Dark Matter with GLAST

Richard E. Hughes
The Ohio State University
LAT Dark Matter and New Physics Working Group

The Hunt for Dark Matter
Fermilab, May 10-12, 2007

GLAST LAT Collaboration

United States

- California State University at Sonoma
- University of California at Santa Cruz - Santa Cruz Institute of Particle Physics
- Goddard Space Flight Center – Laboratory for High Energy Astrophysics
- Naval Research Laboratory
- The Ohio State University
- Stanford University (SLAC and HEPL/Physics)
- University of Washington
- Washington University, St. Louis

France

- IN2P3, CEA/Saclay

Italy

- INFN, ASI

Japanese GLAST Collaboration

- Hiroshima University
- ISAS, RIKEN

Swedish GLAST Collaboration

- Royal Institute of Technology (KTH)
- Stockholm University

PI: Peter Michelson (Stanford & SLAC)

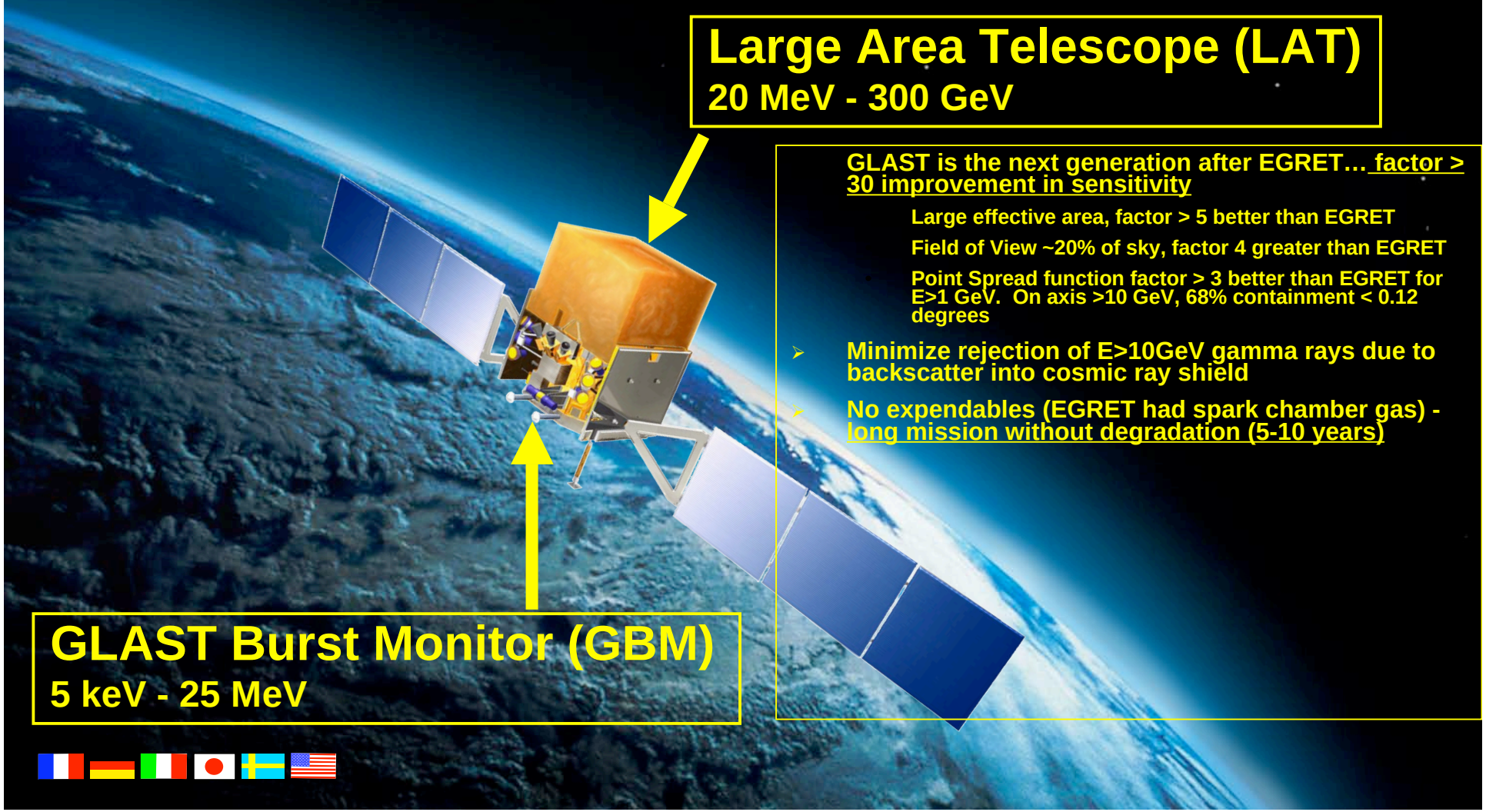
~225 Members (including ~80 Affiliated Scientists, plus 23 Postdocs, and 32 Graduate Students)

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

Managed at Stanford Linear Accelerator Center (SLAC).

GLAST is a NASA/DOE Mission

- Launch: December 2007
- Lifetime: 5-years (10-years goal)
- Orbit: 565 km, circular
- Inclination: 28.5°



Large Area Telescope (LAT)

20 MeV - 300 GeV

GLAST is the next generation after EGRET… factor > 30 improvement in sensitivity

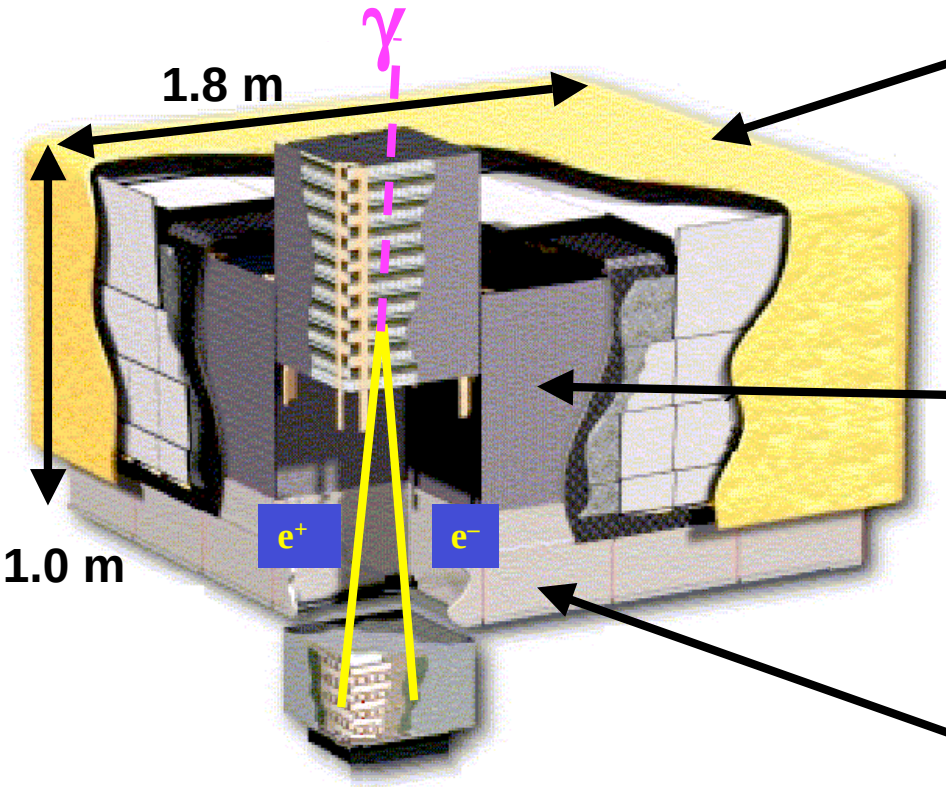
- Large effective area, factor > 5 better than EGRET
- Field of View ~20% of sky, factor 4 greater than EGRET
- Point Spread function factor > 3 better than EGRET for E>1 GeV. On axis >10 GeV, 68% containment < 0.12 degrees

