Constraints on WIMP Annihilation for Contracted Dark Matter in the Inner Galaxy with the *Fermi*-LAT

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MultiDark
Multimessenger Approach for Dark Matter Detection

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Fermi
Gamma-ray Space Telescope

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DM-Induced Gamma rays

The **gamma-ray flux from DM annihilation** has two main contributions: **prompt** photons and photons **induced via ICS**. The former are produced indirectly through **hadronization, fragmentation and decay of the DM annihilation products or by internal bremsstrahlung, or directly through one-loop processes.** The second contribution is originated from **electrons and positrons produced in the DM annihilations, via ICS off the ambient photon background.**

$$\left(\frac{d\Phi_\gamma}{dE_\gamma}\right)_{prompt} = \sum_i \frac{dN_\gamma^i}{dE_\gamma} \frac{\langle \sigma_i v \rangle}{8\pi m_{DM}^2} \bar{J}(\Delta\Omega)\Delta\Omega$$

Gamma-ray Flux

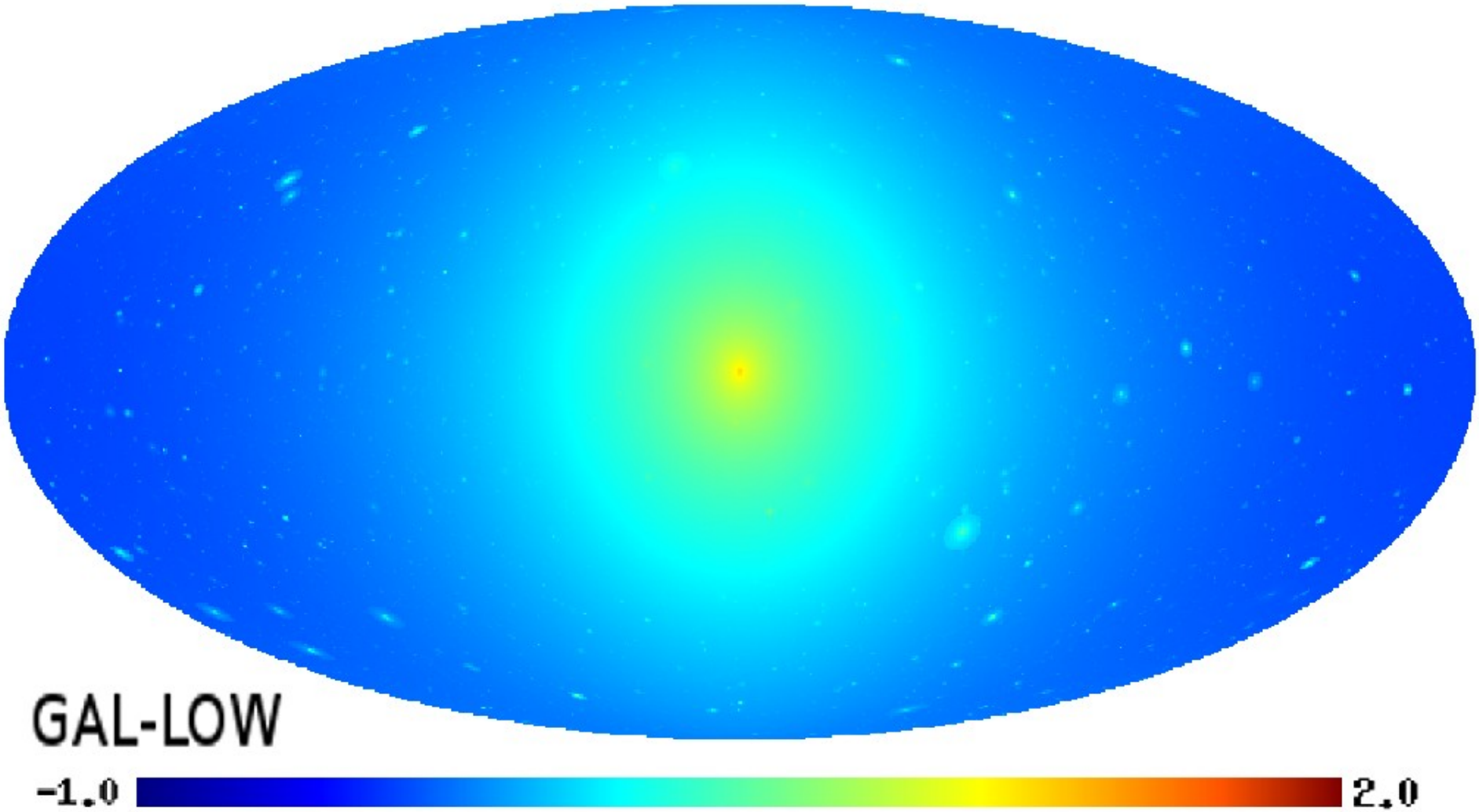
Particle Physics
Spectral information

DM Distribution
(J*-Factor*)
Spatial information

$$\bar{J}(\Delta\Omega) \equiv \frac{1}{\Delta\Omega} \int d\Omega \int_{l.o.s.} \rho^2(r(l,\Psi))\, dl$$

DM all sky map

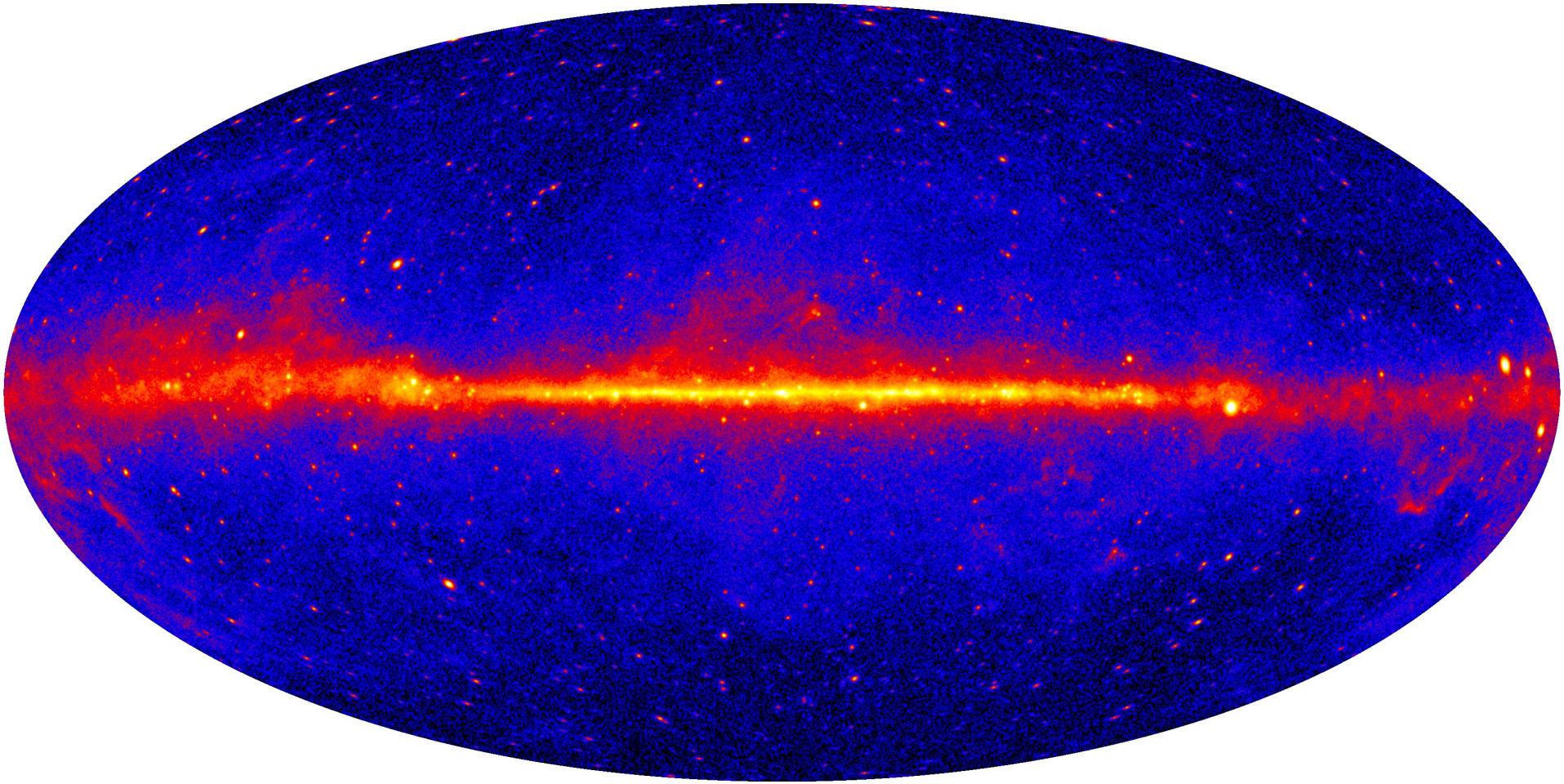
Fornasa et al, 2013, mnras, 429, 1529



N-body simulations predict the Galactic Center as the brightest DM-induced gamma-ray source.

