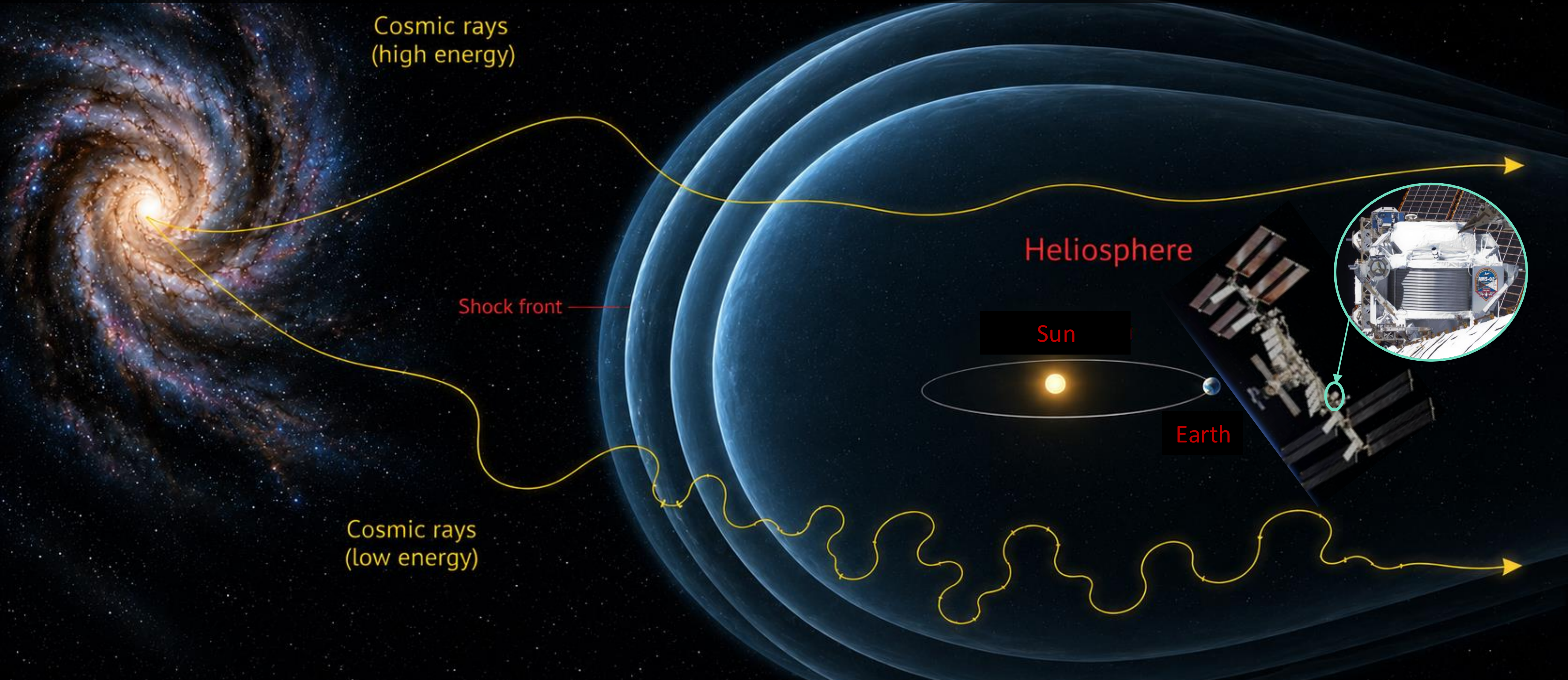
Highlights from the AMS Experiment: Precision measurements the hourly, daily, monthly, and yearly cosmic radiation over 14 years



Dimitrii Krasnopevtsev/MIT
TEVPA 2026, Tendo

Propagation of GCR in Heliosphere - Parker Equation

$$\frac{\partial f}{\partial t} = \underbrace{-\vec{V}_{SW} \cdot \vec{\nabla} f}_{\boxed{\text{Solar wind convection}}} \underbrace{- \vec{V}_D \cdot \vec{\nabla} f}_{\boxed{\text{Particle drifts}}} + \underbrace{\vec{\nabla} \cdot (K \cdot \vec{\nabla} f)}_{\boxed{\text{Particle diffusion}}} + \underbrace{\frac{1}{3} \vec{\nabla} \cdot \vec{V}_{SW} \frac{\partial f}{\partial \ln R}}_{\boxed{\text{Adiabatic energy changes}}}$$

- Convection with the solar wind
- Particle drifts due to heliospheric magnetic field gradients, curvatures and heliospheric current sheet.
- K = diffusion tensor, due to scattering on magnetic irregularities
- Adiabatic energy losses/gains due to expansion/compression of solar wind, proportional to spectral index.

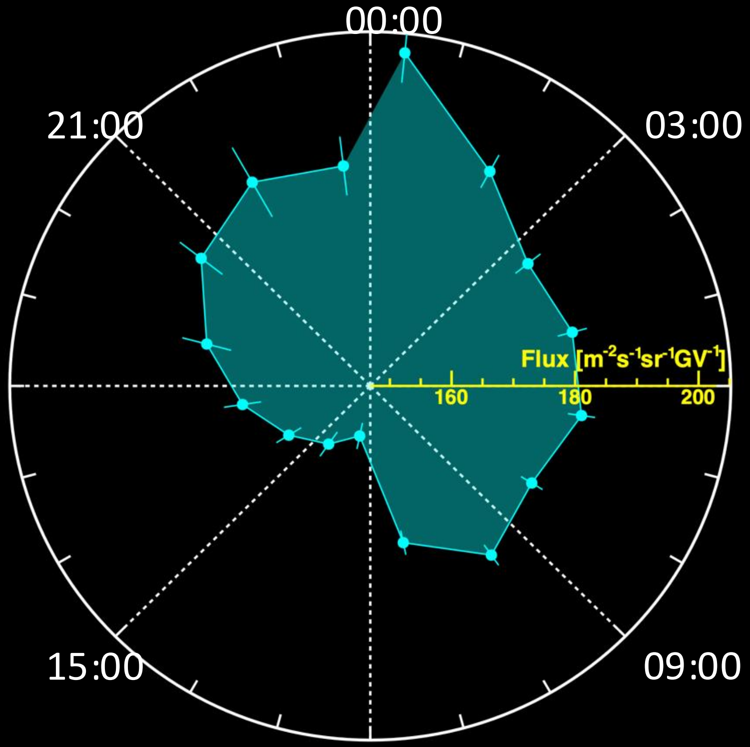
E. N. Parker 1965
Space Science Reviews, 4, 666

Time Variation of Cosmic Radiation

Proton flux

Hourly

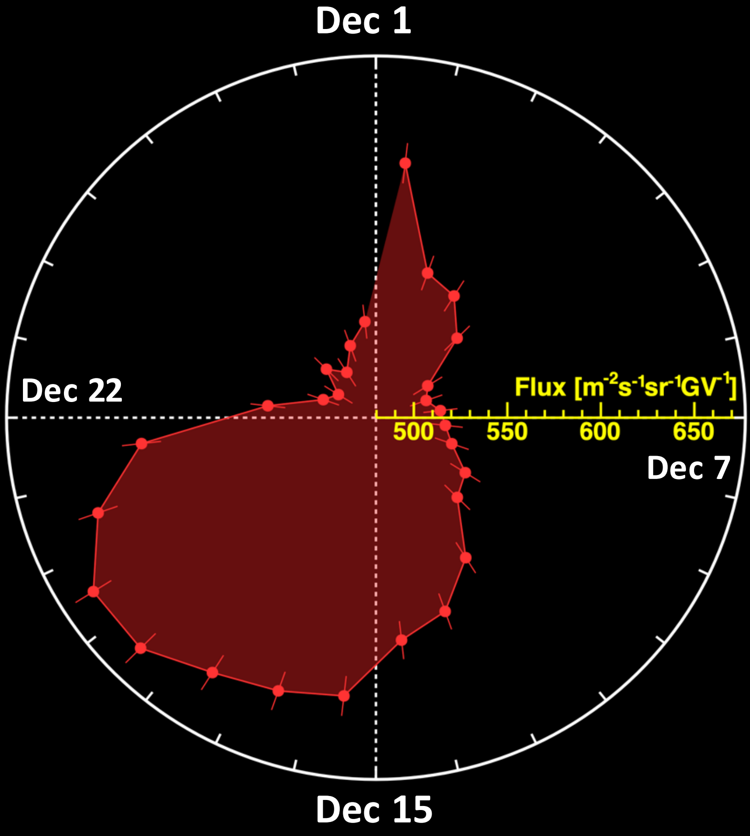
Sep 8, 2017



[4.02-4.43] GV

Daily

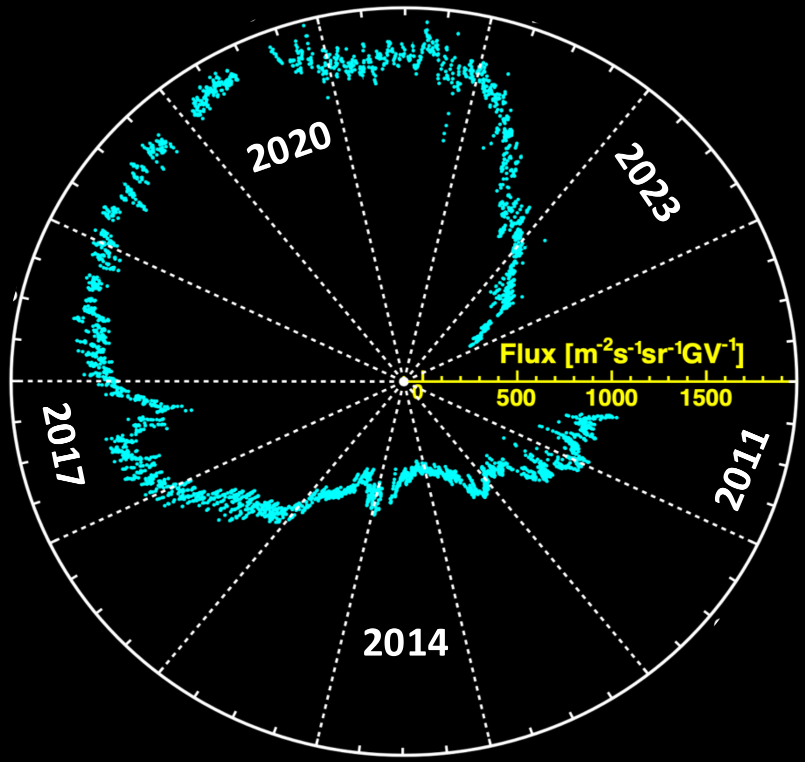
Dec 2014



[1.00-1.16] GV

Yearly

2011- 2023

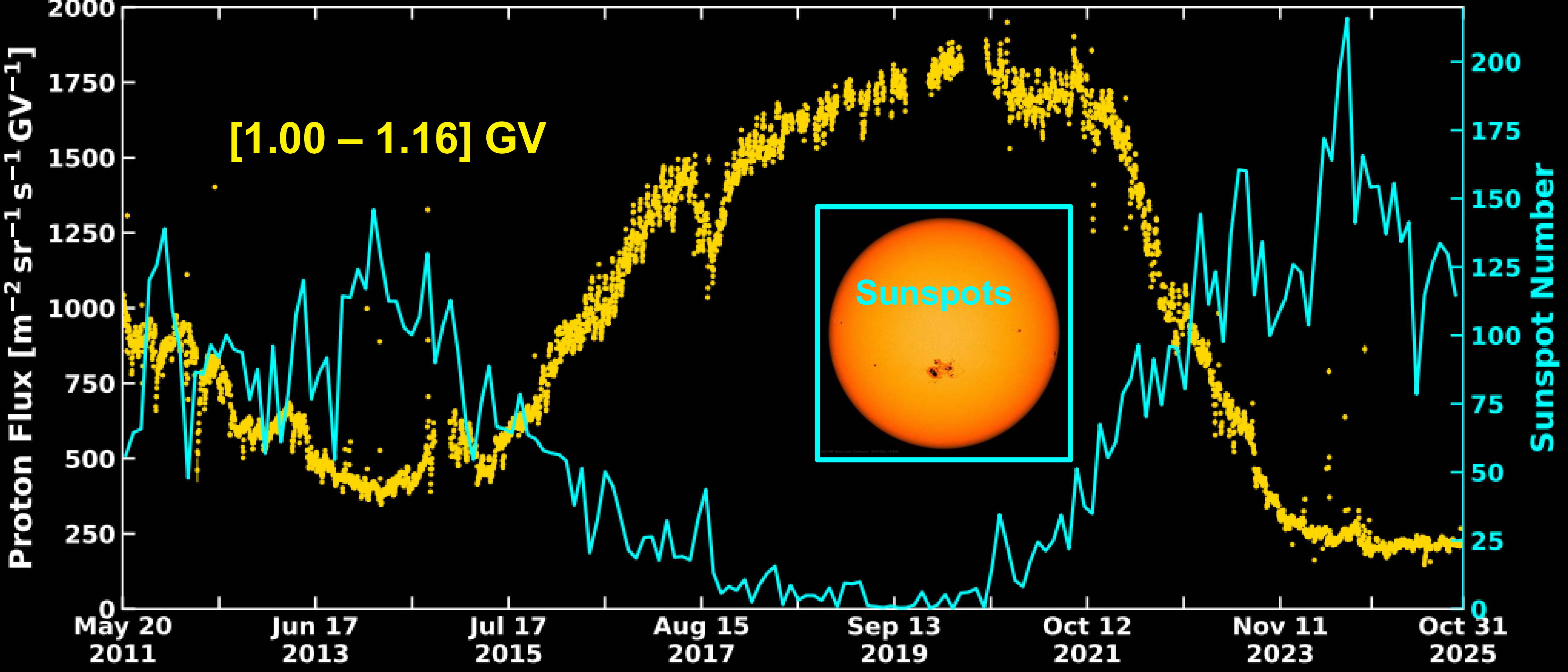


[1.00-1.16] GeV/c

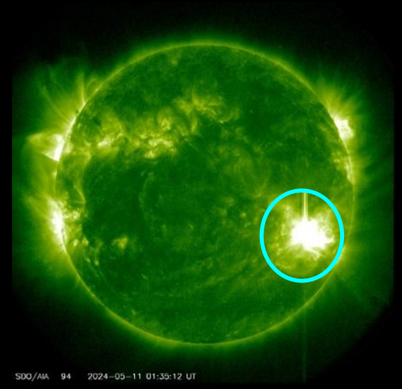
Cosmic radiation varies hourly, daily, and yearly. It cannot be predicted by current models.

