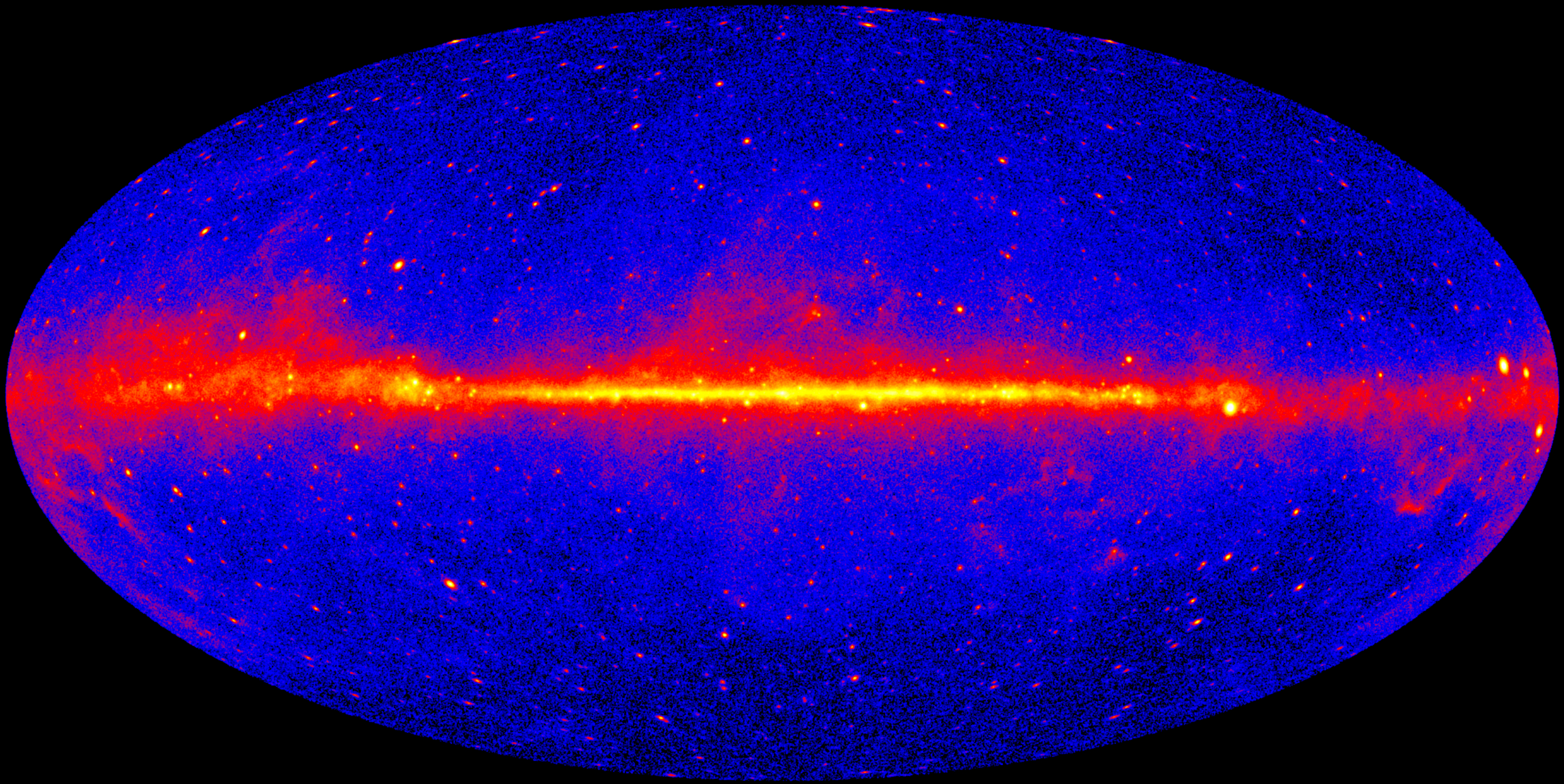
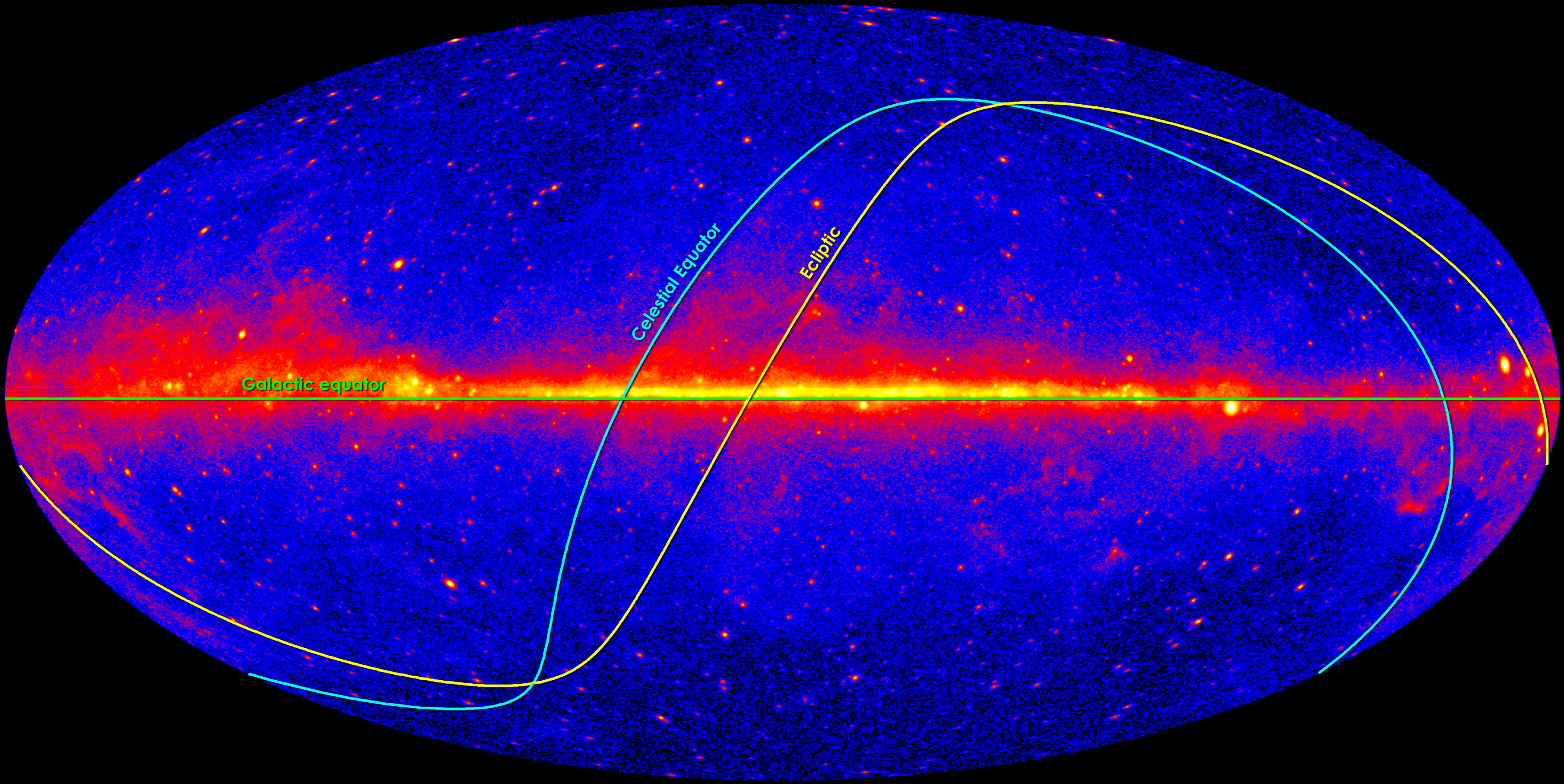
Unexpected Features of Solar Gamma-Ray and Neutrino Emission

Stockholms universitet

$$\left(\frac{d_{\alpha Cen}}{d_{\odot}}\right)^2 = 7 \times 10^{10} .$$




the sun is a
deadly lazer


Celestial Equator
Ecliptic
Galactic equator

CRAZY FINE TUNING

- **Solar gamma-ray flux:**

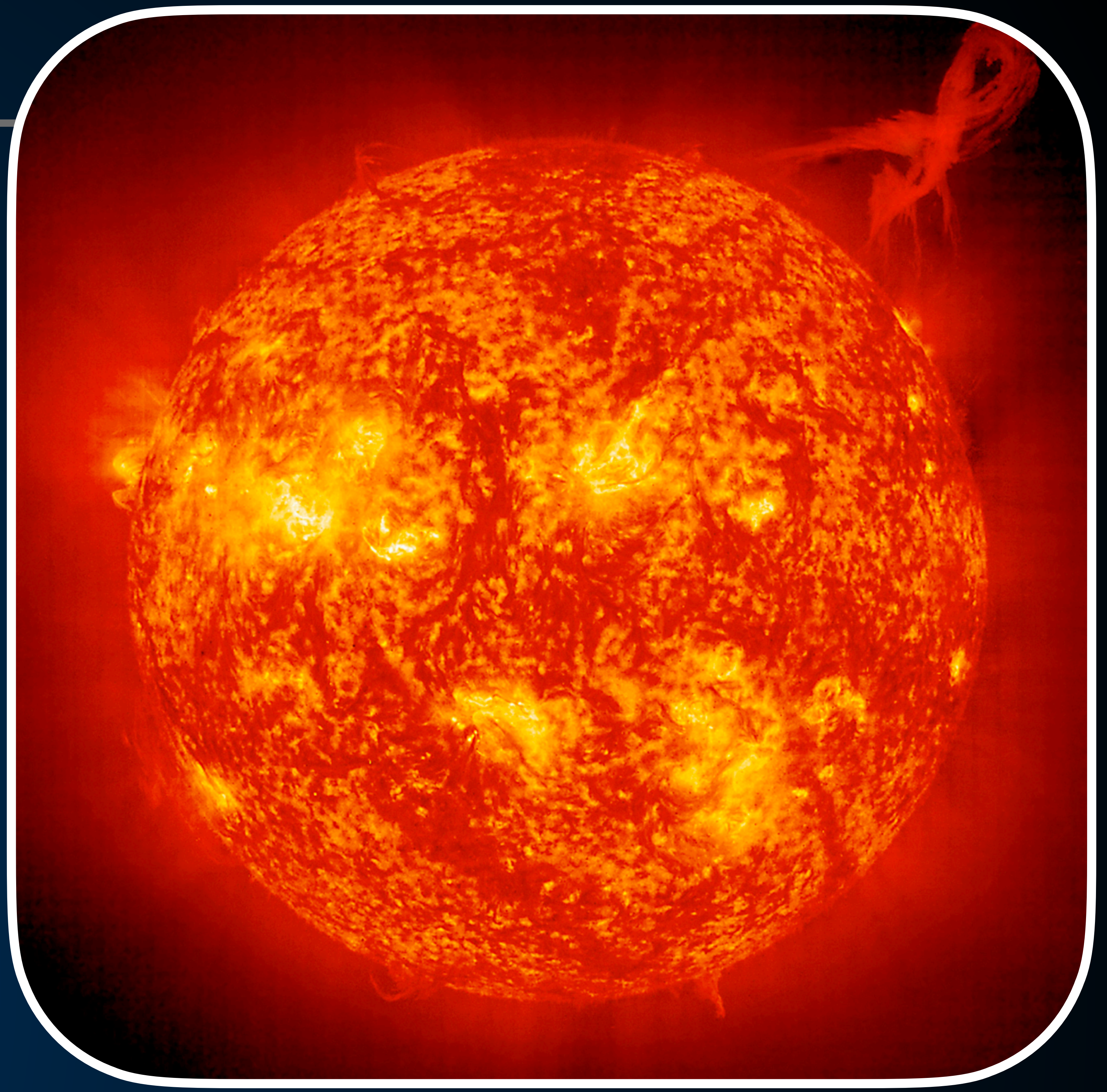
$$3 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$$

- **Solar disk gamma-ray flux:**

$$6 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$$

name	assoc name 1	energy flux [erg/cm^2/s]	assoc name 2
3FGL J0835.3-4510	PSR J0835-4510	8.93008e-09	Vela
3FGL J0633.9+1746	PSR J0633+1746	4.15261e-09	Geminga
3FGL J0534.5+2201	PSR J0534+2200	1.47178e-09	Crab
3FGL J1709.7-4429	PSR J1709-4429	1.31463e-09	
3FGL J2254.0+1608	3C 454.3	1.23418e-09	
3FGL J2021.5+4026	LAT PSR J2021+4026	8.83261e-10	
3FGL J2028.6+4110e	Cygnus Cocoon	6.57388e-10	
3FGL J1836.2+5925	LAT PSR J1836+5925	5.98187e-10	
3FGL J1855.9+0121e	W44	5.35680e-10	
3FGL J2021.1+3651	PSR J2021+3651	5.03626e-10	
3FGL J0617.2+2234e	IC 443	5.02055e-10	
3FGL J1512.8-0906	PKS 1510-08	4.92754e-10	
3FGL J0240.5+6113	LS I+61 303	4.72665e-10	
3FGL J1809.8-2332	PSR J1809-2332	4.47994e-10	
3FGL J0007.0+7302	LAT PSR J0007+7303	4.25538e-10	
3FGL J1801.3-2326e	W28	4.15501e-10	
3FGL J1826.1-1256	LAT PSR J1826-1256	4.14665e-10	
3FGL J0534.5+2201i	Crab	3.92571e-10	
3FGL J1104.4+3812	Mkn 421	3.82949e-10	
3FGL J1923.2+1408e	W51C	3.45801e-10	
3FGL J1907.9+0602	LAT PSR J1907+0602	3.19051e-10	
3FGL J1418.6-6058	LAT PSR J1418-6058	3.10352e-10	

WHY CARE ABOUT GAMMA RAYS?

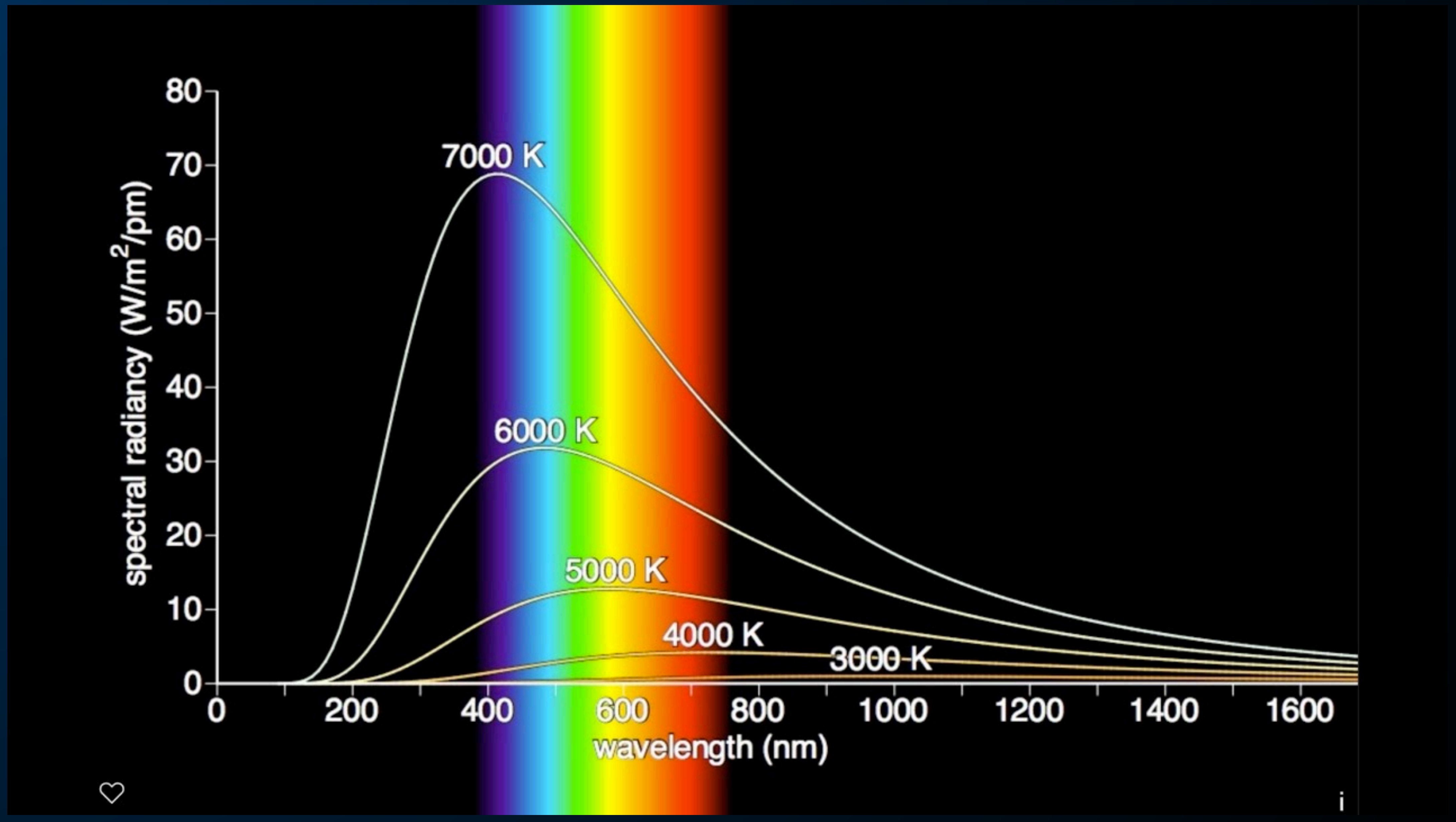


$T_\odot$ = 6000 K = 0.5 eV

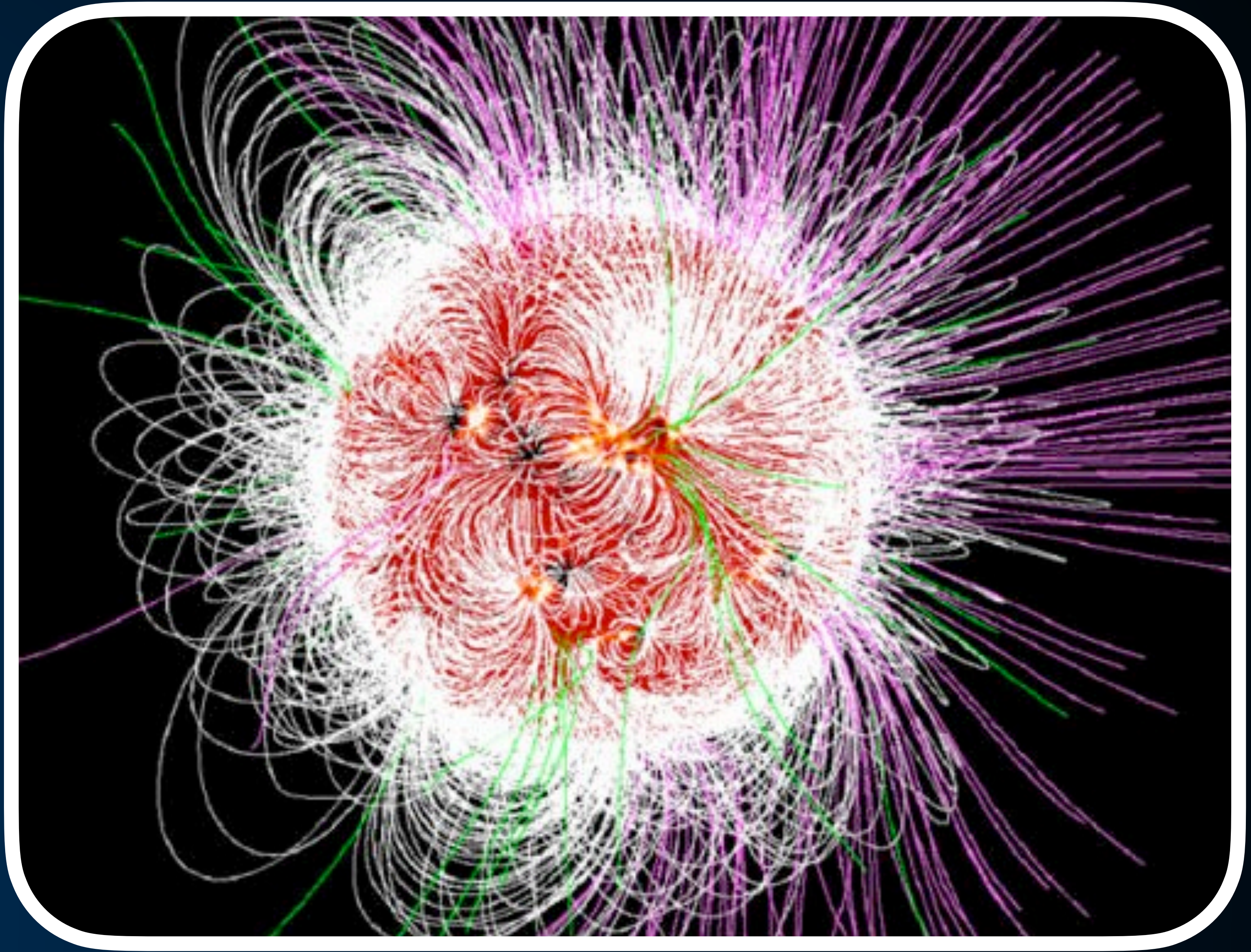
$$B_\nu(\nu, T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

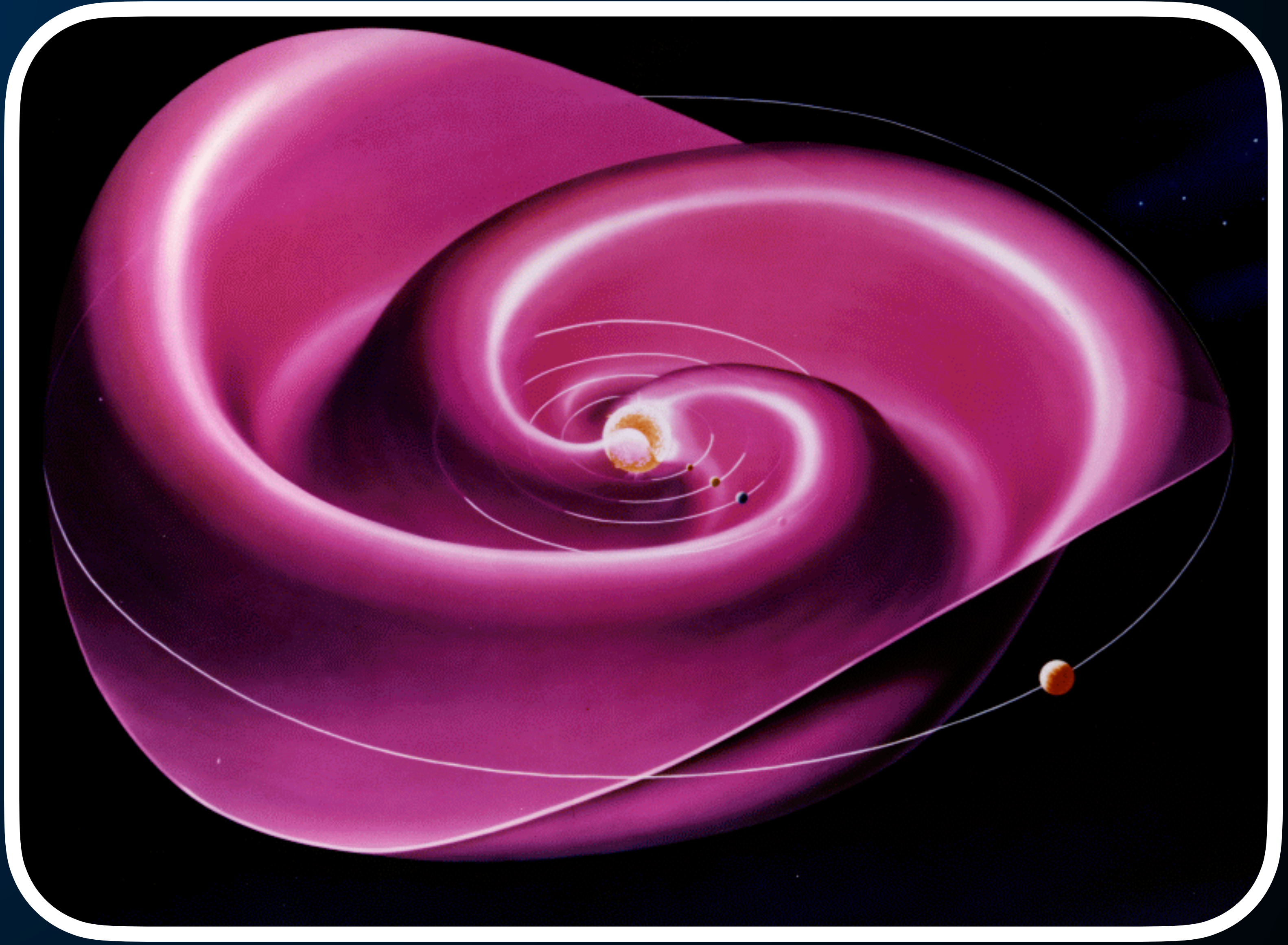
Thermal production of gamma rays

is suppressed by exp[-10^9] = 0

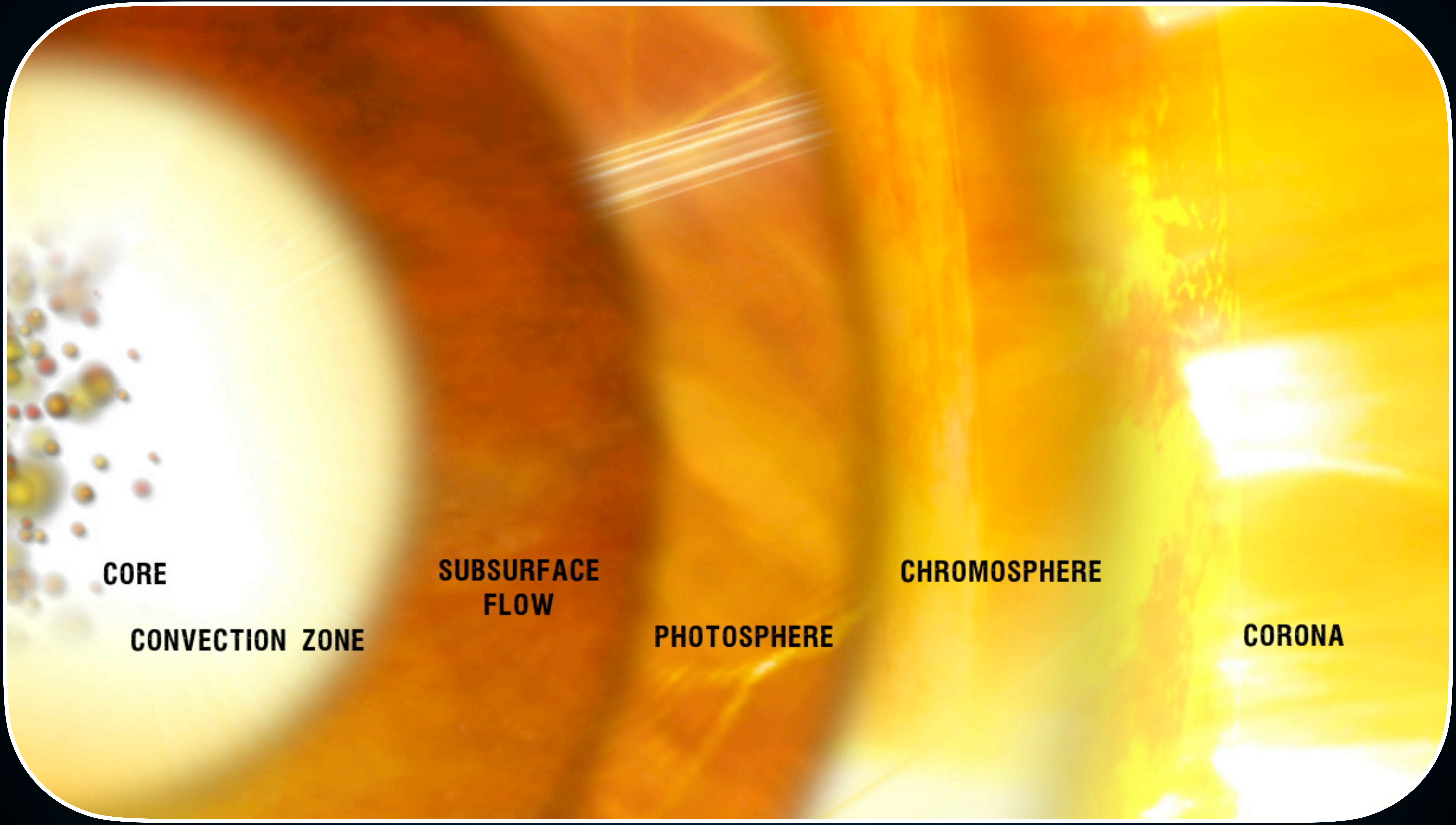


WHY CARE ABOUT GAMMA RAYS?

