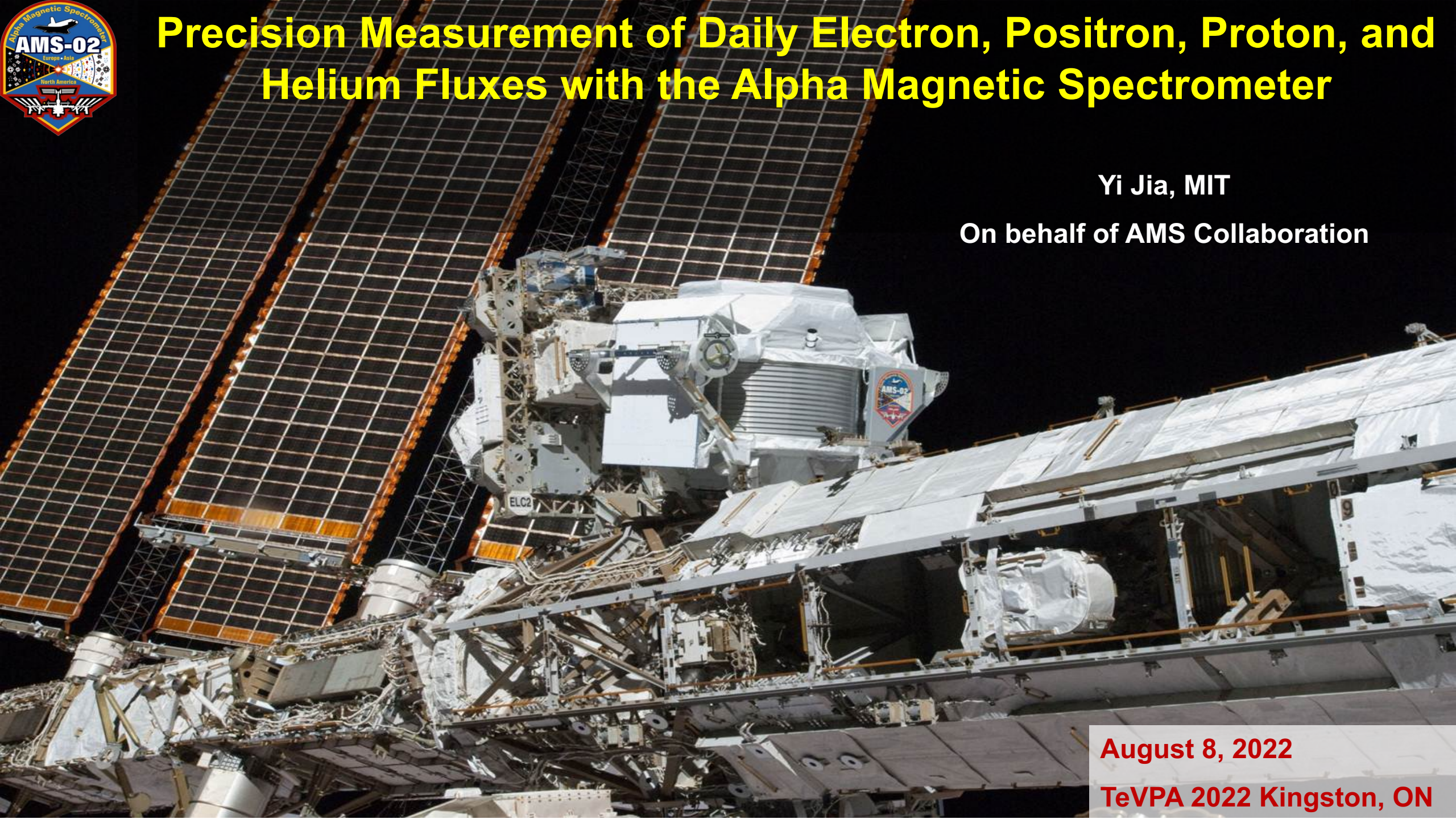
Precision Measurement of Daily Electron, Positron, Proton, and Helium Fluxes with the Alpha Magnetic Spectrometer

Yi Jia, MIT

On behalf of AMS Collaboration



August 8, 2022

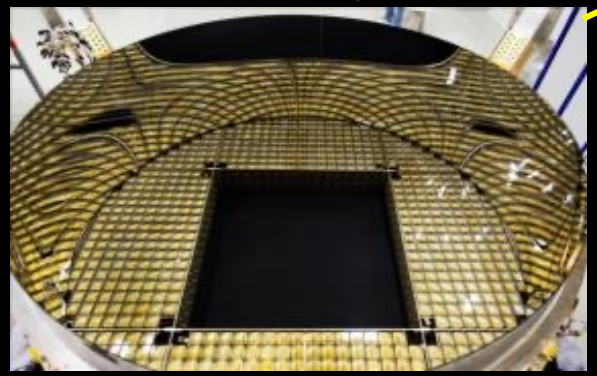
TeVPA 2022 Kingston, ON

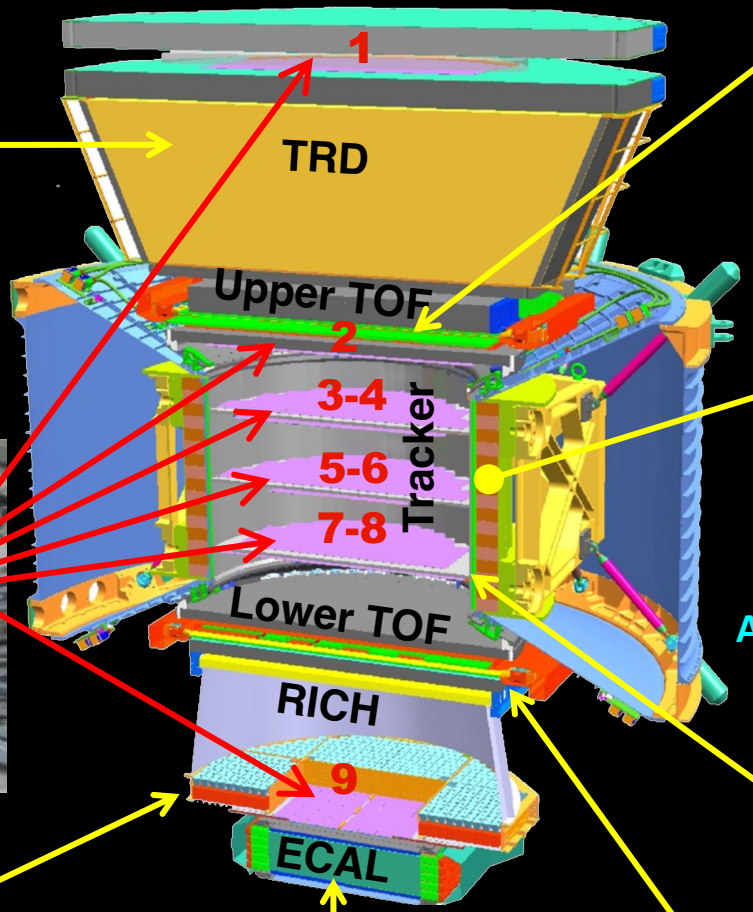
AMS is a space version of a precision detector used in accelerators

Transition Radiation Detector (TRD)
identify e^+, e^-

Silicon Tracker
measure Z, P

Ring Imaging Cerenkov (RICH)
measure Z, E





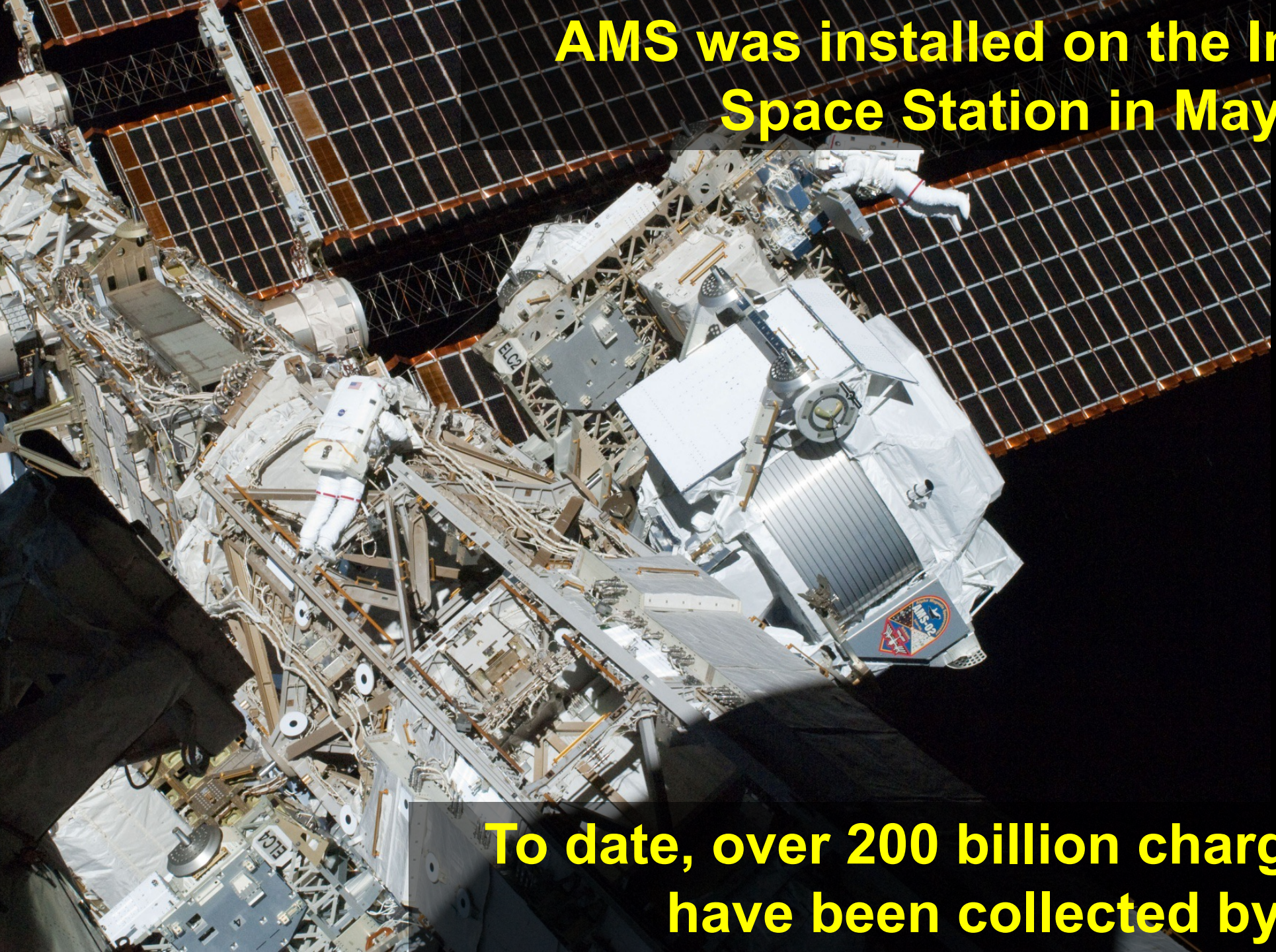
Electromagnetic Calorimeter (ECAL)
measure E of e^+, e^-

Upper TOF measure Z, E

Magnet identify ±Z, P

Anticoincidence Counters (ACC)
reject particles from the side

Lower TOF measure Z, E



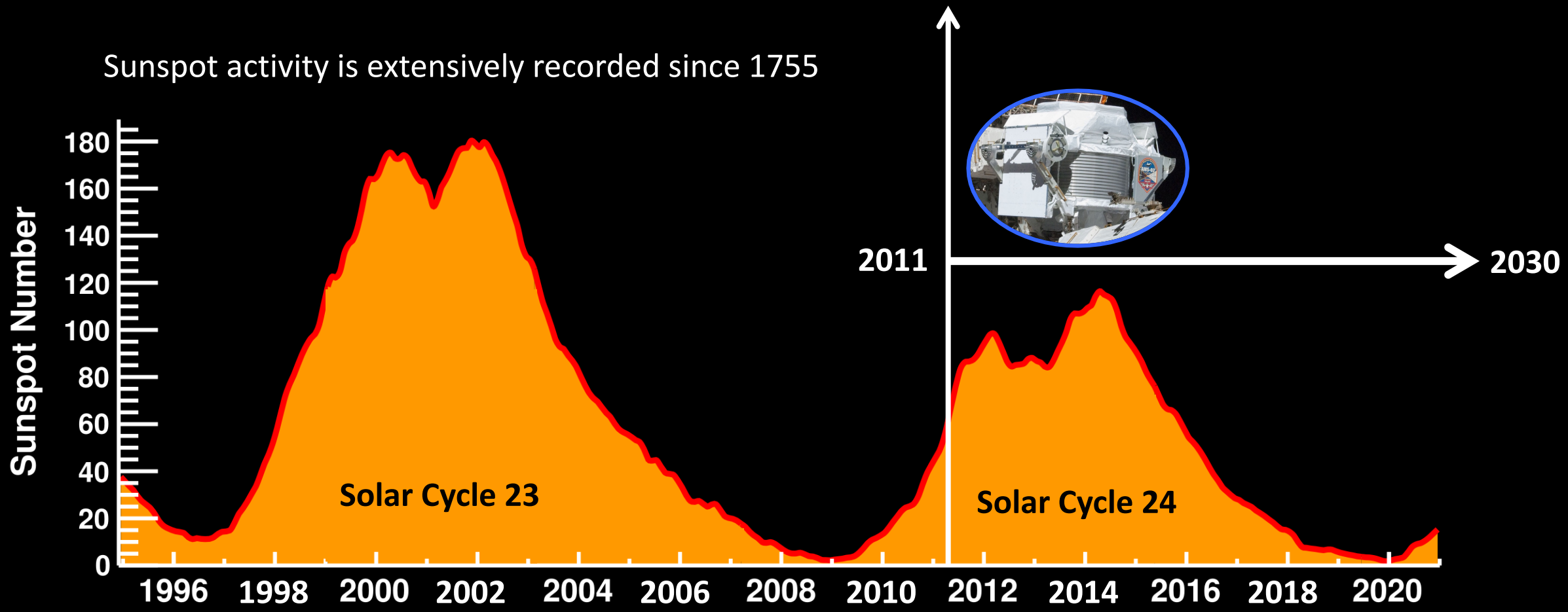
AMS was installed on the International Space Station in May 2011

