Expanding the Probe in Self-interactions Dark Matter

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Abstract

We aim to expand current probes on Self-Interacting Dark Matter (SIDM) models. For this, we estimate the expected signal on the Super-Kamiokande (SK) telescope expanding current limits to lower dark matter masses. Our results were derived by comparing our estimated number of upward muon events in the detector with those of the SK collaboration. Given the self-interaction of dark matter, the number of neutrinos from the Sun will be greater than for CDM without collisions. We analyzed the neutrinos from the annihilation channels in W^+W^- and $b\bar{b}$. The signal obtained in this analysis is consistent with the background of atmospheric muons, therefore, no significant excess of ascending muons induced by neutrinos from the Sun was found. Thus, our results excluded a significant region of SIDM models. The channels of annihilation considered, include more energetic neutrinos coming from the channel W^+W^- and less energetic of the channel $b\bar{b}$. Given the low energy threshold of SK, when compared to the IceCube telescope, we obtained more stringent results for the channel $b\bar{b}$. This is due to the fact that SK energy threshold is lower than IceCube's.

It is known that dark matter whose nature is not yet revealed, interacts gravitationally with known matter and does not present electromagnetic interaction, therefore, it does not emit light. We know of its presence through cosmological measurements such as rotation curves, among other.

Motivation:

We tested SIDM because it could solve cosmological problems on small scales like "Cusp-Core Problem", "Missing Satellites Problem" and "Too Big To Fail Problem".