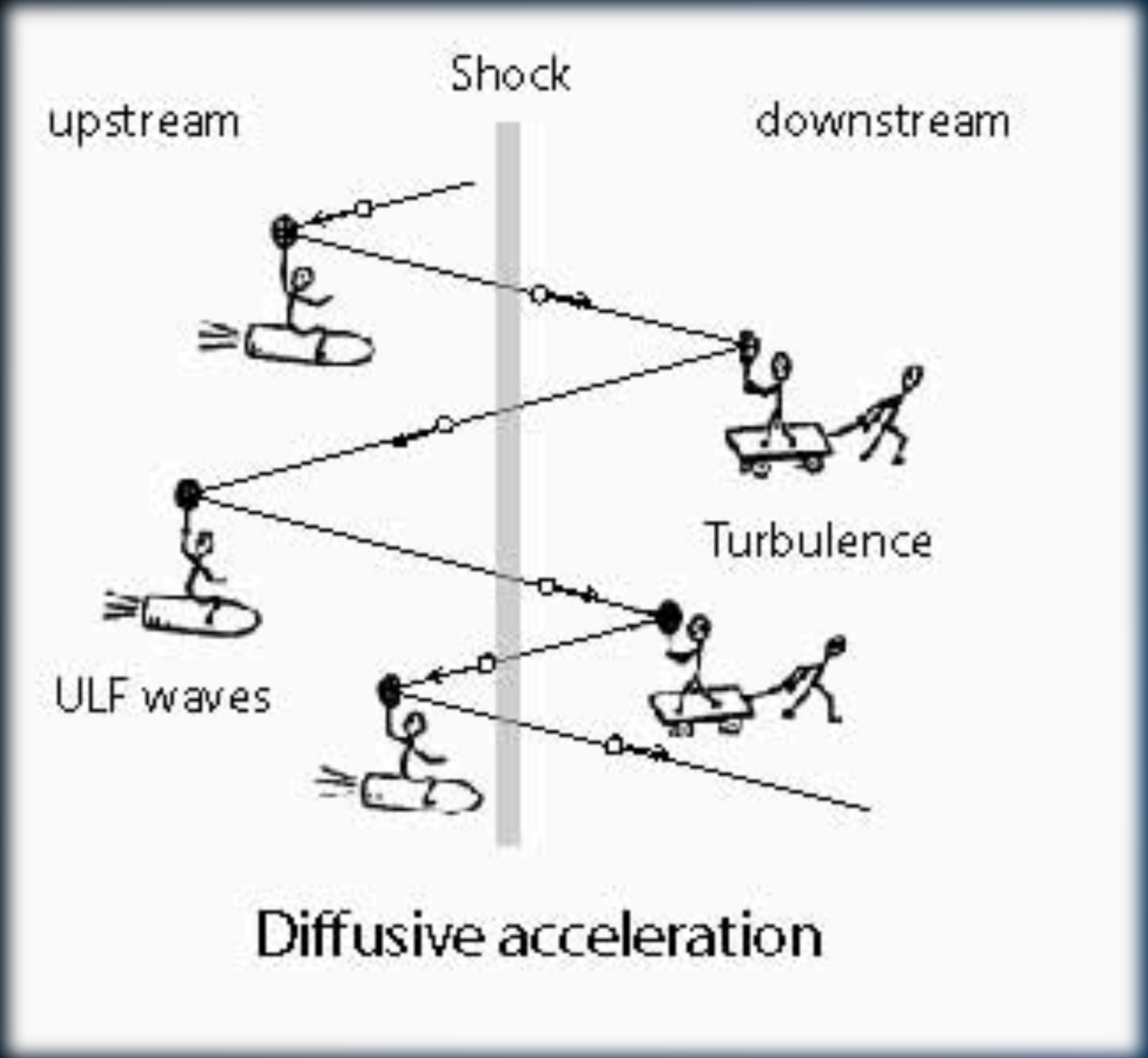


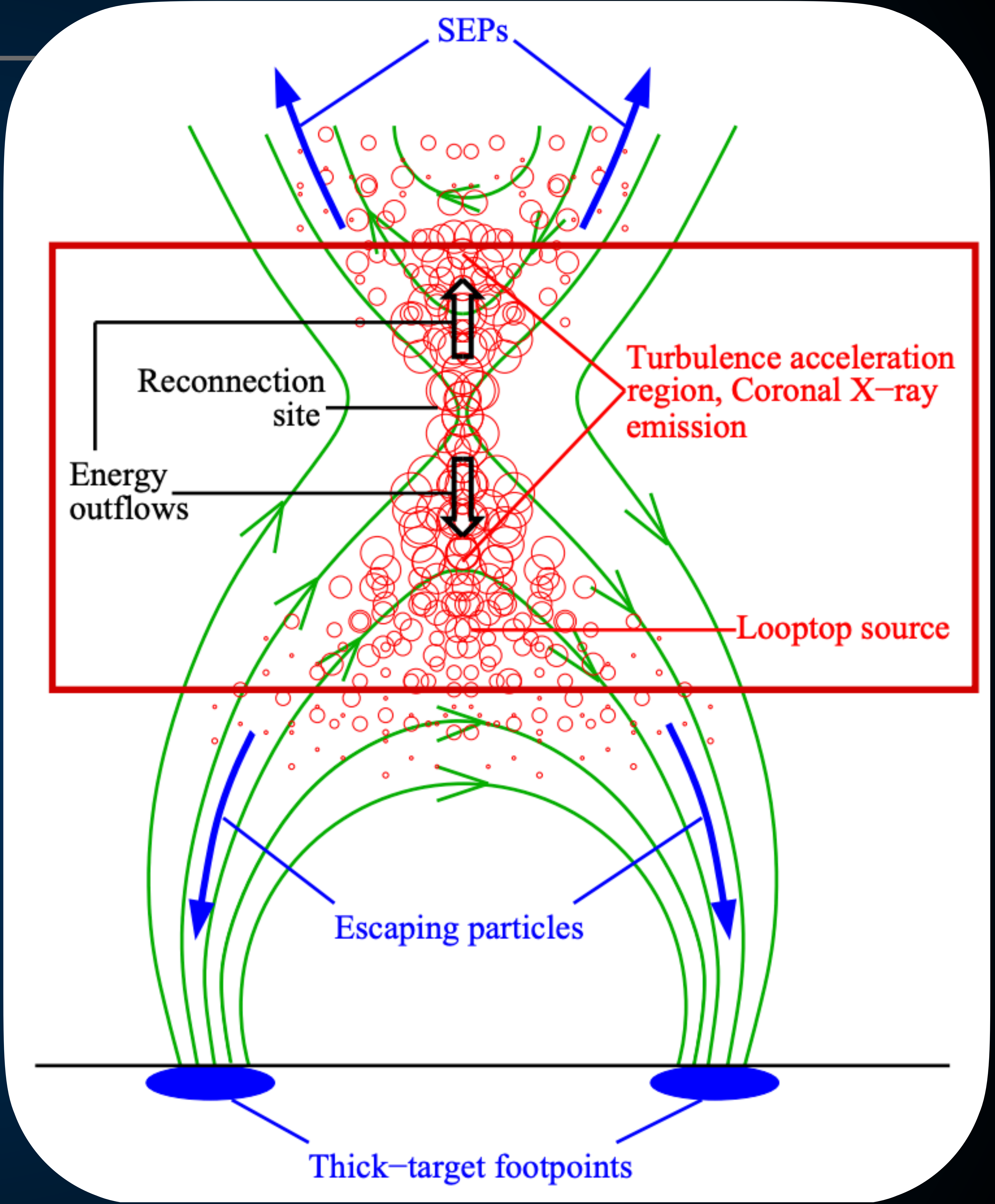


WHY CARE ABOUT GAMMA RAYS?

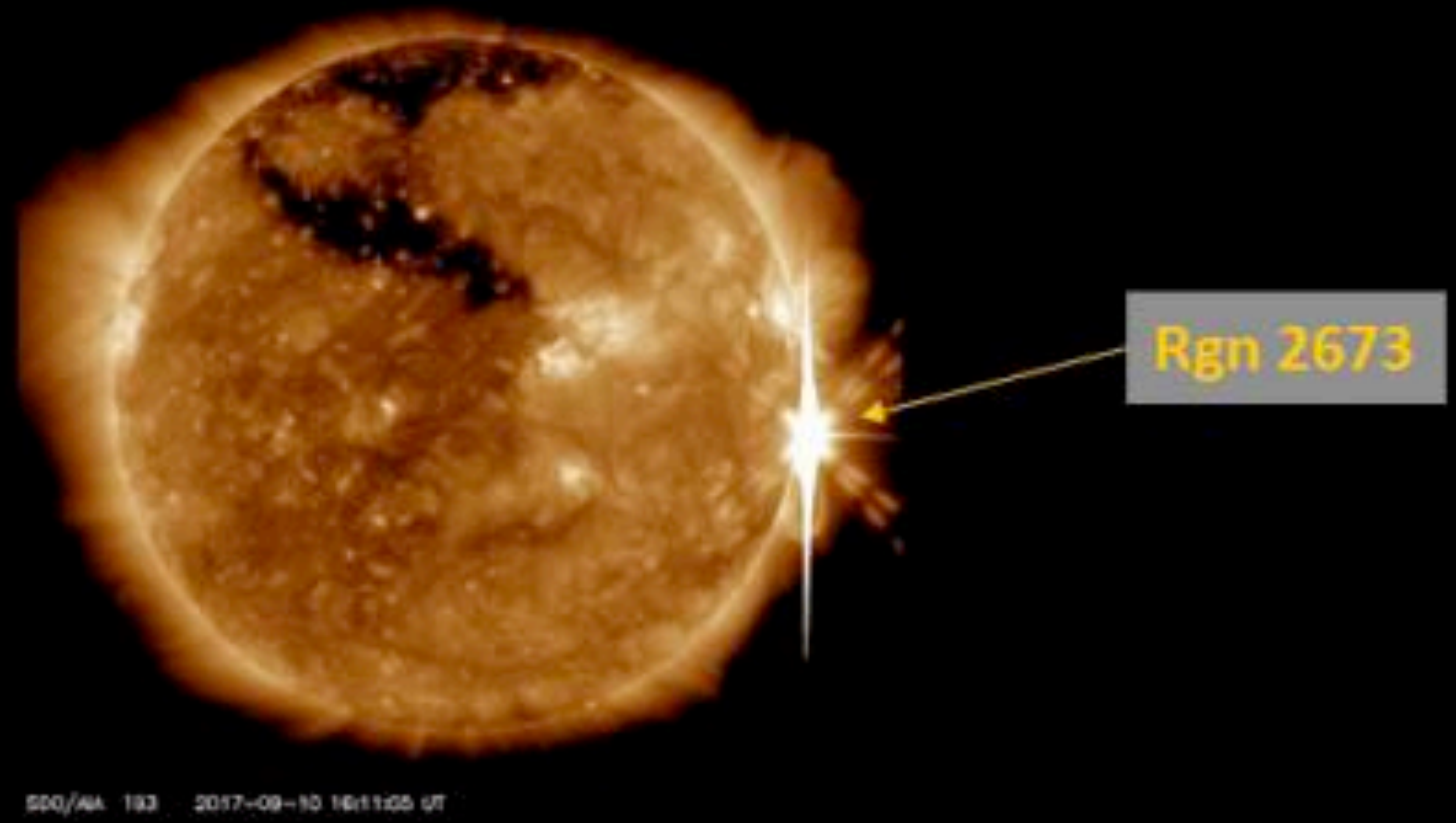


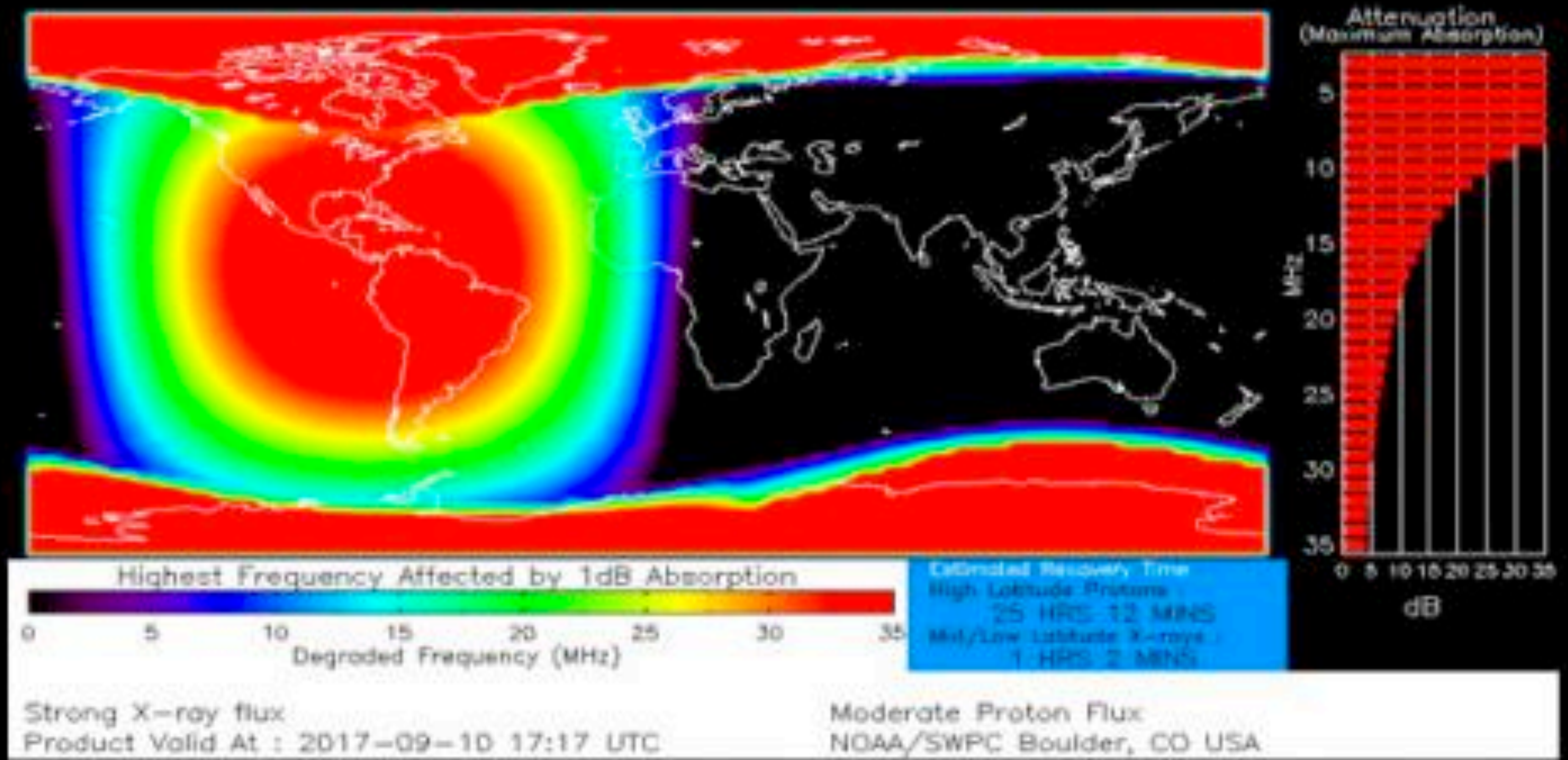
WHY CARE ABOUT GAMMA RAYS?





Strong Radio Blackout 10 Sep 17 at 1606 UTC





R3

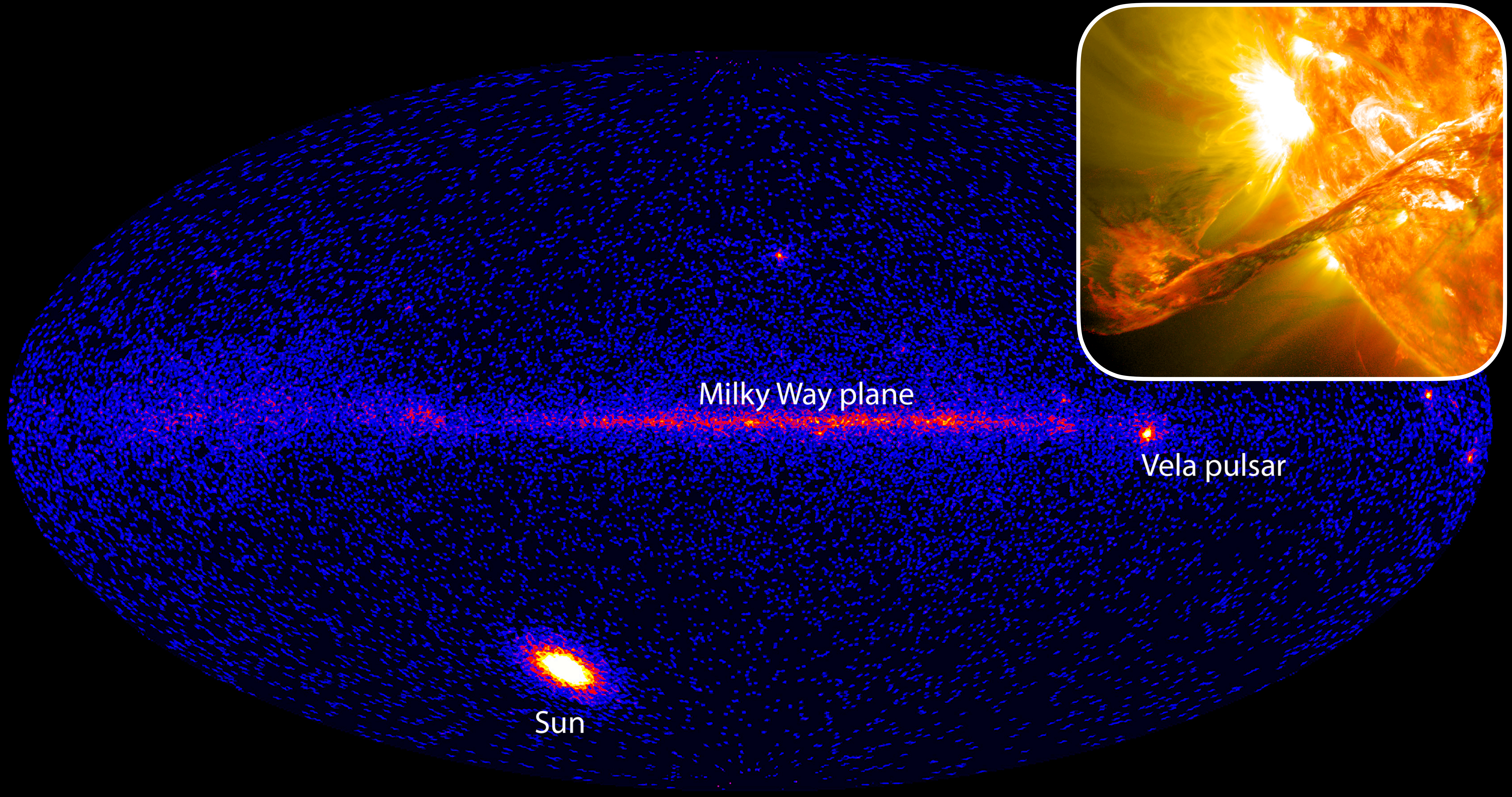
<u>PRIMARY AREA of IMPACTS</u>

Large portions of sunlit side of Earth

<u>POSSIBLE EFFECTS</u>

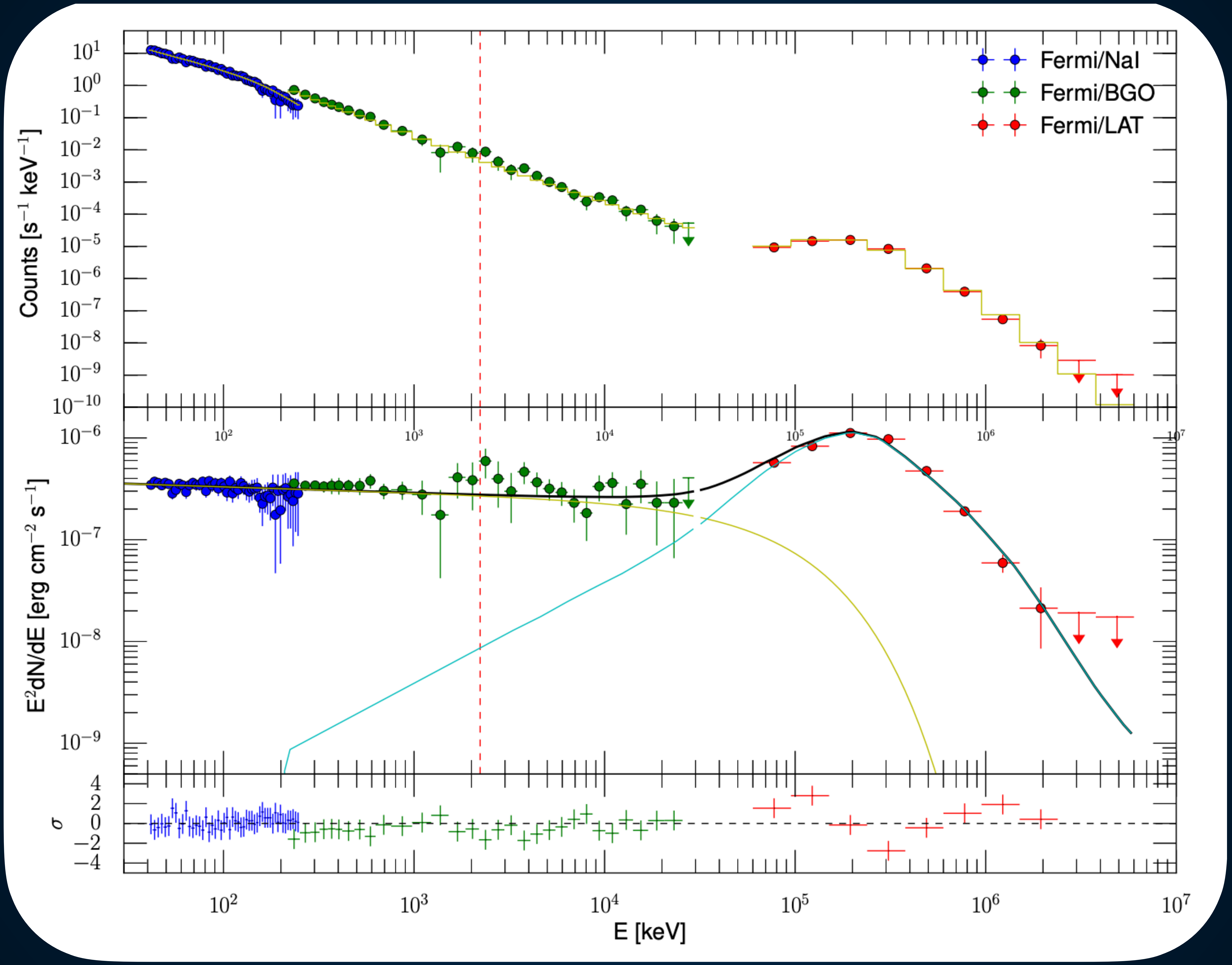
<u>HF Radio</u>: Wide area of blackouts; loss of contact for up to an hour over sunlit side of Earth

<u>Navigation</u>: Low frequency communication degraded for about an hour



Milky Way plane
Vela pulsar
Sun

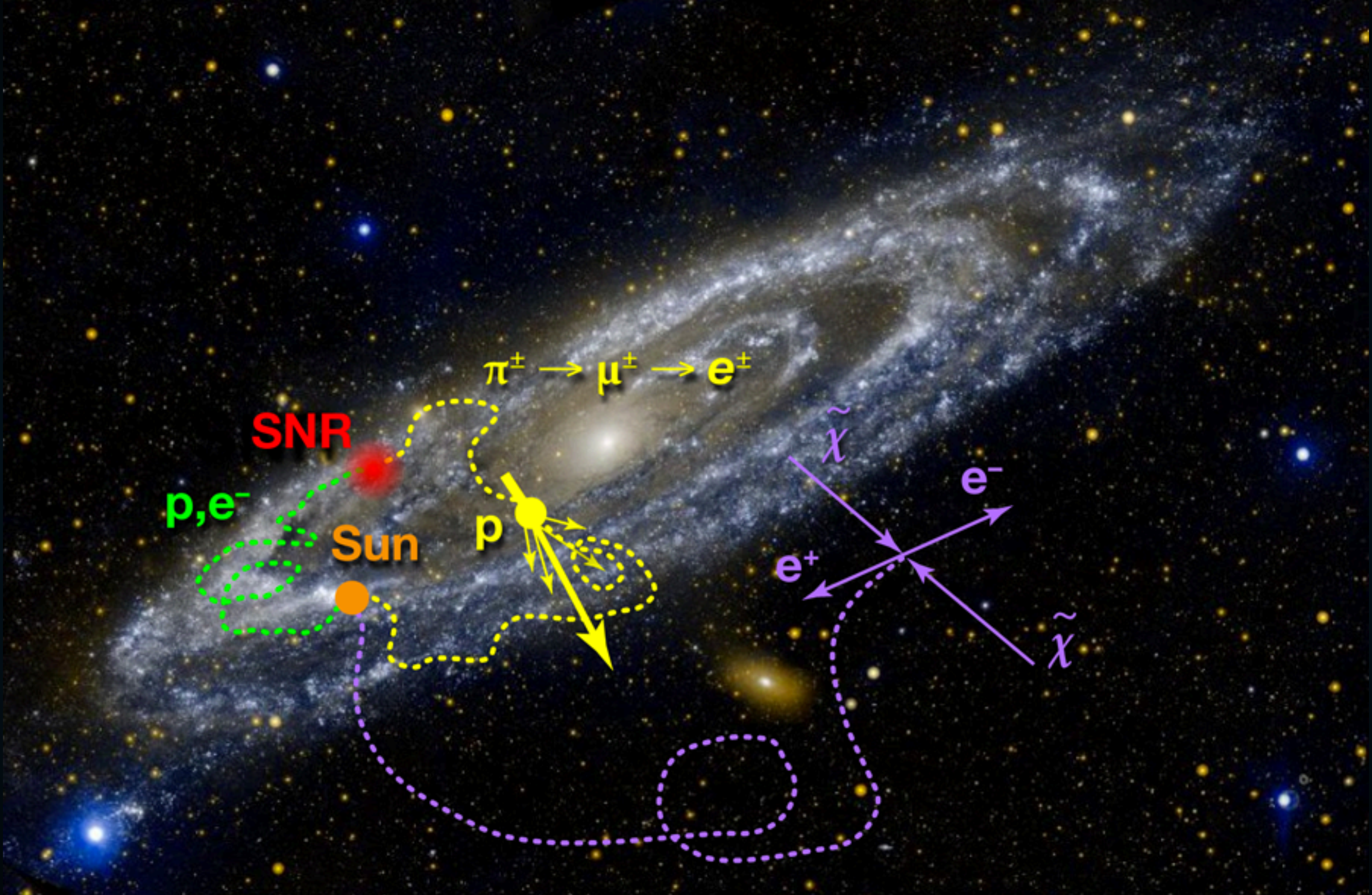
GAMMA-RAYS - HOW?



