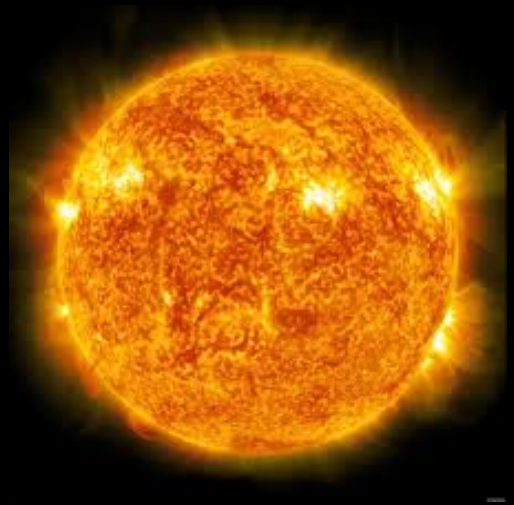
High-energy Solar Gamma Rays and Neutrinos Dark Matter Implications

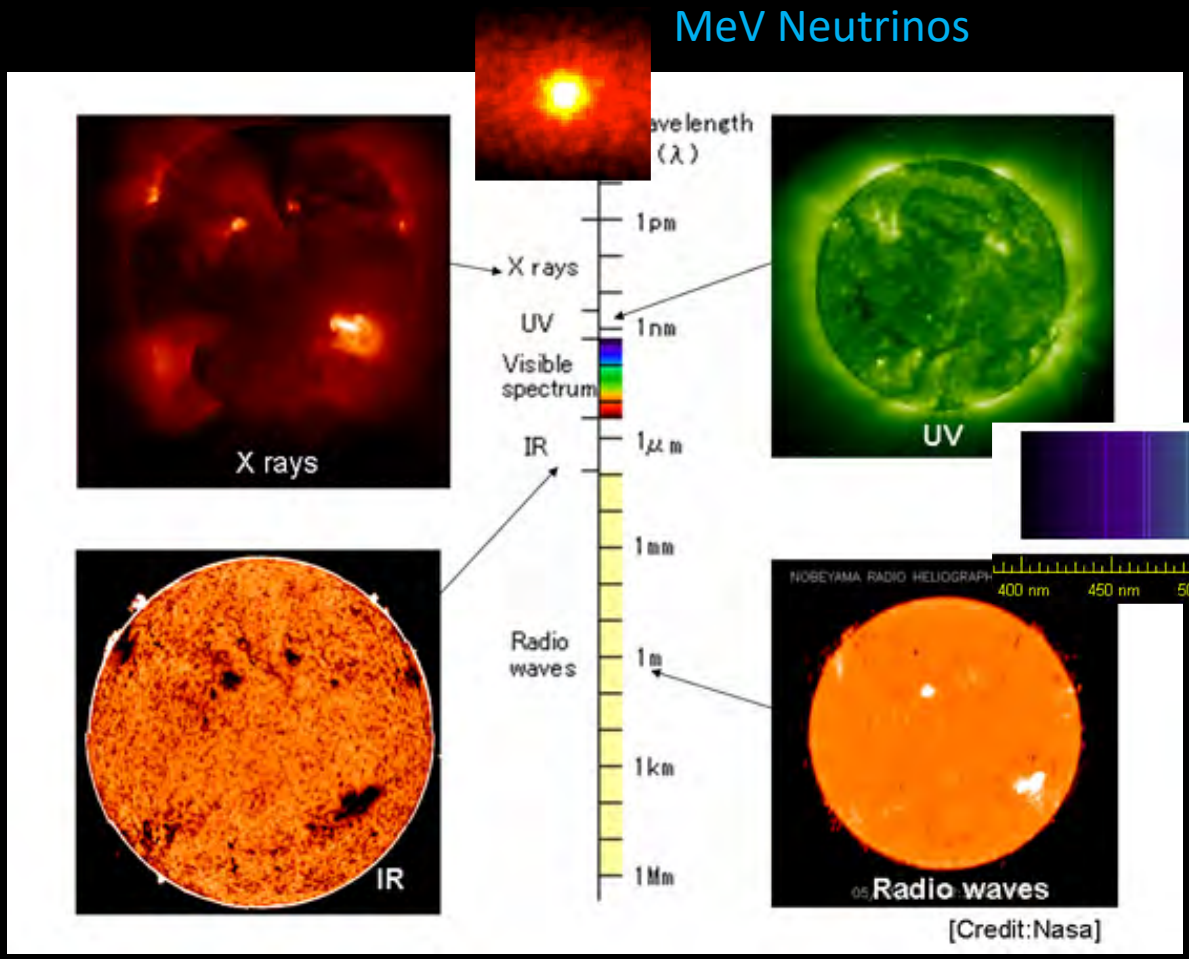


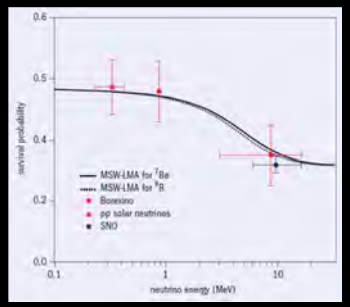
Kenny, Chun Yu Ng (吳震宇)
Weizmann Institute of Science

Observations of the Sun

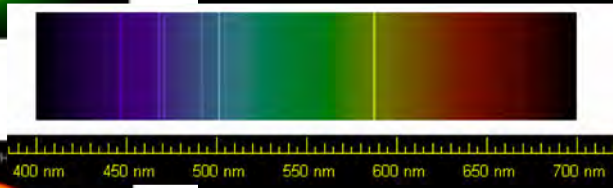
GeV ??? ⟶ The Sun is not hot enough!

MeV Neutrinos



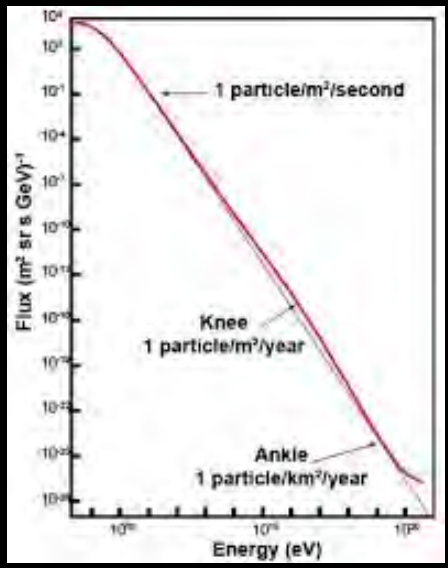


Neutrino Mass



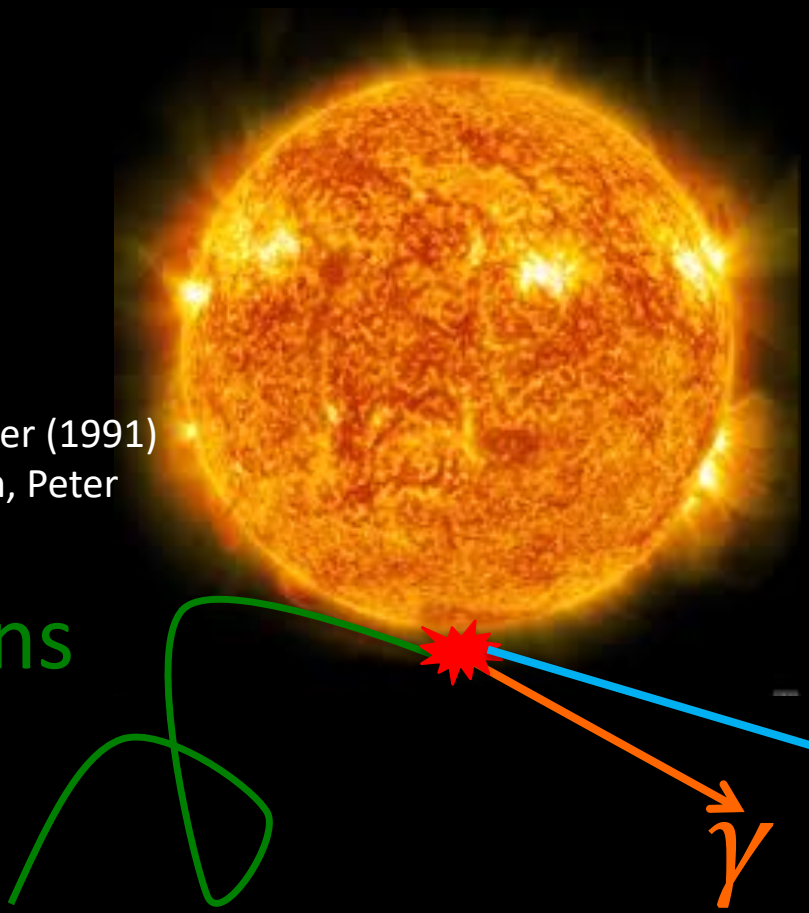
Helium Discovery

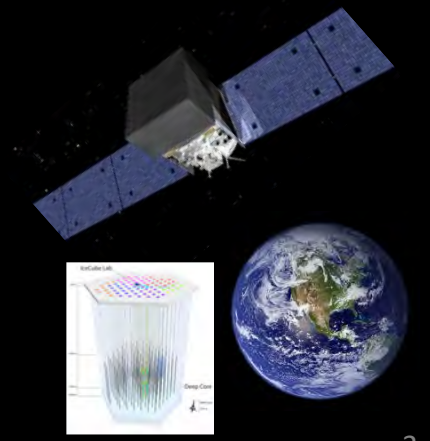
Sun – Cosmic-Ray Beam Dump



Seckel, Stanev, Gaisser (1991)
Zhou, KCYN, Beacom, Peter
[1612.06420]

CR protons
Hadronic



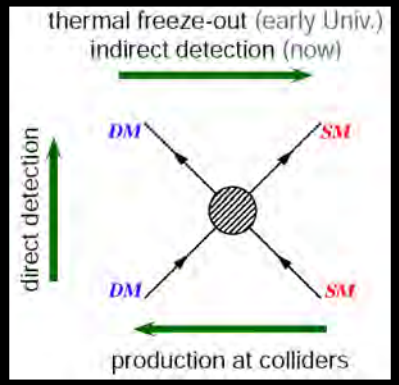


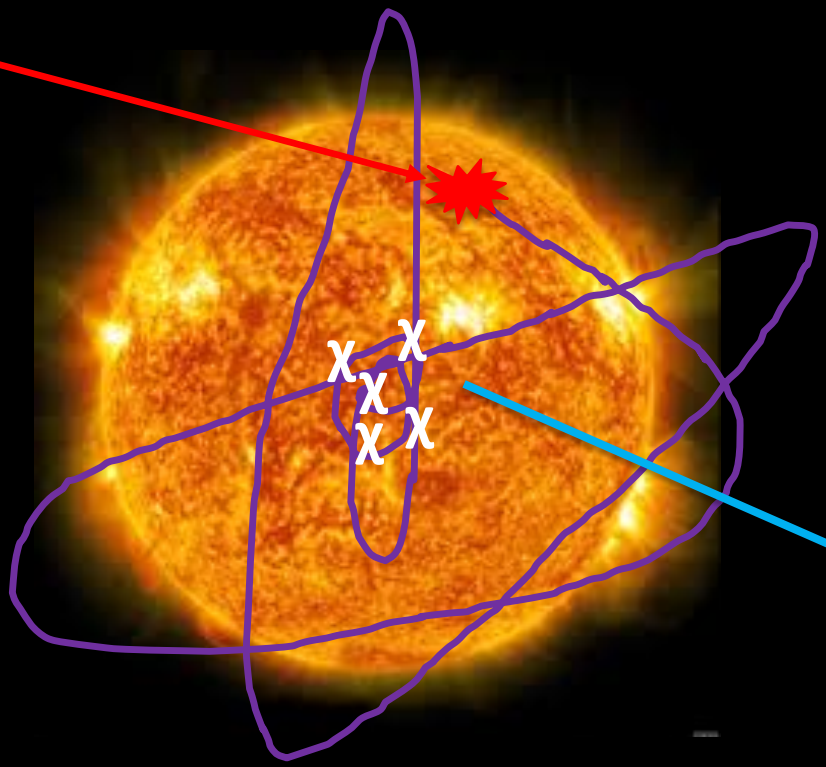
Sun – Dark Matter detector

χ

$$\frac{dN}{dt} = \Gamma_{\rm cap} - C_{\rm ann} N^2$$

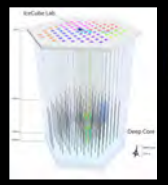
$$\Gamma_{\rm ann} = \frac{1}{2} C_{\rm ann} N^2 = \frac{1}{2} \Gamma_{\rm cap}$$





