Neutralino annihilation into γ rays in the Milky Way and in external galaxies

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We discuss the gamma-ray signal from dark matter annihilation in our Galaxy and in external objects, namely, the Large Magellanic Cloud, the Andromeda Galaxy (M31), and M87. We derive predictions for the fluxes in a low energy realization of the minimal supersymmetric standard model and compare them with current data from EGRET, CANGAROO-II, and HEGRA and with the capabilities of new-generation satellite-borne experiments, like GLAST, and ground-based Čerenkov telescopes, like VERITAS. We find fluxes below the level required to explain the possible indications of a γ-ray excess shown by CANGAROO-II (toward the galactic center) and HEGRA (from M87). As far as future experiments are concerned, we show that only the signal from the galactic center could be accessible to both satellite-borne experiments and to atmospheric Čerenkov telescopes (ACTs), even though this requires very steep dark matter density profiles.

I. INTRODUCTION

The nature of the cold dark matter (CDM) which is believed to compose galactic halos is probably the most important open issue in present cosmology. A popular solution to this puzzle is given by the lightest supersymmetric particle (LSP) which, in most supersymmetry breaking scenarios, is the neutralino χ. In this case dark matter (DM) would be not so dark after all, since χ-χ annihilation is expected to lead, among other final states, to a γ signal which could in principle be detected above known backgrounds. In particular, since the neutralino annihilation rate is proportional to the square of its density, a signal enhancement is expected in high density regions like the center of our Galaxy or that of external ones, with the exciting possibility that such γ rays might be identified by forthcoming or just operating atmospheric Čerenkov telescopes (ACTs) such as VERITAS [1], HESS [2], and MAGIC [3] or by satellite-borne detectors like GLAST [4], let alone the even more intriguing chance that a hint of an exotic source of γ rays could actually be already present in the data of existing experiments, like EGRET [5] or CANGAROO-II [6]. However, assessing the size of such signals depends on many uncertain aspects of both astrophysics and particle physics. For instance, the central structure of the DM halos is far from being well determined, and this can lead to uncertainties in the calculation of expected γ rates spanning several orders of magnitude. Another sensitive issue is the presence of substructures in galactic halos, which can change predictions as compared to a smooth mass distribution.

The aim of the present paper is to investigate the possibility that neutralino annihilations in the halo of our galaxy [7–10], or that of external ones [11,12] (namely, the Large Magellanic Cloud, the Andromeda Galaxy, and M87) could produce detectable fluxes of γ rays. To this purpose we will discuss present astrophysical uncertainties and focus on deriving consistent predictions for these fluxes in a specific realization of supersymmetry, the effective minimal supersymmetric standard model (MSSM).

The plan of the paper is as follows: in Sec. II the main ingredients for the calculation of the γ-ray flux from neutralino annihilation are introduced; in Sec. III we discuss the contribution to the flux calculation coming from astrophysics, while in Sec. IV the contribution from particle physics is discussed, and the effective MSSM is outlined. In Sec. V we show our results and compare them to present data and the prospects of future experiments; finally, Sec. VI is devoted to our conclusions.

II. THE γ-RAY FLUX

The diffuse photon flux from neutralino annihilation in the galactic halo, coming from a given direction in the sky defined by the angle-of-view ψ from the galactic center, and observed by a detector with angular resolution θ can be written as:

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma, \psi, \theta) = \frac{d\Phi^{\mathrm{SUSY}}}{dE_\gamma}(E_\gamma) \times \Phi^{\mathrm{cosmo}}(\psi, \theta). \quad (1)$$

The energy dependence in Eq. (1) is given by the annihilation spectrum:

$$\frac{d\Phi^{\mathrm{SUSY}}}{dE_\gamma}(E_\gamma) = \frac{1}{4\pi} \frac{\langle \sigma_{\mathrm{ann}} v \rangle}{2m_\chi^2} \sum_f \frac{dN_\gamma^f}{dE_\gamma} B_f \quad (2)$$

where $\langle \sigma_{\mathrm{ann}} v \rangle$ is the neutralino self-annihilation cross section times the relative velocity of the two annihilating particles, dN_γ^f/dE_γ is the differential photon spectrum for a given f-labeled annihilation final state with branch-

