Searching for a daily modulation of Dark Matter signal in the DMSQUARE experiment

Speaker: Nicolás E. Avalos (on behalf of DMSQUARE)

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Instituto Balseiro

CONICET

DARK MATTER 2021
FROM THE SMALLEST TO THE LARGEST SCALES

SEPTEMBER 13-16, 2021 | VIRTUAL

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Sideral day modulation of Dark Matter

Main assumptions:

1. There is a Dark Matter wind: DM particles have a velocity distribution such that there is a net flux incoming from the direction of Cygnus.

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1. There is a Dark Matter wind: DM particles have a velocity distribution such that there is a net flux incoming from the direction of Cygnus.
2. The DM particles interact with the nuclei that conform the Earth. Some scatter away before reaching the detector, therefore generating a difference in the event rate between a certain time of the day and 12 hours later.

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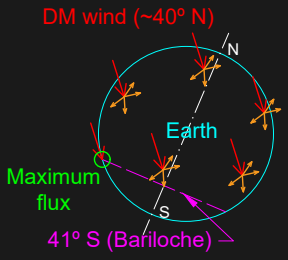

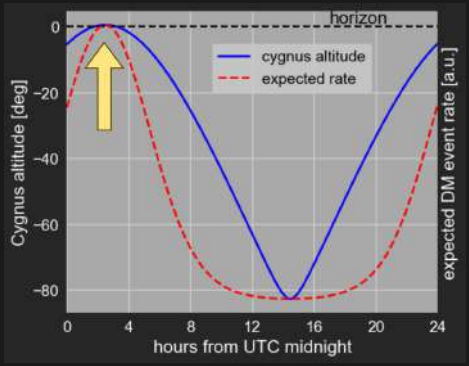

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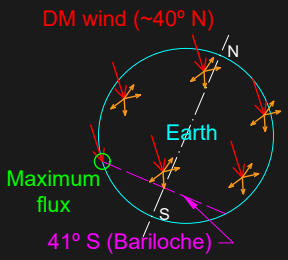

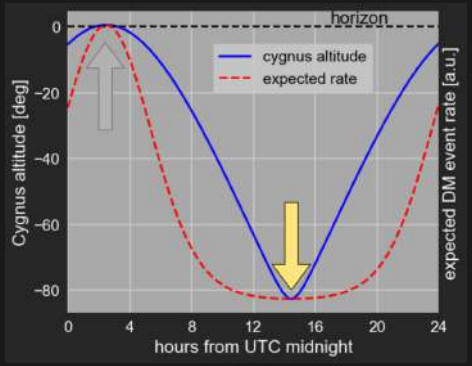

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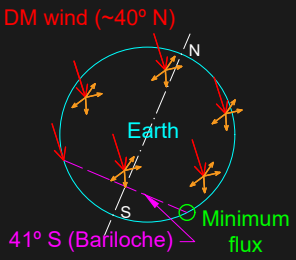

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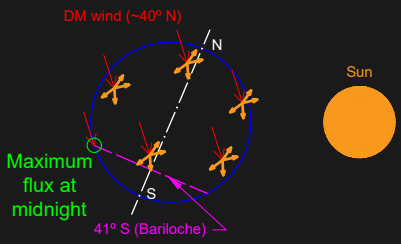

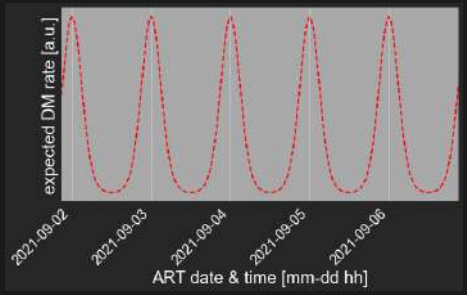

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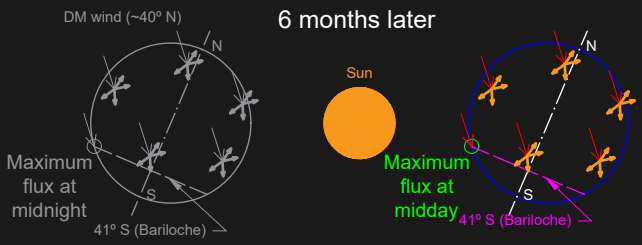