- Minimize rejection of E>10GeV gamma rays due to backscatter into cosmic ray shield
- No expendables (EGRET had spark chamber gas) - long mission without degradation (5-10 years)

GLAST Burst Monitor (GBM)

5 keV - 25 MeV

GLAST Large Area Telescope (LAT)
20 MeV – 300 GeV



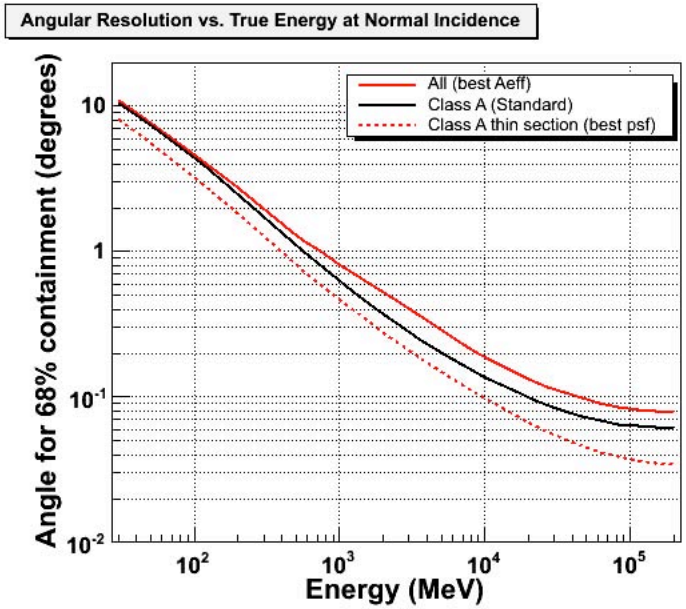
Anti-Coincidence Detector
- 4% R.L.
- 89 scintillating tiles
- efficiency (>0.9997) for MIPs

Tracking detector
- 16 tungsten foils (12x3%R.L.,4x18%R.L.)
- 18 pairs of silicon strip arrays
- 884736 strips (228 micron pitch)

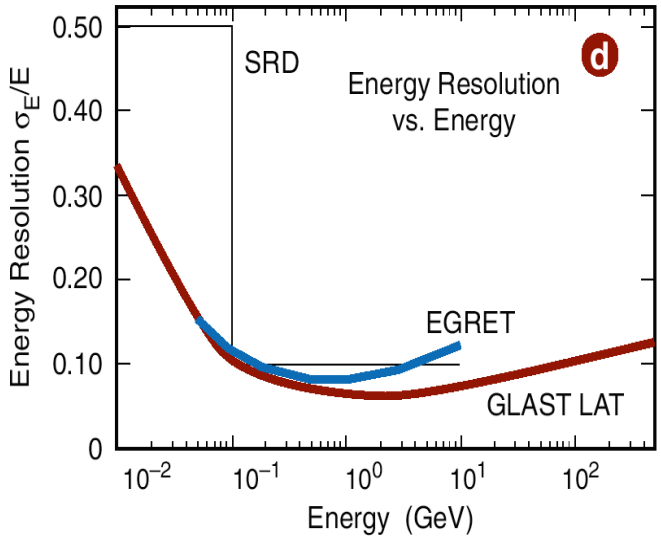
Calorimeter
- 8.5 radiation lengths
- 8 layers cesium iodide logs
- 1536 logs total (1200kg)

Expected GLAST-LAT Performance

- Angular resolution of better than 1 degree at energies > 1 GeV
- Angular resolution of better than 0.2 degree at energies > 10 GeV

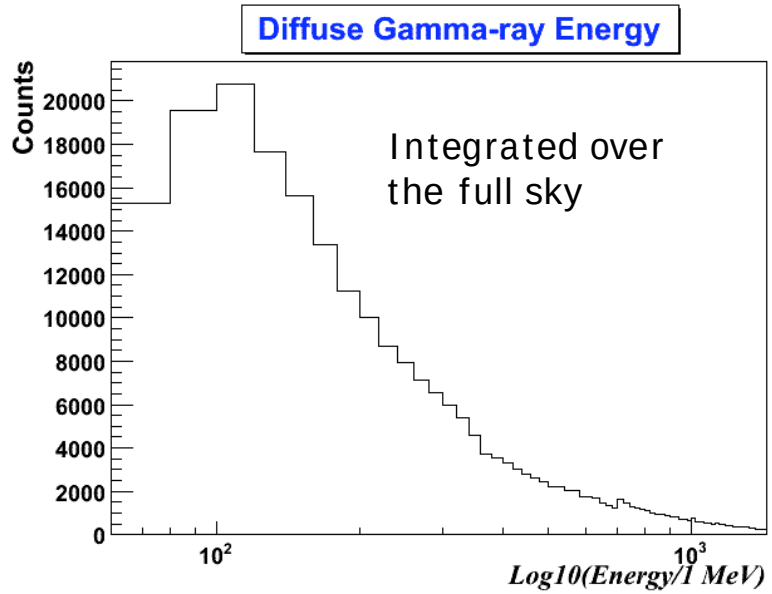


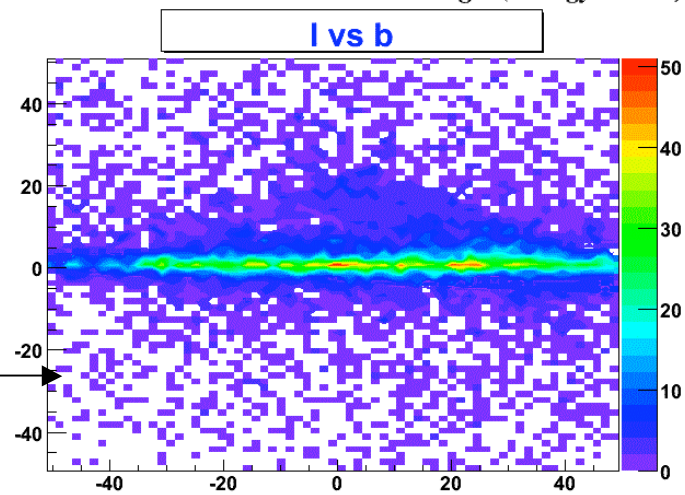
- Better than 10% energy resolution for 100 MeV through 100 GeV
- About 5% around 1 GeV



