# Measuring the universe one electron at a time with Skipper-CCDs

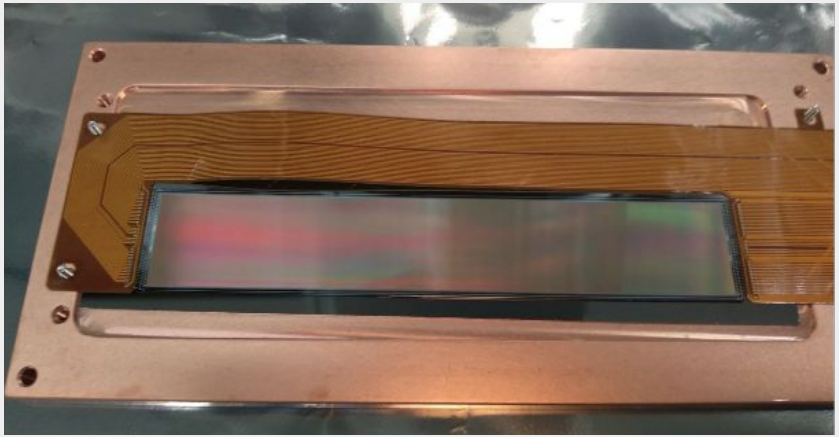


*Image: SENSEI skipper-CCD sensor*

**Ana Martina Botti***

**Fermilab Users Meeting 2024**

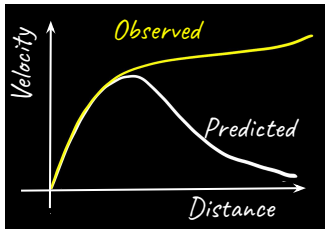
July 11, 2024

* Fermi National Accelerator Laboratory and Kavli Institute for Cosmological Physics, University of Chicago
abotti@fnal.gov

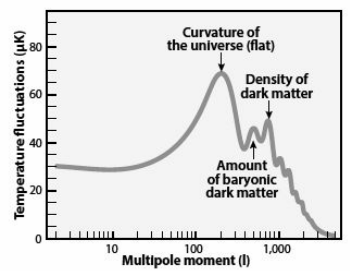
# Dark-matter

**Overwhelming evidence** from cosmology and astrophysics for the existence of dark matter…

Galaxy gas rotation

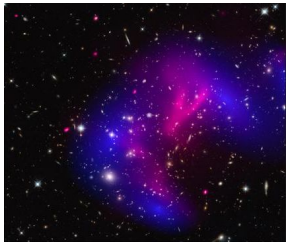



CMB




*Astronomy: Roen Kelly, after Wayne Hu*

Cluster collision

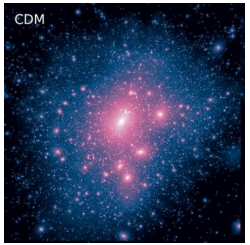


*NASA, ESA, STScI, CXC. Copyright*

Gravitational lensing

*NASA, ESA, M.J. Jee, and H. Ford (Johns Hopkins University)*

Structure formation




*Mark Vogelsberger 2020*

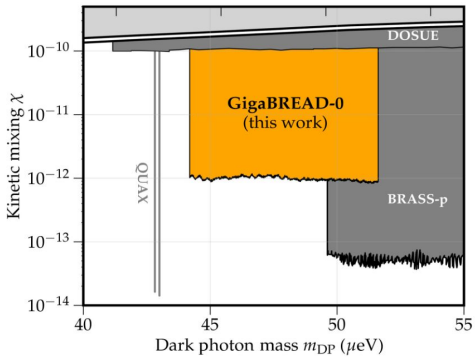
More than **84% of the matter in the universe is dark**… and we have no idea what dark is.

