Skipper-CCDs: current applications and future

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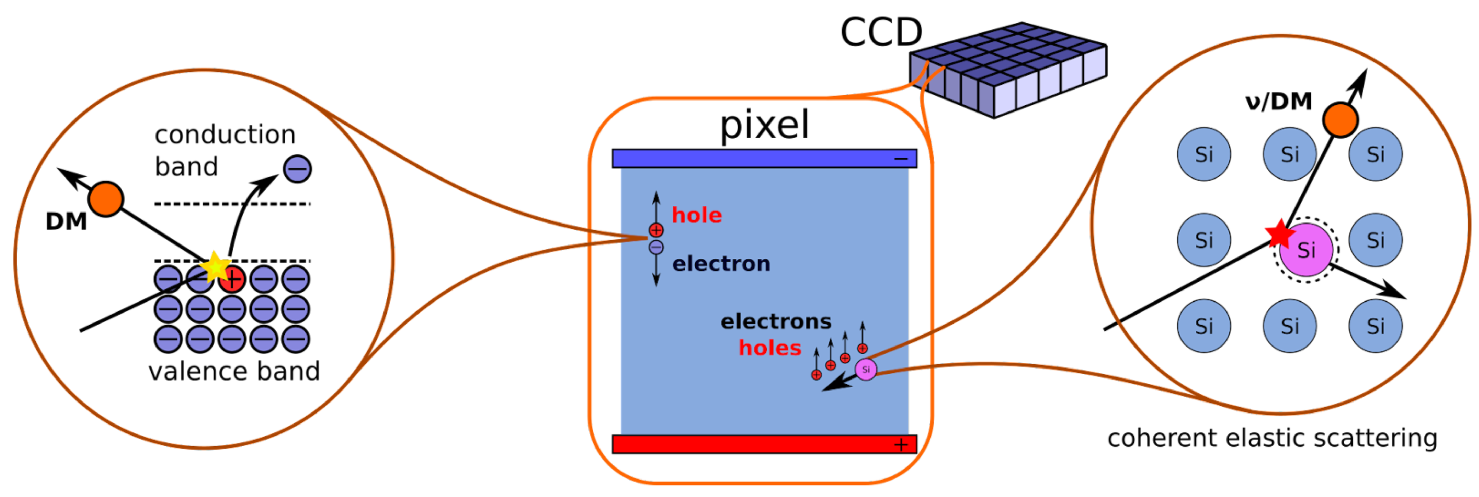
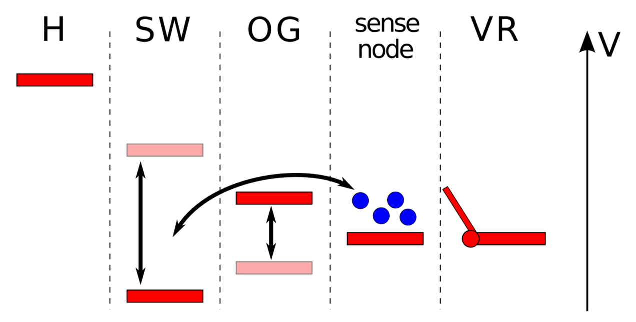
How does a skipper-CCD work?

