
# WP4: *Fermi*-LAT DATA ANALYSIS

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News General Meeting

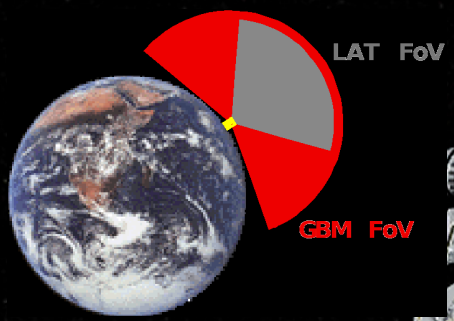
# The *Fermi* Space Telescope

## Gamma-ray Burst Monitor (GBM)

- 12 NaI and 2 BGO detectors
- Energy range: 8 keV–40 MeV

## The Large Area Telescope (LAT)

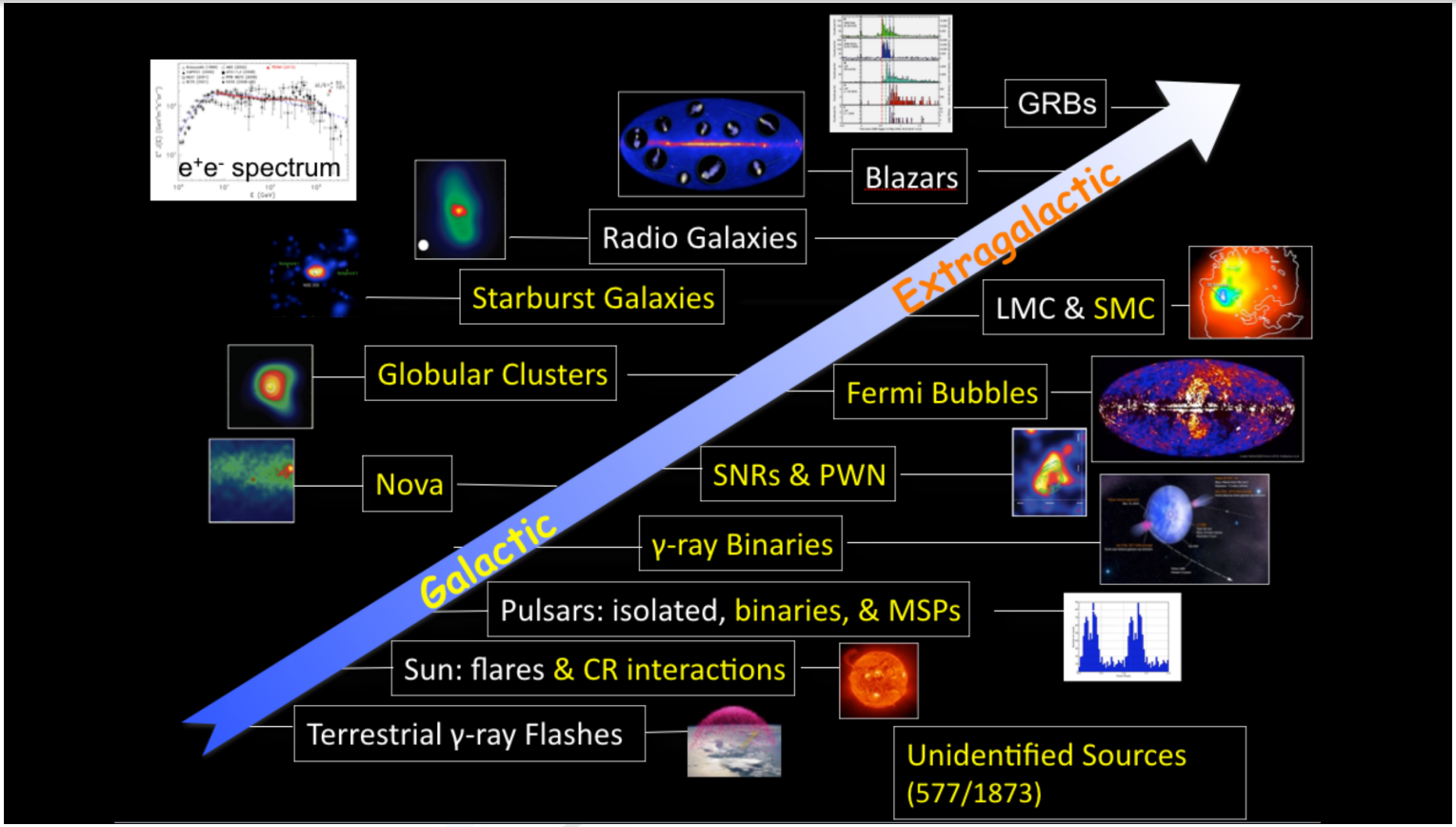
- Pair conversion telescope
- Energy range: 20 MeV–> 300 GeV
- Large field of view ($\approx$ 2.4 sr): 20% of the sky at any time, all parts of the sky for 30 minutes every 3 hours




## LAT key features

- Good energy resolution (<15% for E>100 MeV)
- Good point spread function (<1° for E>1 GeV)
- Large effective area (~8000 cm$^2$ on-axis for E>1 GeV)

