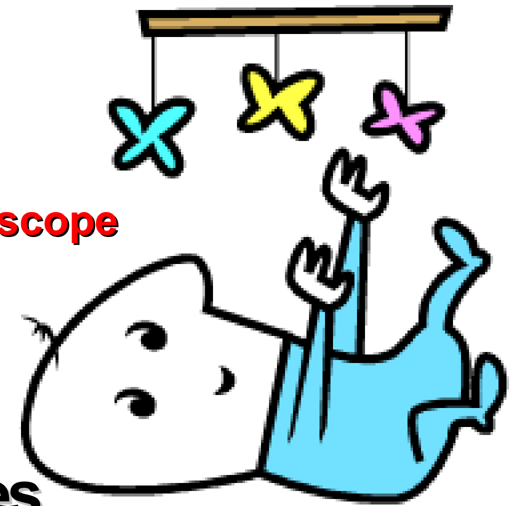
Fermi

Gamma-ray Space Telescope

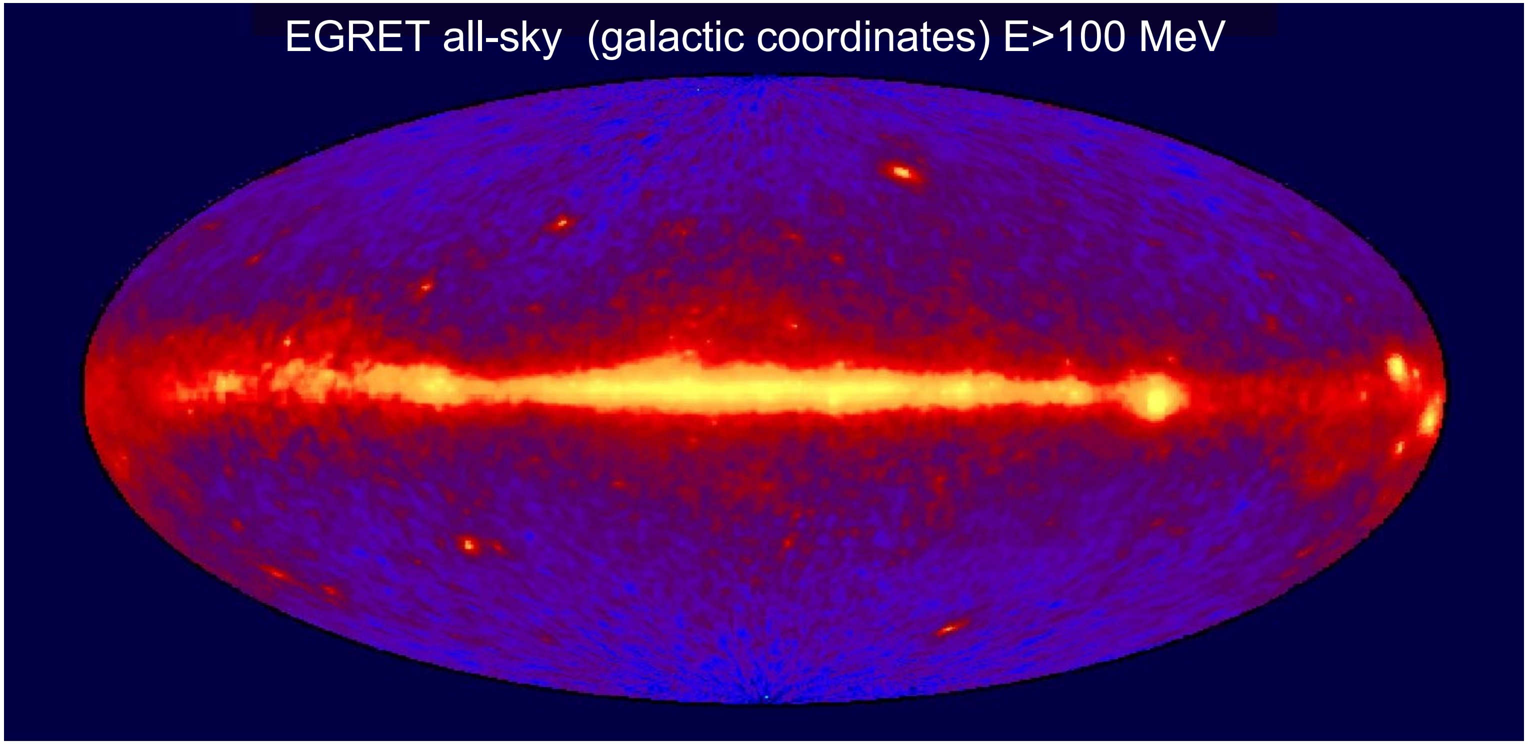


At Six Months and DM searches

E.Nuss
LPTA University of Montpellier 2
on behalf of the Fermi LAT Collaboration
Dark Matter and New Physics Working Group

see http://www-glast.stanford.edu/
http://www.nasa.gov/fermi **and**
http://fermi.gsfc.nasa.gov/ **and**
links therein

Features of the EGRET gamma-ray sky



diffuse extra-galactic background (flux ~ 1.5×10^{-5} $cm^{-2}s^{-1}sr^{-1}$)
galactic diffuse (flux ~30 times larger)
high latitude (extra-galactic) point sources (typical flux from EGRET sources O(10^{-7} - 10^{-6}) $cm^{-2}s^{-1}$)
galactic sources (pulsars, un-ID'd)

An essential characteristic: VARIABILITY in time!

Field of view important for study of transients.

Fermi Science

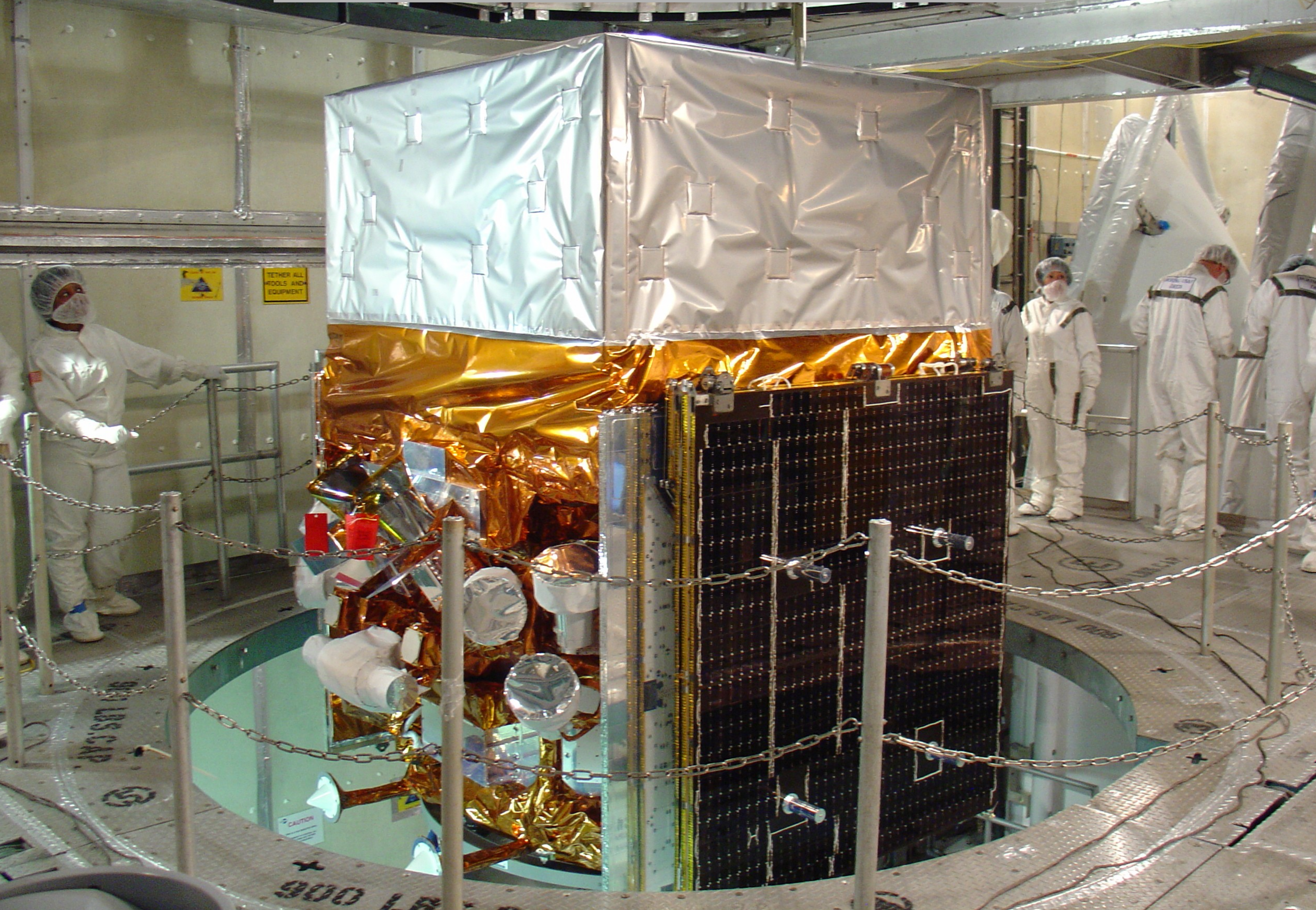
A very broad menu that includes:

- Systems with supermassive black holes (Active Galactic Nuclei)
- Gamma-ray bursts (GRBs)
- Pulsars
- Supernova remnants (SNRs), PWNe, Origin of Cosmic Rays
- Diffuse emissions
- Solar physics
- Probing the era of galaxy formation, optical-UV background light
- Solving the mystery of the high-energy unidentified sources
- Discovery! New source classes. Particle Dark Matter? Other relics from the Big Bang? Other fundamental physics checks.

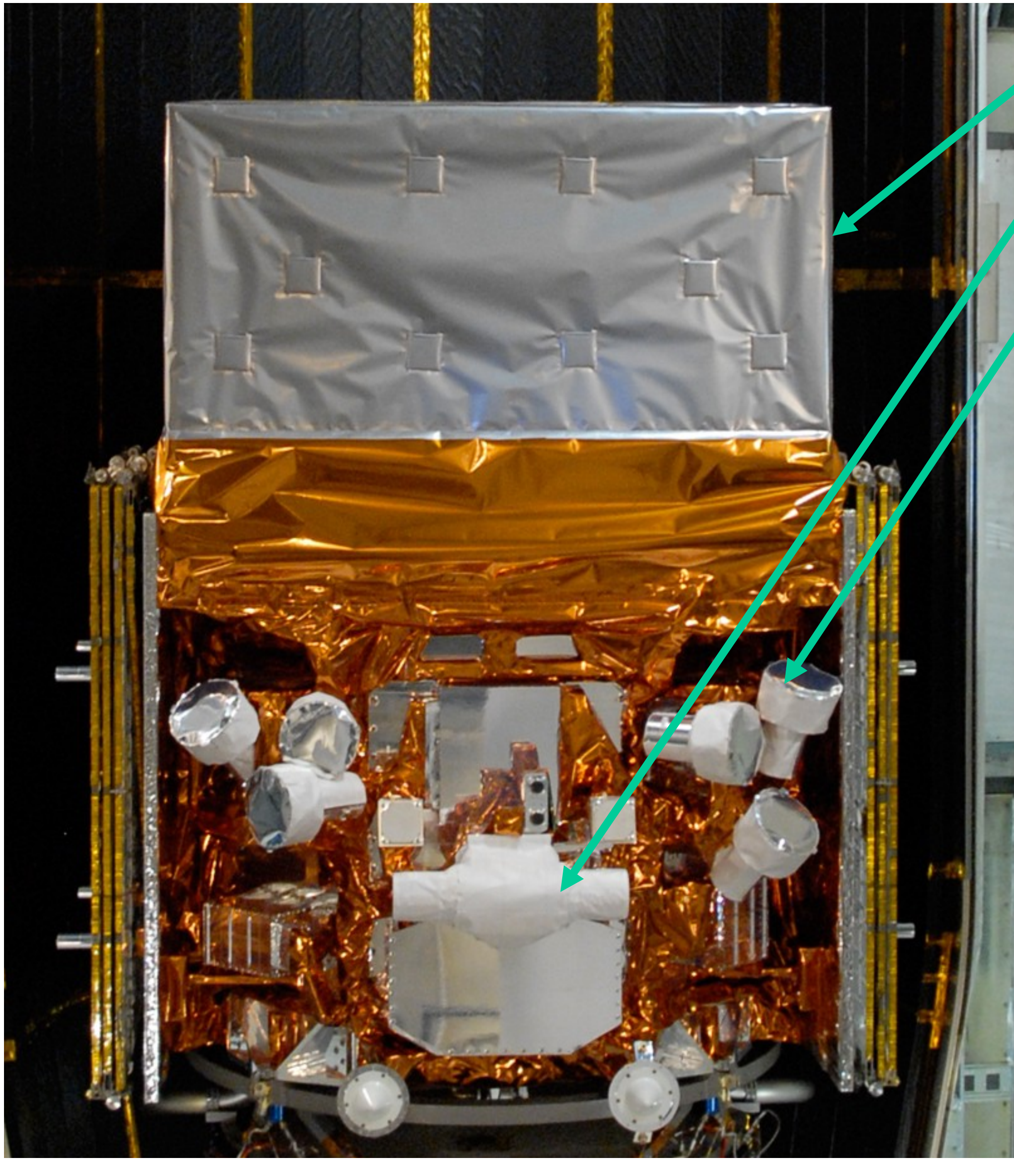
Huge increment in capabilities.

Draws the interest of both the High Energy Particle Physics and High Energy Astrophysics communities.

Prior to Fairing Installation



The Observatory



Large AreaTelescope (LAT)
20 MeV - >300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 30 MeV

KEY FEATURES

- Huge field of view
  - –LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.
- Huge energy range, including largely unexplored band 10 GeV - 100 GeV. Total of >7 energy decades!
- Large leap in all key capabilities. Great discovery potential.

The Accelerator

Launch!

- Launch from Cape Canaveral Air Station 11 June 2008 at 12:05PM EDT
- Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.

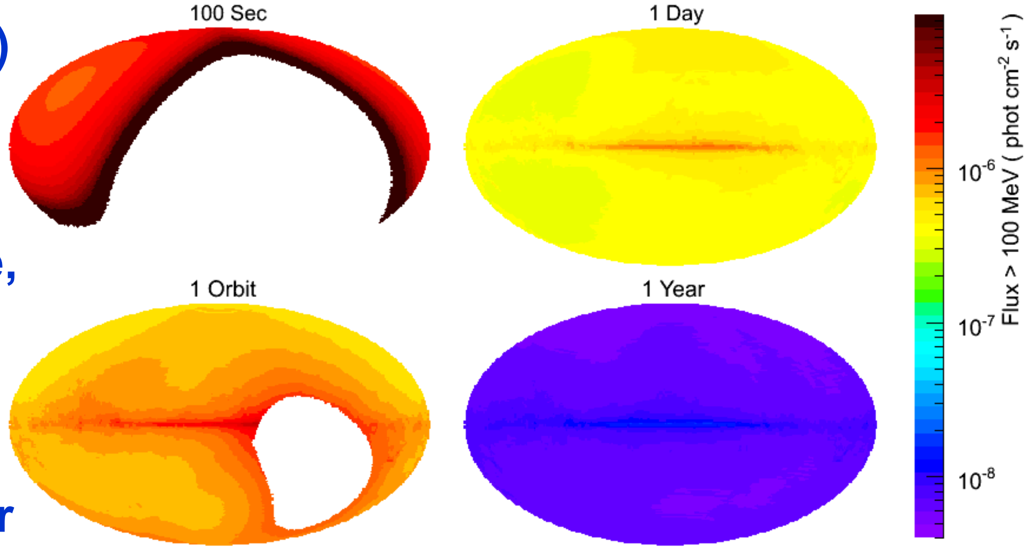
A moment later…

… and then …

… on its way!

