Indirect Dark Matter Searches with with Space Based Experiments

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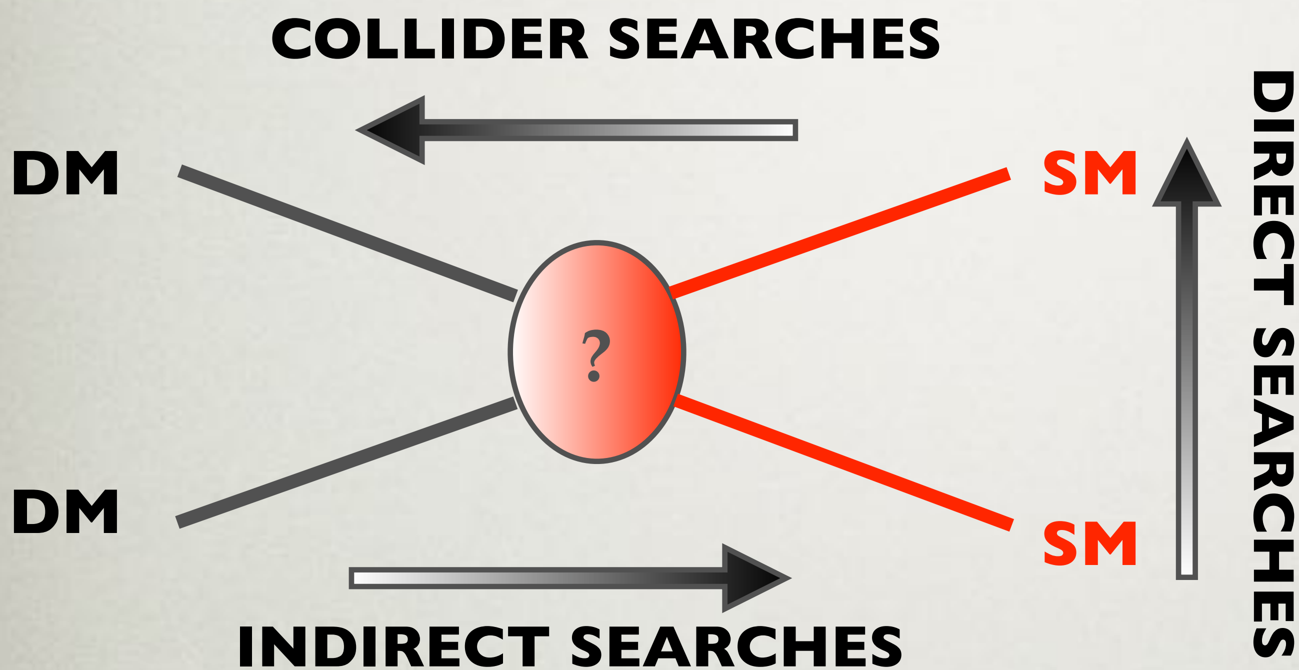
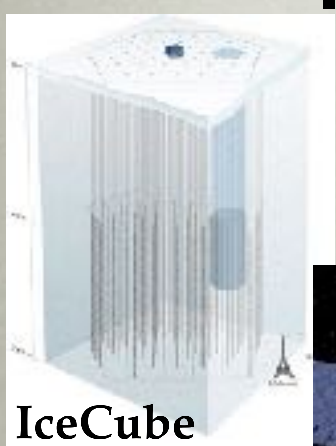
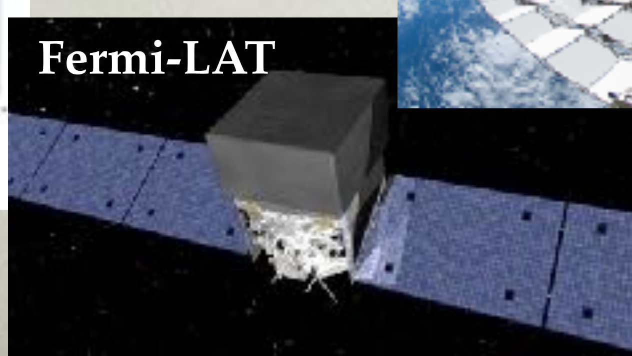
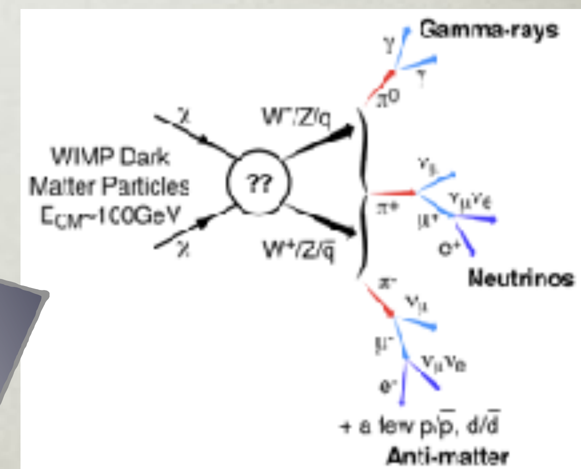
Dark Matter Searches



