Cold Dark Matter substructures and sub-substructures and their influence on γ-rays indirect detection

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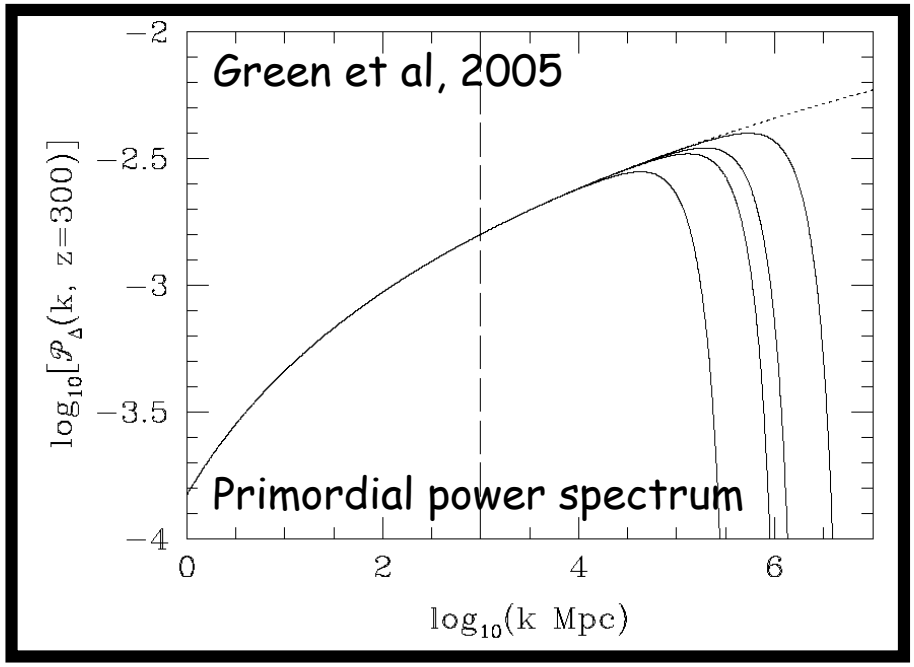
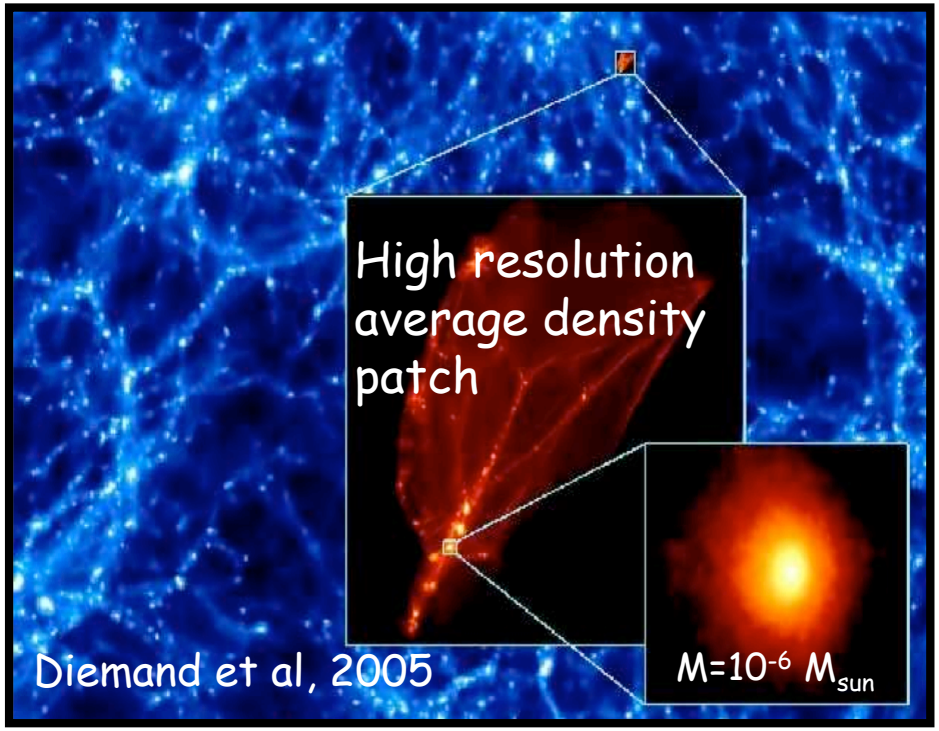
Based on works with Carlo Giocoli and Bepi Tormen

TeVPA08, Beijing, September 24th, 2008

CDM framework



Theory: Damping of the primordial power spectrum due to CDM free streaming gives
$M_{fs}=10^{-6}M_{sun}$ @ $M_{CDM}=100$ GeV



N-body simulations:

Using results of Via Lactea simulation (Diemand et al)

WARNING: recent Aquarius simulation of the MW (Springel et al, 2008) finds less subhalos and fitting an Einasto profile, rather than NFW. All the results of this talk may be upper limits.

Via Lactea results on subhalos

✓ Abundance in the MW: about 10^{16} subhalos with $dN/dM \sim M^{-2}$

✓ The mass of each progenitor accreted by the parent halo has a mass variance associated when it was a isolated halo.
The subhalo material is distributed according to this early σ-peak of the primordial density fluctuation field it belonged to:

$$n_{sh}(M, r, \nu) \propto \frac{dN_{sh}/dM}{\left(\frac{r}{r_\nu(M)}\right)^{\gamma}\left[1+\left(\frac{r}{r_\nu(M)}\right)^{\alpha}\right]^{\frac{\beta_\nu-\gamma}{\alpha}}}$$

$$r_\nu = r_s e^{\frac{\nu}{2}}$$

$$\beta_\nu = 3 + 0.26\nu^{1.6}$$

where ν is the number of σ-peaks.

✓ The concentration parameter inside each subhalo varies with ν :

$$c(\nu, M) = \nu(M)\, c(\nu=1, M)$$

We need to determine $\nu(M)$ …

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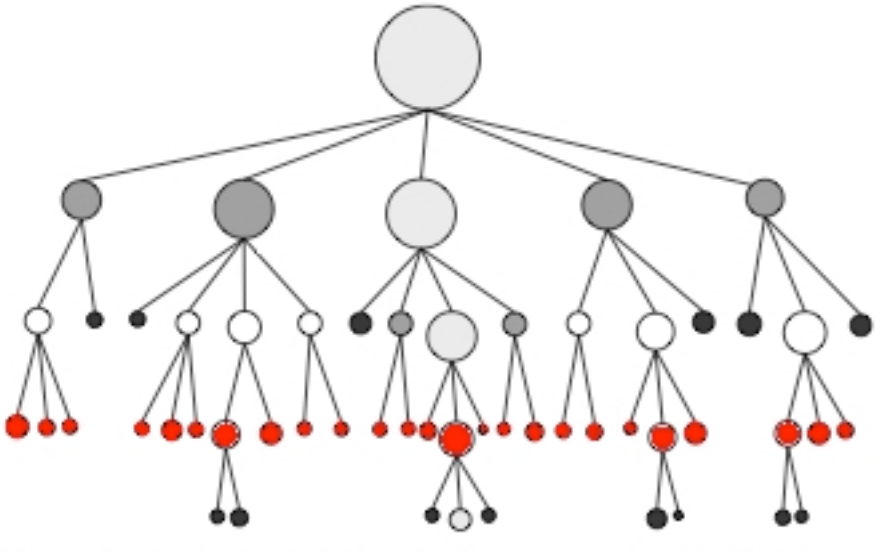
… in order to compute γ-ray flux

$$\Phi(\psi, \Delta\Omega) \propto \int_M dM \int_\nu d\nu \int_c dc \iint_{\Delta\Omega} d\vartheta d\varphi \int_{l.o.s} d\lambda \Big[\rho_{sh}(M, R(R_{sun}, \lambda, \psi, \vartheta, \varphi)) \cdot P(\nu) \cdot P(c) \cdot \Phi^{halo}(M, \nu, c, r(\lambda, \lambda', \psi, \vartheta', \varphi'))\Big]$$

Exploring 2 ways to find $\nu(M)$

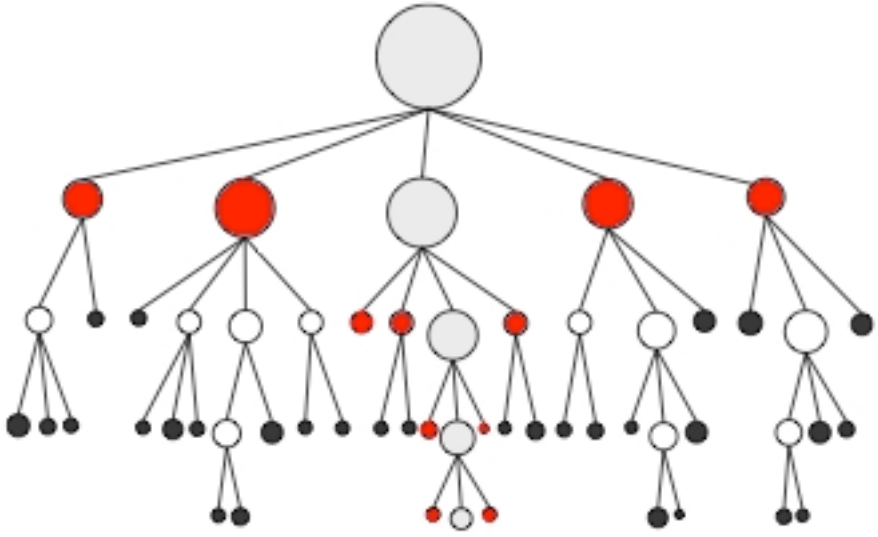


Press & Schecter approach (mass function of all progenitors, normalized such that 10% of the Galaxy mass is in substructures in the $[10^{-5},10^{-2}]M_{gal}$ mass range, and spatially tracing the mass of the galaxy)

C. Giocoli, LP, G.Tormen, 2008 [GPT08]

Merger tree approach (mass function of subhalos, spatially tracing the mass of the galaxy)