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ing ratio B_f, and m_χ denotes the neutralino mass. The geometry dependence is given by the line-of-sight integral, defined as:

$$\Phi^{\text{cosmo}}(\psi, \theta) = \int_{\Delta\Omega(\psi,\theta)} d\Omega' \int_{\text{l.o.s}} \rho_\chi^2[r(\lambda, \psi')]d\lambda(r, \psi') \tag{3}$$

for the diffuse emission of our Galaxy, and

$$\Phi^{\text{cosmo}}(\psi, \theta) = \frac{1}{d^2} \int_0^{\min[R_G, r_{\max}(\Delta\Omega)]} 4\pi r^2 \rho_\chi^2(r)dr \tag{4}$$

for the emission from an extragalactic object located at the direction ψ. In Eq. (3), $\rho_\chi(r)$ is the dark matter density profile, r is the galactocentric distance, related to the distance λ from us by $r = \sqrt{\lambda^2 + R_\odot^2 - 2\lambda R_\odot \cos\psi}$ ($R_\odot$ is the distance of the Sun from the galactic center), and $\Delta\Omega(\psi, \theta)$ is the solid angle of observation pointing in the direction of observation ψ and for an angular resolution of the detector θ. Moreover, in Eq. (4) d is the distance of the external object from us, R_G is the radius of the external galaxy, and $r_{\max}(\Delta\Omega)$ is the maximal distance from the center of the external galaxy which is seen within the solid angle $\Delta\Omega(\psi, \theta)$. The quantity Φ^{cosmo}, expressed in units of $(\text{GeV}/\text{cm}^3)^2$ kpc sr, is related to the dimensionless parameter J of Ref. [13] by the simple relation $\Phi^{\text{cosmo}} = J \times 0.765 \times \Delta\Omega$.

We focus our attention on the fact that Eq. (1) is factorized into two distinct terms: a "cosmological factor" Φ^{cosmo} which takes into account the geometrical distribution of DM in the Universe, and a "supersymmetric factor" Φ^{SUSY} which contains the information about the nature of dark matter. In Secs. III and IV we will present results on the two factors separately.

III. THE COSMOLOGICAL FACTOR

In the following we present the determination of the cosmological factor Φ^{cosmo}, as defined in Eqs. (3) and (4). The dependence of Φ^{cosmo} on the astrophysical and cosmological details that we explore here is based on the determination of the shape of the dark matter halo. This takes into account the possible existence and prominence of central cusps, the study of the physical extent of the constant-density inner core, and the possible presence of a population of subhalos. We remind the reader that, for the moment, no definitive answer can be given to these questions by experimental constraints. In particular, the discussion about the possible existence of a halo with a cuspy behavior in its inner regions is still quite open. Moreover, theoretical predictions differ substantially among themselves, or take into account different input parameters.

These facts reflect themselves in a large uncertainty in the predictions of the gamma-ray fluxes arising from Φ^{cosmo}, as it is discussed and quantified in the following.

A. Modeling the Dark Matter Halo

The modeling of the DM density profile is an open question. It can be addressed through numerical N-body simulations whose scale resolution is about a few $\times 10^{-3} r_{100}$, where r_{100} is defined as the radius within which the halo average density is about $100\rho_c$ (ρ_c is the critical density). The very inner slope of the profile is then usually just extrapolated and does not take into account interactions with the baryons which fall in the DM potential well. A number of profiles have been proposed. Here we discuss some of the profiles which are compatible with observations and which we will use in our analysis.

In our calculation we mainly focus on the NFW profile (hereafter NFW97) [14]

$$\rho_\chi^{\text{NFW97}} = \frac{\rho_s^{\text{NFW97}}}{(r/r_s^{\text{NFW97}})(1 + r/r_s^{\text{NFW97}})^2} \tag{5}$$

and the Moore *et al.* profile (M99) [15]:

$$\rho_\chi^{\text{M99}} = \frac{\rho_s^{\text{M99}}}{(r/r_s^{\text{M99}})^{1.5}[1 + (r/r_s^{\text{M99}})^{1.5}]}. \tag{6}$$

The scale radii r_s^i and the scale densities ρ_s^i ($i =$ NFW97, M99) can be deduced by observations (the virial mass of the halo or the rotation curves) and by theoretical considerations that allow to determine the concentration parameter $c = r_{\text{vir}}/r_s$ (the virial radius r_{vir} is defined as the radius within which the halo average density is $200\rho_c$). The concentration parameters, c_{NFW97} and $c_{\text{M99}} = 0.64 c_{\text{NFW97}}$, have been computed according to Ref. [16] with the assumption of a CDM power spectrum with a shape parameter $\Gamma = 0.2$ normalized to $\sigma_8 = 0.9$.