ν



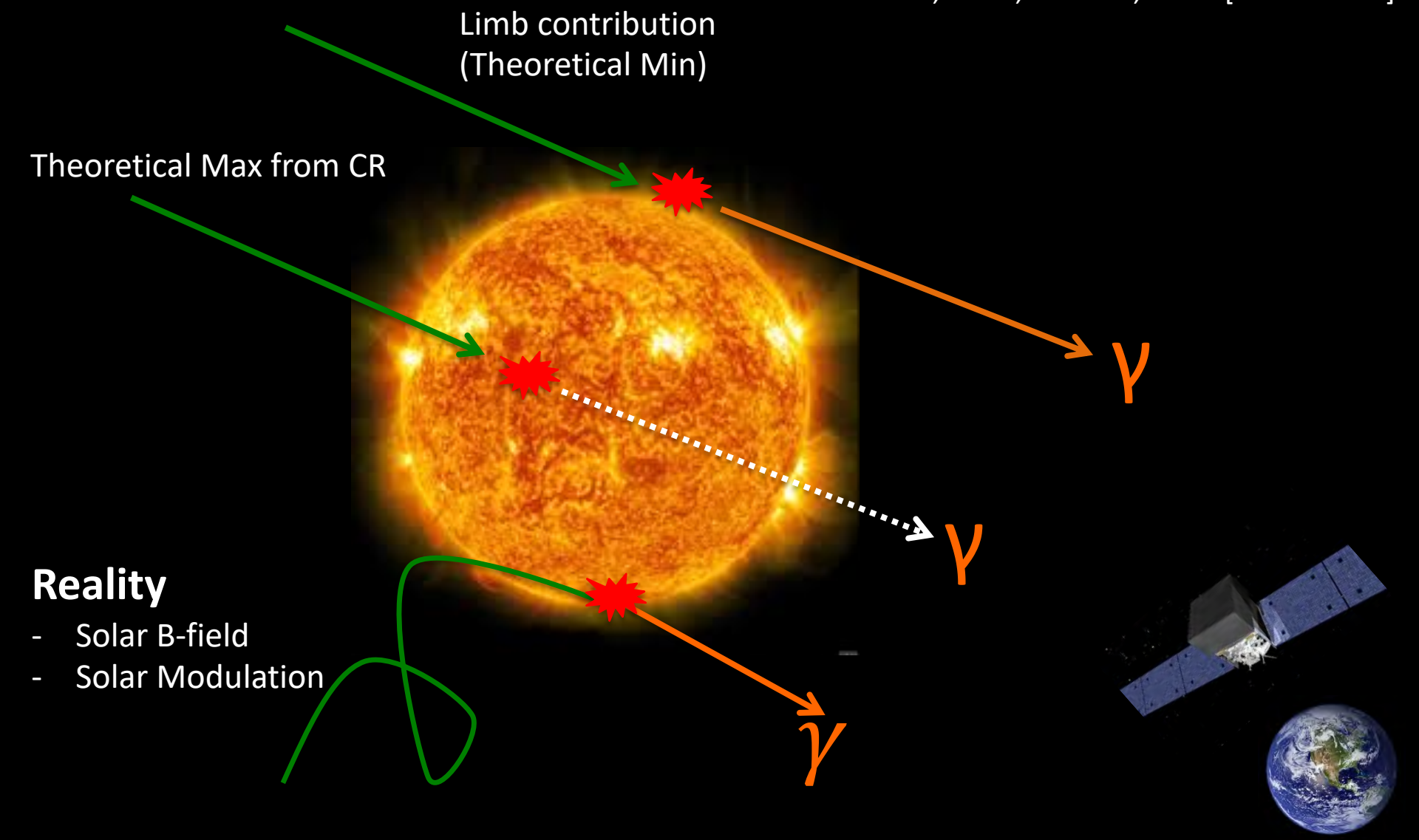




Press, Spergel (1985)
Krauss, Freese, Press, Spergel (1985)
Silk, Olive, Srednicki (1985)

Solar atmospheric gamma rays

Zhou, KCYN, Beacom, Peter [1612.06420]



Solar ATM gamma-ray production

Limb contribution

Theoretical Max from CR



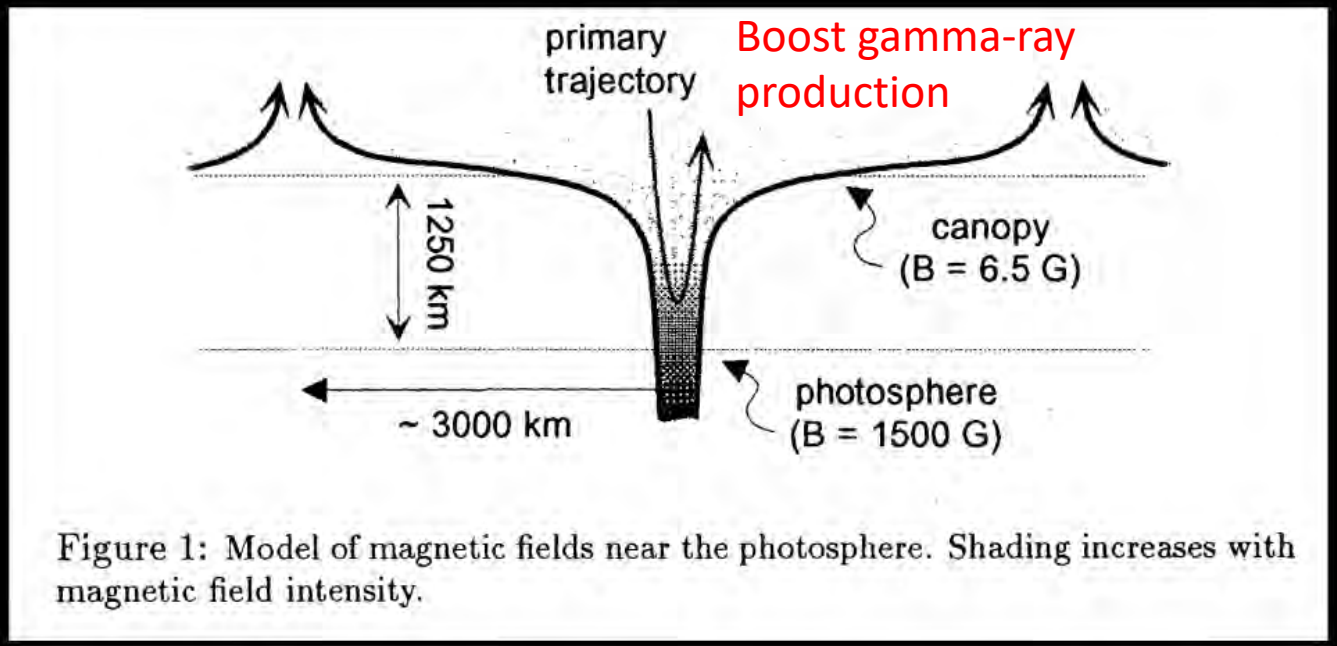
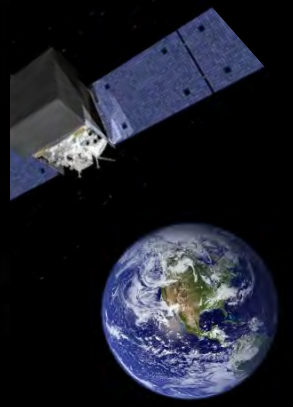


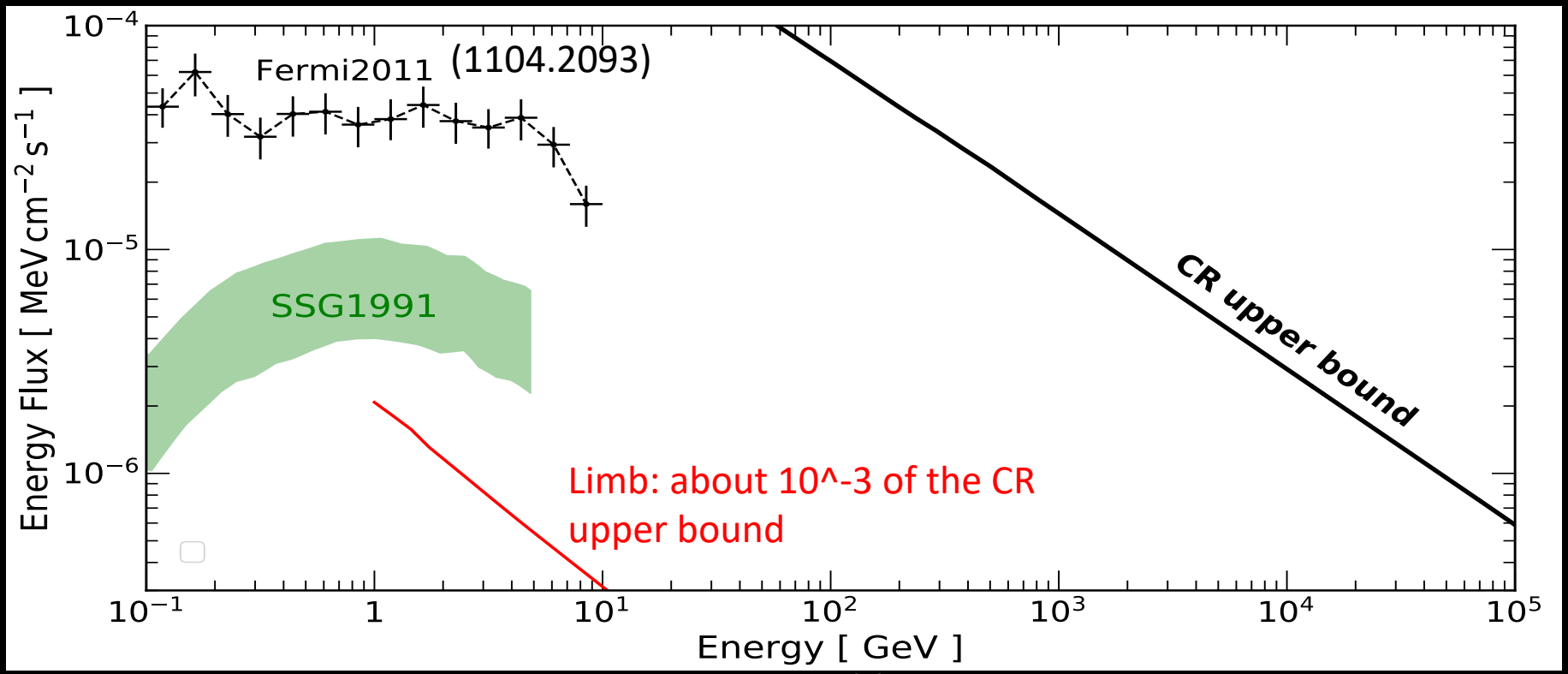
Figure 1: Model of magnetic fields near the photosphere. Shading increases with magnetic field intensity.

Seckel, Stanev, Gaisser (1991)



The overall picture

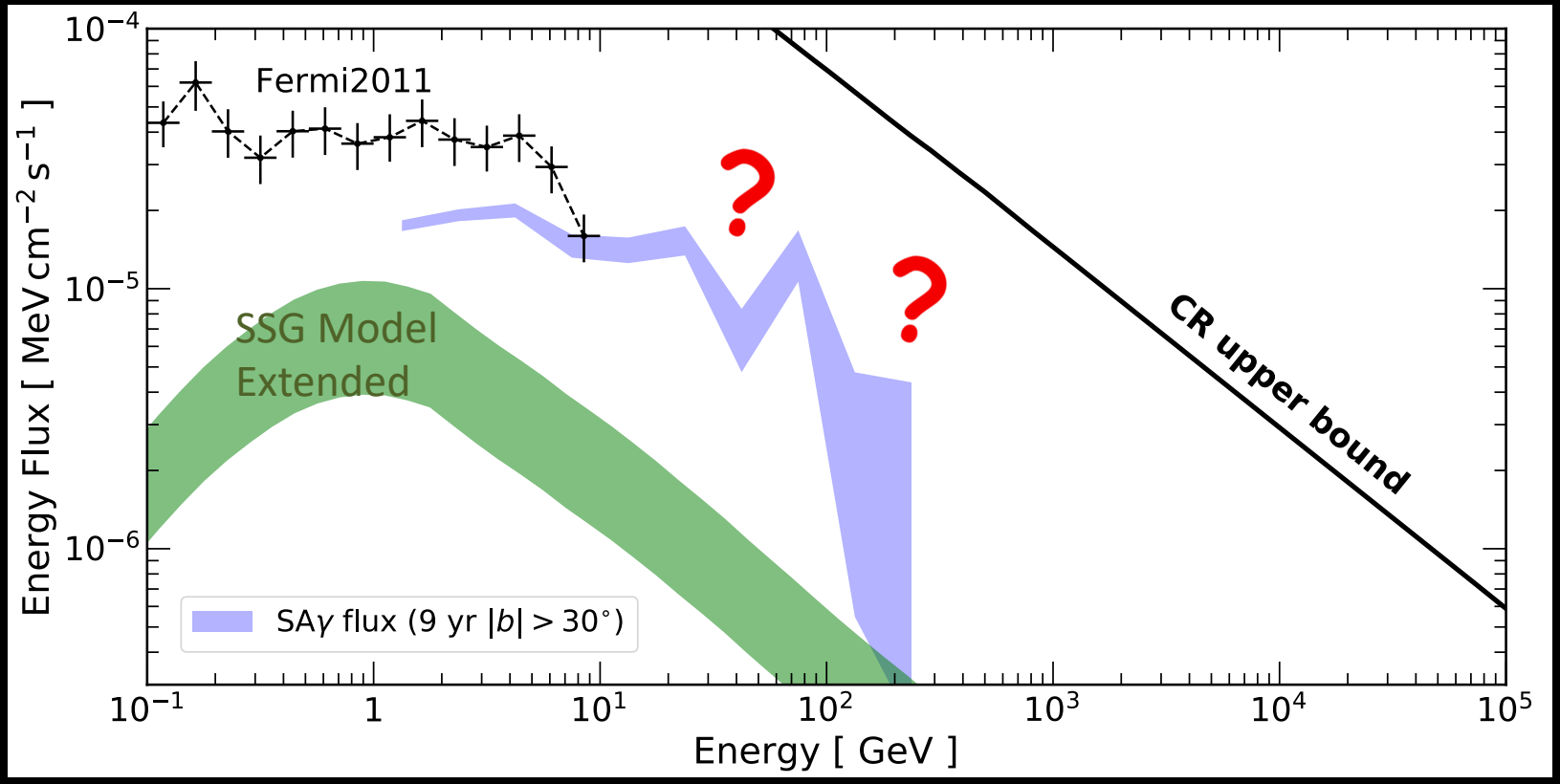
- Model prediction too small
- Limb too small
- Satisfy cosmic-ray bound → CR model with large B-field enhancement