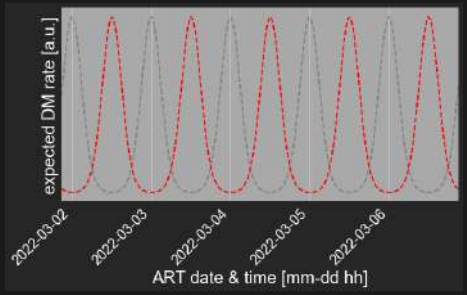

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- Charge-Coupled Devices (CCDs)
- Skipper-CCDs

3 The DMSQUARE experiment

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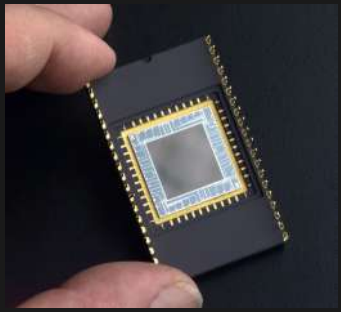
Scientific Charge-Coupled Devices (CCDs)

- Silicon bulk with a two-dimensional array of pixels.



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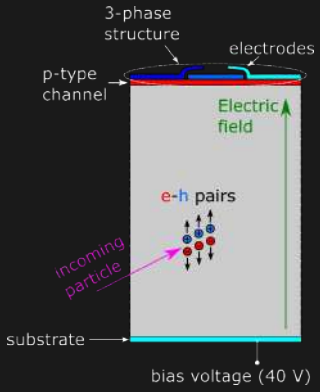

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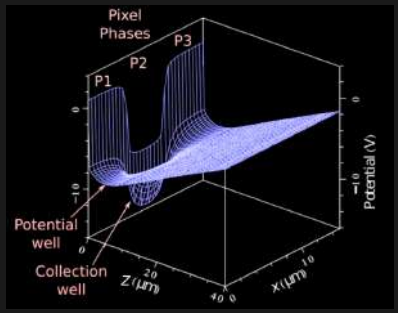

Adapted from Holland, S. E. *et al.* A 200×200 CCD image sensor fabricated on high-resistivity silicon. in *International Electron Devices Meeting. Technical Digest* 911–914 (IEEE, 1996).

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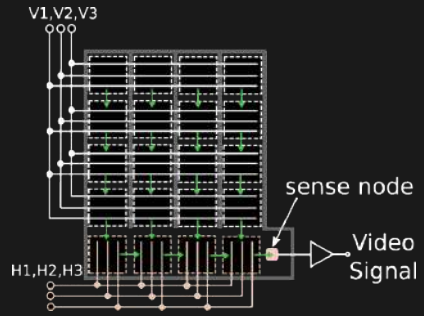

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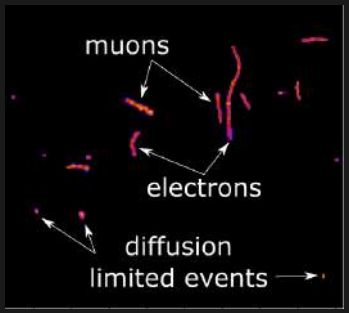

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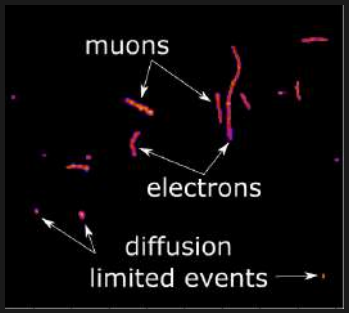

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The readout noise of regular CCDs allows for an energy threshold of $\sim$50 eV.

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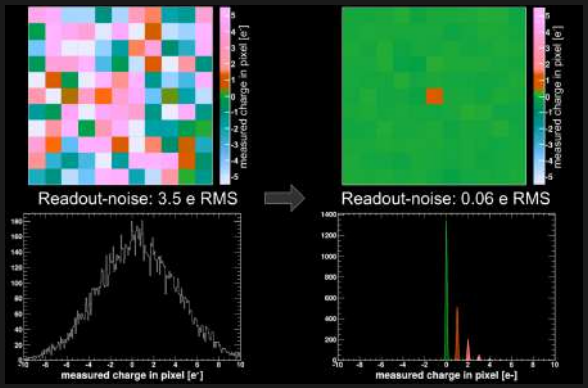

Tiffenberg, J. *et al.* Single-Electron and Single-Photon Sensitivity with a Silicon Skipper CCD. *Phys. Rev. Lett.* 119, 131802 (2017).

