Coronal Magnetic Field Modulates GeV Solar Disk Gamma Ray

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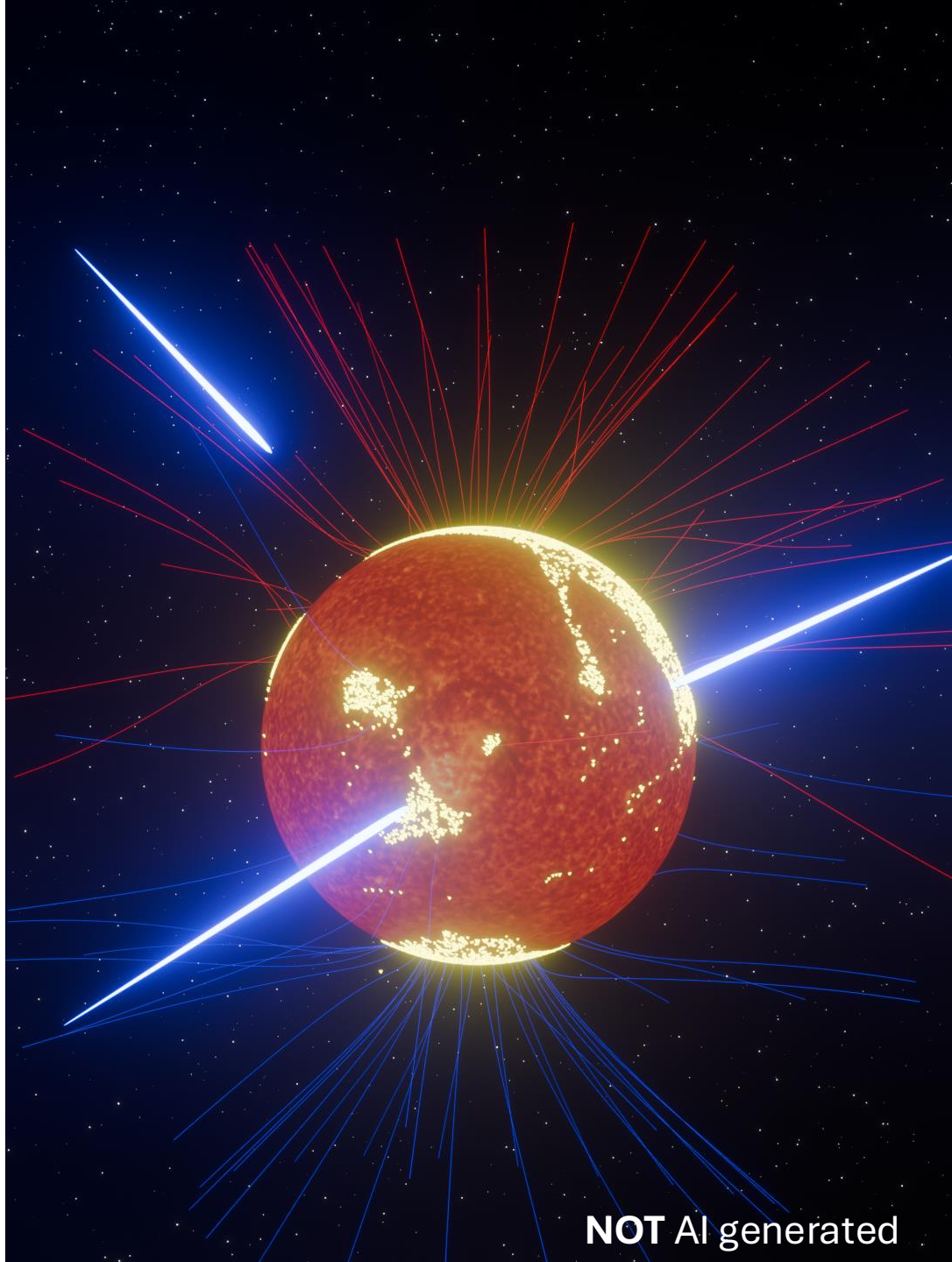
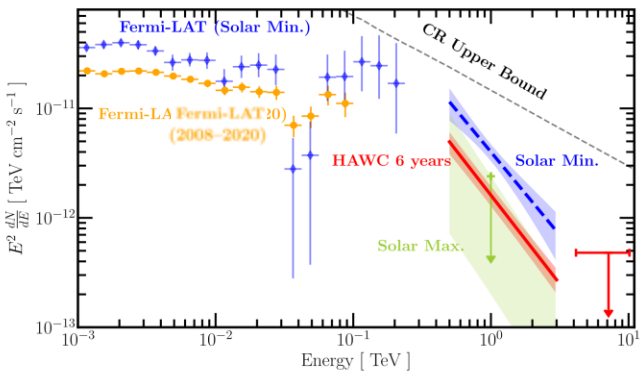