C. Giocoli, LP, G.Tormen in preparation [GPT08inprep]

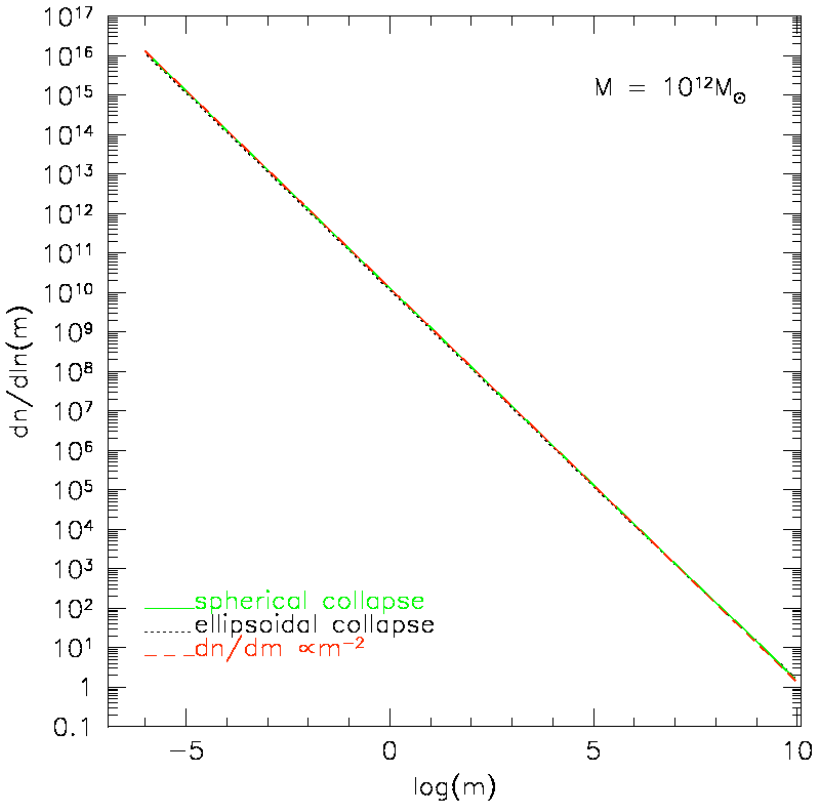


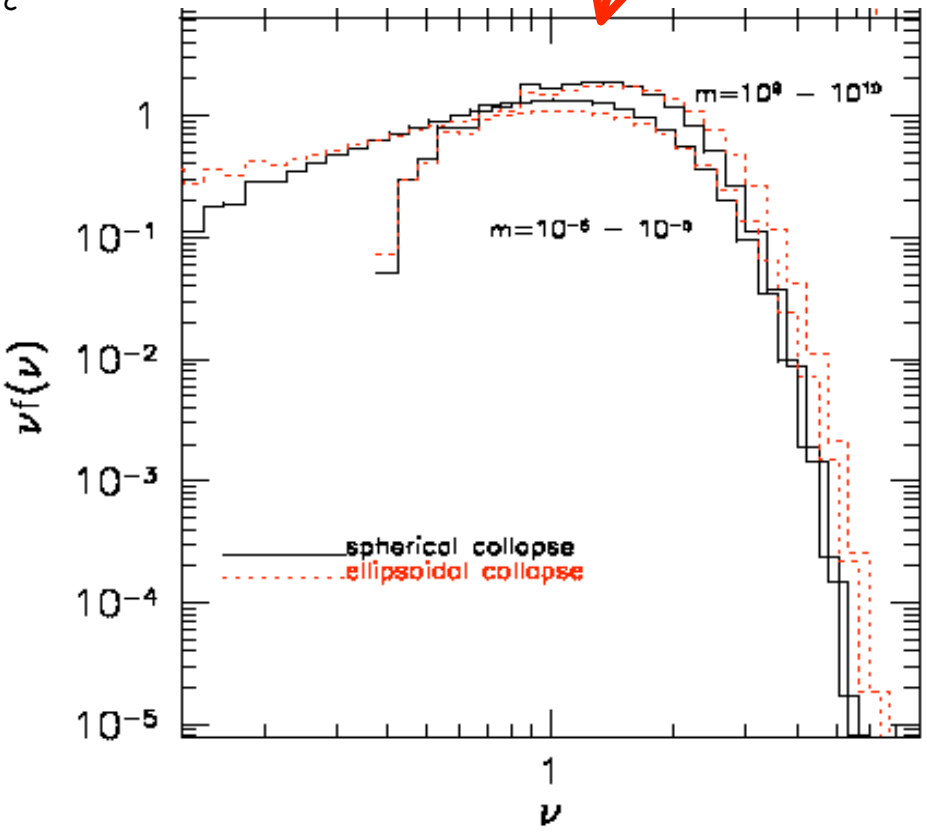
ANALYTICAL APPROACH (MW)

An analytical determination of the number of progenitors as a function of mass and redshift has been obtained, with $M \in [10^{-6}, 10^{10}] M_{sun}$

$$\frac{dN(m)}{dm} = \int_{\delta_0}^{\infty} \frac{M}{m} f(s, \delta_c \mid S, \delta_0) d\delta_c$$

$$\nu(M) = \frac{\delta_c}{\sigma(M)}$$





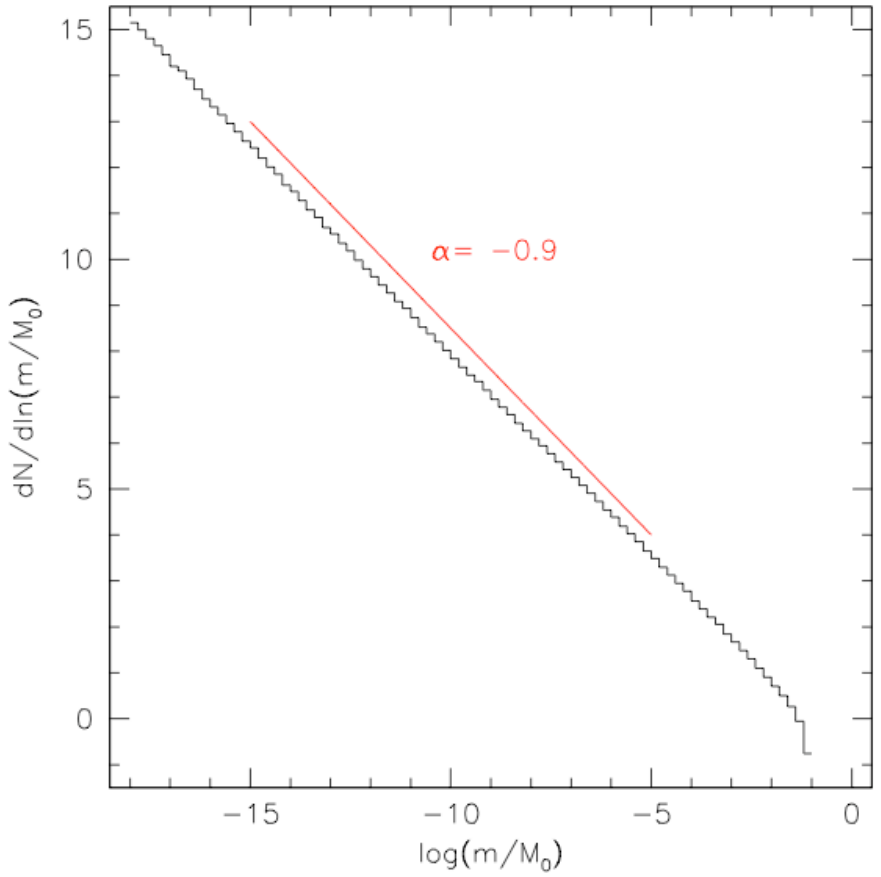
$$P(c) \rightarrow P(c(M)) \times P(\nu(M))$$

merging history epoch

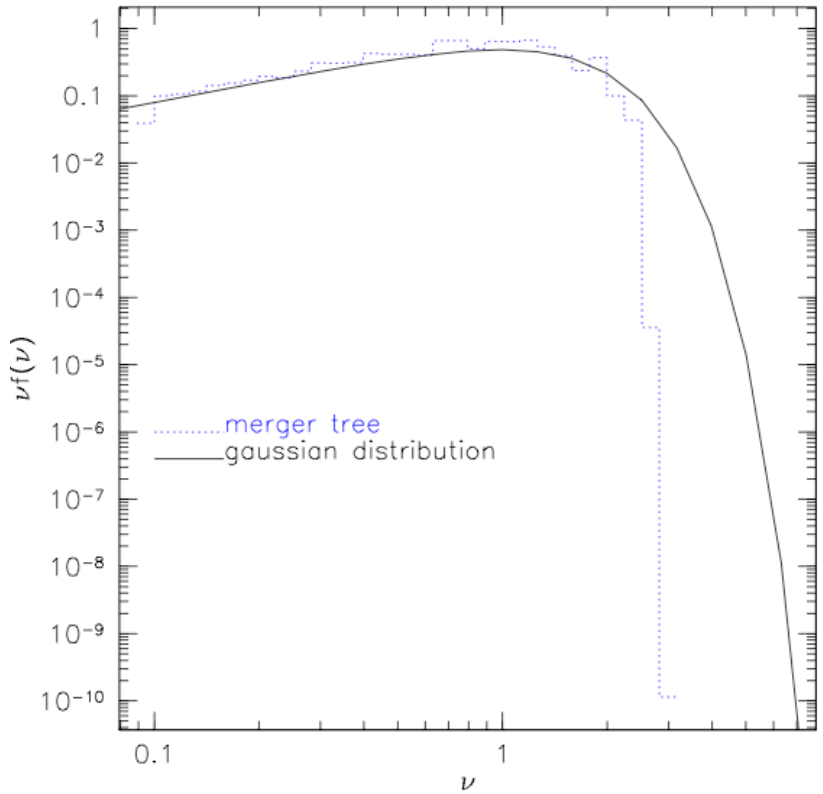
GPT08

MERGER TREE APPROACH (MW)

From merger tree we derived the number of subhalos as a function of mass and redshift, with $M \in [10^{-6}, 10^{10}] M_{sun}$