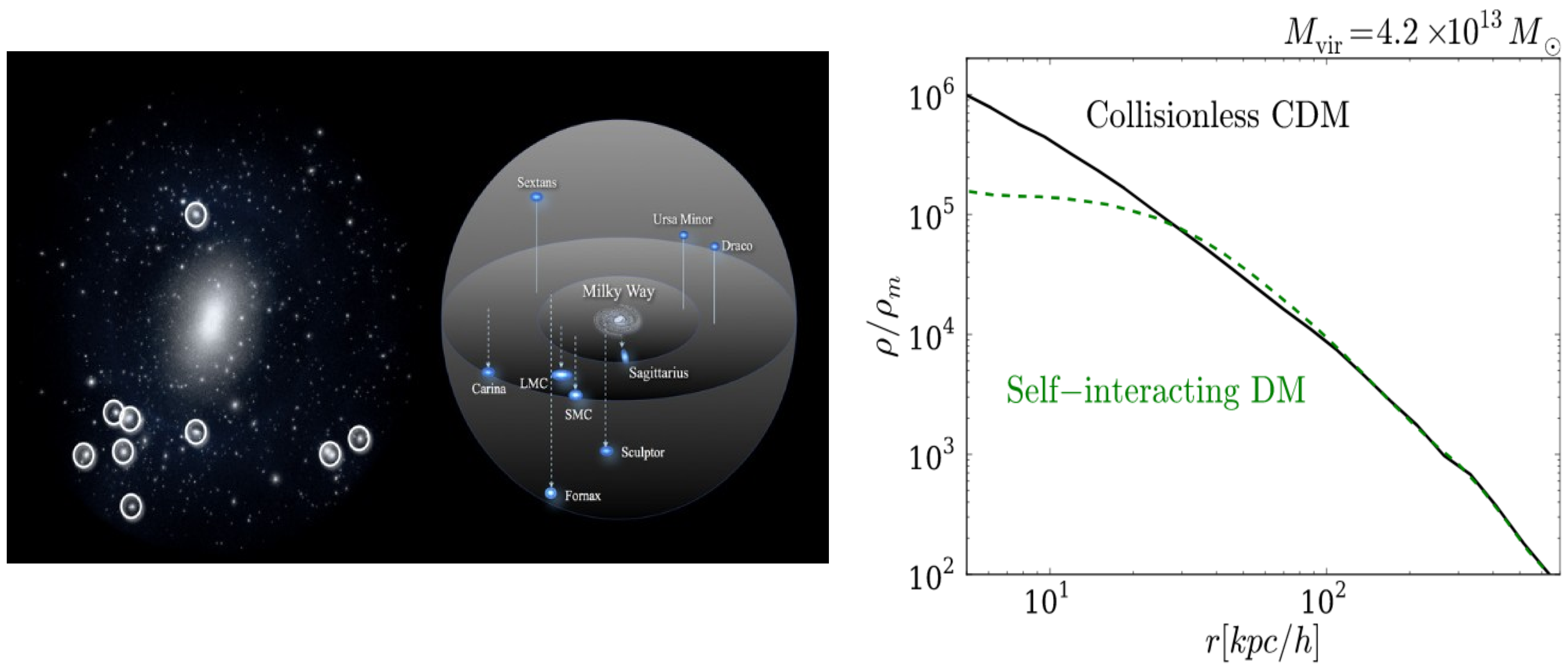

Figure 1. Left. Simulated CDM halo with 10^{12} M. In circles, the nine most massive subhalos of the Milky Way. Right. Comparison of the density profiles of a halo in CDM and SIDM.

SIDM effects on indirect detection:

- It increases the capture rate of DM particles in the Sun.

- It increases the annihilation rate of DM particles in the Sun.

- It accelerates the equilibrium between the capture and annihilation processes.

- It leads to an improvement in the detected neutrino signal.

Our results:

We calculate the temporal evolution of the number of DM particles captured. The three terms on the right are the capture rates with and without self-interactions and the annihilation rate.

