Indirect Dark Matter Searches with Gamma RAYs

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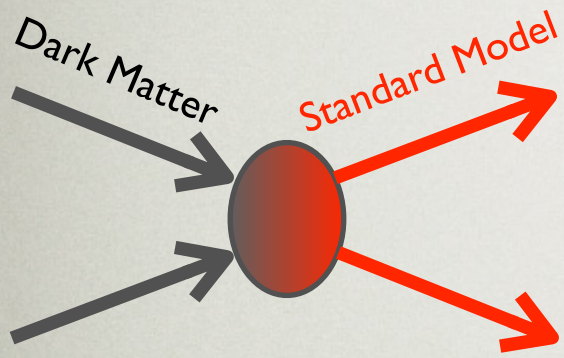
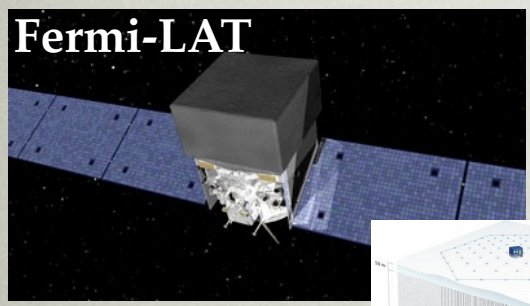
UCLA Dark Matter
21 February 2018

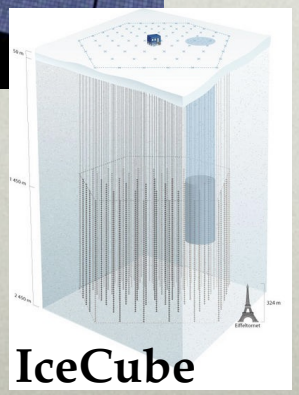
Dark Matter Searches

INDIRECT SEARCHES

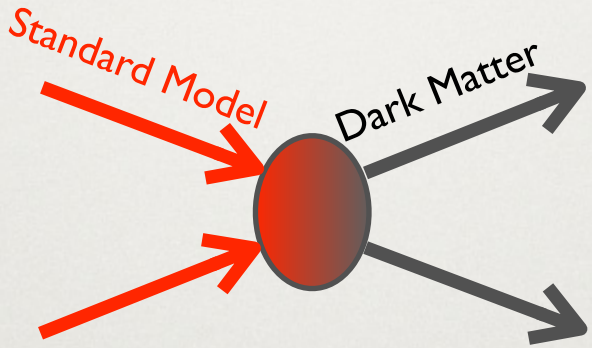


Find its annihilation byproducts



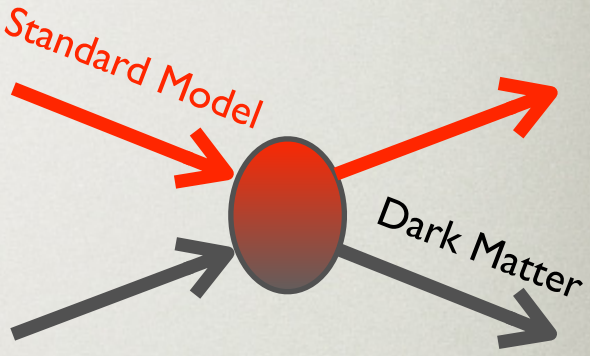


COLLIDER SEARCHES

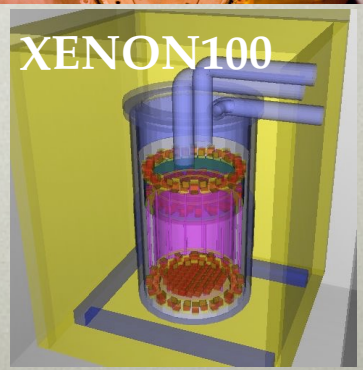


Produce it in the lab

DIRECT SEARCHES



Detect energy it deposits



Dark Matter Searches

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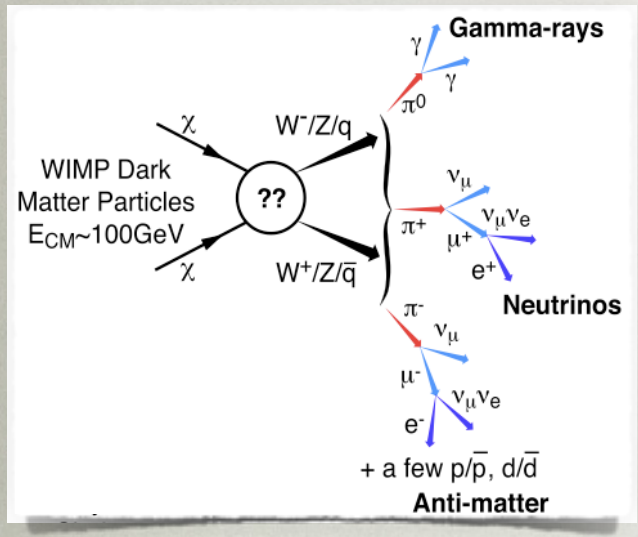

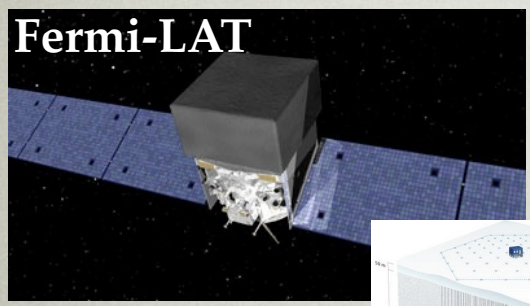

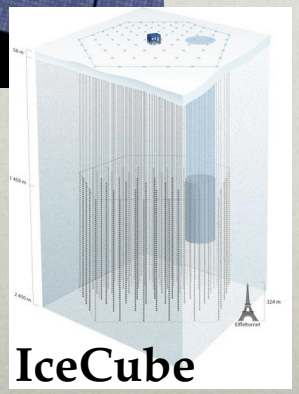

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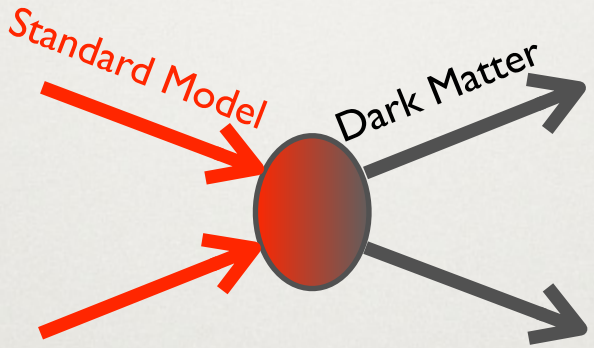

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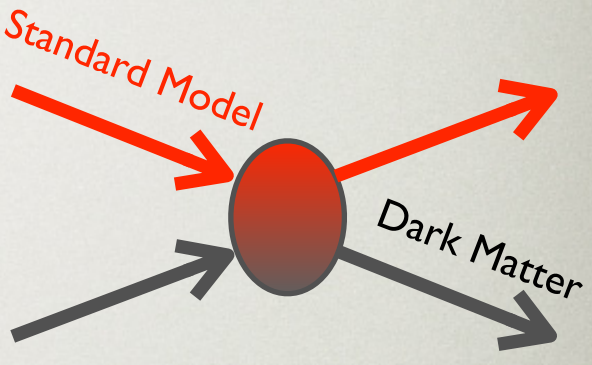

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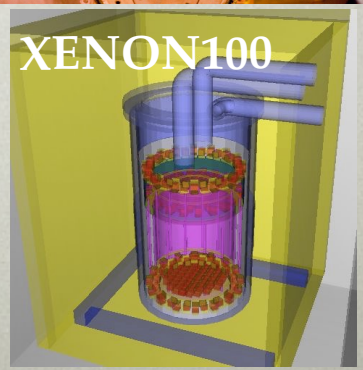
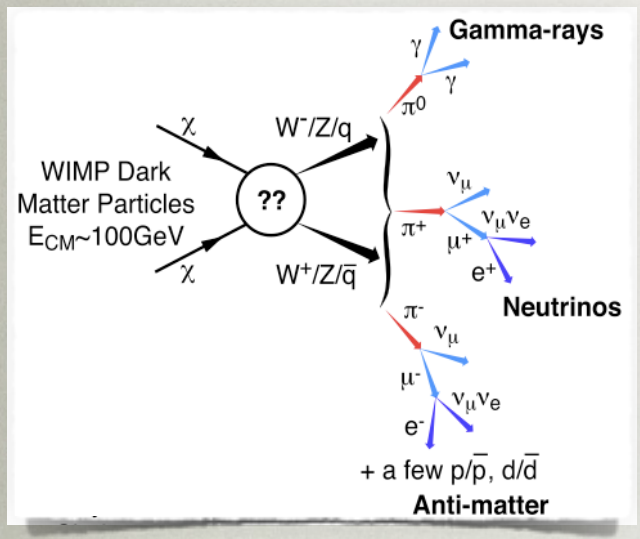


Indirect Searches
Gamma Rays

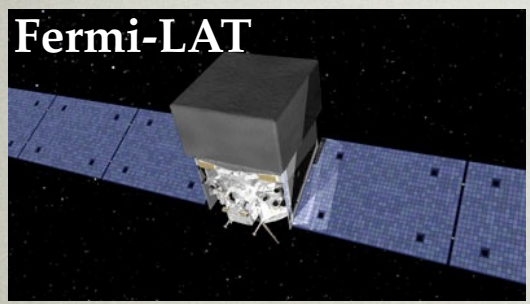


$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\phi,\theta) = \frac{1}{4\pi}\frac{<\sigma_{ann}v>}{2m^2_{WIMP}}\sum_f \frac{dN^f_\gamma}{dE_\gamma}B_f \times \int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{los} \rho^2(r(l,\phi'))dl(r,\phi')$$

