Title: Astroparticle Physics â€“ Observations: Charged particles

Date: Jul 14, 2015 04:00 PM

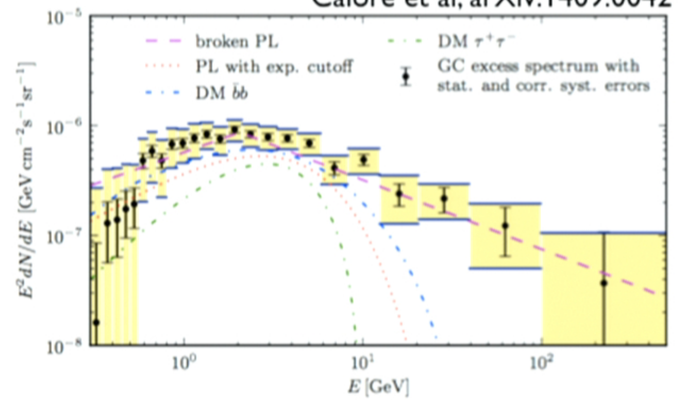
URL: http://pirsa.org/15070046

Abstract:

Galactic Center Dark Matter Searches

- More extensive study of the background model systematics
- Broad range of interstellar emission models
- Results compatible with dark matter annihilation into b-bbar and a mass of ~50 GeV

Calore et al, arXiv:1409.0042

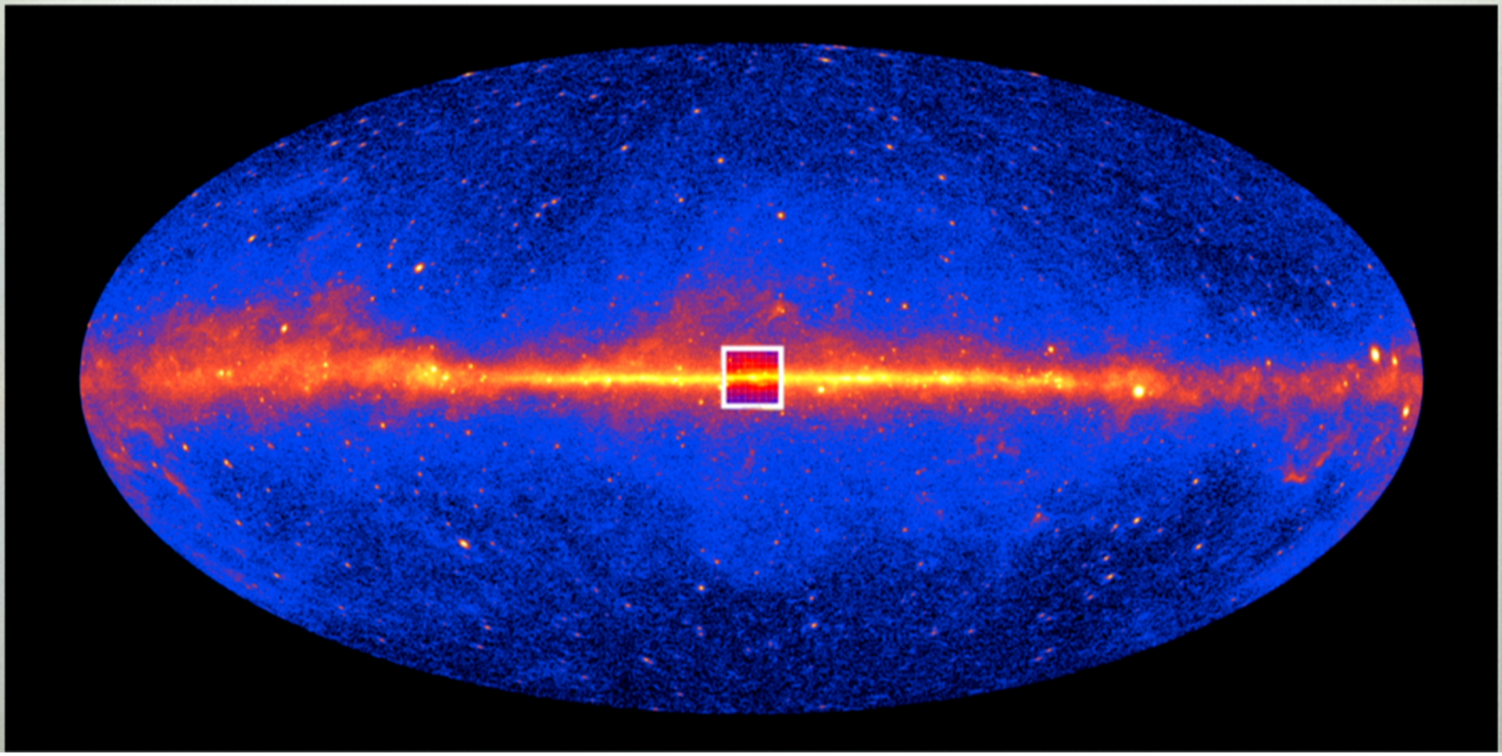


- Recently, Lee, Lisanti et al (arXiv:1506.05124) et al used template analysis that accounts for non-poissonian photon statistics to determine if the excess can be explained by unresolved point sources
- The result by Lee et al favors the excess originating from point sources at/below the Fermi LAT detection threshold
- Improved angular resolution has been recently be made available in the Fermi LAT data (*Pass 8*) and might be useful to test this claim

Galactic Center Region

Fermi LAT Collaboration

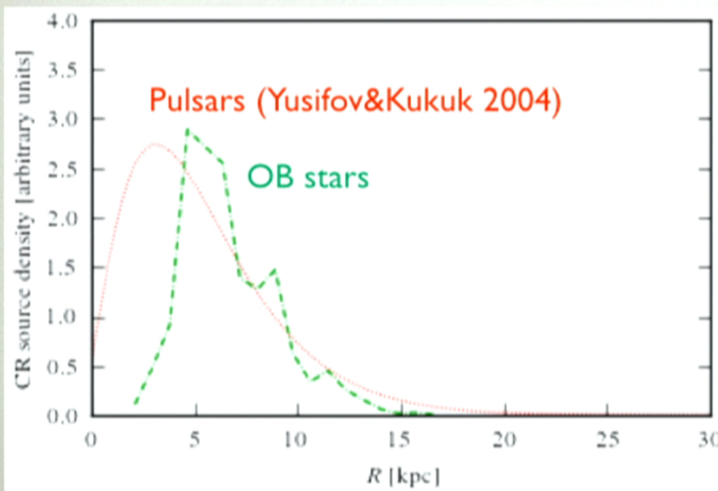
- Focus on a 15°x15° region (~ 1 kpc) around Galactic center

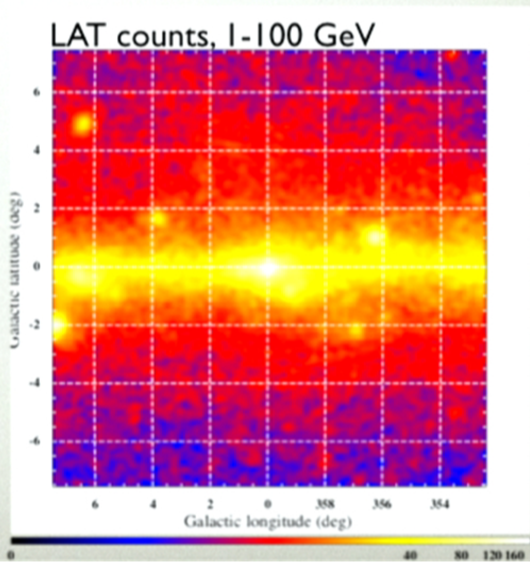


Modeling the Interstellar Emission

Fermi LAT Collaboration

- Interstellar emission models: use GALPROP models with prop. parameters consistent with CR data and in good agreement with all-sky gamma-ray data, from *Ackermann et al, 2012, ApJ 750*. Select two models with broad range in the radial extent of the CR source distribution (Pulsars, OB stars) as baseline
- Tune the baseline models to gamma-ray data outside of the ROI for improved foreground/ background determination





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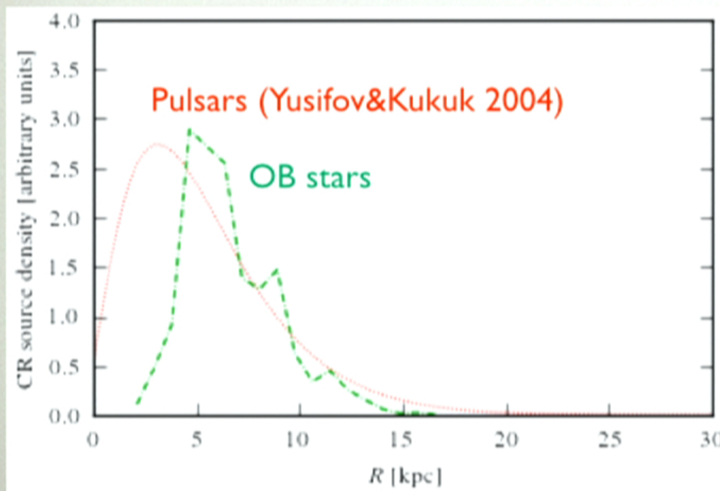
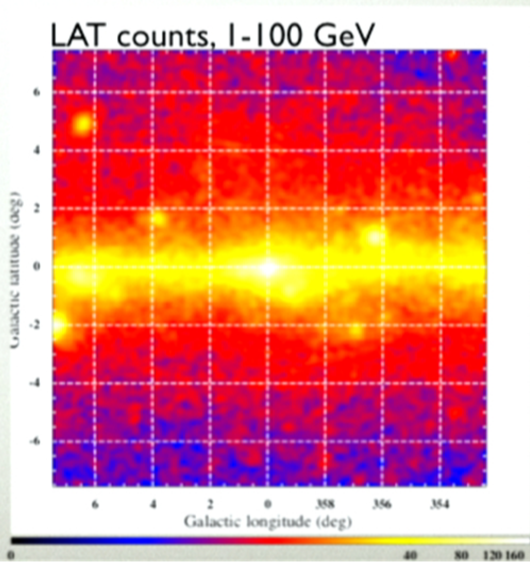




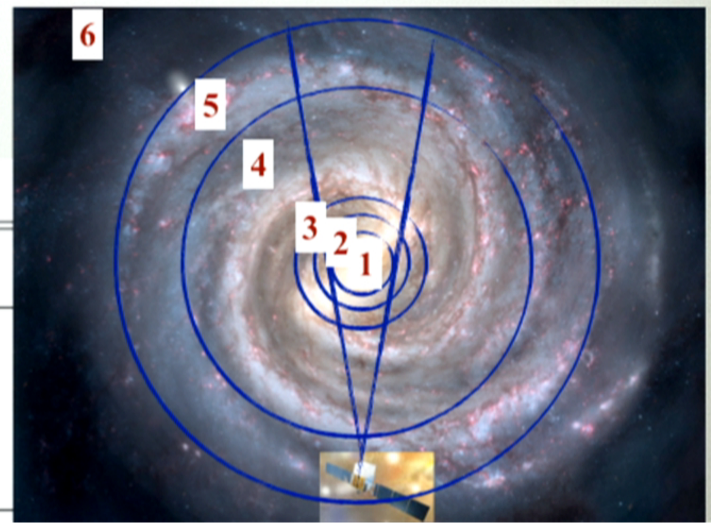
Background Tuning Procedure

Fermi LAT Collaboration

- Determine intensity for π^0 (from HI and H_2 gas) and IC contributions in galactocentric rings,
  - IC component divided in rings (dev. version of GALPROP), same boundaries as the gas: these additional degrees of freedom can compensate for uncertainies in the GALPROP model of the electron spectrum or ISRF used to calculate the IC templates
- Isotropic and Loop I (*Wolleben, 2007, ApJ 664*) emissions also fitted to the data
- Different sky regions are employed based on where the components that are fitted contribute most. Point source locations and spectra taken from the preliminary 3FGL.

Galactocentric ring boundaries.

Ring #	$R_{\rm min}$ [kpc]	$R_{\rm max}$ [kpc]	Longitude Range (Full)
1	0	1.5	$-10° \leq l \leq 10°$
2	1.5	2.5	$-17° \leq l \leq 17°$
3	2.5	3.5	$-24° \leq l \leq 24°$
4	3.5	8.0	$-70° \leq l \leq 70°$
5	8.0	10.0	$-180 \leq l \leq 180°$
6	10.0	50.0	$-180 \leq l \leq 180°$



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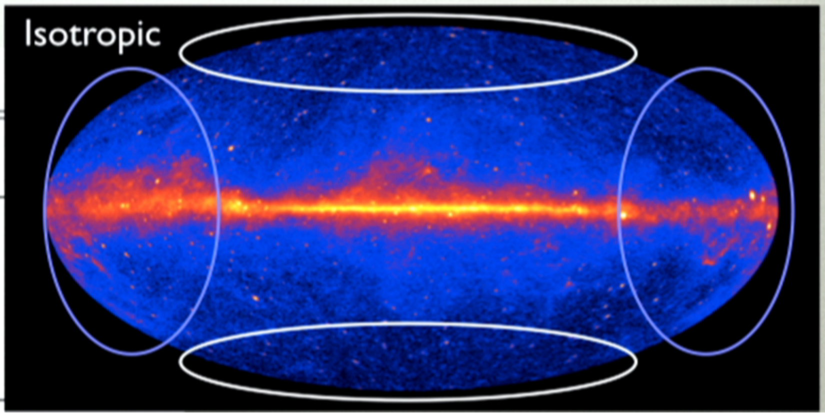
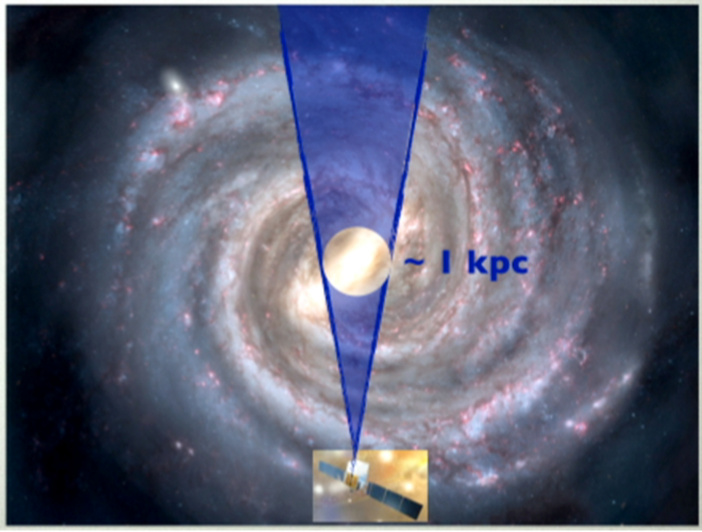