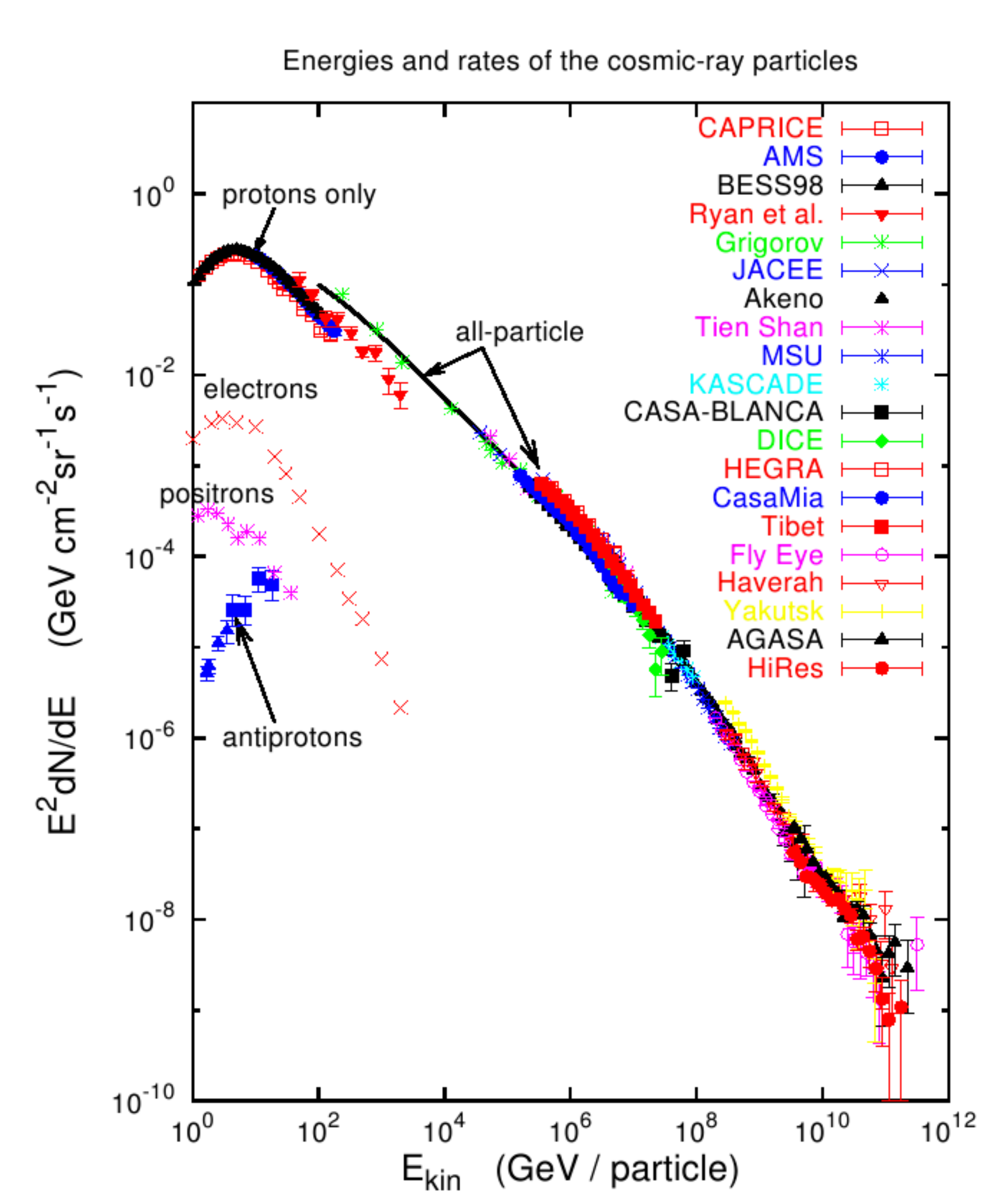
Solar Flare gamma-rays are low energy (E_{max} = 4 GeV)

Exploiting the Energy of

Galactic Cosmic-Rays



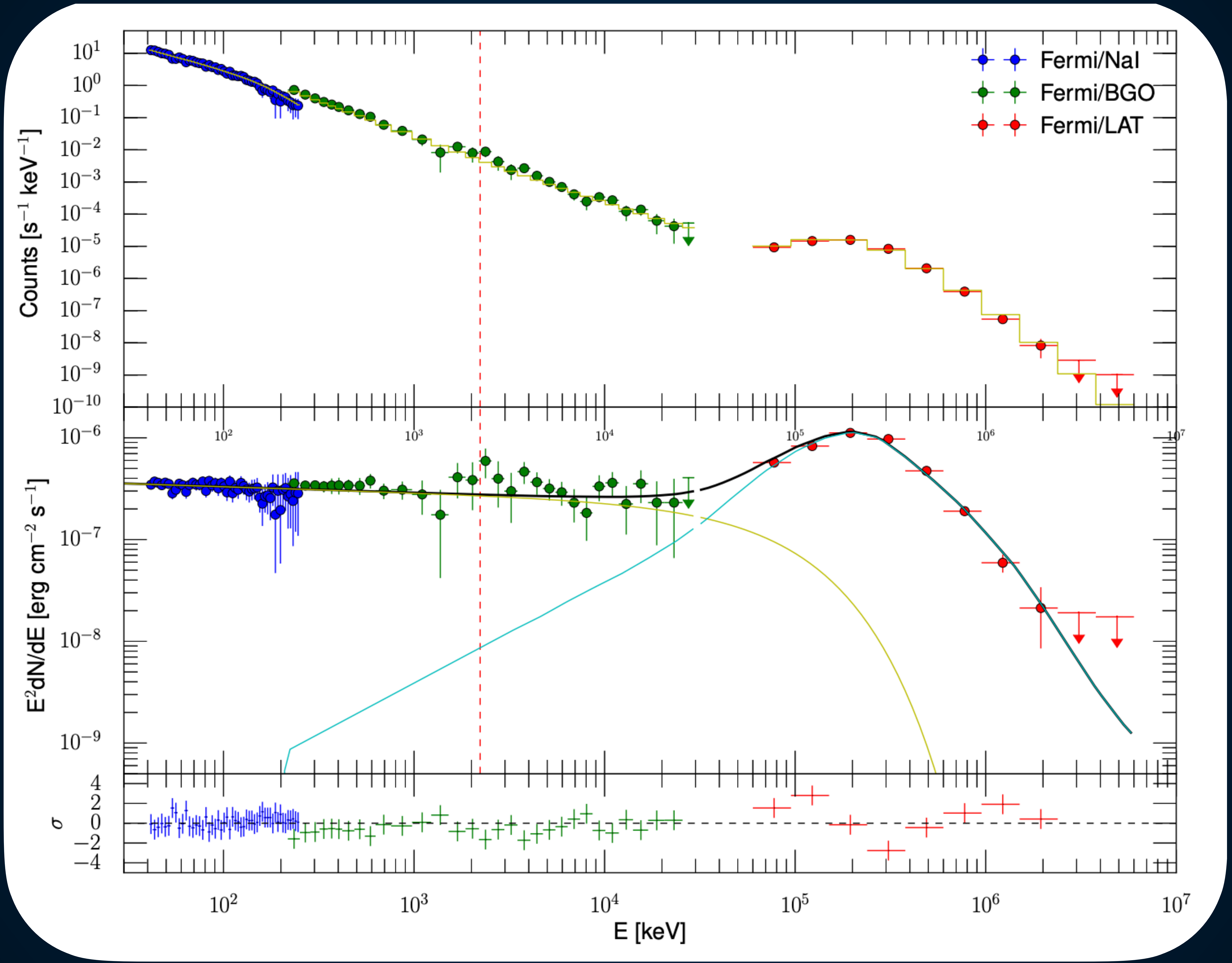
$\pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$
SNR
p, e^{-}
Sun
p
$\tilde{\chi}$
e^{-}
e^{+}
$\tilde{\chi}$



Energies and rates of the cosmic-ray particles
protons only
all-particle
electrons
positrons
antiprotons
CAPRICE
AMS
BESS98
Ryan et al.
Grigorov
JACEE
Akeno
Tien Shan
MSU
KASCADE
CASA-BLANCA
DICE
HEGRA
CasaMia
Tibet
Fly Eye
Haverah
Yakutsk
AGASA
HiRes
E^2dN/dE (GeV $cm^{-2}sr^{-1}s^{-1}$)
E_{kin} (GeV / particle)

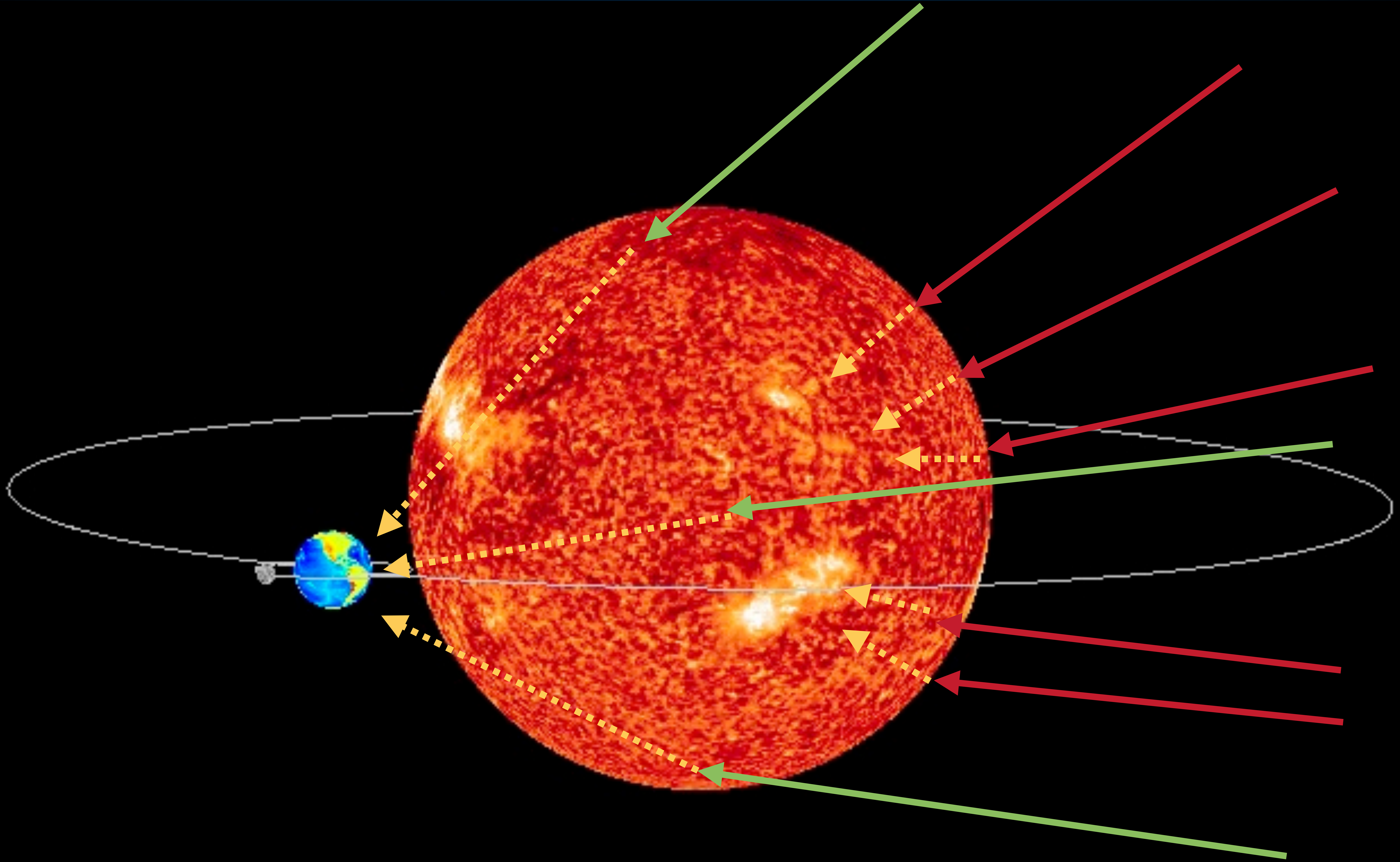

Heliosphere
Interstellar space
Heliopause
Voyager-1
Sun
Solar wind
Termination shock
Cosmic rays

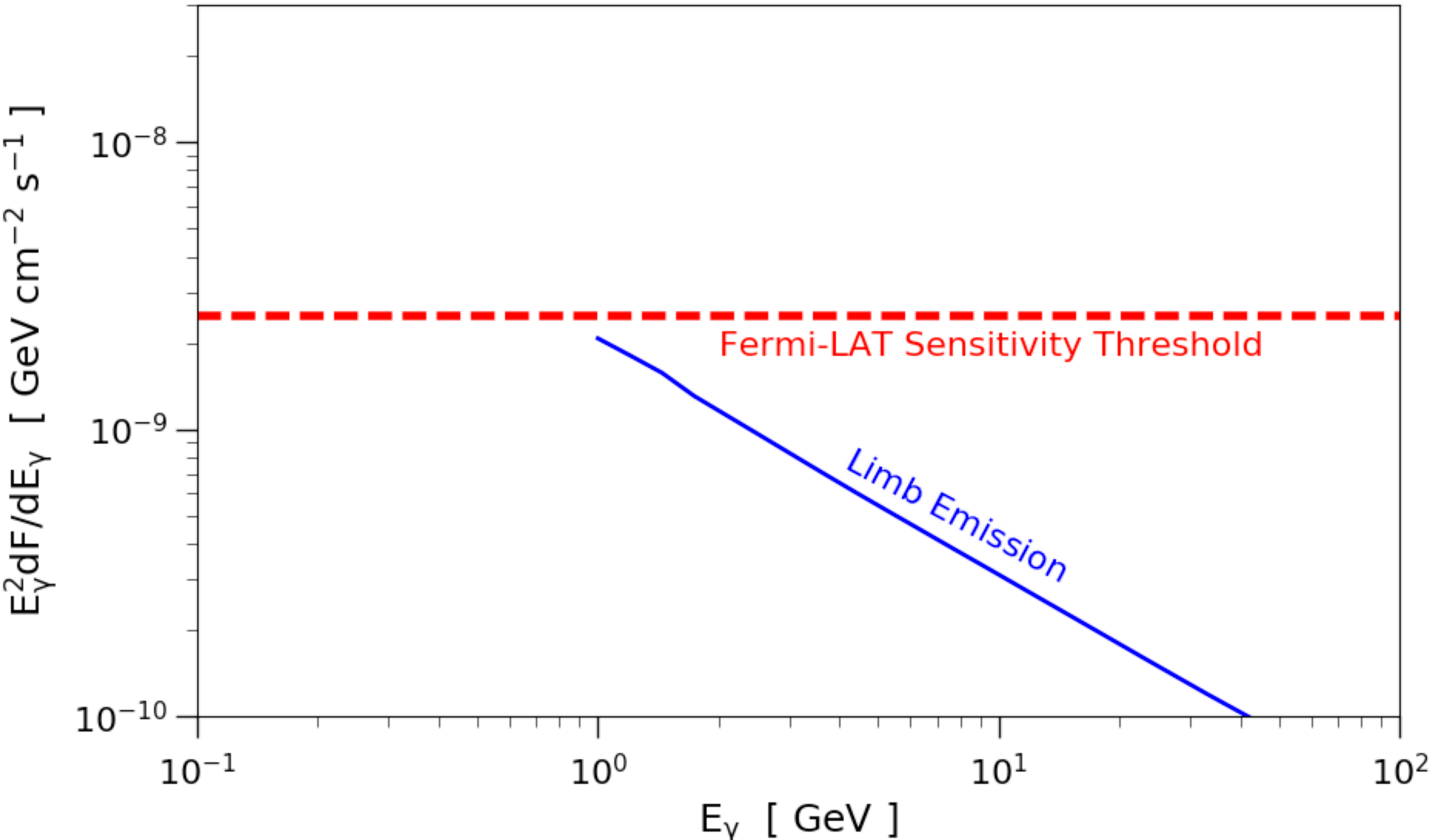
GAMMA-RAYS - HOW?



Solar Flare gamma-rays are low energy (E_{max} = 4 GeV)


High energy photon
High energy electron
Low energy electron
Low energy photon





$E_\gamma^2 dF/dE_\gamma$ [GeV cm^{-2} s^{-1}]
10^{-8}
10^{-9}
10^{-10}
Fermi-LAT Sensitivity Threshold
Limb Emission
10^{-1}
10^{0}
10^{1}
10^{2}
E_γ [GeV]


1991ApJ...382..652S
THE ASTROPHYSICAL JOURNAL, 382:652–666, 1991 December 1
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SIGNATURES OF COSMIC-RAY INTERACTIONS ON THE SOLAR SURFACE
D. SECKEL, TODOR STANEV, AND T. K. GAISSER
Bartol Research Institute, University of Delaware, Newark, DE 19716
Received 1991 March 21; accepted 1991 June 5
ABSTRACT

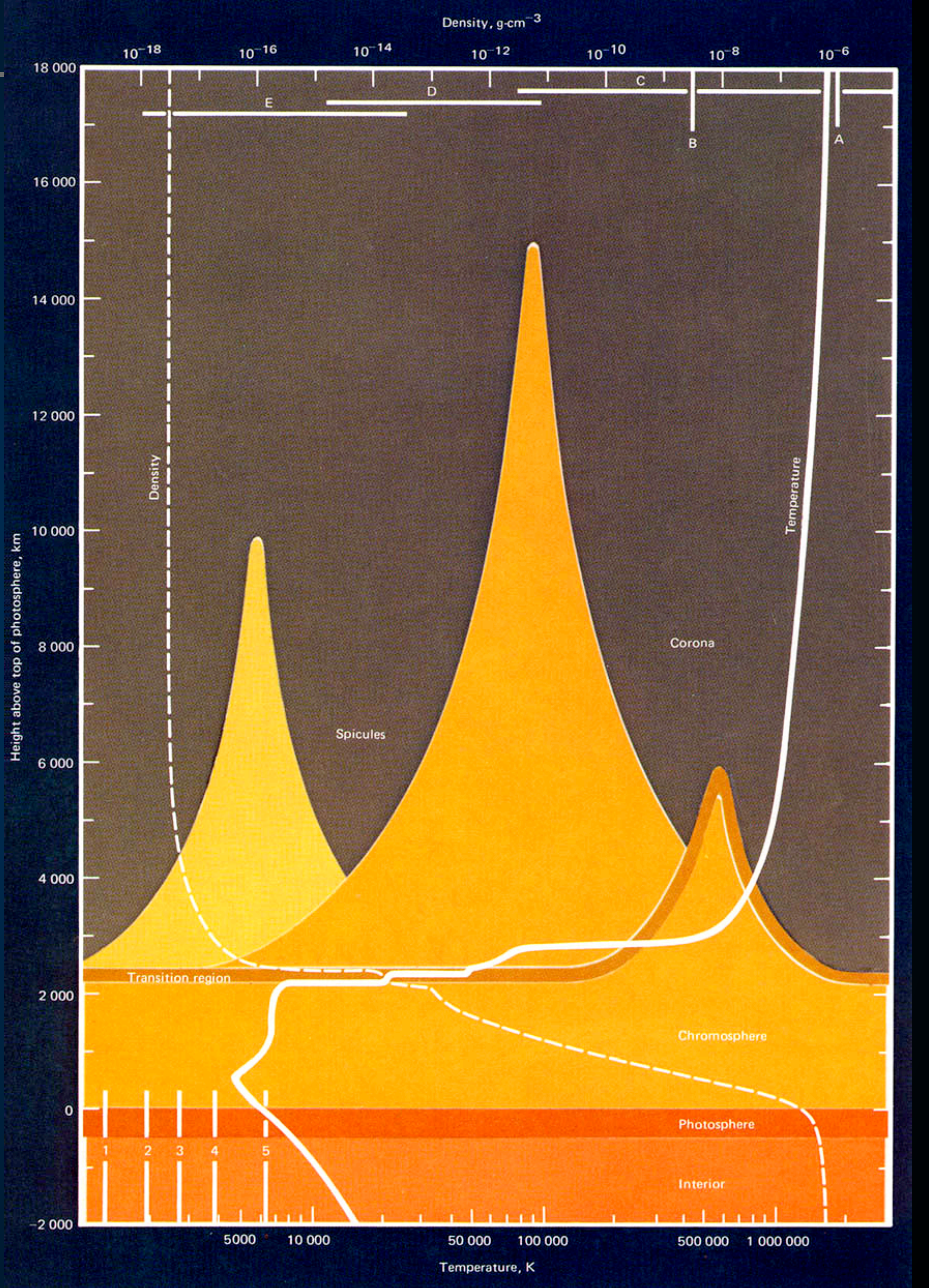
HADRONIC GAMMA-RAYS - HOW?

$$r_g/\text{meter} = 3.3 \times \frac{(\gamma mc^2/\text{GeV})(v_\perp/c)}{(|q|/e)(B/\text{Tesla})}$$

Photosphere Magnetic Field: 1-10 G

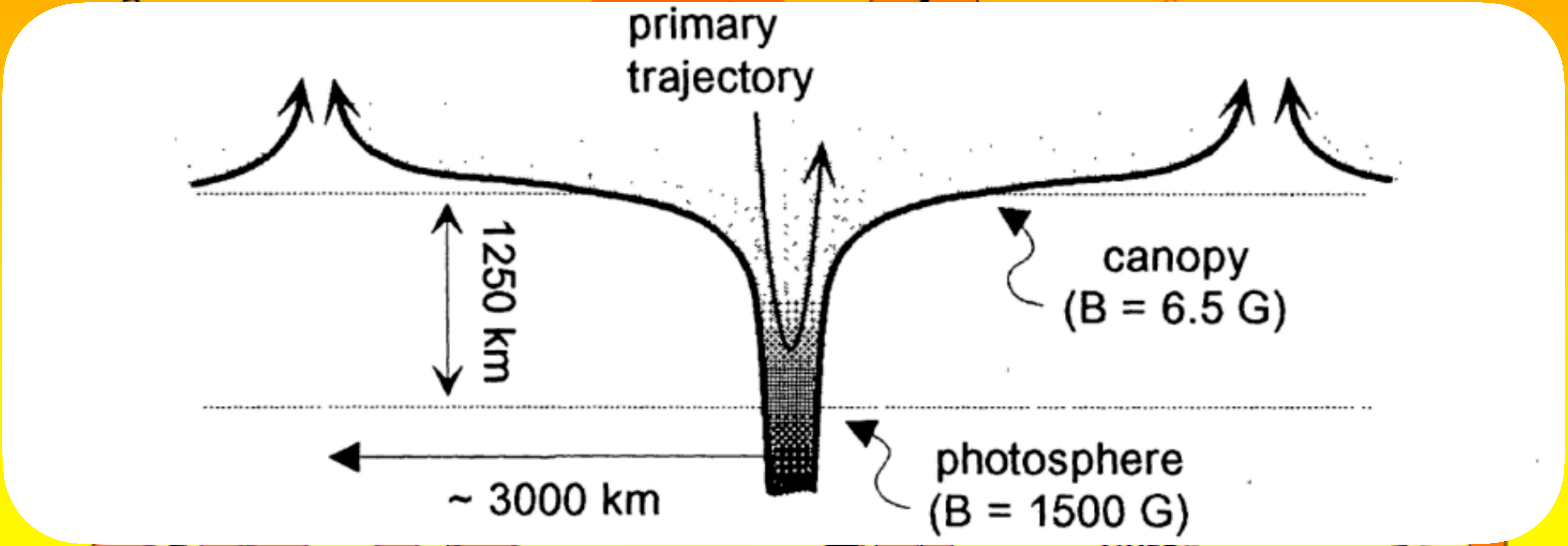
Gyroradius (100 GeV): 3300 km

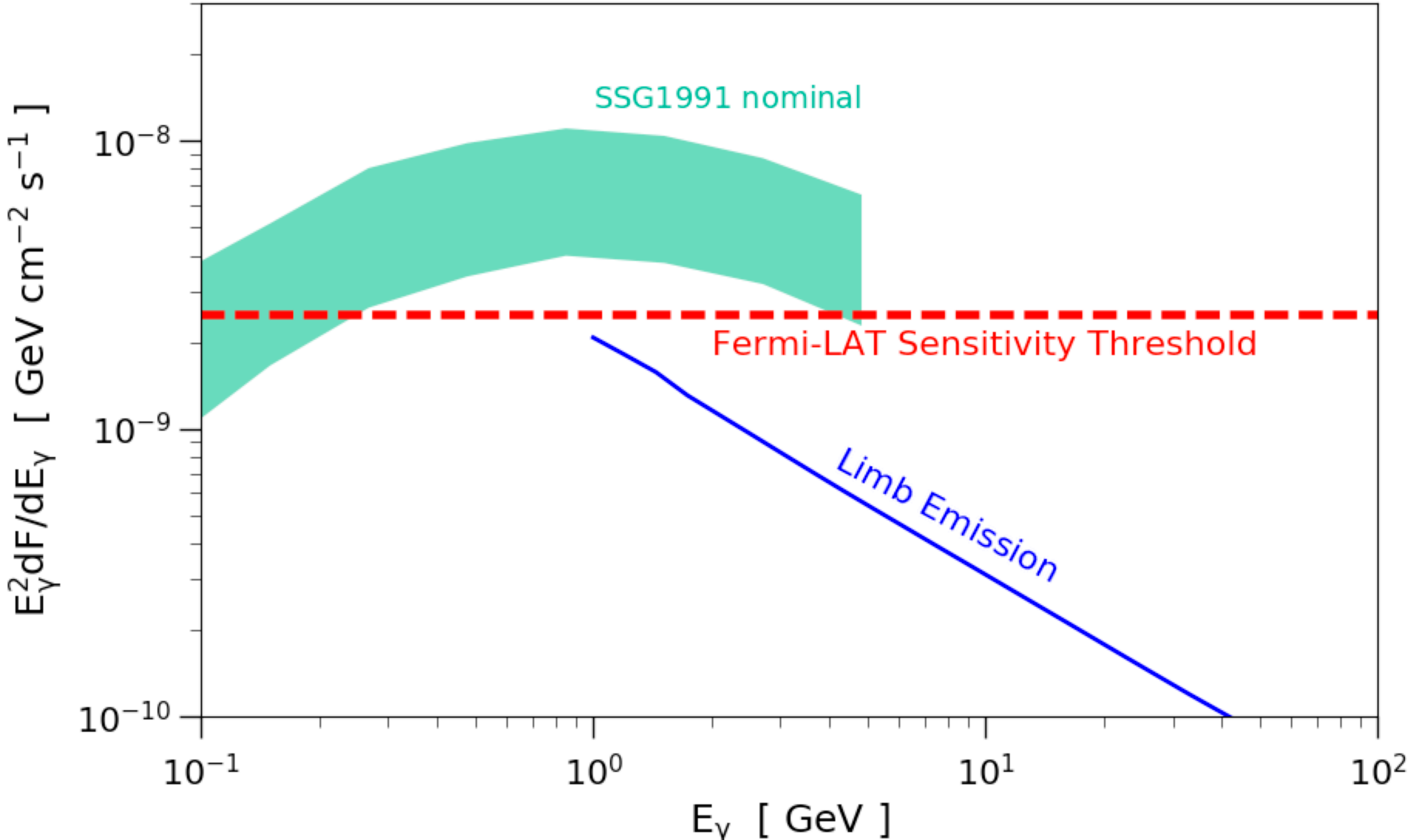
- **Cosmic rays encounter a grammage of 330 g cm^{-2}**
- **Cosmic rays die before reflecting within the solar surface.**



$$r_g/\text{meter} = 3.3 \times \frac{(\gamma mc^2/\text{GeV})(v_\perp/c)}{(|q|/e)(B/\text{Tesla})}$$

