Oscura in 10 Minutes

On behalf of the Oscura Collaboration

Edgar Marrufo

New Perspectives 2024

Dark Matter Evidence

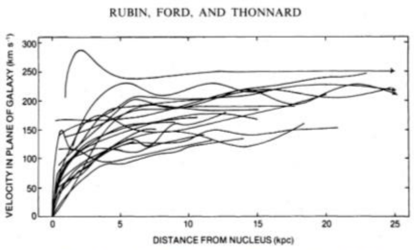
Evidence for the existence of dark matter from Astronomy/Cosmology

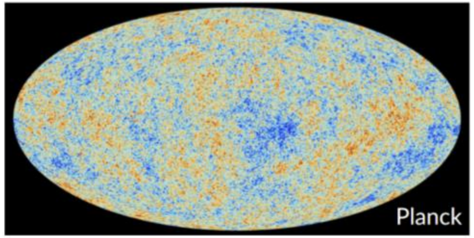
Astrophysical Probes

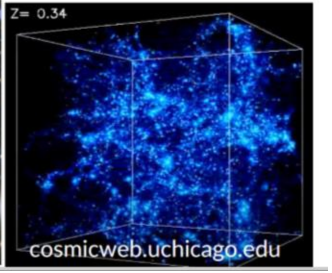
Rotation curves, cluster collisions, gravitational lensing

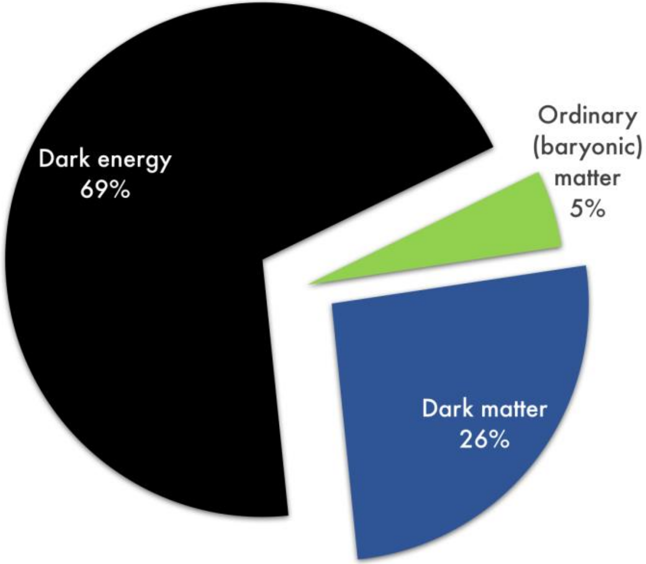
Cosmological Probes

CMB anisotropies
Structure formation



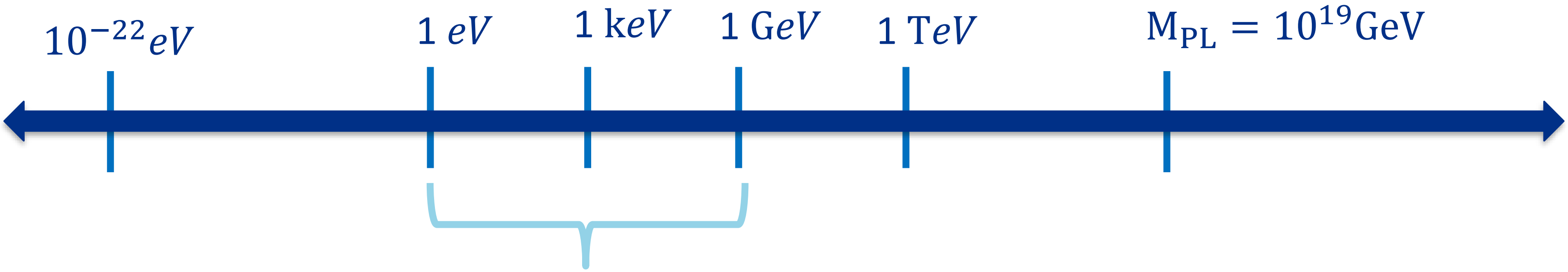






Planck Collaboration 2008

Direct Dark Matter Detection



eV-scale Bosons and Sub-GeV DM:
Absorption and Inelastic scattering as interaction mechanisms (feeble interactions)

