Dark Matter constraint from the Fermi-LAT data

on behalf of the Fermi-LAT collaboration
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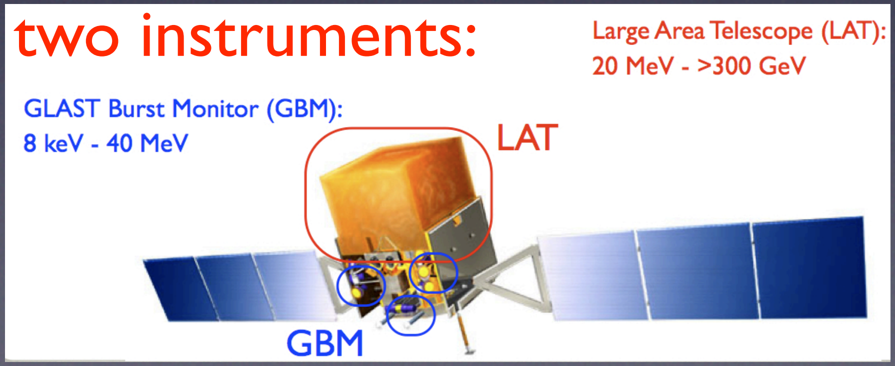
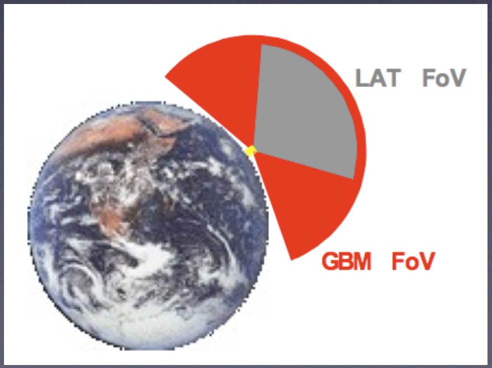
The instrument

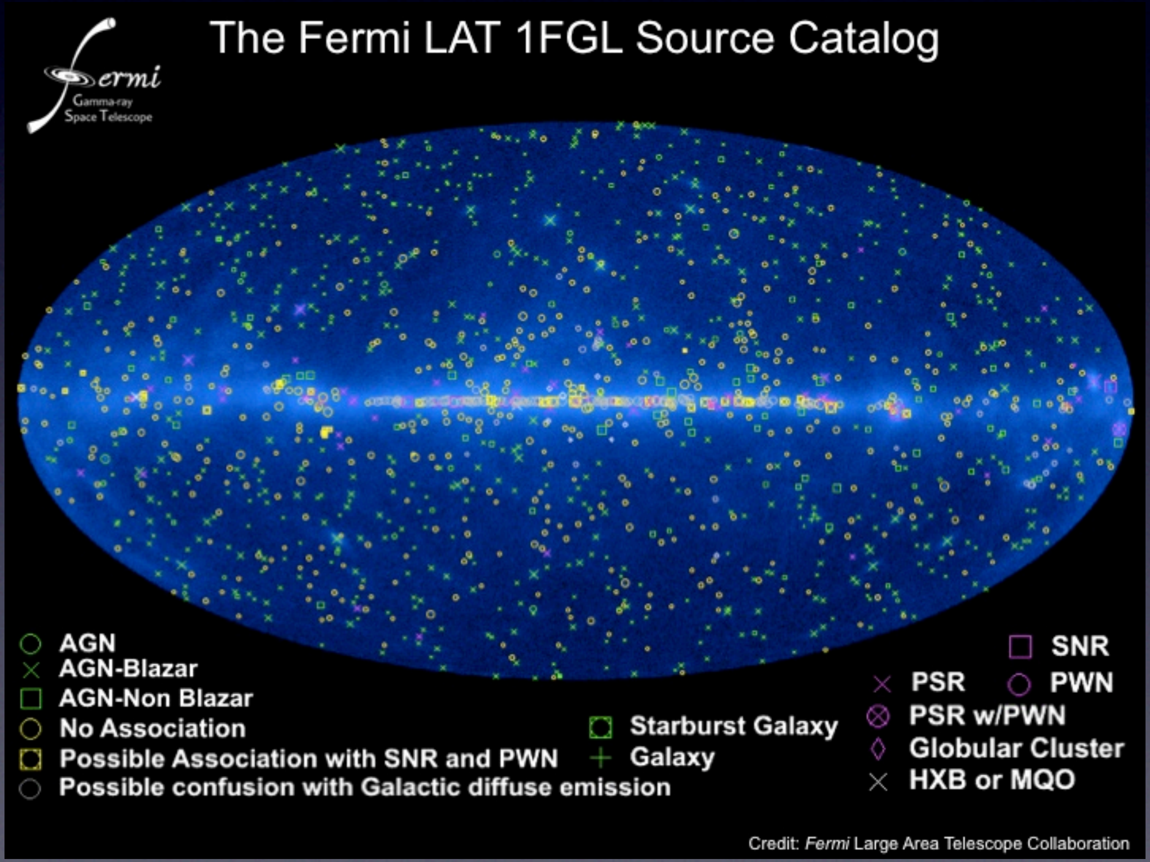
- Key features: Large field of view: 20% of the sky at any instant. In the survey mode exposes every part of the sky for ~30 min, every 3 hours.
- Energy range: 20 MeV to >300 GeV (LAT), includes previously unexplored energy band 10-100 GeV.
- angular resolution ~ 0.1 deg above 10 GeV
- Excellent charged particle discrimination (critical in separating gamma rays from the background cosmic rays).

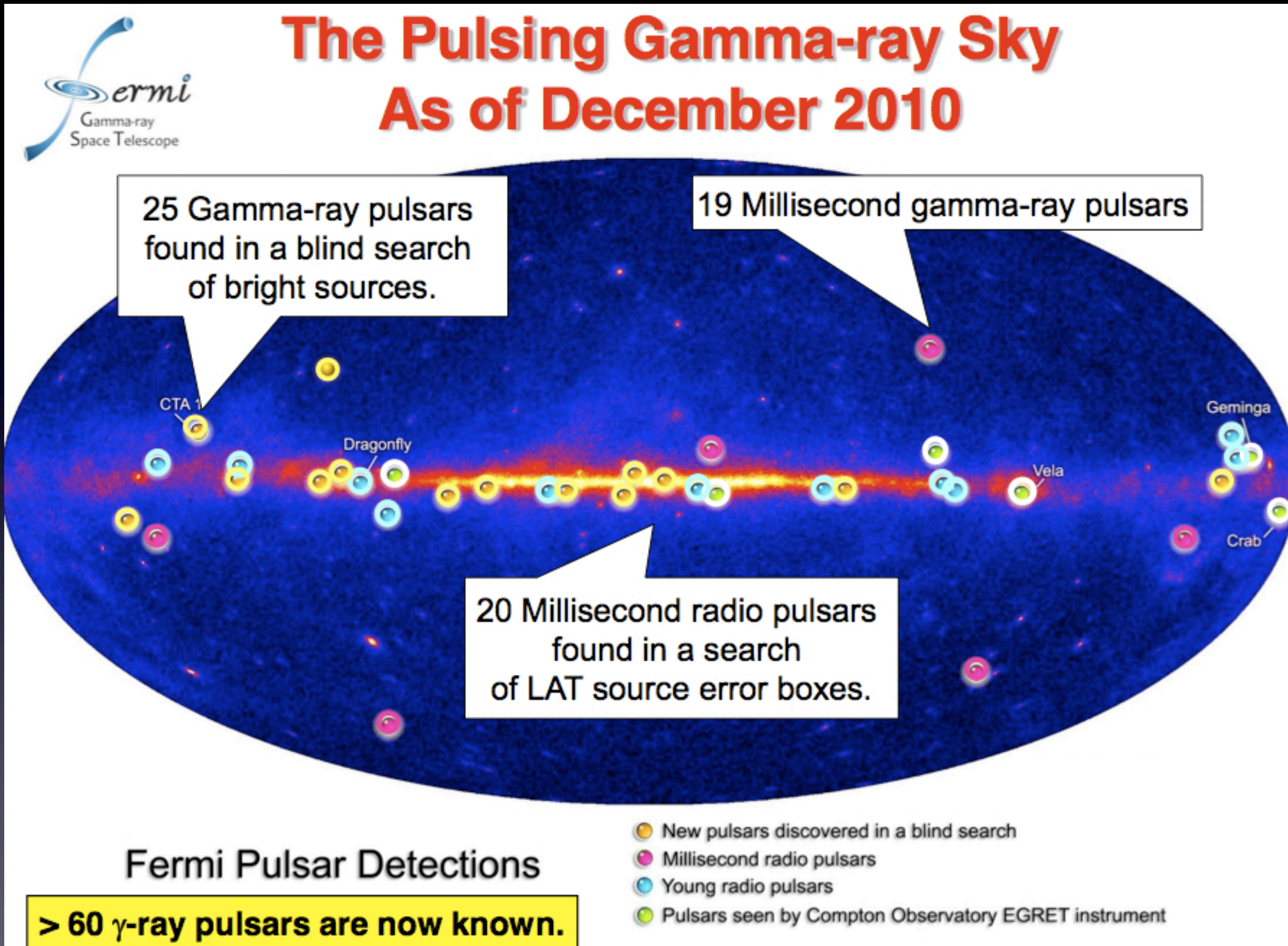




Science with Fermi

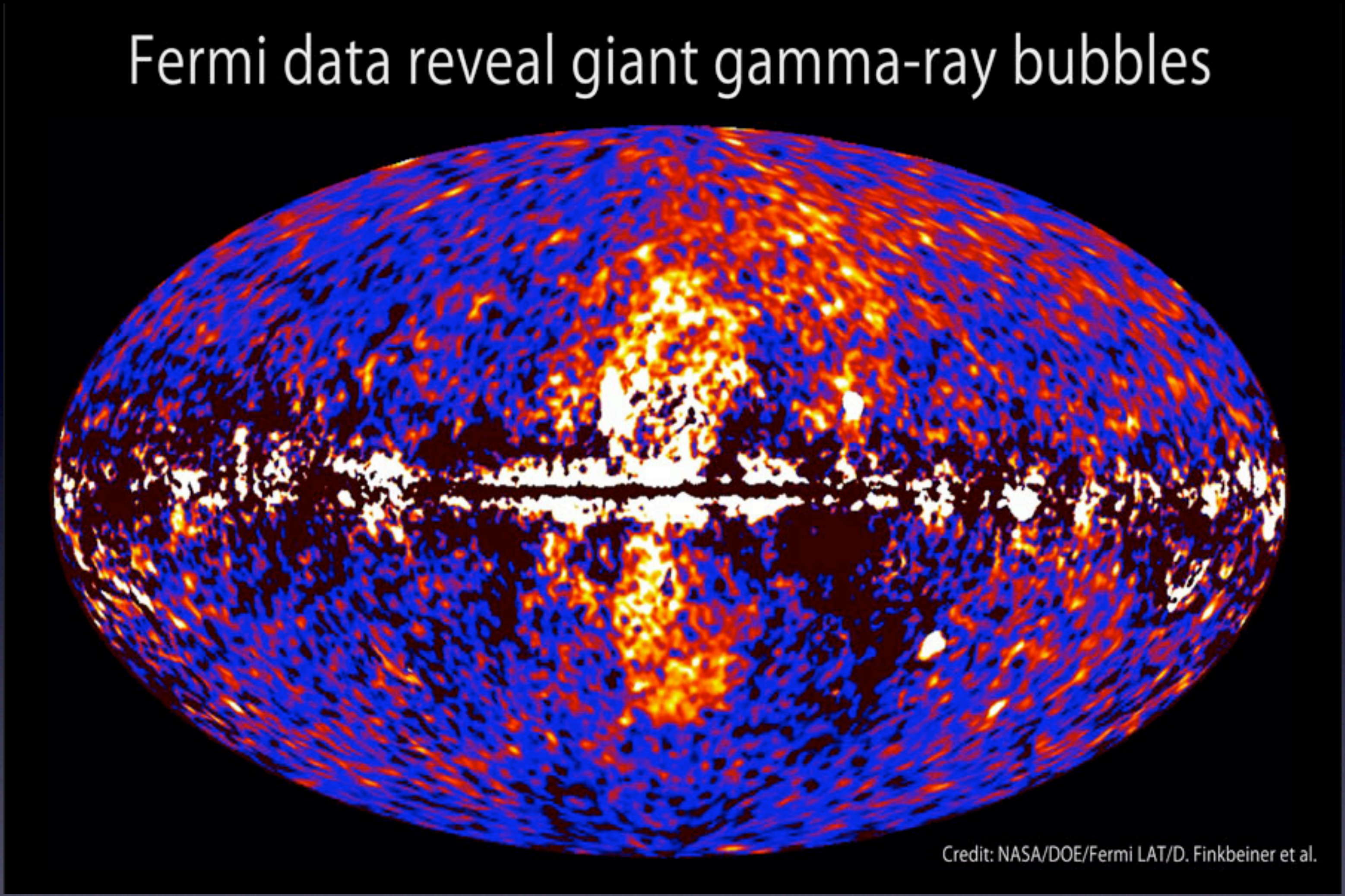
•AGNs (~**700** (EGRET ~60))
•Pulsars (~**50** in a first catalog)
+discovery of ~**10 MSPs**
•SNRs and PWN
•Gamma Ray Bursts
•Source populations and identification
•Diffuse emission
•Cosmic ray electrons
•Solar system (Sun flares, Moon,...)
+ Discovery/constraints:
New source classes?
Dark matter?
...