Modeling the 15°x15° ROI

Fermi LAT Collaboration

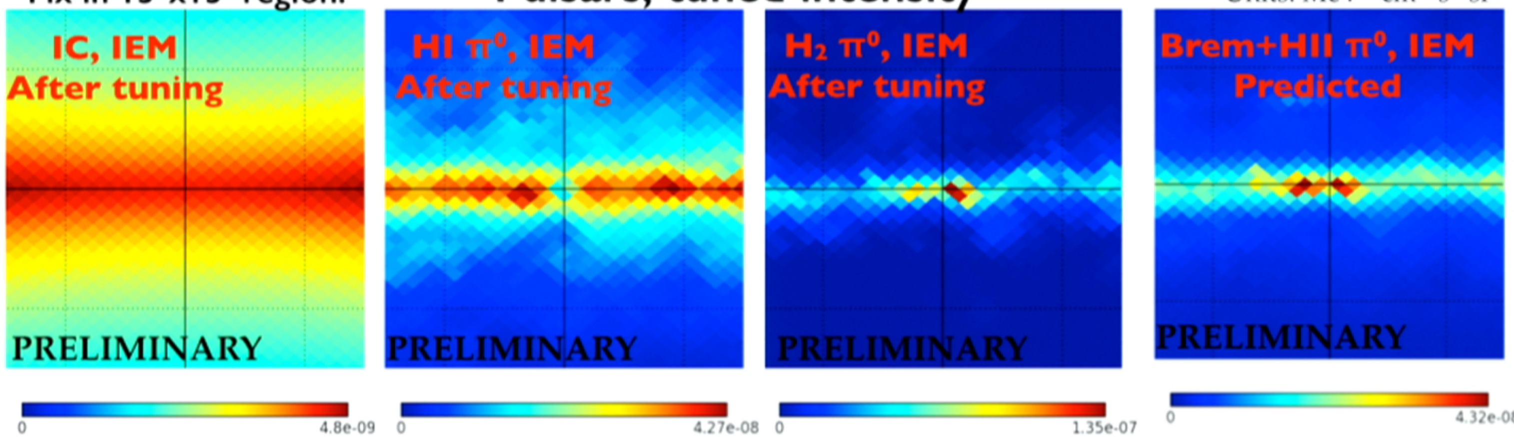
- Model the emission from the 15°x15° ROI for each of the 4 foreground/background models
- Point sources in the region are determined consistently with these models - we do not use existing catalogs
  - identify preliminary locations of point source candidates by applying *PGWave* (*Damiani et al. 1997, ApJ, 483* wavelet algorithm, assumes flat background) to the data in 4 equally spaced LogE bins in the1-100 GeV range
  - for each of the (fixed) models, determine position and initial values of the spectra of the point source candidates (*Pointlike*)
  - obtain list of point source candidates with TS>9 for the analysis of the 15°x15° ROI



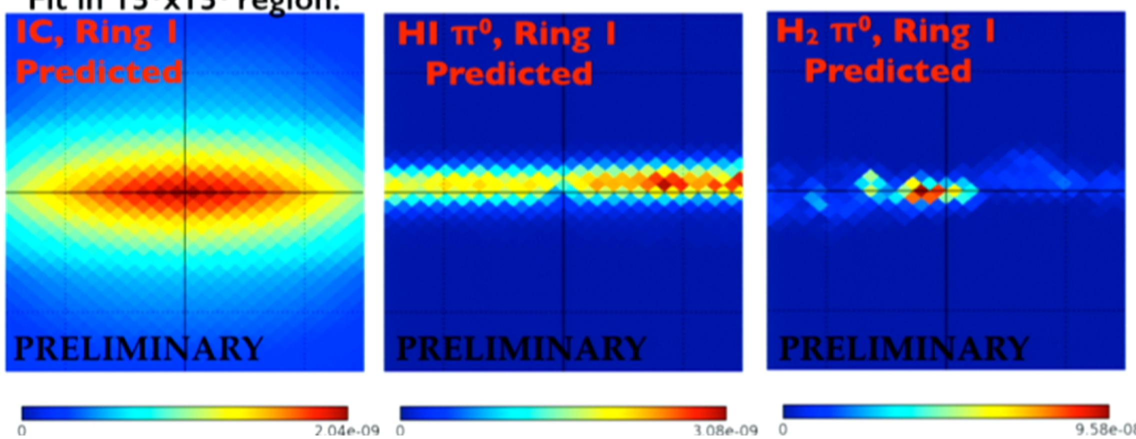
Model Intensities

Fix in 15°x15° region: **Pulsars, tuned intensity**

Fermi LAT Collaboration
Units: $MeV^{-1}\ cm^{-2}\ s^{-1}\ sr^{-1}$



Fit in 15°x15° region:



IEM refers to foreground/ background model

15°x15° ROI
E>1 GeV

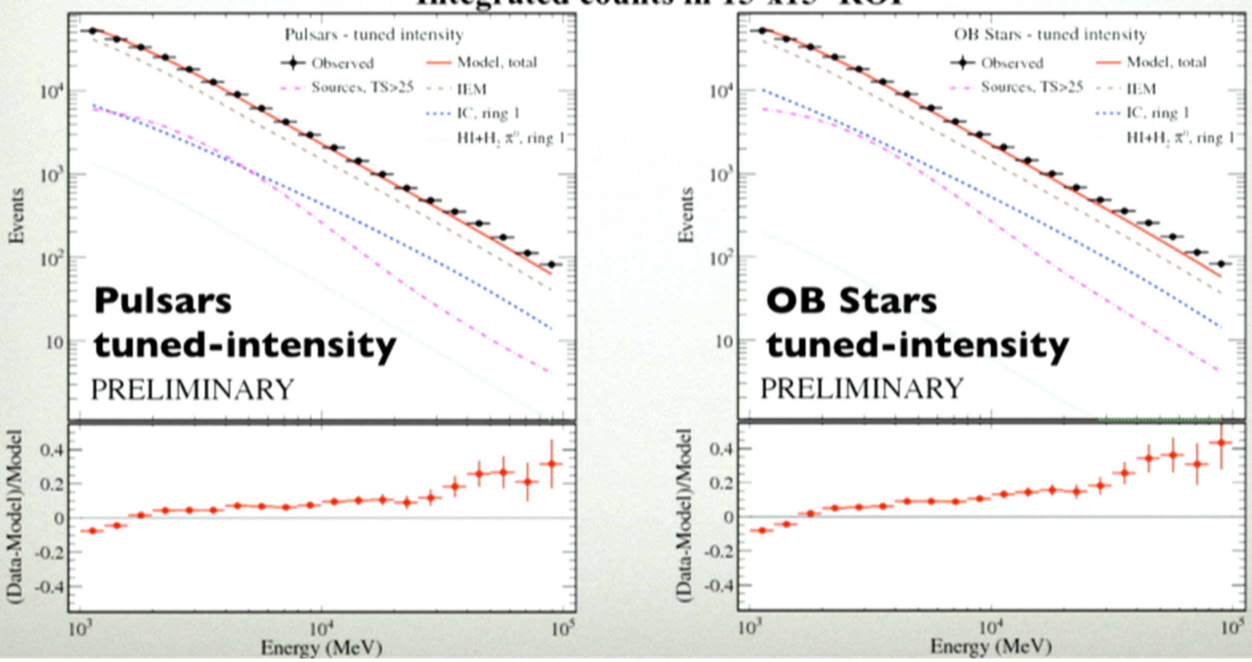
~0.23° pixels

Results

Fermi LAT Collaboration

- The data-model agreement is within 5-10% averaged over the 15°x15° ROI up to ~ 10 GeV. The models are too bright below ~2 GeV, and too dim above
- The foreground/background accounts for most of the emission in the region.

Integrated counts in 15°x15° ROI



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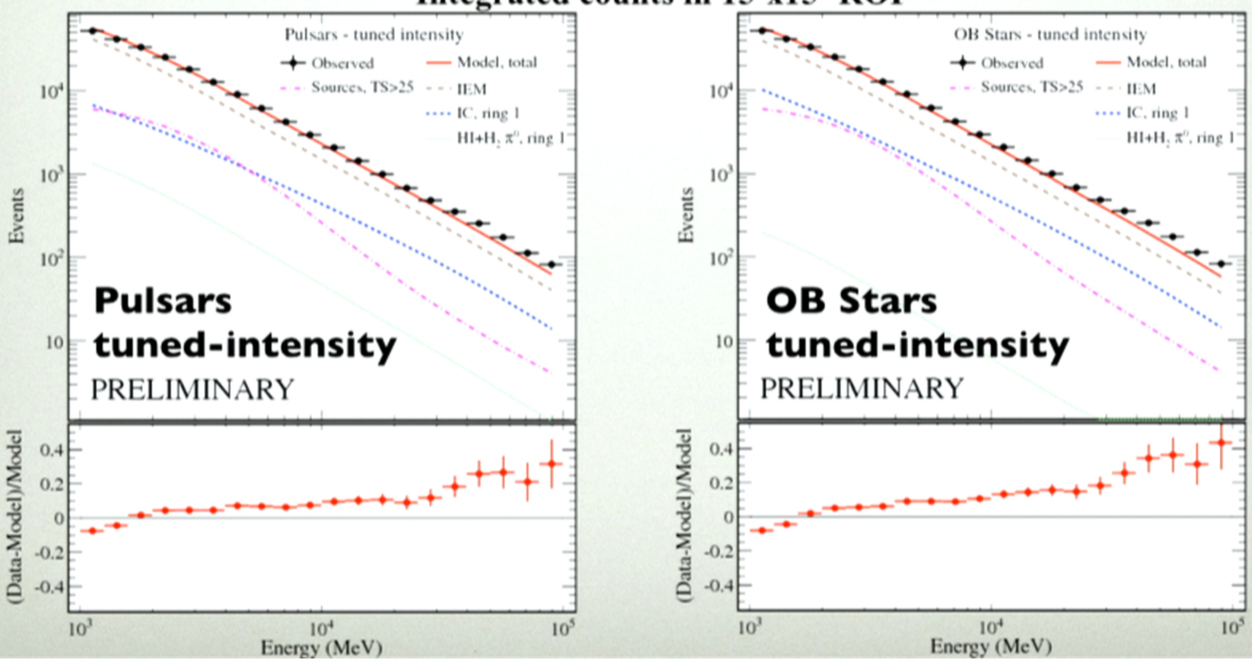
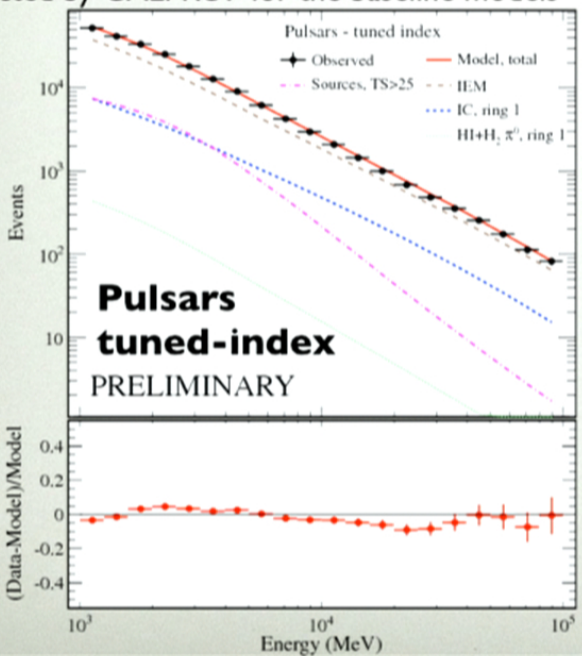


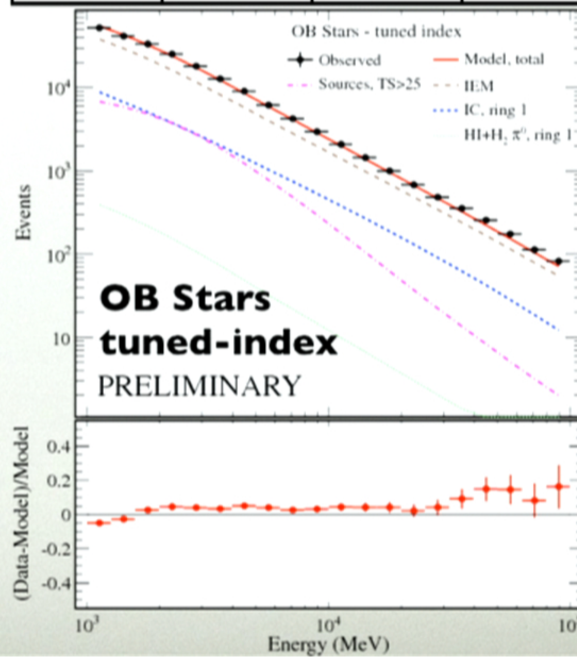
Results

Fermi LAT Collaboration

- Agreement is better for tuned index models
- ➡ For all foreground/background models, the fitted IC emission for ring I is brighter than the gas emission and larger (7-30x) than predicted from GALPROP for the baseline models. This could be due to higher intensity of ISRF and/or higher CR lepton intensities than assumed
- Point source contribution comparable to IC
- HI/H_2 pi0 intensities are subdominant and less than predicted by GALPROP for the baseline models

