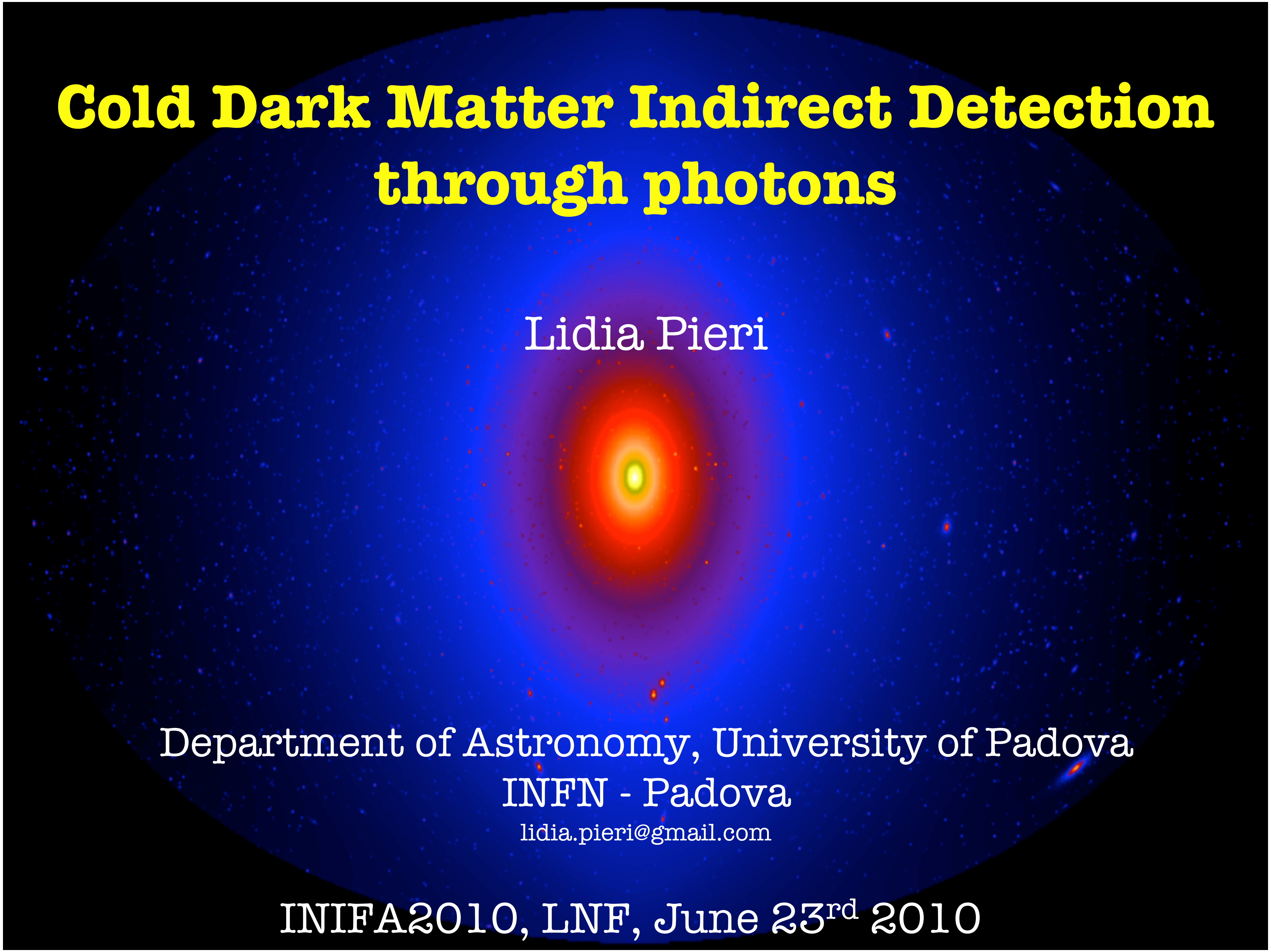

Cold Dark Matter Indirect Detection through photons

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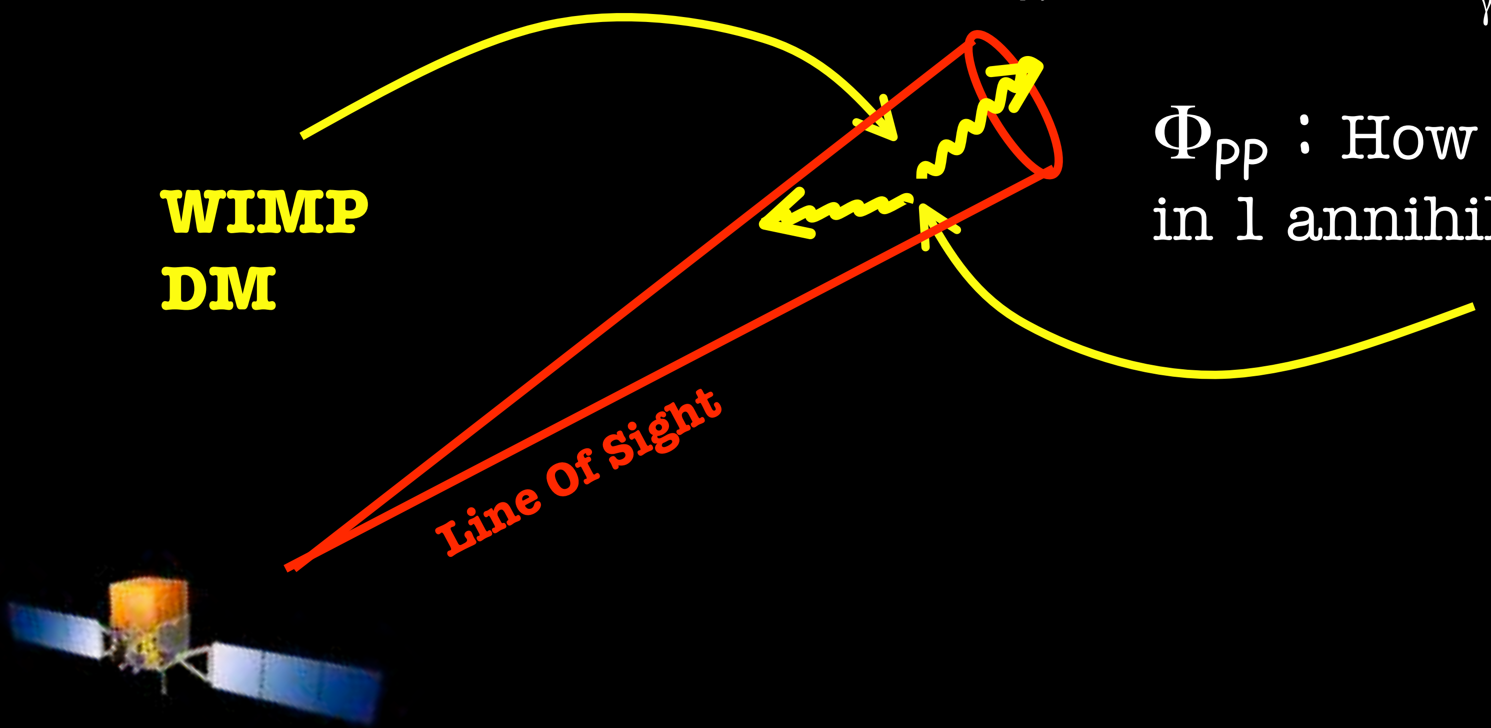
INIFA2010, LNF, June 23rd 2010

Gamma-ray photons from CDM annihilation

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

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



Φ_{PP} : How many γs in 1 annihilation

Gamma-ray photons from CDM annihilation

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

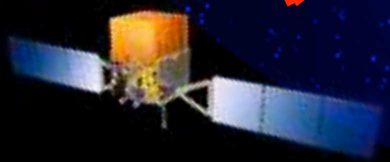
$$\phi_{PP} = \frac{1}{4\pi} \frac{\sigma_{ann} v}{2 m_\chi^2} \int_{E_0}^{m_\chi} \sum_f \frac{dN_f^\gamma}{dE_\gamma} BR_f \, dE_\gamma$$

Φ_{PP} : How many γs in 1 annihilation

WIMP DM

Line Of Sight

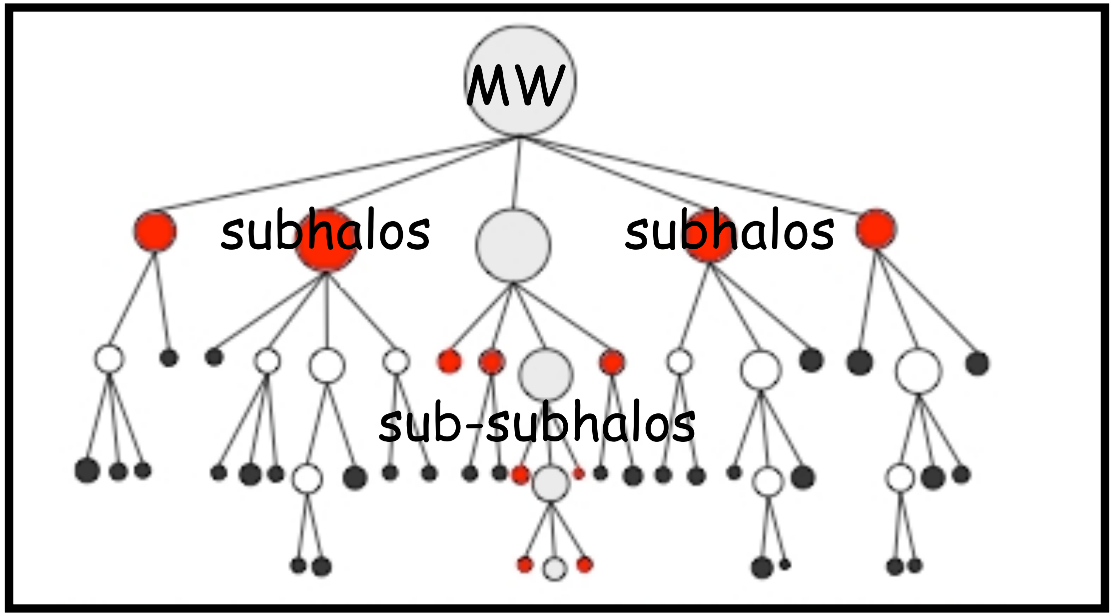
$$\phi_{cosmo} = \int_{\Delta\Omega,\lambda} \frac{\rho^2_{DM}(r(\Delta\Omega,\lambda))}{\lambda^2} d\lambda d\Omega$$



Φ_{cosmo} : How many annihilations $\Leftrightarrow$ How many and which sources

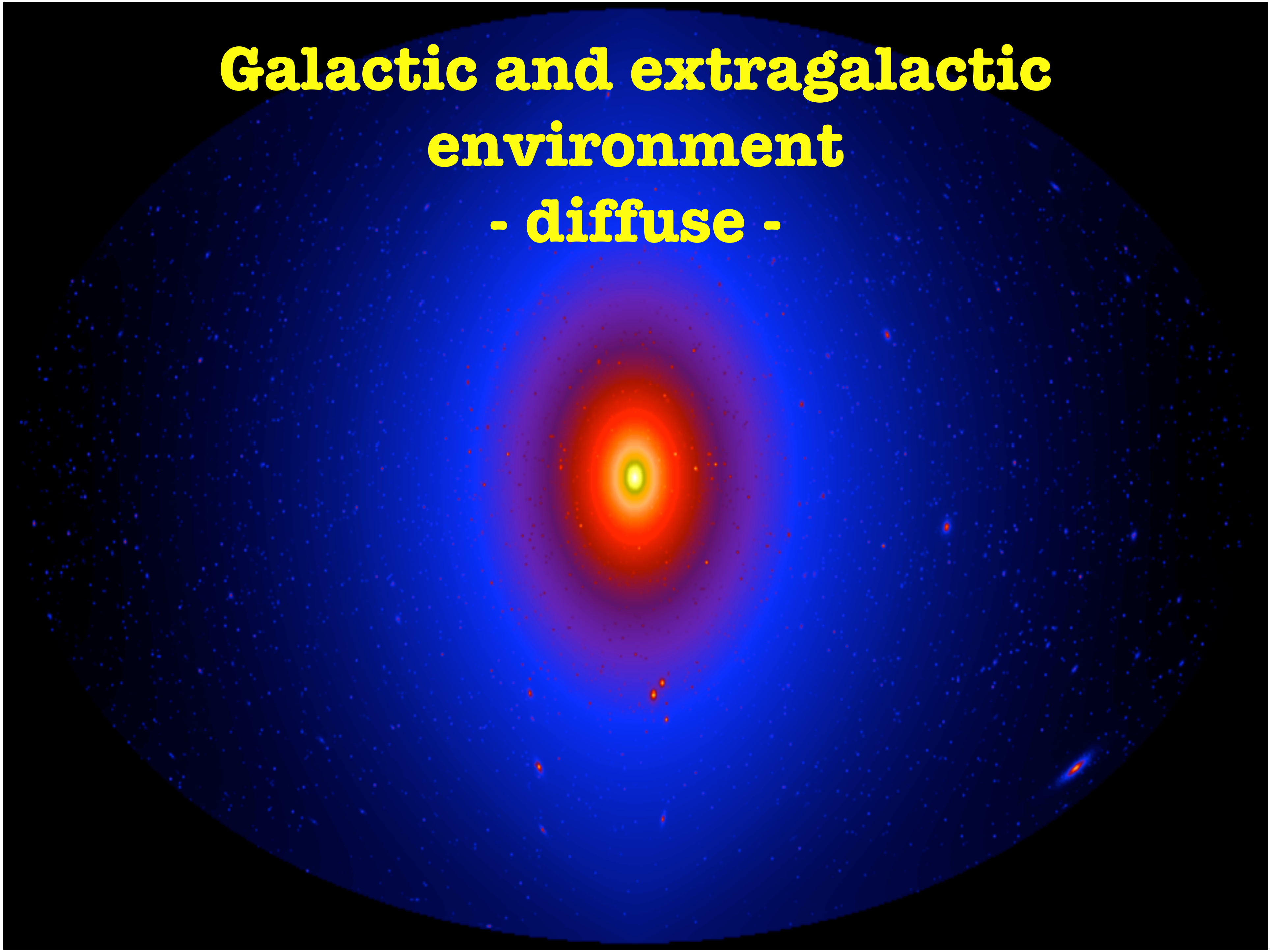
Modeling the structure of dark matter halos

Halos form through a hierarchical process of successive mergers.
The halo of our Galaxy will be self-similarly composed by:
-a smoothly distributed component ($\rho^2_{DM(h)}$ single halo)
-a number of virialized substructures ($\rho^2_{DM(subh)}$ all halos)

