Recent Results on Dark Matter Searches with Fermi

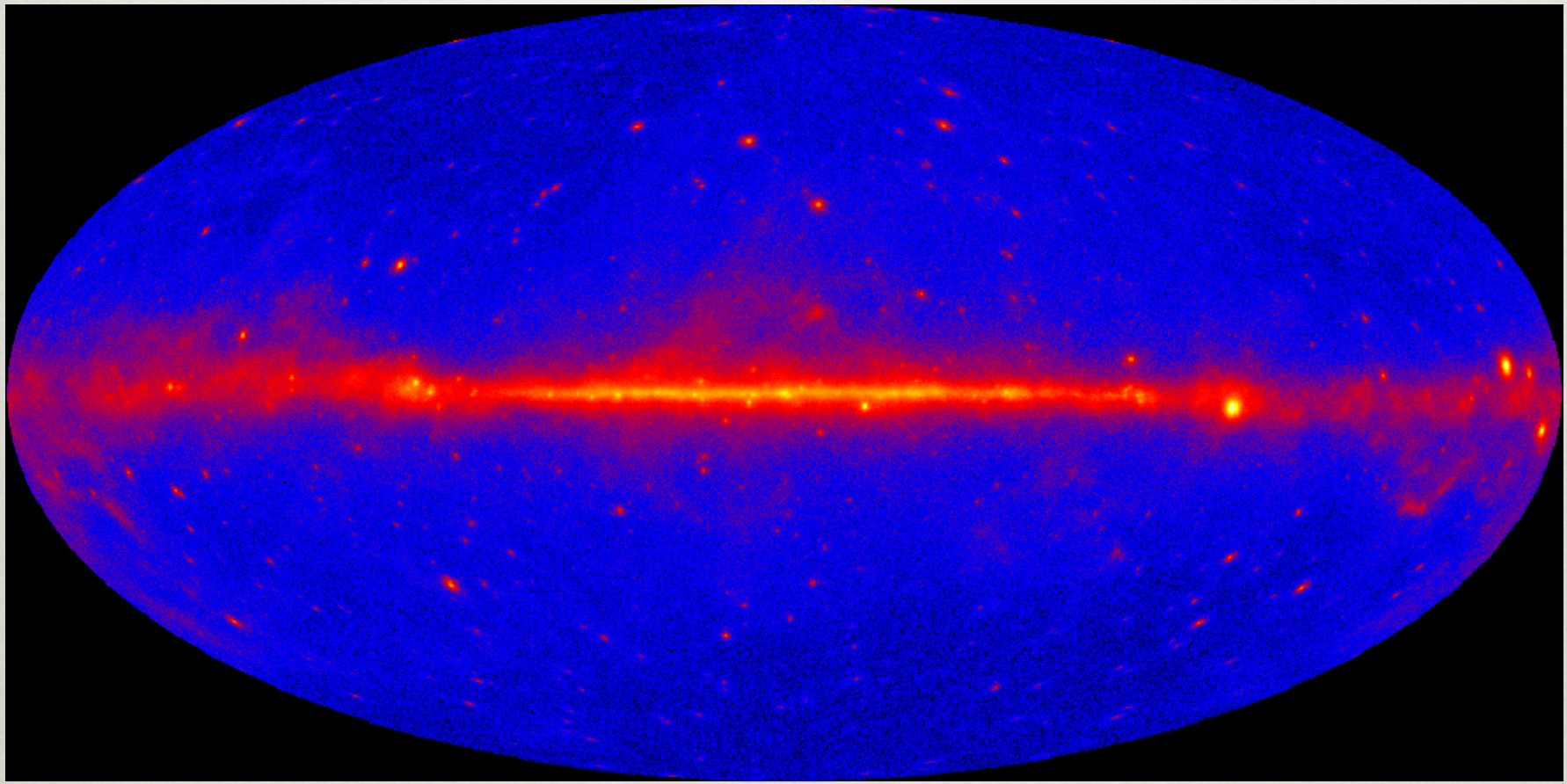
Simona Murgia, SLAC-KIPAC
on behalf of the Fermi-LAT Collaboration

Fermi Gamma-ray Space Telescope

SLAC National Accelerator Laboratory

2009 Fermi Symposium
2-5 November 2009 - Washington DC

Fermi 1 year sky



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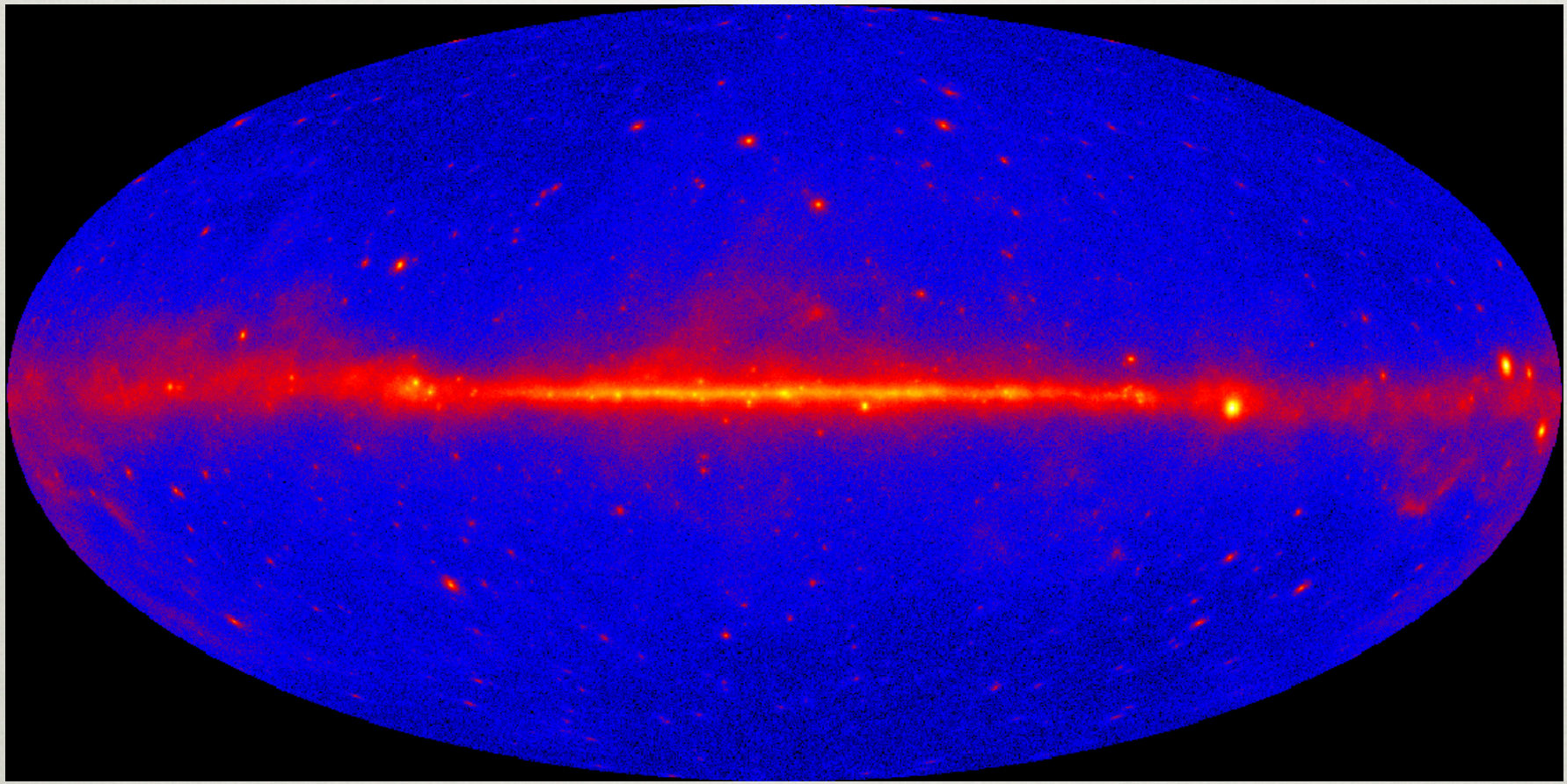
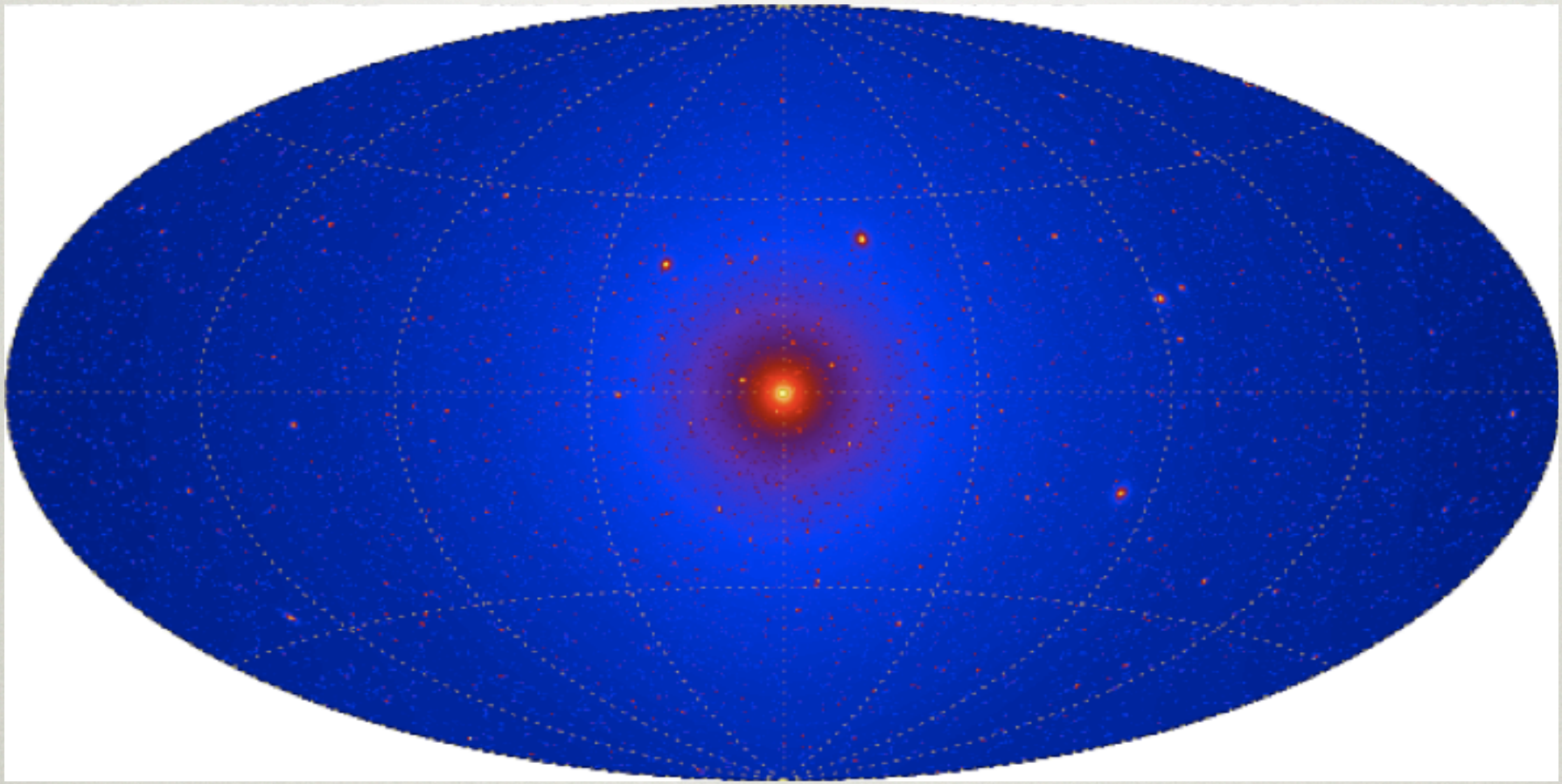


