Fermi Extended Mission Prospects and Planning

Dark Matter and New Physics Perspectives

LAT IFC Meeting
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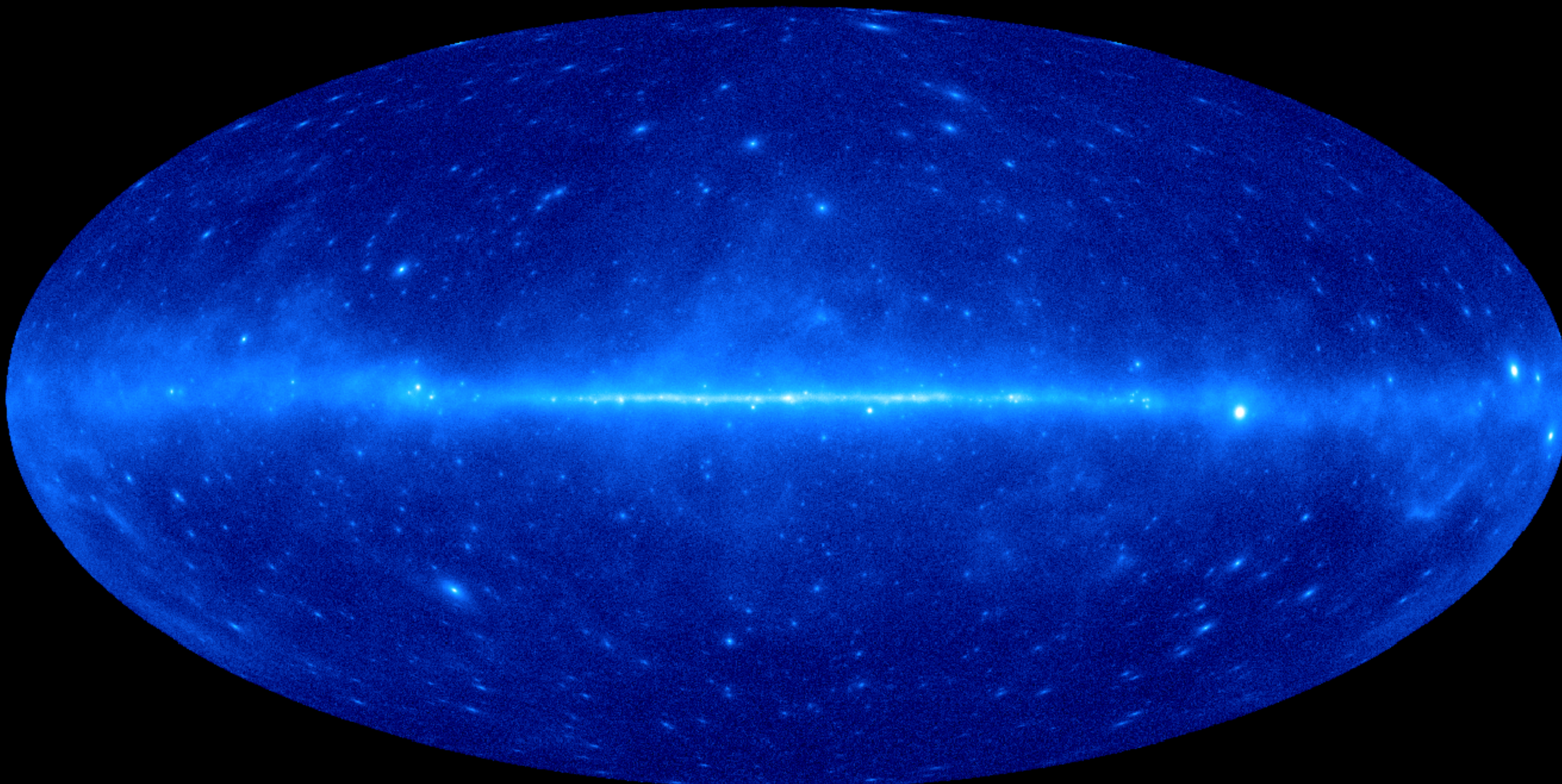
Setting the Stage

- Fermi LAT Sensitivity to New Physics:
  - full-sky coverage
  - huge energy range
    - now starting to accumulate significant statistics at very high energy (thousands of events above 200 GeV)
    - like a new experiment!
  - orders-of-magnitude advances in sensitivity: new physics and new astrophysics together