In addition to the two profiles mentioned before, we include in our predictions the conservative modified isothermal profile with a constant density core (isocore):

$$\rho_\chi^{\text{iso-core}} = \frac{\rho_s^{\text{iso-core}}}{[1 + (r/r_s^{\text{iso-core}})^2]} \tag{7}$$

and a profile which has been recently proposed by Moore and collaborators (M04) [17]:

$$\rho_\chi^{\text{M04}} = \frac{\rho_s^{\text{M04}}}{(r/r_s^{\text{M04}})^{1.16}(1 + r/r_s^{\text{M04}})^{1.84}}. \tag{8}$$

Figure 1 shows the comparison among the above mentioned profiles for the Milky Way, normalized to a local density of 0.3 GeV cm^{-3} and to $R_\odot = 8.5$ kpc. Two more profiles are shown for comparison on Fig. 1. One is the numerical profile obtained in Ref. [18] when the adiabatic growth of a central black hole is taken into consideration (adiab-NFW). This hypothesis of black-hole formation has been applied here to the NFW97 profile, and the density profile has been normalized as previously mentioned. The resulting profile has a behavior at the galactic center which is similar to the one of the M99 profile, therefore we will not discuss it in more detail. The last profile which is shown in the figure is a cored one recently
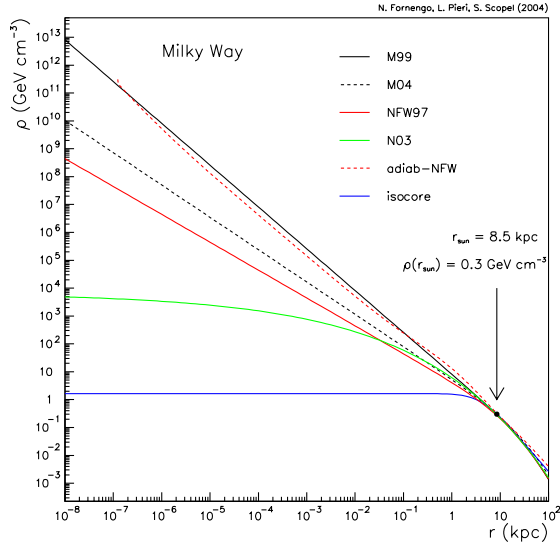
FIG. 1 (color online). Comparison between cuspy and cored dark matter density profiles for the Milky Way, as a function of the distance from the center of the Galaxy. All the curves are normalized to $\rho_0 \equiv \rho(R_\odot) = 0.3 \text{ GeV cm}^{-3}$.

obtained in Ref. [19] (N03):

$$\rho_\chi^{\text{N03}} = \rho_s^{\text{N03}} \exp\left[-\frac{2}{\alpha}\left(\left(\frac{r}{r_s^{\text{N03}}}\right)^\alpha - 1\right)\right] \qquad (9)$$

where $\alpha = 0.17$, $r_s^{\text{N03}} = r_s^{\text{NFW97}}$, and $\rho_s^{\text{N03}} = \rho_s^{\text{NFW97}}/4$. As noticed in Ref. [17], this profile is compatible with the M04 as far as the resolution of the N-body simulation holds. In the inner part of the Galaxy, it is an extrapolation which postulates the existence of a constant density core. Another recently proposed profile which does not exhibit singular behavior, and which has been shown to be able to reproduce to a good precision the rotational velocities of low surface brightness galaxies [20], is given in Ref. [21]. Predictions of gamma-ray fluxes for this profile are given in Ref. [9].

