

Indirect detection of Cold Dark Matter structures with γ -rays

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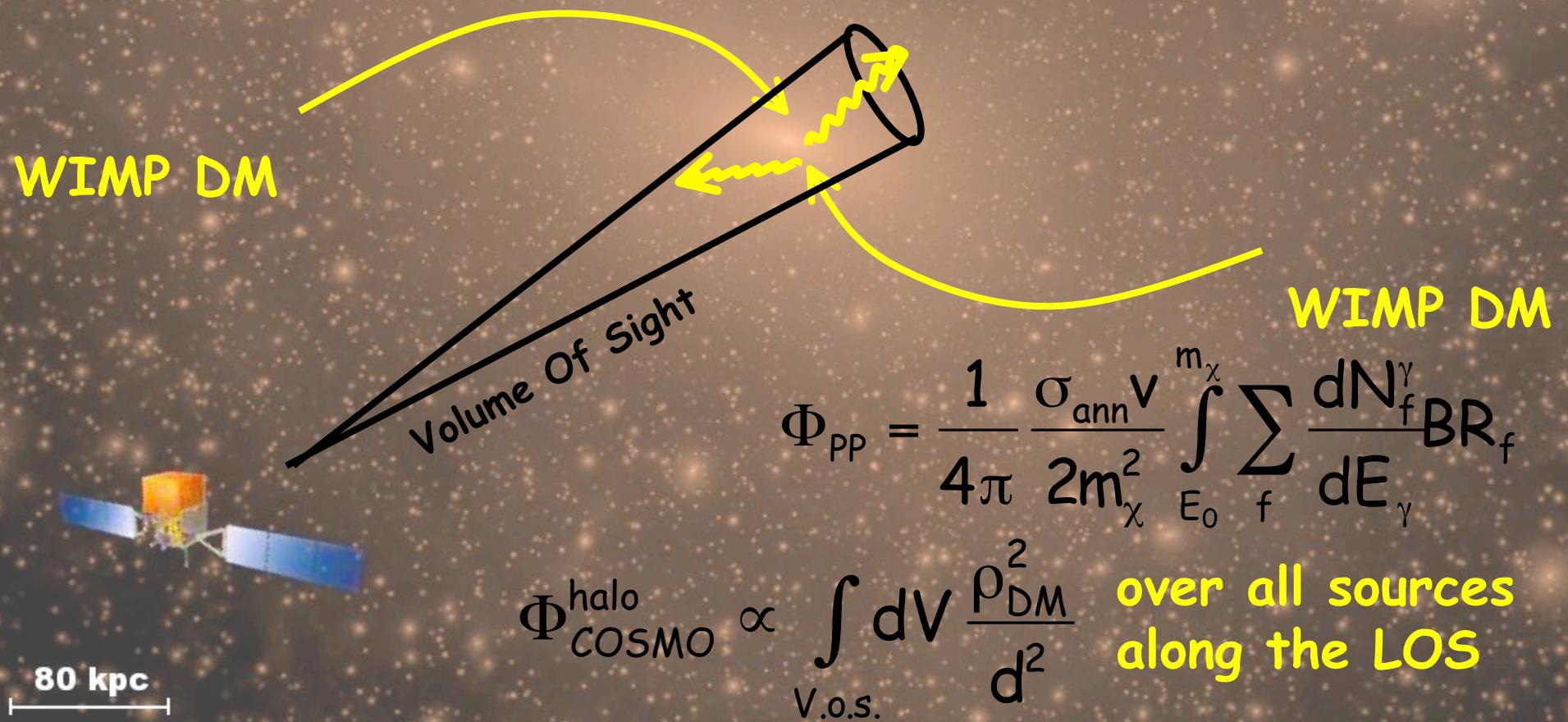


LPTHE, Paris, March 13th, 2009

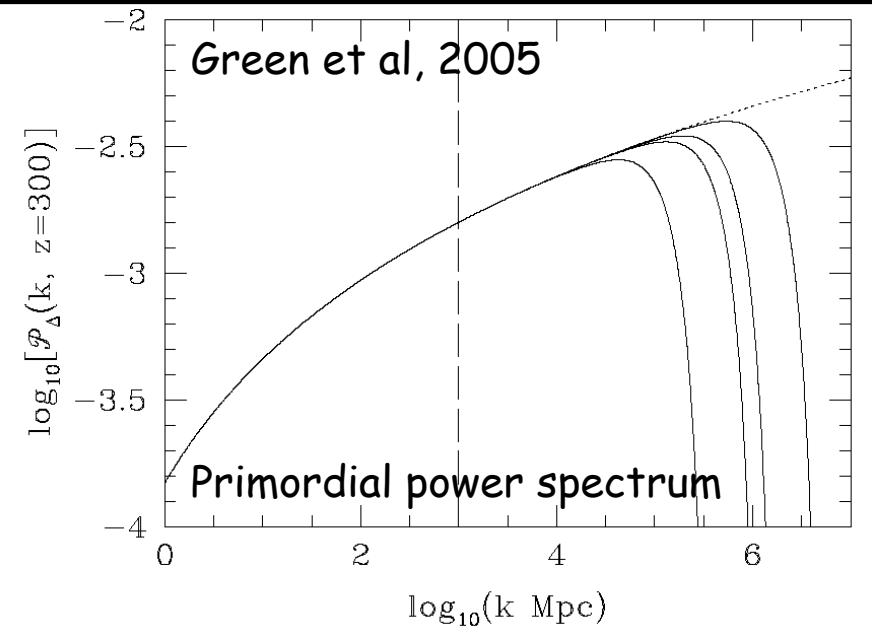
$z=0.0$

Indirect detection of γ -rays:

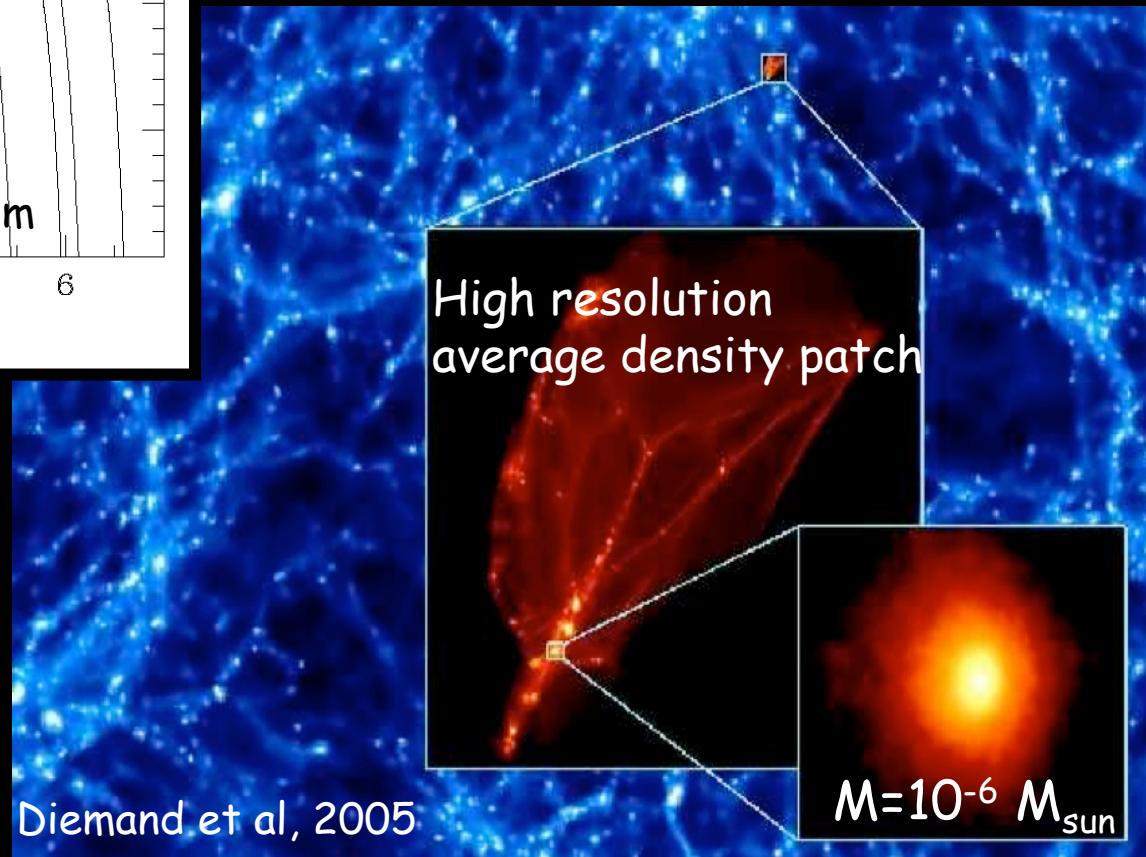
$$\Phi_\gamma = \Phi_{\text{particle physics}} \times \Phi_{\text{cosmology}}$$



1) Model the structure of dark matter halos from theory and numerical simulations



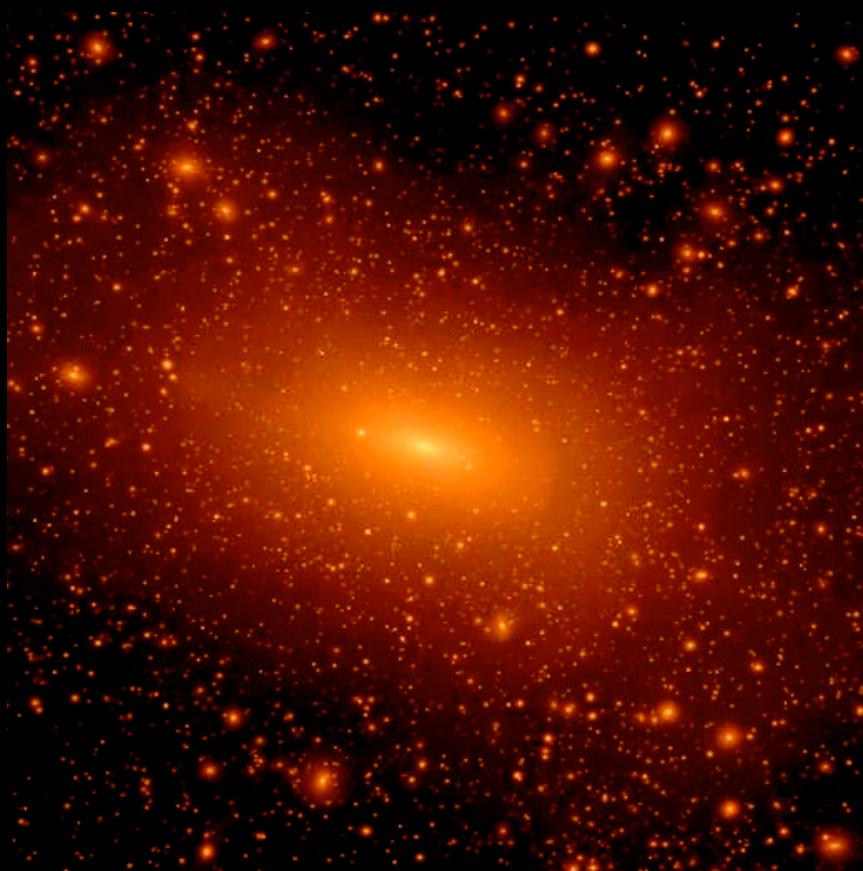
Theory: Damping of the primordial power spectrum due to CDM free streaming gives
 $M_{fs}=10^{-6}M_{\text{sun}}$ @ $M_{CDM}=100 \text{ GeV}$



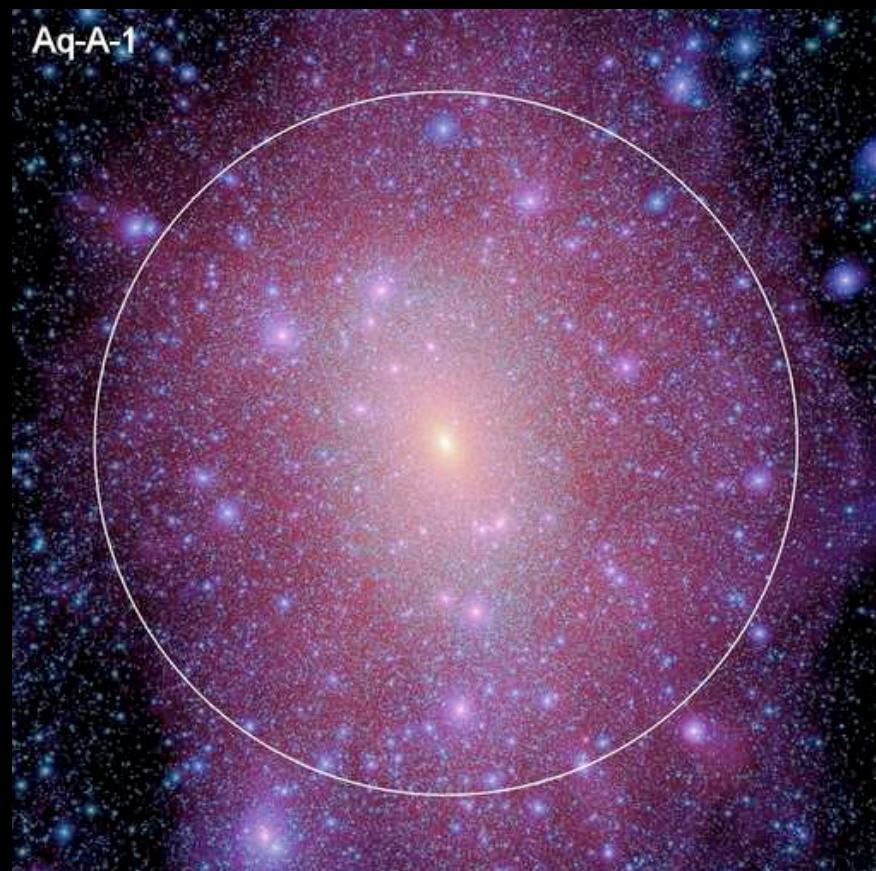
N-body simulations:

Multi-scale technique
stopping at $z=26$
can resolve halos
as small as $10^{-6}M_{\text{sun}}$

- 1) Model the structure of dark matter halos from theory and numerical simulations



Via Lactea 2, Diemand et al



Aquarius, Springel et al

Analysing the simulations

Mass slope $\sim M^{-2}$

$f_{DM} (>10^7 M_{sun}) \sim 11\%$

$f_{DM} (>10^{-6} M_{sun}) \sim 50\%$

Mass slope $\sim M^{-1.9}$

Aq-A $f_{DM} (>10^7 M_{sun}) \sim 13\%$

$f_{DM} (>10^{-6} M_{sun}) \sim 25\%$

Different subhalo spatial distribution

Different subhalo definition or analysis tool?