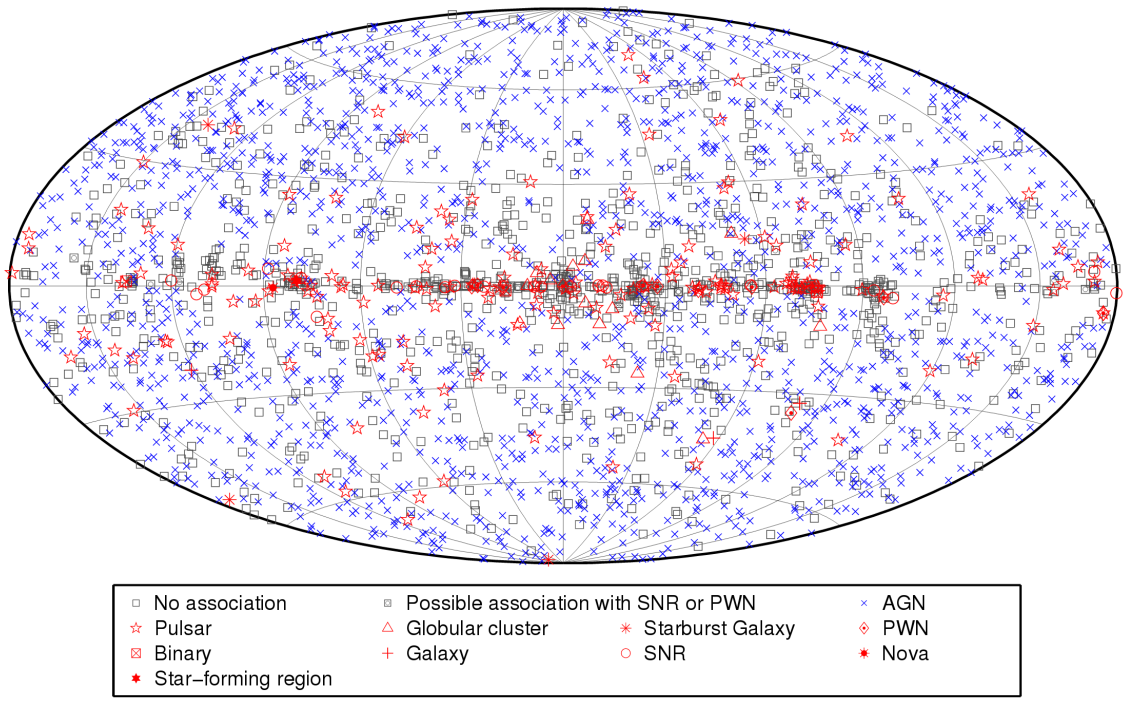
# *Fermi*-LAT SCIENCE MENU



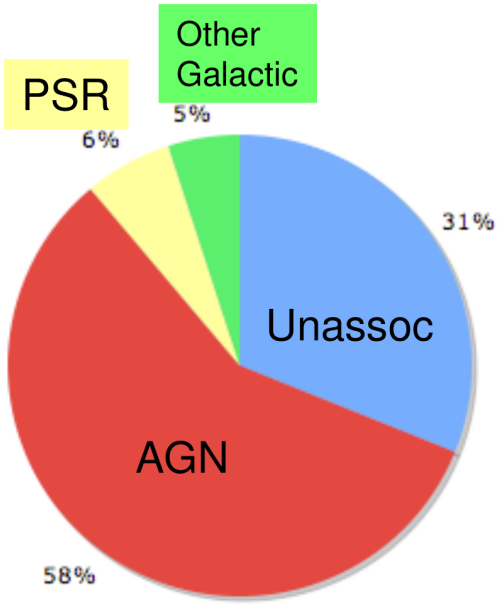

WP4: Focus on four topics

- *Fermi*-LAT source catalog (4FGL)
- WIMP dark matter searches
- Cosmic-Ray Electron science
- Electromagnetic counterparts to gravitational wave events

# The 3$^{th}$ *Fermi* Gamma-Ray Source List




Acero et al 2015, ApJS 218, 23



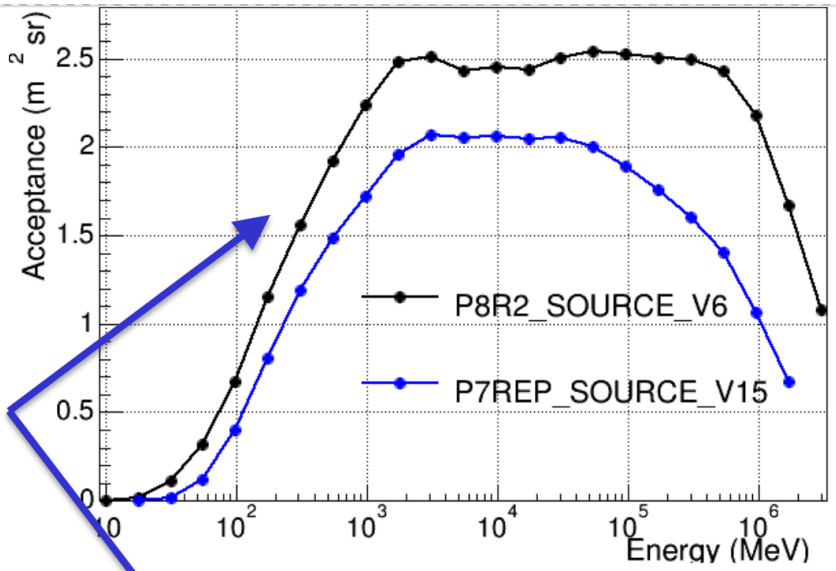

**3FGL**
(3033 sources)

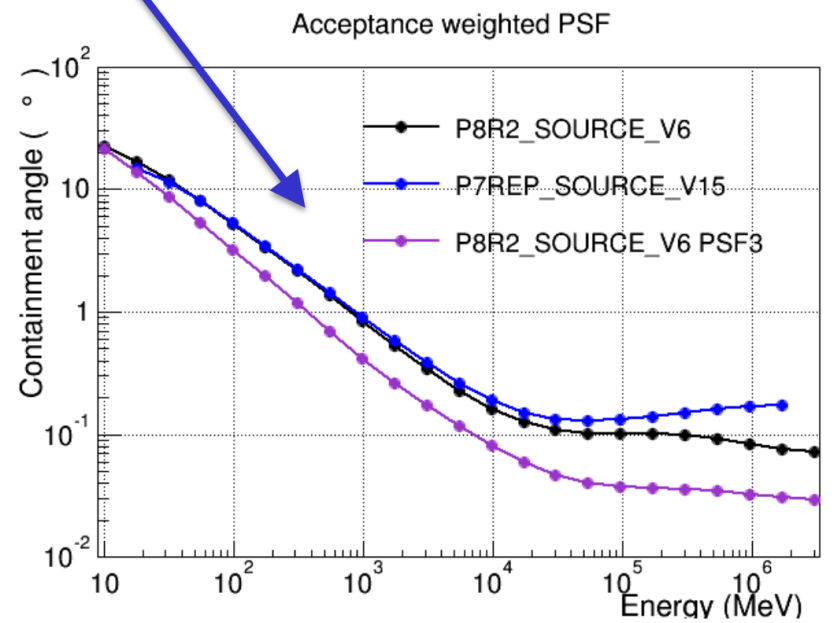
- 3FGL has 3033 gamma-ray sources seen by the LAT at energies above >100 MeV in the first 4 years of the mission
- Catalog reports position, significance, association, basic SED and light curve for each source