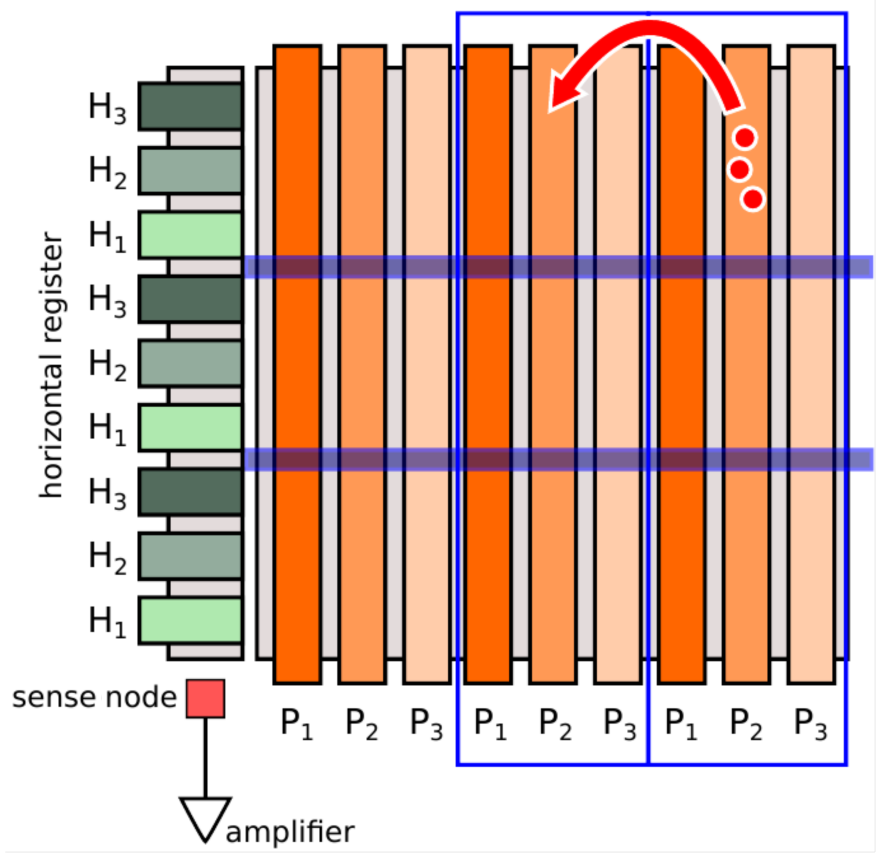
Charge-Coupled Devices (CCDs) are essentially an array of Metal-Oxide-Semiconductor capacitors. Radiation interacting in the active volume produces e-h pairs. Packets of charge are collected below the surface and transferred towards a readout stage.



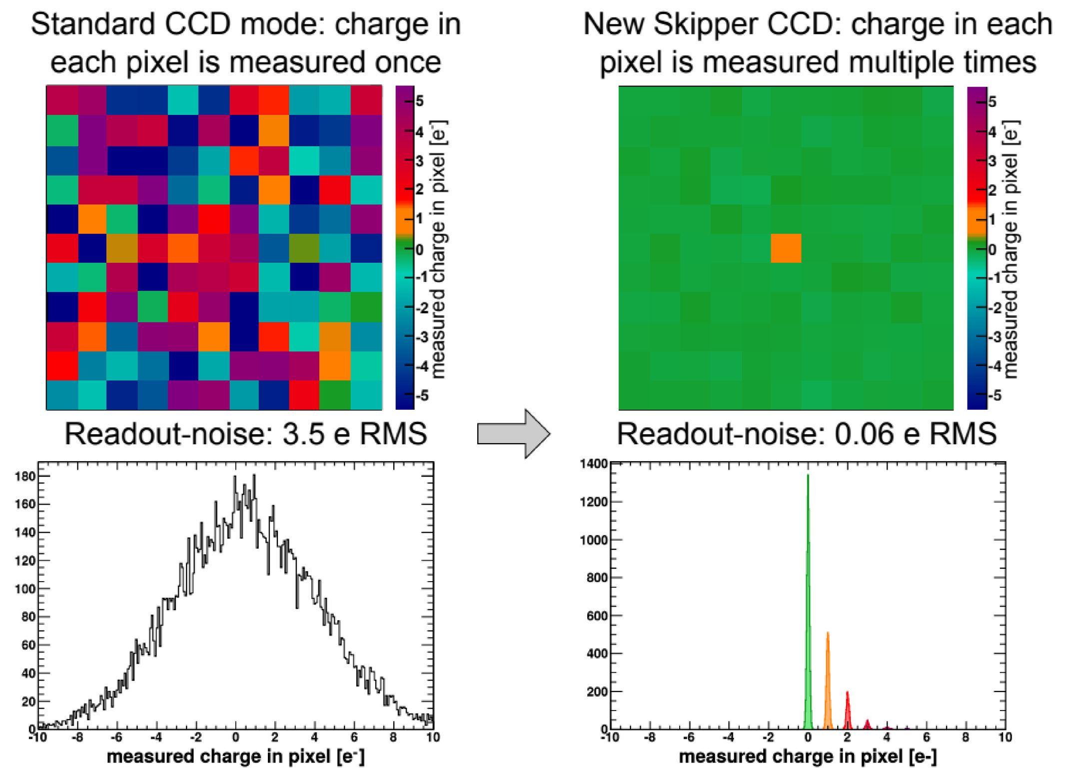
The readout stage in a skipper-CCD allows to perform multiple (N) non-destructive measurements of the same charge packet.

