Development and characterization of novel electronics for the search of dark matter for DAMIC-M

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for the ELBERETH Conference 2020

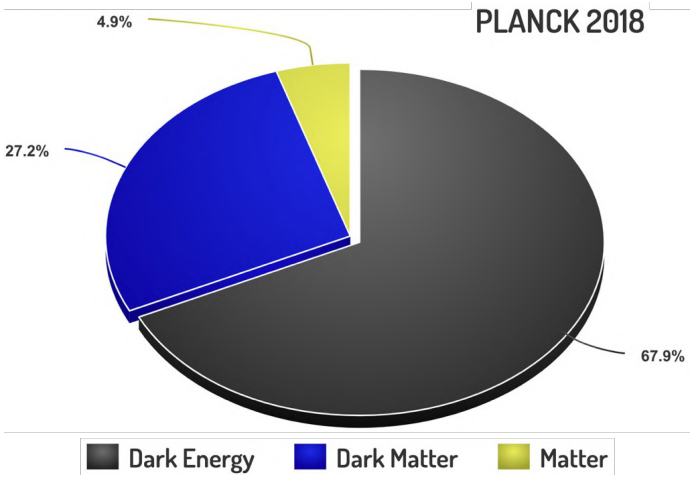
Dark Matter (DM) motivation

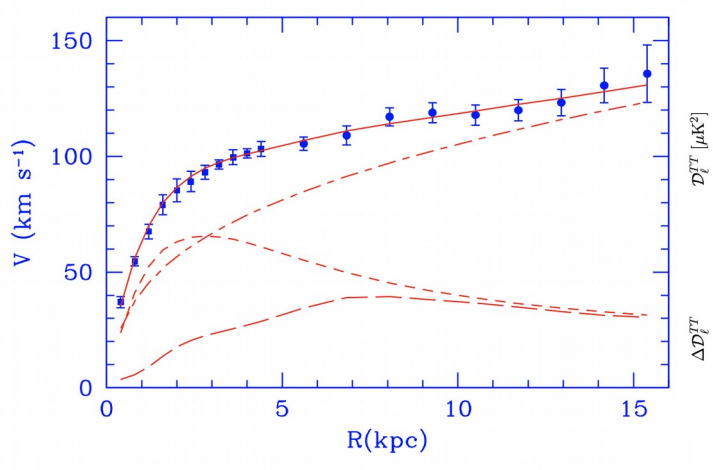
DAMIC : ***DArk Matter*** *In CCDs*

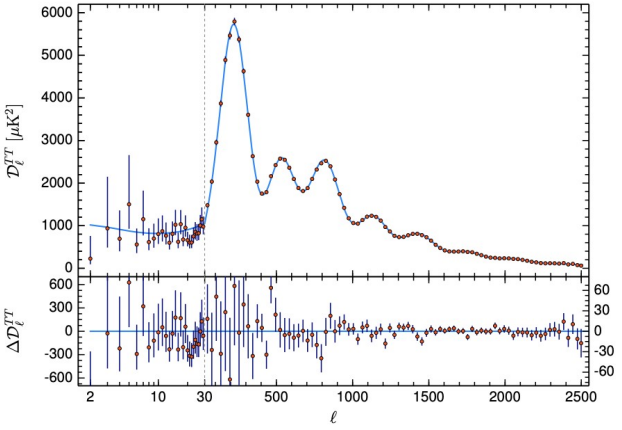
Evidence:

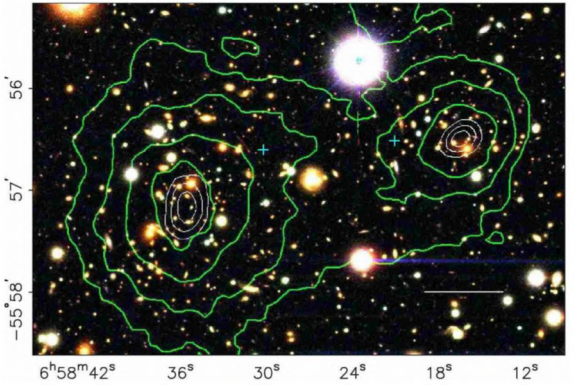
- Galaxy rotation curve [1]
- CMB power spectrum [2]
- Weak field lensing of colliding galaxy clusters [3]
- Mass to luminosity ratio[4]

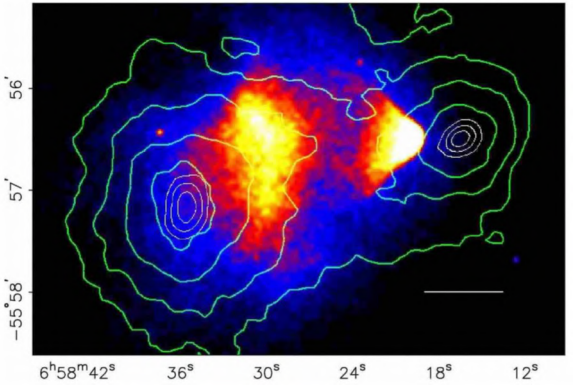
Up to date status:





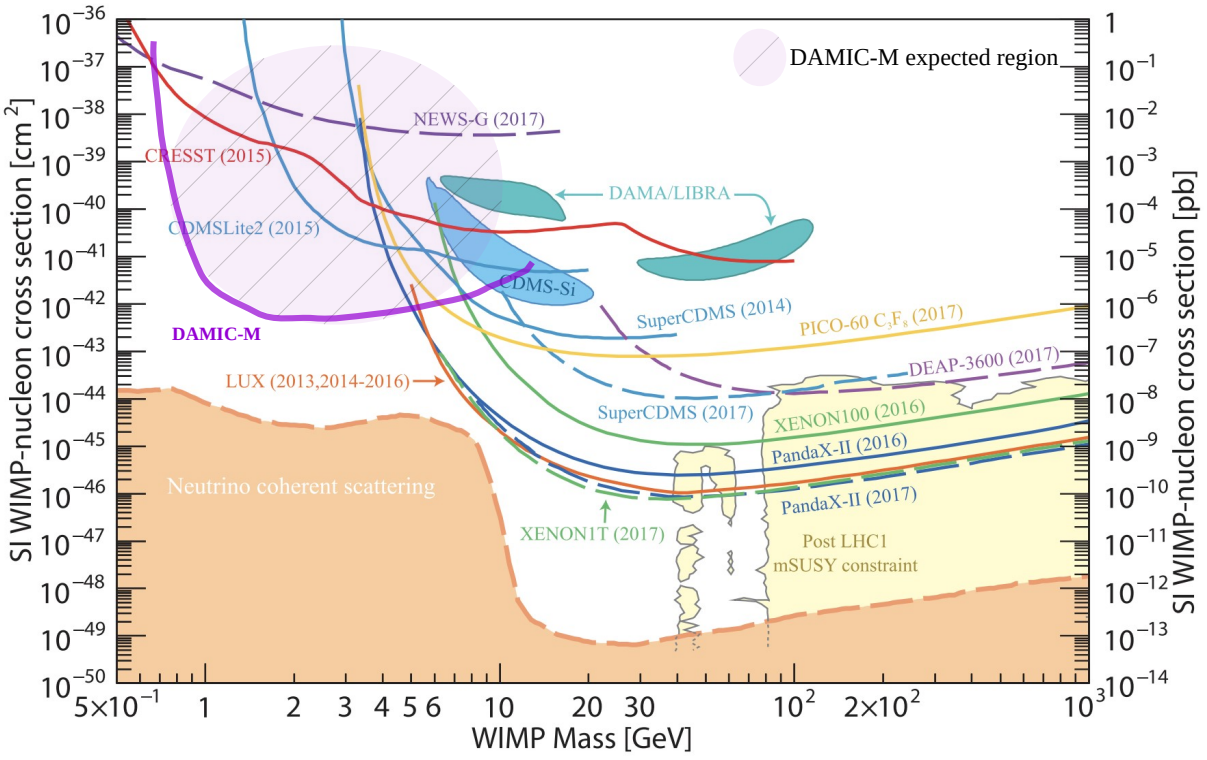






DM current status

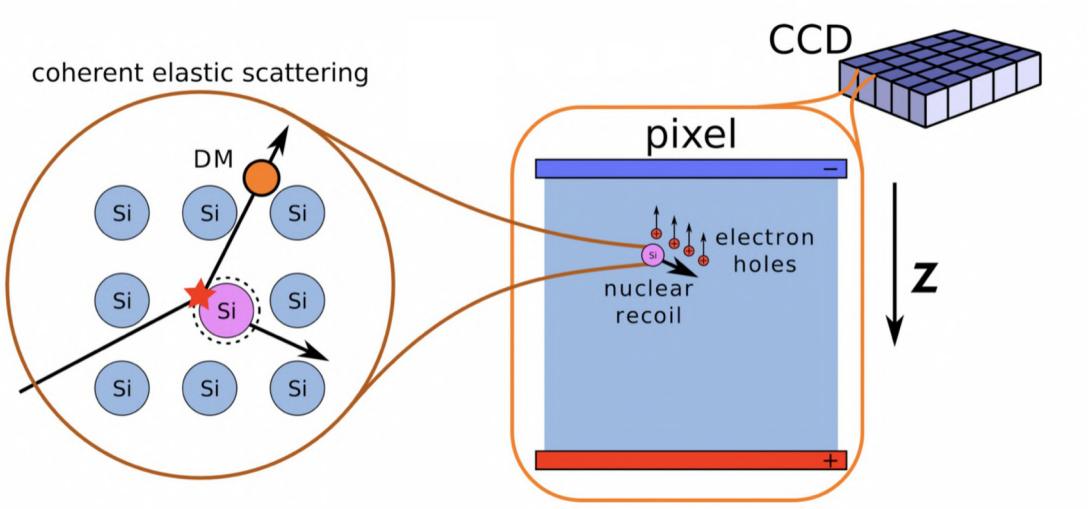
DAMIC-M: search for light WIMPs and hidden sector DM with mass <10GeV.



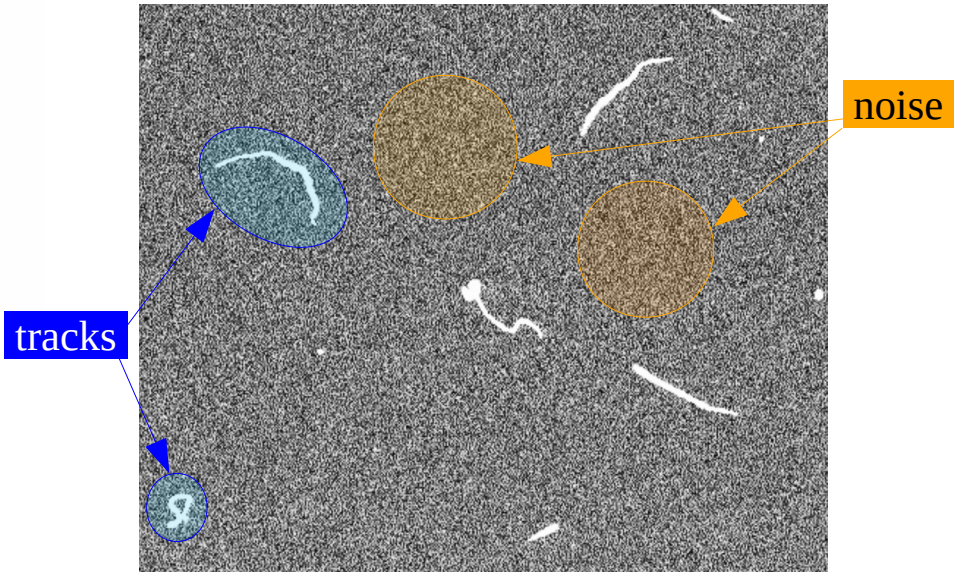
WIMP-nucleon cross sections for Spin-Independent coupling versus mass [5,6]