Long-Term Proton Flux

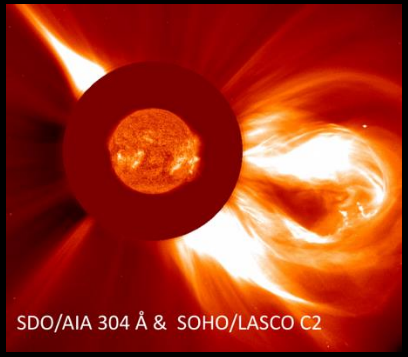
The long-term variation follows the 11-year solar cycle.



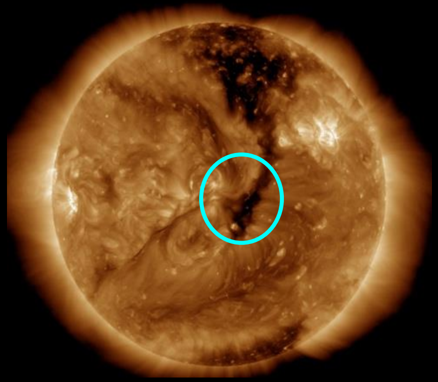
Short Time Scale Phenomena



Solar flares are sudden releases of energy on the Sun, often occurring near sunspot groups. They can accelerate particles and produce **Solar Energetic Particles (SEPs)**.



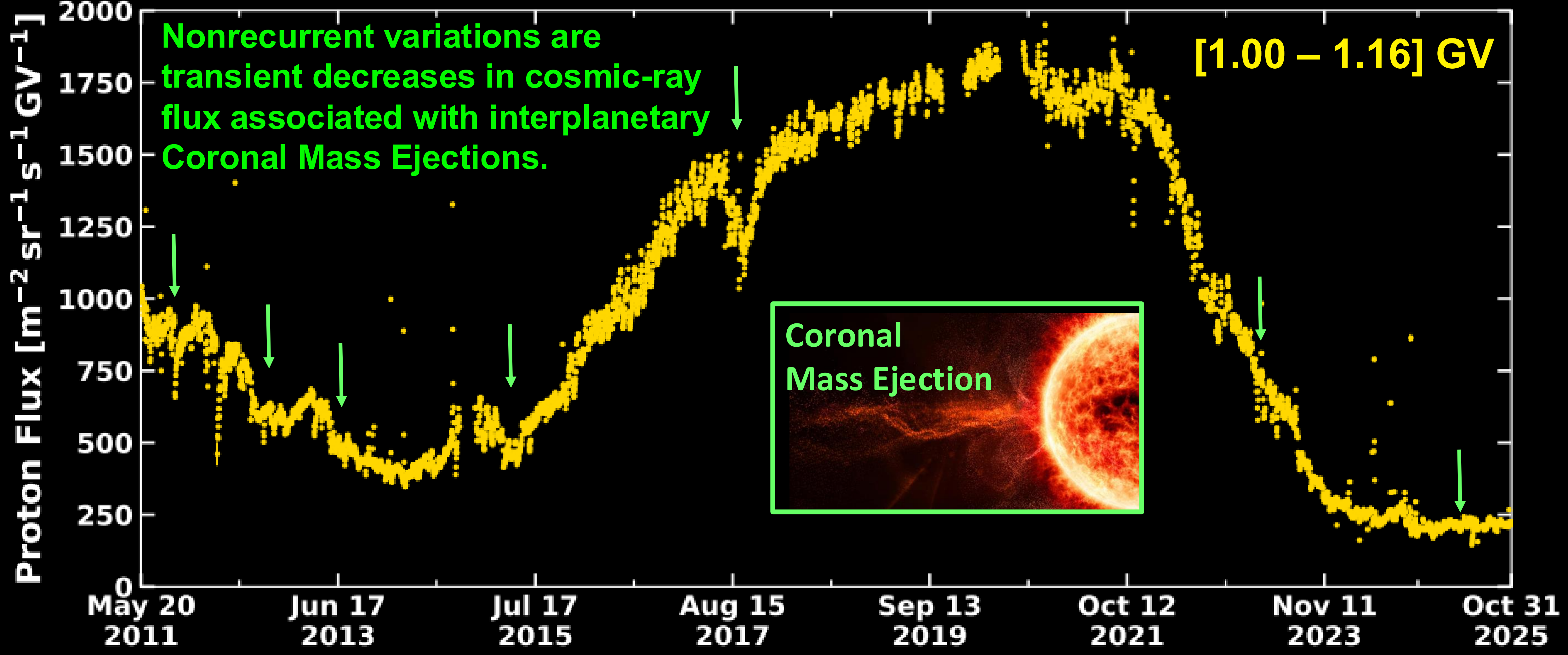
Coronal Mass Ejections (CMEs) release plasma and magnetic fields into the heliosphere. They can accelerate **SEPs** and cause transient decreases in the Galactic Cosmic Ray flux, known as **Forbush decreases (FDs)**.



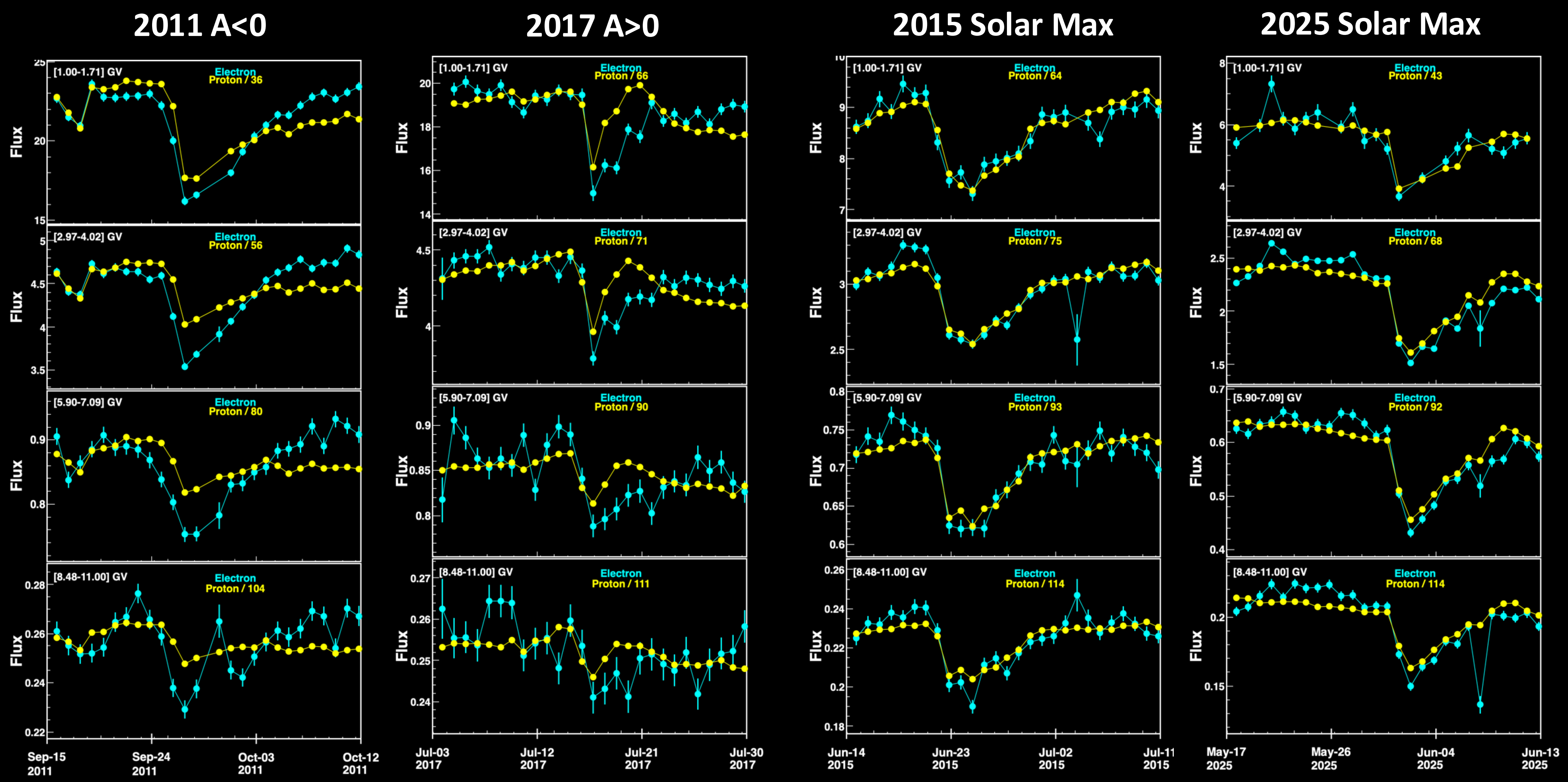
Coronal holes are regions of open magnetic field on the Sun that produce fast solar-wind streams. Their interaction with slower solar wind forms **Co-rotating Interaction Regions (CIRs)**, which produce recurrent variations in the **GCR flux** with periods of approximately **27, 13.5, and 9 days**.