NFW

Effect of the poor resolution?

lower $c(M)$

Einasto

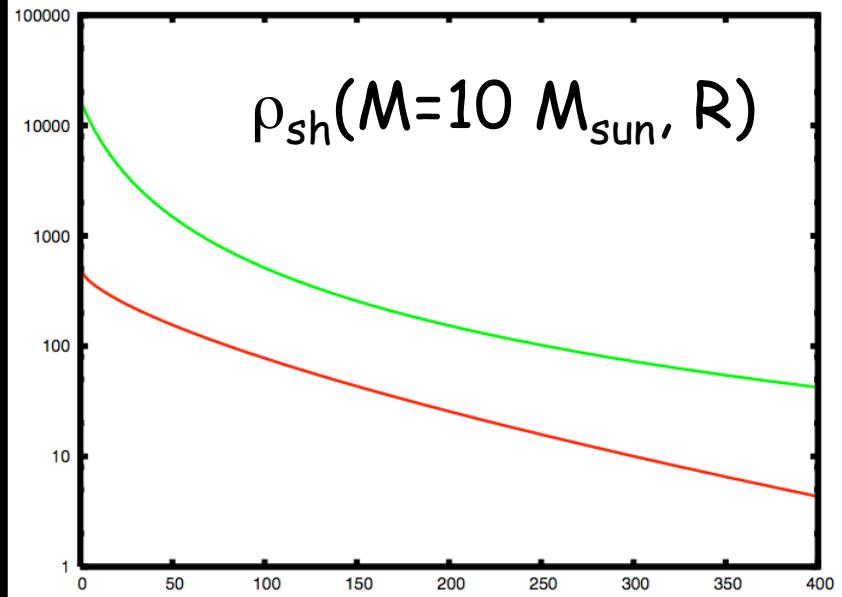
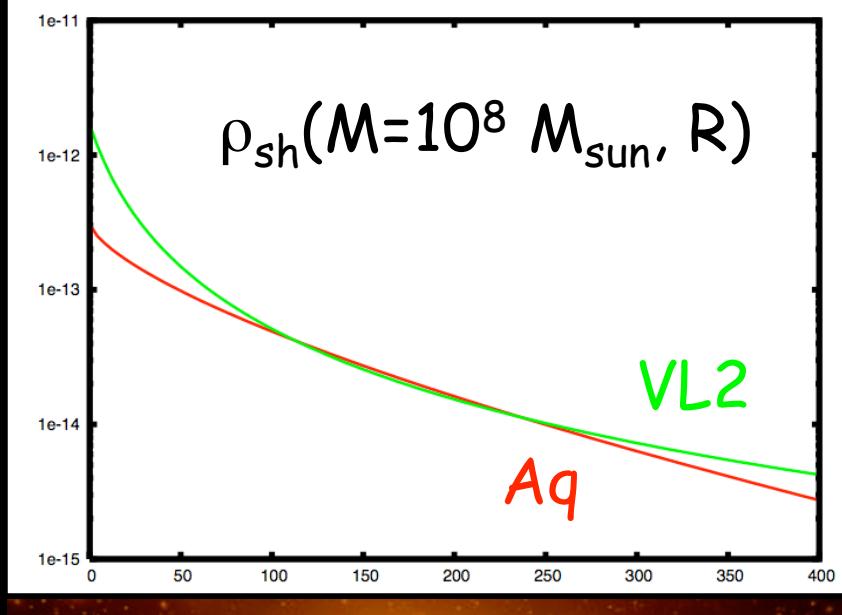
higher $c(M)$

Different cosmology?

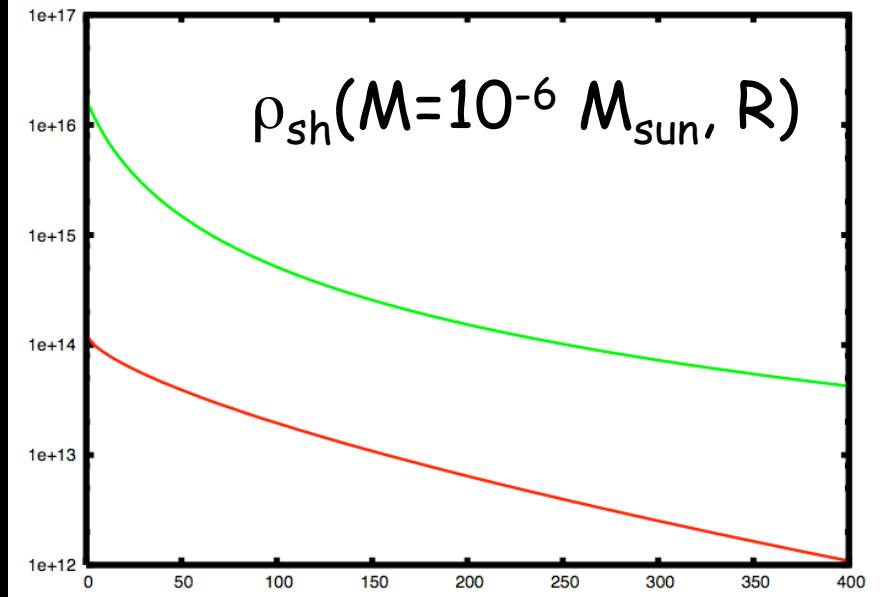
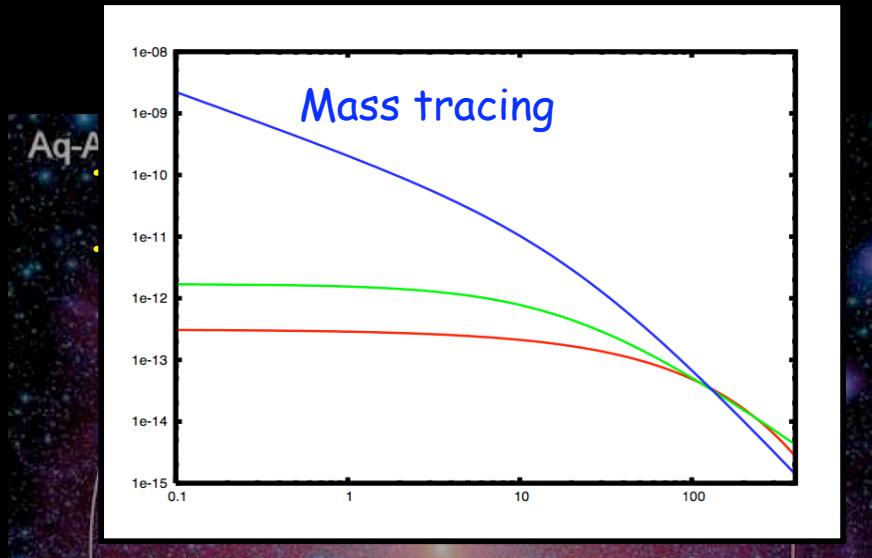
radial dependence of c

Via Lactea 2, Diemand et al

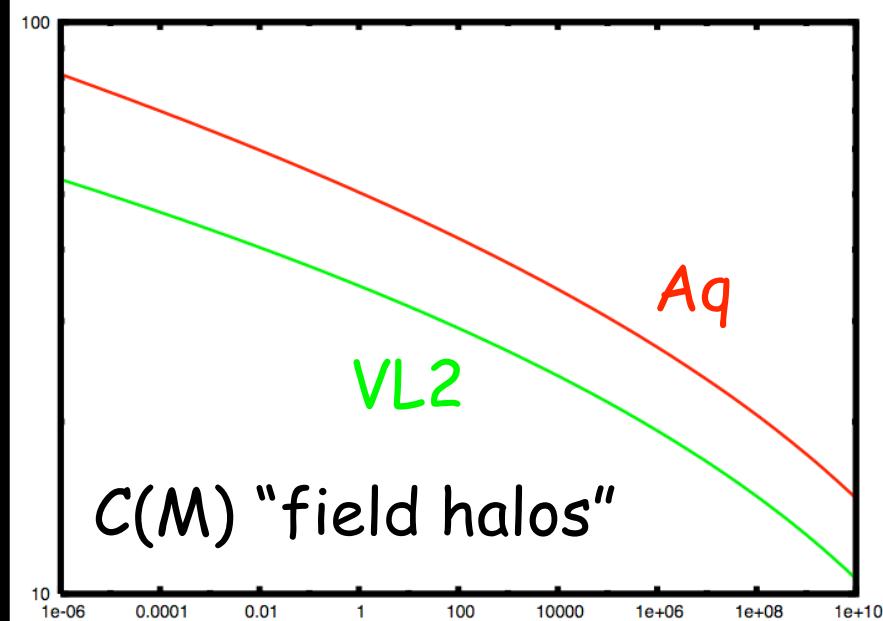
Aquarius, Springel et al



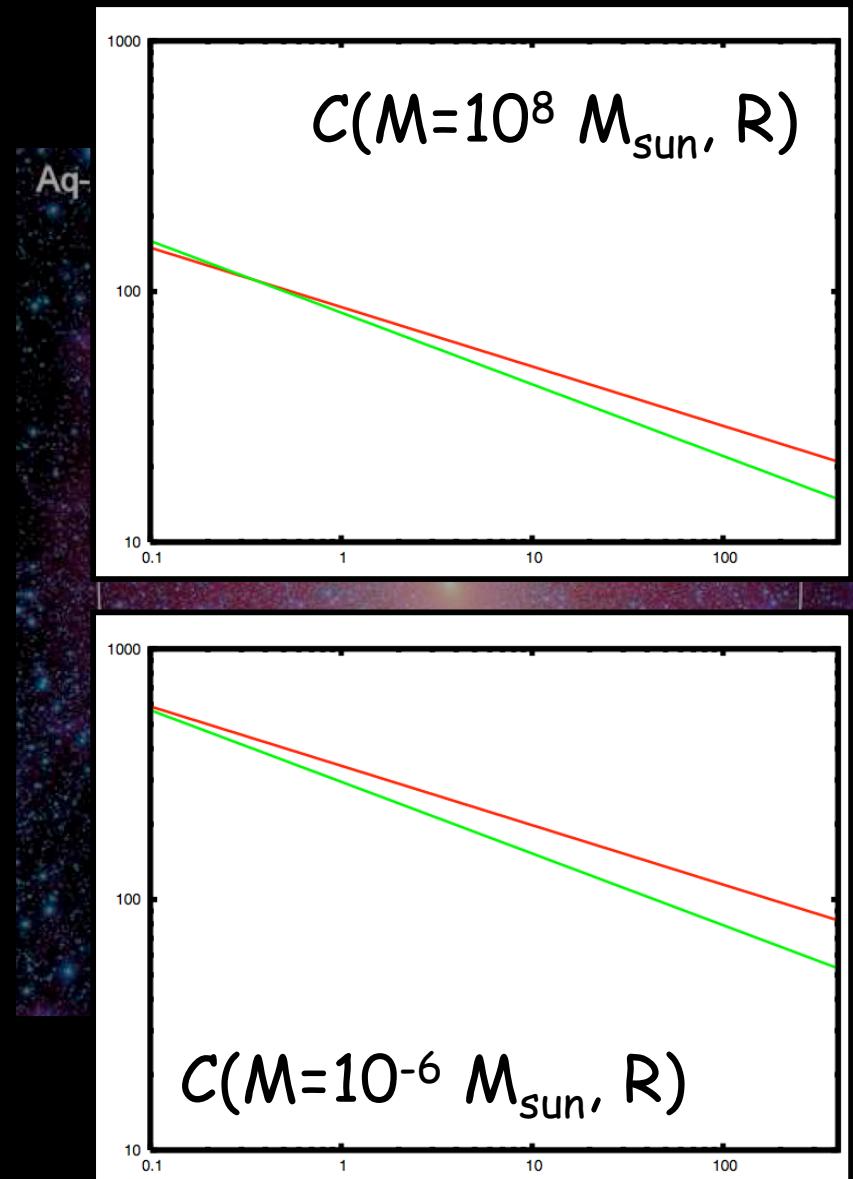
Density distribution



Concentration parameter



Via Lactea 2, Diemand et al



$z=0.0$

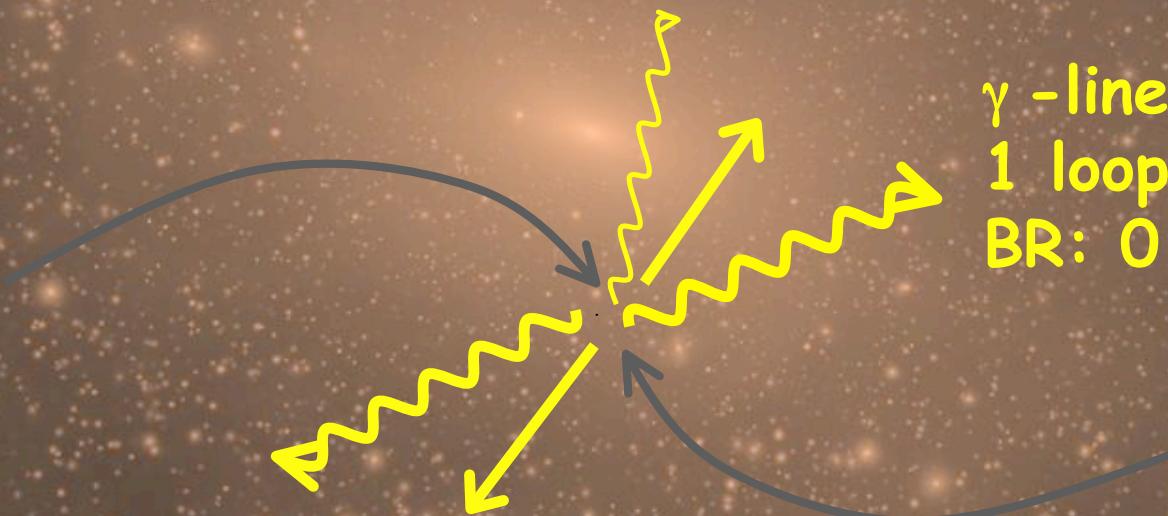
2) Model the yield of photons from particle physics