Fermi's great capabilities give us a unique perspective in investigating the existence of dark matter particles indirectly, primarily through their annihilation or decay into photons and into electrons

Simulated sky map of γ-rays from DM annihilation

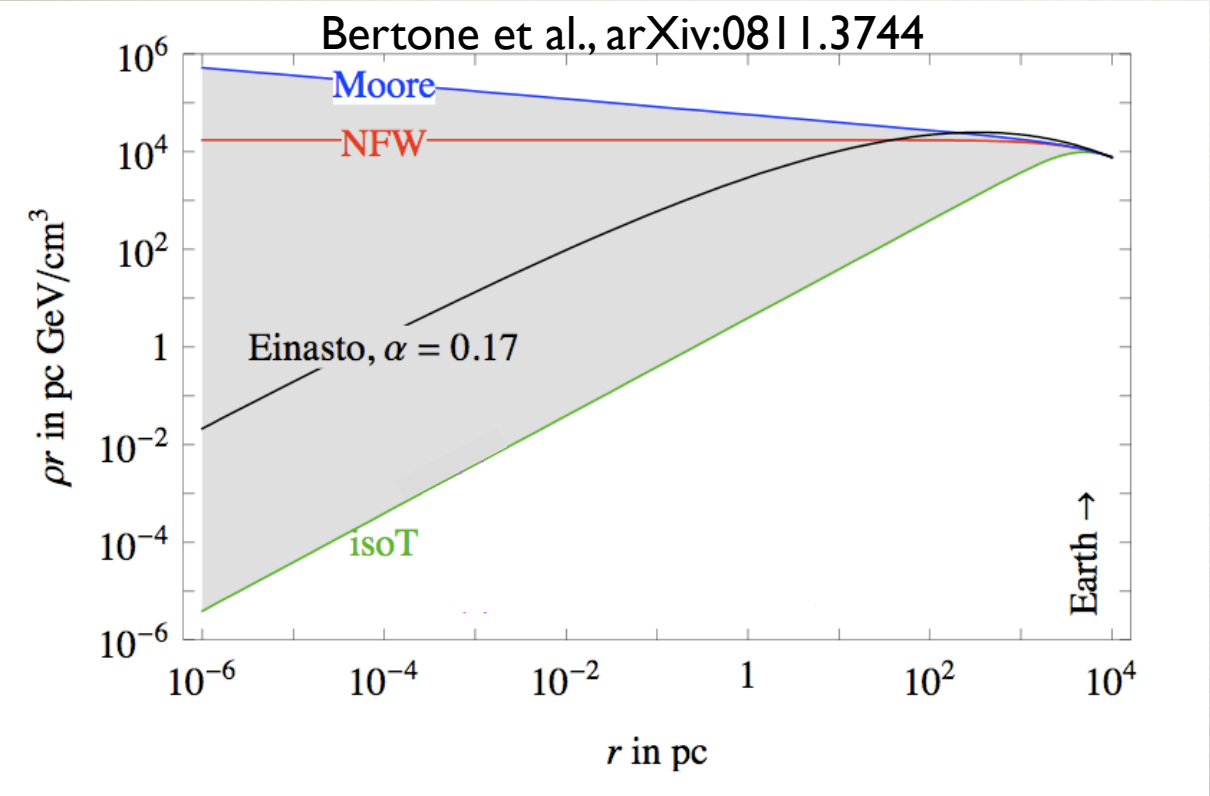


(Pieri et al, arXiv:0908.0195, based on Via Lactea II simulation)

Fermi's great capabilities give us a unique perspective in investigating the existence of dark matter particles indirectly, primarily through their annihilation or decay into photons and into electrons

Dark Matter Distribution

- The dark matter annihilation (or decay) signal strongly depends on the dark matter distribution.
- Cuspier profiles and clumpiness of the dark matter halo can provide large boost factors



NFW profile

$$\rho(r) = \rho_0 \frac{r_0}{r} \frac{1 + (r_0/a_0)^2}{1 + (r/a_0)^2}$$

$$\rho_0 = 0.3 \text{ GeV/cm}^3$$

$$a_0 = 20 \text{ kpc}, \; r_0 = 8.5 \text{ kpc}$$

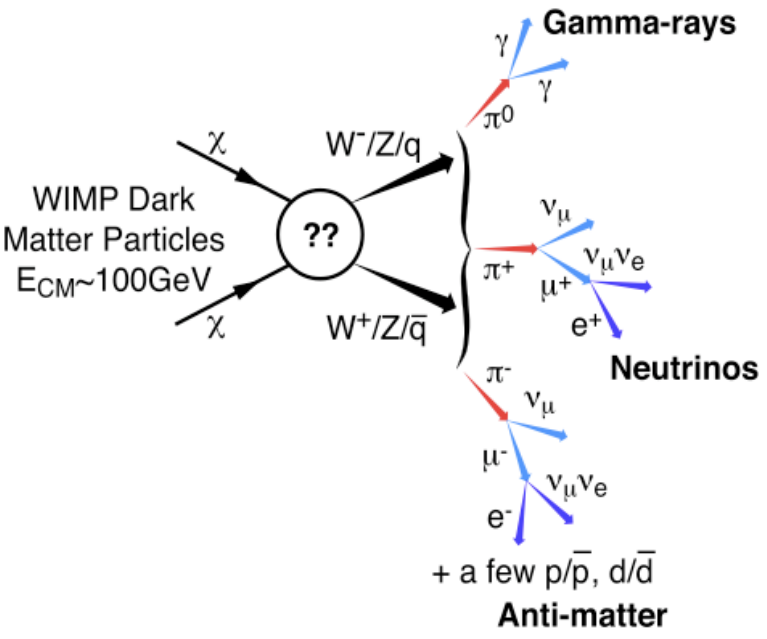
- ✓ Via Lactea II predicts a cuspier profile, $\rho(r) \propto r^{-1.2}$
- ✓ Aquarius predicts a shallower than r^{-1} innermost profile

WIMP Dark Matter Spectrum

- Several theoretical models have been proposed that predict the existence of WIMPs (Weakly Interacting Massive Particle) that are excellent DM candidates
- In addition to photons, with Fermi we can also probe electron+positron final states

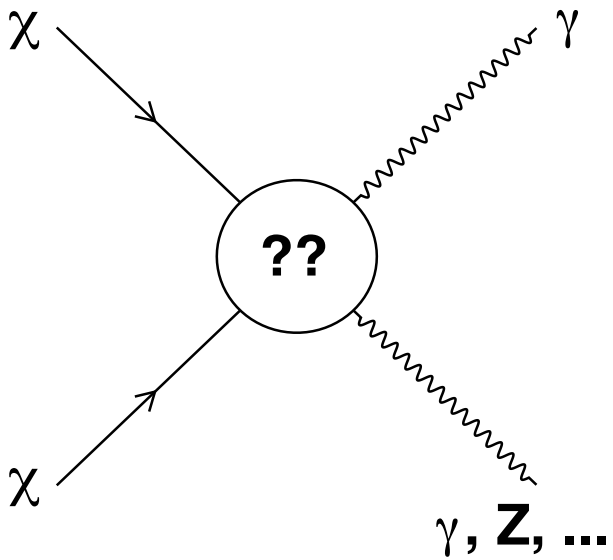
Continuum spectrum with cutoff at M_W

Annihilation (or decay) into γ



Spectral line at M_W

Prompt annihilation into $\gamma\gamma$, γZ, γH^0...
(also prompt decay into photons)



Search Strategies

Galactic center:

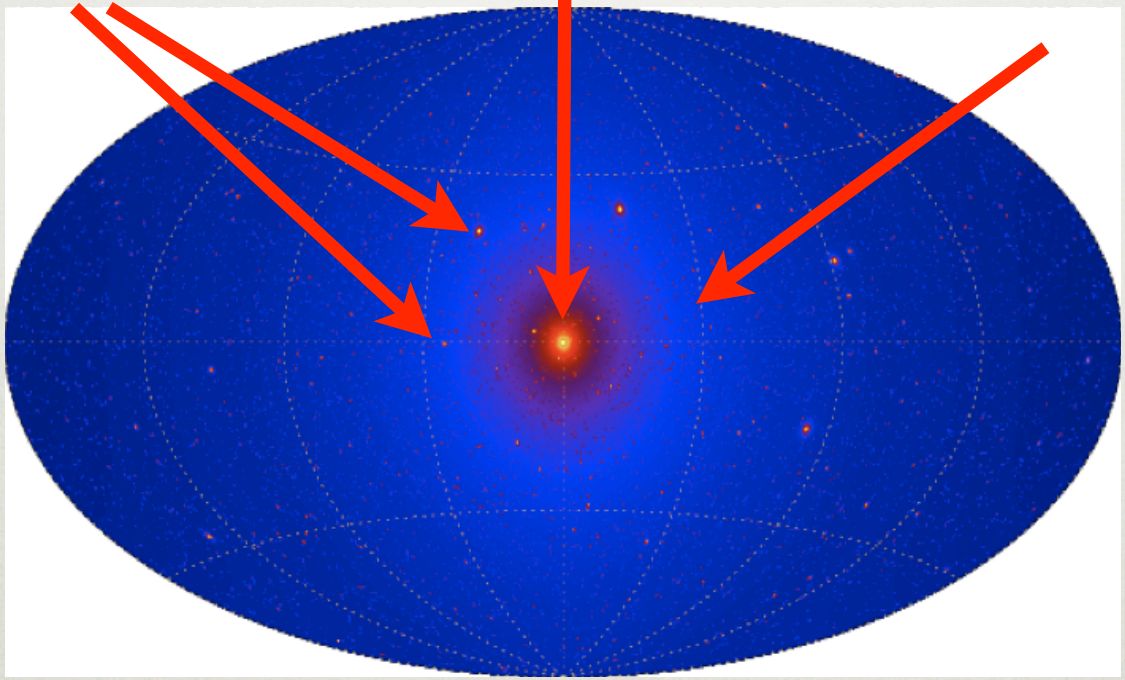
Good statistics but source confusion/diffuse background

Satellites:

Low background and good source id, but low statistics

Milky Way halo:

Large statistics but diffuse background



All-sky map of gamma rays from DM annihilation arXiv:0908.0195 (based on Via Lactea II simulation)

And electrons!
Anisotropies

Spectral lines:

No astrophysical uncertainties, good source id, but low statistics

Galaxy clusters:

Low background but low statistics

Extra-galactic:

Large statistics, but astrophysics, galactic diffuse background

Pre-launch sensitivities published in Baltz et al., 2008, JCAP 0807:013 [astro-ph/0806.2911]

Search Strategies

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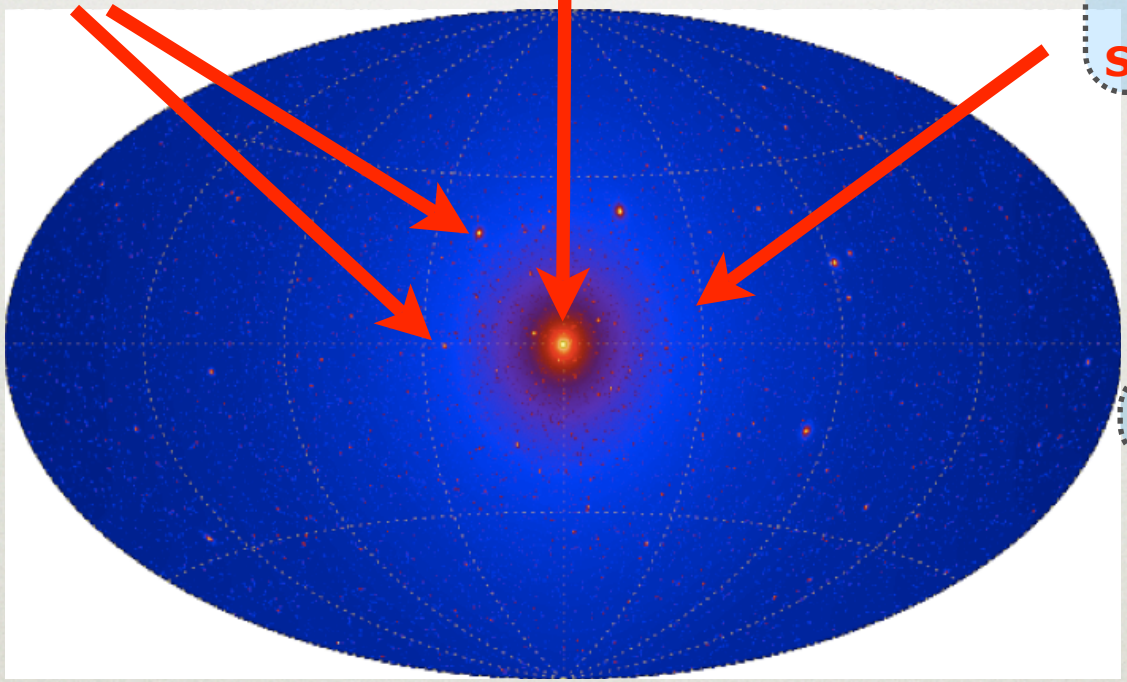
See B. Winer's poster



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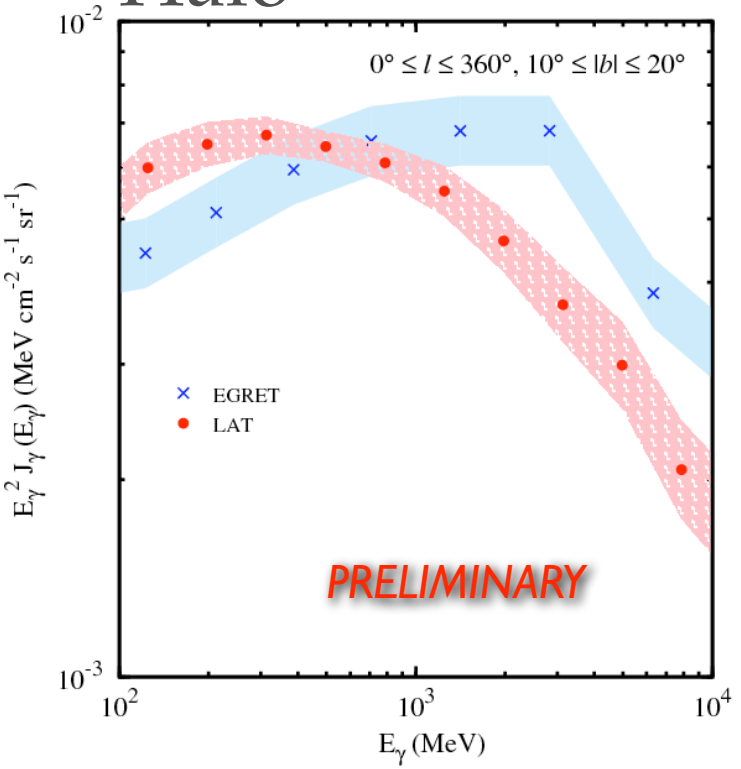
Fermi Early Impact on DM Searches

- With the measurement of the galactic diffuse emission at intermediate latitudes and the CR e^+e^- spectrum, the Fermi-LAT data have made significant impact in the dark matter interpretation of potential signals from other experiments

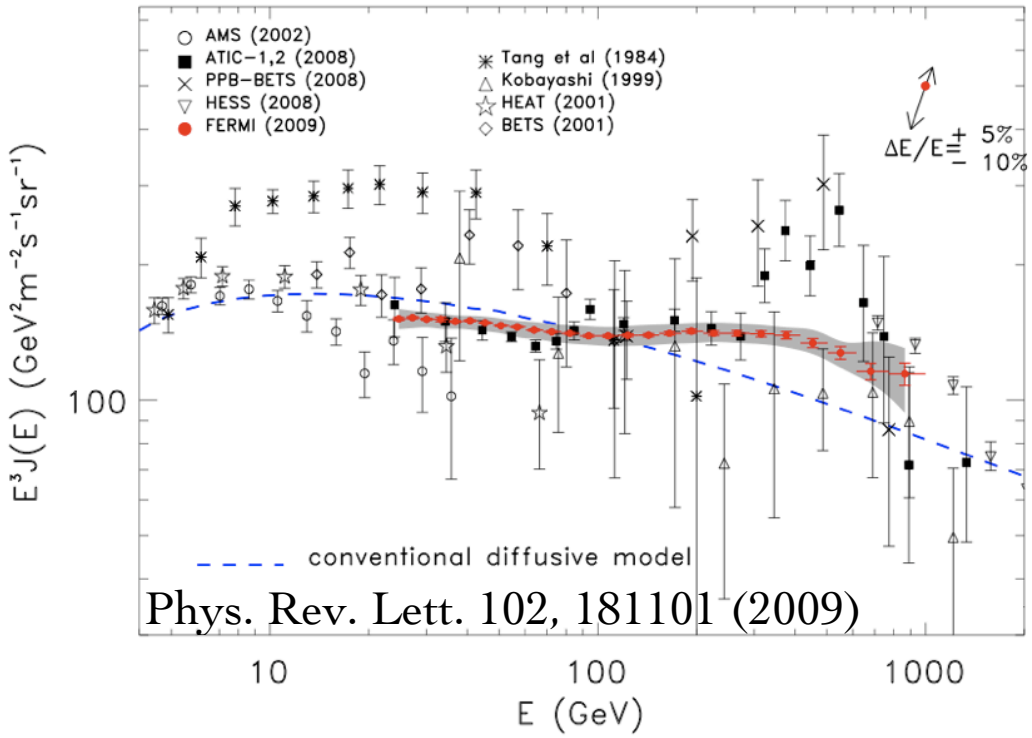
➡ DM contribution is not required, however cannot be ruled out

Halo



Electrons

See L. Latronico's talk



Phys. Rev. Lett. 102, 181101 (2009)

