Effects of Protons irradiations on SWIR p/n low flux MCT detector at cryogenic temperature

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1. Experiment presentation and problematics

Astronomical observations issues

- Very low flux coming from the observed objects
- IR sensors used need high level of performances
  - Dark Current < 0,01 e-/s
  - Quantum efficiency > 80%
  - Low readout noise (20 e- in CDS / 6 e- in FUR)
- Very subject to irradiation effects

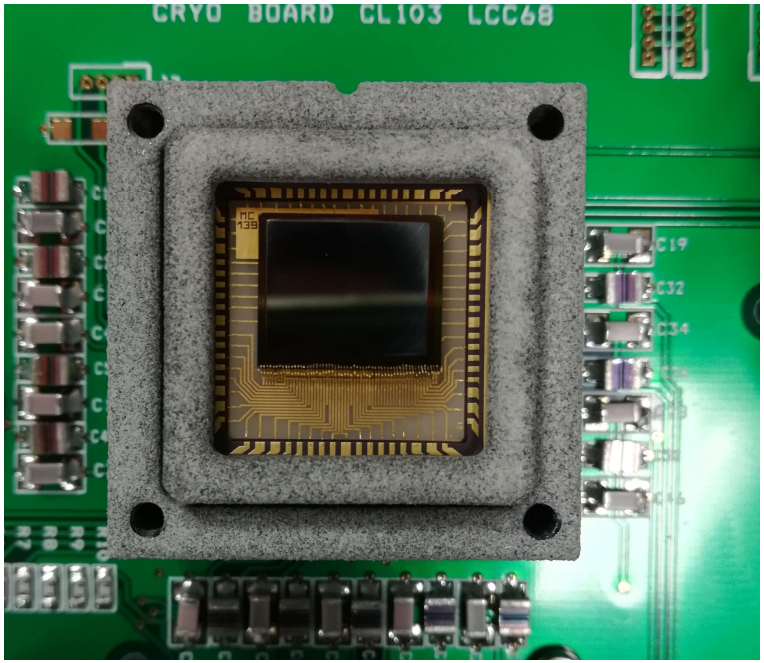


Fig 1. Picture of the sensor

Sensor characteristics

- Study array by CEA Leti
- Mercury Cadmium Telluride material
  - Hybridized circuit with Silicon ROIC
- Short Wave IR (2,1 µm cutoff)
  - Low gap: $E_{g(2{,}1\mu m)} = 0{,}59\ eV$
- P / N SFD type sensor
- 512x640 resolution
- 15µm pitch
- 80K operating temperature
- Biased at 400 mV

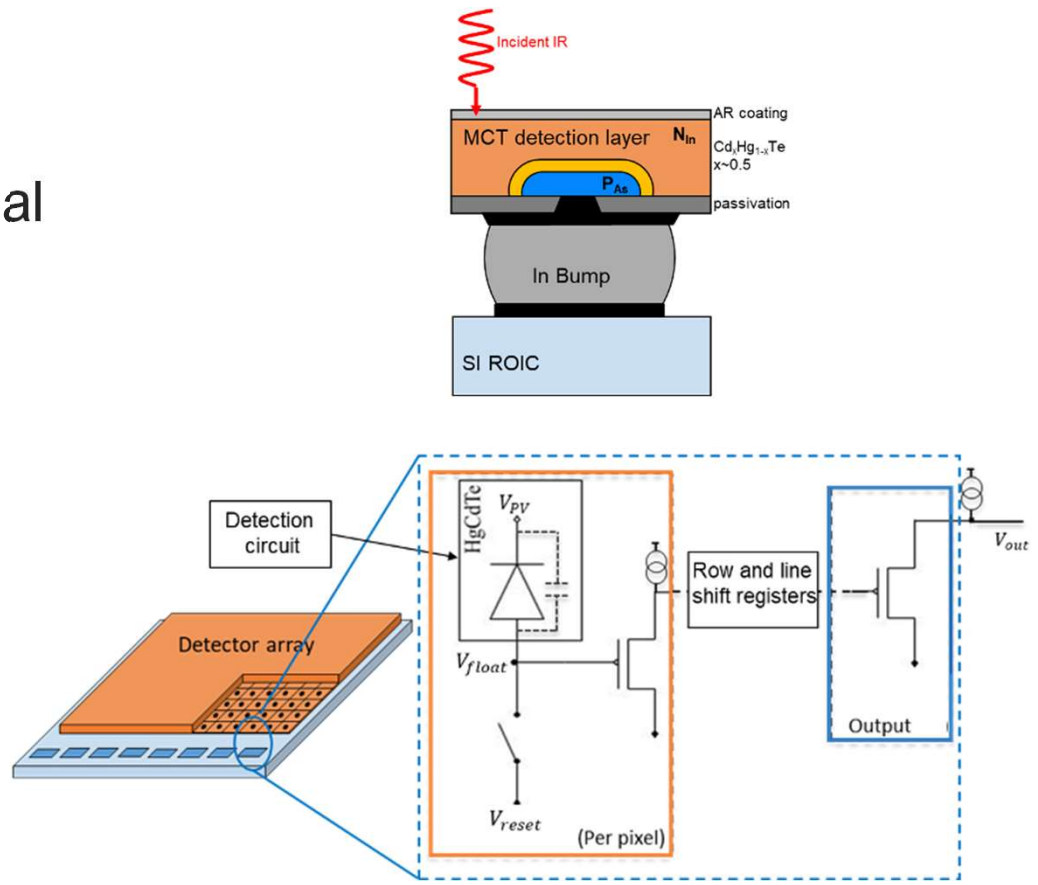


Fig 2. Schematic view of the SFD detector architecture

2. Experimental setup

Irradiation setup

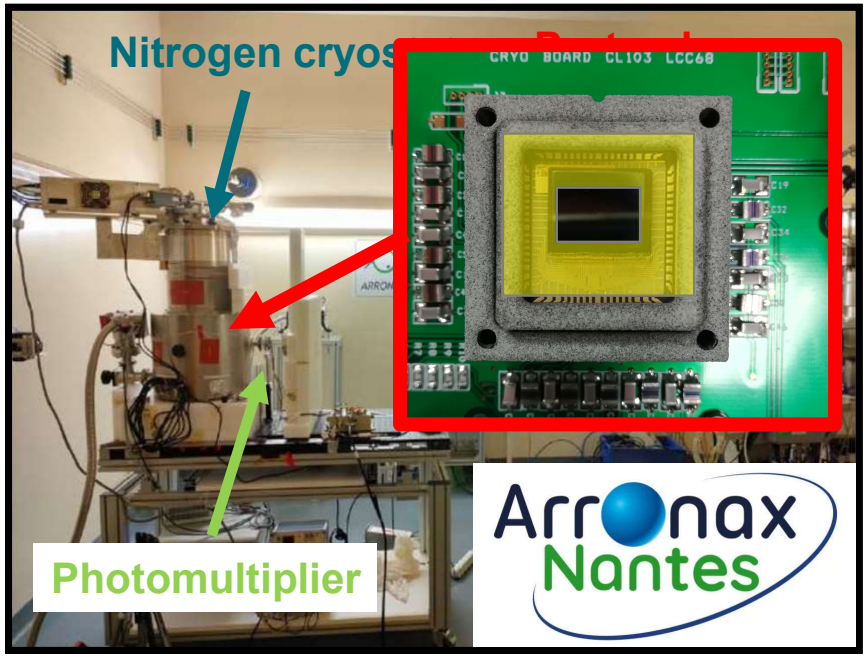


Fig 3. Arronax irradiation setup

	Cumulative fluence measured at the sensor (protons/cm^2)
Step 1	1,60^E+10
Step 2	1,53^E+11
Step 3	4,73^E+11

