Dark Matter Annihilation in Galactic Subhalos

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TeV Particle Astrophysics, Fermilab, July 15st 2005

The Dark Universe

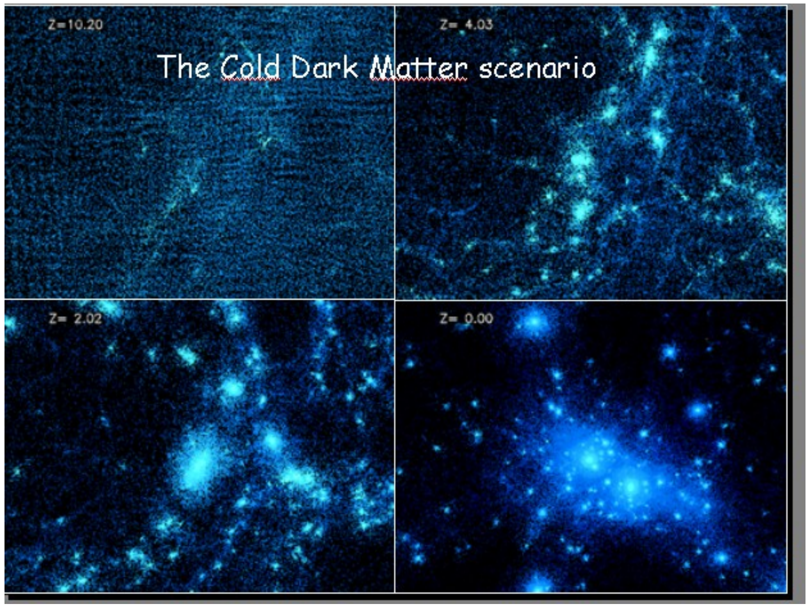
$$\Omega_{tot} \equiv \frac{\rho_\gamma + \rho_\nu + \rho_b + \rho_{DM} + \rho_\Lambda}{\rho_c} = 1.02 \pm 0.02$$

$H_0 \sim 72$ km s^{-1} Mpc^{-1}

$\Omega_\gamma \sim 10^{-5}$ $\quad 1.2 \cdot 10^{-3} \lesssim \Omega_\nu \lesssim 1.5 \cdot 10^{-2}$ $\quad \Omega_b^{BBN} \sim 0.04$ ($\Omega_b^{galaxies} \sim 0.005$) $\quad \Omega_\Lambda \sim 0.7$

$$\Omega_{DM} \sim 0.23$$

cold dark matter $\rightarrow$ axions, **WIMP's**



Supersymmetry

invariance of the theory under the exchange boson↔fermion,
spontaneously broken, unknown breaking mechanism
unknown hidden-visible sectors communication mechanism

- free parameters: **tan**β = <H_2>/<H_1>, μ, $\mathbf{m^2_{H1}, m^2_{H2}}$ $\mathbf{M_i, m^2_{Li}, m^2_{Ei}, m^2_{Qi}, m^2_{Ui}, m^2_{Di}, A_U^i, A_d^i}$ (i=1,2,3)
- R-parity is conserved $\rightarrow$ the **L**ighest **S**upersymmetric **P**article is stable

neutralino $\chi = a_1 \tilde{B} + a_2 \tilde{W}^3 + a_3 \tilde{H}_1^0 + a_4 \tilde{H}_2^0$

- Stable and weakly interacting,
- Ω_χ consistent with data,
- freeze-out $T_f \sim m_\chi/20 \rightarrow$ CDM

Photons from neutralino annihilation

- indirect searches ($\chi\chi$ annihilation)
- in the Galactic halo and other compact objects

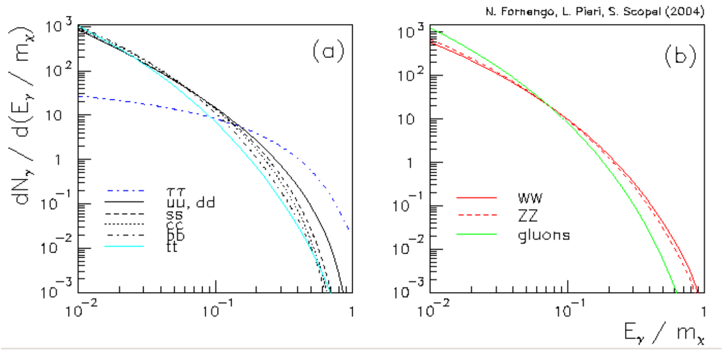
γ-lines | diffuse γ | antimatter | neutrinos

$$\frac{d\phi_\gamma(E,\psi,\Delta\theta)}{dE} = \frac{d\phi^{SUSY}}{dE}(E)\times\phi^{COSMO}(\psi,\Delta\theta)$$

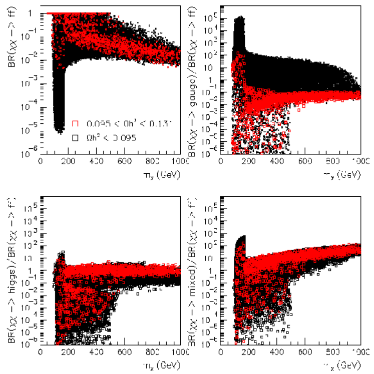
$$\left[N_\gamma\cdot b_{Z\gamma}\,\delta\left(E-m_\chi\left(1-\frac{m_Z^2}{4m_\chi^2}\right)\right)+N_\gamma\cdot b_{\gamma\gamma}\,\delta(E-m_\chi)+\sum_f\frac{dN_\gamma^f(E)}{dE}b_f\right]\cdot\frac{<\sigma v>_{ann}}{2\cdot 4\pi\cdot m_\chi^2}\ \text{x}$$

$$\text{x}\ \int_{\Delta\Omega(\theta)} d\Omega \int_{l.o.s.}\rho_\chi^{\,2}(r(l,\psi))\,dl(\psi)$$

The supersymmetric factor ϕ^{SUSY}



x



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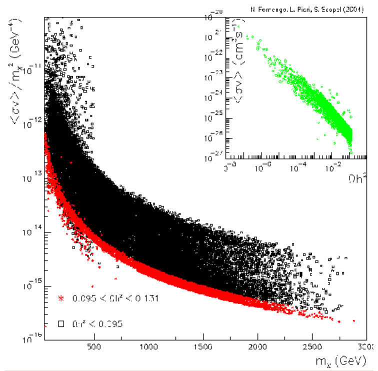