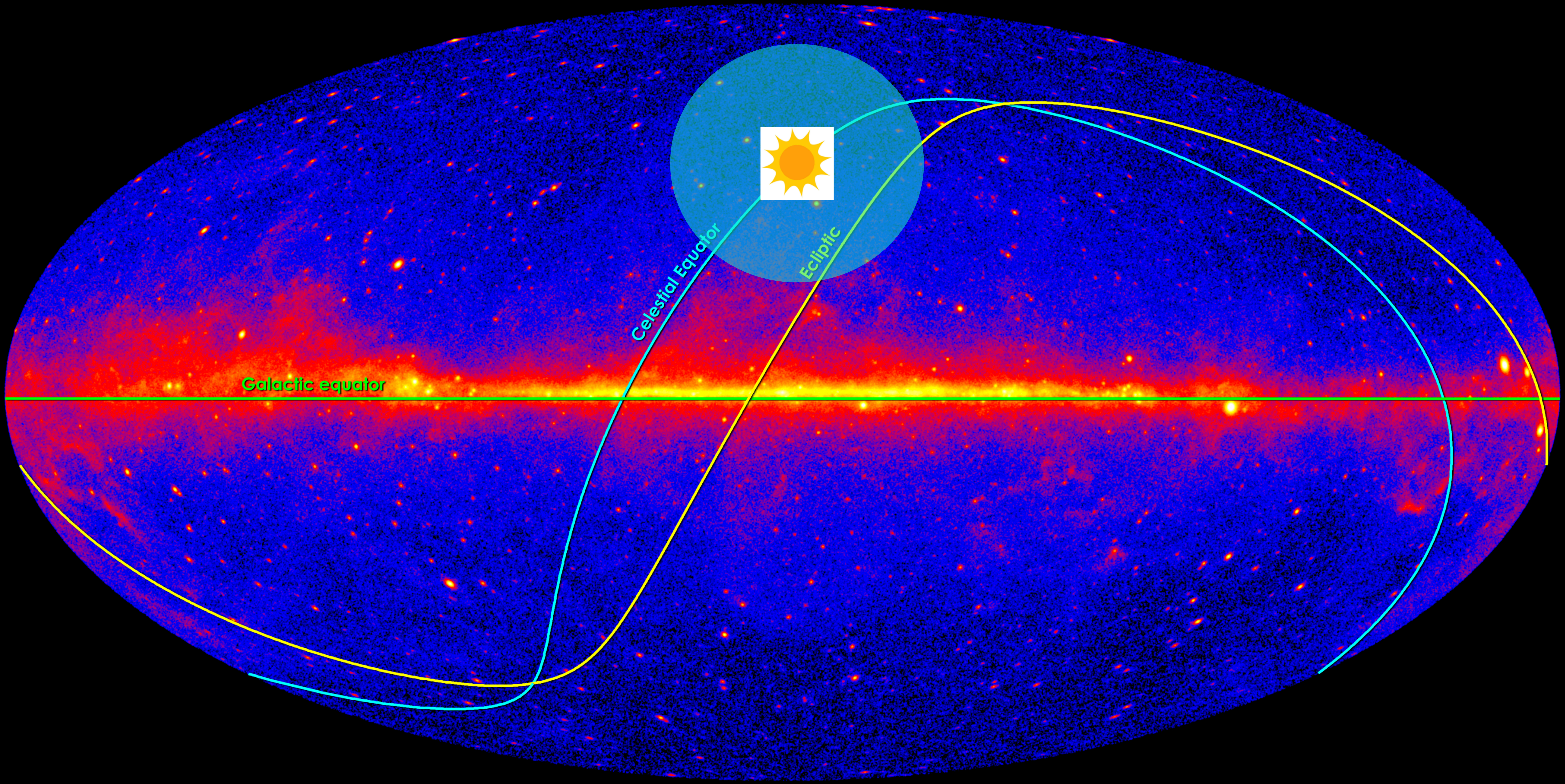
$$r_g/\text{meter} = 3.3 \times \frac{(\gamma m c^2/\text{GeV})(v_\perp/c)}{(|q|/e)(B/\text{Tesla})}$$



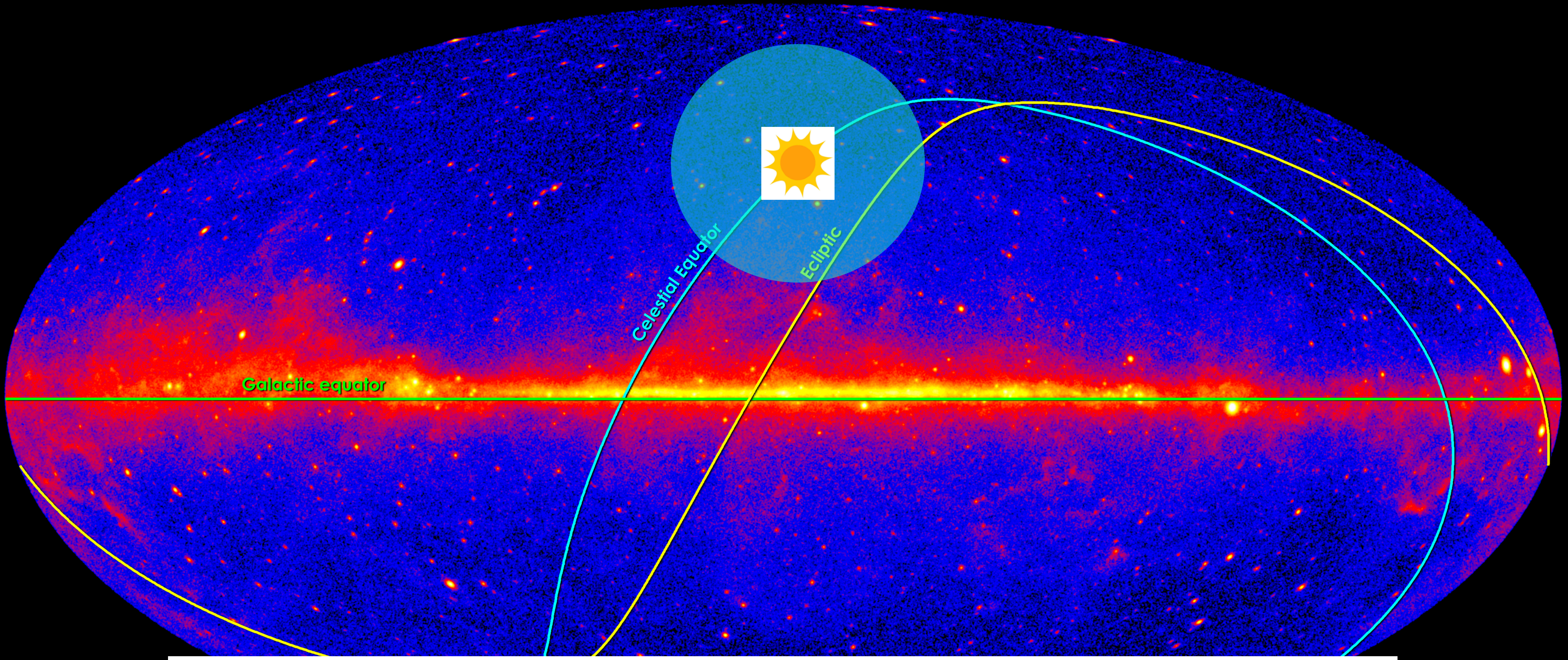

SSG1991 nominal
Fermi-LAT Sensitivity Threshold
Limb Emission
$E_\gamma^2 dF/dE_\gamma$ [GeV cm^{-2} s^{-1}]
10^{-8}
10^{-9}
10^{-10}
10^{-1}
10^{0}
10^{1}
10^{2}
E_γ [GeV]


Analyzing the Fermi-LAT Data

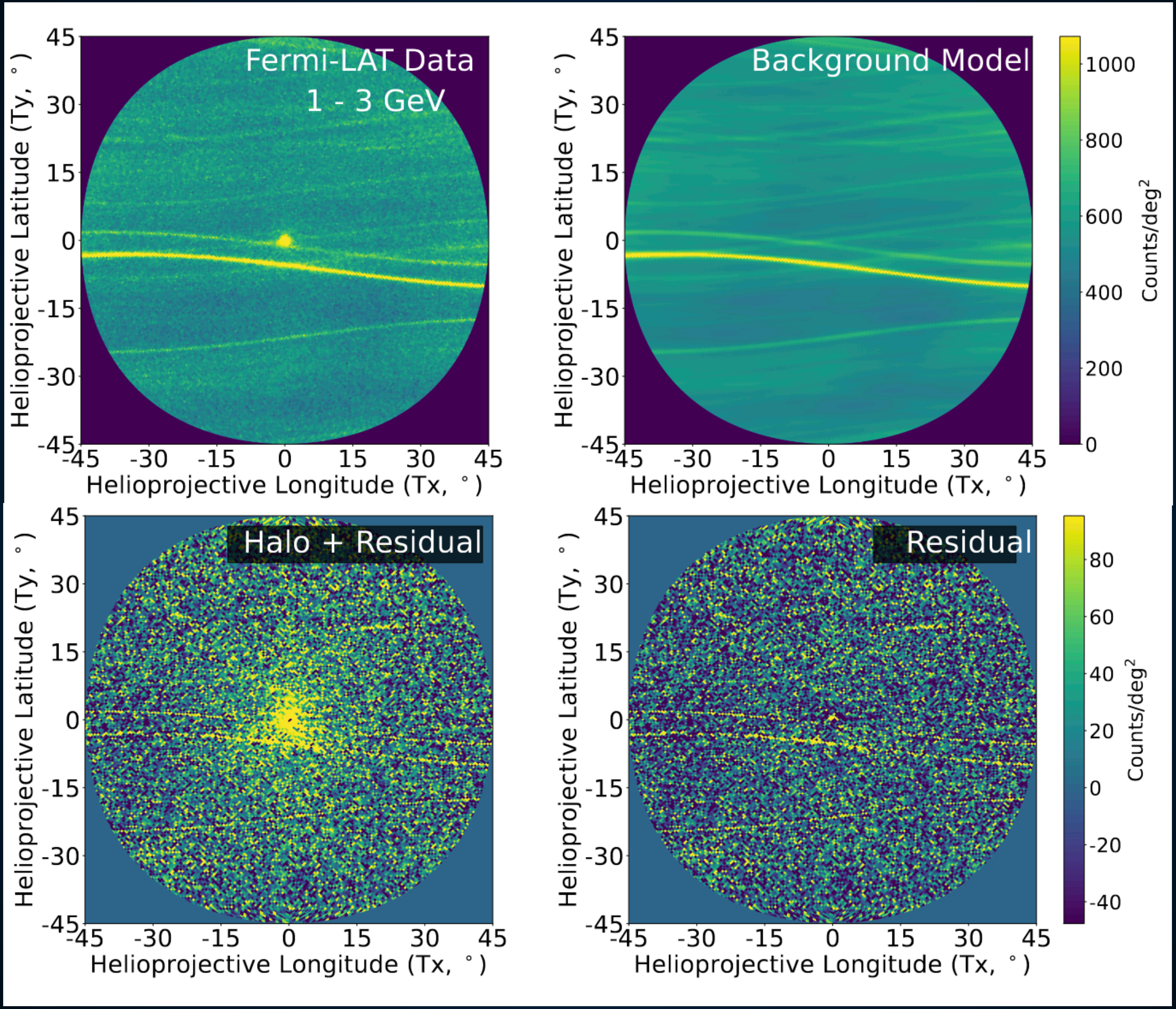
A Completely Data Driven Background Model



A Completely Data Driven Background Model



$$N_b(T_x, T_y) = \sum_{\mathrm{RA,Dec}} \frac{N_o(\mathrm{RA, Dec})}{\epsilon(\mathrm{RA, Dec})} \times \sum_{\mathrm{t}} \epsilon^*(\mathrm{RA, Dec}, T_x, T_y, t)$$



Fermi-LAT Data
1 - 3 GeV
Background Model
Halo + Residual
Residual
Helioprojective Latitude (Ty, °)
Helioprojective Longitude (Tx, °)
45
30
15
0
-15
-30
-45
1000
800
600
400
200
0
Counts/deg^2
80
60
40
20
0
-20
-40
Counts/deg^2

FERMILAB-PUB-25-0301-T

First Observations of Solar Halo Gamma Rays Over a Full Solar Cycle

Tim Linden [1,2,*] Jung-Tsung Li [3] Bei Zhou [4,5] Isabelle John [6,7]
Milena Crnogorčević [1] Annika H. G. Peter [3,8,9] and John F. Beacom [3,8,9]

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[3] *Center for Cosmology and AstroParticle Physics, The Ohio State University, Columbus, OH 43210, USA*
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[6] *Dipartimento di Fisica, Università degli Studi di Torino, via P. Giuria, 1 10125 Torino, Italy*
[7] *INFN — Istituto Nazionale di Fisica Nucleare, Sezione di Torino, via P. Giuria 1, 10125 Torino, Italy*
[8] *Department of Physics, The Ohio State University, Columbus, OH 43210, USA*
[9] *Department of Astronomy, The Ohio State University, Columbus, OH 43210, USA*

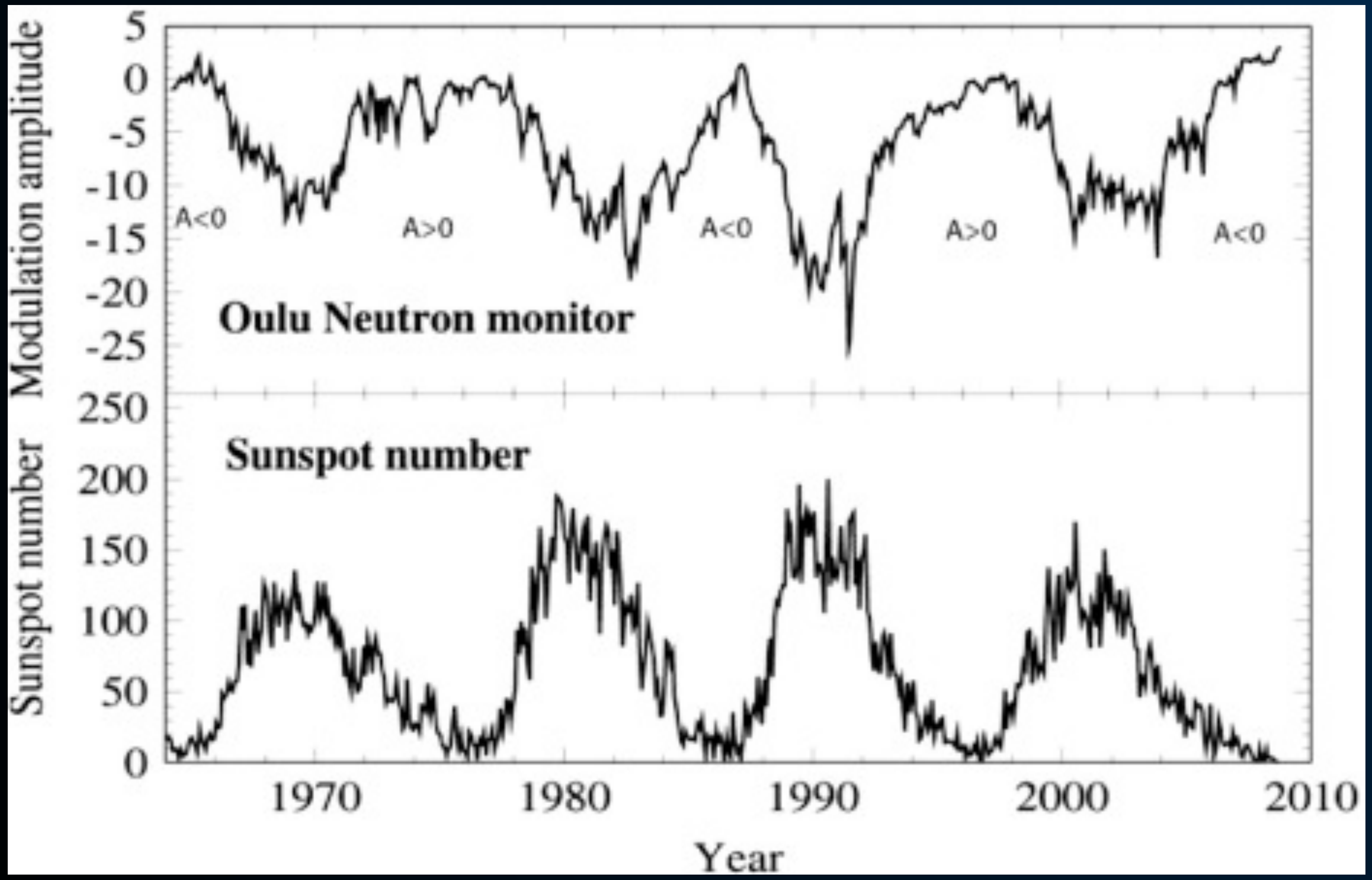
We analyze 15 years of *Fermi*-LAT data and produce a detailed model of the Sun's inverse-Compton scattering emission (solar halo), which is powered by interactions between ambient cosmic-ray electrons and positrons with sunlight. By developing a novel analysis method to analyze moving sources, we robustly detect the solar halo at energies between 31.6 MeV and 100 GeV, and angular extensions up to 45° from the Sun, providing new insight into spatial regions where there are no direct measurements of the galactic cosmic-ray flux. The large statistical significance of our signal allows us to sub-divide the data and provide the first γ-ray probes into the time-variation and azimuthal asymmetry of the solar modulation potential, finding time-dependent changes in solar modulation both parallel and perpendicular to the ecliptic plane. Our results are consistent with (but with independent uncertainties from) local cosmic-ray measurements, unlocking new probes into both astrophysical and beyond-standard-model processes near the solar surface.

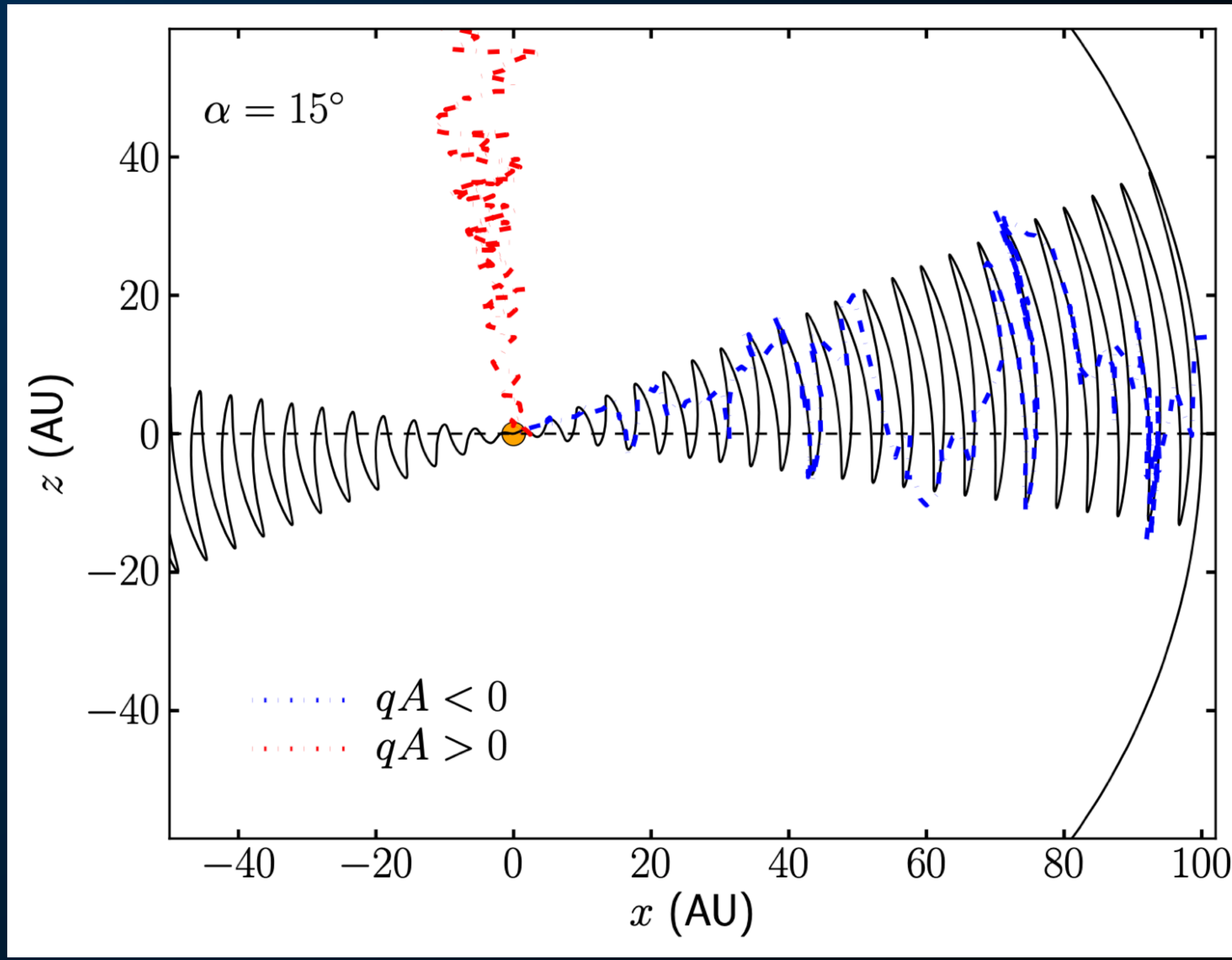
Solar Modulation

Electrons and Positrons are modulated by the solar wind and magnetic field:

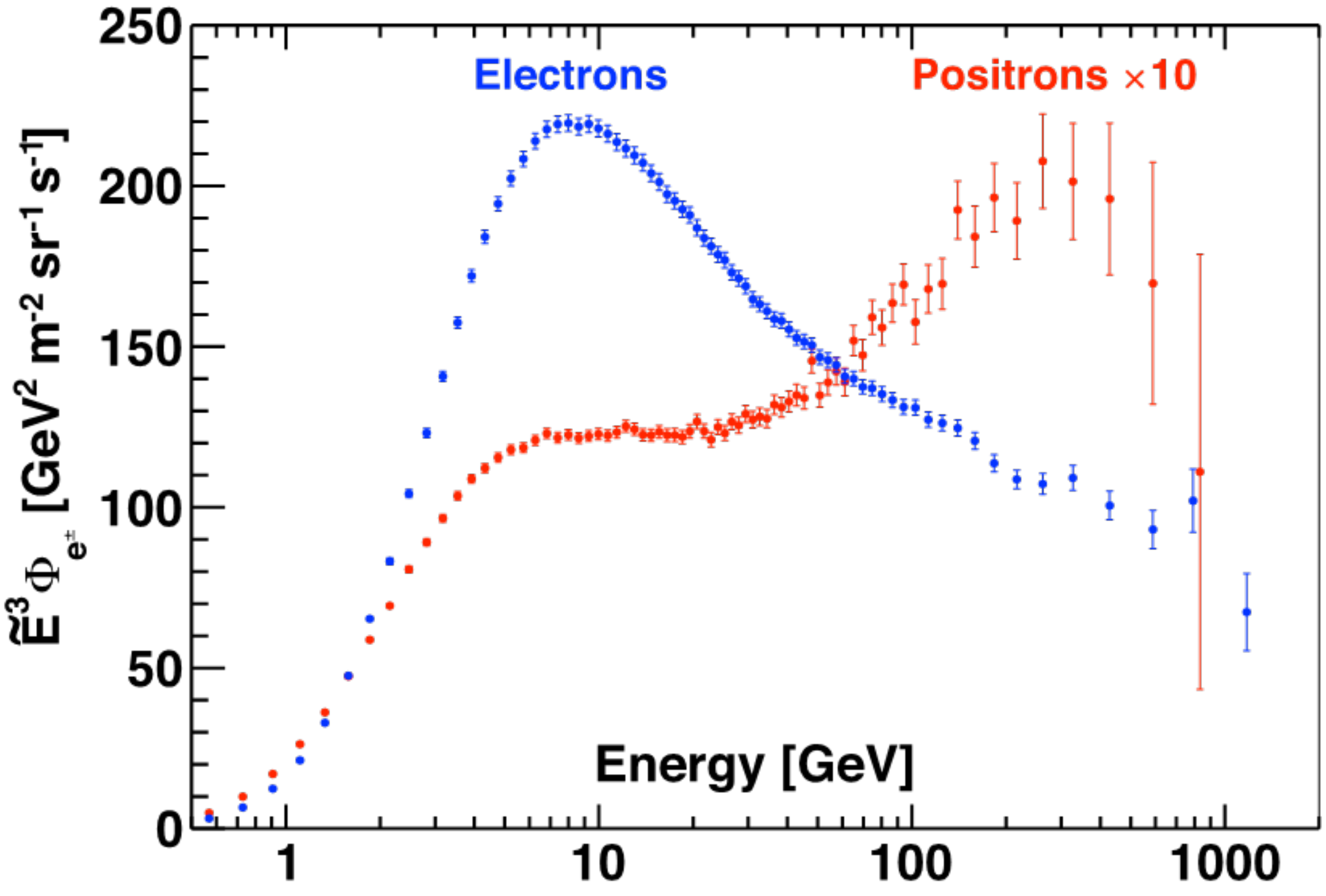
$$\frac{dN^{\oplus}}{dE_{kin}}(E_{kin}) = \frac{(E_{kin}+m)^2 - m^2}{(E_{kin}+m+\mid Z \mid e\Phi)^2 - m^2} \frac{dN^{\mathrm{ISM}}}{dE_{kin}}(E_{kin}+\mid Z \mid e\Phi)$$

Valdes-Galicia & Gonzalez (2016)