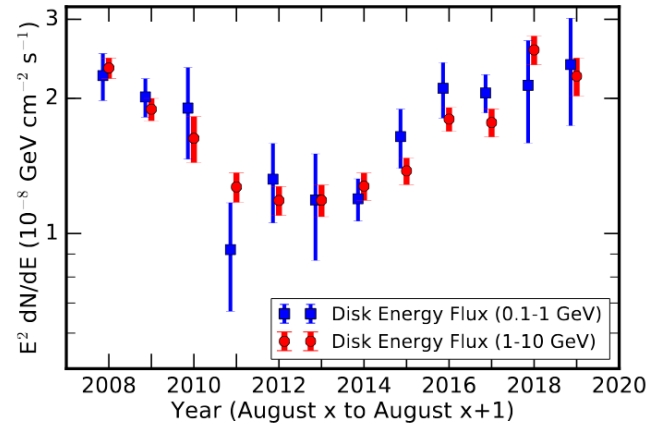
Observation Puzzles

- *Flux:*
  - Flat up to 200 GeV
  - 6x higher than early estimate
- *Time Variation:*
  - Anti-correlates with solar cycle
- *Morphology:*
  - Energy and time dependent

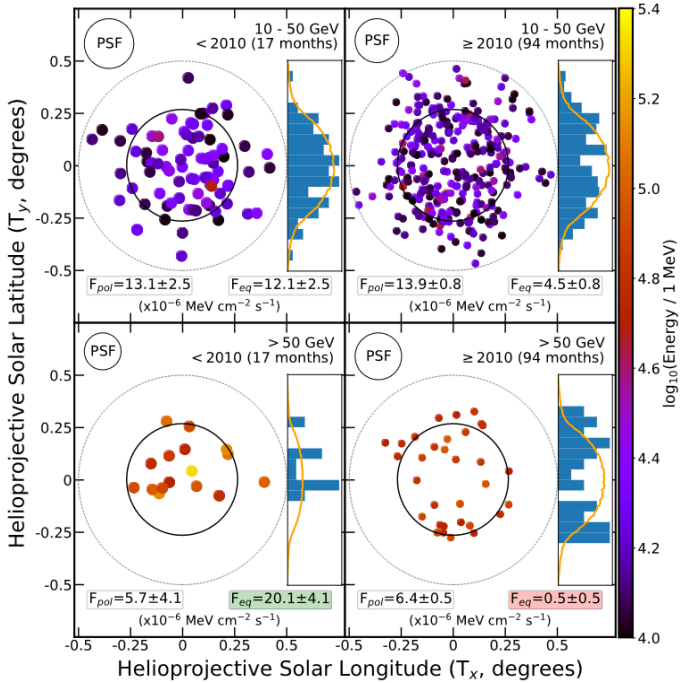
HAWC Collaboration, 2022
arxiv:2212.00815