Near Earth Orbit:
altitude 400km
inclination 52 deg
period 92 min

To date, over 200 billion charged particles have been collected by AMS

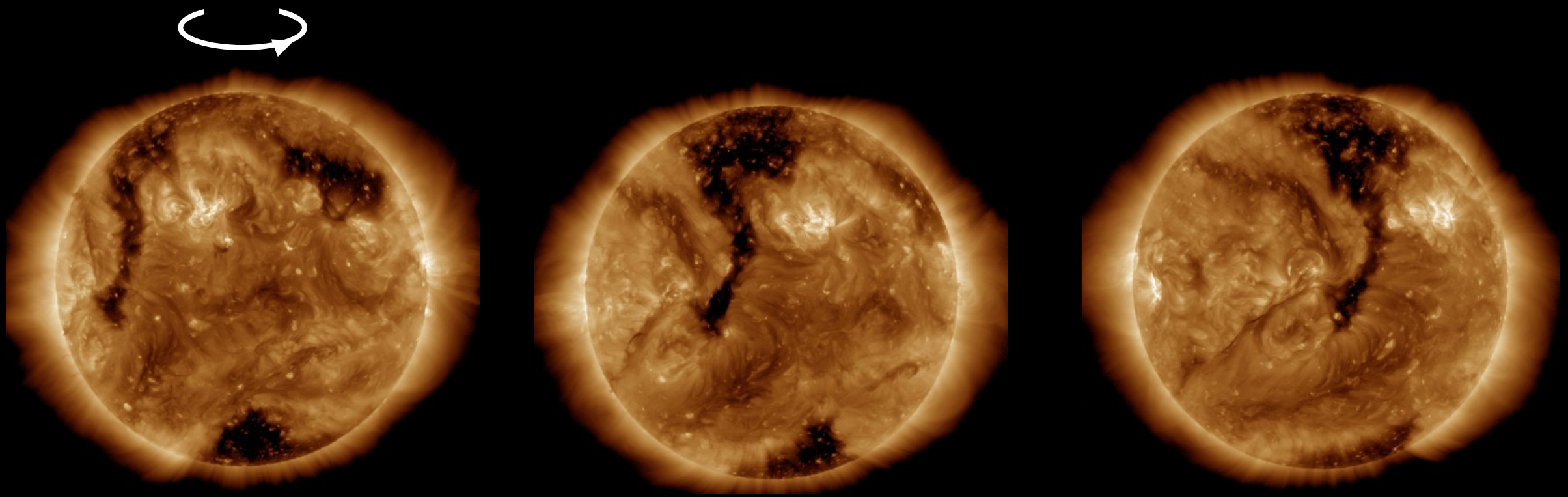
Long-term Scale Variation: Solar Cycle

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



Cosmic Ray Recurrent Variation in Short Scale

Short scale variation of cosmic rays are related to Sun's rotation (Bartels rotation: 27 days).



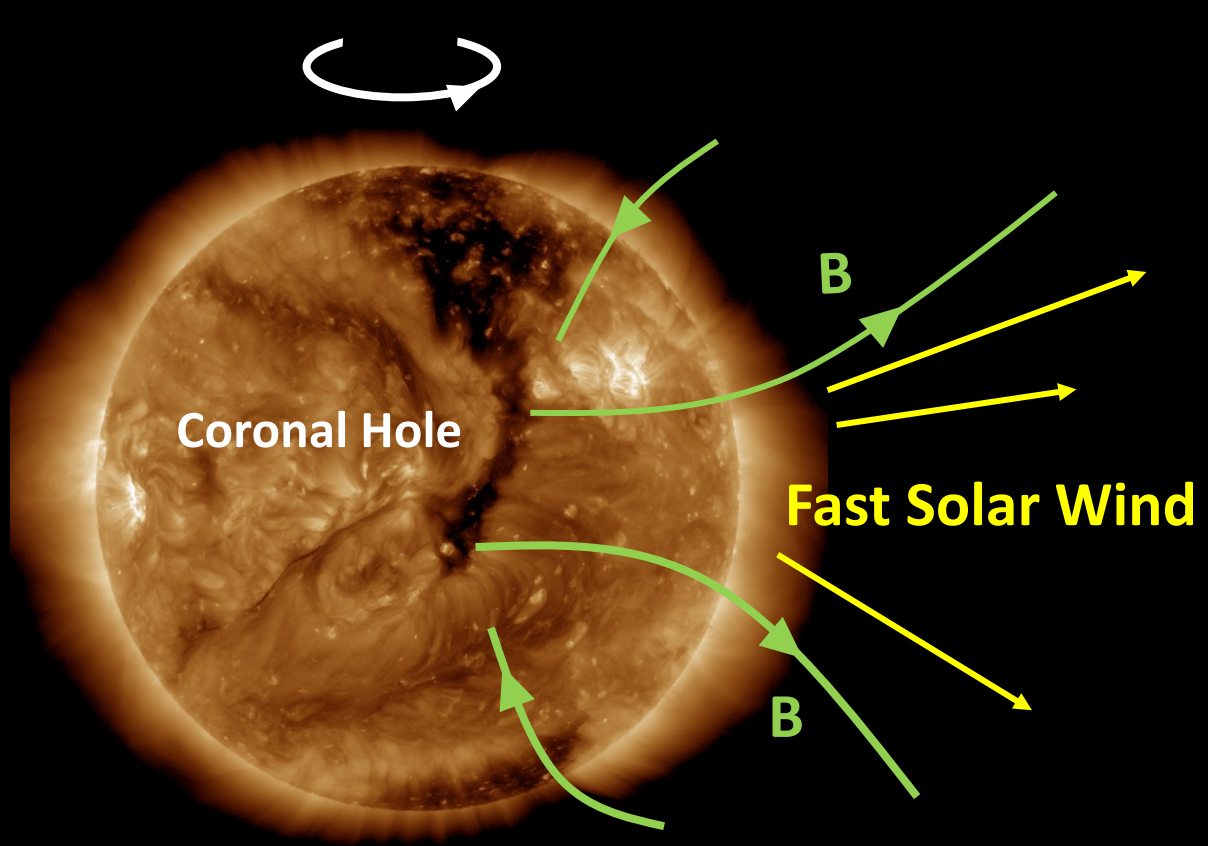
2016-03-22 2016-03-24 2016-03-26

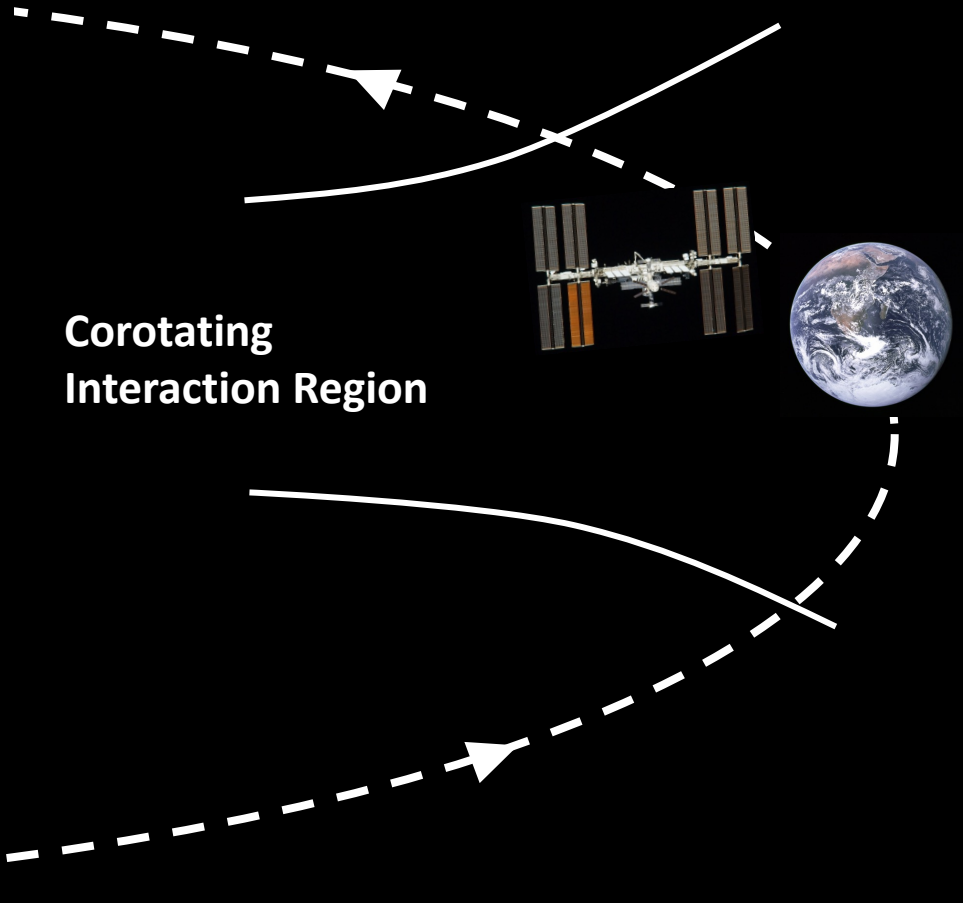
Image taken by Dynamics Observatory (SDO), NASA

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 Hole are sources of high speed solar wind affecting Earth.

