Research on High-energy Gamma-ray with Fermi LAT in Thailand

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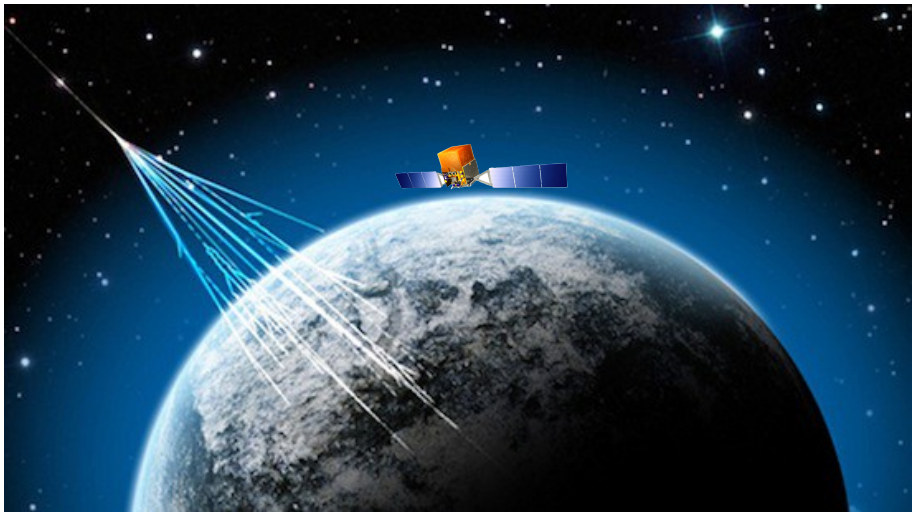
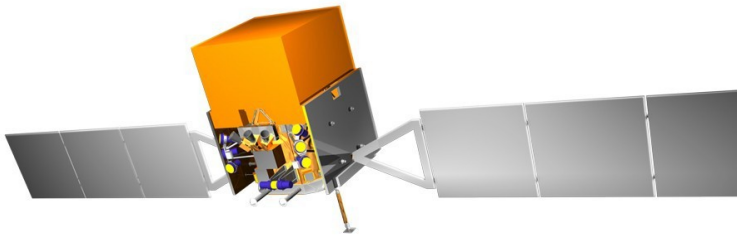
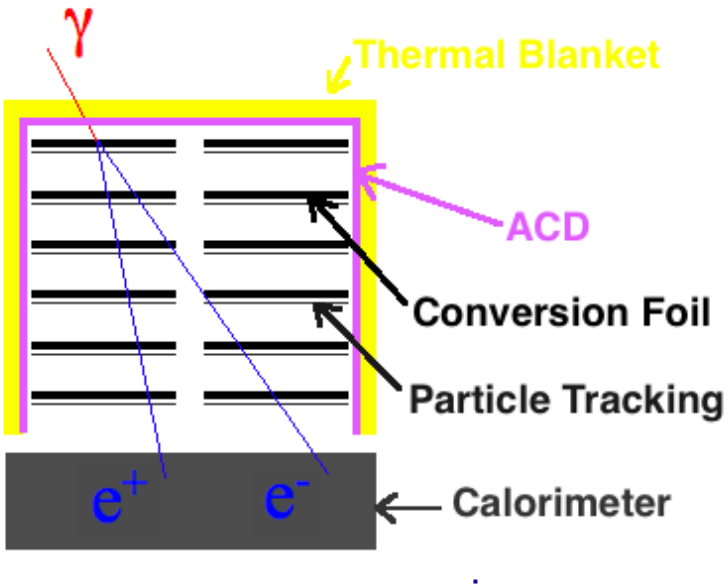
NATIONAL ACCELERATOR LABORATORY

Fermi LAT



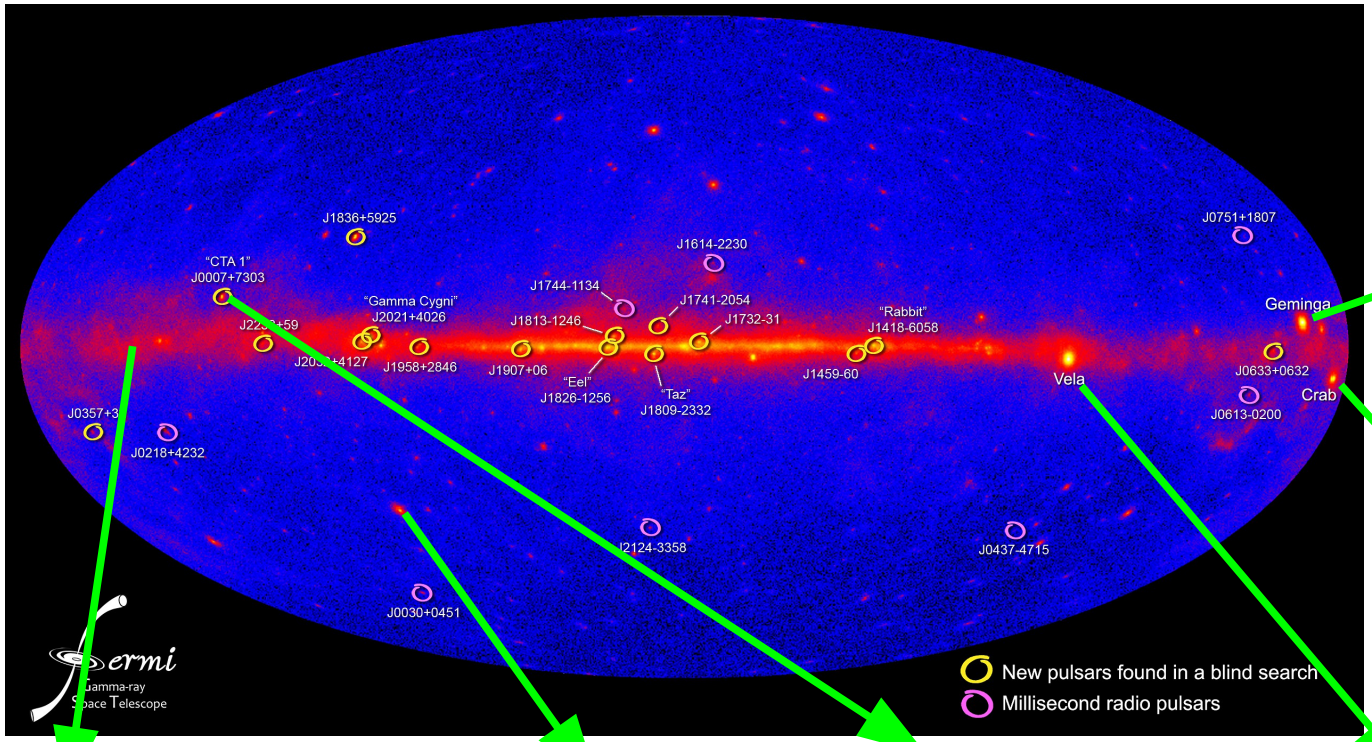
Fermi LAT: Brief Description

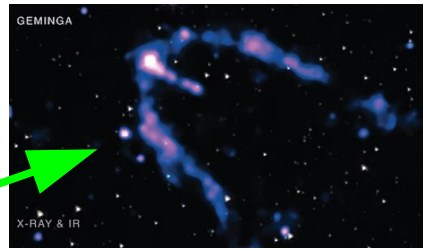


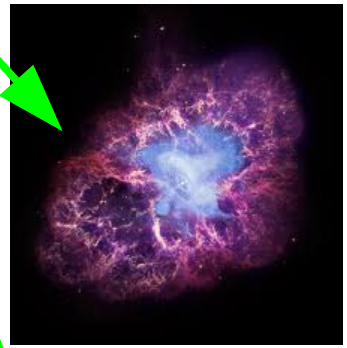


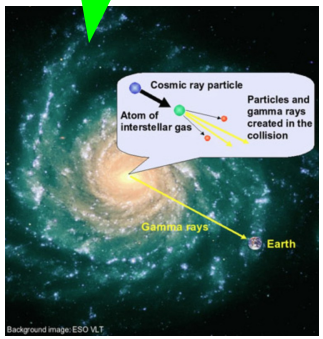
- Launched in June 2008 to ~565 km altitude, observing entire sky every 3 hours
- Pair-conversion telescope designed to detect ~20 MeV to above 300 GeV photons
- 3 main systems
  - ACD
  - Tracker
  - Calorimeter
- ~3 m^2 geometric area
- Angular resolution of ~4º at 100 MeV, improving to better than 0.15º at above 10 GeV

