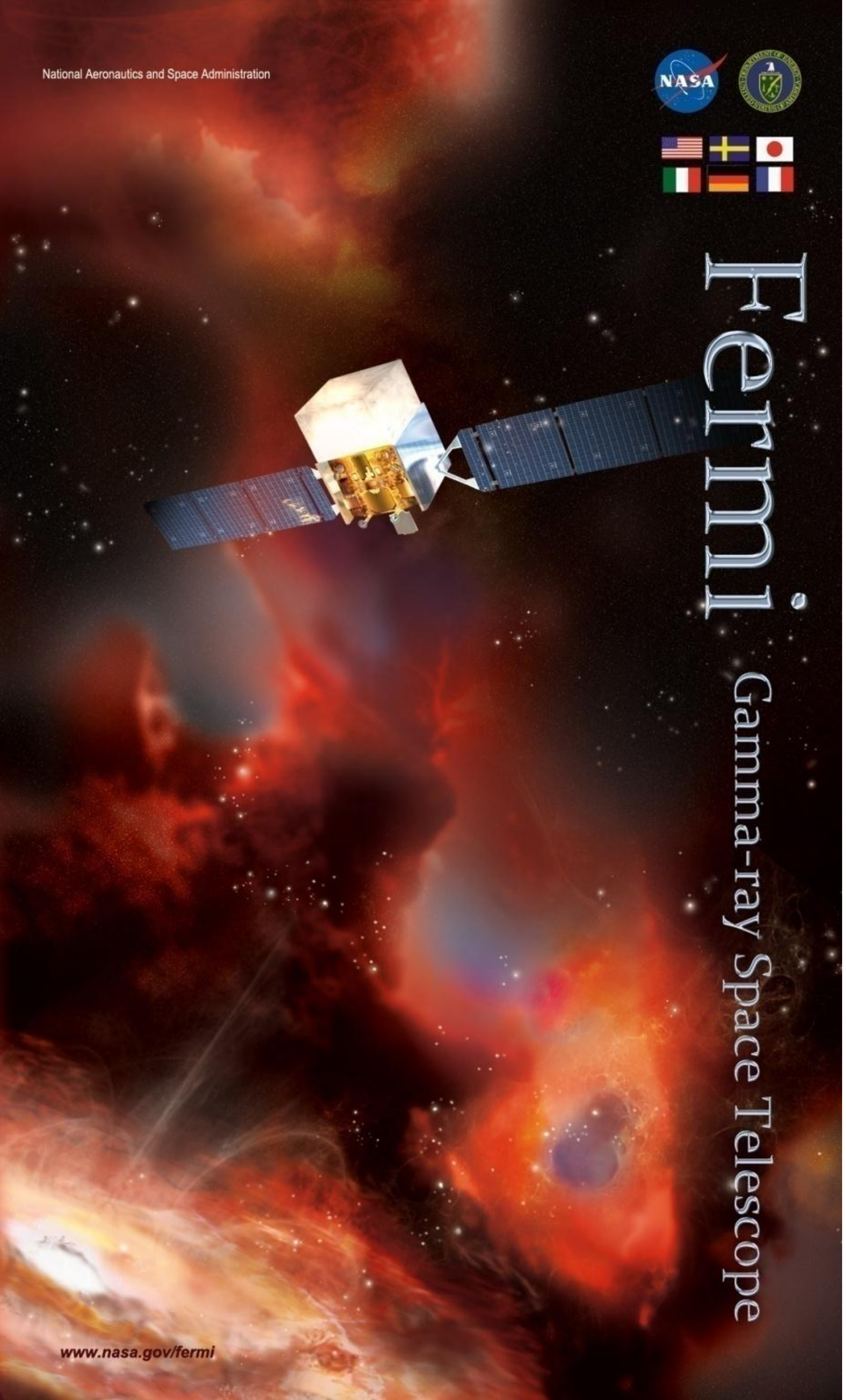


fermi
Gamma-ray
Space Telescope

Results from FERMI

Francesco de Palma

INFN Bari

On behalf of the Fermi-LAT Collaboration

Les Rencontres de Physique de la Vallée d'Aoste · 27.03.2012

Outline

- Schematic description of the Fermi satellite and its modes of operation.
- 2-year Point Source Catalog (2 FGL).
- Skymap above 10 GeV.
- Some results on galactic sources.
- Dark matter indirect search using photons and CR.
- Electrons and positrons spectra.
- Conclusions and future prospective.

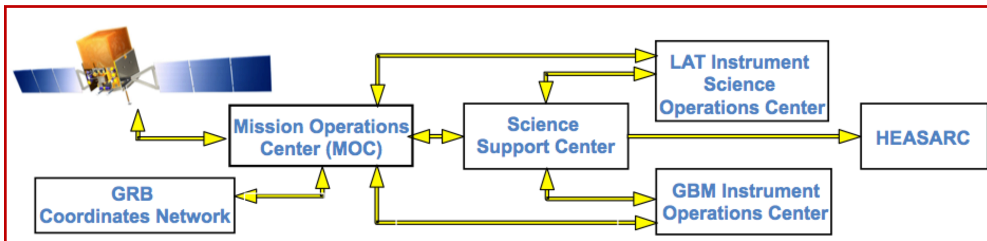
Most LAT team publications are not cited in this talk; complete listings and links are here: https://www-glast.stanford.edu/cgi-bin/pubpub

The Fermi data are public in the website: http://www.nasa.gov/fermi

Fermi Telescope

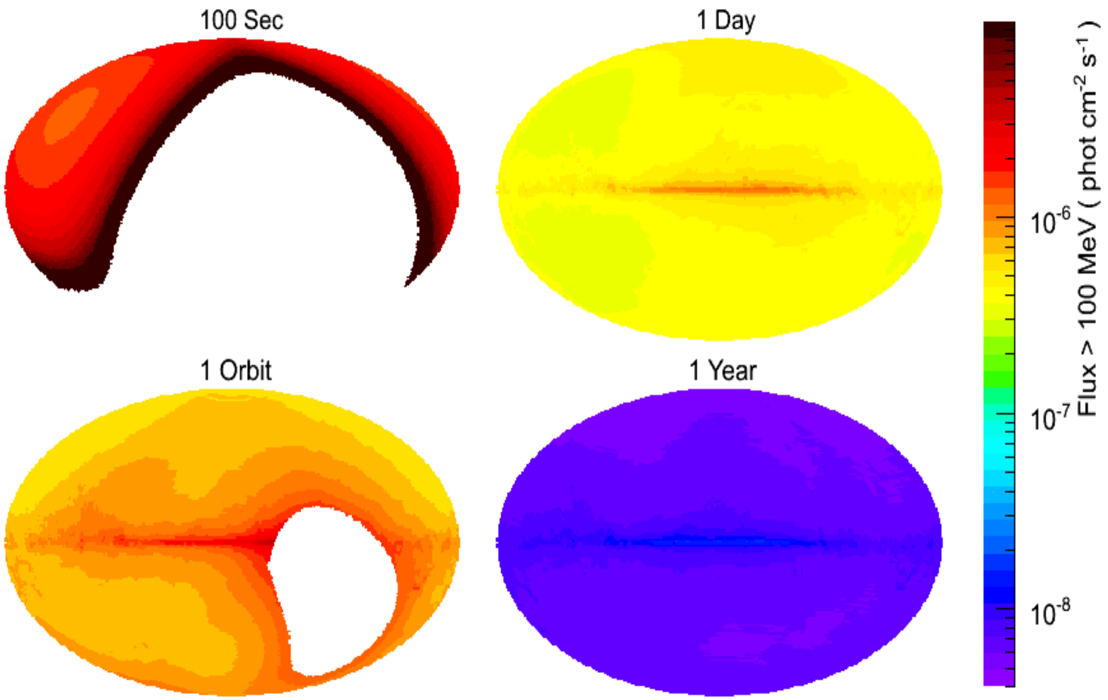
- Fermi Large Area Telescope (LAT) and Gamma-Ray Burst Monitor (GBM)

- Performance of Fermi LAT
  - Large FOV (>2.4 sr)
    - 20% of the sky at any instant;
  - Large effective area
    - Up to a total value of 0.8 m^2
  - Small dead time
    - Detailed light curve, time-resolved analysis
  - Every photon can be time-tagged
    - 1 ms accuracy
  - Wide energy coverage
    - From hundred of MeVs up to > 300 GeV
- Fermi GBM
  - Views entire unocculted sky
  - 12 NaI detectors [8 keV – 1 MeV]
  - 2 BGO detectors [200 keV – 40 MeV]

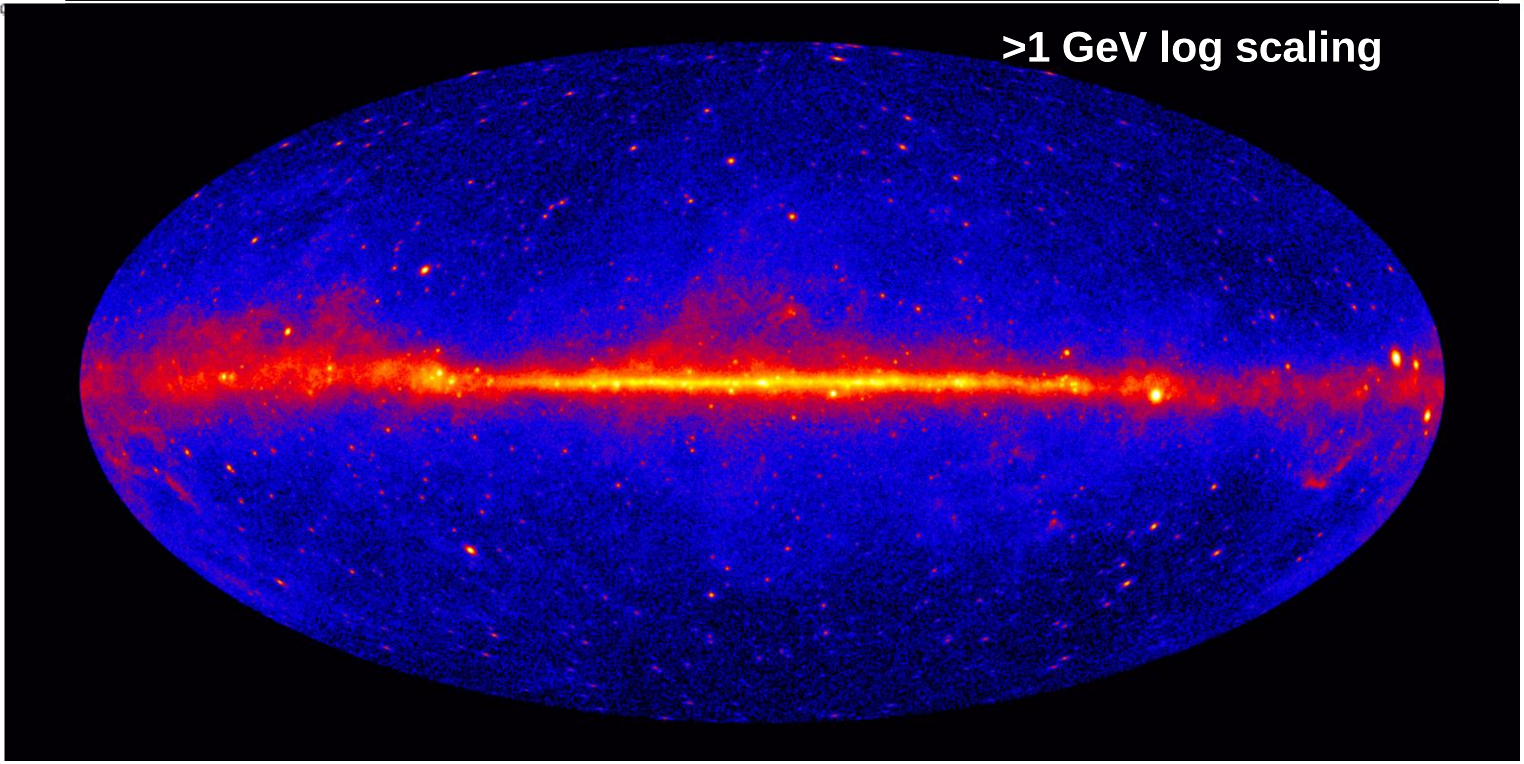


Operational Modes

- **Sky survey mode**
  - **Standard operation mode**
  - **View full sky every 2 orbits, i.e, every 3 hours.**
- **Targets of opportunity (ToO)**
  - **Autonomous repoint (GRBs)**
  - **Slew to keep ToO in FOV**

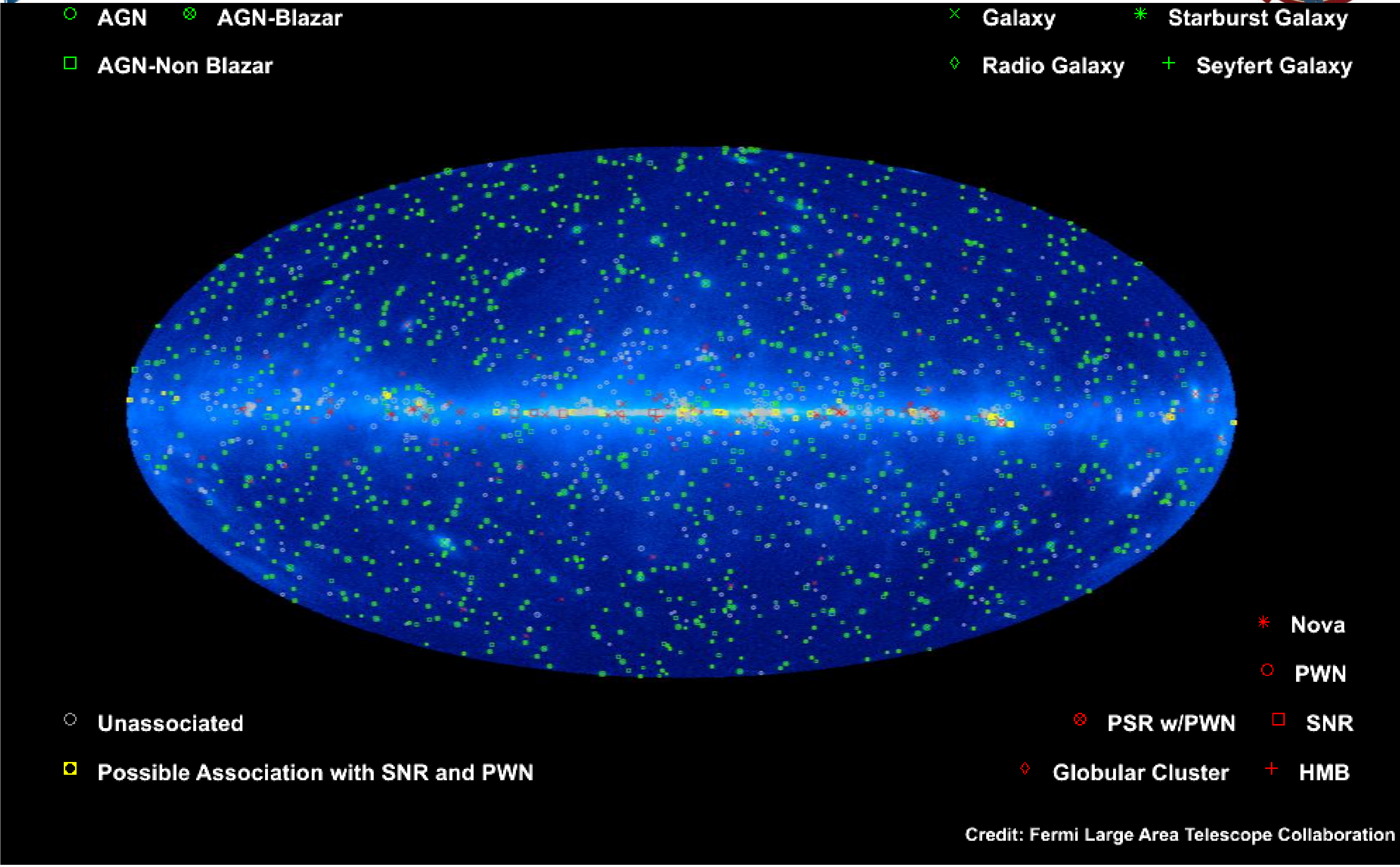


2FGL Analysis Inputs



- Objective: Detect and characterize every significant point source in the sky
- 24 months of data 100 MeV to 100 GeV, 47.7 Ms live time
- 35.7 M events over the whole sky (Pass 7 Source class γ-rays)
- Fairly uniform exposure (range factor ~1.5, ~5 $\times 10^{-7}$ km^2 sr yr)