Daily Proton Flux: Nonrecurrent Variations

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

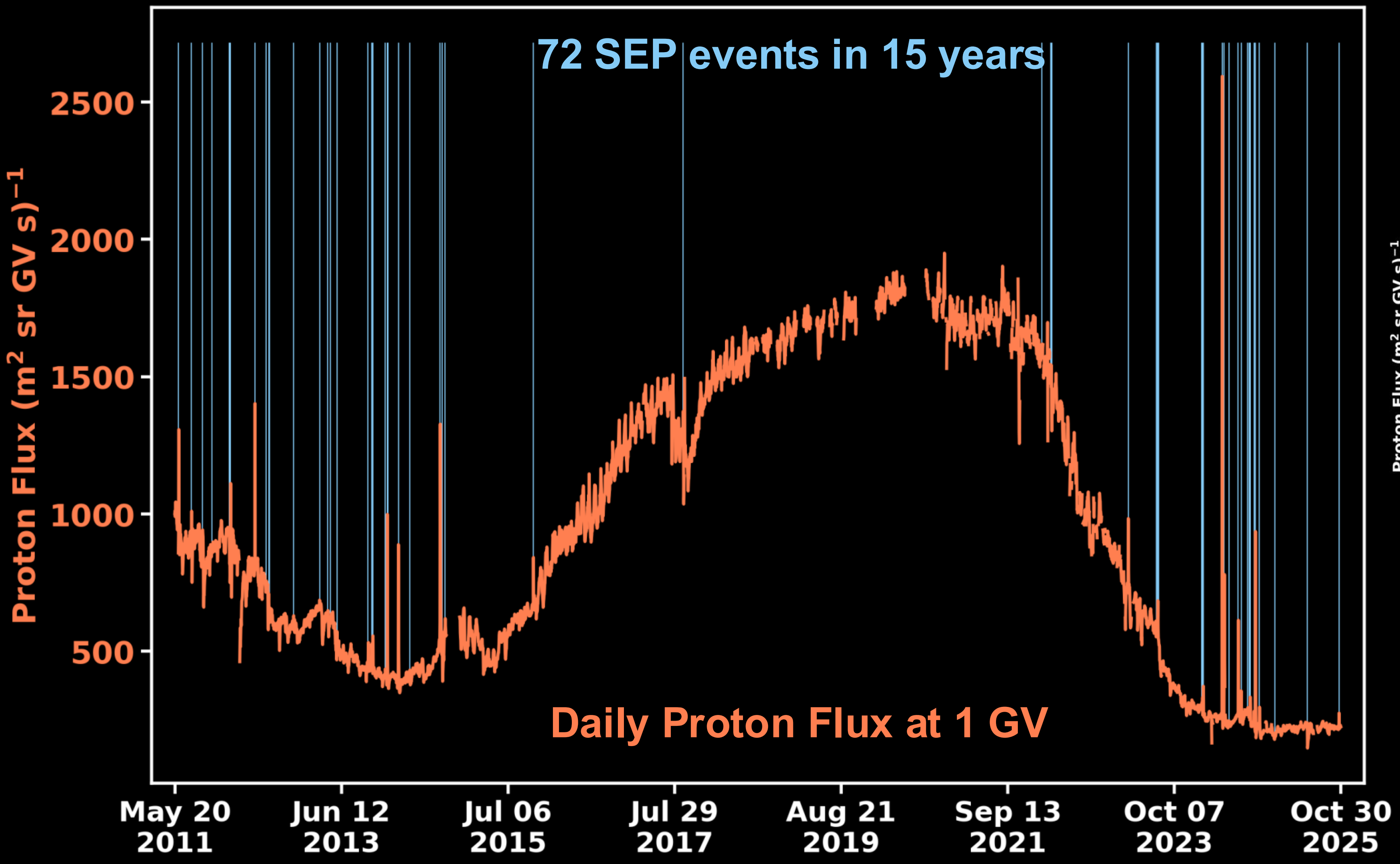


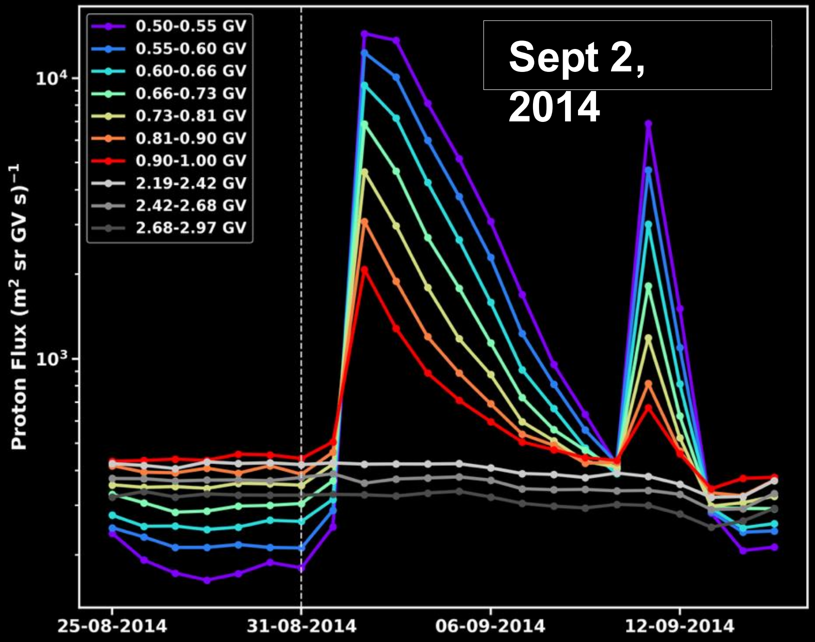
Electron and Proton Forbush Decrease



AMS Proton Flux

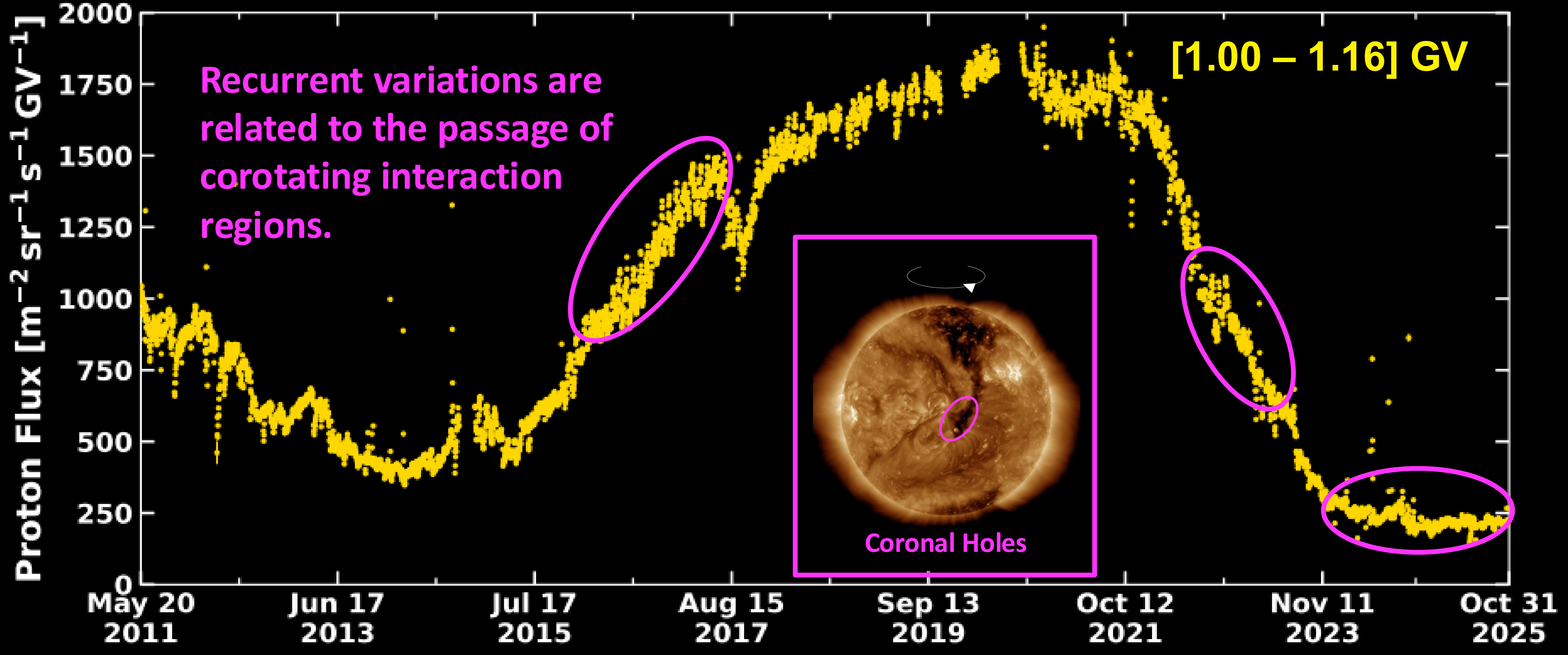
Solar Energetic Particles



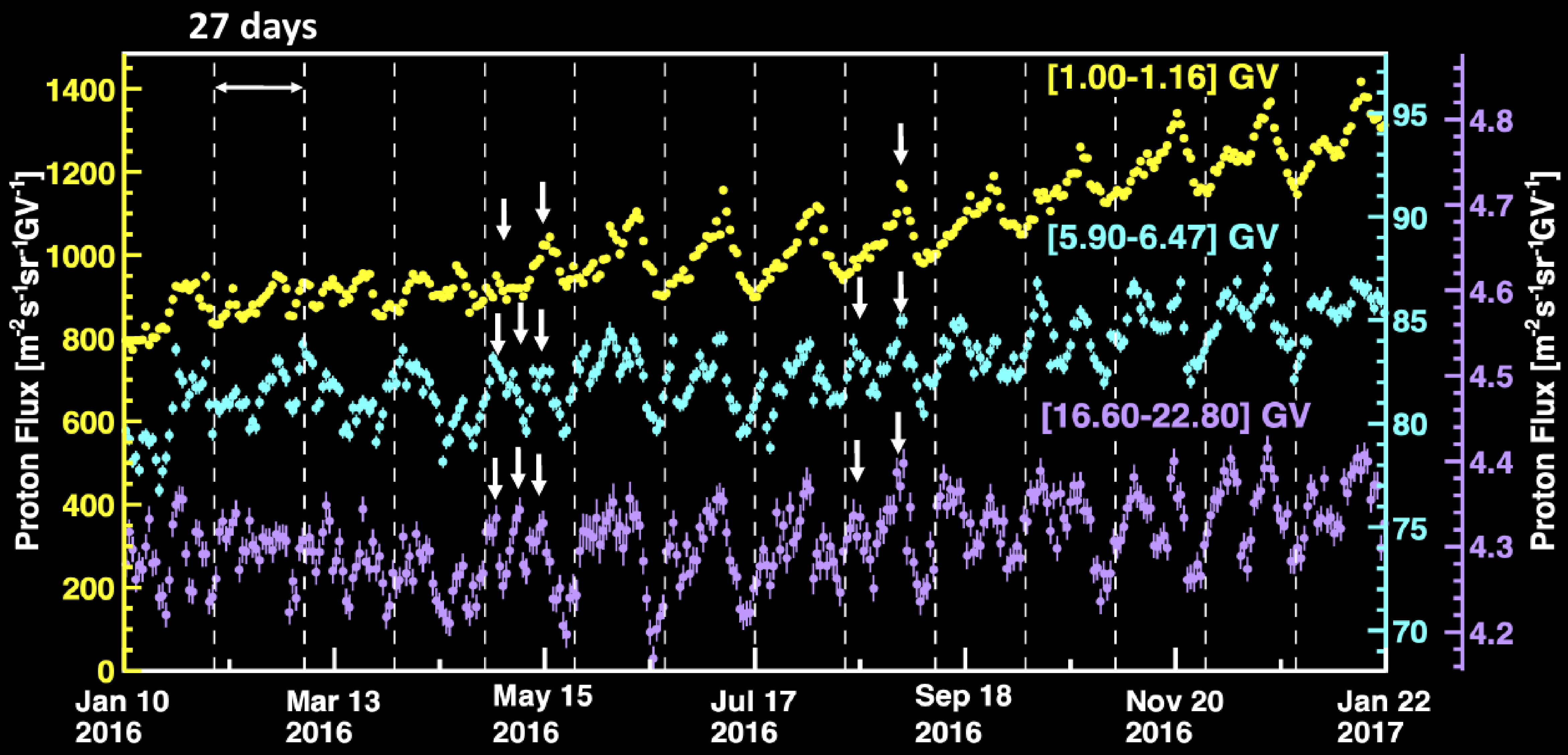


Daily Proton Flux: Recurrent Variations

Short-term variations can be either nonrecurrent or recurrent.



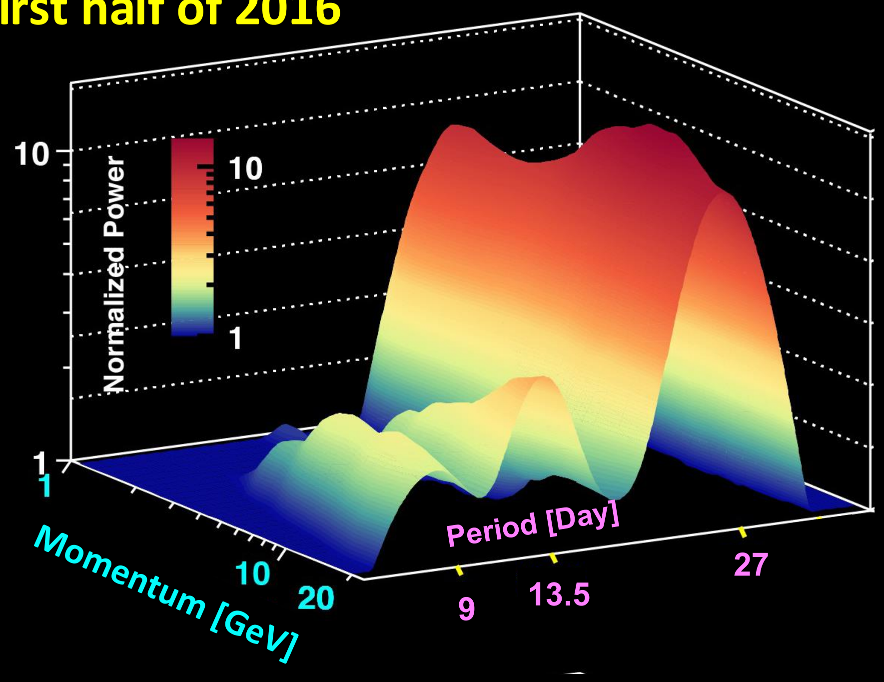
Recurrent Daily Proton Flux Variations



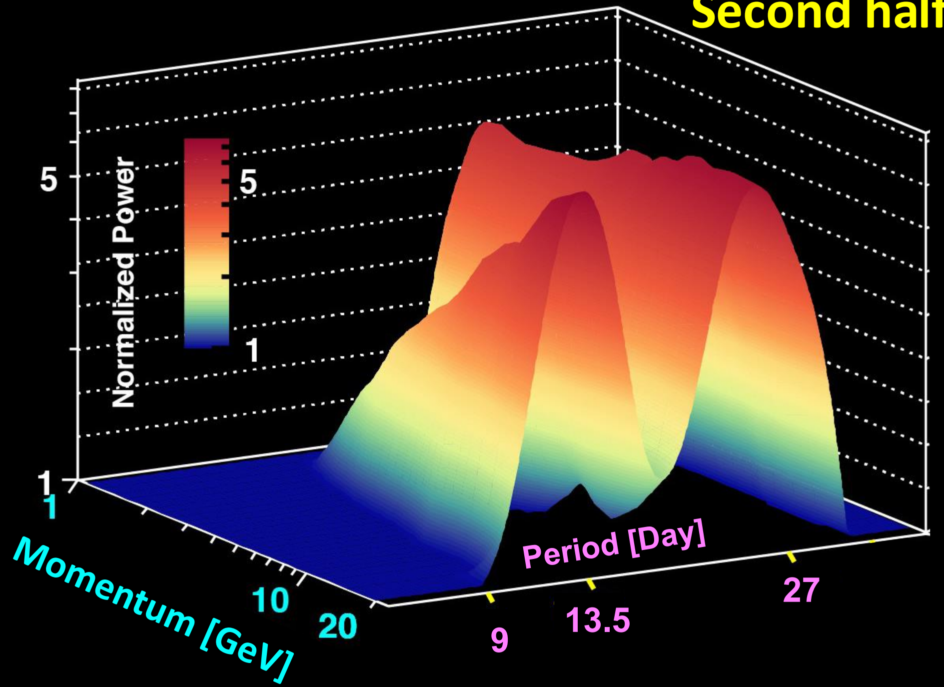
The amplitude depends strongly on rigidity.