DM Kinetic Energy

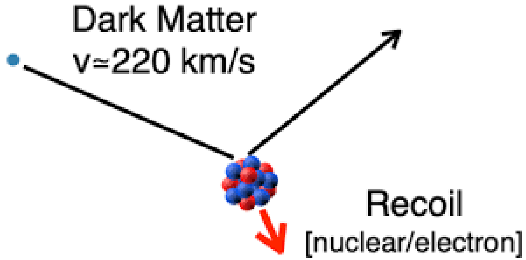
$$\Delta E \sim 10^{-6} m_\chi \sim O(eV)(\frac{m_\chi}{1MeV})$$

Imparted Momentum in Scattering

$$|q| \sim m_\chi v_\chi \sim O(keV)(\frac{m_\chi}{1MeV})$$

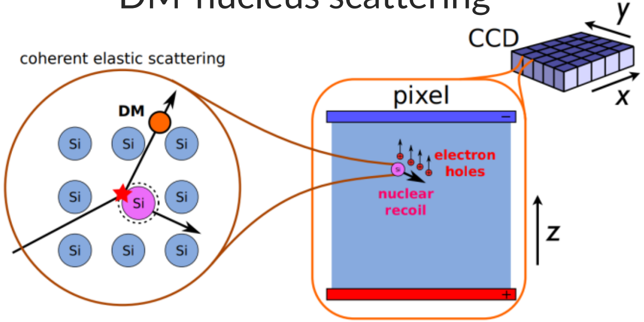
Imparted Energy and Momentum in Absorption

