Unique Properties of Daily Proton and Helium Fluxes up to 100 GV from the AMS

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On behalf of AMS Collaboration

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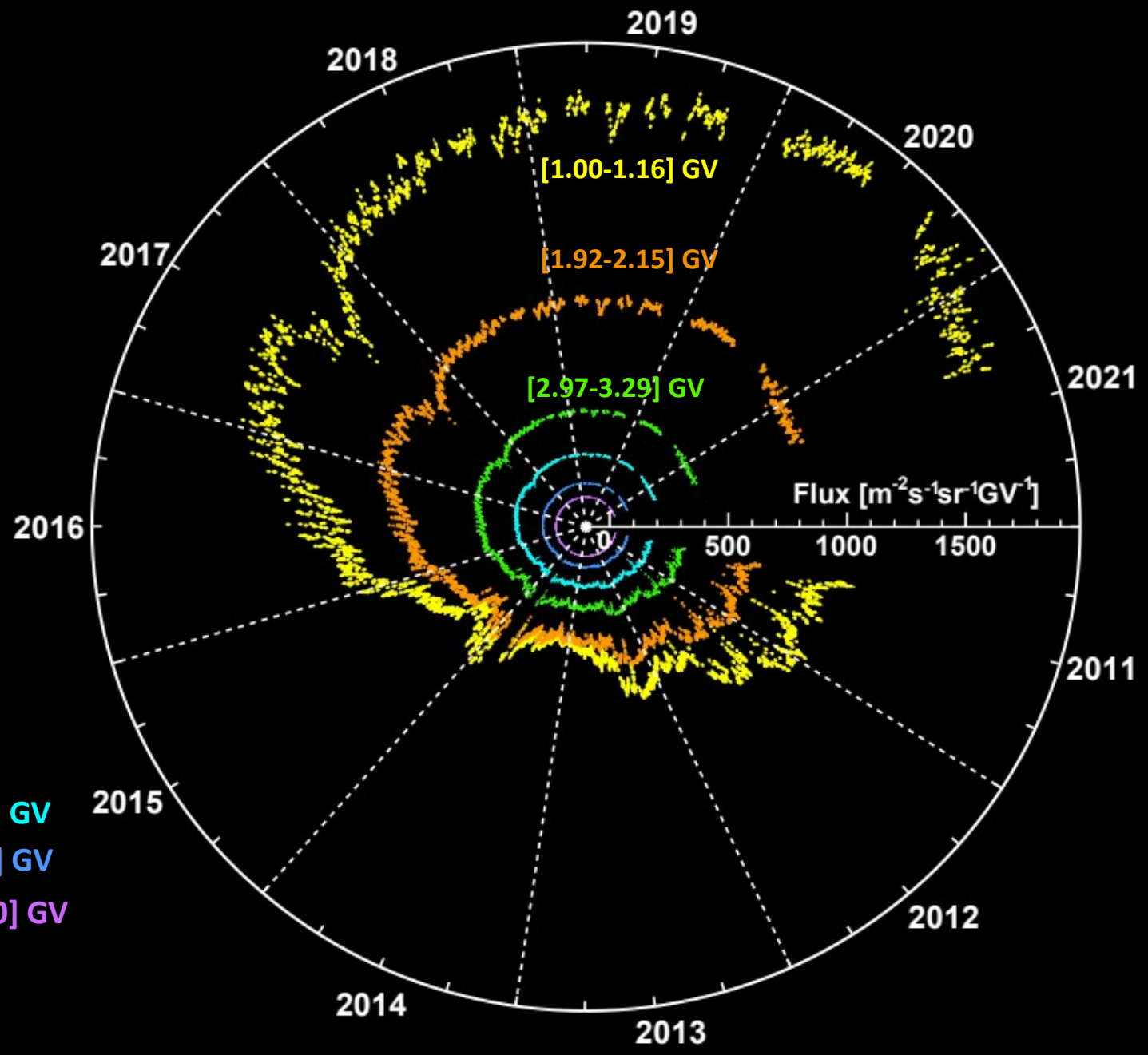
ECRS 2022 Nijmegen

AMS Daily Proton Flux

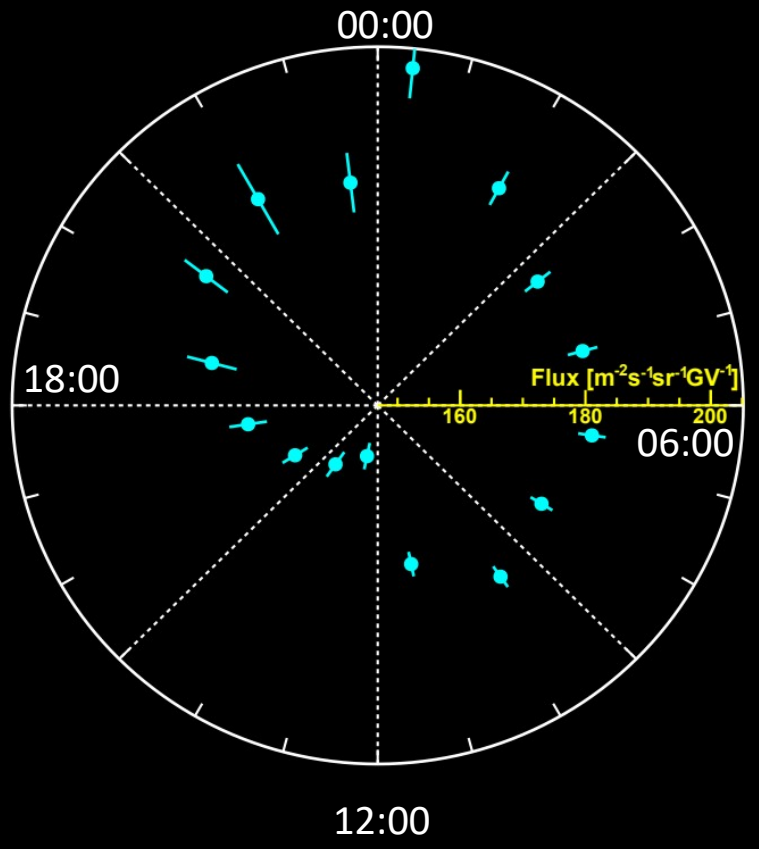
6 billion protons collected from
May 20, 2011 to **May 2, 2021**