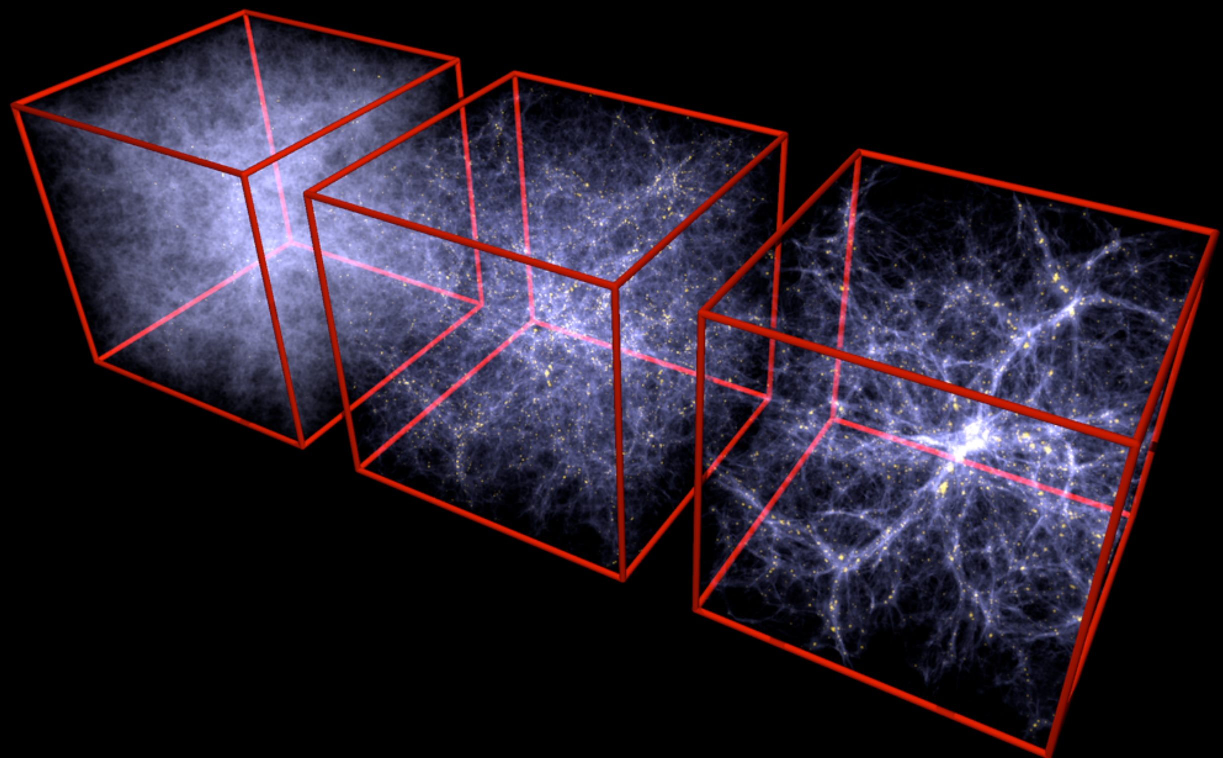


[E. Bloom, POTUS 2011.]

Astronomy picture of a day



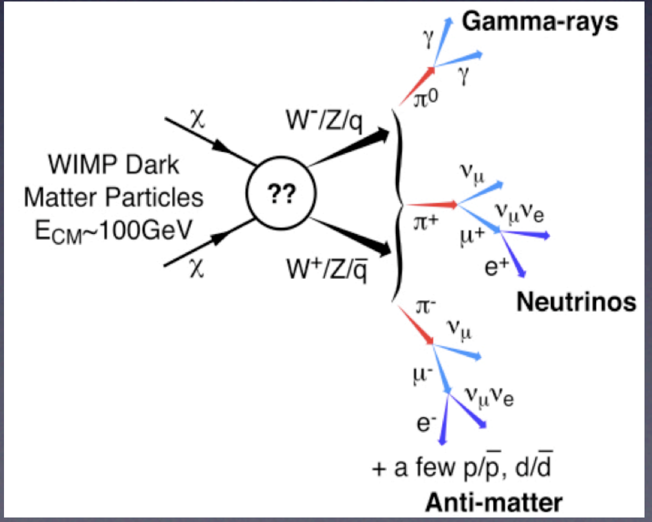
[Su, Slatyer, Finkbeiner, ApJ 724 (2010)]



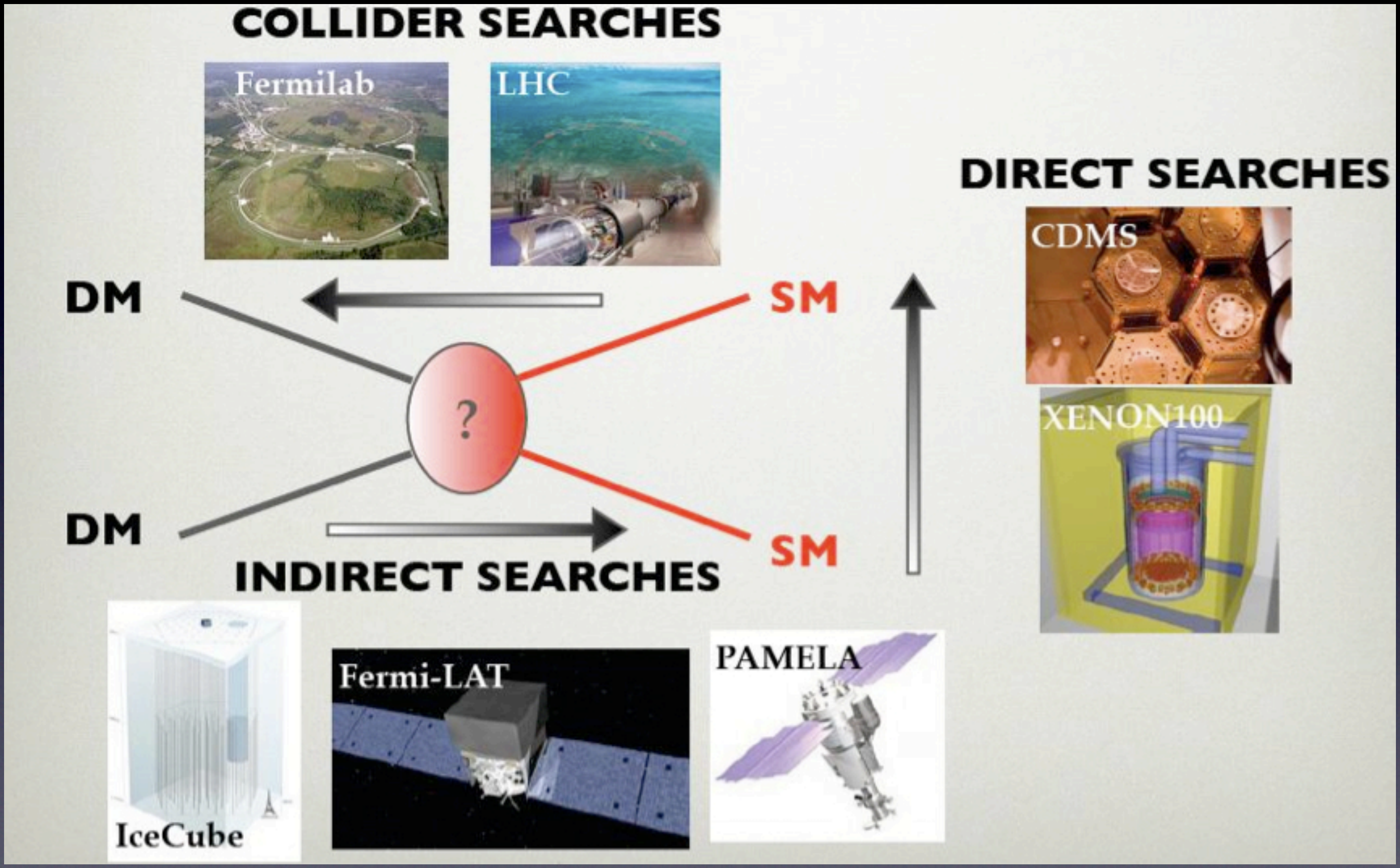
An attractive possibility: *WIMP candidates*-- the annihilation rate comes purely from particle physics and automatically gives the right answer for the relic density!

In turn, we expect dark matter to annihilate to Standard Model particles, with *cross sections which are within near reach of current experiments*.

The gravitational effects of DM have been has been demonstrated from plethora of astrophysical and cosmological observations.

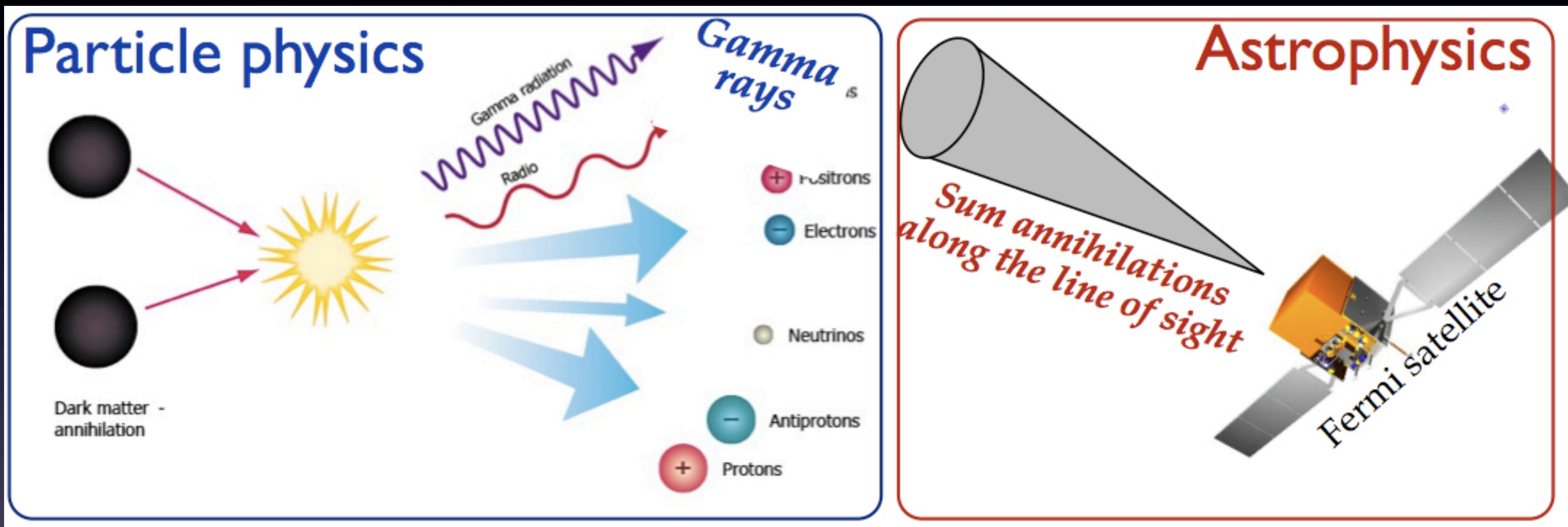


Search strategies:



[E. Bloom, POTUS 2011.]

