A sample study case for (indirect) detection of dark matter particles

Piero Ullio
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Dark matter (indirectly) detected!

Compelling (gravitational) evidence for non-baryonic cold (or coldish - as opposed to hot) DM being the building block of all structures in the Universe! E.g.:

- classical tests on galactic dynamics using gas rotation curves or stellar velocity dispersion profiles;
- classical tests on cluster potential wells applying the viral theorem to galaxy distributions or hydrostatic equilibrium in explaining gas temperature surveys;
- 3-D mass reconstruction of cluster mass profiles via strong lensing and of the cosmic web via weak lensing;
- gravitational support for early Universe photon-baryon acoustic oscillations as seen in the CMBR or in galaxy correlation function;
- a consistent theory for structure formation itself;
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Relying on the assumption that GR is the theory of gravity; still, it is very problematic to explain them all, covering so different length scales in a single alternative theory of gravity and matter made of baryons only

A particle physics connection to the DM problem?

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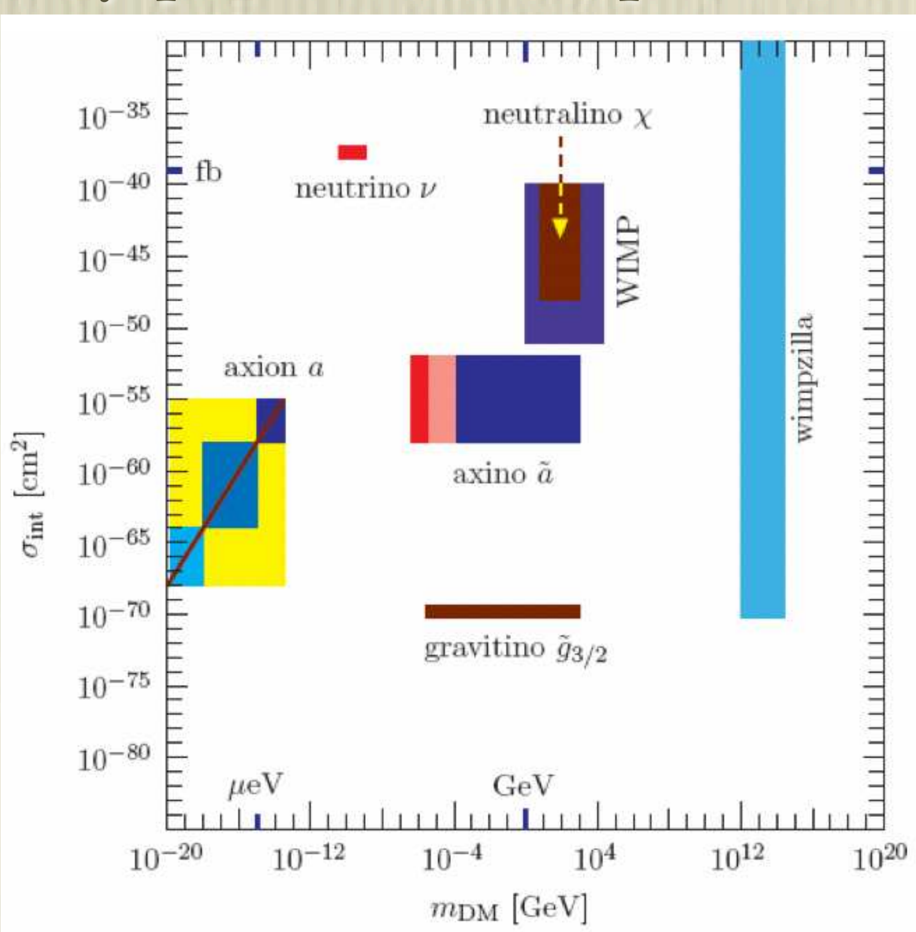
Viable particle frameworks span huge ranges in masses and interaction scales: from sub-eV axions, to keV sterile neutrinos, GeV-TeV WIMPs, up to supermassive DM close to the Planck scale; from gravitational interactions for gravitinos, to weakly interacting DM candidates, mirror DM with strong self-interactions, ...



Kim& Carosi, 2010

Did LIGO detect dark matter?

LIGO detected the merging of two $\sim 30\ M_\odot$ black holes, a spectacular event and a great surprise - in terms of masses and event rate - with respect to expectations for "standard" astrophysical binary black hole systems.

Would it be plausible that the LIGO event is due to primordial black holes (PBHs), formed in early Universe density fluctuations and accounting for the dark matter component of the Universe? **Bird et al., arXiv:1603.00464**

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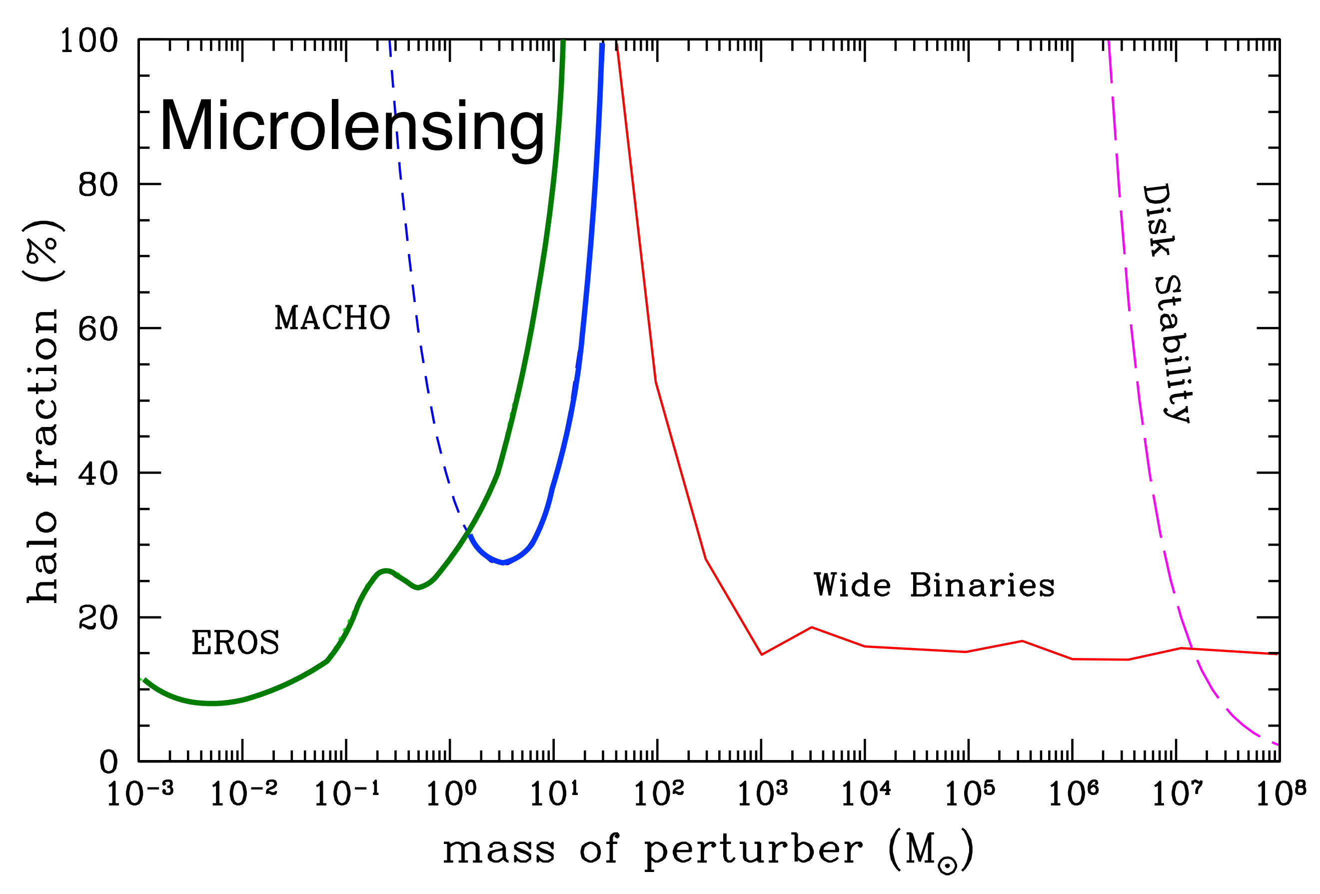
Puzzling coincidence:
$30\ M_\odot$ fits into the allowed window from (in)direct tests on Massive Compact Halo Objects (MACHOs) forming the Milky Way halo:

Yoo, Chanamé & Gould, 2004



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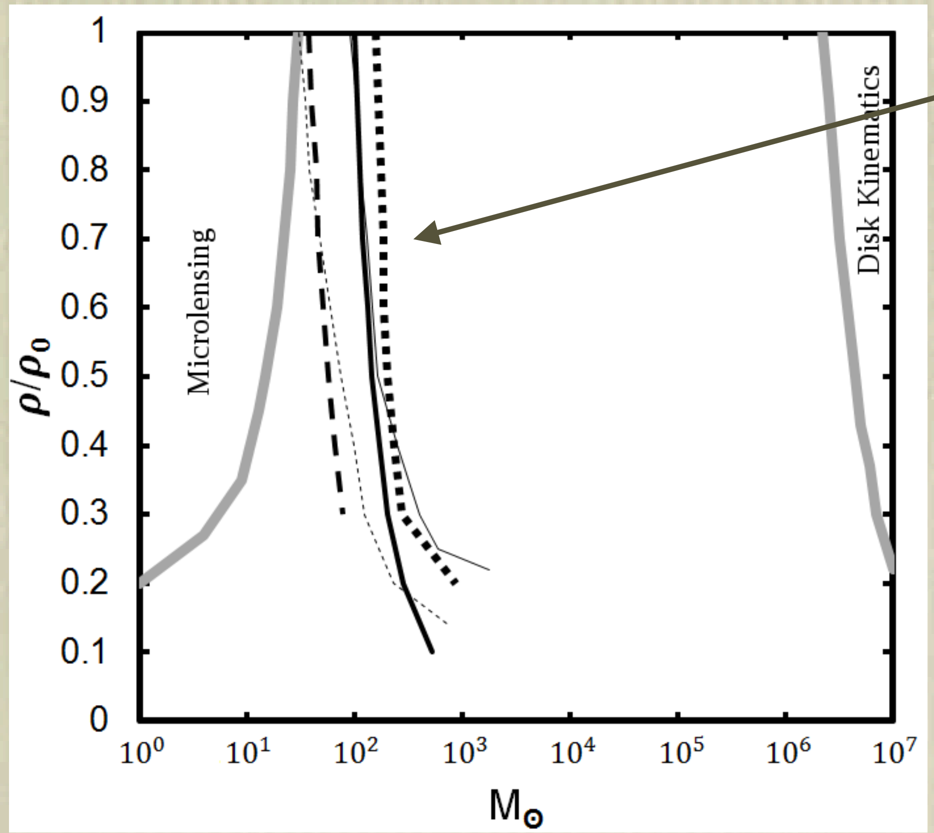

halo wide binary limit, different samples/ assumptions

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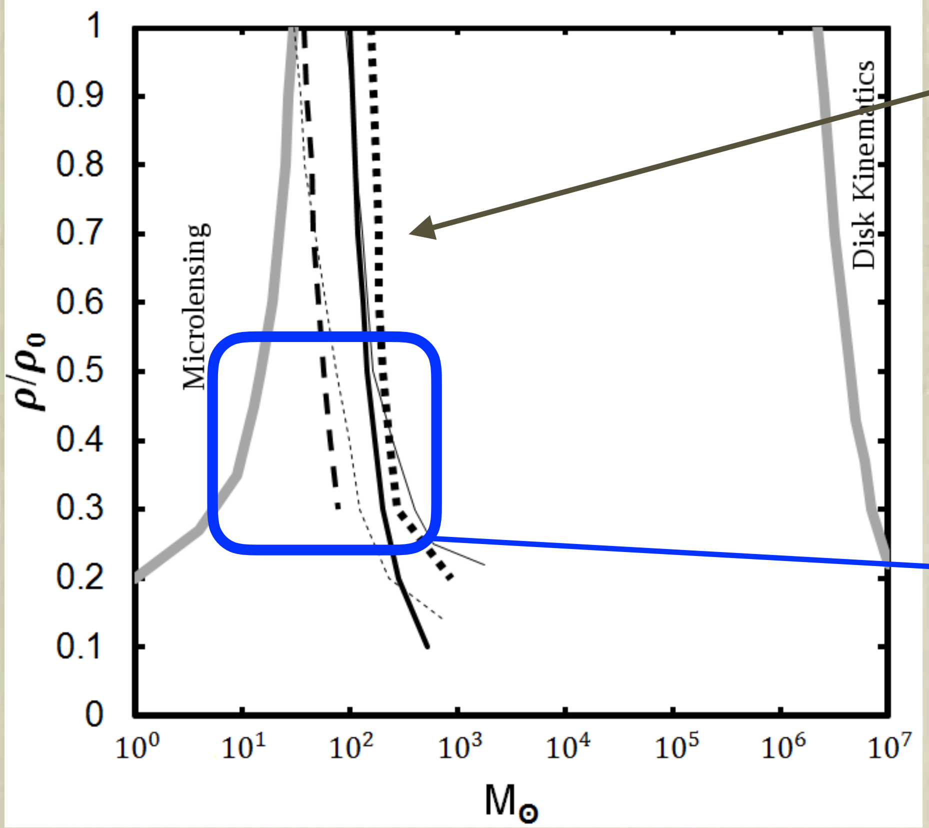

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window closed by CMBR constraints? unclear at this stage

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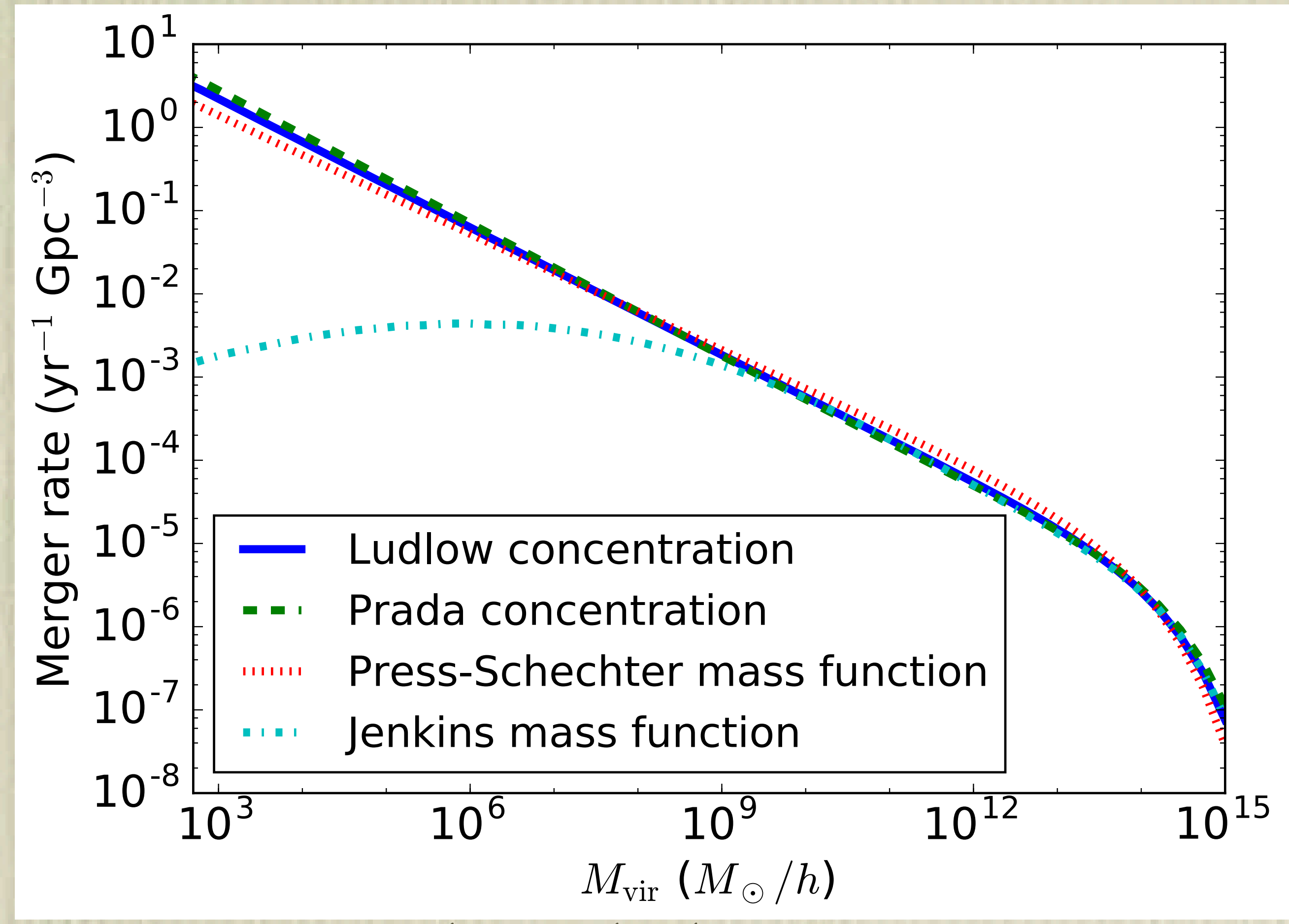
Assuming a proper (?) extrapolation to low mass halos, the expected merger rate for DM PBHs in this mass range may be compatible with the event rate of $2 - 53\ \mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}$ inferred from the LIGO detection (assuming mergers with mass, final spin and energy as in GW150914).



host halo mass

A particle physics connection to the DM problem?

Some of the proposed particle DM detection techniques have produced results compatible with a particle DM signal, e.g.:

- the annual modulation signal in the DAMA & DAMA/LIBRA direct detection rate;
- the excess of positrons at high energy in the locally measured cosmic-ray flux;
- a 3.5 keV line possibly identified by X-ray surveys on a number of DM dominated targets;
- an excess at about a GeV in the γ-ray flux measured by Fermi Gamma-ray Space Telescope towards the Galactic center;
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Unfortunately, there are severe caveats in uniquely and unambiguously associating any of them to a definite particle physics scenario.

On general grounds, these issues regard: incompatibility with (face value) limits from other experiments and/or other detection techniques; failure in discriminating the signal against other interpretations; inconsistency with what we know about DM from cosmo and astro observations.

Signals of DM particle annihilations or decay

In several frameworks for DM candidates and for early Universe DM production mechanisms, one predicts (in principle) detectable signals from the pair annihilation or the decay of particles in dark matter halos.

Since the late '80s, Weakly Interacting Massive Particles (WIMPs) as early Universe thermal relics have been the standard reference (mainly in connection to the fact that most extensions to the Standard Model of particle physics motivated by the hierarchy problem can embed WIMP DM candidates), however especially in the last decade the field has evolved into a more variegated playground.

The target remains unchanged: Look at those yields with clean spectral/angular signatures and/or low or well-understood backgrounds from standard astrophysical sources.

Proposed detection channels include: antimatter (antiproton, antideuteron and positron cosmic-ray fluxes at earth), neutrinos (annihilation/decays in DM halos, or at the center of the earth, the sun or other stars) and photons (prompt or radiative emission).

Signals of DM particle annihilations or decay

Another perspective shift taking place in the last decade: based on data collected by the current generation of detectors and telescopes, there are very few windows of opportunity ("clean channels") in which the dark matter signal can be dominant with respect to backgrounds from other sources (low energy antideuterons? X-ray & gamma-ray lines? multi wavelength signals from dwarfs? ...?). We are mostly fighting with "dirty channels"!

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E.g.: **GeV-TeV DM** particles inducing a **prompt γ-ray signal**. In principle a straightforward channel: photons propagate on straight lines (geodesics) & absorption by the local environment is negligible in this band. For a given target, just sum all contributions along the line of sight!

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Only one "astrophysical" uncertainty term, to be factorized with respect "particle physics" uncertainties (emissivity efficiency and spectrum of the γ-ray yield per annihilation/decay). In case of pair annihilations:

$$J \equiv \frac{1}{\Delta\Omega} \int_{\Delta\Omega} d\Omega \int_{l.o.s.} dl \; \rho_{DM}^2(l)$$

with the DM density in the target ρ_{DM} inferred from dynamical observations or numerical simulation of DM halos.