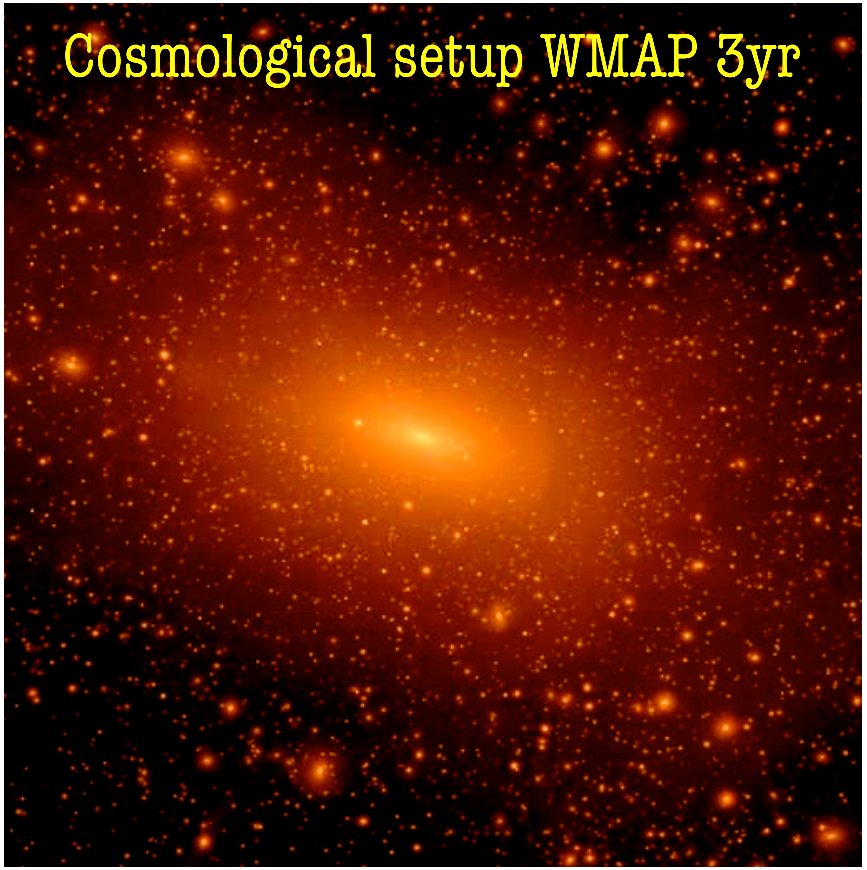


SOURCES
Milky Way - sources and diffuse -
Dwarf Galaxies
Cluster of galaxies - sources and diffuse -

Galactic and extragalactic environment - diffuse -



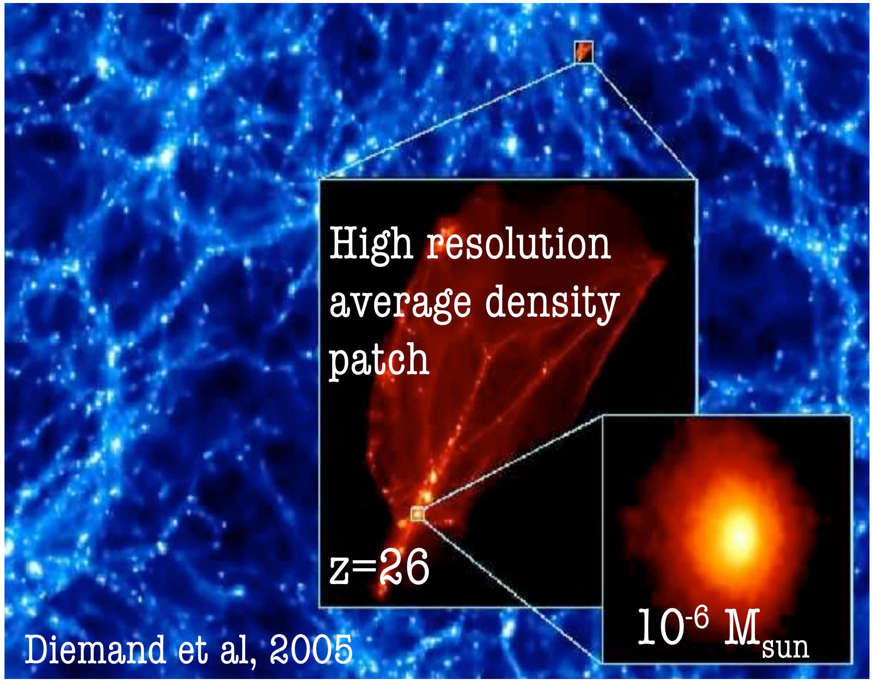
Modeling the structure of dark matter halos from N-body simulations



MW-like halo at z=0

Via Lactea 2, Diemand et al 2008

See also Aquarius, Springel et al 2008



Smallest mass halo at z=26

Cut off in power spectrum imposed by CDM free streaming or acoustic oscillations after kinetic decoupling.

Typical mass 10^{-6} M_{sun} with a spread of up to 6 order of magnitude depending on underlying particle physics.

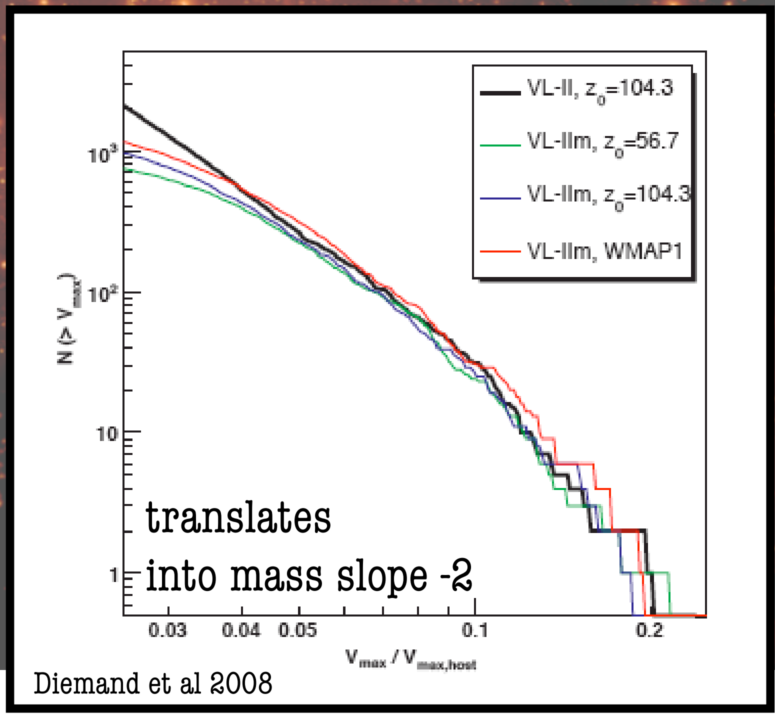
Modeling the structure of dark matter halos from N-body simulations

Subhalo density distribution

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

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

Antibiased radial distribution



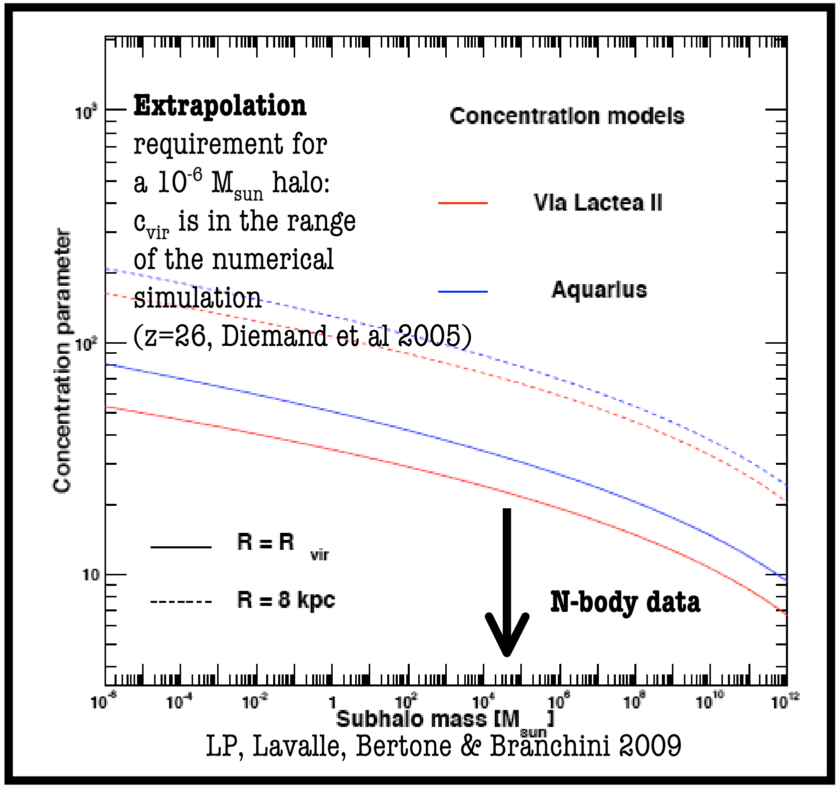
Diemand et al 2008

Note: Aquarius f_{DM} ($>10^7$ M_{sun}) ~ 13% - f_{DM} ($>10^{-6}$ M_{sun}) ~ 25%

Subhalo inner density profile

(R_{vir}/r_s) has radial dependence

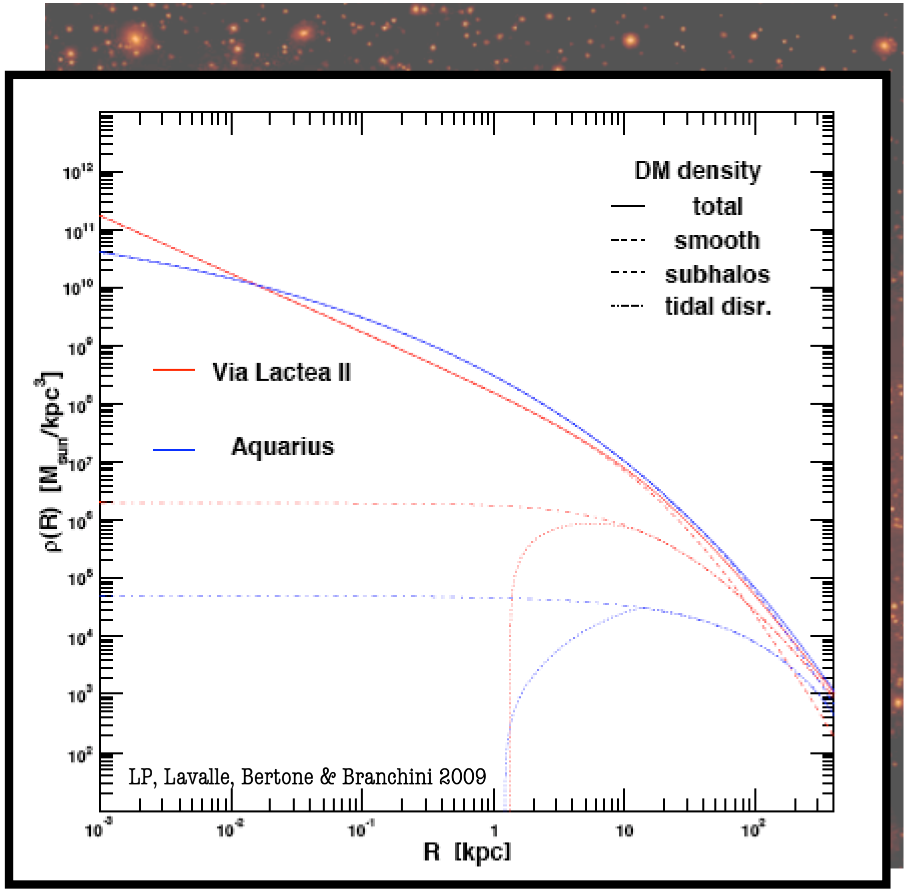
higher concentration -> higher flux!

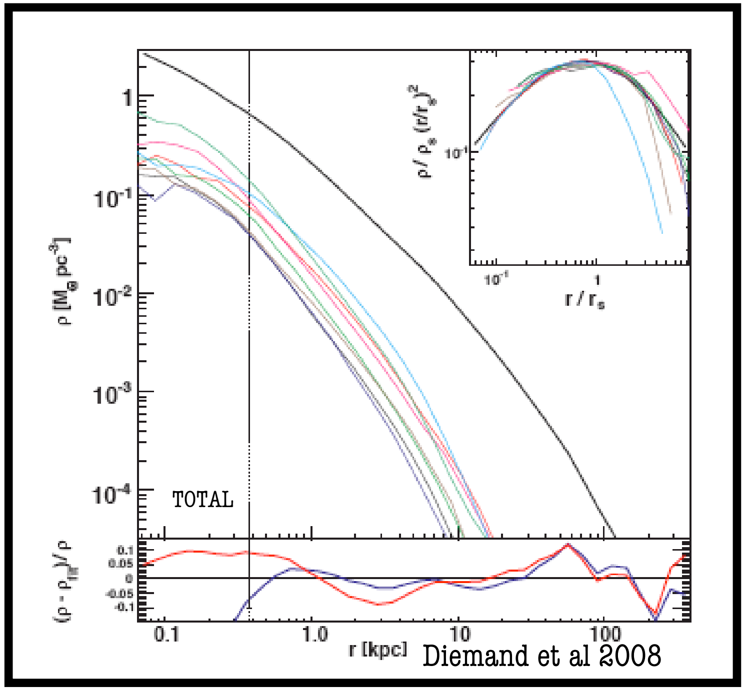


LP, Lavalle, Bertone & Branchini 2009

Modeling the structure of dark matter halos
from N-body simulations

Halo and subhalo profile shape





Warning: NFW or Einasto are
total profiles (smooth + subhalo)

The γ-ray sky

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

MW smooth and single subhalo contribution

$$\Phi^{halo}_{COSMO}(M,R,r) \propto \int_{l.o.s.} d\lambda d\Omega \left[\frac{\rho^2_{DM}\big(M, c(M,R), r, \psi\big)}{d^2} \right]$$

Integrated contribution of all the GALACTIC halos along the LOS

$$\Phi^{allhalos}{}_{COSMO}(\psi, \Delta\Omega) \propto \int_M dM \int_c dc \iint_{\Delta\Omega} d\vartheta d\varphi \int_{l.o.s} d\lambda \rho_{sh}(M,R) \cdot P(c)\, \Phi^{halo}_{COSMO}$$

Integrated contribution of EXTRAGALACTIC halos and subhalos

Computing the cosmological γ-ray flux due to DM annihilation in halos and subhalos

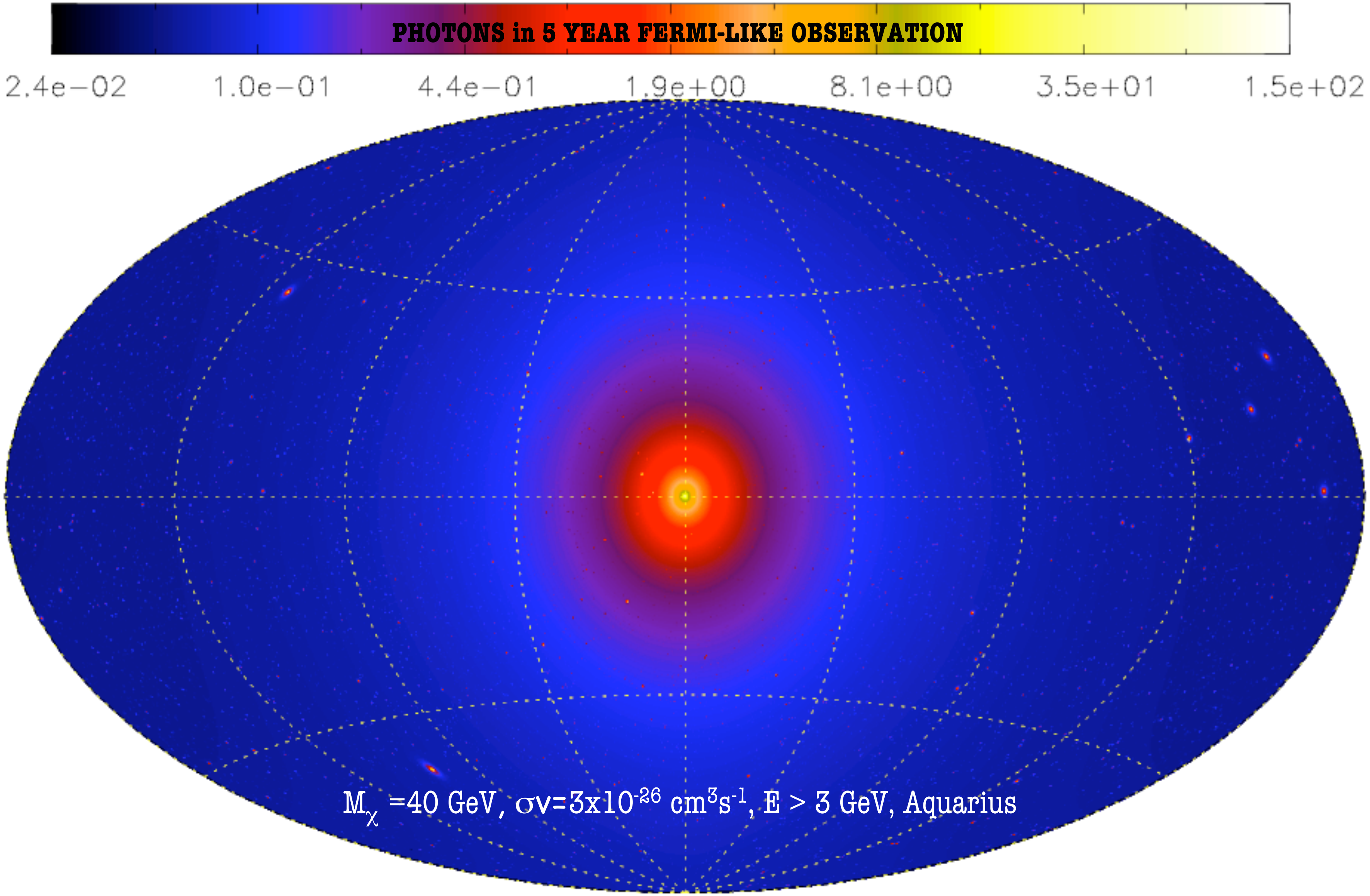
$$\frac{d\phi_\gamma}{dE_0} = \frac{\sigma v}{8\pi} \frac{c}{H_0} \frac{\bar{\rho}_0^2}{m_\chi^2} \int dz (1+z)^3 \frac{\Delta^2(z)}{h(z)} \frac{dN_\gamma(E_0(1+z))}{dE} e^{-\tau(z,E_0)}$$