DM signal in gamma-rays



Advantages of gamma-rays: Not affected by propagation in the Galaxy. Can give clear signatures both in spectral shape and in spatial variation.

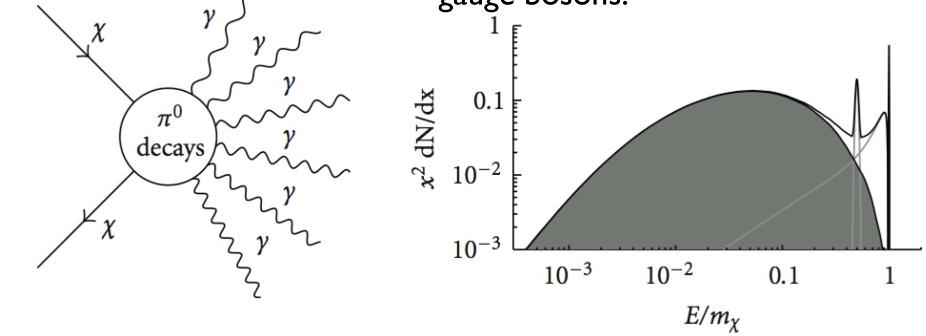
$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\theta,\phi) = \frac{1}{4\pi} \boxed{\frac{\langle\sigma v\rangle_{T_0}}{2\,M_\chi^2} \sum_f \frac{dN_\gamma^f}{dE_\gamma} B_f} \cdot \boxed{\int_{\Delta\Omega(\theta,\phi)} d\Omega' \int_{l.o.s.} dl\ \rho_\chi^2(l)}$$

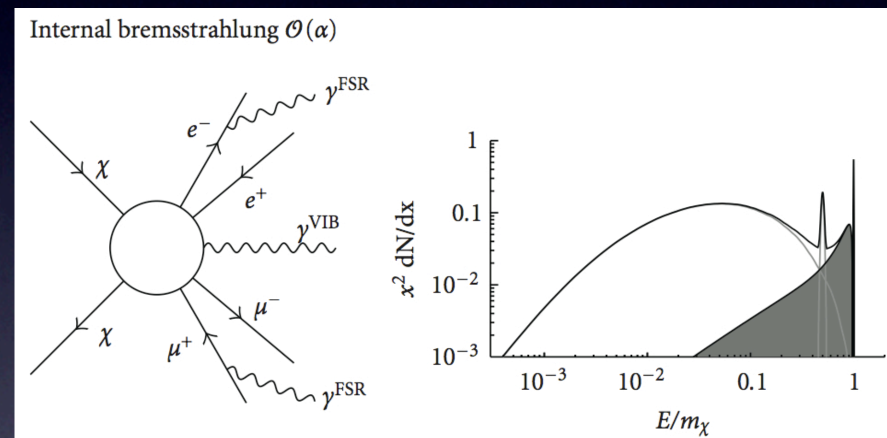
Particle physics　　　　Astrophysics

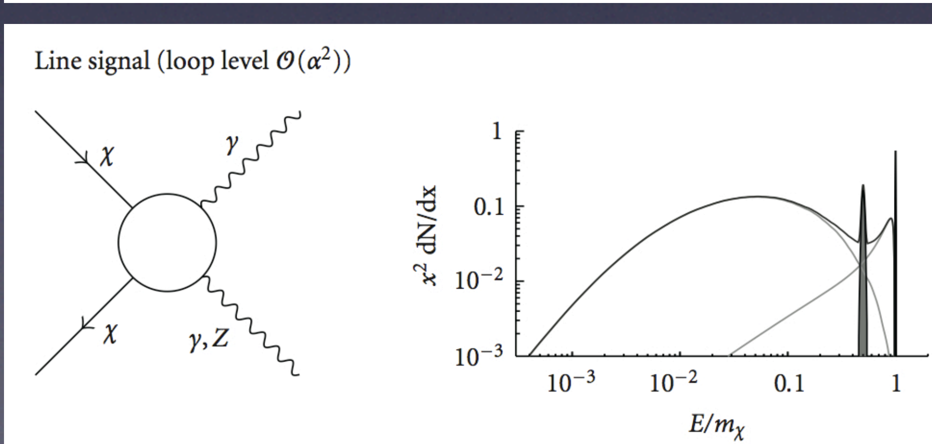
DM signal: spectral shape

Secondary photons (tree level)

quite similar spectra for all annihilations to haeavy quarks and gauge bosons.







Figures: Michael Kuhlen, Advances in Astronomy Volume 2010, Article ID 162083

\+ electroweak corrections (arXiv:1009.0224 and arXiv:0911.0001), important for ~TeV DM.

the annihilation spectra is known considerably well. however we are still learning.

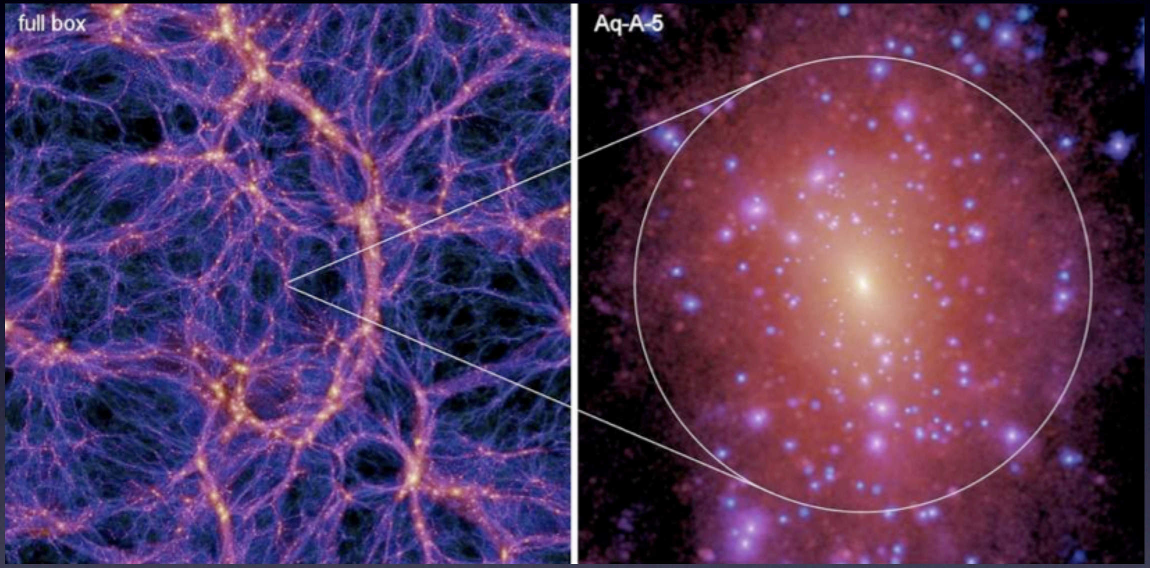
DM signal: spectral shape

Or, through radiative losses in ambient backgrounds and fields.
Important if there is a significant branching ratio to leptons.

$$\chi\,\bar{\chi} \rightarrow \begin{cases} e^+\,e^- \\ l^+\,l^- \text{ or } \phi\,\phi \rightarrow \ldots + e^+\,e^- \\ P\,\bar{P} \rightarrow \ldots + \pi^\pm \rightarrow \ldots + e^\pm \end{cases}$$

ambient backgrounds and fields → {Synchrotron, Inv. Compton, Bremstrahlung, Coulomb, Ionization} → {radio, IR, X-rays, ϒs}

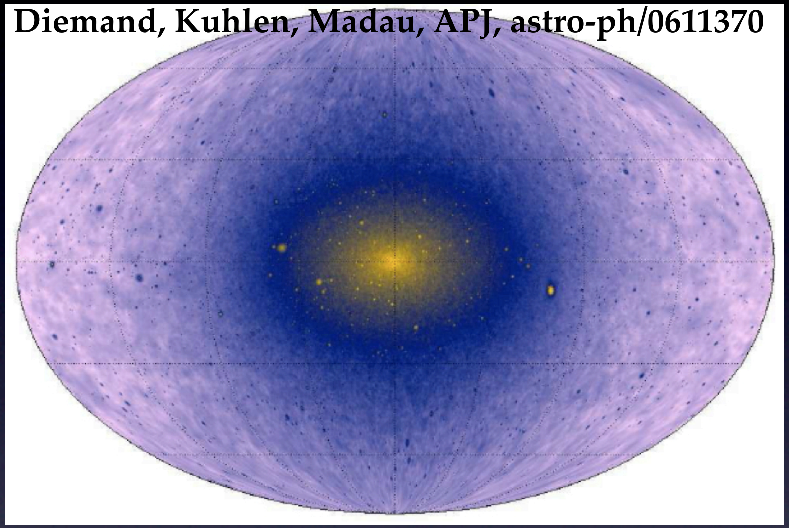
DM signal: morphology

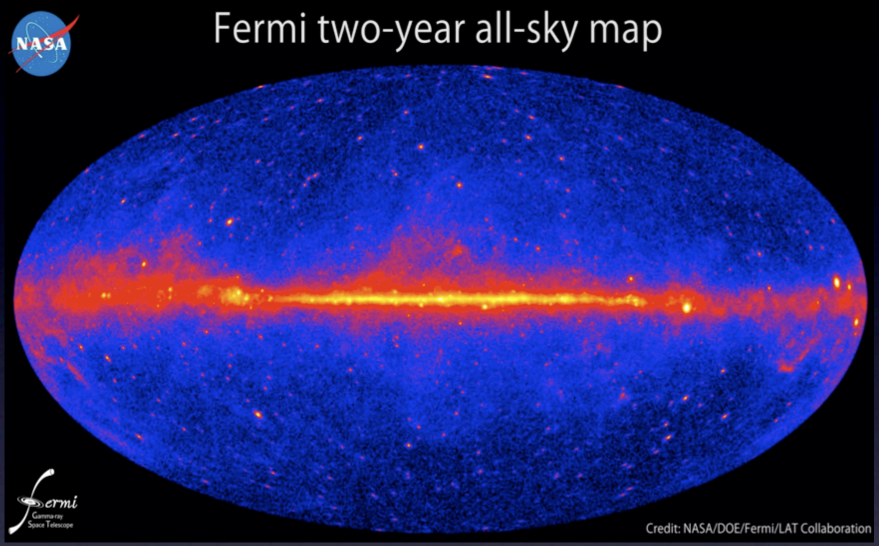


Springel, V. et al, Mon.Not.Roy.Astron.Soc. 391:1685-1711,2008.

Obtained from N-body simulations which have impressive agreement with large scale structures. They find cuspy host halos (NFW or Einasto DM density profile) with numerous subhalos.