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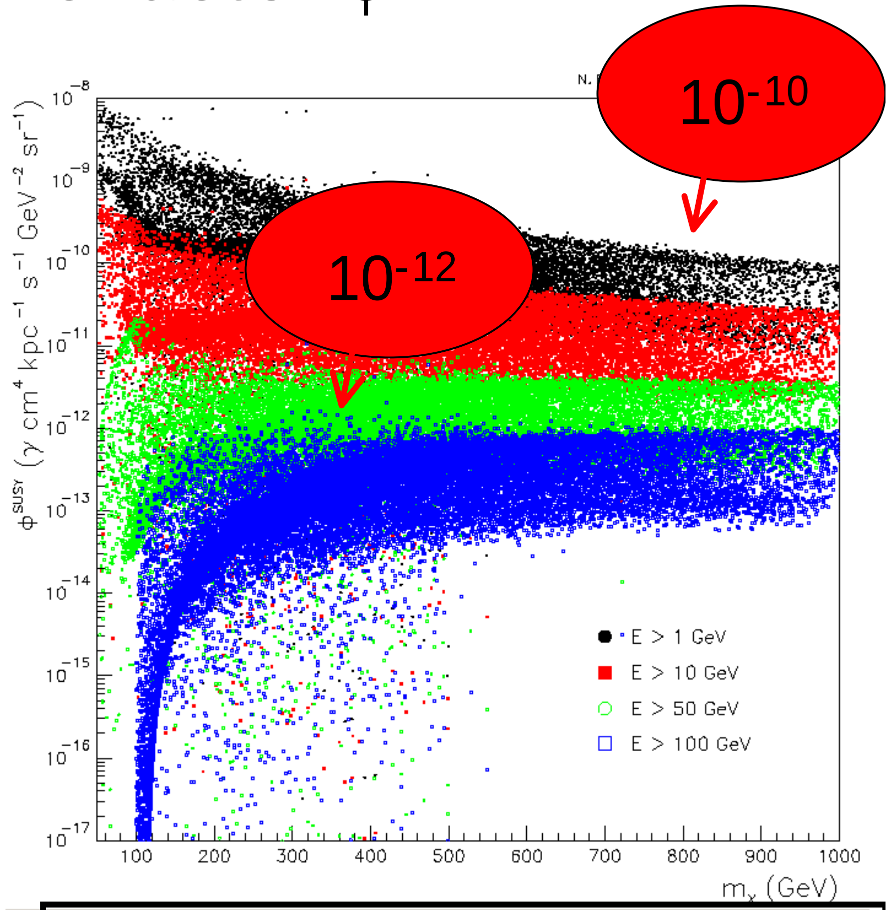


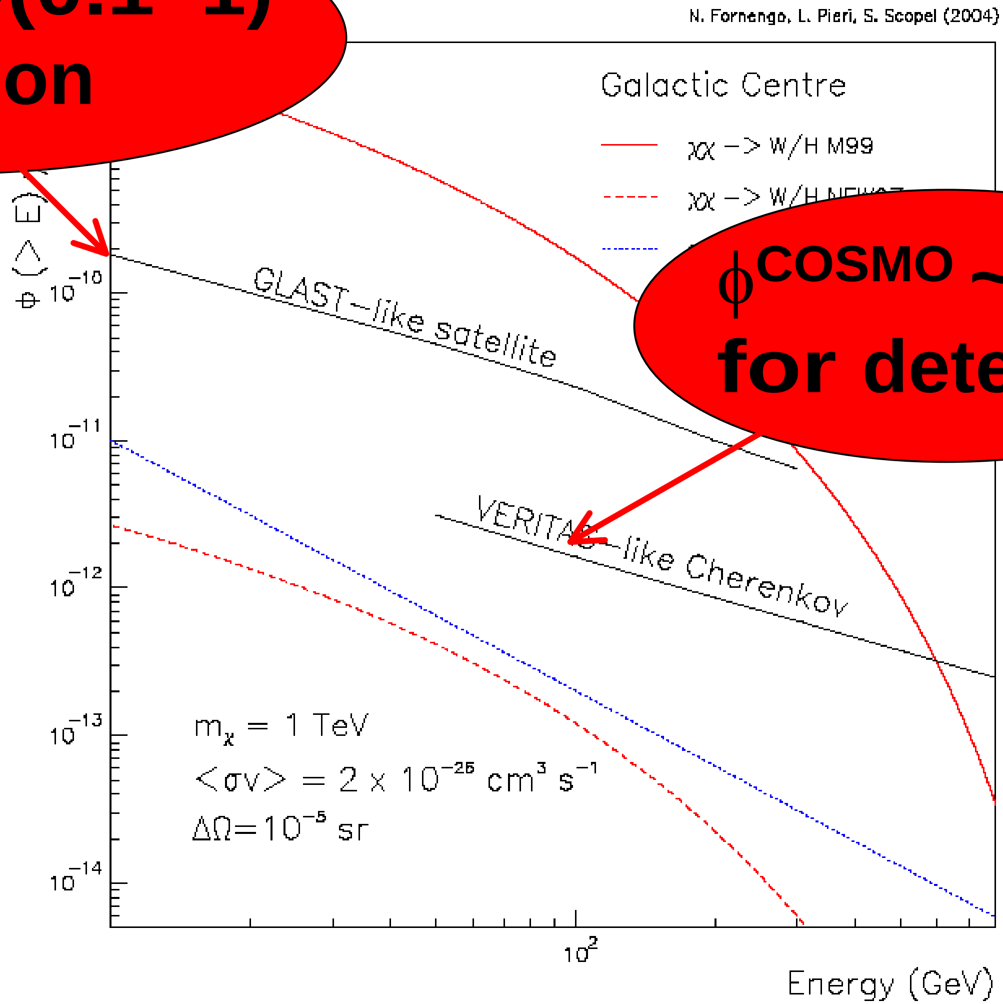
N. Fornengo, LP and S. Scopel PRD 2004

We use the implementation of a SUSY scheme directly at the EW scale, called eMSSM (effective Minimal SuperSymmetric Model). The number of parameters is restricted to those which shape the model at the EW scale

- ✗ 100 GeV $< |\mu|, M_2 <$ 6 TeV
- ✗ 90 GeV $< m_A <$ 1 TeV
- ✗ $M_1 = 5/3 \tan^2 \theta_W M_2$
- ✗ $-3 < A_{t,b,\tau} m_0 < 3$
- ✗ 100 GeV $< m_0 <$ 3 TeV
- ✗ $1 < \tan \beta < 50$