Tab 1. Cumulative fluences for each steps

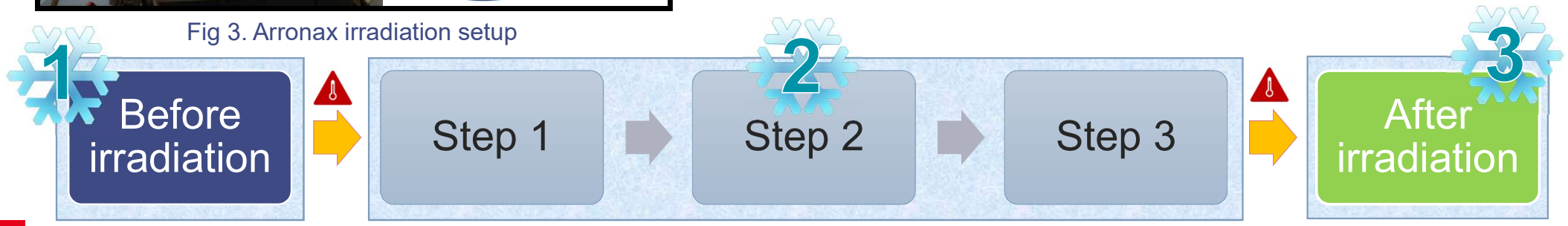


Fig 4. Measurement sequence order

Readout method illustrations

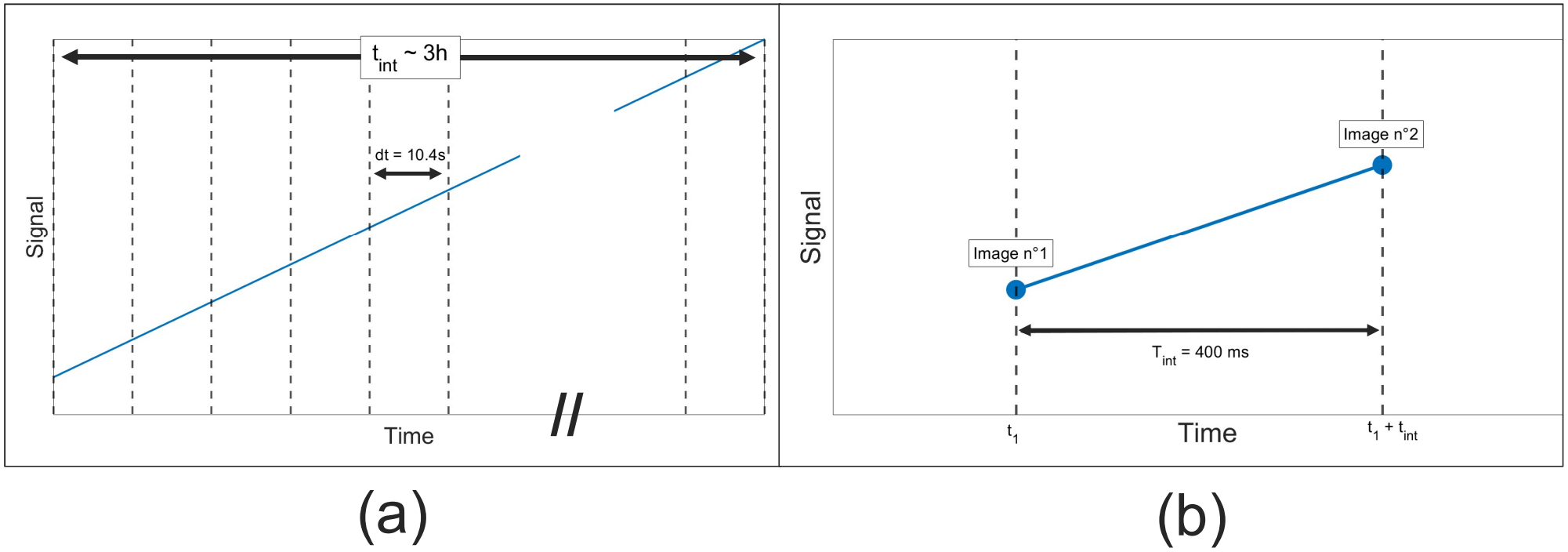


Fig 5. (a) FUR readout illustration. (b) CDS readout illustration. Each vertical dotted line represent a readout of the signal level