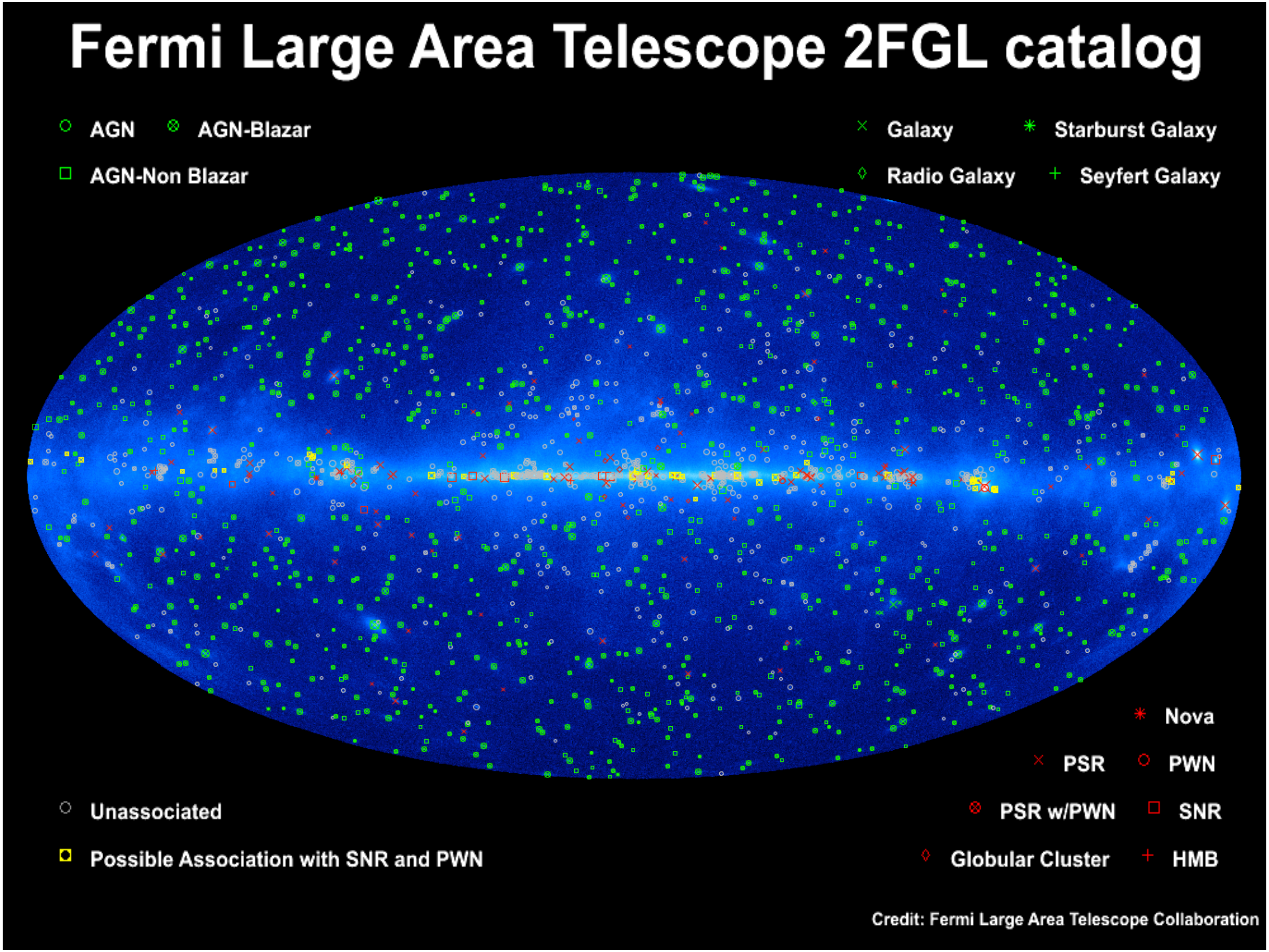
Some Recent Fermi Highlights

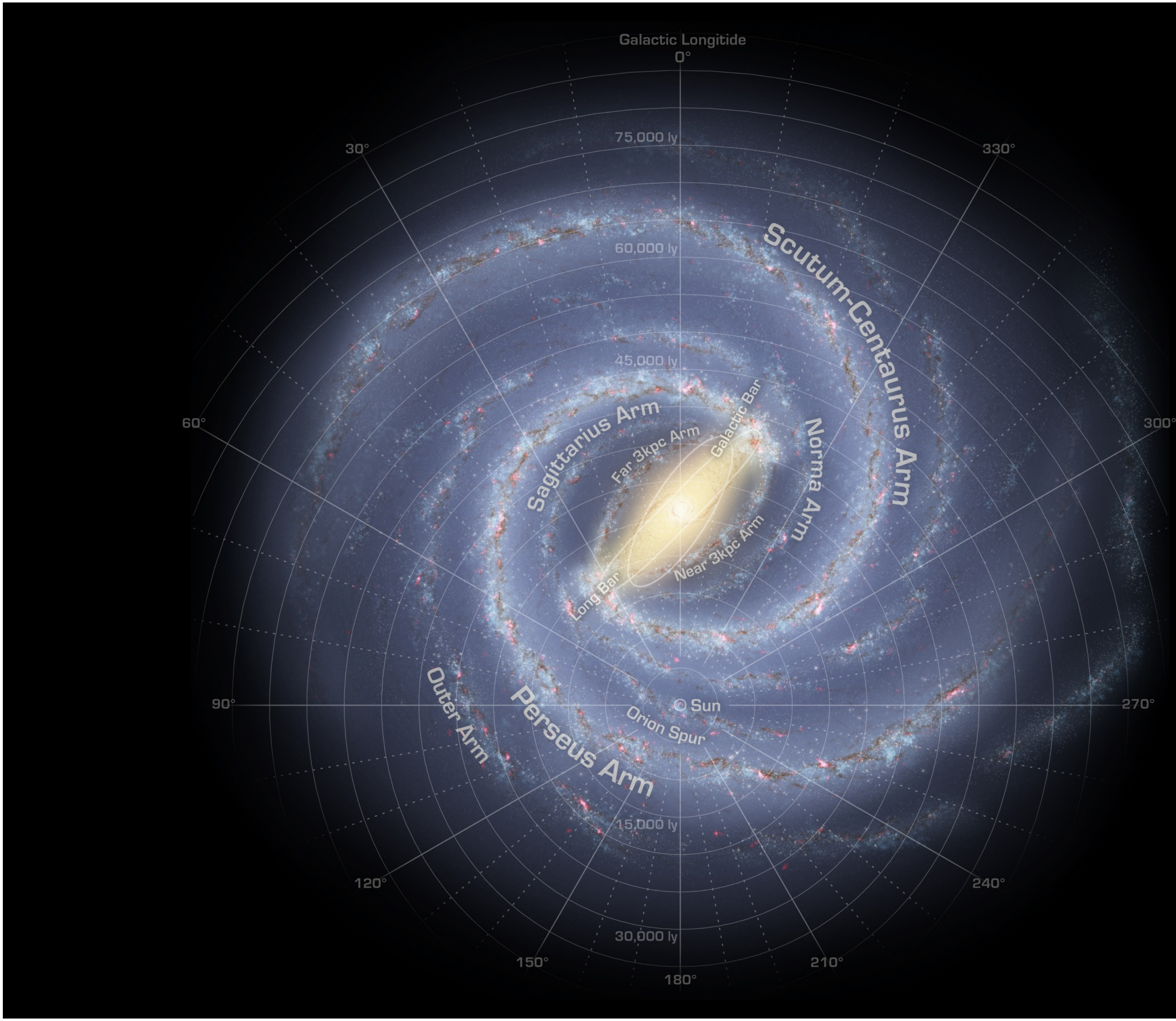
- Early searches for Dark Matter signatures in different kinds of sources
- Remarkable high-energy emission from gamma-ray bursts
  - Starting to see what was missing (Nicola's talk)
  - Also provides interesting limits on photon velocity dispersion
- Very high statistics measurement of the cosmic e+e- flux to 1 TeV
- Nailing down the diffuse galactic GeV emission
- First Fermi determinations of the isotropic diffuse flux
- Extragalactic Background Light constraints
- Anisotropy analyses of diffuse gamma-ray flux and electron-positron flux and new physics constraints.
- New limits on large extra dimensions
- 2^{nd} catalog: 1873 sources, of which ~1/3 are still unassociated with known types of sources.

Fermi Large Area Telescope 2FGL catalog



Credit: Fermi Large Area Telescope Collaboration

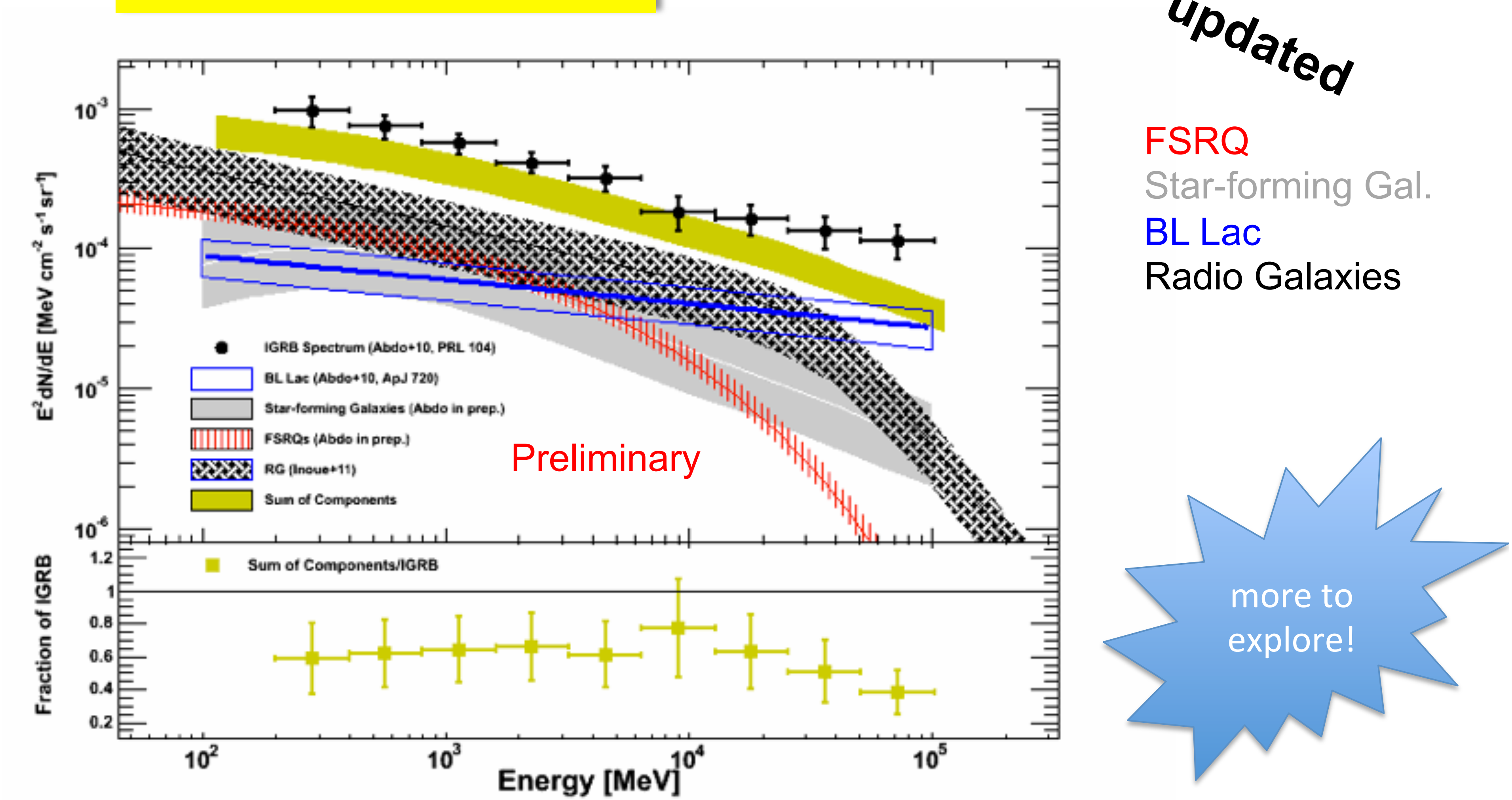

Fermi Large Area Telescope 2FGL catalog
AGN
AGN-Blazar
AGN-Non Blazar
Galaxy
Starburst Galaxy
Radio Galaxy
Seyfert Galaxy
Nova
PSR
PWN
PSR w/PWN
SNR
Globular Cluster
HMB
Unassociated
Possible Association with SNR and PWN
Credit: Fermi Large Area Telescope Collaboration