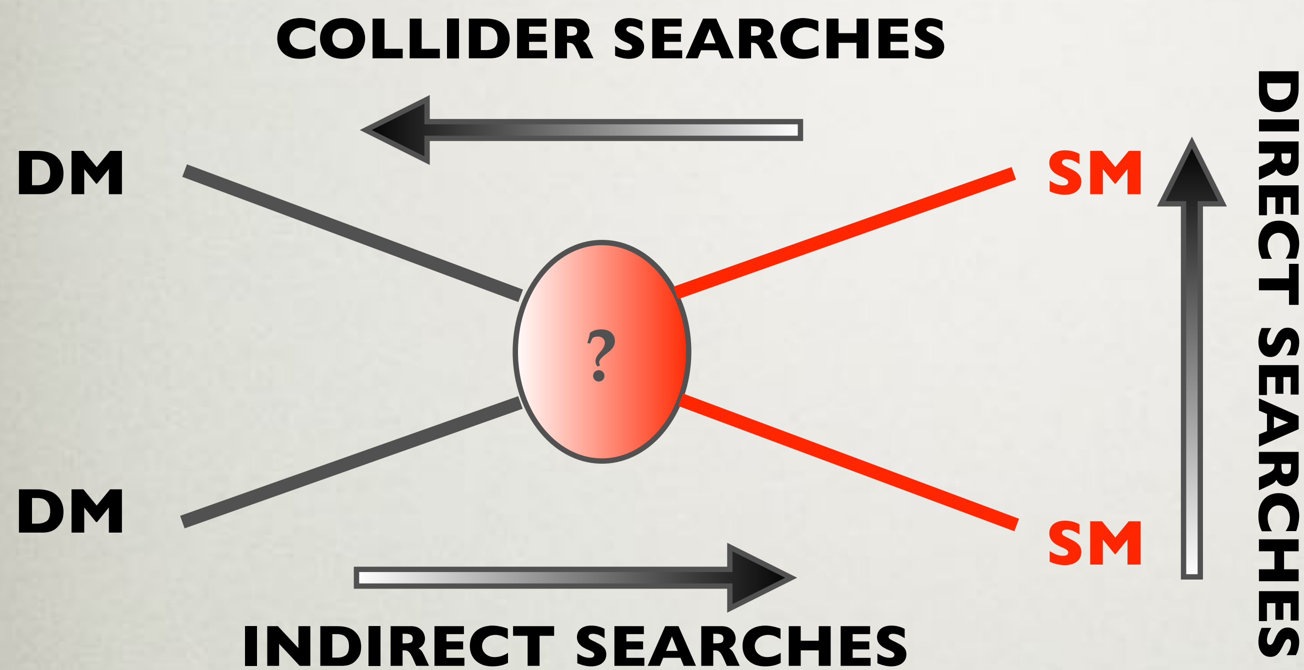


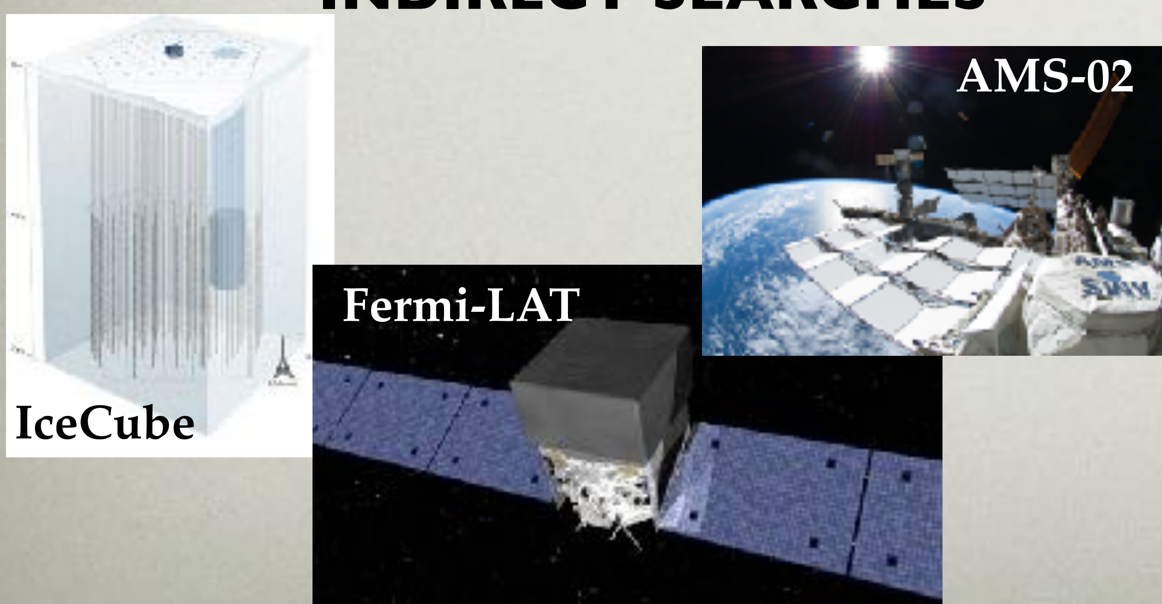




NB: I'll mainly focus on WIMPs

Dark Matter Searches





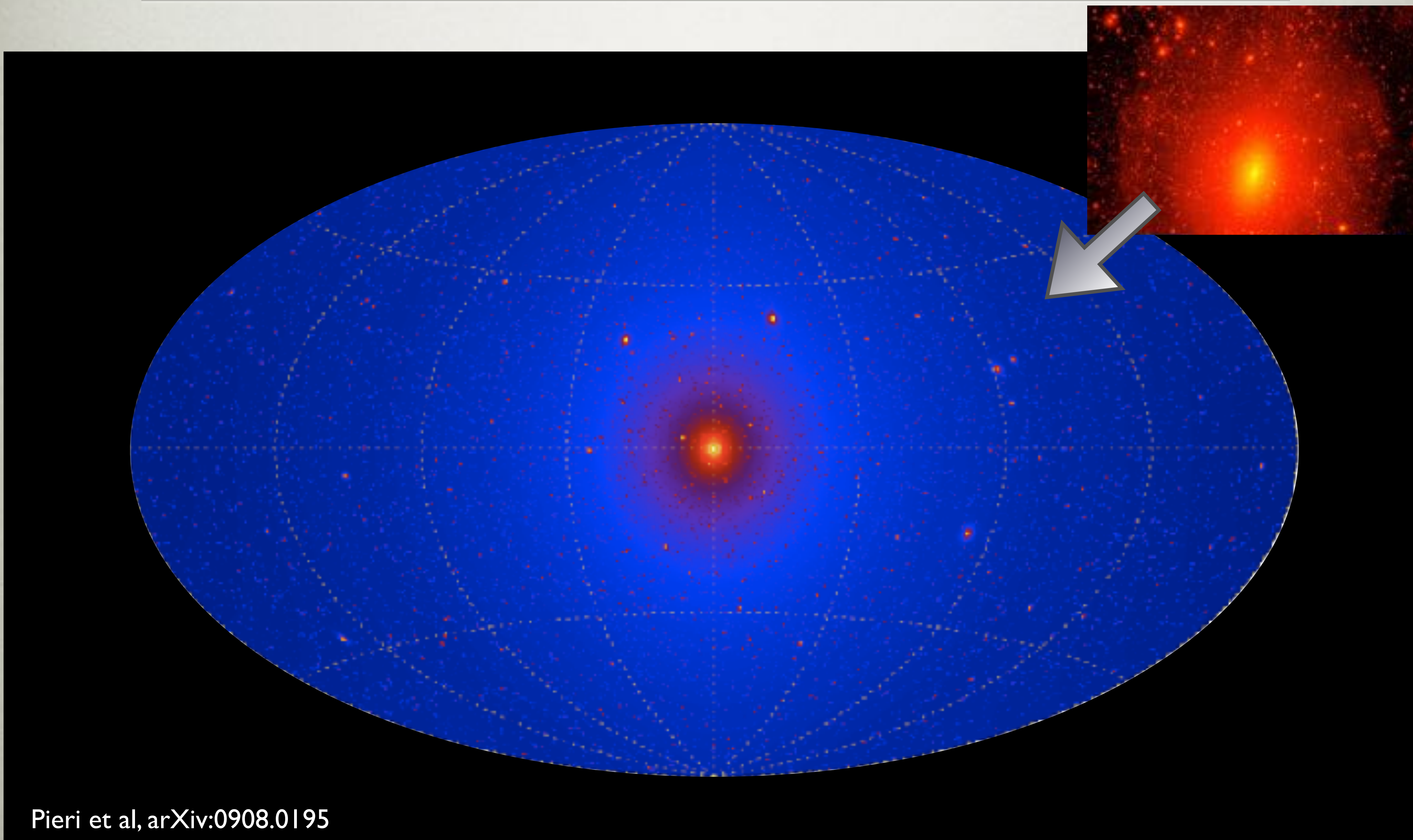
Gamma rays and cosmic rays

- Fermi LAT
- PAMELA, AMS-02
- DAMPE, CALET

X-rays

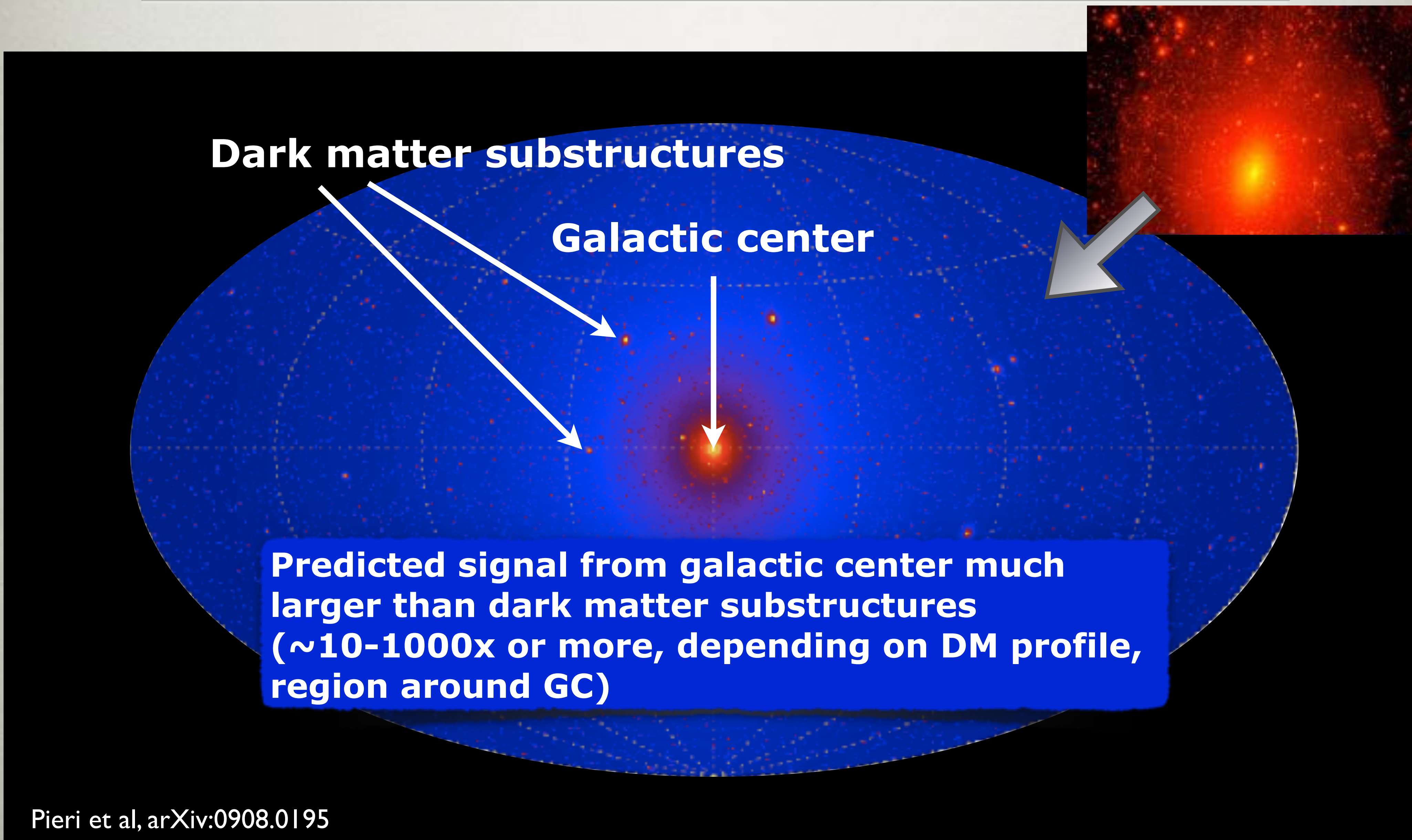
- XMM-Newton, Chandra, Hitomi

Gamma rays from Dark Matter Annihilation

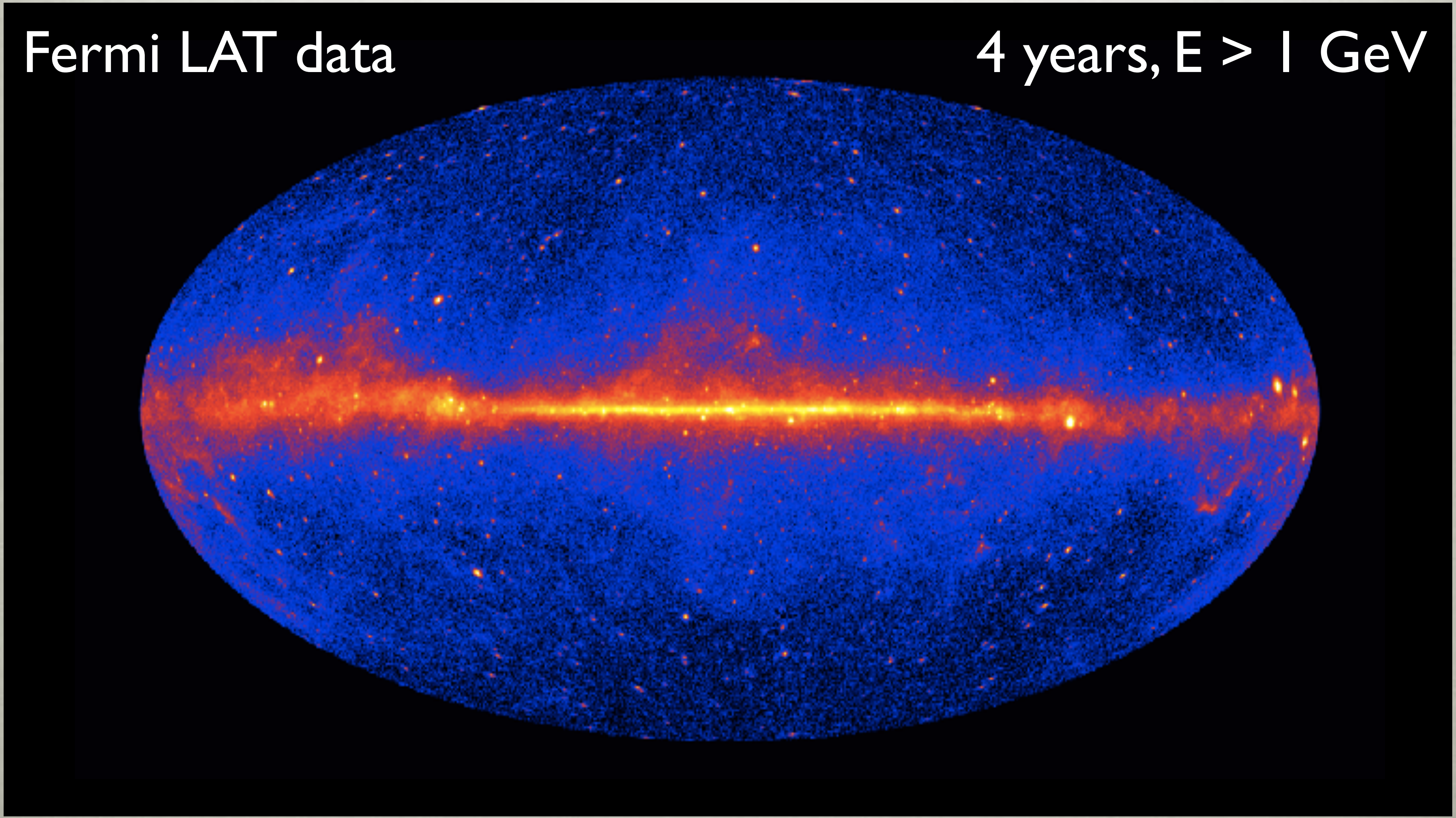


Pieri et al, arXiv:0908.0195

Gamma rays from Dark Matter Annihilation

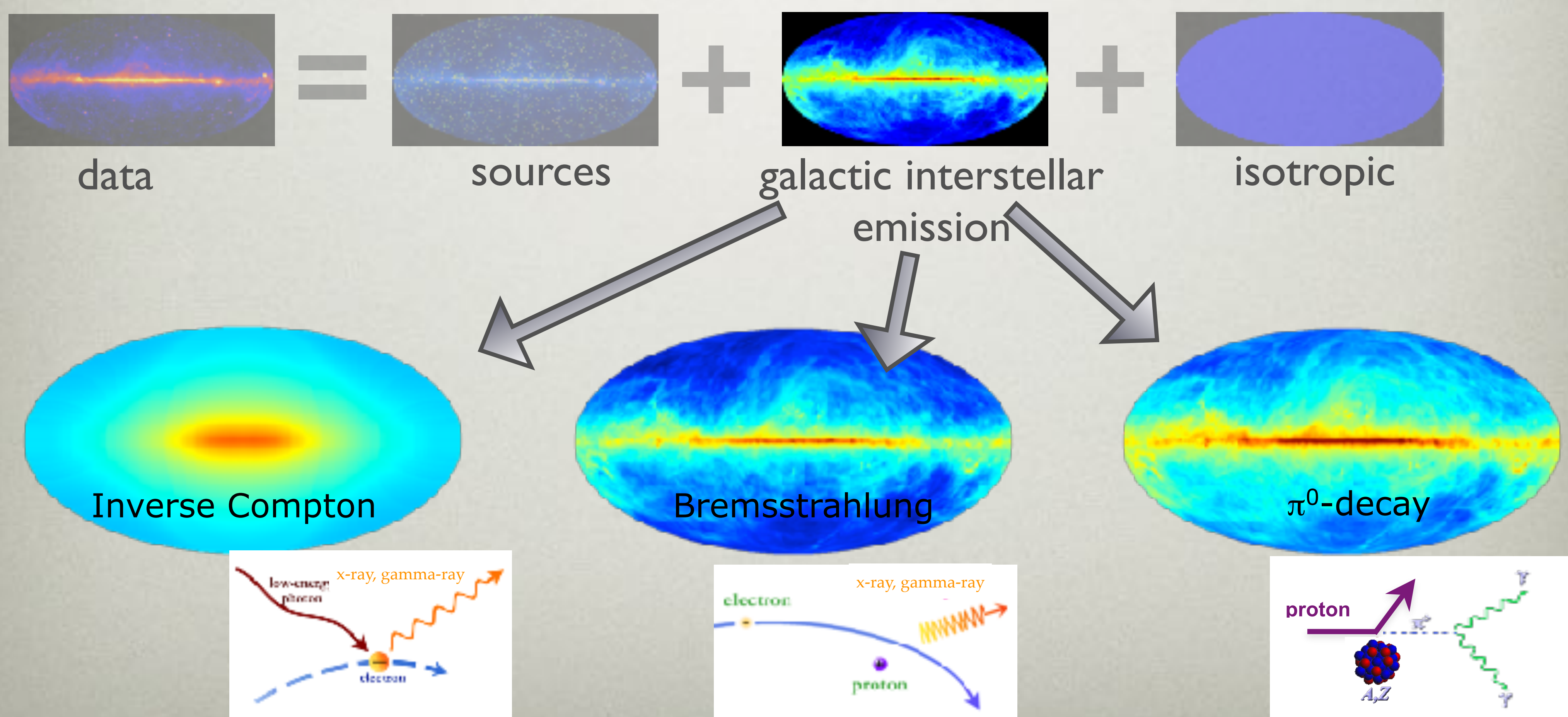


The Gamma-Ray Sky



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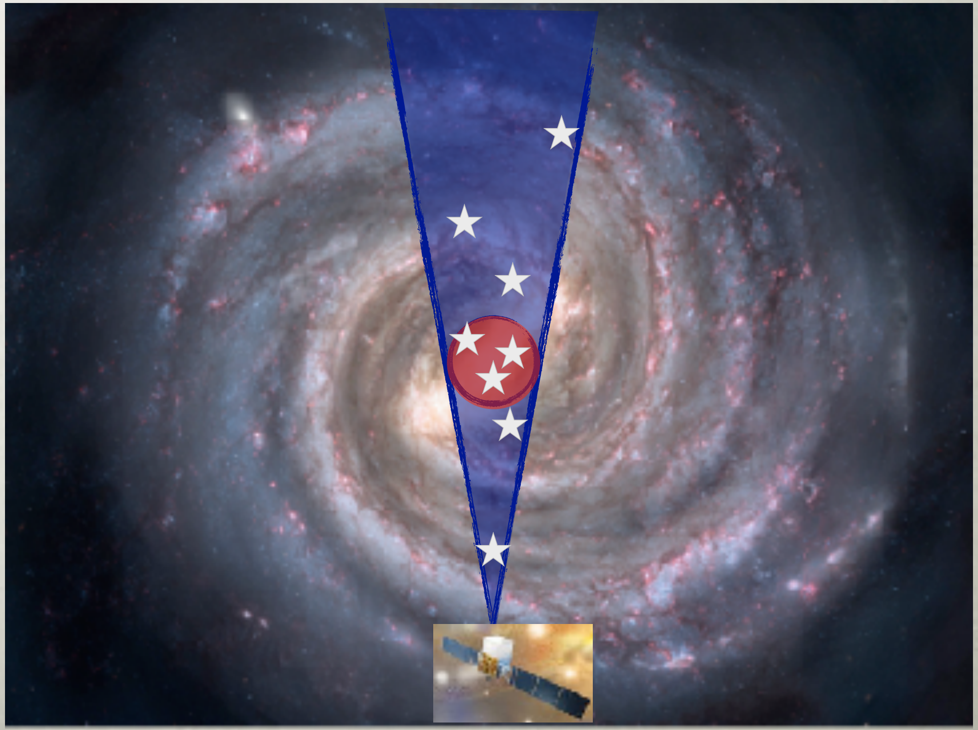
➡ Galactic center region: a dark matter signal is predicted to be largest here, where modeling of the interstellar emission (and sources) is problematic!
CR intensities, density of radiation fields and gas are highest and most uncertain, long integration path over the entire Galactic disc, large density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



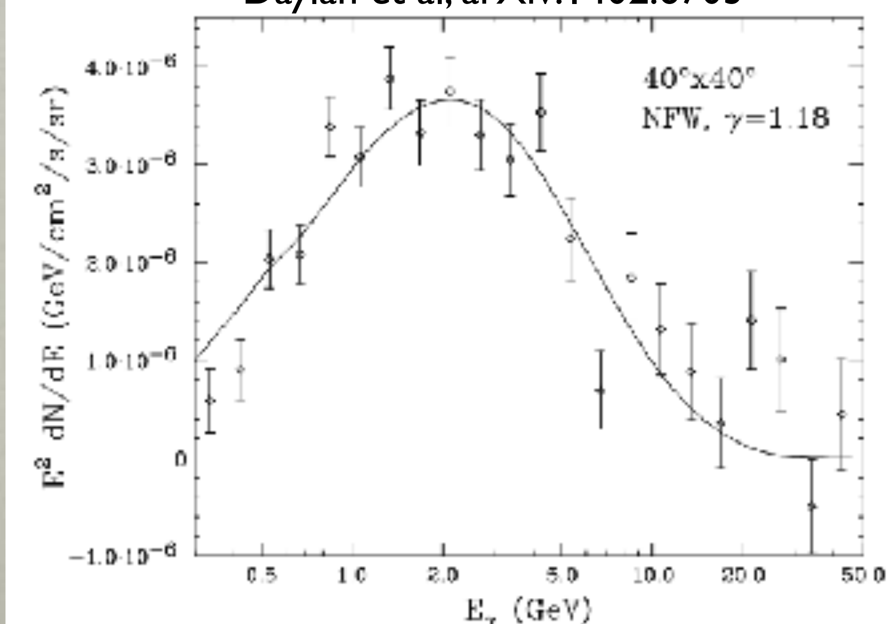
Galactic Center Excess

- An excess in the Fermi LAT GC data consistent with dark matter annihilation was first claimed by Goodenough and Hooper (arXiv:0910.2998.) More recent analyses also find an excess

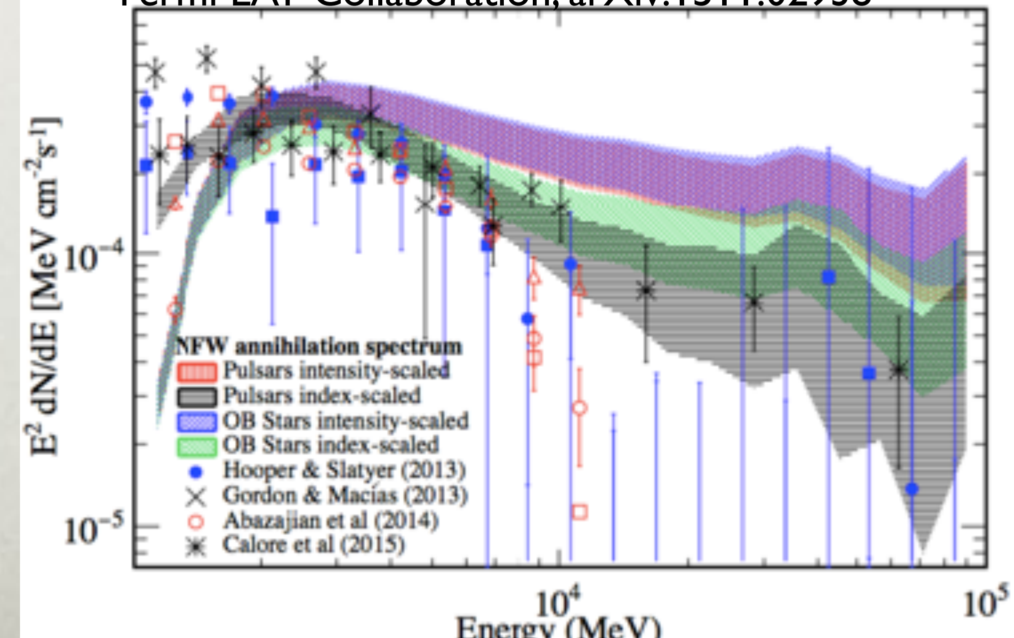
- **Different approaches in modeling the interstellar emission model (IEM): *the characterization of the signal depends on this!***

The spectrum peaks at ~ few GeV

Daylan et al, arXiv:1402.6703



Fermi LAT Collaboration, arXiv:1511.02938

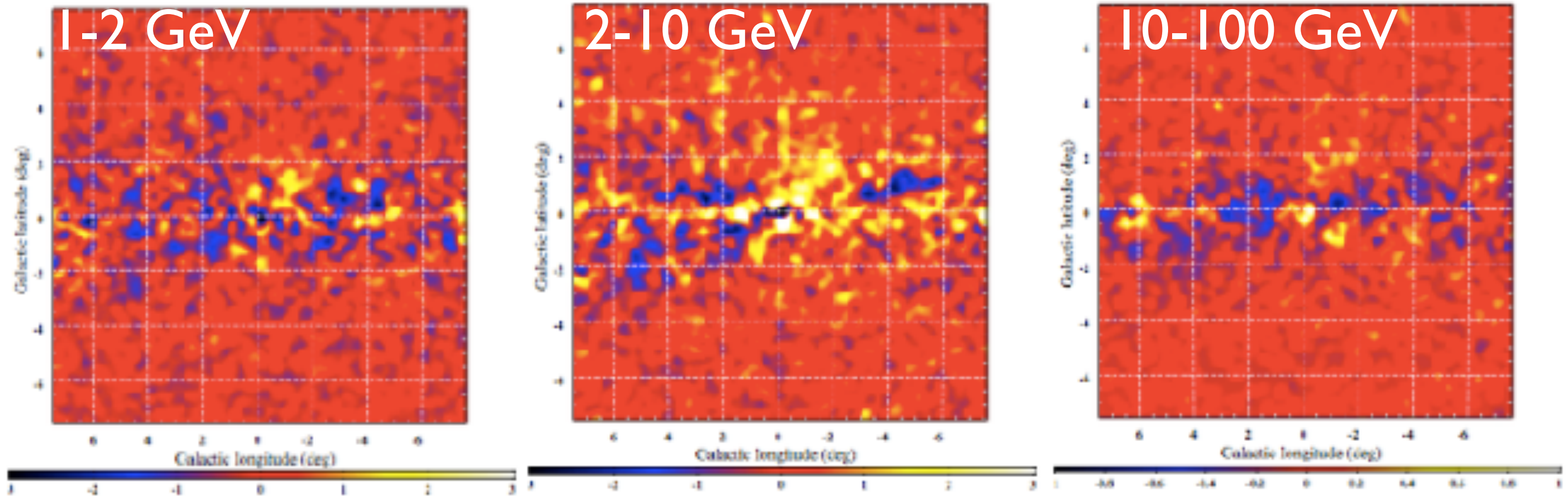


Galactic Center Excess

DATA-MODEL

Fermi LAT Collaboration, arXiv:1511.02938

Without dark matter:



Counts in 0.1°x0.1° pixels, 0.3° radius gaussian smoothing

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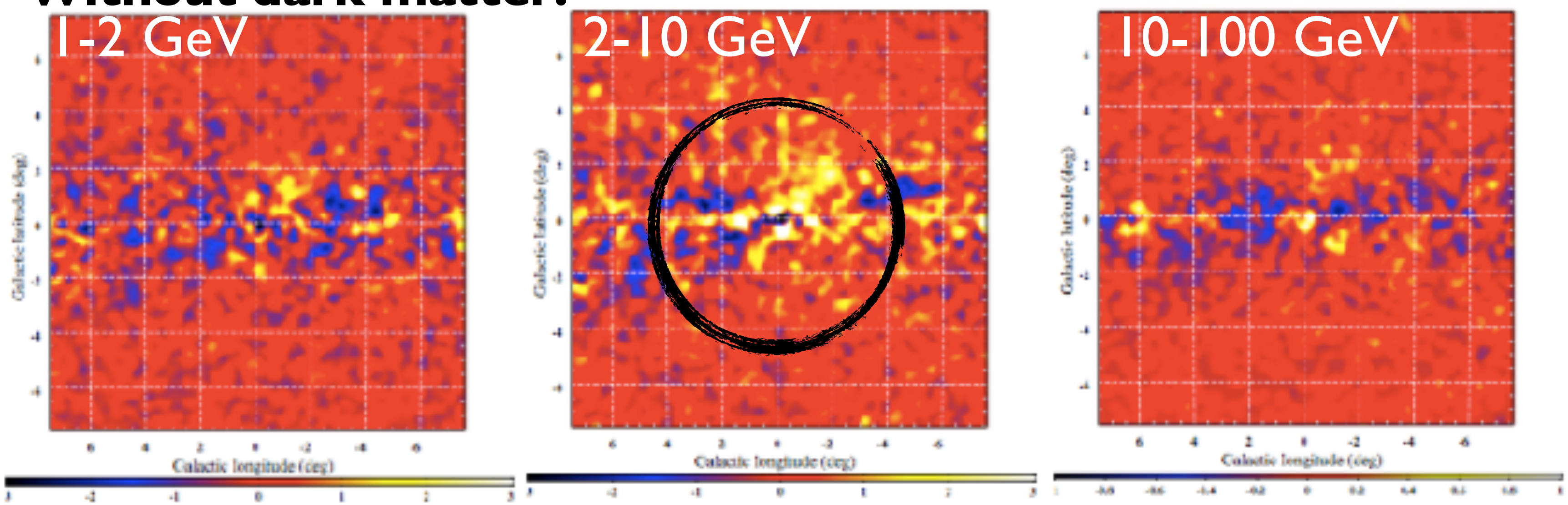

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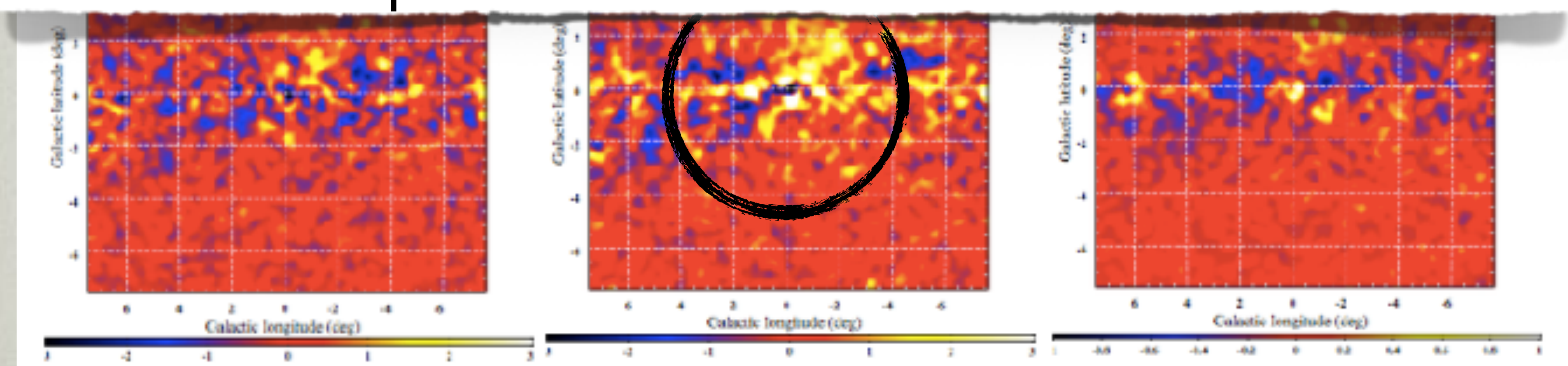
Excess is cuspy, approximately centered at GC and spherically symmetric, extends out to at least ~10° from the GC

Significant improvements when a component with a ***dark matter template*** (NFW annihilation, with slope γ~1-1.3) is included in the model

NB: some discrepancies between data and model remain!



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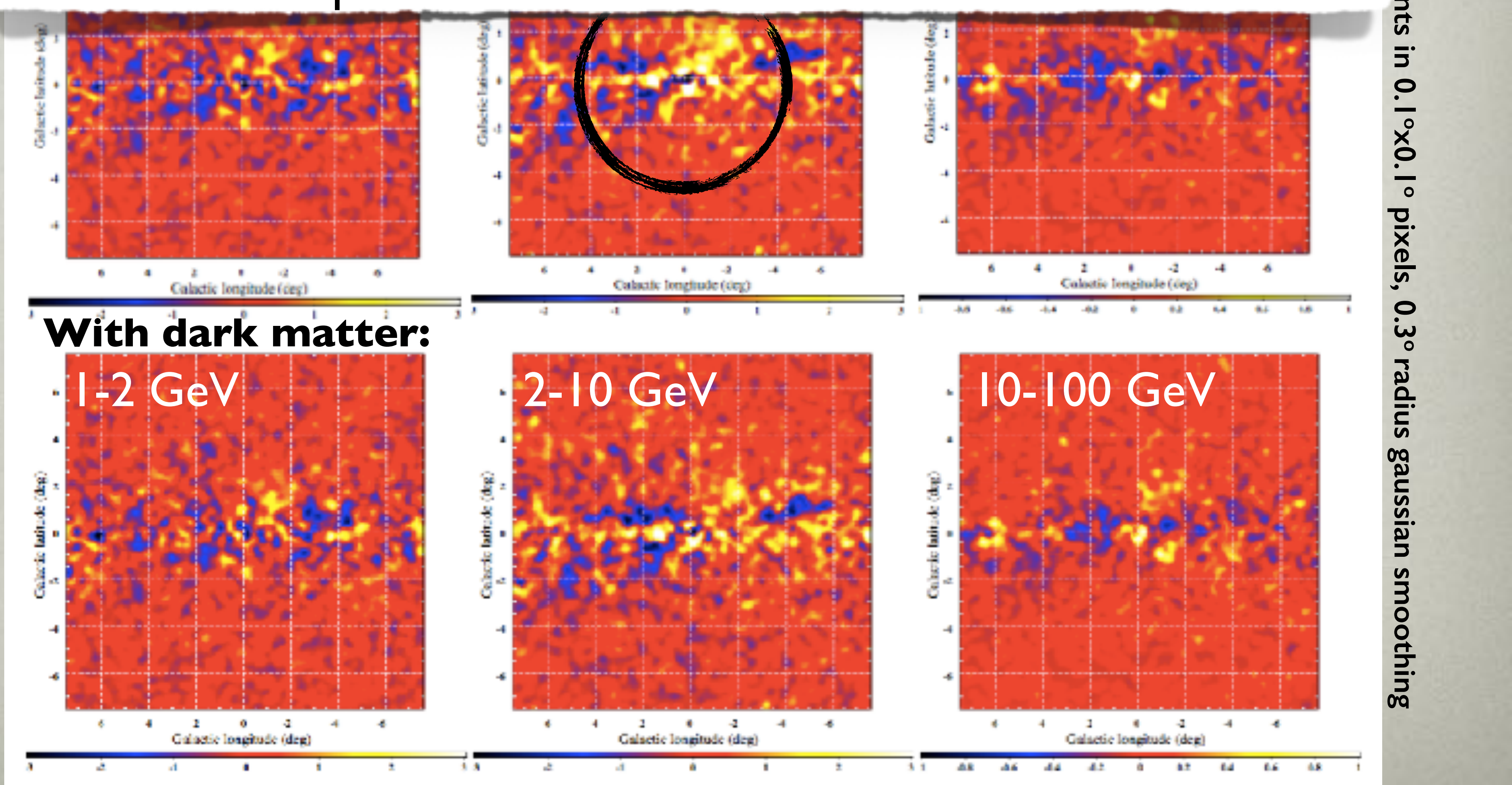

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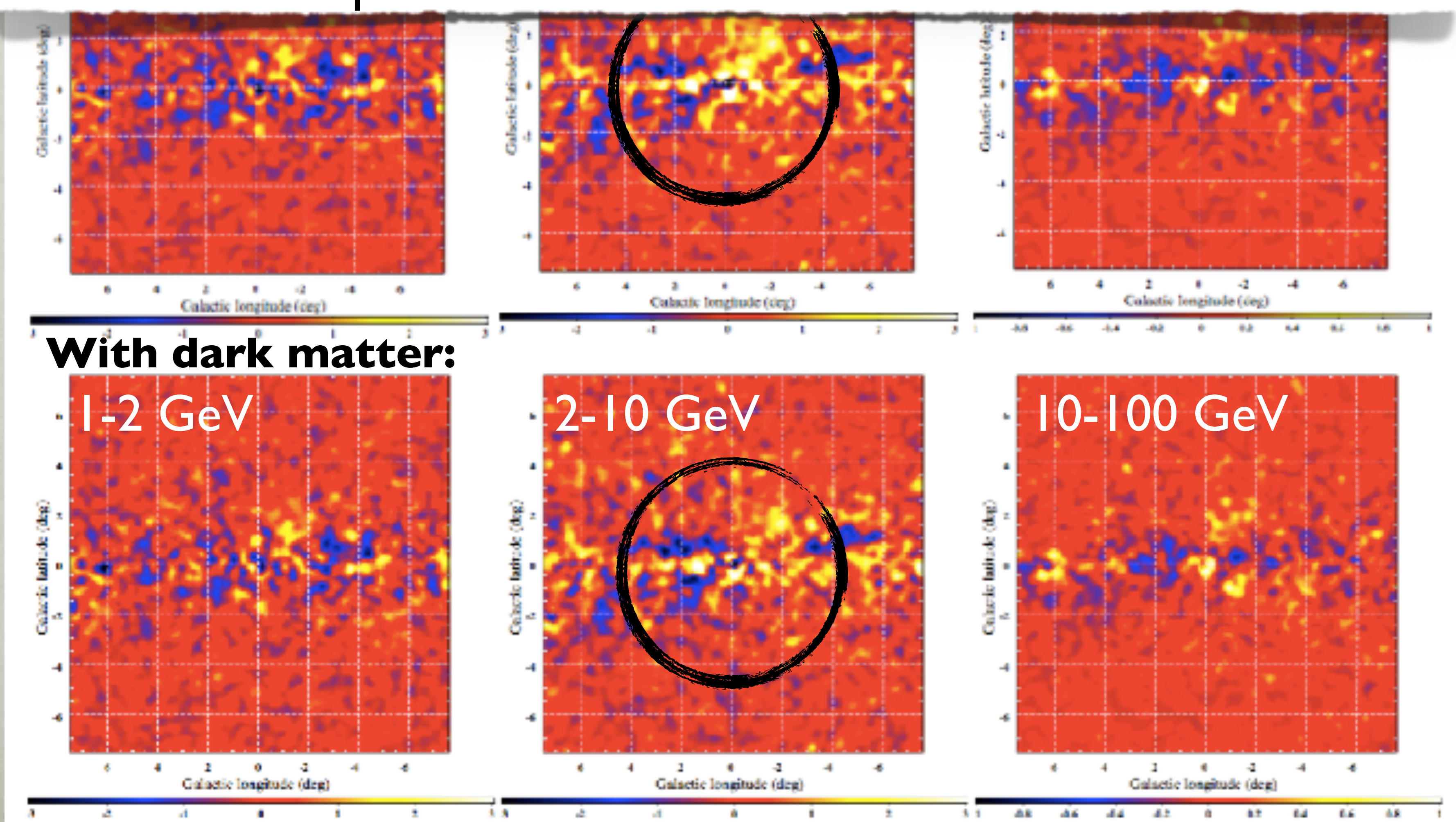

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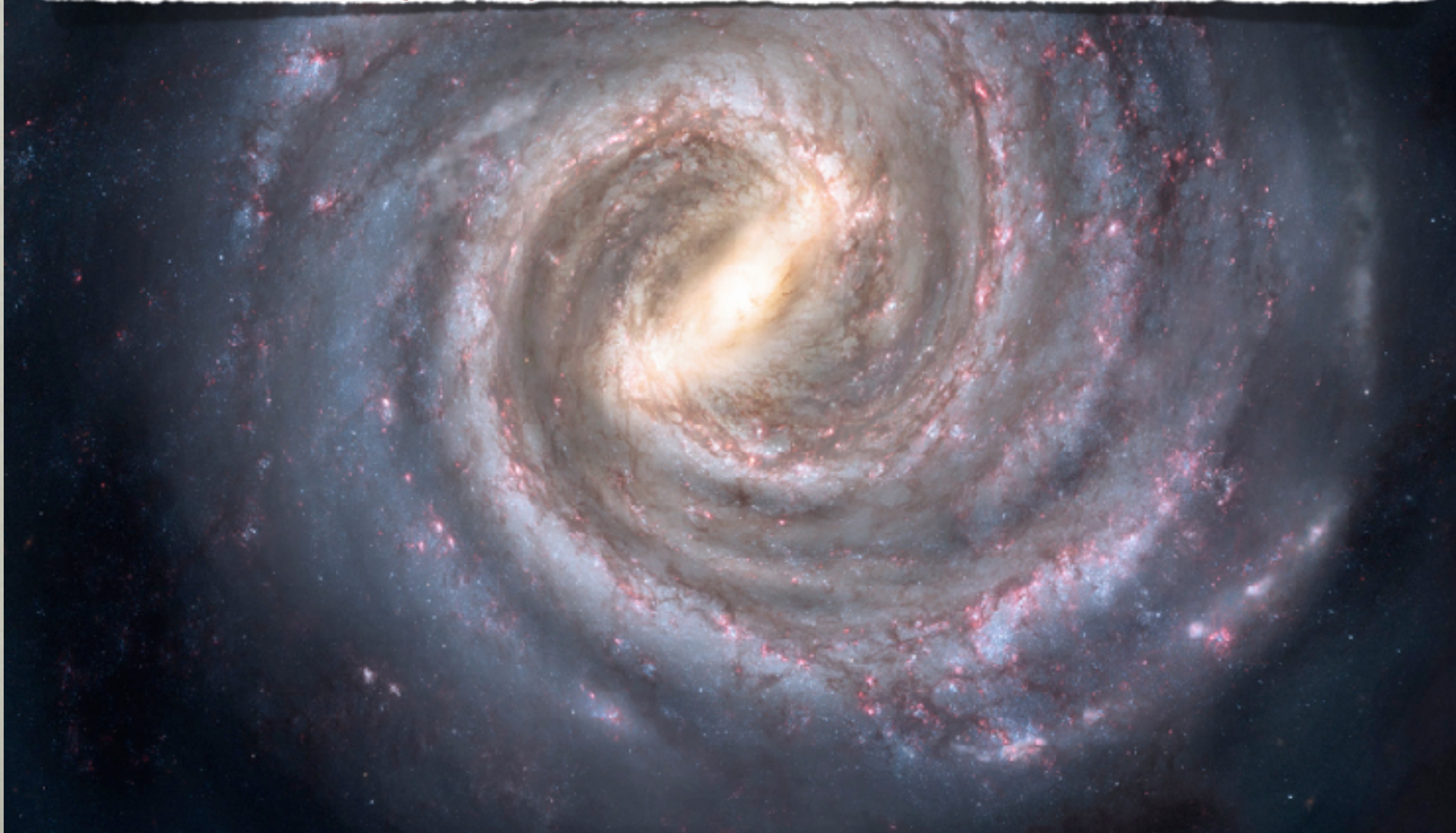
- ✦ There are limitations in all interstellar emission models employed so far (e.g., cylindrical symmetry, the gas distribution, as well as interplay between the interstellar emission and point sources)

➡ Work is underway to improve these models



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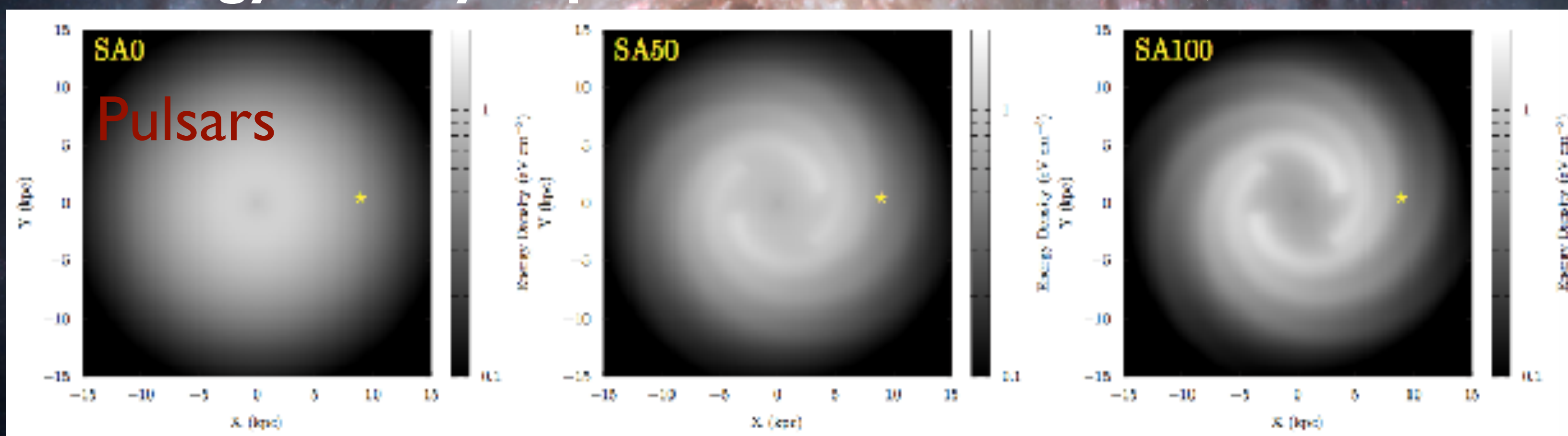
CR energy density at plane T. Porter et al, arXiv:1708.00816



