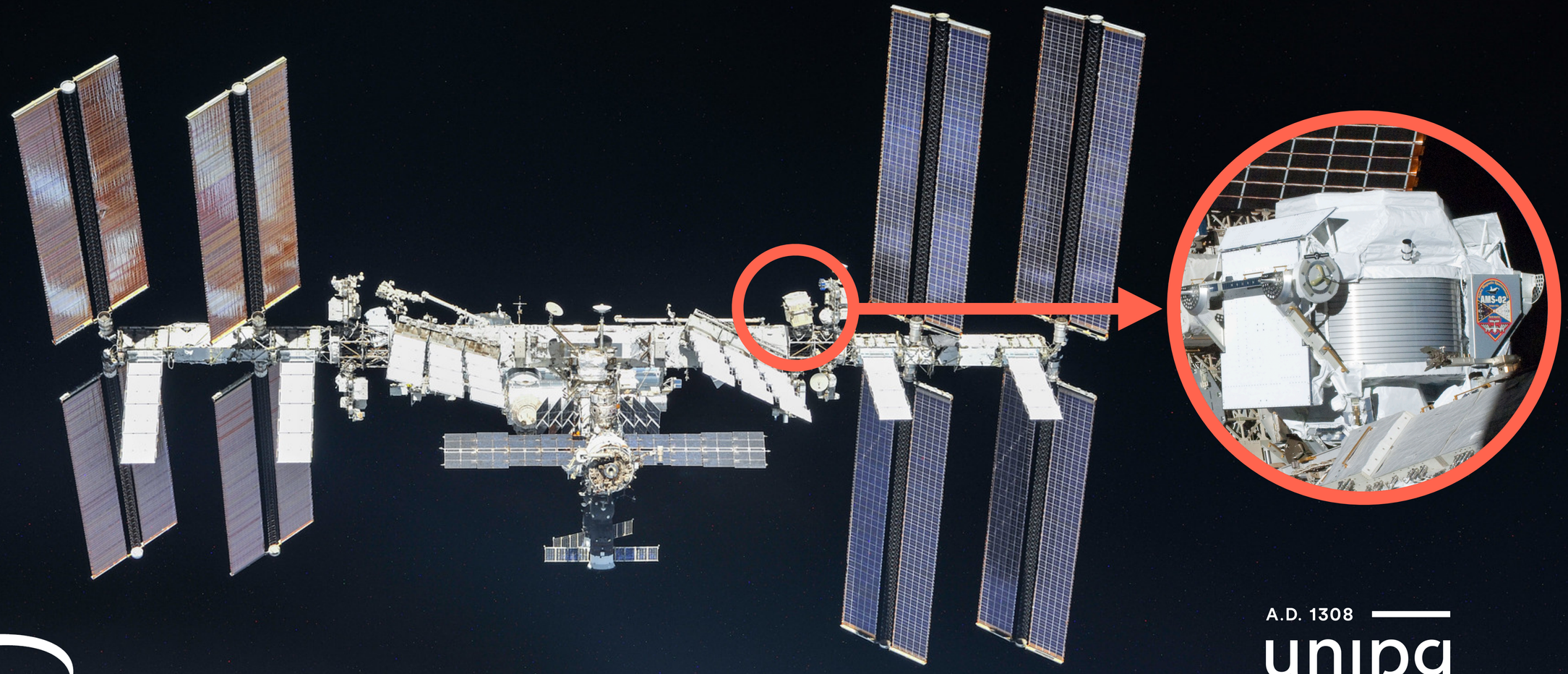
Temporal Evolution of the Daily Proton, Helium, Electron and Positron Fluxes with AMS-02



Francesco Faldi, UniPG, INFN, On Behalf of AMS-02 Collaboration.
Under Agreement ASI-UniPG 2019-2-HH.0
Marcel Grossman Meeting, Pescara, 07-06-2024

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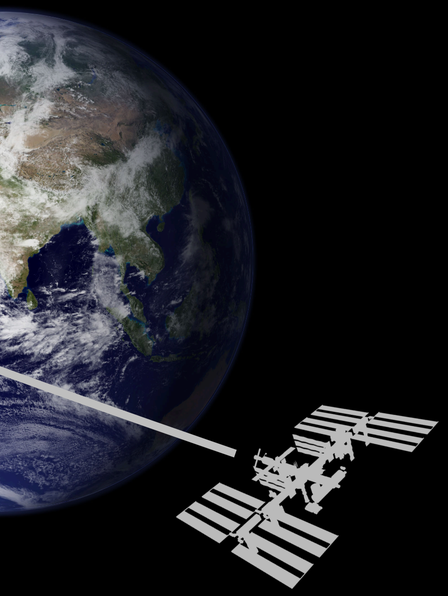
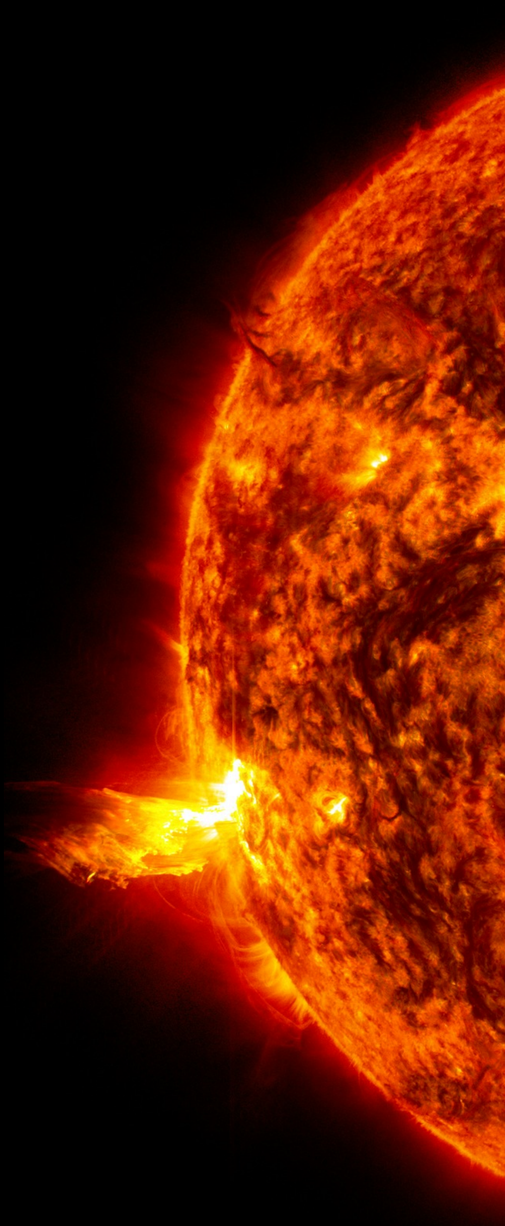
DIPARTIMENTO DI FISICA E GEOLOGIA

DIPARTIMENTO DI ECCELLENZA MUR 2023/2027

Summary



- **Long-term** and **short-term** temporal **variations** in daily CR fluxes.
- **Periodicities** in the daily **proton** flux: 27, 13.5 and 9 days.
- Daily **helium flux**, similar **periodicities**, different **modulation** from proton flux.
- Daily **electron flux**, different **modulation** from both helium and proton fluxes.
- Daily **positron flux**, similar **time dependence and higher modulation** with respect to proton fluxes.

