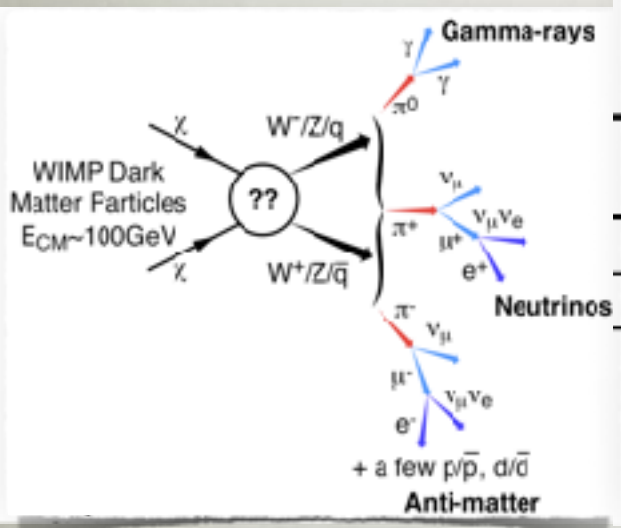
The Gamma-Ray Galactic Center Excess

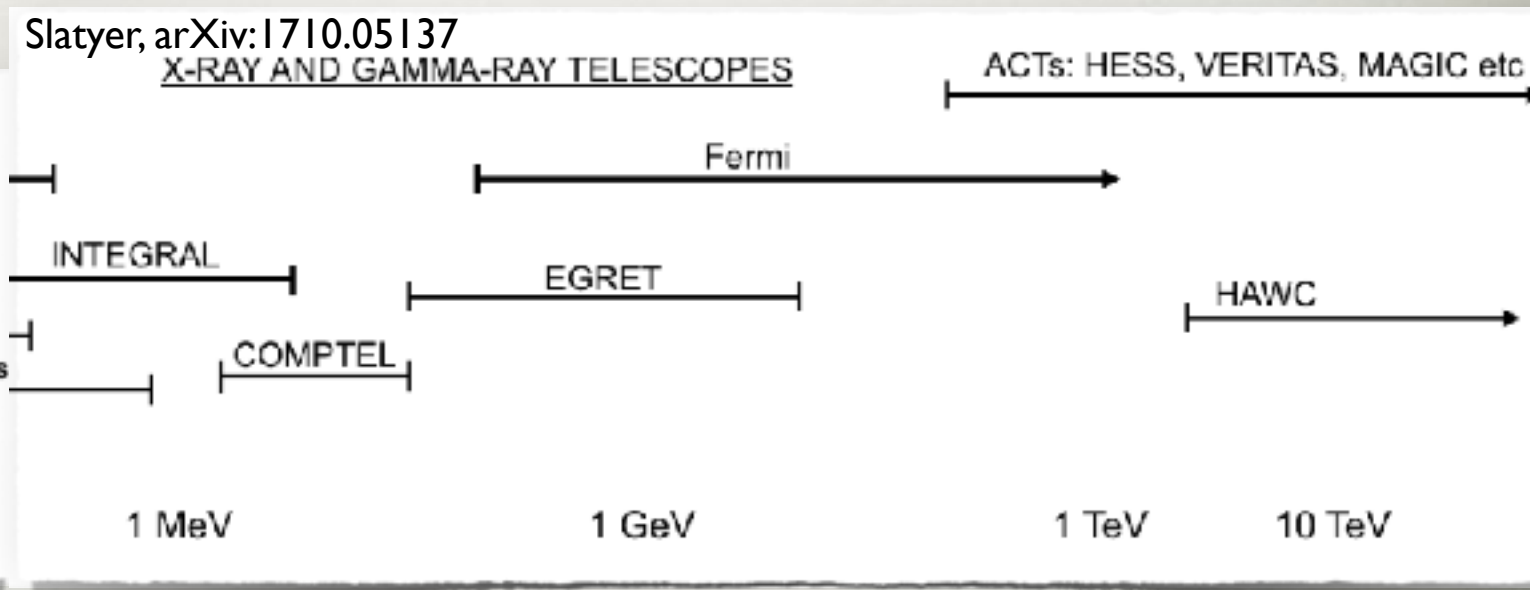
Simona Murgia
University of California, Irvine

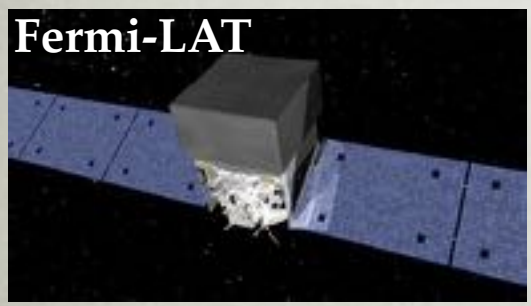
Identification of Dark Matter 2018
Brown University - 27 July 2018