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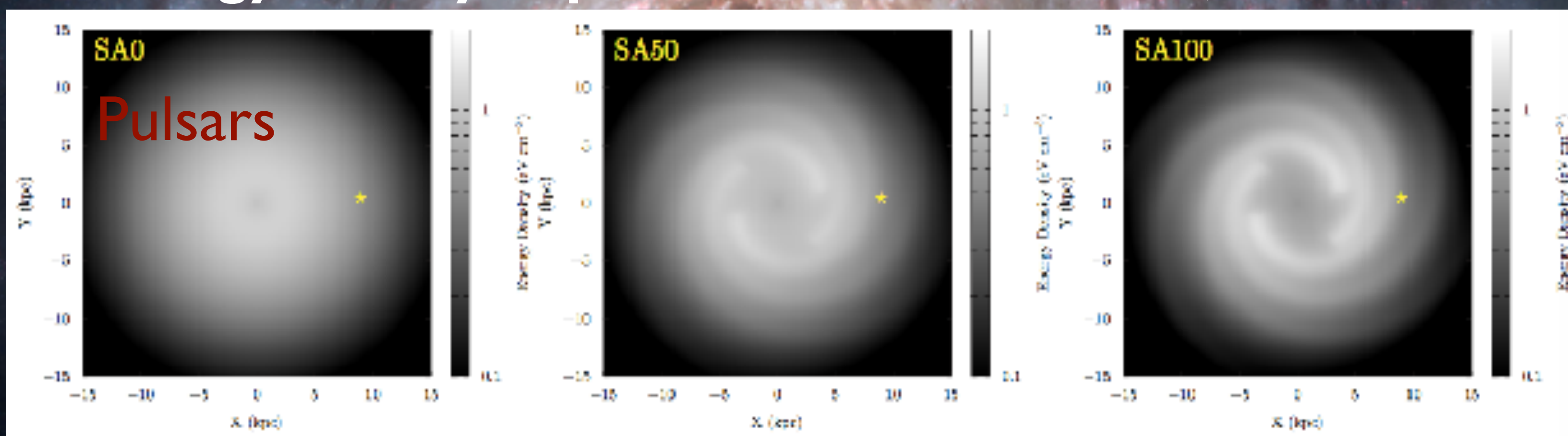
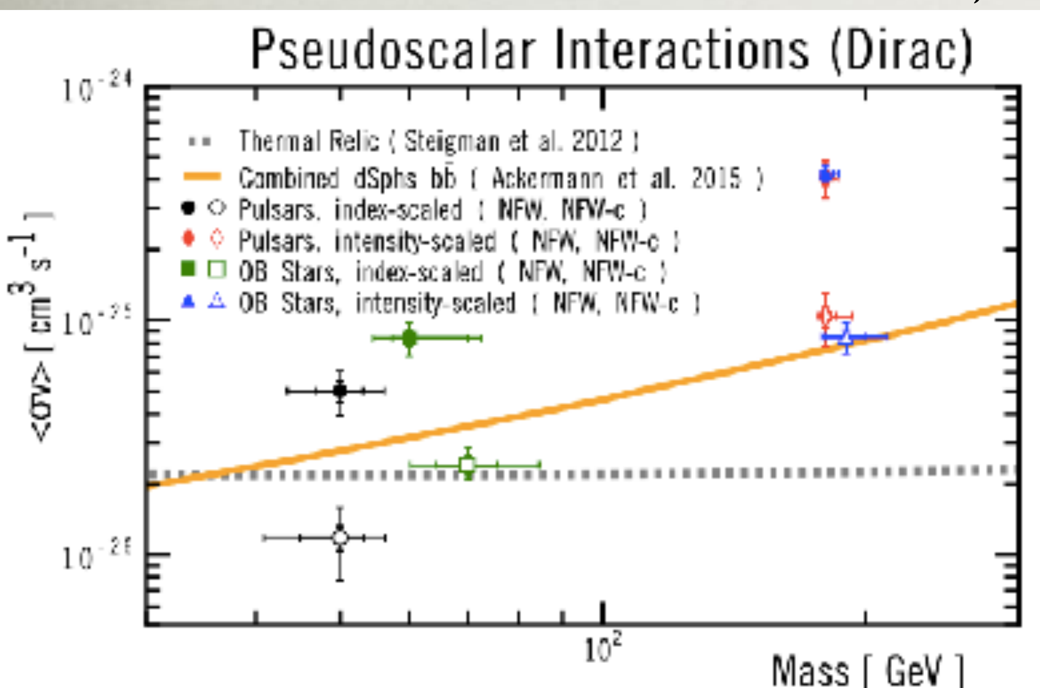


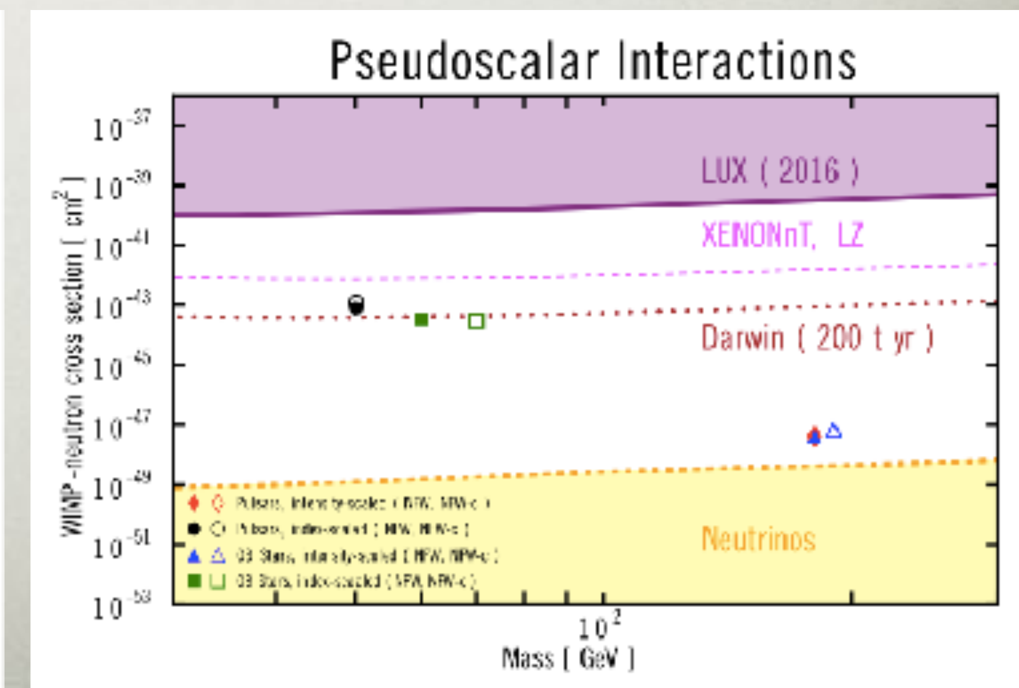
- ✦ **The GC excess is a small fraction of the total observed emission (e.g. ~5-10% in a 15ºx15º region)**
- ➡ **Improvements in modeling the interstellar emission are crucial to confirm the properties of the excess!**

Implications for Dark Matter Models

- Constrain DM mass, <σv>, annihilation channel. E.g. employ EFT framework
  - Consider general models with DM particles annihilating into two-body (fermionic) final states where the interactions between the dark sector and standard model particles occurs via *scalar* or *vector* interactions
  - Fit the relative strengths of couplings to quarks and leptons to the Fermi LAT data with the IEMs+point sources

C. Karwin et al, arXiv:1612.05687





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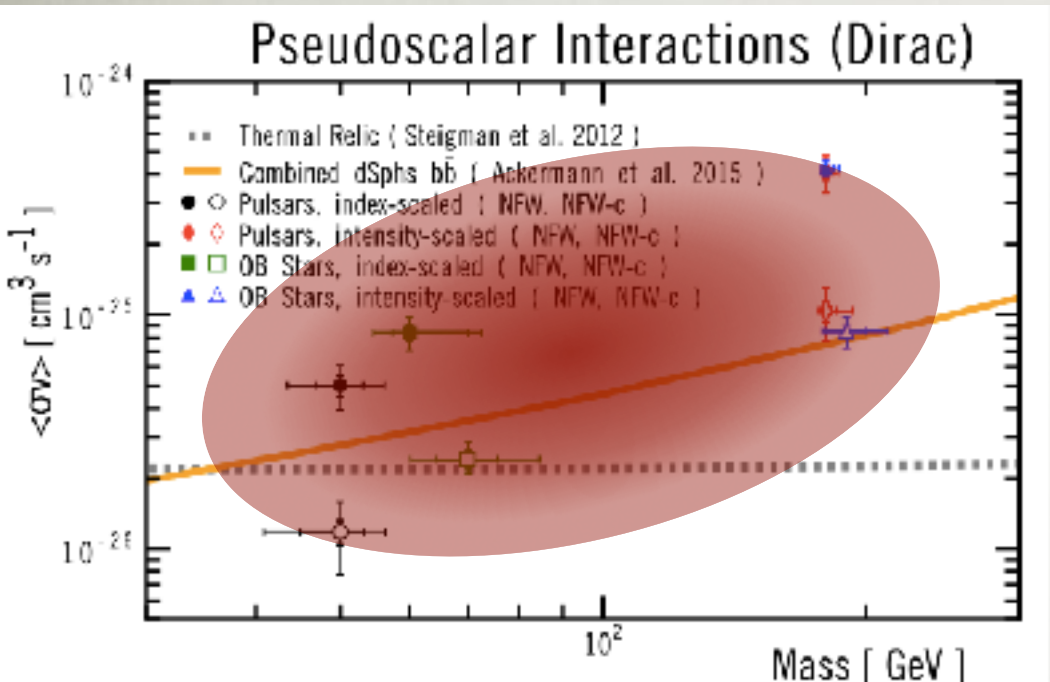

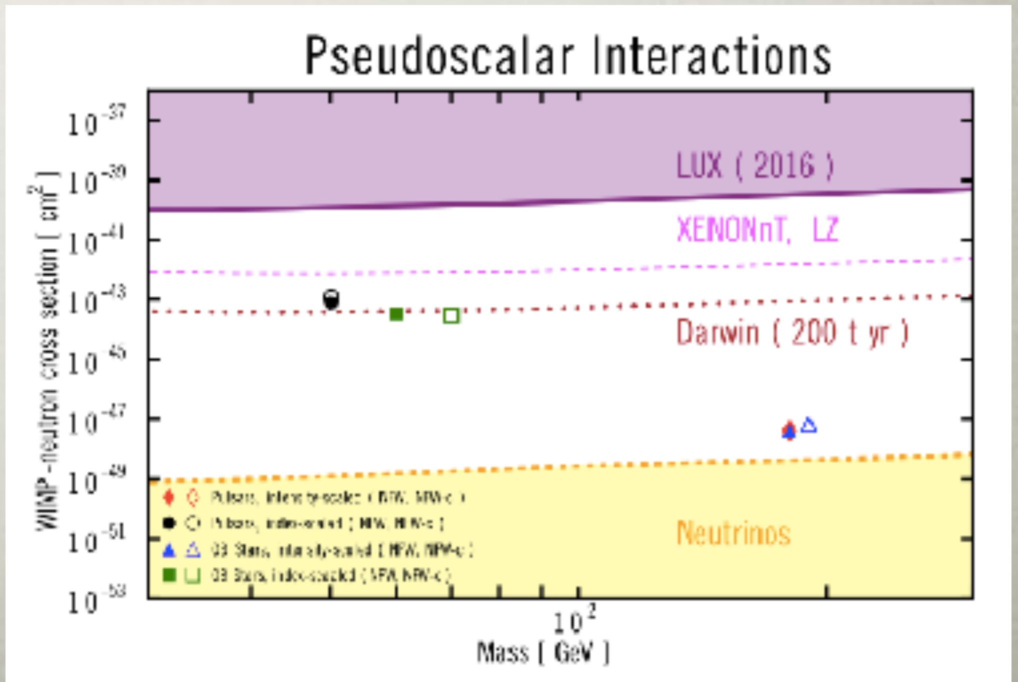

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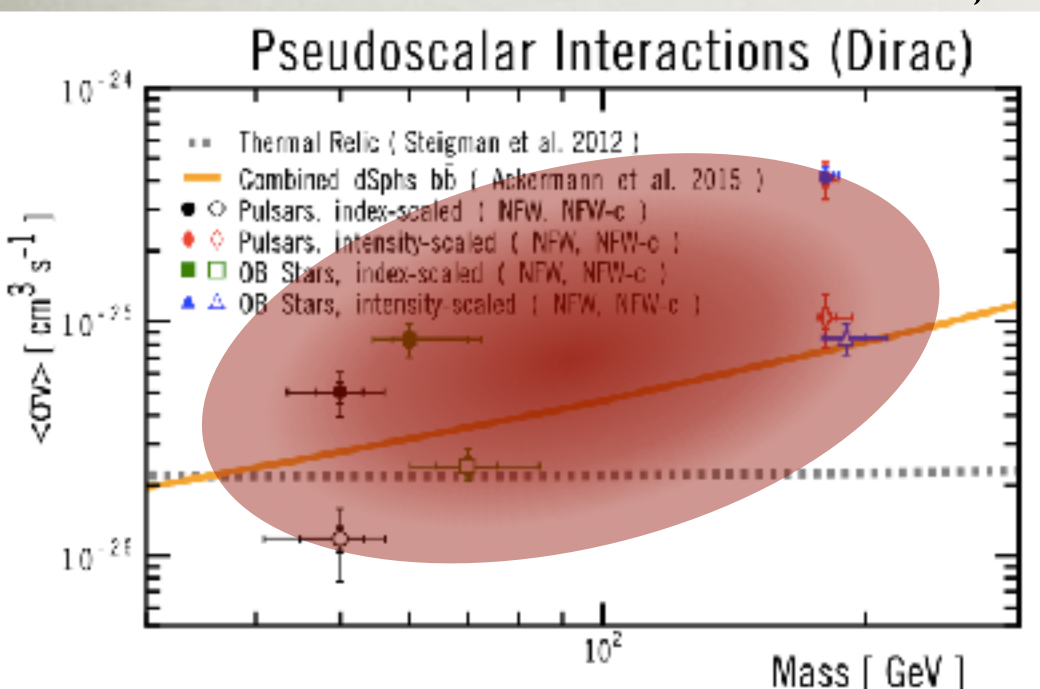
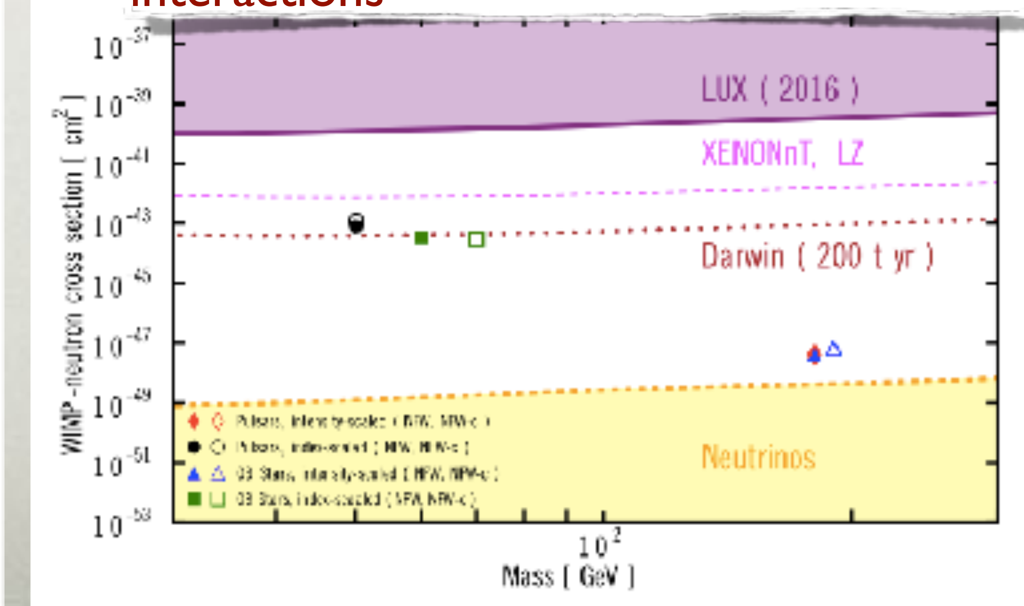
C. Karwin et al, arXiv:1

Direct detection doesn't rule out scalar interactions as an interpretation of the GC excess, but it excludes vector interactions