$$\nu(M) = \frac{\delta_c}{\sigma(M)}$$



$$P(c) \rightarrow P(c(M))\, P(\nu(M))$$

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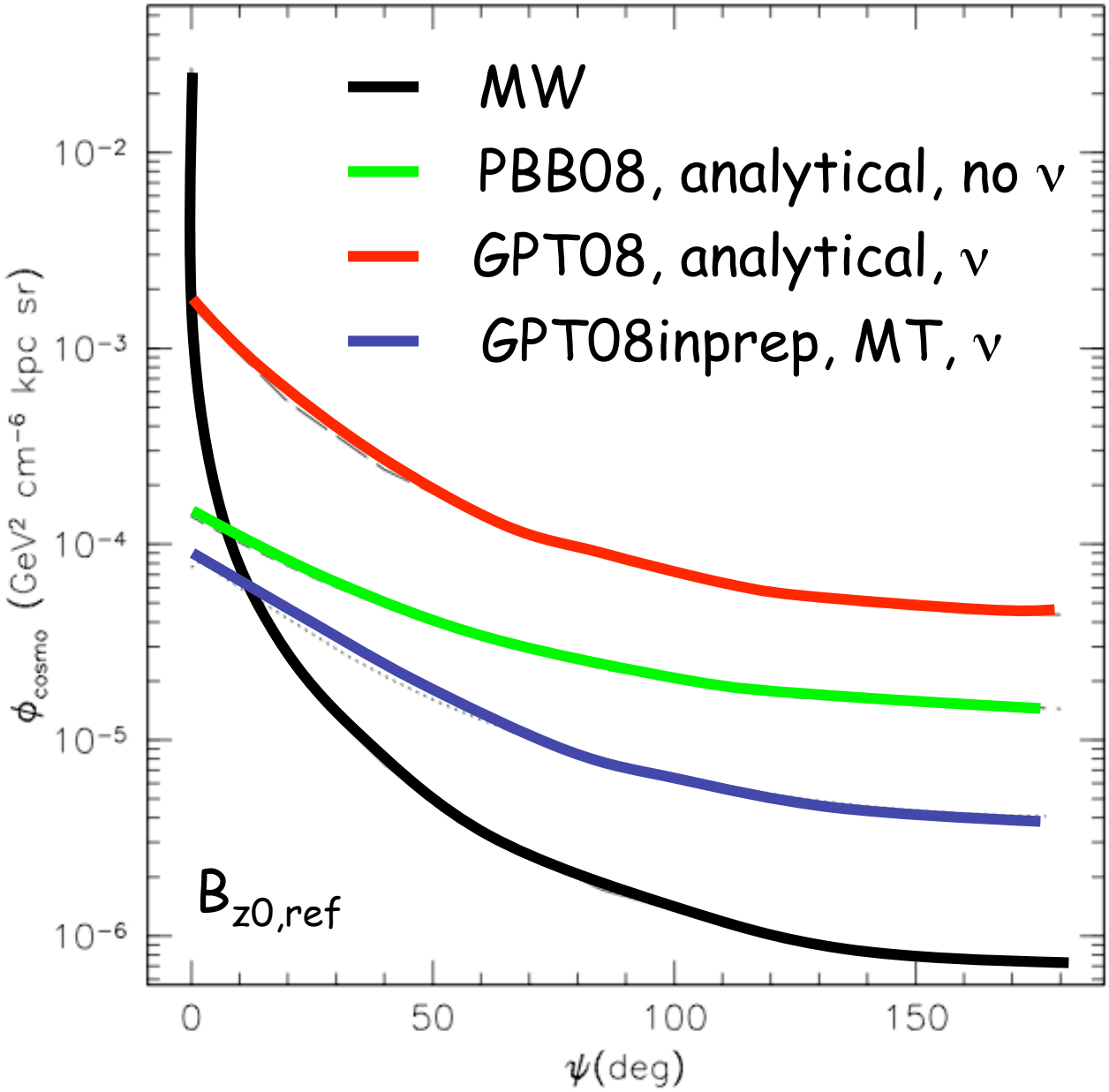
EFFECT ON γ-RAY FLUX BOOST FACTOR OF THW MW



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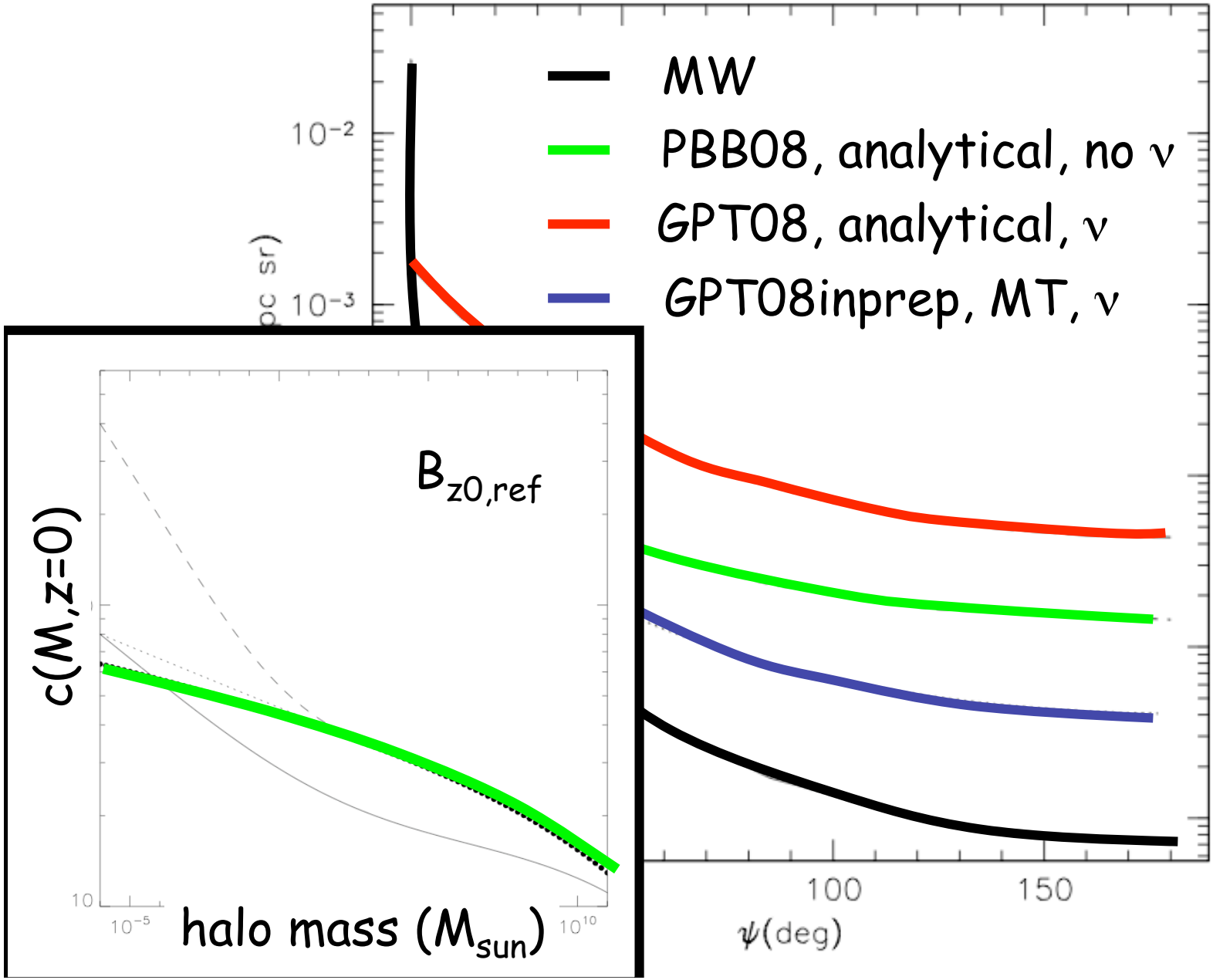
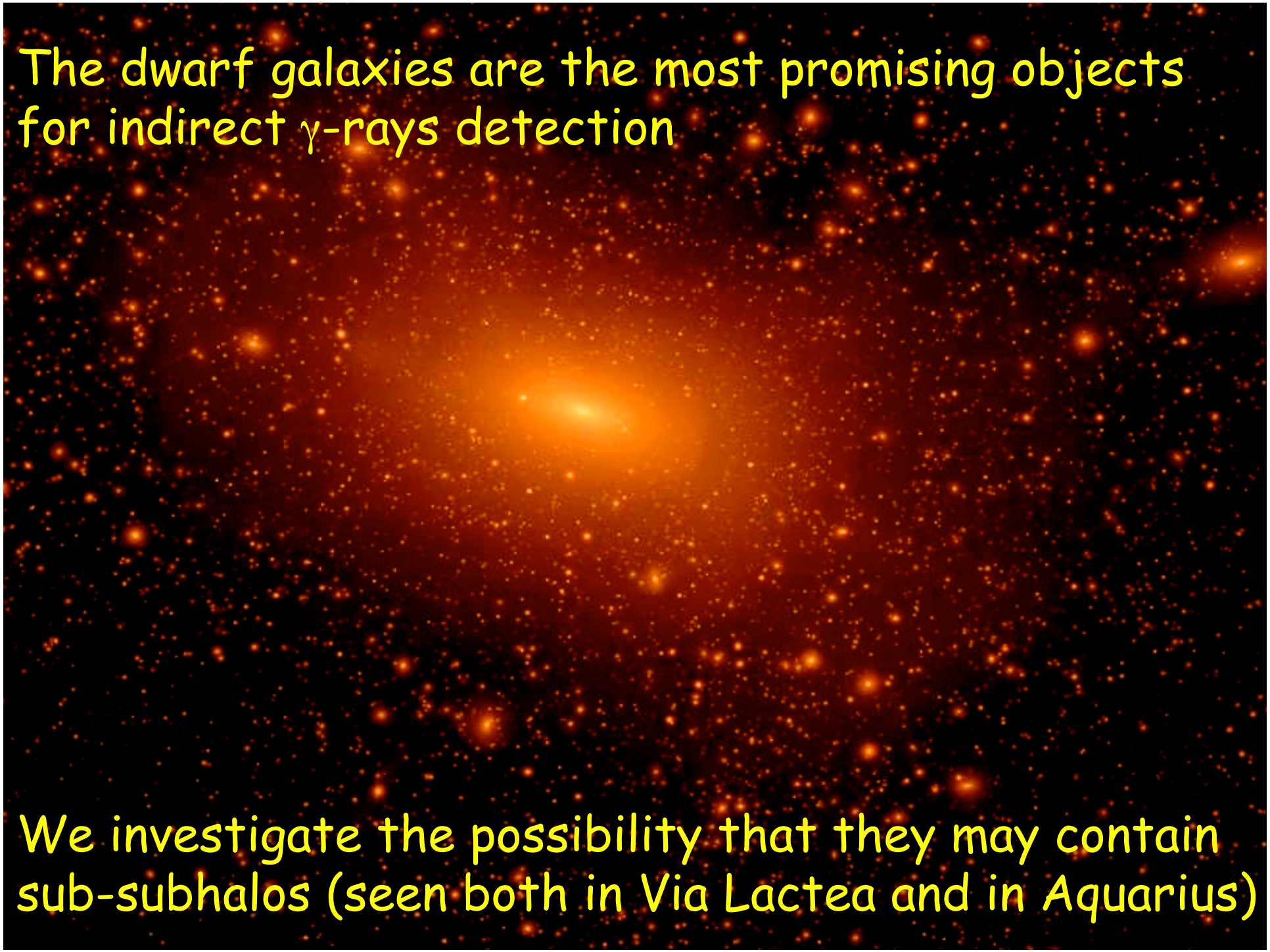
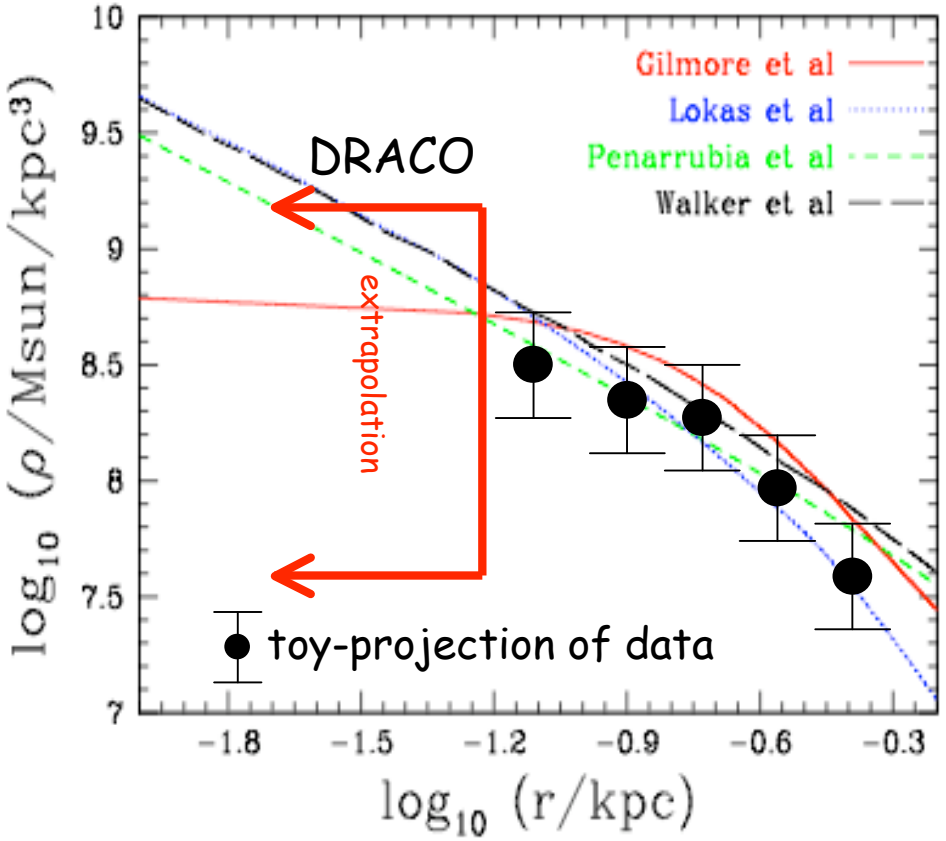