Observation: 9-year averaged spectrum

- 2008 - 2017

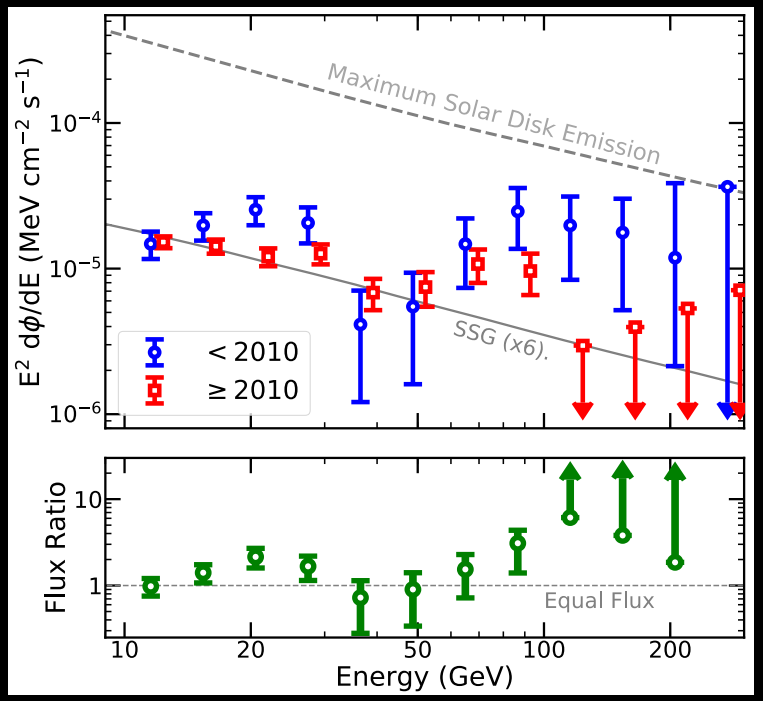
Tang + 1804.06846
PRD 98 no.6, 063019

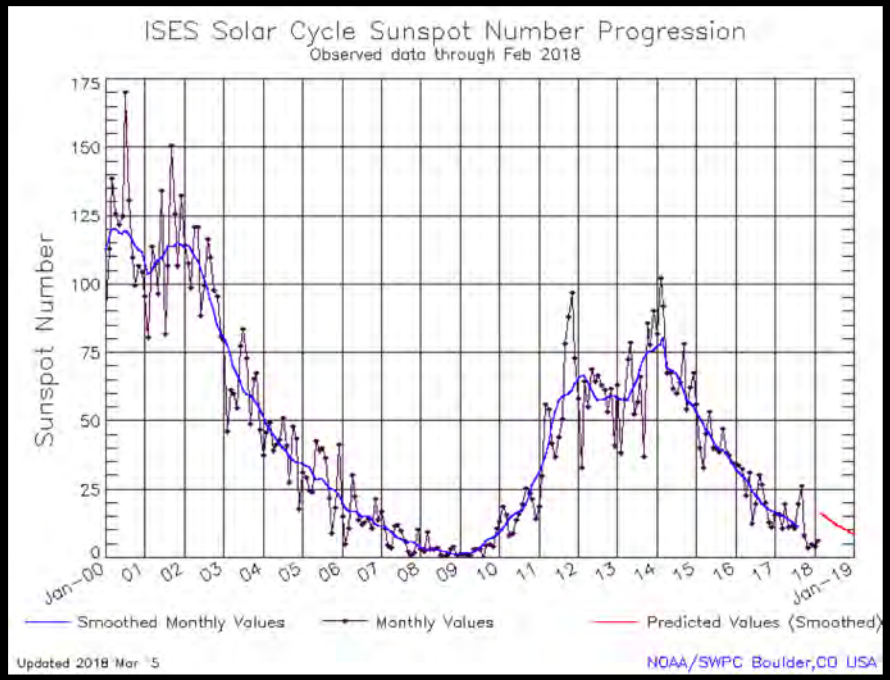


Time variation, *Surprise (1)!*

Linden + 1803.05436
PRL 121 no.13, 131103

- >100 GeV events
- 6 events from AUG 2008 to Jan 2010 (quiet Sun)
- 0 events for the next 7.8 years (active Sun)



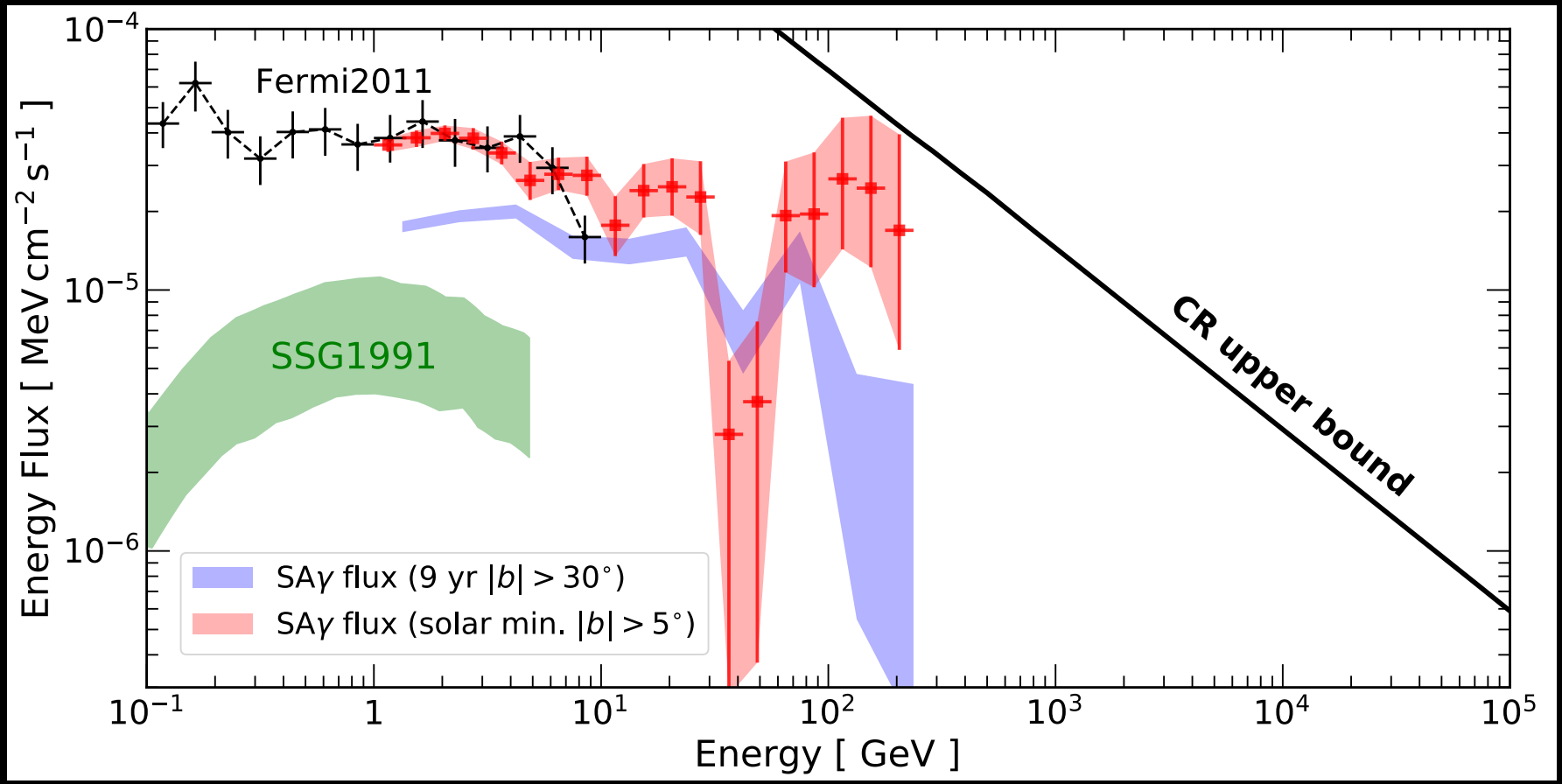


The high-energy photon production are very sensitive to the solar condition

Spectrum, *surprise (2)*

Tang + 1804.06846
PRD 98 no.6, 063019

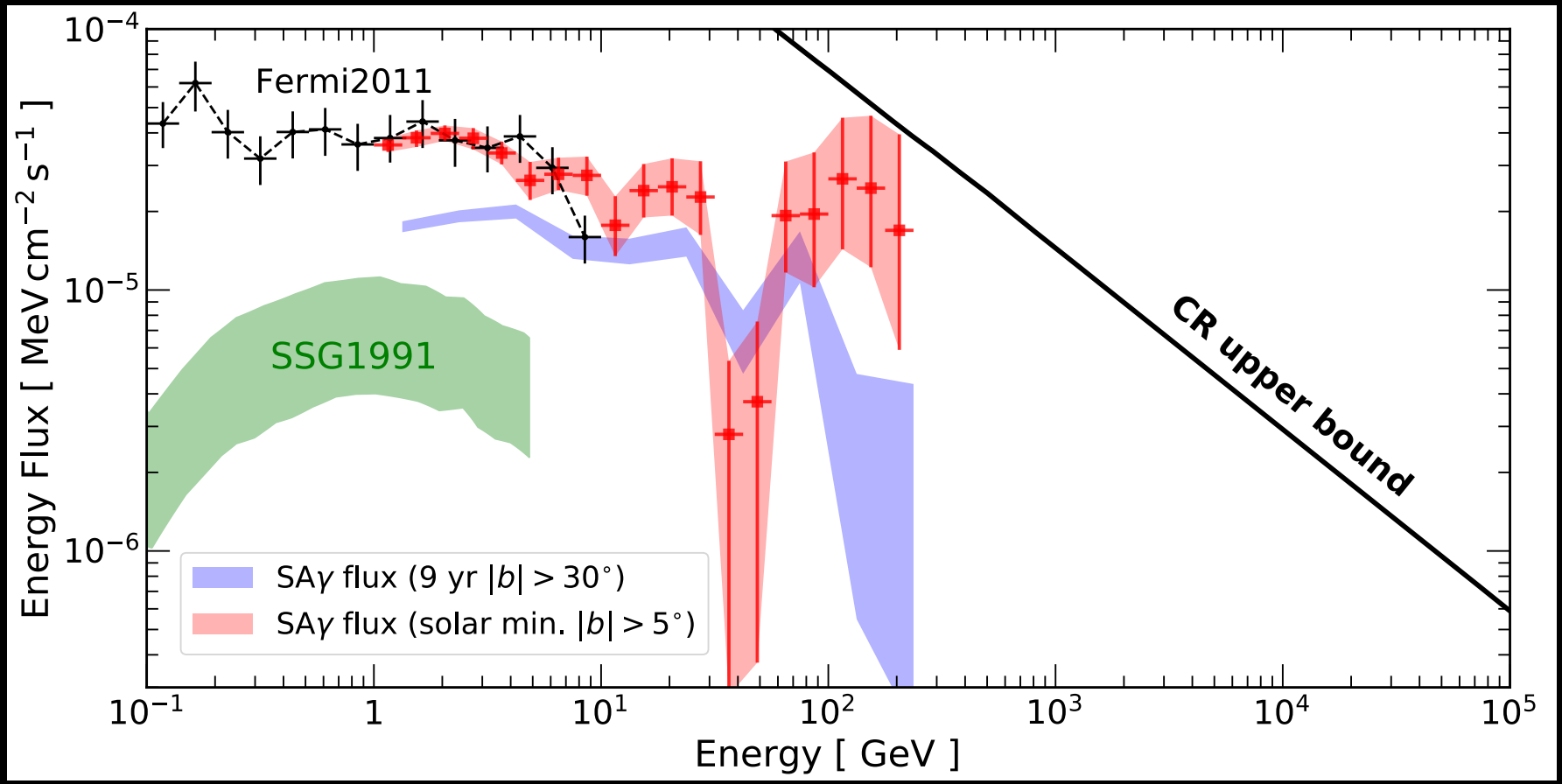
- Hard spectrum till ~100 GeV
  - Magnetic enhancement works for protons ~ TeV
  - Enhancement increasingly efficient! Close to upper bound at HE