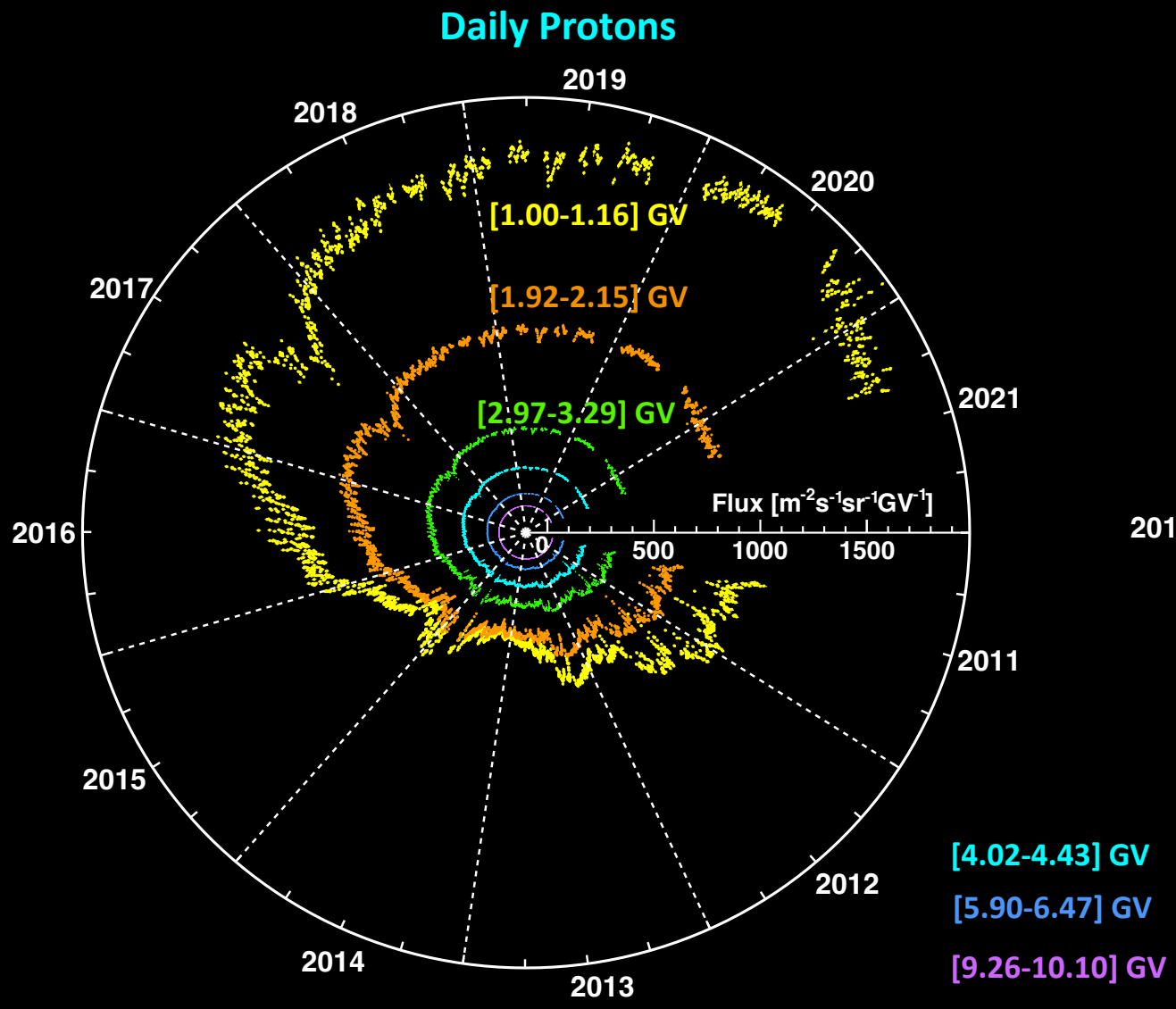


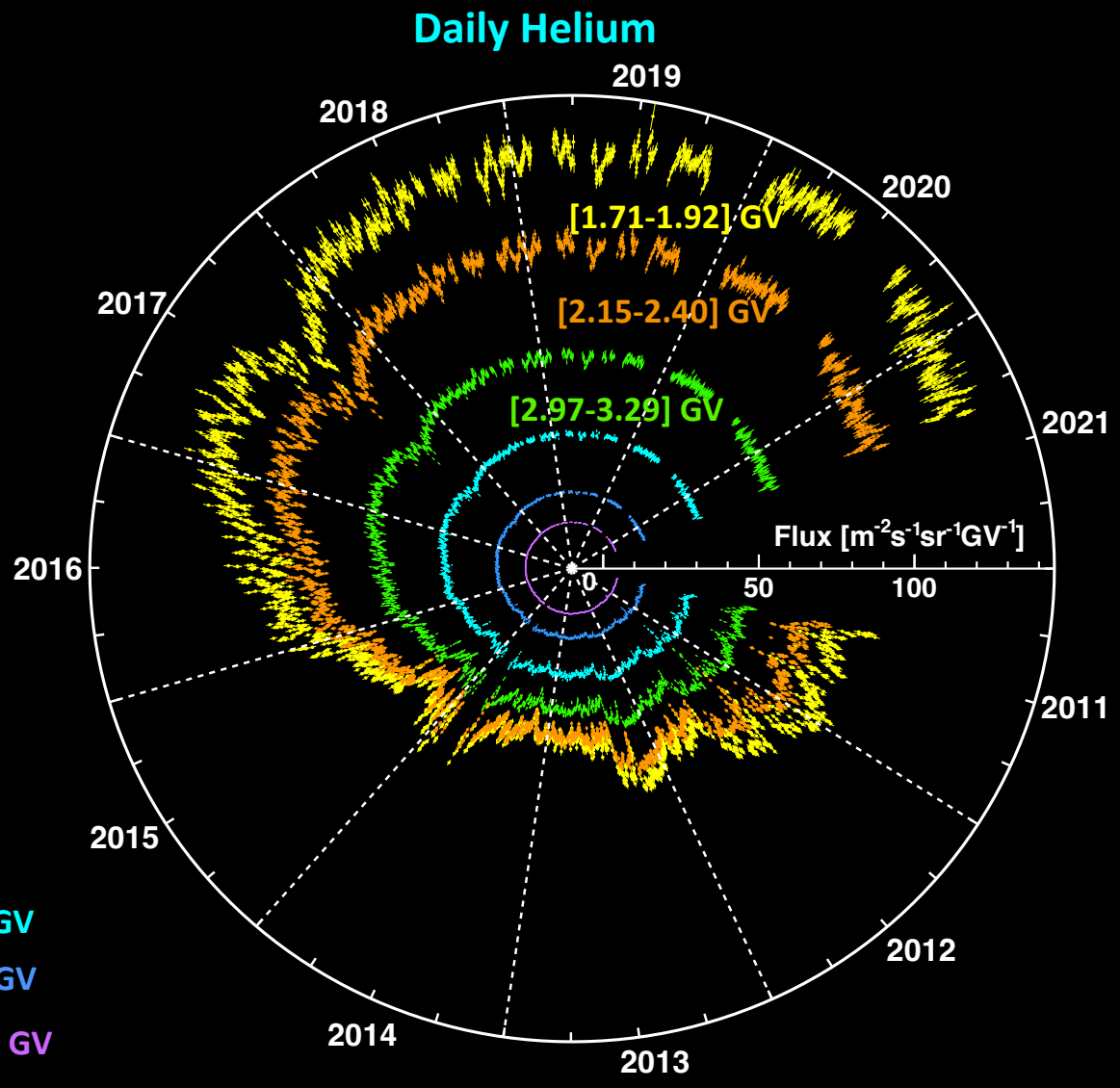


Precision measurements of daily cosmic ray fluxes provide unique inputs for the understanding of cosmic rays in the heliosphere.

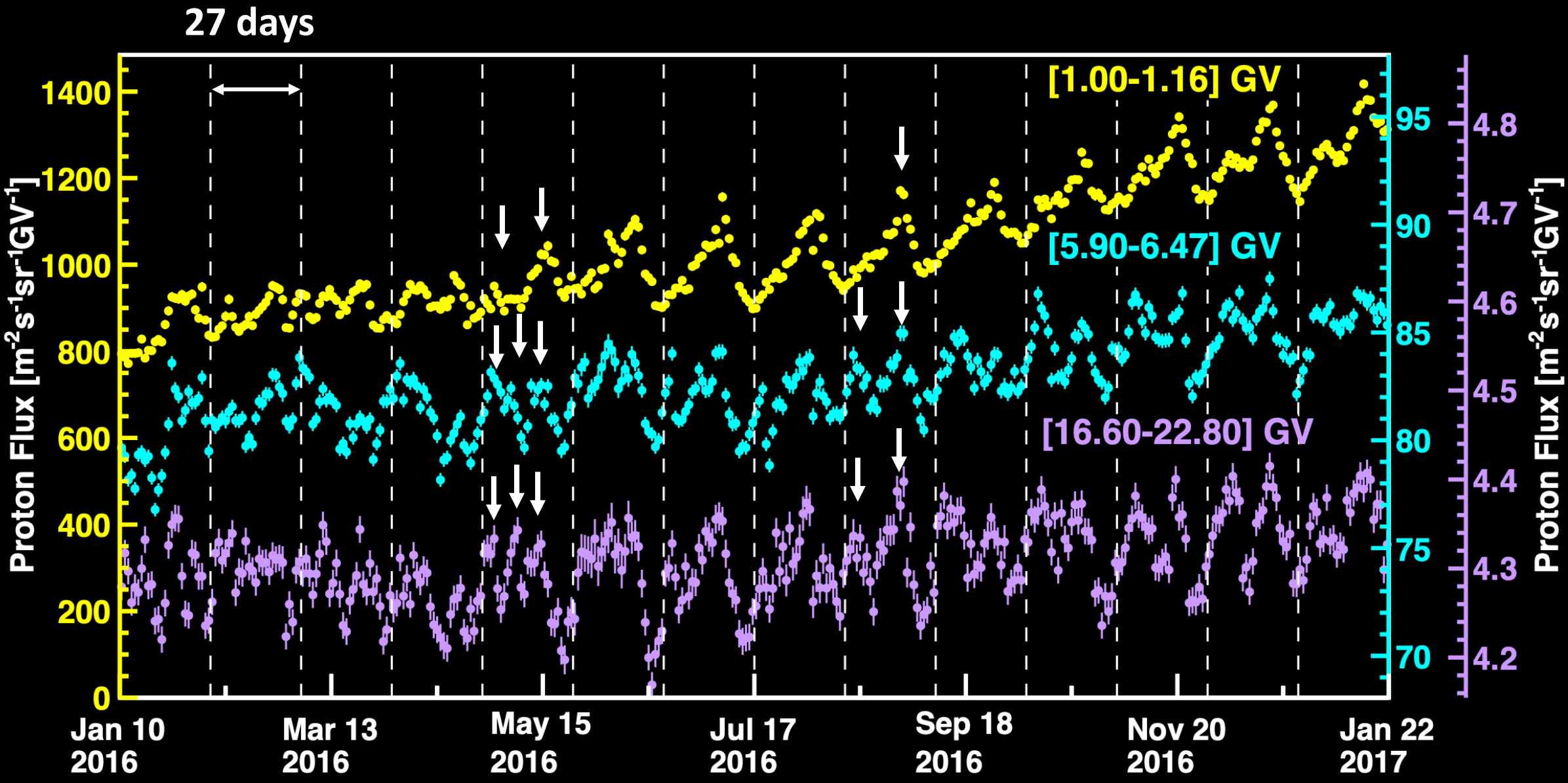
AMS Daily Proton and Helium Fluxes

6 billion protons and 850 million helium nuclei collected from **May 20, 2011** to **May 2, 2021**



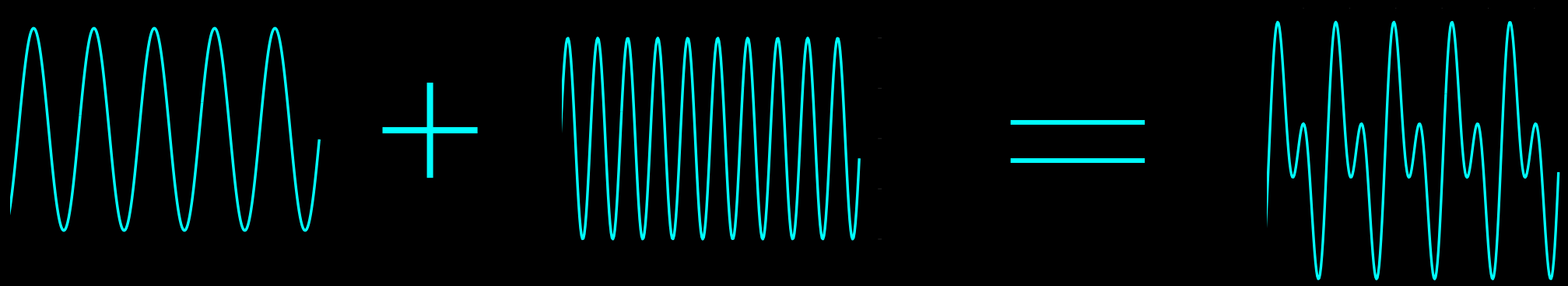


Recurrent Flux Variation with Periods of 9, 13.5, and 27 days in 2016



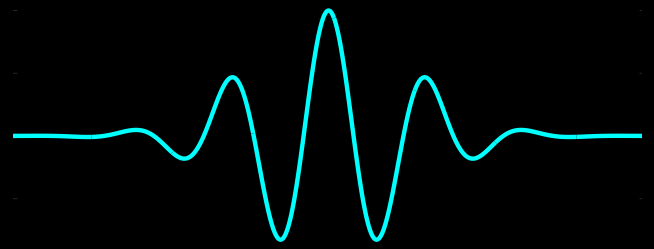
Frequency Analysis of Daily Fluxes

Fourier Transform represents data as a function of sinusoidal waves:



Drawback: sinusoids extend to infinity: not localized in time.

Wavelet: exist for finite duration: localized both in time and frequency space:



C. Torrence and G. P. Compo, Bull. Am. Meteorol. Soc. 79, 61 (1998)

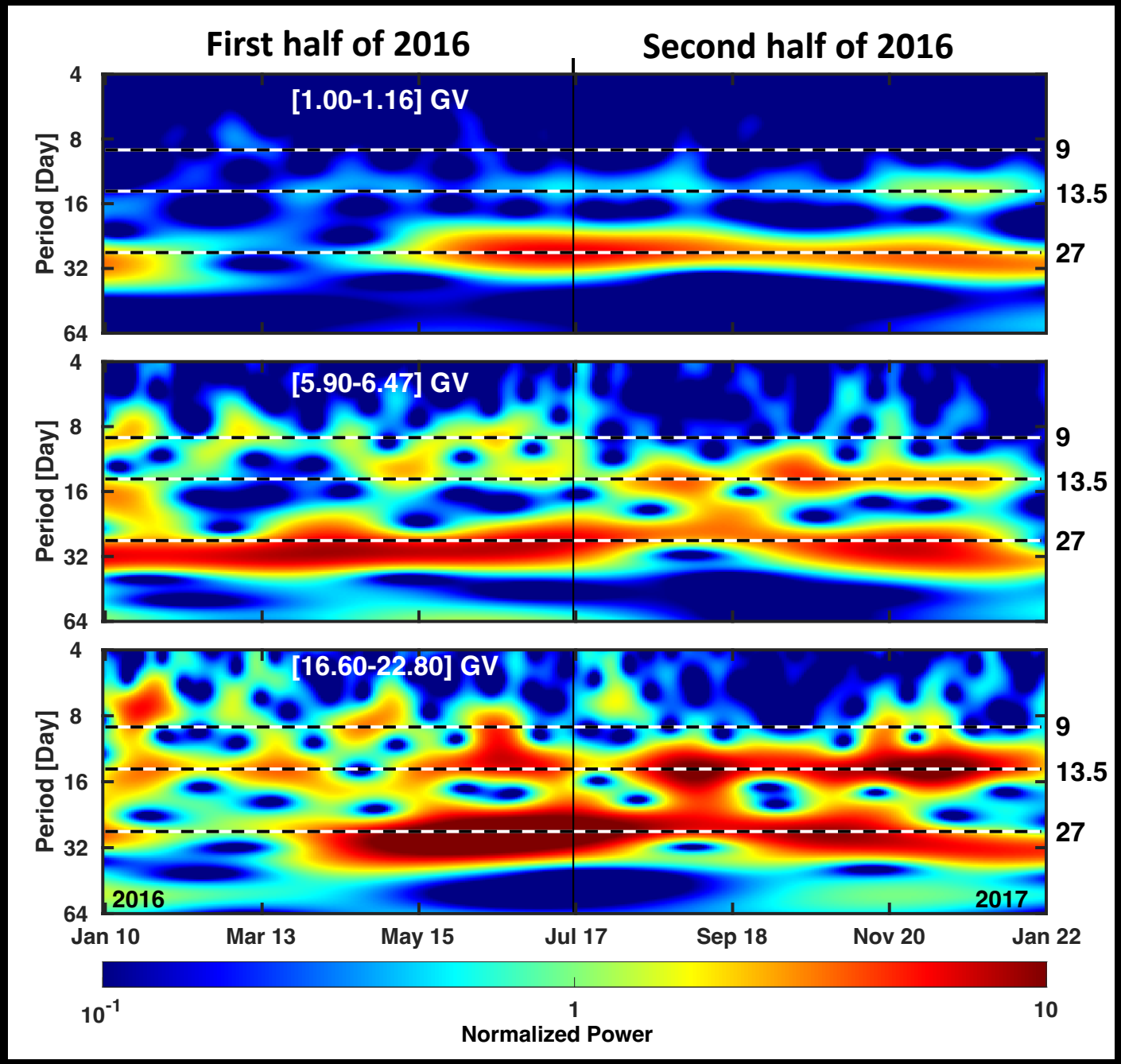
Wavelet Analysis of Proton Fluxes in 2016