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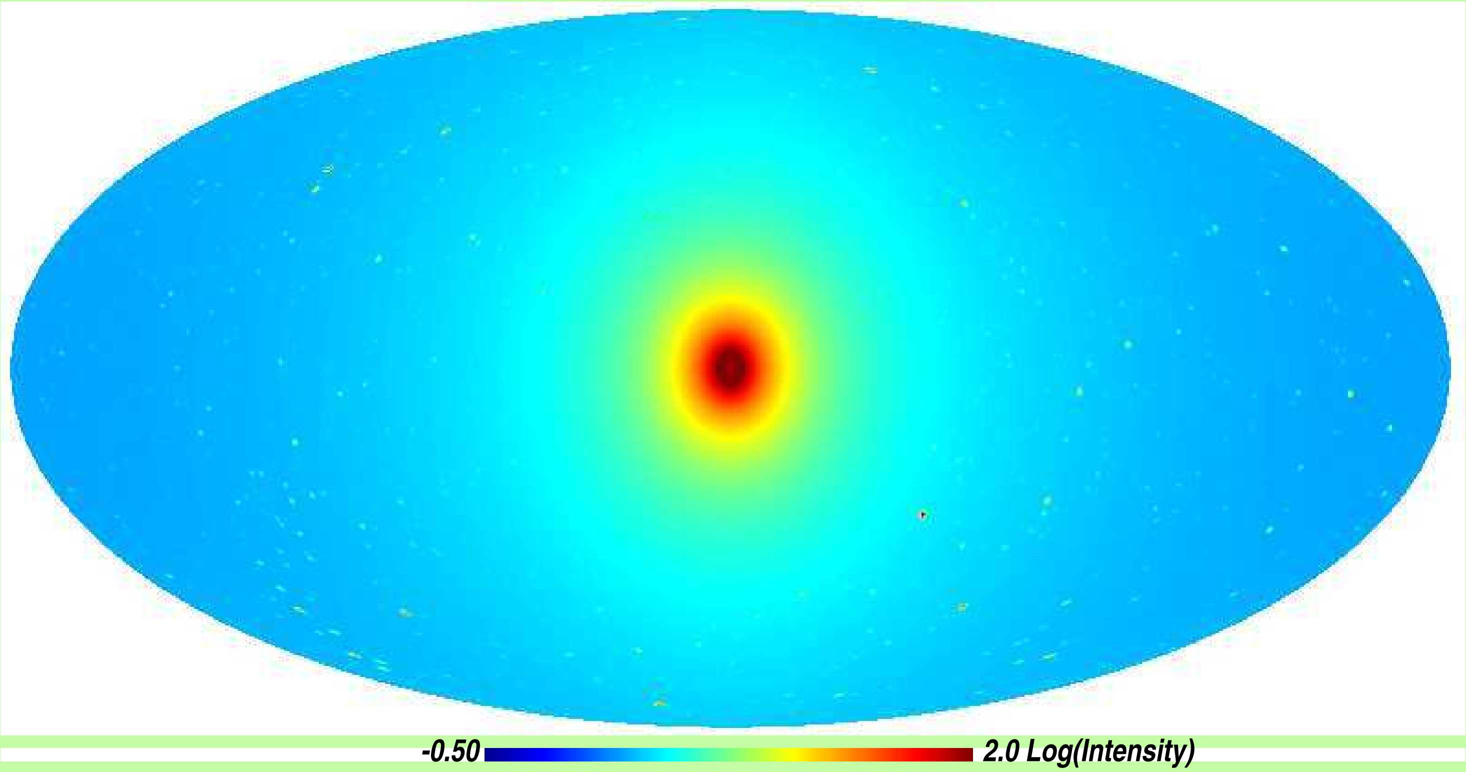
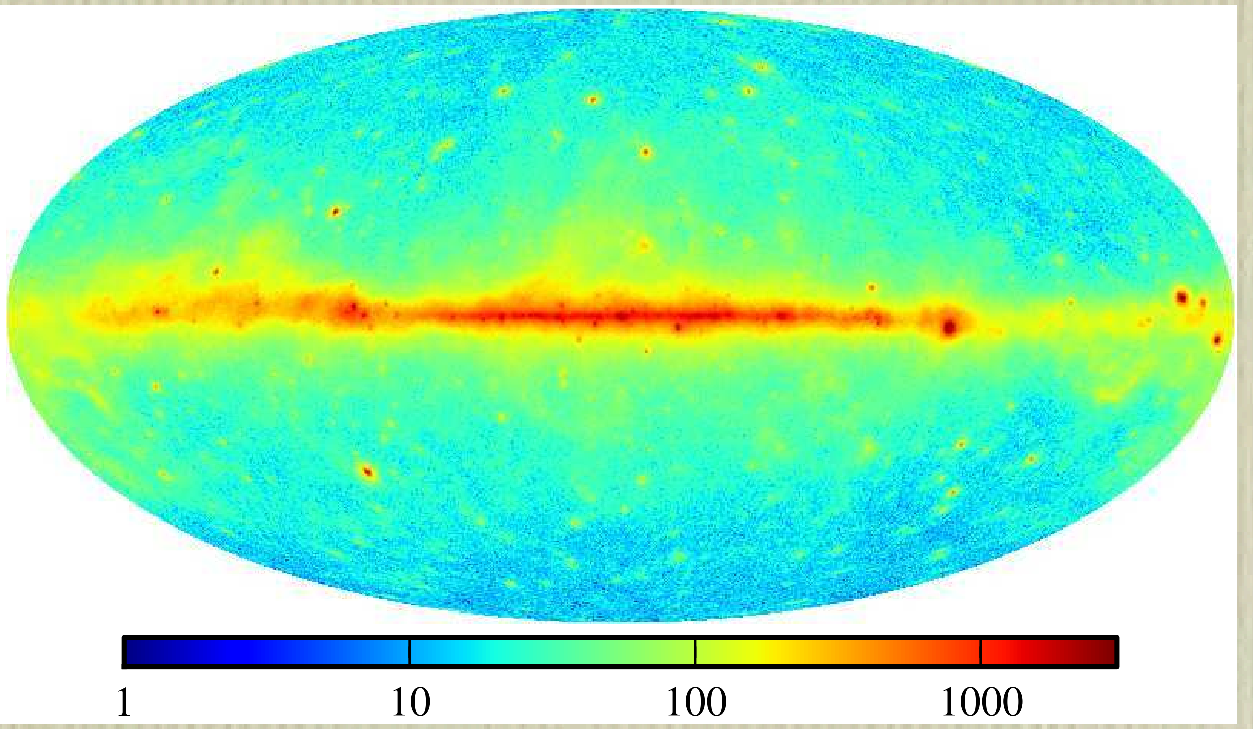
J-factor for the Milky Way (?):



Springer et al., 2008: Acquarius simulation for a Milky-Way-type galaxy

DM γ-ray signals versus γ-ray data

A dramatic improvement in quality and energy coverage of γ-ray data in recent years, due to Air-Cherenkov telescopes and satellites detectors, most notably the Fermi Gamma-ray Space Telescope:



Fermi Coll., 2012: galactic diffuse emission: counts in 200 MeV-100 GeV, after subtracting point sources, isotropic extragalactic flux & instrumental background; it accounts for about 70% of total # of counts

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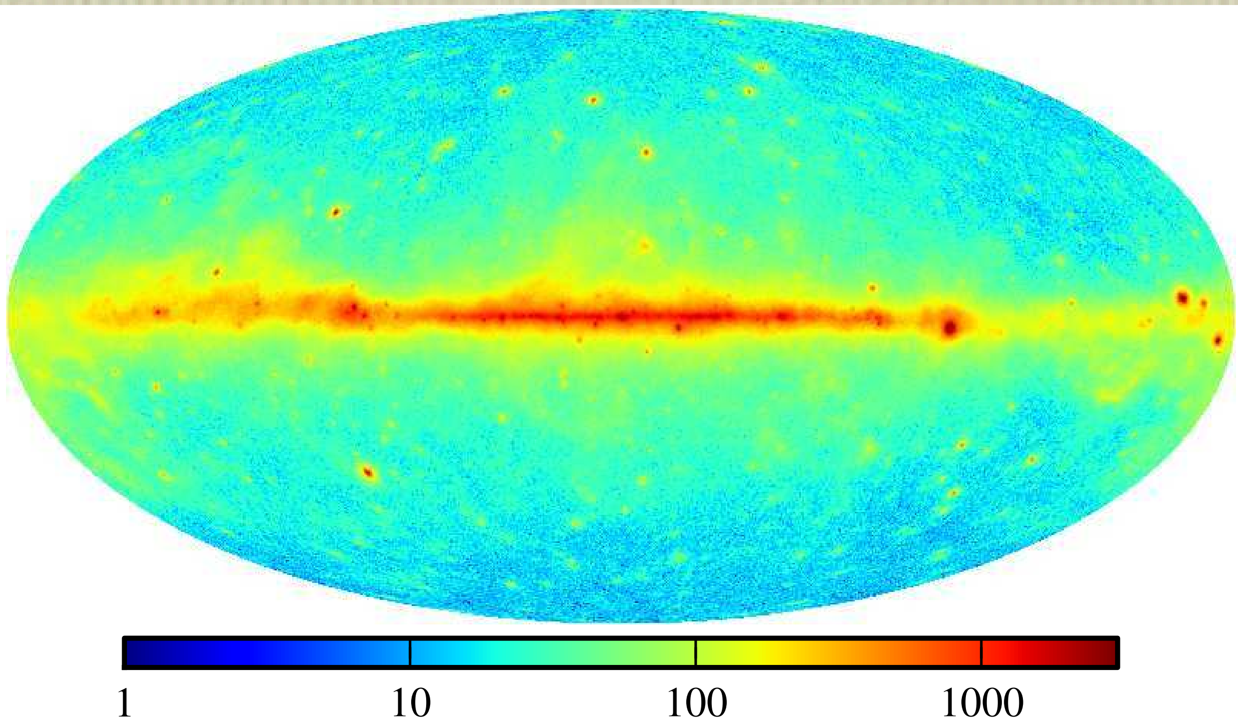

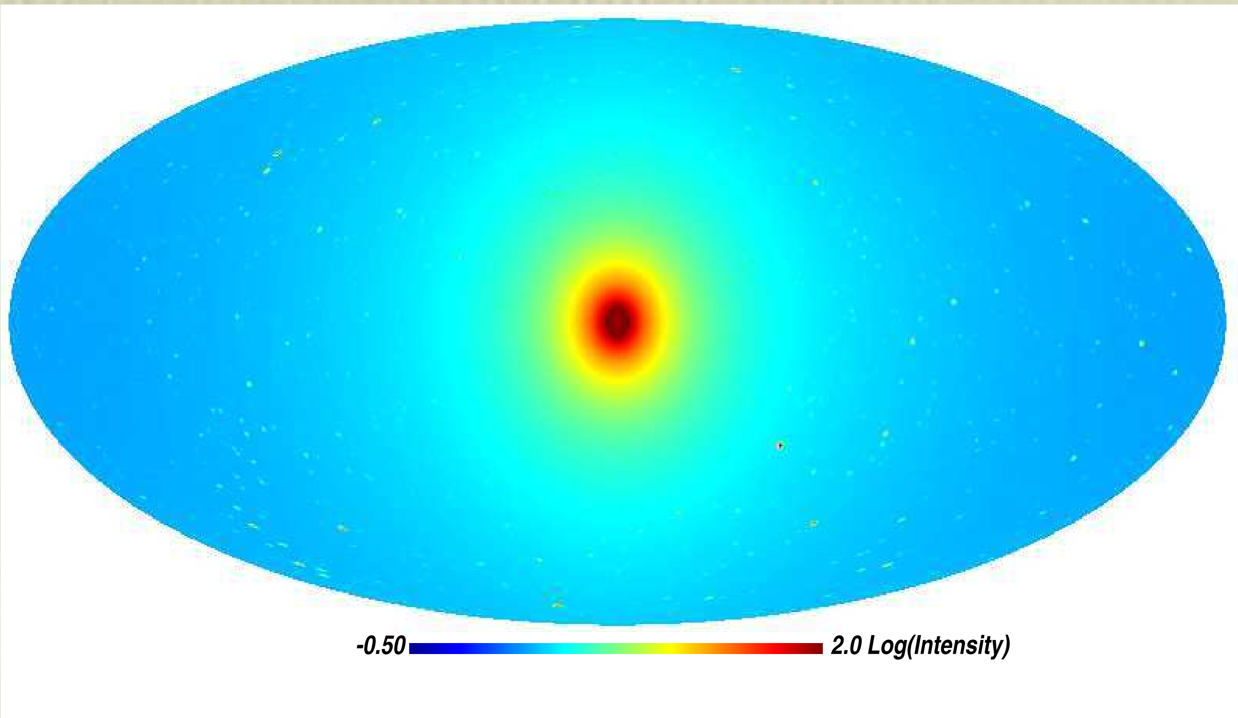

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clearly a very poor match with a DM annihilation template if assumed as dominant emission component

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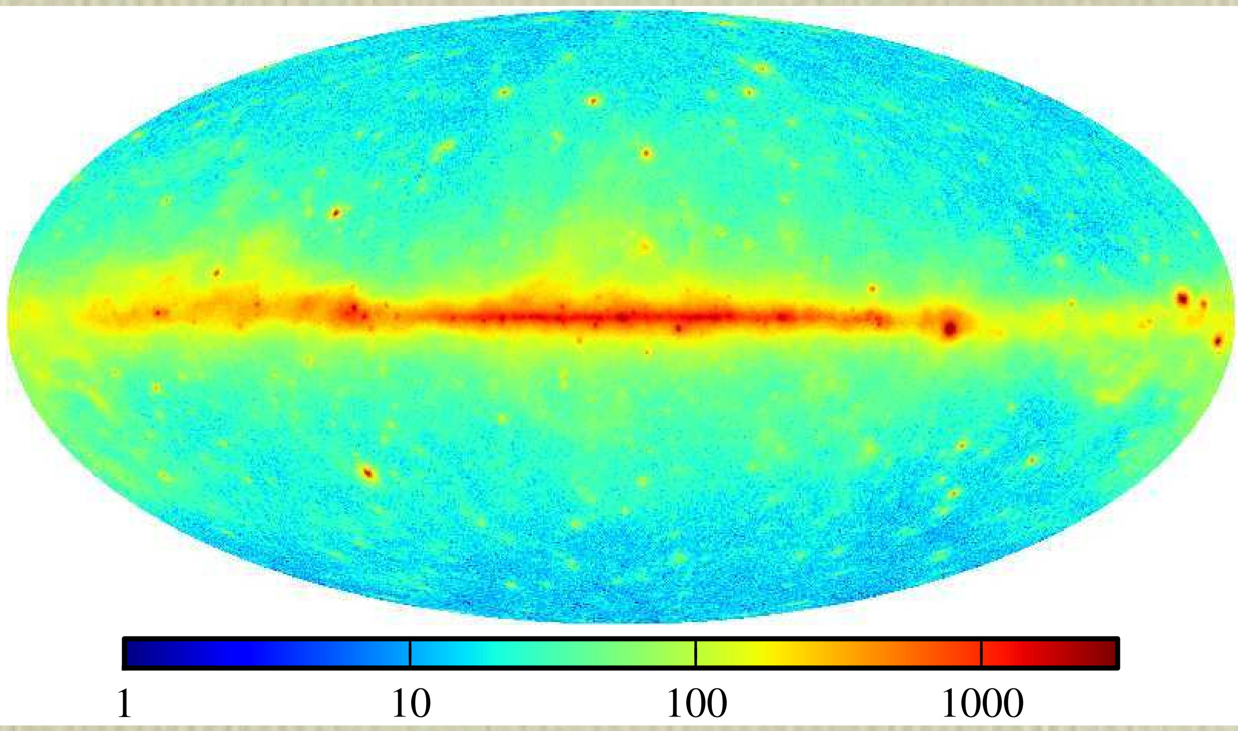

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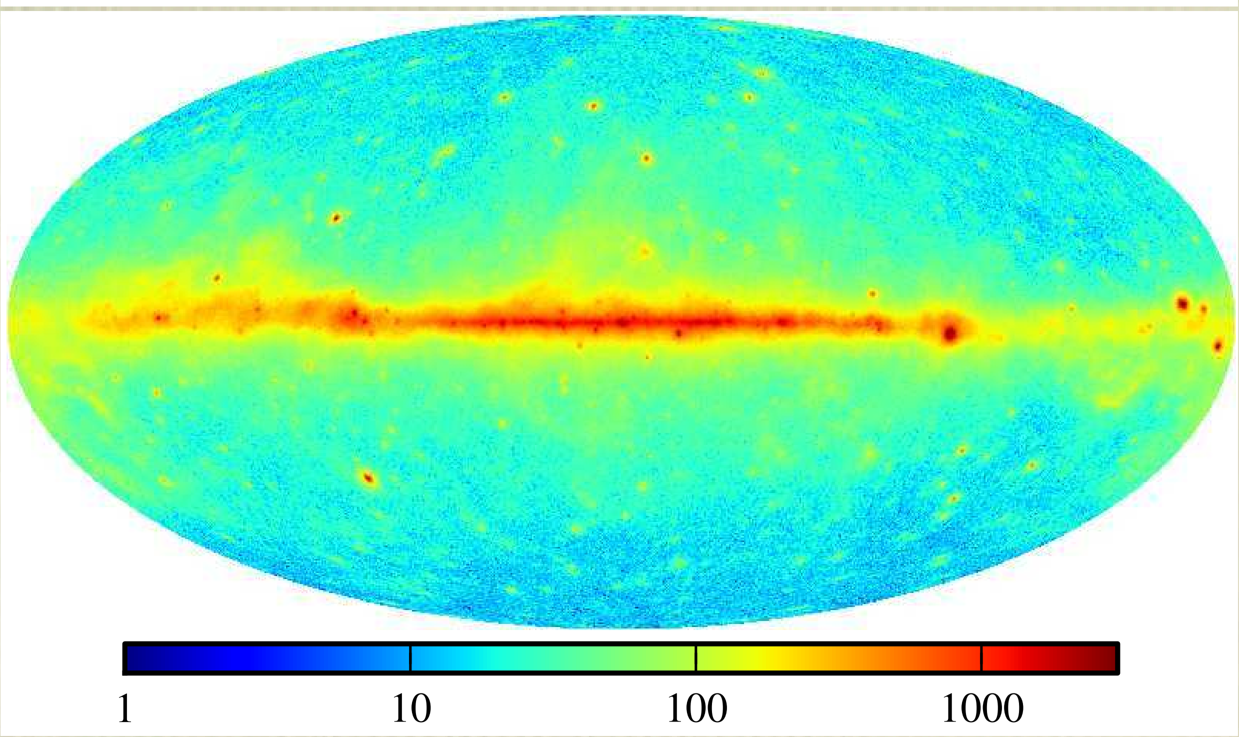

prediction (postdiction ?) of counts for the **Galactic cosmic-ray** emissivities in model $^{S}S^{Z}4^{R}20^{T}150^{C}5$
Fermi Coll., 2012

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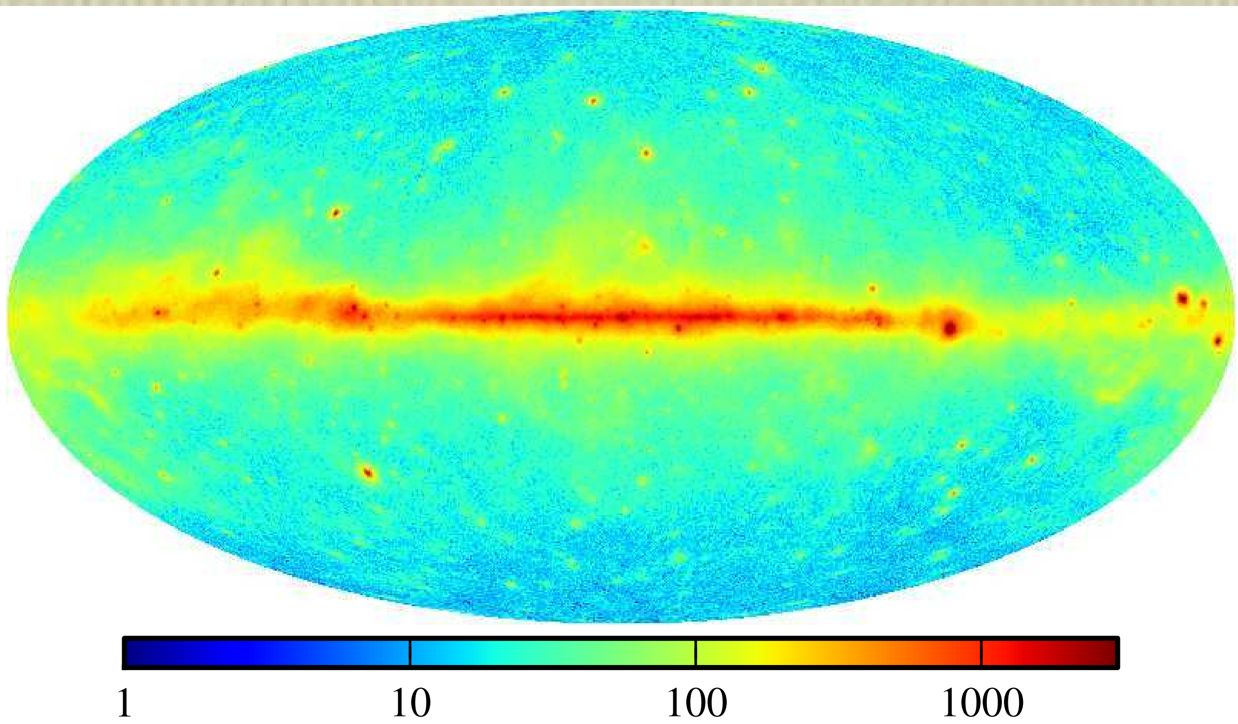

data

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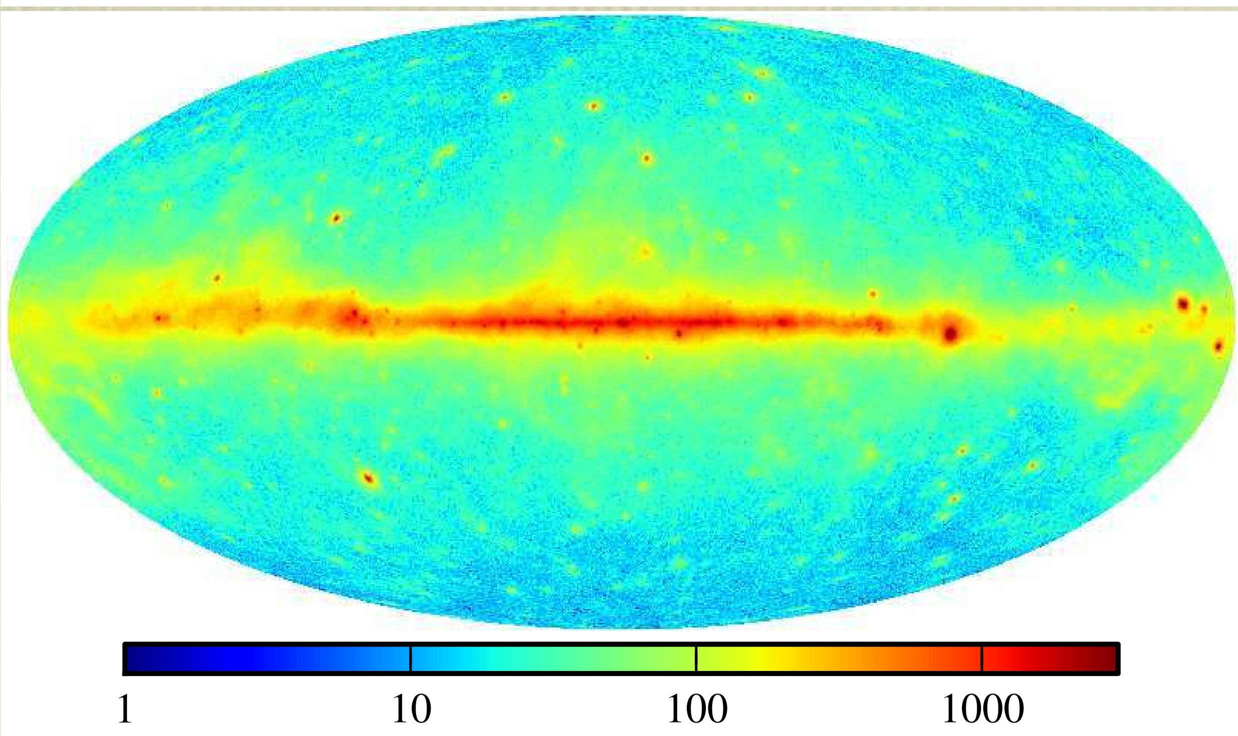

$^{S}S^{Z}4^{R}20^{T}150^{C}5$

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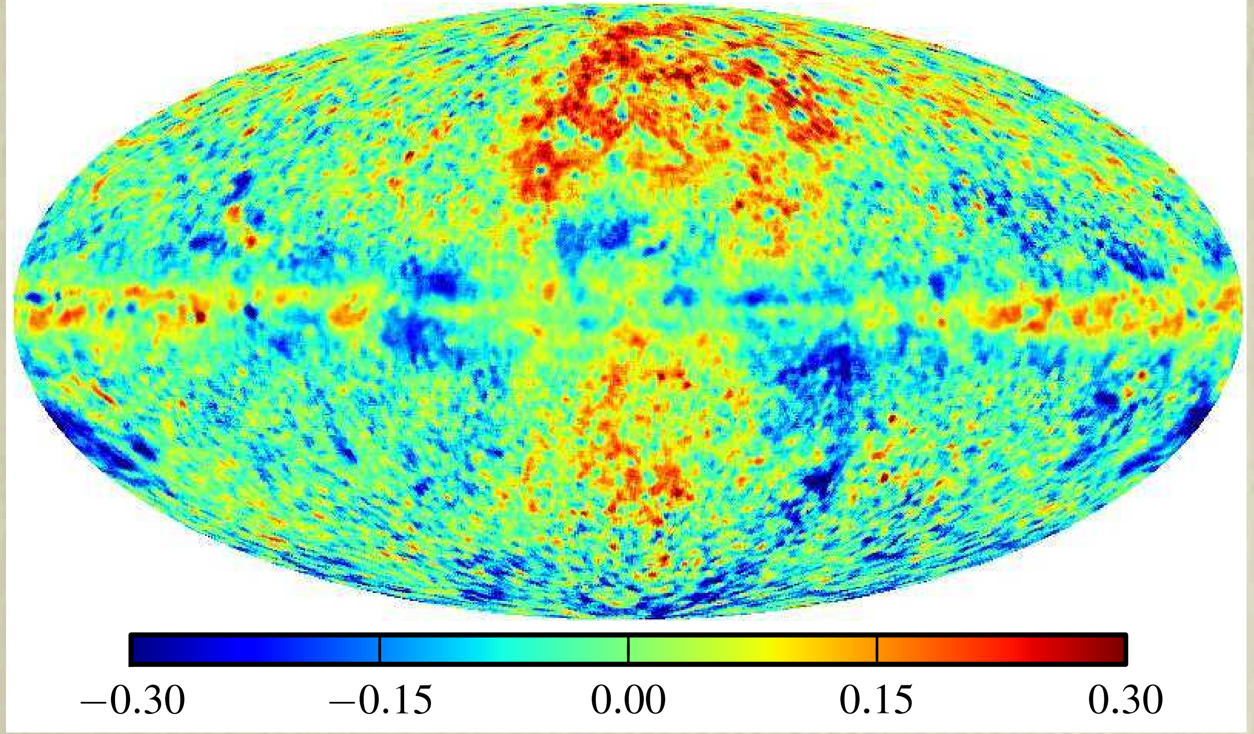
Fractional residuals



After including templates for local features and the so-called Fermi Bubbles + little extra tuning, residuals shrink to below about 10%

A subdominant DM term in γ-ray data?

