Mechanical Design of the Oscura Vessel

Kodjo Akouedjinoude

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Abstract

The Oscura experiment will use a very-large array of skipper Charge-Coupled Devices (CCDs) to search for low-mass dark matter (DM). Building on the success of the SENSEI and DAMIC experiments, Oscura plans to deploy 10 kg of skipper-CCDs at SNOLAB, providing unprecedented sensitivity to low-mass DM interacting with electrons. In this study, we evaluate the feasibility of scaling up the existing SENSEI@SNOLAB vessel to house 10 kg of skipper-CCDs the Oscura experiment. We expand the capacity of the SENSEI@SNOLAB vessel so that it can hold ∼2 kg of skipper-CCDs, providing a first step to conceptualize the size and materials cost of a scaled-up SENSEI vessel. This modified design will be used for thermal modeling studies, to ensure that it meets the temperature requirements of the Oscura experiment. Future work will refine this design based on the results of the thermal modeling studies.

1 Introduction

A large body of evidence points to the existence of dark matter (DM), but the nature of DM remains a mystery. One of the most recent innovations in the search for DM search is the SENSEI experiment, using newly developed highly sensitive sensors with ultra-low readout noise called skipper Charge-Coupled Devices (CCDs), one of which is shown in Fig. 1. The SENSEI experiment set world-leading limits on DM-electron scattering using one 2 g skipper-CCD operated at the MINOS cavern at Fermilab [1]. SENSEI is currently taking data at SNOLAB with 100 g of skipper-CCDs and aims to improve on the previous DM limits set by SENSEI@MINOS.

Figure 1: Picture of a skipper-CCD in copper tray. The copper packaging serves as a light shield and also provides thermal coupling to the cooling system. The flex cable carries voltages in to control the CCD, as well as signals out of the vessel to the DAQ system.

The Oscura experiment will use a larger array with 10 kg of skipper-CCDs to provide improved sensitivity to DM particles, as shown in Fig. 2) [2]. In the research and development phase of the Oscura experiment, the nominal plan is to design a pressure vessel to operate the skipper-CCDs at about 120 K in liquid Nitrogen (LN2), but this immersion cooling scheme has not yet been demonstrated. Alternatively, operating skipper-CCDs in a vacuum chamber has already been validated and employed by the SENSEI and DAMIC experiments. This study evaluates the feasibility of scaling up the existing SENSEI@SNOLAB vessel to conduct the Oscura experiment and assesses the potential challenges in scaling up the vacuum vessel.

2 Materials and Methods

2.1 Methods

The goal of the project is to scale up the SENSEI vessel (see Fig. 3) to house a larger array of skipper-CCDs, which would provide improved sensitivity to DM particles. A detailed study was conducted to understand each component, scale them up individually, and put them back together. The main assembly is composed of the Top-Level Inner and the Under-vessel Services. A schematic of the different components comprising the main assembly is shown in Fig. 4