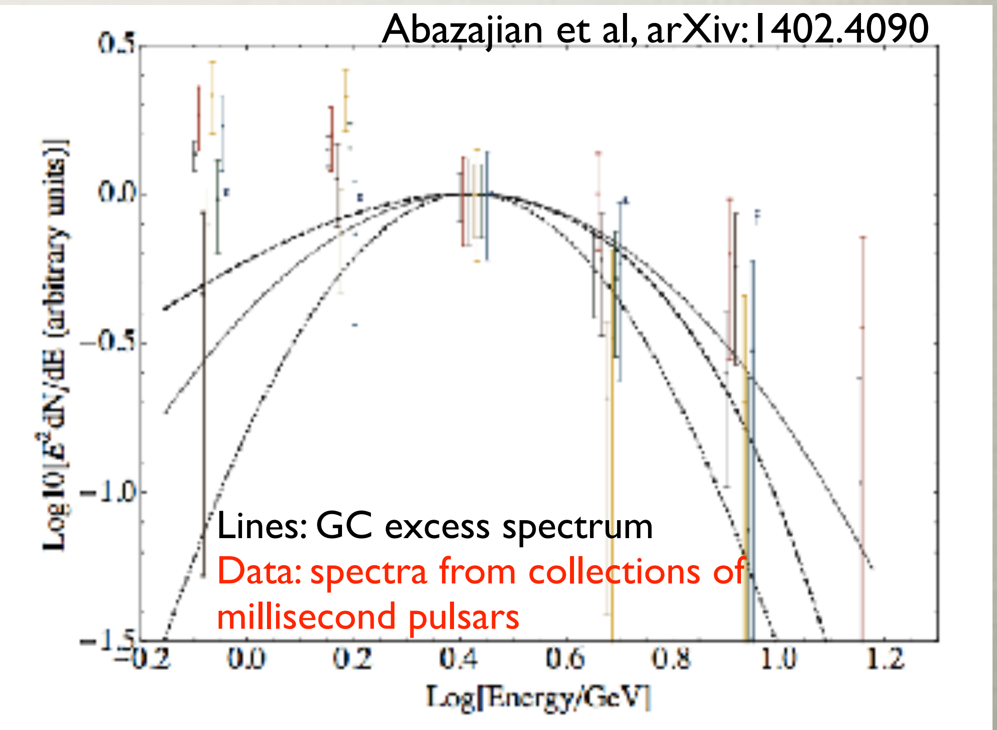




Other Interpretations

- **Unresolved pulsars**
  - **Pulsars γ-ray spectra can mimic a DM signal!**
  - 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)

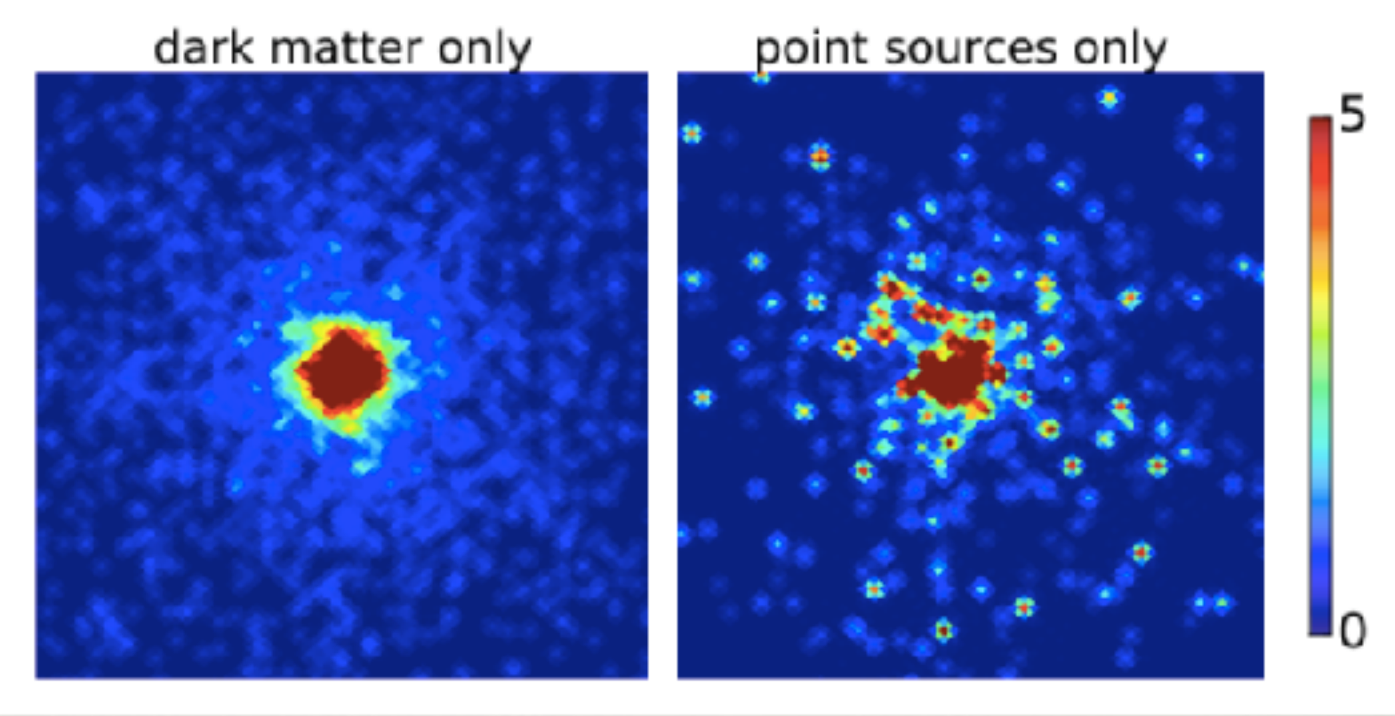
- *(CR proton or electron outbursts interpretations have also been proposed, e.g. Carlson et al arXiv:1405.7685, Petrovic et al 1405.7928, Cholis et al arXiv: 1506.05119)*



Unresolved Sources

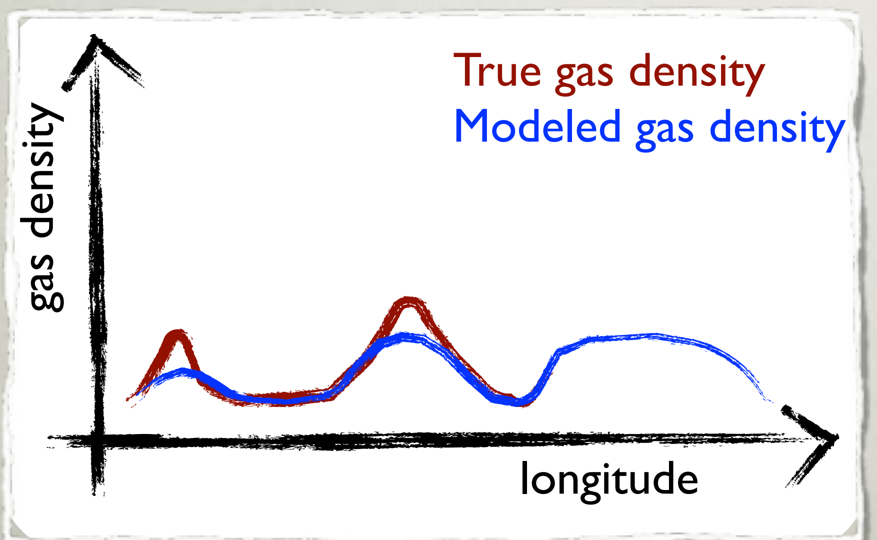
- Analyses based on non-poissonian photon statistics templates and wavelet decomposition (Lee et al arXiv:1412.6099, 1506.05124; Bartels et al arXiv:1506.05104) find that the excess is consistent with a collection of discrete gamma-ray emitters rather than a smooth emission from the dark matter halo
- ***O(100) sources*** right below the Fermi LAT detection threshold could explain the entire GC excess (Lee et al arXiv:1506.05124)

Lee et al, arXiv:1412.6099

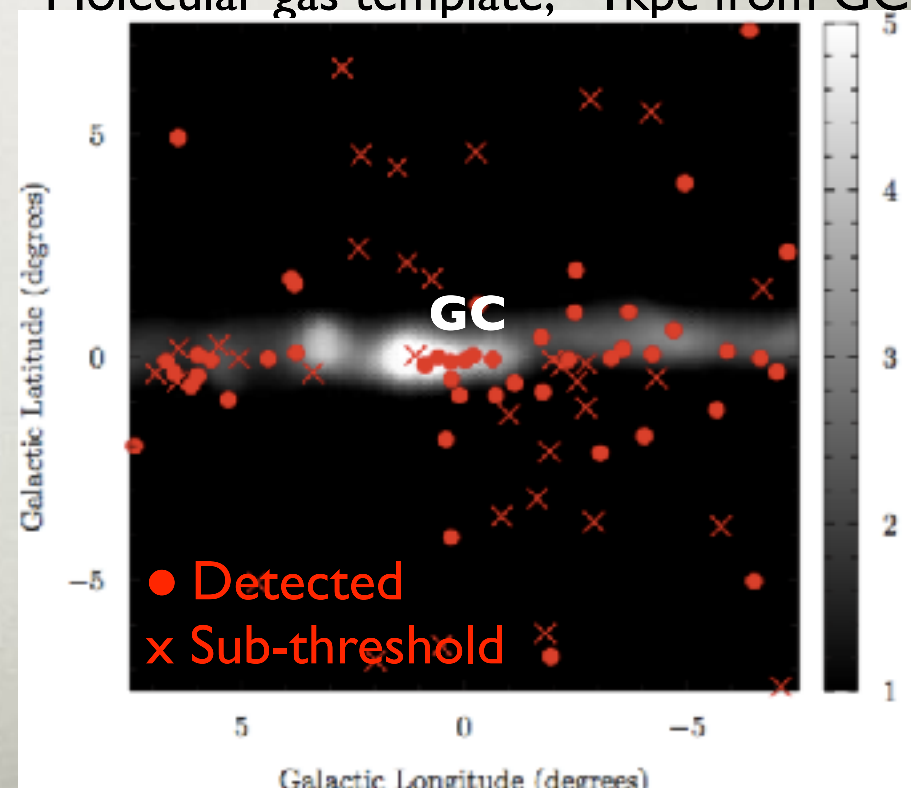


Some Caveats

- The (millisecond) pulsars spatial morphology (and luminosity function) are not well constrained and these parameters could therefore be adjusted to match unrelated contributions, such as the GC excess
- In addition, it is likely that some sources below (and above) the detection threshold are mis-identified interstellar emission from gas



Molecular gas template, ~1kpc from GC



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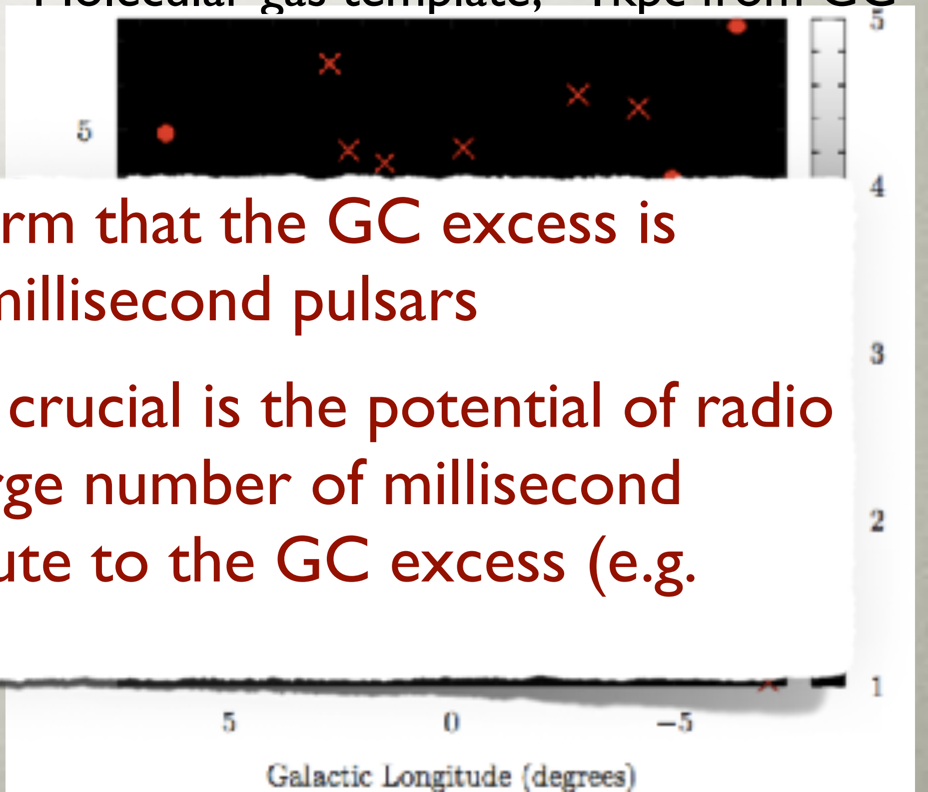


These sources must be detected to confirm that the GC excess is generated by a collection of unresolved millisecond pulsars

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 (e.g. Calore et al arXiv:1512.06825)

Dwarf Spheroidal Galaxies

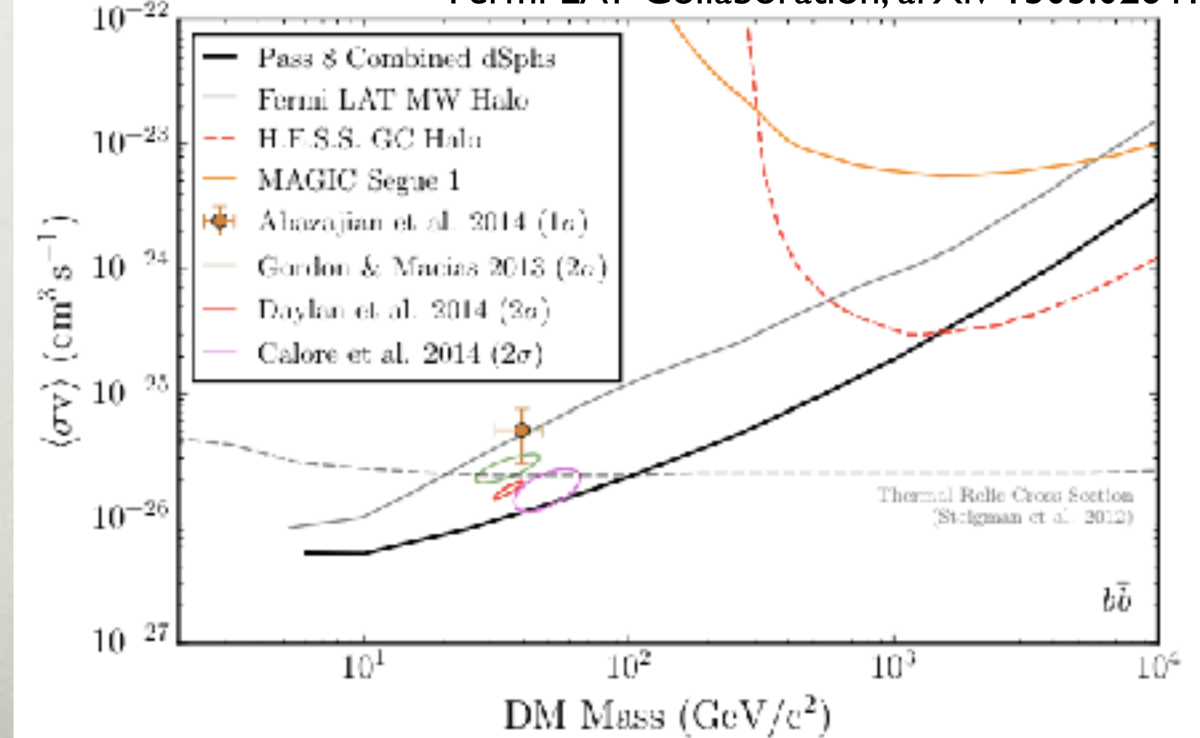
- Optically observed dwarf spheroidal galaxies: largest clumps predicted by N-body simulations

- 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

- Search for a signal in 25 dwarf spheroidal galaxies, 6 years of Fermi LAT data
  - ➡ No significant emission is found
- Limits probe DM explanation of the GC excess

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).