- Readout noise is reduced as $\sigma = \sigma_1/\sqrt{N}$





The skipper-CCD technology first demonstrated a good performance in 2017 [1] using a detector designed by Stephen Holland (LBNL) allowing to count electrons!

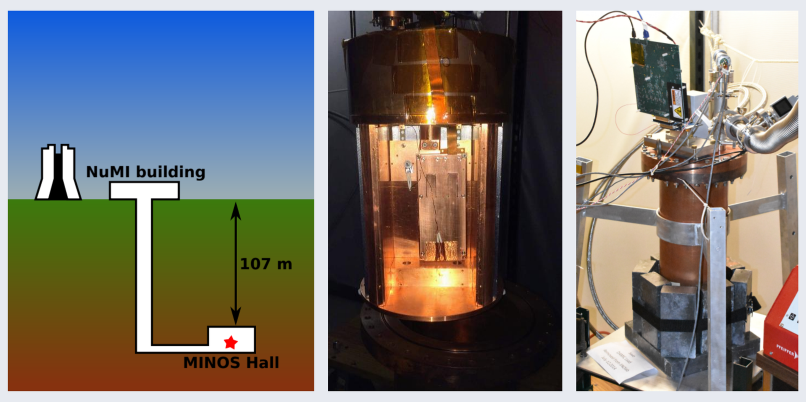


Current applications

Direct DM searches

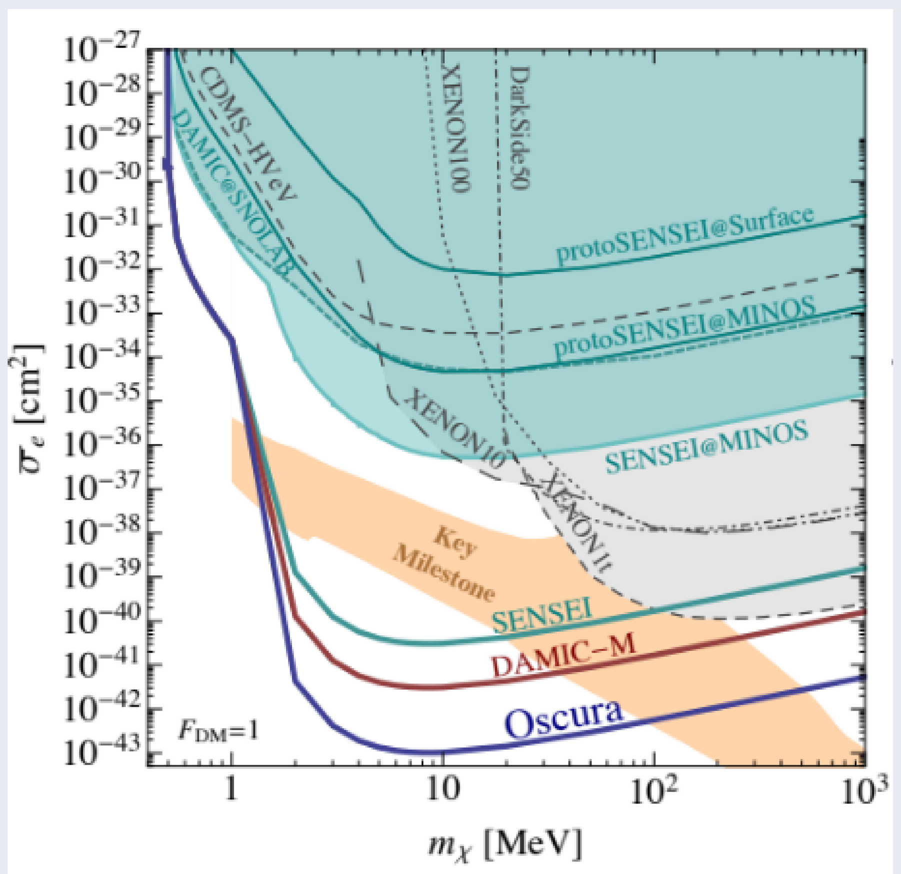
- **SENSEI @ MINOS [2]**

With a mass of ∼2 g, the lowest single-e$^-$ rate in Si detectors was achieved (∼10^{-4} e$^-$/pix/day) imposing world-leading constraints in a large range of sub-GeV dark matter masses.