# The 4th *Fermi* Gamma-Ray Source List

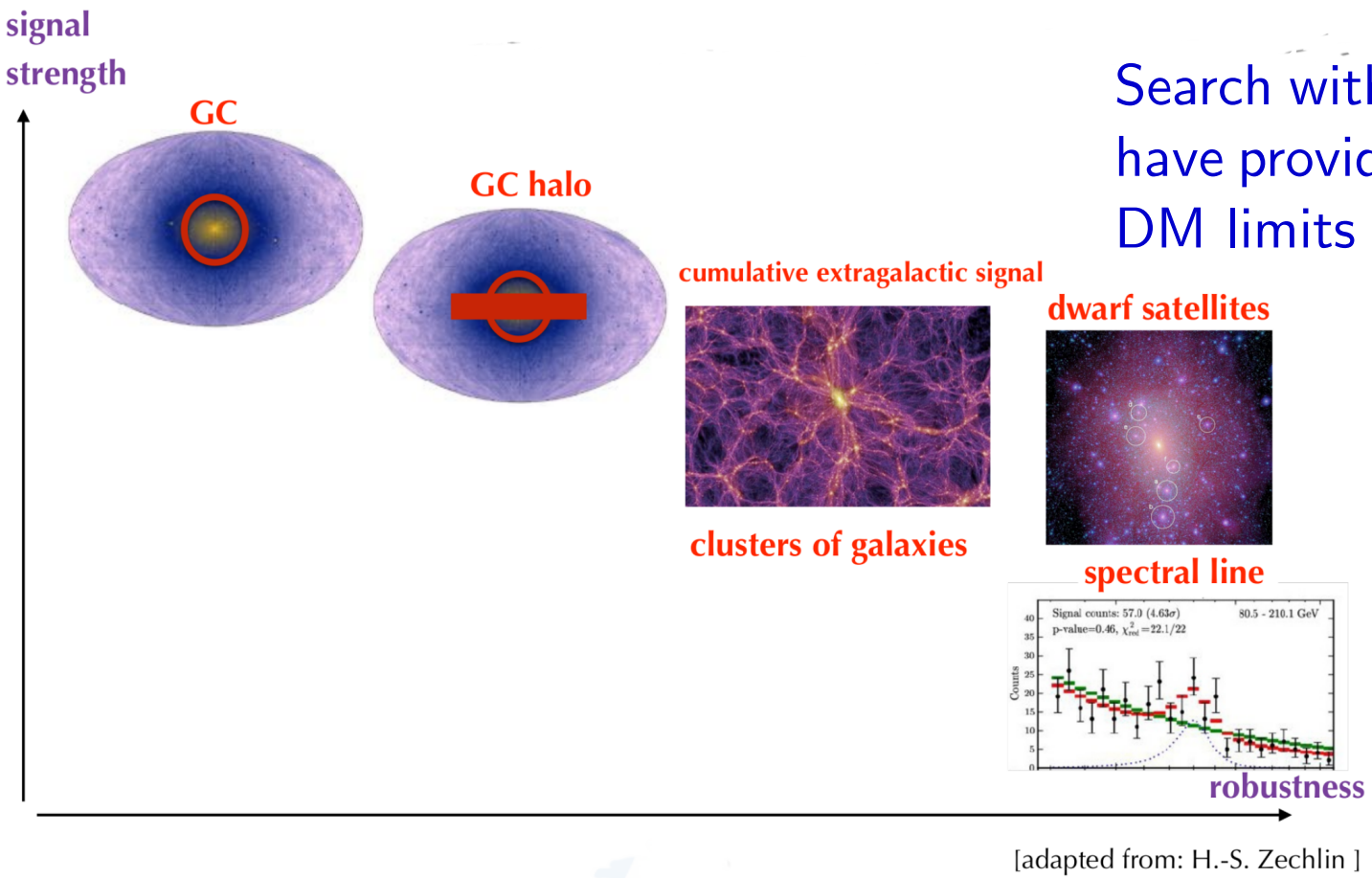
WP4 team will work on the 4th *Fermi* Gamma-Ray Source List (4FGL)

- Follow-up unassociated sources
- Deeper and better data/calibration
  - 3FGL was based on Pass7
  - 4FGL will use Pass8
- Update underlying interstellar emission model
- Look for variable sources
- Based on 8 years of data



# WIMP DARK MATTER SEARCHES



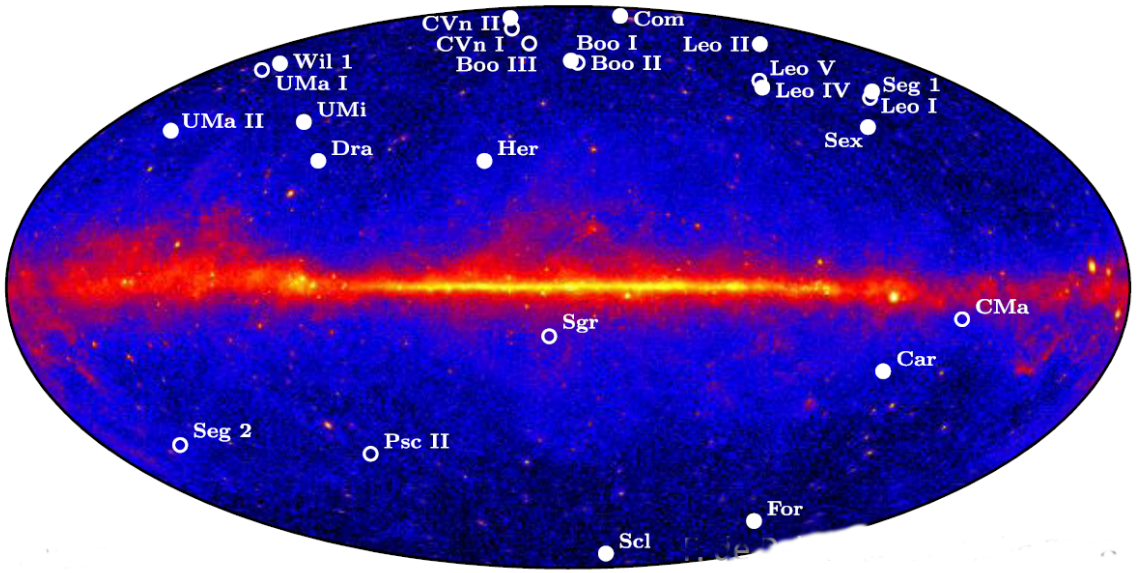

Search with dwarf satellites have provided the strongest DM limits to date!