The DM signal does not stand clearly above the background from other standard astrophysical processes (unfortunately this is the case in any of the tested indirect DM detection channels). What about identifying anyway the DM source as a small contribution on top of the bulk of emissivity due to cosmic rays?

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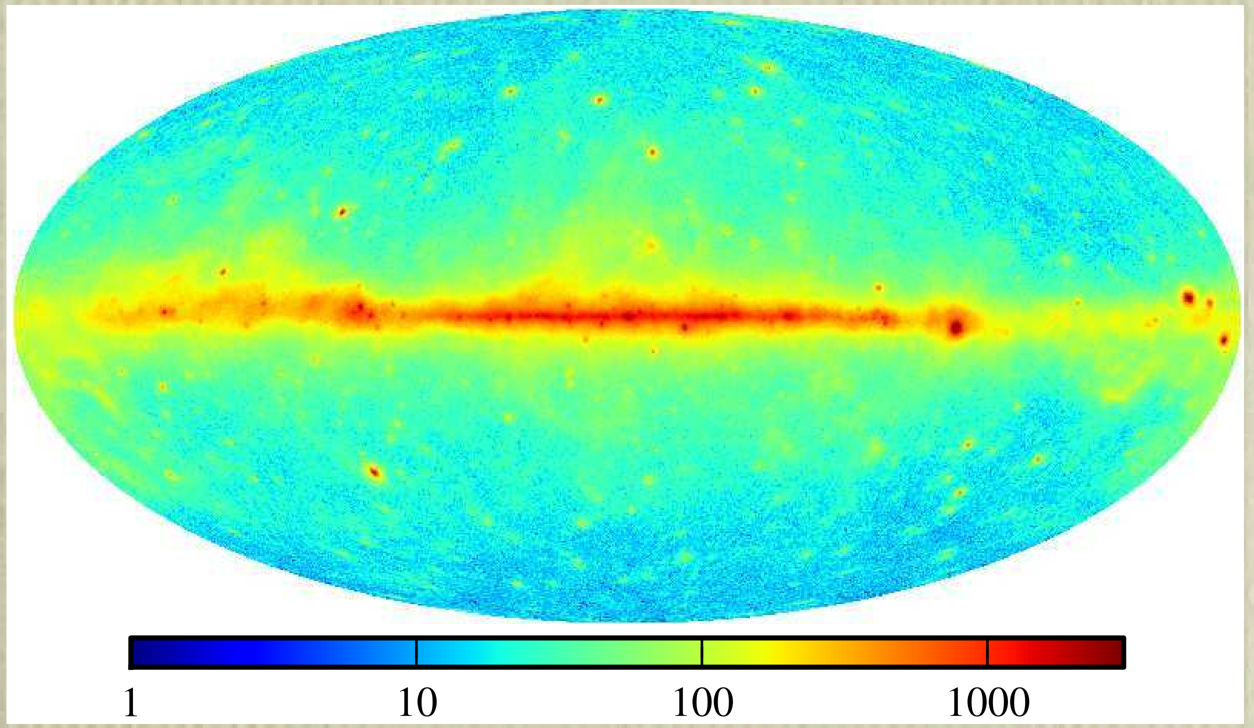

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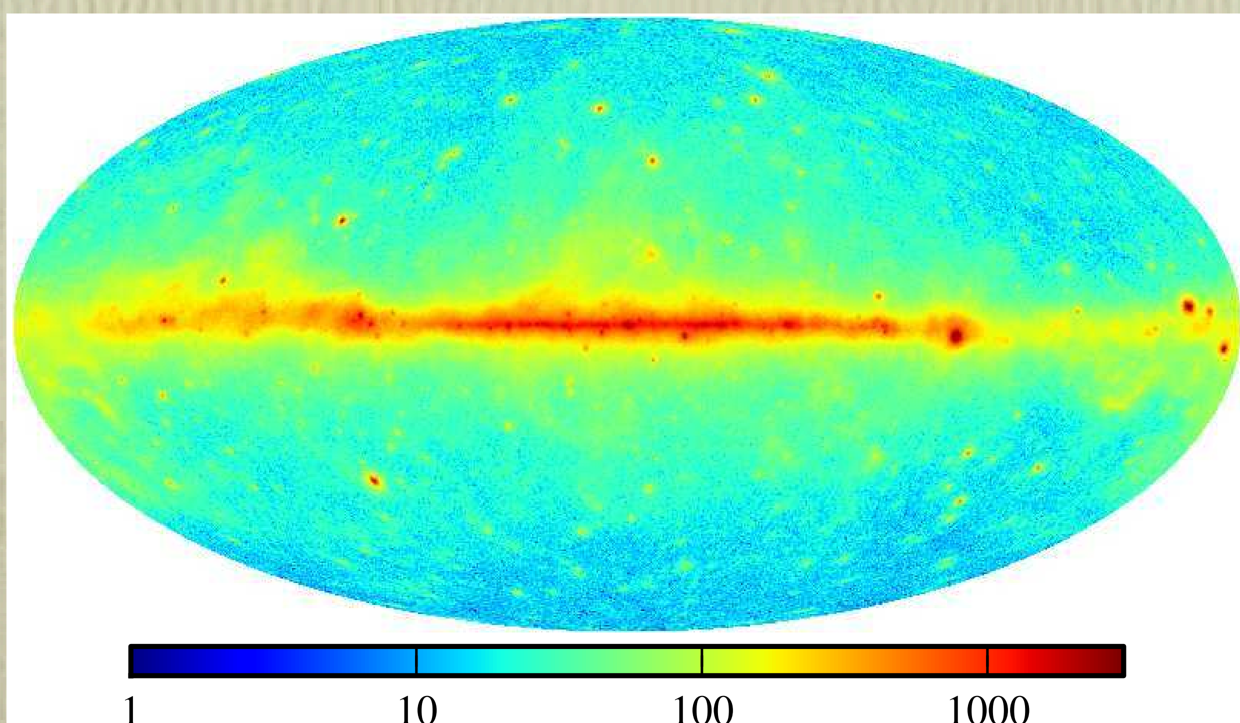

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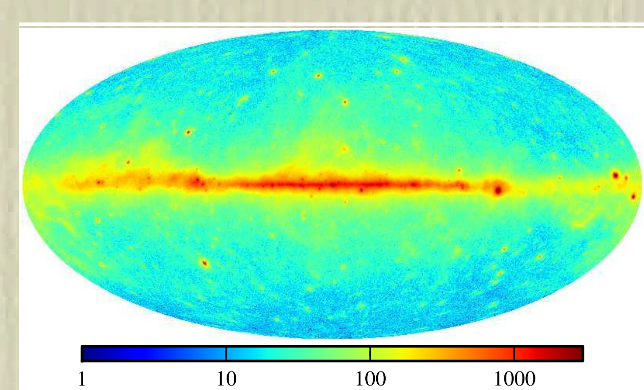
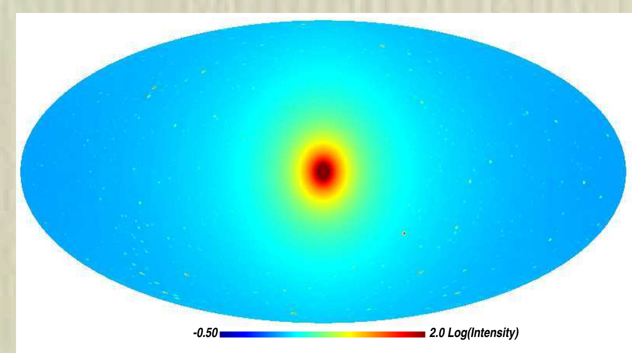


CRs

dominant

+



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up to 10% contribution?

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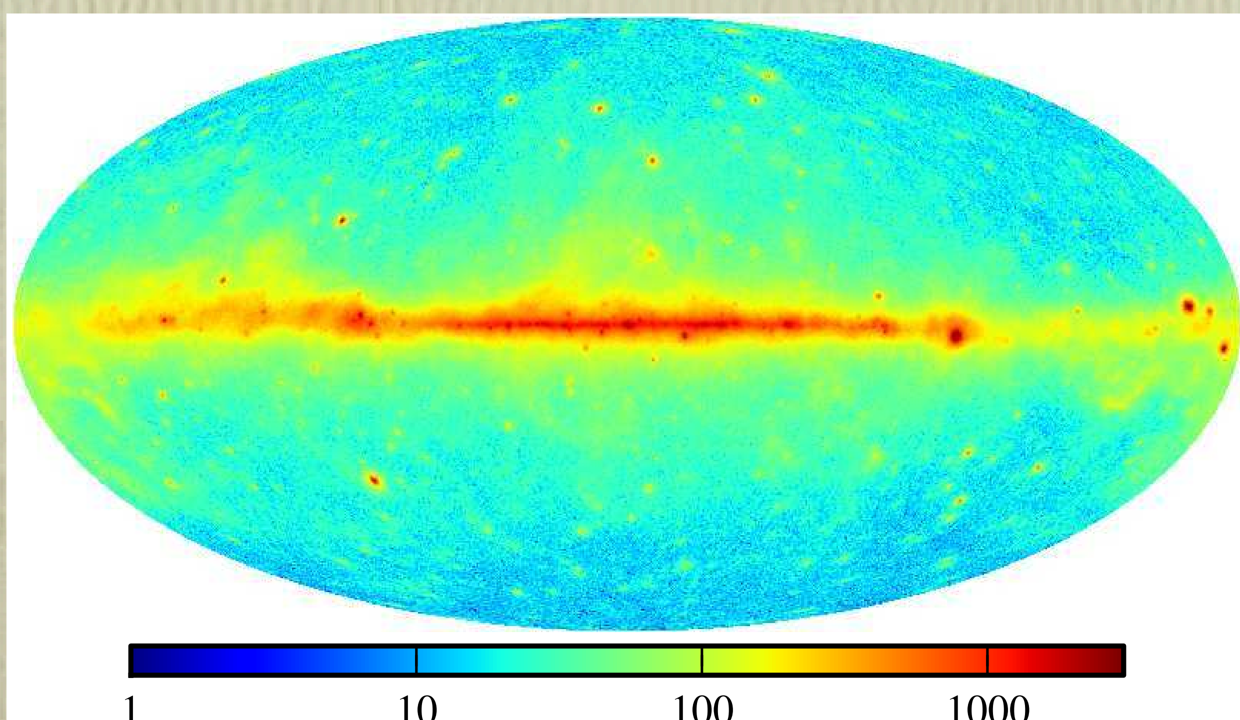

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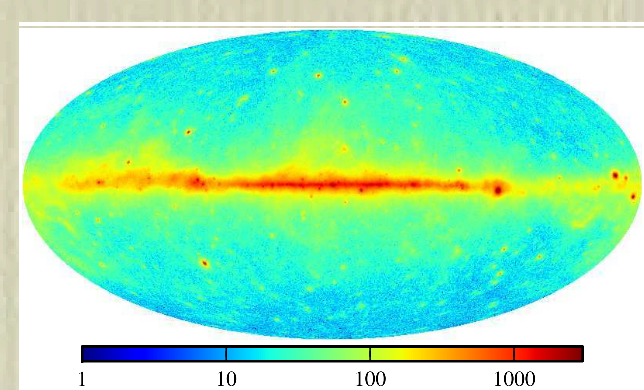

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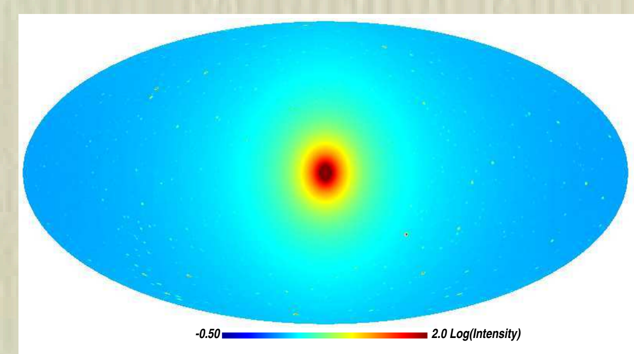


DM

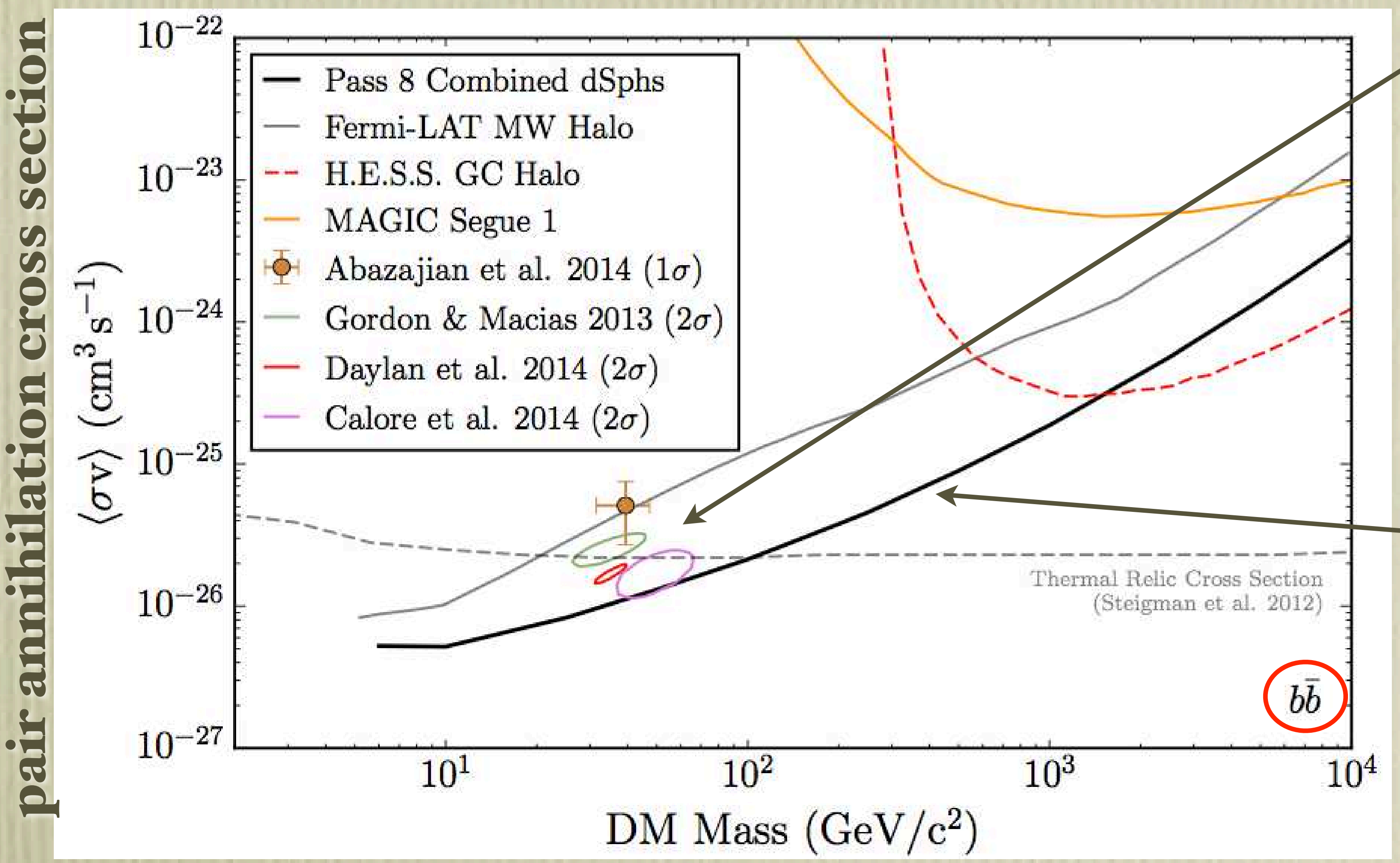
up to 10% contribution?

A route which may lead to unambiguous results only if both signals and backgrounds are well under control!

Two recent results in (apparent) contradiction

- A tentative indication of a DM signal in the inner region of the Galaxy;
- A null detection versus dwarf satellites of the Milky Way (DM matter dominated and cleanest targets from the background point of view), setting a very competitive flux limit.

“Detected” flux and upper limits projected on a plane parametrizing particle physics unknowns: in case of pair annihilations (at given final state)



Hooper et al. 2009-15, **Vitale & Morselli, 2009**, + several analyses by other authors: DM Galactic center excess

Fermi Coll. 2015: limits excluding thermal cross sections for WIMPs lighter than 100 GeV!

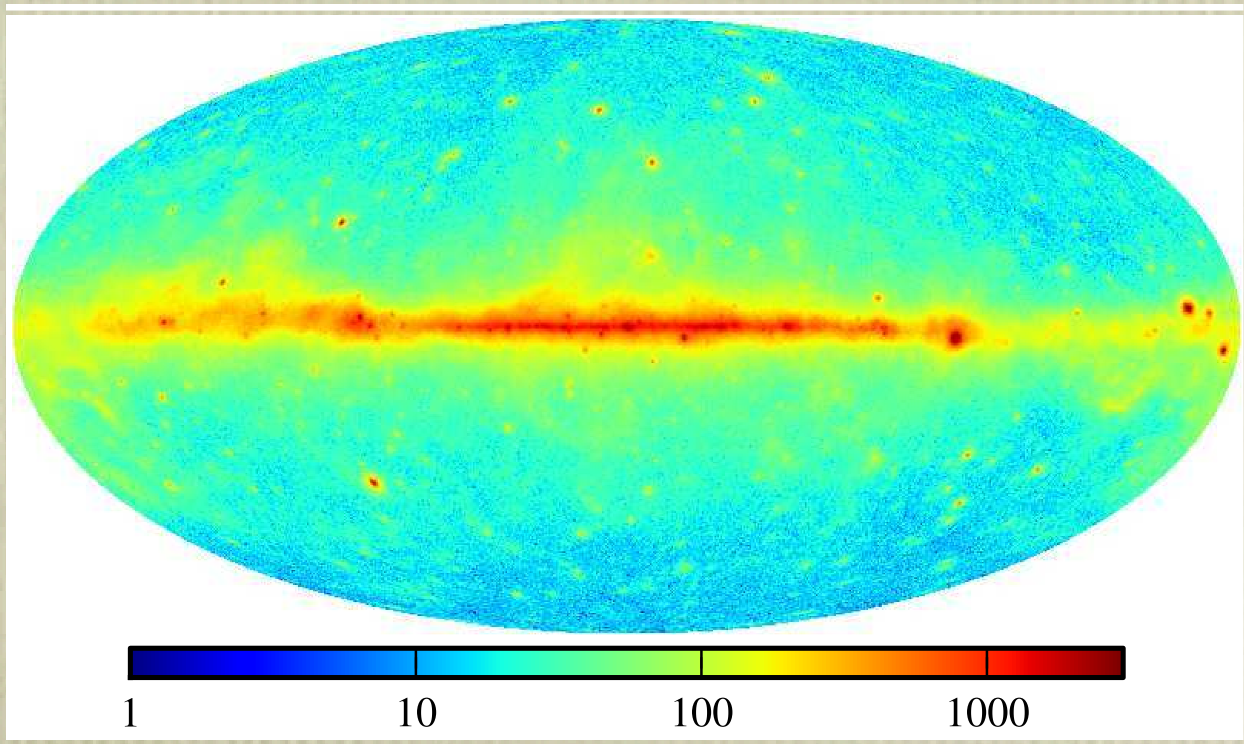
Are these signals and the relative backgrounds under control?

Galactic CRs and the γ-ray emissivity

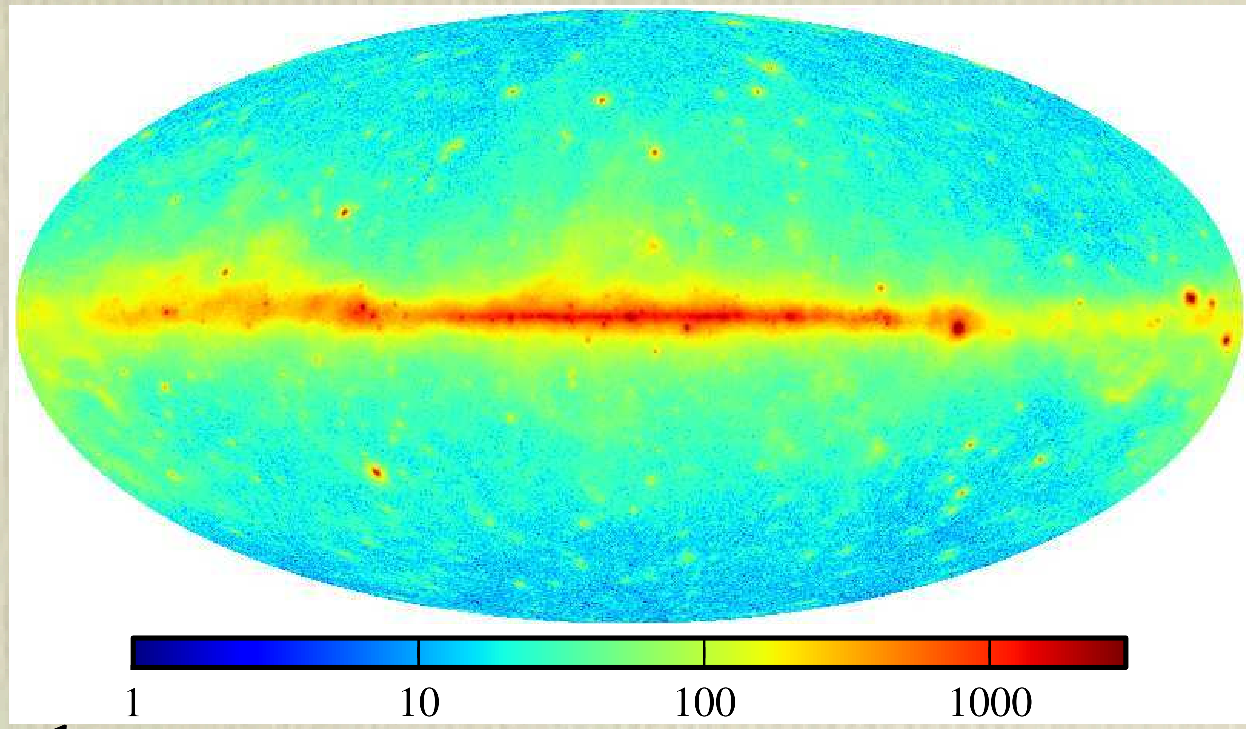
Along propagation the Galactic CRs interact with the interstellar medium (ISM) giving rise to a γ-ray flux (as well as radiation at other wavelengths).
Three main components:

- decay of mesons produced in the interaction of CRs on target ISM gas;
- CR lepton inverse Compton scattering on target CMB, IR and optical γs;
- bremsstrahlung radiation off CR leptons on target ionized gas.