DM targets

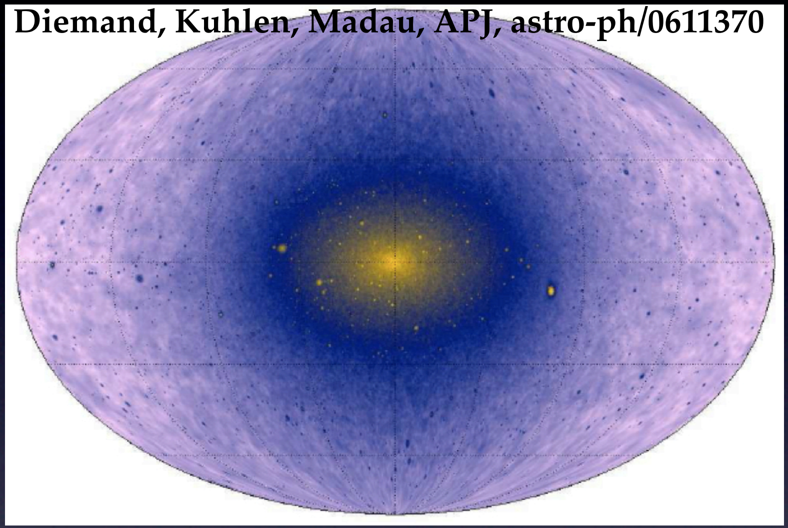


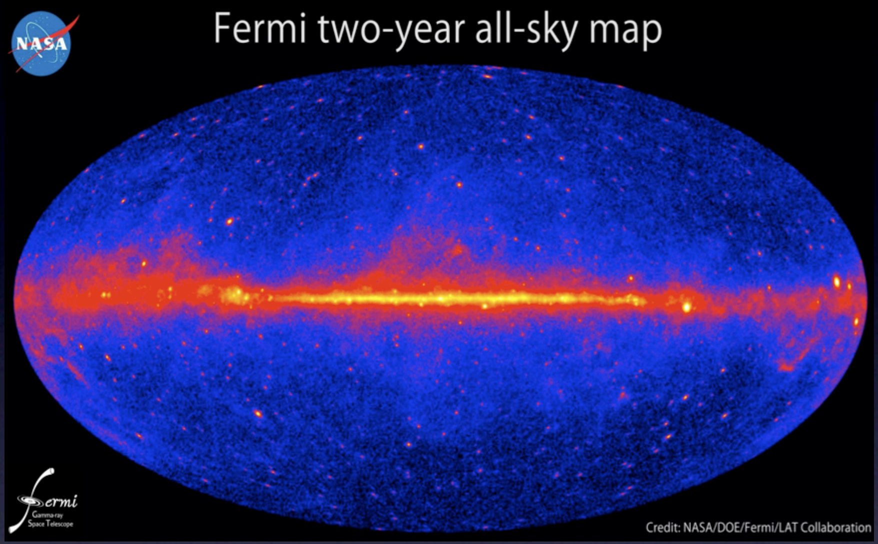


Point sources:

- *Galactic Center:* ✔
- *Dwarf Satellites:* the biggest Galactic subhalos (contain stars) ✔
- *dark subhalos:* search for sources which shine only in gamma-rays
- *Galaxy clusters:* the biggest DM halos yet to form

DM targets



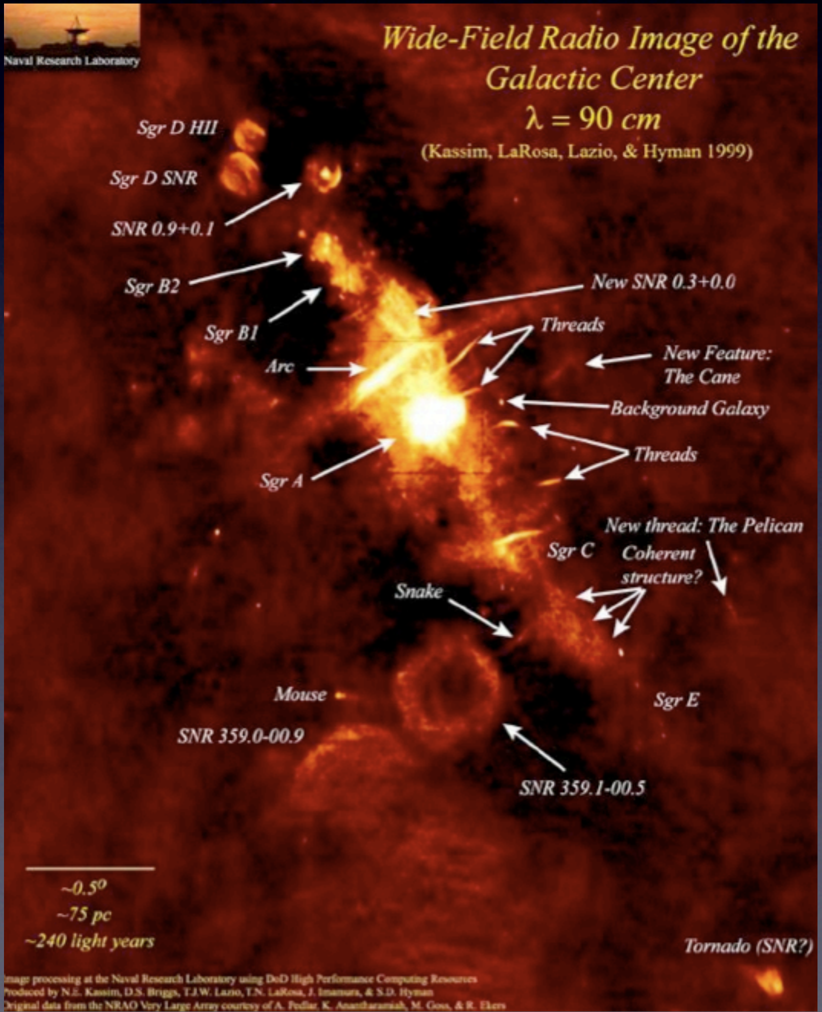


Diffuse emission:

Made possible with the Fermi telescope! (good angular and energy resolution, large field of view, good charge particle rejection)

- ✴ Isotropic (*extragalactic*) signal ✔
- ✴ *Galactic* diffuse emission ✔
- ✴ search for a line feature in the spectra

Point Sources - Galactic Center



Source in the central parsecs of our Galaxy:
-- from radio to X-rays, signal originates from the Sgr A*,
--25 formal associations based on position for *GeV γ-ray emissions* (due to a relatively large angular resolution).

The inner Galaxy region has huge diffuse emissivity due to CRs streaming through very dense clouds + Large Pulsar population ! Inferred population of ~2000 active radio pulsars! +massive star clusters, SNRs, PWN...

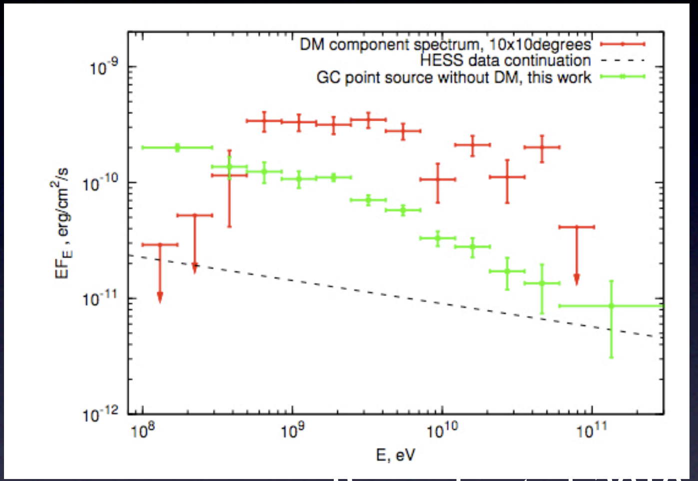
Point Sources - Galactic Center

Fermi-LAT analysis:

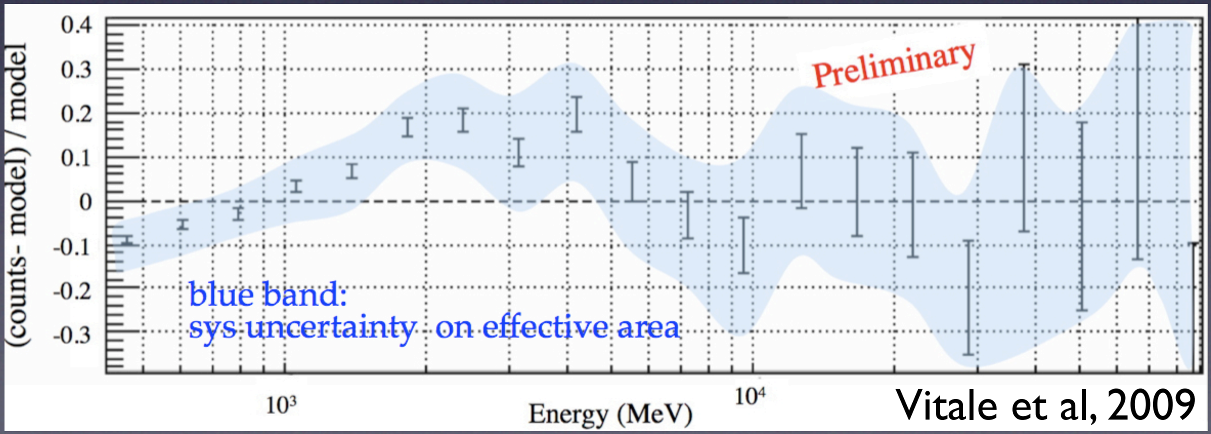
*Unbinned Likelihood analysis of 7x7 deg region around GC
*11 months of data, events > 400 MeV, front-converting (narrower PSF)
* Galactic Diffuse emission from GALPROP
*Sources from Fermi catalog

Possible reasons for the residuals:

*Small-scale diffuse emission
*Sources in the region
*Instrumental effects



Boyarski et al, 2010



Vitale et al, 2009

Non Fermi-LAT analysis:

*Finds similar residuals.
*DM claims too, see [Hooper & Goodenough (arXiv:1010.2752)]. However, modeling of this complicated region is at an early stage, and other possibilities have to be studied before exotic claims are made.

Point Sources - Dwarf Galaxies

•Optically observed dSph are *the largest DM clumps in our halo*. ~25 have been discovered so far (many more expected).

•Dark matter dominated systems, no significant high energy gamma rays originating from astrophysical sources expected.

•DM mass determined based on kinematics of stellar component (KECK data).

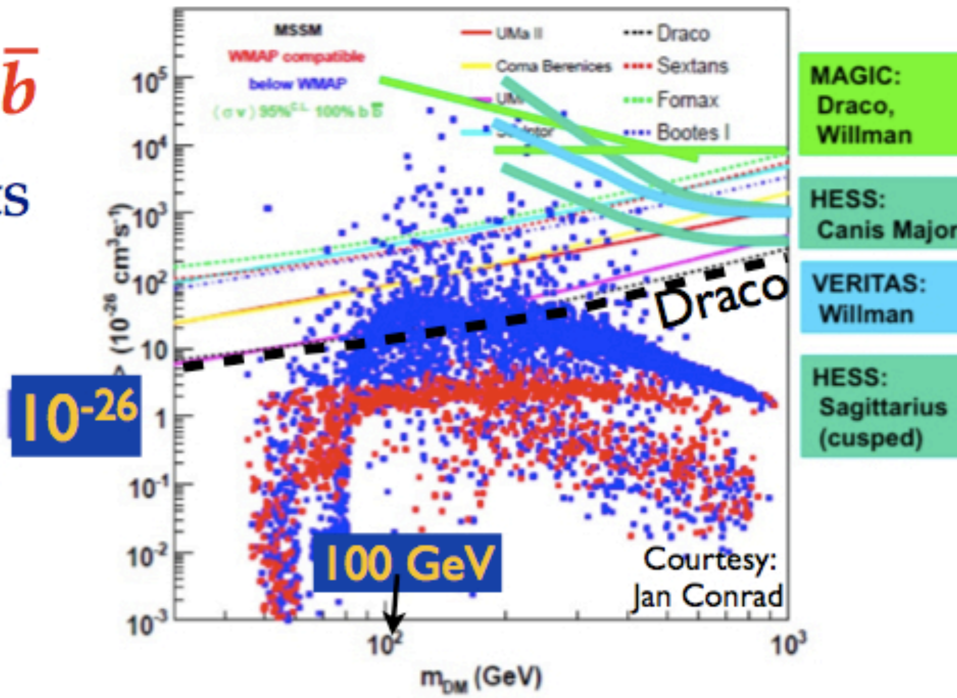
•*No detection of dSph in 2 year Fermi data* → *upper limts on a DM component.*

Point Sources - Dwarf Galaxies

Smaller DM dominated closer objects

$DM\, DM \rightarrow b\bar{b}$

(stronger limits than from clusters, no substructures)

