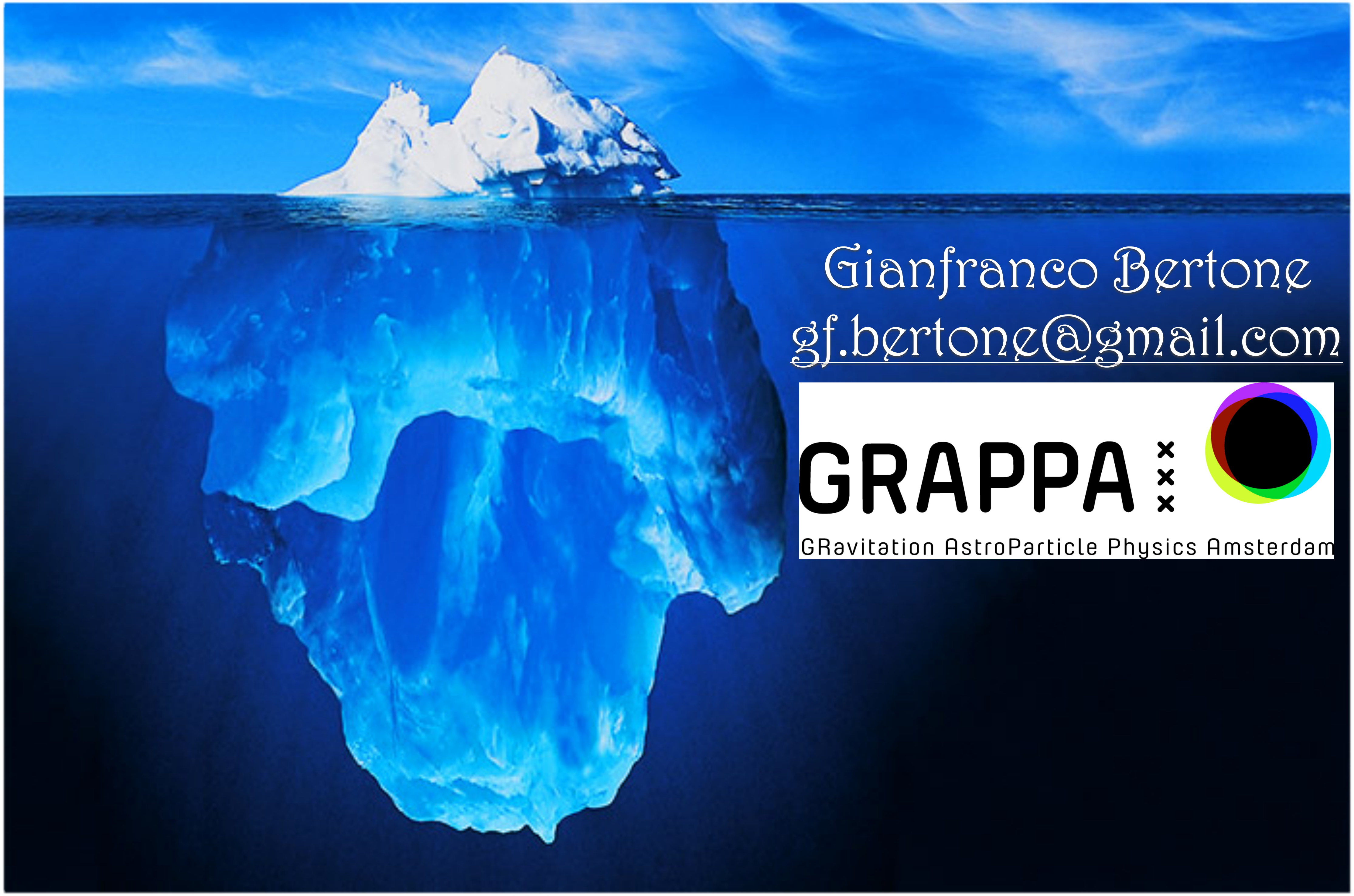
Indirect Detection



Gianfranco Bertone
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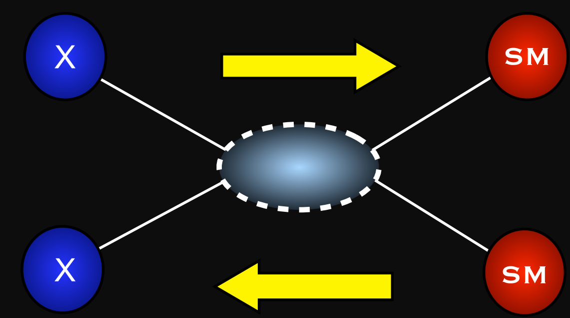
Dark Matter freeze-out

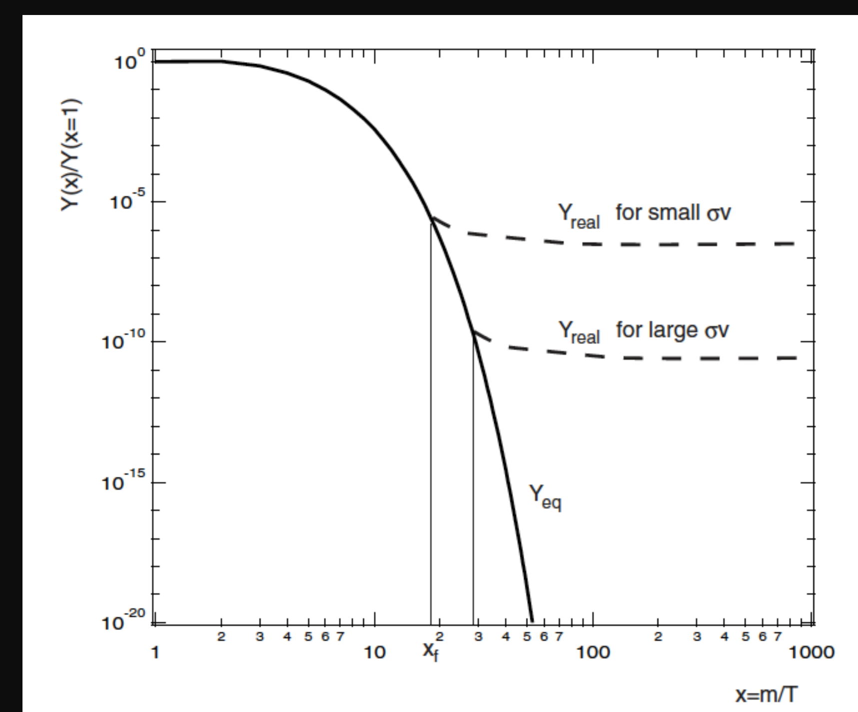
X = DARK MATTER



SM = STANDARD MODEL PARTICLE

The density of dark matter particles is regulated by the so-called Boltzmann equation

$$\frac{dn_\chi}{dt} - 3Hn_\chi = -\langle \sigma v \rangle \left[n_\chi^2 - (n_\chi^{eq})^2 \right]$$



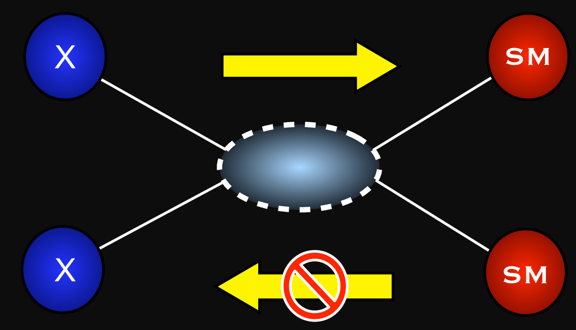
The relic density of Dark Matter particles today is approximately equal to

$$\Omega h^2 \approx \frac{3 \times 10^{-27} cm^3 s^{-1}}{< \sigma v >}$$

...identifies a *thermal* cross section, approximately at the weak scale, this is sometimes referred to as 'the WIMP miracle'!

Dark Matter annihilations today

X = DARK MATTER



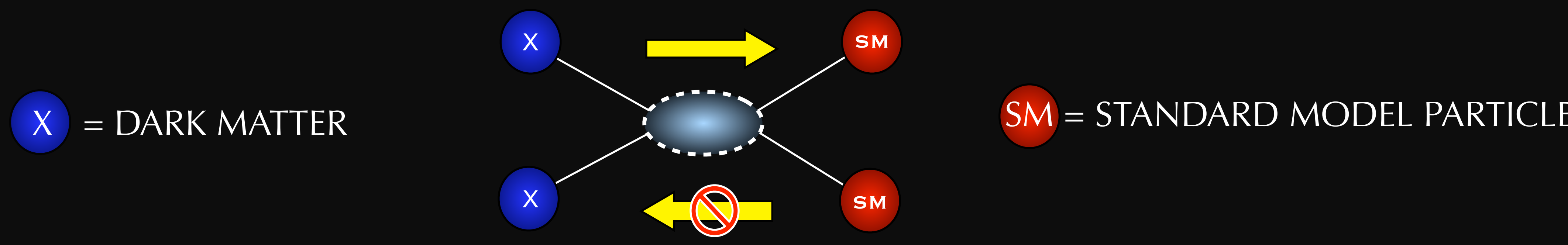
SM = STANDARD MODEL PARTICLE

In regions with very high dark matter density the annihilation rate can be very high!

$$\Phi_i\left(\Omega, E_i\right) = \frac{dN}{dE_i}$$

- dN/dE is the number of particles (e.g. photons) per energy interval produced in the annihilation process

Dark Matter annihilations today

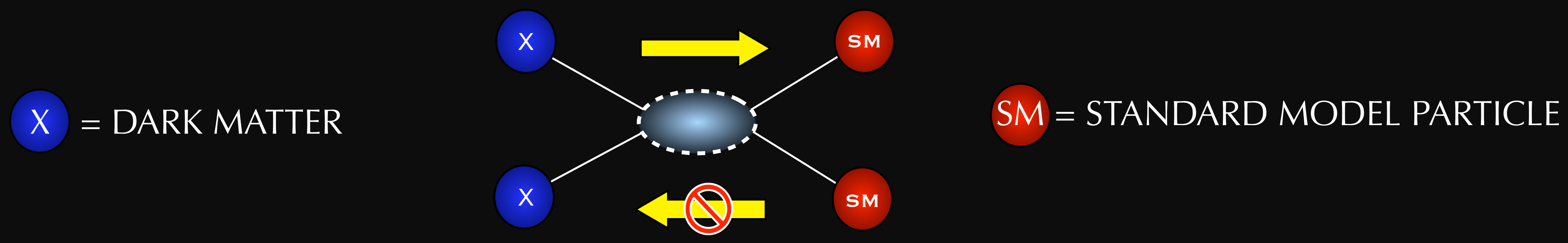


In regions with very high dark matter density the annihilation rate can be very high!

$$\Phi_i\left(\Omega, E_i\right) = \frac{dN}{dE_i}\frac{\langle \sigma v \rangle}{\ }$$

- dN/dE is the number of particles (e.g. photons) per energy interval produced in the annihilation process
- σv is the annihilation cross section

Dark Matter annihilations today



In regions with very high dark matter density the annihilation rate can be very high!

$$\Phi_i(\Omega, E_i) = \frac{dN}{dE_i} \frac{\langle \sigma v \rangle}{8\pi m_\chi^2} \int_{los} \rho_\chi^2(\ell, \Omega) d\ell$$

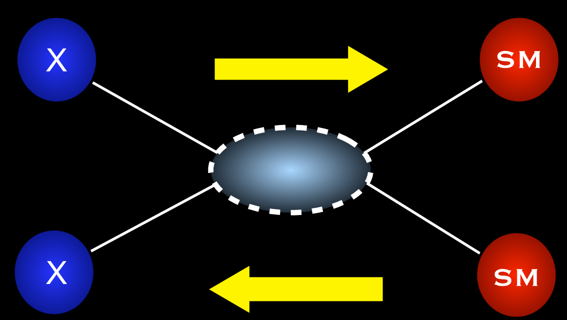
- dN/dE is the number of particles (e.g. photons) per energy interval produced in the annihilation process
- σv is the annihilation cross section
- m is the mass of the Dark Matter particle
- ρ is the mass density

Indirect Detection

Why "annihilations"?