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

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)

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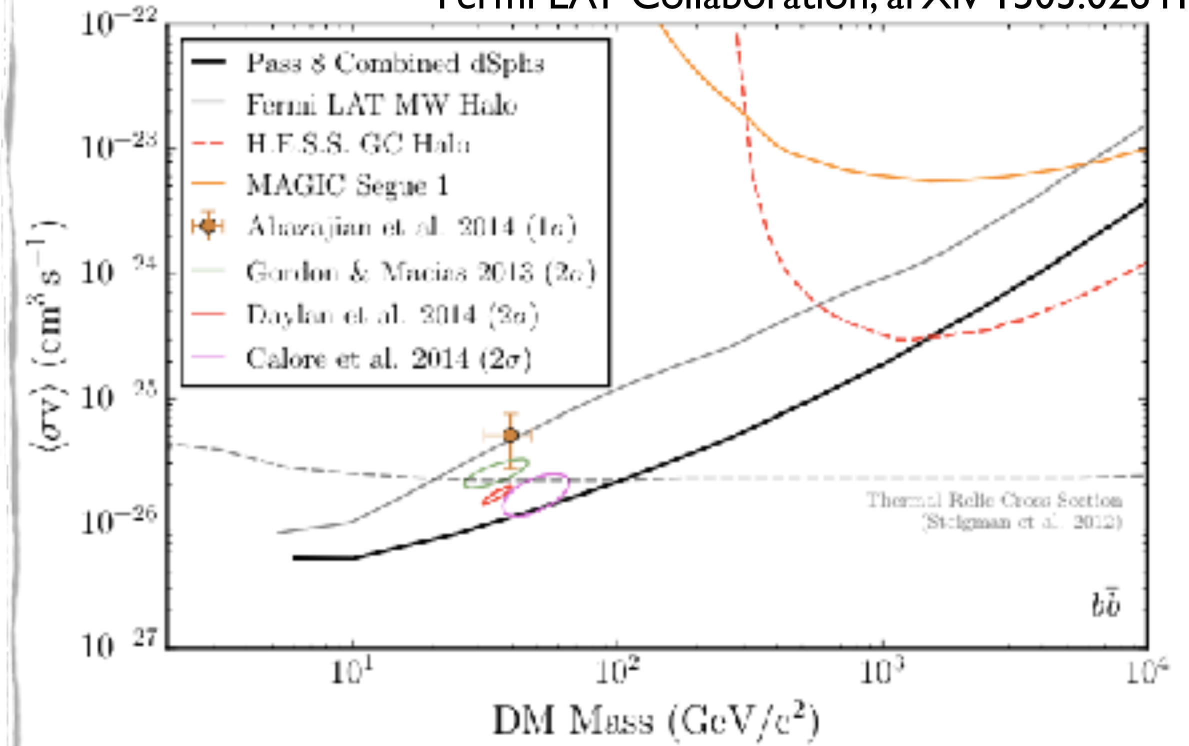

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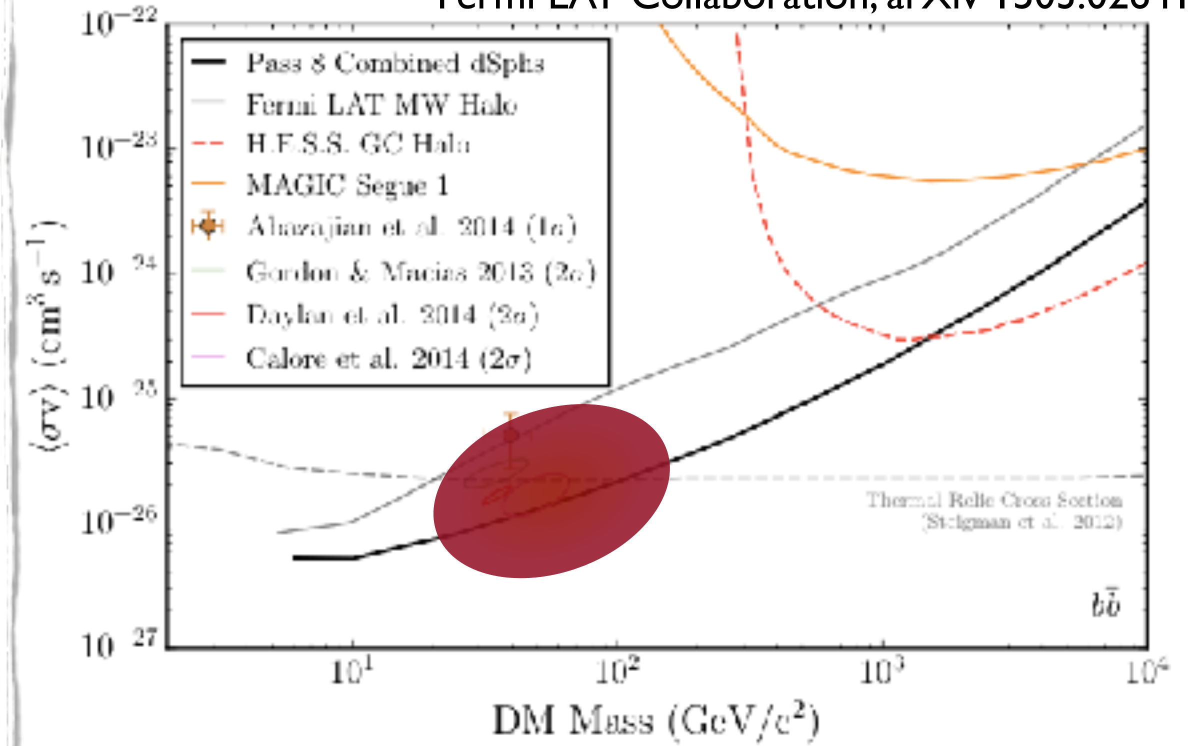
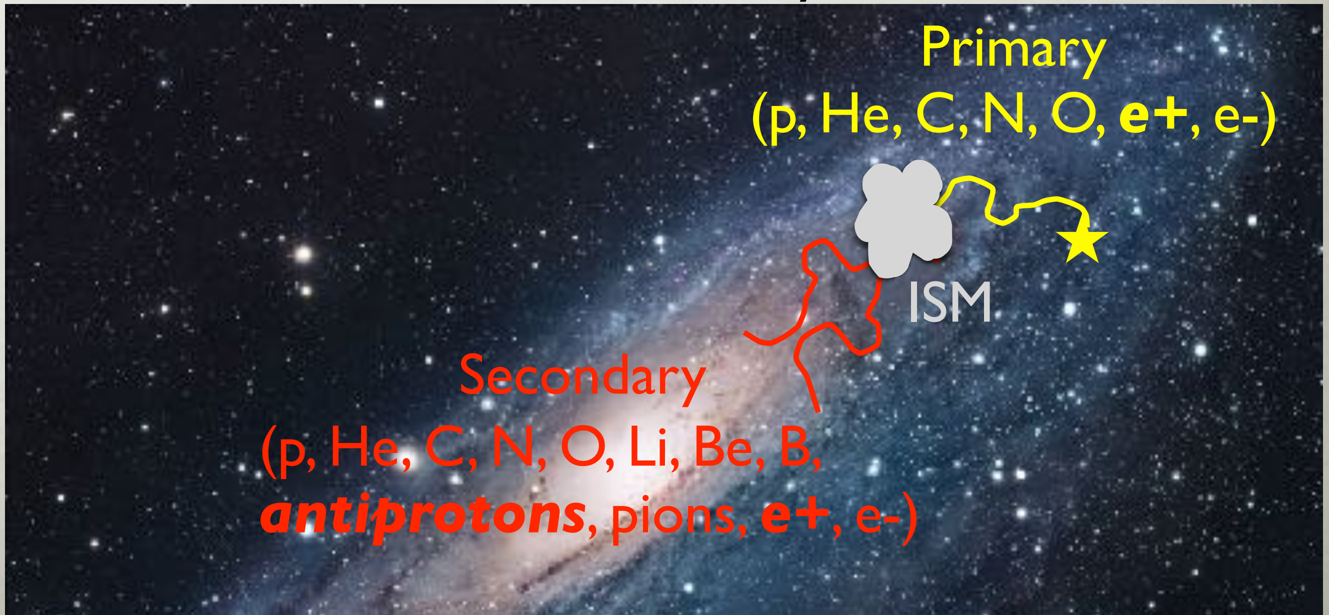


Cosmic rays

- **Antiparticles** are the better candidates for DM searches with charged CRs (far fewer are produced from conventional astrophysical processes)
- It is generally assumed they are produced as **secondaries** by interactions of primary CRs (accelerated at some source, e.g. supernova remnant) with the interstellar medium

➡ Anomalies/excesses in recent years are quoted with respect to this assumption!

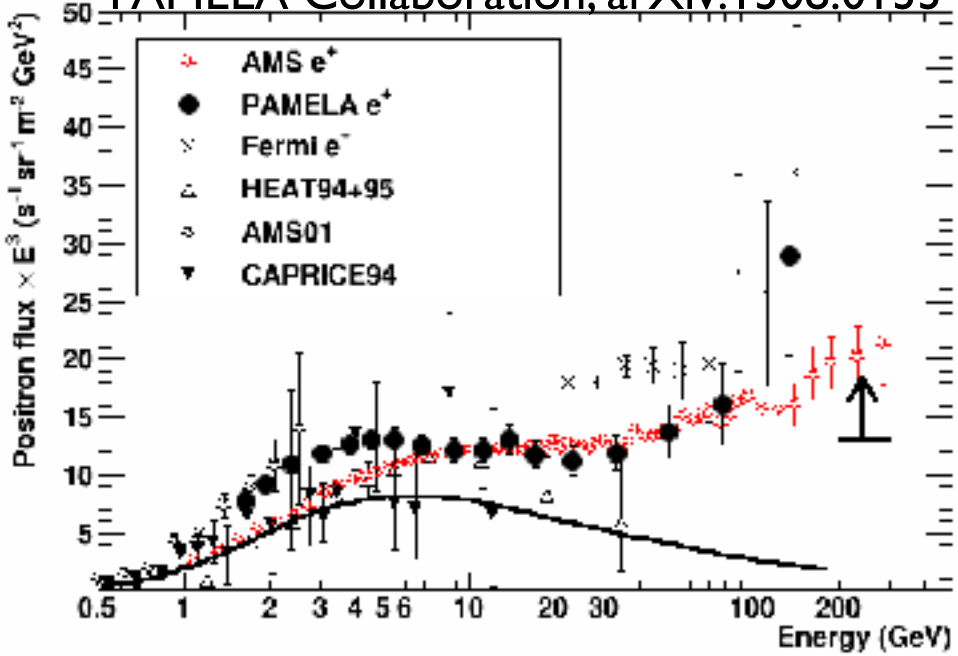
- Other production processes have been proposed to explain recent data, e.g. production and acceleration of secondaries at source, nearby source, in addition to dark matter



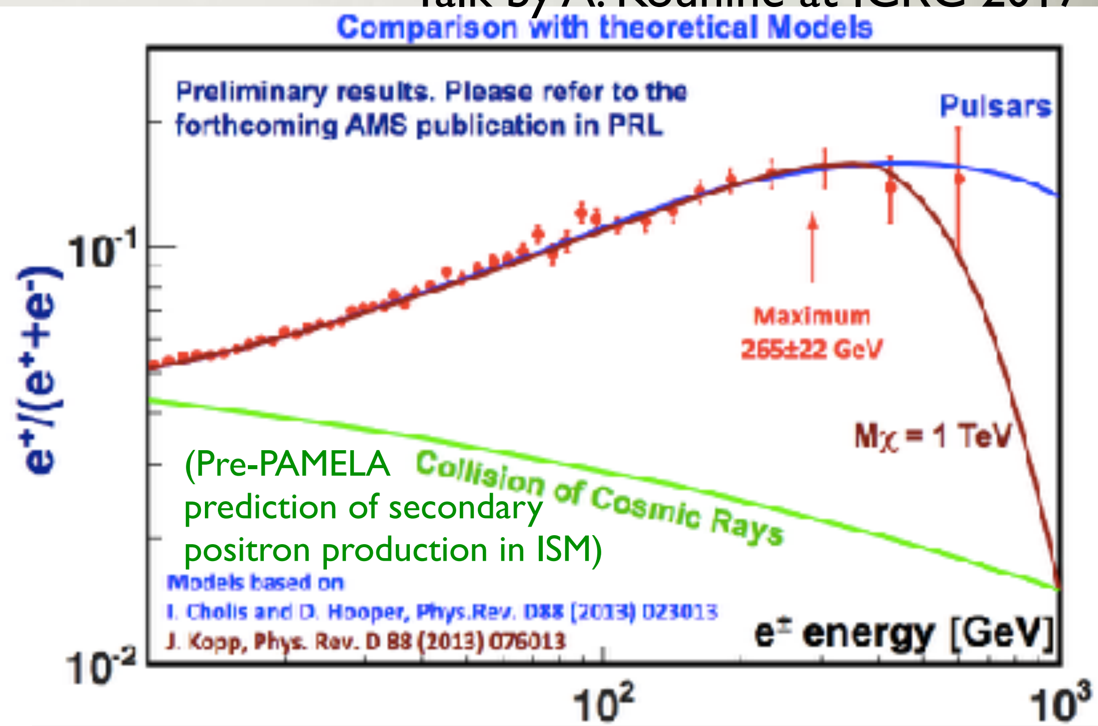
Positrons

- Positron fraction measured up to several hundred GeV (AMS-02). Rises at high energy, up to ~250 GeV

PAMELA Collaboration, arXiv:1308.0133



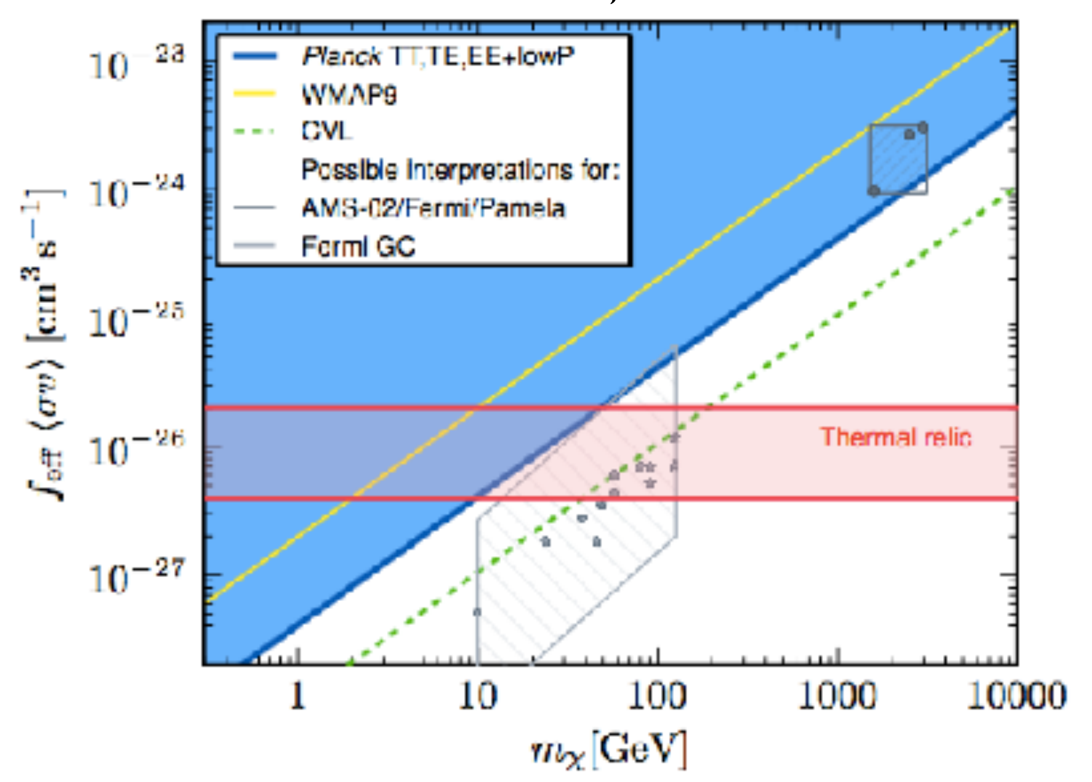
Talk by A. Kounine at ICRC 2017



Positrons

- Positron fraction measured up to several hundred GeV (AMS-02). Rises at high energy, up to ~250 GeV
- Dark matter can reproduce the rise, but it is disfavored by other searches (gamma rays, CMB, …)

Planck Collaboration, arXiv:1502.01589



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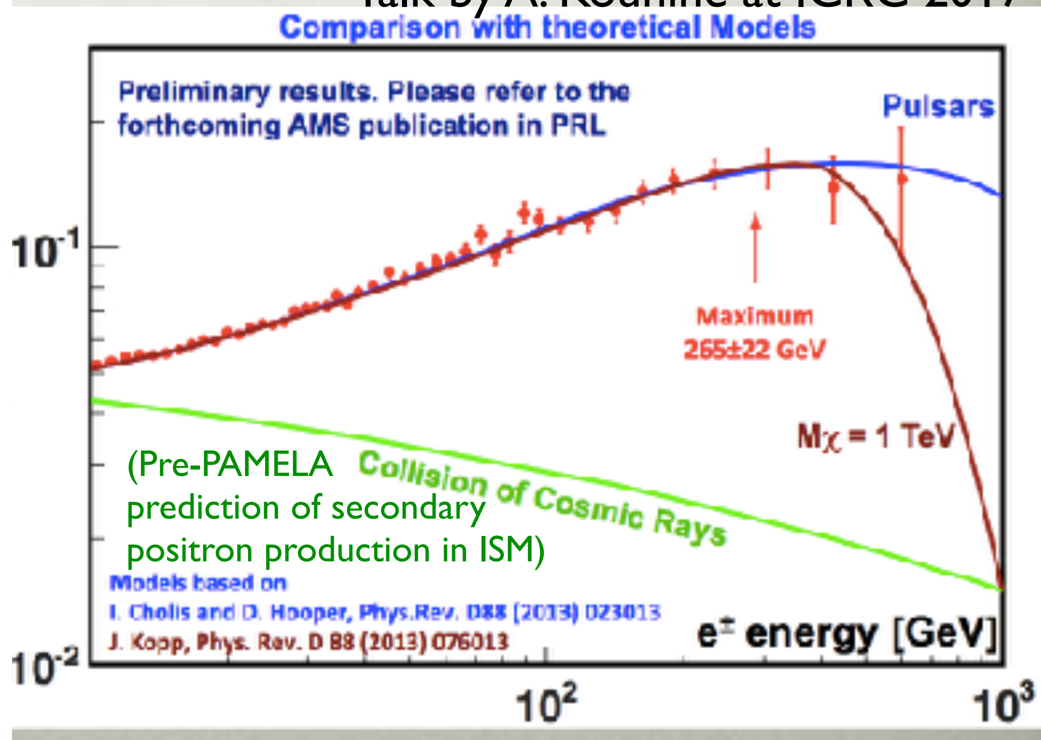


