

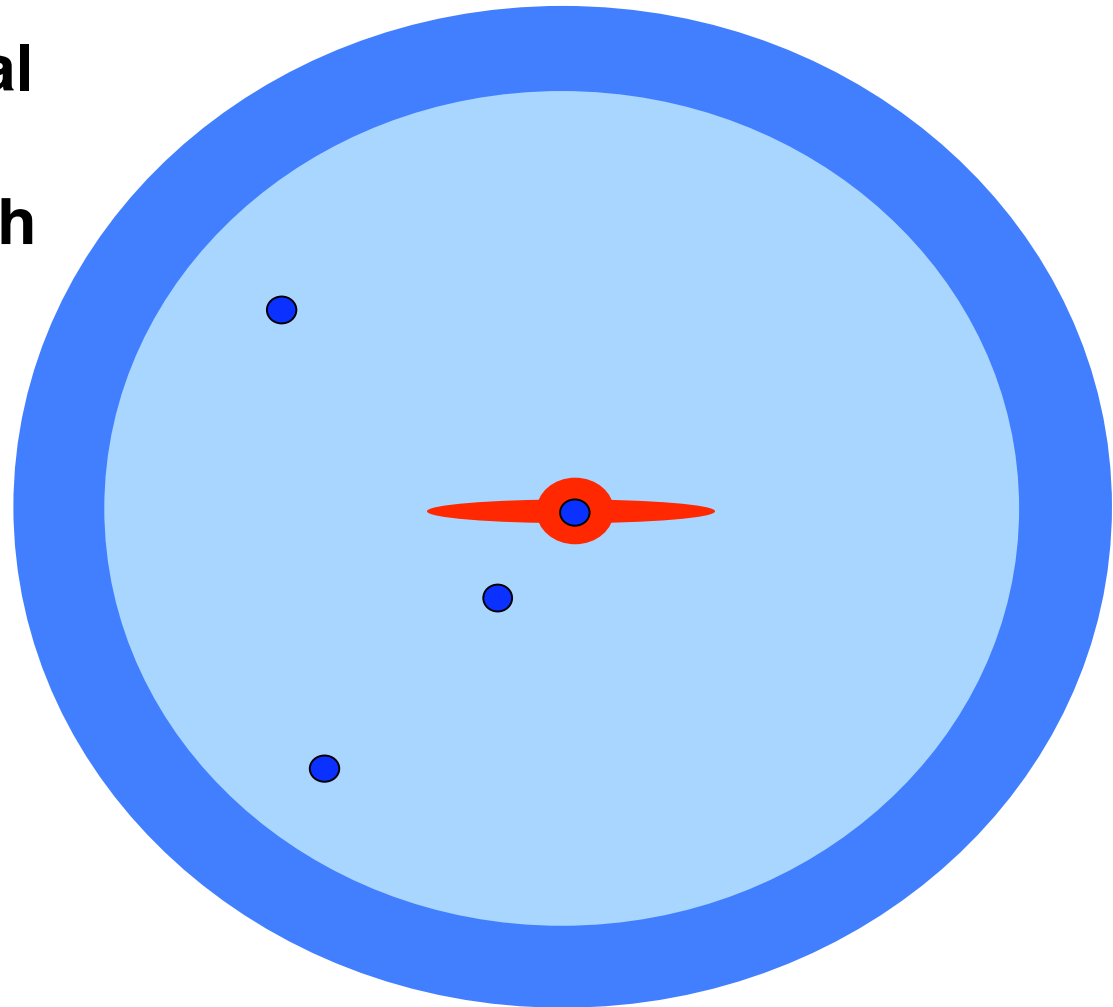
Experimental challenges in GLAST dark matter searches

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SLAC**

Talk Plan

Overview experimental techniques & problems by search region:

- **Galactic satellites**
 - 12 slides
- **Galactic center**
 - 4 slides
- **Galactic halo**
 - 1 slide
- **Extra-galactic**
 - 2 slides



Galactic Satellite Search

Dark matter candidate selection from GLAST point source catalog:

- Selection of “final candidates” using loose cuts on various signatures (see list)
- LAT-wide studies of final candidates, i.e. how likely are the final candidates to be non-WIMP sources according to AGN group, pulsar group
- Comparison of spectra for final candidates, i.e. WIMP annihilation spectrum is universal

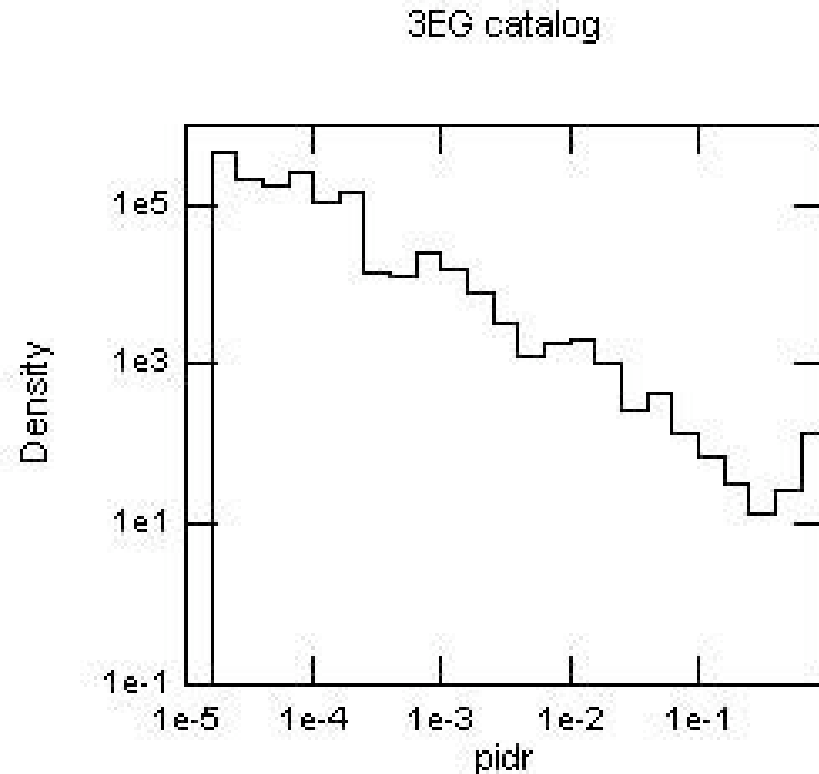
Signature list:

- Lack of association w/ counterparts (mostly)
- Lack of variability (mostly)
- Flat powerlaw index below 100MeV
- Hard, broken powerlaw indices above 100MeV
- cutoff of flux (at mass of WIMP, somewhere $>10\text{GeV}$)
- Line
- Extendedness

Counterparts

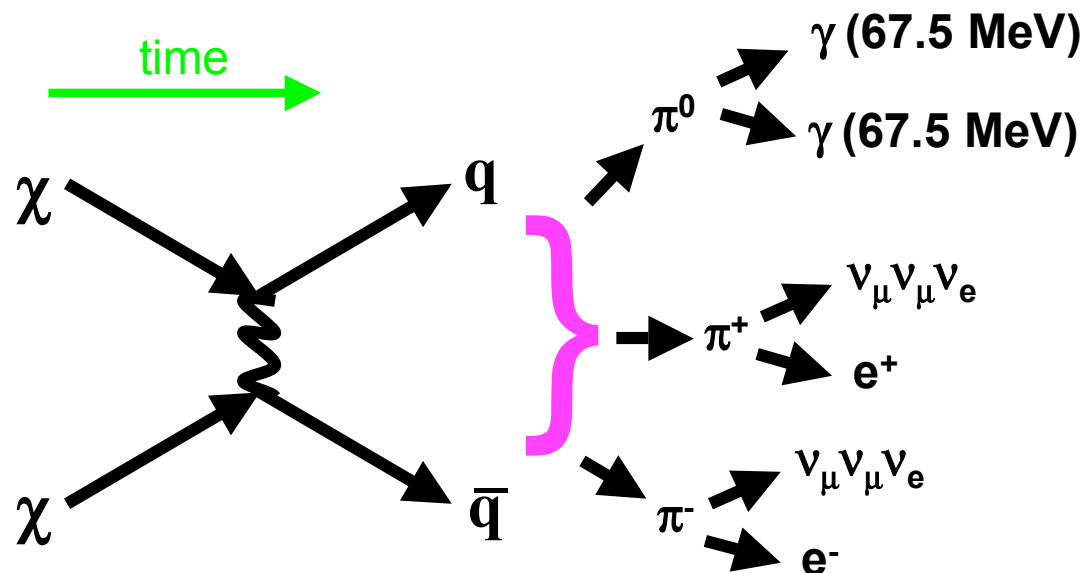
Dark matter is “dark”, i.e. not visible except (we hope) in gamma rays

- Select low probability of association for each point source, for each counterpart catalog:
- E.g. Mattox, Hartman, Reimer 2001 (5GHz catalog); $|b| > 3$
- Loosely cut on high probabilities



Counterparts – Neutrinos & Electrons

- If $\rho_{\text{WIMP}} \sim \rho_{\text{anti-WIMP}}$ or $\text{WIMP} = \text{anti-WIMP}$, expect tree-level annihilation to quark pairs



Counterparts - Radio

Special cases:

- Bertone, Sigl, & Silk (2001) fit radio and gamma data from Sgr A* to WIMP annihilation models
- Baltz & Wai (2004) extended radio source below 1GHz