Follow Up the Ramp example

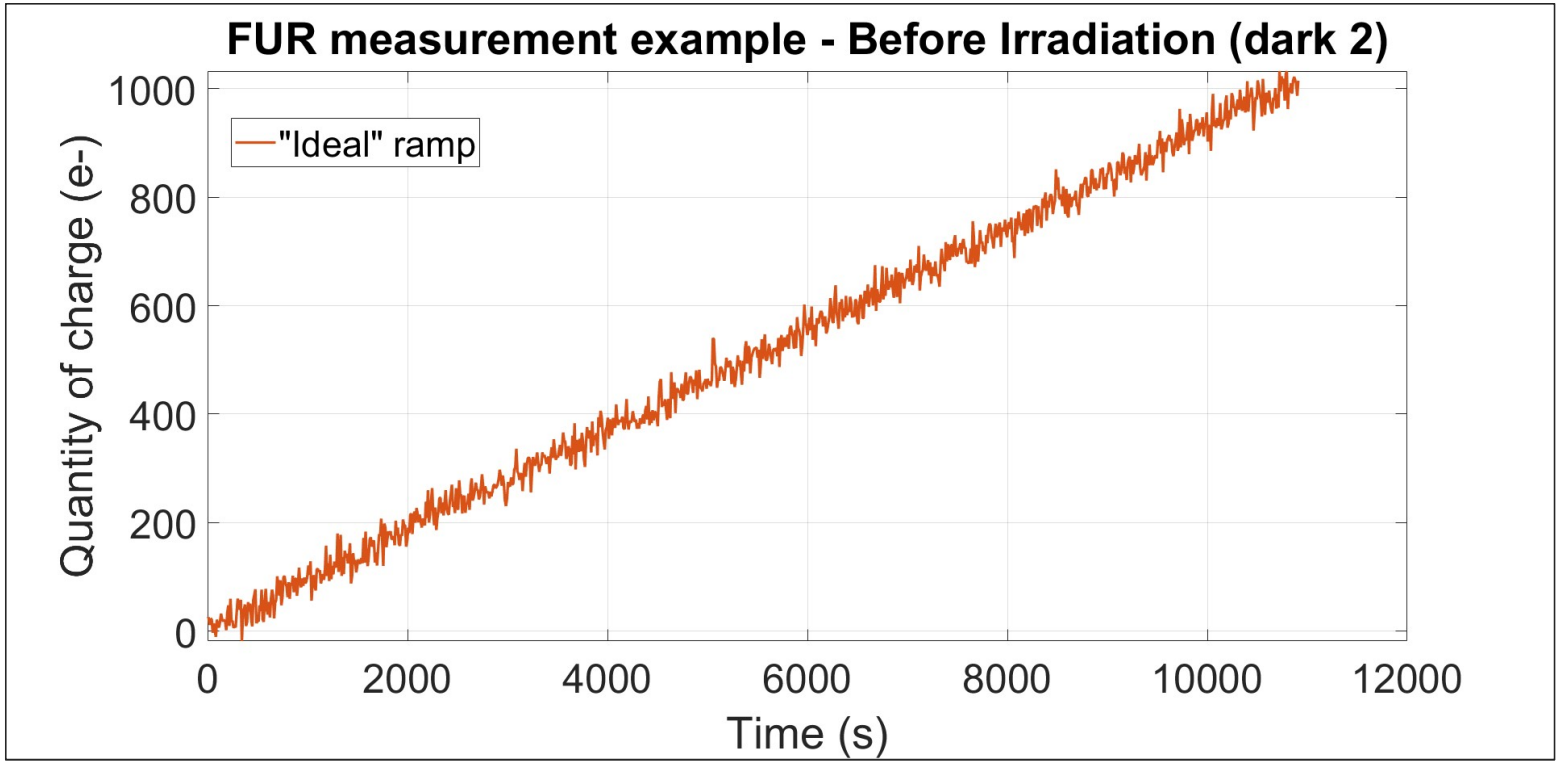


Fig 6. « Ideal » Follow Up the Ramp ramp

Follow Up the Ramp example

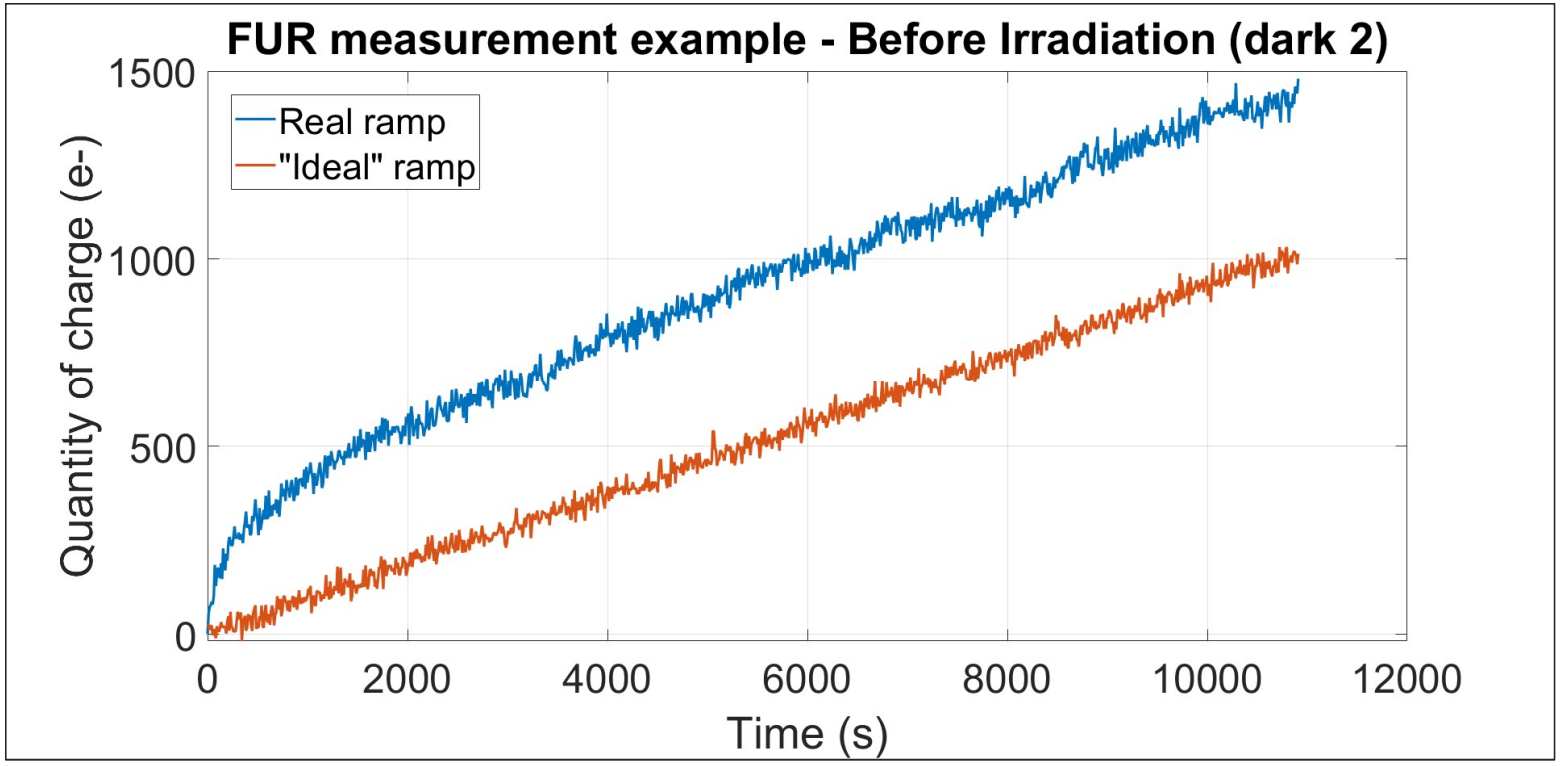
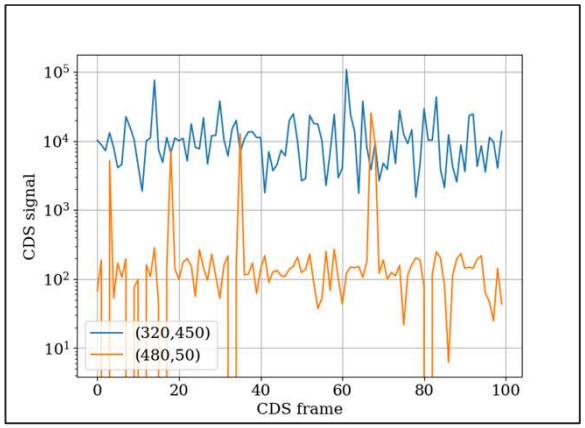


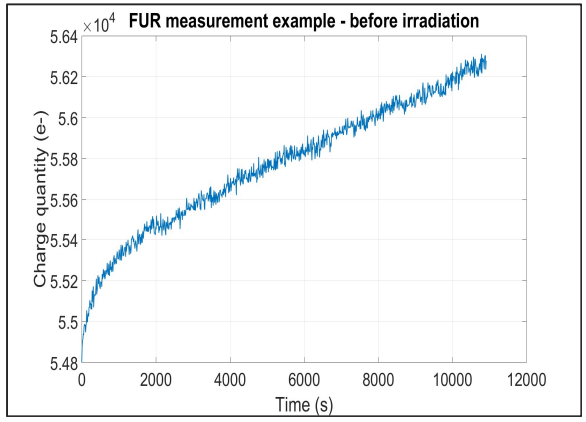
Fig 7. Real Follow Up the Ramp ramp

Measurement sequence for each steps

Irradiations → Buffer time → Dark 1 measurement → Electrical stimulation measurement → Dark 2 measurement

