Dark Matter Decay to Neutrinos

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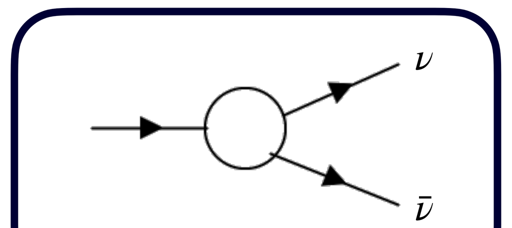
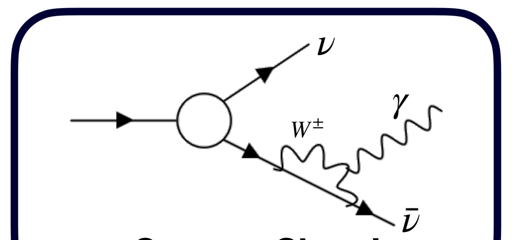
Dark matter (DM) particles are predicted to decay into Standard Model particles which would produce signals of neutrinos, gamma-rays, and other secondary particles. Neutrinos provide an avenue to probe astrophysical sources of DM particles. We review the decay of dark matter into neutrinos over a range of dark matter masses from MeV/c^2 to ZeV/c^2. We examine the expected contributions to the neutrino flux at current and upcoming neutrino and gamma-ray experiments, such as Hyper-Kamiokande, DUNE, CTA, TAMBO, and IceCube Gen-2. We consider galactic and extragalactic signals of decay processes into neutrino pairs, yielding constraints on the dark matter decay lifetime that ranges from $\tau \sim 1.2\times10^{21}$s at 10 MeV/c^2 to 1.5×10^{29}s at 1 PeV/c^2.

INTRODUCTION

- DM particles decay into Standard Model (SM) particles would produce signals of neutrinos, gamma-rays, and other secondary particles. Unlike other cosmic messengers, neutrinos can reach us unstopped from farther distances in the Universe, providing a unique avenue to probe the nature of dark matter.
- We investigate such interactions by considering indirect detection, where Dark Matter from a source either decays or annihilates to SM particles.
- No specialized detectors are needed to observe particles from indirect detection decays. As a result we consider: neutrino detectors gamma-ray telescopes and cosmic-ray experiments all together.
- Searching for products of dark matter decay processes implies looking at large reservoirs of dark matter, in this case, at the Galactic Center.
- We define two types of signals for DM decay to neutrinos: a prompt neutrino signal and neutrinos plus a gamma emission.



Neutrino Signal



Gamma Signal

- Neutrinos are one of the least constrained channels for Dark Matter searches. We expect a correlated signal above the electroweak scale that will strengthen constraints or evidence of Dark Matter.

SIGNAL AND BACKGROUND

The astrophysical differential neutrino flux (galactic contribution) from the decay of dark matter particles is given by:

$$\frac{d\Phi}{dE} = \frac{1}{4\pi}\frac{dN}{dE}\frac{D(\Omega, x)}{m_\chi \tau_\chi} \qquad D = \int d\Omega \int_{l.o.s.} \rho_\chi(\Omega, x)\, dx,$$

where m_χ is the dark matter mass, τ_χ the dark matter lifetime, and dN/dE is either neutrino or gamma production spectrum for decay of DM to neutrinos. The D-factor is the integral over the sky solid angle and along the line-of-sight of the dark matter density.

We also consider the notable extragalactic contribution to the neutrino flux, which depends on the dark matter density and takes into account how gamma-rays get attenuated as they traverse the Universe.