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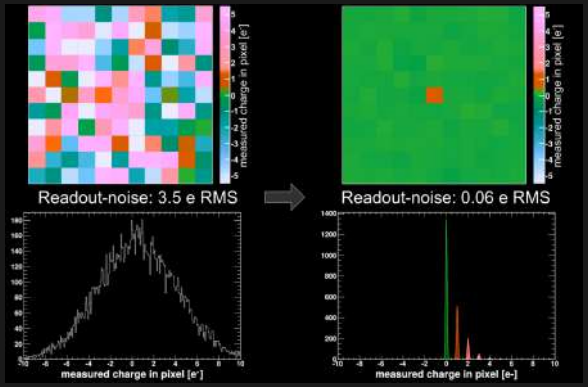

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The detection threshold is lowered down to the silicon band gap ($\sim 1.2\,\text{eV}$)

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- Whole experimental setup

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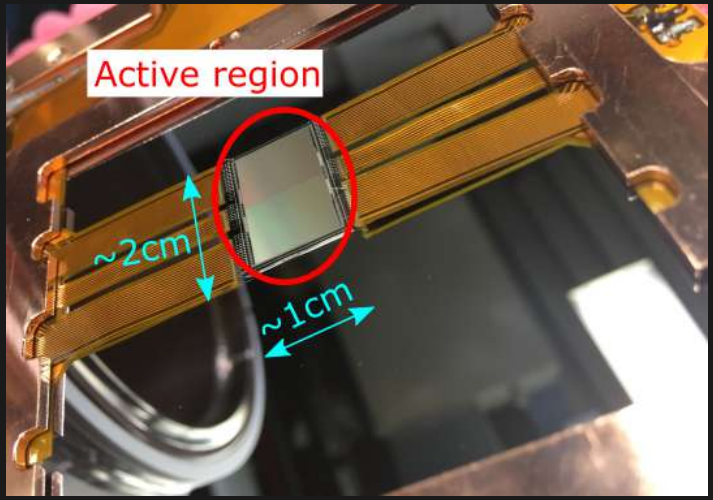
A prototype Skipper CCD: < 100 mg of detection mass



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- 1248×724 pixels
- 200 μm thick
- mass: 0,0947 g
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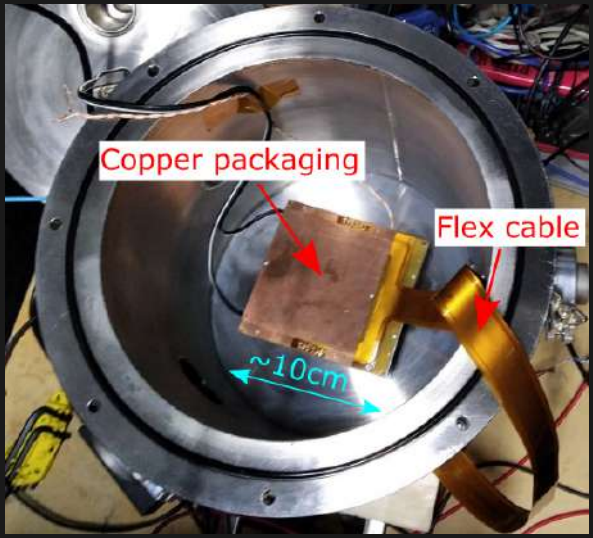

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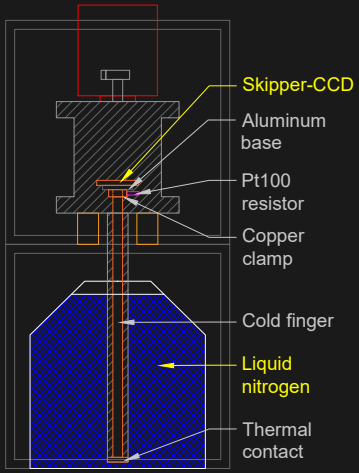

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- Obtaining data from pre-processed images

