Backside-Contact of Skipper-CCDs with Arsenic Ion Implantation and Microwave Annealing

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Collaborators: Guillermo Fernández Moroni, Fernando Chierchie, Miqueas E. Gamero, Agustín J. Lapi, Julie D. Segal, Christopher J. Kenney, Angela Kok, Stephen E. Holland, Juan Estrada.

Coordinating Panel on Advanced Detectors (CPAD).
Instrumentation and Detector R&D Workshop.
University of Washington, Seattle, WA. 2026

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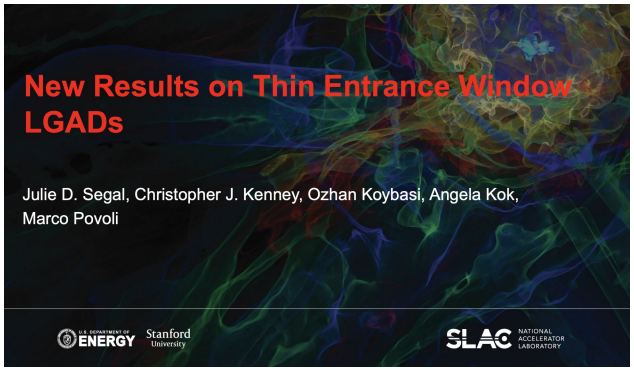
Already been proven…

- J. Segal *et al.*, “Thin-Entrance Window Process for Soft X-Ray Sensors,” *Front. Phys.*, vol. 9, p. 618390, 2021.



What it has been demonstrated:

- **Dopant activation by Microwave Annealing without high temperature**
- **Arsenic activation without significant dopant diffusion results in a shallow entrance window. The entrance window has a depth of about 80nm**
- **A high resistivity n-type substrate of 300µm can be fully depleted with this back contact at a reasonable voltage**

Main advantages of this back treatment process

- Can be performed on finished sensors at wafer level, enabling backside processing after foundry fabrication
- Fast and cost effective

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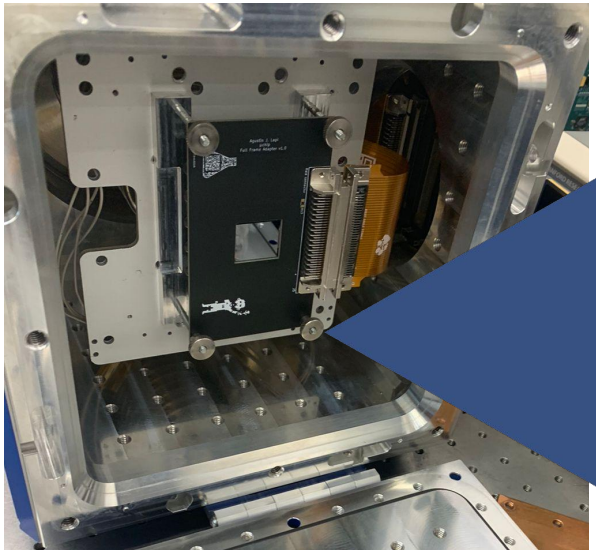
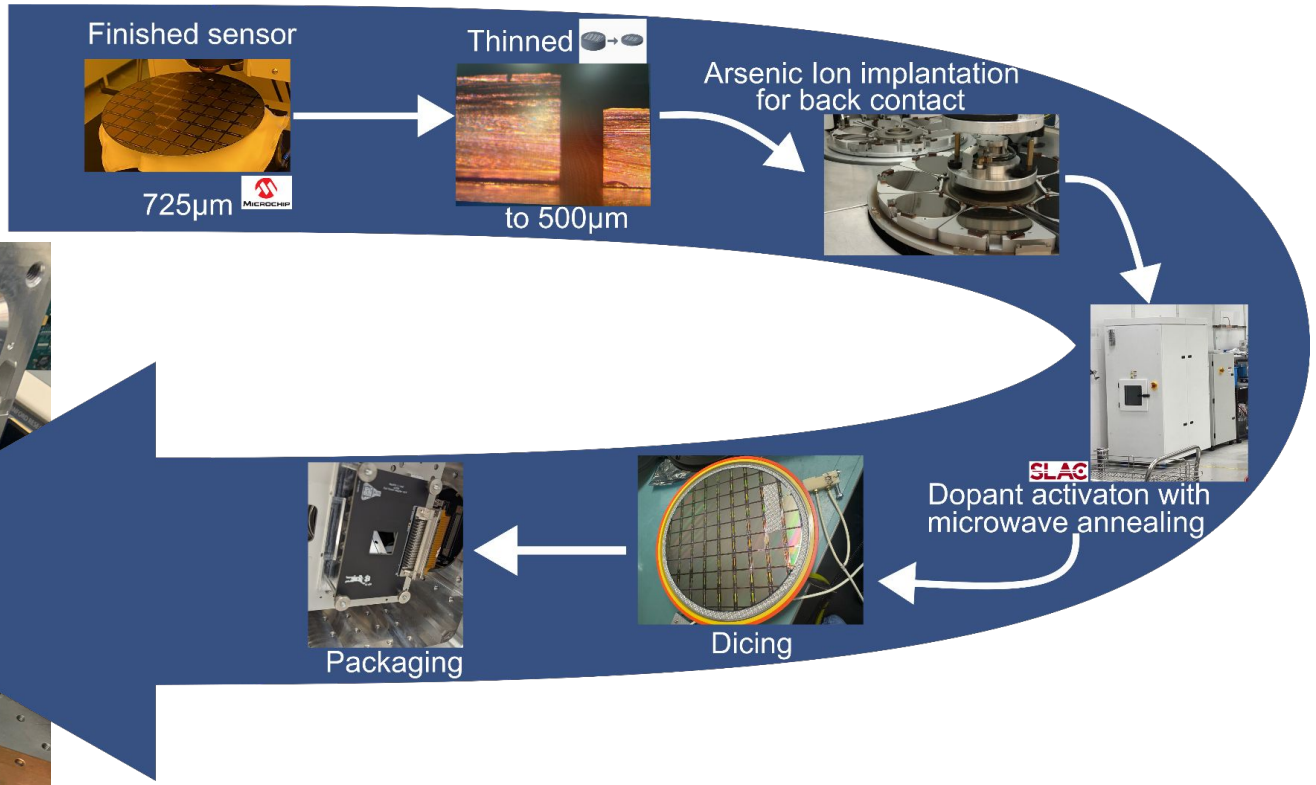
Backside processing of back-illuminated Skipper-CCDs with Arsenic Ion Implantation and dopant activation by microwave annealing

We have implanted one wafer fabricated at Microchip that we had (from OSCURA sensors). And annealed by microwave some sensors at two different temperatures: 380 and 400 °C.

Sensors designed by Stephen Holland at Lawrence Berkeley National Laboratory, LBNL.