The **standard model of particles** cannot explain these phenomena… dark matter is promising gateway towards **physics beyond** the standard model

# But… we have some ideas of what is not!

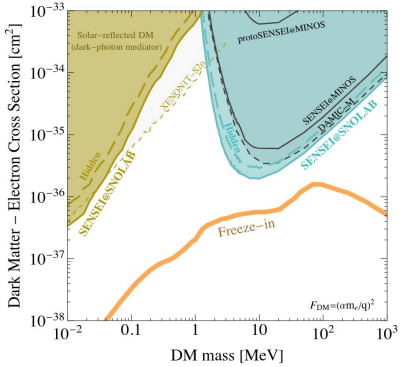
**Interaction probability**

Ultra-light dark matter



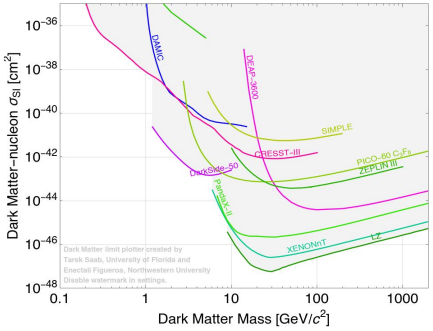

*PhysRevLett.132.131004*

Light dark matter

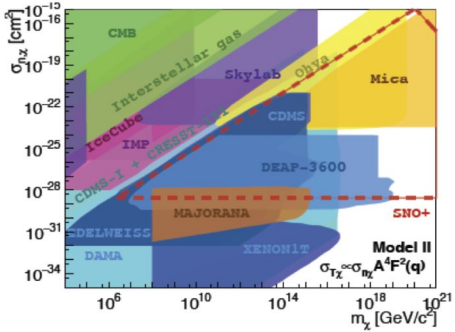



*arXiv:2312.13342*

WIMPs




Ultra-heavy dark matter




*SNOWMASS, Cosmic Frontier report (2023)*

**Mass**

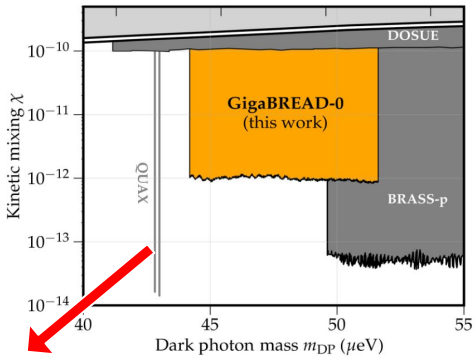
**> 80** orders of magnitude in **mass** and **thousands** of **theoretical models** to explore

**Drawing a line in these plots takes years of work**

# But… we have some ideas of what is not!

Interaction probability

Ultra-light dark matter

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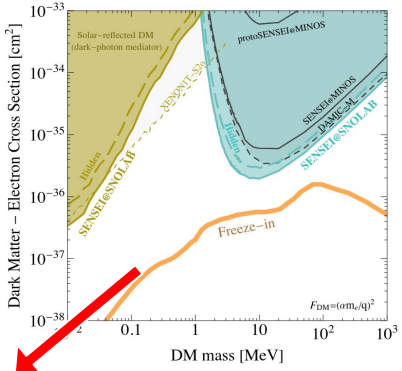


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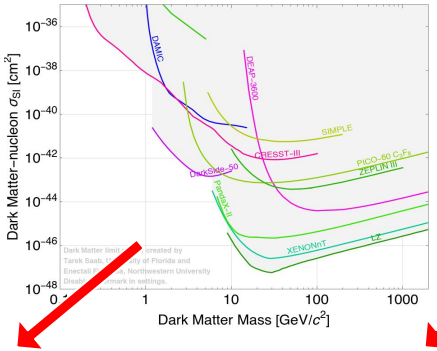


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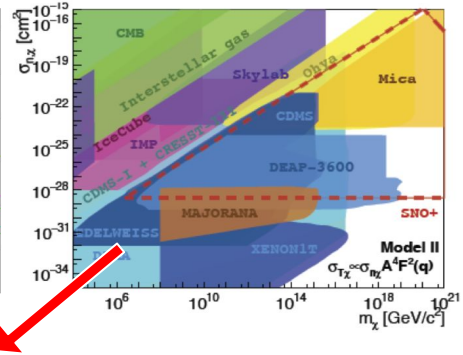