Indirect Searches
Gamma Rays



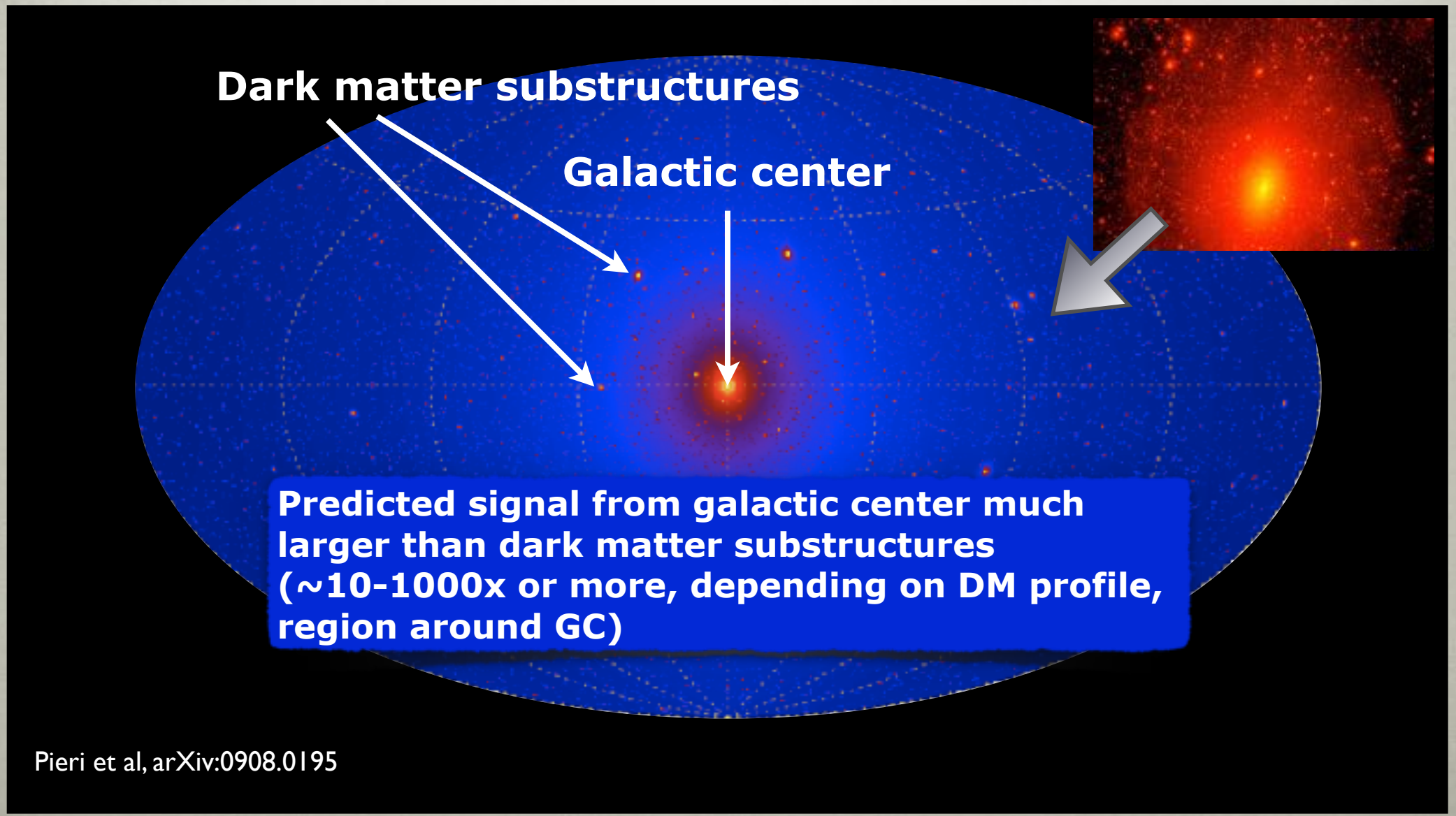
Slatyer, arXiv:1710.05137





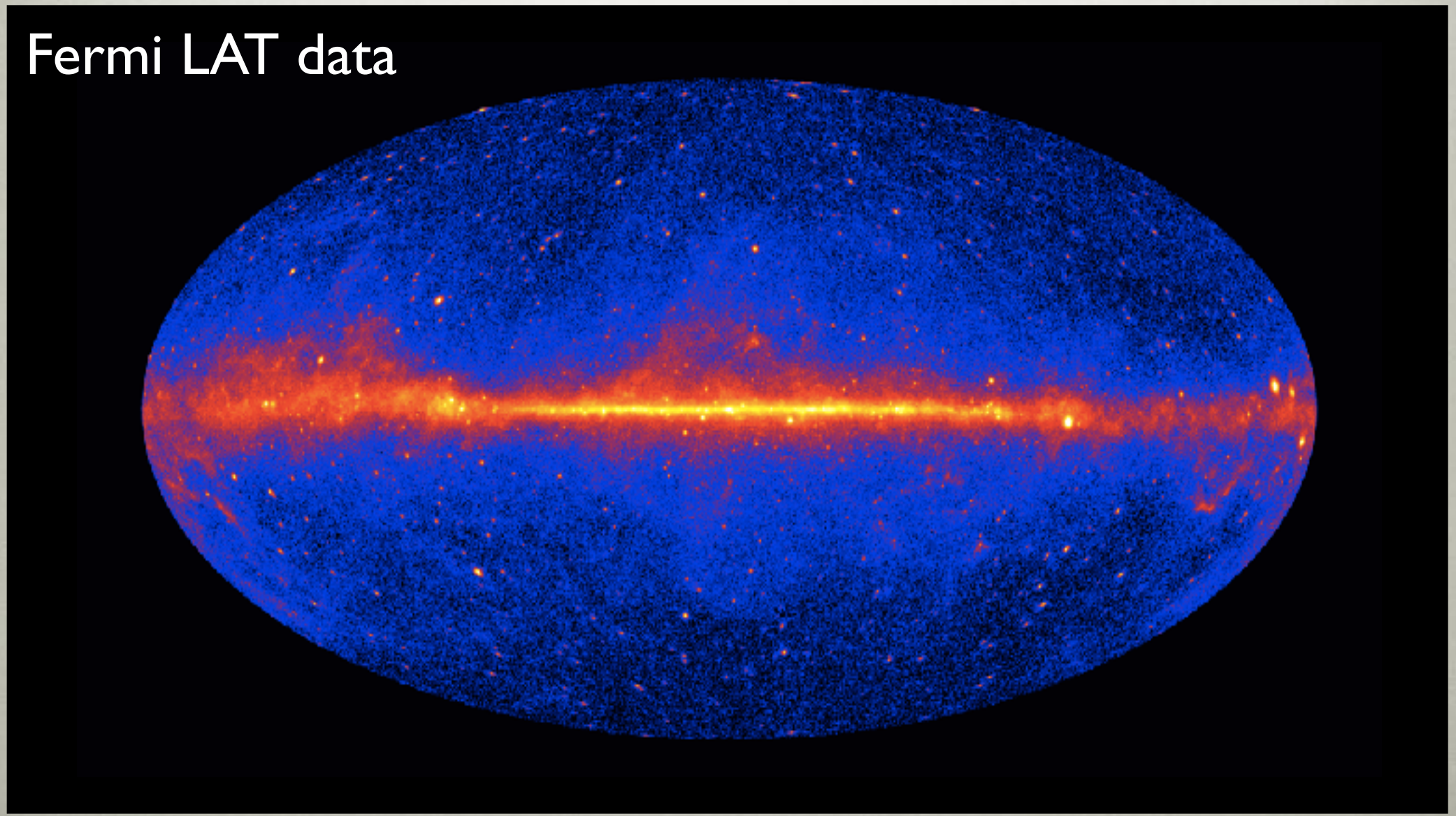
Gamma rays from Dark Matter Annihilation:

The Milky Way & its satellites



Pieri et al, arXiv:0908.0195

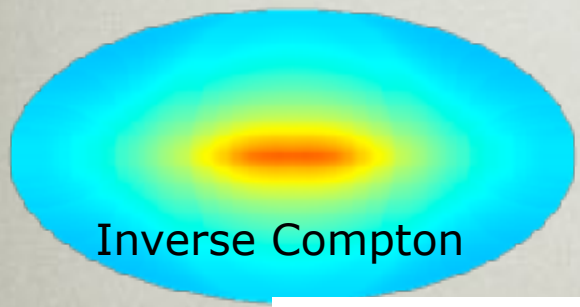
The Fermi Sky

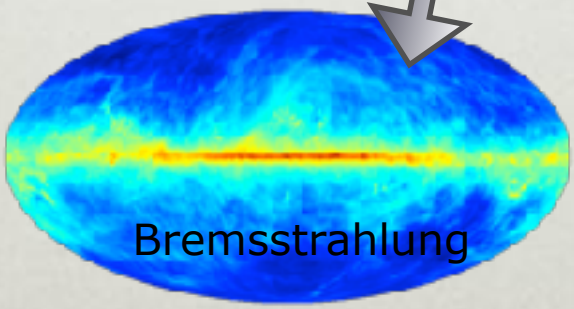


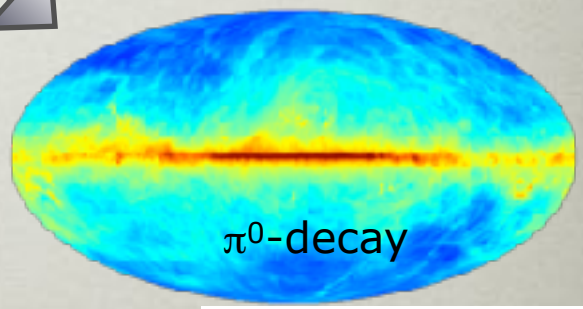
Galactic Gamma-Ray Interstellar Emission

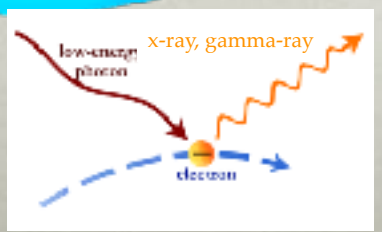
- The interstellar gamma-ray emission in the Milky Way is produced by cosmic rays interacting with the interstellar gas and radiation field