Prediction: loop over models to find the one best matching data, e.g.:



${}^{S}S\,{}^{Z}4\,{}^{R}20\,{}^{T}150\,{}^{C}5$



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Postdiction: beside a tuning on local CR measurements, there is a tuning on the CR source distribution and over all ISM targets (nearly pixel by pixel)

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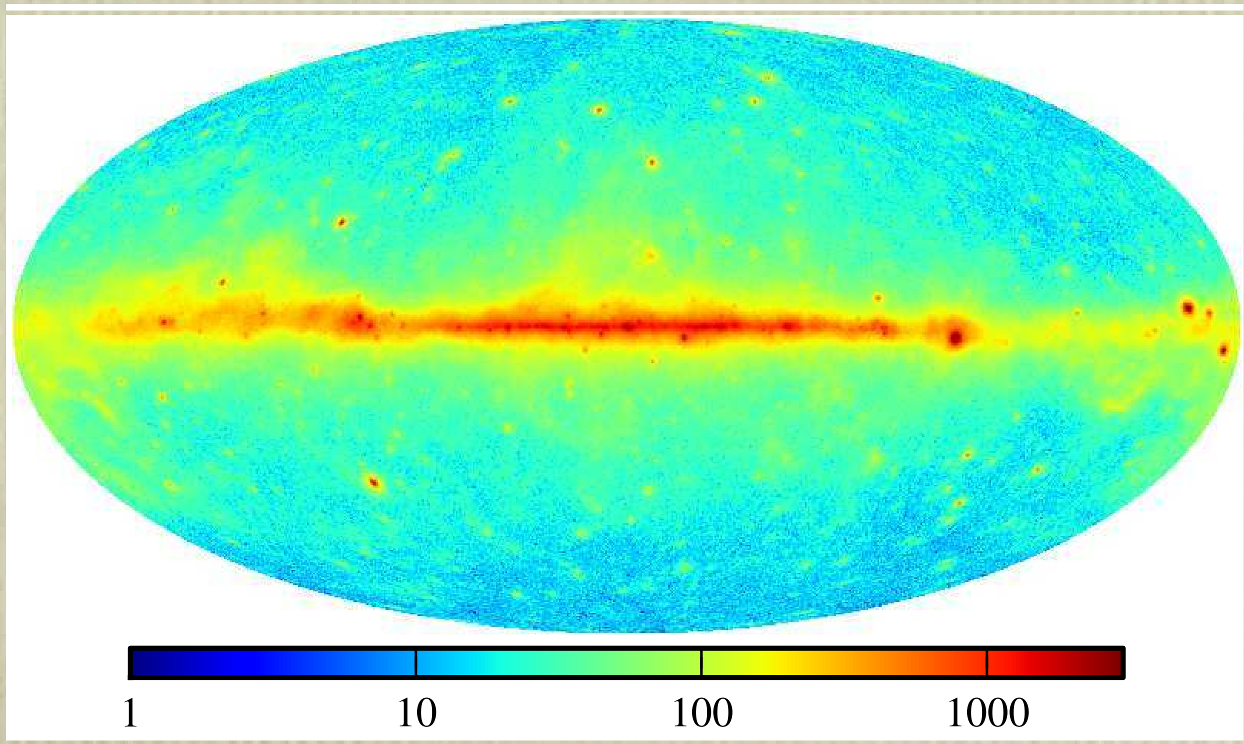

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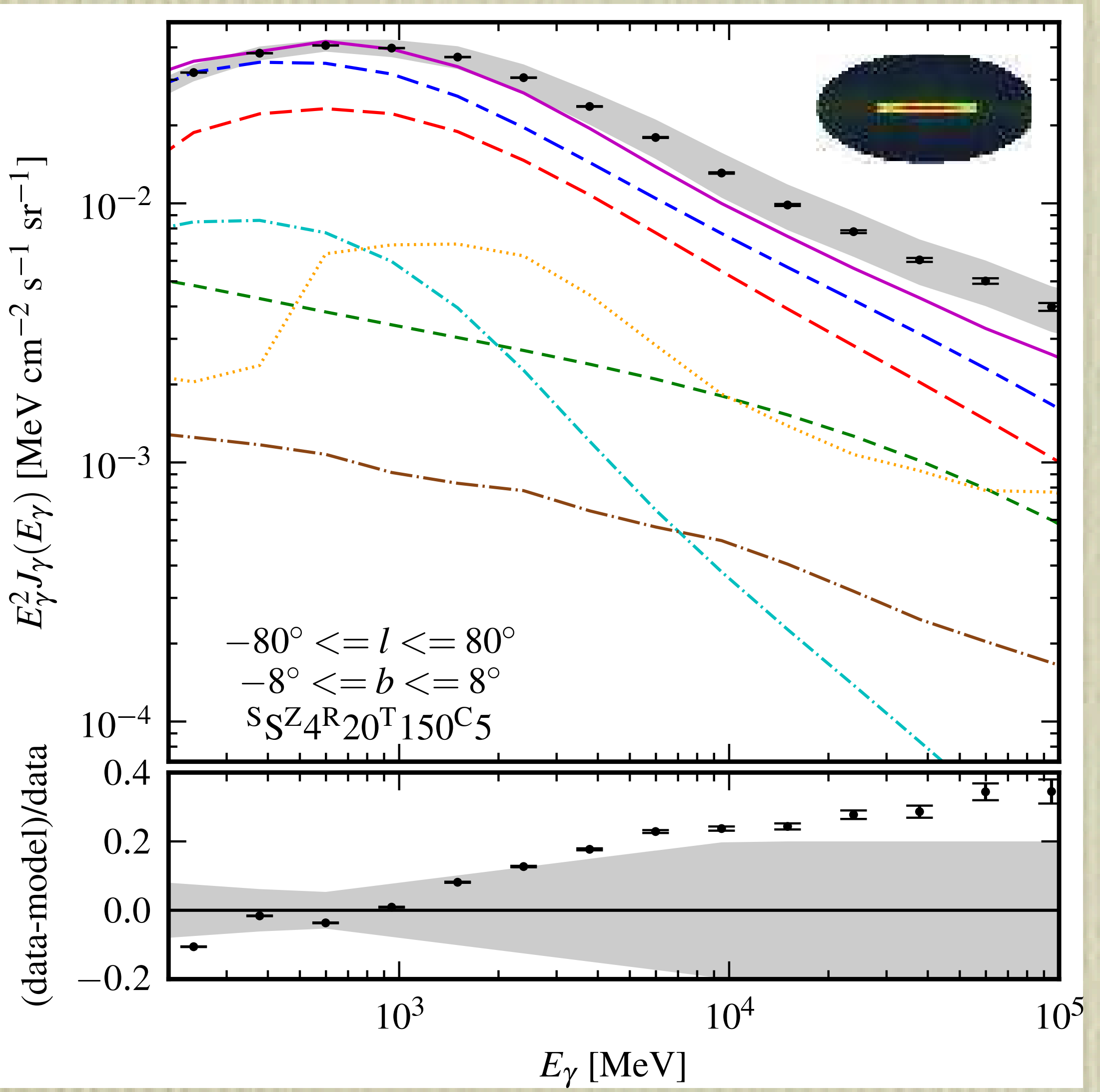
A drastic choice in this prediction/postdiction scheme:
it is assumed that the mean local properties of CR propagation are universal, with a rigid extrapolation to the whole Galaxy what you learn from locally measured grammage!
No environmental dependencies?

Postdiction: beside a tuning on local CR measurements, there is a tuning on the CR source distribution and over all ISM targets (nearly pixel by pixel)

Slight discrepancies: γ-rays in inner Galactic plane

A systematic underestimate of the measured flux above few GeV in any model in the loop of **Fermi Coll., 2012**:



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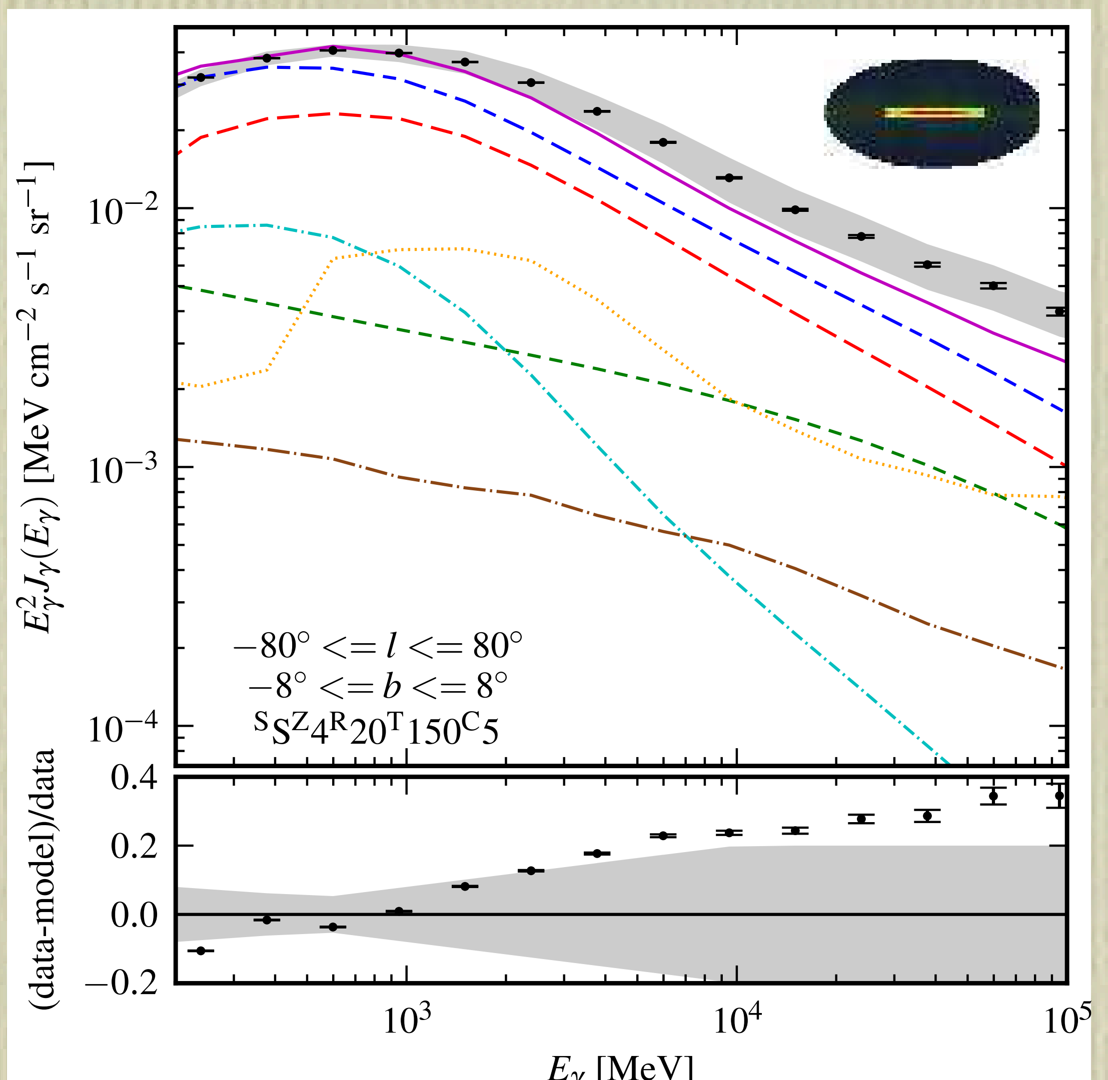

there seems to be the problem of having the wrong spectral index, reflecting an angular gradient of the spectral index in the γ-ray flux:

sky window ($\|b\| < 5°$)	α ($\Phi \sim E_\gamma^{-\alpha}$)	sky window ($\|b\| < 5°$)	α ($\Phi \sim E_\gamma^{-\alpha}$)
$0° < \|l\| < 10°$	2.55 ± 0.09	$40° < \|l\| < 50°$	2.57 ± 0.09
$10° < \|l\| < 20°$	2.49 ± 0.09	$50° < \|l\| < 60°$	2.56 ± 0.09
$20° < \|l\| < 30°$	2.47 ± 0.08	$60° < \|l\| < 70°$	2.60 ± 0.09
$30° < \|l\| < 40°$	2.57 ± 0.08	$70° < \|l\| < 80°$	2.52 ± 0.09

no way to fix such problem by scaling the ISM or SNRs

Gaggero, Urbano, Valli & PU, 2015

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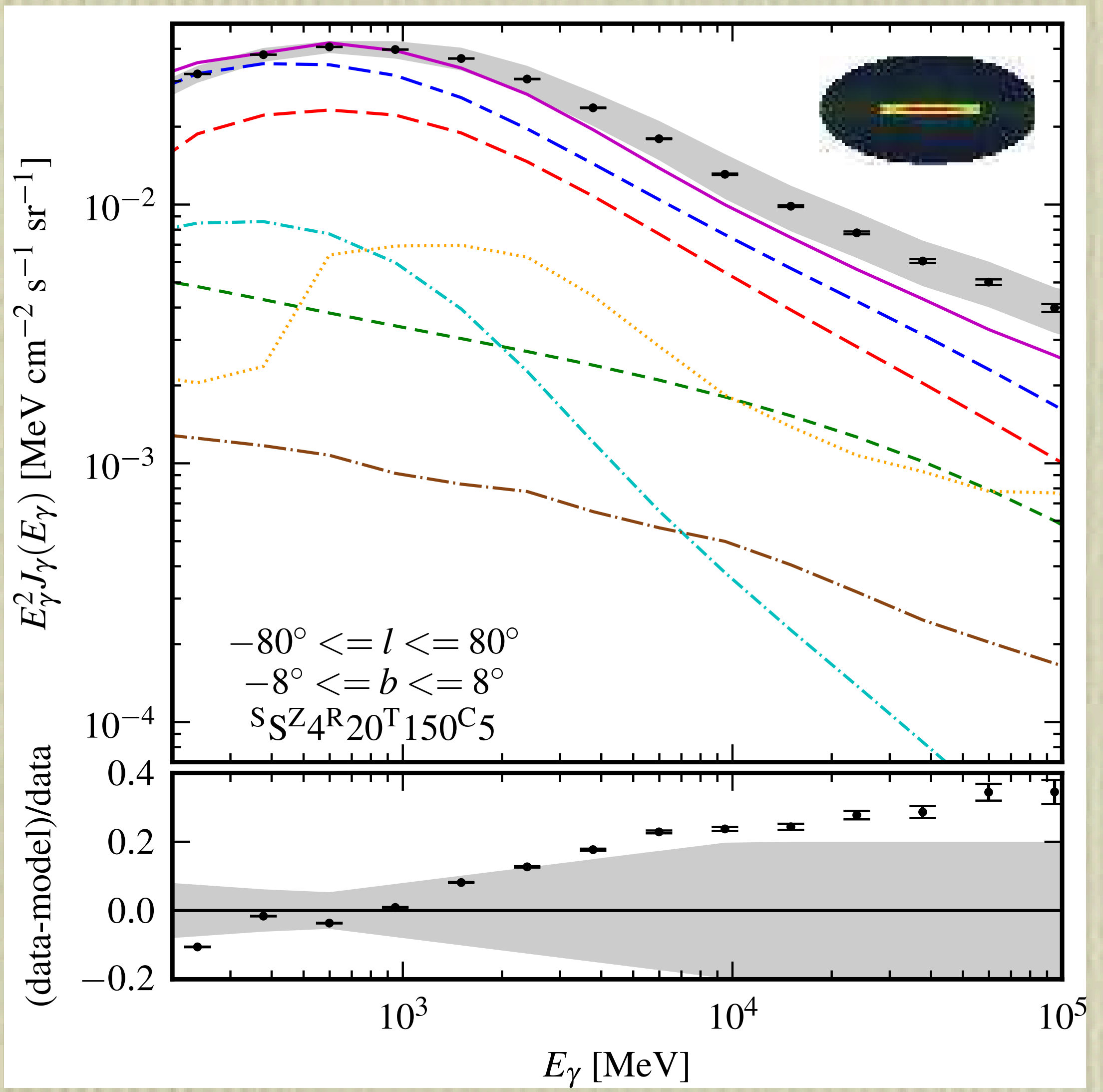


there seems to be the problem of having the wrong spectral index, reflecting an angular gradient of the spectral index in the γ-ray flux:

sky window ($\lvert b\rvert < 5°$)	α ($\Phi \sim E_\gamma^{-\alpha}$)	sky window ($\lvert b\rvert < 5°$)	α ($\Phi \sim E_\gamma^{-\alpha}$)
$0° < \lvert l\rvert < 10°$	2.55 ± 0.09	$40° < \lvert l\rvert < 50°$	2.57 ± 0.09
$10° < \lvert l\rvert < 20°$	2.49 ± 0.09	$50° < \lvert l\rvert < 60°$	2.56 ± 0.09
$20° < \lvert l\rvert < 30°$	2.47 ± 0.08	$60° < \lvert l\rvert < 70°$	2.60 ± 0.09
$30° < \lvert l\rvert < 40°$	2.57 ± 0.08	$70° < \lvert l\rvert < 80°$	2.52 ± 0.09

no way to fix such problem by scaling the ISM or SNRs

Gaggero, Urbano, Valli & PU, 2015

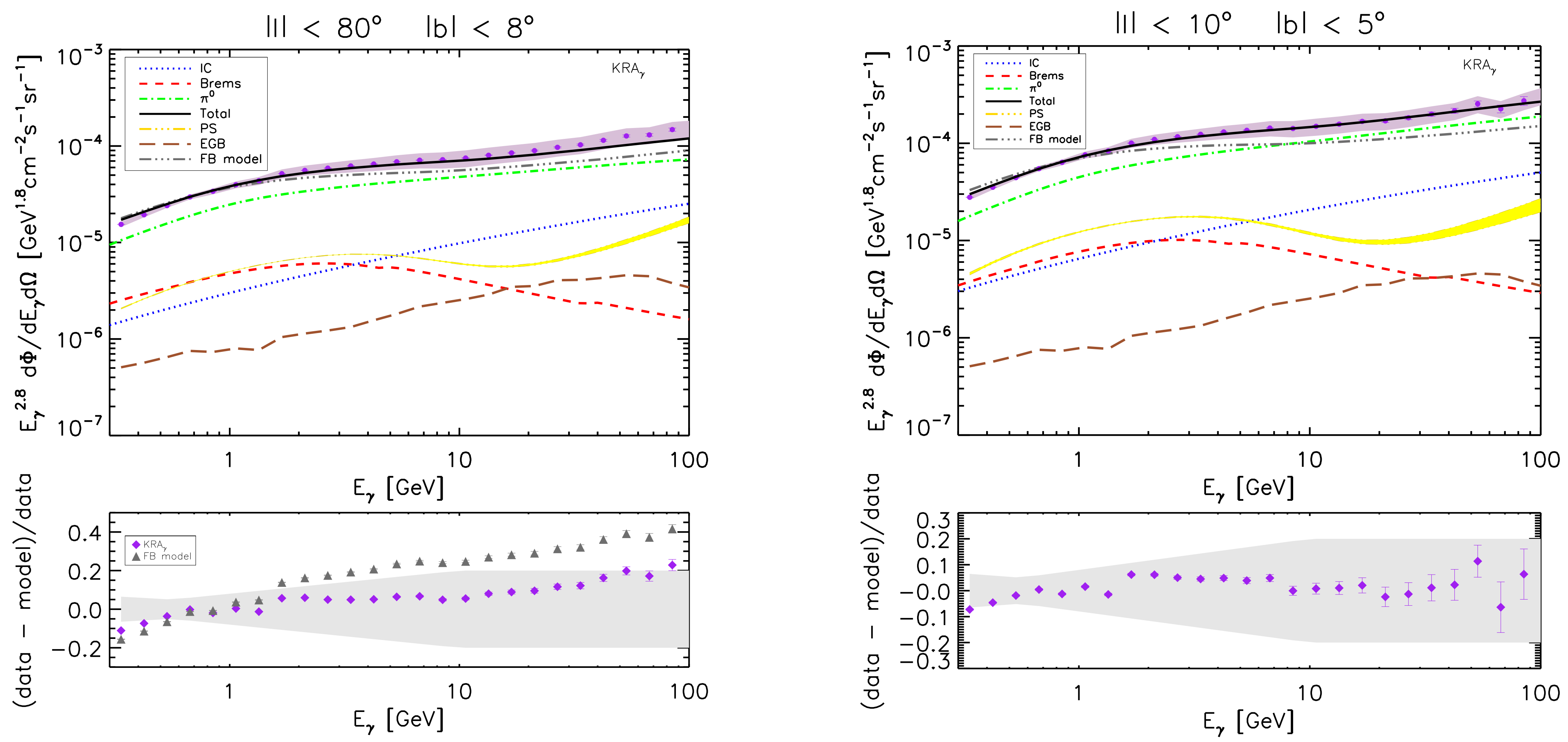
Since in this region the diffuse Galactic flux is dominated by the meson component, the spectral index reflects the spectral index of the CR proton density at the emission spot. In **Fermi Coll., 2012** this is assumed to be the same as the local by construction of the model. What about changing this?

Slight discrepancies: γ-rays in inner Galactic plane

Introduce a radial gradient in the spectral index of the diffusion coefficient:

$$D = D(\rho, R) \propto \rho^{\delta} \quad \text{with:} \quad \delta = \delta(R)$$

Simplest toy-model to be fitted to the data: take a linear dependence.
Sharp increase in the match with data:



Gaggero, Urbano, Valli & PU, 2015

Trend proposed here confirmed in **Fermi Coll., arXiv:1602.07246**; other scenarios without environmental dependence in CR propagation, failing to address it.

Slight discrepancies: γ-rays in Galactic center region

Morphological and spectral mismatches when looking at the central region of the Galaxy - say, the inner 10 to 20 degrees - even when cutting out the Galactic plane component (**Hooper et al. 2009-15**, **Vitale & Morselli, 2009** + several others, see in particular **Calore, Cholis & Weniger, 2014**).

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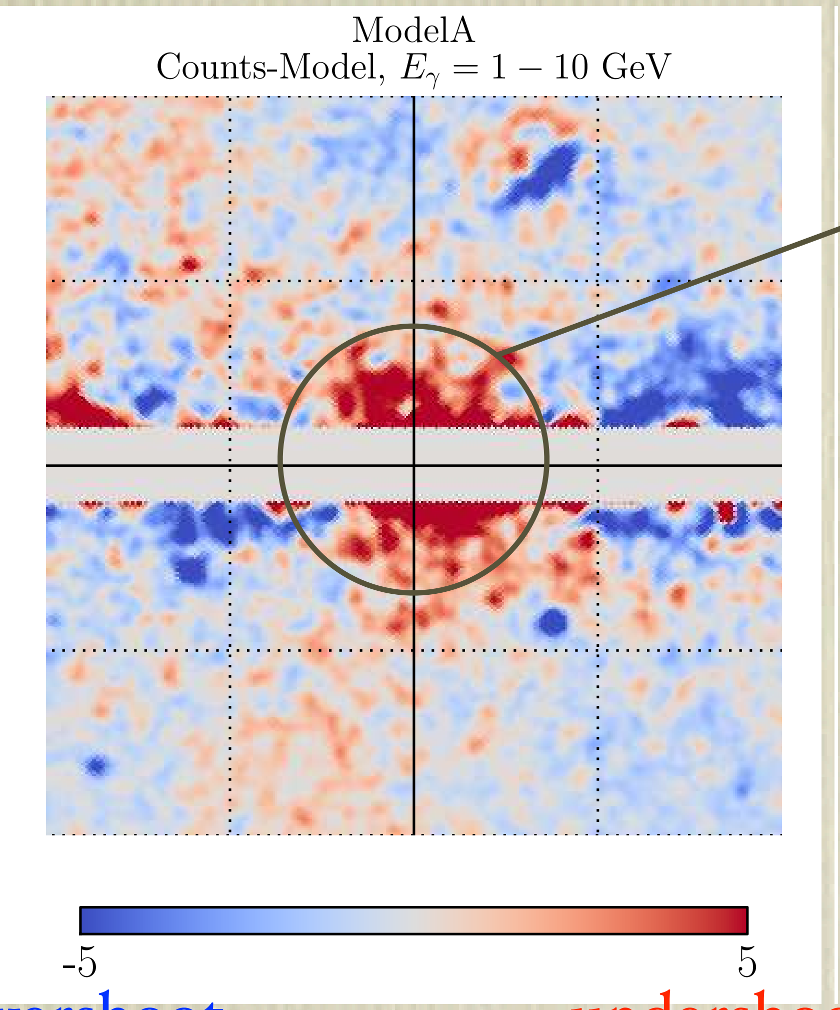
A detailed model in this region is very problematic (while for standard CR models is just a nearly empty spot 8 kpc away from us).

