The Sun is shining in Gamma Rays

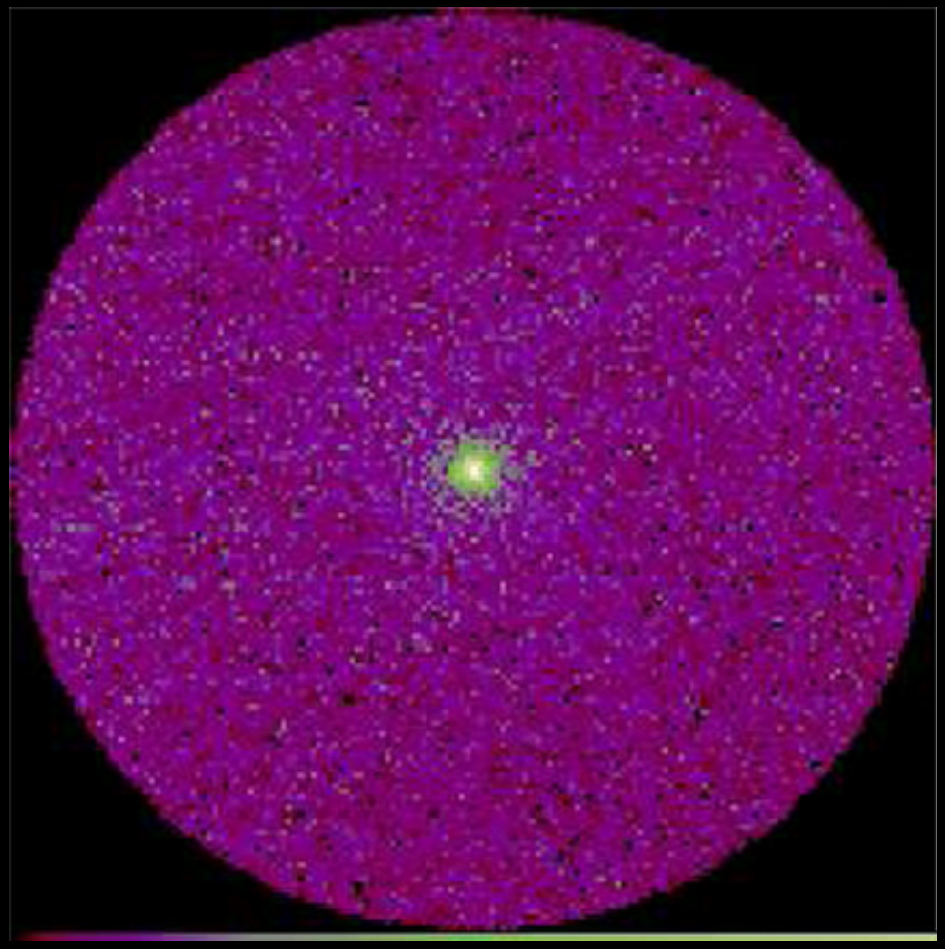
WHY?

Kenny, Chun Yu NG

CCAPP, The Ohio State University

With John Beacom(OSU), Annika Peter(OSU), Carsten Rott(SKKU)

The Gamma Ray Sun



Abdo+ 2011

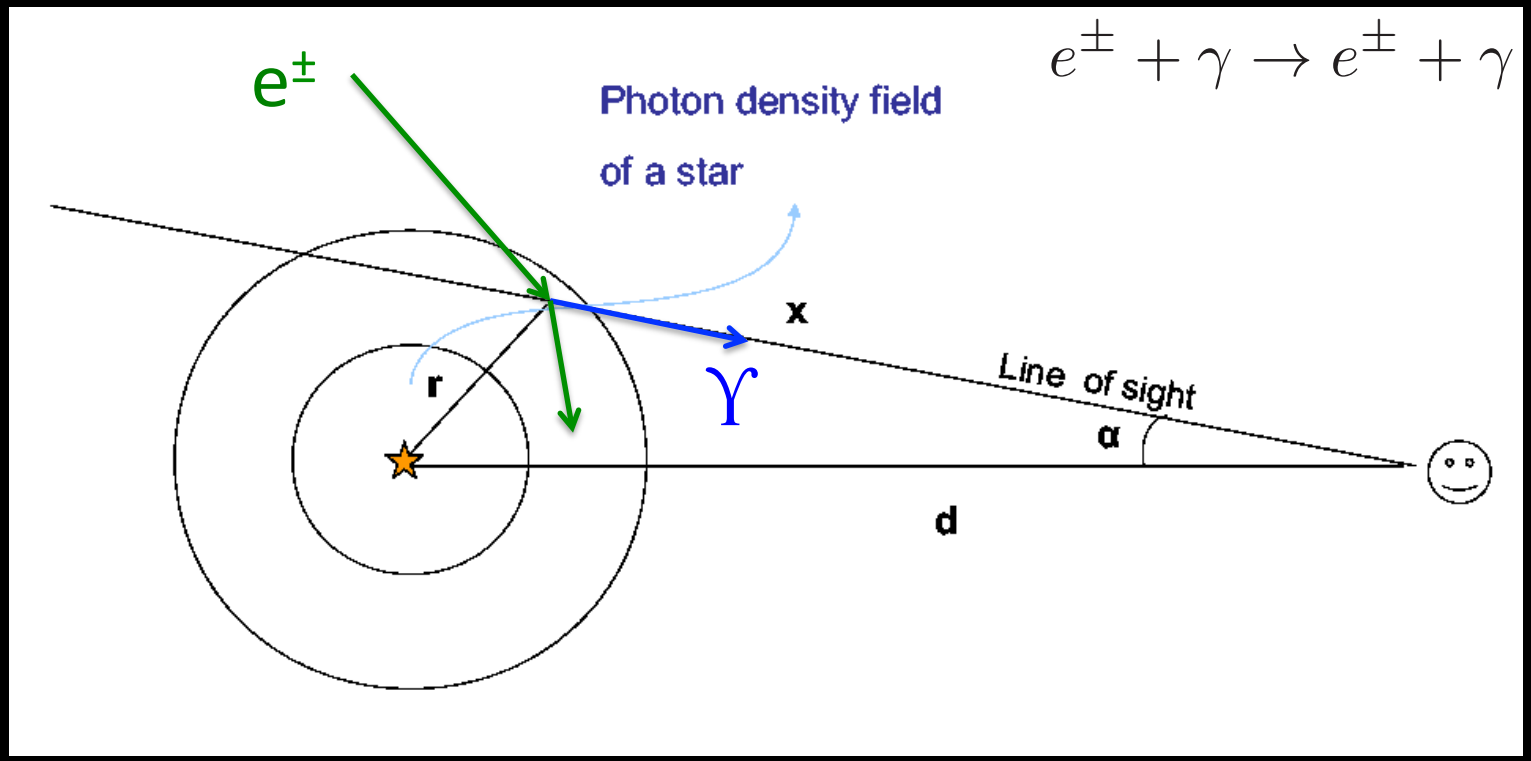
- E > 100 MeV, 40^{o} x40^{o}

Cosmic rays set the Sun on Fire

- The Sun itself is not hot enough
  - Corona T ~ 10^6 k ~ 0.1 KeV
  - Gamma ray solar flares are transients, and limited number
- Cosmic rays + Sun => Gamma rays
  - Inverse Compton component (eϒ interaction)
  - Hadronic component (pp interaction)