Variation of Proton Radiation

Daily

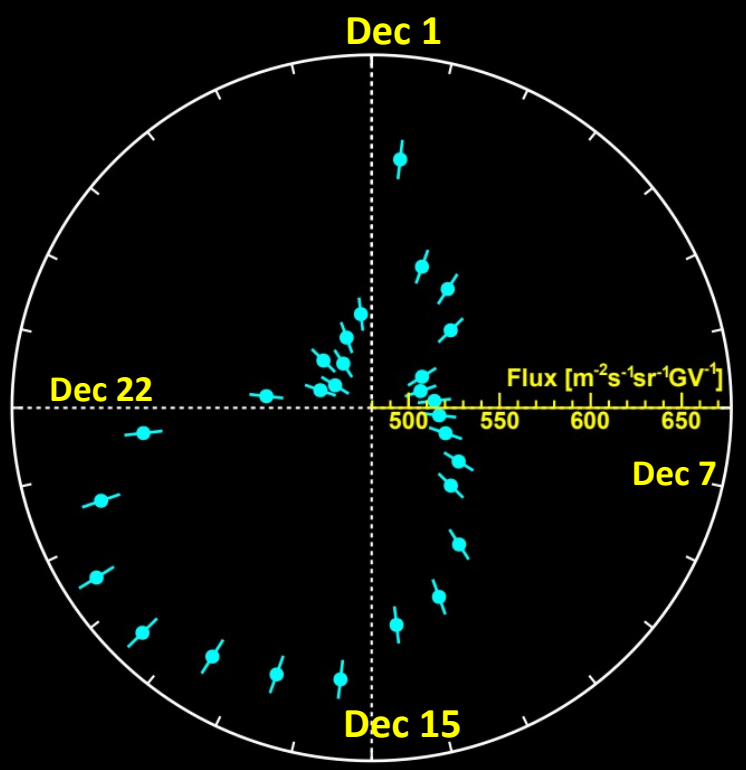
Sep 8, 2017



[4.02-4.43] GV

Monthly

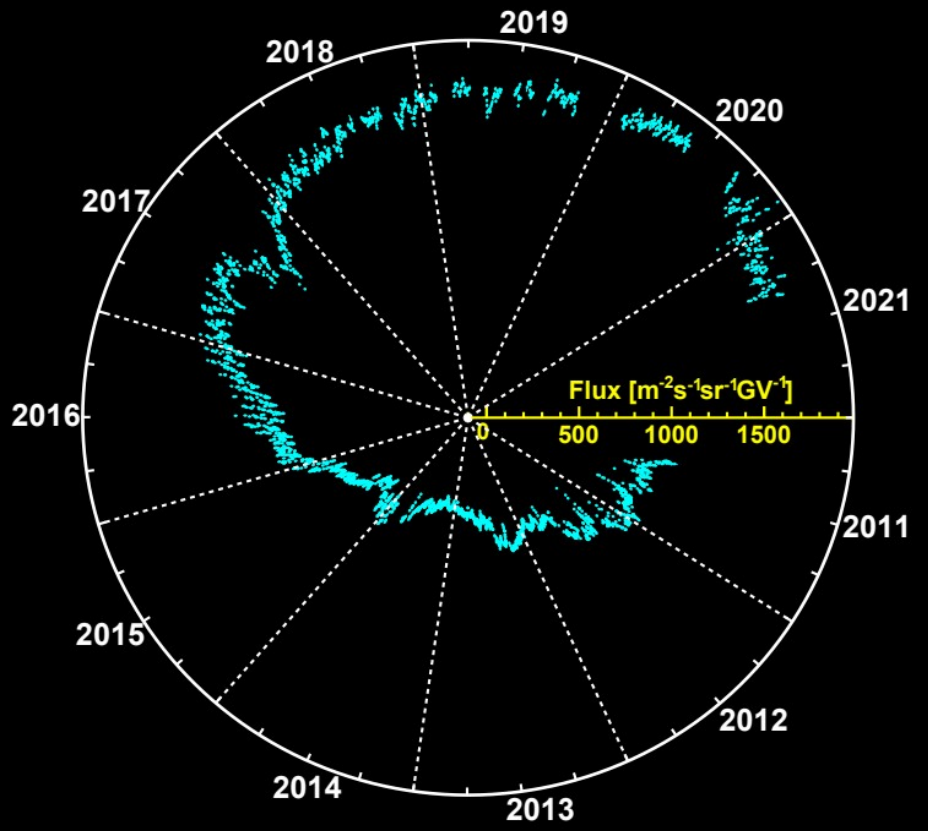
Dec 2014



[1.00-1.16] GV

Yearly

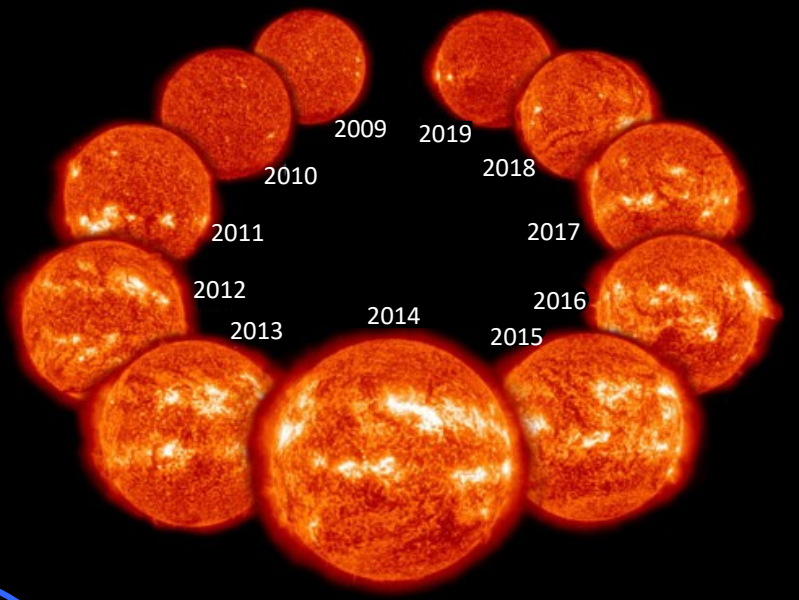
2011-2019



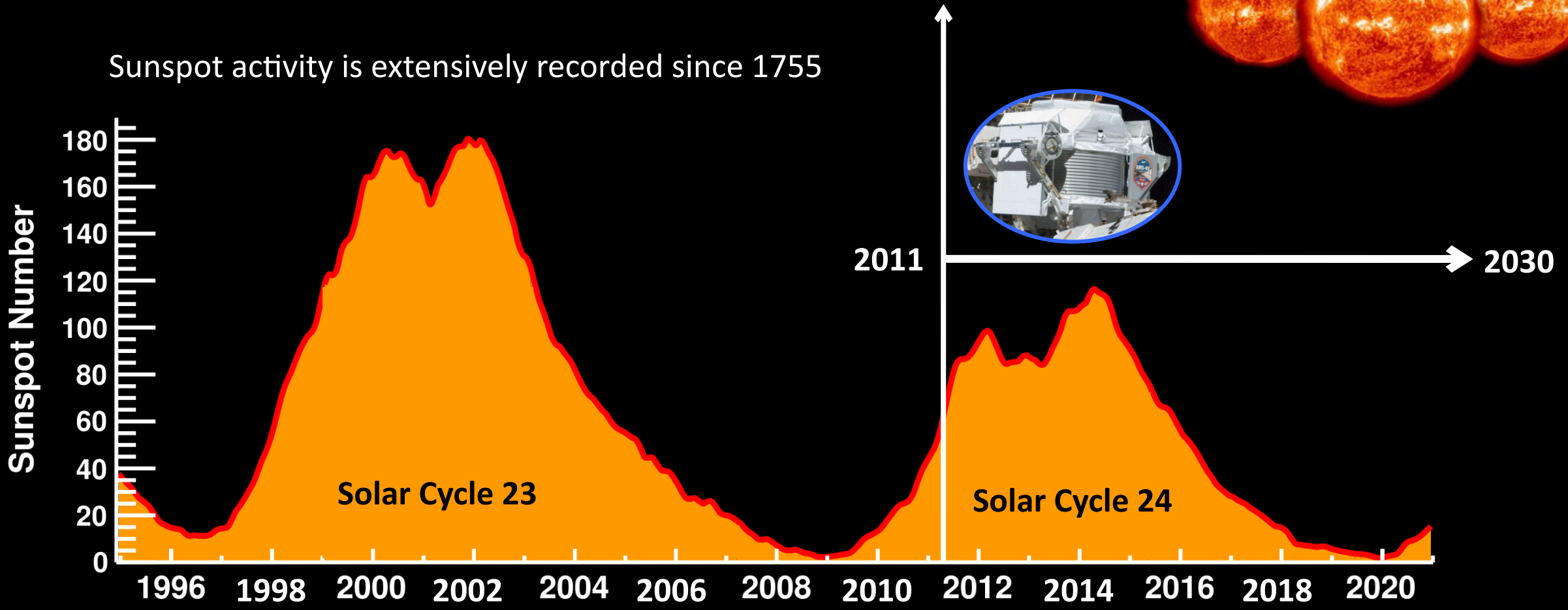
[1.00-1.16] GV

Long-term Scale Variation: Solar Cycle

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