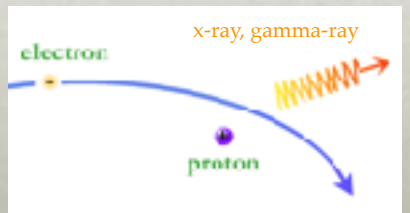
galactic interstellar emission

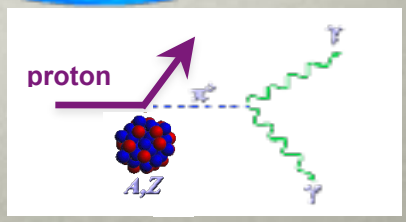








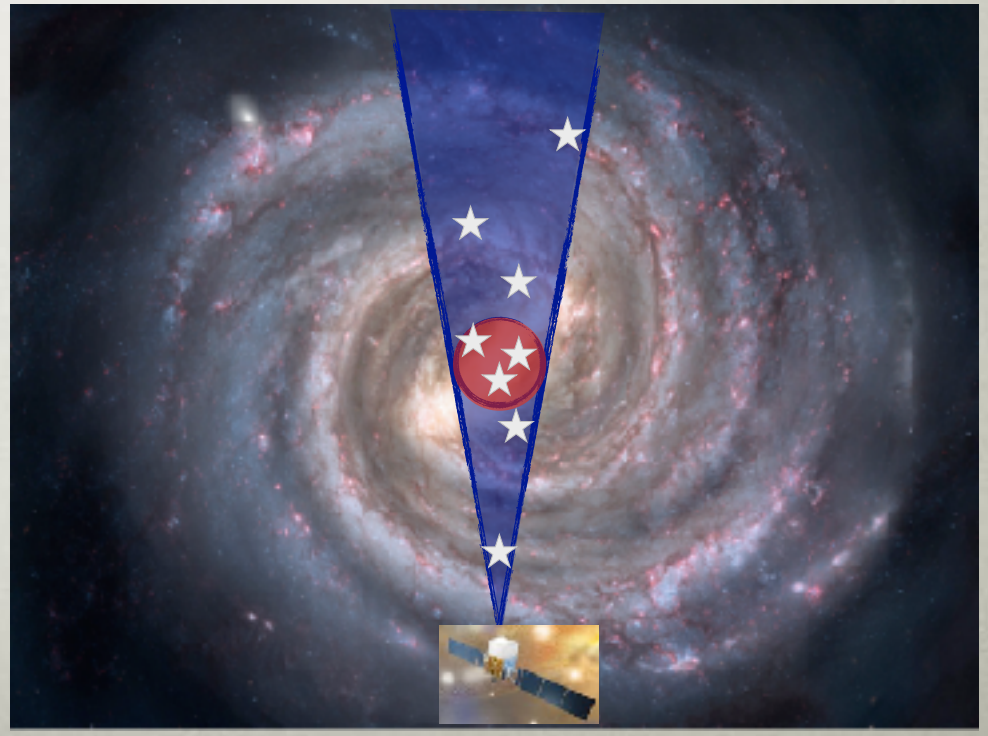




Galactic Gamma-Ray Interstellar Emission

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

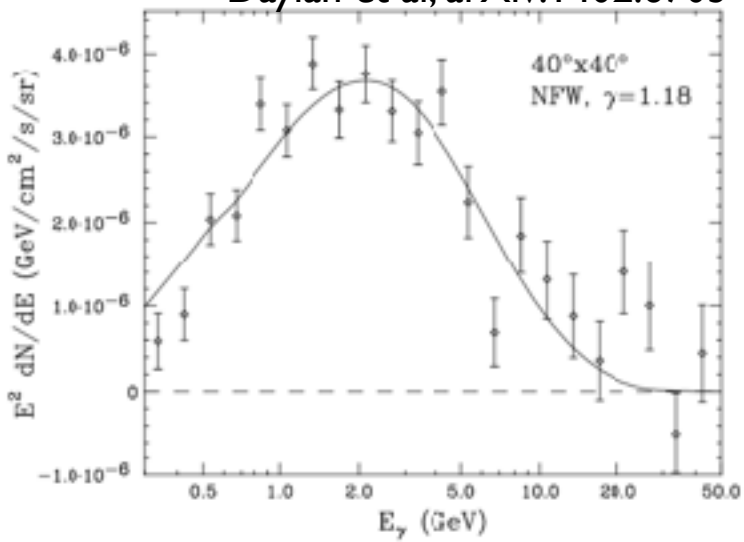
➡ Galactic center region: a dark matter signal is predicted to be largest here, where modeling of the interstellar emission (and sources) is problematic!
CR intensities, density of radiation fields and gas are highest and most uncertain, long integration path over the entire Galactic disc, large density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



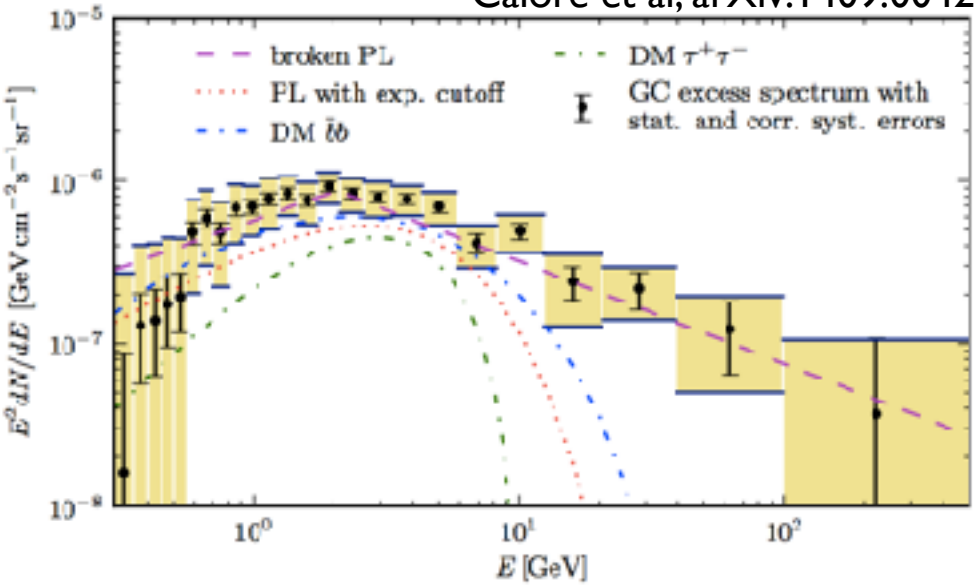
Galactic Center Excess

- 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!

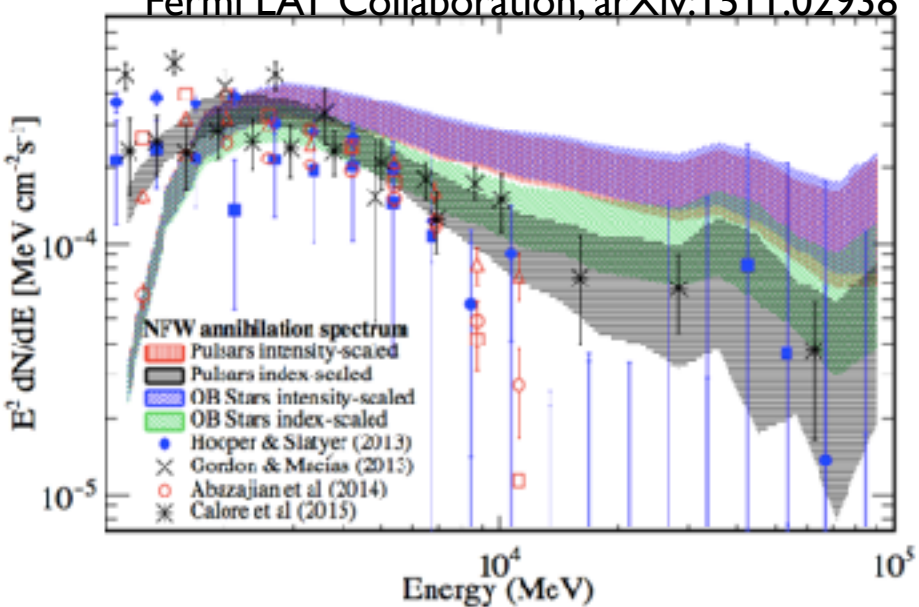
Daylan et al, arXiv:1402.6703



Calore et al, arXiv:1409.0042



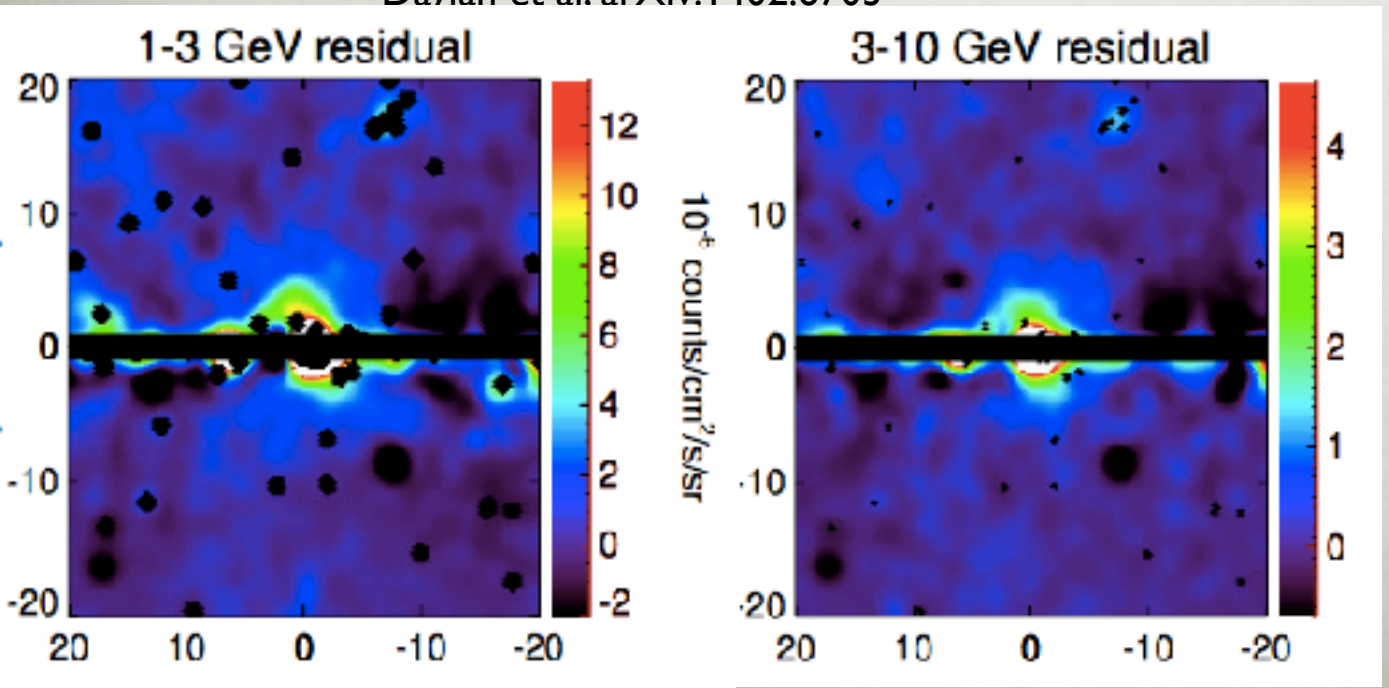
Fermi LAT Collaboration, arXiv:1511.02938