FERMI LAT 2FGL Source Catalog



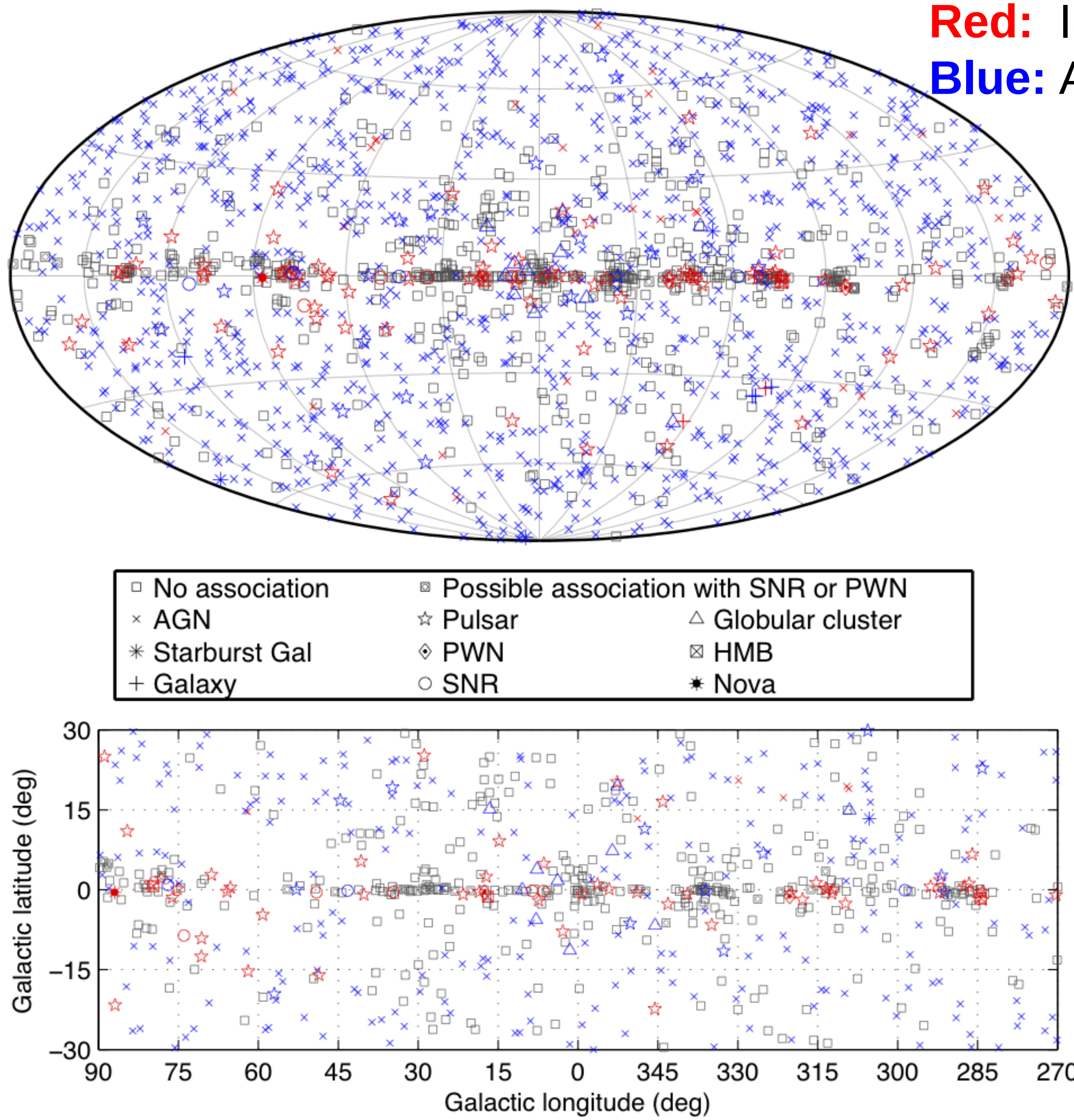
The Fermi LAT 2FGL Source Catalog

1873 sources (~4 σ significance threshold)

2FGL Catalog is available from the Fermi Science Support Center http://fermi.gsfc.nasa.gov/ssc

Red: Identified (127)

Blue: Associated (1043)



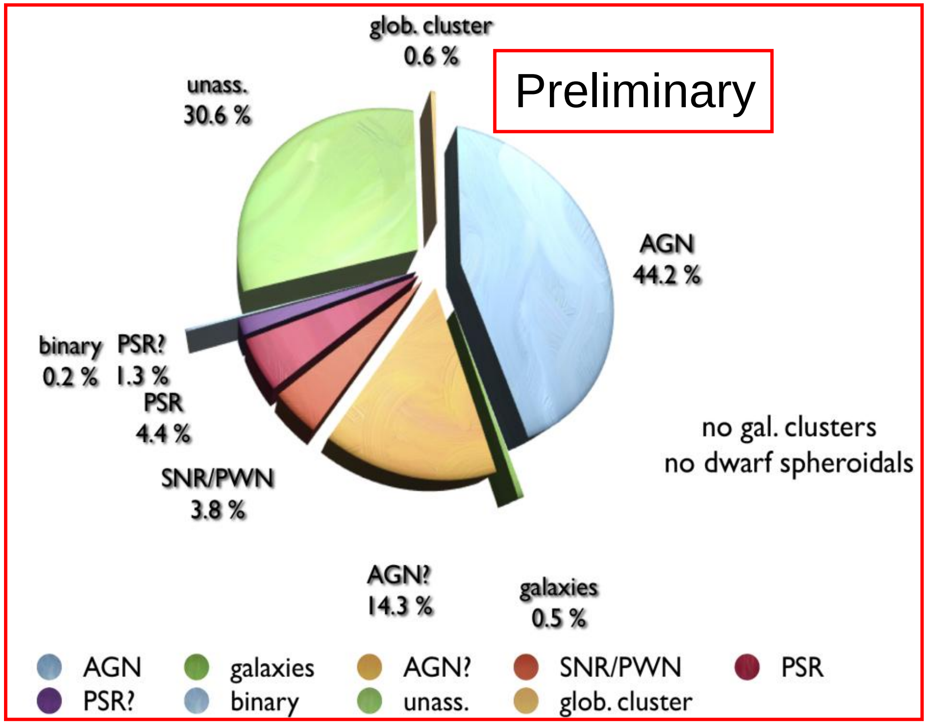
Various kinds of flags are inserted as:

- -Sources in regions with suspected errors in the diffuse emission model (162)
- -sources with properties very sensitive to the diffuse emission model
- -implausibly curved spectrum
- -poor location determination
- -possibly affected by the Sun.

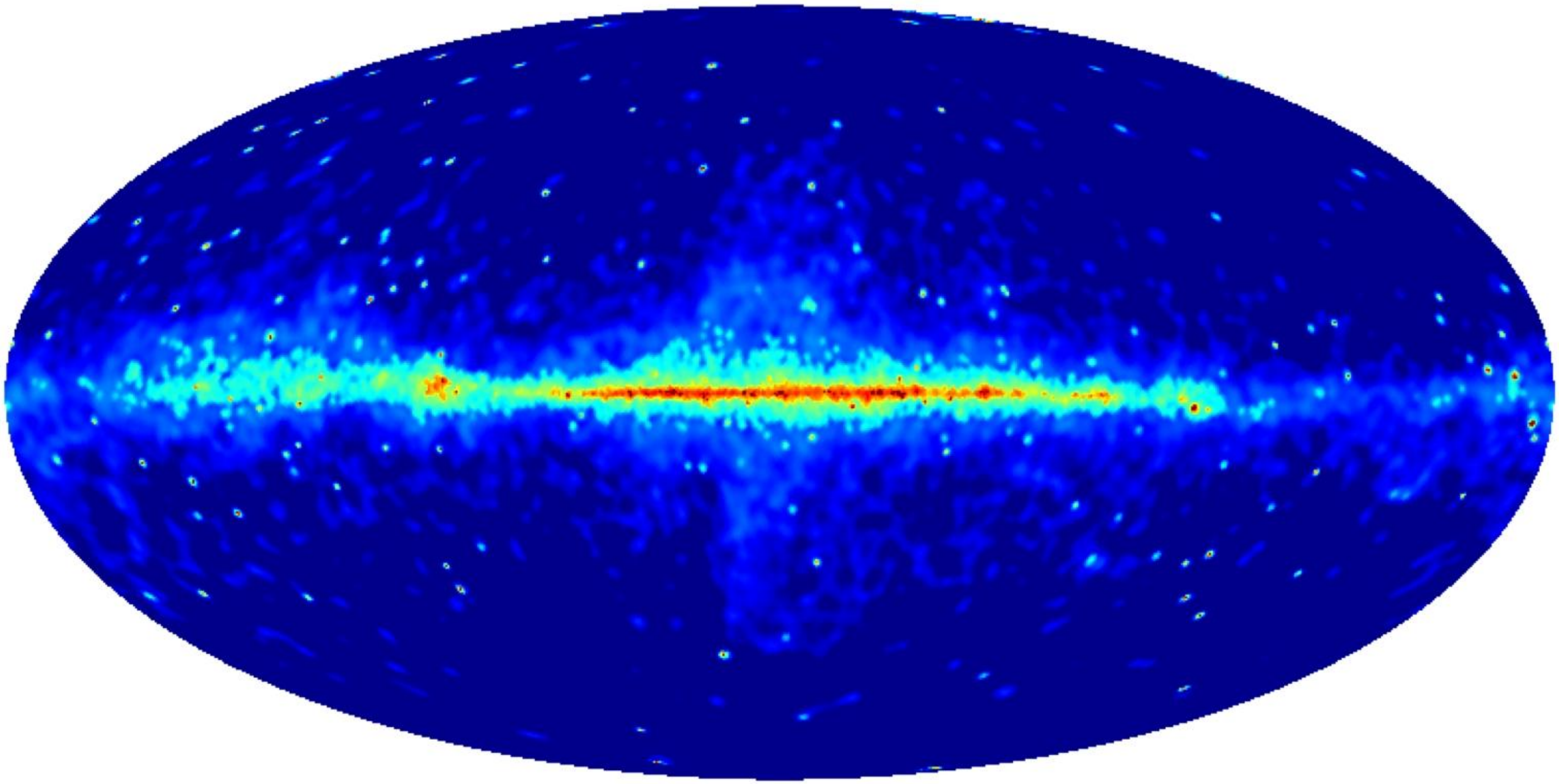
Summary of Source Classes in 2FGL

Table 5. LAT 2FGL Source Classes

Description	Identified		Associated	
	Designator	Number	Designator	Number
Pulsar, identified by pulsations	PSR	83	...	...
Pulsar, no pulsations seen in LAT yet	...	...	psr	25
Pulsar wind nebula	PWN	3	pwn	0
Supernova remnant	SNR	6	snr	4
Supernova remnant / Pulsar wind nebula	...	...	†	58
Globular cluster	GLC	0	glc	11
High-mass binary	HMB	4	hmb	0
Nova	NOV	1	nov	0
BL Lac type of blazar	BZB	7	bzb	425
FSRQ type of blazar	BZQ	17	bzq	353
Non-blazar active galaxy	AGN	1	agn	8
Radio galaxy	RDG	2	rdg	10
Seyfert galaxy	SEY	1	sey	5
Active galaxy of uncertain type	AGU	0	agu	262
Normal galaxy (or part)	GAL	2	gal	4
Starburst galaxy	SBG	0	sbg	4
Class uncertain	...	...	...	1
Unassociated	...	...	...	576
Total	...	127	...	1746



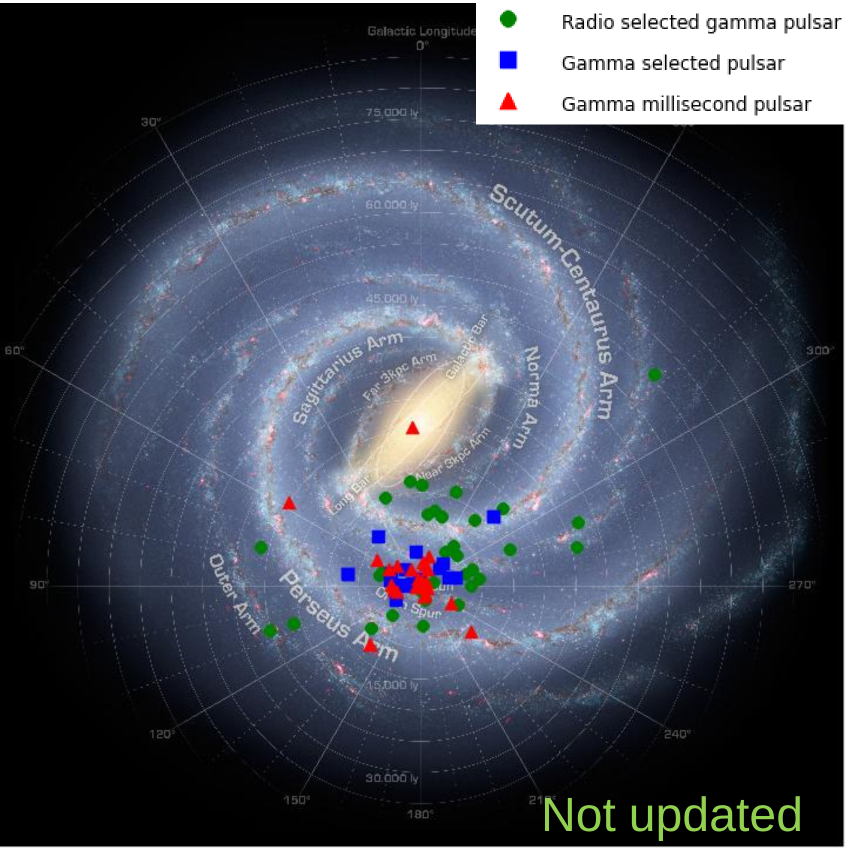
3 years smoothed count map above 10 GeV



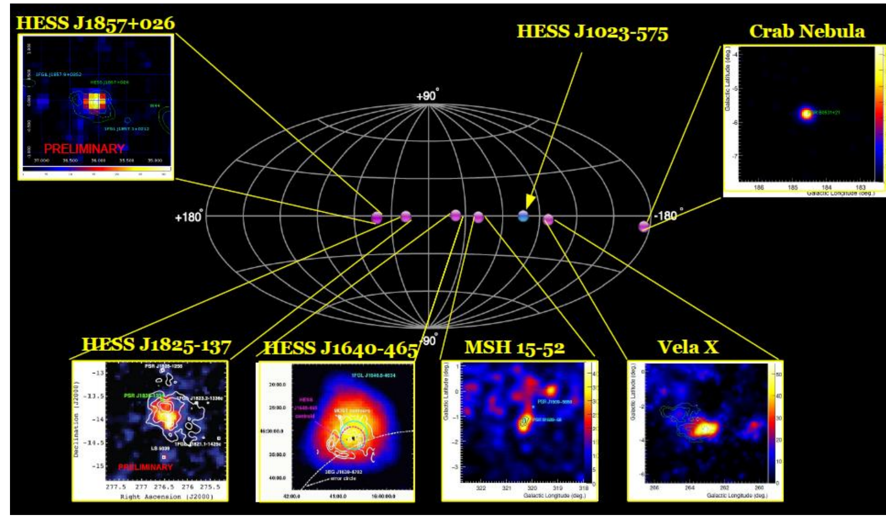
Fermi is starting to reveal large-scale regions of excess high-energy emission not predicted by interstellar emission models, including the “Fermi lobes” *(Su, Slatyer, Finkbeiner, 2010)* and other large scale hard-spectrum diffuse features. At this energies more than 500 sources have been revealed, and around 170 of those are still unassociated and are not observed at other energies.

