Snowmass2021 - Letter of Interest

The Neutrino Physics program of the Global Argon Dark Matter Collaboration

NF Topical Groups: (check all that apply □/■)
□ (NF1) Neutrino oscillations
□ (NF2) Sterile neutrinos
□ (NF3) Beyond the Standard Model
■ (NF4) Neutrinos from natural sources
■ (NF5) Neutrino properties
■ (NF6) Neutrino cross sections
□ (NF7) Applications
□ (TF11) Theory of neutrino physics
□ (NF9) Artificial neutrino sources
□ (NF10) Neutrino detectors
□ (Other)

RF Topical Groups: (check all that apply □/■)
□ (RF1) Weak decays of b and c quarks
□ (RF2) Weak decays of strange and light quarks
□ (RF3) Fundamental Physics in Small Experiments
■ (RF4) Baryon and Lepton Number Violating Processes
□ (RF5) Charged Lepton Flavor Violation (electrons, muons and taus)
□ (RF6) Dark Sector Studies at High Intensities
□ (RF7) Hadron Spectroscopy
□ (Other)

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Collaboration: Global Argon Dark Matter Collaboration

Abstract: The Global Argon Dark Matter Collaboration (GADMC) is planning a set of liquid argon time projection chambers to search for dark matter. The efficient background rejection achievable by these detectors also enables a rich program of neutrino physics covering a wide range of fields. The DarkSide-20k and Argo experiments will be able to detect the next supernova neutrino burst, collecting high enough statistics to significantly constrain supernova models. The measurement of the CNO neutrino flux in Argo could allow a precision determination of the solar metallicity. The measurement of the relatively well known ^{8}B flux with DarkSide-20k and Argo will constrain the neutrino-Ar charged current interaction cross section. The same flux measurement with DarkSide-LowMass through CEνNS will as well improve the knowledge of this process cross section on argon nuclei. Finally, the DarkNoon experiment is a concept to use a xenon-loaded liquid argon time projection chamber to search for the neutrinoless double-beta decay of ^{136}Xe.

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1. Overview

The Global Argon Dark Matter Collaboration (GADMC) is pioneering the use of purified liquid Argon (LAr) as a target for direct dark matter searches [1, 2]. Many of the features that make LAr a desirable target for the direct detection of dark matter also enable a rich neutrino physics program. In addition to the charged current (CC) channel, upcoming GADMC detectors are capable of flavour-blind neutrino flux measurements via $\nu - e$ scattering and through the Coherent Elastic neutrino-Nucleus Scattering (CEνNS) process. The relatively small mass of GADMC targets, if compared to DUNE or Super-Kamiokande, is counterbalanced by the high cross section of CEνNS with respect to CC interactions.

The GADMC has adopted a multi-staged approach to the exploration of the dark matter parameter space [3]. The DarkSide-20k detector [4], with a fiducial (total) mass of 20.2 t (51.1 t), was planned to start scientific operations in 2023, but the schedule needs to be re-evaluated following the global pandemic, and will reach an exposure of 100 t yr in 5 yr. In parallel with this effort, DarkSide-LowMass, a tonne-scale detector specifically optimized for observing low energy events through the ionization channel, will perform searches for light dark matter. The ultimate G3 argon detector, Argo, will feature a 300 t fiducial mass. It will start running in the late 2020s, collect data for roughly 10 yr, and accumulate an exposure of several thousand t yr.

In addition to the rich dark matter and supernova and solar neutrinos physics program, the inherently powerful background suppression capabilities of dual-phase TPCs, together with extensive experience in radon abatement strategies and cryogenic isotopic distillation, could enable the GADMC to pursue the search for the $0\nu\beta\beta$ decay of ^{136}Xe with the DarkNoon experiment, a xenon-doped argon time projection chamber (TPC).

2. Supernova neutrinos

Neutrinos play a central role in the evolution of core-collapse supernovae (SN). Although many aspects of the core gravitational collapse and subsequent outer layers' detonation have been inferred thanks to the observation of SN 1987A [5–7] and simulations, the next supernova event will help clarify the details of the process. Core collapses are thought to undergo three subsequent phases [7, 8]: neutronization, accretion, and cooling. Each stage of the process is expected to produce a very distinct neutrino signature [9] that could provide insight not only on stellar structure and dynamics, but also on open questions in particle physics.

The neutronization phase, not yet experimentally observed, is ignited by the shock-wave generated by the core rebound and is characterized by a sharp ν_e burst emitted from the core [9]. The detection of neutrinos originated during this phase represents a very powerful probe to put constraints on the neutrino mass ordering [10]. The expected number of events from the neutronization phase in DarkSide-20k (Argo) is 3.75 (28.9) and 4.21 (32.5) respectively for a $11_\odot$ and a $27_\odot$ SN progenitor at a distance of 10 kpc.

