DARK MATTER INDIRECT DETECTION WITH FUTURE SPACE-BASED GAMMA-RAY TELESCOPES

TIM LINDEN

UNIVERSITY OF CHICAGO

INDIRECT DETECTION OF WIMPS

Astrophysics

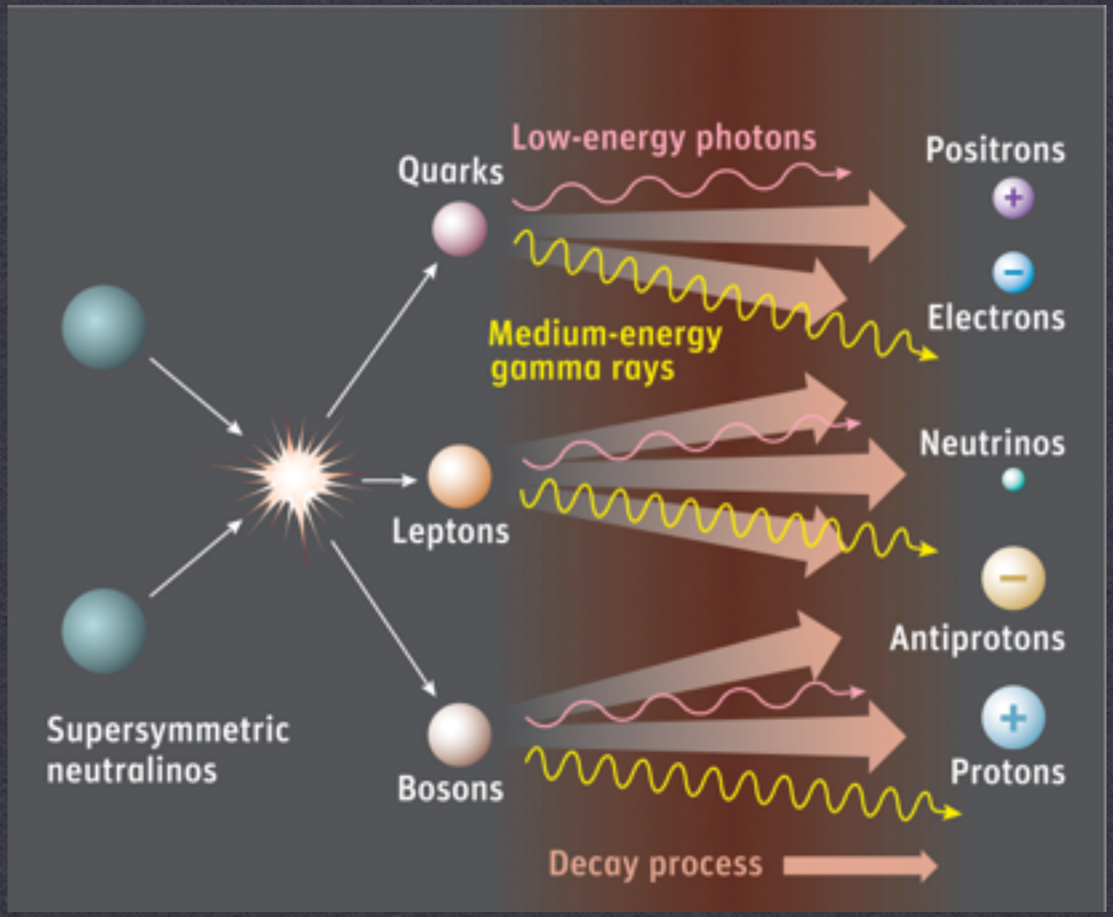
Particle Physics

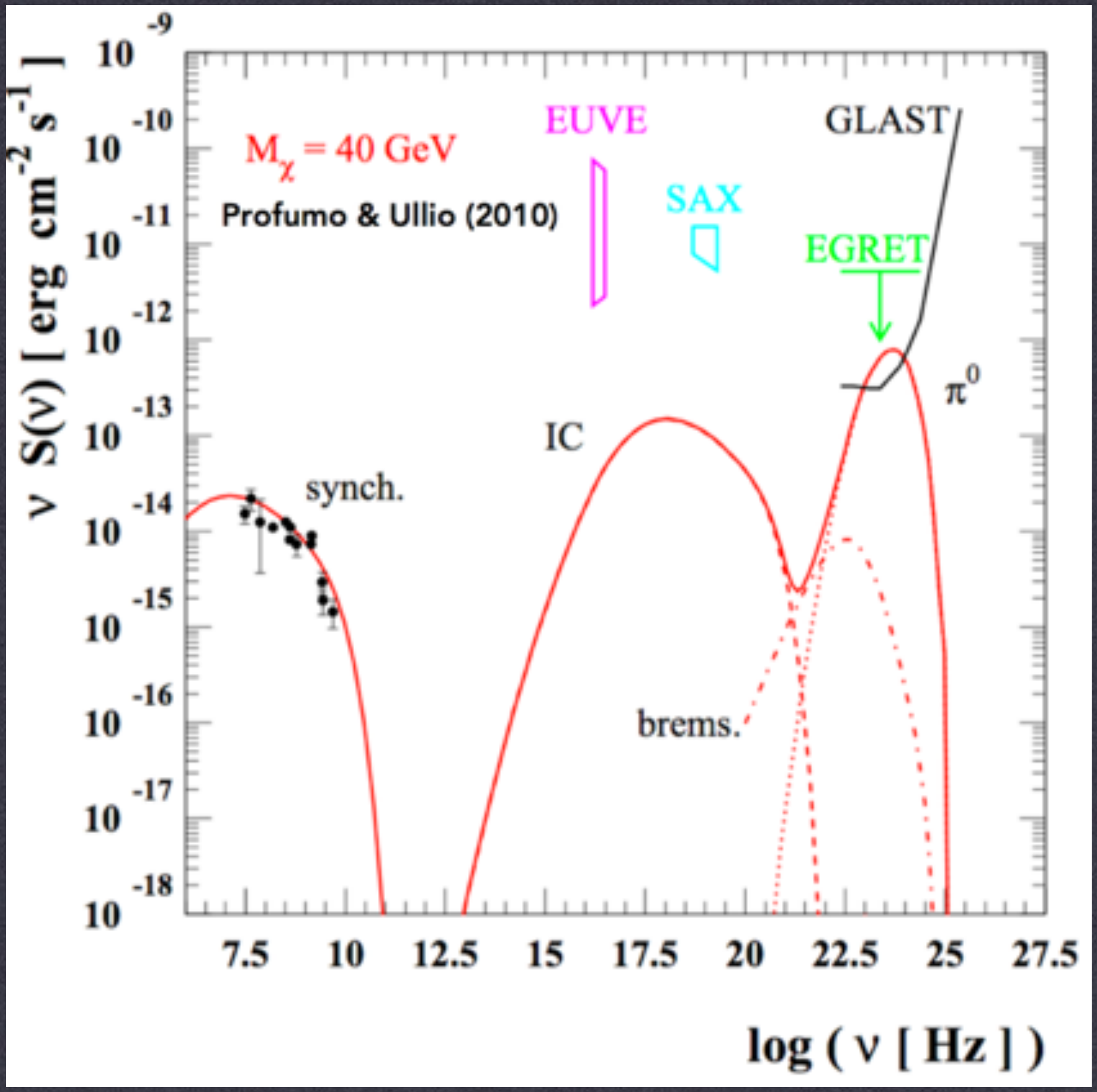
Instrumental Response

EXPECTED DARK MATTER SIGNAL

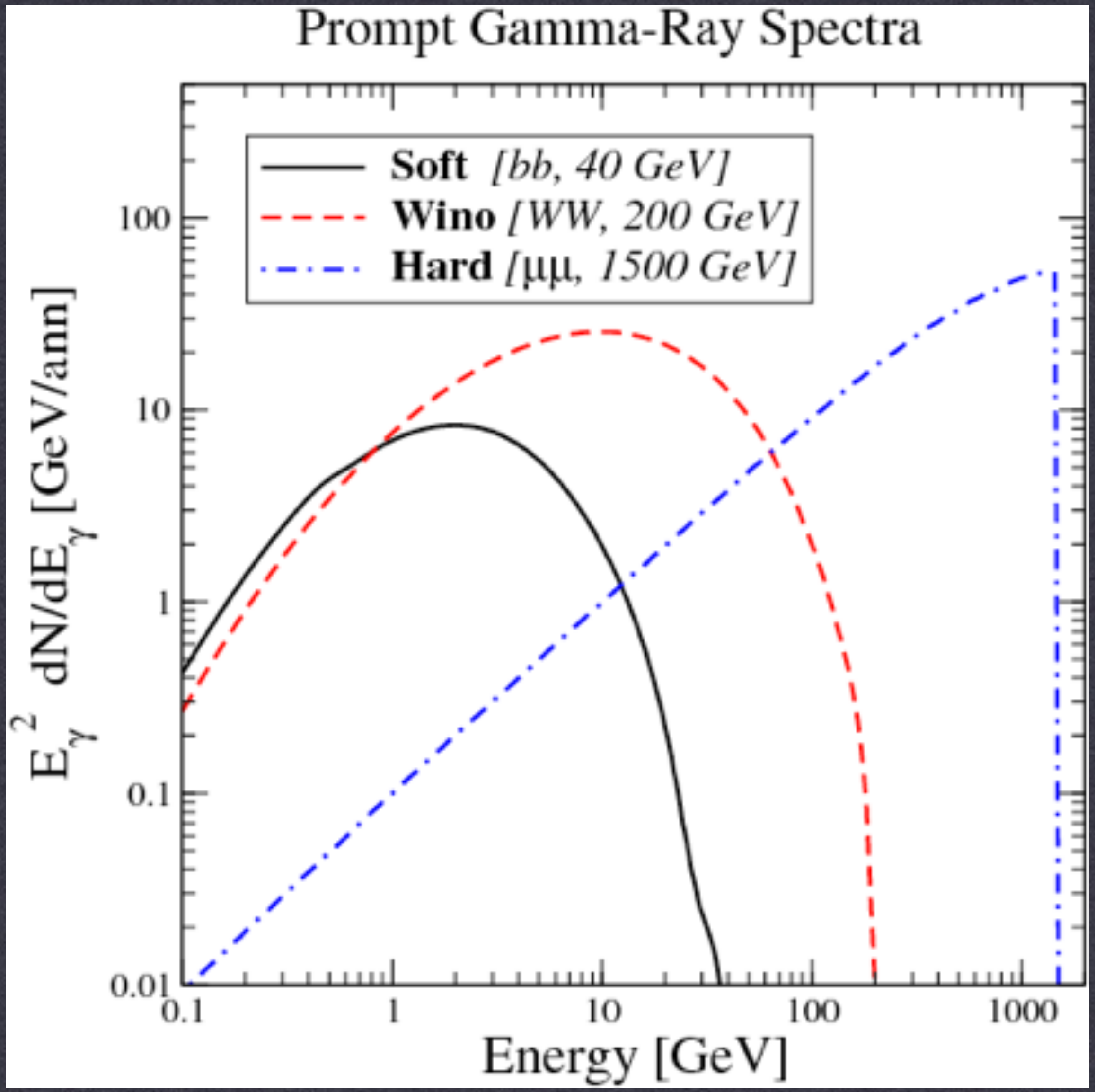
Why Do We Search in Gamma-Rays?