Galactic sources of γ and CR

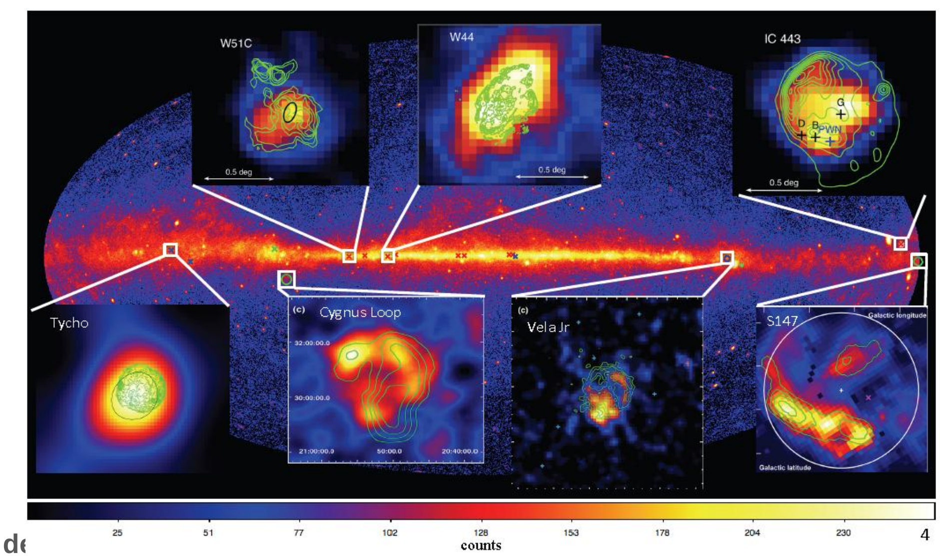
Pulsars map



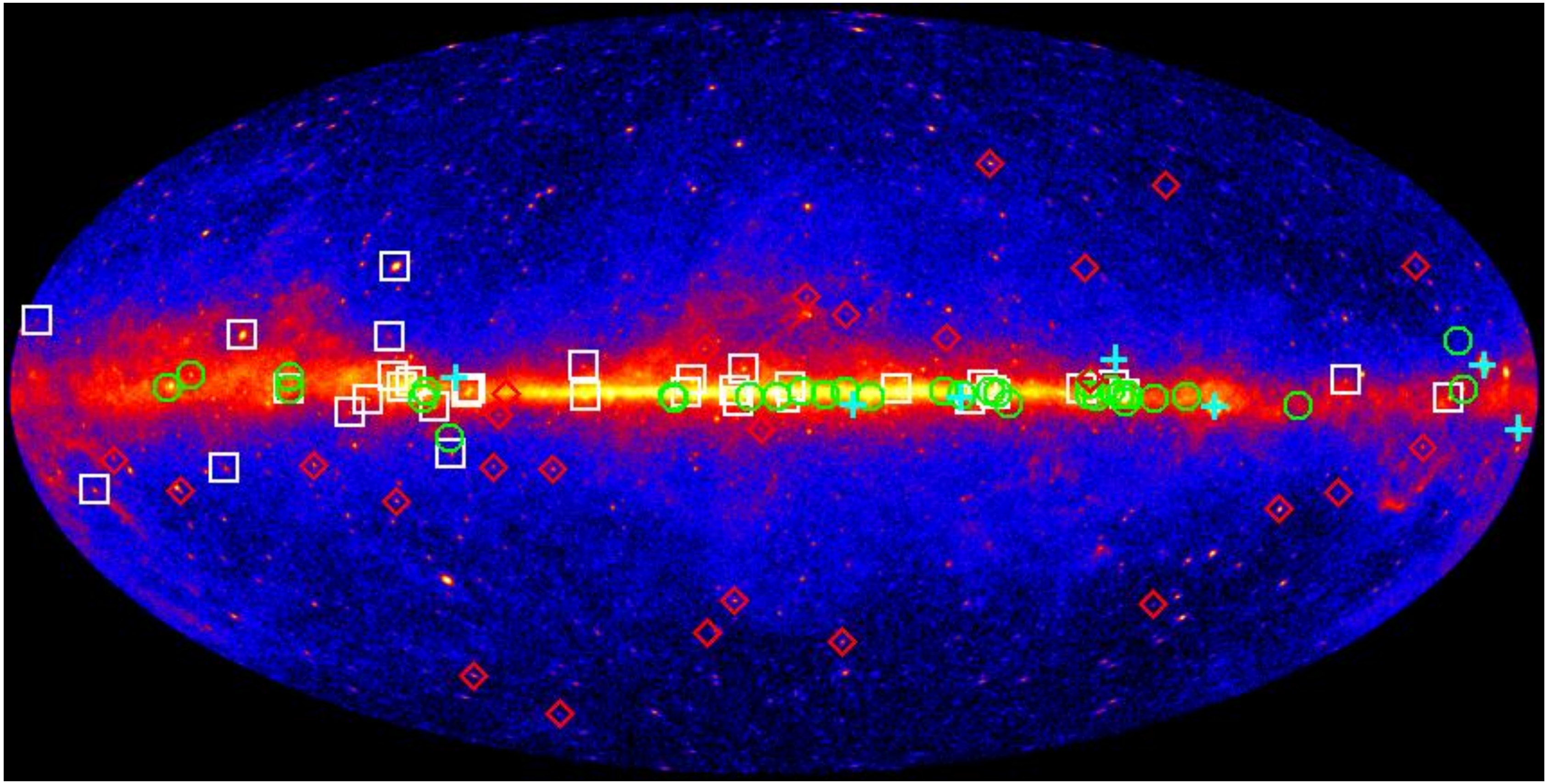
PWN grouped



SNRs grouped

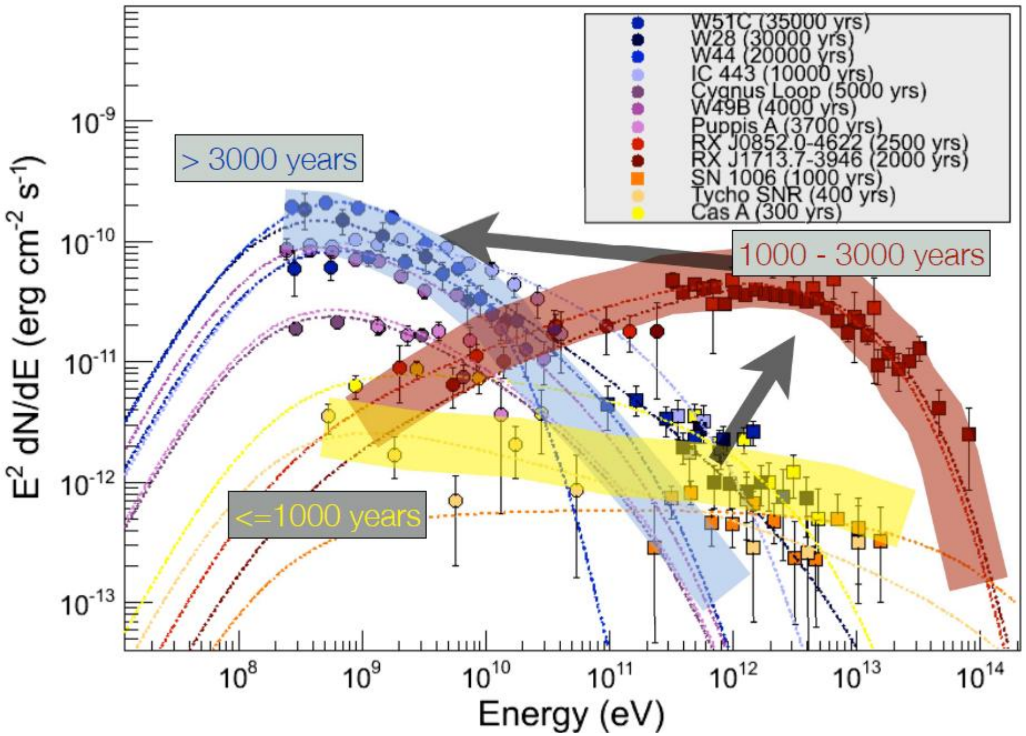


LAT pulsars



The 101 pulsars already found in the 36 month dataset. Red diamonds are MSPs, cyan crosses are CGRO pulsars, green circles are radio selected, non-recycled pulsars, and white squares are gamma-ray selected, non-recycled pulsars.

Fermi Detected SNRs



There are 16 SNRs already detected and 43 2FGL candidates (excluding PWNs, AGNs an PSRs) .The creation of a catalog using 3 years of data will help finding new associations and also help in :

- identify classes of γ-ray SNRs;
- study their temporal evolution;
- understand the role of environment.

Fermi: Dark Matter search strategy

Satellites

Low background and good source id, but low statistics

ApJ, 712, 147 (2010)

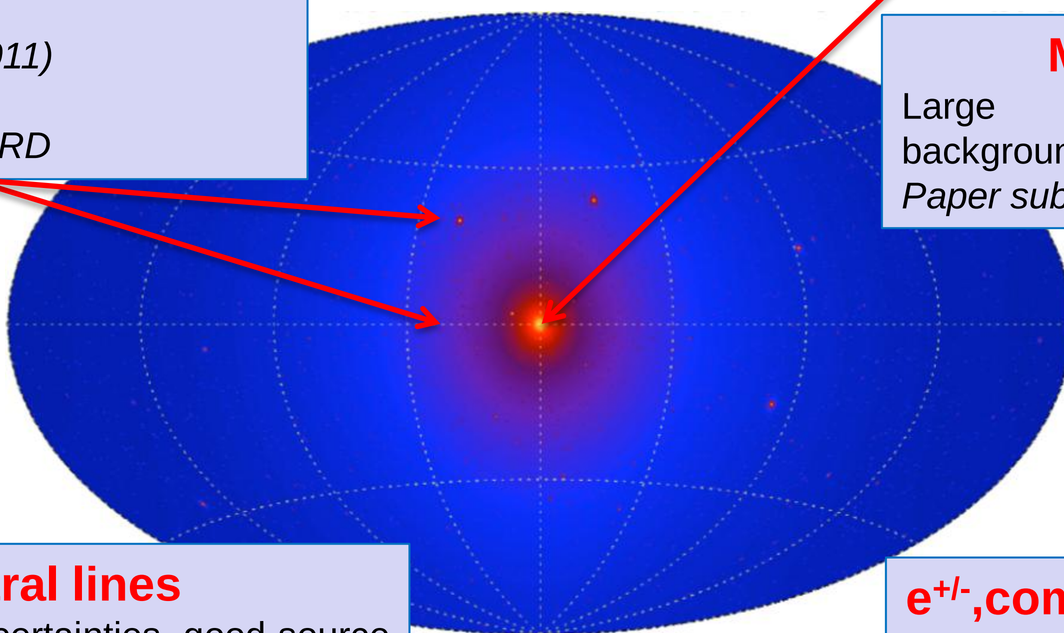
PRL 107, 241302 (2011)

arXiv:1111.2604

Paper submitted to PRD

Galactic center

Good statistics but source confusion and diffuse background



Milky Way halo

Large statistics but diffuse background

Paper submitted to PRD

IGRB anisotropy

Sun

PRD 84, 032007 (2011)

Spectral lines

No astrophysical uncertainties, good source id but small branching ratio.

PRL 104, 091302 (2010)

submitted to Phys. Rev. D (2012)

Galaxy clusters

Low background but low statistics

JCAP 05, 025 (2010)

All-sky map of gamma-rays from DM annihilation from arXiv:0908.0195 (based on Via Lactea II simulation)

$e^{+/-}$, complementary to γs

PRL 102, 181101 (2009)

PRD 82, 092004 (2010)

PRD 82, 092003 (2010)

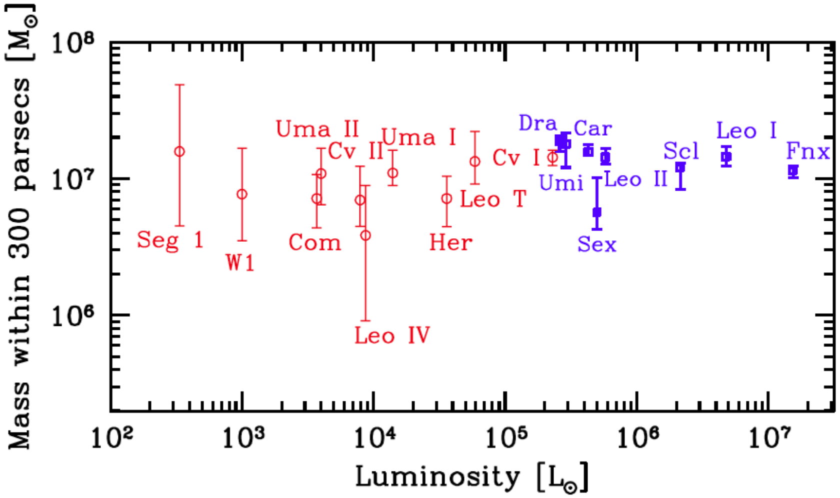
*PRL*108, 011103 (2012)

Extra-galactic radiation

Large statistics, but astrophysics and galactic diffuse background

JCAP 04, 014 (2010)

Clean targets: Nearby Dwarfs Galaxies



Strigari et al. Nature 2008

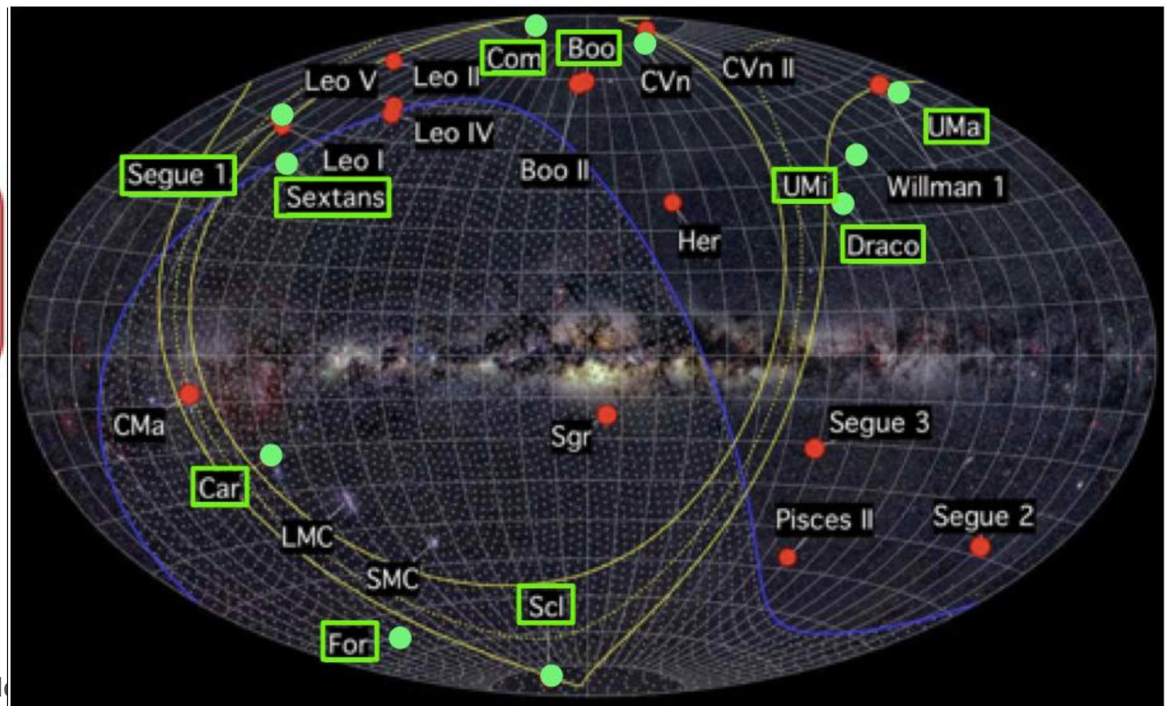
The faintest dwarfs detected have a mass to light ratio of more than 10^4: they are DM dominated system with very little astrophysical signal expected
25 found, 10 used in the following analysis.