Credit: R. Hurt

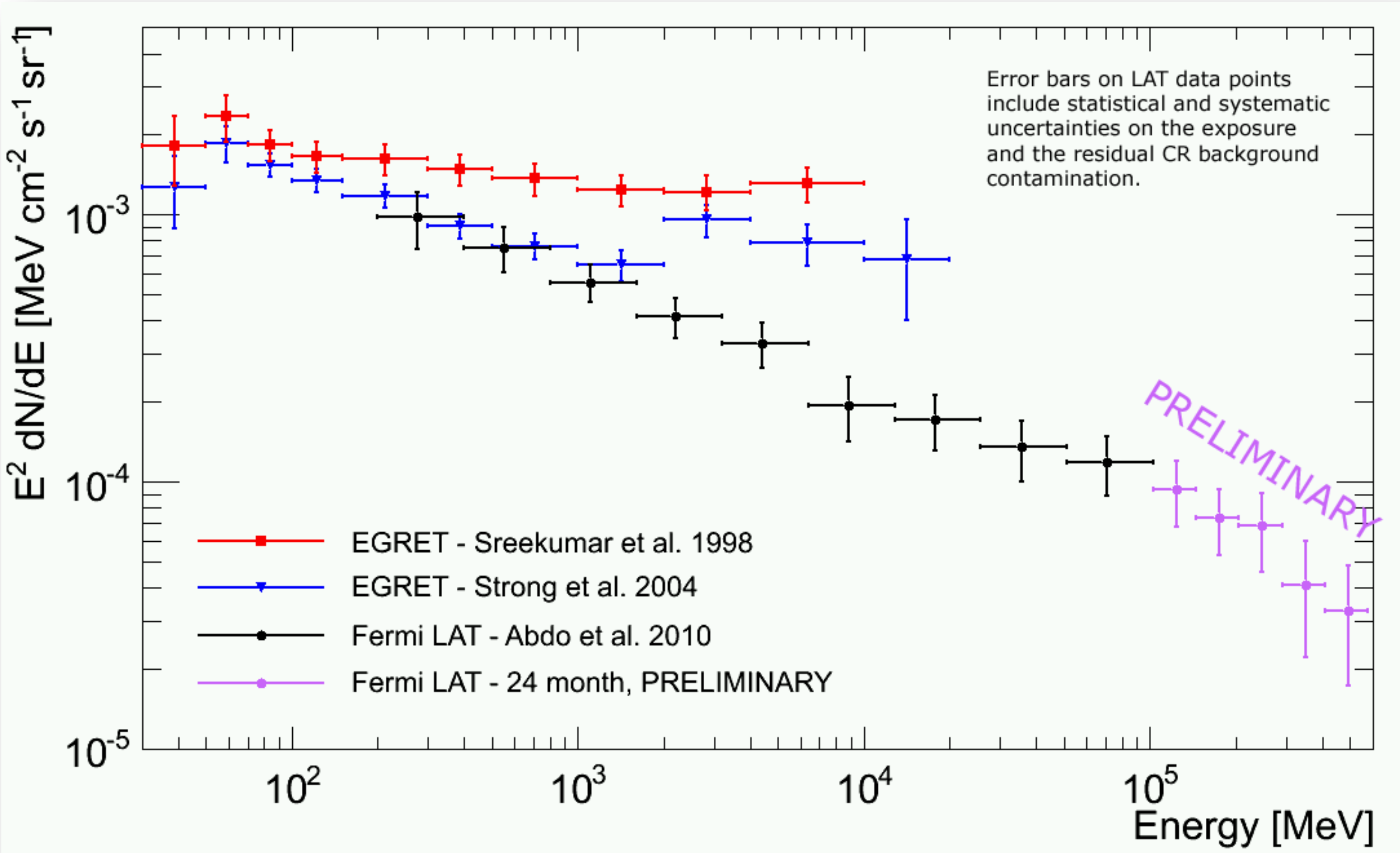
What Produces the Isotropic Flux?

earlier work: arXiv:1002.3603



See other studies by: Stecker&Salomon+96, Pavlidou&Fields+02, Narumoto&Totani06,Dermer07, Bhattacharya+09, Inoue&Totani09, Fields+10, Makiya+10, Inoue+11,Abazajian+10, Ghirlanda+11,Stecker&Venters11,Malyshev&Hogg11

Recent Update to 600 GeV

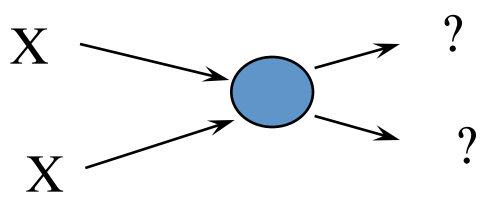


Isotropic Diffuse: What's Next

- What is producing the unaccounted flux?
- What will higher precision above 100 GeV reveal?
  - will we see attenuation due to the extragalactic background light (EBL)?
  - what else is contributing at the highest energies?
- More statistics, with detailed understanding of energy reconstruction and backgrounds at the highest energies.

Dark Matter

Some important models in particle physics could also solve the dark matter problem in astrophysics. If correct, these new particle interactions could produce an anomalous flux of cosmic particles ("indirect detection").



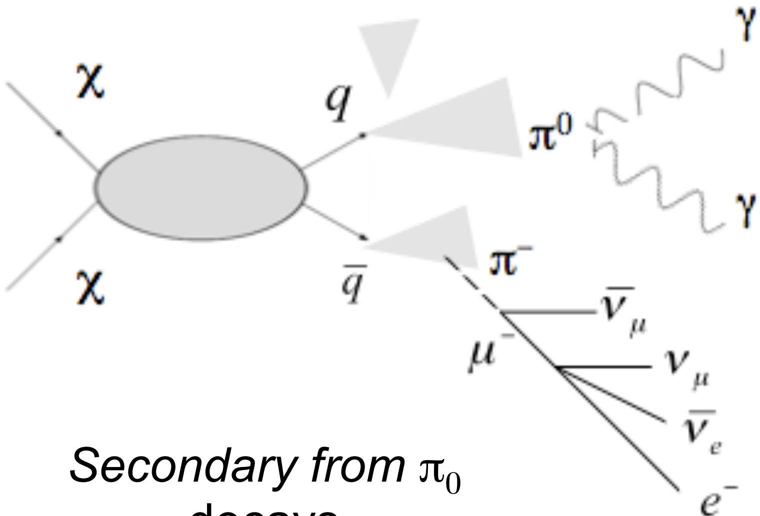
Anomalous gamma ray spectra and/or $\gamma\gamma$ or $Z\gamma$ "lines" and/or anomalous charged cosmic rays and/or neutrinos?

- If particles are stable: rate ~ (DM density)^2
- If particles unstable: rate ~ (DM density)

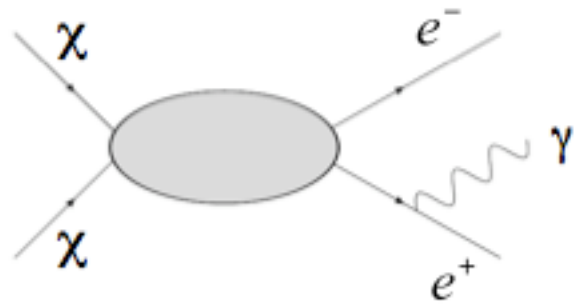
- Key interplay of techniques:
  - colliders (TeVatron, LHC)
  - direct detection experiments underground
  - indirect detection (most straightforward: gamma rays and neutrinos)
    - Full sky coverage look for clumping throughout galactic halo, including off the galactic plane (if found, point the way for ground-based facilities)
    - Intensity highly model-dependent
    - **Challenge is to separate signals from astrophysical backgrounds**

Just an example of what might be waiting for us to find!

Gamma rays from Dark Matter annihilation



Secondary from π_0 decays



Prompt lepton pair production

$$\Phi_{WIMP}(E,\Psi) = J(\Psi) \times \Phi^{PP}(E)$$

Astrophysical factor

$$J(\Psi) = \int_{l.o.s} dl(\Psi)\,\rho^2(l)$$

Particle physics factor

$$\Phi^{PP}(E) = \frac{1}{2}\frac{\langle \sigma v \rangle}{m^2_{WIMP}} \sum_f \frac{dN_f}{dE} B_f$$

Fermi Gamma-ray Space Telescope

Dark Matter: Many Places to Look!

Galactic Center

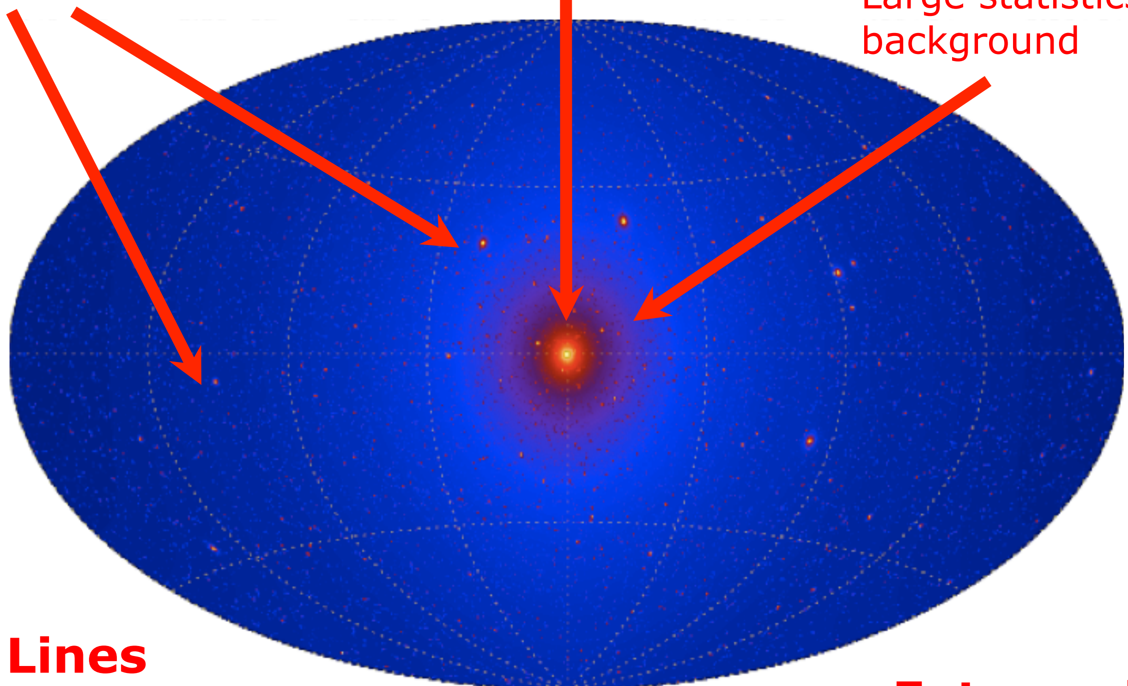
Good Statistics but source confusion/diffuse background

Satellites

Low background and good source id, but low statistics, in some cases astrophysical background

Milky Way Halo

Large statistics but diffuse background



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

And anomalous charged cosmic rays (little/no directional information, trapping times, etc.)