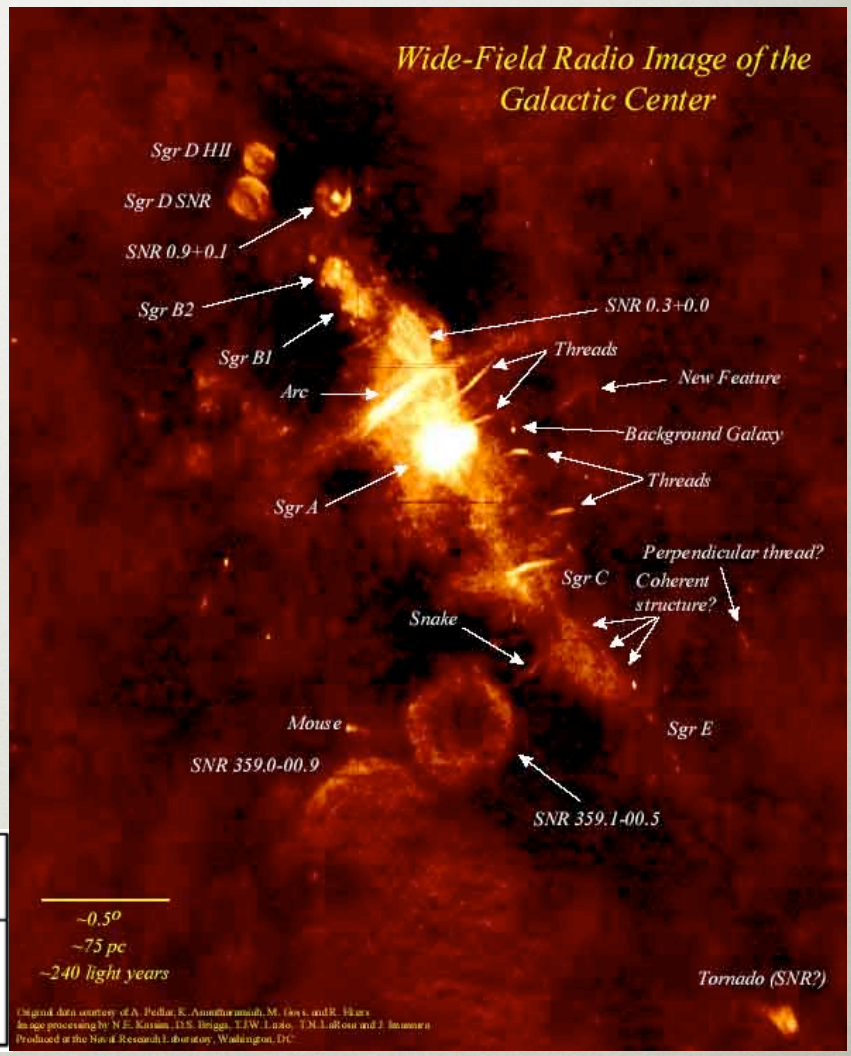
Fermi Galactic Center Source

Very crowded region of the sky!!

- 0FGL J1746.0-2900 is the closest source to the GC in Fermi Bright Source List (>10 σ detection, first 3 months of data).
- Marginal variability is not confirmed with larger statistics

➡ See J. Cohan-Tanugi's talk for results on the Fermi GC source with 11 months of data

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



Search for DM in the GC

Steep DM profiles ⇒ Expect large DM annihilation/decay signal from the GC!

Good understanding of the astrophysical background is crucial to extract a potential DM signal from this complicated region of the sky:

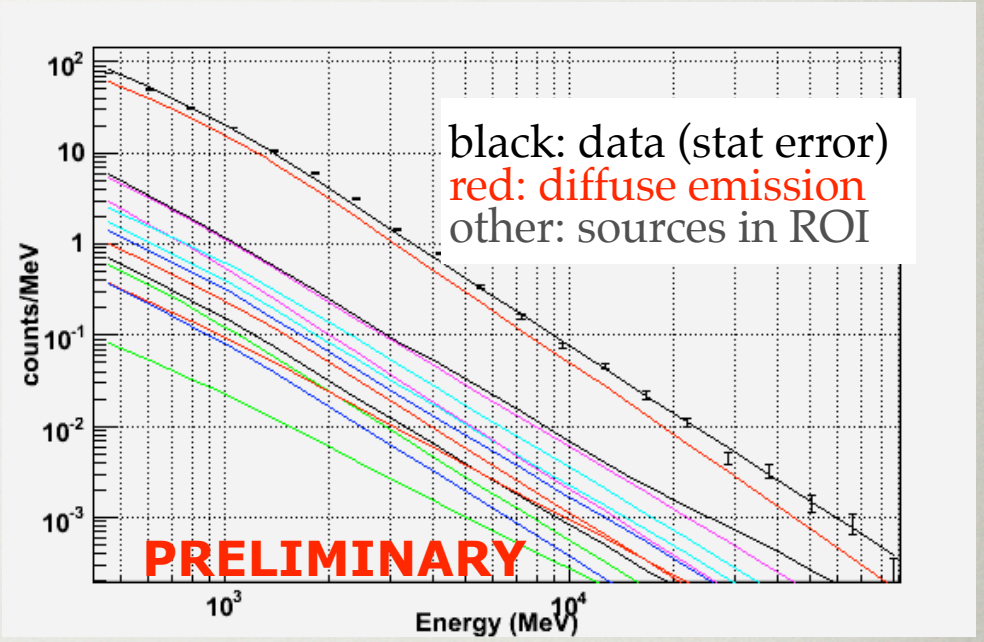
- source confusion: energetic sources near to or in the line of sight of the GC
- diffuse emission modeling: uncertainties in the integration over the line of sight in the direction of the GC, very difficult to model:

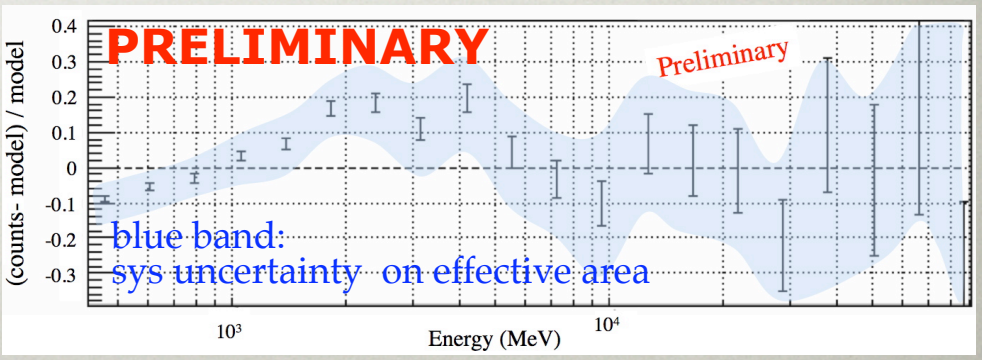
  ➡ See S. Digel's talk on diffuse emission from the inner galaxy and T. Porter's talk on galactic diffuse emission

See V. Vitale's poster

Search for DM in the GC

- Preliminary analysis of a 7° x7° region centered at the GC:
  - binned likelihood analysis of 11 months of data, >400 MeV, front-converting events
  - Model: galactic diffuse (GALPROP) and isotropic emission. Point sources in the region (from Fermi 1 year catalog, to be released)
- ➡ Model generally reproduces data well within uncertainties. The model somewhat under-predicts the data in the few GeV range (spatial residuals under investigation)
- In a 3° region around the GC, the largest residual in the same energy range is ~40%, a ~2σ effect (sources not subtracted, see S. Digel's talk)





See V. Vitale's poster

Search for DM in the GC

- Any attempt to disentangle a potential dark matter signal from the galactic center region requires a detailed understanding of the conventional astrophysics

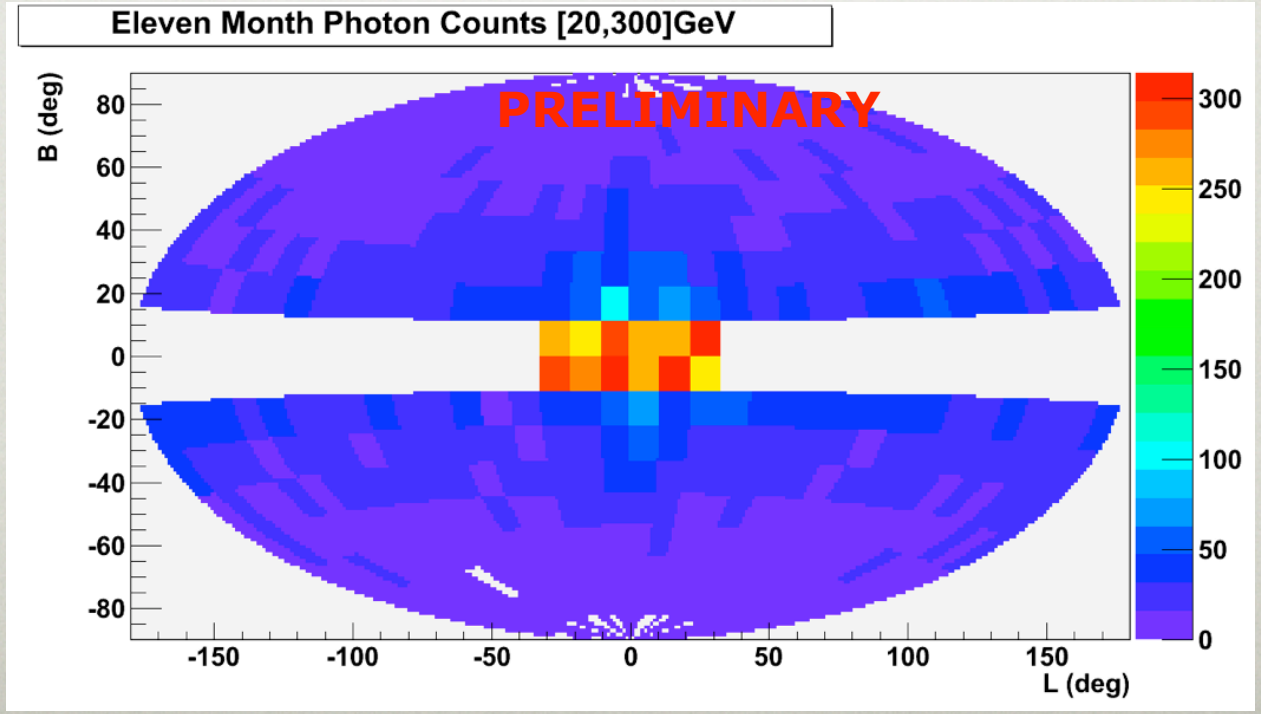
- More prosaic explanations must be ruled out before invoking a contribution from dark matter if an excess is found (e.g. modeling of the diffuse emission, unresolved sources, ...)