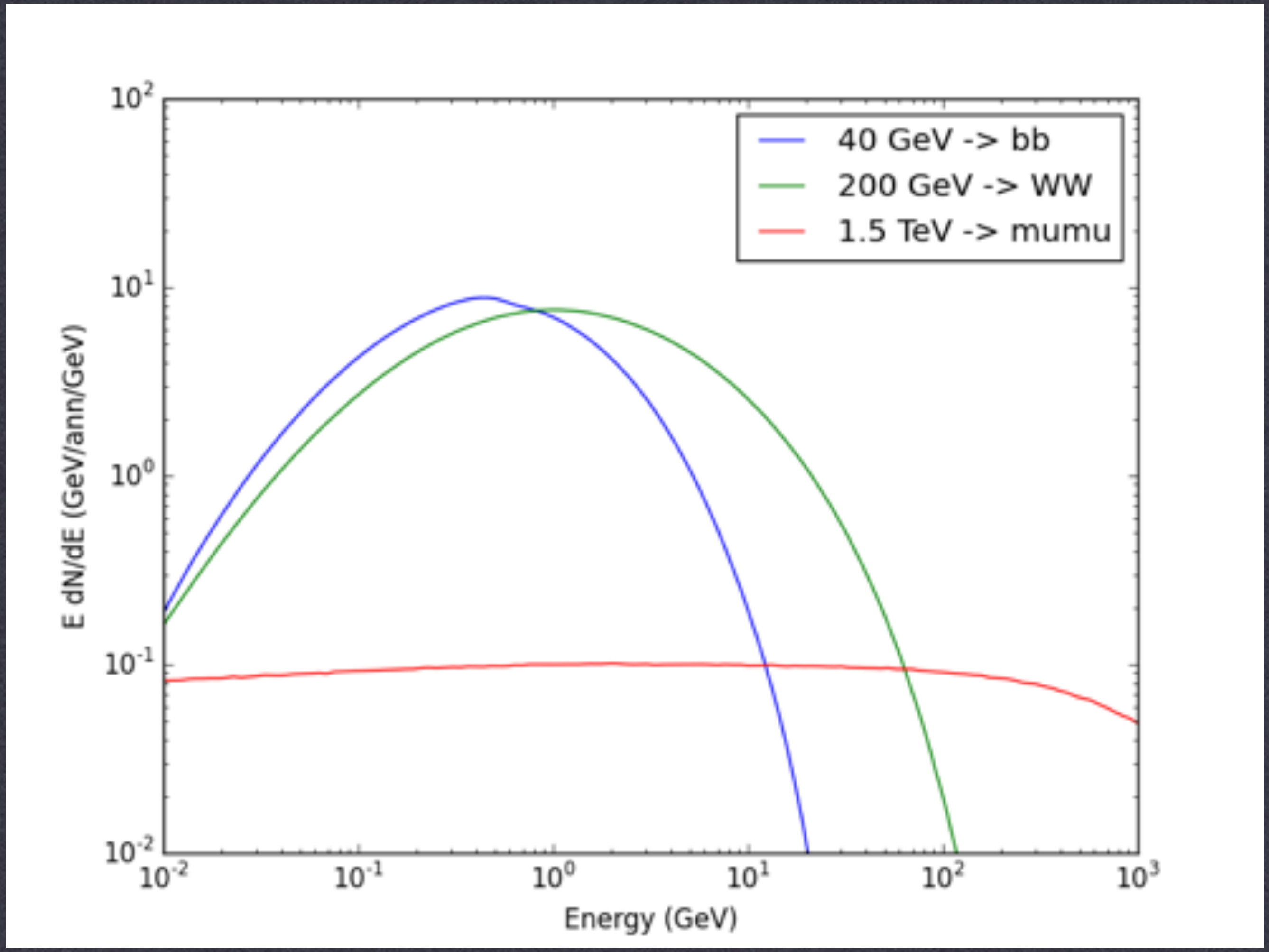
WIMP miracle motivates 100 GeV scale dark matter particles





EXPECTED DARK MATTER SIGNAL





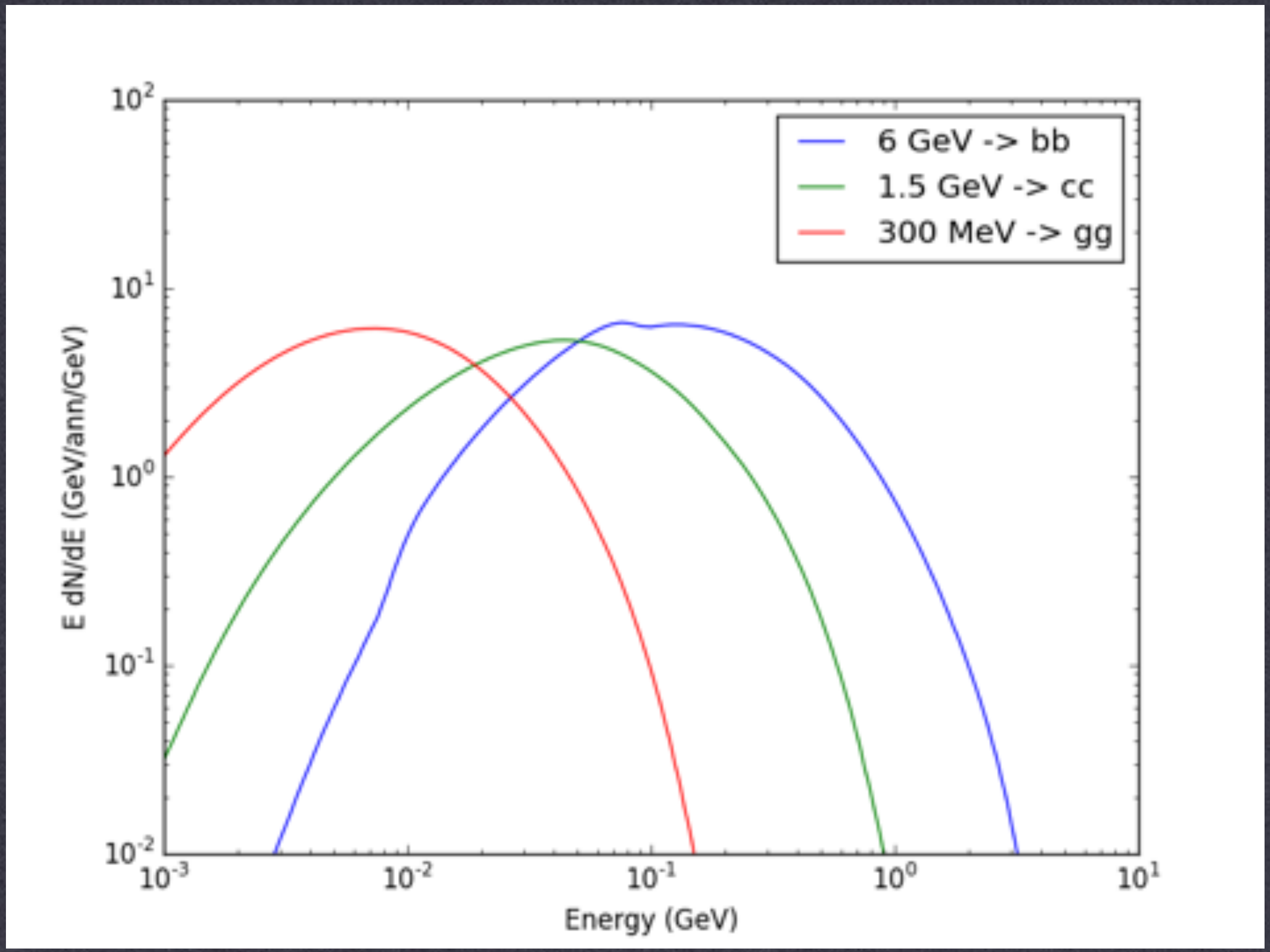
Motivates searches in the 0.1 - 1 GeV range!

CAVEATS

Annihilation of ~MeV scale dark matter produces either neutrinos, or electrons

MeV scale electrons produce gamma rays primarily through bremsstrahlung radiation, which is hard to detect

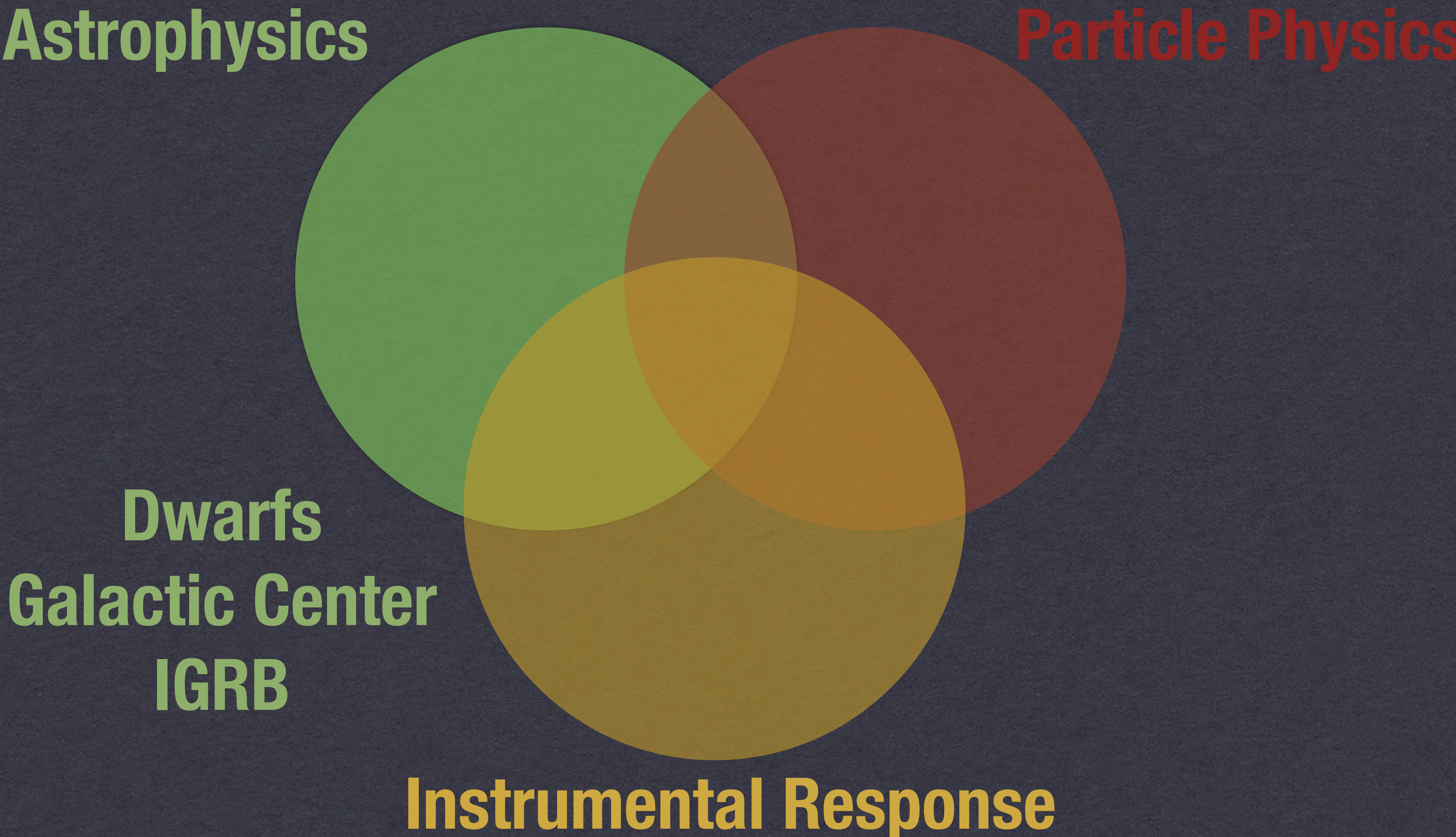
* Diffusion important
* Traces gas density