The dwarf galaxies are the most promising objects for indirect γ-rays detection
We investigate the possibility that they may contain sub-subhalos (seen both in Via Lactea and in Aquarius)

The dwarf galaxies are in the range of masses detectable with GLAST with our universal NFW…

What happens if we use profiles derived by astronomical data?

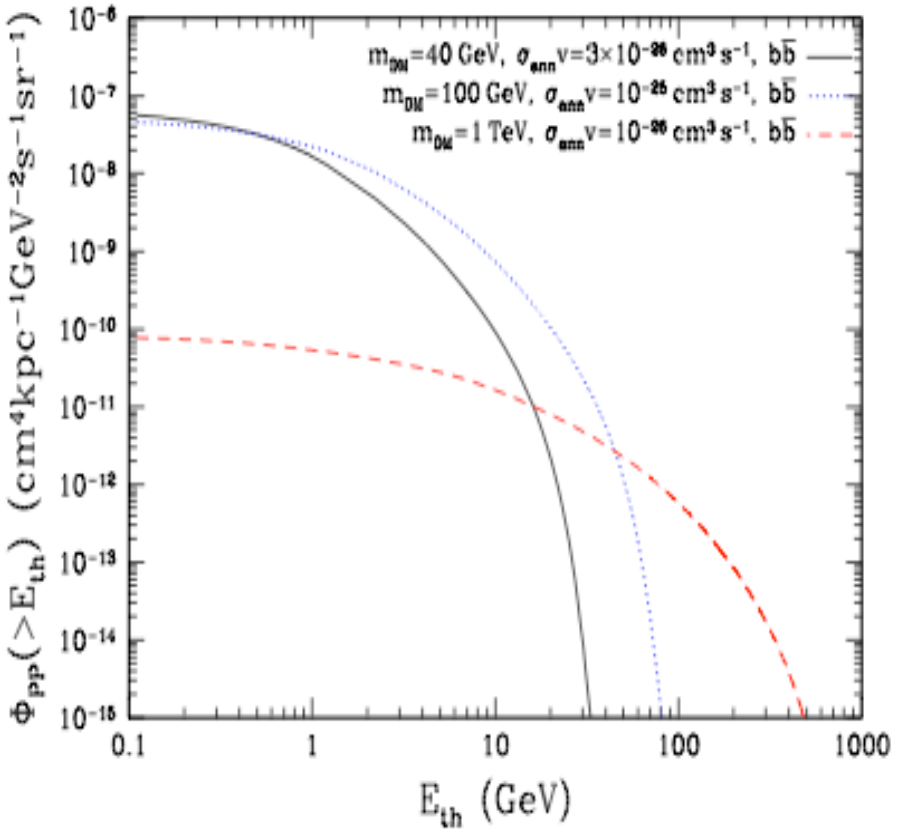


cuspy or cored density profiles are not disentangled by available dispersion velocity measurement

LP, Pizzella, Corsini, Dalla Bontà, Bertola, submitted (Petal08)

Computing $\Phi_\gamma = \Phi_{\text{particle physics}} \times \Phi_{\text{cosmology}}$

$$\phi_{PP} = \frac{1}{4\pi} \frac{\sigma_{ann} v}{2m_\chi^2} \int_{E_0}^{m_\chi} \sum_f \frac{dN_f^\gamma}{dE_\gamma} BR_f \, dE_\gamma$$



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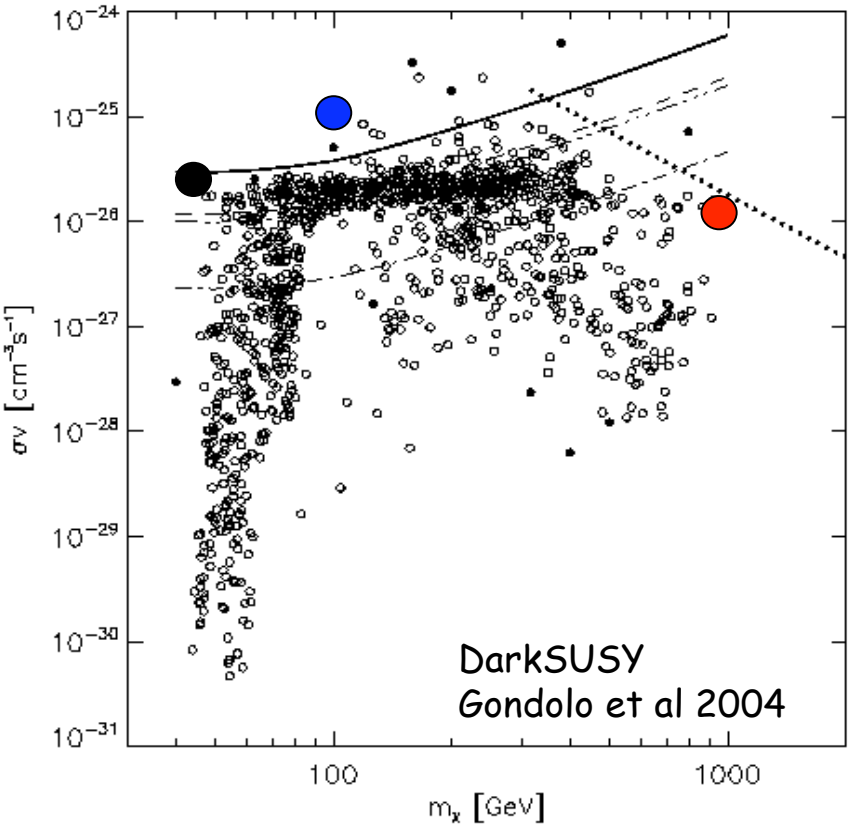

Petal08

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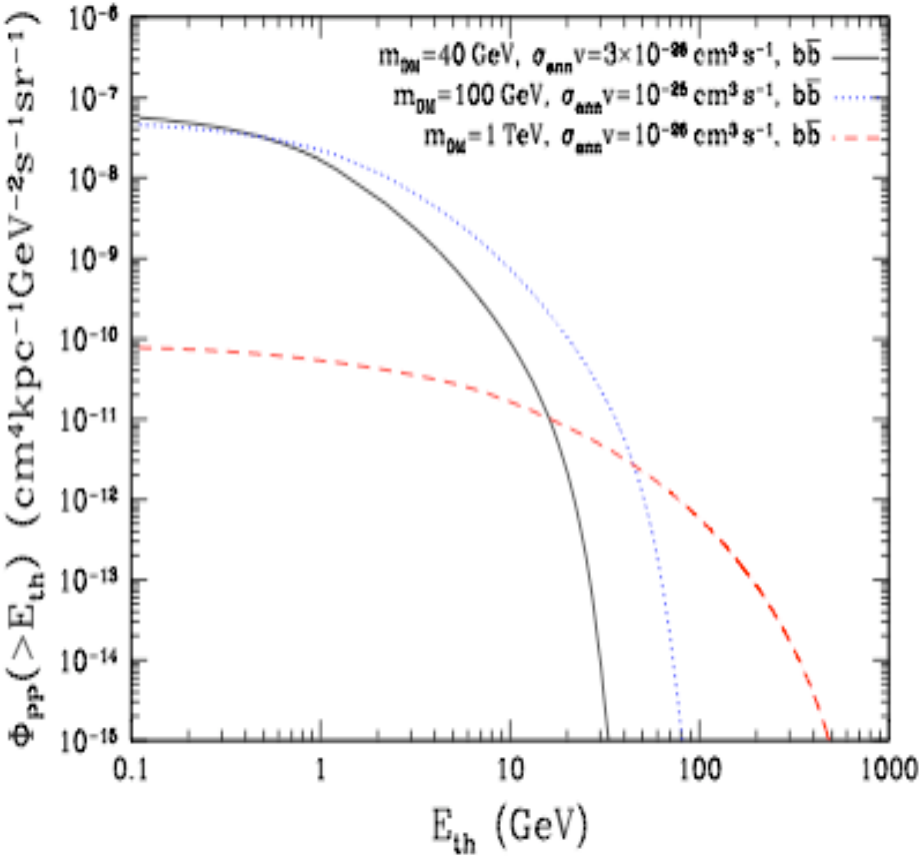
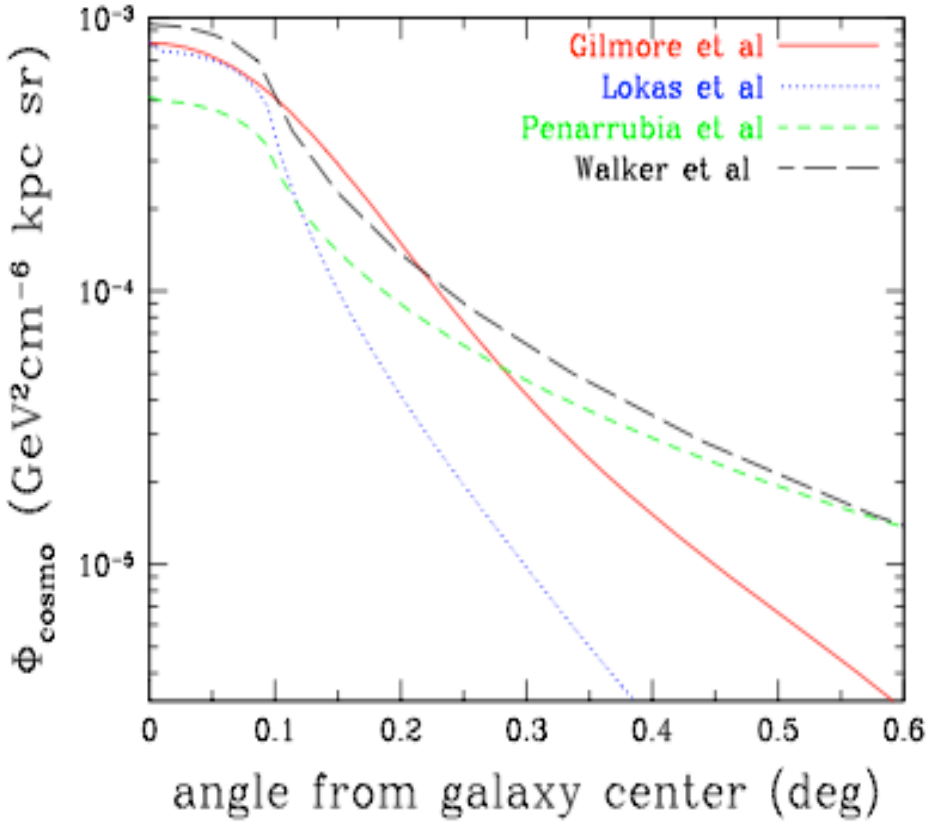