Spectral Lines

No astrophysical uncertainties, good source id, but low sensitivity because of expected small BR

Extra-galactic

Large statistics, but astrophysics, galactic diffuse background

Galaxy Clusters

Low background, but low statistics

They Play Together!

Direct Detection
Relic scattering RIGHT HERE at low energy. Push to larger target mass, lower backgrounds, directional sensitivity?

Accelerators
Direct production. Push to higher energy

Observations
Push toward finding and studying galactic halo objects and large scale structure.

Indirect Detection
Relic interactions (annihilations, decays) Understand the astrophysical backgrounds in signal-rich regions. Reveal the detailed astrophysical distribution of dark matter.

Simulations
Large scale structure formation. Push toward larger simulations, finer details.

Dwarf Spheriodal (dSph) Galaxies

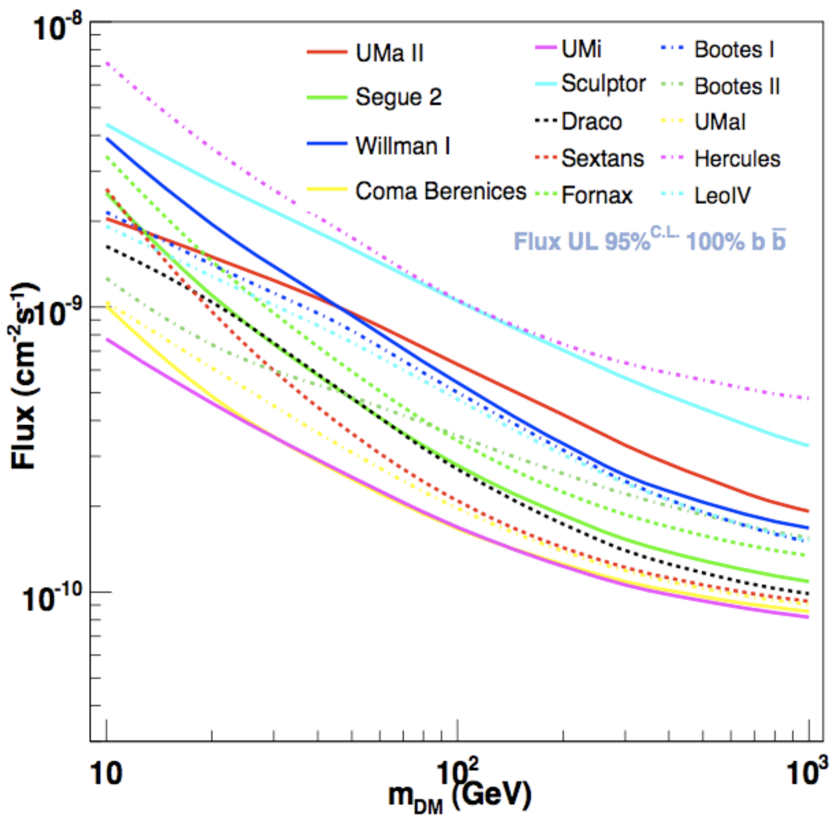
- Largest galactic substructures predicted (in ΛCDM)
- DM-dominated: mass-to-light ratios O(100-1000)
- Very low astrophysical backgrounds
  - no detected gas, low recent star formation activity
- SDSS discovery of many more ultrafaint Milkyway satellites
  - more are welcome!

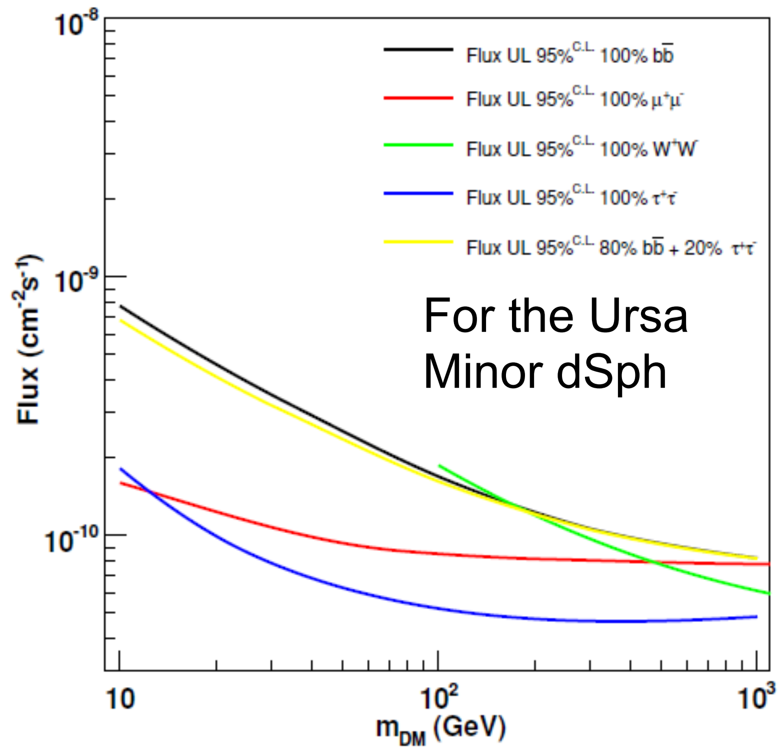
- Great opportunity for indirect DM signal searches!

Search for DM in dSph

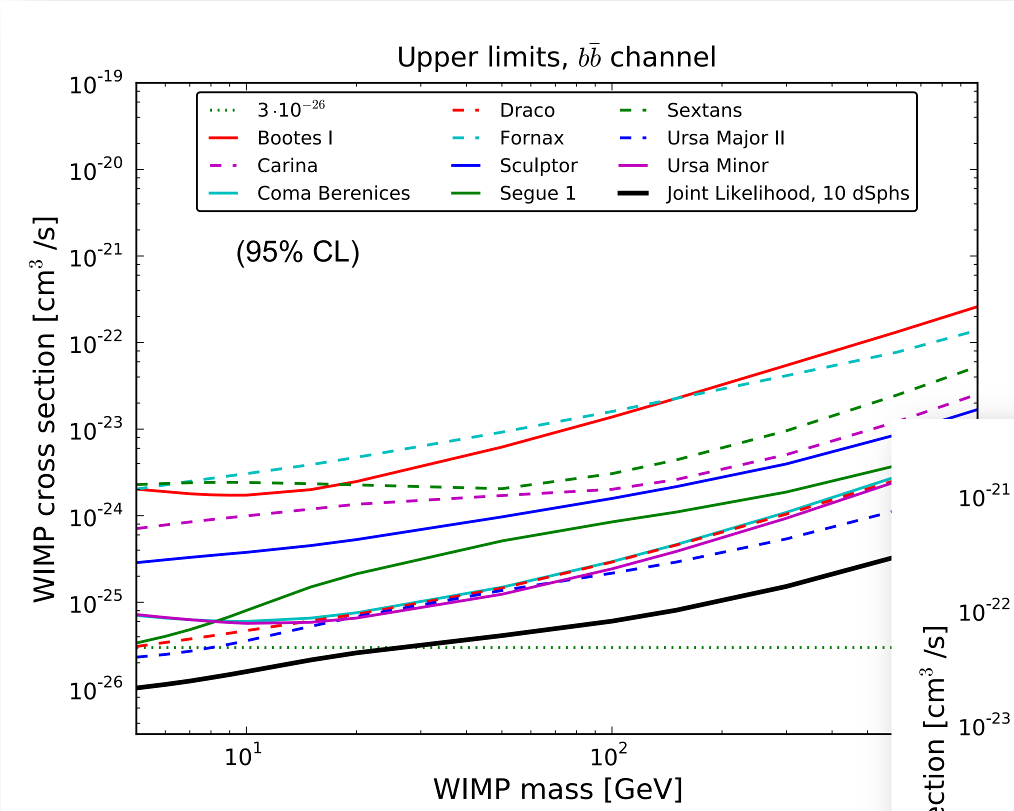
A.A. Abdo et al., ApJ 712 (2010) 147.

No detection by Fermi (100 MeV – 50 GeV) with 11 months of data. 95% flux upper limits are placed for several possible annihilation final states.