- Analysis in progress to updated constraints on annihilation cross section

Search for Spectral Lines

- Smoking gun signal of dark matter

- Search for lines in the first 11 months of Fermi data in the 30-200 GeV energy range
- Search region
  - $|b|>10^{o}$ and 30^{o} around galactic center
- Remove point sources (for $|b|>10^{o}$). The data selection includes additional cuts to remove residual charged particle contamination.

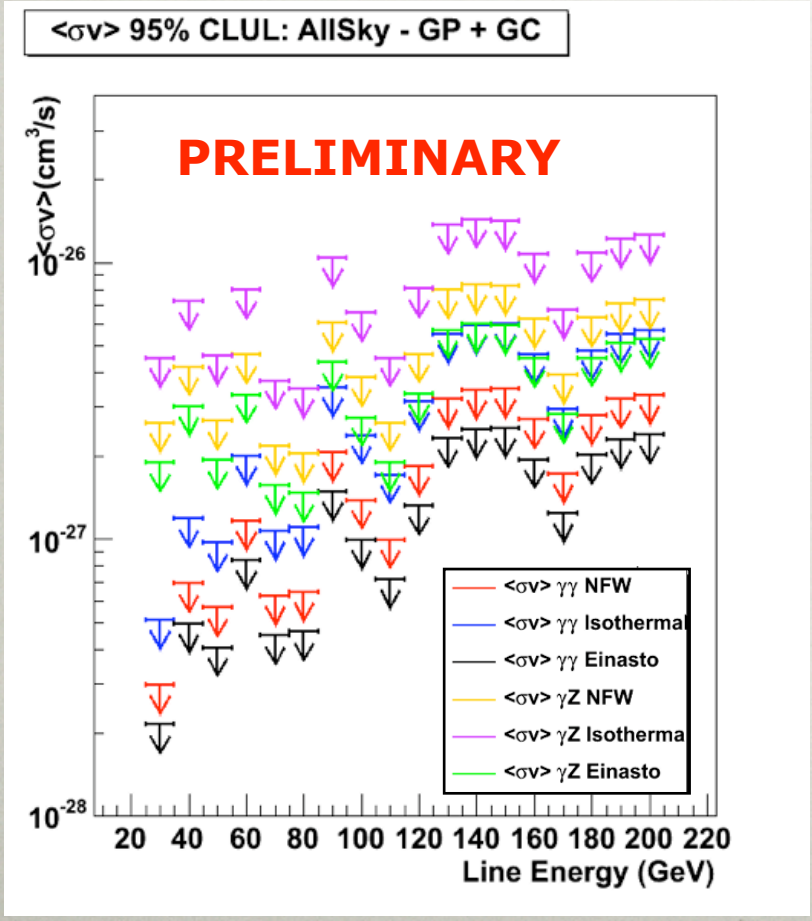


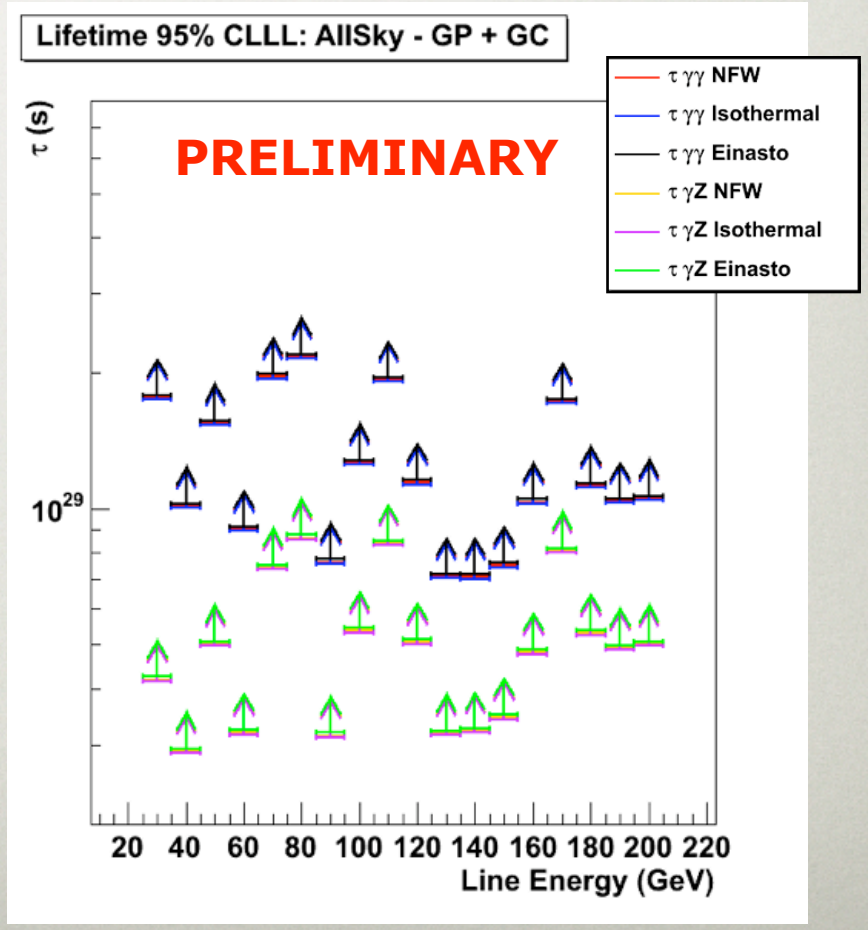
See Y. Edmonds' poster

Search for Spectral Lines

➡ No line detection, 95% CL flux upper limits are placed

- For each energy (WIMP mass) the flux ULs are combined with the integral over the line of sight of the DM density^2 (or density) to extract UL (LL) on the annihilation cross section $<\sigma v>$ (or lifetime for decaying DM particles)