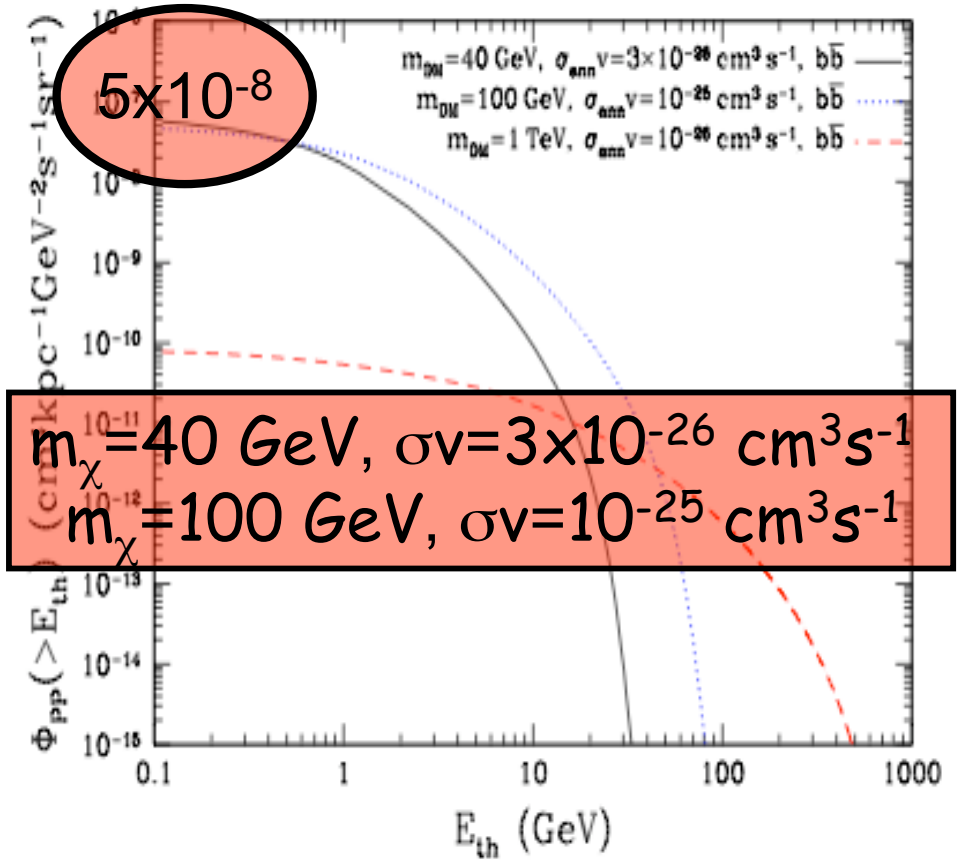


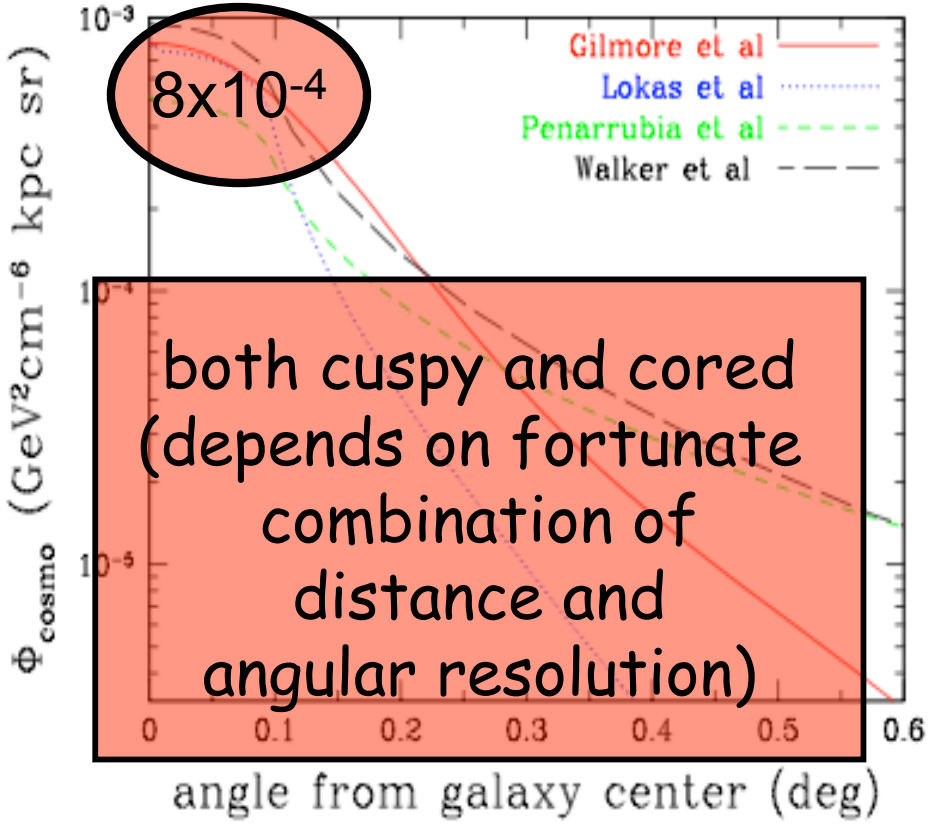
$$\phi_{cosmo} = \int_{\Delta\Omega,\lambda} \frac{\rho^2(r(\Delta\Omega,\lambda))}{\lambda^2} \, dV$$

Petal08

DRACO Φ_γ^{max} (>100 MeV) = $\Phi_{PP} \times \Phi_{cosmo}$ = (4.5±1.5) x 10^{-11} cm^{-2} s^{-1}

$$\phi_{PP} = \frac{1}{4\pi} \frac{\sigma_{ann} v}{2m_\chi^2} \int_{E_0}^{m_\chi} \sum_f \frac{dN_f^\gamma}{dE_\gamma} BR_f \, dE_\gamma$$





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Comparing predictions with GLAST performances

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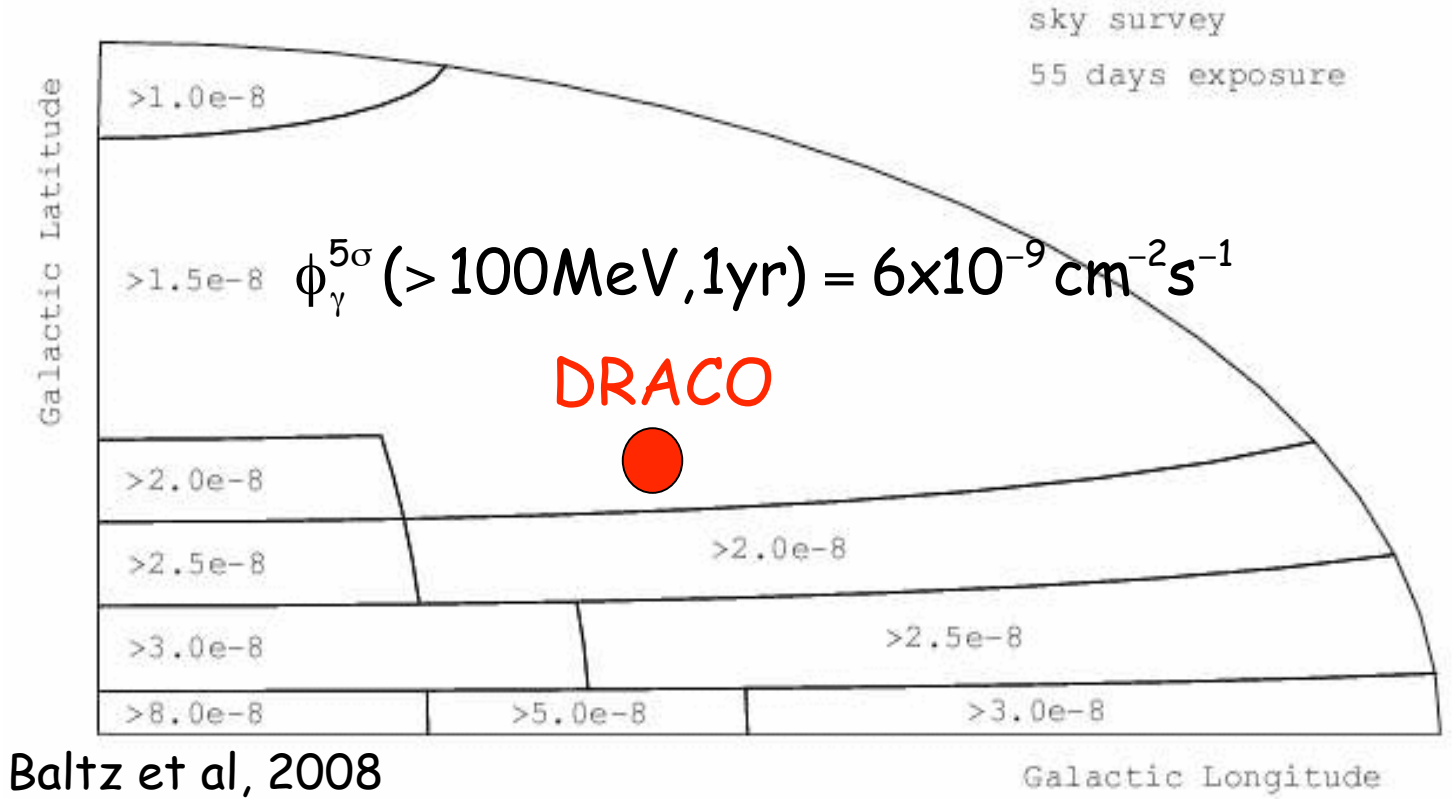