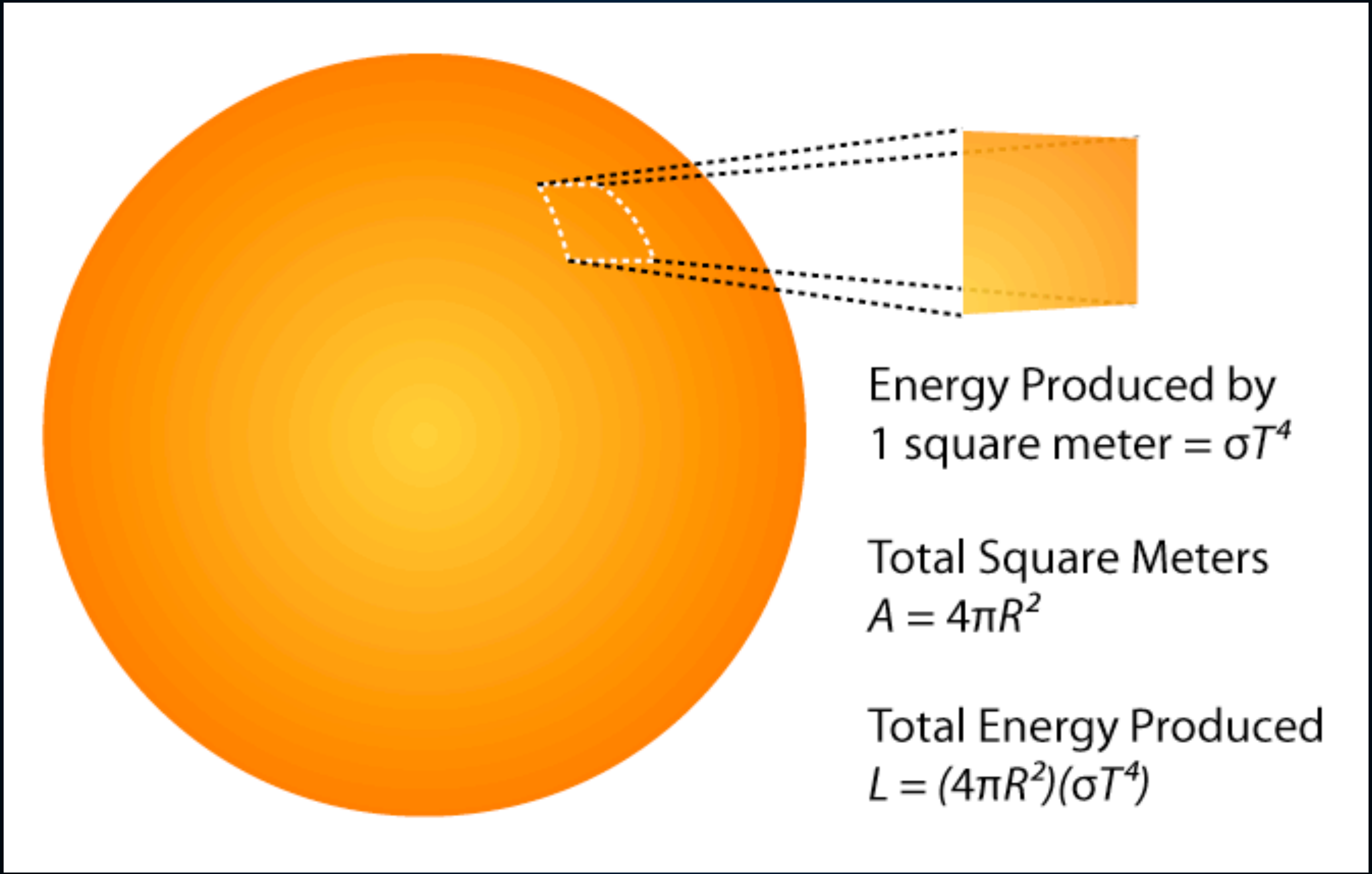




Solar Modulation



Solar Modulation

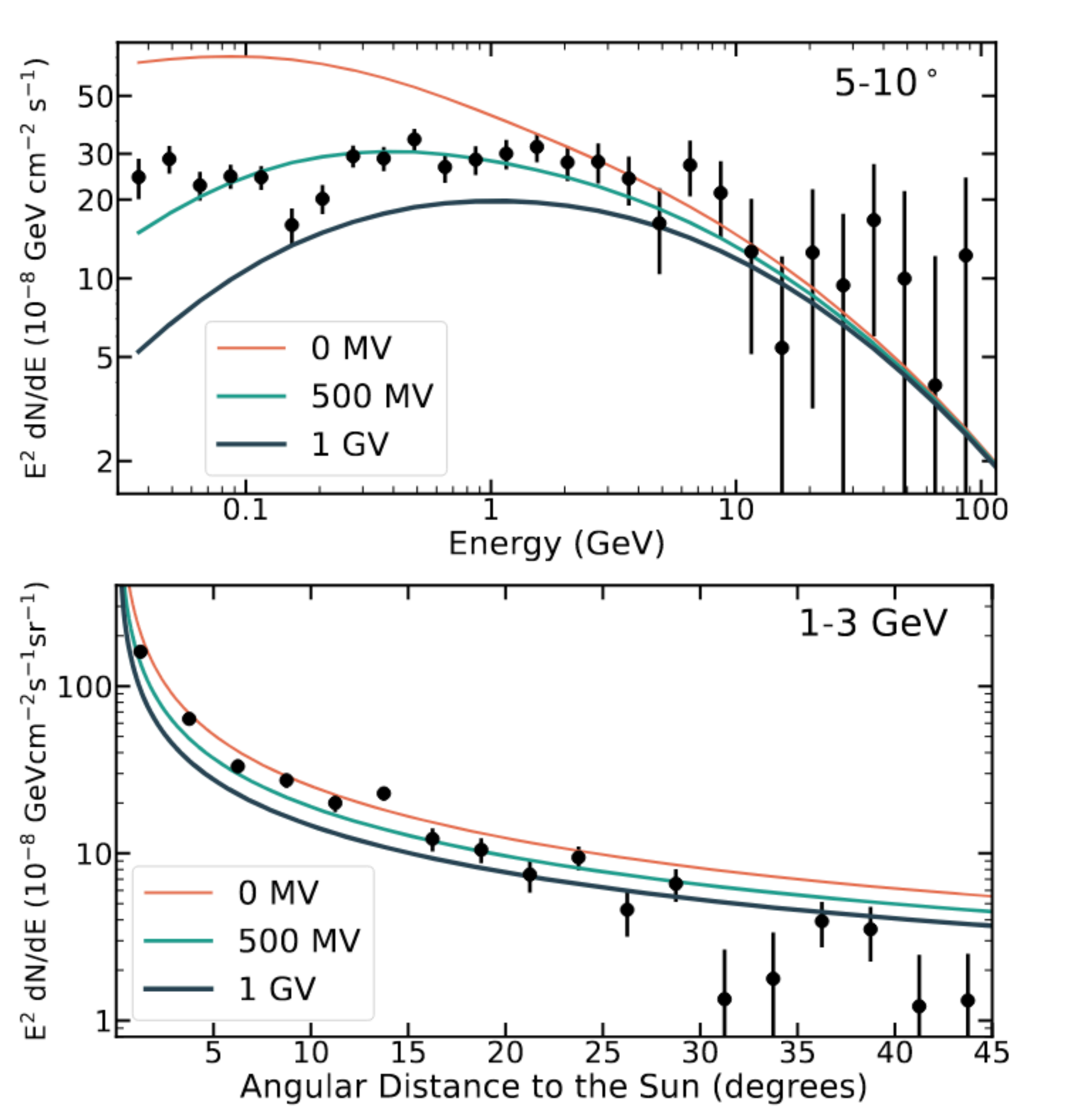


A Perfect Theoretical and Observational Match

TL et al. (2505.04625)

Extremely well measured inverse-Compton spectrum and morphology.

- **30 MeV-100 GeV in energy**
- **0-45 degrees in radius**



Matches with No Degrees of Freedom!

Extremely well measured inverse-Compton spectrum and morphology.

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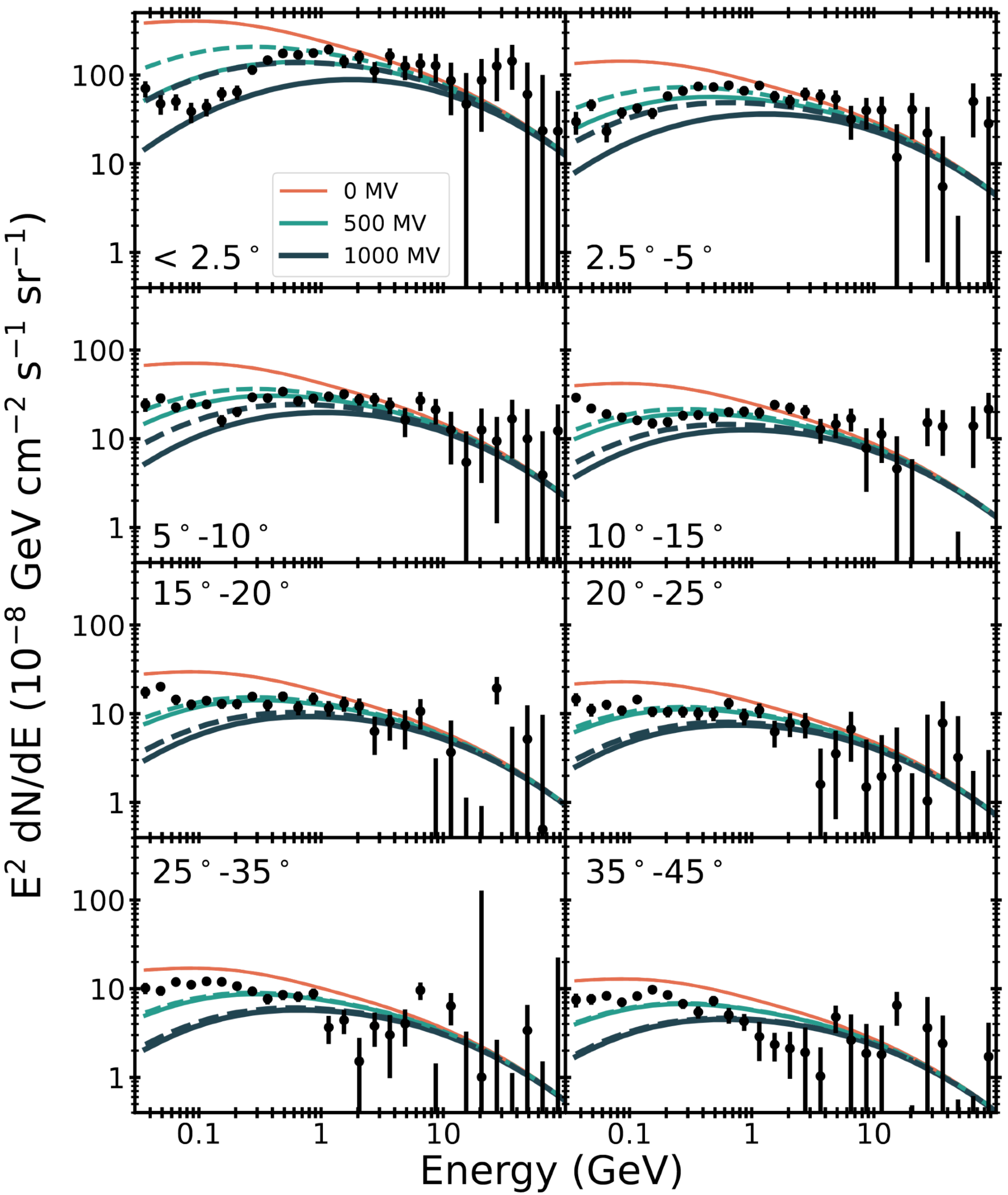
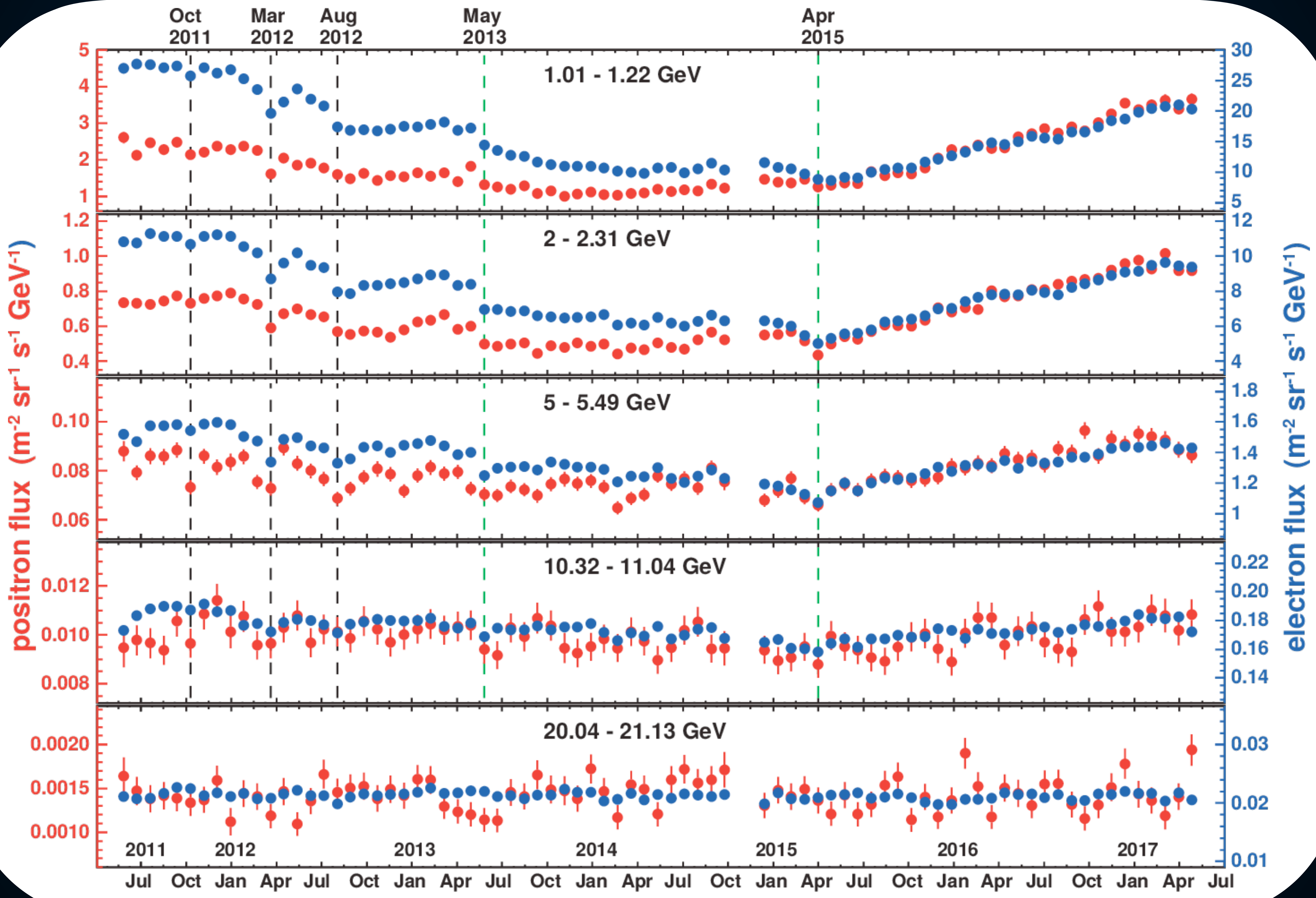


A Perfect Theoretical and Observational Match

AMS-02 Collaboration (PRL, 121 051102)



A Perfect Theoretical and Observational Match

TL et al. (2505.04625)

Our models of cosmic-ray propagation work up to the solar surface.


1991ApJ...382..652S
THE ASTROPHYSICAL JOURNAL, 382:652–666, 1991 December 1
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SIGNATURES OF COSMIC-RAY INTERACTIONS ON THE SOLAR SURFACE
D. SECKEL, TODOR STANEV, AND T. K. GAISSER
Bartol Research Institute, University of Delaware, Newark, DE 19716
Received 1991 March 21; accepted 1991 June 5
ABSTRACT

First Observation of Time Variation in the Solar-Disk Gamma-Ray Flux with Fermi

Kenny C. Y. Ng,[1,2,*] John F. Beacom,[1,2,3,†] Annika H. G. Peter,[1,2,3,‡] and Carsten Rott[4,§]

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[2] *Department of Physics, Ohio State University, Columbus, OH 43210*
[3] *Department of Astronomy, Ohio State University, Columbus, OH 43210*
[4] *Department of Physics, Sungkyunkwan University, Suwon 440-746, Korea*

(Dated: 7 November 2015)

The solar disk is a bright gamma-ray source. Surprisingly, its flux is about one order of magnitude higher than predicted. As a first step toward understanding the physical origin of this discrepancy, we perform a new analysis in 1–100 GeV using 6 years of public Fermi-LAT data. Compared to the previous analysis by the Fermi Collaboration, who analyzed 1.5 years of data and detected the solar disk in 0.1–10 GeV, we find two new and significant results: 1. In the 1–10 GeV flux (detected at $> 5\sigma$), we discover a significant time variation that anticorrelates with solar activity. 2. We detect gamma rays in 10–30 GeV at $> 5\sigma$, and in 30–100 GeV at $> 2\sigma$. The time variation strongly indicates that solar-disk gamma rays are induced by cosmic rays and that solar atmospheric magnetic fields play an important role. Our results provide essential clues for understanding the underlying gamma-ray production processes, which may allow new probes of solar atmospheric magnetic fields, cosmic rays in the solar system, and possible new physics. Finally, we show that the Sun is a promising new target for ground-based TeV gamma-ray telescopes such as HAWC and LHAASO.

PACS numbers: 95.85.Pw, 96.50.S-, 13.85.Qk, 96.50.Vg

I. INTRODUCTION

The Sun is well studied and understood with a broad set of messengers at different energies. For example, the optical photon and MeV neutrino spectra confirm a de-

angular size of the Sun ($\simeq 0.5°$); we denote it (plus any potential non-cosmic-ray contribution) as the solar-disk component.

Theoretical estimation of both components requires taking into account the effects of solar magnetic activity.

Unexpected Dip in the Solar Gamma-Ray Spectrum

Qing-Wen Tang,[1,2,*] Kenny C. Y. Ng,[3,†] Tim Linden,[1,‡]
Bei Zhou,[1,4,§] John F. Beacom,[1,4,5,¶] and Annika H. G. Peter[1,4,5,**]

[1] *Center for Cosmology and AstroParticle Physics (CCAPP), Ohio State University, Columbus, Ohio 43210, USA*
[2] *Department of Physics, Nanchang University, Nanchang 330031, China*
[3] *Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot 76100, Israel*
[4] *Department of Physics, Ohio State University, Columbus, Ohio 43210, USA*
[5] *Department of Astronomy, Ohio State University, Columbus, Ohio 43210, USA*

(Dated: 9th May 2018)

The solar disk is a bright source of multi-GeV gamma rays, due to the interactions of hadronic cosmic rays with the solar atmosphere. However, the underlying production mechanism is not understood, except that its efficiency must be greatly enhanced by magnetic fields that redirect some cosmic rays from ingoing to outgoing before they interact. To elucidate the nature of this emission, we perform a new analysis of solar atmospheric gamma rays with 9 years of Fermi-LAT data, which spans nearly the full 11-year solar cycle. We detect significant gamma-ray emission from the solar disk from 1 GeV up to $\gtrsim$ 200 GeV. The overall gamma-ray spectrum is much harder ($\sim E_\gamma^{-2.2}$) than the cosmic-ray spectrum ($\sim E_{\rm CR}^{-2.7}$). We find a clear anticorrelation between the solar cycle phase and the gamma-ray flux between 1–10 GeV. Surprisingly, we observe a spectral dip between ~30–50 GeV in an otherwise power-law spectrum. This was not predicted, is not understood, and may provide crucial clues to the gamma-ray emission mechanism. The flux above 100 GeV, which is brightest during the solar minimum, poses exciting opportunities for HAWC, LHAASO, IceCube, and KM3NeT.

I. INTRODUCTION

particles accelerated during energetic solar events, such as solar flares and coronal mass ejections [11], can pro-

Evidence for a New Component of High-Energy Solar Gamma-Ray Production

Tim Linden,[1,*] Bei Zhou,[1,2,†] John F. Beacom,[1,2,3,‡] Annika H. G. Peter,[1,2,3,§] Kenny C. Y. Ng,[4,¶] and Qing-Wen Tang[1,5,**]

[1]*Center for Cosmology and AstroParticle Physics (CCAPP), The Ohio State University, Columbus, OH 43210*

[2]*Department of Physics, The Ohio State University, Columbus, OH 43210*

[3]*Department of Astronomy, The Ohio State University, Columbus, OH 43210*

[4]*Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot 76100, Israel*

[5]*Department of Physics, Nanchang University, Nanchang 330031, China*

The observed multi-GeV gamma-ray emission from the solar disk — sourced by hadronic cosmic rays interacting with gas, and affected by complex magnetic fields — is not understood. Utilizing an improved analysis of the Fermi-LAT data that includes the first resolved imaging of the disk, we find strong evidence that this emission is produced by two separate mechanisms. Between 2010–2017 (the rise to and fall from solar maximum), the gamma-ray emission is dominated by a polar component. Between 2008–2009 (solar minimum) this component remains present, but the total emission is instead dominated by a new equatorial component with a brighter flux and harder spectrum. Most strikingly, although 6 gamma rays above 100 GeV are observed during the 1.4 years of solar minimum, none are observed during the next 7.8 years. These features, along with a 30–50 GeV spectral dip which will be discussed in a companion paper, were not anticipated by theory. To understand the underlying physics, Fermi and HAWC observations of the imminent Cycle 25 solar minimum are crucial.

The Sun is a bright source of multi-GeV γ-rays, with emission observed both from its halo — due to cosmic-rays electrons interacting with solar photons — and its disk — due to hadronic cosmic rays (mostly protons) interacting with solar gas. (Emission from solar particle acceleration is only bright during flares and has not been observed above 4 GeV [1–8].) Although the halo emission [9] agrees with theory [10–12], the disk emission does not, and hence is our focus.

Until recently, the most extensive analysis of solar disk

is detected up to $\sim$30 GeV. Most significantly, we discover a spectral dip between 30–50 GeV. This dip is unexpected and its origin is unknown. Here we extend the analyses of Refs. [13, 17] by going to higher energies, studying the time variation in a new way, and performing the first analysis of flux variations across the resolved solar disk. In the following, we detail our methodology, highlight key discoveries, and discuss their possible theoretical implications.

The importance of this work is manifold. Because the disk

First Observations of Solar Disk Gamma Rays over a Full Solar Cycle

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Benjamin J. Buckman,[2,3,§] Bei Zhou,[2,3,5,¶] and Guanying Zhu[2,3,**]

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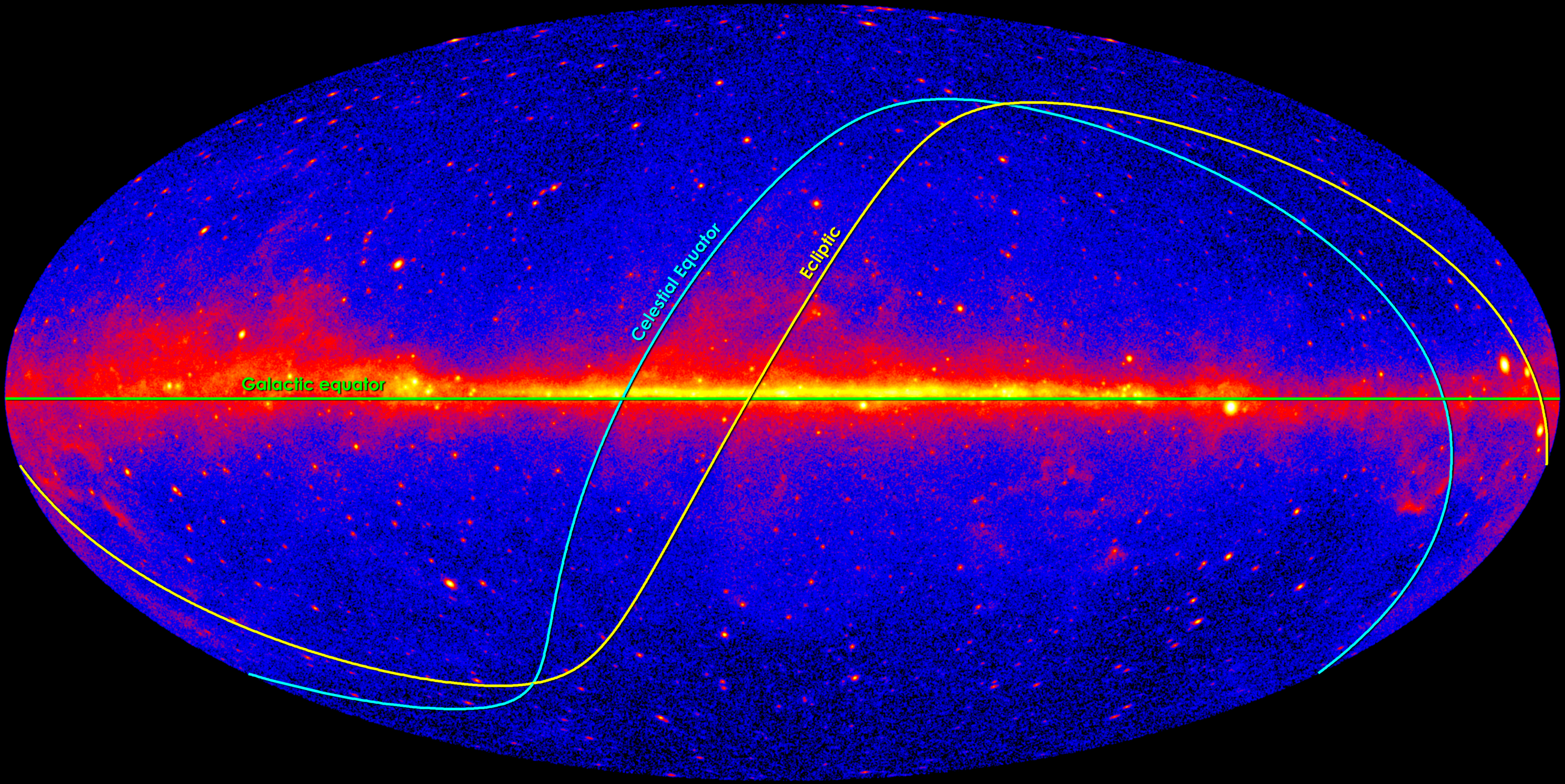
The solar disk is among the brightest γ-ray sources in the sky. It is also among the most mysterious. No existing model fully explains the luminosity, spectrum, time variability, and morphology of its emission. We perform the first analysis of solar-disk γ-rays over a full 11-year solar cycle, utilizing a powerful new method to differentiate solar signals from astrophysical backgrounds. We produce: (i) a robustly measured spectrum from 100 MeV to 100 GeV, reaching a precision of several percent in the 1–10 GeV range, (ii) new results on the anti-correlation between solar activity and γ-ray emission, (iii) strong constraints on short-timescale variability, ranging from hours to years, and (iv) new detections of the equatorial and polar morphologies of high-energy γ-rays. Intriguingly, we find no significant energy dependence in the time variability of solar-disk emission, indicating that strong magnetic-field effects close to the solar surface, rather than modulation throughout the heliosphere, must primarily control the flux and morphology of solar-disk emission.