~4 year Fermi-LAT all sky map

Image Credit: NASA/DOE/International LAT Team

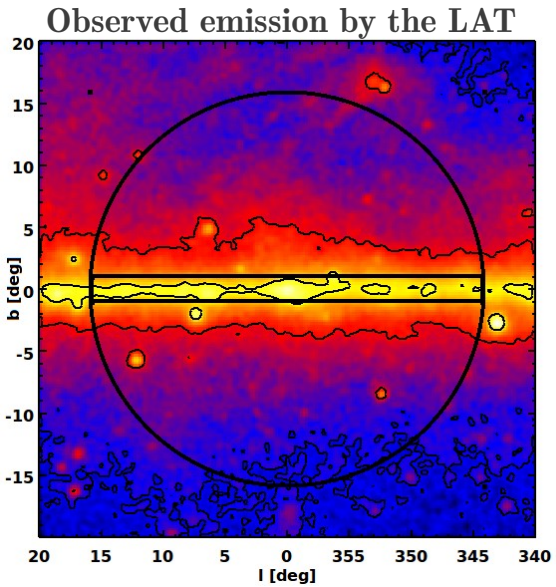


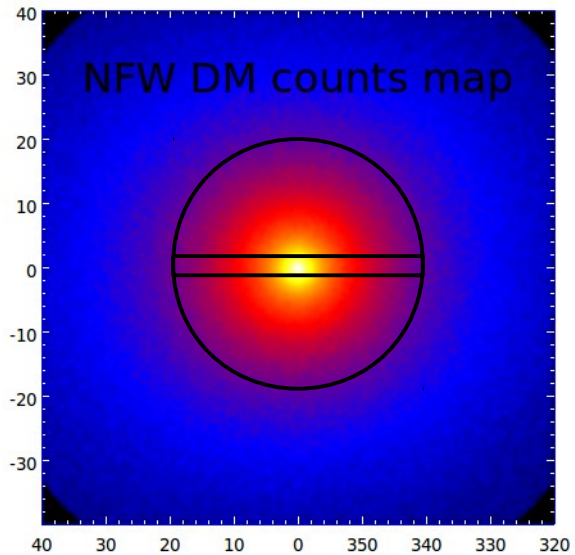
Although several astrophysical processes at work in the crowded GC region make it extremely difficult to disentangle the DM signal from conventional emissions.

Methodology

- Our analysis is **conservative** since it simply requires that the **expected dark matter signal does not exceed the emission observed by the LAT** in an optimized region around the GC.

- Since **N-body simulations are not able to predict the DM distribution towards the GC**, we use four well motivated DM profiles tunned to observables of the Milky Way.





DM density profiles

We use realistic DM density profiles directly derived from MW observational data:

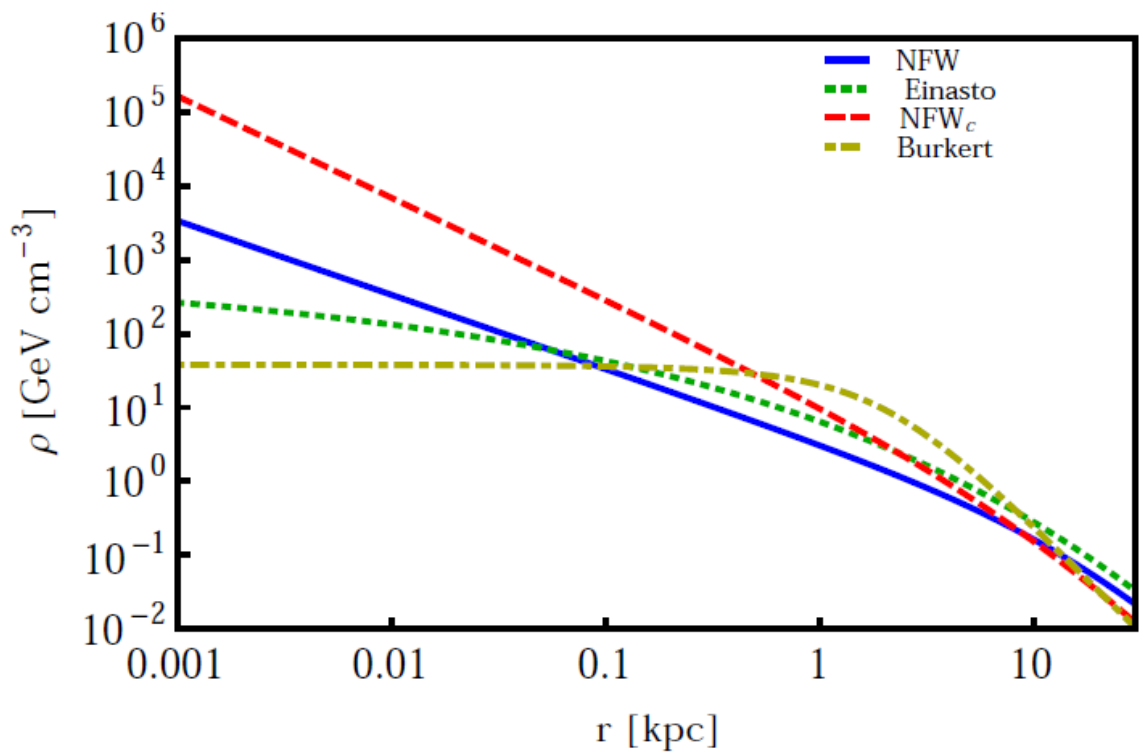
- **NFW (Prada+04)**
- **Einasto (Catena&Ullio10).**
- **Burkert (inspired on Catena&Ullio10).**
- **Adiabatically compressed NFW (Prada+04).**

Profile	α	β	γ	ρ_s [GeV cm^{-3}]	r_s [kpc]
Burkert	−−	−−	−−	37.76	2
Einasto	0.22	−−	−−	0.08	19.7
NFW	1	3	1	0.14	23.8
NFW$_c$	0.76	3.3	1.37	0.23	18.5

$$\rho(r) = \frac{\rho_s}{\left(\frac{r}{r_s}\right)^{\gamma}\left[1+\left(\frac{r}{r_s}\right)^{\alpha}\right]^{\frac{\beta-\gamma}{\alpha}}}$$

$$\rho_{\rm Ein}(r) = \rho_s \exp\left\{-\frac{2}{\alpha}\left[\left(\frac{r}{r_s}\right)^{\alpha}-1\right]\right\}$$

$$\rho_{\rm Burkert}(r) = \frac{\rho_s\, r_s^3}{(r+r_s)\,(r^2+r_s^2)}$$



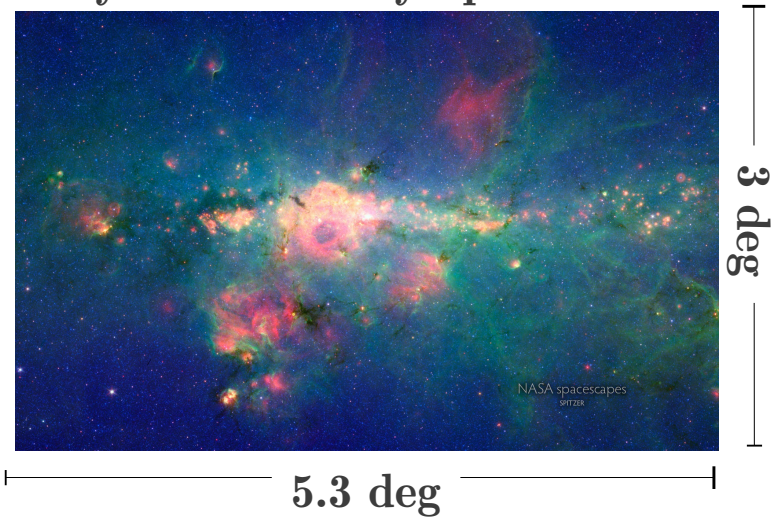
Compressed profiles

- **DM-only simulations predict NFW or Einasto**, but ordinary matter (**baryons**) dominates the **central region of our Galaxy**. Thus, baryons may significantly **affect the DM distribution.**
- As **baryons collapse** and move to the center they **increase the gravitational potential,** which in turn forces the **DM** to contract and **increase its density**.
- The ***adiabatic compression*** is **confirmed by high-resolution hydrodynamic simulations** that self-consistently include complex baryonic physics (gas dissipation, star formation, supernova feedback...) [Gustafsson+06, Colin+06, Tissera+10, Gnedin+11]
- **Caution:** other baryonic effects may **flatten the DM cusp:**