- **Ongoing program**

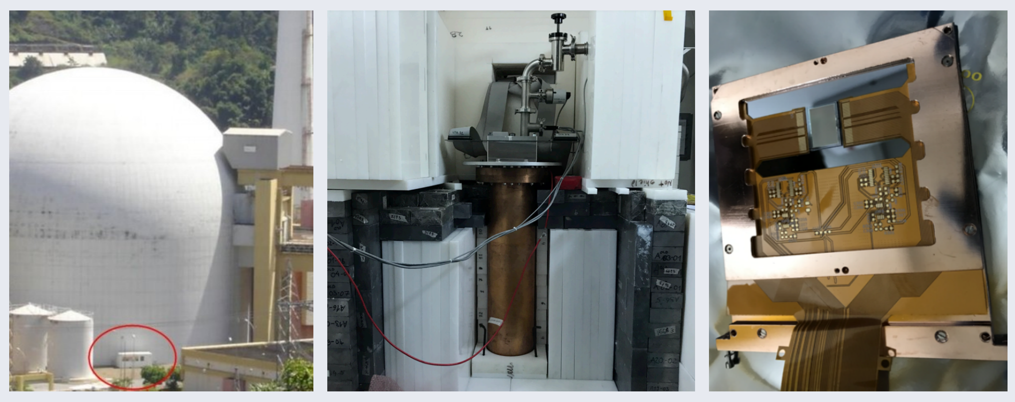
Experiment	Mass	Background	Commissioning
DAMIC @ SNOLAB	~20 g	5 dru	12/2021
DAMIC-M (proto)	~10 g	1 dru	11/2021
SENSEI-100	~100 g	5 dru	mid-2022
DAMIC-M	~1 kg	0.1 dru	2023
OSCURA	10 kg	0.01 dru	~2027



Searching for CEνNS

- **CONNIE [3]**

Located ∼30 m away from the core of the Angra 2 nuclear reactor in Brazil, CONNIE has recently installed 2 skipper-CCDs currently running stable.

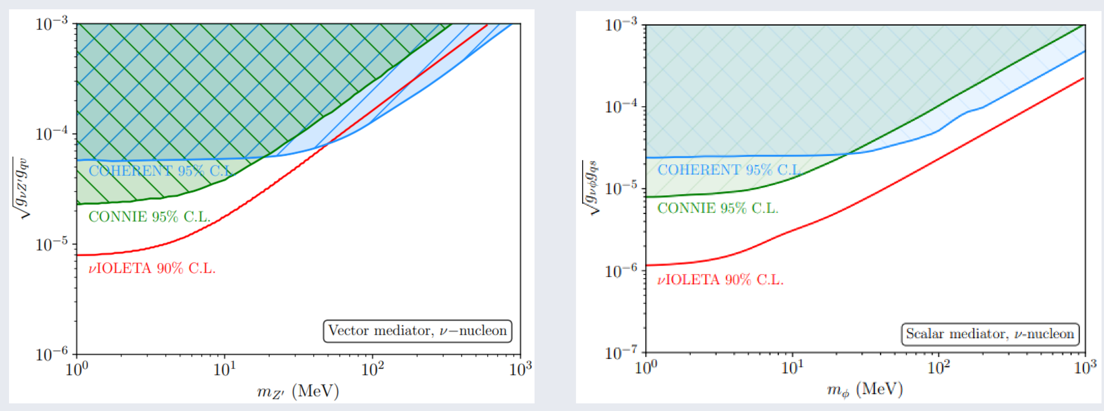


With 4 kdru of bkgd and 1 kg mass, a skipper-CCD detector at the CONNIE site should run for 9 days (if Lindhard) or 2 months (if Chavarria) to observe CEνNS at a 90% C.L..