X = Dark Matter   SM = Standard Model Particle

Early Universe



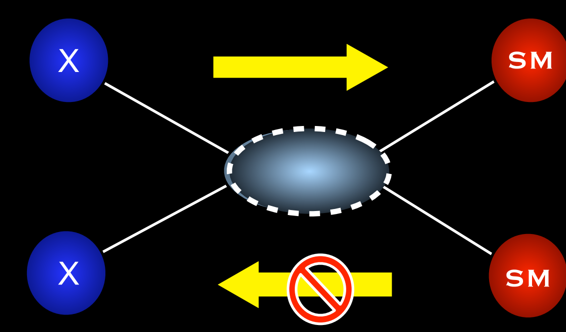
$$\frac{dn_\chi}{dt} - 3Hn_\chi = -\langle \sigma v \rangle \left[n_\chi^2 - (n_\chi^{eq})^2 \right]$$

Relic density (NR freeze-out)

$$\Omega h^2 \approx \frac{3 \times 10^{-27} cm^3 s^{-1}}{< \sigma v >}$$

Electroweak-scale cross sections can reproduce correct relic density.

Today



$$\frac{dn_\chi}{dt} = -(\sigma v)_o n_\chi^2$$

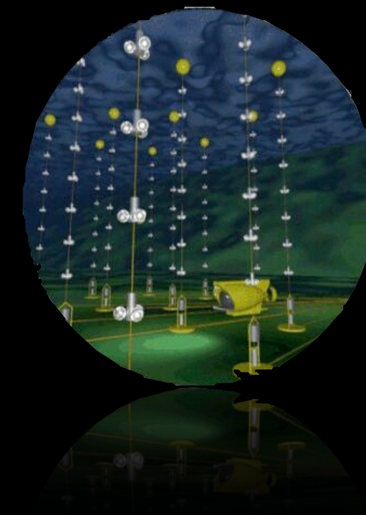
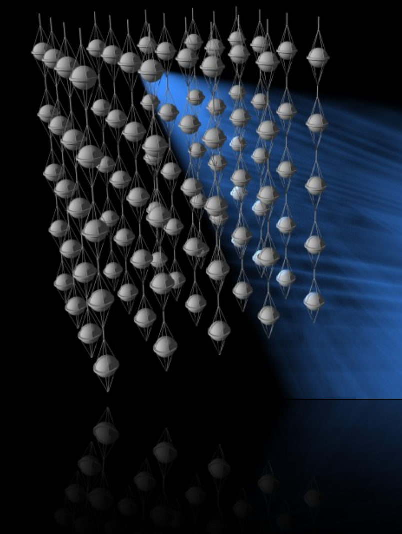
Annihilation Flux

$$\Phi_i(\Omega, E_i) = \frac{dN}{dE_i} \frac{\langle \sigma v \rangle}{8\pi m_\chi^2} \int_{los} \rho_\chi^2(\ell, \Omega) d\ell$$

Particle physics input from extensions of the Standard Model. Need to specify distribution of DM along the line of sight.

Indirect Detection



Gamma-ray telescopes

- ACTs: HESS, MAGIC, VERITAS, (CTA)
- Space satellite FERMI LAT
- Future: CTA (Gamma400?, DAMPE?)

Anti-matter Satellites

- PAMELA
- AMS-02
- Future: Herd?

Neutrino Telescopes

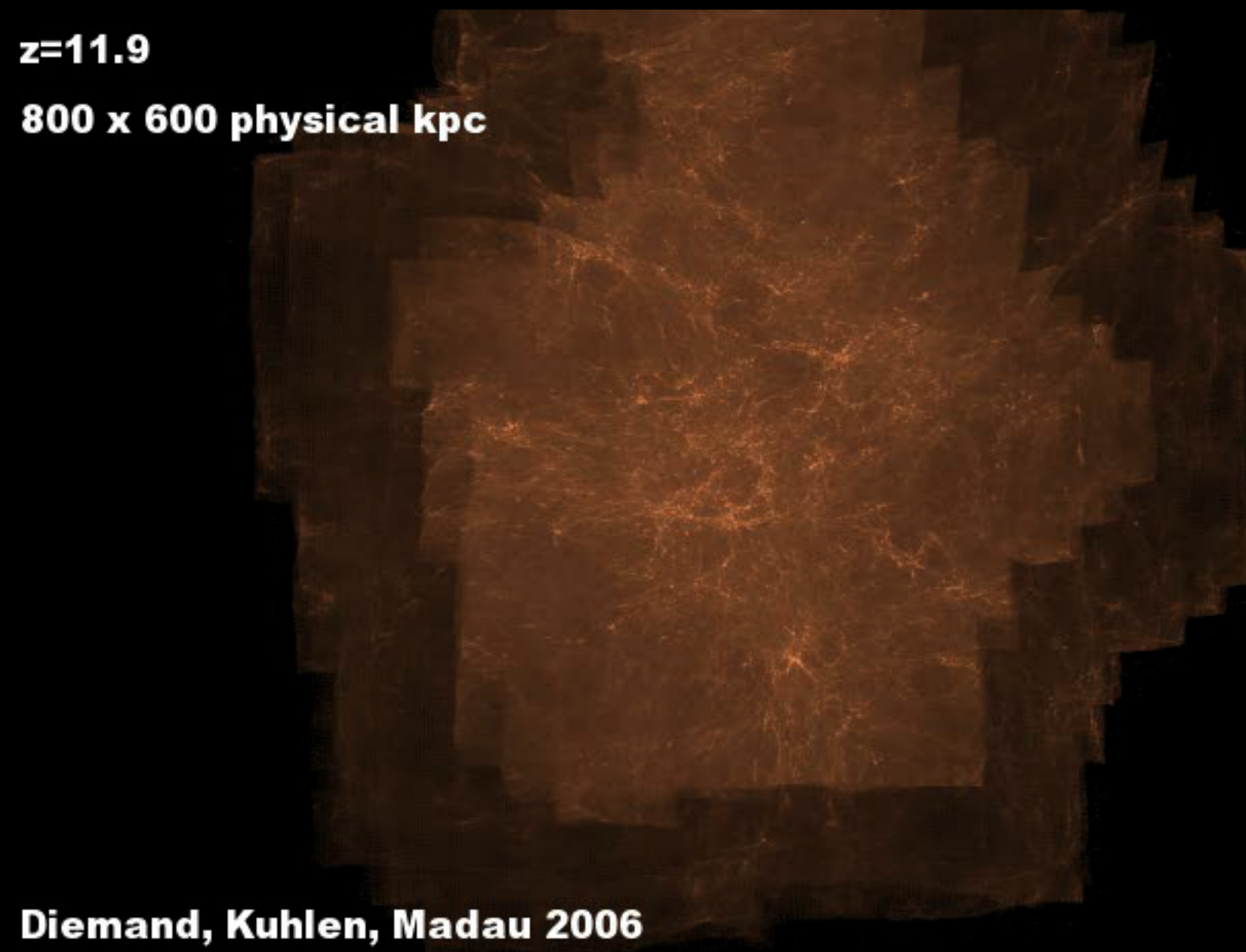
- Amanda, IceCube
- Antares, Nemo, Nestor
- Km3Net

Other

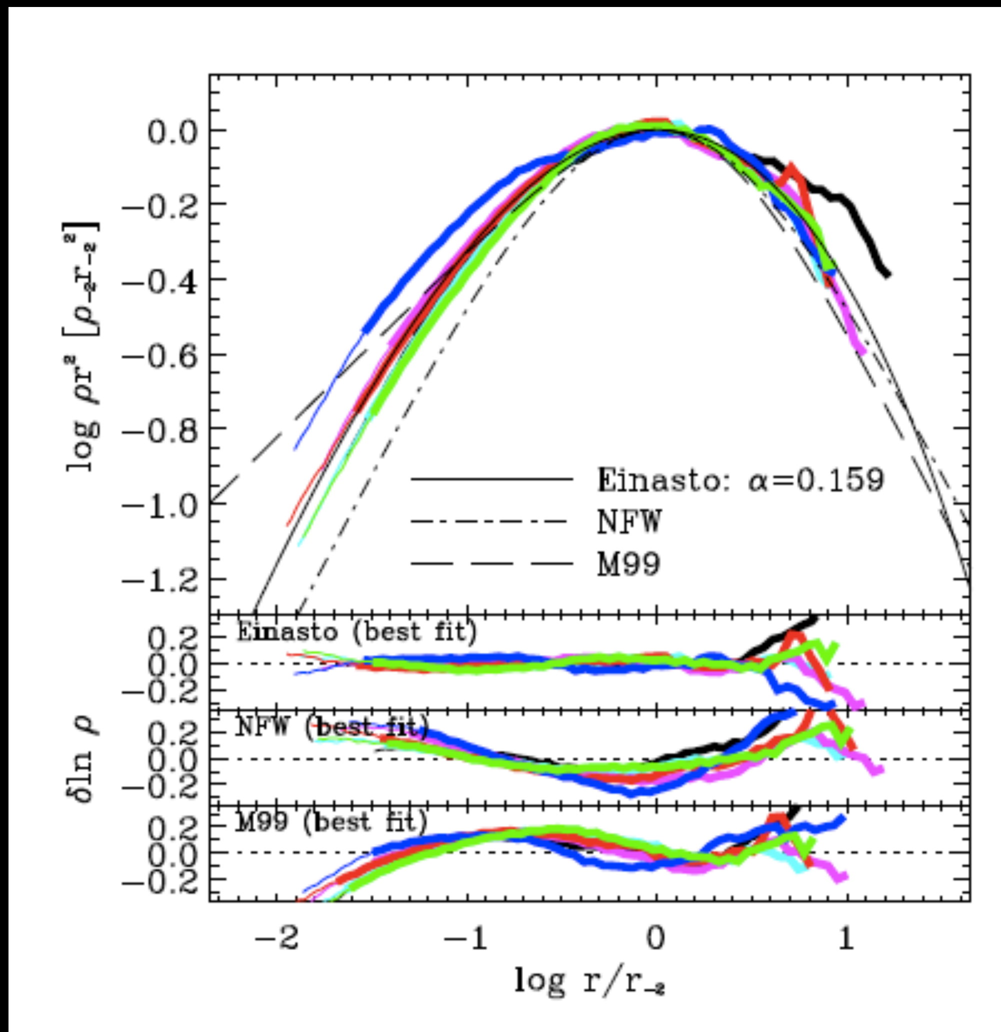
- Synchrotron Emission
- SZ effect
- Effect on Stars
- X-ray telescopes
- Axion searches (recent ‘discovery’…)