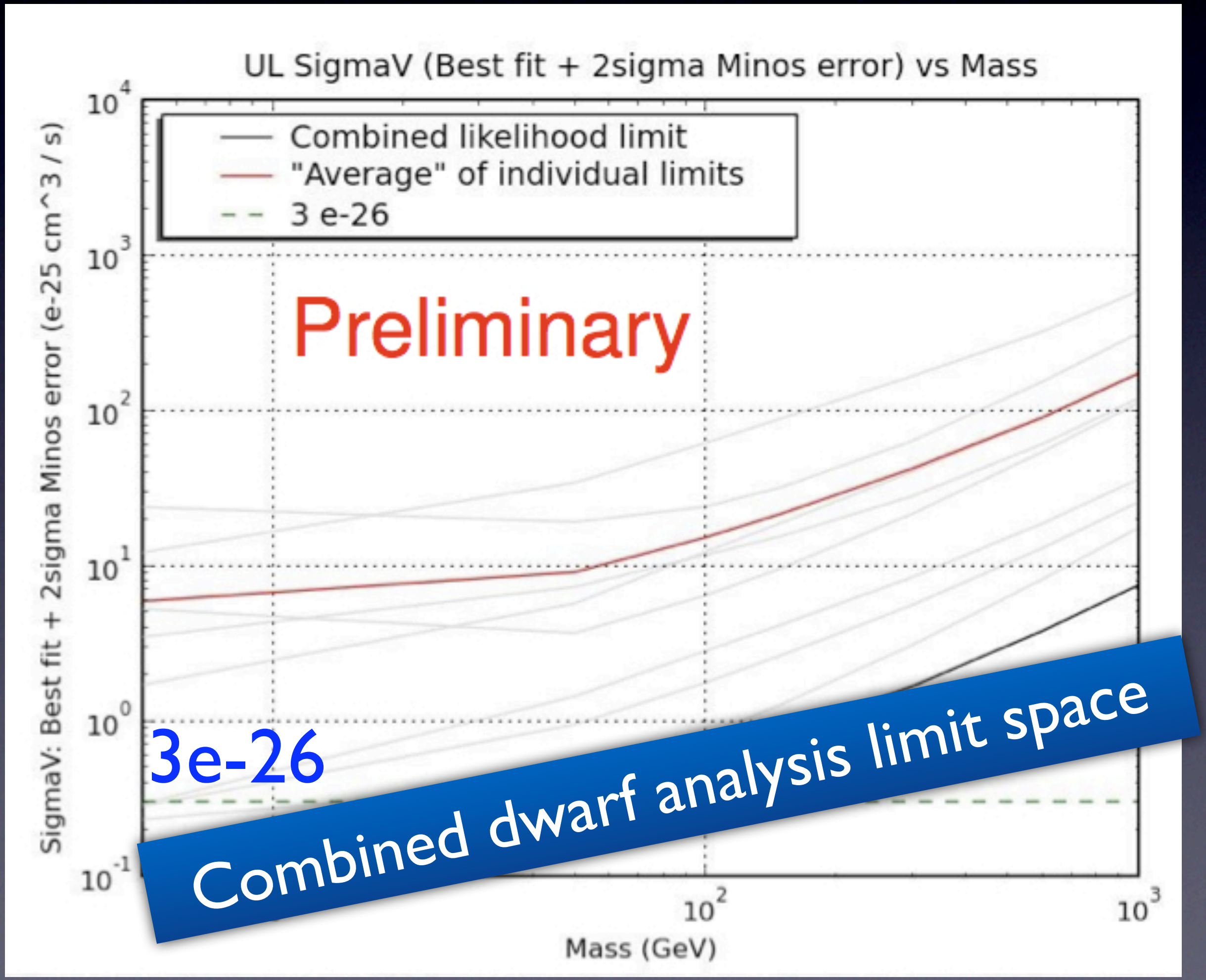


[Astrophys. J. 712, 147 (2010)]

Point Sources - Dwarf Galaxies

Combined limits for 8 dSph, using 21 months data.

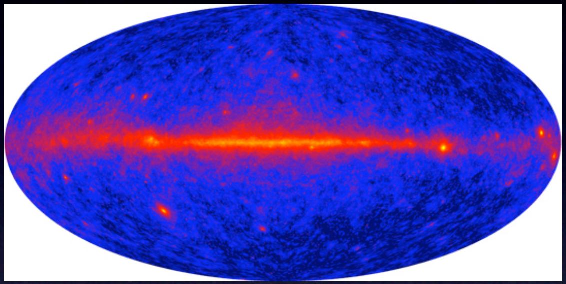
Improvements of DM limits by a factor of ~ 2, 3 expected.



‘Diffuse’ DM searches by the Fermi team

- analysis of the diffuse emission in terms of DM signal from the DM halo of our Galaxy.
- analysis of the diffuse Extragalactic (Isotropic) Signal to study DM annihilation at the cosmological scales, by using:
  - the *intensity and spectral shape* of the signal or
  - *angular anisotropies*.

- *Extra Galactic diffuse signal* inferred the isotropic gamma-ray emission by multicomponent fit to Fermi-LAT gamma-ray data.


full sky data

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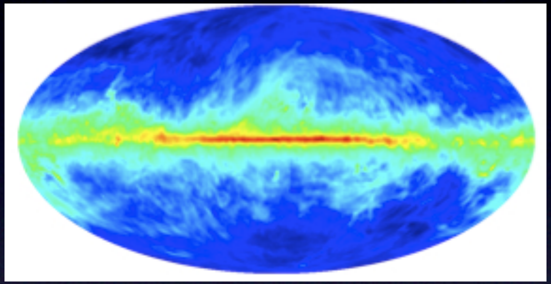
galactic diffuse emission

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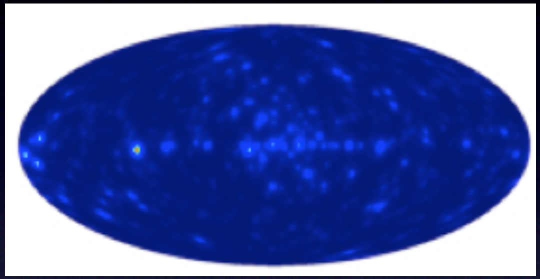
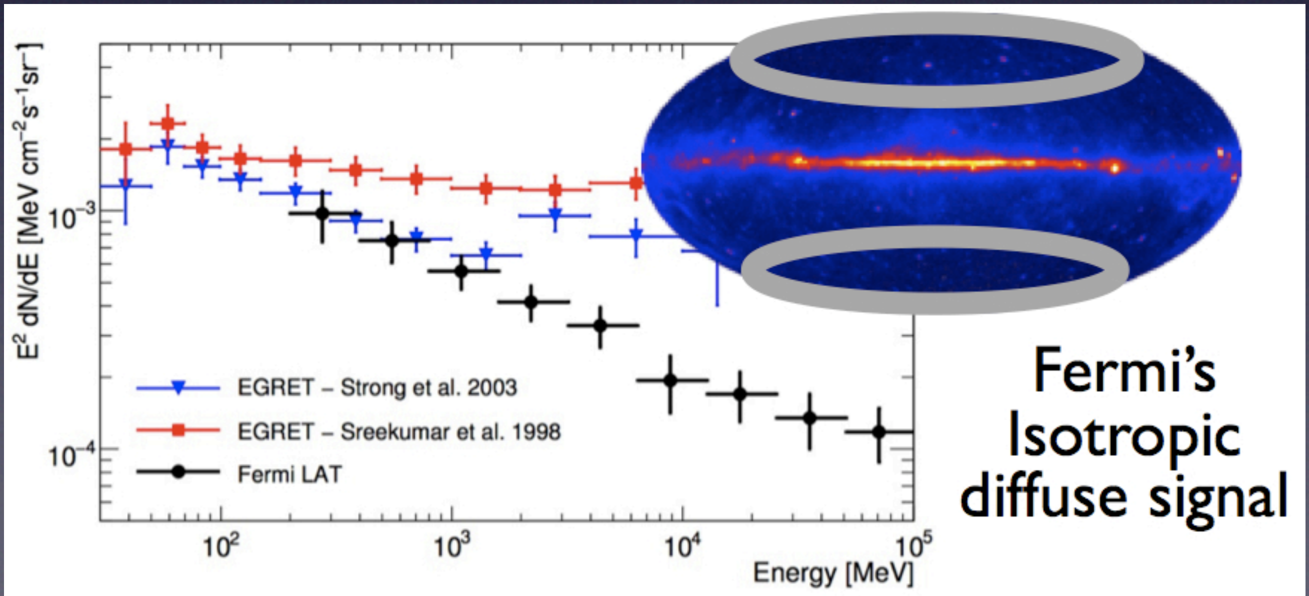
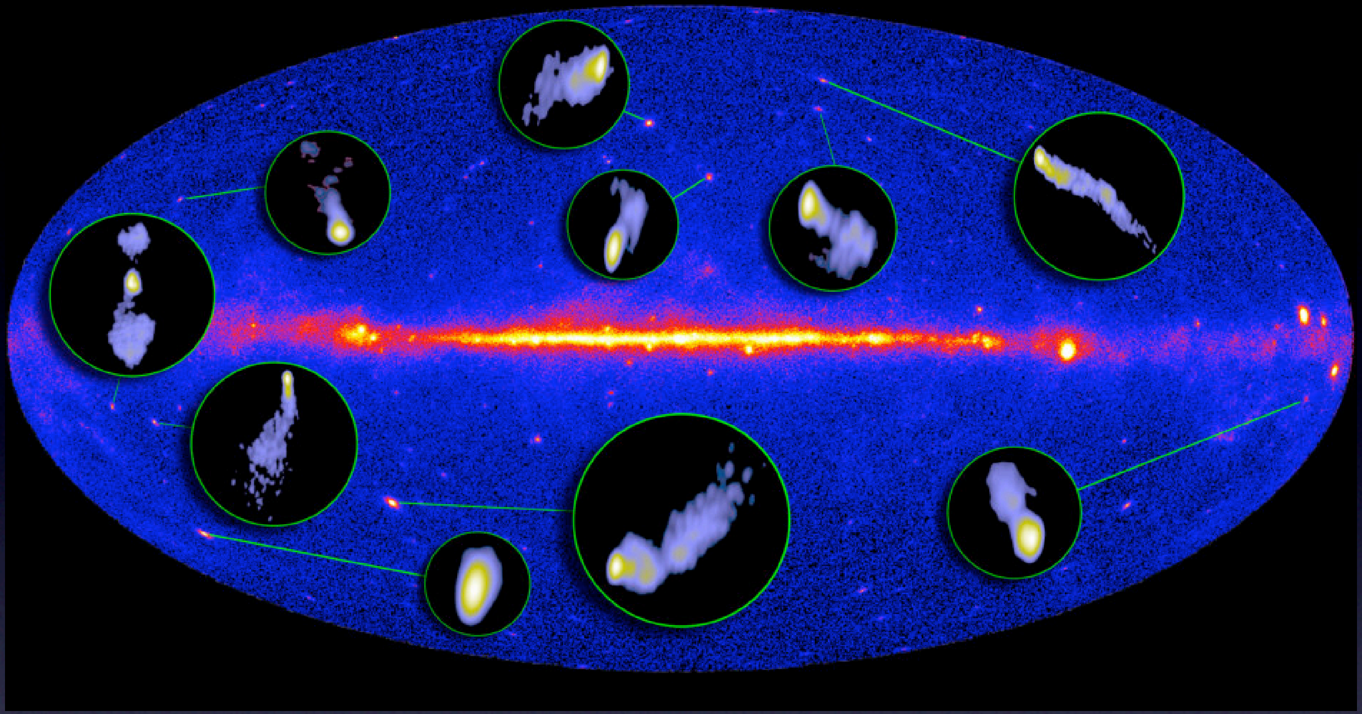

point sources

NB: the features of the inferred isotropic signal depend on the modeling of the galactic diffuse emission. Estimates of error~20%.