$$|q| \sim 0, \Delta E \sim m_\chi(O(eV))$$

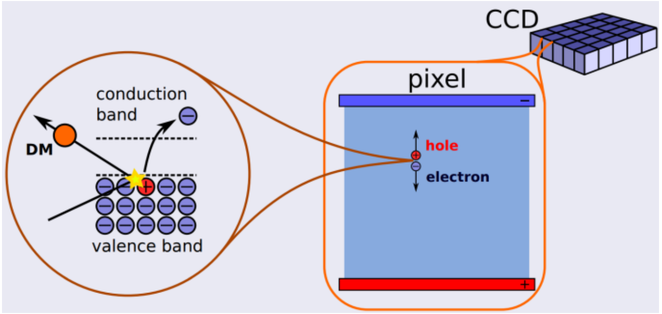


DM direct detection with CCDs

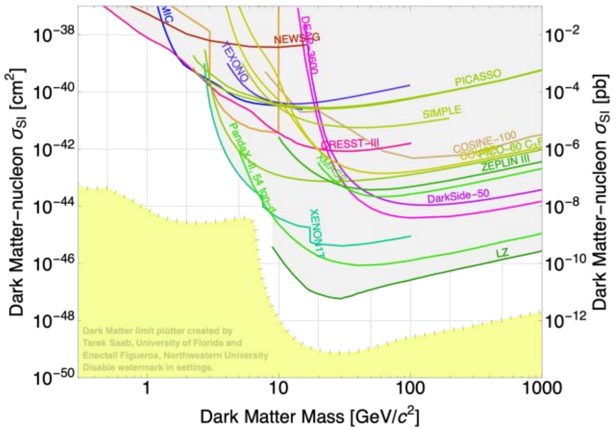
DM-nucleus scattering

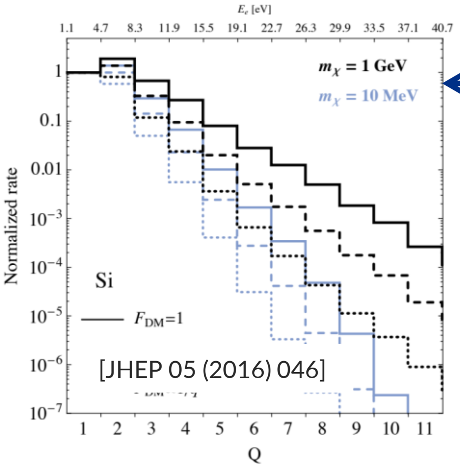


Sub-GeV DM needs other detection channels



m_χ ~ GeV → energy transfer is a few keV





DM-electron scattering
m_χ ~ MeV-GeV
→ energy transfer is a few eV

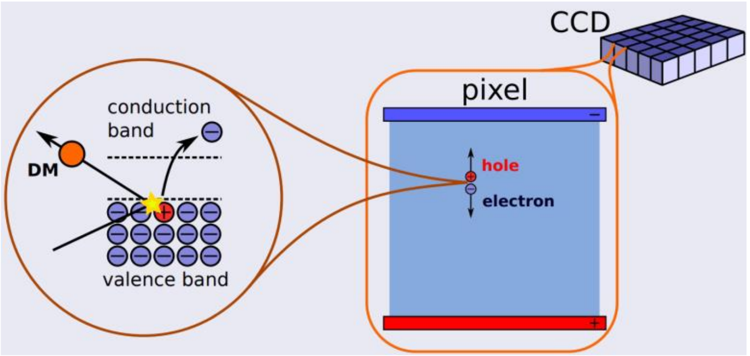
DM absorption
Bosonic DM at the eV scale
→ energy transfer equals m_χ

Fermilab

Skipper-CCDs for direct DM search

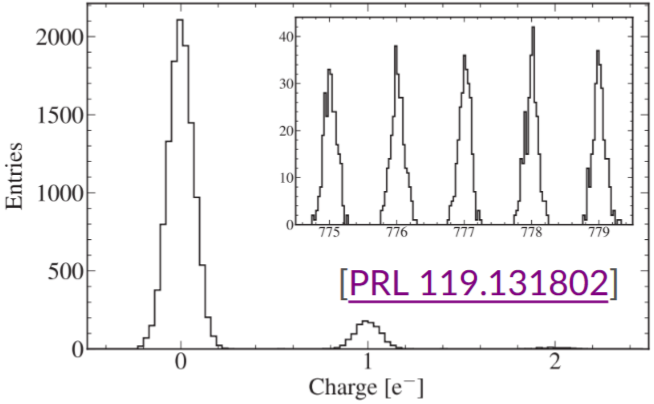
Skipper CCD qualities for direct detection:

- Energy threshold of Si bandgap(~1.1 eV)
- Low dark current (10^{-4}e-/pix/day)
- Sub-electron (~0.1e-) readout noise



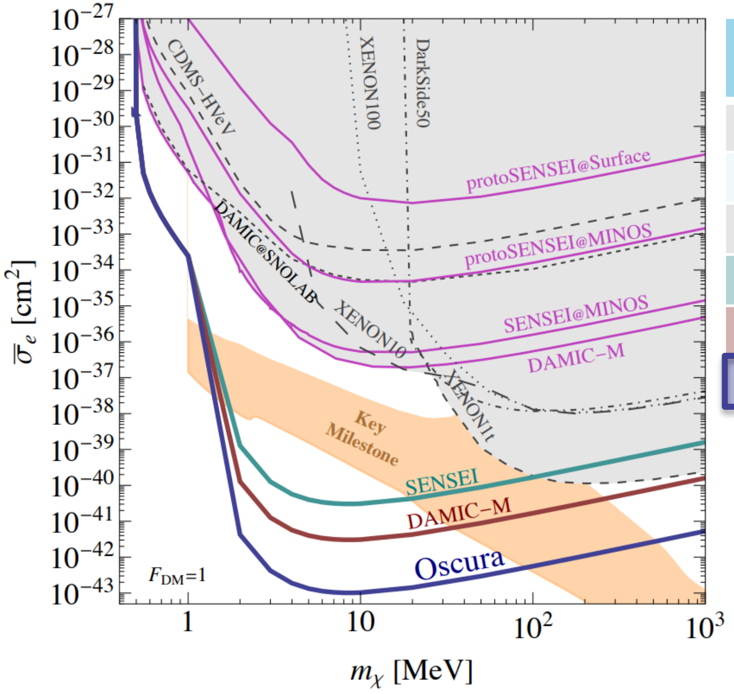
Low Threshold enables low-mass searches:

- Electron scattering of 1-1000 MeV DM
- Absorption of 1-1000 eV DM



Skipper-CCDs for direct DM search

World best limits for sub-GeV DM candidates with this technology → Ongoing program



Experiment	Mass [kg]	#CCDs	Radiation bkgd [dru]	Instrumental bkgd [e-/pix/day]	Commissioning
SENSEI @ MINOS	~0.002	1	3400	1.6 x 10^{-4}	late-2019
DAMIC @ SNOLAB	~0.02	2	~10 (exp*)	~3 x 10^{-4} (exp*)	late-2021
DAMIC-M LBC	~0.02	2	10	3 x 10^{-3}	late-2021
SENSEI-100	~0.1	50	10 (goal)		mid-2022
DAMIC-M	~1	200	0.1 (goal)		~2023
OSCURA	~10	20,000	0.01 (goal)	1 x 10^{-6} (goal)	~2028