particle physics

DM distribution

J - factor



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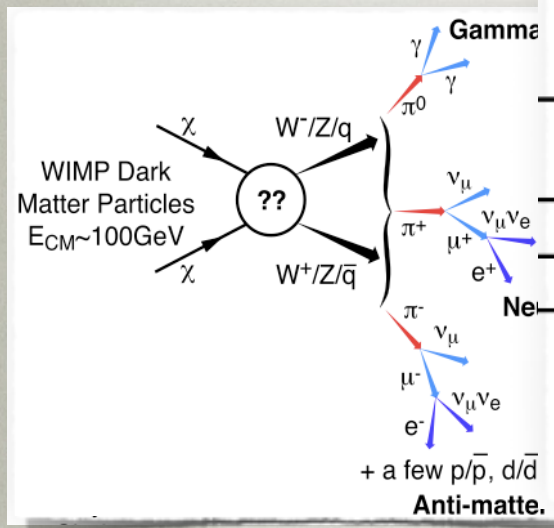
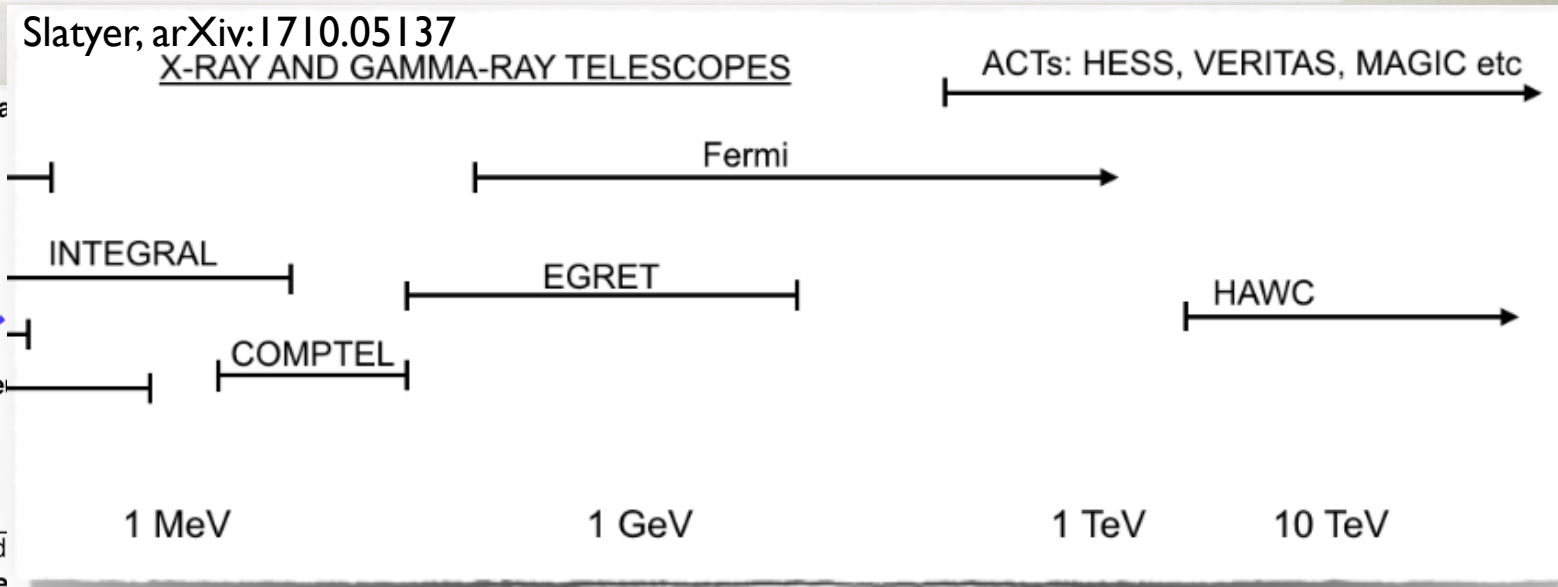
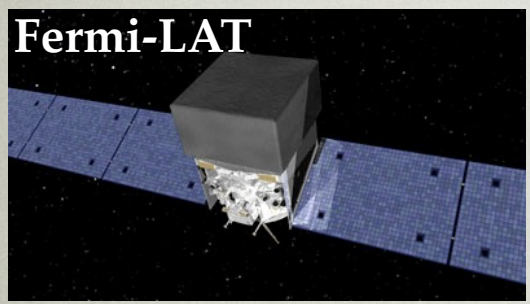
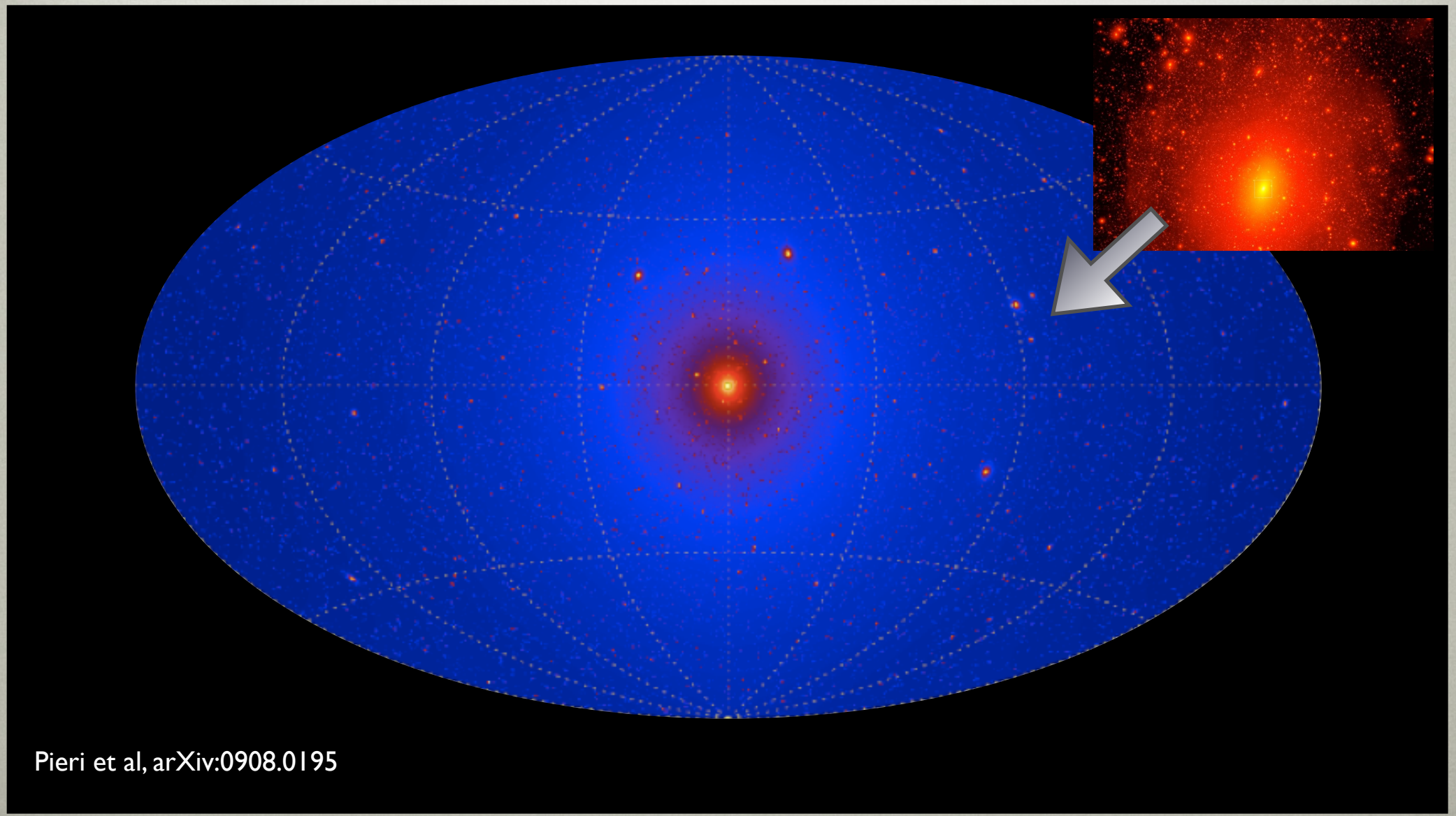






Gamma rays from Dark Matter Annihilation:

The Milky Way & its satellites



Pieri et al, arXiv:0908.0195

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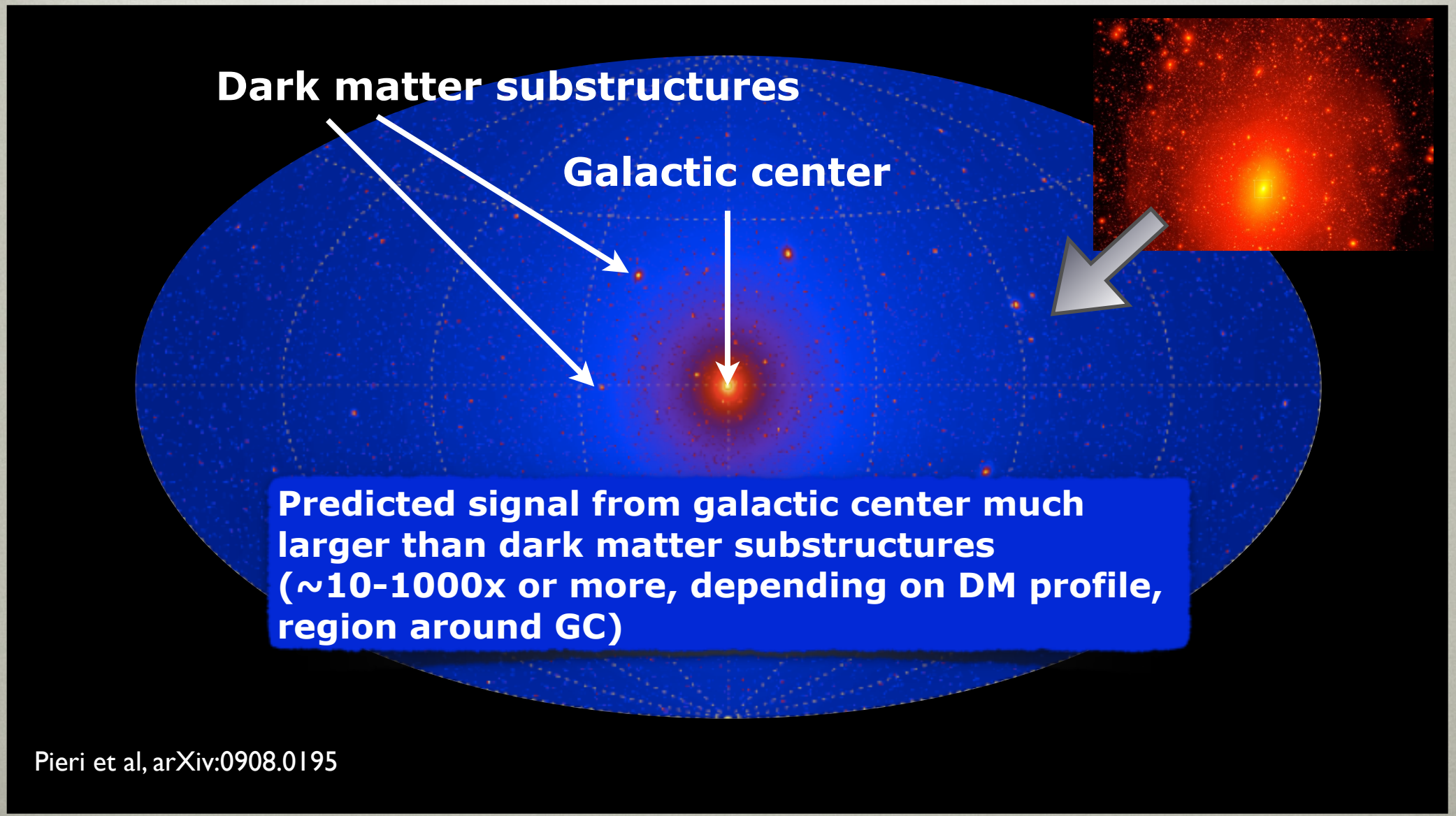
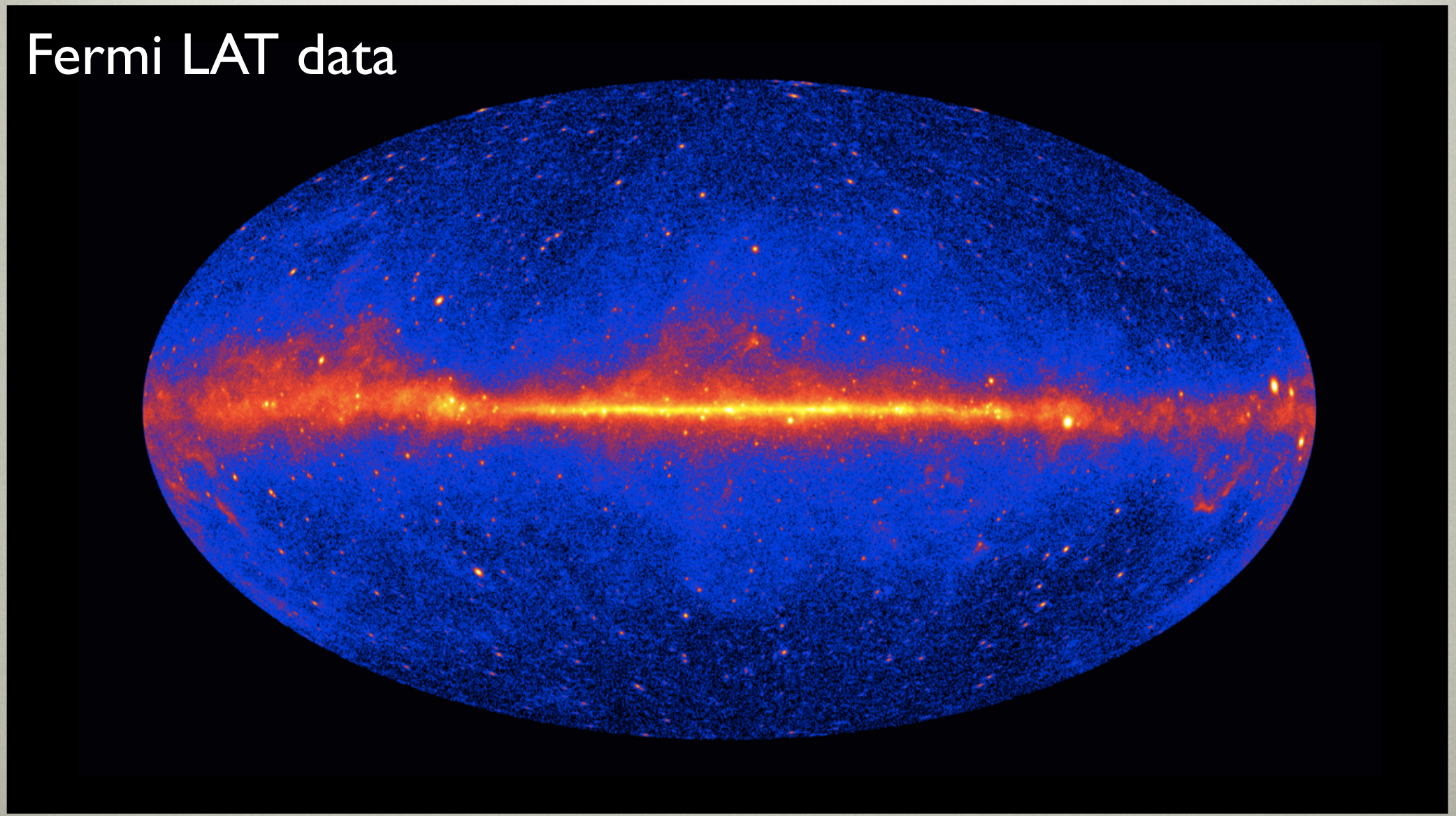
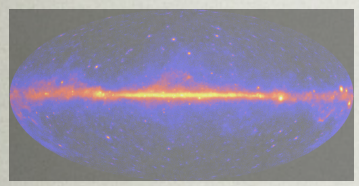


