Precision Measurement of the Monthly Proton and Helium Fluxes in Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station

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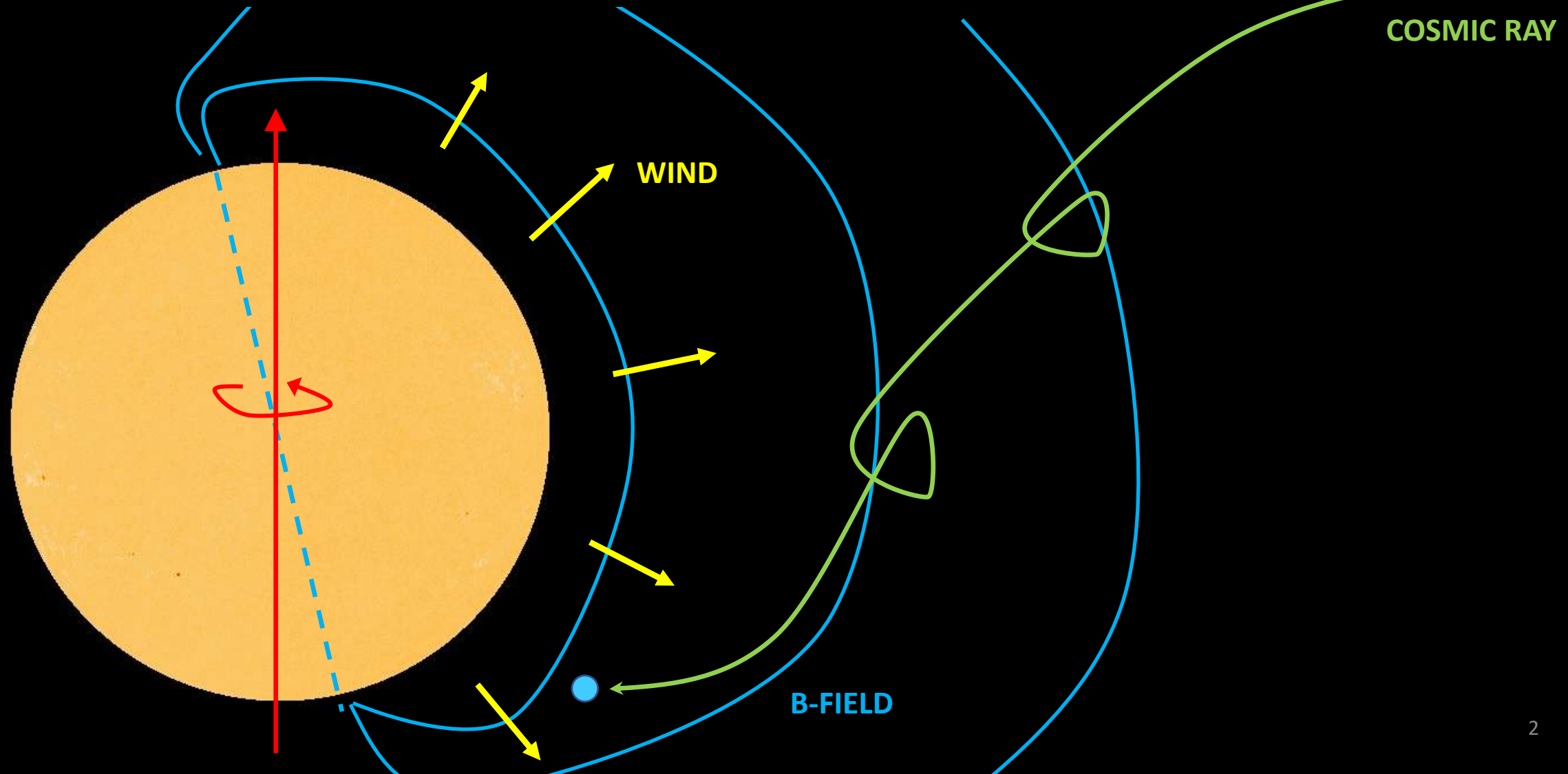
International Cosmic Ray Conference, 36th ICRC – 2019, 24 July – 02 August, Madison, USA

Presented on behalf of the AMS Collaboration
In collaboration with ASI under agreement ASI-UniPG 2019-2-HH.0

Sunspot number and the Solar Cycle

The Sun's activity governs the magnetic flux, plasma wind, and CR radiation in heliosphere creating hazardous space weather



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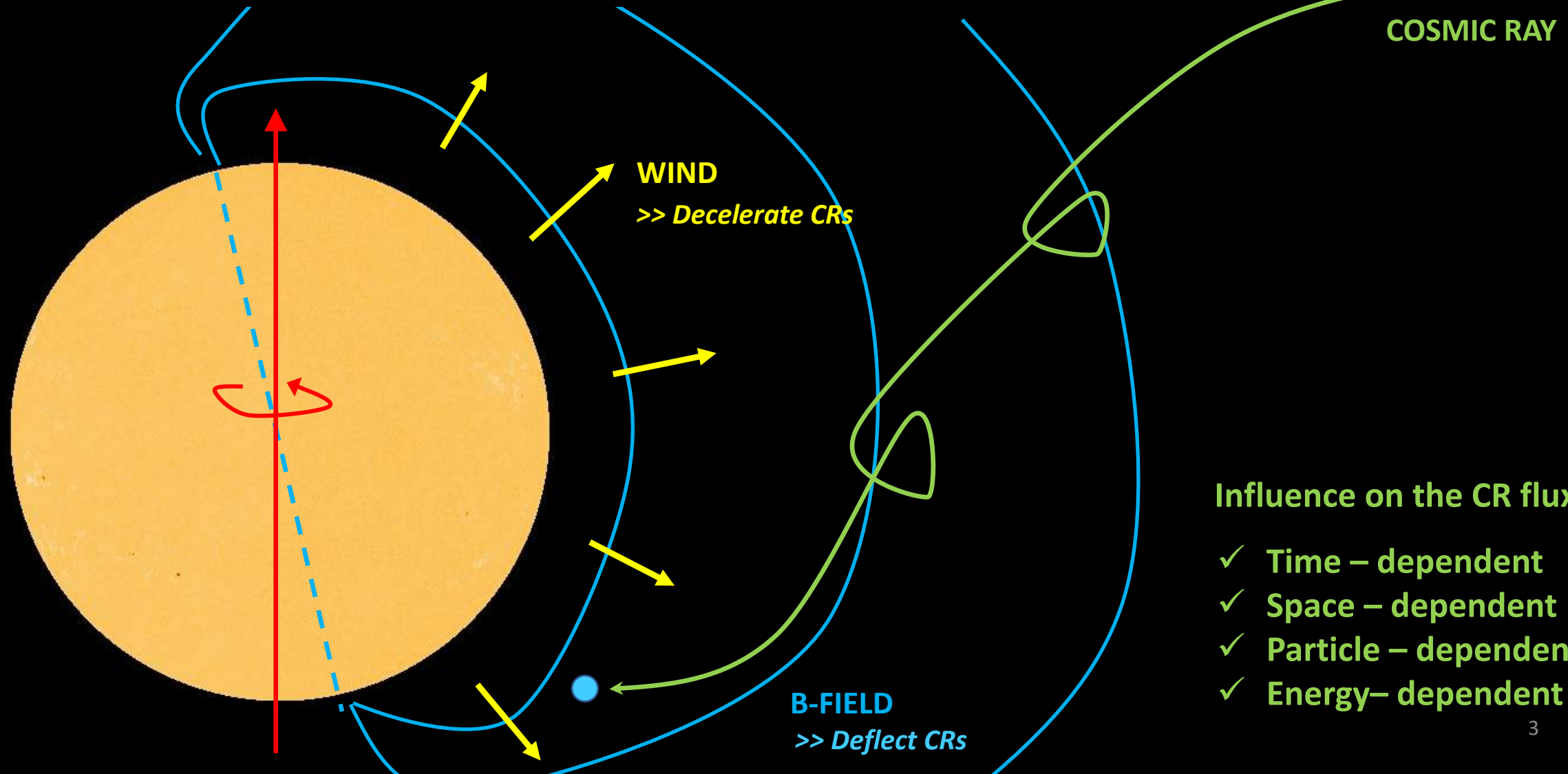
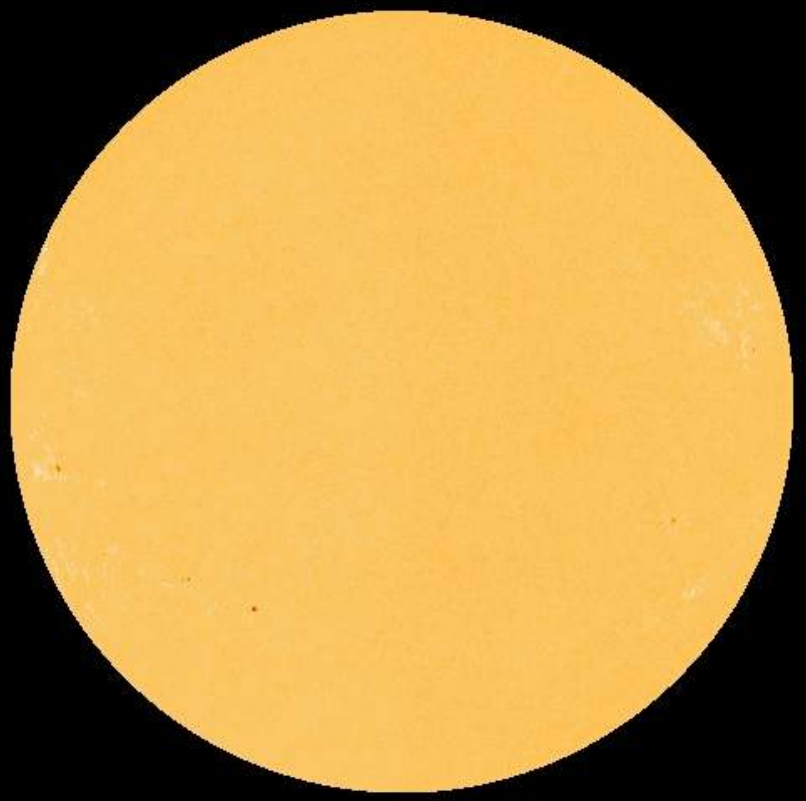


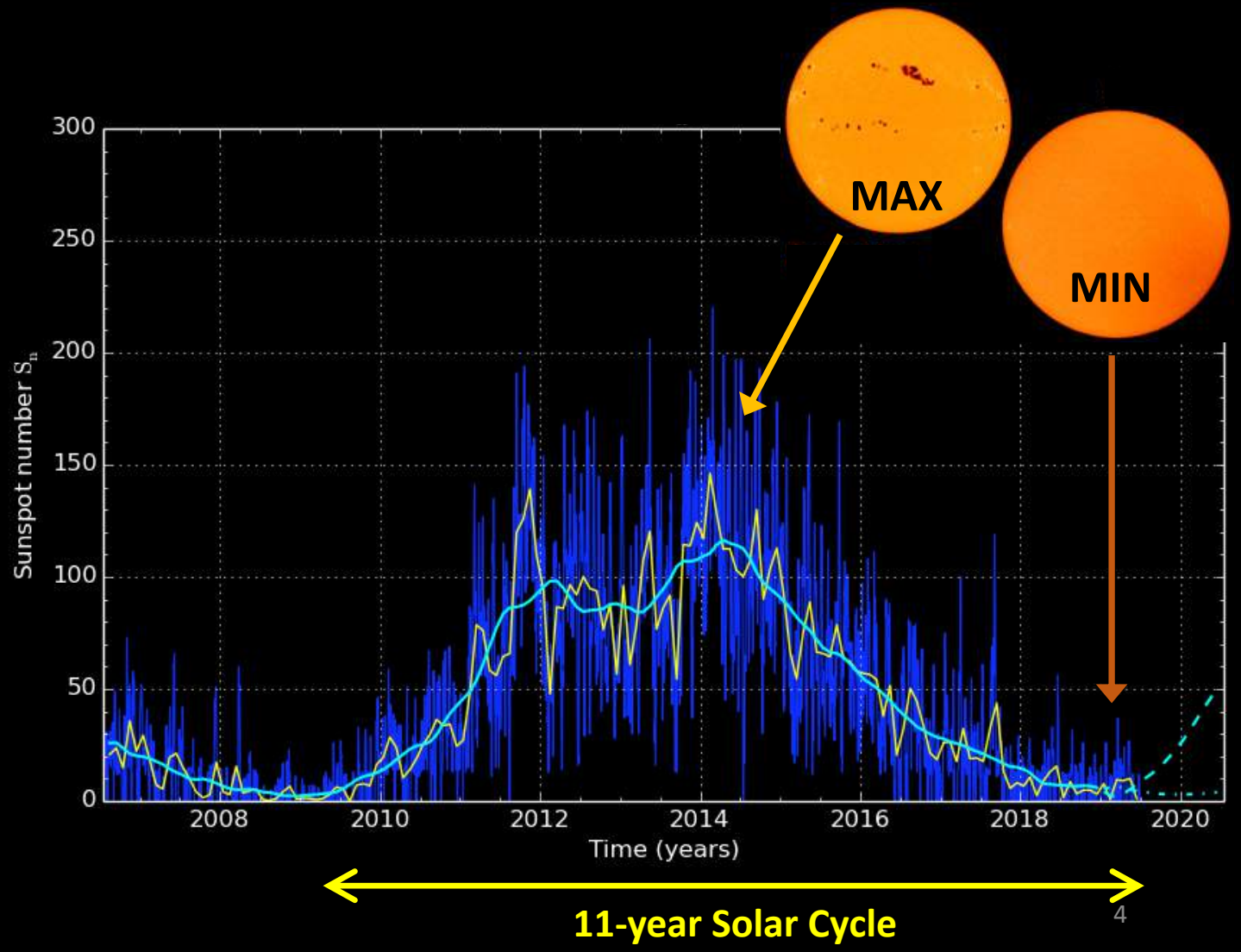
Influence on the CR flux:

- ✓ Time – dependent
- ✓ Space – dependent
- ✓ Particle – dependent
- ✓ Energy– dependent

Sunspot number and the Solar Cycle

The Sun's activity governs the magnetic flux, plasma wind, and CR radiation in heliosphere creating hazardous space weather