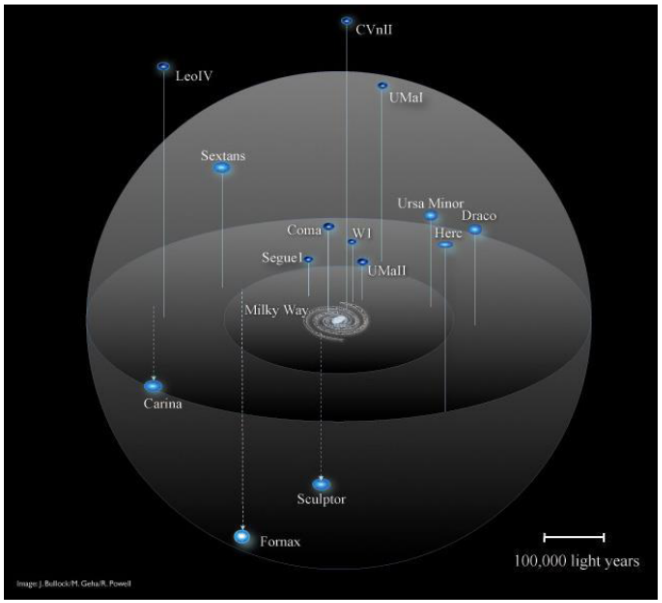
[adapted from: H.-S. Zechlin ]

- *Fermi*-LAT team has performed several dark matter searches over a wide range of astrophysical targets
- WP4 team will contribute in the development of the analysis framework
  - Applying to new targets such as the dwarf galaxies found by DES

# Dark matter searches in dSph Galaxies

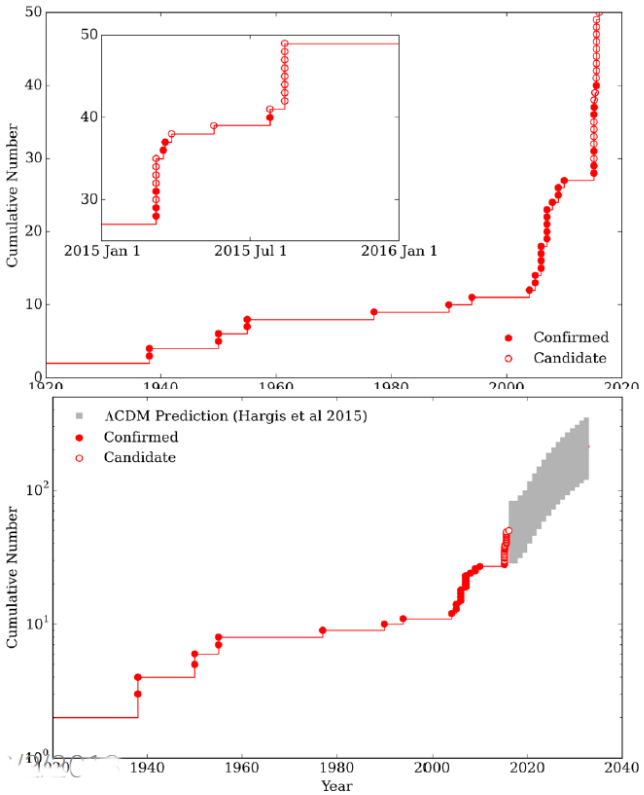
- dSph Galaxies are the cleanest target for DM searches:
  - DM-dominated (1000:1)
    - Mostly old stars
    - Few gamma-ray emitters (pulsars, SNRs)
    - Little gas content
  - often high latitude ➔ low diffuse background
  - nearby (<250 kpc)
  - many! (50+) ➔ allows for joint analyses