Experimental sensitivity

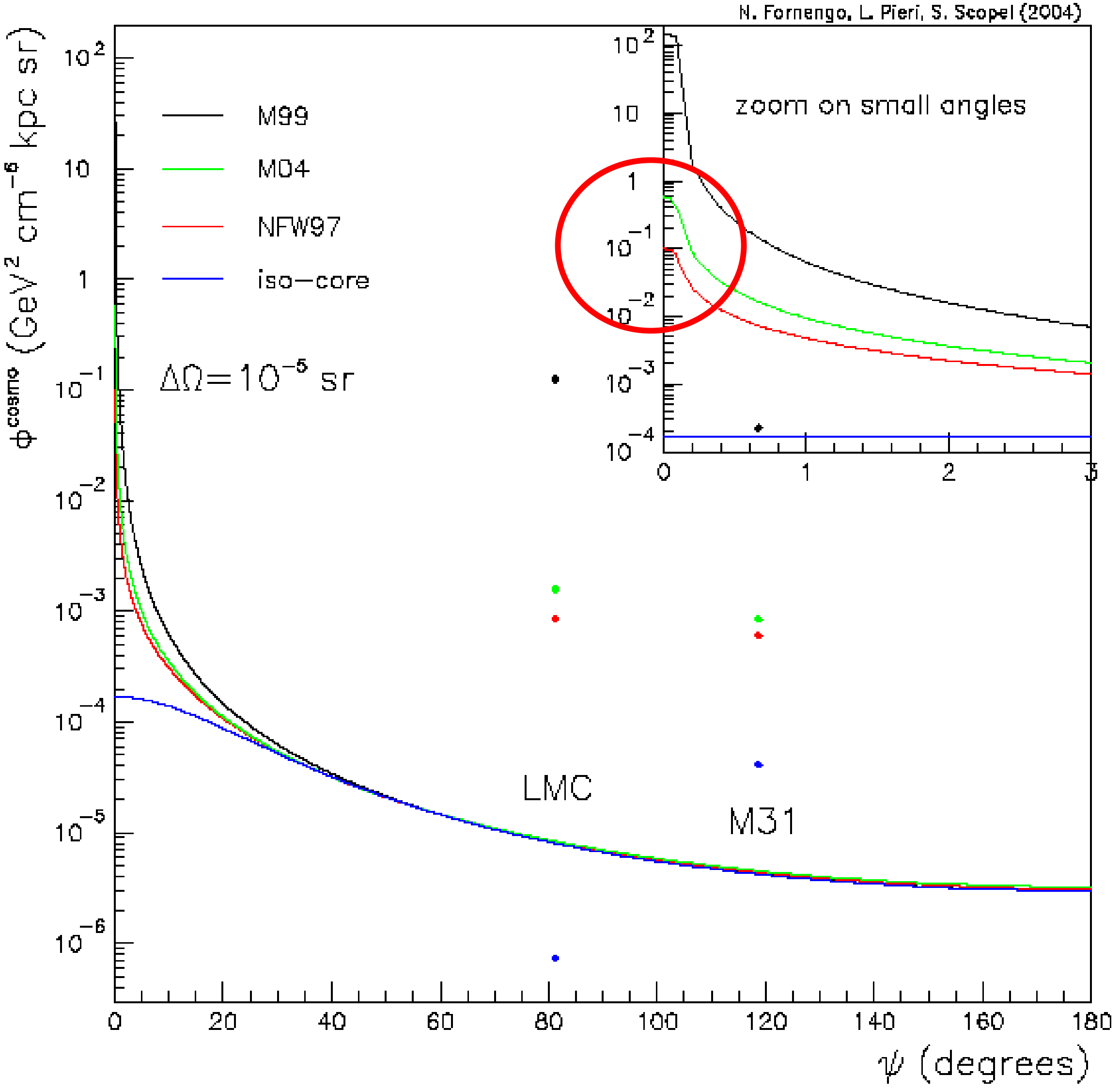
$\phi^{COSMO} \sim O(0.1\text{- }1)$ for detection



$\phi^{COSMO} \sim O(1)$ for detection

N. Fornengo, LP and S. Scopel PRD 2004

The cosmological factor ϕ^{COSMO}



N. Fornengo, LP and S. Scopel PRD 2004

Influence of subhalos revised

Large scale structure formation for CDM

$$\frac{\delta\rho}{\rho} \equiv \Delta(k,z) = T_{\Delta}^{1/2}(k,z)\,\Delta(k,z_i)$$

inflation ↓ initial data ↓ $\Delta(k,z_i)$

$T_{\Delta}^{1/2}$ ↑ transport function ↑ gravitational evolution

$\Delta(k,z) \propto \ln(k/k_{eq})$ ⟶ No linear regime $\forall k$

Substructure crisis: What about small scales?

✕ The damping of the primordial power spectrum due to collisional damping (after chemical decoupling and just before kinematic decoupling a local thermal equilibrium is achieved by elastic scattering processes which give viscous coupling to the radiation) and free streaming of WIMPy CDM halos has been calculated.
<u>The free streaming leads to a CDM power spectrum cut-off at about 10^{-6} $M_{\odot}$</u>

✕ The transfer function taking into account the suppression in the growth of the CDM density contrast after matter-radiation equality due to the baryons has been calculated to obtain a <u>CDM power spectrum</u>

A.M.Green, S. Hofmann, D.J. Schwarz JCAP 2005

Influence of subhalos revised

$$D(k) \equiv \frac{\Delta_{WIMP}(k,\eta)}{\Delta_{WIMP}(k,\eta_i)} = \left[1 - \frac{2}{3}\left(\frac{k}{k_{fs}}\right)^2\right] \exp\left[-\left(\frac{k}{k_{fs}}\right)^2 - \left(\frac{k}{k_d}\right)^2\right]$$

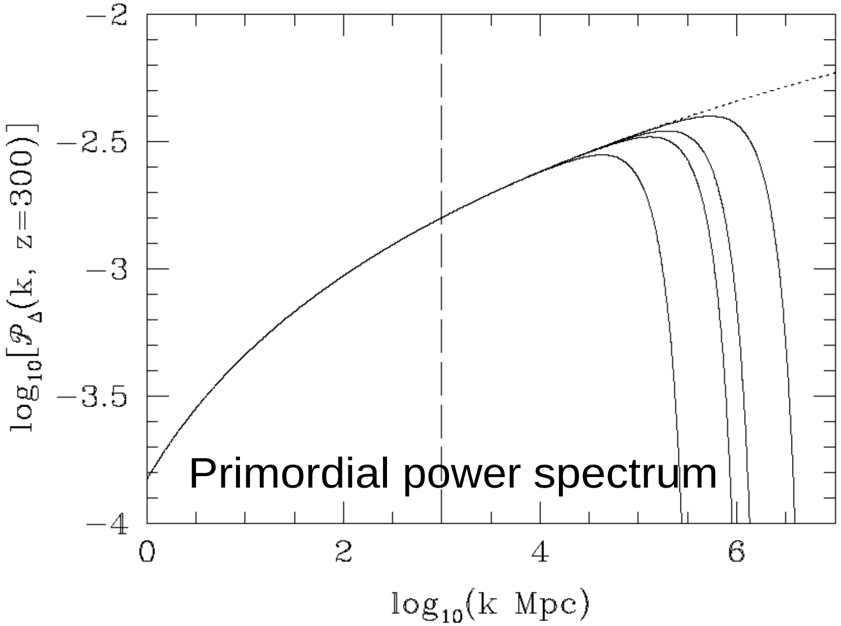
$$\frac{\delta\rho}{\rho} \equiv \Delta(k,z) = T_\Delta^{1/2}(k,z) D(k) \Delta(k,z_i)$$

