# Abstract

Astrophysical and cosmological observations suggest the existence of dark matter as an essential component of the total energy budget of the Universe. Weakly Interacting Massive Particles (WIMPs) remain a phenomenologically viable candidate for particulate dark matter that share non-gravitational interactions with the standard model states. Despite extensive searches, no conclusive evidence for WIMPs has been observed. This thesis explores the potential detection of signatures of WIMP-like dark matter through celestial capture that allows probing even weaker cross-sections beyond the reach of present-day direct detections experiments.

As a celestial body moves through the galactic halo, it can gravitationally focus dark matter particles into its interior, where energy loss from scattering with celestial constituents can trap the dark matter. The Sun, a prime candidate for detecting captured dark matter, may produce observable gamma-ray signals via annihilation of captured dark matter via long-lived particles. We utilize solar gamma-ray flux data from the Fermi Large Area Telescope and High Altitude Water Cherenkov observatory to constrain the dark matter and electron scattering cross-section, obtaining bounds that are four to six orders of magnitude stronger than existing bounds for dark matter of GeV and PeV scales. To extend the search beyond solar annihilation signatures, we explore dark matter capture in a distribution of neutron stars near the galactic center and the corresponding annihilation via long-lived mediators could generate an observable neutrino flux detectable by gigaton detectors like IceCube/KM3NeT. Our analysis shows improved constraints on both spin-dependent and spin-independent DM-nucleon cross-sections for TeV to PeV scale dark matter mass.

Next we turn our discussion to the multipolar dark matter models which share momentum dependent coupling with the photons. Such momentum dependency enhances the capture rate significantly and the corresponding limits from solar neutrino observations of IceCube these models surpass direct detection, including those we update with latest DarkSide-50 and LUX-ZEPLIN data. The unexplored phenomenologically interesting region in the anapole avatar of these models remains within the reach of possible detection of neutron star heating through celestial capture at infrared telescopes like JWST.

**Keywords:** dark matter phenomenology, celestial capture of dark matter.