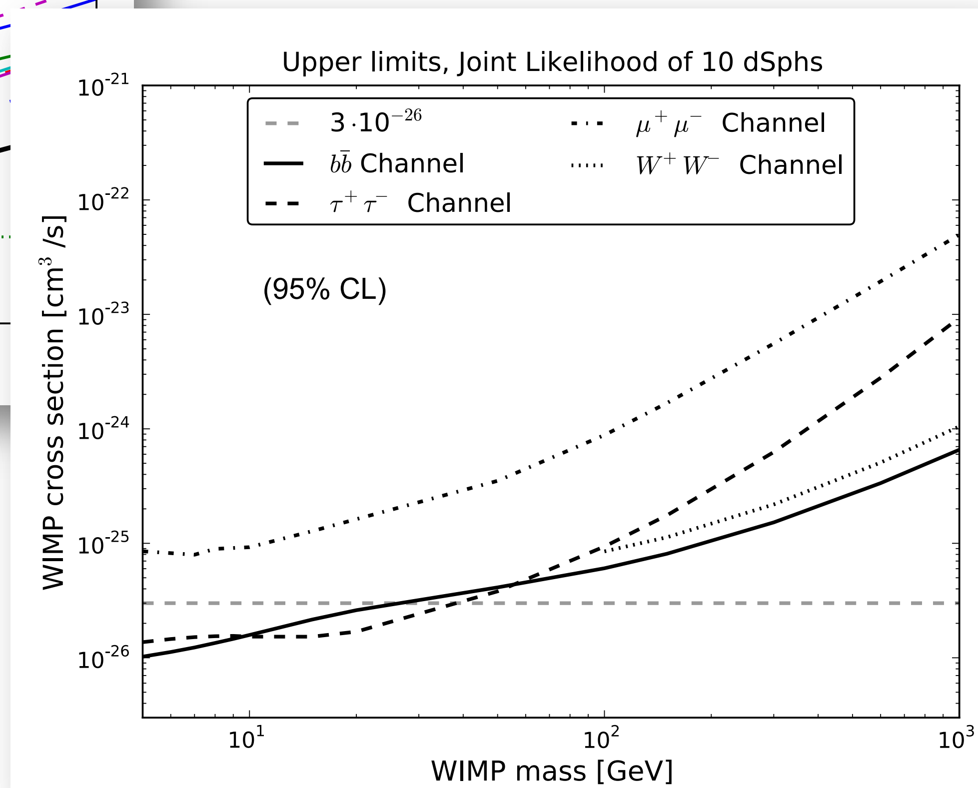


Combining dSph Limits



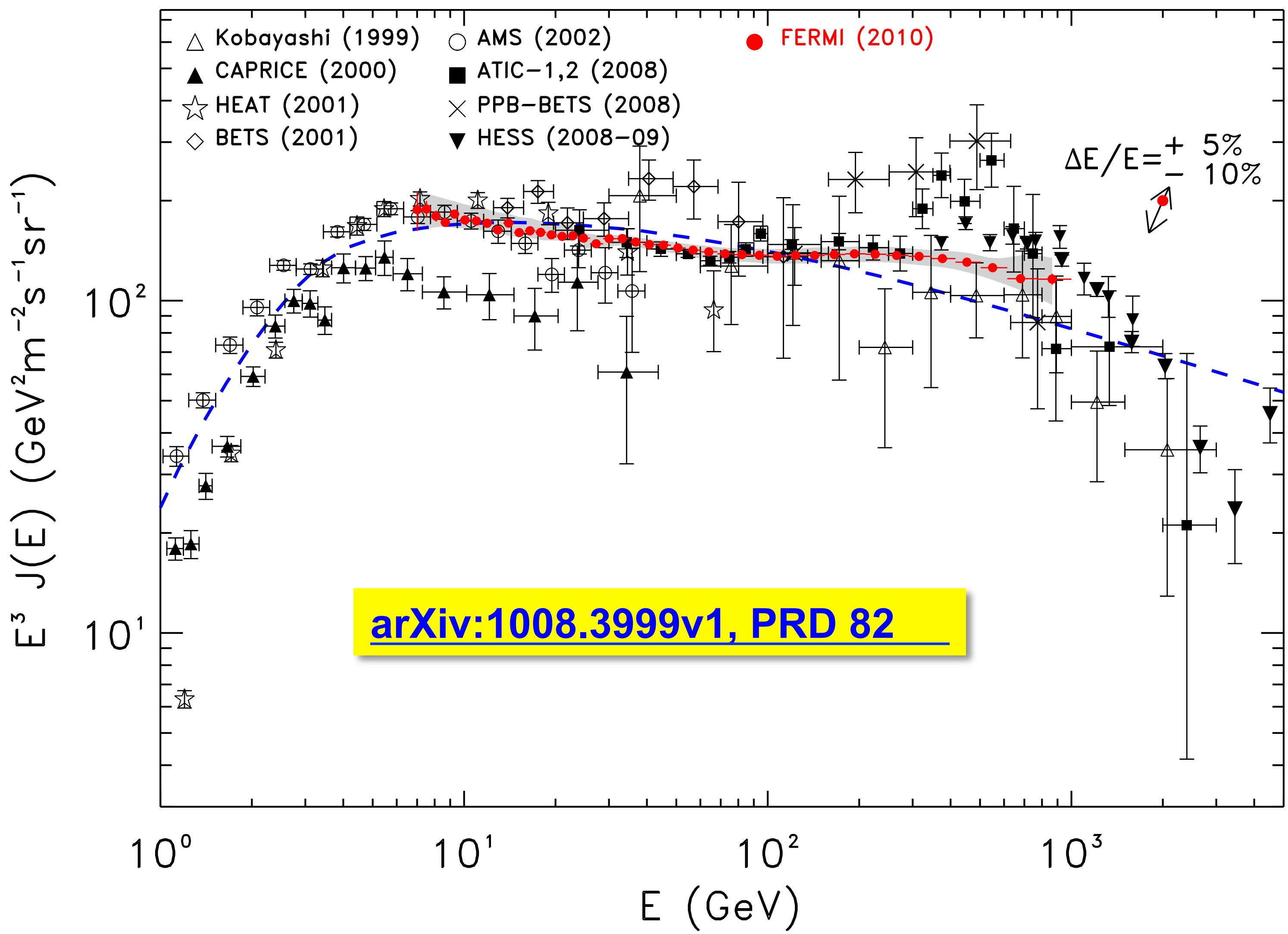
arXiv:1108.3546v2

Accepted for publication in PRL



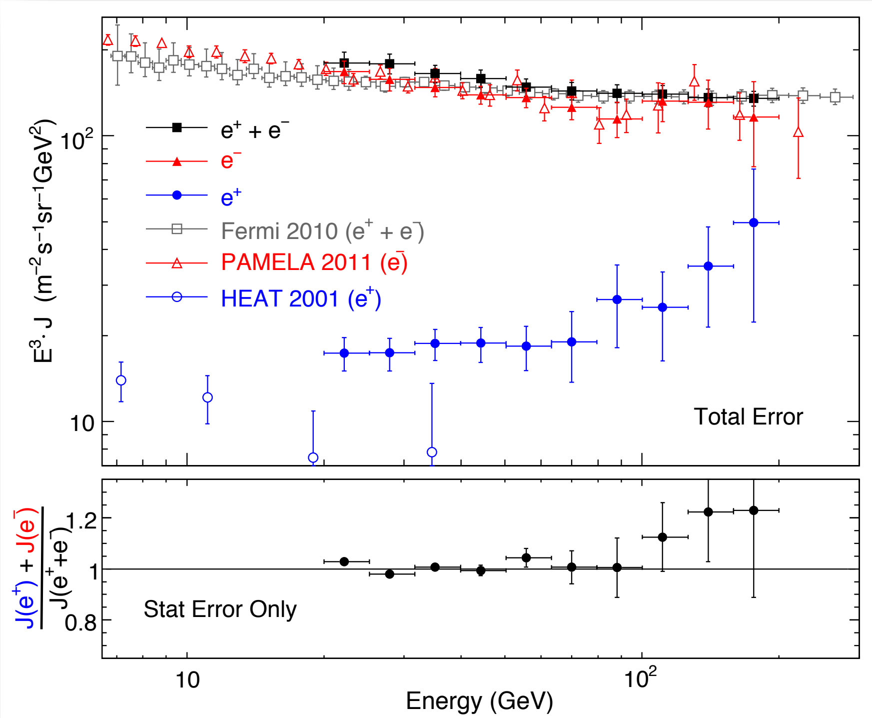
Now getting to very interesting sensitivity ranges!