Since profiles shallower than the NFW97 hardly give observable fluxes of photons, we will not discuss it in detail. Studying the cored halos, we will limit ourselves to the isocore profile, which is pretty conservative.

Integrating the squared density along the line of sight introduces divergences when cuspy profiles are considered. Therefore we enforce a cutoff radius r_{cut} to the density profile, with a constant density core therein. The

TABLE I. Masses, distances and virial radii for the Milky Way, the LMC and M31.

Galaxy	mass ($M_\odot$)	distance (kpc)	r_{vir} (kpc)
MW	1.0×10^{12}	8.5	205
LMC	1.4×10^{10}	49	49
M31	2.0×10^{12}	770	258

TABLE II. Scale radii and scale densities for the NFW97, M99, M04, and isocore density profiles calculated for the Milky Way.

Profile	scale radius r_s (kpc)	scale density ρ_s ($M_\odot \text{kpc}^{-3}$)
NFW97	21.746	5.376×10^6
M99	34.52	1.060×10^6
M04	32.625	2.541×10^6
isocore	4	7.898×10^6

smallest value for the cutoff radius which we will use is $r_{\text{cut}} = 10^{-8}$ kpc, a value we will discuss in the next section, where the effect of varying r_{cut}, both for our Galaxy and for the external ones, will be discussed.

The analysis of Ref. [11] shows that a number of external galaxies shine above the galactic foreground. In the following we will focus on the two most prominent galaxies at large angles with respect to the galactic center, namely, the Large Magellanic Cloud (LMC) and the Andromeda Galaxy (M31) [11]. Table I shows the astrophysical parameters for the Milky Way, the LMC, and M31, while Tables II, III, and IV show the scale radius and the scale density parameters used in our calculations.

1. Comment on the experimental constraints on the inner part of galaxies

As we have seen, theoretical estimates of the inner slope α of the DM density profile $\rho(r) \propto r^{-\alpha}$ are still uncertain. Moreover, observations which should constrain the α parameter do not give clear and definitive answers on its value. A number of works give in fact non-unique values for the slope.

In Ref. [22] spatially resolved spectra of the diffuse hot (x rays) gas of galaxies and clusters measured with the Chandra satellite were used to infer the radial mass distribution of the considered systems. An analysis was done on two clusters which are relaxed in their cores on $O(10^2 \text{ kpc})$ to $O(\text{Mpc})$ scales and do not have strong radio sources in their center. Resulting values for α are 1.25 and 1.35. A value of α less than 1 is found when disturbed x-ray surface brightness clusters are used. Yet the x-ray method uses the double assumption of a single phase gas in hydrostatic equilibrium, which for instance is questionable in the central regions where rapid cooling occurs.

TABLE III. Scale radii and scale densities for the NFW97, M99, M04, and isocore density profiles calculated for the LMC.

Profile	scale radius r_s (kpc)	scale density ρ_s ($M_\odot \text{kpc}^{-3}$)
NFW97	4.353	8.50×10^6
M99	6.8	1.80×10^6
M04	6.426	3.22×10^6
isocore	1.5	2.17×10^7

TABLE IV. Scale radii and scale densities for the NFW97, M99, M04, and isocore density profiles calculated for M31.

Profile	scale radius r_s (kpc)	scale density ρ_s ($M_\odot \text{kpc}^{-3}$)
NFW97	30.271	4.20×10^6
M99	47.298	0.86×10^6
M04	44.697	1.55×10^6
isocore	4	7.898×10^6

Other studies of radial mass profiles inferred by the radial profile of the intracluster medium density and temperature measured with Chandra can be found in Ref. [23] where the analysis of five clusters gives $1 < \alpha < 2$.

Different results are found by Ref. [24] using low surface brightness (LSB) galaxies' rotation curves. Fits to their measured curves give a mean value $\langle \alpha \rangle = 0.2$, although tails in the distribution extend further, up to $\alpha = 2$. In Ref. [25] a combination of strong-lensing data and spectroscopic measurements of stellar dynamics of the brightest cluster galaxies was used to derive values of α. Three clusters, containing both radial and tangential arcs, have been found. The obtained distribution gives $\langle \alpha \rangle = 0.52$ with $\Delta \alpha = 0.3$.