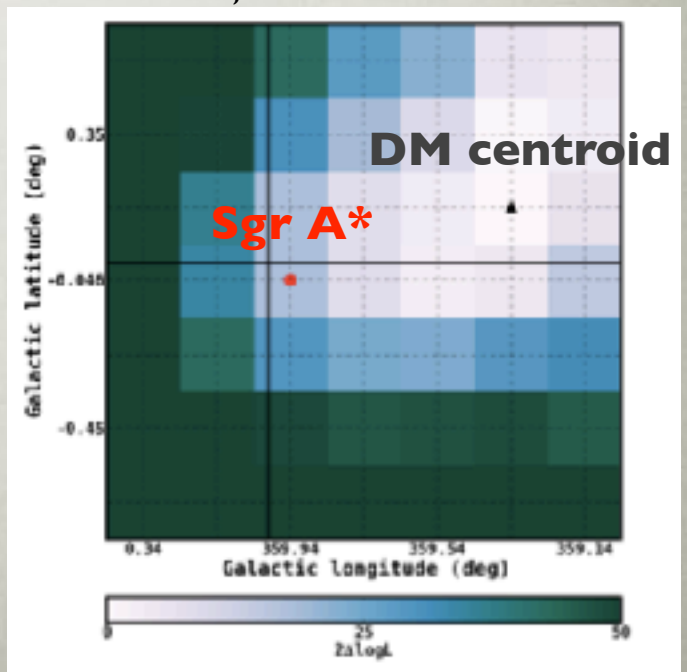
Galactic Center Excess

- 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)