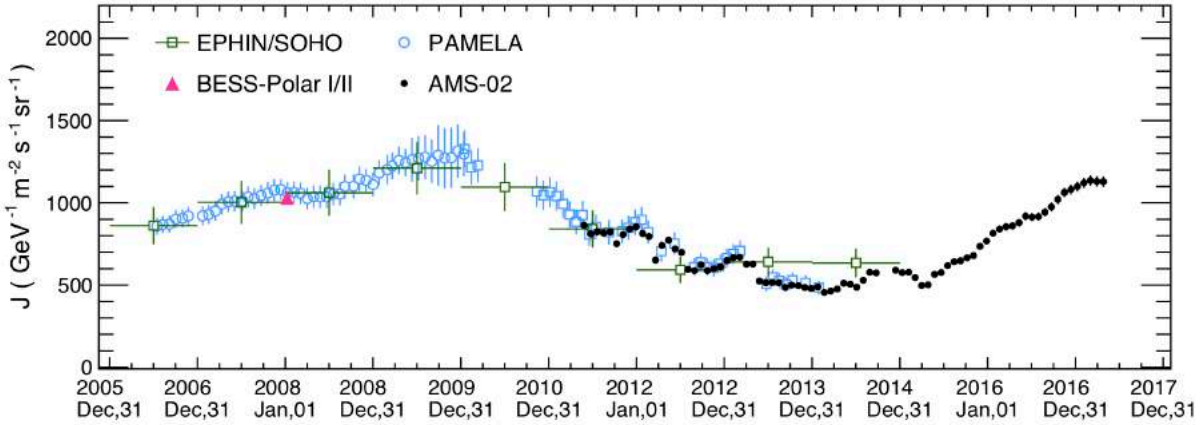


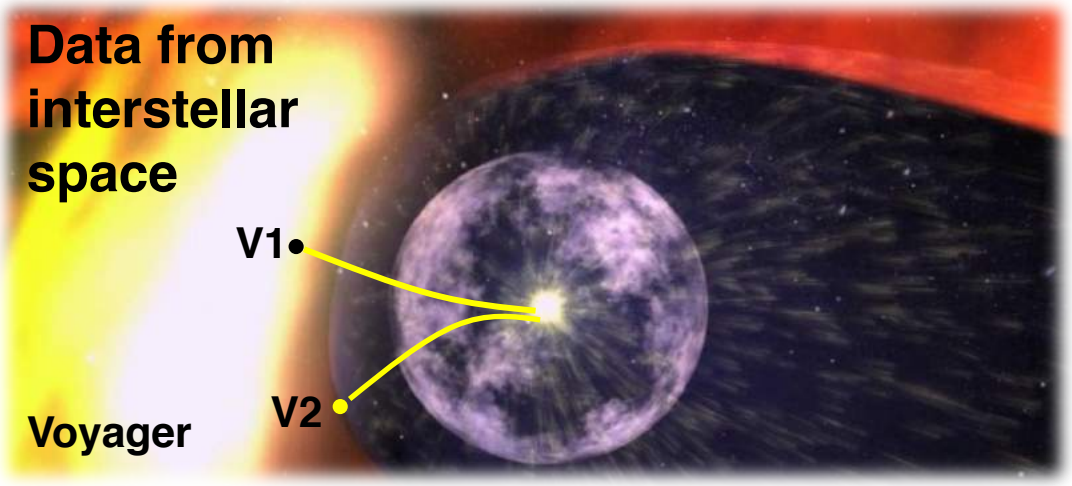


Solar modulation of GCR: a golden age

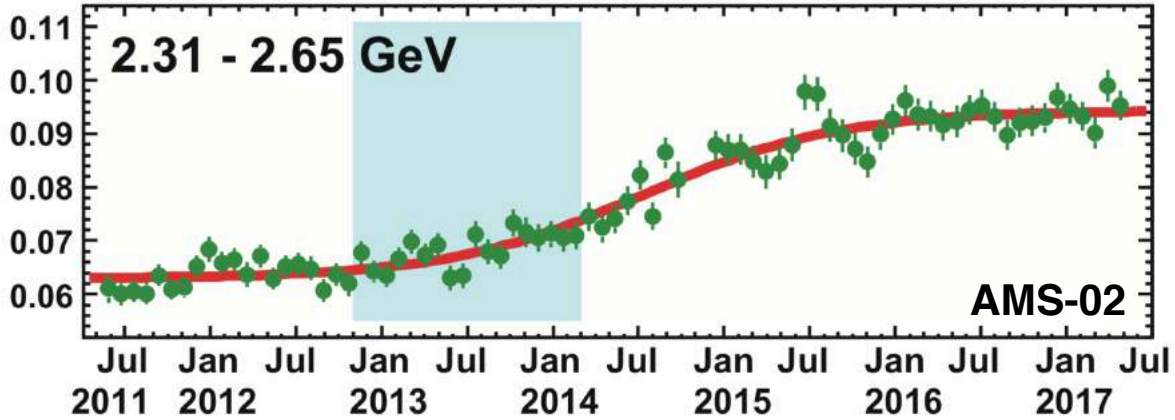
The effect is time-, space-, energy-, and particle-dependent ➔ need for multichannel, time-resolved & E-resolved GCR data

Time-resolved proton data

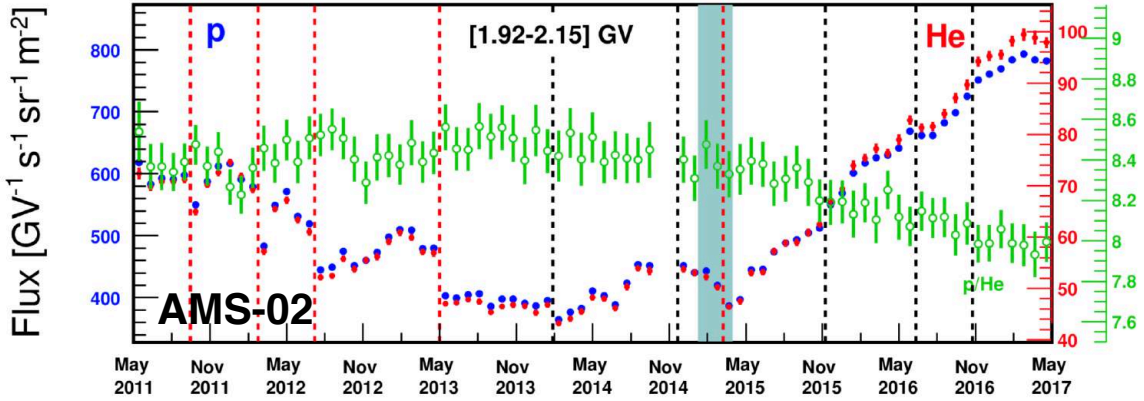




Time dependence of antimatter



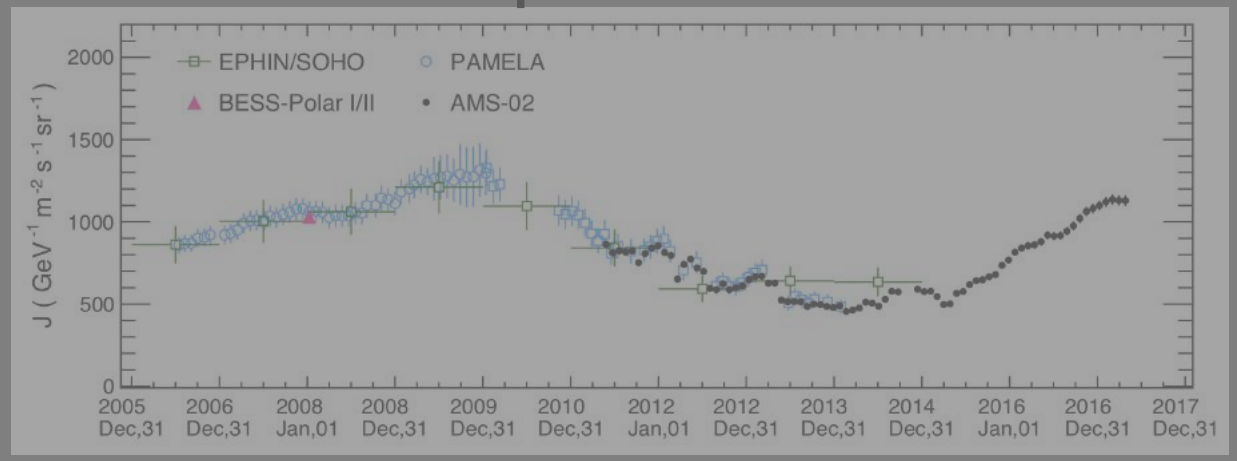
Time dependence of Z>1 CR nuclei

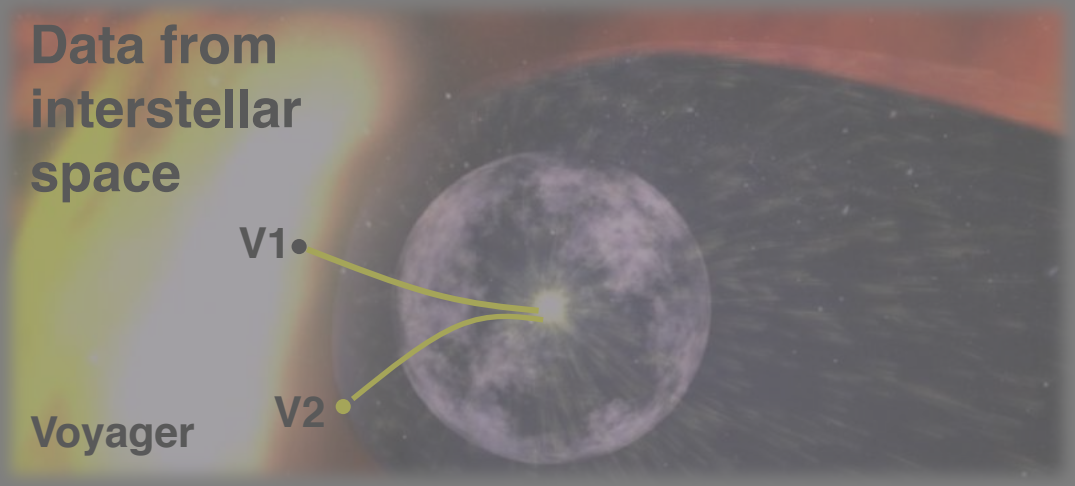


Solar modulation of GCR: a golden age

The effect is time-, space-, energy-, and particle-dependent → need for multichannel, time-resolved & E-resolved GCR data

Time-resolved proton data





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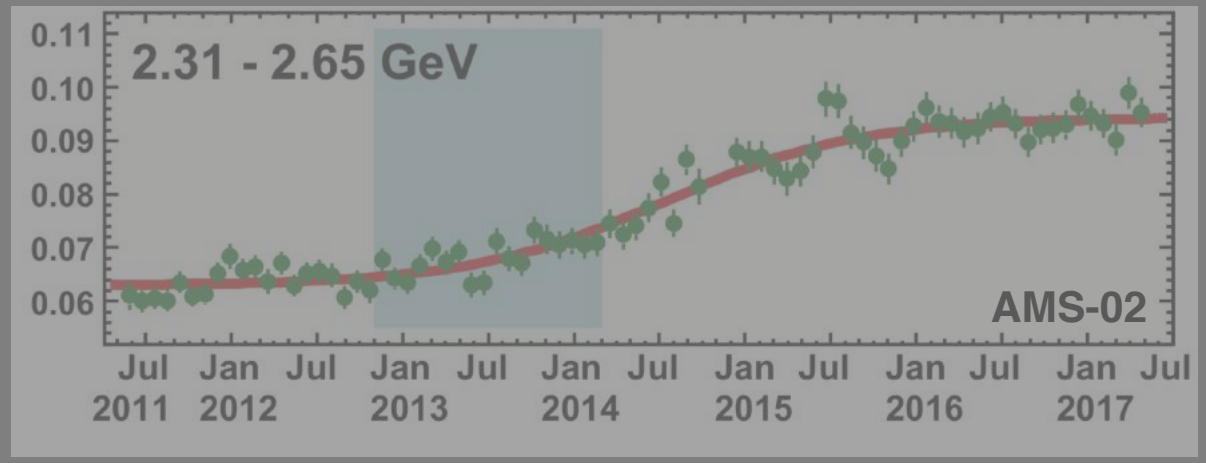
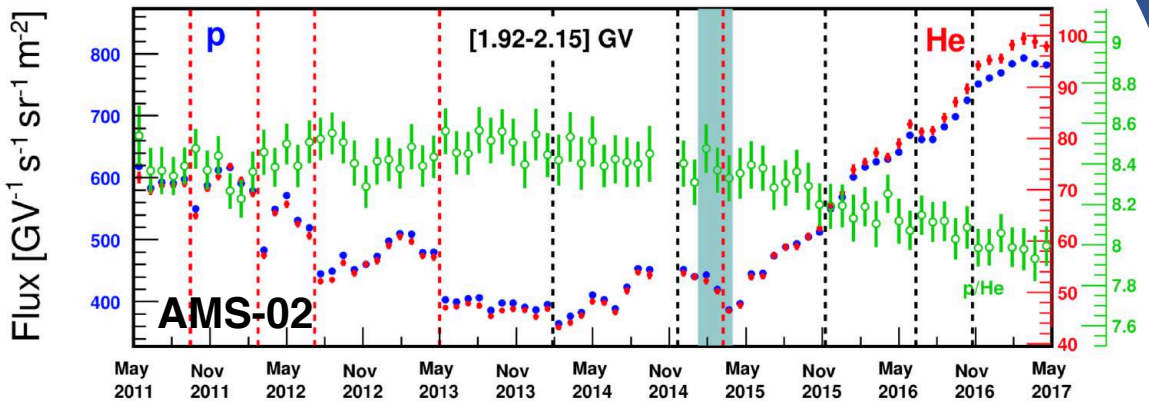