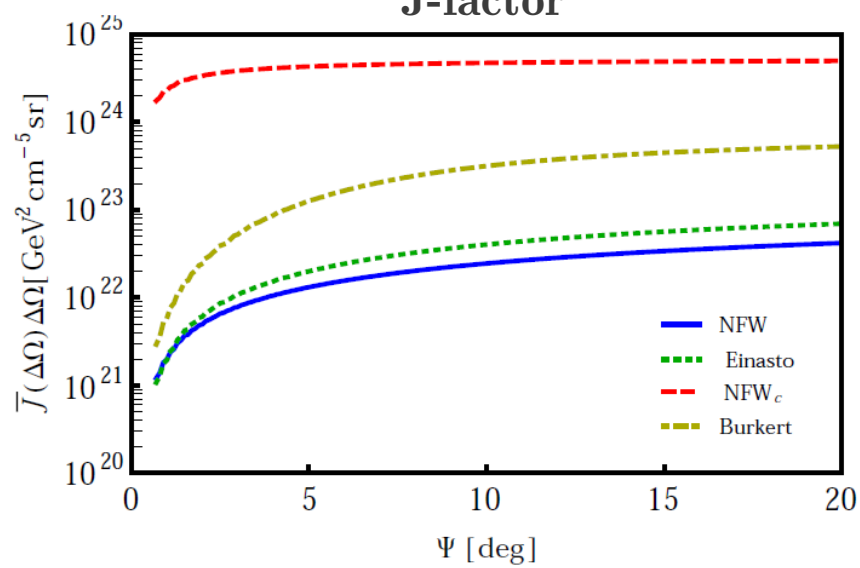
1. Strong bursts of star formation with a series of multiple explosions
2. inner material expelled, causing a DM density decrease

[Mashchenko+06, Mashchenko+08, Governato+10, Pontzen+12]

Baryons as seen by Spitzer in IR



J-factor



Particle physics models

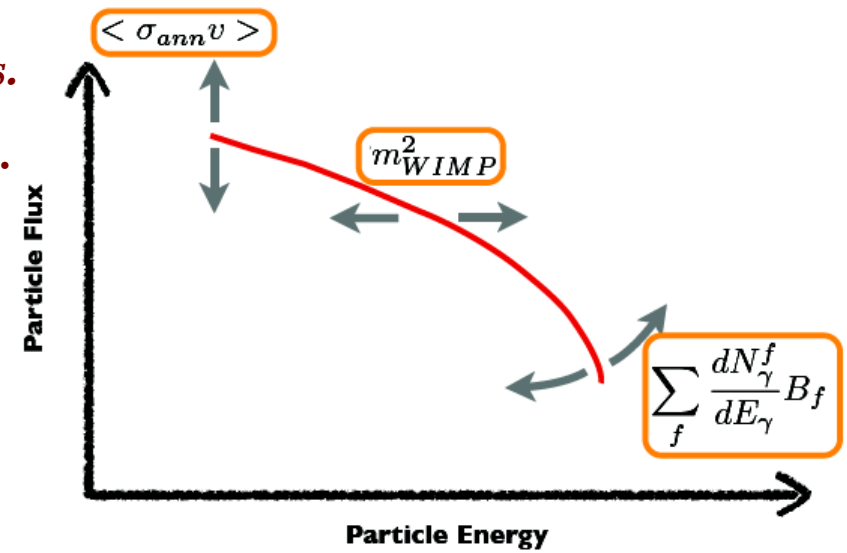
Particle physics factor:

Vanilla-like DM: ***Prompt, FSR, and ICS processes.***

PPPC 4 DM ID tables: **used for prompt and FSR.**

DM mass range: **5 GeV – 3 TeV**

Channels: **bb, $\tau^+\tau^-$, $\mu^+\mu^-$, W^+W^-**



Inverse Compton Scattering calculation:

For heavy DM it can be dominant over prompt in the *Fermi*-LAT energy range used.