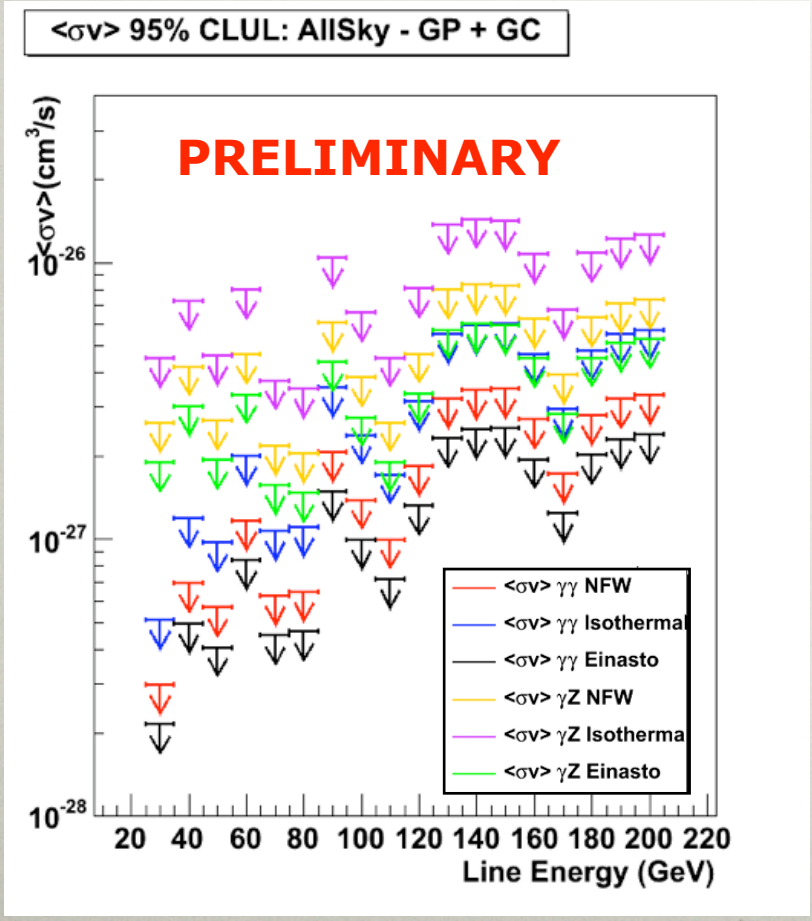


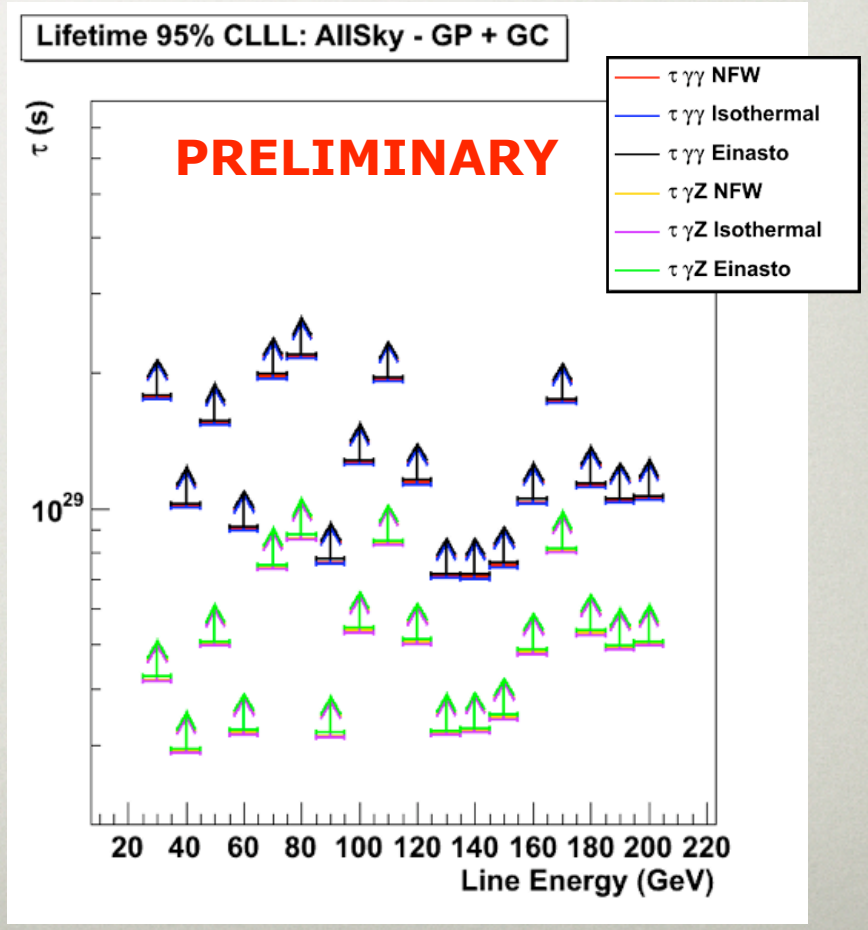


See Y. Edmonds' poster

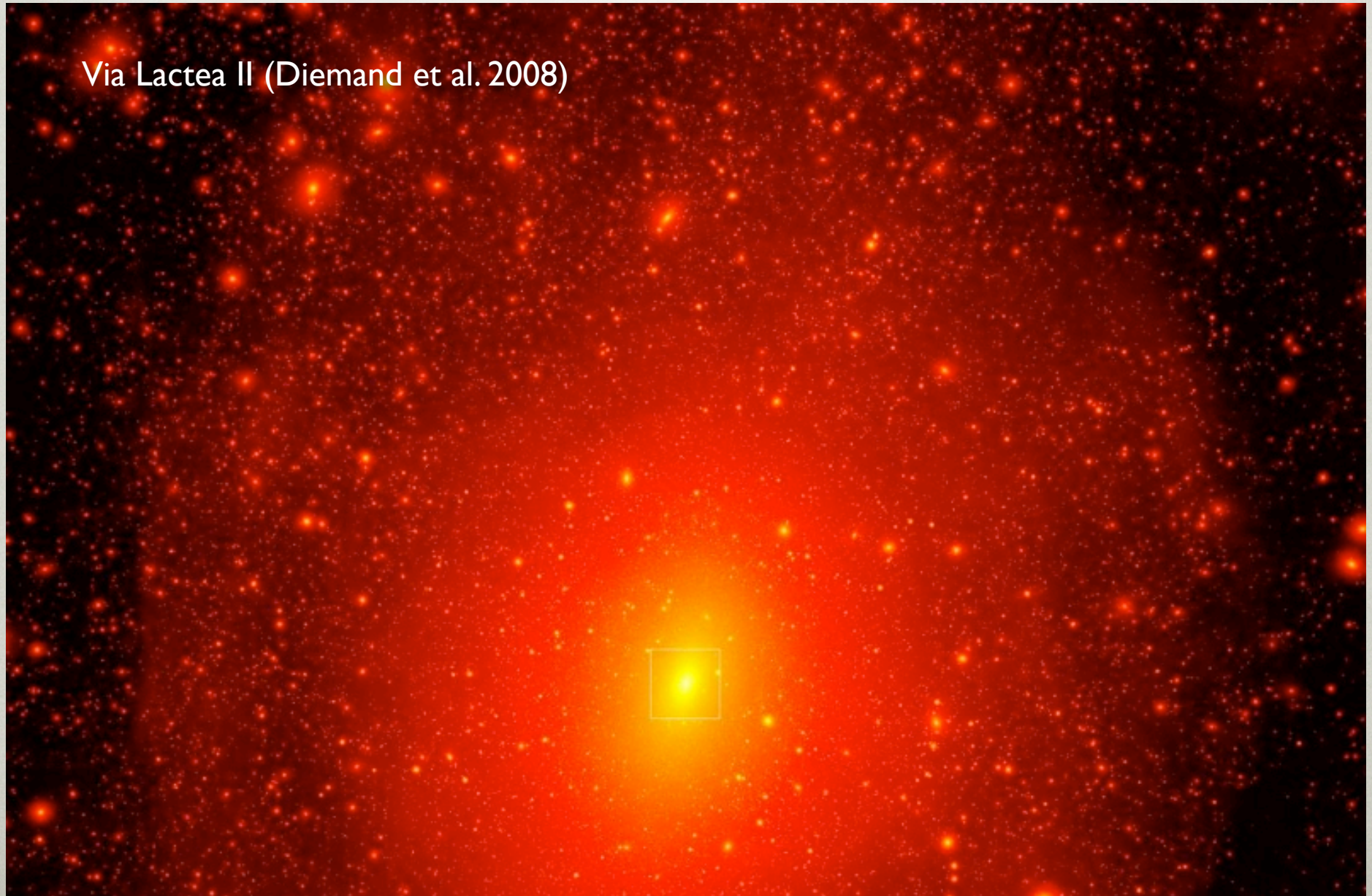
Search for Spectral Lines

- ✓ Limits on $\langle\sigma v\rangle$ are too weak (by O(1) or more) to constrain a typical thermal WIMP
- ✓ Some models predict large annihilation cross sections into lines:
  Wino LSP (Kane 2009): γZ line has $\langle\sigma v\rangle \sim 1.4\times10^{-26}$ cm^3s^{-1} ⇒already disfavored by a factor of 2-5 depending on the halo profile





Search for DM Subhalos



Search for DM Subhalos

➡ DM substructures: very low background targets for DM searches

- Never before observed DM substructures (DM satellites):
  - Would significantly shine only in radiation produced by DM annihilation/decay.
  - Some of these satellites could be within a few kpc from the Sun (N-body simulations). Their extension could be resolved by the LAT
  - All sky search for promising candidates with the LAT

- Optically observed dwarf spheroidal galaxies (dSph): largest clumps predicted by N-body simulation. 25 have been discovered so far, many more are predicted.
  - Most are expected to be free from other astrophysical gamma ray sources and have low content in dust/gas, very few stars (Segue 1 might have 65 stars associated with it, Geha&Simon 2009)
  - Given the distance and the LAT PSF, they are expected to appear as point sources
  - Select most promising candidates for observations

Search for DM Satellites

- **Search criteria:**
  - More than 10^o from the galactic plane
  - No appreciable counterpart at other wavelengths
  - Emission constant in time (1 week interval)
  - Spatially extended: ~1^o average radial extension for nearby, detectable clumps
  - Spectrum determined by DM (both b-bbar and FSR spectra are tested vs a (soft) power law hypothesis)
- Blind analysis: finalize selection method with 3 months of data and apply to 10 months
- Search for sources (>5σ significance) passing these criteria in the 100 MeV to 300 GeV energy range.
- Background: point sources+diffuse galactic and isotropic emission

See E. Bloom's poster

Search for DM Satellites

4 sources above 5σ survive all criteria but the spectral requirement: their spectra do not favor the DM hypothesis.

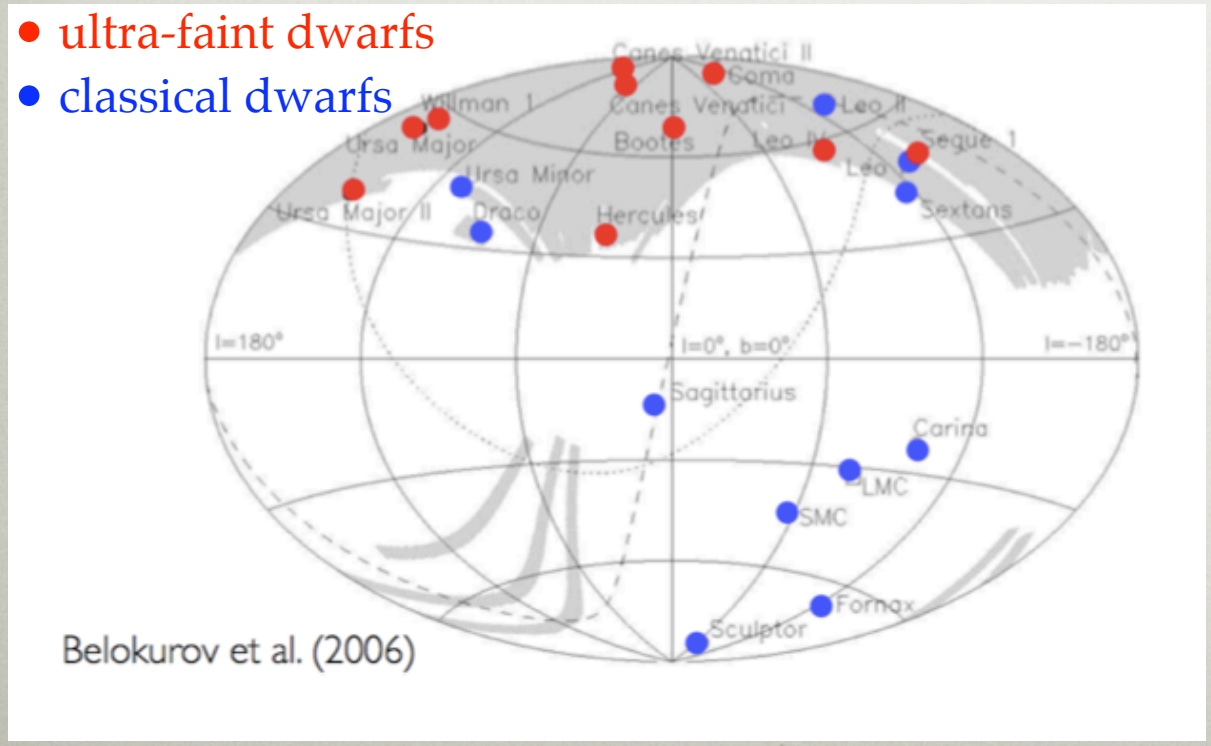
➡ No DM satellite candidates are found in 10 months of data

✓ Consistent with result of sensitivity study based on Via Lactea II predictions for the DM distribution for a 100 GeV WIMP annihilating into b-bbar, $\langle\sigma v\rangle = 3 \times 10^{-26}\ cm^3\ s^{-1}$ (paper in preparation)

✓ Work is ongoing to evaluate the sensitivity for other models.