Diffuse Gamma-ray Production

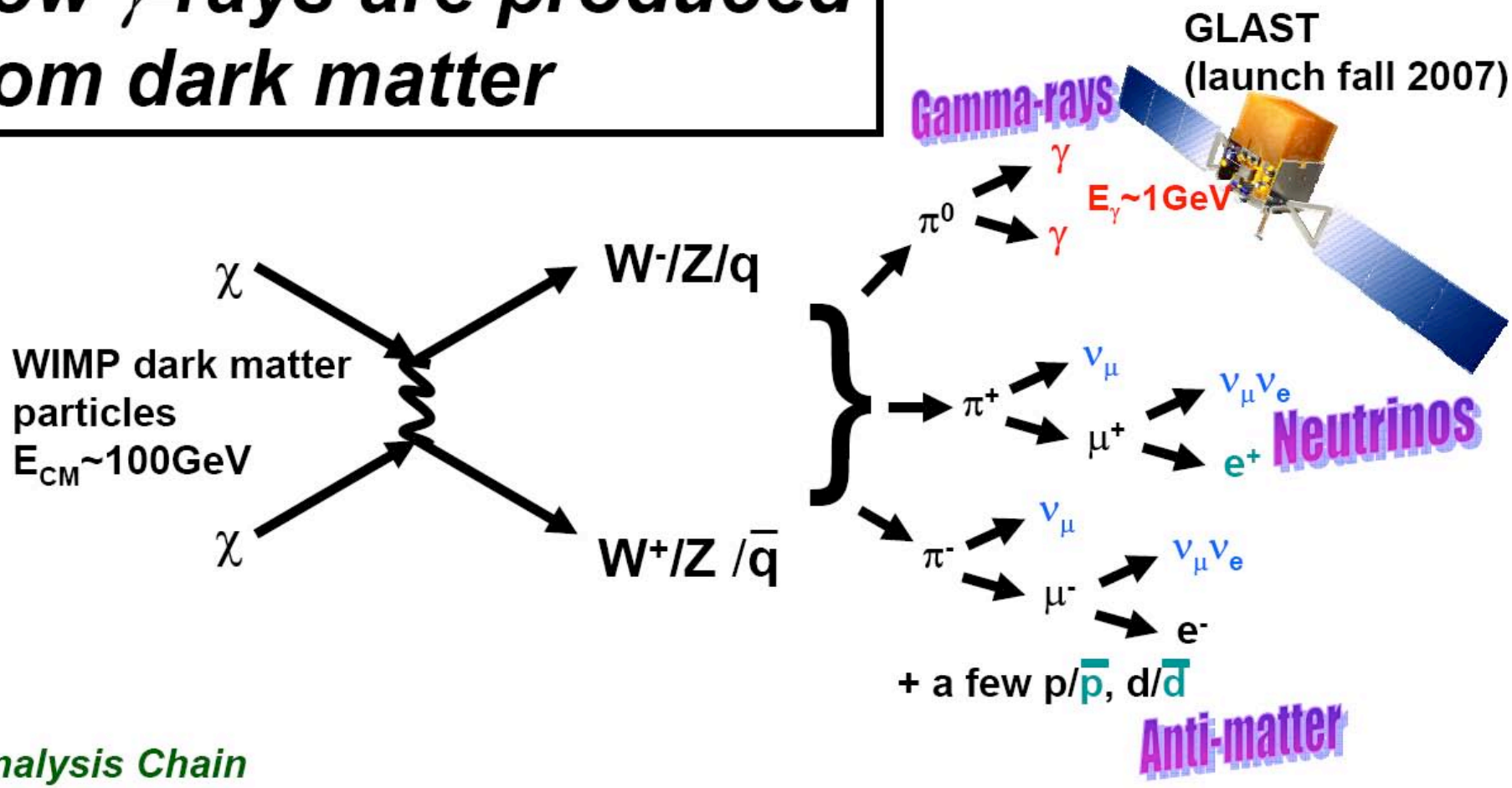
- Mechanisms:
  - Production and decay of pi0's
  - Inverse Compton scattering
  - Brem
- Above 1 GeV
  - Dominant contribution is pi0 decay
    - Cosmic ray scattering off of interstellar medium
  - Spectrum can be described by a power law with spectral index 2-3





Diffuse counts map after full detector sim,
Using conventional diffuse model
Trigger, filter and ID cuts applied
7 days of data

How γ-rays are produced from dark matter



Analysis Chain

??

Dark matter density e.g. N-body simulation

??

New particle theory e.g. SUSY, extra-dim

Final state hadronization e.g. PYTHIA simulation

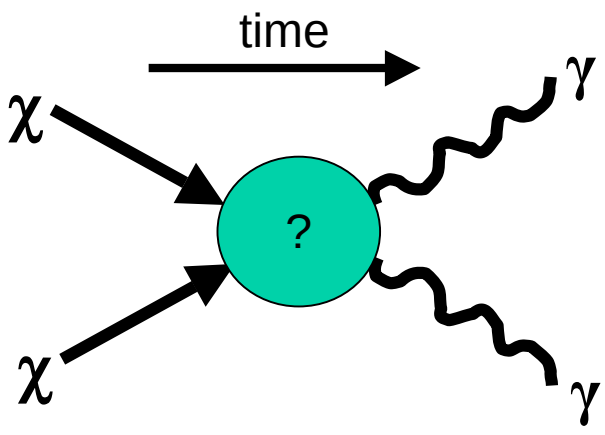
?

Cosmic ray propogation and galactic interaction i.e. GALPROP

Detector simulation i.e. GEANT4

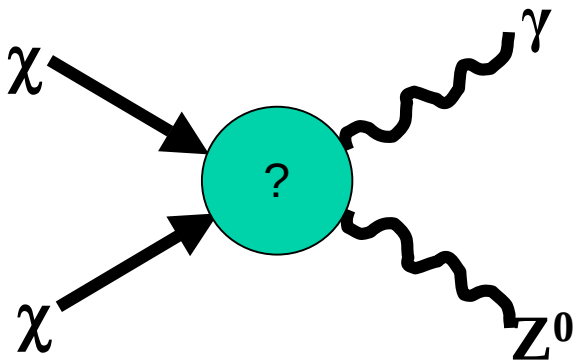
Gammas from lines

Branching fractions are in the range 10^{-2} - 10^{-4}

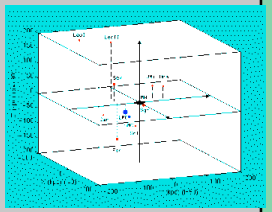
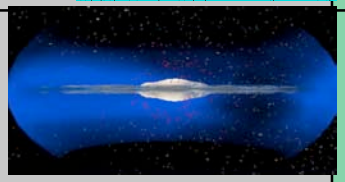
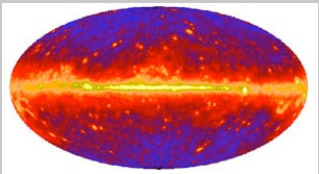


- **For $\gamma\gamma$ Line, energy = WIMP mass**
- **For WIMP masses > M_Z /2 can also have γZ^0 line**