Gamma Ray Sun: IC component

- Cosmic ray electrons up scatter solar photons

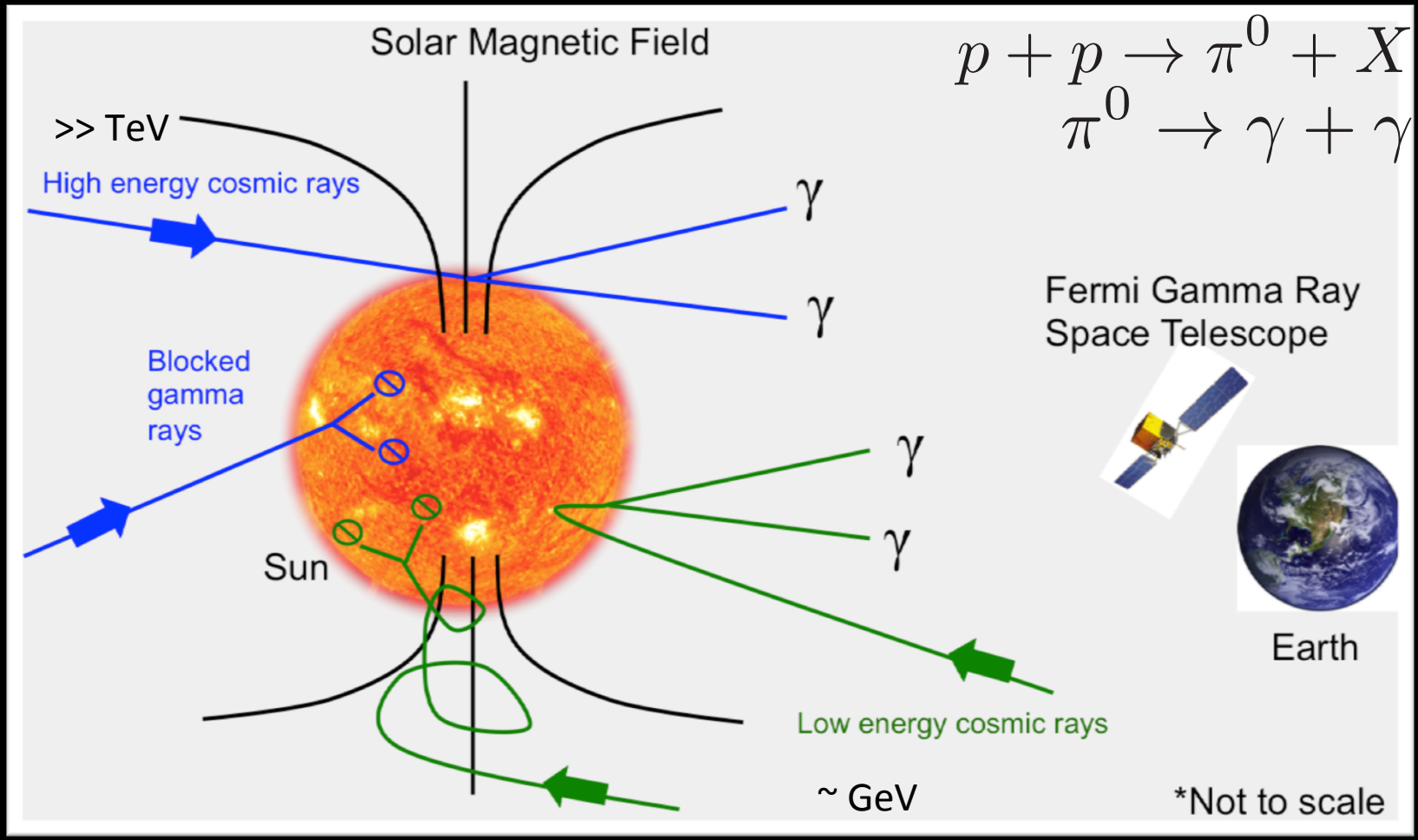


Moskalenko, Porter, Digel 2006
Orlando, Strong 2007

Orlando, Strong 2008

- Result: A diffuse gamma ray halo around the Sun

Gamma Ray Sun: Hadronic component



- Result: The Sun disk is emitting gamma rays
- +Magnetic field enhance gamma ray production