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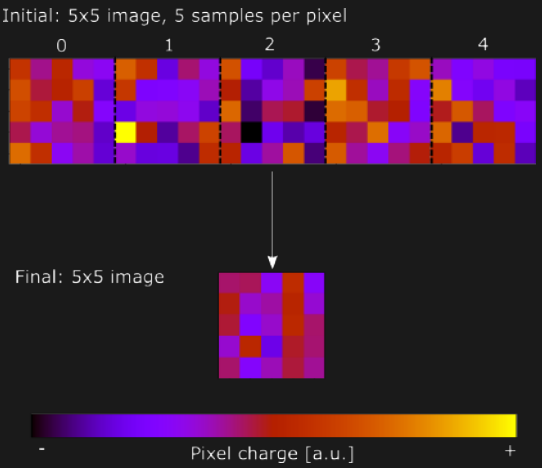
Pre-processing tasks:

- Average the Skipper samples



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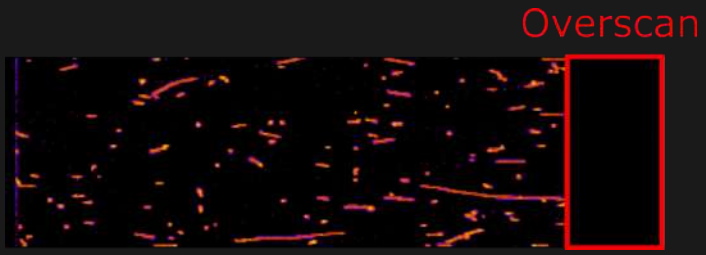

Pre-processing tasks:

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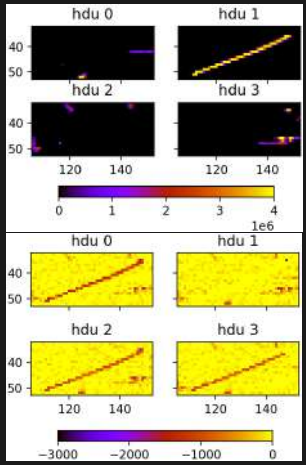
- Remove cross-talk

positive values:

negative values:



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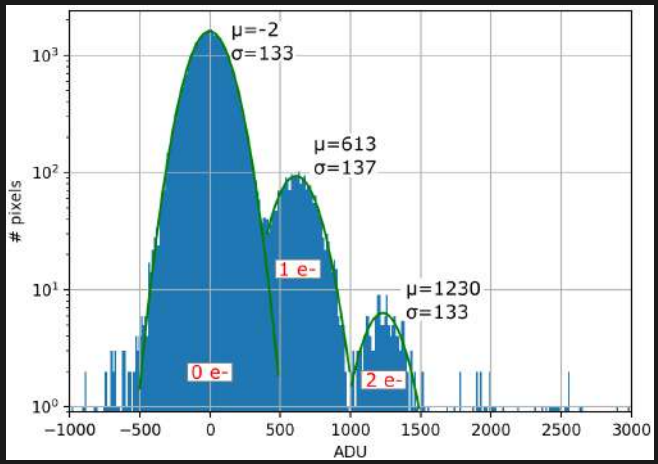

Pre-processing tasks:

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- Remove cross-talk
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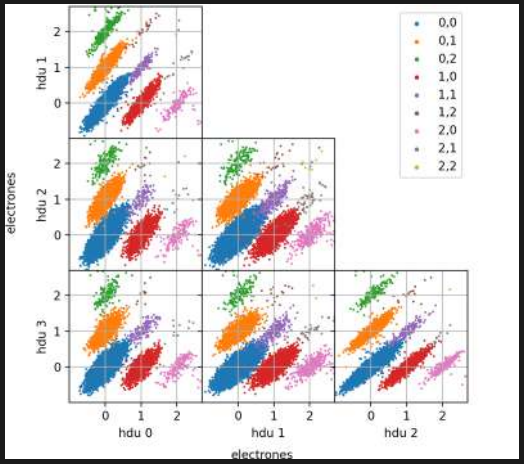
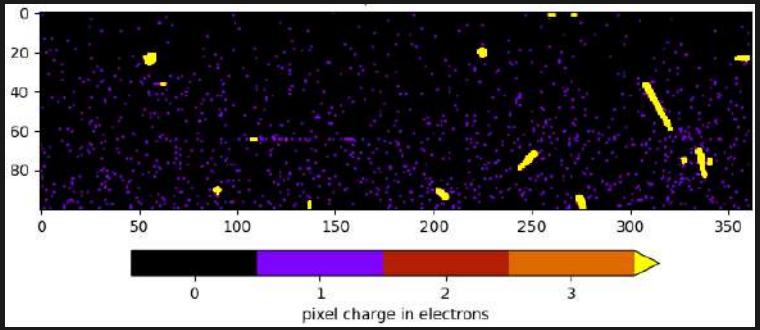