Spectrum, *surprise (3)*

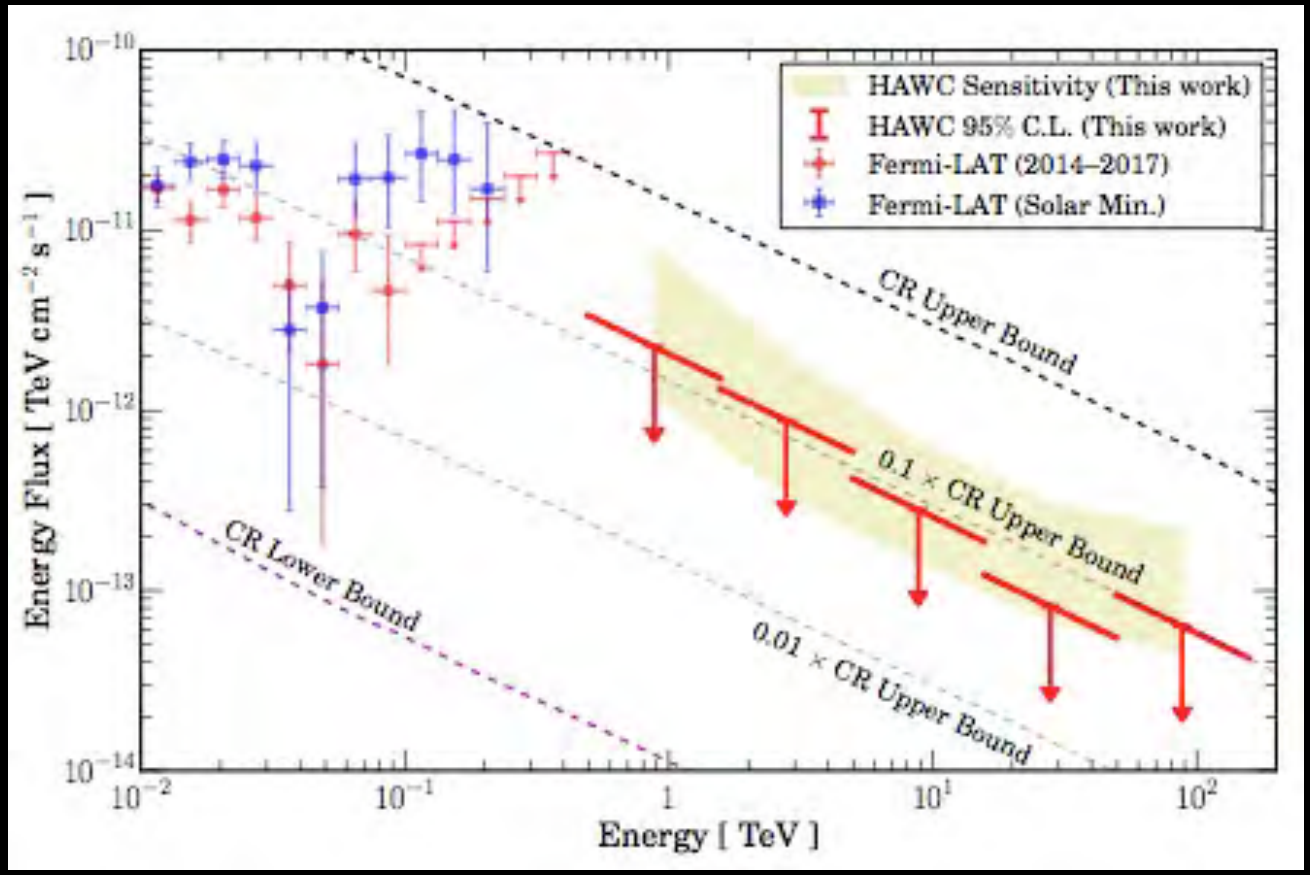
- Strange “dip” between 30-50 GeV
  - Naively, two components, but not easy
  - No obvious instrumental explanation
  - Seems shallower outside solar minimum
  - Statistical fluke? Time-dependent feature/systematics? Will know soon

Tang + 1804.06846
PRD 98 no.6, 063019

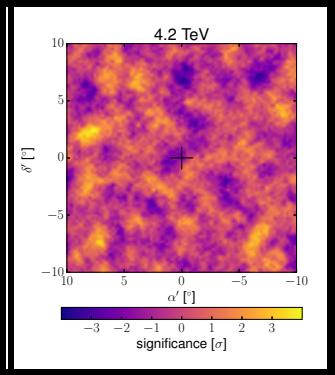


First HAWC analysis of the Sun (2014-2017)

- Constrain ~10% of CR upper bound (active phase)
- Exciting prospect for current solar min (2018 -)



HAWC 1808.05620
To PRD

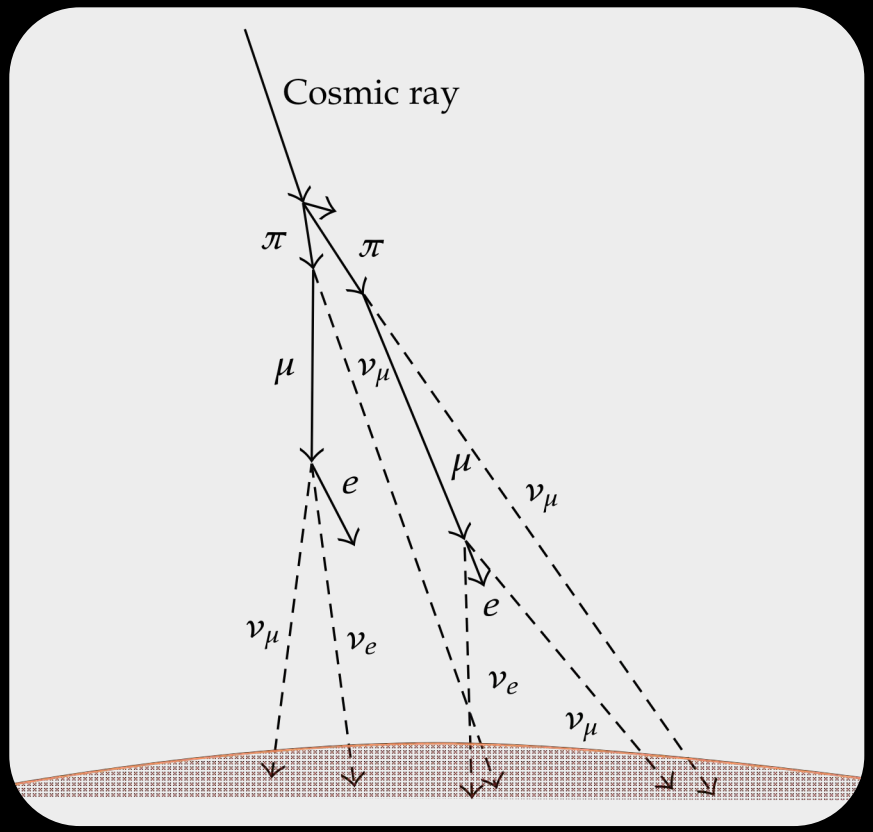


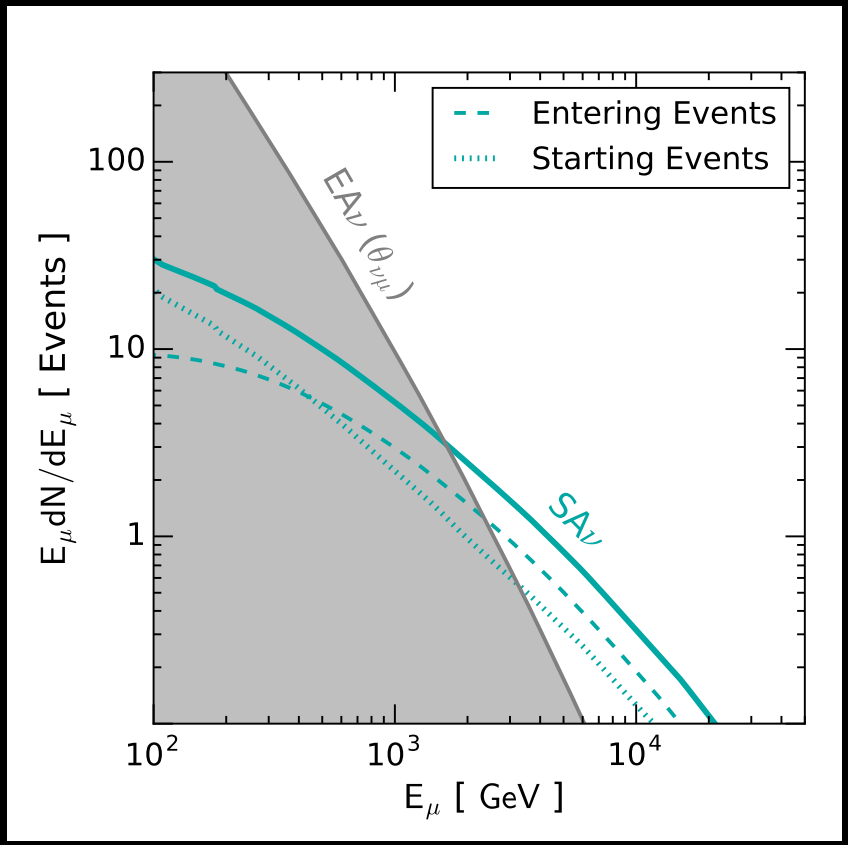
Solar Atmospheric Gamma rays

Complicated……

Solar Atmospheric Neutrinos

KCYN, Beacom, Peter, Rott 2017



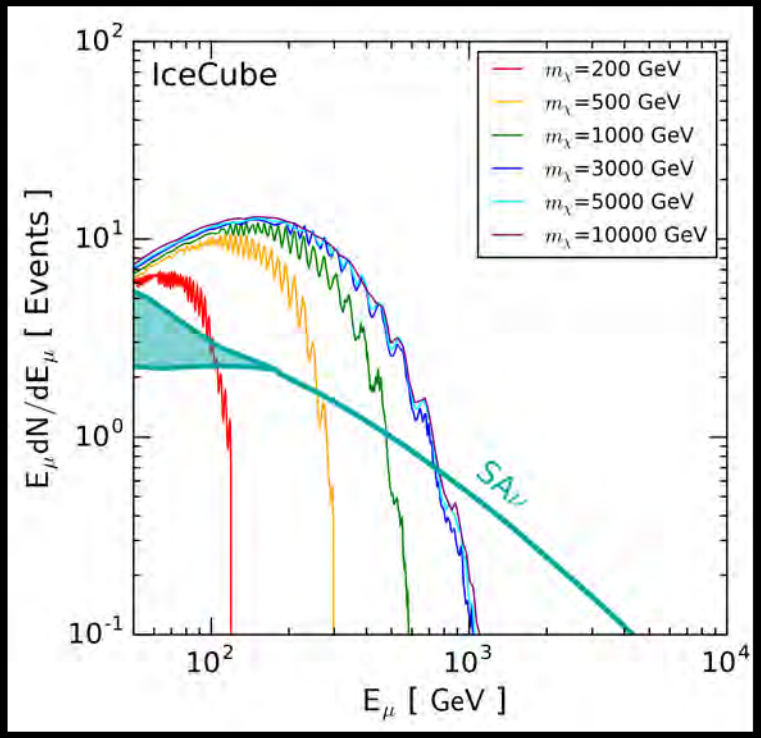


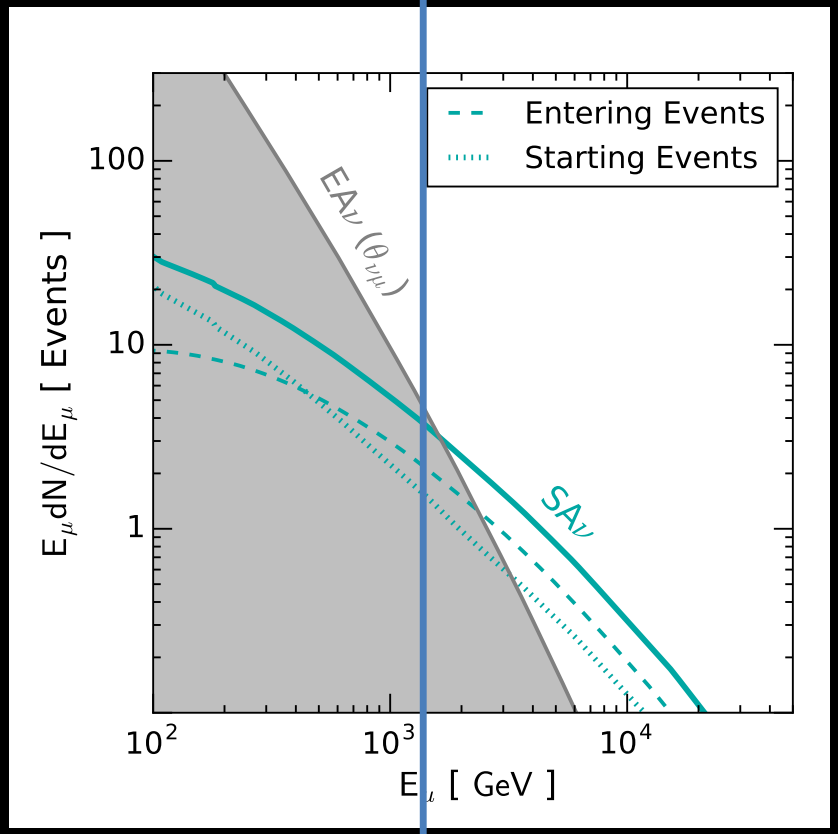
- Dilute atmosphere, larger neutrino flux

Seckel+ 1991, Moskalenko+, 1993, Ingelman+ 1996, Hettlage+ 2000, Fogli+ 2003

C.A. Argüelles+ 1703.07798
Joakim Edsjo+ 1704.02892

Background or Signal? (Both!)