$k_{fs} \sim 10^{-5}\ M_\odot$ @ m_χ=1 TeV

$k_{fs} \sim 10^{-6}\ M_\odot$ @ m_χ=100 GeV

$k_d \sim 10^{-9}\ M_\odot$ @ m_χ=1 TeV

$k_d \sim 10^{-10}\ M_\odot$ @ m_χ=100 GeV

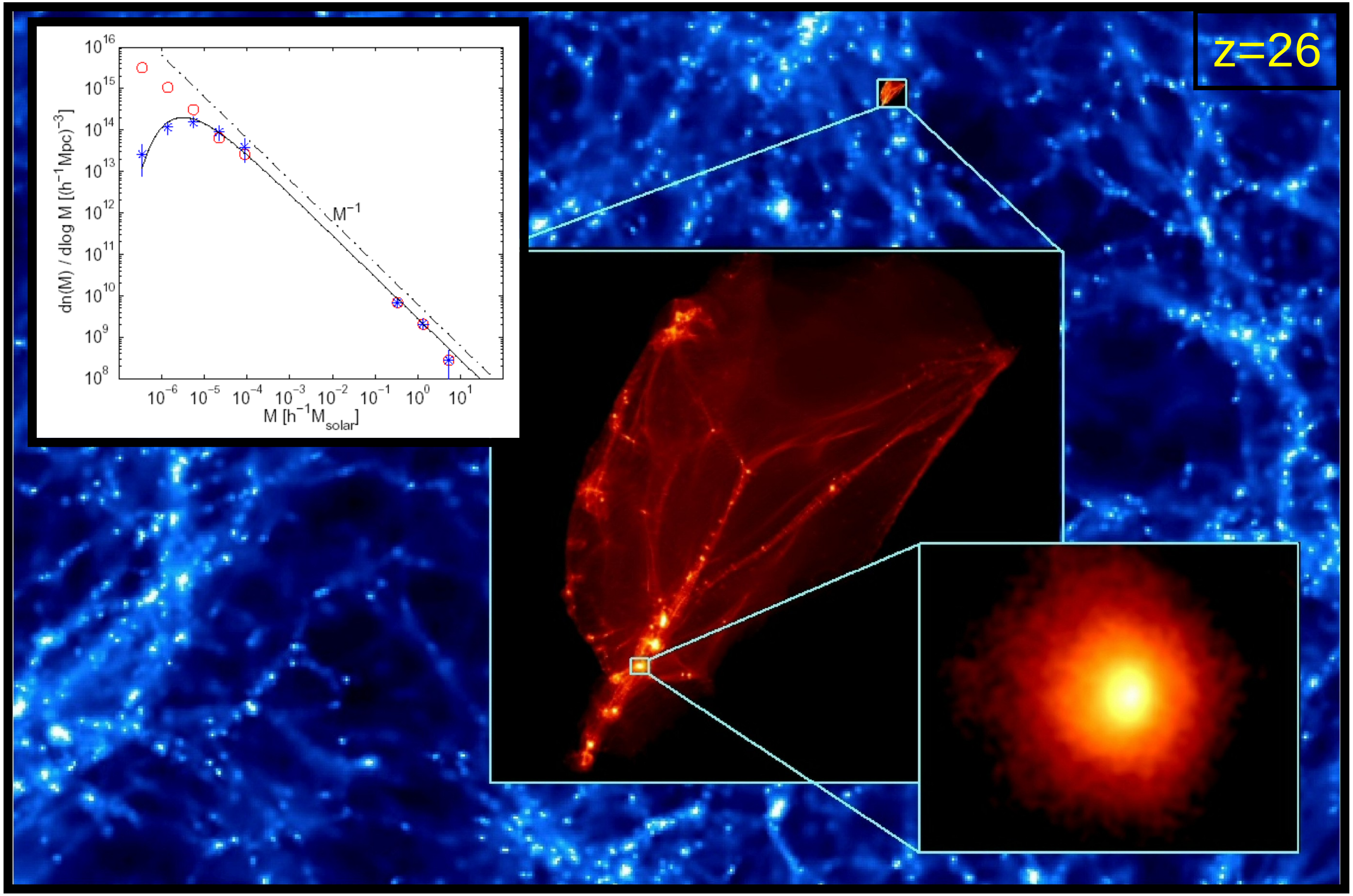


Typical first halos:

- ✕ $z_{nl} \sim 60 \pm 10$
- ✕ $M(r) = 21.6 \times 10^{-7}\ M_\odot\ \frac{\Omega_m}{0.14}\left(\frac{R}{1pc}\right)^3$
- ✕ $r = 1.05\ \frac{R_{min}}{1+z_{nl}^{max}} \sim 0.02$ pc @ R_{min} = 1 pc
- ✕ Δ_0=(0.2 - 1.8) x 10^6 -> $c^{NFW}_0 \sim 40$

A.M.Green, S. Hofmann, D.J. Schwarz JCAP 2005

Influence of subhalos revised



J. Diemand, B. Moore and J. Stadel, Nature 2005

Modeling subhalos

Density distribution function $$\rho(M_{sh}, r_{sh}) = AM^{-2} \frac{1}{\left(\frac{r}{r_s^{MW}}\right)\left(1+\frac{r}{r_s^{MW}}\right)^2}$$

NORMALIZED TO : 10% of the MW mass is in subhalos with masses $> 10^7\ M_\odot$

↓

about 50% of the MW mass is in subhalos with masses $> 10^{-6}\ M_\odot$

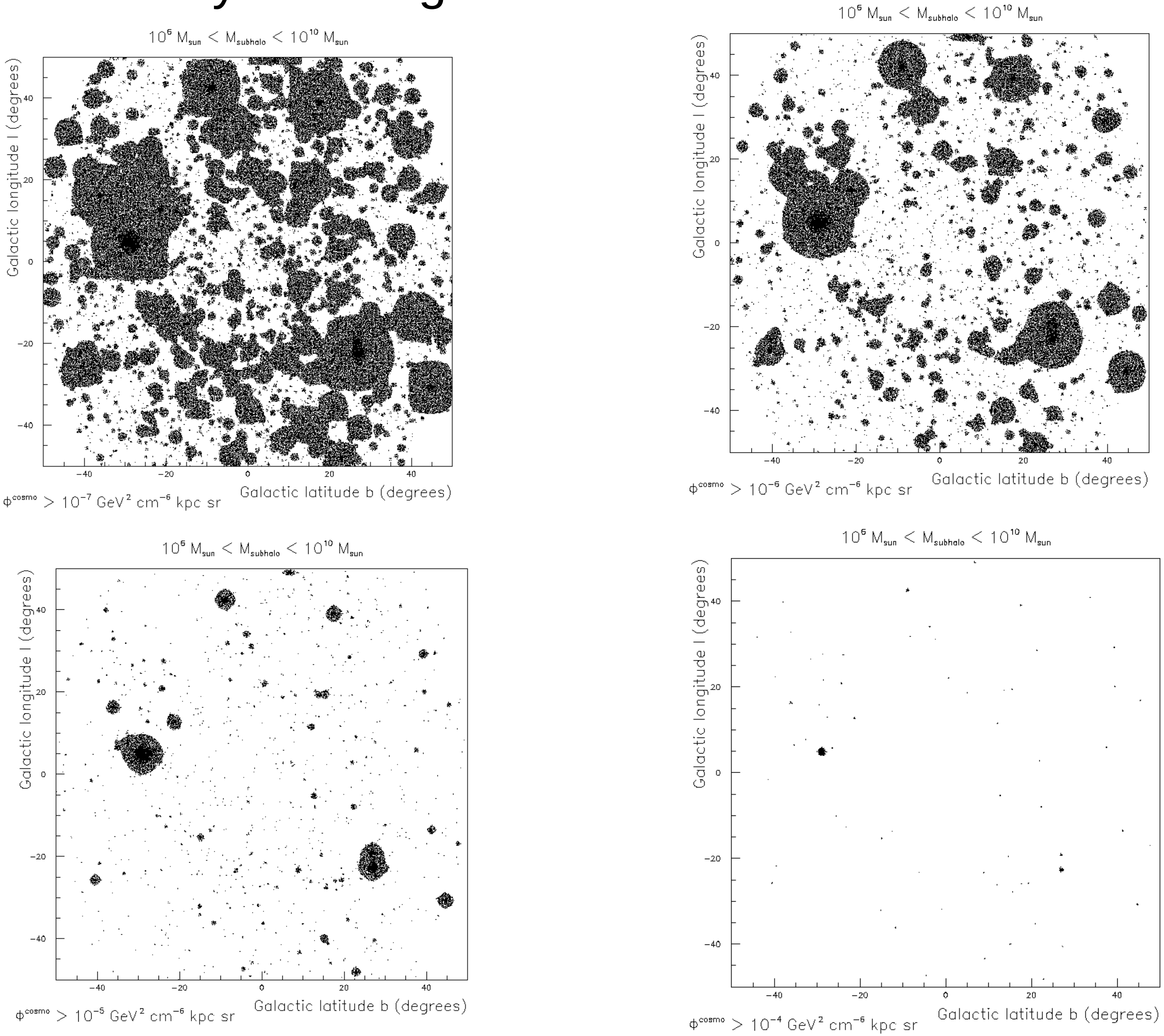
the total number of subhalos is abut 1.5 x 10^{16}