Enhancement due to halo weighted
for the halo and subhalo mass function

$$\propto \frac{d\log N}{d\log M} \Phi^{halo}_{COSMO}$$

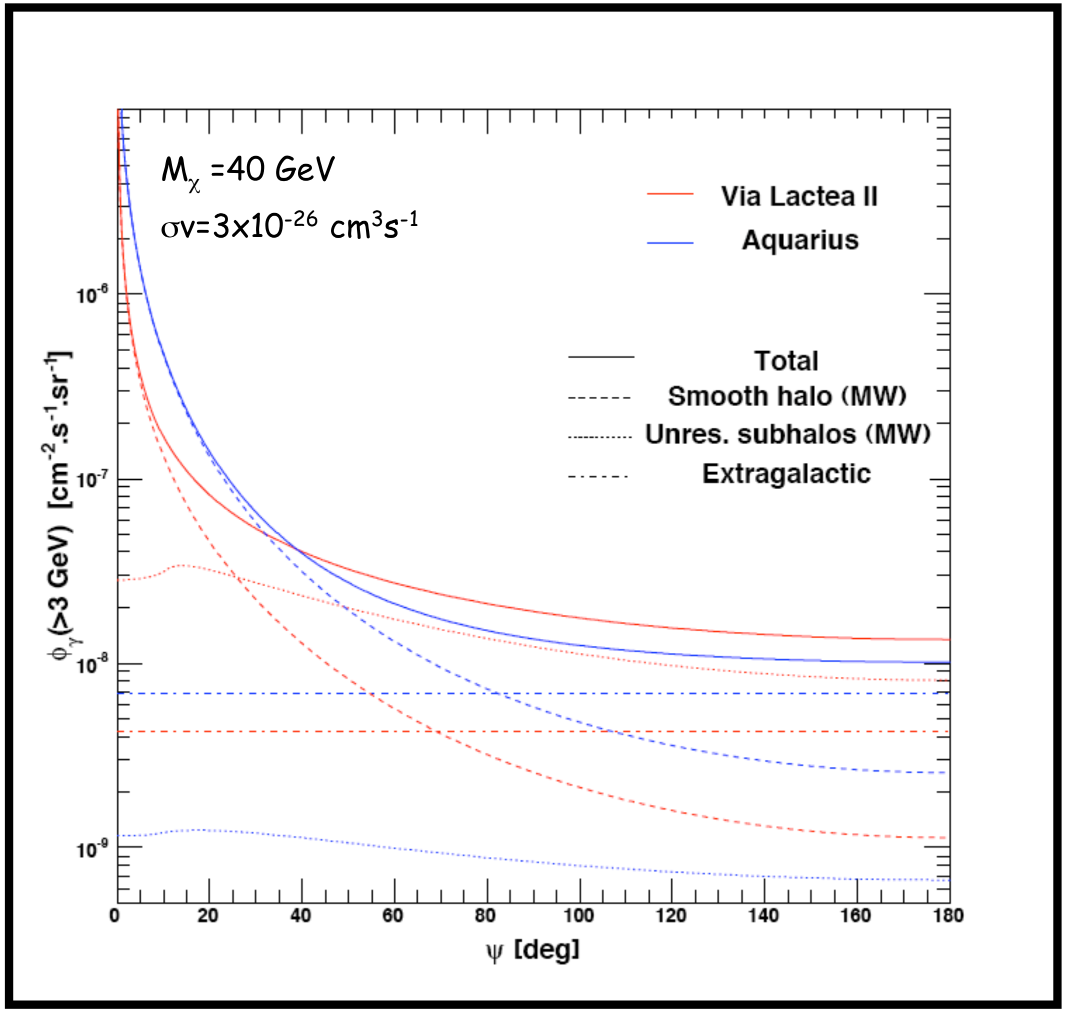
The γ-ray sky

Galactic and extragalactic: smooth + subhalos



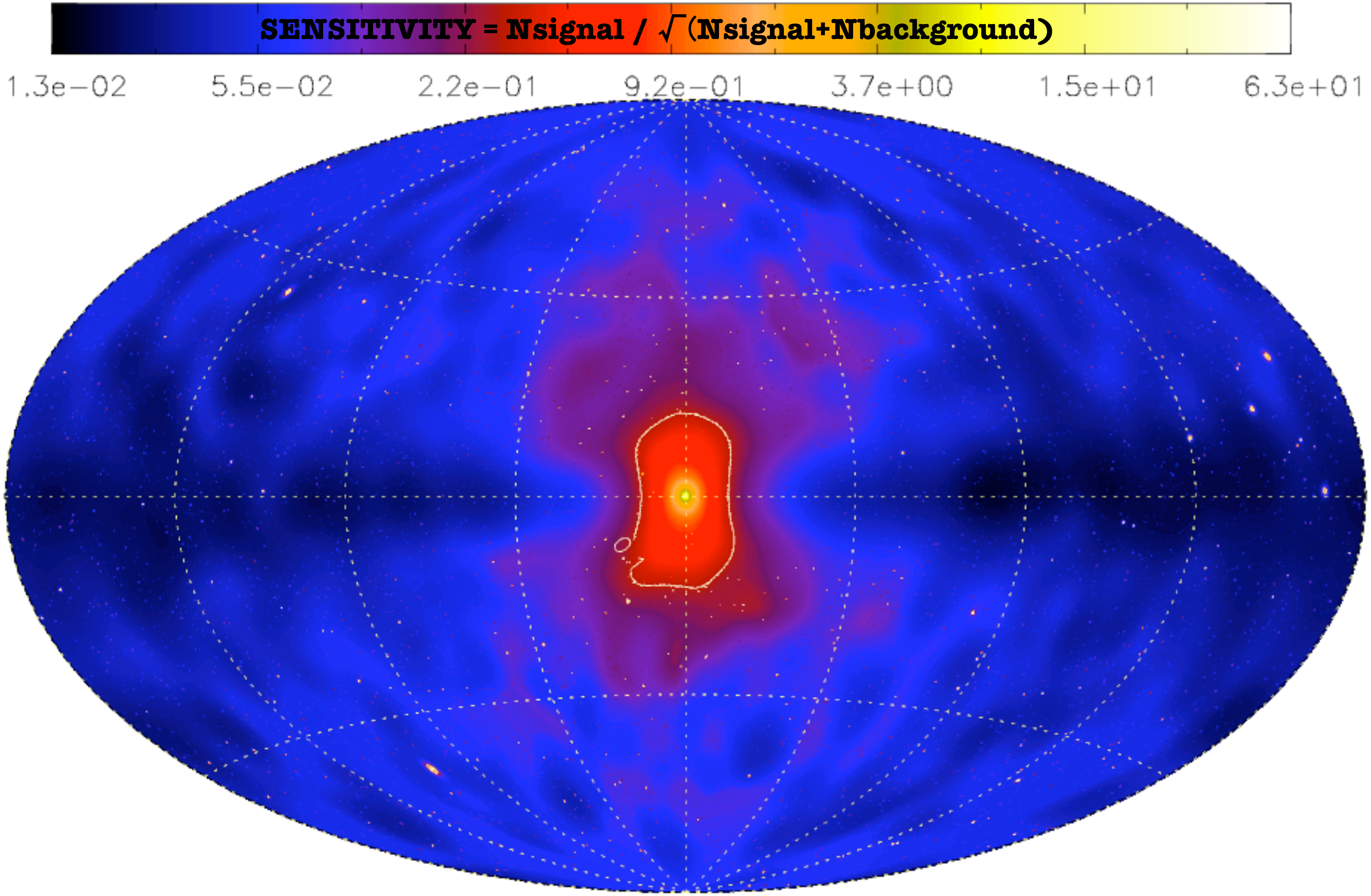
LP, Lavalle, Bertone & Branchini 2009

The γ-ray sky
Galactic and extragalactic: smooth + clumpy

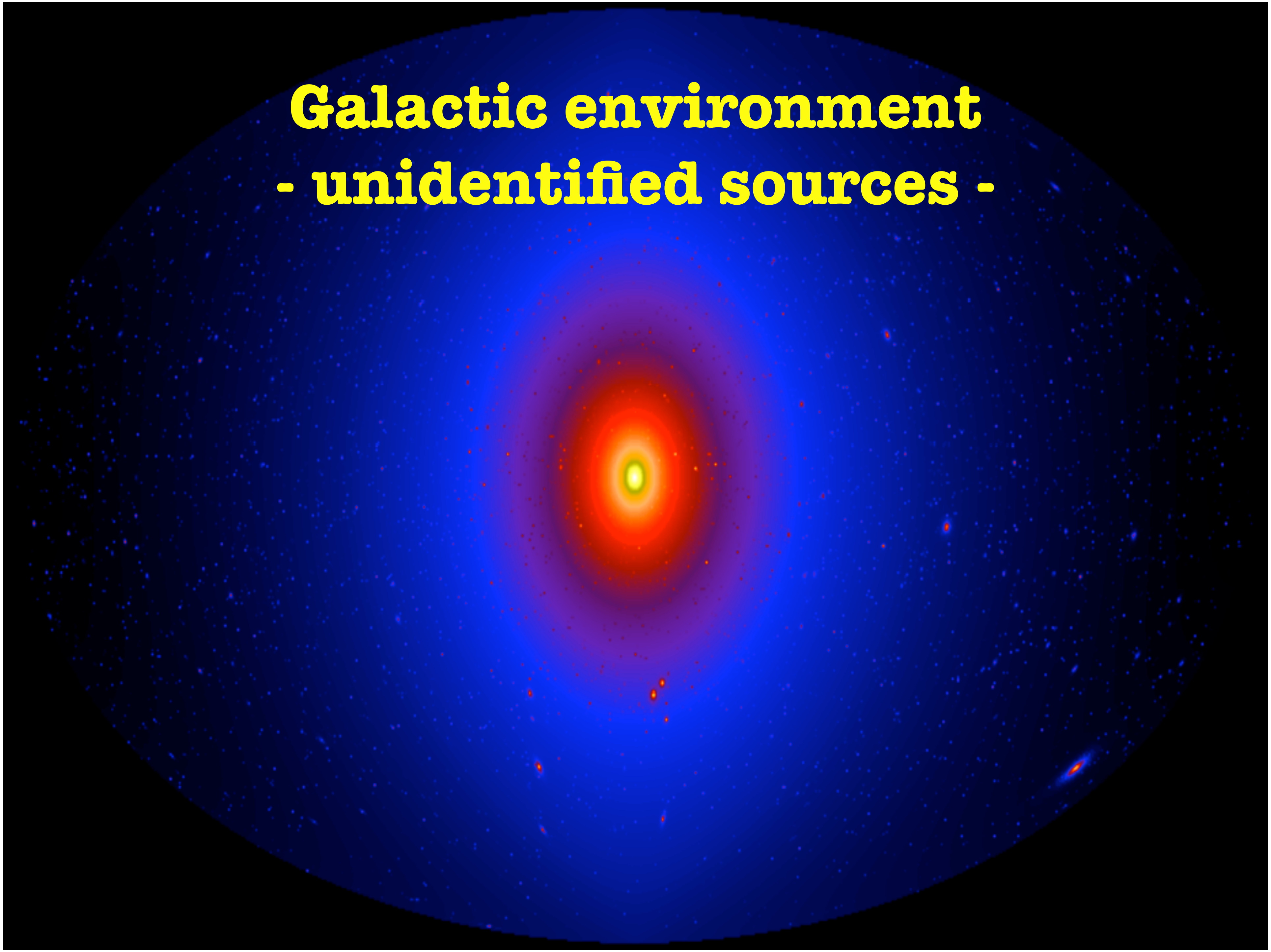


LP, Lavalle, Bertone & Branchini 2009

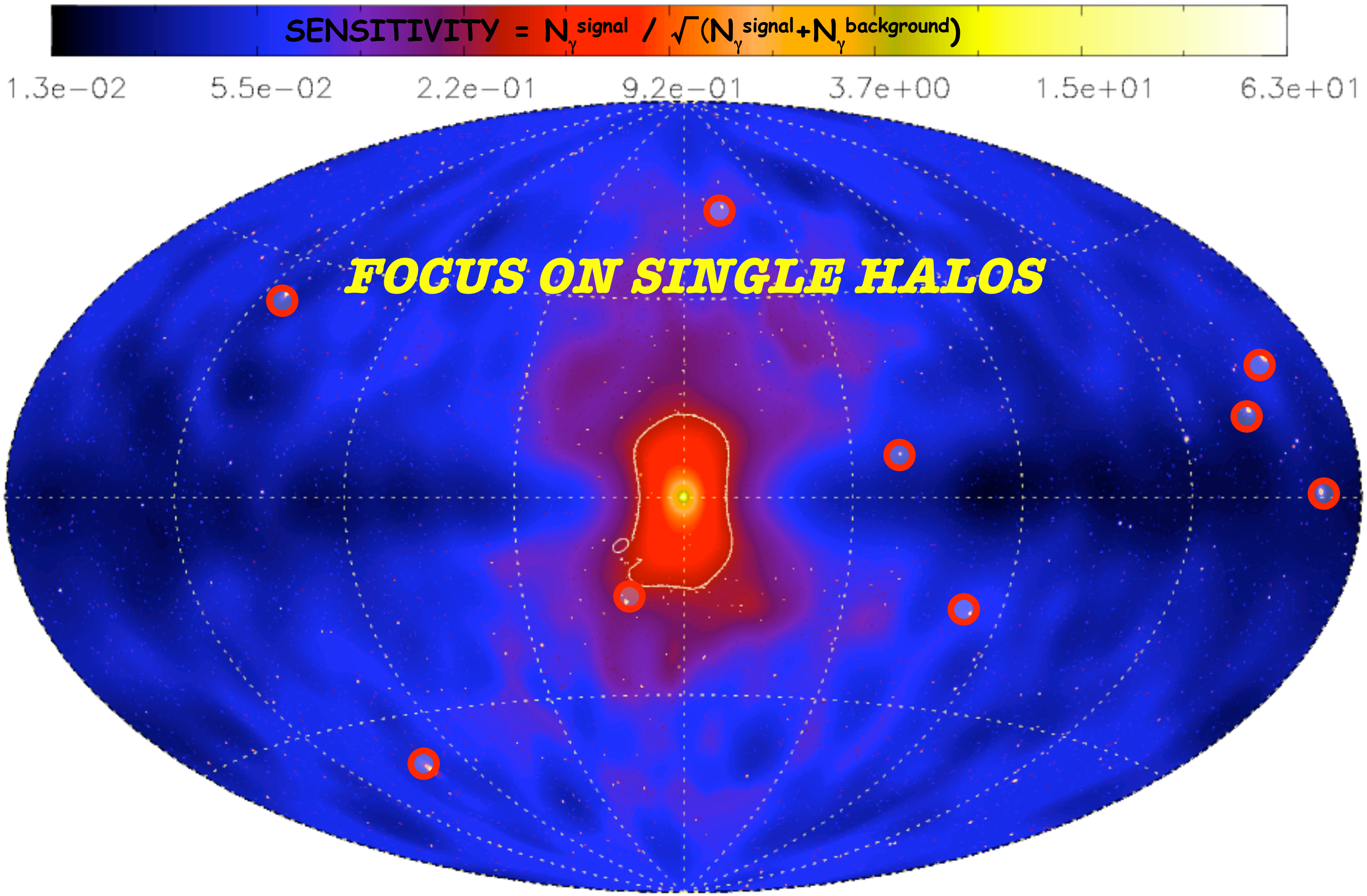
Is the γ-ray sky from DM annihilation DETECTABLE?



