15aSN-5

Latest Results from Observation of High-energy Gamma-rays by CALET

CALETによる高エネルギーガンマ線観測の最新成果

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他CALETチーム

M. Mori, D. Zenita, Y. Asaoka, S. Torii, Y. Kawakubo, N. Cannady, M.L. Cherry for the CALET collaboration

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Japan Physical Society 2020 Fall Meeting (online), September 14-17, 2020

Cannady et al., ApJS 238:5 (2018)

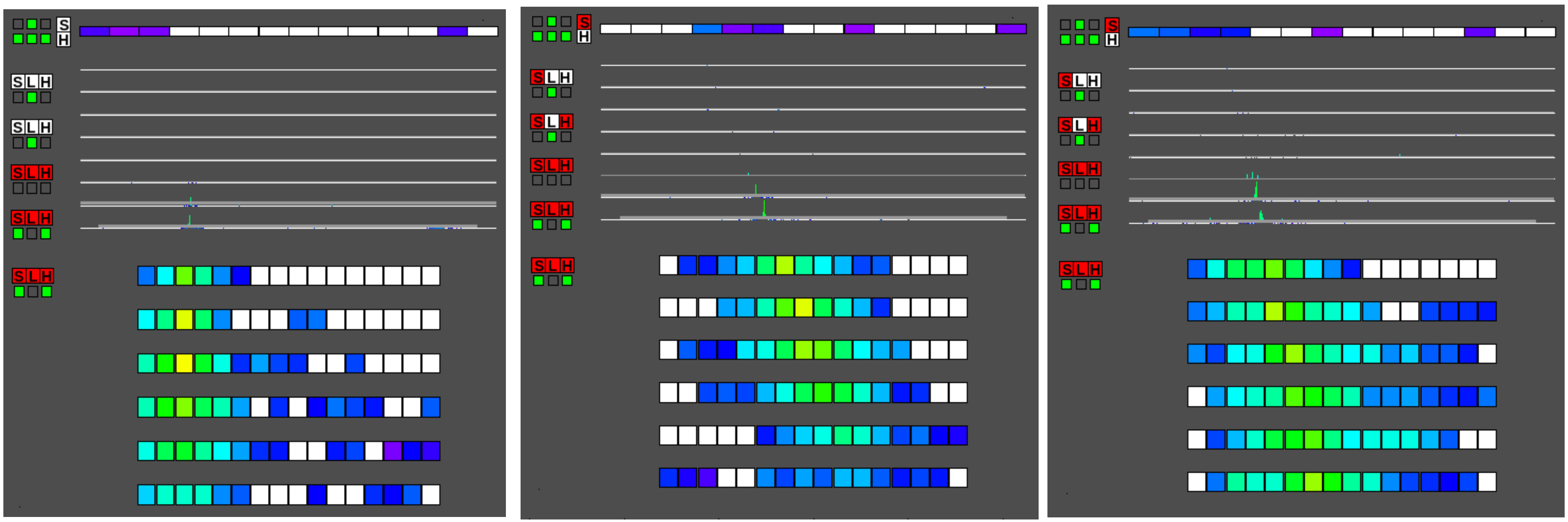
Gamma Ray Event Selection

= Electron Selection Cut + Gamma-ray ID Cut w/ Lower Energy Extension

<u>100 GeV Event Examples</u>

gamma ray | electron | proton

Charge Z=0 | Charge Z=1

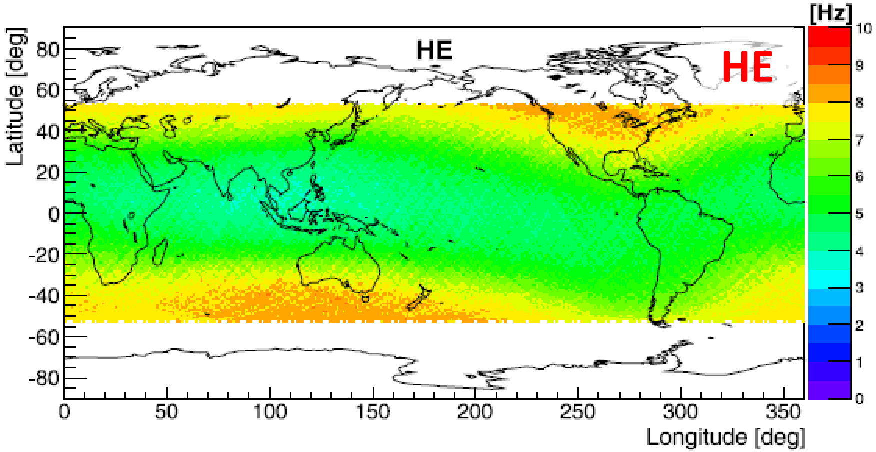


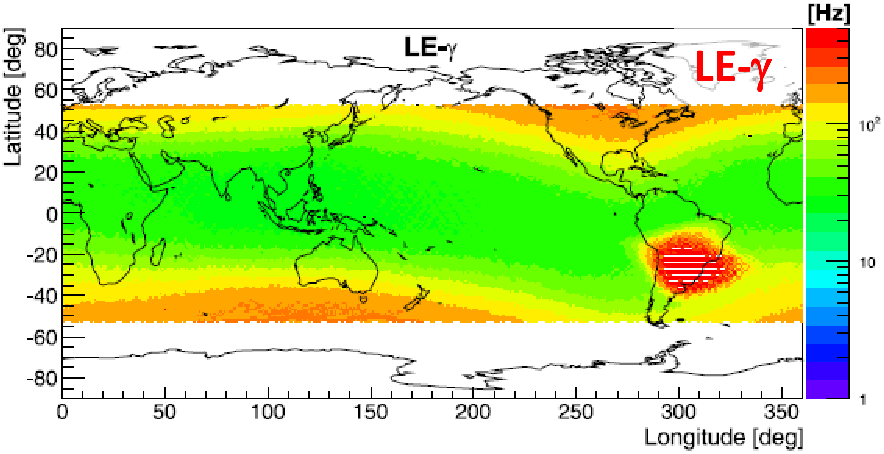
Electromagnetic Shower | Hadron Shower

well contained, constant shower development | larger spread

CALET triggers and gamma-ray observation

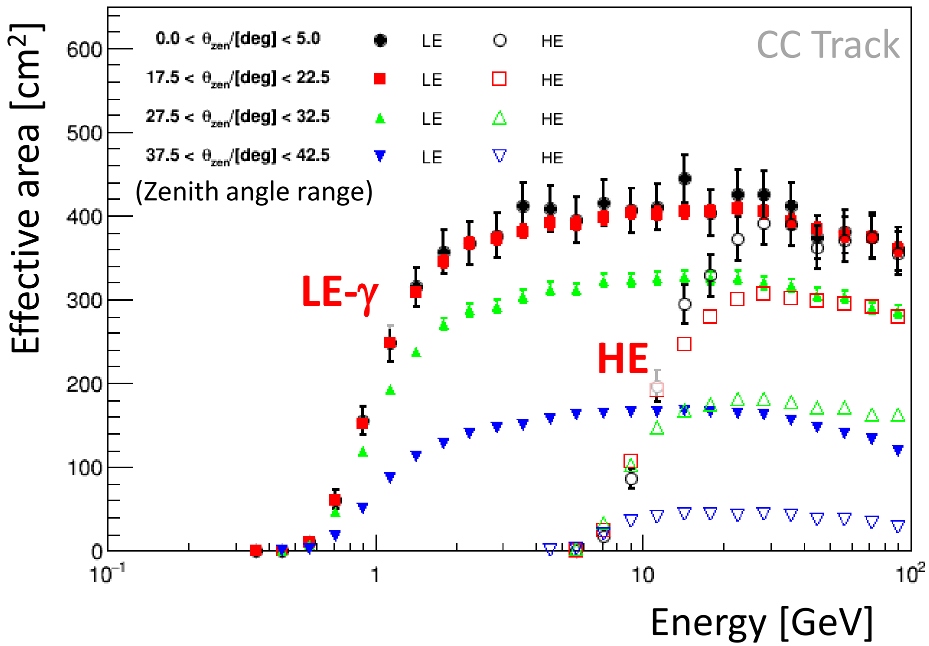
Trigger rate vs ISS position





Asaoka et al., Astropart.Phys. 100, 29 (2018)