Deriving Exclusion Plots

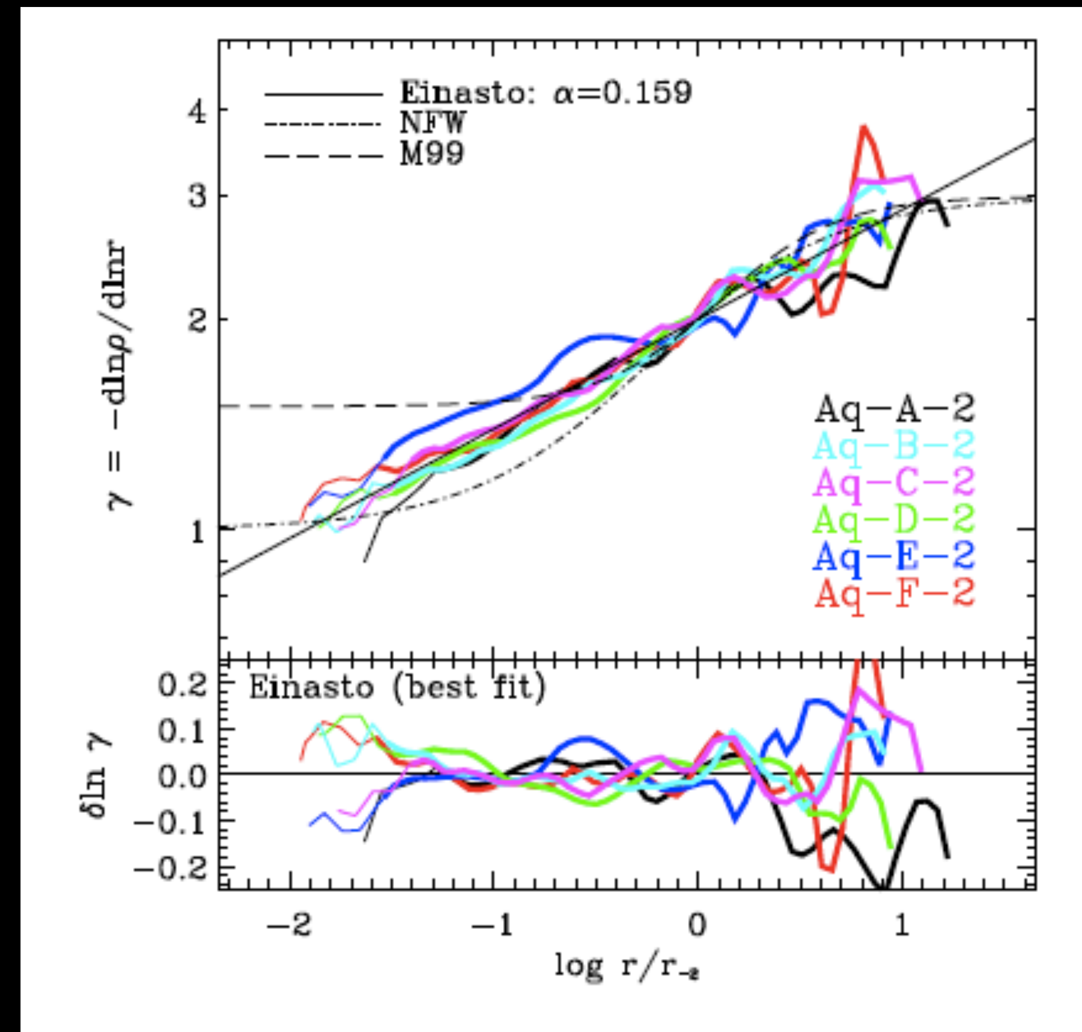
I. Take a numerical simulation



Density profiles "observed" in N-body simulations



Navarro et al. 2008



Navarro et al. 2008

"Universal" profiles, characterised by 2 parameters. Surprisingly accurate for most purposes.

$$\rho(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2},$$ Navarro-Frenk-White

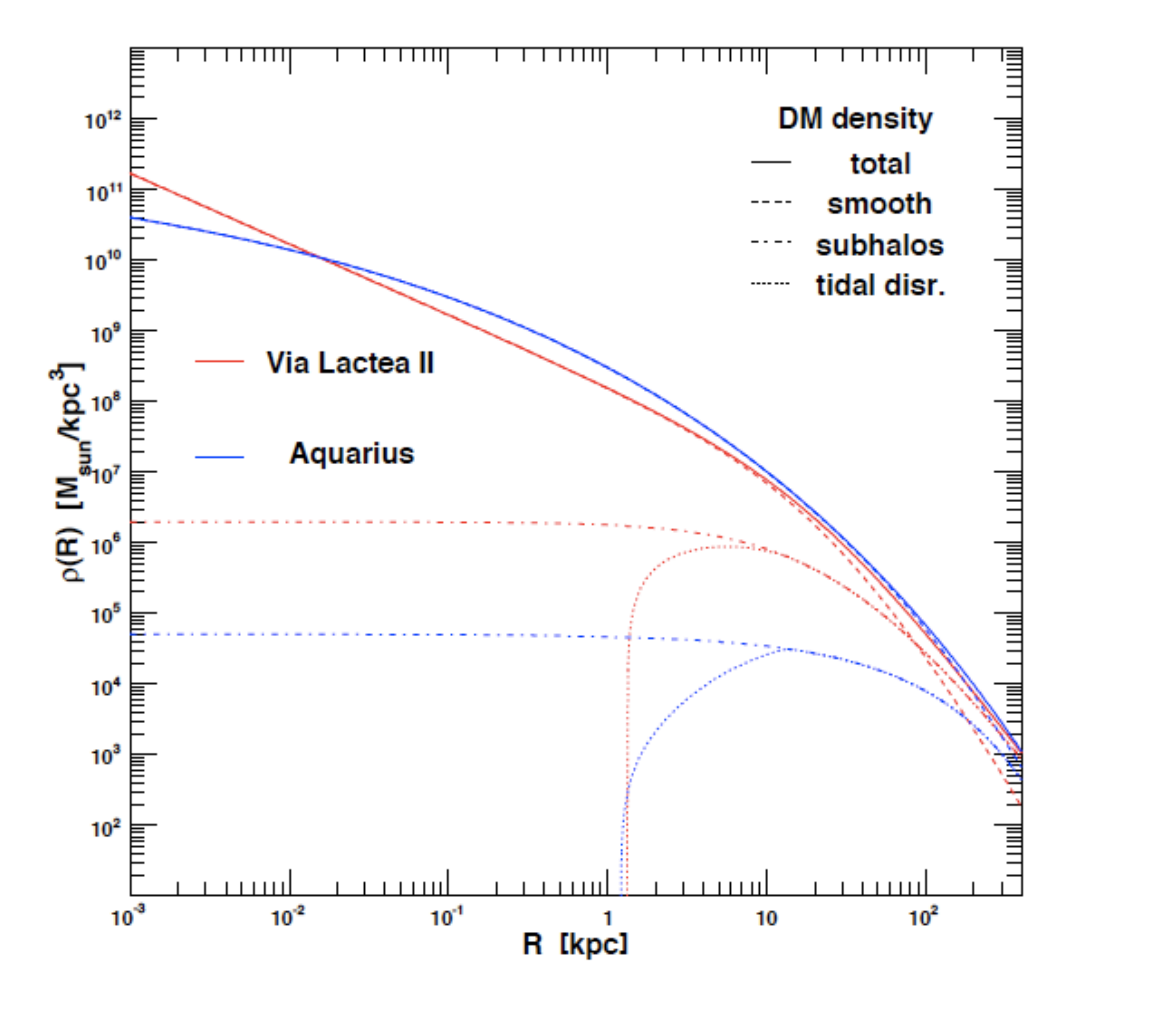
$$\rho(r) = \frac{\rho_M}{(r/r_M)^{1.5}[1+(r/r_M)^{1.5}]},$$ Moore

$$\ln(\rho(r)/\rho_{-2}) = (-2/\alpha)[(r/r_{-2})^{\alpha} - 1].$$ Einasto

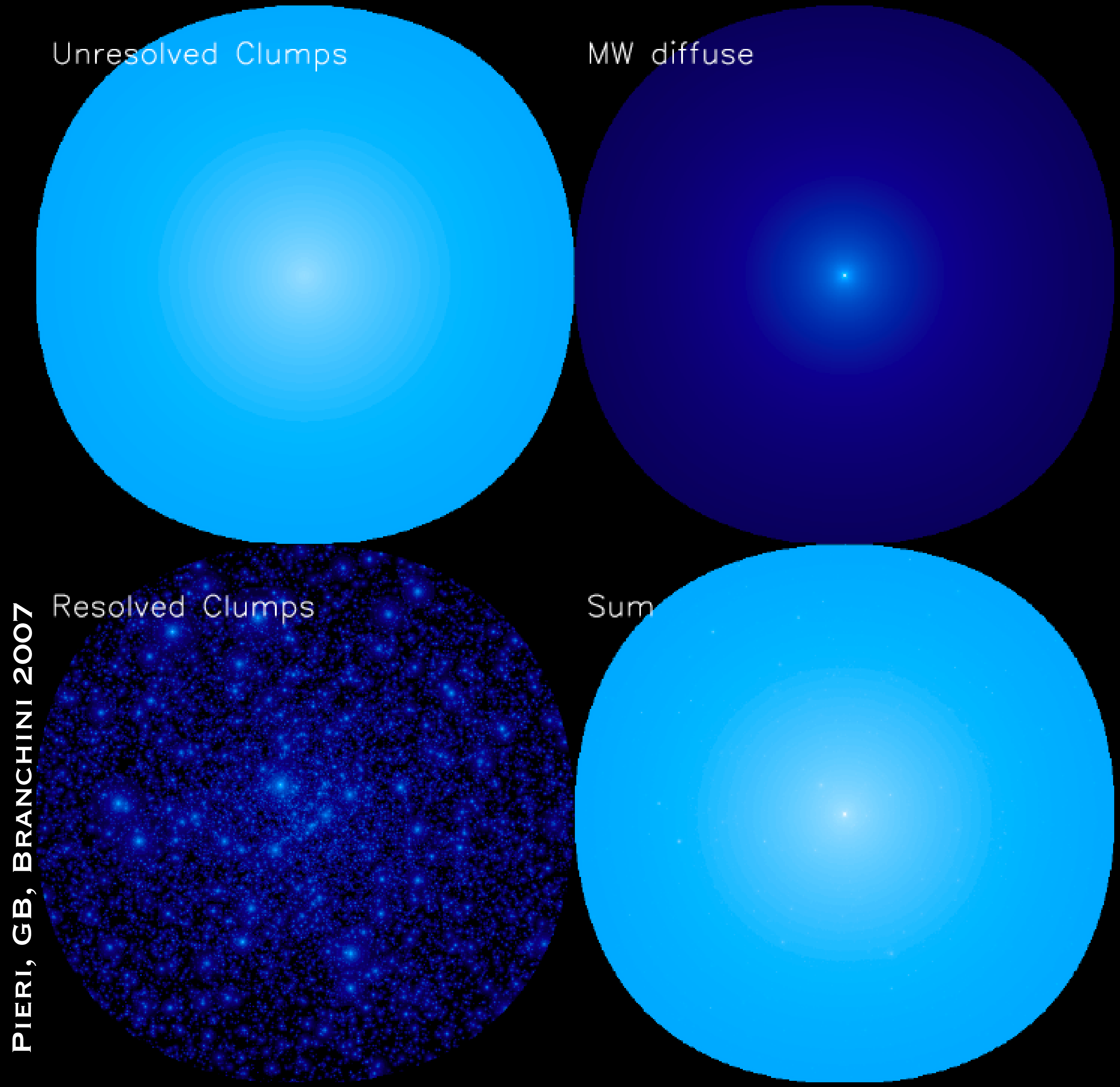
Gamma-rays from DM annihilation

$$\Phi_\gamma(\psi) \simeq 0.94 \cdot 10^{-13} \left(\frac{N_\gamma\, v\sigma}{10^{-29}\ \mathrm{cm^3 s^{-1}}}\right)\left(\frac{100\,\mathrm{GeV}}{m_\chi}\right)^2 \ J(\psi)\ \mathrm{cm^{-2}\ s^{-1}\ sr^{-1}}$$

$$J(\psi) = \frac{1}{8.5\,\mathrm{kpc}} \cdot \left(\frac{1}{0.3\,\mathrm{GeV/cm^3}}\right)^2 \int_{line\ of\ sight} \rho^2(l)\, dl(\psi)$$