LP, Lavalle, Bertone & Branchini 2009

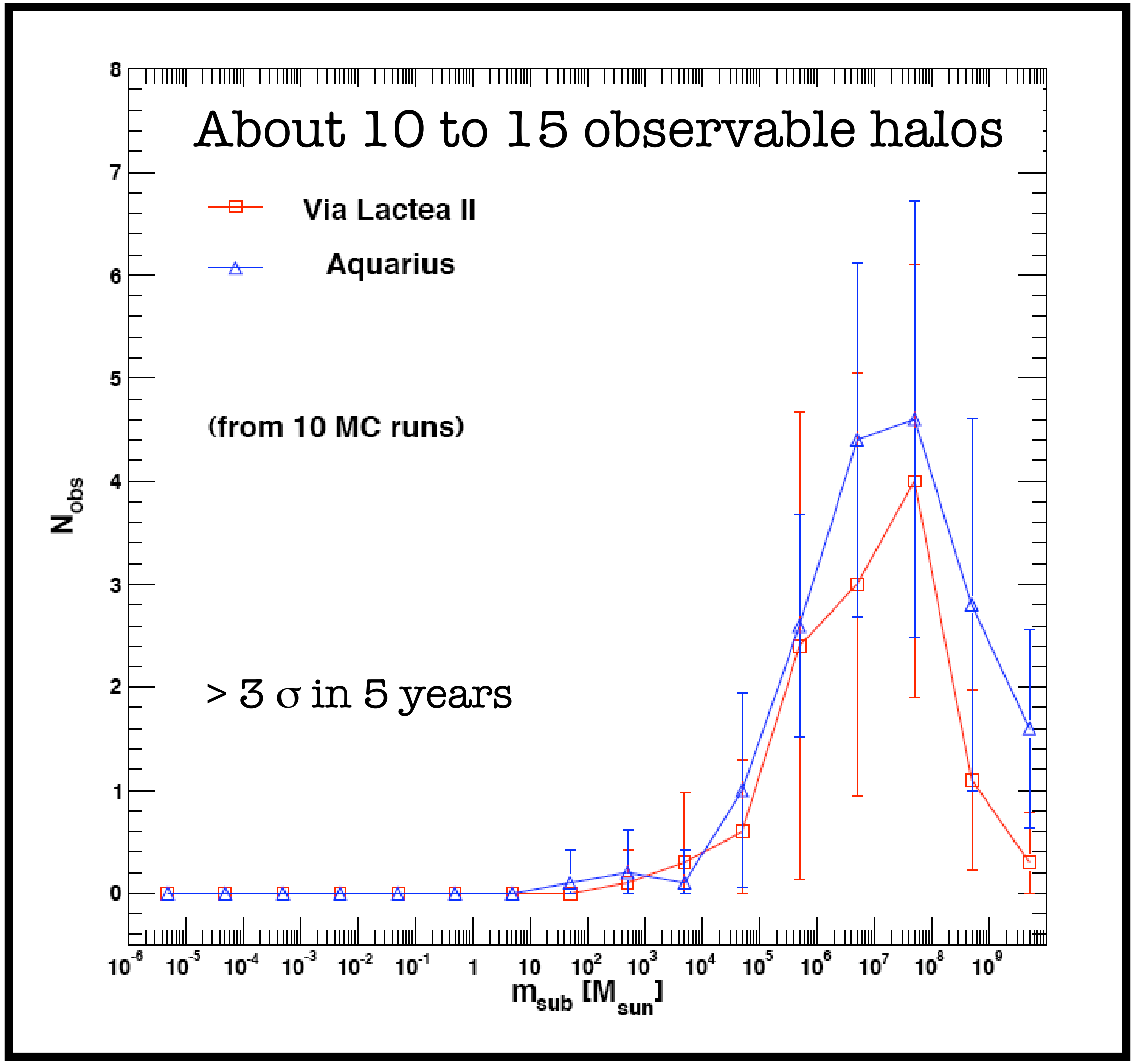

Galactic environment
- unidentified sources -

Is the γ-ray sky from DM annihilation DETECTABLE?

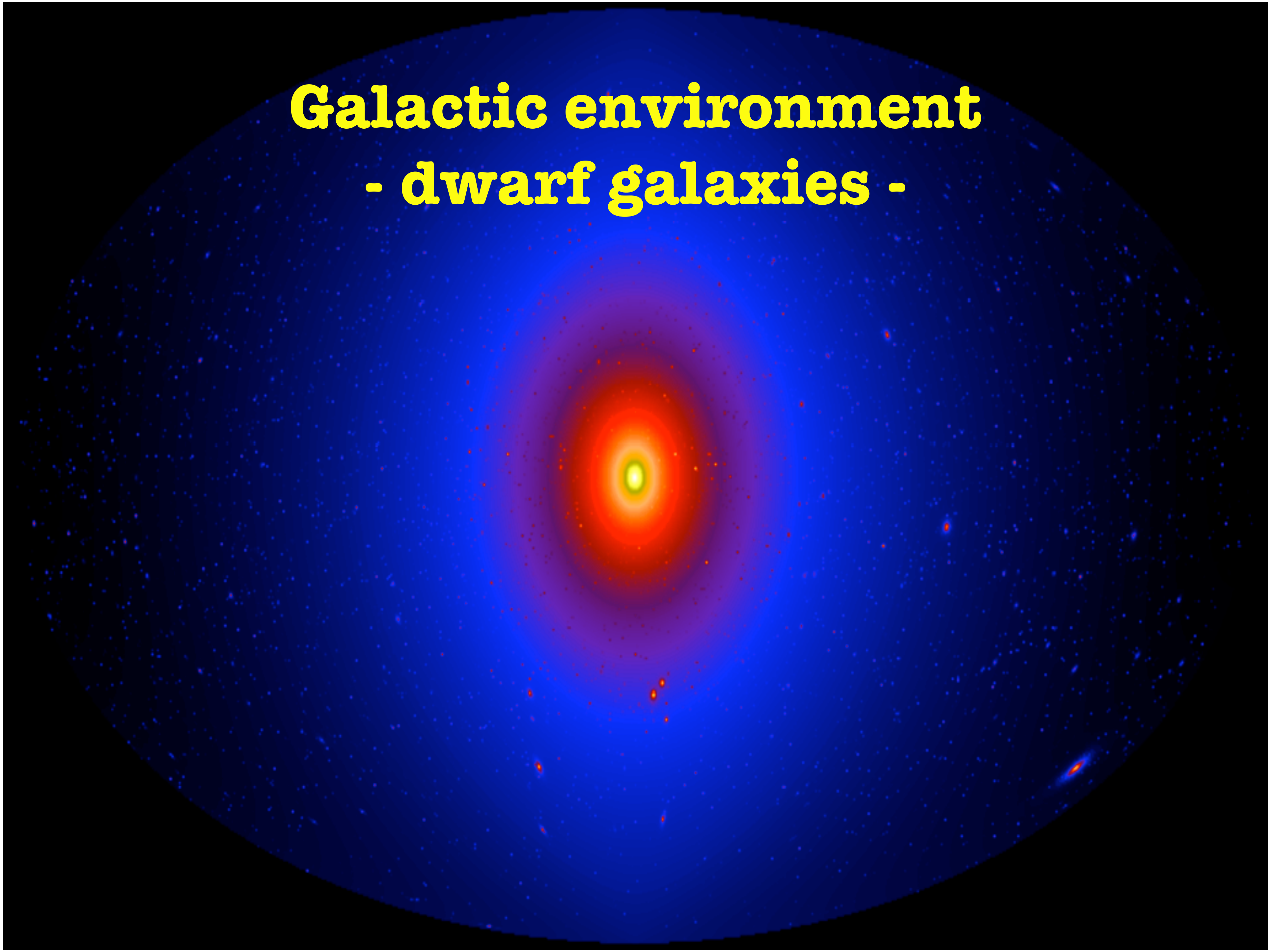


LP, Lavalle, Bertone & Branchini 2009

Is the γ-ray sky from DM annihilation DETECTABLE?



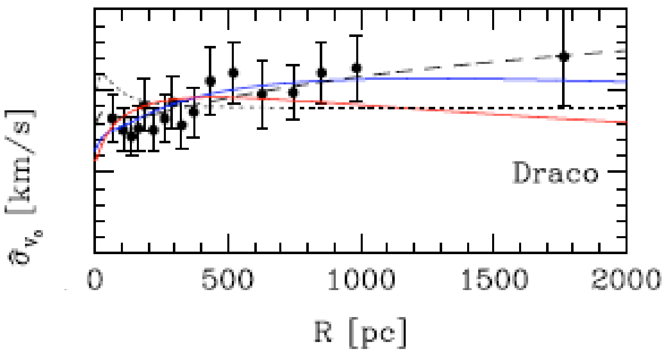
LP, Lavalle, Bertone & Branchini 2009


Galactic environment
- dwarf galaxies -

Dwarf galaxies are the only objects whose density profiles are nicely inferred by astronomical measurements

-> small astrophysical uncertainty

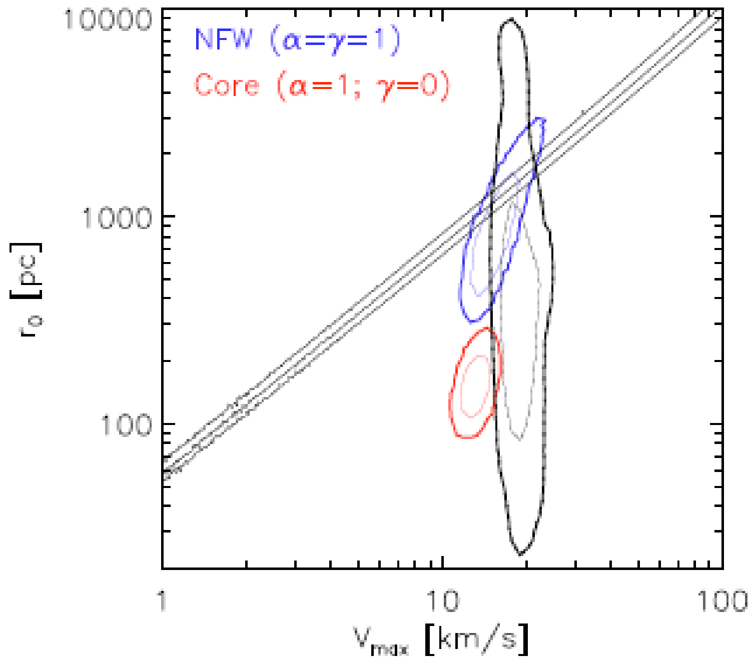
from velocity dispersions..



... to density profiles.

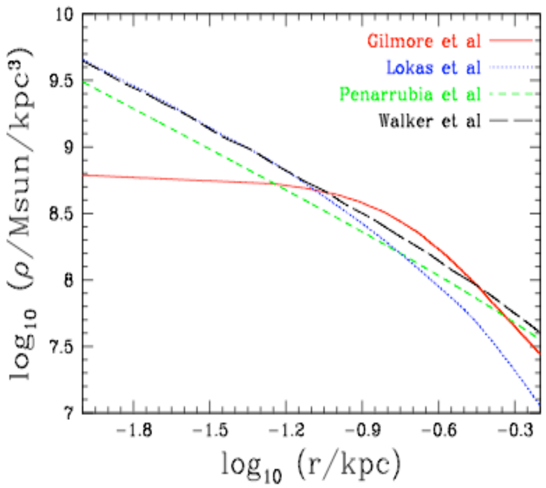
Universal behaviour!