Search for DM in dSph

- Select most promising dSph based on proximity, stellar kinematic data: less that 180 kpc from the Sun, more than 30° from the galactic plane
- 14 dSph have been selected for this analysis. More promising targets could be discovered by current and upcoming experiments (SDSS, DES, PanSTARRS, ...)
- Very large M/L ratio: 10 to ~> 1000 (M/L ~ 10 for Milky Way galaxy)



Distance: ~30 to 160 kpc

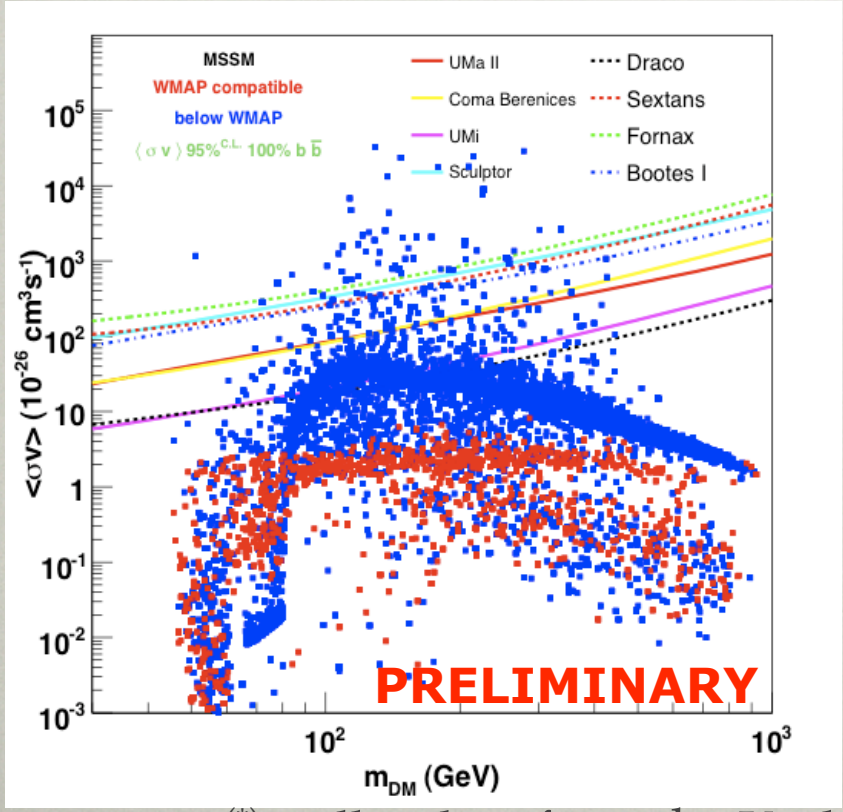
Ursa Major II
Segue 2
Willman 1
Coma Berenices
Bootes II
Bootes I
Ursa Minor
Sculptor
Draco
Sextans
Ursa Major I
Hercules
Fornax
Leo IV

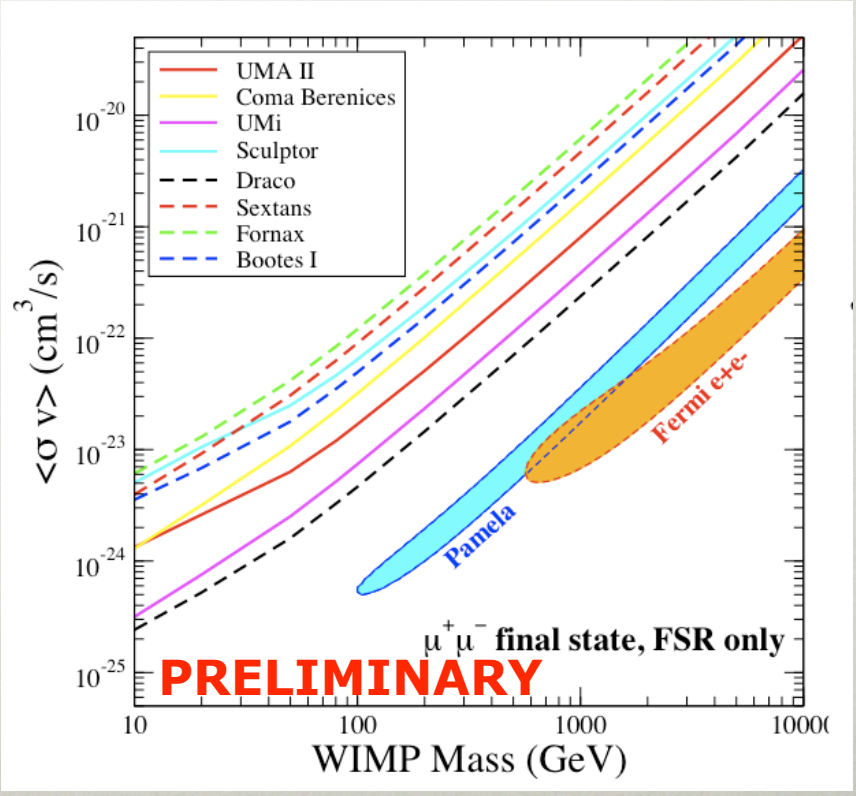
See C. Farnier's talk
and P. Scott's poster

Search for DM in dSph

➡ No detection by Fermi with 11 months of data. 95% flux upper limits are placed for several possible annihilation final states.

- Flux upper limits are combined with the DM density inferred by the stellar data(*) for a subset of 8 dSph (based on quality of stellar data) to extract constraints on $\langle\sigma v\rangle$ vs WIMP mass for specific DM models



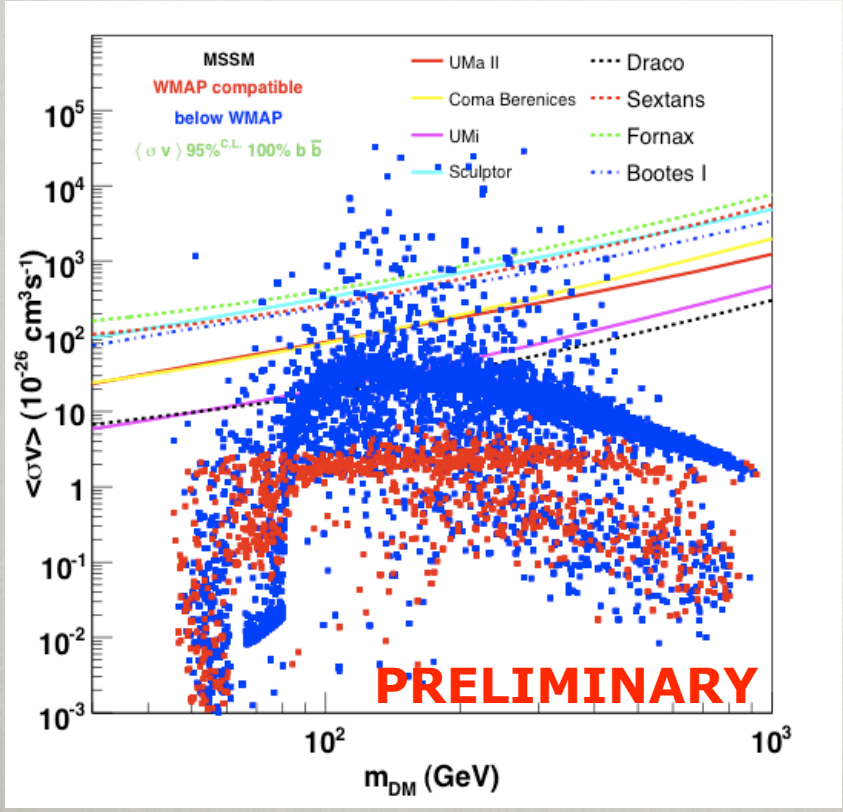


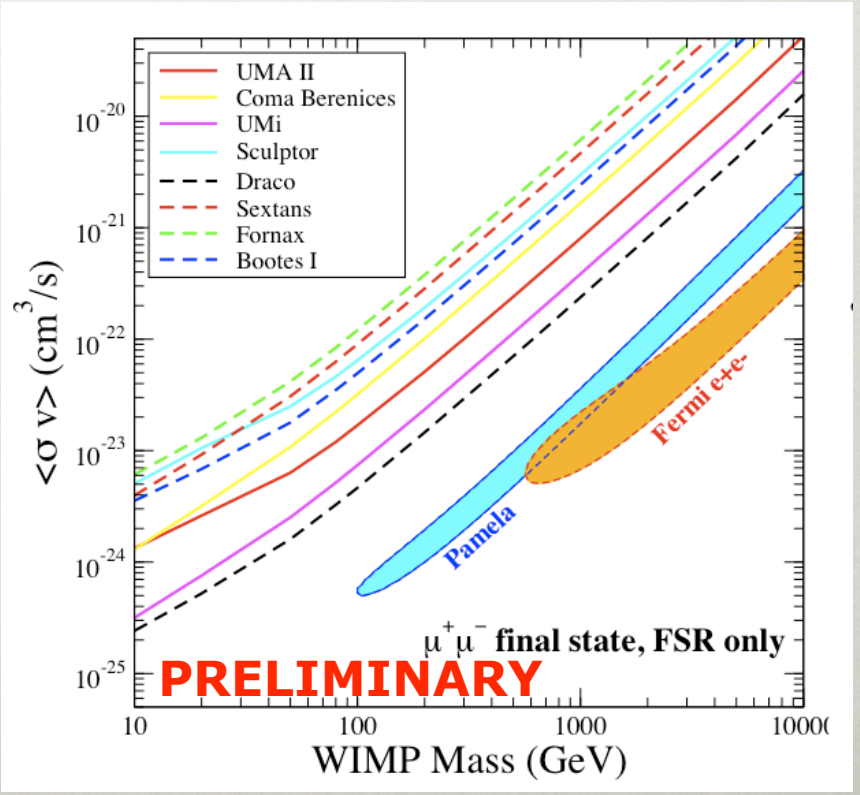
(*) stellar data from the Keck observatory (by Martinez, Bullock, Kaplinghat)