Charge Coupled Device (CCD)

DAMIC : *DArk Matter* ***In CCDs***



- Direct detection: χ + SM → χ + SM
- CCD is made of silicon, separated in pixels
- Incident particles deposit energy in the bulk



Real CCD image on surface level

CCD Operation

Exposure

charge generation
and collection

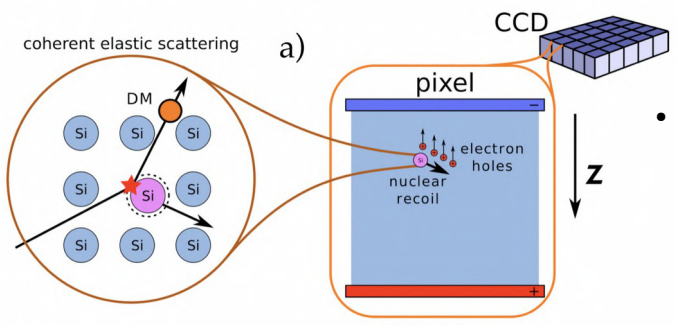
* Static condition of the detector

Readout

charge transfer
and recording

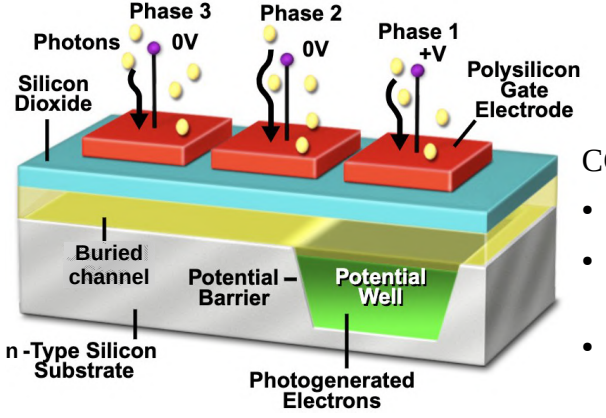
CCD Operation

1. Charge generation - Exposure



- Electron-hope pairs generation

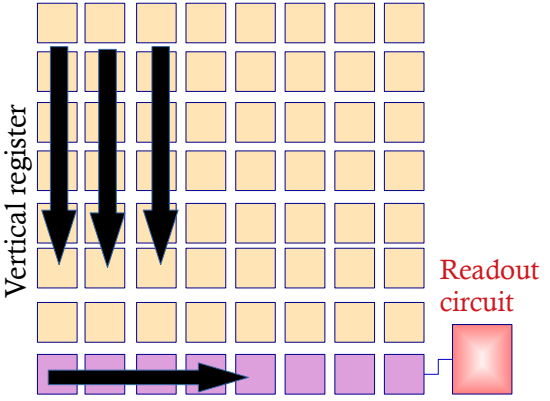
2. Charge collection - Exposure

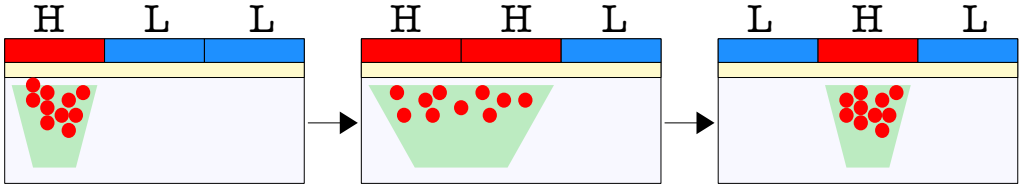


CCD single pixel.

- 3 electrodes: 1 “active”
- Charge collection under the active electrode
- Size: 15 µm x 15 µm