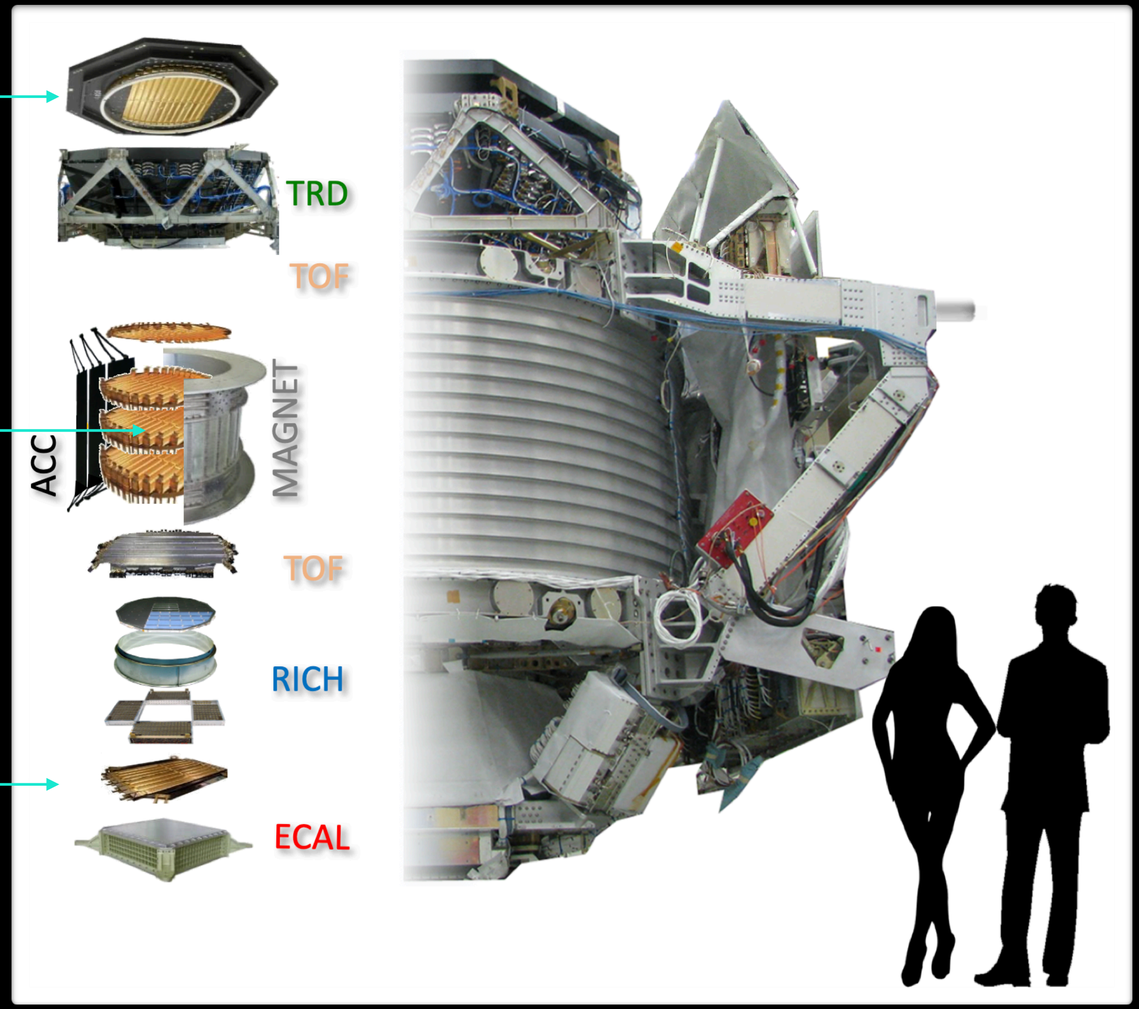


The AMS-02 Experiment

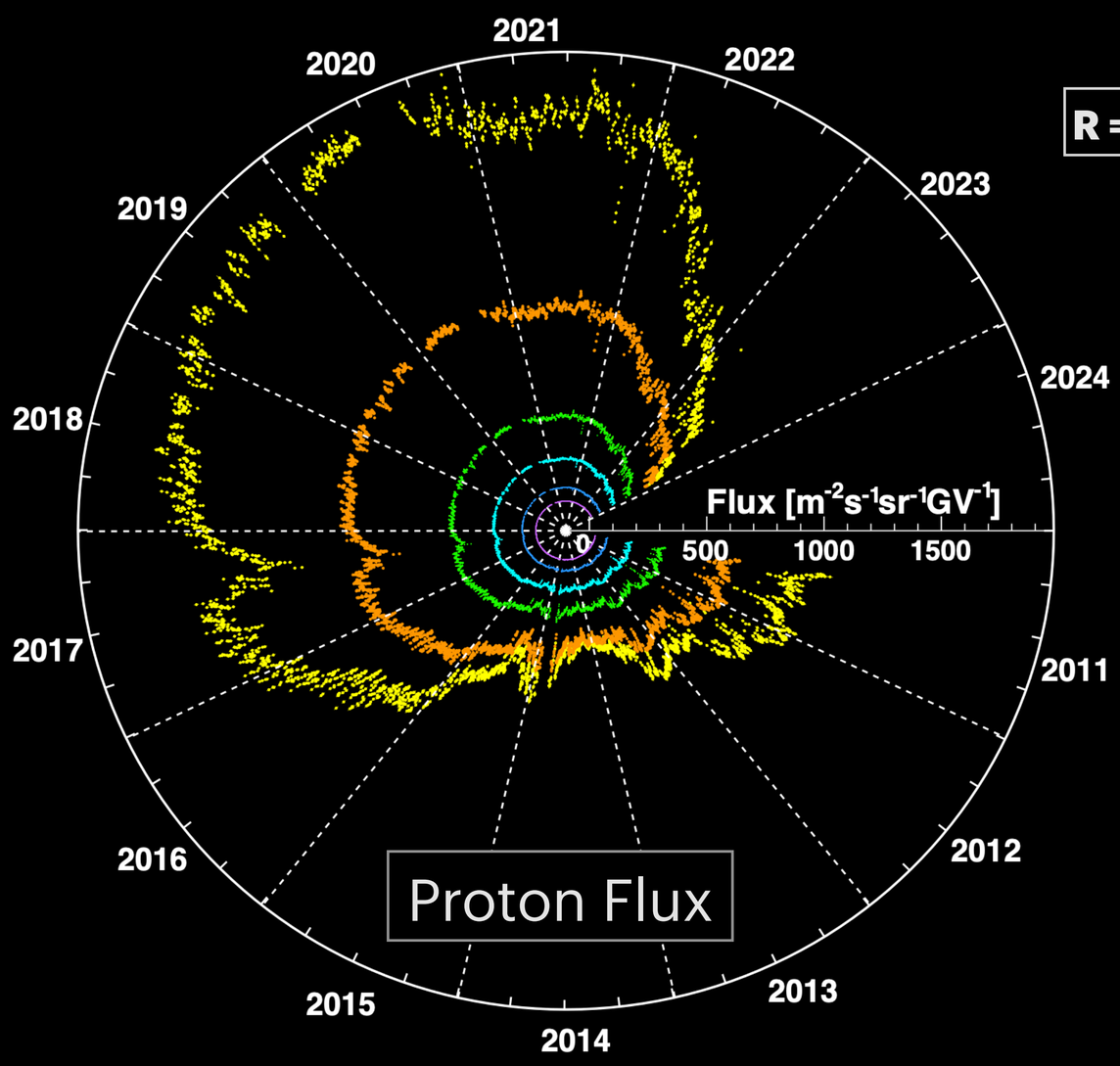
AMS-02 is a **precision magnetic spectrometer**, in the GeV-TeV energy range, on the ISS since may 2011.

Objectives:

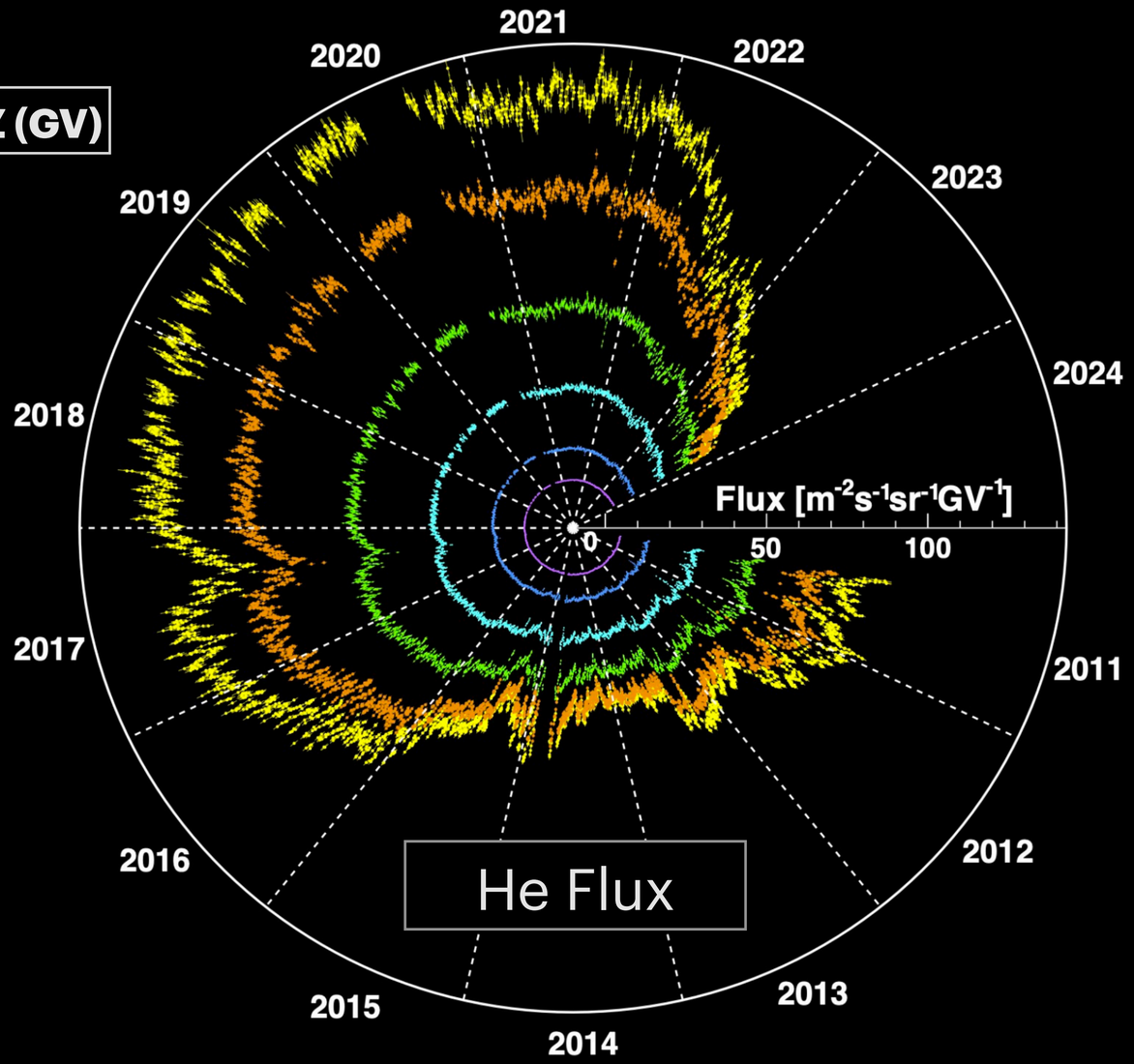
- Measure Cosmic Rays fluxes.
- Search for primordial antimatter.
- Indirect search for dark matter.
- **Solar modulation of CR in heliosphere**.



Daily Fluxes



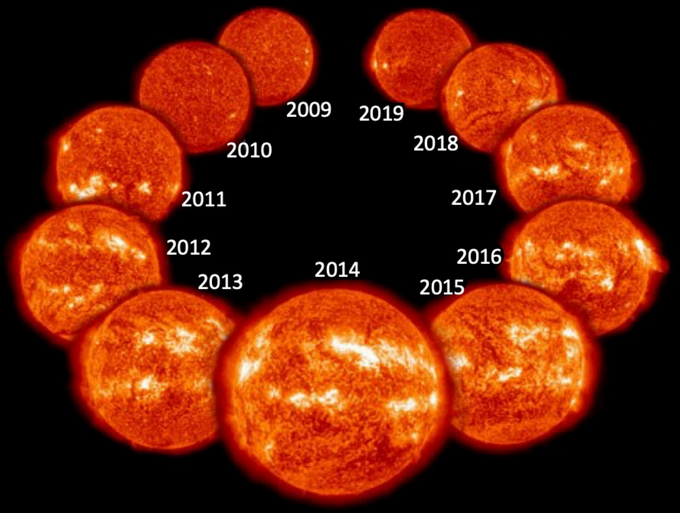
R = p/Z (GV)



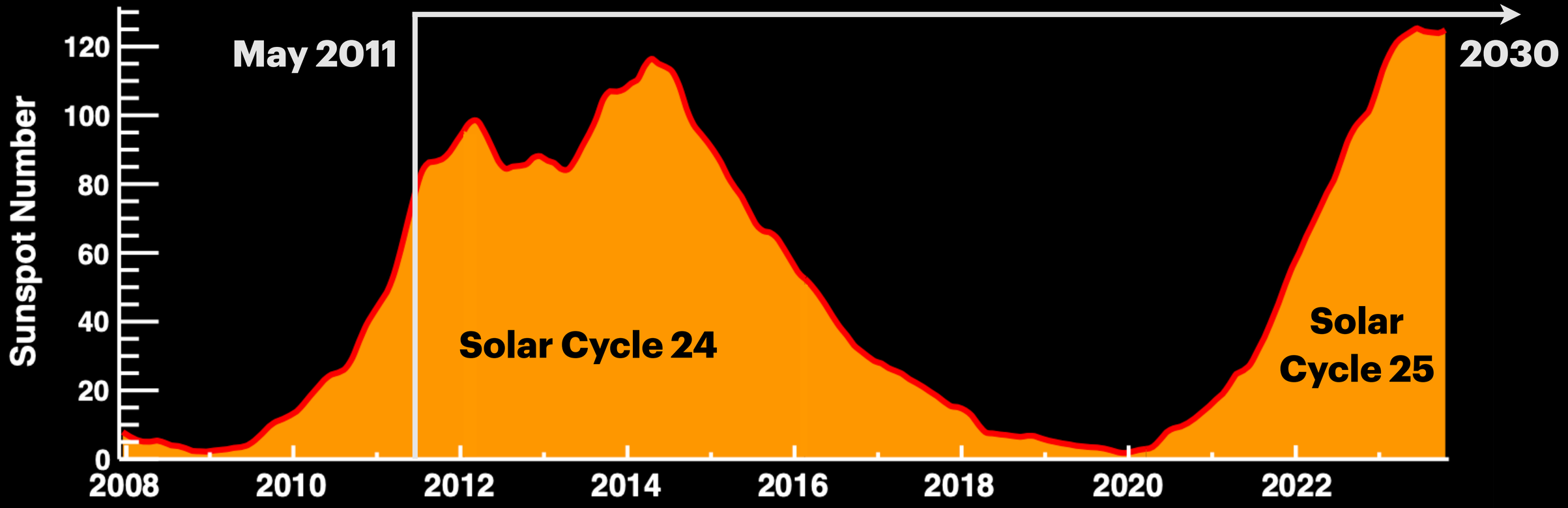
[1.00-1.16] GV [2.97-3.29] GV [5.90-6.47] GV
[1.92-2.15] GV [4.02-4.43] GV [9.26-10.10] GV