- ***Measurement of line branching fractions would constrain particle theory***



GLAST complementary searches

Search Technique	advantages	challenges
Galactic center	Good Statistics ✓	Source confusion/Diffuse background
Satellites, Subhalos, 	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

WIMP annihilation: gamma-ray flux

Spectral shape & flux magnitude

γ-ray flux factors

$\int(\sum_i dN/dE\ B_i)dE$

X

$4\pi \int \rho^2(r) r^2 dr / M^2_{WIMP}$

x

$\langle\sigma v\rangle / 2$

x

$1/4\pi d^2$

Energy spectrum
(depends upon particle mass, branching fractions)

x

number density^2
(depends upon dark matter clustering)

x

annihilation cross-section
(depends upon underlying particle physics, inflation…)

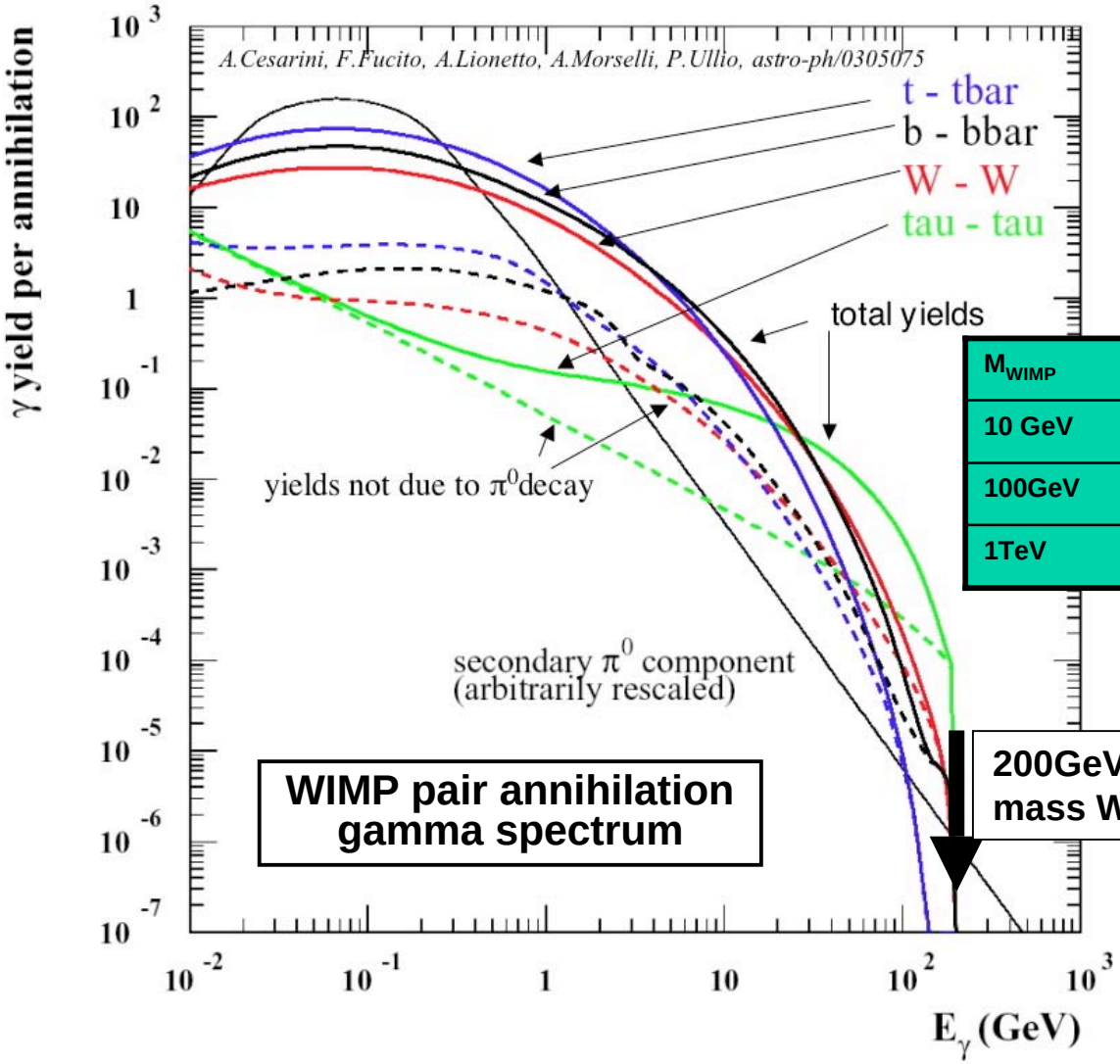
x

distance^{-2}
(depends upon dark matter clustering)

Spectral shape: Universal

Flux magnitude: *Factors difficult to disentangle for single point source*

WIMP annihilation: gamma-ray yield



WIMP pair annihilation gamma spectrum

200GeV mass WIMP

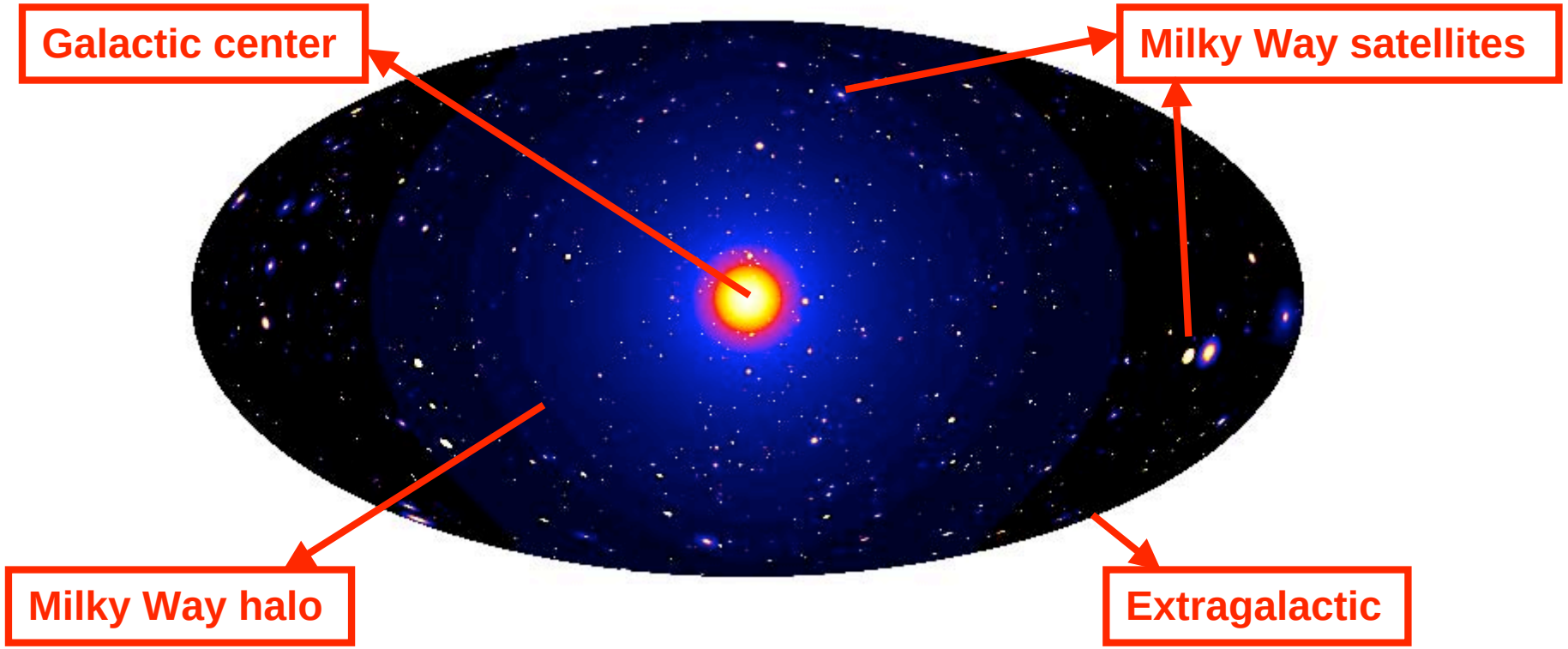
Gamma ray yield per final state $b\bar{b}$