I. INTRODUCTION

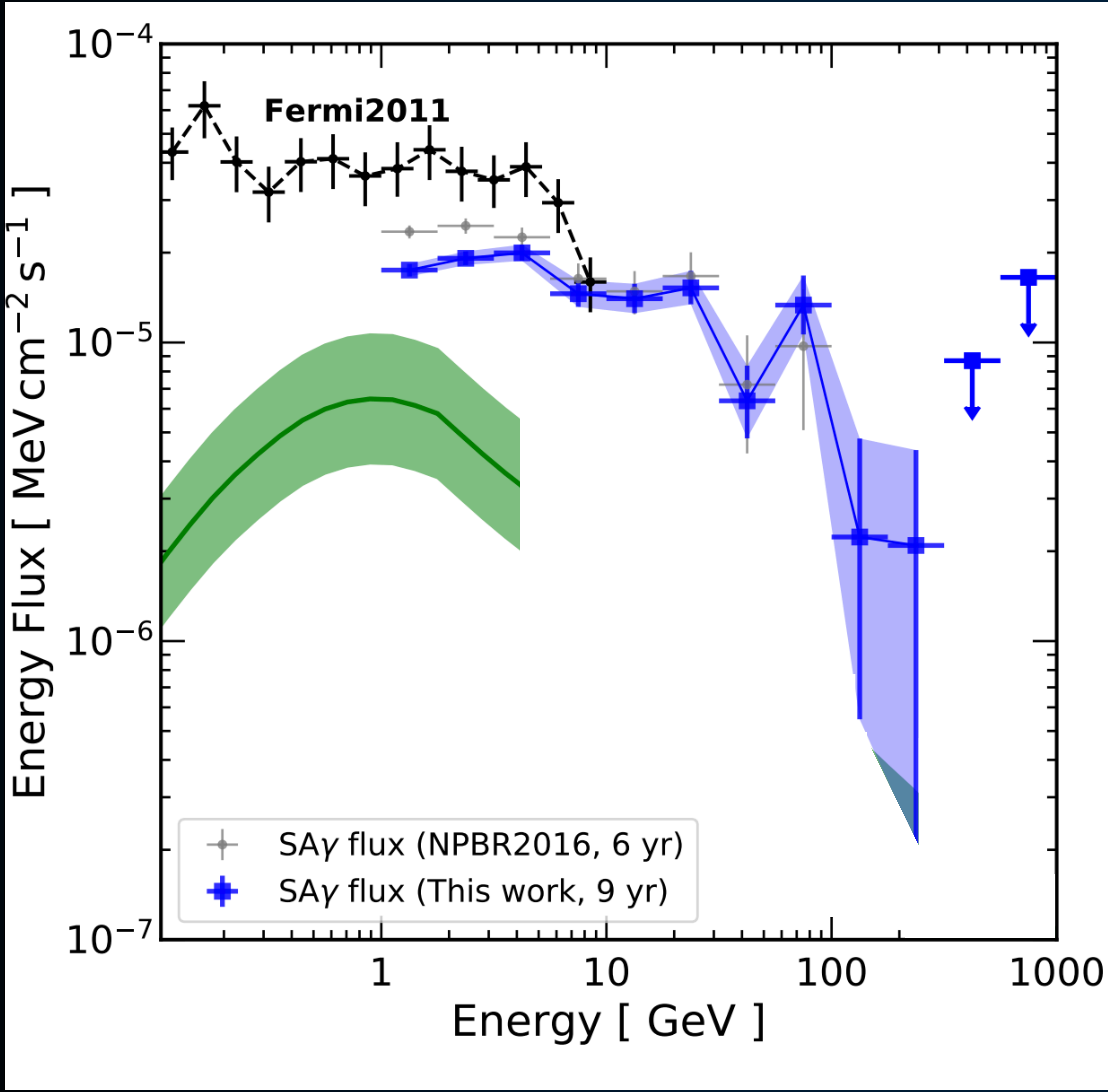
The Sun is a special astrophysical source. Its close proximity allows detailed studies critical to understanding other stars. The ability to spatially resolve solar emission is especially important for probing high-energy, nonthermal processes, which can be highly local. These processes reveal charged-particle

The Sun's γ-ray emission is dramatically affected by its magnetic fields. Without magnetic fields, the disk emission would have two components. At energies above $\sim$1 GeV, the γ-ray direction increasingly follows that of the parent cosmic ray. Accordingly, only cosmic rays that graze the solar surface can interact and have the γ-rays escape [14]. The corresponding emission from the solar limb is too faint to be observed


Celestial Equator
Ecliptic
Galactic equator

Our Limited Knowledge

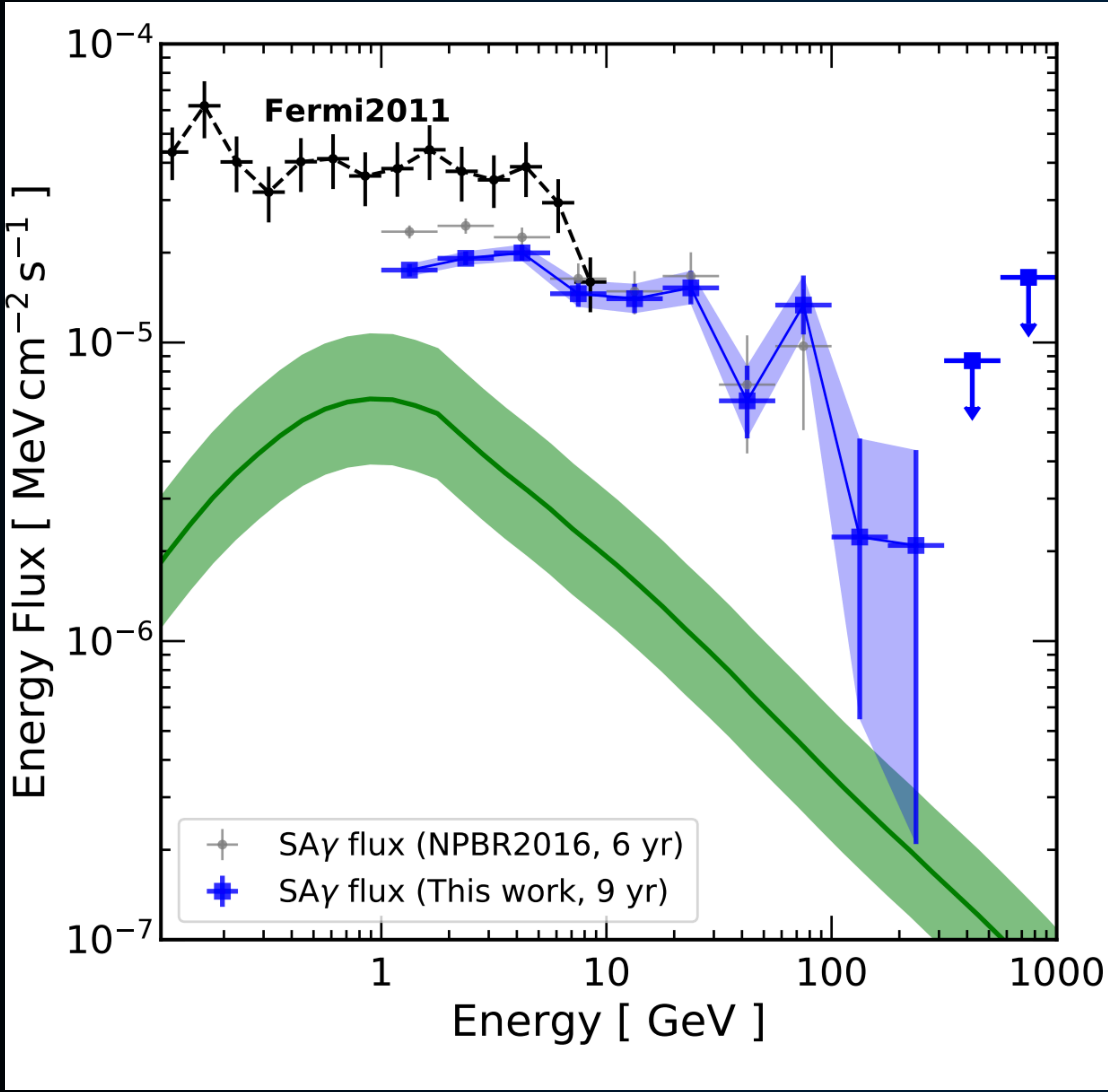
Ng et al. (1508.06276)



Intensity X

Our Limited Knowledge

Ng et al. (1508.06276)

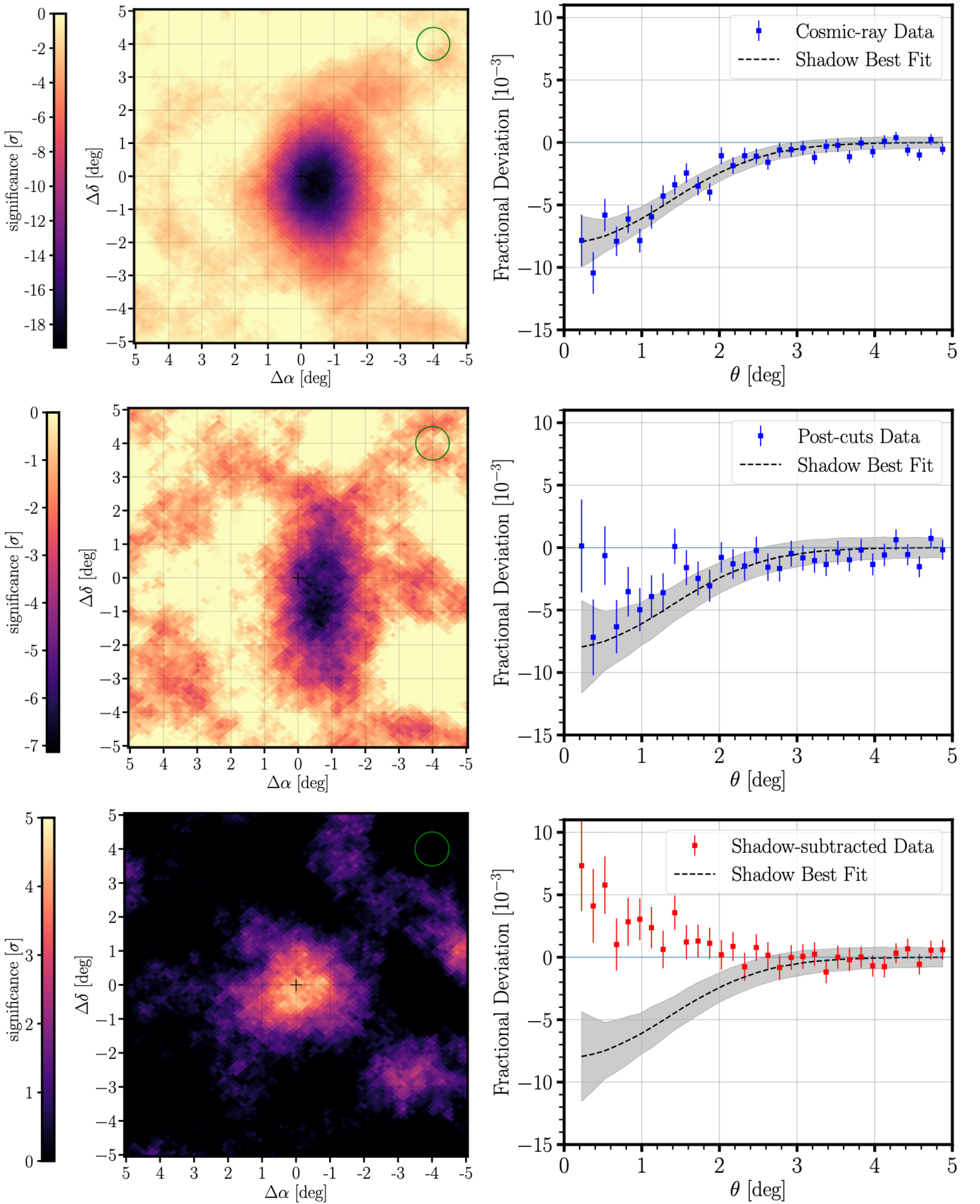


Intensity X

Spectrum X

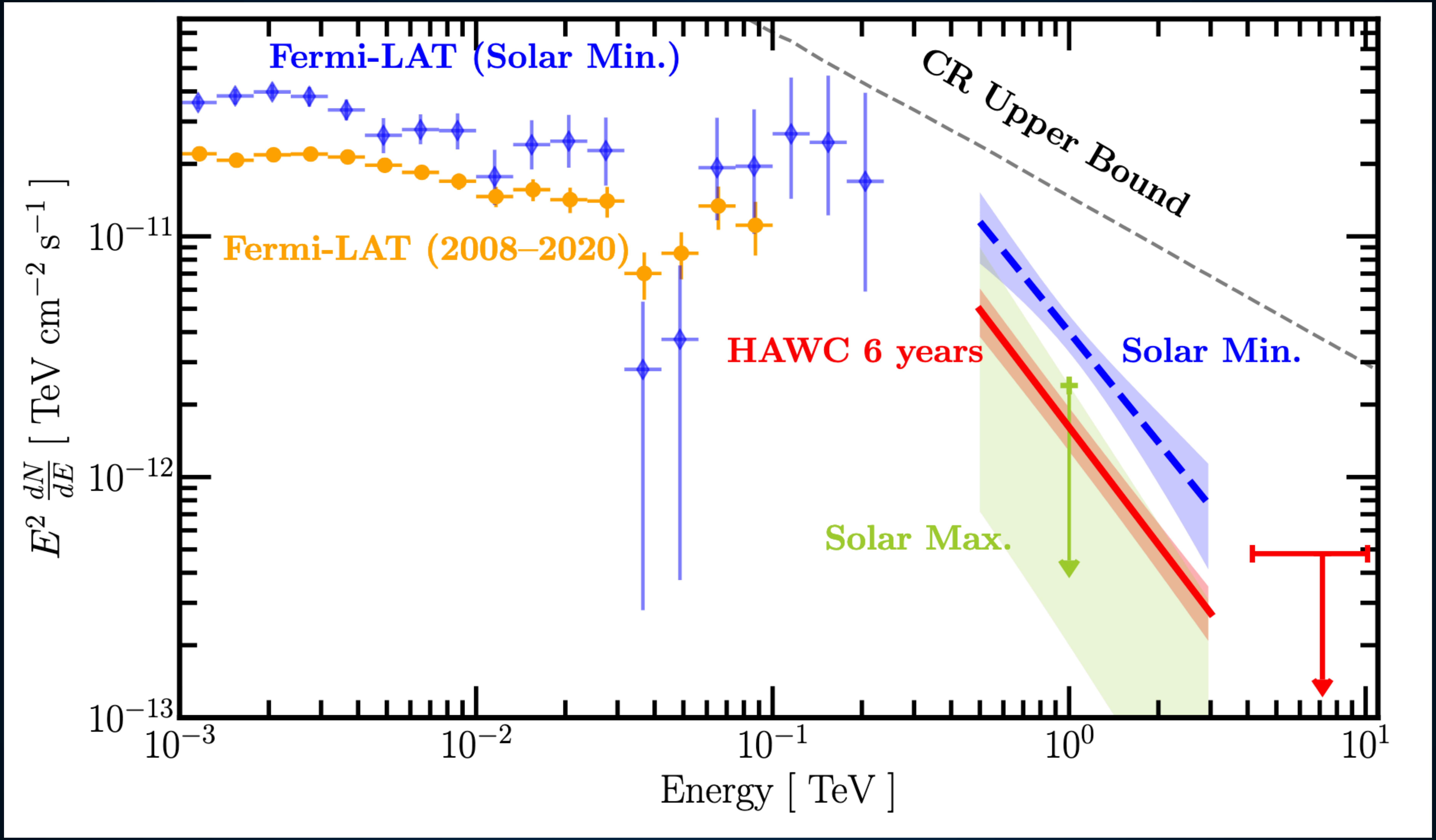
HAWC Observations

Water-Cherenkov telescopes can observe solar gamma rays up to even higher energies!



Spectrum

HAWC Collaboration (incl. TL) 2212.00815



Gamma-Rays Continue up to 3 TeV during Solar Minimum!

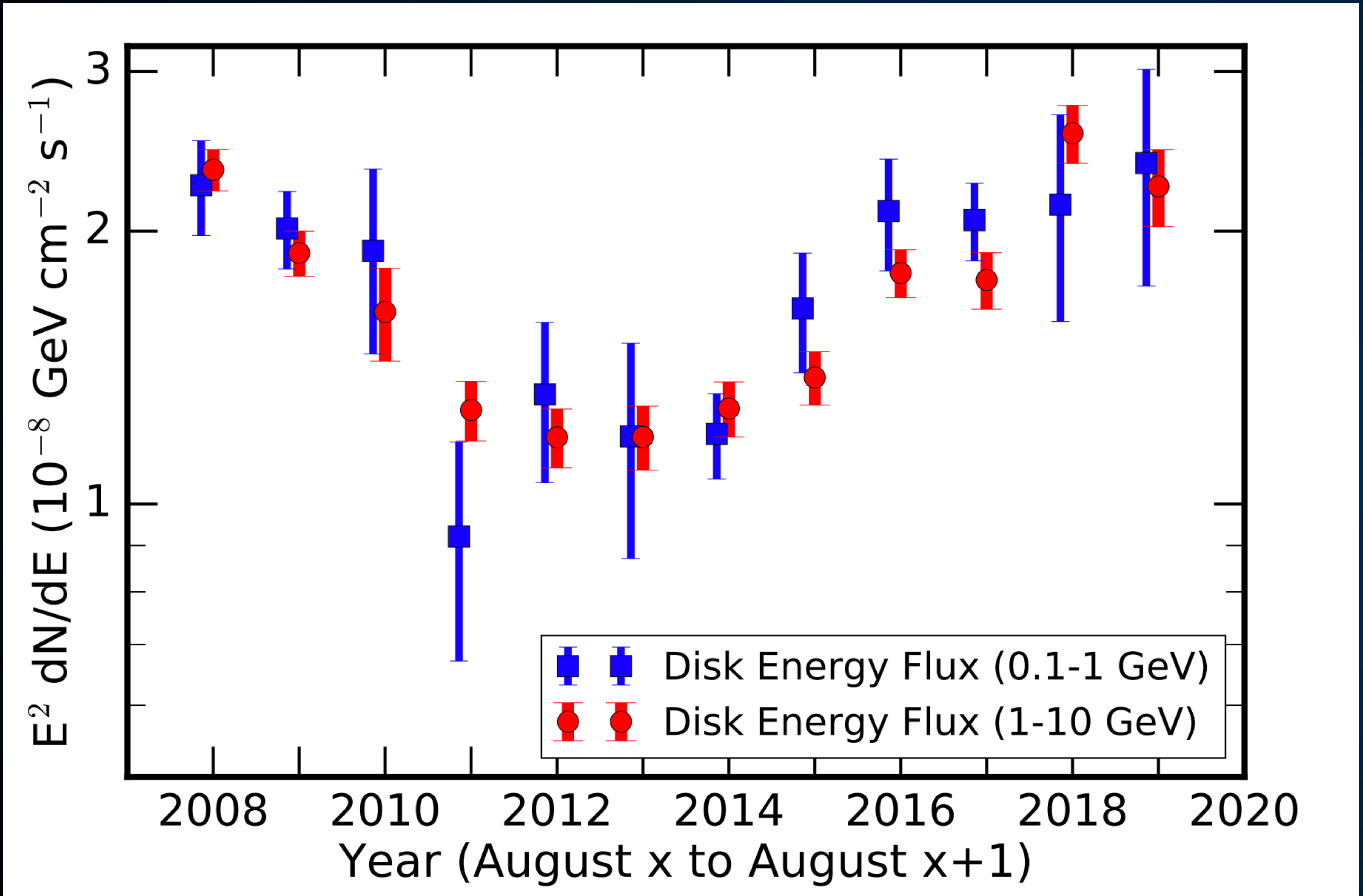
Spectrum

TL et al. (2012.04654)

Low-Energy Spectrum does not cut off either!

Our Limited Knowledge

TL et al. (2012.04654)

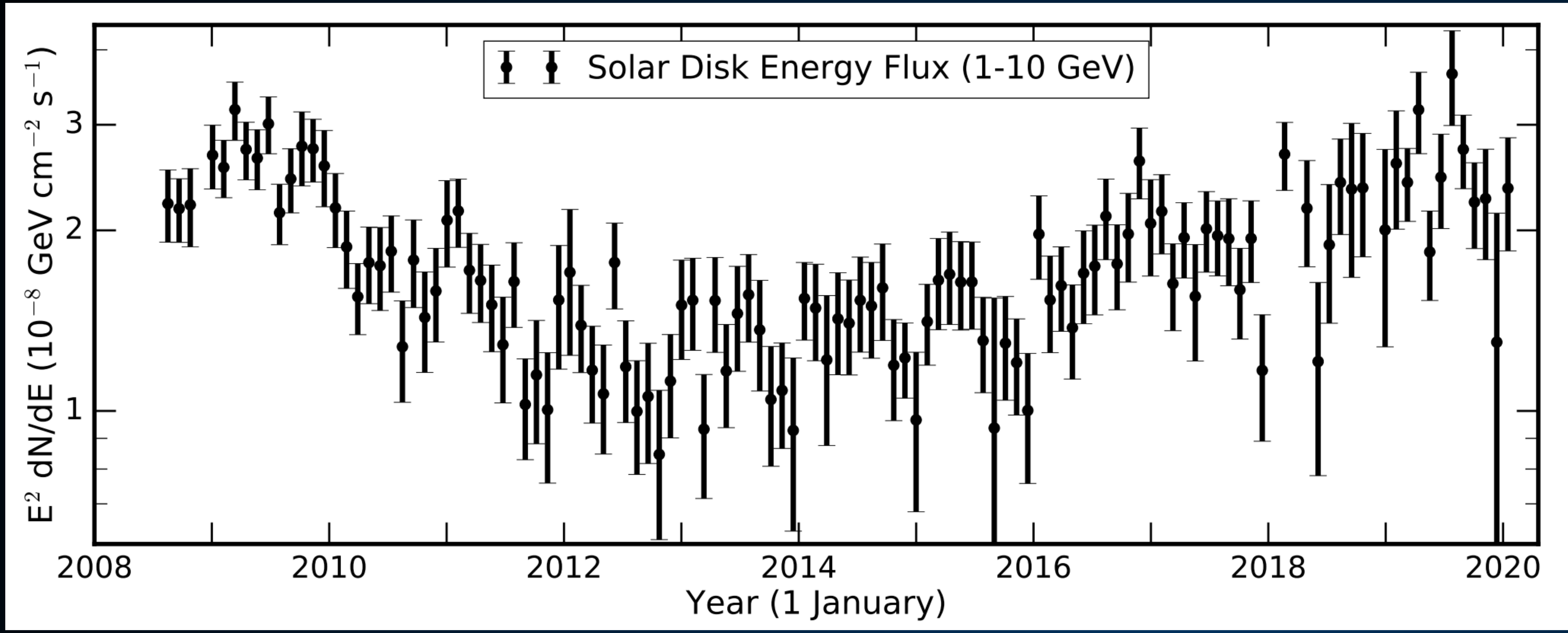


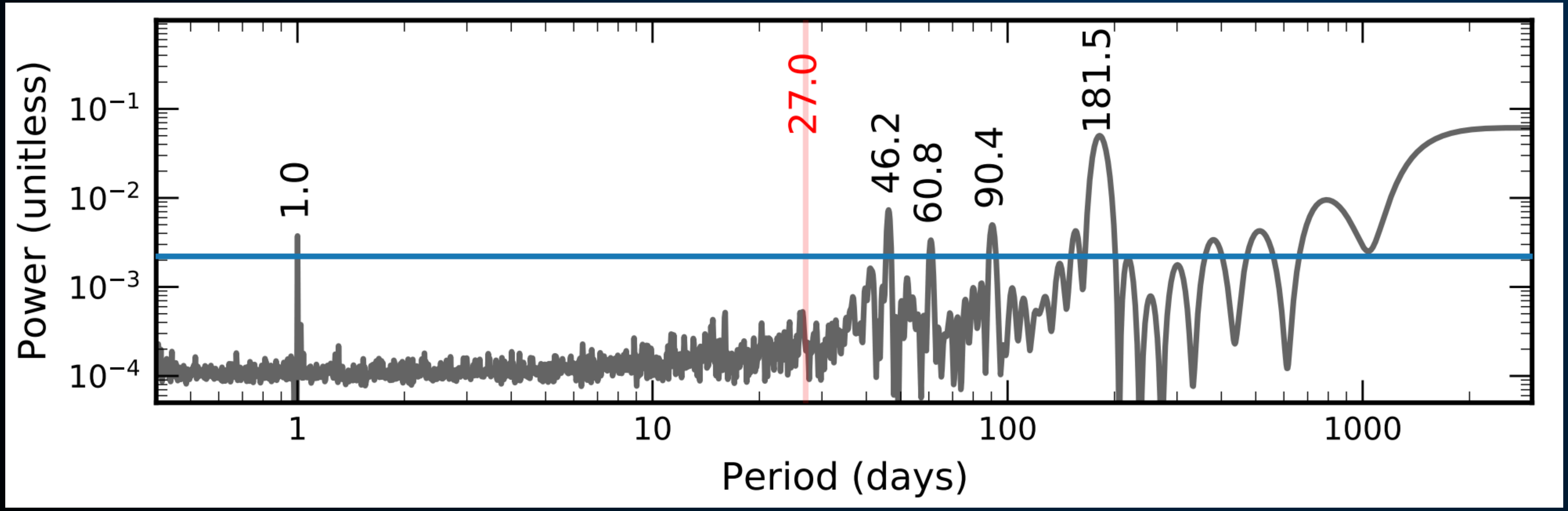
Intensity X

Spectrum X

Time Variability X

Our Limited Knowledge





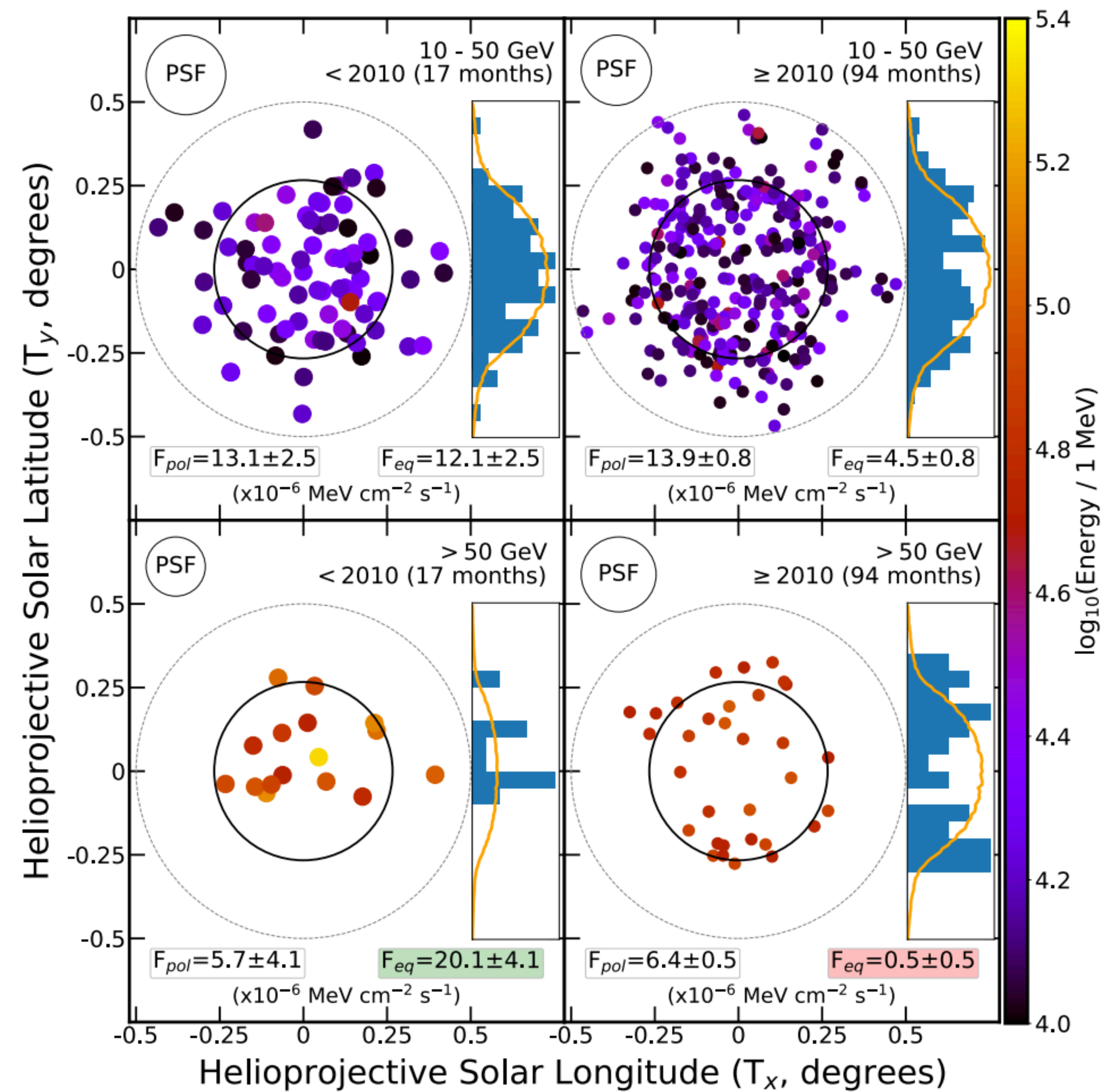
Intensity X

Spectrum X

Time Variability X

Our Limited Knowledge

TL et al. (1803.05436)