Daylan et al. arXiv:1402.6703



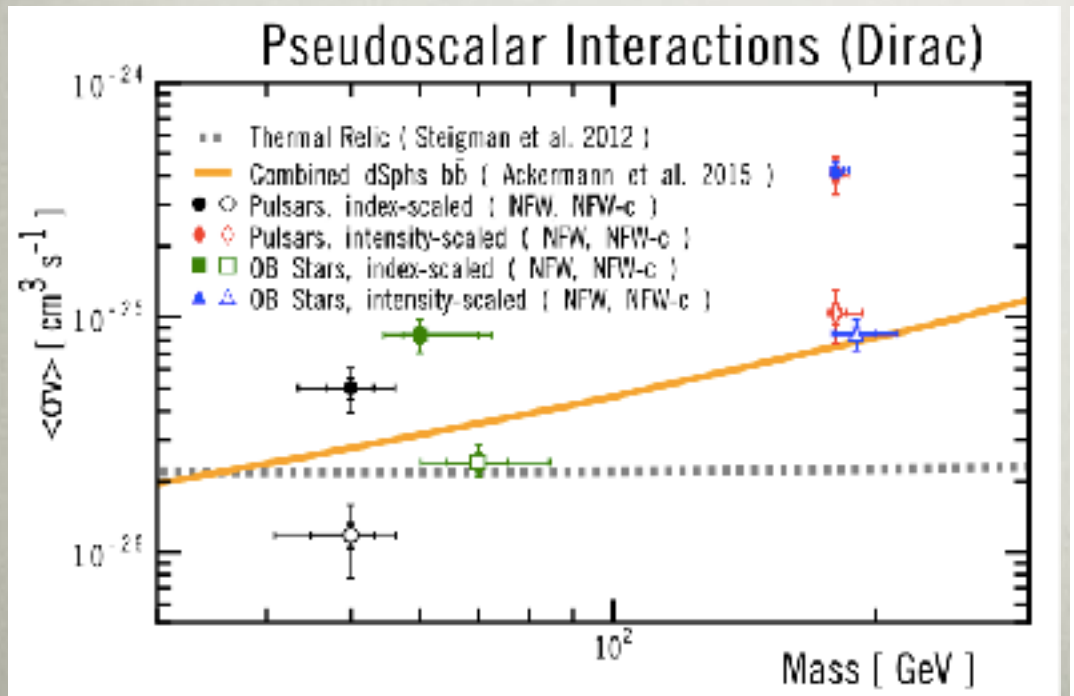
Karwin et al, arXiv:1612.05687

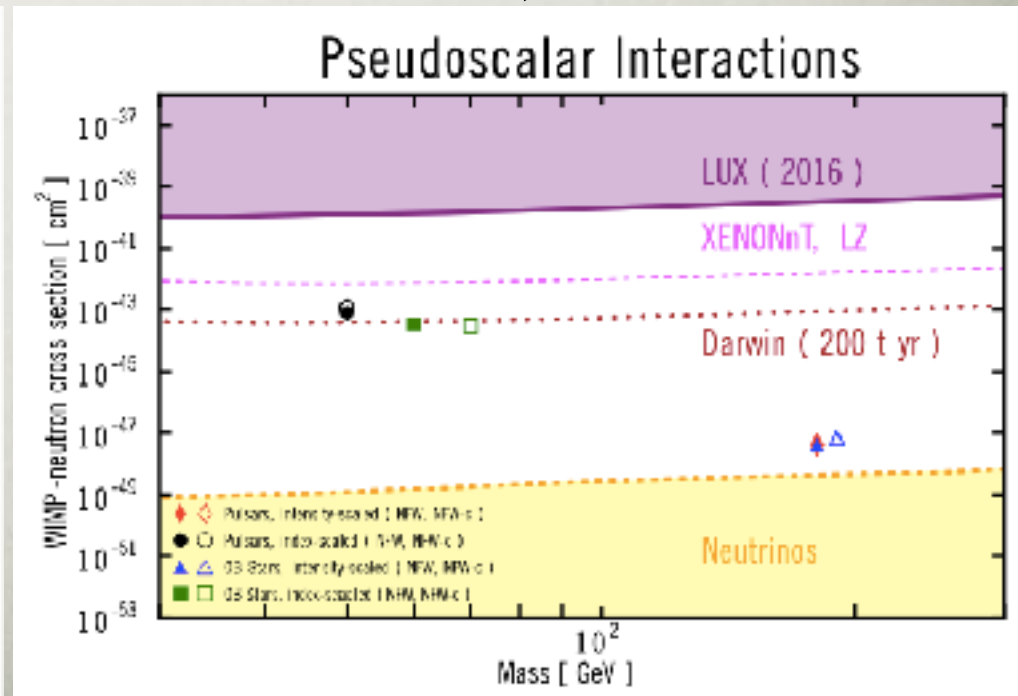


Implications for Dark Matter Models

- 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

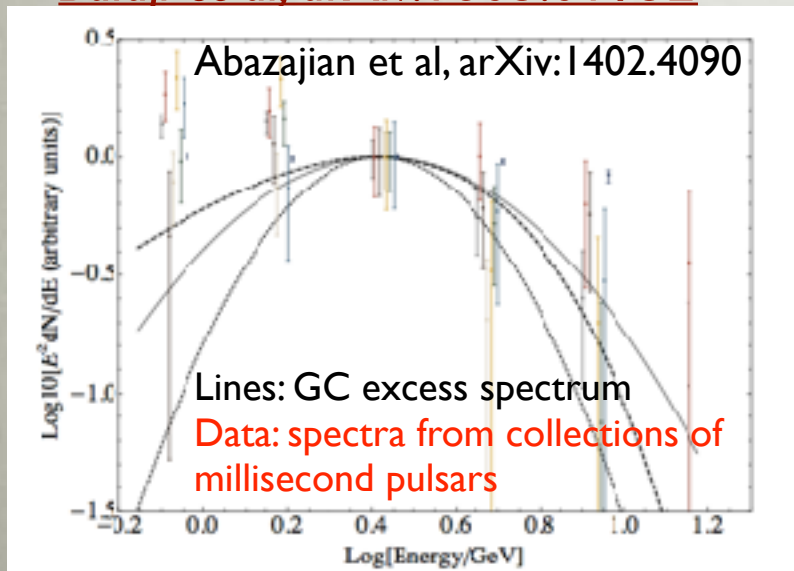




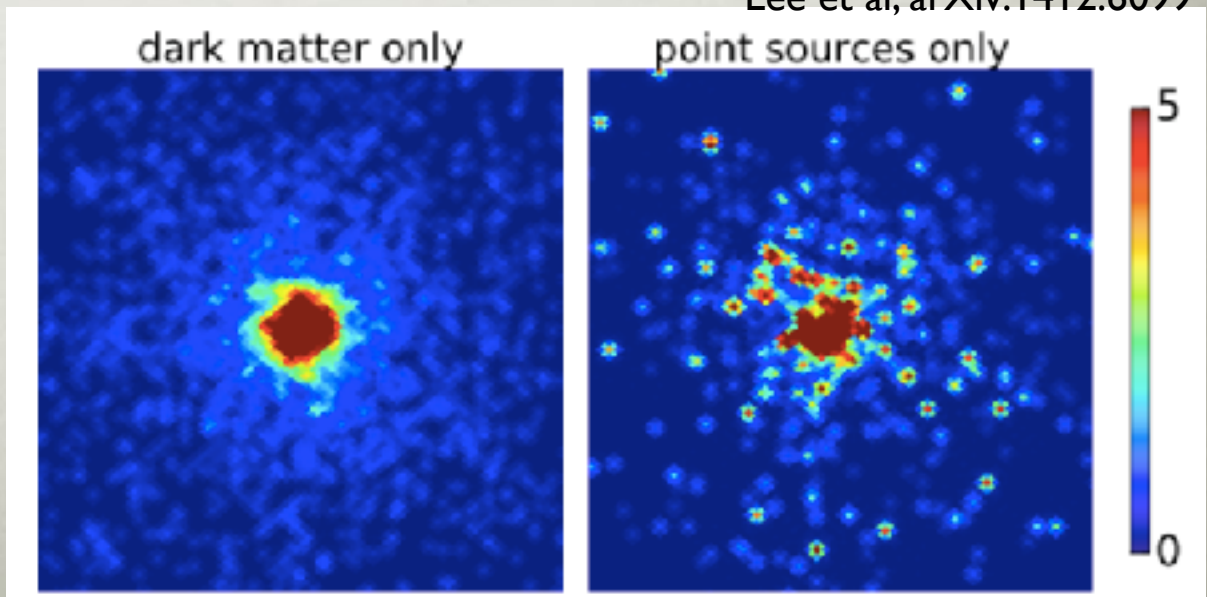
Pulsars

- An unresolved population of millisecond pulsars can explain the excess
  - Claimed excess is found consistent with *O(1,000) millisecond pulsars* within ~1 kpc of GC (Abazajian et al arXiv:1402.4090, but see also Hooper et al arXiv:1606.09250.) Gonthier et al arXiv:1806.11215 estimate *O(10,000) millisecond pulsars* from the Galactic bulge
  - 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 (O(100) for Lee et al), however see Balaji et al, arXiv:1803.01952*



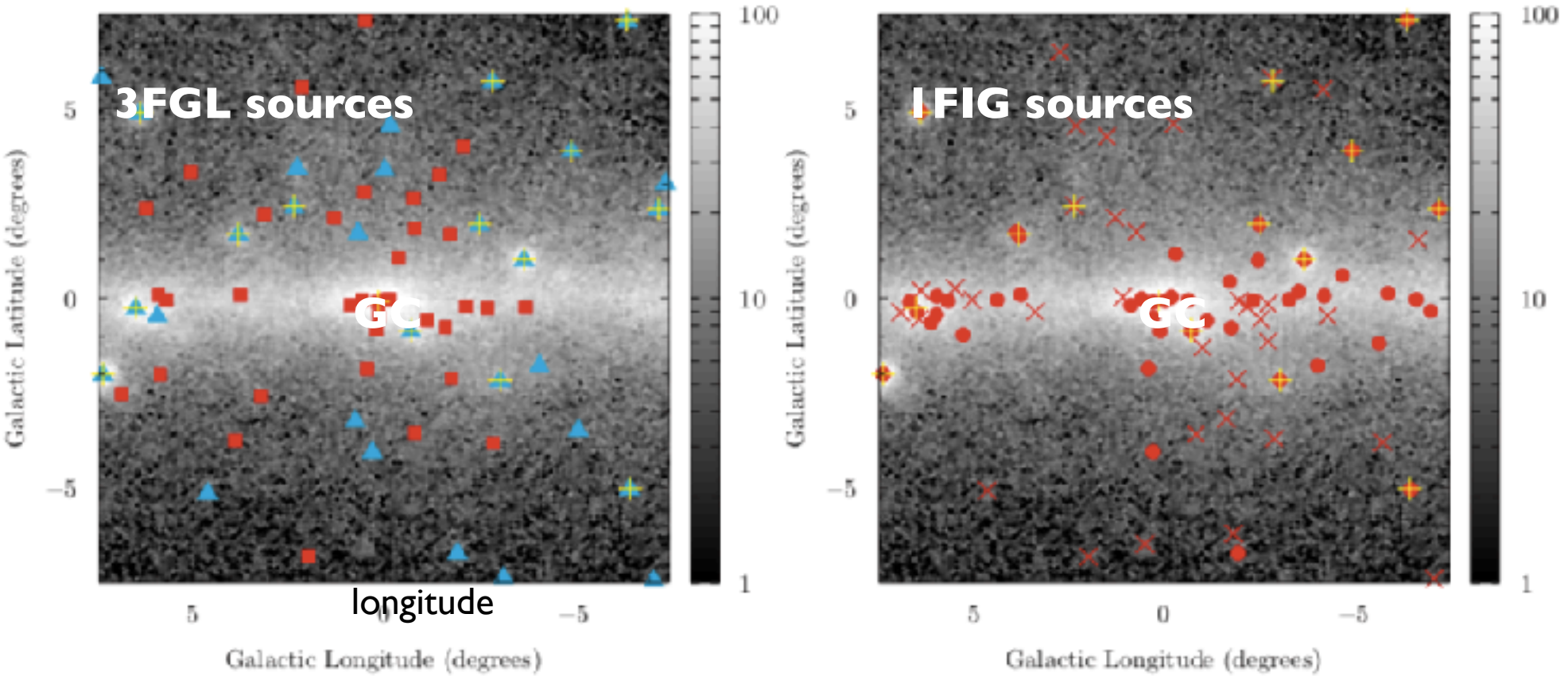
Lee et al, arXiv:1412.6099



Caveats

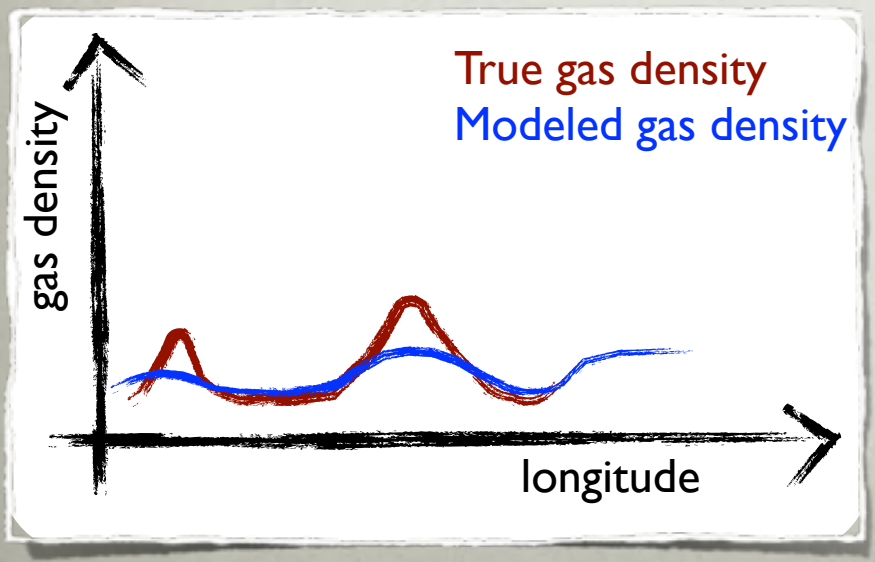
- The distribution of gamma-ray point sources in the inner Galaxy in uncertain, with a significant dependence on the interstellar emission model, i.e. some are spurious (they trace features in the molecular gas)!