[1.71-1.92] GV [2.97-3.29] GV [5.90-6.47] GV
[2.15-2.40] GV [4.02-4.43] GV [9.26-10.10] GV

Long-Term Variation: Solar Cycle

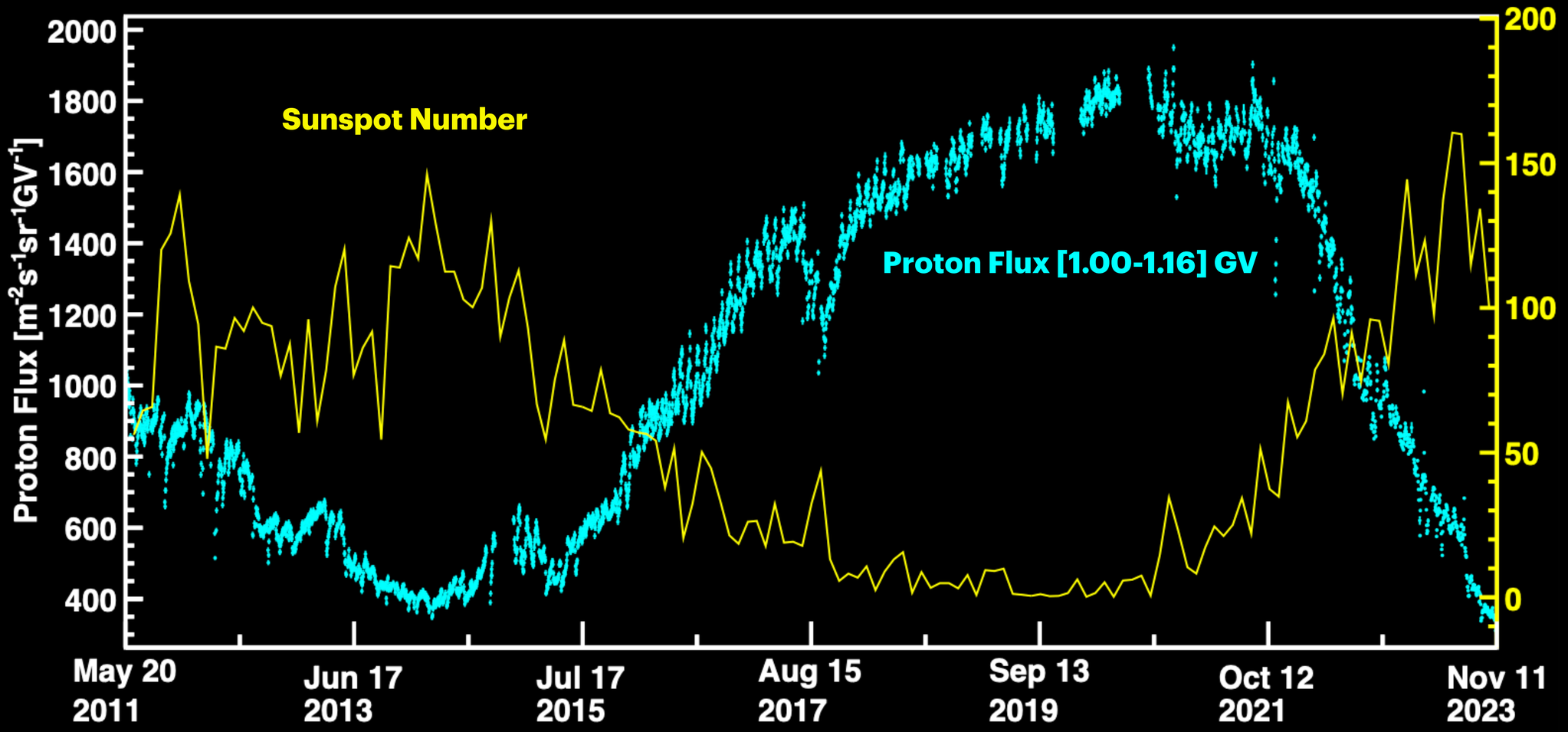


The most significant long-term scale variation of CR flux is related to the 11-year solar activity cycle.



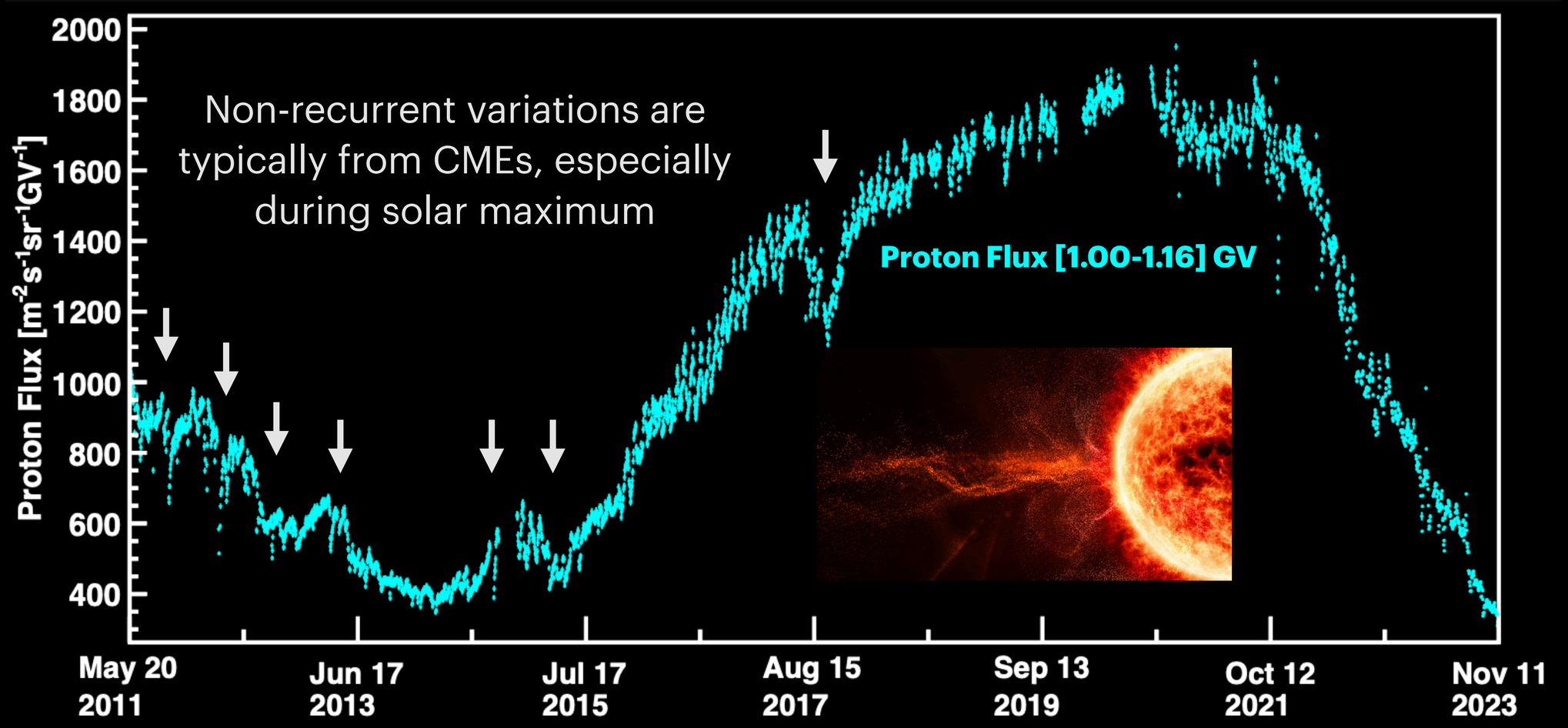
Long-Term Variation: Solar Cycle

Long-term variations are related to the 11-year solar cycle.



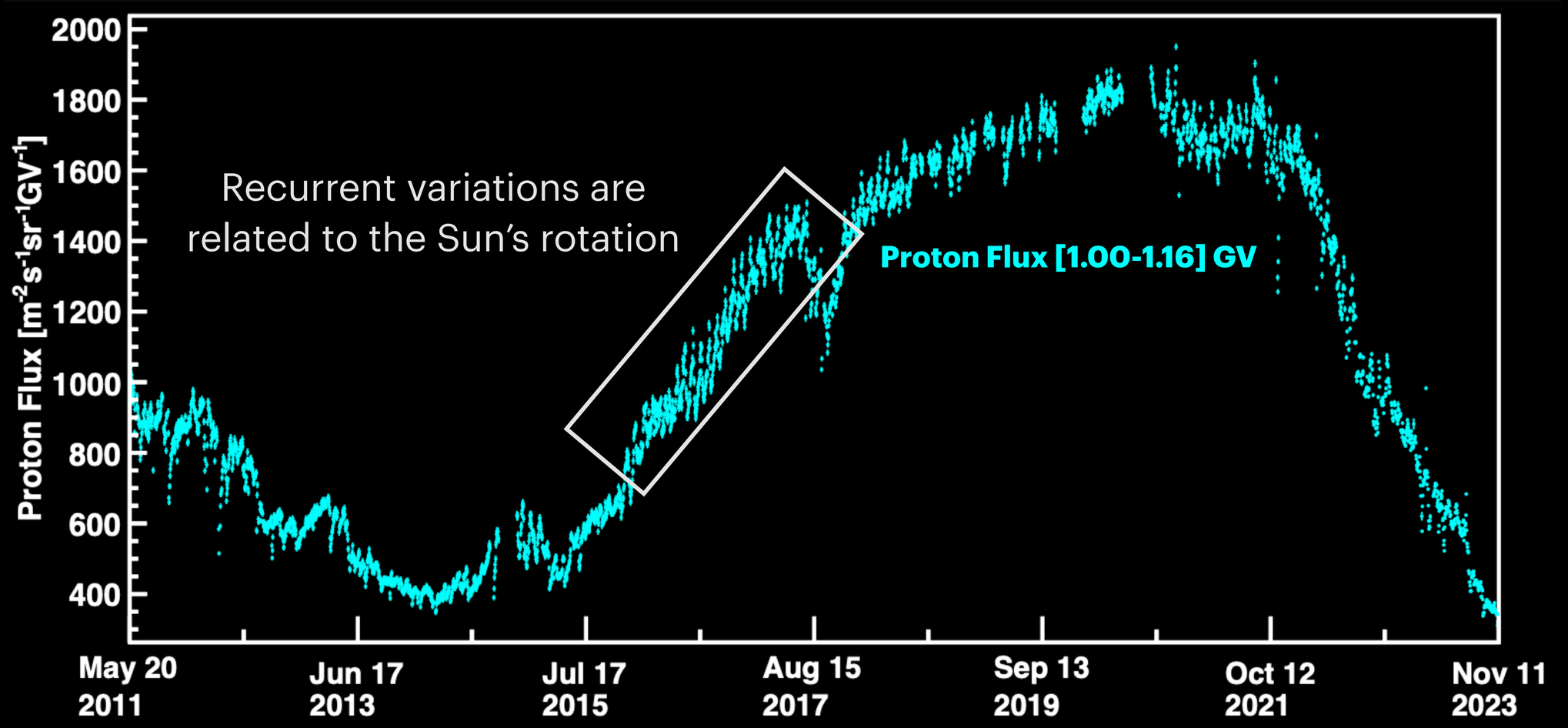
Non-Recurrent Short-Term Variations

Short-term variations can either be **non-recurrent** or recurrent.