When the accretion phase begins, the neutronization shock-wave is stalled in the central regions of the collapsing core by the ram pressure of in-falling matter. Neutrinos play an important role in re-energizing the shock-wave, providing it with the necessary outward momentum to propagate to the core surface and eventually ignite the explosion of the convection layers [11]. During the last phase, the formed proto-neutron star cools down, emitting neutrinos following the black-body radiation law. The detection of accretion and cooling neutrinos, and in particular the measurement of their total and mean energy, will greatly help to constrain SN models and clarify the dynamics of the explosion mechanism. Argo (DarkSide-20k) is expected to reconstruct the total neutrino energy at 3σ level with an accuracy of 11% (32%) in the accretion phase and of 7% (21%) summing the accretion and cooling contributions. Similarly, the mean neutrino energy can be measured at 3σ level with 7% (21%) accuracy during the accretion phase and 5% (13%) accuracy combining accretion and cooling data by Argo (DarkSide-20k).

DarkSide-20k and Argo are expected to detect supernova events with a 5σ confidence level up to the Milky Way edge and almost to the Small Magellanic Cloud respectively. The GADMC will join the SuperNova Early Warning System (SNEWS) program [12], contributing to the constant monitoring of neutrino fluxes to provide timely warning for astronomers to observe the event with all available instruments.

3. Solar neutrinos

The GADMC detectors will contribute to solving the outstanding "solar metallicity problem", *i.e.*, the discrepancy between solar metallic content estimations as directly measured with precise spectroscopy and inferred by sound speed profiles provided by helioseismological observations [13, 14]. A precise measurement of the CNO neutrino flux, which directly depends on metallicity, would point to the correct solar model. The Argo experiment is expected to observe between 3500 and 5000 CNO cycle neutrinos via $\nu - e$ elastic scattering above the ^{39}Ar Q-value in a 1500 t yr exposure, depending on the metal content [15]. In the same energy range, Argo will also detect roughly 6000 neutrinos from the *pep* chain and 16000 from ^{7}Be [15].

The flux of ^{8}B neutrinos has been well characterized by the SNO [16] and SuperK [17] experiments. The DarkSide-20k and Argo experiments will observe thousands of CC interactions from these neutrinos, allowing precise constraints on this cross section. The DarkSide-LowMass detector, optimized for the observation of very low energy nuclear recoils, will detect ∼180 CEνNS from ^{8}B solar neutrinos per t yr, providing an improved measurement of this cross-section compared to the recent COHERENT observation [18]. If needed, the LAr target of DarkSide-LowMass could be depleted of the radioactive ^{39}Ar beyond the values achieved so far with underground argon [19] using cryogenic distillation in the Aria apparatus. In this case, the DarkSide-LowMass detector energy threshold could be pushed below 200 eV$_{nr}$, and *pep* and CNO neutrinos fluxes will also be measurable via CEνNS.

4. $0\nu\beta\beta$ decay

The DarkNoon experiment [20] is a concept to use a 50 tonne fiducial mass dual-phase TPC with a 20% molar fraction mixture of enriched LXe (^{136}Xe at 90%) in LAr to search for the the $0\nu\beta\beta$ decay of ^{136}Xe. The temperature of the Ar-Xe mixture, near the Ar boiling point, would lower radon emanation rates [21] and result in better working efficiency for radon purification charcoal traps [22]. In addition, ^{214}Bi decay, the most dangerous radon daughter for this search, could be efficiently rejected by Bi-Po tagging, bringing its rate in the ROI down to $\sim 10^{-8}$ events/tonne/yr/keV. In an optimistic scenario, the background rate in the ROI would be dominated by ^{8}B $\nu - e$ scattering and $2\nu\beta\beta$ events at a rate of $< 5 \times 10^{-4}$events/tonne/yr/keV, resulting in a sensitivity exceeding $\mathrm{T}_{1/2}^{^{136}\mathrm{Xe}} > 10^{29}$ yr for a 1000 t yr exposure. It may also be possible to discriminate single-ionization from multiple-ionization track events in the TPC using Cherenkov light [23, 24]. Successful application of this Cherenkov background rejection technique would further reduce the background rate, potentially providing a path to sensitivities exceeding 10^{30} yr and effective Majorana masses down to $\mathrm{m}_{\beta\beta} \sim 1$ meV when assuming the light neutrino exchange mechanism.

5. Conclusions

The GADMC is exploring the WIMP dark matter parameter space using LAr as a target. The unique background rejection power of dual-phase TPCs, together with the extreme purity of the extracted underground argon and established radon abatement strategies will allow the DarkSide-20k, DarkSide-LowMass, Argo, and DarkNoon experiments to pursue a rich neutrino physics program, spanning from multi-messenger astronomy to solar physics and neutrinoless double-beta decay.

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