Time dependence of Z>1 CR nuclei



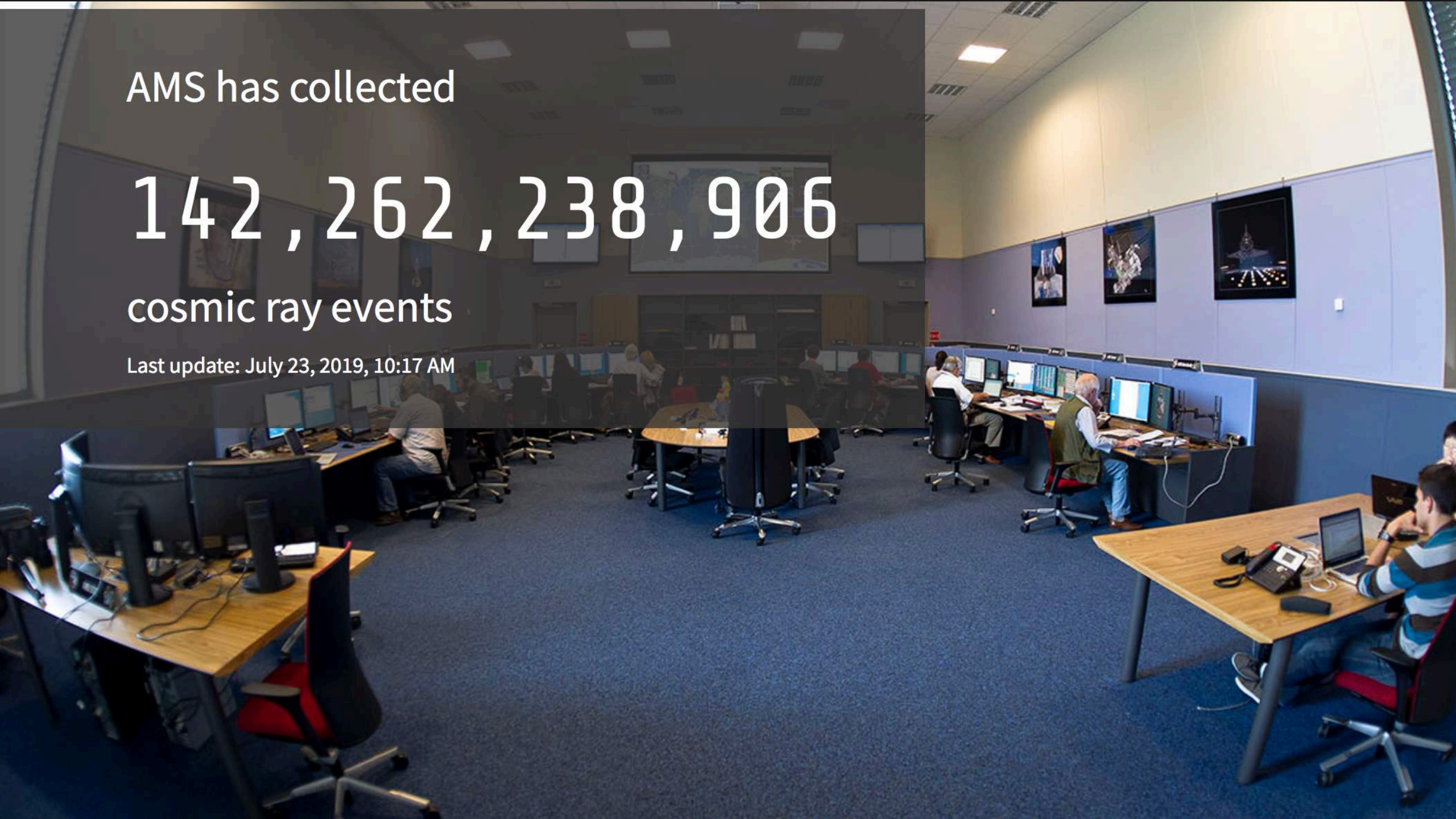
The Alpha Magnetic Spectrometer

- LEO: on the ISS at ~400 km altitude
- Active since May 19th, 2011

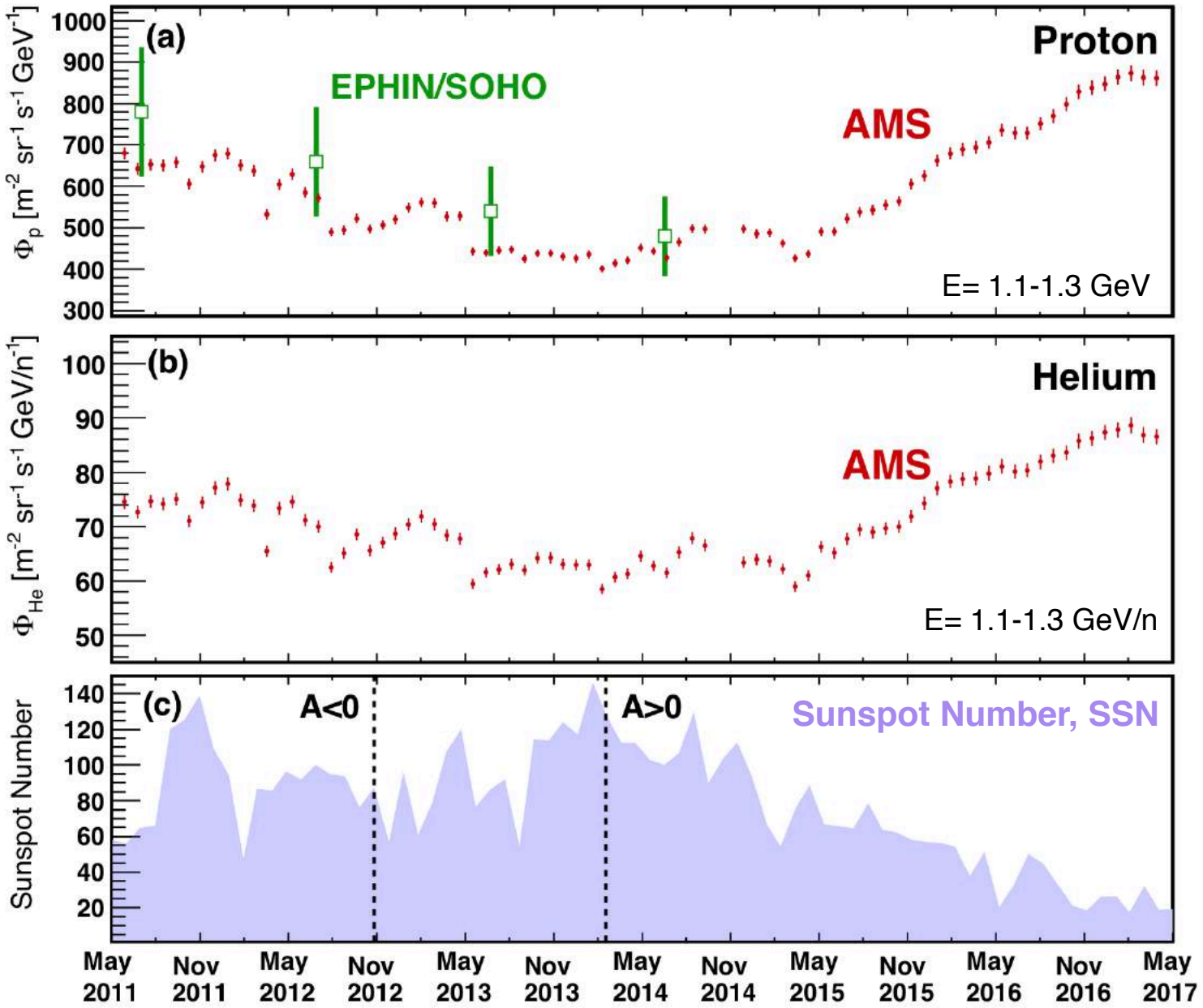
- Continuous operation 7/24
- Average trigger rate ~ 700 Hz
- 141+ giga-particles collected

- High acceptance
- Complete particle ID (mass, charge, sign)
- Redundant energy measurements

- ☑ Particle-resolved
- ☑ Time-resolved
- ☑ Energy-resolved
- ☐ Space resolved


AMS has collected
142,262,238,906
cosmic ray events
Last update: July 23, 2019, 10:17 AM

AMS-02 results: time evolution of the GCR fluxes

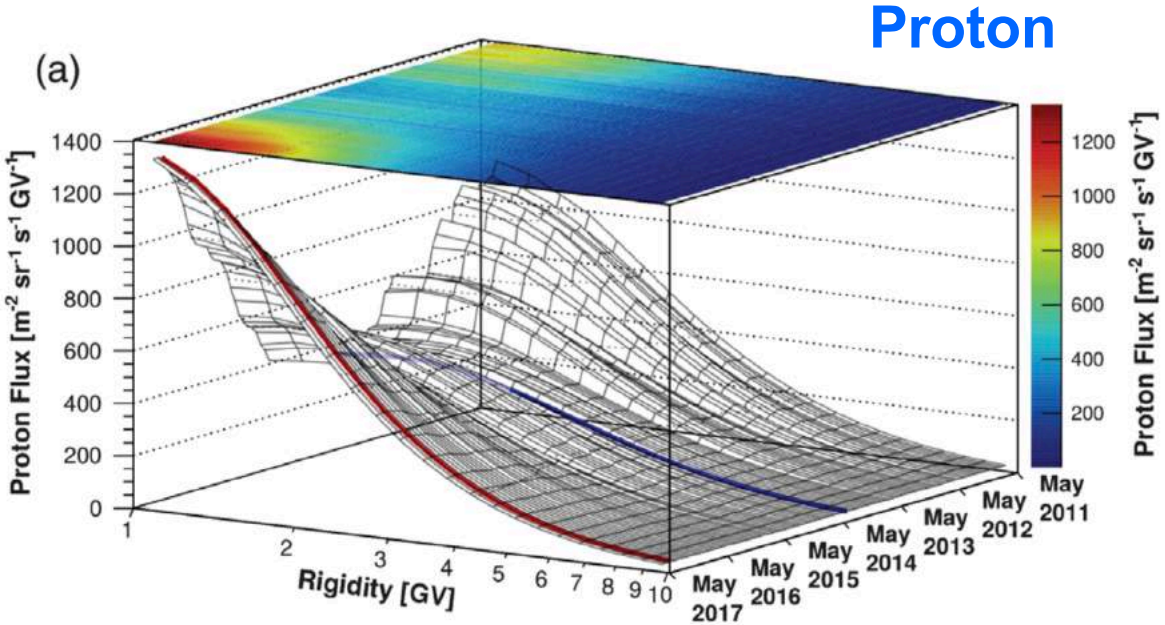


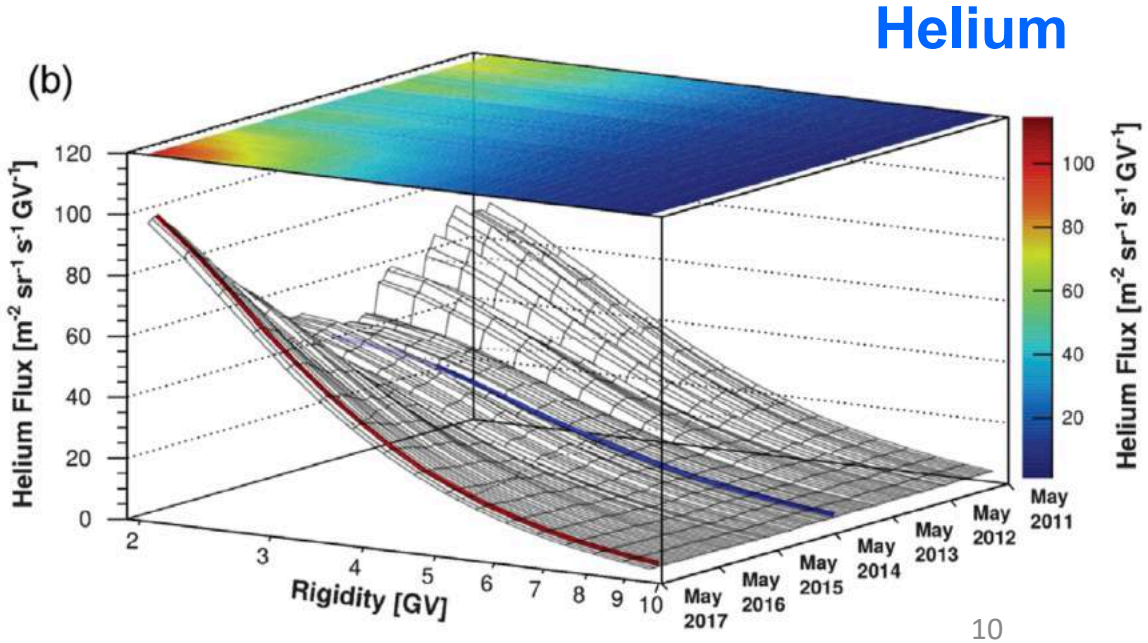
M. Aguilar et al. (AMS-02)
Phys. Rev. Lett. 120 (2018) 051101

Measurements of CR proton and helium fluxes for 79 Bartel Rotations (27-days), at rigidity R from 1 GV to 50 GV.

Flux variation behavior at monthly timescales, apparently correlated with the monthly SSN in the solar corona.