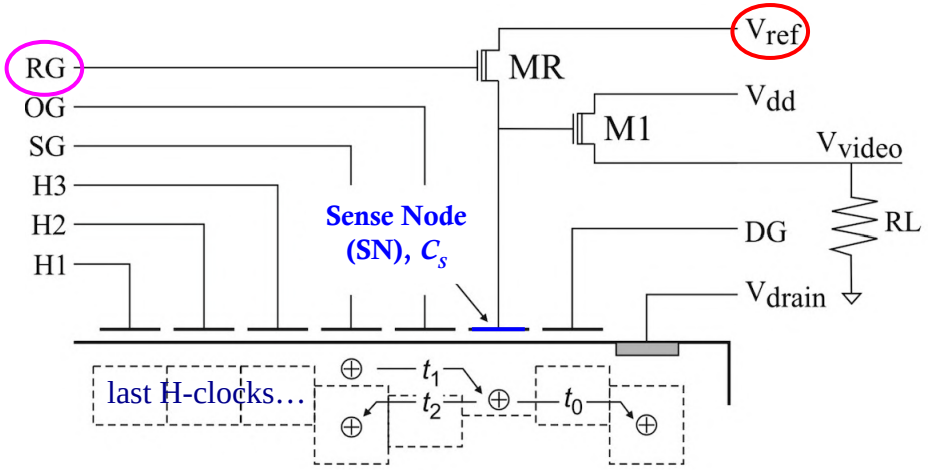
3. Charge transfer - Readout

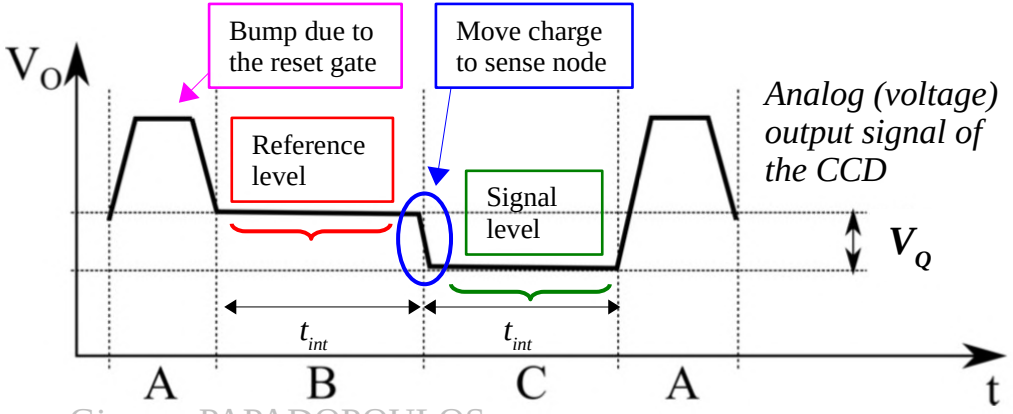




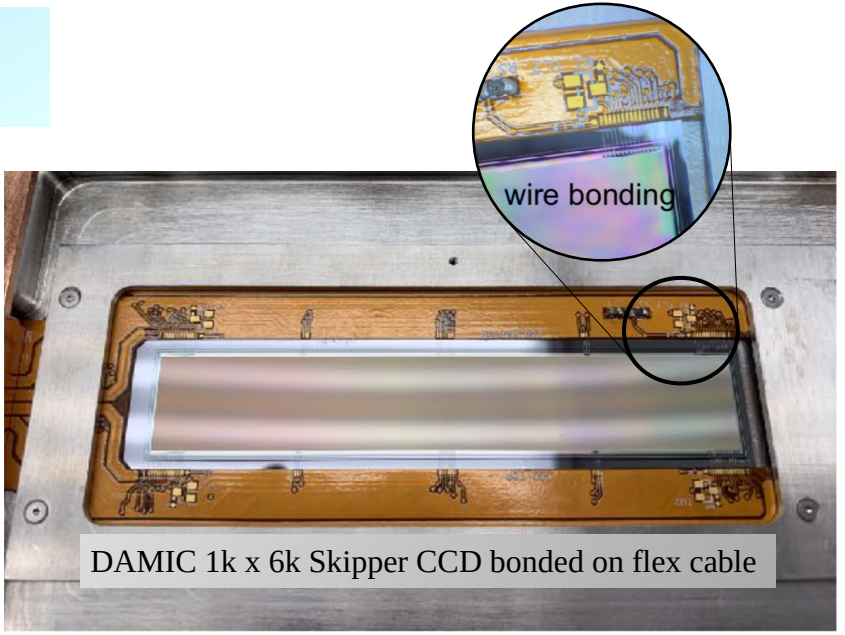
- Move the charge by alternating the voltage of the electrodes (vertical and horizontal clocks) to the Readout circuit

CCD readout circuit





Analog (voltage) output signal of the CCD



DAMIC 1k x 6k Skipper CCD bonded on flex cable

Reaching the end of the CCD, there is a circuit to convert the pixel charge into voltage.

- The Reset Gate sets the Sense Node at a voltage reference value. This will cause a bump in the output signal which will decay quickly, resulting in an outcome reference level *around* Vref.
- The charge Q is injected to the SN changing the voltage by $\boldsymbol{V_Q = Q / C_S}$, where C_S is the capacity of the sense node which is known.
- Measure and subtract the reference and signal levels to find the $\boldsymbol{V_Q}$.

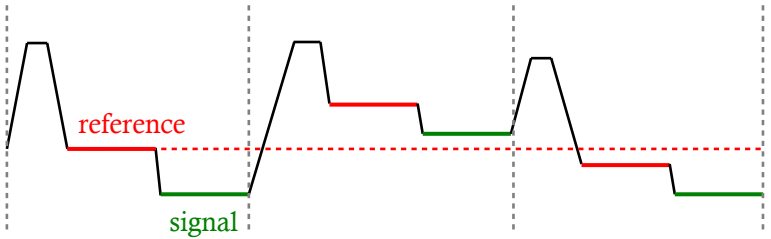
CCD noise sources

Dark current

- Thermally generated electrons in the bulk of the CCD
- Linear dependence on time → limits the exposure duration. The longer the exposure, the worse the Signal to Noise Ratio.
- Lower the temperature (~100-140K) to decrease the dark current

Reset or *kTC* noise

- After reset pulse thermal noise is generated by the resistance of the reset FET. The small capacitance of the Sense Node ~fF leads to a significant uncertainty of the reference level.
- *Correlated Double Sampling* (CDS): measure both the reference and signal levels and subtract them to eliminate the reset noise.