Could theoretically detect the FSR line off of an electron final state.

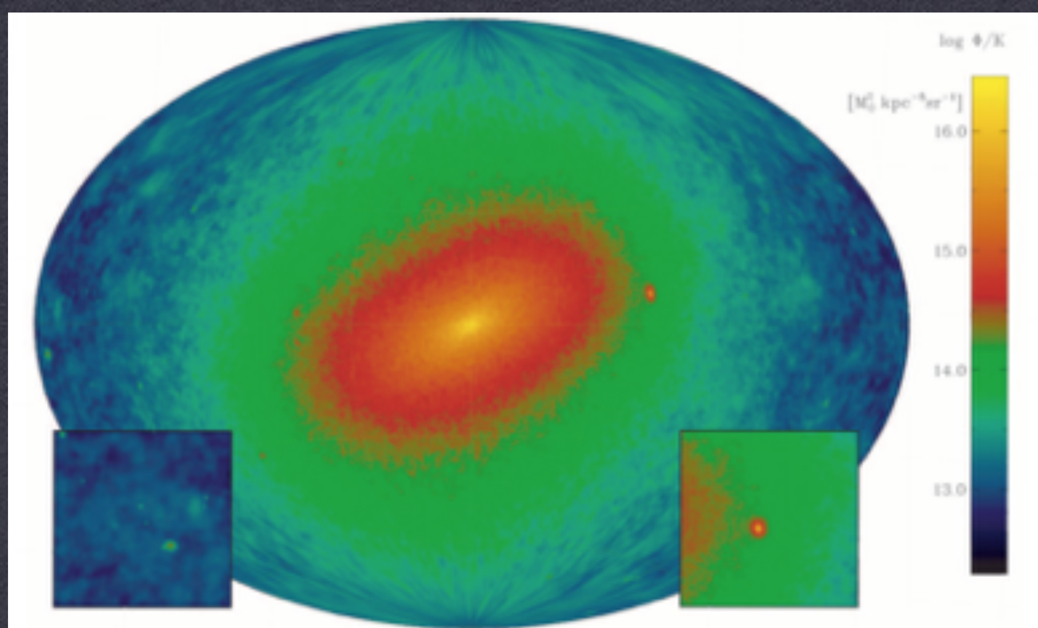
<u>These models are not particularly well motivated.</u>

INDIRECT DETECTION OF WIMPS



DIFFERENT TACTICS FOR DIFFERENT ENVIRONMENTS

GALACTIC CENTER



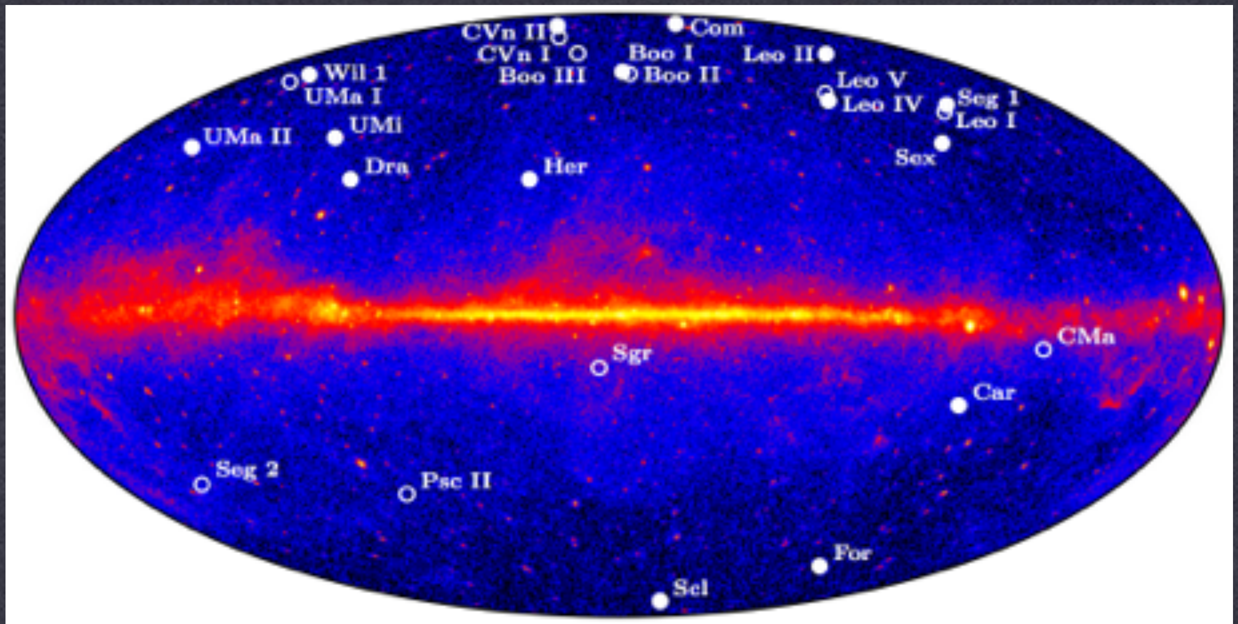
For typical parameters from an NFW profile:

$J \sim 10^{21}$ GeV^2 cm^{-5}

DWARFS

Name	GLON (deg)	GLAT (deg)	Distance (kpc)	$\log_{10}(J^{NFW})^a$ ($\log_{10}$[GeV^2 cm^{-5} sr])
Bootes I	358.1	69.6	66	18.8 ± 0.22
Bootes II	353.7	68.9	42	–
Bootes III	35.4	75.4	47	–
Canes Venatici I	74.3	79.8	218	17.7 ± 0.26
Canes Venatici II	113.6	82.7	160	17.9 ± 0.25
Canis Major	240.0	-8.0	7	–
Carina	260.1	-22.2	105	18.1 ± 0.23
Coma Berenices	241.9	83.6	44	19.0 ± 0.25
Draco	86.4	34.7	76	18.8 ± 0.16
Fornax	237.1	-65.7	147	18.2 ± 0.21
Hercules	28.7	36.9	132	18.1 ± 0.25
Leo I	226.0	49.1	254	17.7 ± 0.18
Leo II	220.2	67.2	233	17.6 ± 0.18
Leo IV	265.4	56.5	154	17.9 ± 0.28
Leo V	261.9	58.5	178	–
Pisces II	79.2	-47.1	182	–
Sagittarius	5.6	-14.2	26	–
Sculptor	287.5	-83.2	86	18.6 ± 0.18
Segue 1	220.5	50.4	23	19.5 ± 0.29
Segue 2	149.4	-38.1	35	–
Sextans	243.5	42.3	86	18.4 ± 0.27
Ursa Major I	159.4	54.4	97	18.3 ± 0.24
Ursa Major II	152.5	37.4	32	19.3 ± 0.28
Ursa Minor	105.0	44.8	76	18.8 ± 0.19
Willman 1	158.6	56.8	38	19.1 ± 0.31

DWARFS: EFFECTIVE AREA IS KEY



Backgrounds in dwarf galaxies are minimal.

Furthermore, the Fermi-LAT angular resolution places us in a convenient regime where the uncertainties from the J-factor of various dwarfs is minimized.

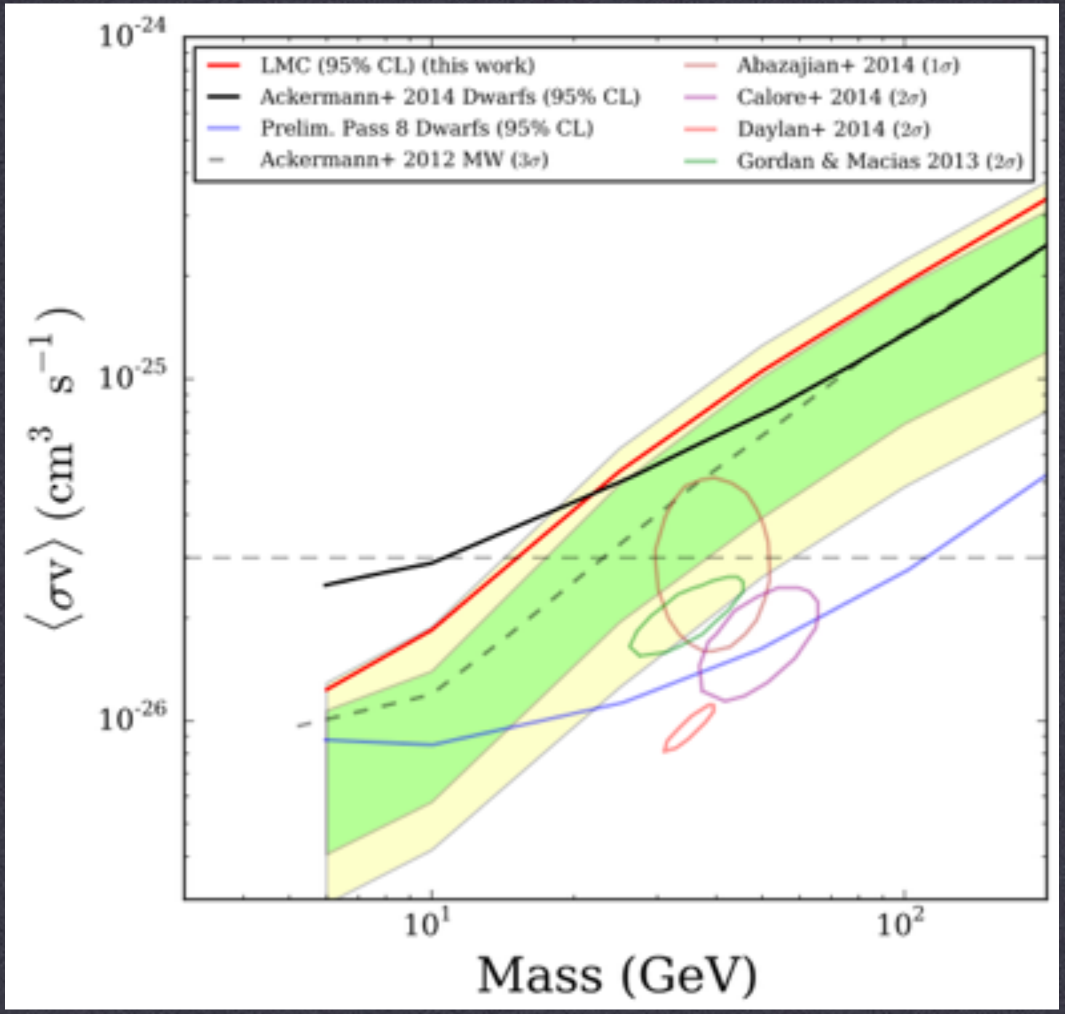
Thus, the key issue is the total exposure of dwarf spheroidal objects. Effects from angular and energy resolution are secondary.