AMS-02 results: time- and rigidity- dependence of the p-He fluxes





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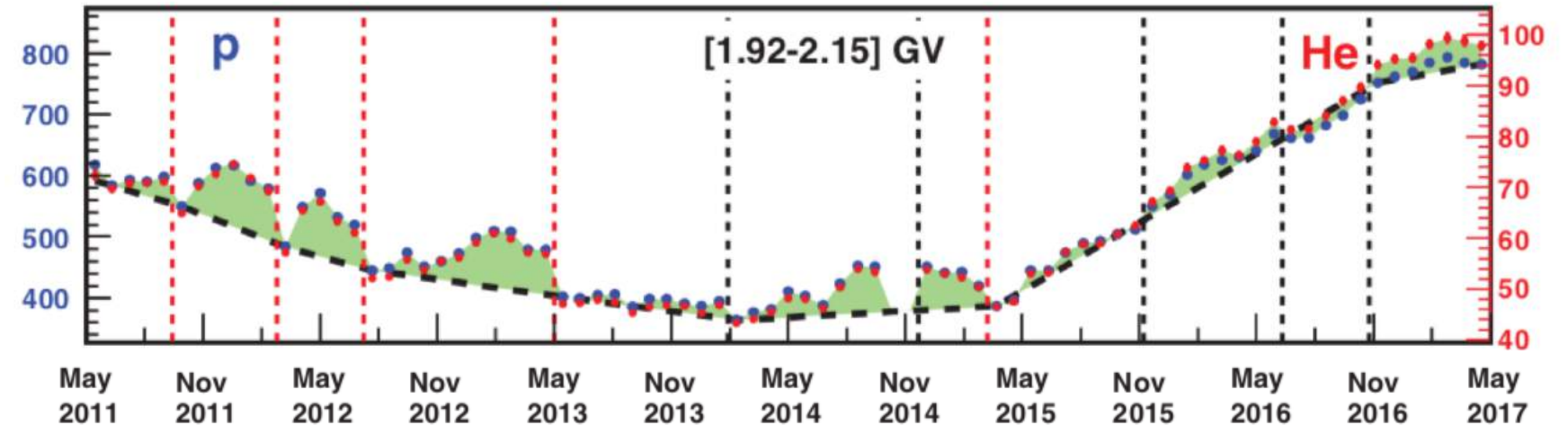

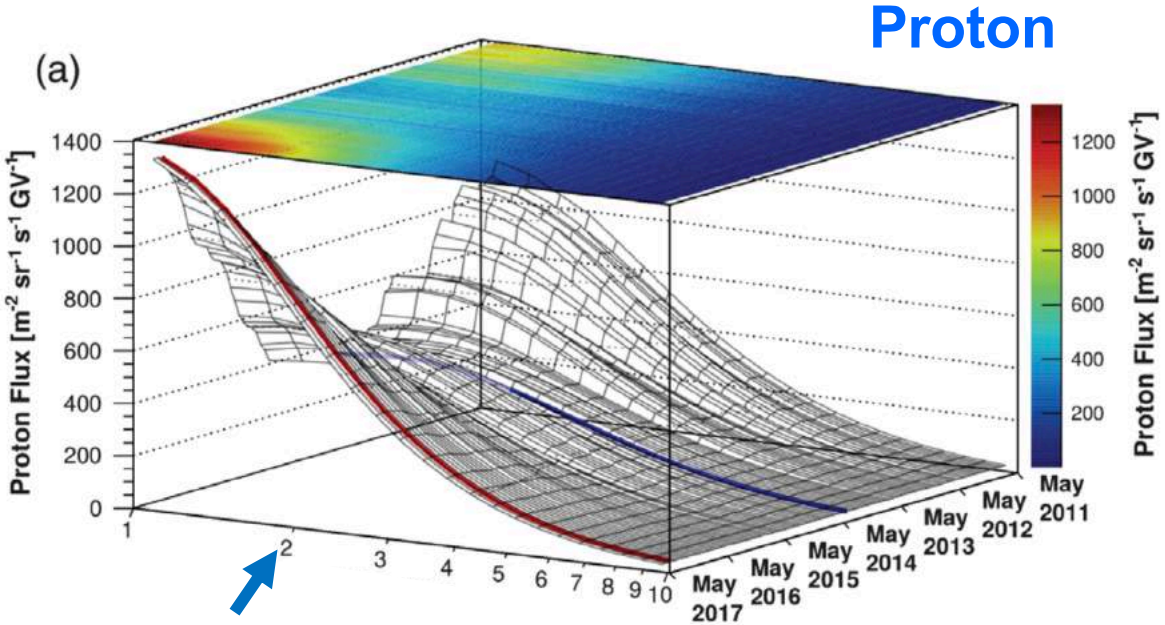

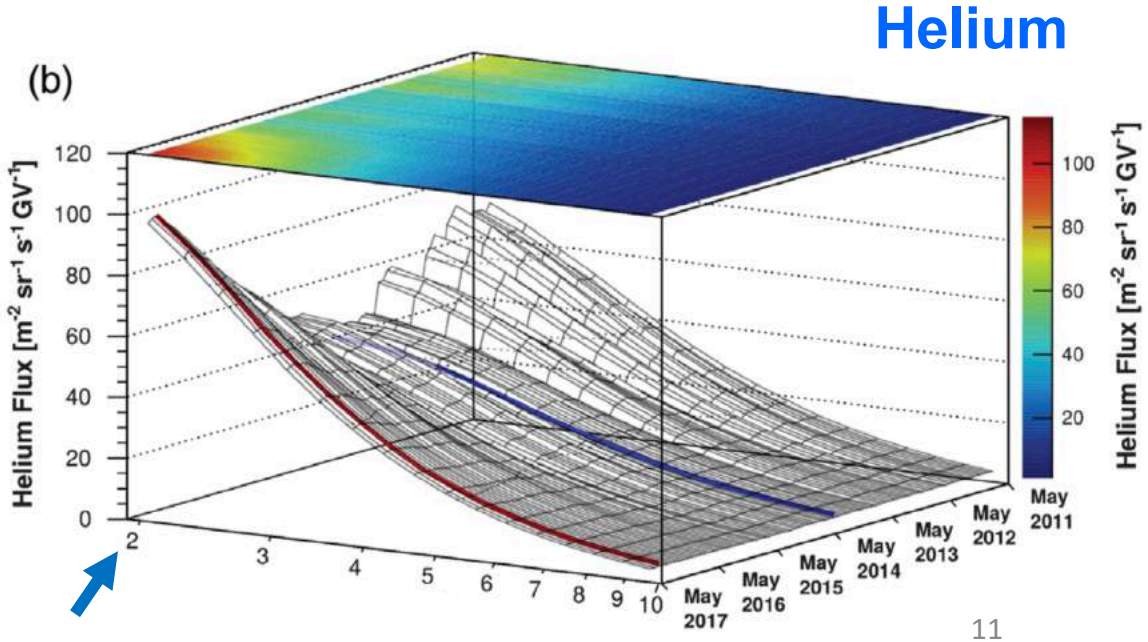

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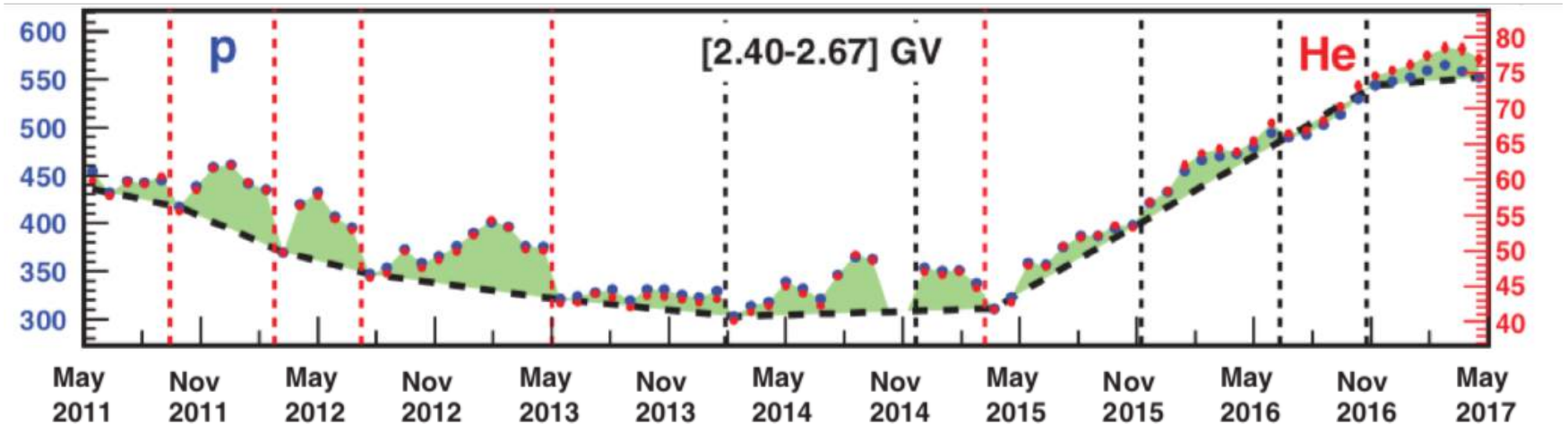
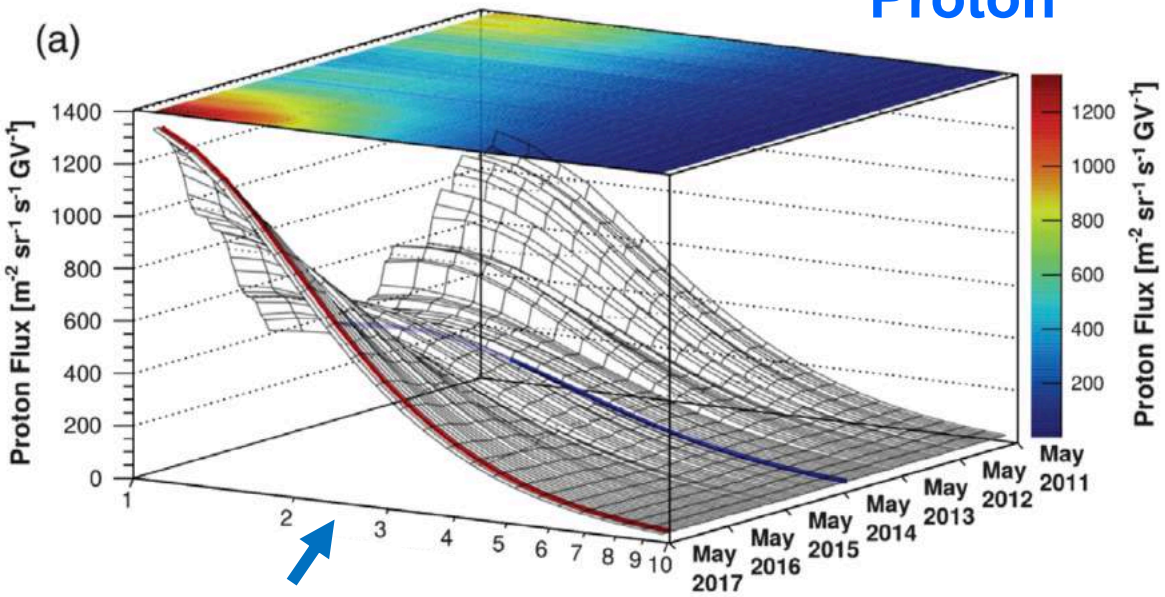
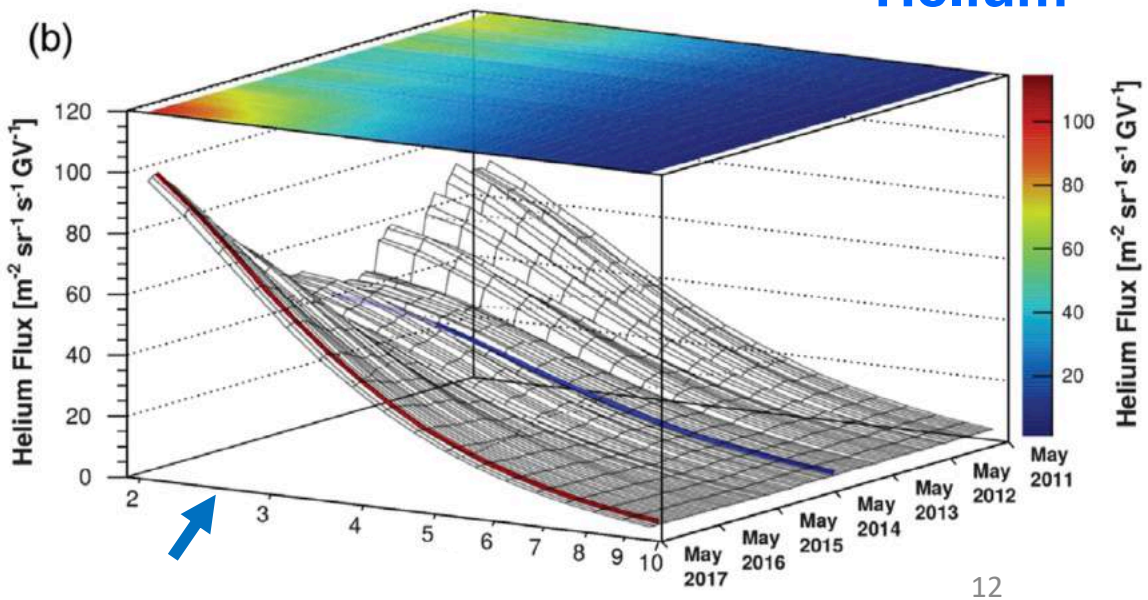