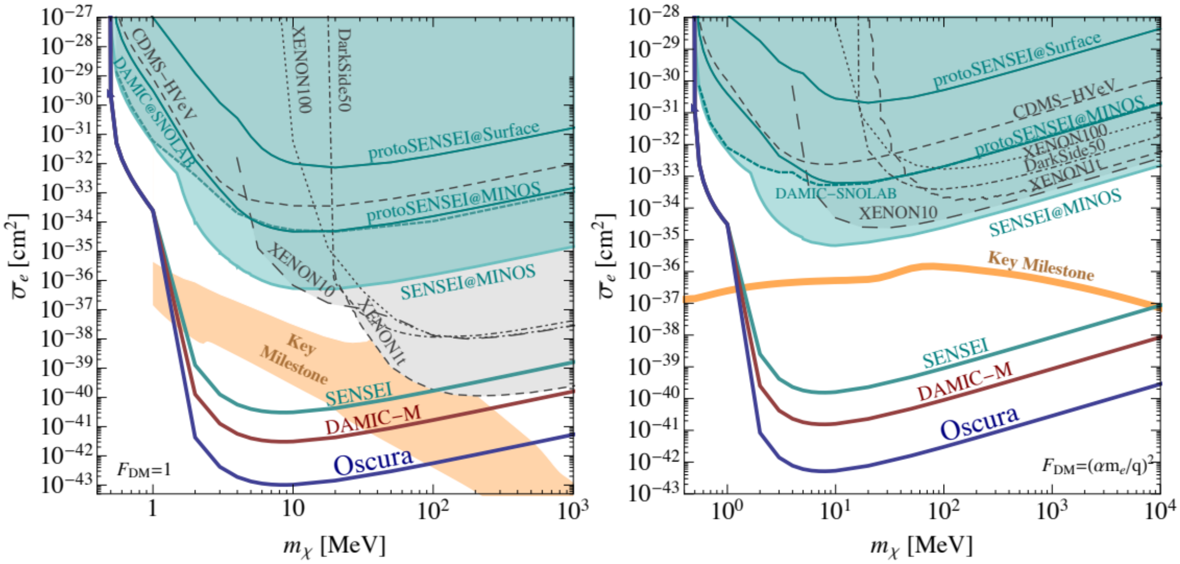

Figure 2: Projected sensitivity of the Oscura experiment to dark matter-electron scattering, assuming a 30 kg-year exposure. Figure from [2].

The under-vessel services include the electronics, which are housed separately from the detectors because the electronic components are not radiopure. The Top-Level Inner with its different layers provides room for the detectors, the cryocooler system, and radiation shields.

Studying each component helped us identify what we consider to be the most important part of the vessel for scaling up: the Cold Box, which is shown in Fig. 6. The Cold Box houses the skipper-CCDs, and provides a thermal coupling to the cryocooler to keep the detector temperatures in the optimal range.

To assess the feasibility of scaling up the SENSEI vessel to hold 10 kg of skipper-CCDs, we focused on increasing the capacity of the Cold Box to house Based on the modified Cold Box design, we can conduct thermal modeling studies to ensure the modified design produces acceptable temperature gradients throughout the cold box. In the future, we will modify the other components to achieve a complete design of the scaled-up SENSEI vessel.

2.2 Materials

Materials Used:

- AutoCAD was used to design, create, and modify different parts of the vessel

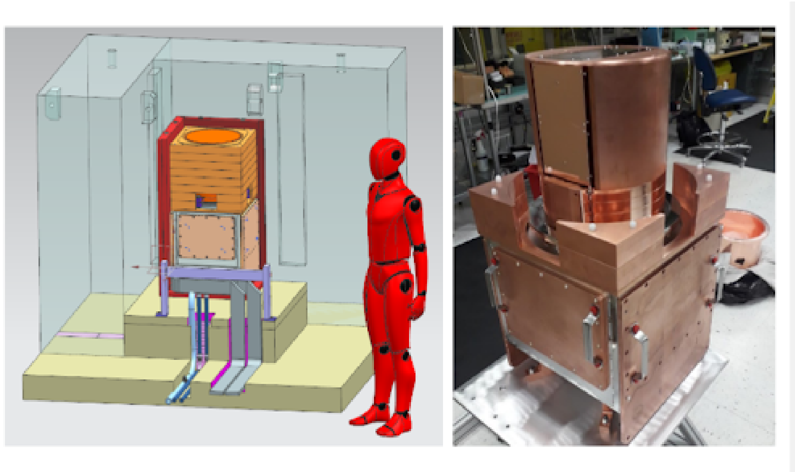

Figure 3: (Left) Design of the SENSEI vessel alongside a human for scale; (Right) SENSEI vessel in the lab.

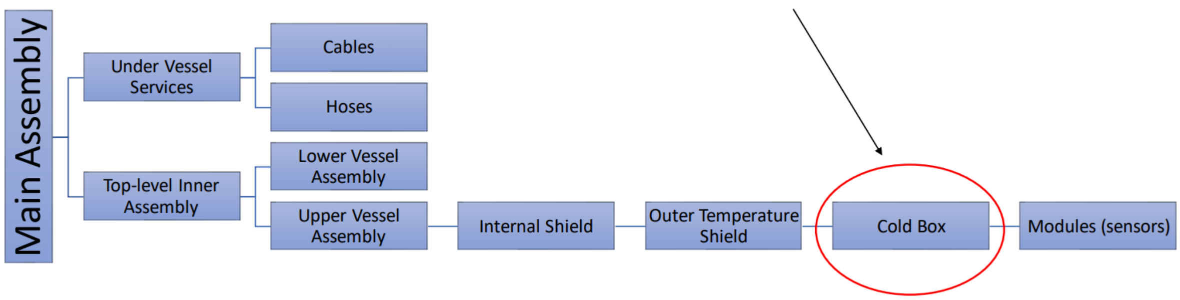

Figure 4: Flowchart describing relationship between each component in the main assembly. To assess the feasibility of scaling up the SENSEI vessel to house 10 kg of skipper-CCDs, we focused on increasing the capacity of the Cold Box, which is circled in red.