Linden et, al 2020
arxiv:2012.04654



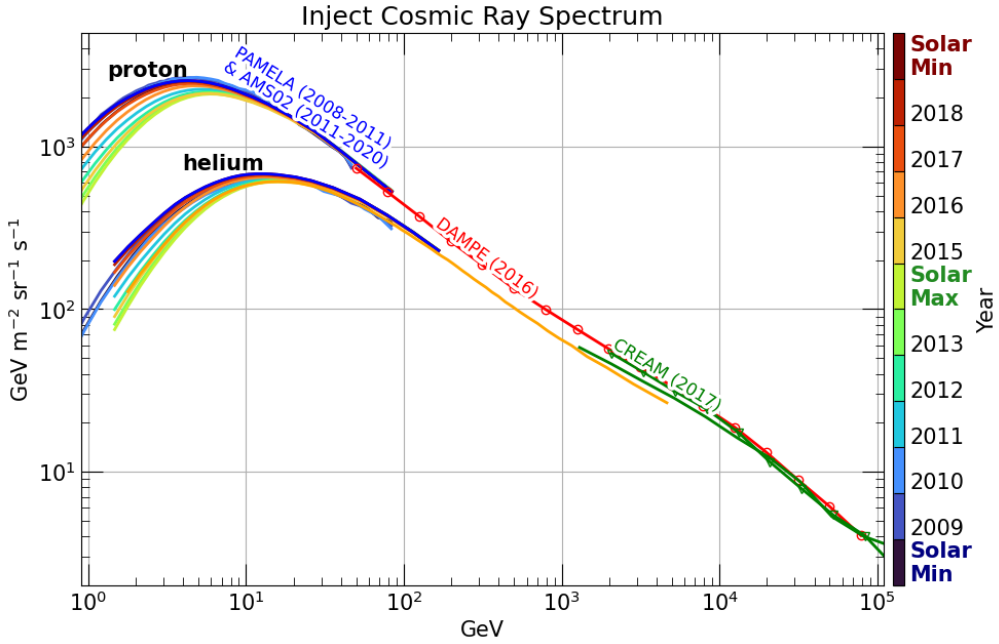
Quiet Active



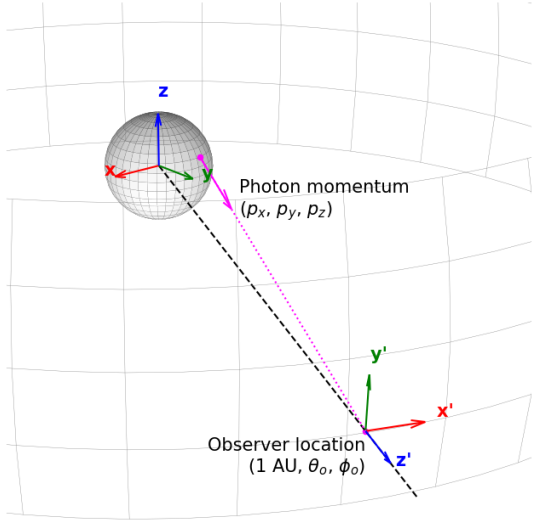
Linden et, al 2018
arxiv:1803.05436

Simulation Toolkit G4SOLAR

- Written in Geant4, first developed by Zhe Li (2009.03888)
- Isotropic inject Cosmic Ray, normalize to 1 AU flux
  - Time dependent Proton & Helium flux
- Innovation: first study considered of Earth orbit geometric constraint.