Gamma Ray Sun: Hadronic component

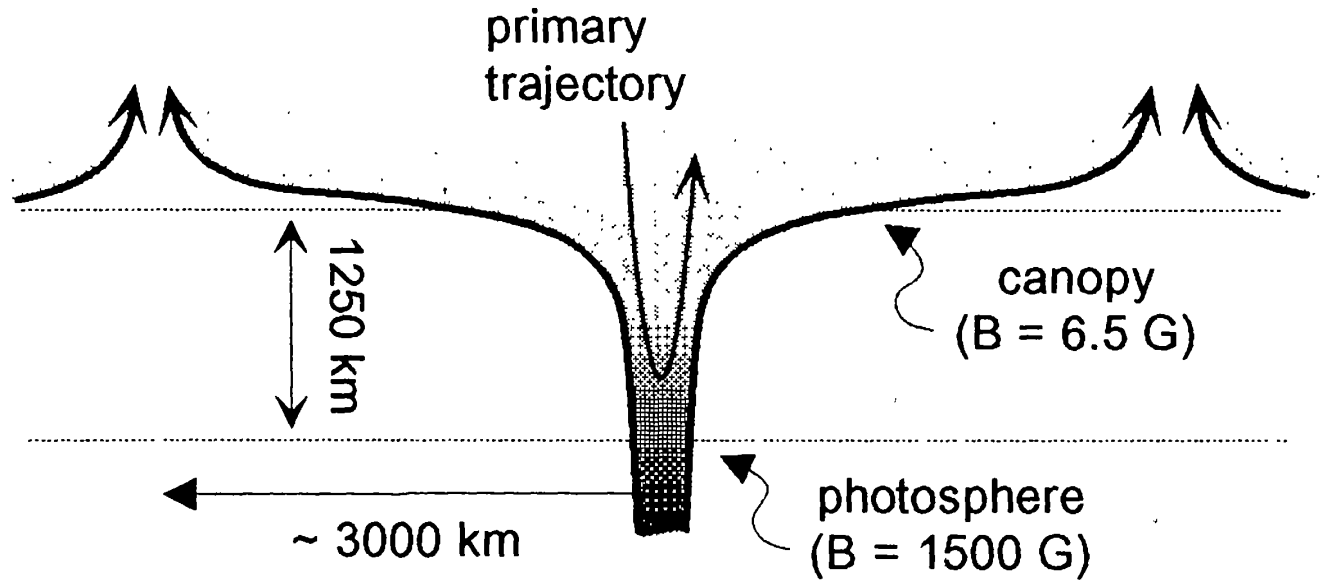


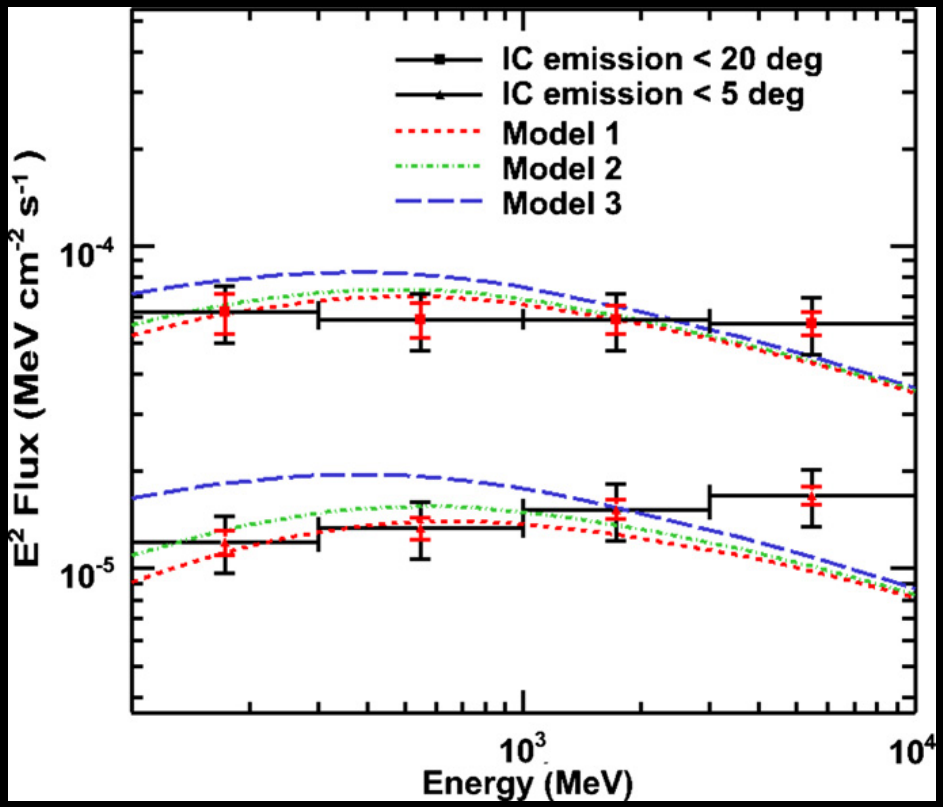
Figure 1: Model of magnetic fields near the photosphere. Shading increases with magnetic field intensity.

Seckel+ 1992

- Result: The Sun disk is emitting gamma rays
- +Magnetic field enhance gamma ray production

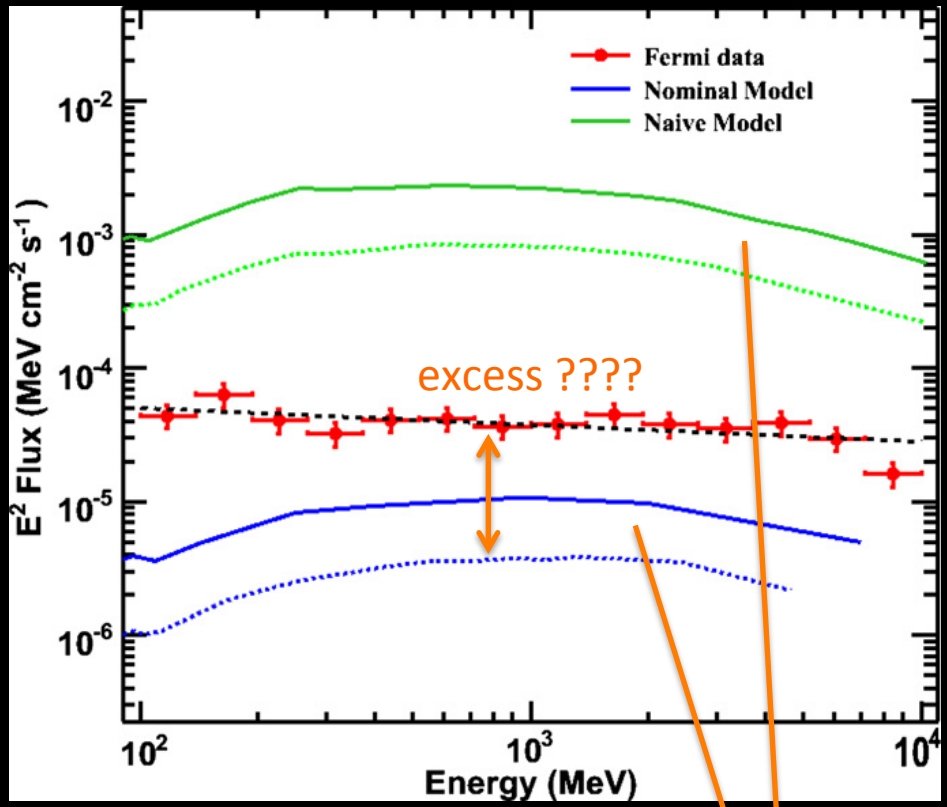
Both Components were found by Fermi, *but*