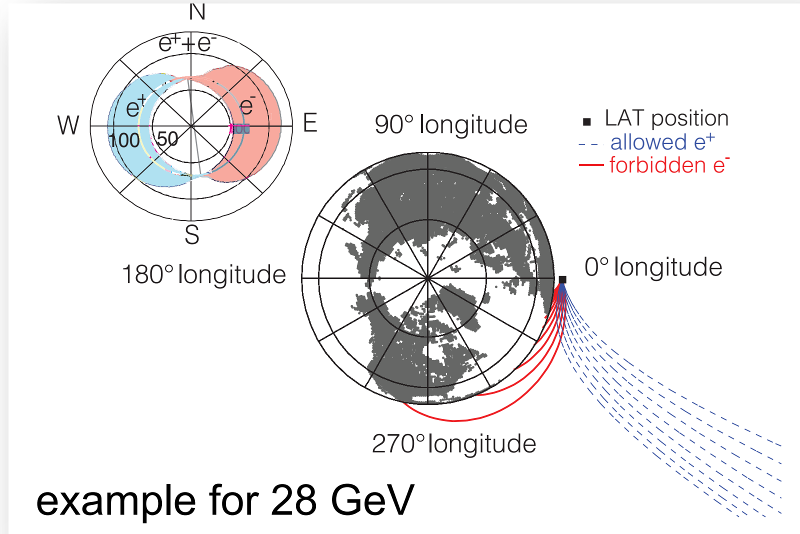
LAT e+e- Spectrum Update



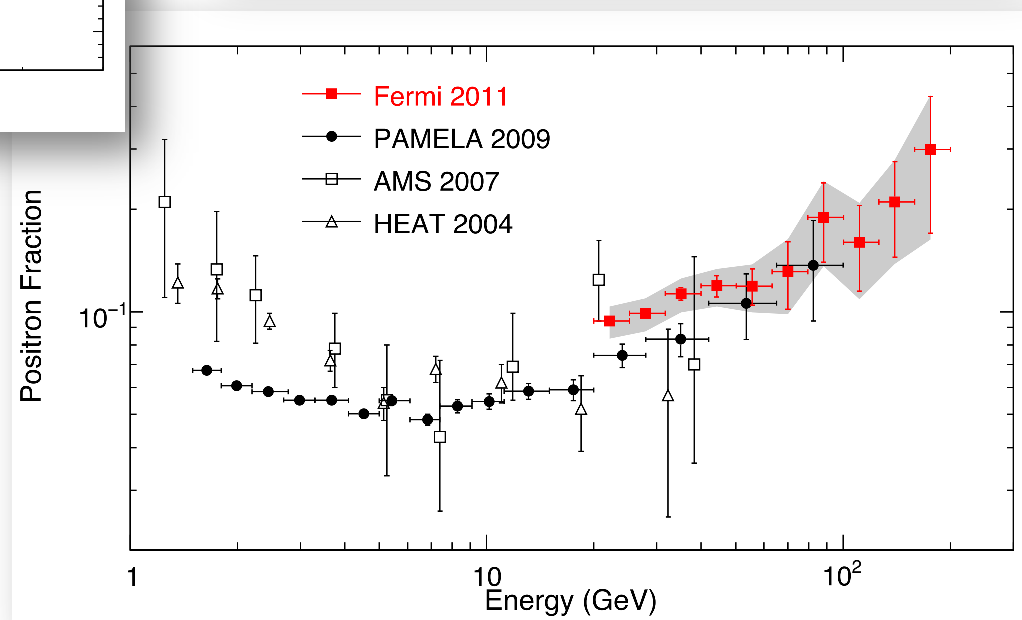
7 GeV – 1 TeV, double statistics (8M events)

LAT e+ and e- Measurement





arXiv:1109.0521



…and AMS-02 is flying!

No Significant e+e- Excess or Deficit from the Sun

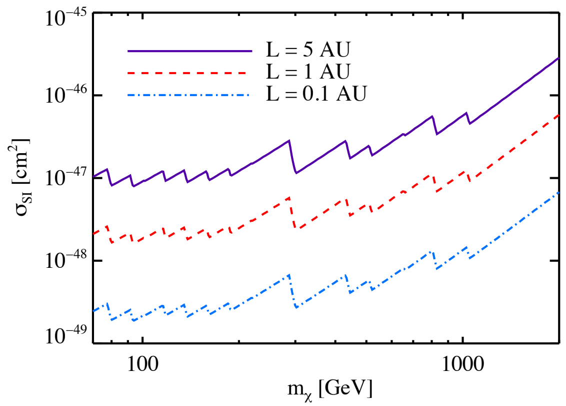


FIG. 6: Constraints on DM annihilation to e^+e^- via an intermediate state, from solar CRE flux upper limits. Solar capture of DM is assumed to take place via spin-independent scattering. The constraints obtained for three values of the decay length L of the intermediate state are shown. Models above the curves exceed the solar CRE flux upper limit at 95% CL for a 30° ROI centered on the Sun.

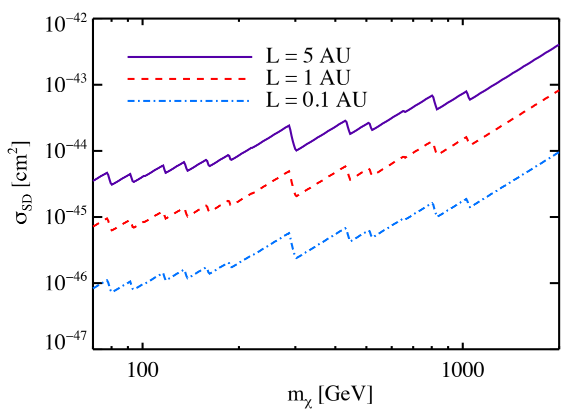
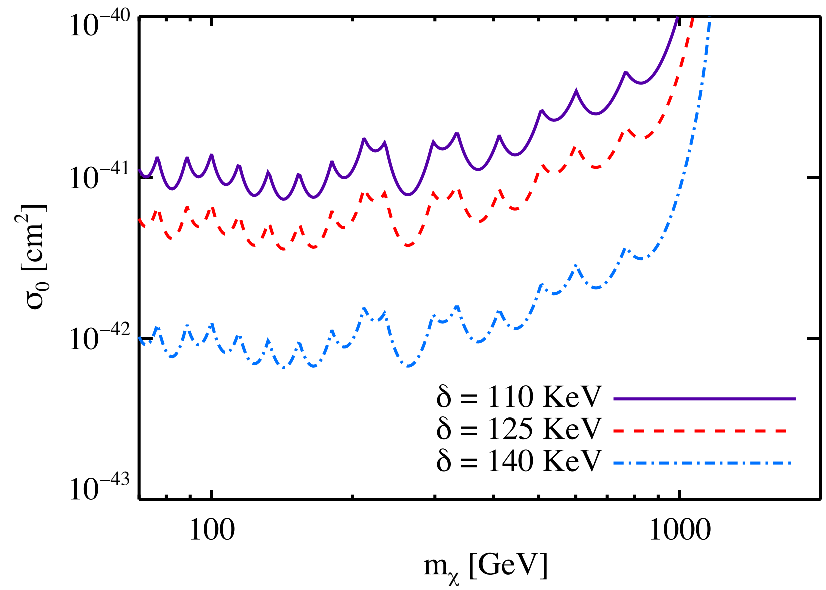


FIG. 7: Constraints on DM parameters for annihilation to e^+e^- via an intermediate state as in Fig. 6, except assuming solar capture by spin-dependent scattering.

arXiv:1107.4272

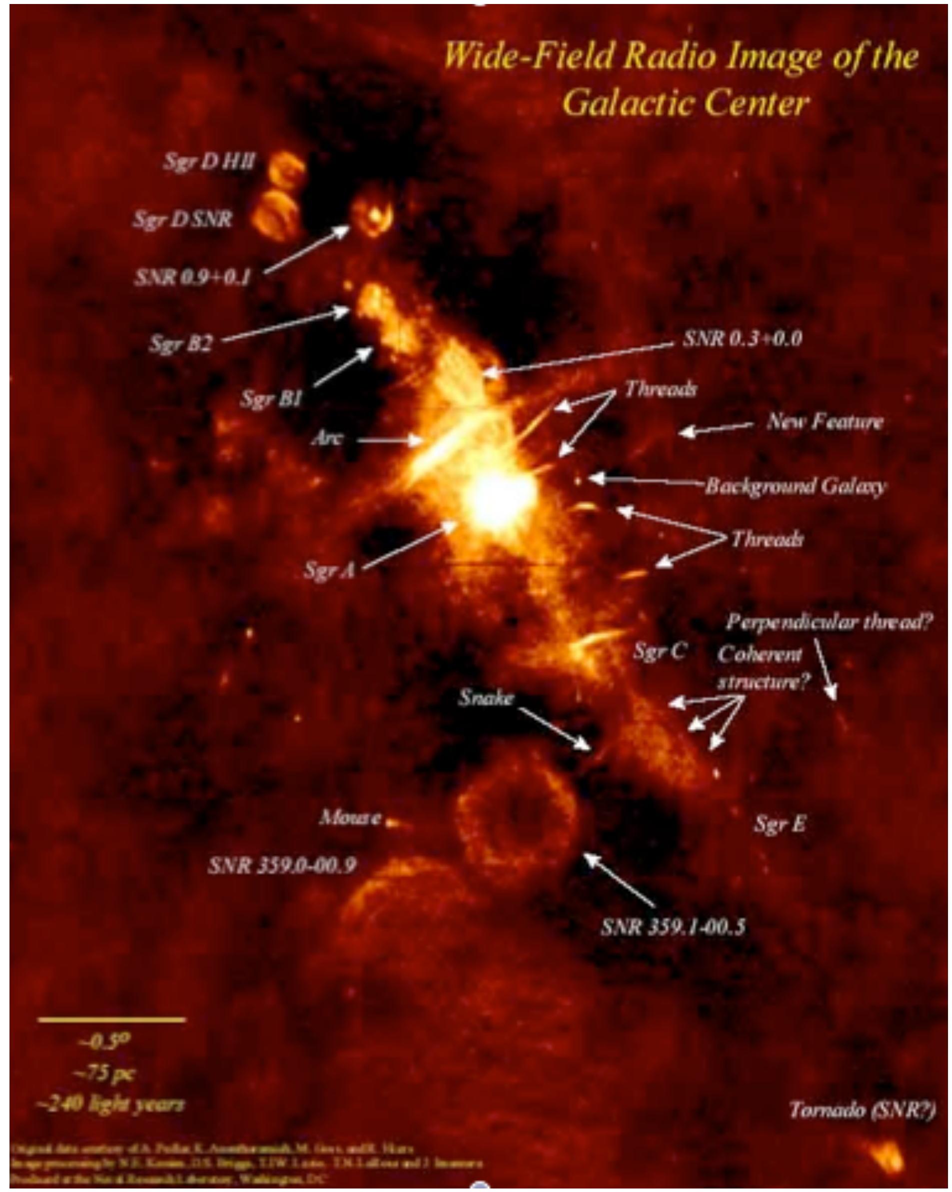


strongly excludes iDM explanation for DAMA/LIBRA – CDMS inconsistency for m>70 GeV and annihilation to e+e-