In Ref. [26] the full radial extent of LSB galaxies' rotation curves, instead of their inner portions, was used to determine the inner slope of the DM density profile. Convergence criteria for the N-body simulations taken from Ref. [27] give a minimum radius for which simulations are reliable, $r_{\text{conv}} = 1h^{-1}$ kpc. It is shown that, at that radius, 2/3 of the sample in Ref. [24] is consistent with a profile which lies between the simulated NFW97 and M99 ones. There are inconsistencies with CDM predictions in those galaxies which show a sharp transition between the rising and flat part of the rotation curve. This is due to the fact that rotation curves of gas disks are compared with the spherically-averaged circular velocity profiles of DM halos. This assumption may not be correct in non-regular galaxies.

Another study of high resolution H_α rotation curves for dwarf and LSB galaxies has been recently carried out in Ref. [28]. In that work it is shown that rotation curve data are insufficient to rule out halos with $\alpha = 1$, although none of the galaxies require an inner cuspy profile instead of a core density feature. Results on α range from 0 to 1.2, although the quality of the fit is good only up to $\alpha = 1$. Other analyses on large sets of data of high-resolution rotation curves also show consistency with cored mass distributions [29].

An indirect estimate of α can be inferred through the weak gravitational lensing measurements of x-ray luminous clusters [30]: one finds $0.9 < \alpha < 1.6$.

The analysis of the microlensing optical depth toward the galactic center was performed in Ref. [31]. Assuming a naïve spherically symmetric profile normalized to our

position in the Milky Way, the authors find $\alpha = 0.4$. They argue that the value $\alpha = 1$ can be reached by considering a flattened halo with a ratio of polar to equatorial axis of 0.7.

2. Comment on the unknown effect of baryons on the inner part of galaxies

Dark matter density profiles obtained in N-body simulations do not always take into account the effect that baryons can have in the formation or disruption of the central cusp.

The numerical adiab-NFW profile shown in Fig. 1, for instance, takes into account the effect of the adiabatic growth of a central black hole, which pulls in DM and enhances the spike of an initial NFW97 profile. Spikes in the center of the DM halo could in principle be created either by the growth of a black hole [32] or by the dissipation of the baryons which steepens the radial profile in the inner regions of the DM halo [33,34]. In Ref. [33] a high-resolution cosmological simulation which includes the effects of baryons cooling, gas dynamics, and star formation has been performed. The results show that, by starting from an NFW97 profile, the inner slope could sizably increase and reach the value of $\alpha \sim 1.6$ at $r \lesssim 0.1 r_{\text{vir}}$. Following the same line, the authors of Ref. [34] find that the effect of baryon cooling on an NFW97 initial profile could lead to an enhancement of the expected γ-ray flux from the galactic center of more than 3 orders of magnitude.

It is worth noticing, however, that if the central supermassive black hole (SBH) is formed by the merging of halos hosting SBHs, the subsequent formation of an SBH binary would lead to a depletion of the central spike, because DM particles would be given enough energy to be thrown out of the system. The final slope would then result in a shallower profile with $\alpha \sim 0.5$ [35]. Also, as shown in Refs. [36,37], the central spike due to the presence of a black hole could be dissolved by the interaction of DM with the population of stars, due both to the kinetic heating of the DM by stars, and to the DM capture by the SBH, as an effect of scattering into an eccentric orbit around the SBH. The authors of Refs. [36] find that this effect results in a depletion of the expected γ-ray flux of even up to 6 orders of magnitude, depending on the initial slope of the spiky profile.

All these effects stress the uncertainty in the astrophysical/cosmological modeling of the problem, and show how much attention must be paid when comparing predictions to data.

B. Including the effect of the inner core

There exists a physical minimal radius, r_{cut}, within which the self-annihilation rate $t_l \sim [\langle \sigma_{\text{ann}} v \rangle n_\chi (r_{\text{cut}})]^{-1}$ equals the dynamical time $t_{\text{dyn}} \sim (G\bar{\rho})^{-1/2}$ [38], where $\bar{\rho}$ is the mean halo density and n_χ is the neutralino number

density. When this procedure is applied to the density profiles we are using, the evaluated r_{cut} are of the order of 10^{-8} to 10^{-9} kpc for the M99 profile and of 10^{-13} to 10^{-14} kpc for an NFW97. Another estimation of the minimum physical radius can be inferred by taking into account the effect of baryons. The presence of a central black hole would reduce the central density of DM particles, which are lost inside a radius of the order of about 3×10^{-10} kpc for the Milky Way and 3×10^{-7} kpc for M87. Moreover, it has been shown [36] that scattering of DM particles into the black hole by stars could imply a vanishing DM density below a radius of the order of a few $\times 10^{-9}$ kpc.