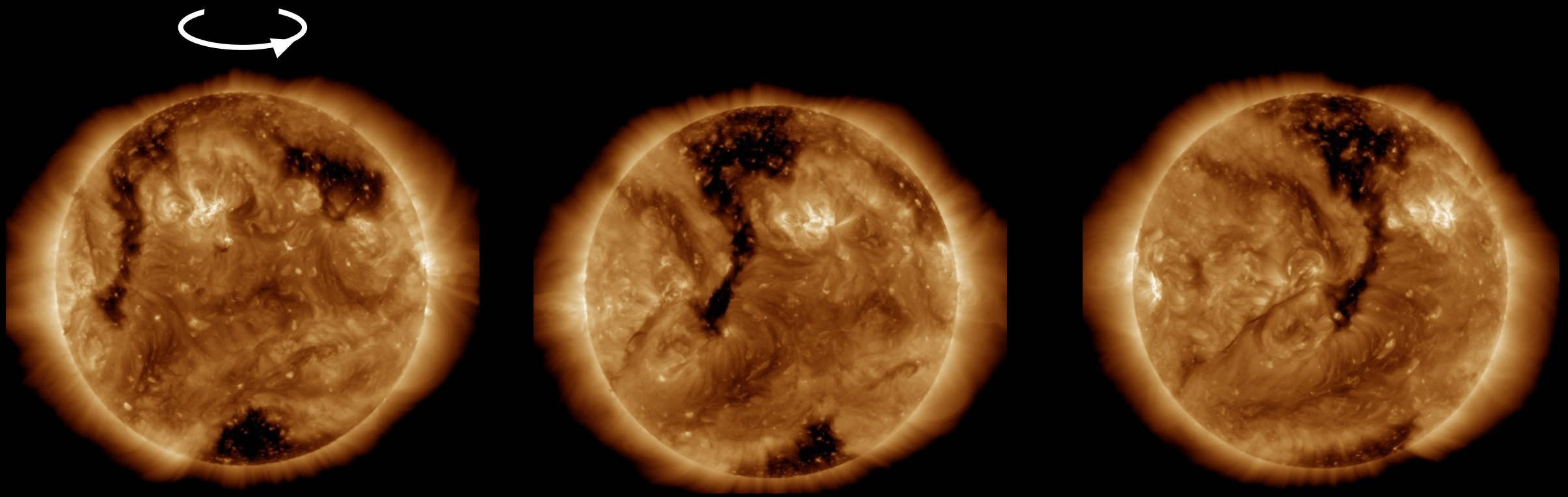


Sunspot activity is extensively recorded since 1755



Cosmic Ray Recurrent Variation in Short Scale

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



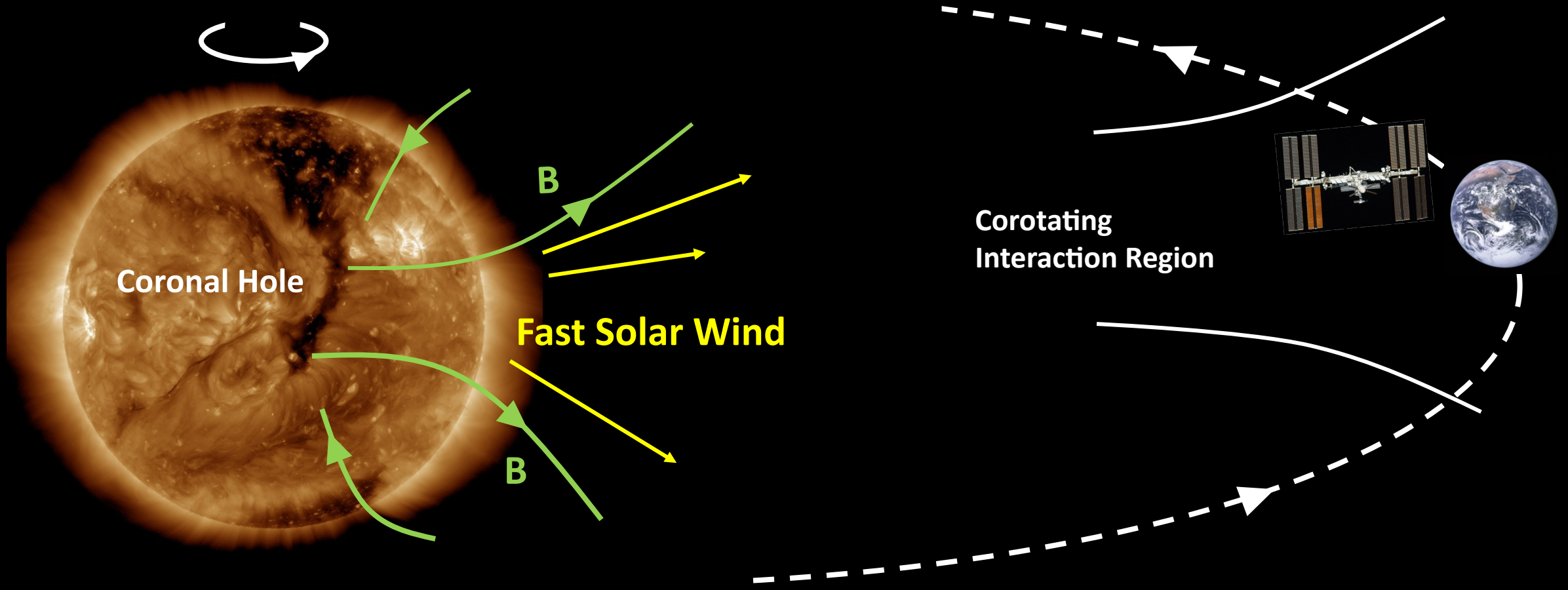
2016-03-22 2016-03-24 2016-03-26

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

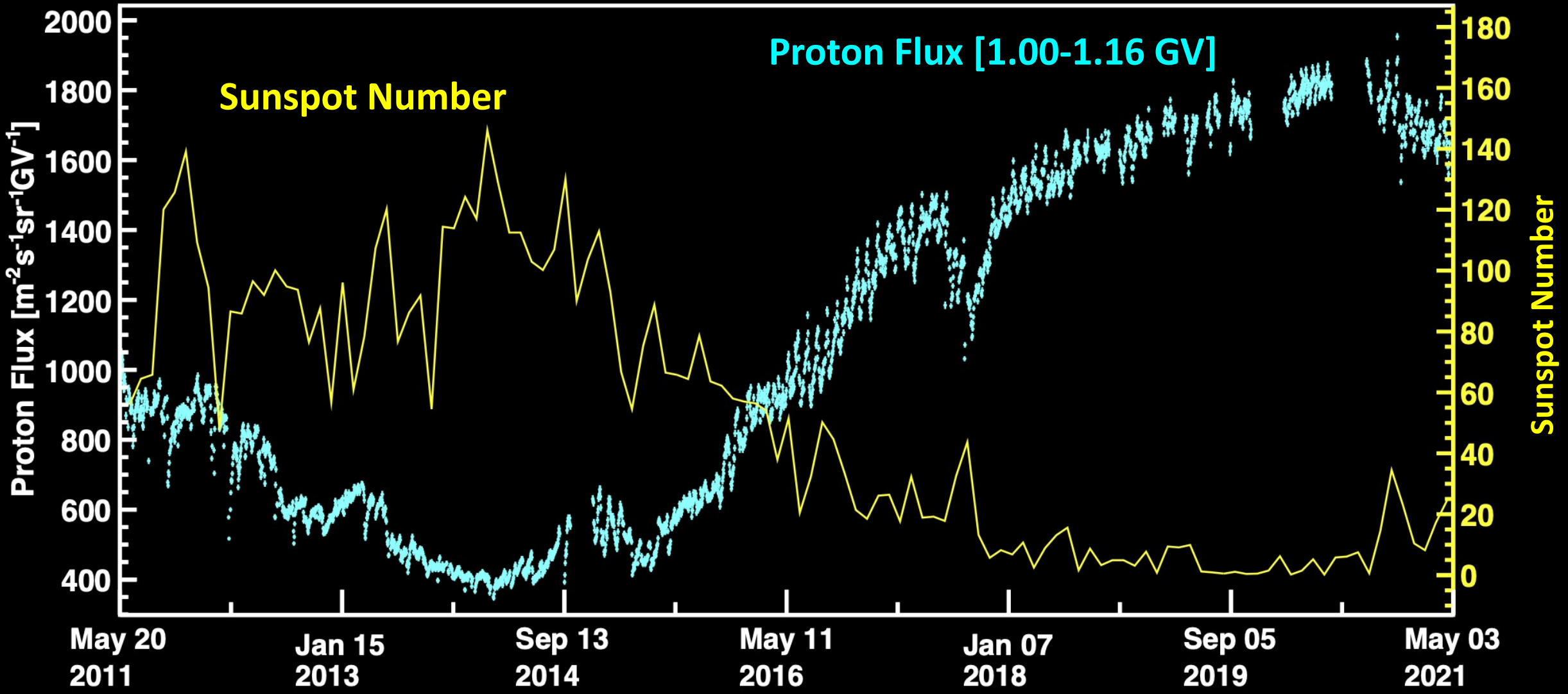
Coronal Hole are sources of high speed solar wind affecting Earth.