* expected from DAMIC with standard CCDs [PRL 123, 181802/PRL 125, 241803]

Oscura builds on existing efforts

The challenges are to increase mass (from 10s to 10,000s CCDs) and to reduce the backgrounds (2 orders of magnitude)

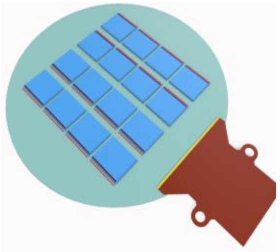
Major R&D

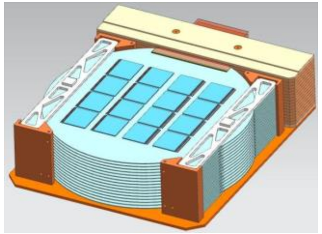
Fermilab

Oscura: 10-kg skipper-CCD experiment

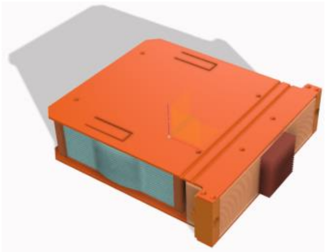
[arXiv:2202.10518]

Multi-Chip Module
(16 skipper-CCDs)

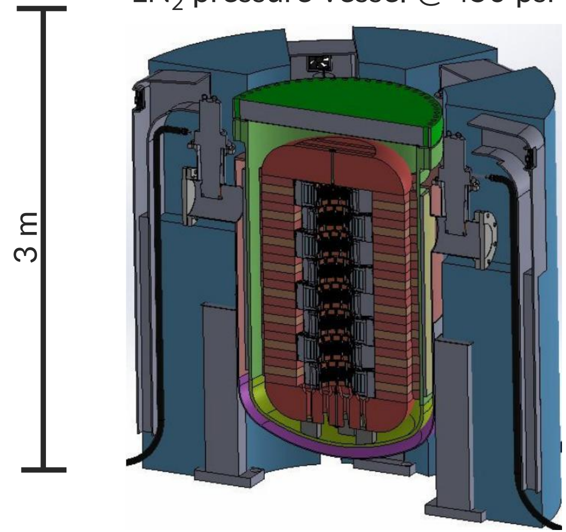




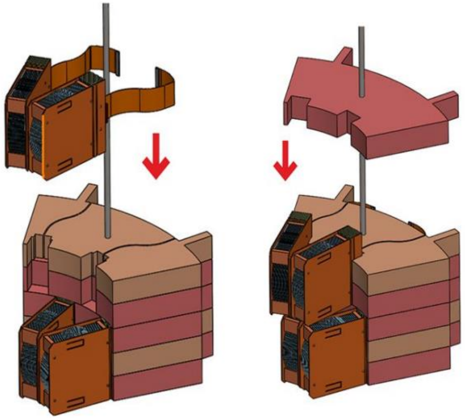
Super Module
(16 MCMs)

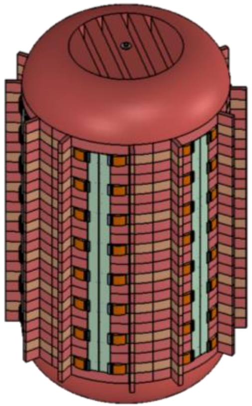


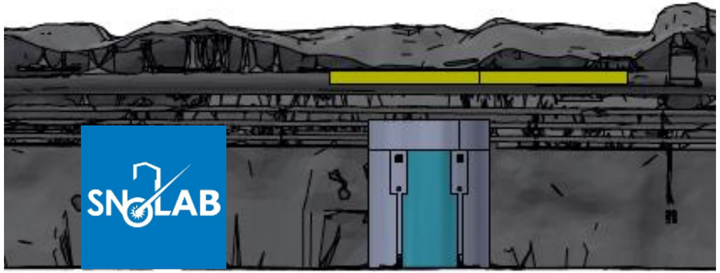
LN_2 pressure vessel @ 450 psi



Detector payload in 6 columnar slices (96 SMs)