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

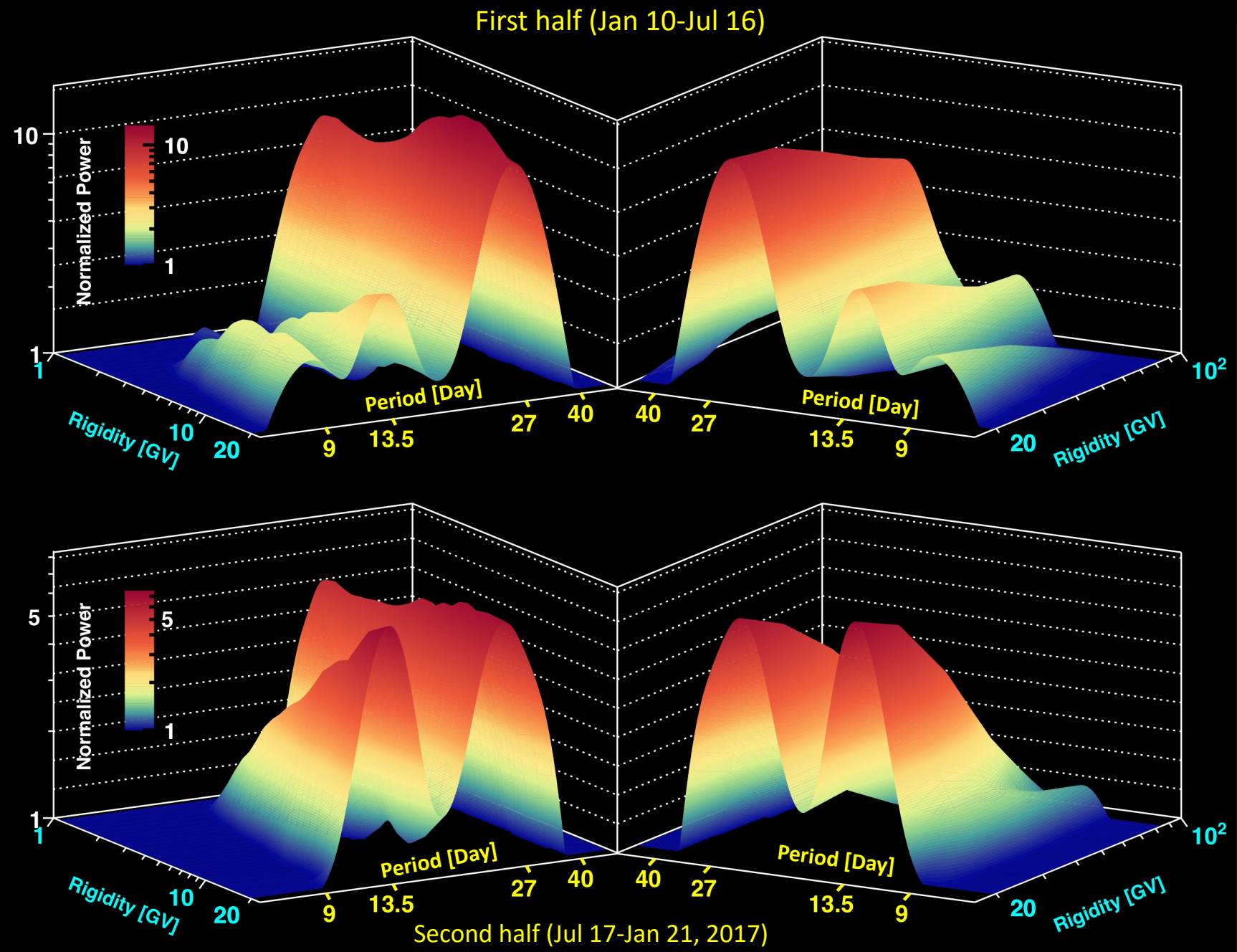
Periods of 9, 13.5, and 27 days are observed in 2016.

The strength of all three periodicities change 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

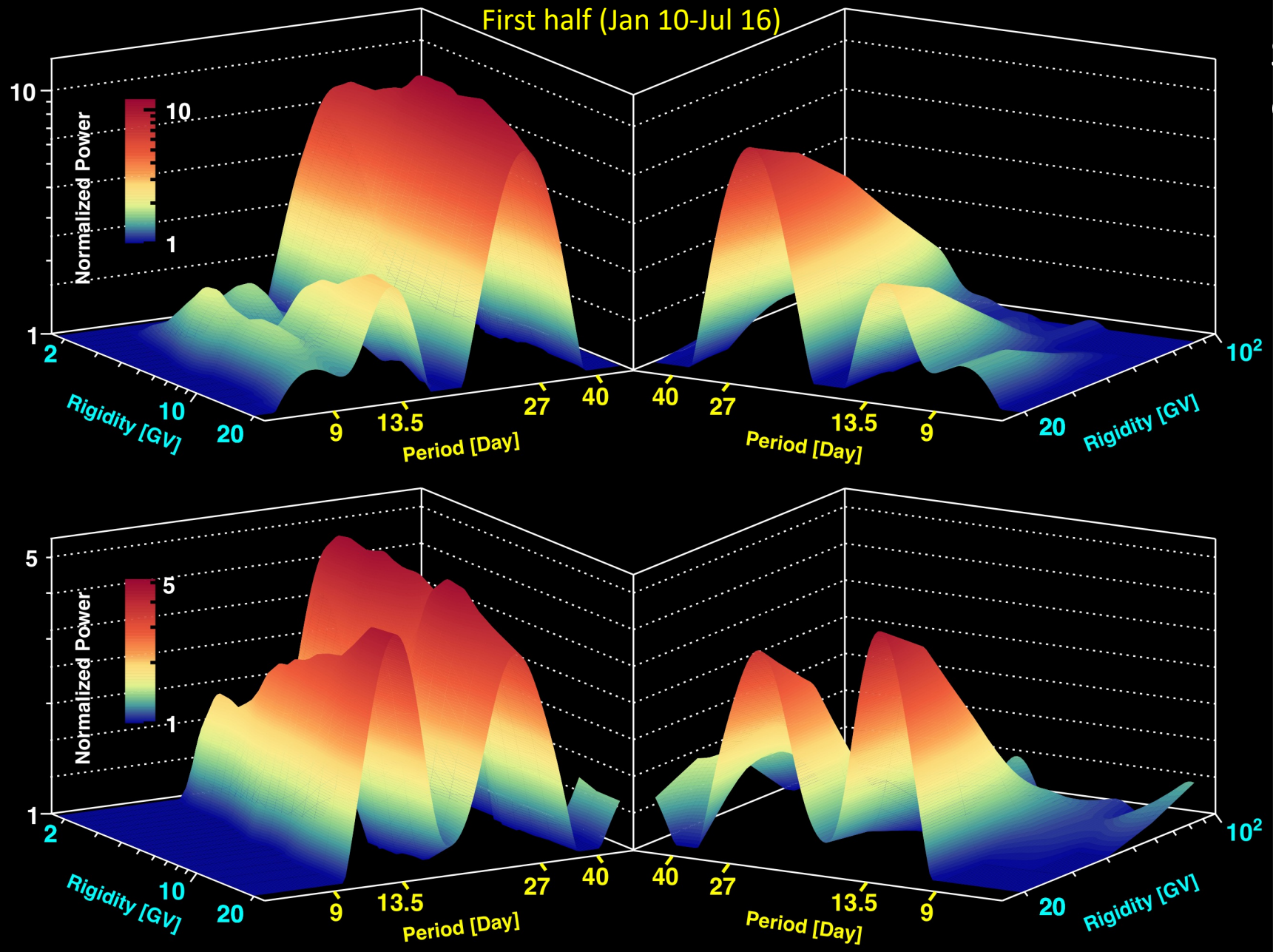


Unexpectedly, the strength of **9-day and 13.5-day periodicities** increases with increasing rigidity up to **~10 GV** and **~20 GV,** respectively. Then the strength decreases with increasing rigidity up to **100 GV.**

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)

Periodicities of Daily Helium Fluxes in 2016



Similar periodic structures are observed for helium.

The strength of **9-day and 13.5-day periodicities** increases with increasing rigidity, and then decreases with increasing rigidity up to **100 GV.**

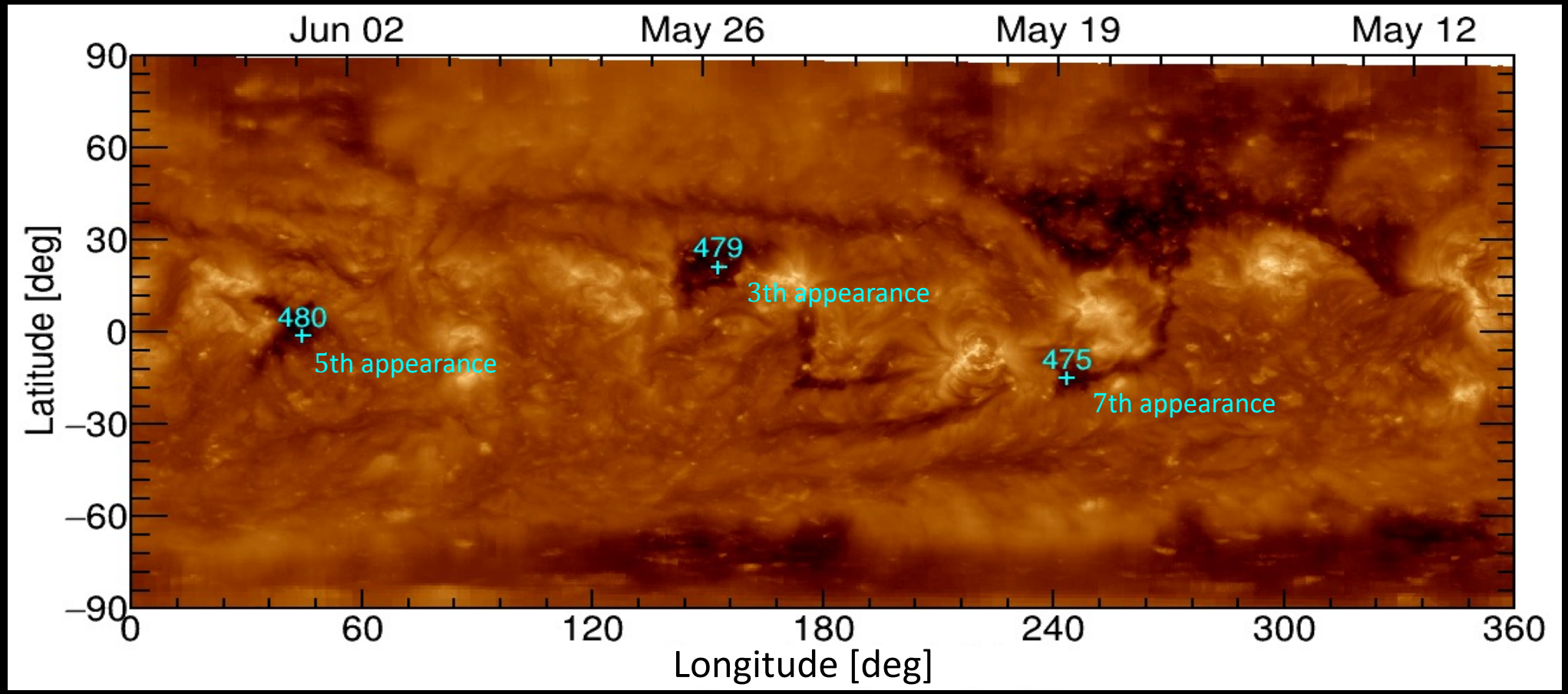
Thus, the AMS results do not support the general conclusion that the strength of the periodicities always decreases with increasing rigidity

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

Connection to the Activities on the Surface of the Sun

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

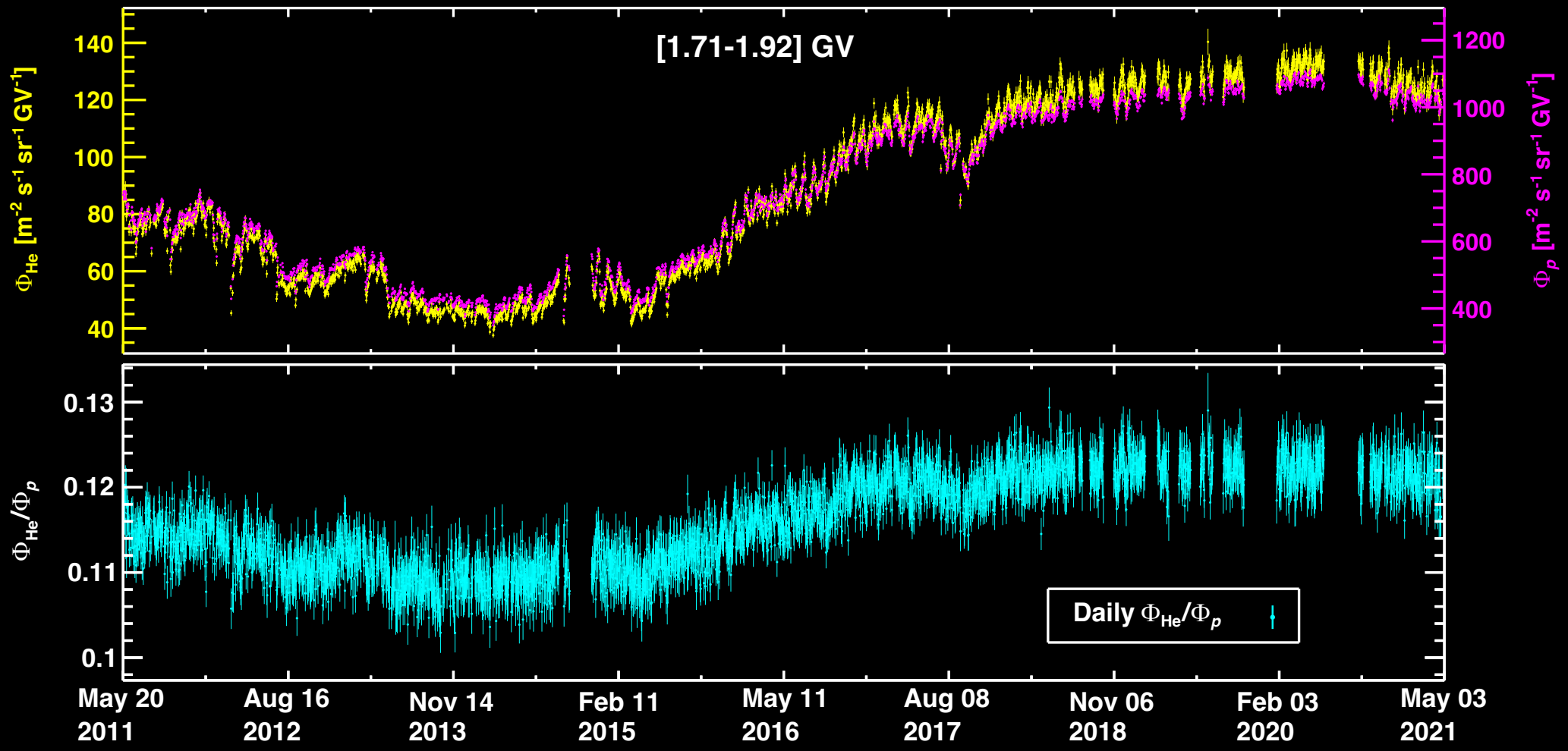
0 coronal hole: ⟶ No apparent periods
1 coronal hole ⟶ 27-day period (a Bartels rotation)
2 coronal hole separated by 180° ⟶ 13.5-day period
3 coronal holes separated by 120° ⟶ 9-day period