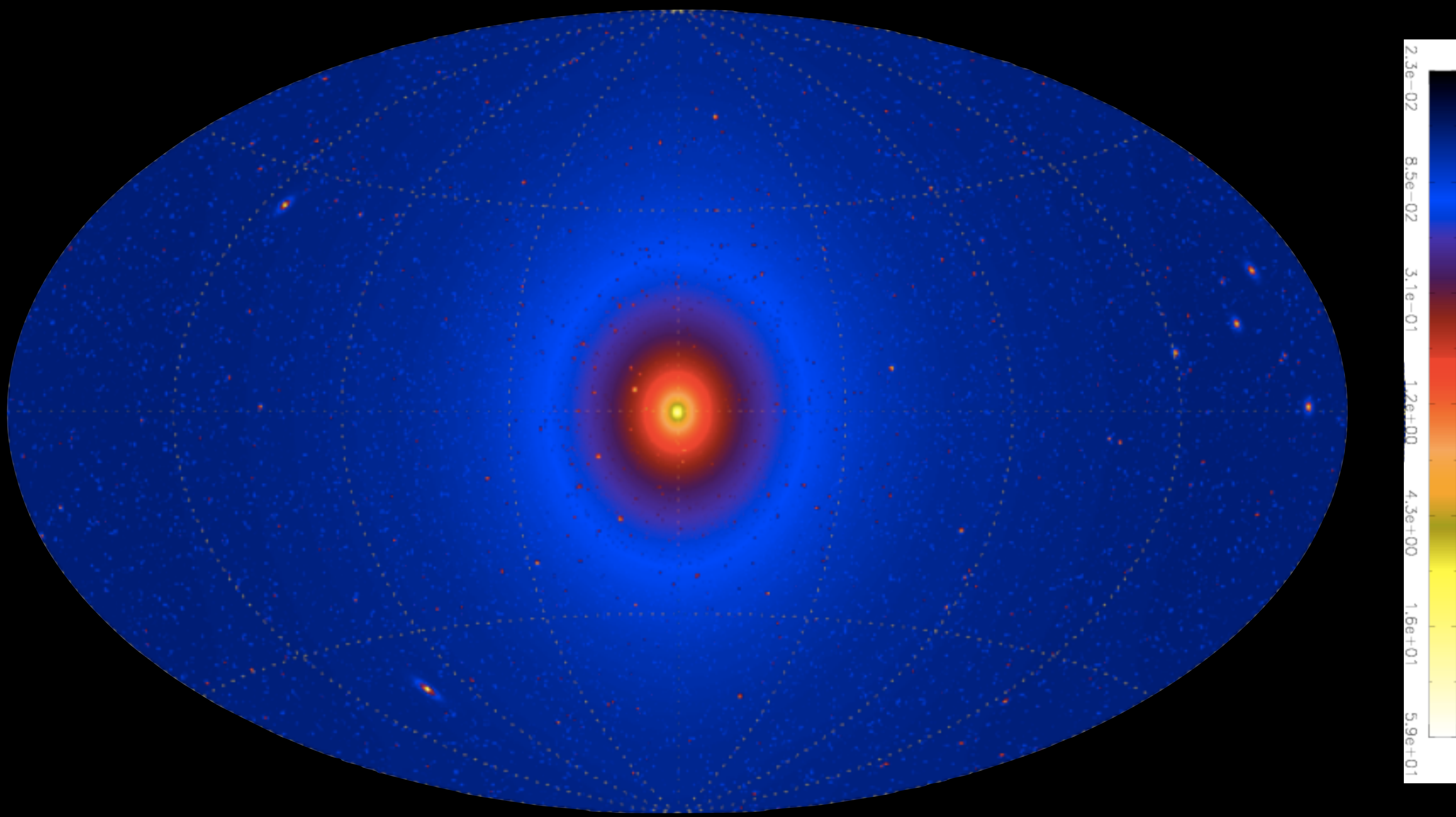
Total gamma-ray flux



The integral along the line of sight will give something proportional to the figures on the right, but then to convert this into a flux, one needs to specify N_gamma, i.e. the photon spectrum per annihilation...