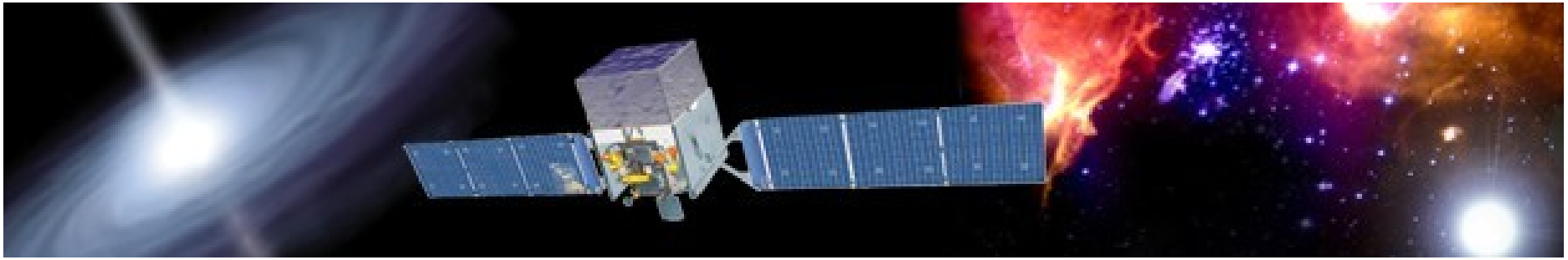
Numerical calculation of galactic CR diffusion-loss equation.

MIN, MED, MAX model + b(E) suitable for GC region.

MIN and MAX models do not imply minimal or maximal expected gamma-ray signal, respectively.

ICS is more significant for leptonic channels

Fermi-LAT data analysis



- Ferm-LAT: **2008 Aug. 4 – 2012 June 15.**
- Energy range: **1-100 GeV.**
- Class events: **Pass 7 V6 Ultraclean front conversion**. This choice reduces the cosmic-ray background contamination and takes advantage of a narrower PSF w.r.t. back-converting events
- Science tools: **V9r28**
- Region of analysis: **30 deg around the GC**
- We build a set of 0.2 deg/pixel resolution flux maps ***f(E,l,b)*** at different energies.

Fermi-LAT data analysis

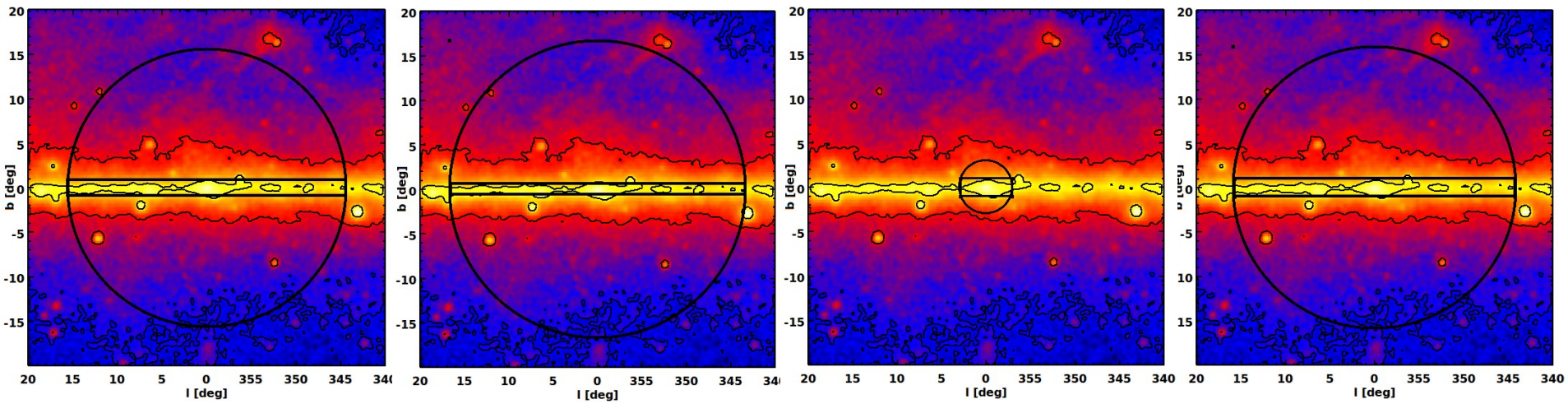
We choose the region of interes driven by a S/N optimization:

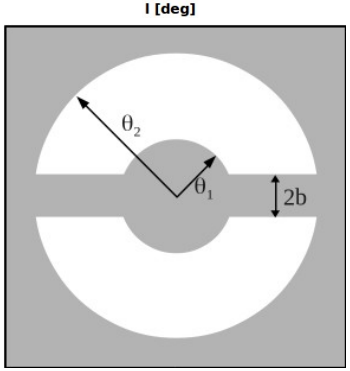
- ***Signal***: J-factor maps for every DM density profile.