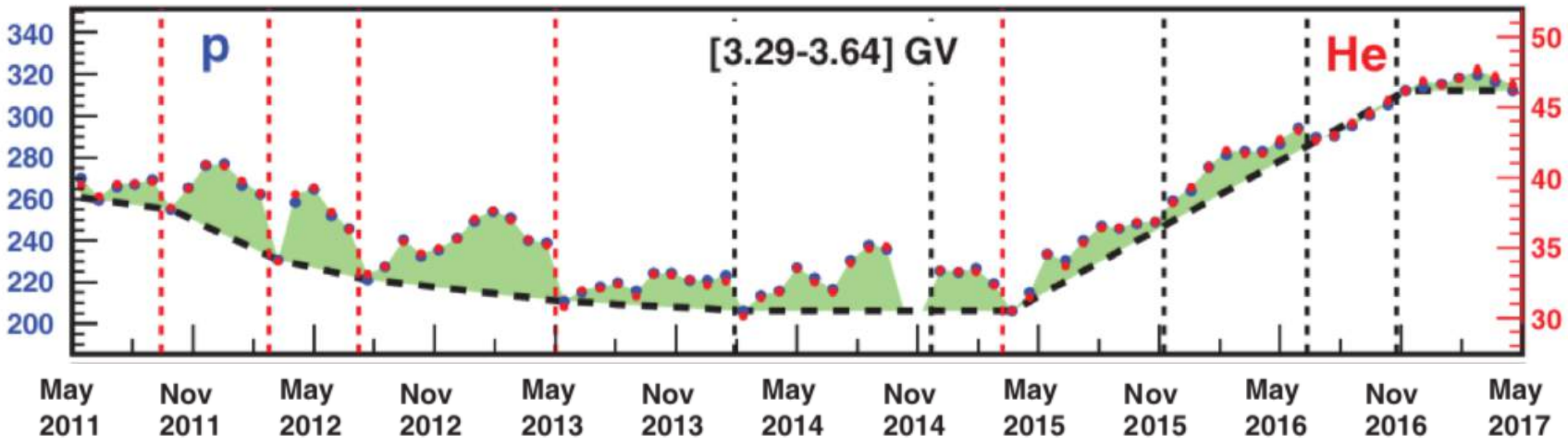
Proton

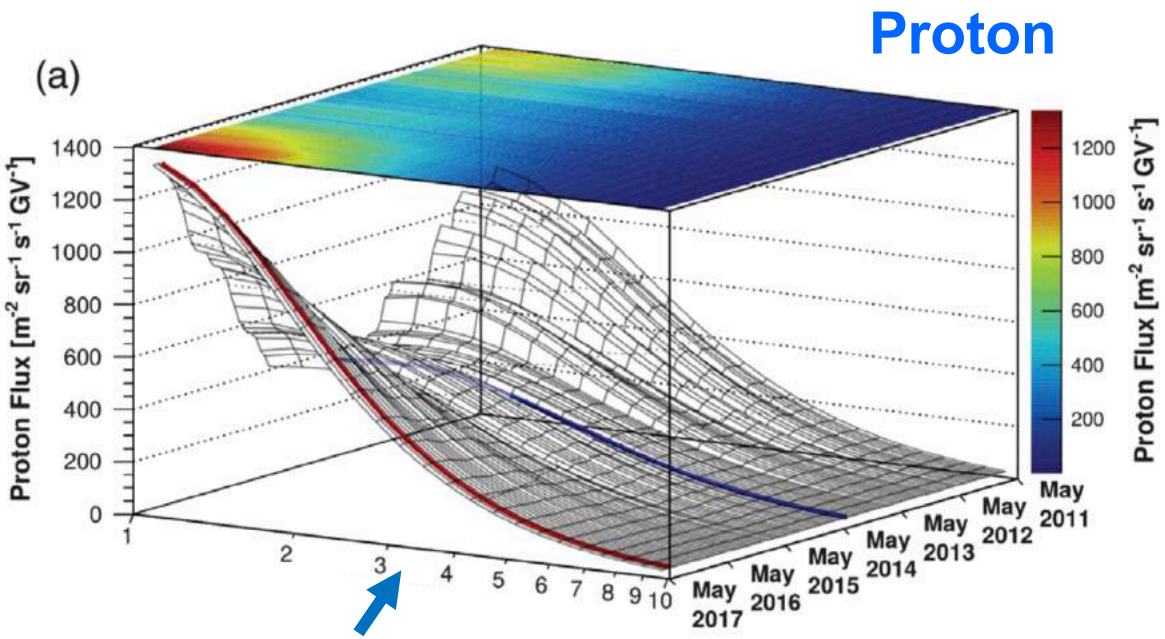


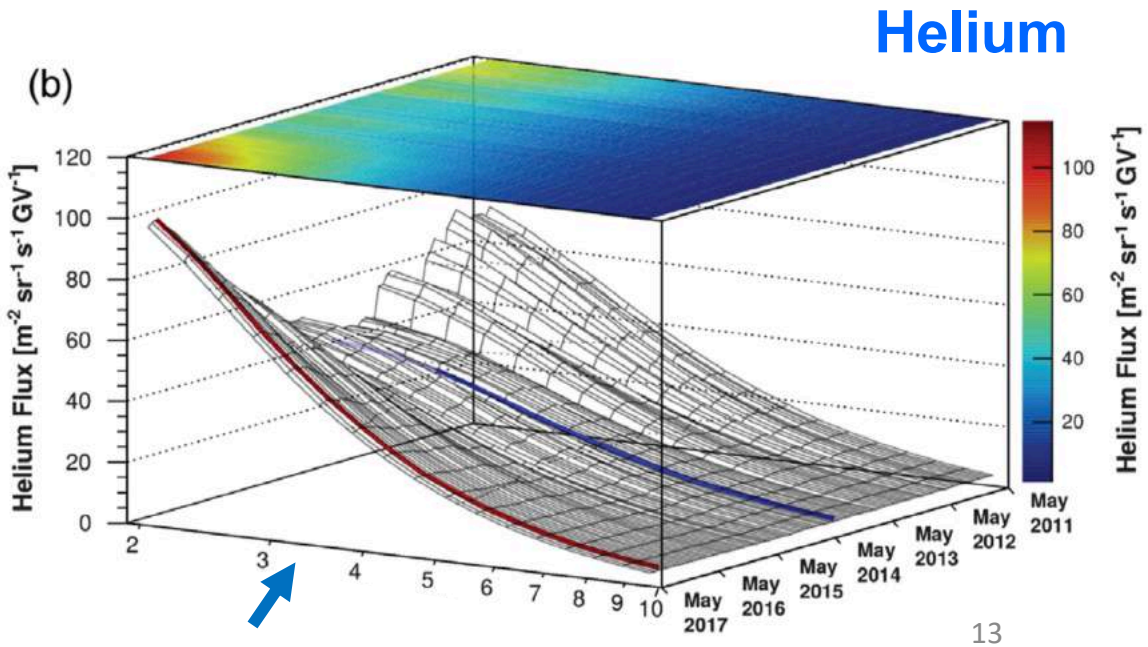
Helium



AMS-02 results: time- and rigidity- dependence of the p-He fluxes







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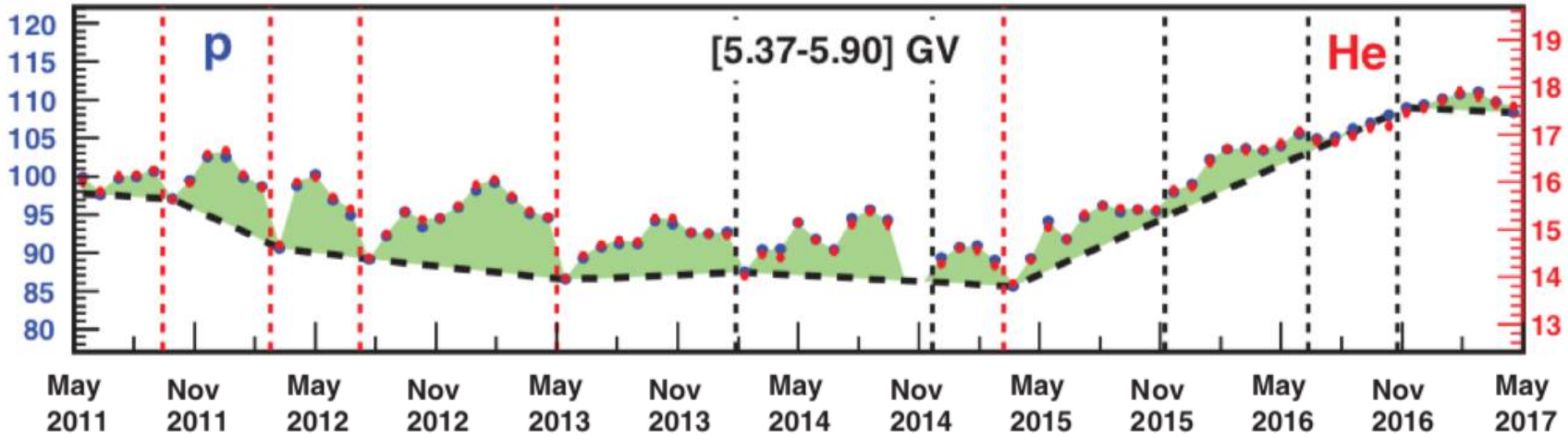

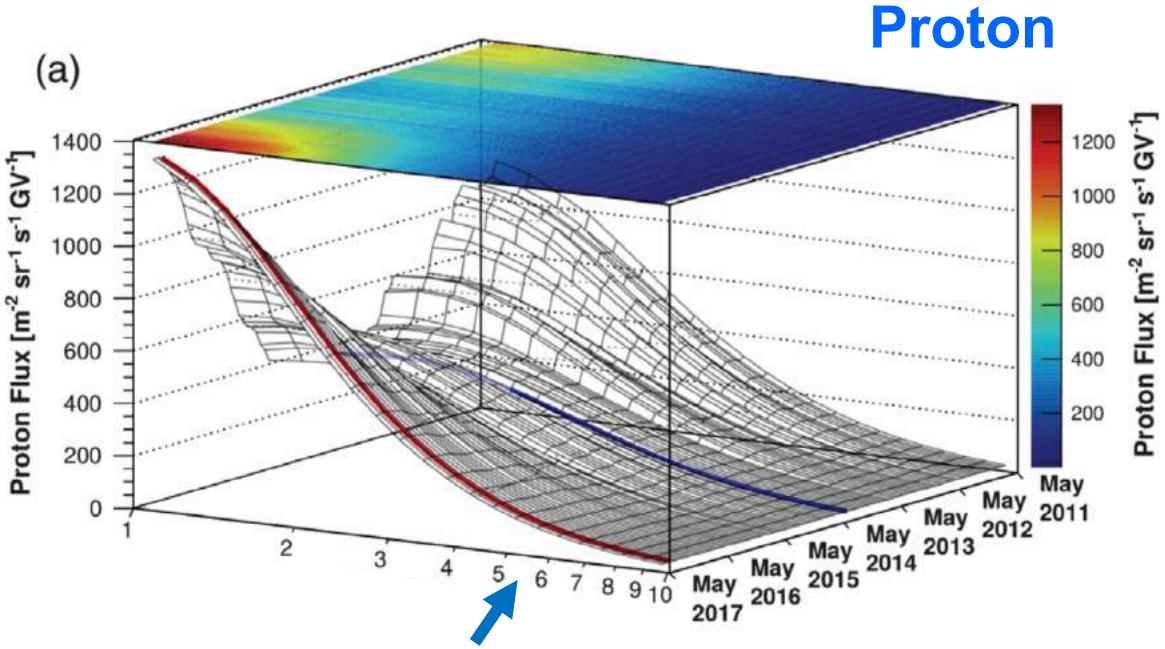

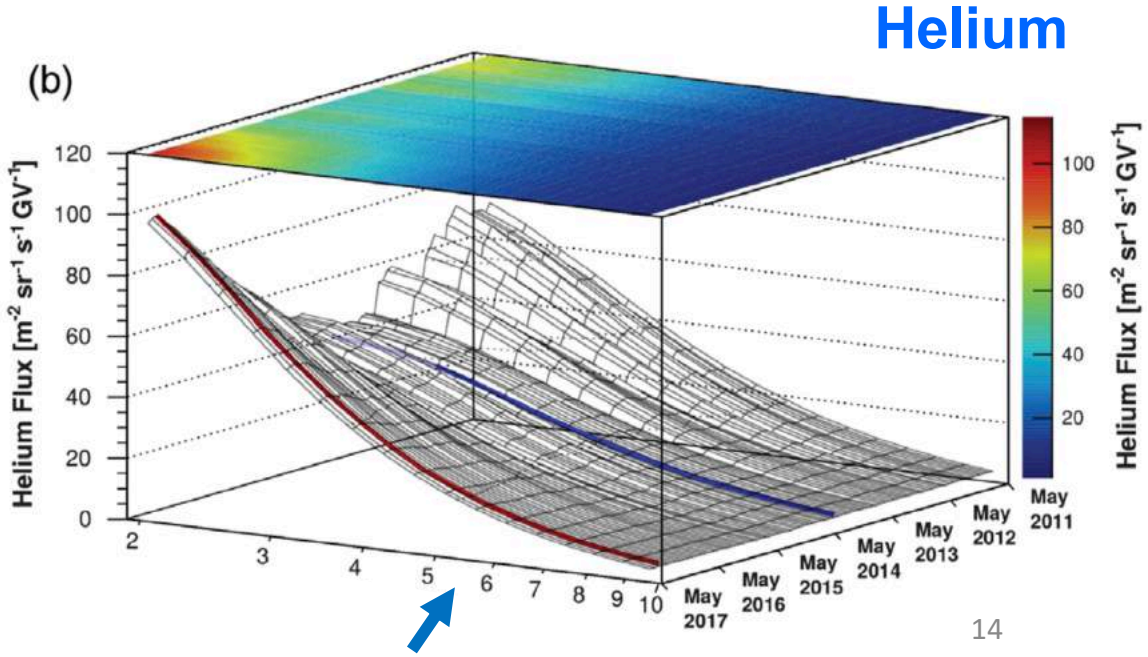

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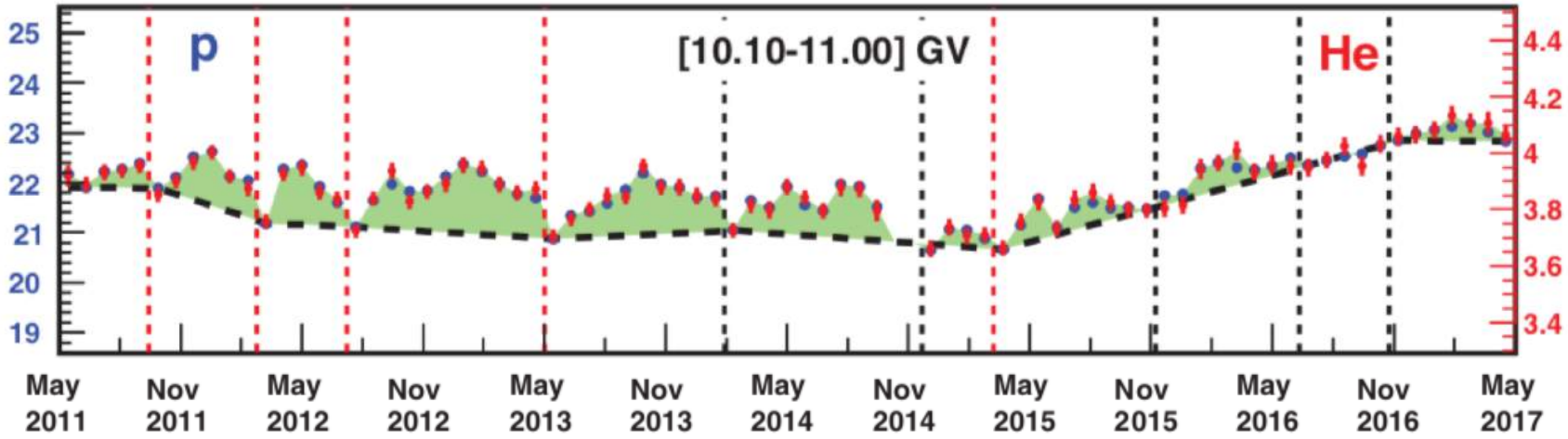