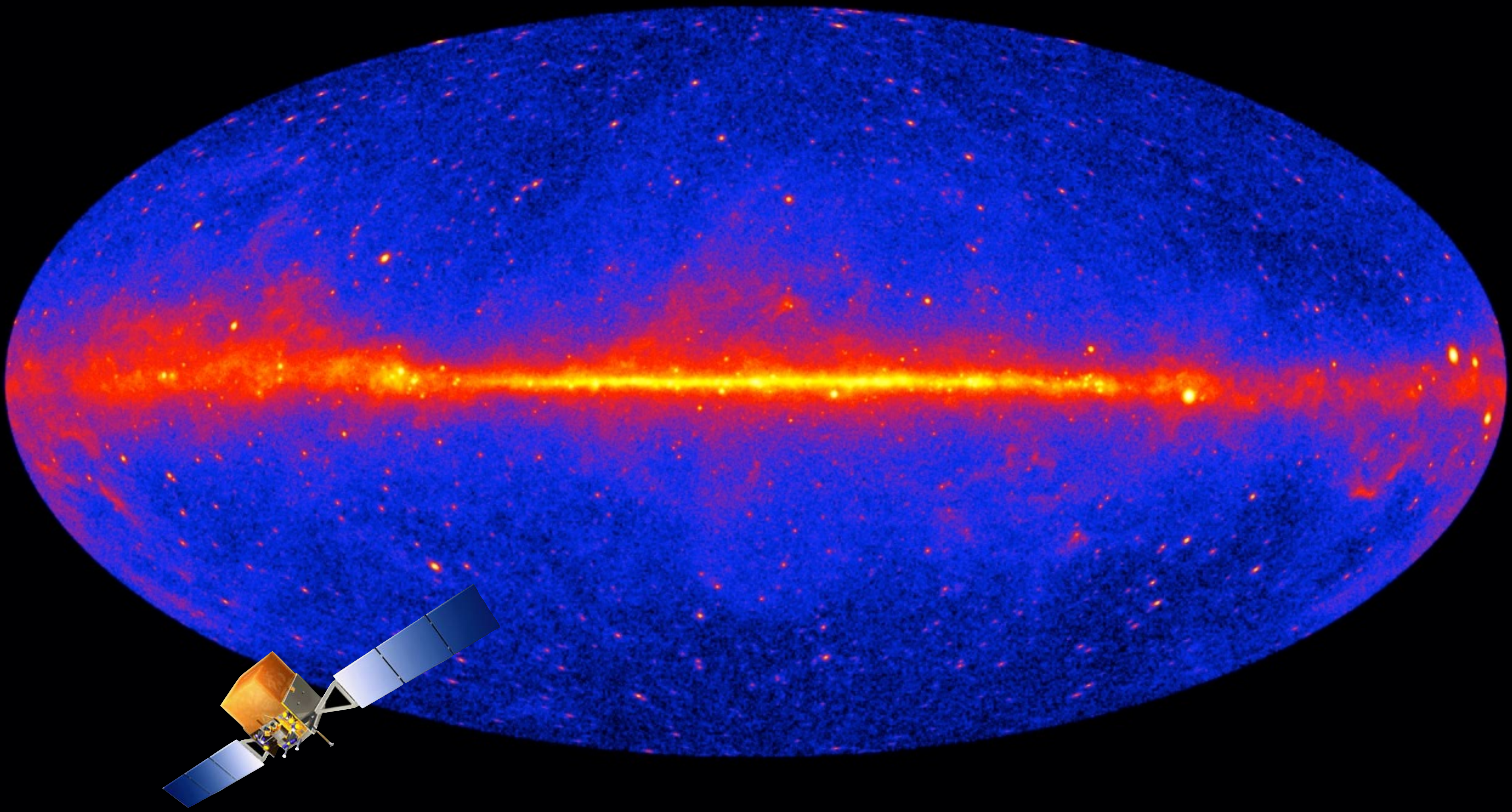
Predicted Annihilation Flux

Pieri, GB, Branchini 2009

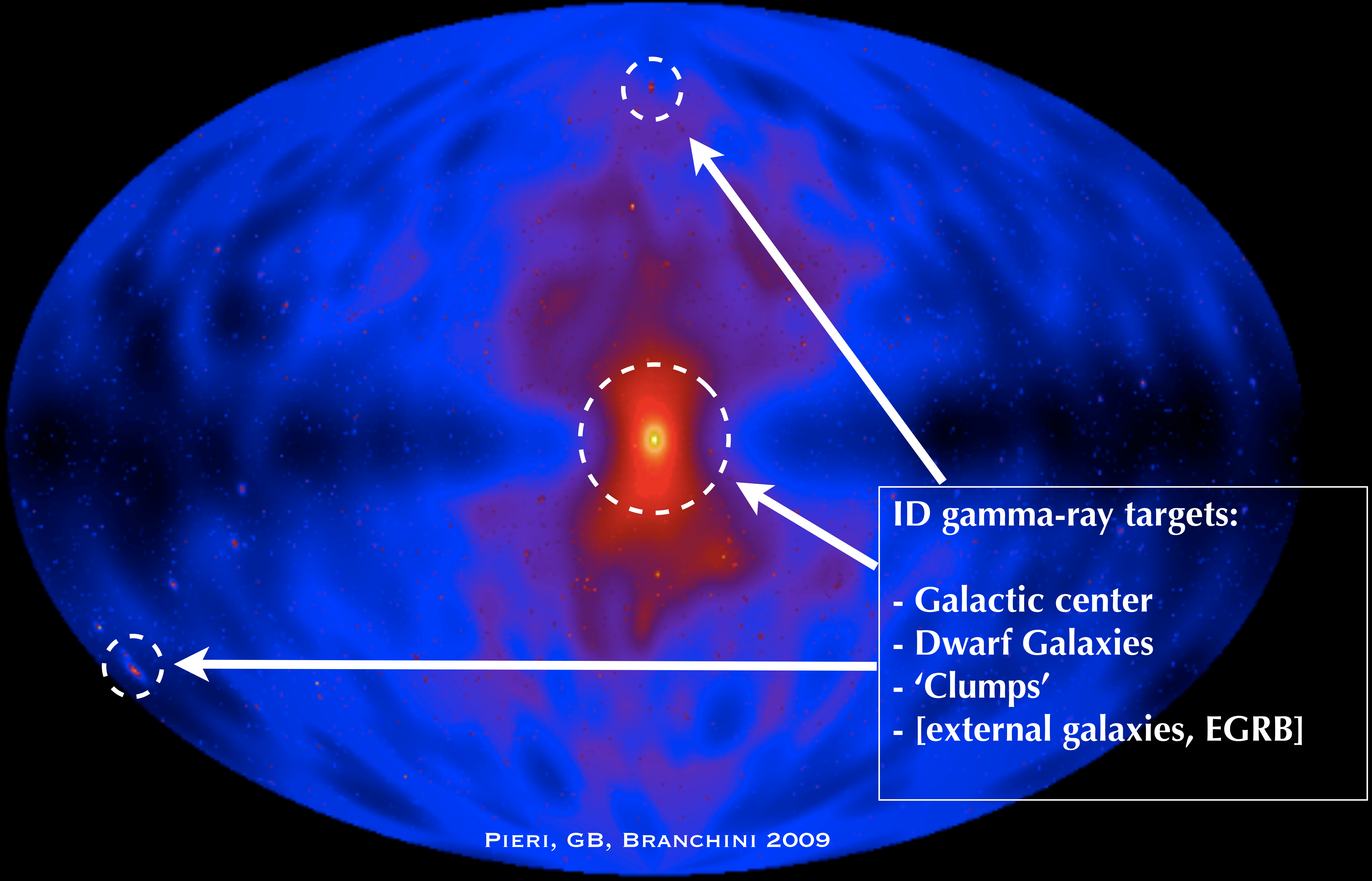


Full sky map of Number of photons above 3 GeV

The FERMI sky



Sensitivity Map



Indirect Detection

Recent results: Daylan et al. arXiv:1402.6703

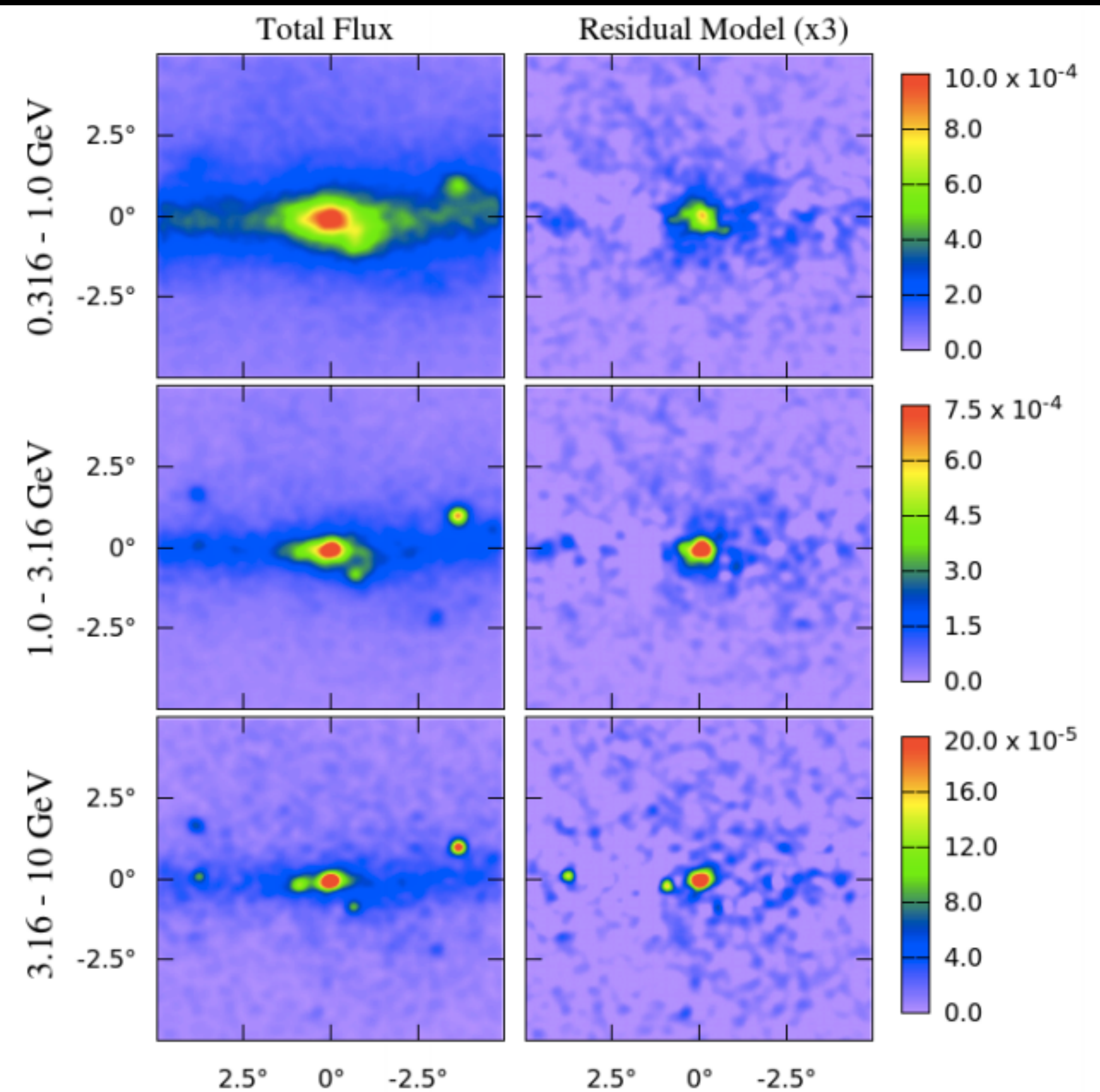
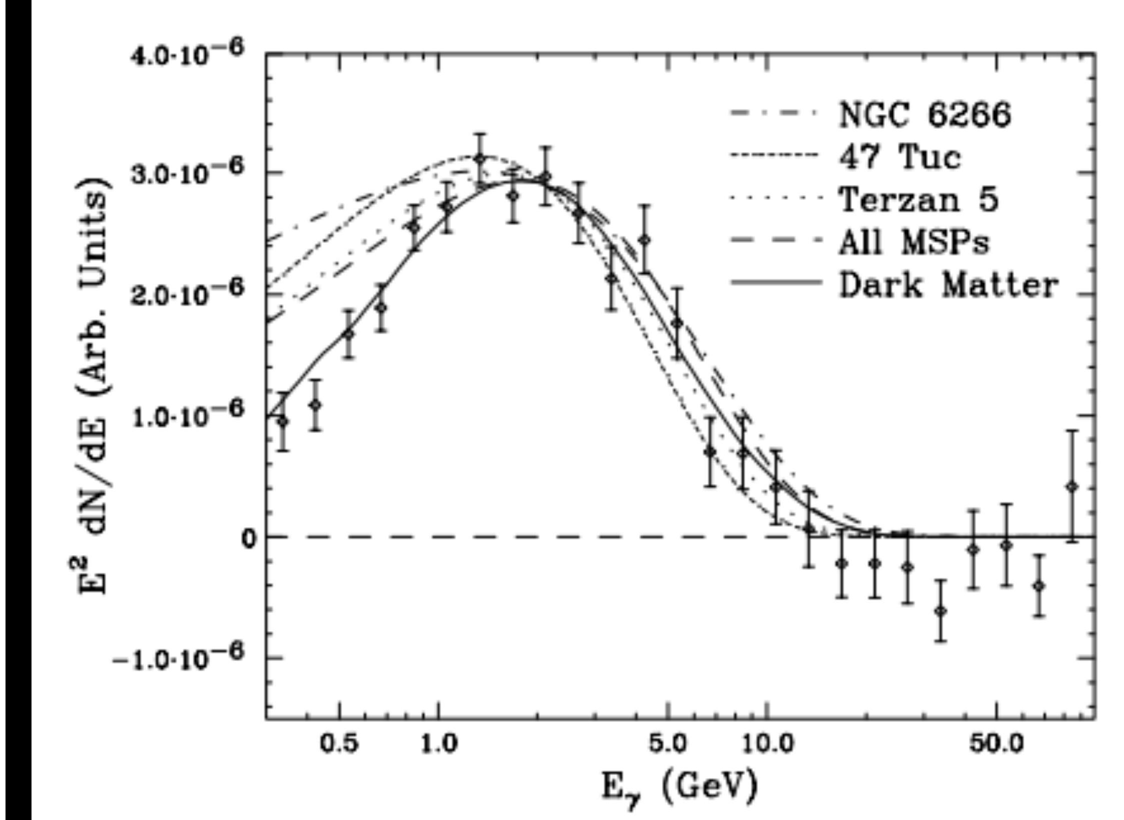


FIG. 9: The raw gamma-ray maps (left) and the residual maps after subtracting the best-fit Galactic diffuse model, 20 cm template, point sources, and isotropic template (right), in units of photons/cm^2/s/sr. The right frames clearly contain a significant central and spatially extended excess, peaking at ~1-3 GeV. Results are shown in galactic coordinates, and all maps have been smoothed by a 0.25° Gaussian.

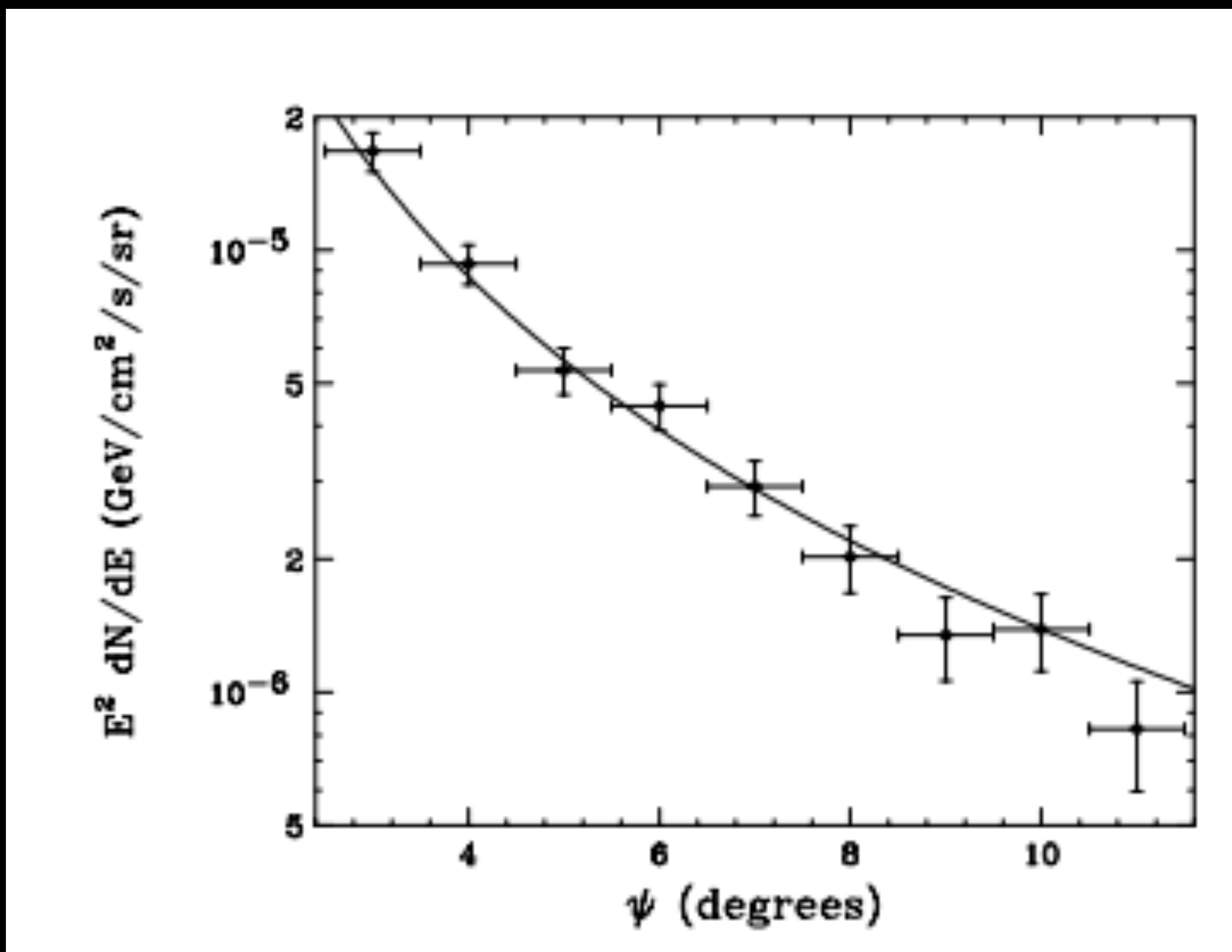


"Within these maps, we find the GeV excess to be robust and highly statistically significant, with a spectrum, angular distribution, and overall normalization that is in good agreement with that predicted by simple annihilating dark matter models"

See also thorough analysis in Calore et al. arXiv:1409.0042

The GeV excess

http://arxiv.org/abs/1402.6703



"To constrain the degree to which the gamma-ray excess is spatially extended, we have repeated our Inner Galaxy analysis, replacing the dark matter template with a series of concentric ring templates centered around the Galactic Cen-
ter.