1h30 400ms **CDS** measurements	**Aprox. 7h**	3h **FUR** measurements	9h for each Steps	3h **FUR** measurements





Dose estimation during the irradiations

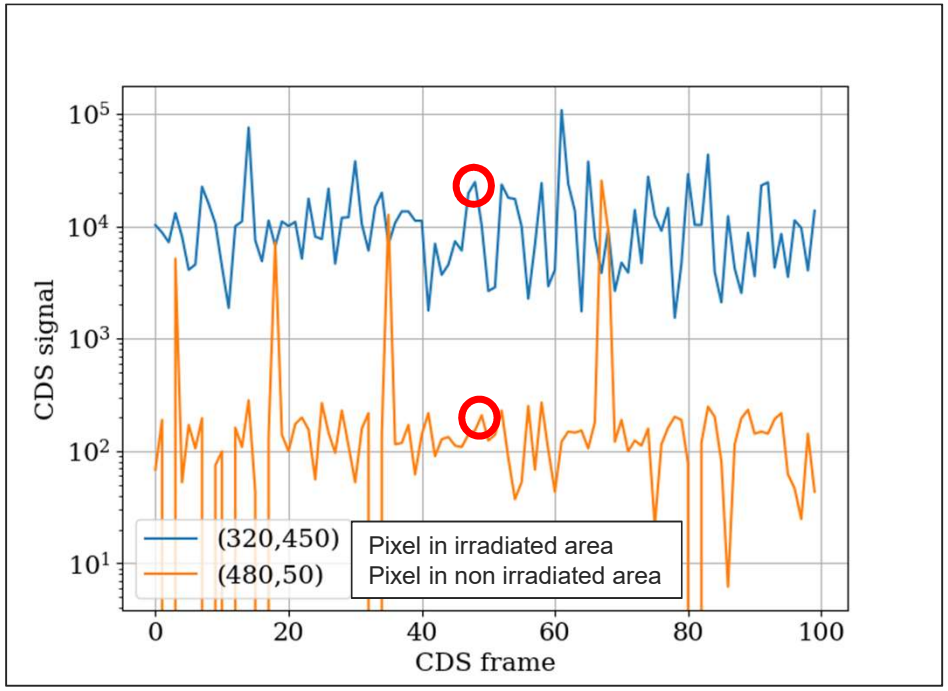


Fig 8. CDS measurement during Step 1 irradiation

How we estimate the dose?

1. We estimate the number of electrons created by 1 proton:
   - $N_{e-/proton} = \frac{(LET \times thickness)}{E_{creation}}$
2. We estimate the number of proton that hit each pixels in 400 ms
   - $N_{(protons/400ms)} = \frac{\boldsymbol{CDS_{signal}}}{N_{e-/proton}}$
3. We estimate the number of protons in 1s
4. We estimate the dose