See C. Farnier's talk and P. Scott's poster

Search for DM in dSph

✓ Exclusion regions already cutting into interesting parameter space for some WIMP models





See C. Farnier's talk
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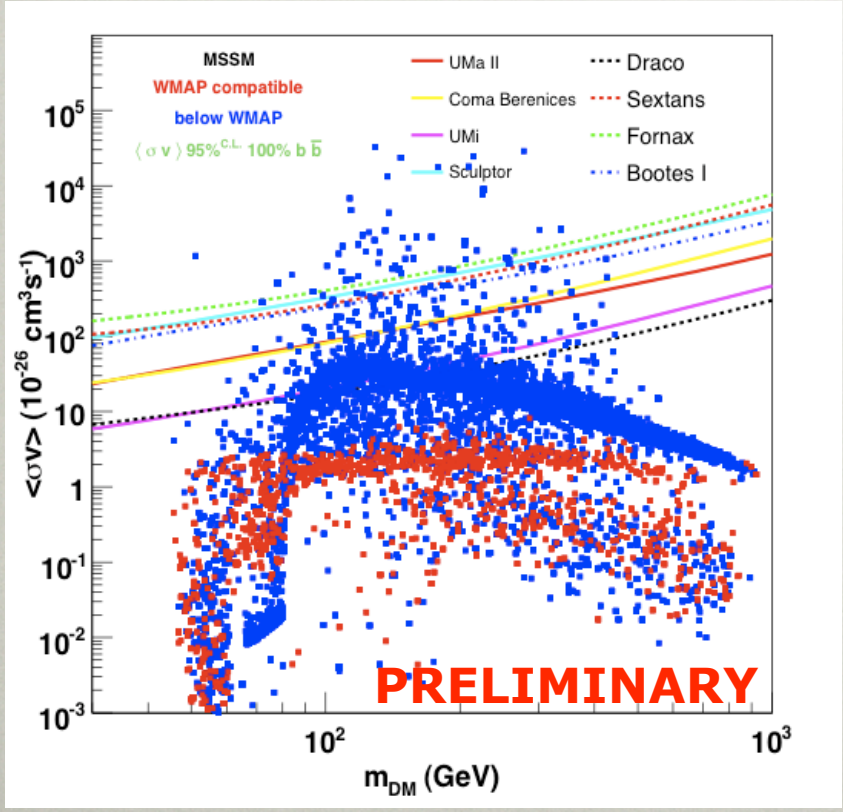
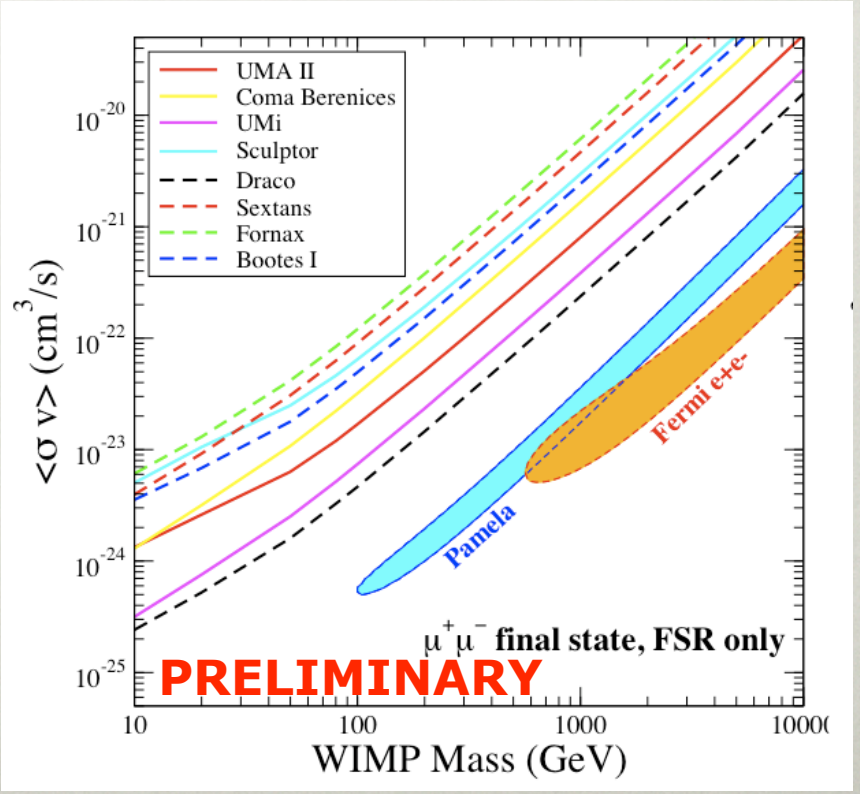
Search for DM in dSph

✓ Exclusion regions already cutting into interesting parameter space for some WIMP models

Stronger constraints can be derived if IC of electrons and positrons from DM annihilation off of the CMB is included, however diffusion in dwarfs is not known ⇒ use bracketing values of diffusion coefficients from cosmic rays in the Milky Way





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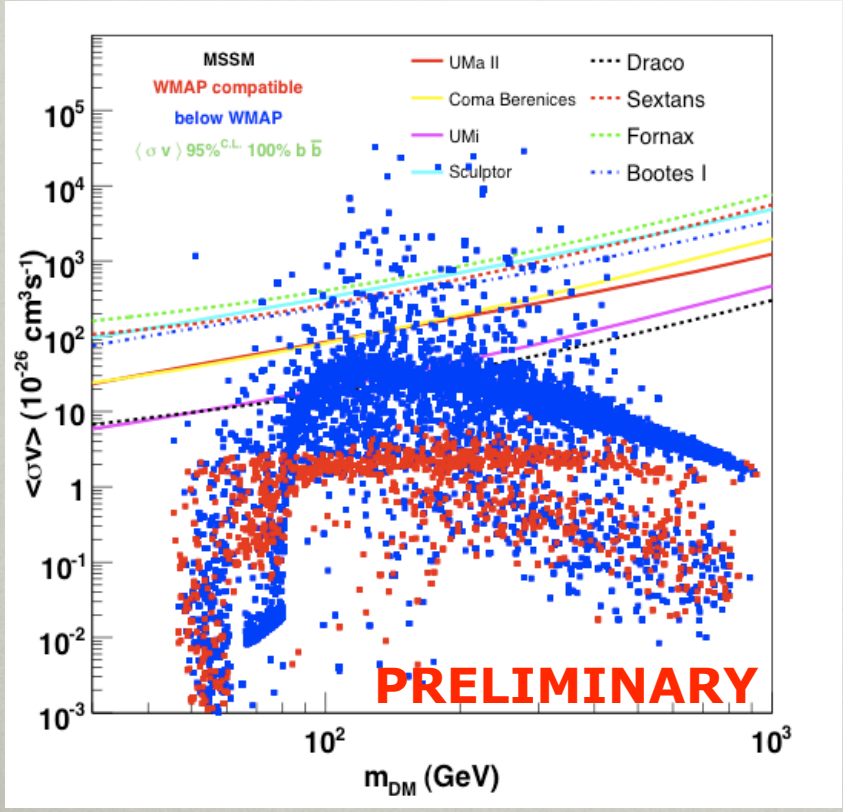

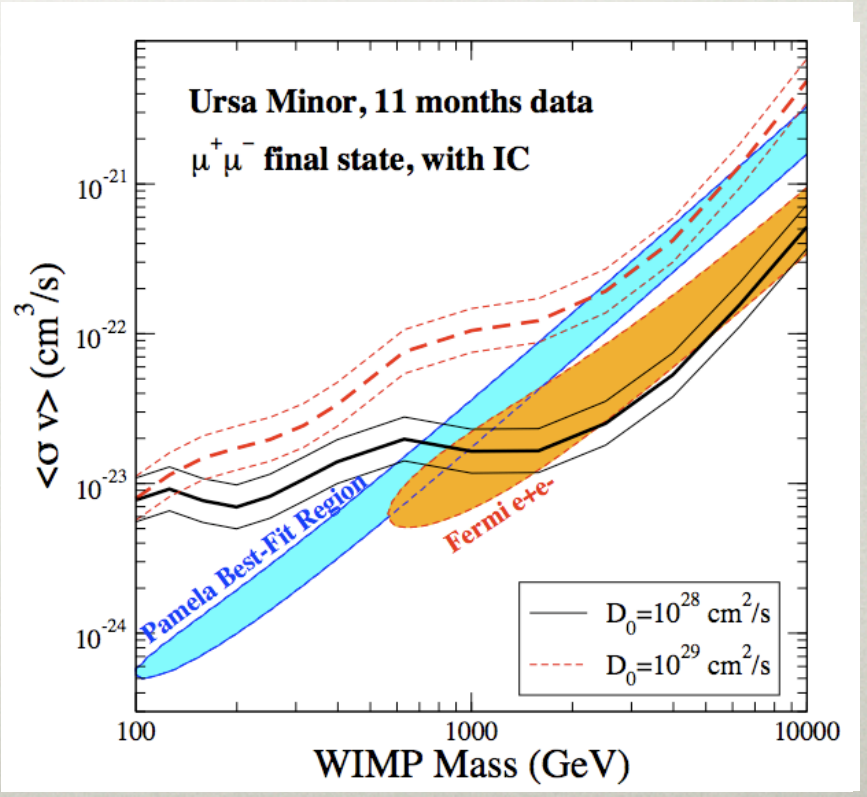

Conclusions/Outlook

- No discovery....
- .... however promising constraints on the nature of DM have been placed
- In addition to increased statistics, better understanding of the astrophysical and instrumental background will improve our ability to reliably extract a potential signal of new physics or set stronger constraints
- Further improvements are anticipated for analysis that benefits from multi-wavelength observations (for example galactic center, dwarf spheroidal galaxies and DM satellites)