Fermi LAT Collaboration, arXiv:1511.02938

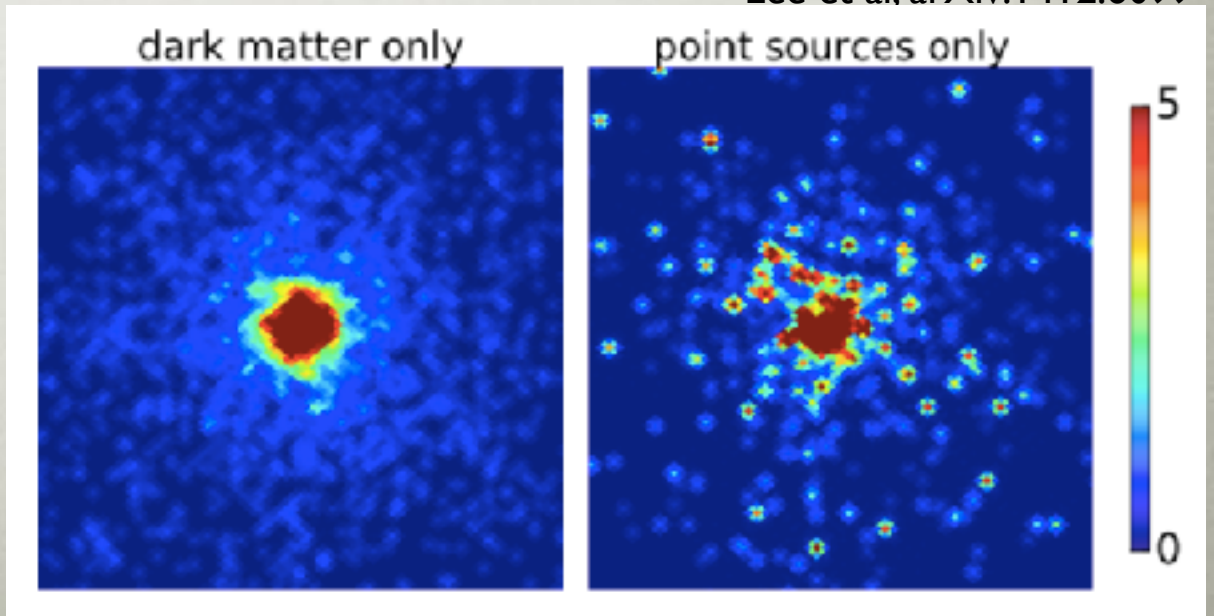


Caveats

- The distribution of gamma-ray point sources in the inner Galaxy in uncertain, with a significant dependence on the interstellar emission model, i.e. some are spurious (they trace features in the molecular gas)!
- It is likely that some of the point sources are mis-identified structured gas emission