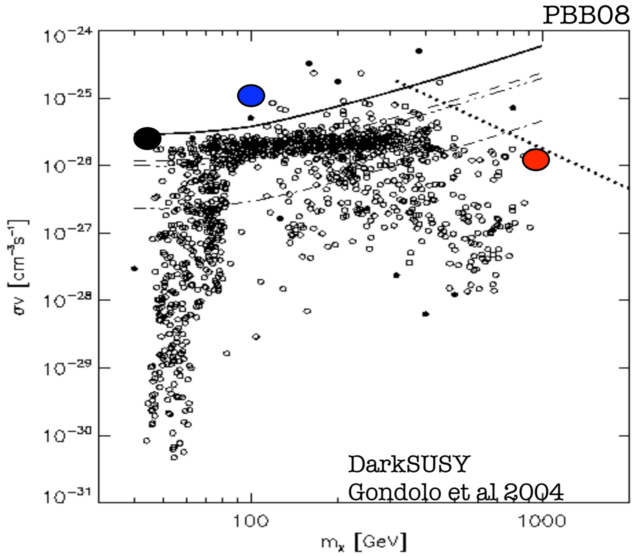
NFW preferred by χ^2 analysis



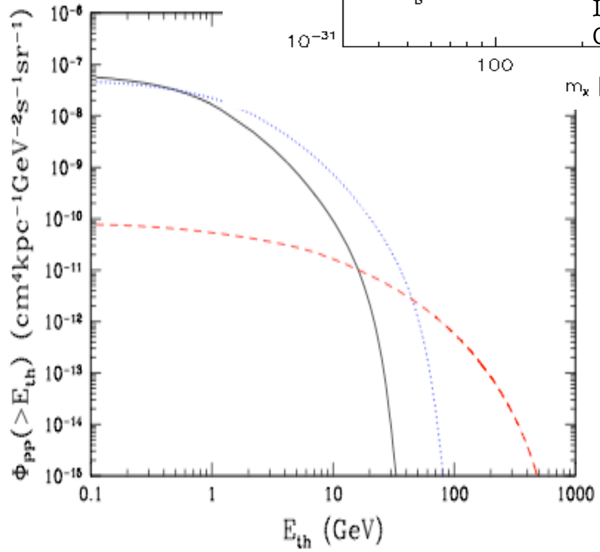
Walker et al, 2009

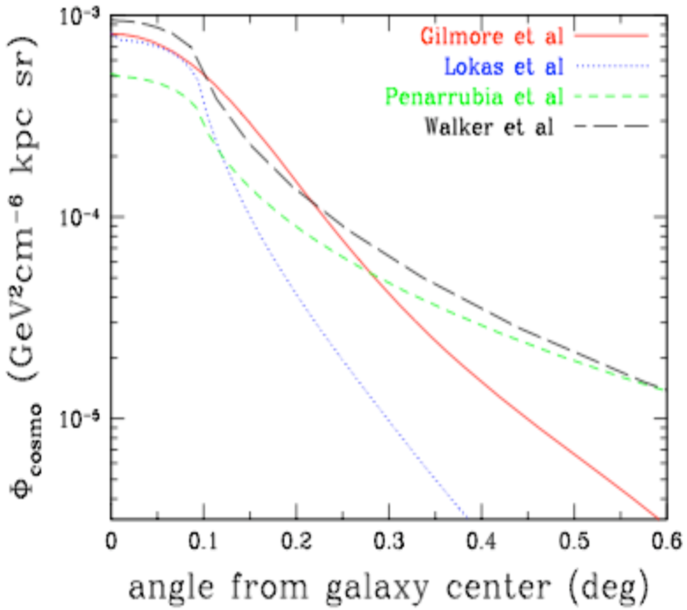
Computing Φ_γ





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



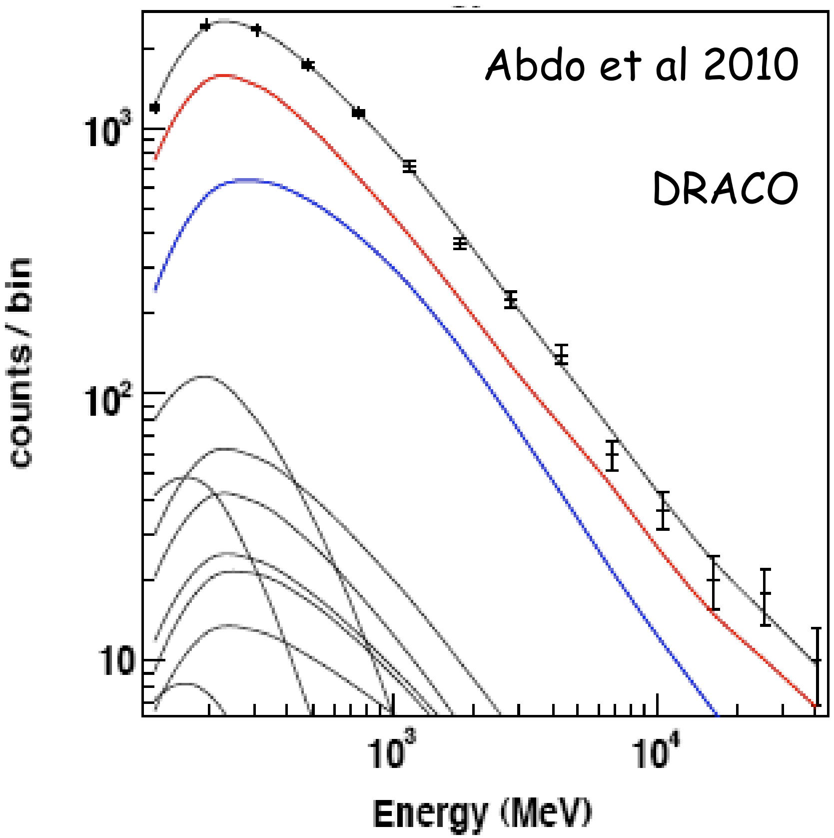


$$\phi_{PP} = \frac{1}{4\pi}\,\frac{\sigma_{ann}v}{2m_\chi^2}\int_{E_0}^{m_\chi}\sum_f \frac{dN_f^\gamma}{dE_\gamma}\,BR_f\,dE_\gamma$$

LP, Pizzella, Corsini, Dalla Bontà & Bertola 2008

Comparing predictions with Fermi performances

DRACO Φ_γ^{max} (> 100 MeV, 1 yr) = $(4.5\pm1.5) \times 10^{-11}$ cm^{-2} s^{-1}



$\phi^{95\%CL}_{\gamma,Fermi}$(> 100 MeV, 1 yr)

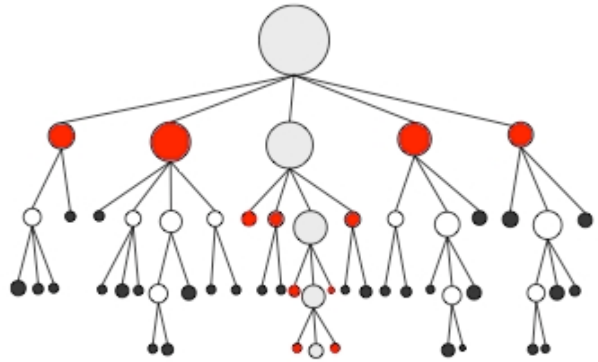
$(0.1\text{-}2.0) \times 10^{-9}$ cm^{-2} s^{-1}

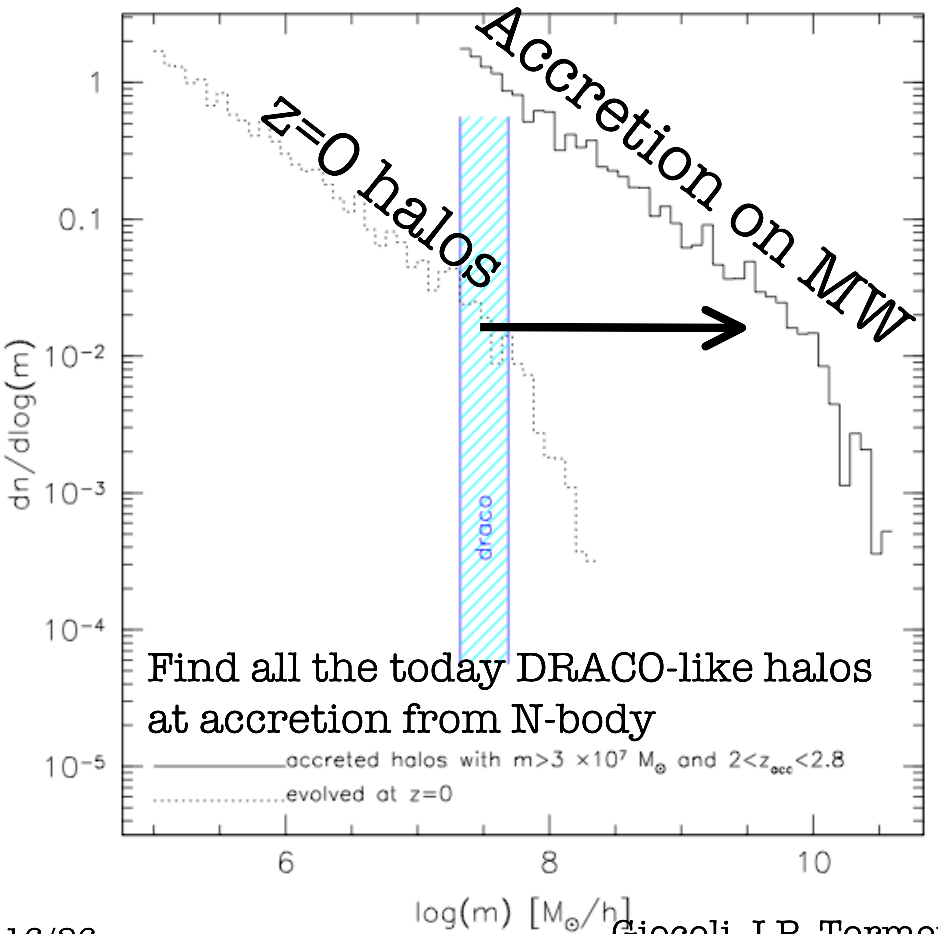
DRACO and other dwarfs are now only <u>slightly</u> below the detection limit

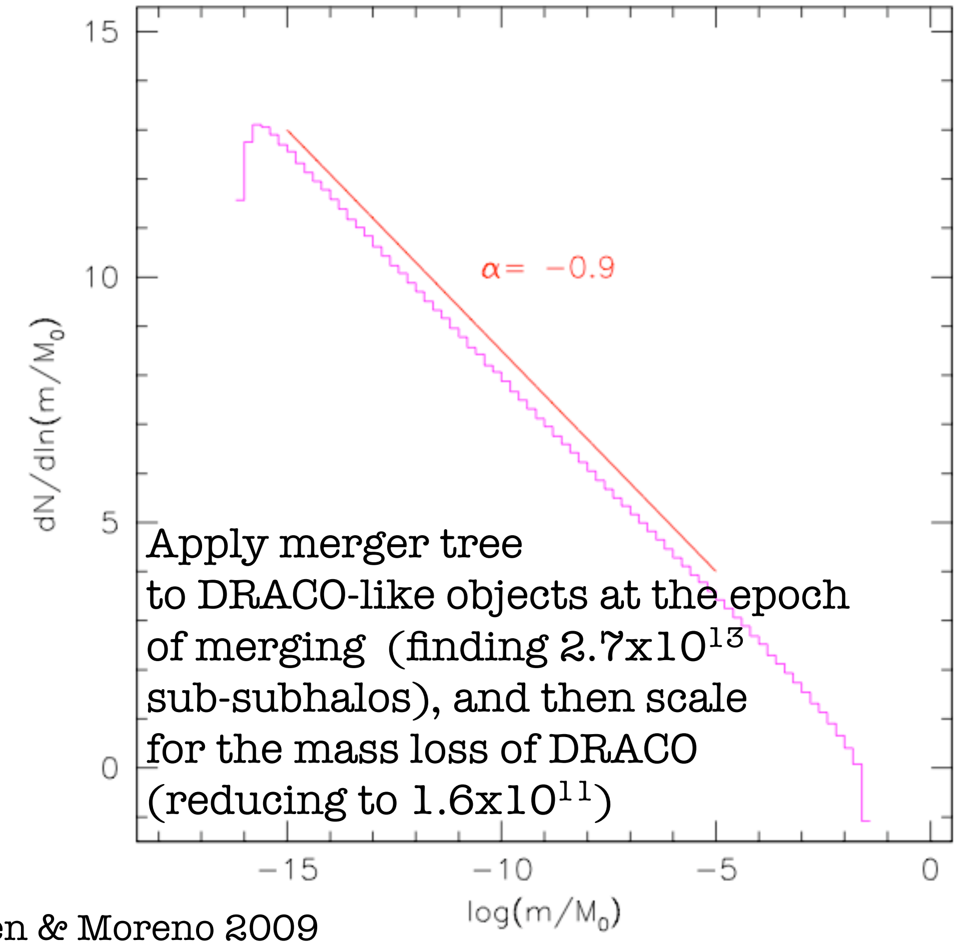
(for our PP scenarios)

And very clean astro-objects poor astrophysical background stable astrophysical predictions

Can an astrophysical boost factor affect our computation?

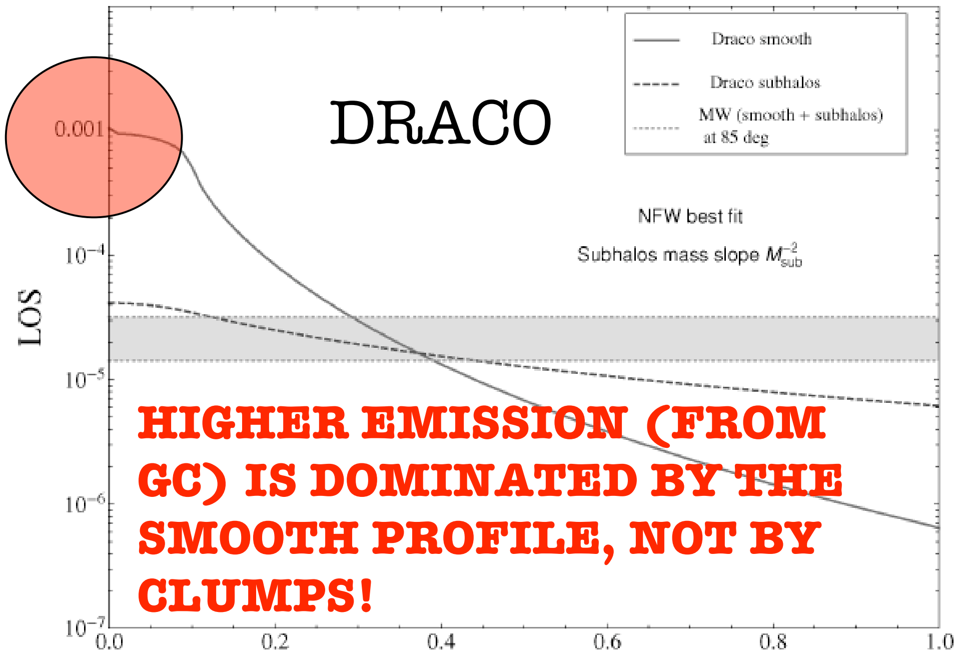






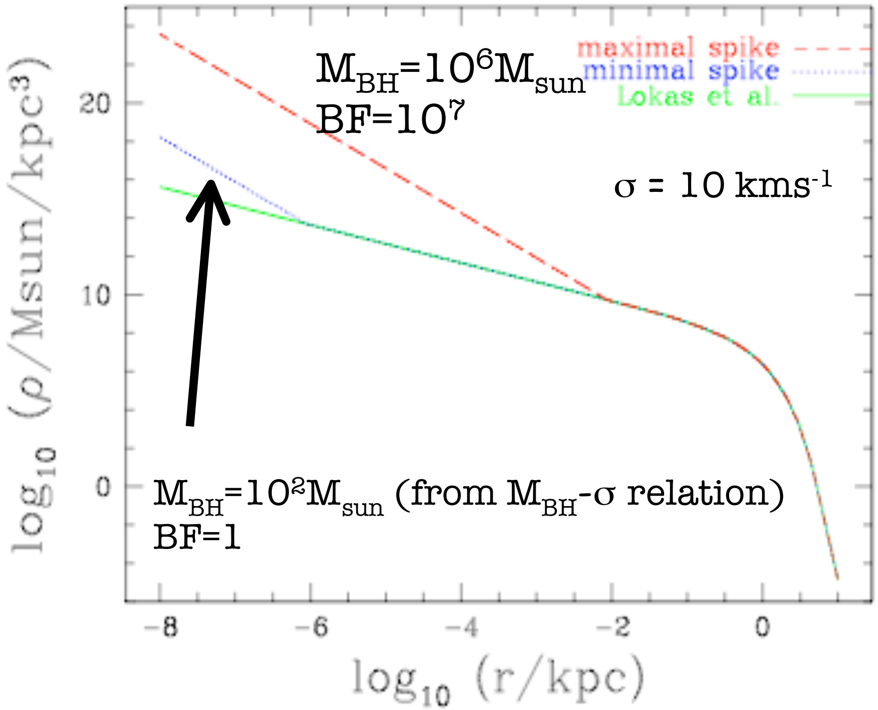
Giocoli, LP, Tormen & Moreno 2009

Stability of Draco predictions: boost factors?