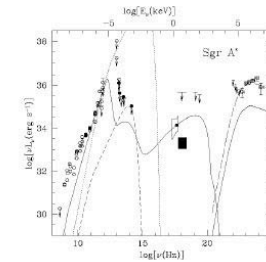
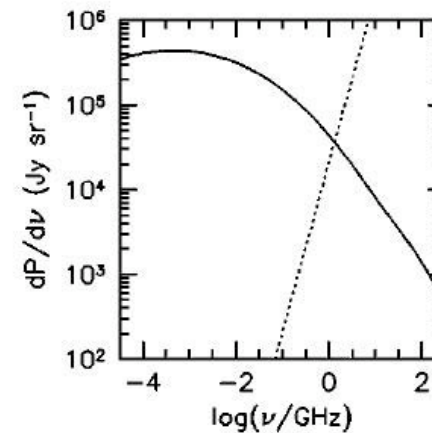
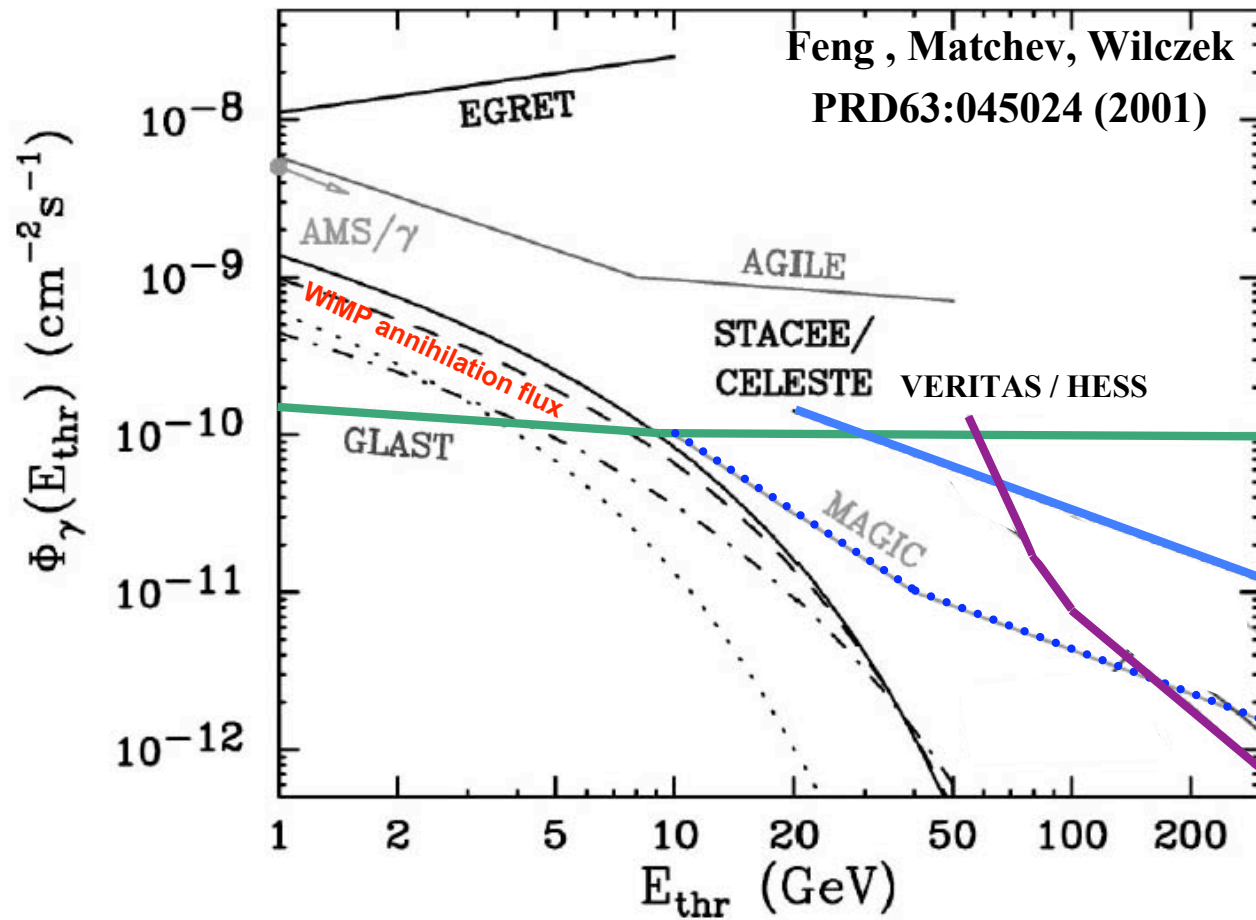


Figure 1: From [3]: circles represent various flux measurements and upper limits of Sgr A*. The four peaks from left to right represent: synchrotron radiation, Compton scattering, bremsstrahlung, pion production. The dotted line is the spectrum corresponding to a standard thin accretion disk with accretion rate $1e-4$ solar mass, and the short-dashed line is thin disk with accretion rate $1e-9$ solar mass. The solid line is the advection dominated accretion flow (ADAF). The long dashed line shows ADAF with pion peak artificially raised by 1 order of magnitude. Of course, all of these models apply strictly to non-dark matter accretion scenarios. The Chandra observation in the 2-10 keV band [4] is shown as the black box.



Counterparts - TeV



- **GLAST is superior for continuum radiation**
- **GLAST provides a list targets for ACT's**
- **ACT's are more sensitive in the WIMP line region**

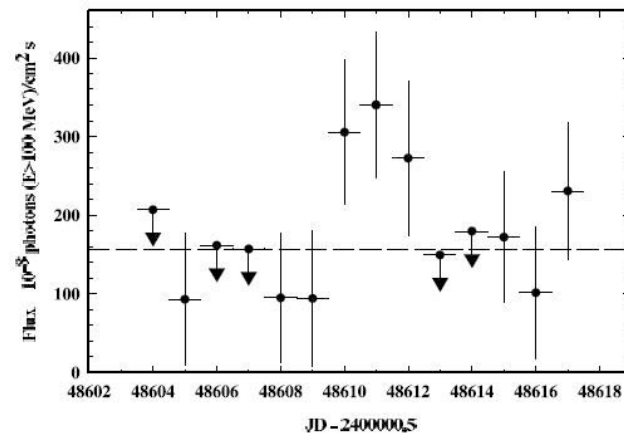
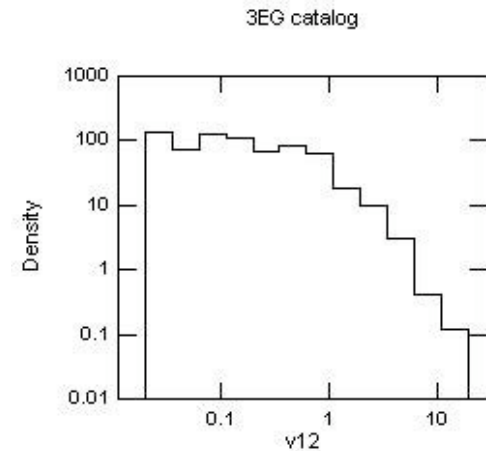
Variability