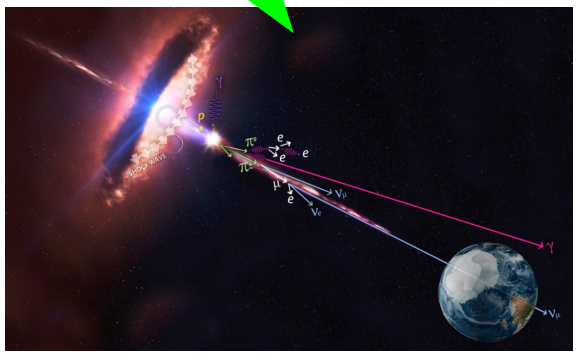
Astrophysical γ-Ray Objects

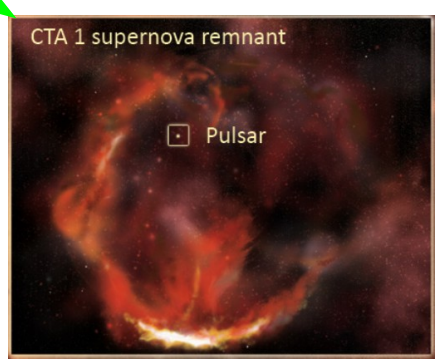


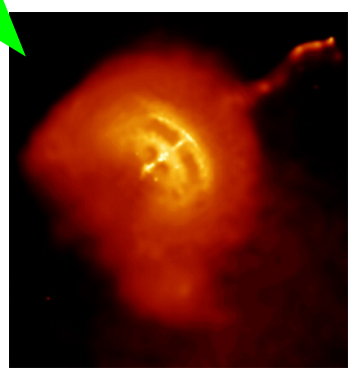










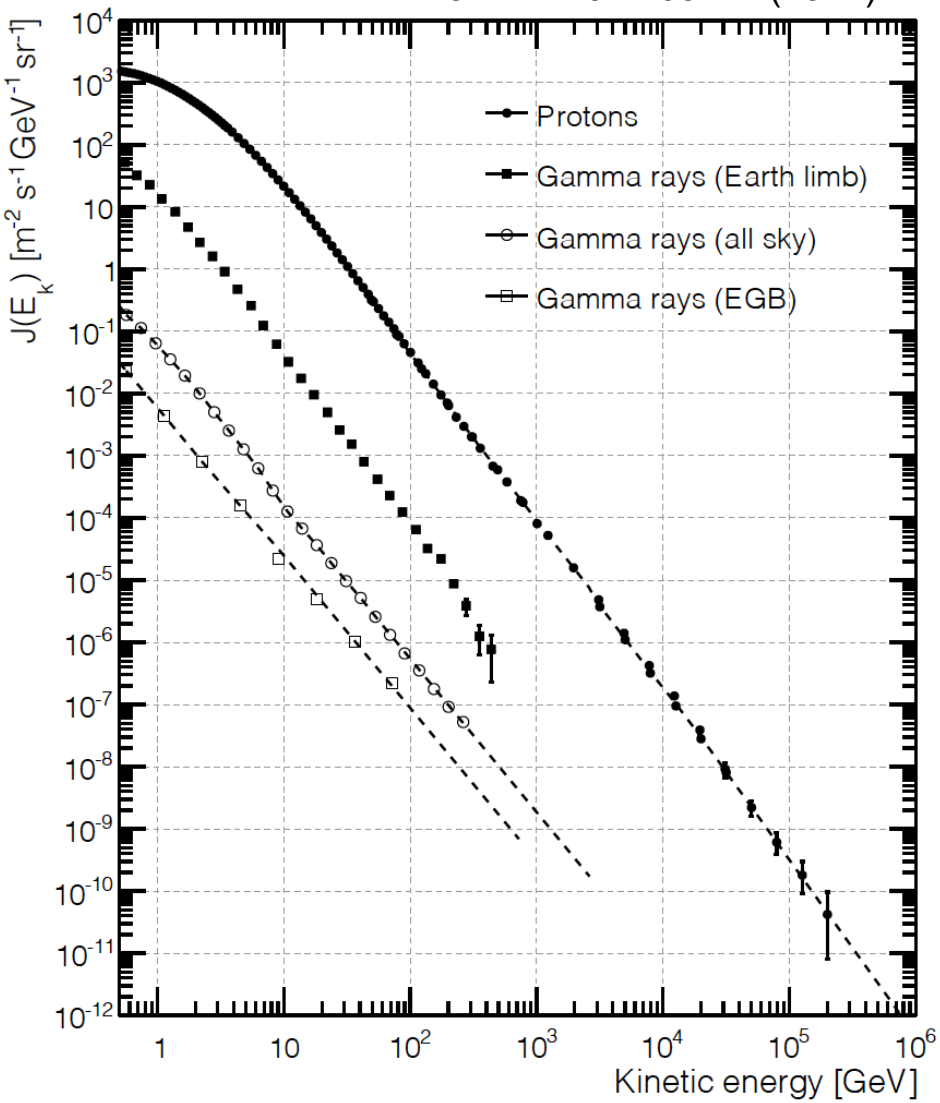


Research at Mahidol University, Thailand

- Earth's γ-ray emission

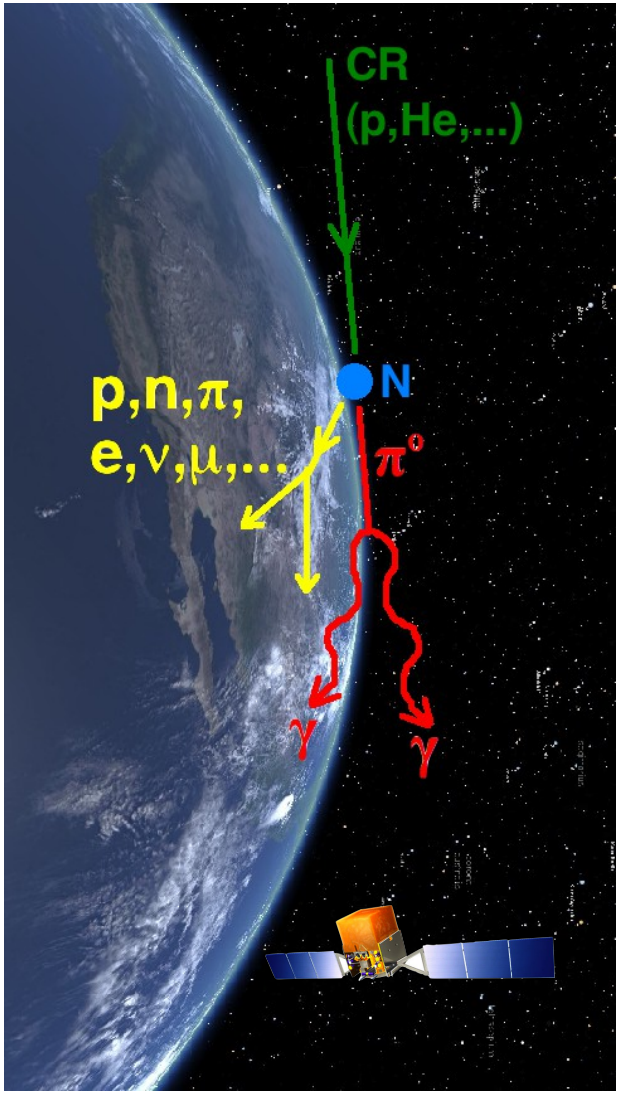
Cosmic Ray (CR)

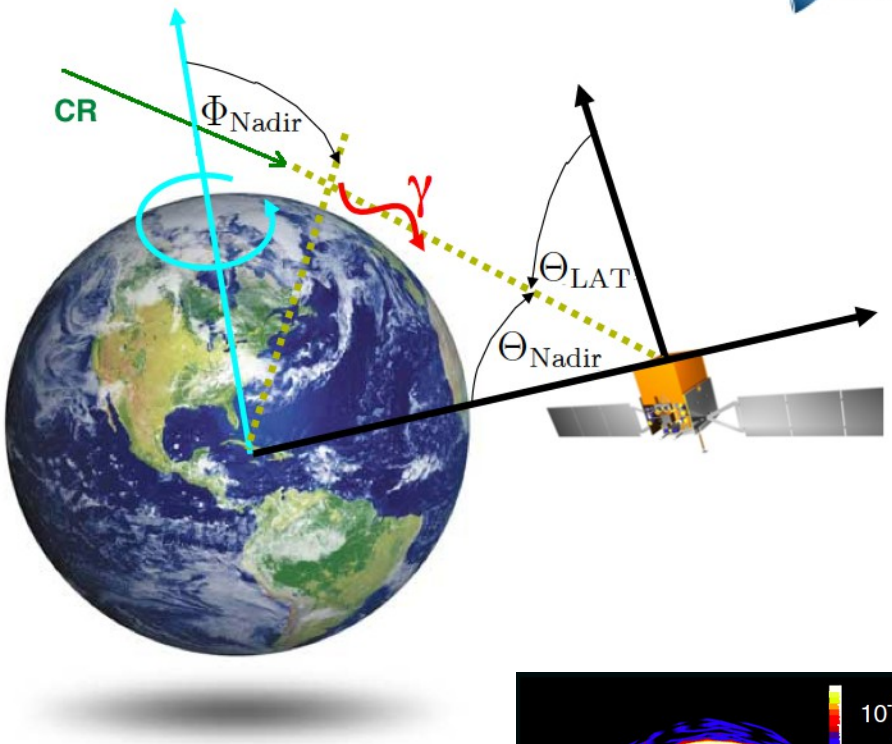
arXiv:1407.7631v2 (2014)



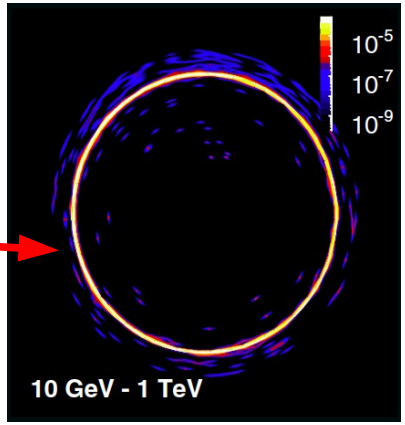
- **Energetic particles in space**
- **~90% protons, ~9% He, and small fraction of heavy nuclei, e^-, e^+, γ, etc.**
- **Sources: Supernovae, AGNs, pulsars, stellar winds, Sun, etc.**
- **Importance:**
  - **Probes of interstellar and intergalactic environment**
  - **Problems for space travel and electronics onboard satellites or airplanes**
  - **Roles in evolution, carbon dating, and climate change?**

CR-Induced γ-Ray Emission from Earth's Atmosphere

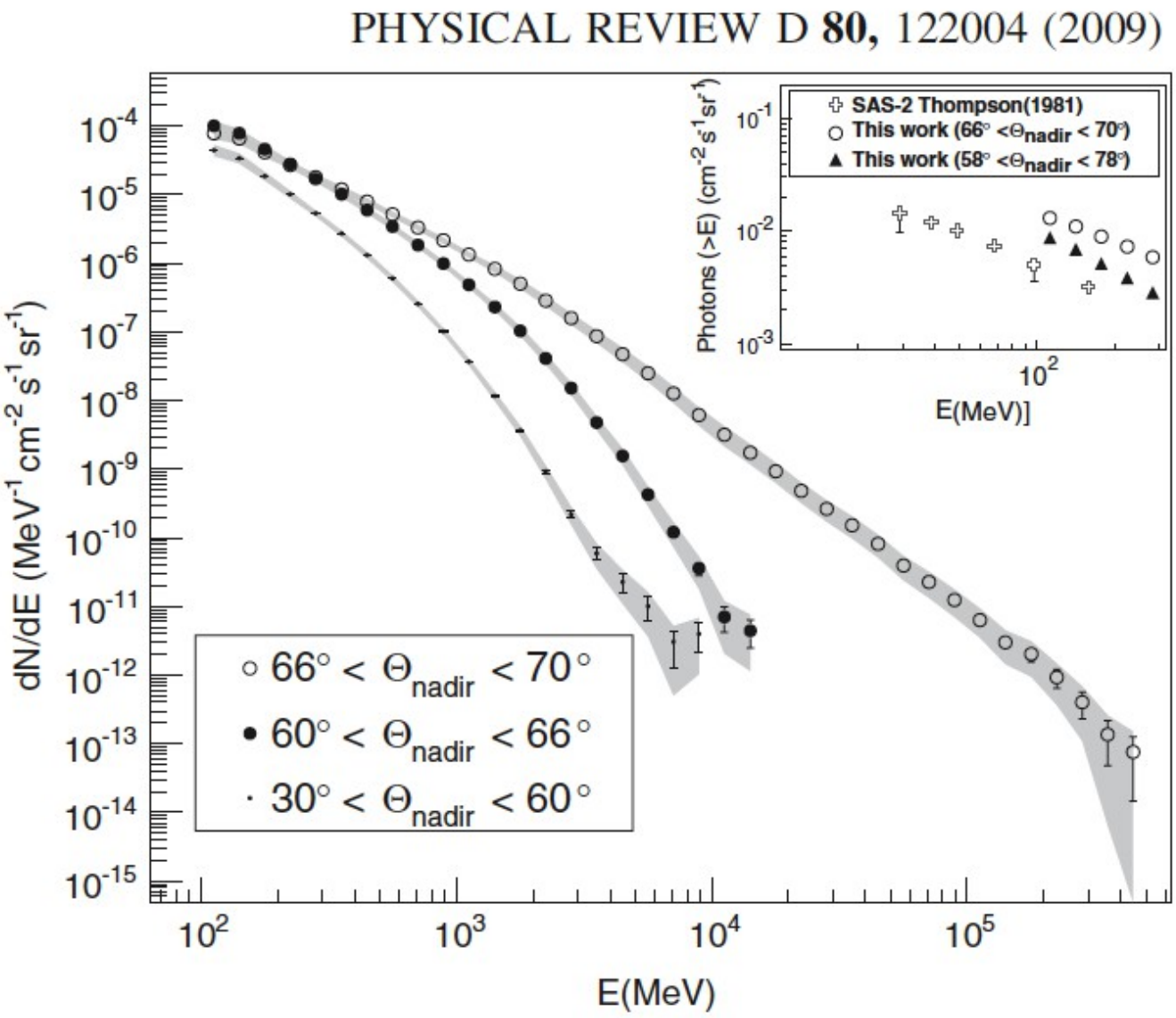




- Earth is extremely bright in γ ray due to proximity
- How Earth "looks" in γ ray
- Emission peaks at ~50 km above ground