Frequency Analysis of daily fluxes

First half of 2016



Second half of 2016

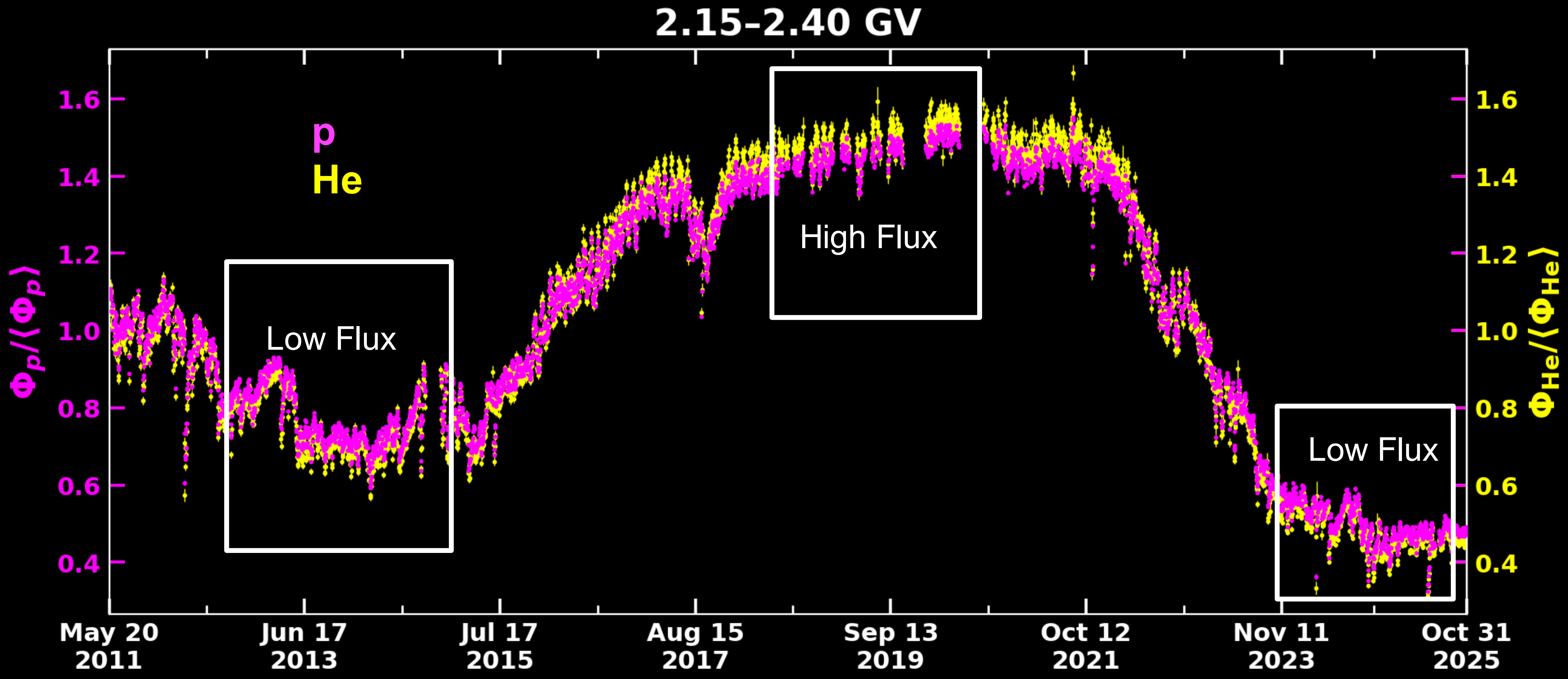


Recurrent variations with periods of 27, 13.5, and 9 days are observed.

The models predict that the strength of the periodicity decreases with increasing rigidity.

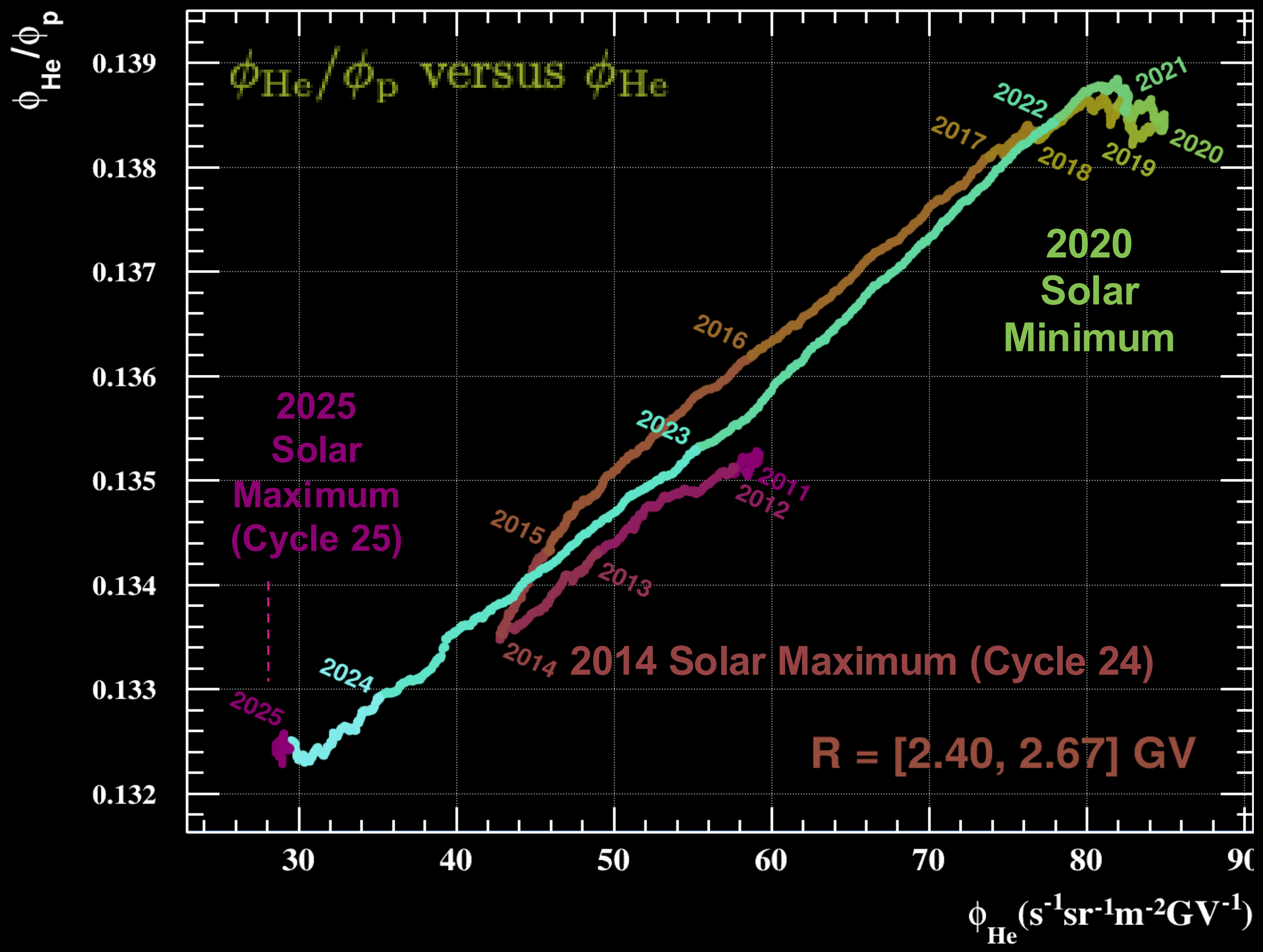
On the contrary, we observed the strength of the 9- and 13.5-day periodicity increases with increasing rigidity.

Difference in p and He Flux Long Term Modulation



Below ~ 7GV the helium flux exhibits larger time variations than the proton flux.