the local population of subhalos is about 100 pc^{-3}

LP, E. Branchini and S. Hofmann 2005

A subhalo sky: the large halos

LP, E. Branchini and S. Hofmann 2005



A subhalo sky: the small halos

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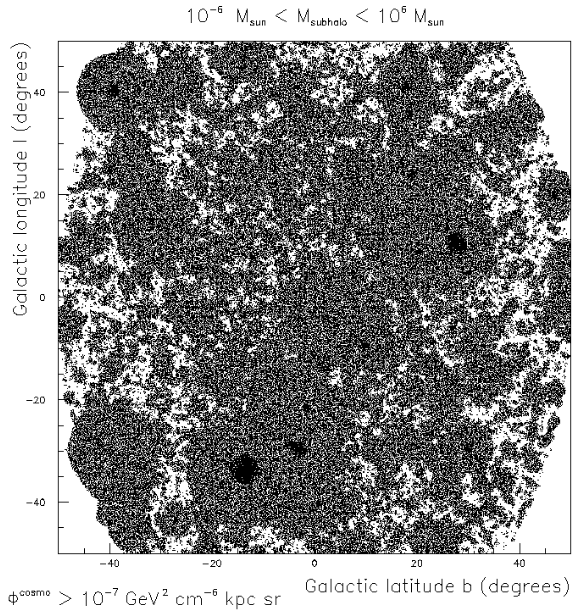
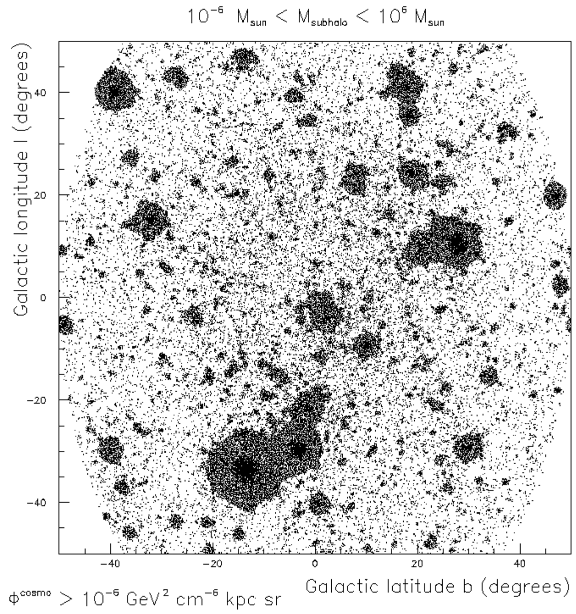
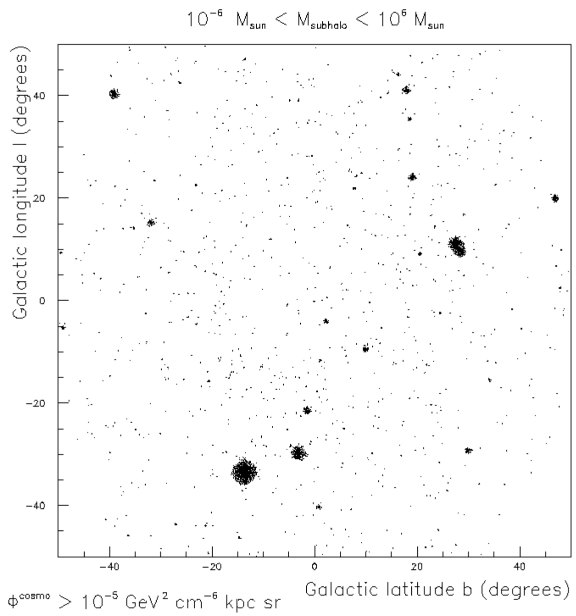
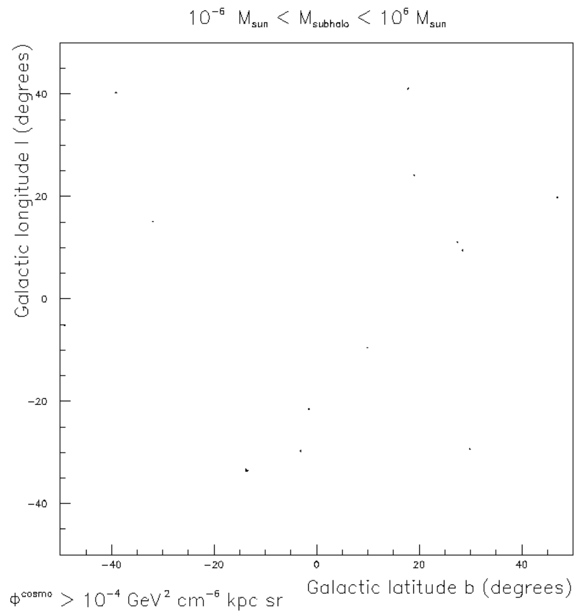




