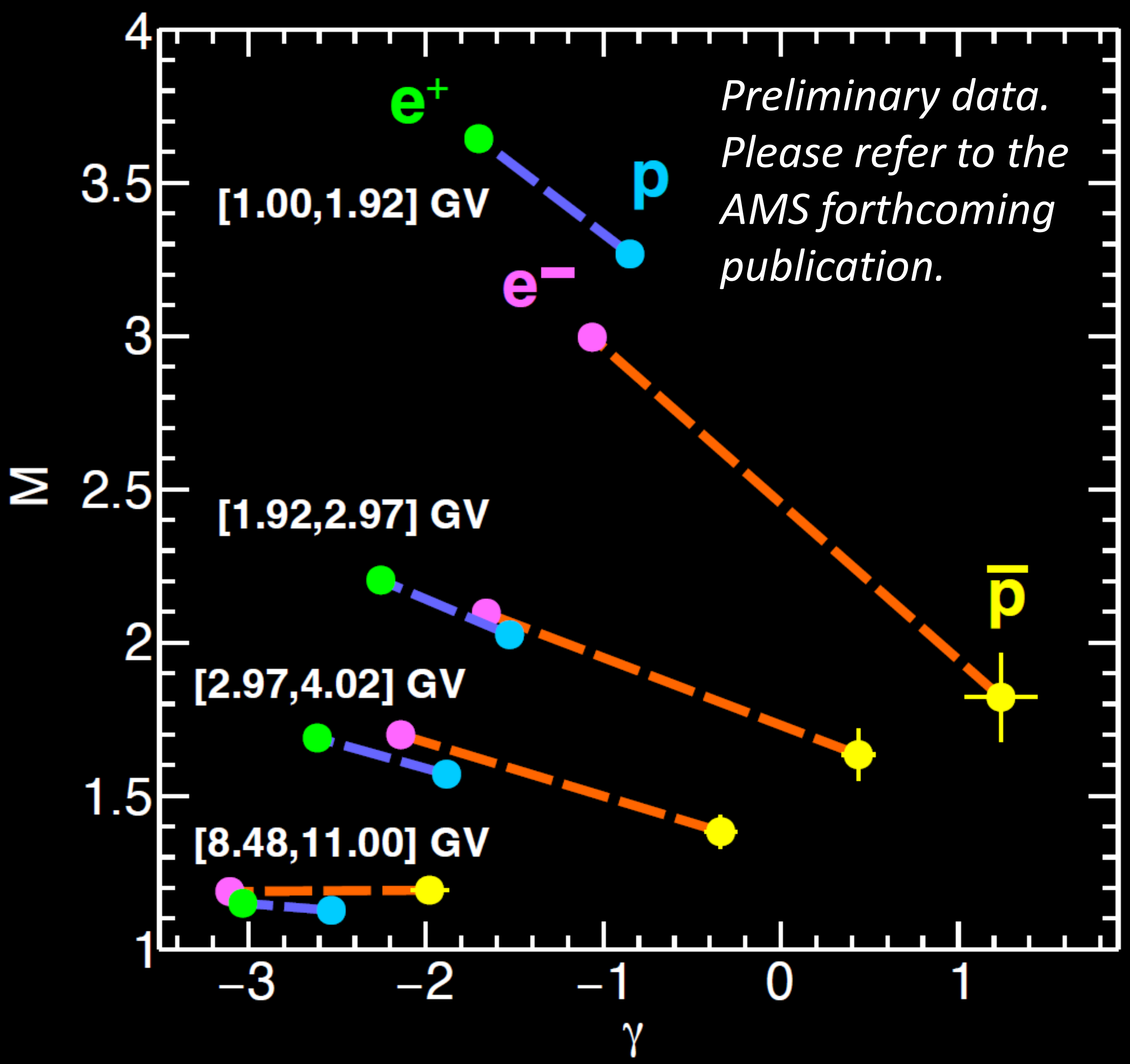


Variation Magnitudes and Spectral Index



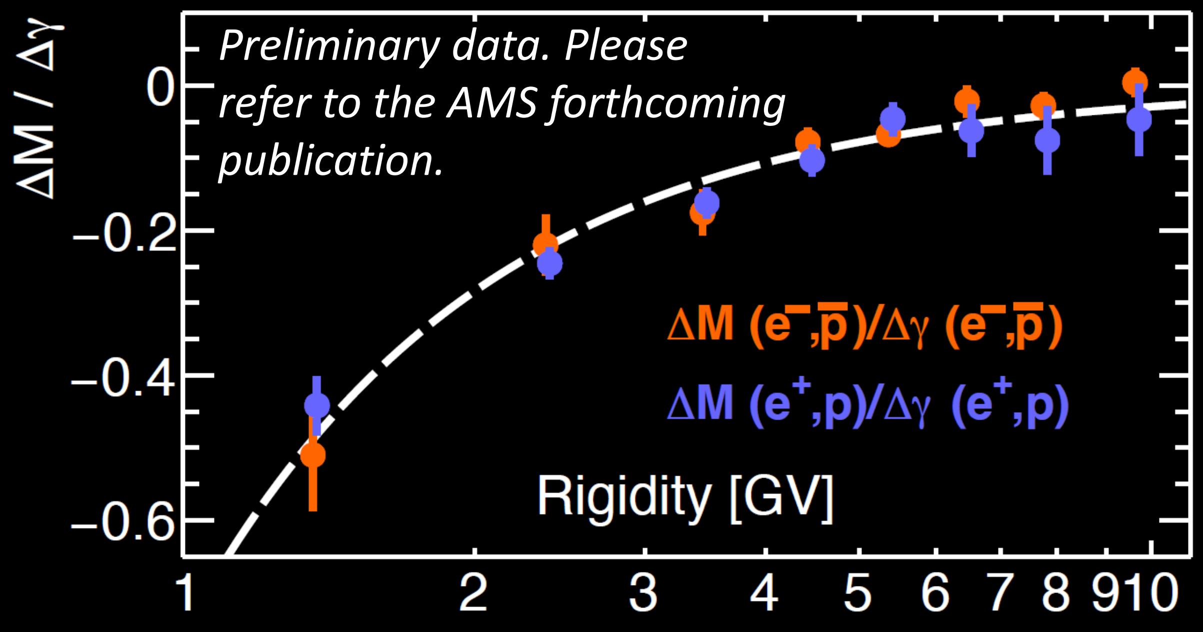
Preliminary data. Please refer to the AMS forthcoming publication.

Variation Magnitudes and Spectral Index