SNOWMASS, Cosmic Frontier report (2023)

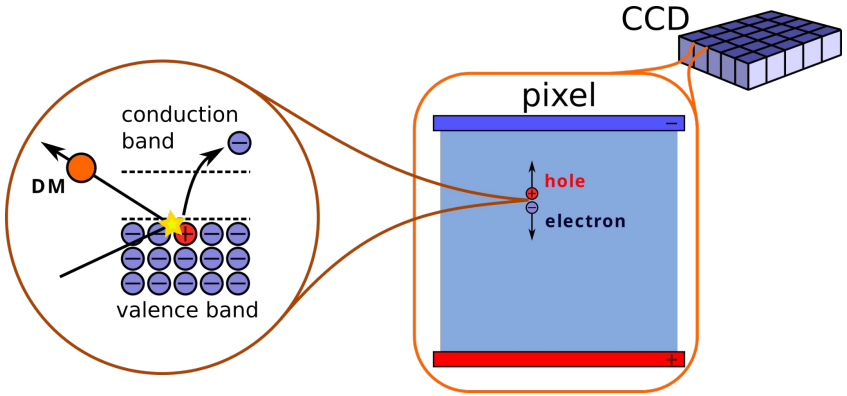
Mass

We need **bigger** and **more sensitive** detectors to push these limits

We all want to **find dark matter**. We are **running** a race! New detectors, new runs, new analysis every year.

# Skipper-CCDs: a (rather) new approach

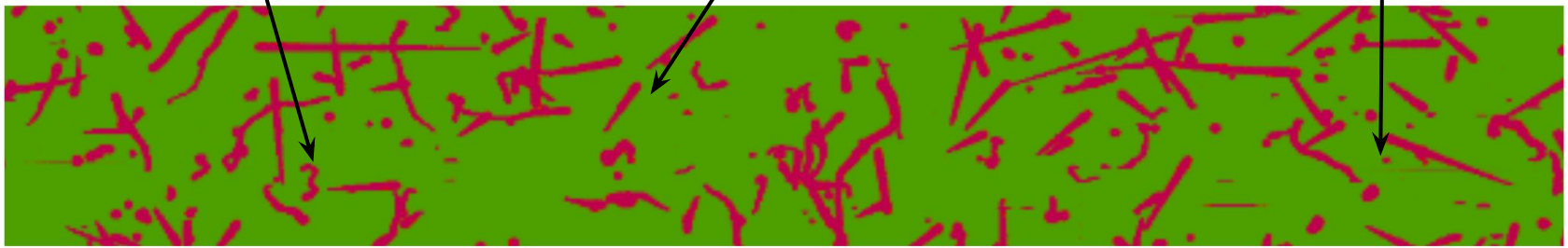
**New generation** Charge Couple Devices (**CCD**)
Pixeled silicon detectors
S. Holland (LBNL) Design
First demonstrated in **Fermilab** (Tiffenberg et al.)




Electrons (curly tracks)

Muons (straight tracks)

X-rays / γ-rays (point-like events)



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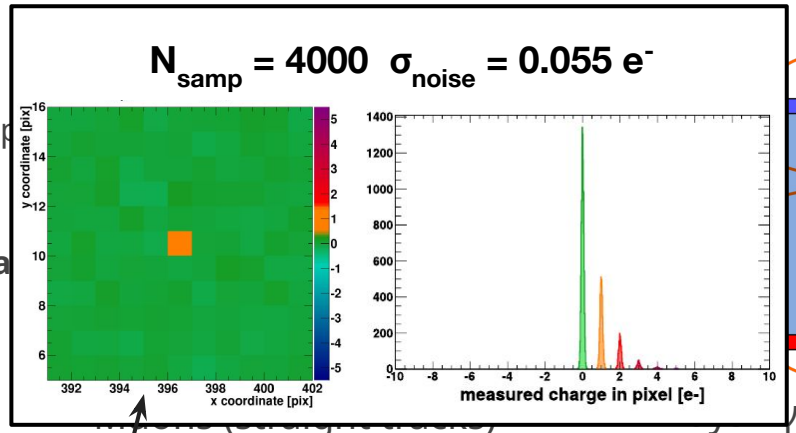