J-factor

$$J(\psi)= \int_{\Delta\Omega(\theta,\phi)} d\Omega' \int_{l.o.s.} dl\, \rho_\chi^2(l)$$

J-factors (DM signal) and their uncertainties can be calculated from stellar kinematical data of the dwarfs

Dwarfs probed in γ-rays with LAT



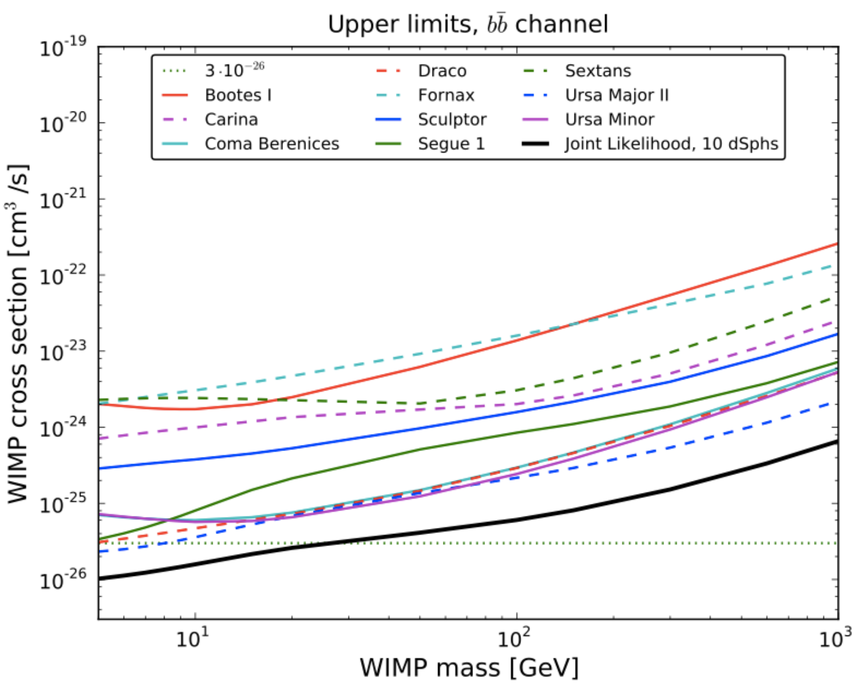
Milky way satellites combined likelihood approach

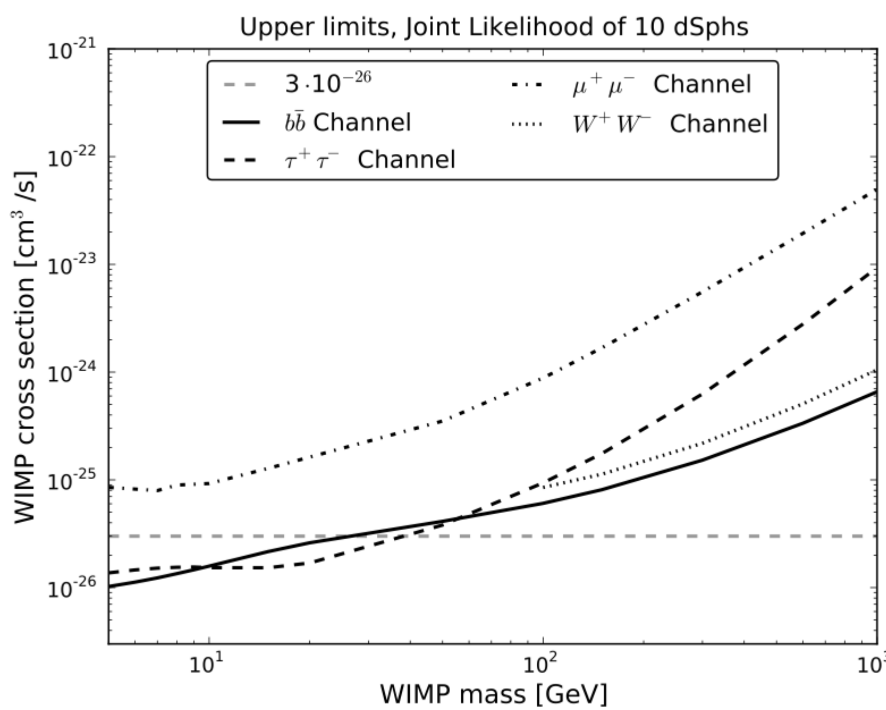
Using a combined likelihood of 10 dwarfs (4 of them contribute more) and 2 years of P6V11 data, 4 annihilation channels were tested.

$$\mathcal{L}(\langle\sigma v\rangle, m_{\mathrm{WIMP}}; \vec{\Theta}) = \prod_{i=1}^{N} \mathcal{L}_i(\langle\sigma v\rangle, m_{\mathrm{WIMP}}, b_i; \vec{\Theta}_i)$$

Same for all satellites ($\langle\sigma v\rangle, m_{\mathrm{WIMP}}$)

Fit for each satellite (b_i)

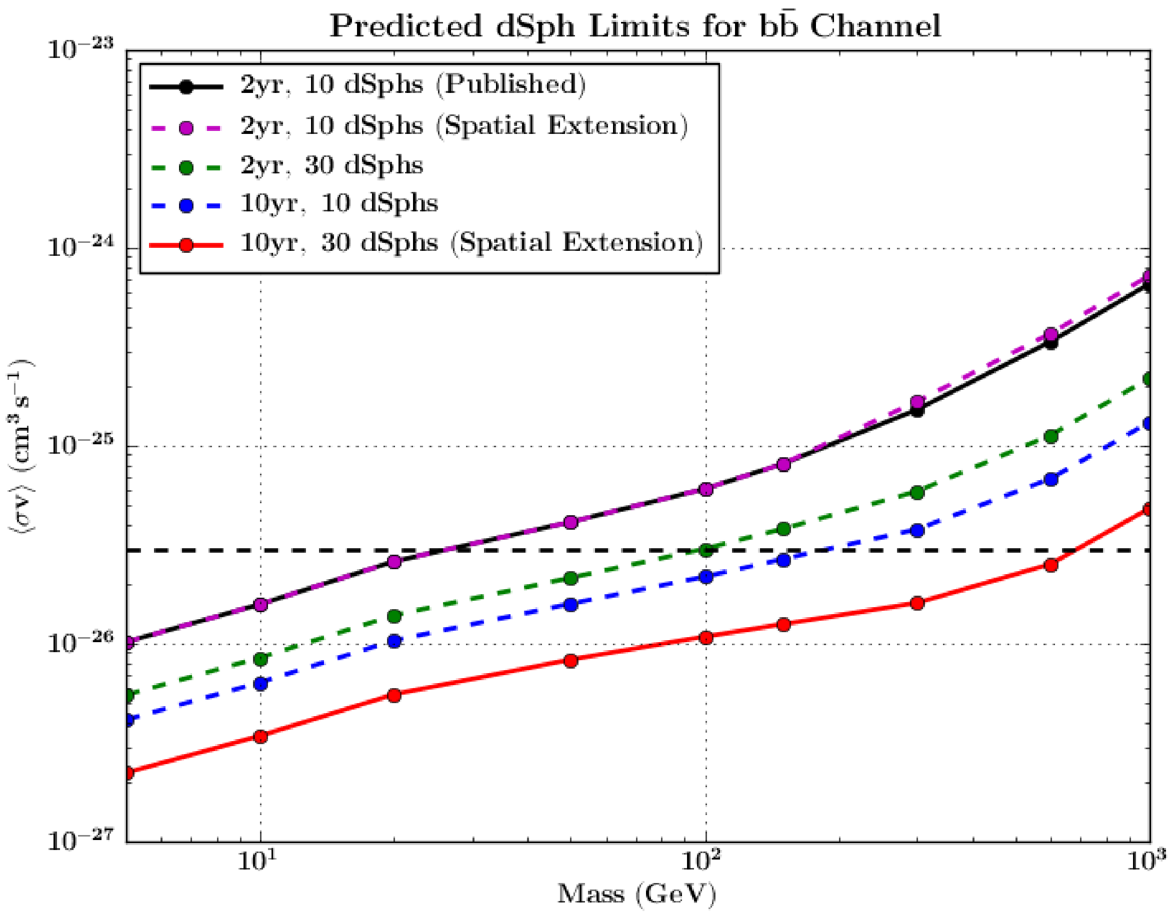




Ackermann, M. et al., Phys. Rev. Lett. 107, 241302 (2011)

DM limit improvement estimate in 10 years with the composite likelihood approach

- 10 years of data instead of 2(5x)
- 30 dSphs (3x) (supposing that the new optical surveys will find new dSph)
- -10% from spatial extension (source extension increases the signal region at high energy)
 [E > 10 GeV, M > 200 GeV]



- There are many assumptions in this prediction!!!
- Doesn’t deal with a possible detections.

Milky way satellites model independet approach

- Using 3 years of SOURCE_P7V6 data and masking the 2fgl sources;
- The bkg is evaluated in an annulus around each source (the diffuse model is not used);
- The expected γ-ray flux from the DM was evaluated using the DMFIT package.

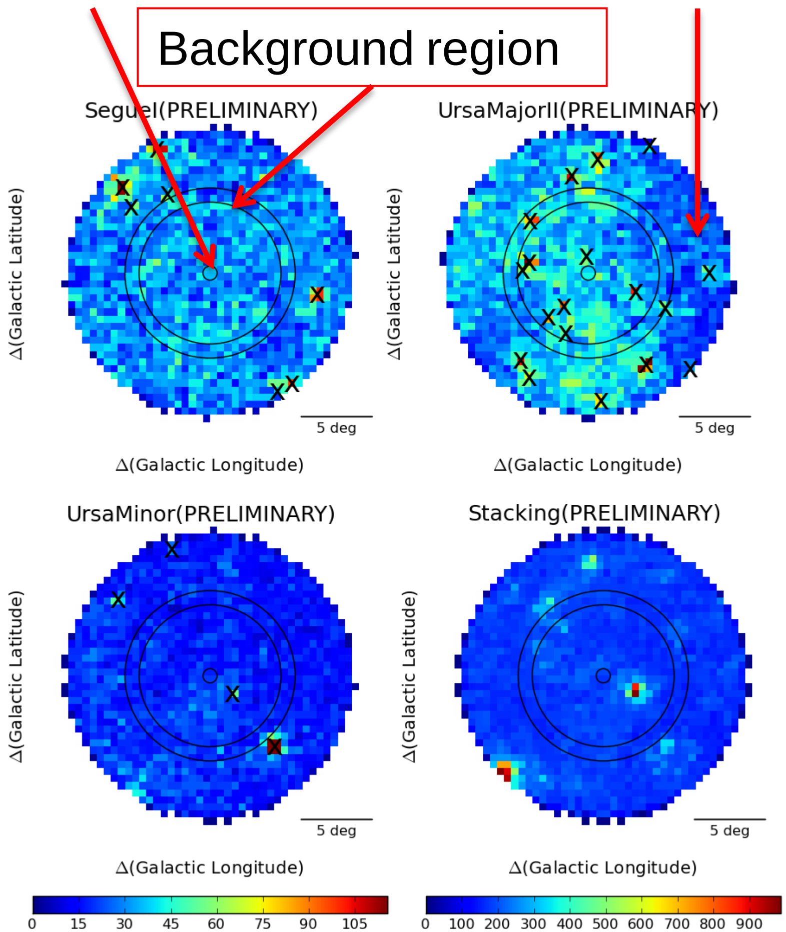
Source region

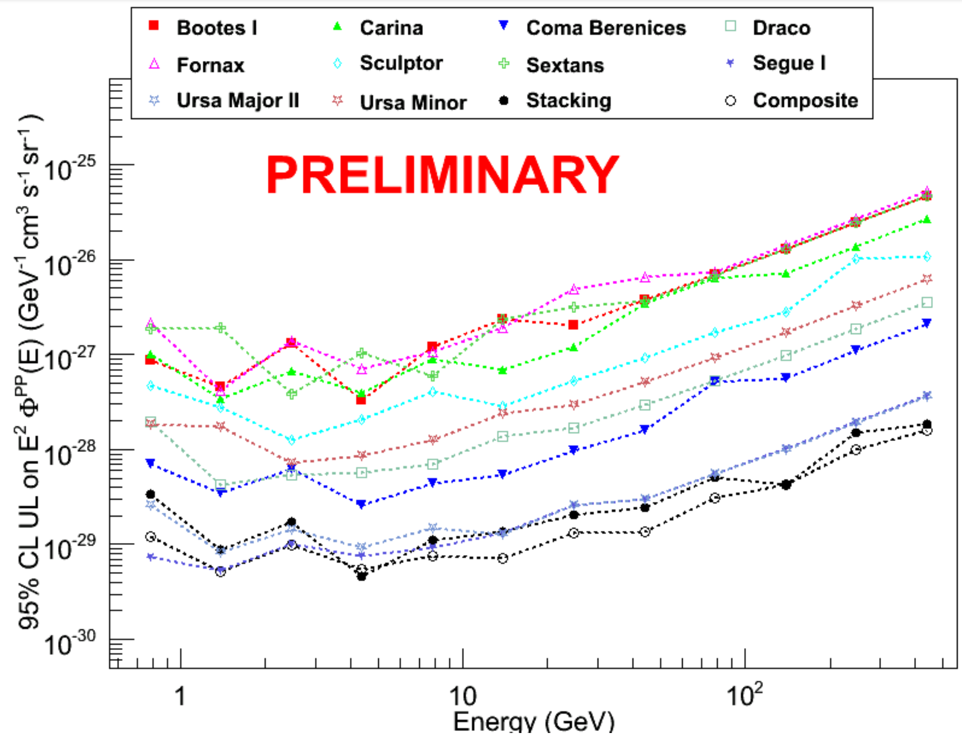
Masked sources

Background region

Phys. Rev. D Sumbitted

$$\Phi^{PP}(E) = \frac{1}{J(\Delta\Omega)}\Phi_\gamma(E,\Delta\Omega) = \frac{1}{2}\frac{\langle\sigma v\rangle}{4\pi m_\chi^2}\sum_f N_f(E,m_\chi)B_f$$