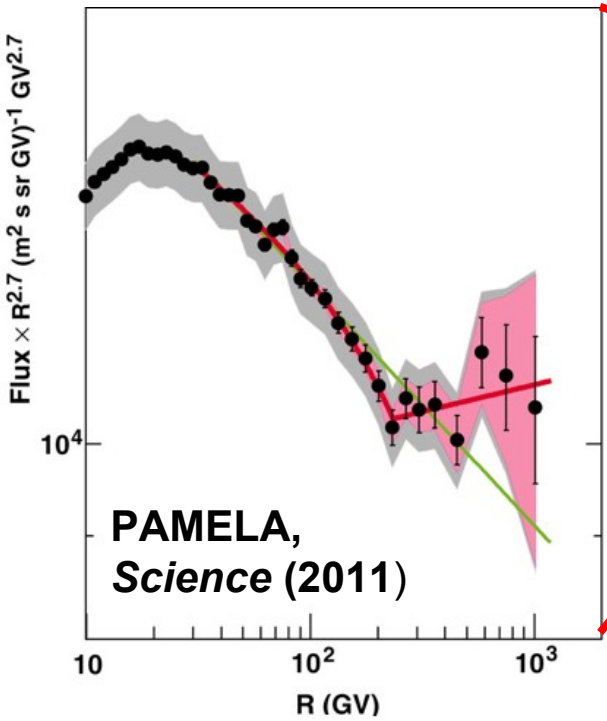


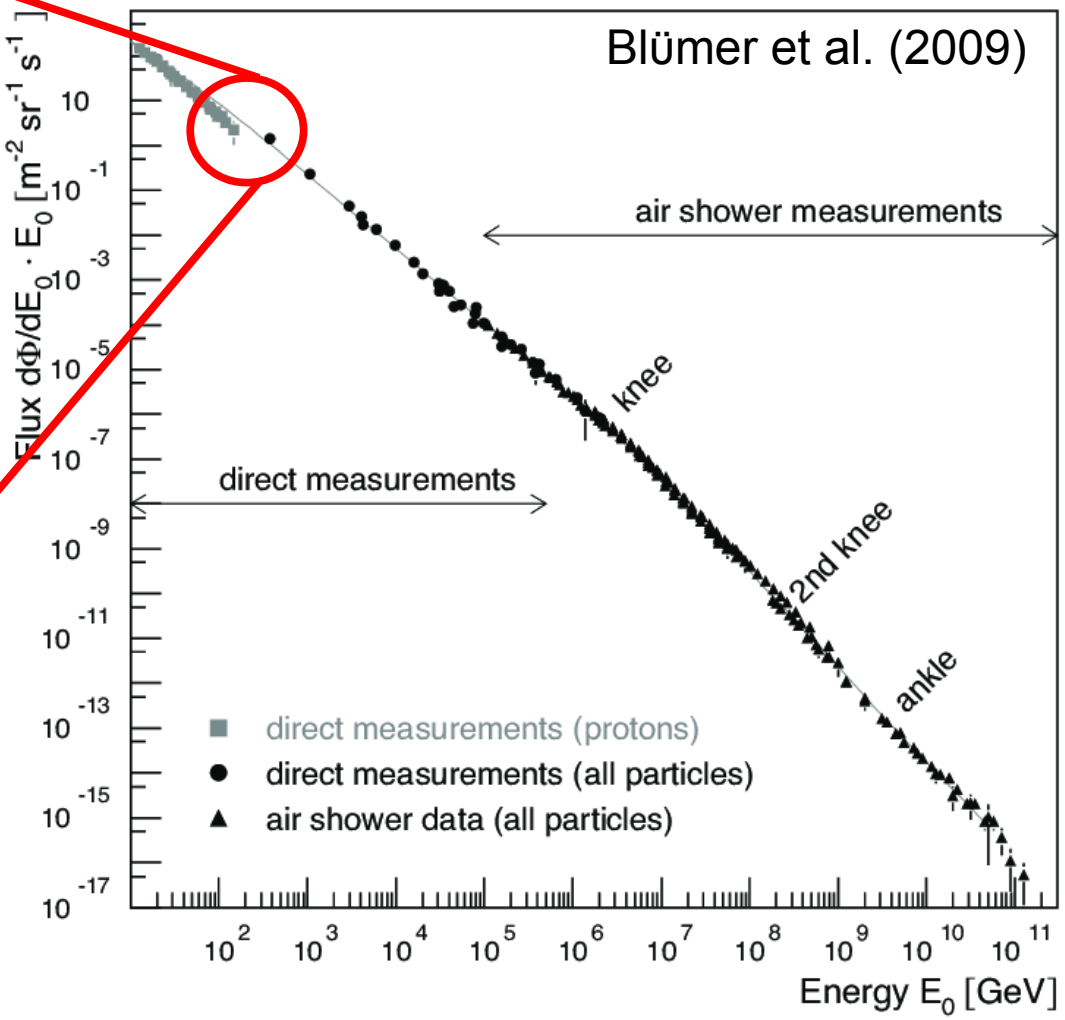
Earth's γ-Ray Spectrum



Limb spectrum above ~5 GeV is well described by a power-law $1/E^{\sim 2.8}$

CR Proton Spectrum





- **Power law ($F \propto 1/E^{\sim 2.7}$) for very wide range of energy with "knees" and "ankle"**
- **Hint of new feature at ~250 GV by PAMELA, CREAM, and ATIC-2**

Fitting Procedure

CR Proton spectrum parameters (normalization, indices, break energy)

$pN \rightarrow \gamma$ models

Resulting γ-ray flux predicted by the models

Calculate likelihood to the measured Earth γ-ray spectrum

Vary proton parameters to maximize likelihood

Input proton models

- Single power-law (SPL): $F = F_0/E^i$
- Broken power-law (BPL): $F = F_0(E_b/E)^{i1}$ for $E < E_b$
  $= F_0(E_b/E)^{i2}$ for $E > E_b$

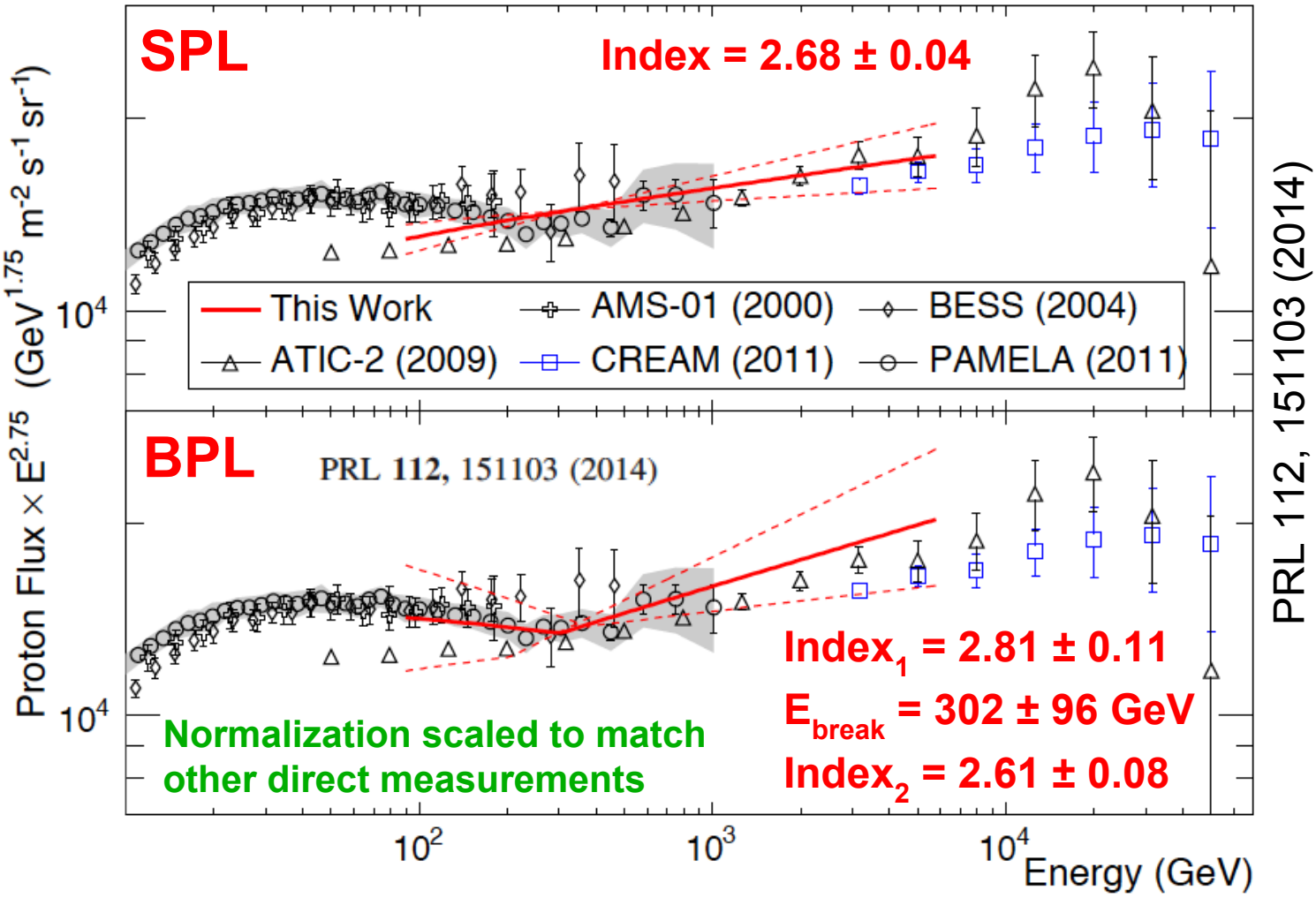
N energy bins

$$L = \prod_{i=1}^{N} P_{Poisson}\left(n_i^{obs}, n_i^{mod}\right)$$

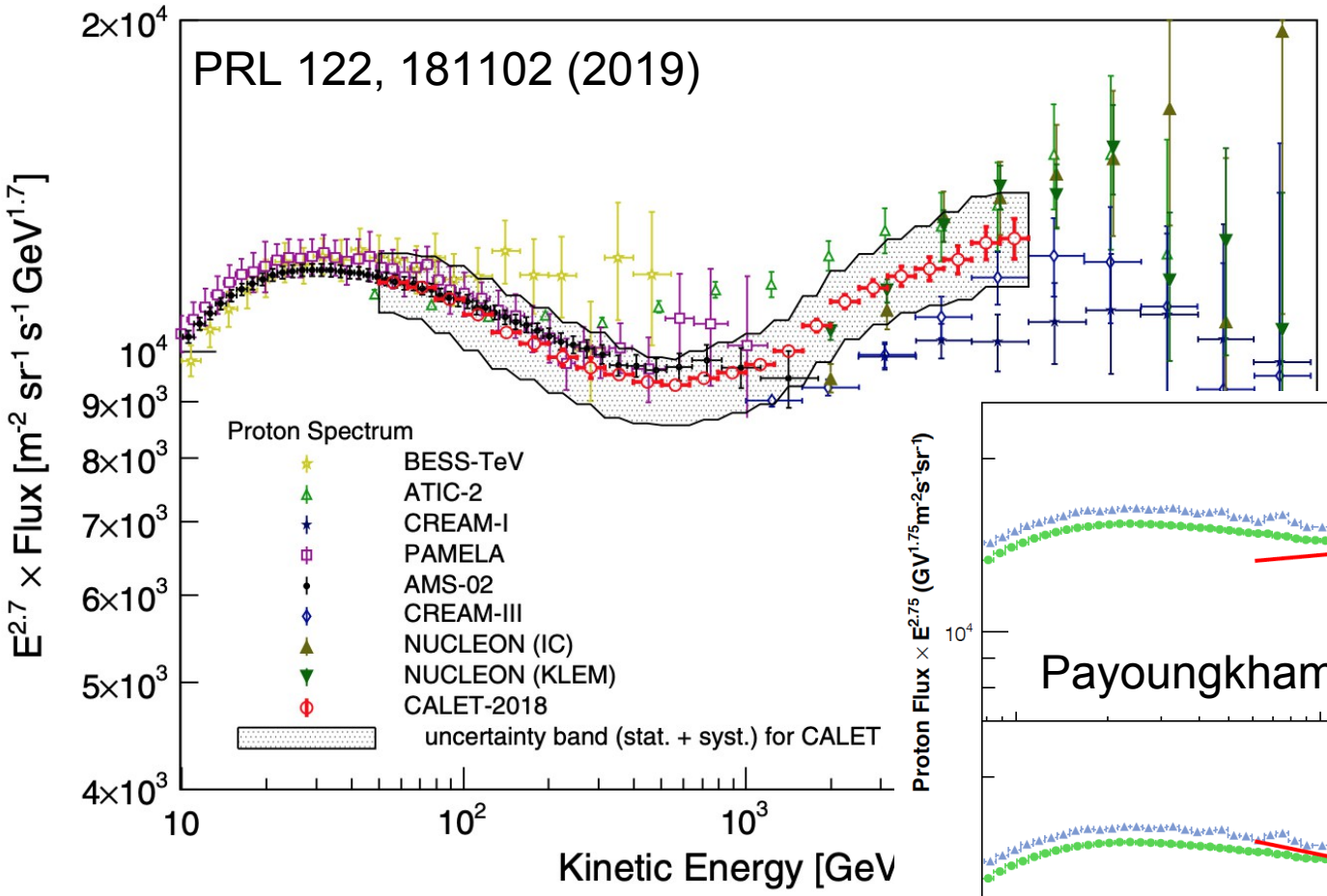
Poisson probability of observing n^{obs} photons if a model predicts n^{mod} photons in the i^{th} energy bin