- **νIOLETA [4]**

Planned kg-size skipper-CCD experiment to run ∼12 m away from the core of Atucha II nuclear reactor, in Argentina. Recently installed skipper-CCDs.

Reactor experiments searching for CEνNS are competitive constraining BSM physics! [5] [6]

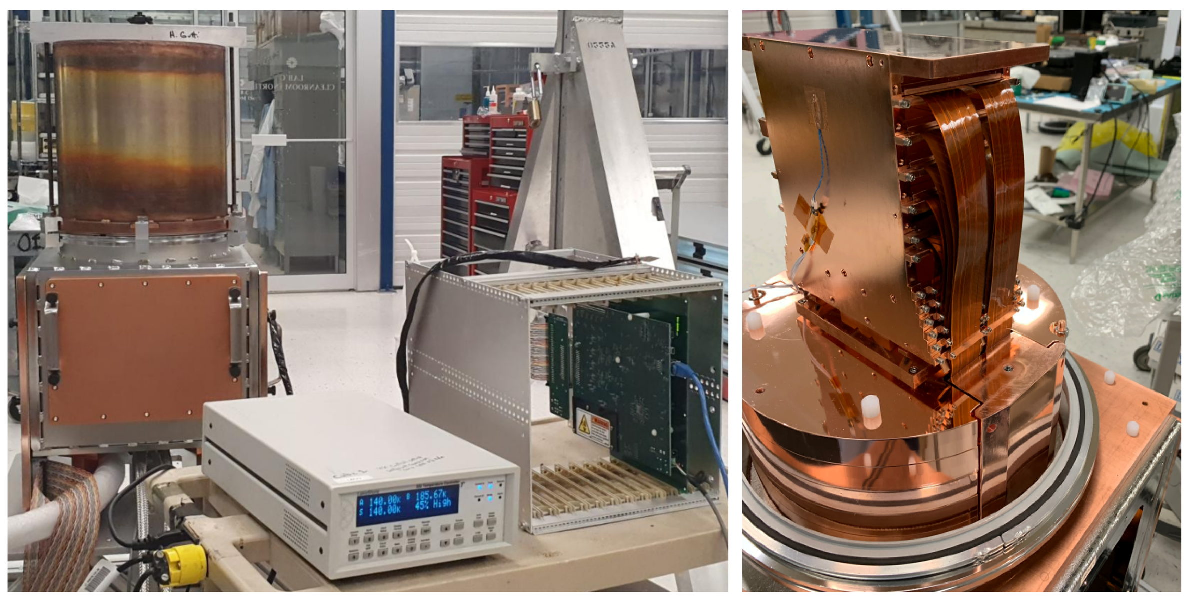


Other applications

- Astronomy: Observation of faint objects and high-resolution spectroscopy
- Quantum imaging

Towards multi-kg experiments

With the current technology, a ∼100 g skipper-CCD experiment (∼50 sensors) is plausible.