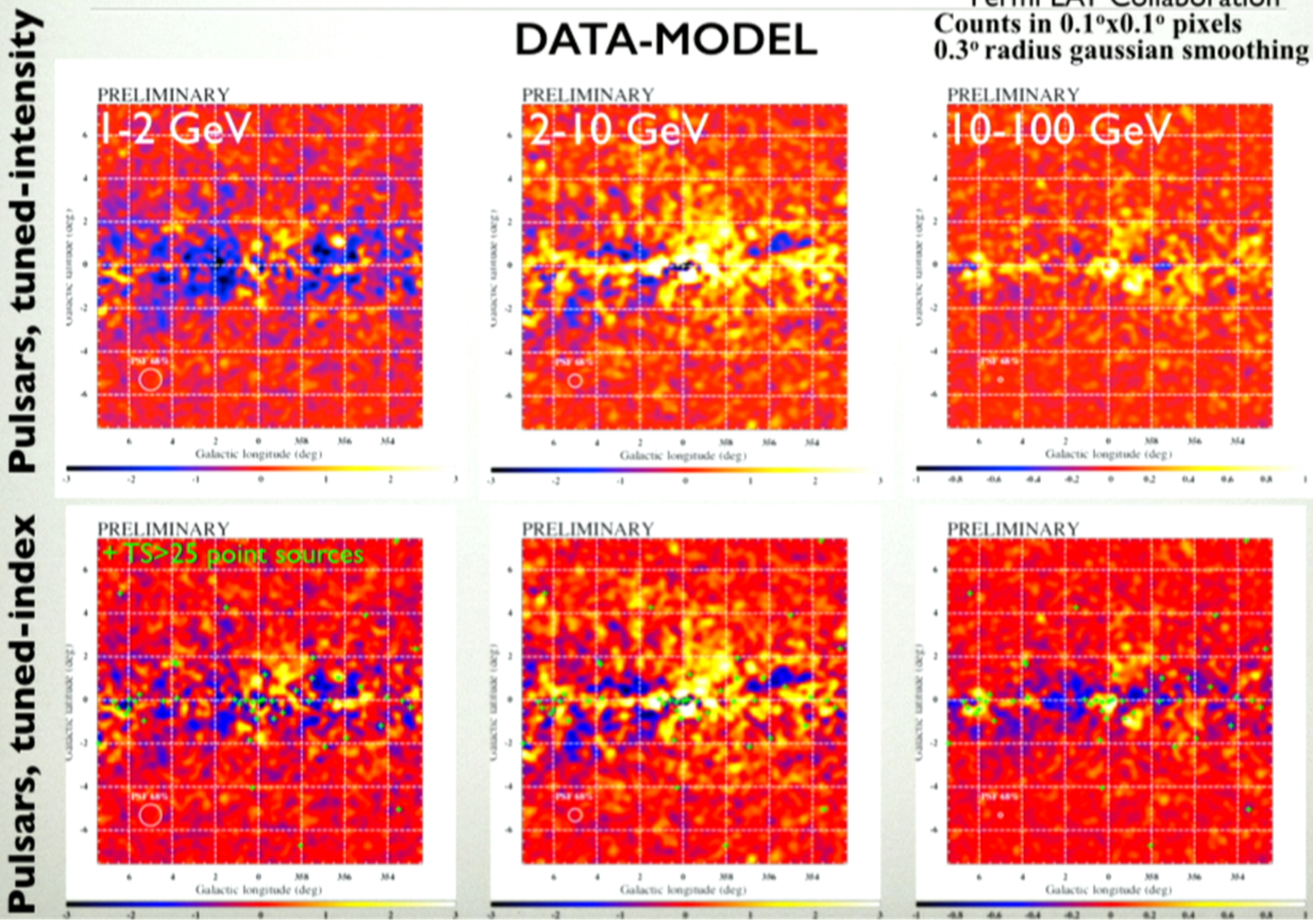
Integrated flux in 15°x15° ROI, E>1GeV, 10^{-8} ph cm^{-2} s^{-1}			
IC, Ring 1	π^0, Ring 1	IC, IEM	π^0, IEM
41-59	1-8	**24-33**	151-164





Results - Residual Maps

Fermi LAT Collaboration

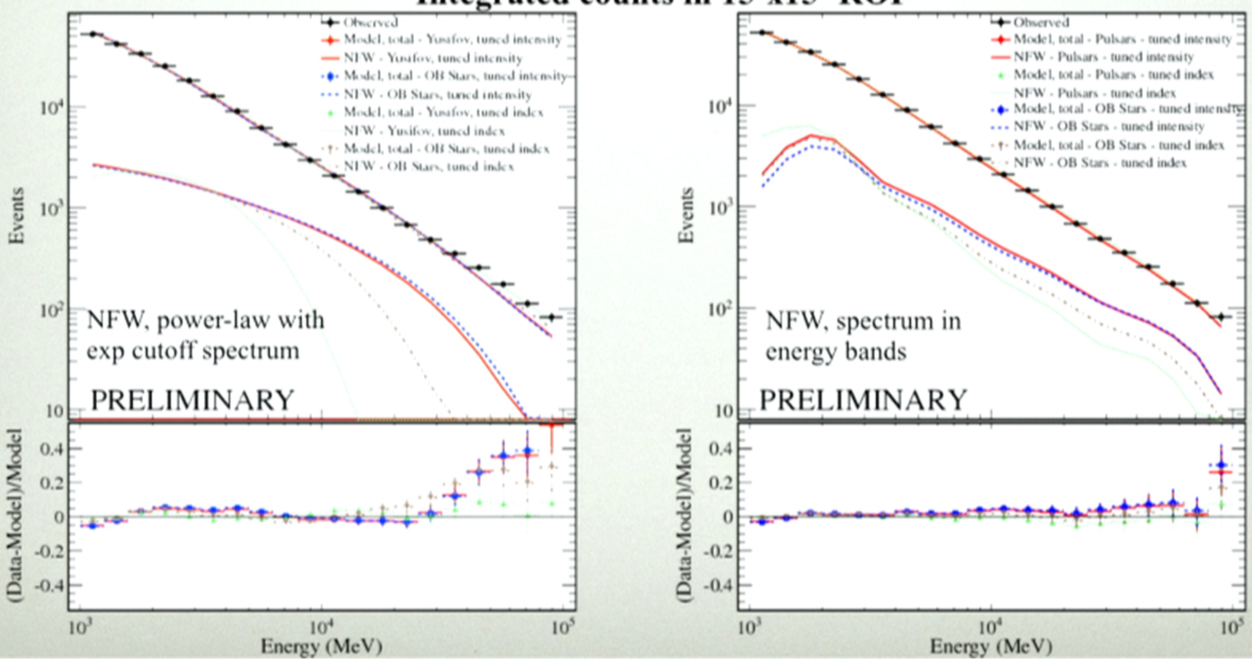


Additional Templates

Fermi LAT Collaboration

- We test the possibility that an additional component centered at the GC contributes to the data (2D gaussians, Navarro-Frenk-White, or a gas-like distribution as proxy for unresolved sources)
- Peaked profiles with long tails (NFW, NFW contracted) yield the most significant improvements in the data-model agreement for the four variants of the foreground/background models. IC ring I contribution ~2-3x smaller than without additional component and HI ring I contribution is ~2-5x larger
- ➡ The predicted spectrum depends on the foreground/background models.

Integrated counts in 15°x15° ROI



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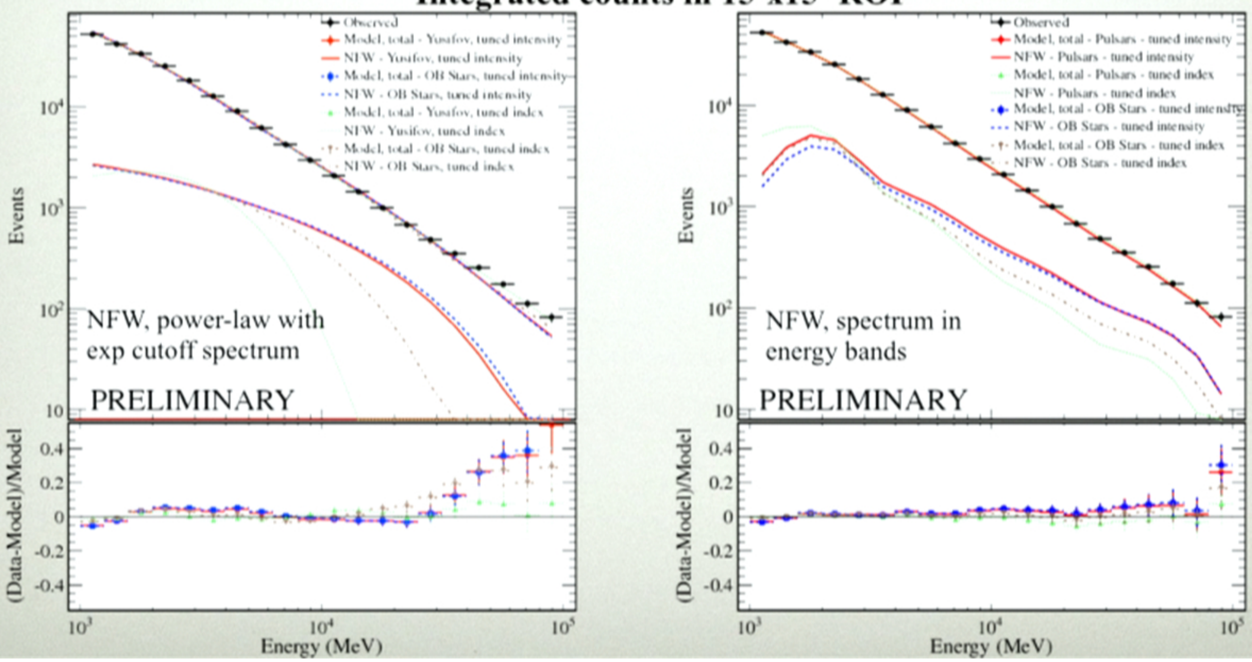
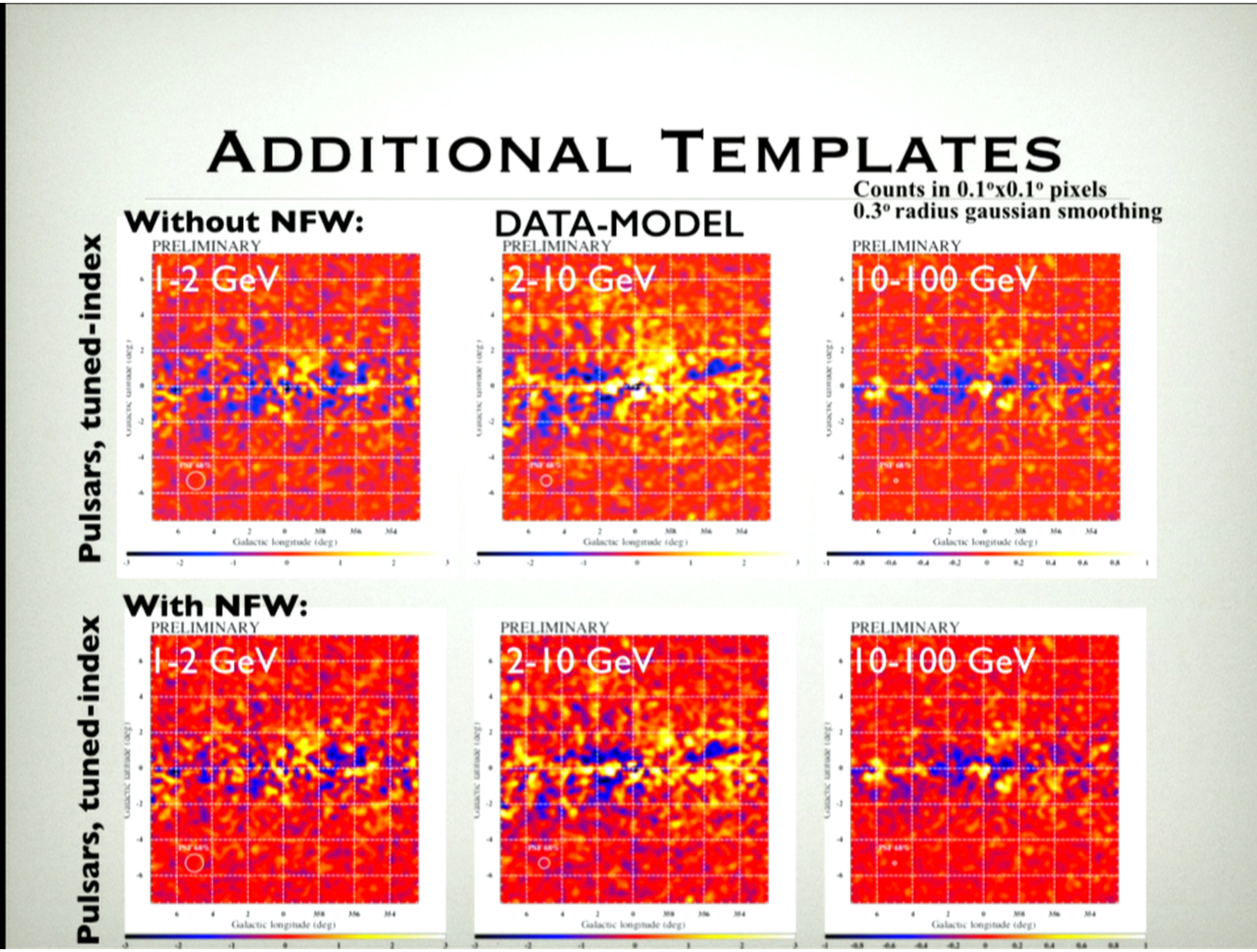
- ➡ The predicted spectrum depends on the foreground/background models.

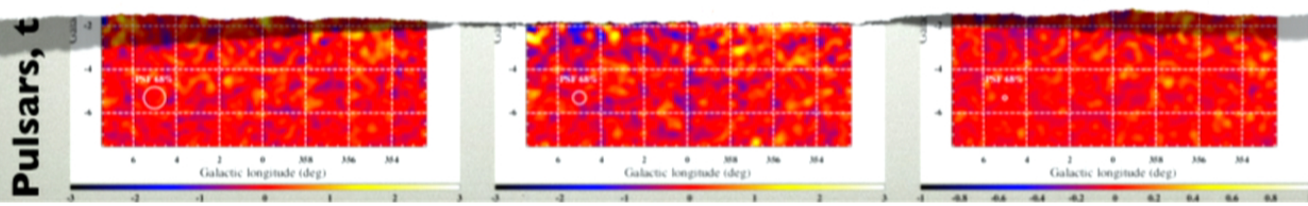
Integrated counts in 15°x15° ROI




ADDITIONAL TEMPLATES
Counts in 0.1°x0.1° pixels
0.3° radius gaussian smoothing
Without NFW:
DATA-MODEL
With NFW:
Pulsars, tuned-index
Pulsars, tuned-index
PRELIMINARY
1-2 GeV
2-10 GeV
10-100 GeV
Galactic longitude (deg)

- We have systematically developed a set of models for the diffuse emission in the inner 15°x15° of the Milky Way, by fitting GALPROP-derived templates in a way not done before
- We determined the point sources as part of the development of this model
- We employ all sky data to constrain the foreground/background emission, excluding the 15°x15° region, <u>for different assumptions on the CR source distribution, gas intensity and spectral index, and IC intensity across galactocentric rings</u>
- We find:
  - We find an excess approximately centered the Galactic center with a spectrum that peaks in the GeV range, that persist across the models we have employed. The spectral properties vary widely depending on the modeling of the interstellar emission
  - IC emission from inner kpc is higher than predicted and is the dominant interstellar emission component in this region. We are exploring the origin of the enhanced IC in the IG to see what combination of ISRF and CR leptons best explains the data.
  - Foreground/background accounts for most of the emission. Its determination is crucial in extracting the contribution from the Galactic center region

➡ We are further exploring the systematic uncertainties in the IEM, e.g. <u>gas distribution, ISRF, cylindrical symmetry</u>. This is crucial in determining properties of the IEM in the innermost kpc and to confirm the presence and properties of an additional component