also see: Phys.Rev.Lett. 107 (2011) 241303

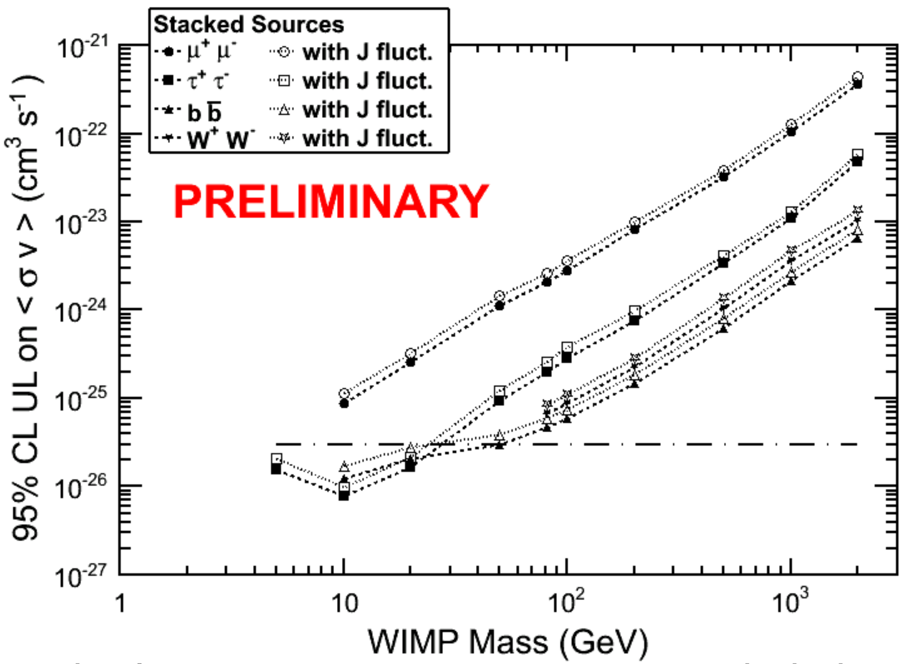
Milky way satellites model independent approach

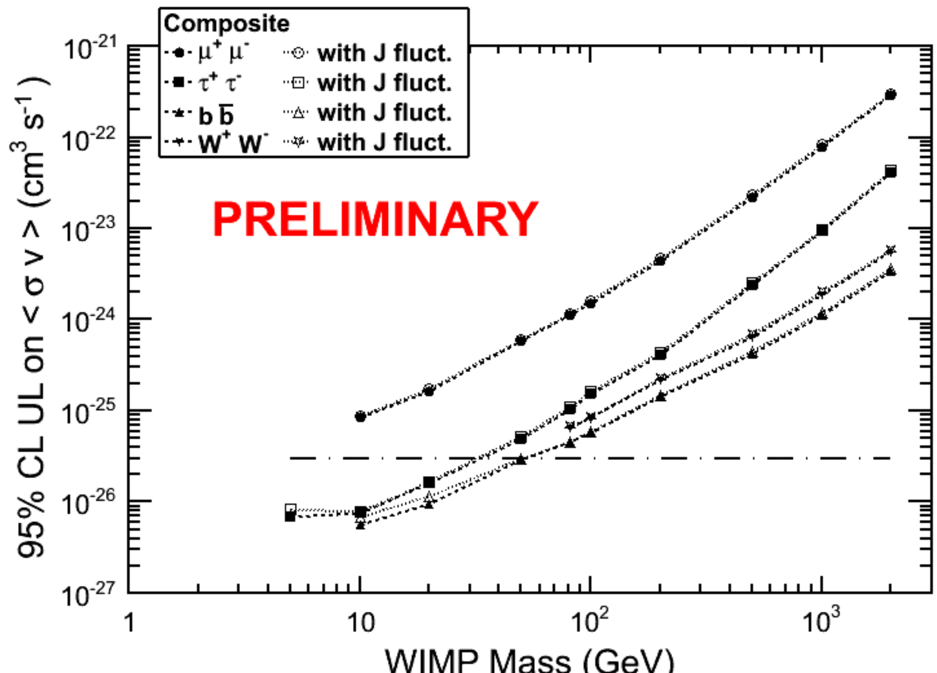
All the 10 dsphs are stacked as their exposure and the J factor is averaged on the various exposures

The standard bayesian method for UL evaluation with flat prior as for the single dsph

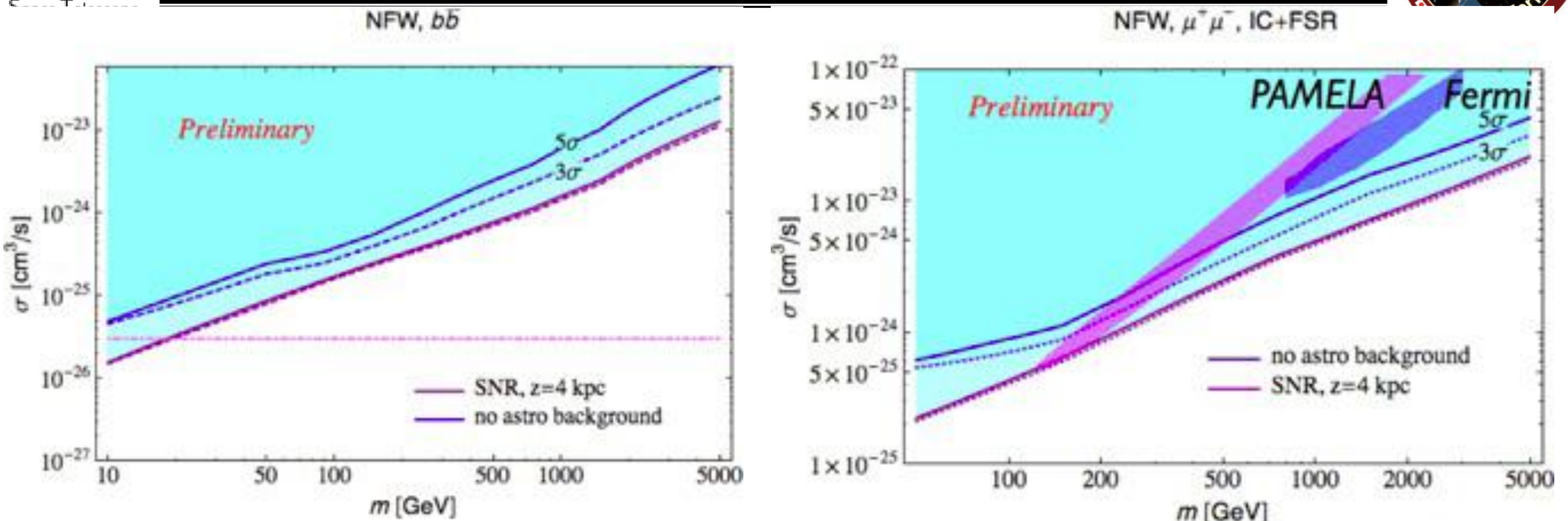
Developed for weight differently dsph with different J values.

Each posterior pdf is combined and the UL is evaluated





Milky way halo likelihood limits



Zaharijas, Cuoco, Yang, Conrad for the Fermi-Lat Collaboration, Fermi Symposium 2011

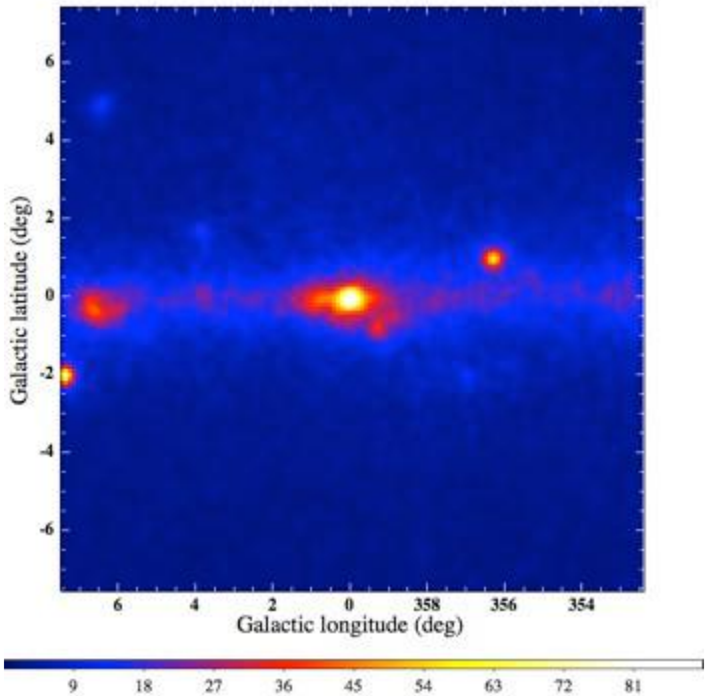
- No-background limits are very conservative limits obtained requiring that the DM signal does not exceed the observed gamma-ray emission
- With some minimal modeling of the background the limits are improved of a factor 2-3.
- Further understanding of the background can bring better limits in the future.
- DM interpretation of the Pamela and Fermi CREs excesses excluded (independently from the DM profile NWF or cored)

See also Cirelli Panci & Serpico 2010 and Strumia & Papucci 2010

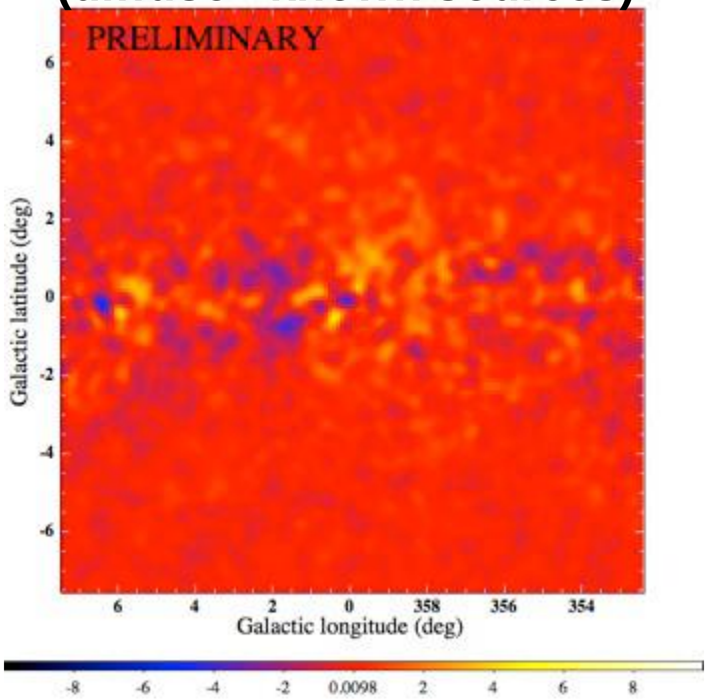
Inner galaxy
15° x15° region

Fermi LAT preliminary results with 32 months of data, E>1 GeV (P7CLEAN_V6, FRONT)

DATA



DATA-MODEL (diffuse+ known sources)

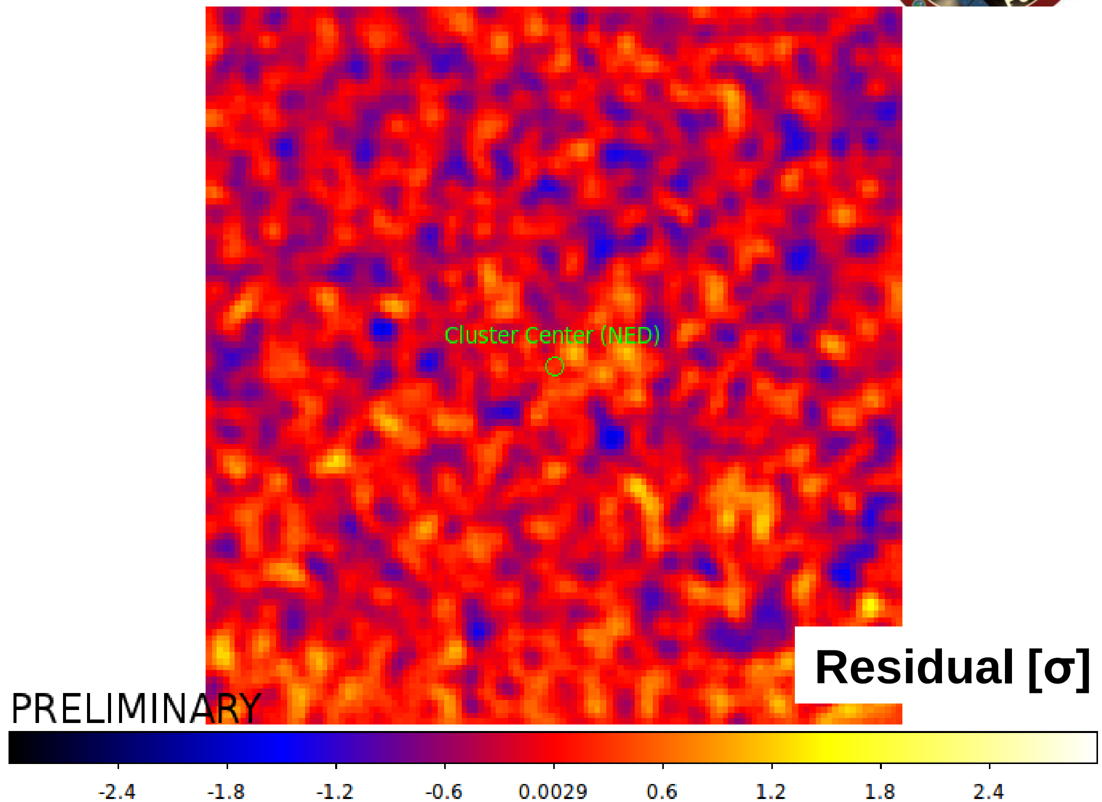


Diffuse emission (all sky GALPROP model tuned to the inner galaxy) and point sources accounts for most of the emission observed in the region.