Effective area



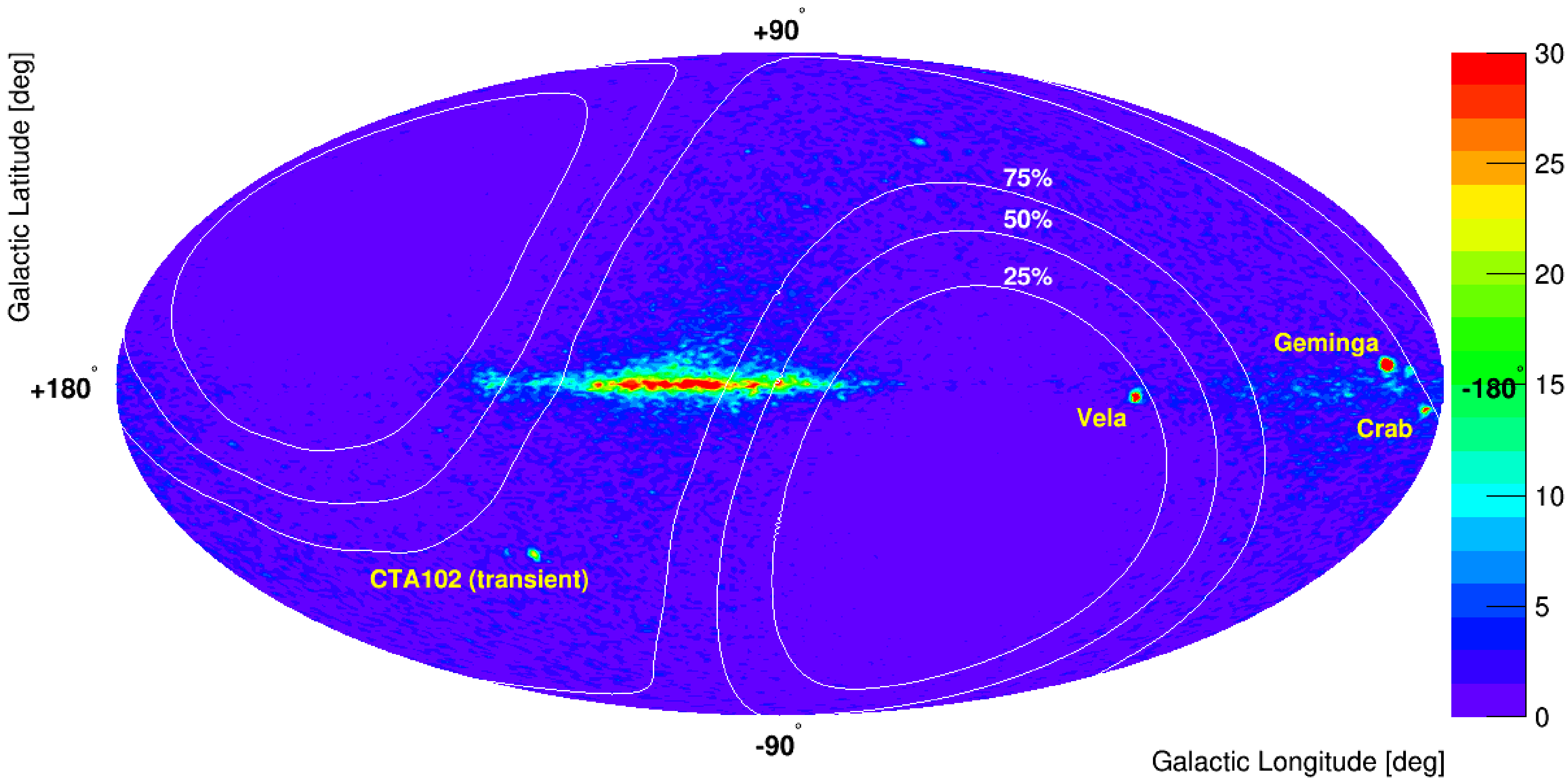
HE trigger: $E_\gamma > 10$ GeV
LE-γ trigger: $E_\gamma > 1$ GeV

- HE trigger mode: always ON
- LE-γ mode is activated when the geomagnetic latitude is below 20° and following a CALET Gamma-ray Burst Monitor (CGBM) burst trigger

Cannady et al., ApJS 238:5 (2018)