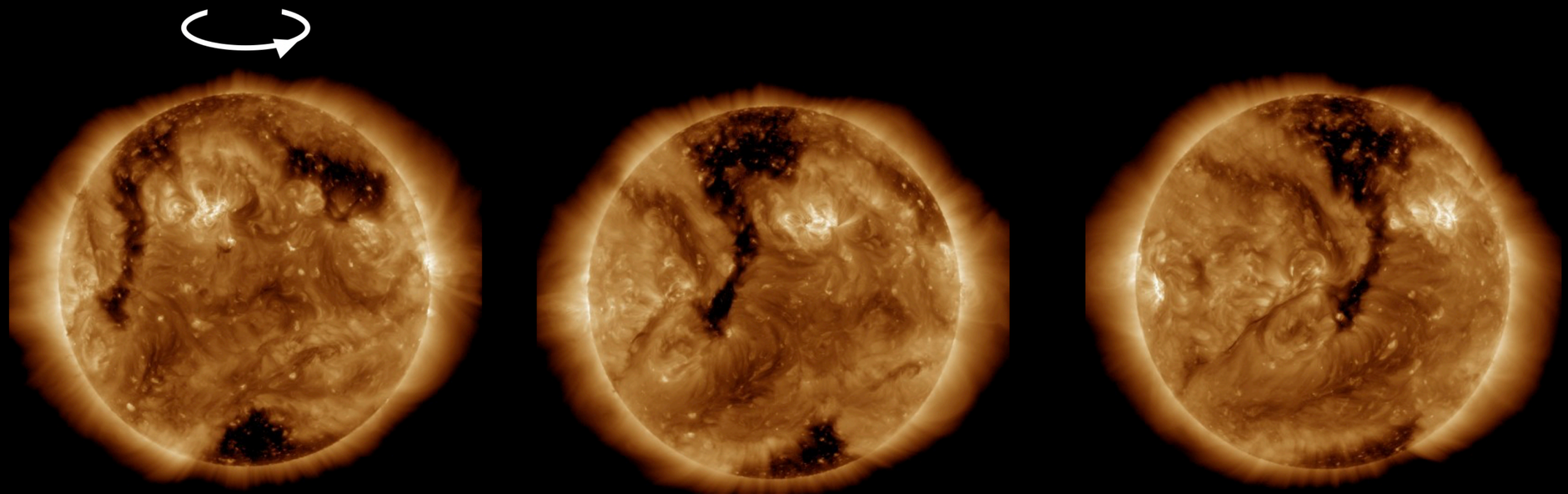
Recurrent Short-Term Variations

Short-term variations can either be non-recurrent or **recurrent**.



Recurrent Short-Term Variations

Short-term variations are related to Sun's rotation (Bartels' rotation: 27 days)

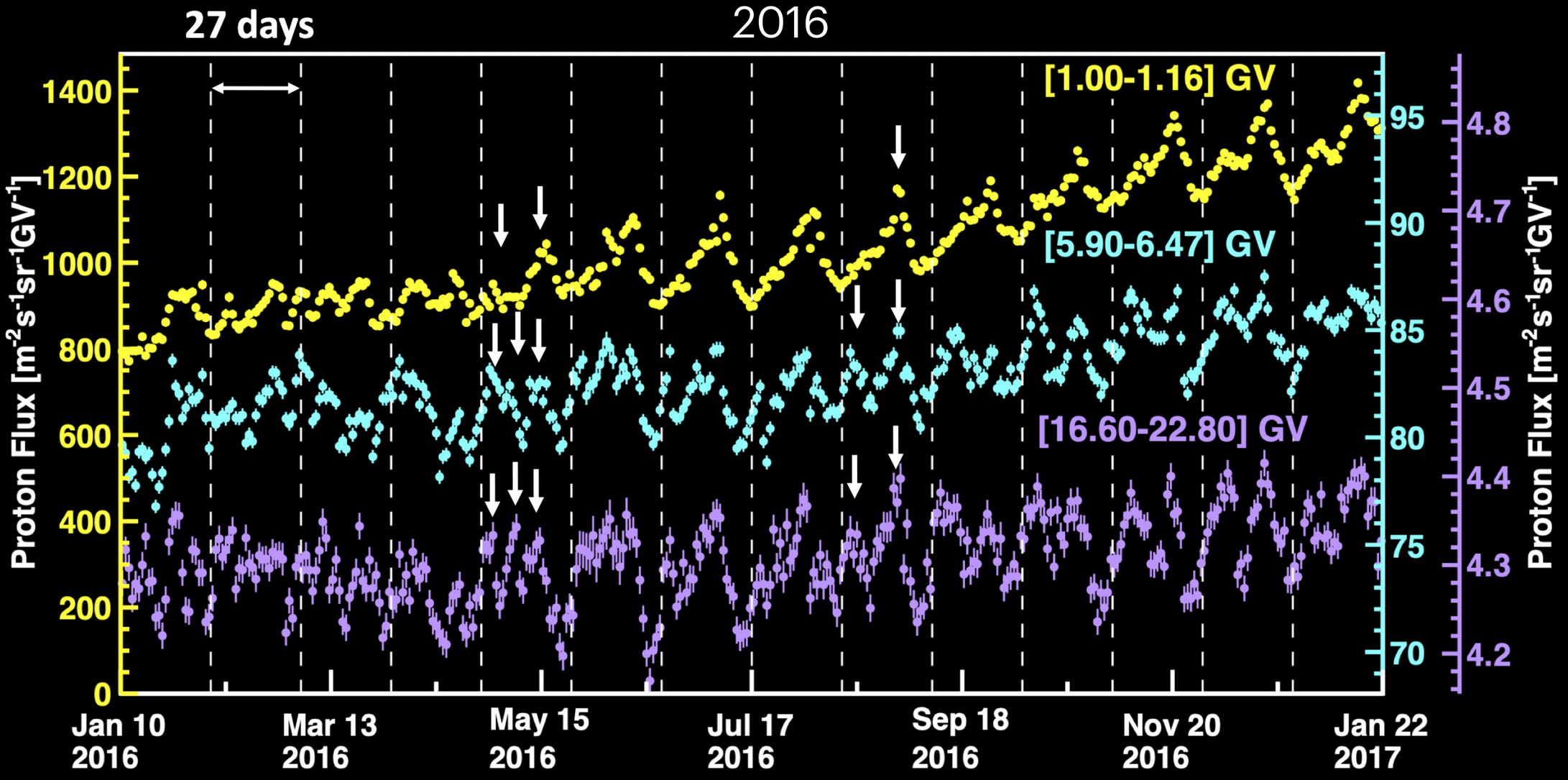


2016-03-22 2016-03-24 2016-03-26

Image taken by Dynamics Observatory (SDO), NASA

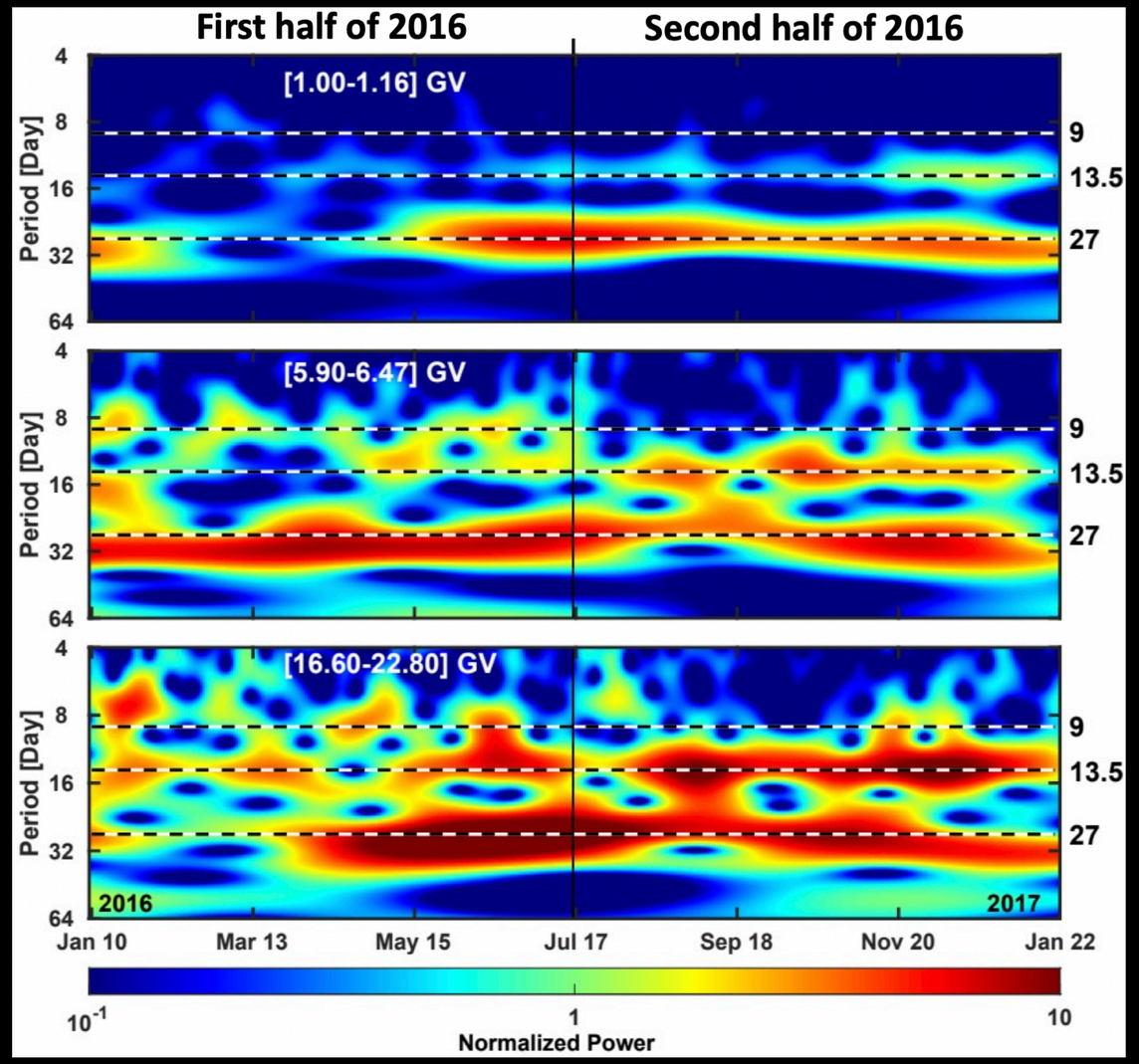
Coronal Holes are regions where plasma density and temperature are lower, so they appear darker in images.