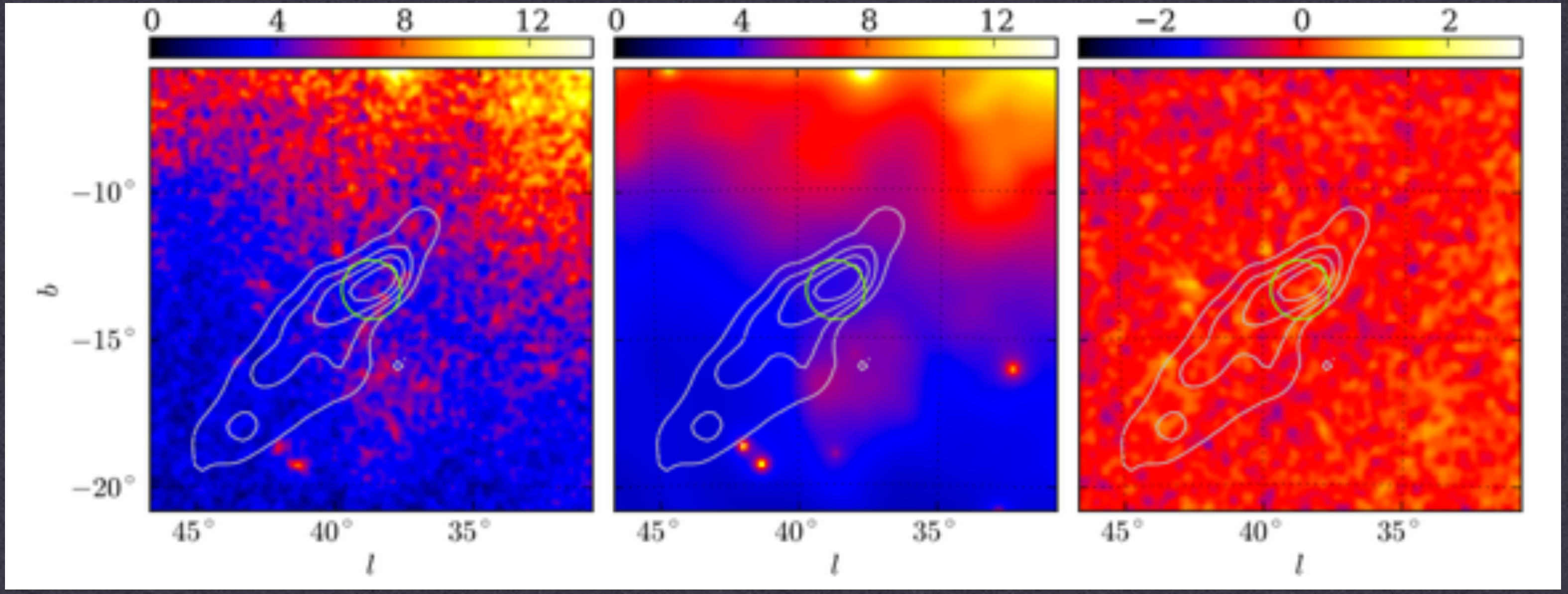
DWARFS: EFFECTIVE AREA IS KEY

This gives great future discovery potential - we are still in a linear regime for data gathering, and limits are improving quickly with time.

Can look for new targets:

* New dwarfs
* LMC/SMC
* High Velocity Clouds



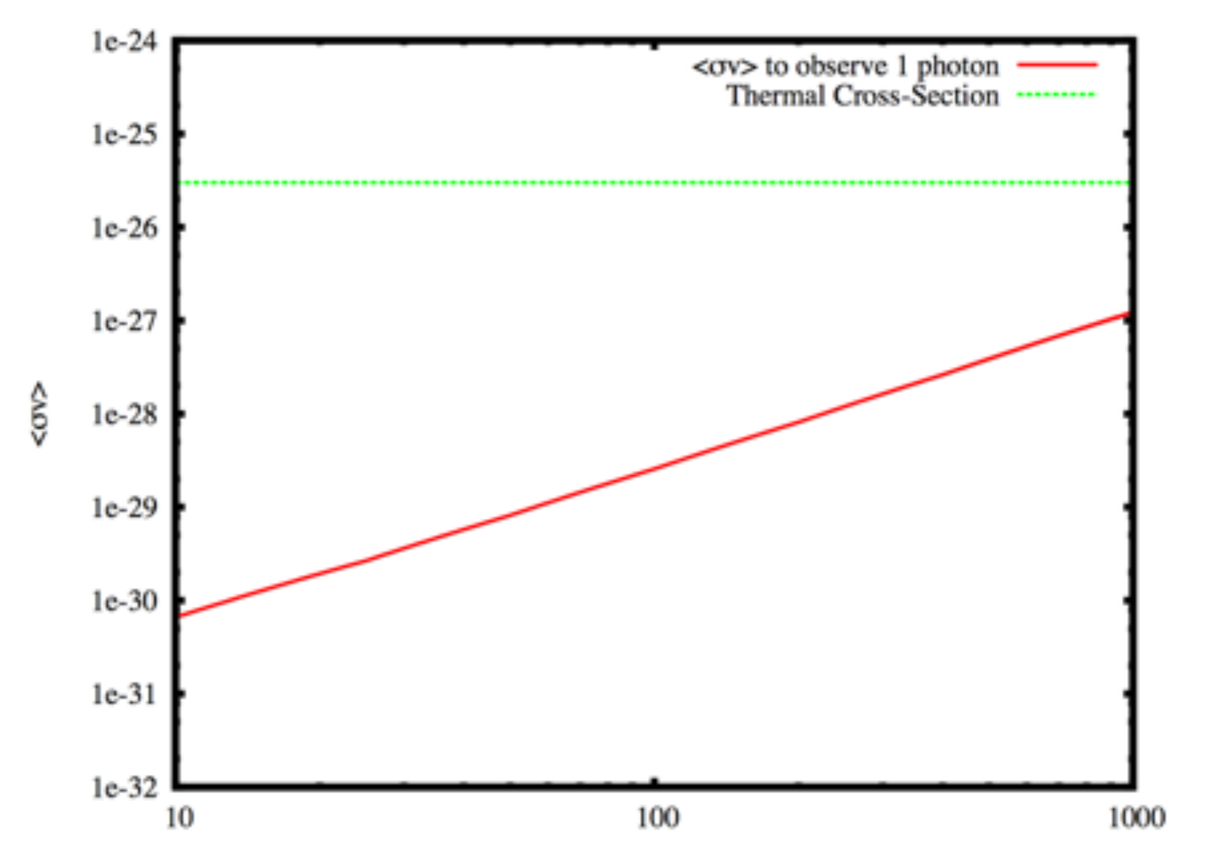


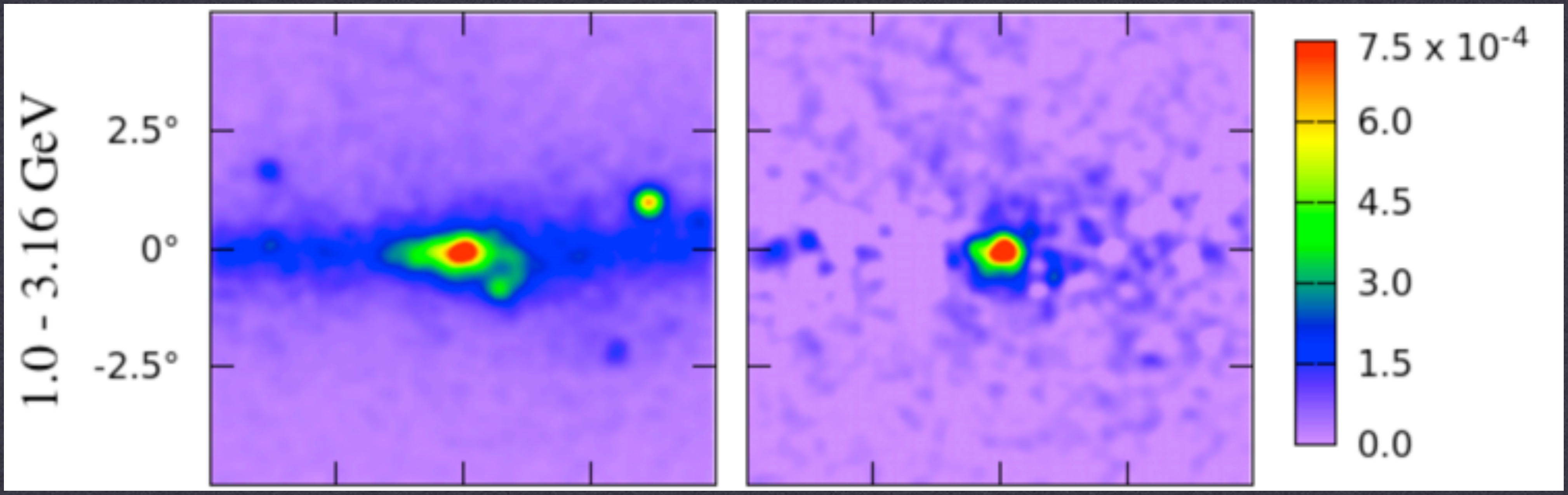
GC: ANGULAR AND ENERGY RESOLUTION IS KEY

Unlike dwarf spheroidal galaxies, the GC provides plenty of photons.