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

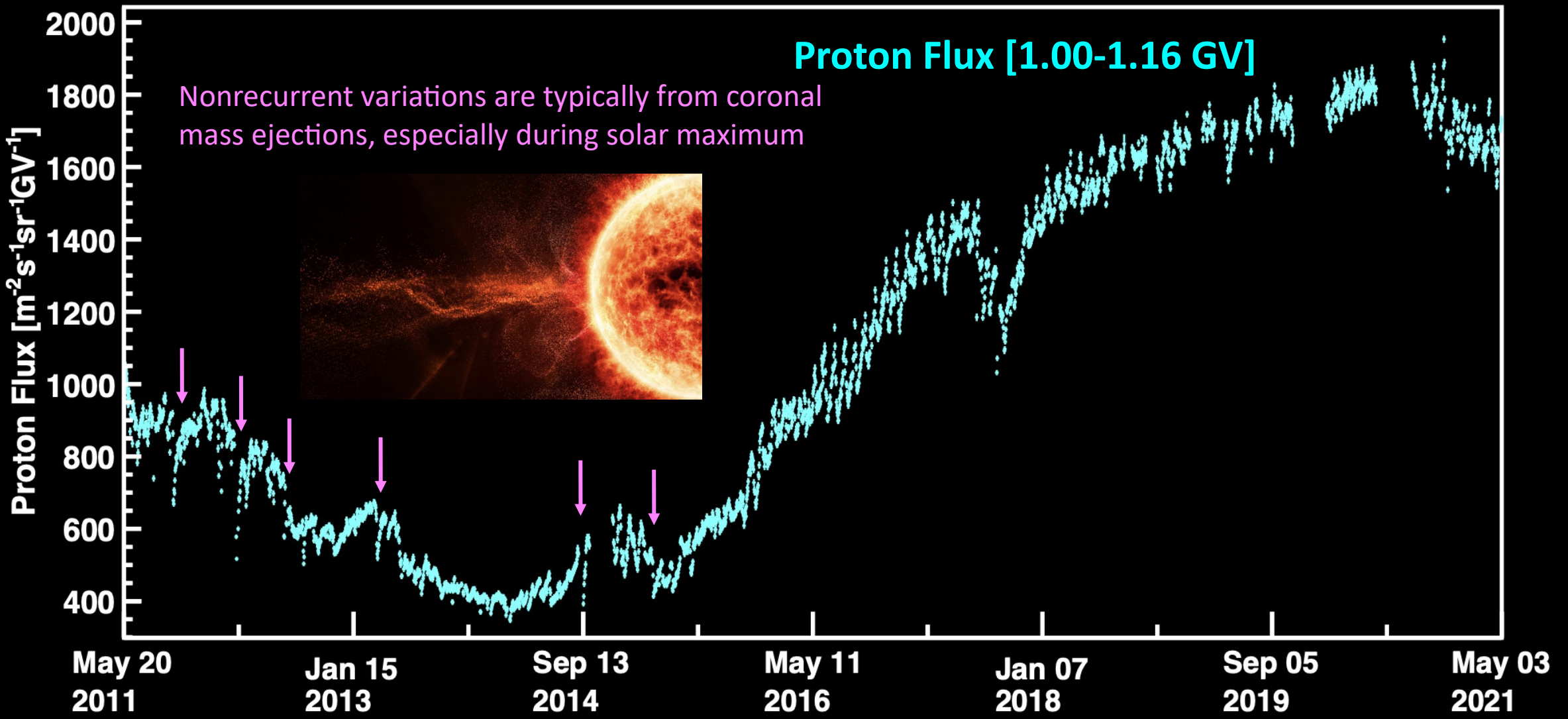
AMS Daily Proton Flux

Long Scale Variations are related to the 11-year Solar Cycle.



AMS Daily Proton Flux

Short scale variations can be either **nonrecurrent** or recurrent.



AMS Daily Proton Flux

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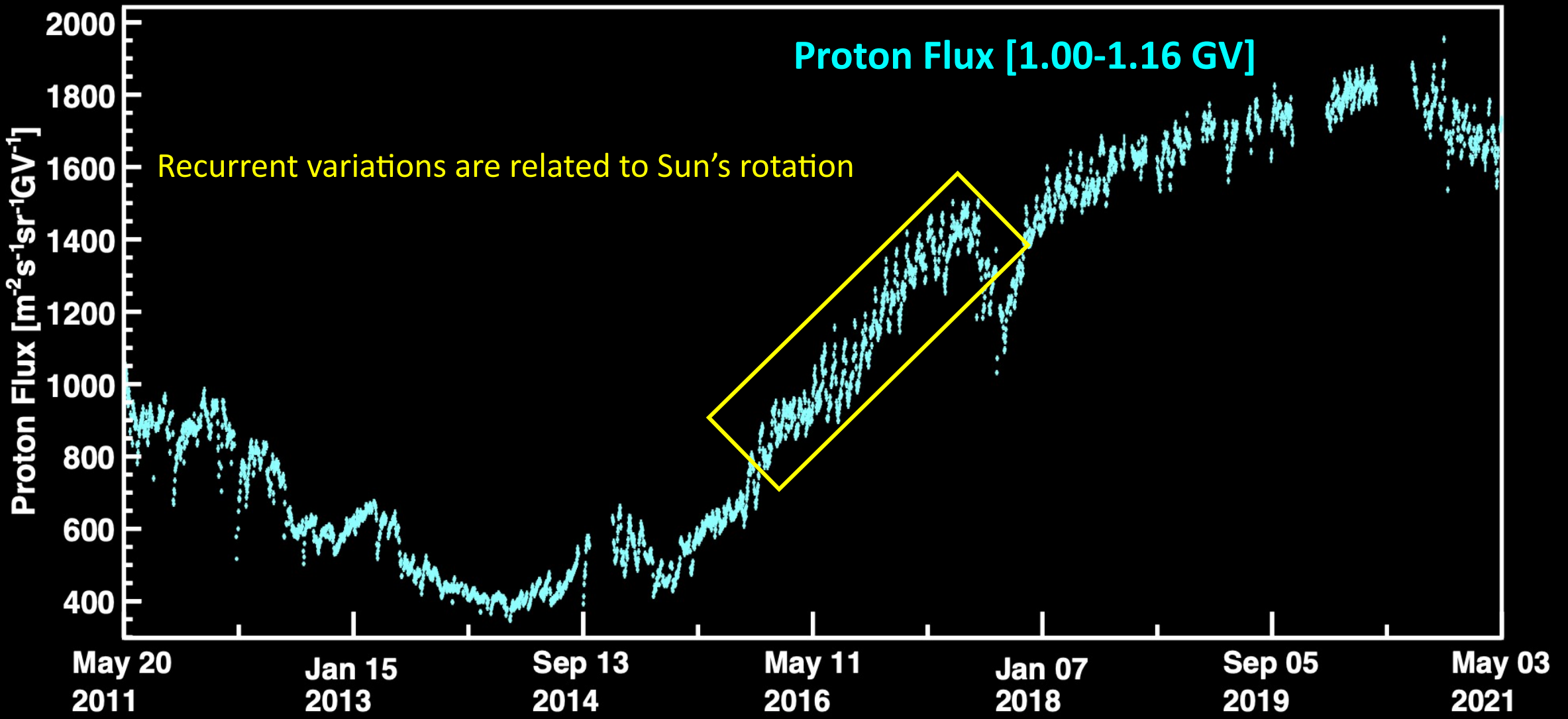
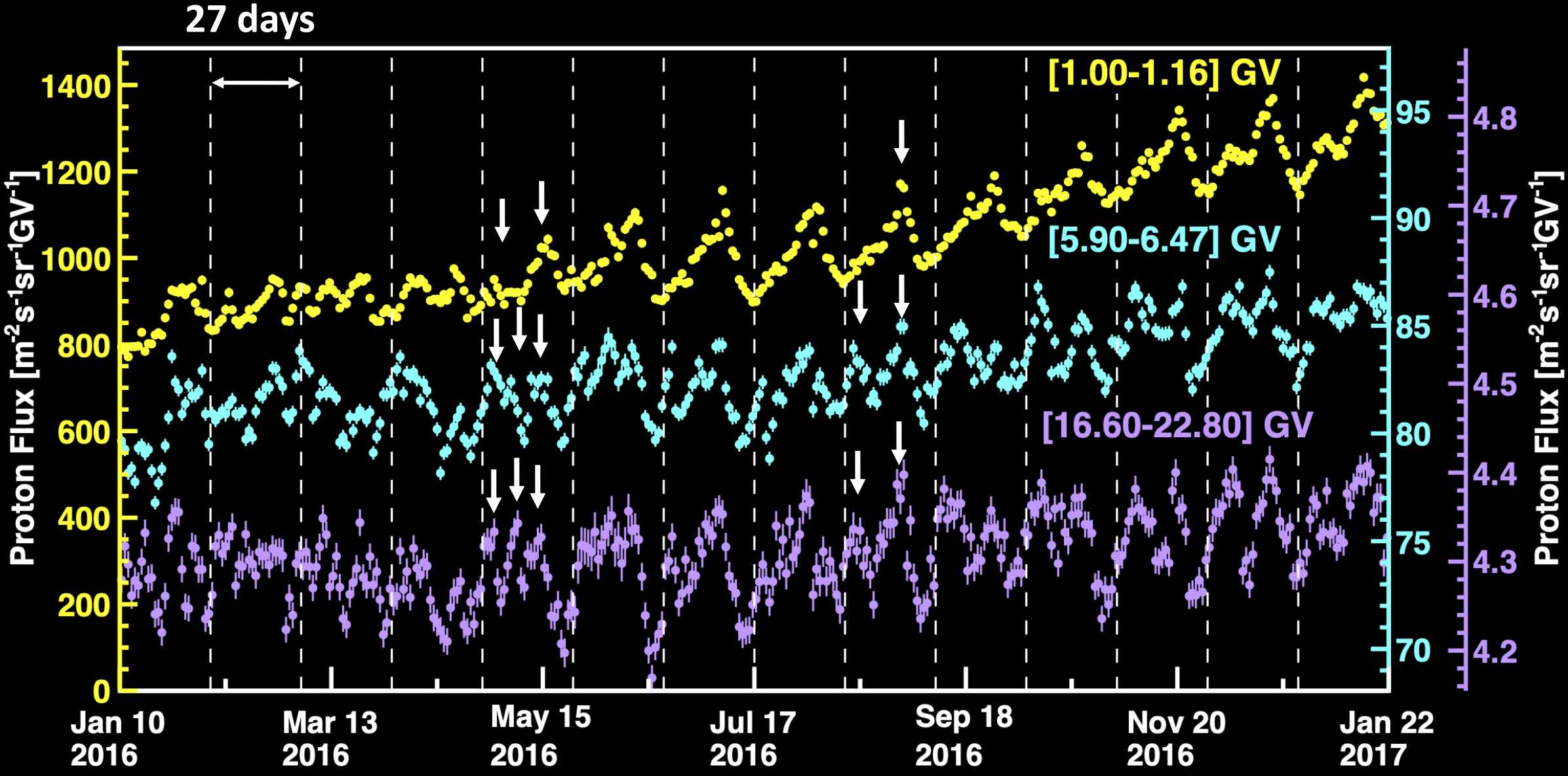
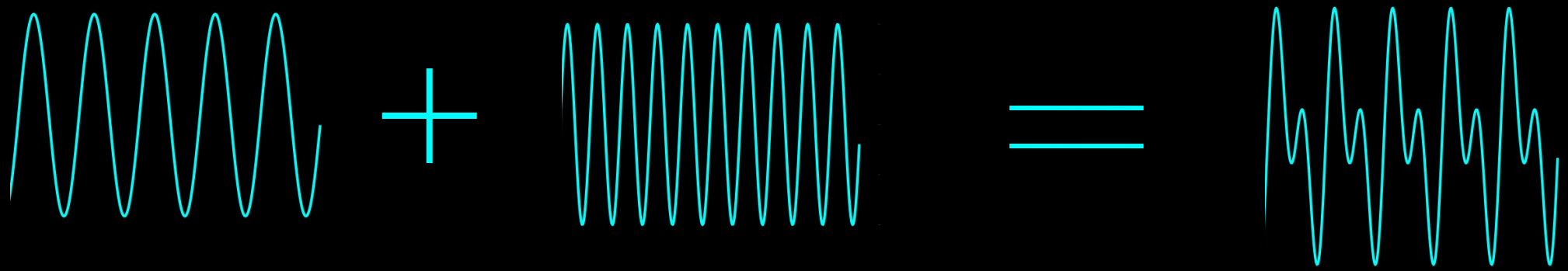


