

Direct Searches for Dark Matter

In this white paper from the dark matter search community, we wish to convey to the Astro2010 Decadal Committee our shared vision of the dark matter science and our consensus on a roadmap for a powerful dark matter search program in the coming decade.

The nature of dark matter is obviously a central question of astrophysics and cosmology and its solution is likely to involve physics at the very fundamental level. Two particularly promising candidates have been proposed to solve *concurrently* the dark matter problem and some deep problems in particle physics: axions that also would explain the absence of CP violation in quantum chromodynamics and the Weakly Interacting Massive Particles (WIMPs) that are related to new physics required to stabilize the electroweak scale such as supersymmetry or large additional dimensions. The scientific arguments for WIMPs and a roadmap for their detections are given in community-based white papers written for the Deep Underground Science and Engineering Laboratory scientific justification (DUSEL S1 study): <http://lanl.arxiv.org/abs/astro-ph/0605719> , <http://lanl.arxiv.org/abs/0902.0358> and <http://lanl.arxiv.org/abs/0810.4551>. A website devoted to the axion search can be found at <http://www.phys.washington.edu/groups/admx/home.html> .

Both leading candidates – Axions and WIMPs – are accessible to direct detection in laboratory experiments. If they exist, dark matter particles will be concentrated in the halo of our galaxy. Axions could be then detected on the earth through their excitation of tunable RF cavities in a strong magnetic field. WIMPs could be detected through scattering on suitable targets in an underground terrestrial laboratory (direct detection). At the same time, these particles could be detected in the cosmos, e.g. in the form of photon lines for axions interacting with astrophysical magnetic fields, or through their annihilation products (positrons, antiprotons, neutrinos) for WIMPs. They could also have marked effects on stellar evolution.

Thanks, in large part, to the support of NSF Physics and Astronomy and DOE High Energy Physics, the United States has played a pioneering role in the development of the technologies needed for direct detection. We are living at an exciting moment, when the search methods begin to enter the interesting region of sensitivity: Axion search experiments are already reaching cosmologically significant limits. The US Axion dark matter experiment, ADMX, has been recently upgraded to use ultra low noise SQUID-based RF amplifiers and has demonstrated improved sensitivity. A second phase will incorporate a dilution refrigerator in the detector, to cool the resonant cavity and SQUID amplifier to ~ 100 mK, reducing the system background noise by an order of magnitude. This should enable ADMX to search for axions in a mass interval representing one decade out of the three still allowed by astrophysical or laboratory observations with sensitivity adequate either to detect such axions or to rule them out as a component of the halo.

Similarly, using either scintillating crystals, low temperature detectors or noble liquids with sophisticated background rejection technologies, WIMP direct detection experiments are entering the generic region of mass and cross section expected for minimum supersymmetry or large additional dimensions. At the same time, the Large Hadron Collider

(LHC) is being put into operation and may be able to produce WIMPs in the laboratory. The Fermi/GLAST satellite, which was launched in June 08 or IceCube, under completion at this time, provide significantly increased sensitivity to WIMP annihilations. The combination of direct searches, indirect observations and accelerator experiments has a significant chance to lead to a discovery in the coming years.

A large number of detector technologies have been proposed to search for WIMPs scattering in underground experiments and the signatories are pursuing a number of them in various underground laboratories around the world. We have two goals: discover a potential signal in a time frame similar to the LHC, Fermi/GLAST and IceCube, and understand the advantages and limits of the various direct detection approaches to prepare for the next steps. In addition, we are actively engaged in a longer term R&D program, which is crucial to ensure competitiveness of the US dark matter effort for the next suite of experiments.

The US effort in the search of WIMPs, and for the possible identification of their nature and measurement of their properties will culminate with the DUSEL dark matter program. The dark matter effort proposed by our community, ranks among the most important justifications for the Deep Underground Science and Engineering Laboratory. Even if a discovery has been made in the next few years, we will need to accumulate statistics on several targets to study the WIMPs (mass, couplings) and the distribution of dark matter in the galaxy (directionality, modulations, phase space distribution). If the WIMPs have not been detected in the pre-DUSEL direct detection program, we will need very sensitive detectors to explore lower cross-section regions. This would be particularly urgent if LHC will have discovered new particles originating from supersymmetry or extra dimensions—in which case it would be essential to show that such particles are stable and indeed present in the cosmos. It would also be compelling if indirect detection observations have provided credible smoking guns for particle dark matter (e.g., gamma rays originating from subhalos/dwarf galaxies). Likewise, the possible direct detection of dark matter particles and the possible measurement of their mass by the comparison of rate and spectra obtained with different targets may provide, in absence of signals at the LHC, important parameters for the design of future accelerator facilities.

There is a broad consensus in our community that the DUSEL dark matter program requires several experiments with different detector technologies to cross-check each other, provide insurance against backgrounds unexpectedly appearing as we push down the sensitivity level, and determine the nature of couplings of WIMPs to nucleons—e.g., by measuring the atomic number dependence. This program should also be dynamic with the systematic inclusion in the first suite of experiments of the lessons learned during the pre-DUSEL phase. We will also need directional detectors to unambiguously link the signal to the galaxy. Dark matter would also naturally be a major theme of the DUSEL education and outreach program. The powerful dark matter program that we envision at DUSEL will involve significant foreign participation and will be coordinated worldwide with other efforts to prevent duplication of major investments.

Finally, we would like to point out the many synergies between this dark matter search program and the rest of astrophysics. Most of us come from a particle or nuclear physics

background, but we need a strong involvement of astronomers. The interpretation of the current limits requires such collaboration, as not only the cross-section but also the local density and the velocity spectrum and angular distribution of dark matter have to be reckoned with. In case of discovery, our experiments will naturally become dark matter observatories, able for instance through the energy spectrum or directionality to identify streams of dark matter, if they have not fully virialised.

As with many other fields of astrophysics, this program is totally dependent on state-of-the-art instrumentation, and it is essential that the agencies support a long-term R&D program. For instance, a series of successive scientific demonstrations of increasing sensitivity is needed since we never know whether the next stage of our experiments will be background free, before trying. Note that our technologies have a number of synergies with instrumentation in other fields of astrophysics. The ultra low noise amplifiers of axion searches may also be interesting in radioastronomy in situations where you are not dominated by sky/antenna backgrounds. Low temperature detectors for WIMP searches have both influenced and benefited from bolometers for submillimeter astronomy and cosmic microwave background measurement, and some RF multiplexing methods are very close to modern correlator designs (FPGA) in radioastronomy. Noble liquids share photomultiplier technologies with extensive air shower arrays and atmospheric Cerenkov detectors. Low background aspects of WIMP searches are similar to what is needed for solar neutrinos (actually some of our proposed experiments would like to contribute to both fields). More generally speaking the high sensitivity techniques we are developing may be important for Homeland security, non-proliferation applications or medical imaging, in ways similar to other astrophysical instrumentation.

We should add that the interactions between two different cultures—one originating from particle and nuclear physics, and one from astronomy—are already scientifically productive and likely to be even more fecund if discoveries are indeed made. Moreover, because this field gets significant support from different offices in the Federal Agencies, this is not a zero-sum game and direct dark matter searches add resources to the astrophysical community.

We hope therefore that the Astro2010 Decadal Survey will support a strong dark matter search program and underline the many synergies with other activities prioritized by the Committee.

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