Theoretical expectations:

- **Expect WIMP annihilation to be non-variable at GLAST timescales, i.e. clump crossing time $\sim 10\text{Myr}$**
- **Except for the case of dark matter accumulation near black holes (e.g. galactic center); in that case can have variability at scale of black hole orbits (as short as 10min timescales for GC)**

Variability analyses

- **Month time scale, i.e. Nolan et al (2003)**
- **Day time scale, i.e. Wallace et al (2000)**

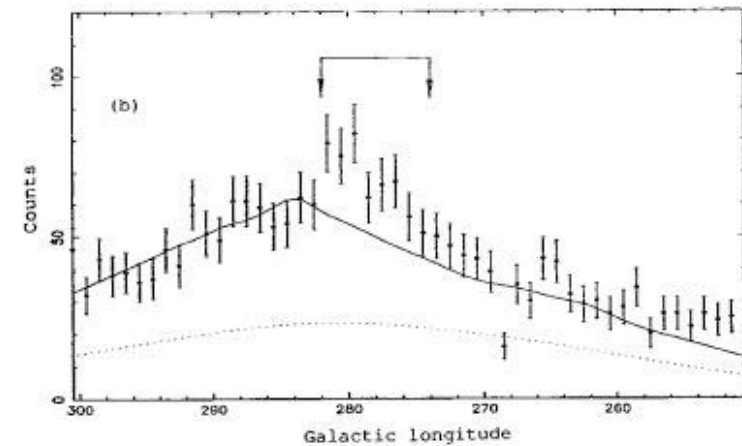
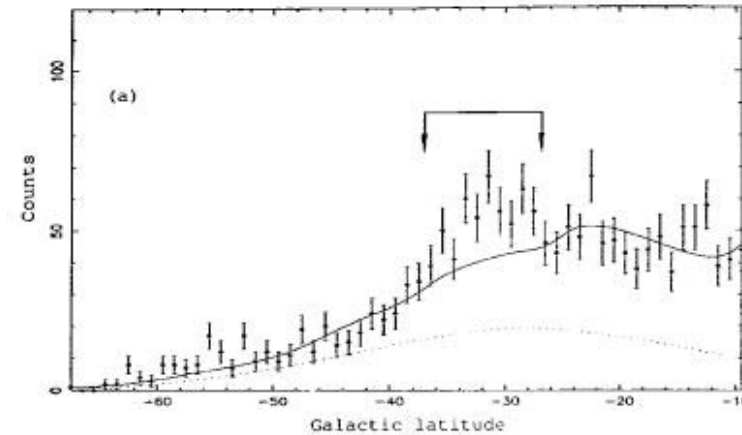


Extended sources

- Dark matter is in general extended due to weak interaction, i.e. can't get rid of angular momentum
- Also can have extended emission a la Baltz & Wai (2004), i.e. inverse Compton of WIMP produced electrons
- For \sim psf extended sources leverage off of GLAST catalog, i.e. for prompt emission from "close" clumps
- For very large (~ 10 deg) extended sources need special analysis, i.e. inverse Compton signal

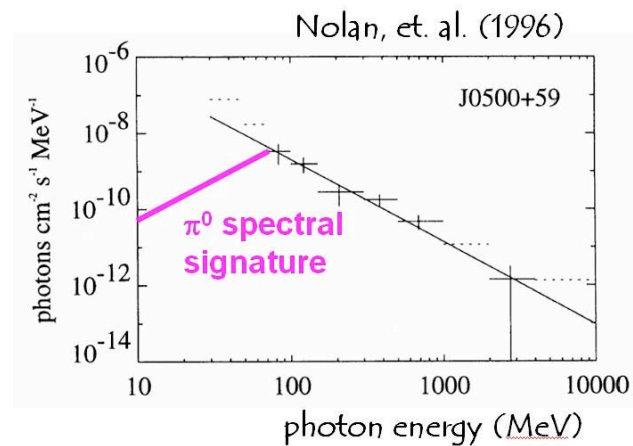
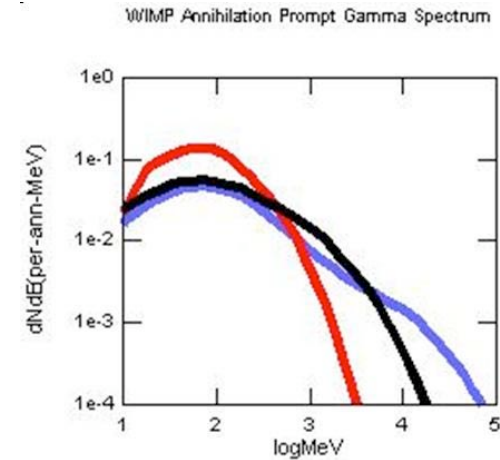
Extended Sources

- Only confirmed extended source in 3rd EGRET catalog: specialized analysis of LMC by Sreekumar et.al. (1992)
- 3rd EGRET catalog ~50% of sources “possibly” extended (“em” label under “notes”)