Recurrent Short-Term Variations



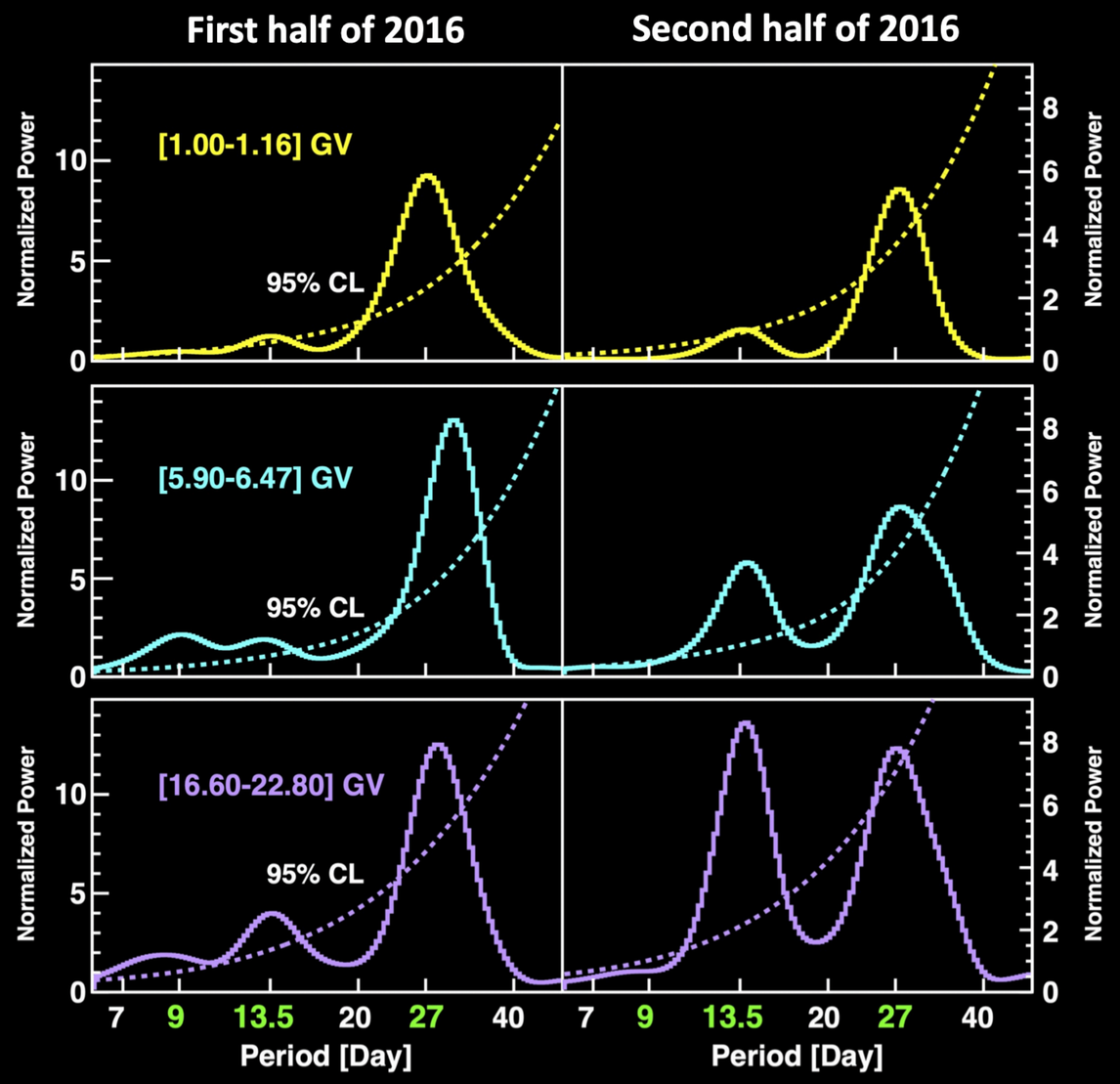
Wavelet Analysis of Proton Flux

- Normalized power is defined as the power divided by the variance of the time series.
- Periods of 9, 13.5 and 27 days are observed in 2016.
- The shorter periods of 9 and 13.5 days, when present, are more visible at 20 GV.



Average Power Spectra

- First half of 2016: 9 and 13.5 day periods strength increases with increasing rigidity.
- Second half: 13.5 day period strength increases with increasing rigidity, 9 day period not significant.
- 27 day period varies with rigidity in both time intervals.

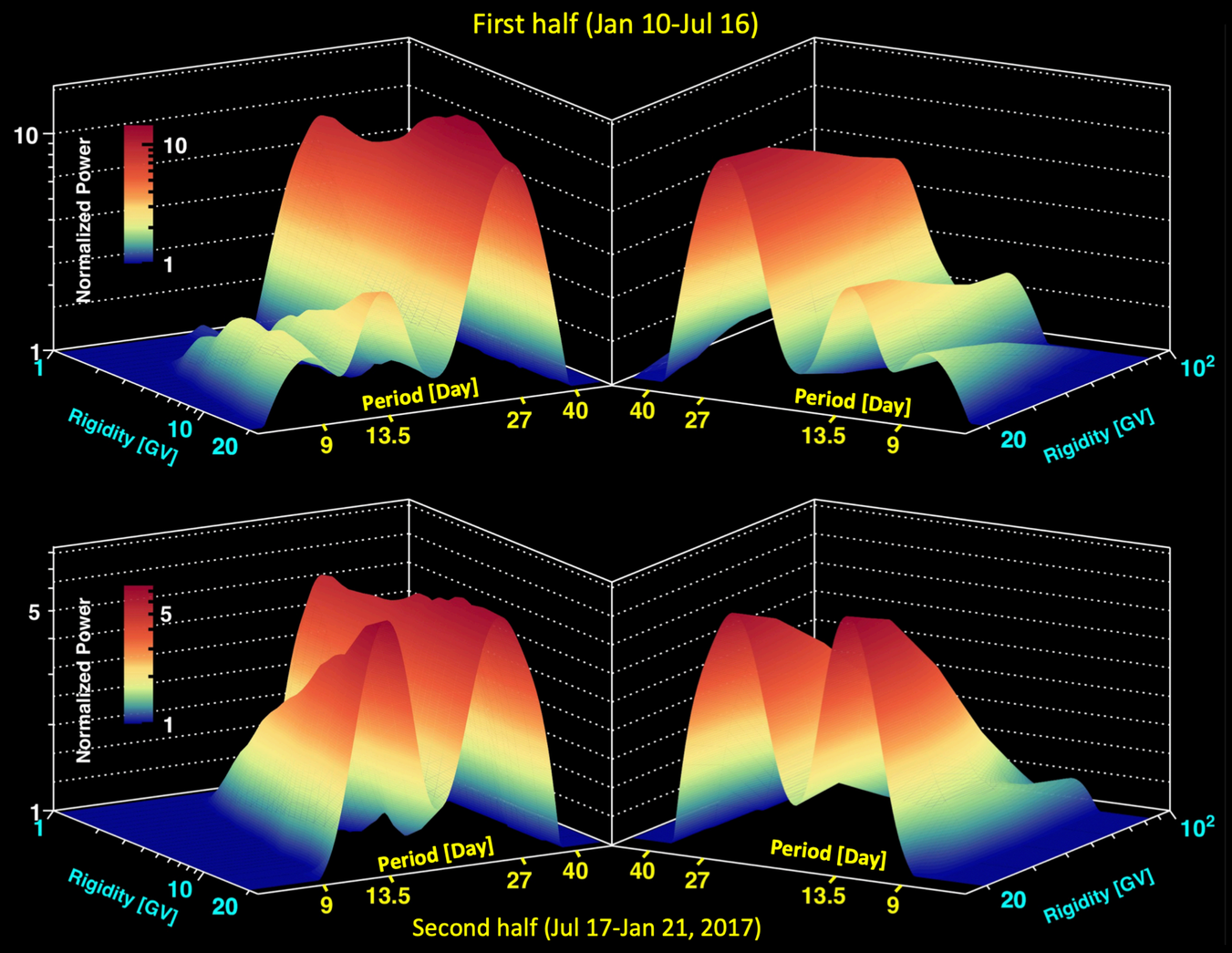


Short-Term Periodicities, Proton Flux

9 and 13.5 day periodicities increase with increasing rigidity up to 10 GV and 20 GV, respectively. Then the strength decreases 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.

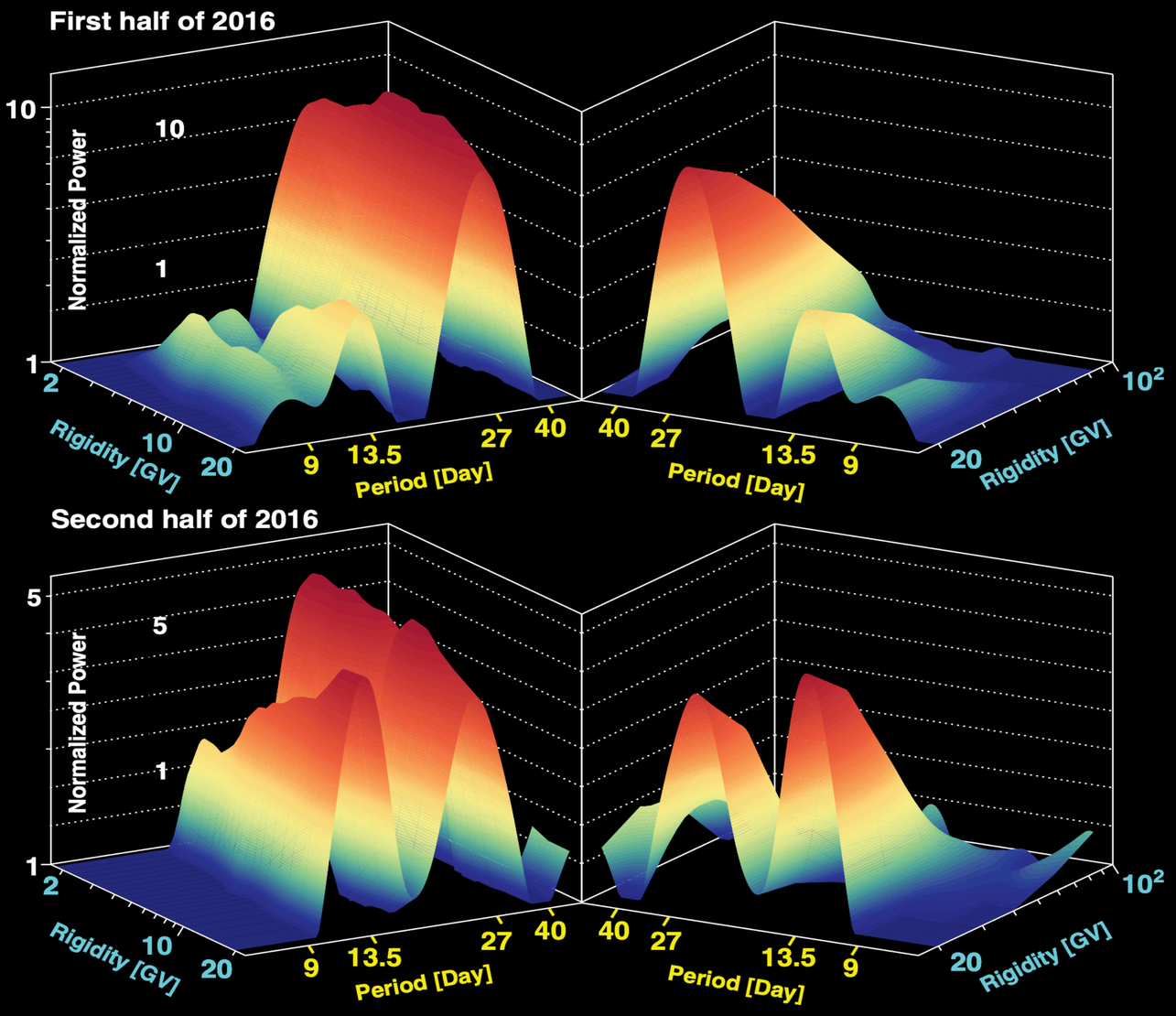
Phys. Rev. Lett. 127, 271102 (2021)



Short-Term Periodicities, Helium Flux

A similar rigidity dependence in the strength of He periodicities is observed.