M_{WIMP}	Total# γ	>100MeV	>1GeV	>10GeV
10 GeV	17.3	12.6	1.0	0
100GeV	24.5	22.5	12.4	1.0
1TeV	31.0	29.3	22.4	12.3

Dark Matter in the gamma ray sky

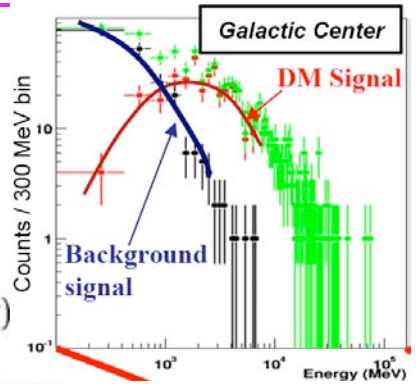
Milky Way Halo simulated by Taylor & Babul (2005)

All-sky map of DM gamma ray emission (Baltz 2006)



Only dm annihilation radiation shown….

Dark Matter From the Galactic Center

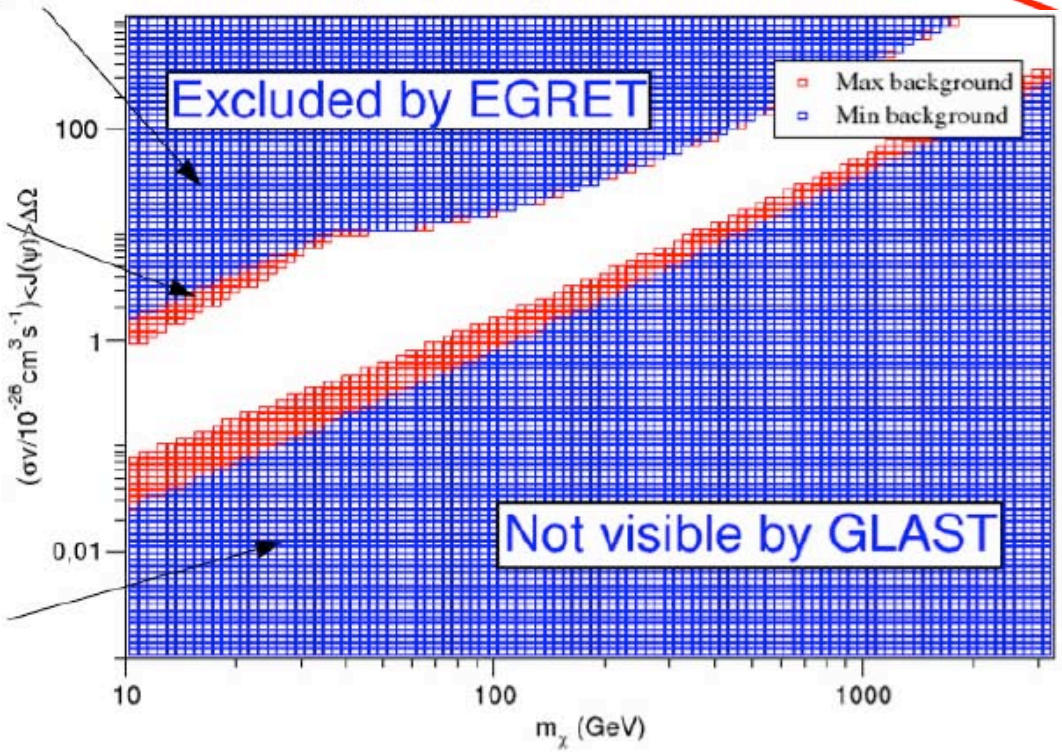


WIMP contribution higher than the maximum allowed by EGRET

uncertainties:
H column density

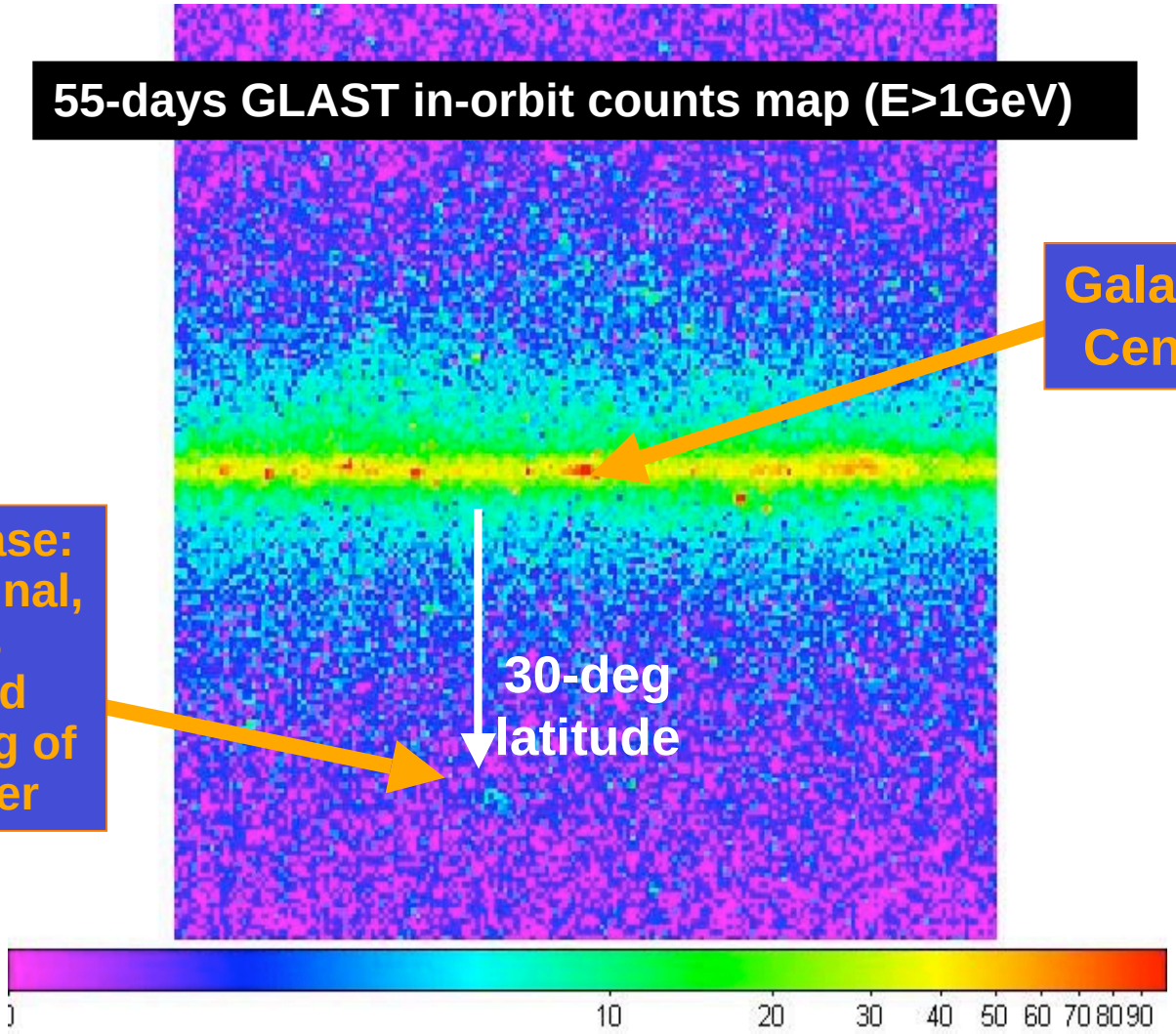
Analytic calculation, cross-checked by fast detector simulation