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Recipe

Arsenic Ion Implantation		Microwave Annealing					
Energy (keV)	Dose (cm^{-2})	Step 1		Step 2		Microwave frequency (GHz)	Maximum Temperature (°C)
		Power (kW)	Time (s)	Power (kW)	Time (s)		
10	1×10^{15}	3.3	90	1.5	300	2.45	380
		3.3	110	1.8	300	2.45	400

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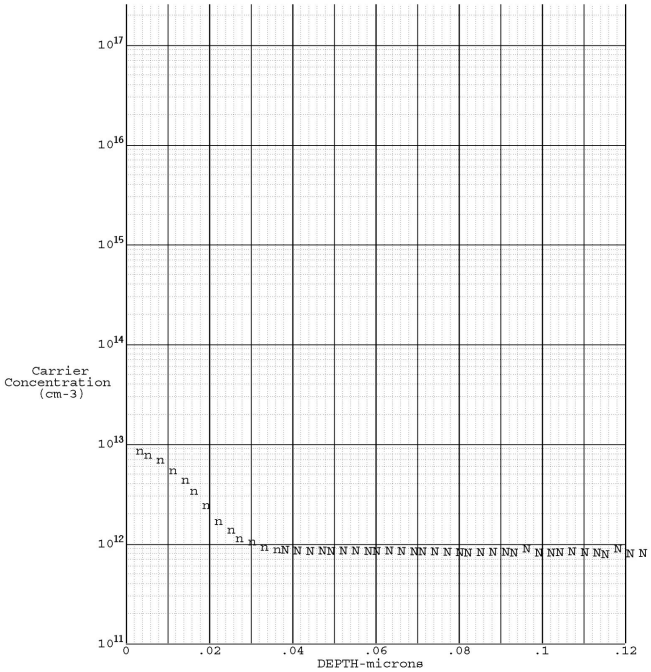
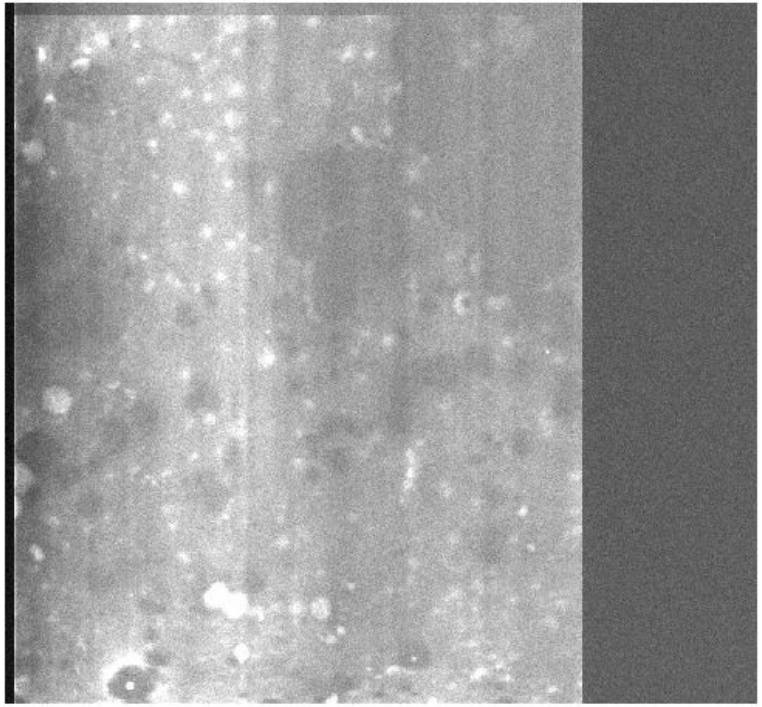
First attempt: Ion implantation failed. Implanted on the opposite side?





SRP measurement after ion implantation and AFTER microwave annealing

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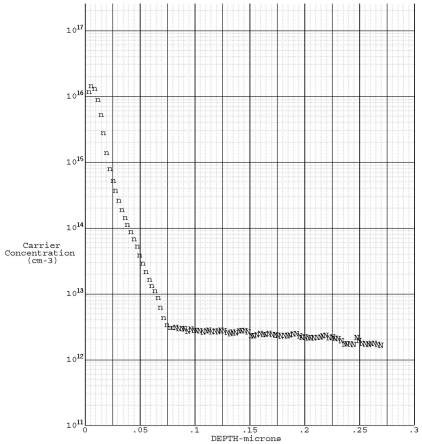
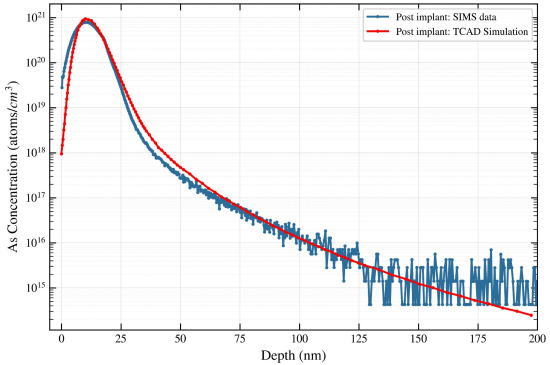
Processing results

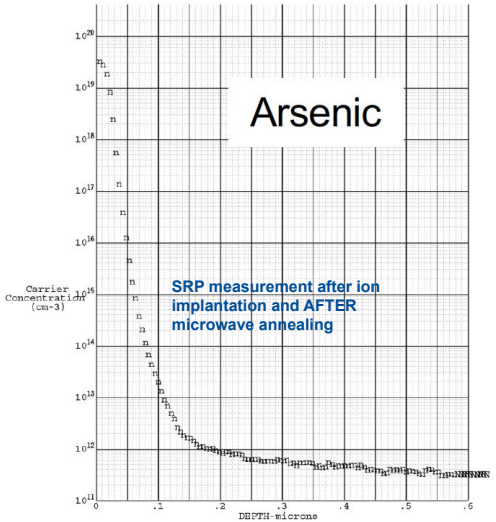


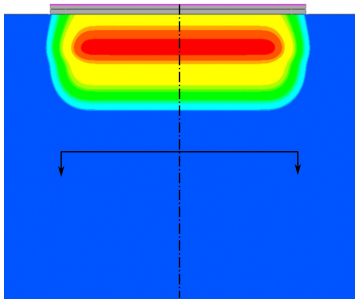
SRP measurement AFTER ion implantation and BEFORE microwave annealing

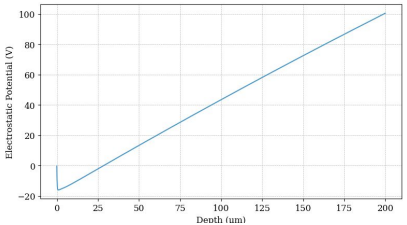


SIMS measurement

What we expected after the annealing based on the reference and our TCAD simulations…







J. Segal, “Design, fabrication, and preliminary test results of a new inverse-LGAD for soft X-ray detection,” HSTD13, Vancouver, Canada, 2023, presentation slides.