Evaluating the constant core is indeed a much more complicated issue. Taking into account additional effects, especially tidal interactions, the central core of galaxies can significantly exceed the values quoted above, reaching values as large as $\mathcal{O}(0.1 - 1)$ kpc [39]. We want to remind that also numerical simulations, from which the cuspy behavior is deduced for the inner parts by means of extrapolation, are actually testing the halo shape down to $\mathcal{O}(0.1)$ kpc [17,19].

In our analysis we will take into account this large uncertainty in the inner core radius by varying r_{cut} in the range $[10^{-8}, 10^{-1}]$ kpc.

C. Results for Φ^{cosmo}

The results of the calculations of the cosmological factor Φ^{cosmo} for the Milky Way are shown in Fig. 2, for the four main profiles previously discussed and for a detector with angular resolution equal to 1° and 0.1°. A constant-density central region of radius $r_{cut} = 10^{-8}$ kpc has been used for the cuspy profiles. Since the value of r_{cut} used in Fig. 2 somehow represents a lower bound on the acceptable values of this parameter, the values of Φ^{cosmo} shown in Fig. 2 can be taken as an upper bound on the cosmological factor, for any given halo profile and for the two representative acceptance angles. Clearly the non-cuspy profiles are not affected by the choice of r_{cut}.

In the same figure, the values of Φ^{cosmo} for LMC and M31 are also shown. We see that these external galaxies can be resolved against the galactic signal in all cases, except for the case of LMC with an isocore density profile. These two external galaxies can therefore be looked at as gamma-ray sources from DM annihilation (provided that the ensuing gamma-ray flux can be detected against the gamma-ray background). If a gamma-ray signal were detected, for instance from the galactic center, it should be correlated to a corresponding signal both from LMC and from M31. Since the supersymmetric factor is the same for all the sources, the relative strength of the gamma-ray fluxes from the galactic center, LMC, and M31, could then be used to deduce information on the halo shape, since it depends only on the DM density profile. However, this possibility is strongly limited by

the fact that Φ^{cosmo} for LMC and M31 is much smaller than the one from the galactic center, as is clear from Fig. 2. The ensuing fluxes from external galaxies will therefore be much smaller than the ones from the galactic center.

The dependence of the cosmological factor on the cut-off radius of the inner core is shown in Fig. 3 for the Milky Way and in Fig. 4 for LMC and M31. In these figures we plot the ratio $\Phi^{cosmo}(\text{profile}, r_{cut}, \psi)/$
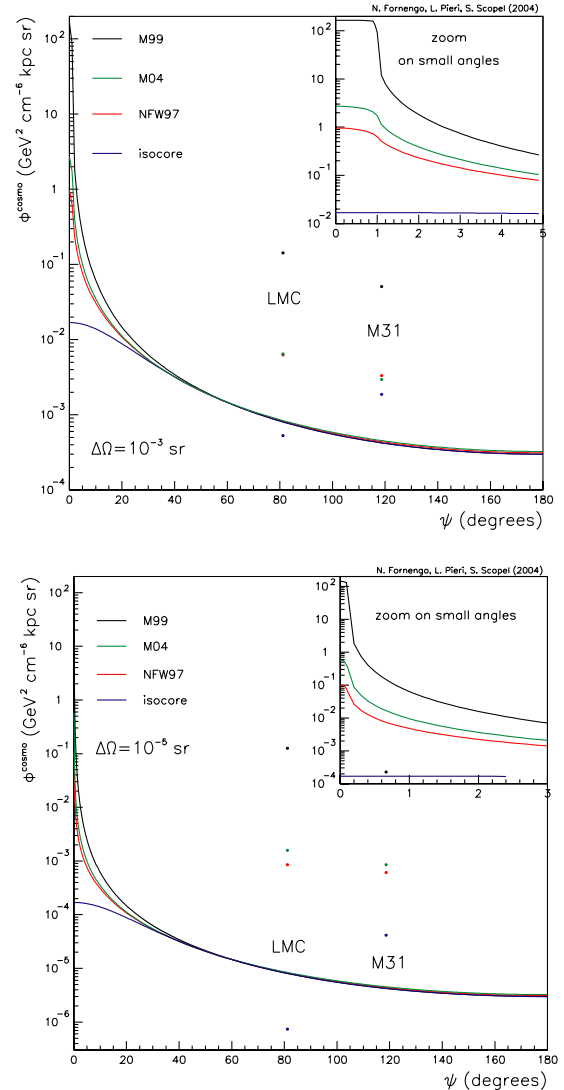