Fluence calculation

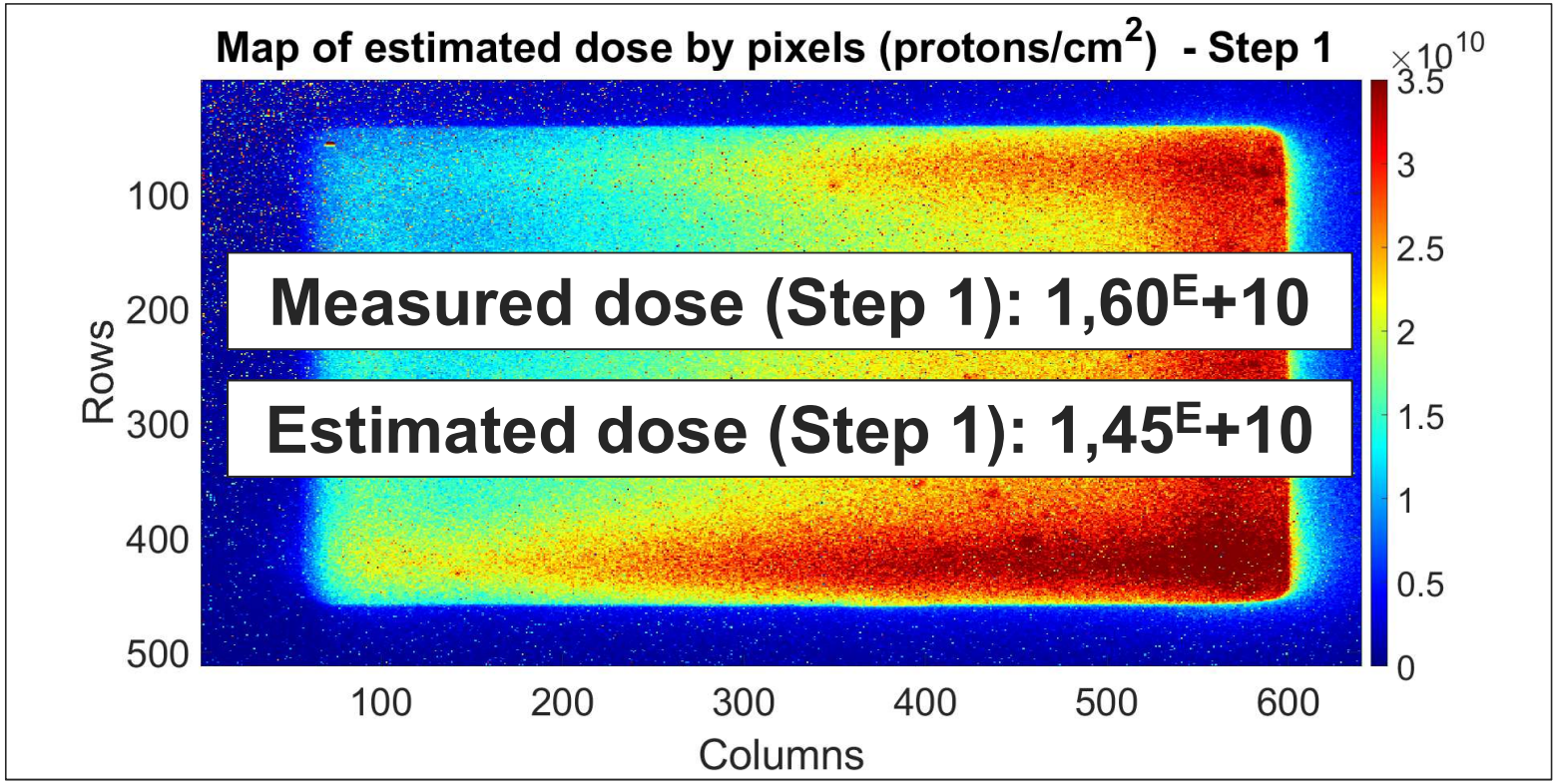


Fig 9. Estimated dose map during Step 1 irradiations

Secondary particles impacts

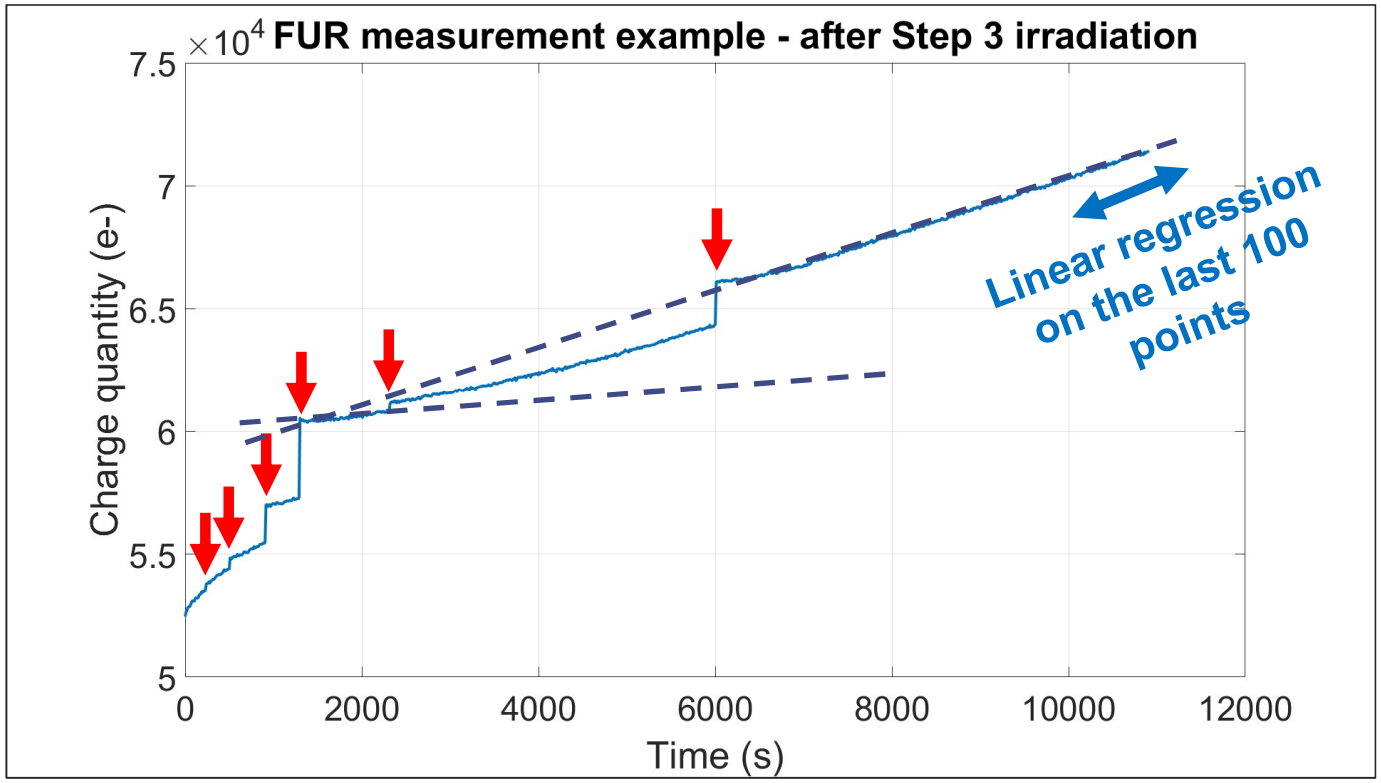


Fig 10. FUR acquisition of one pixel after Step 3 irradiation

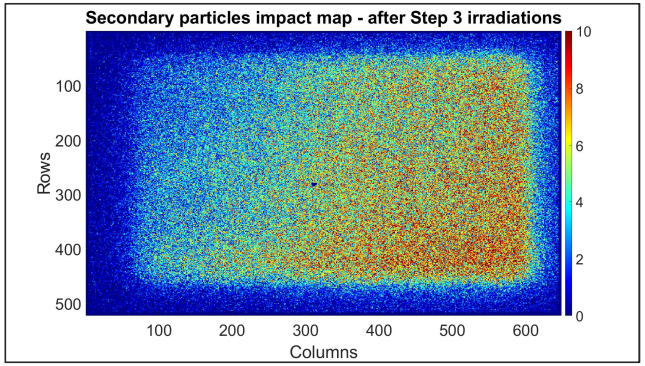
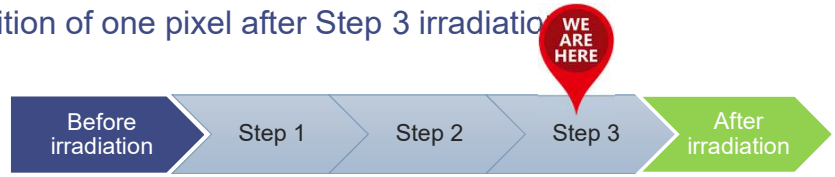