4 years exposure



A. Morselli et al, First Glast Symposium, 2007

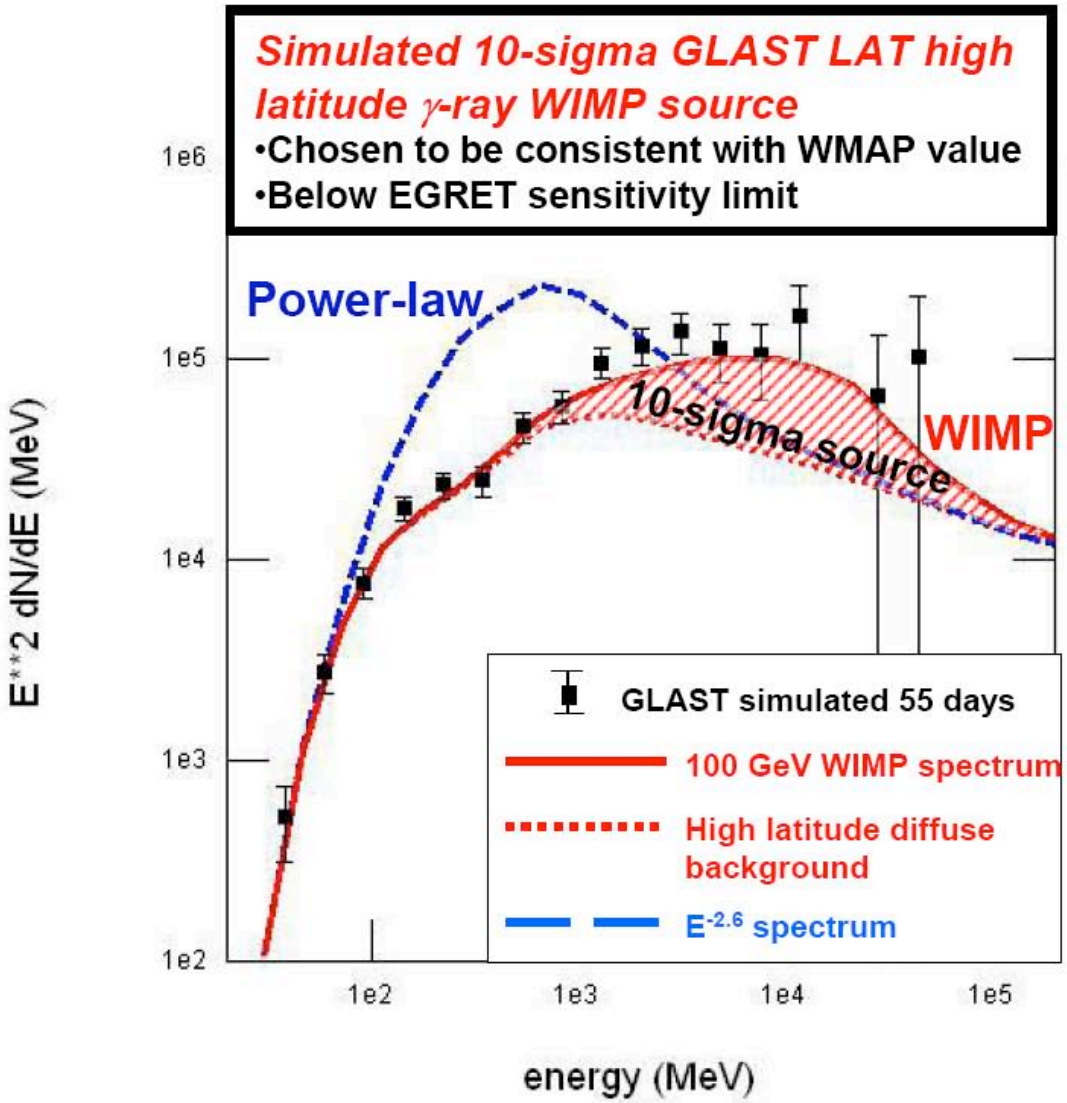
Simulation Example: DM Satellite



Optimistic case: 70 counts signal, 43 counts background within 1.5 deg of clump center

P. Wang et al, First Glast Symposium, 2007

What are the characteristics of WIMP γ-ray sources?