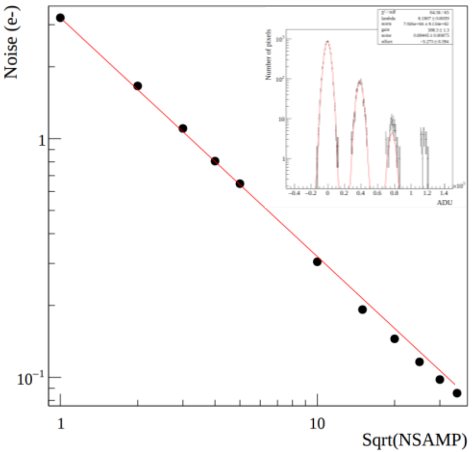


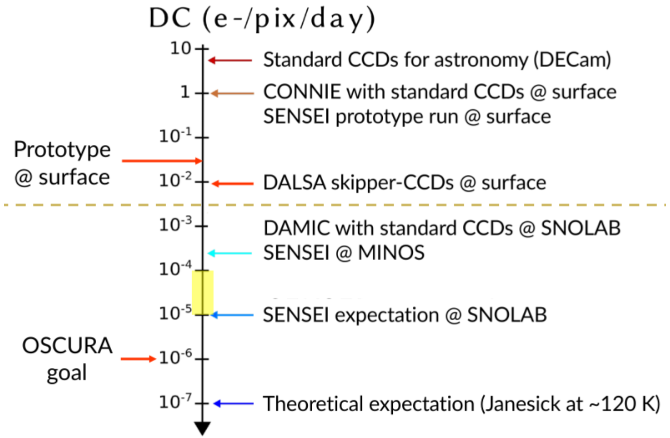


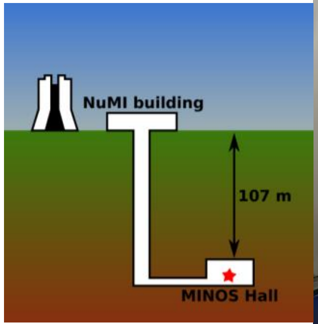
Oscura: Sensors performance

Parameter	No events with >1e-	No events with 3e- or more		Prototype	Units
Dark current	1×10^{-6}	1.6×10^{-4}	✓	3×10^{-2}	e^-/pix/day
Readout time for full array	< 2	< 5	✓	3.4 (4.2)	hours
Pixel readout rate	> 188	> 76	✓	111 (89)	pix/s
Readout noise	< 0.16	< 0.20	✓	0.19 (0.20)	e^- RMS
Spurious charge	$< 10^{-10}$	$< 10^{-8}$		7.2×10^{-7}	e^-/pix/transfer
Trap density with $\tau > 5.3$ ms	< 0.12		✓	< 0.015	traps/pix
Charge transfer inefficiency	$< 10^{-5}$		✓	$< 5\times10^{-5}$	1/transfer
VIS/NIR light blocking	$> 90\%$		✓	95%	

- Sensors reach sub-electron noise and meet almost all constraints to reach desired instrumental background
- Spurious charge is under study and new approaches are being implemented
- Installed underground setup at MINOS (MOSKITA) to measure the ultimate DC