Internal bremmstrahlung

GeV-TeV γ

$E > 0.6 m_{DM}$

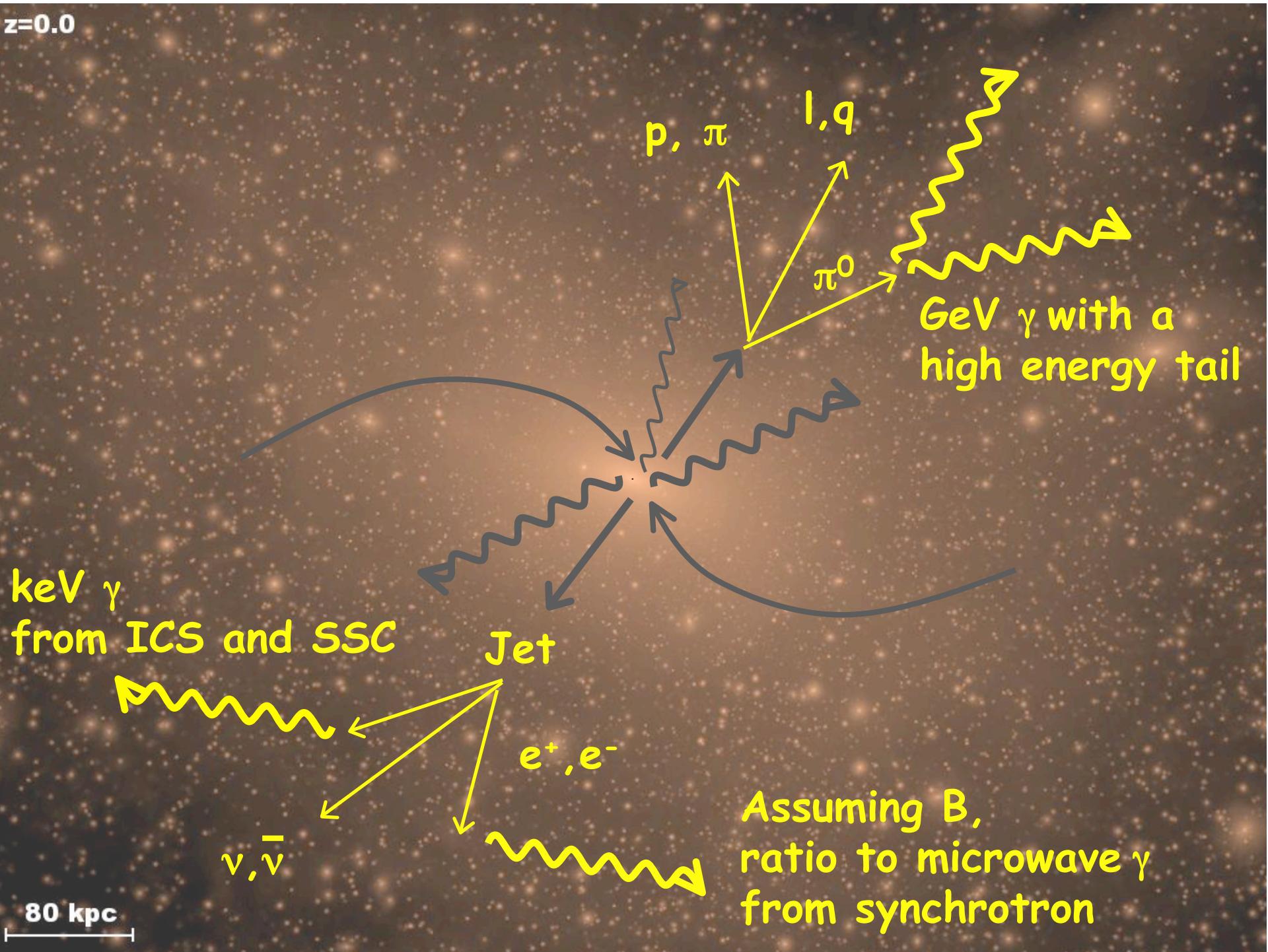
γ -line $E = m_{DM}$
1 loop process
BR: 0.001%



W, Z, H, f
BR $\sim 100\%$

80 kpc

$z=0.0$



Indirect detection of γ -rays:

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

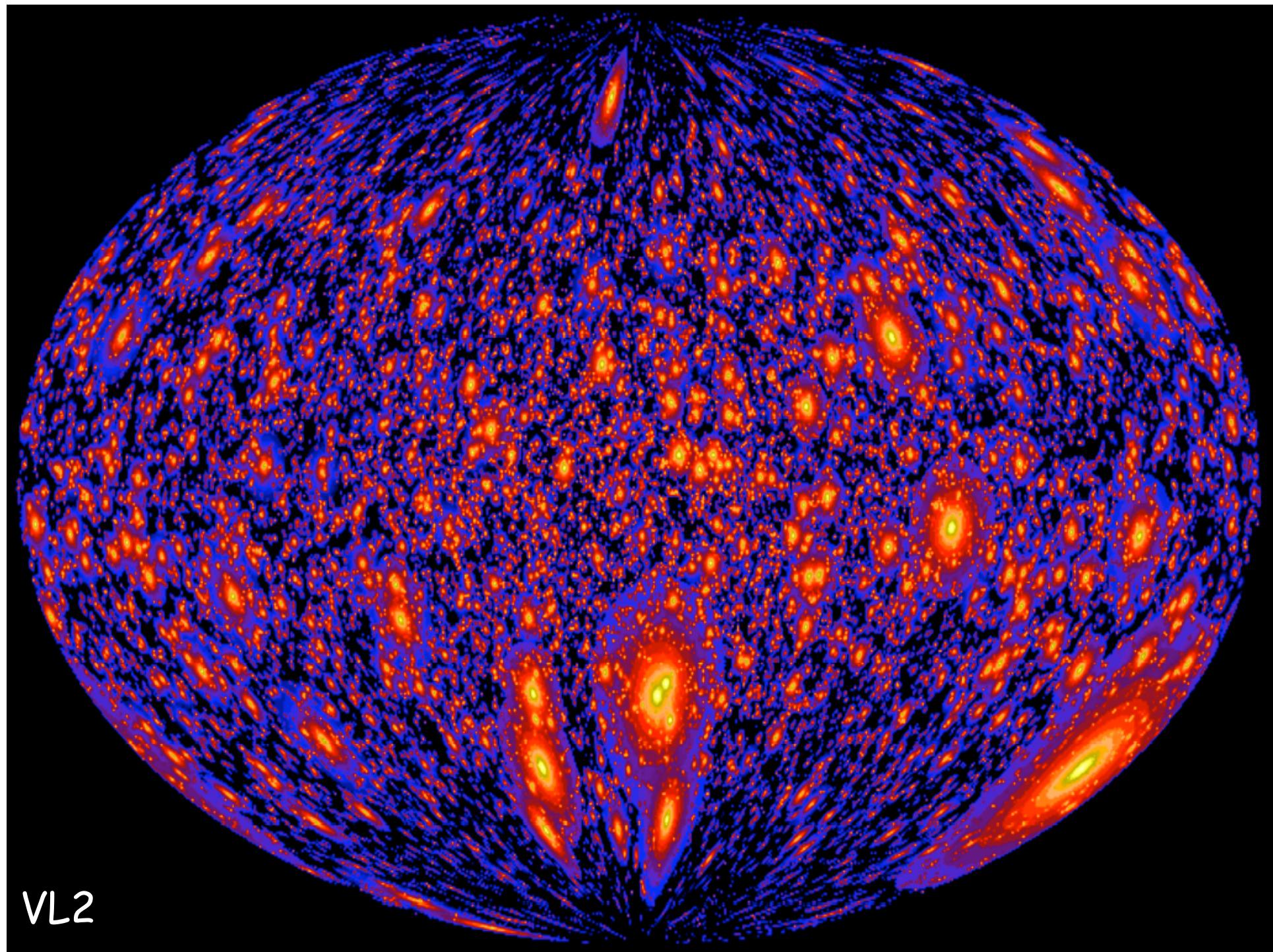
$$\Phi_{\text{PP}} = \frac{1}{4\pi} \frac{\sigma_{\text{ann}} v}{2m_\chi^2} \int_{E_0}^{m_\chi} \sum_f \frac{dN_f^\gamma}{dE_\gamma} BR_f$$

Single halo contribution (both MW or subhalos)

$$\Phi_{\text{COSMO}}^{\text{halo}}(M, c, r) \propto \int_{V.\text{o.s.}} dV \left[\frac{\rho_{\text{DM}}^2(M, c, r(d, V(\lambda', \theta', \varphi'), \psi))}{d^2} \right]$$

The DM density profile is a function of the halo mass, the concentration parameter and the radial distance from the halo centre

Both ρ_{DM} and c are not univocally established.



Indirect detection of γ -rays:

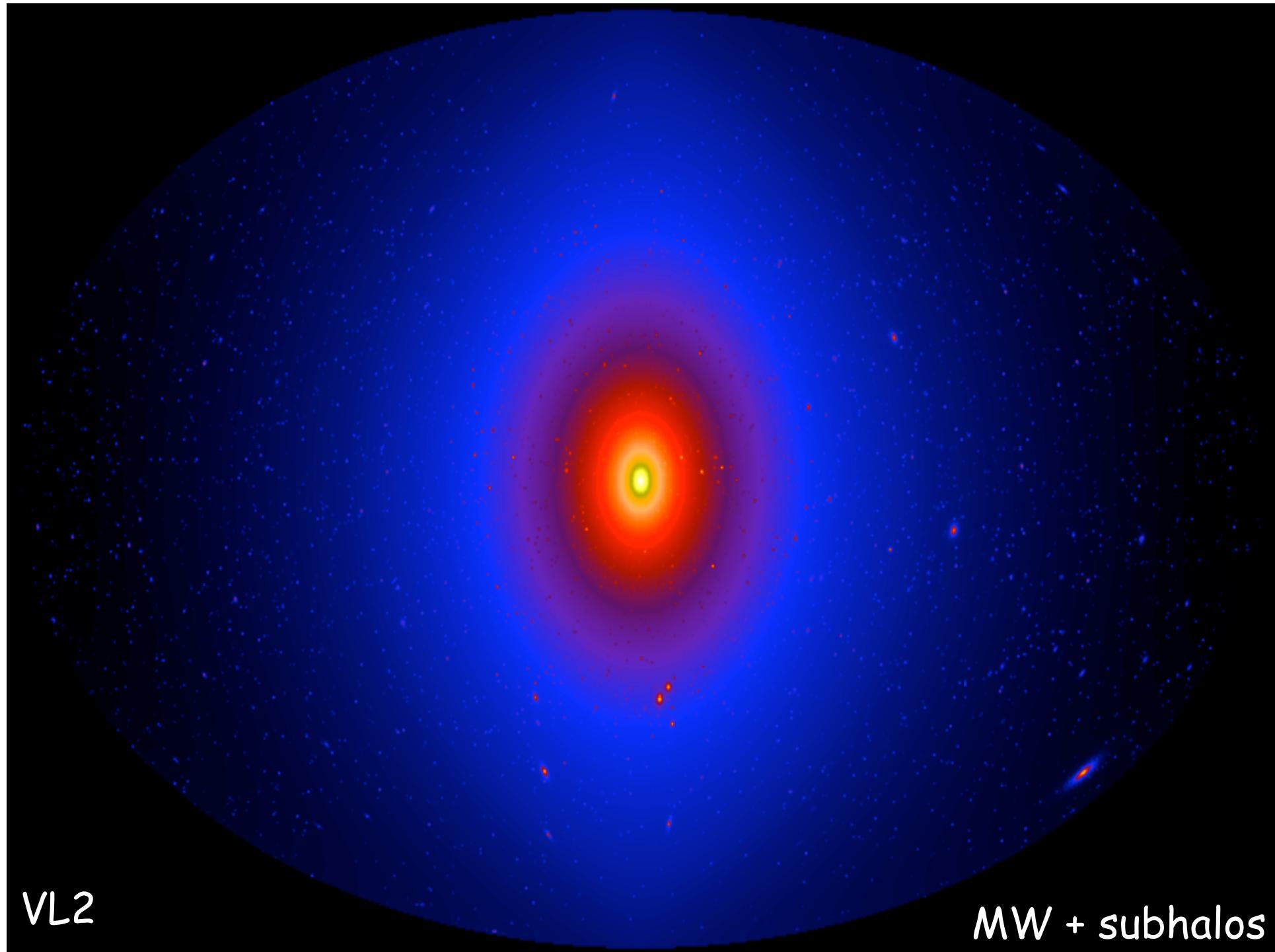
$$\Phi_\gamma = \Phi_{\text{particle physics}} \times \Phi_{\text{cosmology}}$$

UNRESOLVED subhalos
summing up over all the halos

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

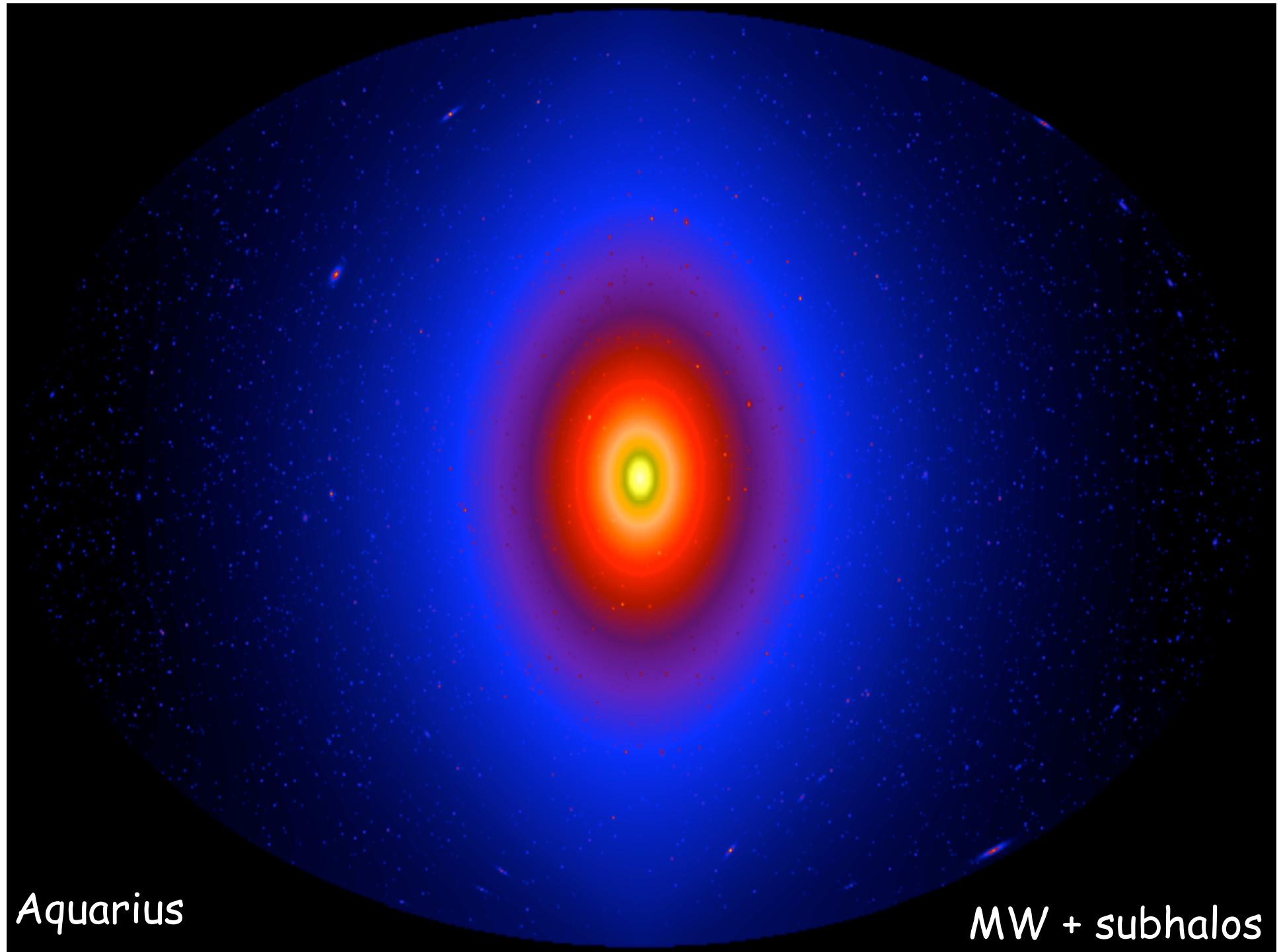
The single halo expression must be convolved
with the subhalo mass and spatial distribution function
and with the concentration parameter distribution function