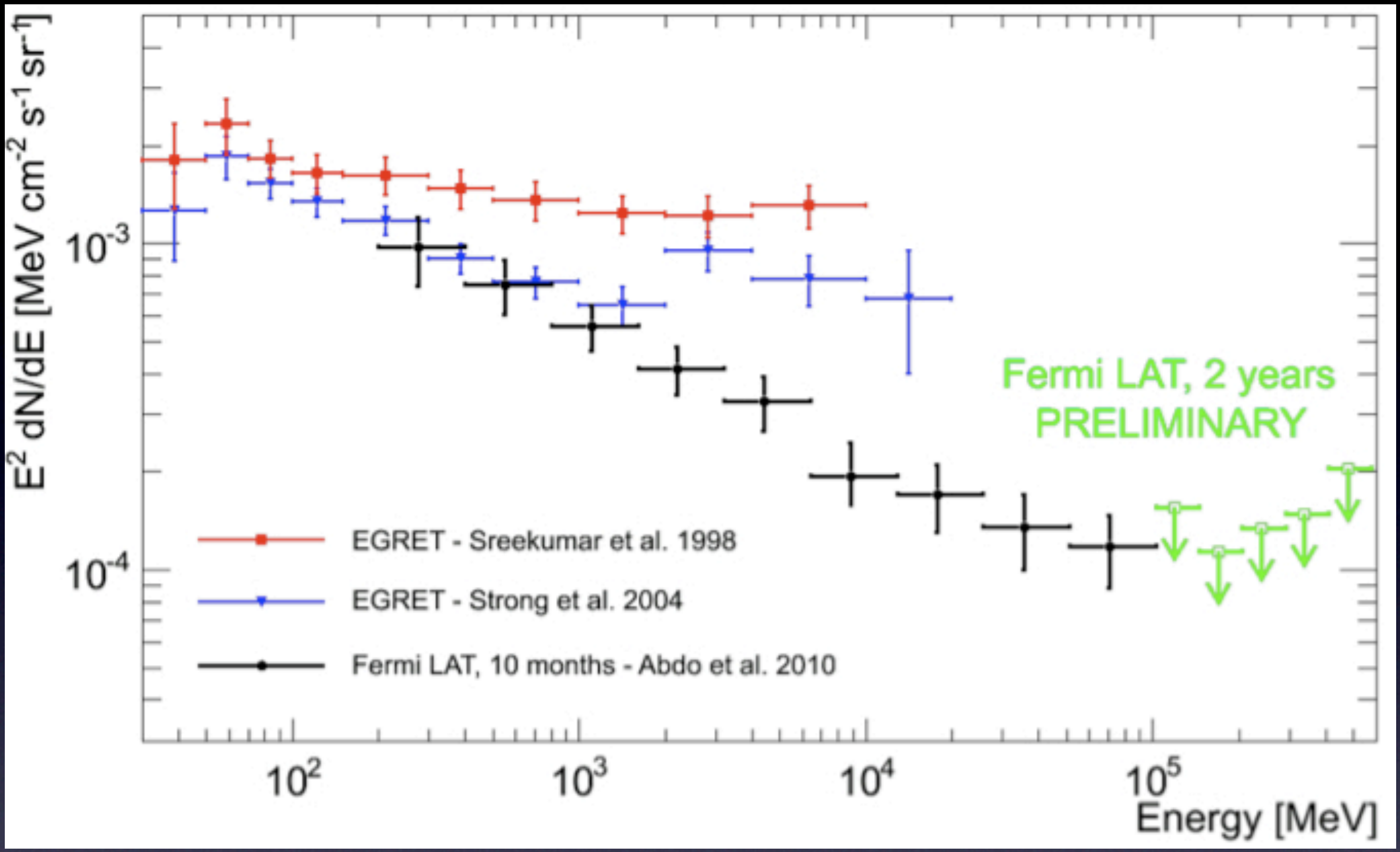


Produced by *unresolved* energetic phenomena over cosmological scales:

i) AGN
ii) star burst and star forming galaxies
iii) DM...?

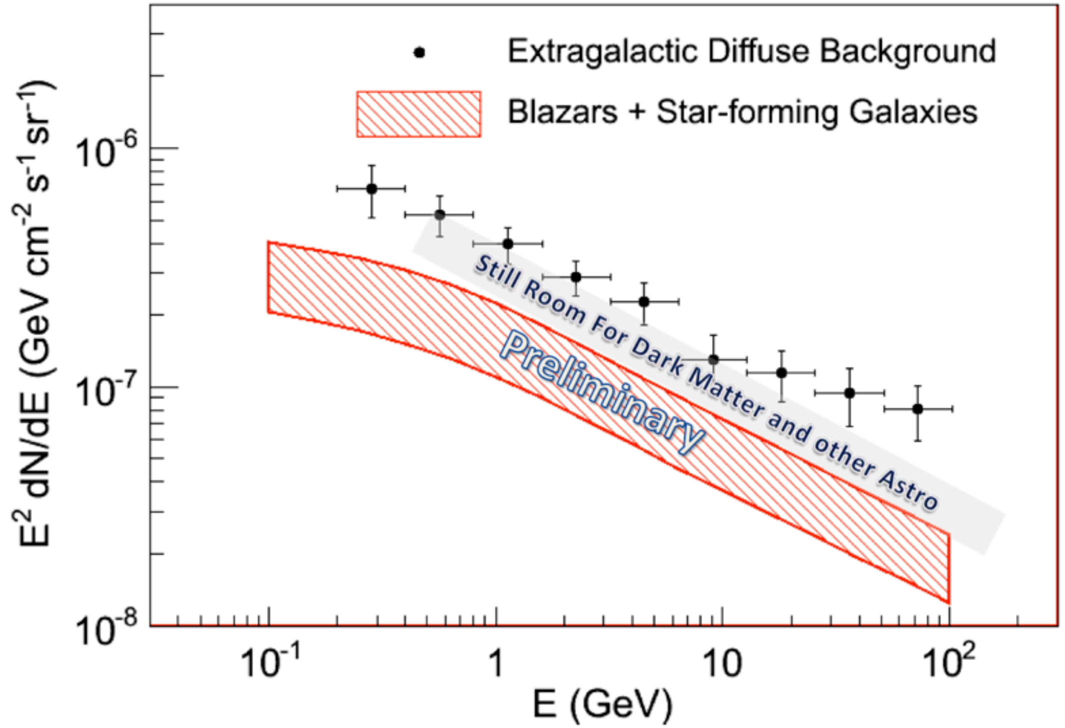


Selected Active Galactic Nuclei observed in radio by the VLBA (which has a million times better resolution than the Fermi-LAT) and gamma-rays by the Fermi-LAT.



First year data extended to 100 GeV.
>100 GeV the available Fermi MC simulation of residual CR contamination is too statistically limited.
A dedicated analysis is ongoing.
Only *upper limits* for data >100 GeV shown here.

Comparison of the Extragalactic Diffuse γ–ray Background[1)] to Calculations of Contributions from Blazars[2)] + Star-forming Galaxies[3)]



1) Abdo, A. A. et al. 2010, Phys. Rev. Letts. **104**, 101101;
2) Abdo, A. A., et al. 2010, ApJ. **720**, 435; 3) Fermi LAT Collaboration Preliminary.

Blazar contribution is derived from *a source population study*, while the starburst contribution is coming from deriving the luminosity function based on multi-wavelength tracers of star-burst galaxies, having only detected *a few (4) in gamma-rays* → *indicates that the majority of the IGRB does not originate from members of the source classes already detected by Fermi.*

The studies of angular anisotropy of the isotropic background also detect an extragalactic source population:

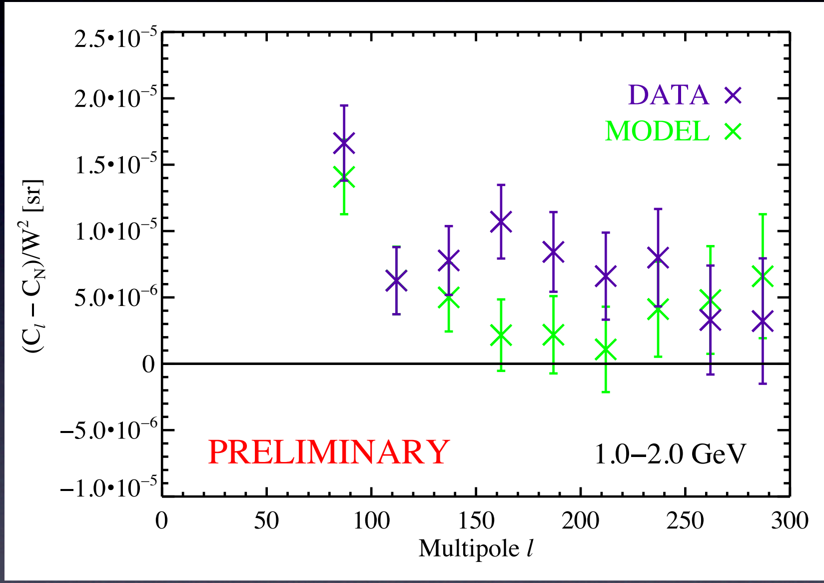
1 - 2 GeV

fluctuation angular power spectra

predictions for C_ℓ at l = 100 for a single source class (LARGE UNCERTAINTIES):

- blazars: ~ 1e-4
- starforming galaxies: ~ 1e-7
- dark matter: ~ 1e-4 to ~ 0.1

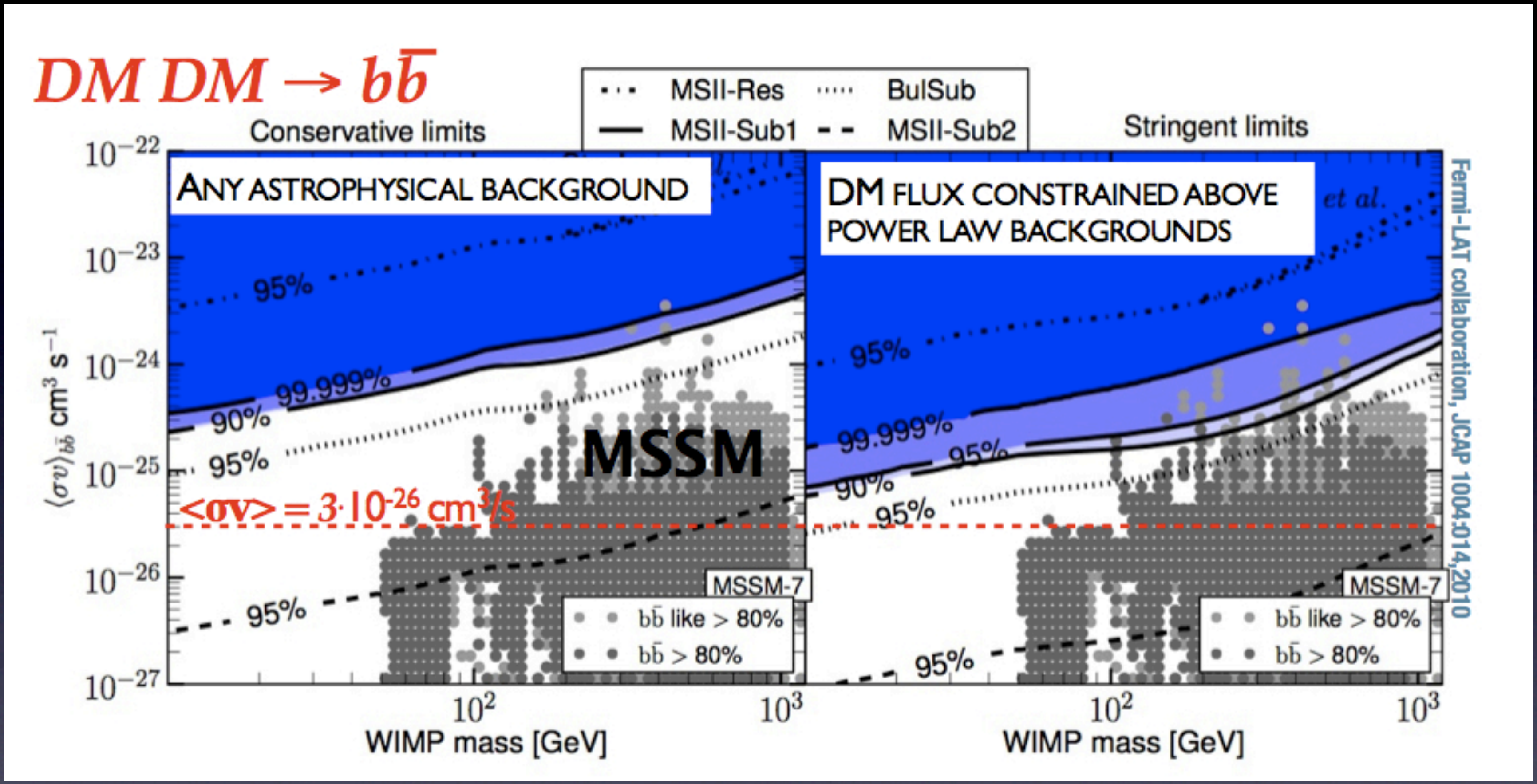
early, pre- Fermi estimates...