- ***Noise***: Square root of the photon flux map.

ROI's optimal parameters are those that make the S/N the largest for every profile

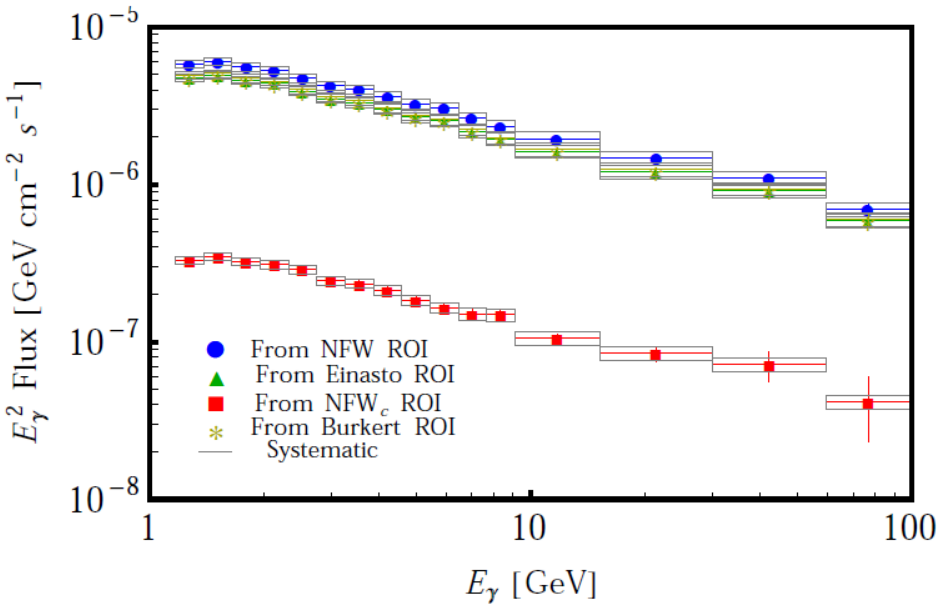
Einasto **NFW** **NFW-compressed** **Burkert**





Profile	θ_1 [°]	θ_2 [°]	$\lvert b\rvert$ [°]	$\Delta\Omega$ [sr]	$\bar{J}(\Delta\Omega)\,\Delta\Omega$ [$\times 10^{22}$ GeV^2 cm^{-5} sr]	Flux (1 – 100 GeV) [$\times 10^{-7}$ cm^{-2}s^{-1}]
Burkert	0.8	15.9	0.8	0.225	41.9	32.1 ± 0.3
Einasto	0.7	15.6	0.7	0.217	5.1	31.4 ± 0.3
NFW	0.6	16.7	0.6	0.253	3.3	38.0 ± 0.3
NFW$_c$	1.0	3.0	1.0	0.005	86.8	2.2 ± 0.1

Setting up constraints



Profile	$\bar{J}(\Delta\Omega)\,\Delta\Omega$ [$\times 10^{22}$ GeV^2 cm^{-5} sr]
Einasto	5.1
NFW	3.3
NFW$_c$	86.8
Burkert	41.9