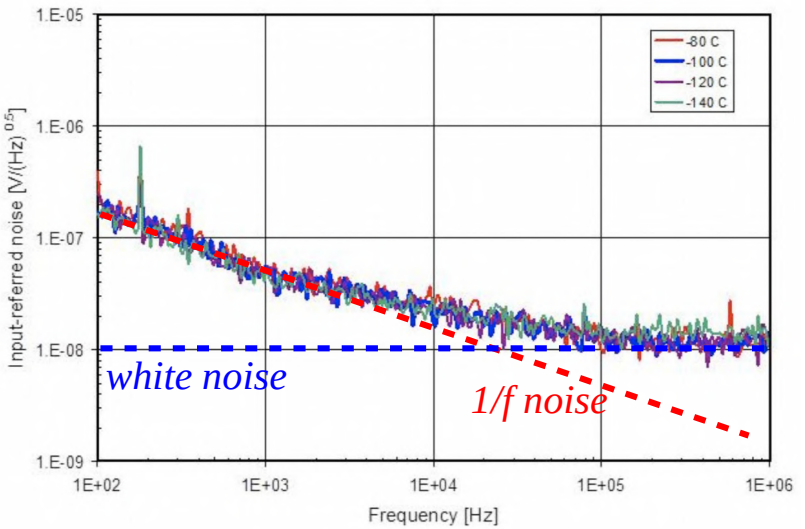


White noise

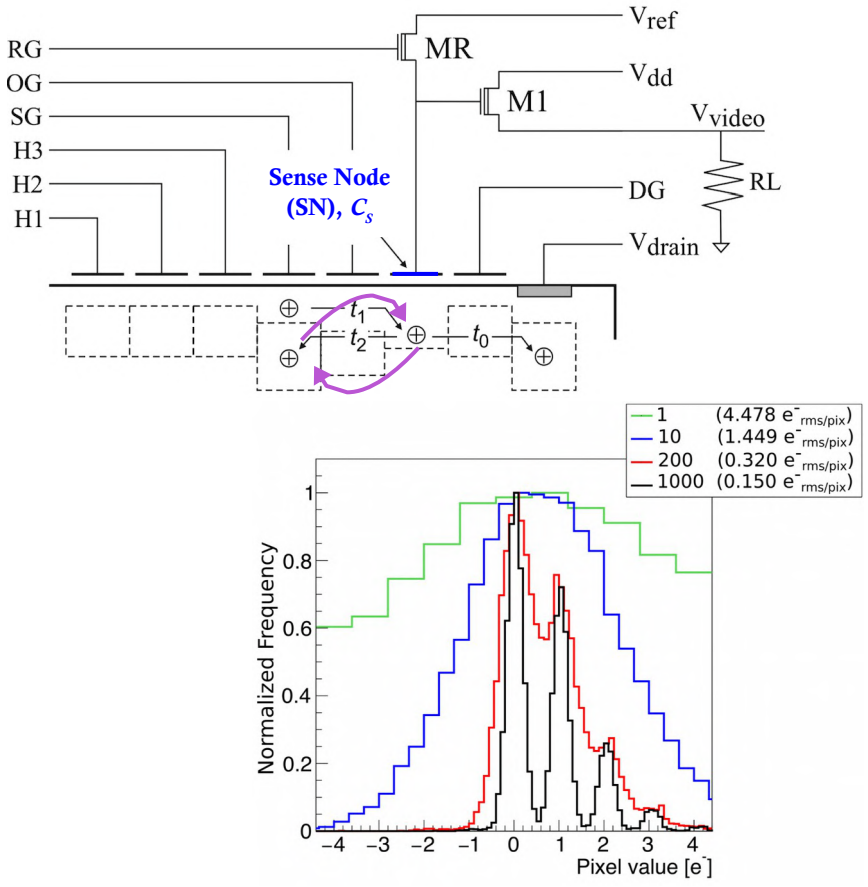
Thermal noise generated by the output amplifier MOSFET.