Next step: count the number of pixels with 1 electron in each image



charge in e-	# of pixels
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4 or more	257

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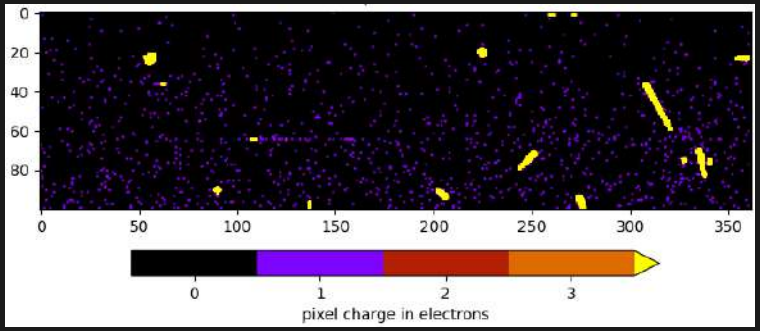

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Other important data:

- Date & time of readout start
- Total readout time

With these data we compute the incidence angle of the DM wind, enabling us to compare with theoretical models.

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- The method
- The results
- Improving the results

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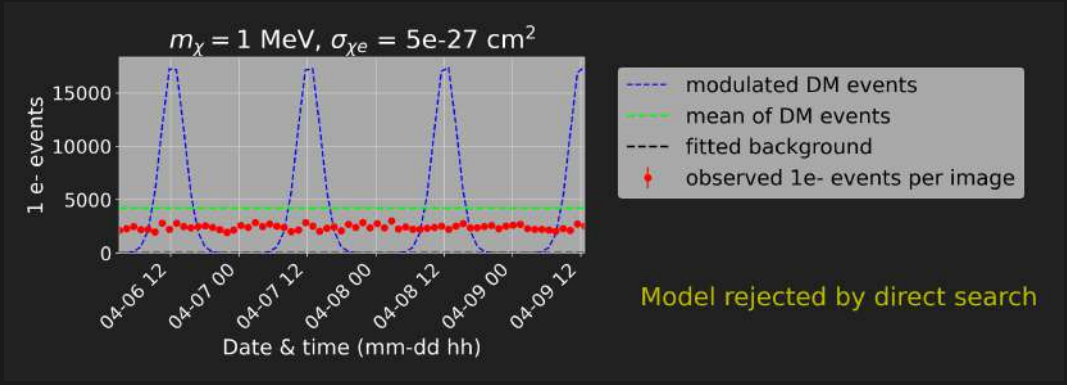
We compare the observed 1 e- rate with the expected rate for different DM parameters



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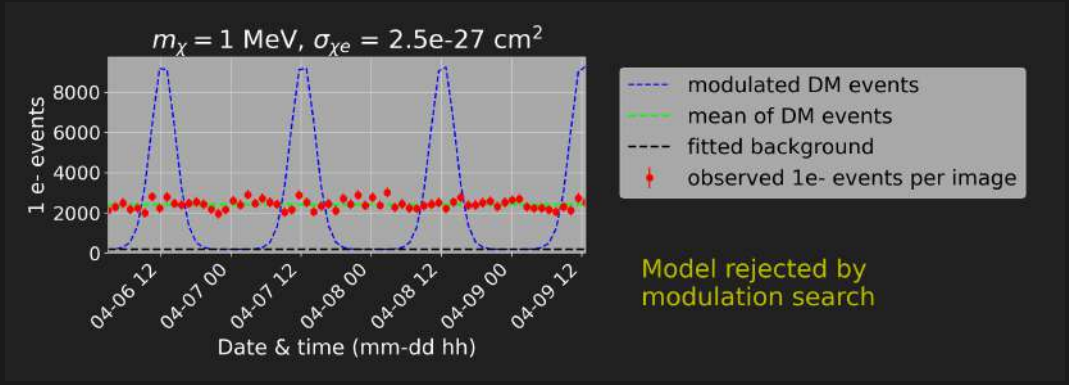