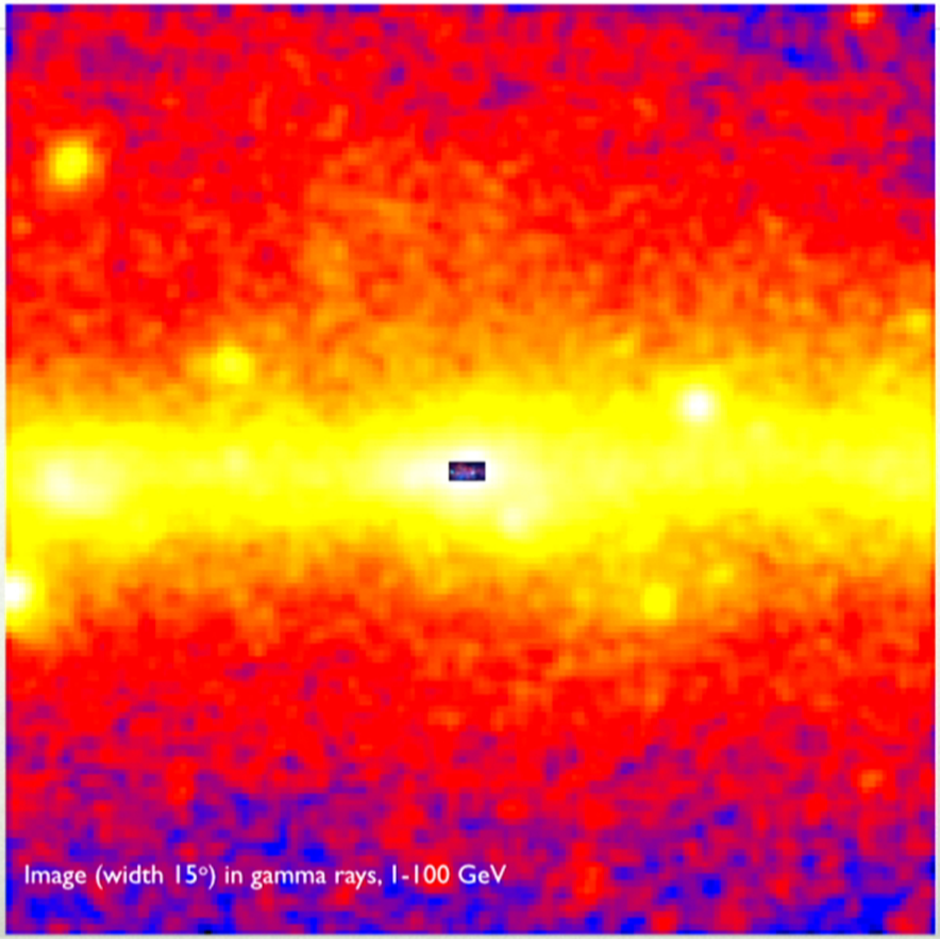
GC Excess Summary

- Systematics on the fore/background considered so far are not fully bracketing
- Models are simplified (the Galaxy is a complex system!)
- Although several "independent" analyses yield similar results, many important assumptions made in the modeling of the fore/background are the same!
- ➡ Incredible progress in better understanding the gamma-ray sky has been made, but more work needs to be done to firmly establish the presence of an excess and its characteristics
- Synergy with other wavelengths will continue to provide more insight in the important issues that limit this analysis
- Complementarity with other DM searches is crucial
- Better instruments could provide a huge leap forward

Central Region of the Milky Way

Image (width~0.5°) combines a near-infrared view from the Hubble Space Telescope (yellow), an infrared view from the Spitzer Space Telescope (red) and an X-ray view from the Chandra X-ray Observatory blue and violet) into one multi-wavelength picture.

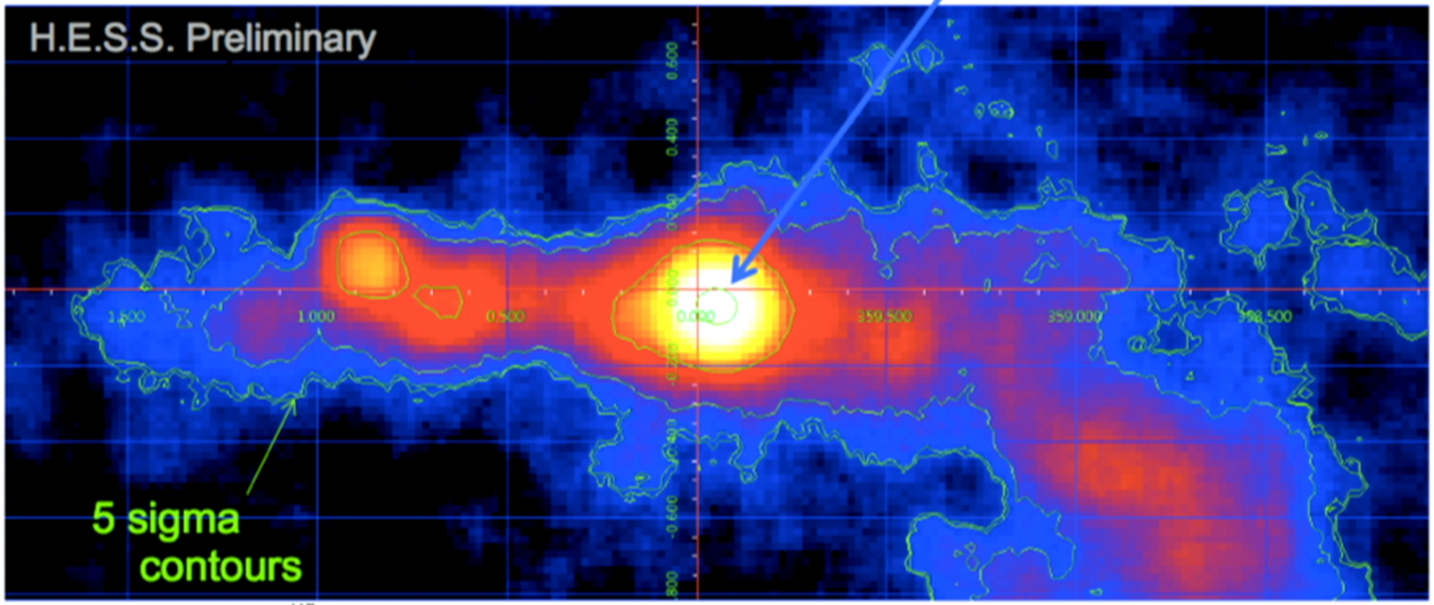
Central Region of the Milky Way



H.E.S.S.: Galactic Center Region

Slide: W. Hoffman, AMS Days 2015

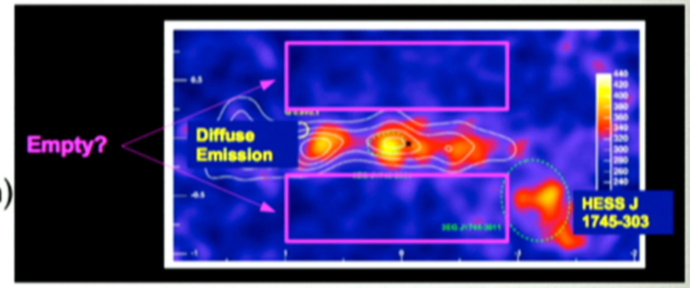
Source consistent with BH within 13″ error

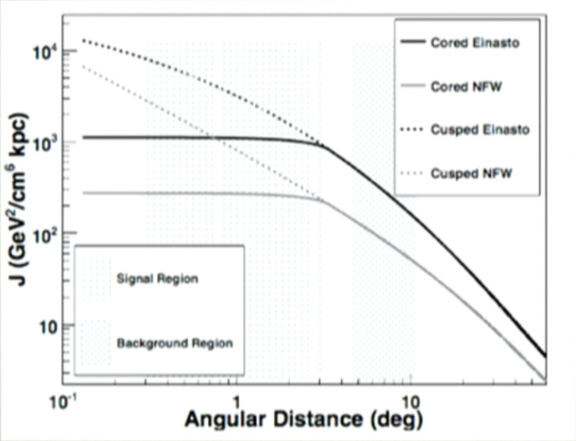


2° 300 pc

H.E.S.S.: Galactic Center Region

- GC is complicated by astrophysics, look away from it!
- Signal region: relatively close to GC but "free" from astrophysical background
- Select a region where the contribution from DM is smaller for background subtraction (background region)
- Small dependence on DM profile
- Limits are also derived for cored (constant within 500 pc from the GC) DM profiles





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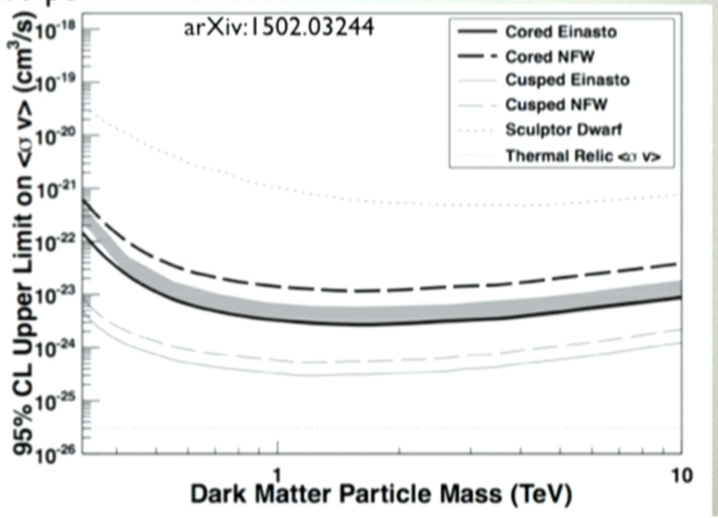

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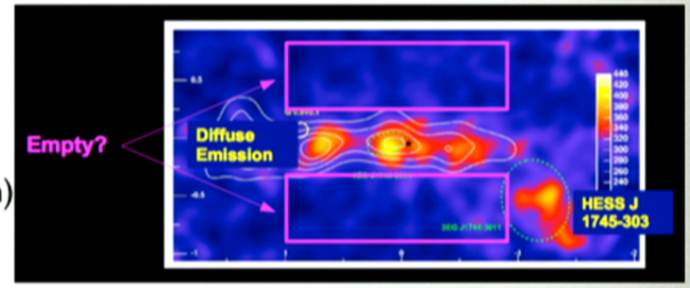

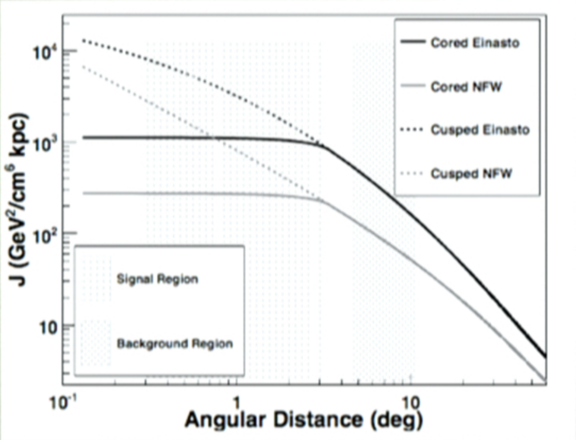

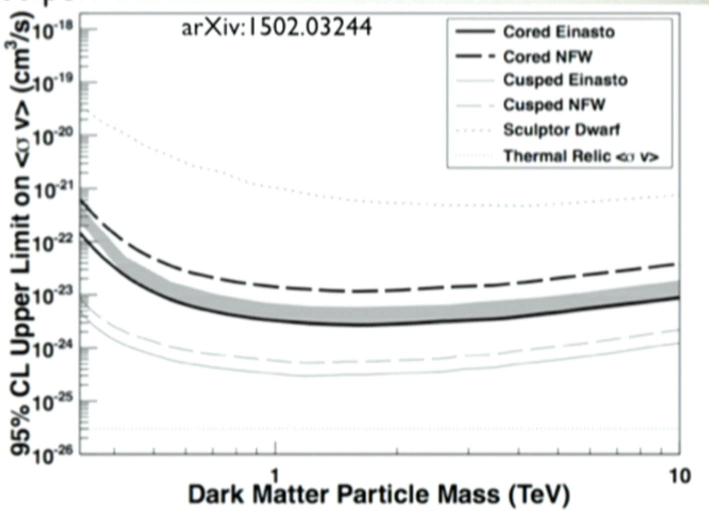

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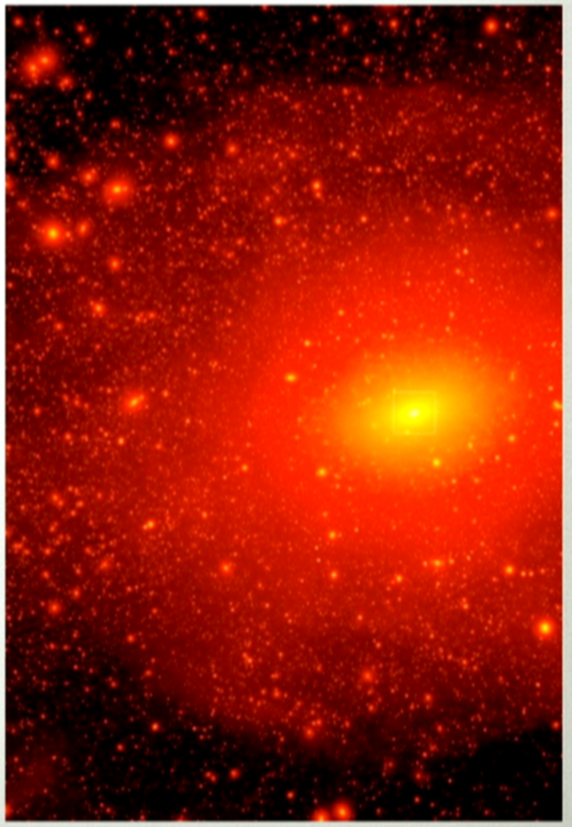
Dwarf Spheroidal Galaxies

- Optically observed dwarf spheroidal galaxies (dSph): largest clumps predicted by N-body simulation.
- 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! Data so far cannot discriminate, in most cases, between cusped or cored dark matter profiles.