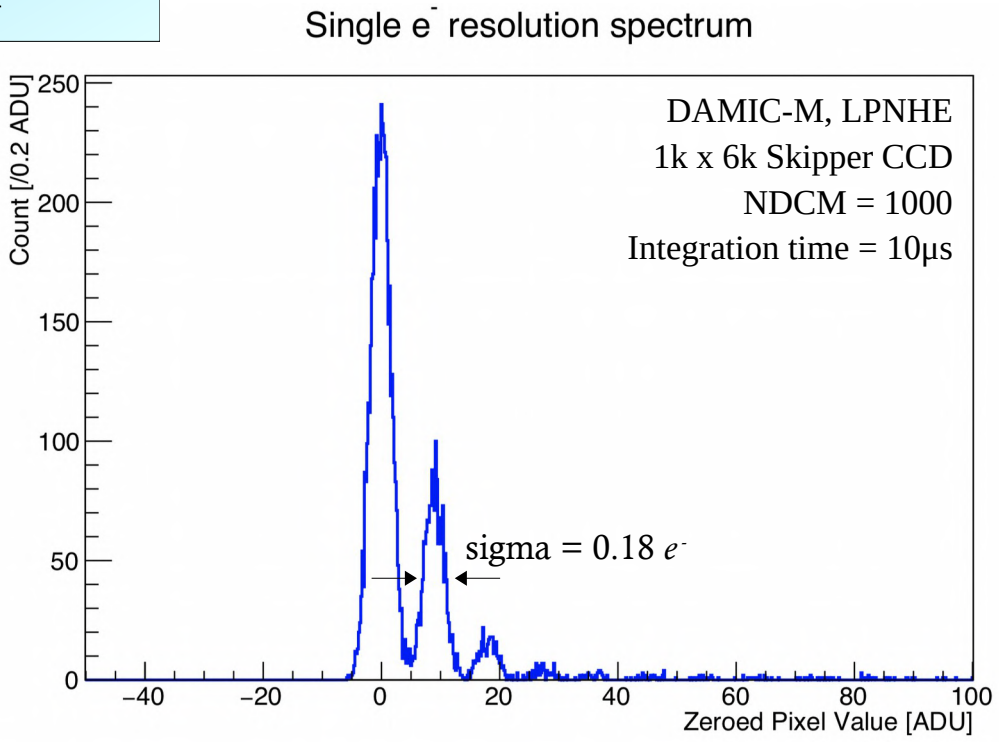
Flicker or *1/f* noise

- The *flicker* noise depends approximately on the inverse of the sampling frequency.
- Dominant up to ~0.1MHz readout speed



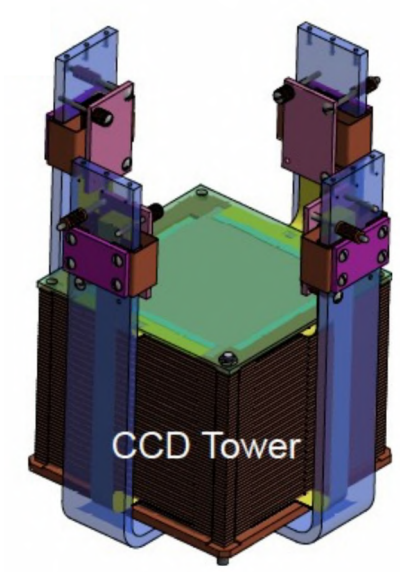
Skipper CCD – sub-e^- resolution

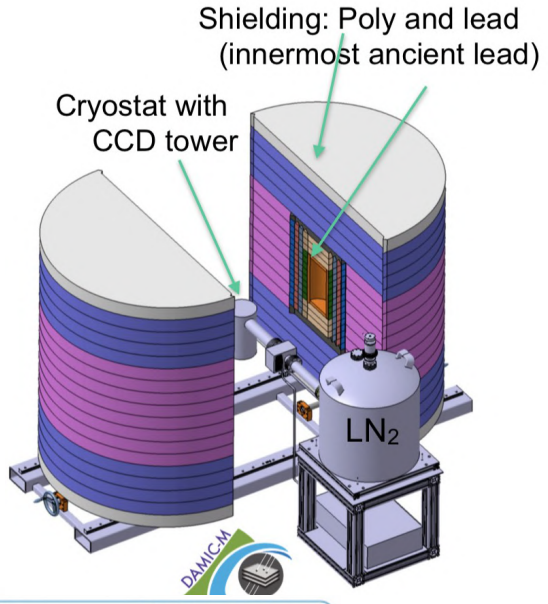


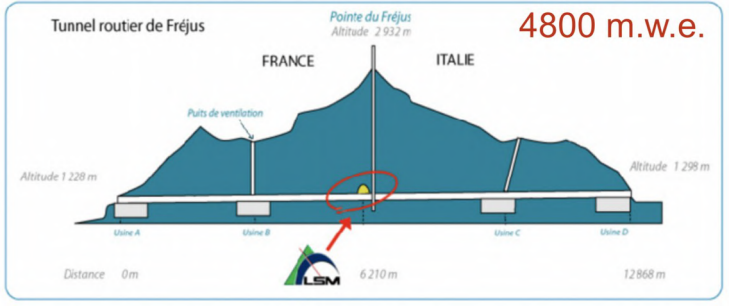


The Skipper technique allows for a Non-Destructive Multiple pixel Charge Measurement (NDCM) which reduce the electronic noise which decreases as 1/√NDCM.

DAMIC-M Overview







DArk Matter In CCDs at Modane (DAMIC-M):