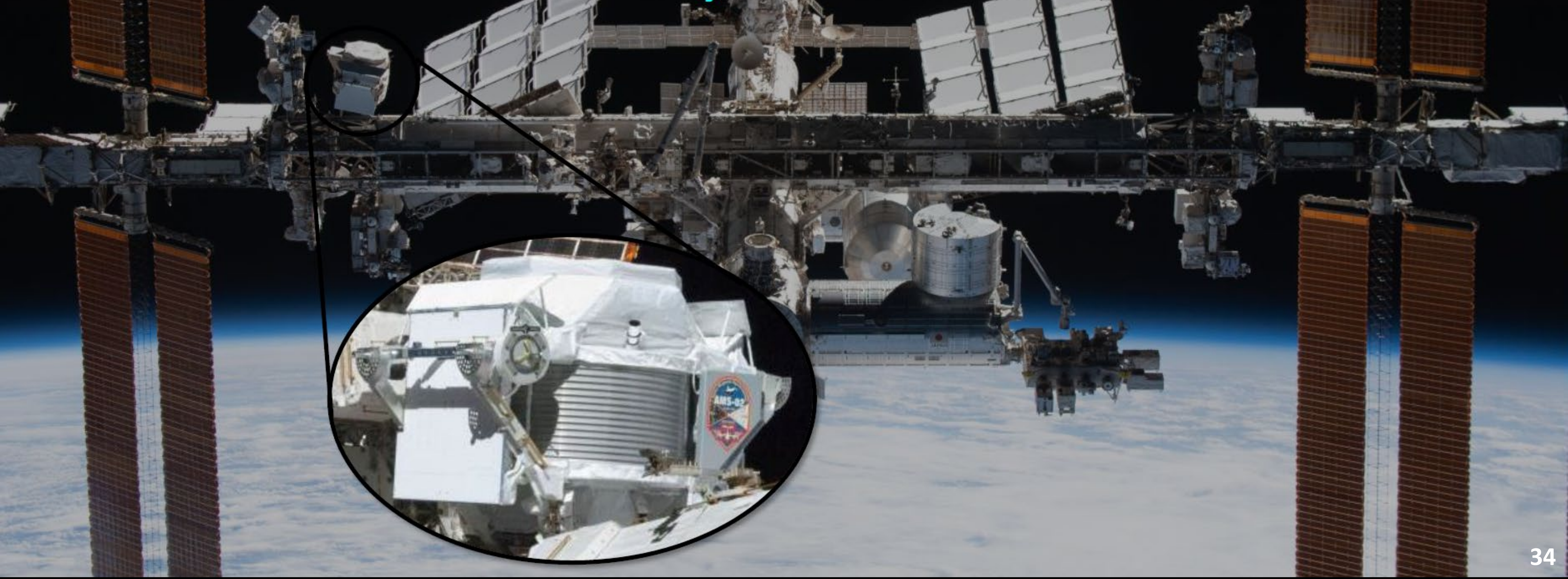
This universal relation shows that the differences in modulation between $\overline{p}$ and e^-, and between p and e^+ are mainly due to the difference in their spectral shape.

