Indirect Search for Dark Matter from the Milky Way center with the Fermi/LAT

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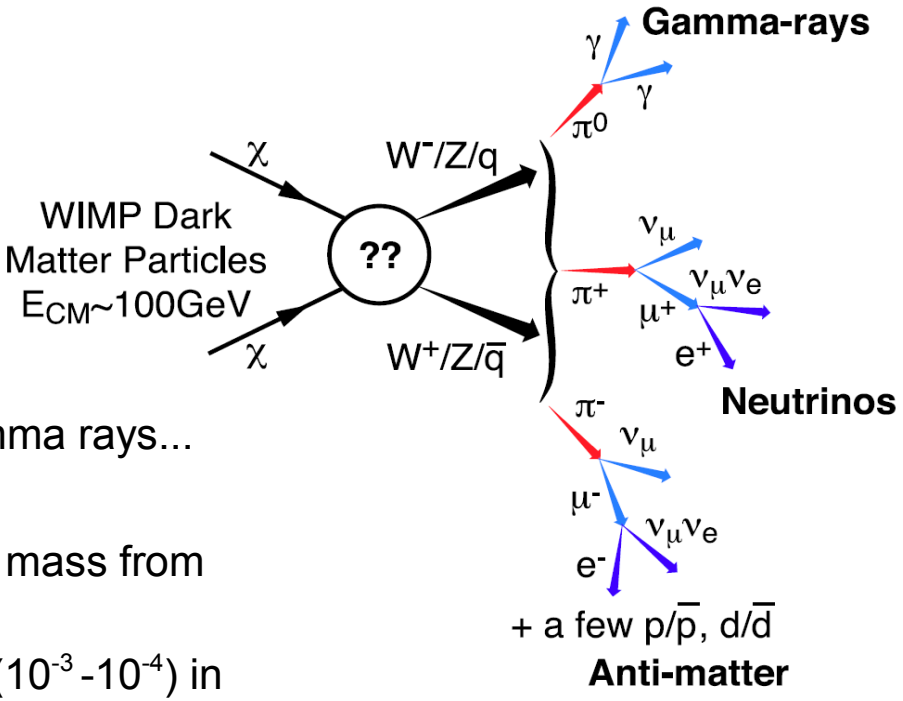
OUTLINE

- Indirect Search for Dark Matter in gamma rays
- The Galactic Halo
- Dark Matter signature
- Other wave-lengths
- EGRET Observations of the Galactic Center
- Early Fermi Observations of the Galactic Center
- Summary

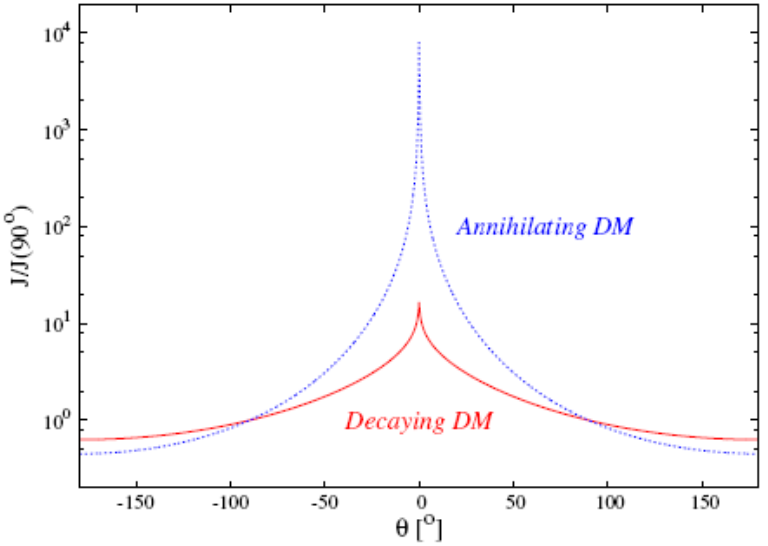
Gamma Rays from Dark Matter



- DM particle candidate might produce gamma rays...
- ... if DM particles self-annihilation in pairs
- Gamma-ray continuum with cut-off at DM mass from hadronization
- Gamma-Gamma production suppressed (10^{-3}-10^{-4}) in many models (while enhancements are predicted with int. brem.)
- Gamma-ray flux decomposed in Particle and Astrophysical factors

$$\phi_{WIMP}(E,\psi) = \frac{1}{2}\frac{<\sigma v>}{4\pi}\sum_f \frac{dN_f}{dE}B_f \int_{\text{l.o.s}} dl(\psi)\frac{\rho(l)^2}{m^2_{WIMP}}$$

Gamma Rays from Dark Matter



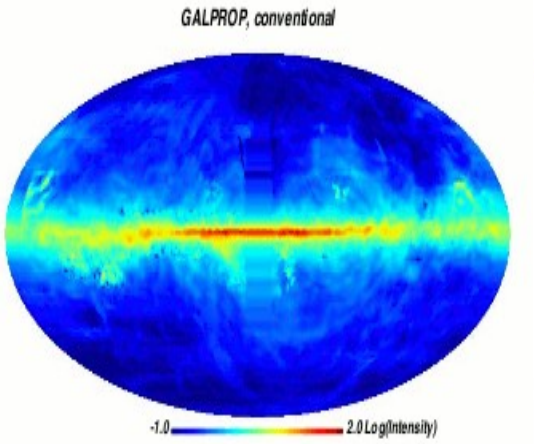
$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\Omega) = \frac{\Gamma}{4\pi m_{\rm DM}}\frac{dN_\gamma}{dE_\gamma}\int_{\rm los}\rho_{\rm DM}(r,\Omega)dr$$