Most analyses consider the template fitting technique:
I) fix the morphology of each component of the CR diffuse emission (plus sources, plus bubbles) from some theory/data-driven prior;
II) scale freely the templates in each energy bin to minimize the residuals.

Residuals:



overshoot undershoot

A blob-like excess seems to emerge

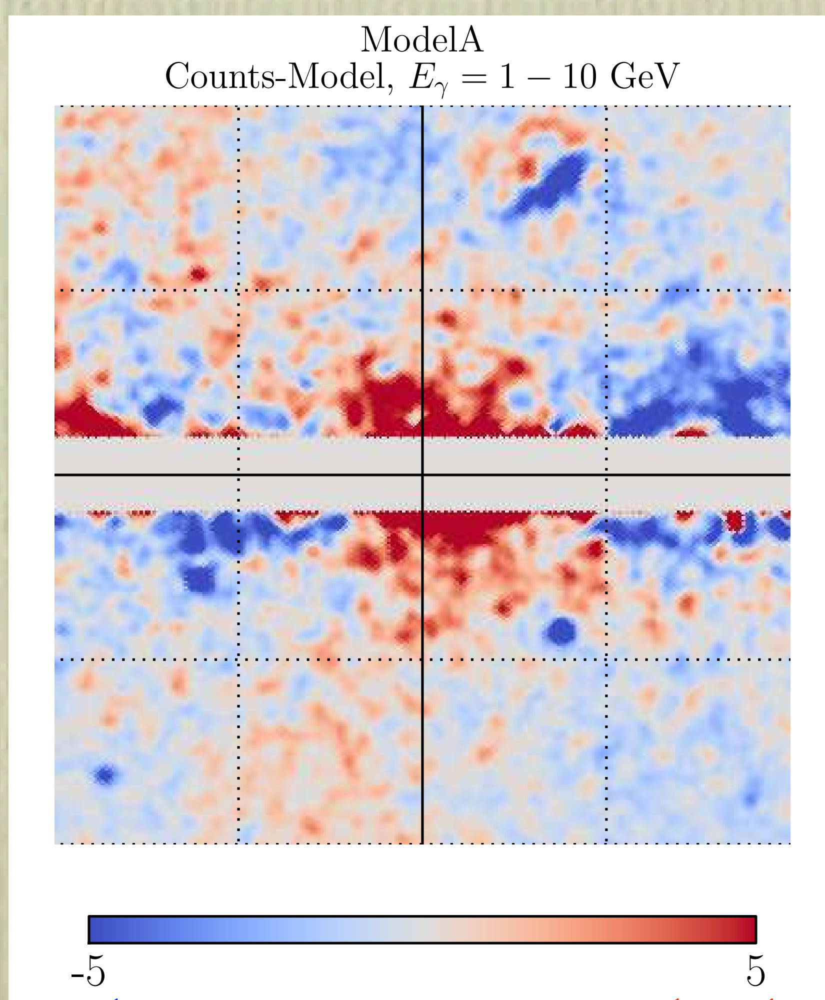
Slight discrepancies: γ-rays in Galactic center region

A component from DM pair annihilations is expected to be centrally concentrated: try to wipe out the blob adding an extra template scaling like

$$J \equiv \frac{1}{\Delta\Omega} \int_{\Delta\Omega} d\Omega \int_{l.o.s.} dl \; \rho^2_{DM}(l) \quad \text{with} \quad \rho_{DM}(r) = \rho_0 \left(\frac{r}{r_s}\right)^{-\gamma} \left(1 + \frac{r}{r_s}\right)^{3-\gamma}$$

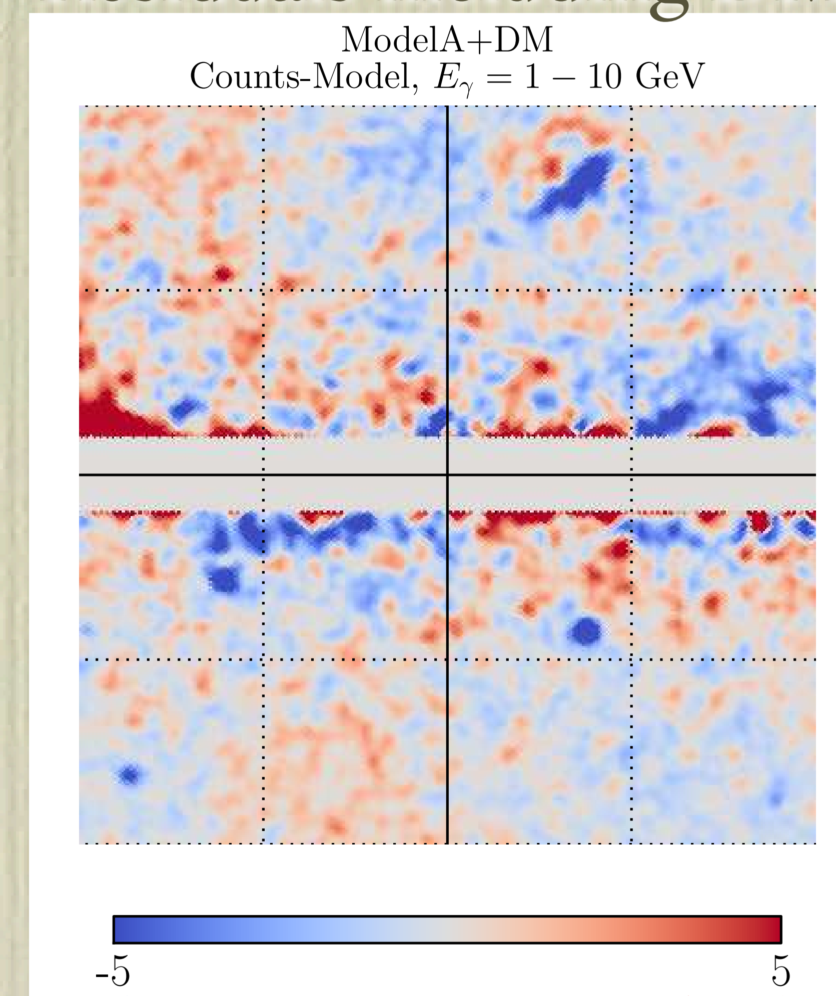
and $\gamma = 1.26$, analogously to numerical simulation results.

Residuals without DM



overshoot undershoot

Residuals including DM

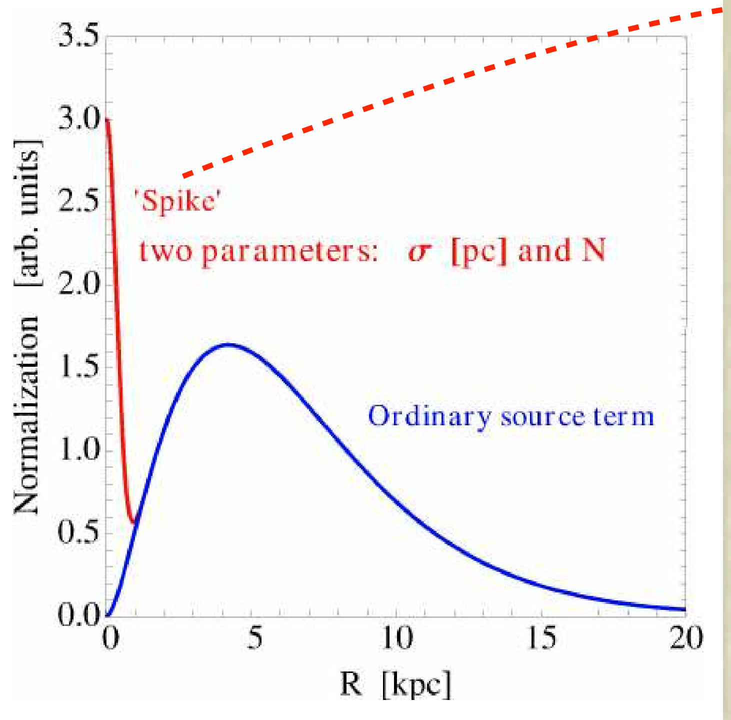


overshoot undershoot

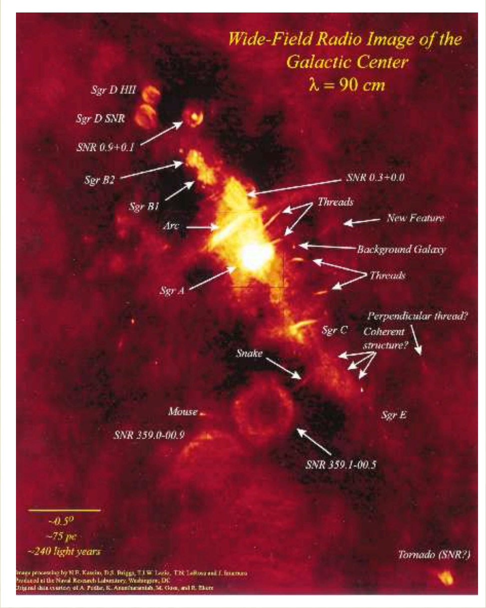
The fit has clearly improved!

Slight discrepancies: γ-rays in Galactic center region

What about including an extra SNR source, connected to the "Central Molecular Zone", usually neglected in standard CR models?
Toy model: a gaussian term with tunable width.

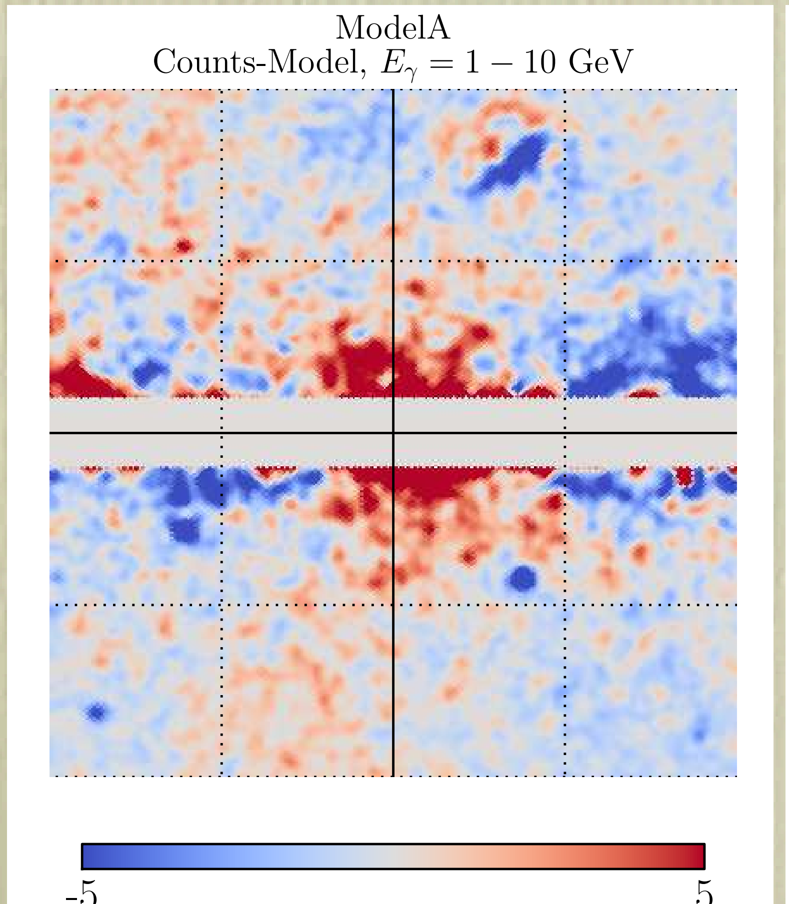


CMZ



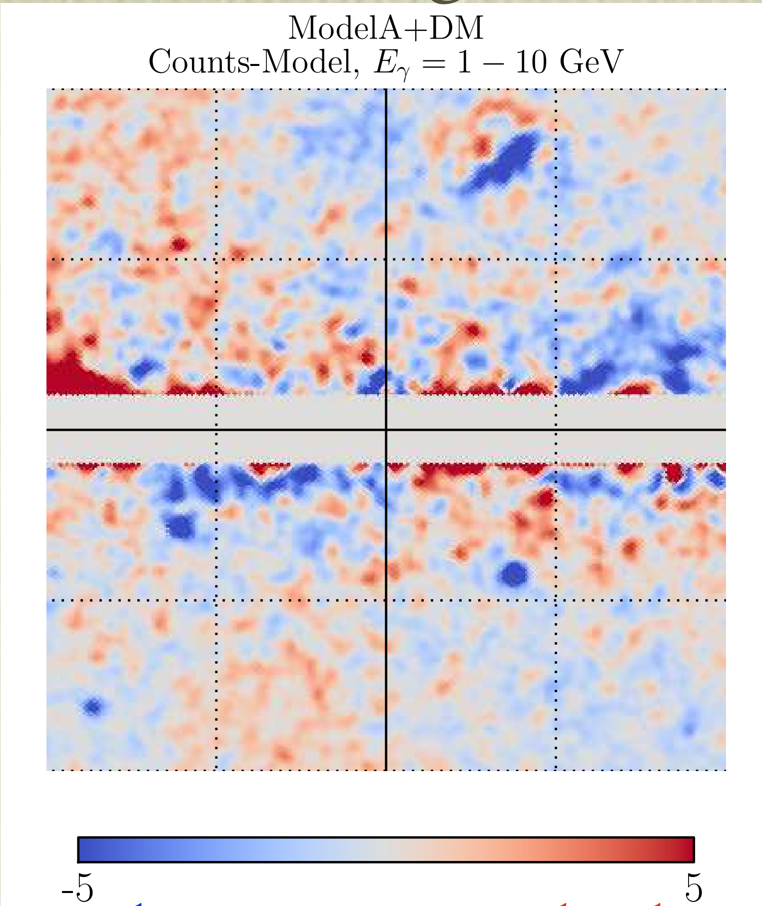
Gaggero, Taoso, Urbano, Valli & PU, 2015

Fiducial CR model



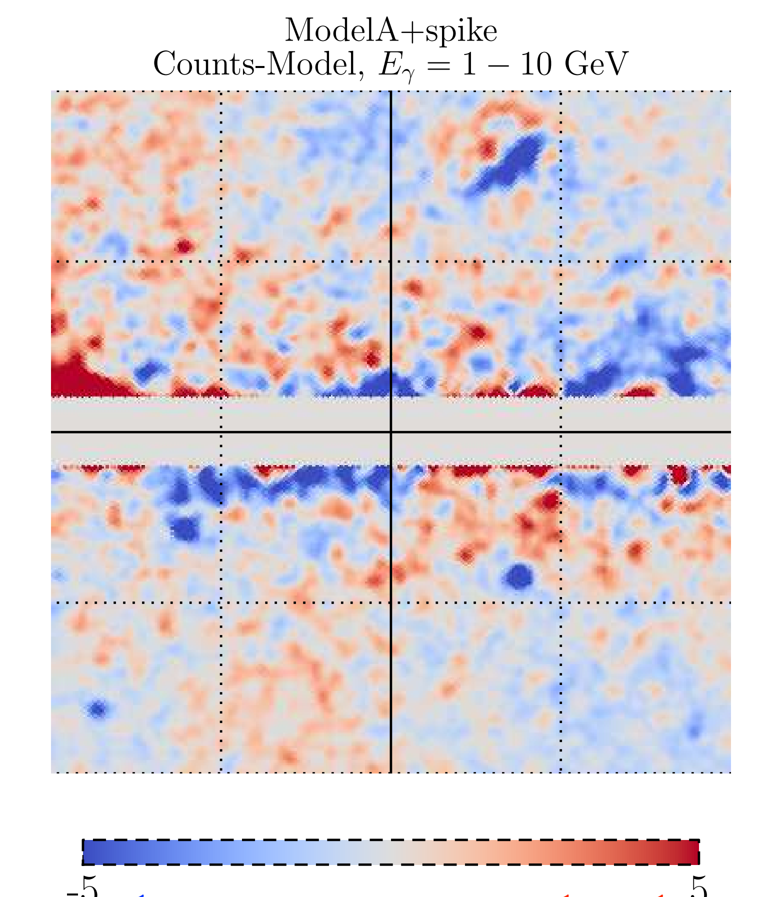
overshoot undershoot

Including DM



overshoot undershoot

Including spike



overshoot undershoot

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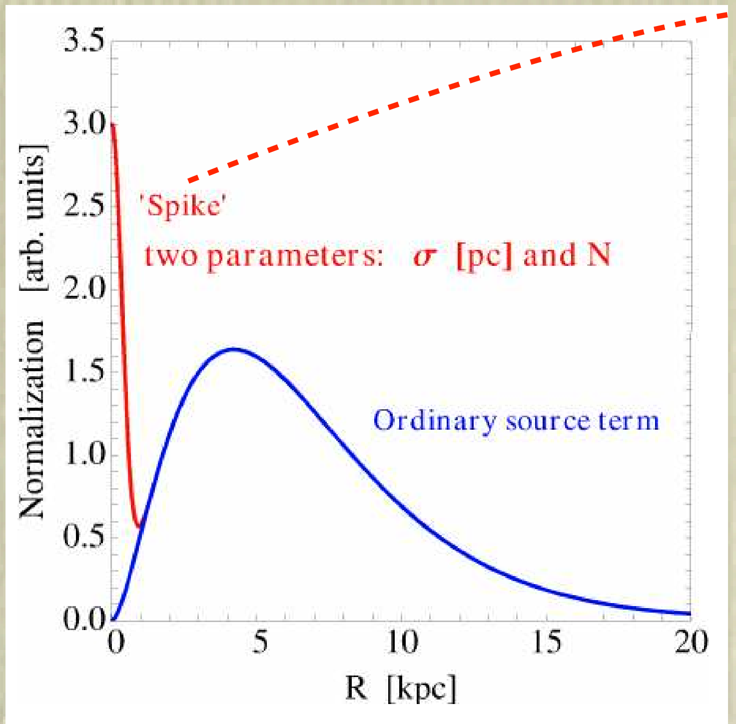

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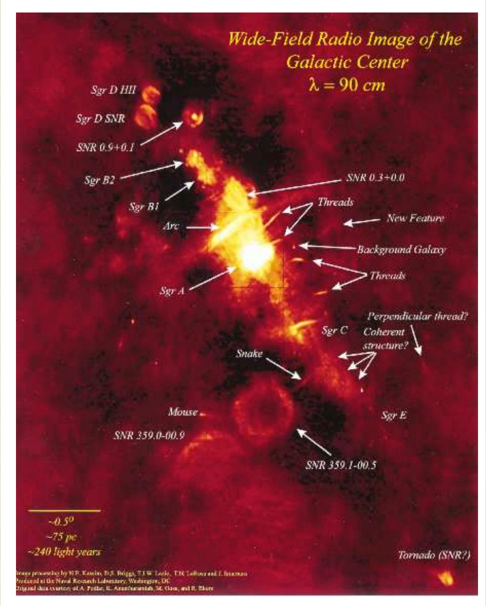

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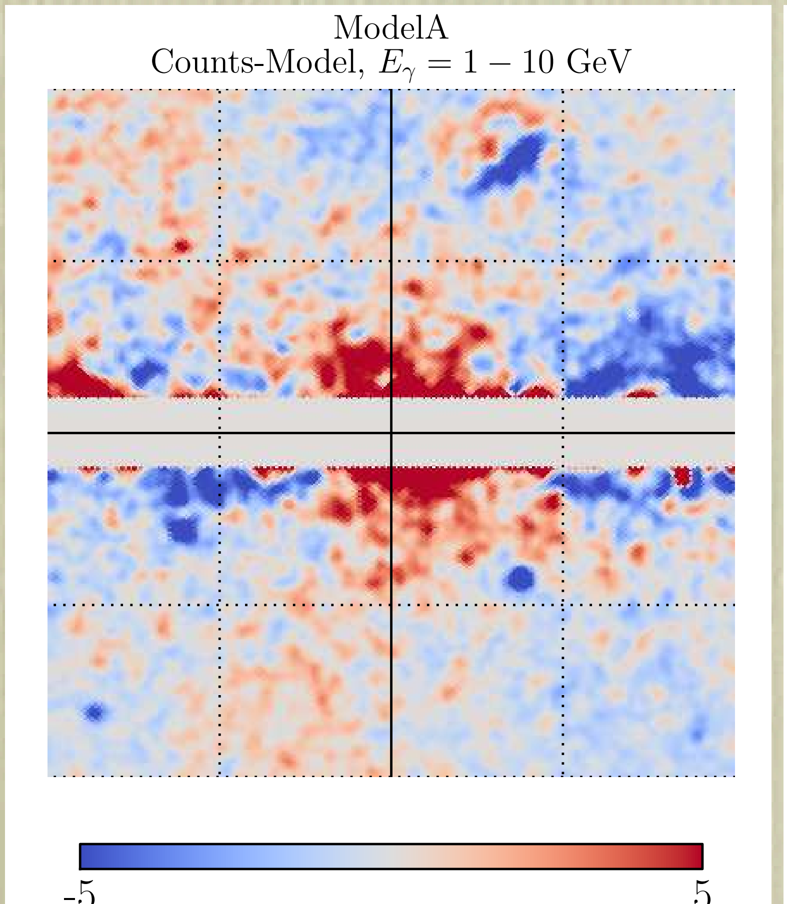
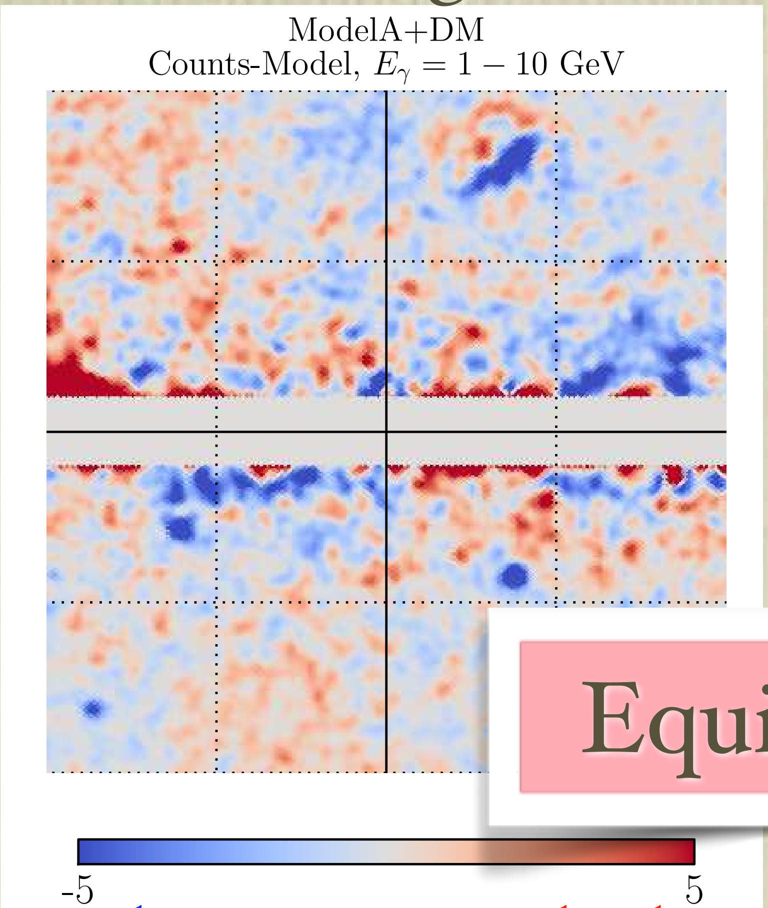


