Neutrinos from the Sun can discover dark matter-electron scattering

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Motivation

- Around 85% of the matter content of the Universe is made up of dark matter (DM). Various astrophysical and cosmological observations support the existence of DM.
- All the evidences point towards the gravitational nature of DM. The non-gravitational nature of DM is still unknown. The well-motivated candidates span a mass range of $\sim 10^{-22}$ eV to $\sim 10^{3}$ $M_\odot$.
- We study the elastic scattering of DM particles with Standard Model (SM) particles (such as electrons).

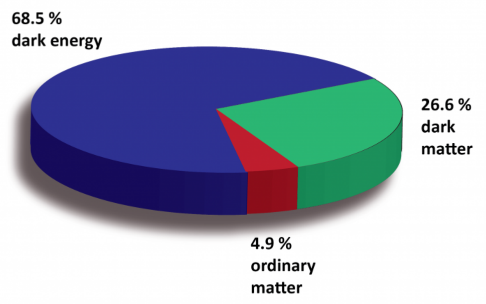
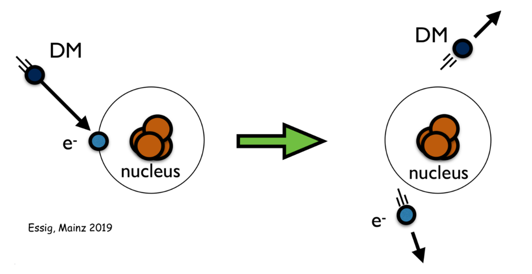


Fig. credit: NIST

Status of Dark Matter-Electron Scattering



- The DM-electron scattering has been investigated in several "Direct Detection" experiments such as, XENON1T, SENSEI, PandaX. These experiments are most sensitive for DM masses ~ 10 MeV to ~ 200 MeV.
- As we increase the DM mass, the number of DM particles going through the detector drops. So for all the terrestrial direct detection experiments the sensitivities decrease linearly for heavy DM masses.
- Xenon1T experiment has an exposure of $\sim$ **22 tonne-day**. For the Sun, this number is $\sim$ **10^{27} tonne-Gyr**.

CAN WE USE THE SUN AS A DM DETECTOR ?!