6 Clusters 'Stacked Residual Map'

FERMI-LAT Preliminary

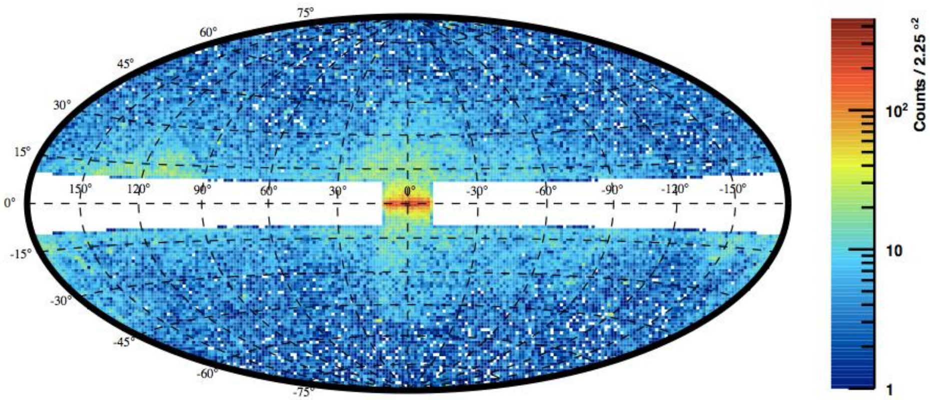
- 24 Months of LAT **P6V11 Diffuse** data (P7V6 analysis is ongoing)
- Binned analysis, **10 deg ROI**, 20 Energy Bins from 200 MeV to100 GeV
- Clusters modeled as **point sources**!
- **No significant excess in stacked residual map!**



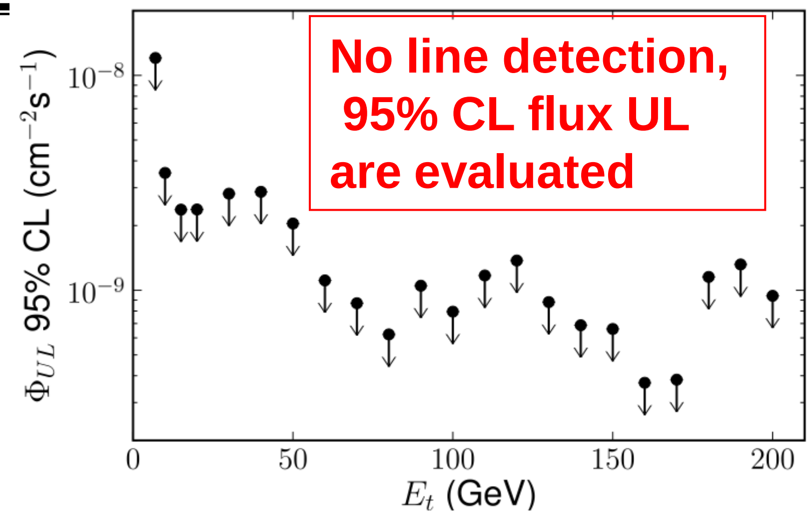
And from outside the collaboration:

- Using 3y P7V6 data and 8 clusters (together and singularly) authors of JCAP01(2012)042 don't find signal above 3σ.
- Authors of arXiv:1201.1003v1, using 3 years of P7V6 data and assuming no CR emission, they obtain a detection of DM in Virgo at 4.4σ .

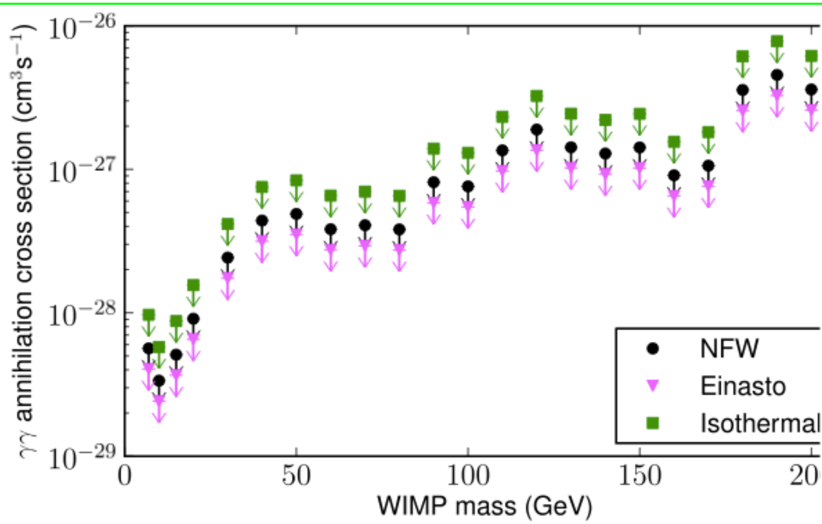
Spectral line from WIMP search

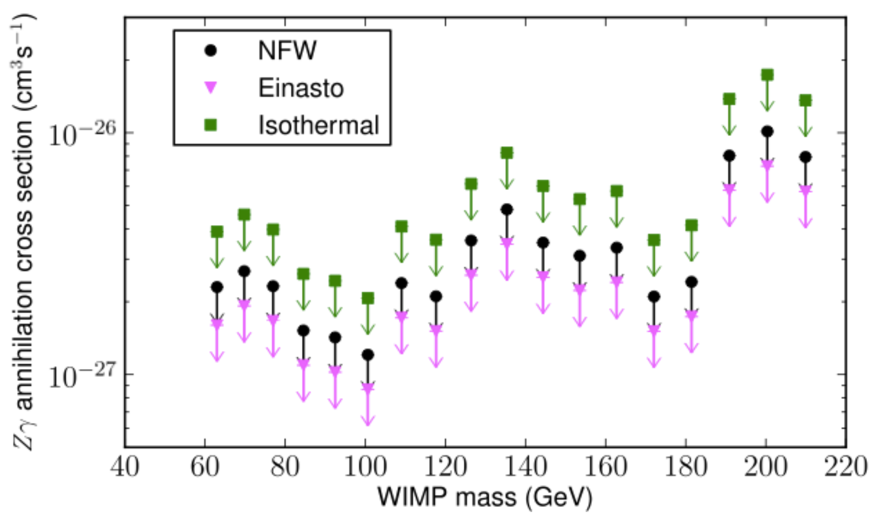


Ackermann, M. et al.,
submitted to Phys. Rev. D (2012)

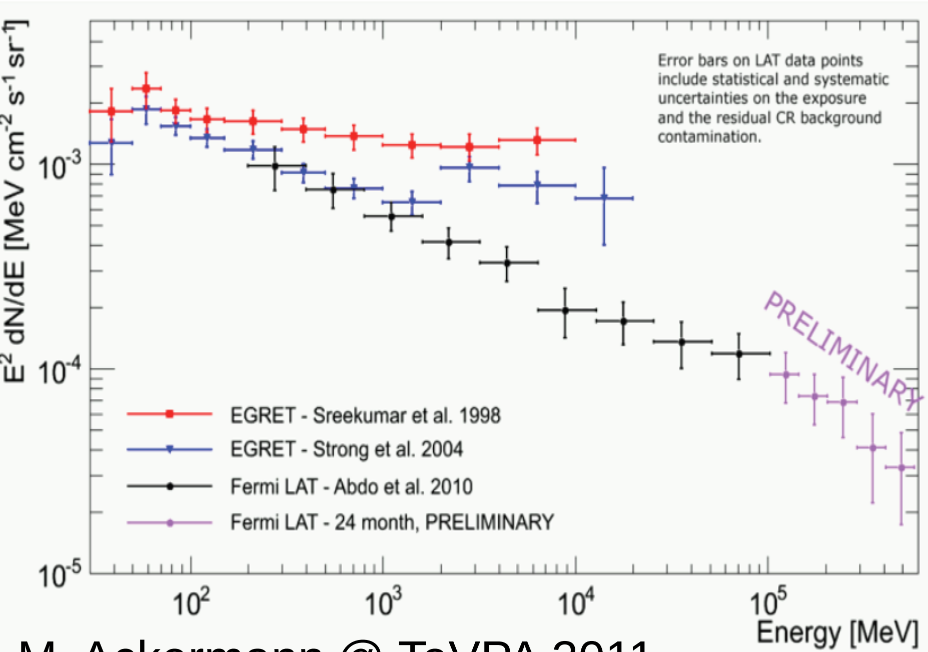


- WIMP annihilation into monoenergetic photons is the “smokin gun” signal
- 2 years of data from high galactic latitude and the galactic center (increased statistics)
- Inclusive photon spectrum 4.8 - 264 GeV (remove photons from point sources)

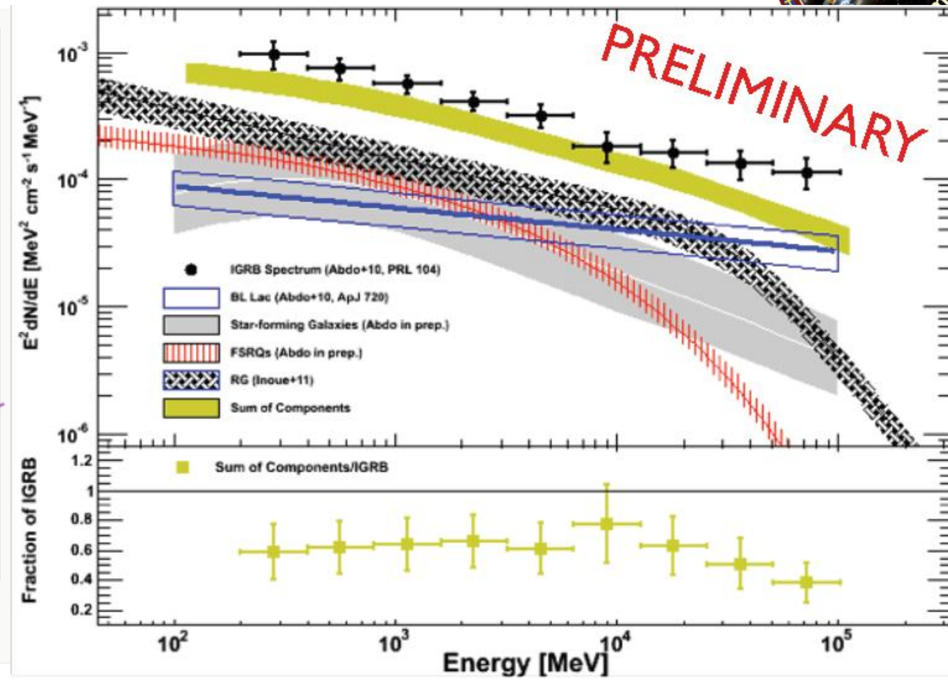




Extragalactic Background Spectrum



M. Ackermann @ TeVPA 2011

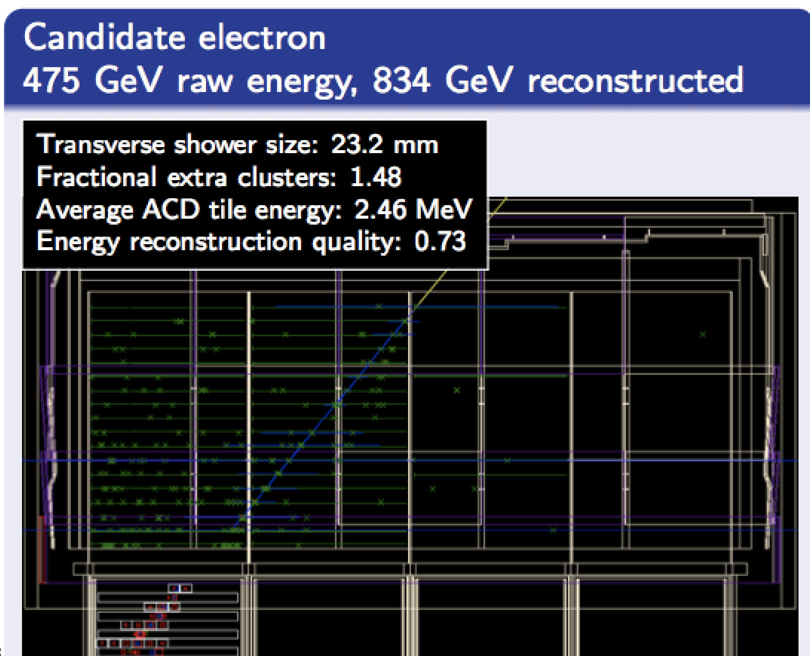


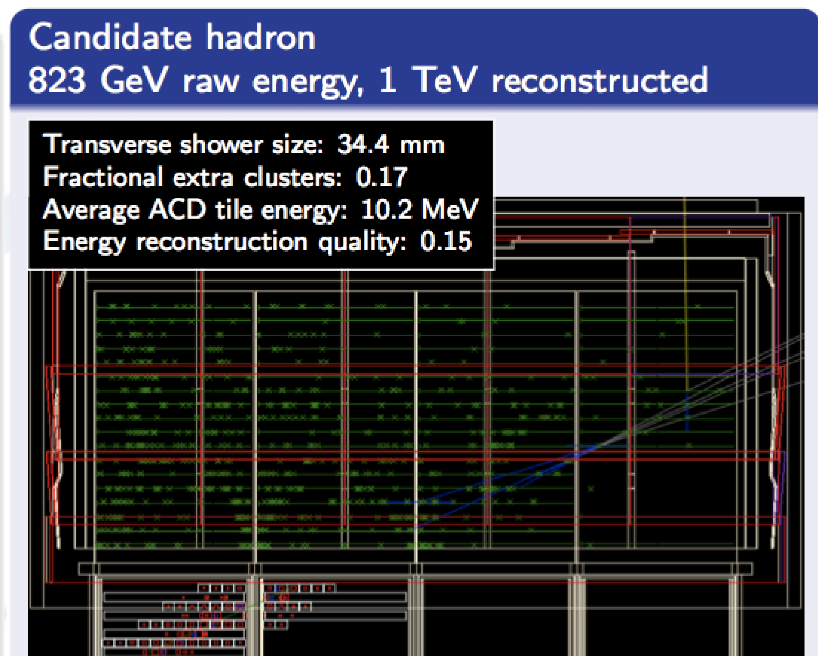
- The EGB spectrum is compatible with a feature-less power-law spectrum between 200 MeV -100 GeV
- Smooth spectrum for energies > 100 GeV
- Indications of spectral softening at high energies

- Total contribution from FSRQ + BL Lac + Radio galaxies + Star-forming galaxies: ~ 50% - 80%
- ~ 25% foreground modeling uncertainty not included in EGB error bands.
- The remaining contribution could be due to more unresolved point sources populations or different diffuse process (as cosmological DM annihilation).