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

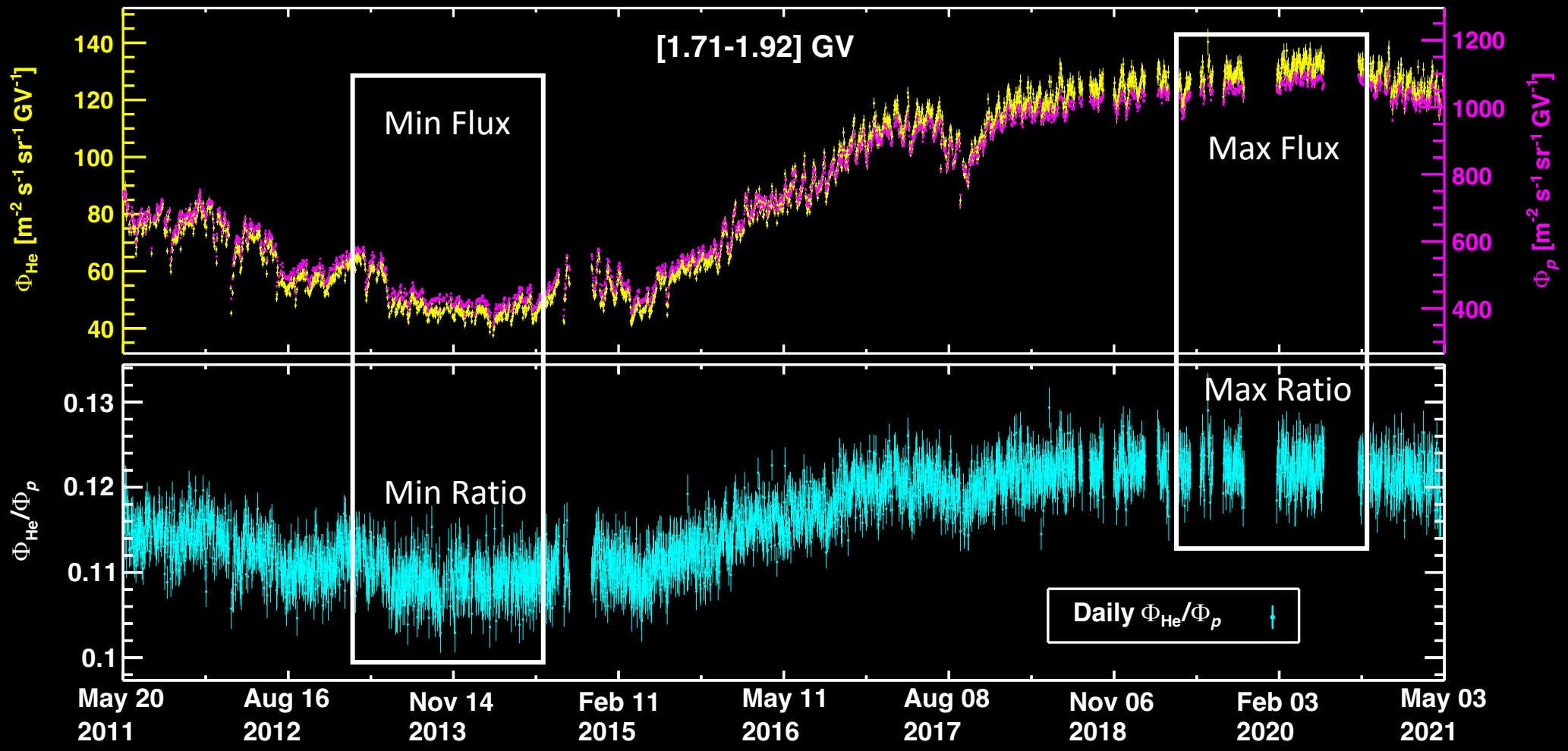
Daily He, p and He/p Flux Ratio

The helium to proton flux ratio exhibits variations on multiple timescales

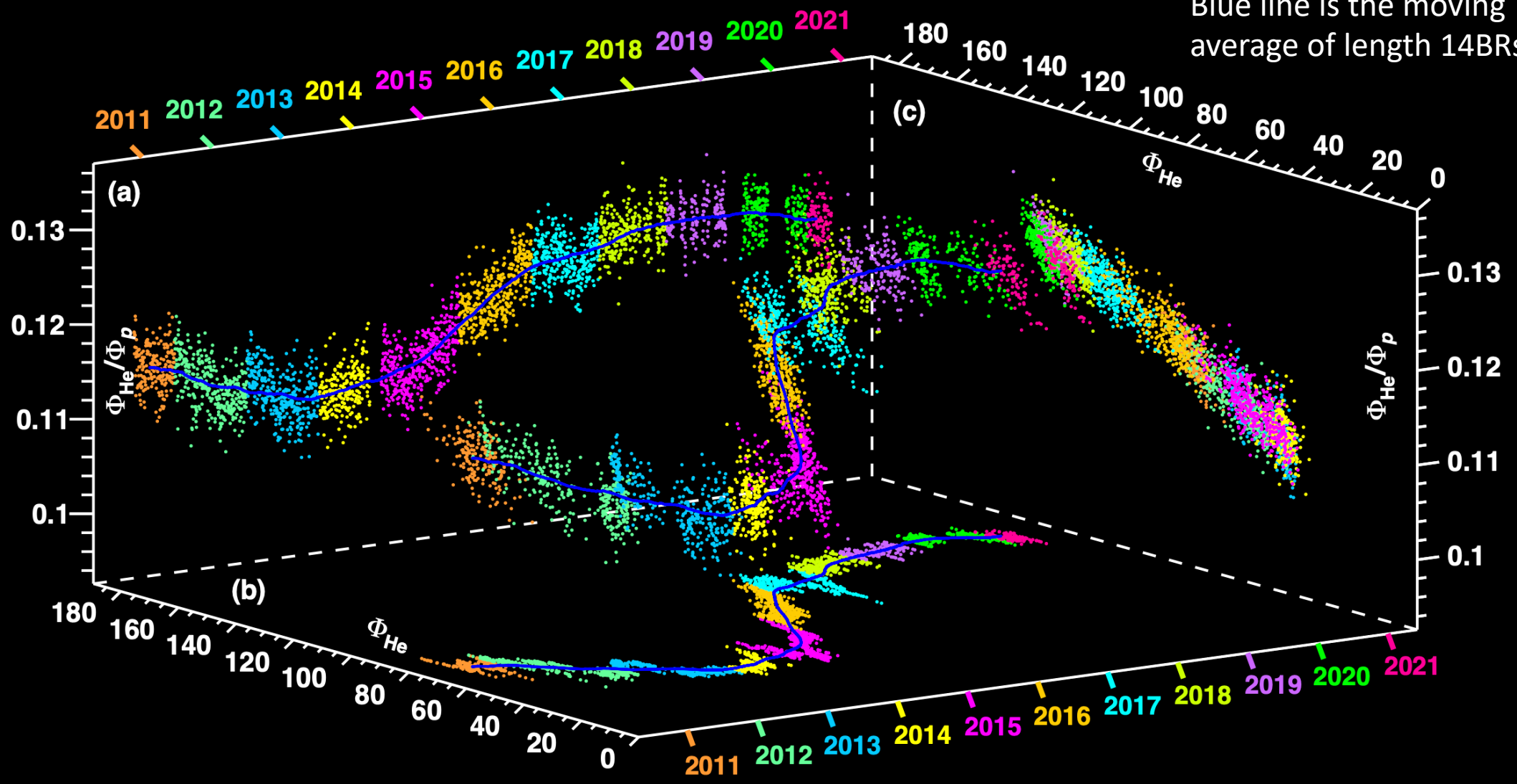


Daily He, p and He/p Flux Ratio

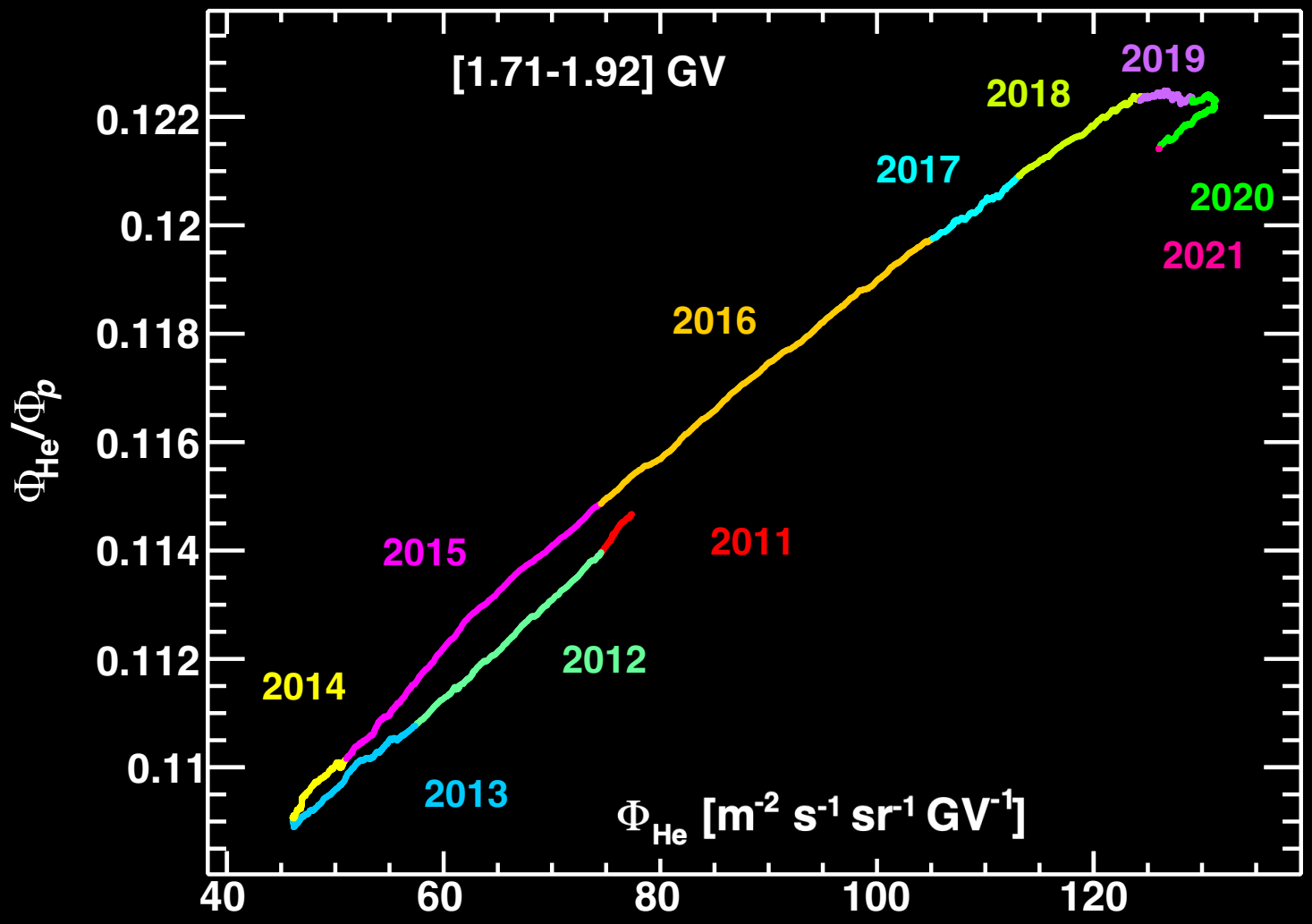
The helium flux exhibits larger time variations than the proton flux



3D functional dependence of (Φ_{He}/Φ_p, time, and Φ_{He})