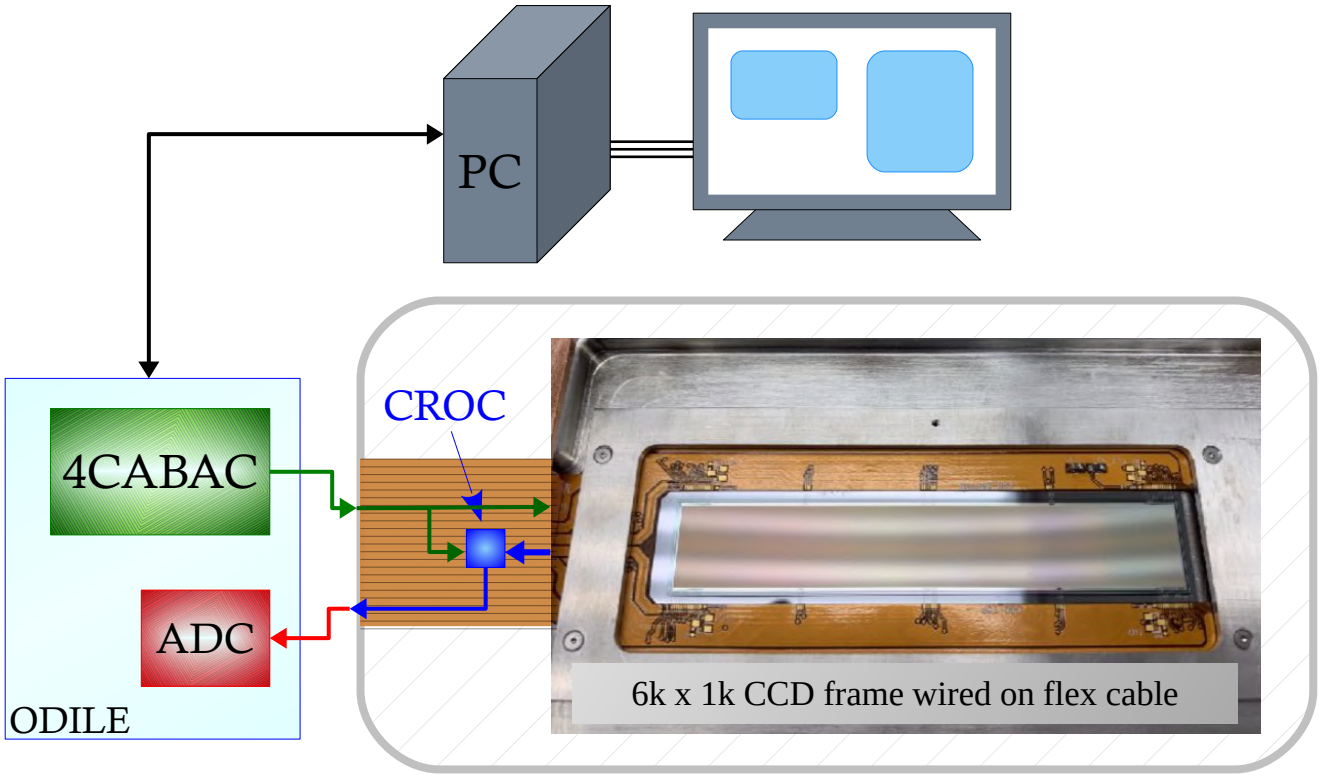
- 50 scientific grade Charge Coupled Devices (CCDs) made of Si with Skipper readout
- 36Mpix large and ~20g each, a total kg-size target mass
- Sub-electron resolution
- 0.1 event/(keV·kg·day) background

- R&D of the electronics to control the CCD
- Simulations of the detector design and shielding
- Underground Laboratory in Modane (LSM). ~2km of rock to stop cosmic background.
- Low Background Chamber (2020) test detector to evaluate new CCDs, test electronics and measure background
- Final experiment data taking will start in 2022.
- DAMIC-M will pioneer in the low mass WIMPs and hidden-sector DM research.
- ERC grant 2017

Full Setup & New Electronics

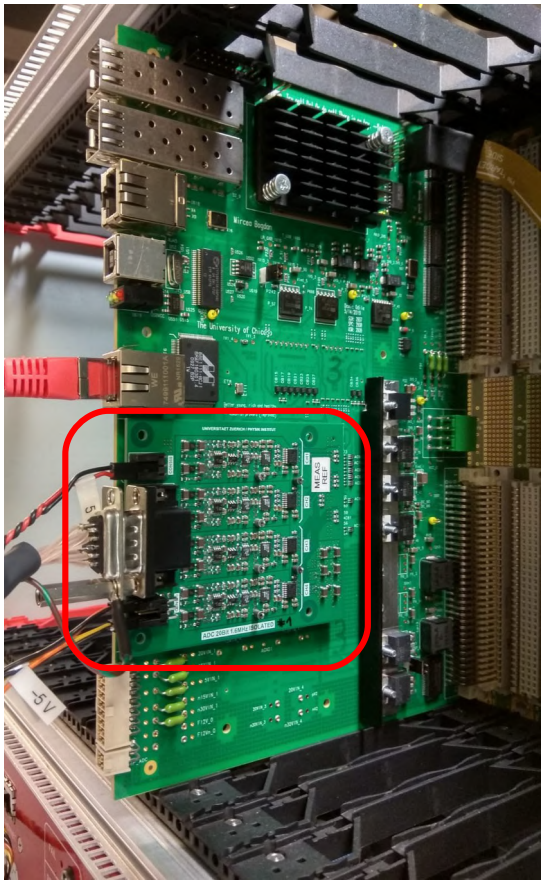
The CCD is placed in a cryostat and is controlled and readout by external electronics.

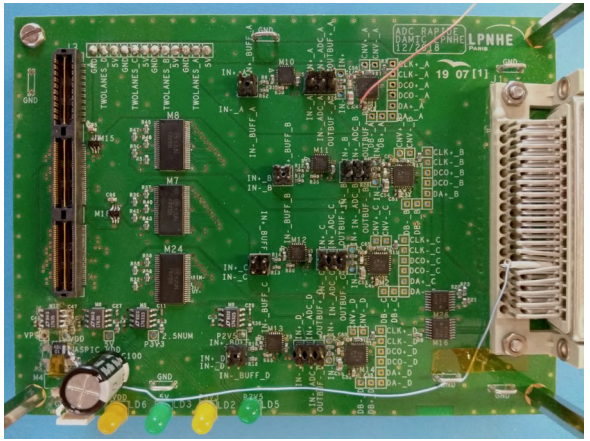
- All voltages and clocks during the expose and readout phases will be provided by the **Clocks And Biases ASIC for CCD** (**CABAC**) board.
- The **CCD ReadOut Chip** (**CROC**) will preprocess and amplify the signal to improve the Signal-to-Noise Ratio.
- An **Analog to Digital Converter** (**ADC**) will perform the transition from the analog domain to the digital one. The ADC can only apply the conversion in certain specified moments.
- Everything is going to be controlled by the FPGA, the brain of the, so called, **ODILE - Online Digital Interface for Low-noise Electronics** - motherboard