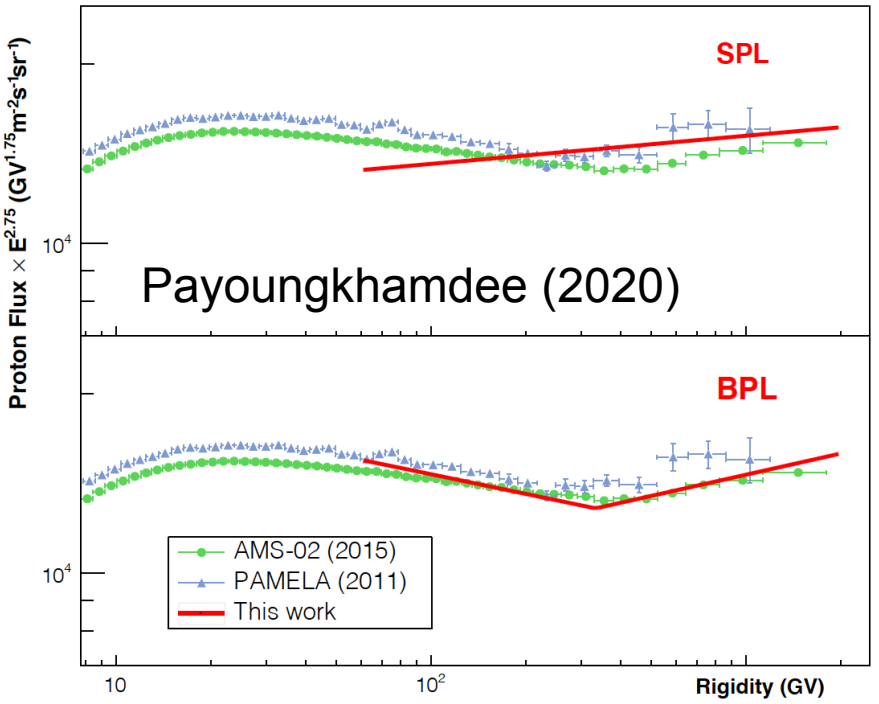
Inferred CR Proton Spectrum from Earth's γ-Ray Emission

Red lines = Best-fit CR models to Earth's γ-ray measurement

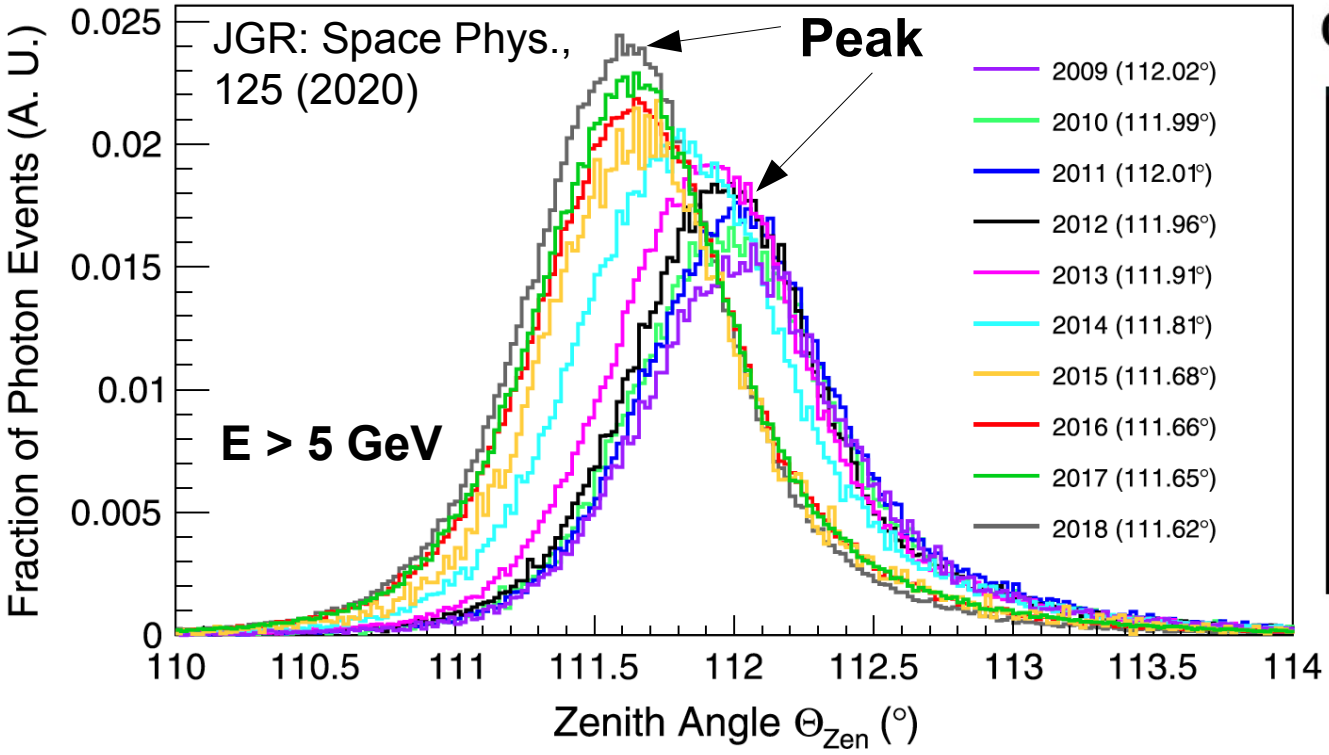


Confirmed by later analyses

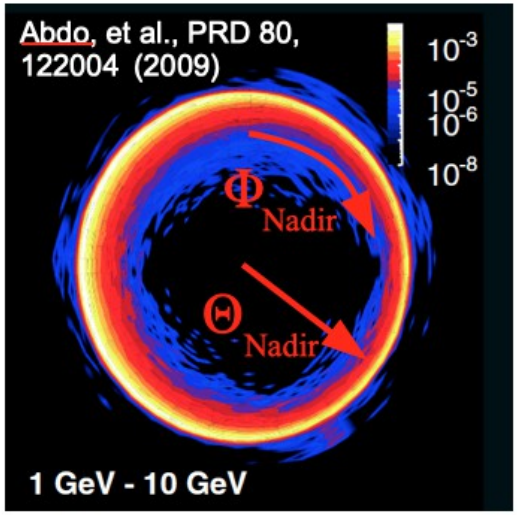




Earth's γ-Ray Zenith Profile

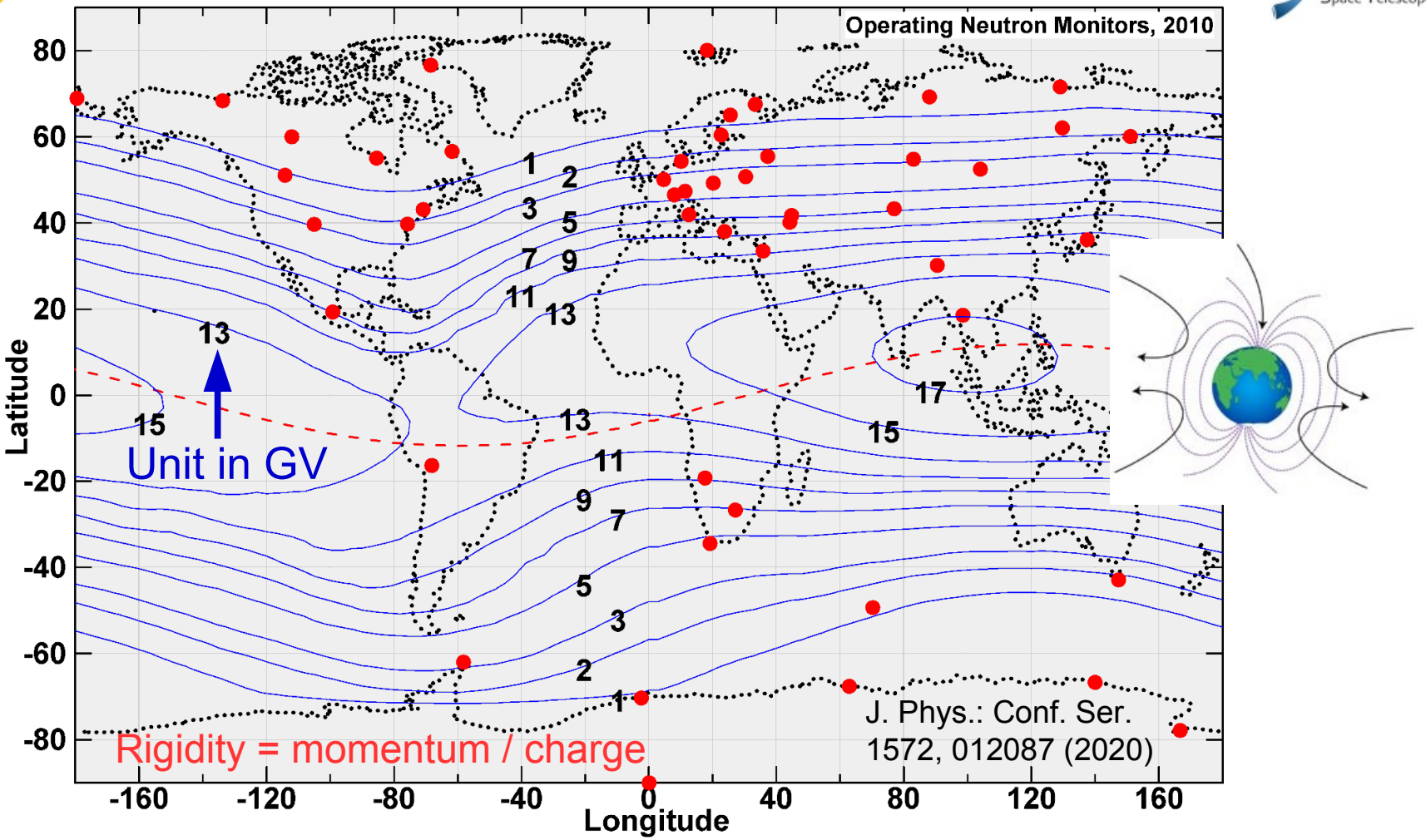


$\Theta_{Zen} = 180° - \Theta_{Nadir}$



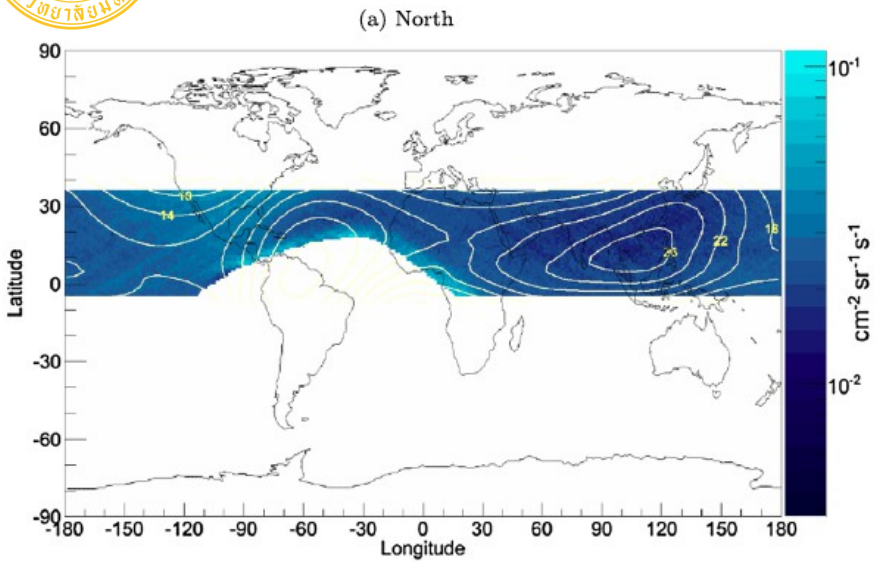
- **Peak of profile moved over time due to LAT orbital decay**
- **Use data from Peak < Θ_{Zen} < Peak + 2.0° so we can assume that these γ rays were produced at ~50-km altitude (top of stratosphere)**
- **γ rays with Θ_{Zen} < peak were produced at unknown altitude**