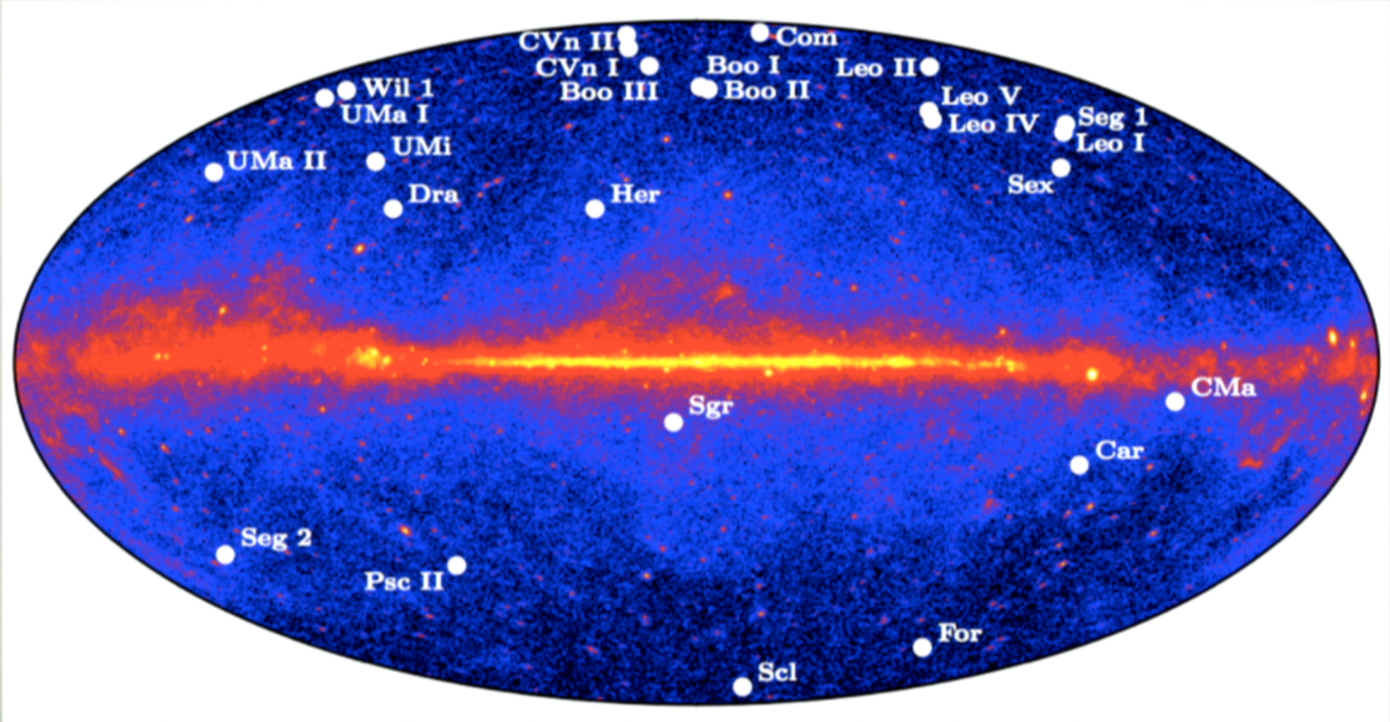
    However, Fermi's DM constraints with dSph do not have a strong dependence on the inner profile
  - Expected to be free from other gamma ray sources and have low dust/gas content, very few stars



Dwarf Spheroidal Galaxies

Fermi LAT Collaboration

- Search for a signal in 25 dSphs
- 6 years of data, Pass 8, 500 MeV to 500 GeV
- Updated third LAT point-source catalog



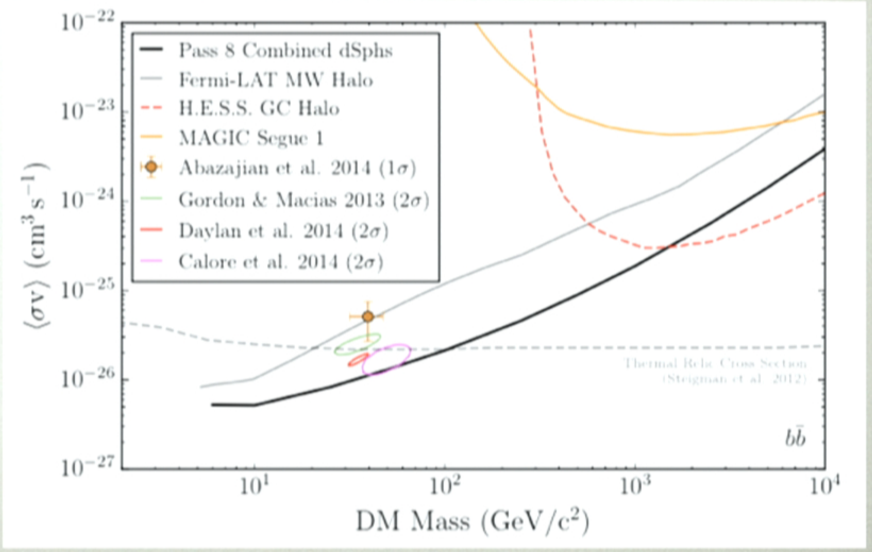
Dwarf Spheroidal Galaxies

Fermi LAT Collaboration, arXiv 1503.02641

- Search for a signal in 25 dSphs
- 6 years of data, Pass 8, 500 MeV to 500 GeV

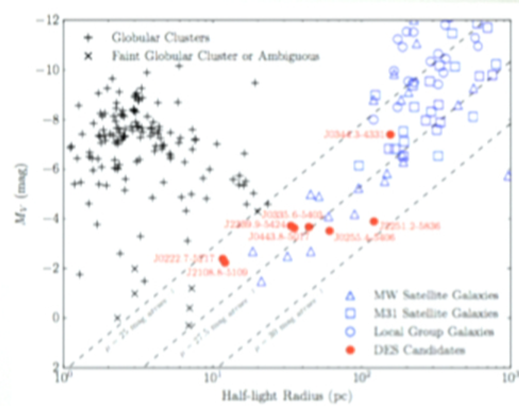
➡ No significant emission is found

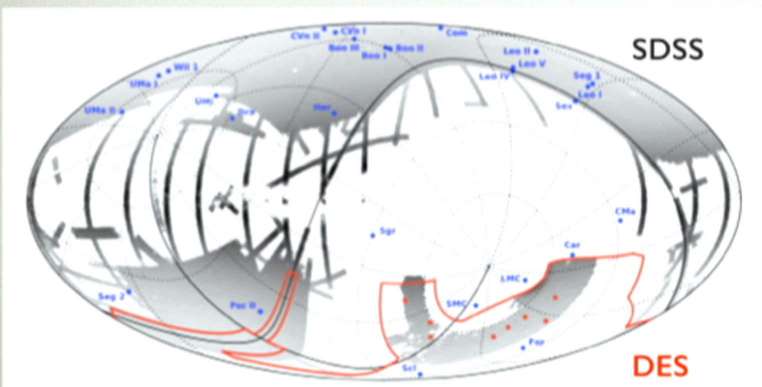
- Limits begin to probe DM explanation of the GC excess

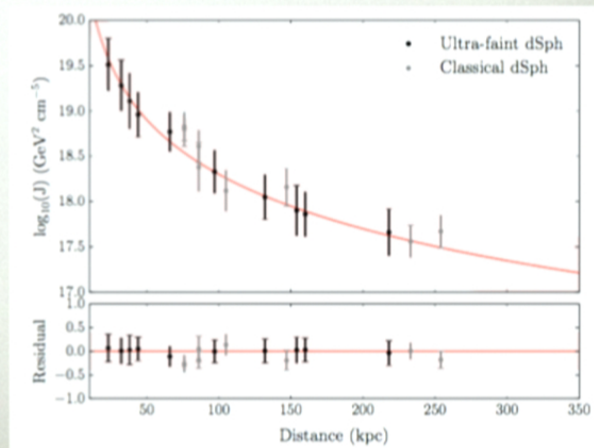


Dwarf Spheroidal Galaxies

- Eight candidates recently discovered by the Dark Energy Survey (DES)
- Assumption they are dSphs and have DM distributions similar to known dSphs



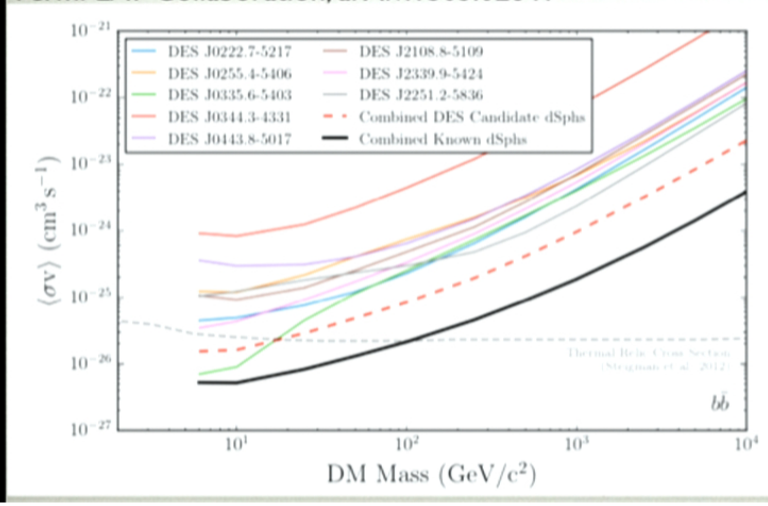




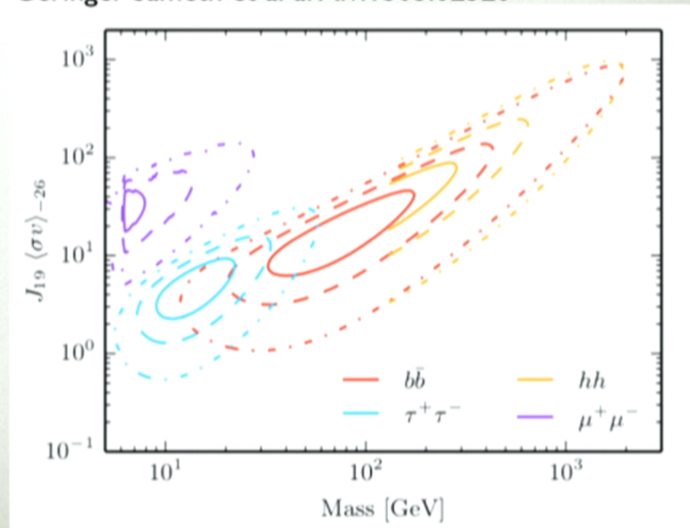
Dwarf Spheroidal Galaxies

- Eight candidates recently discovered by the Dark Energy Survey (DES)
- Limits determined under the assumption they are dSphs and have DM distributions similar to known dSphs (Fermi LAT Collaboration)
- Excess gamma-ray emission between 2-10 GeV in the direction of one of the candidates (2.3-3.7σ, depending on background modeling) claimed by Geringer-Sameth et al

Fermi LAT Collaboration, arXiv:1503.02641



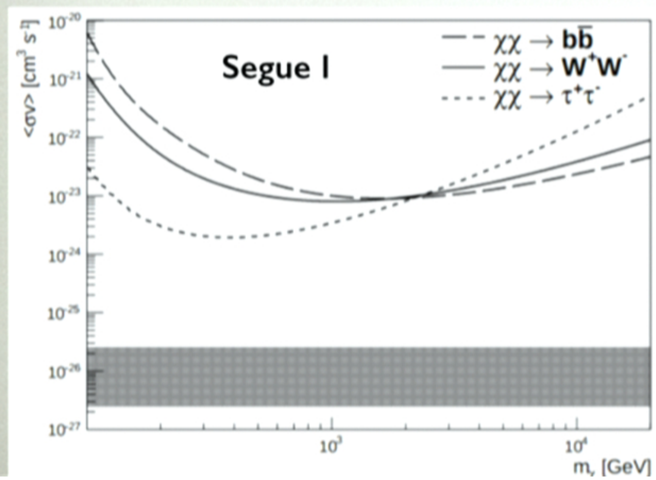
Geringer-Sameth et al arXiv:1503.02320



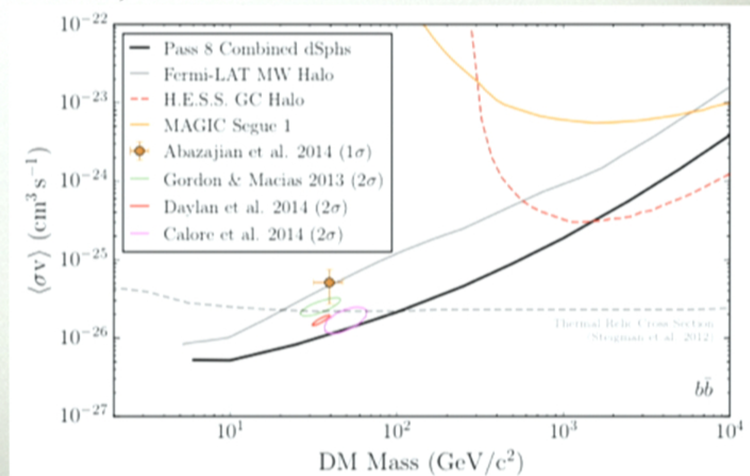
Dwarf Spheroidal Galaxies
IACTs

- Observations of dSphs with IACTs competitive with Fermi above DM masses ~3 TeV
- MAGIC latest results corresponding to 160 hrs of observation of Segue I are the strongest

VERITAS, 48 hours

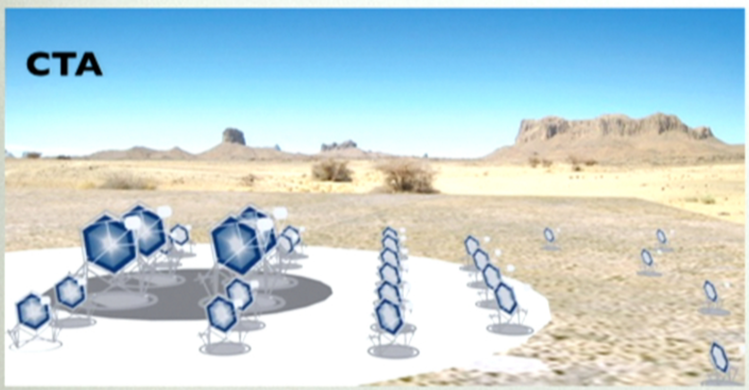


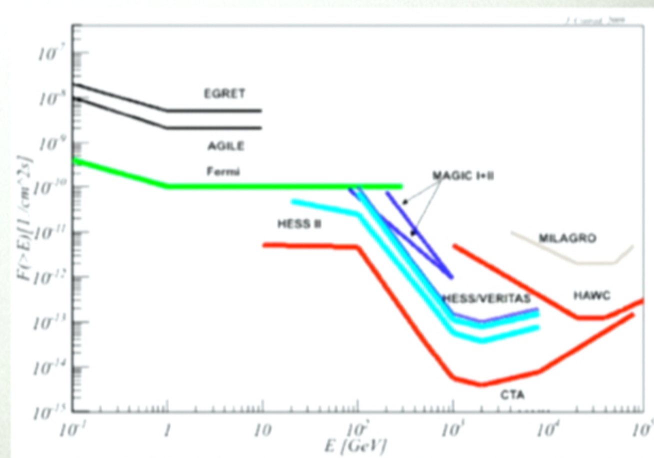
MAGIC, 160 hours



CTA

- Next generation gamma ray observatory
- Basic design: small core of large telescopes, surrounded by mid size telescopes and an outer ring of small telescopes
- Improve sensitivity of current ATCs (~10x), extend to lower and higher energies (~ 10s GeV to >100 TeV).