The Fermi Sky



Galactic Gamma-Ray Interstellar Emission

- The interstellar gamma-ray emission in the Milky Way is produced by cosmic rays interacting with the interstellar gas and radiation field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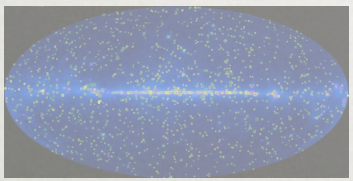
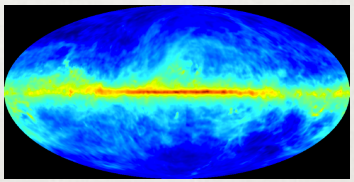
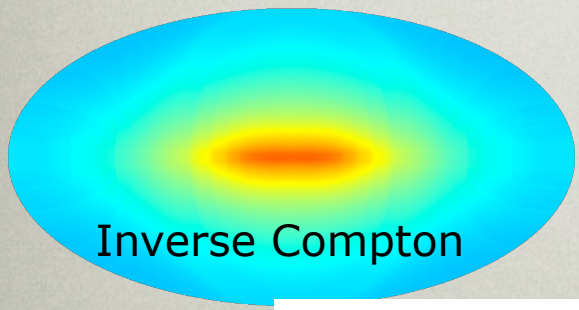

sources

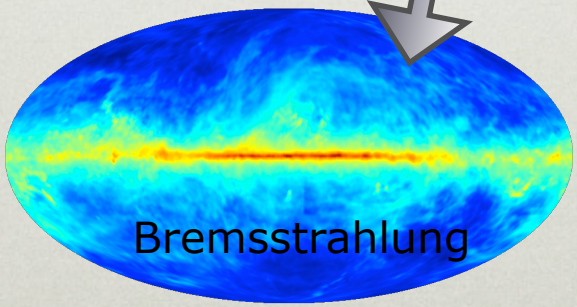
+

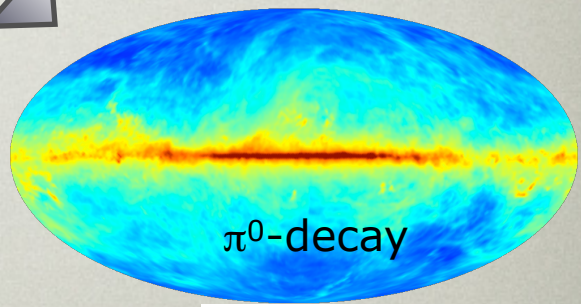

galactic interstellar emission

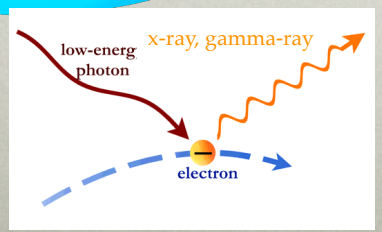
+

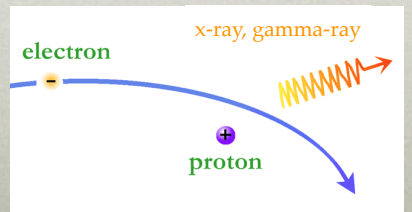

isotropic

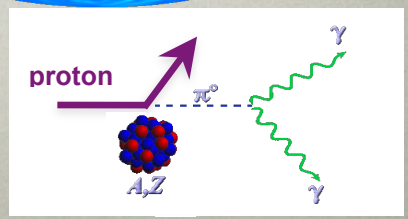








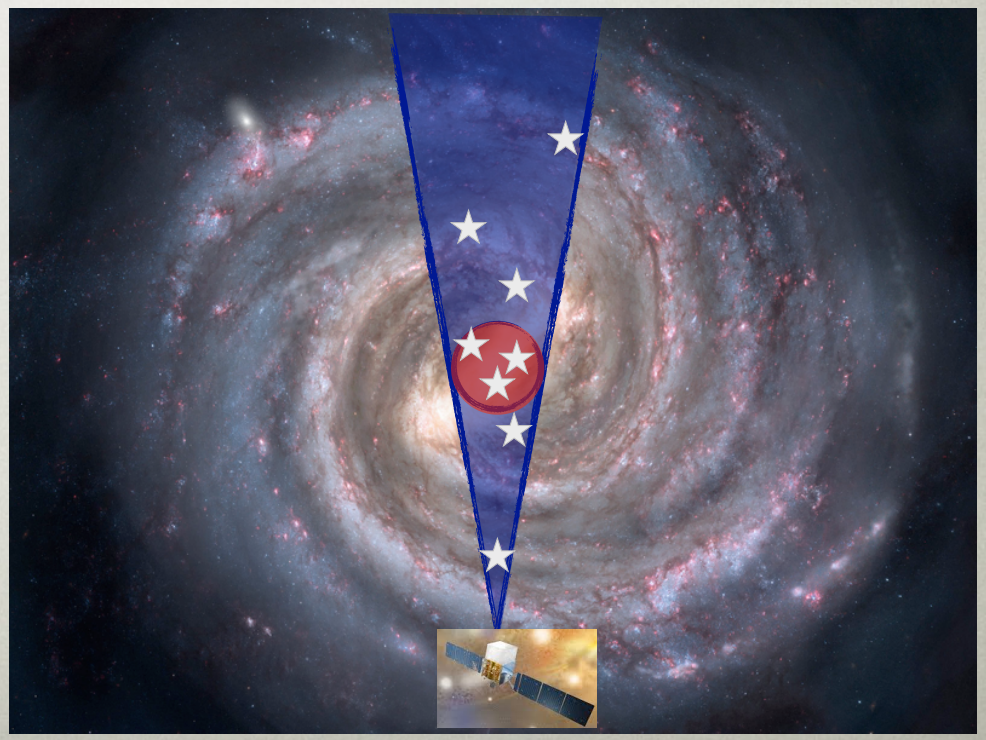




Galactic Gamma-Ray Interstellar Emission

- The interstellar gamma-ray emission in the Milky Way is produced by cosmic rays interacting with the interstellar gas and radiation field

➡ Galactic center region: a dark matter signal is predicted to be largest here, where modeling of the interstellar emission (and sources) is problematic!
CR intensities, density of radiation fields and gas are highest and most uncertain, long integration path over the entire Galactic disc, large density of sources

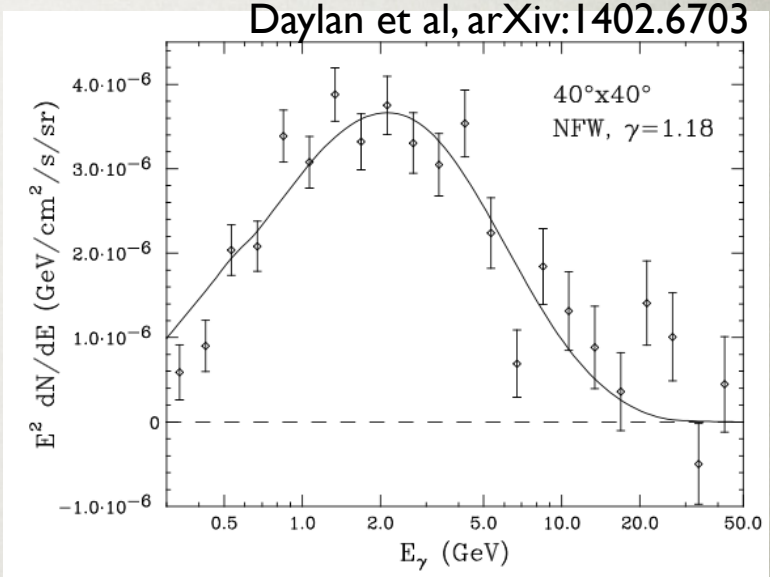


Galactic Center Excess

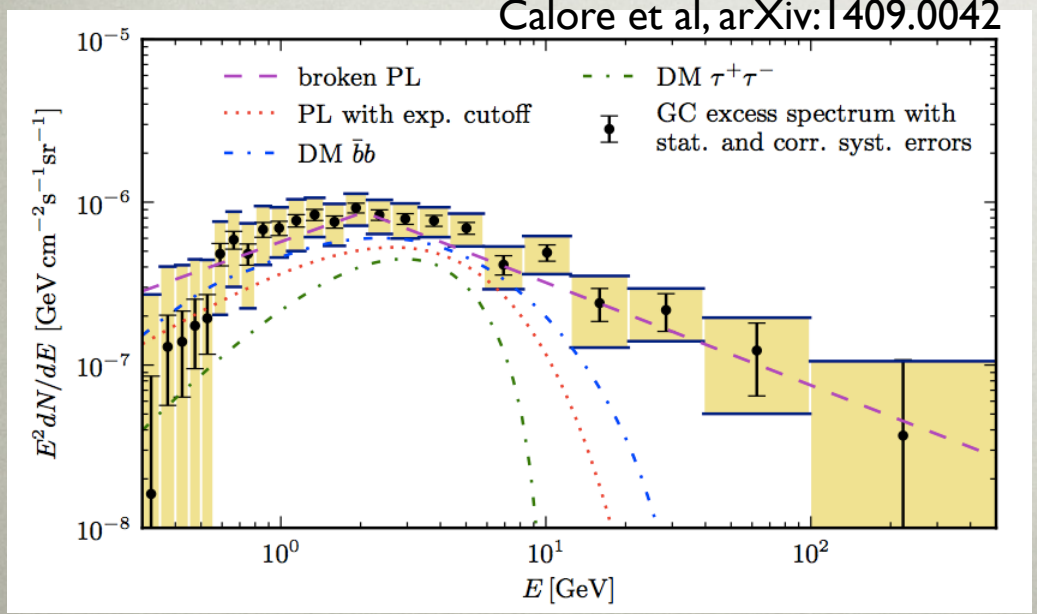
- An excess in the Fermi LAT GC data consistent with dark matter annihilation was first claimed by Goodenough and Hooper in 2009 (arXiv: 0910.2998.) Several analyses since then confirm the excess
- Different approaches in modeling the interstellar emission model:
  the characterization of the signal depends on this!