Baltz et al, 2008

DRACO and other dwarfs
are well below the detection limit

Boost factors are needed to hope for detection

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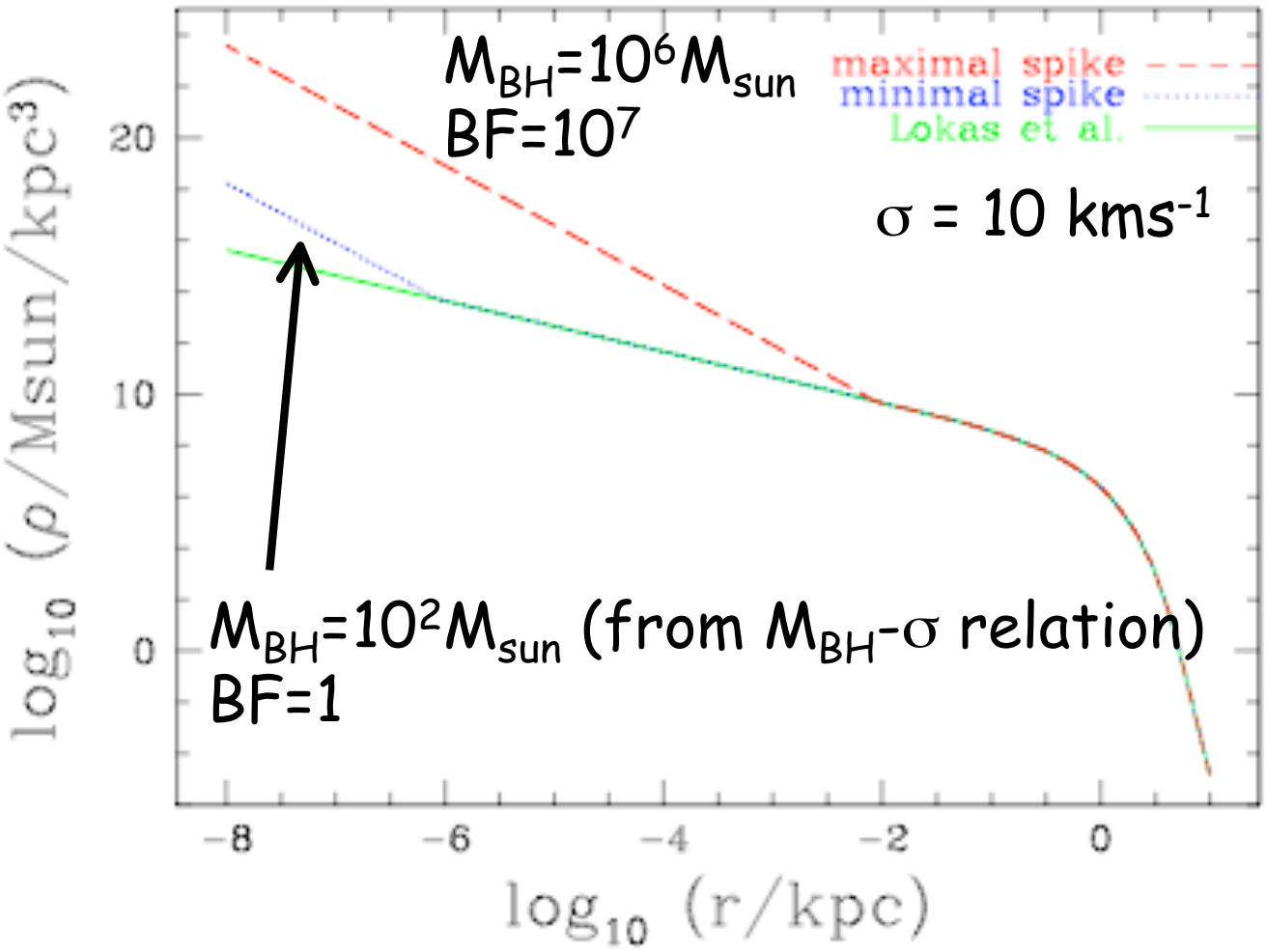
BF due to the presence of a Black Hole?

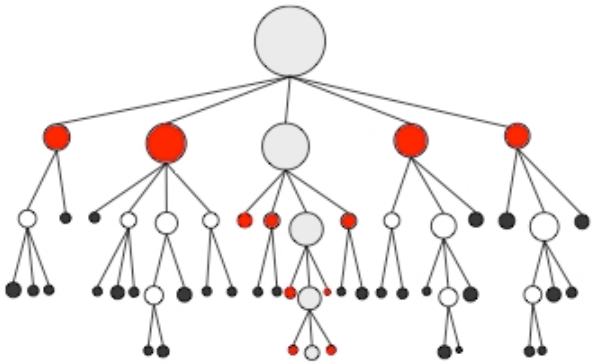


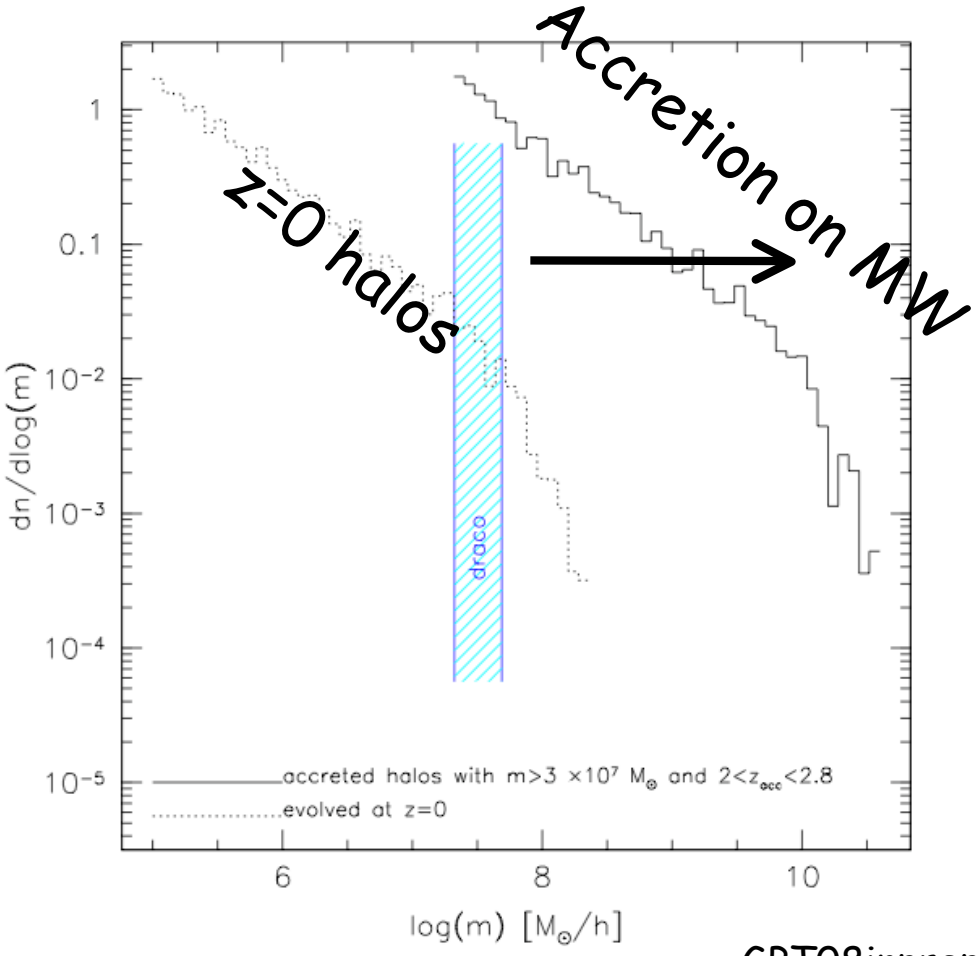
A Black Hole, if any, is not likely to be significant for detection

Petal08

BF due to sub-subhalos?

Make use of merger tree technique to study the sub-subhalo population in DRACO





Find all the today DRACO-like halos at accretion

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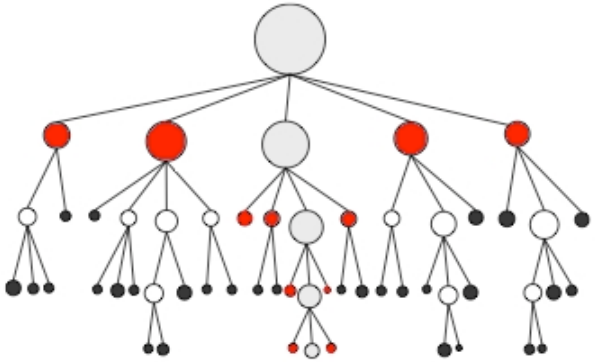
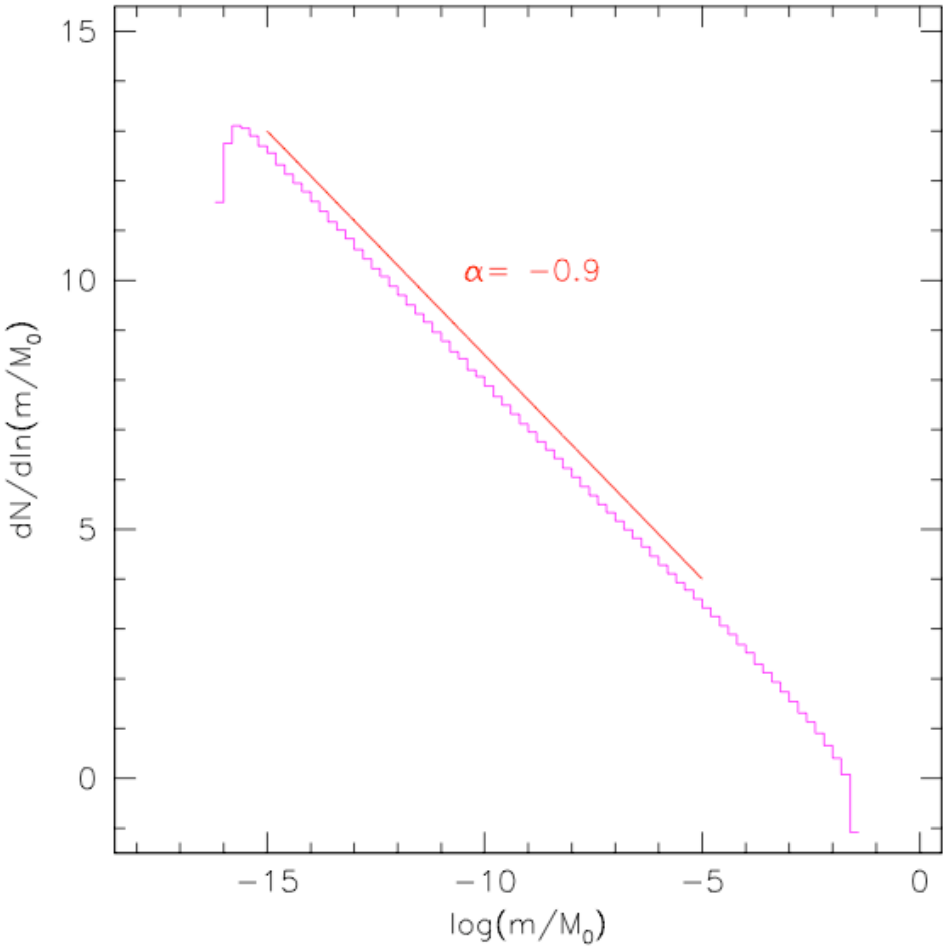
Make use of merger tree technique to study the sub-subhalo population in DRACO