$$\frac{dN_\chi(t)}{dt} = \Gamma_c + C_s N_\chi(t) - 2\Gamma_a. \tag{1}$$

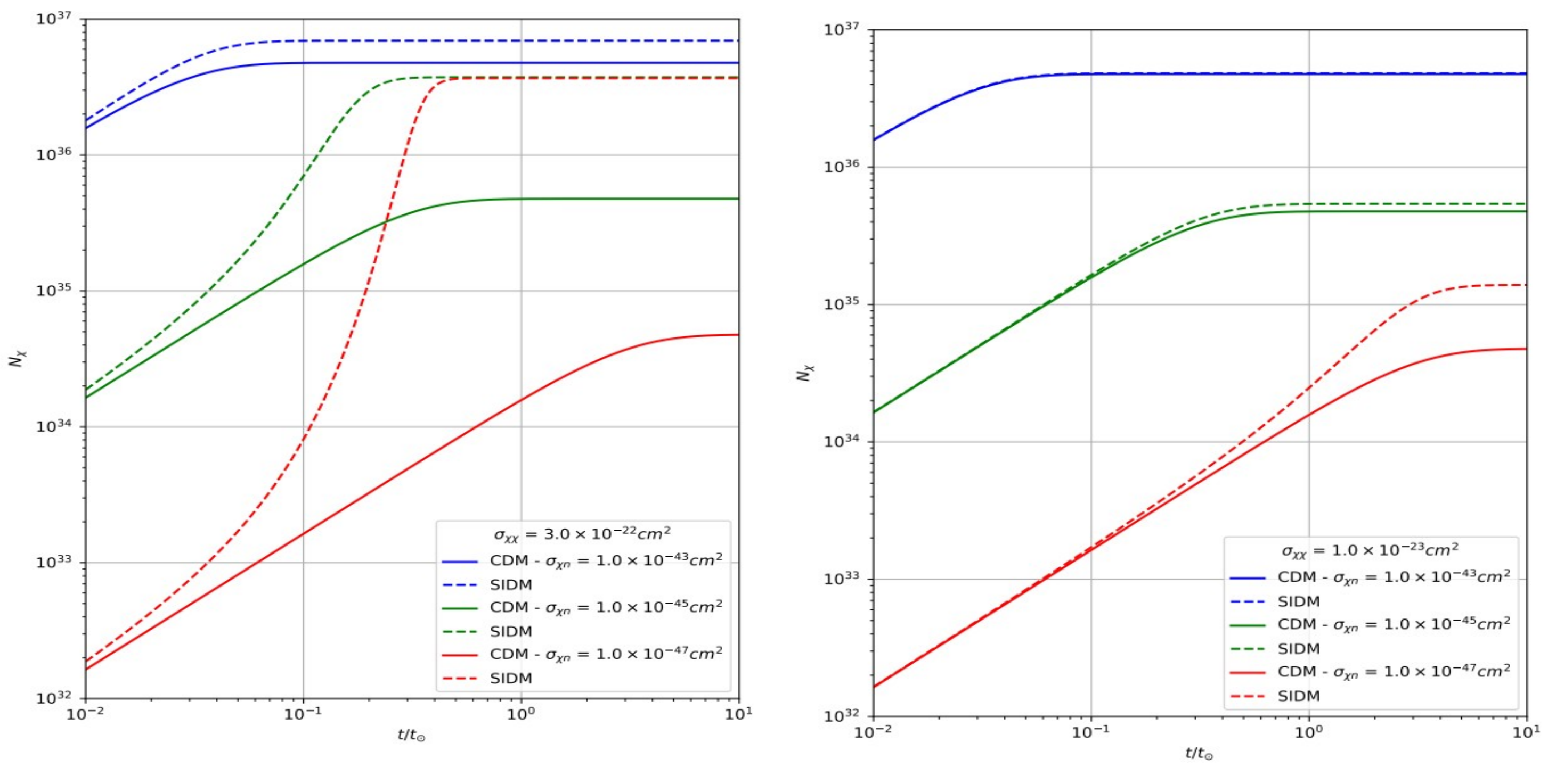

Figure 2. Temporal evolution of the number of DM particles captured in the Sun. The continuous curves are obtained without considering the capture rate due to self-interactions, the discontinuous curves if they consider this term. The graphs are for different values of the cross-section of self-interaction [1].

$$N_\mu = \Gamma_a t_{exp} \int_{E_{thr}}^{E} \frac{d\phi_\mu}{dE_\mu} A_{eff}(\theta)\, dE \tag{2}$$

The number of muons estimated on the detector SK, dependent on: the annihilation rate, the data collection time (3109.6 days for SKI-III), the flux of upward muons into the detector, the threshold energy and the effective area of the detector, being theta zenith angle.