SPECTRUM

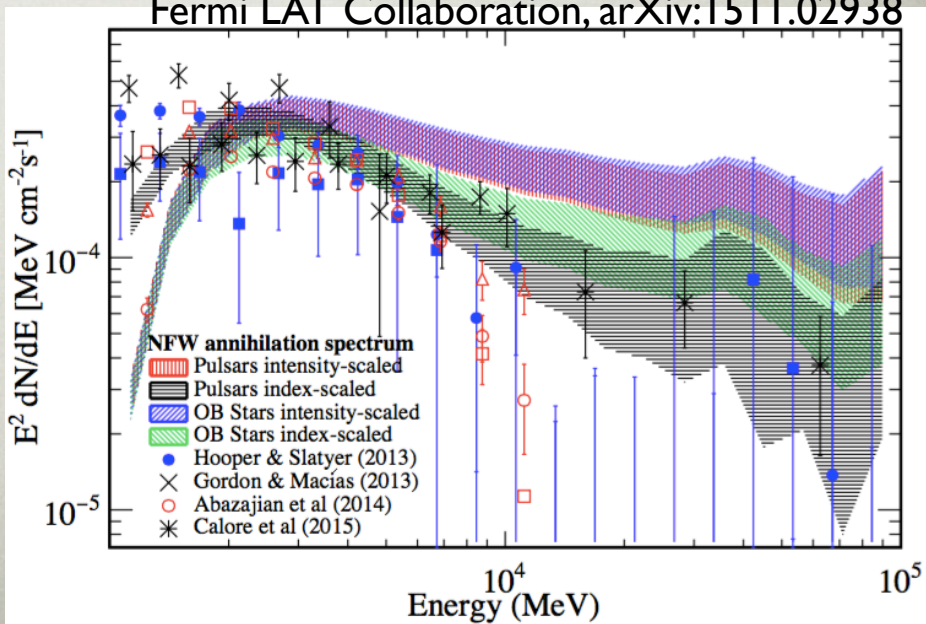
Daylan et al, arXiv:1402.6703



Calore et al, arXiv:1409.0042



Fermi LAT Collaboration, arXiv:1511.02938

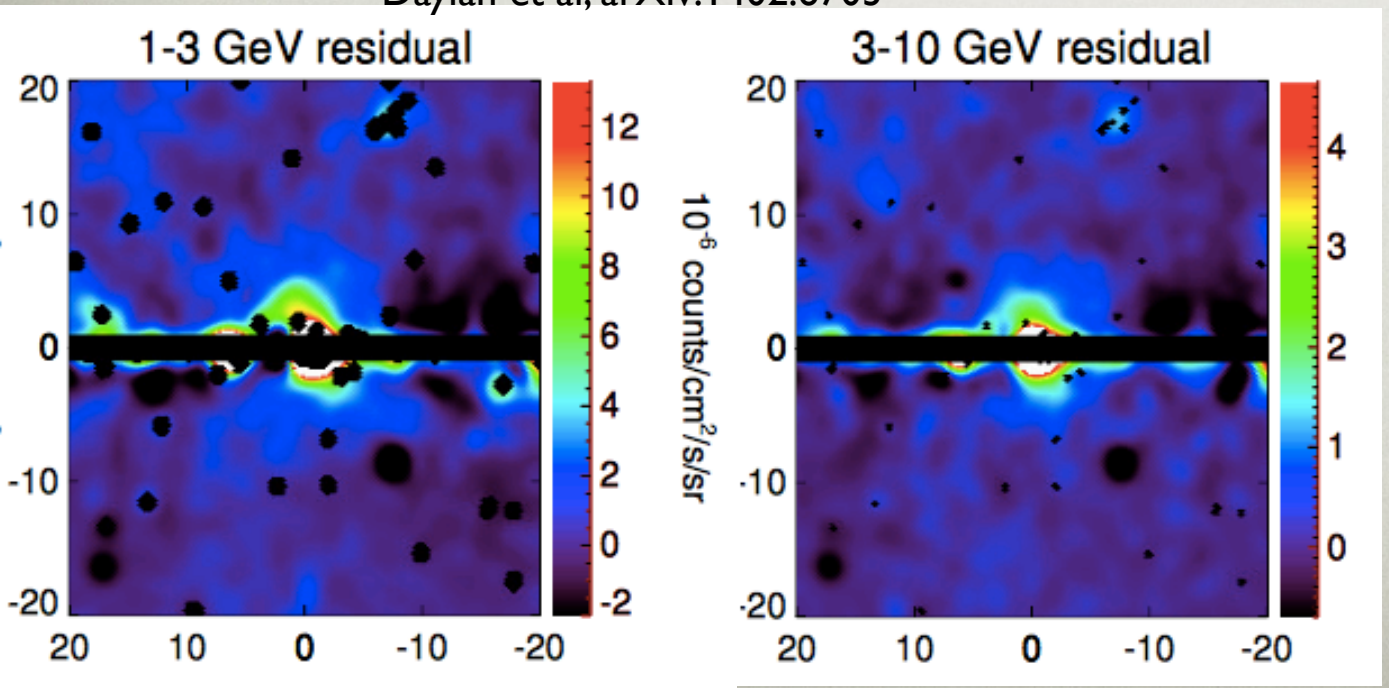


Galactic Center Excess

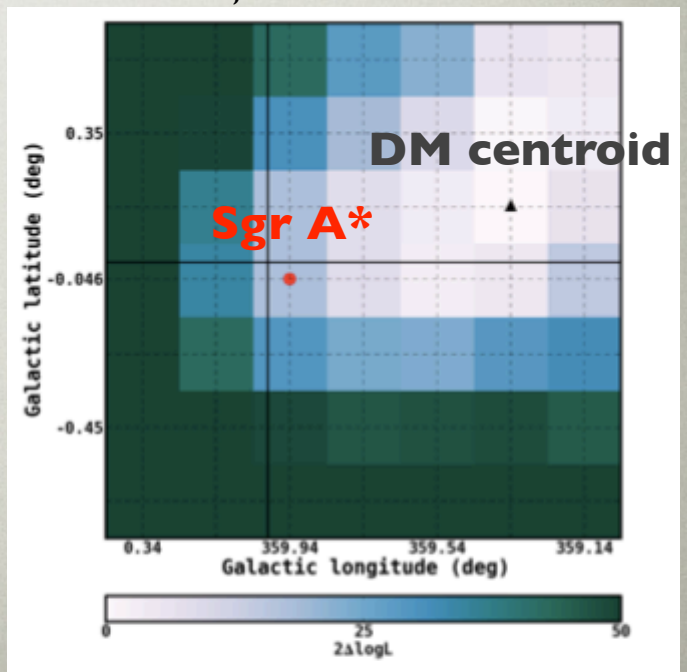
- Excess extends out to 10° from GC, approximately spherically symmetric NFW profile with slope γ=1-1.3 (but see also Linden et al arXiv:1604.01026, Horiuchi et al arXiv:1604.01402, Macias et al arXiv:1611.06644, Bartels et al arXiv: 1711.04778)
- Possibly offset from GC (Calore et al arXiv:1409.0042, Linden et al arXiv: 1604.01026, Karwin et al arXiv:1612.05687)

MORPHOLOGY

Daylan et al, arXiv:1402.6703



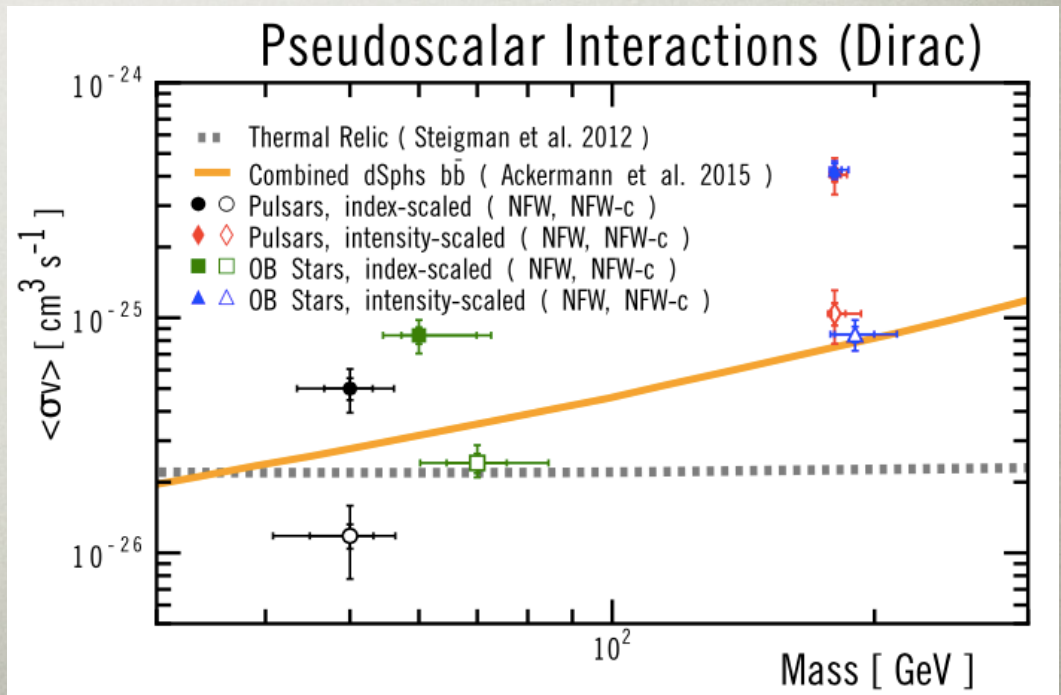
Karwin et al, arXiv:1612.05687



Implications for Dark Matter Models

- The data favor a DM particle with mass in the range ~50 (200) GeV, annihilating mainly into bottom (top) quarks with an annihilation cross section consistent with predictions for a thermal relic, ~ 10^{-26} cm^3/s (see e.g. EFT interpretation by Karwin et al arXiv:1612.05687)
- *In the framework of the MSSM, a neutralino annihilating into a pair of top quarks with DM masses above 250 GeV is favored (A. Butter et al arXiv:1612.07115). Direct detection rules out much of the lower mass range (see also Achterberg et al arXiv: 1502.05703, Bertone et al arXiv:1507.07008)*

Karwin et al, arXiv:1612.05687

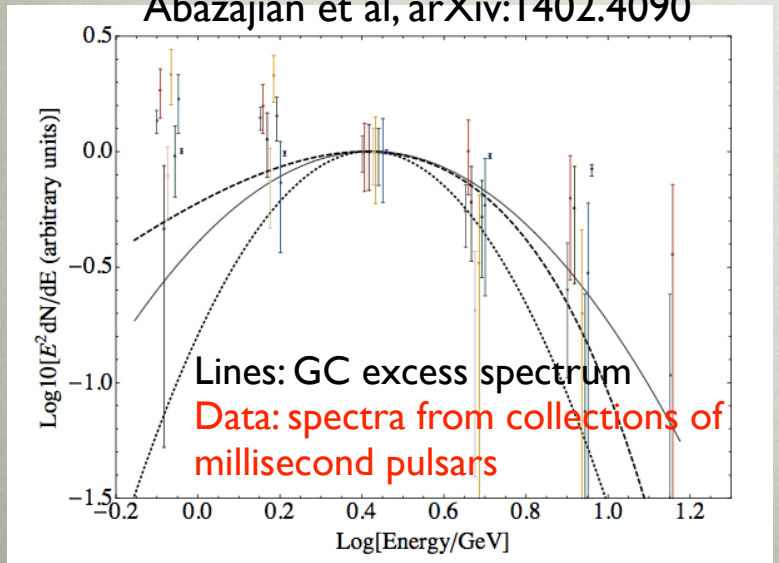


Pulsars

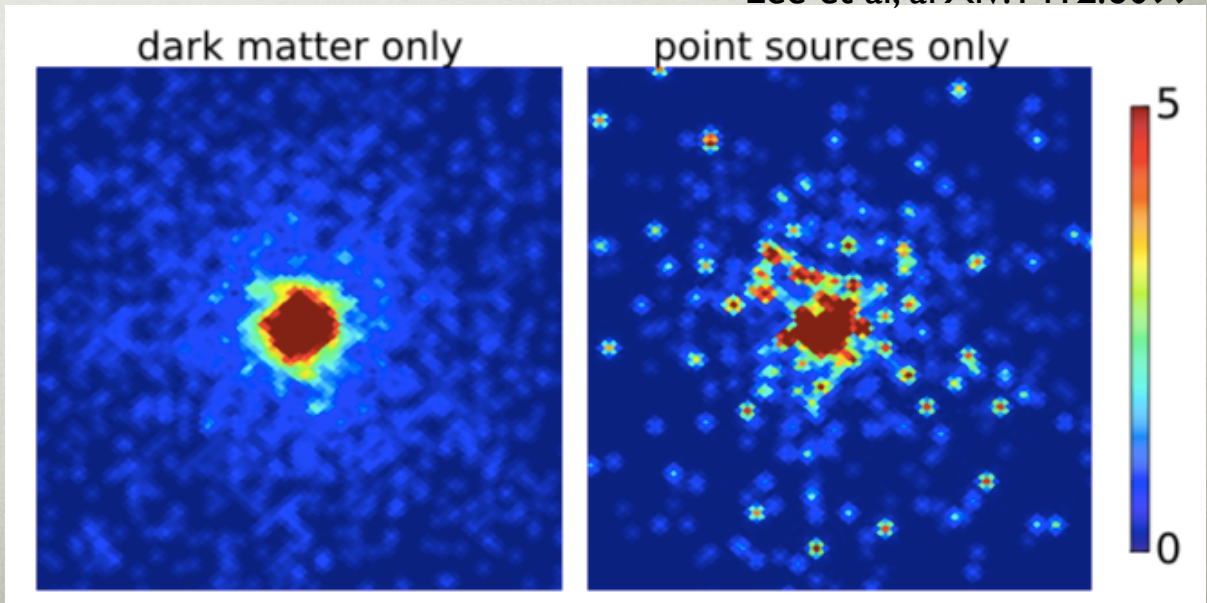
- An unresolved population of millisecond pulsars can explain the excess
  - Claimed excess is found consistent with *O(1000) millisecond pulsars* within ~1 kpc of GC (Abazajian et al arXiv:1402.4090, but see also Hooper et al arXiv:1606.09250.) Very young pulsars might also contribute to the excess (O'Leary et al arXiv:1504.02477)
  - *Spherical symmetry? Cuspy distribution? Extend out to 10°? Possibly* (e.g. Abazajian et al arXiv: 1402.4090, Brandt et al arXiv:1507.05616)

➡ Analyses based on non-poissonian photon statistics templates and wavelet decomposition (Lee et al arXiv:1412.6099, 1506.05124; Bartels et al arXiv:1506.05104) find that the **excess is consistent with a collection of discrete gamma-ray emitters**