The gamma-ray signal from the galactic center currently provides ~10^4 photons with a typical energy of 1 GeV

The difficulty is to determine the source of these events. This requires enhanced angular resolution.





GALACTIC CENTER

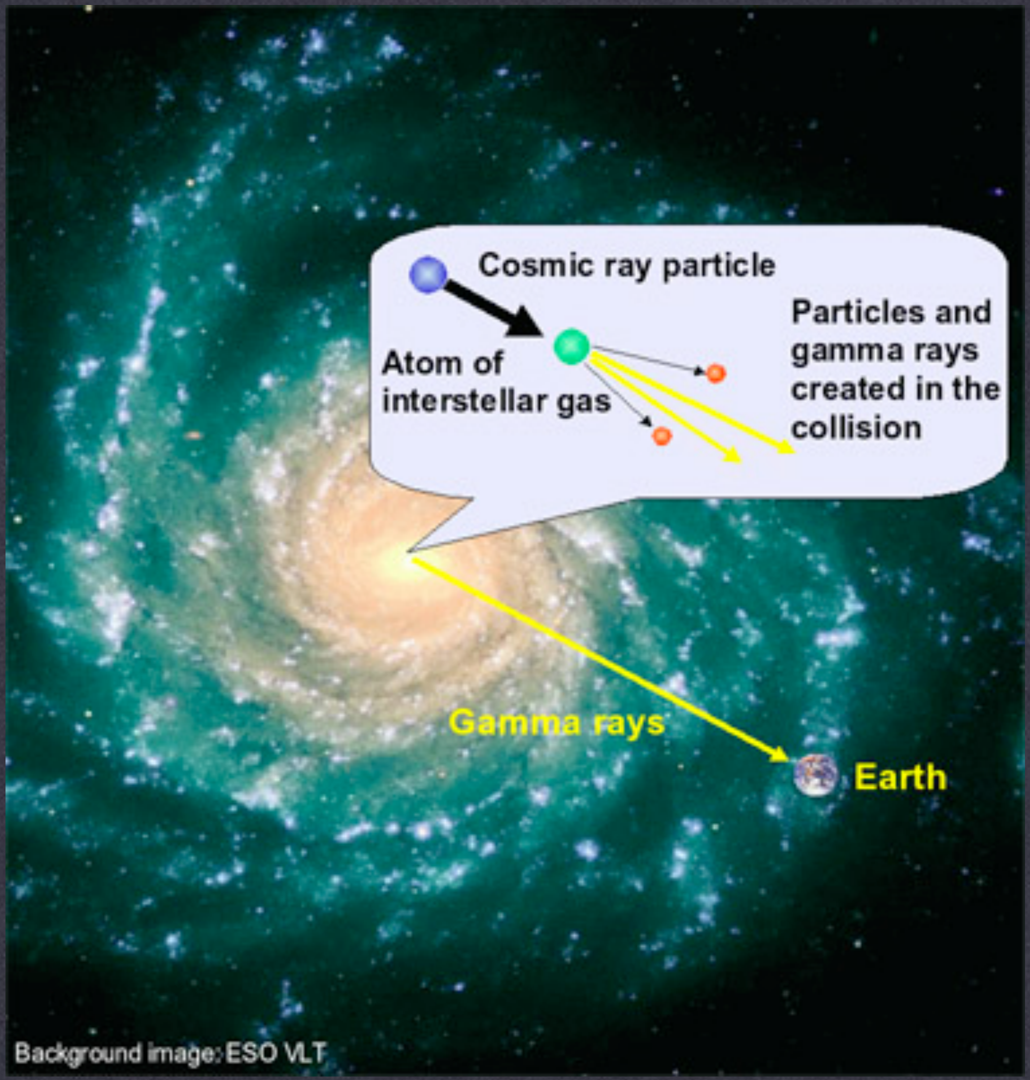
Galactic Center Backgrounds:

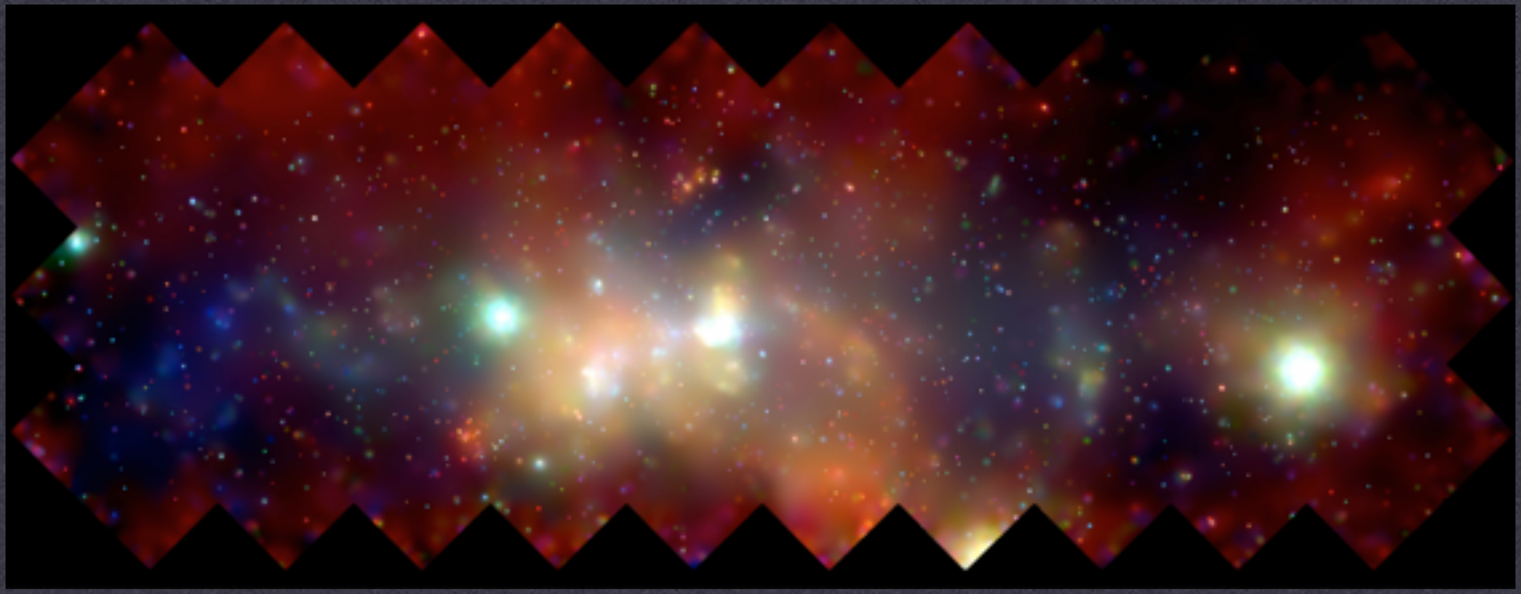
* Point Sources (SNR, pulsars, etc.)

* Hadronic Interactions (pp -> π^0 -> $\gamma\gamma$)