Both ρ_{sh} and $P(c)$ are not univocally established



VL2

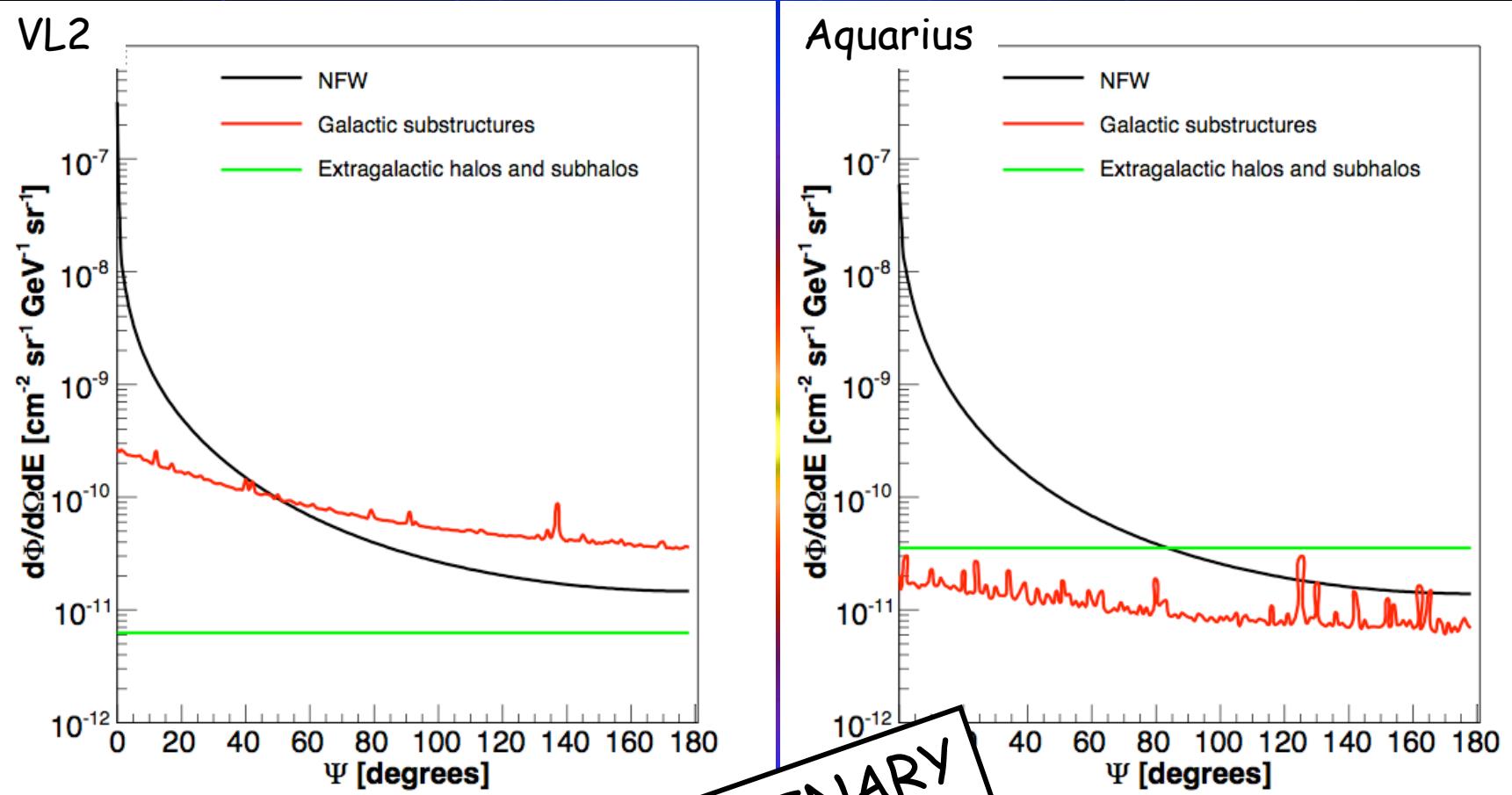
MW + subhalos



Aquarius

MW + subhalos

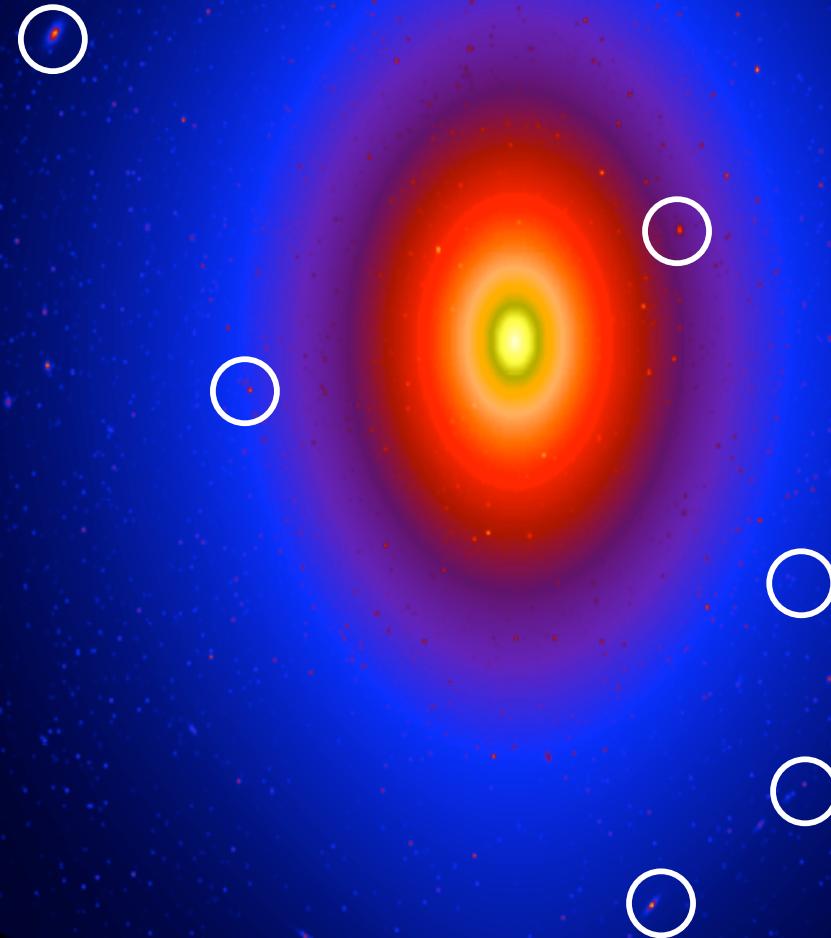
Photon flux @ 10 GeV



PRELIMINARY
LP et al
2009 in preparation

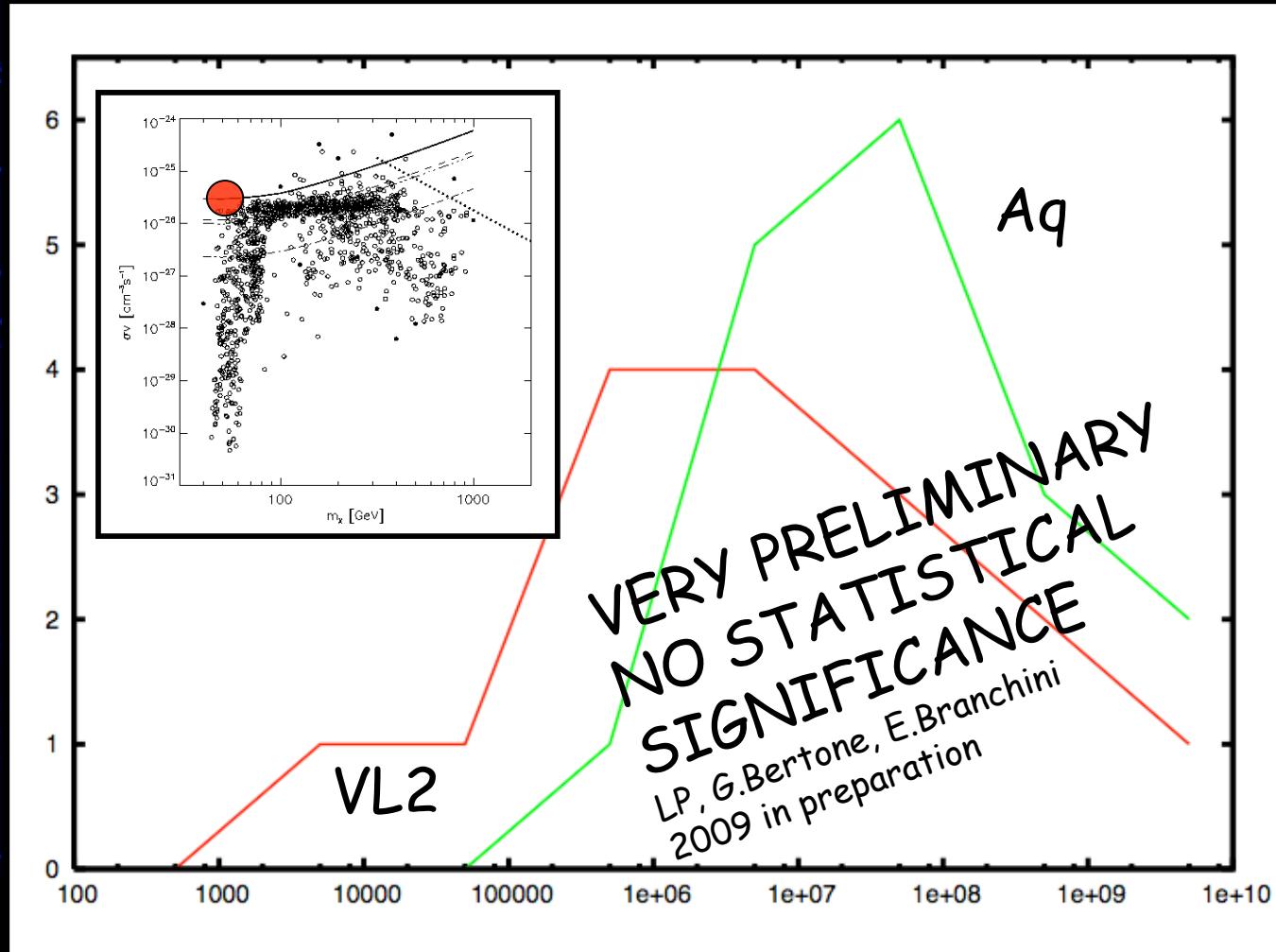
$M_\chi = 40 \text{ GeV}$, $\sigma v = 10^{-26} \text{ cm}^3 \text{s}^{-1}$

Any detectable halo?



Aquarius

Number of halos detectable at 3σ in 1 yr with Fermi



But the farthest is 40 kpc away

**WARNING: there is no clear message
from both theory and experiments, from both
particle physics and astrophysics...**

- **Observations** ... (cuspy or cored density profiles are not disentangled, no DM signal observed so far, astrophysical background poorly modelled) ... don't help

uncertainty from "standard" astrophysical background

- **Theory**... (the initial power spectrum of density fluctuations, the density profile and mass function of halos, the evolution and survival of structures, the effect of baryons, the effect of black holes.....) is far from being understood.



Several orders of magnitude of **uncertainty** in the prediction of fluxes from cosmology and astrophysics