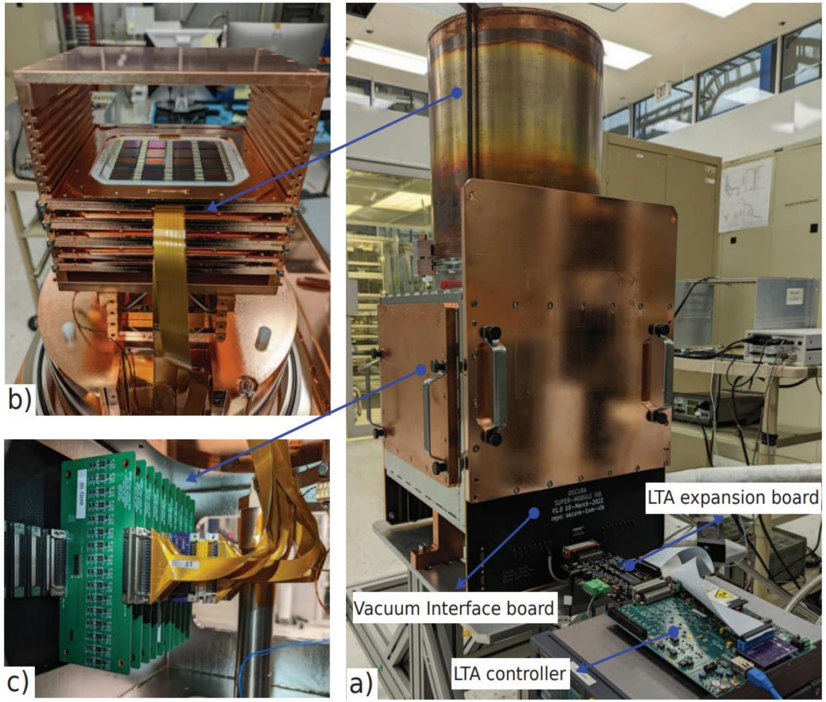


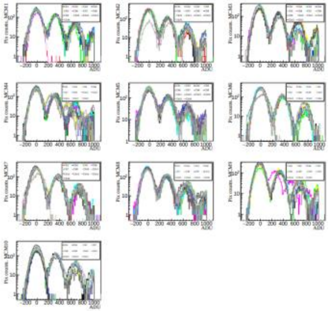
Fermilab

Oscura: Massive testing setup with 10 MCMs (160 sensors)

[JINST 18 P01040]

- Copy of SENSEI-100 vessel with 10 prototype ceramic MCMs and the discrete readout electronics
- **Largest ever built instrument with skipper-CCDs** controlled by 1 LTA → Demonstrates electronics solution

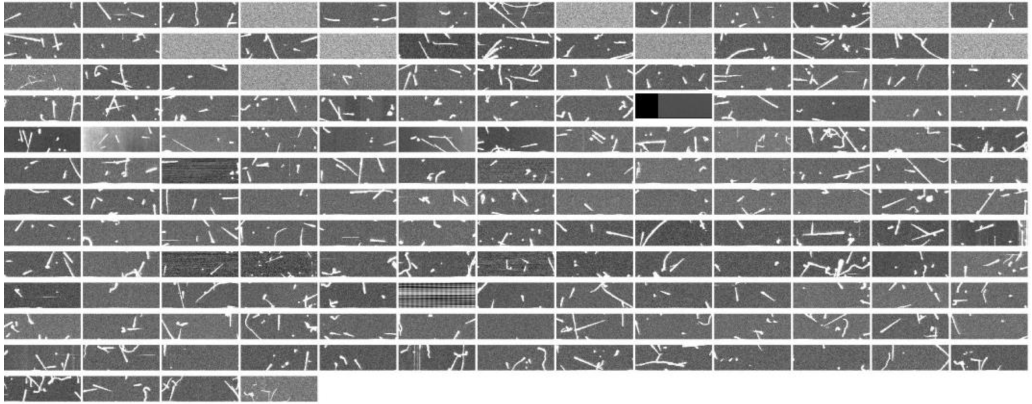




~90% of the sensors working without a preselection! This is a BIG deal!*

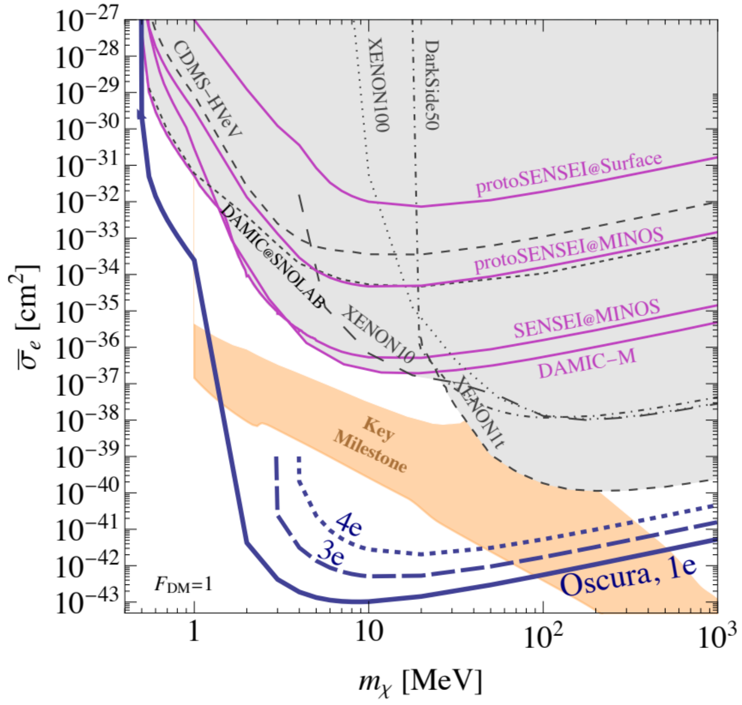
*LSST, the largest "astronomical camera" has 189 CCDs!

