Snowmass2021 - Letter of Interest

Searching for Dark Matter with Liquid Argon

Thematic Areas: (check all that apply □/■)
■ (CF1) Dark Matter: Particle Like
□ (CF2) Dark Matter: Wavelike
□ (CF3) Dark Matter: Cosmic Probes
□ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
□ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
□ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
□ (CF7) Cosmic Probes of Fundamental Physics
□ (Other) *[Please specify frontier/topical group]*

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Collaboration: The Global Argon Dark Matter Collaboration

Abstract: The Global Argon Dark Matter Collaboration (GADMC) is pursuing the construction of a series of liquid argon-based detectors to cover the spin-independent WIMP hypothesis parameter space down to the neutrino floor for WIMP masses from $1\,\mathrm{GeV}/c^2$ to several hundreds of TeV/c^2. This LoI focuses on aspects of the GADMC effort that fall under the Cosmic Frontier. Separate LoIs covering the neutrino-specific components of the GADMC experimental program and the instrumentation needed to support future experiments have been submitted to the Neutrino and Instrumentation Frontiers, respectively.

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Liquid argon (LAr) is a particularly favorable target for the detection of WIMPs thanks to its excellent event discrimination capabilities. Scintillation light initiated by particles recoiling from atomic electrons (ERs), the primary source of background in a WIMP direct detection experiment, has a time constant of approximately a microsecond. This is in stark contrast to the nanosecond time constant of scintillation light emitted during an expected WIMP-nuclear recoil event (NR). The DEAP-3600 experiment has exploited this effect via pulse shape discrimination (PSD) to achieve ER background rejection of 2.4×10^8 and achieve the world's strongest limit on spin-independent dark matter with an argon detector [1, 2].

Excellent event discrimination in an argon-based detector was demonstrated by the DarkSide-50 (DS-50) experiment, which uses a two-phase time projection chamber to measure both the prompt argon scintillation light and the ionized electrons resulting from a particle interaction in the detector. This technique provides excellent position reconstruction resolution and efficient detector fiducialization while maintaining PSD capabilities better than 1.5×10^7 [3, 4]. Using an argon target with very low ^{39}Ar ($\sim$ 0.7 mBq/kg or 1400 times lower than atmospheric argon) sourced from underground CO_2 wells in Colorado, DS-50 has performed a blind analysis of their data and observed no background events over a run period in excess of two years [5]. In addition to sensitivity to WIMPs with masses above $30\,\mathrm{GeV}/c^2$, the two-phase DS-50 detector has extended its reach to WIMP masses below $10\,\mathrm{GeV}/c^2$ by detecting single ionization electrons extracted from the liquid argon volume [6, 7]. The observed rate in the detector at $0.5\,\mathrm{keV}_{ee}$ is about $1.5\,\mathrm{event}/\mathrm{keV}_{ee}/\mathrm{kg}/\mathrm{d}$ and is almost entirely accounted for by known background sources.

Given the potential reach of argon-based detectors, scientists from all of the major groups currently using LAr to search for dark matter, including ArDM, DS-50, DEAP-3600, and MiniCLEAN, joined to form the Global Argon Dark Matter Collaboration (GADMC) with the goal of building a series of future experiments that maximally exploit the advantages of LAr as a detector target.

Several key technologies enable the GADMC LAr detector program. These technologies are discussed in greater detail in an LoI submitted by the GADMC to the Instrumentation Frontier. The Urania plant will perform high-throughput extraction of low-radioactivity underground argon that is naturally depleted in ^{39}Ar (UAr) and will serve as the target volume for GADMC detectors. This UAr can be further purified and isotopically separated using the Aria cryogenic distillation column. Light detection in GADMC detectors relies on large-area cryogenic photodetector modules (PDMs) made of custom-designed silicon photomultipliers (SiPMs) and assembled in a special-built facility. Detectors will operate within an active veto of liquefied atmospheric argon inside a membrane cryostat built with the technology developed at CERN for ProtoDUNE.

The immediate objective of the GADMC is the construction of the DS-20k two-phase LAr detector, which will operate in Hall-C of the Gran Sasso National Laboratory (LNGS). The DS-20k detector consists of a two-phase TPC surrounded by an active veto, all housed within a ProtoDUNE-style membrane cryostat [8, 9]. The DS-20k detector is designed to achieve ultra-low backgrounds via a combination of low radioactivity materials and construction procedures and the ability to measure residual backgrounds *in situ* in the TPC and veto detectors. This results in an expected sensitivity to WIMP-nucleon cross sections of $7.4 \times 10^{-48}\,\mathrm{cm}^2$ ($6.9 \times 10^{-47}\,\mathrm{cm}^2$) for $1\,\mathrm{TeV}/c^2$ ($10\,\mathrm{TeV}/c^2$) WIMPs for a $200\,\mathrm{t\,yr}$ exposure, covering a large fraction of the parameter space currently preferred by supersymmetric models [10] and a 5σ discovery sensitivity beyond that of second generation xenon-based experiments above 50 GeV/c^2, see Fig. 1. During the $200\,\mathrm{t\,yr}$ exposure, 3.2 NR events are expected from the coherent scattering of atmospheric neutrinos, possibly making DS-20k the first-ever direct dark matter detection experiment sensitive to this signal. The DS-20k experiment was planned to run in 2023, but the schedule needs to be re-evaluated following the global pandemic. DarkSide-20k will either detect WIMP dark matter or exclude a large fraction of favored WIMP parameter space.