Apply merger tree to DRACO-like objects at the epoch of merging (finding 2.7×10^{13} sub-subhalos, and then scale for the mass loss of DRACO (reducing to 1.6×10^{11})

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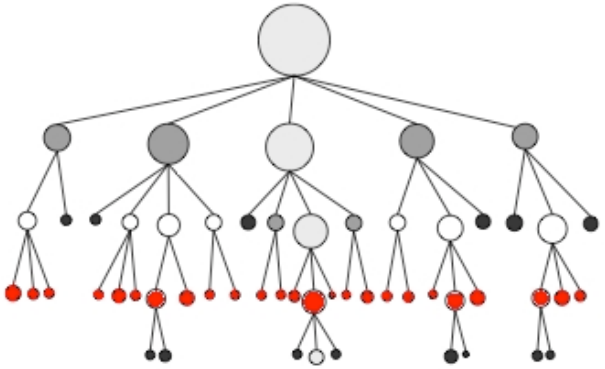
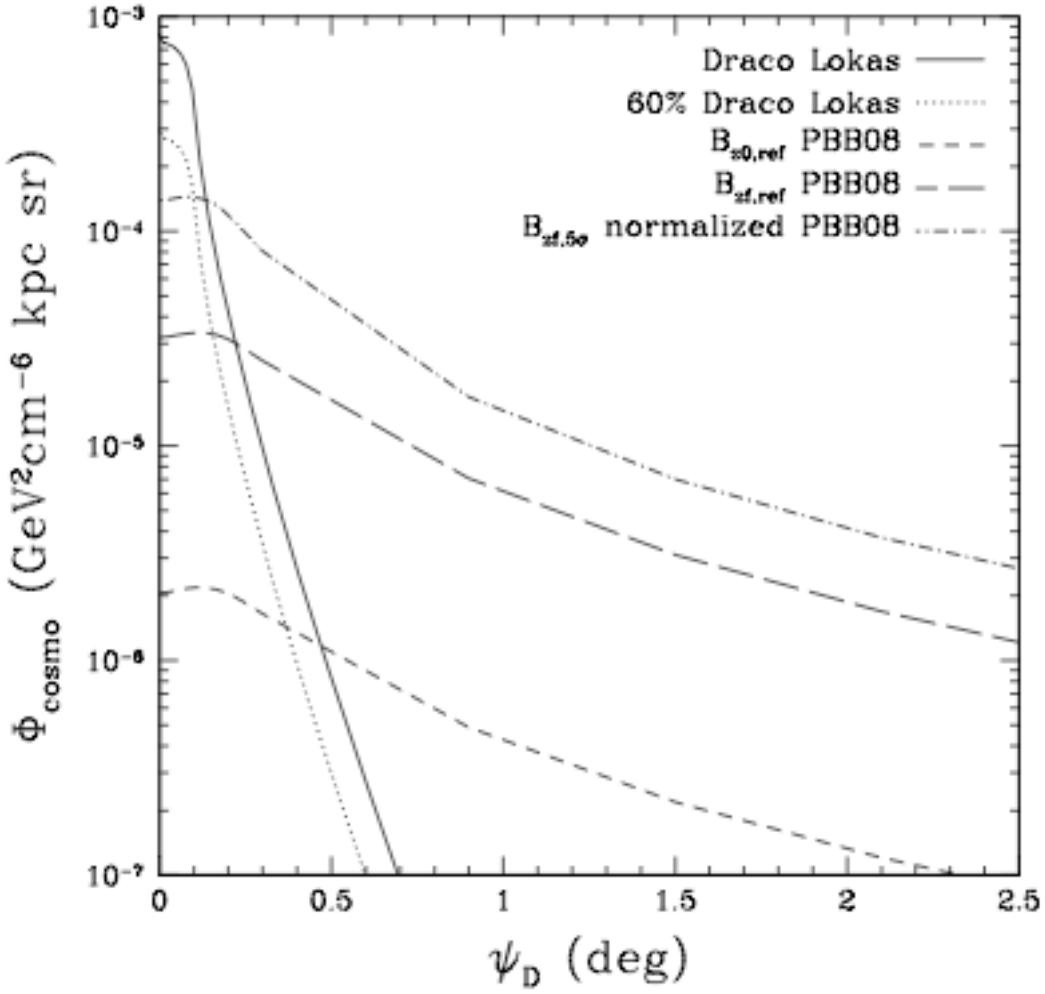
Make use of analytical technique to study the sub-subhalo population in DRACO





Finding about 10^{12} sub-subhalos, $dN/dM \sim M^{-2}$

Compute the radial dependence of ϕ_{cosmo} with and without sub-subhalos

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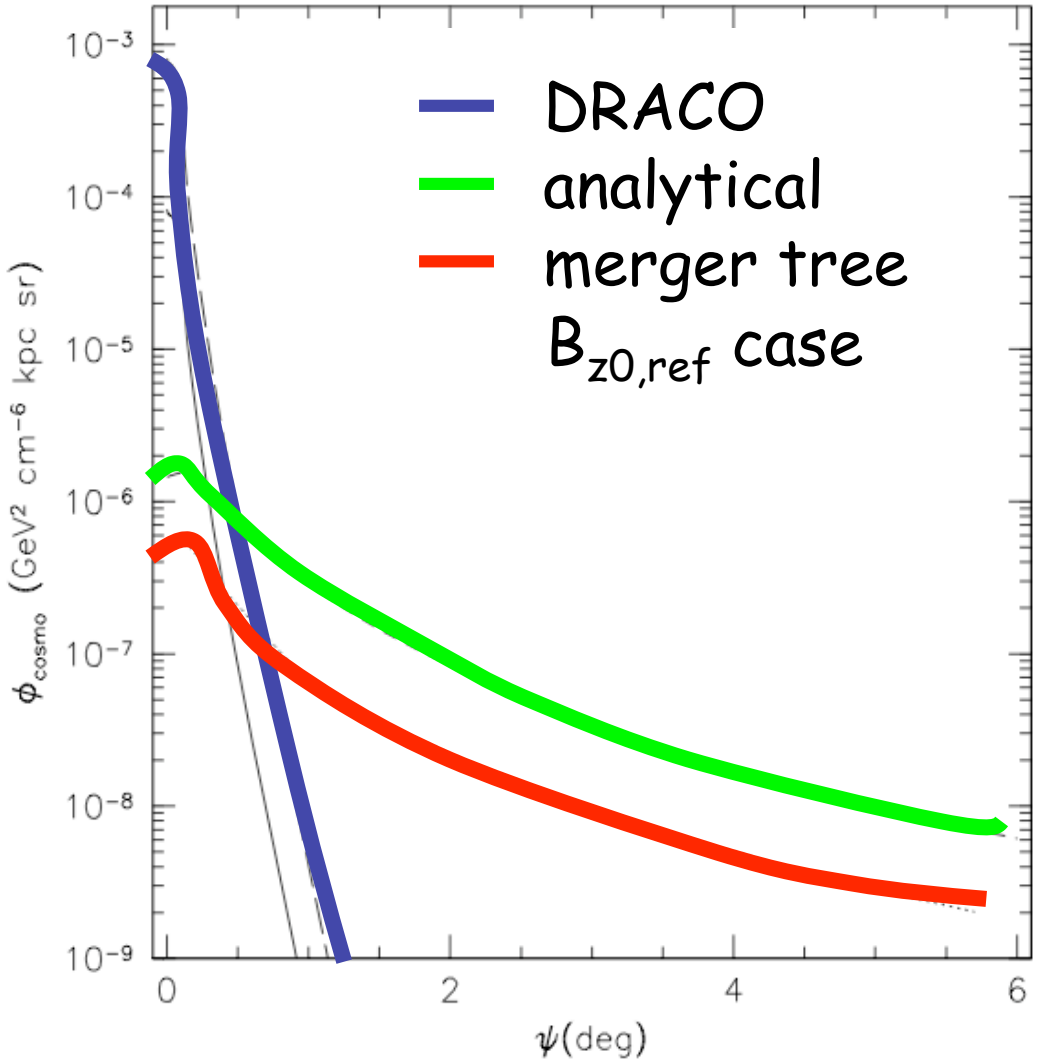
Effect of the sub-subhalo population in DRACO on the γ-ray flux from DM annihilation



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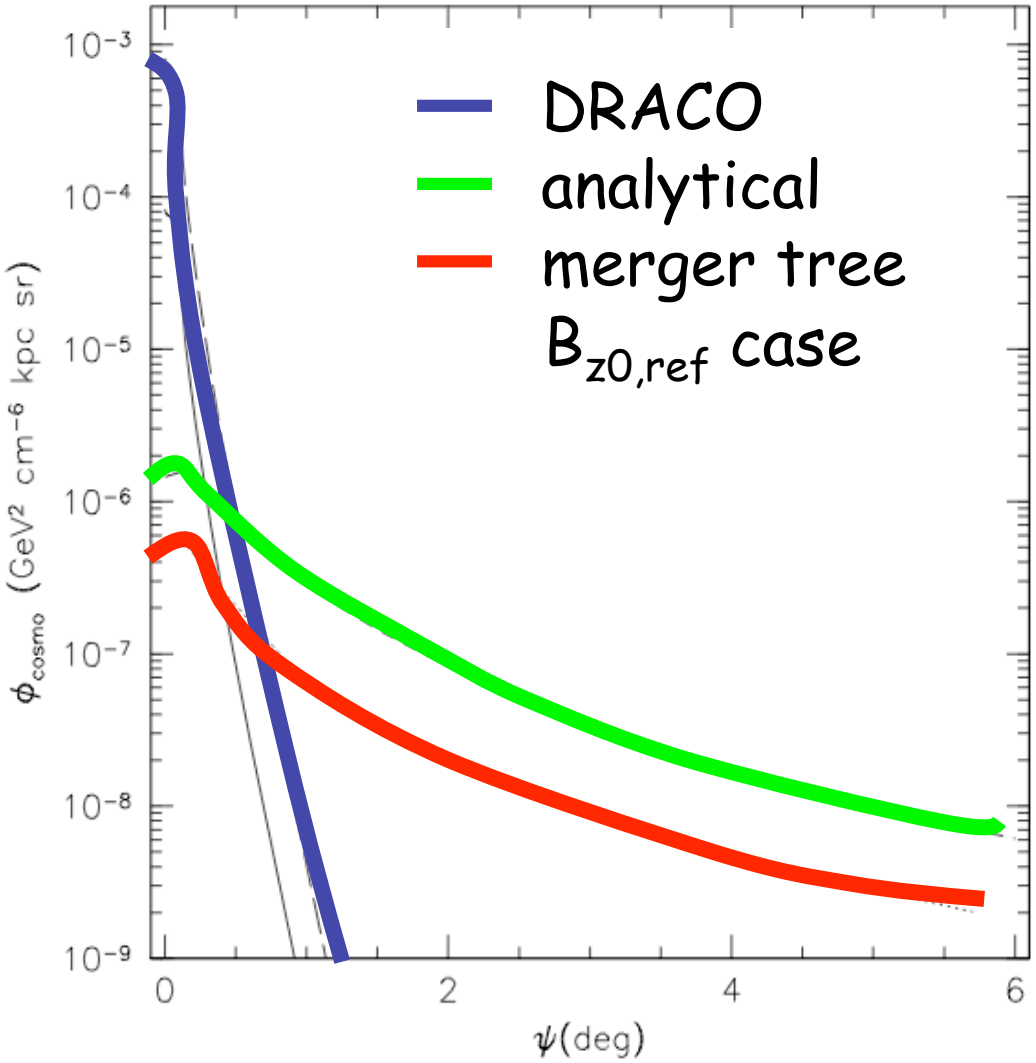

Large BF at large angles, but undetectable..