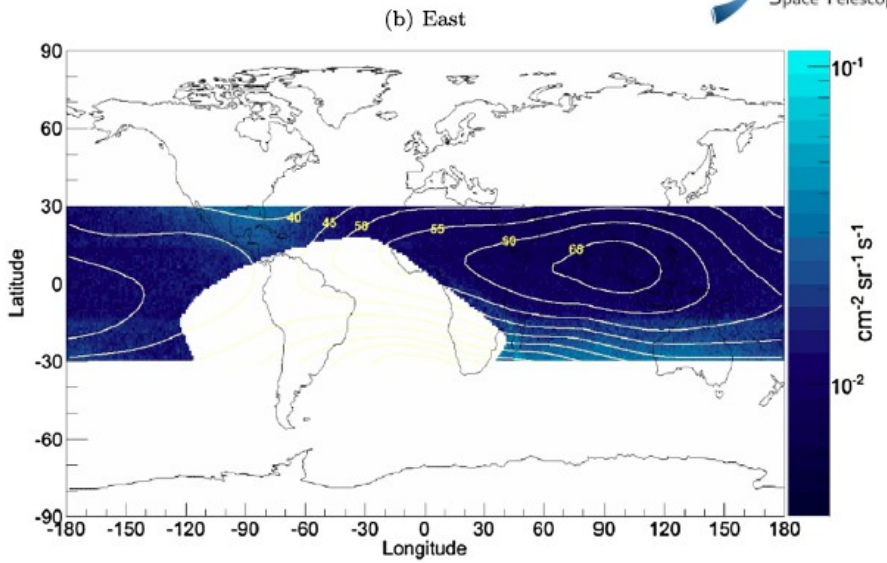
Vertical Geomagnetic Cutoff Rigidity



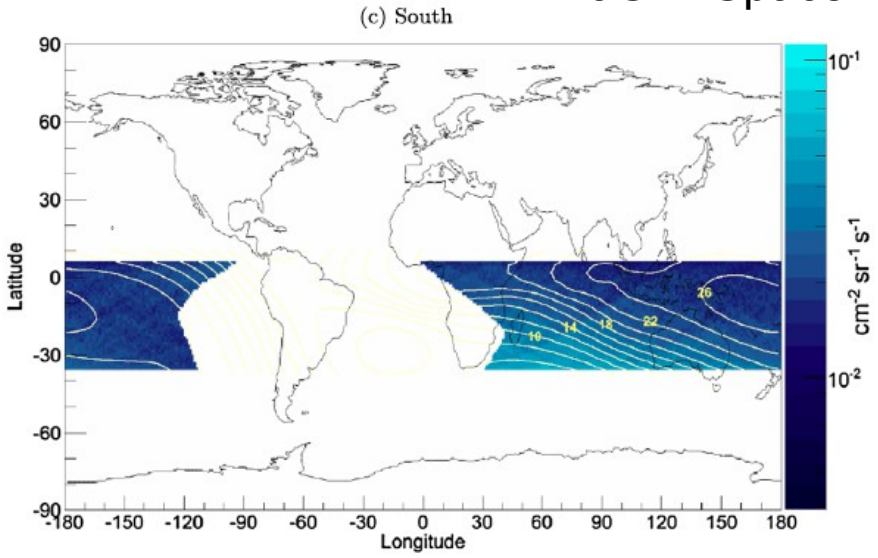
Earth's magnetic field blocks CRs below cutoff rigidities for certain locations

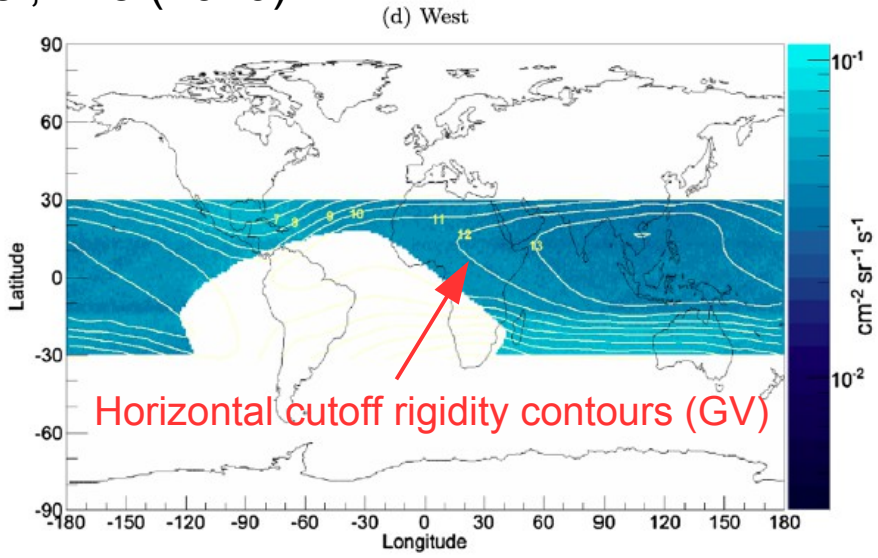
Earth's Stratospheric γ-Ray Intensity Maps



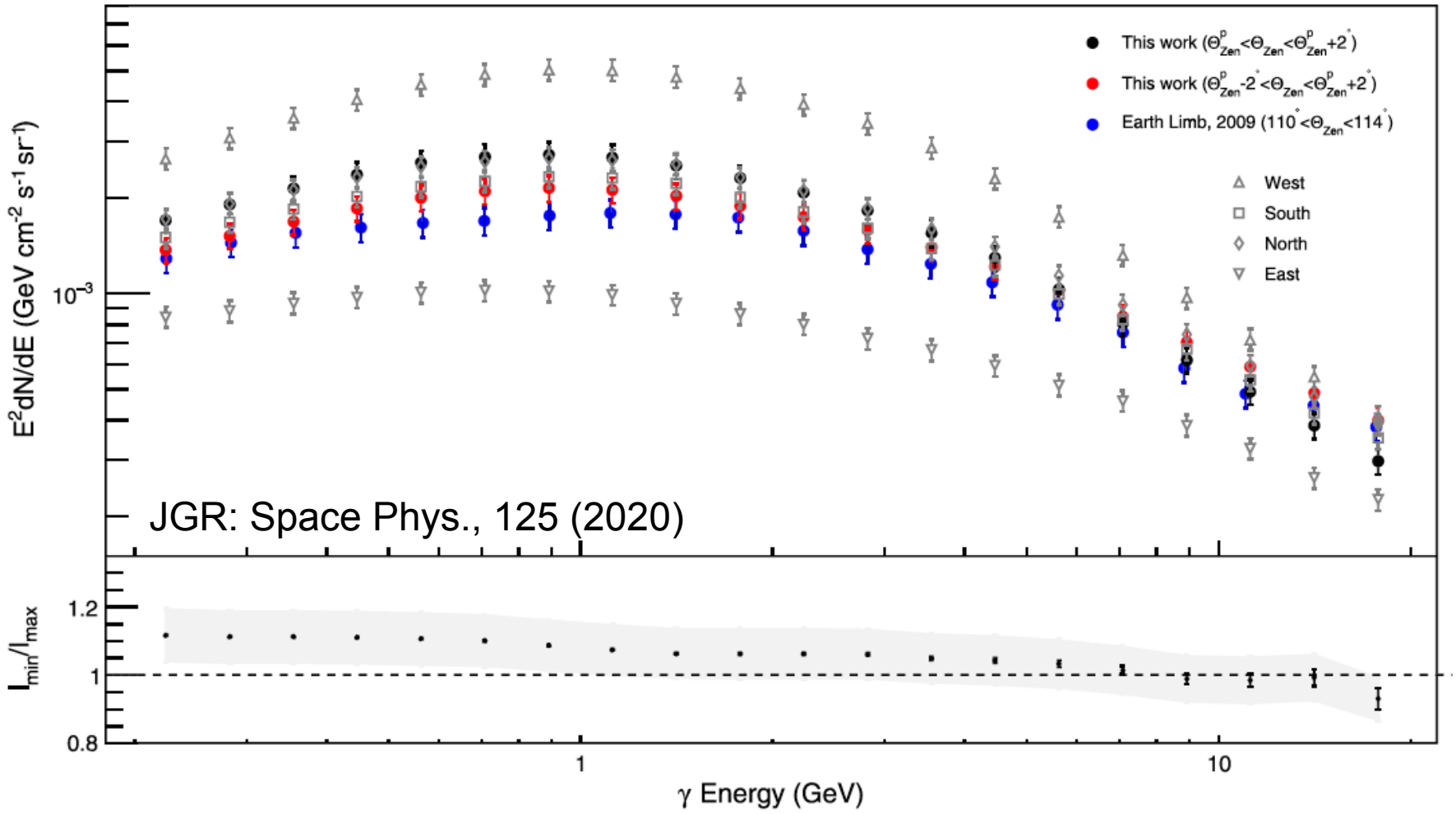


JGR: Space Phys., 125 (2020)





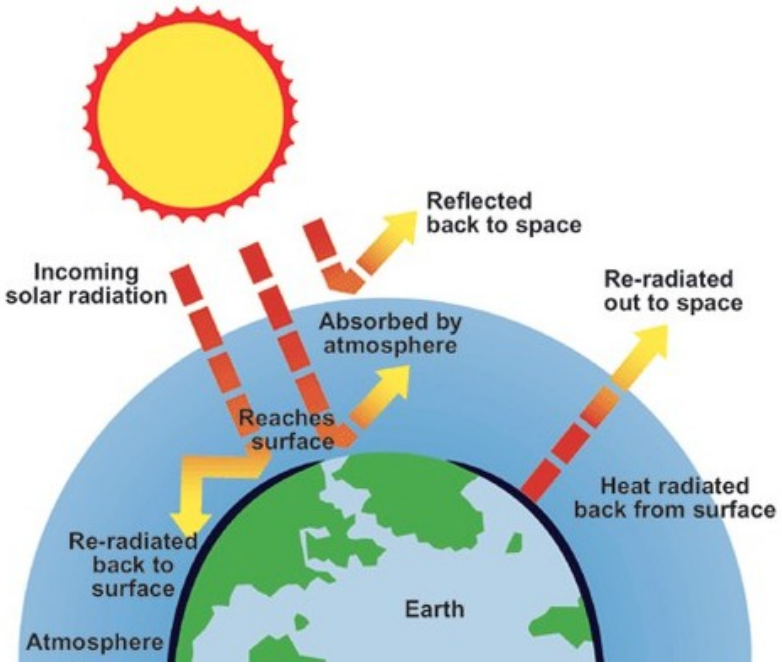
Earth's γ-Ray Spectral Changes

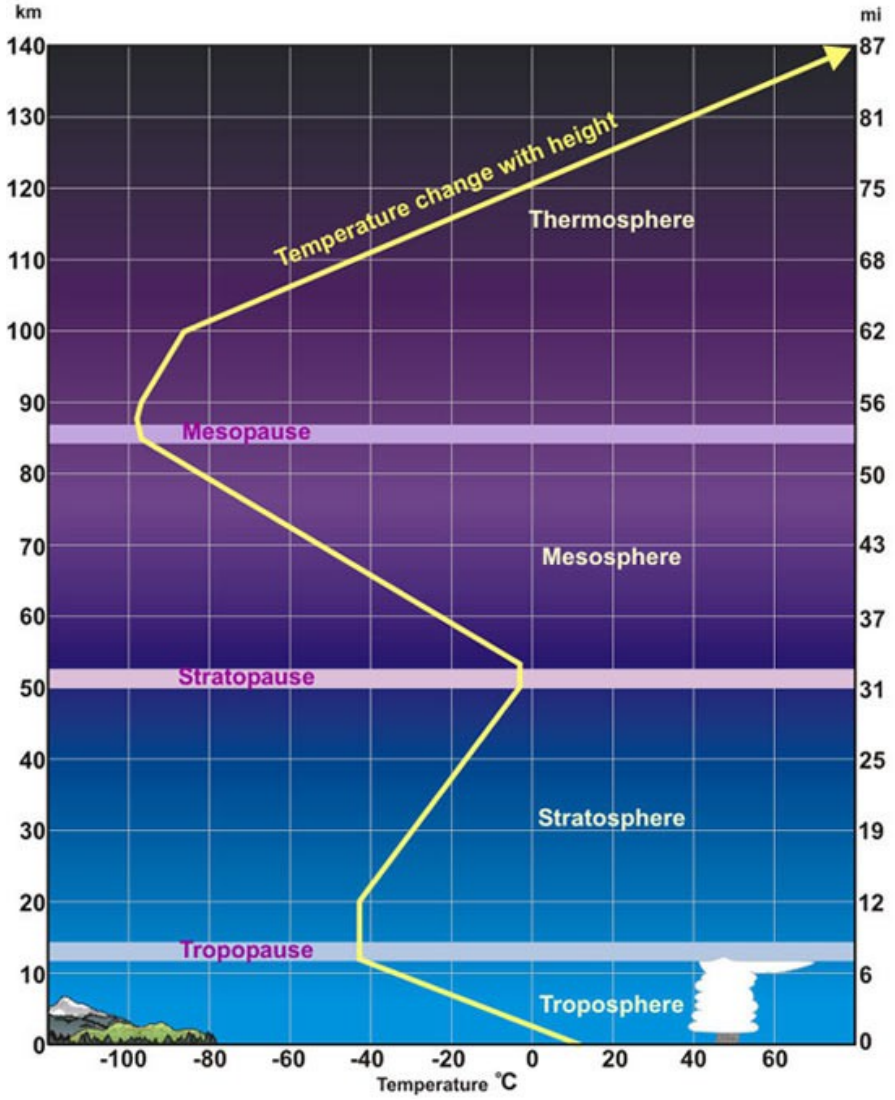


I_{min} = Intensity during solar minimum period (2012 – 2017)