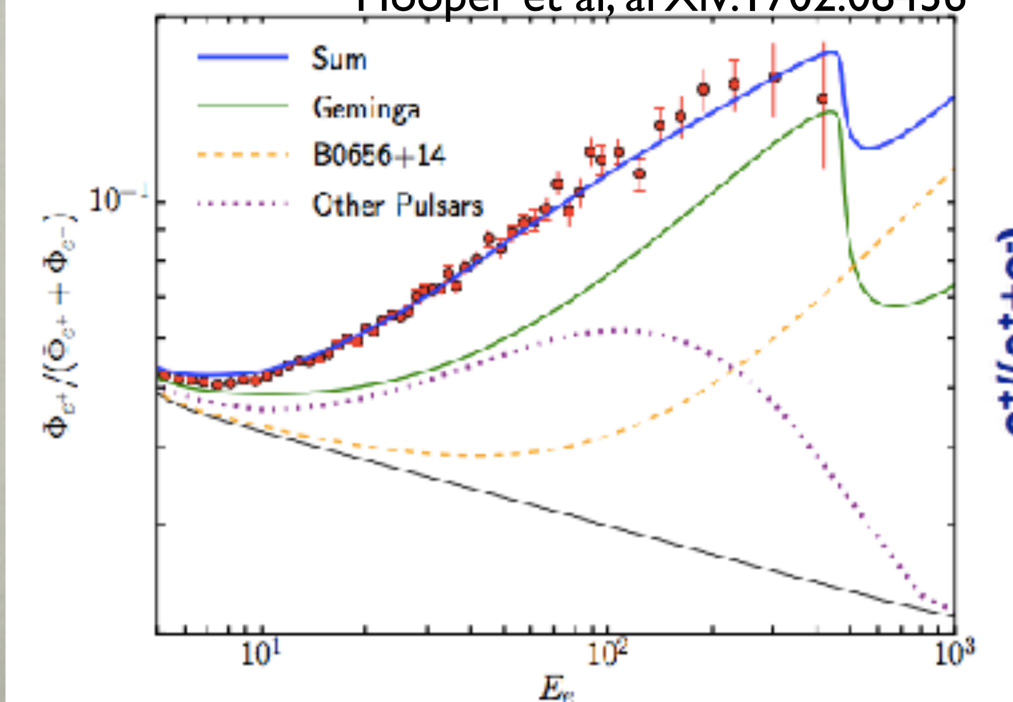
Positrons

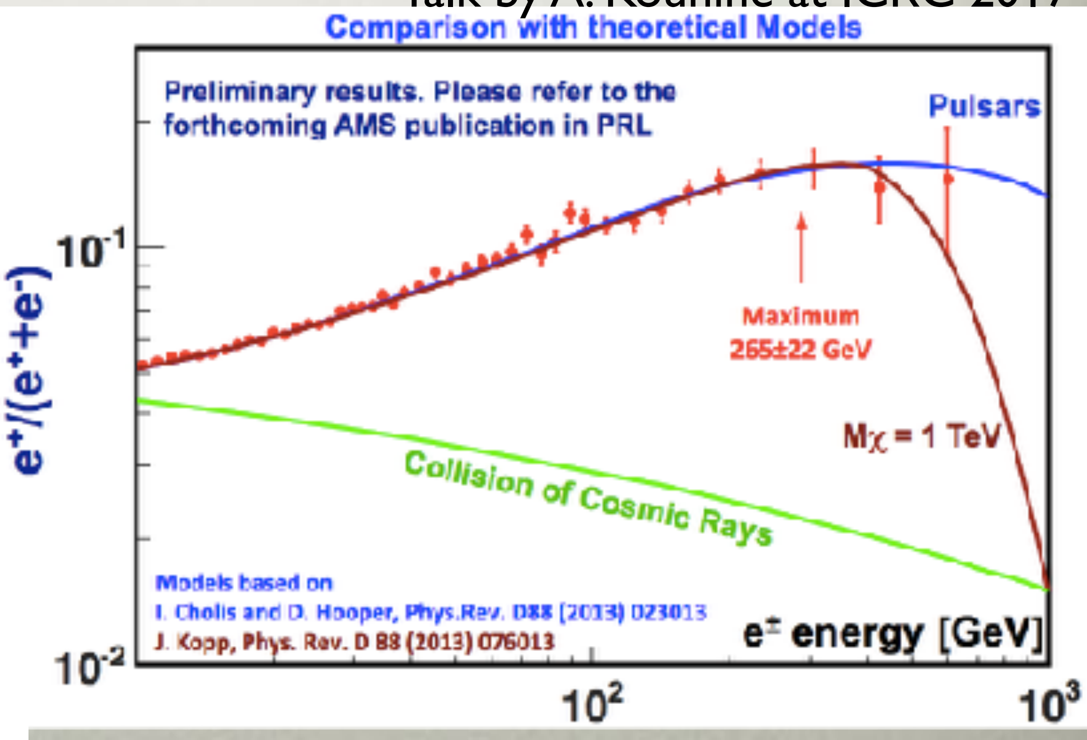
- Other plausible interpretations (**nearby single source**, population of sources, production of secondaries at source, …)
- E.g., observations of very high energy gamma rays (HAWC and Milagro) from nearby pulsars predict a significant contribution from these sources to the high energy positron flux, which could explain the AMS-02 and PAMELA data

➡ Anisotropy in the e+e- data could confirm the nearby source hypothesis. Predicted anisotropy is consistent with current bounds (Fermi LAT, AMS-02)

Talk by A. Kounine at ICRC 2017

Hooper et al, arXiv:1702.08436

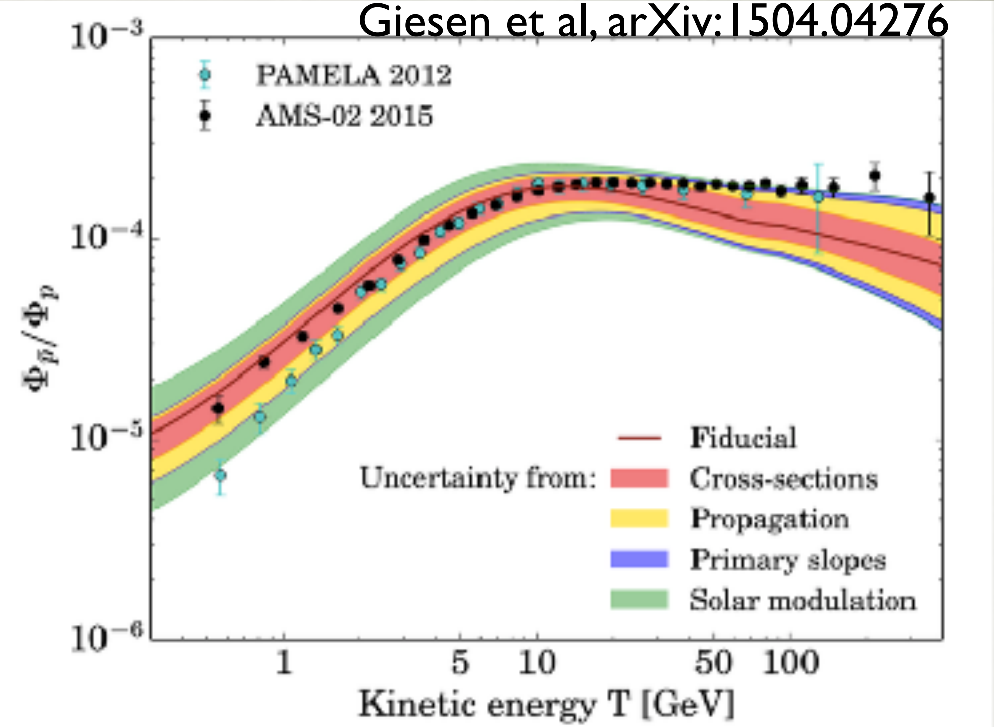




Antiprotons

- Generally in agreement with secondary production predictions (based on B/C measurements and antiprotons produced by CR interactions in the interstellar medium) also consistent with primary source to explain positron fraction

Giesen et al, arXiv:1504.04276



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➡ LHCb measurement of the antiproton production cross section in p-He collisions crucial in reducing uncertainties in predictions for CR antiprotons

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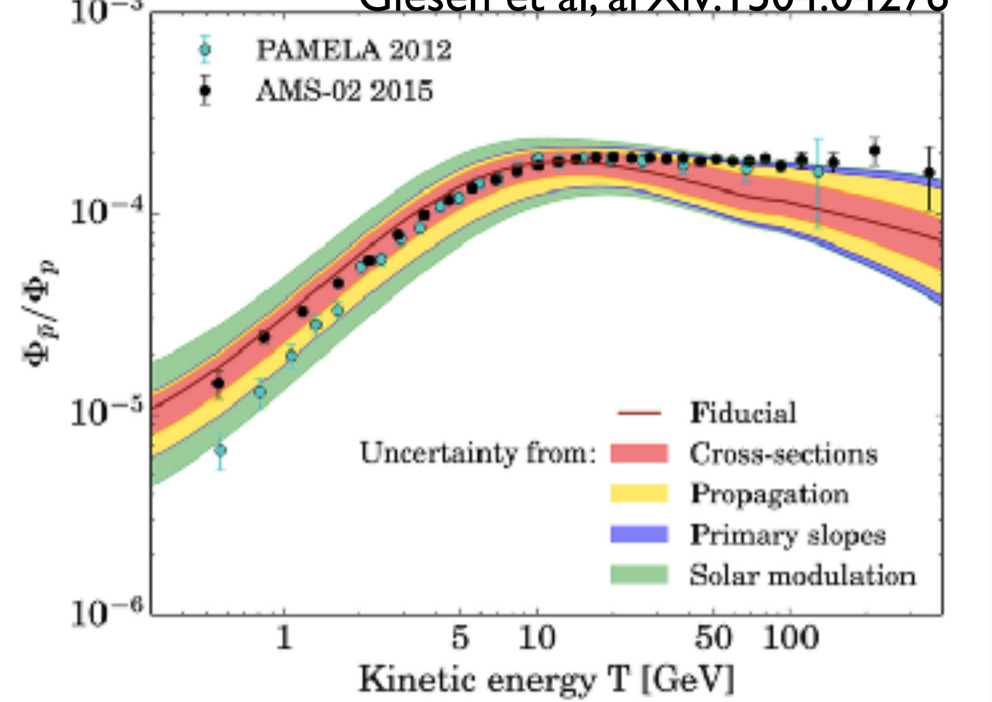
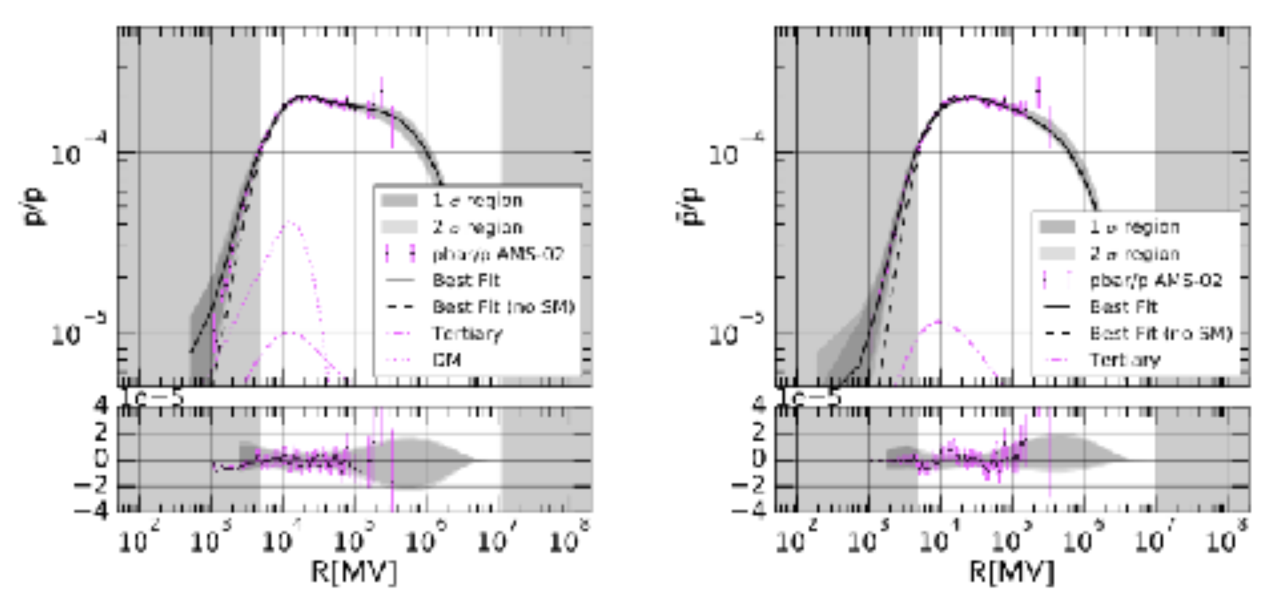
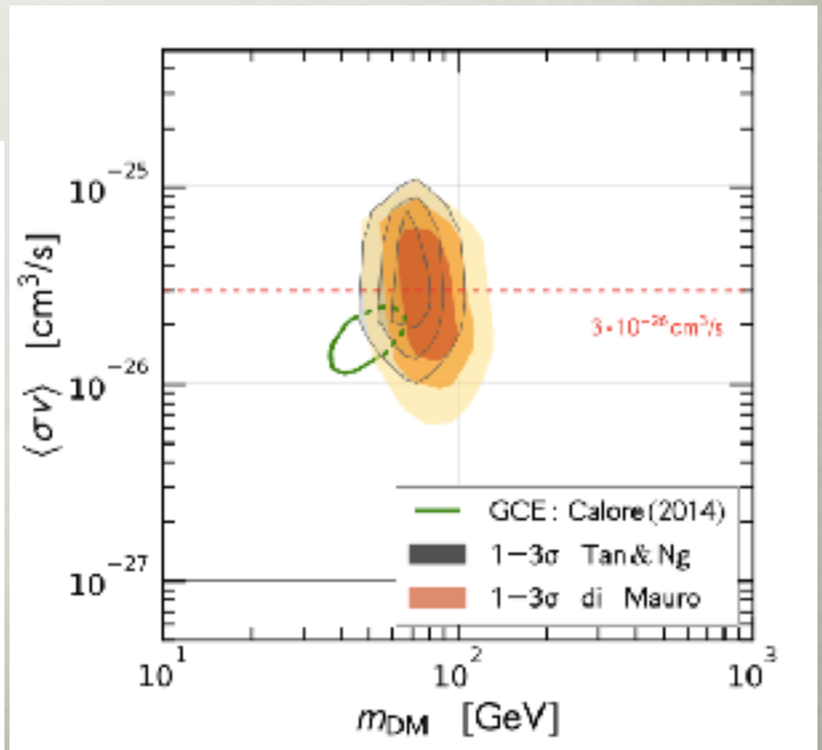


Antiprotons

- However, if a dark matter signal is fitted concurrently with CR propagation parameters, a signal is observed which is consistent with GC excess (assuming B/C is not representative of propagation for light nuclei, Johannesson et al, arXiv:1602.02243)

Cuoco et al, arXiv:1610.03071

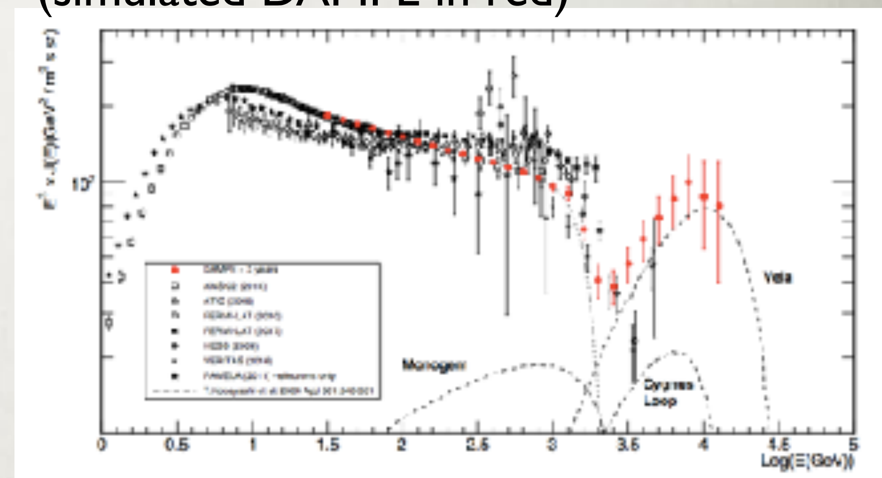




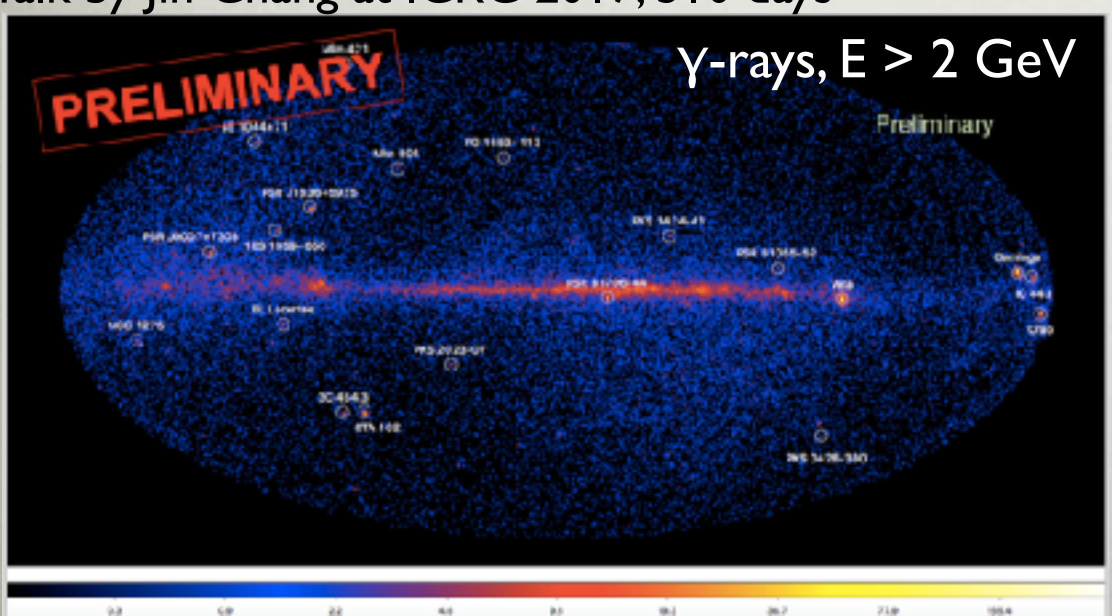
DAMPE

- Launched in Dec 2015. 1GeV - 10 TeV e/γ, 100 GeV - 100 TeV cosmic rays. Tracker+thick imaging calorimeter, excellent energy resolution (~1% @100 GeV, compare to ~10% for Fermi-LAT)
- Search for γ-ray lines, features in electron and positron spectra