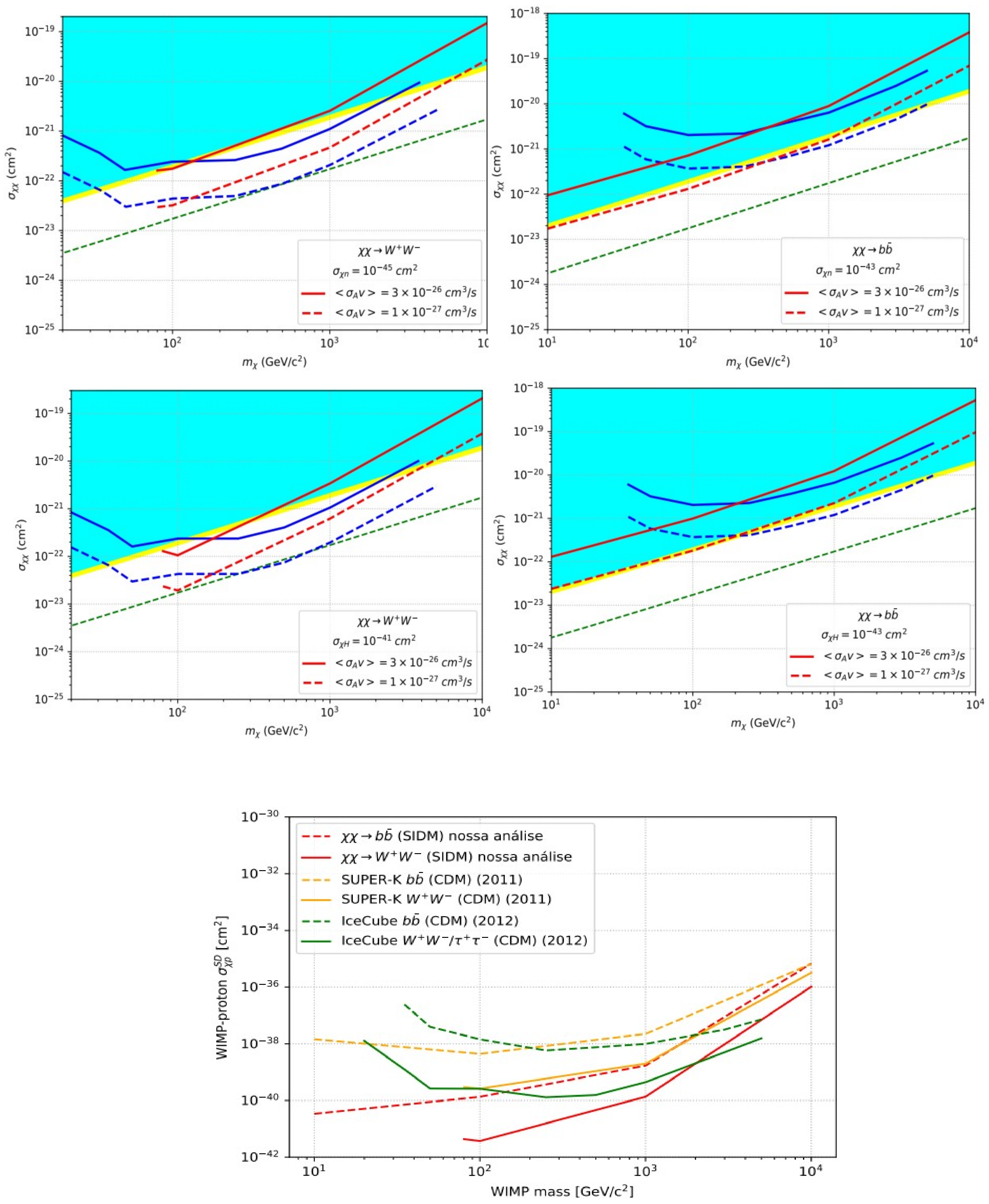

Figure 3. (First four graphics) $\sigma_{\chi\chi}$ as a function of m χ annihilating in $b\bar{b}$ and $W^+ W^-$ [1]. Our result (red curve) excludes, at 90% C.L., SIDM models with $\sigma_{\chi\chi}/m_\chi$ in the regions above the curves. The results of other analyzes are shown by comparison. Above the blue curves, te region is excluded at 90% C.L by the analysis made to the IceCube results considering SIDM. The region between and above the yellow band is excluded by halo density profiles and halo shapes. The light blue colored region is excluded by the analysis of the Bullet Cluster. The region under the green line is where SIDM is not effective for resolving CDM tensions on small scales, according to the analysis of dwarf spheroidals. Bottom. Upper limit at 90% C.L. for $\sigma_{\chi p}$ SD [2].

CONCLUSIONS

1) We simulate SIDM, being captured in the Sun and annihilating itself in the nucleus. We determine and compare the estimated number of muon events with the upper limit of SK Collaboration Events.
2) We exclude 90% C.L. several SIDM models, considered as potential solutions to CDM problems on small scales.
3) We established the new interval, $\sim 0.7 cm^2/g \leq \sigma_{\chi\chi}/m_\chi \leq 1.0 cm^2/g$, for the $\sigma_{\chi\chi} / m_\chi$ ratio if the DM annihilates in W^+W^- with $<\sigma_a V> = 3 \times 10^{-27} cm^3/s$.
4) We established the strictest upper limit of exclusion, at 90% CL, in $\sigma_{\chi p}$, for $m_\chi = 100$ GeV/c^2, with 1.3×10^{-40} cm^2 in $b\bar{b}$ and 3.7×10^{-42} cm2 in $W^+ W^-$.

[1] https://www.teses.usp.br/teses/disponiveis/43/43134/tde-28052020-134852/en.php

[2] Paper in Preparation