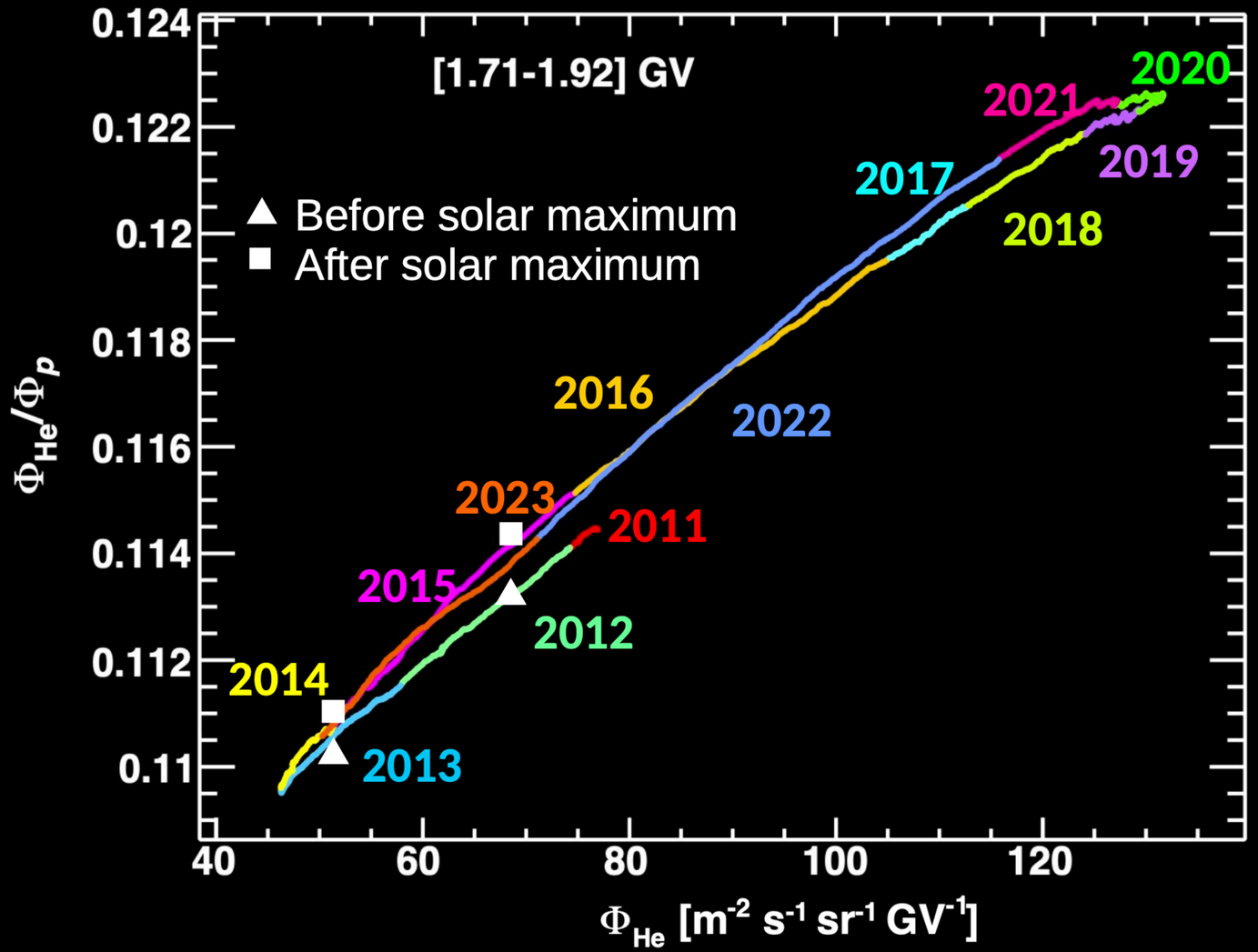
Thus, the AMS results do not support the general conclusion that the strength of the periodicities always decreases with increasing rigidity.



Phys. Rev. Lett. 128, 271102 (2022)

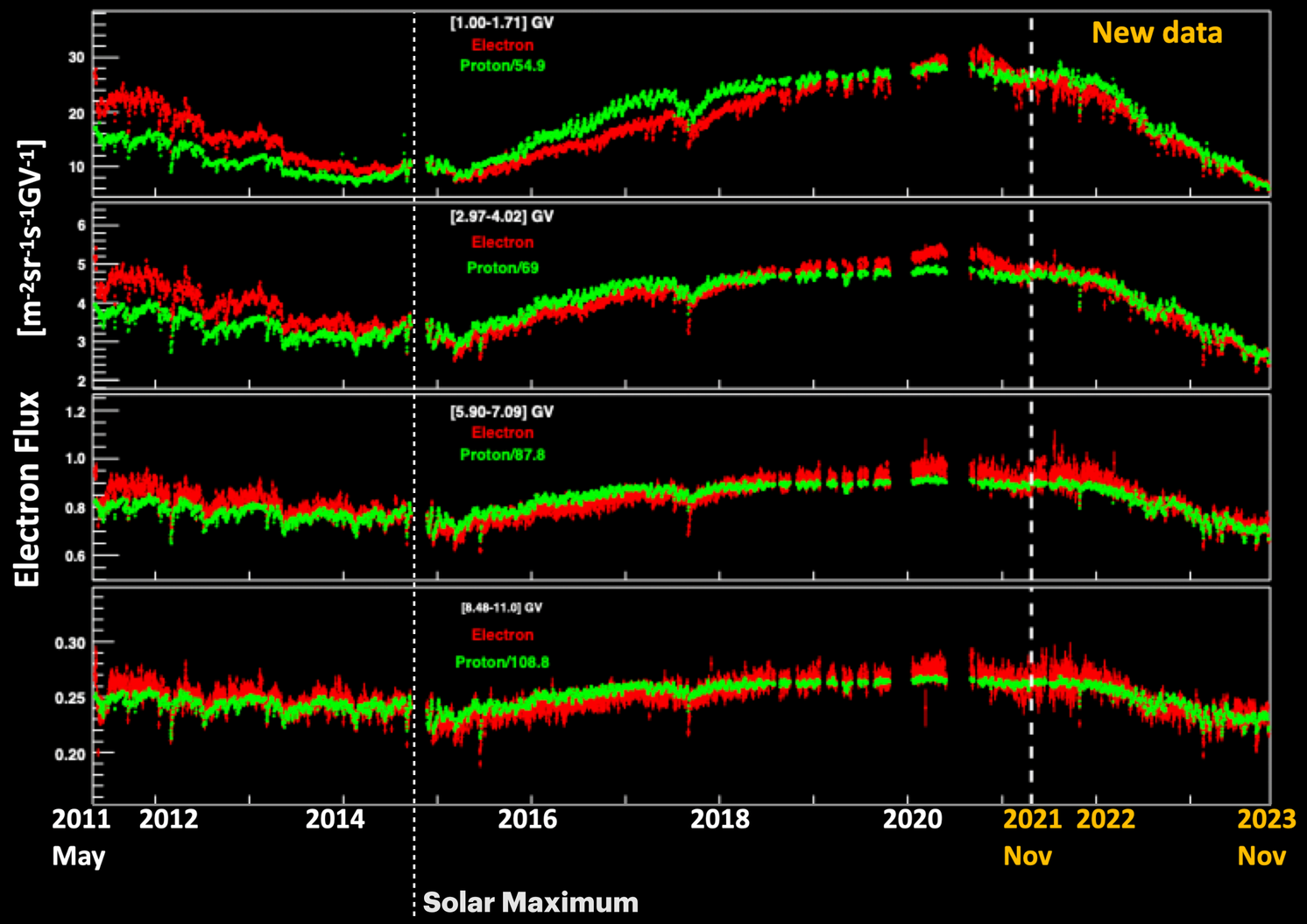
He/p Hysteresis

- **Correlation plots** between helium and proton fluxes. Data points are the moving average of 14 Bartels' Rotations (BR), with a step of 1 day.
- For R < **2.4 GV** we observe an **hysteresis** between proton and helium fluxes.
- Hysteresis in the flux ratio indicates a **different solar modulation** of the two species.



Daily Electron Flux

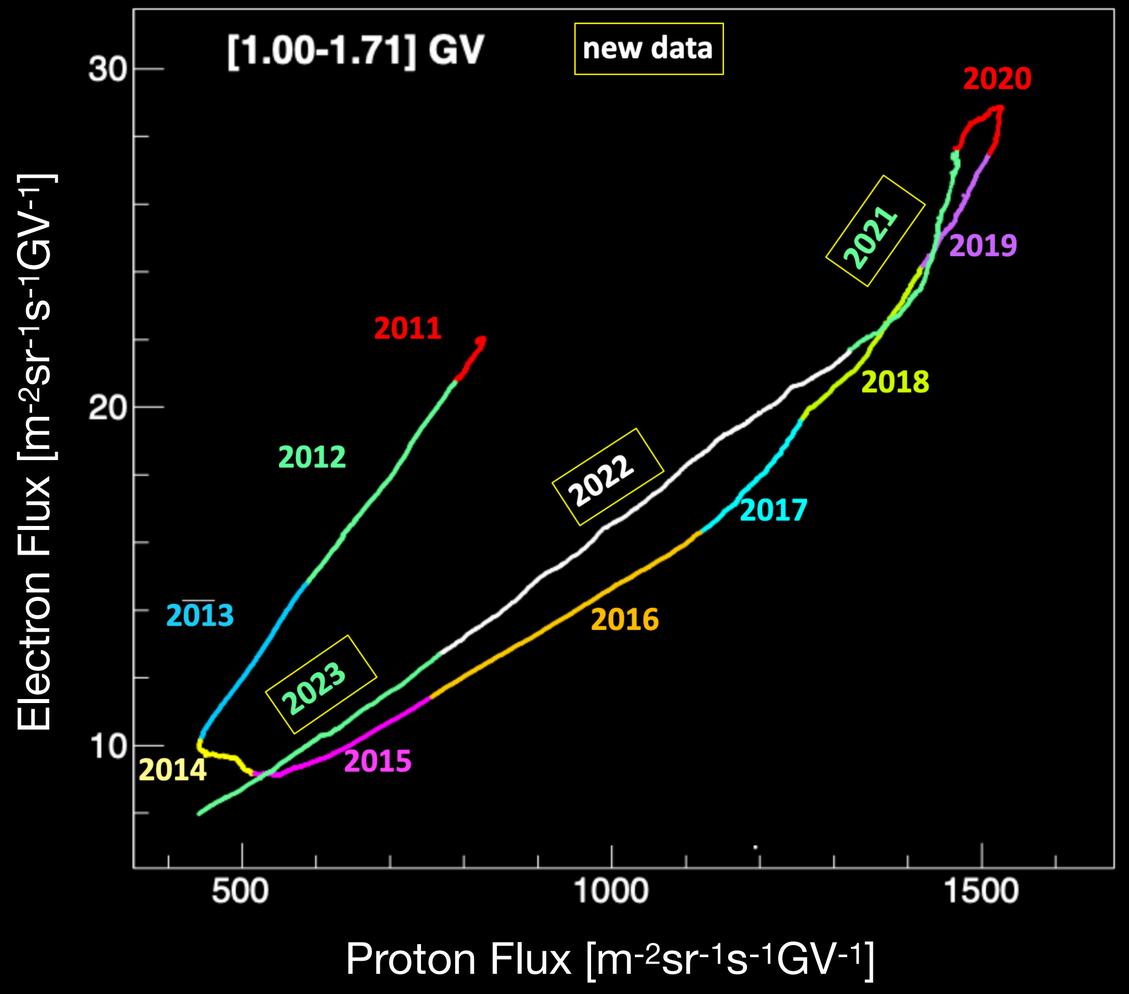
- Electrons are **modulated differently** than protons for R < 8.5 GV.
- Differences are most significant at lower rigidities.
- Two distinct regions:
  - 2011-2014 **faster** decrease of **e⁻**
  - 2014-2017 **slower** increase of **e⁻**