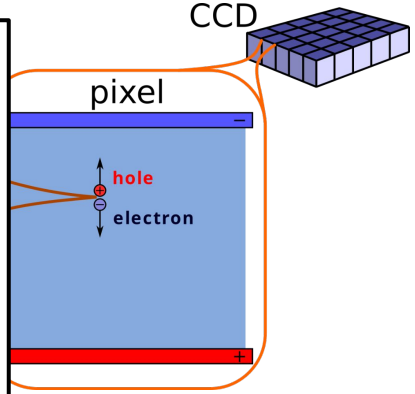


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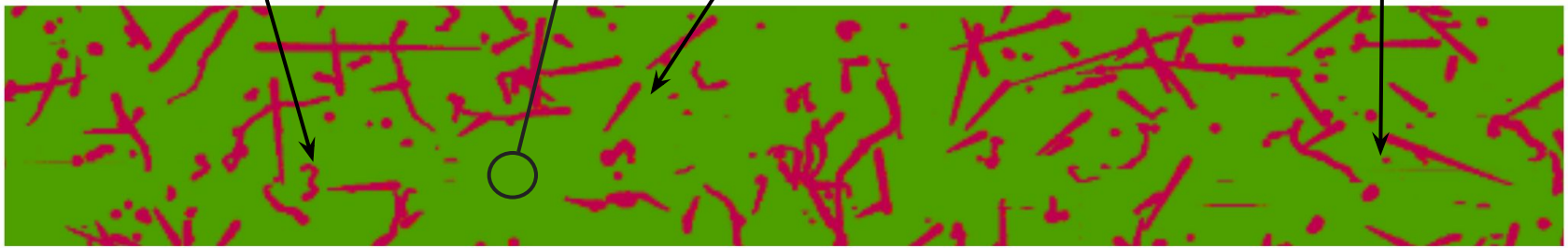

# **SENSEI** to push **sensitivities…**

**First** experiment using **skippers for dark matter**

**40 g** of mass (19 CCDs) after **3** commissioning **campaigns**

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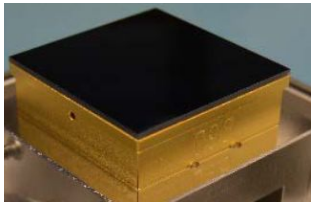
**First** experiment using **skippers for dark matter**

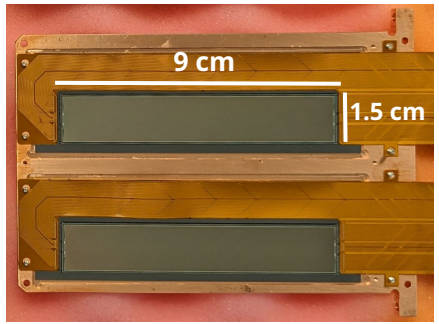
**40 g** of mass (19 CCDs) after **3** commissioning **campaigns**

**Lowest dark current on silicon detectors (1 e-/pixel every 200 years)**

**Best constraints in Light dark matter on 2023-2024!!!!**



LSST focal plane CCD DC ~ 1000 $e^-$/pix/day

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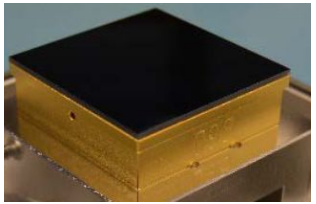