LP, Lattanzi, Silk 2009

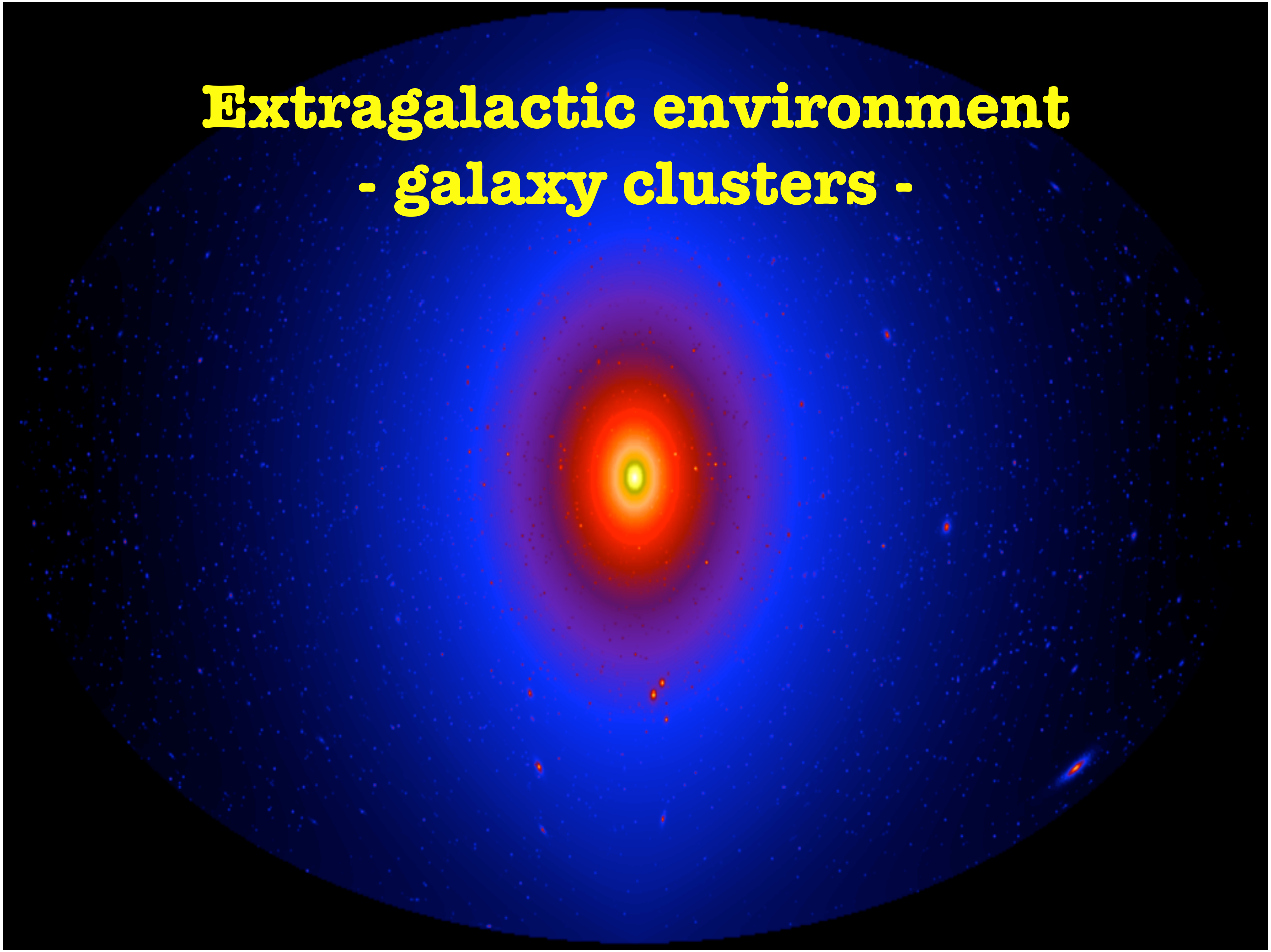
LP, Pizzella, Corsini, Dalla Bontà & Bertola 2009



NFW fit to DRACO velocity dispersion (Walker et al 2008)
$M=5 \times 10^9\ M_{sun}$
$c=22$, $r_s=2$ kpc
$\rho_s=2.16 \times 10^7\ M_{sun}\ \mathrm{kpc}^{-3}$

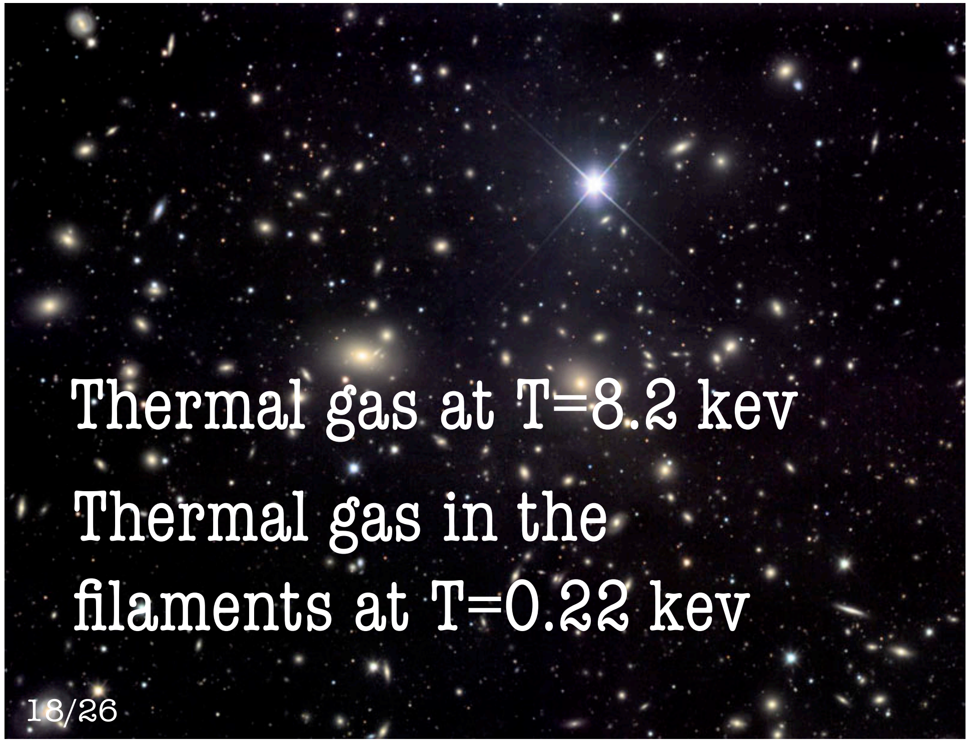
A Black Hole, if any, is not likely to give any significant boost

Extragalactic environment
- galaxy clusters -



The Coma Galaxy Cluster

$D = 100$ Mpc
$M_{DM} = 1.2 \times 10^{15}\ M_{sun}$
$R_{vir} = 2.7$ Mpc
$B(r) = 4.7\ n_{th}(r)^{0.5}\ \mu G$
$\langle B \rangle = 2\ \mu G$
No cooling flow observed.
Radio, EUV, X-ray observation



Non-thermal electrons

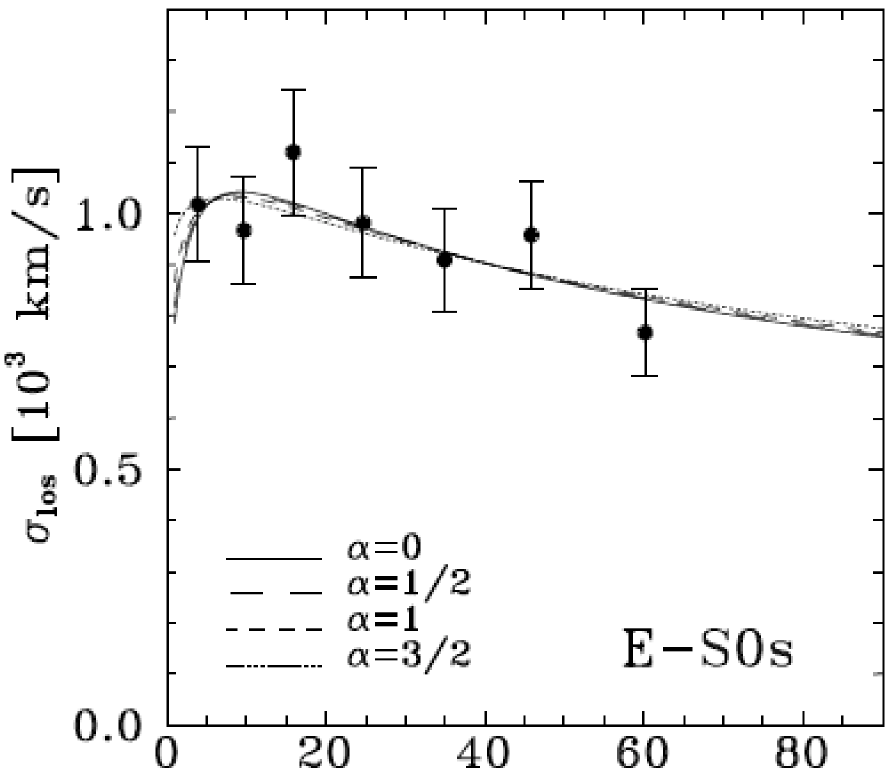
1) Produced by astrophysical sources and continuously reaccelerated by cluster turbolences or merger shock waves

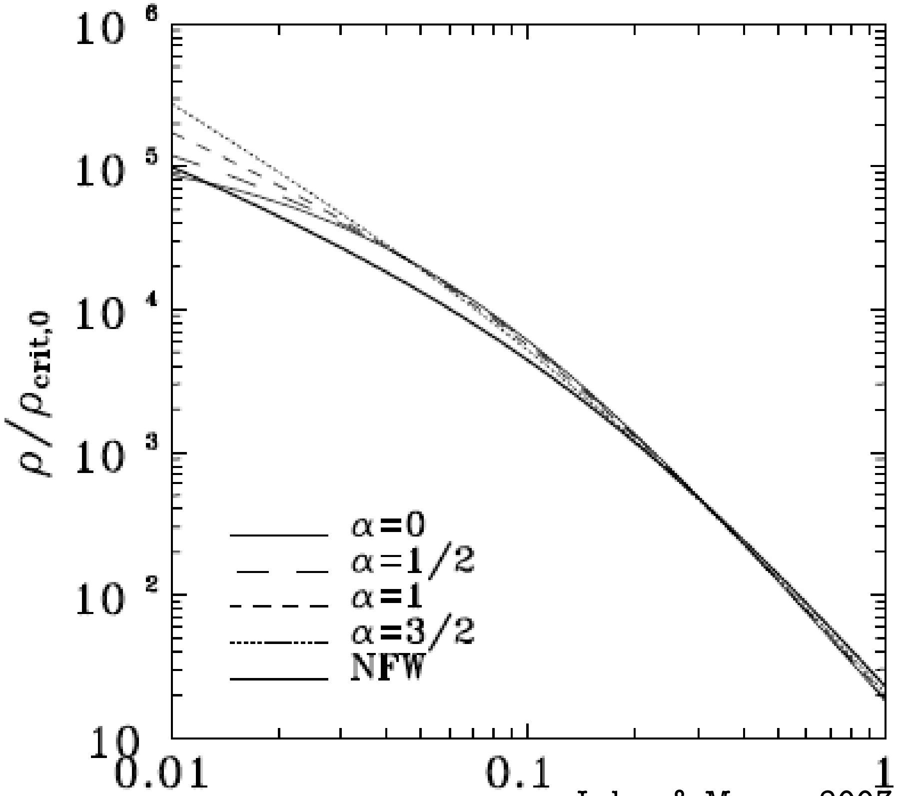
2) Produced by interaction of CRs with thermal ions

3) Produced by DM annihilation

An Alternative Non Thermal Hypothesis:
(although non asked for...)
Relativistic electrons are produced by DM annihilation

DM Density profiles can be inferred from astronomical measurements or derived from numerical simulations

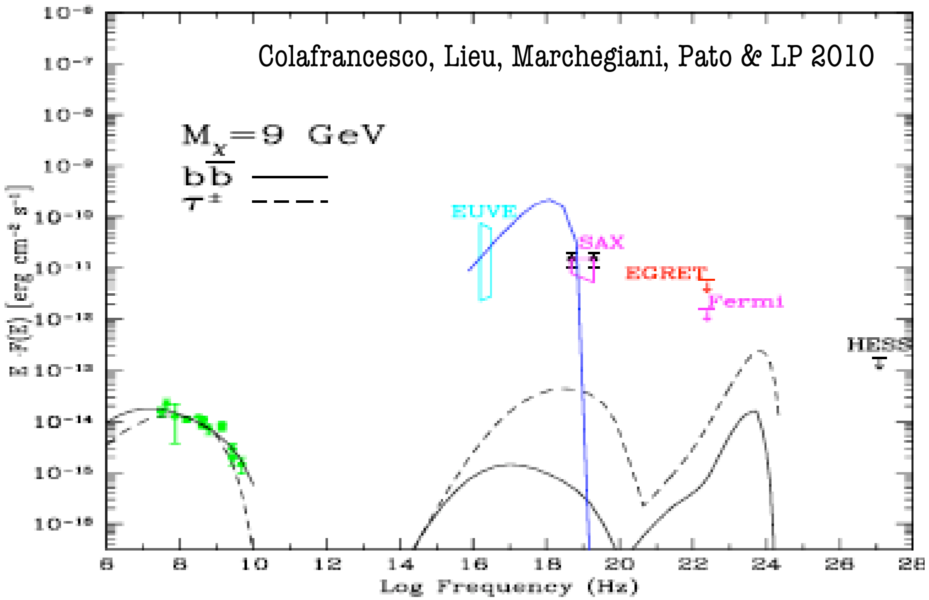


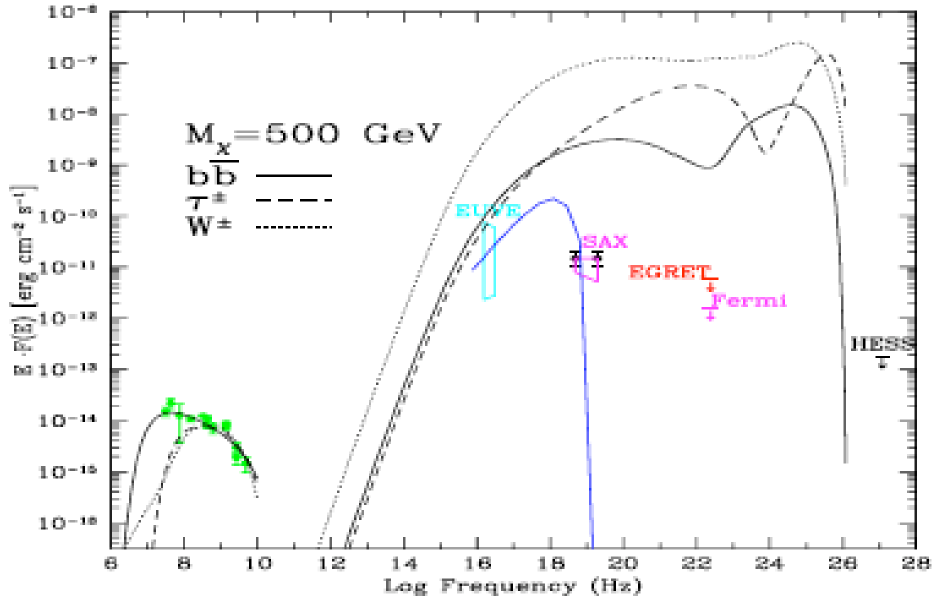


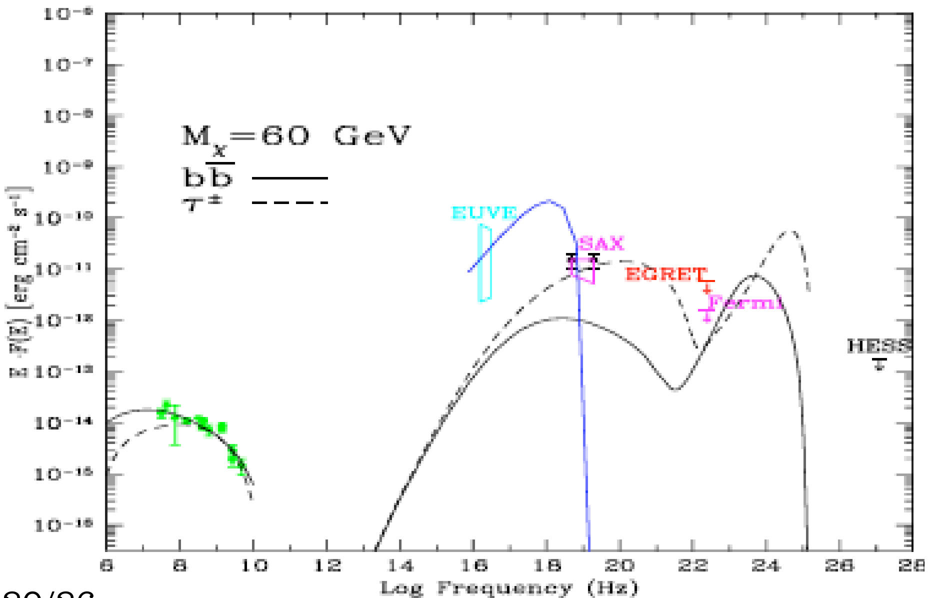
Lokas & Mamon 2003

Bullock et al 2001

Multiwavelenght DM interpretation or exclusion?