These results on the effect of spectral shape in solar modulation provide crucial input to understand the antiproton local interstellar spectrum.



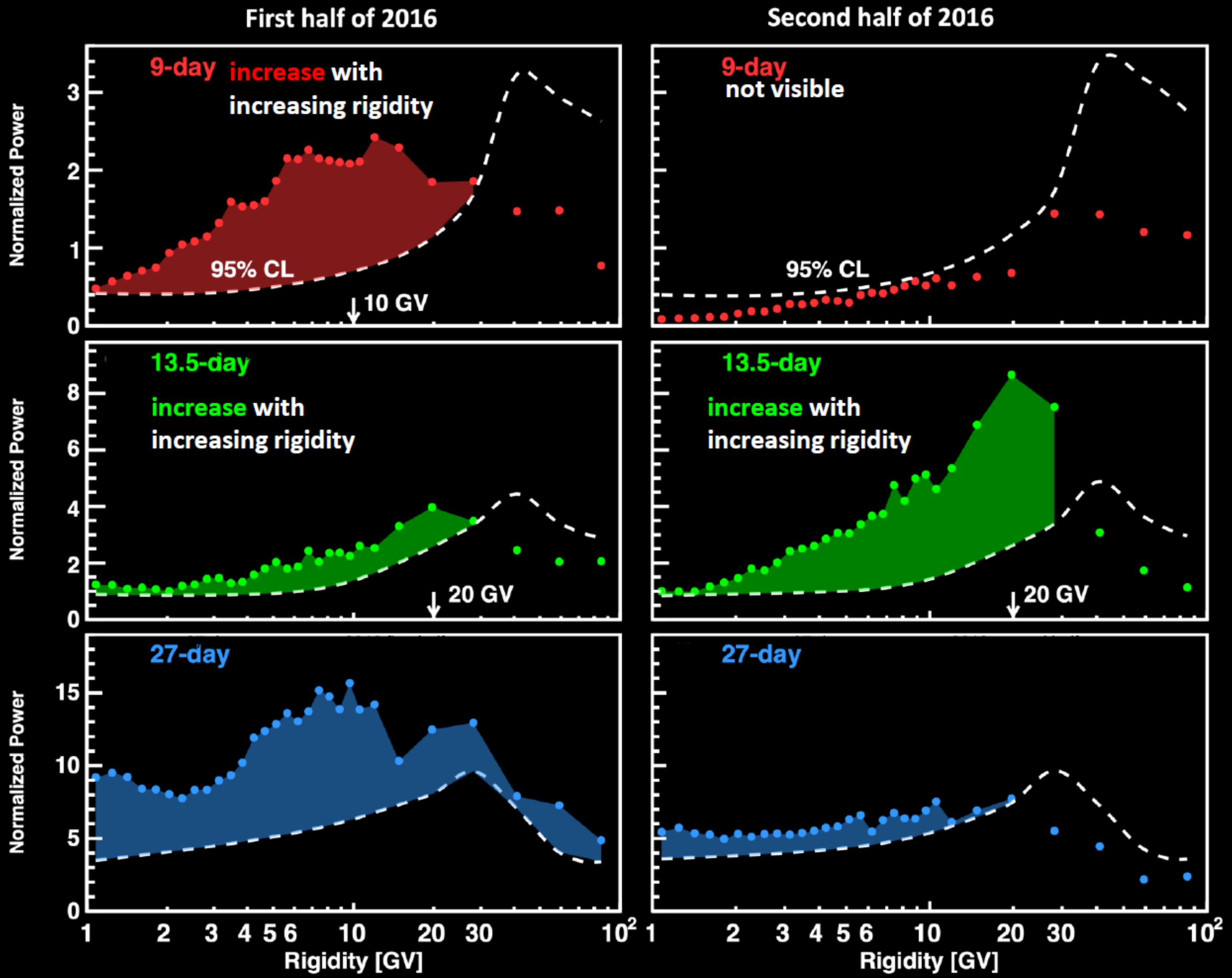
Thanks to its large acceptance, identification capabilities and long-term mission in space, AMS is a unique experiment to carry out precise studies on the time variability of the individual species in cosmic rays