Recurrent Flux Variation with Periods of 9, 13.5, and 27 days in 2016



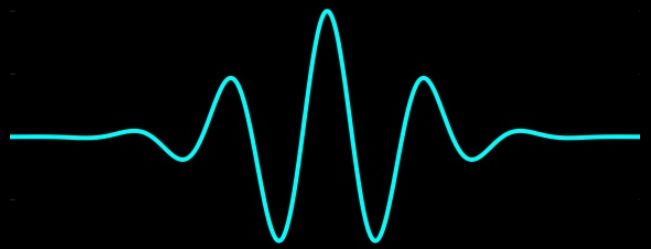
Frequency Analysis of Proton Fluxes

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)

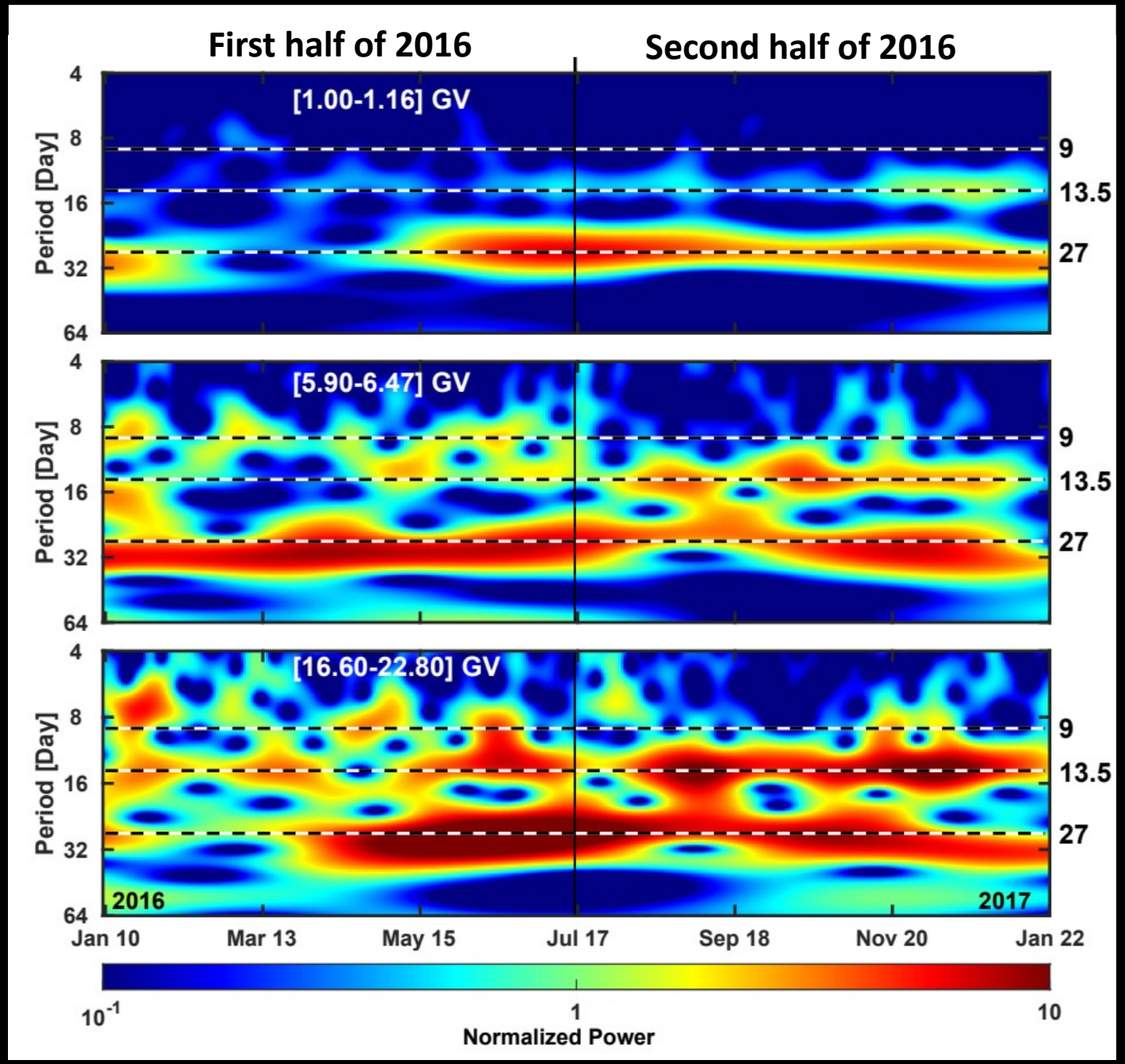
Wavelet Analysis of Proton Fluxes in 2016

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.