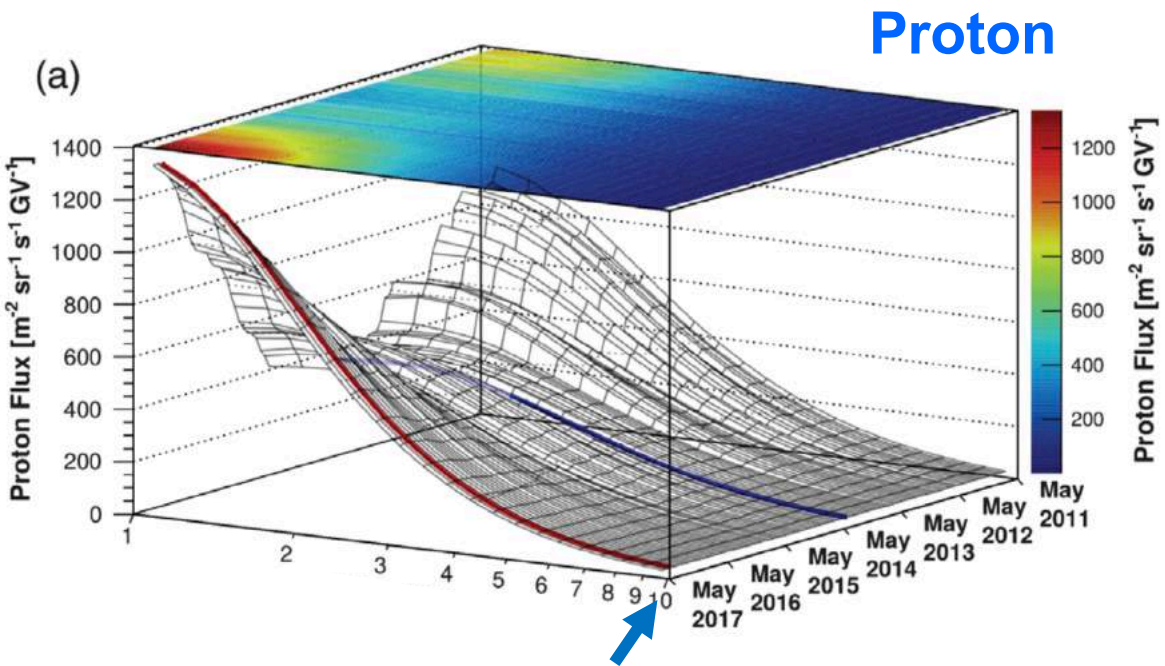

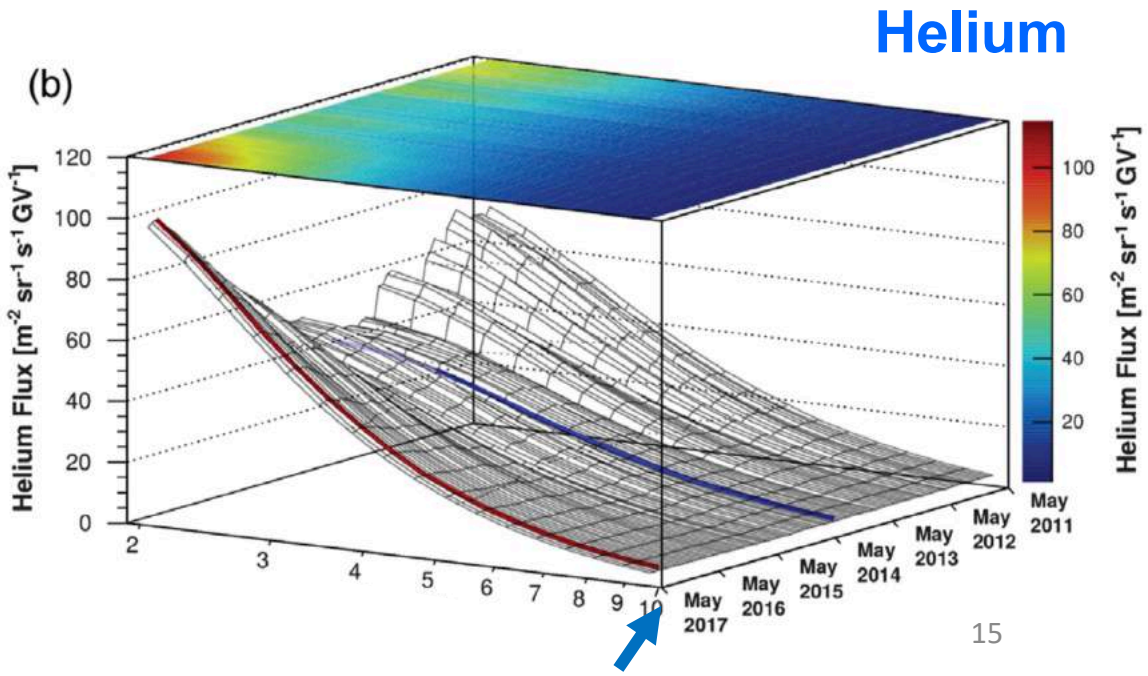

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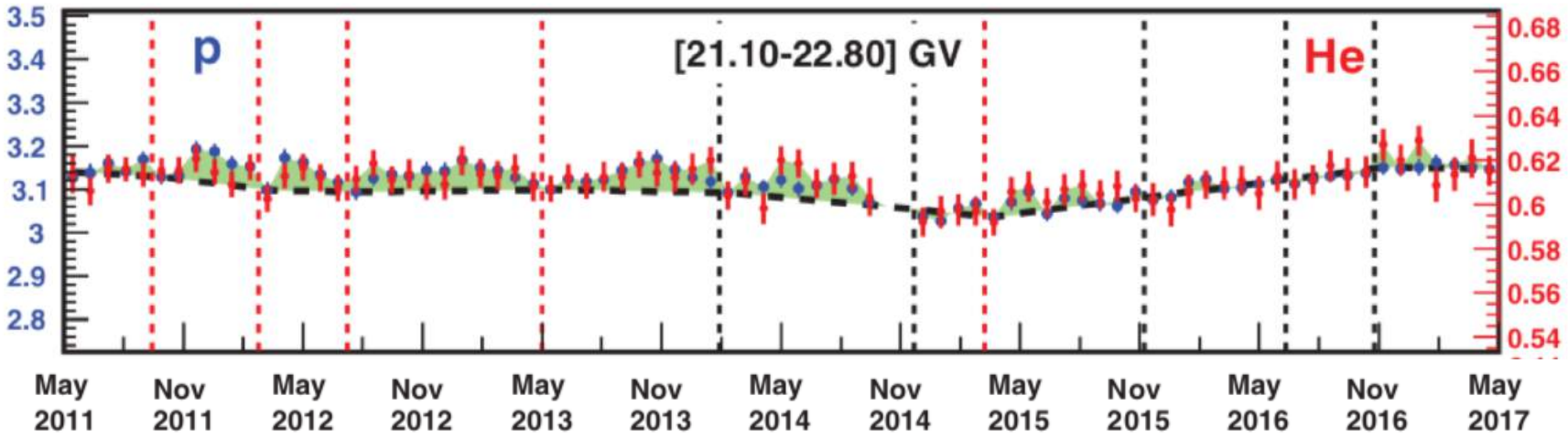