Abazajian et al, arXiv:1402.4090

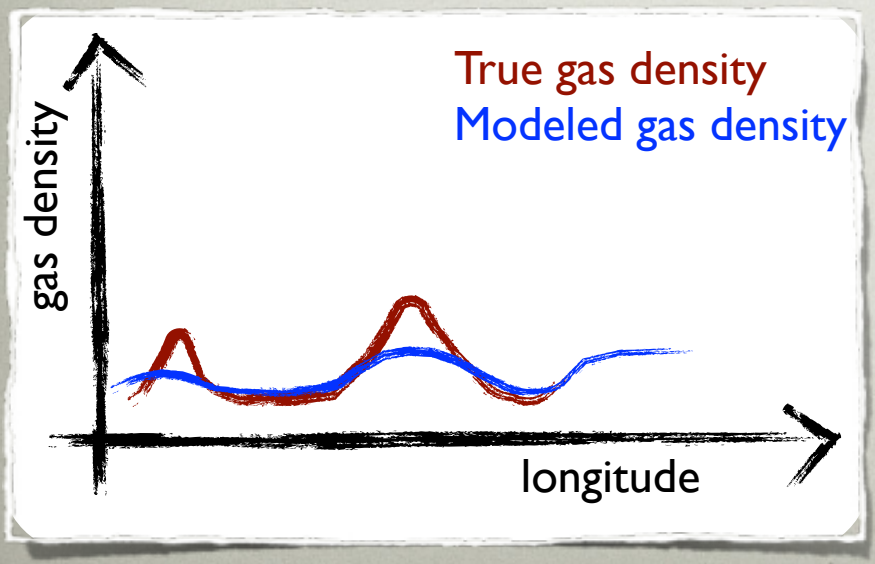


Lee et al, arXiv:1412.6099

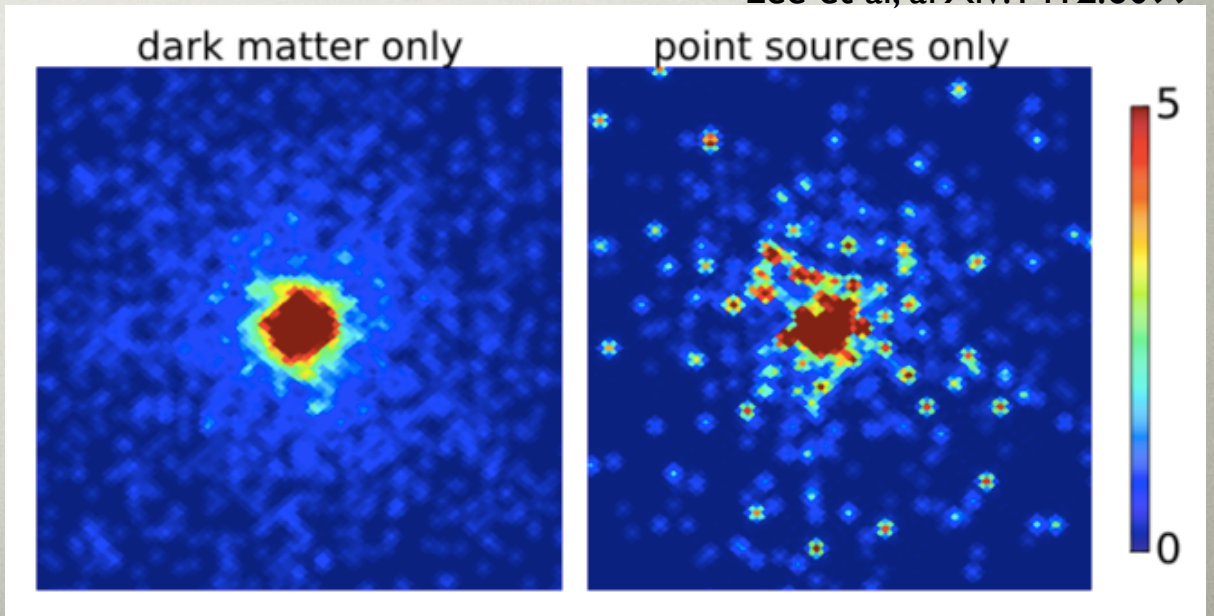


Caveats

- It is likely that some of the point sources are mis-identified structured gas emission



Lee et al, arXiv:1412.6099

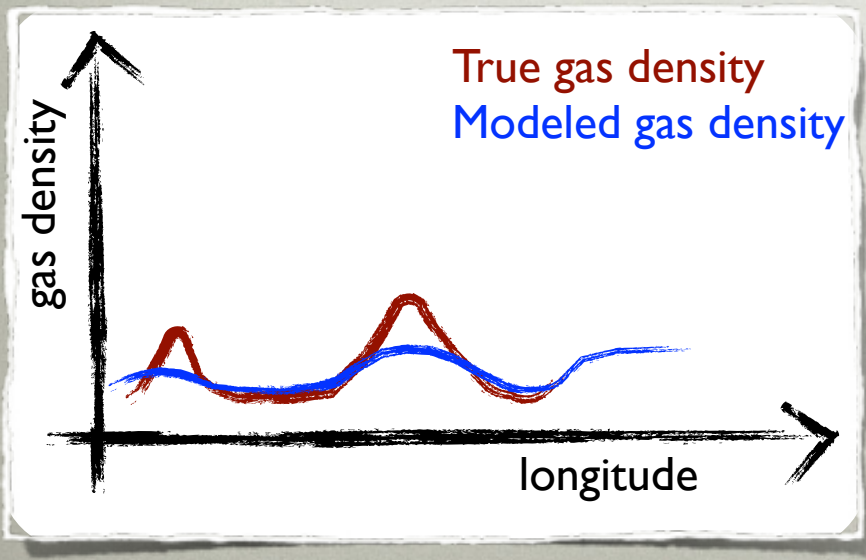


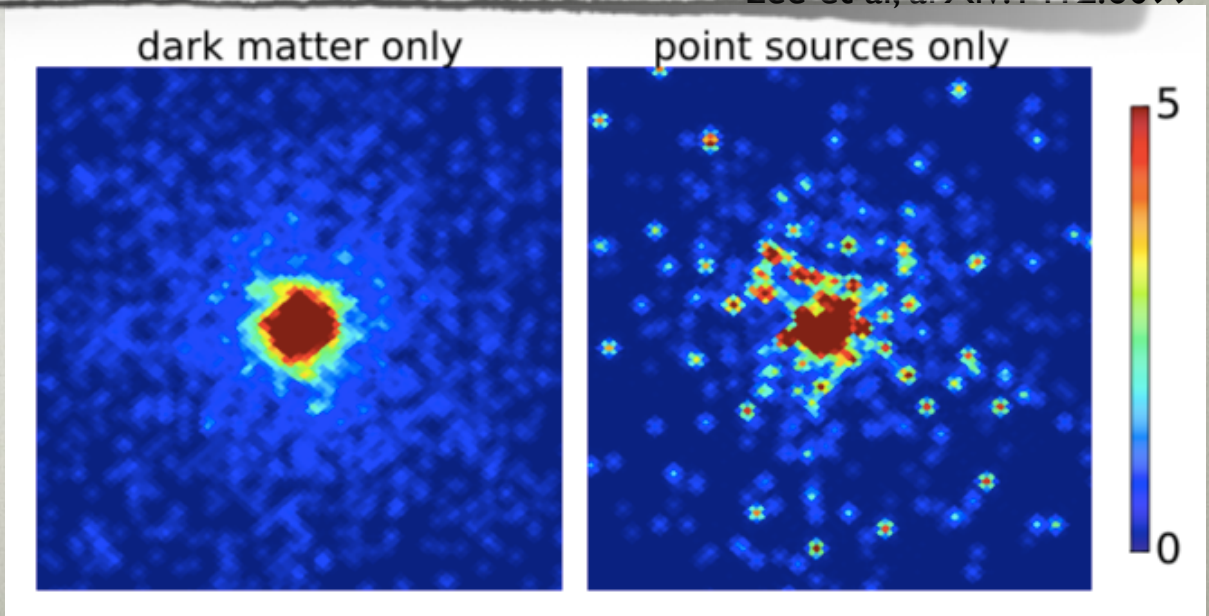
Caveats

These sources must be detected to confirm that the GC excess is generated by a collection of millisecond pulsars

More γ-ray data will help, but even more crucial is the potential of radio surveys (MeerKAT, SKA) to uncover a large number of millisecond pulsars in the Galactic bulge that contribute to the GC excess (Calore et al arXiv:1512.06825)

(A recent claim by the Fermi LAT collaboration on the detection of the point sources generating the Galactic center excess has been retracted, see Fermi LAT Collaboration arXiv:1705.00009 and Bartels et al arXiv:1710.10266)





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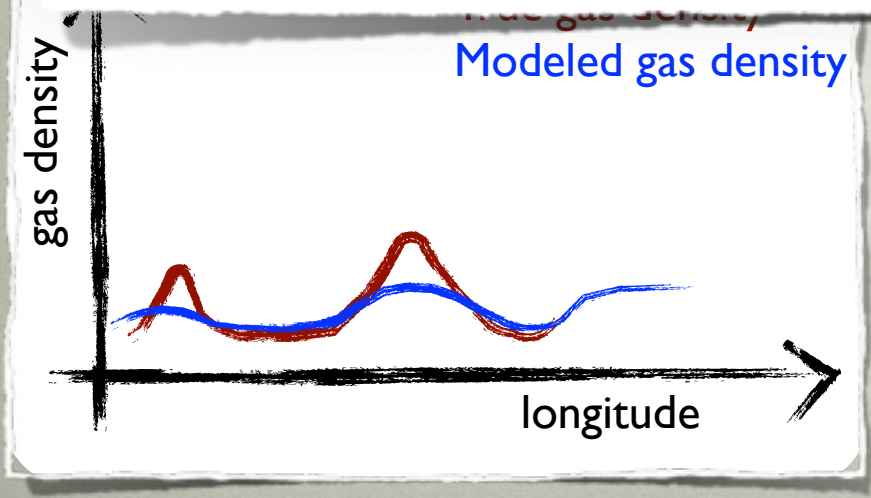
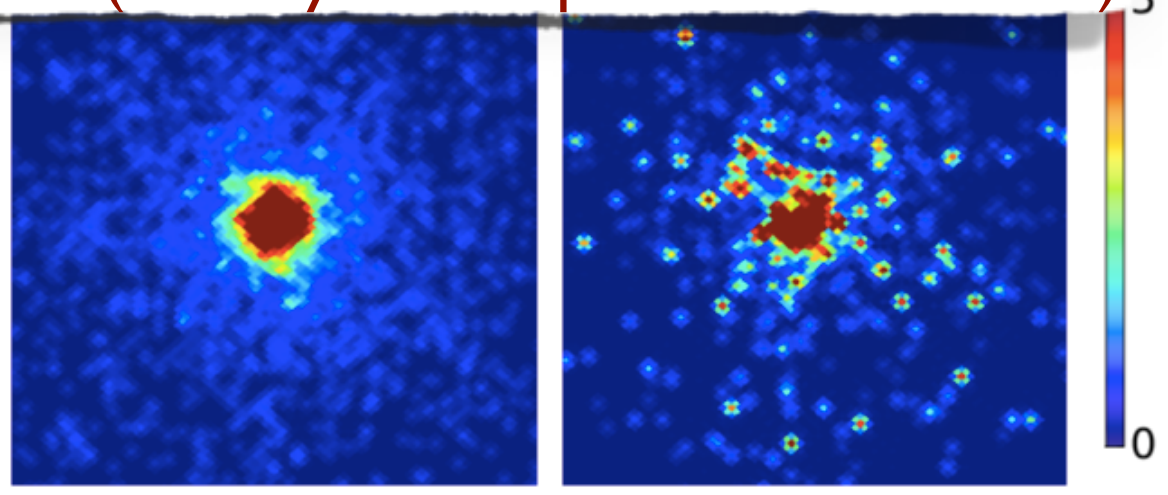
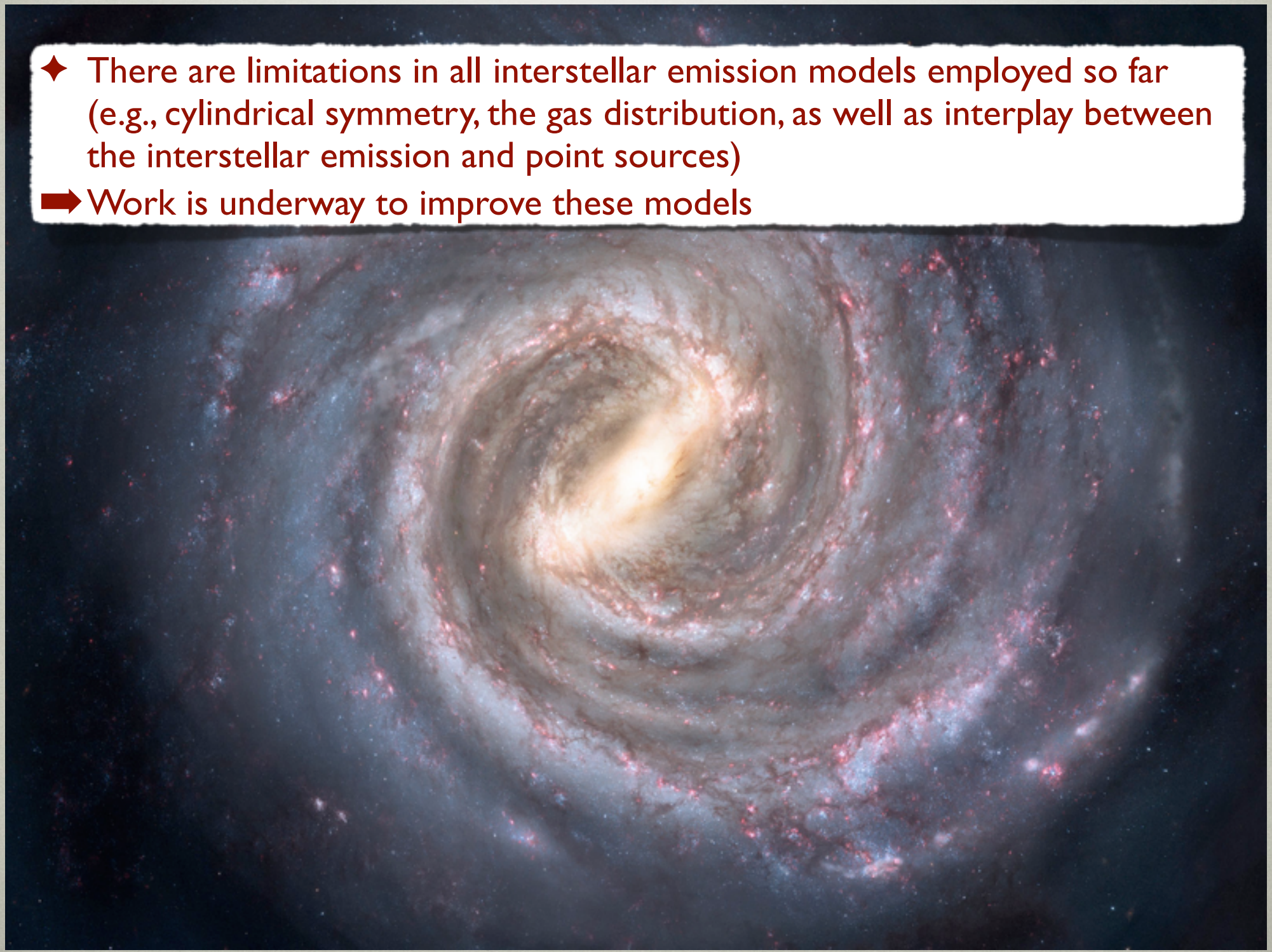
➡ More on GC excess tomorrow (talks by D. Hooper and W. de Boer)