I_{max} = Intensity during solar maximum period (2009 – 2011 and 2017 – 2018)

“Breathing” of Earth's Atmosphere



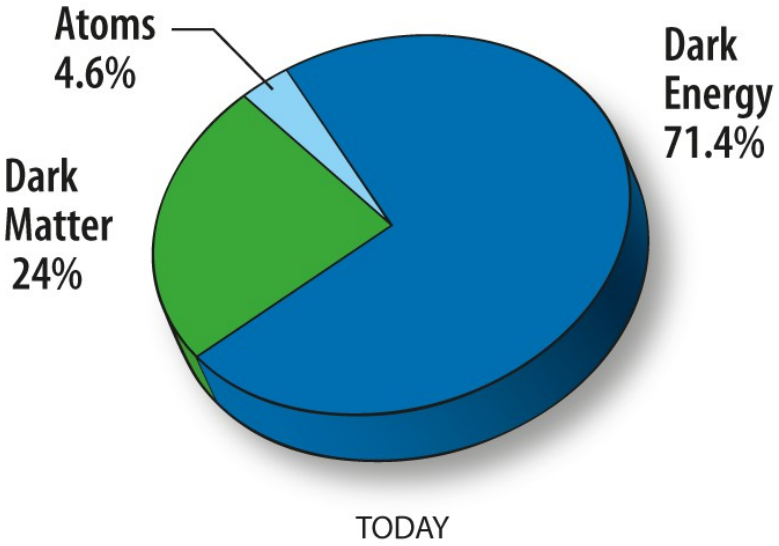


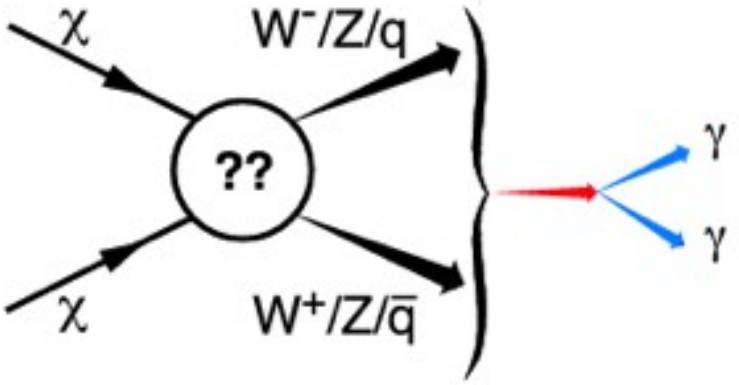
The Sun affects the thermosphere and the mesosphere through UV and solar winds (see, e.g., Chang, L.C., et al. (2009), *Geophys. Res. Lett.*, 36, L15813)

Research at Mahidol University, Thailand

- Dark matter line search

Dark Matter (DM)

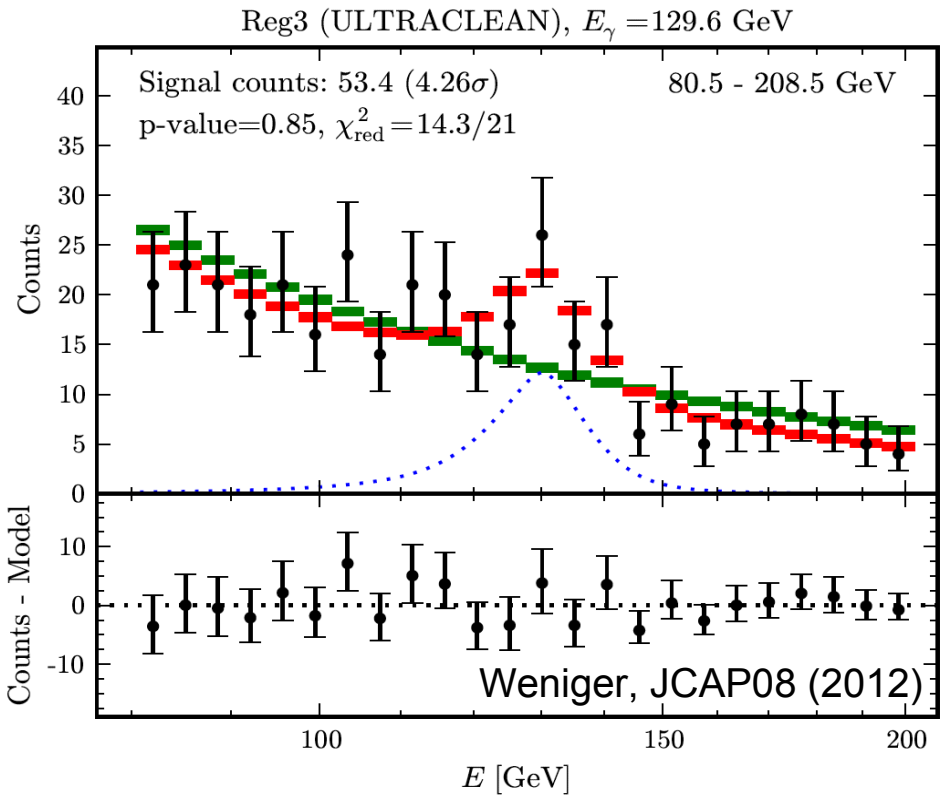




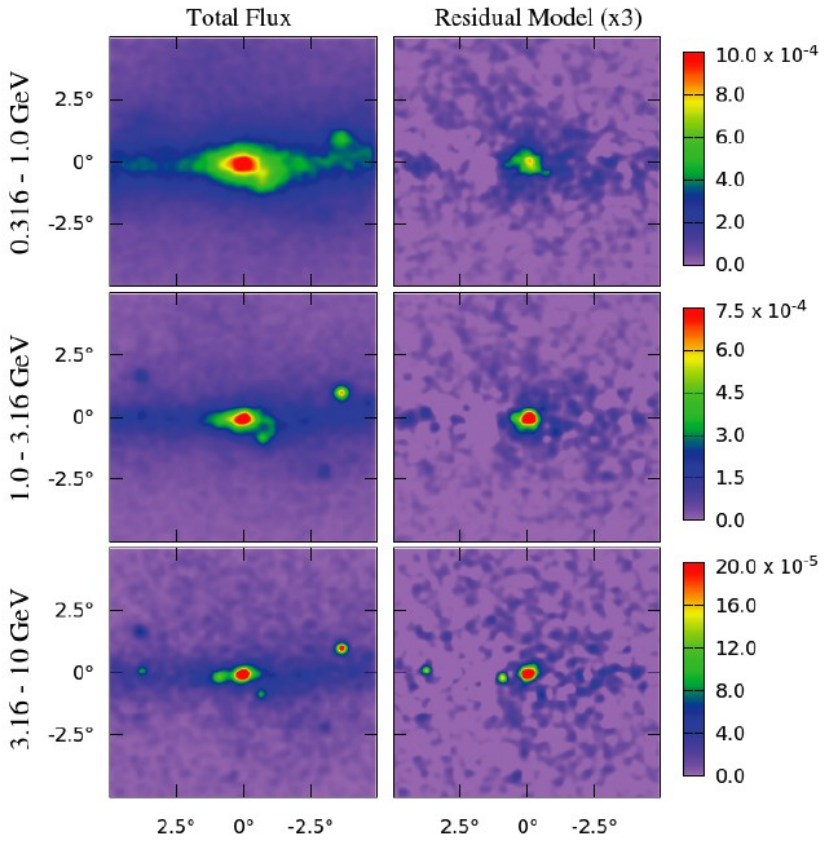
- **DM = hypothetical particles which interact with ordinary matter or light very weakly, mainly through gravity only**
- **Measurements indicate that there is much more DM than ordinary matter in the universe**
- **DM particles might annihilate or decay into γ rays**

DM Search with γ Rays

Spectral Line



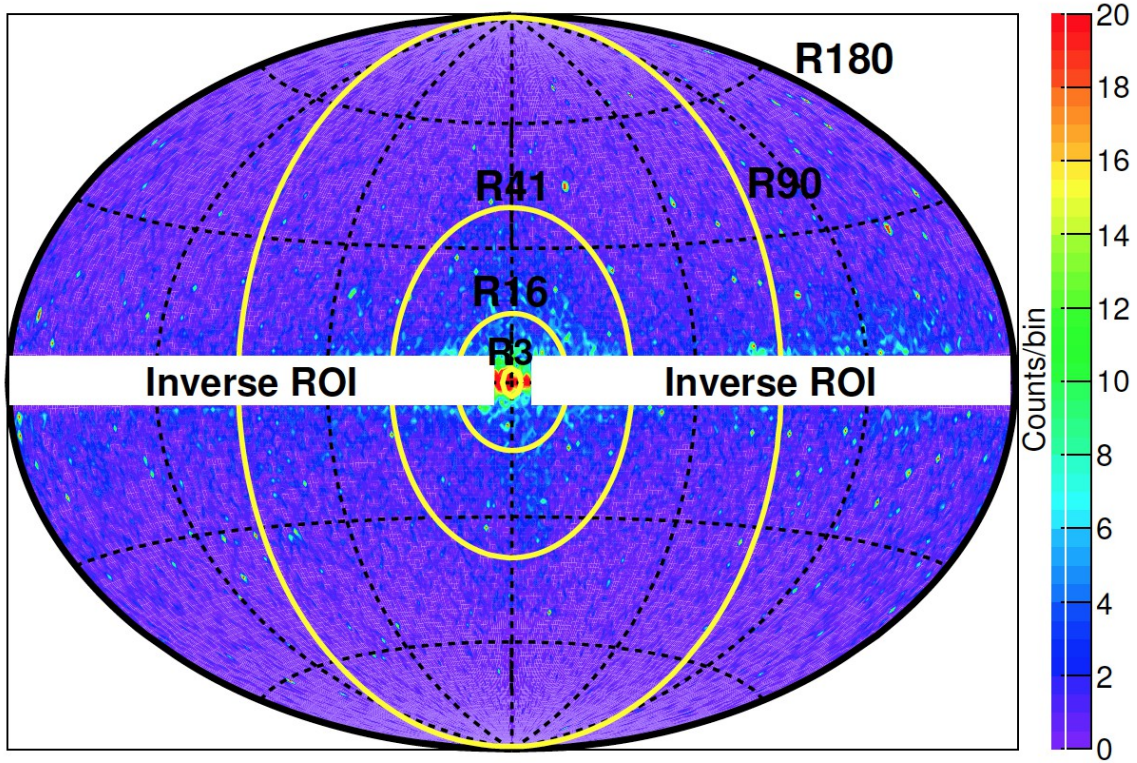
Excess Signal



arXiv:1402.6703 (2014)

Use the Earth's γ-ray emission to calibrate and verify that the instrument has no spurious effects

Our DM Line Analysis



J. Phys.: Conf. Ser. 901 (2017) 012002

- **8 years of LAT data (2008 – 2016) between 40 – 300 GeV**
- **Define different regions around the Galactic center**
- **The background and dark-matter photon count spectra are modeled as**