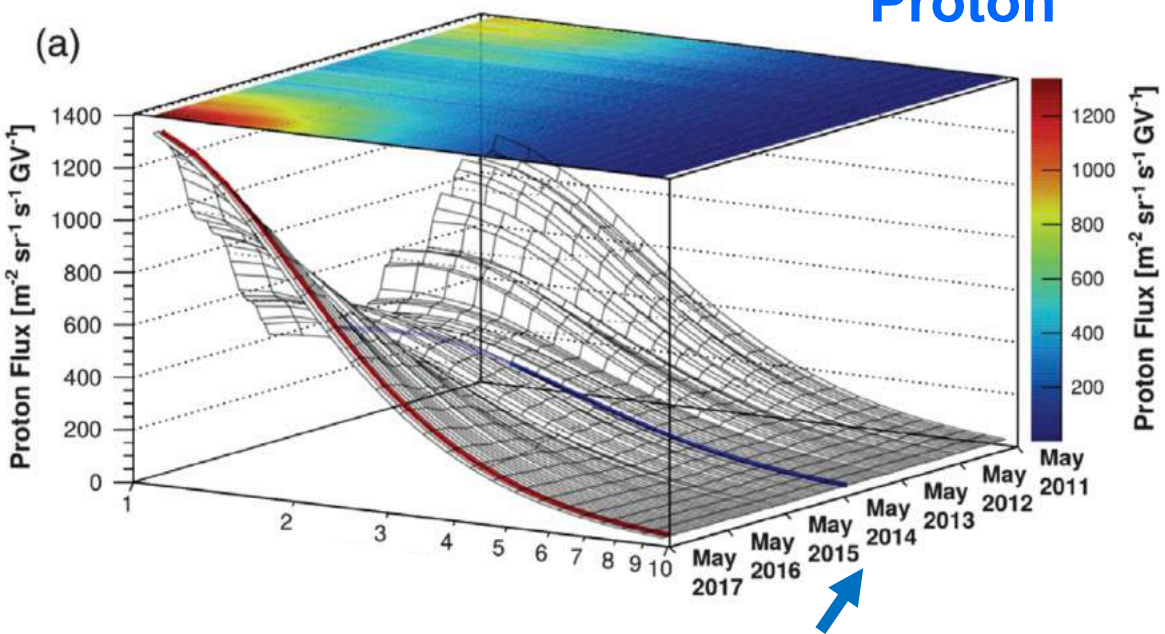

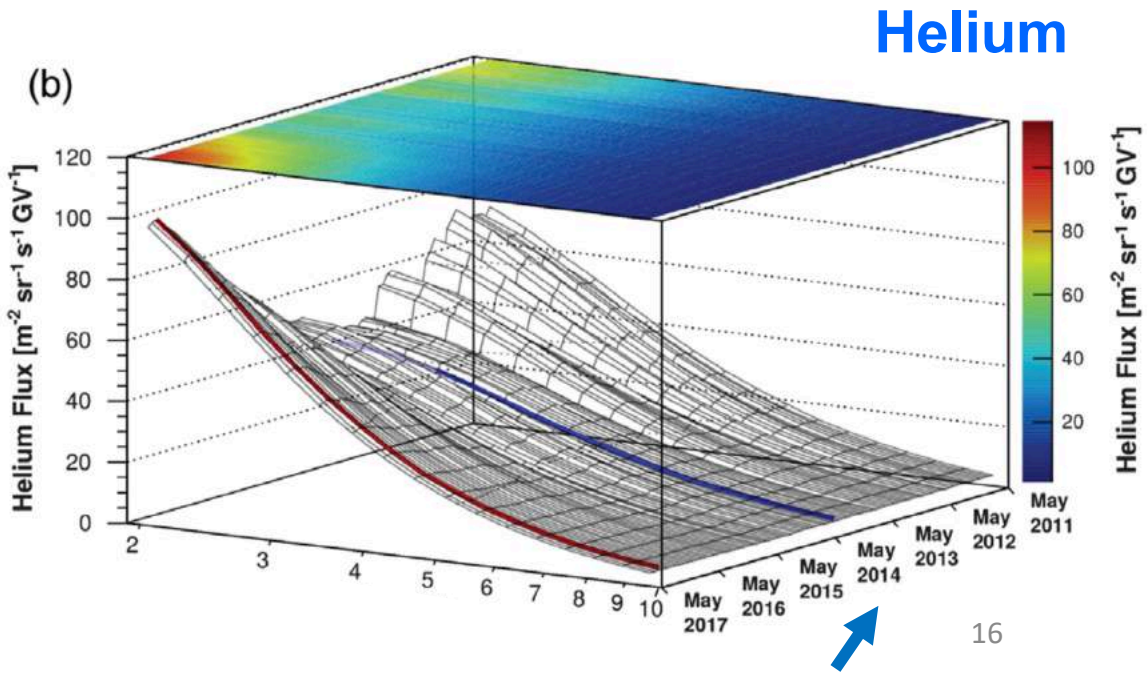

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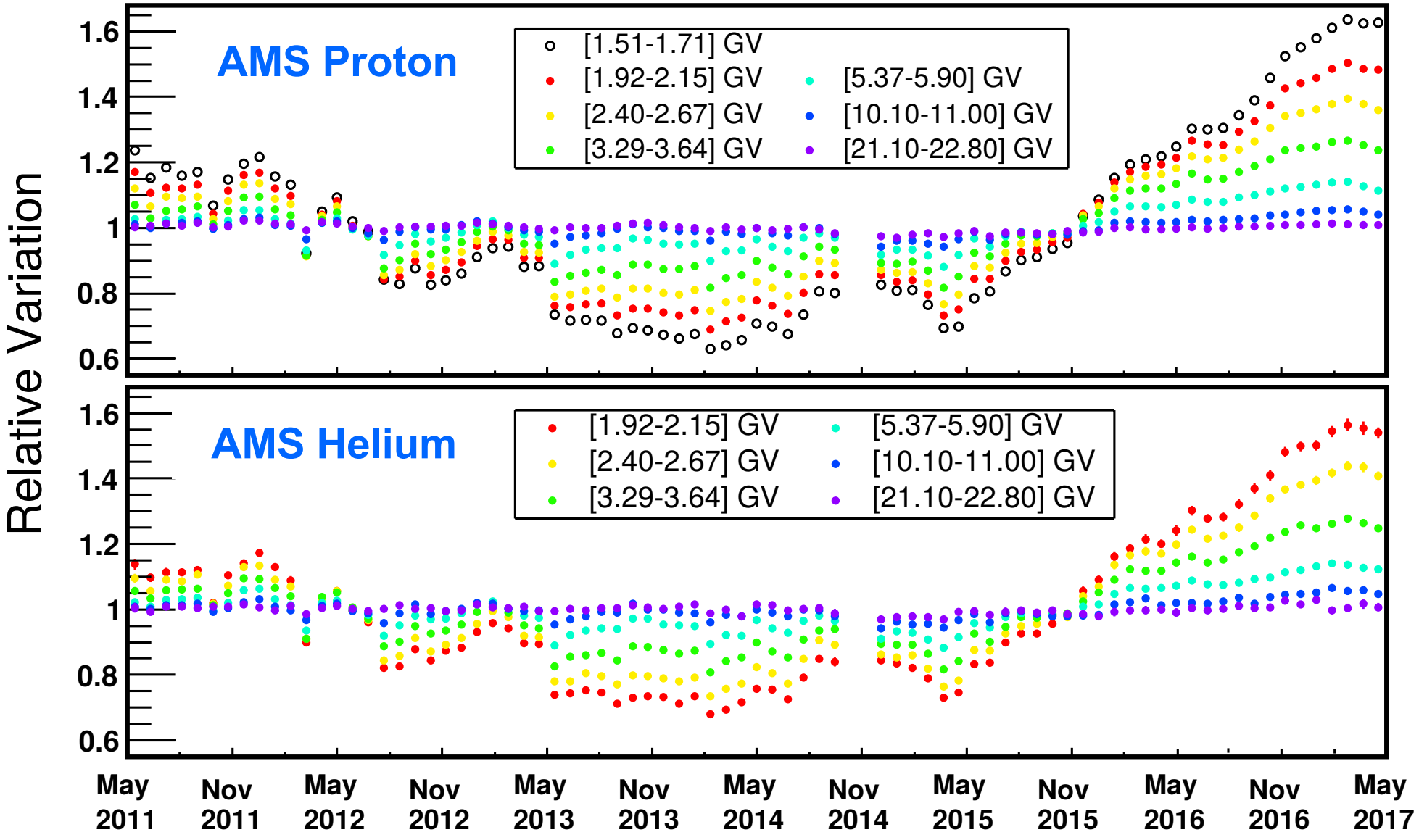
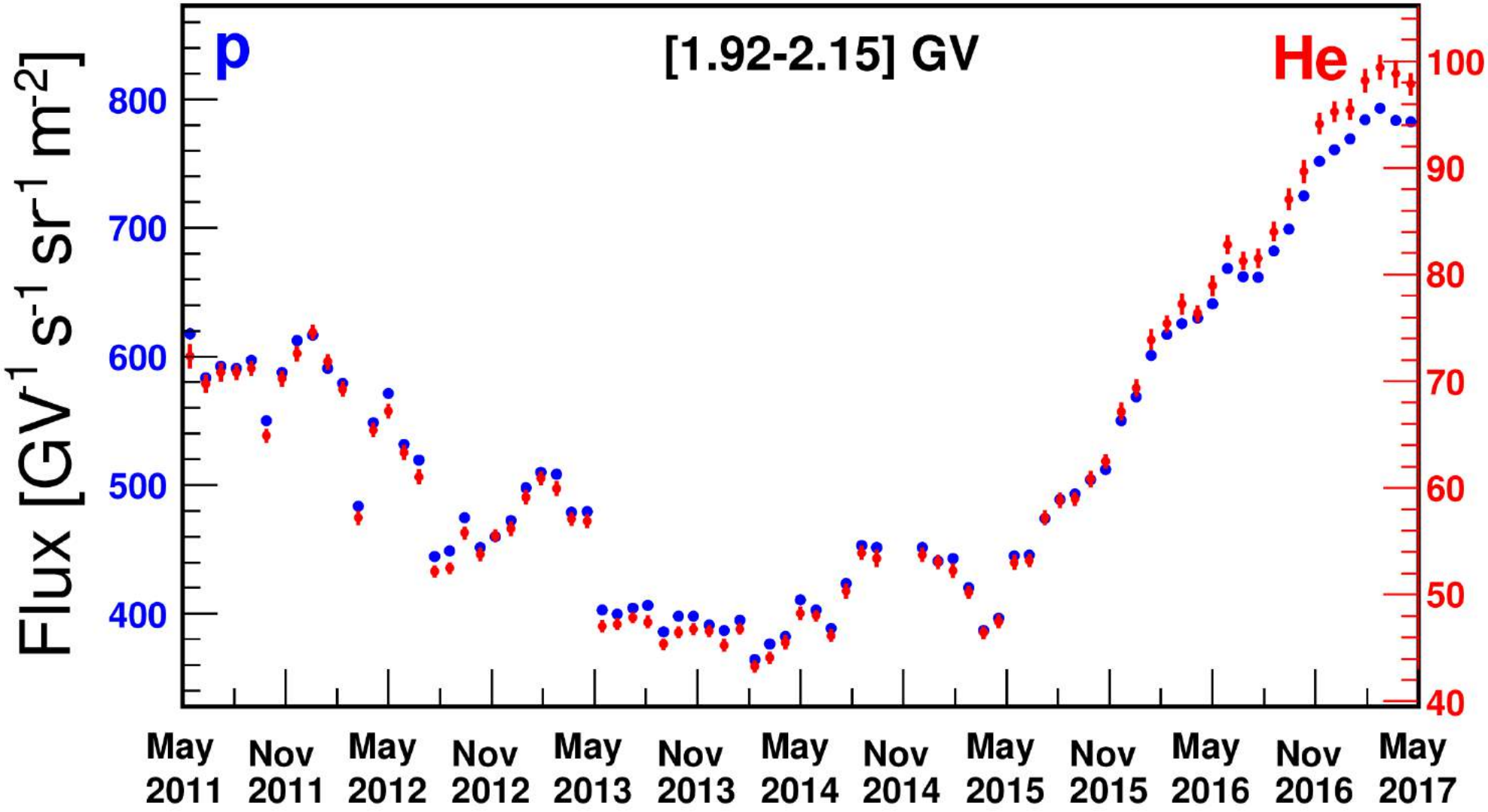


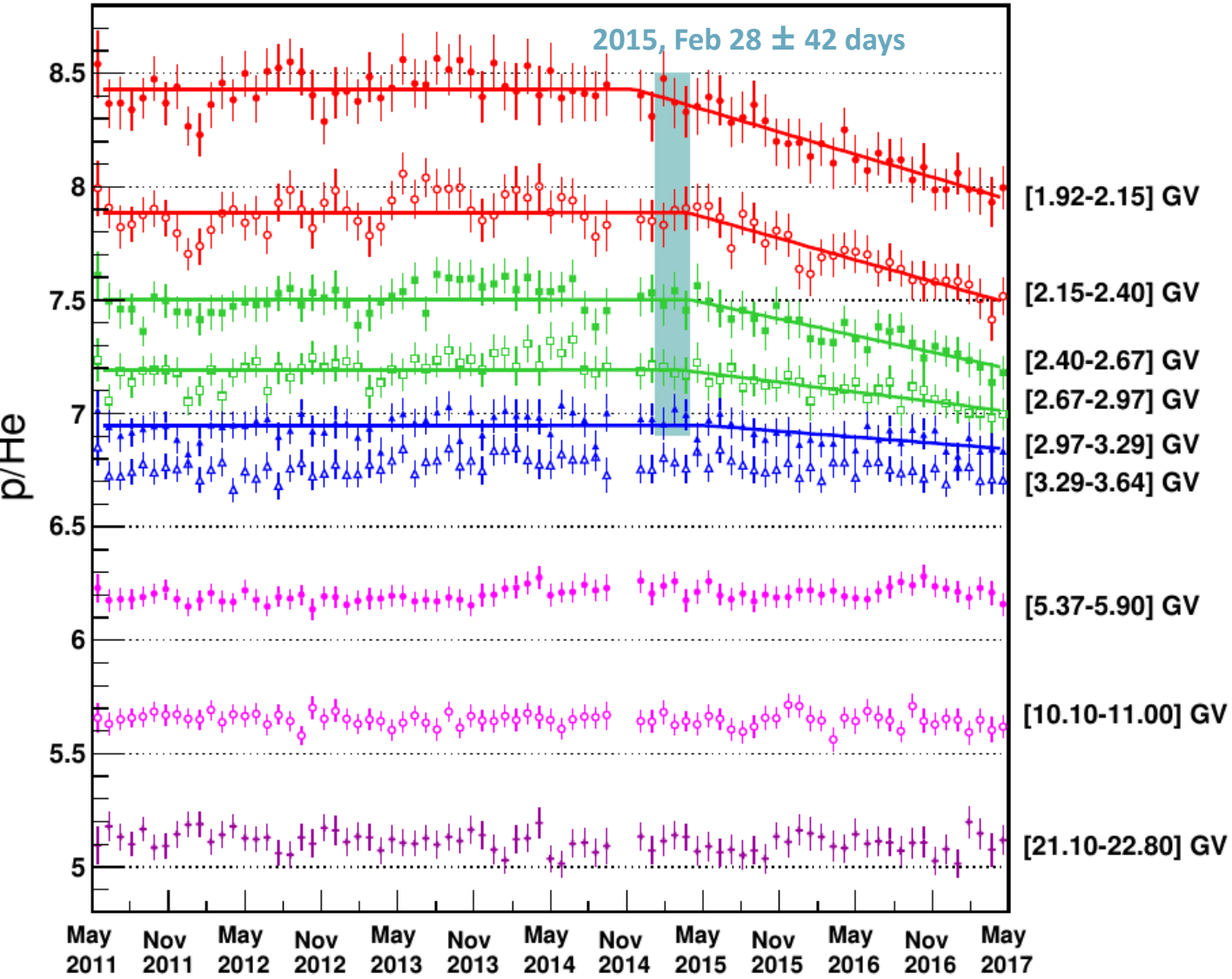
relative variations of proton and helium fluxes at the same rigidity

AMS-02 results: time- and rigidity- dependence of the p-He fluxes



variations of proton and helium fluxes at the same rigidity are not identical

AMS-02 results: time- and rigidity- dependence of the p/He ratio



M. Aguilar et al. PRL 120 (2018) 051101

p/He ratio

- ✓ **Nearly constant with time at R > 3 GV**
- ✓ **Long-term structure appearing at R < 3 GV**

Parameteric description

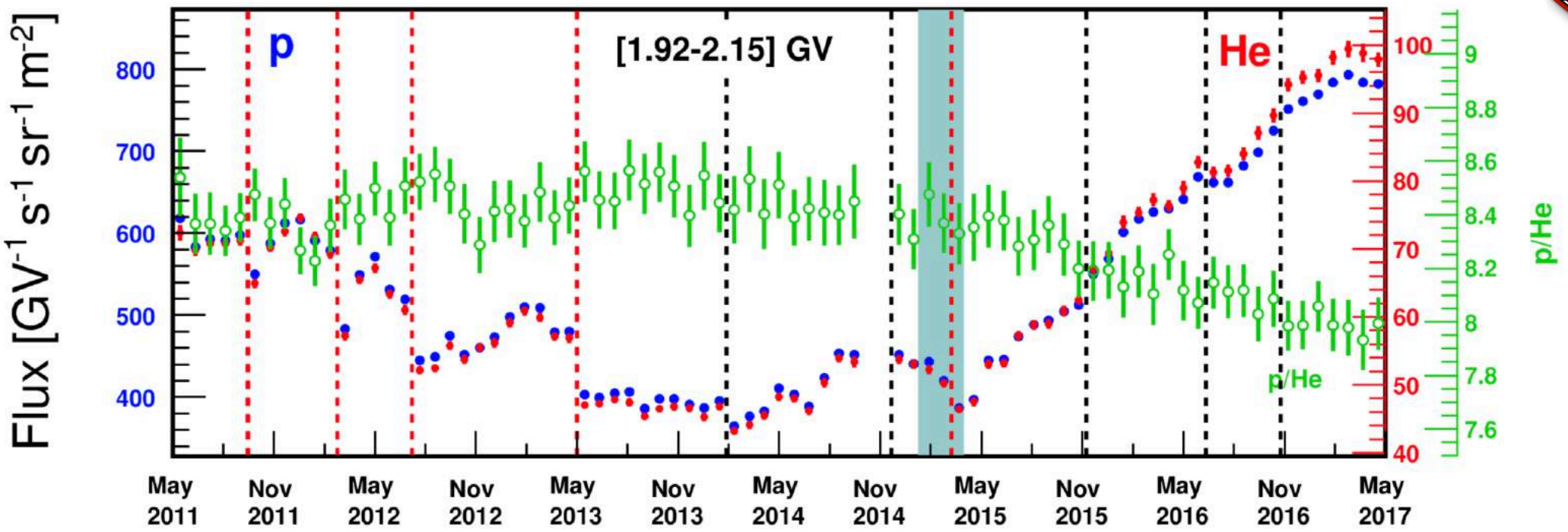
$$r_i(t) = \begin{cases} a_i & t < t_i \\ a_i + b_i(t - t_i) & t \geq t_i, \end{cases}$$

Brocken-line model. Ti= 2015 Feb 28 ± 42 days.

Recent models for the p/He evolution

- *Tomassetti et al. PRL 121, 251104 (2018)*
- *Corti et al. ApJ 871, 253 (2019)*
- *Gieseler et al. JGR 122, 10964 (2017)*
- *Boschini et al. arXiv 1903.07501 (2019)*

AMS-02 results: time- and rigidity- dependence of the p/He ratio



Origin of long-term structure in the p/He ratio

- Mass/charge dependence of CR **diffusion** appearing at low-rigidity
- Differences in the **interstellar spectra** of proton and helium
- Role of 3He and 4He **isotopic composition effects**

Tomassetti et al. PRL 121, 251104 (2018)
Corti et al. ApJ 871, 253 (2019)
Gieseler et al. JGR 122, 10964 (2017)

➢ Improved models of CR modulation are being developed
➢ Multichannel investigation w/ other data: 3He/4He, C/O