Operating modes

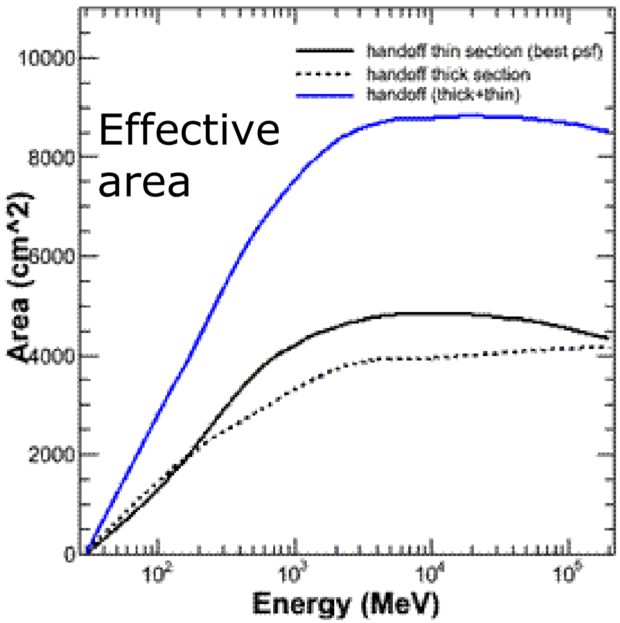
- **Primary observing mode is Sky Survey**
  - **Full sky every 2 orbits (3 hours)**
  - **Uniform exposure, with each region viewed for ~30 minutes every 2 orbits**
  - **Best serves majority of science, facilitates multiwavelength observation planning**
  - **Exposure intervals commensurate with typical instrument integration times for sources**
  - **EGRET sensitivity reached in days**

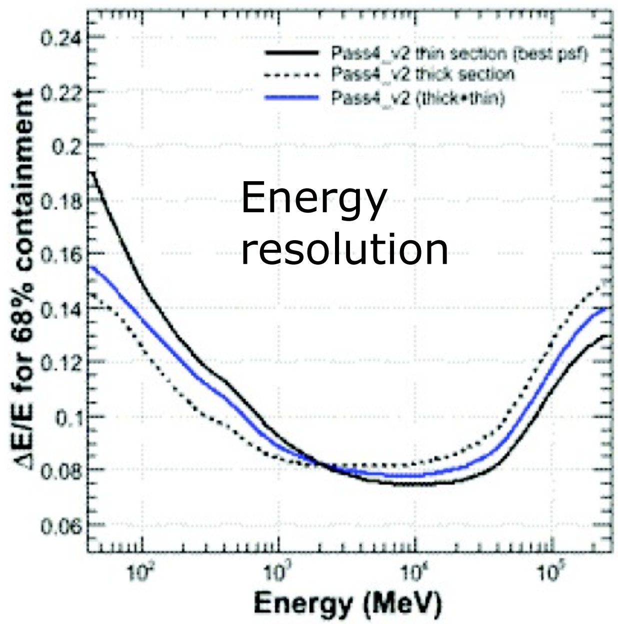


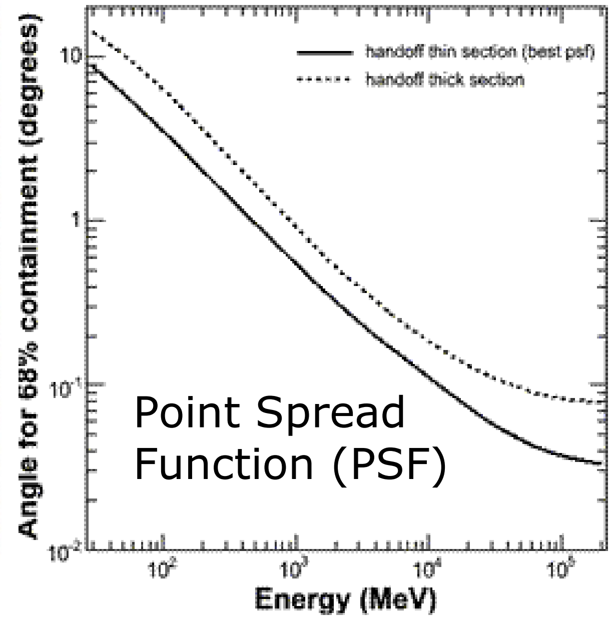
Sensitivity to point sources
(1-year survey, assuming $dN/dE \sim E^{-2}$)

- **Pointed observations when appropriate (selected by peer review in later years) with automatic earth avoidance selectable. Target of Opportunity pointing.**
- **Autonomous repoints for onboard GRB detections in any mode.**

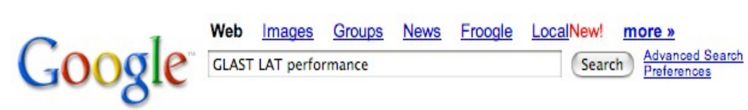
Observatory performance





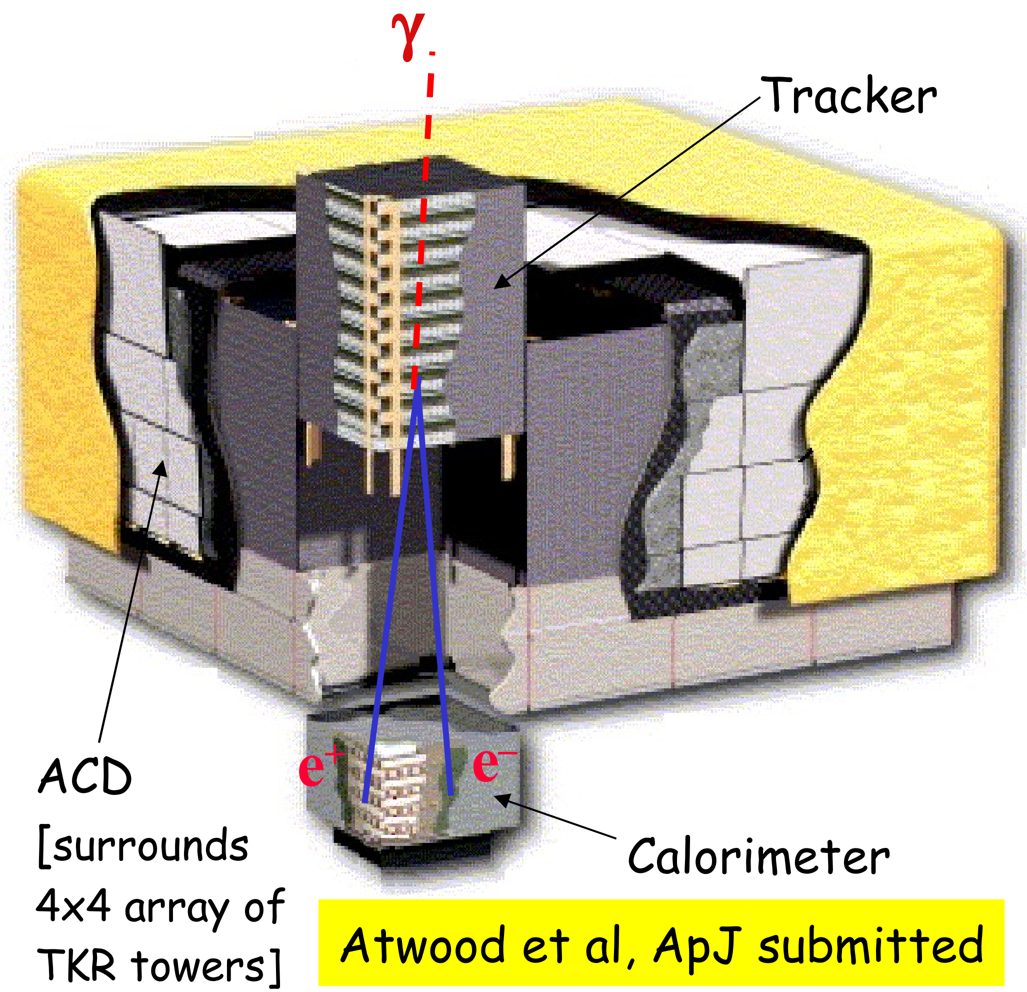


Energy Resolution:	**~10%**
PSF (68%) at 100 MeV:	**~ 3.5°**
PSF (68%) at 10 GeV:	**~ 0.1°**
Field Of View:	**2.4 sr**
Point Source sens. (>100 MeV):	**3×10^{-9} cm^{-2} s^{-1}**



Overview of LAT: How it works

- Precision Si-strip Tracker (TKR) Measure the photon direction; gamma ID.
- Hodoscopic CsI Calorimeter (CAL) Measure the photon energy; image the shower.
- Segmented Anticoincidence Detector (ACD) Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
- Electronics System Includes flexible, robust hardware trigger and software filters.



Atwood et al, ApJ submitted

Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

LAT Collaboration

- **France**
  - CNRS/IN2P3, CEA/Saclay
- **Italy**
  - INFN, ASI, INAF
- **Japan**
  - Hiroshima University
  - ISAS/JAXA
  - RIKEN
  - Tokyo Institute of Technology
- **Sweden**
  - Royal Institute of Technology (KTH)
  - Stockholm University
- **United States**
  - Stanford University (SLAC and HEPL/Physics)
  - University of California, Santa Cruz - Santa Cruz Institute for Particle Physics
  - Goddard Space Flight Center
  - Naval Research Laboratory
  - Sonoma State University
  - The Ohio State University
  - University of Washington

PI: Peter Michelson (Stanford)

~390 Scientific Members (including 96 Affiliated Scientists, plus 68 Postdocs and 105 Students)

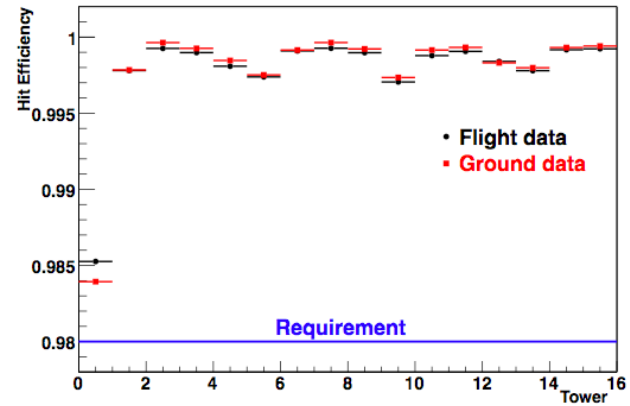
Cooperation between NASA and DOE, with key international contributions from France, Italy, Japan and Sweden.

Managed at SLAC.

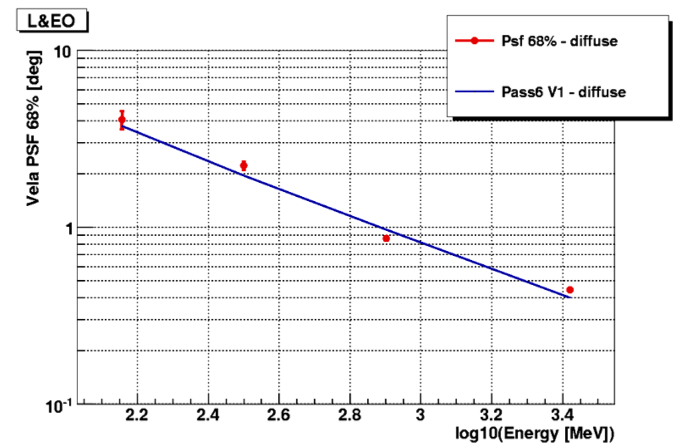
LAT Working Very Well On Orbit!

- **Total background rates very close to expectation (non-trivial!)**

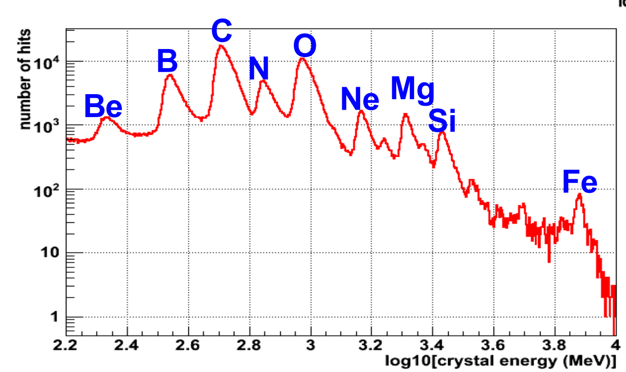
- **Spectacular charged-particle hit efficiency:**



- **PSF on-orbit as expected (note intrinsic energy dependence => localization is source-dependent)**
  - **verify using on-pulse photons from Vela, compare with detailed MC simulation:**

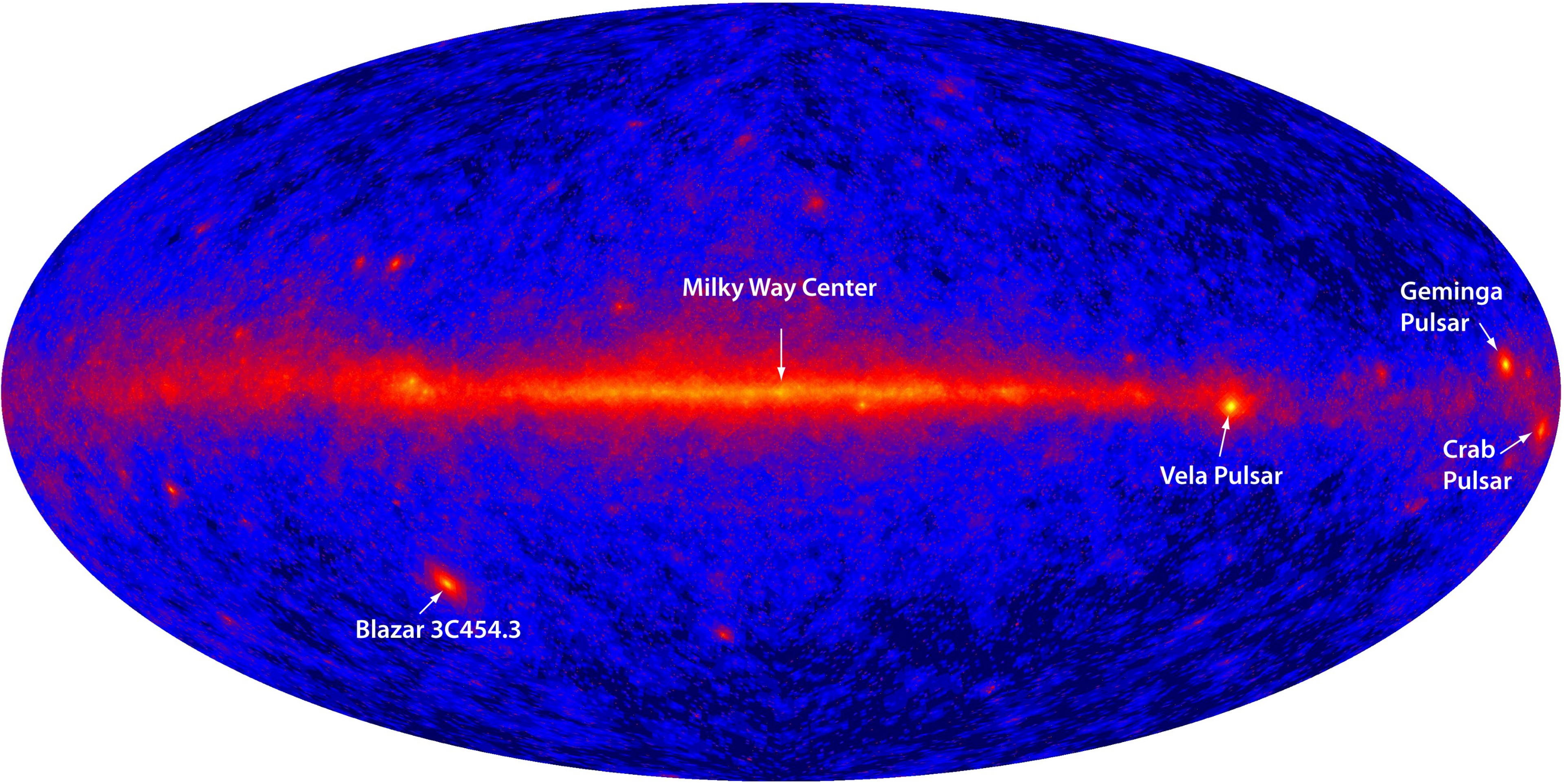


- **On-orbit calorimeter calibration stable**
  - **use cosmic ray heavy ions:**



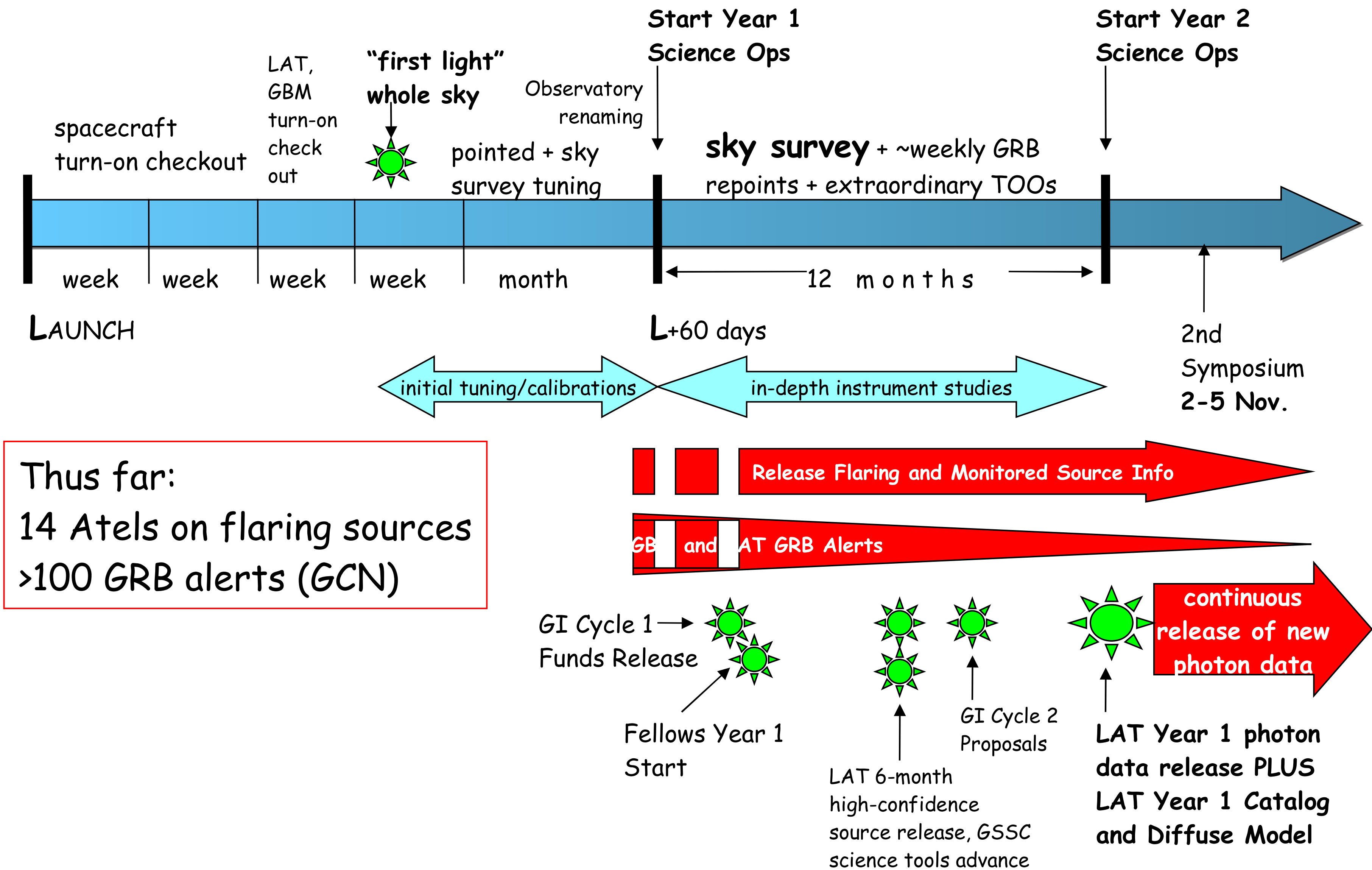
E.Nuss, on behalf of the Fermi LAT Collaboration

First Light!