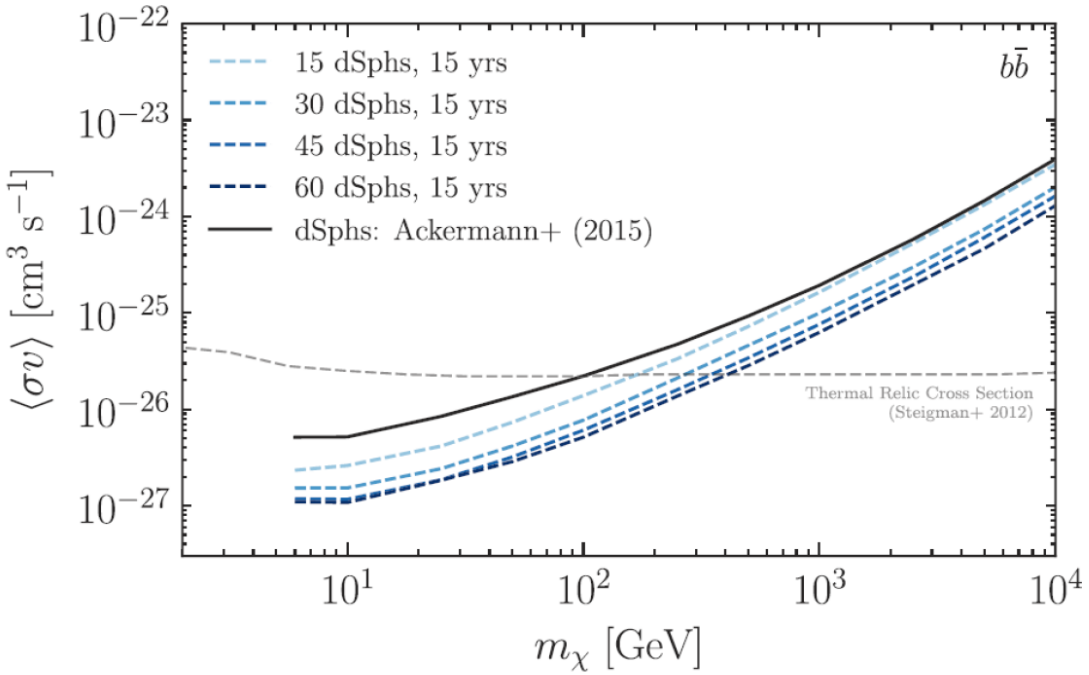


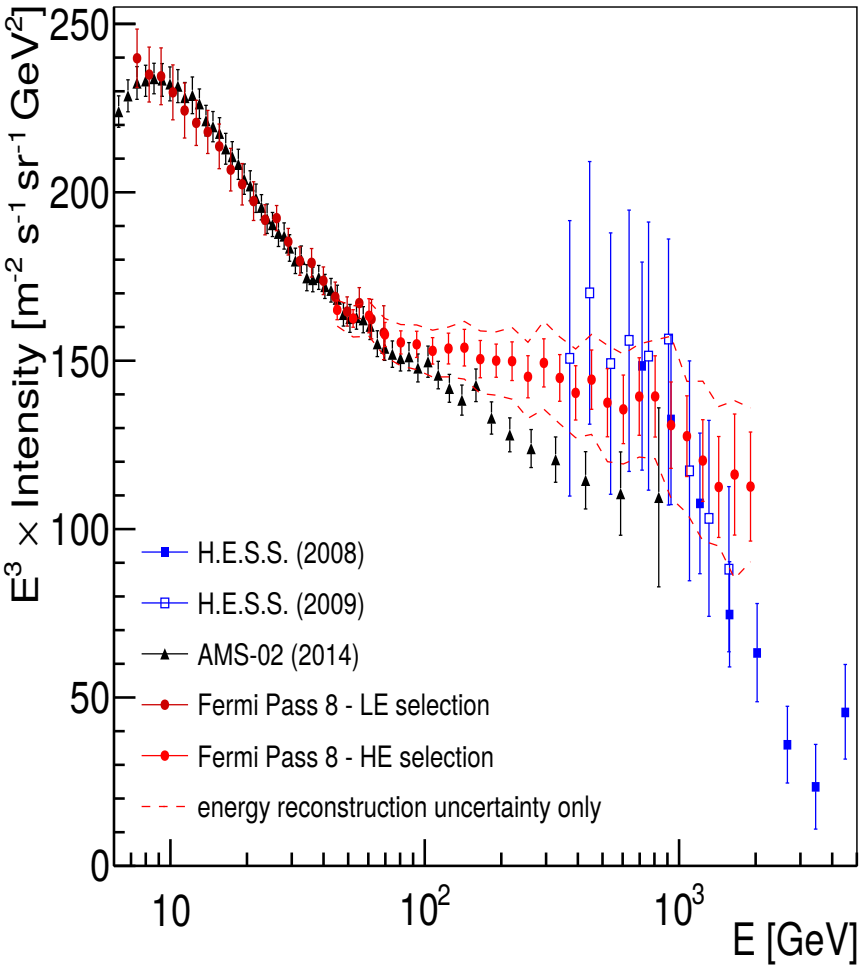
# Dark matter searches in dSph Galaxies

- dSph Galaxies are among the most promising target for future DM searches
  - Discovery of new dSph Galaxies
    - ~20 new targets from the dark energy survey (DES)
      - Waiting on spectroscopic follow-up for J-factors
    - Even more with the upcoming LSST survey
  - Increased statistics
- Can reach thermal relic cross section up to DM masses >100 GeV
  - For further details see Phys. Rep. 636 (2016), 1-46