Intermediate state ➔ e+e- constraints

Inner Galaxy

- "*Lasciate ogne speranza, voi ch'entrate"* – Dante Alighieri
- *"If you're going through hell, KEEP GOING!" - Winston Churchill* (emphasis added)

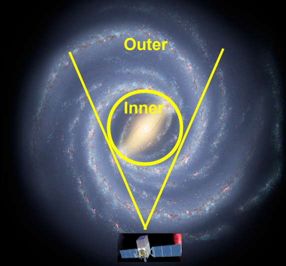


Inner Galaxy

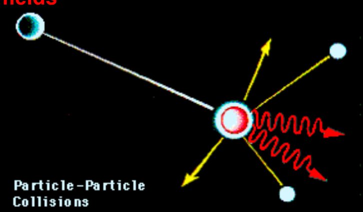
Disentangling the Many Sources of Gamma-Ray Emission is Challenging …

The emission from the inner Galaxy consists of a number of components:

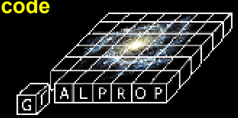
- Outer Galaxy
- True inner Galaxy
- Point sources
- Unresolved sources



Diffuse gamma rays produced by cosmic rays interacting with the interstellar gas and radiation fields

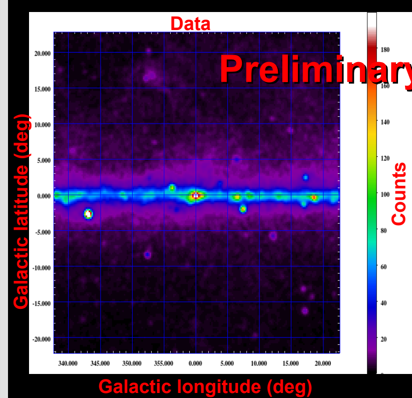


Use galprop cosmic ray propagation/diffuse emission code

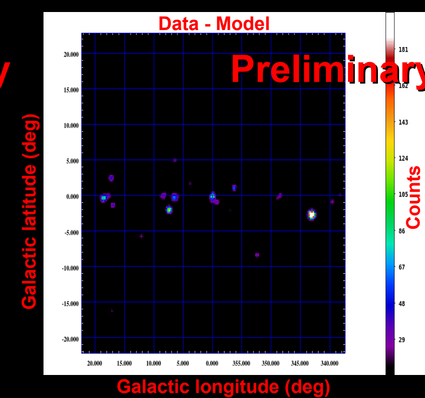


http://galprop.stanford.edu

Subtraction of the Diffuse Emission



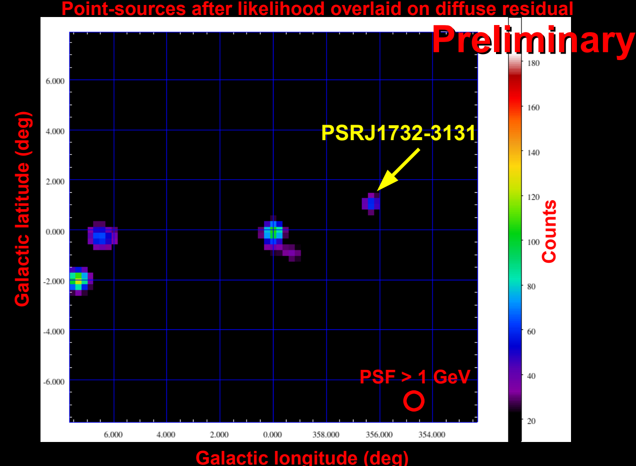
Data > 1 GeV for 45°x45° region about GC



Data - Model > 1 GeV for 45°x45° region about GC

32 Months Data (Front)

Residual Emission for 15°x15° about GC

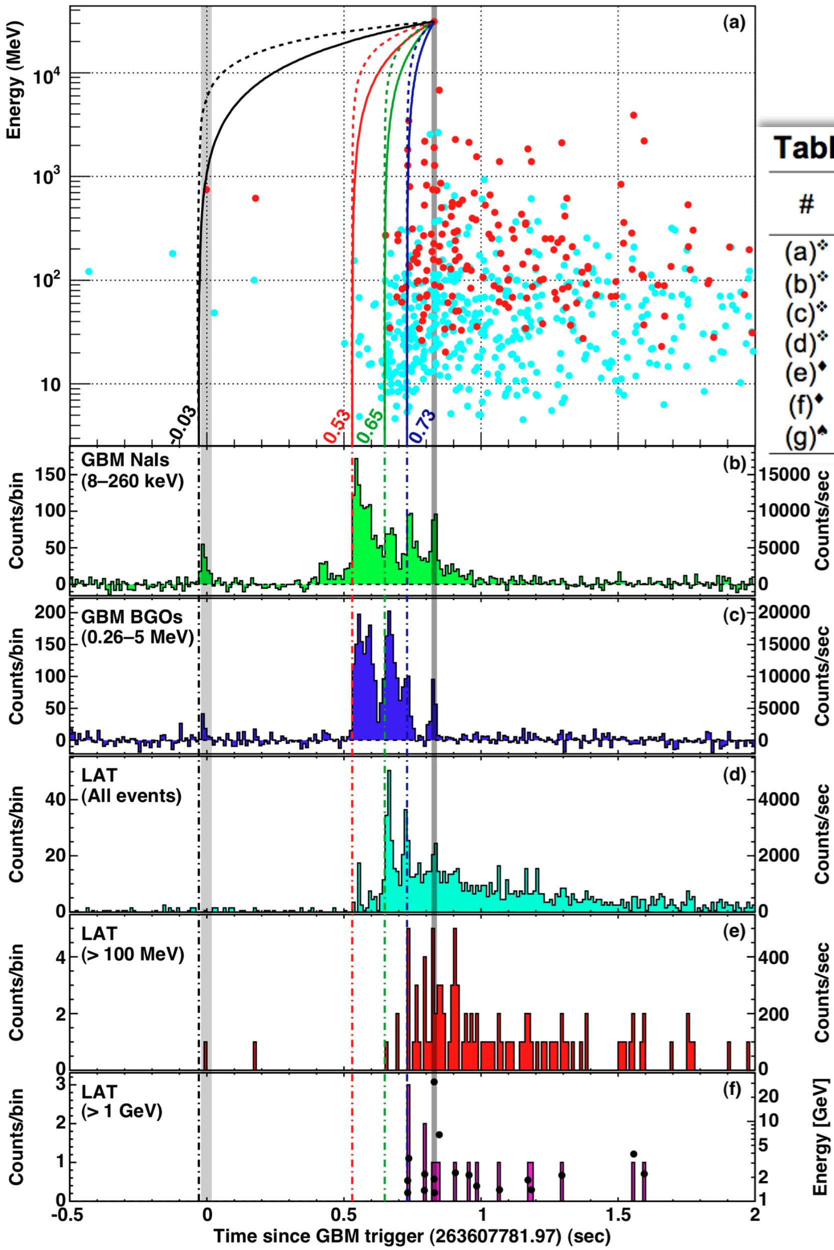


Bright excesses remain after model subtraction

Summary

- The majority of the diffuse emission is removed using a physically-motivated model based on GALPROP
- Peaks in residual emission consistent with known sources
- Work in progress to characterise the low-level residual structures and point sources
- Forthcoming paper(s) will describe the method and results in detail

QG-Related Limits from GRB 090510



Published in Nature, vol 462, p331 (plus comment on p291)

Table 2 | Limits on Lorentz Invariance Violation

#	$t_{start} - T_0$ (ms)	Limit on $\lvert\Delta t\rvert$ (ms)	Reasoning for choice of t_{start} or limit on Δt or $\lvert\Delta t/\Delta E\rvert$	E_l † (MeV)	Valid for s_n*	Lower limit on $M_{QG,1}/M_{Planck}$
(a)✣	−30	< 859	start of any < 1 MeV emission	0.1	1	> 1.19
(b)✣	530	< 299	start of main < 1 MeV emission	0.1	1	> 3.42
(c)✣	*648*	< 181	start of main > 0.1 GeV emission	100	1	> 5.63
(d)✣	730	< 99	start of > 1 GeV emission	1000	1	> 10.0
(e)♦	—	< 10	association with < 1 MeV spike	0.1	±1	> 102
(f)♦	—	< 19	If 0.75 GeV‡ γ-ray from 1st spike	0.1	−1	> 1.33
(g)♠	$\lvert\Delta t/\Delta E\rvert$ < 30 ms/GeV		lag analysis of > 1 GeV spikes	—	±1	> 1.22

…with the assumption that the HE photons are not emitted *before* the LE photons.

also see, e.g., Ellis, Mavromatos, and Nanopoulos **arXiv:0901.4052** / **Phys.Lett. B674 (2009) 83-86** and Amelino-Camelia, Ellis, Mavromatos, Nanopoulos and Sarkar, **Nature 393, 763 (1998)**.