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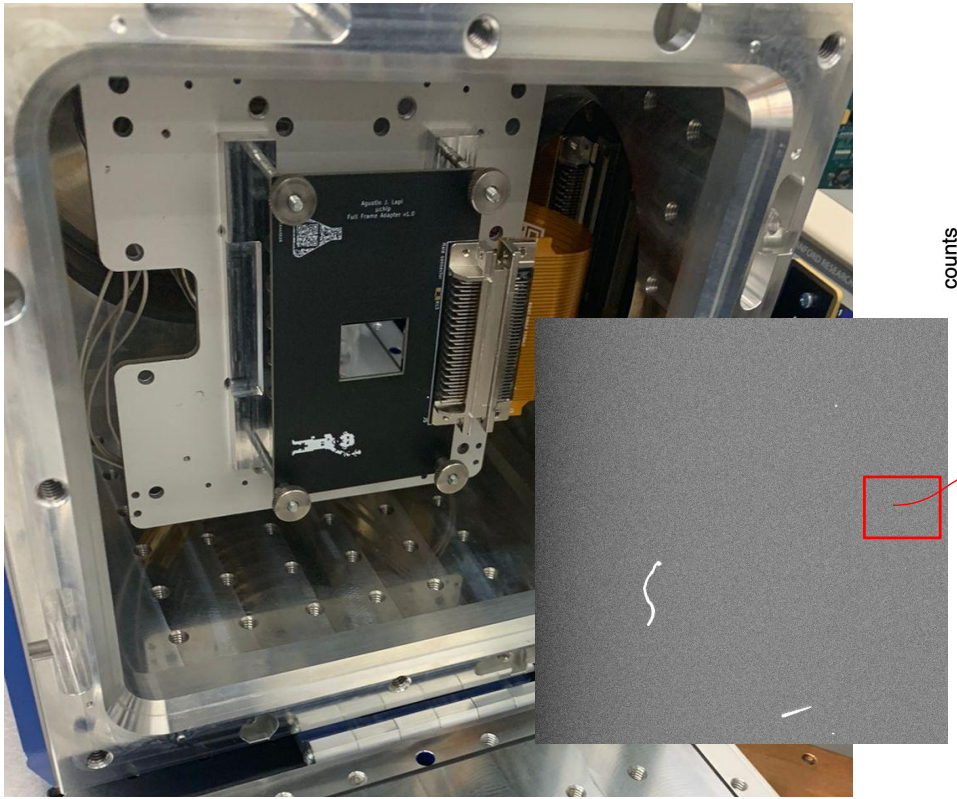
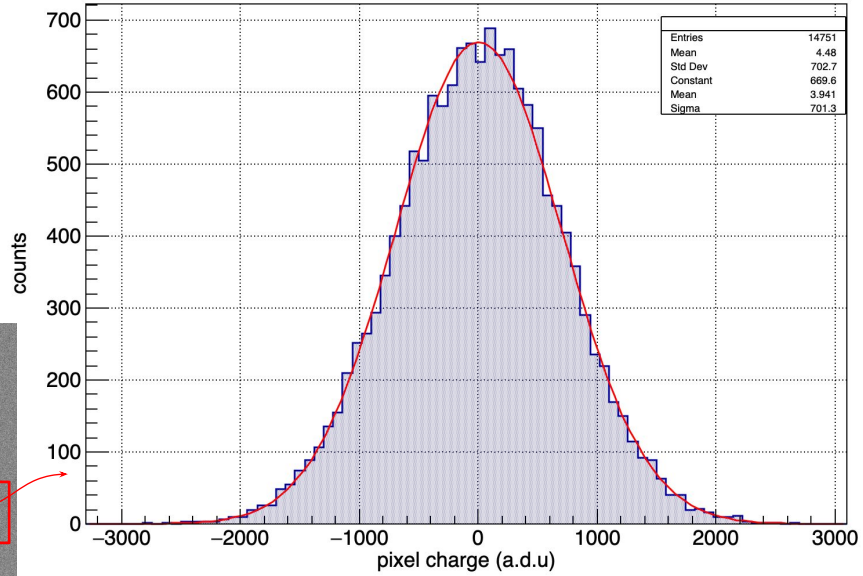
Experimental testing: The sensor still works (tested at 140K)





We were able to see events. The single sample readout noise is similar to the standard sensors. The image shows around 3.3 electrons of noise.

The best measured Dark Current is ~1.536 e-/pix/day. Similar to the standard sensors under the same conditions

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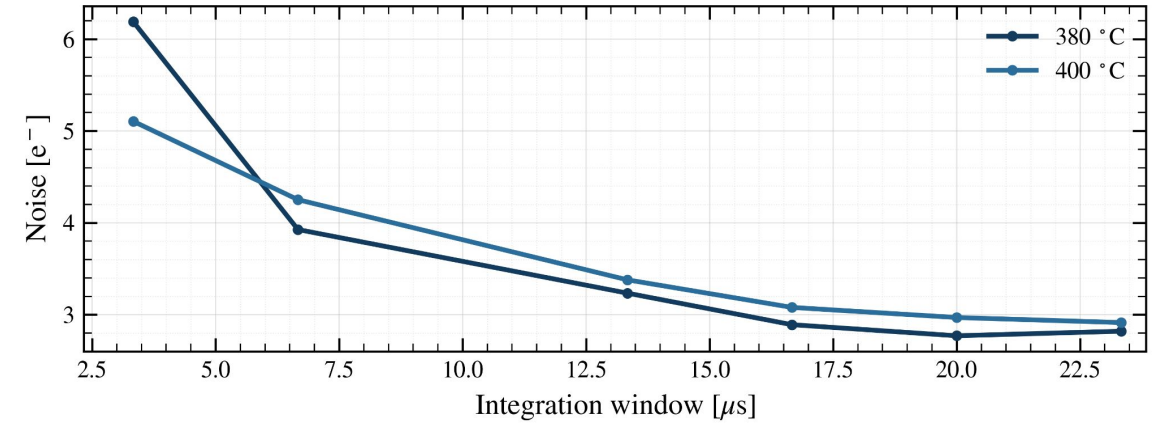
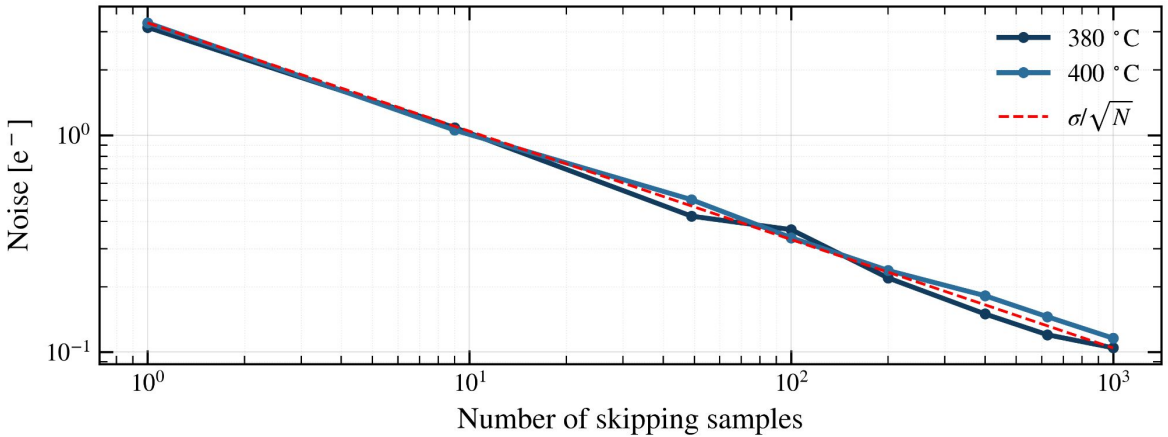
Readout noise 140K (sensors annealed at 380 and 400°C):





