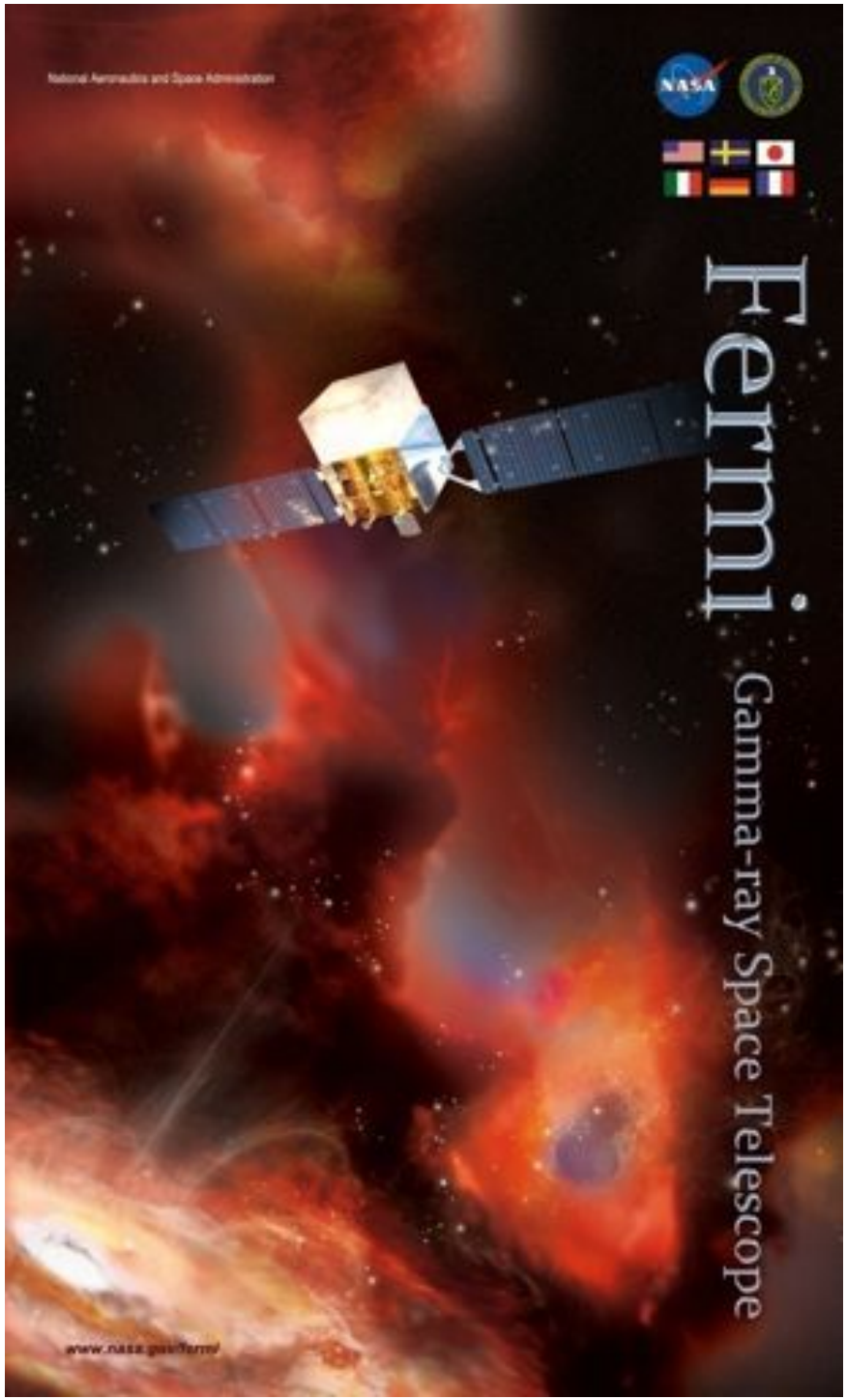


The Fermi Large Area Telescope at five years and future prospects

Luca Latronico
(luca.latronico@to.infn.it)
INFN-Torino
On behalf of the Fermi Mission Team

Workshop on the Future of Dark Matter Astro-Particle Physics: Insights and Perspectives
ICTP, Trieste
8-11 October 2013

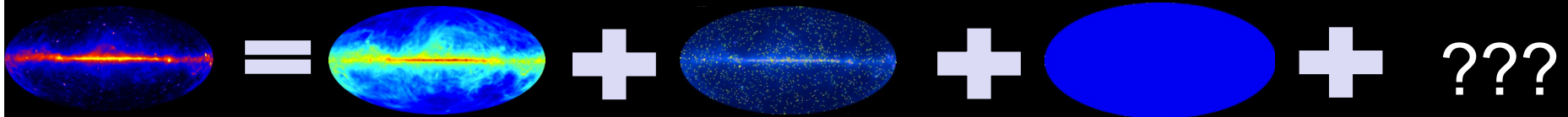
Talk outline

Science with the Fermi Observatory

Mission Status and Future prospects

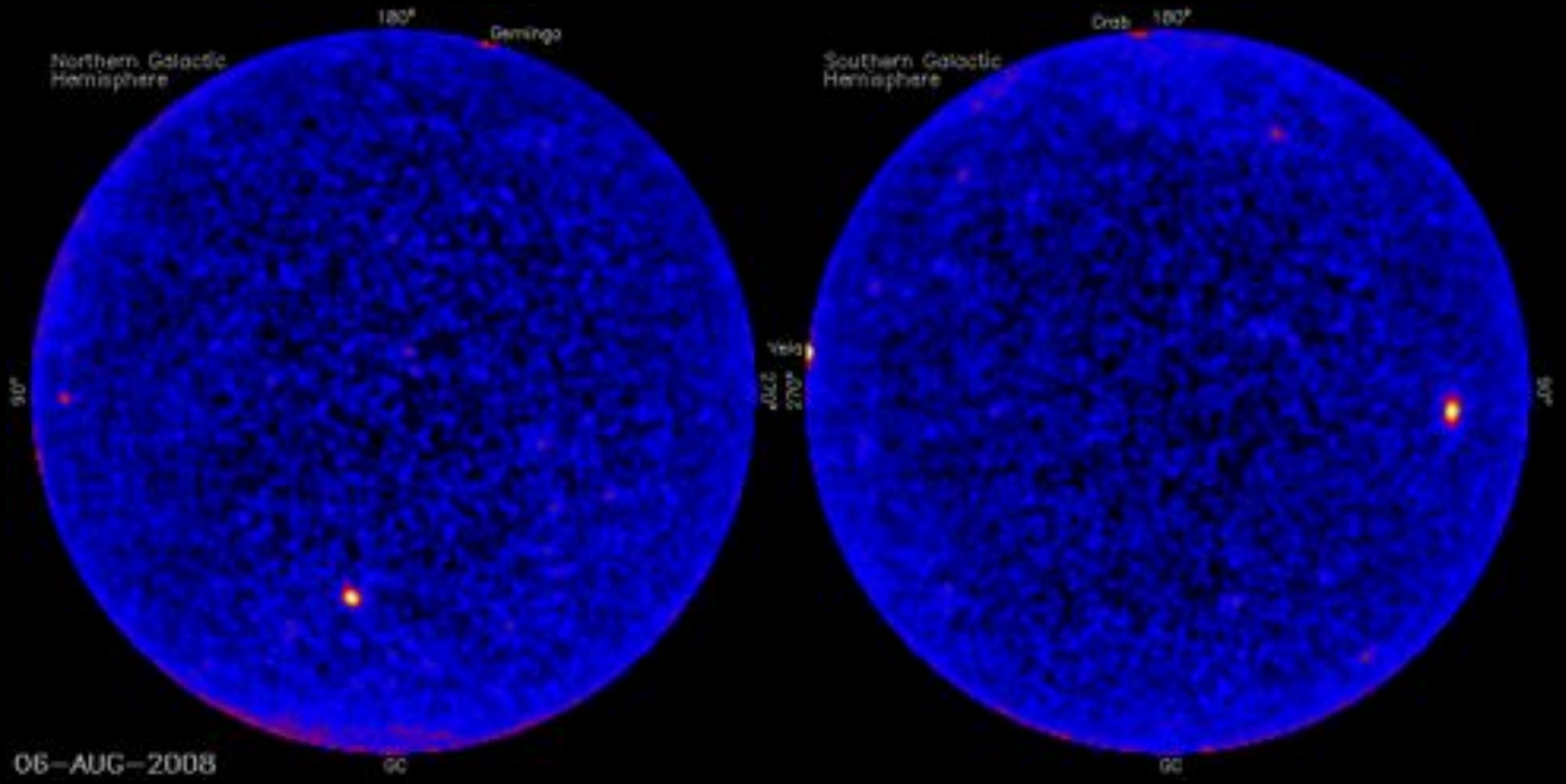
Discovering the gamma-ray sky

LAT – 5 years skymap



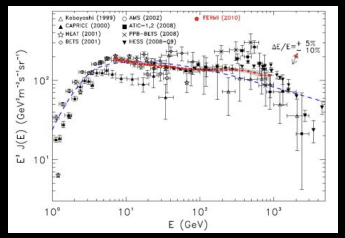
GeV Sky Galactic Point Sources Isotropic

The variable gamma-ray sky

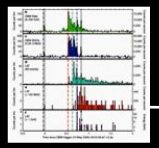


LAT – daily count maps of North South skies – 3 months

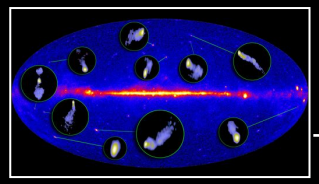
Increasing Classes of Fermi-LAT Sources



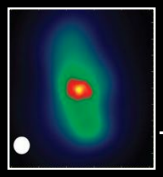
e^+e^- spectrum



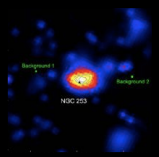
GRBs



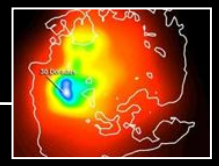
Blazars (782)



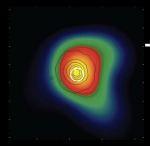
Radio Galaxies (12)



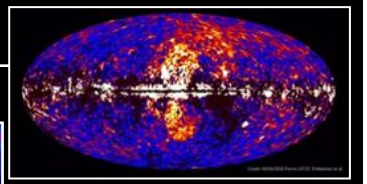
Starburst Galaxies (4)



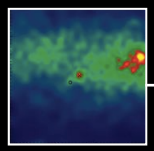
LMC & SMC



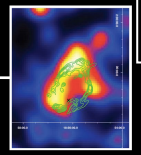
Globular Clusters (11)



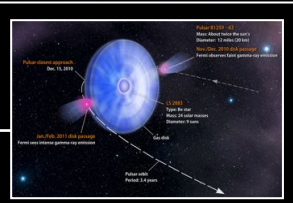
Fermi Bubbles



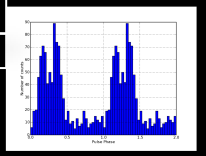
Nova (4)



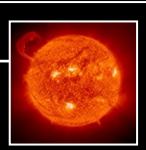
SNR & PWN (68)



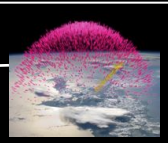
γ-ray binaries (6)



Pulsars: young & millisecond (MSP) (117+)



Sun: flares & CR interactions



Terrestrial Gamma-ray Flashes

Local

Galactic

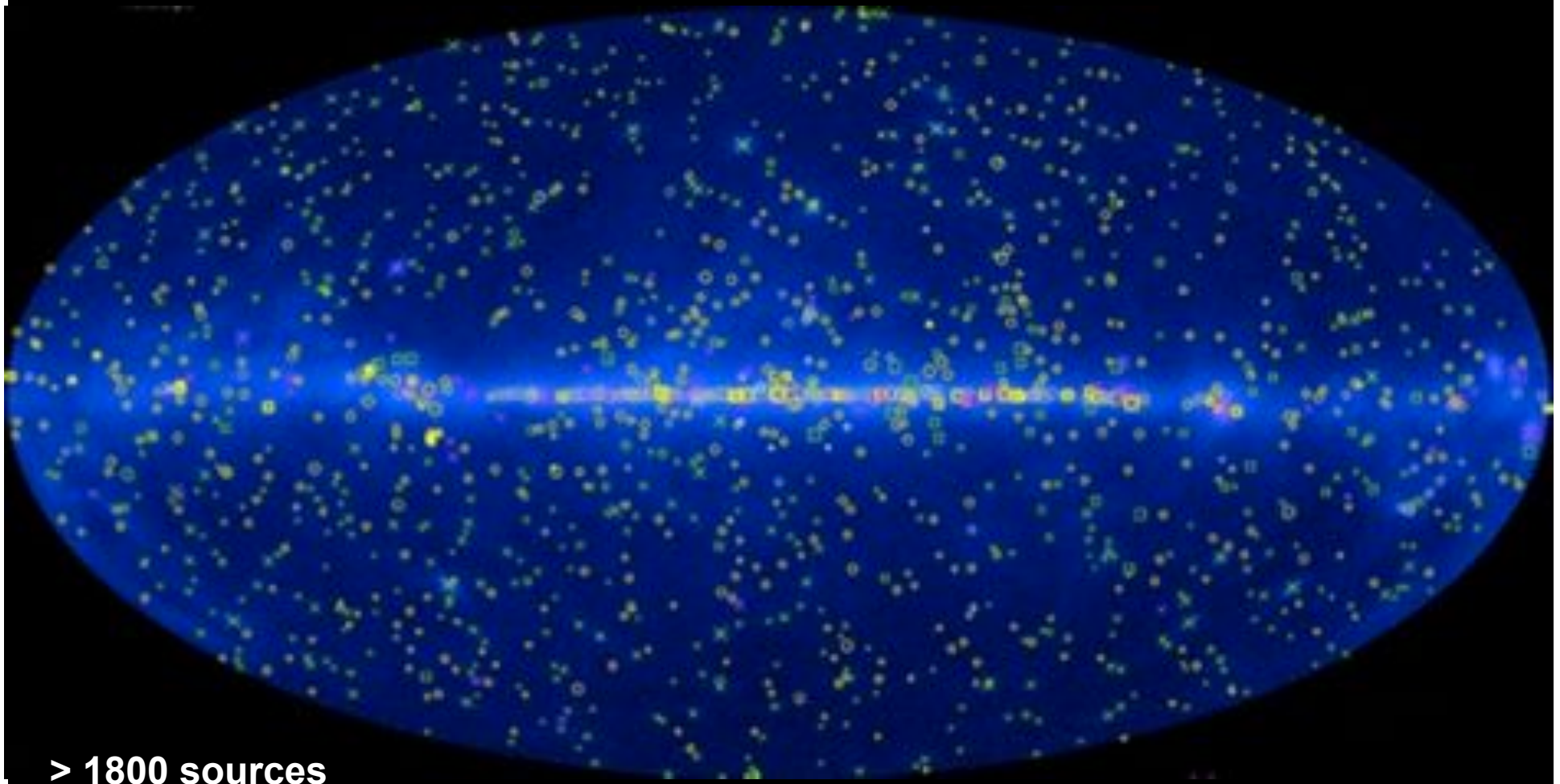
Extragalactic

Ackermann+ (LAT) [arXiv:1108.1202]

Unidentified Sources (~600)

Fermi 2FGL catalog

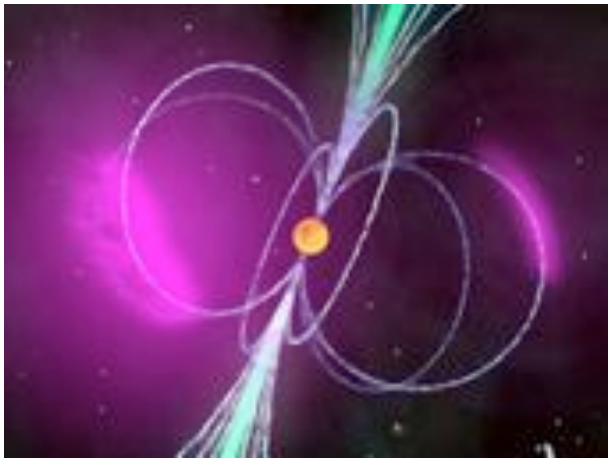
Nolan et al.: 2012ApJS..199...31N



> 1800 sources
> 10 source classes
known classes (AGN, Pulsars, PWN, SNR...)
New emitters (Novae, ms PSR, starbursts,
~30% unidentified