Conclusions

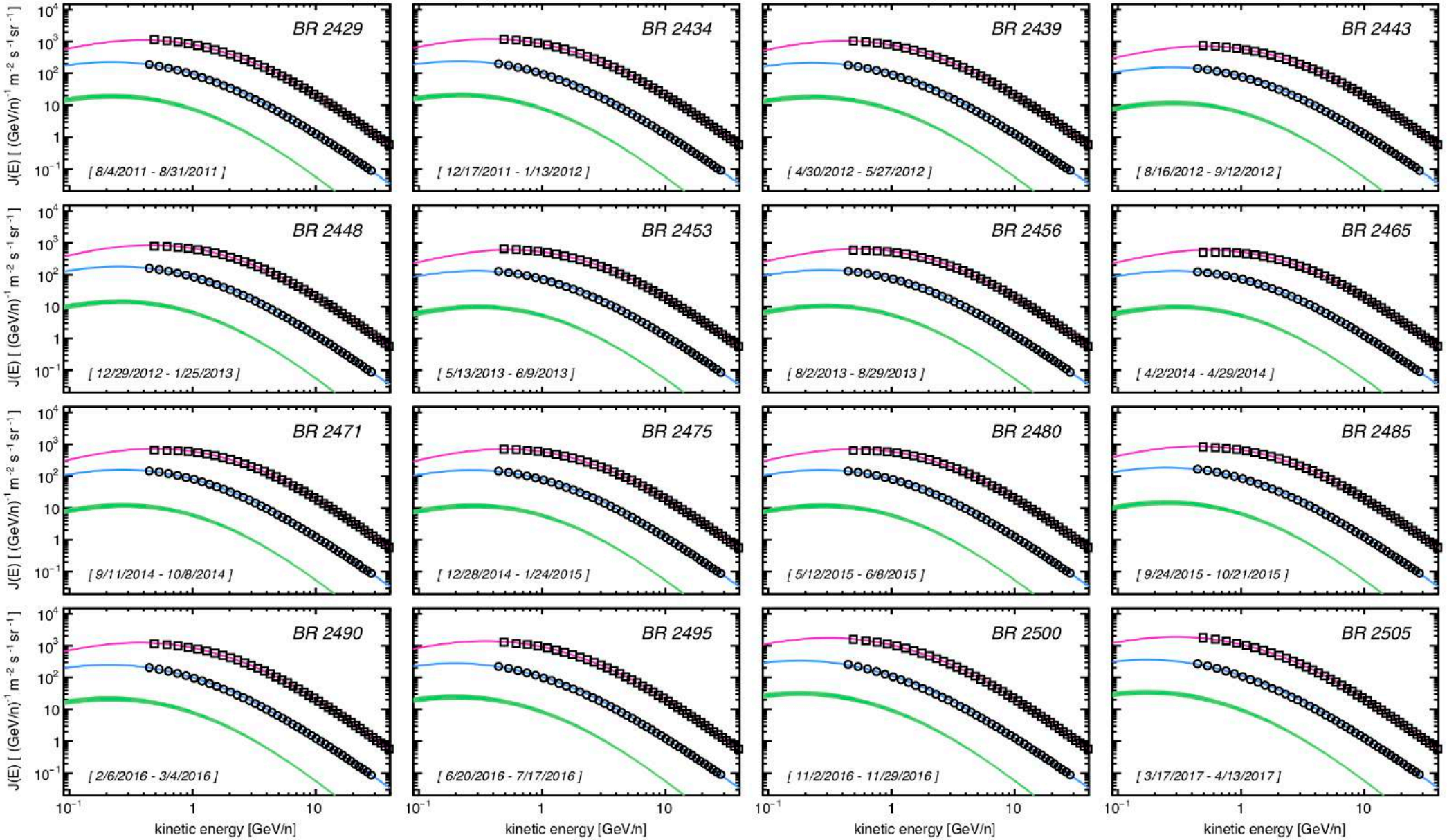
- ✓ Precision CR data provide substantial advance in understanding Solar Modulation.
- ✓ We have presented the monthly fluxes of proton and helium in CRs measured by AMS during ascending phase of Cycle 24, through its maximum, and toward its minimum.
- ✓ The high precision of these data enables us to observe fine time structures in the fluxes, at monthly and yearly time scale phenomena.
- ✓ Prominent time structures are observed in proton and helium up to 40 GV of rigidity.
- ✓ In the p/He ratio, the short-term structures of the fluxes largely cancel out. At R> 3 GV, the p/He ratio is remarkably constant. Below 3 GV, it shows a clear long-term behavior.
- ✓ The long-term behavior of the ratio gives information on CR diffusion in heliosphere, but there are other effects. Modeling challenge: how to make sense of all nuclear data.

backup

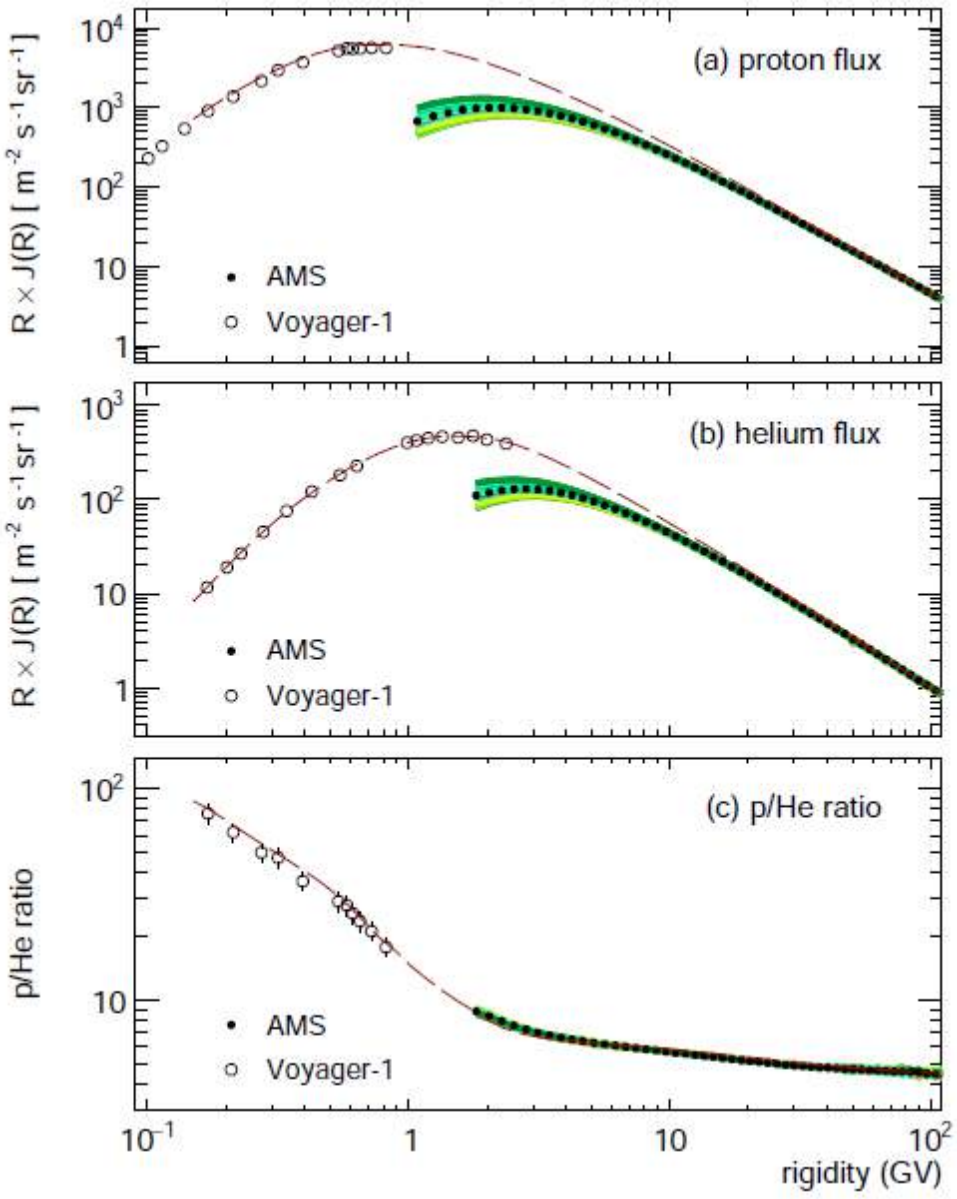
Energy spectra

Proton and helium energy spectra for 16 (out of 79) time periods

NT+ ASR 2019 [1906.11477]



AMS + Voyager-1



Quantitative inspection of proton and helium fluxes by making a comparison between:

- AMS data collected in low-Earth-orbit.
- Voyager-1 data collected in the interstellar space.

Calculations of local interstellar spectra are shown, in order to smoothly connect the Voyager-1 data (interstellar) with AMS data at high-energy (where solar modulation is negligible).

The green band represents the envelope of the AMS time-series

For the p/He ratio, the band appears tight: The LIS model connects well the AMS and Voyager-1 data. No variation?

Explanation for the long-term p/He behavior

- Different p-He LIS and their uncertainties accounted
- Isotopic composition accounted.
- Tested various diffusion coefficients with numerical models

NT+ PRL 121, 251104 (2018) [1811.08909]
NT+ Adv Space Res. (2019)[1906.11477]

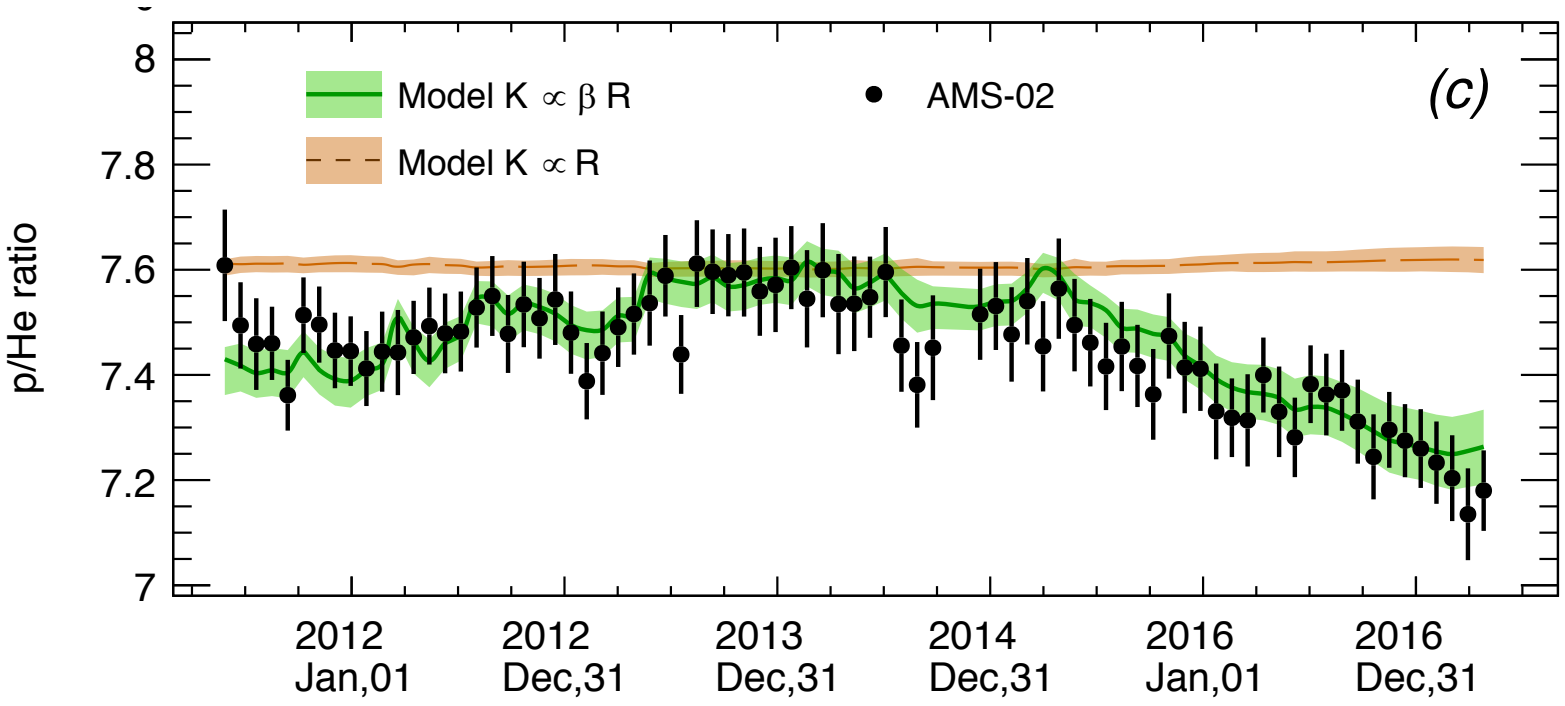
K(R) = (**v**/3)λ(R) parallel diffusion coefficient

λ(R) = universal *composition-blind* mean free path

$$K(R,t) = \frac{\beta c}{3}\lambda(R,t) \equiv k_0(t) \times \beta(R) \times f(R)$$

Time dependence

rigidity dependence



Rigidity and M/Z dependence:

$$\beta(R) = \frac{R}{\sqrt{R^2 + (M/Z)^2}}$$

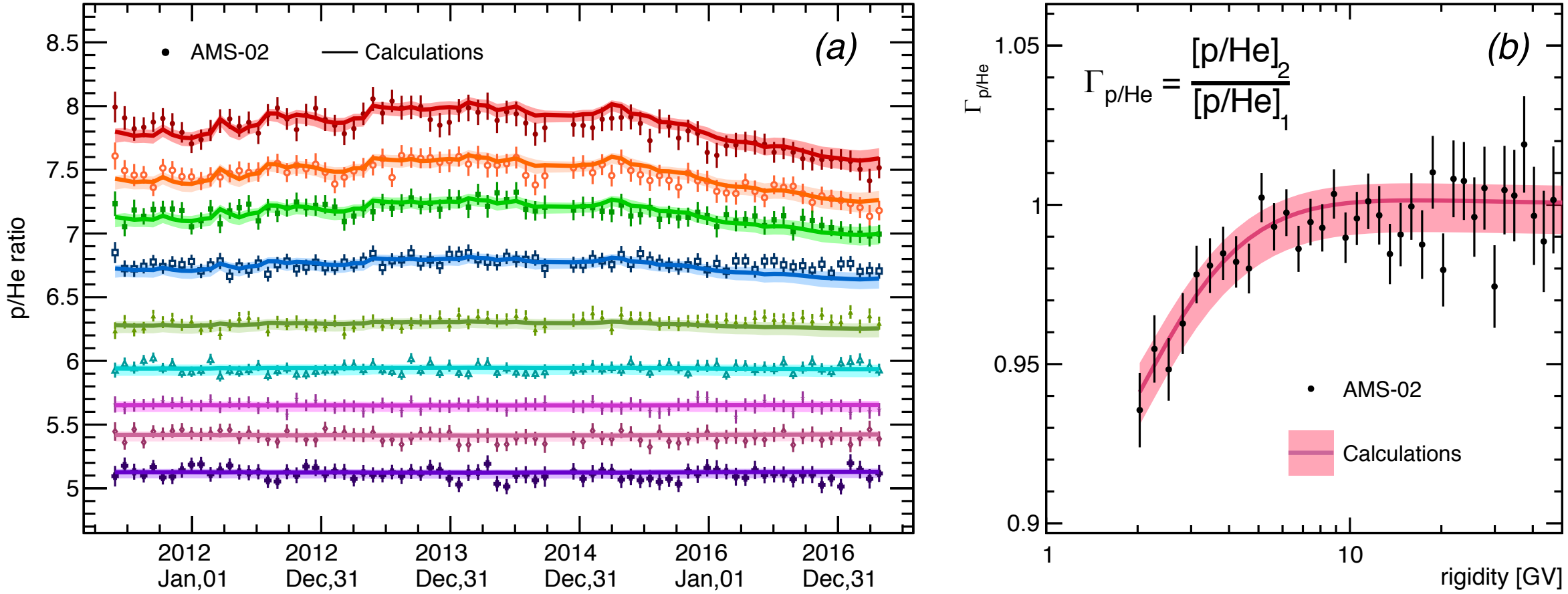
At the same value of rigidity R:

- *Protons are faster than He (4He or 3He)*
- *Diffusion coefficient of protons is larger*

Explanation for the long-term p/He behavior

- ✓ **The p/He time-dependence is *predicted* from a proton-driven model**
- ✓ **The p/He structure is expected to disappear at relativistic rigidities**

NT+ PRL 2018 [1811.08909] & NT+ ASR 2019 [1906.11477]



The p/He long-term structure is a signature of the universality of the CR mean free paths λ(R)

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24 July – 02 August 2019, Madison, USA

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