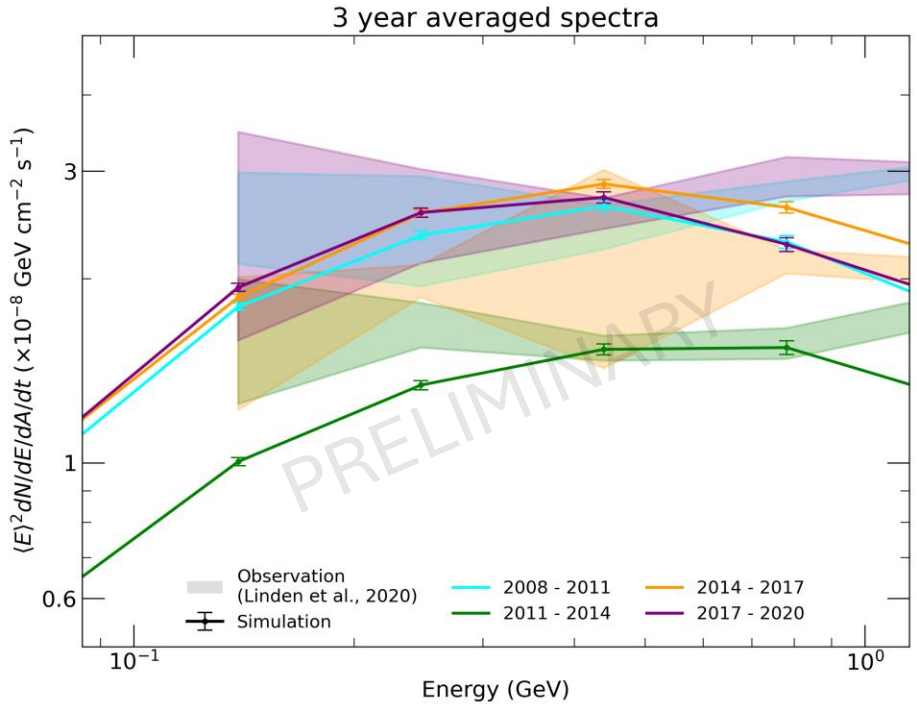


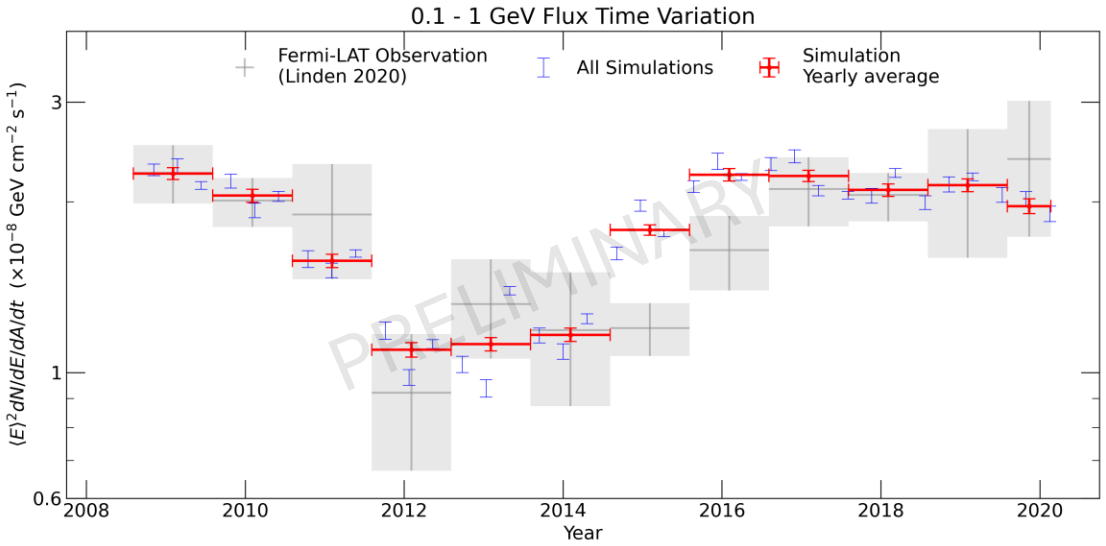
tools.ssdc.asi.it/CosmicRays/



Time Varying 0.1-1 GeV Gamma Flux

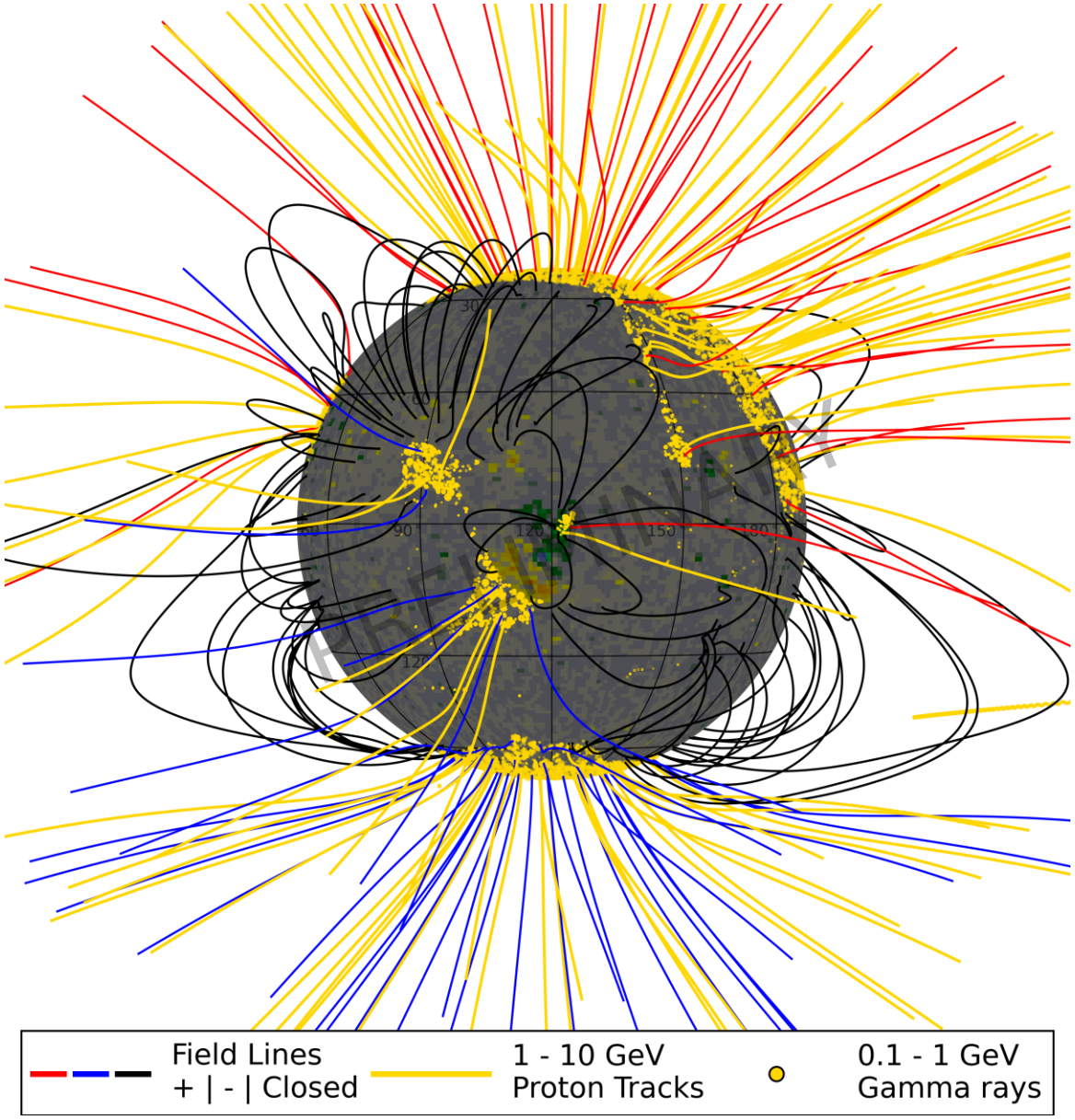
- Gamma ray spectra from 36 magnetic field models, from 2008 - 2020
- Both flux and time variation match observation
- *First study pointing out corona field as a cause of solar time variation!*