# Cosmic-Ray Electron (CRE) science

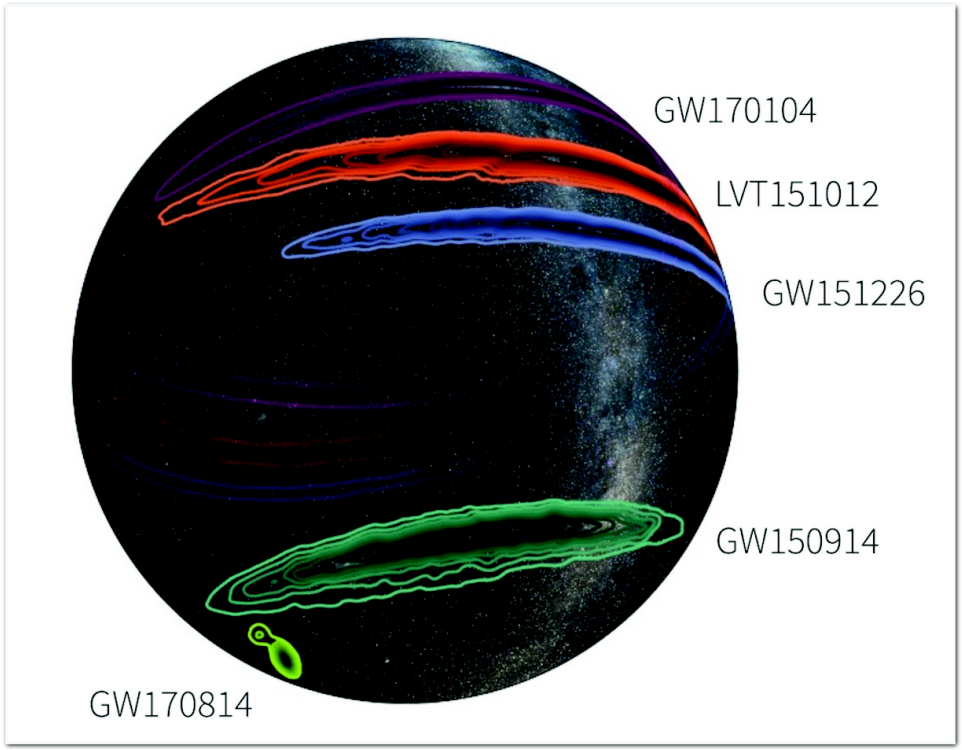



Phys. Rev. D 95, 082007

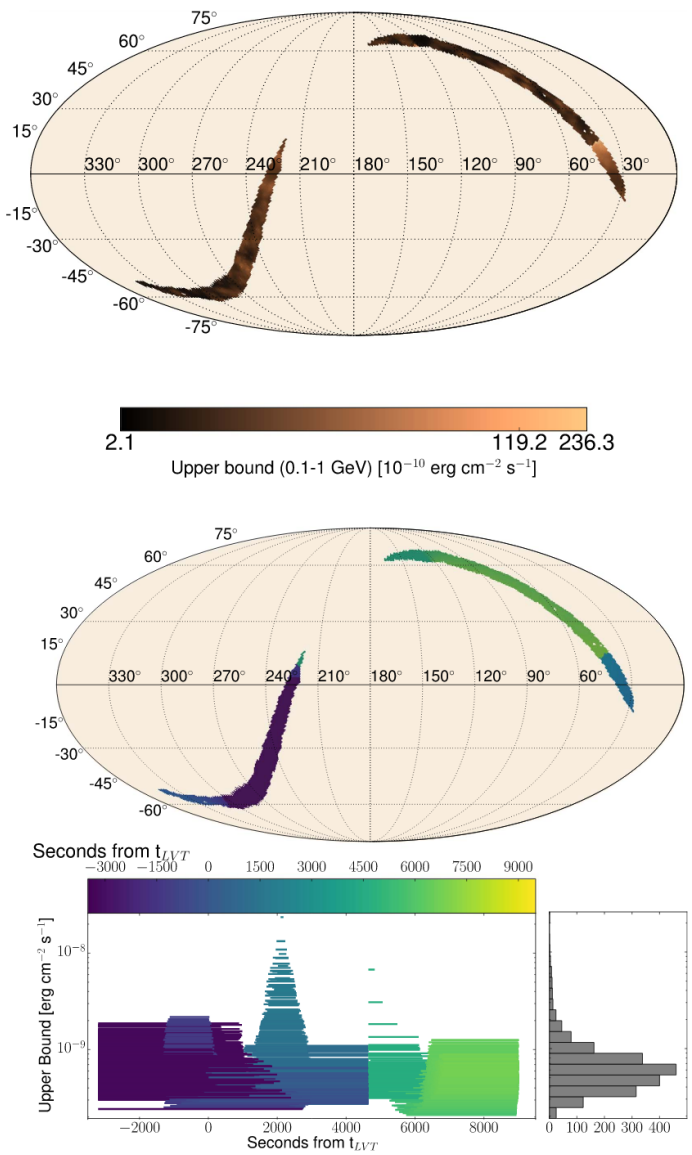
- Cosmic-ray $e^+ + e^-$ spectrum from 7 GeV to 2 TeV measured by *Fermi*-LAT
  - First space-based instrument to explore the region above 1 TeV
  - High-energy cutoff excluded up to 1.8 TeV at 95% CL
- Thanks to large amount of statistics we can now perform anisotropy searches to help constrain existence of local CRE sources
- WP4 team has contributd in the effort of the spectral and anisotropy studies of the CRE with *Fermi*-LAT

# Following up on LIGO events

- **6 GW events announced by the LIGO/VIRGO Collaboration:**
  - **5 BH- BH: GW150914, LVT151012, GW151226,GW170104, GW170814;**
  - **1 NS-NS: GW170817;**
- **BH-BH mergers are not expected to produce EM radiation.**
- **NS-NS: predicted (and confirmed) to have EM radiation.**
- **General strategy for Fermi-LAT searches at high-energy:**
  - **Automated full sky searches of transients;**
  - **Specific searches in the LIGO contours;**
  - **Specific followups of detected counterparts;**
  - **All done automatically in pipelines to quick alert the community;**



# EM follow-up to gravitational wave events



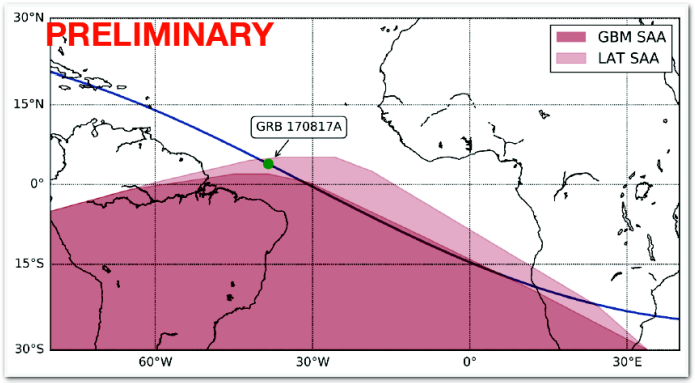

Racusin et al. 2017, ApJ, 835, 1

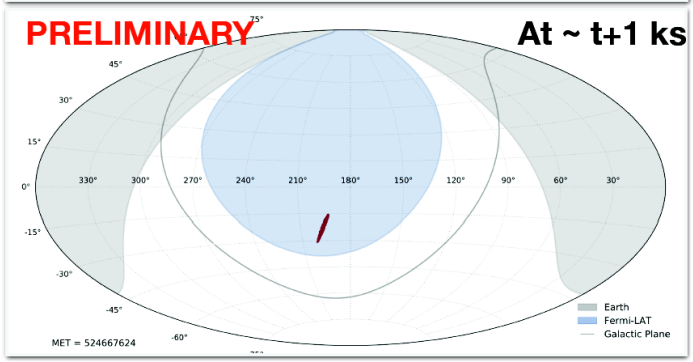
- *Fermi*-LAT is continuously observing the entire sky
- Covering localization probability maps of gravitational wave events within hours of their detections
- In the case of a detection of an EM counterpart, the LAT could substantially reduce the localization uncertainty
- Facilitating follow-ups at other wavelengths
- Five papers published so far
- Sixth submitted to ApJ on follow-up of GW170817
  - Paper on archive arXiv:1710.05450

# EM follow-up to gravitational wave events


- WP4 team has helped to set up pipeline to automatically perform dedicated analyses to search for electromagnetic counterparts to gravitational wave events in Fermi-LAT data
  - The pipeline is triggered by the arrival of a LIGO/Virgo Gamma-ray Coordinates Network (GCN)
- Team will help in rapidly distributing GCN notices on potential EM counterparts to the community