EBL Constraints

arXiv:1005.0996

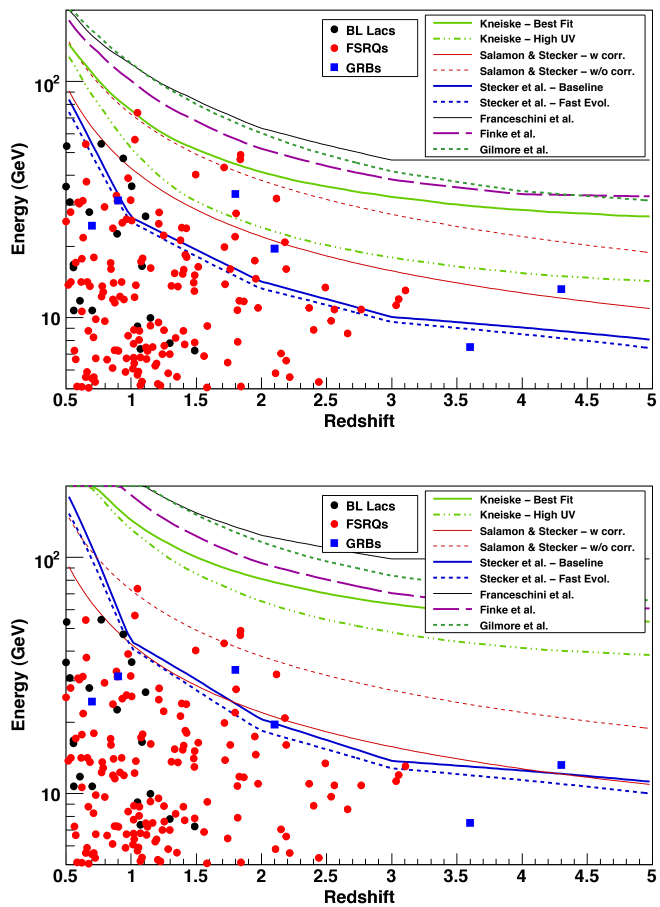


Fig. 2.— Highest-energy photons from blazars and GRBs from different redshifts. Predictions of $\gamma\gamma$ opacity $\tau_{\gamma\gamma} = 1$ (top panel) and $\tau_{\gamma\gamma} = 3$ (bottom panel) from various EBL models are indicated by lines. Photons above model predictions in this figure traverse an EBL medium with a high γ-ray opacity. The likelihood of detecting such photon considering the spectral characteristics of the source are considered in the method presented in section 3.2.1.

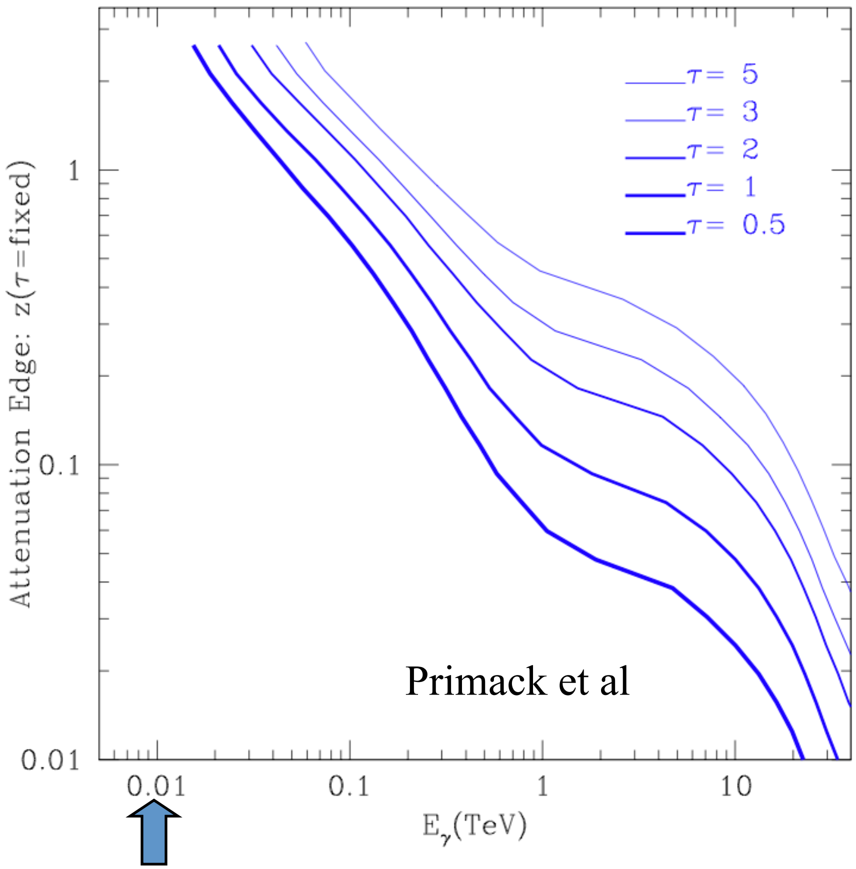
Source	z	Energy (GeV)	P_{bkg}	HEP method applied to Stecker 06 P_{HEP}	$P_{rejection}$	HEP Rejection Significance
J1147-3812	1.05	73.7	7.0×10^{-4}	1.2×10^{-4}	8.1×10^{-4}	$3.2\ \sigma$
J1504+1029	1.84	48.9	5.6×10^{-3}	6.7×10^{-5}	5.7×10^{-3}	
		35.1	9.8×10^{-3}	6.8×10^{-3}	1.7×10^{-2}	
		23.2	5.6×10^{-3}	1.8×10^{-1}	1.9×10^{-1}	
				Combined $P_{rej} = 1.7 \times 10^{-5}$		$4.1\ \sigma$
J0808-0751	1.84	46.8	1.5×10^{-3}	1.9×10^{-4}	1.7×10^{-3}	
		33.1	2.7×10^{-3}	3.7×10^{-3}	6.4×10^{-3}	
		20.6	6.9×10^{-3}	2.5×10^{-1}	2.6×10^{-1}	
				Combined $P_{rej} = 2.8 \times 10^{-6}$		$4.5\ \sigma$
J1016+0513	1.71	43.3	1.1×10^{-3}	5.4×10^{-4}	1.6×10^{-3}	
		16.8	8.2×10^{-3}	4.9×10^{-1}	4.9×10^{-1}	
		16.1	8.2×10^{-3}	6.5×10^{-1}	6.5×10^{-1}	
				Combined $P_{rej} = 5.3 \times 10^{-4}$		$3.3\ \sigma$
J0229-3643	2.11	31.9	1.7×10^{-3}	8.9×10^{-5}	1.8×10^{-3}	$2.9\ \sigma$
GRB 090902B	1.82	33.4	2×10^{-6}	2.0×10^{-4}	2.0×10^{-4}	$3.7\ \sigma$
GRB 080916C	4.24	13.2	8×10^{-8}	6.5×10^{-4}	6.5×10^{-4}	$3.4\ \sigma$

Table 4: Listed are the significance of rejecting the "baseline" model (Stecker et al. (2006)), calculated using the HEP method as described in Section 3.2.1. For completeness, we also report individually the probability of the HEP to be a background event (P_{bkg}) and the probability for this HEP not to be absorbed by the EBL if it were emitted by the source (P_{HEP}). As explained in the text: $P_{rejection} = P_{bkg} + P_{HEP} \times (1 - P_{bkg})$. For those sources with more than one constraining photon, the individual and combined $P_{rejection}$ are calculated. The "fast evolution" model by Stecker et al. (2006) is more opaque and leads to an even higher significance of rejection. Applying this method to less opaque models leads to no hints of rejection since the probability P_{HEP} is large in those cases (e.g. $\gtrsim 0.1$ for the Franceschini et al. (2008) EBL model). Note that a log parabola model was used as the intrinsic model for source J1504+1029 since evidence of curvature is observed here even below 10 GeV (see Table 2).

Even just a few high-Z GRBs and additional HE photons from Pass8 reanalysis will be VERY helpful

An Important Energy Band

Photons with E>10 GeV are attenuated by the diffuse field of UV-Optical-IR extragalactic background light (EBL)



No significant attenuation below ~10 GeV.

only $e^{-\tau}$ of the original source flux reaches us

EBL over cosmological distances is probed by gammas in the 10-100 GeV range.

In contrast, the TeV-IR attenuation results in a flux that may be limited to more local (or much brighter) sources.

A dominant factor in EBL models is the star formation rate -- <u>attenuation measurements can help distinguish models</u>.

Prospects and Promise

- DM:
  - With dSphs: as LAT moves to 1 TeV and beyond with Pass 8 sensitivity for high mass WIMPs will increase ~linearly with time. We could be able to exclude WIMP masses to ~> 200 GeV at below 3×10^{-26} cm^3/s with 10 years of data. More dSphs will also help!
  - Galactic Center: Pass8, use of covariance information, and improved analysis will enable us to dissect the Galactic Center. *This will take time.*
  - All the other DM venues: clusters, lines, other DM-dominated satellites, …
- Other new physics analyses in the pipeline
- Every high-z GRB is precious
  - additional probes of velocity dispersion effects
  - golden EBL constraints
    - does the whole picture hang together? Large boosts also probe Lorentz Invariance.
- …and, of course, there is plenty of room for more surprises!