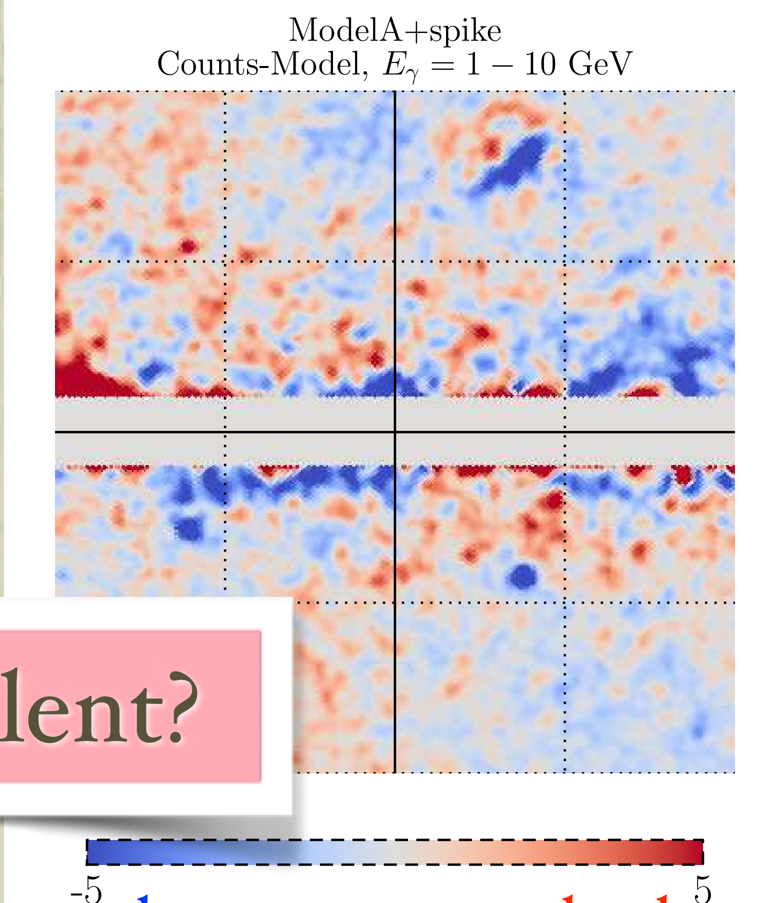
overshoot undershoot

Including DM



overshoot undershoot

Including spike

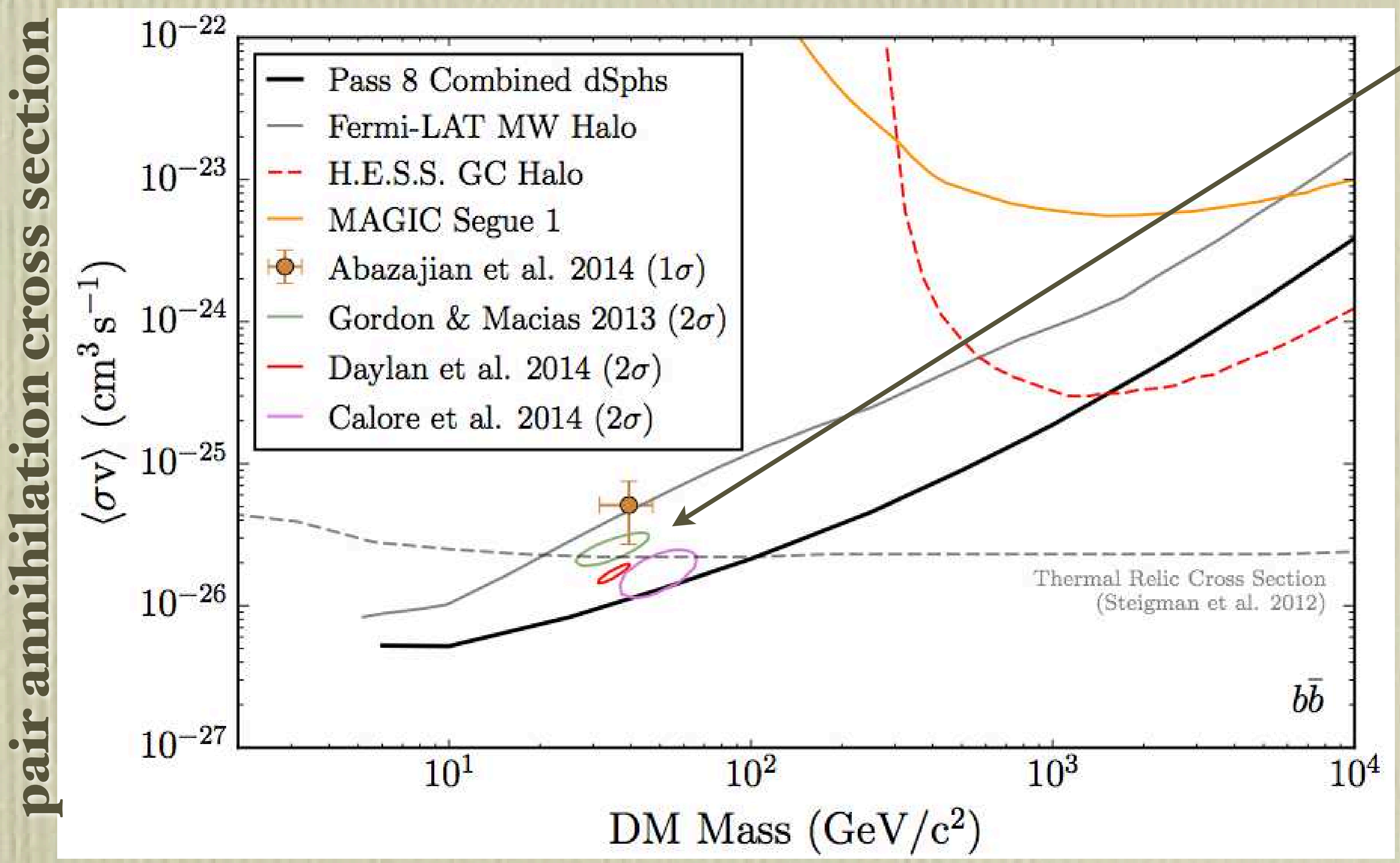


overshoot undershoot

Equivalent?

Slight discrepancies: γ-rays in Galactic center region

Back to the plot with tentative indication of a DM signal in the inner region of the Galaxy:

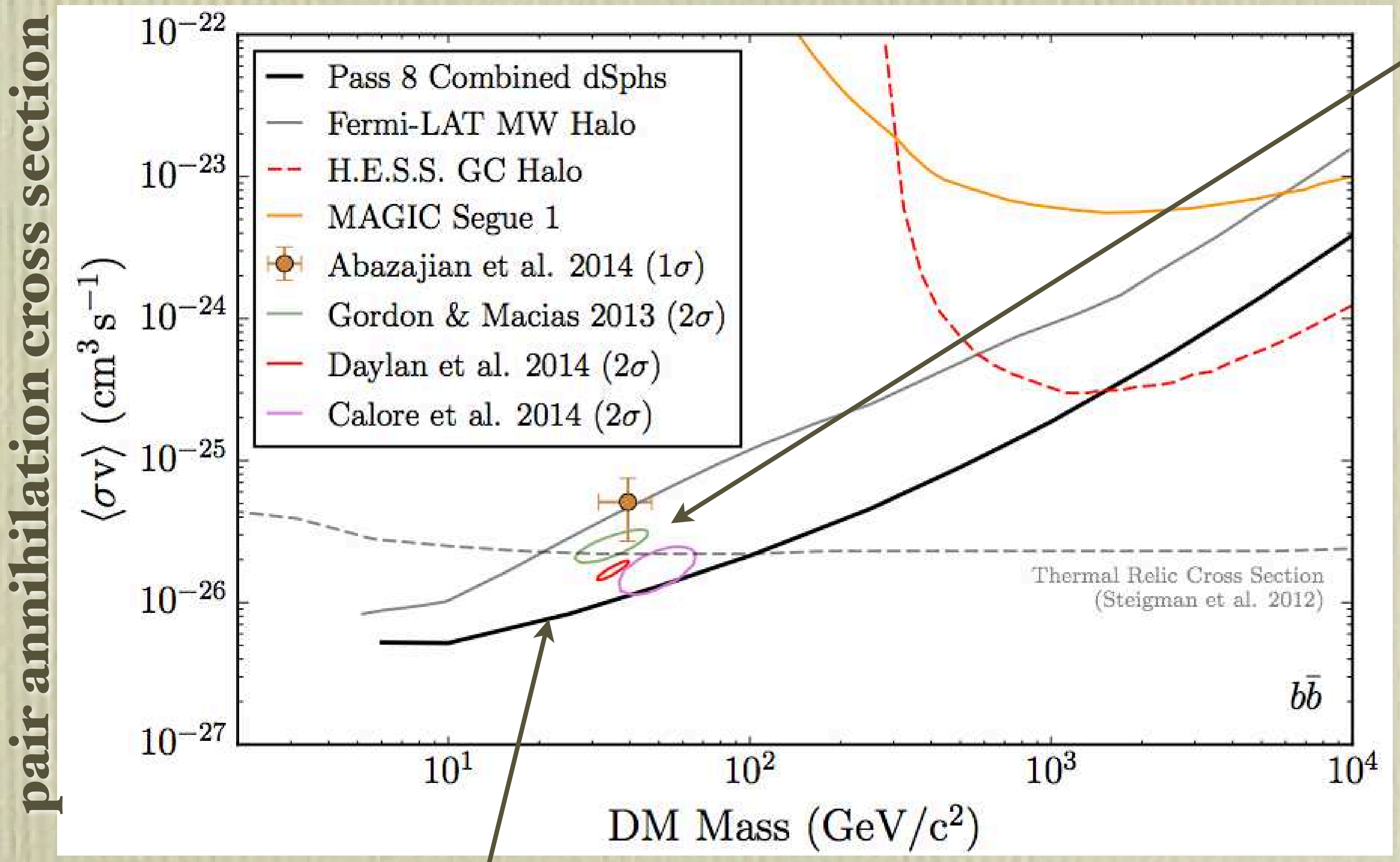


highest level at which you might have a DM signal;

would the GC excess be real, it may correspond to something else: see, e.g., the vast recent literature on explaining the excess in terms of a population of unresolved point sources (pulsars?)

Slight discrepancies: γ-rays in Galactic center region

Back to the plot with tentative indication of a DM signal in the inner region of the Galaxy:



highest level at which you might have a DM signal;

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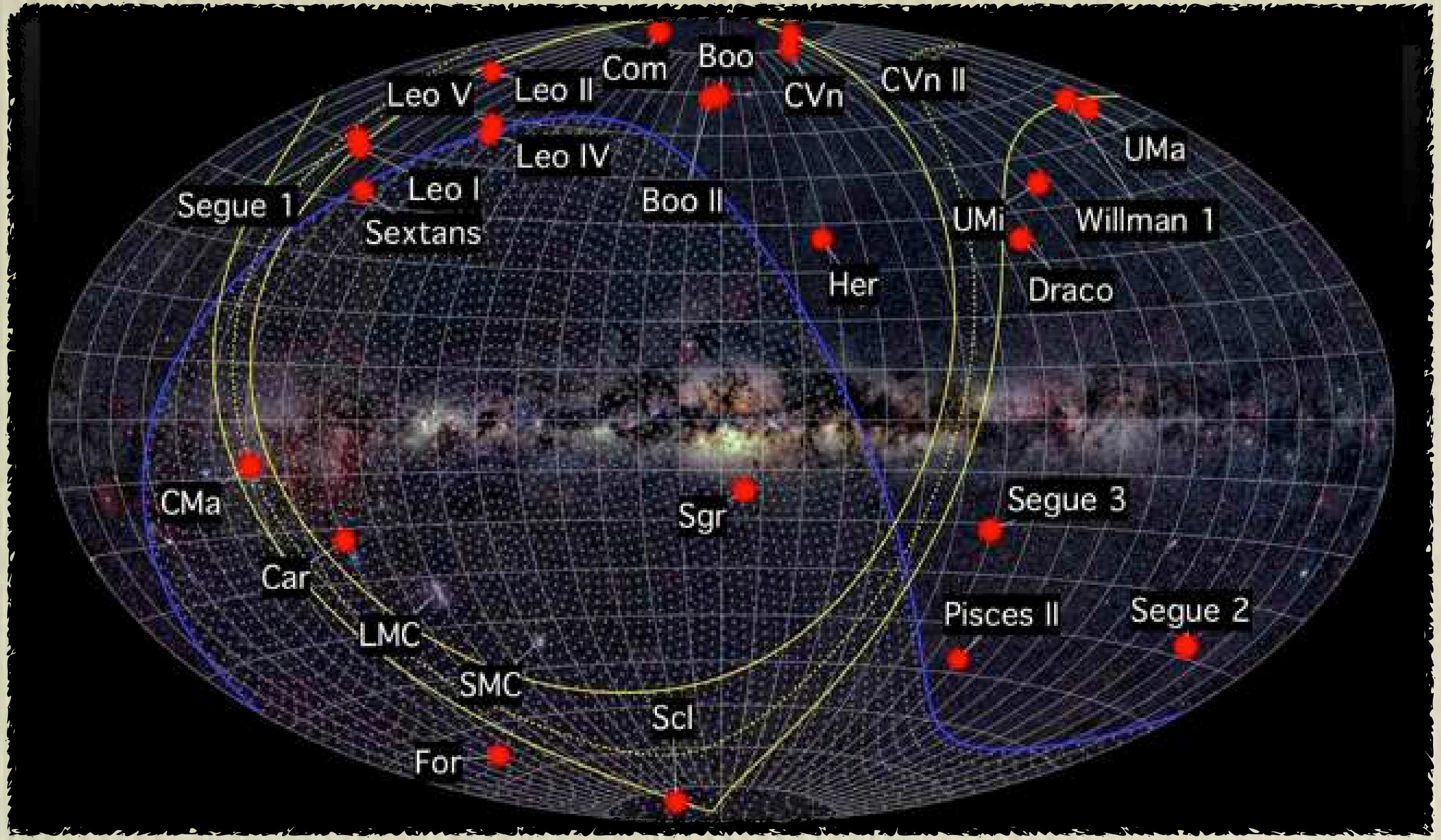
Is the DM signal in tension with the **Fermi Coll. 2015** limit from dwarf satellites?

Milky Way dwarfs as Dark Matter detection Labs

Ideal targets for **detecting** a DM signal (prompt or radiative emission from DM particle pair annihilations or decays):

- objects with fairly large DM densities, located fairly close to the Sun (about 10 to 200 kpc);

- intrinsic backgrounds from “standard” astrophysical sources below detection sensitivities (?)
+ low Milky Way foregrounds (intermediate to high latitude locations).



About 33 (spectroscopically) identified; 8 with extended kinematic data samples, the so-called “classical” dwarfs.

Are they ideal targets for **setting limits** as well? For the classical dwarfs 1-σ uncertainties on J-factors often assumed within factors of 1.5 ≪ the “astro” uncertainty in any other indirect detection tool! Where does it come from?

Mass models for dwarf galaxies

A stellar population as tracer of the gravitational potential (i.e. the DM distribution) assuming dynamical equilibrium. Velocity moments of the collision-less Boltzmann equation. Spherical symmetry for all components:

$\Rightarrow$ a single Jeans equation

$$\frac{d}{dr}(\nu\sigma_r^2) + \frac{2\,\beta(r)}{r}\nu\sigma_r^2 = -\nu\frac{M(r)}{r^2}$$

Usually solved for the radial pressure: $p(r) \equiv \nu(r)\sigma_r^2(r)$ in terms of the 3 unknown functions:

the star density profile	the star anisotropy profile	the DM mass profile
$\nu(r)$	$\beta(r) \equiv 1 - \dfrac{\sigma_\theta^2 + \sigma_\phi^2}{2\,\sigma_r^2}$	$M(r)$

$$-\infty \;\leq\; \beta(r) \;\leq\; 1$$

circular orbits

radial orbits

isotropy: $\beta(r) = 0$

Mass models for dwarf galaxies (ii)

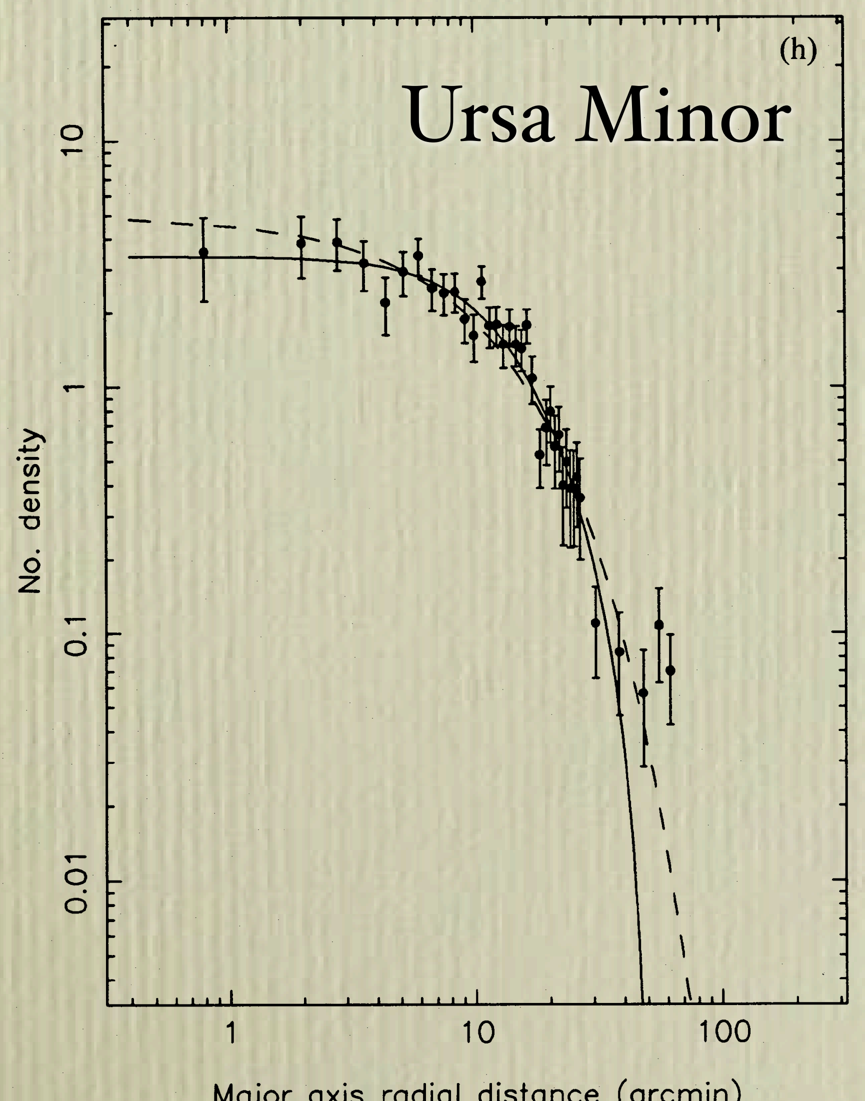
The 3 unknowns: $\nu(r)$, $\beta(r)$ and $M(r)$ can be mapped into 2 observables:

the star surface brightness

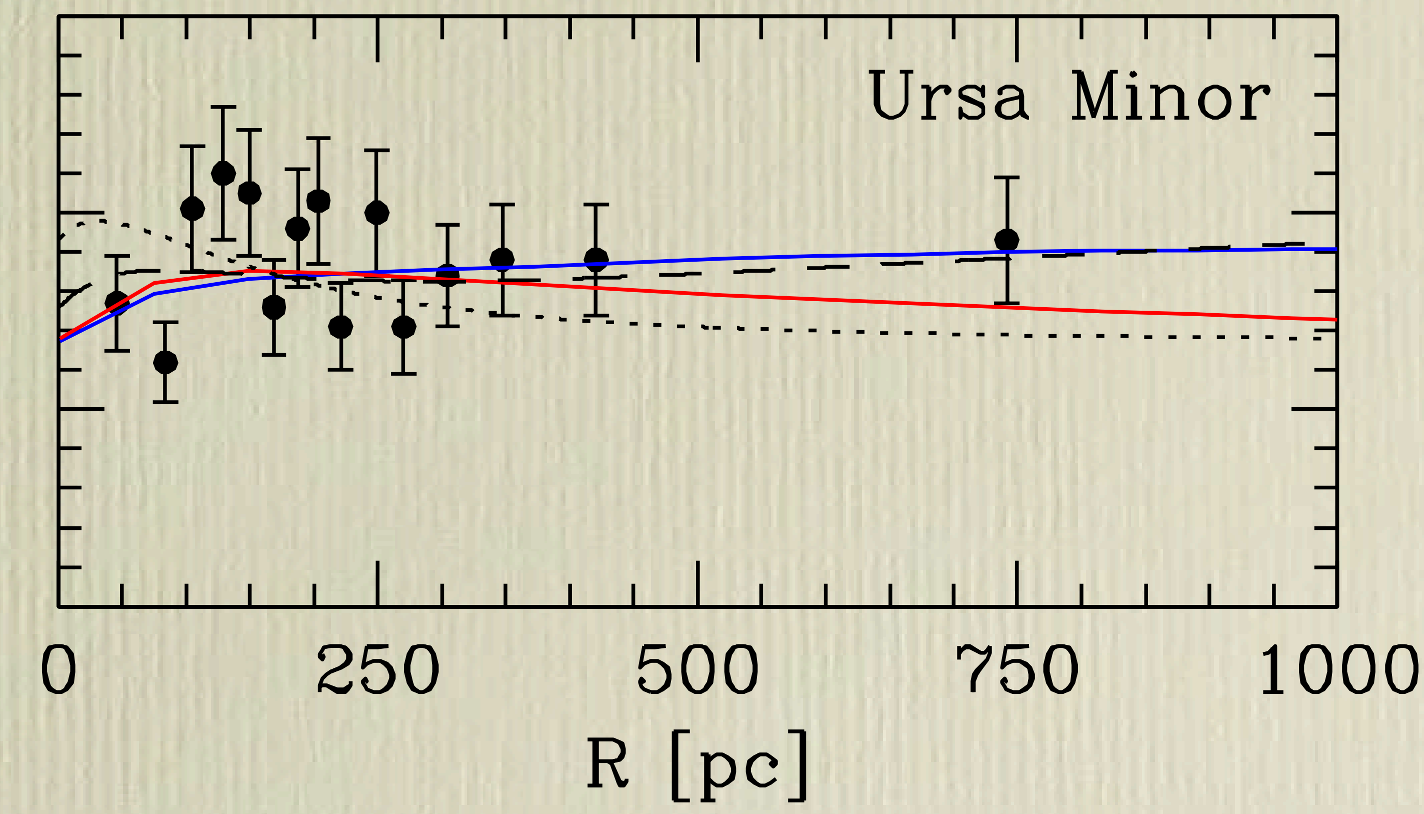
$$I(R) = 2\int_R^\infty \frac{dr\, r}{\sqrt{r^2 - R^2}}\nu(r)$$

the l.o.s. velocity dispersion

$$\sigma^2_{l.o.s.}(R) = \frac{2}{I(R)}\int_R^\infty \frac{dr\, r}{\sqrt{r^2 - R^2}}\left(1 - \beta(r)\frac{R^2}{r^2}\right)p(r)$$



Irwin + Hatzidimitriuo 1995



e.g.: **Walker et al. 2009**

Mass models for dwarf galaxies (iii)

The mapping is usually done introducing parametric forms for:

$\nu(r)$ - Plummer, King, Sersic ... profile as supported from star profiles in other observed systems;

$M(r)$ [or DM $\rho(r)$] - from N-body simulations or DM phenomenology;

$\beta(r)$ - as an arbitrary choice, since there is no real observational handle.

and performing:

- a frequentist fit of $\nu(r)$ to data on $I(R)$;

- a Markov-Chain Monte Carlo sampling of a likelihood defined from data on $\sigma^2_{l.o.s.}(R)$: posteriors on $M(r)$ [or $\rho(r)$] parameters after marginalization over $\beta(r)$ parameters [prior choice for the latter again arbitrary]. The derived posterior for J (and its small error bar) is what will enter as an input for particle physics limits.