Lee et al. arXiv:1412.6099

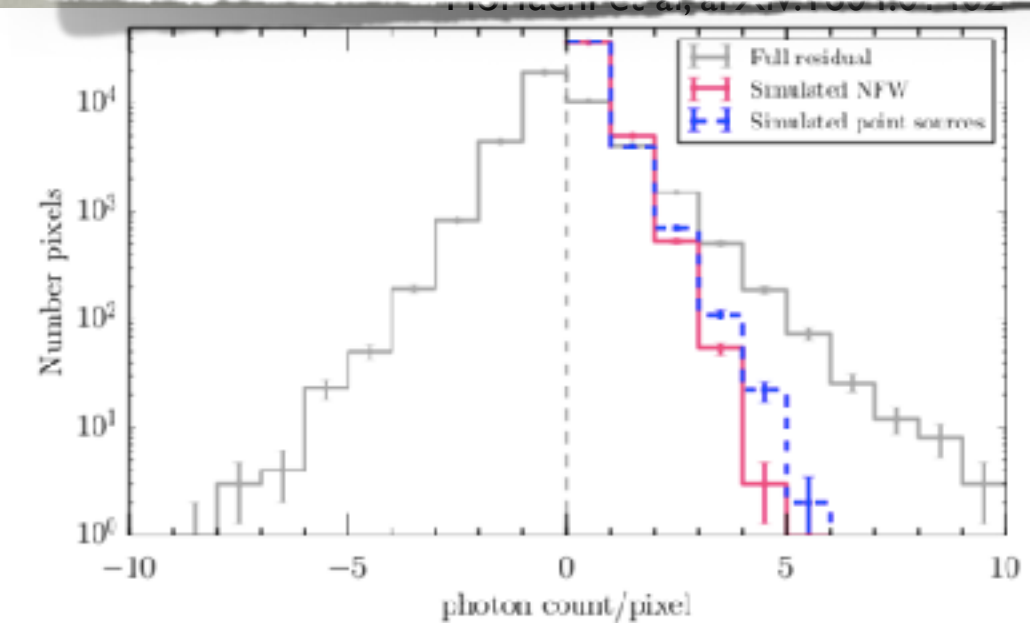


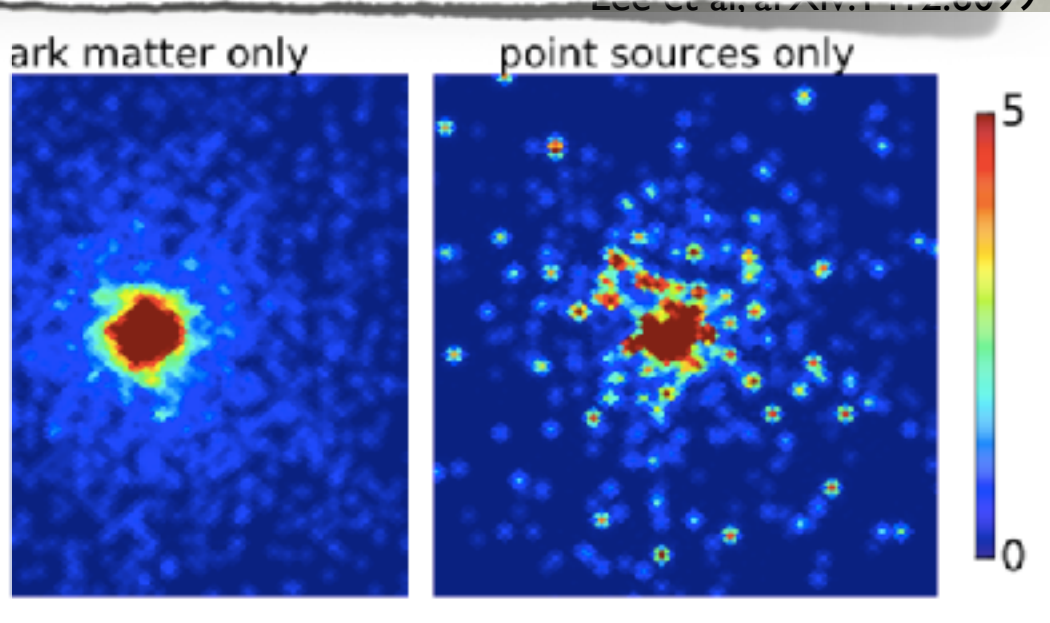
Caveats

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

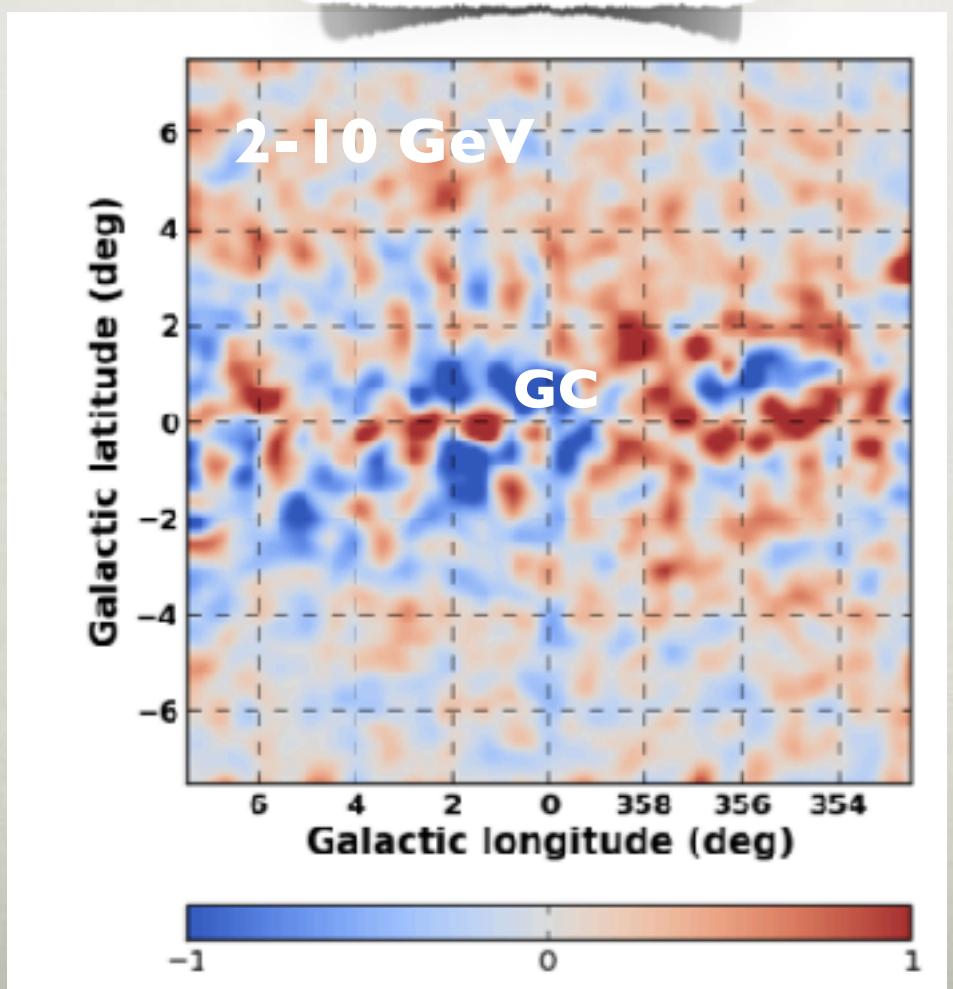




Caveats

- Improvements in the data-model agreement after including a dark matter component, but discrepancies between data and model remain.

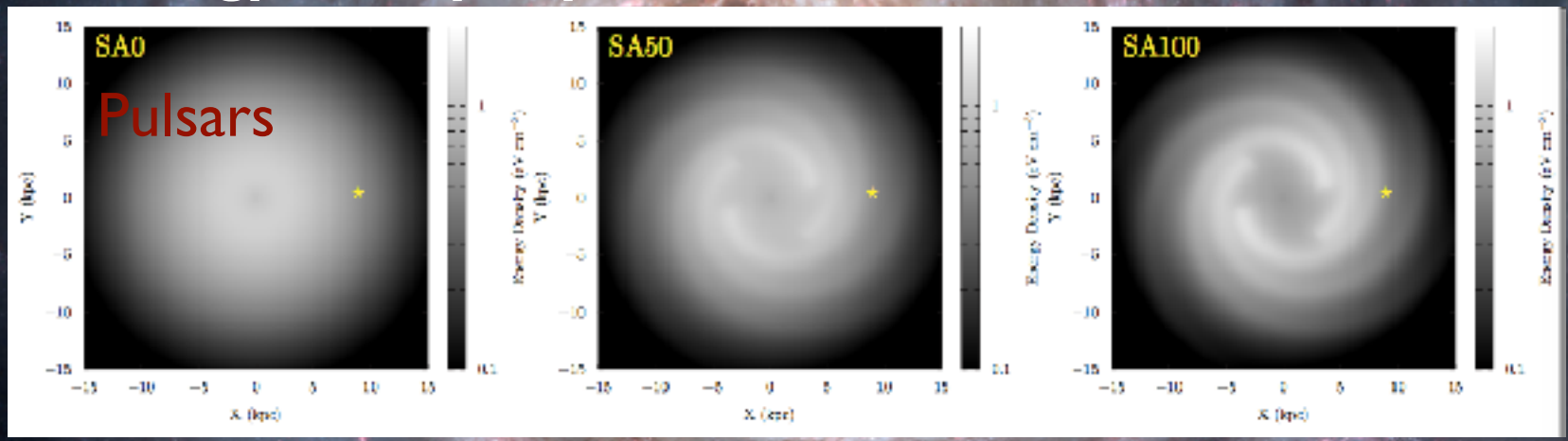
DATA-MODEL



C. Karwin et al, arXiv:1612.05687

- 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

CR energy density at plane Porter et al, arXiv:1708.00816



- **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

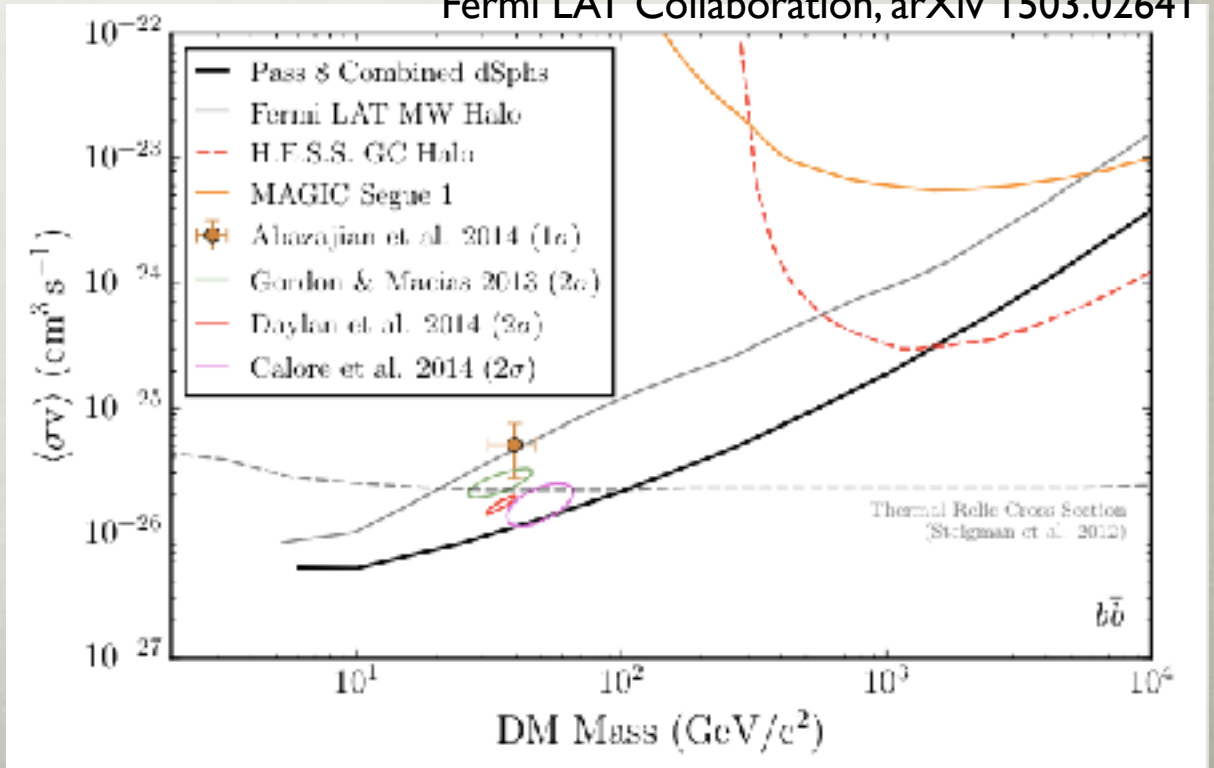
- Optically observed dwarf spheroidal galaxies: largest clumps predicted by N-body simulations

- 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
- NB: excesses in Reticulum II and Tucana III, spectrum and <σv> compatible with GC excess, Geringer-Sameth et al arXiv:1503.02320, Albert et al arXiv:1611.03184