IC component



Abdo+ 2011

Sun-disk component

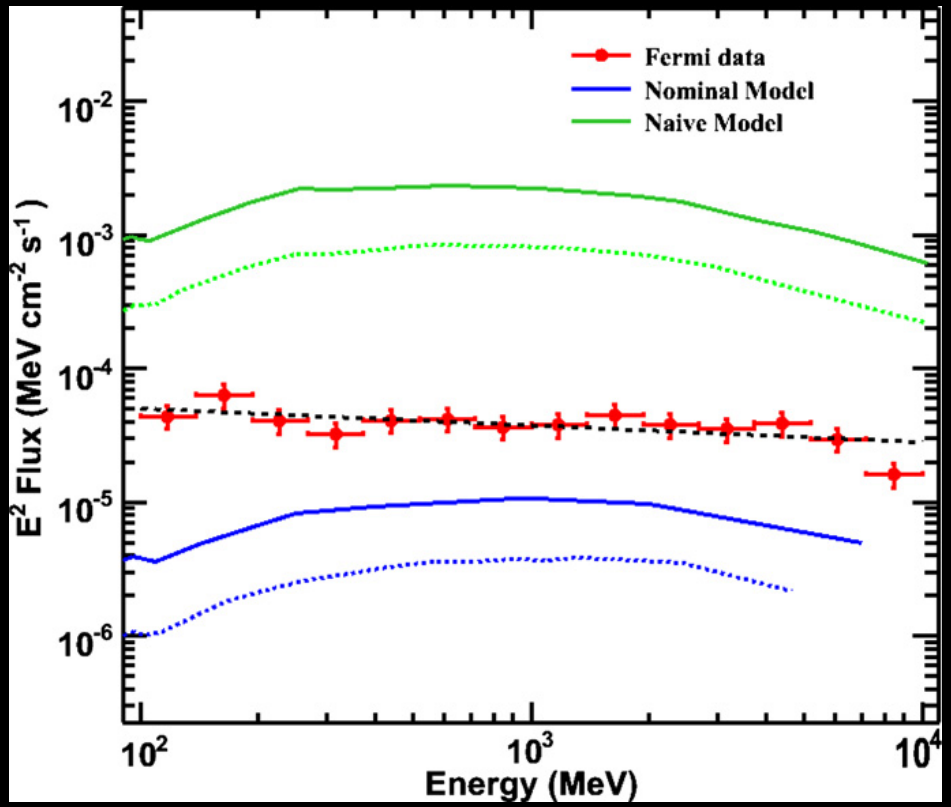


Abdo+ 2011

Seckel+ 1991

More info on the Sun-disk component?

- Fermi: 2008 – Now
  - More than 6 years
- Photons > 10 GeV ?
  - Is the Sun still bright?



?

Abdo+ 2011

The most energetic light from the Sun

- E = 10 - 100 GeV, 6 years of exposure

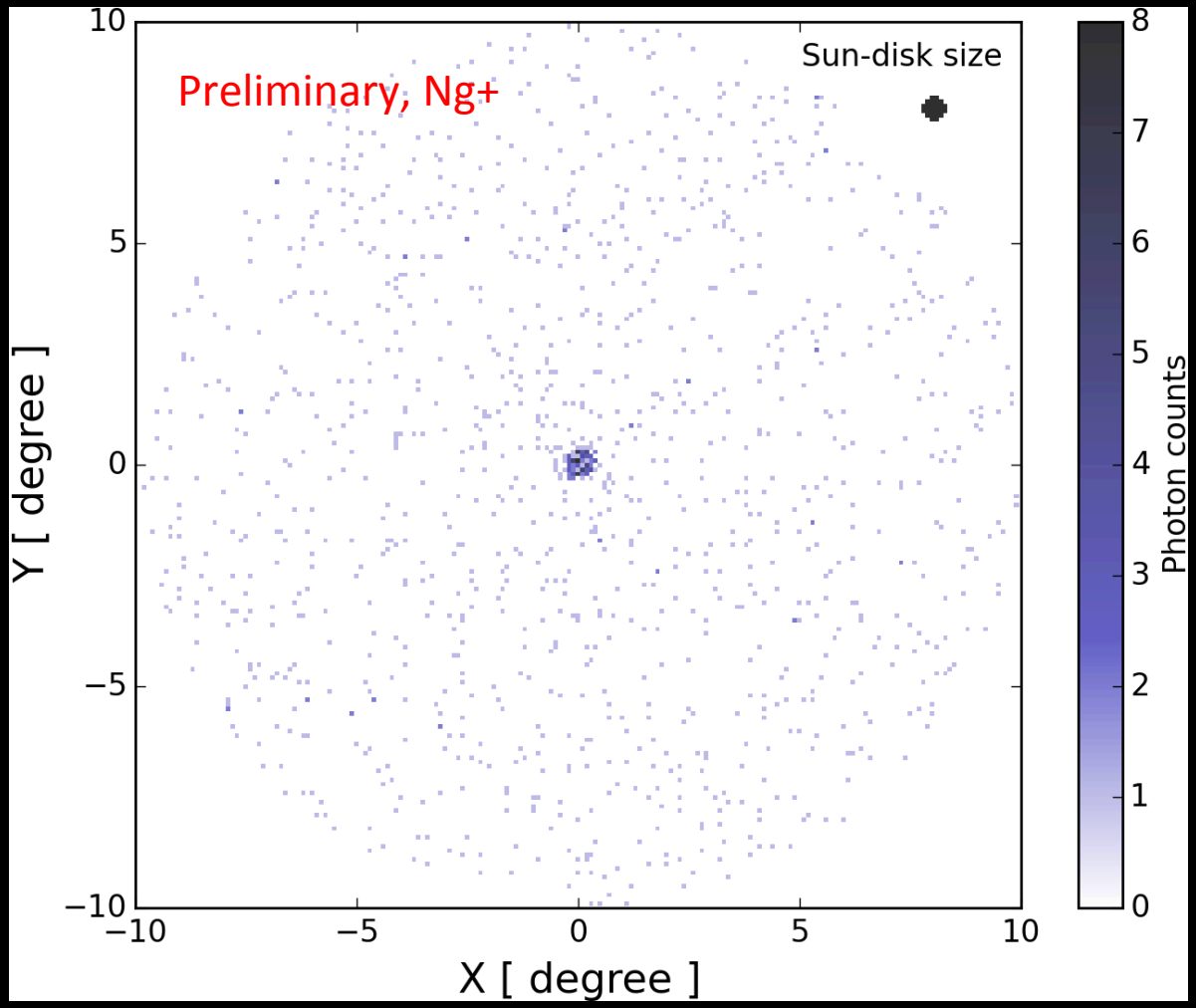
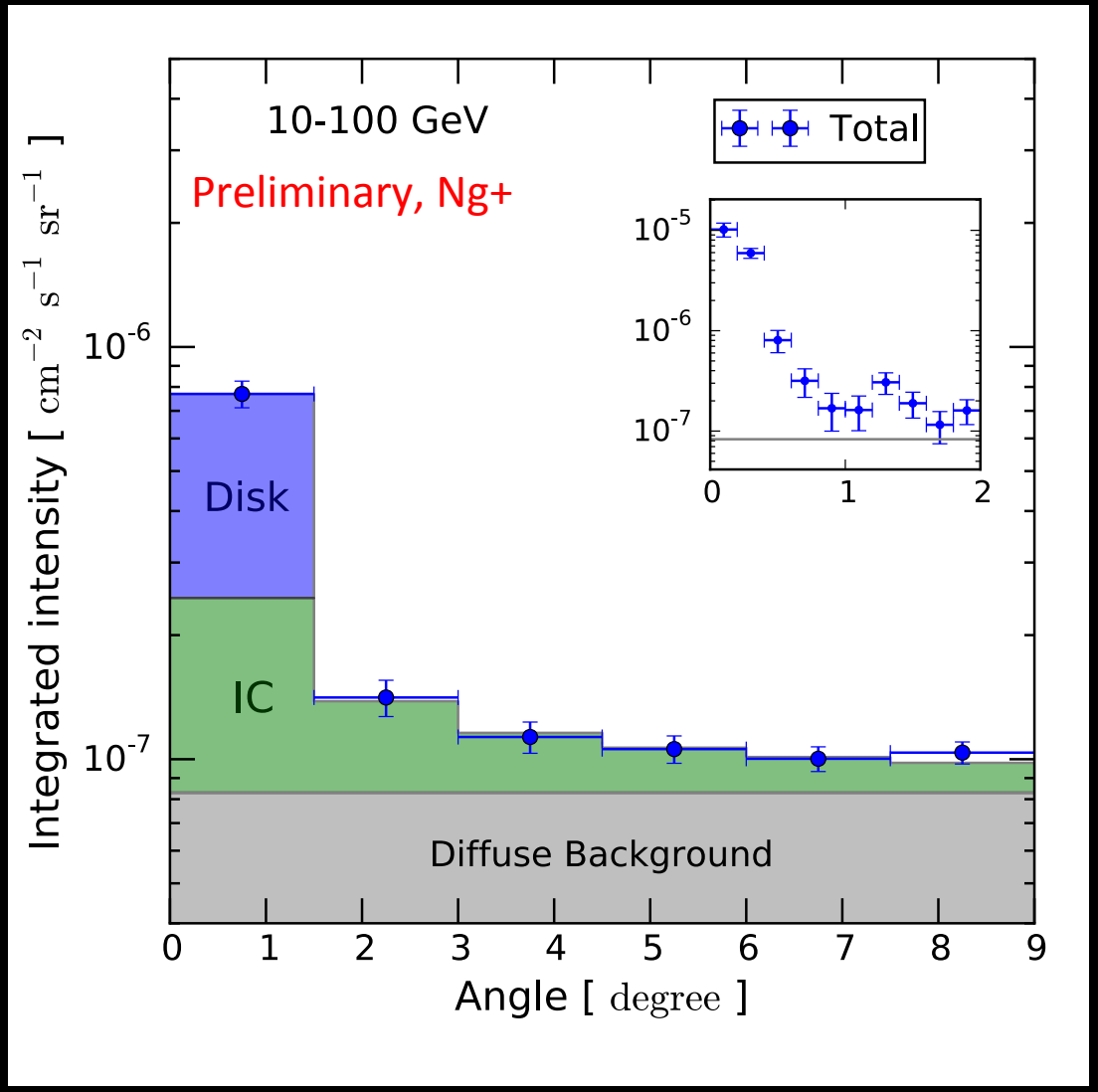