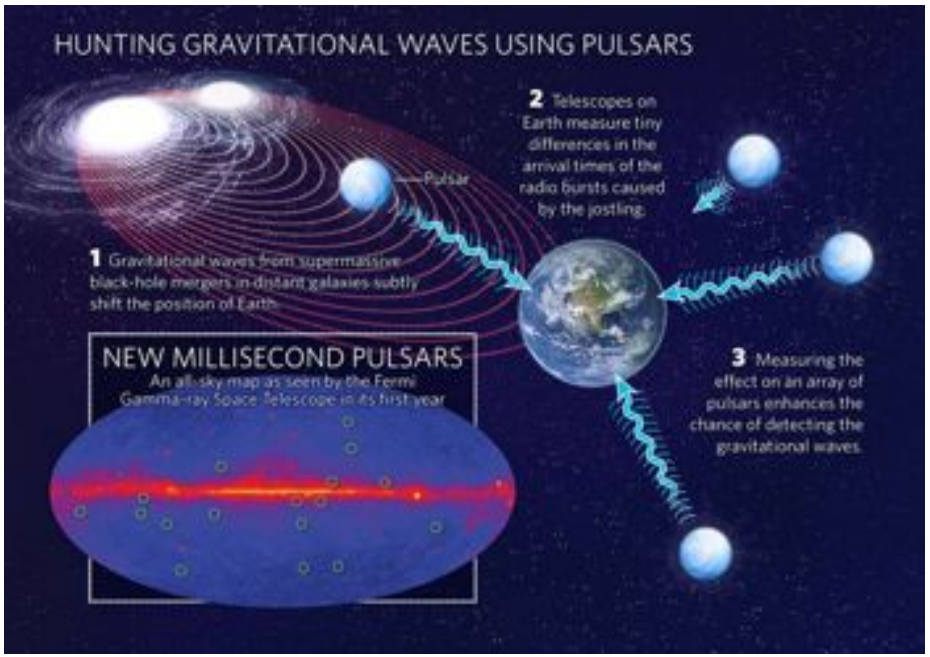
3FGL in preparation

A new picture for pulsars



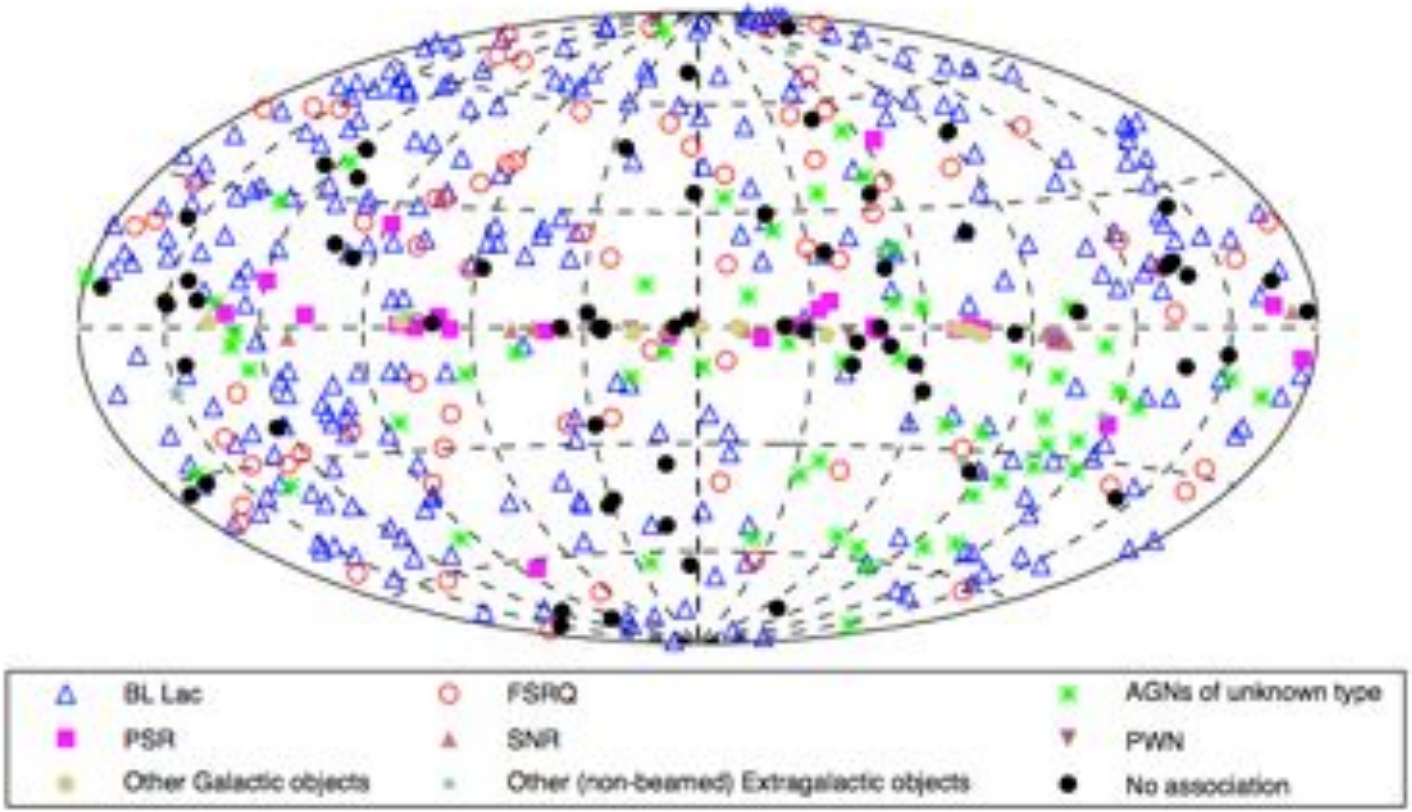
- Emission mechanism away from star
- Many γ-ray only PSR
- ms PSR in γ-ray
  - Pulsar timing array for gravitational waves detection
- ms PSR in radio searches from LAT UNIDs

Pletsch, H. J. et al. 2012, ApJ, 744, 105
Saz Parkinson, P. M. et al. 2010, ApJ, 725, 571
Abdo, A. A. et al. 2010, ApJS, 187, 460
Abdo, A. A. et al. 2009, Science, 325, 840
Abdo, A. A. et al. 2009, Science, 325, 845
Abdo, A. A. et al. 2009, Science, 325, 848
Abdo, A. A. et al. 2008, Science, 322, 1218
…. plus many other
2013 AAS/HEAD Rossi Prize



Hard Source List

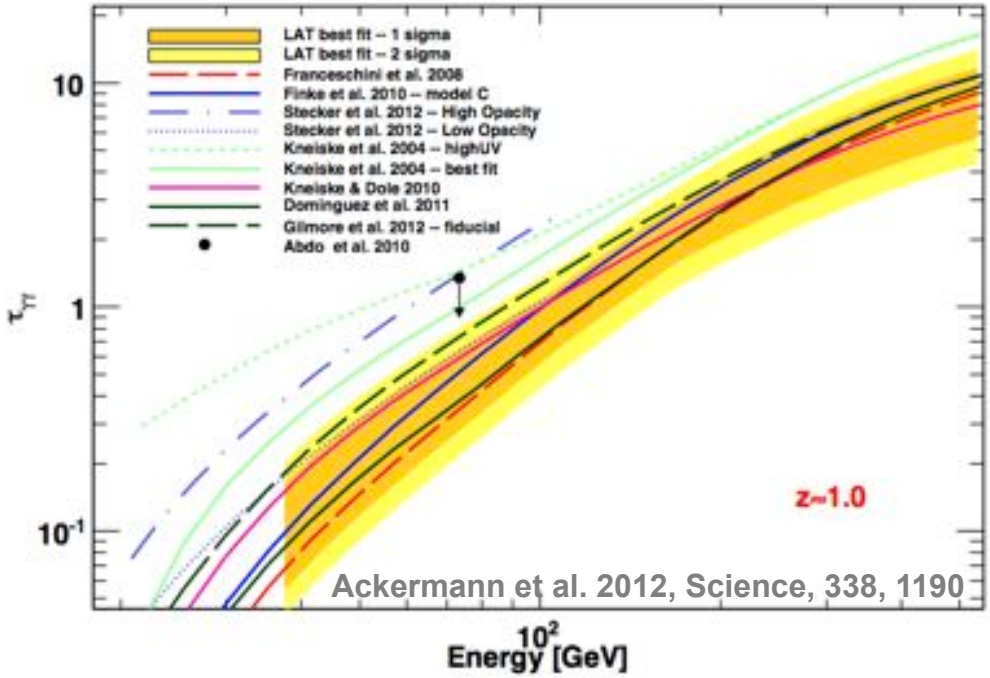
arxiv 1306.6772



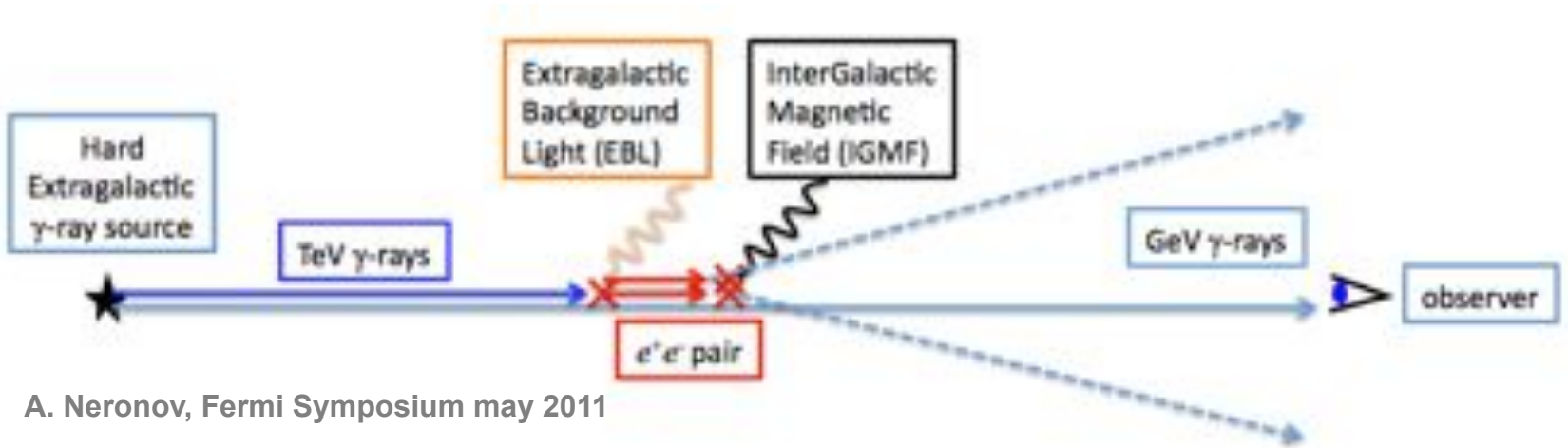
- First catalog of 514 source above 10 GeV
- Synergies with Cerenkov telescope

AGNs for fundamental physics

- Opacity of the Universe
  - Constraining EBL models
- Axion searches
- Pair halo and limits to inter-galactic magnetic fields
  - Currently lower bounds (no halo!) at 10^{-16} – 10^{-17} G



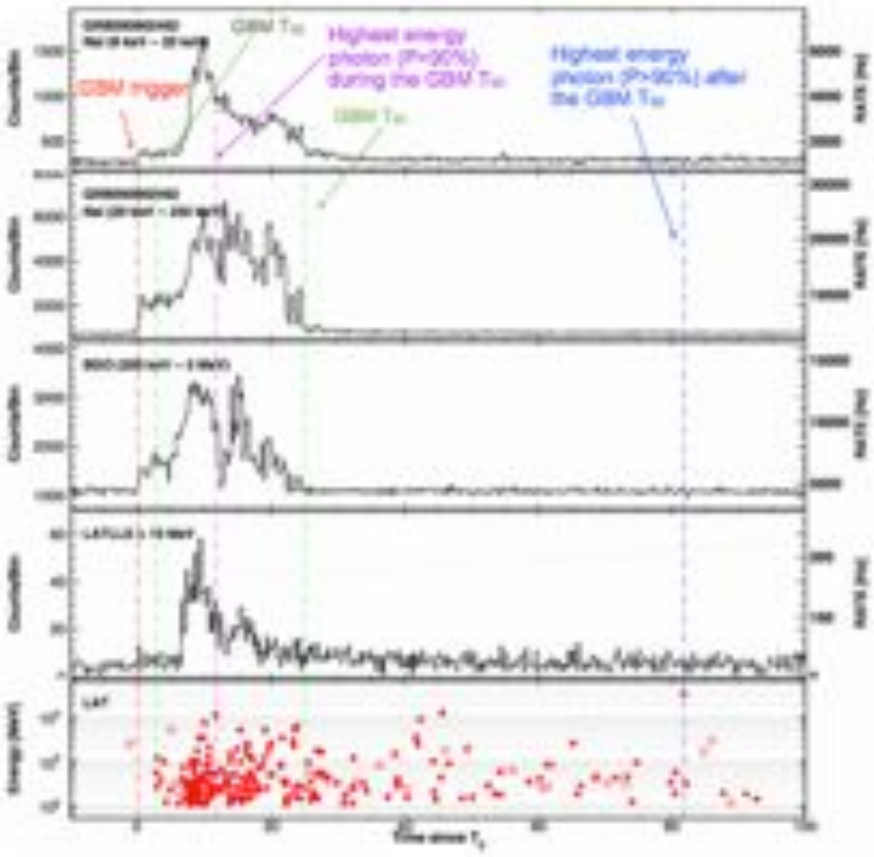
Ackermann et al. 2012, Science, 338, 1190



A. Neronov, Fermi Symposium may 2011

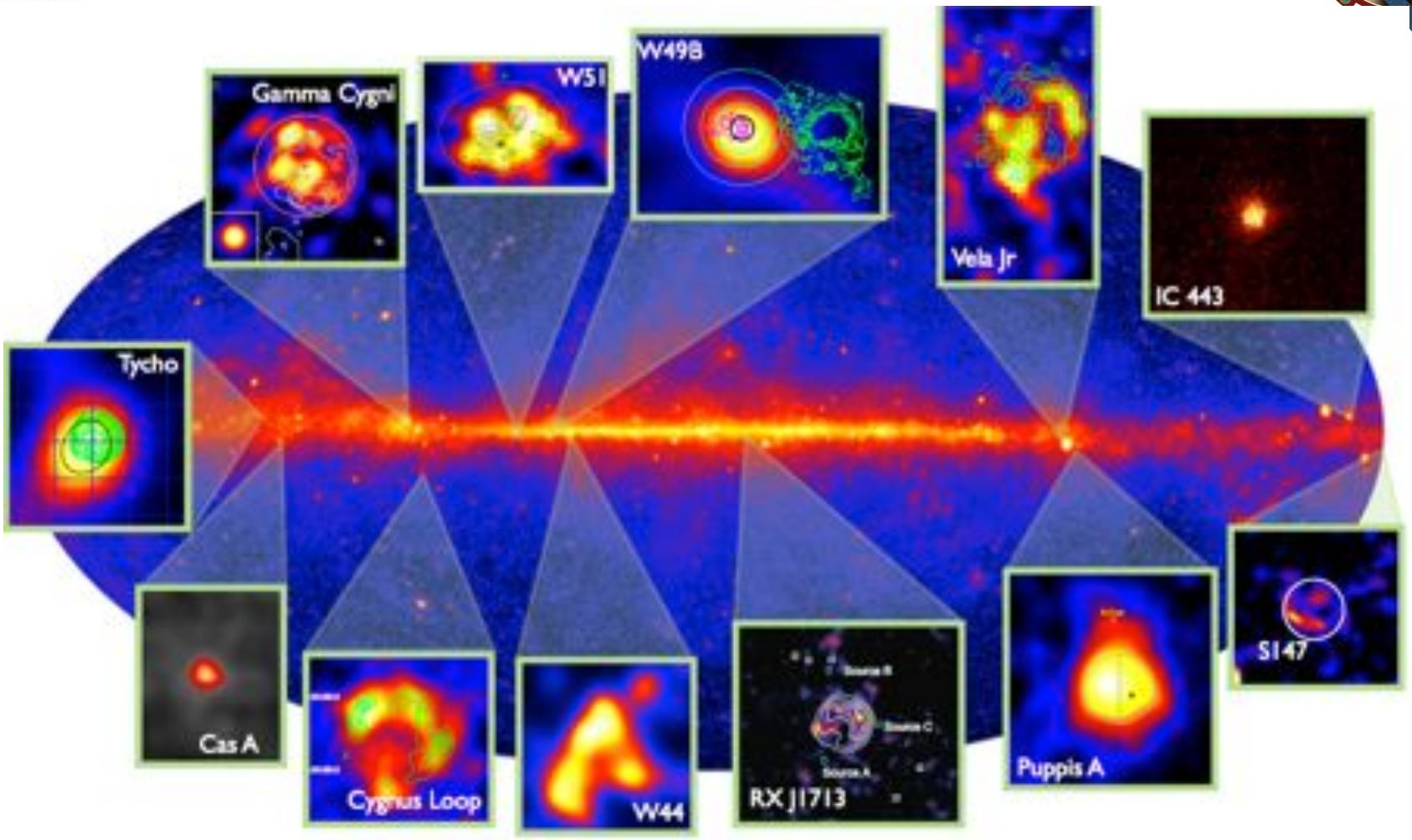
Gamma-Ray Bursts with the Fermi-LAT

- Individual bursts plus LAT GRB catalog
- Common properties in the sample
  - Delayed HE emission
  - Longer HE duration
  - Evidence for multi-component spectra
- Emission mechanism
  - And connection to Cosmic Rays
- Fundamental physics
  - Lorentz Invariance Violation
  - Limits on Extra Galactic Background Light from single high energy photons