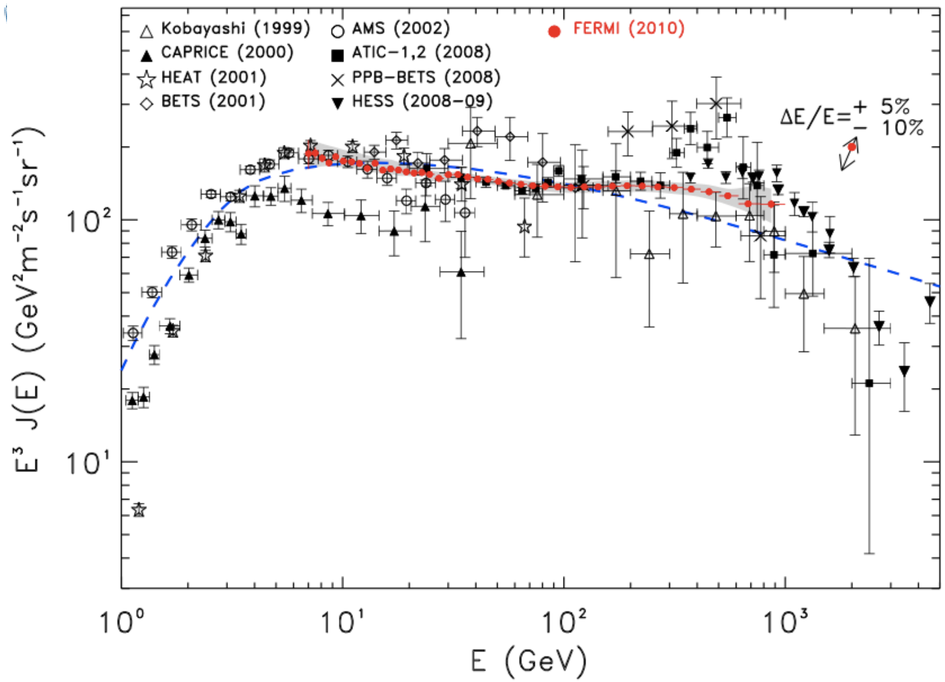
Using the LAT as an e^+/e^- detector

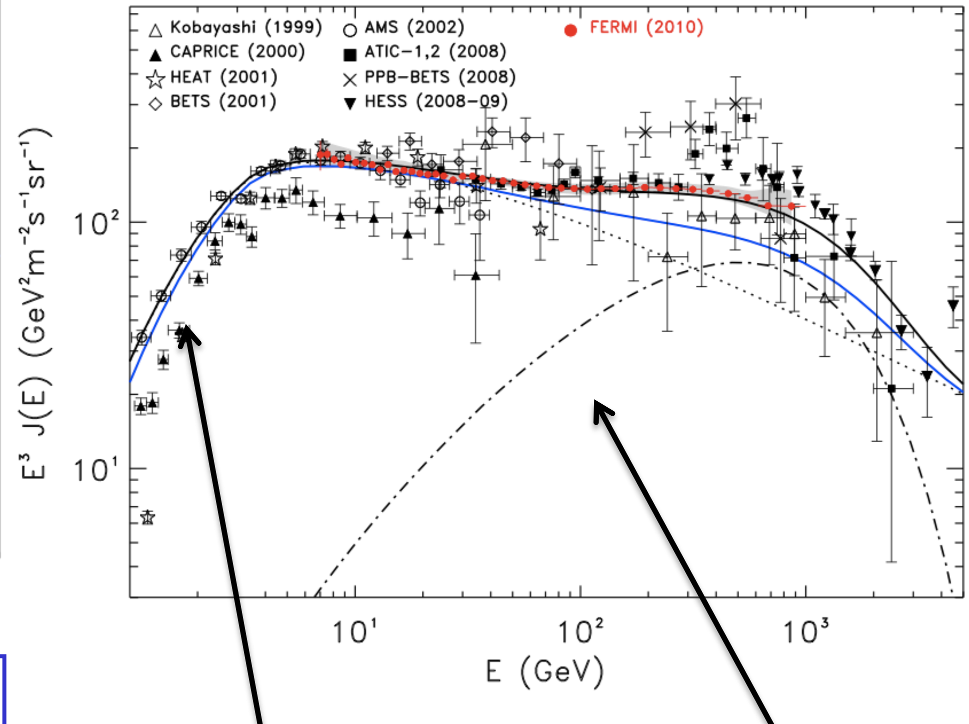
- Since the LAT is a pair conversion telescope, the energy reconstruction and background rejection of electrons are similar with the standard photon analysis,
- the LAT is triggering on almost all the particles that enter in it, including electrons.
- The on board filtering to fit bandwidth, remove many charged particles:
  - keep and downlink all events with more than 20 GeV in the CAL (HE) (around 10M per year)
  - prescaled (1:250) sample of unfiltered triggers (LE)
- Two separate analyses for HE and LE were needed (good agreement in the overlapping region)
- A rejection power of 10^3-10^4 of proton background is required





e+/e- spectra from 7 GeV to 1 TeV





- The spectrum is harder than in pre-Fermi GALPROP model (Γ ~ 3.08).
- The Fermi LAT measured spectrum suggests some spectral flattening at 70–200 GeV and a noticeable excess above 200 GeV.
- Diffusive models don't reproduce the spectral features.

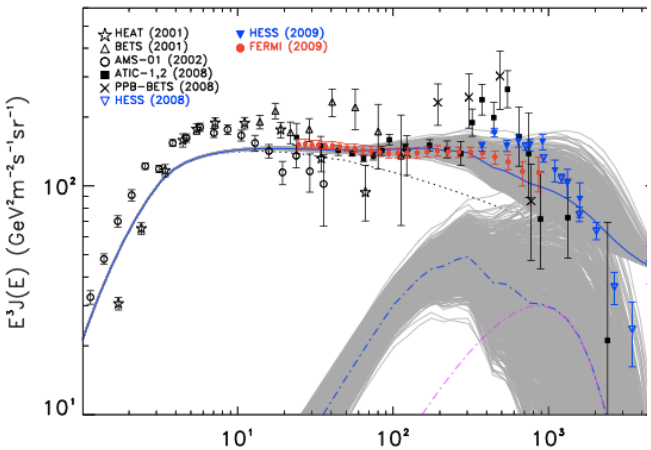
Γ = 1.6/2.7
(below/above 4 GeV)

Γ = 1.5
cutoff at 1 TeV

Ackermann, M. et al., Phys. Rev. D 82, 092004 (2010)

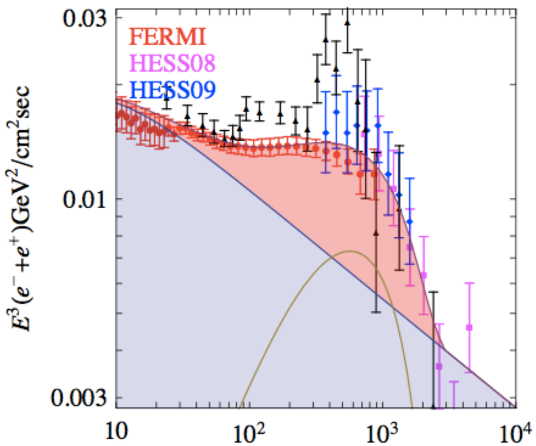
Possible explaination of the extracomponent

1. Nearby pulsars



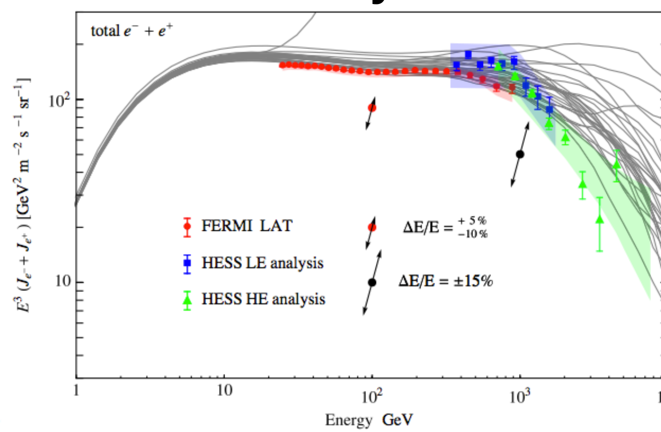
Kobayashi et al. arXiv 038470
Grasso et al. arXiv 0905.0636

2. Dark Matter



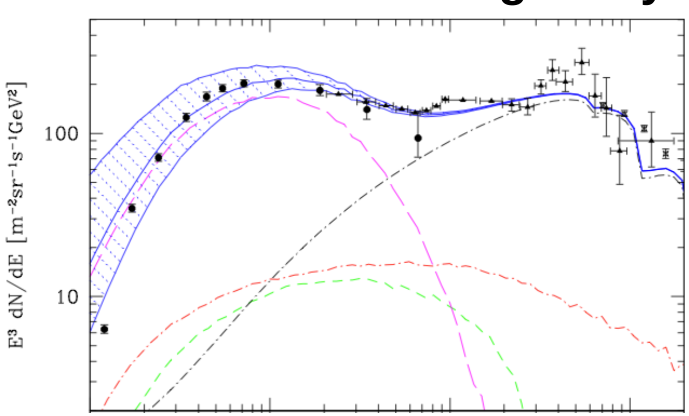
Strumia et al.
arXiv 0905.0480

3. Secondary CR acc.



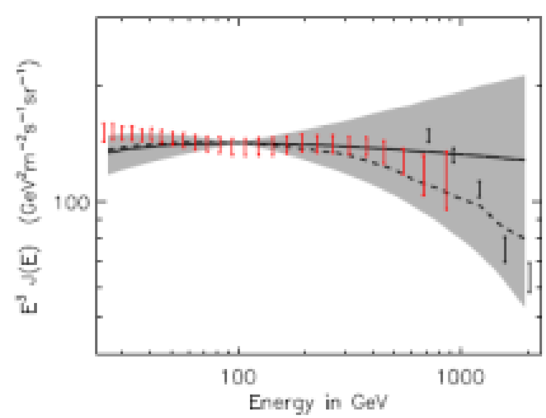
Blasi et al. arXiv 0903.2794
Ahlers et al. arXiv 0909.4060

4. SNR inhomogeneity



Piran et al. arXiv 0902.0376

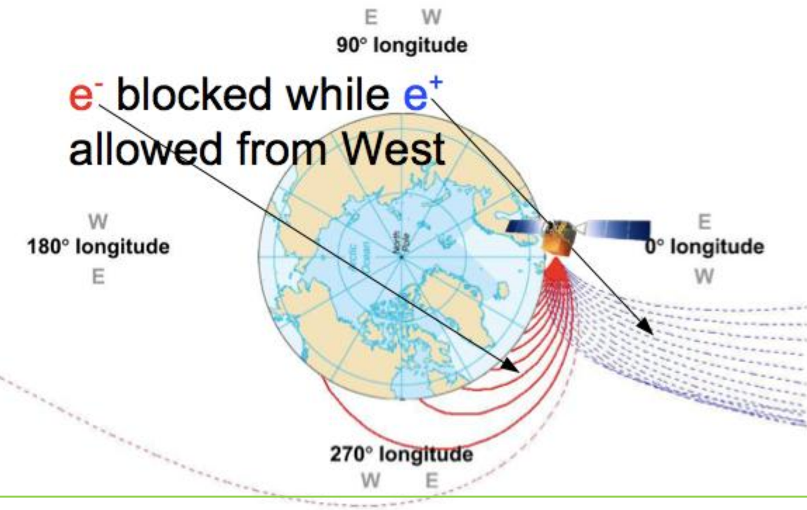
5. Source stochasticity



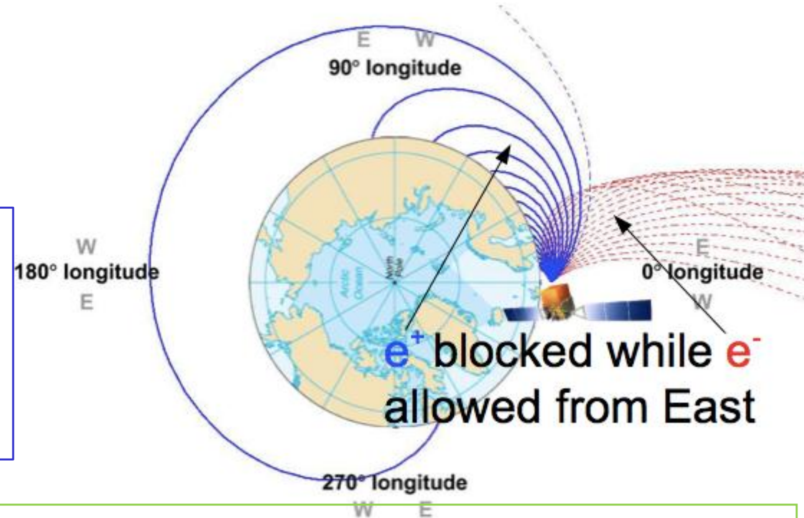
Grasso et al. arXiv 0905.0636

6. and more

Electron-positron distinction with Fermi

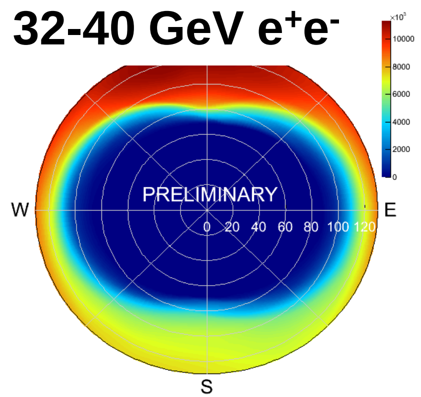


Total observation time of 39.0 days

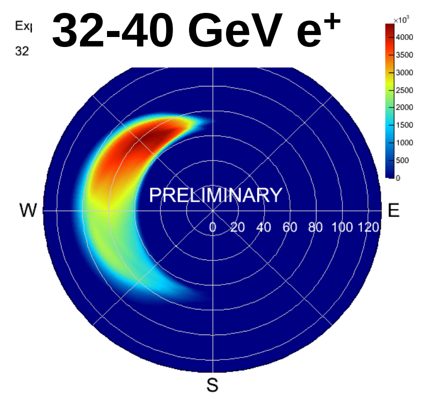


- pure e^+ region in the West and pure e^- region in the East;
- the regions vary with particle energy and the LAT geomagnetic coordinates;
- to locate these regions, we use a code written by Smart and Shea, which numerically calculates a particle's trajectory in the Earth geomagnetic field