Phys. Rev. Lett. 130, 161001 (2023)

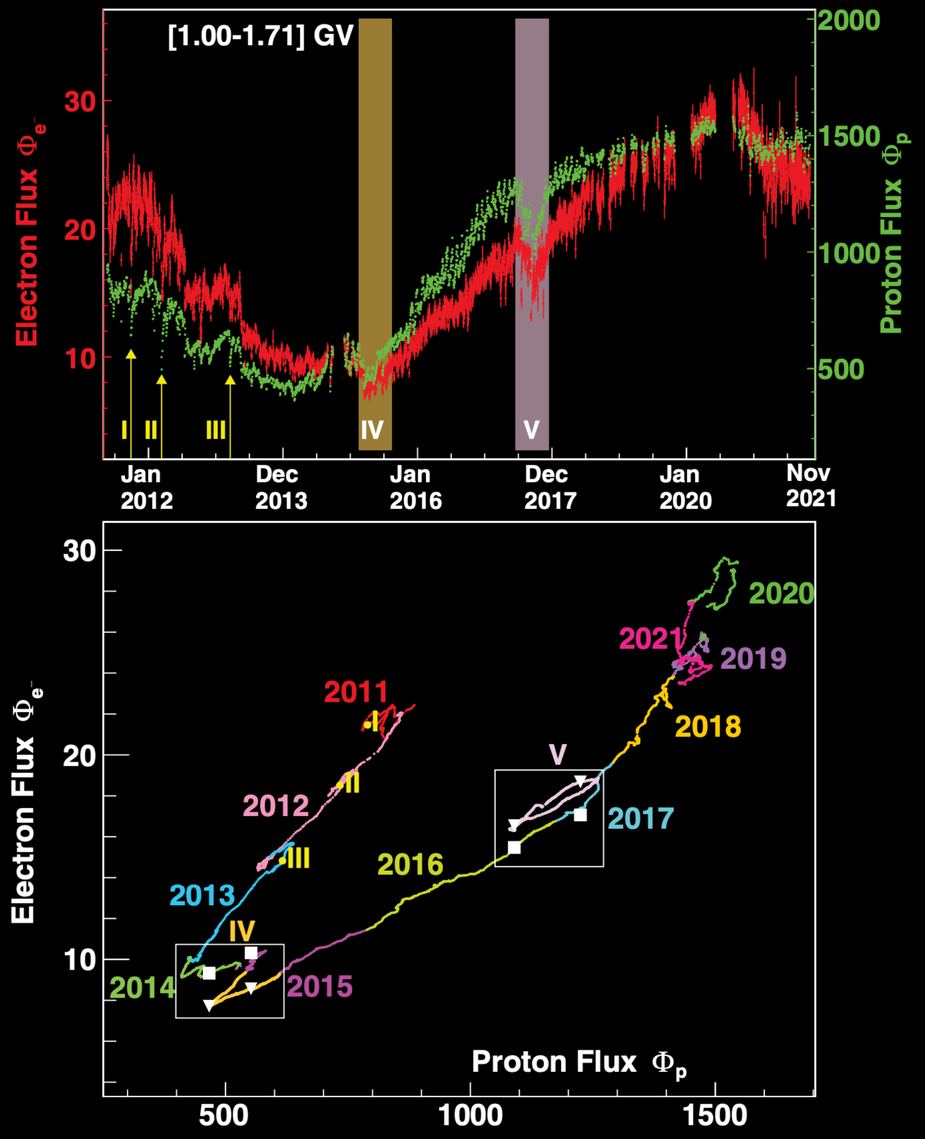
e^-/p Hysteresis

- **Correlation plots** between electron and proton fluxes. Data points are the moving average of 14 BR, with a step of 1 day.
- **Hysteresis** and **change in behaviour** at solar maximum, opposite behaviour as seen in the helium comparison with proton.
- **Charge sign dependence** of solar modulation.



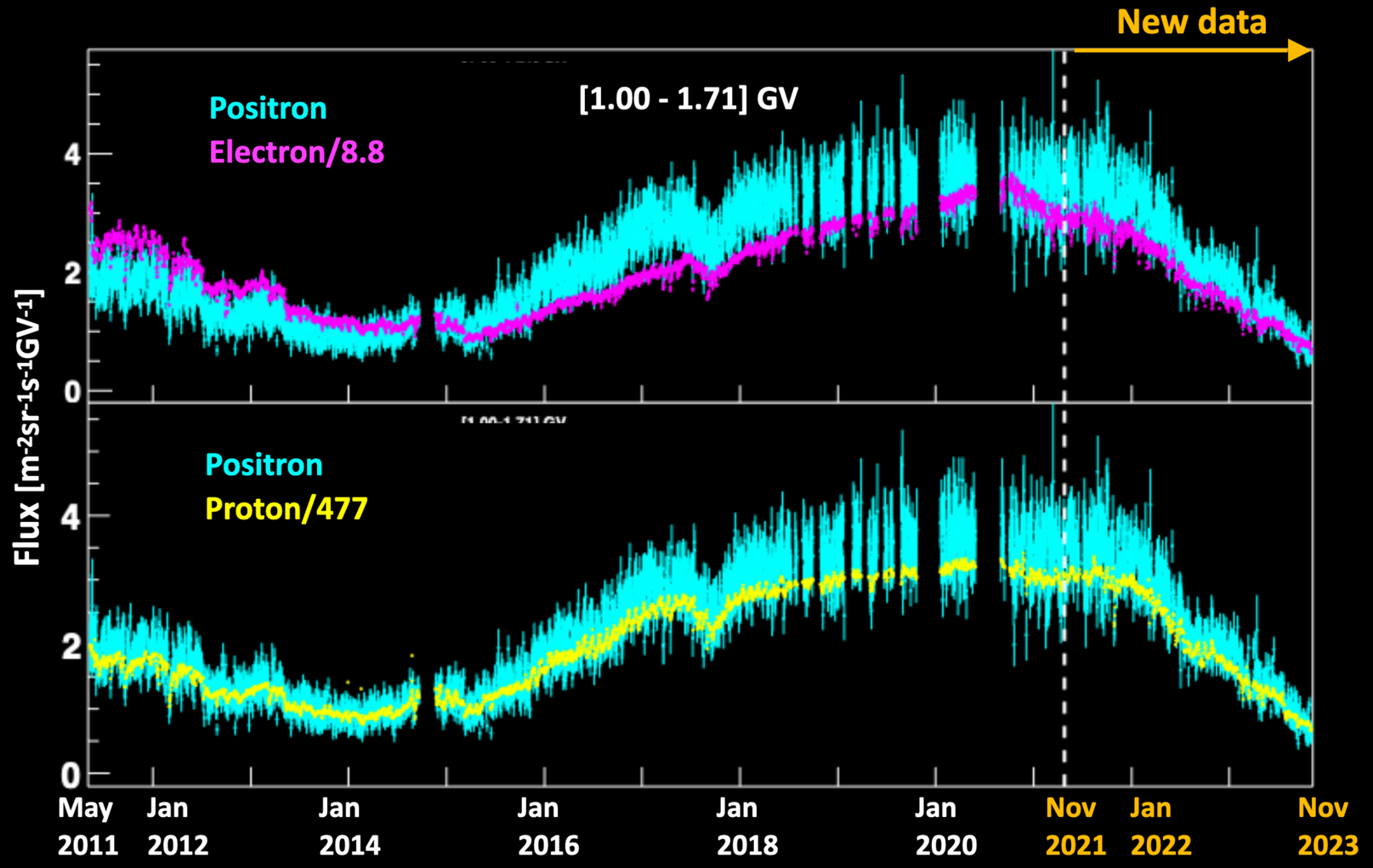
Structures in Electron Hysteresis

- A finer moving average (2 BR, 1 day step) shows **structures** in the correlation plot.
- The likely cause of these structures are transient **Coronal Mass Ejections**.
- **Charge sign dependence** in the modulation during these events, on the timescale of several BRs.