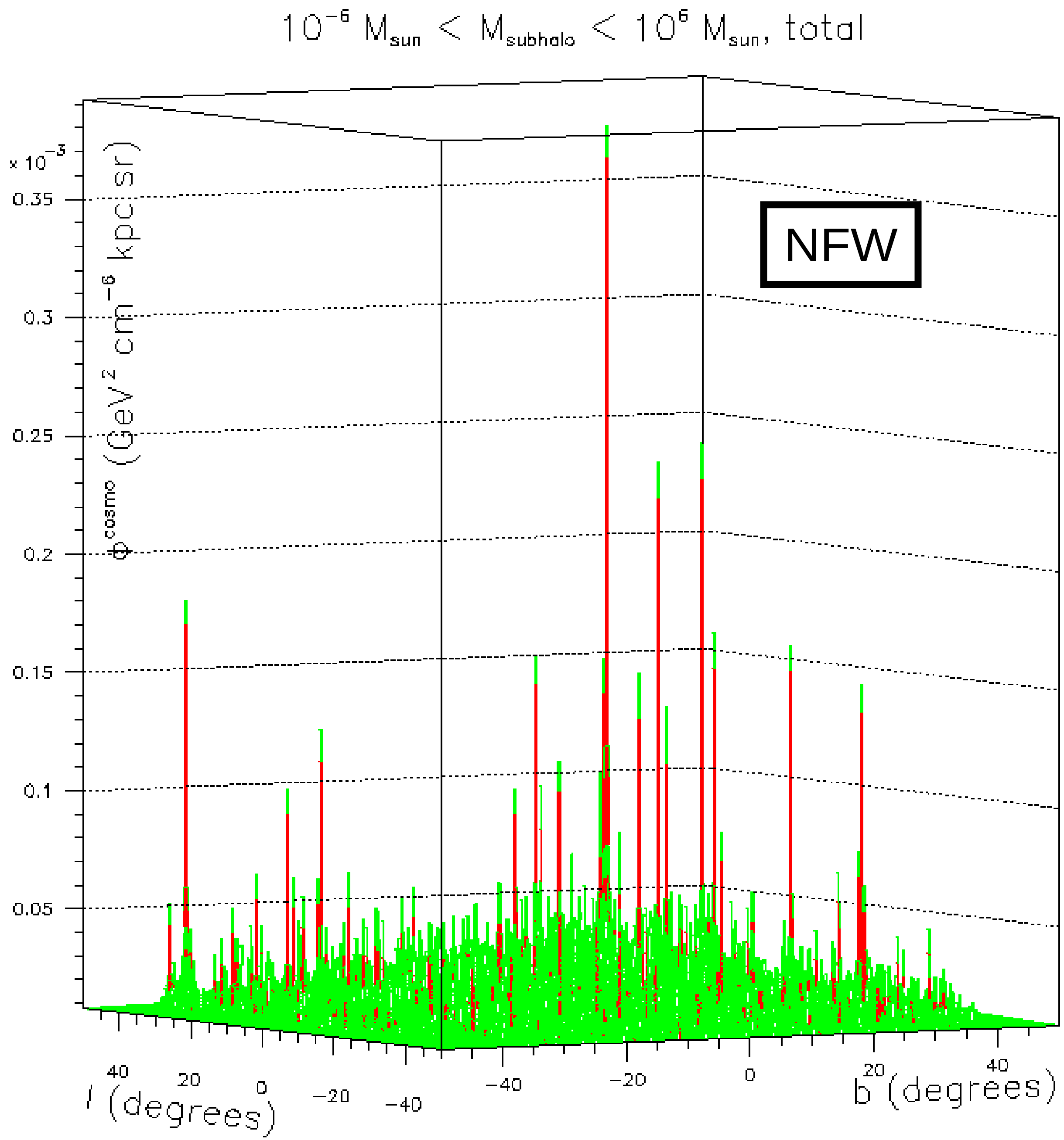




3D contribution
of the population
of small subhalos

GREEN is the
average contribution

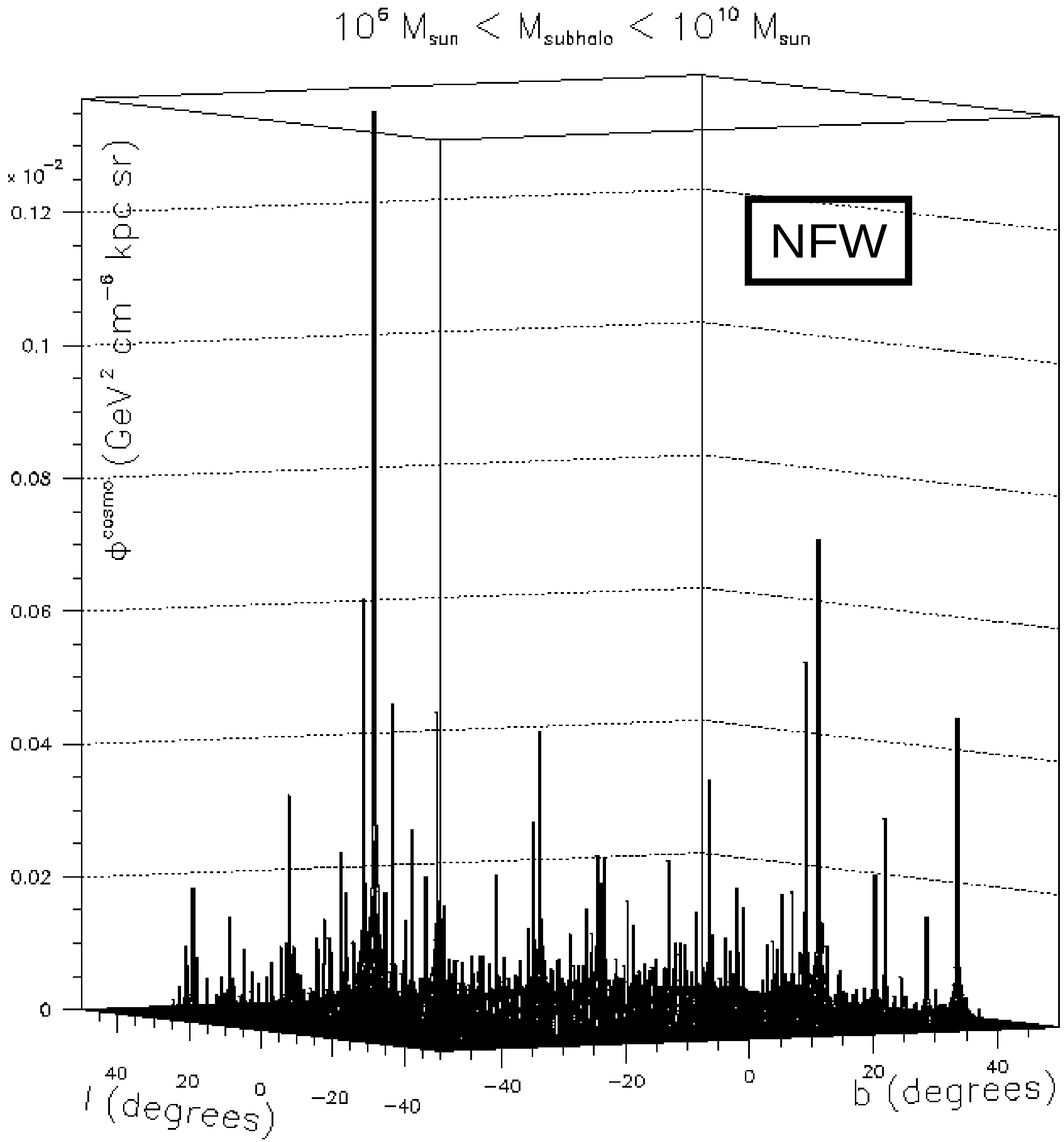
RED is the variance
with respect to the
average flux



LP, E. Branchini and S. Hofmann 2005

3D contribution
of the population
of large subhalos

The density distribution
of these subhalos in the
Galactic halo has been
revised to match the
small halos density
distribution