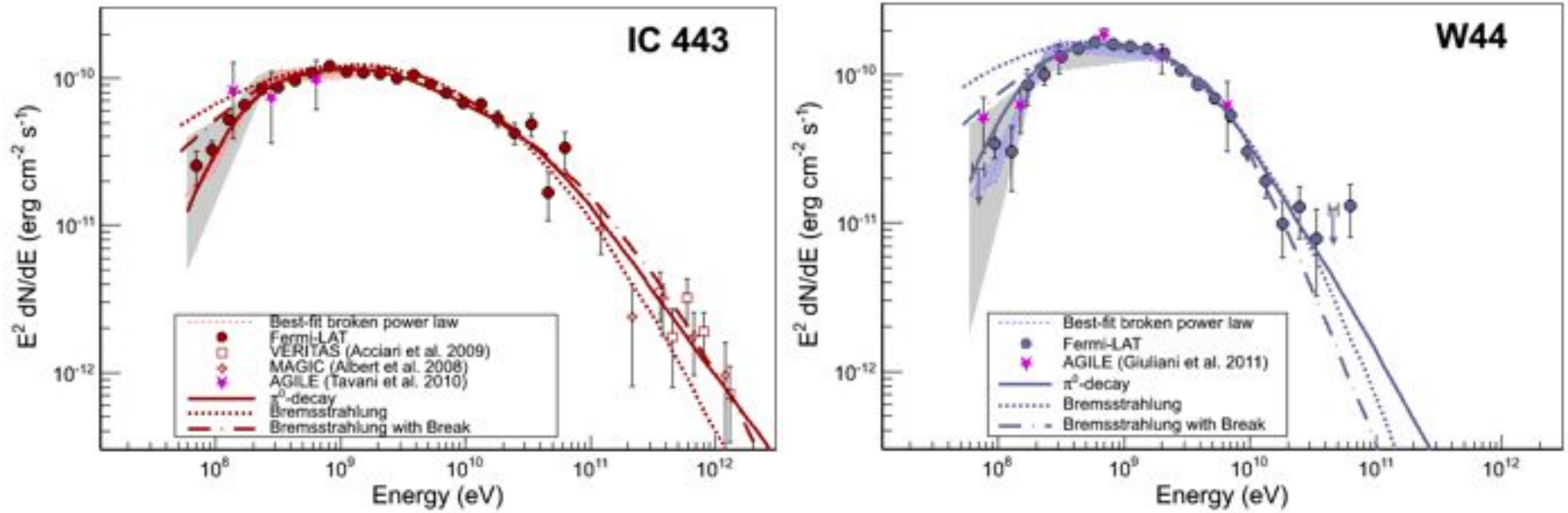
Abdo, A. A. et al. 2009, Nature, 462, 331
Abdo, A. A. et al. 2009, Science, 323, 1688
The First LAT GRB Catalog, arxiv 1303.2908, Submitted to ApJS

SuperNova Remnants – towards a catalog



- 25 published SNRs + 30 candidates in 2FGL
- Requires combination of spatial and energy information
- Diffuse emission modeling is a key systematic uncertainty

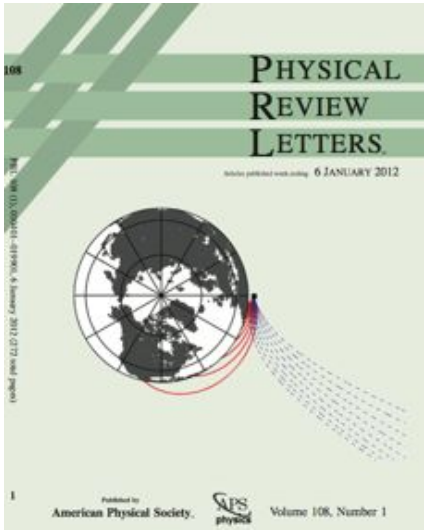
Science Highlights – CR protons in SNR

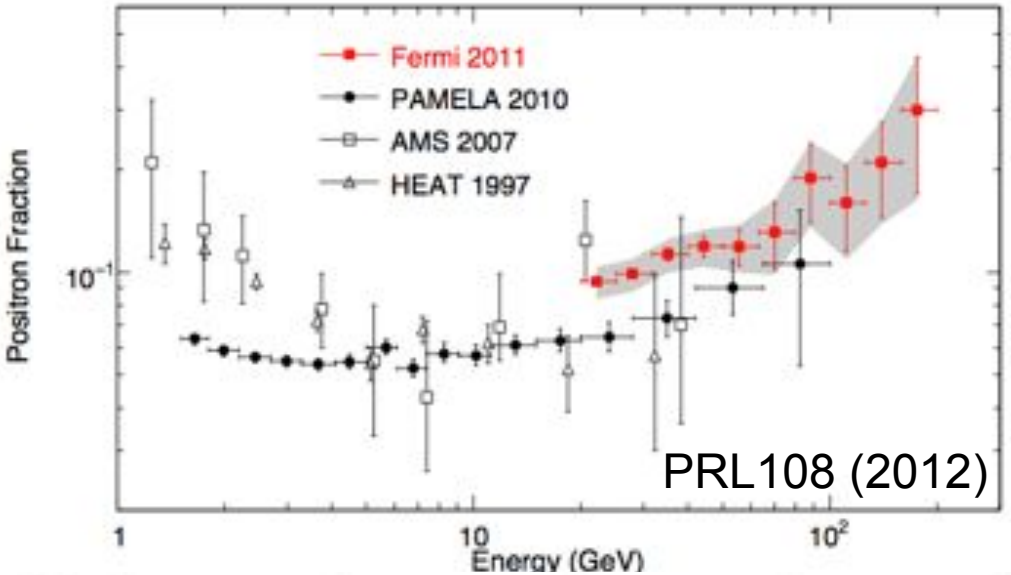


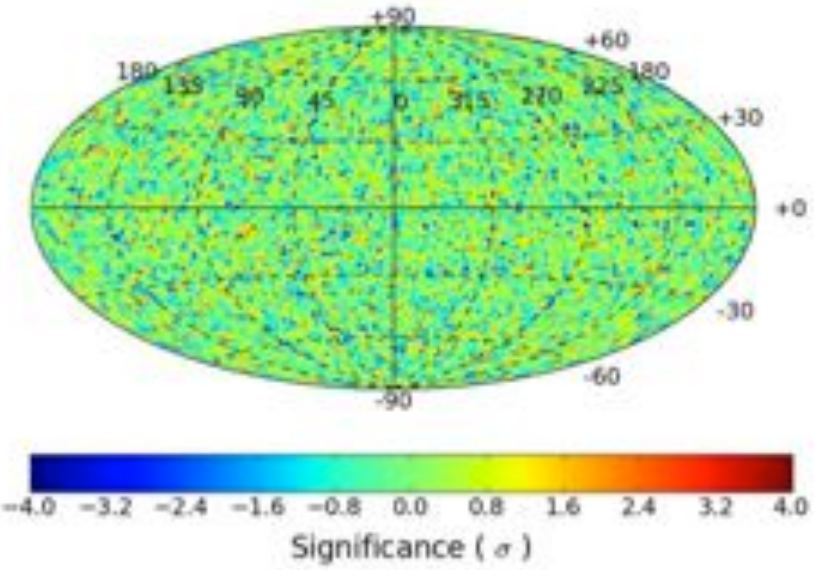
- Unambiguous and robust detection of pion decay bump in W44 and IC443 (thanks to increased low energy Pass7 acceptance)
- Proof that SNR accelerate protons

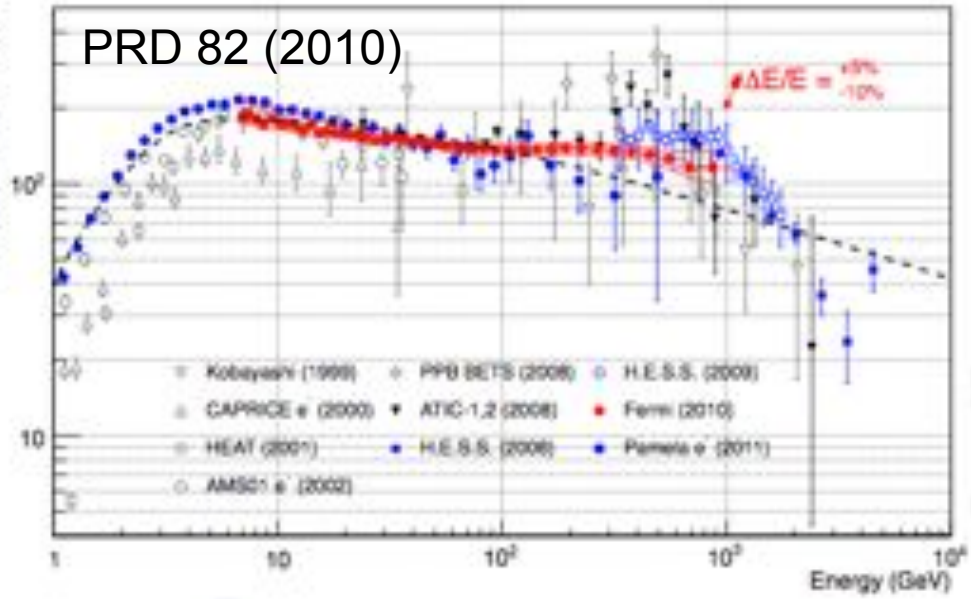
Detection of the pion-decay cutoff in Supernova remnants
2013, Science, 339, 807

Cosmic Ray Electrons - Highlights









Dark Matter Search Strategies

Satellites

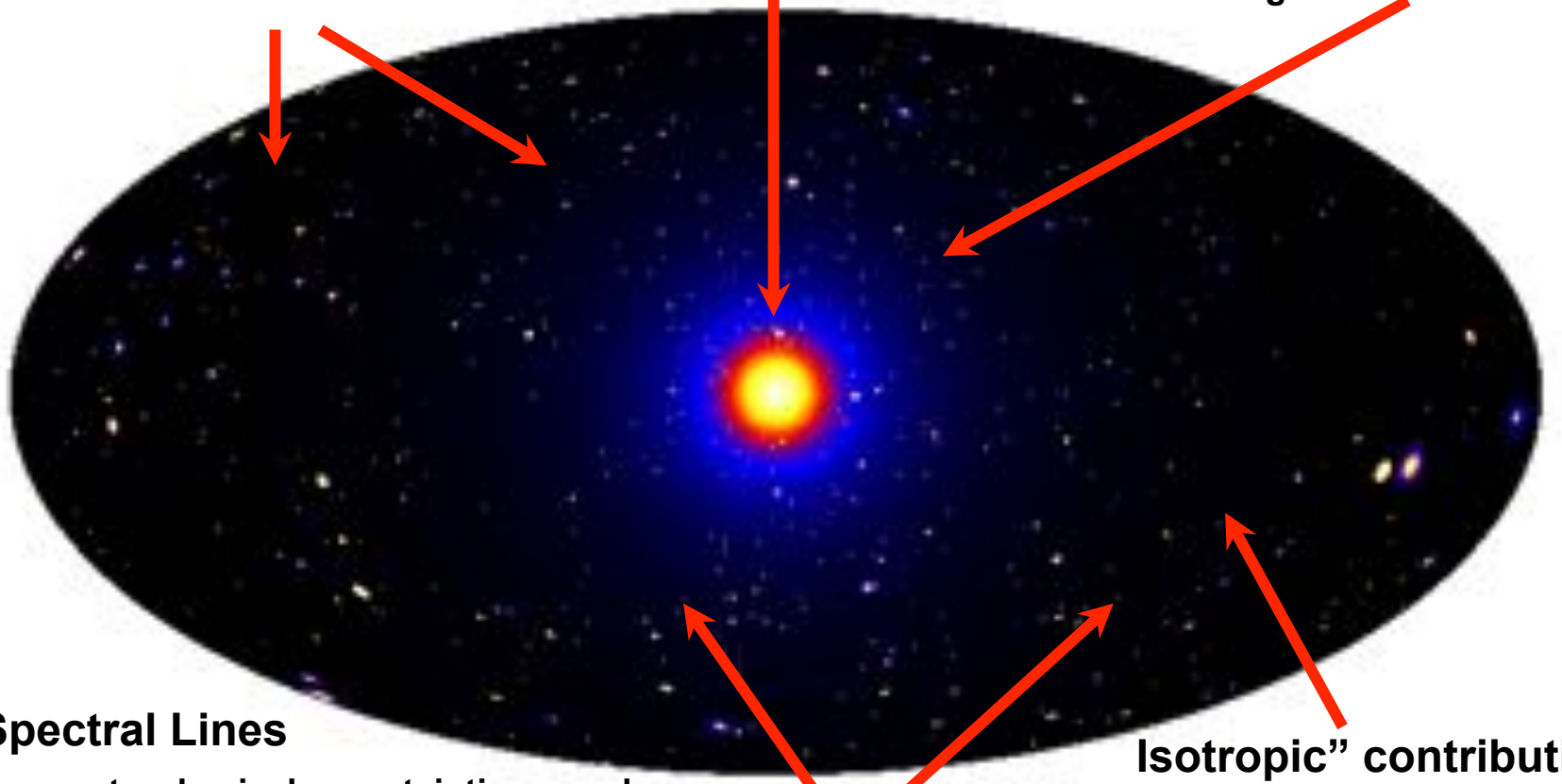
Low background and good source id, but low statistics

Galactic Center

Good Statistics, but source confusion/diffuse background

Milky Way Halo

Large statistics, but diffuse background



Spectral Lines

Little or no astrophysical uncertainties, good source id, but low sensitivity because of expected small branching ratio

Galaxy Clusters

Low background, but low statistics

Isotropic" contributions

Large statistics, but astrophysics, galactic diffuse background

Dark Matter simulation:
Pieri+(2009) arXiv:0908.0195

Limits on $\langle \sigma v \rangle$ at 10GeV ($cm^3 s^{-1}$)