- The SENSEI Installation at SNOLAB Manual provided a useful reference to understand the SENSEI vessel and the purpose of and interplay between each component.

To optimize the space available, we decided to use the modified version of the SENSEI package that contains four skipper-CCDs each. This will improve the packing fraction of the Cold Box and increase the active mass of sensors in the payload. In order to scale up the mass of the SENSEI detector payload, we increased the capacity of the Cold Box by increasing its height by a factor of four, and we included four modified Cold Boxes in the modified design.

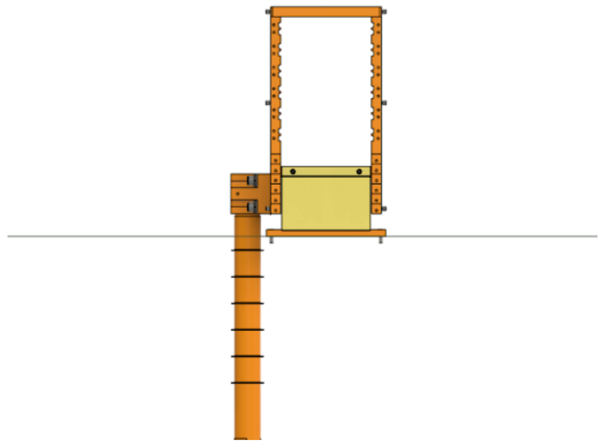

Figure 5: Original design of the SENSEI Cold Box.

Table 1: Comparison of dimensions of original and modified Cold Box.

	Original	Modified
Dimensions	219 mm x 361 mm x 110 mm	825 mm x 361 mm x 110 mm
Pitch (distance between slots)	8.76 mm	8.76 mm

3 Results

We successfully developed a modified cold box that will be useful in assessing the feasibility of scaling up the SENSEI vessel for the Oscura experiment. The modified cold box can hold up to 240 skipper-CCDs in each tower, and we include four towers in the modified design providing capacity for 960 skipper-CCDs. Each CCD has a mass of 1.93 g, which means that the modified design can hold a total active mass of 1.85 kg of skipper-CCDs. While this design currently does not have capacity for 10 kg of skipper-CCDs, it provides an important first step to conceptualize the size and material cost of a scaled-up SENSEI vessel, and will serve as a testbed for thermal modeling studies. The cold box height is now 825 mm so its height could be further increased while satisfying the space requirements at SNOLAB.

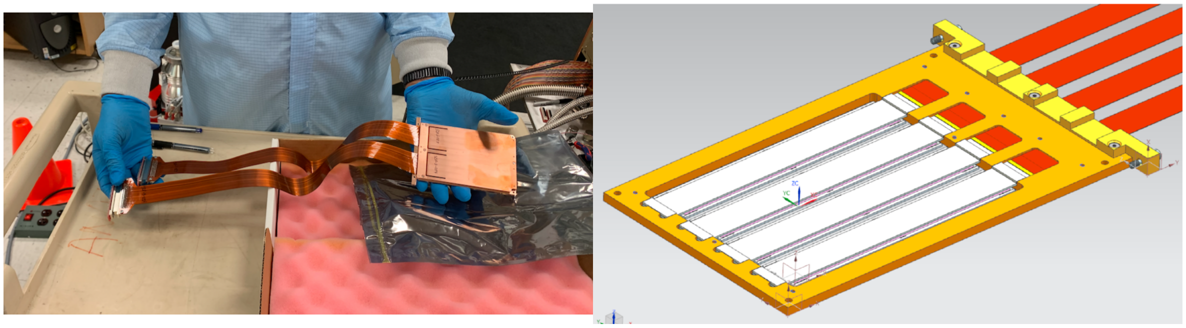

Figure 6: (Left) Photo of the SENSEI package with two CCDs; (Right) Modified version of the SENSEI package with four CCDs each.

4 Discussion

This work developed a modified design for the SENSEI vessel that can house 2 kg of skipper-CCDs for the Oscura experiment. This design can be further extended to house the full 10 kg Oscura payload. Future studies will model the thermal management of this design to ensure that it meets the thermal requirements of the Oscura experiment. Specifically, thermal studies will assess the temperature gradient between detectors at different heights in the cold box, and ensure that the SENSEI@SNOLAB cryocooler has sufficient capacity to remove heat from the enlarged detector payload. Further refinements to this design will be made based on the thermal modeling results.

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