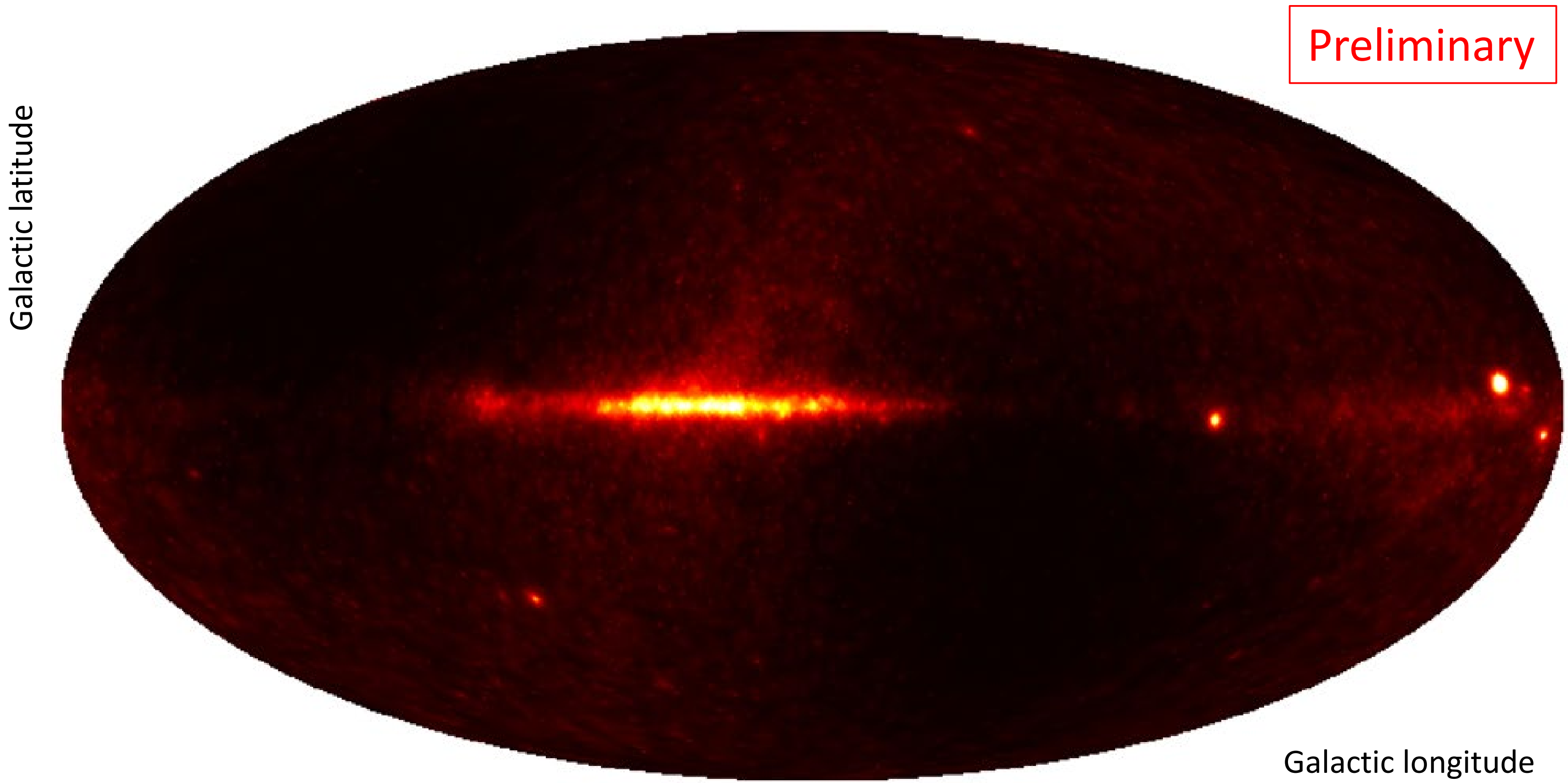
Mori, Asaoka et al., ICRC2019

Gamma-ray skymap (2.5 yr)



LE-γ mode, from 2015 November to 2018 May
(Contours show relative exposures)

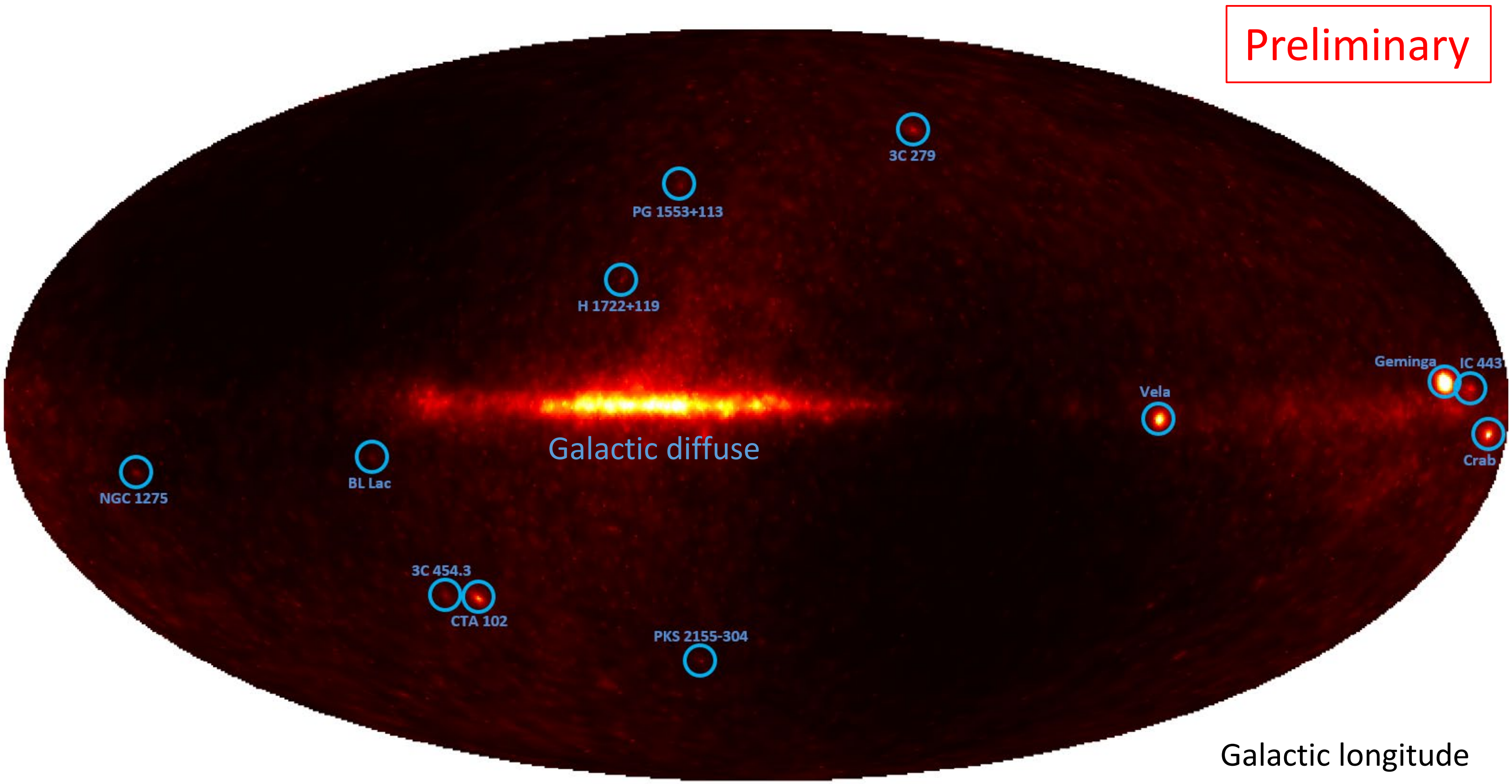
Gamma-ray skymap (4 yr)



LE-γ mode, from 2015 November to 2019 Dec
(Note that the exposure is non-uniform)

Gamma-ray skymap (4 yr)