Satellites

dSph ~ 2×10^{-26}

UNID ~ 2×10^{-24}

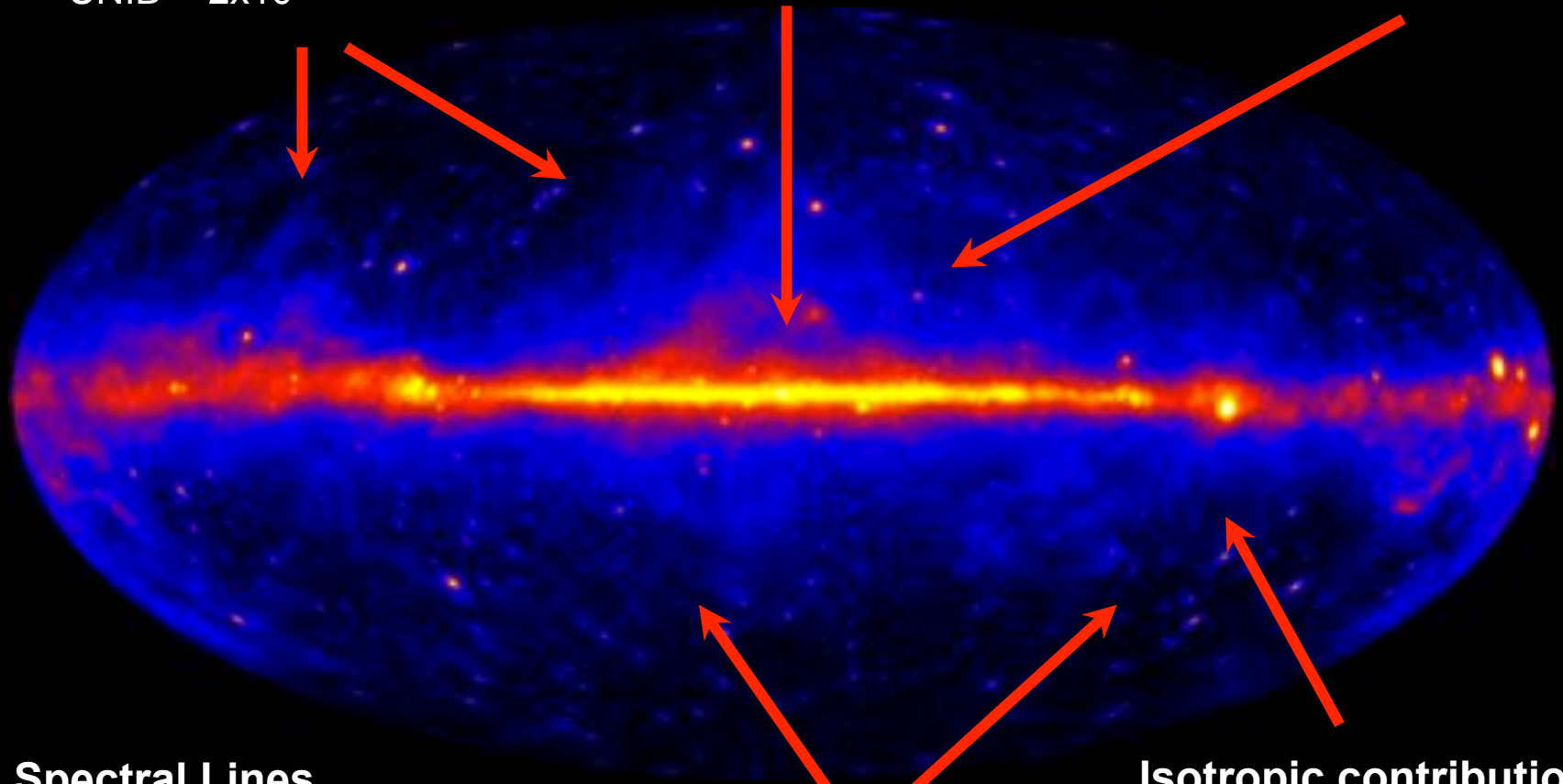
Galactic Center

Vary w/ model & method

Milky Way Halo

W/ bkg. model: 2×10^{-26}

No bkg. model: 2×10^{-25}



Spectral Lines

100 GeV ~ 8×10^{-27}

Galaxy Clusters

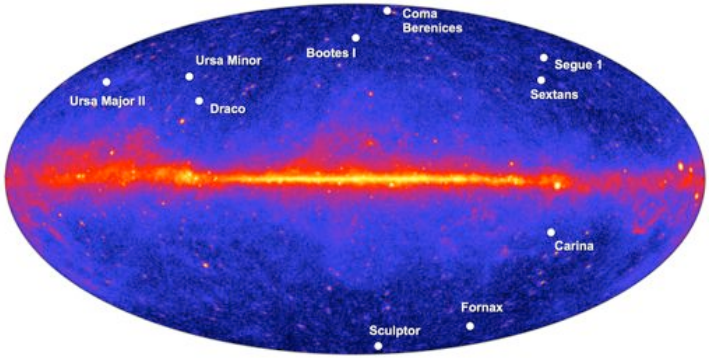
~5×10^{-25}

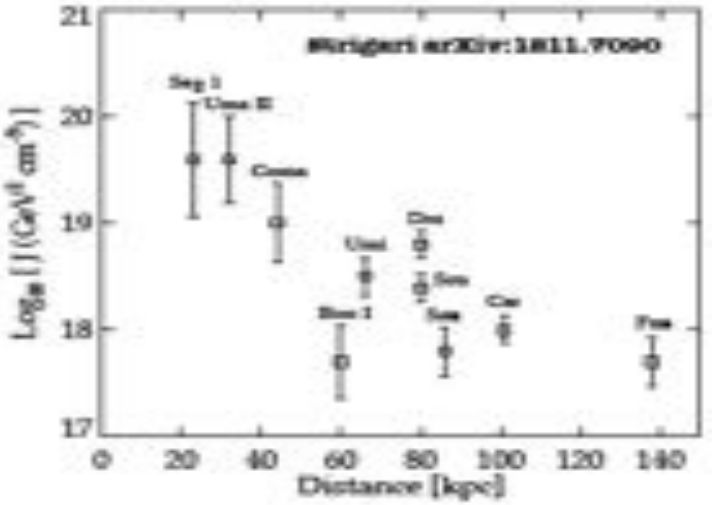
Isotropic contributions

Vary w/ model & method

Dwarf spheroidal galaxies

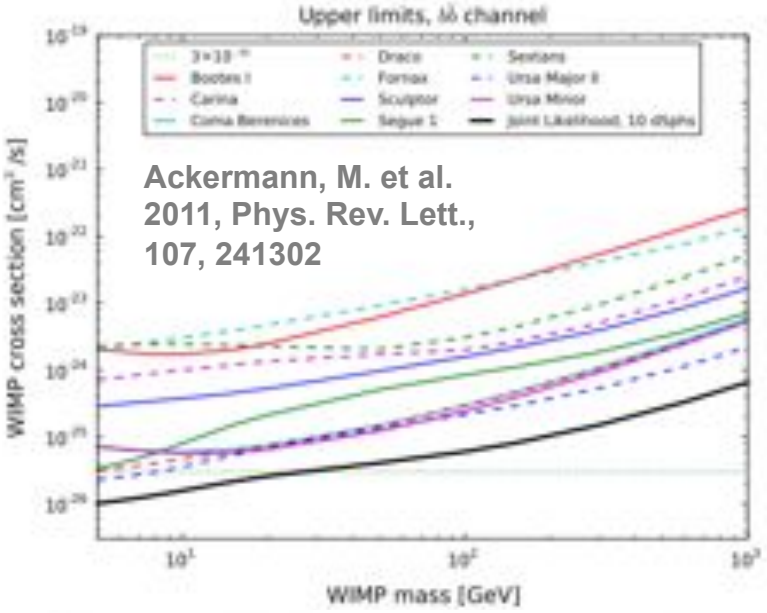
- **Dark Matter Dominated**
  - **100-1000x visible matter**
  - **DM estimated from stellar velocity → uncertainties!**
- **Close (25-150 kpc)**
- **Free from astrophysical background**
  - **No active star formation (no energy injection)**
  - **No appreciable magnetic fields (no acceleration)**
  - **No gas or dust (no target material)**
- **Good prospects for significantly more dwarfs**
- **Standard clean search for isolated source away from Galactic plane**

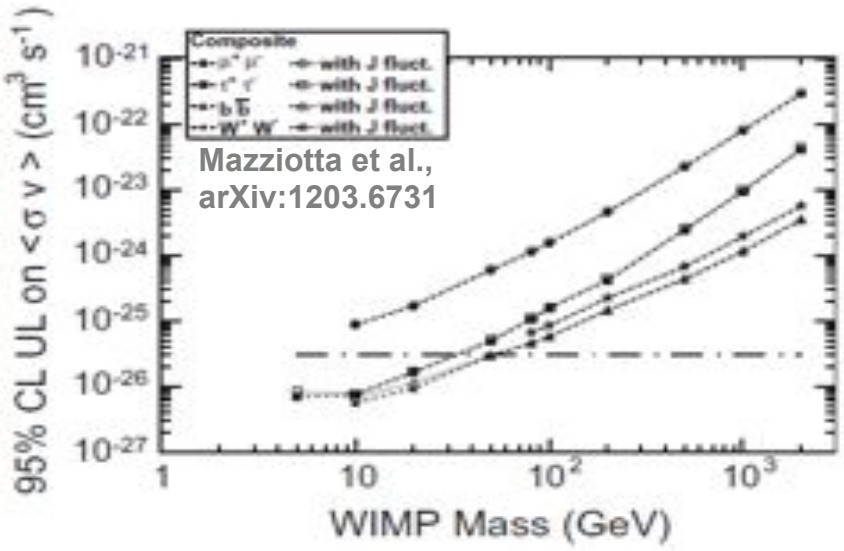


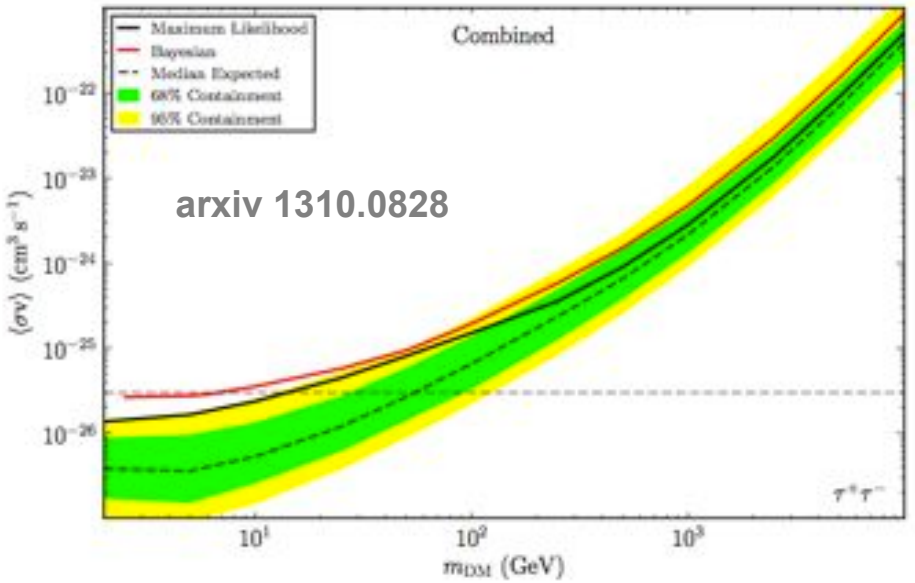


Dark Matter constraints with dwarfs

- **Current limit close to thermal relic σ below ~ 30 GeV**
  - **Different analysis techniques**
  - **Updated J factors and 4 years of data**
  - **Extended studies of sensitivity and systematics**

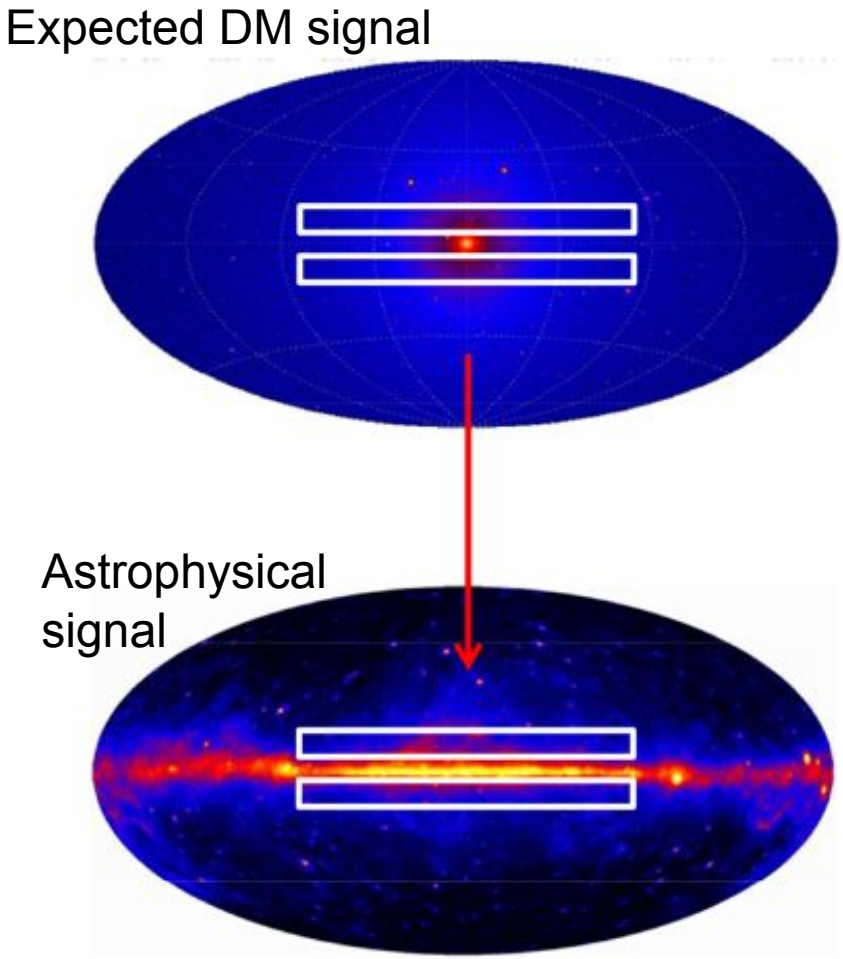






Constraints from Milky Way Halo

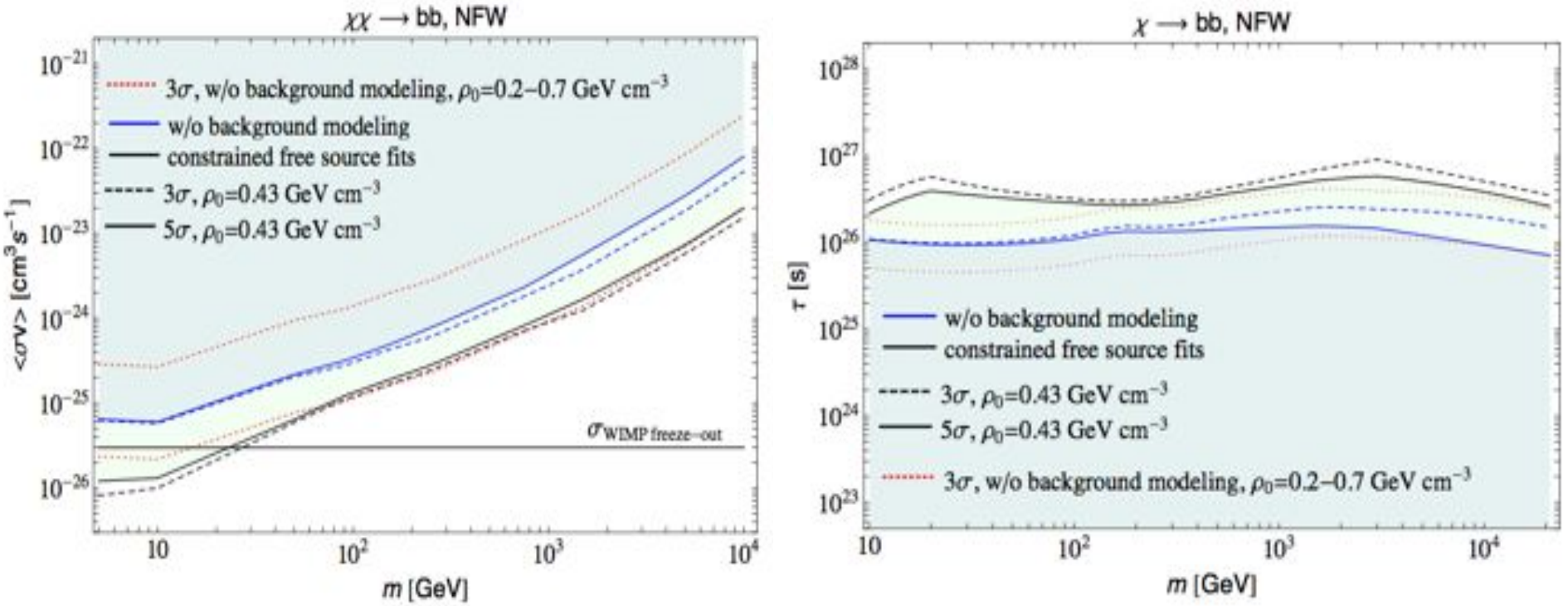
Ackermann+ ApJ 761 (2012) 91



- **two 10° bands 5° off the plane**
  - **minimize astrophysical background**
  - **mitigate uncertainties from inner DM density profile**
- **Two approaches to set limits:**
  1. **more conservative: assume emission only from DM**
  2. **more accurate: fit the DM and astrophysical emission simultaneously**
- **Explores systematics of diffuse emission modeling**

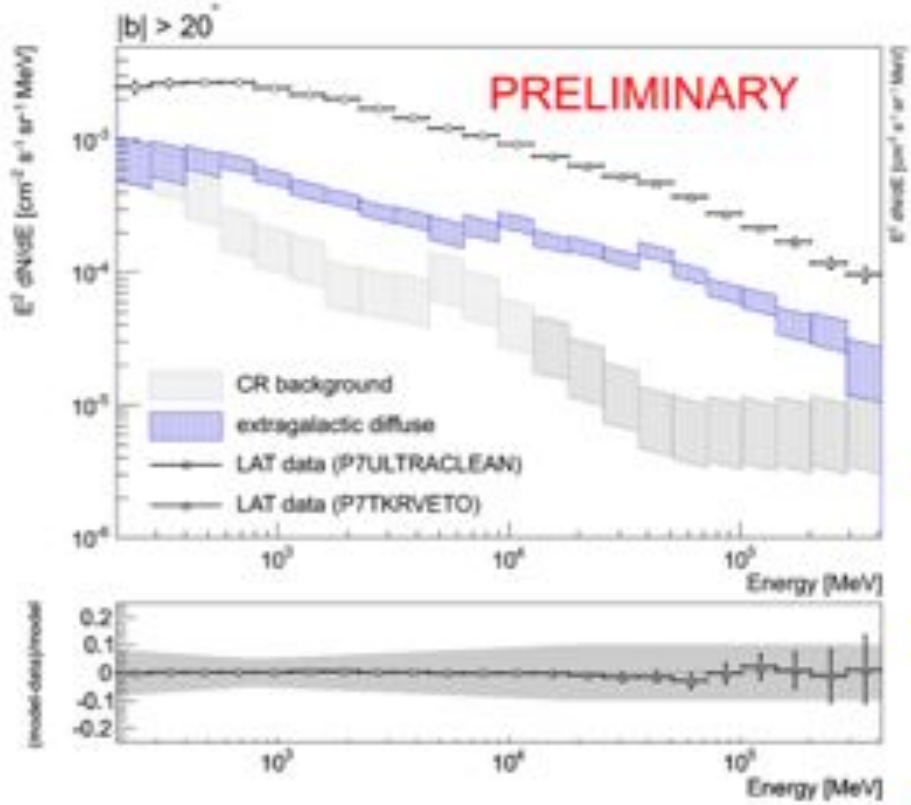
Constraints from Milky Way Halo

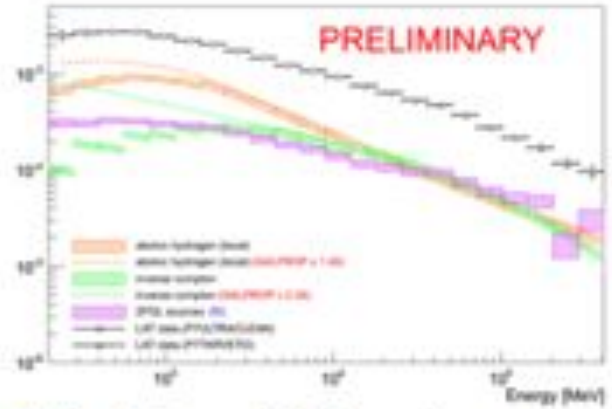
Ackermann+ ApJ 761 (2012) 91



- **Including modeling of the astrophysical emission improves the DM constraints by a factor of ~5**
- **With inclusion of astrophysical backgrounds, the limit constrains a canonical thermal annihilation cross section into b-quarks to a WIMP mass $\gtrsim$ 30 GeV**
- **Marginalizes over many different diffuse emission models to take into account uncertainties in astrophysical foreground subtraction**

Preliminary new LAT EGB spectrum





> Preliminary EGB spectrum between 200 MeV to 410 GeV for default foreground model.

> Error bands include systematics from effective area uncertainty and CR background subtraction.

> ... but **NOT** systematics from foreground model uncertainties. (still under evaluation).

> Publication in preparation for EGB spectrum up to 820 GeV.