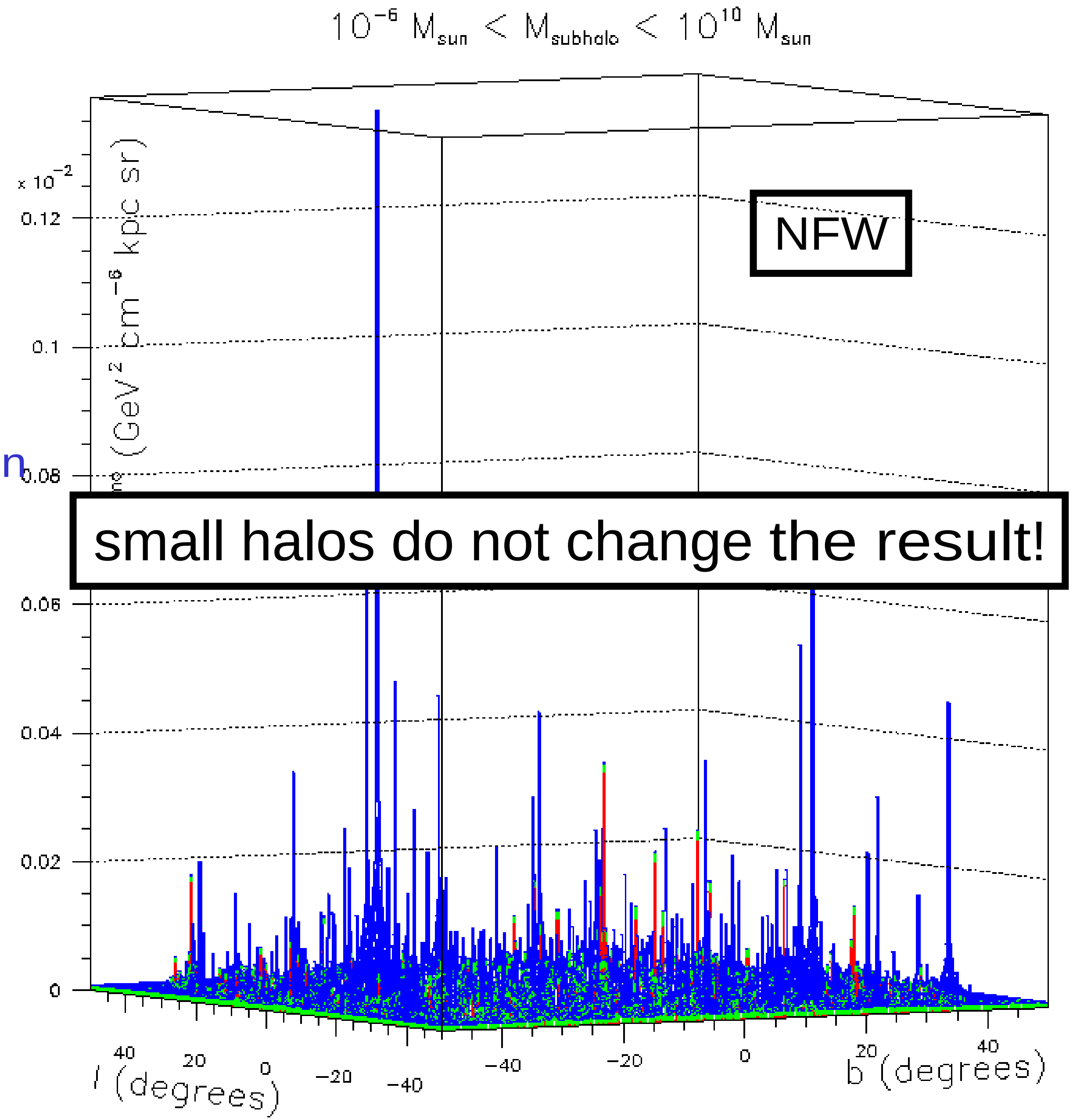
LP, E. Branchini and S. Hofmann 2005

3D contribution
of the whole population
of subhalos

BLUE is the contribution
of large subhalos

GREEN is the
average contribution
of small subhalos

RED is the variance
contribution of small
subhalos



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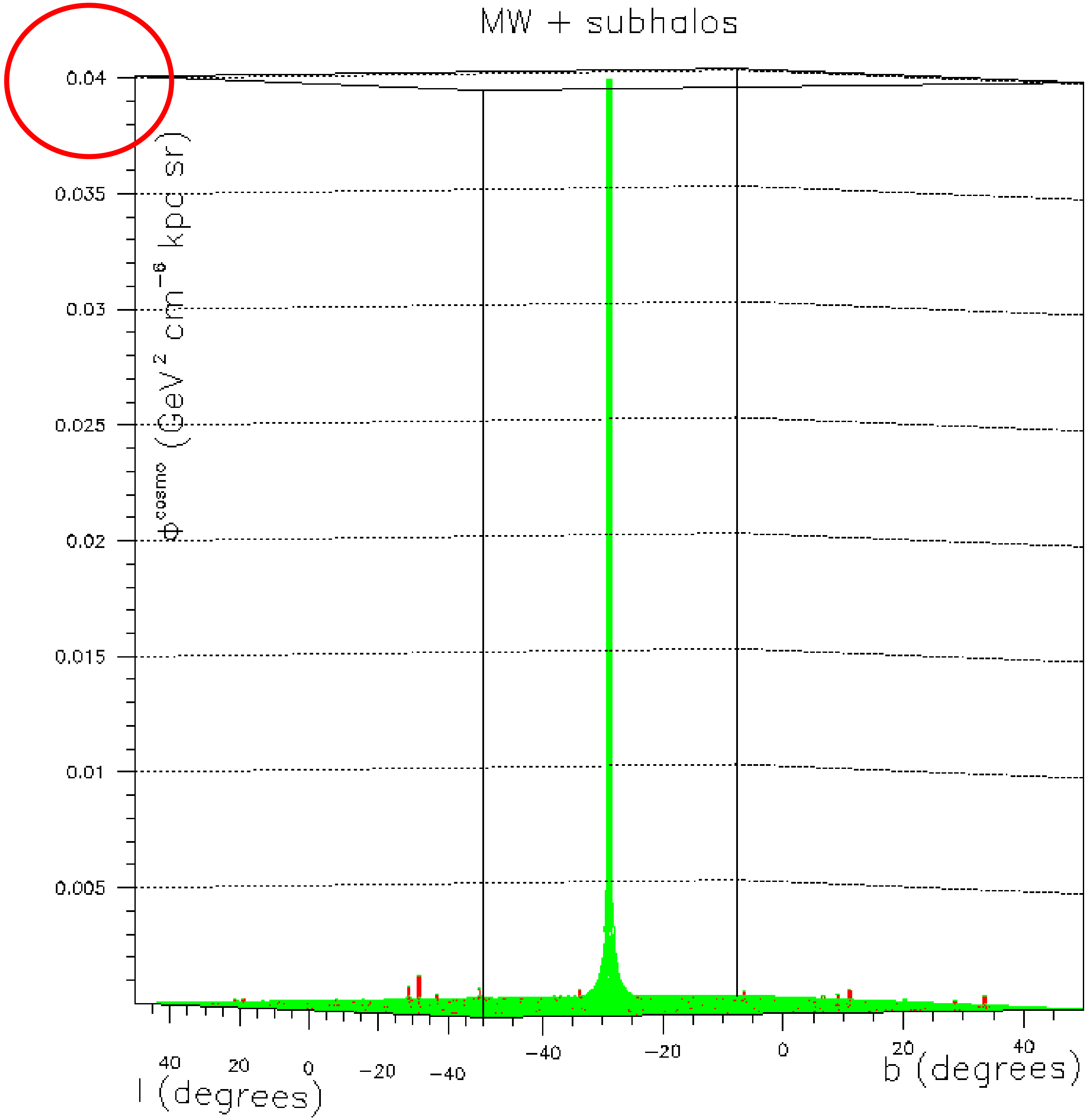
3D contribution
of MW+subhalos

GREEN is the
MW smooth
contribution

RED is the all-halos
contributions...