Daily Positron Flux

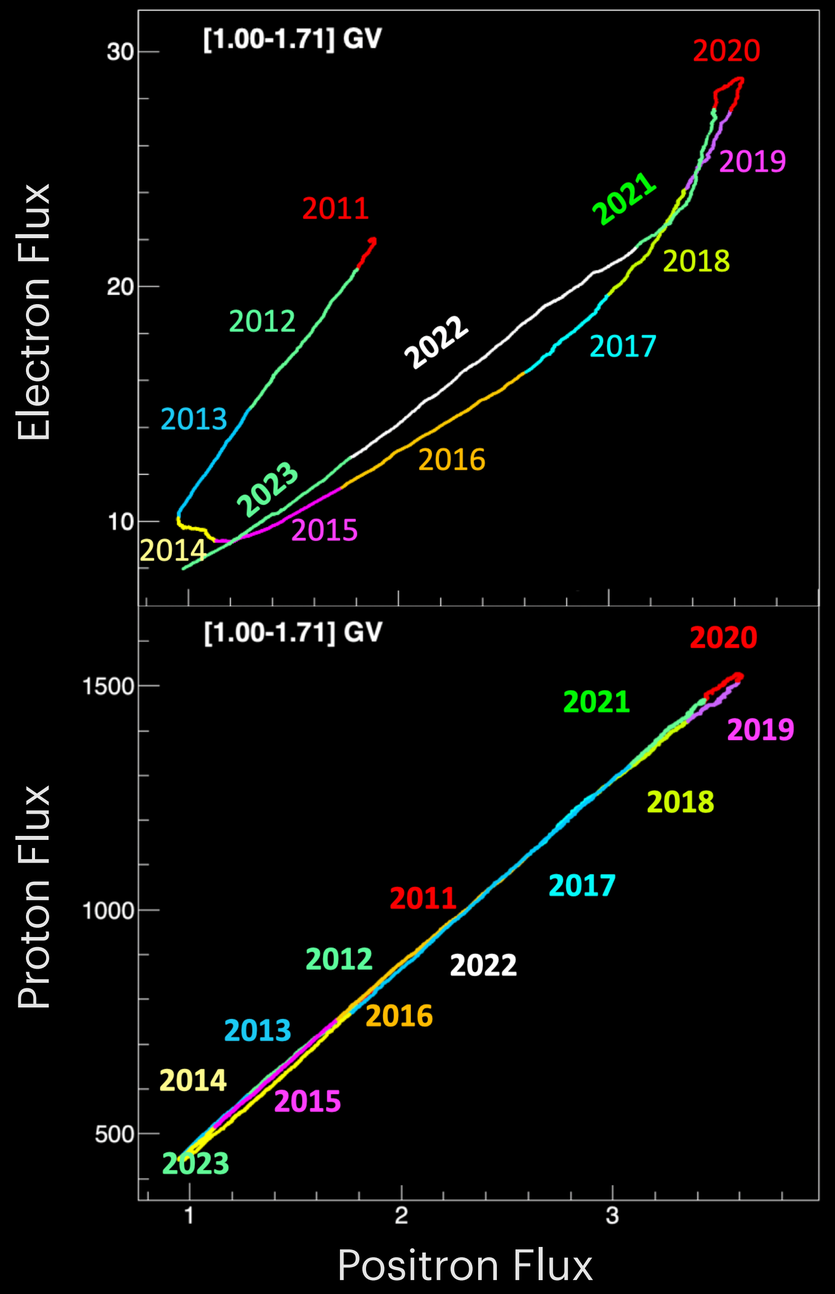
- The positron flux matches the long-term trend of proton flux.
- Similar differences with electron flux, as seen in electron VS proton, are observed for R < 8.5 GV.



Phys. Rev. Lett. 131, 151002 (2023)

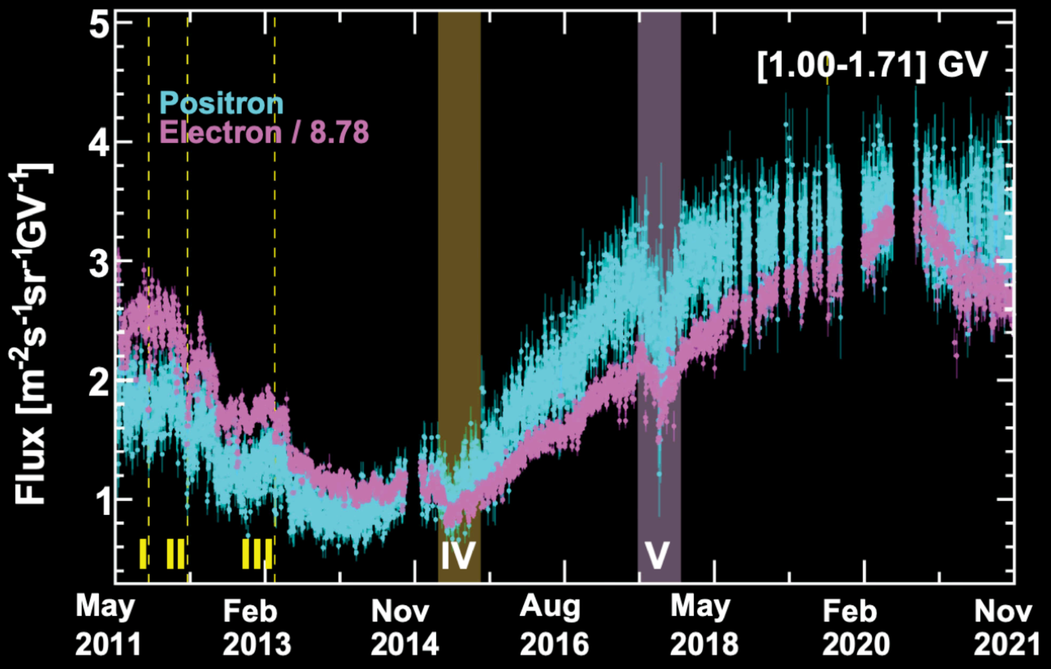
e^-/e^+ and p/e^+ Hysteresis

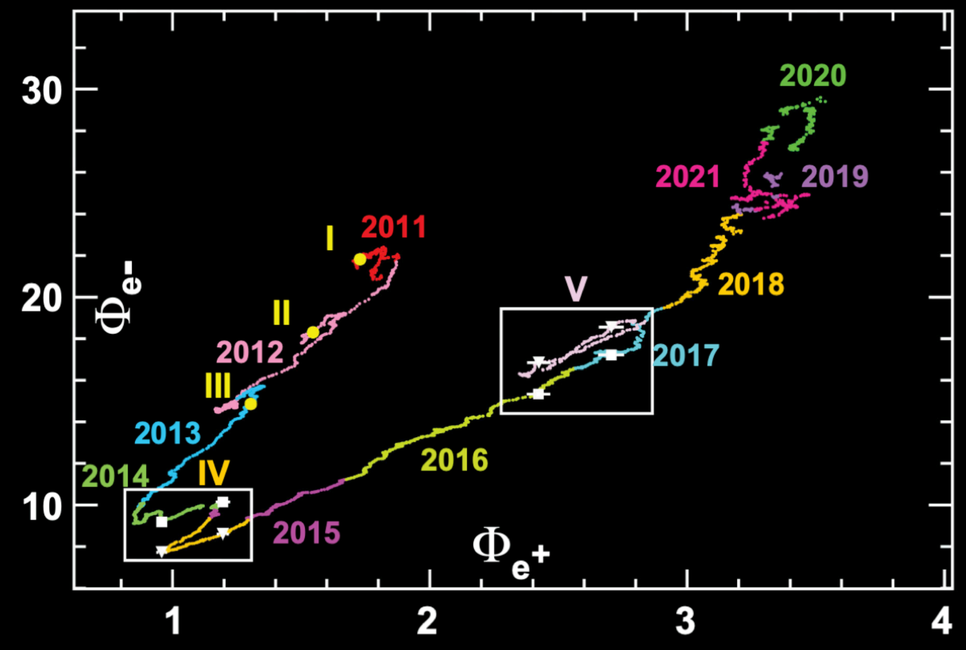
- **Correlation plots**: electron VS positron and proton VS positron. Moving average of 14 BR, with a step of 3 days.
- **Similar hysteresis** with **electron**, as seen with **electron VS proton**.
- **Linear relation** with **proton**: modulation is the **same** for equal **charge** and different mass species.



Structures in Positron Hysteresis

- **Similar finer structures**, as in electron VS proton hysteresis, in **electron** VS positron.
- **No significant structures** in the **proton** VS positron hysteresis.

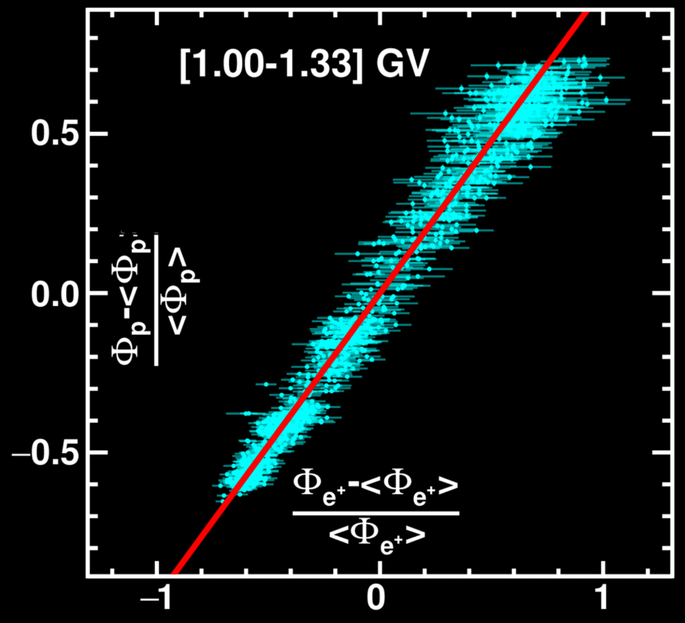


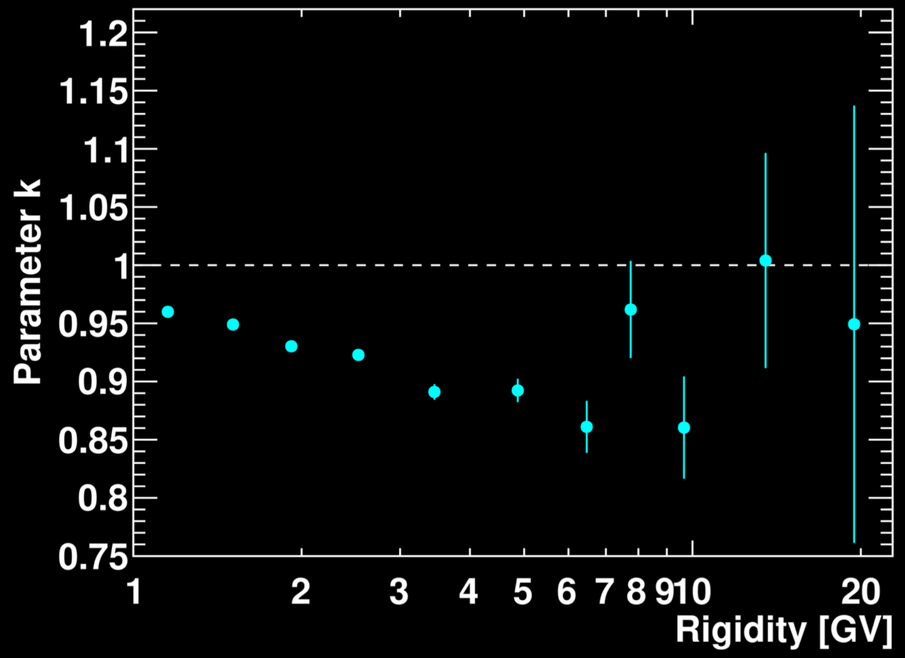


Differences in Solar Modulation in Positrons

- **K Parameter**: linear coefficients between relative daily **variations** of **positron** and **proton** fluxes, for each rigidity bin i.
- **K < 1** indicates that the positron flux is **more modulated** than proton flux.

$$\frac{\Phi_p^i - <\Phi_p^i>}{<\Phi_p^i>} = k^i \frac{\Phi_{e^+}^i - <\Phi_{e^+}^i>}{<\Phi_{e^+}^i>}$$





Conclusions

- **Daily charged CR fluxes**, from 1 GV to 100 GV in 2011-2023, exhibit **variations** on different time scales.
- Recurrent flux variations with a **period** of 27, 13.5 and 9 days are observed.
- Unexpectedly, the **strength** of 9 and 13.5 day **periodicities** reaches a maximum at 10 GV and 20 GV respectively.
- **Solar modulation** shows a clear **charge sign dependence**, being similar between proton and positron and differing for electrons.
- Evident **charge sign dependence** also during **CME events**.