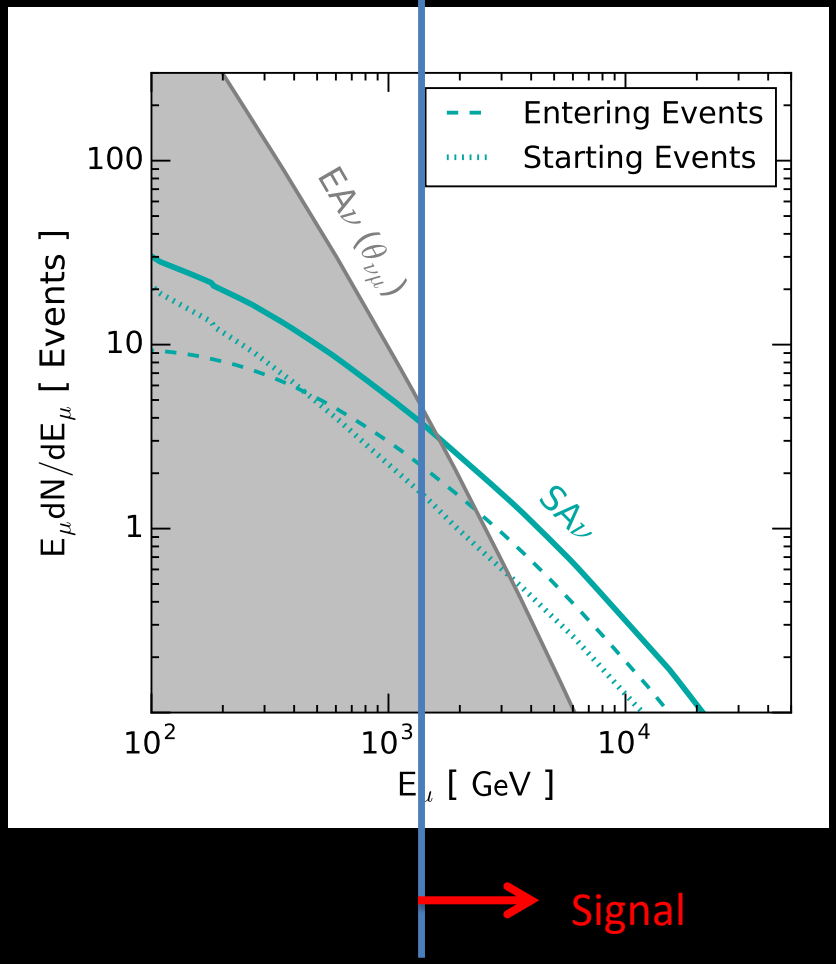


BAD energy-resolution
Difficult to distinguish from DM signal
Background!

Some energy-resolution
No DM signal*
Astrophysical signal!

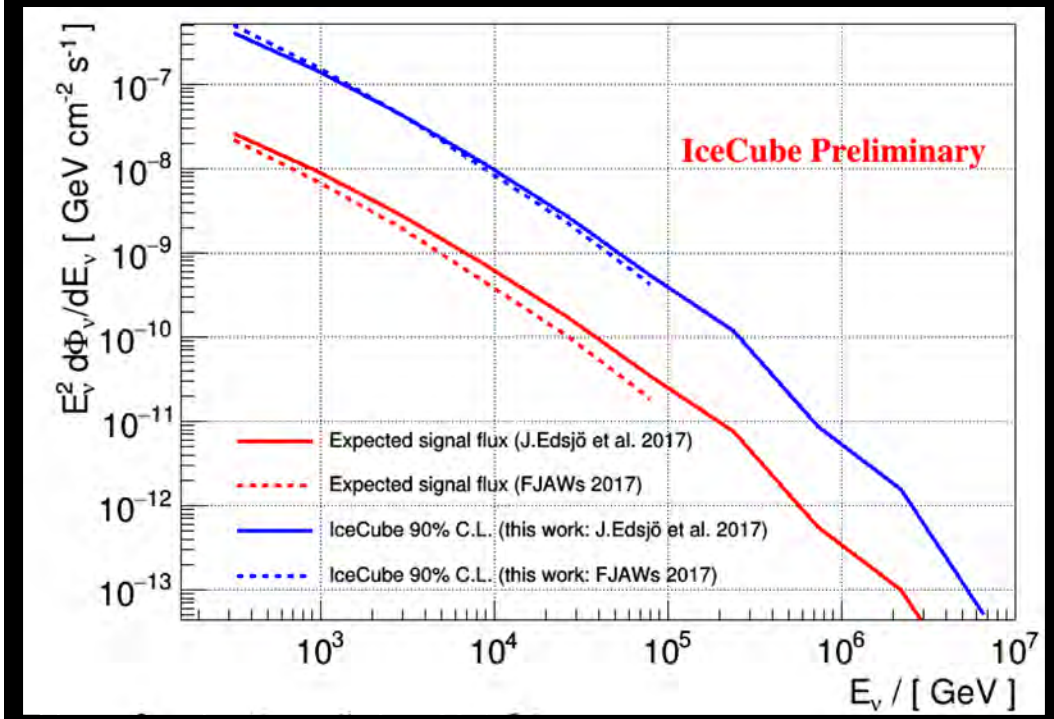
IceCube Search

Theorist Expectation

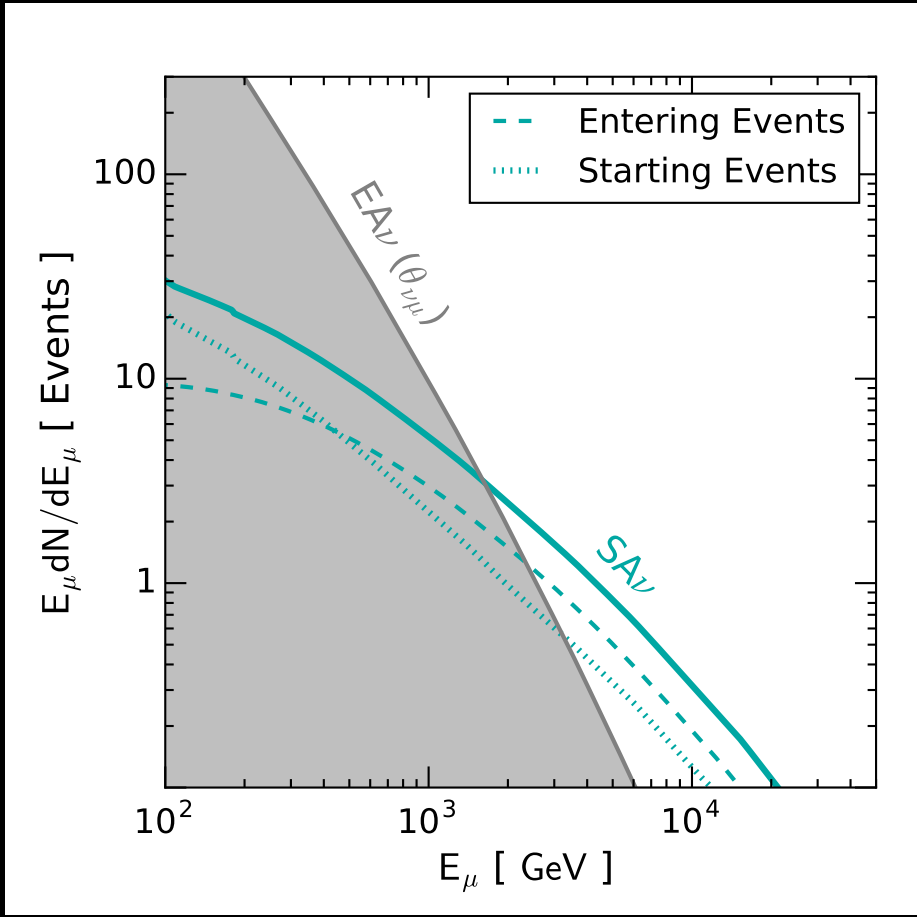


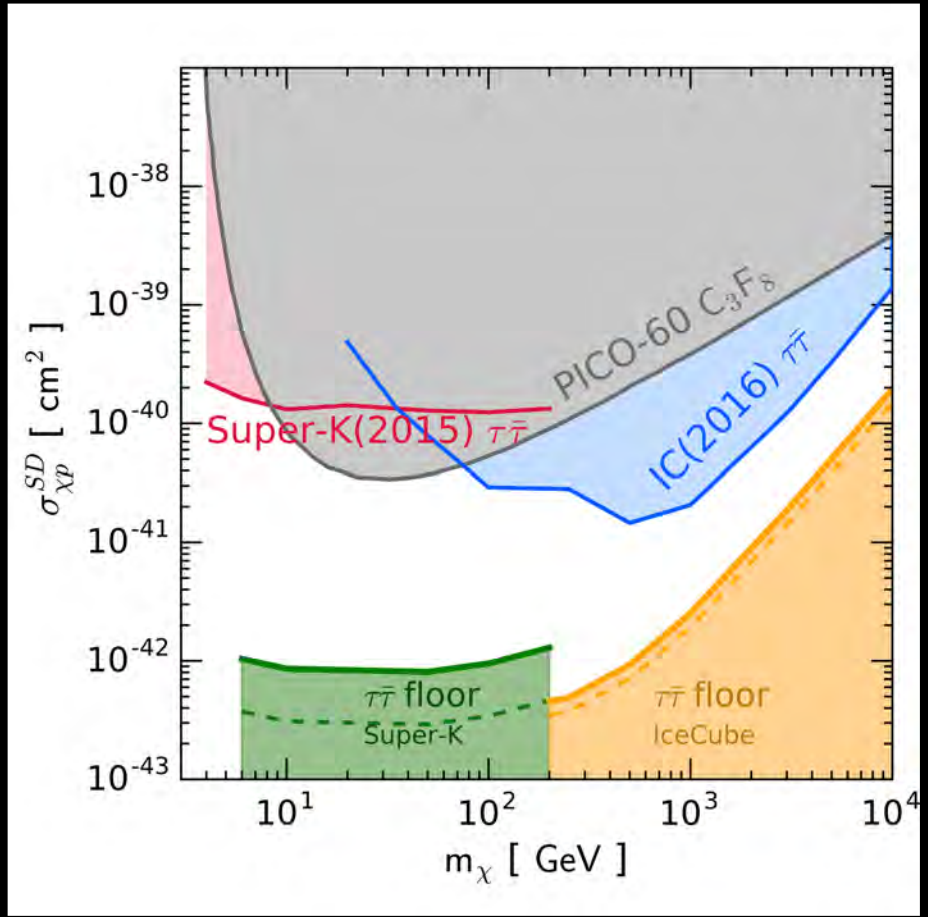
Signal

Rott, KIAS workshop 2018



Solar ATM neutrino – indirect detection Neutrino Floor





No B-field effect are considered

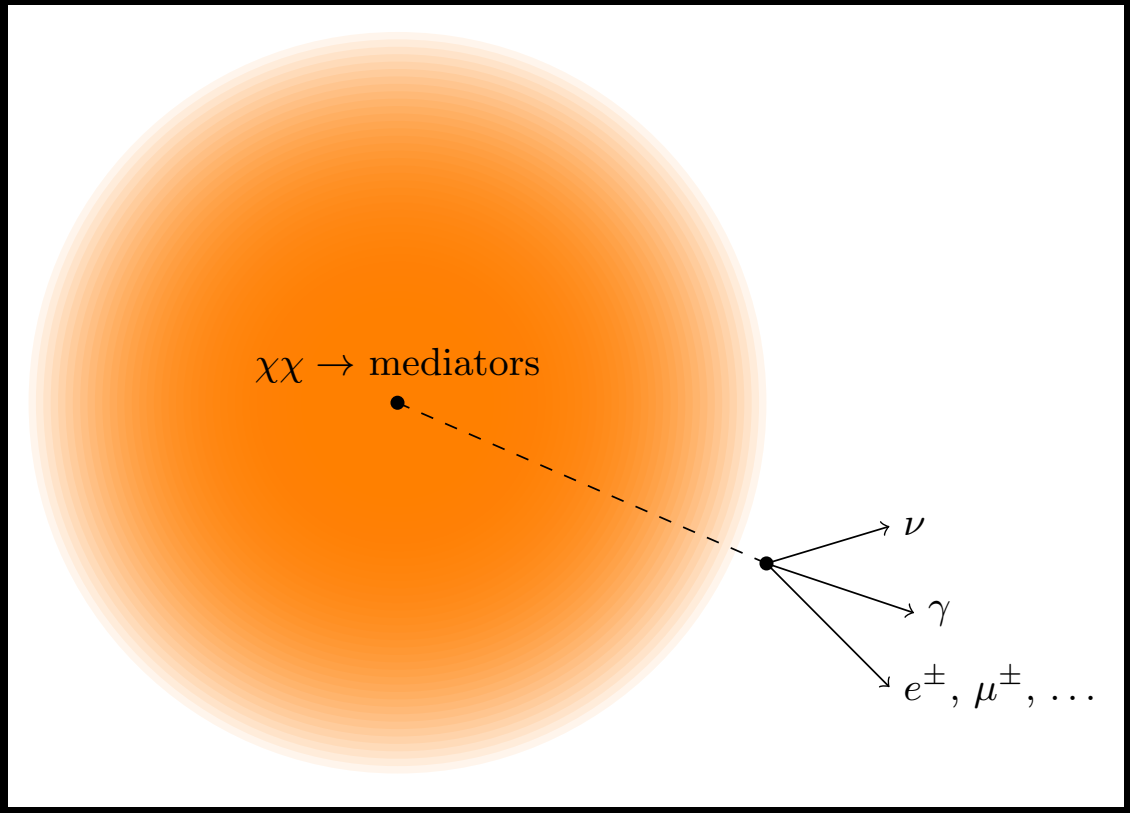
IceCube Search ongoing [S. In & C. Rott ICRC17 (965)]

KCYN, Beacom, Peter, Rott, 1703.10280
See also
Arguelles+ 1703.07798
Edsjo+ 1704.02892

Dark Matter with long-lived mediators

Leane, KCYN, Beacom 1703.04629

- Unlock
  - Gamma rays
  - Electrons, muon, etc
- U suppressed
  - Neutrinos!