Four days of all-sky survey engineering data.

Year 1 Science Operations Timeline Plan



E.Nuss, on behalf of the Fermi LAT Collaboration

Big Questions From EGRET Era

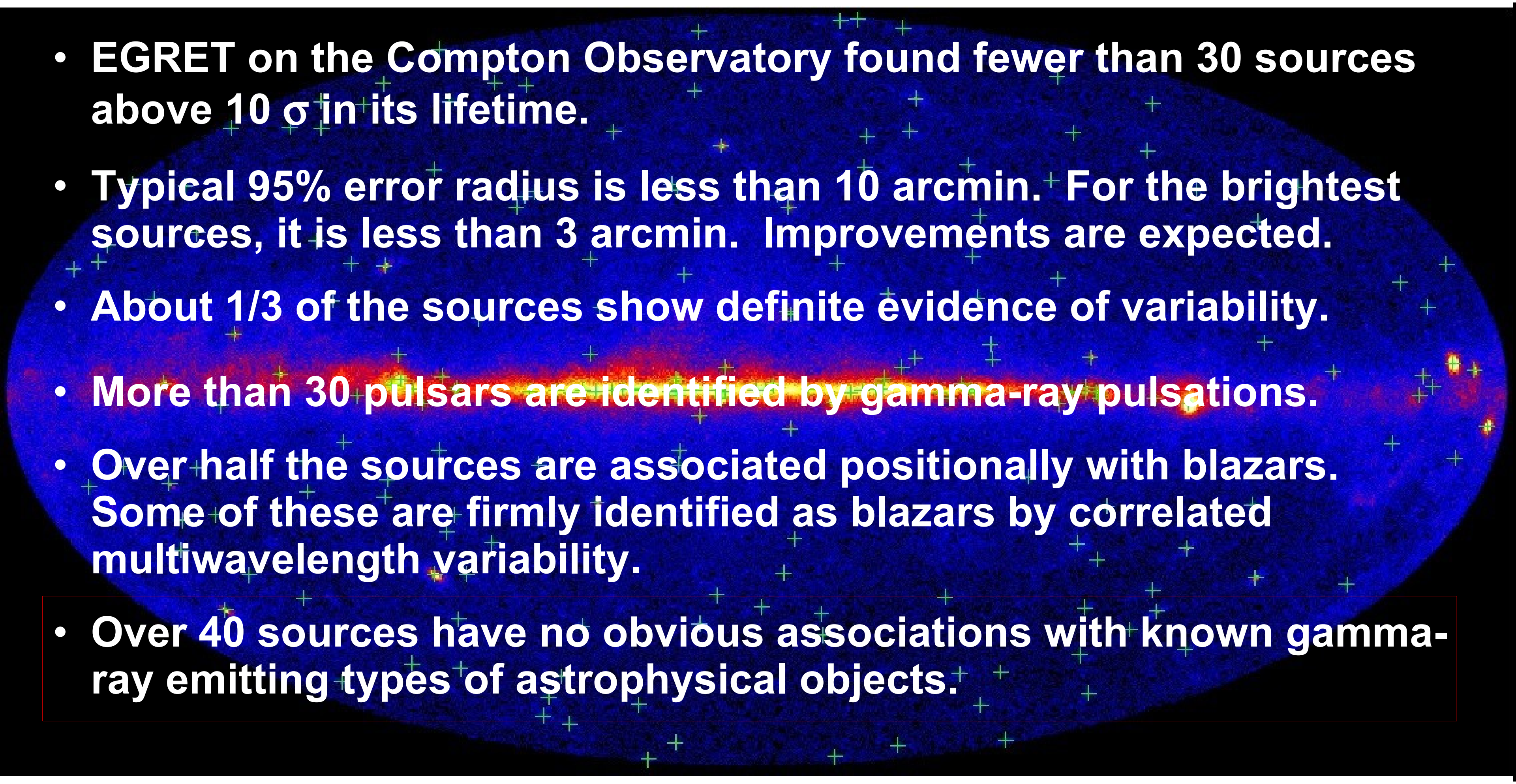
- How and where do pulsars emit gamma rays? How common are radio-quiet pulsars?
  - necessary clue to magnetic field configurations and dynamics
- What are the EGRET Unidentified Sources?
  - most of the EGRET source identifications are a mystery
- What are the energy budgets of gamma-ray bursts? What are the temporal characteristics of the high-energy emission?
  - not well characterized yet, key tests of models.
- What are the origins of the diffuse emissions?
  - galactic: cosmic-ray and matter distributions; sources
  - extragalactic: populations
  - new sources (Dark Matter annihilations, clusters, …)
- How do the supermassive black hole systems of AGN work? Why do the jets shine so brightly in gamma rays?
  - temporal and spectral variability over different timescales
- What remains to be discovered with great new capabilities??
  - EGRET showed us the tip of the iceberg. New sources and probes for new physics.

LAT Bright Source List

- Releasing information about the brightest sources early had two principal goals:
  - Provide opportunities for multiwavelength studies of these sources;
  - Facilitate proposals for the second cycle of Fermi Guest Investigator proposals, due on March 6.
- The target release date for the bright source (>10σ CL) list was February 6.
  - Source location and simple error radius (RA/DEC, L/B)
  - Flux and statistical error (F>100 MeV)
  - Test statistic/significance (with point source hypothesis)
  - Hardness ratio
  - Source associations where possible (including sources released as flaring objects)
  - Overall systematic error (in flux measurement)

  http://fermi.gsfc.nasa.gov/ssc/data/access/lat/bright_src_list/
- First step toward the first LAT catalog, due in the late summer 2009.

205 Preliminary LAT Brightest Sources



- EGRET on the Compton Observatory found fewer than 30 sources above 10 σ in its lifetime.
- Typical 95% error radius is less than 10 arcmin. For the brightest sources, it is less than 3 arcmin. Improvements are expected.
- About 1/3 of the sources show definite evidence of variability.
- More than 30 pulsars are identified by gamma-ray pulsations.
- Over half the sources are associated positionally with blazars. Some of these are firmly identified as blazars by correlated multiwavelength variability.
- Over 40 sources have no obvious associations with known gamma-ray emitting types of astrophysical objects.

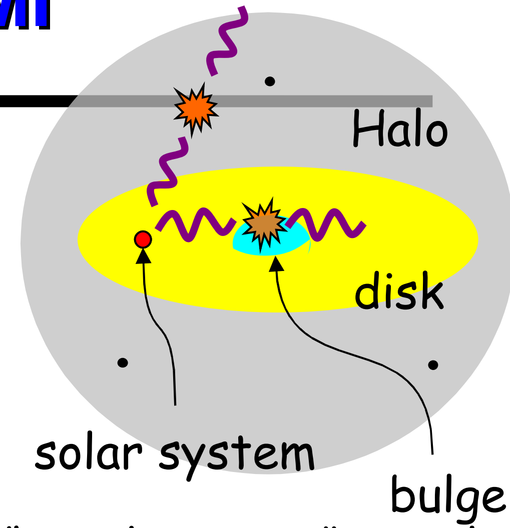
Crosses mark source locations, in Galactic coordinates.

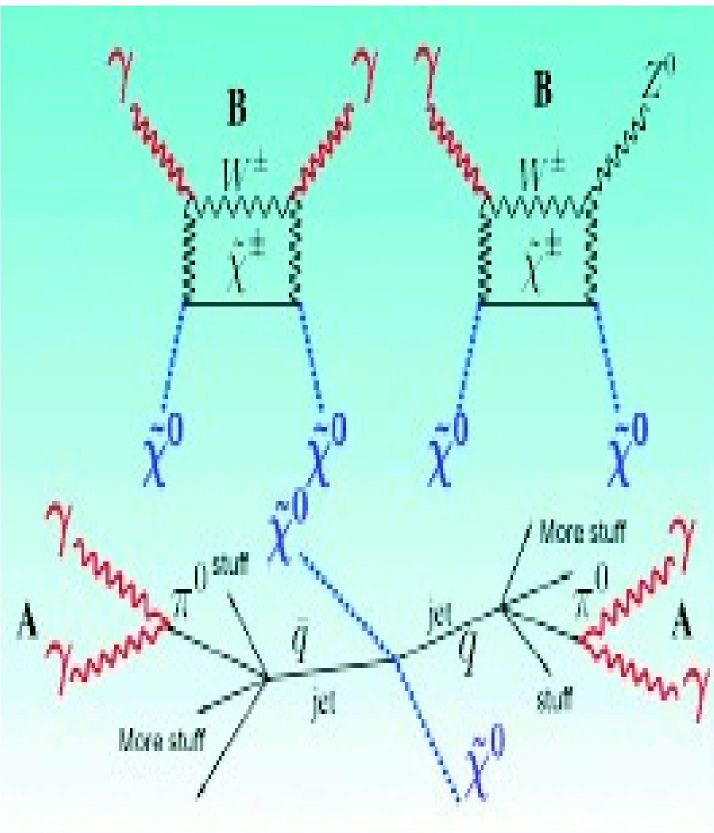
A list, not a catalog!

Dark Matter searches with FERMI

$$\frac{d\Phi_\gamma}{dE_\gamma} = \frac{1}{4\pi} \underbrace{\frac{\langle\sigma v\rangle}{2m_\chi^2} \sum_f \frac{dn_\gamma^f}{dE_\gamma} B_f}_{Particle\ Physics} \underbrace{\int_{\Delta\Omega} \int_{l.o.s} \rho^2(l)\ dl(\psi)\ d\Omega}_{Astrophysics}$$

$J(\psi)$



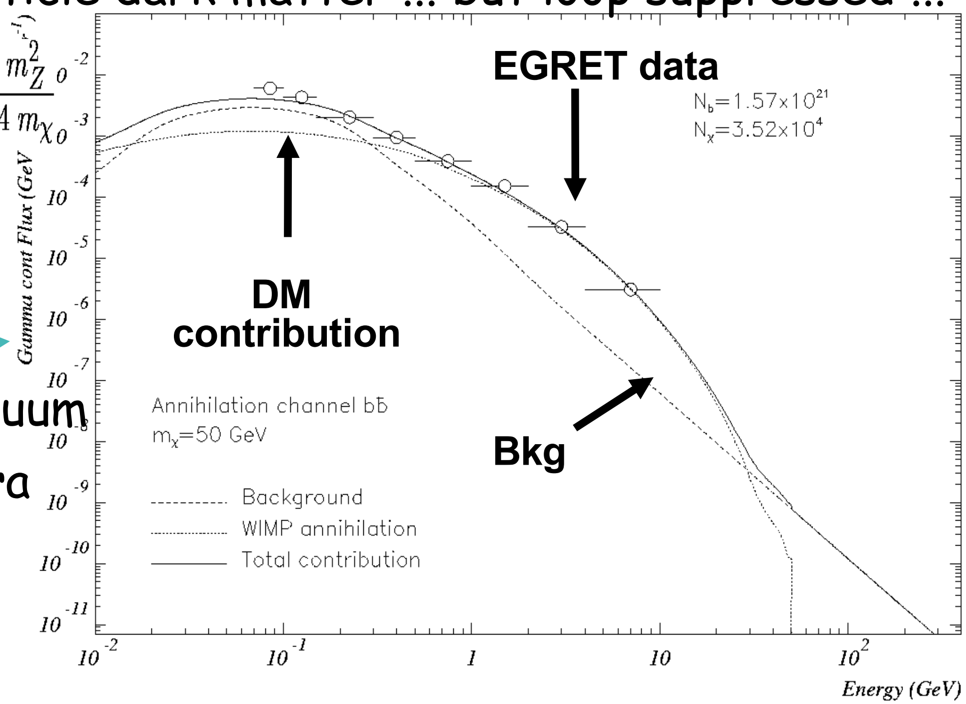


Gamma ray lines, the " smoking gun " signal of particle dark matter ... but loop suppressed ...

$$E_\gamma = m_\chi - \frac{m_{Z^0}^2}{4\, m_{\chi^0}}$$

$$E_\gamma = m_\chi$$

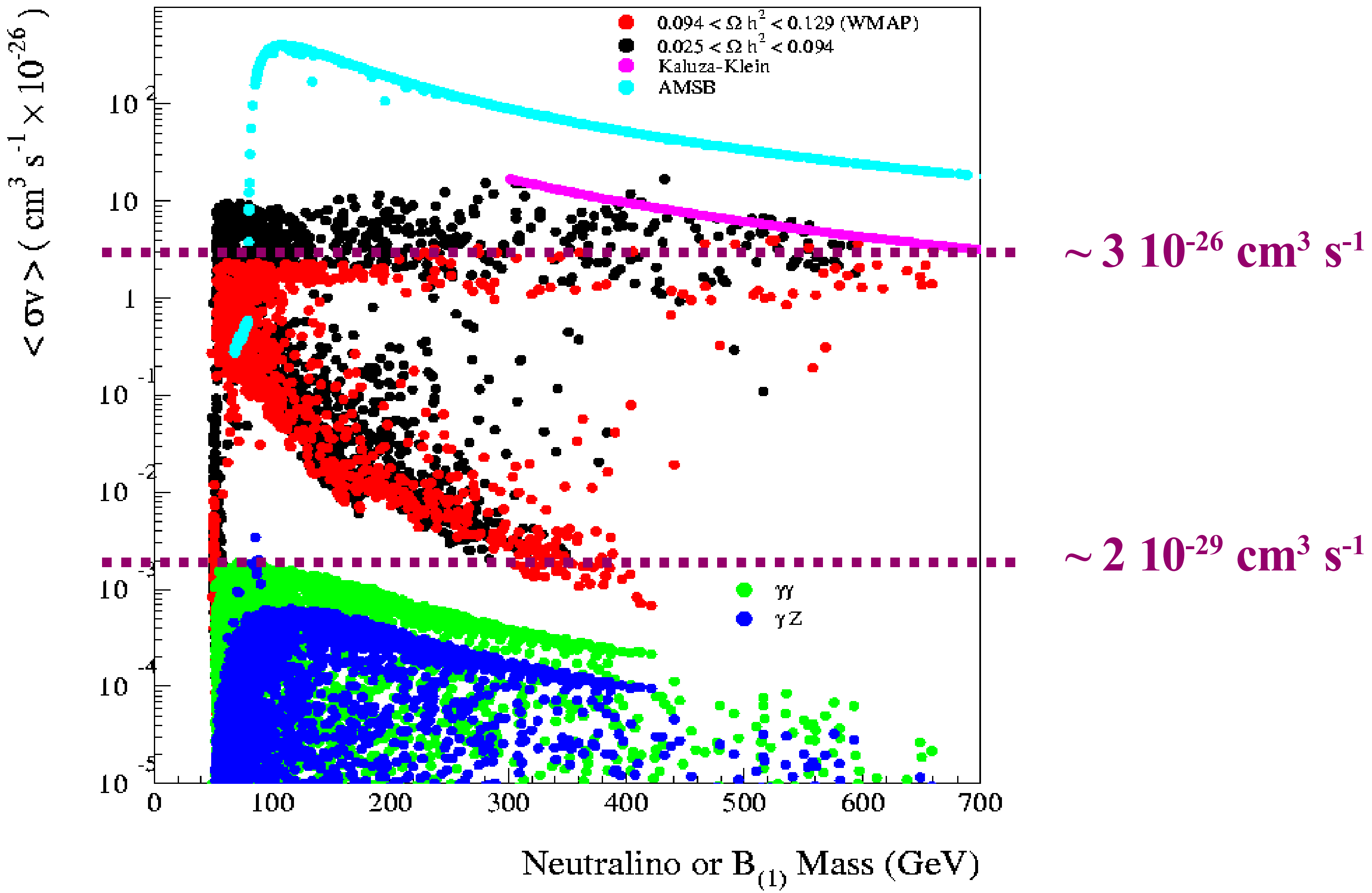
Continuum spectra



E.Nuss, on behalf of the Fermi LAT Collaboration

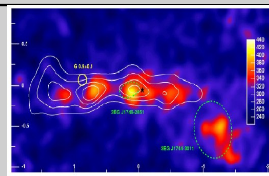
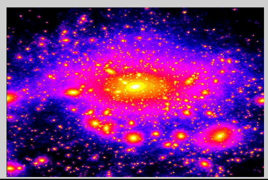
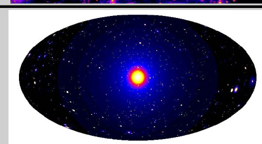
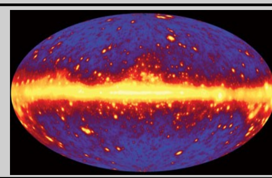
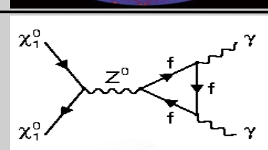
Expected cross sections

Continuum, γγ and γZ lines annihilating cross sections



E.Nu

How the FERMI-LAT telescope could help to disentangle the Dark Matter puzzle ?