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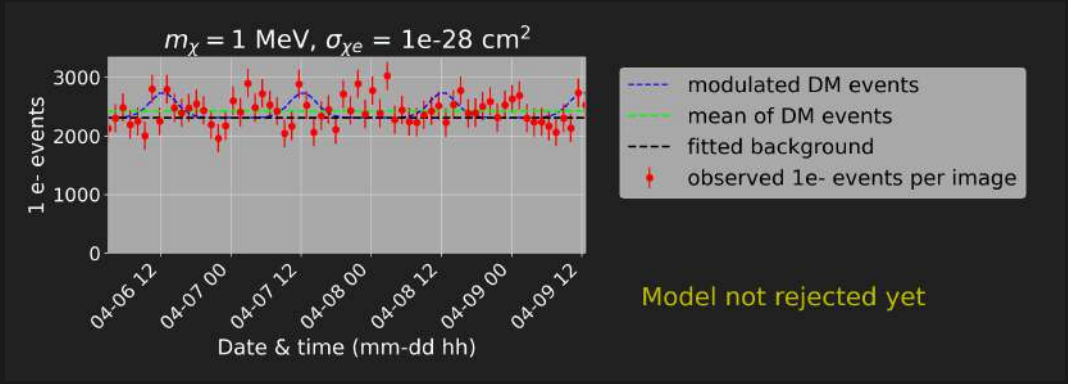

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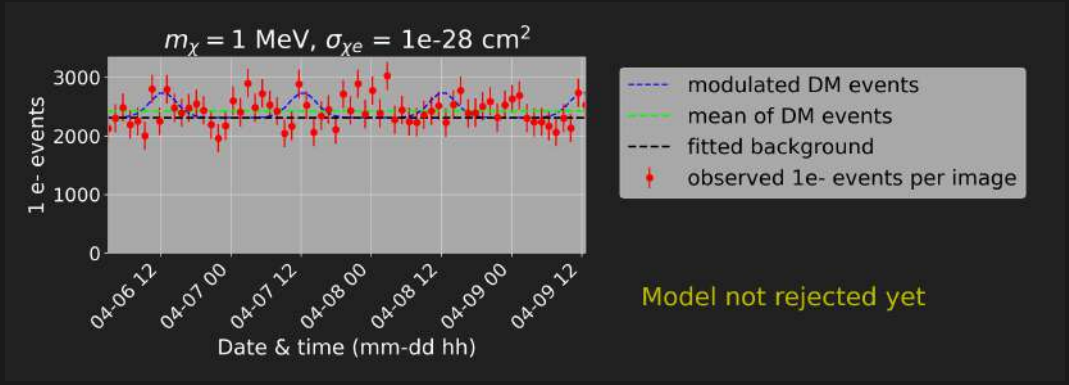

The search for the modulation allows us to set stronger limits to DM-electron cross-section, even if we can't reduce the background.

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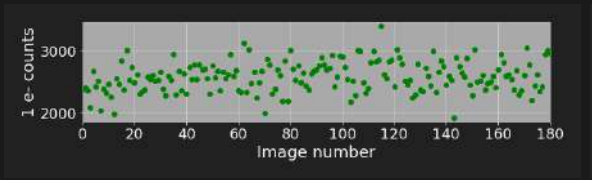