✦ There are limitations in all interstellar emission models employed so far (e.g., cylindrical symmetry, the gas distribution, as well as interplay between the interstellar emission and point sources)
➡ Work is underway to improve these models

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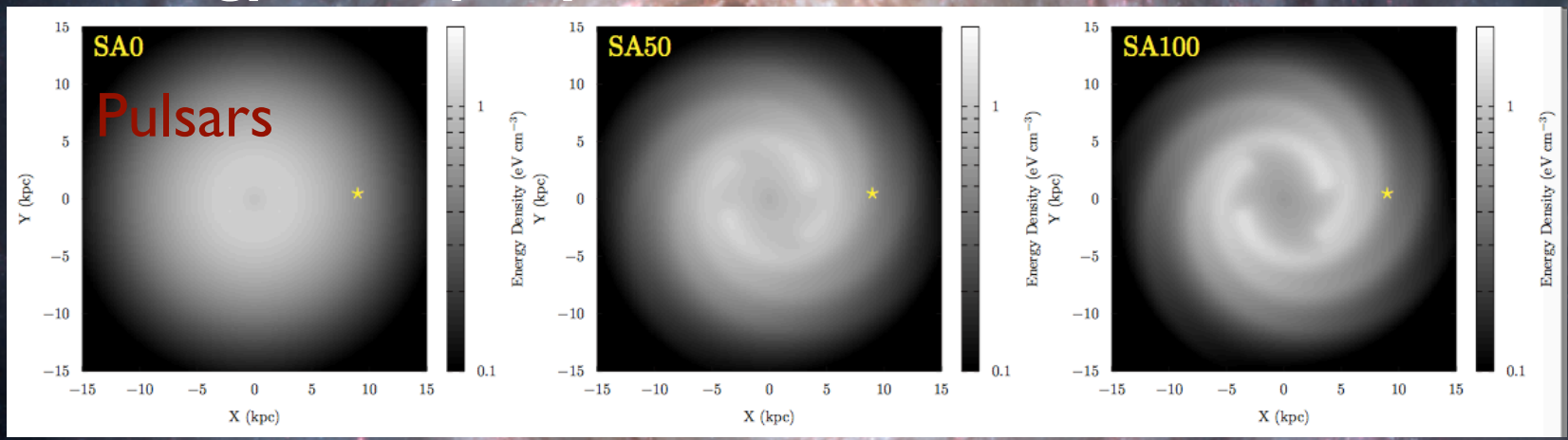
CR energy density at plane

Porter et al, arXiv:1708.00816



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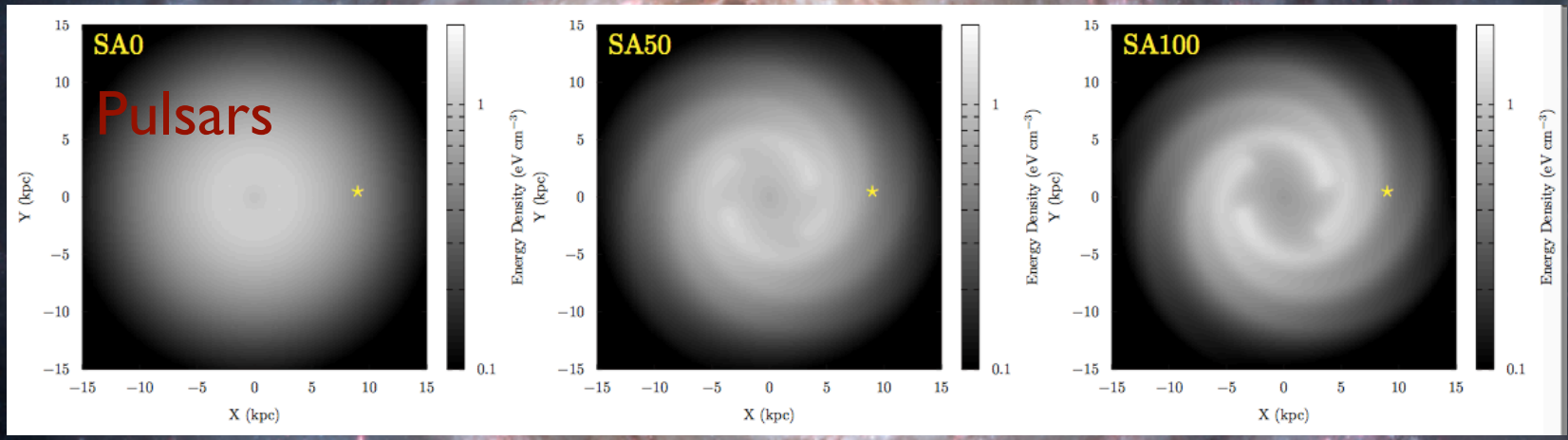
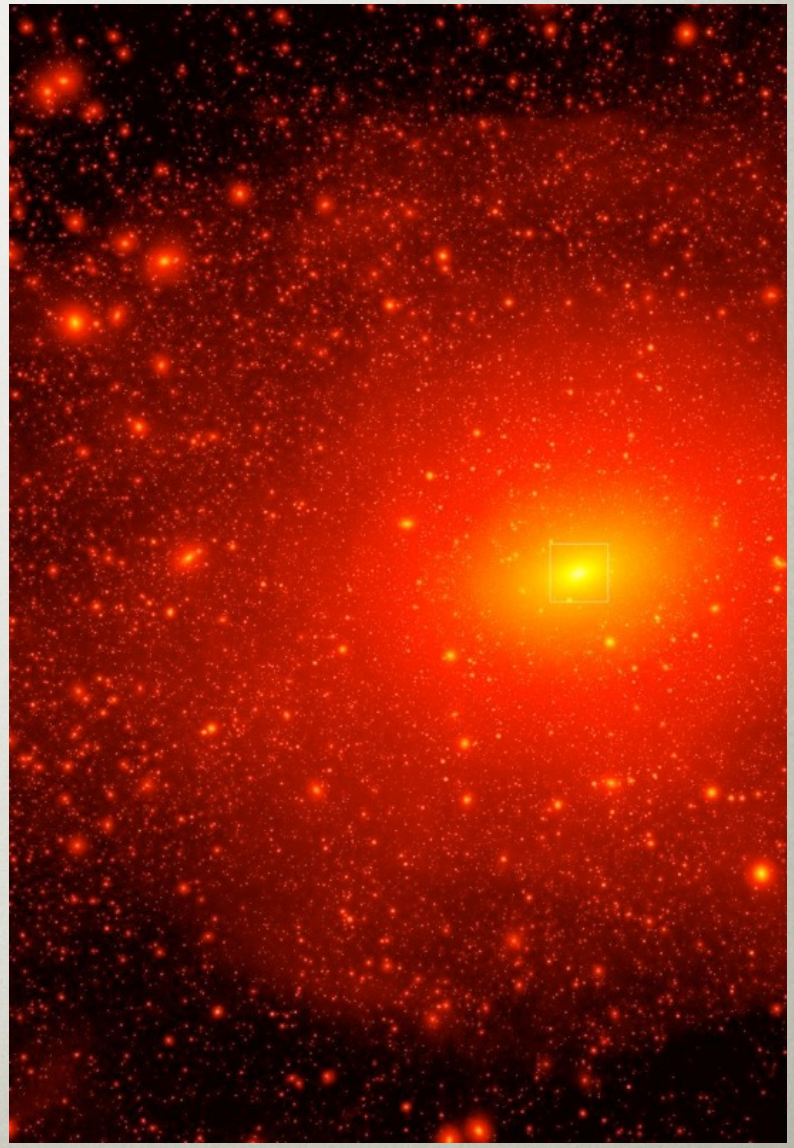


- **The GC excess is a small fraction of the total observed emission (e.g. ~5-10% in a 15°x15° region)**
- ➡ **Improvements in modeling the interstellar emission are crucial to determine/confirm the properties of the excess!**

Dwarf Spheroidal Galaxies

- Optically observed dwarf spheroidal galaxies: largest clumps predicted by N-body simulations

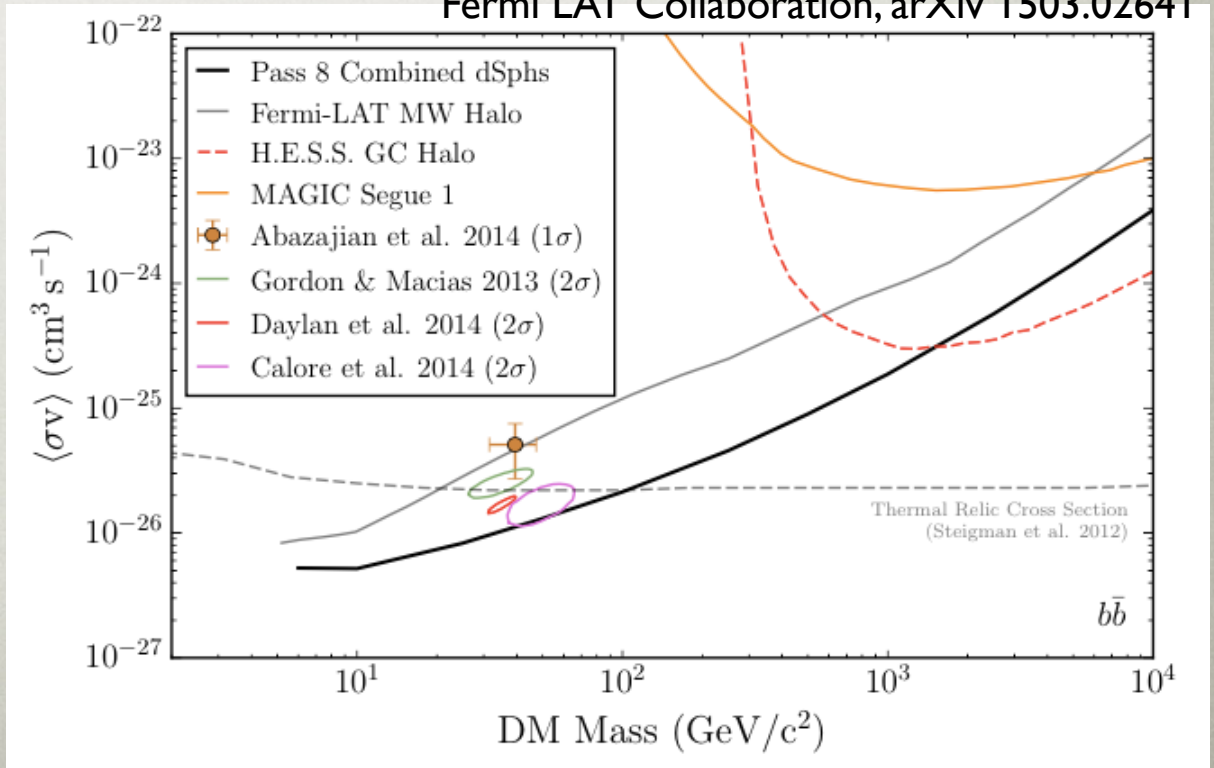
- Excellent targets for gamma-ray DM searches
  - Very large M/L ratio: 10 to ~> 1000 (M/L ~10 for Milky Way)
  - DM density inferred from the stellar data!
  - Expected to be free from other gamma ray sources and have low dust/gas content, very few stars



Dwarf Spheroidal Galaxies

- No significant emission in stacked analysis of dwarf spheroidal galaxies with Fermi LAT 6 yrs of data (Fermi LAT Collaboration arXiv 1503.02641, Albert et al arXiv:1611.03184)
- Limits probe DM explanation of the GC excess