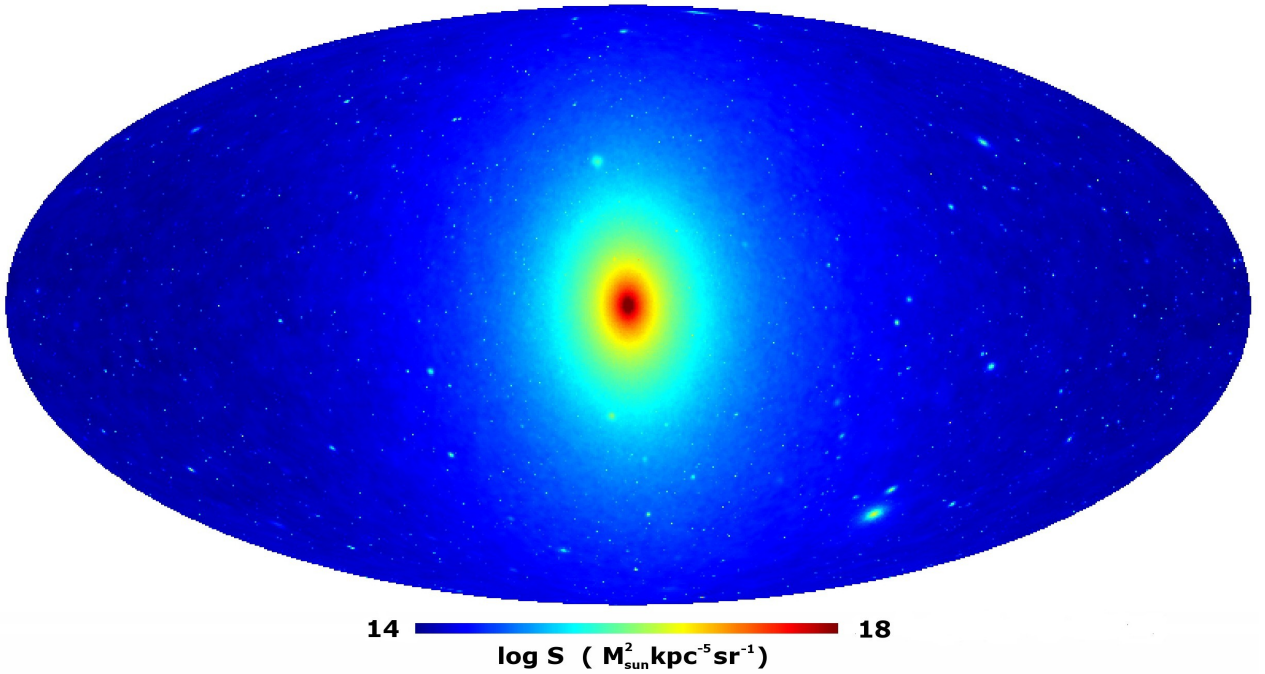
Bertone et al. JCAP 0711:003,2007

- ... if pseudo-stable DM particle decay in gammas
- Gamma ray flux proportional to the Dark Matter particle density
- DM decay constant > 10^{27} s (model dep.)

Dark Matter Galactic Halo

Galactic Diffuse background





Springel at al. NATURE 456, 44,
simulated gamma emission from annih. DM

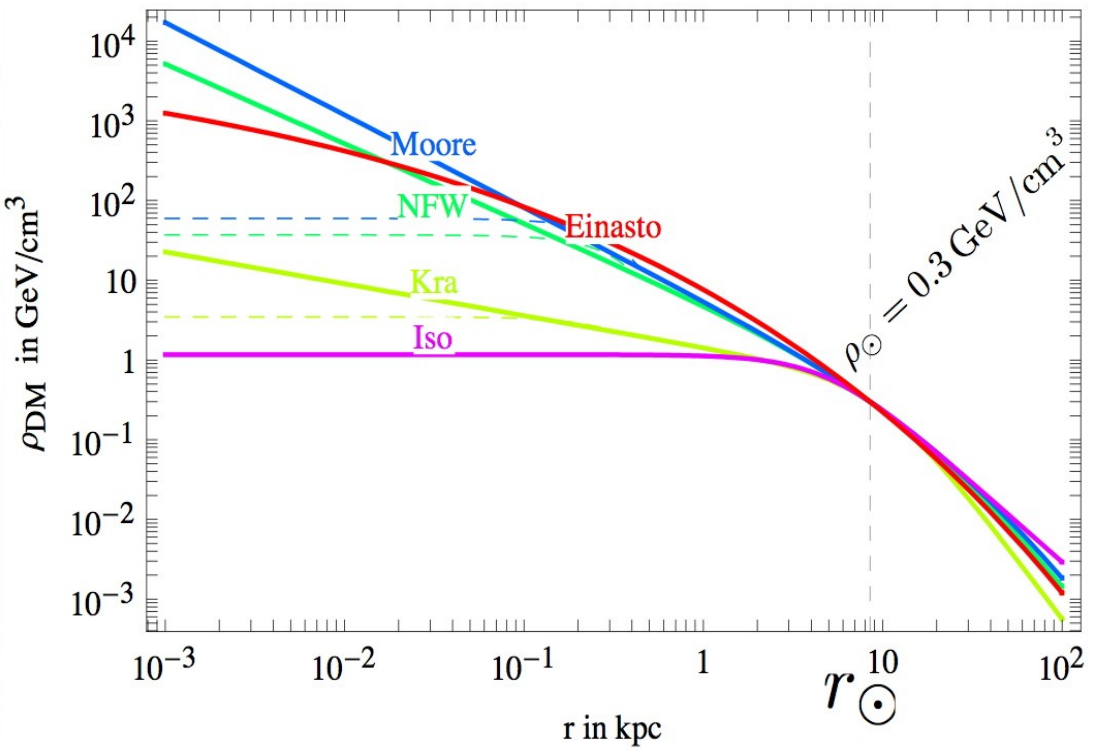
- Halos with central density cusps made by DM
- Milky Way embedded in a DM halo
- DM annihilation gamma rays from GC maybe detectable
- !! Major background contribution by bright gamma ray sources

Dark Matter Density Profile

$$\rho(r) = \rho_{\odot} \left[\frac{r_{\odot}}{r}\right]^{\gamma} \left[\frac{1 + (r_{\odot}/r_s)^{\alpha}}{1 + (r/r_s)^{\alpha}}\right]^{(\beta-\gamma)/\alpha}$$

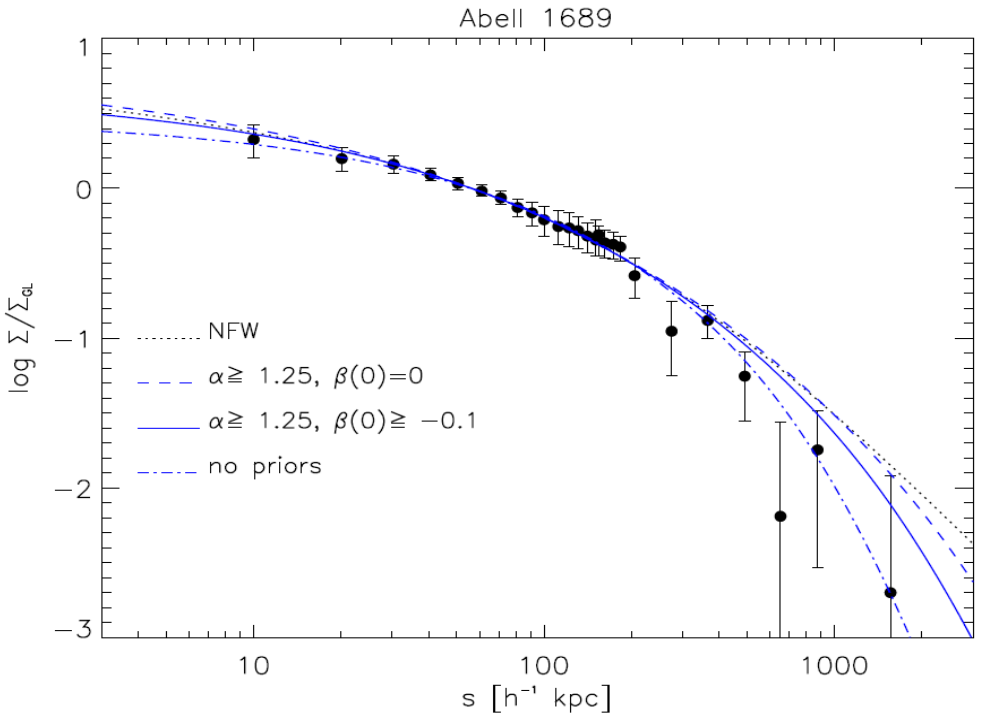
Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