Furthermore, particle physics is unknown

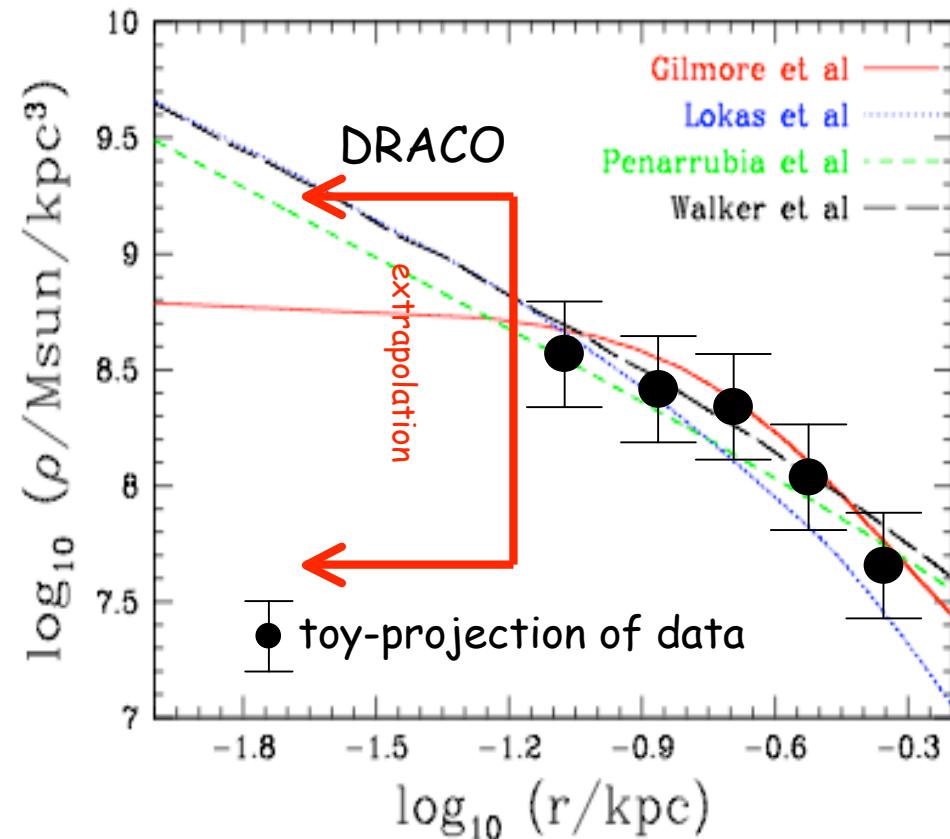


other orders of magnitude of **uncertainty**

1b) Model the structure of dark matter halos from astronomical measurements

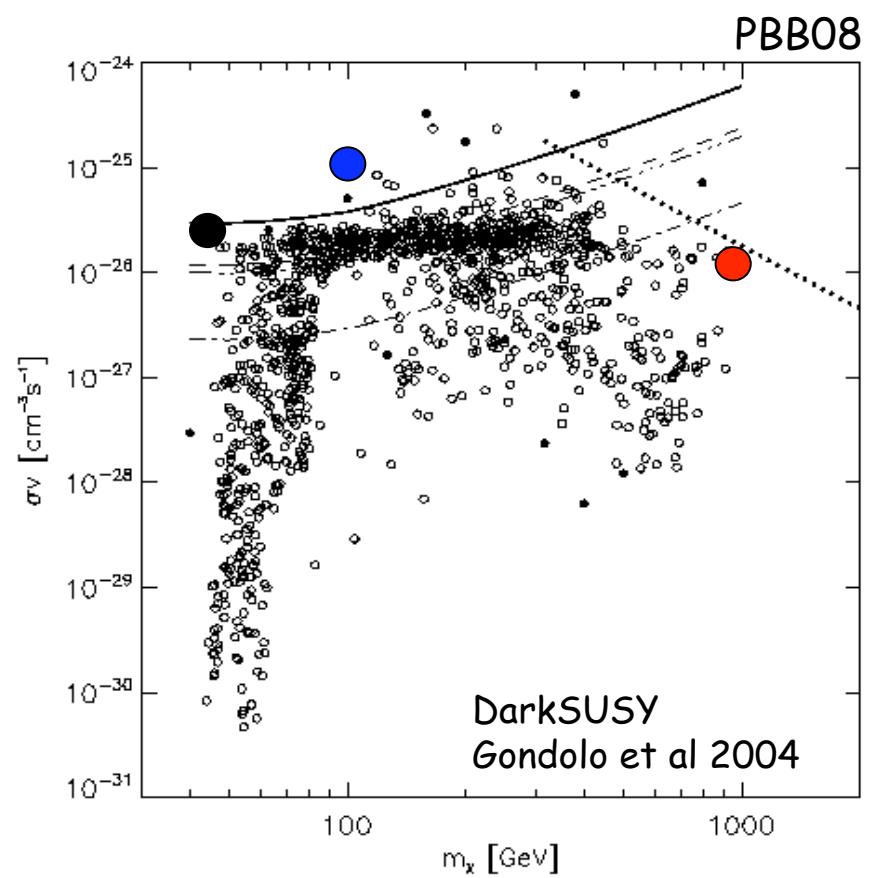
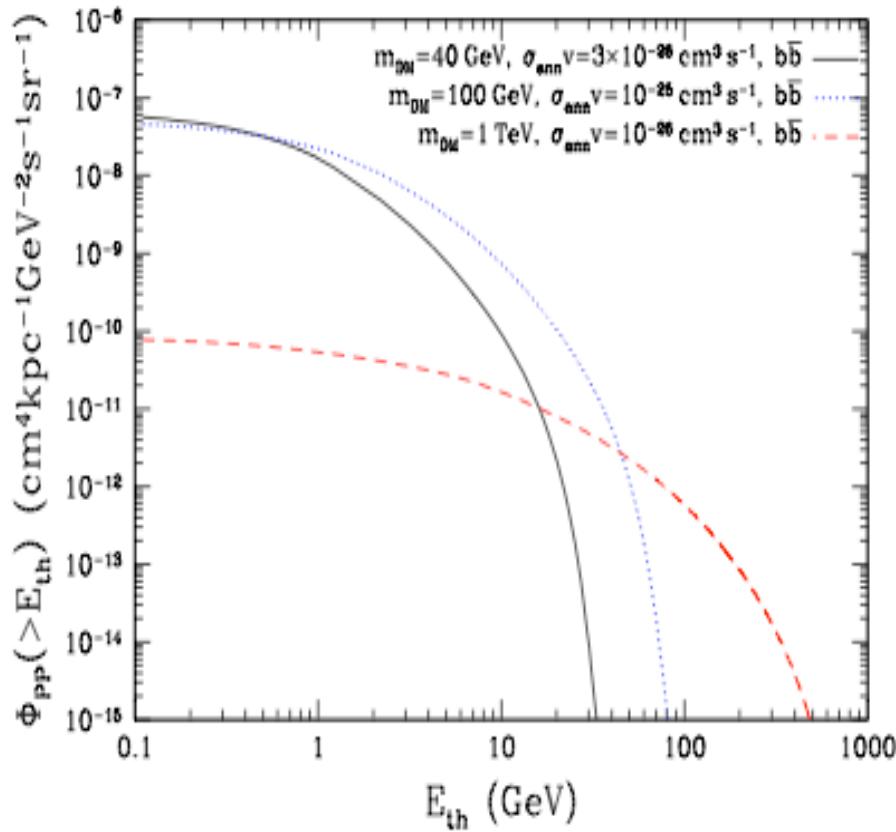
Dark matter profiles can be extracted by astronomical data

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



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

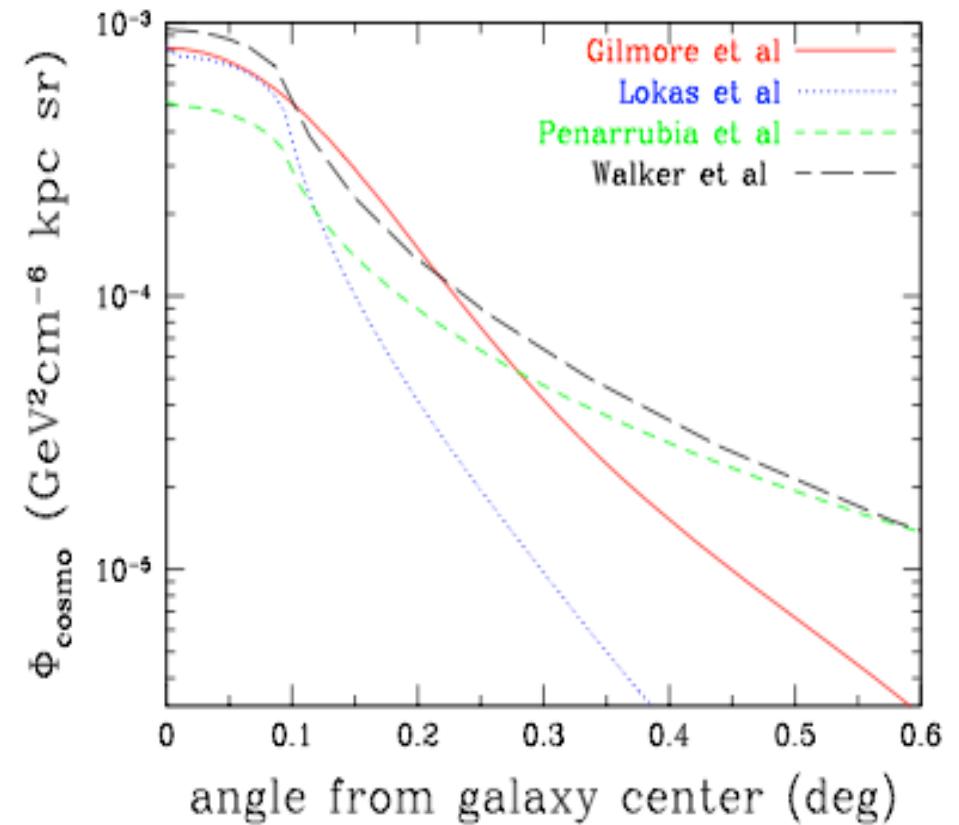
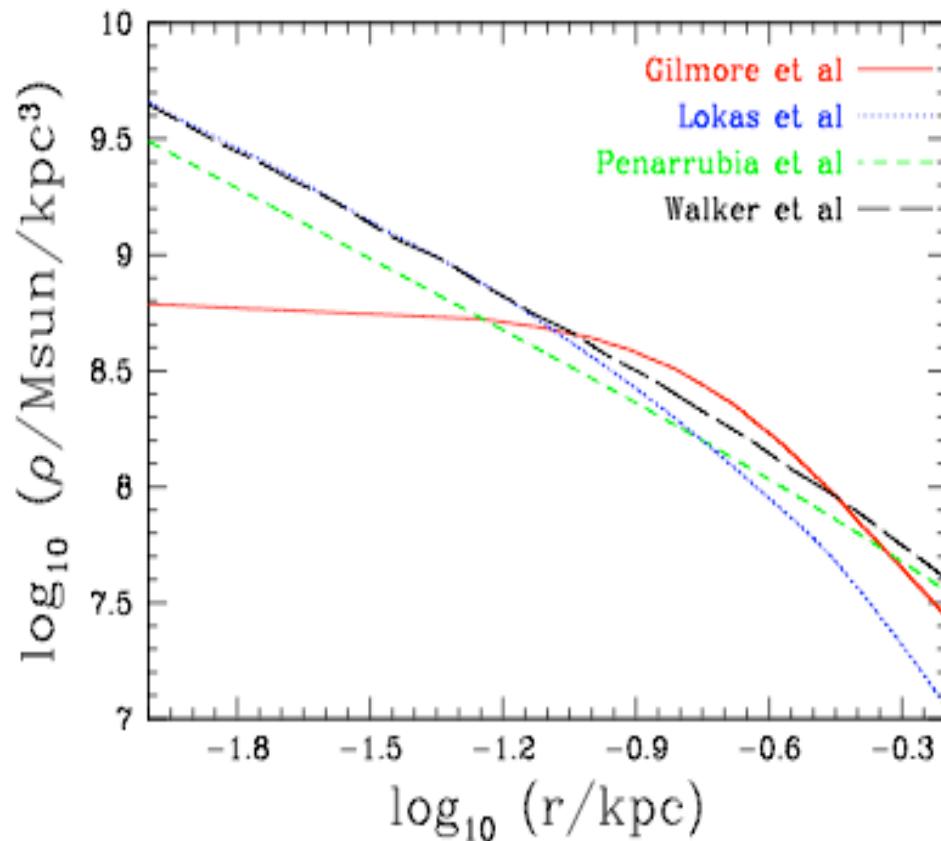
$$\Phi_{\text{PP}} = \frac{1}{4\pi} \frac{\sigma_{\text{ann}} v}{2m_\chi^2} \int_{E_0}^{m_\chi} \sum_f \frac{dN_f^\gamma}{dE_\gamma} BR_f dE_\gamma$$



Petal08

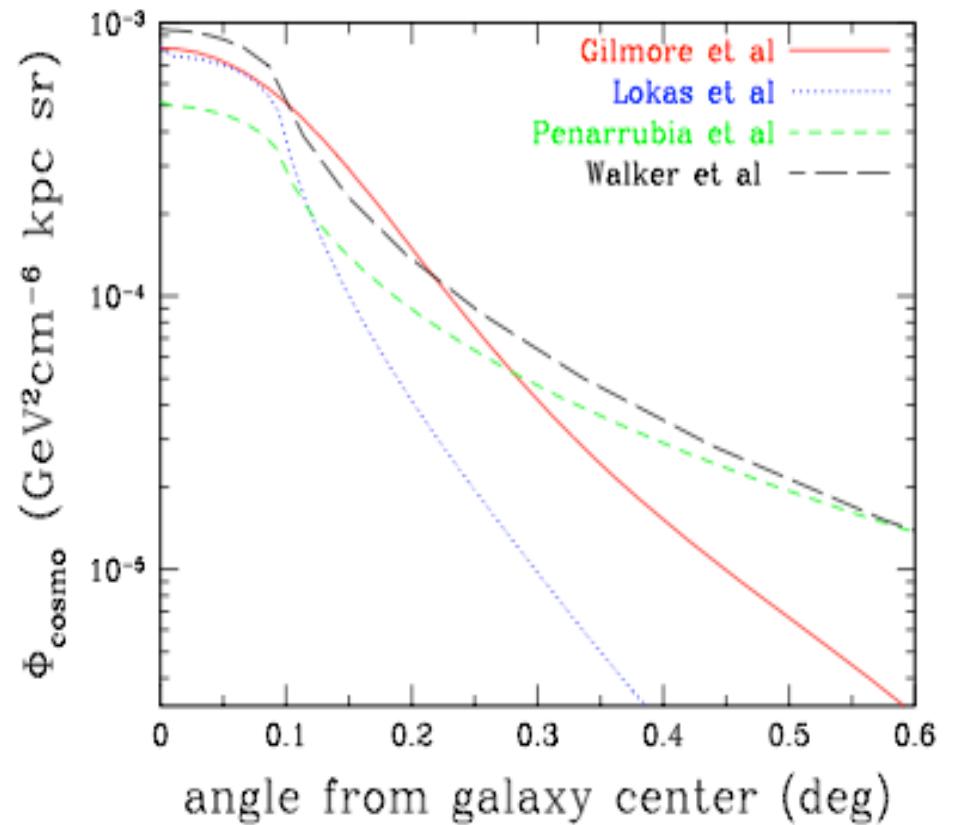
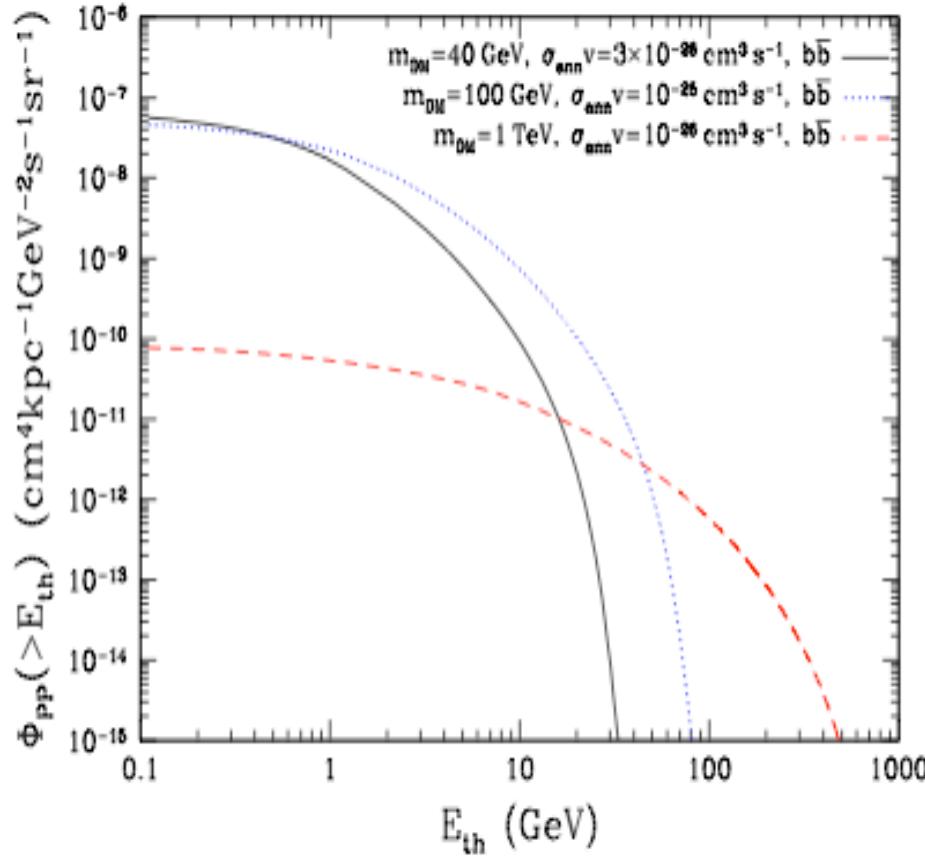
Computing $\Phi_\gamma = \Phi_{\text{particle physics}} \times \Phi_{\text{cosmology}}$