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

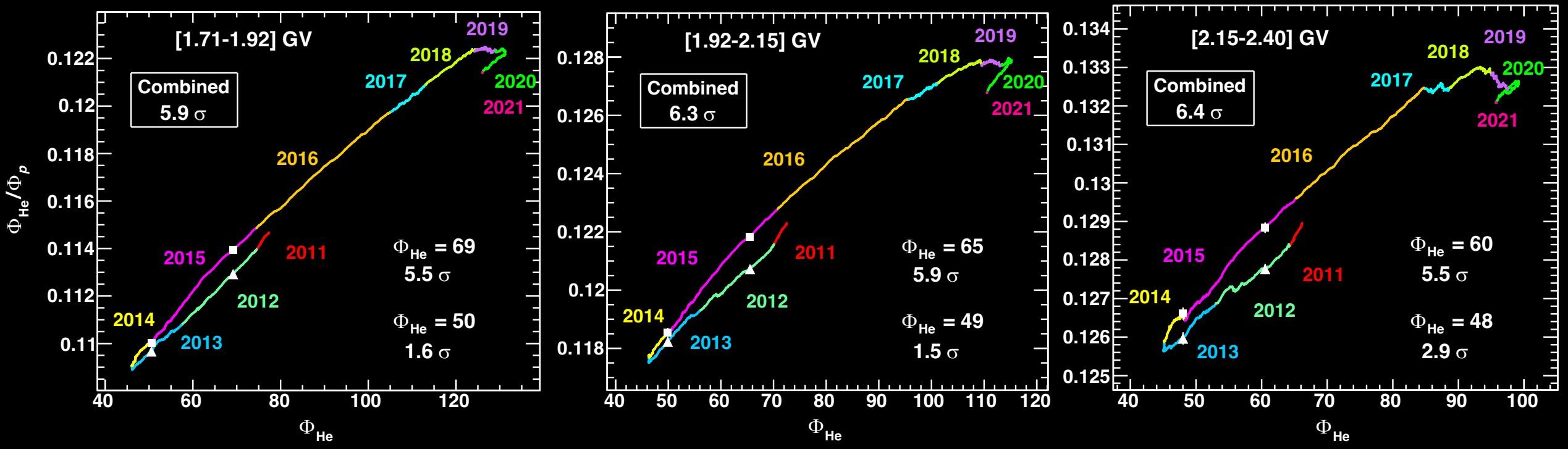


Moving averages of length 14BRs with a step of one day

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

A hysteresis between $\Phi_{\mathrm{He}}/\Phi_p$ and Φ_{He}: 7σ effect

We study the significance of the difference of $\Phi_{\mathrm{He}}/\Phi_p$ at the same Φ_{He} but different solar conditions:

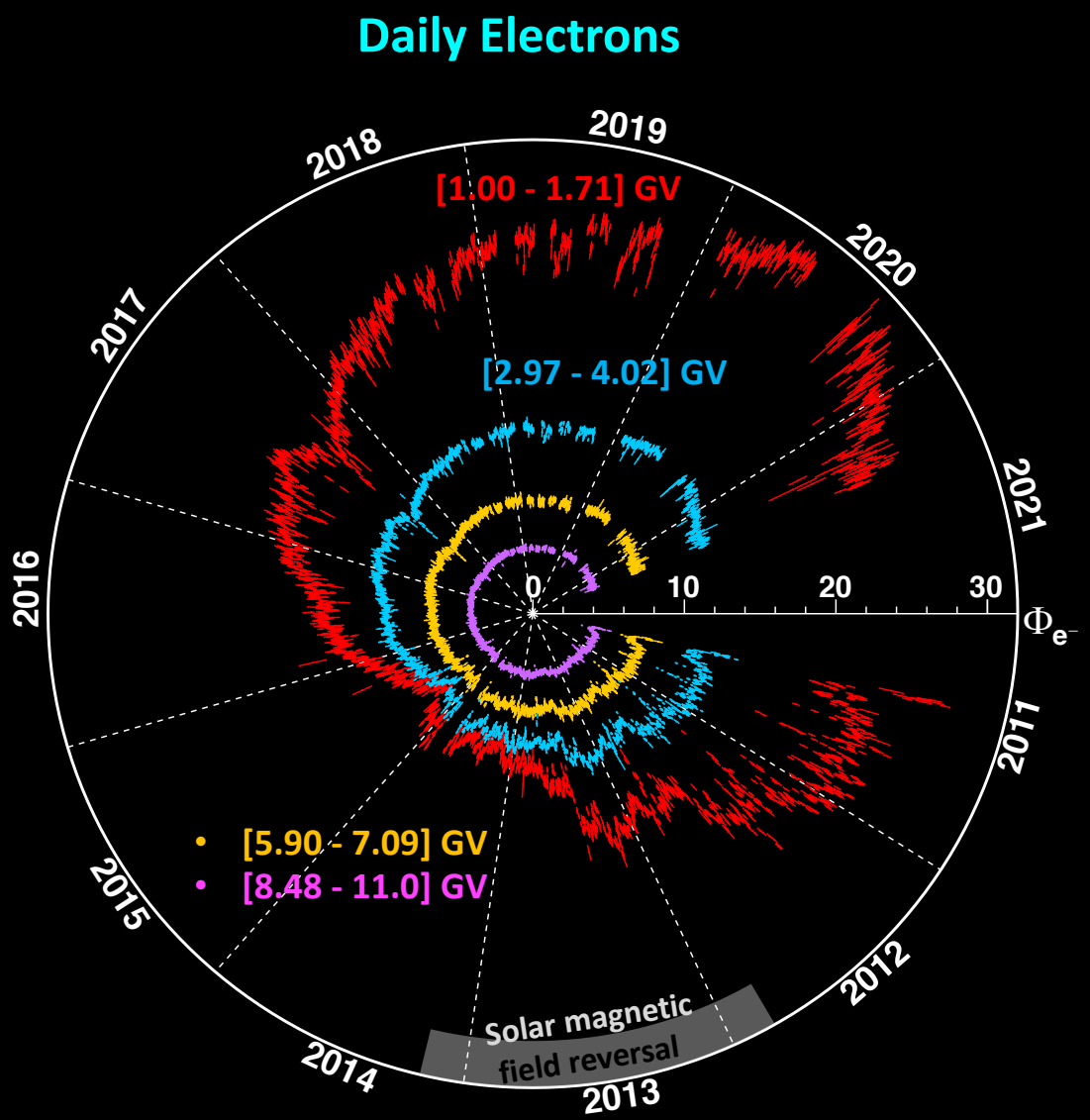


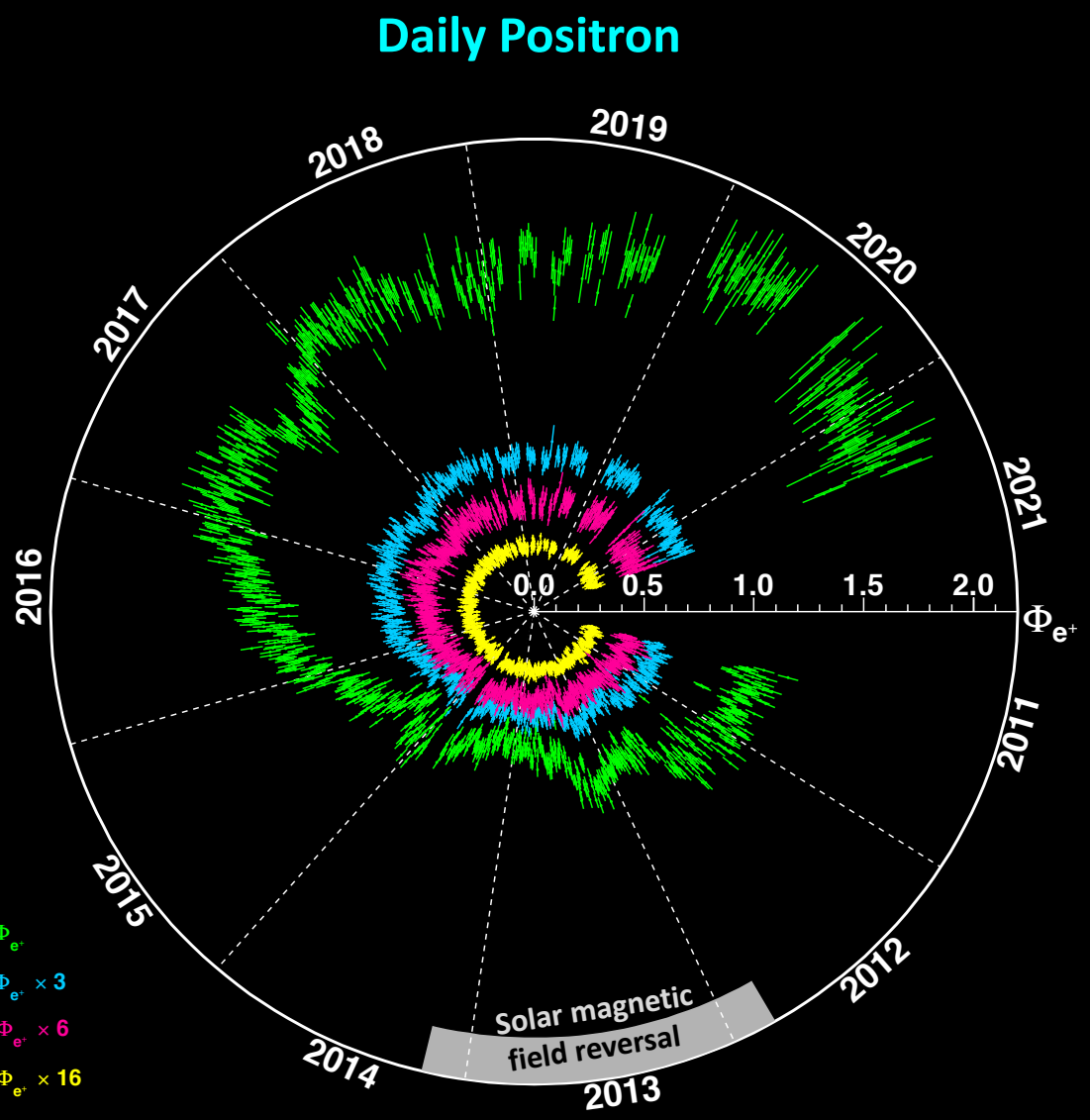
▲ : $\Phi_{\mathrm{He}}/\Phi_p$ before the solar maximum 2014

■ : $\Phi_{\mathrm{He}}/\Phi_p$ after the solar maximum 2014

The hysteresis is observed with a significance greater than 7σ with combined three rigidity bins below 2.4 GV.