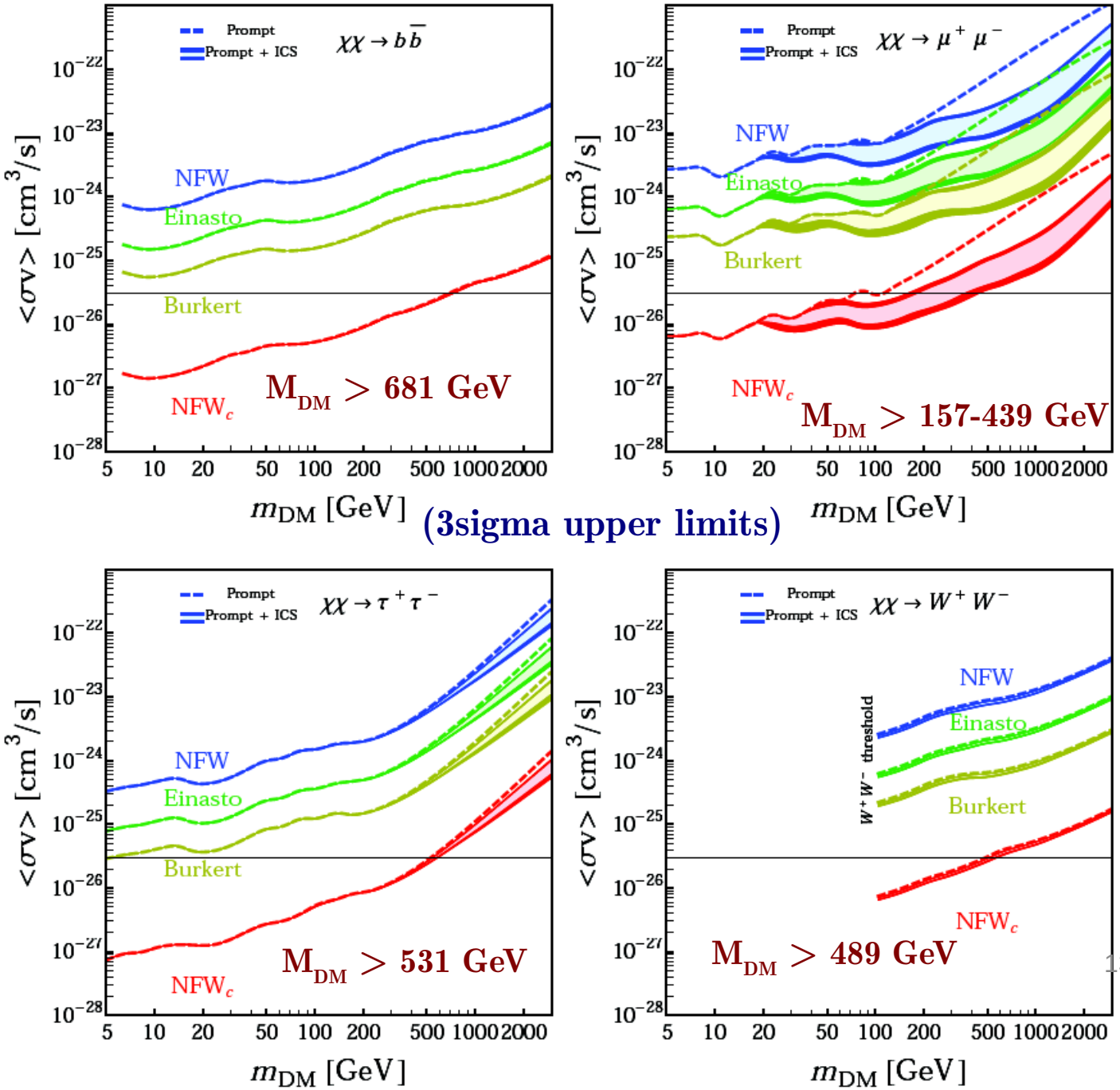
Energy spectrum as directly obtained from the data

VS.

J-factors

By comparing the inclusive energy spectrum extracted from the data for every ROI and the J-factors for every profile, we set DM constraints only requesting that the DM-induced gamma-ray emission *does not overshoot* the flux measurement at *3sigma* level.

Results:



(3sigma upper limits)

Theoretical comments

We have analyzed **four annihilation channels** but **in general** the **final state will be a combination of them** e.g., in SUSY, the neutralino annihilation modes are **70% bb - 30% tau+tau-** for a Bino DM, and 100% W+W- for a Wino DM.

Also, the value of **sigmav in the Galactic halo** might be **smaller than 3 x10-26 cm3 s-1,** e.g., in SUSY, in the early Universe coannihilation channels can also contribute to sigmav. Also, DM particles whose annihilation in the Early Universe is dominated by velocity dependent contributions would have a smaller value of sv in the Galactic halo, where the DM velocity is much smaller, and can escape this constraint

Conclusions

We derived constraints on the parameter space of generic DM candidates using Fermi-LAT inner Galaxy measurements.

We considered well motivated DM density profiles which are perfectly compatible with current observational data of the Milky Way.

A compressed DM profile allows to place much stringent u.l. then thermal <sigmav> excluded up to few hundreds GeV depending on channel

A large region of the vanilla WIMP parameter space models and contracted DM profiles are incompatible given the Fermi data.

Although the constraints are very strong, the analysis is conservative:

1. **Expected DM signal does not exceed the observed gamma-ray emission.**
2. **No modeling of the astrophysical background.**