Fig 7. Secondary particles impact map – after Step 3 irradiations



3. Results

Dark Current Map

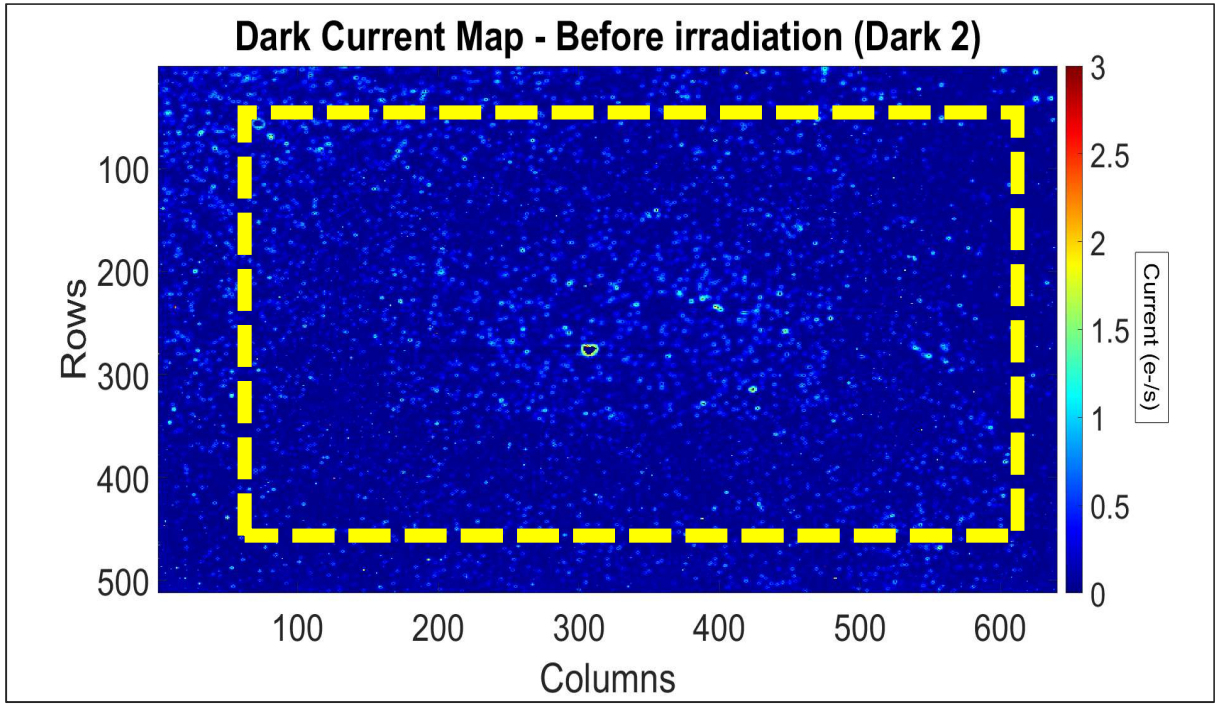


Fig 11. Dark Current Map

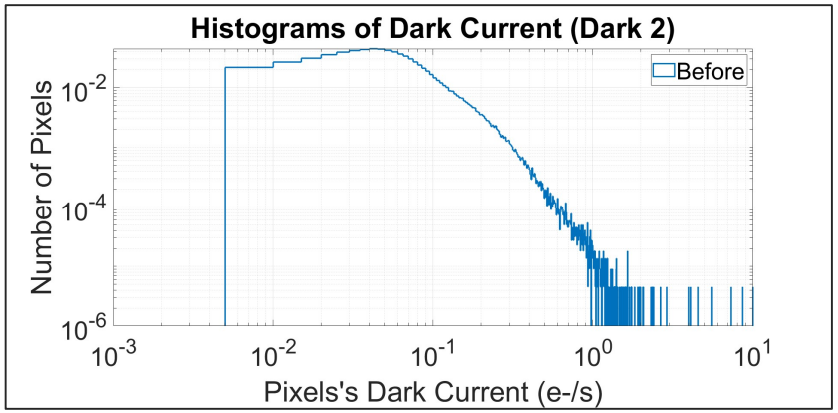
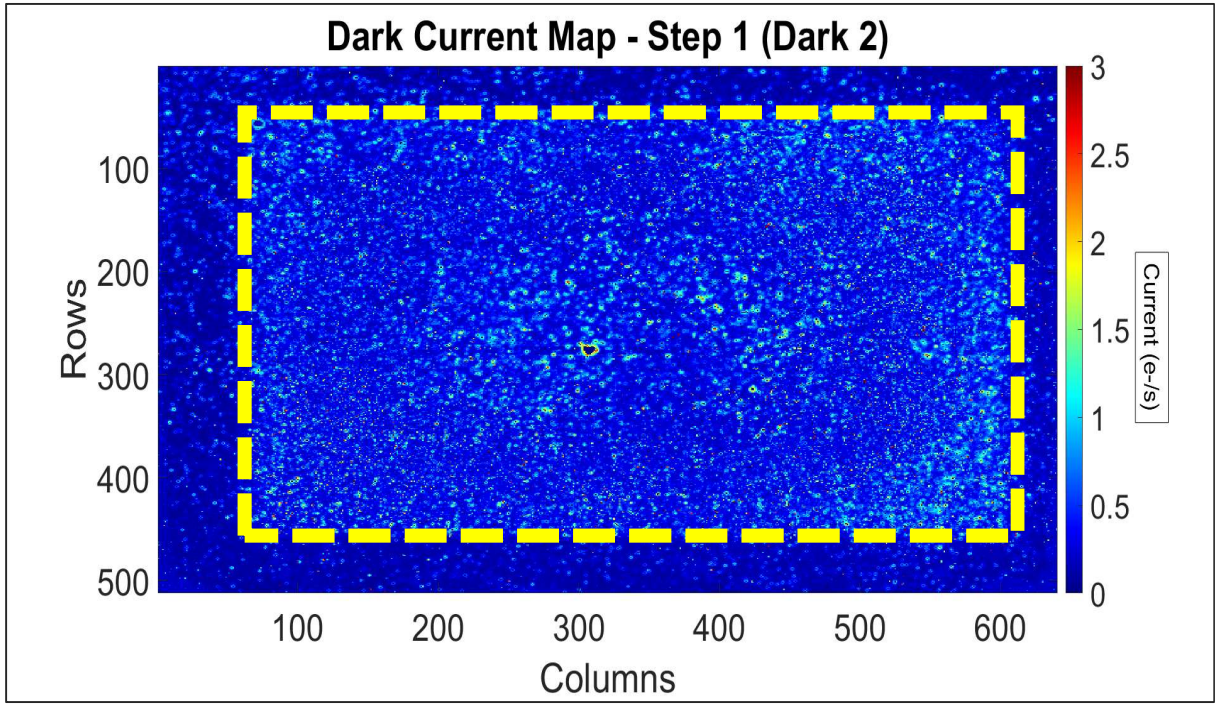


Fig 12. Dark Current Histogram

Dark Current Map



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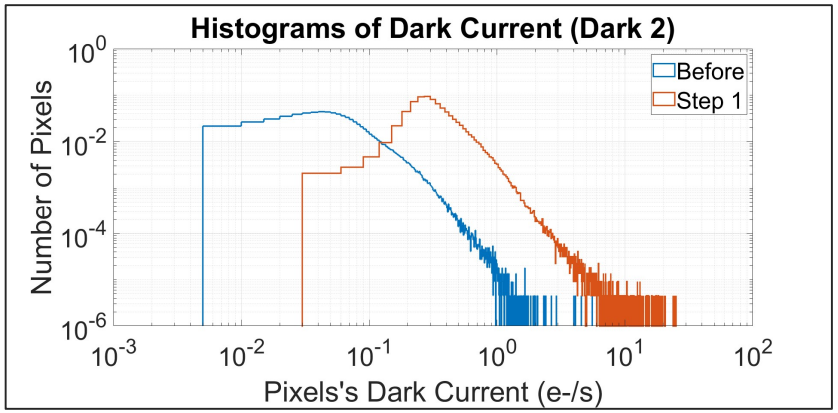