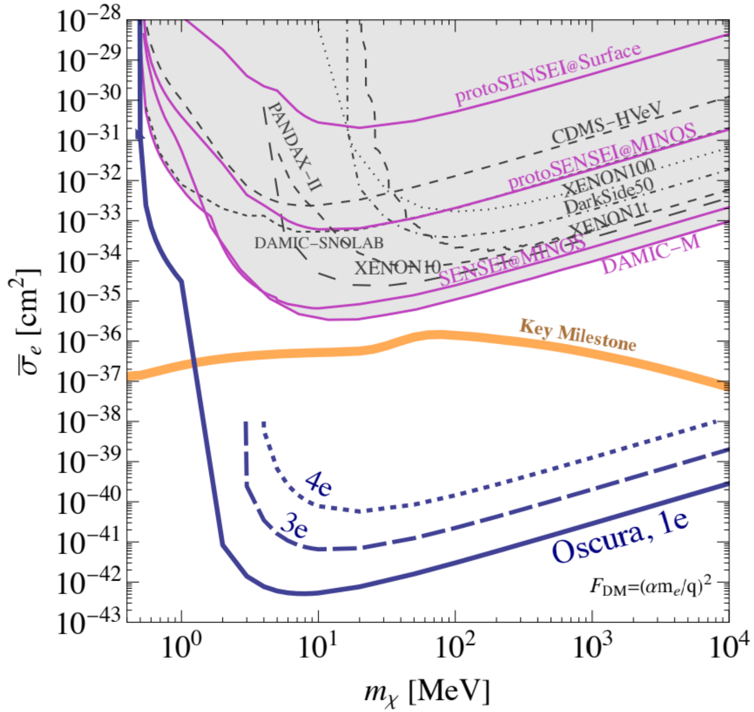
Setup is being used to develop analysis software and could be used for early science



Oscura: Projected sensitivities for 30 kg-year

With the current sensors performance, we have zero background events with 4e$^-$ or more (4e curve)





DM-electron scattering mediated by a heavy (left) or light (right) mediator

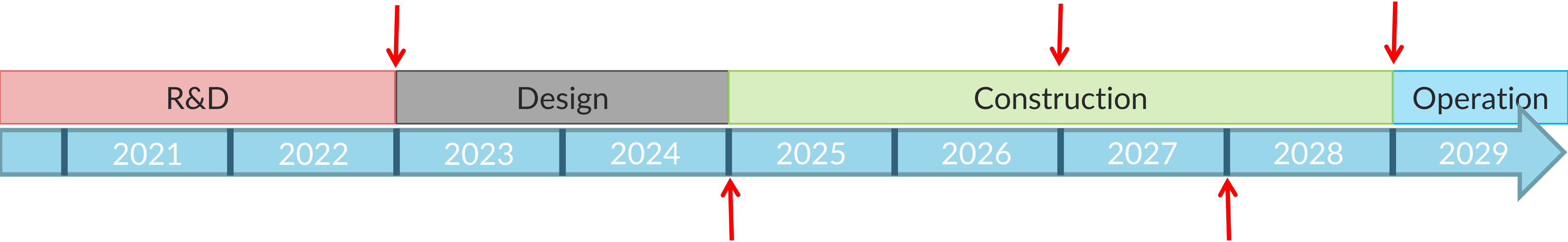
Fermilab

Oscura: Timeline and goals per period

- ✓ Evaluation of new sensors
- ✓ Demonstration of MCM readout
- ✓ Decision on cold-end electronics
- SM full backgrounds simulation

Sensor packaging facility
Integration test (10%)

Sensors, cryostat and electronics at SNOLAB for assembly



Sensor preproduction
Operation of SM in LN2
Project Execution Plan

Full DAQ
Shield at Snolab

✓ - Achieved

* Technically driven Oscura timeline

Take-home messages

- Oscura is the next step in skipper-CCD DM searches (10 kg)
- It will provide unprecedented sensitivity to sub-GeV DM interacting with electrons
- R&D work has been successfully completed and main risks have been addressed
- Oscura is moving into design phase, with plan to begin construction in FY25 and operations at SNOLAB in FY29
- With a partial load, Oscura can do early science producing very competitive results

Stay tuned!

THANK YOU!