The dark-matter-like emission is clearly and consistently present in each ring template out to 12^o , beyond which systematic and statistical limitations make such determinations
difficult. For comparison, we also show the predictions for a generalized NFW profile with γ = 1,4"

The GeV excess

Thorough analysis by Calore, Cholis & Weniger, in http://arxiv.org/abs/1409.0042

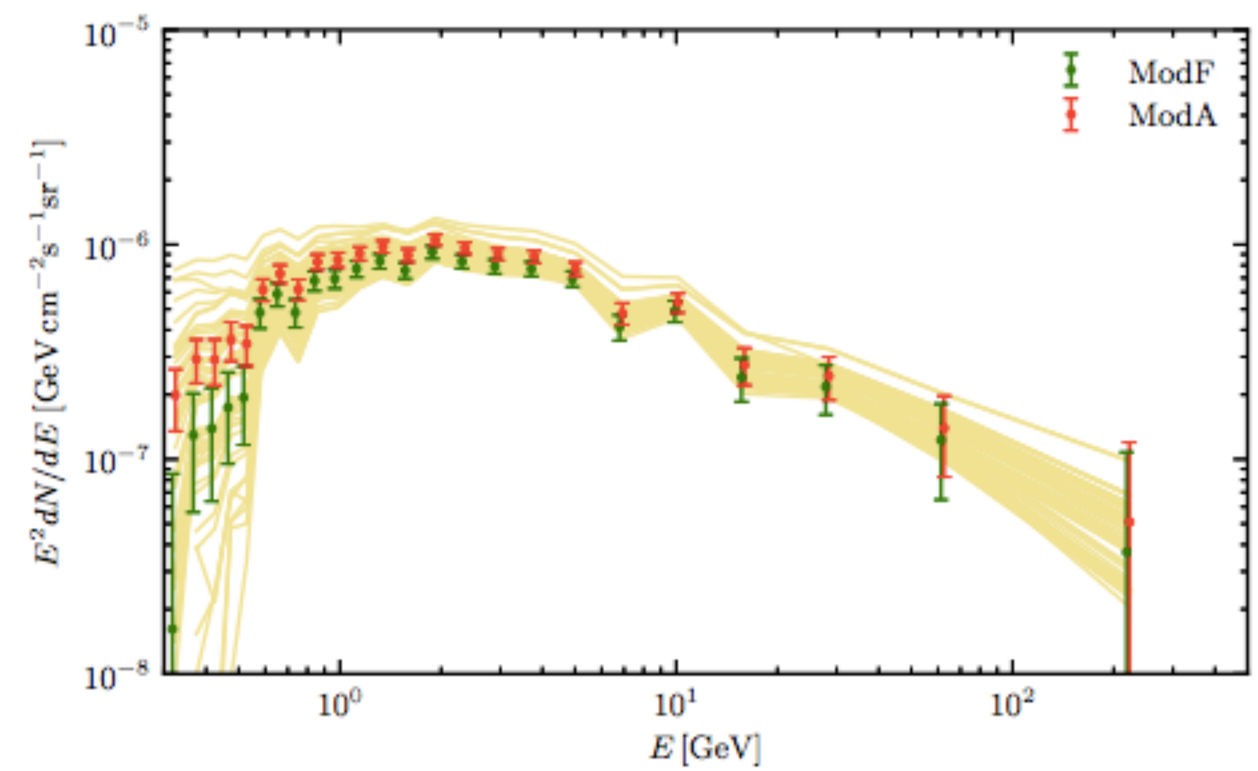


Figure 7. Plain GCE energy spectrum as extracted from our baseline ROI, assuming a generalized NFW profile with an inner slope $\gamma = 1.2$, for all of the 60 GDE models (*yellow lines*). We highlight the model that provides the best overall fit to the data (model F, *green points*) and our reference model from the discussion in section 3 (model A, *red points*), together with $\pm 1\sigma$ statistical errors. For all 60 GDE models, we find a pronounced excess that peaks at around 1–3 GeV, and follows a falling power-law at higher energies.

The GeV excess

Through analysis by Calore, Cholis & Weniger, in http://arxiv.org/abs/1409.0042

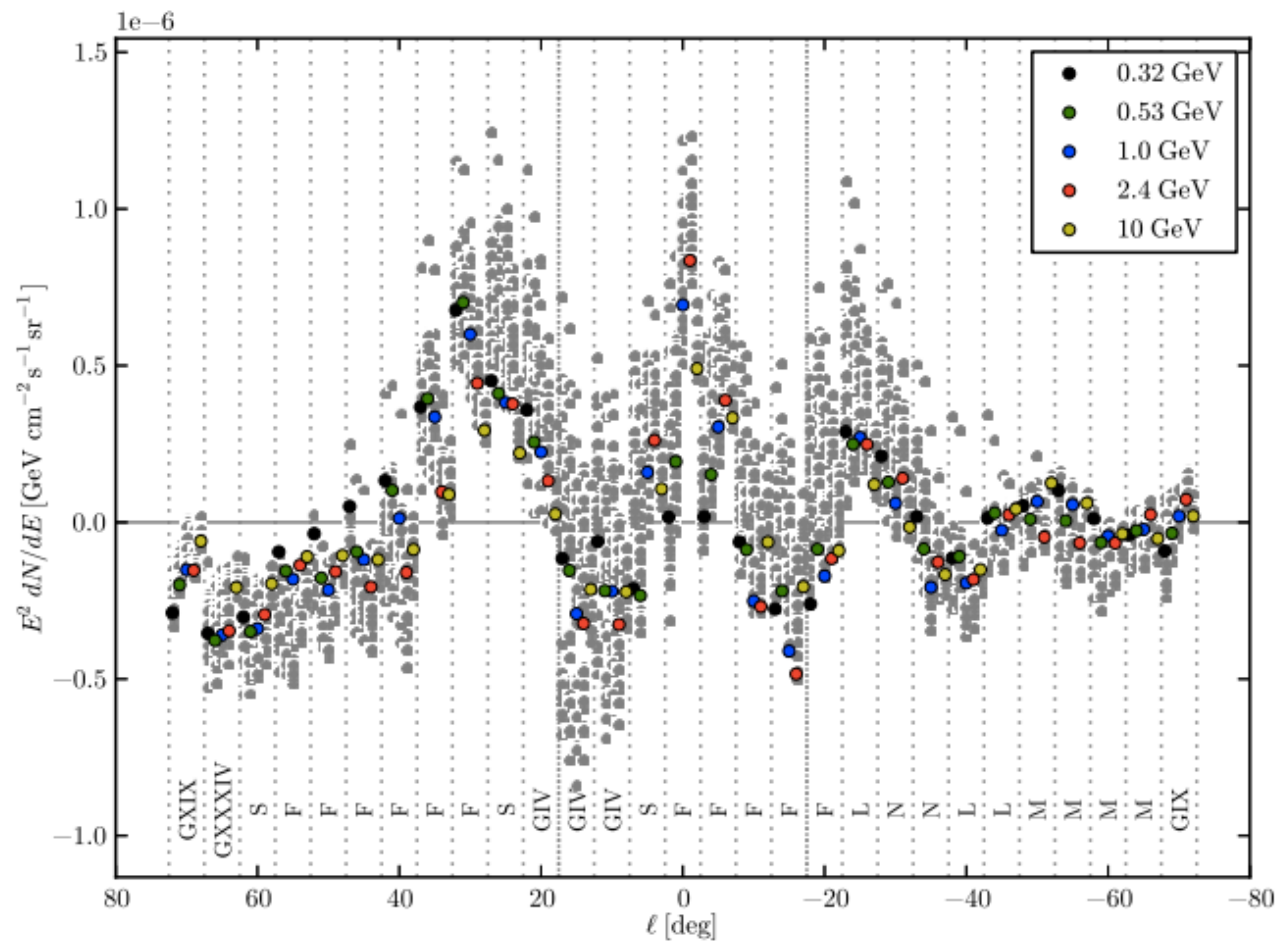
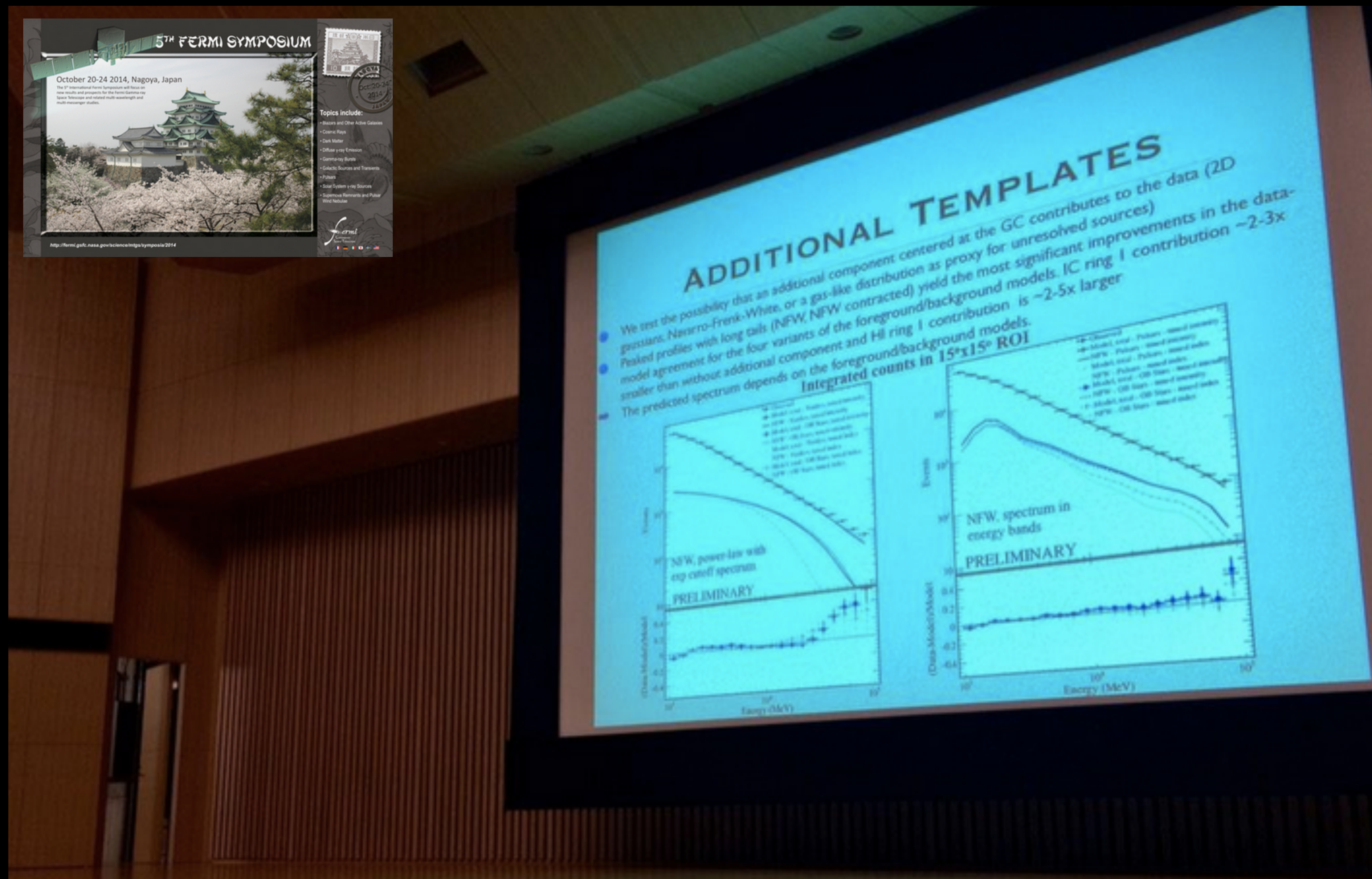