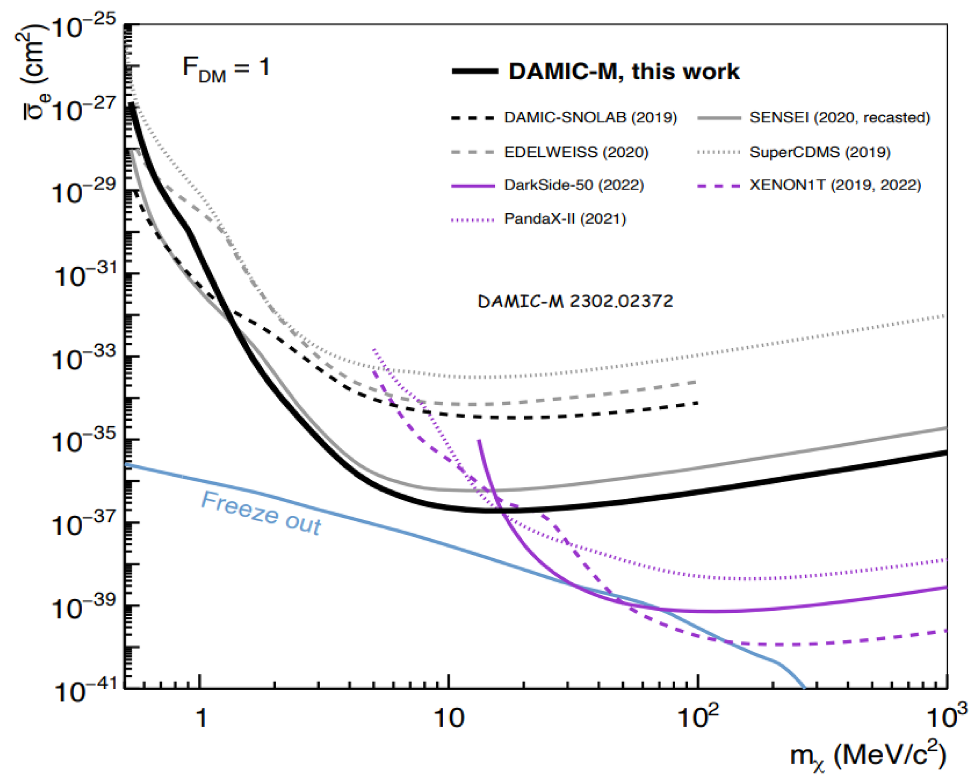


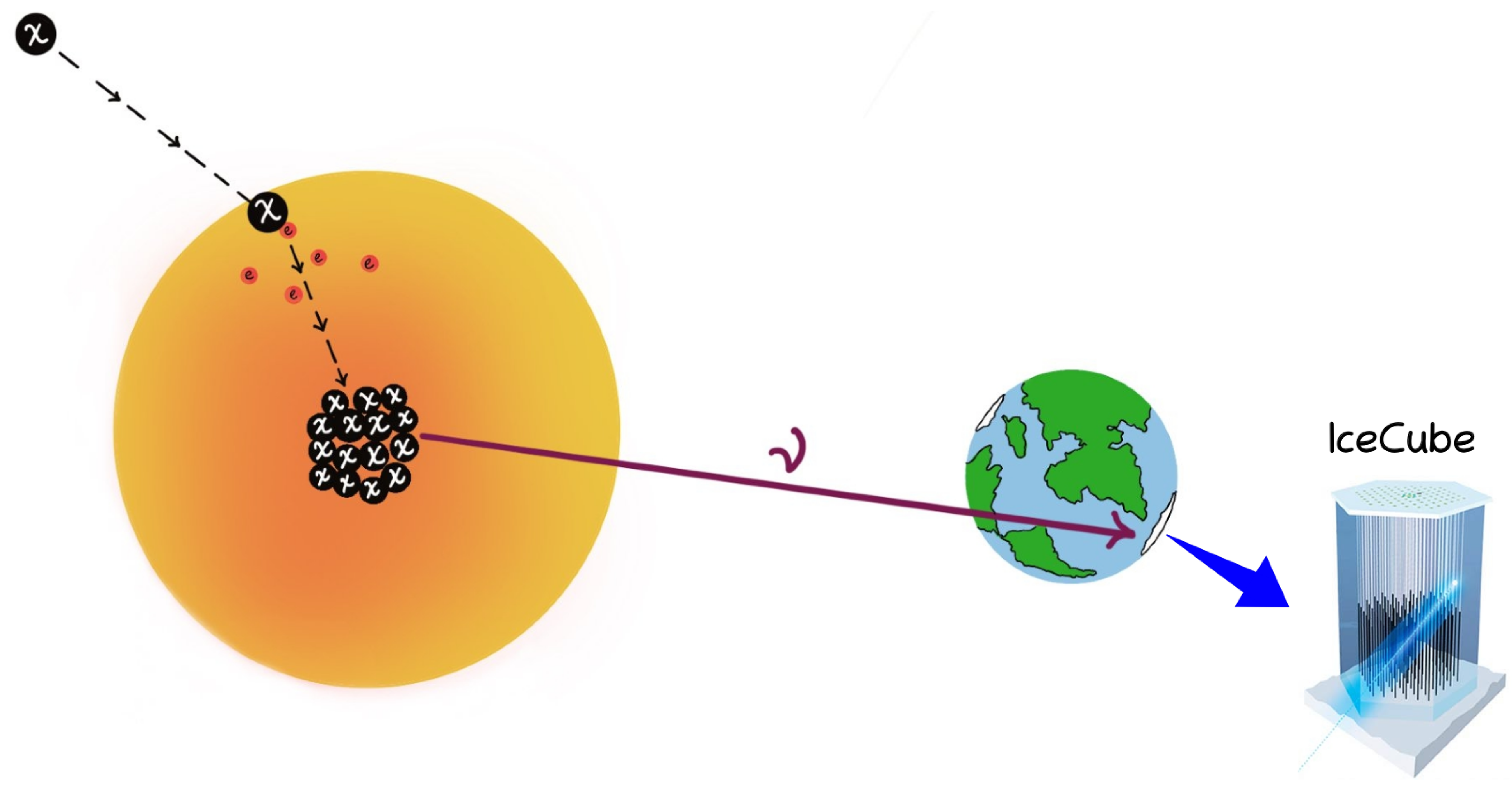
Fig. : 2302.02372

Dark Matter Capture in the Sun

$$C_\odot = \int_0^{R_\odot} 4\pi r^2 n_e(r)dr \int_0^{\infty} du_\chi \left(\frac{\rho_\chi}{m_\chi}\right) \frac{f_{v_\odot}(u_\chi)}{u_\chi}(u_\chi^2 + v_e^2(r))g(w)\sigma_e$$