Einasto | $\alpha = 0.17$ $r_s = 20\,\mathrm{kpc}$ $\rho_s = 0.06\,\mathrm{GeV/cm^3}$



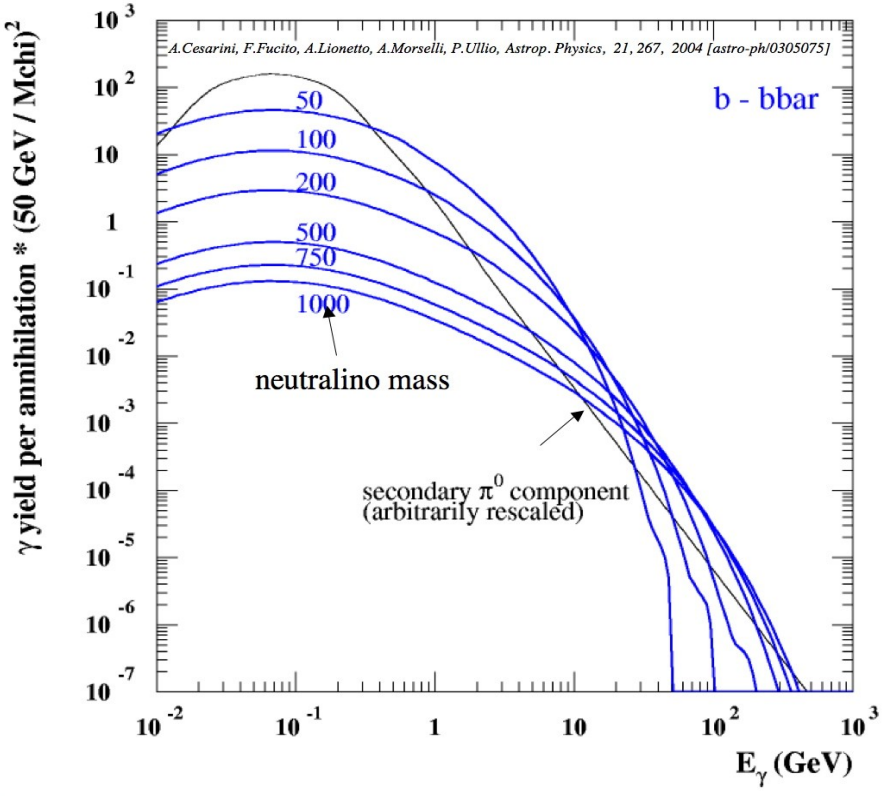
- DM halo not experimentally known in the GC region
- Parametrization from N-Body Simulations
- DM density profile fundamental for indirect gamma-ray detection

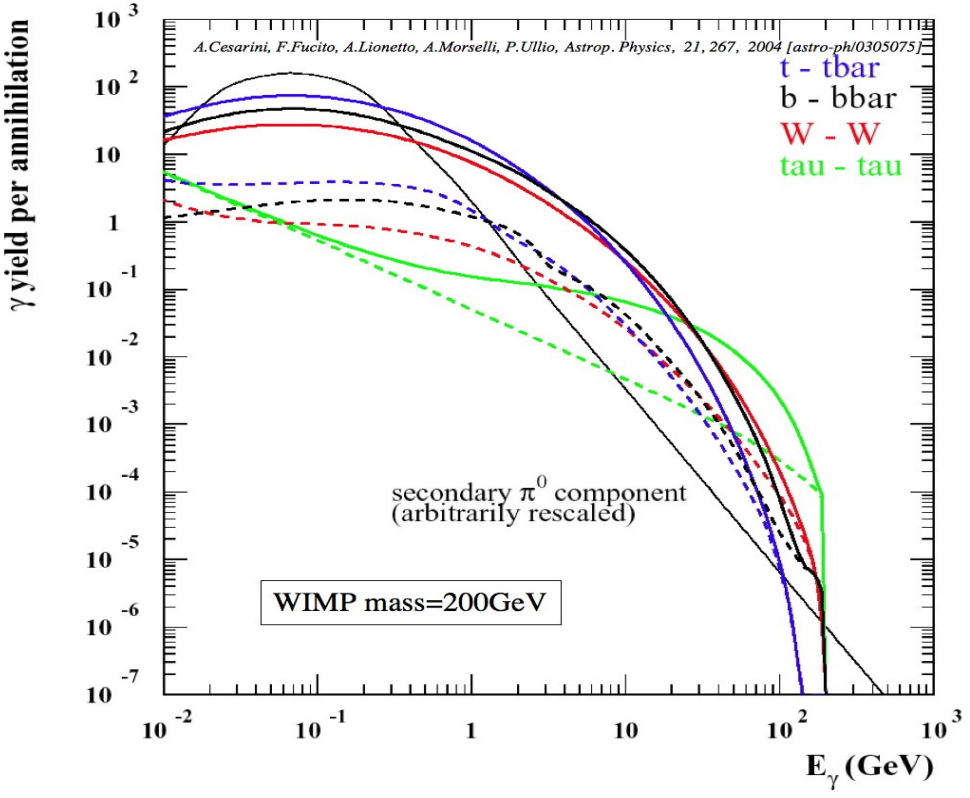
Dark Matter Density Profile



- Different approach: solution (+analytic fit) based on the Jeans Equation (Lapi & Cavaliere 2009 ApJ 692,174)
- Flatter core, steeper outer cut-off than NFW, then finite mass in the halo
- No discontinuity at the halo center
- Tested on Galaxy Clusters (Lapi & Cavaliere 2009 ApJ 695, 125)