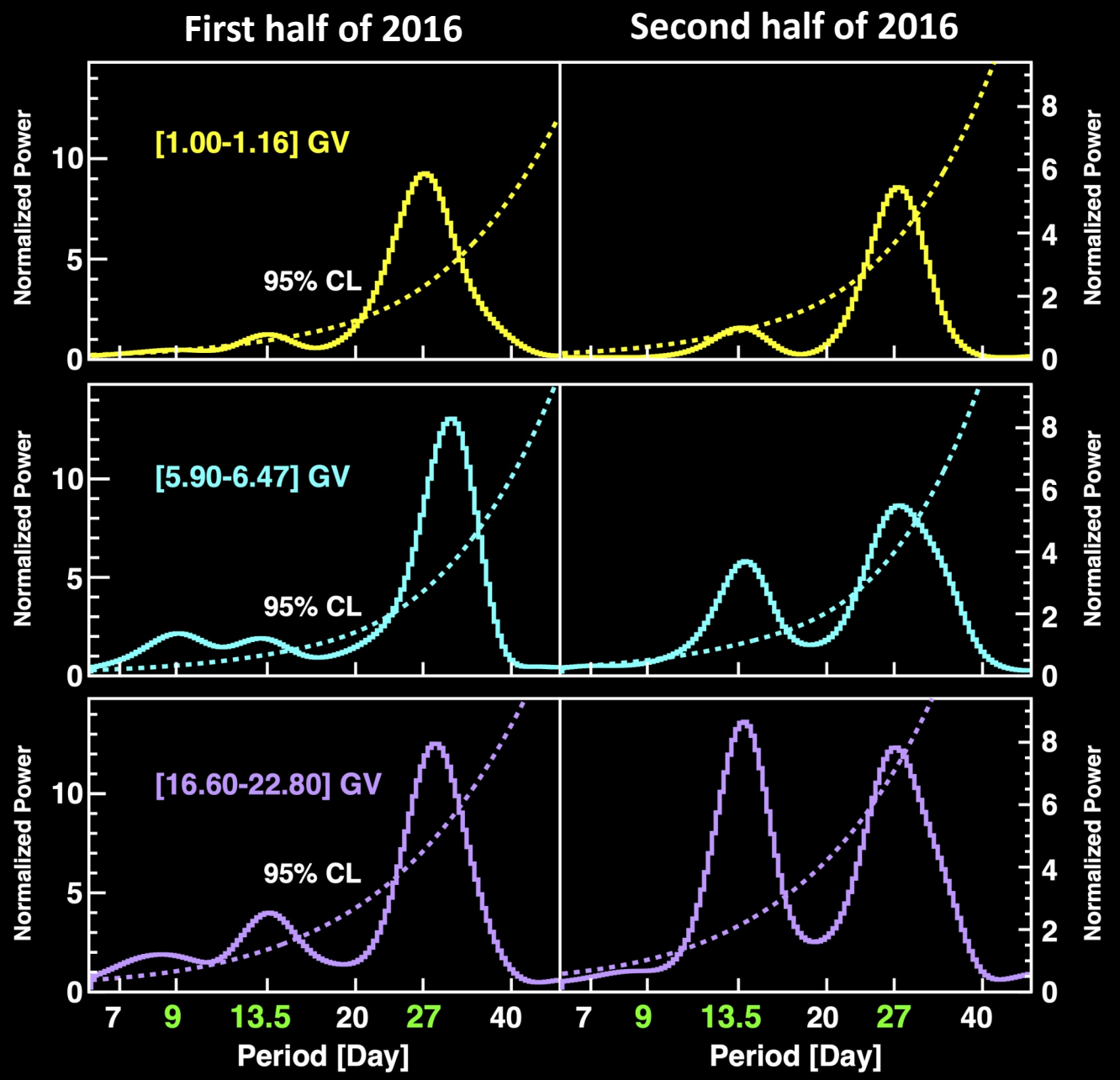


Power spectra of Proton Fluxes averaged over the First and Second Half of 2016

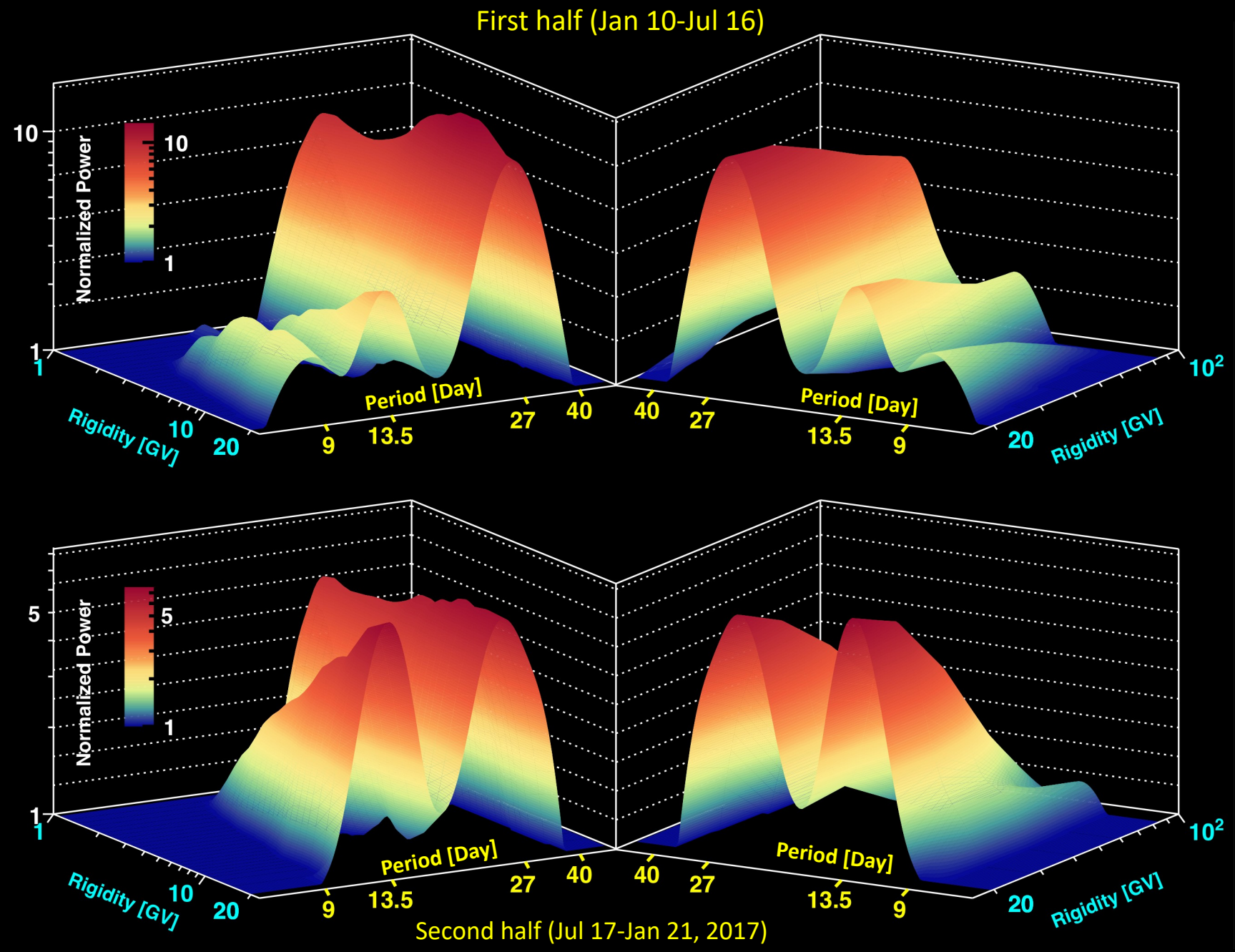
In the first half of 2016:
the strengths of **9-day and 13.5-day periods** increase with increasing rigidity.

In the second half of 2016:
the strength of **the 13.5-day period** increases with increasing rigidity, and **the 9-day period** is not visible.

The strength of **the 27-day period** varies with rigidity in both time intervals.



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

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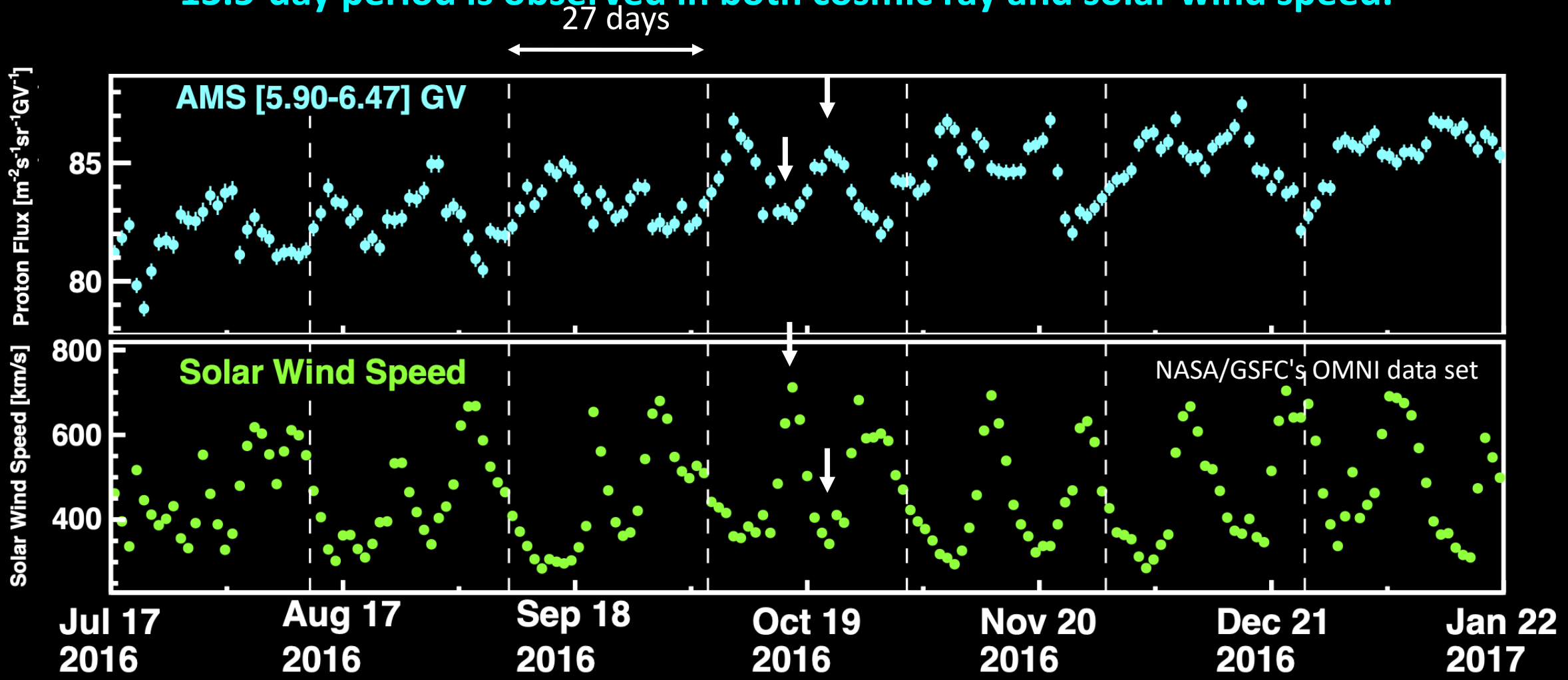
Example of Relation between the AMS Daily Flux and Solar Environment Parameter:

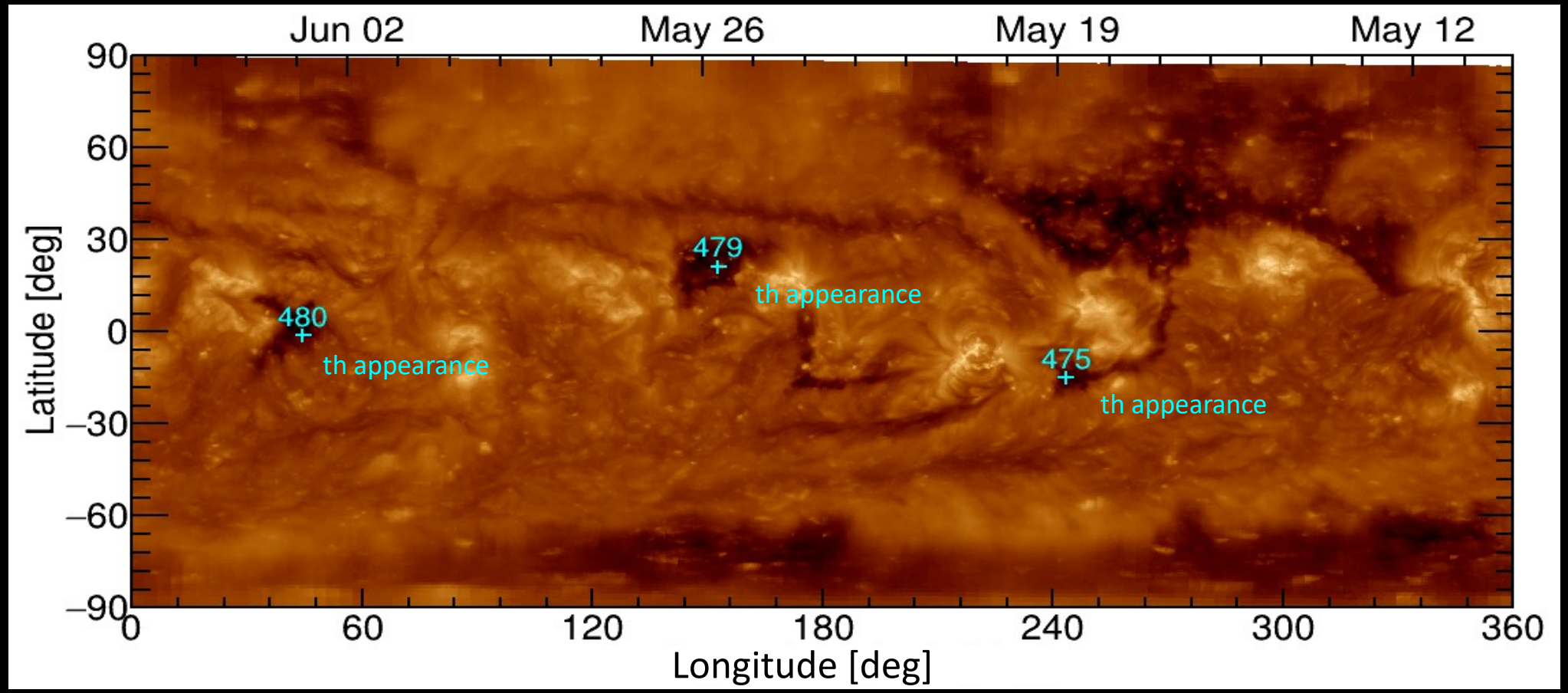
13.5-day period is observed in both cosmic ray and solar wind speed.



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:

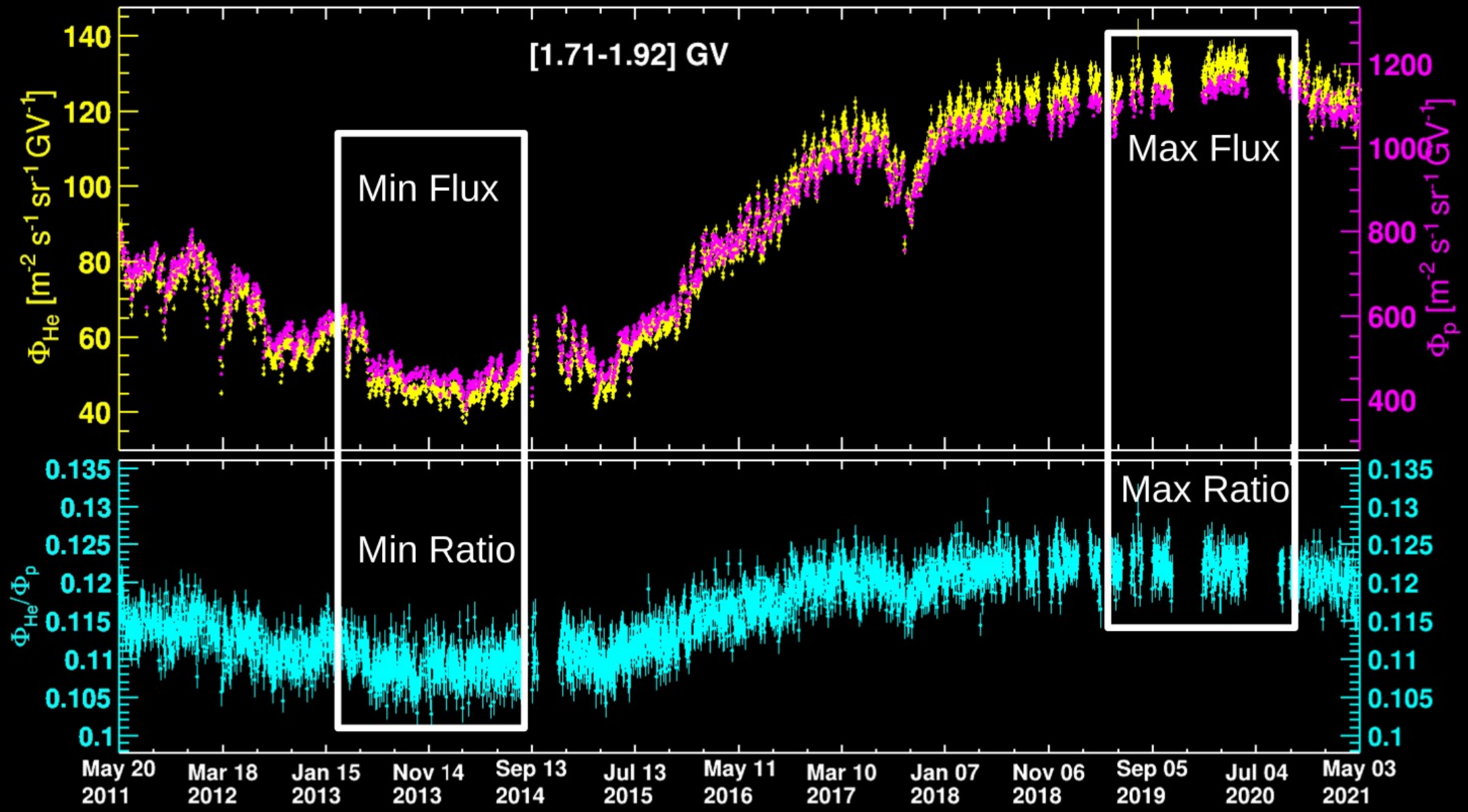
0 coronal hole:	⟶	No apparent periods
1 coronal hole	⟶	27-day period (a Bartels rotation)
2 coronal hole separated by	⟶	13.5-day period
3 coronal holes separated by	⟶	9-day period