Fermi LAT Collaboration, arXiv 1503.02641



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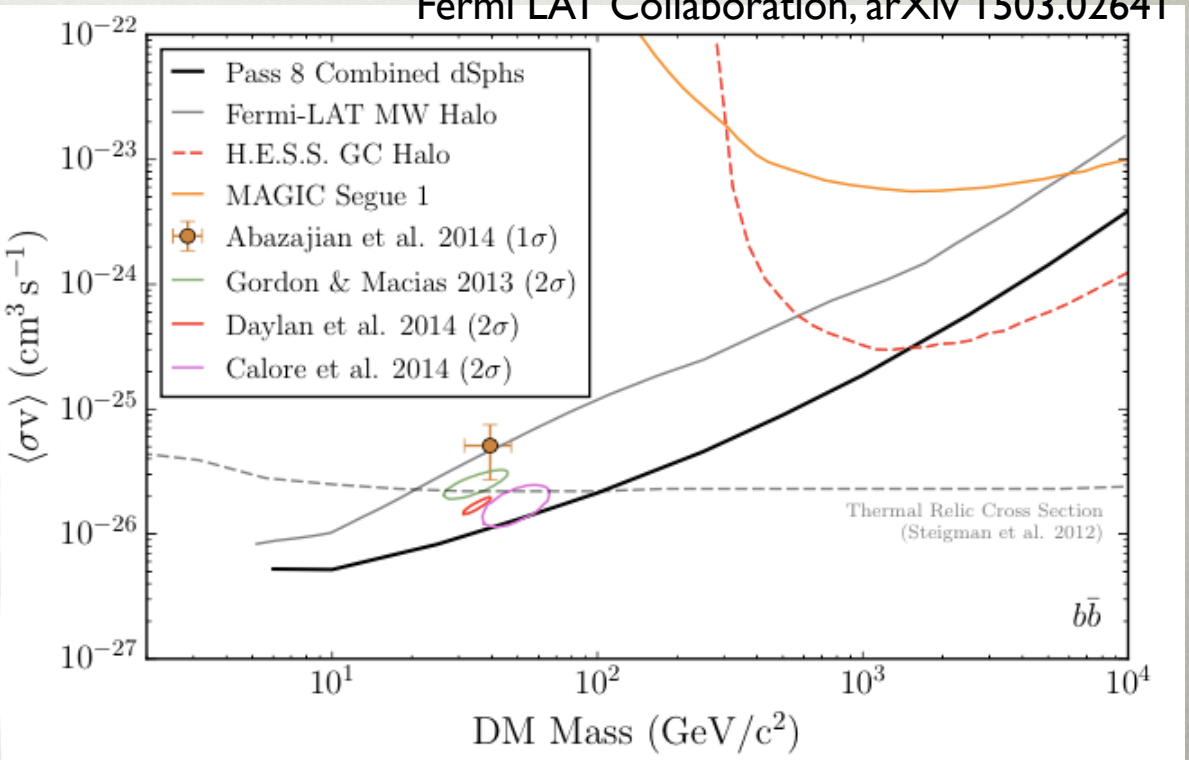

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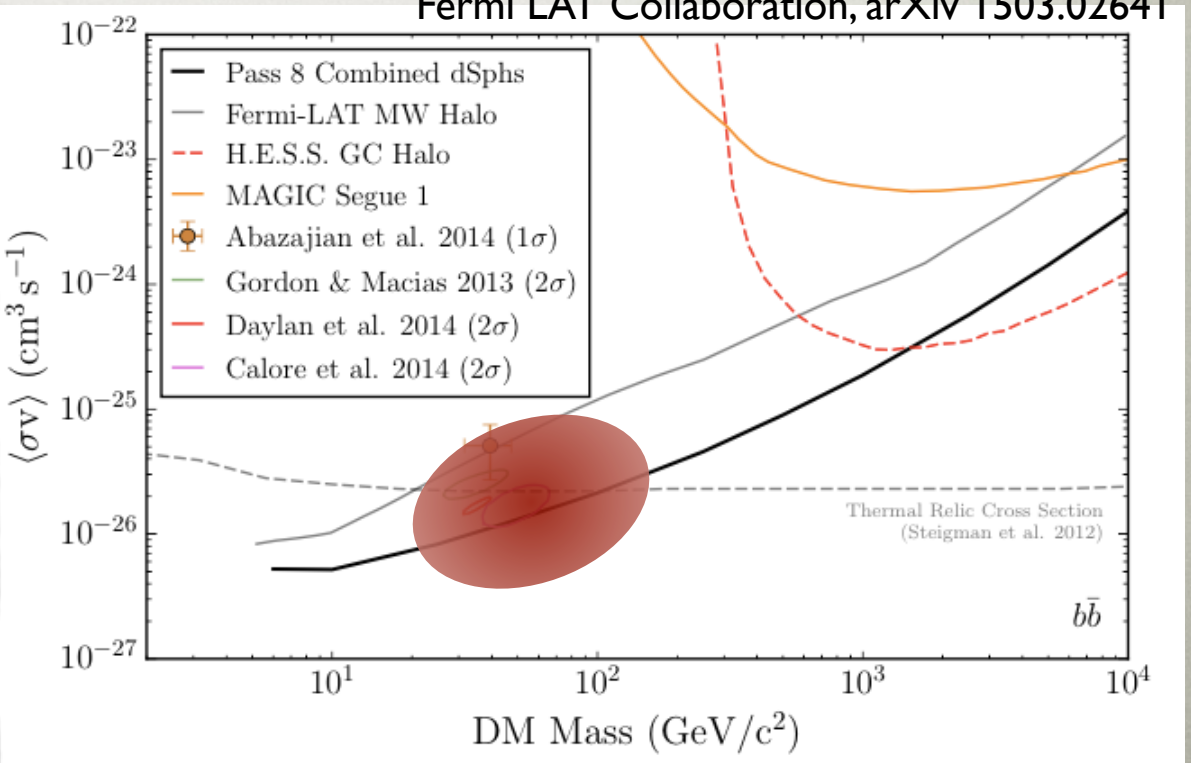

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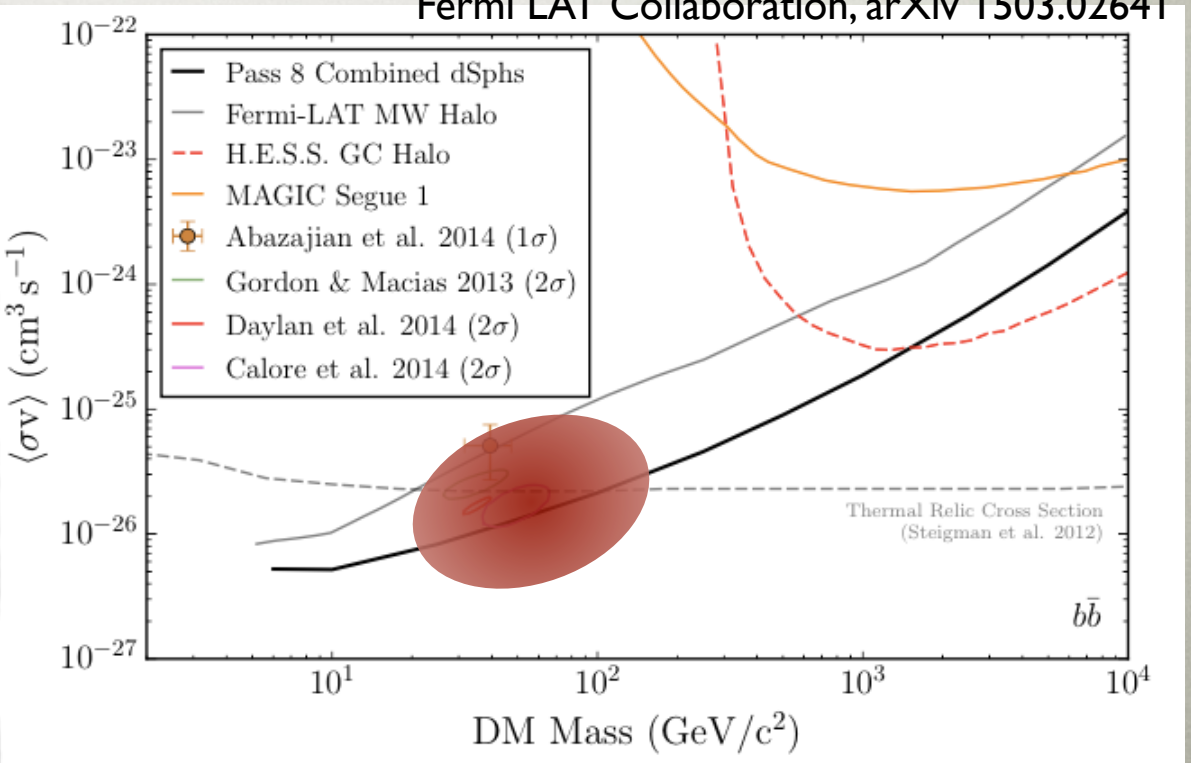
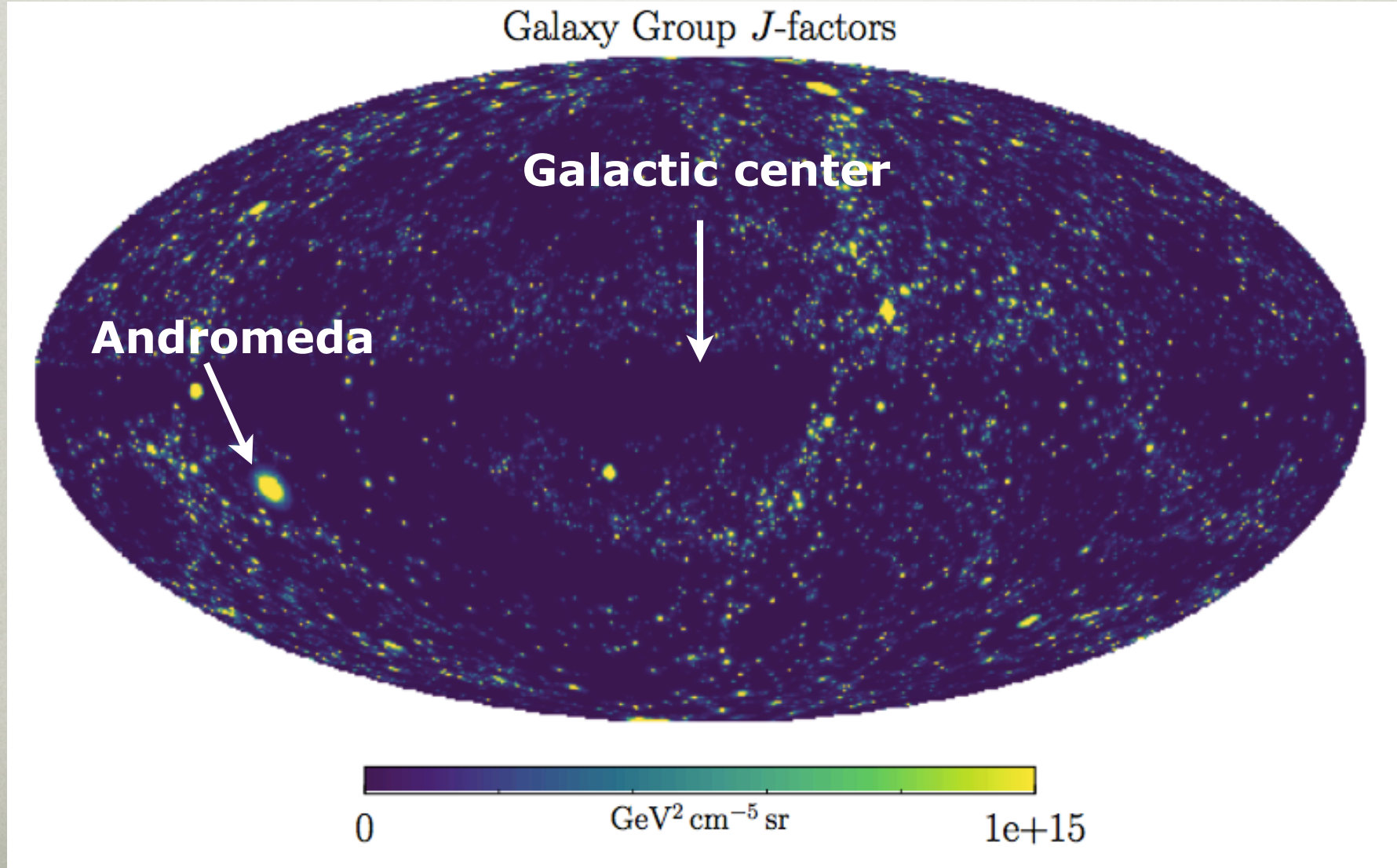


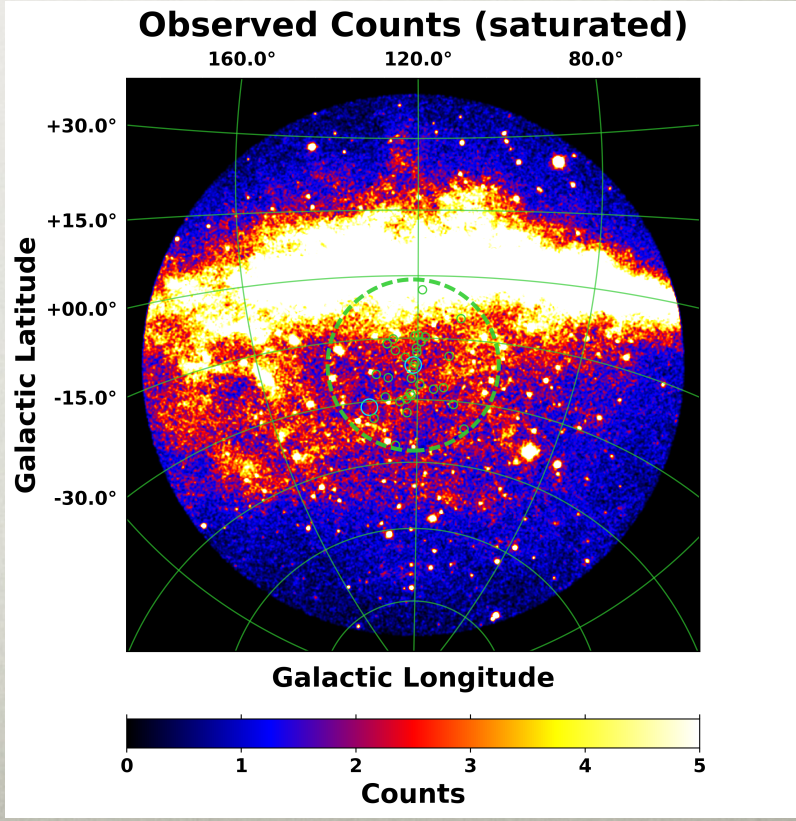
Gamma rays from Dark Matter Annihilation: Beyond the Milky Way

Lisanti et al, arXiv1708.09385



Andromeda (M31)

- DM halo extends several degrees across the sky, with a gradient strongly dependent on DM distribution, substructures and profile.
- Disentangling a DM contribution from M31 is complicated by conventional astrophysics, including the foreground from the Milky Way.