By 2030, AMS will cover two solar cycles, and more unexpected results are yet to come



Backup

Rigidity Dependence of 9-day, 13.5-day, and 27-day periods of protons

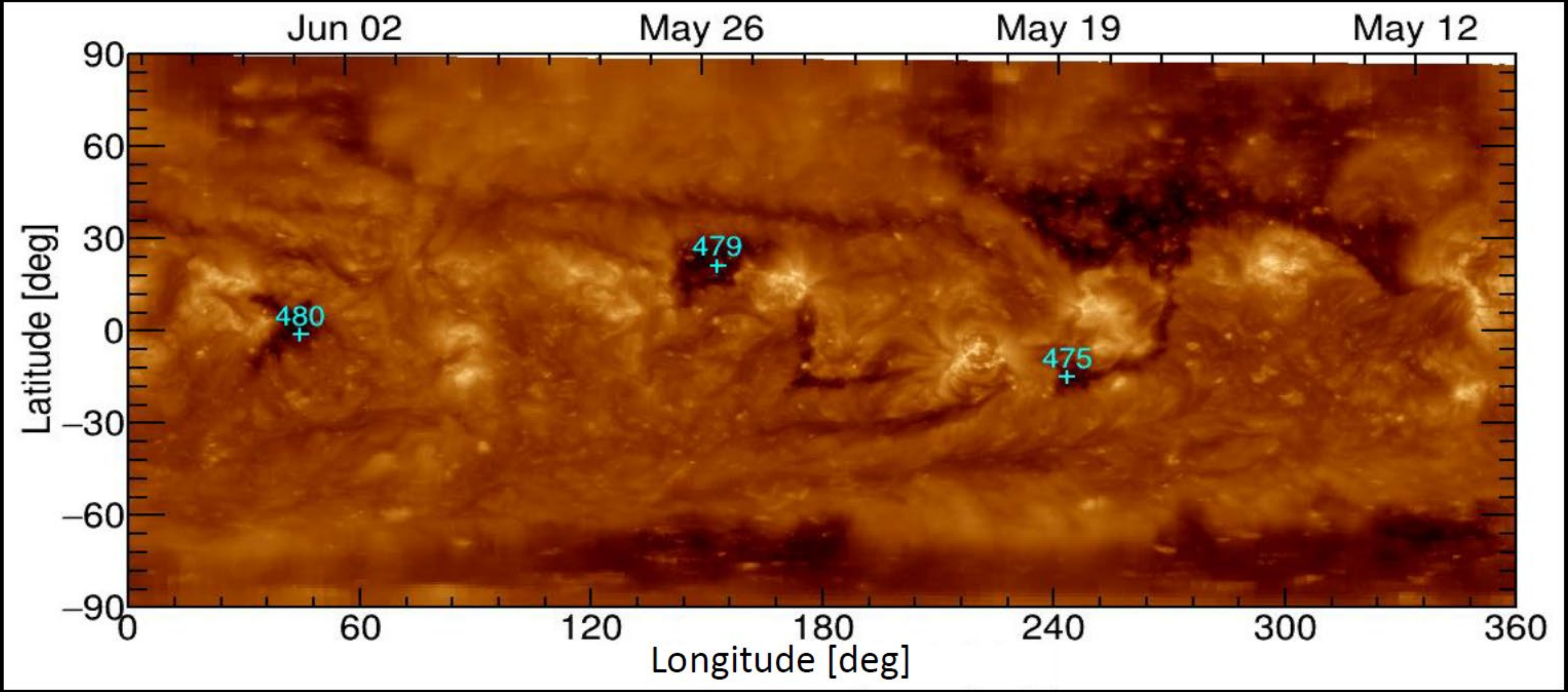


Shaded areas are the rigidity intervals where the periodicity is prominent

Cosmic Ray Periodicities and the Rotation of the Sun

Coronal Holes are sources of high speed solar wind affecting Earth. The rotation of the Sun causes multiple periods in the flux:

0 coronal hole:	⟶	No apparent periods
1 coronal hole	⟶	27-day period (a Bartels rotation)
2 coronal holes separated by 180°	⟶	13.5-day period
3 coronal holes separated by 120°	⟶	9-day period



(May 10, 2016-Jun 06, 2016) Image taken by Solar Dynamics Observatory (SDO), NASA