Search Technique		advantages	challenges
Galactic center		Good Statistics	Source confusion/Diffuse background
Satellites, Subhalos, Point Sources		Low background, Good source id	Low statistics
Milky Way halo		Large statistics	Galactic diffuse background
Extra-galactic		Large Statistics	Astrophysics, galactic diffuse background
Spectral lines		No astrophysical uncertainties, good source id	Low statistics

E.A. Baltz et al. JCAP07 (2008) 013, arXiv:08062911

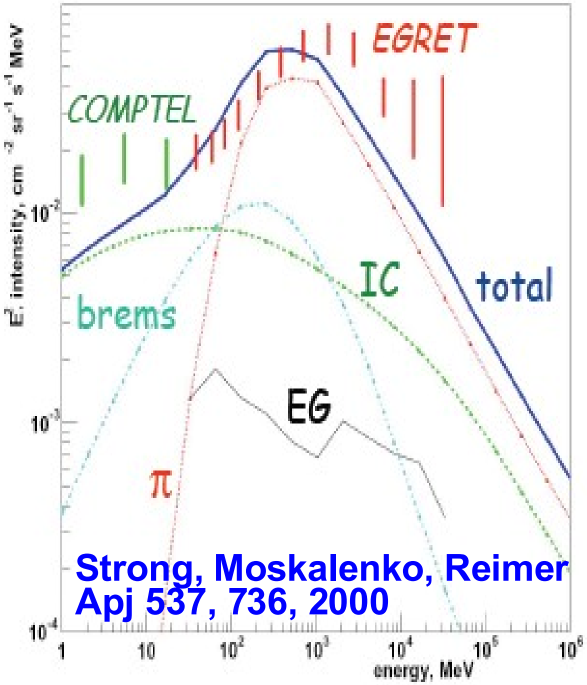
Backgrounds strategy in LAT paper JCAP*

Galactic Diffuse Emission :

Due to interaction (IC, π° decay, bremsstrahlung) of CR particles with gas in the ISM.

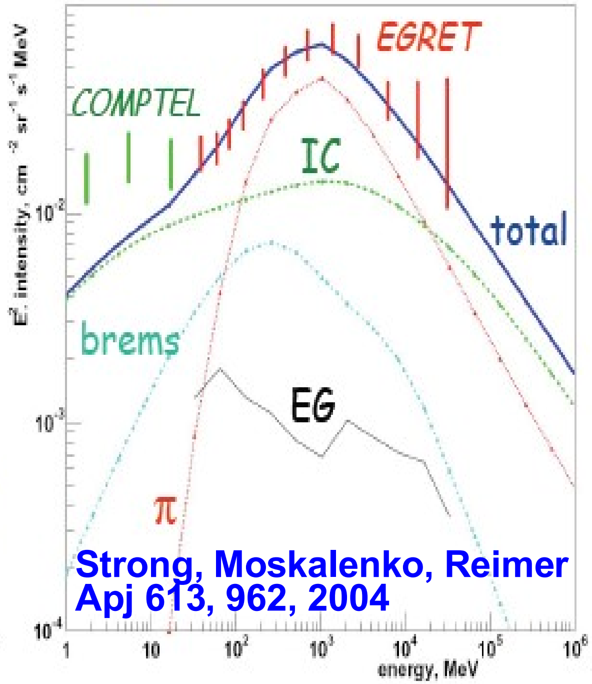
Contribution from IC and π° can be adjusted without violating independent astrophysical constraints

Galprop Conventional



Strong, Moskalenko, Reimer
Apj 537, 736, 2000

Galprop Optimized

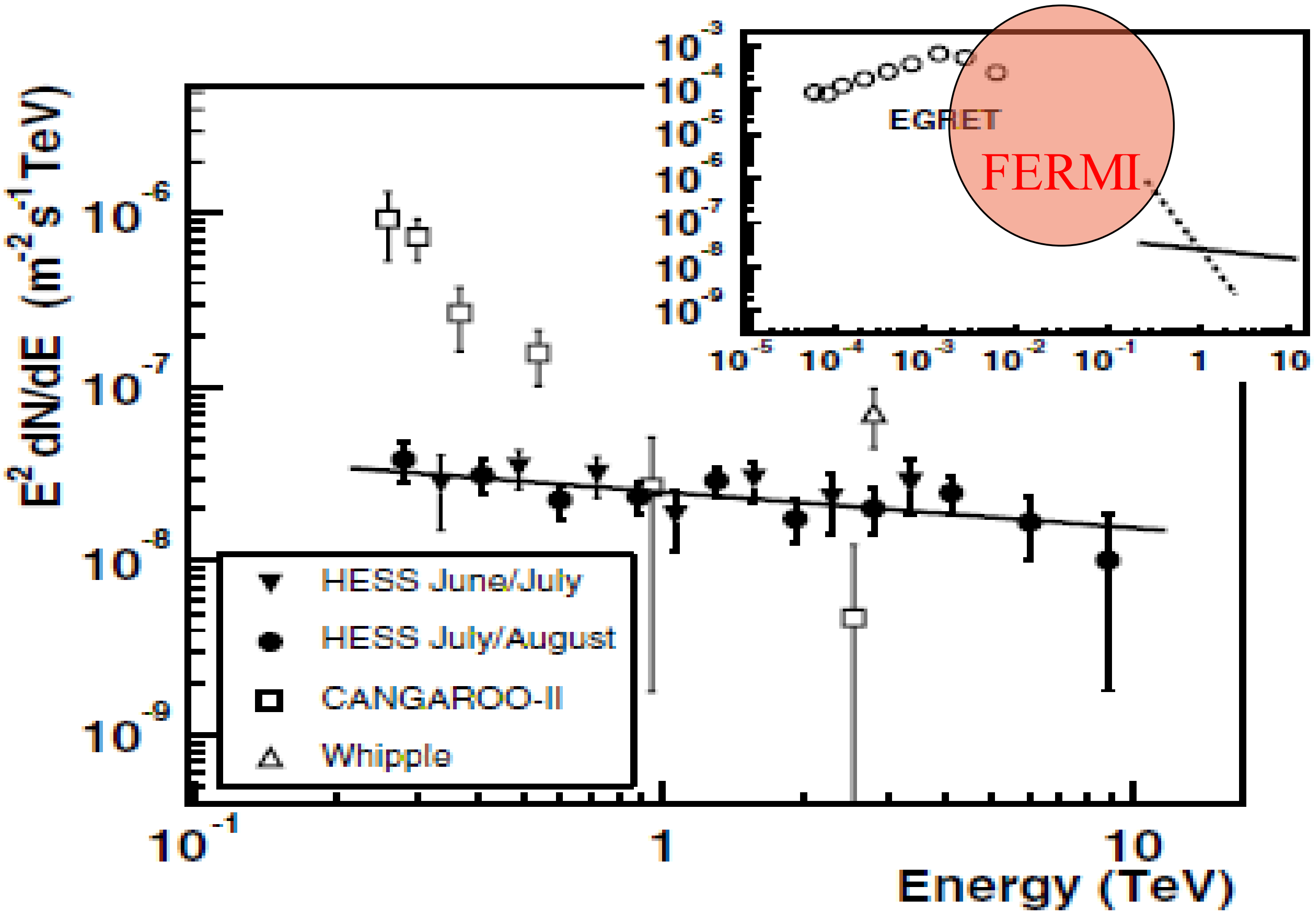


Strong, Moskalenko, Reimer
Apj 613, 962, 2004

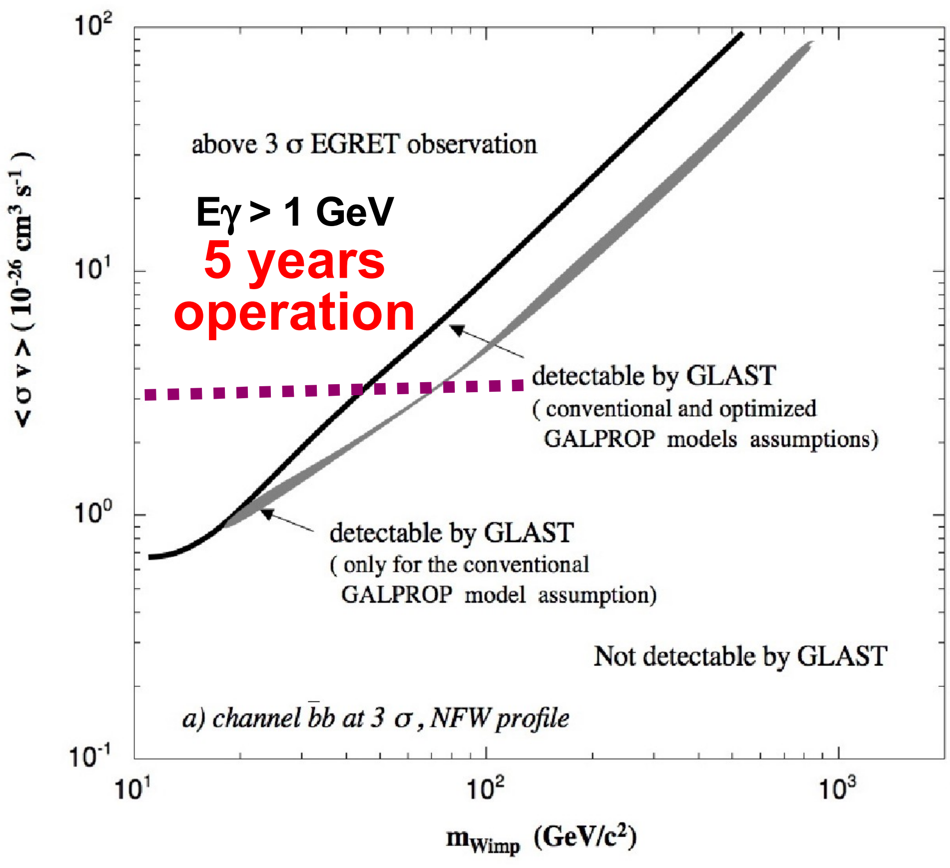
Extragalactic diffuse : P.Sreekumar et al Astrophys J. 1998

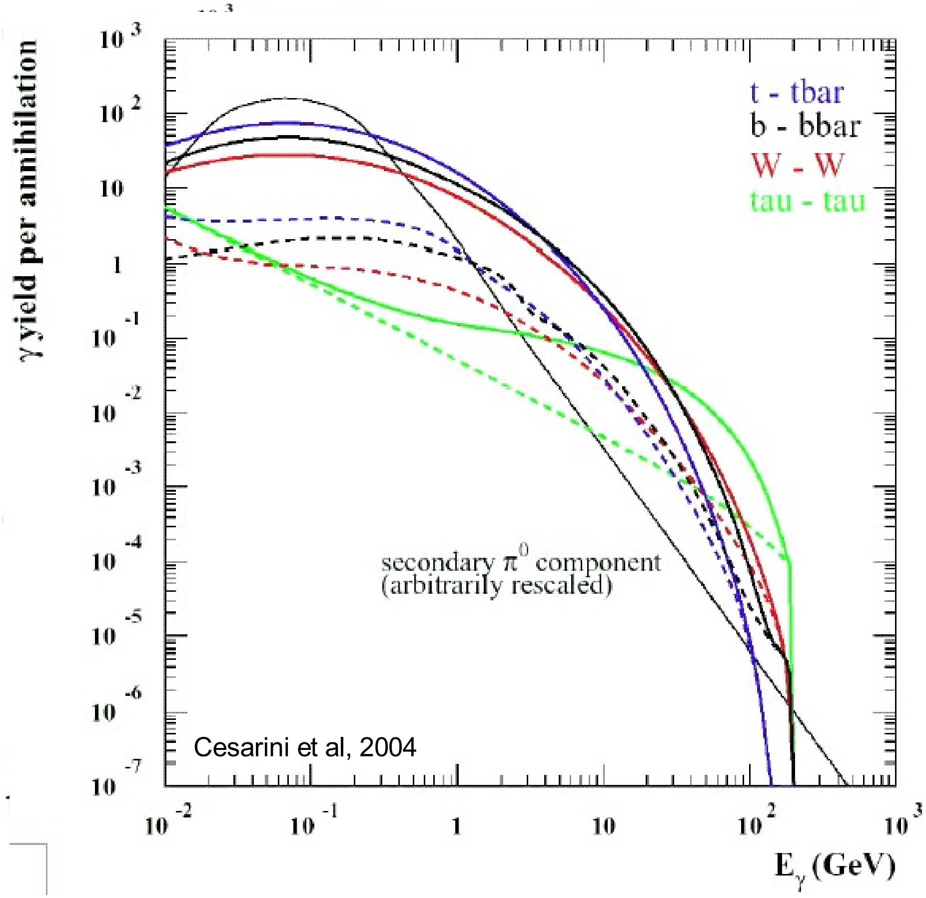
*E.A. Baltz et al. JCAP 0807:013,2008

Dark Matter search at GC with FERMI



Sensitivity map for GC with FERMI





Others annihilating channels have been investigated : t-tbar, $W^+ W^-$, $\tau^+\tau^-$, ...