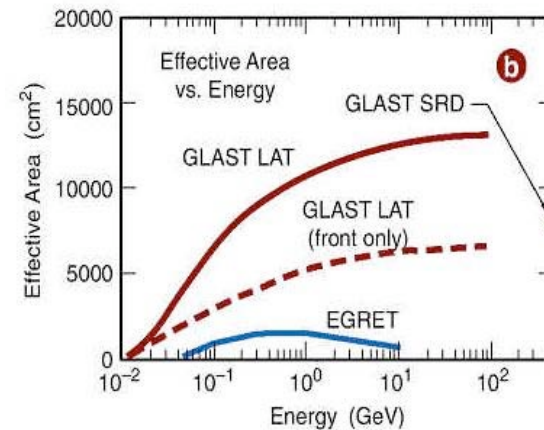
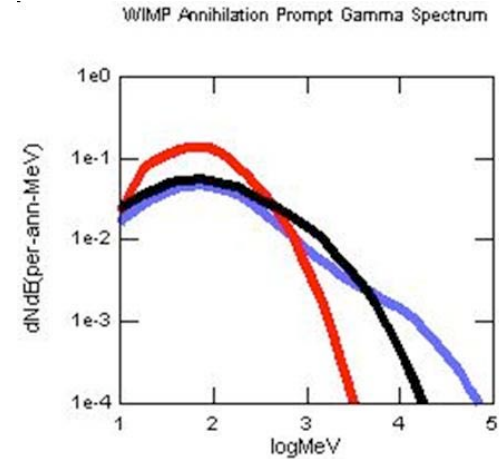
Below 100 MeV

- Boosted pi-zero spectra peak at 67.5 MeV
- EGRET catalog does not go below 100 MeV
- Can any of the GLAST sources be shown to have flat spectra below 100 MeV?



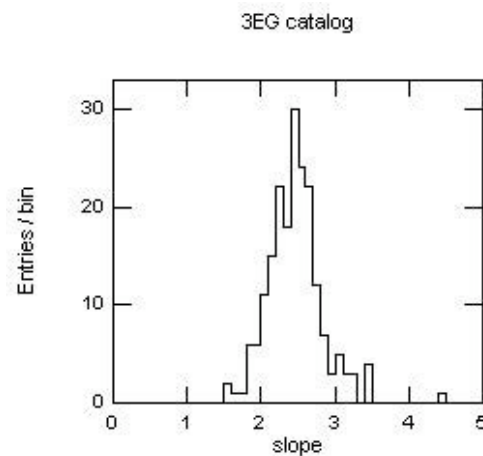
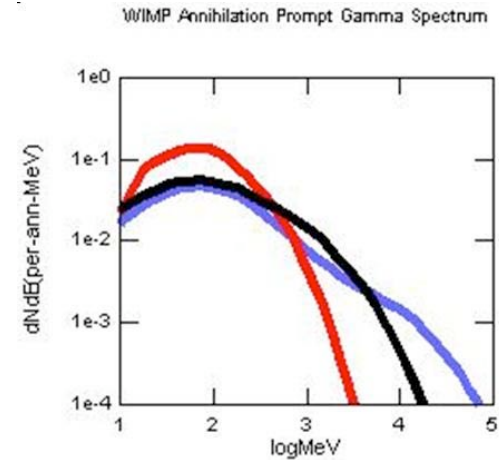
Below 100 MeV

- Effective area drops sharply below 100 MeV due to low reconstruction efficiency; thus, all observed spectra will “roll over” below 100 MeV, whether powerlaw or pi-zero spectrum
- Pi-zero spectrum will have “greater deficit” than expected for straight powerlaw
- Need careful study of effective area vs energy below 100 MeV
- Use Van de Graaff at 18.6MeV; push limits of SLAC test beam below 100MeV

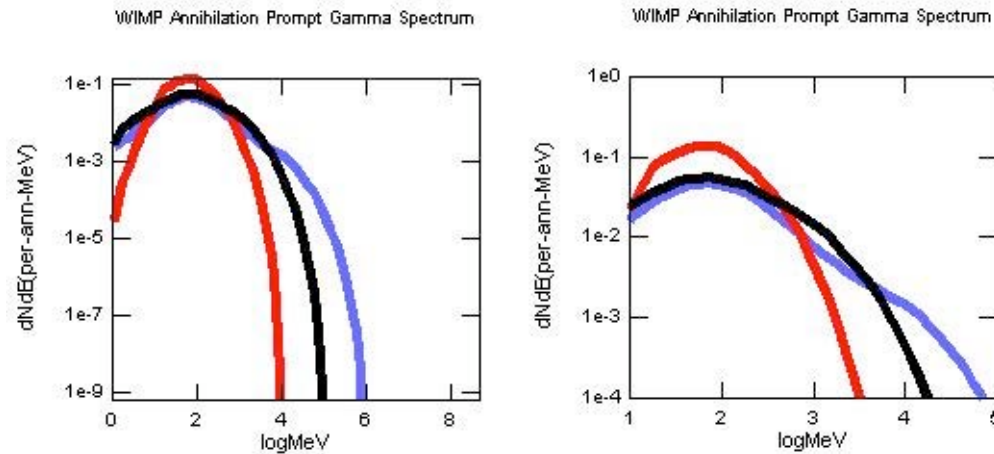


From 100 MeV to 10 GeV

- Select sources with extremely hard spectra (power law slope > -1.5)
- Select sources with broken power law