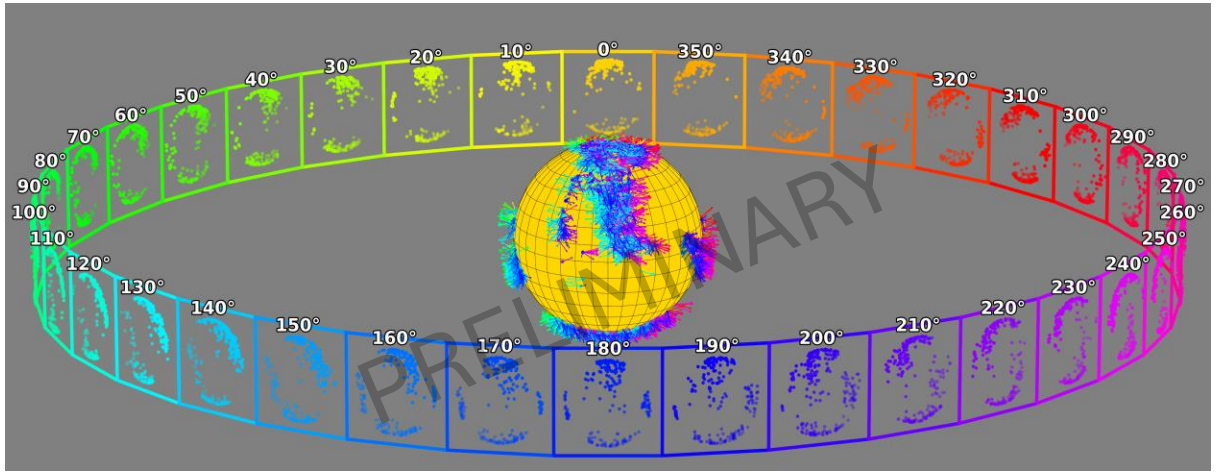
Cosmic Ray Affected by Open Corona Field

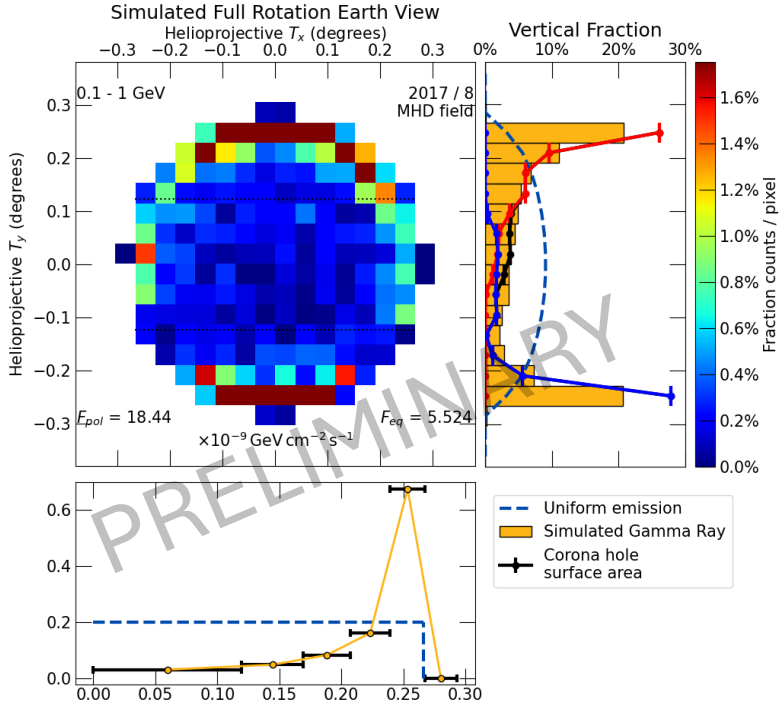
- We trace individual cosmic ray (CR) propagation and interaction
- CR < 10 GeV is heavily influenced by corona B field.
  - To reach solar surface, CR must follow open field lines
- ***The area of open field directly decides GeV gamma ray flux***