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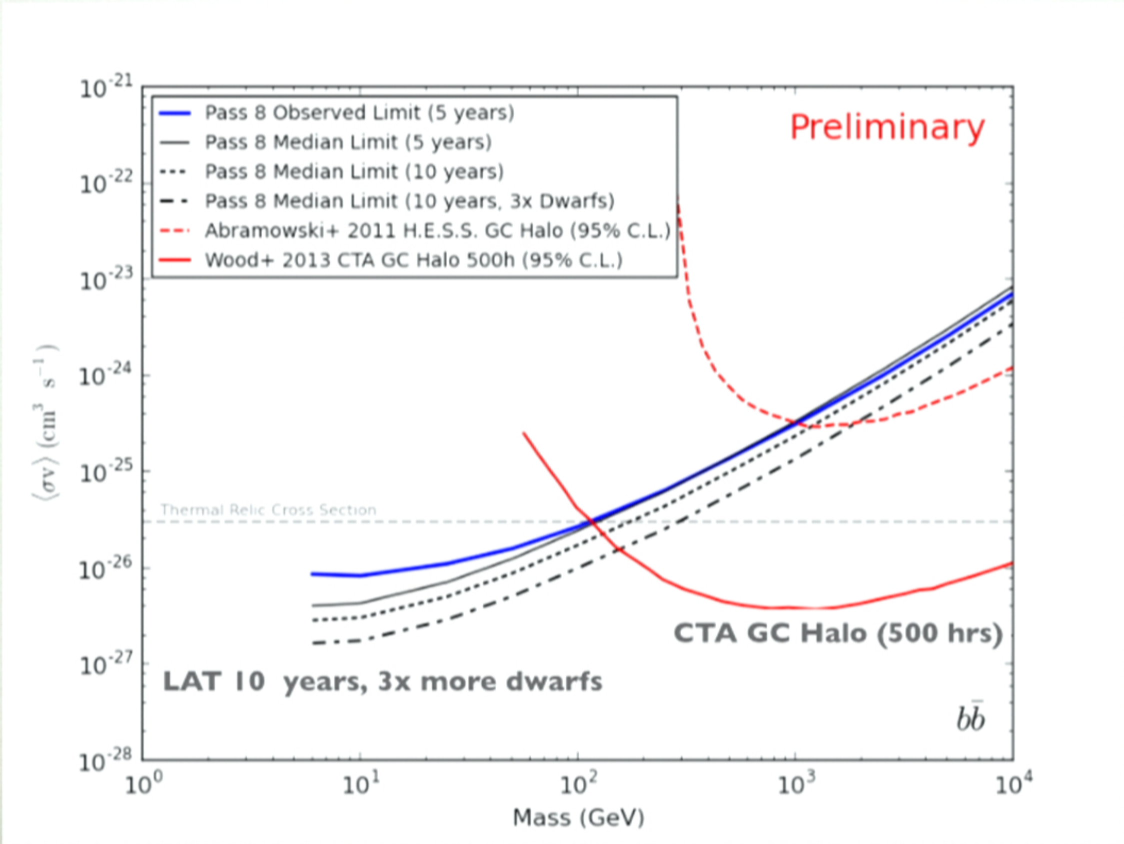
Putting it all Together



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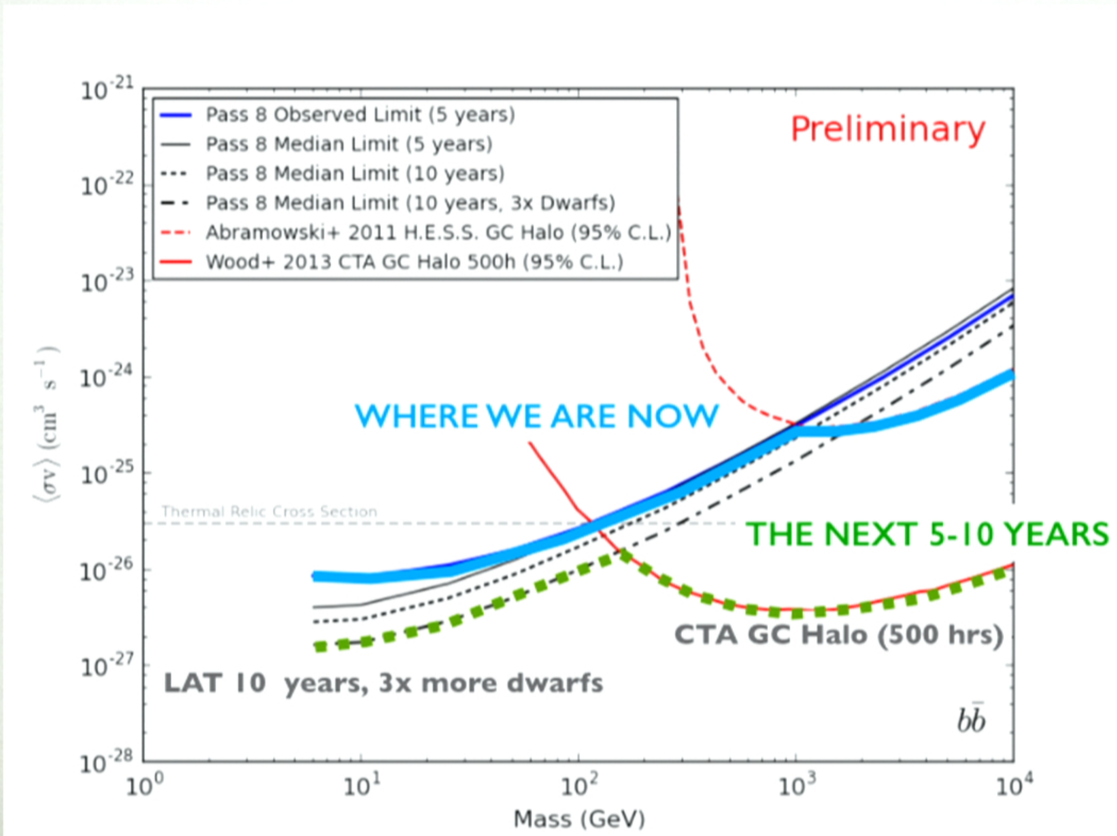

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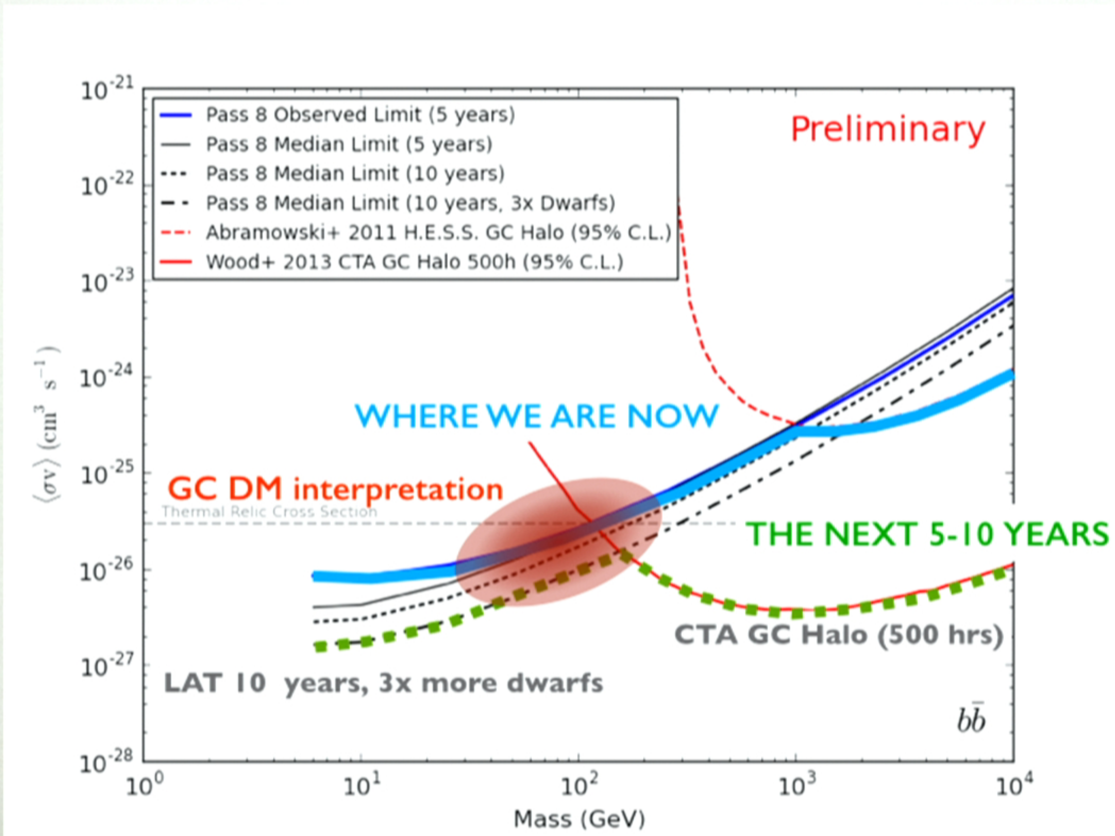
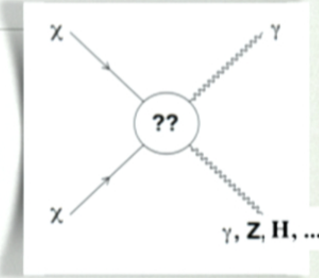


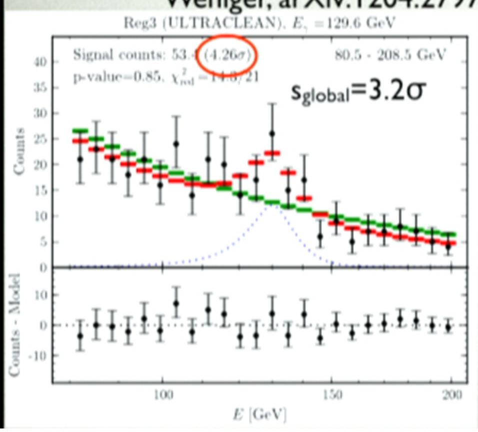
Search for Spectral Lines

- ☺ "Smoking gun" signal of dark matter.
- ☹ The line signal is generally suppressed (but enhanced in some models!)

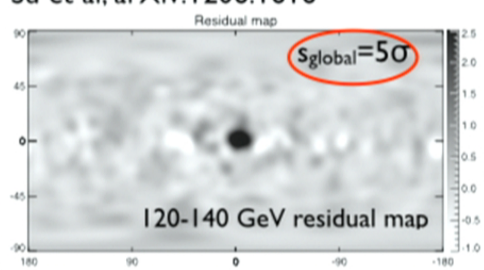


- Some evidence for a line at ~130 GeV was claimed (Bringmann et al, arXiv:1203.1312 (internal brem), Weniger, arXiv:1204.2797, Su et al, arXiv:1206.1616)
- More statistics, data reprocessing, and improved energy dispersion model yield a decrease in significance

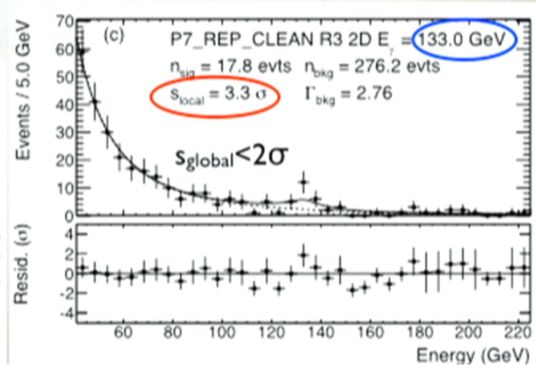
Weniger, arXiv:1204.2797



Su et al, arXiv:1206.1616



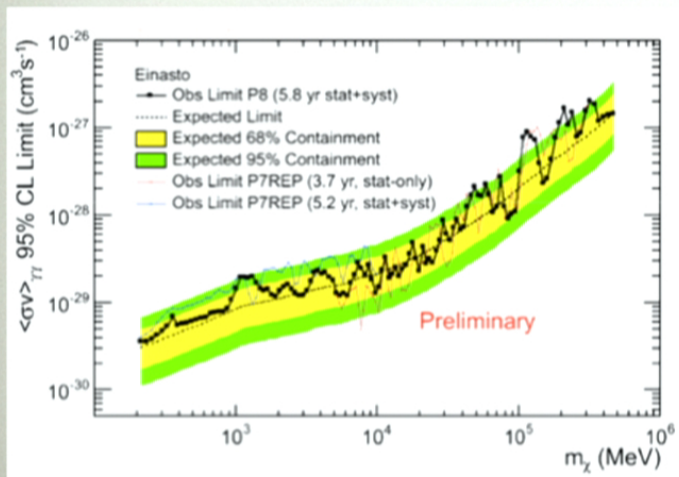
Fermi LAT Collaboration, arXiv:1305.5597

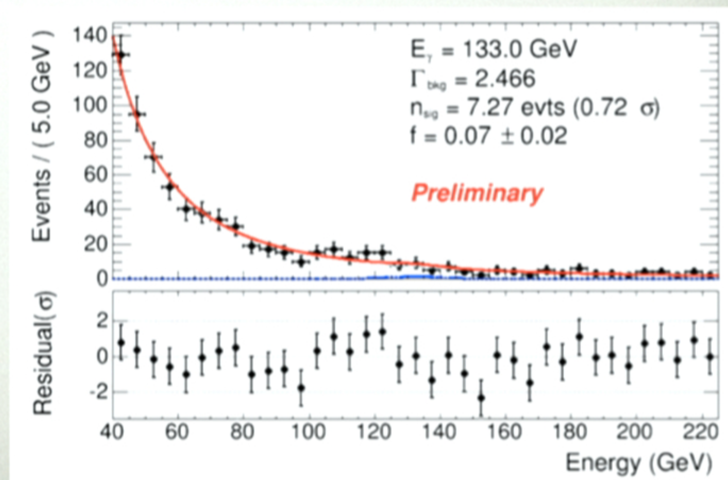


Search for Spectral Lines

Fermi LAT Collaboration

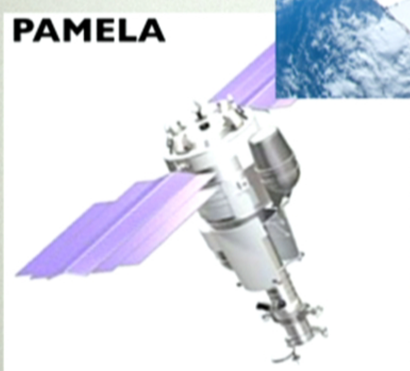
- Updated results with new event level reconstruction and selection (*Pass 8*)
- 200 MeV-500 GeV, 5.8 years
- No significant lines detected
- No significant feature at 133 GeV