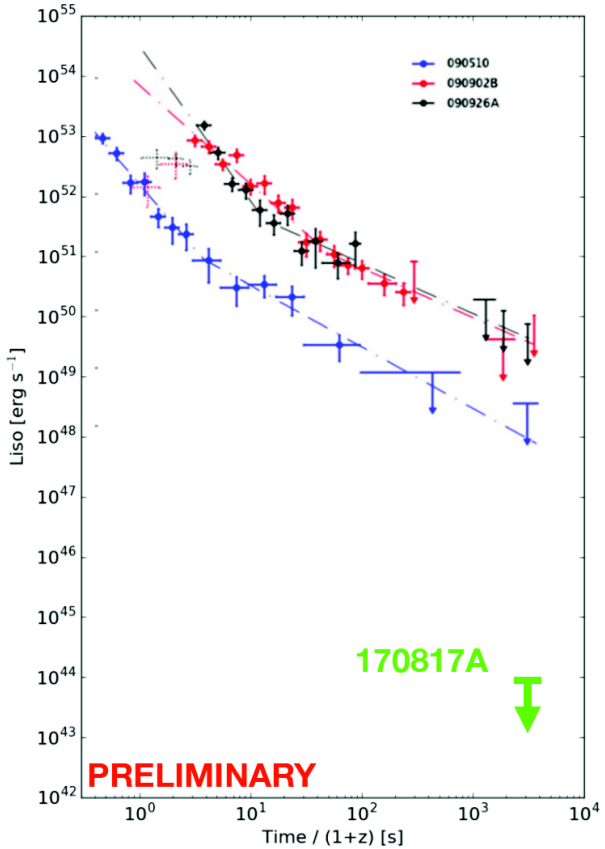
# GW170817/GRB170817A



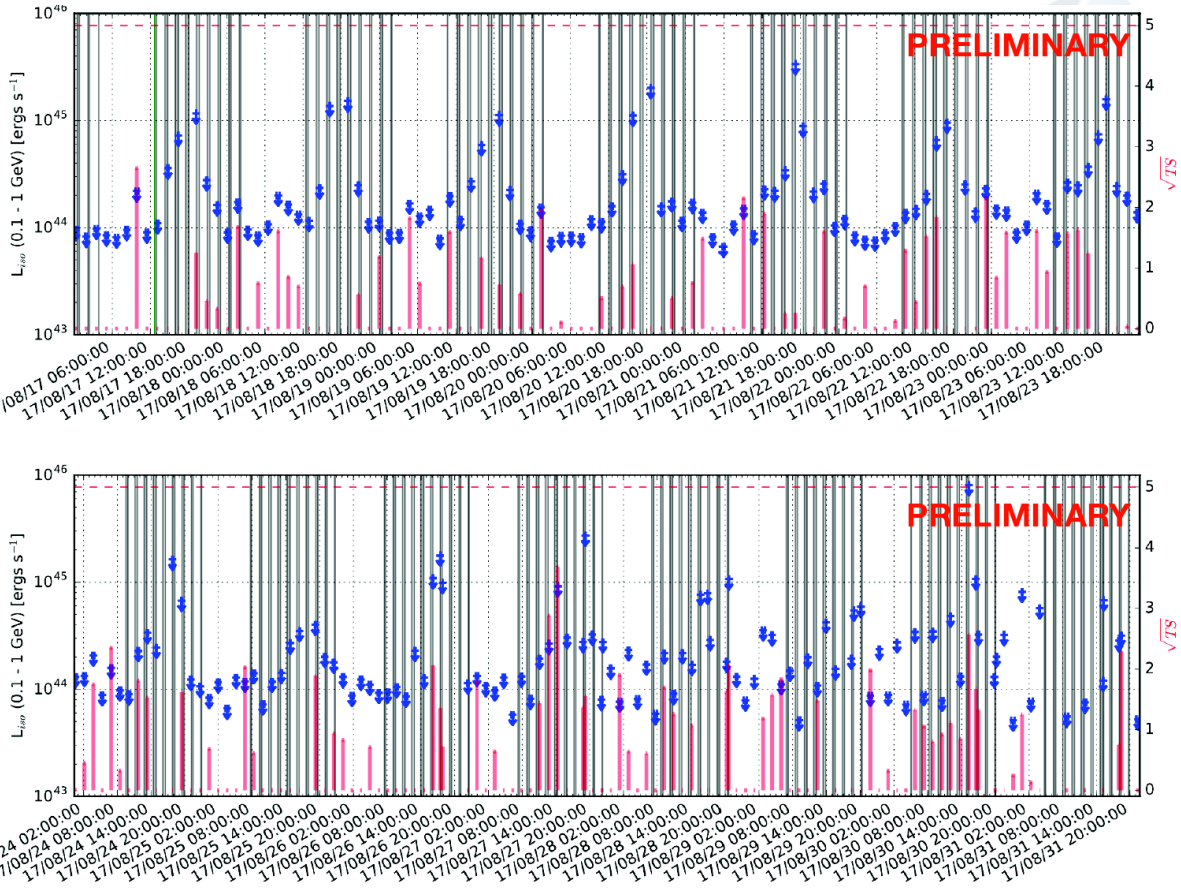

- **The LAT and the GBM do not collect data when in the SAA**
  - **For different instument requirements, the SAA definition for the LAT is slightly larger (14%) than the GBM one;**
  - **At the time of the GW event (and GBM trigger), the LAT was in the SAA;**
  - **We observe the entire region between $t_{GW}$+1153 – $t_{GW}$+2017;**
  - **Upper bound (0.1–1 GeV):**
    - **$F < 4.5 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$**
  - **At the distant of GW170817:**
    - **$L_{iso} < 9.3 \times 10^{43}$ erg s$^{-1}$**