measured fluctuation C_ℓ of ~ 1e-5 at multipoles above ~ 100 at low energies falls generally in the range predicted for some astrophysical source classes and some dark matter scenarios for emission from a single source class

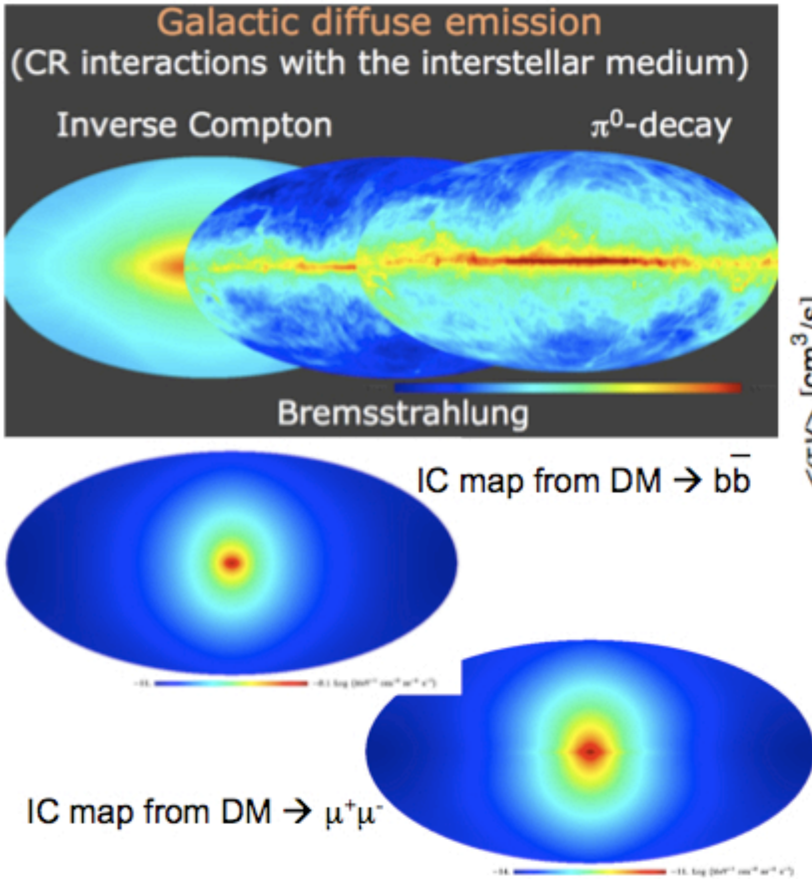
[J. Siegal-Gaskins, IDM2010]

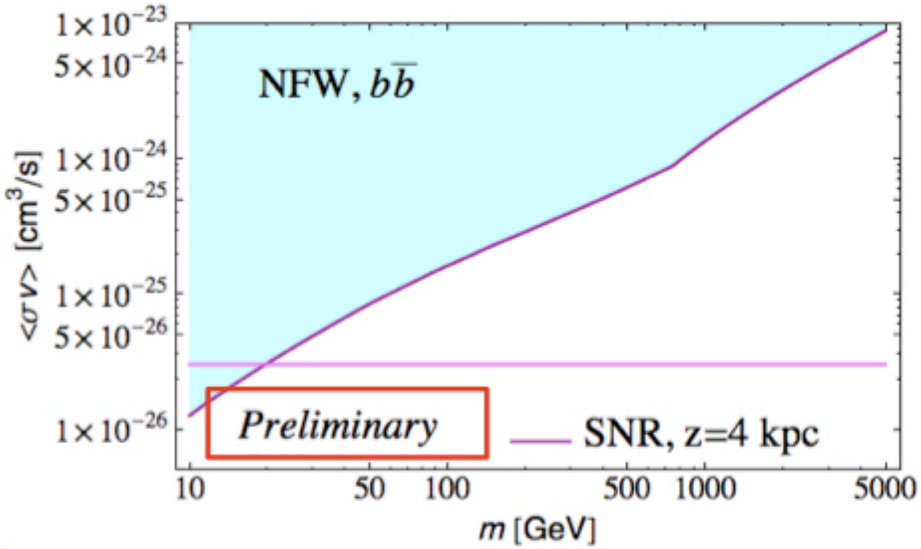
DM limits based on the first year isotropic diffuse data:



→ A two year spectrum will become available soon
+ we have also learned a lot about the contribution to the signal from astrophysical extragalactic source classes → improved sensitivity for DM searches.

- *Galactic diffuse signal:* limits on a DM component in the Milky Way halo.





Exploits both spectral and spatial features of gamma-ray signal to disentangle DM from astrophysical diffuse emission

This search relies heavily on modeling of the cosmic ray propagation.
Among considered astrophysical models we choose the one expected to give most conservative DM constraints.
Work in progress.

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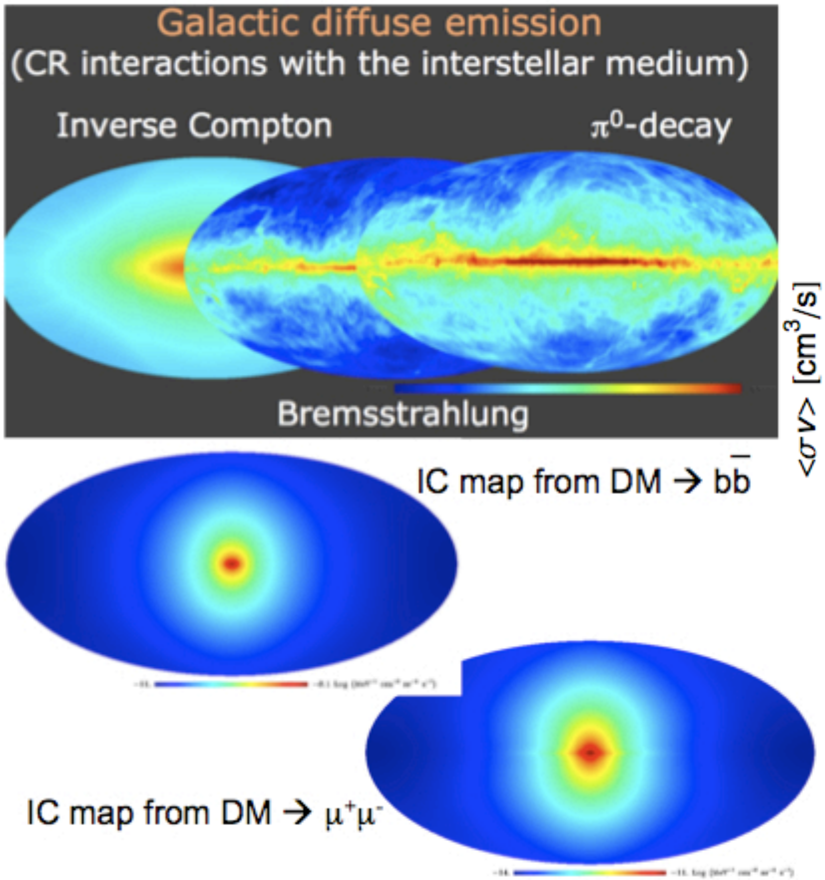

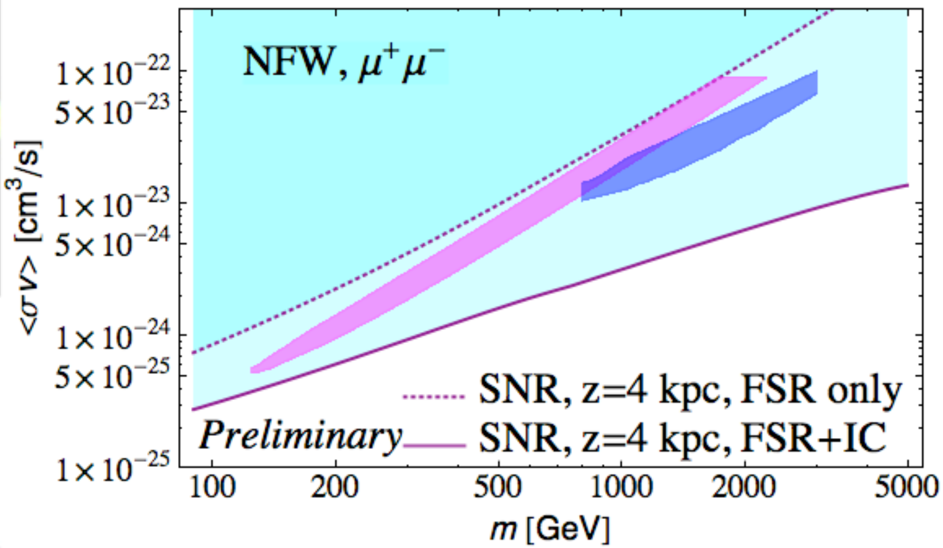

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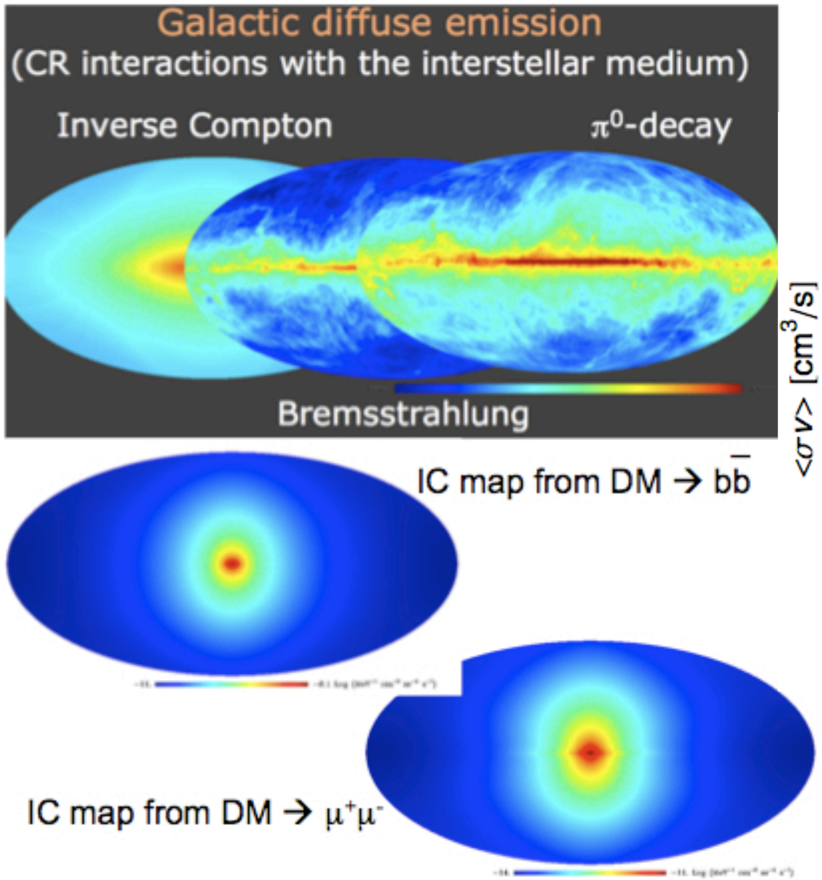