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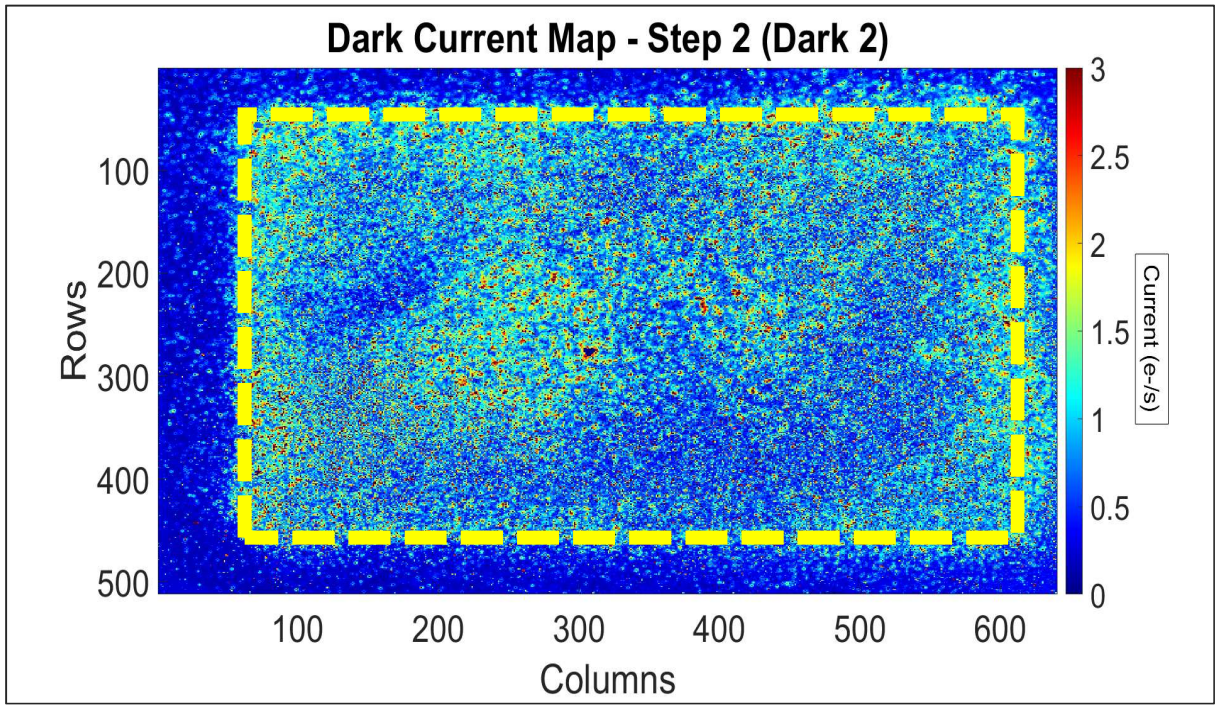
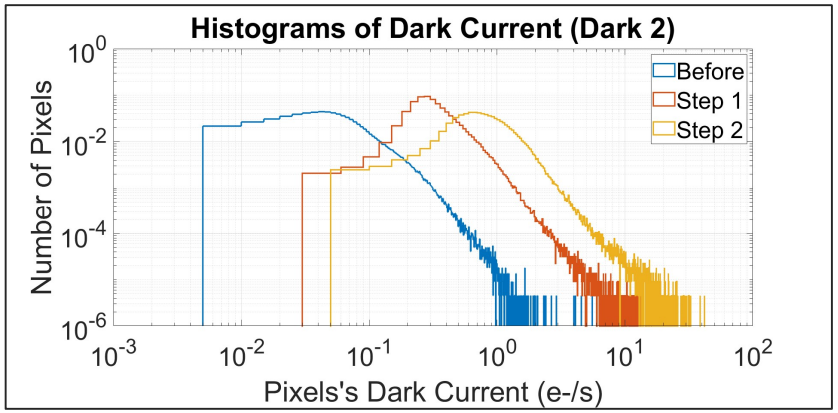


Fig 11. Dark Current Map



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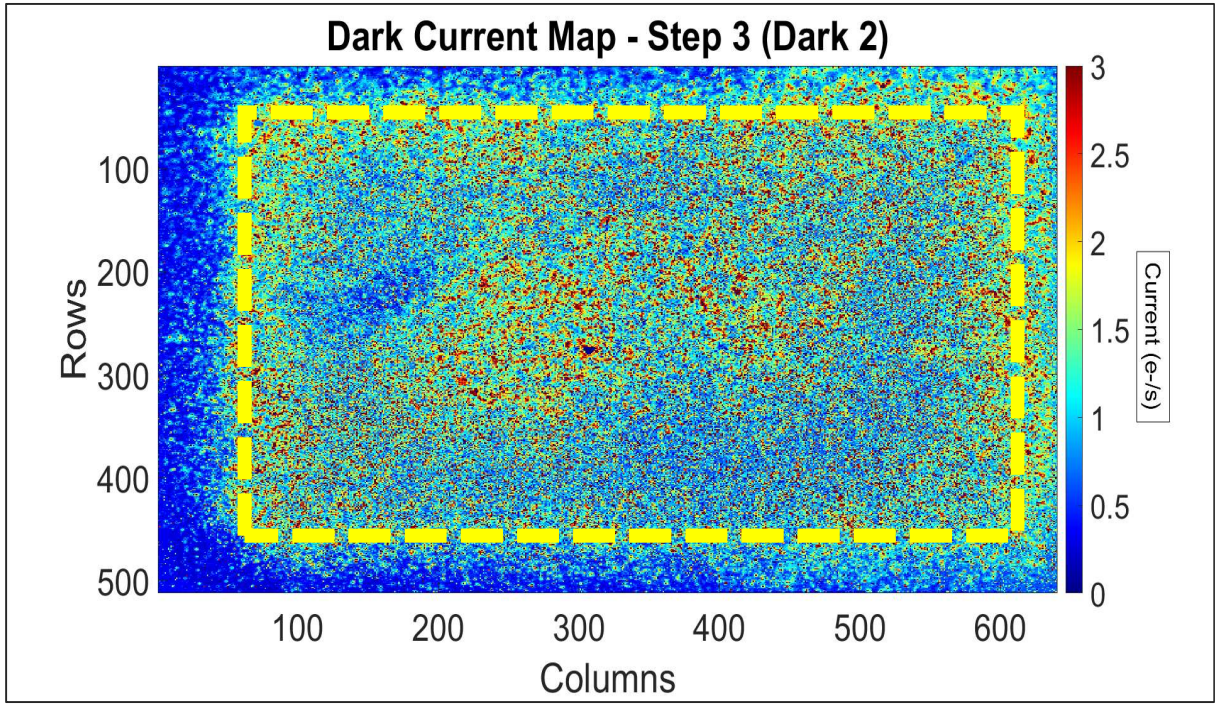

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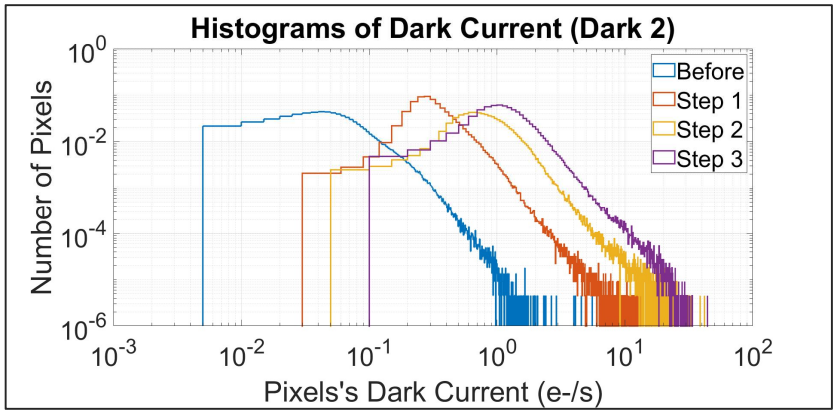