Galactic latitude

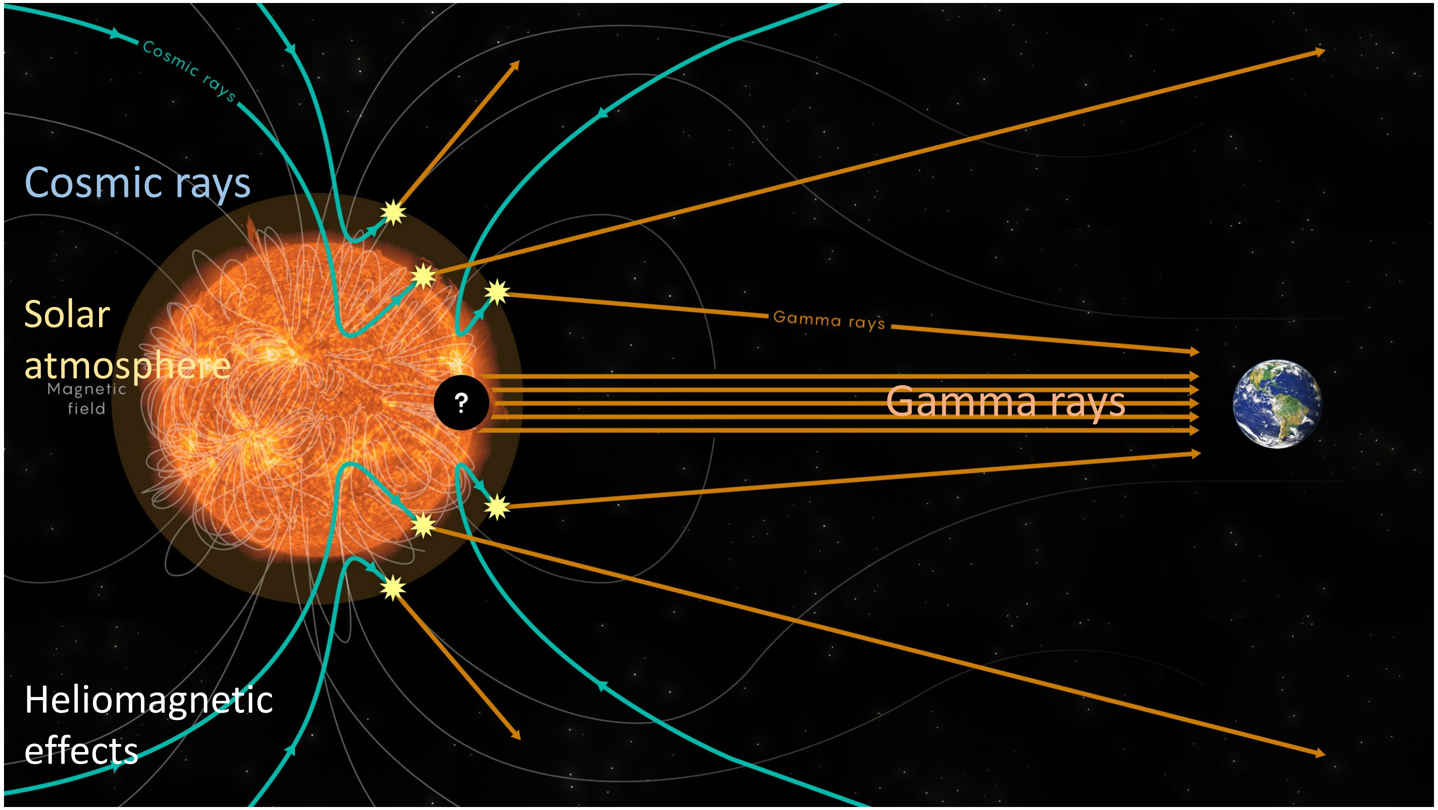


Galactic longitude

LE-γ mode, from 2015 November to 2019 Dec
(Note that the exposure is non-uniform)

Solar atmospheric gamma-rays
(Gamma-rays from solar disk and halo)

https://www.quantamagazine.org/gamma-ray-data-reveal-surprises-about-the-sun-20190501/



"Disk" (cascade) emission: Galactic CR + solar surface → gamma rays
"Extended" (IC) emission : CR electrons + solar photon halo → gamma rays

Fermi-LAT, ApJ 734:116, 2011

→ Reflect CR modulation (and solar activities) and HE CR electrons

Solar atmospheric gamma-rays

Tang et al., PR D98, 063019 (2018)
Linden et al., PRL 121, 131103 (2018)

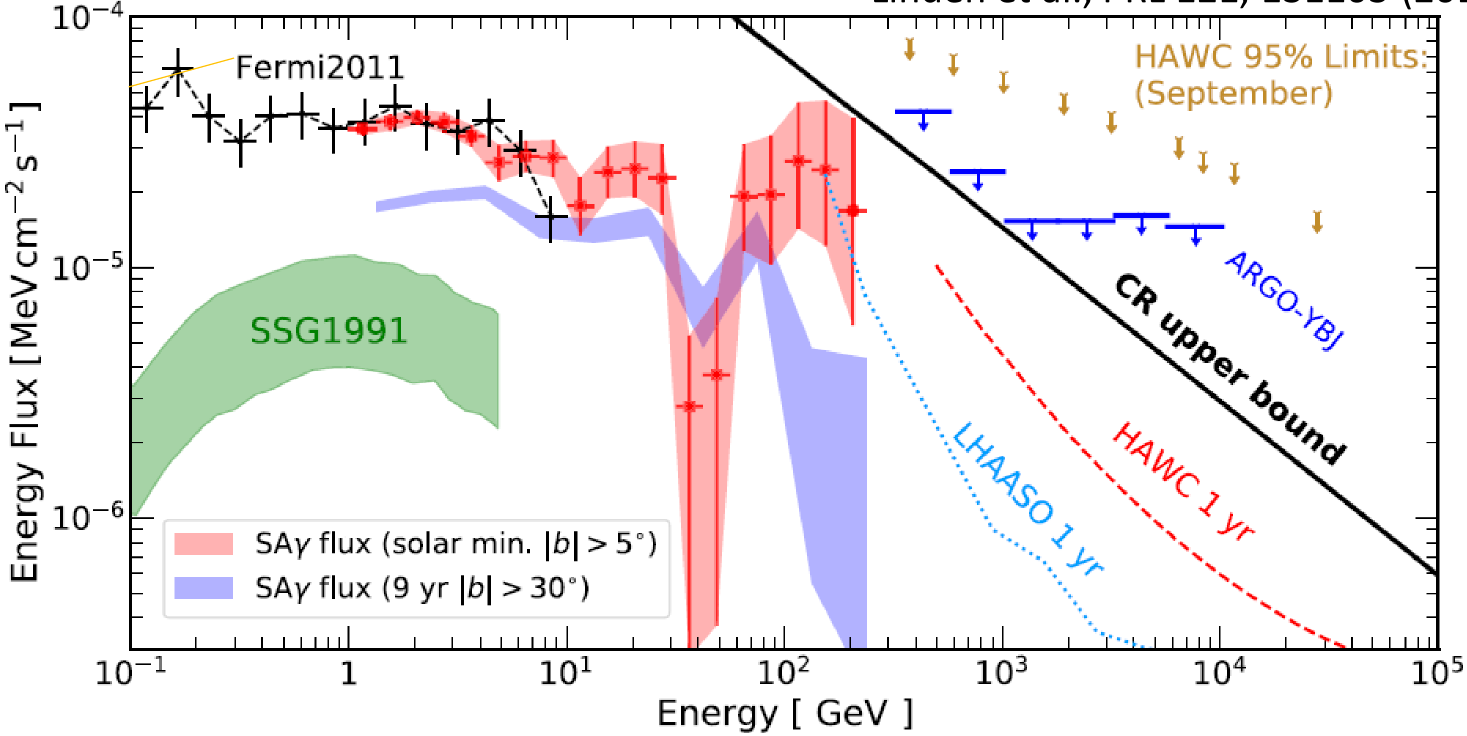


FIG. 5. The 9 year averaged SAγ flux and the solar minimum SAγ flux (76 weeks of data from 2008-8-7 to 2010-1-21), which is significantly harder above 100 GeV. We also show the point source sensitivities of HAWC [23] and LHAASO [24,25], as well as the preliminary limits from HAWC ([47], one month of data) and ARGO-YBJ [48]. The theoretical maximum gamma-ray flux that the Sun can produce with cosmic rays (CR upper bound; see text for detail) is shown by the black solid line.

SSG1991: Seckel, Stanev & Gaisser ApJ 382, 652 (1991)
CR electrons and protons interacting with Solar photosphere and corona