Capture rate of DM inside the Sun — Total number of Solar electrons — Incident DM flux — Capture probability

- DM particles in our Galactic halo can scatter with Solar electrons. If after one scattering (true in weak cross section limit), the DM velocity becomes less than the Solar escape velocity, they will get gravitationally captured inside the Sun.
- The captured DM particles undergo further scattering with the Solar electrons and eventually thermalize inside the Sun.
- The capture rate of the DM particles depend on the DM mass, the DM-electron scattering cross-section, local DM density, the Solar electron density, and the velocity distribution of DM.



https://skyandtelescope.org/wp-content/uploads/IceCube-

Dark Matter Annihilation in the Sun

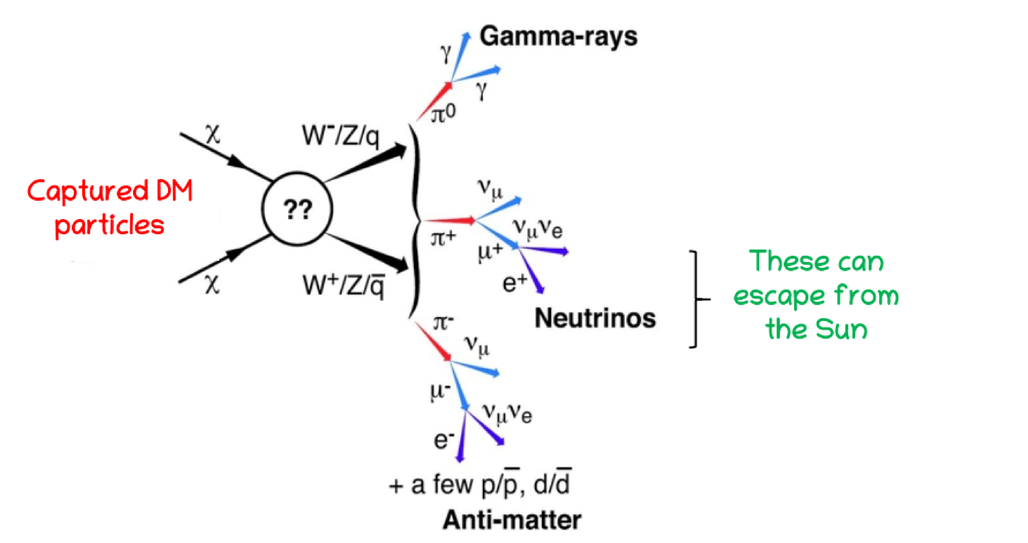
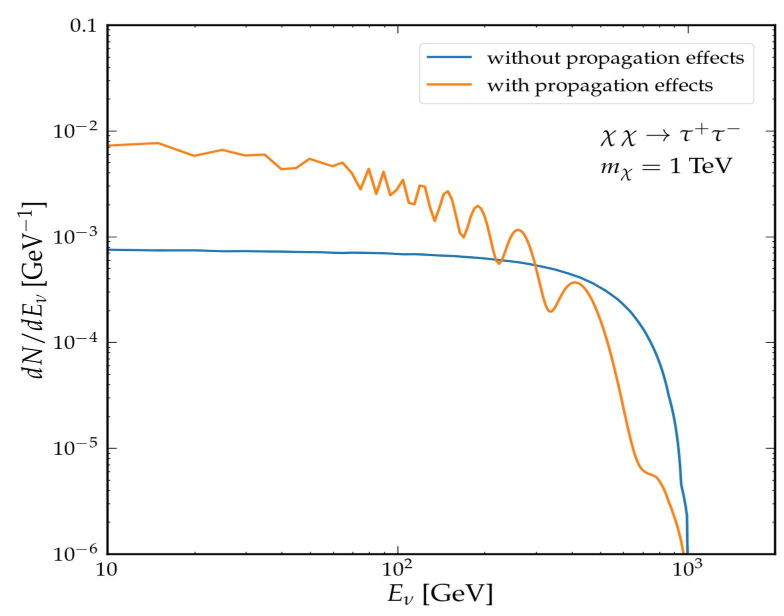