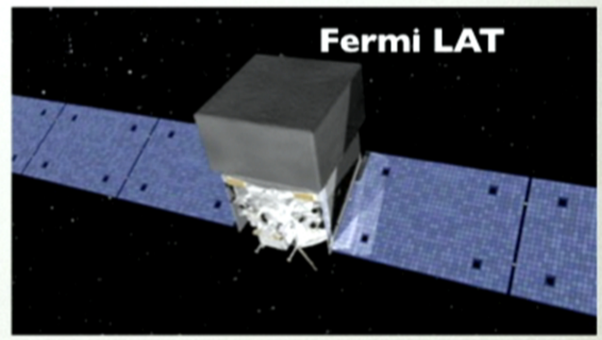


Cosmic rays

Magnetic spectrometers+

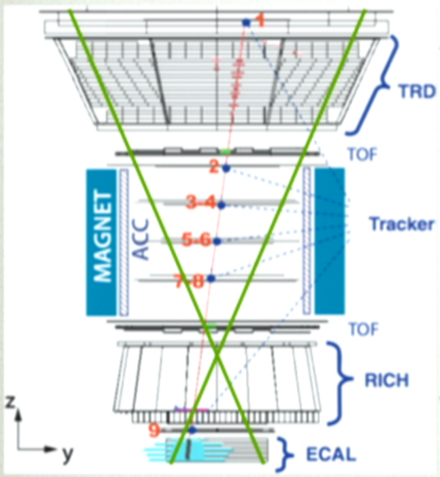


Calorimeters+

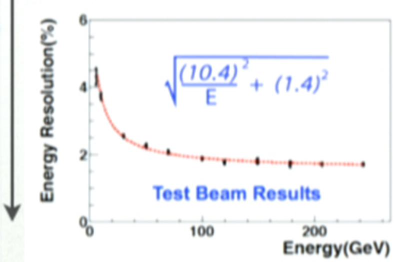


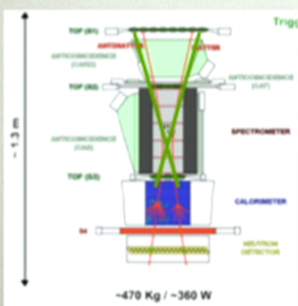
Cosmic rays

Magnetic spectrometers+
Charge discrimination, but smaller field of view and heavy



AMS-02



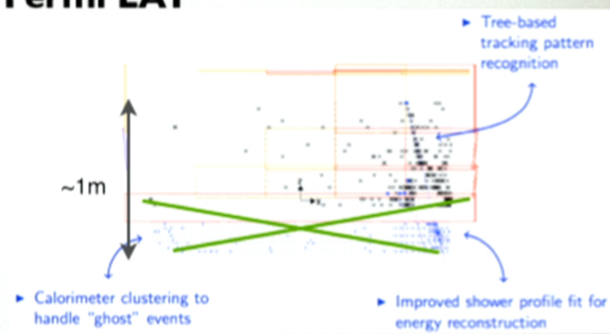


PAMELA

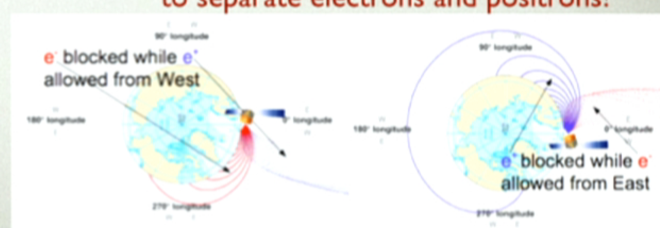
Energy resolution for e,γ: 5-15%

Calorimeters+

Fermi LAT

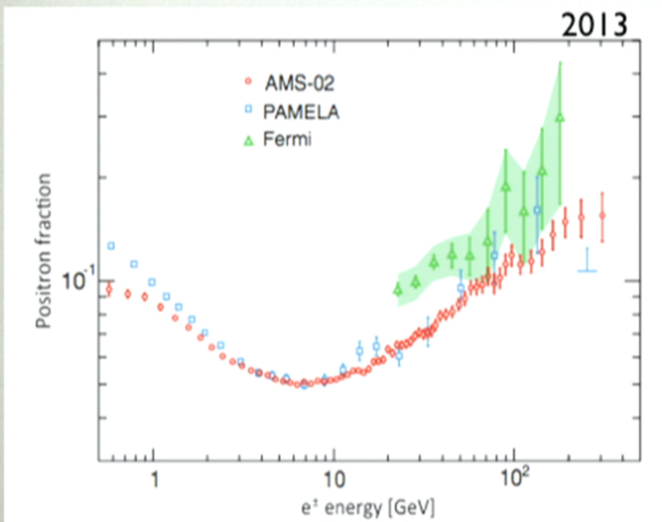


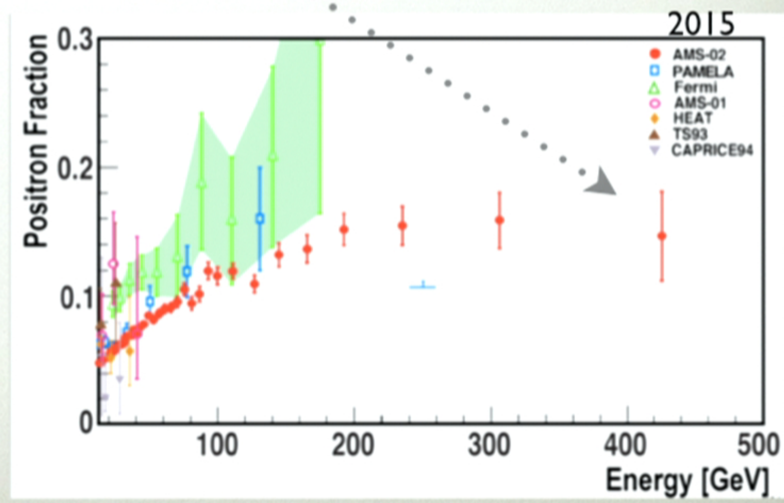
But can use the Earth magnetic field to separate electrons and positrons!



Results - Positrons

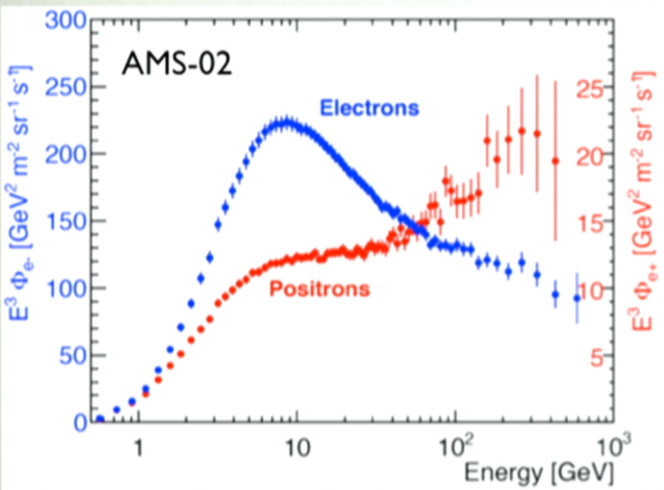
- Positron fraction up to 500 GeV. Raises at high energy, up to ~250 GeV

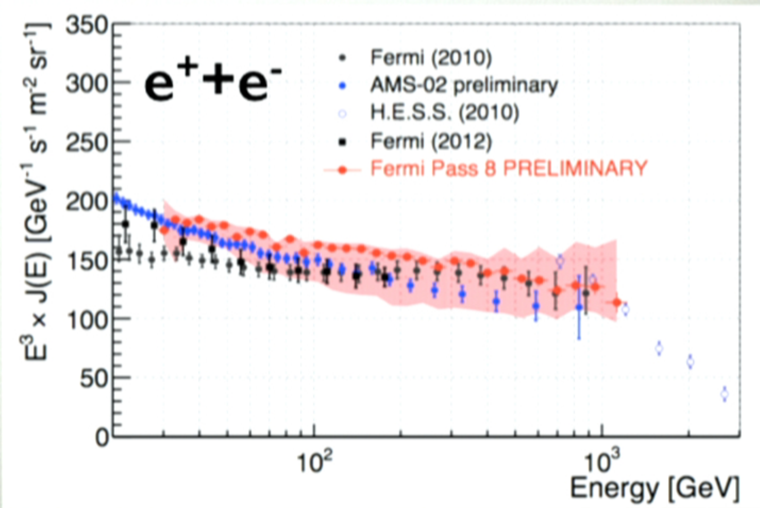




And Electrons

- Separate spectra for positrons and electrons confirm rise in positron spectrum (no softening in the electron spectrum is observed); no single power law describes either spectra
- Electron+positron spectrum extends to above 1 TeV (Fermi LAT); smooth power law function 30.2 GeV - 1 TeV with spectral index γ=-3.17

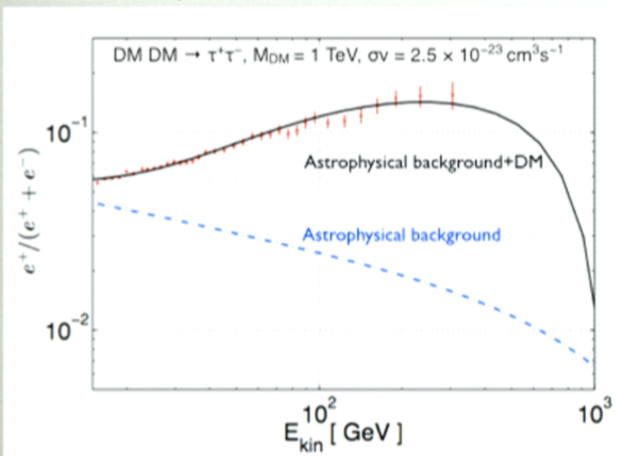




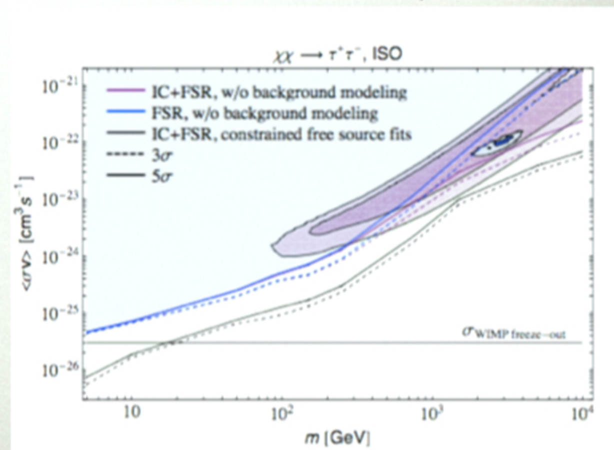
Could it Be Dark Matter?

- Dark matter can reproduce the raise in the positron fraction, but it is disfavored by other searches
- Other explanations exists!

De Simone et al, arXiv:1304.1336



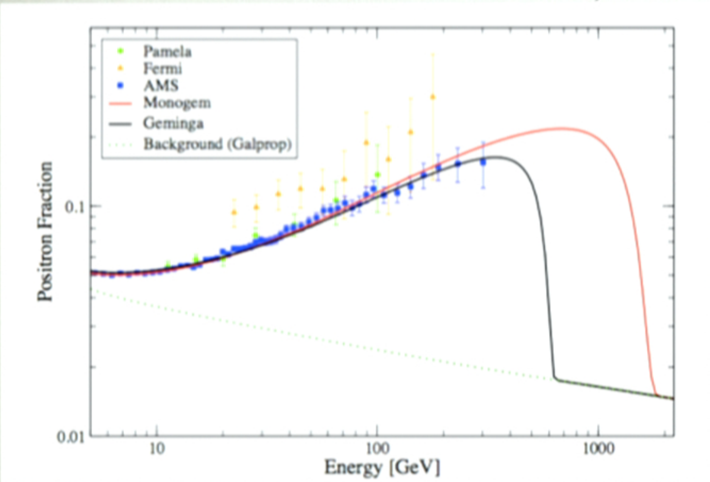
Fermi LAT Collaboration, arXiv:1205.6474



Could it Be Dark Matter?

- A single, nearby source can reproduce well the observed rise in the positron spectrum
- Anisotropy in the e+e- data could confirm this hypothesis. Predicted anisotropy is consistent with current bounds (Fermi LAT, AMS-02)
- Also, contribution from a population of sources well describes the data

Linden et al, 2013



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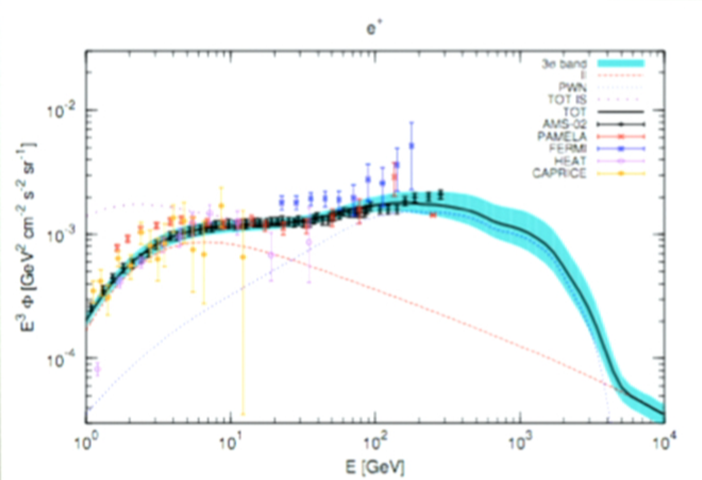
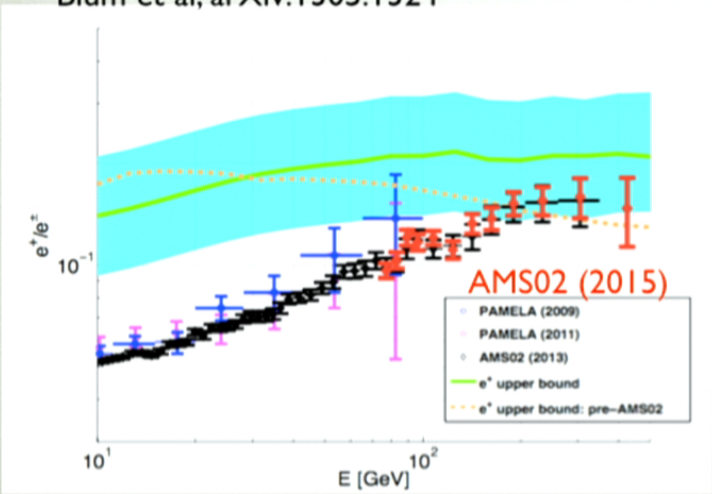
DiMauro et al, 2014



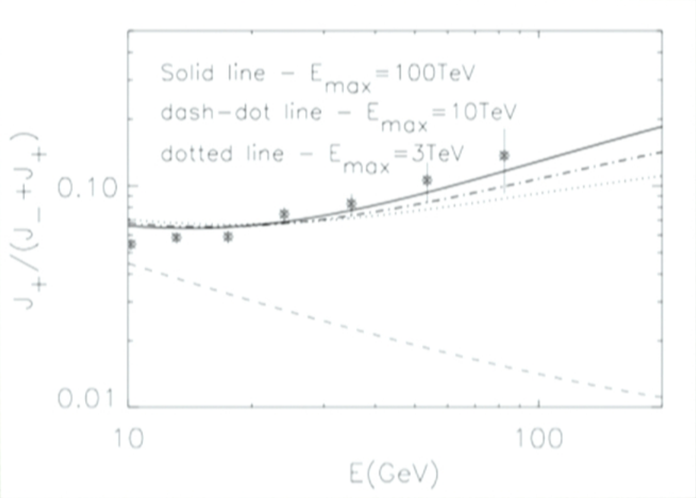
Secondary Production

- Is secondary production a plausible explanation?
- Secondary production in a nearby SNR has also been proposed as a possible explanation...