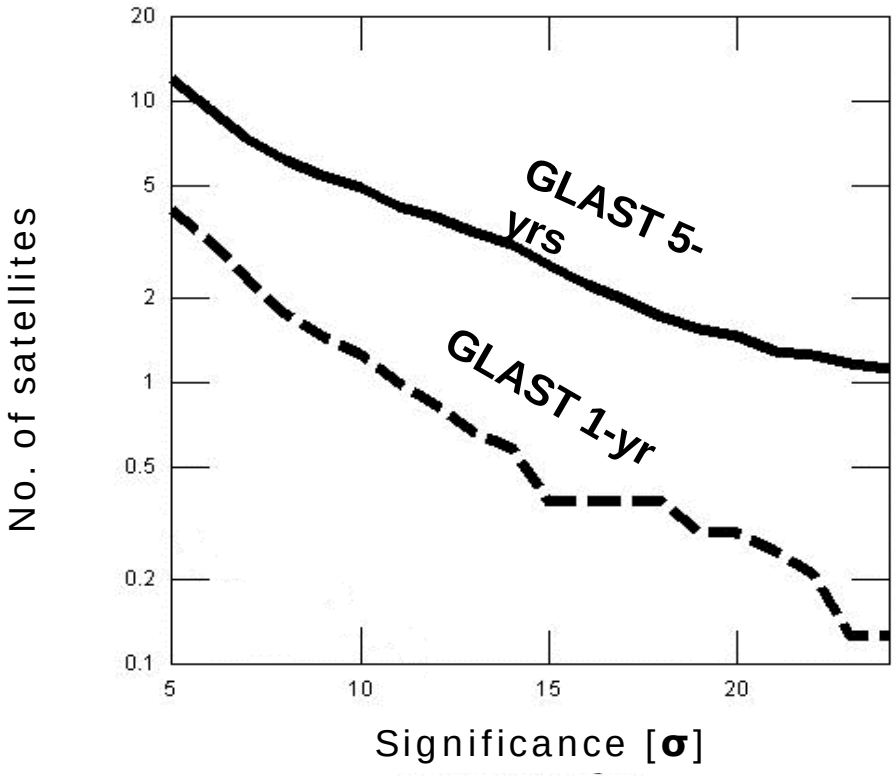


- Extended / diffuse
- High galactic latitude
- Non-variable
- Typically no counterparts
- Hard non-powerlaw spectrum w/ the following observable parameters:
  1. WIMP mass
  2. $\tau^+\tau^-$ / hadron branching fraction ratio
  3. $\gamma\gamma$ line branching fraction
  4. γZ^0 line branching fraction

Pulsars are the main source class with a spectrum which can match the WIMP annihilation spectrum (BTW06, astro-ph/0610731); check for counterparts, spectral lines

Dark Matter satellites/sub-halo ("generic" WIMP Model)

How many sources at which signficiance ?



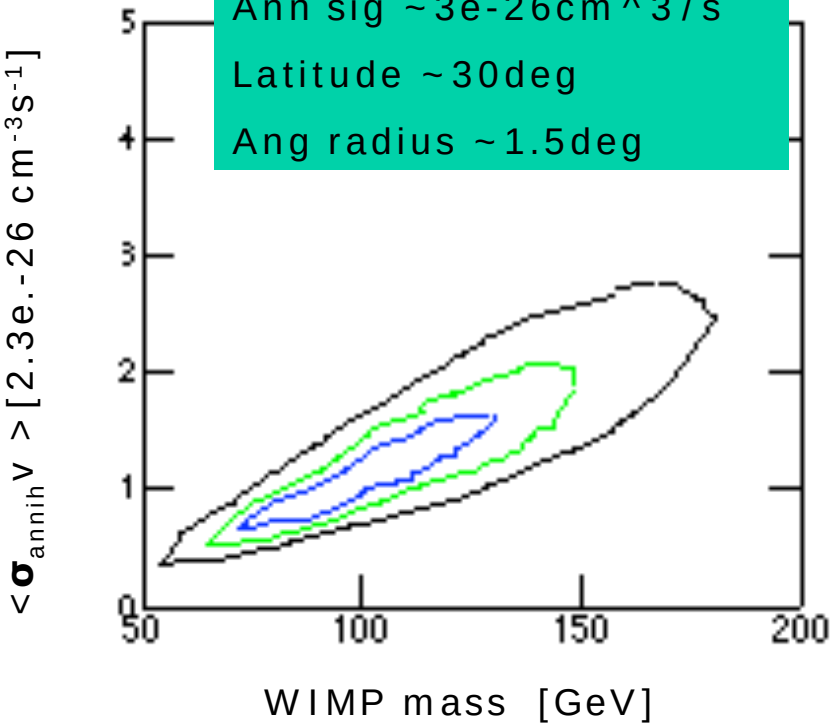
100 GeV WIMP, 10 σ detection after 1yr

E>1GeV

Ann sig ~3e-26cm^3/s

Latitude ~30deg

Ang radius ~1.5deg



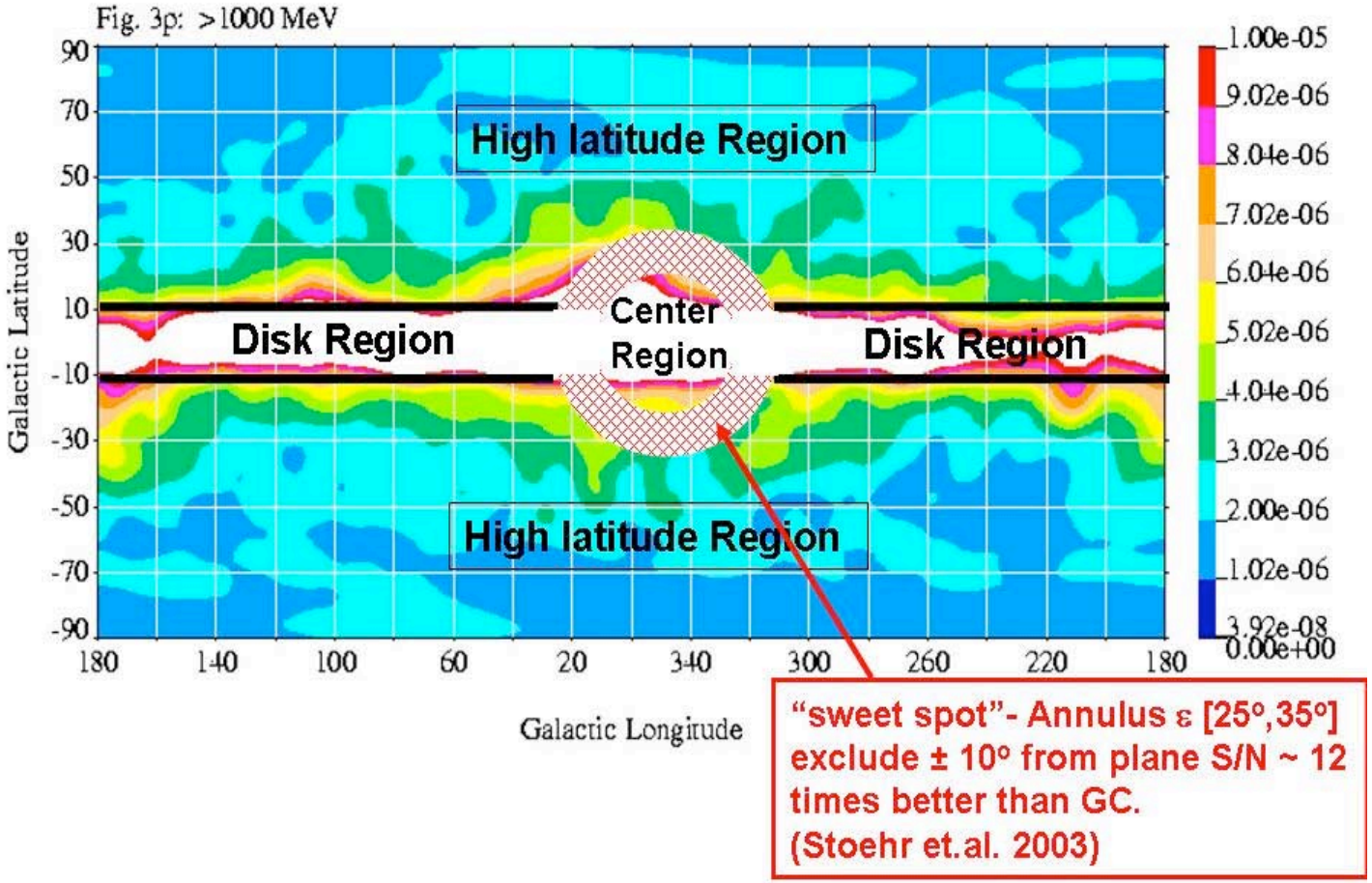
Simulation of Milky Way dark matter satellites from Taylor & Babul (2004,2005)