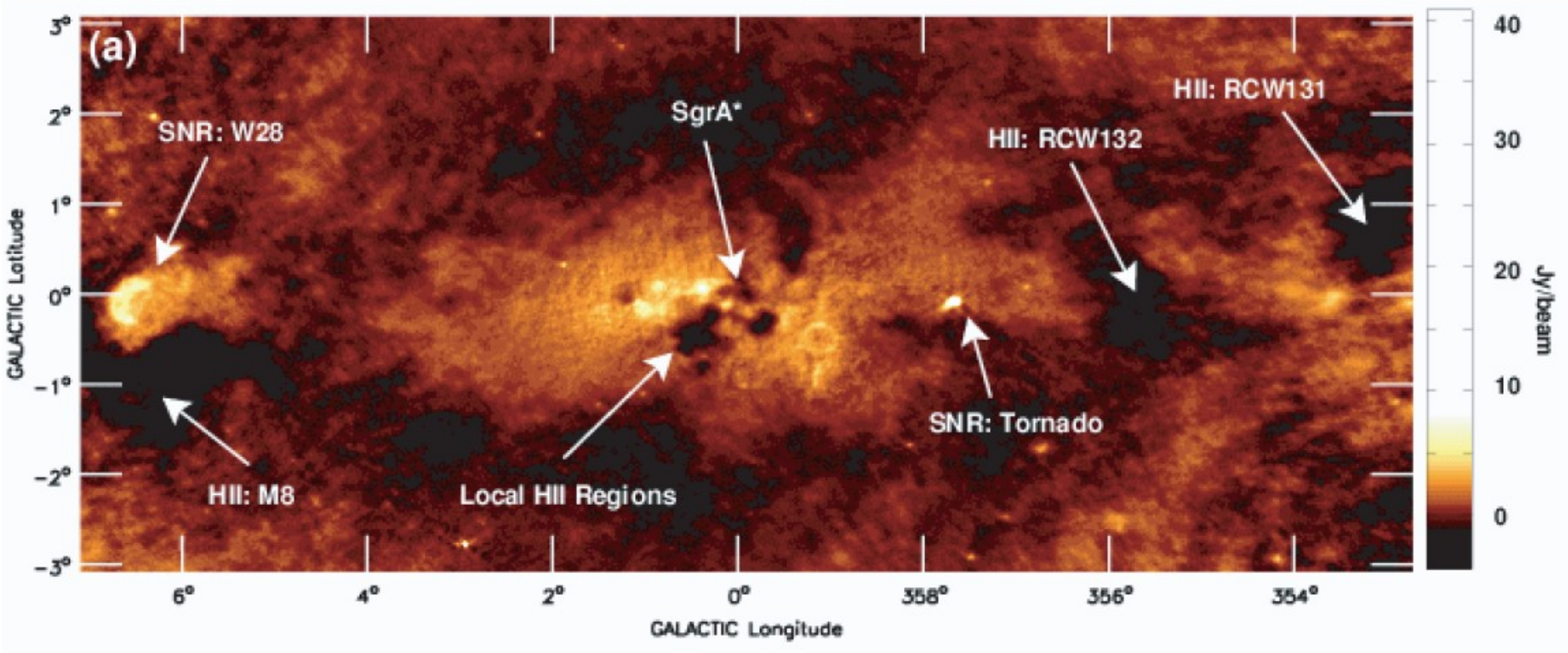
Dark Matter Signature





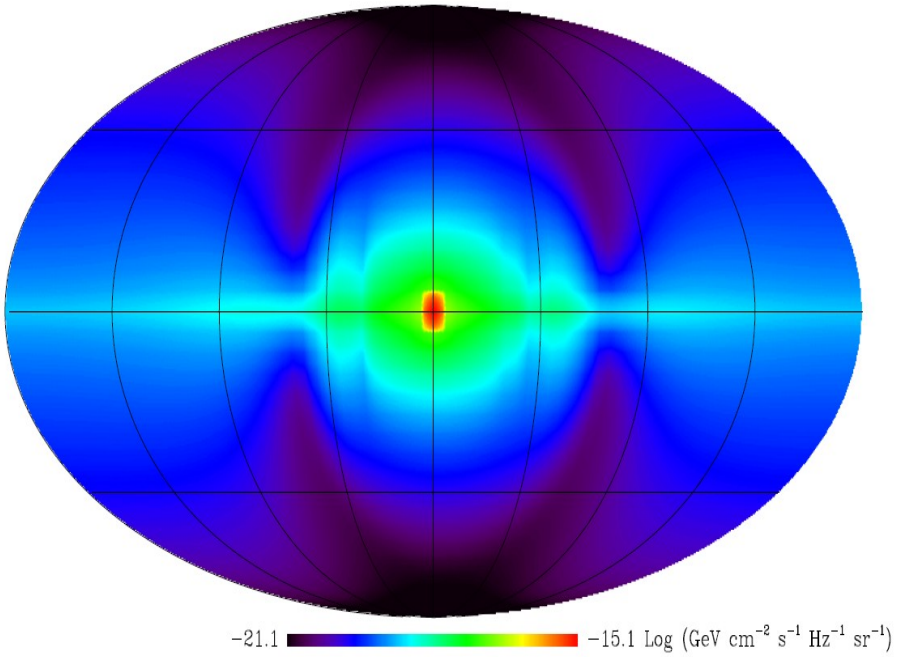
- Quite distinctive spectrum (no power-law)
- Dark Matter annihilation emission is not point-like..
- ... nor isotropic or Galactic-Ridge like (Dodelson et al 2007, arXiv0711:4621)
- Optimal Region of Interest from 0.5 to 10 deg
- Optimal energy threshold from 0.1 to 1 GeV

Other Wave-Lengths: Radio

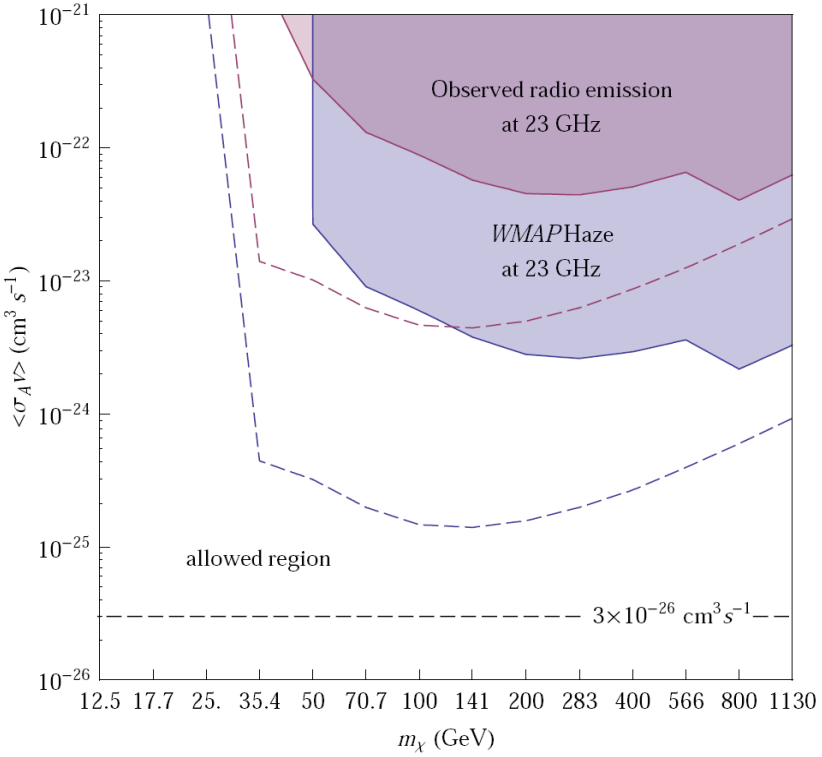


- Radio Map of the GC region
- VLA 74 MHz (La Rosa et al. ApJ 626,L23, 2005)
- Non-thermal emission from many structures (energetic electrons)