In parallel to the DS-20k detector, the GADMC will pursue the development of an approximately 1 t detector specifically optimized for the detection of low-mass dark matter, DarkSide-LowMass (DS-LM), inspired by the successful demonstration provided by DS-50. DS-LM is designed with a

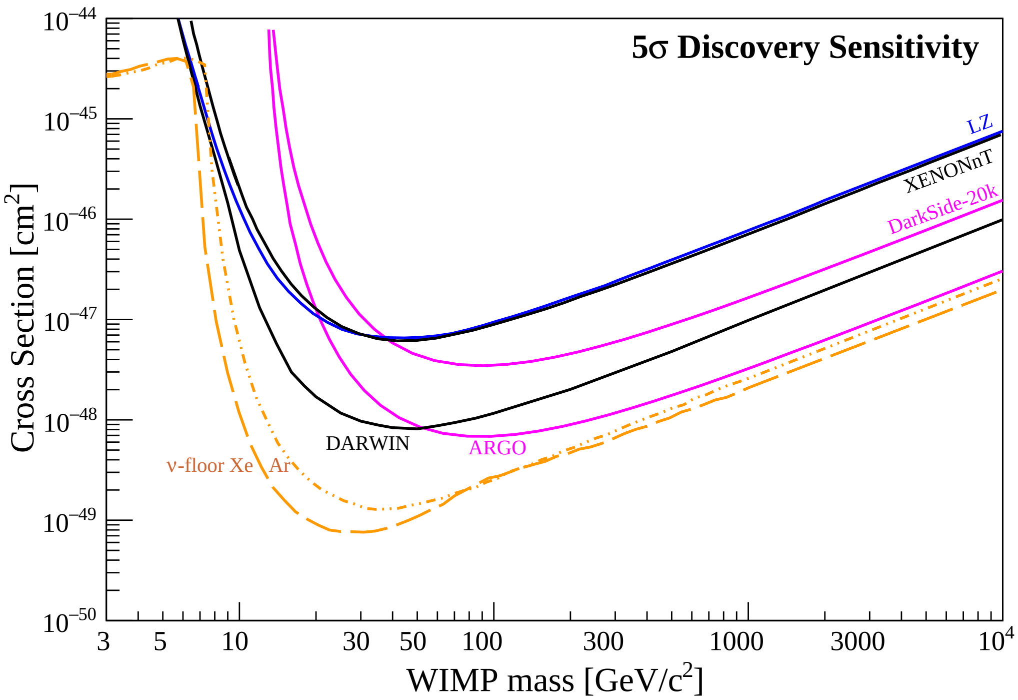

FIG. 1. 5σ discovery sensitivity of current and planned spin-independent direct dark matter detection experiments from the APPEC Dark Matter Report (to be published).

lower energy threshold than DS-20k, achieved by triggering on the electroluminescence signal from ionization electrons, thereby optimizing its sensitivity to WIMP masses below $10\,\mathrm{GeV}/c^2$. This technique comes at the expense of the PSD power afforded by argon prompt scintillation light, but with the potential of reaching world-breaking sensitivity with a much smaller detector. Without PSD, contributors to the ER background in DS-LM must be reduced well beyond the requirements of DS-20k through careful detector design and material selection. The goal of DS-LM is to reach the solar neutrino floor for WIMP masses between $1\,\mathrm{GeV}/c^2$ and $10\,\mathrm{GeV}/c^2$. Success in reaching this target requires the continued development of low-background PDMs [11, 12] and the operation of the Aria cryogenic distillation column to remove ^{85}Kr with very high efficiency and, possibly, to reduce ^{39}Ar levels below $50\,\mu\mathrm{Bq/kg}$ and beyond.

The ultimate objective of the GADMC is the construction of the Argo detector, with a 300 t fiducial mass and a target exposure of several thousand t yr, which will push experimental sensitivity to the point at which the coherent scattering of atmospheric neutrinos turns the WIMP search into a background-limited measurement. The excellent ER rejection possible in argon allows discrimination against electron scattering of solar neutrinos, essential to reaching the design sensitivity of Argo and providing an edge over technologies with more limited ER discrimination, see Fig. 1. The throughput of the Urania plant and Aria facility will enable 400 t of UAr to be extracted and purified over a period of about 4 yr. In addition to dark matter detection, such a large detector will have excellent sensitivity to neutrino bursts associated with a galactic supernova and solar neutrinos [13]. The neutrino physics accessible to GADMC detectors is discussed in an LoI submitted to the Neutrino Frontier. The implementation of the DarkSide-20k project will pave the way for the development of Argo towards the end of this decade.

Combined, DS-20k, DS-LM, and Argo will completely cover the spin-independent WIMP hypothesis parameter space down to the neutrino floor for WIMP masses from $1\,\mathrm{GeV}/c^2$ to several hundreds of TeV/c^2.

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