* Bremsstrahlung

* Inverse Compton Scattering

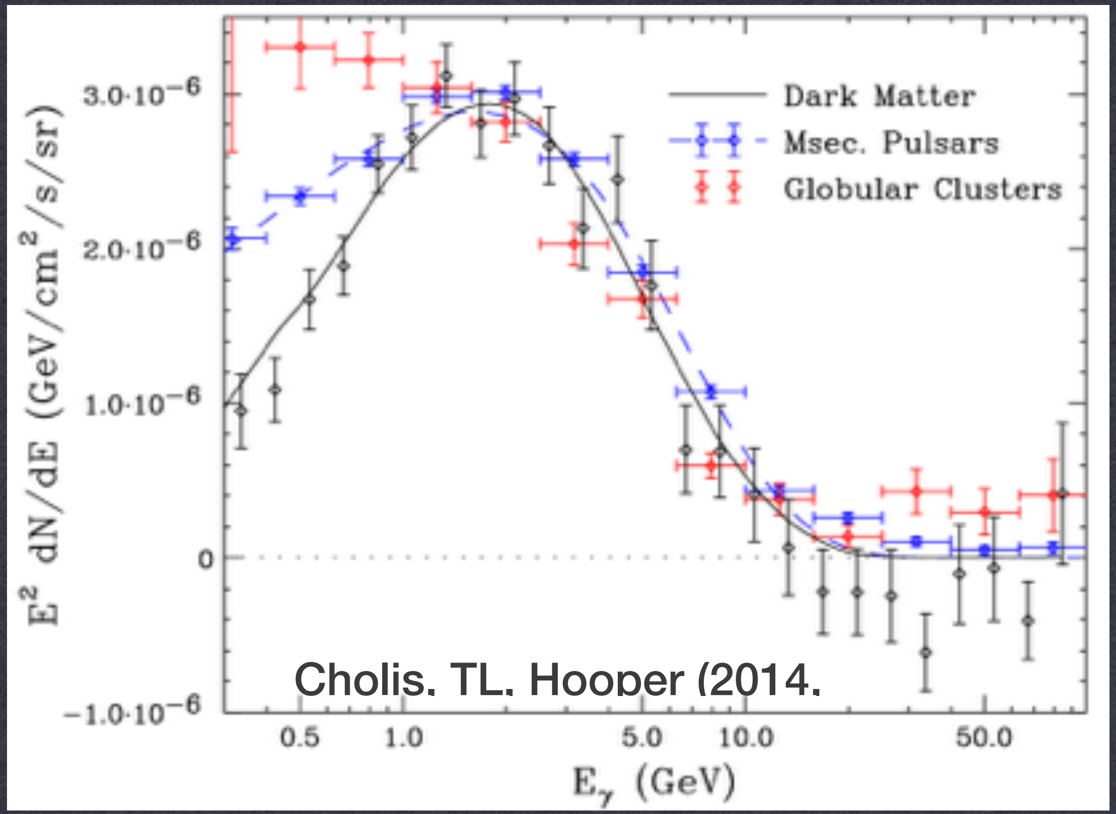


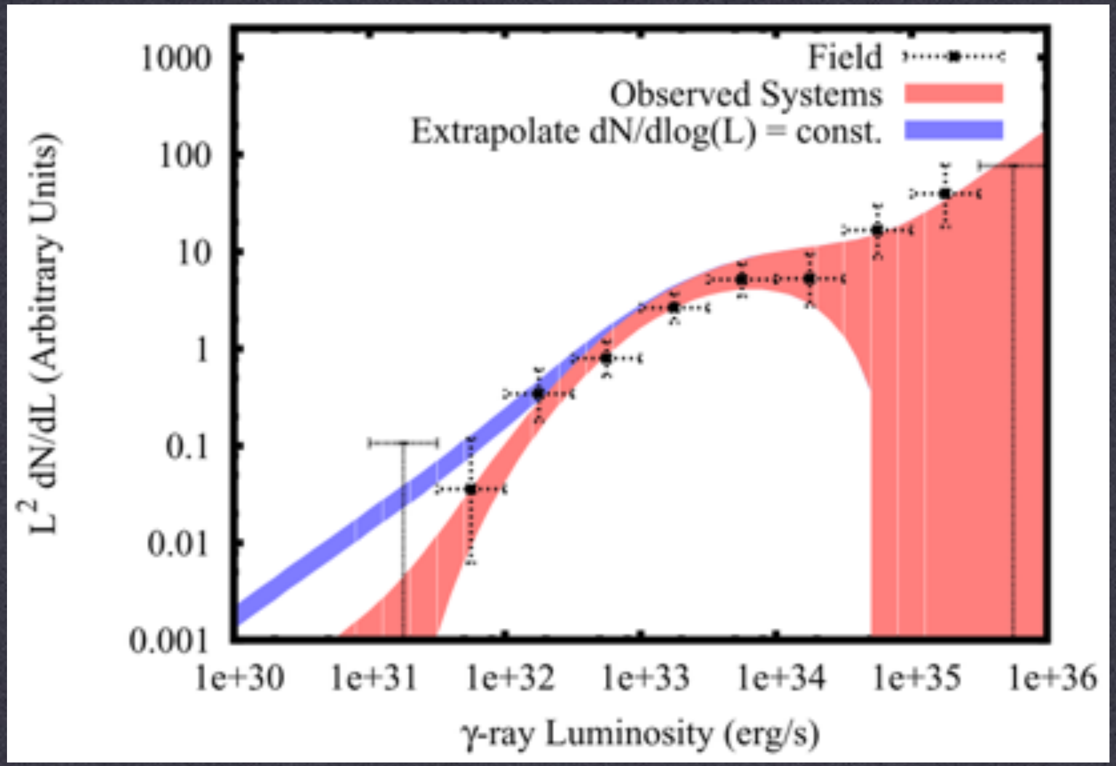


EXAMPLE: MSPS

- To first order, the peak of the MSP energy spectrum matches the peak of the observed excess
- MSPs are thought to be overabundant in dense star-forming regions (like globular clusters, and potentially the galactic center)

- Much larger than Fermi energy resolution!





TS VALUES AS A FUNCTION OF ENERGY

- 3FGL Sources with Power Law Spectral Index between 2.0 - 2.1

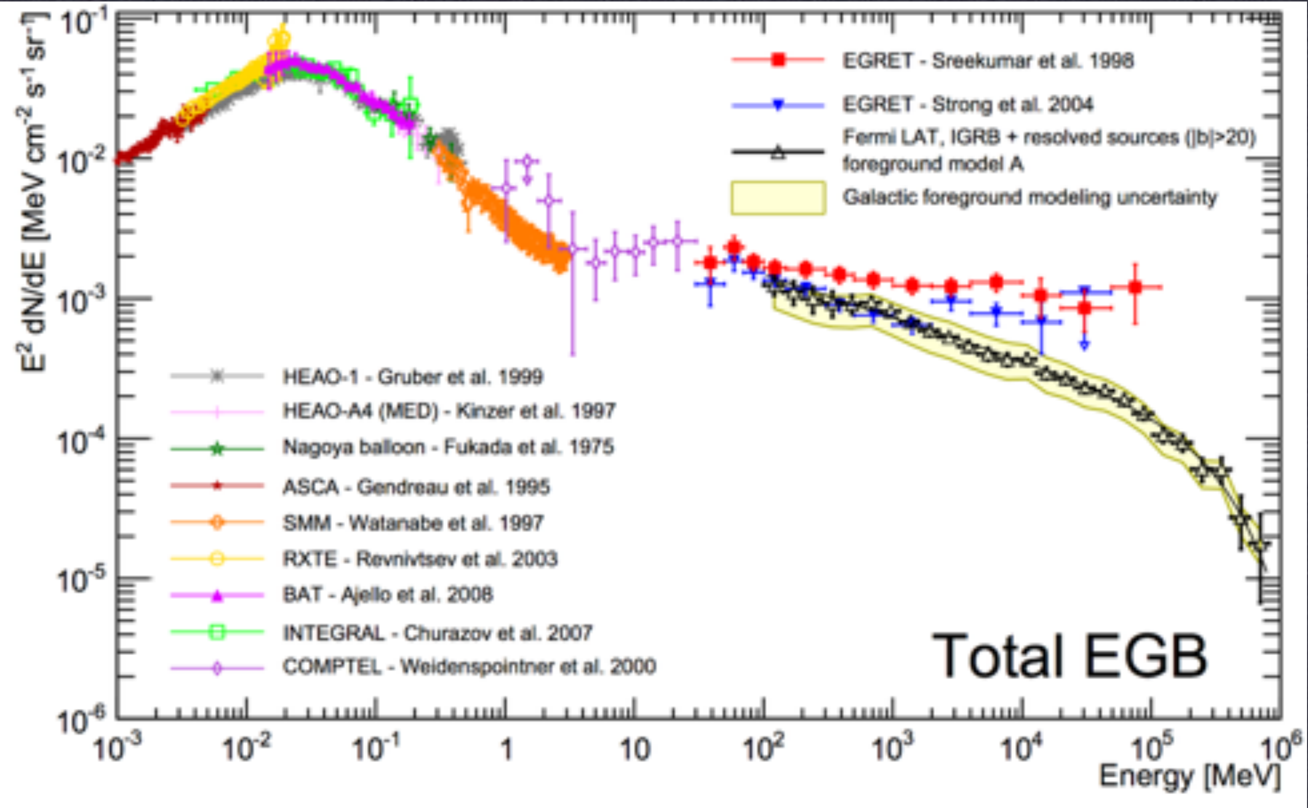
  - TS (0.1 - 0.3 GeV) = 6.37
  - TS (0.3 - 1.0 GeV) = 34.45
  - TS (1 - 3 GeV) = 65.82
  - TS (3-10 GeV) = 68.16
  - TS (10 - 100 GeV) = 38.06

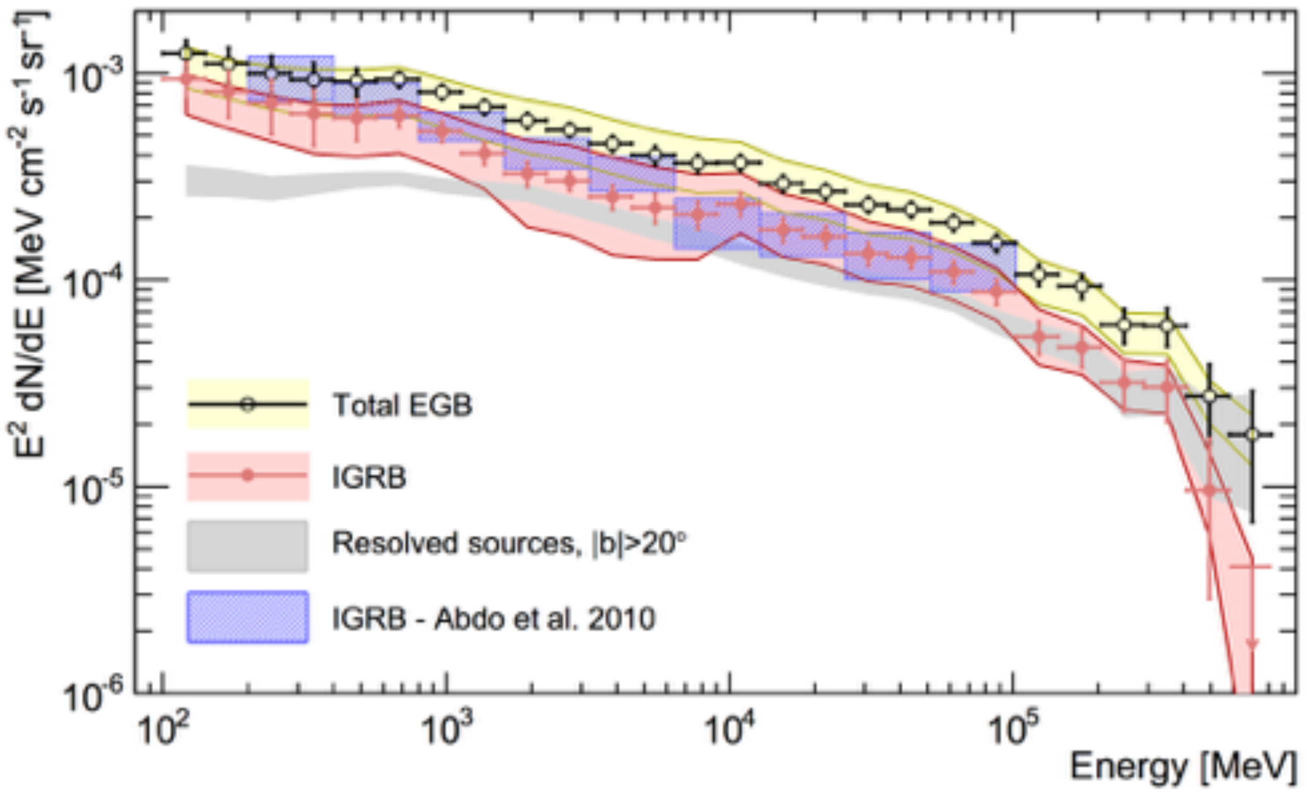
- Rough Indication that PSF is critical for point source observation and analysis. Small Instruments operating at low energies are highly powerful for point source extraction.

EXTRAGALACTIC BACKGROUND

- The intensity of the IGRB continues to decrease, as more sources are discovered and removed from the IGRB intensity.