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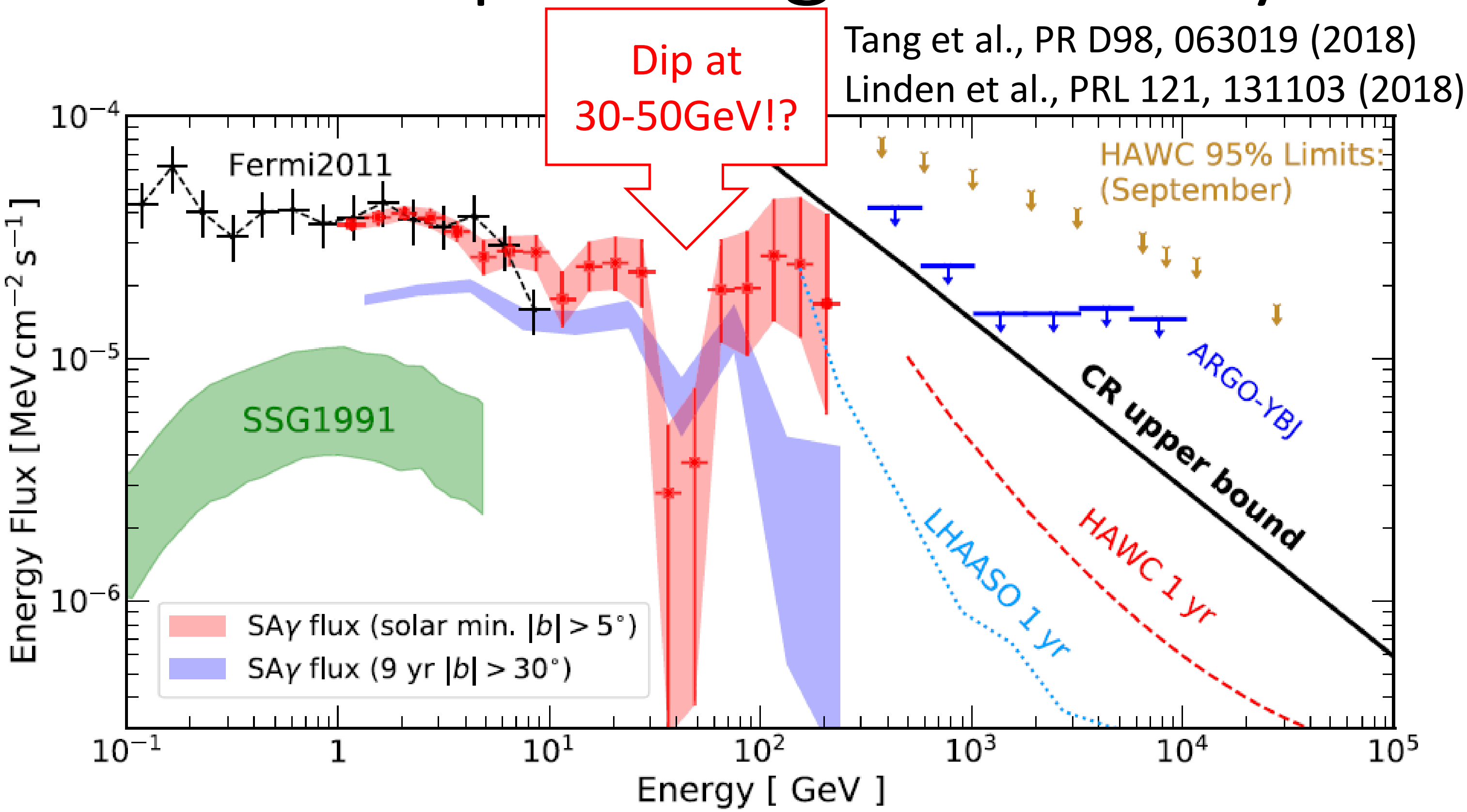

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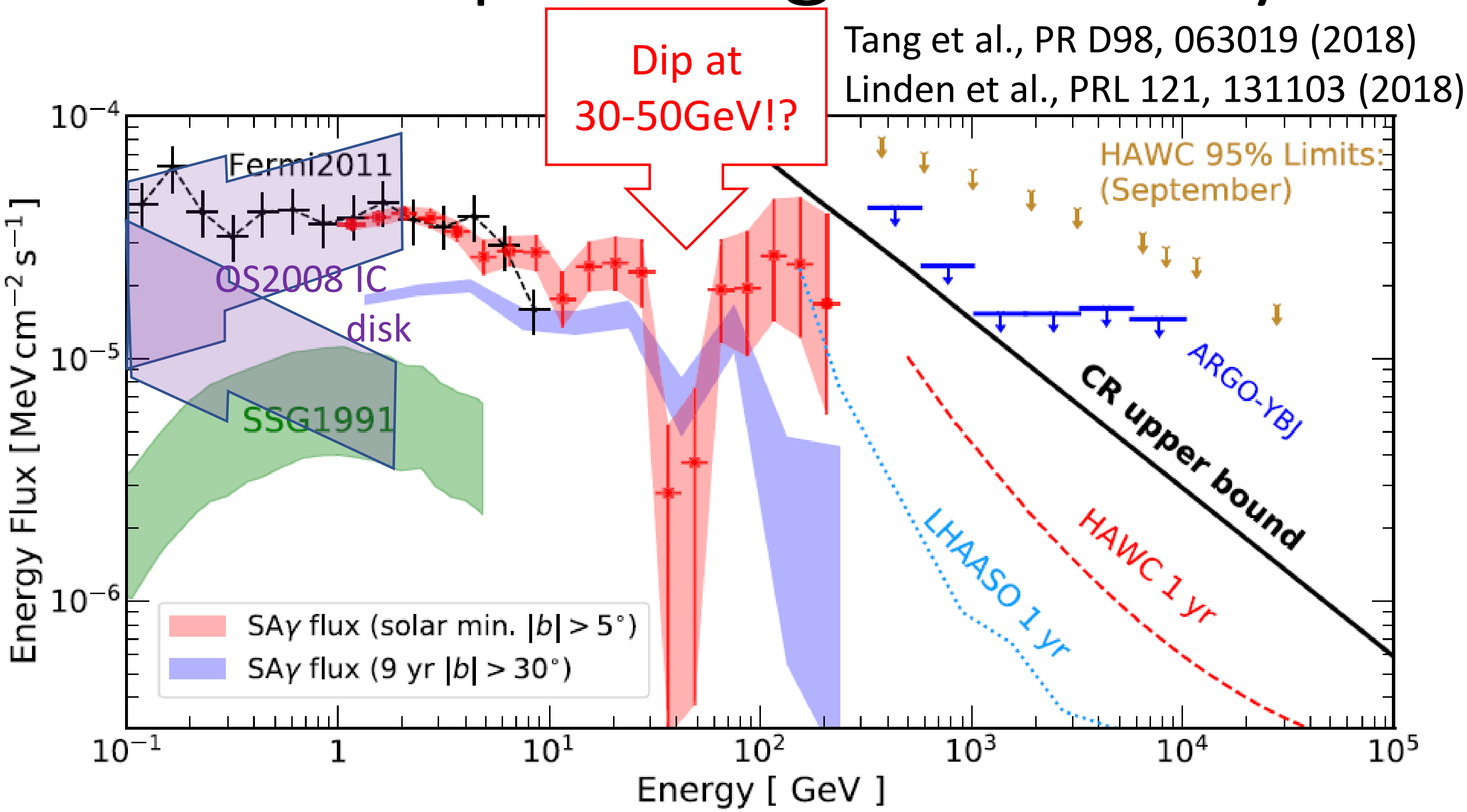