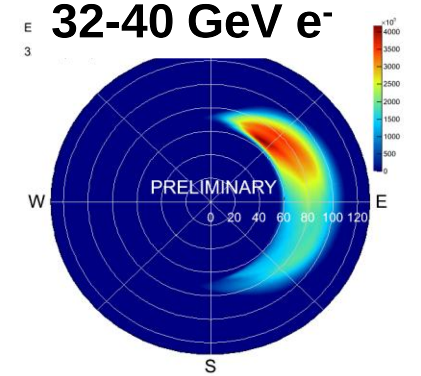
32-40 GeV e^+e^-



32-40 GeV e^+

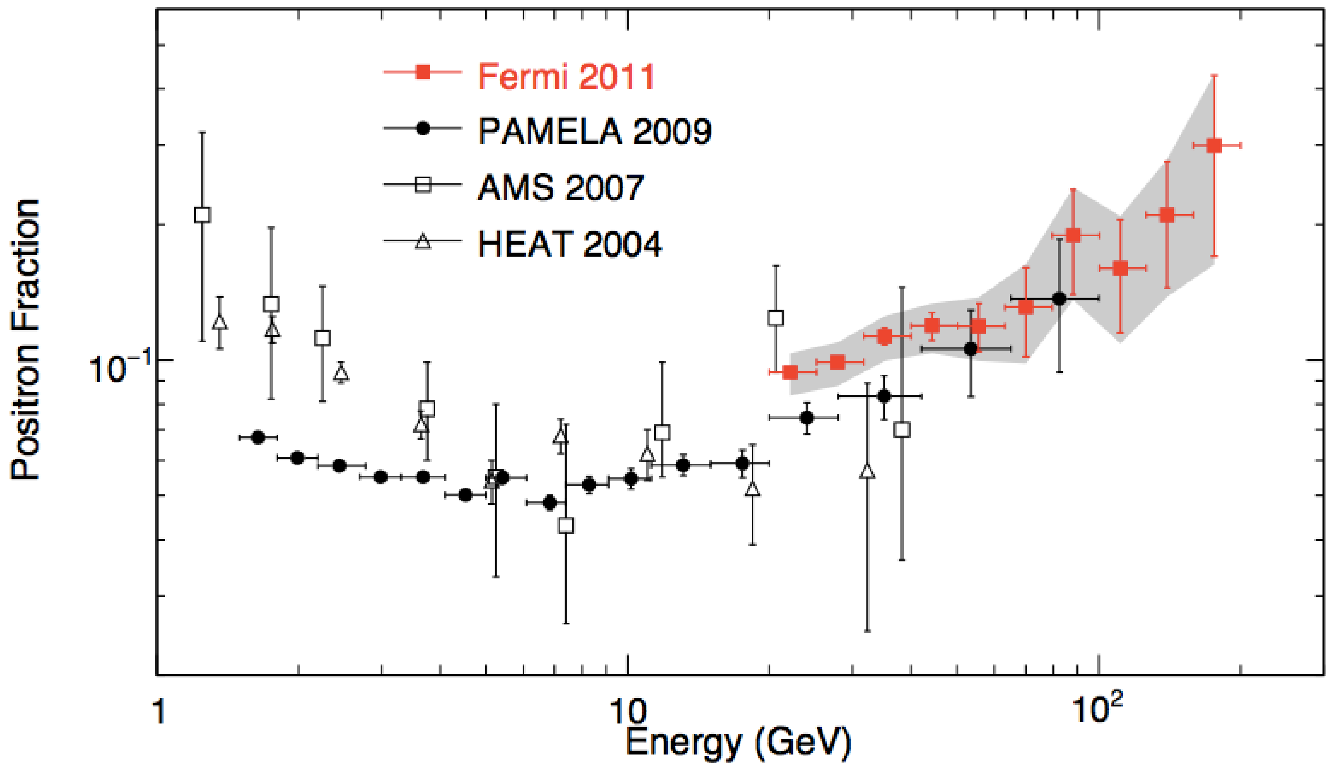


32-40 GeV e^-



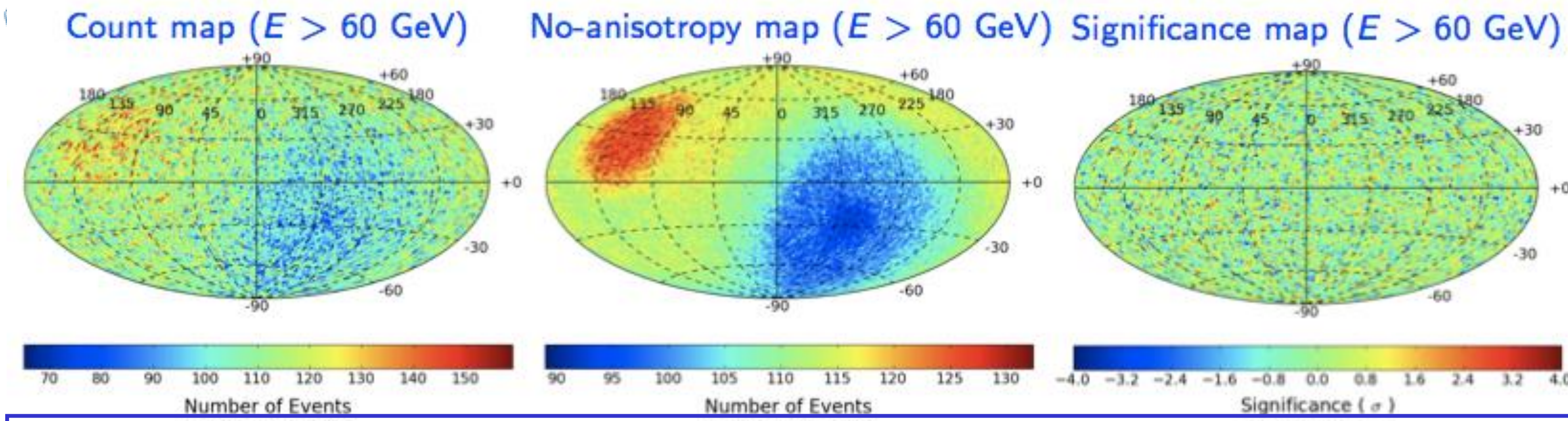
Ackermann, M. et al., Phys. Rev. Lett. 108, 011103 (2012)

Positron fraction



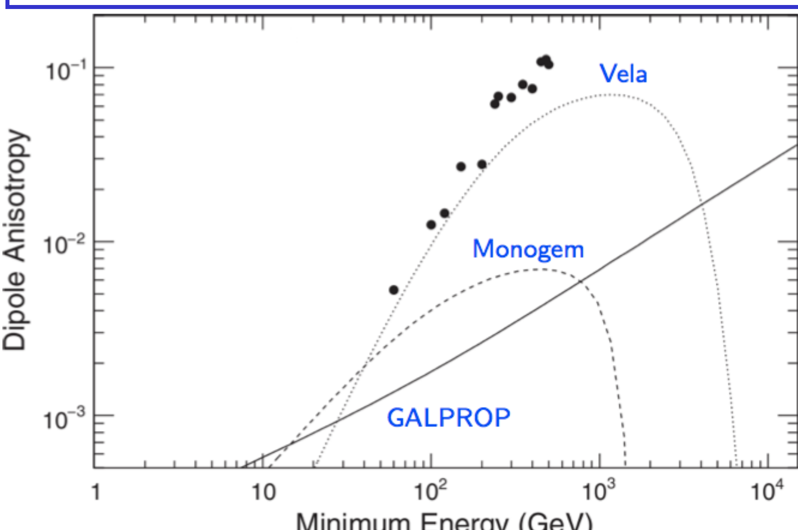
We find that the positron fraction increases with energy between 20 and 200 GeV, consistent with results reported by PAMELA.
New measurement are needed for distinguish the cause of the increase.

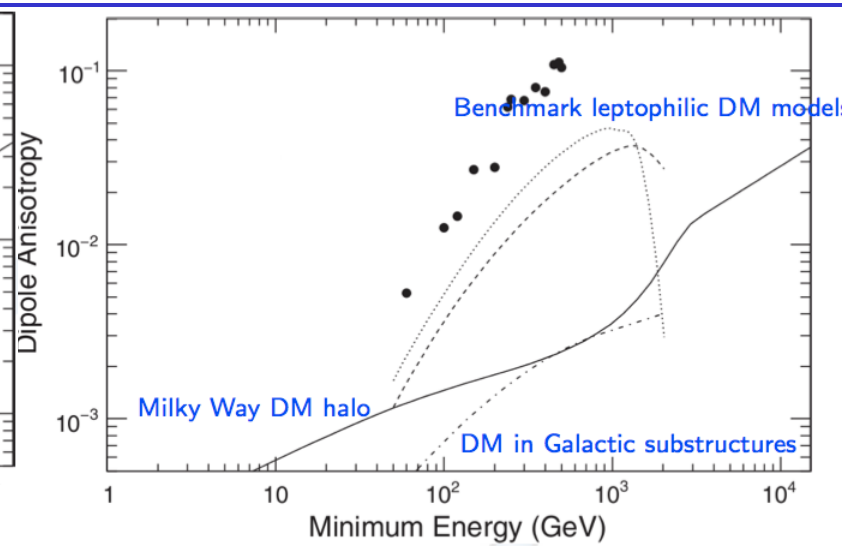
Search for anysotropy from CRE flux



Ackermann, M. et al., Phys. Rev. D 82, 092003 (2010)

- more than 1.6 M candidate electrons above 60 GeV in the first year of the mission
- entire sky searched for anisotropies in Galactic coordinates: <u>no anisotropies found</u>
- upper limits for the dipole case ranging from 0.5% to 10% (comparable to the values expected for a single nearby source dominating the high-energy electron spectrum)



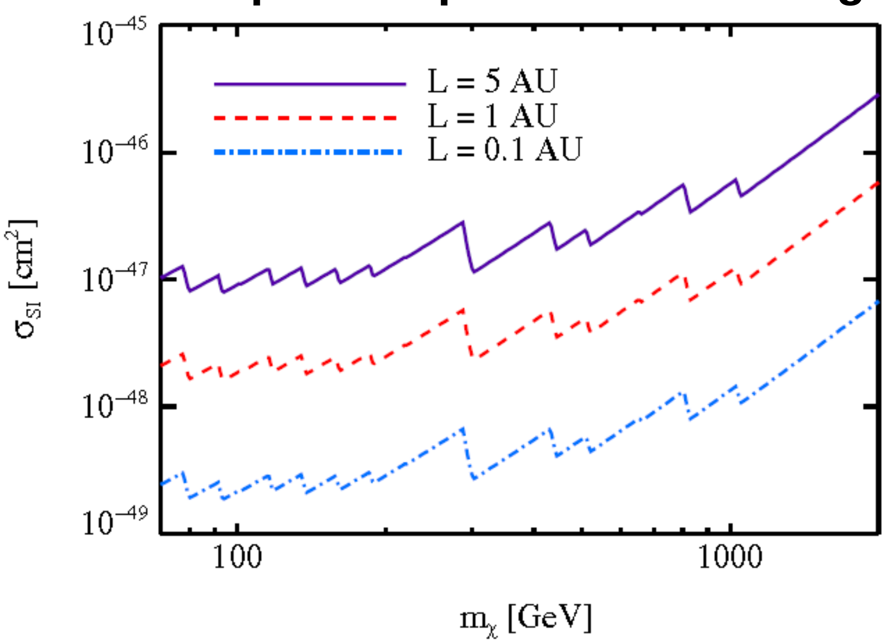


These DM models were tuned to match Fermi & Pamela results.

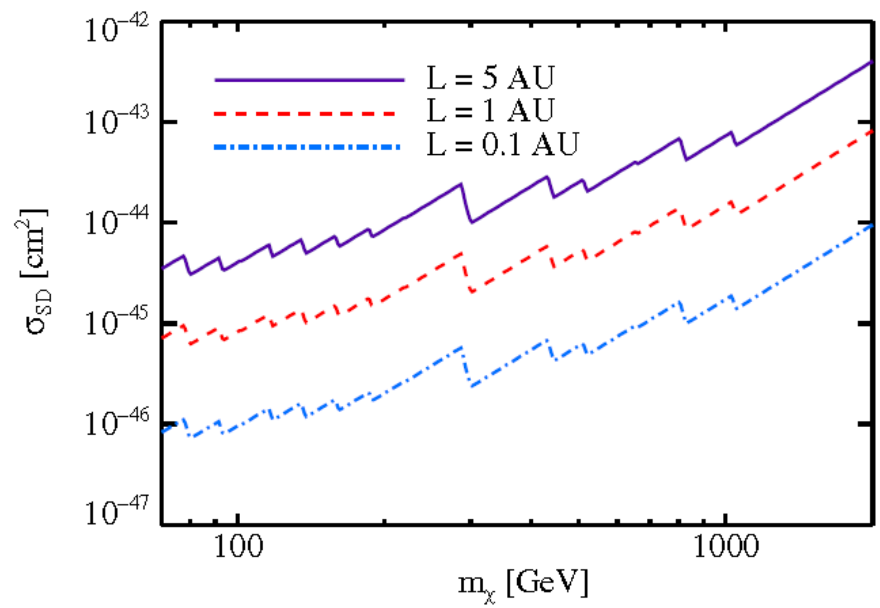
Constraints on DM from Fermi UL on CRE from the Sun

Constraints on DM annihilation to e^+e^- via an intermediate state(ϕ, with M_ϕ=1GeV) from solar CRE flux upper limits. The constraints obtained for three values of the decay length L of the intermediate state are shown. Models above the curves exceed the solar CRE flux upper limit at 95% CL for a 30° ROI centered on the Sun.

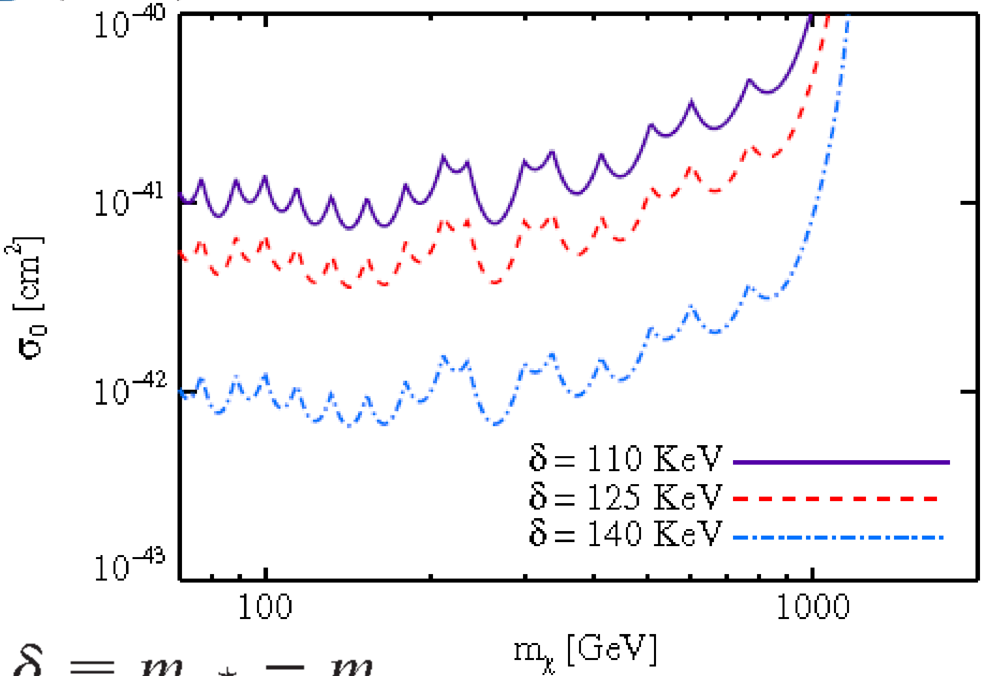
Solar capture via spin-independent scattering



Solar capture via spin-dependent scattering



Constraints on Inelastic DM from Fermi UL on CRE from the Sun



$$\delta = m_{\chi^*} - m_\chi$$

Constraints on iDM model parameters for three values of the mass splitting. Models above the curves produce a solar CRE flux that exceeds the 95% CL flux upper limit for a 30° ROI centered on the Sun in one or more energy bins.

PRD 84, 032007 (2011)

Inelastic dark matter (iDM) models have garnered interest recently in light of claims that iDM could naturally explain such observations as the 511 keV line observed by INTEGRAL/SPI and the apparently inconsistent results of DAMA/LIBRA and CDMS if the DM scattered inelastically and thereby transitioned to an excited state with a slightly heavier mass.

The bounds we derive exclude the relevant cross sections by 1–2 orders of magnitude → the parameter space of models preferred by DAMA/LIBRA can be ruled out for m >70 GeV for annihilation to e^+e^-

Conclusions

- Astrophysics results:
  - Published 2FGL catalog with accurate information on location, spectra and association.
  - Several relevant analysis on extragalactic sources, that I have not discussed here, were published and are ongoing (GRBs, AGN,…).
  - Numerous advancements in the systematic study of galactic sources, really useful also for the understanding the CR spectra.
- Indirect constraint on DM:
  - No detected signal.
  - Really promising analysis using different targets (dSphs, clusters) are starting to reduce the parameter space of various models.
- Direct Cosmic-Ray measurements:
  - First systematic-limited measurement of the Cosmic-Ray Electron spectrum up to 1 TeV.
  - No evidence for anisotropies in the arrival directions of CREs above 60 GeV.
  - Measured positron fraction up to 200 GeV.
- In the next years: higher statistics, better knowledge of the instrument and of the background-> <u>New interesting results will come!</u>