Blum et al, arXiv:1305.1324



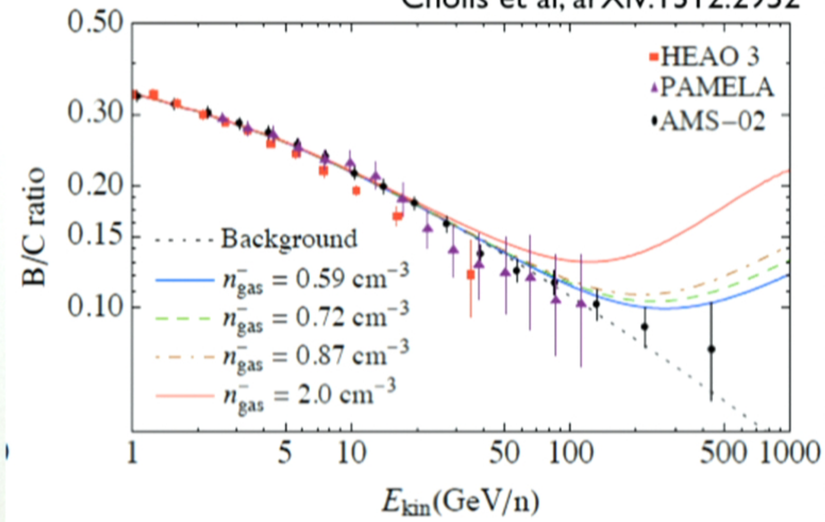
Blasi, arXiv:0903.2794



Secondary Production

- However secondary production at the source might also cause a rise in the B/C ratio, in conflict with observations

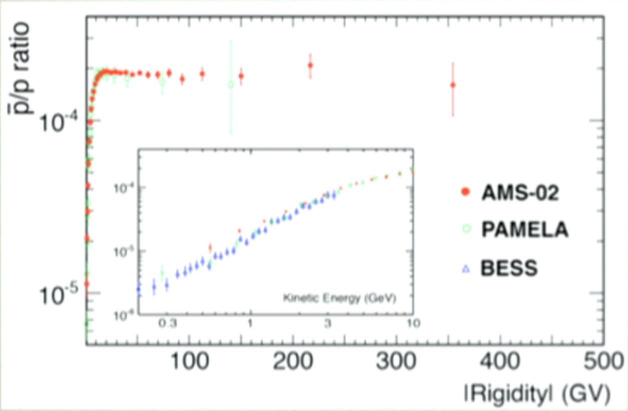
Cholis et al, arXiv:1312.2952

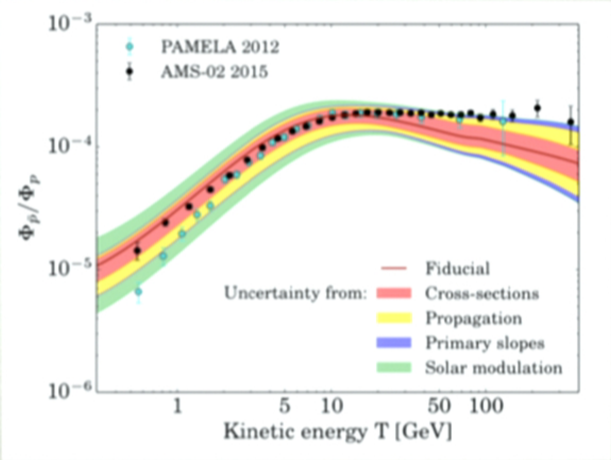


Results - Antiprotons

- Measurement of the antiproton fraction up to 450 GeV
- In agreement with secondary production predictions (based on B/C measurements and antiprotons produced by CR interactions in the interstellar medium)

antiproton to proton fraction

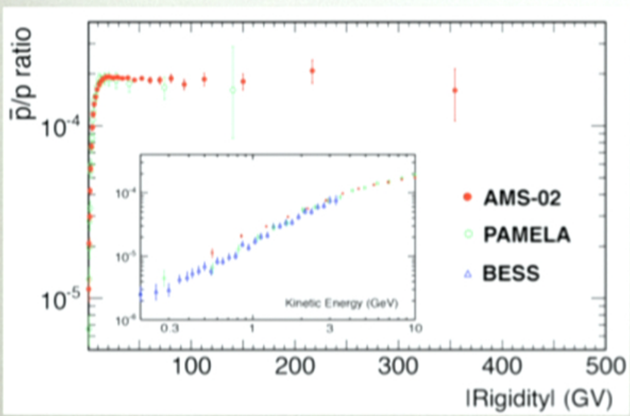


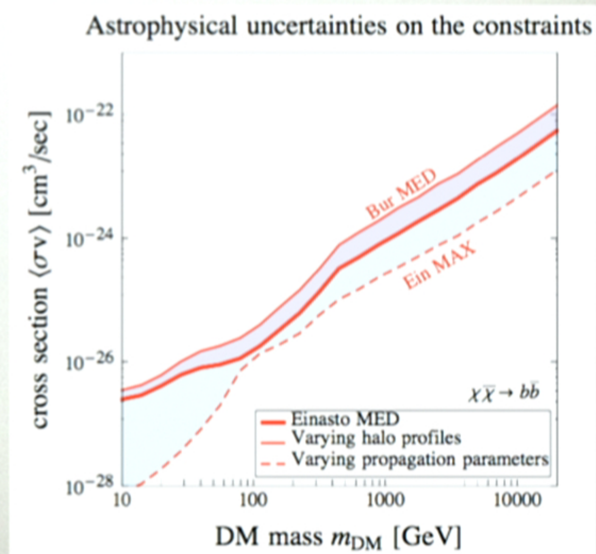


Results - Antiprotons

- Measurement of the antiproton fraction up to 450 GeV
- In agreement with secondary production predictions (based on B/C measurements and antiprotons produced by CR interactions in the interstellar medium)
- Constraints can be derived with assumptions on CR production and propagation

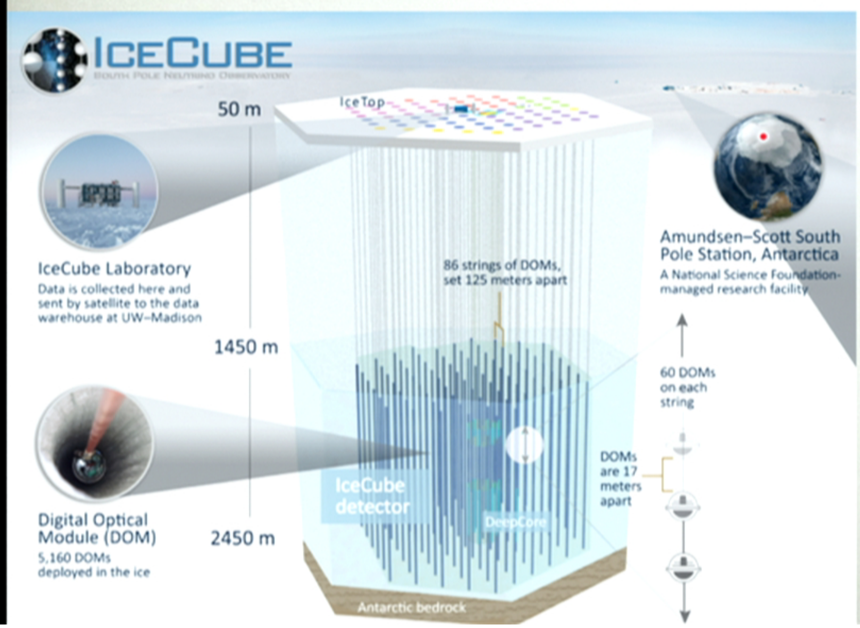
antiproton to proton fraction

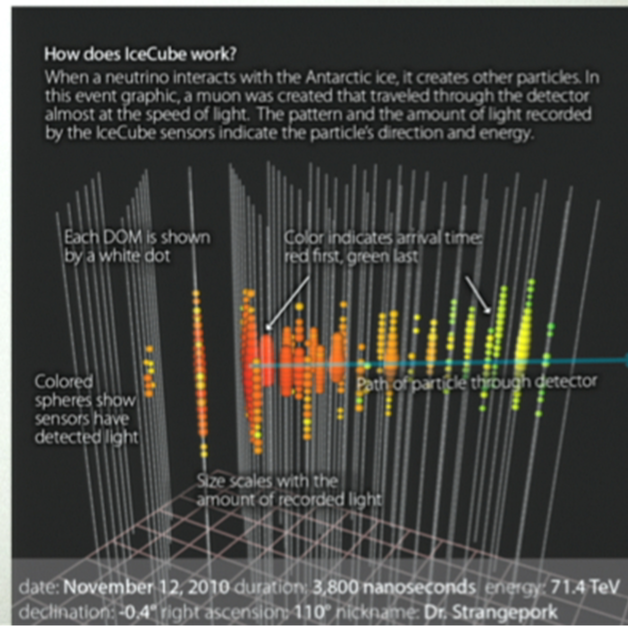




Neutrinos: IceCube

- Neutrinos are generated by accelerated protons and nuclei interacting with surrounding medium
- Neutrinos can travel unimpeded from the source where they were generated thus carrying unique information on the origin of CRs
- The cubic-km IceCube neutrino observatory searched for these events



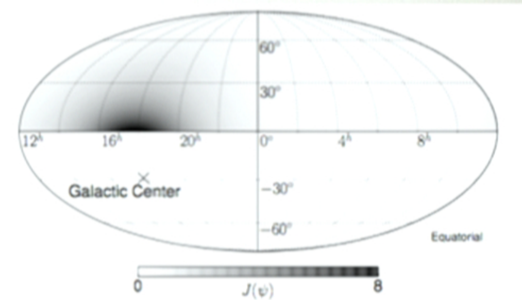


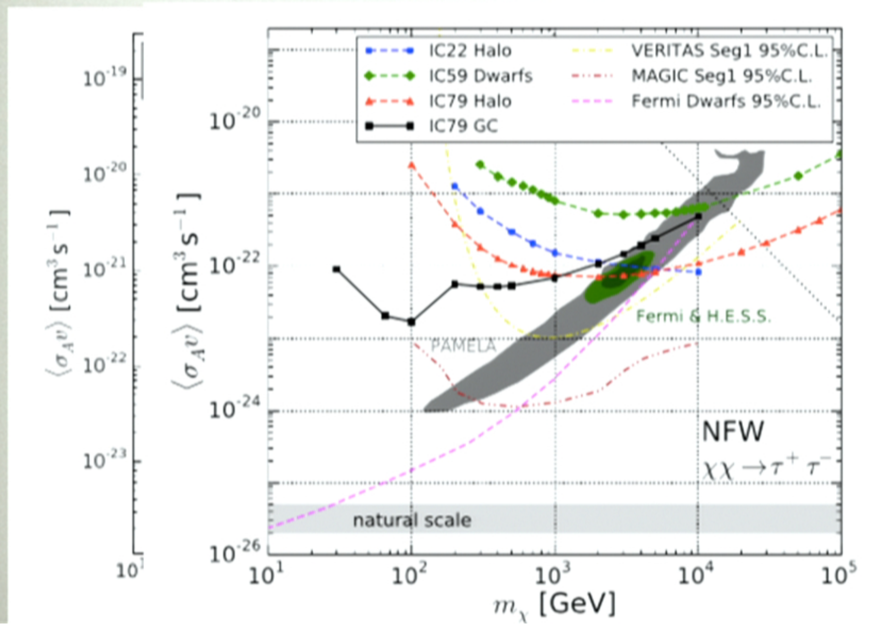
Conclusions

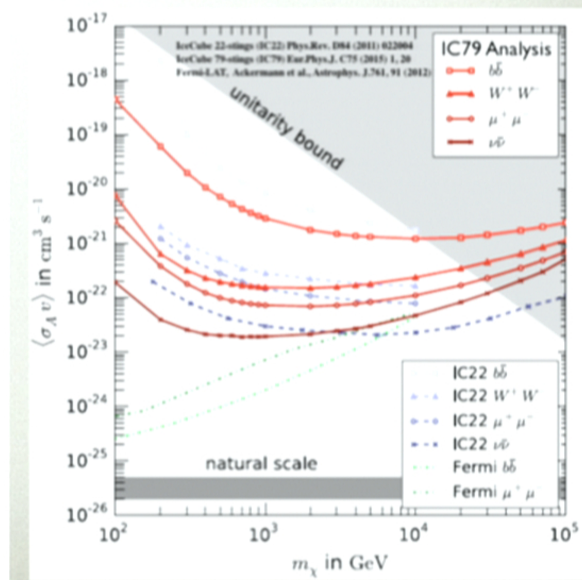
- Intriguing hints of potential signals in gamma-ray data have been claimed and persist, e.g. few GeV excess in Galactic center in gamma-rays
- However the astrophysical background is currently a limitation for the Galactic center, were a dark matter signal is predicted to be brightest and has therefore huge potential in terms of discovery or setting constrains. More work and more data are required to better understand the data
- The anomaly in the CR positron fraction remains, but many viable interpretations other than DM exist
- In the meanwhile, indirect dark matter searches continue to set strong constraints on the nature of DM
- Improvements in current experiments as well as upcoming experiments promise more interesting results to come
- Complementarity with direct detection and collider searches is crucial

IceCube: Galactic Center and Halo

- Search for a signal from the galactic center or halo
- Cleaner analysis than for solar DM
- Limits complementary to gamma-rays searches for heavy dark matter







IceCube: Sun

- Dark matter captured in the Sun
- Model uncertainties (velocity distribution, density, capture rate, scattering cross-section, annihilation cross-section, annihilation channel, and propagation/interaction/oscillation of neutrinos)
- Competitive limits compared to direct detection for spin-dependent interactions for heavy DM

$$\text{Soft} \rightarrow b\bar{b}$$
$$\text{Hard} \rightarrow W^{+}W^{-} \ (\tau \text{ below } W \text{ mass})$$