Intensity X

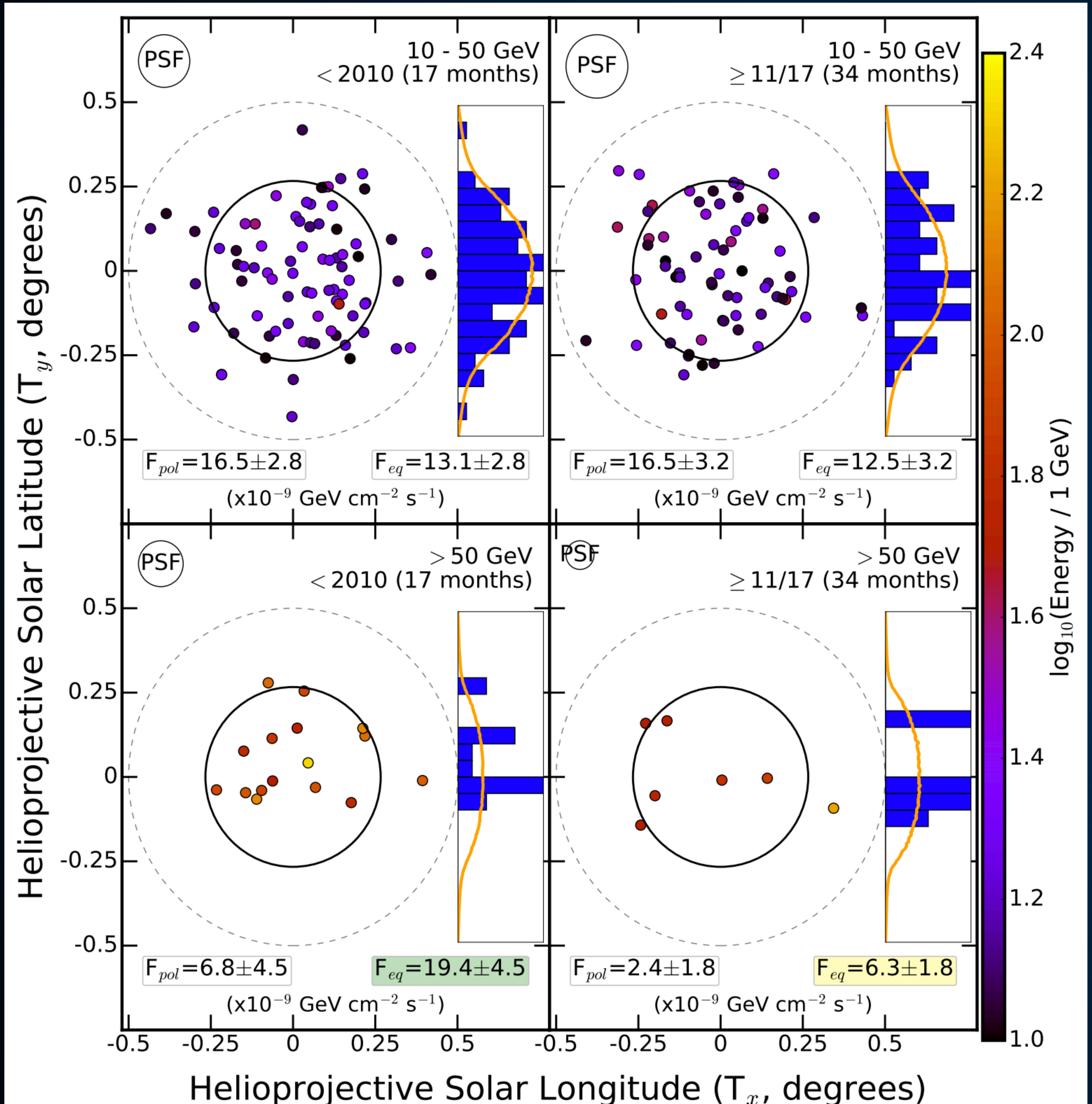
Spectrum X

Time Variability X

Morphology X

Our Limited Knowledge

TL et al. (1803.05436)



Intensity X

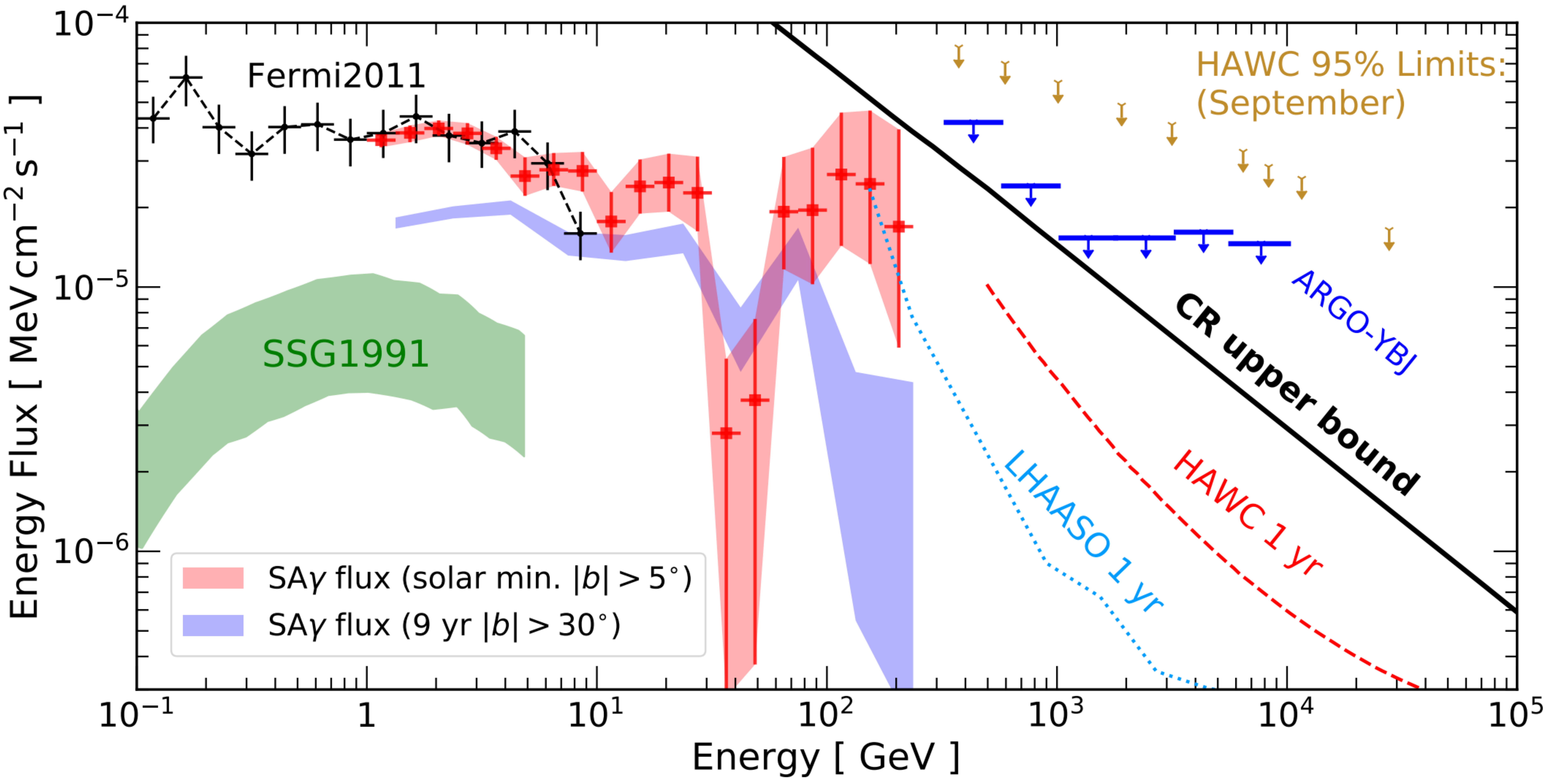
Spectrum X

Time Variability X

Morphology X

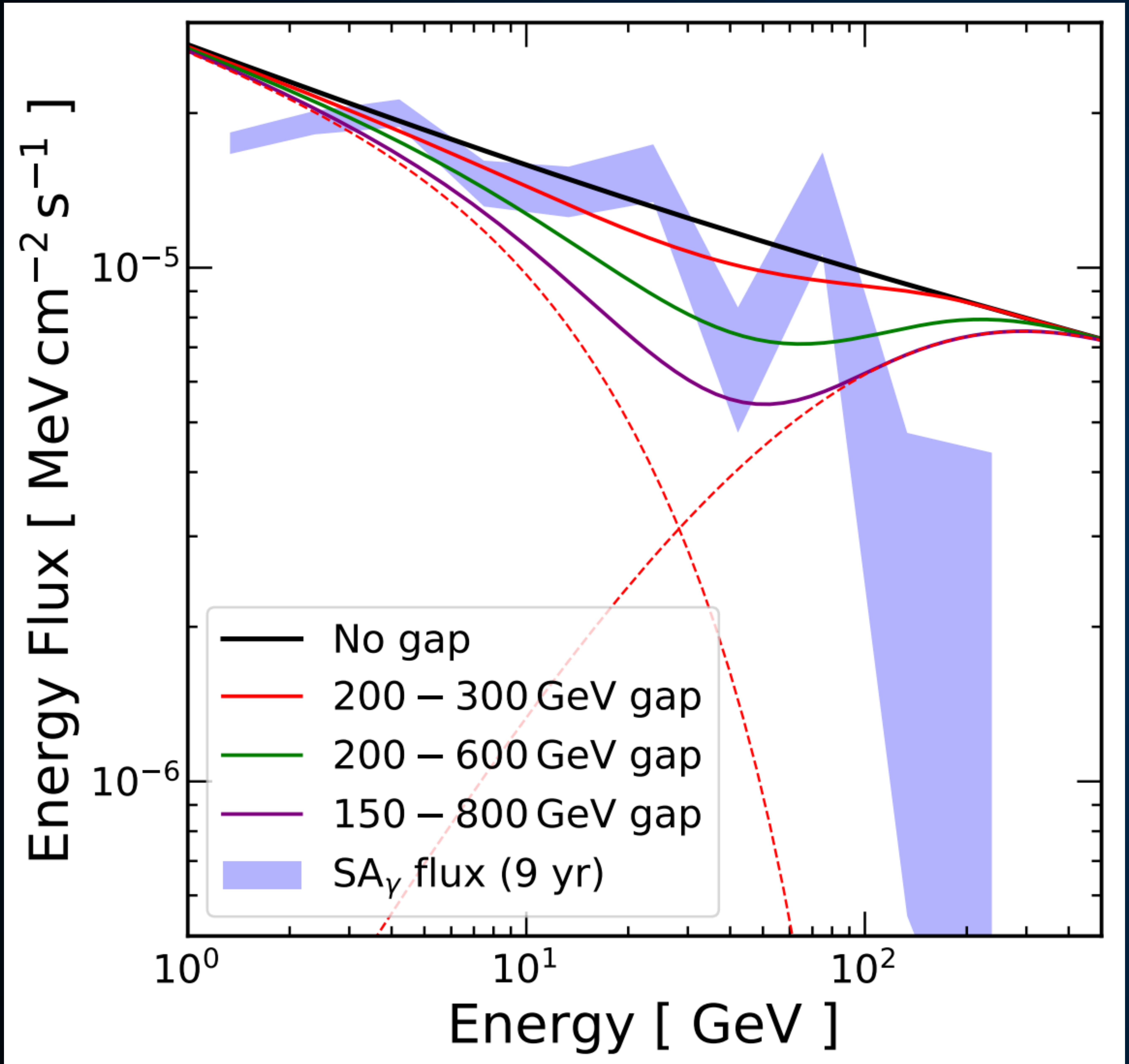
Our Limited Knowledge

HAWC Collaboration, incl. TL (1808.05620)



Our Limited Knowledge

Tang et al. (1804.06846)



Intensity X

Spectrum X

Time Variability X

Morphology X

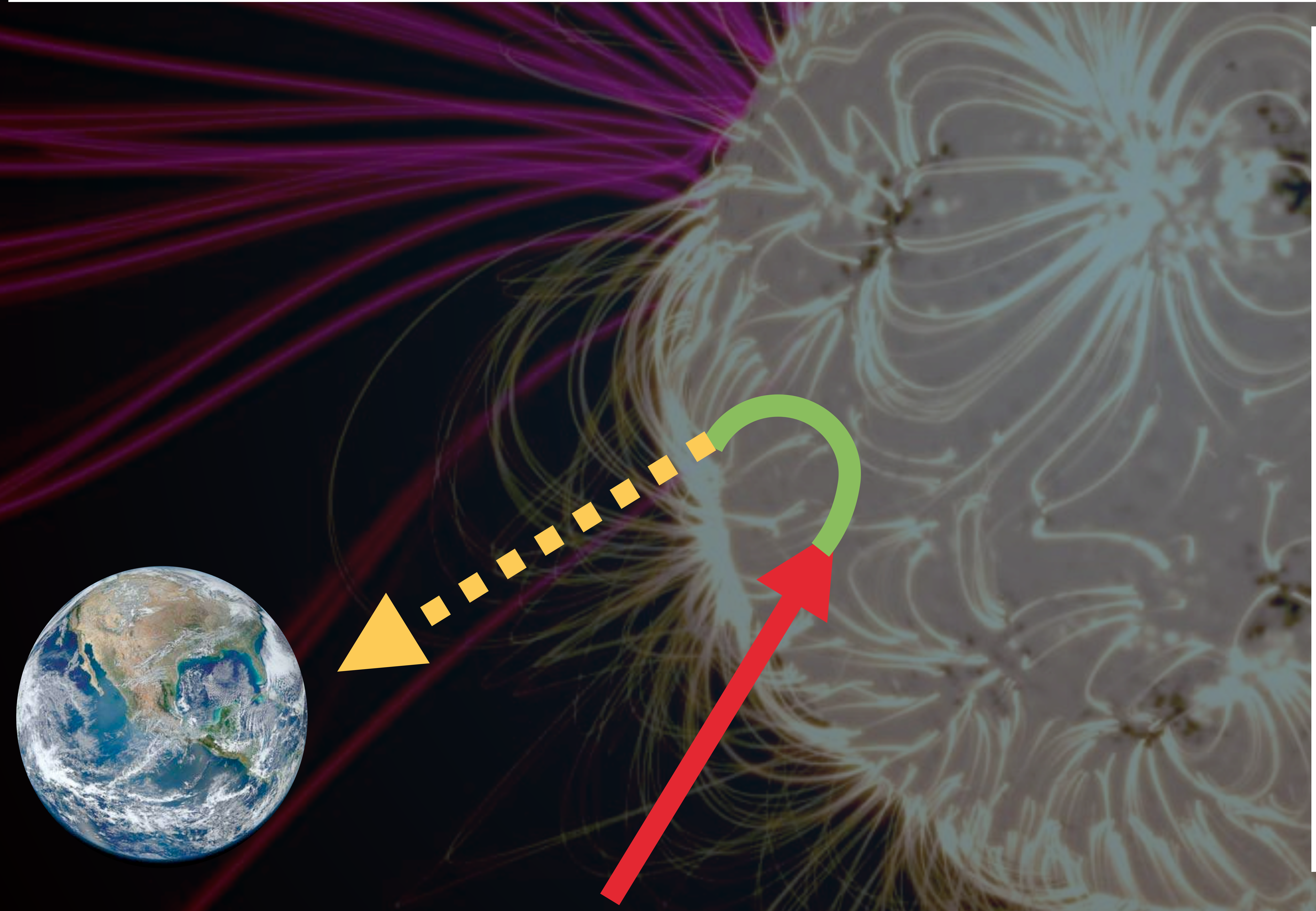
Spectral Dip X

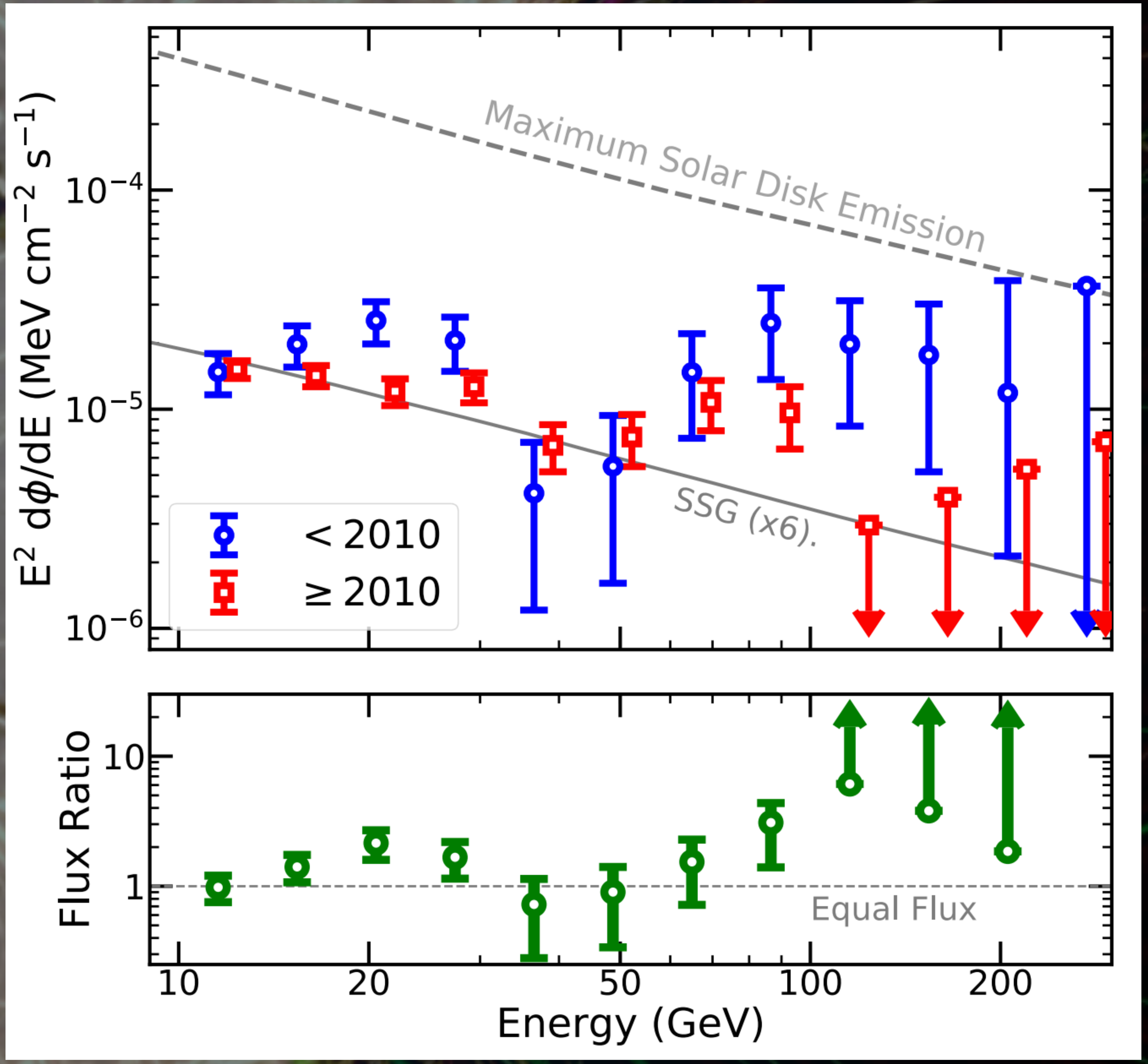
So basically everything is wrong….

How do we model this?

Gamma-Ray Emission much brighter than expected

$$\Phi_{\odot}(E_{\gamma}) = \pi R_{\odot}^{2} \Phi_{\mathrm{CR}}(E_{\mathrm{CR}}) C(E_{\gamma}, E_{\mathrm{CR}}) f_{\mathrm{sur}} f_{\mathrm{turn}} f_{\mathrm{int}}$$

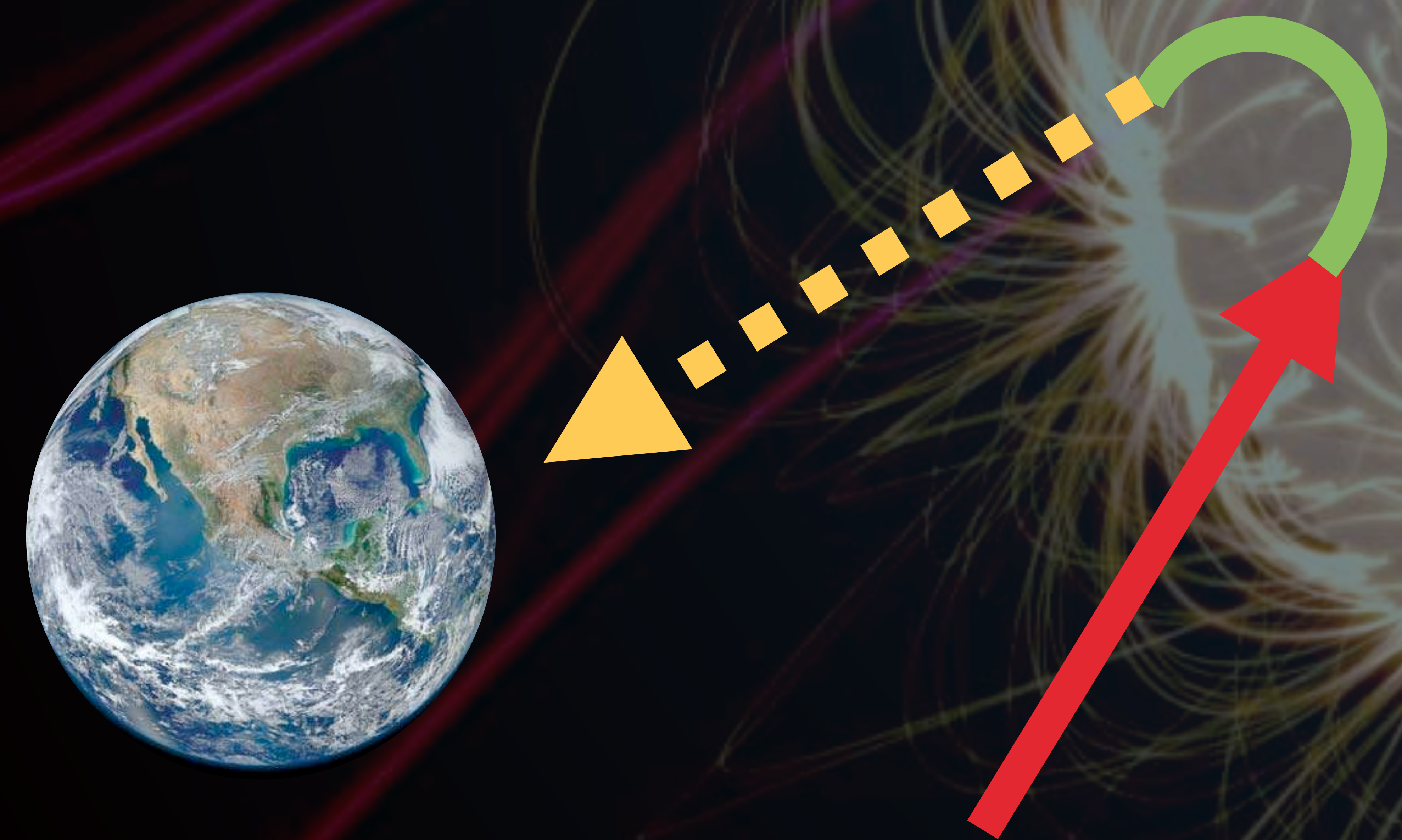


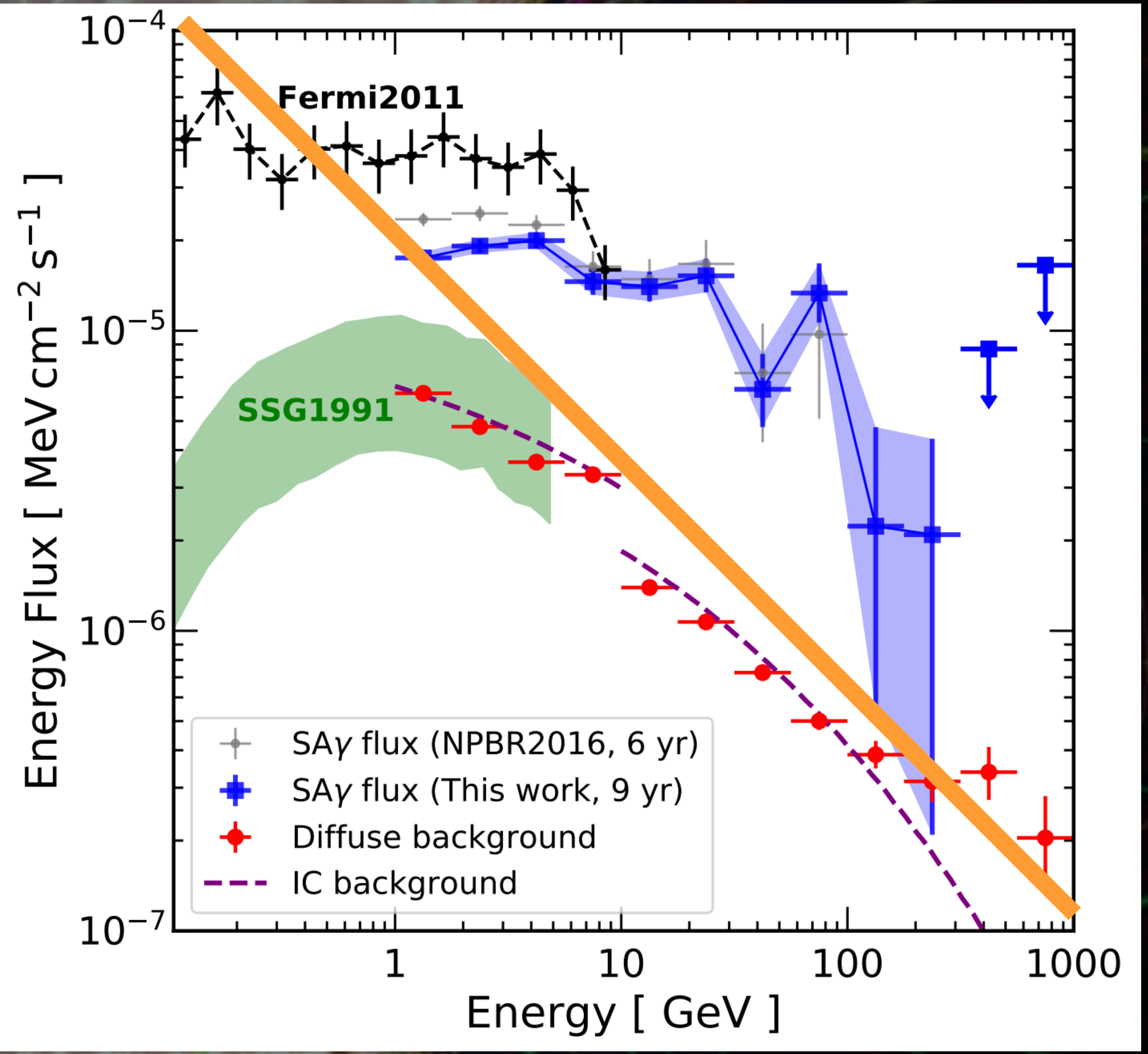


Gamma-Ray Spectrum Harder than Expected

$$\Phi_\odot(E_\gamma) = \pi R_\odot^2 \Phi_{\mathrm{CR}}(E_{\mathrm{CR}}) C(E_\gamma, E_{\mathrm{CR}}) f_{\mathrm{sur}} f_{\mathrm{turn}} f_{\mathrm{int}}$$