The multiwavelength yield is compared with available measurements or upper limits

Compute Inverse Compton Scattering,

$$P_{\rm IC}\,(E_\gamma, E) = c\,E_\gamma \int d\epsilon\, n(\epsilon)\,\sigma(E_\gamma, \epsilon, E)$$

$$j_{\rm IC}\,(E_\gamma, r) = \int dE\,\left(\frac{dn_{e^-}}{dE} + \frac{dn_{e^+}}{dE}\right) P_{\rm IC}\,(E_\gamma, E)$$

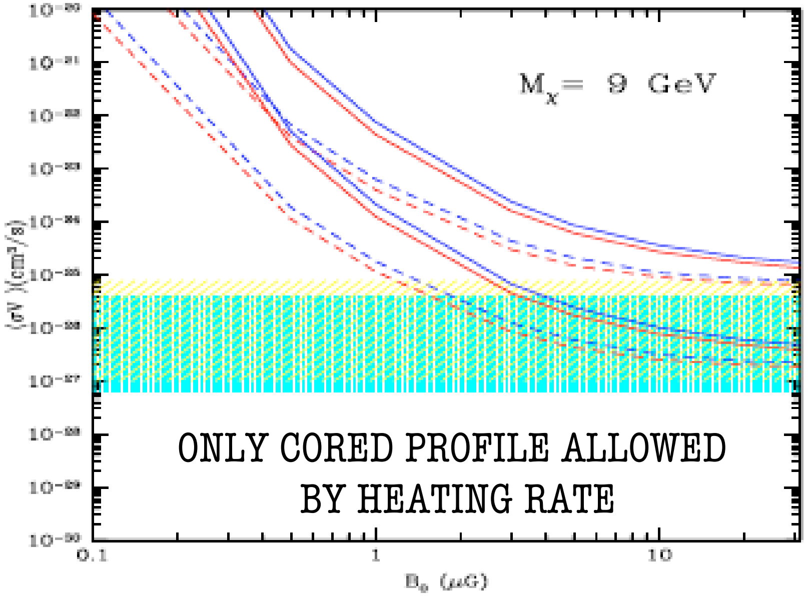
$$S_{\rm IC}(E_\gamma) = \int d^3r\, \frac{j_{\rm IC}\,(E_\gamma, r)}{4\pi\, D^2_{\rm Coma}}$$

non-thermal bremsstrahlung

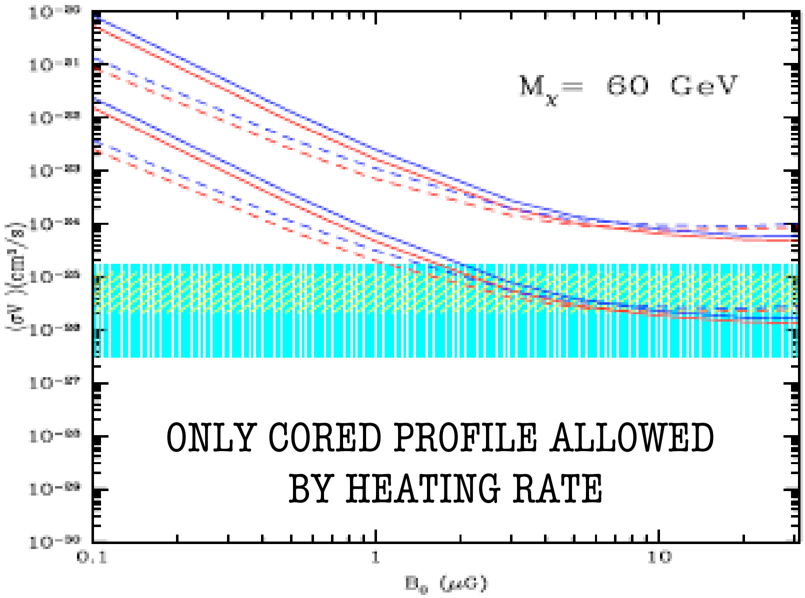
$$P_{\rm B}\,(E_\gamma, E, r) = c\,E_\gamma \sum_j n_j(r)\,\sigma_j(E_\gamma, E)$$

and prompt γ-ray emission (more later)

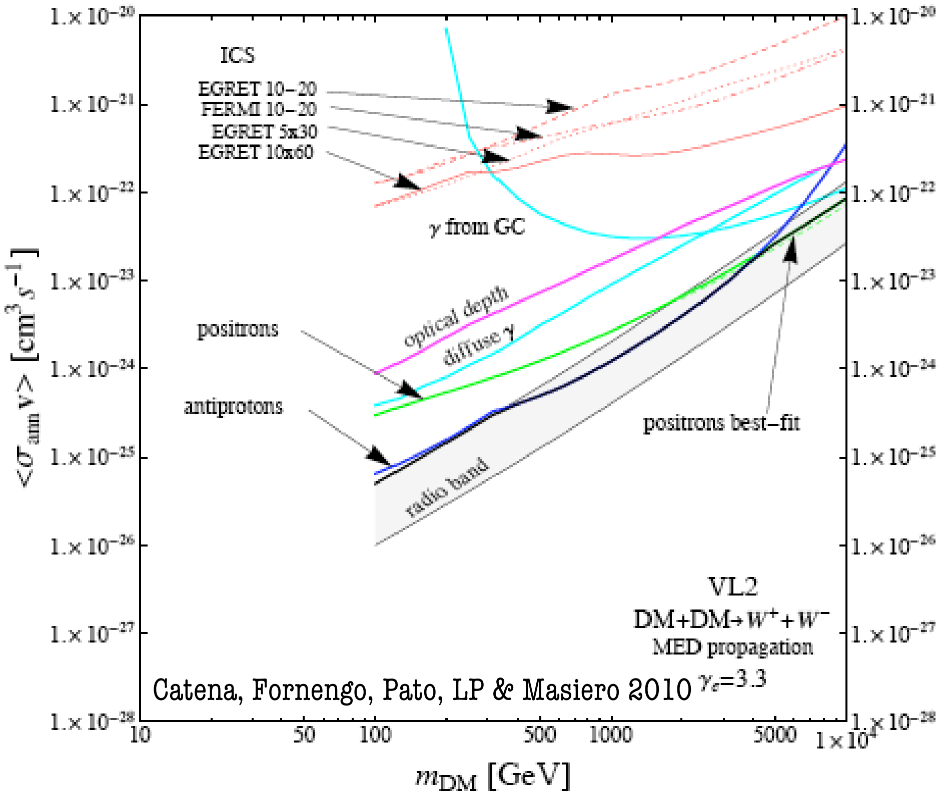
Compatibility with multimessenger constraints



Cross-sections needed to explain the radio emission are compared with available constraints from GC γs, diffuse γs, antimatter, CMB, radio ...
which excludes ANY dark matter interpretation for smooth profiles



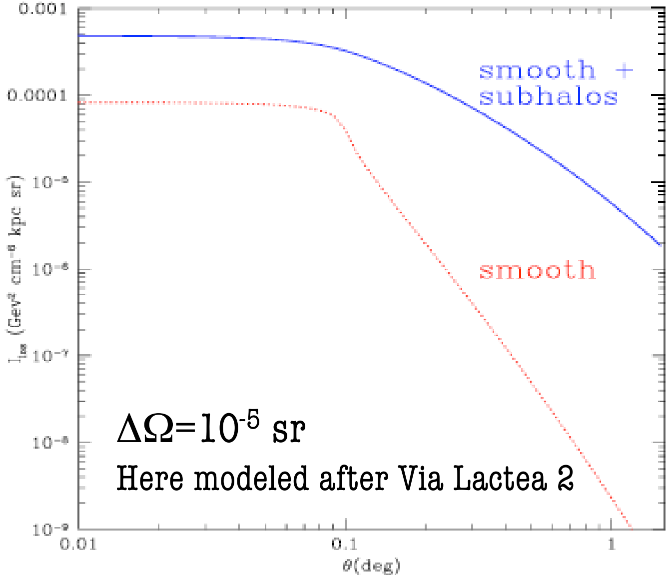
Look at the upper curves: smooth cluster halo
All DM explanation are excluded