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



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

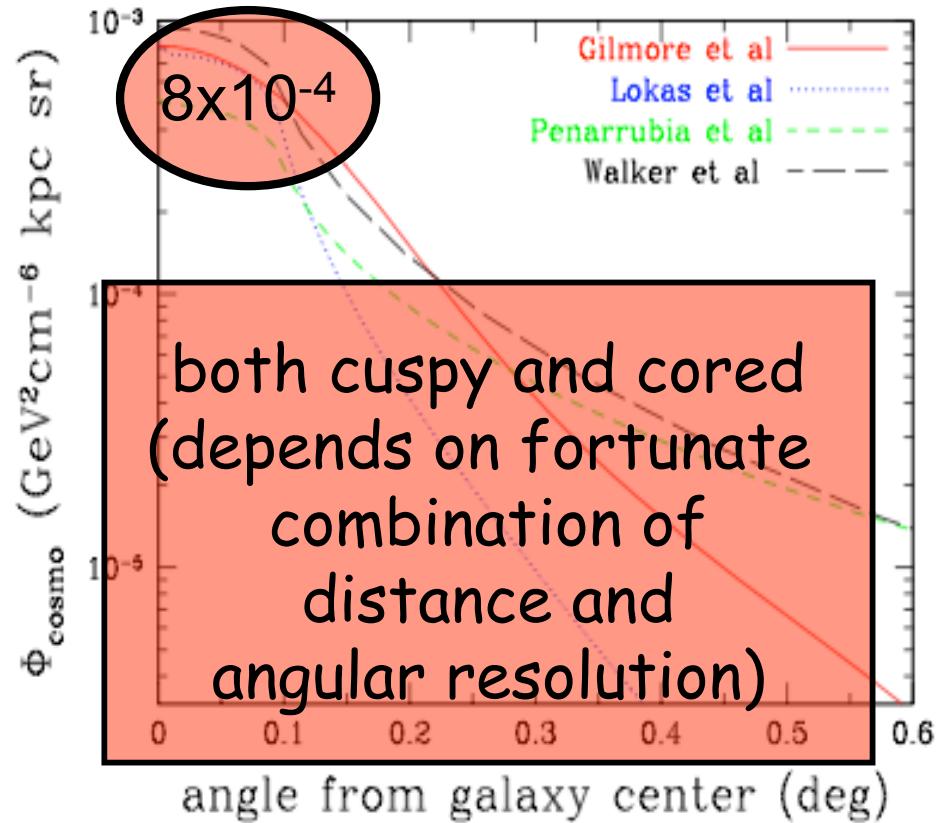
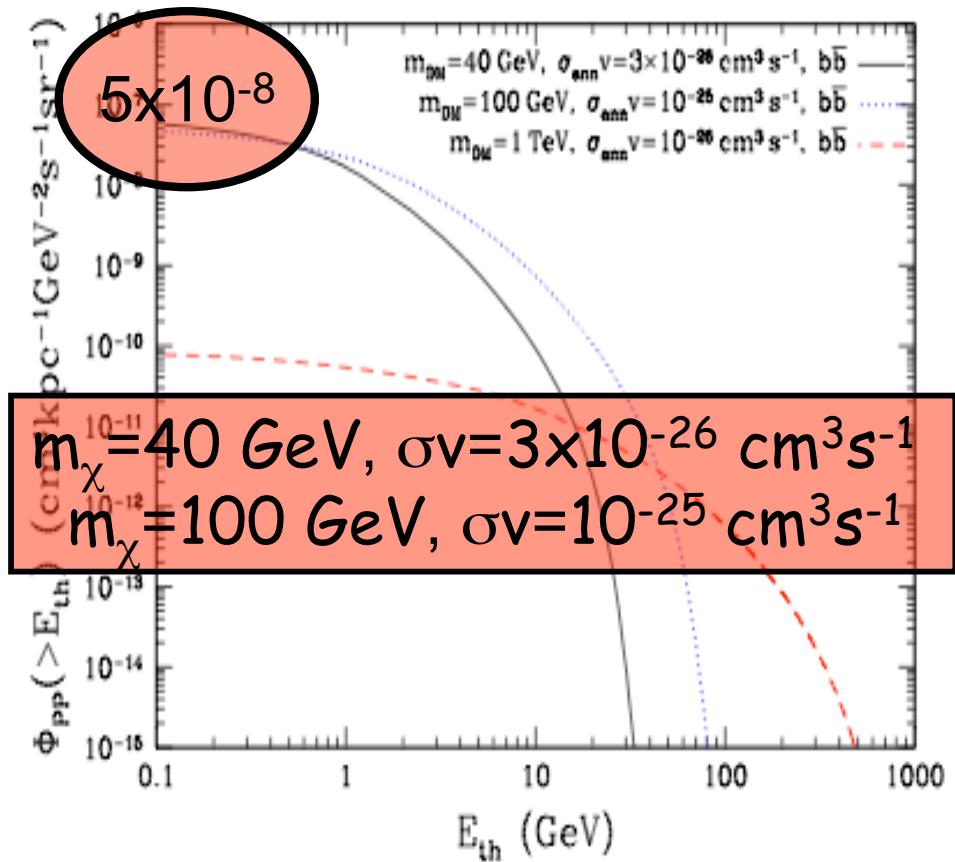
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$$\Phi_{\text{cosmo}} = \int_{\Delta\Omega, \lambda} \frac{\rho^2(r(\Delta\Omega, \lambda))}{\lambda^2} dV$$

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

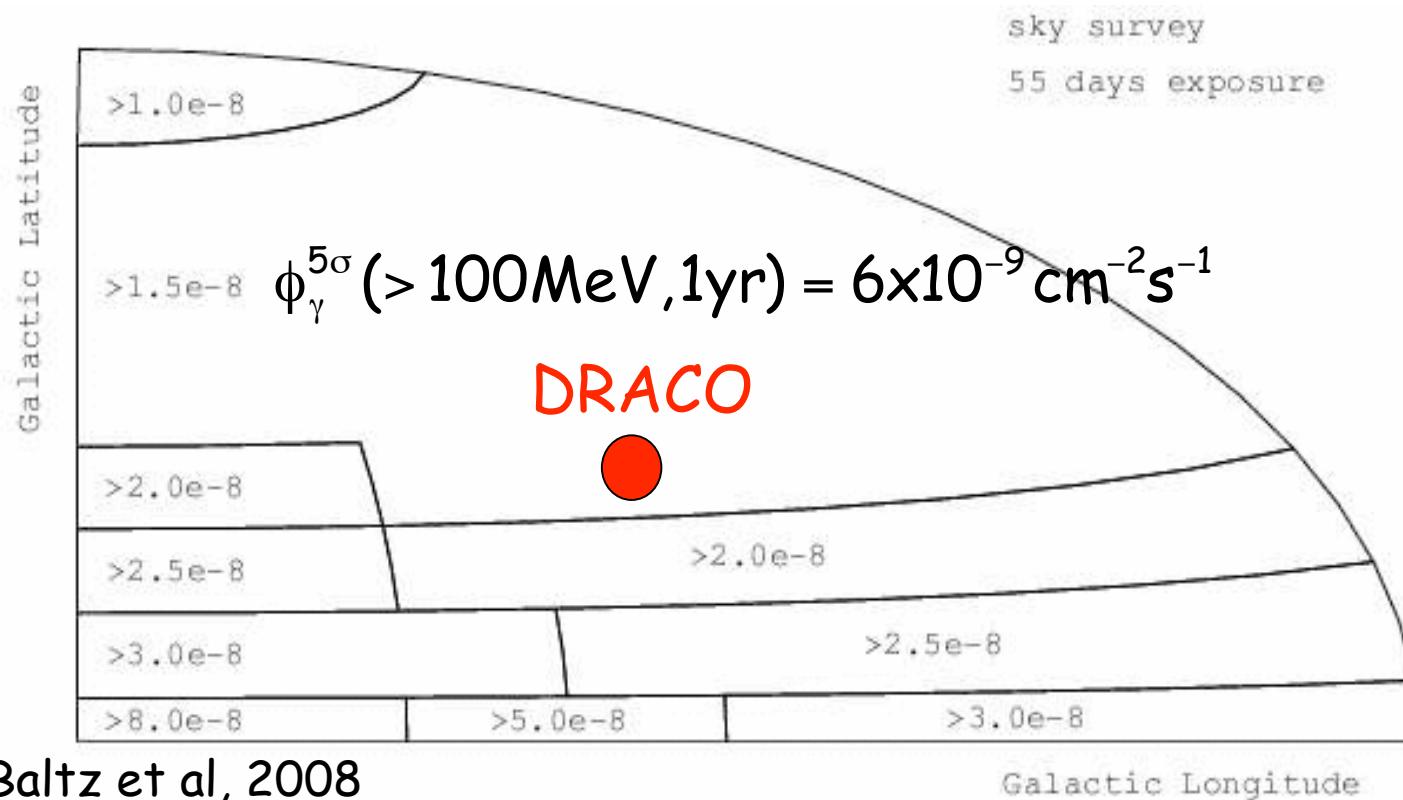
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$$\Phi_{\text{cosmo}} = \int_{\Delta\Omega, \lambda} \frac{\rho^2(r(\Delta\Omega, \lambda))}{\lambda^2} dV$$

Comparing predictions with *GLAST* performances

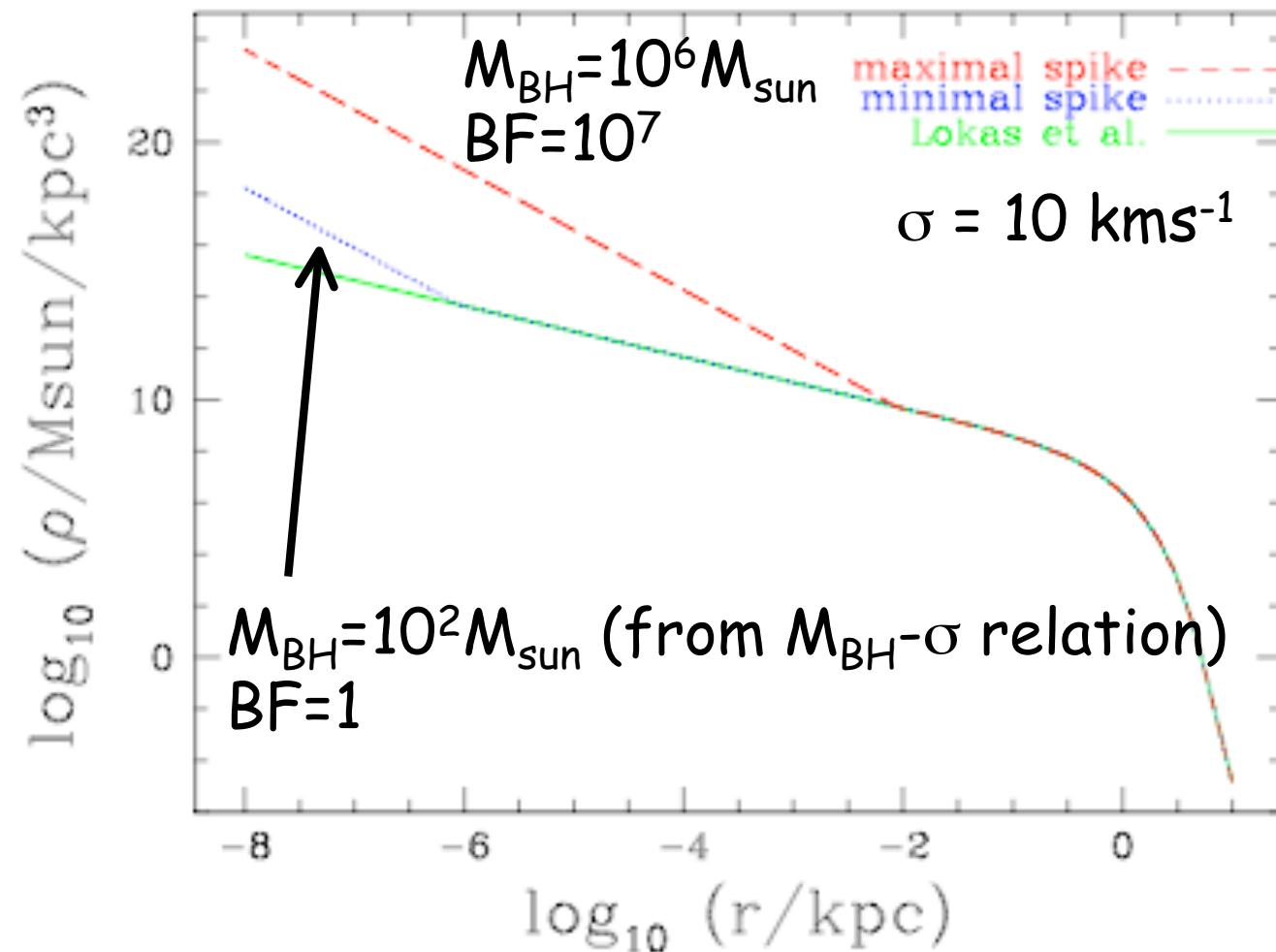
$$\text{DRACO } \Phi_{\gamma}^{\max} (> 100 \text{ MeV}) = (4.5 \pm 1.5) \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$$



DRACO and other dwarfs
are well below the detection limit
Boost factors are needed to hope for detection

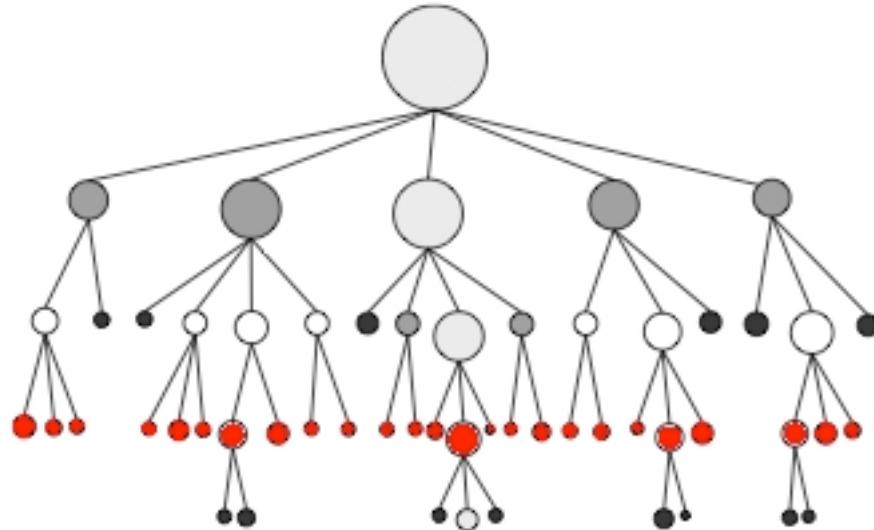
Petal08

Astrophysical BF: presence of a Black Hole?