LSST foc
plane CC
DC ~ 10C
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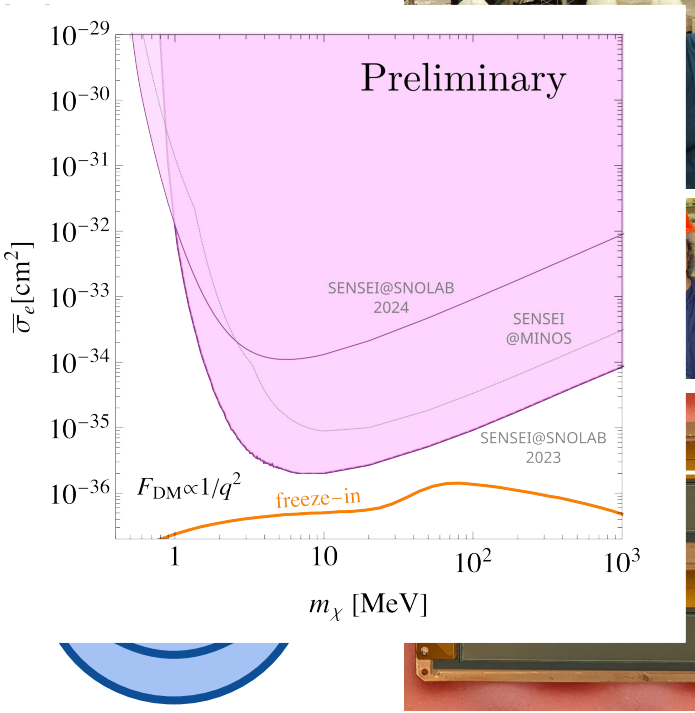
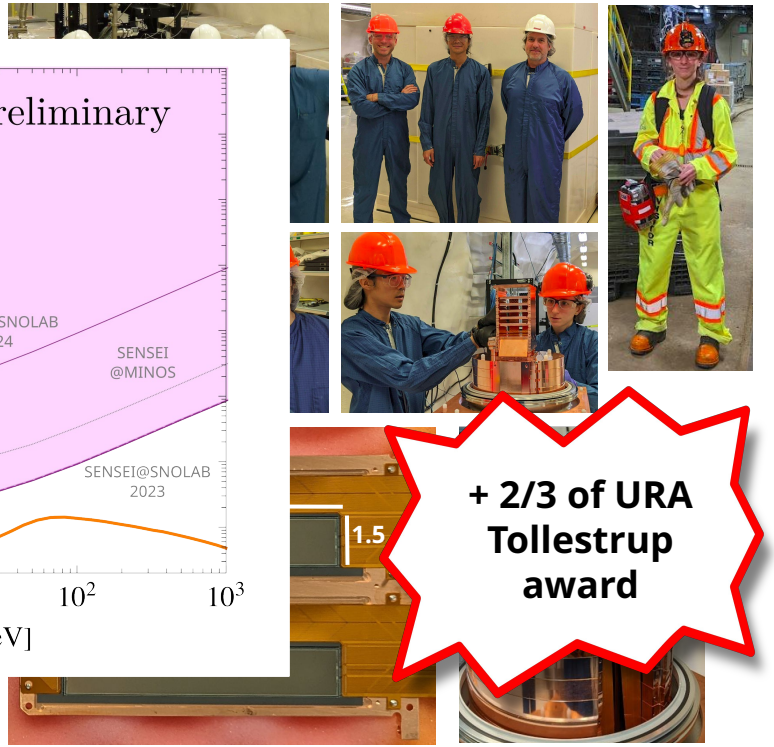
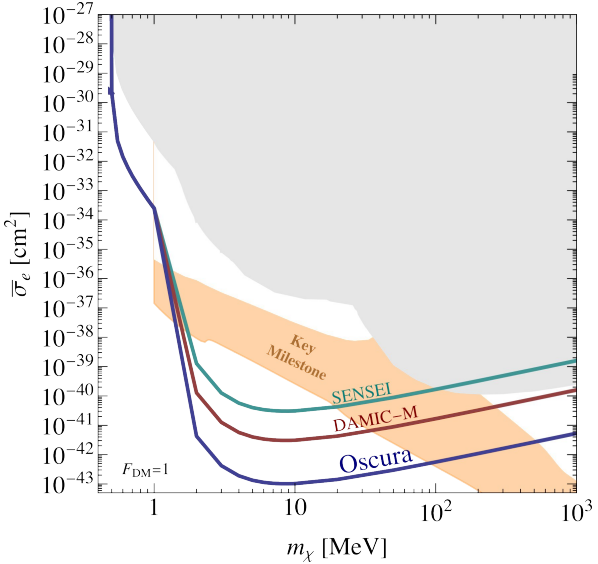