Searches for cosmological dark matter annihilations into γ-rays

The signal : Ullio et. al. Phys.Rev. D66 (2002) 123502

$$\frac{d\Phi_\gamma}{dE_0} = \frac{\sigma v}{8\pi}\,\frac{c}{H_0}\,\frac{\bar{\rho}_0^2}{m_\chi^2} \times \int dz\,(1+z)^3\,\frac{\Delta^2(z)}{h(z)}\,\frac{dN_\gamma(E_0(1+z))}{dE}\,e^{-\tau(z,E_0)}$$

Contributions from

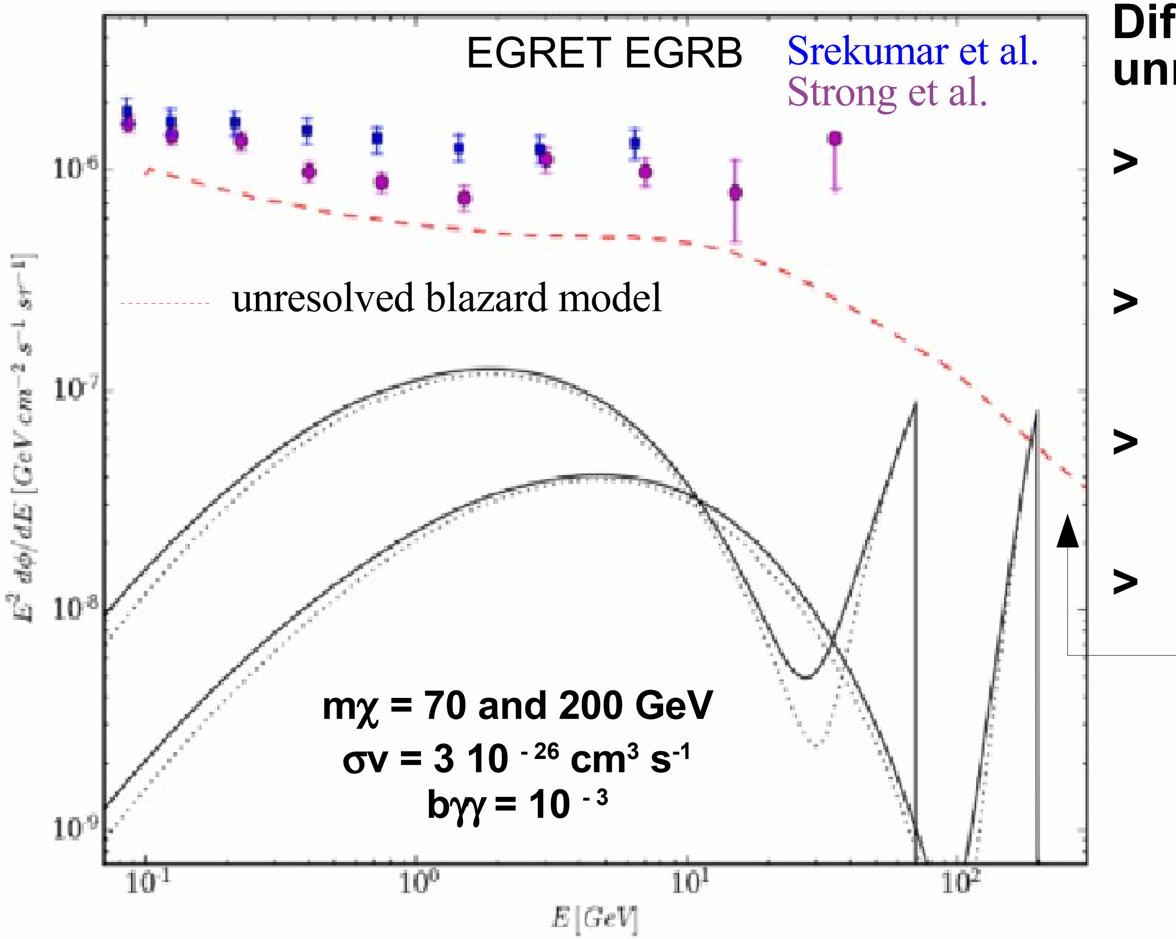
> **Particle physics**
> annihilation cross sections : $<\sigma v> \sim 3\ 10^{-26}\ cm^3\ s^{-1}$ (WMAP)
> WIMP mass : from ~ 45 GeV up to few TeV (Susy,KK, ...)
> continuum plus line yield : $b\gamma\gamma \sim 3 \times b\gamma Z \sim 10^{-3}$ (loop supression)

> **Astrophysics :**
> halo structures : choice of profile and concentration parameter
> subhaloes contribution : 'clumpiness' boost factor, $10^4 < \Delta^2(z) < 10^6$
> absorbtion (optical depth τ) : pair production on extraglactic light

> **Cosmology : cosmological parameters and expansion of the Universe**

$$h(z) = \sqrt{\Omega_M(1+z)^3 + \Omega_K(1+z)^2 + \Omega_\Lambda}$$

Backgrounds & Cosmological WIMP annihilation spectrum



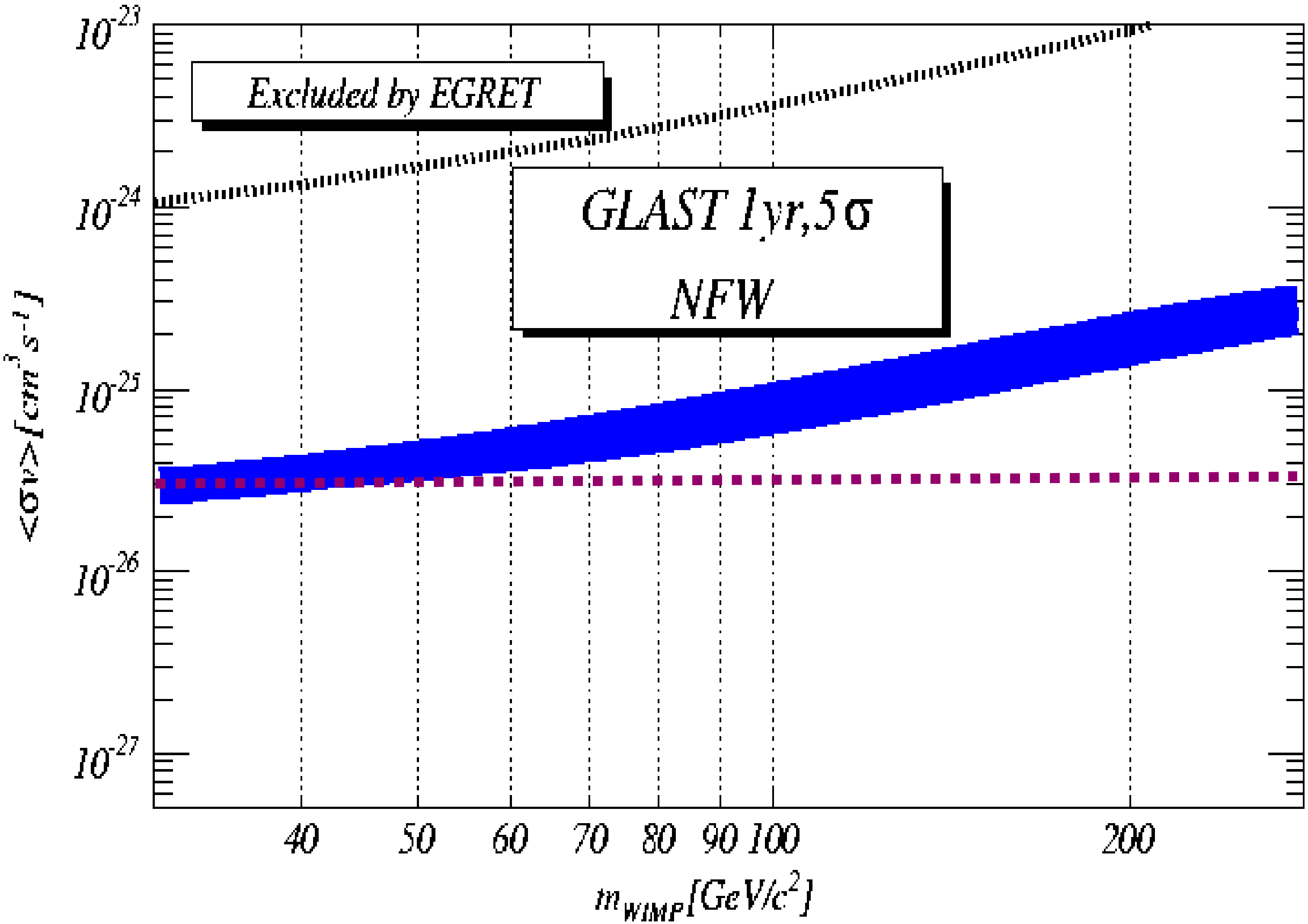
Diffuse emission from unresolved point sources :

- **AGNs (Dermer 2006) (20%-50%)**
- **Starburst galaxies (Thompson et al. 2006)**
- **Starforming galaxies (Pavlidou & Fields 2002)**
- **Structure formation (Keshet et al. 2002)**

Background considered for this analysis

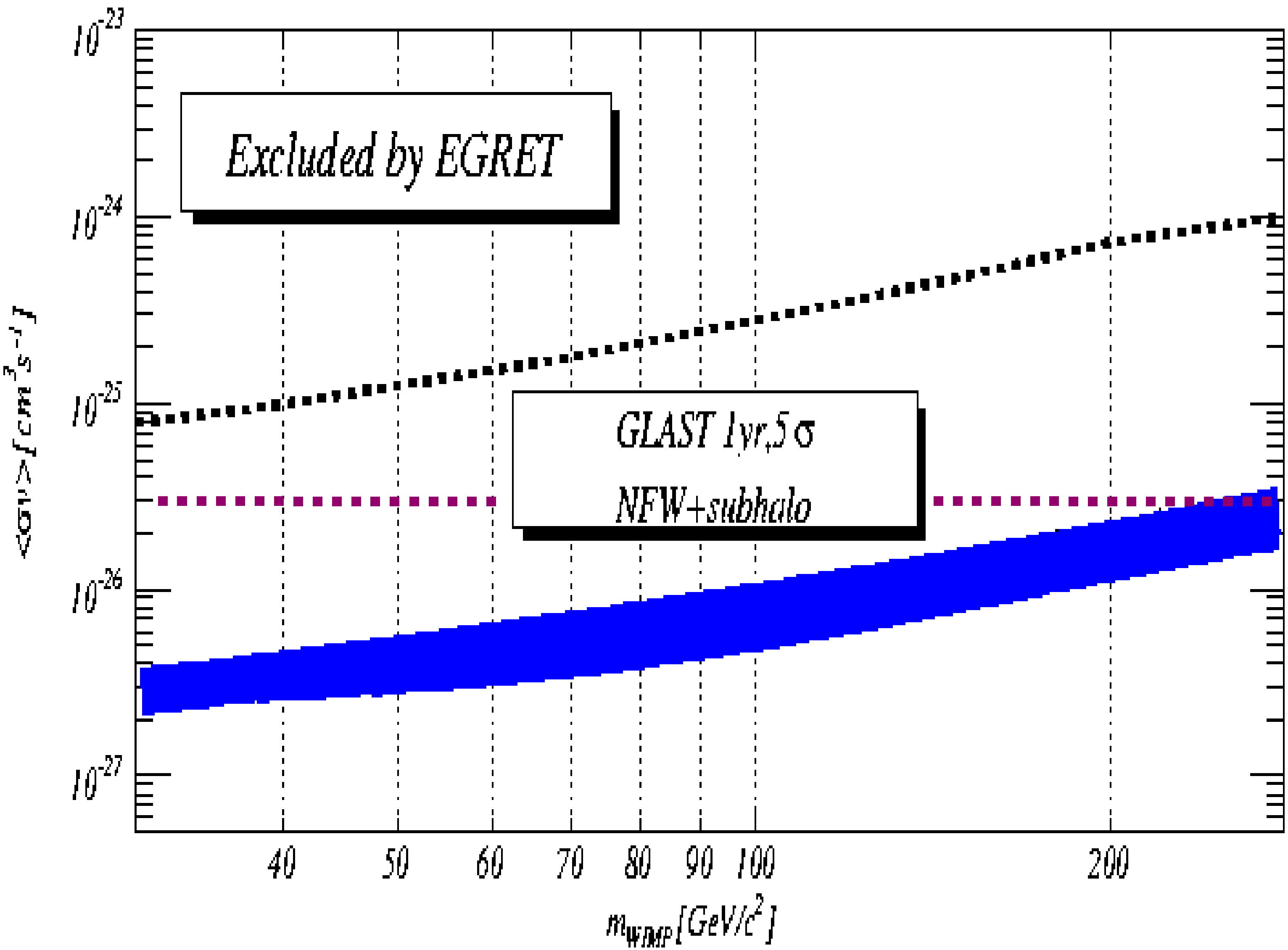
$$\frac{dN_\gamma}{dE}(E) = \underbrace{2b_{\gamma\gamma}\,\delta(E-m_\chi) + b_{\gamma Z}\,\delta(E-m_\chi[1-\frac{m_Z^2}{4m_\chi^2}])}_{\text{lines}} + \underbrace{\sum_F \frac{dN^F_{\text{count}}}{dE}(E)}_{\text{continuum}}$$

Sensitivity to generic WIMP (assuming only blazar background) for NFW profiles



$b_{\gamma\gamma} = 10^{-3}$

Sensitivity to generic WIMP (assuming only blazar background) for NFW profiles + subhalos



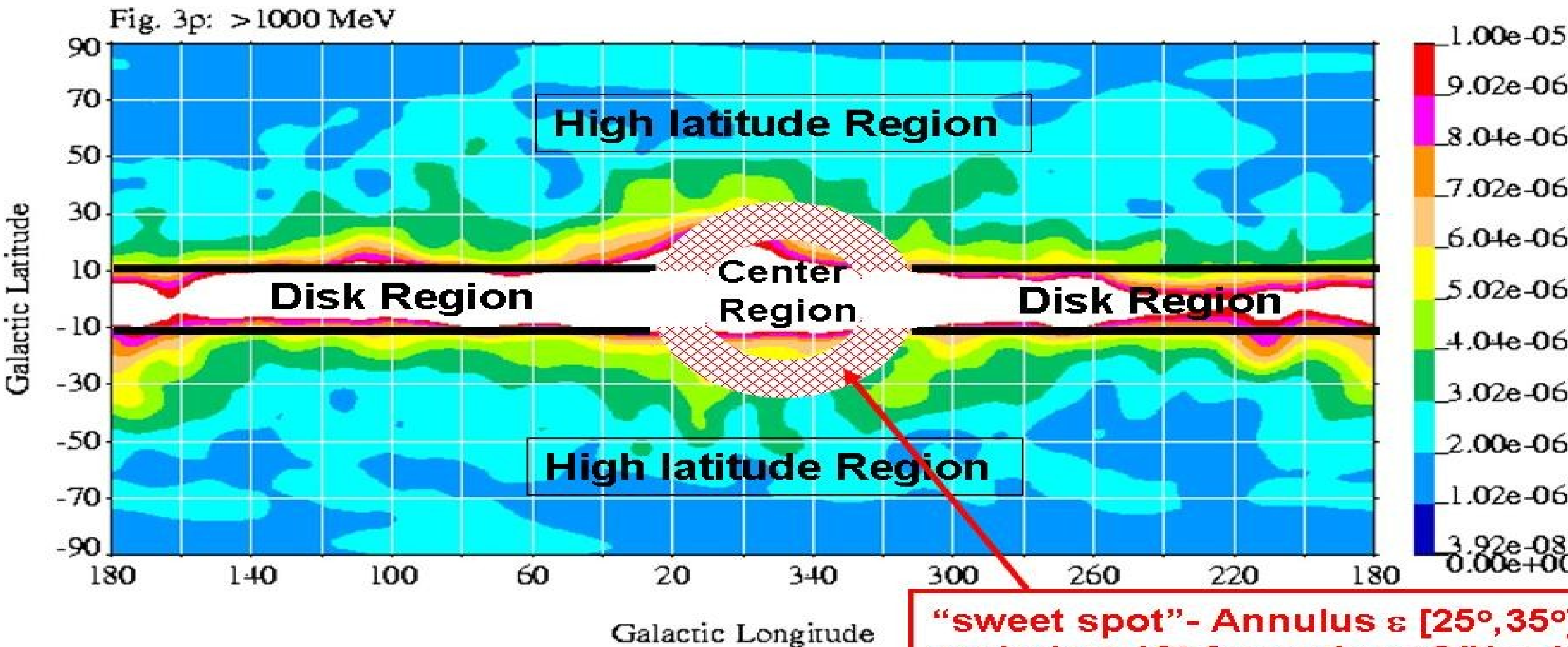
$b\gamma\gamma = 10^{-3}$
f = 5%,
$c_{sub}/c=4$

E.Nuss, on behalf of the Fermi LAT Collaboration

Line searches from WIMP annihilation into $\gamma\gamma$ and/or γZ final states

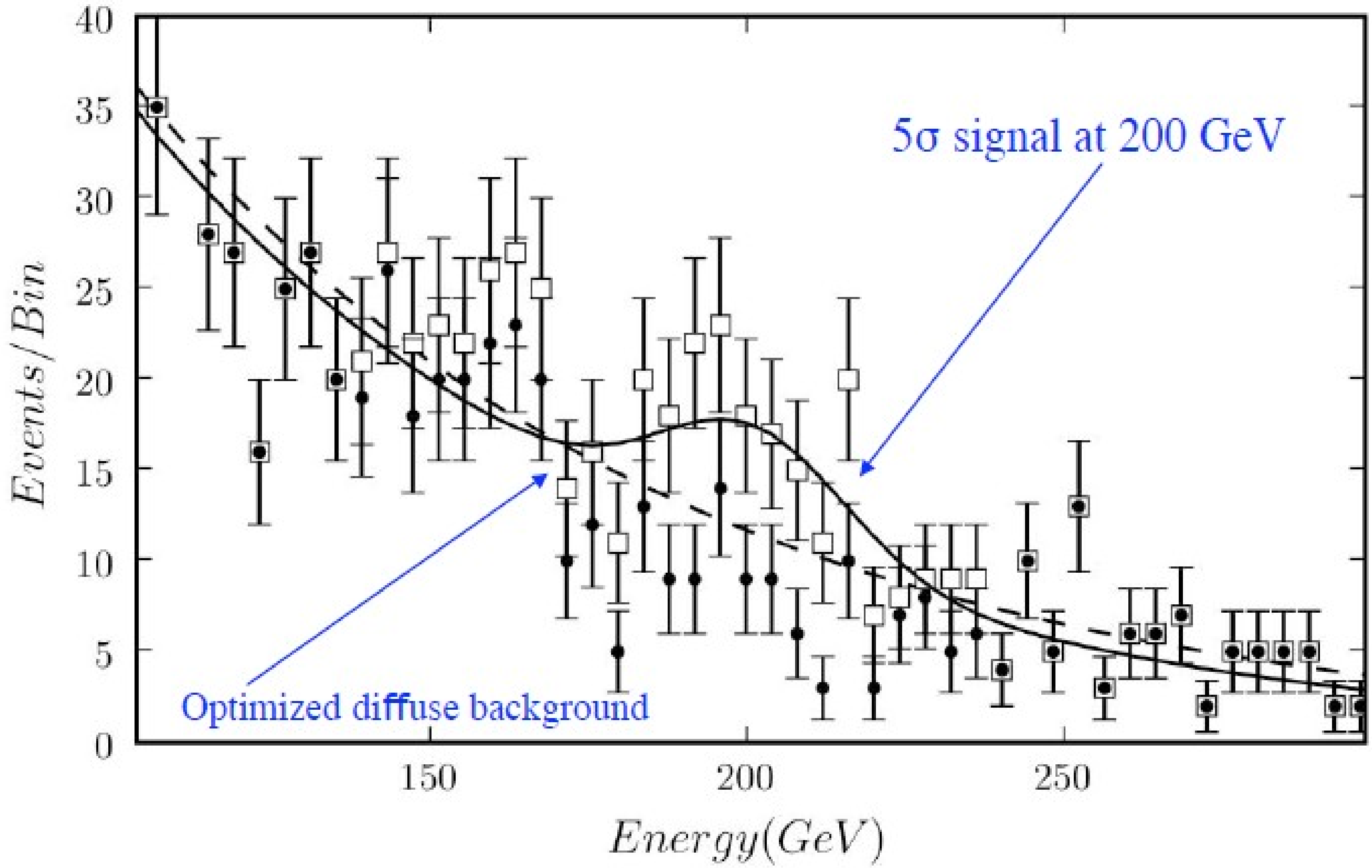
Where to look ?