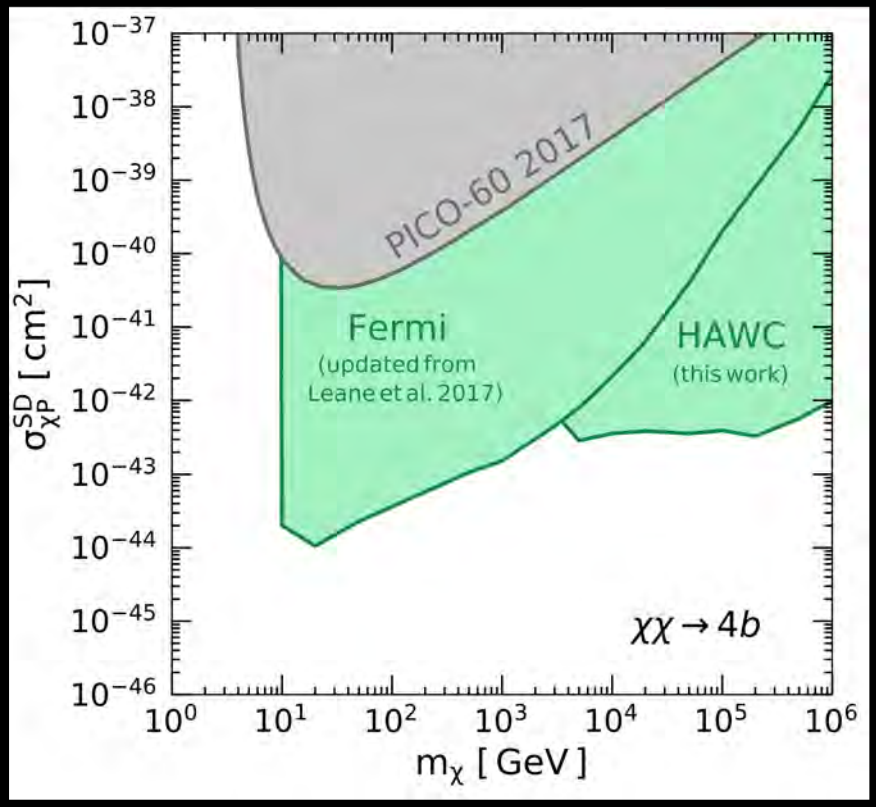
Batell, Pospelov, Ritz, Shang, 0910.1567
Bell, Petraki, 1102.2958
Feng, Smolinsky, Tanedo, 1602.01465
Arina, Backovic, Heisig, Lucente, 1703.08087
etc

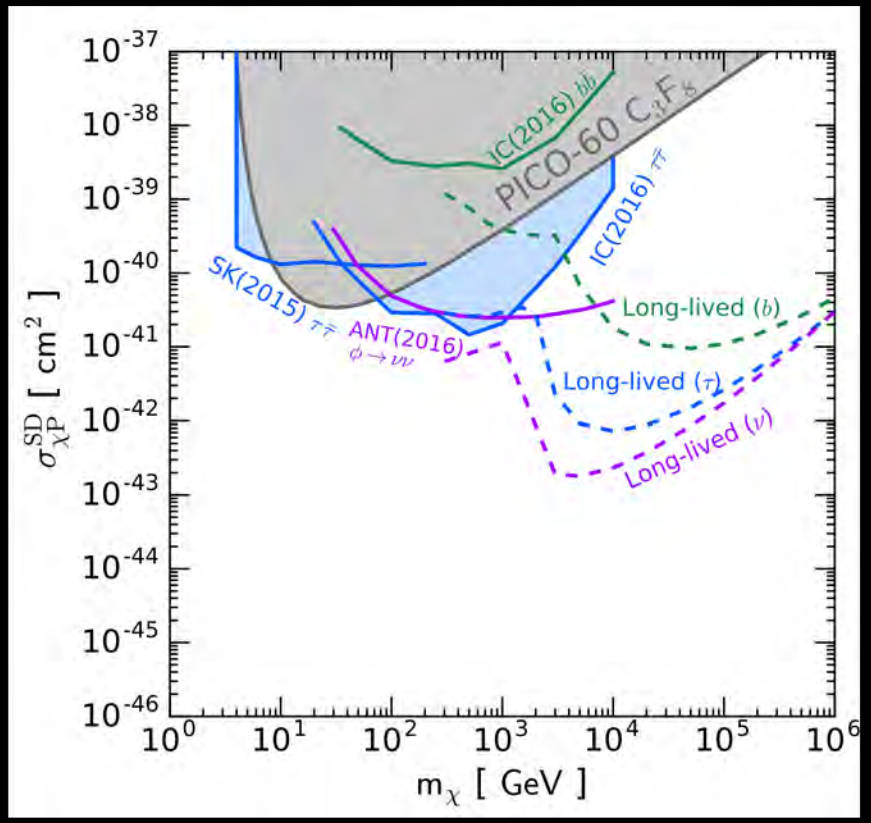
Dark Matter with long-lived mediators

HAWC 1808.05624

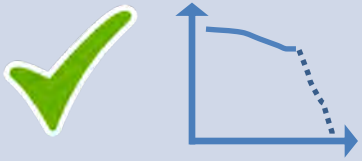
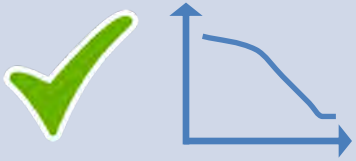
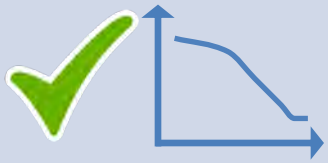
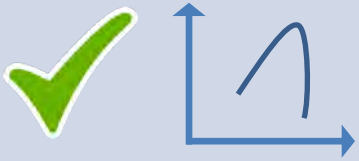
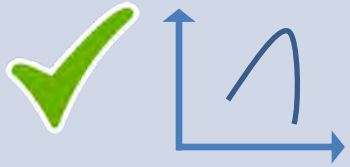
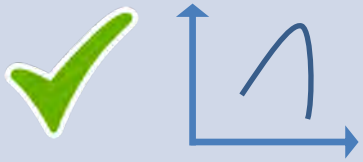
Also Leane, KCYN, Beacom 1703.04629

- Optimal mediator life time + capture equilibrium
- Complementary to direct detection (SD cross section)





HE Solar Messengers

	Gamma Rays	Neutrinos (< TeV)	Neutrinos (> TeV)
Cosmic rays + Solar Atmosphere			
WIMP Dark Matter			
Dark Matter + Mediators			

Summary

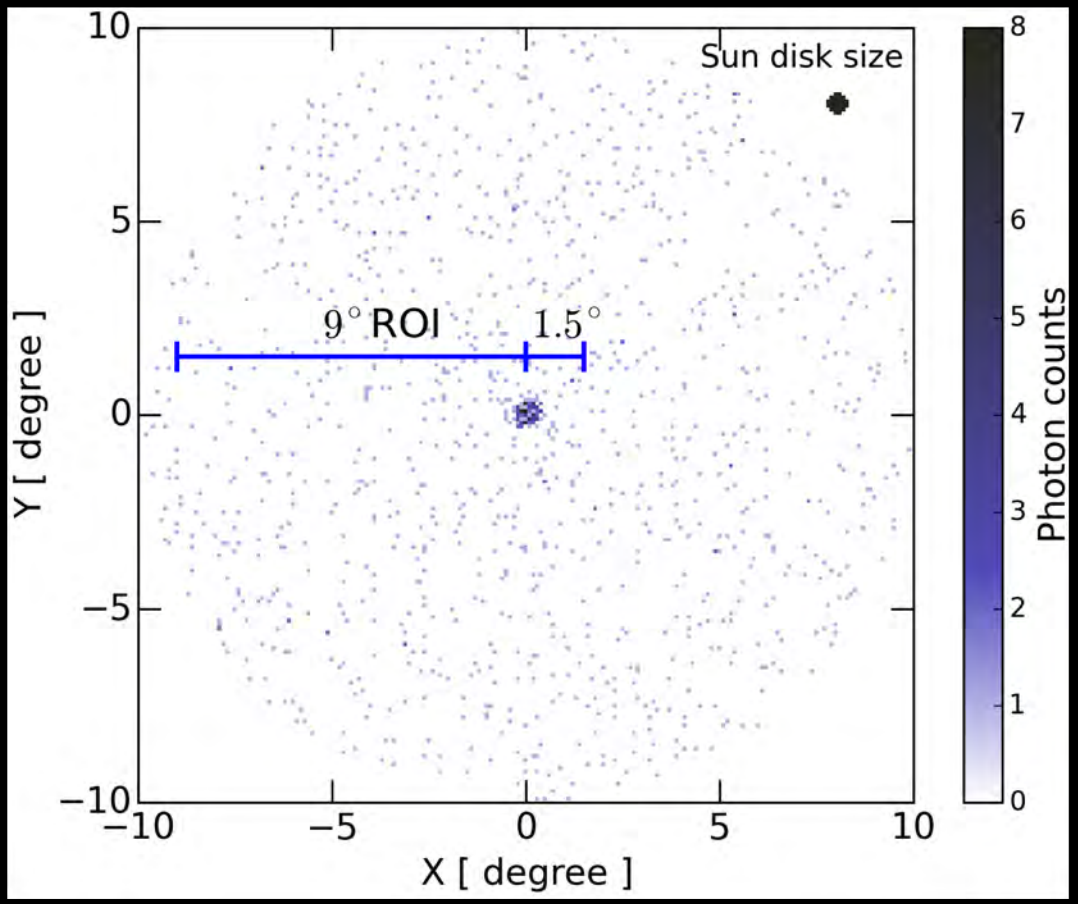
- Solar gamma rays
  - *Complicated*
  - *TeV*
  - *More time (solar minimum starting this year)*
- *Solar atmospheric neutrinos*
  - *Not yet detected*
- *Looking for anomalous signal/new physics*

Thanks!