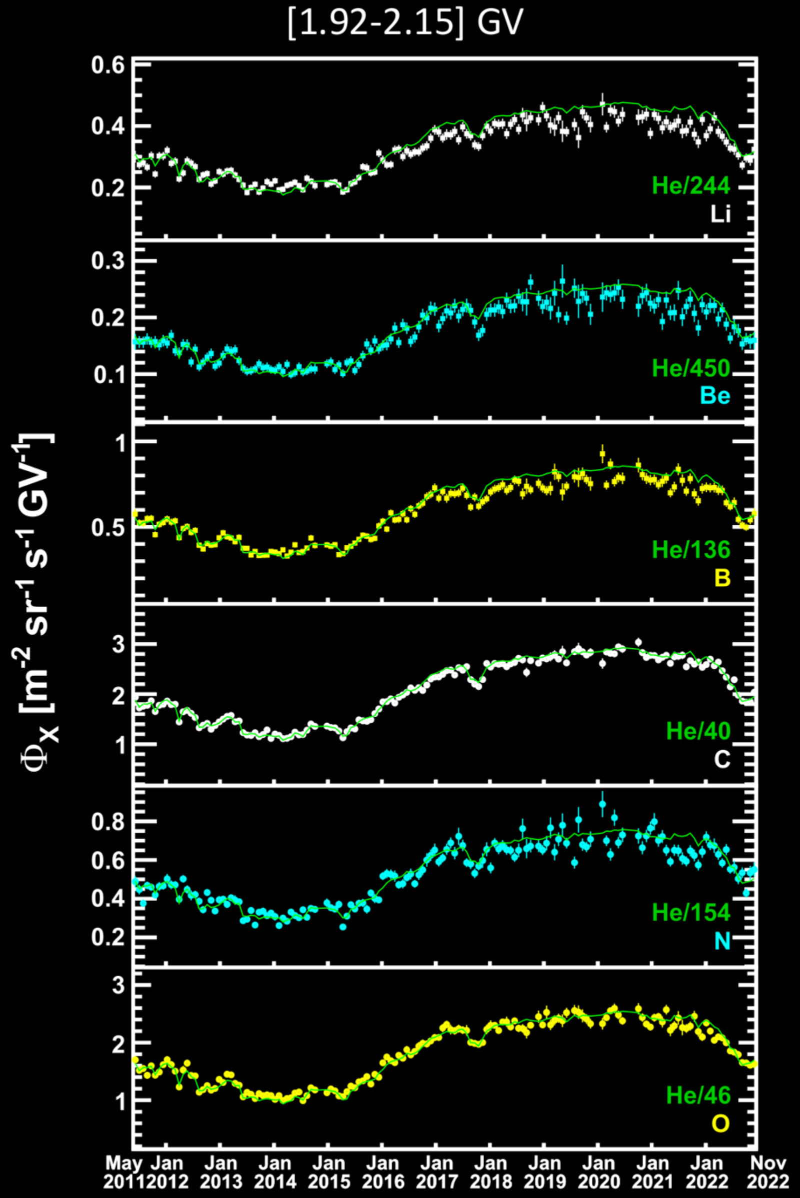
He/p Flux Ratio vs. He Flux Hysteresis



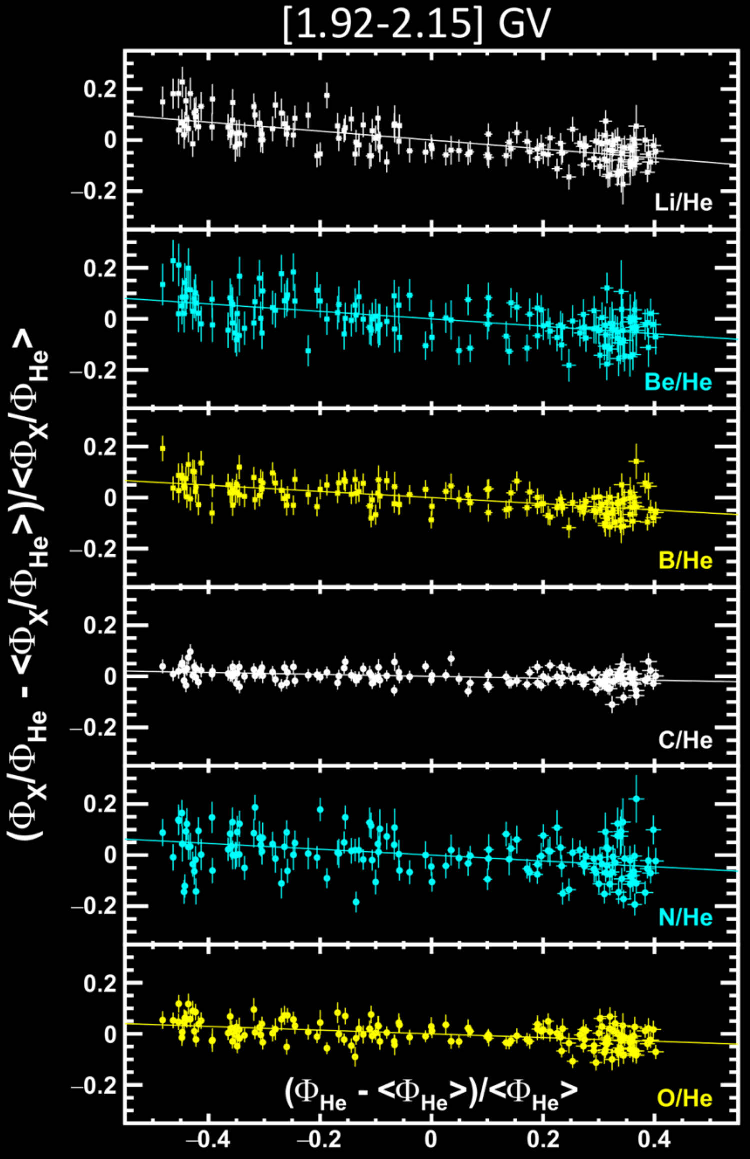
Between 2012 and 2015 an hysteresis is observed with a significance greater than 7σ with combined rigidity bins below 2.4 GV and two time intervals.

The Hysteresis follows different paths through the ascending phases of solar max. 2014 and 2025

Light Nuclei AMS measurement Time Variation



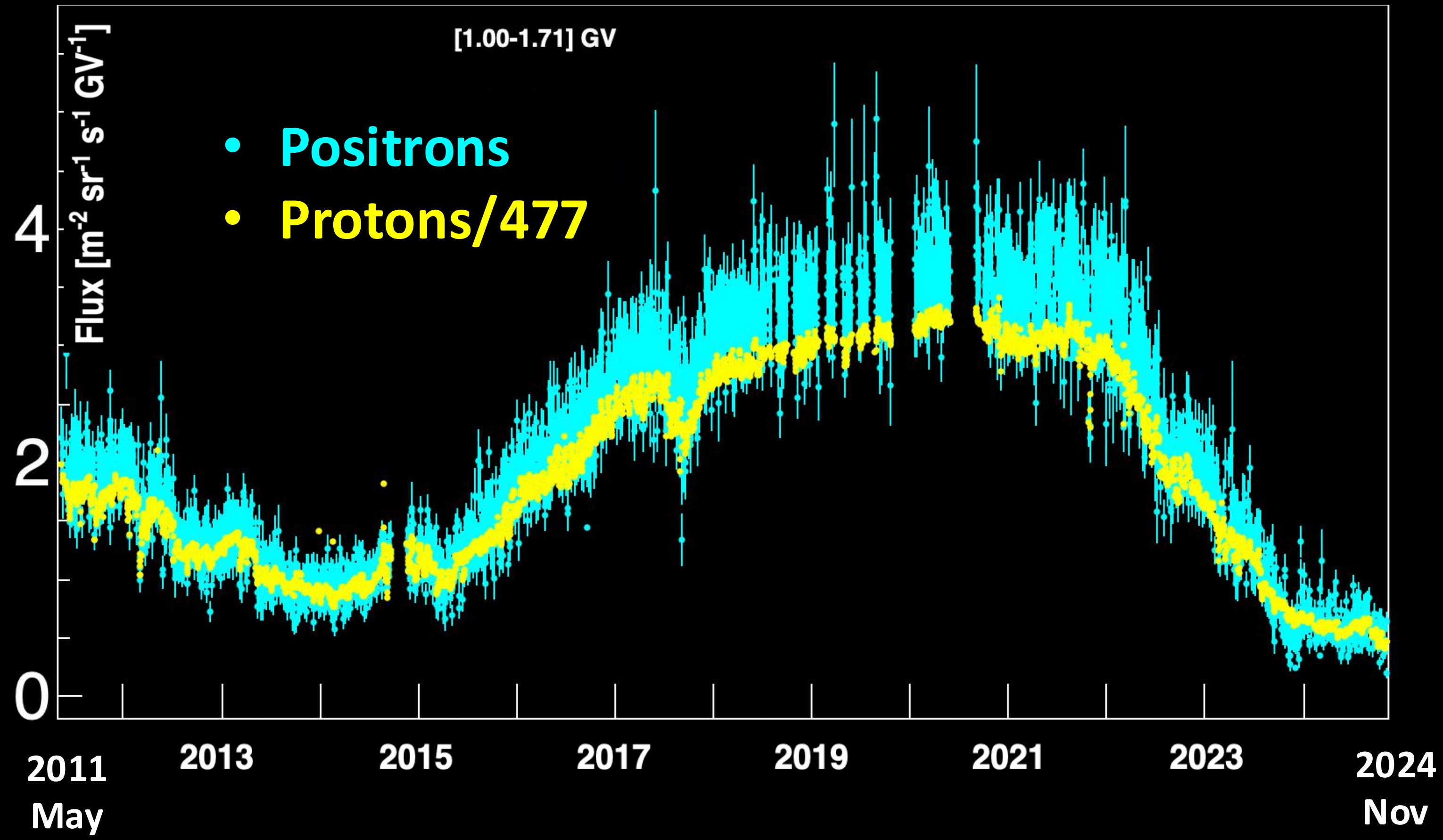
Helium
Lithium
Beryllium
Boron
Carbon
Nitrogen
Oxygen

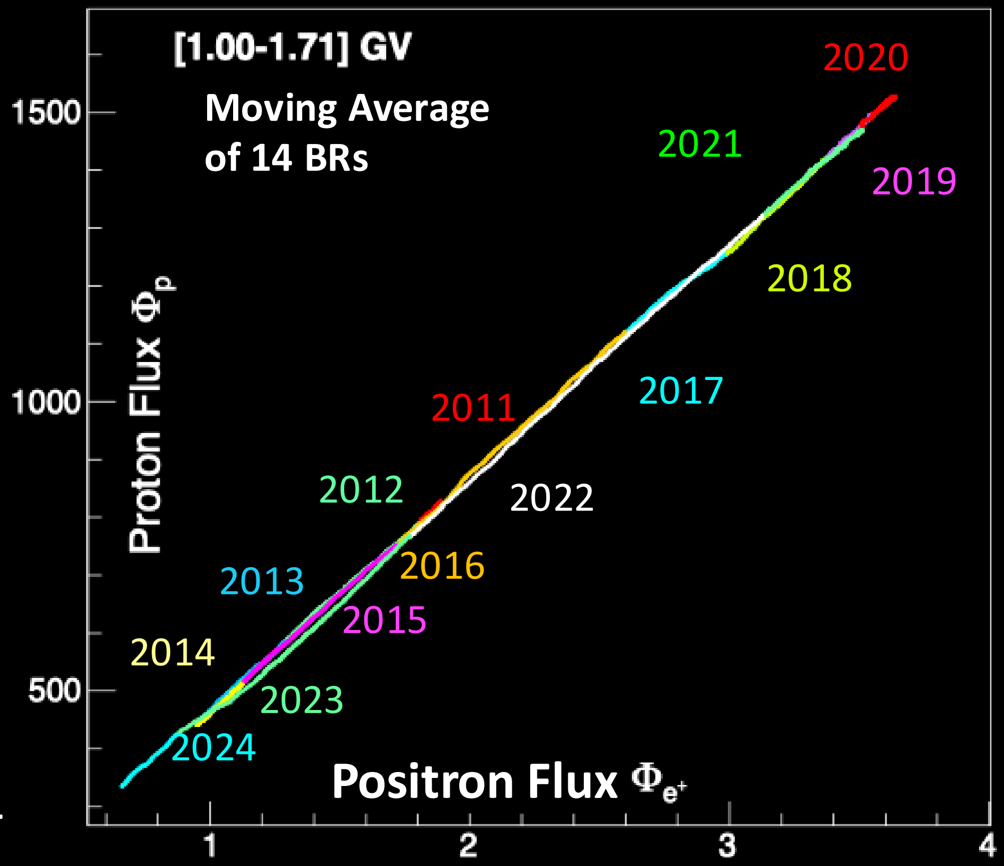


Li/He
Be/He
B/He
C/He
N/He
O/He

Li, Be, B are less modulated then He up to 3.6 GV
C, N, O are less modulated then He up to 2.15 GV

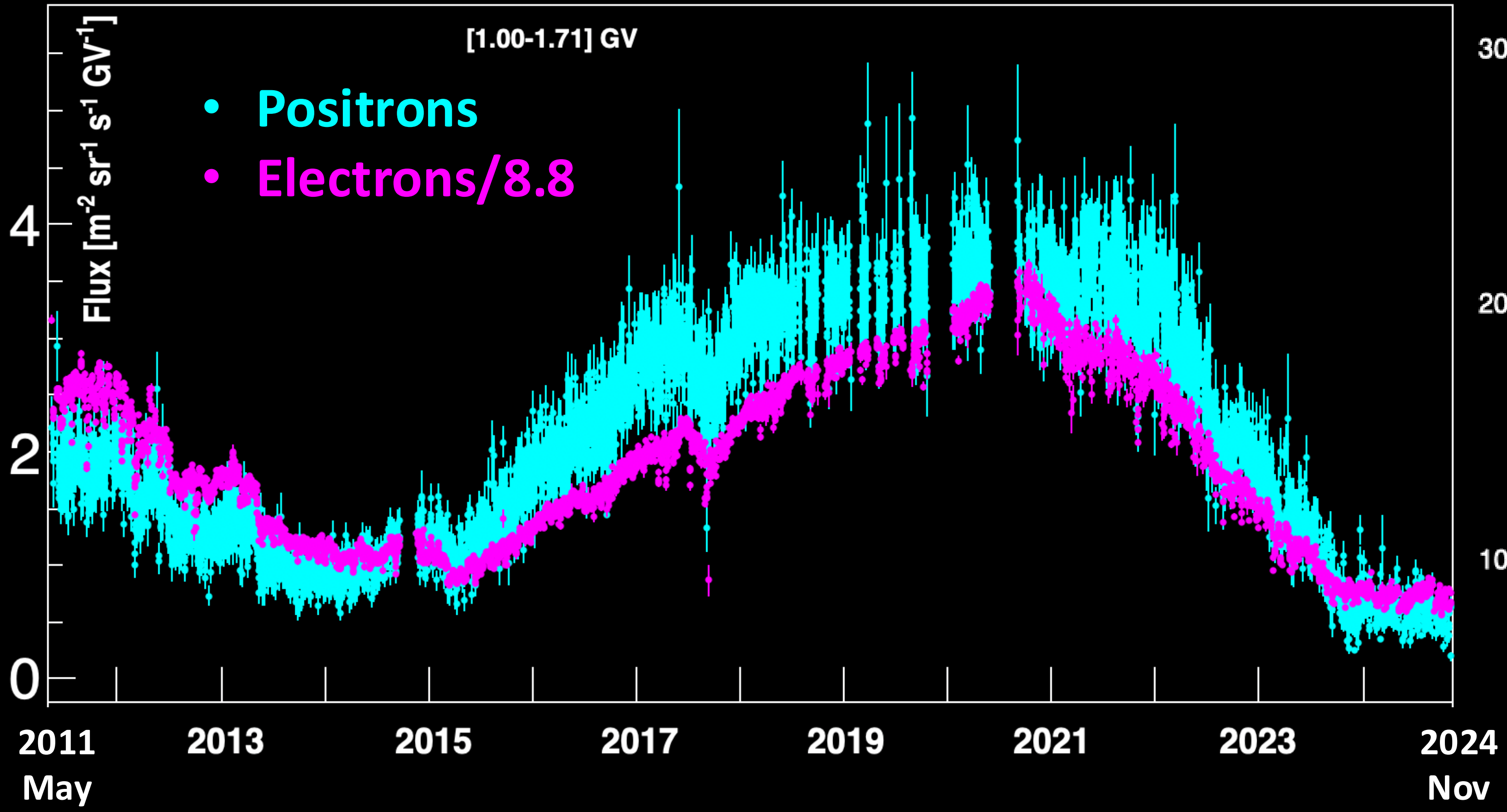
Relationship between Positrons and Protons