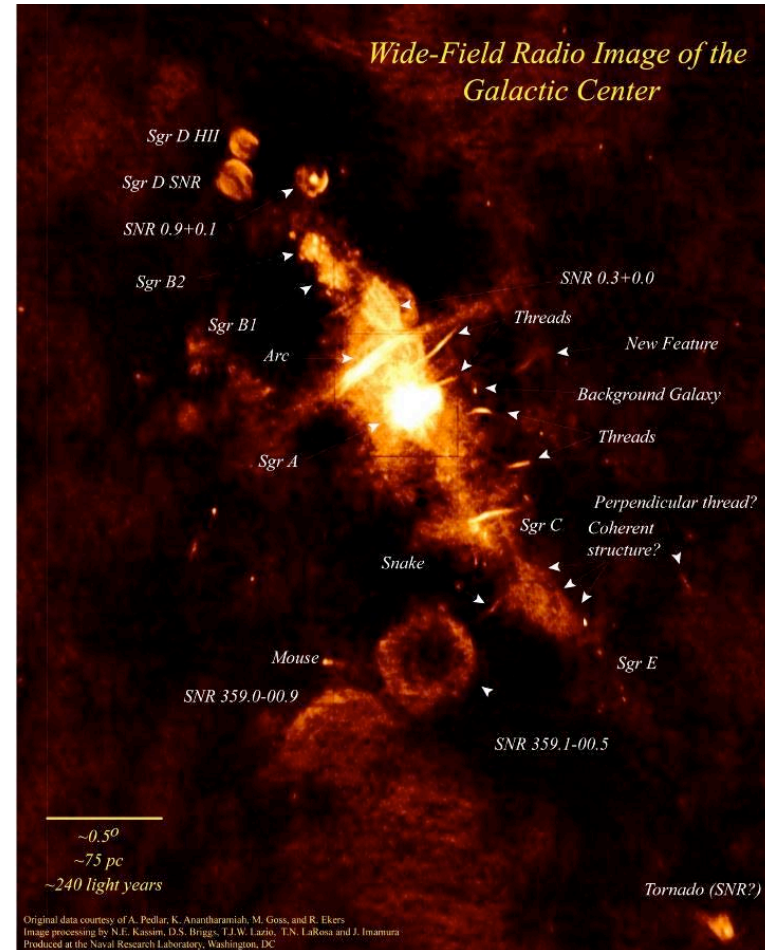
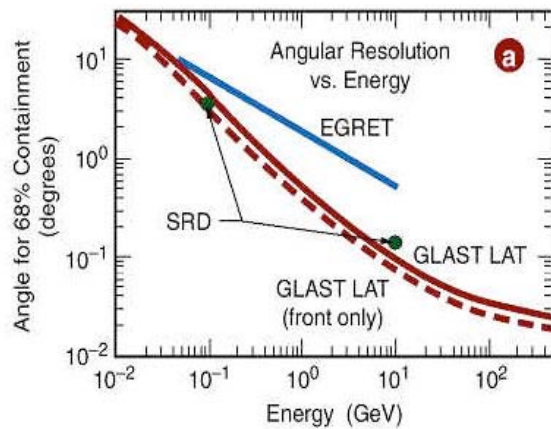
Above 10 GeV



- Search for steepening of spectrum, “cutoff” of source flux (at mass of WIMP) – need careful study of $>10\text{GeV}$ diffuse background spectrum
- Search for lines – need good validation of energy dispersion in MC $>10\text{GeV}$, i.e. SLAC test beam

Galactic center

- Specialized modeling of gamma ray emitters within 200pc of GC (i.e. 1.5deg) for 1 GeV analysis



Galactic Center

Need DM variability
estimate < 1 pc

- ~day timescale variability observed by Wallace et.al. (2000)
- ~month timescale variability observed by Nolan et.al. (2003)

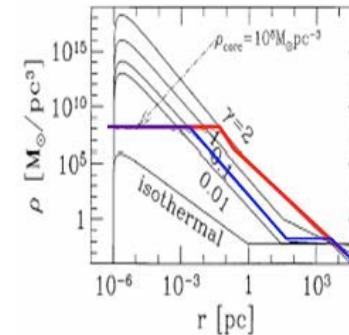
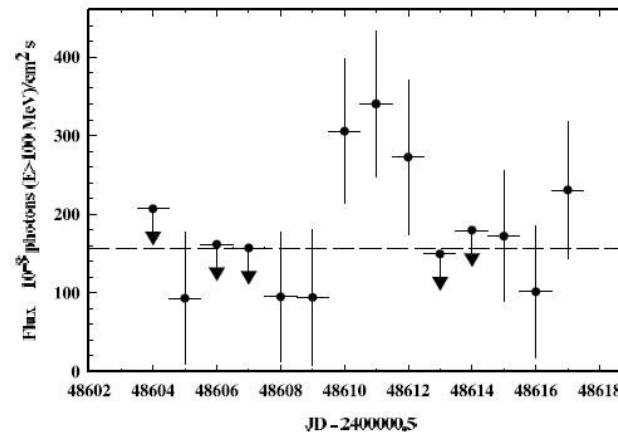


FIG. 1. Examples of spike density profiles.

Gondolo & Silk, PRL 83, no.9, p.1719 (1999)



Galactic Center

Nolan et.al.(2003); GC delta=0.48 (0.29-0.75)