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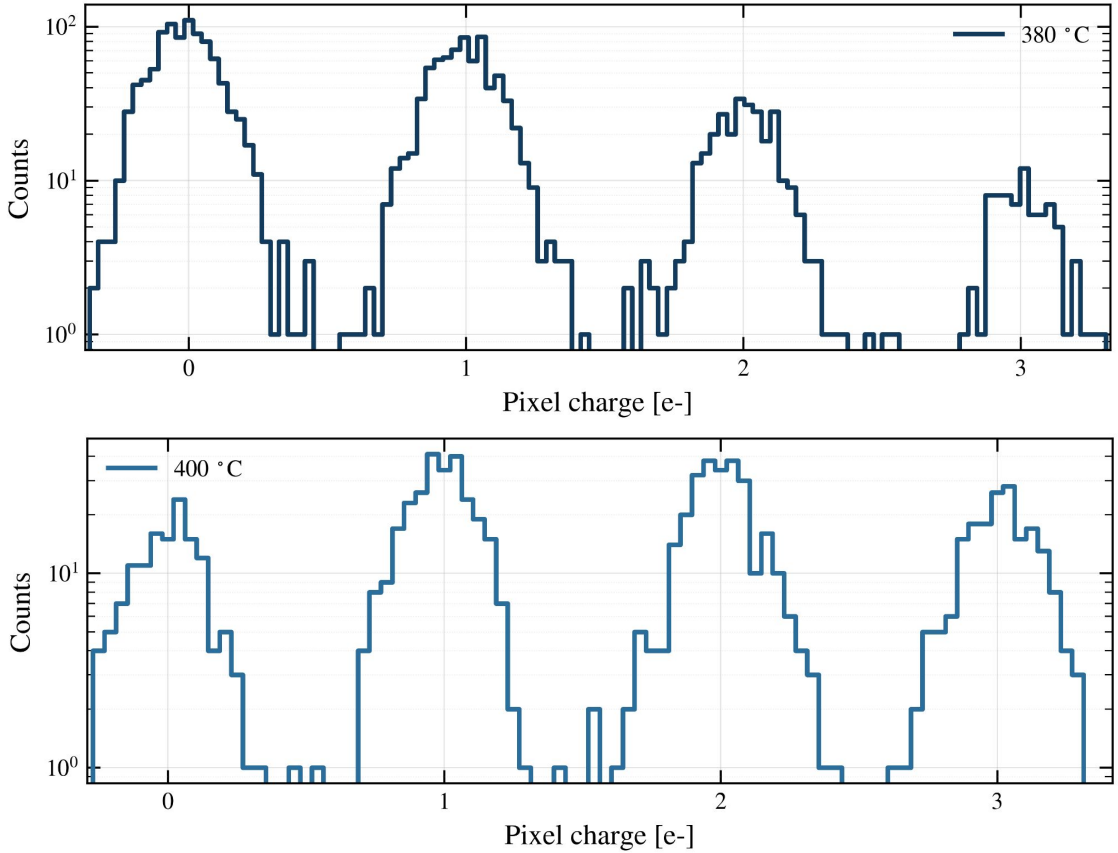
Single-electron resolution (1000 skipping samples)



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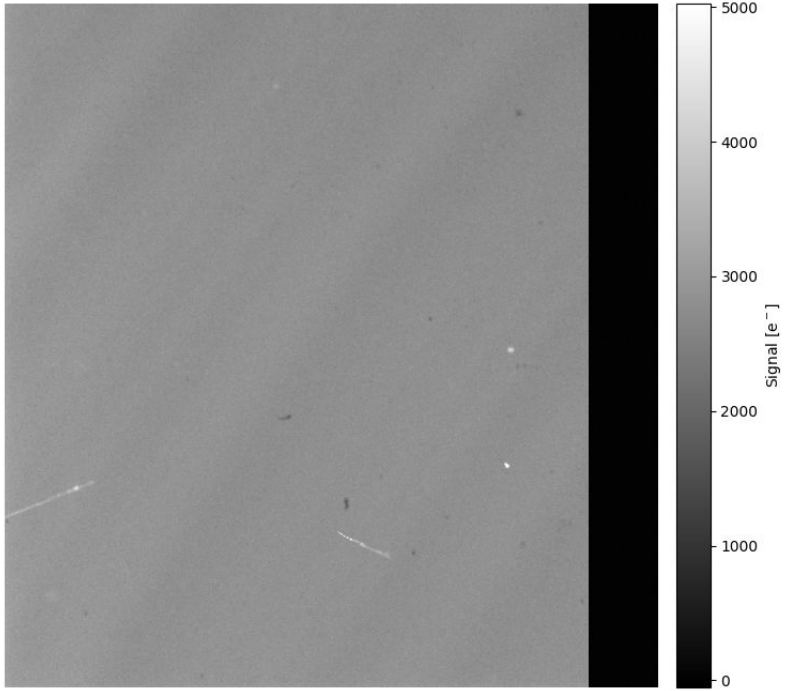
Effect observed when illuminating the sensor but **not related to the backside processing:**

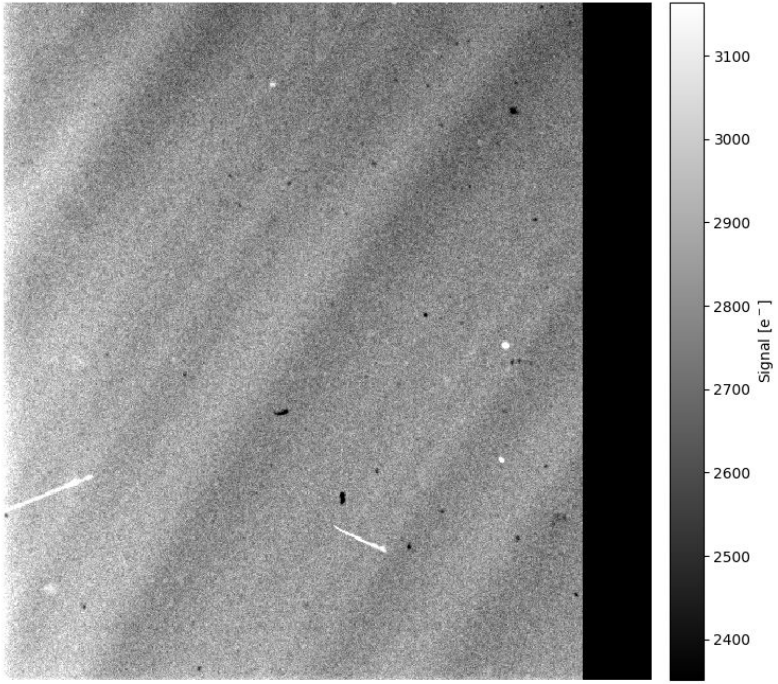
“tree rings pattern”