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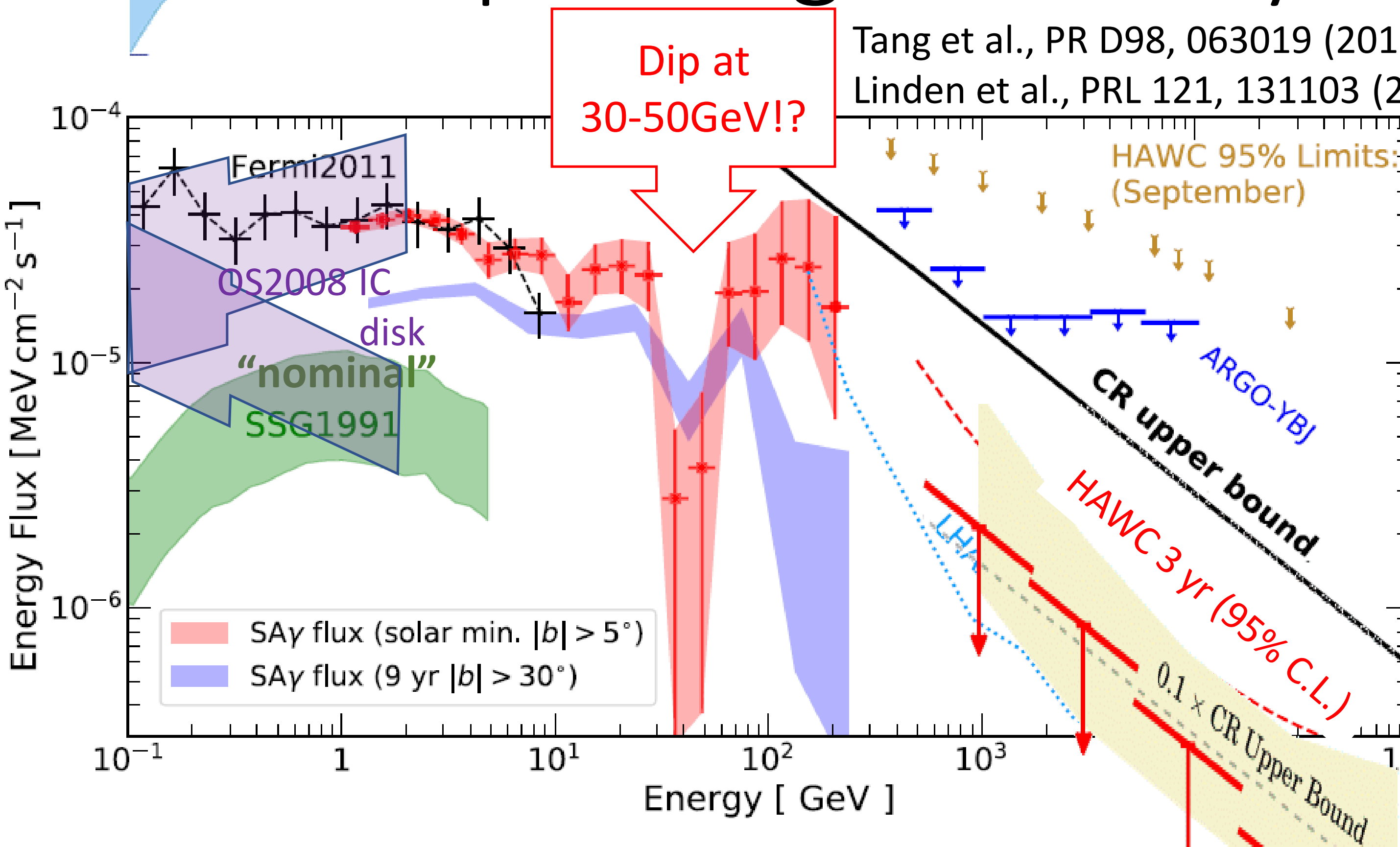
OS2008: Orlando & Strong AA 480, 847 (2008)
EGRET analysis for disk and extended (halo) emission

HAWC: PR D98, 123011 (2018)

Solar atmospheric gamma-rays

Tang et al., PR D98, 063019 (2018)
Linden et al., PRL 121, 131103 (2018)



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Observations with CALET

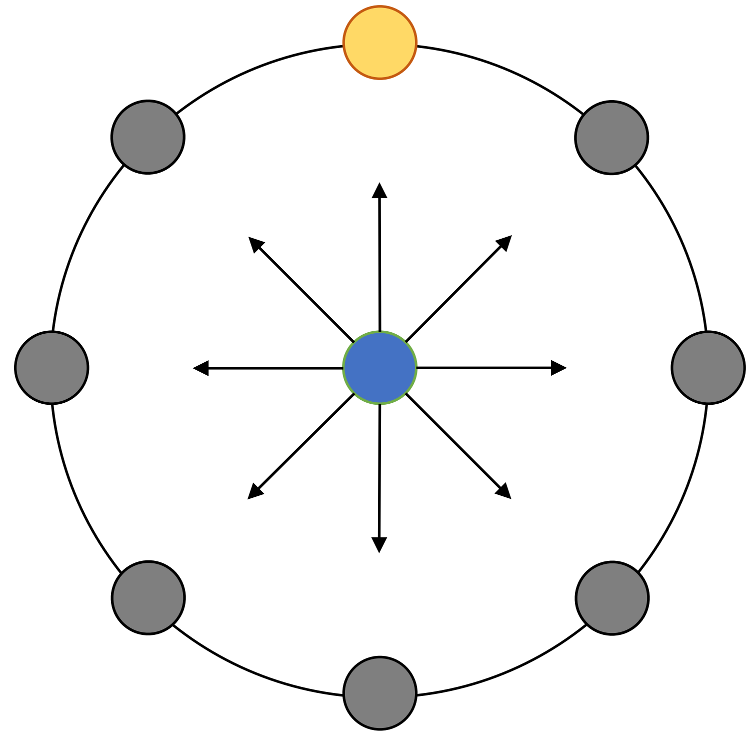
- Data sample covers the time period 2015/11 – 2019/10 (48 months)
  - LE-γ data (E > 1 GeV) available for low geomagnetic latitude
  - HE data (E > 10 GeV) available with >95% duty cycle
- Bright background sources are vetoed for event selection and exposure generation:
  - Galactic plane ($|b| < 20°$)
  - Moon (5° window)
    - daily 12:00 moon position for exposures
    - moon position at precise time for event selection
  - Point sources (5° window)
    - Pulsars, AGN, etc.
    - Some redundancy with galactic plane cut
- Rotated into solar frame defined in terms of Sun position and normal to ecliptic plane

Analysis methodology

- Selection of events
  - Events chosen using energy- and tracking-dependent PSF relative to z-axis in Solar frame
  - Narrow window (< 2° overall, much smaller for most energies) contains primarily disk component. IC component contamination under investigation
- False Sun trials
  - Positions chosen along ecliptic leading or trailing actual Sun
  - In this analysis spaced by 45° (7 equally spaced false Suns)
  - Analysis repeated for these frames same as for real Sun frame
- Accumulation of exposure and background model
  - Full sky transformed for every day according to Sun position
  - Fermi-LAT background model used to validate observed event numbers

False Sun trials

- Better estimation of background than galactic diffuse model
- Sun position shifted further along the ecliptic plane
  - Calculate i^{th} fake Sun out of N using observation time $T_0 + (i * 365.25 \text{ days} / N)$
- Repeat analysis of Sun region in each false Sun window

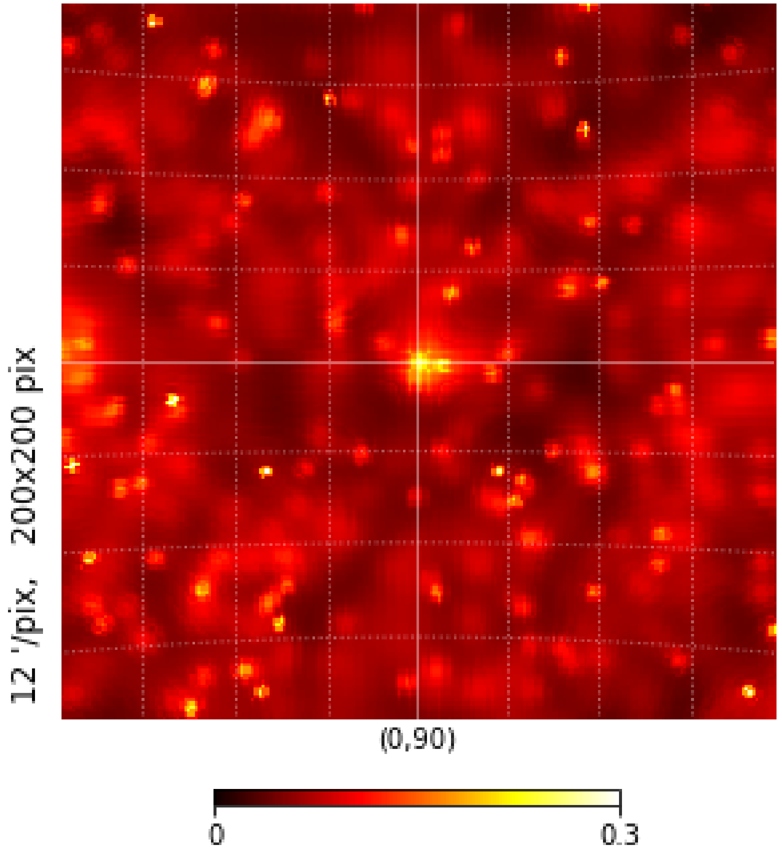


Currently using 7 false Sun trials, each shifted by 45° along the ecliptic, well outside of a 20° region of interest.