Milky Way dark matter halo Annulus about the Galactic Center

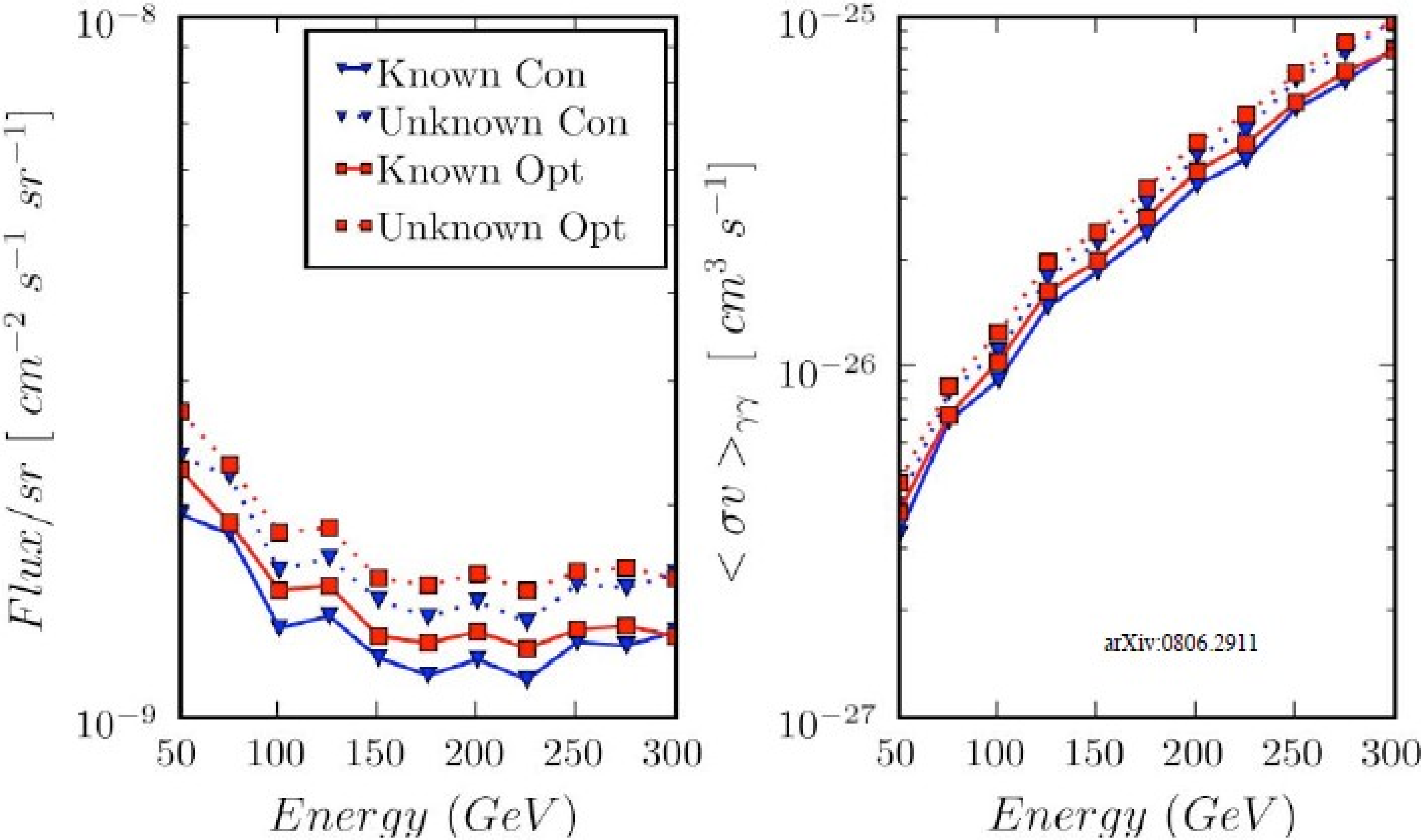


"sweet spot"- Annulus ε [25°,35°] exclude ± 10° from plane S/N ~ 12 times better than GC. (Stoehr et.al. 2003)

Optimized diffuse background and a 5 σ line signal at 200 GeV

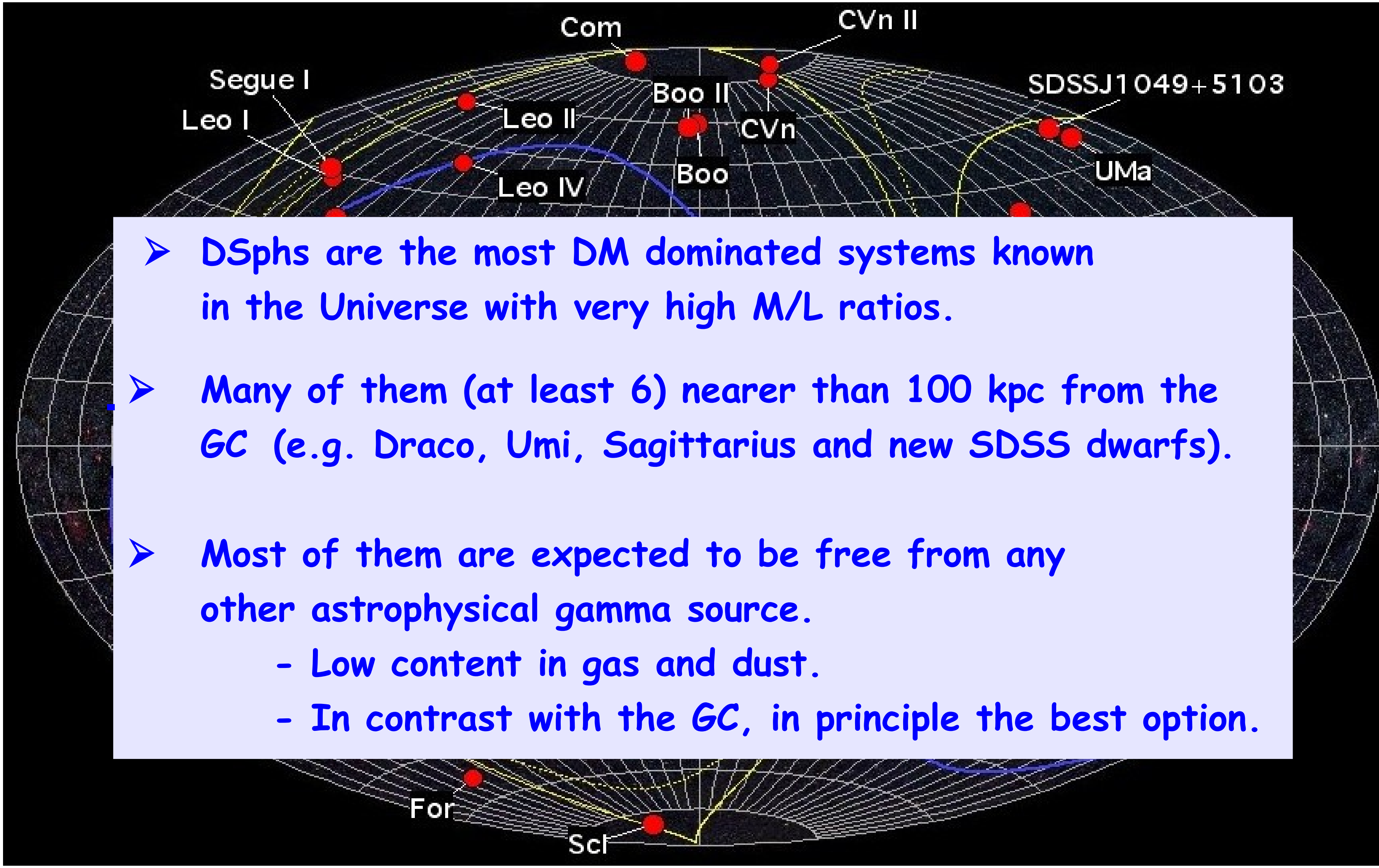


5 σ sensitivity countours to line signal (5 years)



con: conventional Galactic background model opt: Optimized Galactic background model

Dwarfs galaxies as promising targets for indirect dark matter detection

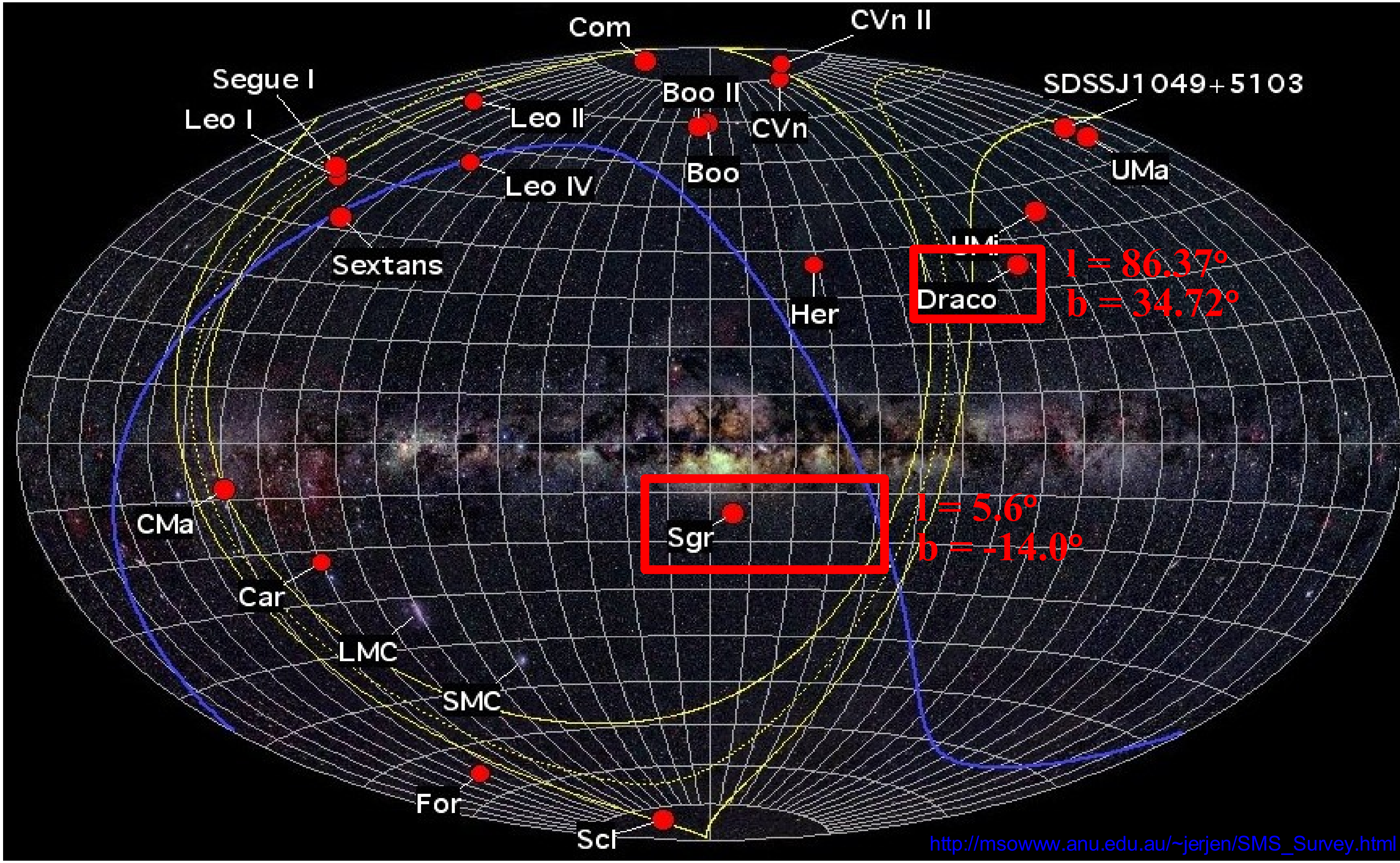


- DSphs are the most DM dominated systems known in the Universe with very high M/L ratios.
- Many of them (at least 6) nearer than 100 kpc from the GC (e.g. Draco, Umi, Sagittarius and new SDSS dwarfs).
- Most of them are expected to be free from any other astrophysical gamma source.
  - Low content in gas and dust.
  - In contrast with the GC, in principle the best option.

A tentative list (non exhaustive !) of good candidates

Name	Distance (kpc)	year of discovery	Radius (deg)	M/L	l	b
Sagittarius	23.4	1994	7.5	25	5.61	-14.08
Segue	23 ± 2	2007	0.12	1320^{+2680}_{-940}	220.48	50.42
Ursa Major II	30	2006	0.25	1722 ± 1226	152.46	37.44
Coma Berenices	43.2	2006	0.2	448 ± 297	241.9	83.6
Willman 1	45 ± 10	2004	0.02	700	158.57	56.78
Usra Minor	64.5	1954	0.27	580	104.95	44.80
Sculptor	77.4	1937	0.3	7	287.15	-83.16
Draco	80.1	1954	0.2	320	86.37	34.72
Sextans	84	1990	0.3	90	243.4	42.2
Carina	98.7	1977	0.17	40	260.11	-22.22
Fornax	135	1938	0.3	10	237.1	-65.7
Ursa Major I	106	2005	0.26	1700 ± 636	159.43	54.41
Hercules	138	2006	0.25	332 ± 221	28.73	36.87
Canes Venatici II	151	2006	0.11	336 ± 240	113.58	82.70
Leo IV	158	2006	0.1	151 ± 177	265.44	56.51

Two dwarfs as benchmarks for sensitivity studies



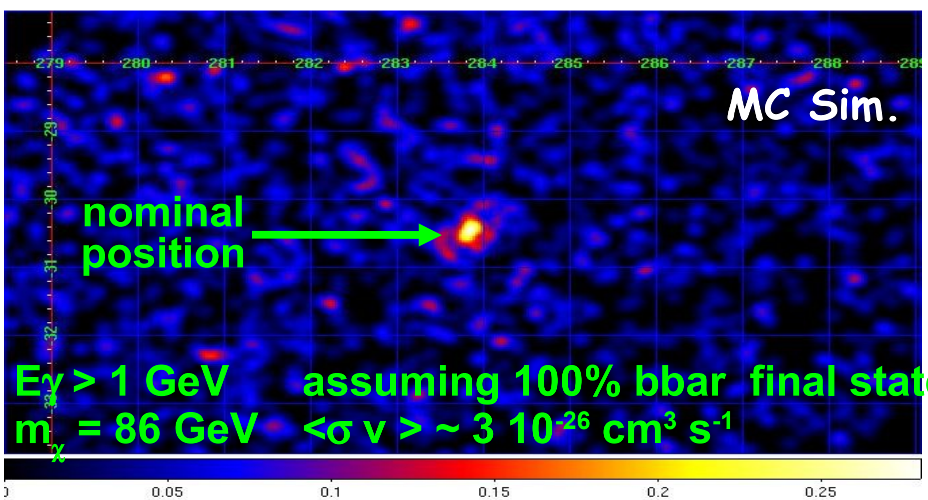
Sensitivity studies using Extended Maximum Likelihood and Test Statistic