AMS Daily Electron and Positron Fluxes over Ten Years





[1.00–2.97] GV Φ_{e^+}

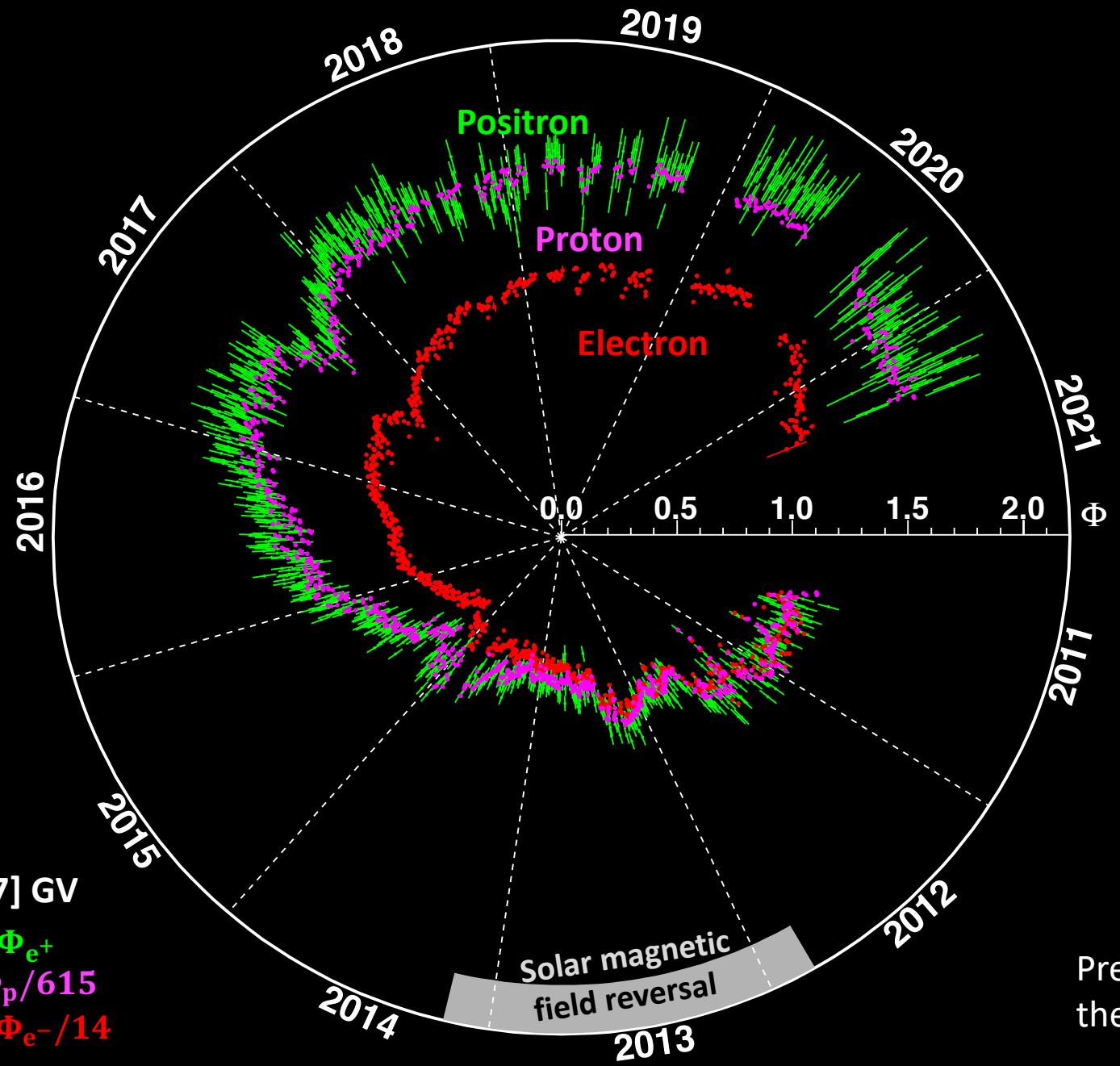
[2.97–4.88] GV Φ_{e^+} × 3

[4.88–5.90] GV Φ_{e^+} × 6

[7.09–11.0] GV Φ_{e^+} × 16

Preliminary data. Please refer to the AMS forthcoming publication

Comparison between Positron, Proton, and Electron

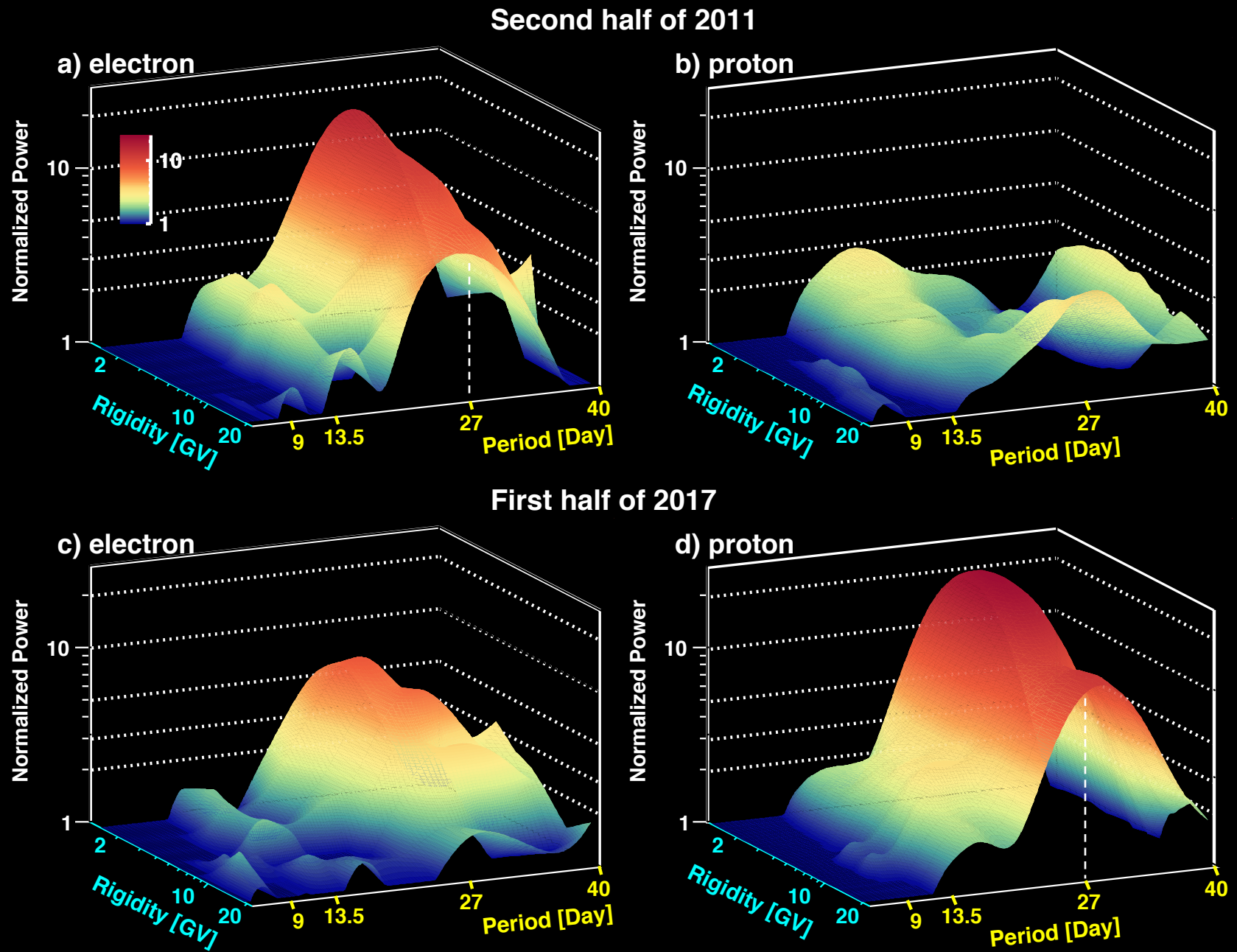


[1.00 - 2.97] GV

- Positron Φ_{e^+}
- Proton $\Phi_p/615$
- Electron $\Phi_{e^-}/14$

Preliminary data. Please refer to the AMS forthcoming publication

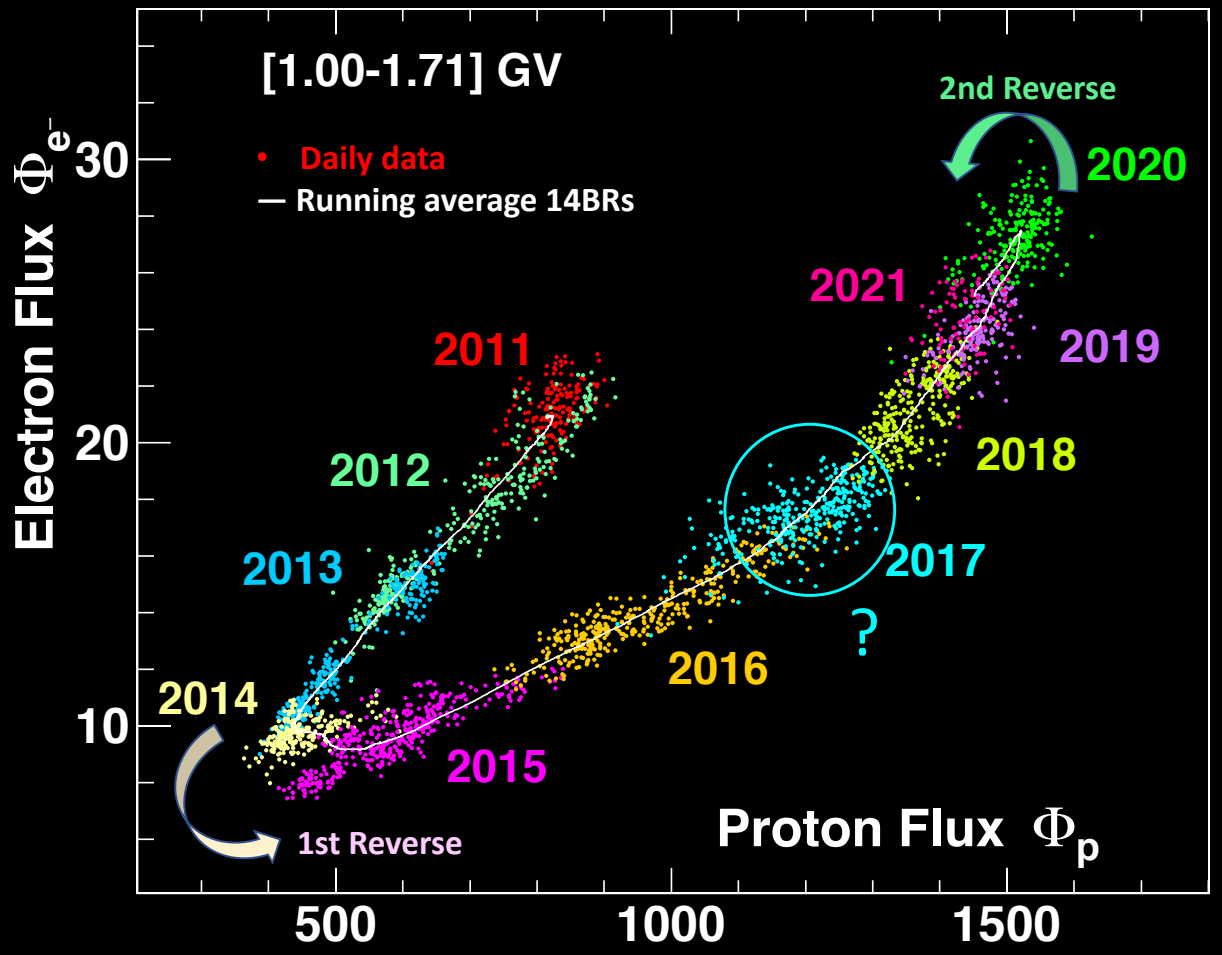
Periodicities of Daily Electron Fluxes in 2016



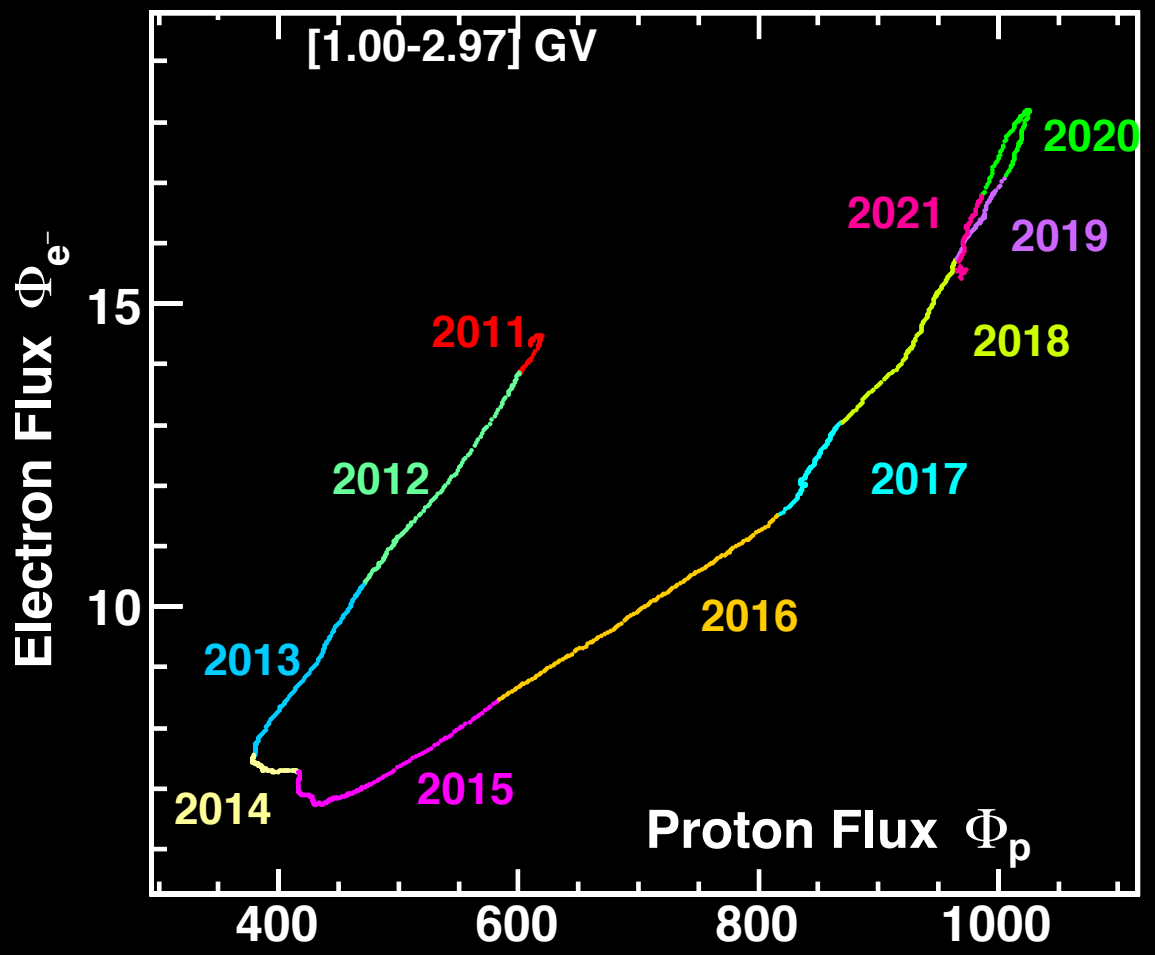
The rigidity dependence of the electron periodicities is different from that of protons