Illuminating the sensor: “tree rings” pattern

470nm. Vsub=40V



stretched image range



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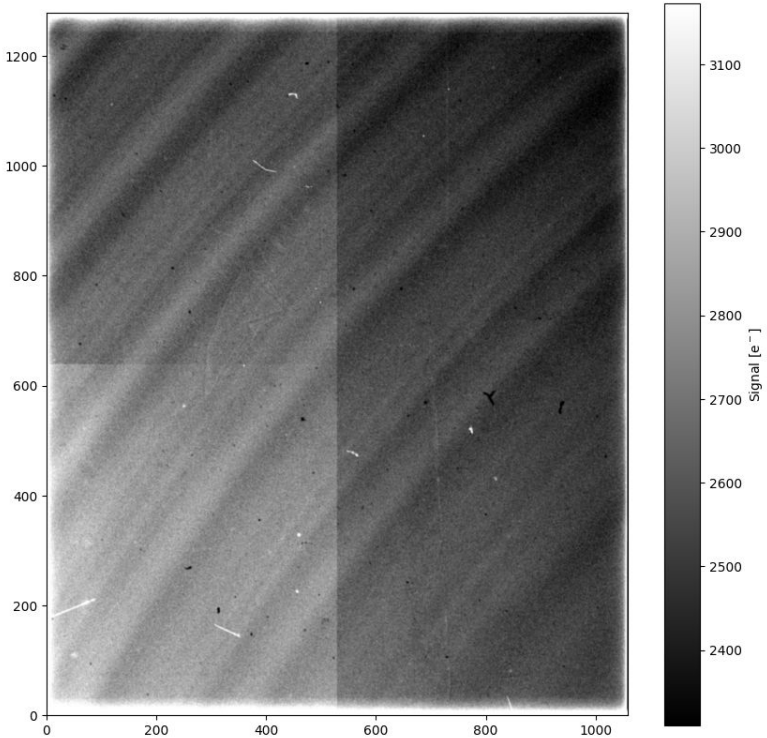
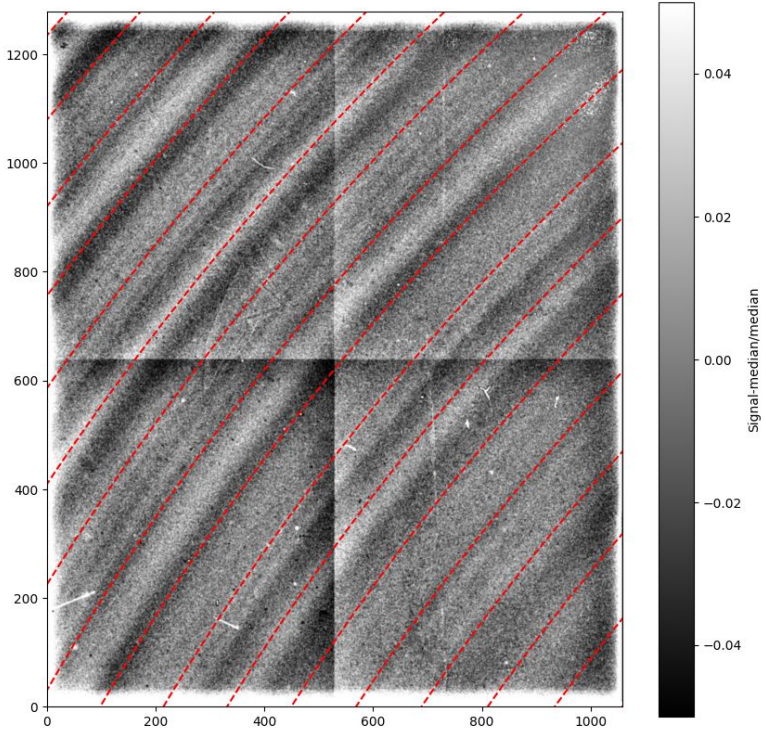
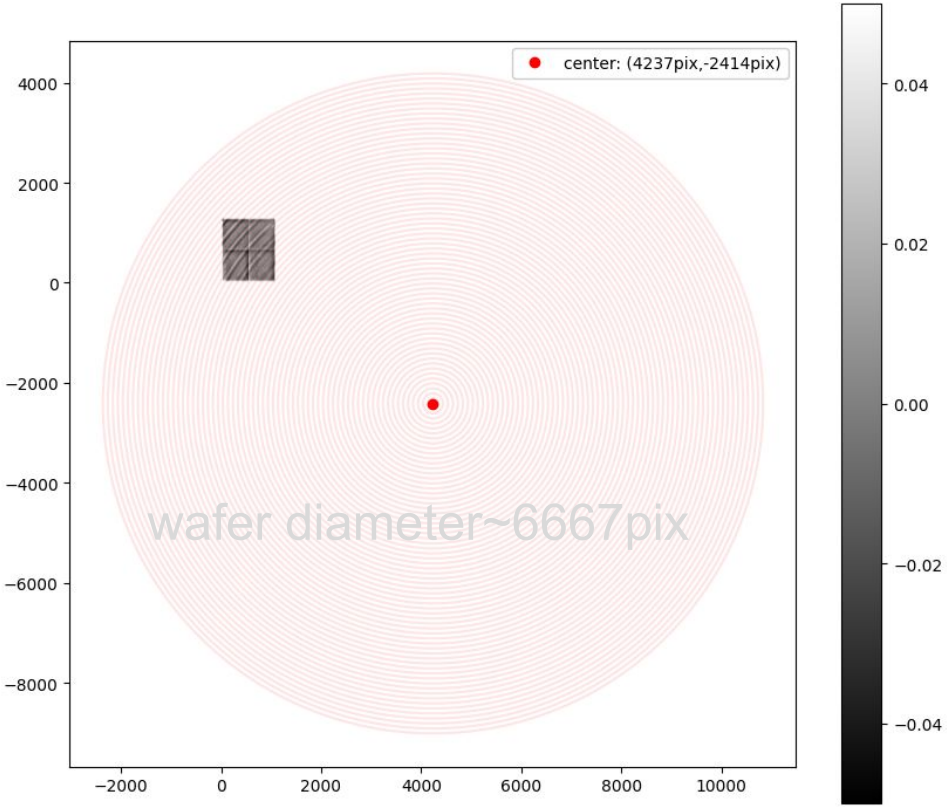
Illuminating the sensor: “tree rings” pattern