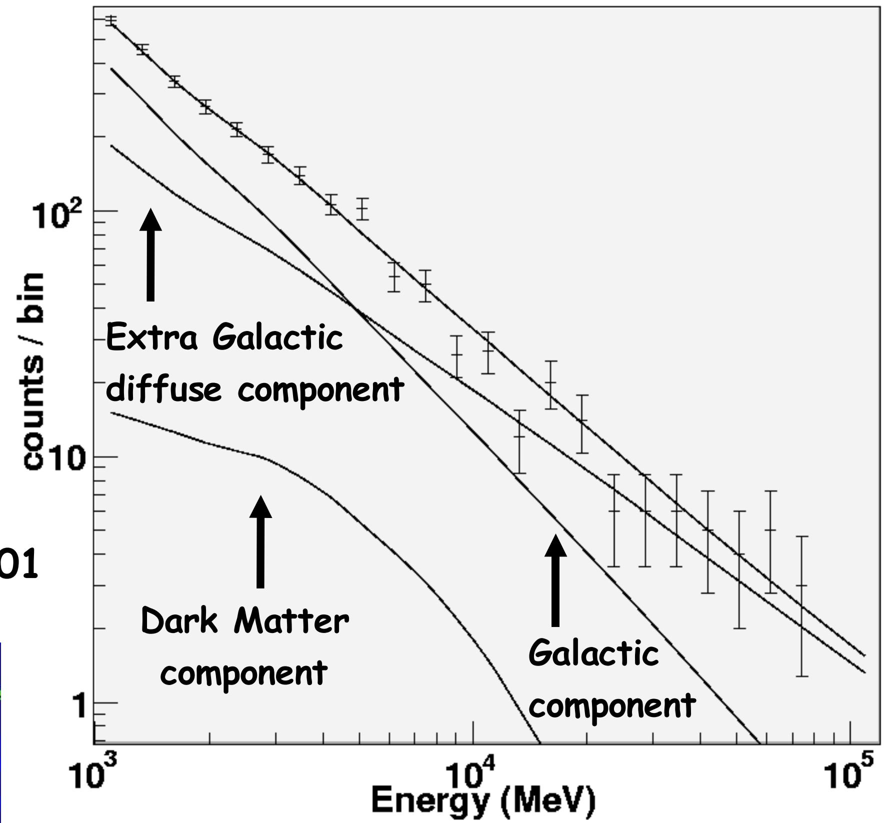
Sagittarius
Dark Matter halo modelling :

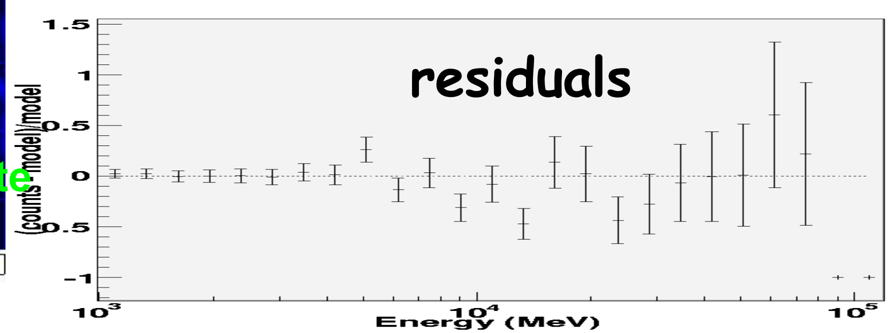
"Cored"/Moore profile :
J(ΔΩ=0.054 sr) ~ 75 10^{-19} GeV^2 cm^{-5}

NFW profile :
J(ΔΩ=0.054 sr) ~ 15 10^{-19} GeV^2 cm^{-5}

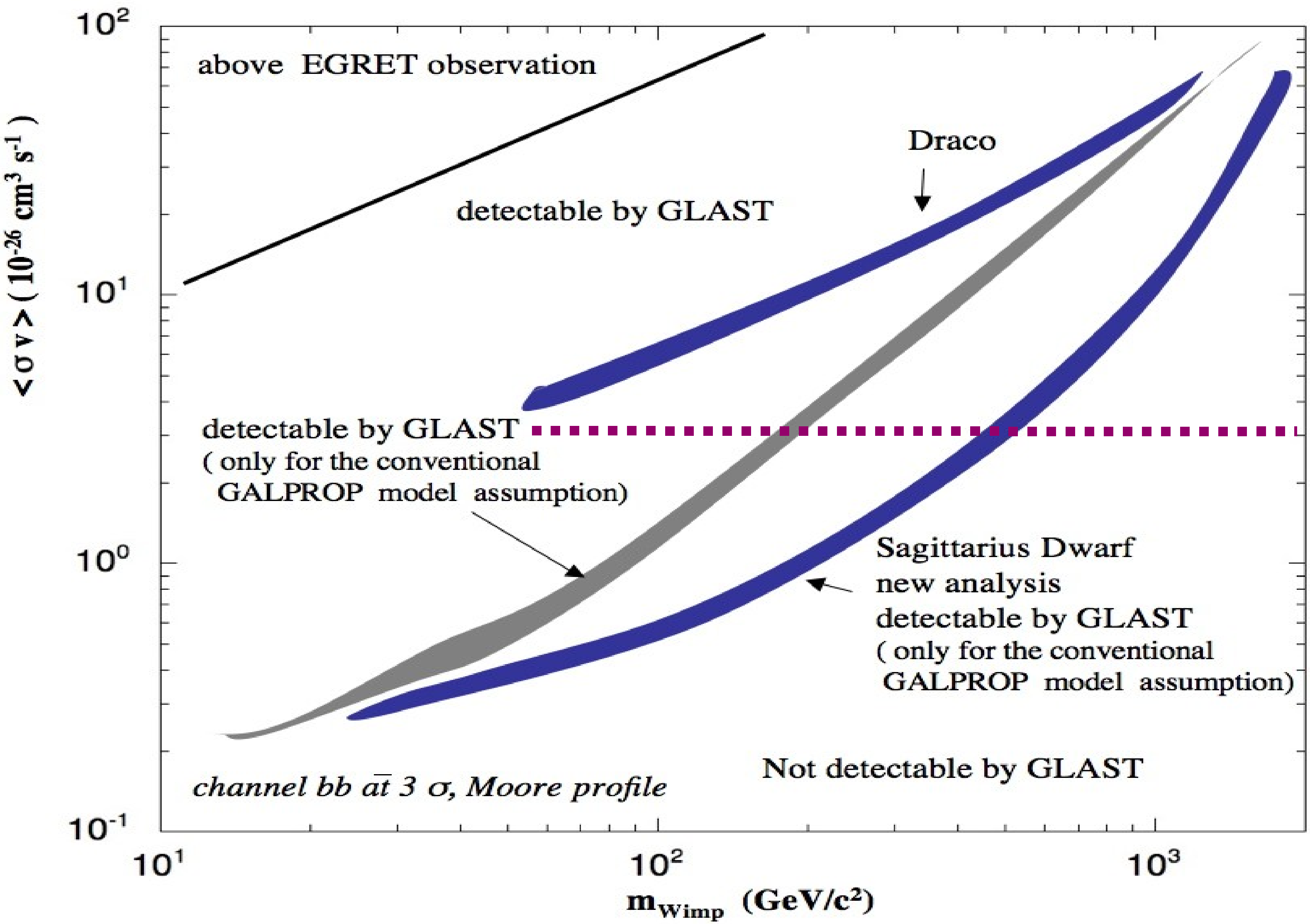
N.W.Evans et al. Phys.Rev. D69 (2004) 123501





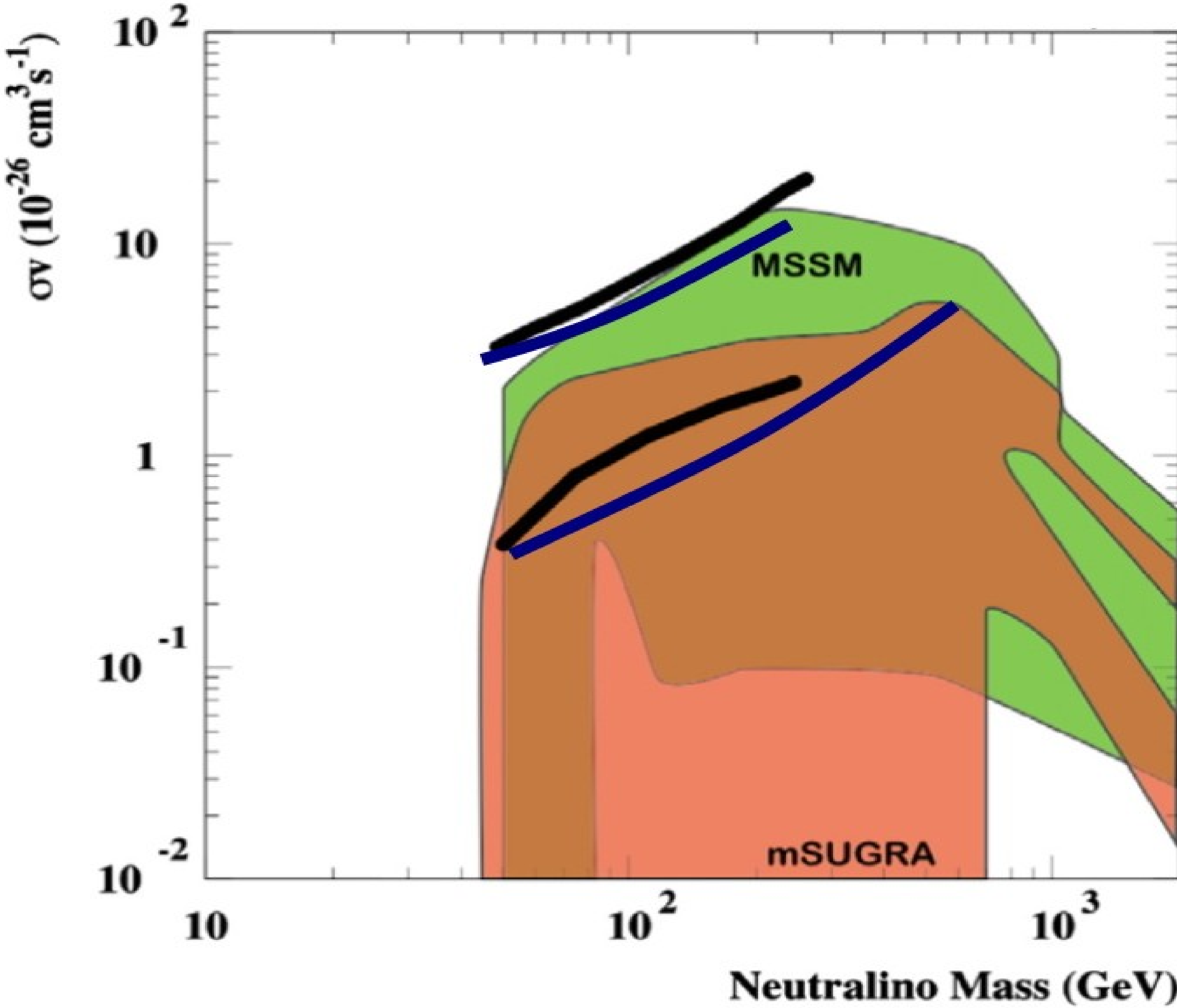


Summary of Sensitivities to Sagittarius and Draco



Sensitivity improved (×2-4) using Extended Maximum Likelihood and Test Statistic

GLAST senstitivity and minimal supersymmetric extensions to the Standard Model

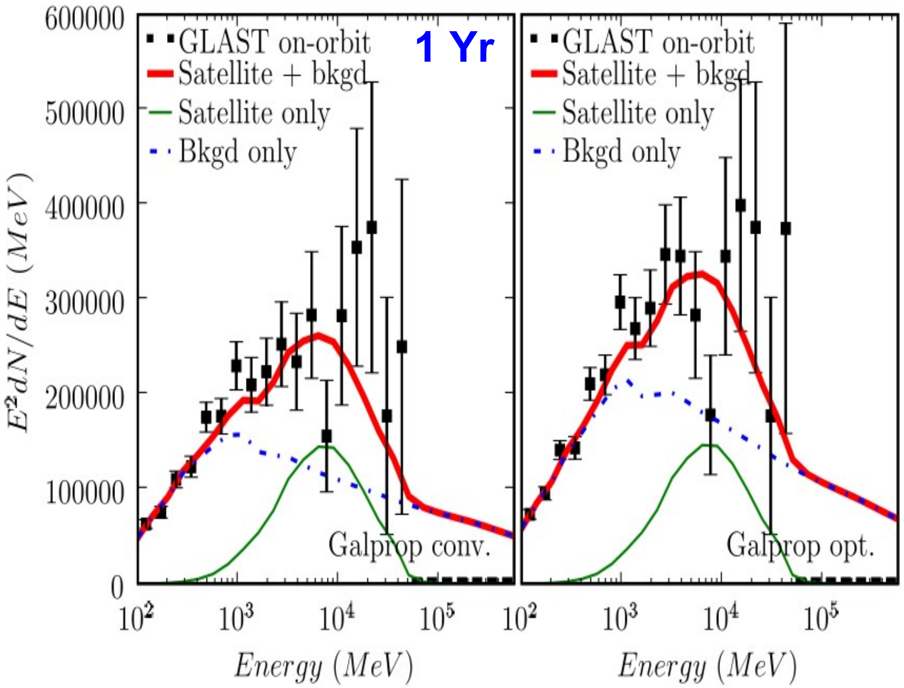


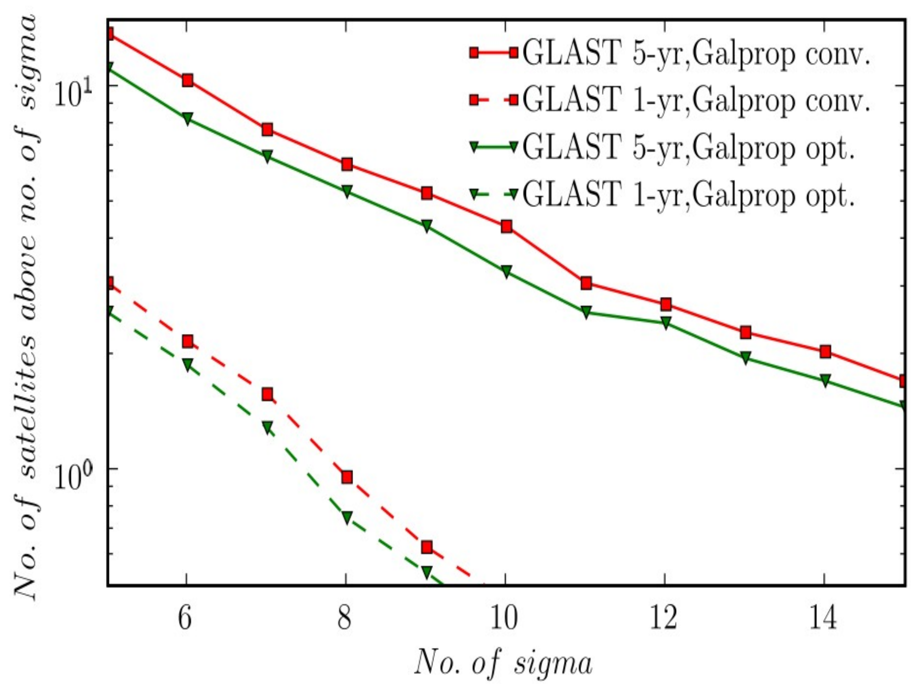
mSUGRA and MSSM models pass all accelerator constraints and are consistent with the WMAP data

From Dwarfs Spheroidals to DM satellites

- Expect isotropic distribution of subhaloes in the galactic halo
- DM spectrum very different from power law, no appreciable counterpart in radio, optical, X-ray,TeV; the emission is expected to be constant in time
- Assume NFW profile+tidal stripping. Satellite distribution by Taylor&Babul (Mon.Not.Roy.Astron.Soc. 364 (2005) 535-551)
- Consider 100 GeV WIMP, $\langle\sigma v\rangle = 2.3\times10^{-26}$ cm^3/sec annihilating into b-bar. Background: extra galactic, galactic diffuse (including instrumental background doesn't change the sensitivity significantly)
- Generic observable (5σ, 1 yr) satellite: high galactic latitude,

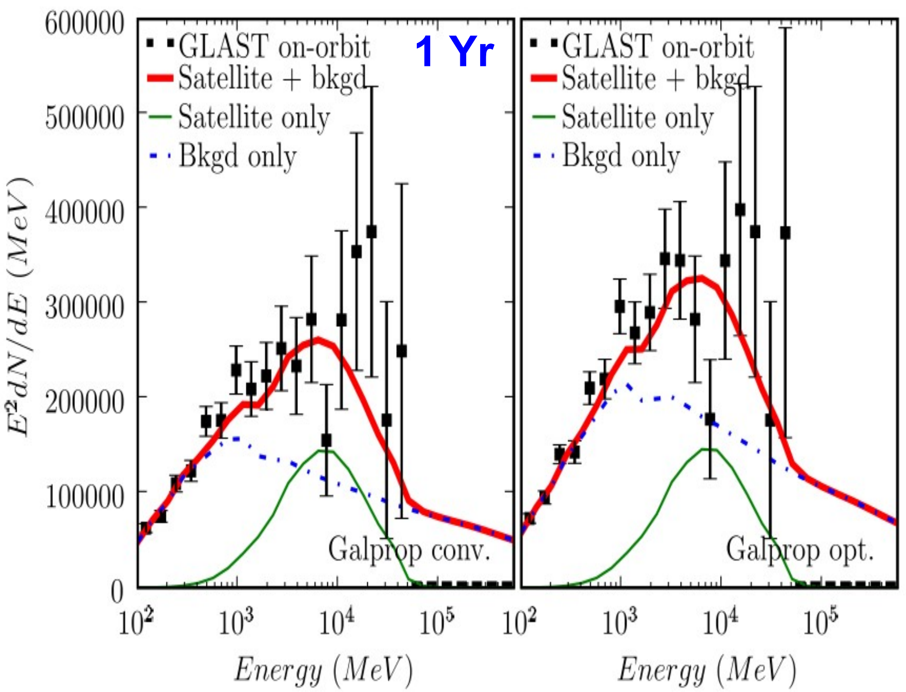
  ~9 kpc from $3\times10^7\ M_\odot$, ~1^o angular size