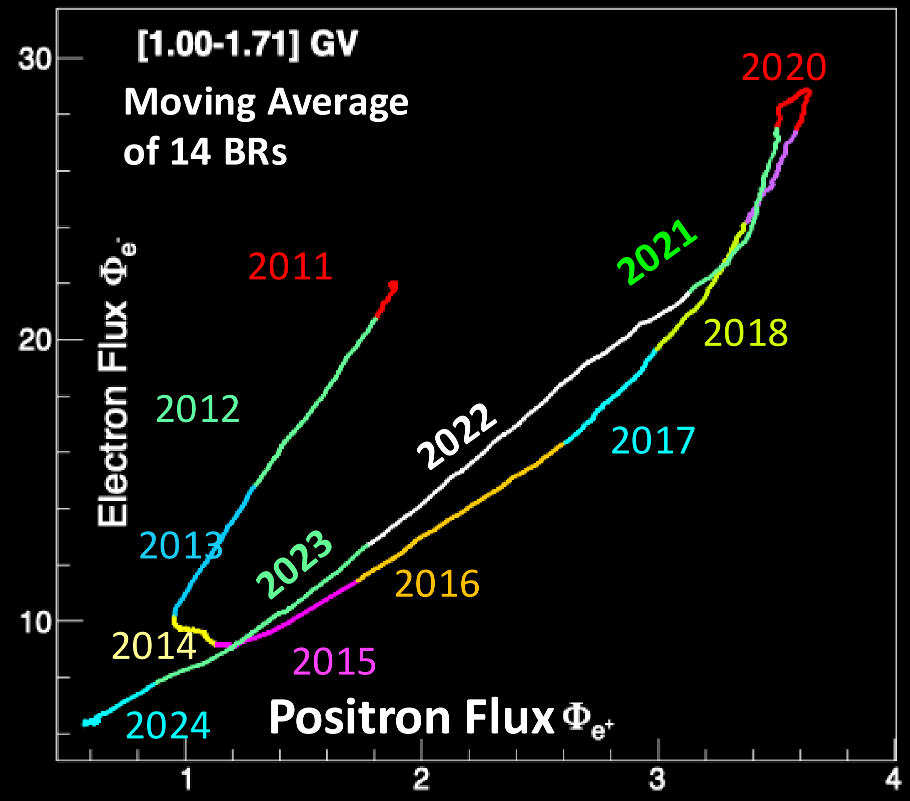




Same charge, different mass: Linear relationship with an offset

Relationship between Positrons and Electrons

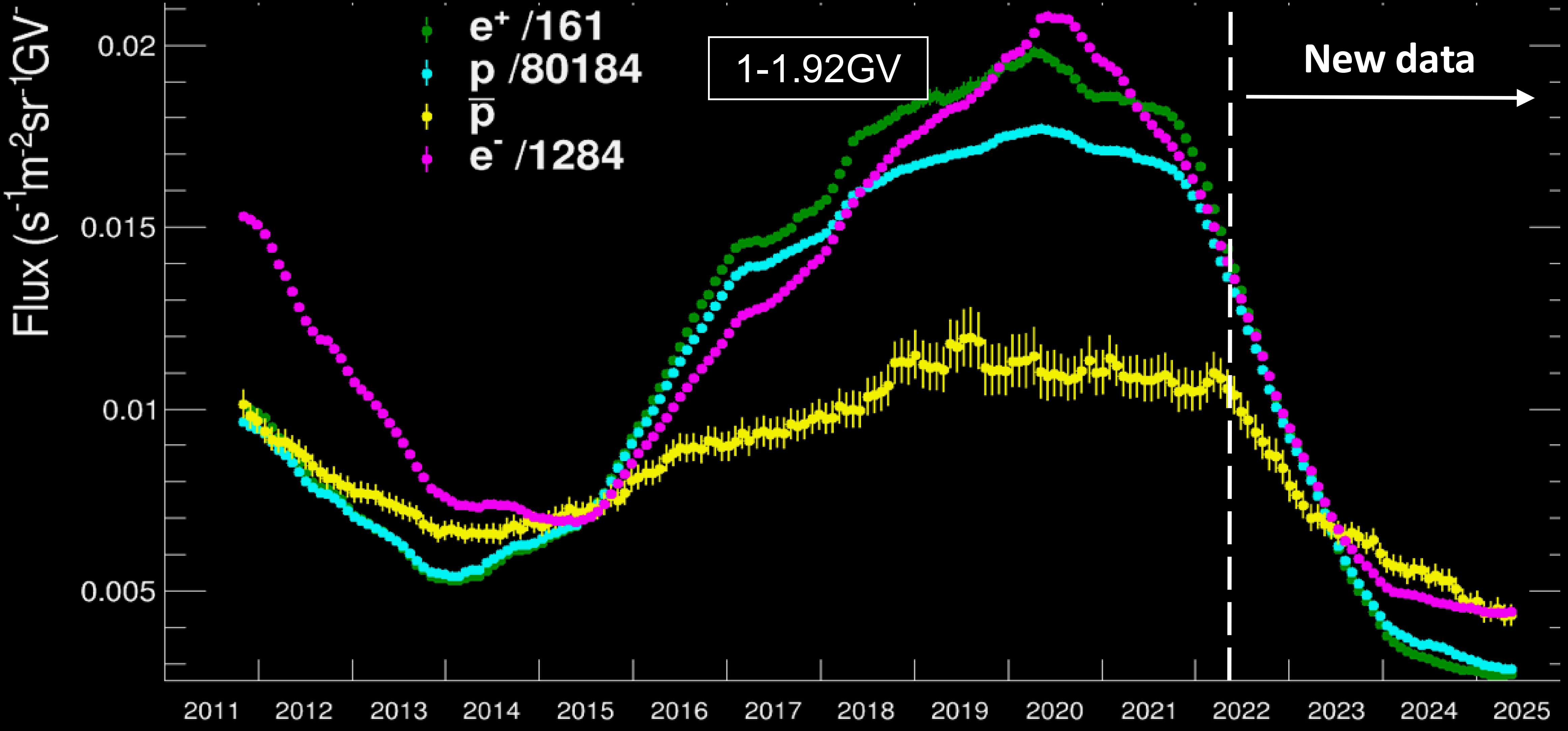




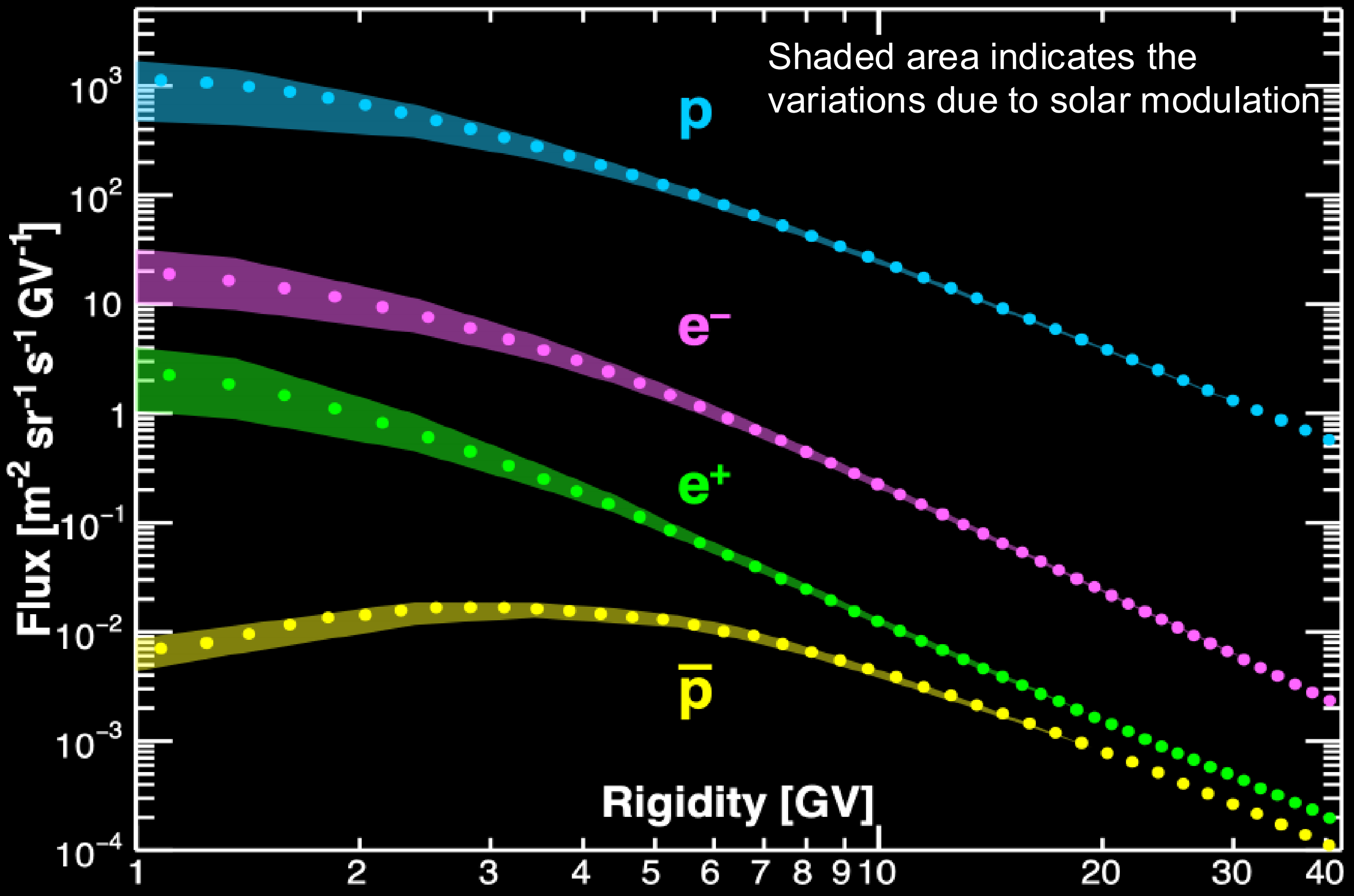
Same mass, opposite charge: Hysteresis behavior

Electron, Positron, Proton and Anti-proton

Antiprotons are less modulated than the other elementary particles.



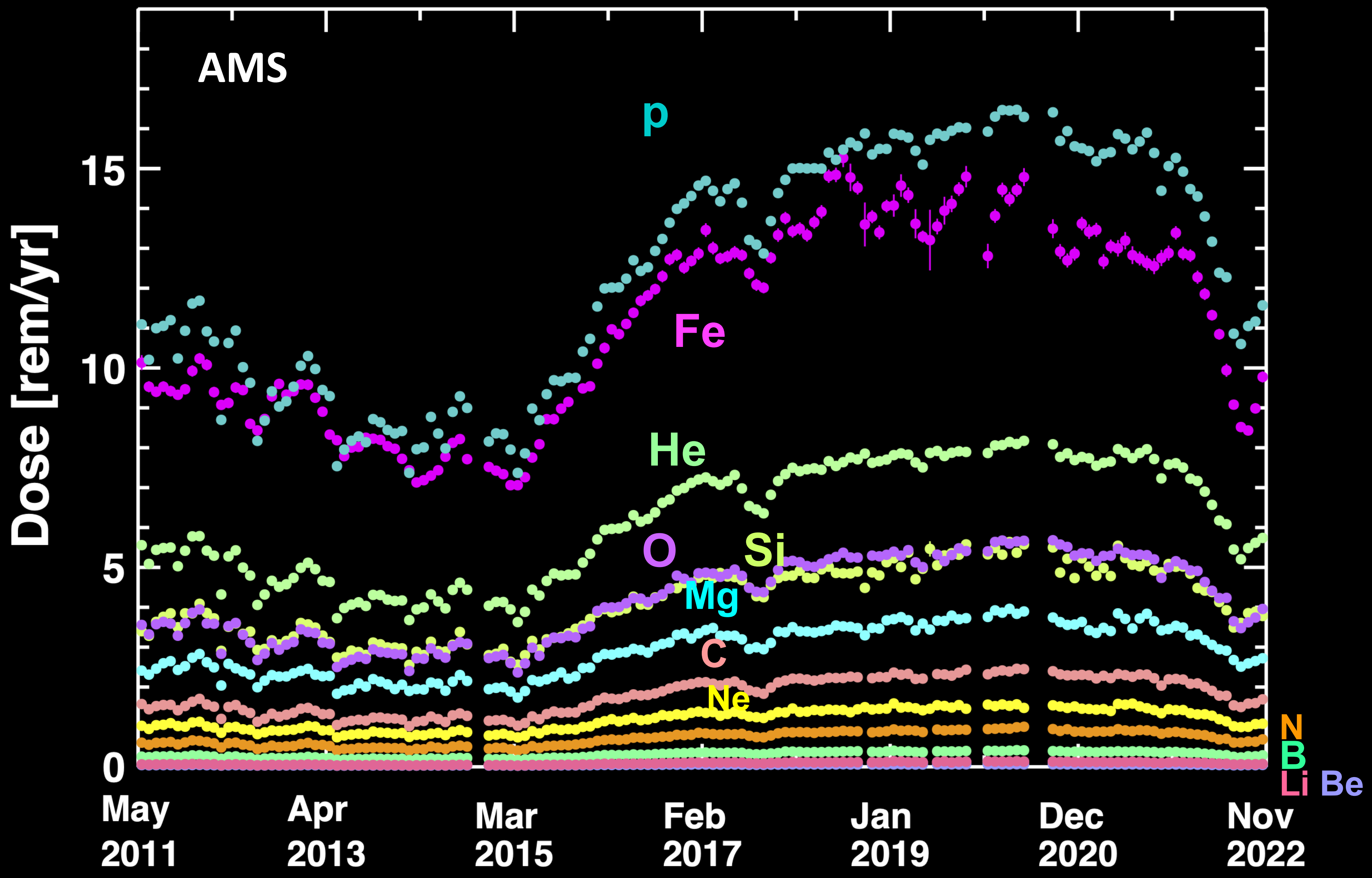
AMS Electron, Positron, Proton and Anti-proton



The different modulation of antiprotons is primarily associated with their different spectral shape, rather than their mass or charge sign.