**+ 2/3 of URA Tollestrup award**

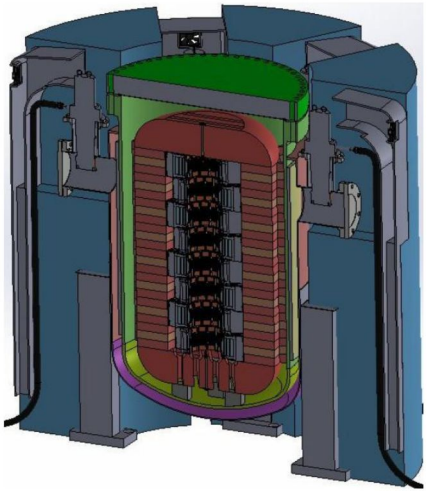
# **OSCURA** to make it **BIG**

**10 kg of skipper-CCDs**





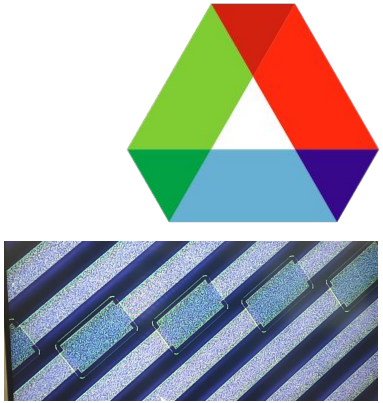
$LN_2$ pressure vessel @ 450 psi

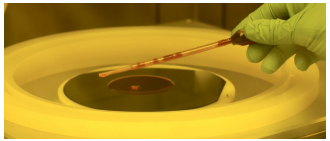


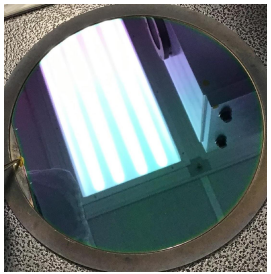
# **OSCURA** to make it **BIG**

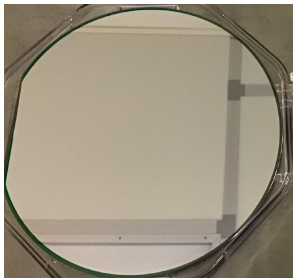
10 kg of skipper-CCDs

**New low-background compact packages**





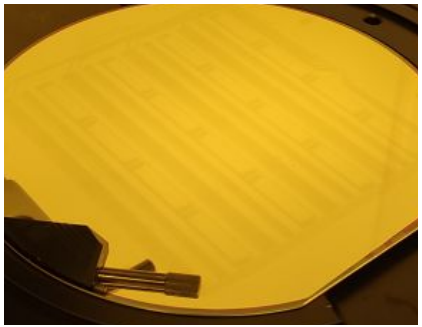


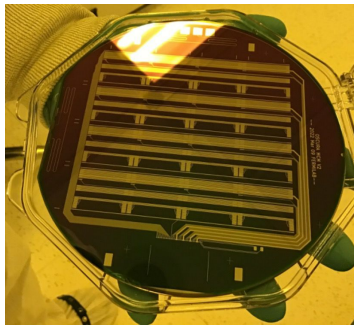
# **OSCURA** to make it **BIG**

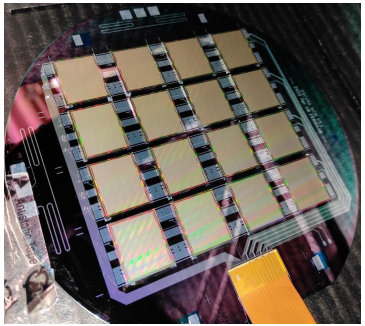
10 kg of skipper-CCDs

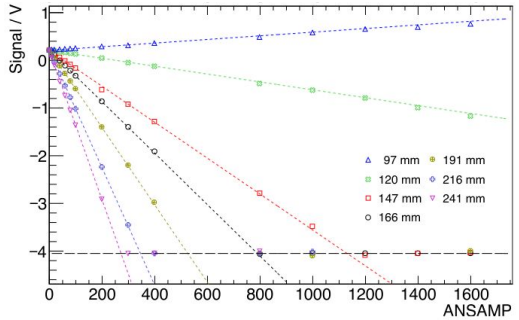
New low-background compact packages