Karwin et al, in prep

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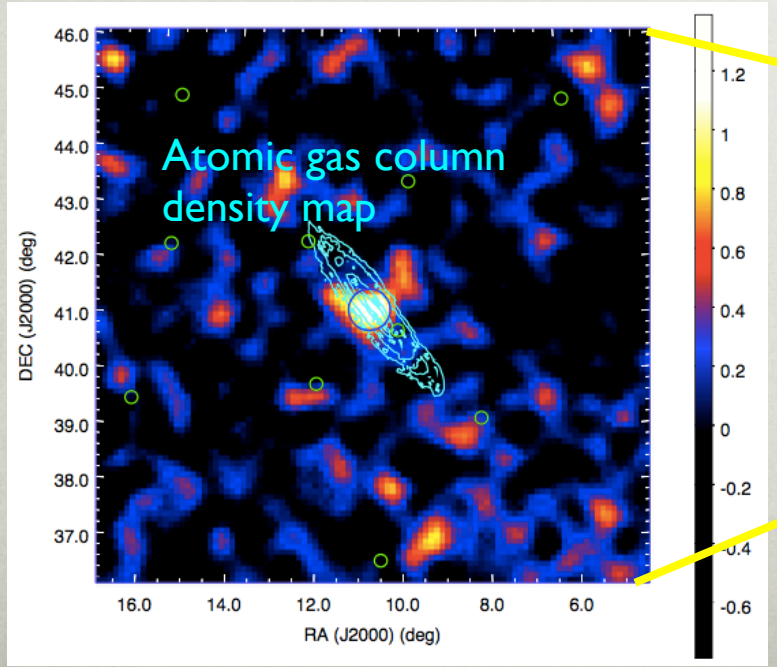

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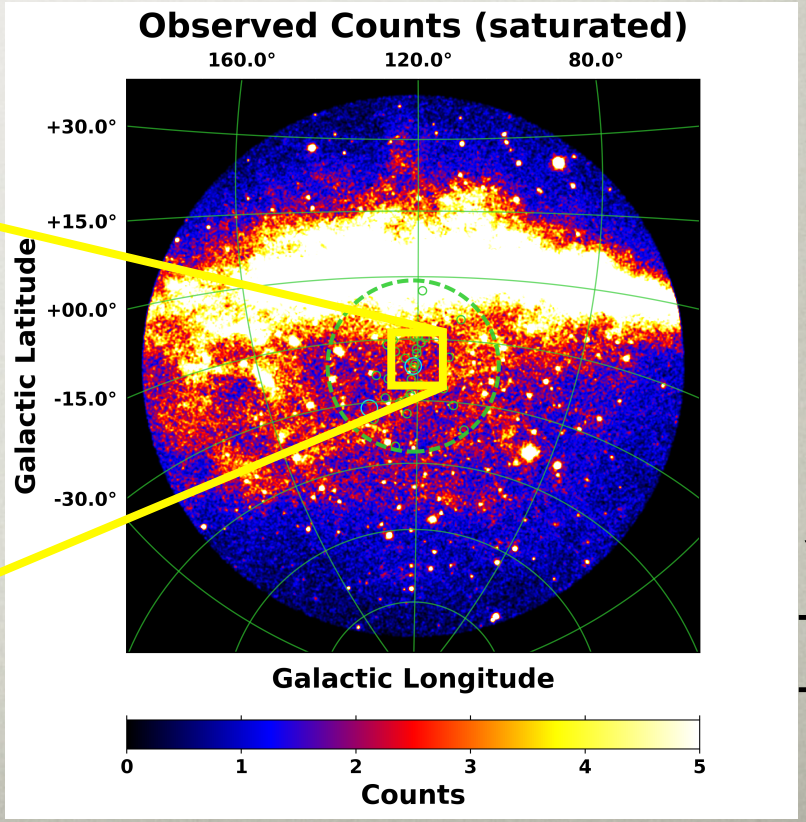

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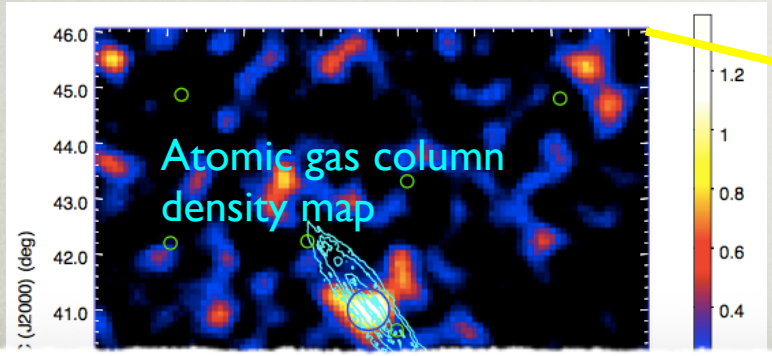
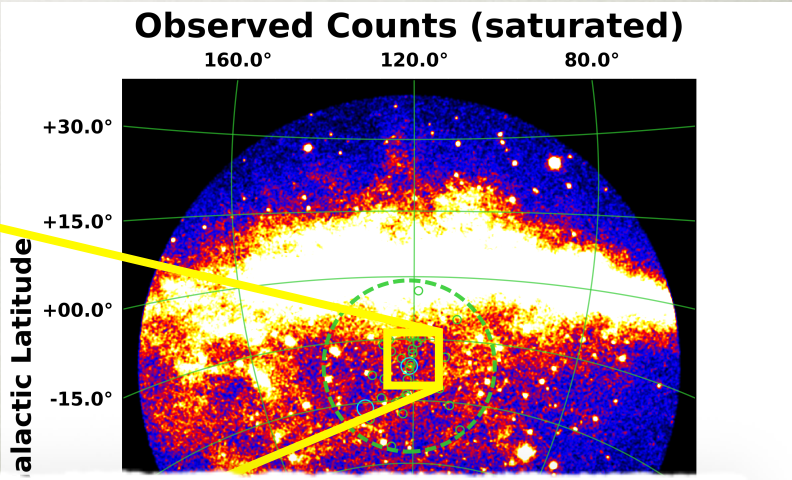


Fermi LAT arX



Karwin et al, in prep

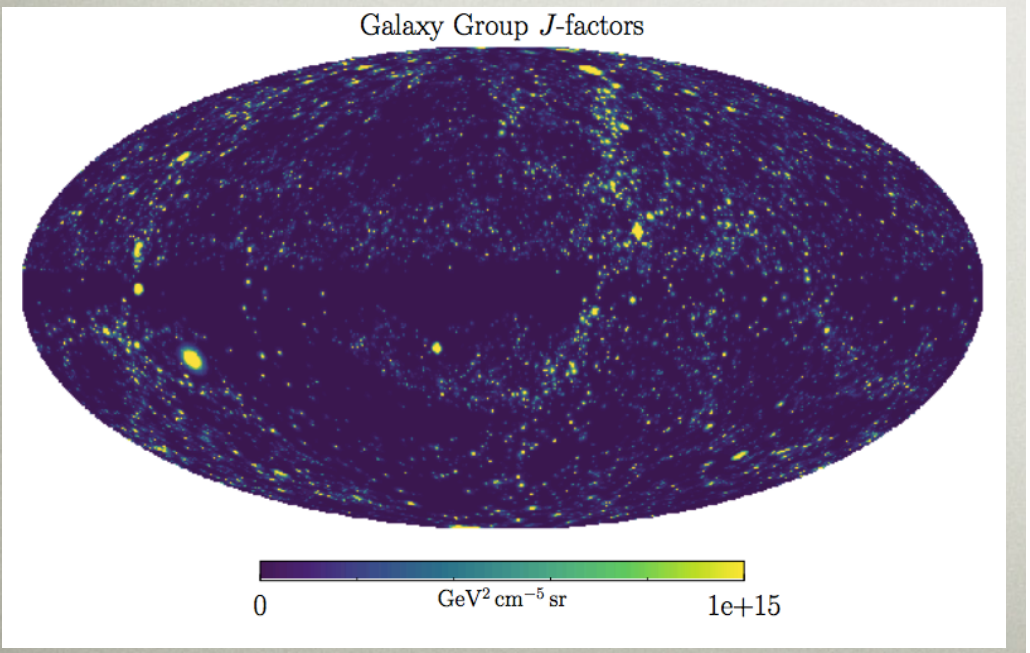
DM and/or millisecond pulsars are possible interpretations of the spherical γ-ray halo, also compatible with GC excess

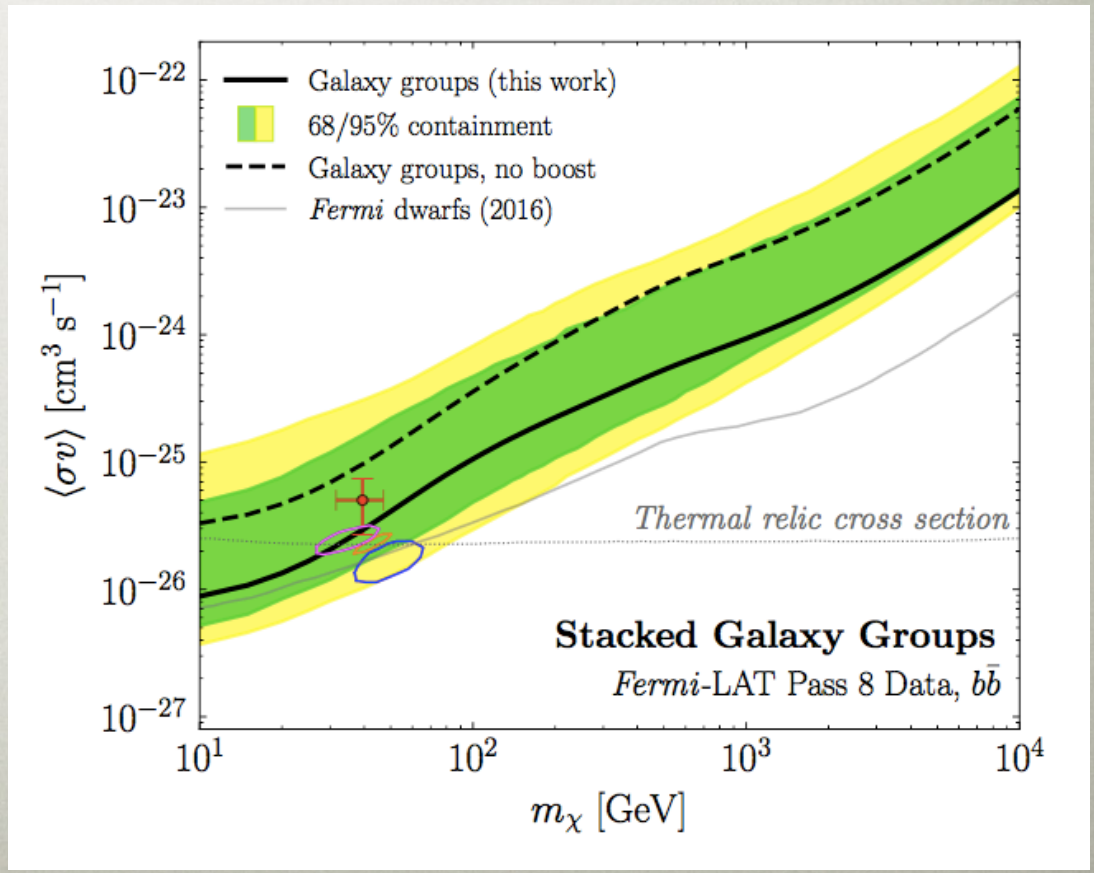
Search for γ-ray emission beyond the boundaries of the M31 galactic disk is complicated by Milky Way foreground (see poster by C. Karwin)

Beyond the Local Group

- A stacked analysis of ~500 galaxy groups ($z < 0.03$, $M \gtrsim 10^{12}\ M_\odot$) from recent catalogs shows no evidence for a DM signal and set constraints comparable to the dwarf spheroidals
- J-factors inferred by luminosity-based mass estimates and mass-to-concentration relations

Lisanti et al, arXiv1708.09385





Summary

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- Although other plausible interpretations exist (notably millisecond pulsars), a DM interpretation of the excess from the Galactic center cannot be ruled out

  Complementarity with other searches is crucial, e.g. a consistent signal from other DM targets/searches (e.g. dSph, direct and collider DM searches) would provide the most compelling confirmation of a DM origin

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THANK YOU!