★ **Very strong constrain on the luminosity of GRB170817A at high energy**



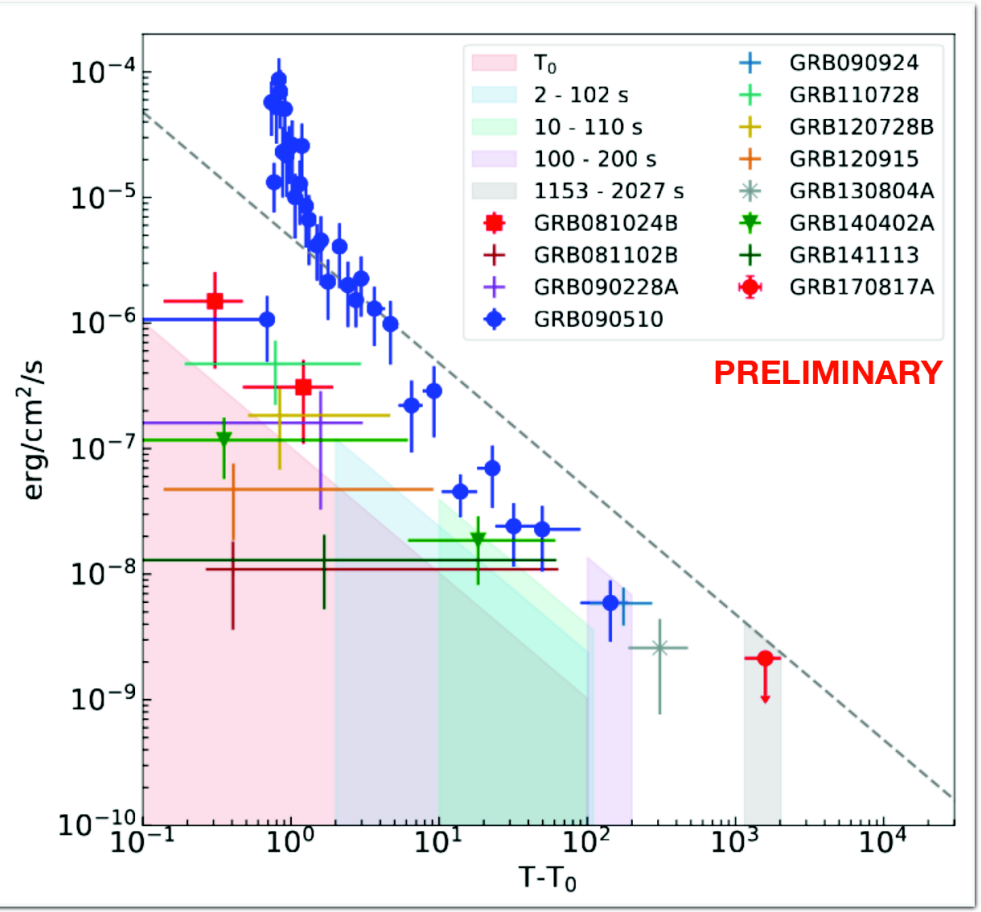
# Spare slides

# GW170817/GRB170817A LONG TERM MONITORING



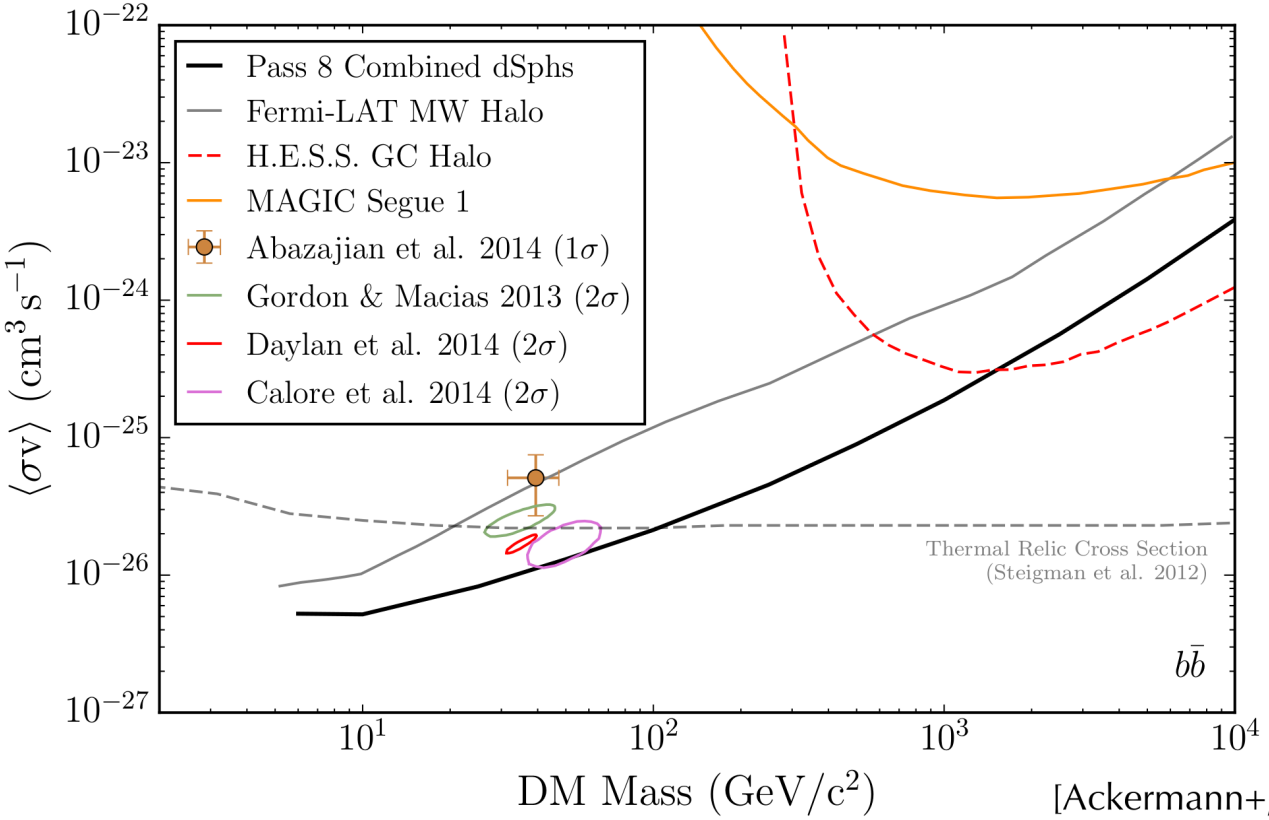

- **Given the continuous evolution of the transient, we are keeping the source monitored;**
- **No significant excess at later time:**
  - **$F < 9.7\times10^{-11}$ to $3.7\times10^{-8}$ erg cm$^{-2}$ s$^{-1}$**
  - **$L < 2.1\times10^{43}$ to $8.1\times10^{45}$ erg s$^{-1}$**
- **On the life time of the mission (9 years):**
  - **$F < 1.32 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$**
  - **$L < 2.9\times10^{41}$ erg s$^{-1}$**

# Fermi-LAT sensitivity to SGRBs




- **LAT detected GRBs exhibit a long lasting high-energy emission (lasting ~200 seconds for SGRBs);**
- **We estimate the average flux a SGRB would need to be detected by the LAT (50% of the time with TS≥25)**
  - **In a 100 s exposure starting at $T_0$, $T_0$+2s, +10, +100 (typical for LAT detected SGRBs)**
  - **Between $T_0$+1153 and $T_0$+2027 (as GRB170817A);**
- **LAT detected SGRB consistent with our significance estimation;**
- **Even the brightest SGRB detected by the LAT (090510) would have not been detected if the observation had started at ~1000 seconds;**
- **We need to start observing a burst within ~100s to really have a chance of seeing it;**
- **Rate estimation:**
  - **LAT sees 23% of the all sky SGRBs within 100 s (either a detection or upper bound)**
  - **LAT detects 5% of all GBM-detected SGRB**
  - **Assuming 1 (2) GW+SGRB events per year : 5% (10%) probability to detect it in the LAT**
  - **Modifying the observing profile (re-pointing every SGRB within 100 seconds): 7% (13%)**

# WIMP DARK MATTER SEARCHES




[Ackermann+, 1503.02641]

- *Fermi*-LAT team has performed several dark matter searches over a wide range of astrophysical targets
- Using the joint likelihood to combine info from 15 dSphs
- One of the strongest DM limits to date