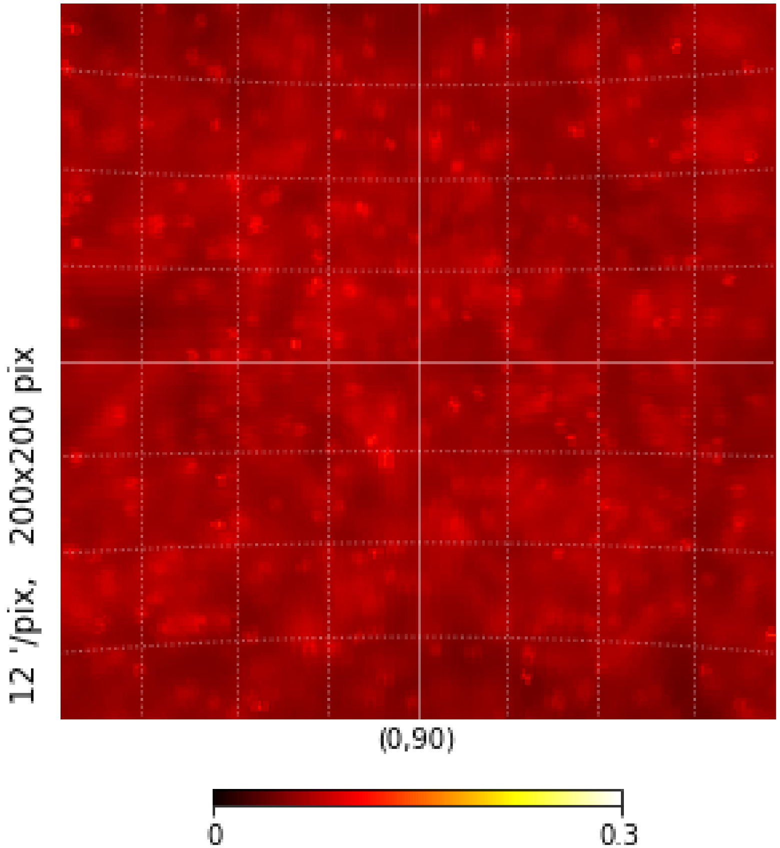
Count map: Sun frame vs. background frame

Preliminary

Sun frame

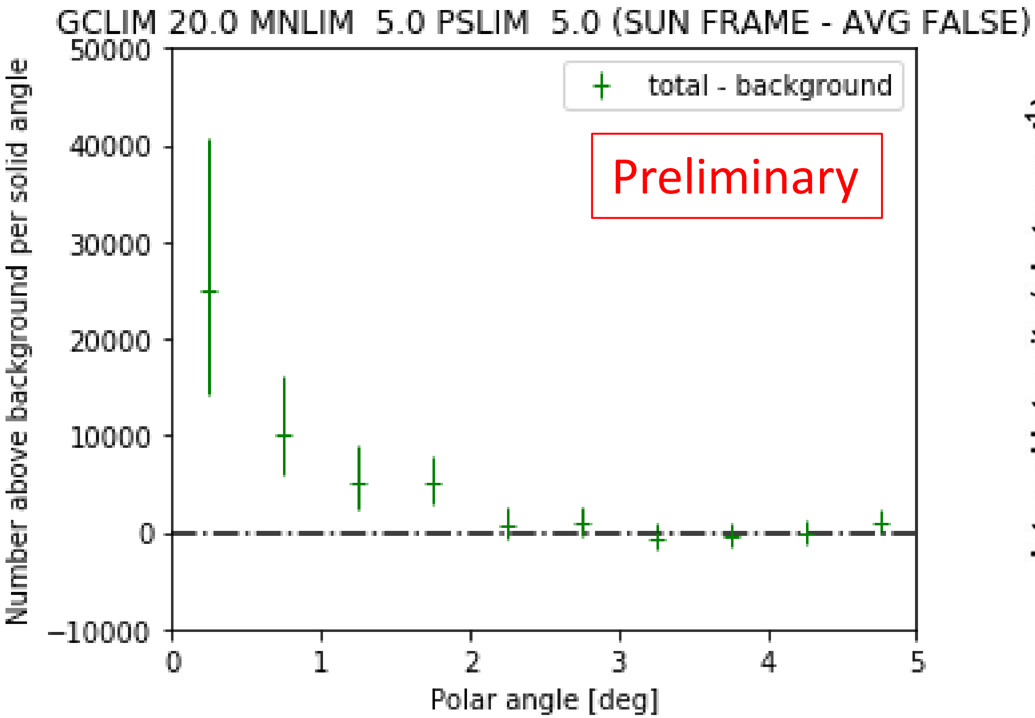


False Sun average



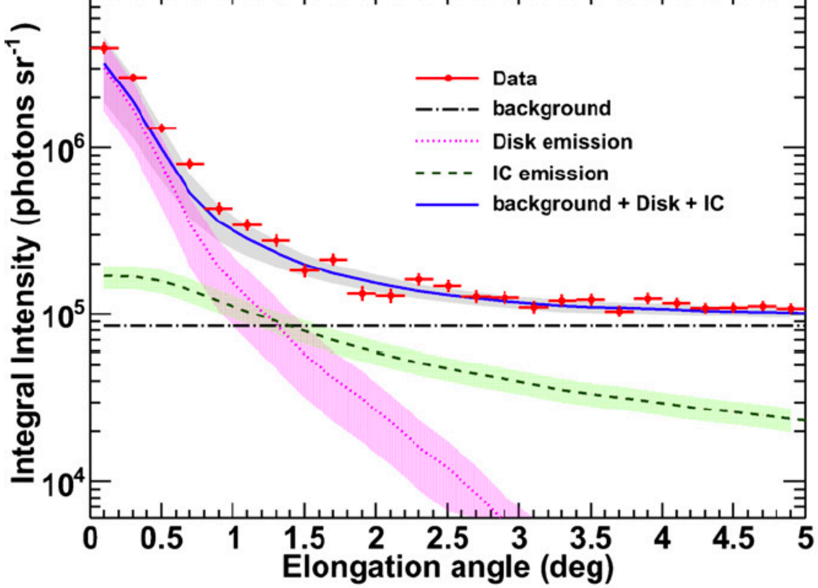
Events vs. opening angle

Background number of events calculated from average of false Sun trials
NB absolute value on y-axis is dependent on effective area and observation time



Solar radius (16’)