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

Astrophysical BF: presence of sub-subhalos?

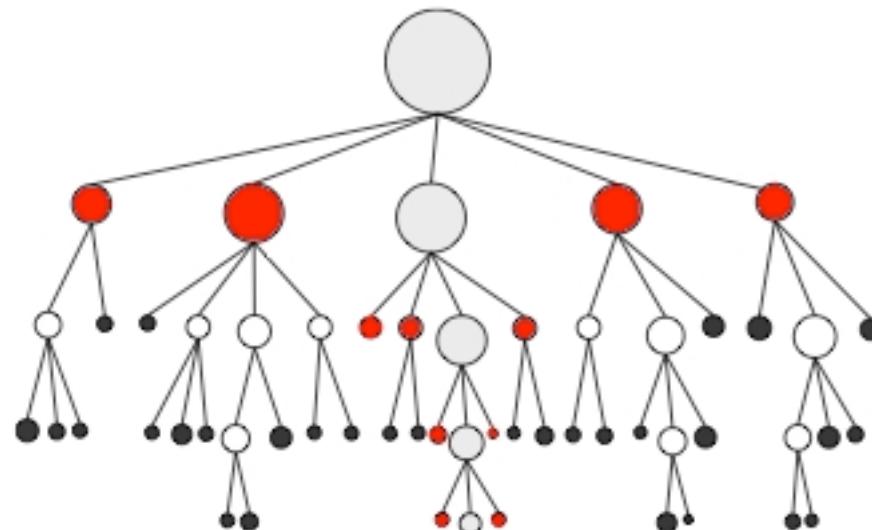


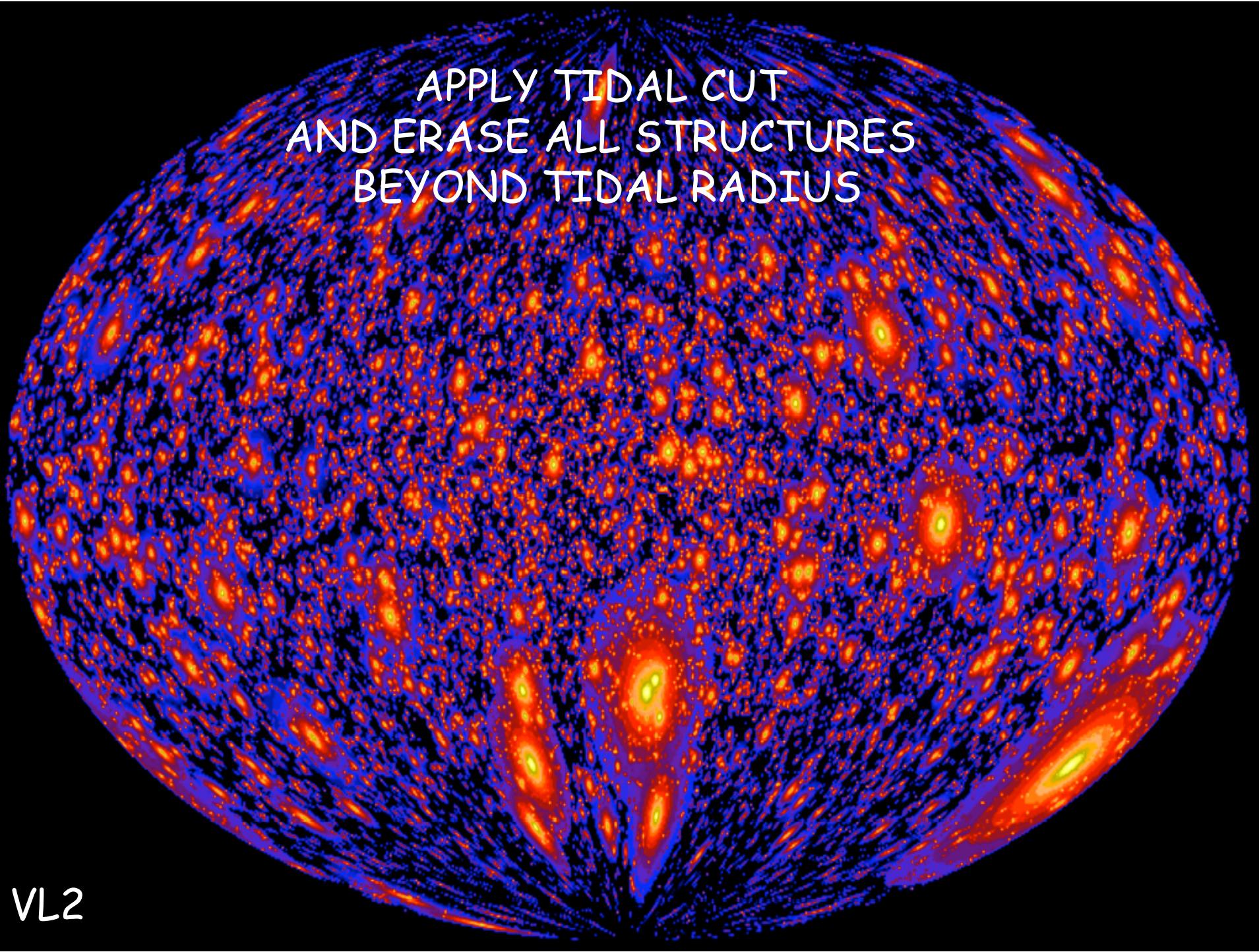
Press & Schechter approach
(mass function of all
progenitors, normalized
such that 10% of the Galaxy
mass is in substructures in
the $[10^{-5}, 10^{-2}] M_{\text{gal}}$ mass
range, and spatially tracing
the mass of the galaxy)

C. Giocoli, LP, G.Tormen, 2008 [GPT08]
L.Pieri, A. Pizzella, E.M. Corsini, E. Dalla Bontà,
F. Bertola [Petal08]

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

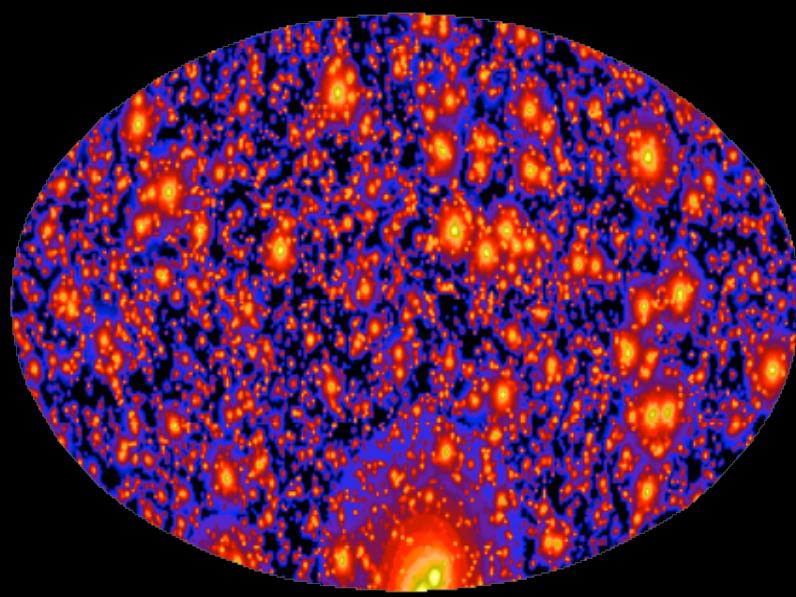
C. Giocoli, LP, G.Tormen, J. Moreno
[GPTM08]





APPLY TIDAL CUT
AND ERASE ALL STRUCTURES
BEYOND TIDAL RADIUS

VL2

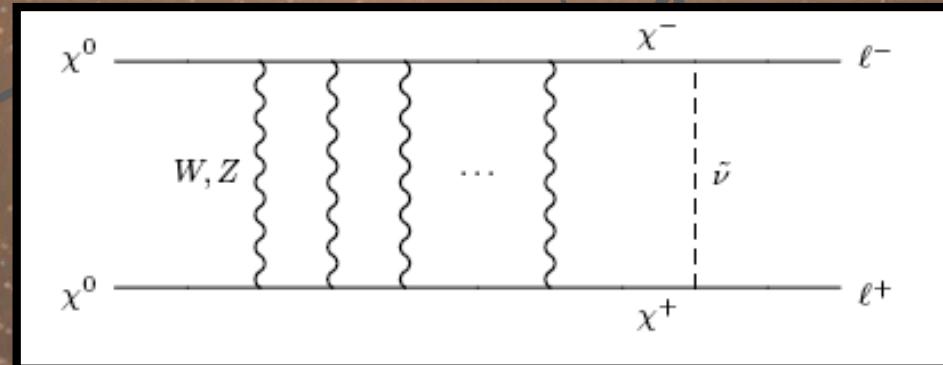
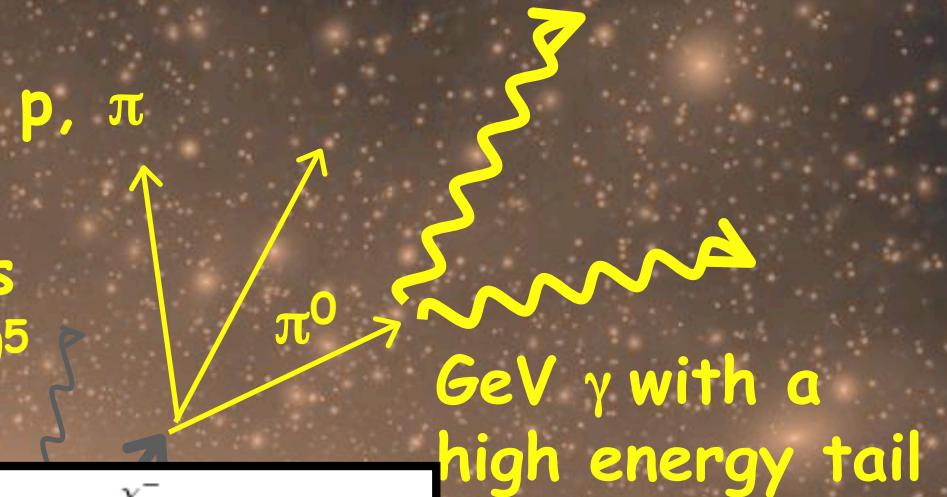


VL2

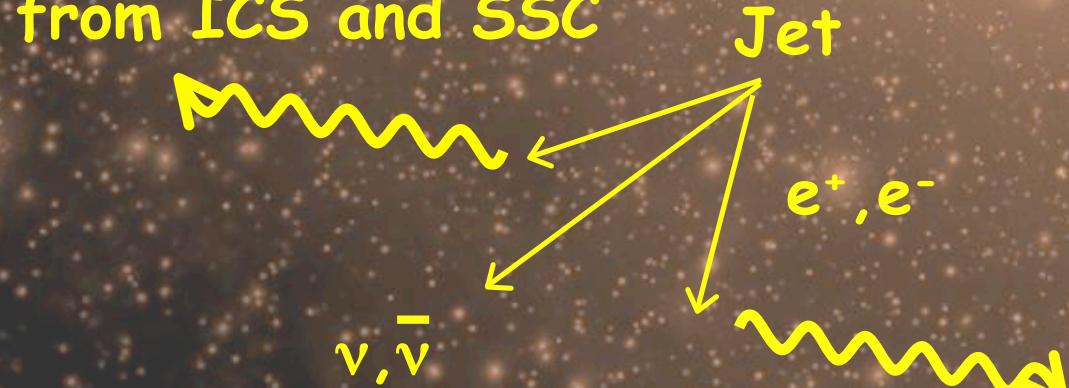
$z=0.0$

ADD BOOST FACTOR FROM PARTICLE PHYSICS

Sommerfeld enhancement may happen at low β , for special resonance mass values giving boost factors up to 10^5