Other Wave-Lengths: Radio



1GHz map

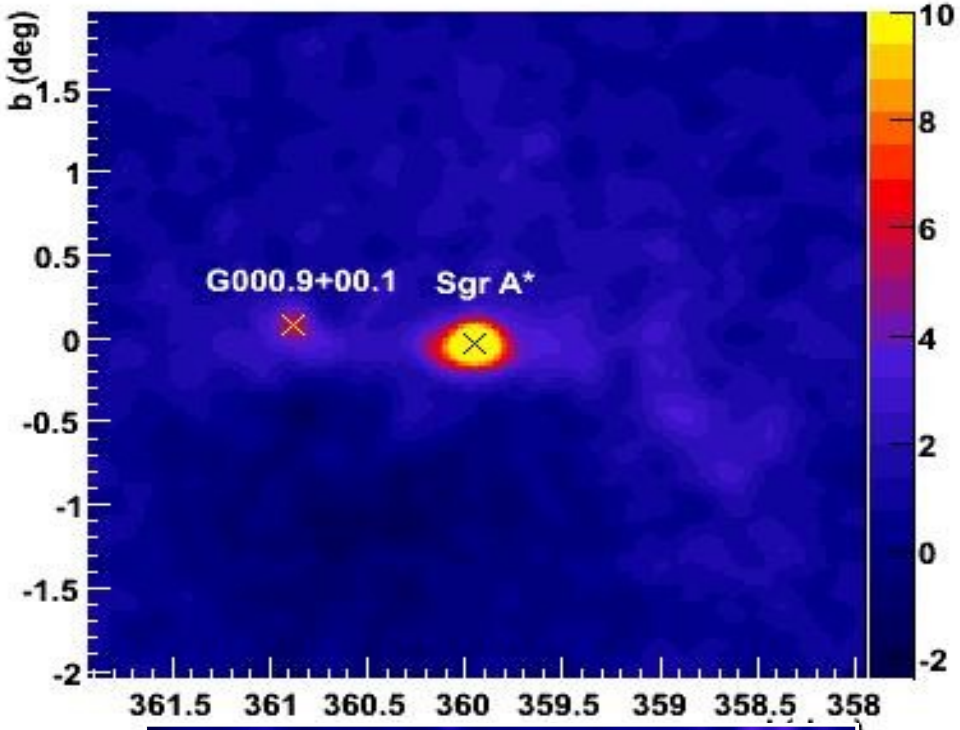


23GHz map

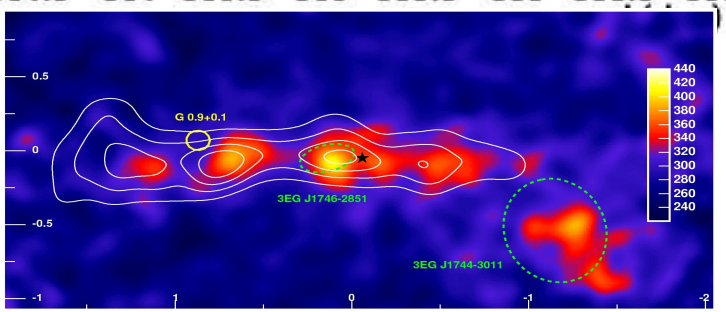
- DM Annihilation → electrons(positrons) → synchrotron (within magnetic field)
- Radio emission from Galactic Halo + substructures (Borriello et al 0809)
- Tinyakov and Tkachev model (TT) for magnetic field: 7-10 microG
- Very sensitive to magnetic field assumption

Other Wave-Lengths: TeV

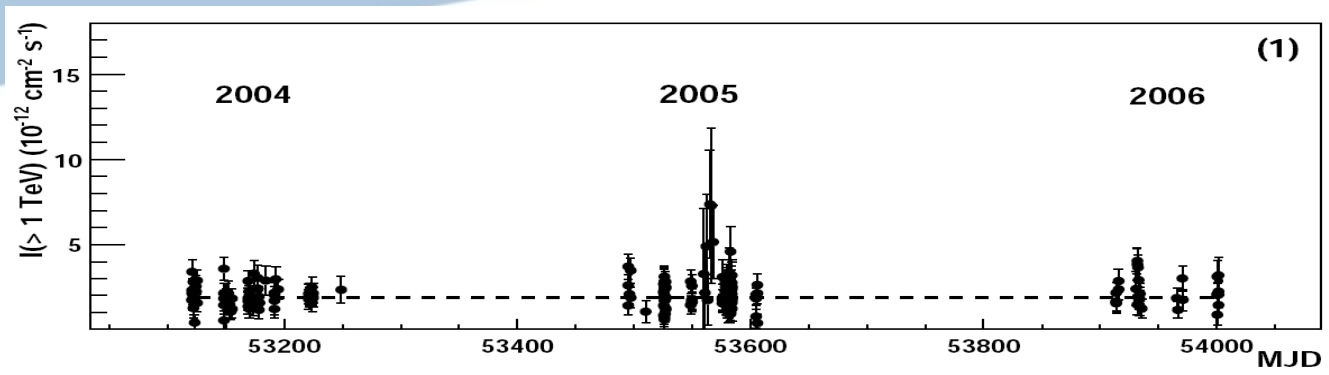
- TeV Galactic Center Source
- Detected by: CANGAROO coll. ApJ 606,L 115; VERITAS coll. ApJ 608, L97; HESS coll. A&A 425, L13; MAGIC coll. ApJ 639, 761
- Steady flux - PowerLaw ph.in. =2.25± 0.04
- HESS data disfavour DM emission (~10TeV, Phys.Rev.Lett. 97,221102)
- SgrA East excluded (van Eldik et al. ArXiv0709.3729)
- PWN G359.95-0.04 (Chandra, Wang et al. MNRAS 367, 936) possibly associated with GC TeV emssion