Backup slides

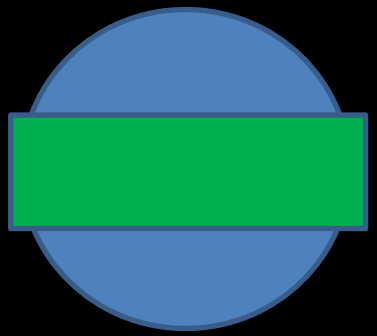
Sun > 10 GeV

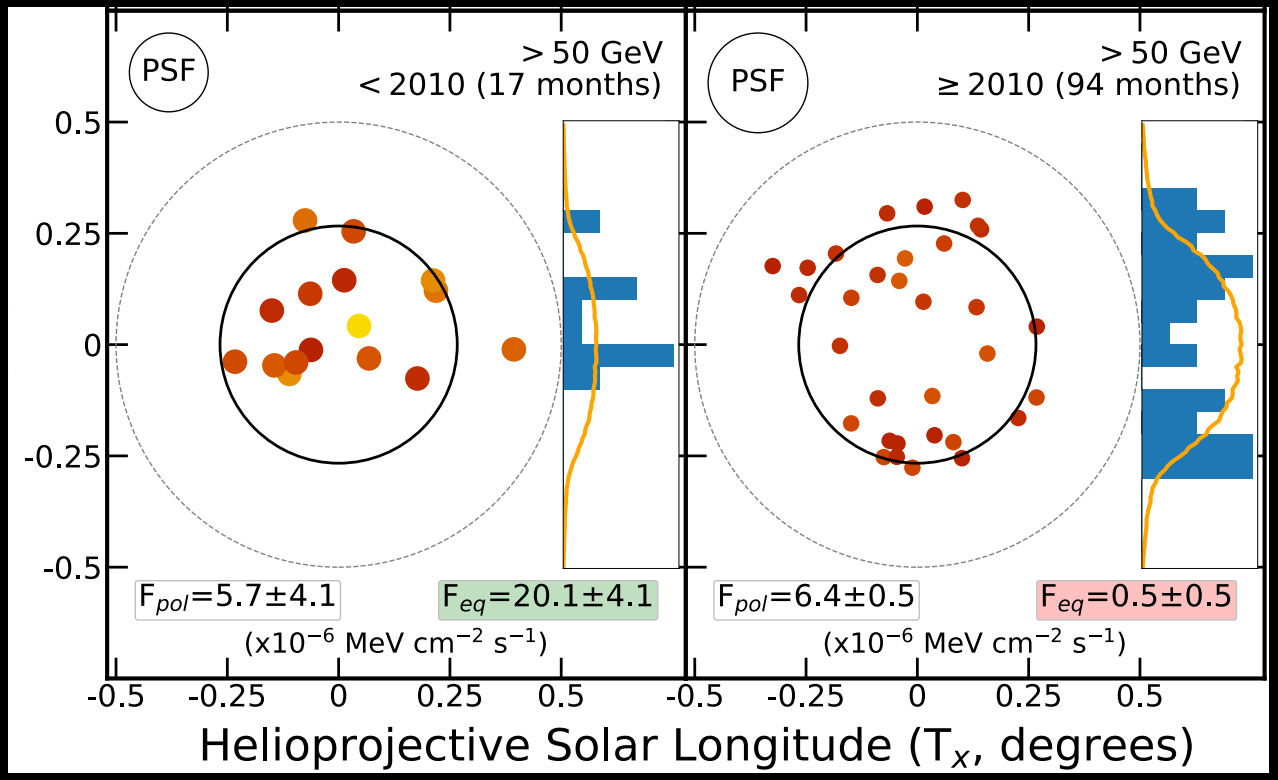
- Photon map



Morphology, *surprise(4)*

Linden + 1803.05436
PRL 121 no.13, 131103



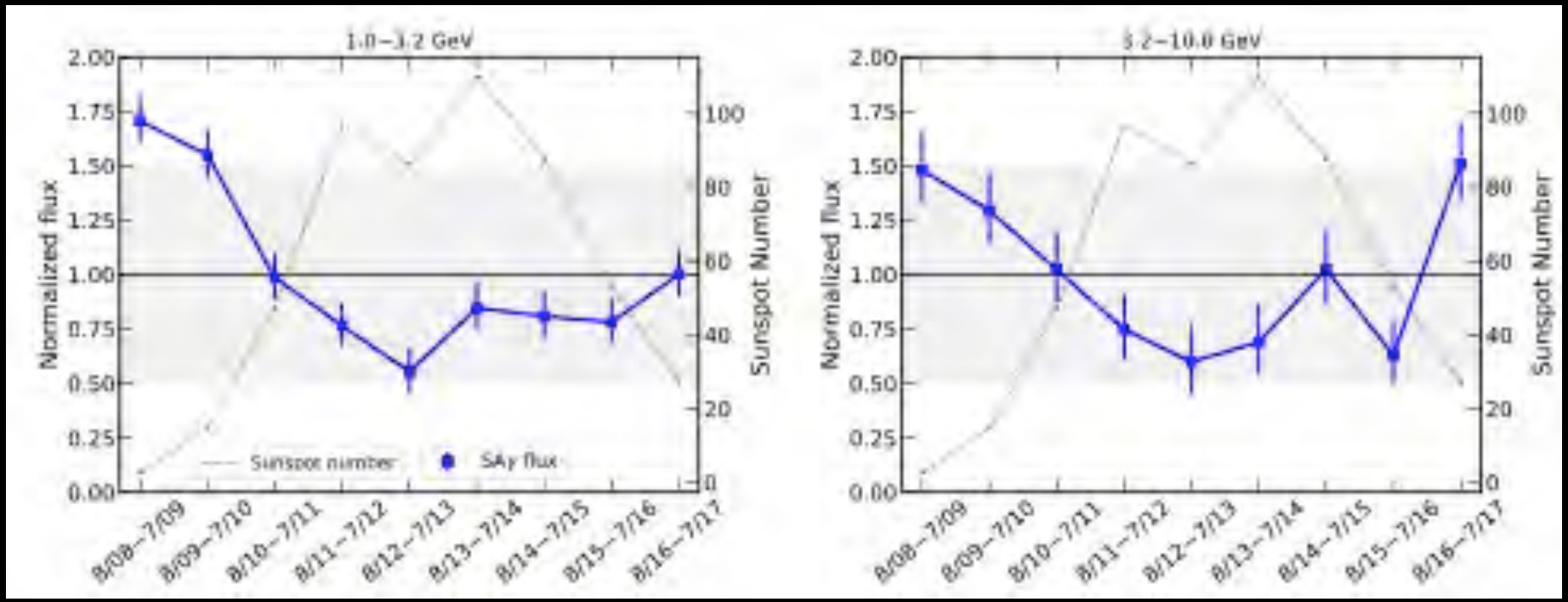


- Equatorial component: Drop by 10x!
- Polar Component: ~ stable

Flux anticorrelation with solar activity

Tang + 1804.06846

- Larger amplitude CR modulation measured on Earth

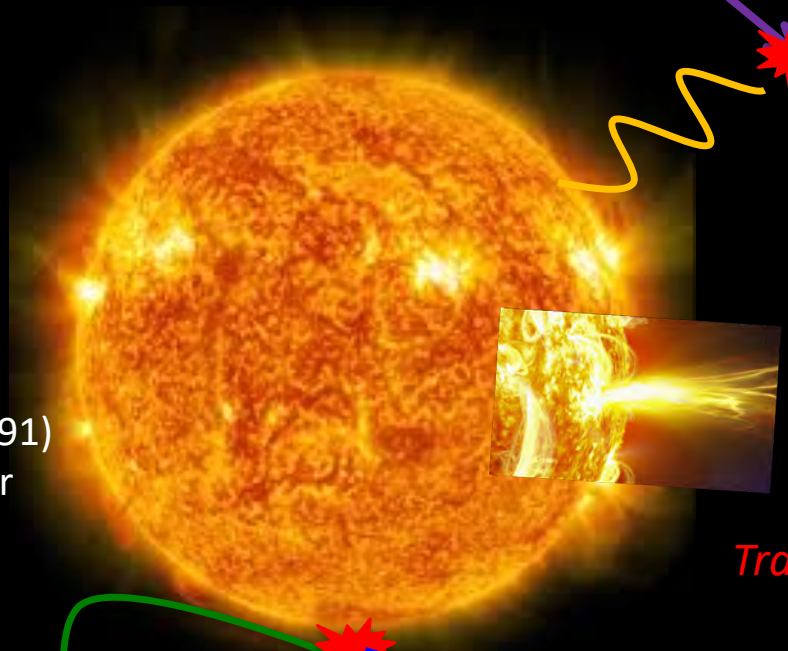


Cosmic Ray Beam Dump Experiments

CR electrons *Steady*

Inverse-Compton

Moskalenko et al (2006),
Orlando & Strong (2007),



γ

γ

Transient

Seckel, Stanev, Gaisser (1991)
Zhou, KCYN, Beacom, Peter
[1612.06420]