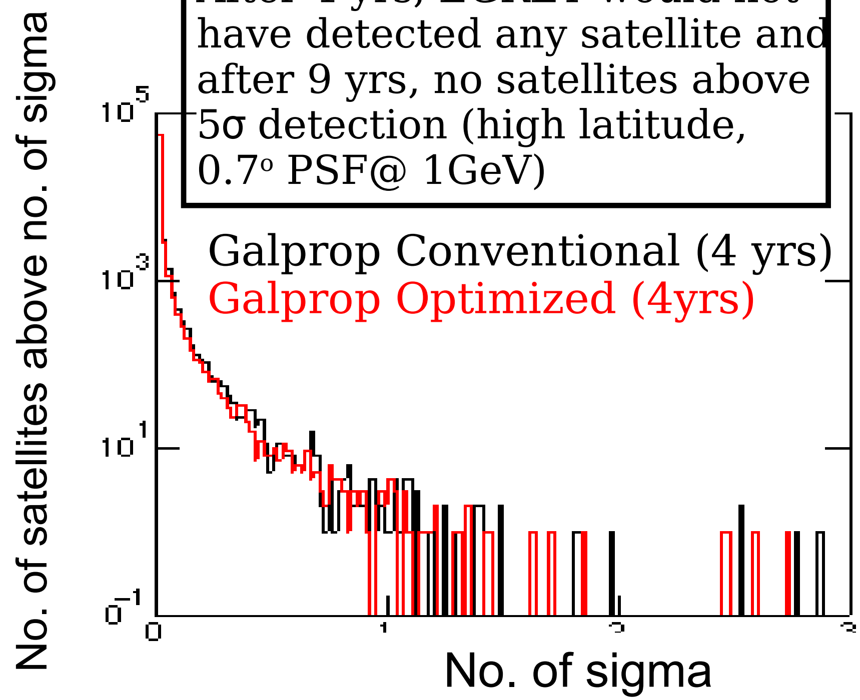


From Dwarfs Spheroidals to DM satellites

- Expect isotropic distribution of subhaloes in the galactic halo
- DM spectrum very different from power law, no appreciable counterpart in radio, optical, X-ray,TeV; the emission is expected to be constant in time
- Assume NFW profile+tidal stripping. Satellite distribution by Taylor&Babul (Mon.Not.Roy.Astron.Soc. 364 (2005) 535-551)
- Consider 100 GeV WIMP, $\langle\sigma v\rangle = 2.3\times10^{-26}$ cm^3/sec annihilating into b-bar. Background: extra galactic, galactic diffuse (including instrumental background doesn't change the sensitivity significantly)
- Generic observable (5σ, 1 yr) satellite: high galactic latitude, ~9 kpc from 3×10^7 $M_\odot$, ~1^o angular size

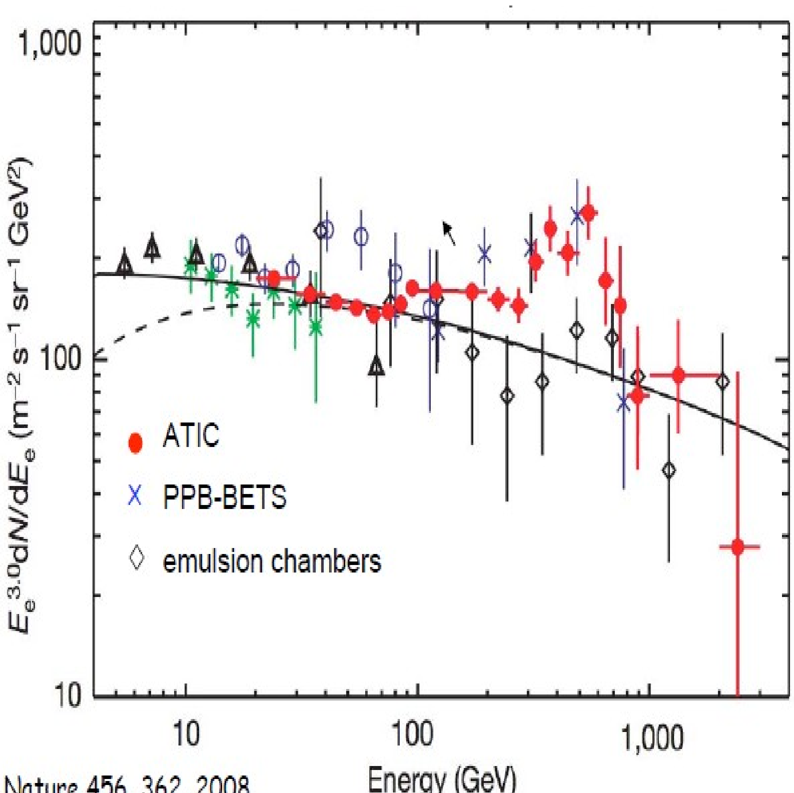


After 4 yrs, EGRET would not have detected any satellite and after 9 yrs, no satellites above 5σ detection (high latitude, 0.7^o PSF@ 1GeV)

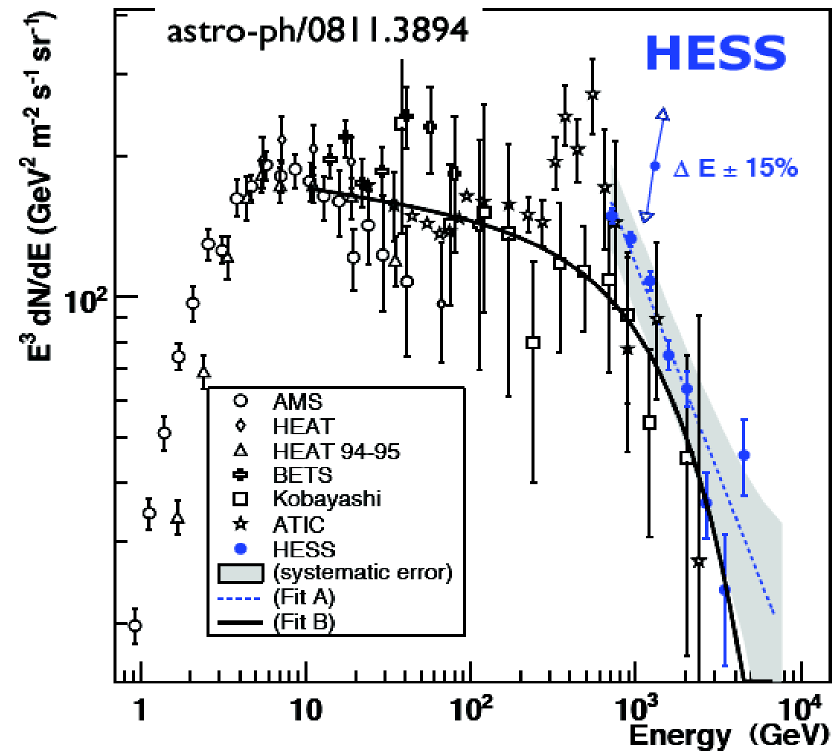


electron + positron flux with the LAT

- ATIC has observed an excess of electrons in the 300-800 GeV range with a steepening at the high energy end also observed by HESS
- In addition to astrophysical explanations for these measurements (nearby source of high energy electrons), heavy dark matter primarily annihilating into leptons, such as suggested by UED theories, could explain the excess and the high energy downturn



Nature 456, 362, 2008

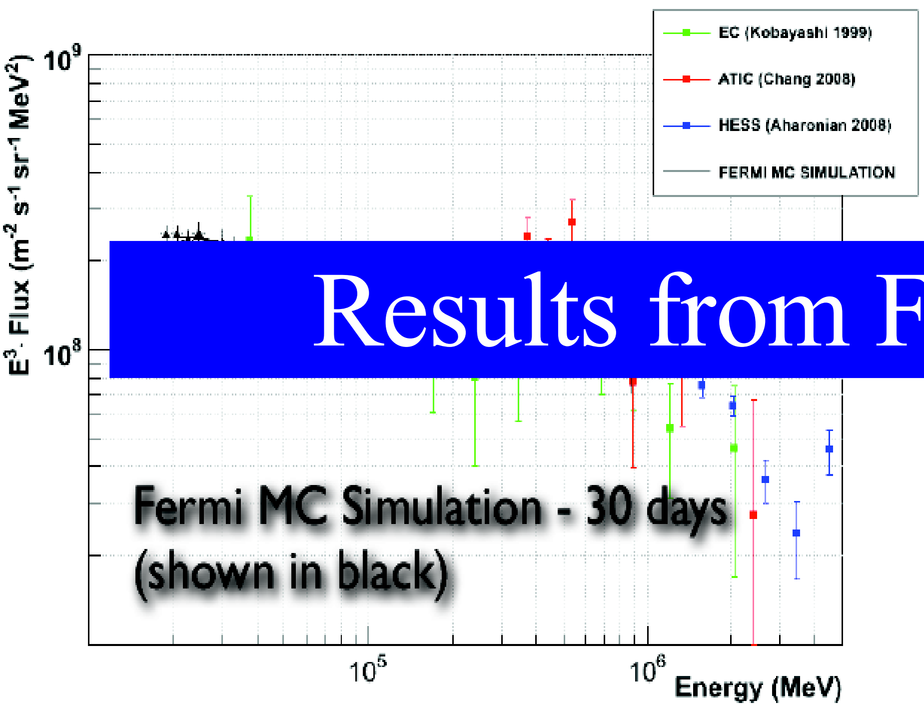


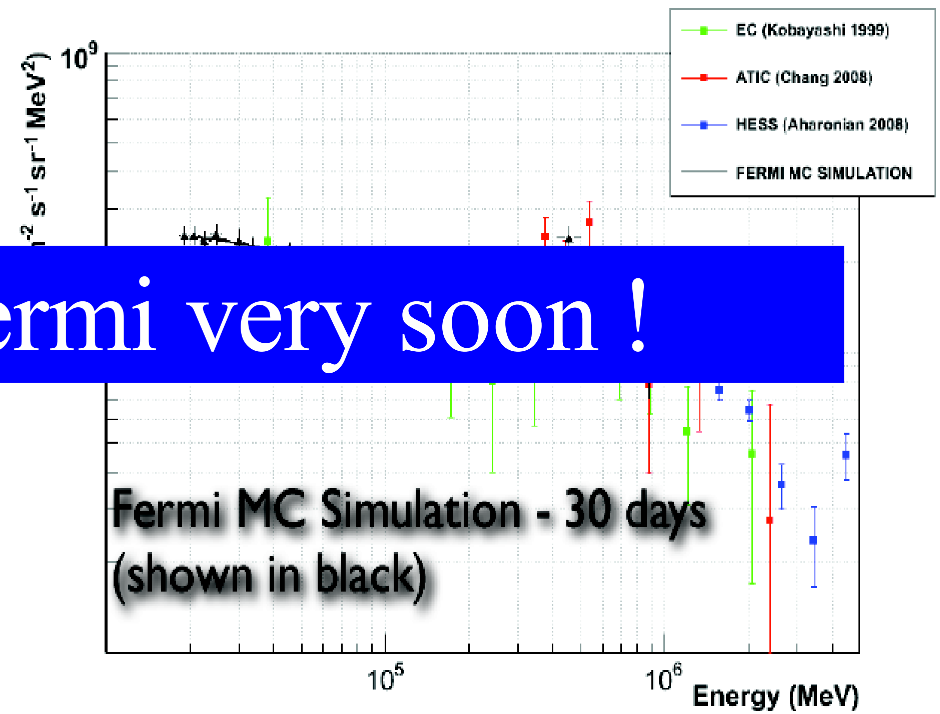
E.Nuss, on behalf of the Fermi LAT Collaboration

electron + positron flux with the LAT

- The Fermi LAT is an excellent electron+positron detector (but it can't discriminate charge)
- It will provide a measurement of the combined CR electron+positron spectrum (up to energies of ~1 TeV?) with very large statistics:

  over 200k events above 100 GeV (2.5k above 500 GeV) in 6 months
- It can achieve very low hadron contamination (rejection power >10^3, and larger at higher energies)



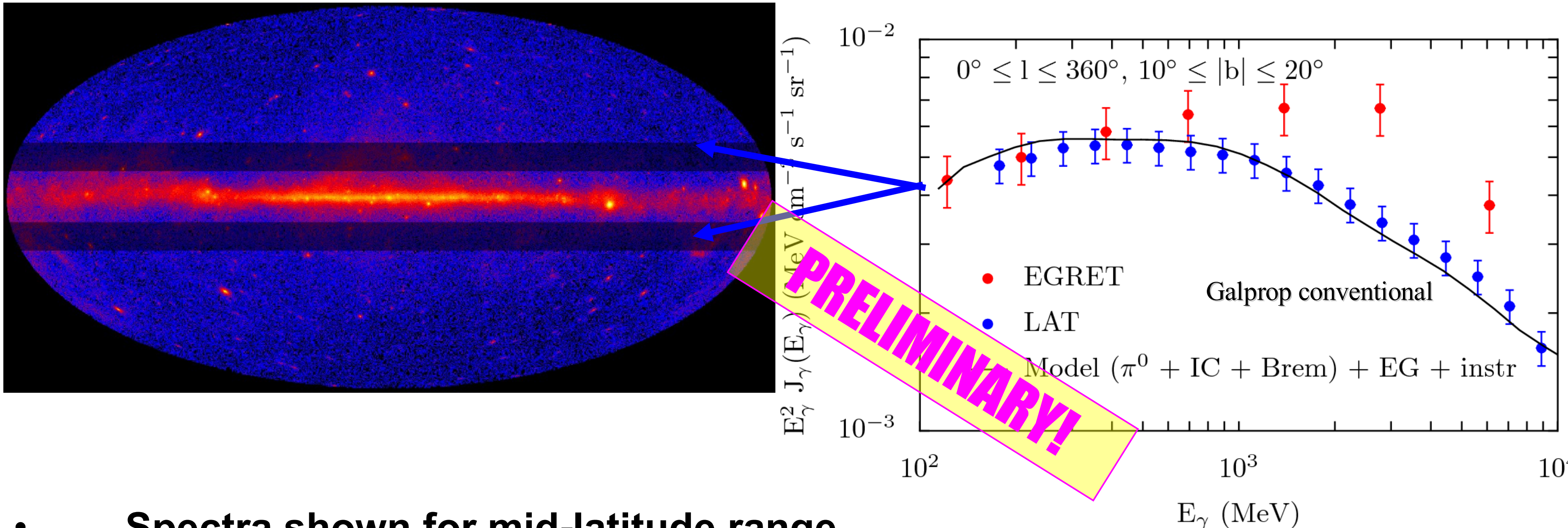


Results from Fermi very soon !

Big Questions From EGRET Era

- How and where do pulsars emit gamma rays? How common are radio-quiet pulsars?
  - necessary clue to magnetic field configurations and dynamics
- What are the EGRET Unidentified Sources?
  - most of the EGRET source identifications are a mystery
- What are the energy budgets of gamma-ray bursts? What are the temporal characteristics of the high-energy emission?
  - not well characterized yet, key tests of models.
- What are the origins of the diffuse emissions?
  - galactic: cosmic-ray and matter distributions; sources
  - extragalactic: populations
  - new sources (Dark Matter annihilations, clusters, …)
- How do the supermassive black hole systems of AGN work? Why do the jets shine so brightly in gamma rays?
  - temporal and spectral variability over different timescales
- What remains to be discovered with great new capabilities??
  - EGRET showed us the tip of the iceberg. New sources and probes for new physics.

Diffuse Emission, Nailing the EGRET "GeV Excess"



- Spectra shown for mid-latitude range
  ➜ The EGRET GeV excess is not seen in this part of the sky with the LAT.
- Sources are not subtracted but are a minor component.
- LAT errors are dominated by systematic uncertainties and are currently estimated to be ~10% ➜ this is preliminary.
- EGRET data is prepared as in Strong, et al. 2004 with a 15% systematic error assumed to dominate (Esposito, et al. 1999).
- EG + instrumental is assumed to be isotropic and determined from fitting the data at |*b*| > 10°.

Summary

- Fermi is off to a great start!
  - instruments are beautiful. The gamma-ray sky is keeping its promise. Great cooperation across the international team.
- Already addressing many important questions from EGRET era
  - new analysis techniques and approaches are essential -- new topics!
  - the challenge of great discovery potential
- The FERMI LAT collaboration will explore many complementary searches for DM signal.
  - We have shown that GLAST has the potential to either discover or to constrain a range of DM models and astrophysical scenarios.
- November 2-5 2009 International Fermi Symposium in Washington, DC
- July 26-30 2010 Identification of Dark Matter in Montpellier, France
- Gamma-ray data are for you! JOIN THE FUN!!