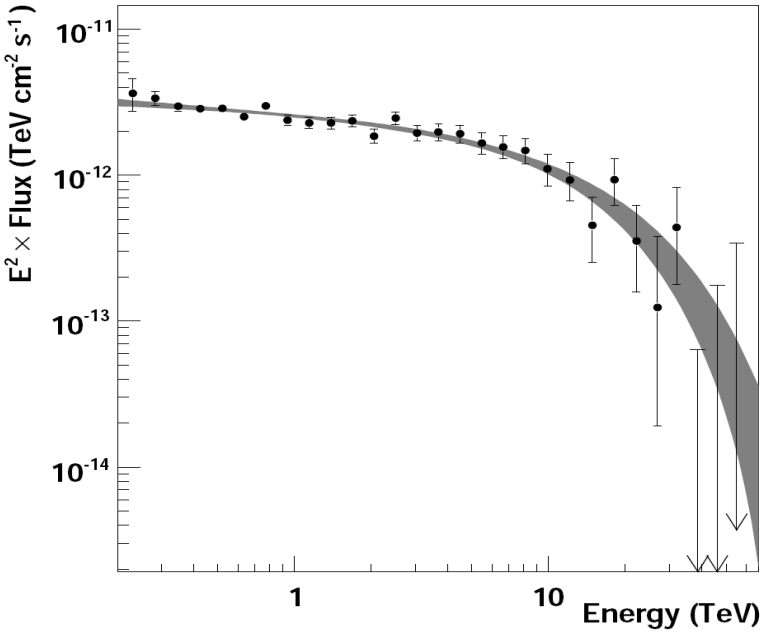
- TeV Diffuse Emission
- Detected by HESS (Aharonian et al. NATURE 439, 695)
- Associated to a dense Molecular Clouds region (Molecular Clouds-G.C.R. Interaction ?)



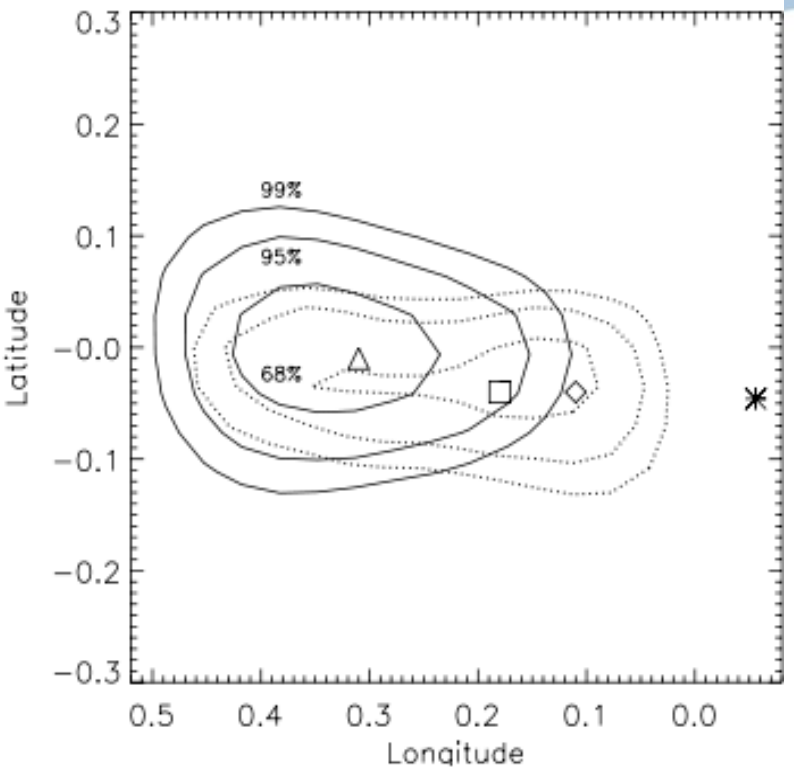
Other Wave-Lengths: TeV



- HESS J1745-290 3 years study (2004-2005-2006)
- Power-law with exponential cut-off or smoothed broken power-law
- No variability
- No flaring or QPOs



EGRET Results



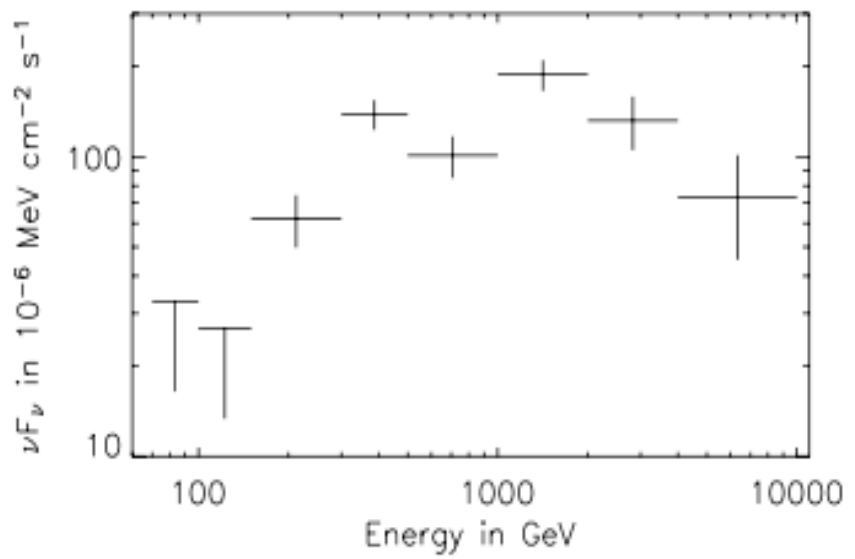


FIG. 1.—The νF_ν spectrum of 3EG J1746−2851 as derived from an analysis of the combined data as listed in Table 1. The spectrum is similar to that of the Galactic diffuse emission.