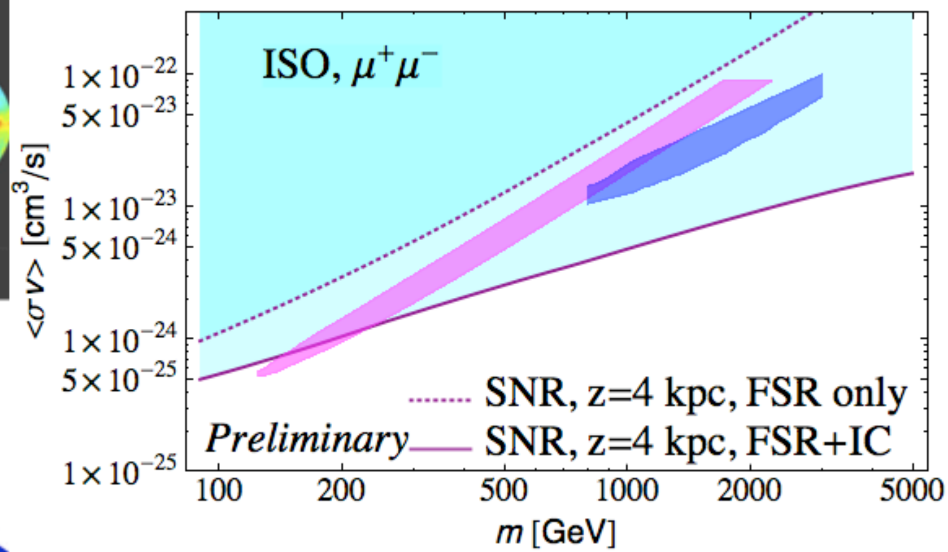

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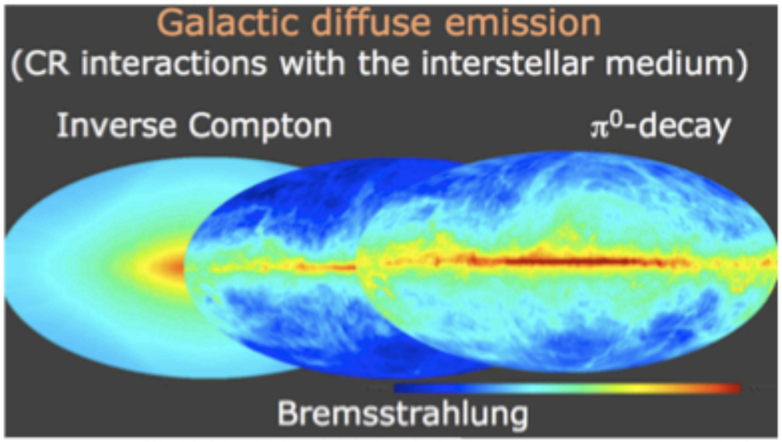

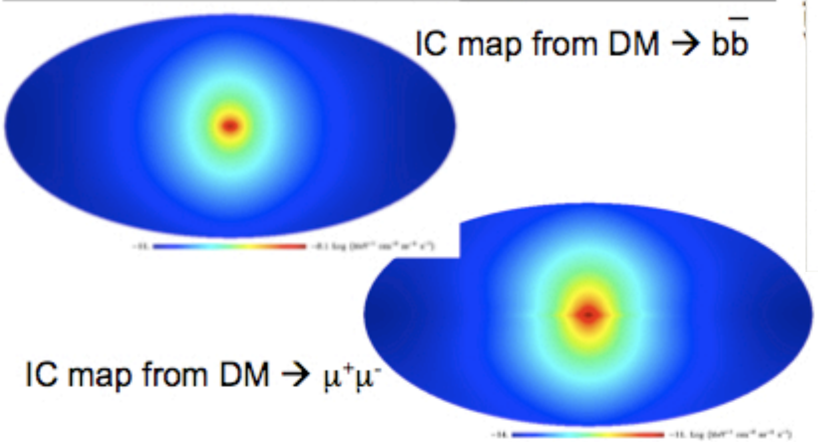

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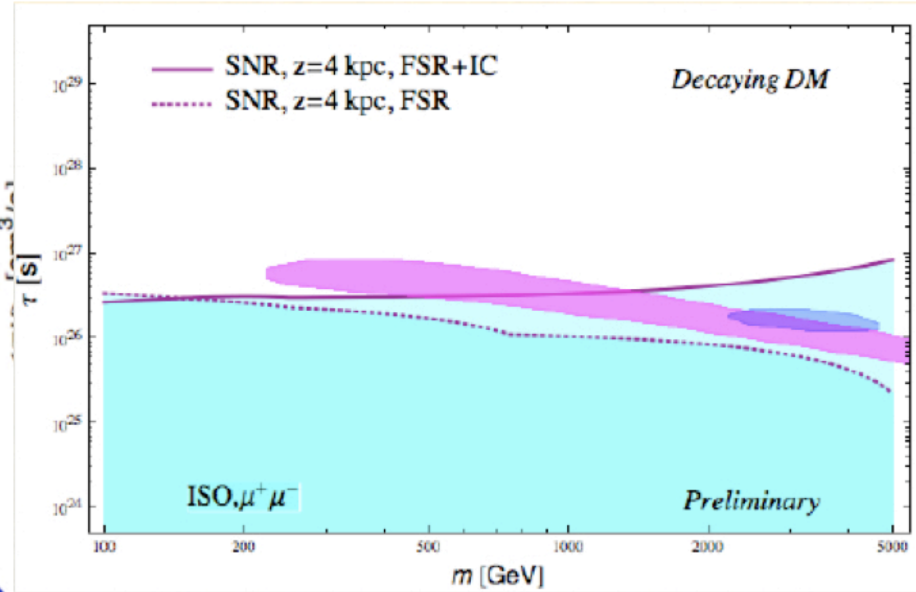

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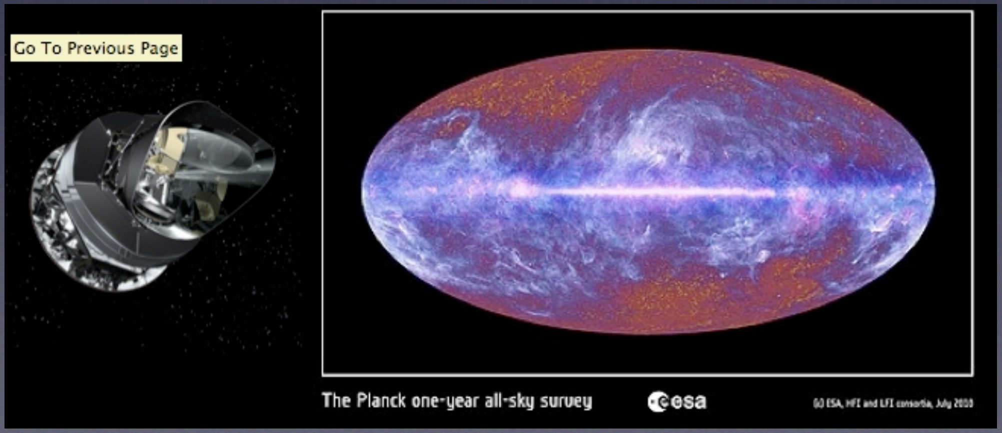
Summary and future prospects

- The DM signal from our halo is potentially a strong DM search tool (due to the strength of the signal). It heavily relies on the models of the diffuse emission.
- DM limits obtained by using the 1st year Fermi isotropic flux are quite strong, but not the most robust. Expected improvements with the 2yr data.
- The combined limits from dwarf spheroidal galaxies are cutting into the WIMP parameter space.
- many other DM analysis ongoing within Fermi: Galactic Center, dark subhalos....

Future prospects

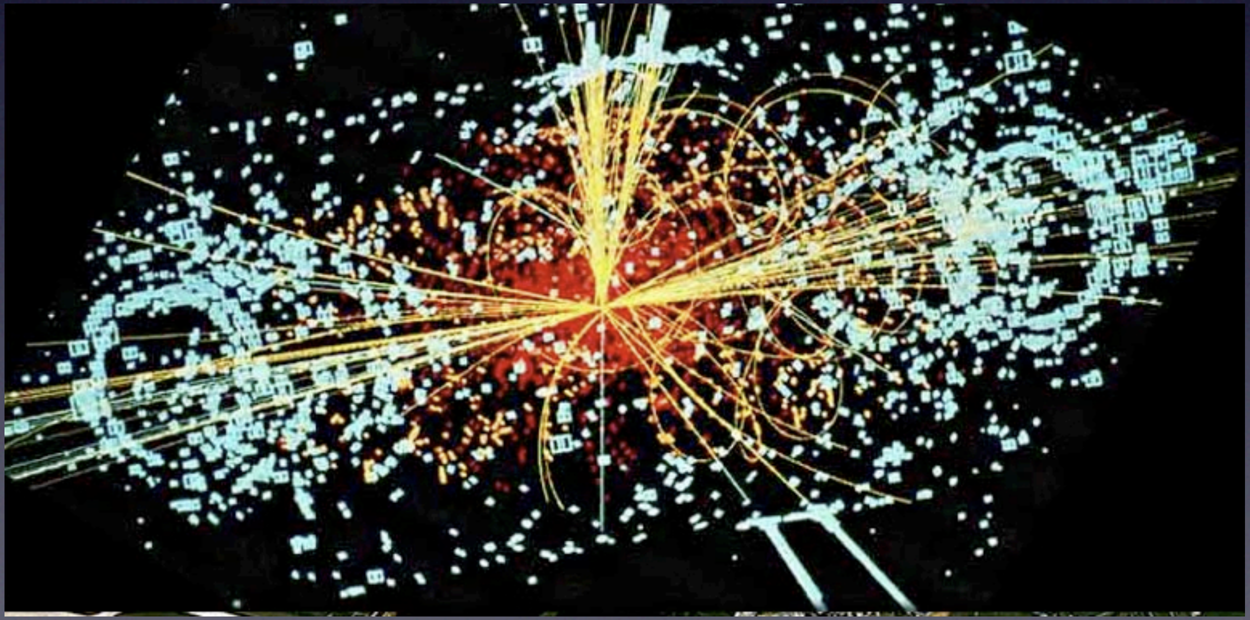
- Cosmic ray experiments (*AMS02, CREAM*...), are expected to improve our knowledge of the cosmic ray propagation in our Galaxy.

- *Planck* will determine cosmological parameters with improved sensitivity and aid in the predictions for the DM cosmological signal. The measure the dust content of our Galaxy will improve our modeling of the gas content, and therefore that of the Galactic diffuse emission. Multiwavelength studies with synchrotron band will also bring in improvements.



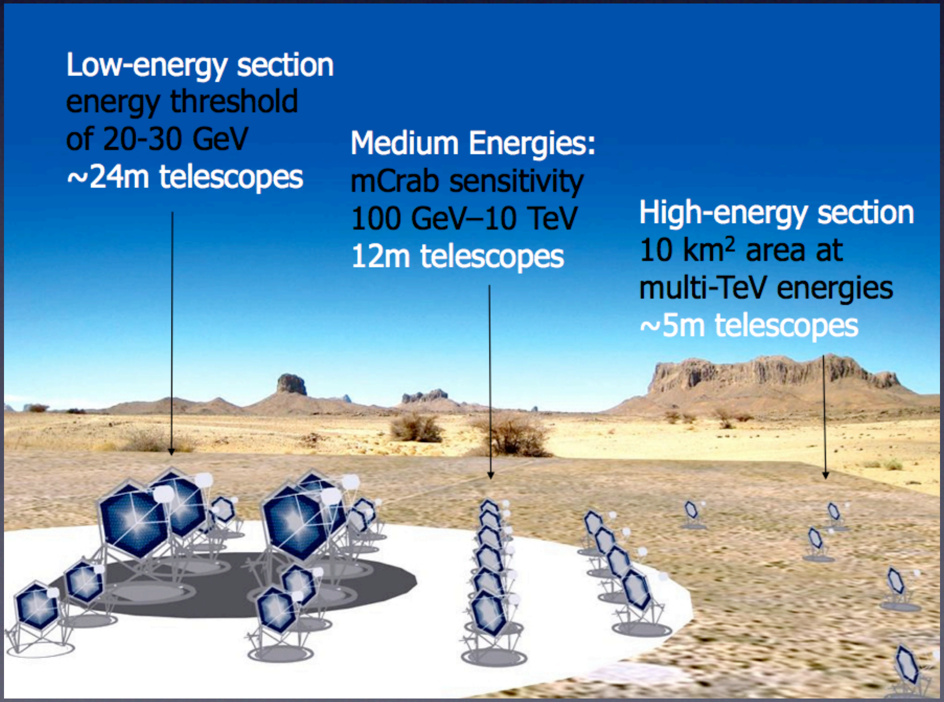
Future prospects

- *LHC* is expected to give us first hints of the new physics at the EW breaking scale soon, and hopefully aid us in where to look (in terms of the energy spectra) for the dark matter signatures.



Future prospects

- *CTA*, a kilometer square array of Cerenkov telescopes will have a sensitivity improvement of over order of magnitude with respect to Fermi and current ACTs. It will have a superior angular resolution and due to the large number of telescopes employed, might also have a significant potential to measure extended (diffuse) emission.



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