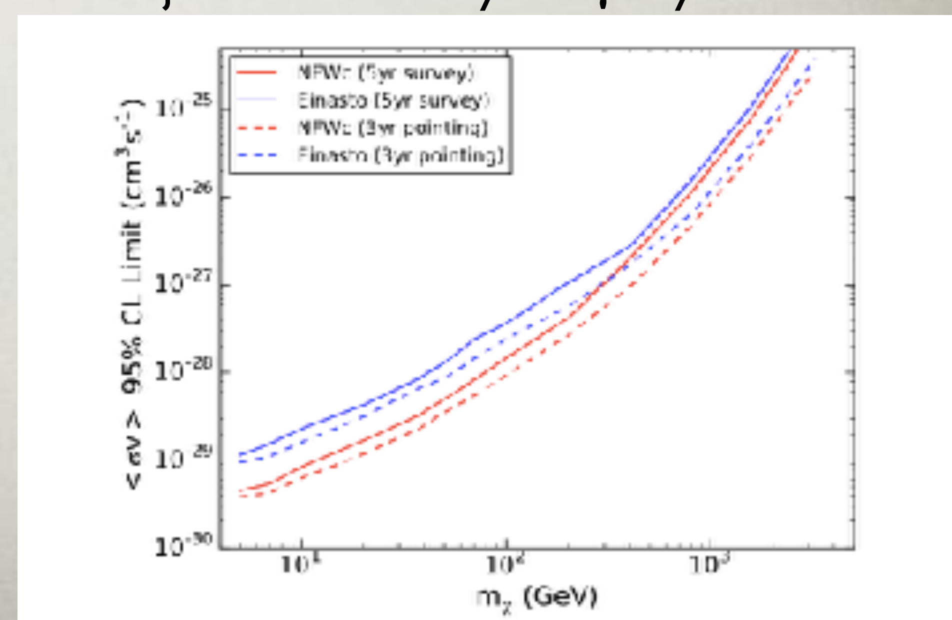
Electron and positron spectrum (simulated DAMPE in red)



Talk by Jin Chang at ICRC 2017, 510 days



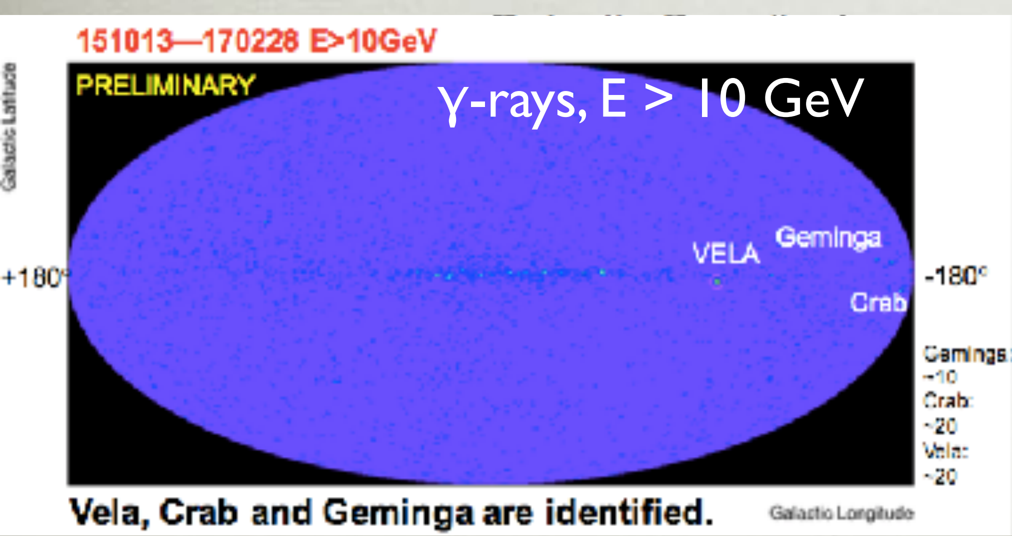
Projected sensitivity for γ-ray line search

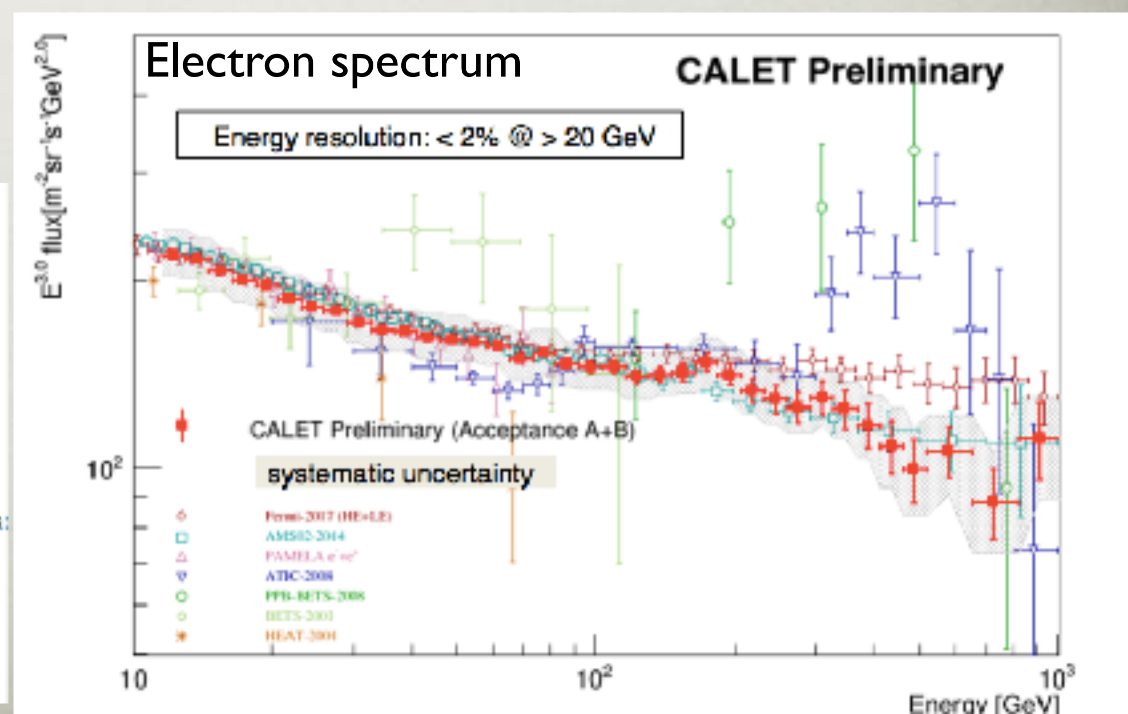


CALET

- On ISS since Aug 2015. 10 (1) GeV - 10 (20) TeV γ (e), 10's GeV - 1000 TeV nuclei. Thick calorimeter, excellent energy resolution.
- Test dark matter scenarios and interpretation via spectral features in e+e- and γ spectra, e.g. lines, LKP. Detection of nearby astrophysical sources of electrons
- High precision measurement of the electron spectrum at high energy with excellent energy resolution might reveal evidence of a nearby source (e.g. SNR)

Talk by Shoji Torii at ICRC 2017

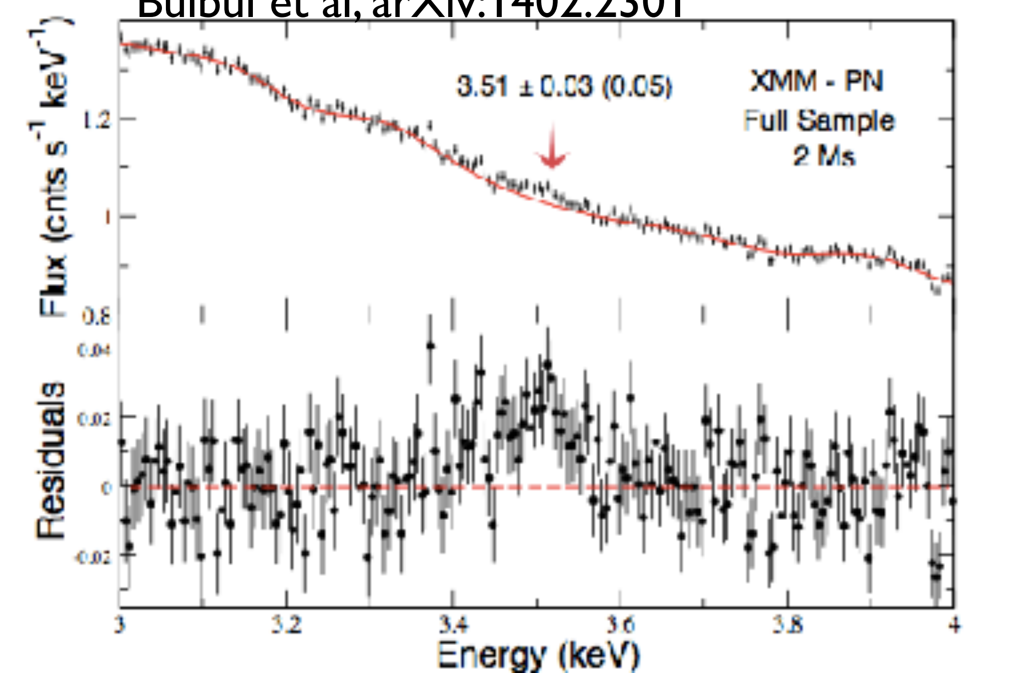




X-rays

- X-ray line at 3.5 keV observed by XMM-Newton and Chandra in the (stacked) data from clusters of galaxies, Perseus cluster, Andromeda galaxy, Galactic center (Bulbul et al, arXiv:1402.2301, Boyarsky et al, arXiv:1402.4119). Stacked clusters cover 0.01 < z < 0.35. *Line at same energy in the blue-shifted frame.*
- Possible interpretations: emission line of heavy ions (e.g. K, Ar) in the thermal plasma, DM in the form of a 7 keV **sterile neutrino**

Bulbul et al, arXiv:1402.2301



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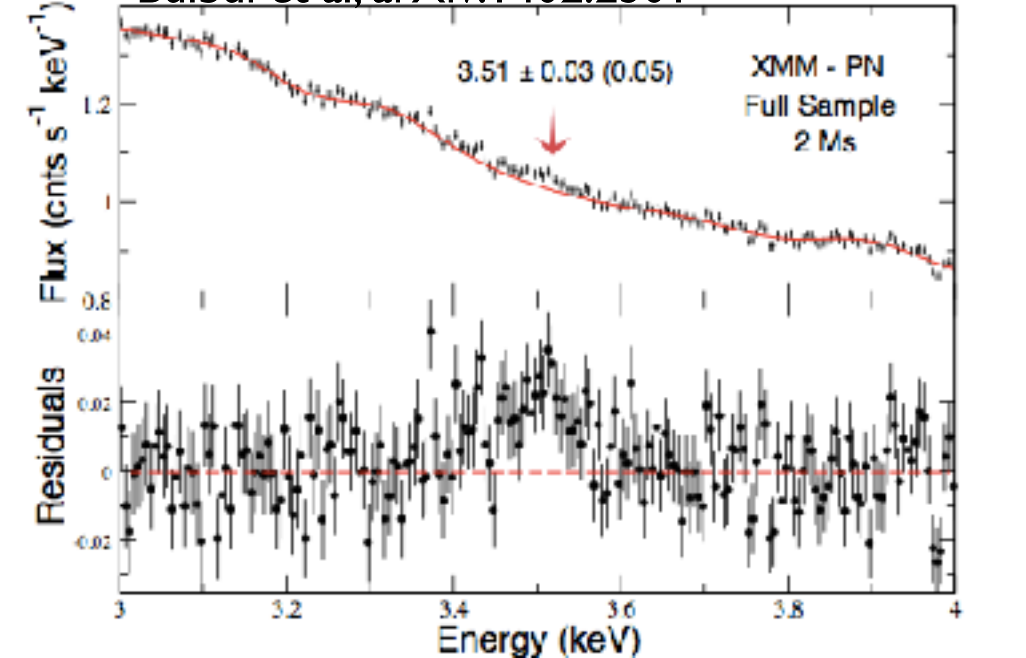
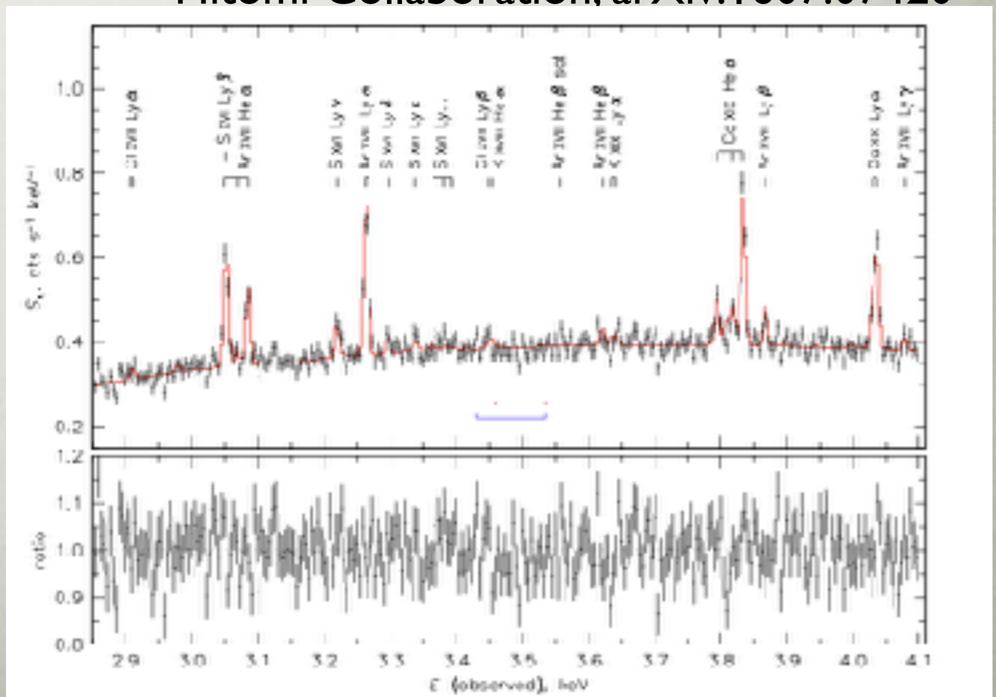


Hitomi Collaboration, arXiv:1607.07420



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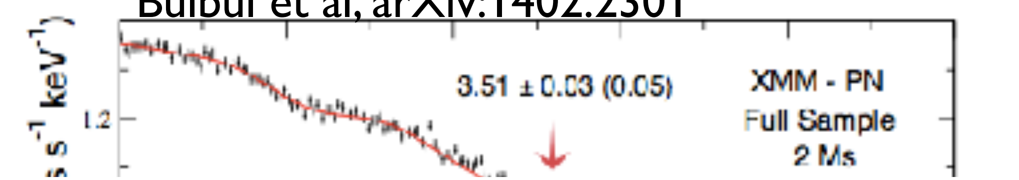
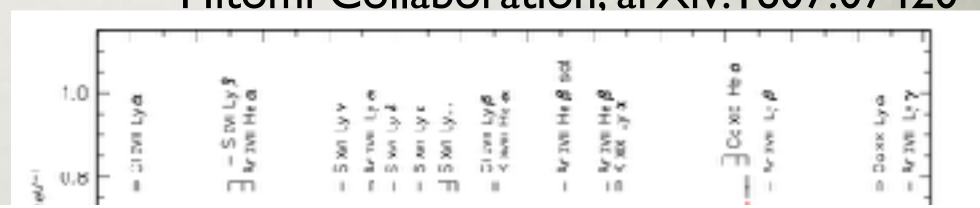
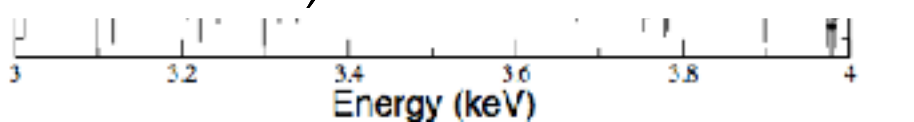
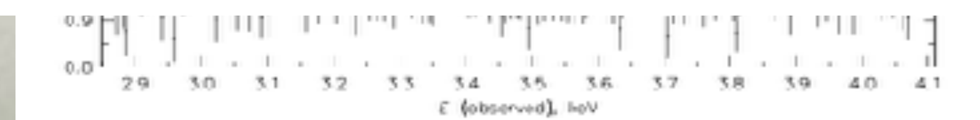




➡ Future experiments will shed more light on this (e.g. Hitomi's replacement XARM in early 2020, Athena in late 2020)

➡ Dark matter velocity spectroscopy might be able to distinguish between DM, astrophysical, or instrumental origin of line emission (Speckhard et al, arXiv: 1507.04744)





Summary

- Intriguing hints of potential signals has been claimed, e.g. in gamma rays from the Galactic center. However the conventional astrophysics background is currently a limitation!

  Complementarity will also help, 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 for the GC gamma-ray excess

- The rise in the CR positron fraction continues to be investigated. Many viable interpretations other than DM exist.

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THANK YOU!