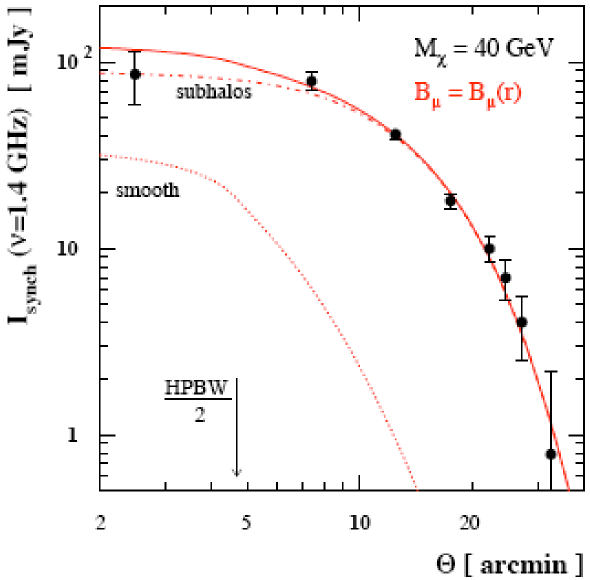


 Colafrancesco, Lieu, Marchegiani, Pato & LP 2010

Compatibility with multimessenger constraints adding subhalos

Colafrancesco, Lieu, Marchegiani, Pato & LP 2010



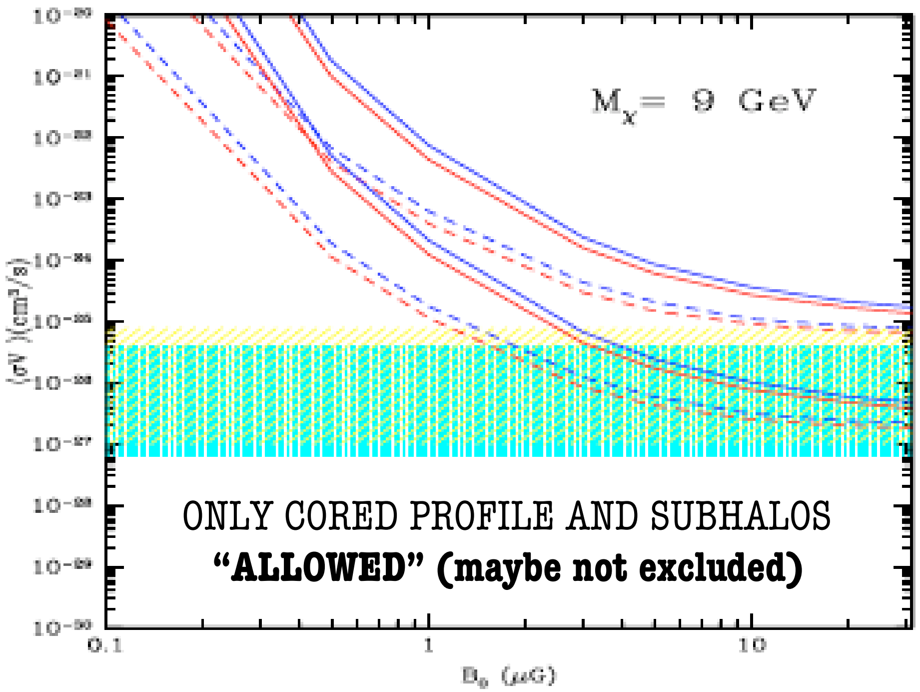


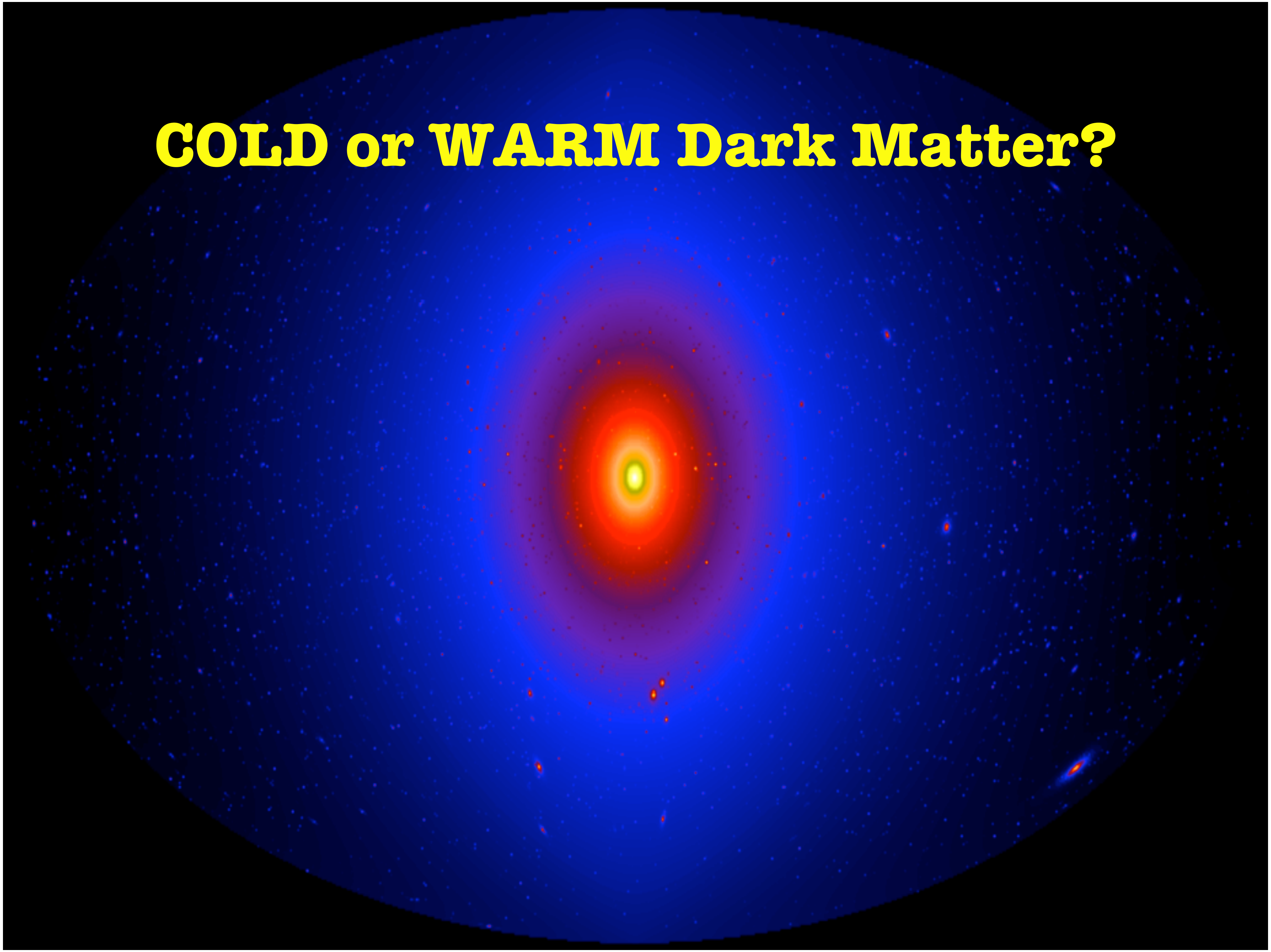
Colafrancesco, Profumo & Ullio 2006

Subhalo population

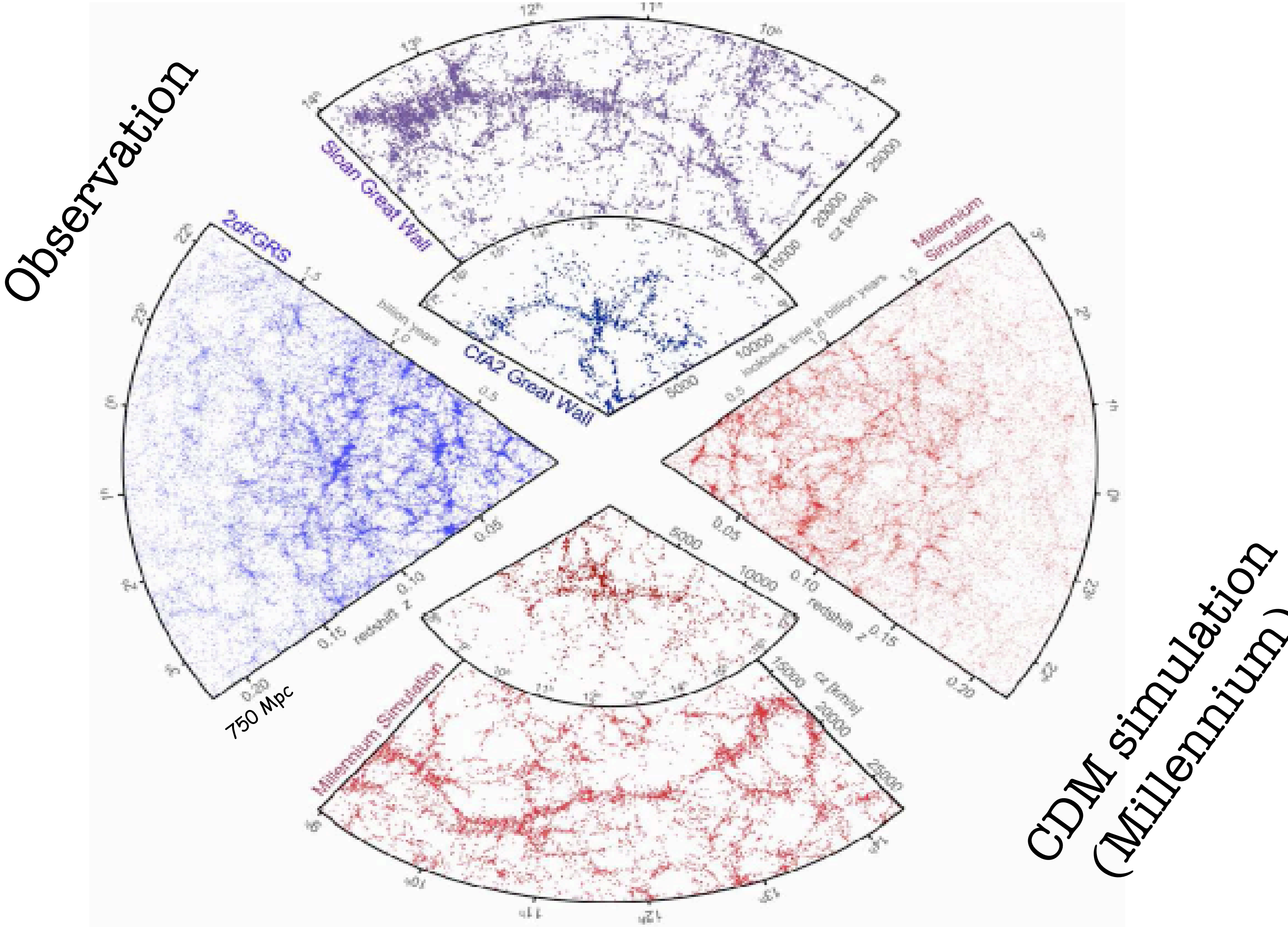
In presence of a population of substructures with $M_{min}=10^{-6}$ Msun and radial dependence of the concentration parameter, a boost of ~ 35 still let some models allowed, providing a favourable environment (MW DM structure and propagation model)

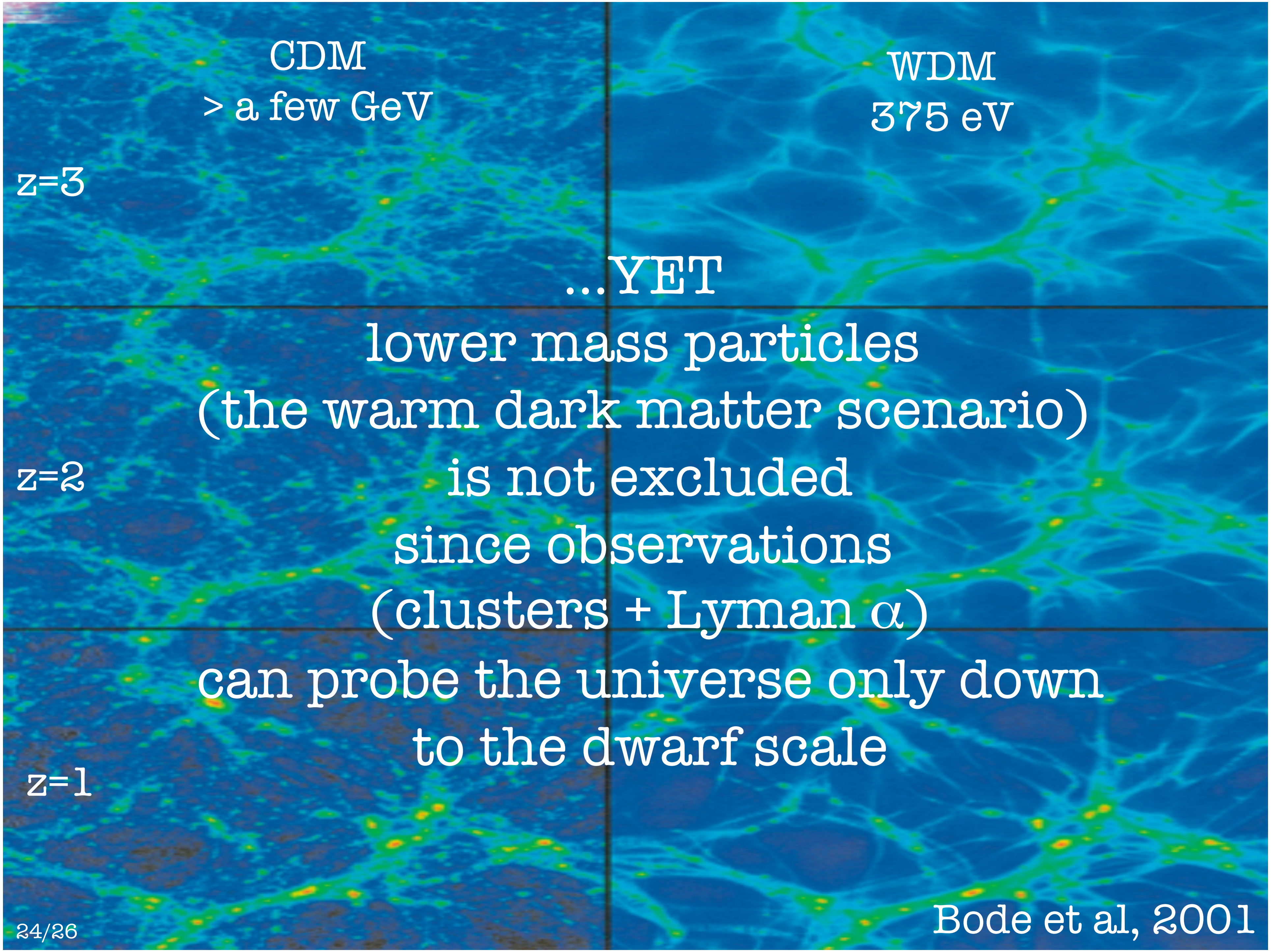
Note that subhalos are also needed to explain the surface brigthness profile of the radio halo



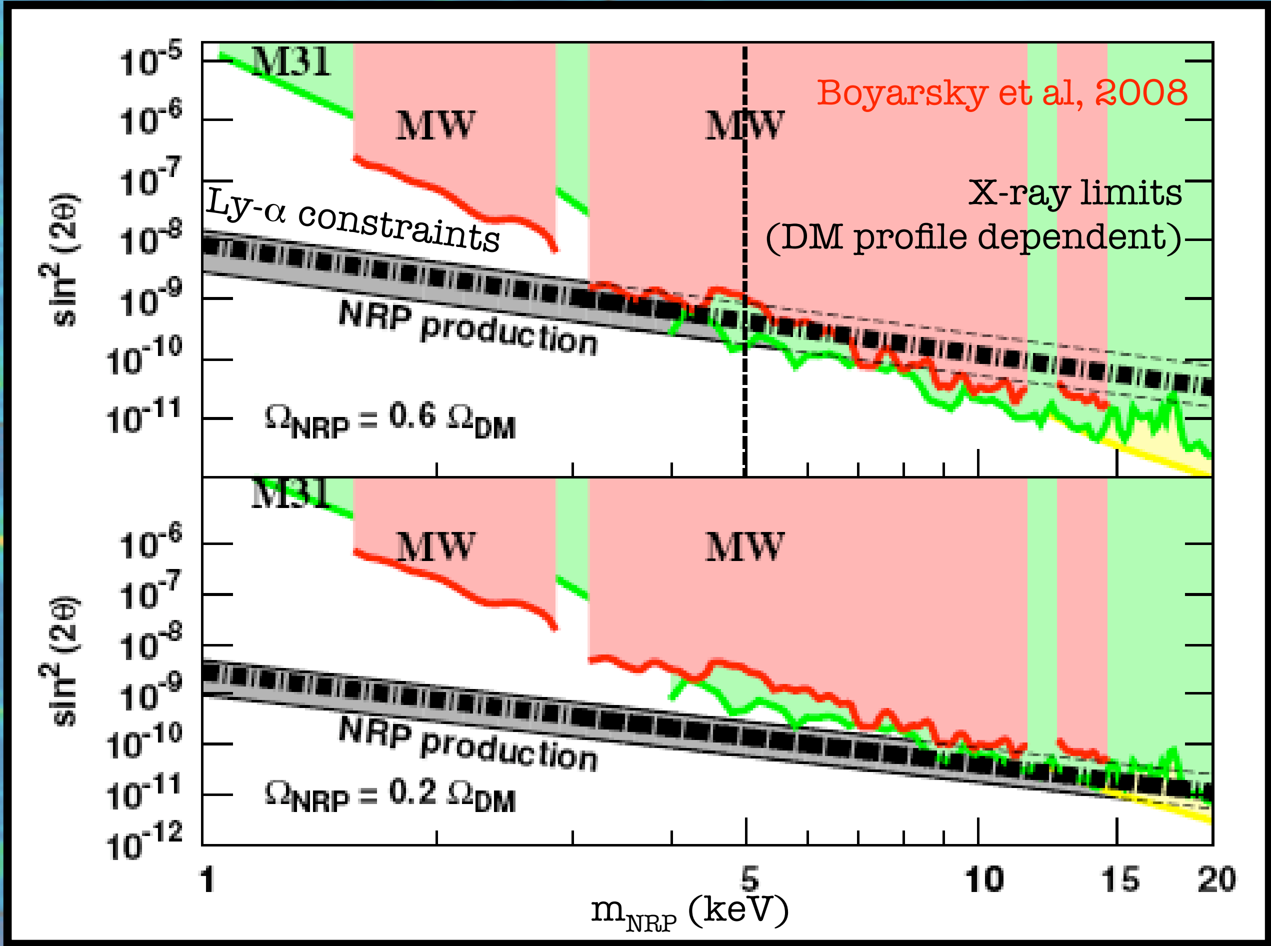

COLD or WARM Dark Matter?

CDM N-body simulations better reproduce the data





...YET
lower mass particles
(the warm dark matter scenario)
is not excluded
since observations
(clusters + Lyman α)
can probe the universe only down
to the dwarf scale



current limits (conservative):

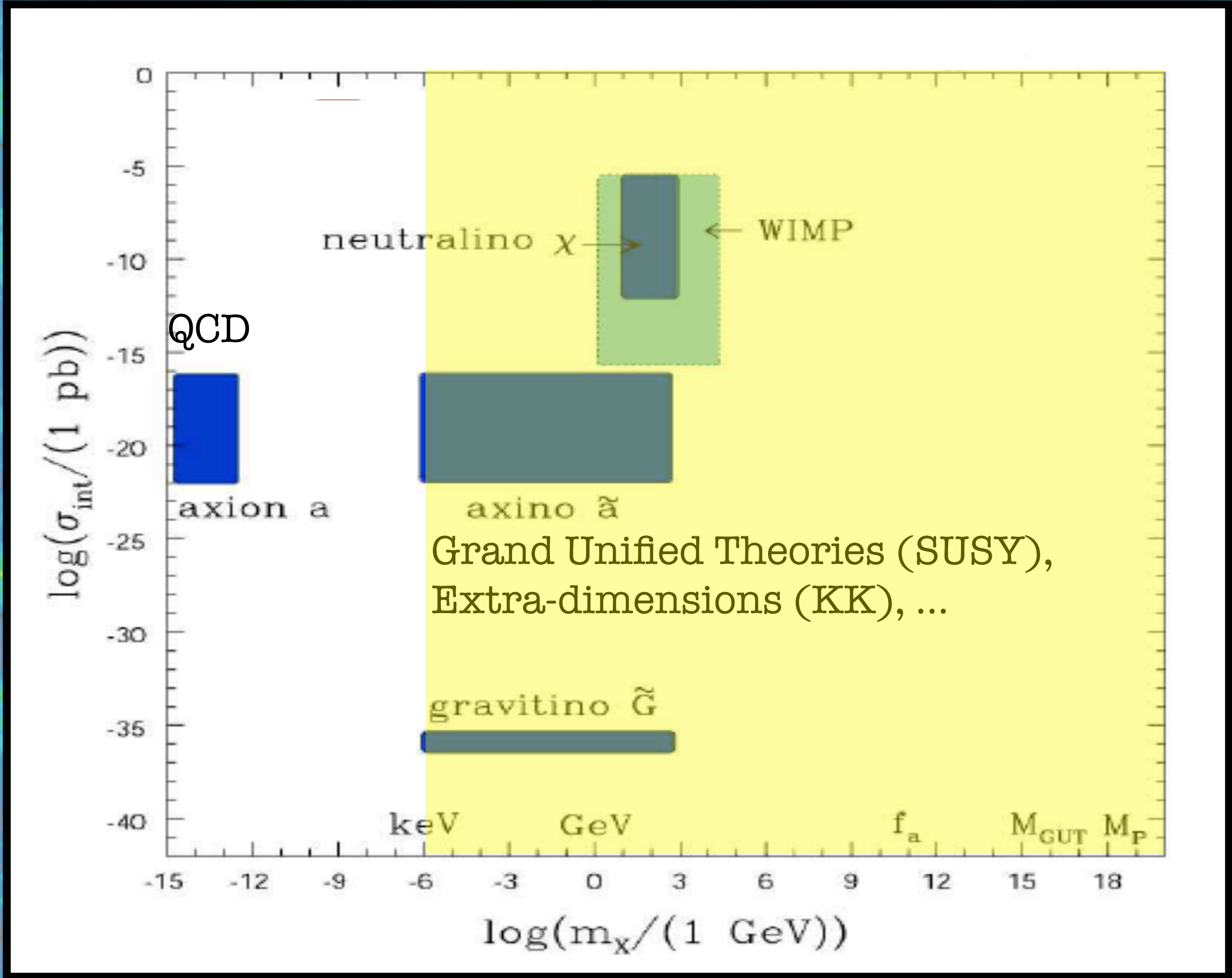
ΛWDM -> m_{NRP} (sterile n) > 9.5 keV at 95% CL

m_{TR} > 1.7 keV at 95% CL

ΛCWDM -> m_{NRP} = 5 keV, 40% of WDM allowed at 95% CL

m_{TR} = 1.1 keV, 40% of WDM allowed at 95% CL

WDM is also plausible for a Particle Physics point of view



Conclusions

Galactic and extragalactic sources and features may be observed or tested in the next years, if particle physics is favourable.

Otherwise, no distinction can be done among

-CDM scenario with unfavourable particle physics

-WDM scenario (undetectable in γ-rays)

-A more exotic explanation for the DM