CR protons

Hadronic

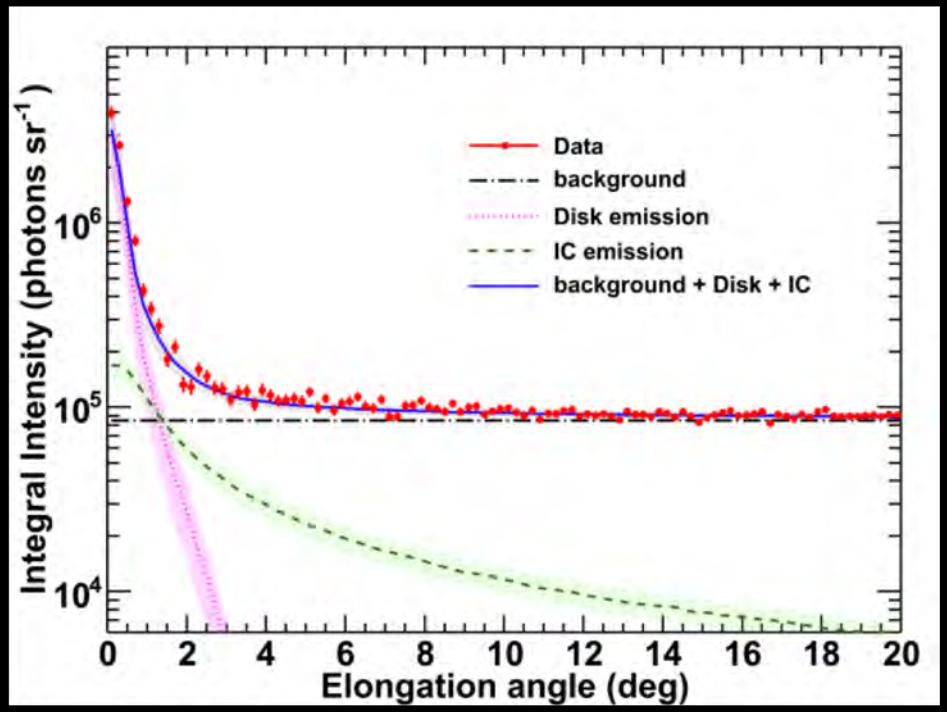
Steady

γ ν

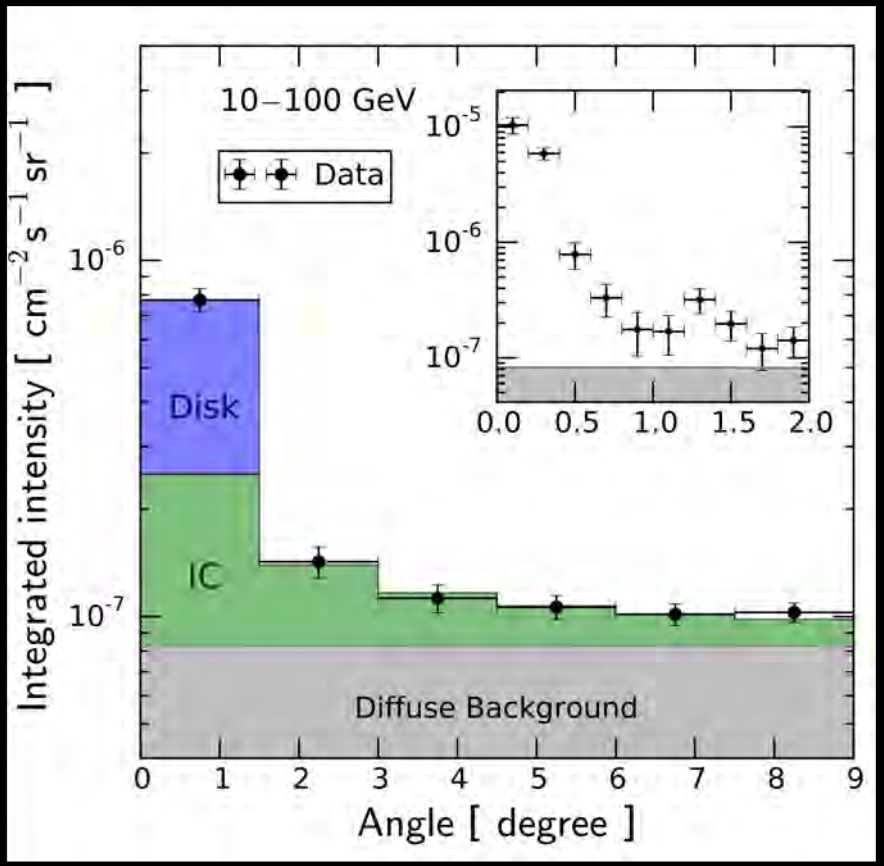


Sun disk gamma

- Separation



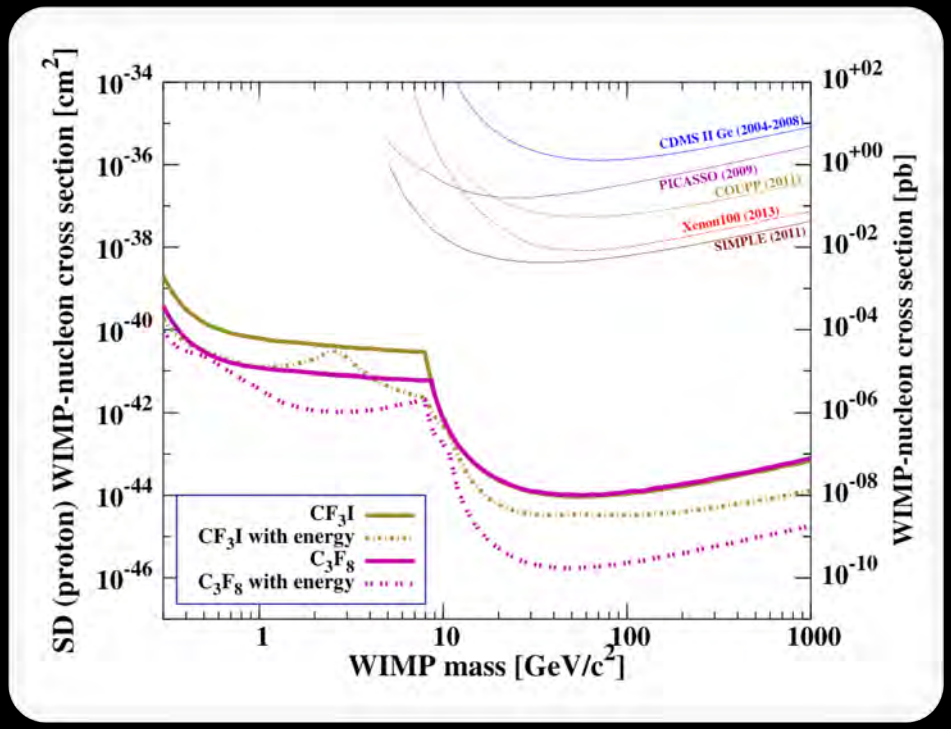
Abdo et al. 2011



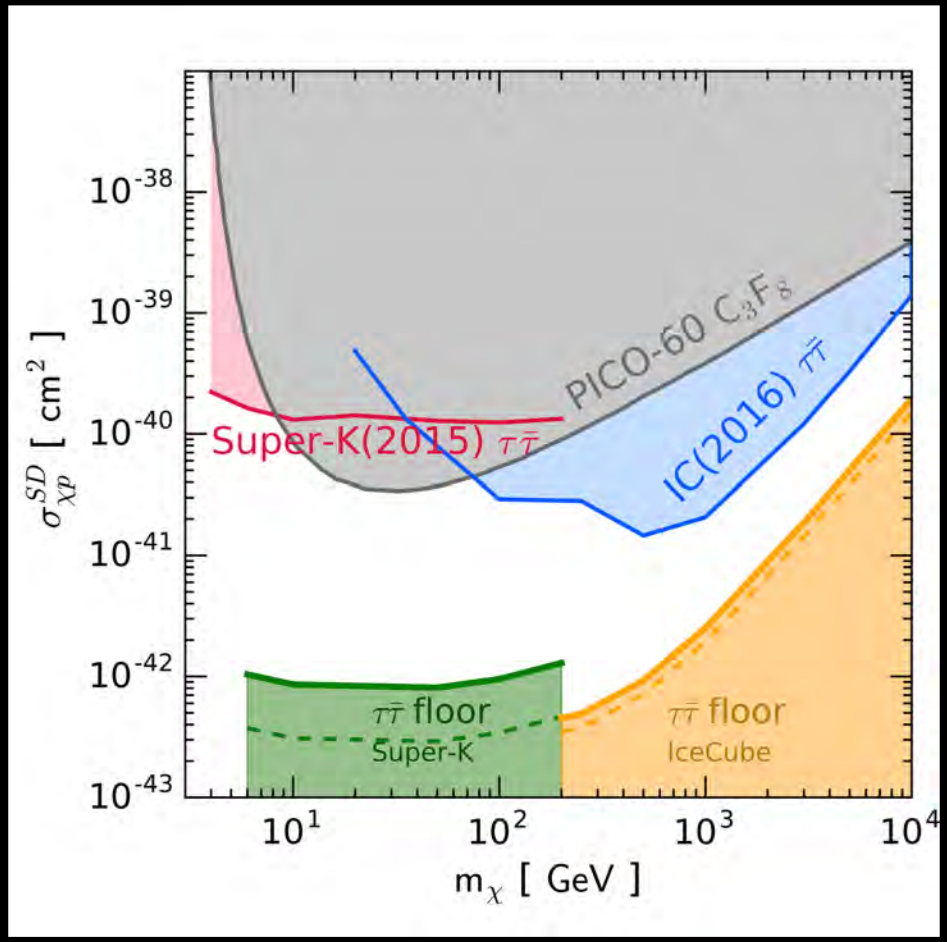
Ng et al. 2015

Solar Atmospheric Neutrino Floor

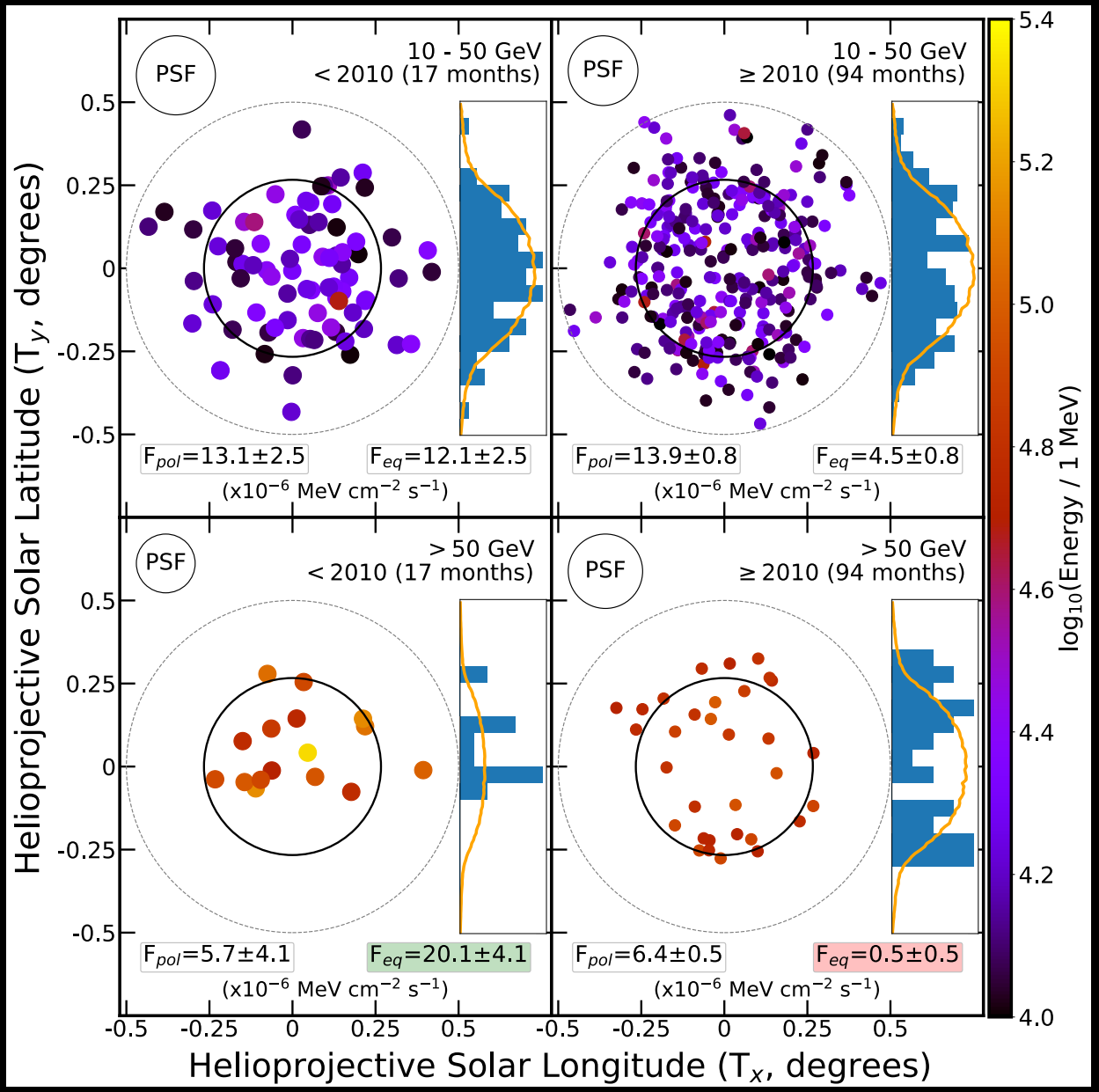
- Large direct detection experiments are needed to reach 10^{-44} cm^2



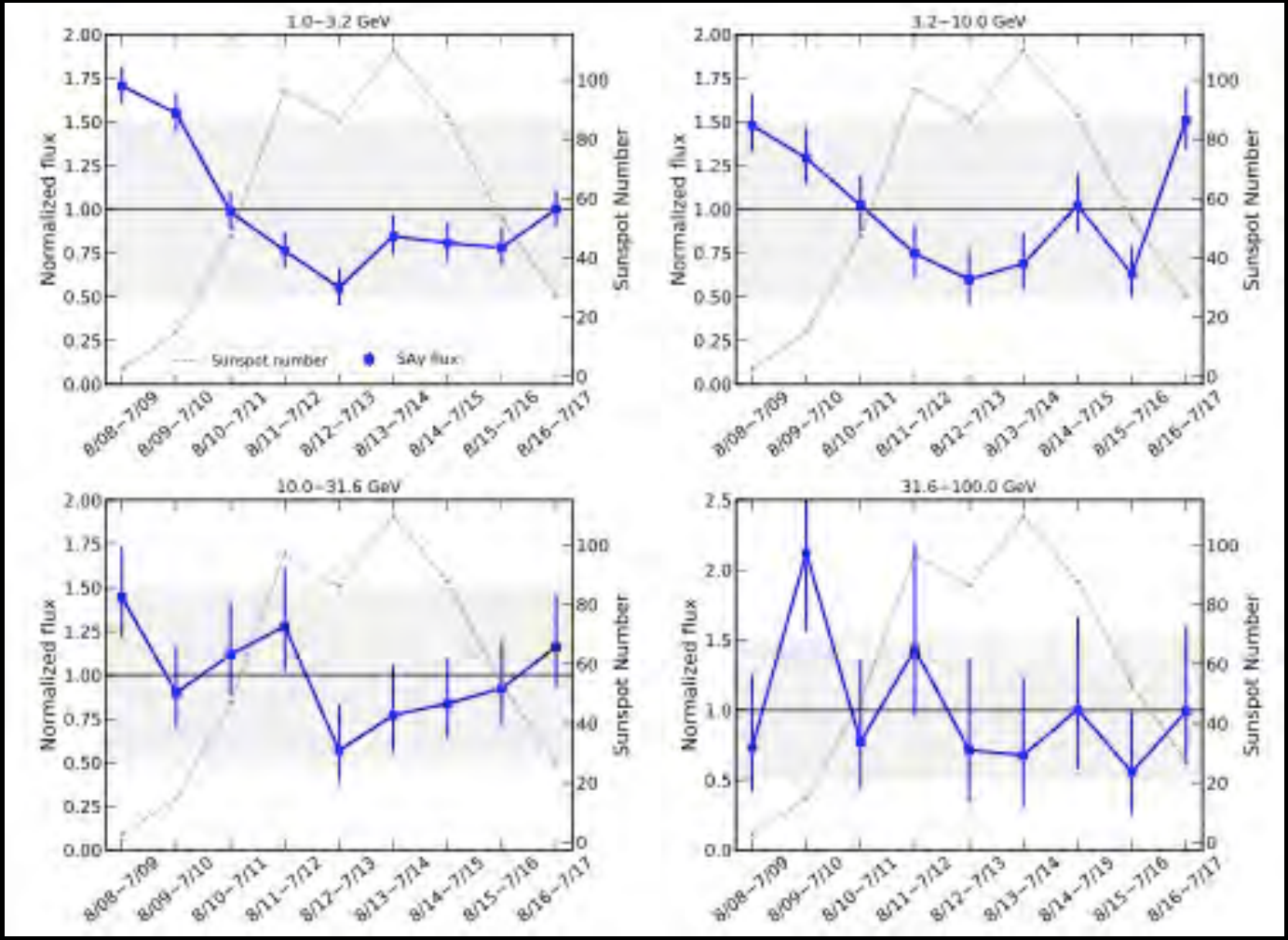
Solar, diffuse supernova, atmospheric neutrinos
Ruppin et al. 2014



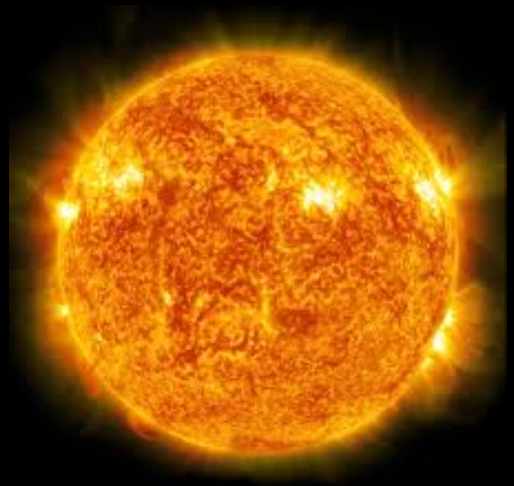
1803.05436


PSF
10 - 50 GeV
< 2010 (17 months)
PSF
10 - 50 GeV
≥ 2010 (94 months)
PSF
> 50 GeV
< 2010 (17 months)
PSF
> 50 GeV
≥ 2010 (94 months)
F_pol=13.1±2.5
F_eq=12.1±2.5
(x10^−6 MeV cm^−2 s^−1)
F_pol=13.9±0.8
F_eq=4.5±0.8
(x10^−6 MeV cm^−2 s^−1)
F_pol=5.7±4.1
F_eq=20.1±4.1
(x10^−6 MeV cm^−2 s^−1)
F_pol=6.4±0.5
F_eq=0.5±0.5
(x10^−6 MeV cm^−2 s^−1)
Helioprojective Solar Latitude (T_y, degrees)
Helioprojective Solar Longitude (T_x, degrees)
log10(Energy / 1 MeV)
0.5
0.25
0
-0.25
-0.5
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0

1804.06846


1.0–3.2 GeV
3.2–10.0 GeV
10.0–31.6 GeV
31.6–100.0 GeV
Normalized flux
Sunspot Number
Sunspot number
SAy flux
8/08–7/09
8/09–7/10
8/10–7/11
8/11–7/12
8/12–7/13
8/13–7/14
8/14–7/15
8/15–7/16
8/16–7/17

Recent results on Solar Atmospheric Gamma rays



1803.05436, accepted in PRL
1804.06846, accepted in PRD
Tim Linden (OSU)
Qingwen Tang (NanChang U)
KCYN (Weizmann Institute)
Bei Zhou (OSU)
John Beacom (OSU)
Annika Peter (OSU)

1808.05620
1808.05624

+ HAWC collaboration
(Mehr Un Nisa, Rochester)