VARIABILITY OF SELECTED CLASSES OF SOURCES

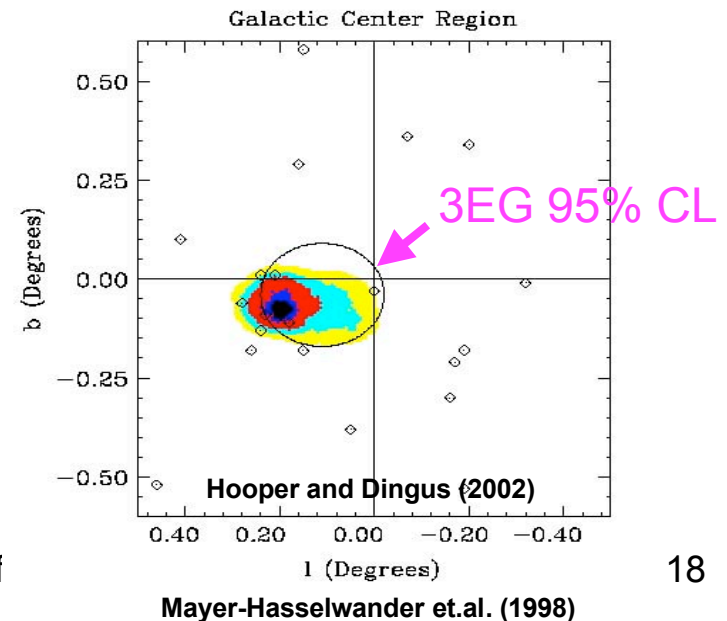
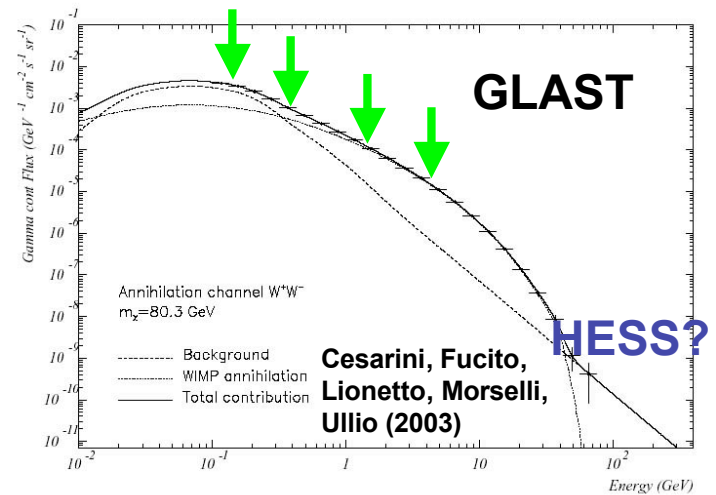
Source Class	No. Members	$\langle \delta \rangle$	rms (δ)	Symbol
3EG Classification:				
Pulsars	6	0.11 ± 0.02	< 0.07	PSR
SNR associations	10	0.27 ± 0.09	< 0.19	SNR
AGNs ("A" in 3EG)	67	0.70 ± 0.08	0.27 ± 0.05	
Quasars	51	0.77 ± 0.09	0.25 ± 0.08	QSO
BL Lac objects	15	0.49 ± 0.16	< 0.32	BLL
Unidentified, $ b < 5^\circ$	47	0.42 ± 0.06	0.17 ± 0.08	U0
Unidentified, $5^\circ < b < 15^\circ$	37	0.56 ± 0.12	0.23 ± 0.09	U5
Unidentified, $15^\circ < b < 30^\circ$	45	0.42 ± 0.12	< 0.16	U15
Unidentified, $ b > 30^\circ$	29	0.84 ± 0.15	< 0.27	U30
Possible isolated neutron stars:				
Geminga-like objects	3	0.13 ± 0.11	< 0.16	Gem
Pulsars without PWN	7	0.21 ± 0.15	< 0.15	noPWN
Pulsars with PWN	6	0.66 ± 0.29	0.28 ± 0.16	PWN
Gould Belt, unidentified, $ b > 5^\circ$	33	0.49 ± 0.13	< 0.26	G
Persistent, unidentified (Gehrels et al. 2000)	88	0.32 ± 0.05	0.10 ± 0.05	Per
Steady, unidentified (Grenier 2000)	120	0.35 ± 0.05	0.11 ± 0.04	Std
Associations from Romero et al. (1999):				
SNR	17	0.28 ± 0.10	< 0.17	RSN
W-R stars	6	0.45 ± 0.22	< 0.27	WR
Of stars	4	0.26 ± 0.15	< 0.19	Of
OB associations	22	0.40 ± 0.10	0.17 ± 0.08	OB

Galactic Center

Mayer-Hasselwander (1998)
 - EGRET point source
 “close to” the galactic center

Spatial analysis

- 100MeV-300MeV ($l \sim -0.75\text{deg}$)
- 300MeV-1GeV ($l \sim -0.30\text{deg}$)
- $> 1\text{GeV}$ ($l \sim 0.05\text{deg}$)
- $> 5\text{GeV}$ ($l \sim 0.20\text{deg}$)



Galactic Halo

- Stoehr et.al. (2004):
flux from WIMP
annihilation largest at
 ~ 10 deg from GC
- Need to study
uncertainties in IC
and dust components
of galactic diffuse
model