And sub-subhalos seem not to help at the centre

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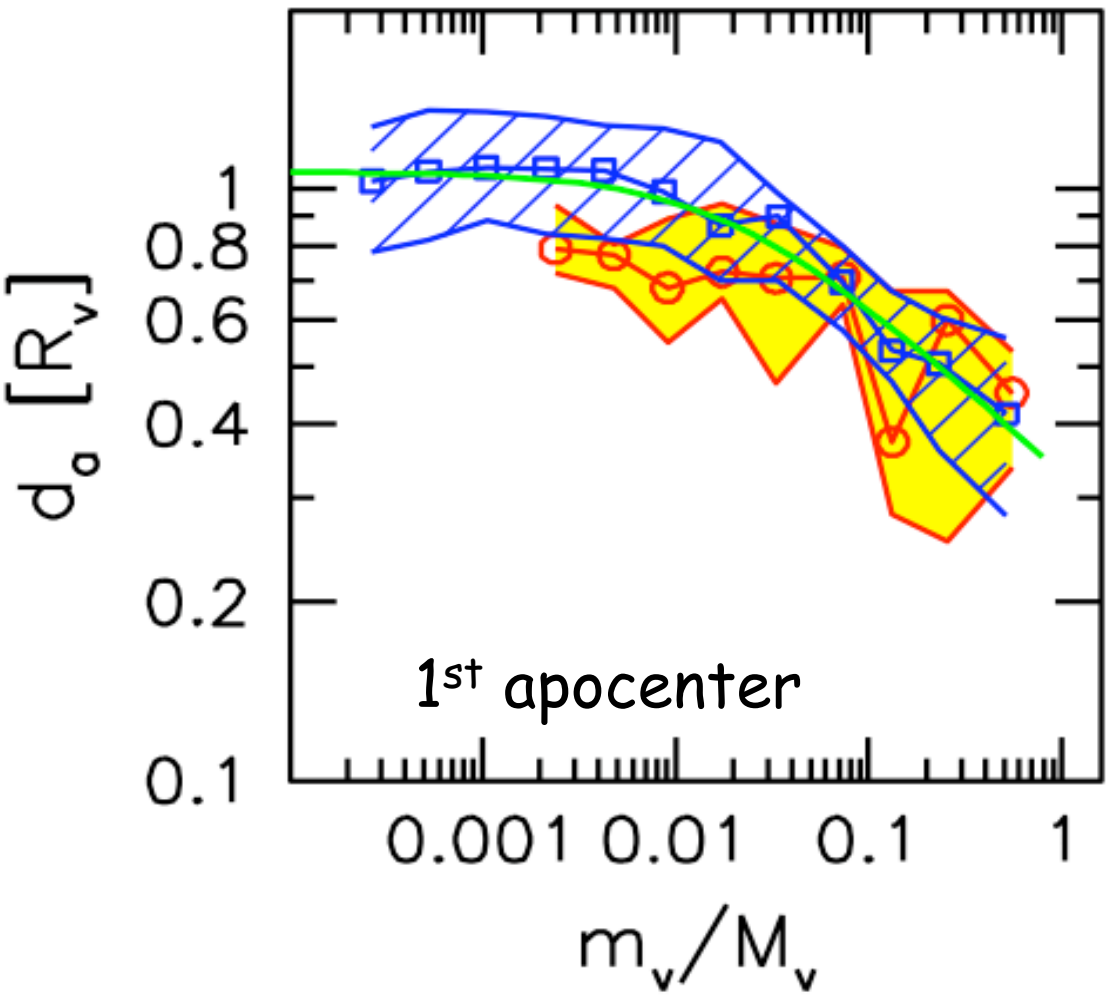
Effect of the sub-subhalo population in DRACO on the γ-ray flux from DM annihilation

Tormen, Moscardini, Yoshida 2004



NB: to be more realistic we should remove all sub-subhalos (half of the total) which went out of DRACO-like (and dispersed in the MW)

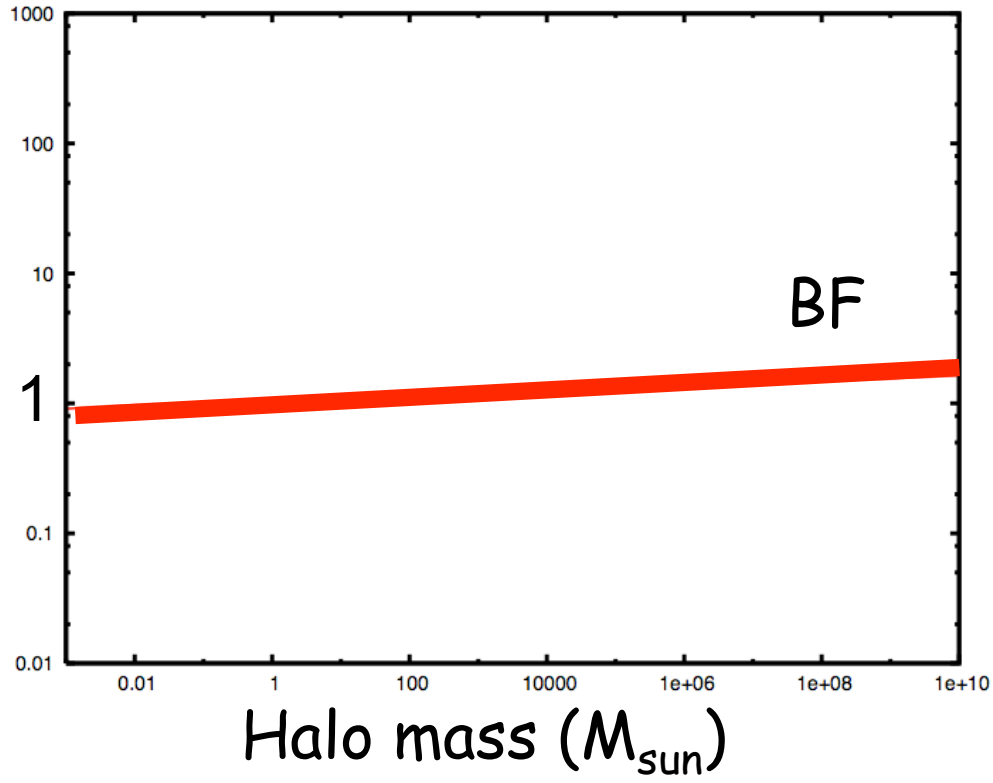
Is Merger Tree the correct approach? (can we ignore sub-sub-subhalos?)

Compute BF for every mass

It doesn't change so much

$B_{z0,ref}$ case
Others to come

$$\frac{\int_{gal} dV\rho^2_{gal,sm} + \int_{gal}\int_{M_{sh}} dVdM\ \rho_{sh} \int_{halo} dV\ \rho^2_{halo}}{\int_{gal} dV\rho^2_{gal,sm}}$$



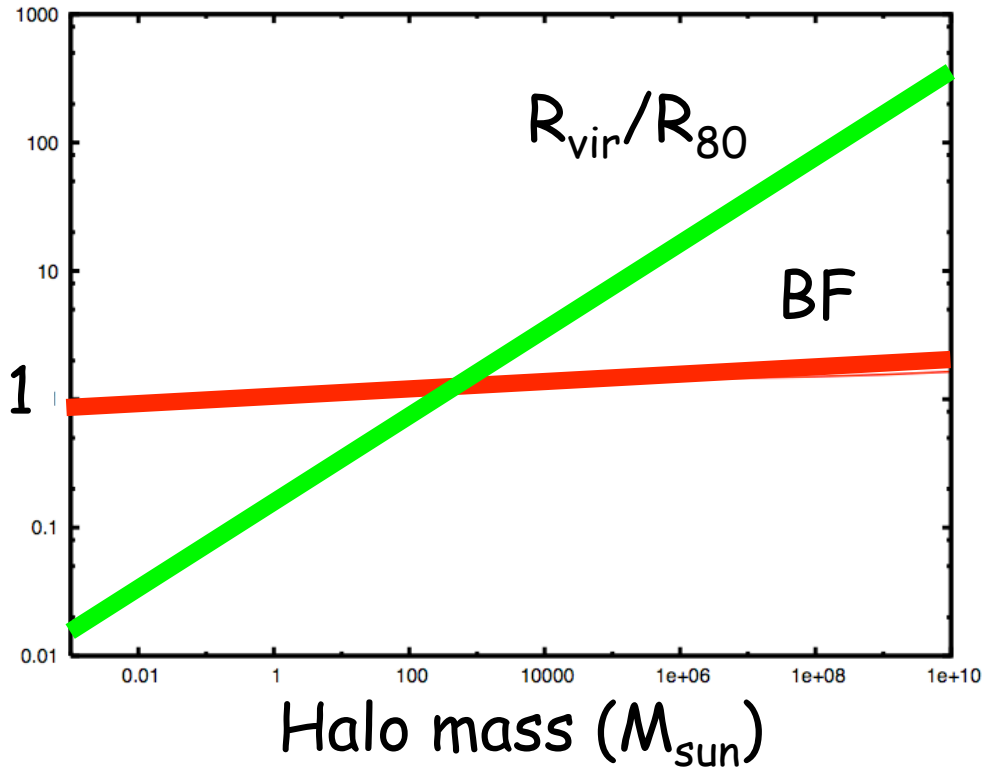
Is Merger Tree the correct approach? (can we ignore sub-sub-subhalos?)

The higher the R_{vir}/R_{80} ratio, the smaller the contribution to BF around the galaxy center.

Higher total BFs belong to halos where extension decreases central BF.

BF is always <= 1

$B_{z0,ref}$ case
Others to come



Conclusions

We computed the effect of sub-subhalos on the boost factor needed for detecting a DWARF galaxy with the FERMI LAT.

We use both analytical estimates of the subhalos properties, normalized on numerical simulations, and merger tree tecniques.

We found that the boost factor due to sub-subhalos for DRACO is less than 1, even when we use optimistic models for the subhalo concentration parameters.
This is due to the fact that DRACO is close enough to cover a large portion of sky.

No help comes going to sub-sub-subhalos because of the closeness of DRACO.

Still the door is open to other ways to let the sub(sub(sub))halos be useful.