Fig: https://fermi.gsfc.nasa.gov/science/eteu/dm/

- DM particles captured inurrently running neutrino telescopes like side the Sun can annihilate to produce SM particles. Of all these SM final states, only neutrinos and anti-neutrinos can escape from the Sun and reach the ground-based neutrino telescopes. For obtaining the neutrino spectra from DM annihilation inside Solar medium, we have used publicly available code χaroν (arXiv: 2007.15010).
- For the Sun, one can show that the capture rate and annihilation rate of DM particles are in equilibrium, i. e., annihilation rate = capture rate/2, for the parameters of interest in our work.
- We have also taken into account the propagation effects (neutrino trapping, tau regeneration, and neutrino oscillation) for the final state neutrinos from the Solar core till the terrestrial neutrino detector. For this we have used publicly available code nuSQuIDS (arXiv:2112.13804).



The IceCube Neutrino Detector

- IceCube is a gigaton effective volume neutrino detector at South Pole. It has 5160 Digital Optical Modules distributed over 86 strings. The innermost 8 strings constitutes DeepCore.
- Neutrinos can interact in ice to produce corresponding charged leptons. These charged leptons can produce Cherenkov light which then can then be detected by IceCube and DeepCore.

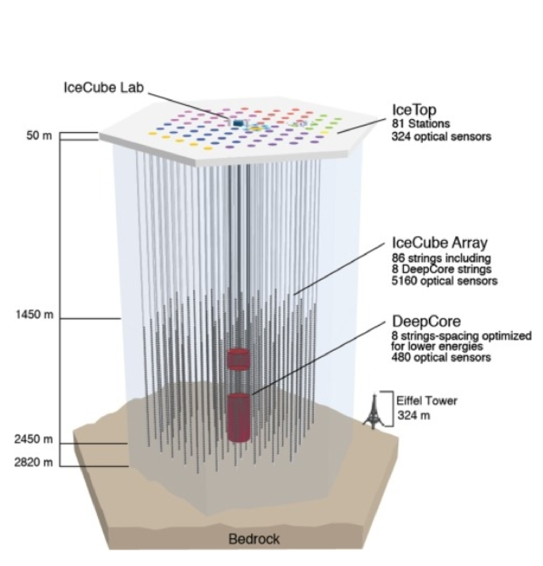
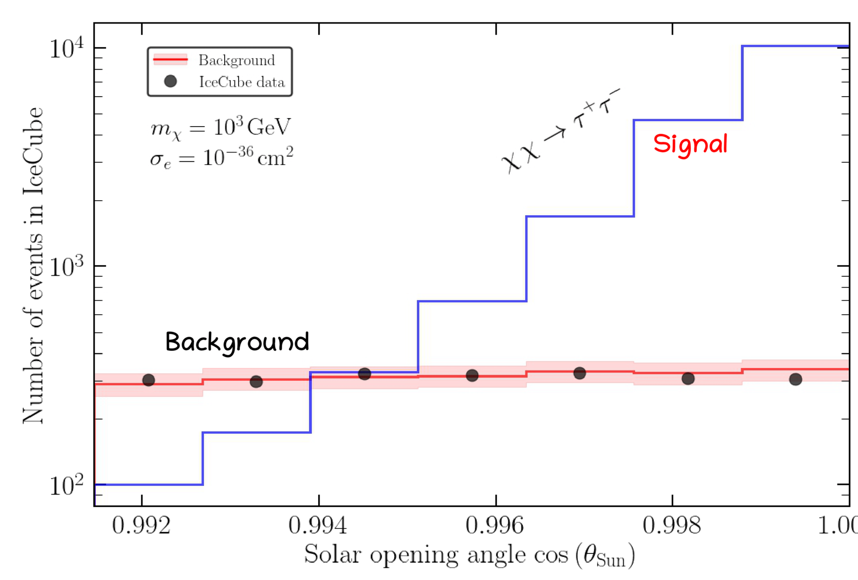