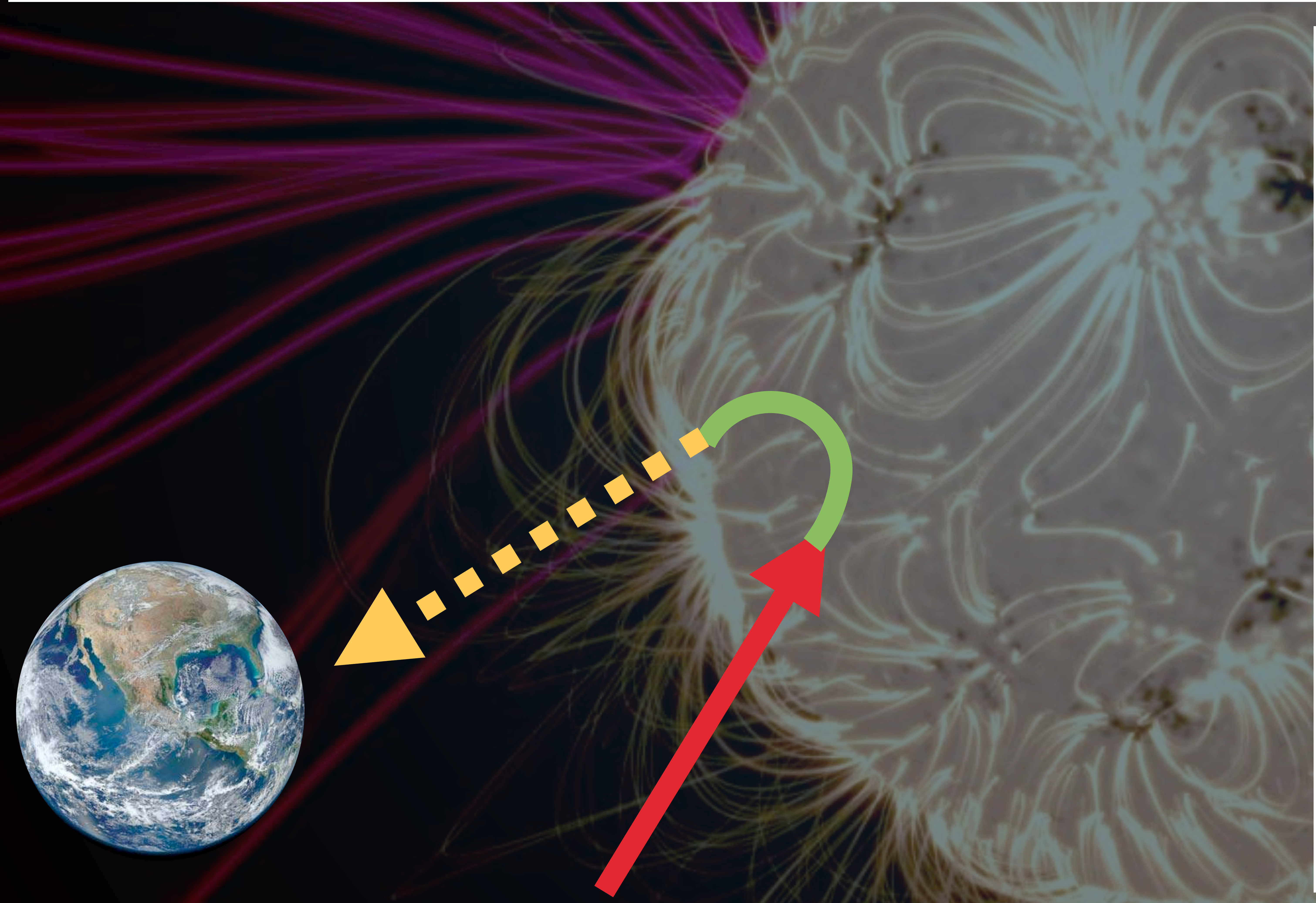
$$r_c = 3.3\ \mathrm{m} \times \frac{(\gamma m c^2/\mathrm{GeV}) \cdot (v_\perp/c)}{(|q|/e) \cdot (B/\mathrm{T})}$$

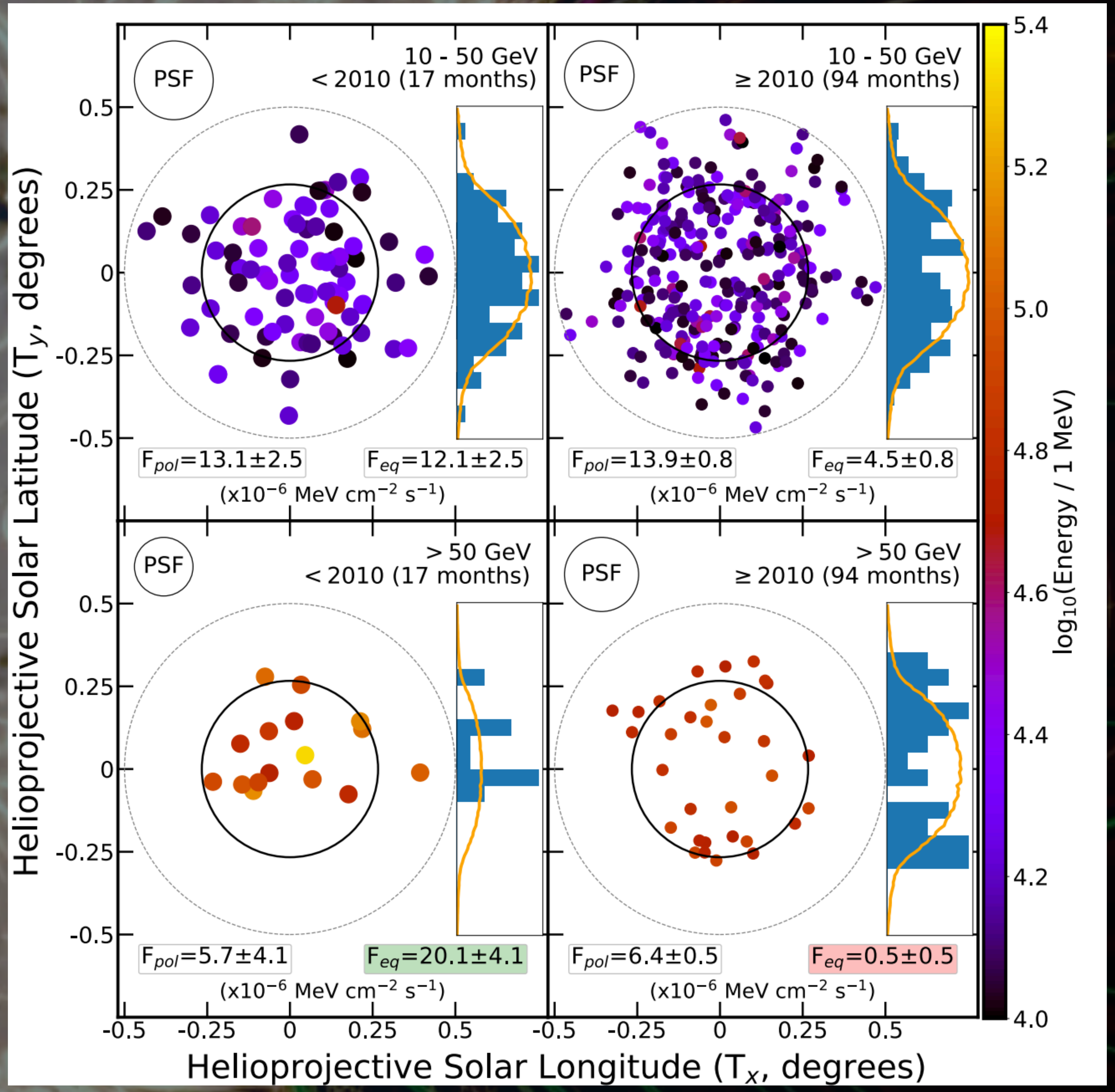




Gamma-Ray Emission Not Uniform

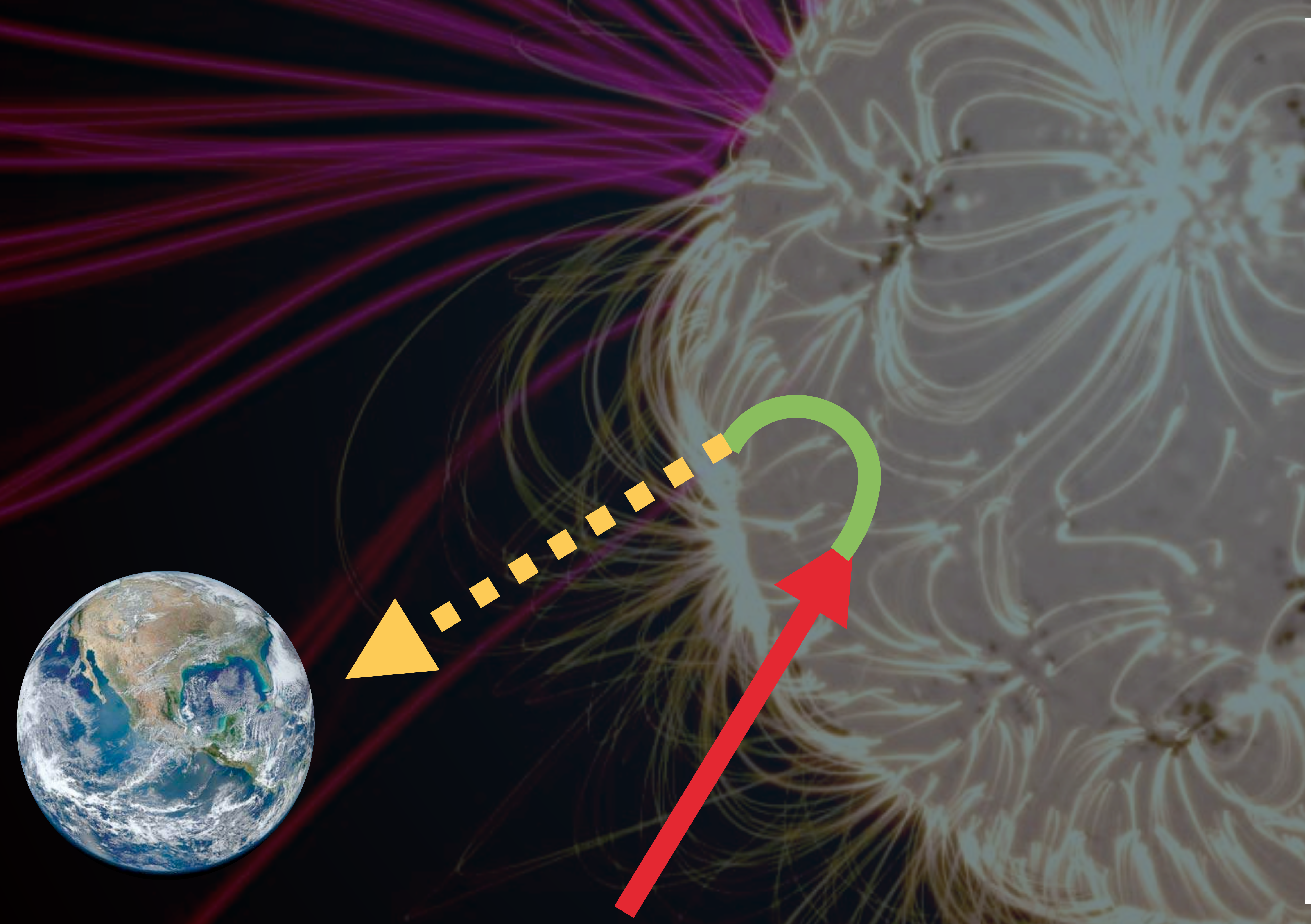
$$\Phi_\odot(E_\gamma) = \pi R_\odot^2 \Phi_{\mathrm{CR}}(E_{\mathrm{CR}}) C(E_\gamma, E_{\mathrm{CR}}) f_{\mathrm{sur}} f_{\mathrm{turn}} f_{\mathrm{int}}$$

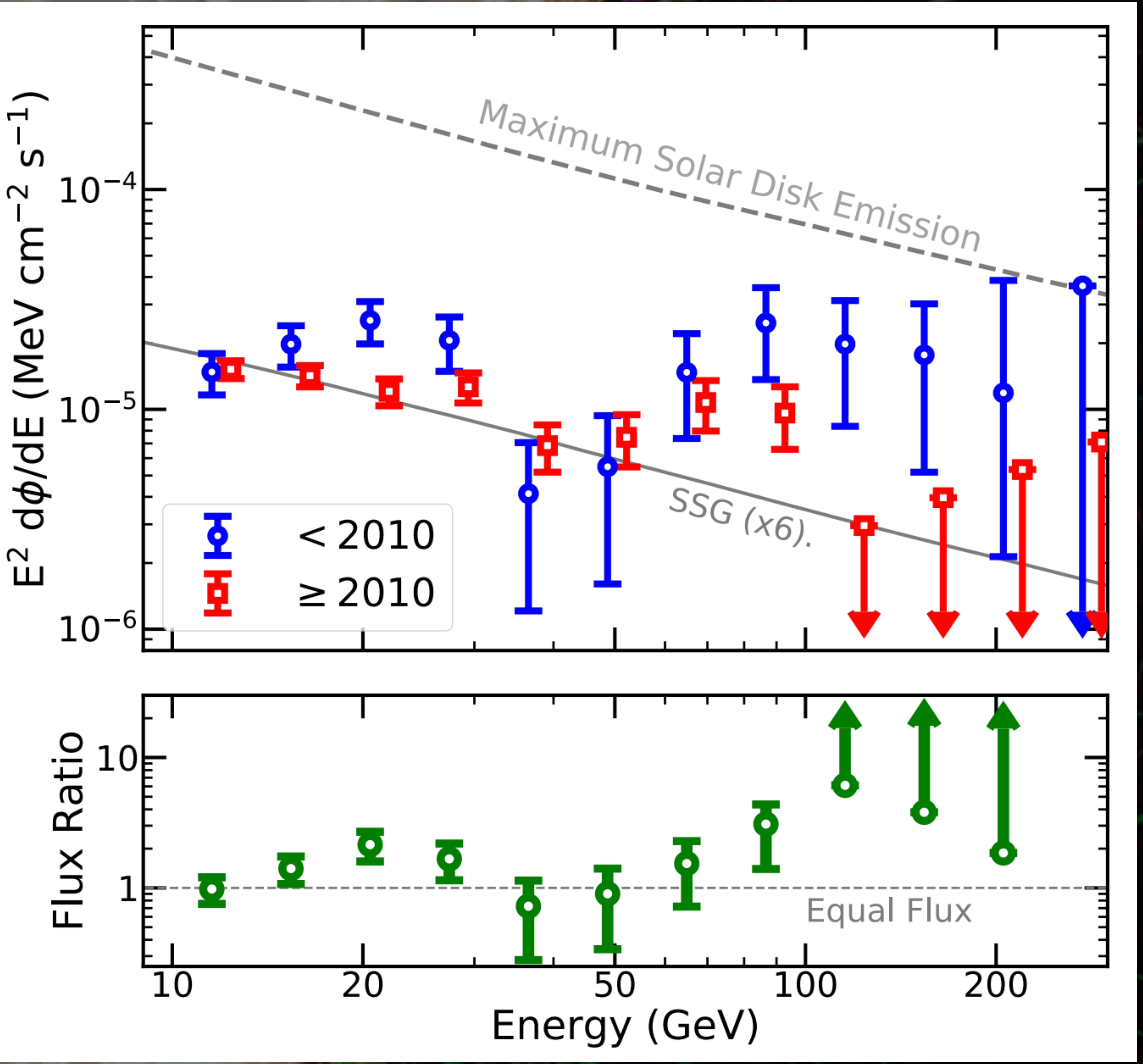




Two Different Emission Mechanisms?

$$\Phi_{\odot}(E_\gamma) = \pi R_{\odot}^2 \Phi_{\mathrm{CR}}(E_{\mathrm{CR}}) C(E_\gamma, E_{\mathrm{CR}}) f_{\mathrm{sur}} f_{\mathrm{turn}} f_{\mathrm{int}}$$





Convection-Driven Multi-Scale Magnetic Fields Determine the Observed Solar-Disk Gamma Rays

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(Dated: August 21, 2025)

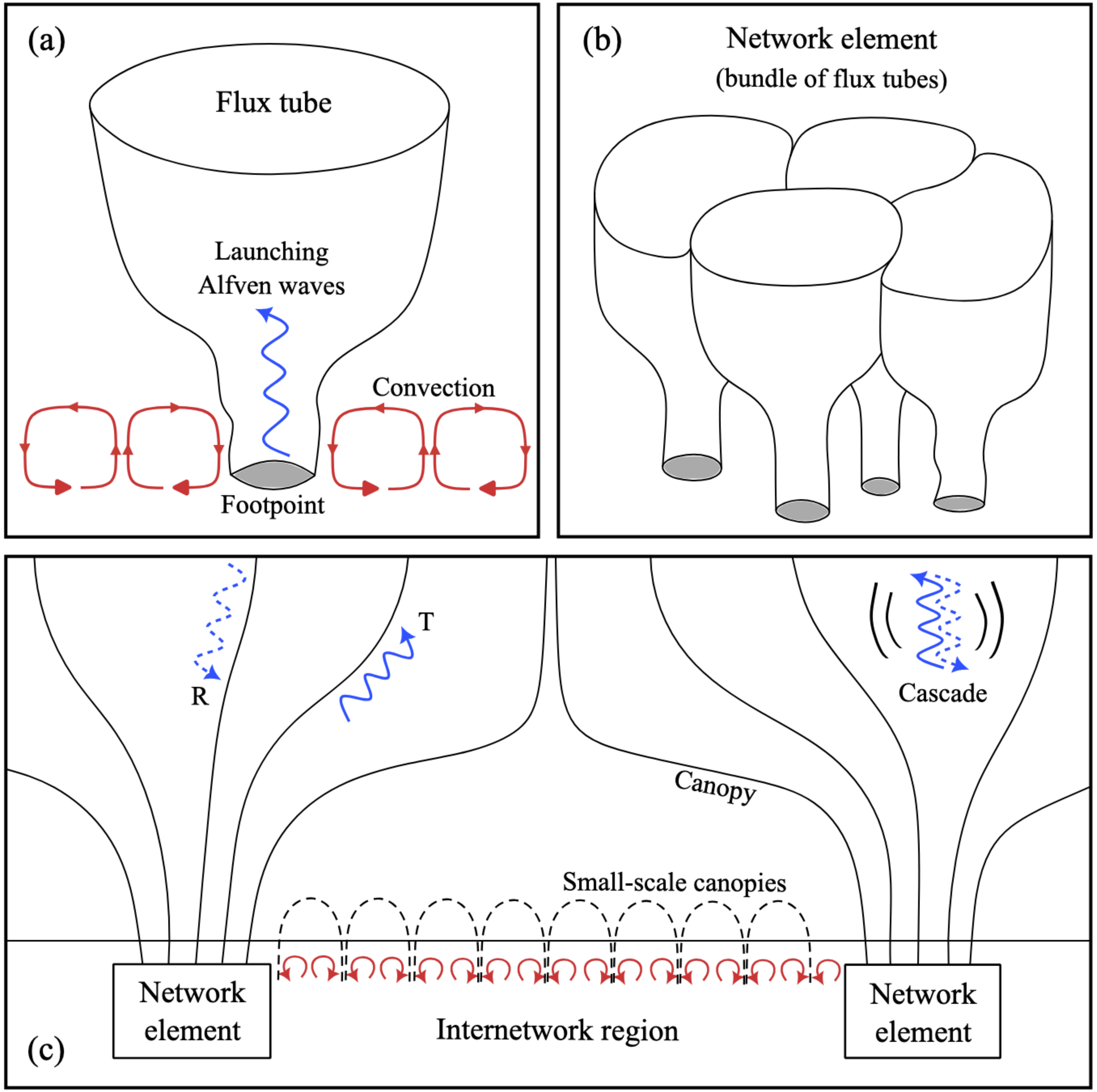
ABSTRACT

The solar disk is a continuous source of GeV–TeV gamma rays. The emission is thought to originate from hadronic Galactic cosmic rays (GCRs) interacting with the gas in the photosphere and uppermost convection zone after being reflected by solar magnetic fields. Despite this general understanding, existing theoretical models have yet to match observational data. At the photosphere and the uppermost convection zone, granular convection drives a multi-scale magnetic field, forming a larger-scale filamentary structure while also generating turbulence-scale Alfvén wave turbulence. Here, we demonstrate that the larger-scale filamentary field shapes the overall gamma-ray emission spectrum, and the Alfvén wave turbulence is critical for further suppressing the gamma-ray emission spectrum below ~ 100 GeV. For a standard Alfvén wave turbulence level, our model's predicted spectrum slope from 1 GeV to 1 TeV is in excellent agreement with observations from Fermi-LAT and HAWC, an important achievement. The predicted absolute flux is a factor of 2–5 lower than the observed data; we outline future directions to resolve this discrepancy. The key contribution of our work is providing a new theoretical framework for using solar disk gamma-ray observations to probe hadronic GCR transport in the lower solar atmosphere.

First Theoretical Attempts

Echo the idea of an infinite magnetic mirror

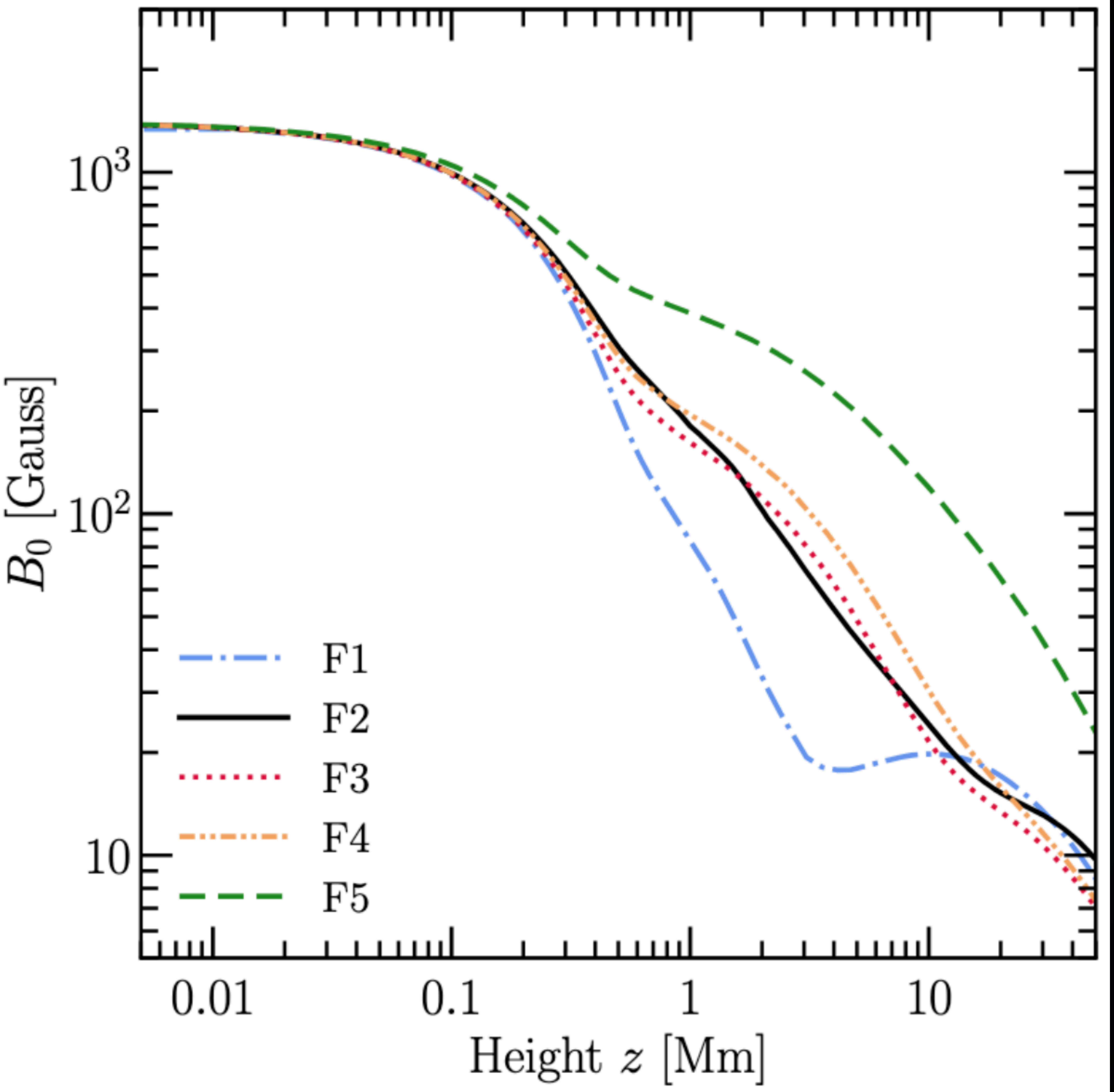
- Large flux tube at top of the photosphere directs CRs towards footprint, with kG magnetic fields.
- Small scale canopies ensure CRs directed towards the footprints.



First Theoretical Attempts

Magnetic field at the base of the footprints can be huge.

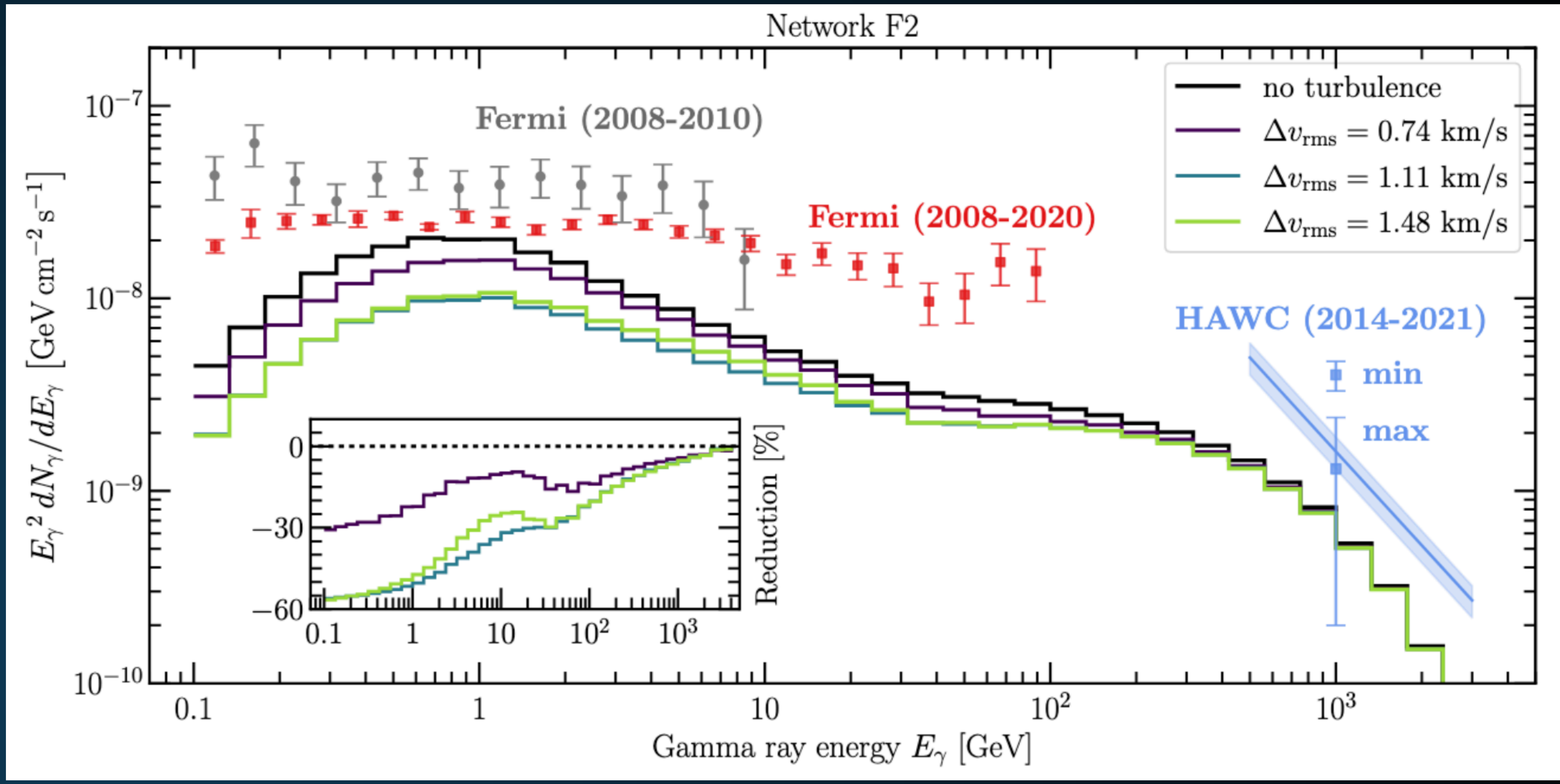
Means that cosmic rays get reflected at similar positions at many different energies.



First Theoretical Attempts

First Theoretical Attempts

Current Issues:



- Underproduces flux by a factor of 5.
- Low-energies are an issue (though backsplash not yet included).
- Cannot explain modulation at high-energies.

Conclusions

We see, but we don't understand.

Help?

Solar disk gamma-rays provide a new handle into fundamental questions in solar magnetohydrodynamics.

Huge Potential For Cross-Correlations with other wavelengths