SUSY model definitions from Baltz, et.al. (2006);

P. Wang et al, First Glast Symposium, 2007

Searching for Gamma-Ray Lines

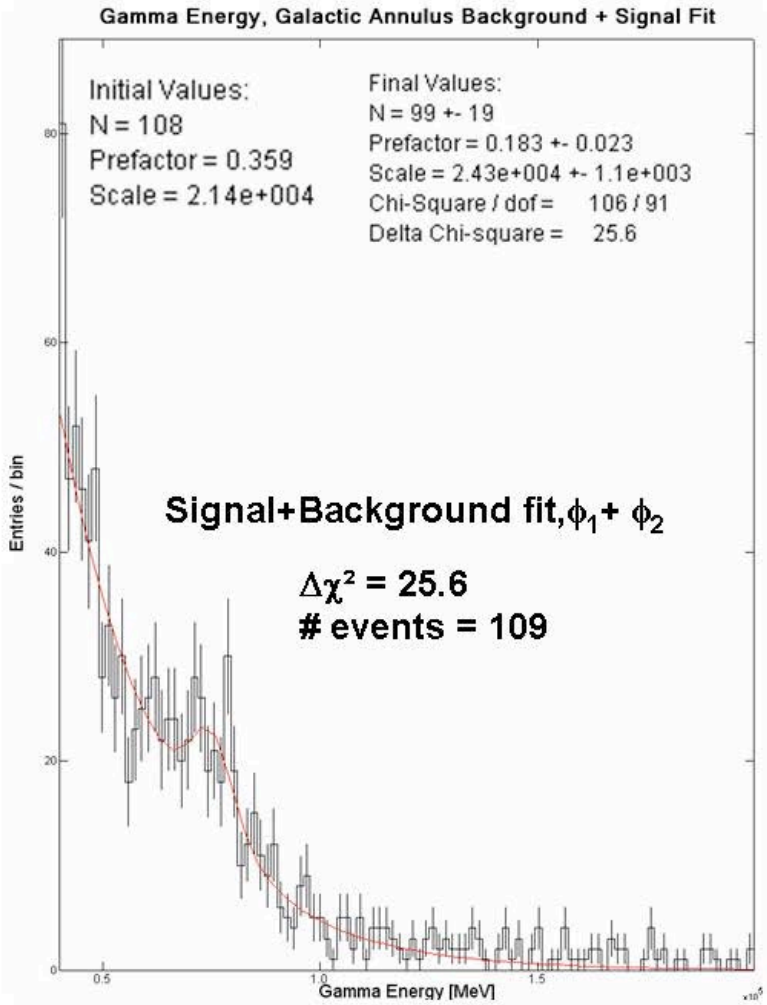
Milky Way dark matter halo Annulus about the Galactic Center

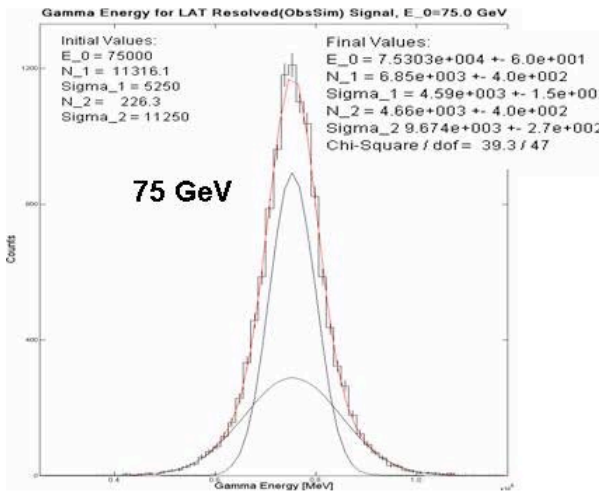


"sweet spot"- Annulus ε [25°,35°] exclude ± 10° from plane S/N ~ 12 times better than GC. (Stoehr et.al. 2003)

Y. Edmonds et al, First GLAST Symposium, 2007

GLAST Sensitivity to Gamma Ray Lines

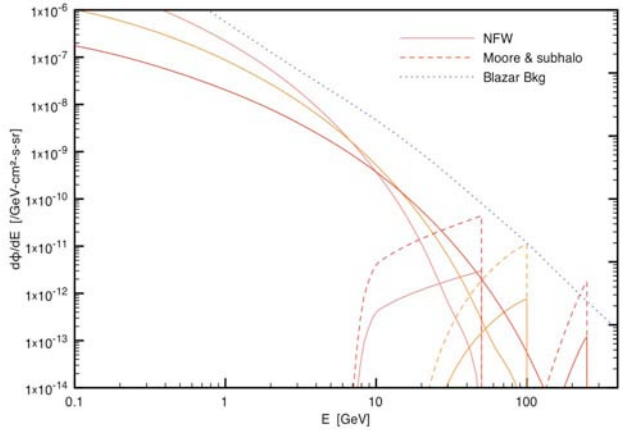




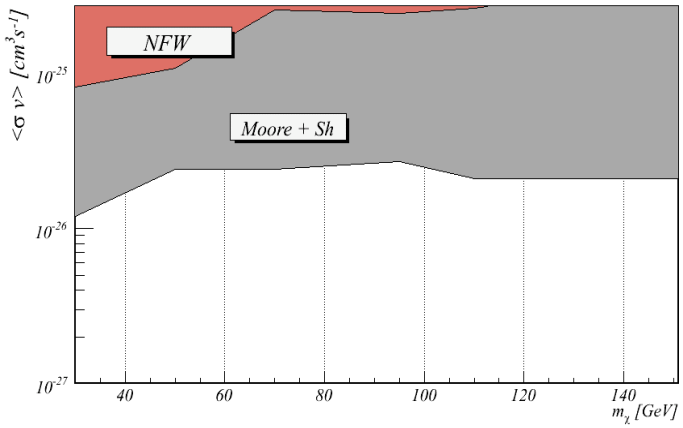
E. Bloom et al, First GLAST Symposium, 2007

Cosmological Wimp annihiliation

- Flux from cosmological WIMPs
  - Into both 2γ and continuum
  - Annihilation into b/bbar
  - WIMP masses 50,100,250 GeV
  - Ann xsec 3e-26 cm^2/s



- 3σ exclusion curve for 1y of GLAST simulated data
  - assumes background of unresolved blazars
  - GLAST is sensitive to annihilation cross sections on the order of 1e-25 – 1e-26 cm^3/s depending on the halo model



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

Summary

- GLAST LAT offers a unique opportunity to discover WIMP dark matter by the gamma rays produced in pair annihilations
- GLAST collaboration will search for WIMP annihilation gamma rays from galactic center, galactic halo, galactic satellites and extragalactic
- Looking forward to launch in Dec 2007!

GLAST LAT Mounted to Space Craft at General Dynamics in Gilbert, AZ.