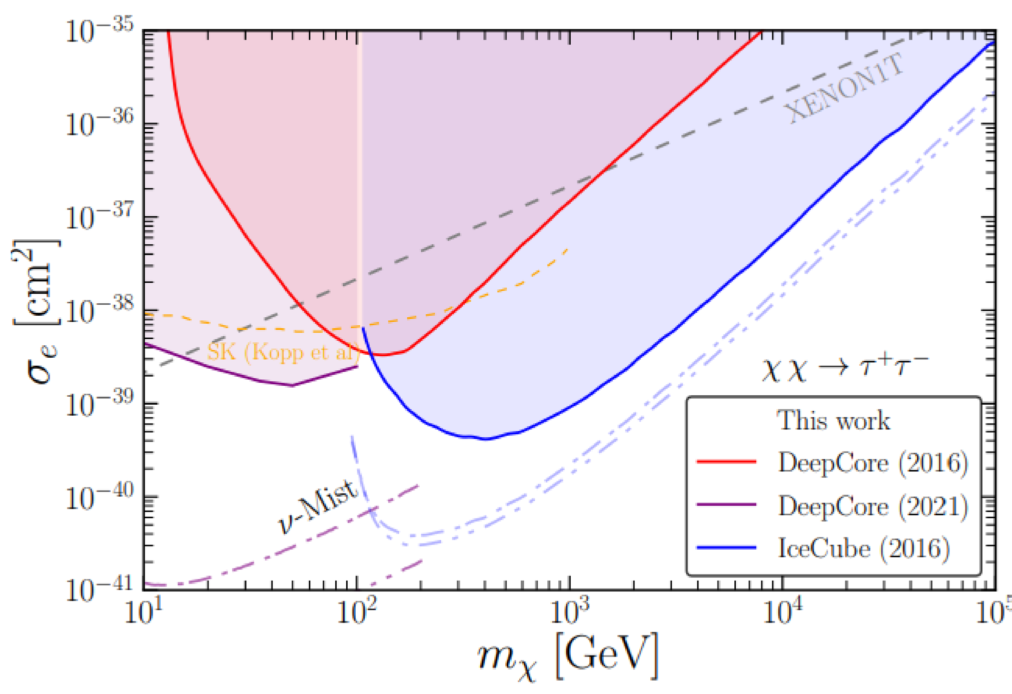
Fig. credit: IceCube Collaboration

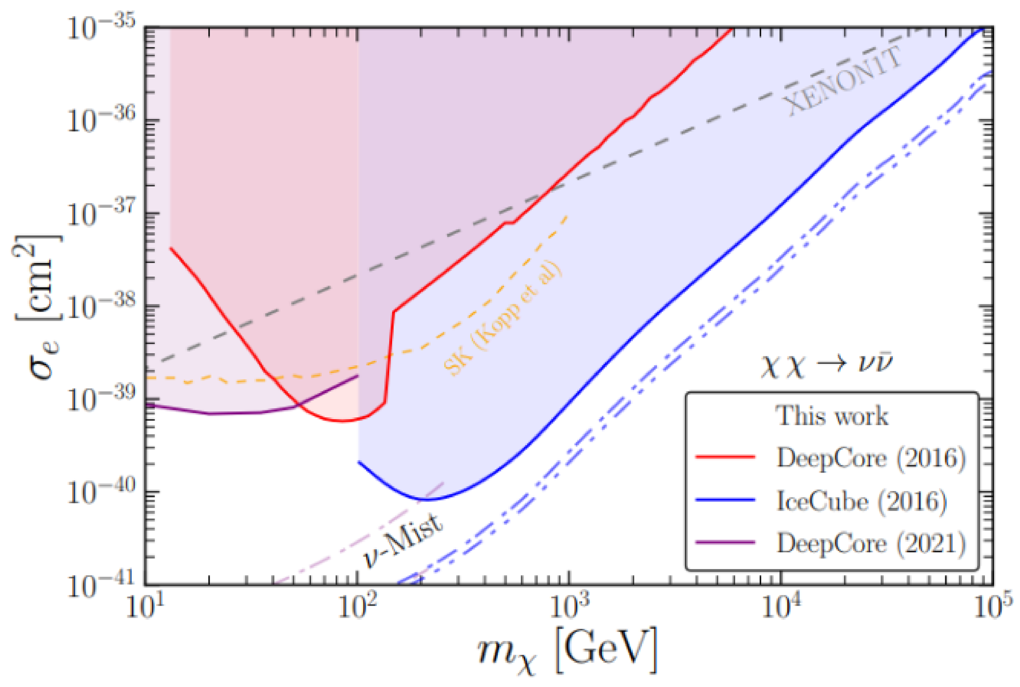
High-Energy Neutrino Signals at IceCube

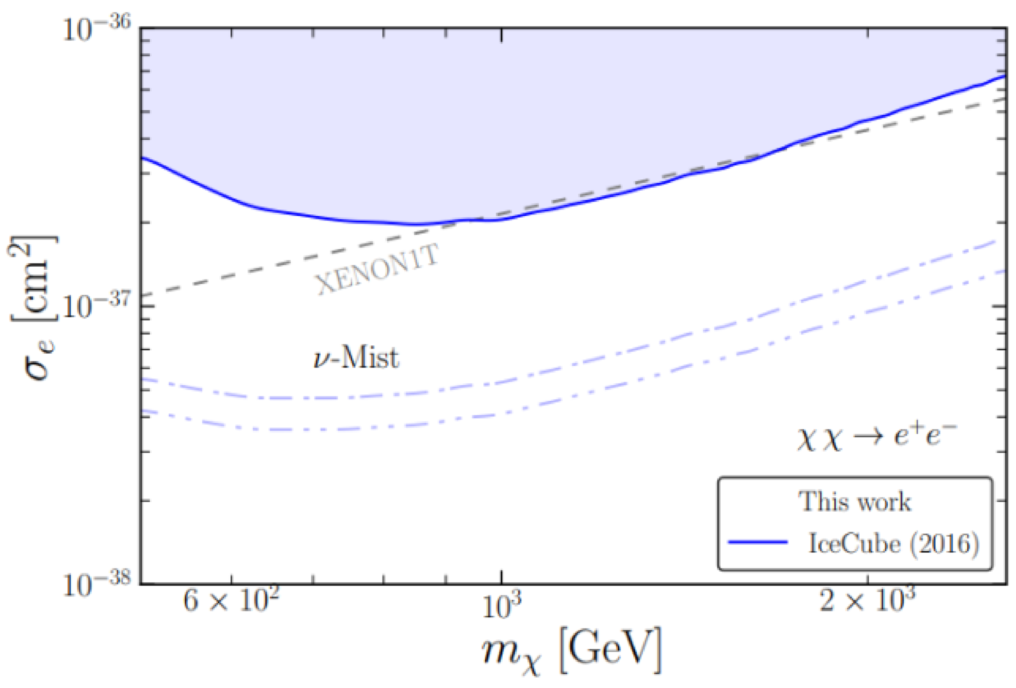
- We use the existing IceCube [2] and DeepCore [2][3] datasets to calculate the corresponding event rate resulting due to new physics.
- In the right figure, the Solar opening angle θ_{Sun}, is the angle between the direction of the muon tracks produced due to muon neutrino interactions in IceCube and the Sun. We do not find any excess in the dataset.
- Using this, we put constraints on DM-electron scattering cross-section for a wide range of DM masses. In most cases, our method is probing new regions of the parameter space.



Our Results







Conclusions and Future Prospects

- In our work, we use the Sun as a target to probe DM-electron scattering cross-section. Using existing results from the IceCube and DeepCore neutrino telescopes, we derive the most stringent bounds on the DM-electron scattering cross-sections for different DM annihilation final states.
- Besides IceCube and DeepCore, upcoming telescopes like KM3NeT, IceCube-Gen2 can improve upon the existing limits and potentially discover DM-electron interactions.

References

[1] TN Maity, AK Saha, S Mondal, R Laha, arXiv: 2308.12336; [2] IceCube collaboration, M. G. Aartsen et al., Eur. Phys. J. C 77 (2017) 146, [1612.05949]; [3] IceCube collaboration, R. Abbasi et al., Phys. Rev. D 105 (2022) 062004, [2111.09970]