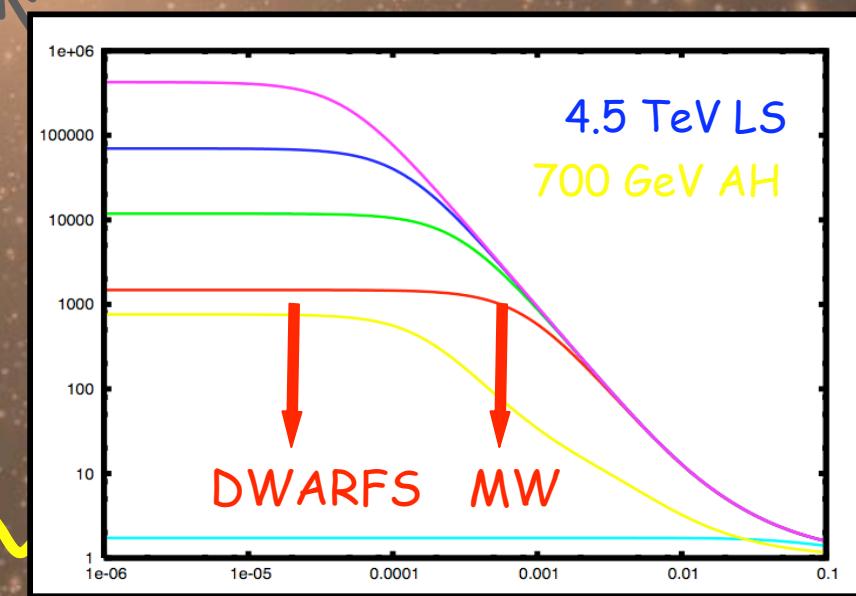
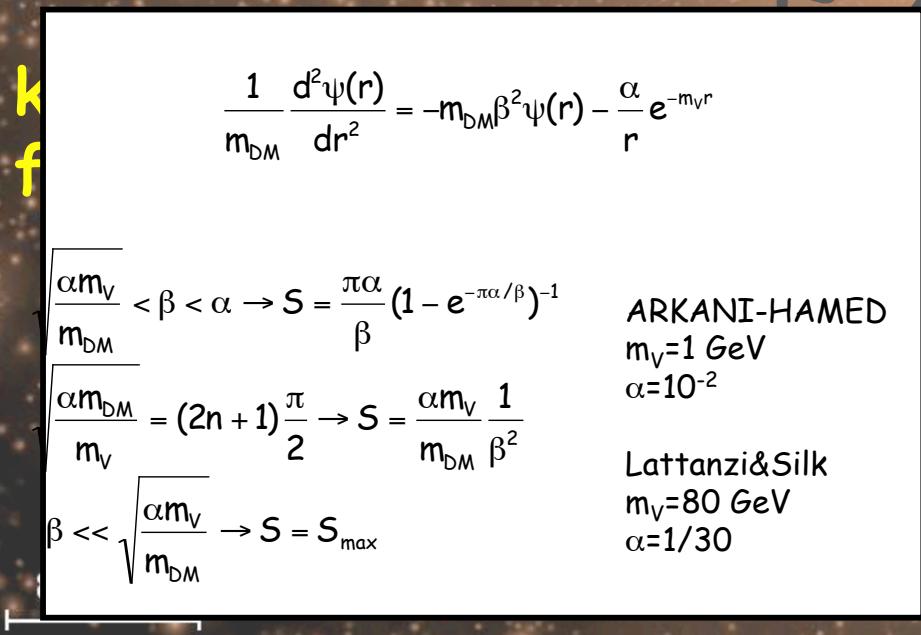
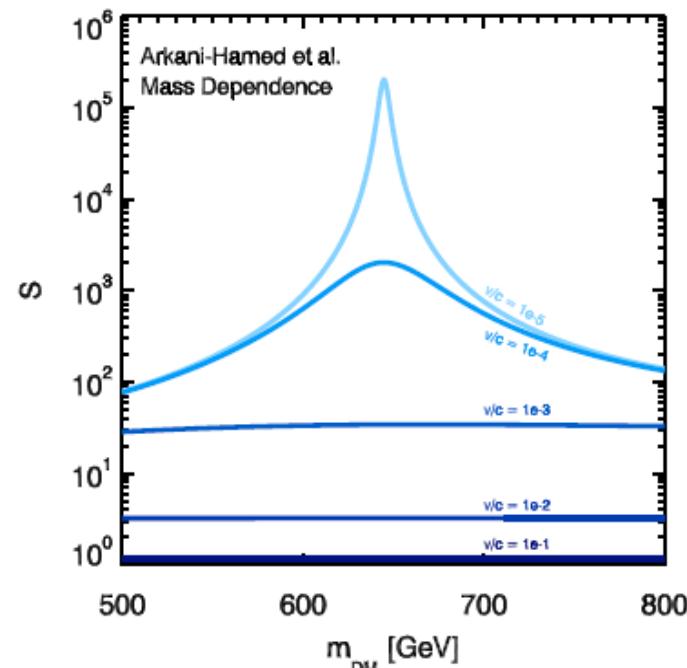
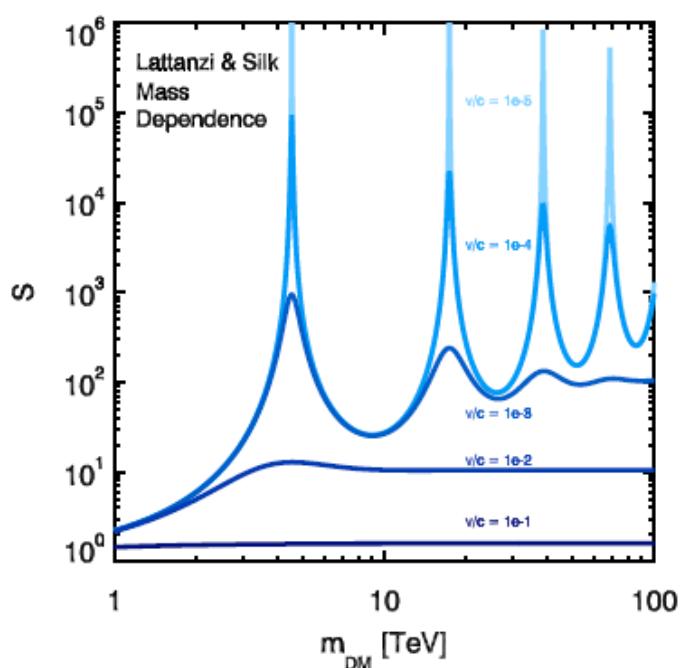
keV γ
from ICS and SSC



80 kpc

Assuming B ,
ratio to microwave γ
from synchrotron

$z=0.0$



Particle Physics BF: Sommerfeld enhancement?

Dwarf galaxies have low velocity dispersions,
hence a possibly high Sommerfeld enhancement
convolved with the subsubhalo contribution

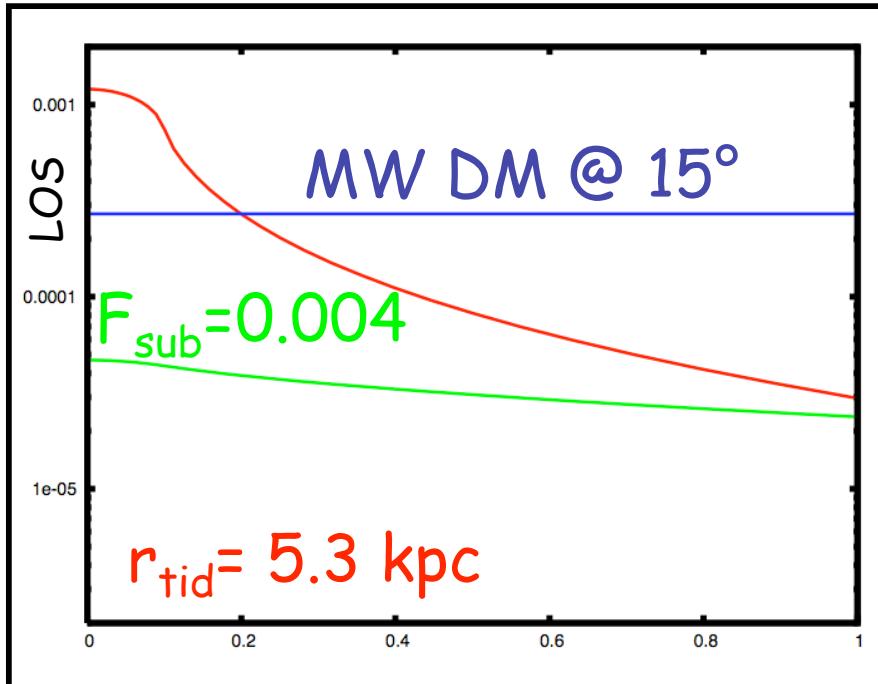
$$\sigma_{\text{ann}} v = (\sigma_{\text{ann}} v)_{\text{primordial}} S(\beta(r))$$

$$\Phi_{\text{PP}} = \frac{1}{4\pi} \frac{(\sigma_{\text{ann}} v)_{\text{primordial}}}{2m_\chi^2} \int_{E_0}^{m_\chi} \sum_f \frac{dN_f^\gamma}{dE_\gamma} BR_f$$

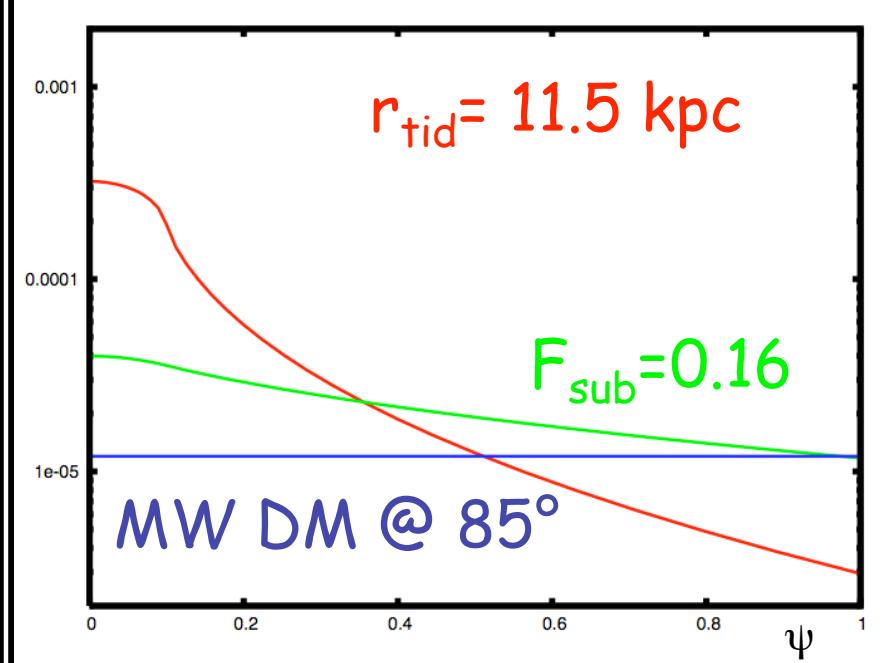
$$\Phi_{\text{COSMO}}^{\text{halo}}(M, c, r) \propto \int_{\text{LOS}} d\lambda S(\beta(M, r)) \rho_{\text{DM}}^2(M, c(M, r), r(d, V(\lambda', \theta', \varphi')), \psi)$$

Computing subhalo effect

SAGITTARIUS

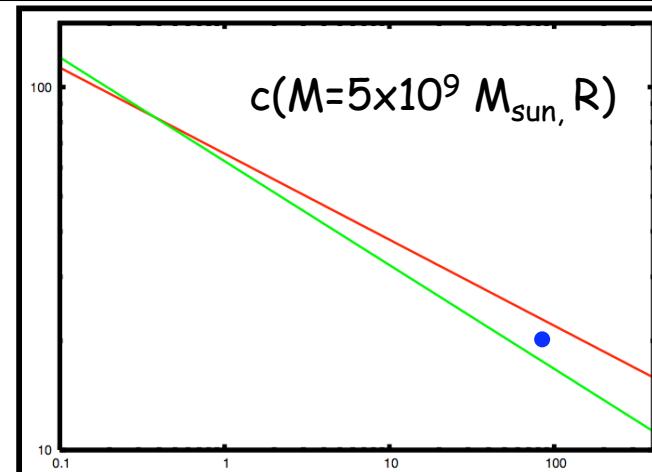


DRACO



NFW fit to DRACO velocity
Dispersion (Walker et al 2008)

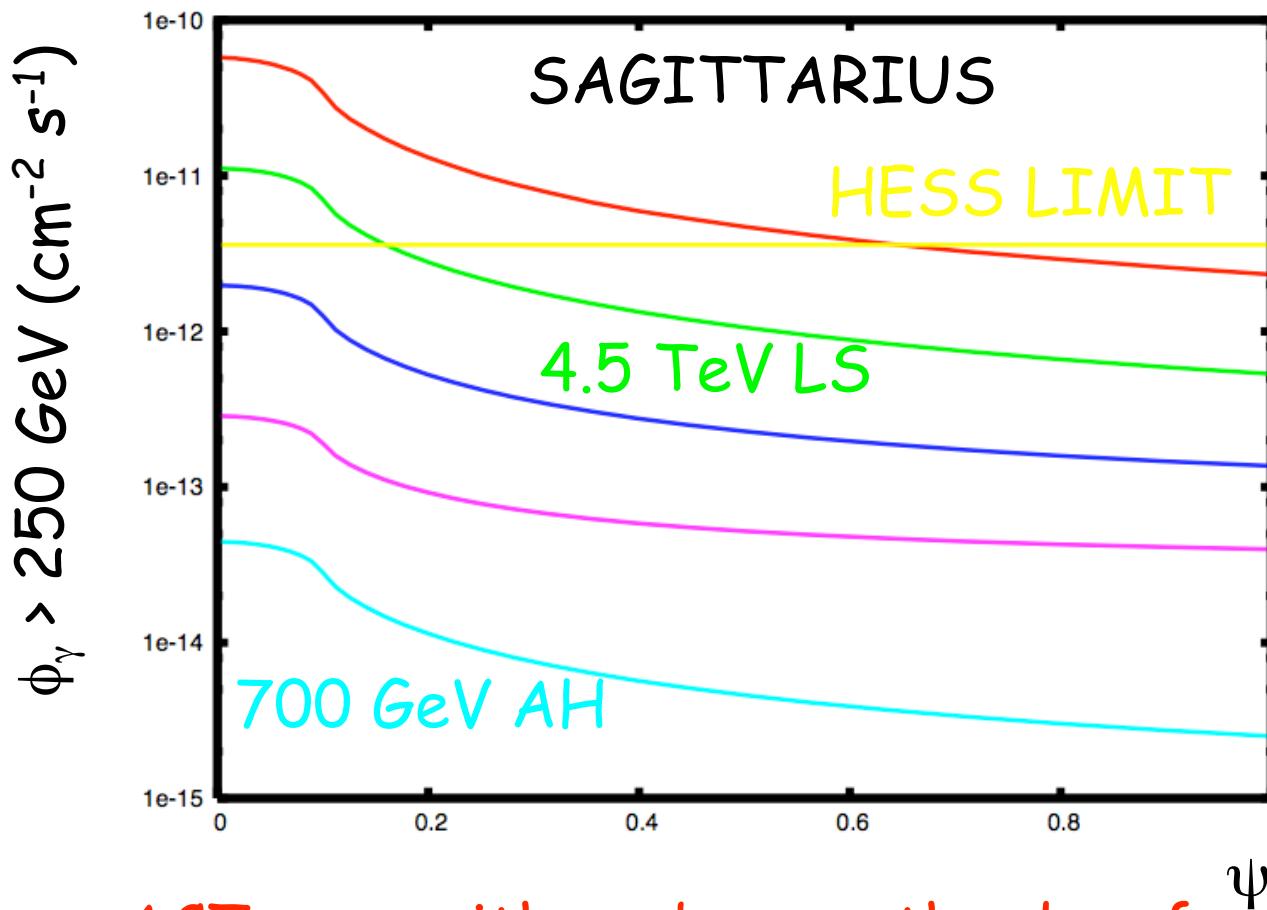
$c=22$
 $r_s=2 \text{ kpc}$
 $\rho_s=2.16 \times 10^7 M_{\text{sun}} \text{ kpc}^{-3}$



PLS09

Particle Physics BF: Sommerfeld enhancement?

Dwarf galaxies have low velocity dispersions,
hence a possibly high Sommerfeld enhancement
convolved with the subsubhalo contribution



ACTs may either observe the dwarfs
or constrain the Sommerfeld enhancement

Conclusions

Detection of individual structures?

Highly model-dependent.

In the best case scenario high mass halos are "detectable"

Small mass halos determine the foreground

Detection of dwarfs?

Unlikely, even if subhalos are included.

Possible with Sommerfeld enhancement at ACTs.