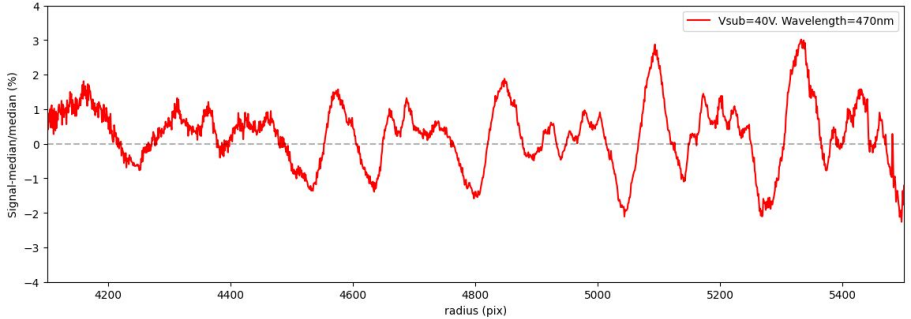




S. Karpov, “Tree rings analysis.”
https://github.com/karpov-sv/lsst-misc/blob/master/Tree_Rings_Analysis.ipynb.

Illuminating the sensor: “tree rings” pattern





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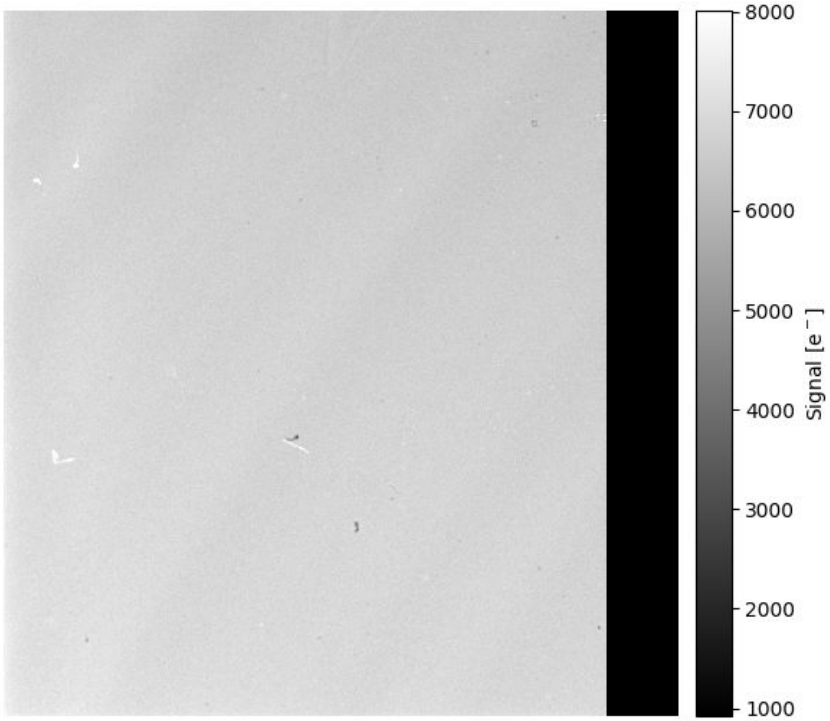
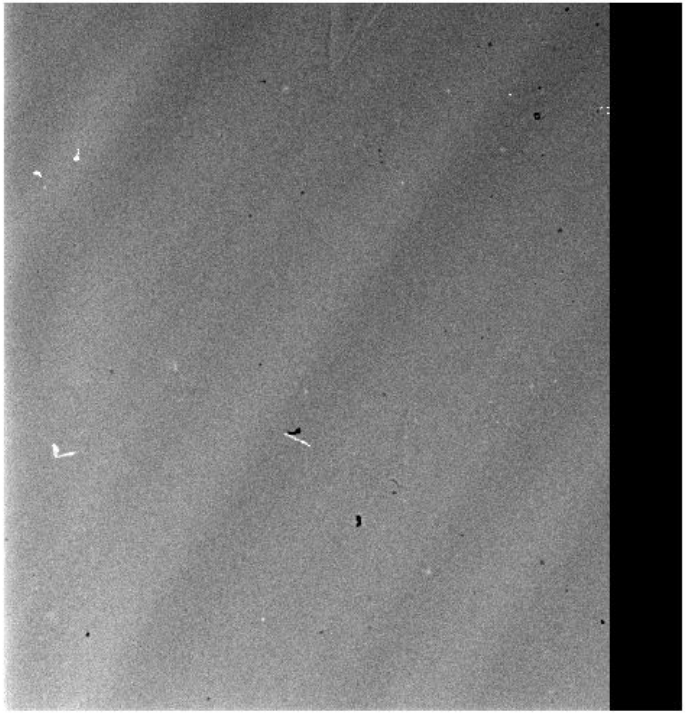
Illuminating the sensor: “tree rings” pattern

850nm. Vsub=70V



stretched image range



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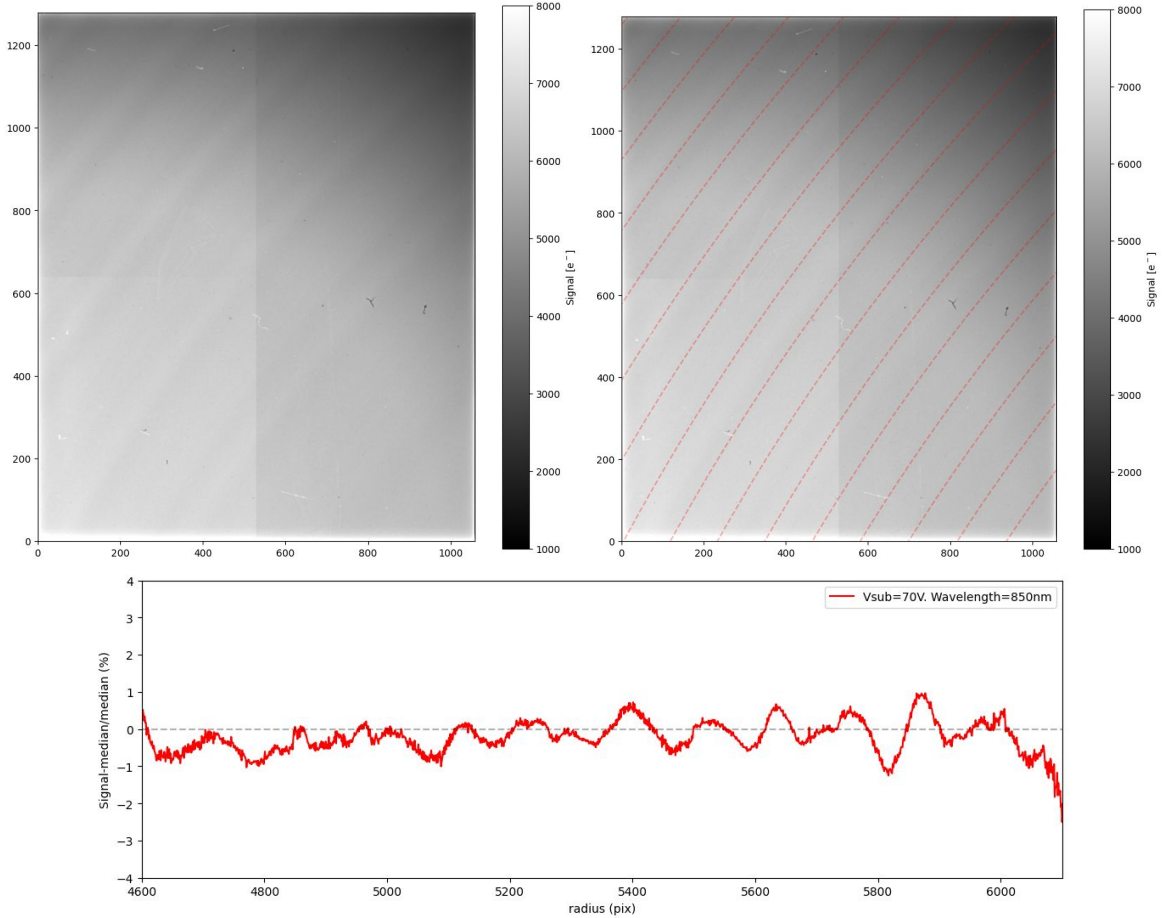
Illuminating the sensor: “tree rings” pattern