Image = Disk + IC + Background

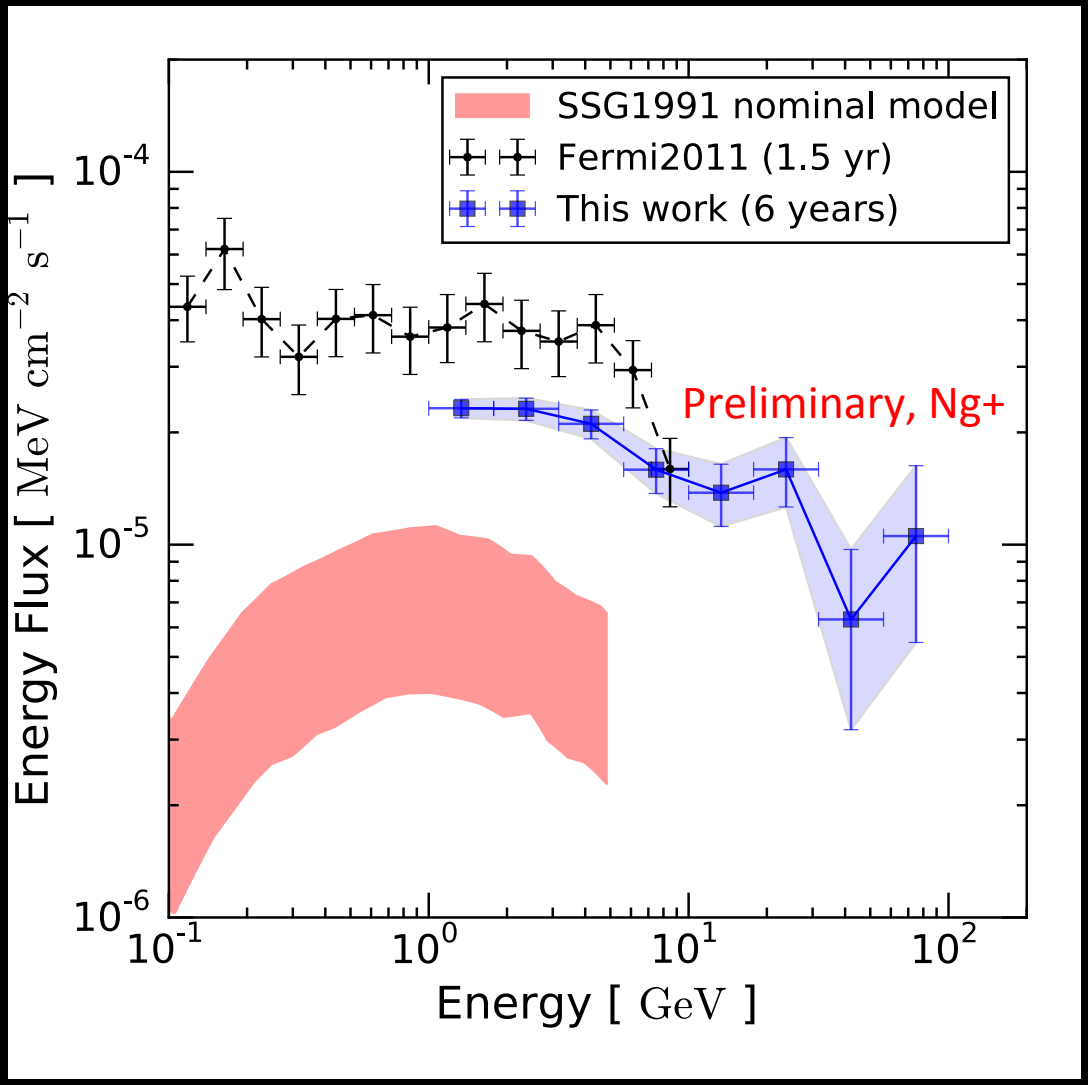
- Sun disk
  - ~point source
- IC halo
  - Solar photon distribution
- Background
  - Isotropic