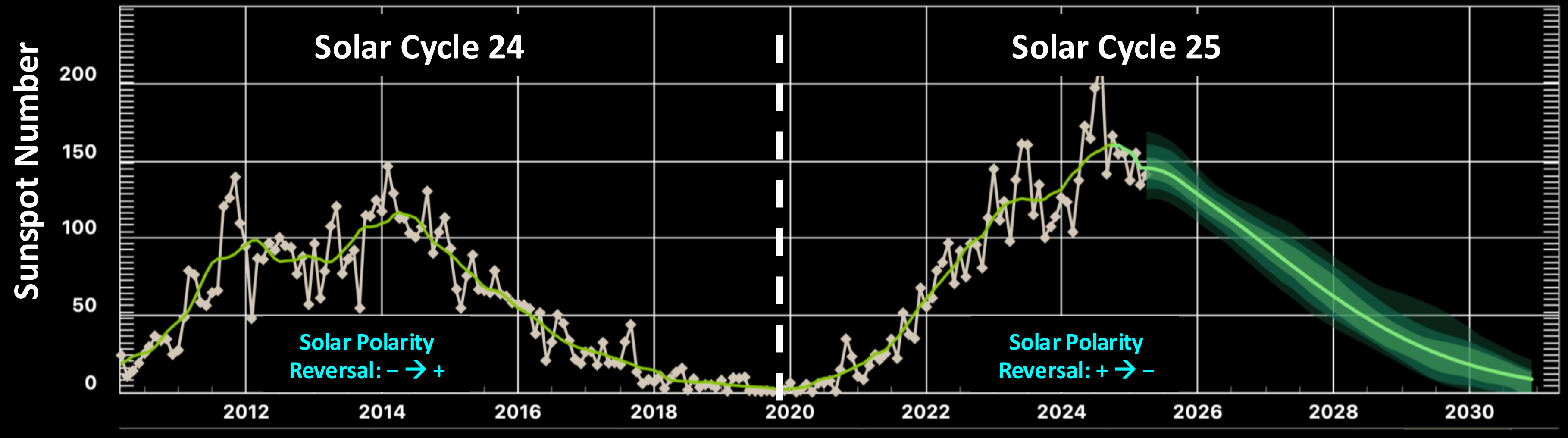
AMS provides long-term radiation information relevant to lunar and Mars missions.
GCR modulation and high-energy solar particle events are important for mission planning.

Radiation environment at low-Earth orbit.
Example: Skin Dose from Different Nuclei over a Solar Cycle



Summary

- ✓ AMS provides precision measurements of cosmic-ray temporal variations from hourly to solar-cycle timescales.
- ✓ The modulation depends on particle rigidity, mass, and charge sign, providing new constraints on heliospheric transport.
- ✓ Continued operation through the next solar polarity reversal will complete measurements over two consecutive 11-year solar cycles.

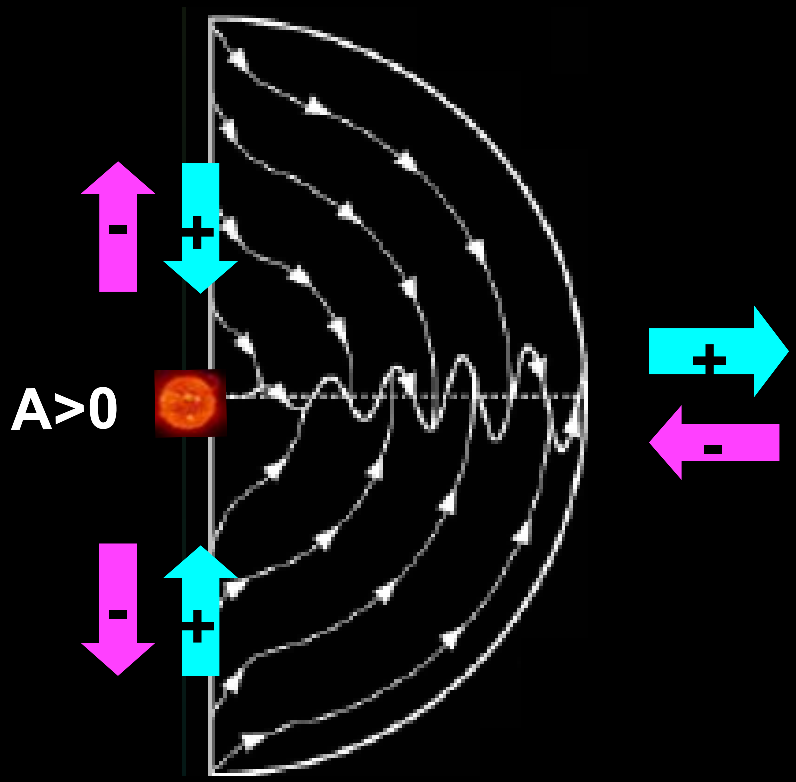


Backup

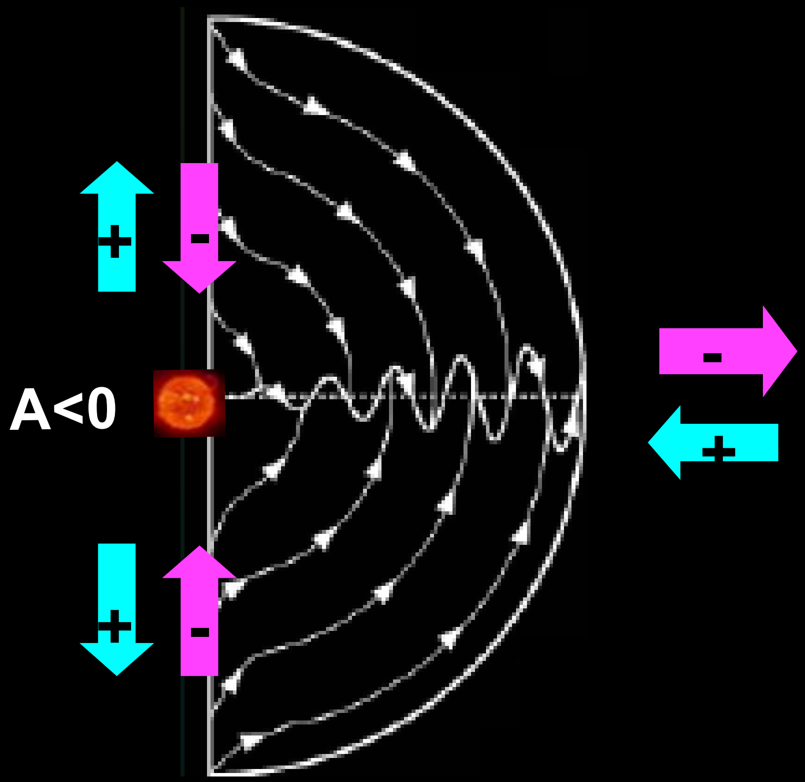
Drift Effect of Opposite Charged Particles

During **positive epochs (A>0)** **negative** charged particles mainly drift in the Heliosphere **from the equator** and **drift out trough the poles.** The opposite is true for **positive** charged particles.