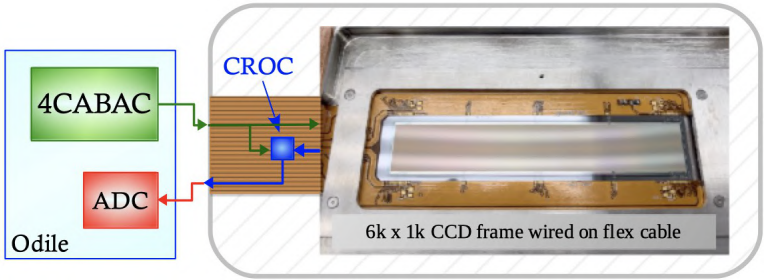


Setup of a single DAMIC-M CCD

New Electronics



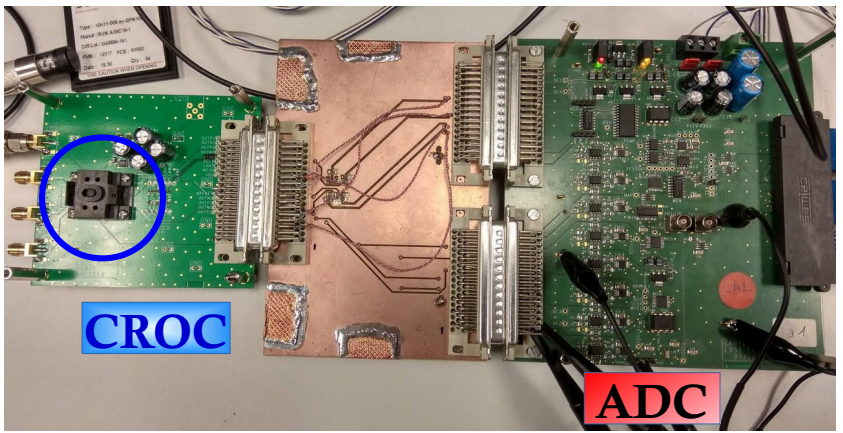




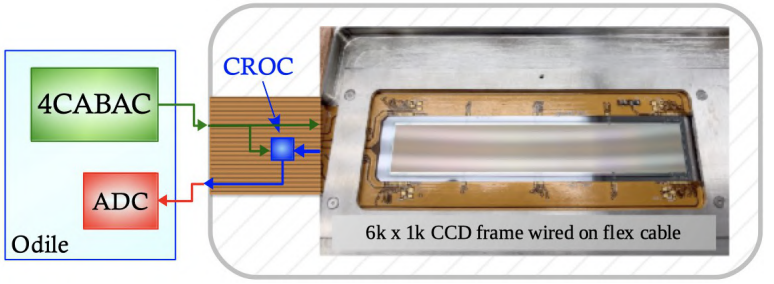
LTC2387-18 18-bit
15 MHz ADC
candidate prototype
board

ODILE board with
MAX11905 20-bit
1.6 MHz ADC
candidate

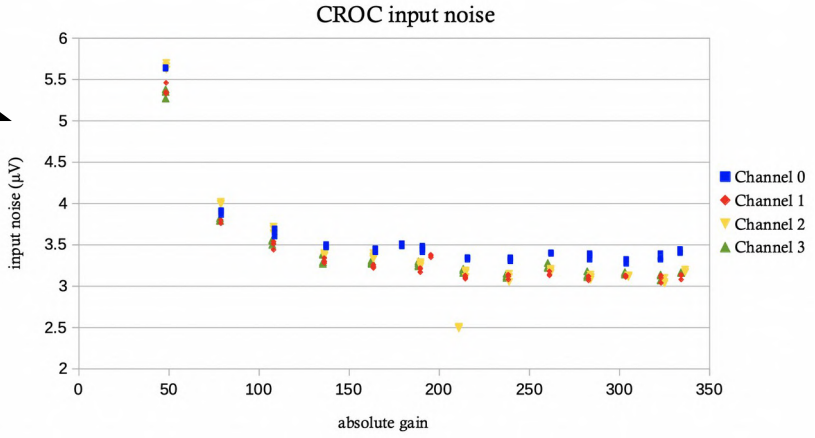
CROC
evaluation
setup



Near Future



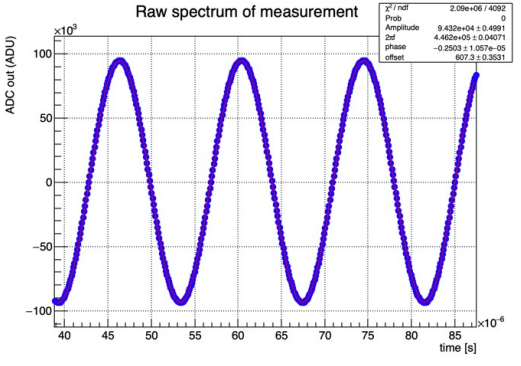
- The CROC chip is operational with low input noise at room temperature
- Test in low temperature → to be done
- Integrate in a setup for real CCD input signals → to be done



- A first version of the fast ADC was evaluated verifying the expected behaviour
- New design compatible with ODILE → in process

- 4CABAC board will be evaluated soon

- An ODILE board with a 20-bit ADC is functional and soon will be tested with a CCD.



References :
[1] arXiv:astro-ph/9909252
[2] arXiv:1507.02704
[3] arXiv:astro-ph/0608407
[4] *On the masses of nebulae and of clusters of nebulae*, F. Zwicky, 1937
[5] *The Review of Particle Physics*, M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018)
[6] *DAMIC-M Experiment: Thick, Silicon CCDs to search for Light Dark Matter*, N. Castello-Mor for the DAMIC-M Collaboration, 2020