Pohl 2005, ApJ 626,174

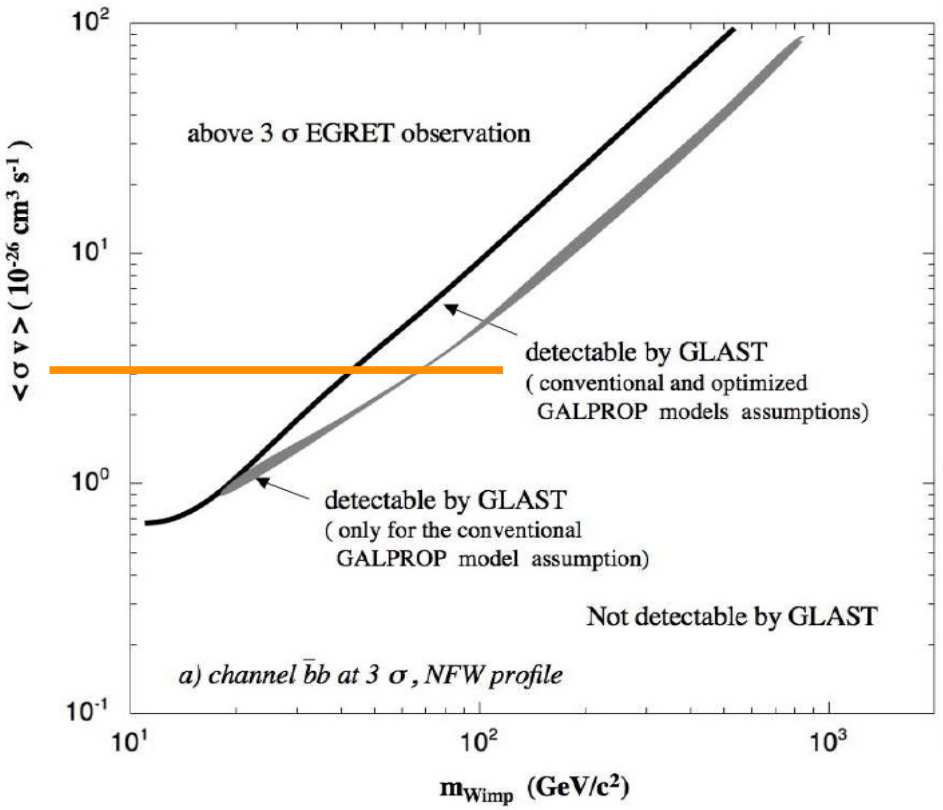
- 3EG J1746-2851
- $F_{GC}(>0.1\text{GeV})=(50\pm7)\times10^{-8}$ cm^{-2} s^{-1}
- Unidentified
- Source as DM emission (A. Morselli et al. Astrop.Ph. (2004), 21, 267)

Pre-launch expectation

TABLE I

LAT SENSITIVITY IN THE σV VS ENERGY PLANE. IN THIS TABLE THE MINIMUM DETECTABLE σV, WITH 3 σ CONFIDENCE LEVEL AND IN 5 YEARS OF LAT OPERATION, AS A FUNCTION OF THE ENERGY, ARE REPORTED. RESULTS FROM FIGURES 5, 6, 7 OF [18].

Annihilation Channel	DM Mass (GeV)	σv 10^{-26}cm^{3}s^{-1}
$b\bar{b}$	10	0.7
$b\bar{b}$	100	4
$t\bar{t}$	100	10
$t\bar{t}$	1000	80
W^+W^-	100	15
W^+W^-	650	90
$\tau^+\tau^-$	100	10

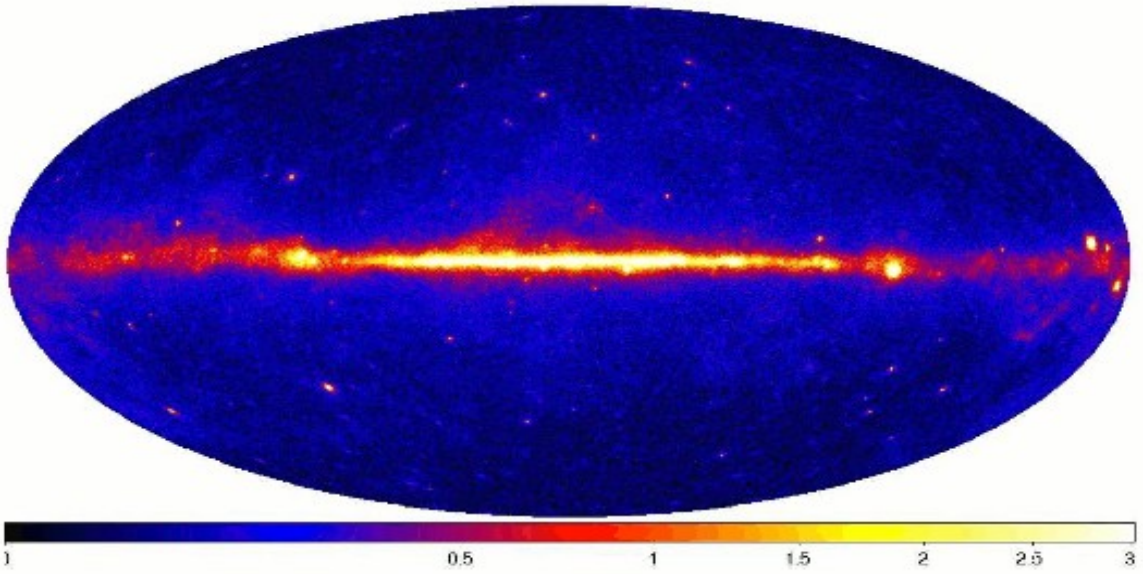


- Baltz et al JCAP 2008, 7, 13
- Diffuse Background only
- Astrophysical sources not included
- Chi-Square analysis

Fermi Bright Sources List

- Bright Sources List, Submitted to ApJS arXiv:0902.1340
- Sources above 10σ in 3 months
- Int.Flux(E>0.1GeV) > 0.05 to 0.4 10^{-6} $cm^{-2}s^{-1}$
- 0FGL J1746.0-29.00 source closest to the GC
- Marginal variability, **not confirmed with larger statistics**