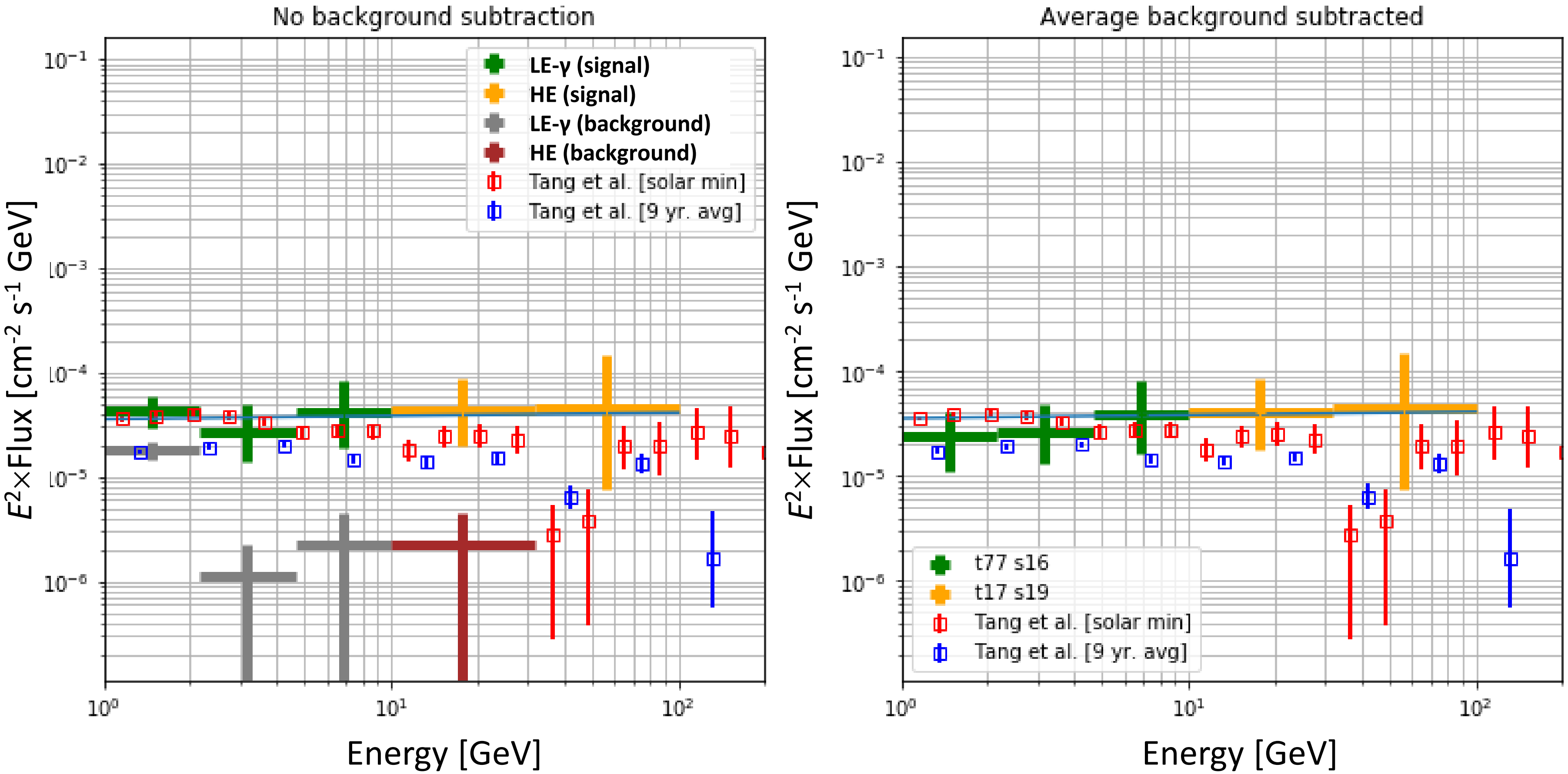
Fermi-LAT (ApJ 734:116, 2011)



CALET gamma-ray spectrum from the Sun

Preliminary

Flux considering only 2017 – 2018 data (low sunspot number)

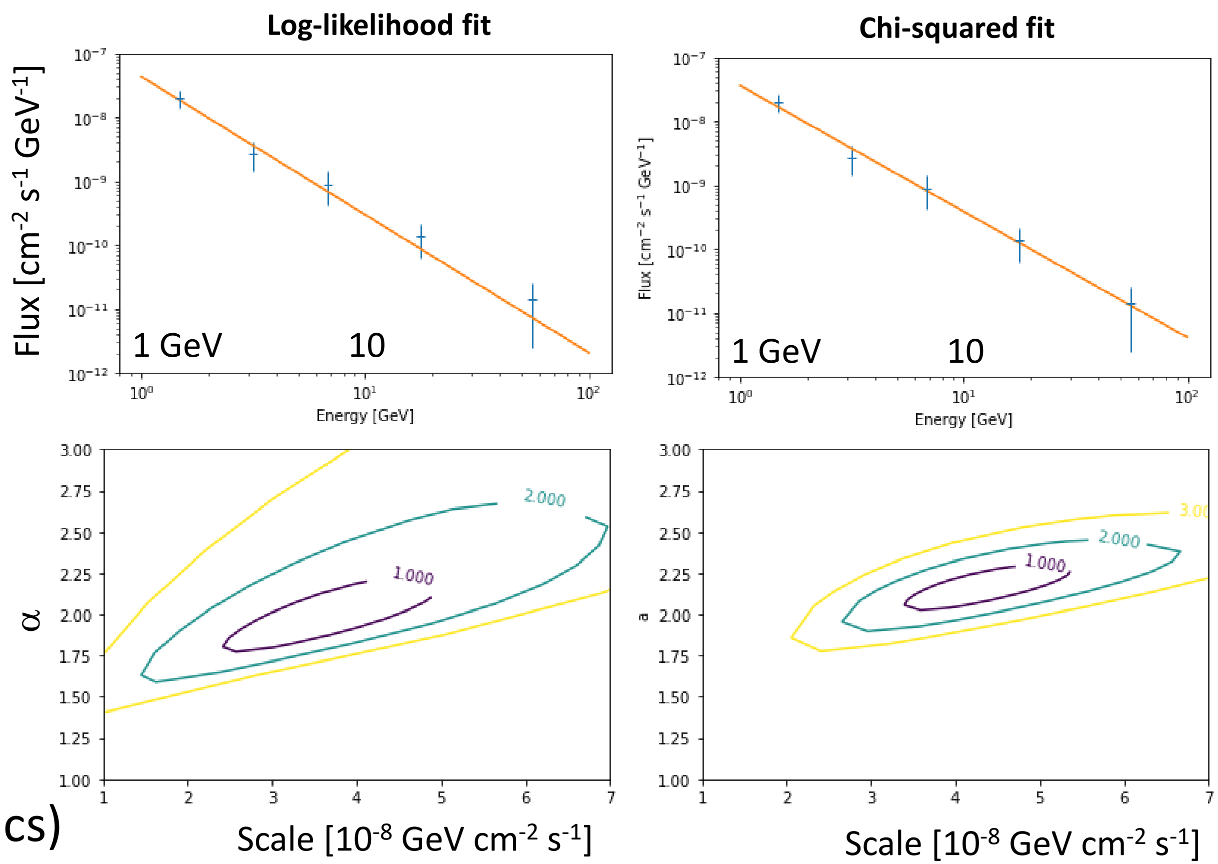


CALET spectral fit

Preliminary

- Preliminary flux calculated and a power law ($dN/dE \propto E^{-\alpha}$) was fit
  - CAVEAT: No treatment of the IC flux is taken into account (for now)

- Chi-squared fitting
  - Scale: $(3.6 \pm 1.2)\times10^{-8}$
  - Index: (1.97 ± 0.22) (error statistical only)
- Likelihood fitting
  - Scale: $(4.3 \pm 1.1)\times10^{-8}$
  - Index: (2.16 ± 0.14) (error statistical only)
- Fermi2011 results
  - Index: (2.11 ± 0.73) (includes full systematics)



Summary

- CALET is monitoring the gamma-ray sky above 1 GeV for more than 4 years since 2015.
- CALET detects the Sun in GeV gamma rays significantly over the background signal
  - Events from the 48-month dataset clearly shows excess toward the Sun above 1 GeV
  - Power-law spectral fit is consistent with Fermi-LAT (Tang et al. 2018) continuum
  - Dip at 30-50 GeV not detected in CAL analysis, but not confidently ruled out
  - Continued accumulation of statistics in Solar minimum