Figure 11. Flux absorbed by the GCE template when moving it, as well as the ROI, along the Galactic disk in steps of $\Delta\ell = \pm 5°$, for five different reference energies. The *colored dots* indicate the flux for the GDE model that gives *locally* the best-fit (these models are listed in the bottom of the plot), whereas the *gray dots* indicate the fluxes for all other models. The excess observed at the GC is – at around 1–3 GeV – clearly the largest in the considered region, although other excesses exist as well (see text for a discussion). Regions with $|\ell| \gtrsim 20°$ (indicated by the *vertical dotted lines*) will be used as test regions for estimates of the empirical model uncertainties of the adopted GDE models.

The GeV excess

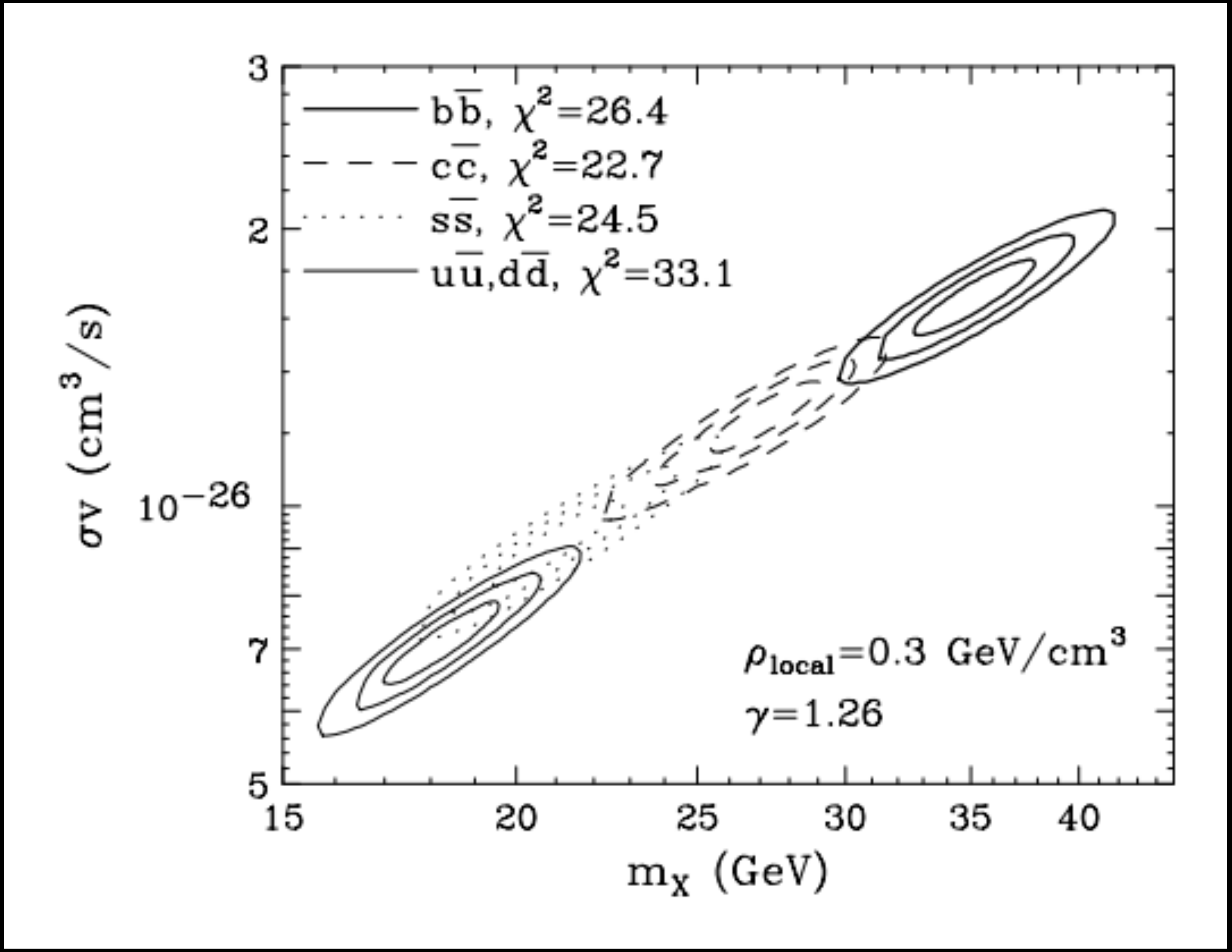


Kevork Abazajian @kevaba · 4h
Murgia: Galactic Center peaked NFW #darkmatter profiles provide the best improvement of the fits. #FermiSymposium14
1

Presented a few *hours* ago at the Fermi Symposium, Nagoya, Japan

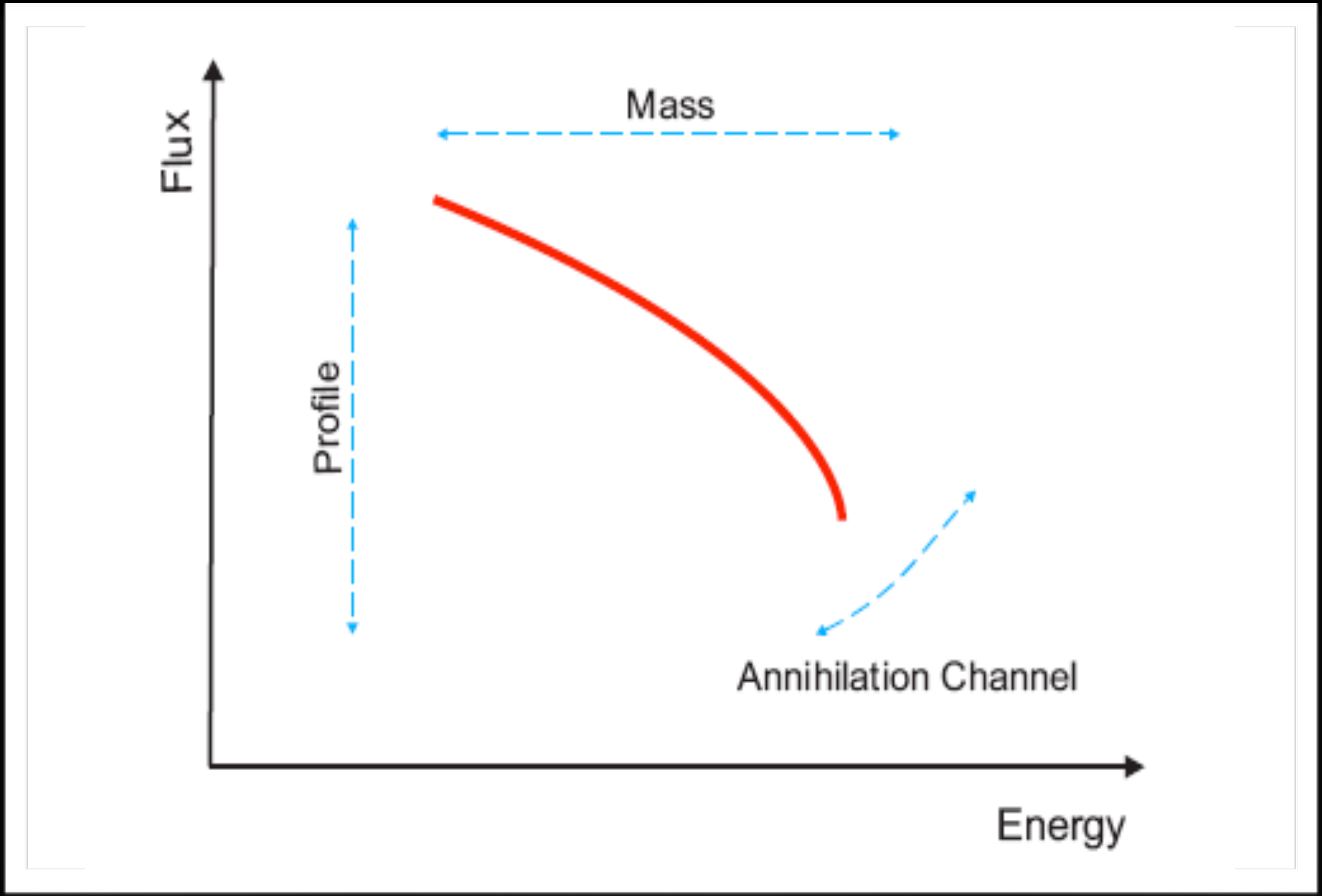
The GeV excess

http://arxiv.org/abs/1402.6703



…so what?!

The trouble with indirect searches



... the "inverse problem" always admits a solution, even when the data have nothing to do with DM!