Implication for Observed Morphology

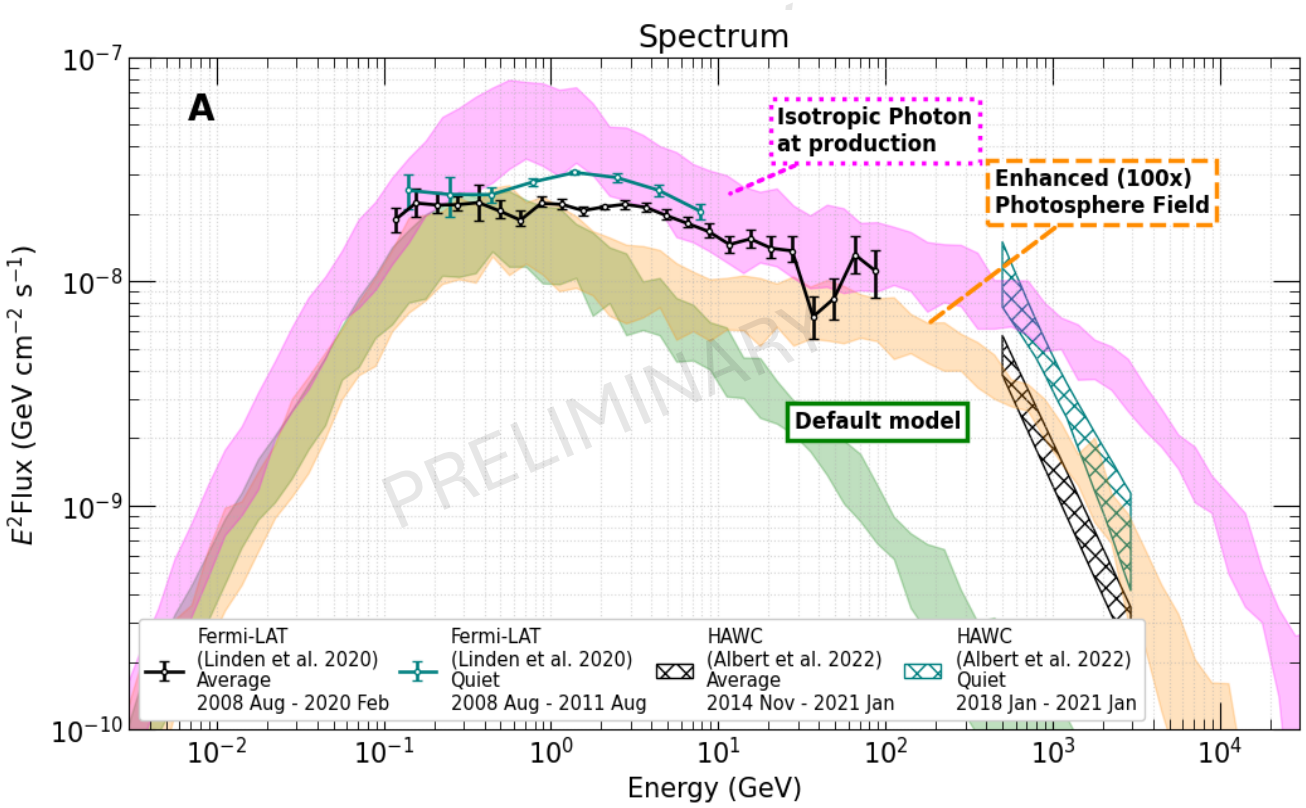
- We convert the collected gamma ray to observed flux morphology.
- The coronal field – flux connection is also observable in morphology.
- *Solar gamma ray morphology is a powerful tool to probe coronal field.*





Photosphere Field Effect on TeV Flux

- We test 2 different "toy models" photosphere field
  - 100x field strength
  - isotropic photon production
- Almost no effect on low energy result, enhances high energy flux
- *Low and high energy gamma ray are caused by different solar magnetic field components!*



Conclusions

- Corona field has significant effect on low energy cosmic ray propagation near the Sun and solar gamma ray
  - Simulation result matches observed flux and time variation < 1 GeV
- Our full Sun simulation allows us to study morphology of gamma ray, which can verify corona models
- Exercise in photosphere field shows high energy gamma are influenced by field inside the Sun