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

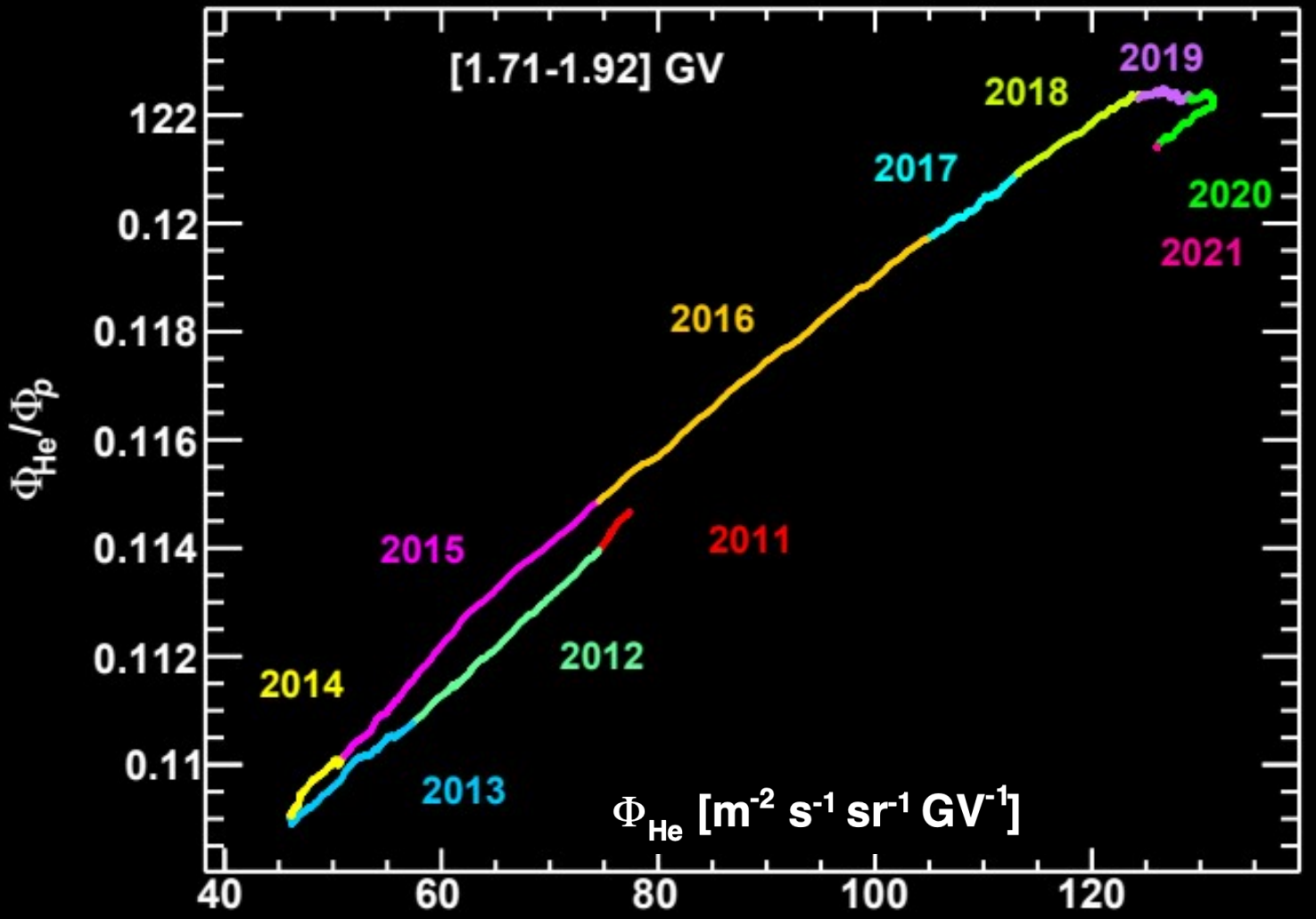
Comparison between proton and Helium flux at the same rigidity

The helium flux exhibits larger time variations than the proton flux



Helium to proton ratio long term trend

Helium to proton flux ratio vs. helium flux

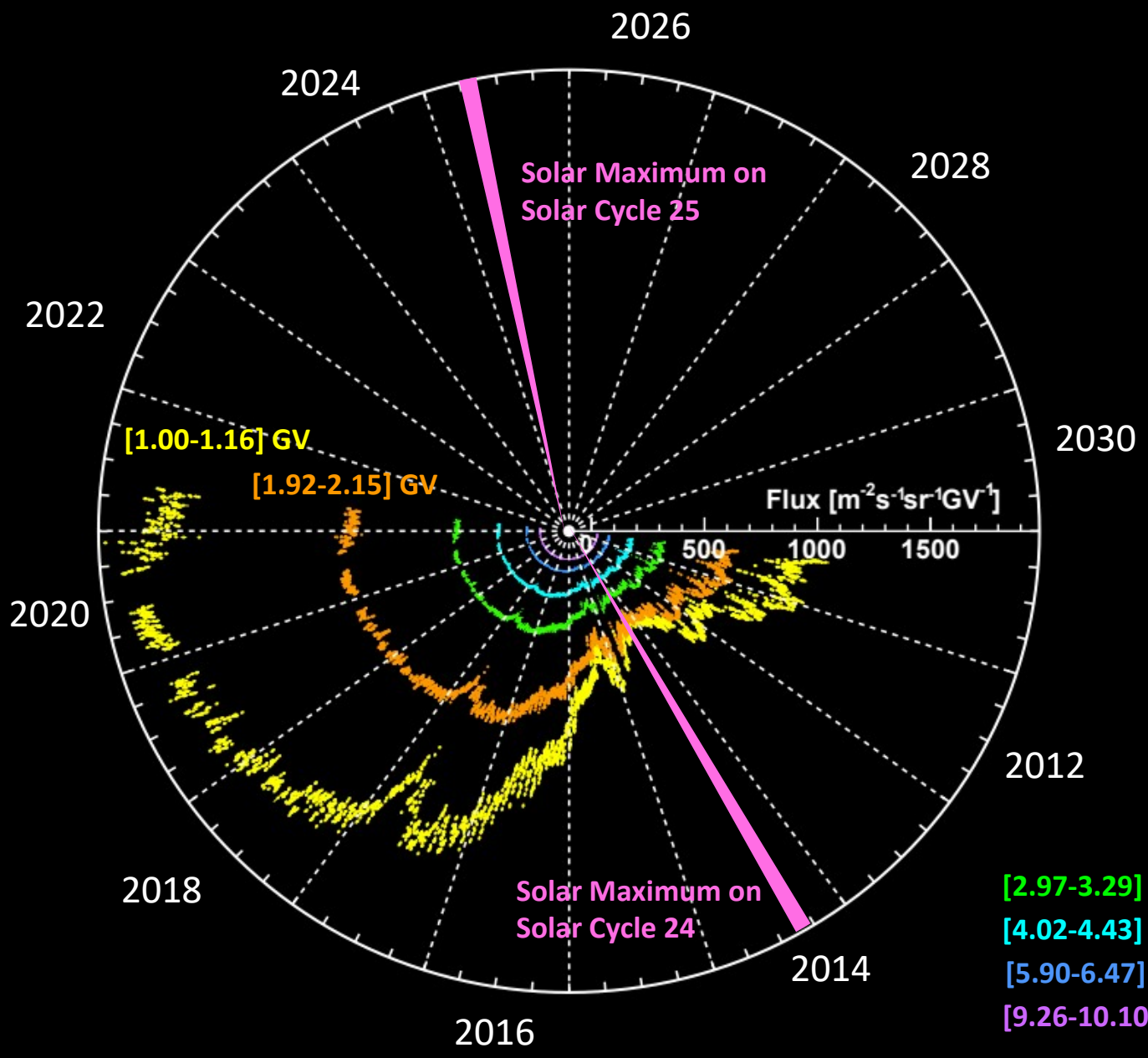


Moving averages of length around 1 year with a step of one day

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

Unexpectedly, the Helium flux recovers faster after Solar maximum.

Future Measurements on the example of proton Fluxes



[2.97-3.29] GV
[4.02-4.43] GV
[5.90-6.47] GV
[9.26-10.10] GV

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

Summary

- We have presented the precision measurements of the daily proton and Helium fluxes in cosmic rays **from 1 GV to 100 GV** between **May 20, 2011 and May 2, 2021**. The fluxes exhibit variations on different time scales, in days, months, and years.

- From **2014 to 2018**, we observed recurrent flux variations with a period of **27 days**. Shorter periods of **9 days and 13.5 days** are observed in 2016.

- The strength of all three periodicities changes with both time and rigidity. Unexpectedly, the strength of **9-day and 13.5-day** periodicities reaches a maximum at **10 GV and 20 GV** respectively. **The AMS results do not support the general conclusion that the strength of the periodicities always decreases with increasing rigidity**

- **Below 2.4 GV a hysteresis between the helium to proton flux ratio and the helium flux with a significance greater than 7σwas observed for the first time.** This shows that at low rigidity the behavior of the helium to proton flux ratio is different before and after the solar maximum in 2014.

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