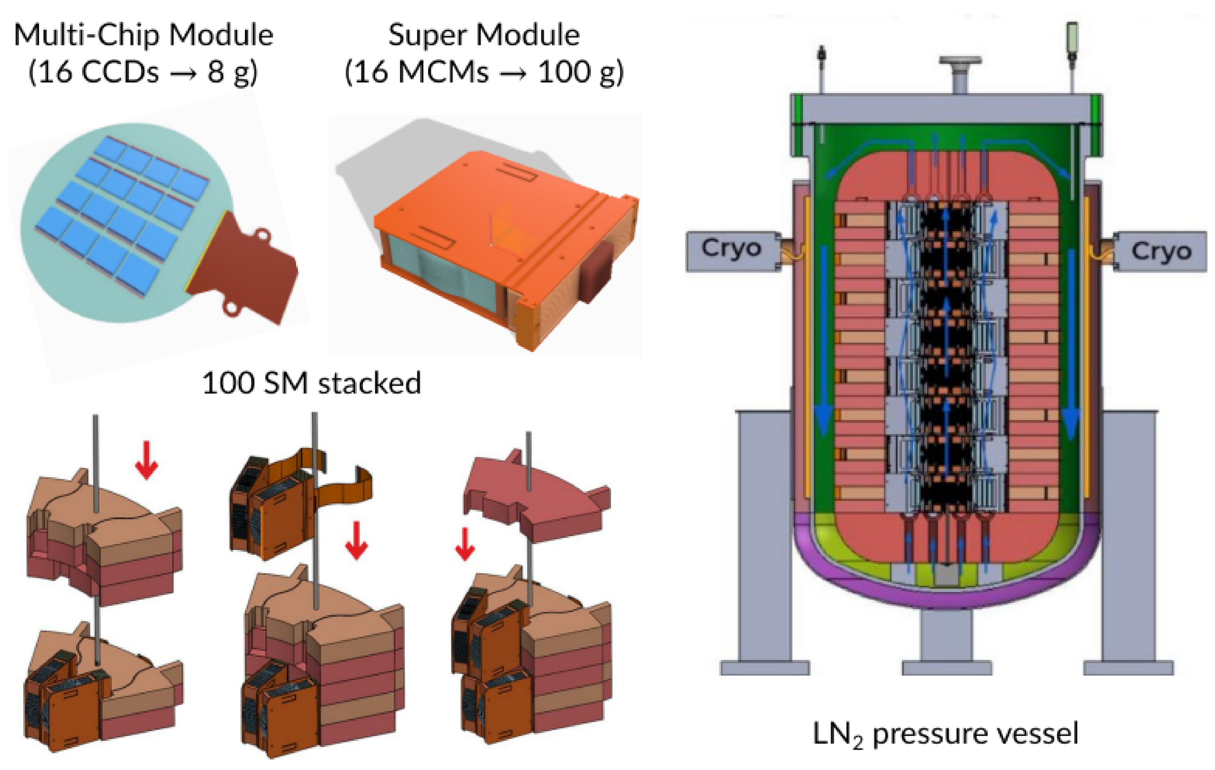
But for a 10 kg experiment (∼24,000 sensors), it is needed:

- To engage new foundries for mass production of sensors*
- To develop new front-end electronics to read and control multiple channels
- To come up with packaging ideas in terms of the system design
- To explore new ways to efficiently cool down 24,000 sensors

and this should be done while having a good radioactive background control.

*DALSA, our previous foundry, discontinued this production line.

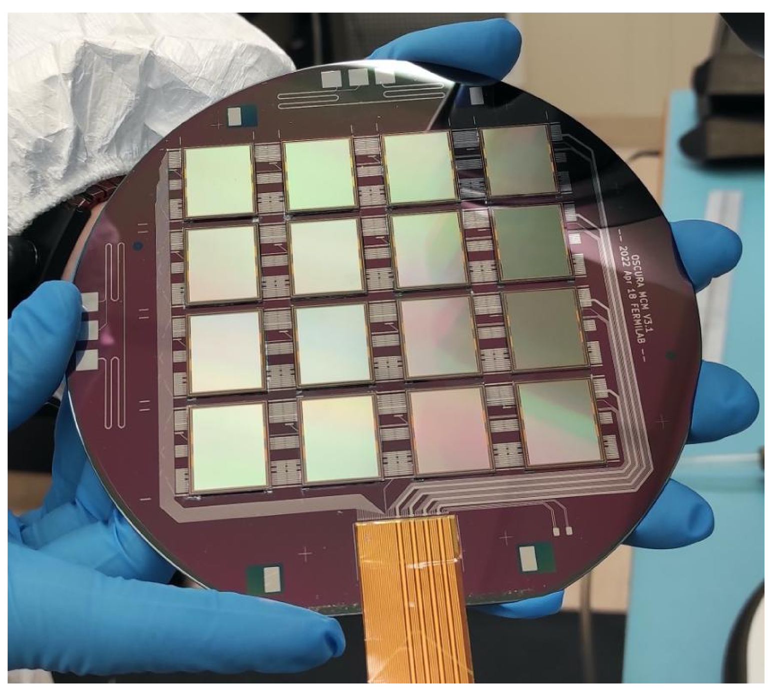
Oscura's envisioned design [7]:

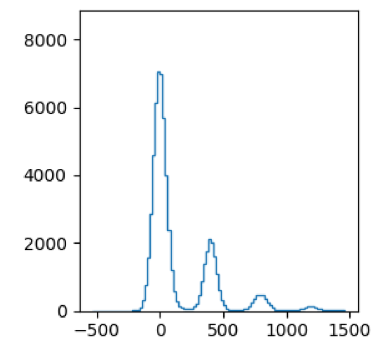


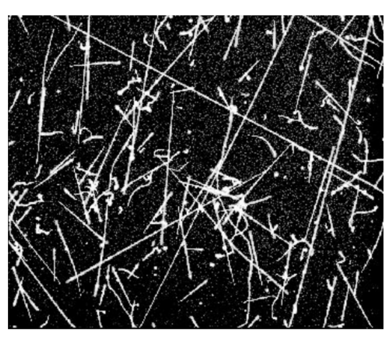
Ongoing progress (Oscura R&D effort)

- **Sensors**

The first batch of e$^-$-counting sensors was successfully fabricated at Microchip Inc. achieving 10^{-1} e$^-$/pix/day. Characterization ongoing.

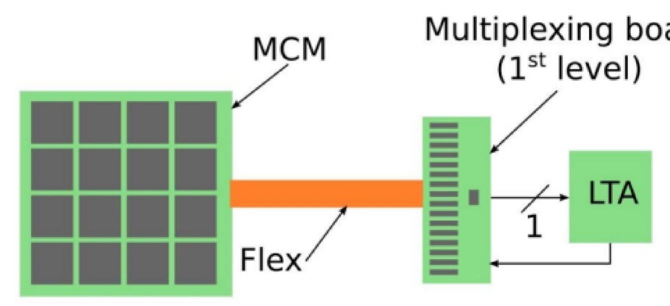




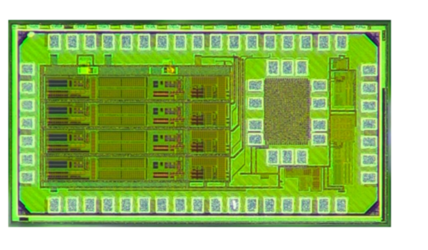


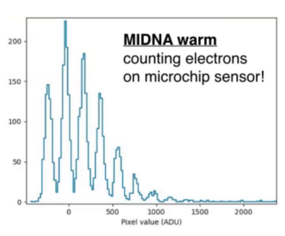
- **Electronics**

Demonstrated good performance of 16-channel multiplexer board with analog pile-up circuits [8].



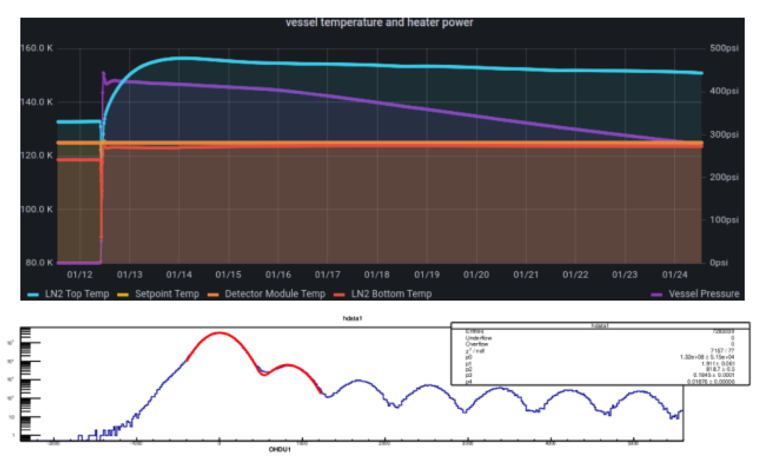
Demonstrated operations of the multi-channel cryogenic low-noise skipper-CCD readout ASIC (MIDNA) [9].





- **Cryogenics**

Demonstrated skipper-CCD operation in pressurized LN$_2$ vessel. Environmental background characterization ongoing.



[1] [PRL 119, 131802 (2017)]
[2] [PRL 125, 171802 (2020)]
[3] [JHEP 05 (2022), 017]
[4] [Poster #521 @ Neutrino 2020]
[5] [JHEP 02 (2022), 127]
[6] [JHEP 04 (2020), 054]
[7] [10.48550/ARXIV.2202.10518]
[8] [JINST 16 P11012]
[9] [10.2172/1841383]