Fermi LAT Collaboration, arXiv 1503.02641



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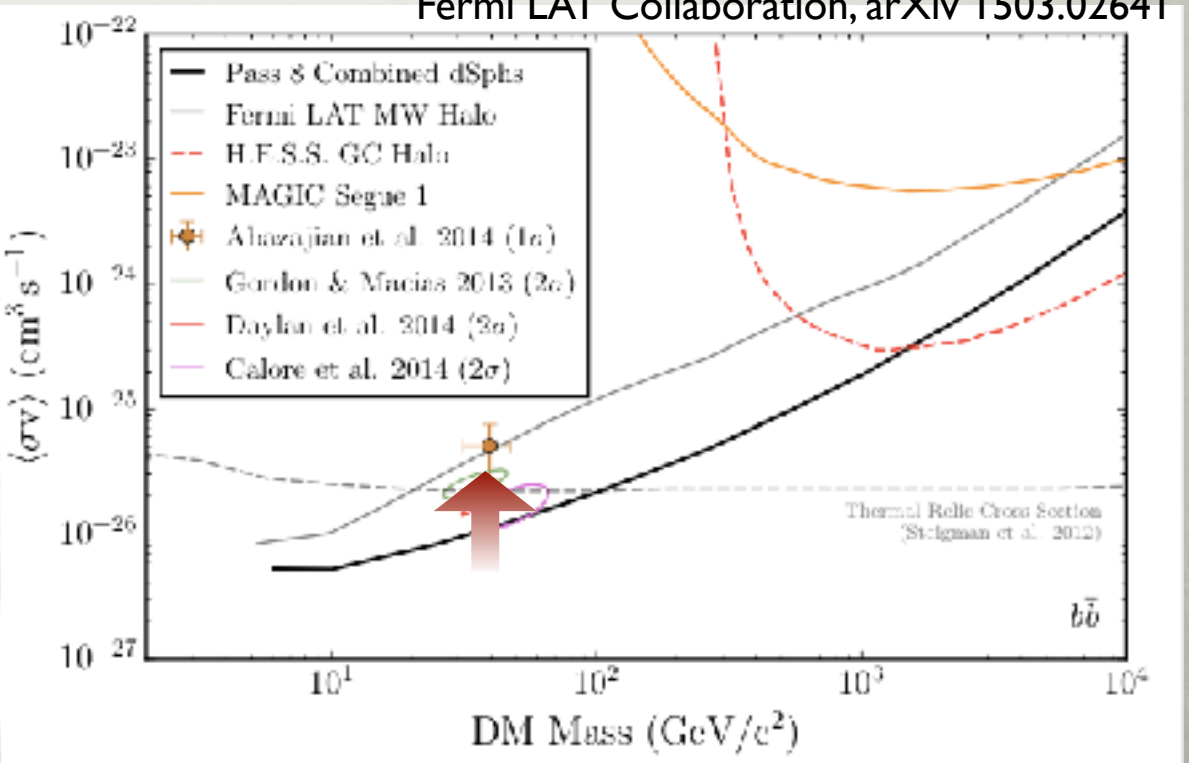
N.B.:
Non-spherical DM halos weaken dSph limits by ~2x (see e.g. Hayashi et al, arXiv: 1603.08046, Klop et al, arXiv:1609.03509).

Fermi LAT Collaboration, arXiv 1503.02641



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GC excess contours do not fully reflect uncertainties in the DM distribution (also see Abazajian et al, arXiv:1510.06424, Benito et al arXiv:1612.02010)

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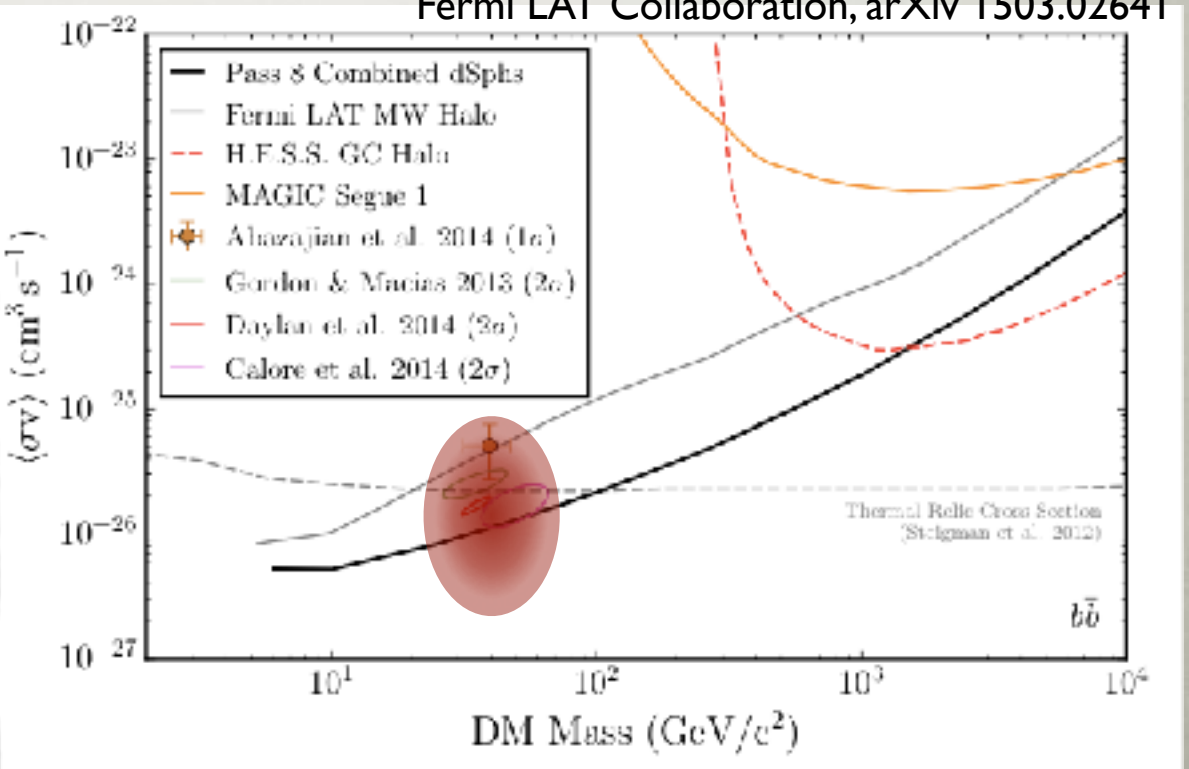

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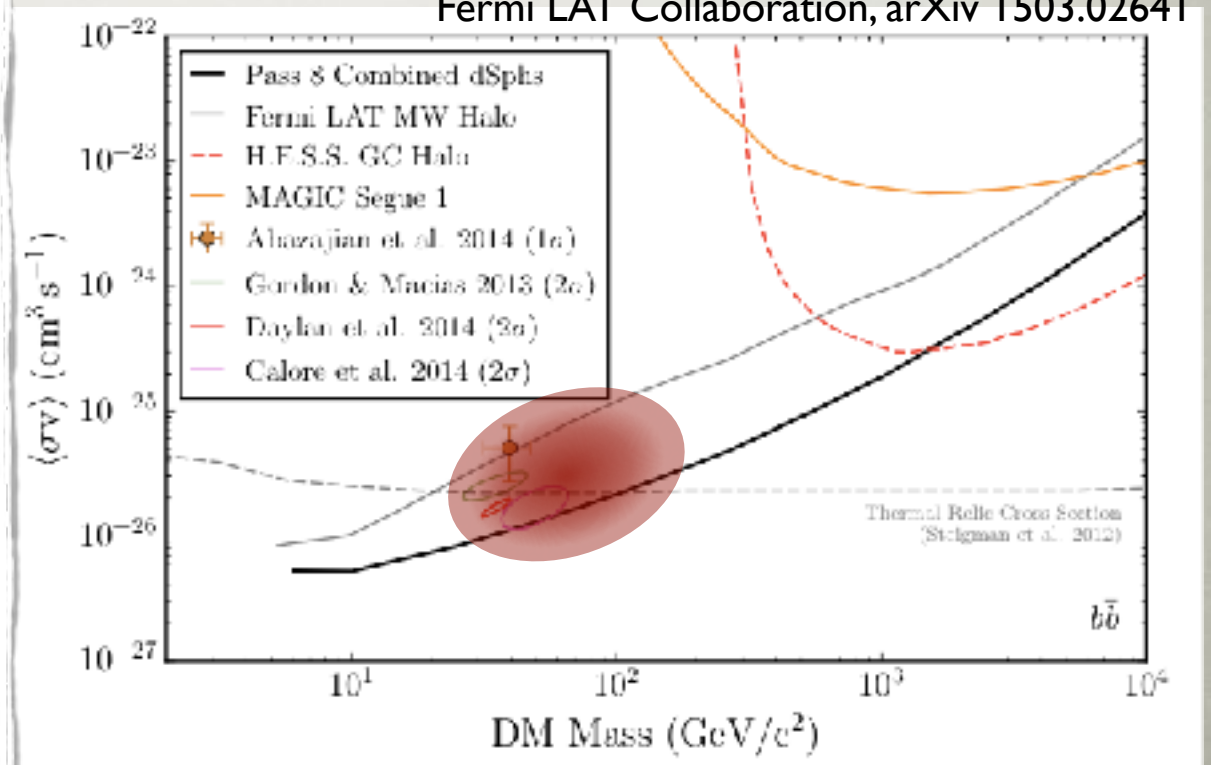
Uncertainties in the astrophysical background model also allow for a broader range of DM masses and annihilation channels (see e.g. Agrawal et al, arXiv: 1411.2592, Karwin et al arXiv:1612.05687)

Fermi LAT Collaboration, arXiv 1503.02641



Conclusions

- The Galactic center excess in gamma rays continues to intrigue
- The conventional astrophysics background is currently the biggest limitation in interpreting it
- Complementarity, e.g. a consistent signal from other DM targets, searches (e.g. dSph, direct and collider DM searches) would provide most compelling confirmation of the DM interpretation

Thank you!