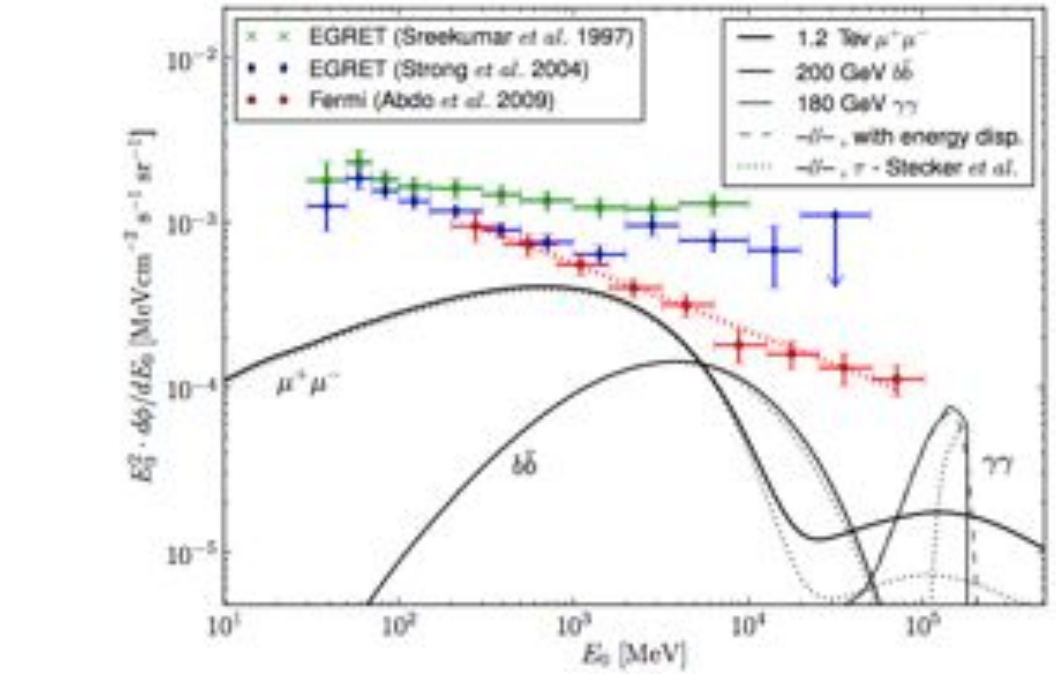
Markus Ackermann | Fermi Symposium, Monterey | 11/01/2012 | Page 19

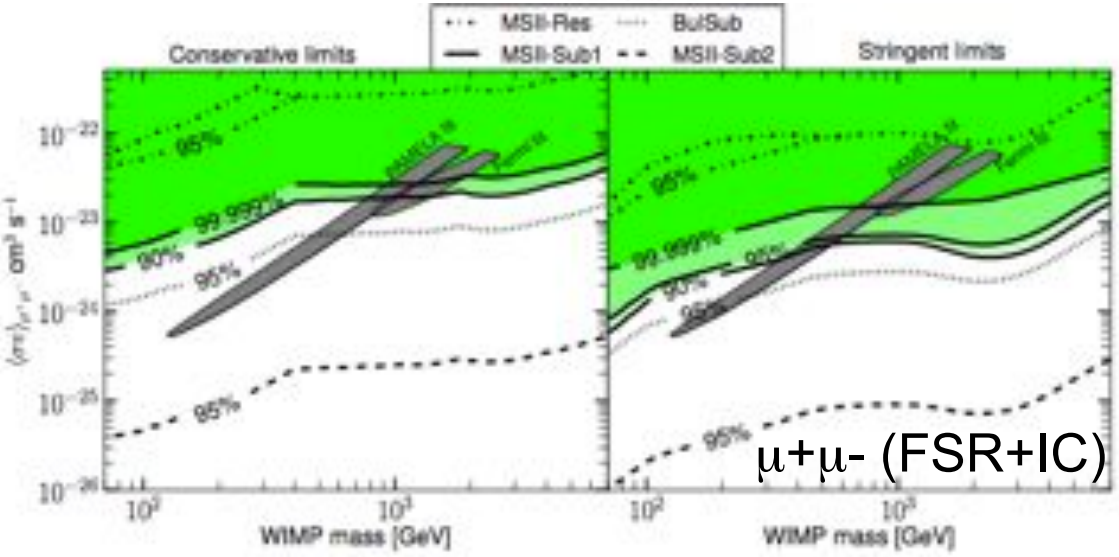
Will follow earlier publication Abdo, A. A. et al. 2010, Phys. Rev. Lett., 104, 101101

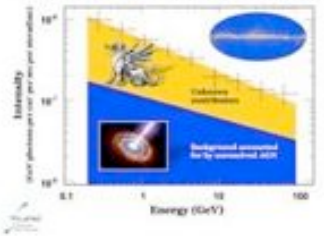
Constraints on Cosmological DM

Ackermann, M. et al. 2011, ApJ, 726, 81

- Search for a DM signal from all halos at all redshifts
- Limits from Fermi EGB
- Predictions affected by
  - DM distribution
  - γ-ray opacity
- Under reasonable assumptions can exclude most DM models explaining CR lepton excess from Fermi and Pamela

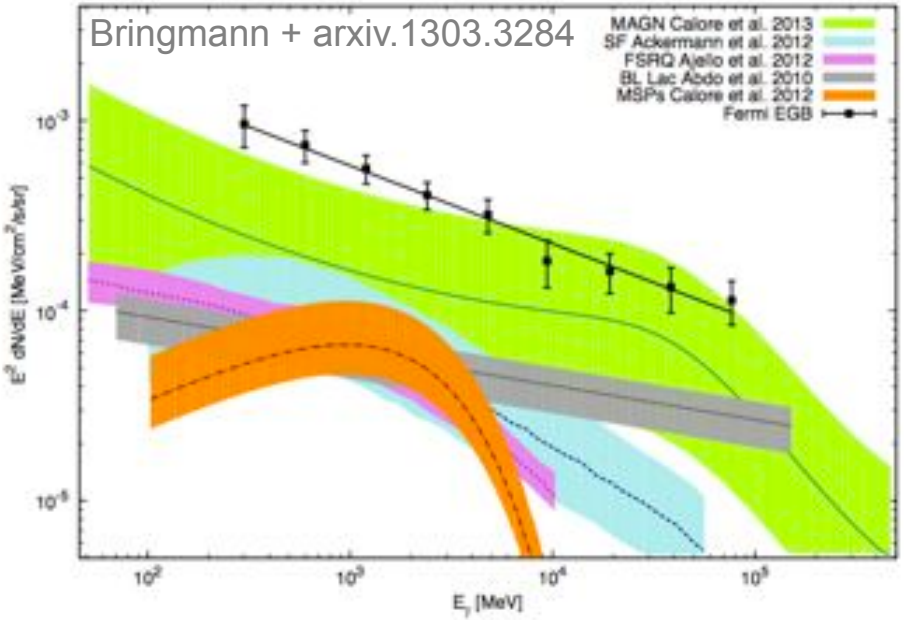


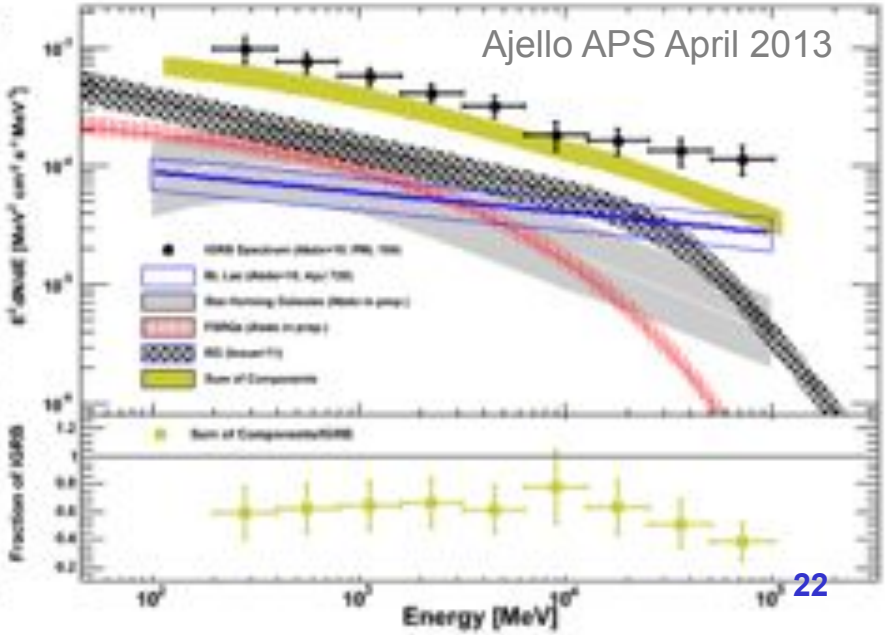




EGB – modeling source contributions

- **Undetected sources**
  - **AGN, Star-Forming Galaxies, ms PSR, Gamma-Ray Bursts**
- **Diffuse processes**
  - **Shocks, Dark Matter, UHECR scattering EBL, large CR halo**
- **Large theoretical uncertainties**
- **For some classes no gamma-ray luminosity functions**
  - **Using radio / IR correlation functions**

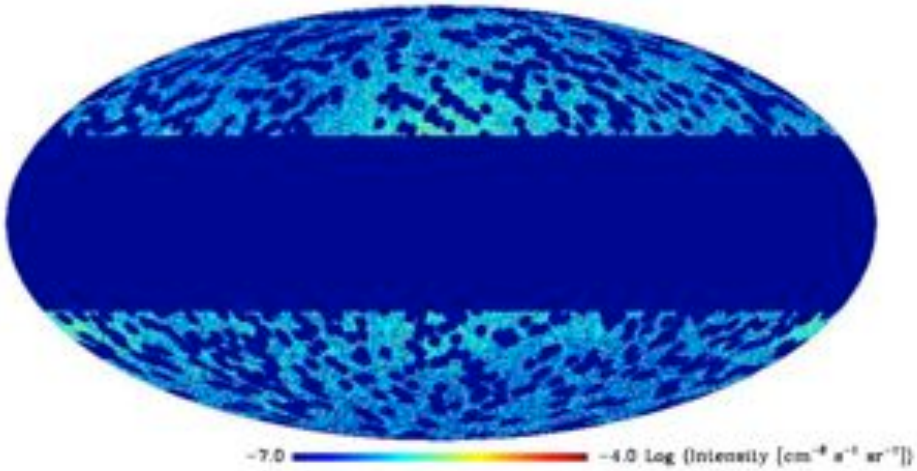


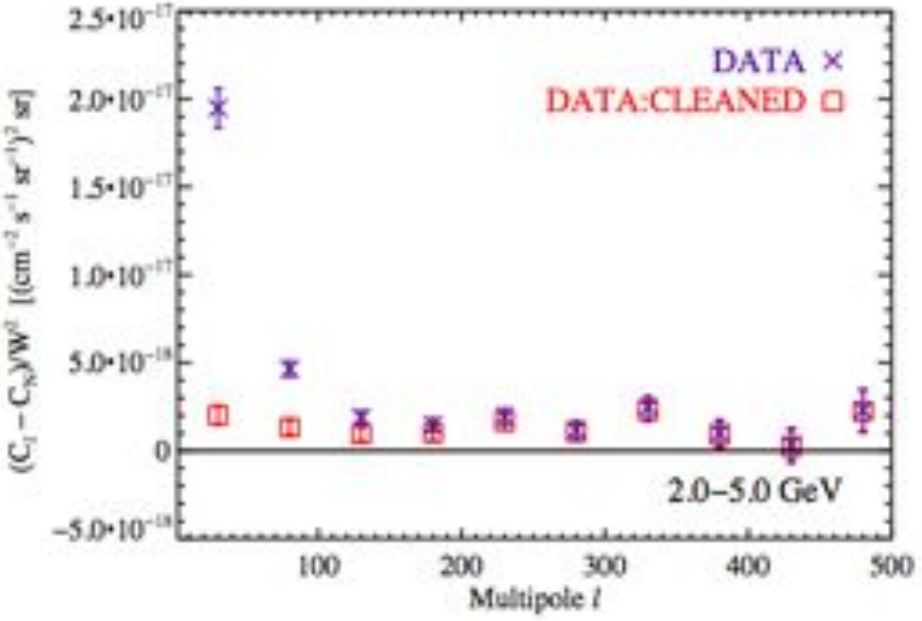


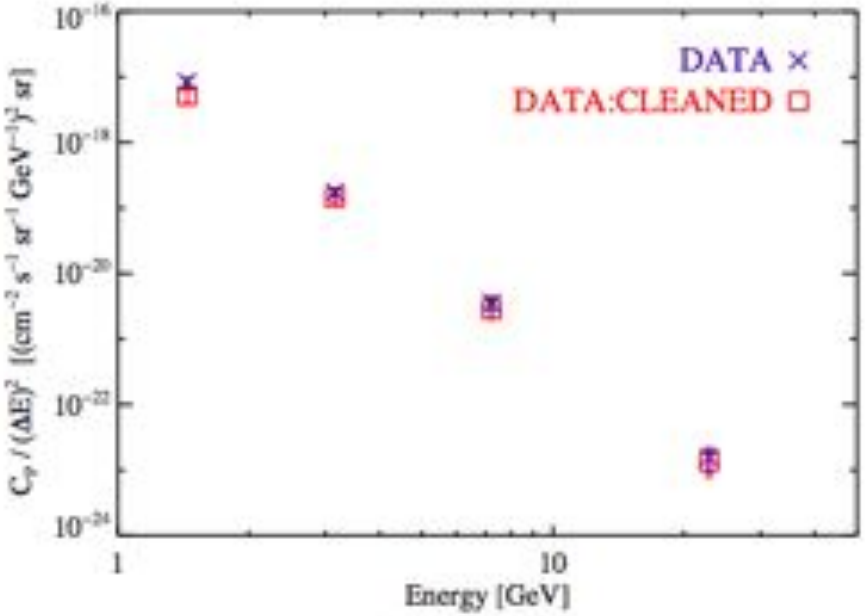
Other targets and techniques for DM searches

2012, Phys. Rev. D, 85, 083007

- **Anisotropy in diffuse emission**
- **High multiple power spectrum and its energy dependence**