**Silicon multi-chip modules to scale 2 orders of magnitude in mass**









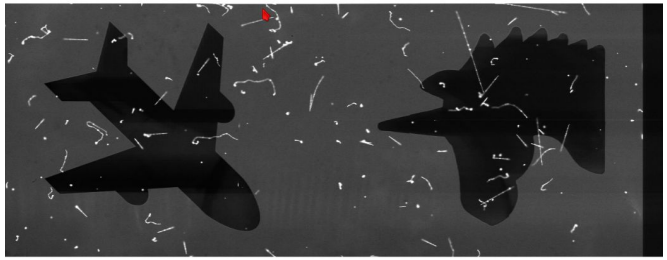
# **OSCURA** to make it **BIG**

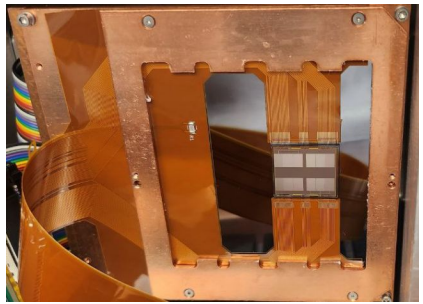
10 kg of skipper-CCDs

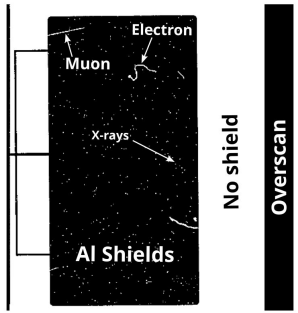
New low-background compact packages

Silicon multi-chip modules to scale 2 orders of magnitude in mass

**Aluminum shield to reduce the backgrounds orders of magnitude**







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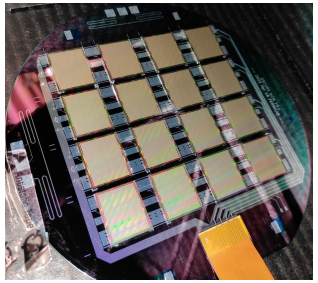
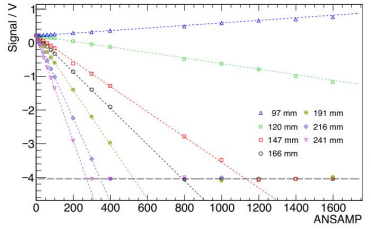
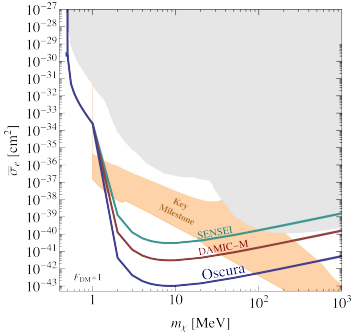
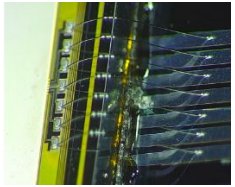
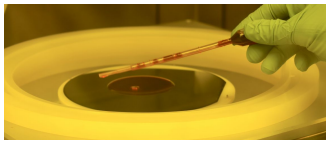