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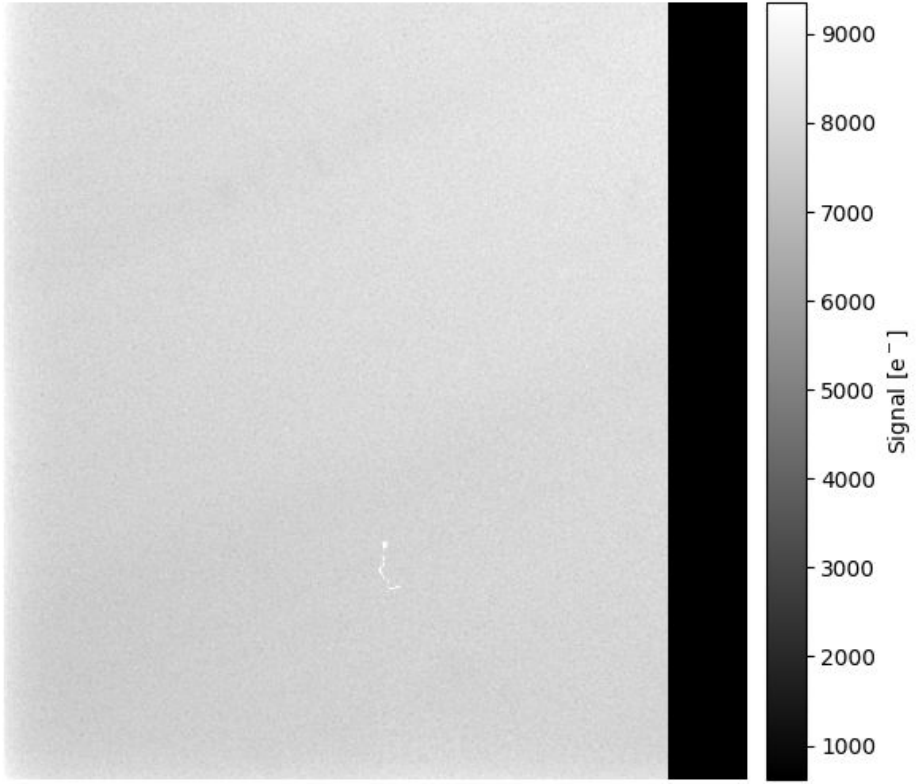
Non back-treated OSCURA sensor

850nm. Vsub=70V



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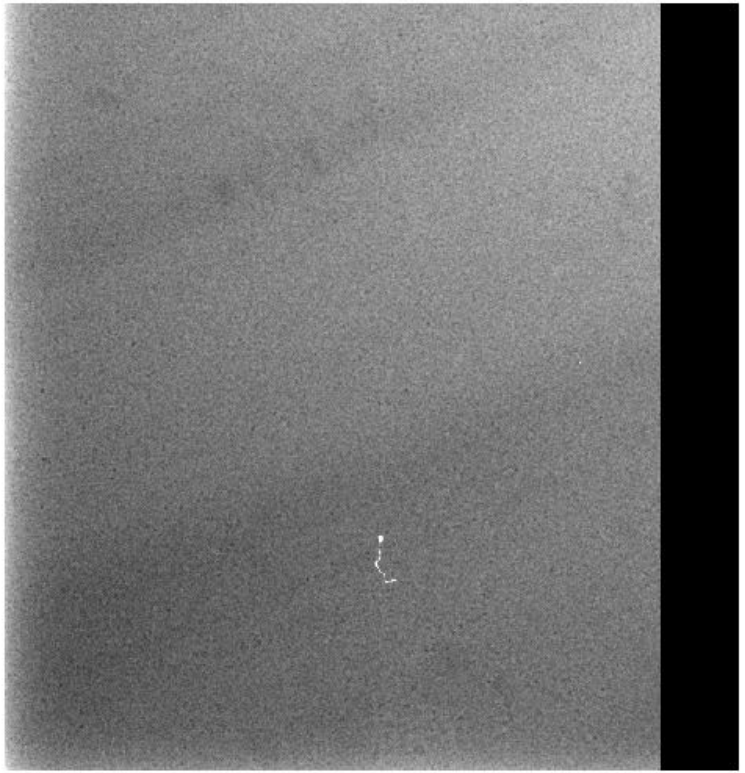

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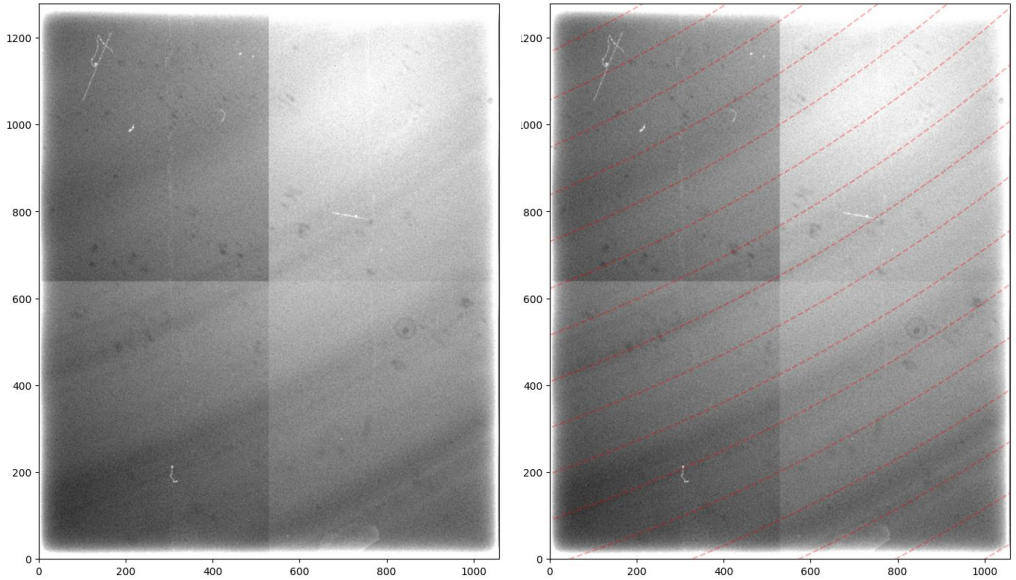
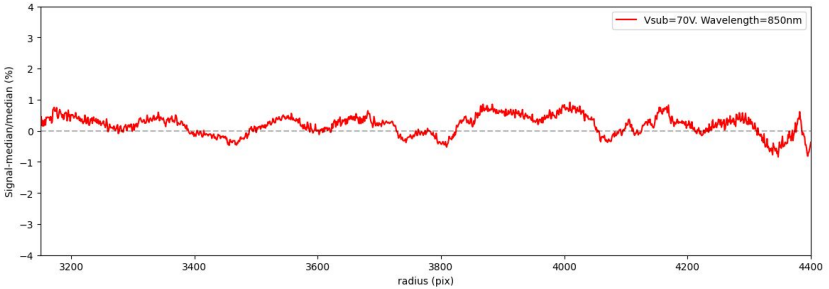
Non back-treated OSCURA sensor