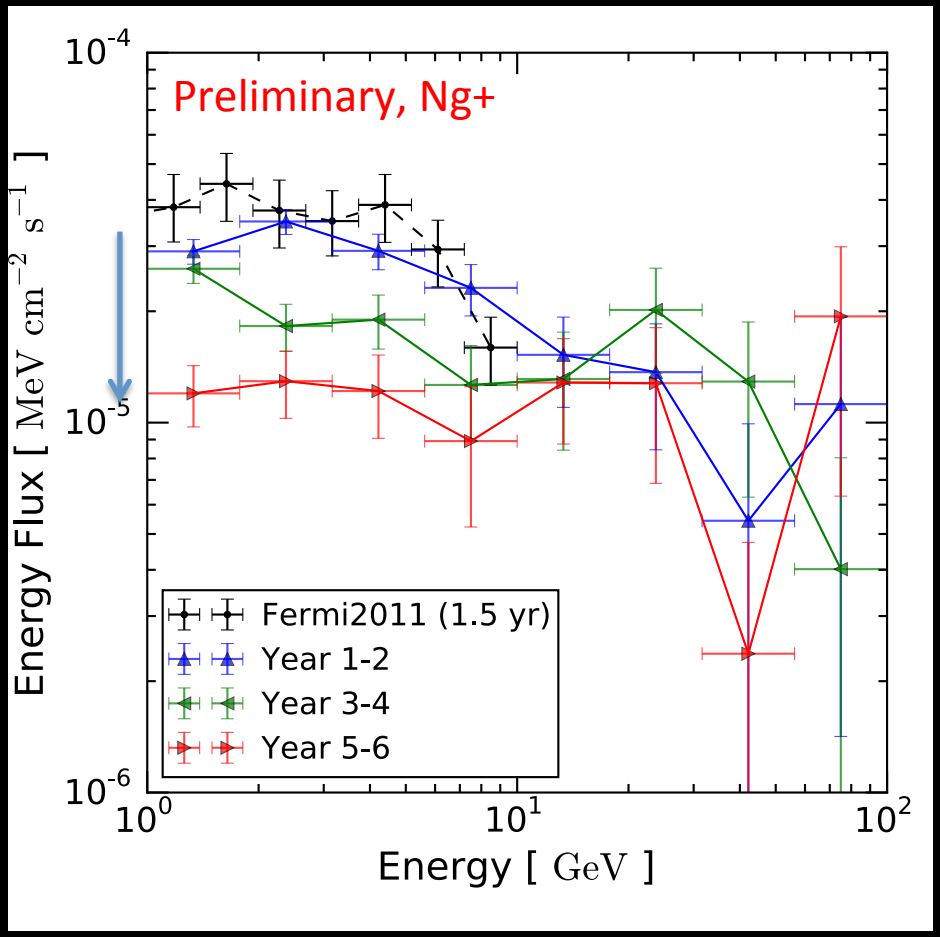
6 years analysis on the Sun disk

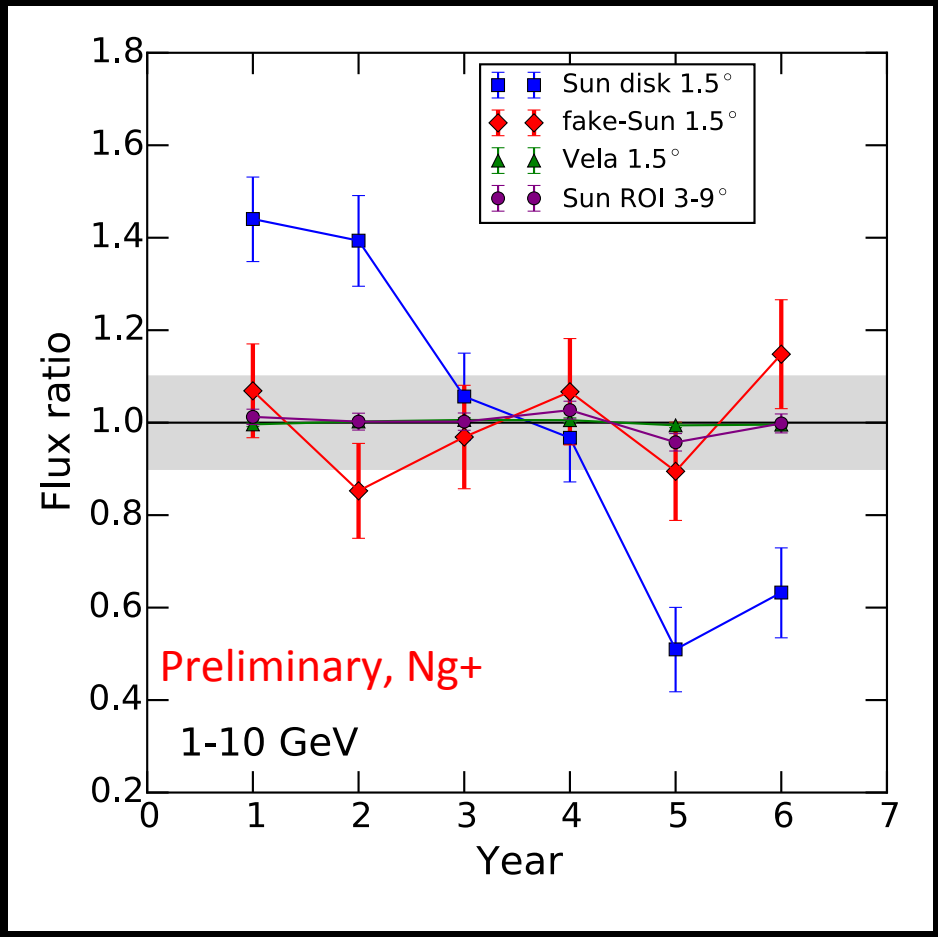
- Detection up to 30 GeV
- ~2 sigma up to 100GeV

- Disagreement in the overlapping range?