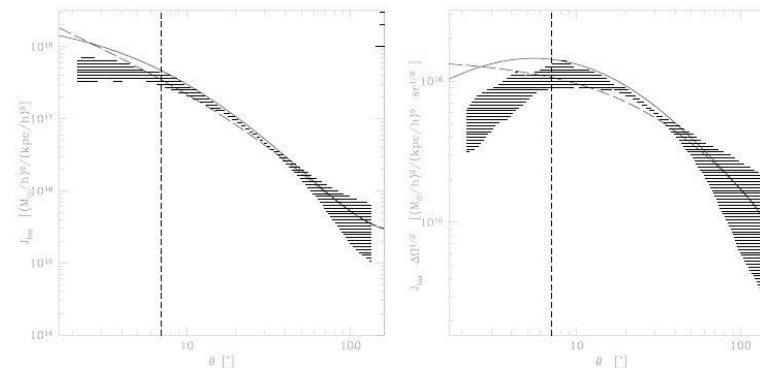
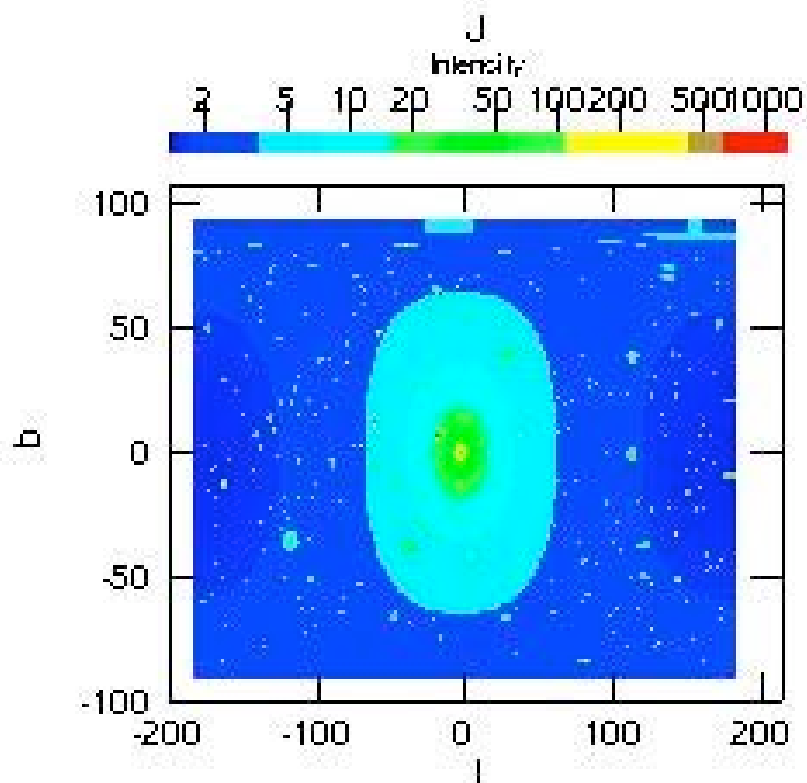


Figure 7. Mean predicted surface brightness of annihilation radiation as a function of angular distance from the Galactic Centre. The hatched regions enclose profiles estimated directly from six different 'solar' positions 8kpc from the centre of GA3n, while the two curves gives results based on SWTS (solid) and NFW (dashed) fits to the circular velocity curve, together with an enhancement factor of 1.7. In the left-hand panel the surface brightness profiles are plotted directly, whereas on the right they are multiplied by one power of the angle θ to represent the signal-to-noise expected in an observation of fixed duration of a region whose size increases in proportion to θ , (specifically $[\theta, 1.01\theta]$). Vertical dashed lines indicate the angle subtended by the gravitational softening length at the distance of the Galactic Centre.

Extra-galactic

For galactic satellites below detection threshold:

- Search for non-variable, galacto-centric non-uniformity in extra-galactic diffuse background
- AGN below detection threshold will be uniform across sky, variable



Extra-galactic

For “cosmological”
extra-galactic DM:

- Ullio et.al. (2002):
search for redshifted
lines; background is
unresolved blazars

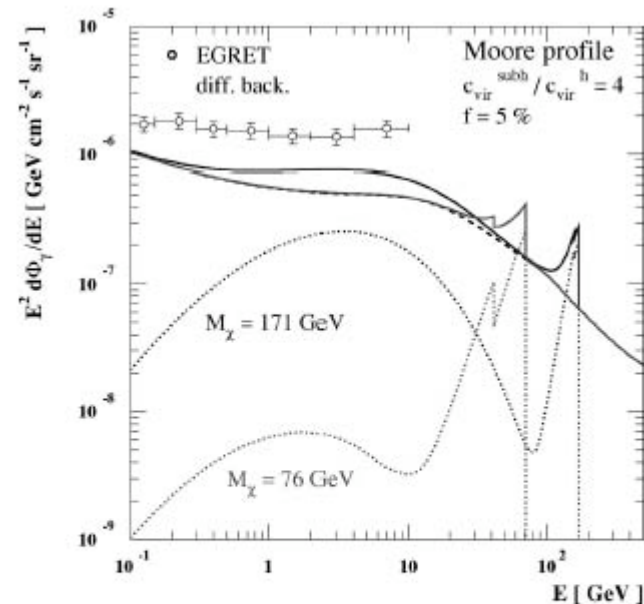


FIG. 13. Extragalactic gamma-ray flux (multiplied by E^2) for two sample thermal relic neutralinos in the MSSM (dotted curves), summed to the blazar background expected for GLAST (dashed curve). Normalizations for the signals are computed assuming halos are modelled by the Moore profile, with 5% of their mass in substructures with concentration parameters 4 times larger than c_{vir} as estimated with the Bullock *et al.* toy model.

Summary

Main search regions are at high latitude:

- galactic satellites
- galactic halo
- extra-galactic

One low latitude search region:

- the galactic center

Main signatures:

- ultra-hard spectra
- broken powerlaws
- Lines ($>10\text{GeV}$)
- lack of variability (except possibly galactic center)
- Lack of counterparts (except possibly galactic center)
- Extendedness

Experimental Challenges

Modeling

- Galactic diffuse – what is expected w/o WIMP annihilation
- Galactic Center – what is expected w/o WIMP annihilation
- Dark matter halo realizations
- Dark matter spectra for various masses

Analysis for all GLAST catalog sources:

- powerlaw indices
- broken powerlaws
- lines
- Extendedness
- Variability
- counterpart associations

Special analyses:

- Galactic Center
- Large extended sources (~10deg)
- Galactic halo
- Extragalactic diffuse