How much should we trust this procedure?

Mass models: our approach **PU & Valli, 1603.07721**

the star surface brightness

$$I(R) = 2\int_R^\infty \frac{dr\, r}{\sqrt{r^2 - R^2}}\nu(r)$$

the l.o.s. velocity dispersion

$$\sigma^2_{l.o.s.}(R) = \frac{2}{I(R)}\int_R^\infty \frac{dr\, r}{\sqrt{r^2 - R^2}}\left(1 - \beta(r)\frac{R^2}{r^2}\right)p(r)$$

are in a form which resembles the Abel integral transform for the pair $f \leftrightarrow \widehat{f}$:

$$f(x) = \mathbf{A}[\widehat{f}(y)] = \int_x^\infty \frac{dy}{\sqrt{y-x}}\,\widehat{f}(y) \quad\longleftrightarrow\quad \widehat{f}(y) = \mathbf{A}^{-1}[f(x)] = -\frac{1}{\pi}\int_y^\infty \frac{dx}{\sqrt{x-y}}\frac{df}{dx}$$

Actually $I(R^2) \leftrightarrow \widehat{I}(r^2) = \nu(r)$. Analogously you can invert also the projected dynamical pressure $P(R^2) \equiv I(R)\,\sigma^2_{l.o.s.}(R)$ and find:

$$M(r) = \frac{r^2}{G_N\,\widehat{I}(r)}\left\{-\frac{d\widehat{P}}{dr}[1 - a_\beta(r)] + \frac{a_\beta(r)}{r}\cdot b_\beta(r)\left[\widehat{P}(r) + \int_r^\infty d\tilde{r}\frac{a_\beta(\tilde{r})}{\tilde{r}}\mathcal{H}_\beta(r,\tilde{r})\,\widehat{P}(\tilde{r})\right]\right\}$$

having defined: $a_\beta(r) \equiv -\dfrac{\beta}{1-\beta}$ $\qquad b_\beta(r) = 3 - a_\beta(r) - \dfrac{d\log a_\beta}{d\log r}$

$$\mathcal{H}_\beta(r,\tilde{r}) \equiv \exp\left(\int_r^{\tilde{r}} dr'\,\frac{a_\beta(r')}{r'}\right)$$

see also: **Wolf et al. 2010** + **Mamon & Boué 2009**.

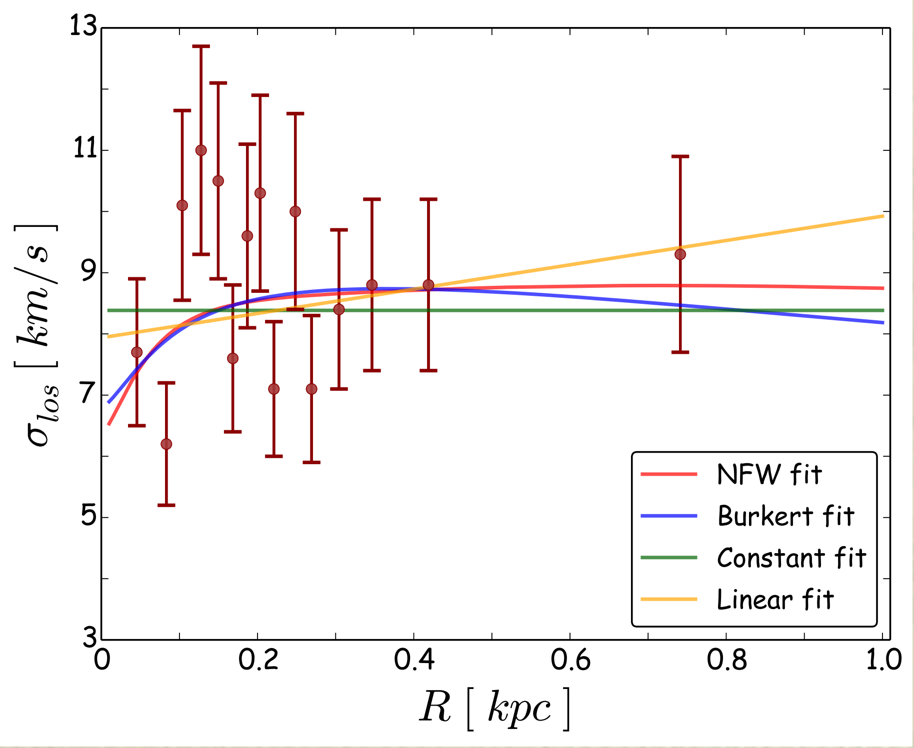
Mass models: our approach (ii)

Now: model $I(R)$ and $\sigma_{l.o.s.}(R)$ with a direct parametric fit on data for these observables. E.g.: assume for the surface brightness a Plummer model:

$$I(R) = \frac{L_0}{\pi R_{1/2}^2} \frac{1}{(1 + R^2/R_{1/2}^2)^2}$$

and fit the half-light radius $R_{1/2}$, i.e. in Ursa Minor: $R_{1/2} \simeq 0.3$ kpc .

For the line-of-sight projected velocity dispersion in general data are less constraining and one can consider different possibilities, e.g.:

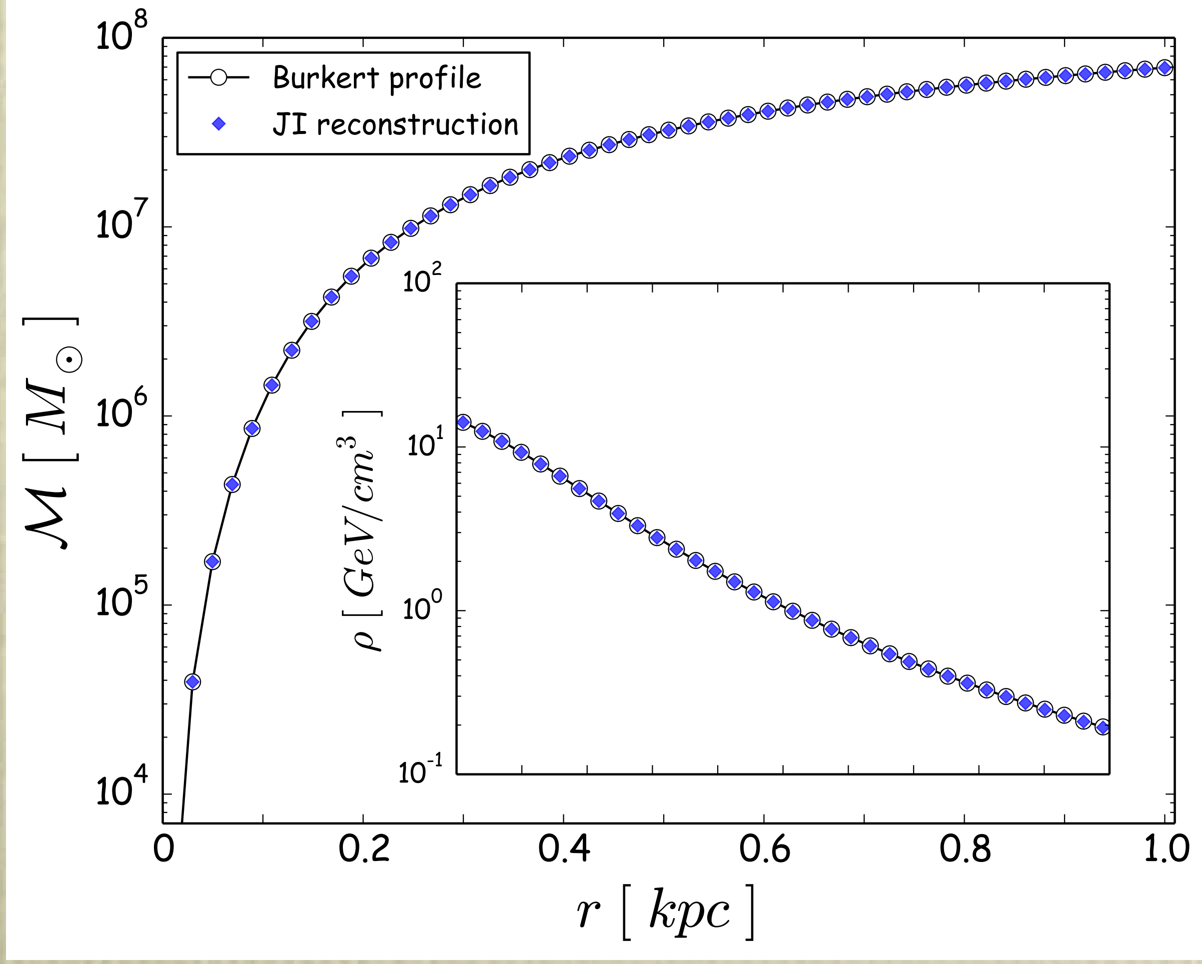


The Abel transforms $\widehat{P}(r)$ and $\widehat{I}(r)$ are computed numerically, and then one can perform a direct projection of what you do (not) know about $\beta(r)$ into a prediction for $M(r)$, $\rho(r)$ and J , and hence have a more direct assessment of uncertainties in the predictions for dark matter signals.

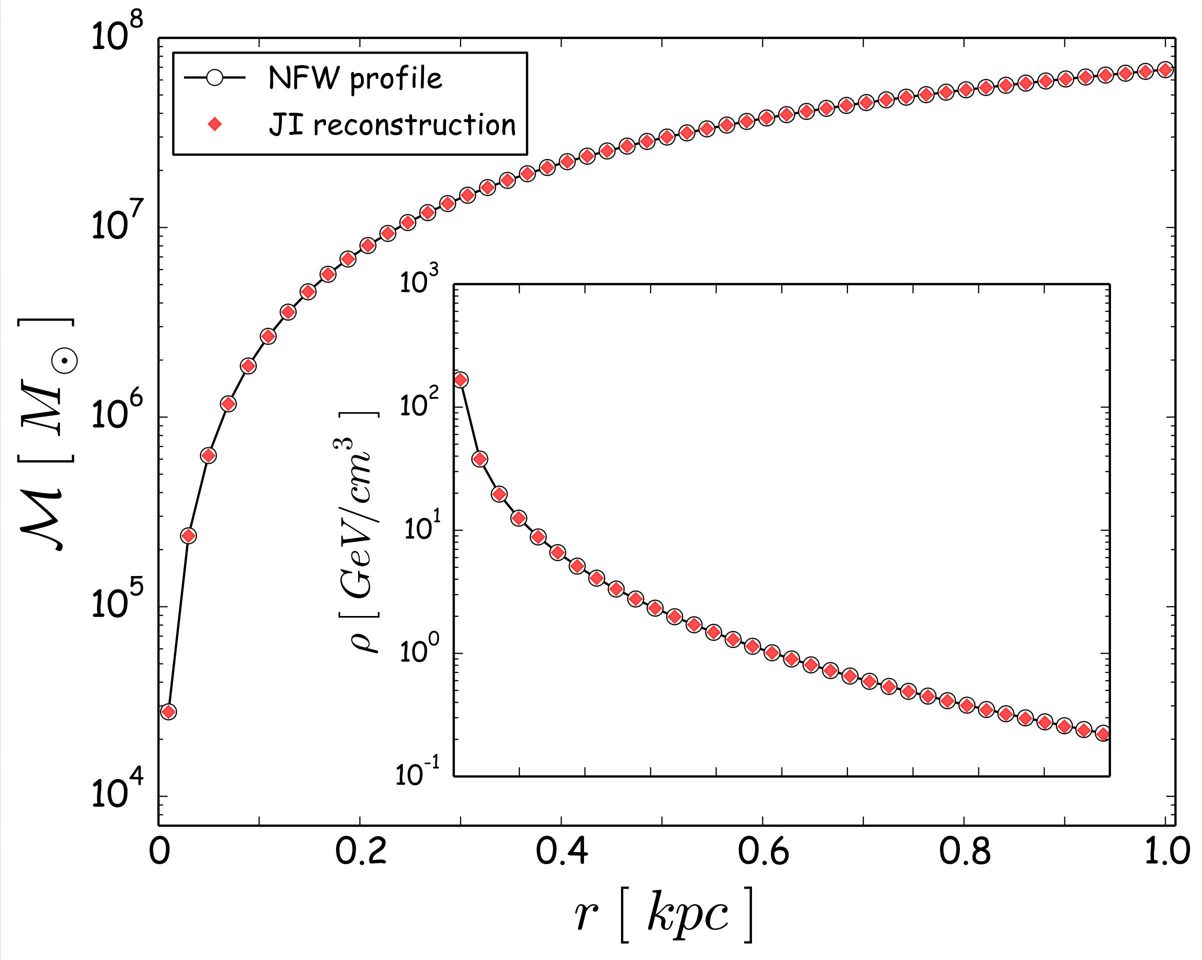
We have a numerical tool that works:

Sample check: assume given $M(r)$ [or $\rho(r)$] and $\beta(r)$, compute for these the projected dynamical pressure $P(r)$, Abel transform the latter into $\widehat{P}(r)$ and use this to retrieve $M(r)$ [or $\rho(r)$].

The check shown here is on the best fit of Ursa Minor $\sigma_{l.o.s.}(R)$:



Burkert profile



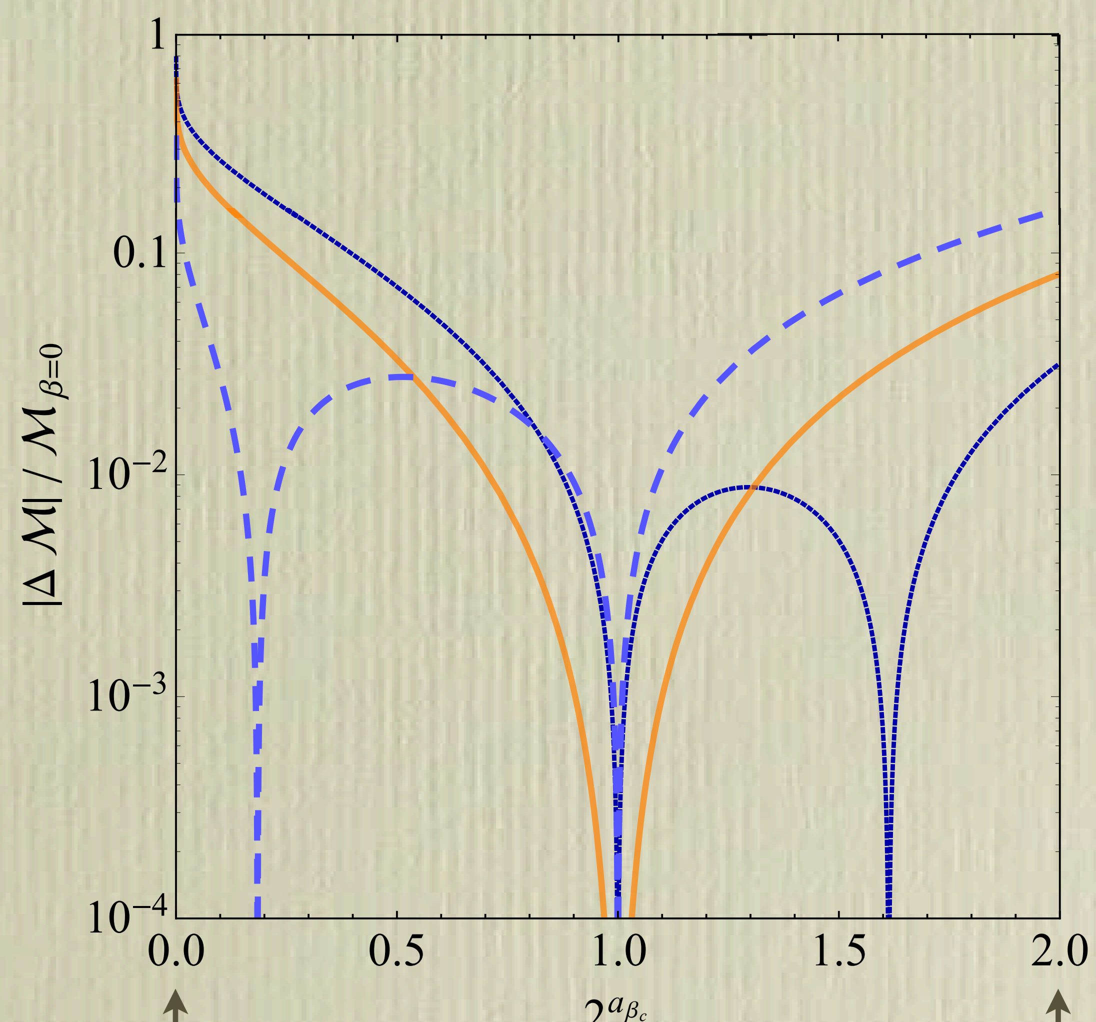
NFW profile

Direct check on the existence of a mass estimators:

It has been claimed, first from MCMC scans (**Strigari et al. 2008**) and then with closer look to features in the Jeans eq. solution (**Wolf et al. 2010**) that there is a radius $r_\star$ such that $M(r_\star)$ is nearly independent on choice of $\beta(r)$ ($r_\star \simeq 1.23\, R_{1/2}$ for a Plummer surface brightness).

Assuming, e.g., a flat velocity dispersion $\sigma_{l.o.s.}(R) = \text{const.}$ as well as a constant $\beta(r) = \beta_c$, from the mass inversion formula we find:

mass differences compared to the isotropic case



results at fixed radius:

$r / r_* = 0.95$
$r / r_* = 1.0$
$r / r_* = 1.10$

radial orbits

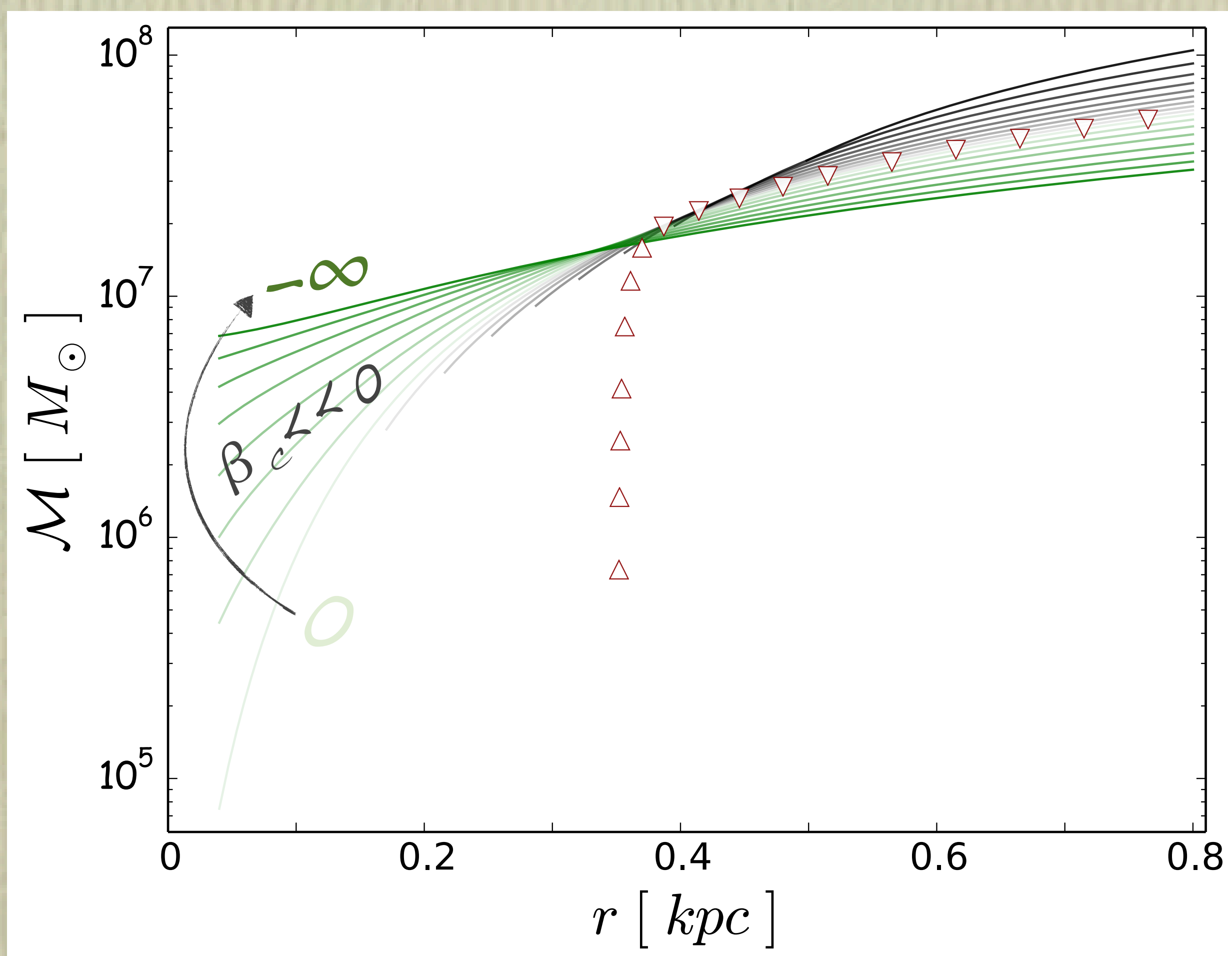
isotropy

circular orbits

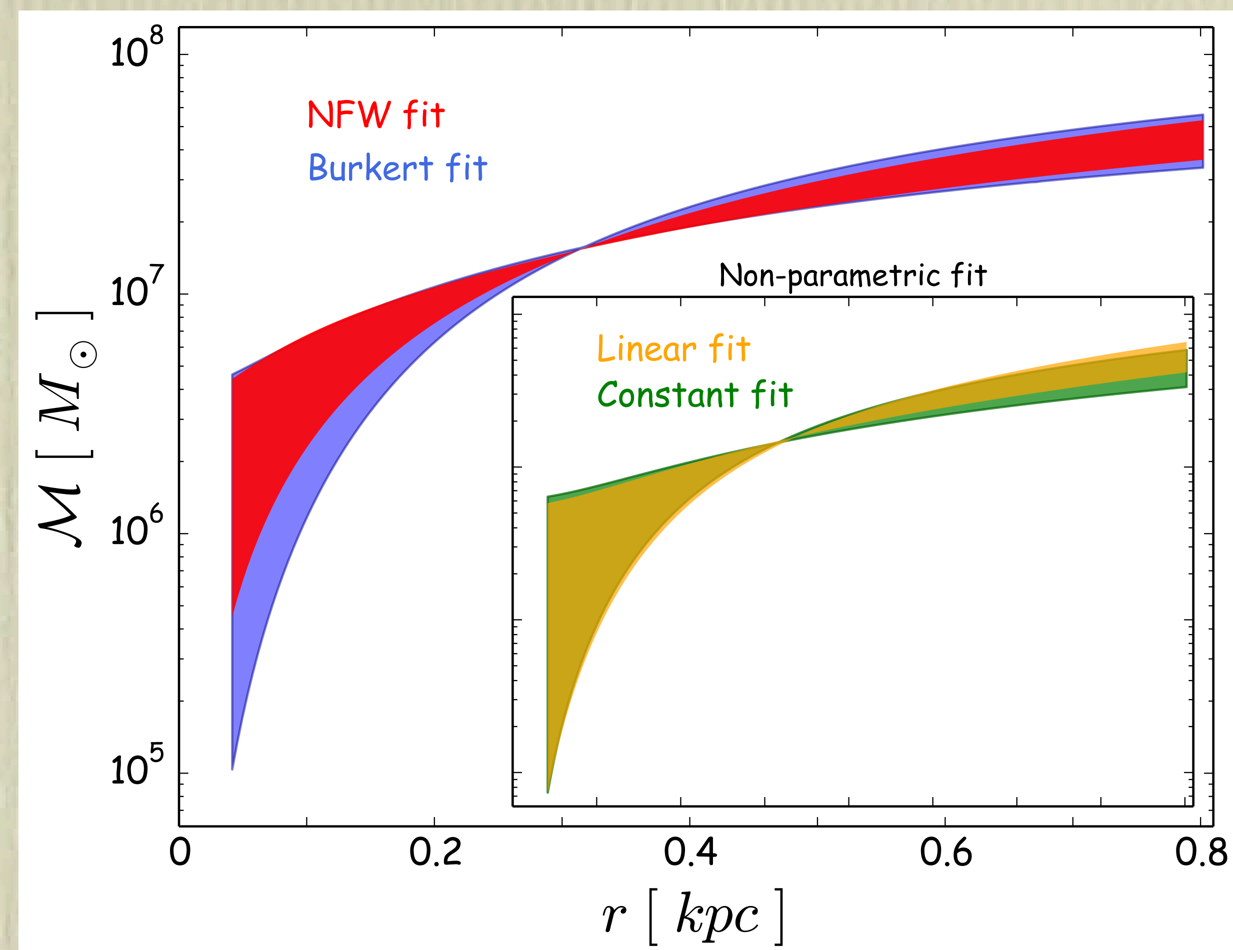
$$a_\beta \equiv -\frac{\beta}{1-\beta}$$