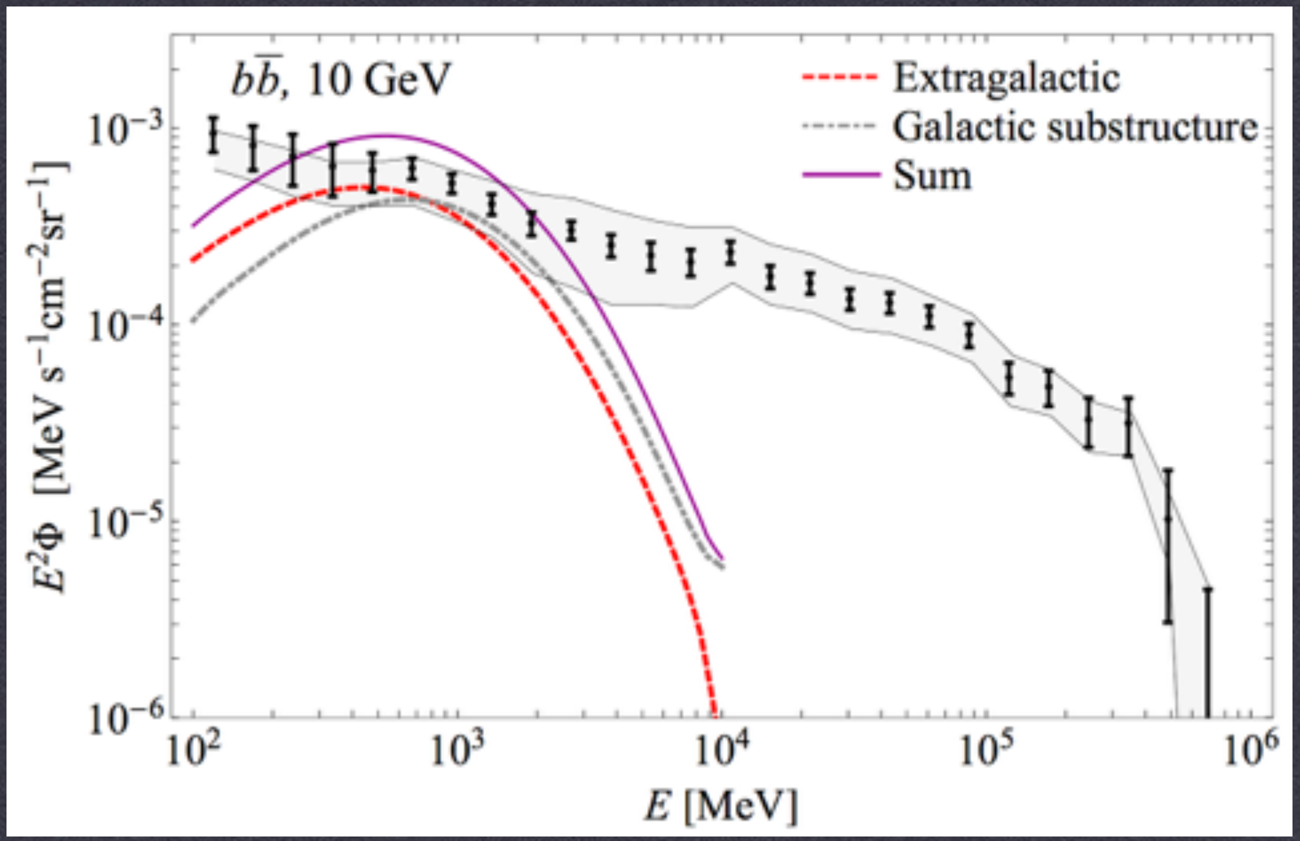
- Additionally, subtraction of the CR background is a major uncertainty, an instrument capable of effectively removing proton backgrounds is highly beneficial for this measurement.

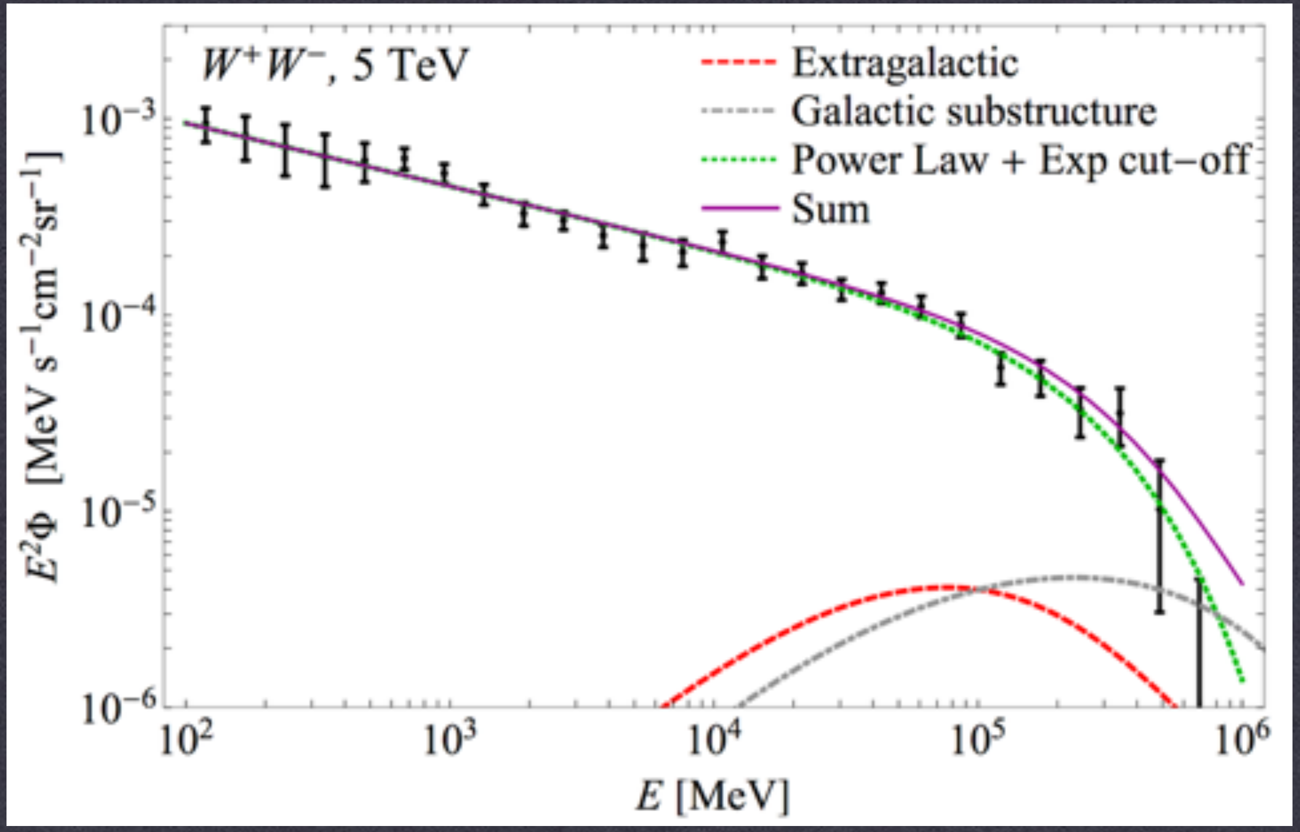




EXTRAGALACTIC BACKGROUND

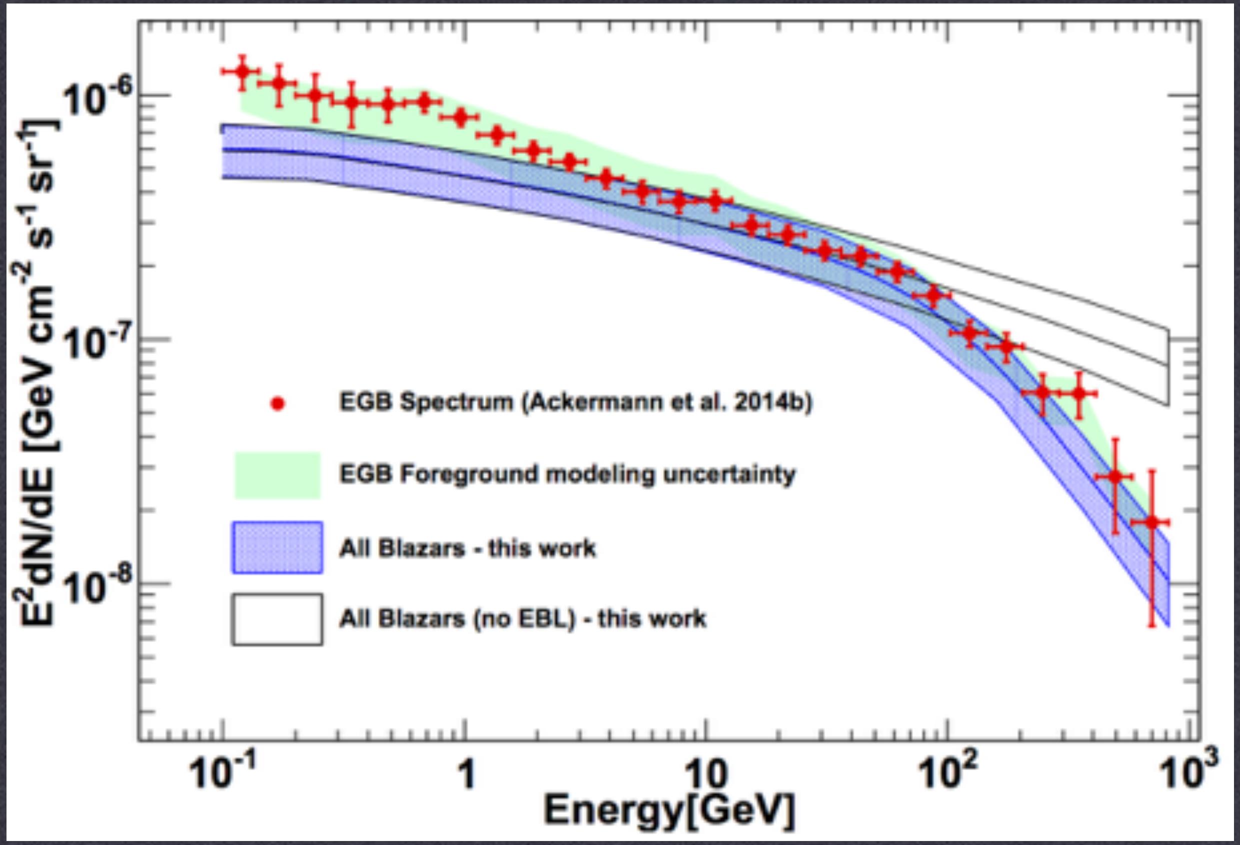
- This implies that dark matter annihilation limits from the extragalactic background can increase more quickly than sqrt(t), even though we are not in a statistically limited regime.