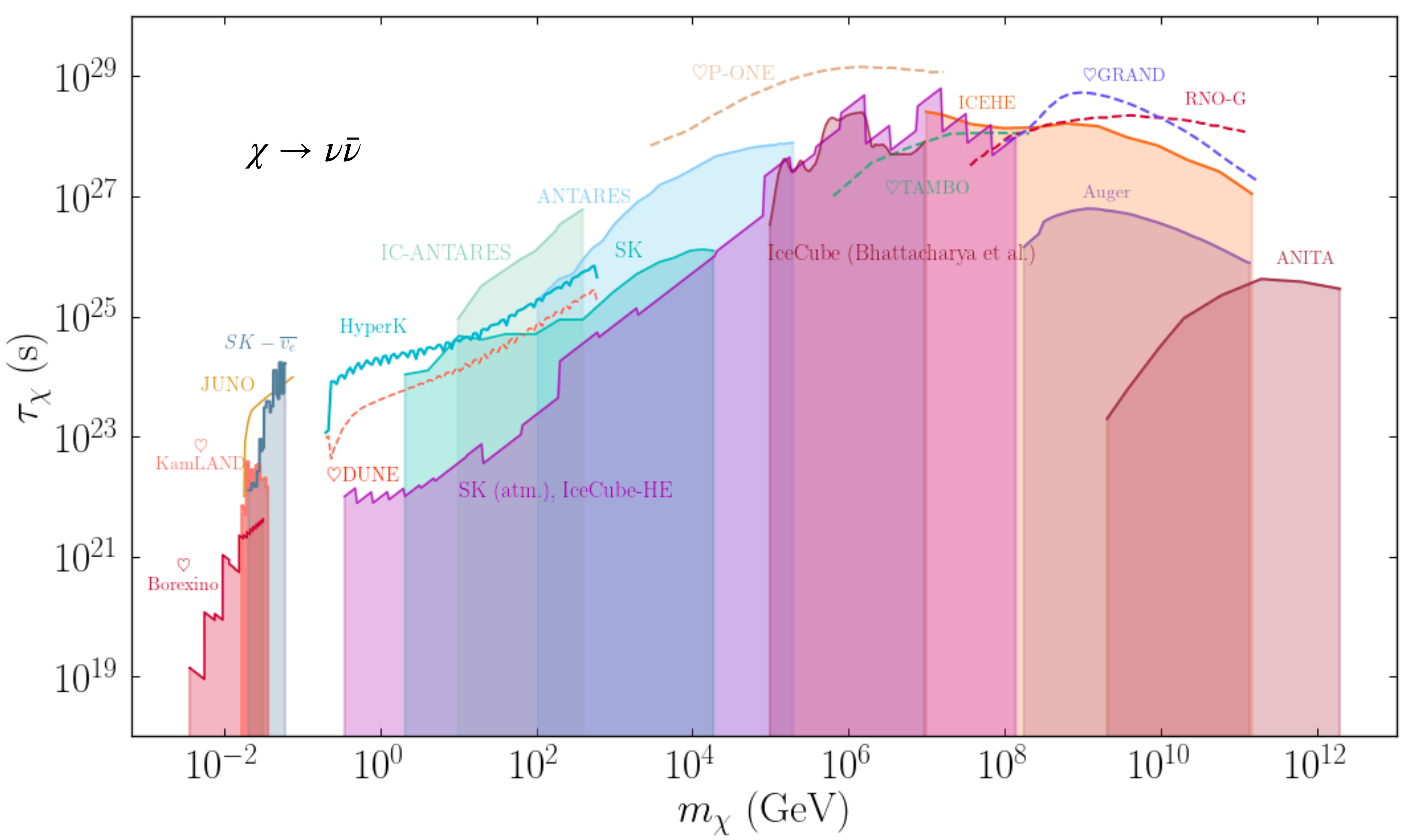
In the case of the gamma signal, the expected background is determined by the expected number of events given by,

$$N_{evt} = \int dE\, A_{eff}\, \frac{d\Phi}{dE}\, T_{obs}$$

Effective area (A_{eff}), observation time (T_{obs}) and differential flux sensitivities are collected from several experiments. Similarly, the expected Dark Matter signal is derived using the calculated astrophysical flux. We determine the constraints or sensitivities to the DM lifetime by exploring regions where the expected number of events from background and signal are in agreement with each other.

SENSITIVITIES

The plot below show the constraints (solid) and projected sensitivities (dashed) of the analysis calculated for the $\nu\bar{\nu}$ channel. The sensitivities have been calculated at 90% C.L. without systematic uncertainties.



NEUTRINO EXPERIMENTS*

- **Borexino**: Liquid scintillator (MeV range). Active mass: 278 tons.
- **KamLAND**: Liquid scintillator (MeV range). Active mass: 1 kiloton.
- **DUNE**: Liquid Argon TPC (GeV range). Active mass: 17 kilotons.
- **Antares**: Sea Water Cherenkov. (GeV-TeV range)
- **SuperKamiokande** (SK): Water Cherenkov (GeV-TeV range). Active mass: 22.5 kilotons.
- **IceCube**: Ice-Cherenkov detector (TeV-PeV range). Active mass: 1 gigaton.
- **P-ONE**: Sea Water Cherenkov (PeV range).
- **TAMBO**: Water Cherenkov. (PeV range)
- **Auger**: Water Cherenkov. Ultra-High-Energy Cosmic Rays (EeV range)
- **GRAND**: Radio Array. (EeV range)

* Not a complete list of experiments considered.

GAMMA-RAY EXPERIMENTS

- **LHAASO**: Hybrid Air Shower. Gamma Rays (GeV - PeV)
- **HAWC**: Water Cherenkov. Gamma Rays and Cosmic Rays (GeV - TeV)
- **CTA**: Air Cherenkov. High Energy Gamma Rays (TeV)

CONCLUSION AND OUTLOOKS

- The nature of Dark Matter and origin of neutrino mass remain a mystery. Dark Matter neutrino connections offer solutions to both problems.
- We can measure both neutrinos and gamma-rays as final products of Dark matter decay to neutrinos which results in a correlated signature between the neutrino and gamma signal.
- Major experimental advances in neutrino and gamma-ray detection allows us to explore a wide mass range (MeV - ZeV).
- New constraints for gamma rays contribution lifetime limits will be reported on an upcoming paper