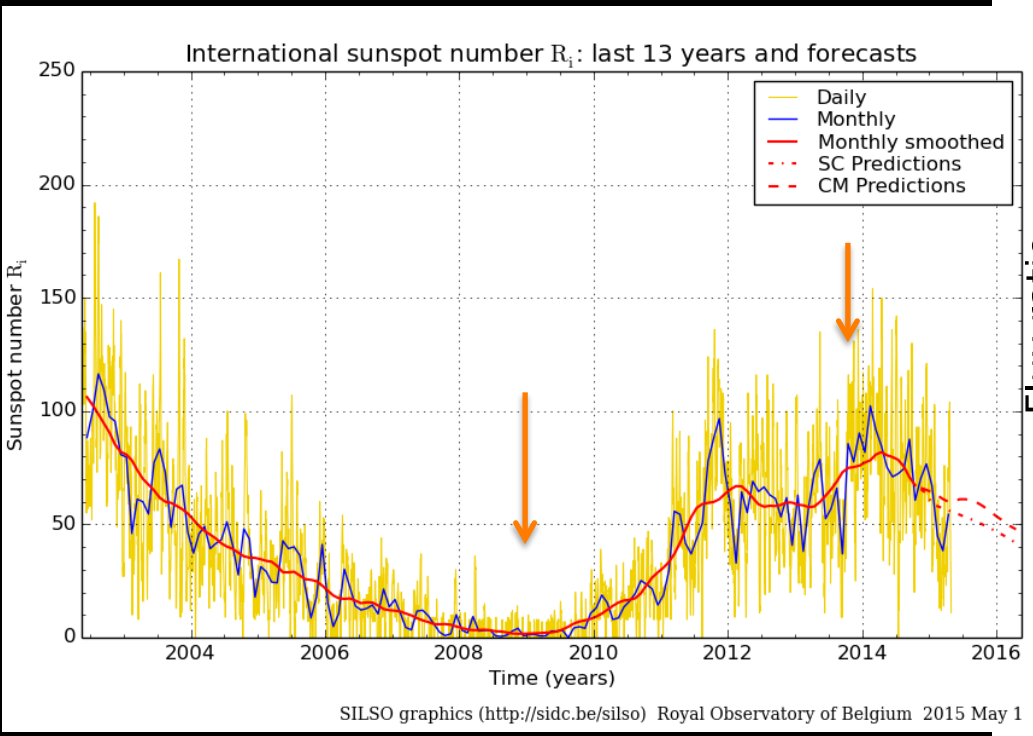
The gamma ray flux was changing!

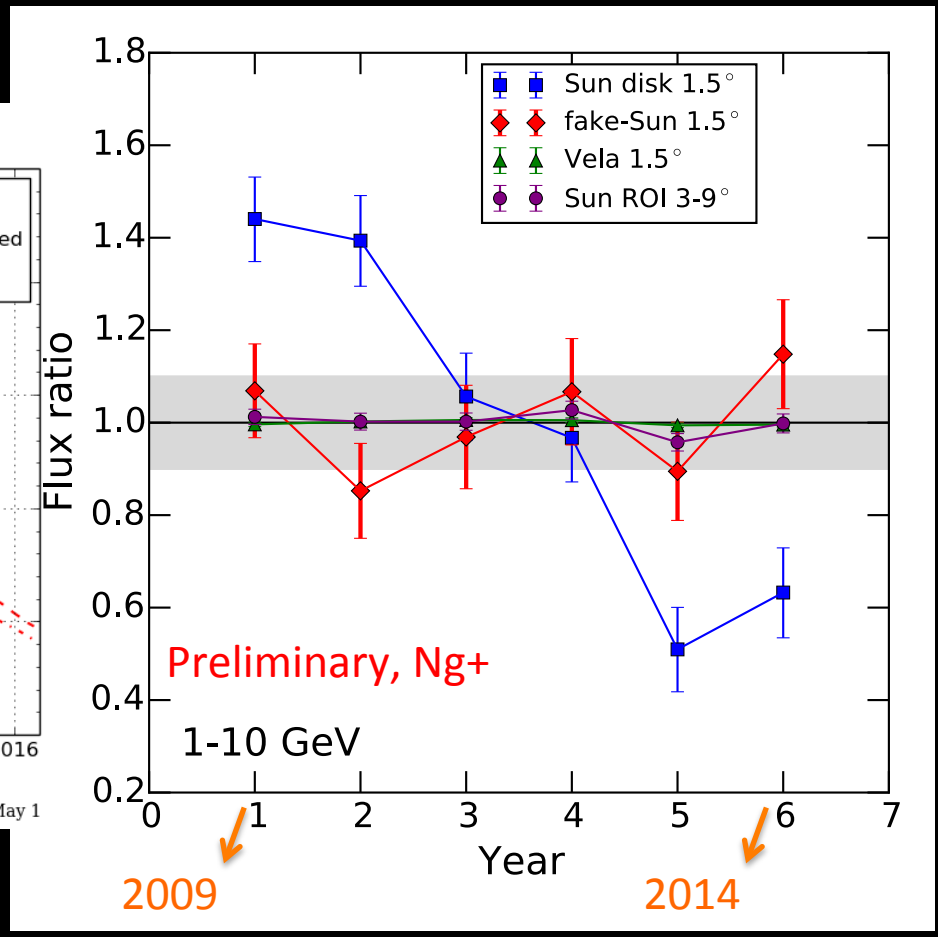




- The flux dropped by more than a factor of **2!**

Solar activity?