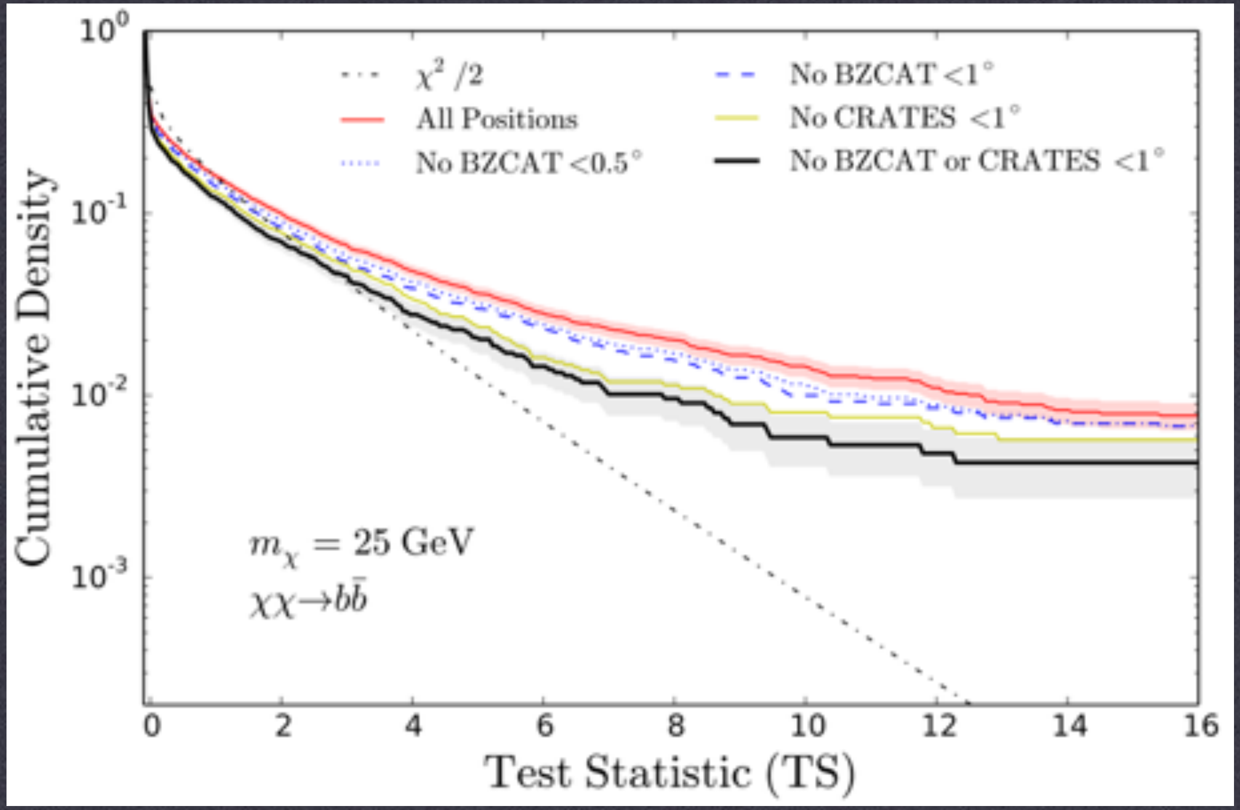




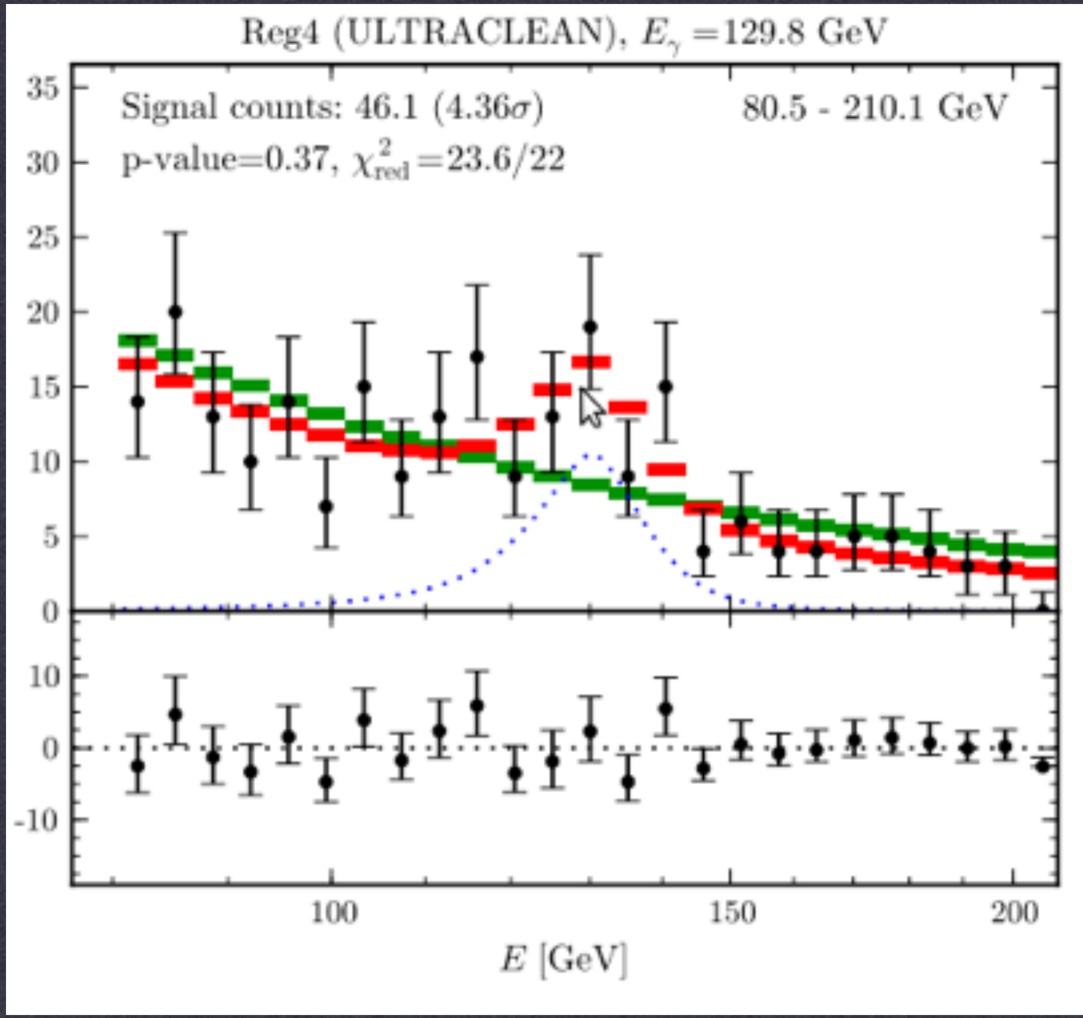
BACKGROUND BLAZARS

- Statistically, we know that much of this background is due to blazars
- In fact nearly 50% of the sources with TS ~ 10 — 25 are consistent with the position of known radio blazars
- More discoveries await, and this limit will continue to improve

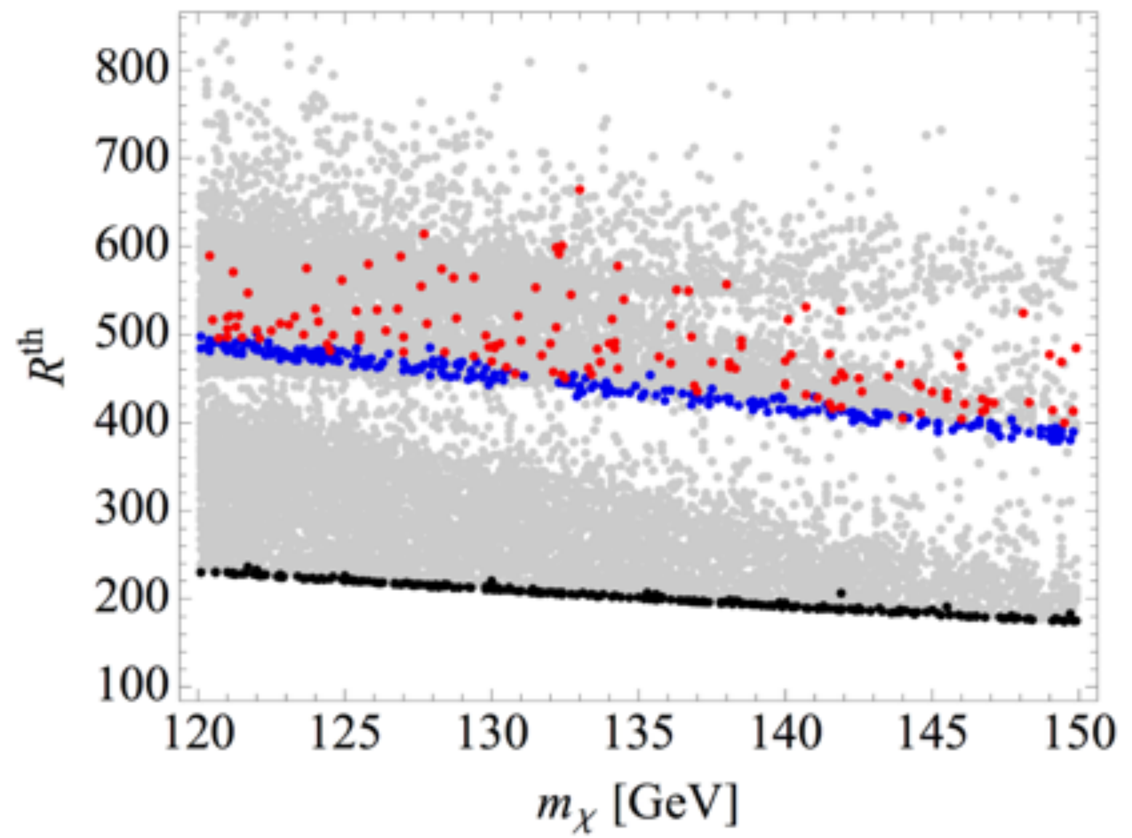




GAMMA-RAY LINES



- Gamma-Ray Lines may always pop up!
- Would be a strong smoking-gun signal for dark matter annihilation
- Can be difficult to predict, many MSSM models would provide lines that are very difficult to detect
- Lines at low energies stem from low mass dark matter, less motivated.



MULTIWAVELENGTH COMPLEMENTARITY

- **Upcoming Experiments Will Improve our Sensitivity in all Targets!**

  - **Dwarfs**
    - **DES**

  - **Galactic Center**
    - **Gaia**
    - **Pan-Starrs**
    - **Missing Pulsar Problem / Radio Pulsars**

  - **Extragalactic Background**
    - **Multiwavelength detection of Extragalactic Sources**

CONCLUSIONS (1/2)

- **<u>What Instrument Would I Build for Indirect Detection:</u>**
  - Energy Range (0.1 GeV - 10 GeV)
  - Large Field of View (key for dwarf studies)
  - High angular resolution throughout the energy range
    - Note, could sacrifice angular resolution in some sky regions (e.g. dwarfs, but keep angular resolution along the plane)
  - Energy Resolution is helpful, but not critical

CONCLUSIONS (2/2)

- Smoking Gun Signals
  - Gamma-Ray Line
  - Individual Detection in Multiple Dwarfs (J-factor / TS correlation)
  - A consistent detection in multiple sources (dwarfs/GC/IGRB)

- Current observations are just beginning to probe the thermal relic cross-section. Lots of models exist just below the surface.

- Even if dark matter is observed by LHC/Direct Detection, these above observations will be critical for proving that the observed signal is dark matter.