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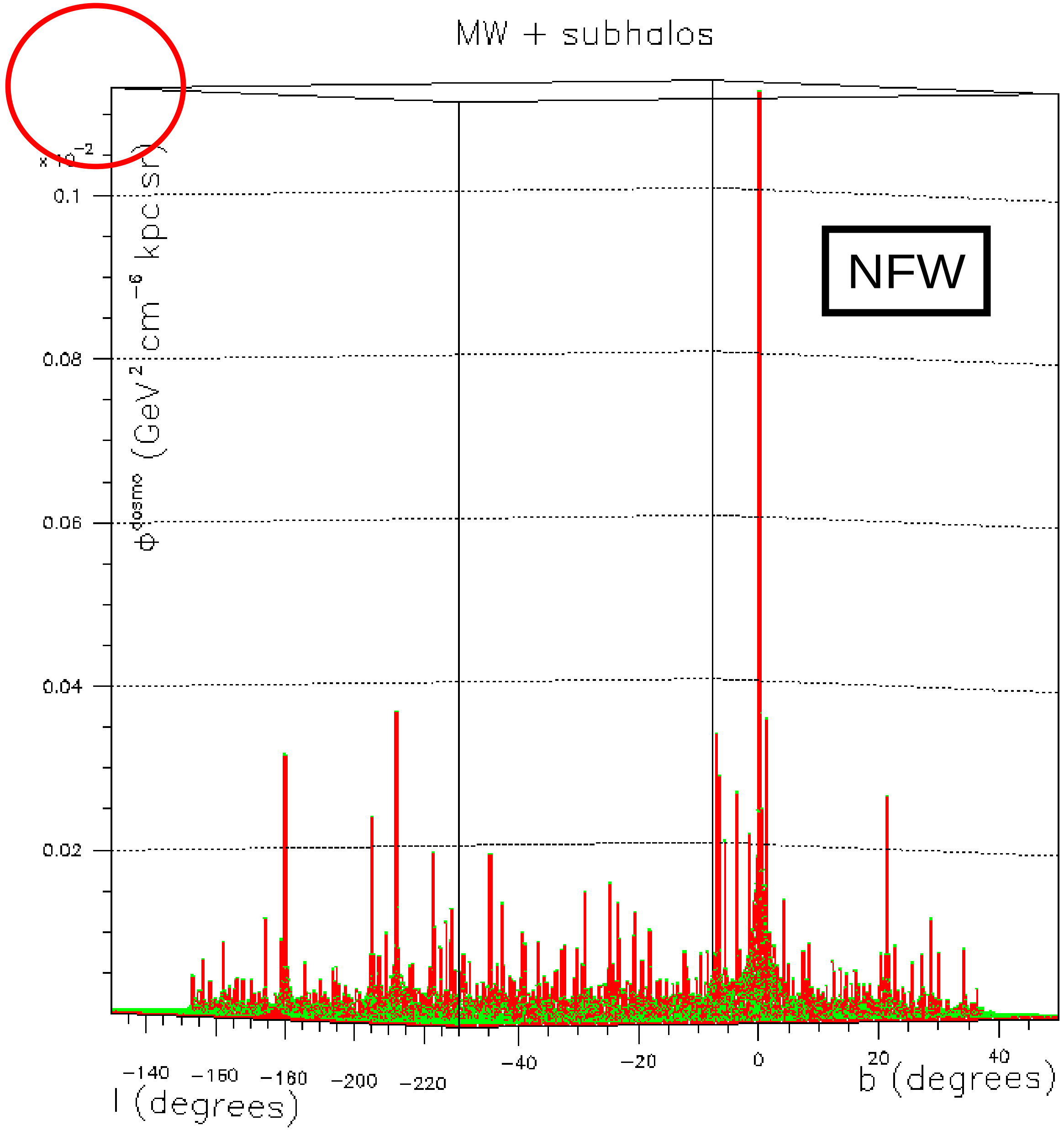
3D contribution of MW+subhalos towards the Galactic anticenter

GREEN is the MW smooth contribution

RED is the all-halos contributions…



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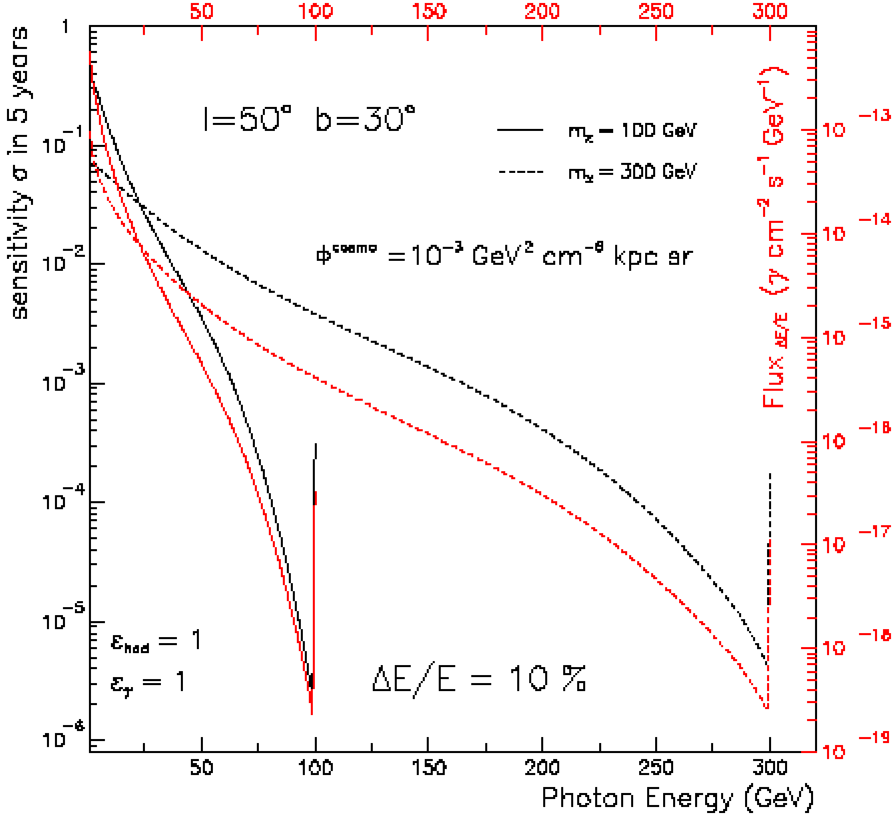
Is there any hope for detection with GLAST?

The cross section for the neutralino annihilation can hardly exceed
$\langle\sigma v\rangle_{ann} = 2 \times 10^{-26}\ cm^3 s^{-1}$

However, to detect the γ-lines one can take into account the energy resolution of next-coming experiments, such as GLAST.

SIGNAL FROM MINIHALOS
SEEMS TO BE TOO FAINT



$\langle\sigma v\rangle_{ann} = 2 \times 10^{-26}\ cm^3 s^{-1}$
$\Phi^{COSMO} = 10^{-3}\ GeV^2 cm^{-6}\ kpc\ sr$
$BR(\gamma\text{-line}) = 10^{-3}$

LP, E. Branchini and S. Hofmann 2005


Conclusions
Particle physics and astrophysics/ cosmology of Dark Matter phenomenology has been explored
"To see" dark matter at γ-rays is a very challenging task, unless a spiky profile of dark matter halos is assumed.