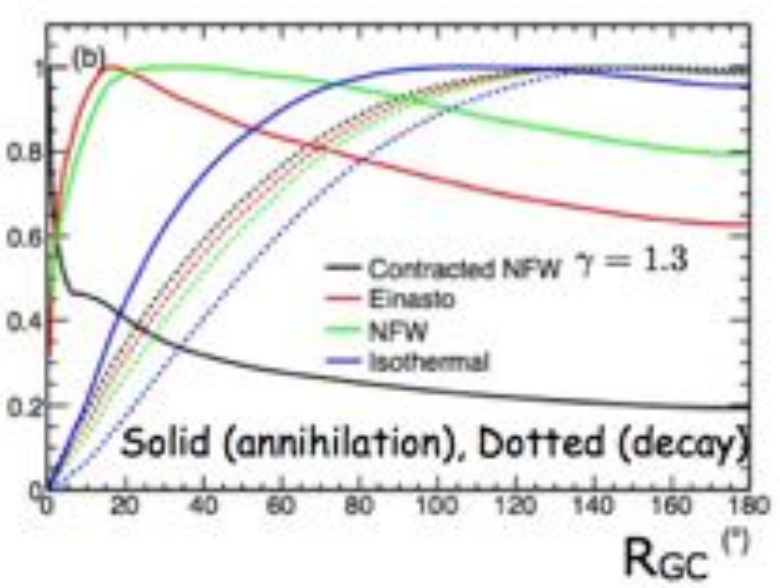


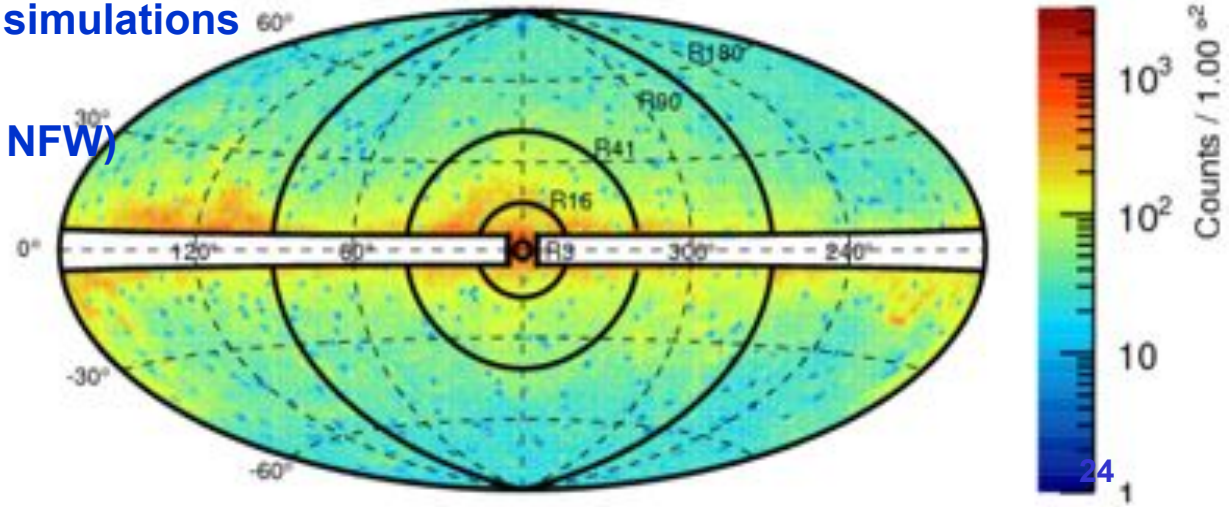


Fermi-LAT Line Search - 4 years data

arXiv:1305.5597, accepted by PRD

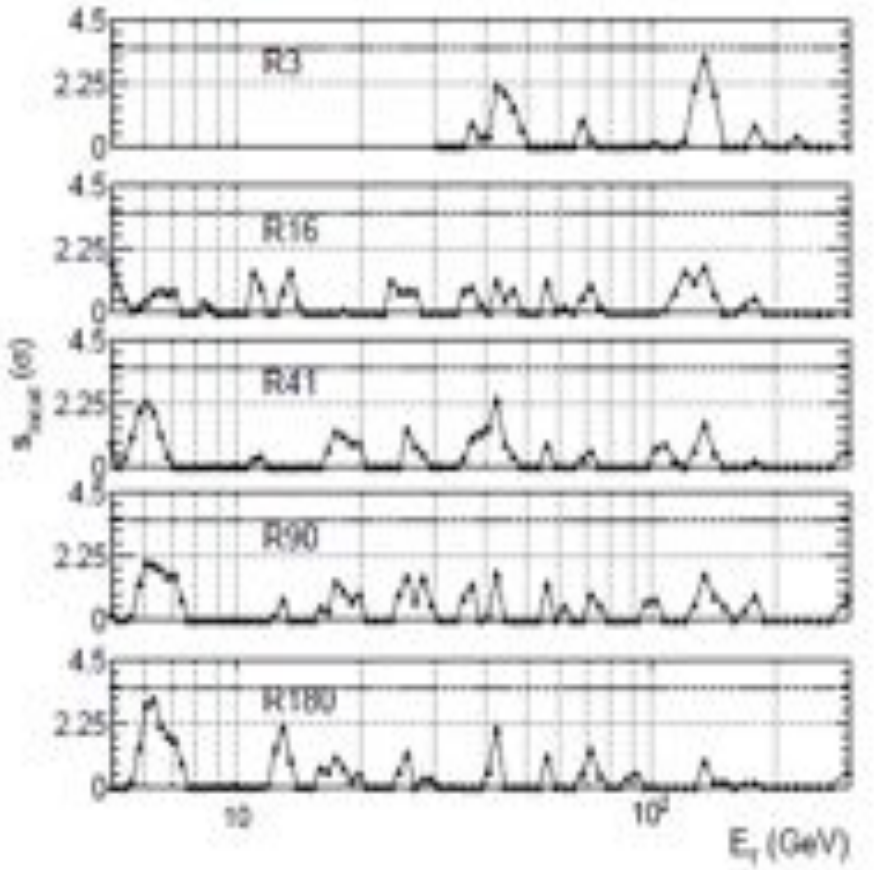
- Search for lines from 5 – 300 GeV using 3.7 years of data
- Use P7REP_CLEAN (REP = "reprocessed")
  - Updates to CAL calibration and reconstruction
    - Improved PSF
    - Energy shifts upwards ~3-4%
  - Mask bright (>10σ for E > 1 GeV) 2FGL sources
- Optimize ROI for a variety of DM profiles
  - Find R_{GC} that optimizes S/sqrt(B)
  - Background from LAT simulations
- Search in 5 ROIs
  - R3 (3° GC Circle, cont. NFW)
  - R16 (Einasto)
  - R41 (NFW)
  - R90 (Isothermal)
  - R180 (DM Decay)

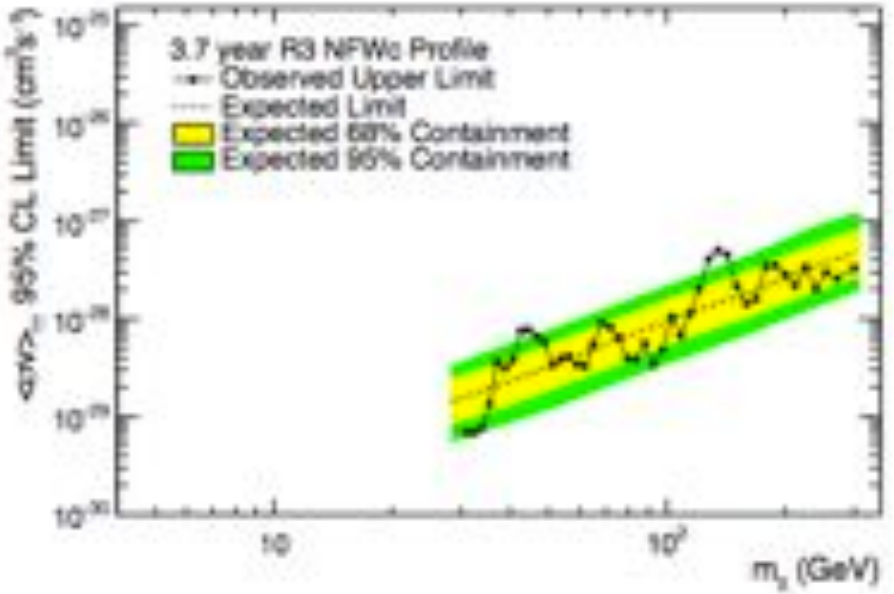


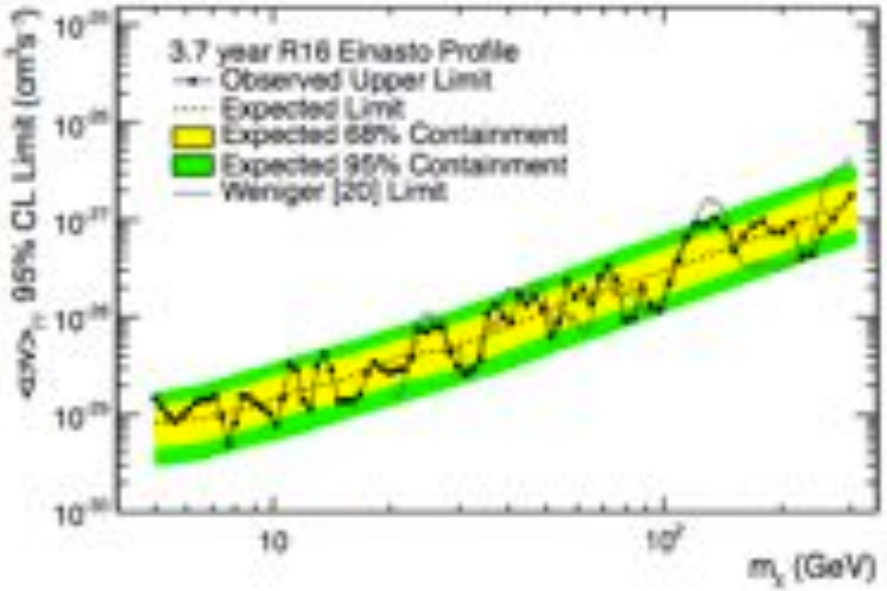


Search for Dark Matter lines

arxiv.1305.5597, accepted by PRD







- **No globally significant lines detected**
  - **All fits have global significance < 2σ**

Mission Status and Timeline

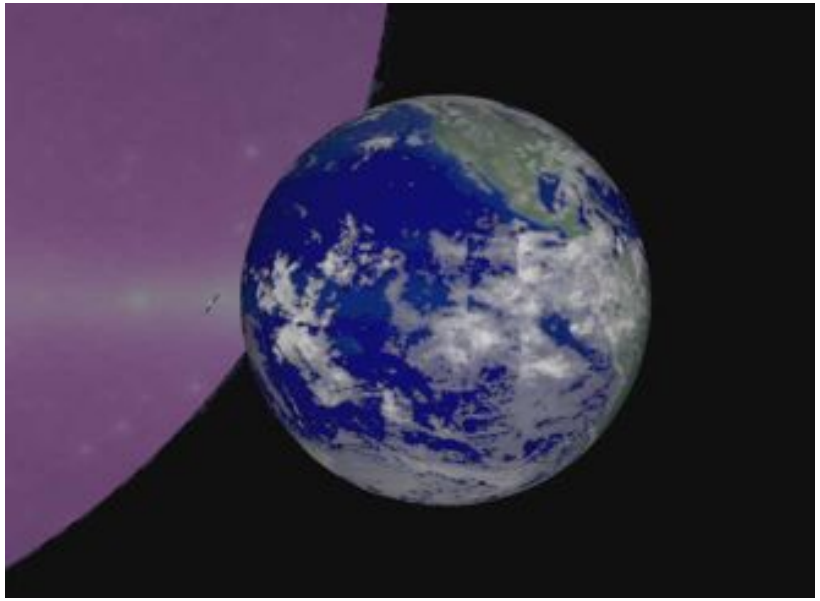
Present and Future

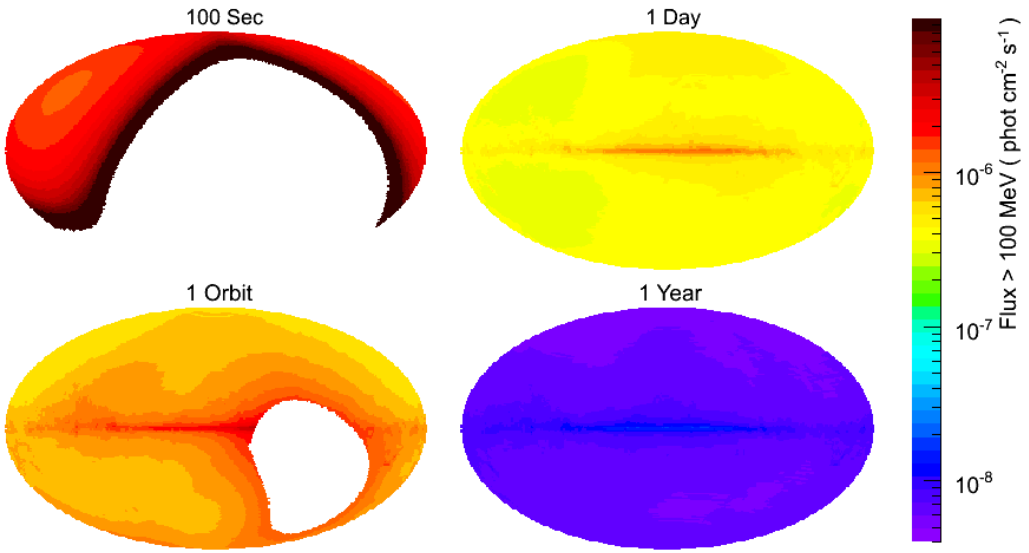
The Fermi observatory

- Satellite gamma-ray telescope
  - Large Area Telescope (LAT)
    - 20 MeV – > 300 GeV
  - Gamma Burst Monitor (GBM)
    - 8 KeV – 40 MeV
- Key features
  - Huge field of view (2.4sr)
    - 20% sky any instant
    - All sky for 30’ every 3h
  - Huge energy range
    - Including unexplored 10-100 GeV range

Mission Elements

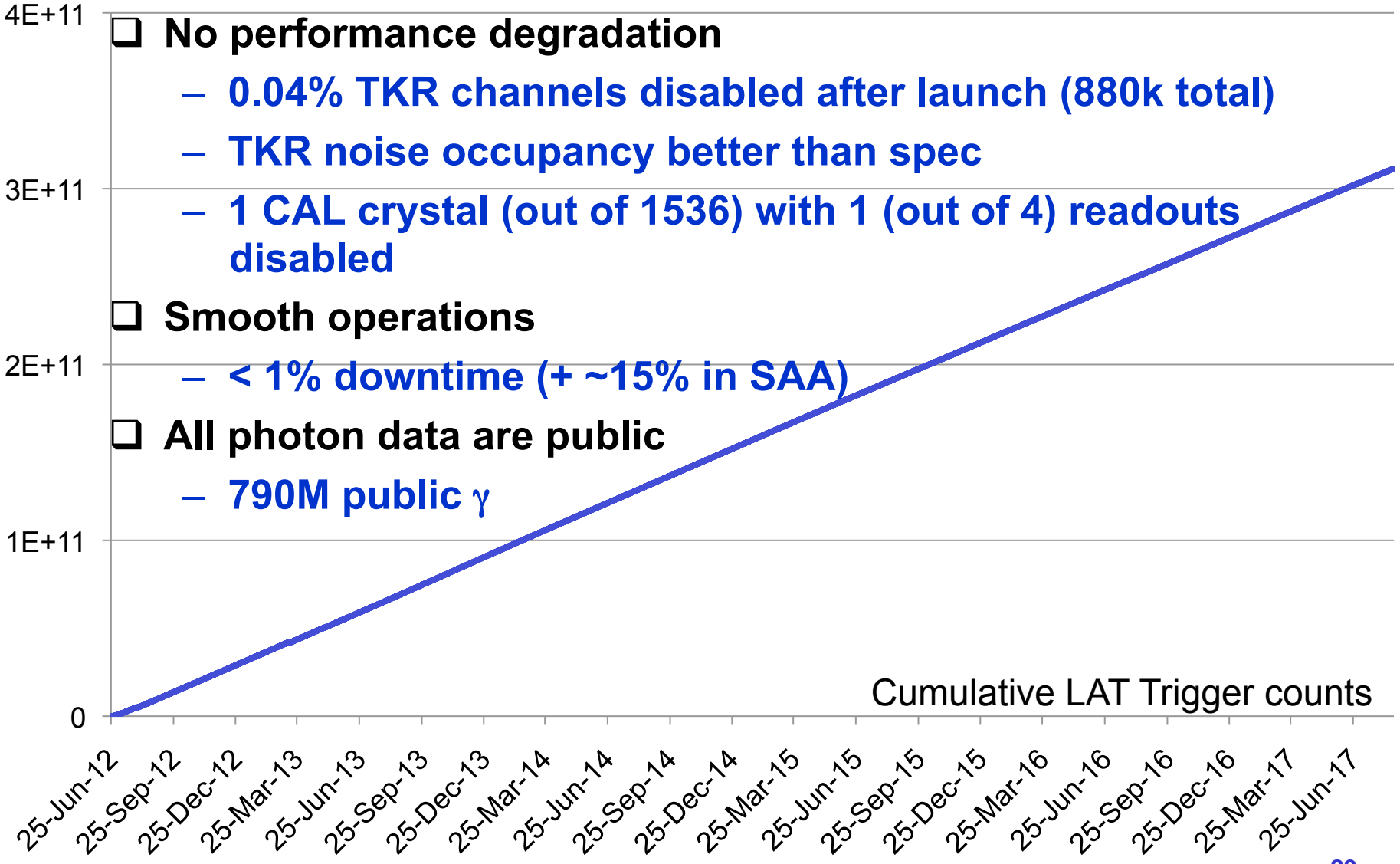
- Launched 11 june 2008, Delta II Rocket
  - Circular orbit, 565km altitude, 25.6 deg inclination
- Operations
  - Primary (95% so far): sky survey
    - scan entire sky every 3 hours
  - Autonomous Repoint Request
  - Target of Opportunity





Fermi observatory status

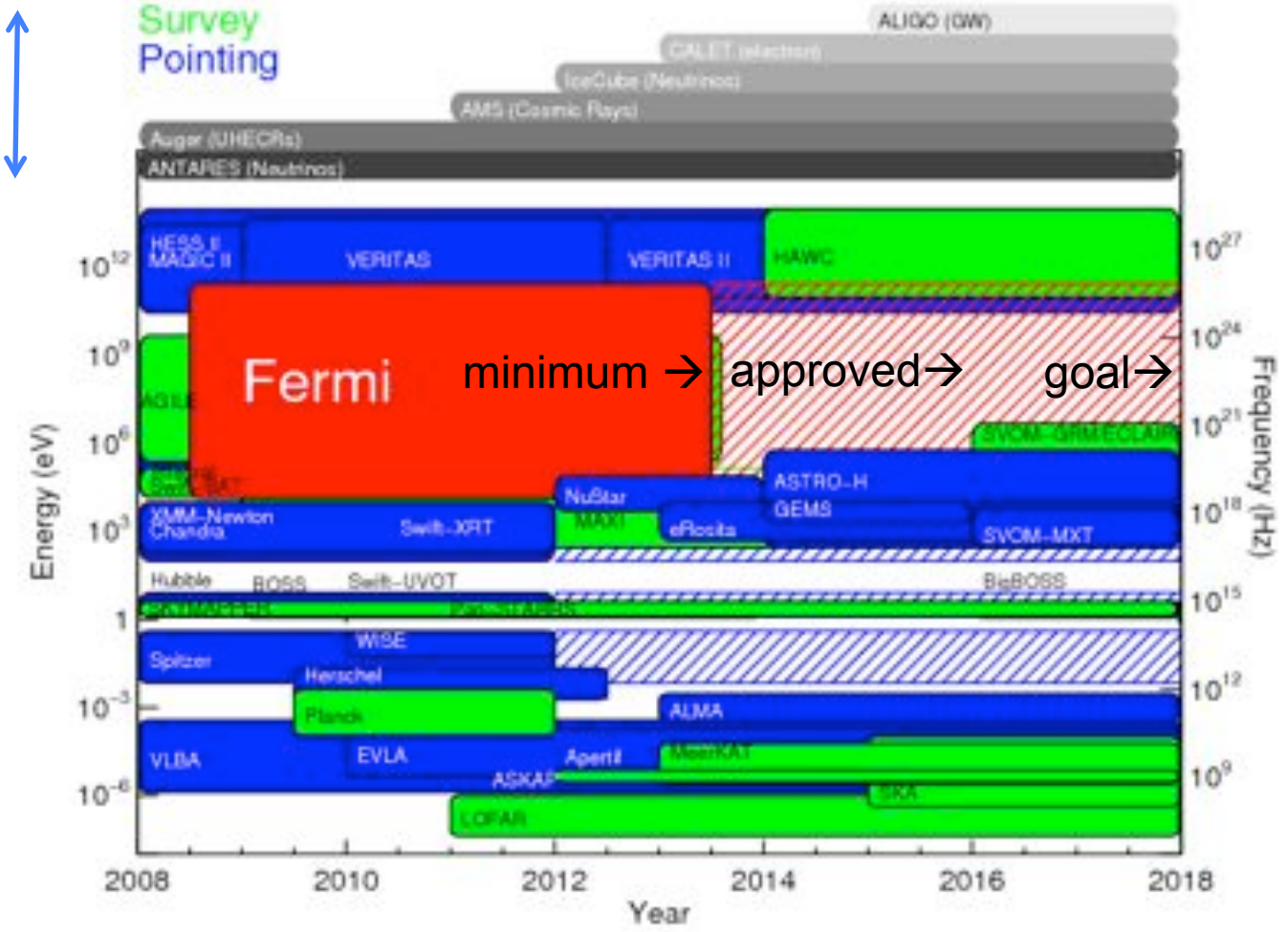
- No performance degradation
  - 0.04% TKR channels disabled after launch (880k total)
  - TKR noise occupancy better than spec
  - 1 CAL crystal (out of 1536) with 1 (out of 4) readouts disabled
- Smooth operations
  - < 1% downtime (+ ~15% in SAA)
- All photon data are public
  - 790M public γ