The GeV excess

Colis, Hooper and Linden,
http://arxiv.org/abs/1407.5625

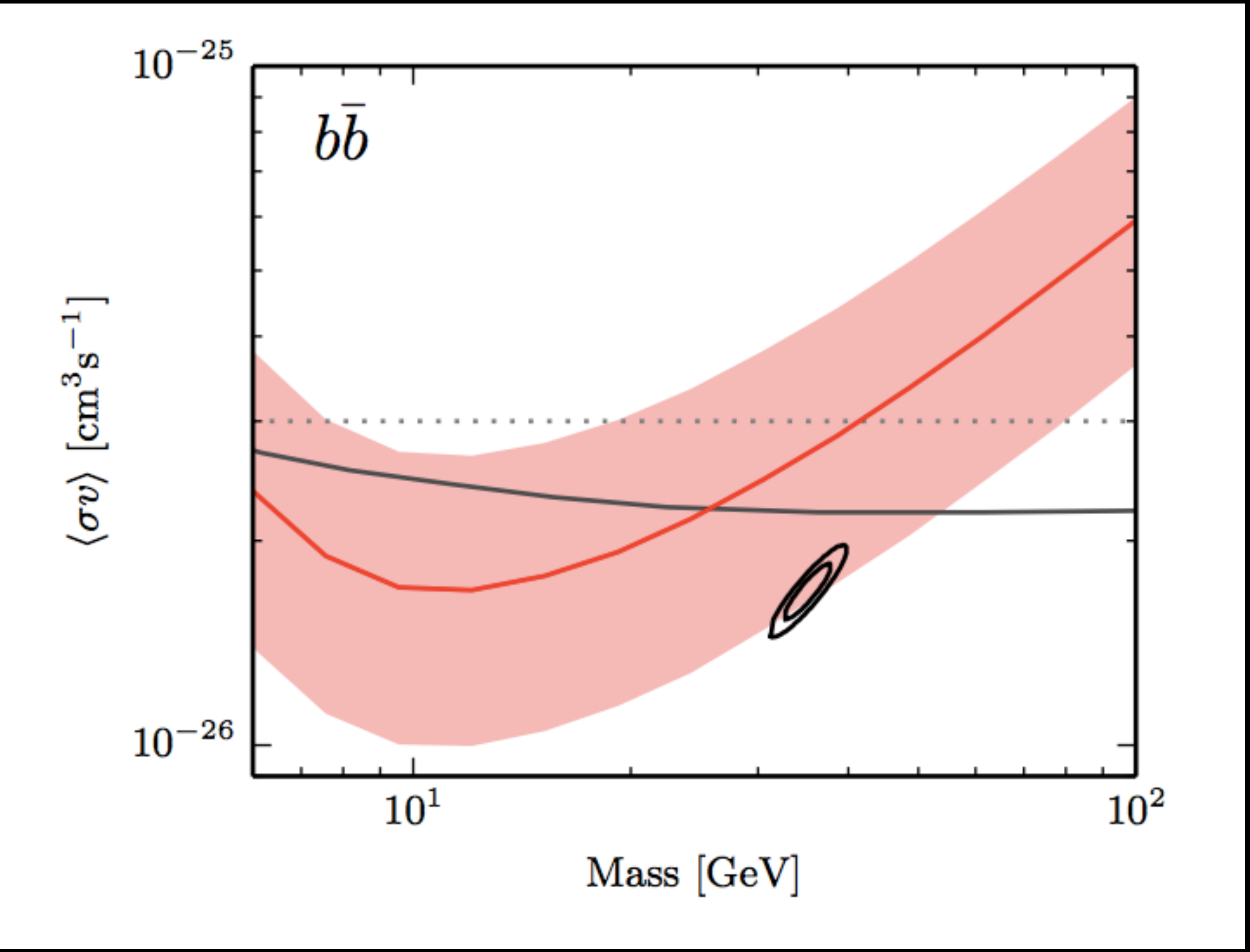
Astrophysical sources?

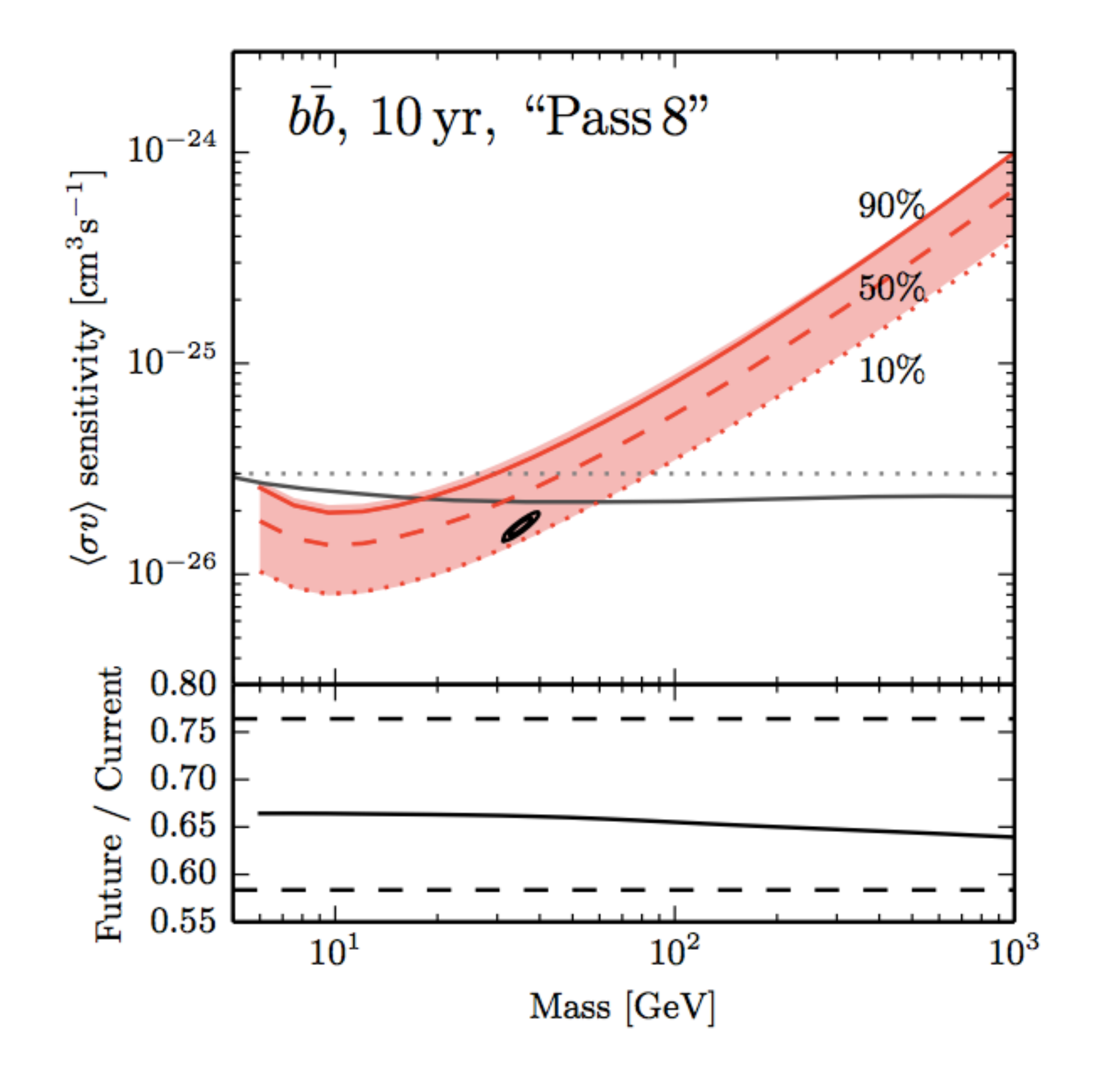
Gamma-ray point sources should be faint (no sources brighter than $\sim 10^{34}$ erg/s), and extremely numerous (tens of thousands of sources within the innermost kpc).

[The luminosity function of millisecond pulsars, in contrast, is observed to extend to at least $\sim 2 \times 10^{35}$ erg/s, plus observed energy spectrum is softer]

How do we convince ourselves?

CROSS-CHECK WITH DWARF GALAXIES!

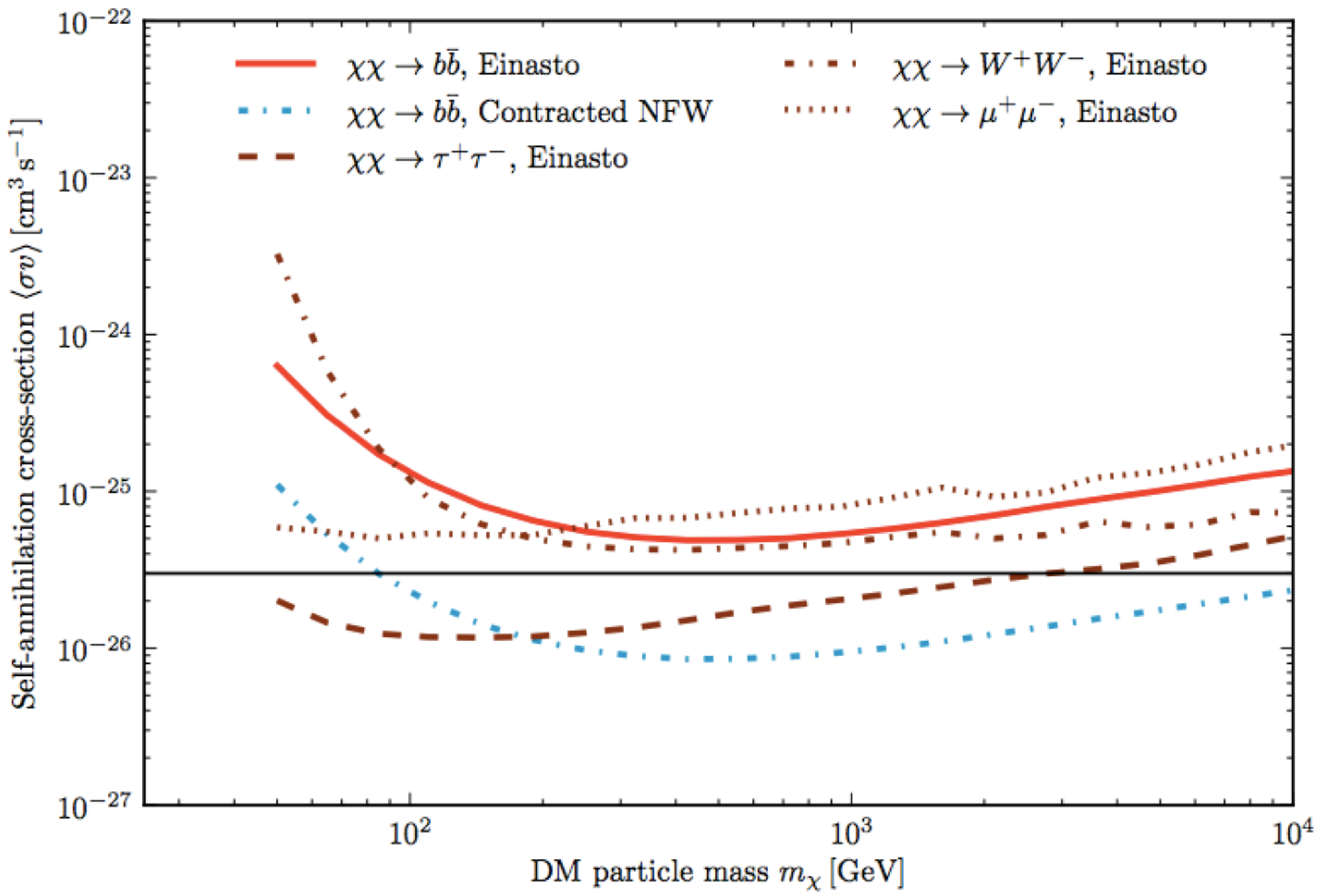




Geringer-Sameth et al., arXiv:1410.2242

What can CTA do?

Silverwood, Weniger, Scott, Bertone, arXiv:1408.4131



Comparison of $\langle\sigma v\rangle$ limits from CTA observations of the GC, assuming different annihilation channels and DM halo profiles. Einasto lines assume the main halo profile described in Sec. 3. The contracted NFW profile with an inner slope of $\gamma = 1.3$ can also be found in that section. All lines assume 1% systematics, 100 hr of observations and include GDE.

GRAPPA GRavitation AstroParticle Physics Amsterdam

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