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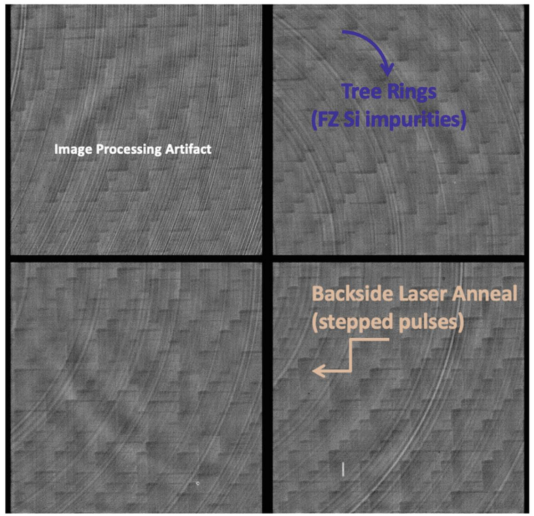
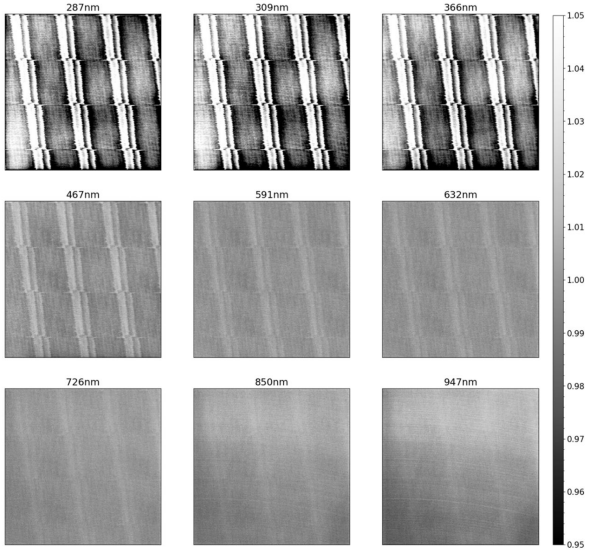
Good news: no other patterns have been observed

“Brick wall” pattern
Under dark conditions



MIT Lincoln Lab CCID-80s (TESS CCDs)
stepped-laser annealing entrance window treatment.
Suntharalingam, V., Prigozhin, I., Warner, K., Young, D., Woods, D., & Berthiaume, G. 2023, Astron. Nachr., 344, e20230058. https://doi.org/10.1002/asna.20230139

Peak to valley value from 18% to 0.5%.
(287nm-947nm)



Laser-annealed backside-illuminated E2V CCD201-20 EMCCD.
Zun Luo *et al* 2024 *AJ* 168 275 DOI 10.3847/1538-3881/ad83b6

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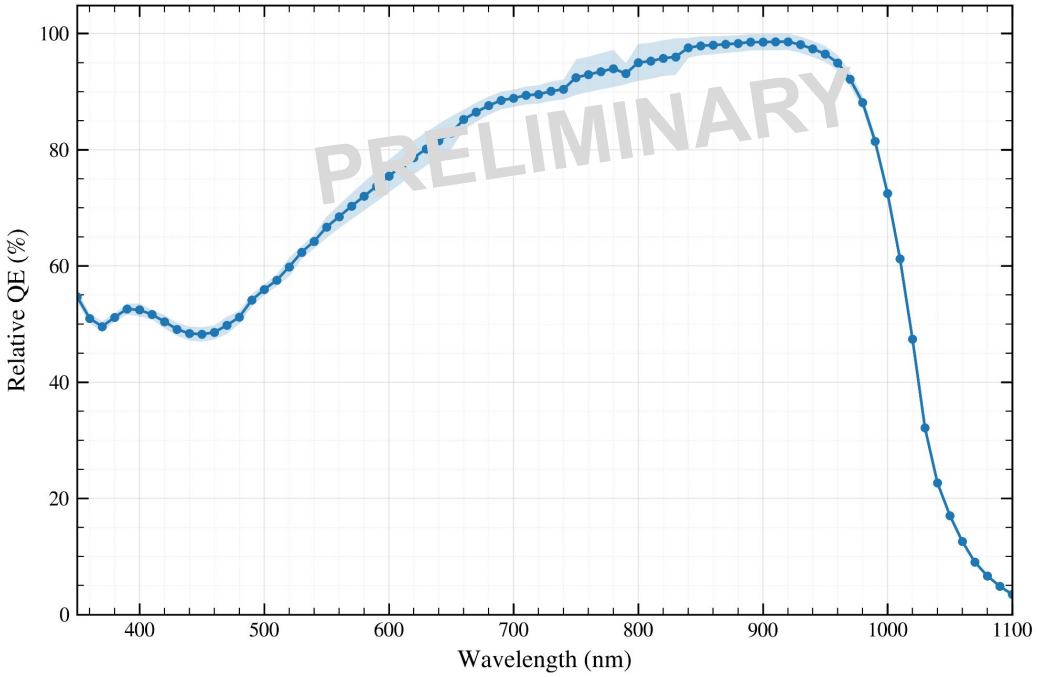
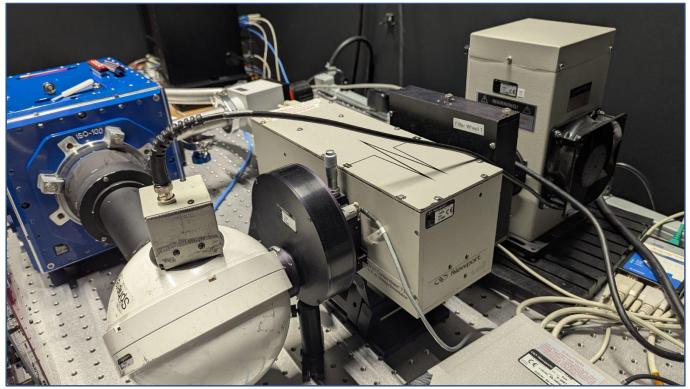
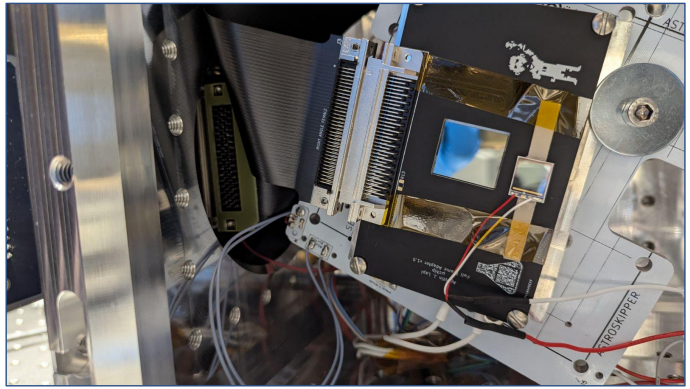
Measured relative quantum efficiency (reflection-limited)







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THANK YOU

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