Mass profiles in Ursa Minor as a function of constant β:

In practice, agnostic mass reconstruction with our inversion formula not always give physical results. In a concrete example we need to restrain (a posteriori) to cases in which we get $M(r) > 0$, $dM/dr > 0$ and $d\rho/dr \leq 0$:



Burkert fit of the line-of-sight projected velocity dispersion: imposing radial orbits gives unphysical results at low radii



Span of results for 4 different possible fits of the line-of-sight projected velocity dispersion

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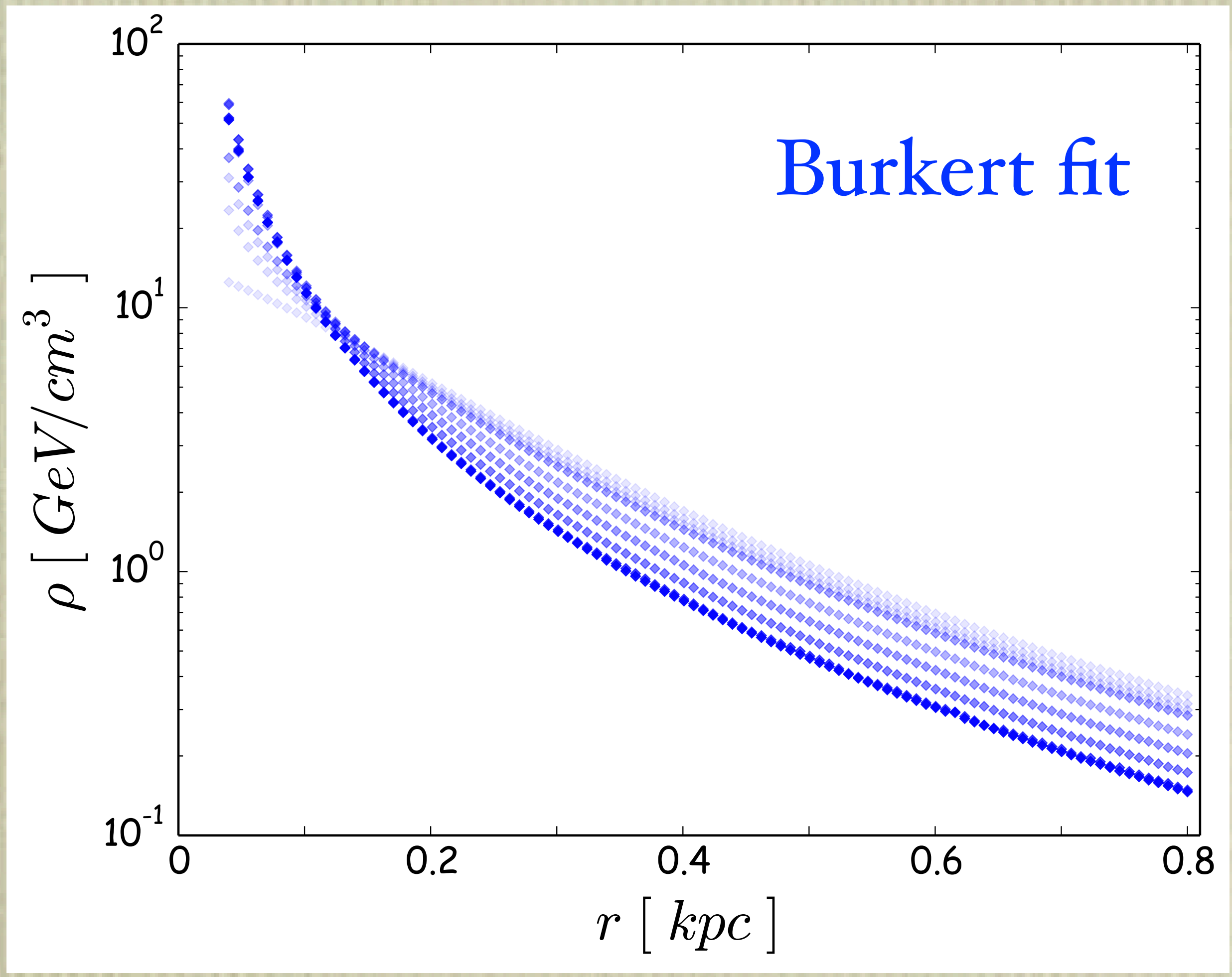
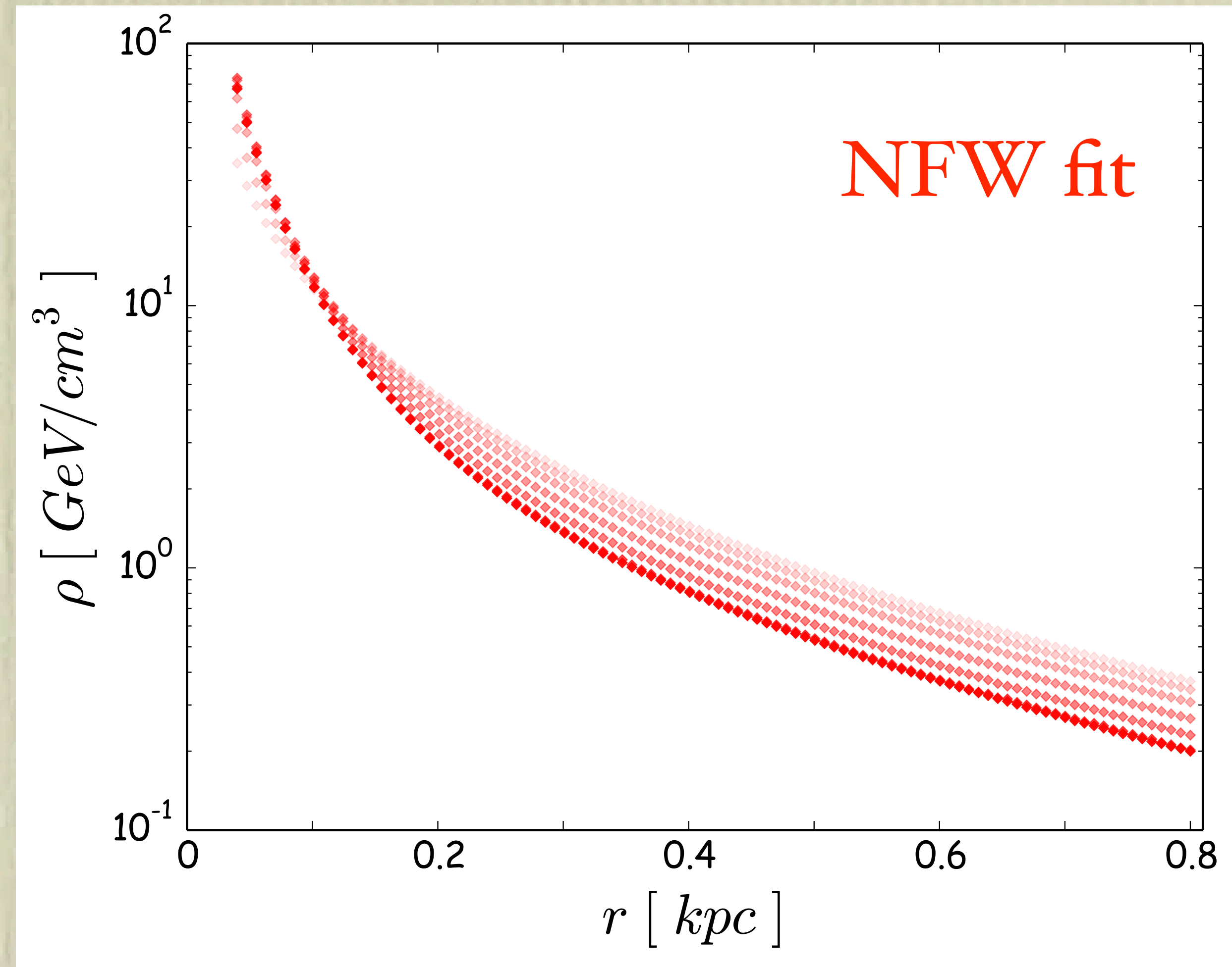




Sample limits:

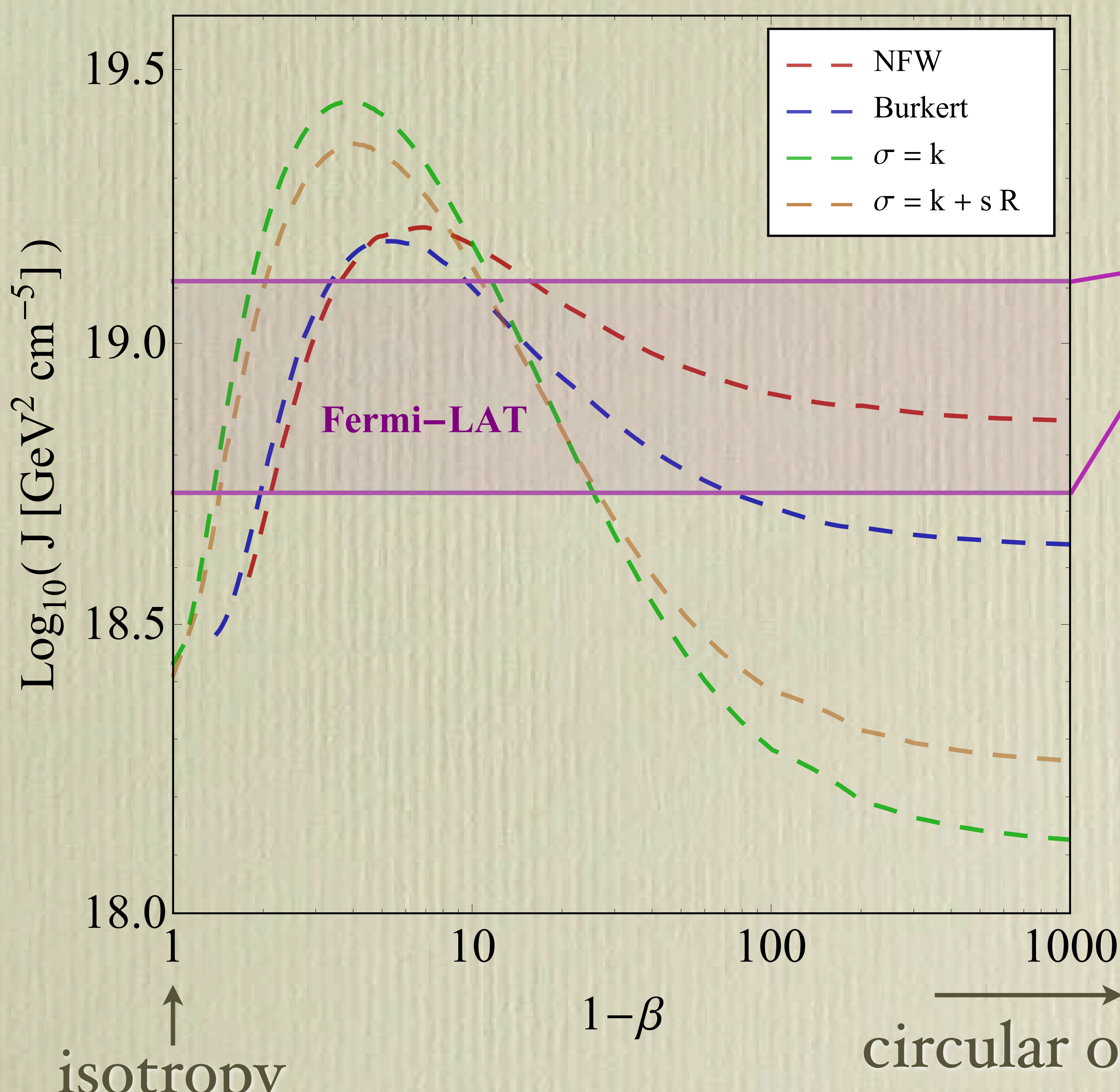
- for $\sigma_{l.o.s.}(R) = \text{const.}$, Plummer $I(R)$ + $\beta(r) = 0$ $\Longrightarrow$ $\rho(r) \overset{r \to 0}{\simeq} \text{const}$
- for $\sigma_{l.o.s.}(R) = \text{const.}$, Plummer $I(R)$ + $\beta(r) = -\infty$ $\Longrightarrow$ $\rho(r) \overset{r \to 0}{\propto} r^{-1}$ + black hole

J-factors in Ursa Minor as a function of constant β:

In line-of-sight integrals: $J \equiv \frac{1}{\Delta\Omega}\int_{\Delta\Omega} d\Omega \int_{l.o.s.} dl\ \rho^2_{DM}(l)$

we conservative set $\rho(r)$ to a constant at radii smaller than the radius at which $\sigma_{l.o.s.}(R)$ can be measured (smallest radius in our data binning):

Span of predictions for the 4 sample fits of $\sigma_{l.o.s.}(R)$



1-σ band for Ursa Minor in **Fermi Coll. 2015** apparently not fully catching the β uncertainty

J-factors in Ursa Minor as a function of constant β:

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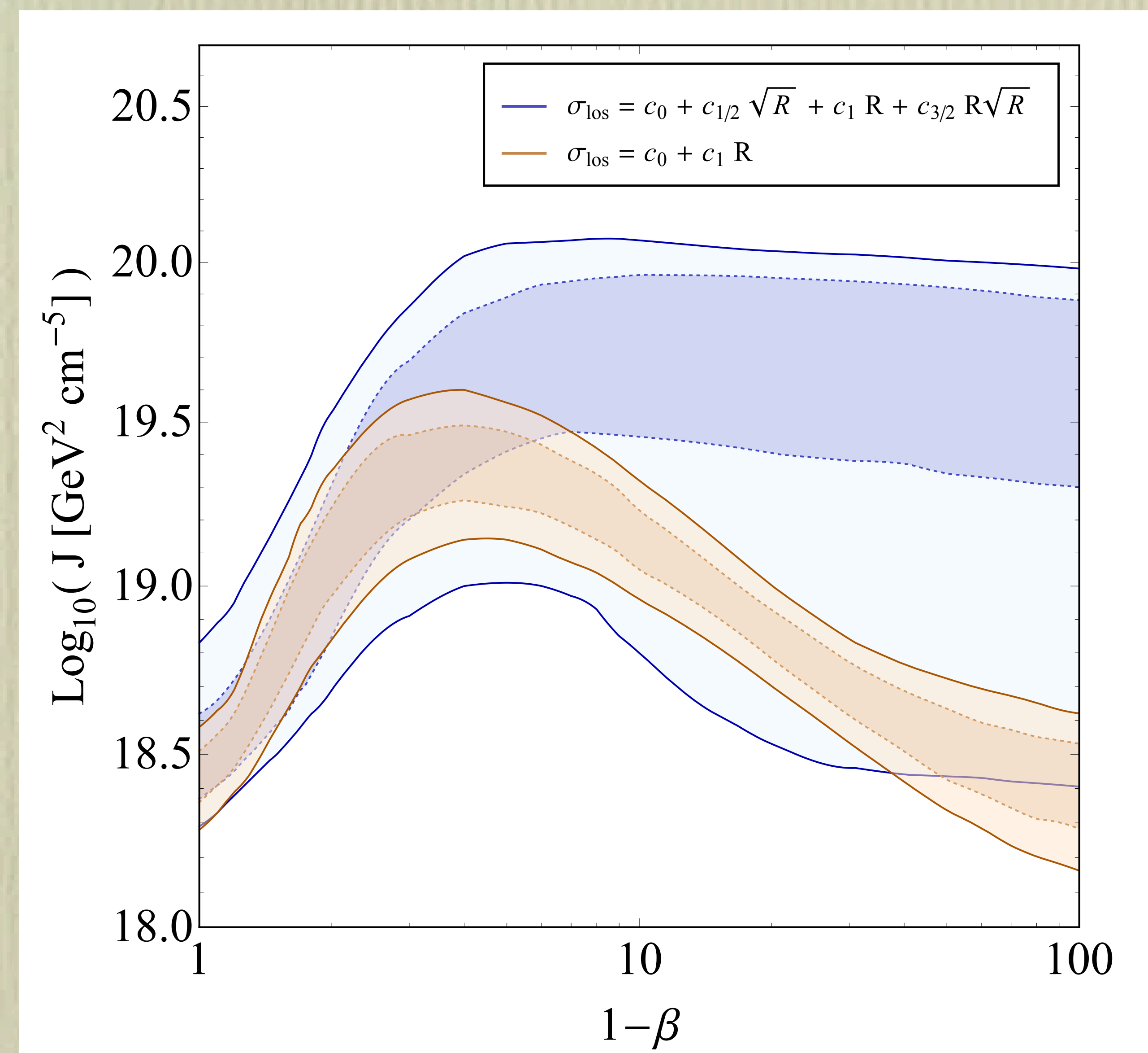
Span of predictions for two possible parametric fits of $\sigma_{l.o.s.}(R)$



MCMC with flat priors on c_i coefficients; 68% and 95% contours for J posterior displayed

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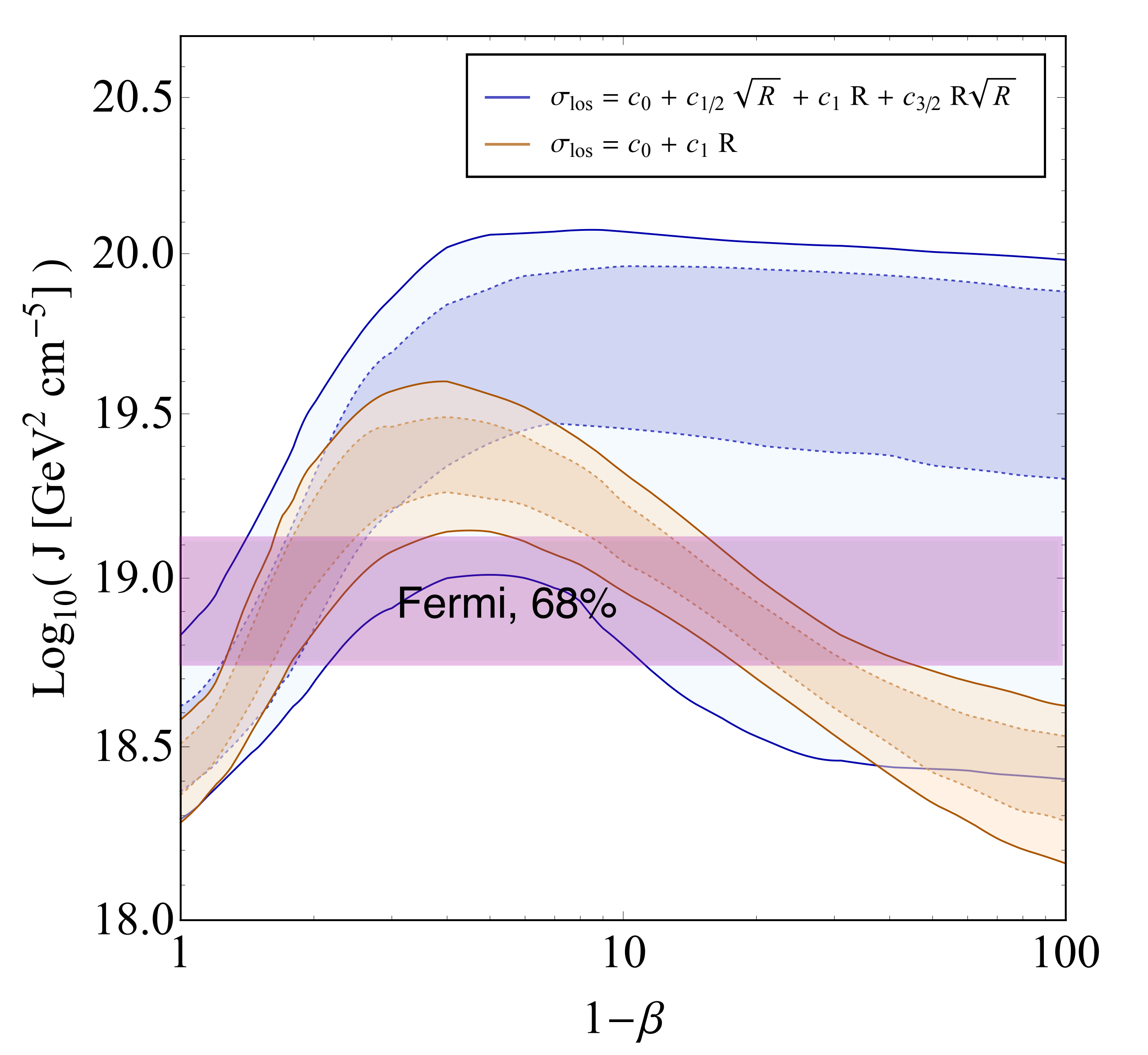

A bulk of very singular profiles, possibly irrelevant for the phenomenology; note however also the more shallower ones giving lower J!

Take home message: current and projected limits from dwarfs need caution!

Conclusions:

Dark matter particles may still be indirectly detected (as well as directly detected in underground labs or produced at accelerators), but the playground for almost all detection channels proposed so far is that a small signal is expected on top of a large background.

Particular caution is then needed in this playground, examining critically what are the assumptions involved in both background estimates and signal predictions.

The point has been illustrated here via two examples which received particular attention recently: a tentative DM γ-ray signal from the central region of the Galaxy and DM γ-ray limits from dwarf satellites.