Sky map flux intensity E>300MeV,



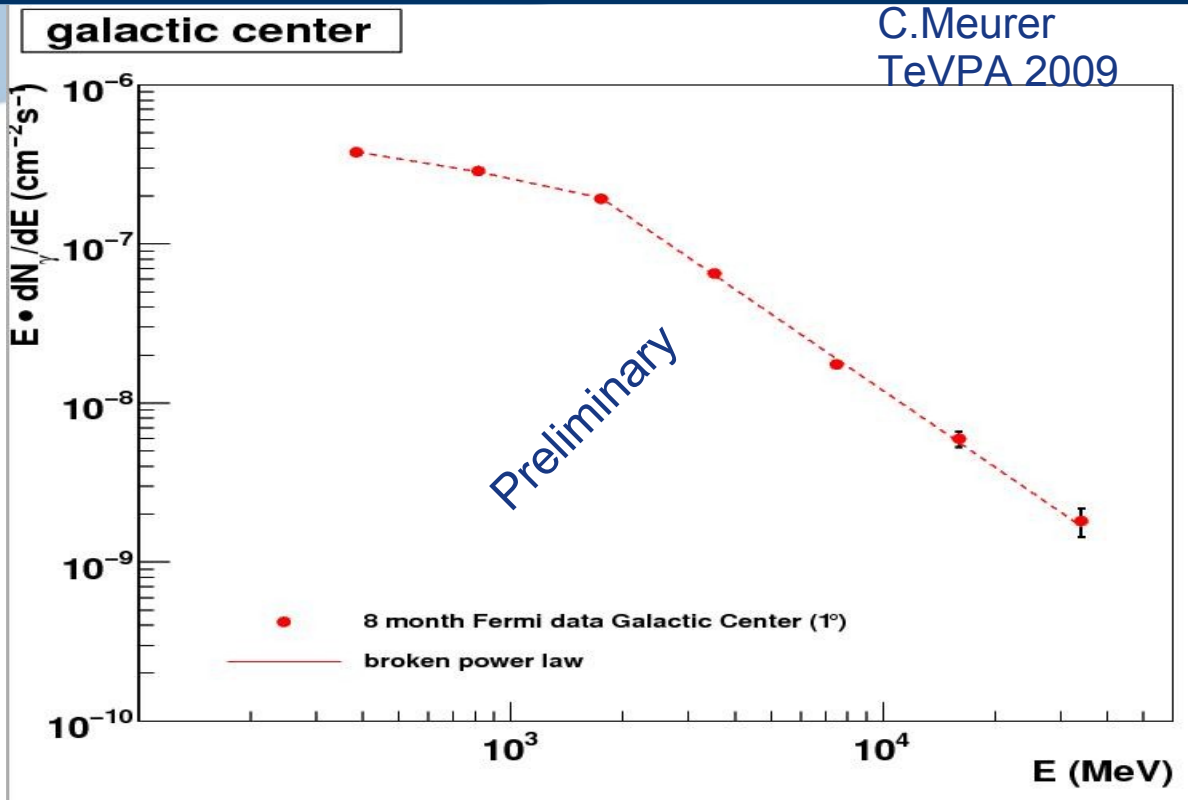
$m^{-2}s^{-1}sr^{-1}$

Source	l (°)	b (°)	θ_{95} (°)	Int.Flux(1<E<100GeV) $cm^{-2}s^{-1}$ 10^{-8}
0FGL J1732.8-3135	356.287	0.920	0.087	3.890±0.33
0FGL J1741.4-3046	357.959	-0.189	0.197	2.00±0.31
0FGL J1746.0-2900	359.988	-0.111	0.068	7.92±0.47

Preliminary Analysis

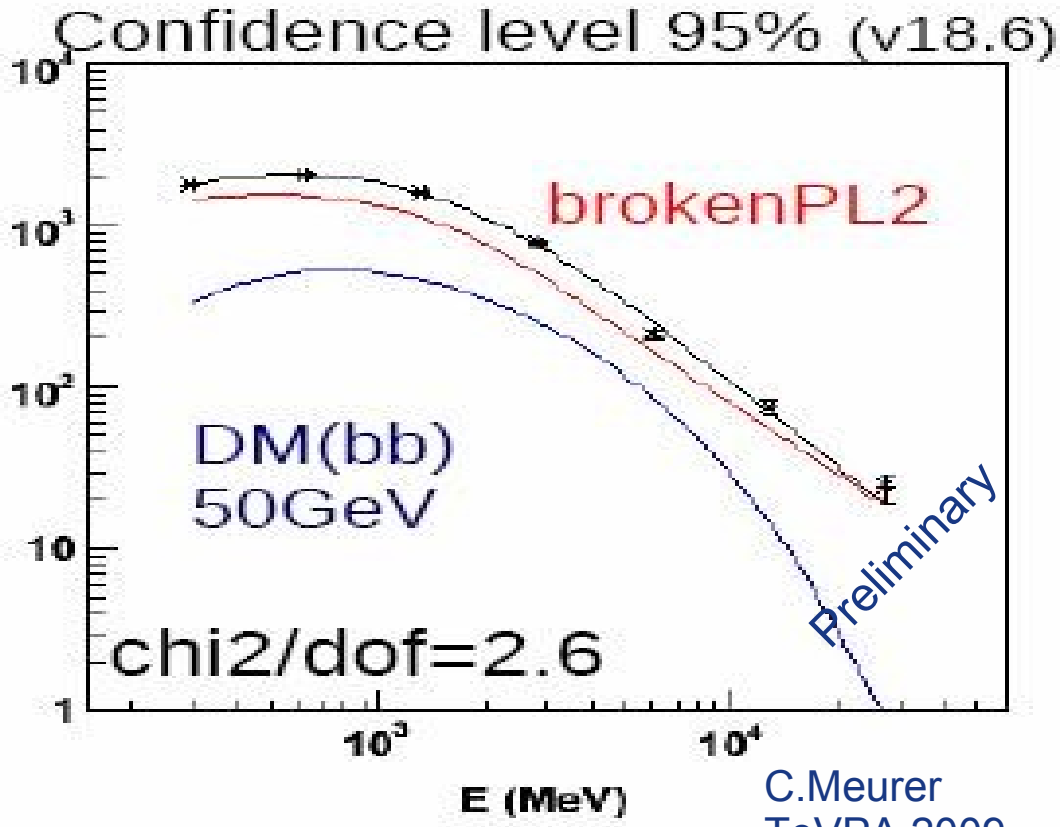
- **Conservative upper limit estimate on the gamma-ray flux from DM annihilation**
- Likelihood analysis for the LAT data requires a detailed model of the background (both diffuse emission and known sources)
- Detailed study of the Galactic Diffuse emission in the GC ongoing
- Preliminary analysis on a small region
- Data Selection: 8 months (8/2008-4/2009)
- 1deg X 1deg with center in RA = 266.46, Dec=-28.97
- Energy range 200MeV-40GeV, IRFs=P6_V3_DIFF
- Model function – IRF convolution
- Fit to data with -log(Likelihood) minimization, only spectral info

Fermi Preliminary Results



- Broken Power law model function
- Int.Flux(0.1-100GeV) = (1.22±0.02) 10^{-6} $cm^{-2}s^{-1}$
- Ind.1 = -1.38 ± 0.04
- Ind.2 = -2.60 ± 0.05
- E_Break = (1.6 ± 0.1)GeV

Upper Limit on <σv> parameter



C.Meurer
TeVPA 2009

- DM mass benchmark 50GeV
- DM annihilation yield between 0.1 and 50GeV
- If Int.Flux(E>0.1GeV) < (2.43±0.02) 10^{-7} $cm^{-2}s^{-1}$ (95% confidence level) ....
- ...then <σv> less than 39.8 10^{-26} cm^3s^{-1}

Summary

- 11 months Fermi observations
- LAT data very promising but ...
- ... Analysis complicated because of the bright background (both diffuse and sources)
- Here results with 8 months data
- Study of a 1degX1deg region
- Emission well described with a broken power-law
- Very conservative Upper-Limit on the $\langle \sigma v \rangle$ parameter
- More detailed study to be published soon