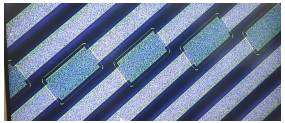
## Silicon multi-chip interconnect



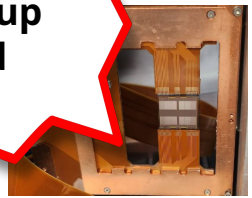



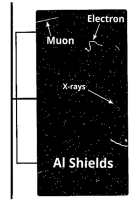


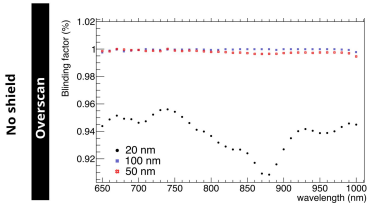


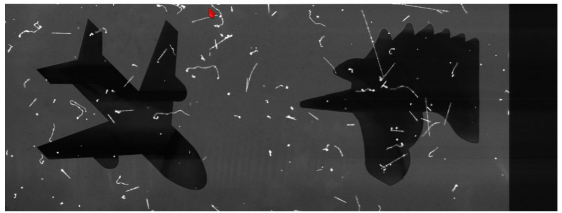
**+ 1/3 of URA Tollestrup award**

## inum light shield





# And more… exploring new ideas:

The current leading **light dark-matter** direct detection **technology** comes from **astronomical instruments**.

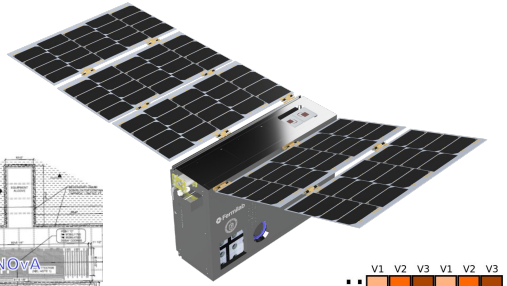
(Near)Far-future experiments will probably not come from HEP.

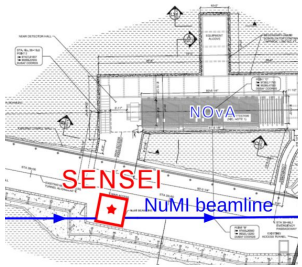
Maybe **CM, Quantum, weird thermodynamics,** etc.

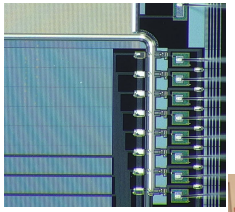
**This is the time to explore new ideas and foster cross-disciplinary collaborations:**

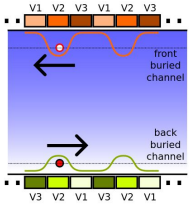
- DarkNESS
- MiliCharge @ beams and reactors
- Dual-side CCD
- MAS-CCD
- Nuclear reactor neutrinos
- Quantum skipper-CCD camera

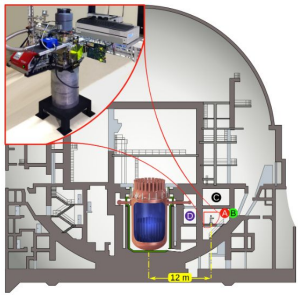
The next generation of **astronomical instruments** might come from the current leading **light dark-matter** direct detection **technology**

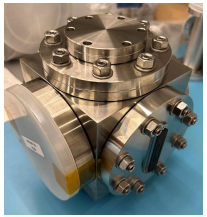






# Many thanks to:

**Fermilab, ANL and SNOLAB technical staff**

**CCD Group @ Fermilab:**

- J. Estrada
- G. Fernandez Moroni
- J. Tiffenberg
- B. Cervantes
- N. Saffold
- S. Uemura
- C. Chavez

+ our many collaborators/visitors from UBA, UNS, UNC, etc.

**SENSEI and OSCURA collaborations**

**URA Tollestrup selection committee and URA board and personnel**

**Family and friends (of course)**