Snowmass2021 - Letter of Interest

HydroX- Using hydrogen doped in liquid xenon to search for dark matter

Topical Group(s): (check all that apply by copying/pasting ☐/☑)

☑ (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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Abstract: (maximum 200 words)
This LOI discusses HydroX, an upgrade to large liquid xenon TPC detectors to add hydrogen after the initial dark matter run is complete. For example, adding hydrogen to the LUX-ZEPLIN detector would open up sensitivity to O(100 MeV)-scale dark matter for both spin dependent and spin independent interactions.

The main idea of HydroX is to deploy hydrogen, the nucleus with the smallest atomic mass, into the LZ or future G3 liquid xenon detector at the level of a percent by number density, providing e.g. ~1 kg in the LZ fiducial mass. The LXe becomes the sensor, and hydrogen is the DM target. The response of liquid xenon to recoiling protons has yet to be measured, but can be inferred from known detector physics. Unlike xenon nuclear recoils, which lose ~80% of their energy invisibly to collisions with other xenon atoms, the lighter and faster proton recoils will transfer most of their energy to visible electronic excitation. Preliminary studies with SRIM indicate sensitivity in LXe to proton recoils with energies below 1 keV is feasible, giving sensitivity to <300 MeV dark matter particles. Projected sensitivities to DM for HydroX runs in LZ based on more detailed calculations are shown in Fig. 1. Dissolving hydrogen into a G3 liquid xenon experiment would give a ~10x increase in sensitivity, approaching the neutrino floor.

The use of H_2 and D_2 provides sensitivity to both spin independent and spin dependent channels, for both DM-proton and DM-neutron interactions. No other set of target nuclei provides sensitivity to this broad menu of interaction types for DM masses below the proton mass. Many recent experiments search for DM-electron scattering, for example SENSEI/DAMIC and SuperCDMS-HVeV; however, as many DM models predict suppressed leptonic interactions, there is a clear need for experiments designed to detect all possible DM-nucleus interactions at these mass scales.

By utilizing LZ as the host facility, HydroX takes advantage of the unparalleled low-background environment developed by the LZ project. The LXe provides self-shielding from external gamma-rays and neutrons, which would not be available in a similar mass target composed purely of a light nucleus, and the addition of H_2 will come *after* the main WIMP search, at which time the background field in LZ will be fully characterized.

Before HydroX can be deployed, significant R\&D is still required. In particular, current efforts have two main goals: 1) Measuring detector properties of H_2 doped liquid xenon, including the signal yields of proton, electron, and xenon recoils; and 2) Understanding the cryogenics of H_2 doped LXe, including the solubility of H_2 in LXe and the techniques needed to manage a mixture of H_2 and Xe in a large scale cryogenic installation like the LZ detector.

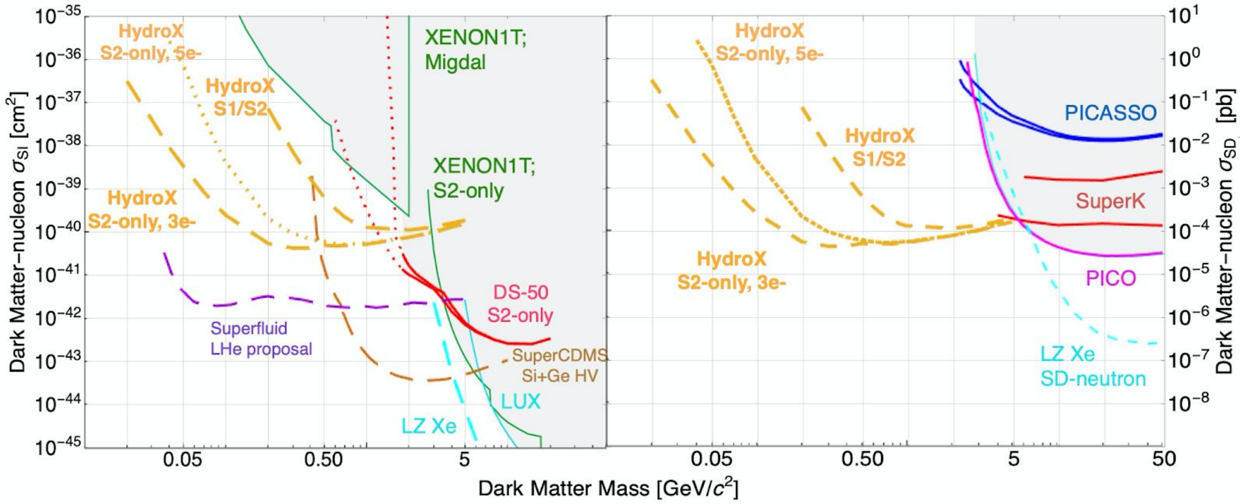

Figure 1: The left panel shows in orange the projected sensitivity of a 250 day run of LZ doped with 1% H_2 (by mole) to SI interactions, under three different analysis assumptions. The right panel shows the projected sensitivity to SD DM-proton interactions, where there are no other sensitive experiments at low DM masses. The sensitivity extends well below 100 MeV in mass.

References: (hyperlinks welcome)

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