Fermi mission status

http://science.nasa.gov/astrophysics/2012-senior-review/

Multi Messenger synergies



Multi wavelength synergies

- ❑ **NASA 2012 Senior Review recommended extended operations**
- ❑ **NASA HQ will extend the mission to at least 2016**
- ❑ **Upcoming 2014 Senior Review**

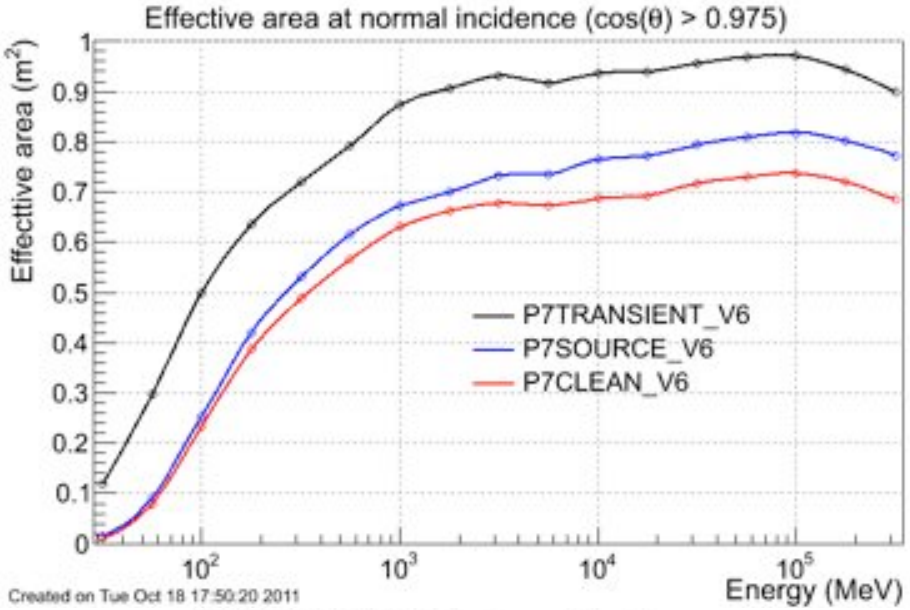
Fermi as a public observatory

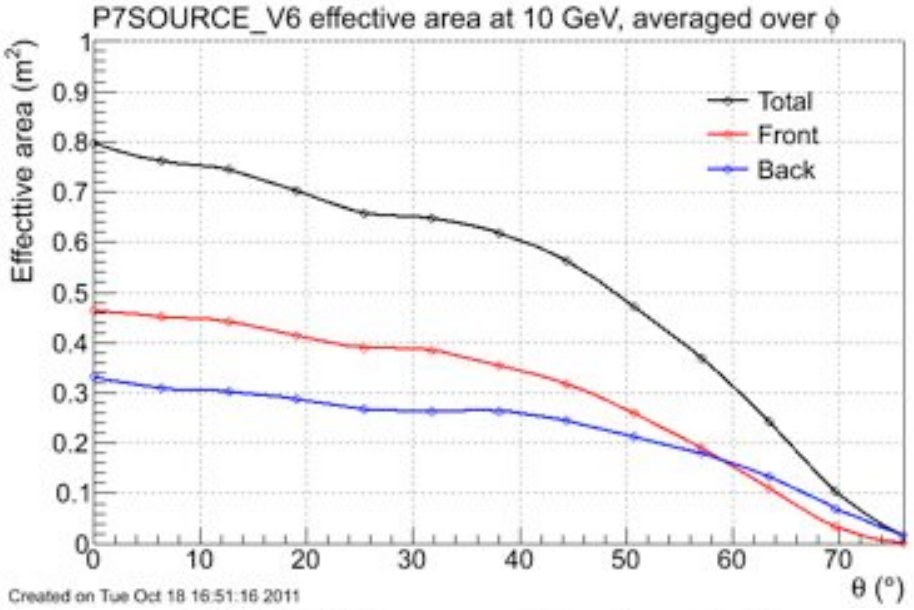
http://fermi.gsfc.nasa.gov/ssc/

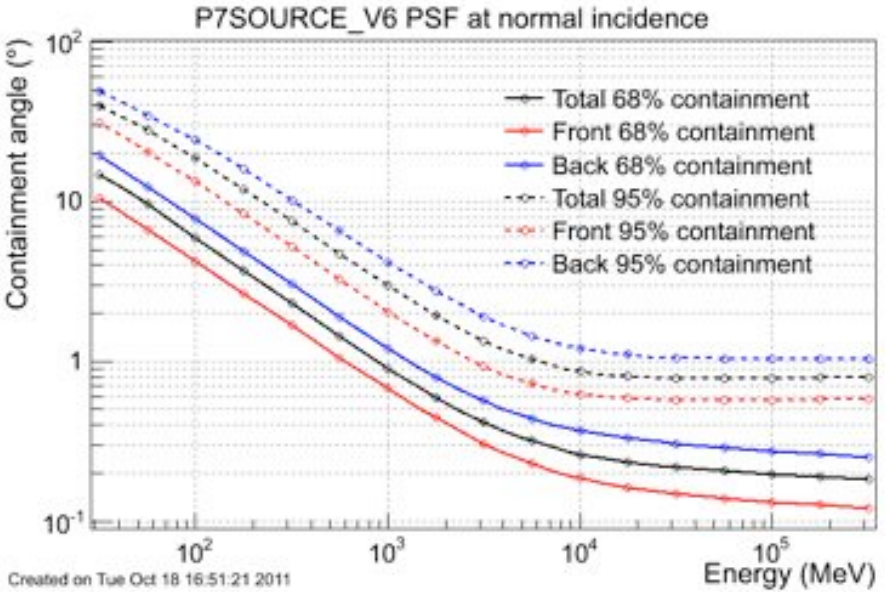
- ❑ > 800M γ and public within ~hours from trigger, 20TB served
- ❑ Full Science Tools data analysis suite
- ❑ > 1100 papers, > 20k citations collectively
- ❑ 6 guest investigator programs supported so far

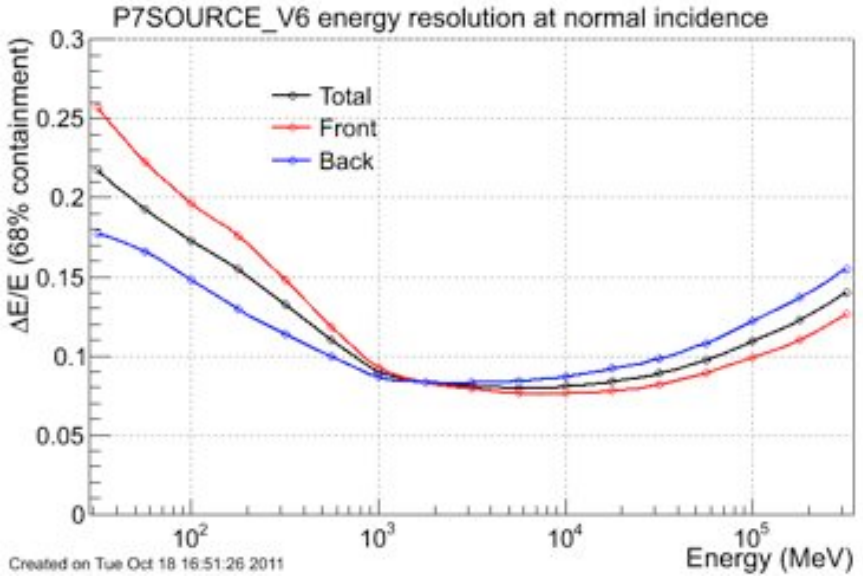
LAT performance

http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm



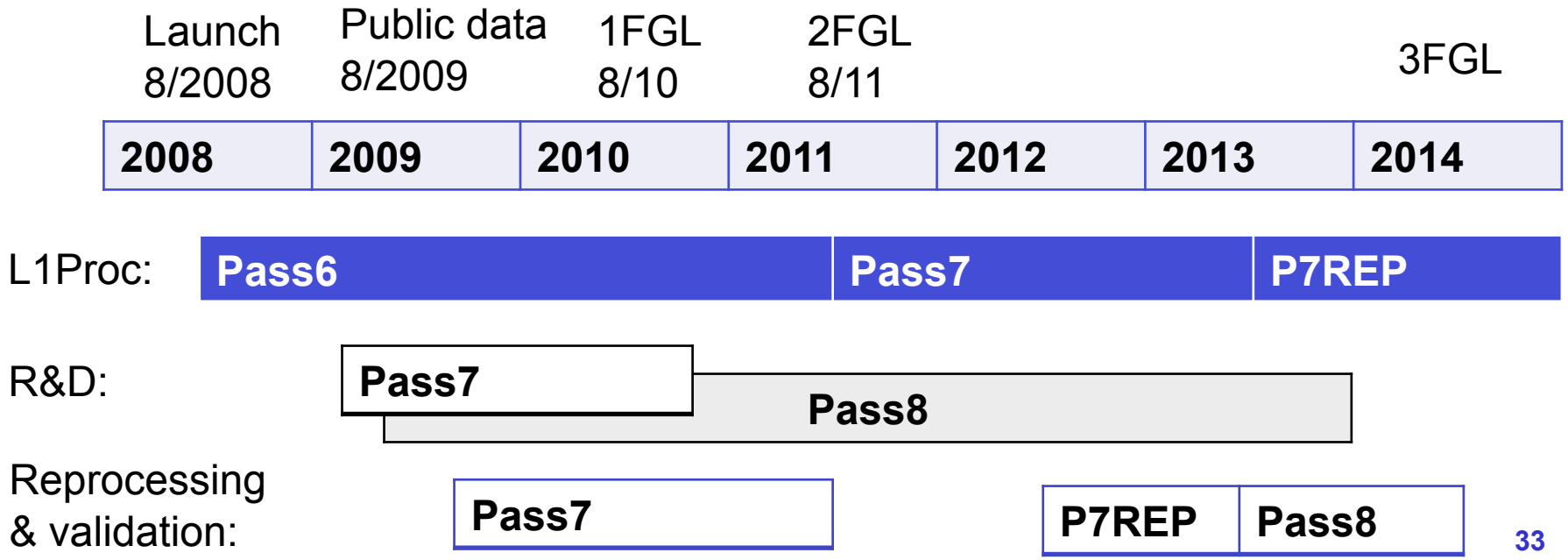






Global Analysis Timeline

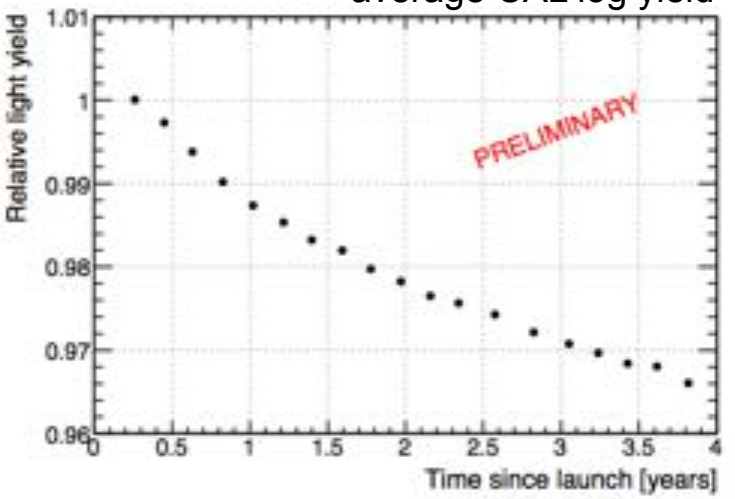
- **Continuous effort to improve performance and release better datasets**
  - **Pass6: pre-launch recon and event selection, optimized post-launch IRFs (to describe effect of ghosts)**
  - **Pass7: pre-launch recon, optimized post-launch event selection and associated IRFs**
  - **Pass8: post-launch recon, event selection and IRFs**



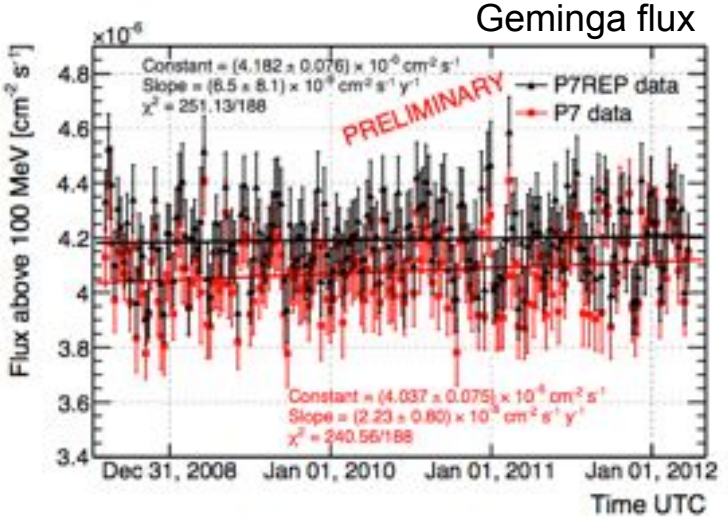
P7REP Data - overview

- Updated LAT calibrations & CALRecon
  - Map ~1%/year CAL light yield decrease from irradiation
  - CAL logs light collection asymmetry
  - TKR routine updates
  - Improved CAL moment analysis
- Main effects
  - Few % upward energy shift
  - Improved high-energy PSF
- Data Release log
  - Weekly FT1 pre-released on 5/31
  - Full FT1 release in progress