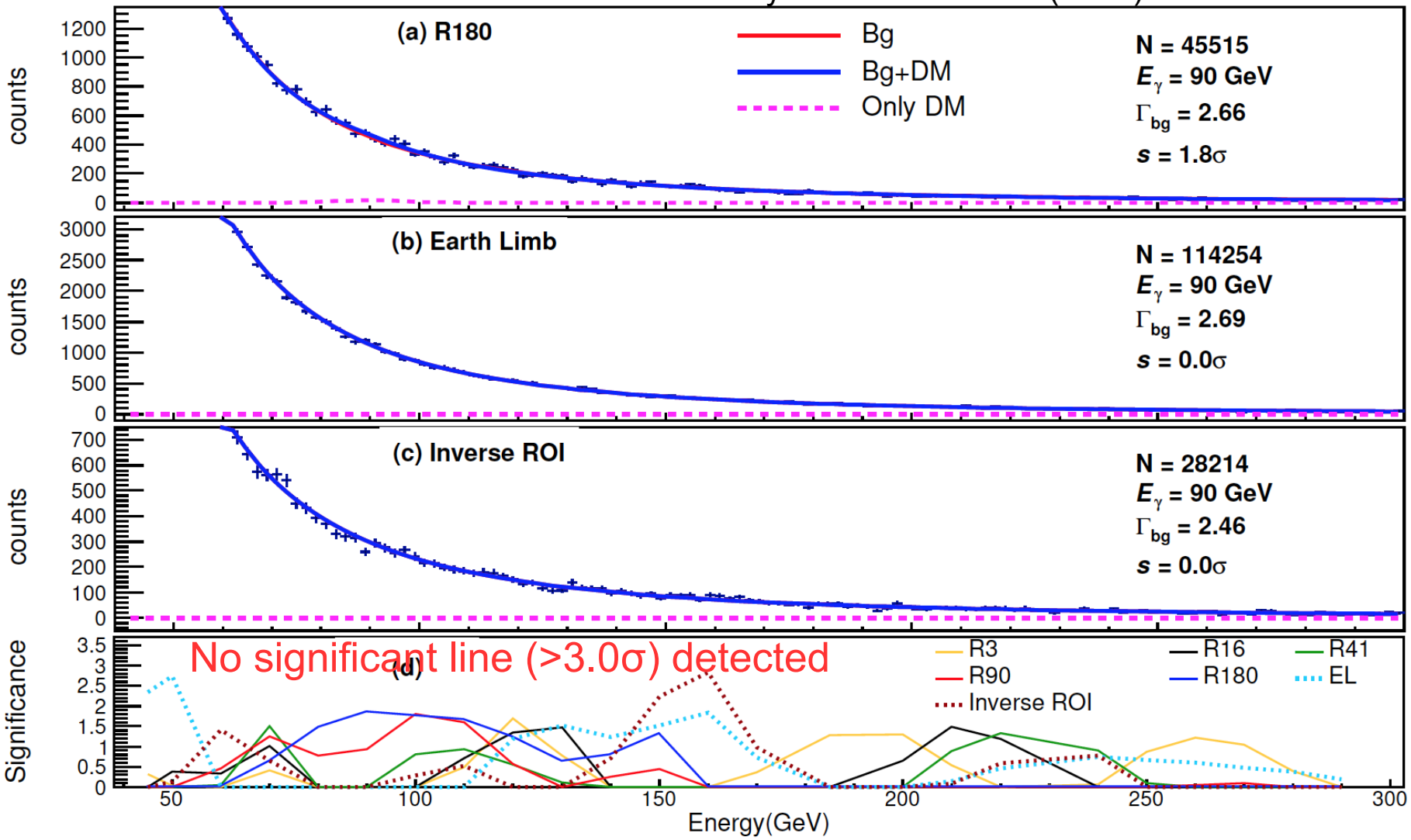
$$F_{\mathrm{Bg}}(E) = N_{\mathrm{Bg}} E^{-\Gamma_{\mathrm{Bg}}}$$

$$F_{\mathrm{DM}}(E) = N_{\mathrm{DM}} \exp\left(-\frac{(E - E_\gamma)^2}{2w^2} \right)$$

- **By varying the value of DM line (E_γ), we fit and compare the likelihood of Bg and Bg+DM models to determine the significance**

DM Line Search Results

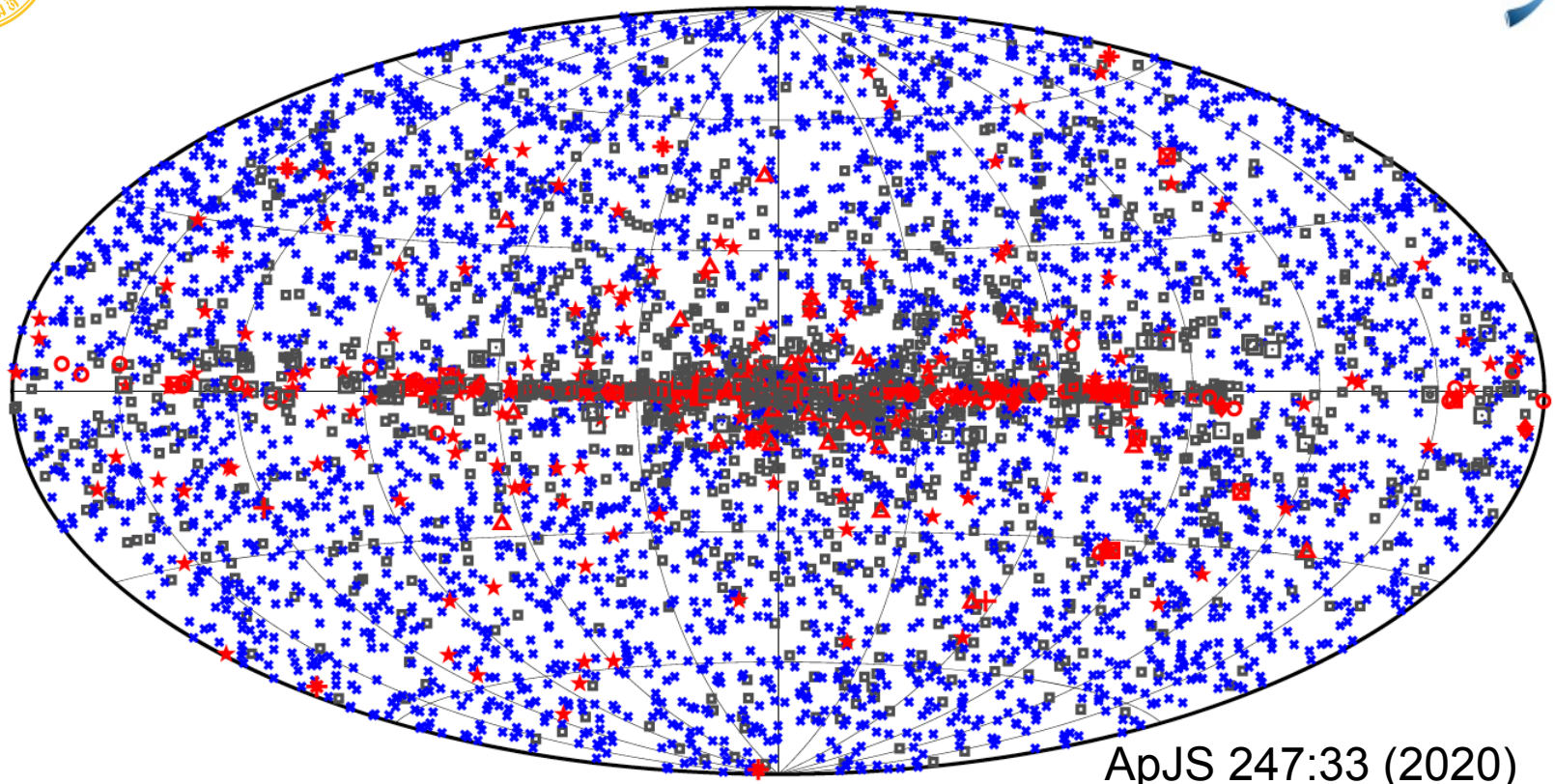
J. Phys.: Conf. Ser. 901 (2017) 012002



Research at Mahidol University, Thailand

- Clusters of high-energy γ-ray photons search

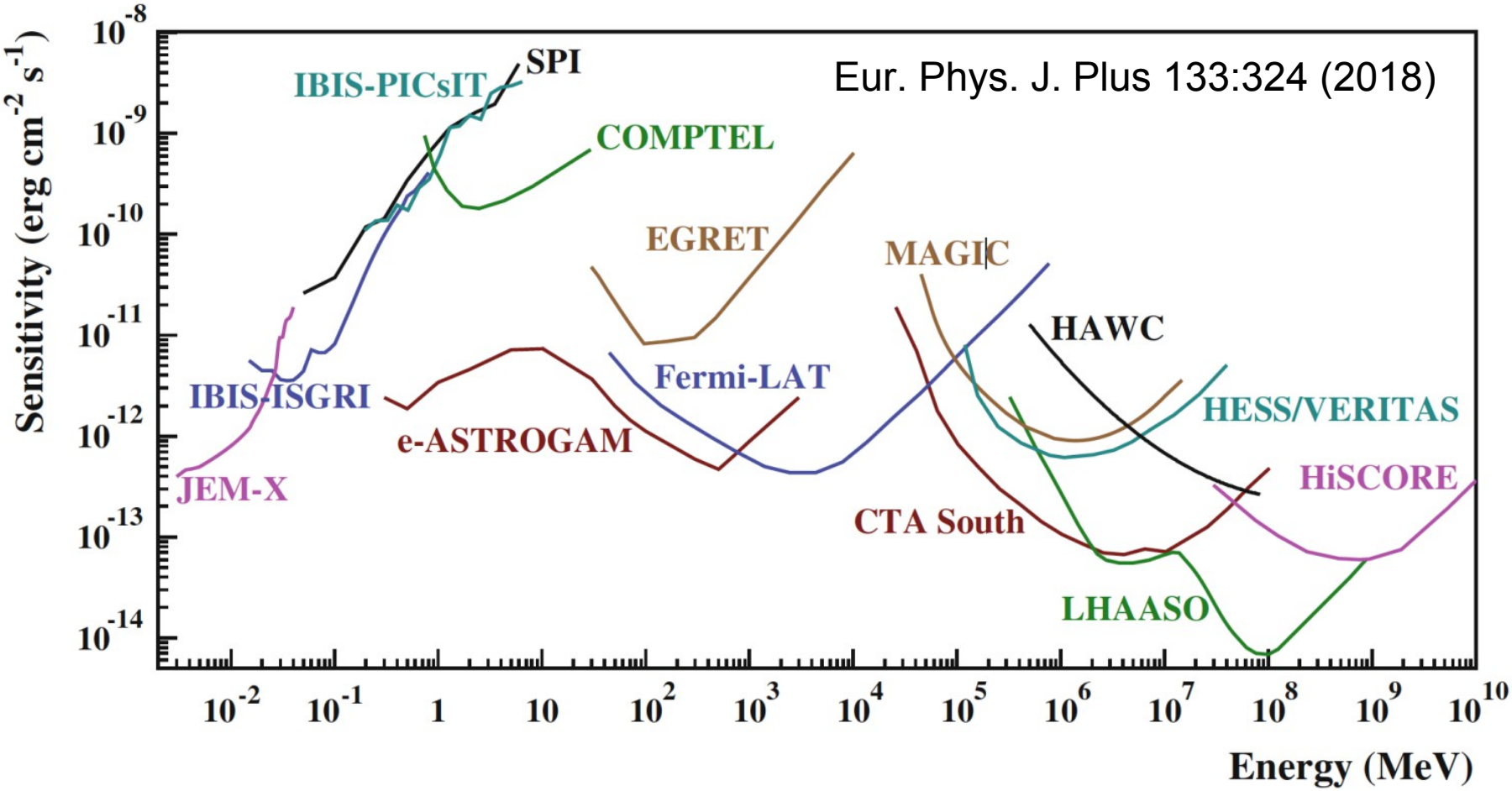
Fermi LAT Source Catalog



ApJS 247:33 (2020)