A>0 negative particles are more modulated than positive particles

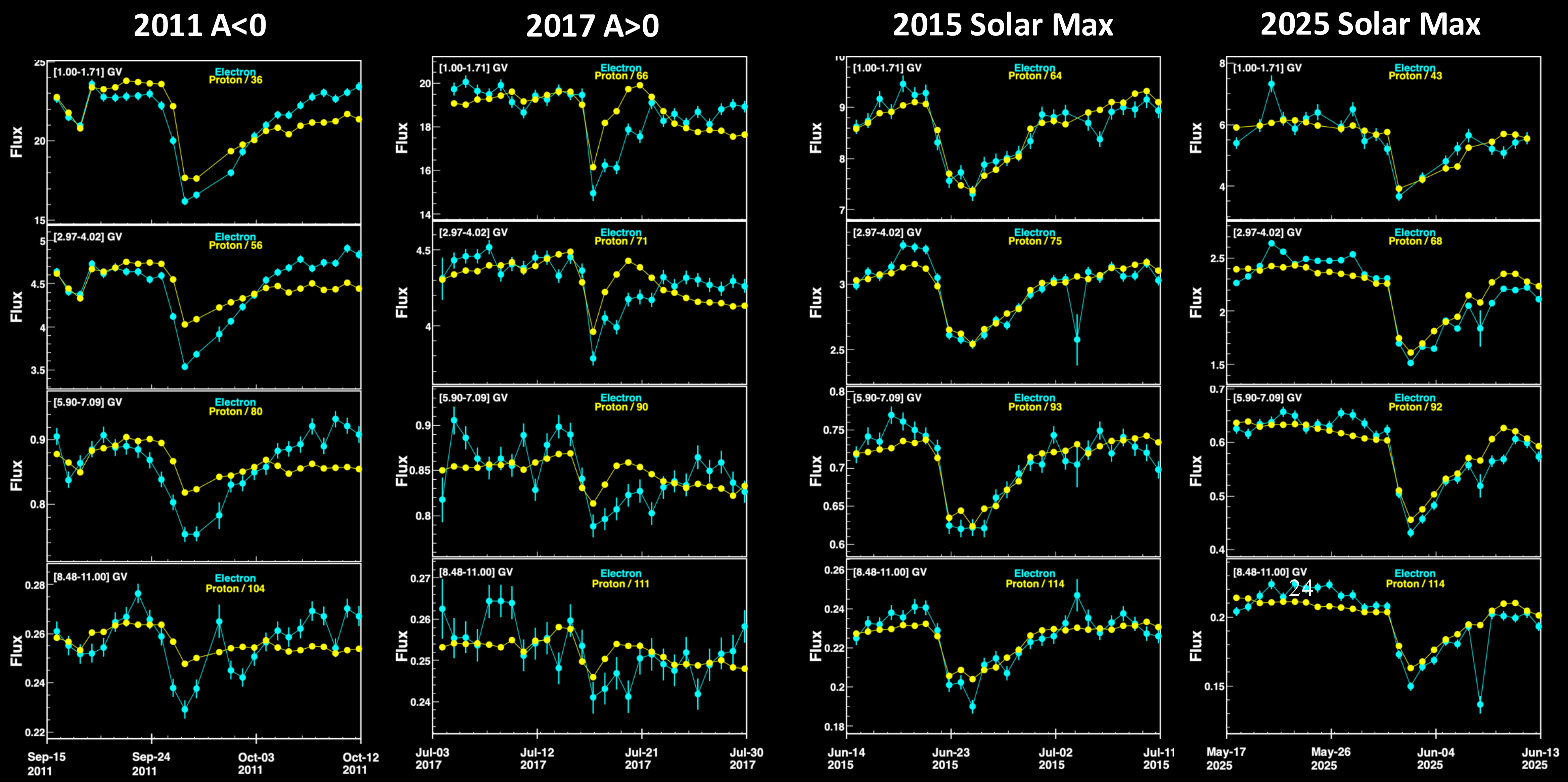


A<0 negative particles are less modulated than positive particles



J.R. Jokipii and B. Thomas 1981 The Astrophysical Journal, 243, 1115

Electron and Proton Forbush Decrease

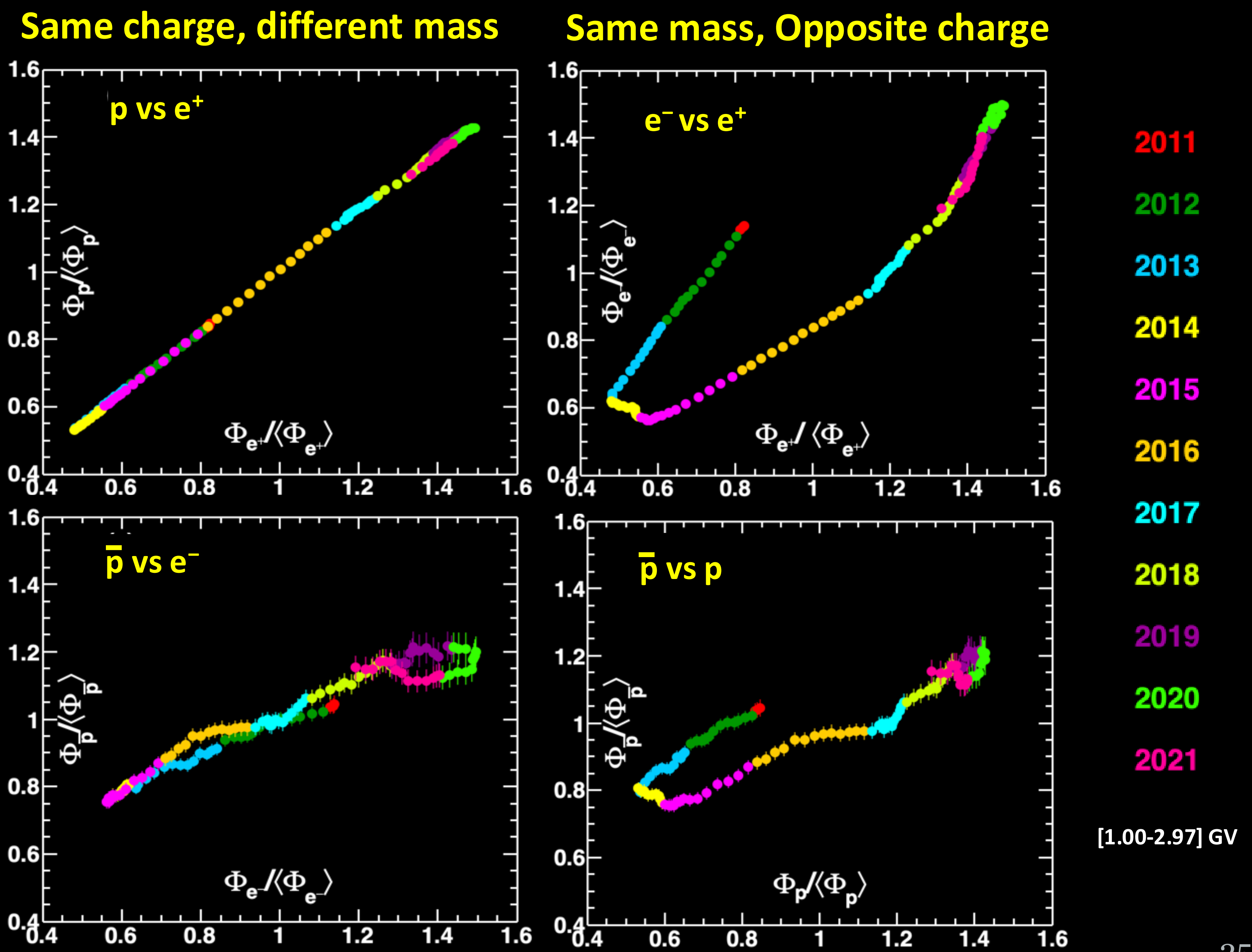


Unexpected Relationship between Elementary Particles

Linear relation between particles with same charge, different mass

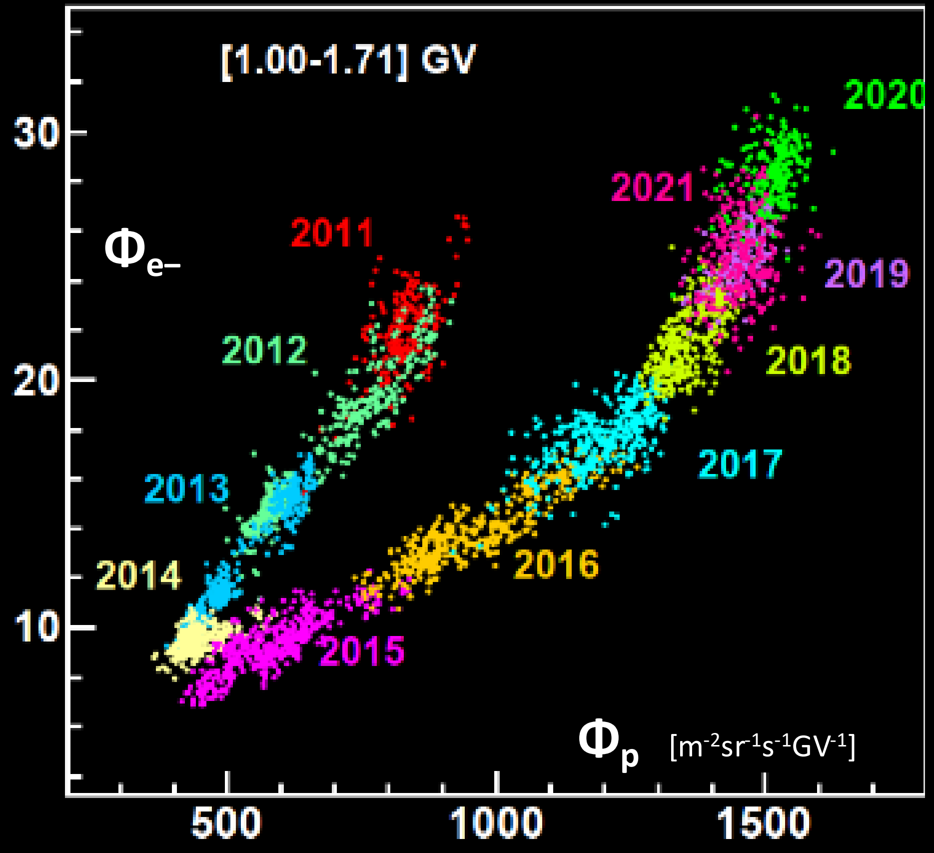
Hysteresis between particles with opposite charge and same mass

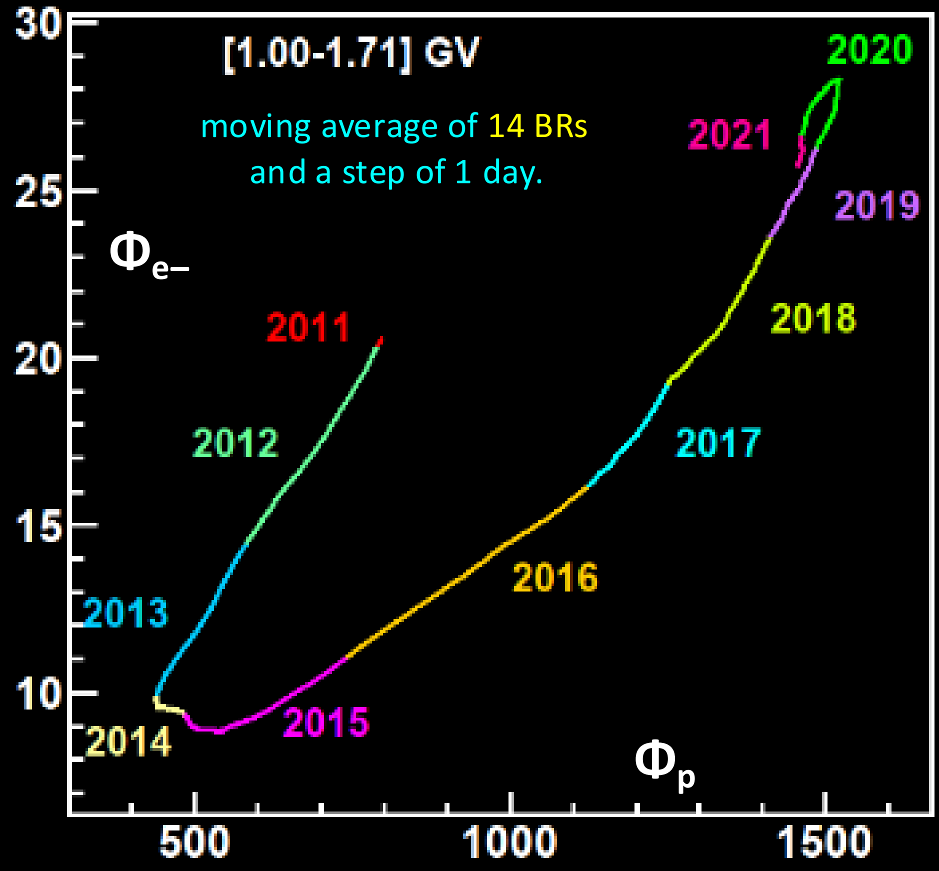
The magnitude of flux variations during the 11 years, are affected by their spectral shape



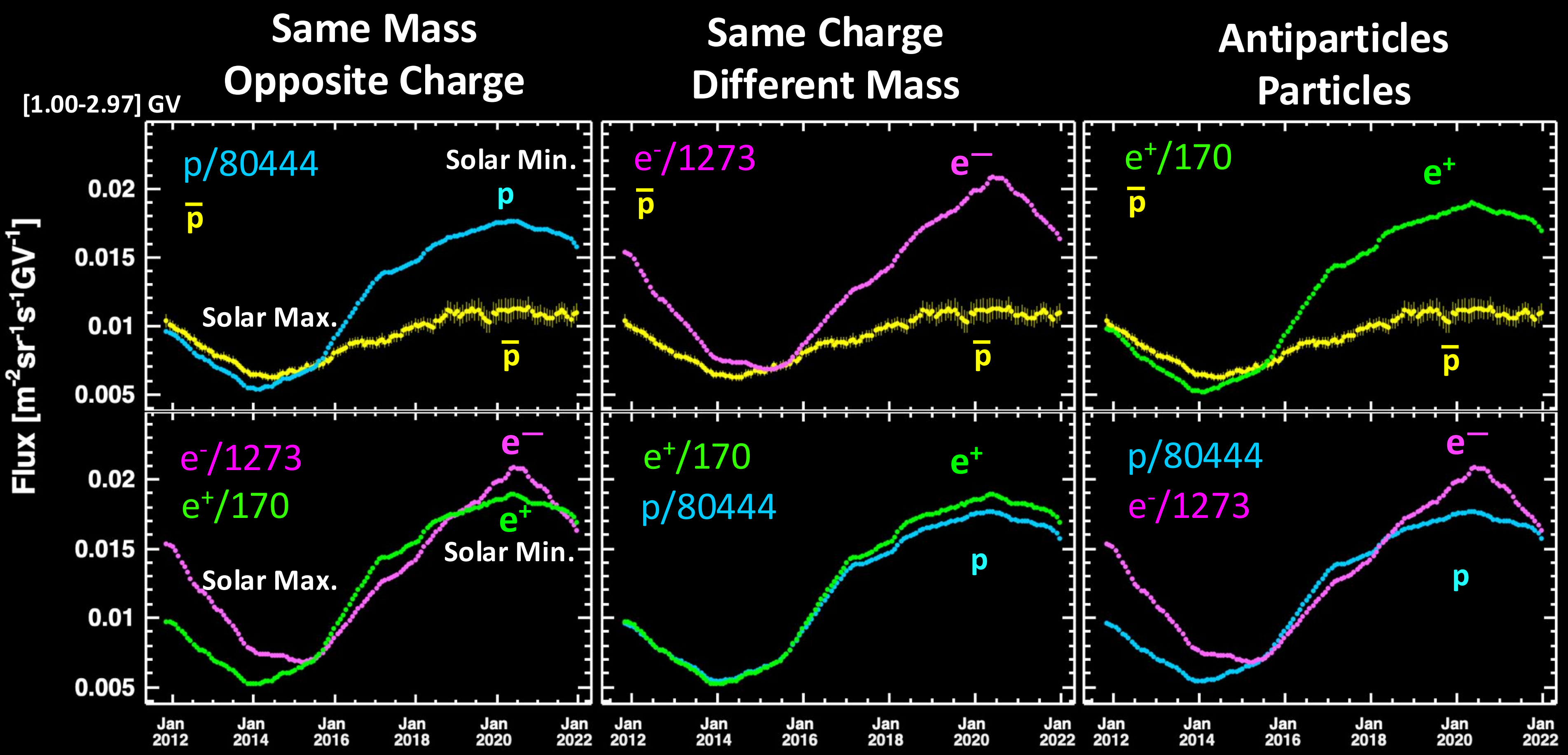
Elementary Particles in the Heliosphere

Observation of a hysteresis between daily electron flux Φ_{e-} and daily proton flux Φ_p





Elementary Particles (e+, e-, p, $\bar{p}$) in Interplanetary Space over an 11-year Solar Cycle



At the same rigidity, particles with different masses and charge signs exhibit distinct temporal variations.

Daily Time Variation of Helium and Proton in a 27-day period