FIG. 2 (color online). The lines denote the cosmological factor Φ^{cosmo} for the Milky Way, calculated for different dark matter profiles, for a solid angle $\Delta\Omega = 10^{-3}$ sr (upper panel) and $\Delta\Omega = 10^{-5}$ sr (lower panel). The insets show a zoom at small angles toward the galactic center. A constant-density central region of radius $r_{cut} = 10^{-8}$ kpc has been used for the cuspy profiles. The points at $\psi \simeq 81°$ and $\psi \simeq 119°$ denote the values of Φ^{cosmo} for LMC and M31, respectively. From top to bottom the points refer to different halo profiles: Moore, NFW97, M04, and isocore in the upper panel; Moore, M04, NFW97, and isocore in the lower panel.
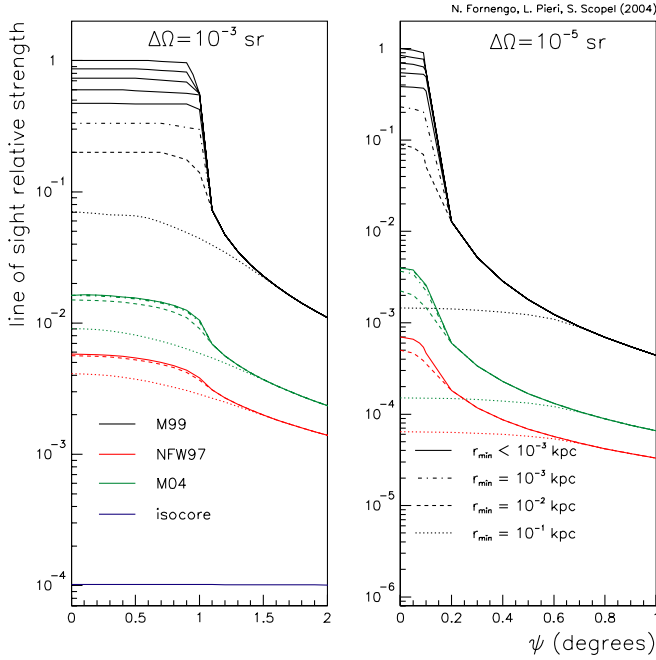
FIG. 3 (color online). Relative strength of the line-of-sight integral with respect to different halo profiles and different inner core radii for the Milky Way. Numbers are normalized to the highest value of the Φ^{cosmo} given by an M99 profile with a physical cutoff radius of 10^{-8} kpc and at $\psi = 0$. Left panel: solid angle $\Delta\Omega = 10^{-3}$ sr. Right panel: solid angle $\Delta\Omega = 10^{-5}$ sr.
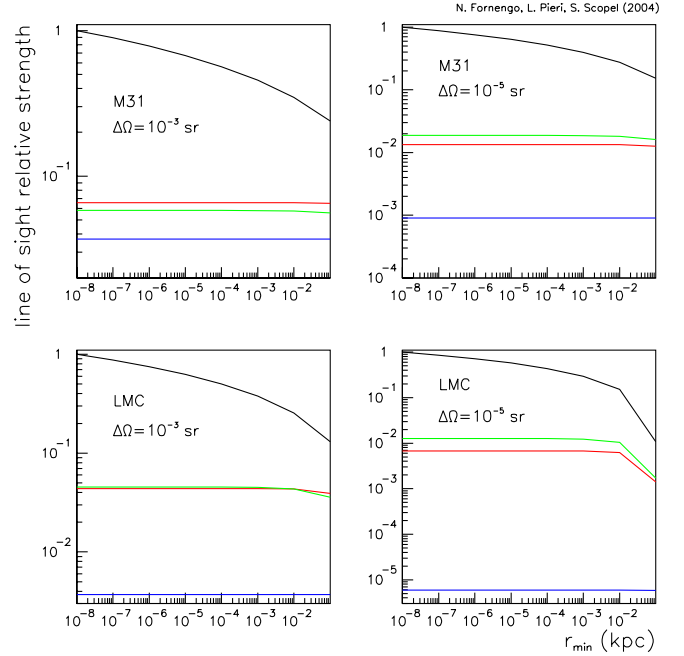