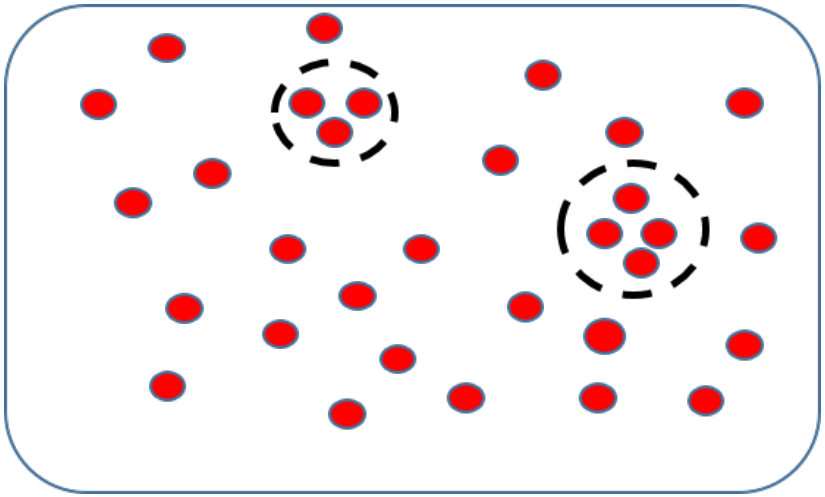
Most recent catalog (4FGL) above 50 MeV from 8 years of data include more than 5,000 sources, with ~1300 at no other wavelengths

Fermi LAT's Energy Overlap with Ground-based Detectors



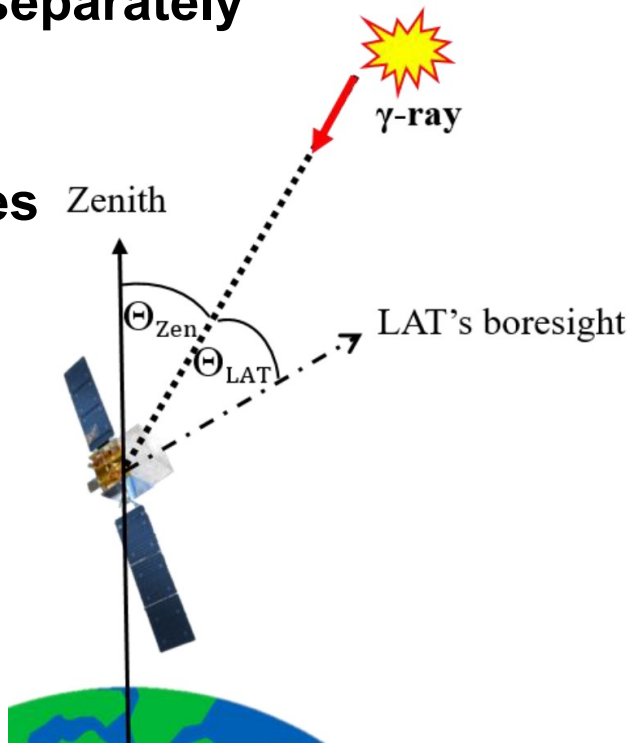
Fermi LAT = Good sky coverage, but limited sensitivity above 100 GeV
Ground-based detectors = Less coverage, but high sensitivity above 100 GeV

Clusters of High-energy γ rays



- **Search for groups of >2 photons above 10 GeV within 1.0º radius and within 20, 96, and 192 minutes**
- **Analyze the Galactic plane (within ±10º latitude) and high-latitude regions separately**

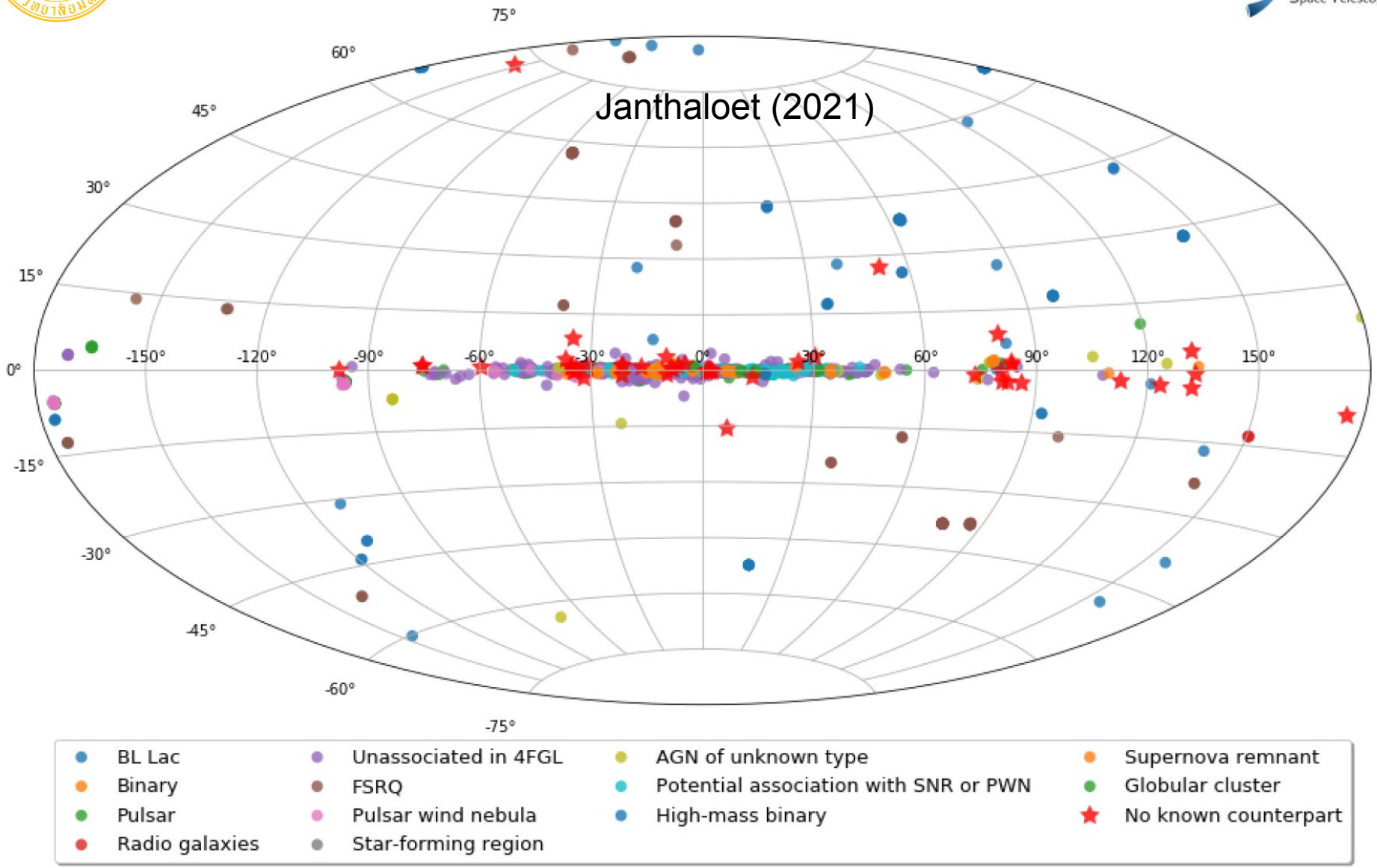
- **More sensitive to hard-spectrum γ-ray flares**



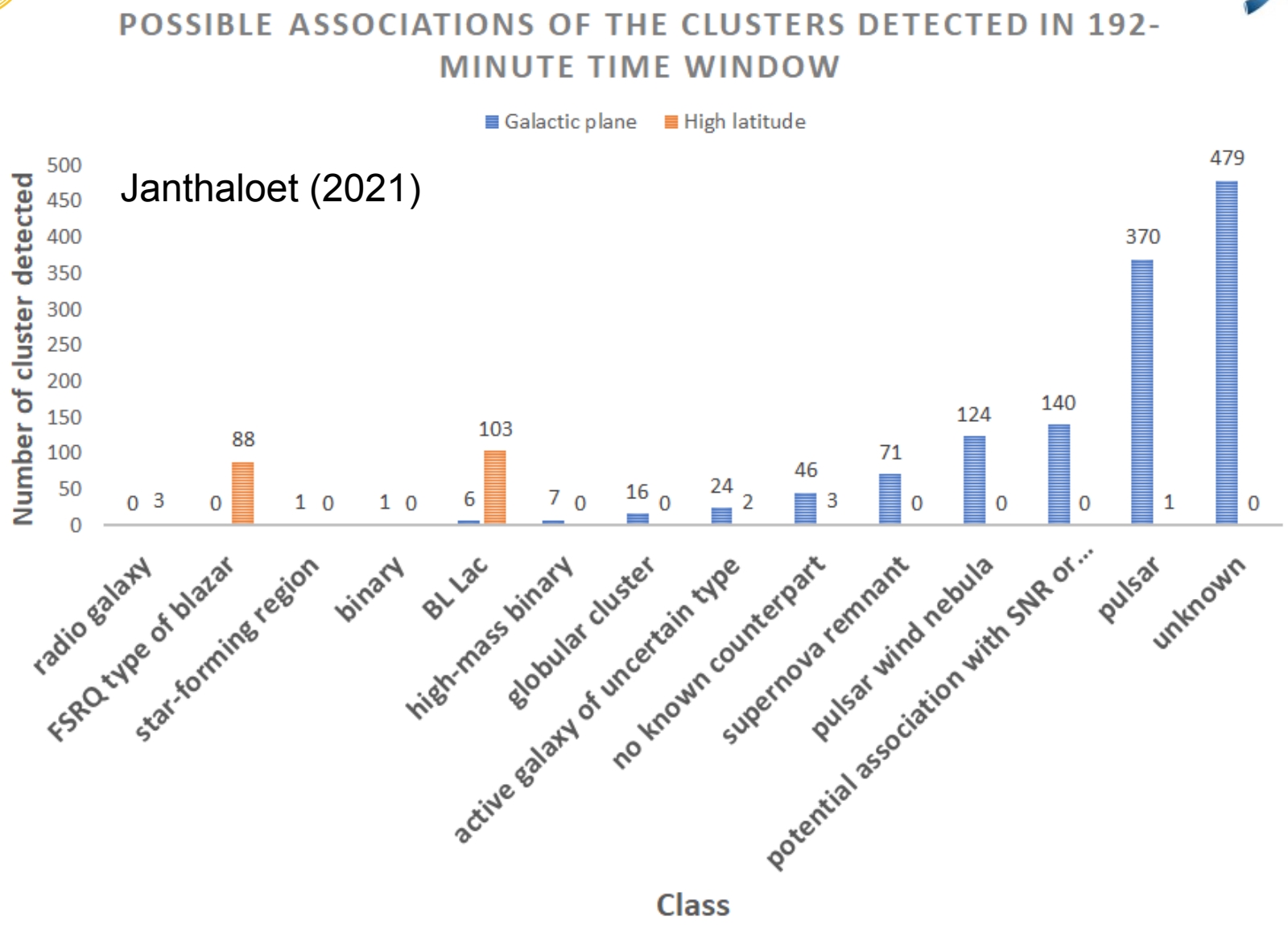
Data Set

- **10 years (2008 – 2018) above 10 GeV**
- **Θ_{Zen} < 100º (to avoid Earth's photons)**
- **~850,000 photons analyzed**

Clusters in 196-min Interval



Source Types of Detected Clusters



Cluster Search Summary

	Galactic plane		High latitude	
	Number of total clusters	Number of clusters with no known counterpart	Number of total clusters	Number of clusters with no known counterpart
20-minute	85	2	31	2
96-minute	238*	5*	36*	-
192-minute	934**	39**	134**	1**

* Not in 20-minute search
** Not in 20-minute or 96-minute search

Janthaloet (2021)

Summary

- Earth's γ-ray analysis
  - CR spectrum reconstruction
  - Instrument calibration
  - γ-ray monitor in space
  - CR spectral variation
  - Geographical γ-ray map
- Dark matter line emission analysis: no significant line found found in 8 years of data
- Clusters of high-energy photons analysis: some sources with no known counterparts are potentially newly discovered sources
- More to come

Back Up

Abstract

The Fermi Large Area Telescope (LAT) is a space-based gamma-ray observatory launched in 2008 and is currently still in operation with unprecedented capability. It has revolutionized our understanding of the GeV gamma-ray sky and cosmic ray (CR). Working at Mahidol University in Thailand, I am an affiliated scientist of the Fermi LAT Collaboration. My research with Fermi LAT largely involves analyzing the CR-induced gamma-ray emission of the Earth's atmosphere which is useful for the study of CR spectrum, the geomagnetic field, and the CR-air interactions. We search for sharp gamma-ray lines in the direction of the Galactic center which could hypothetically be emitted from dark matter decay. We also experiment with a different method to uncover faint transient gamma-ray sources at sub-TeV energy which may potentially be candidate targets for ground-based detectors such as CTA at higher energy ranges.