average CAL log yield



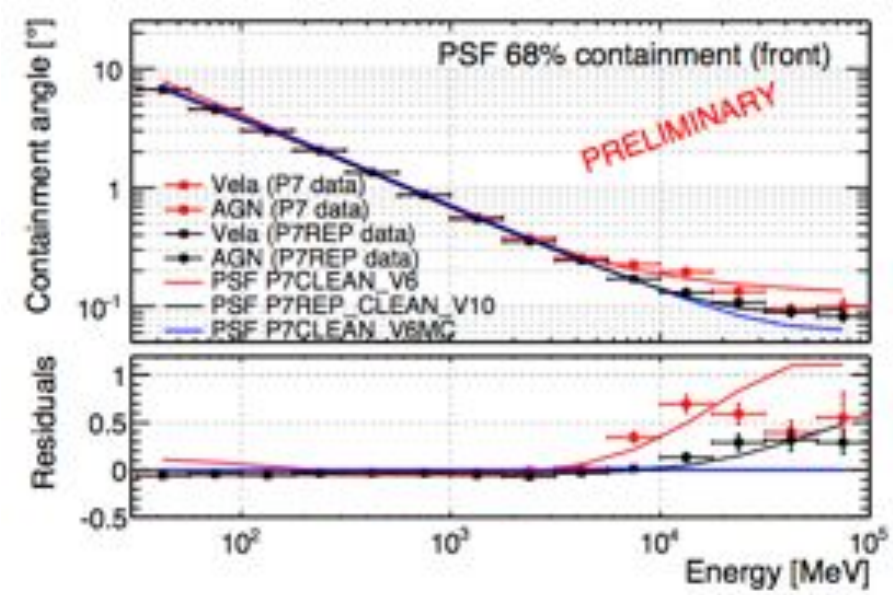
Geminga flux

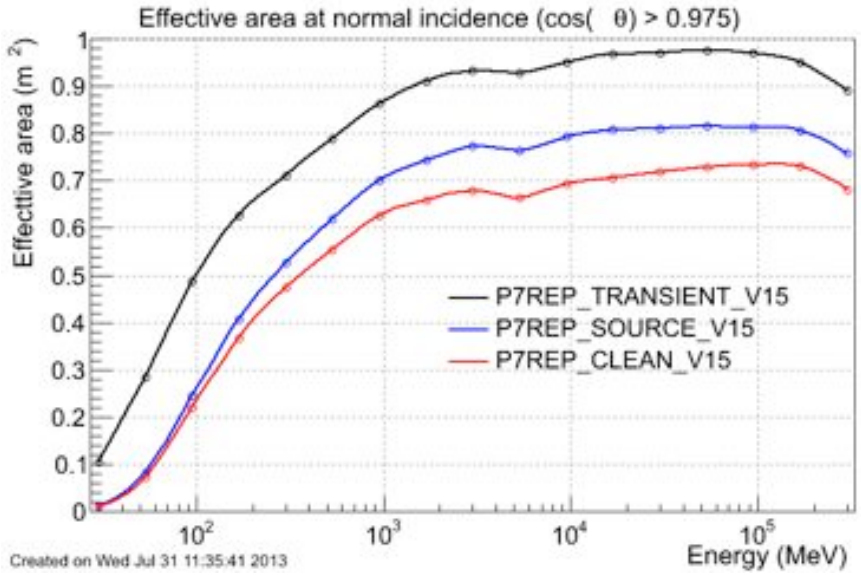


arxiv:1304.5456

P7REP Instrument Response Functions

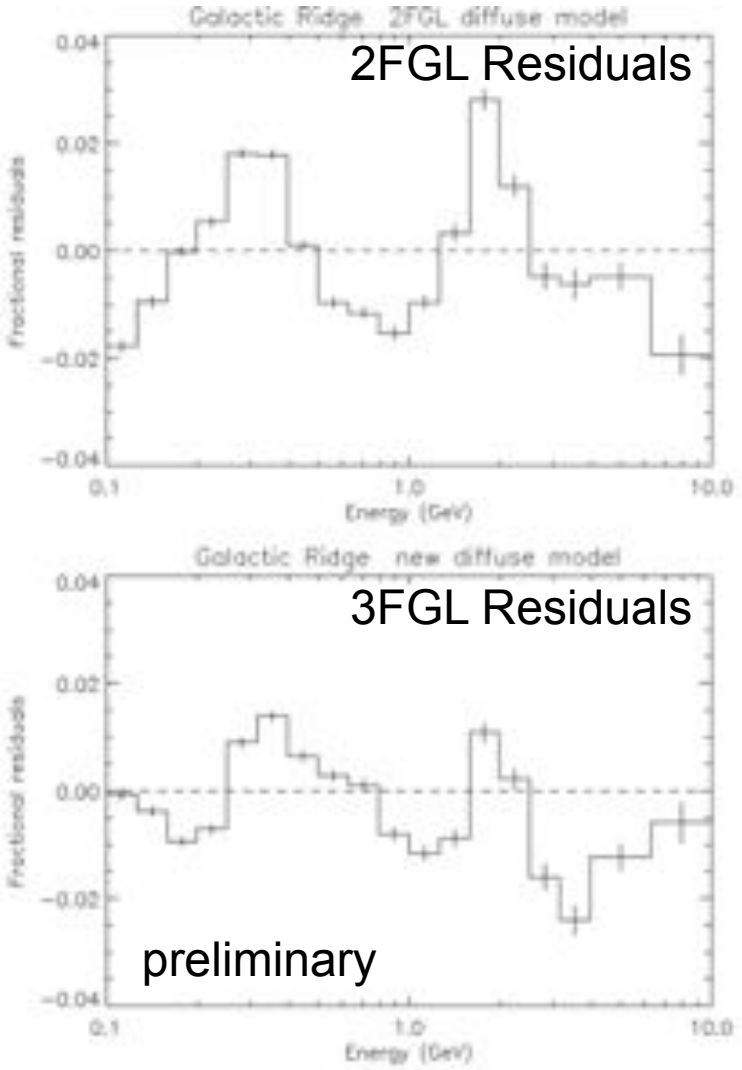
- **Better IRFs**
  - Improved Point Spread Function > few GeV
  - Flight PSF parameterization retains MC dependence on inclination angle
  - Front/Back scaled effective area
  - Better systematic uncertainties
- **IRF Release log**
  - V10 with pre-release and DM line analysis (1305.5597)
  - V15 final set uses improved instrument simulation





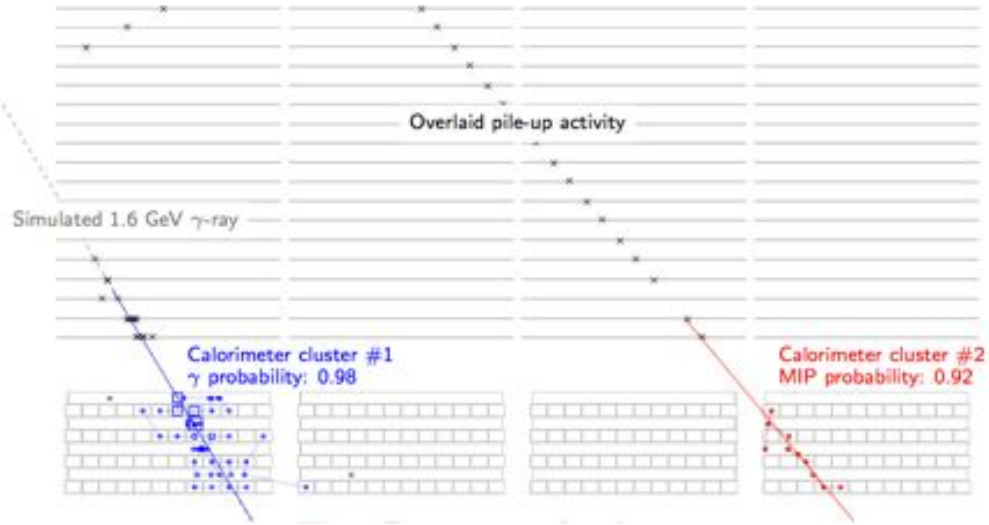
Diffuse emission models for P7REP data

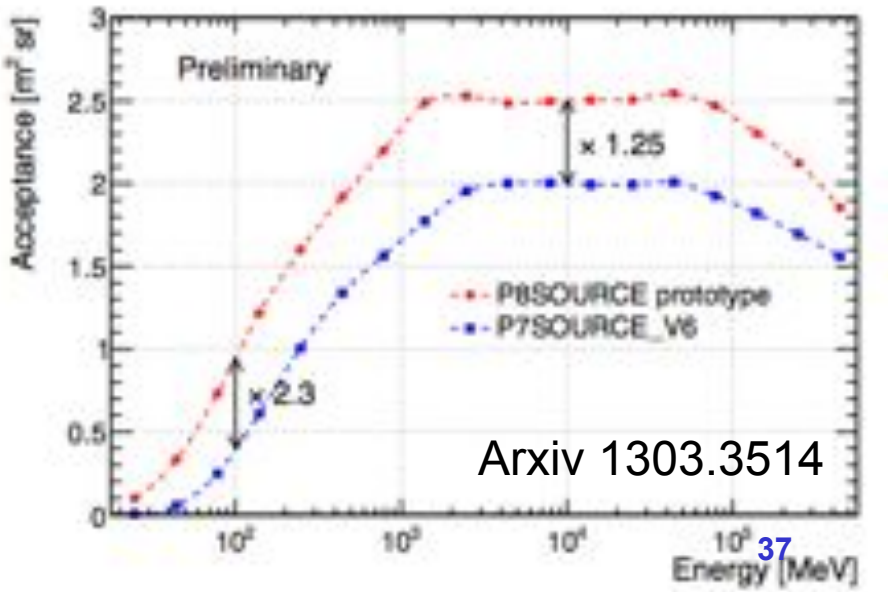
- **Same method as 2 FGL**
  - Rings of HI, CO, dark gas are fit to gamma-ray data
  - Inverse Compton from Cosmic-Ray data (GALPROP)
  - Isotropic emission fit to gamma-ray data
- **Improvements wrt 2FGL**
  - Physical spectral shapes
  - Extended structures (Loopl, Fermi bubbles) from large scale positive residuals
- **Results**
  - Smaller fractional residuals
  - Ideal for catalog analysis (→ 3FGL)
  - Not suited for extended regions



Pass8 Status and plans

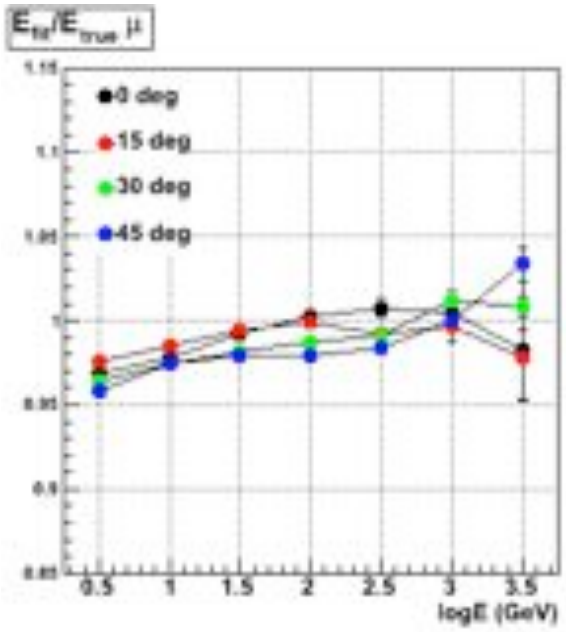
- Complete rewrite of event reconstruction in the LAT
  - Well beyond original motivation of suppressing cosmic-ray pileup
- Significant improvements wrt Pass7 performance
  - Larger acceptance
  - Increased energy range (low and high energy)
- Status
  - 3 years of data reprocessed
  - Very encouraging preliminary results
- Will be used for 5 year catalog and LAT analyses starting 2014

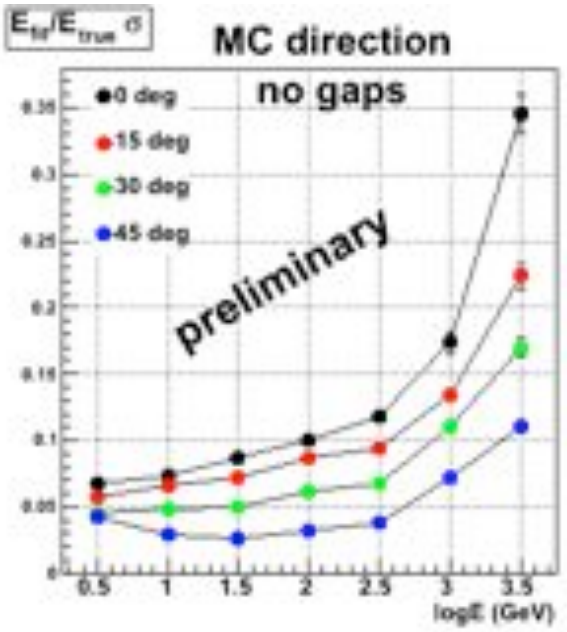


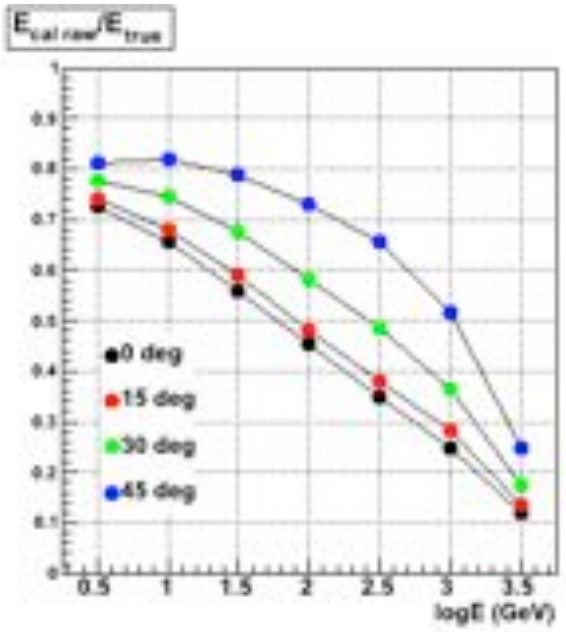


Pass8 CAL performance

Ph. Bruel 2012 J. Phys.: Conf. Ser. 404 012033



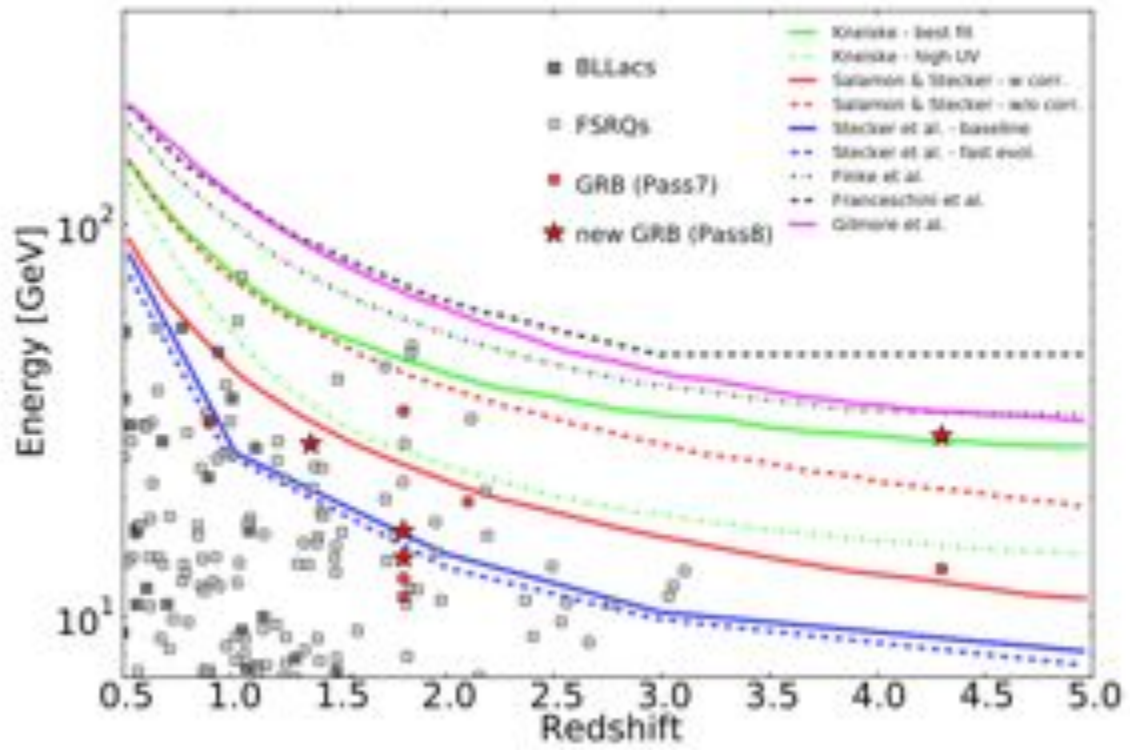




- Good energy resolution up to ~ 1 TeV
- Above 1 TeV crystal saturation and poor containment degrade resolution

Pass8 at work: new high energy GRB photons

Atwood et al 2013 ApJ 774 76, arxiv 1307.3037

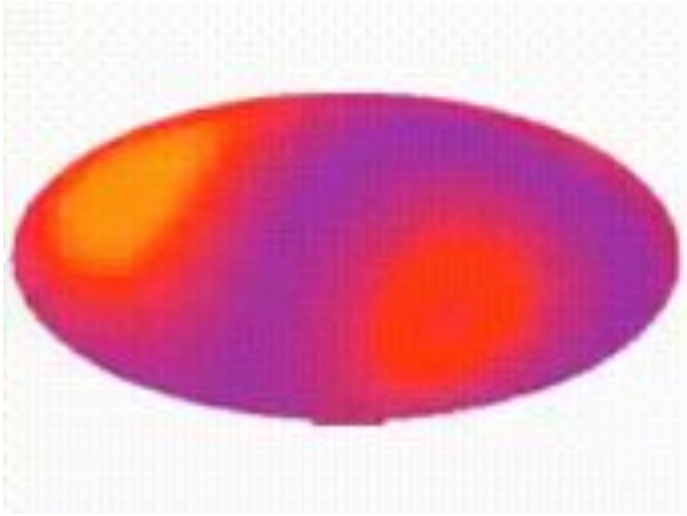


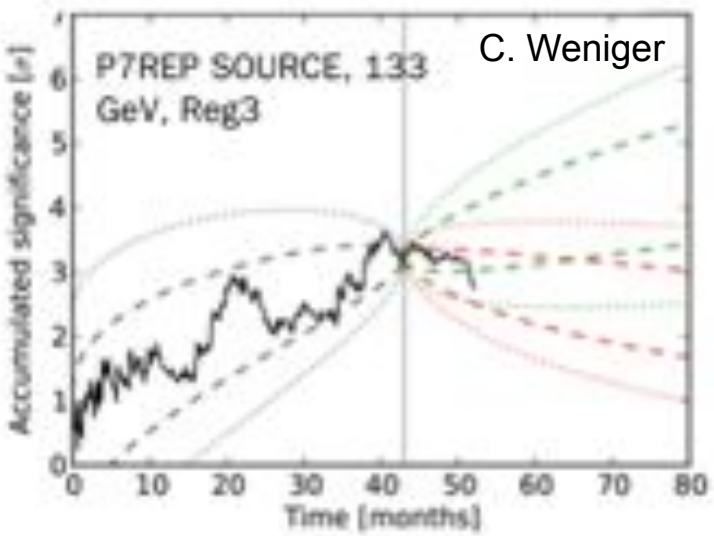
- Pass8 reveals more high-energy gamma rays from GRB
- Sample of 10 GRBs with measured redshift re-analized
  - 4 new photons above 10 GeV (in addition to the 6 known)
  - Interesting implications for γ-ray opacity
- First Pass8 science paper

Observing strategies

http://fermi.gsfc.nasa.gov/ssc/proposals/alt_obs/obs_modes.html

- Recommendation for increased exposure towards Galactic Centre for at least one year
  - Mission devised a modified survey profile to keep good full sky exposure
    - ☺ line, e^+, GC emission, short transients, subset of AGN and PSR
    - ☹ dwarfs, EGB, pulsar monitoring, catalog
- Main Science drivers
  - Passage of G2 cloud around SgrA*
  - Increased discovery potential for young pulsars
  - Boost in statistics from GC and control samples to confirm / rule out hint of 133 GeV Dark Matter line





Summary and look ahead

- The LAT Science Analysis continues to be rich and broad
  - Focusing on catalogs of different populations
    - Benefits from large statistics high quality data
  - Exploring the richness of alternative diffuse emission models in all science areas
    - Including Dark Matter searches
- Mission entered extended operations
  - Funding subjected to competitive NASA Senior Reviews
  - About to delivery Pass7 reprocessed data
    - Current best knowledge of LAT data
  - Very exciting prospects from new Pass8 analysis
    - Reprocessing on-going
  - Modified survey favoring GC recommended to start in 2013