FIG. 4 (color online). Relative strength of the line-of-sight integral with respect to different halo profiles and different inner core radii for M31 (upper panels) and the LMC (lower panels). Numbers are normalized to the highest value of the Φ^{cosmo} given by an M99 profile with a physical cutoff radius of 10^{-8} kpc and at $\psi = 0$. Left panels: solid angle $\Delta\Omega = 10^{-3}$ sr. Right panels: solid angle $\Delta\Omega = 10^{-5}$ sr.

Φ^{cosmo}(M99, $r_{\mathrm{cut}} = 10^{-8}$ kpc, $\psi = 0$) for the M99, NFW97, M04, and isocore profiles and for r_{cut} in the range discussed above . As expected, a cored distribution or a less cuspy profile than the M99 decreases the cosmological factor by a significant amount with respect to the most optimistic hypotheses of an M99 profile with an inner core radius $r_{\mathrm{cut}} = 10^{-8}$ kpc. Figures 3 and 4 quantify this effect.

In the case of the Milky Way, the reduction factor at the galactic center can be sizable: for instance, when an NFW97 profile with $r_{\mathrm{cut}} = 0.1$ kpc is used, the reduction is of the order of 4×10^{-3} for a solid angle of observation $\Delta\Omega = 10^{-3}$ sr and 6×10^{-5} for $\Delta\Omega = 10^{-5}$ sr. In the case of the isocored distribution the reduction factor is as large as 10^{-4} for $\Delta\Omega = 10^{-3}$ and 10^{-6} for $\Delta\Omega = 10^{-5}$.

The same trend is observed for the external galaxies which we have considered, although the net effect is less prominent. In the case of M31, the reduction is at most a few $\times 10^{-2}$ for $\Delta\Omega = 10^{-3}$ and it can reach 10^{-3} for $\Delta\Omega = 10^{-5}$ and the isocore profile. For LMC, the reduction is again of the order of 10^{-2} to 10^{-3}, except for the isocore profile and $\Delta\Omega = 10^{-5}$, for which it reaches values of the order of 10^{-5}.

In the following, for definiteness we will refer to the most optimistic values of Φ^{cosmo} shown in Fig. 2, obtained for an M99 profile with a cutoff radius of 10^{-8} kpc and to an NFW97 shape, with the same cutoff radius.

Results for different halo profiles or core parameters can be easily obtained by scaling the results according to Figs. 3 and 4.

D. Including substructures

In the CDM scenario, subhalos that accrete into larger systems are tidally stripped of a fraction of their mass, originating debris streams [40]. Their dense central cores, however, survive the merging event and continue to orbit within the parent halo. High resolution N-body simulations [15,41] have indeed shown that DM halos host a population of subhalos with a distribution function depending on the subhalo mass and on the distance of the subhalo from the halo center [42].

The effect of including subhalos in the Milky Way and in the galaxies of the local group has been discussed in Refs. [11,43–45], where different parameters for the subhalo distribution, along with the existence of mass stripping and tidal heating, have been considered, and a minimum mass of $10^6 M_\odot$ was assumed for the subhalos. The existence of such a subhalo population leads to average boost factors for expected rates which depend on the modeling of the subhalo distribution and on the density profile, and can range from few unities to more than 10^4. In no case, however, is the field of view toward the galactic center affected, since in that region the gravita-