Preliminary data. Please refer to the AMS forthcoming publication

Hysteresis in the electron and proton flux

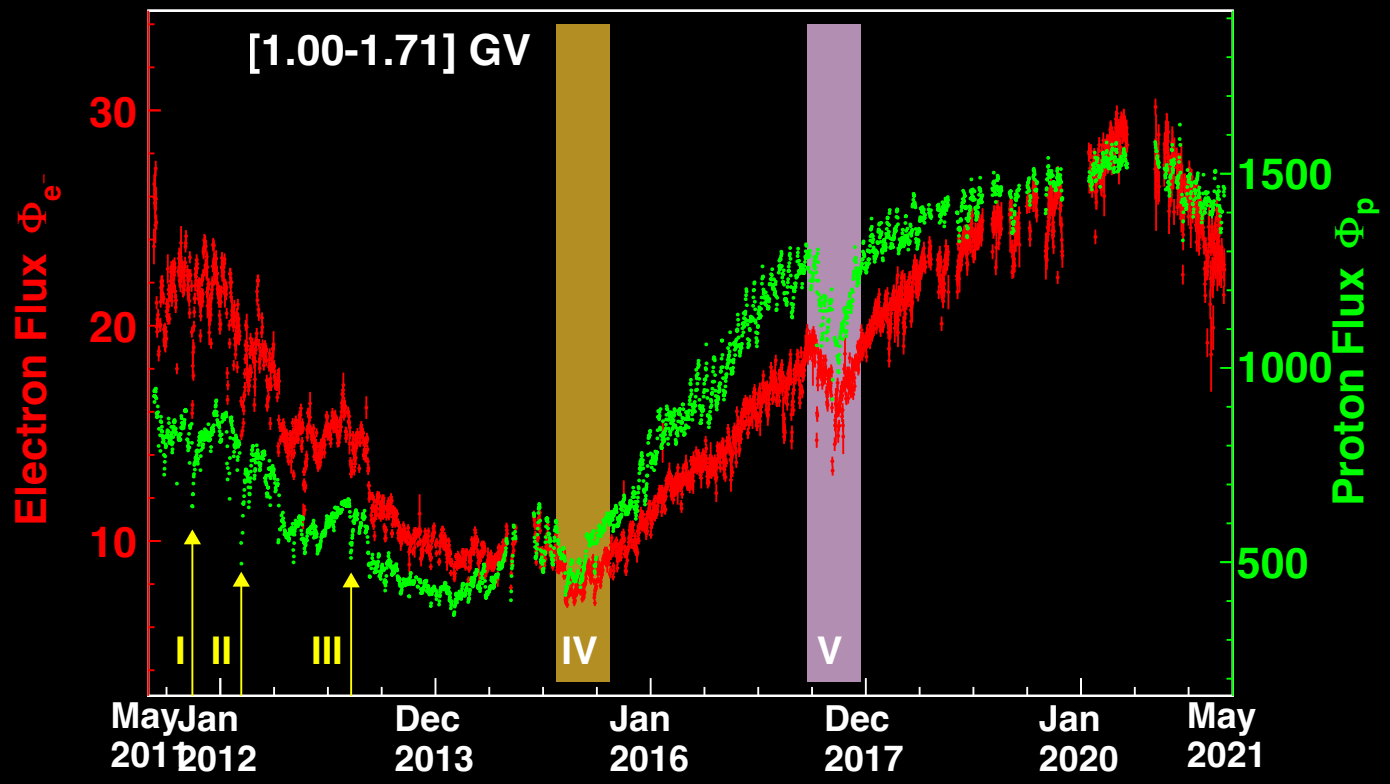


Moving averages of length 14BRs
with a step of one day

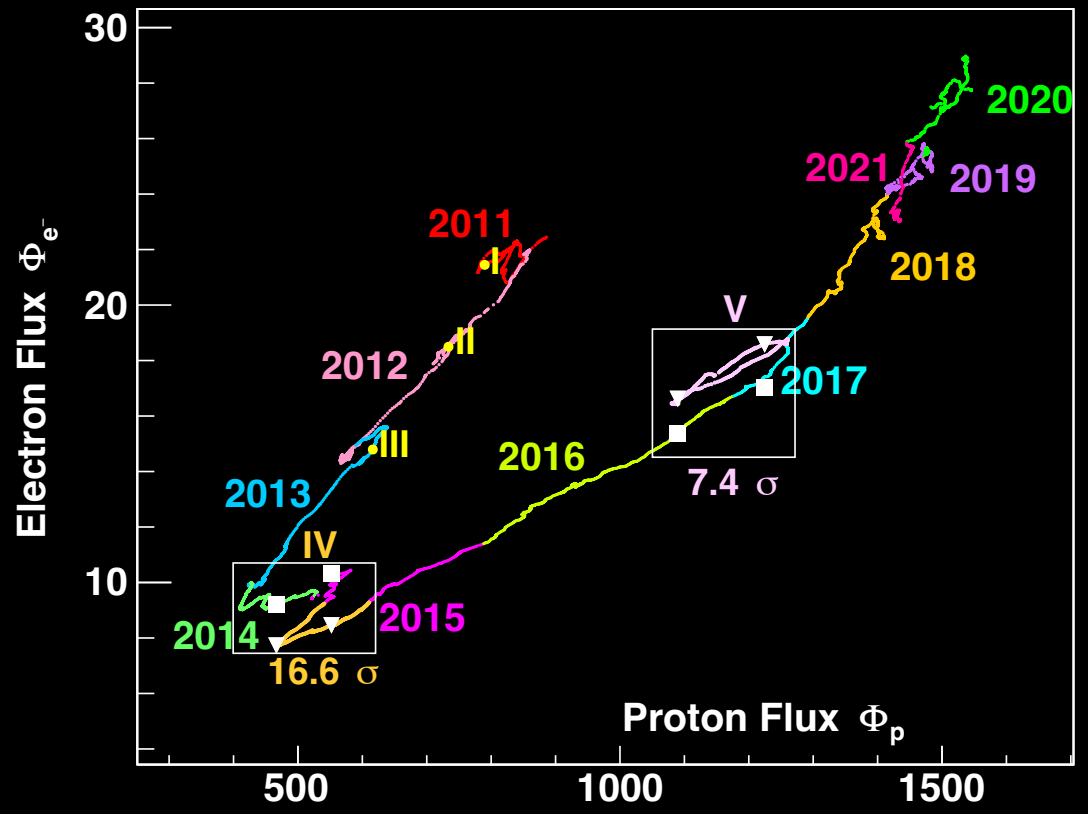


Preliminary data. Please refer to the AMS forthcoming publication

Structures in the Electron-Proton Hysteresis



Moving averages of length 2BRs
with a step of one day

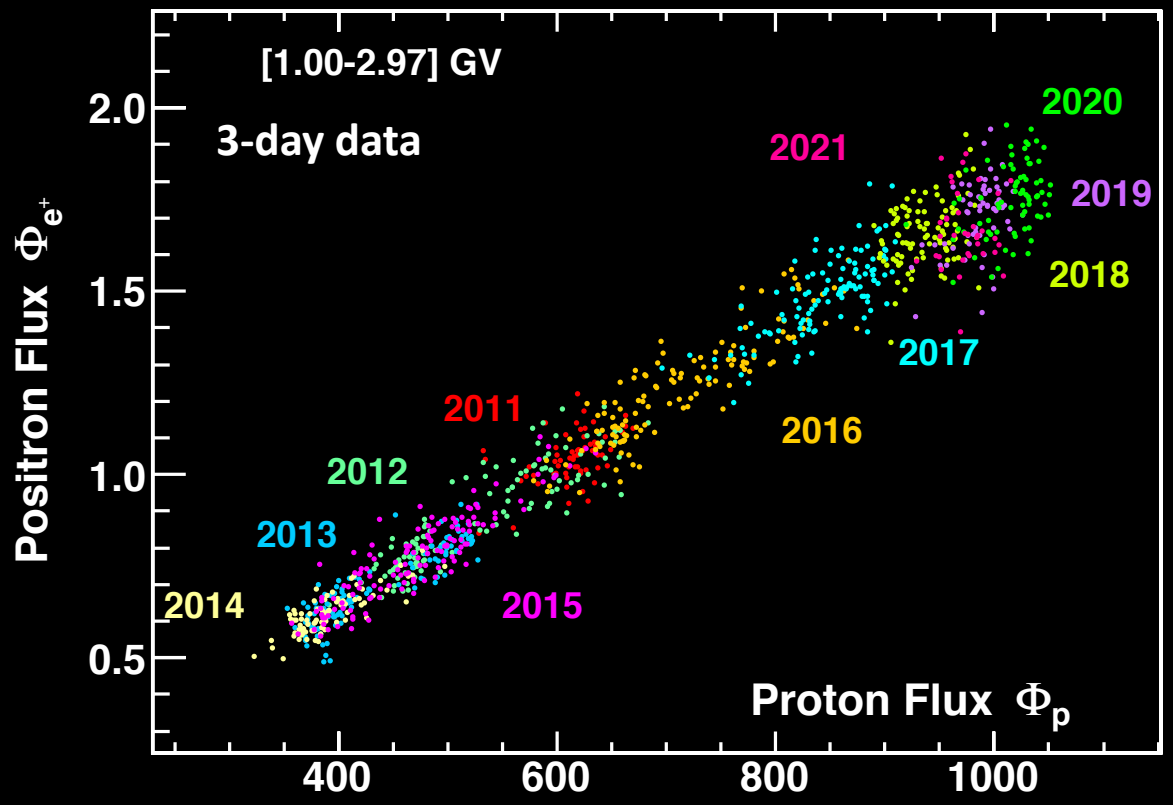


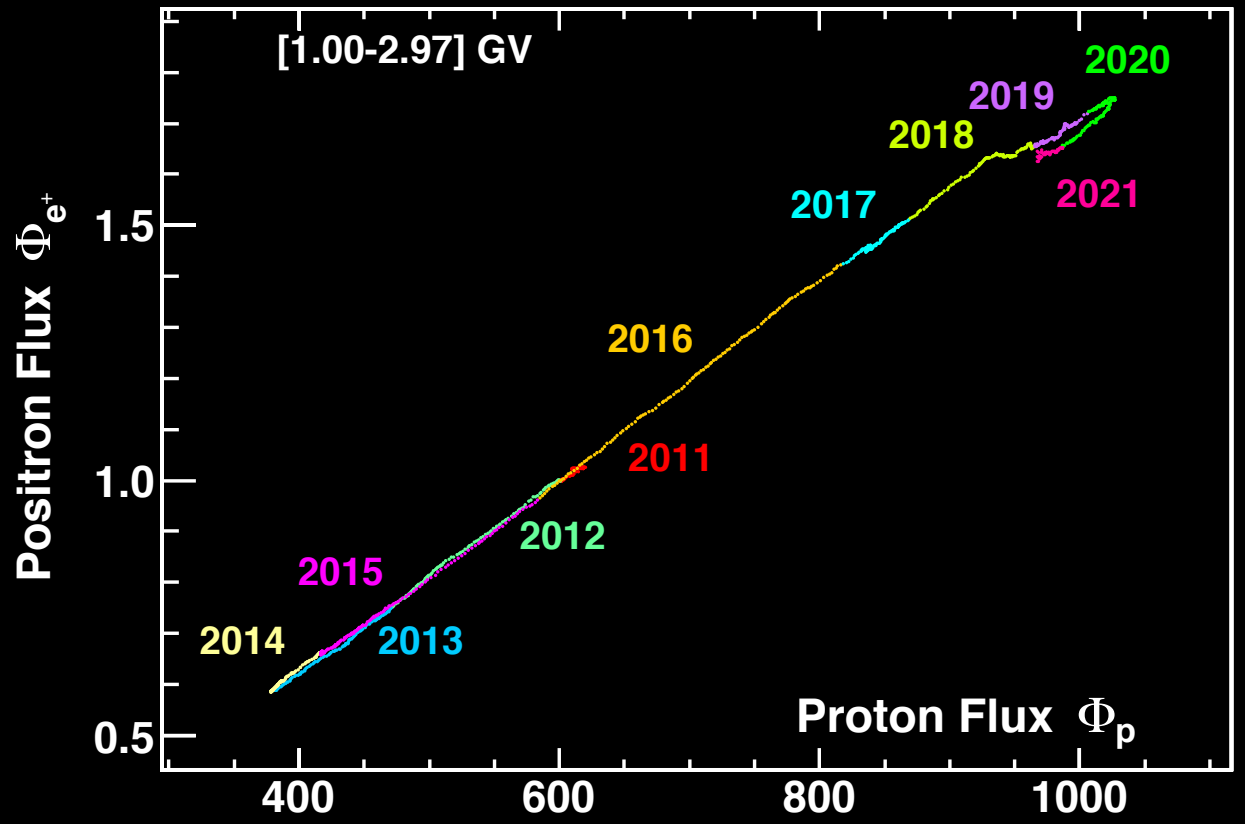
Significant structures in the electron-proton hysteresis are observed corresponding to sharp variations in the fluxes

Preliminary data. Please refer to the AMS forthcoming publication

Approximately Linear Relation between Positron and Proton

Moving averages of length 14BRs
with a step of one day

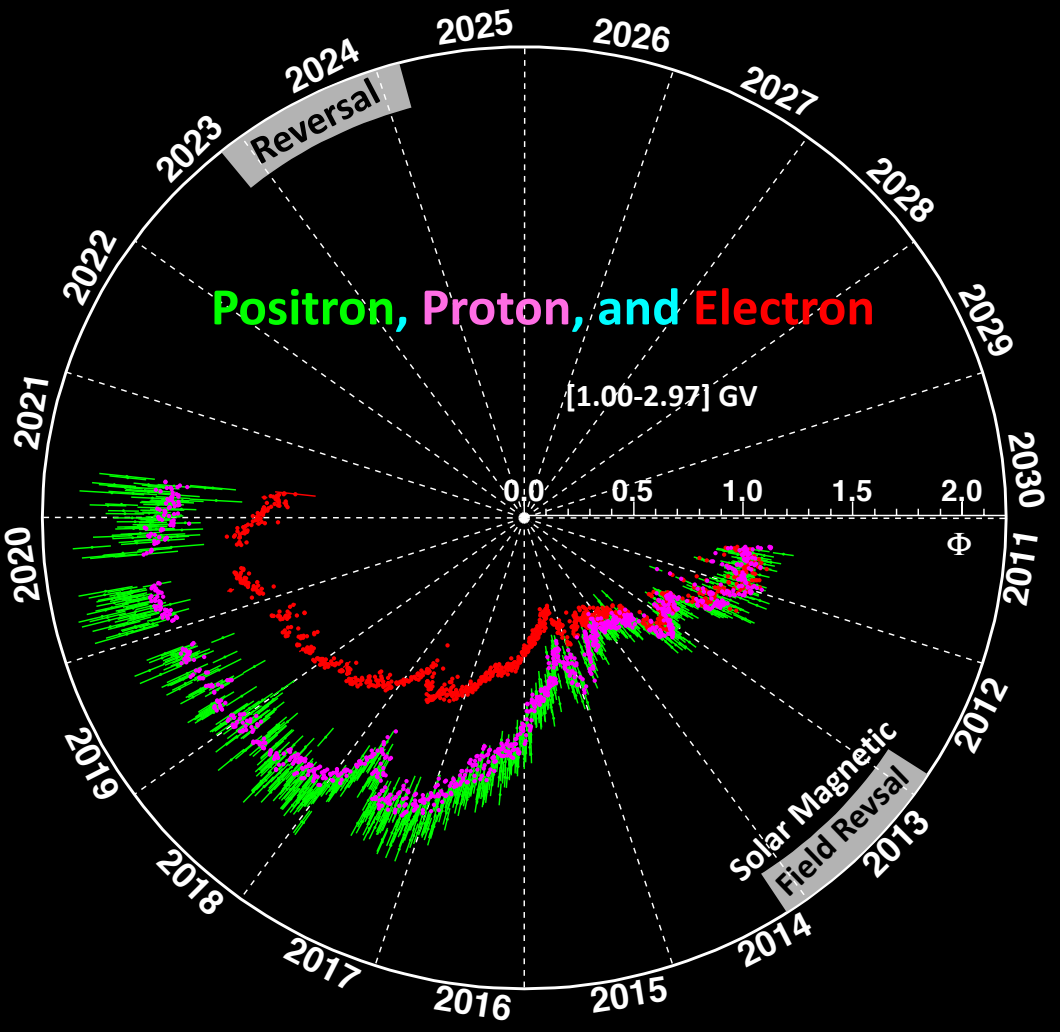




Preliminary data. Please refer to the AMS forthcoming publication

Summary

We have presented the precision AMS measurements of **ten years** of **daily proton, helium, electron, and positron fluxes** in cosmic rays. All the fluxes exhibit variations on different time scales. These results provide unique input to the understanding of cosmic rays in the heliosphere.



AMS will continue taking data for the lifetime of the International Space Space.

We will study whether the behavior will repeat in the next solar cycle.