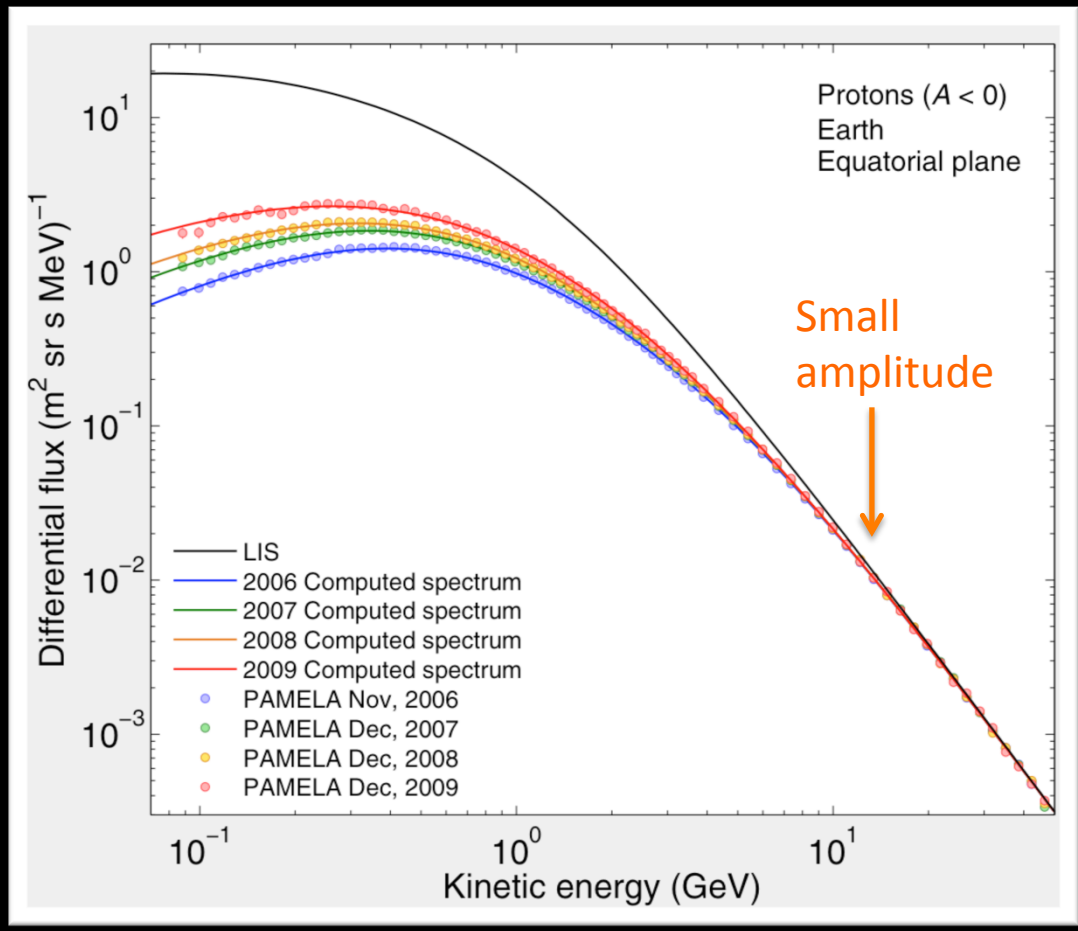




- Seems to anti-correlate with solar activity

What is causing the time dependence?

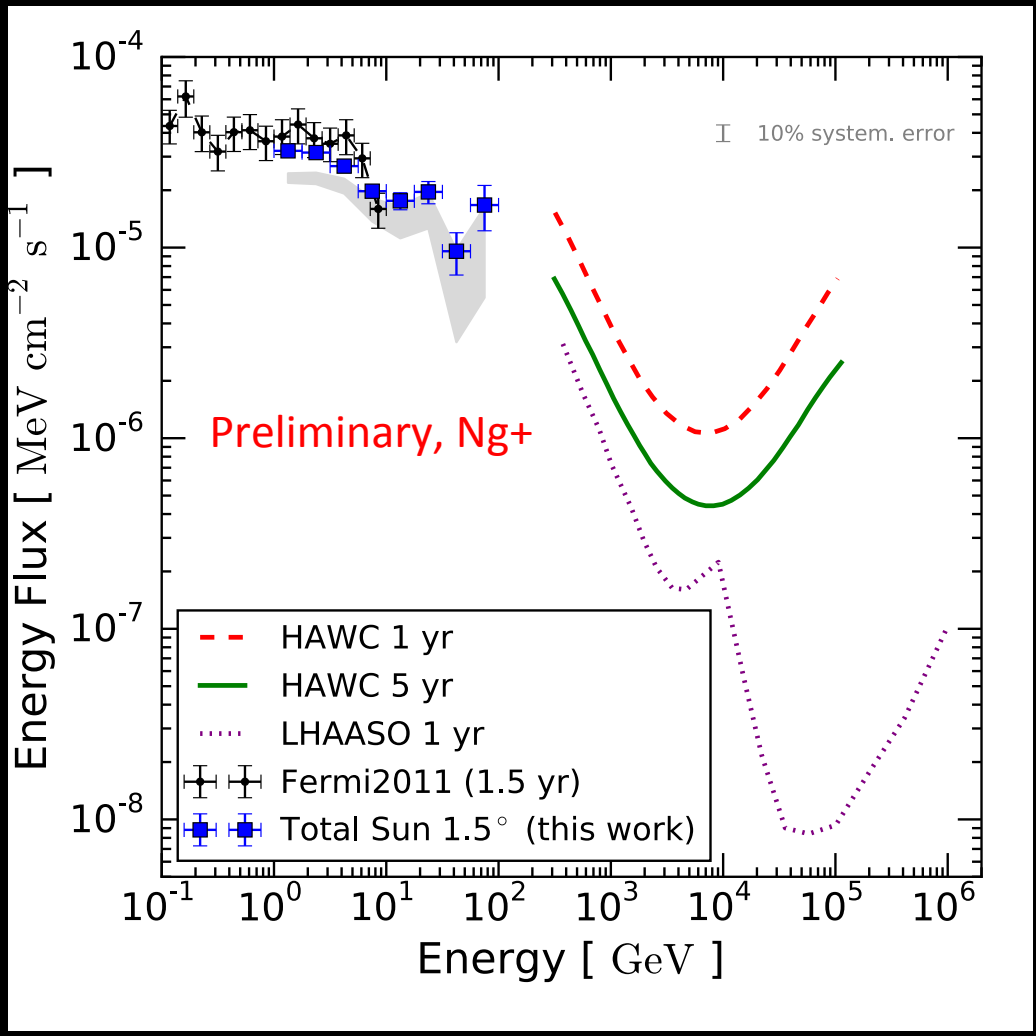
- Cosmic rays on **Earth**
  - 1-10 GeV gamma => 10-100 GeV protons
  - Extra CR modulation?
  - Solar magnetic field?
- We don't know, yet! *(work in progress)*



Adriani+ 2013

High energy information

- Only water Cherenkov
- HAWC (Now running)
- LHAASO (Proposed)
  - Spectral cutoff ?
  - Continue to higher E ?



Solar Atmospheric Neutrinos

- pp interactions => gamma rays ⇔ Neutrinos
- Dilute atmosphere, larger neutrino flux in the same angular region. Seckel+ 1991, Moskalenko+, 1993, Ingelman+ 1996, Hettlage+ 2000, Fogli+ 2003
- No HE neutrino calculations with magnetic fields.
- Work in progress (Ng+)

Summary

The Sun as a source and a laboratory.

- We knew:
  - Cosmic rays + Sun => hadronic gamma rays, but brighter than expected
- We find:
  - Gamma ray up to 100 GeV
  - Anti-correlate with solar activities (surprise?) (1505.xxxxx)
- Next:
  - Understand how the gamma rays are produced.
    - Cosmic rays, cosmic ray propagation, solar magnetic fields +
  - Many interesting related studies!

Thanks!