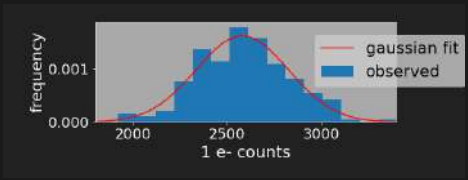

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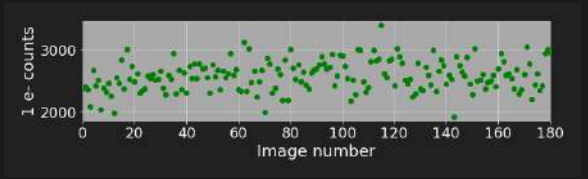
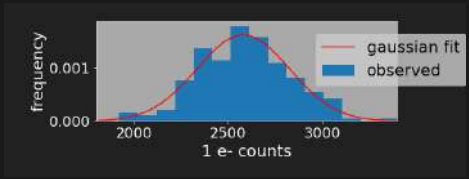
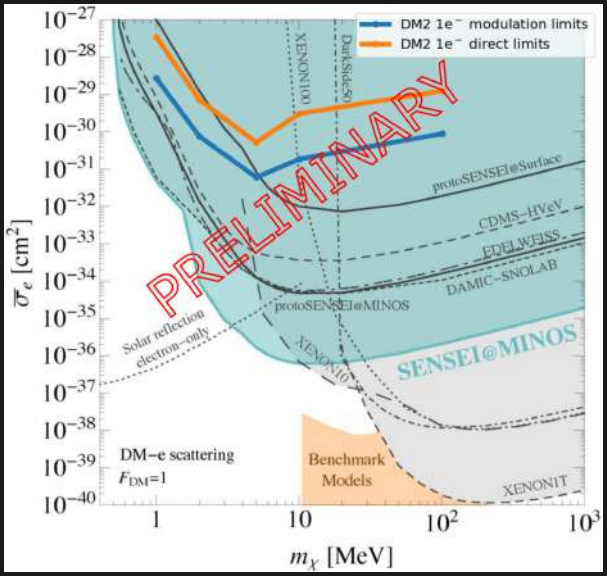
- After this quality cut 2515 images remained, summing up to 3.11 g.day of total exposure.





DMSQUARE limits for WIMP mass and DM-electron cross-section



Background plot taken from Barak, L. *et al.* SENSEI: Direct-Detection Results on sub-GeV Dark Matter from a New Skipper CCD. *Phys. Rev. Lett.* **125**, 171802 (2020).

How to improve the rejection limits

Option 1: Increasing exposure

As discussed before, the search of the modulation allows to reduce the error bars by $\sqrt{N}$ if we increase the exposure N times. This can be achieved by installing more and/or bigger CCDs.

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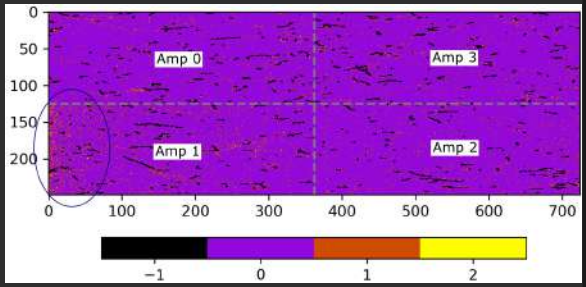
- Charge generation when turning on the acquisition board
- Light emission in one of the amplifiers



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As discussed before, the search of the modulation allows to reduce the error bars by $\sqrt{N}$ if we increase the exposure N times. This can be achieved by installing more and/or bigger CCDs.

Option 2: Reducing the fluctuations of 1e- events

Single-electron events are being under study. We know the sources of some of them and are actively looking for ways of reducing them:

- Charge generation when turning on the acquisition board
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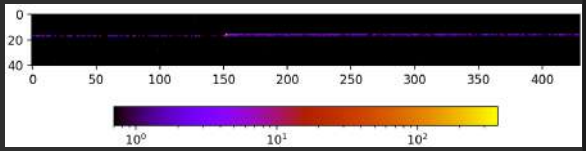

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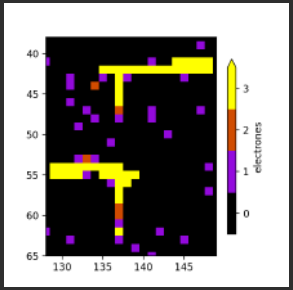

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- Fluorescence, Cherenkov radiation or charges that spread from cosmic ray events

This is what dominates our background right now.

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1 The Dark Matter signal diurnal modulation

2 The detector

3 The DMSQUARE experiment

4 Data generation

5 Seeking for the diurnal modulation in the data

6 The future of DMSQUARE
- Sierra Grande Experimental Site

Going underground: moving the experiment to Sierra Grande

A similar search was carried during the 90s there, using germanium detectors:

Abriola, D, *et al.* Searching for Cold Dark Matter in the Southern Hemisphere. The Experiment at Sierra Grande. *Astroparticle Physics* **6**, 63–69 (1996).

Going underground: moving the experiment to Sierra Grande

There is an inactive iron mine with horizontal access to around 400 m underground:

We are planning to move the experiment here by the end of October this year (2021).

Concluding remarks

With a <100 mg prototype detector operating on surface we are able to improve current surface limits to DM-electron interactions.

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Thank you.