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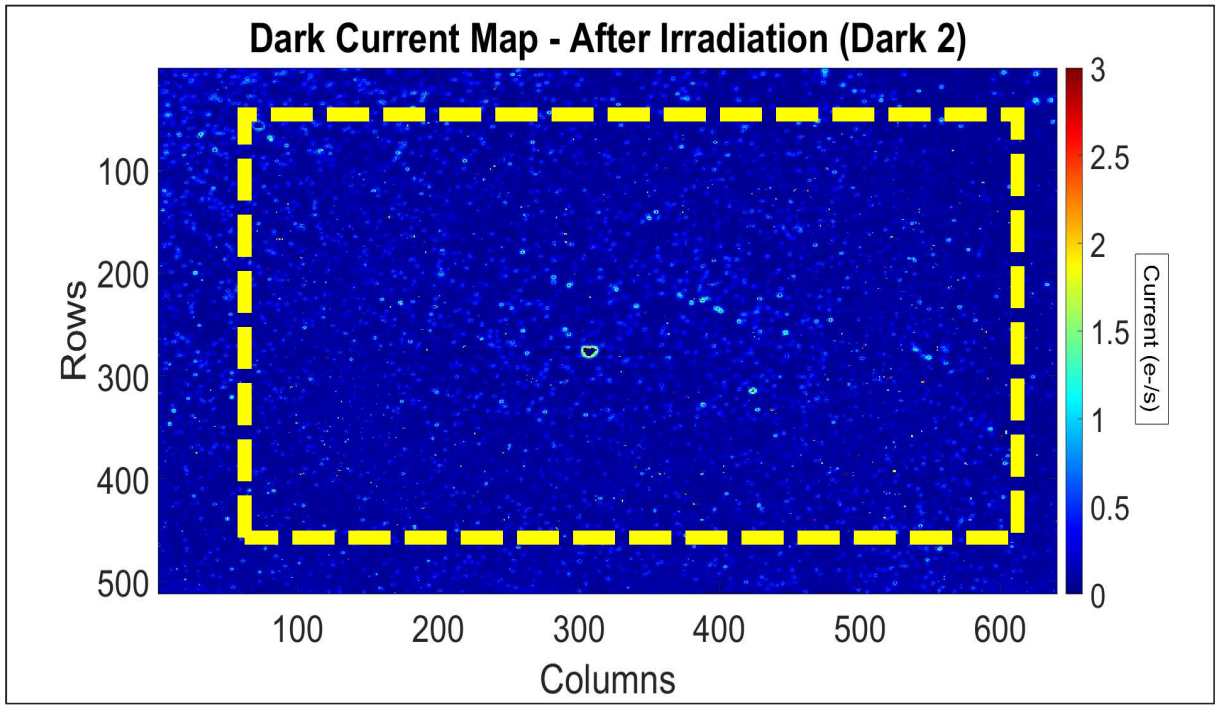

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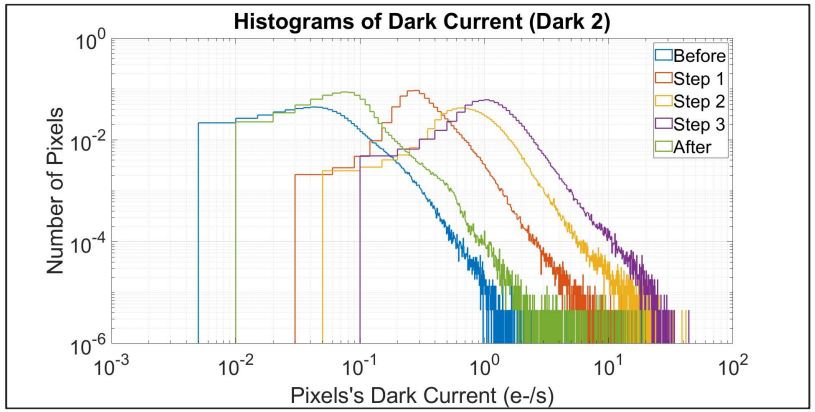


Fig 12. Dark Current Histogram

Dark current results (with time)

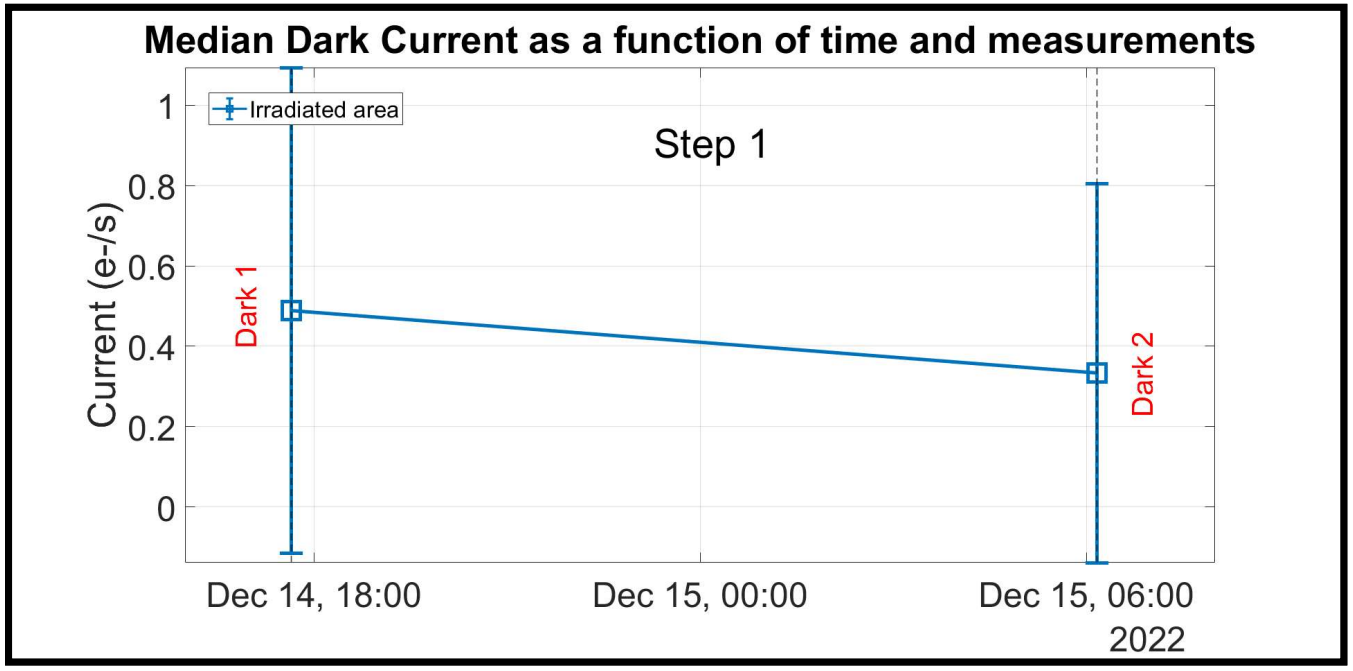


Fig 13. Median Dark Current as a function of the time and the measure

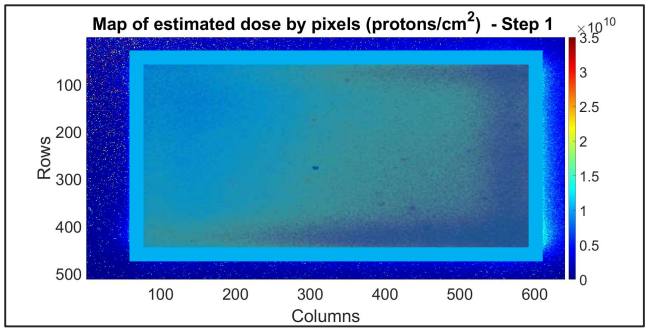
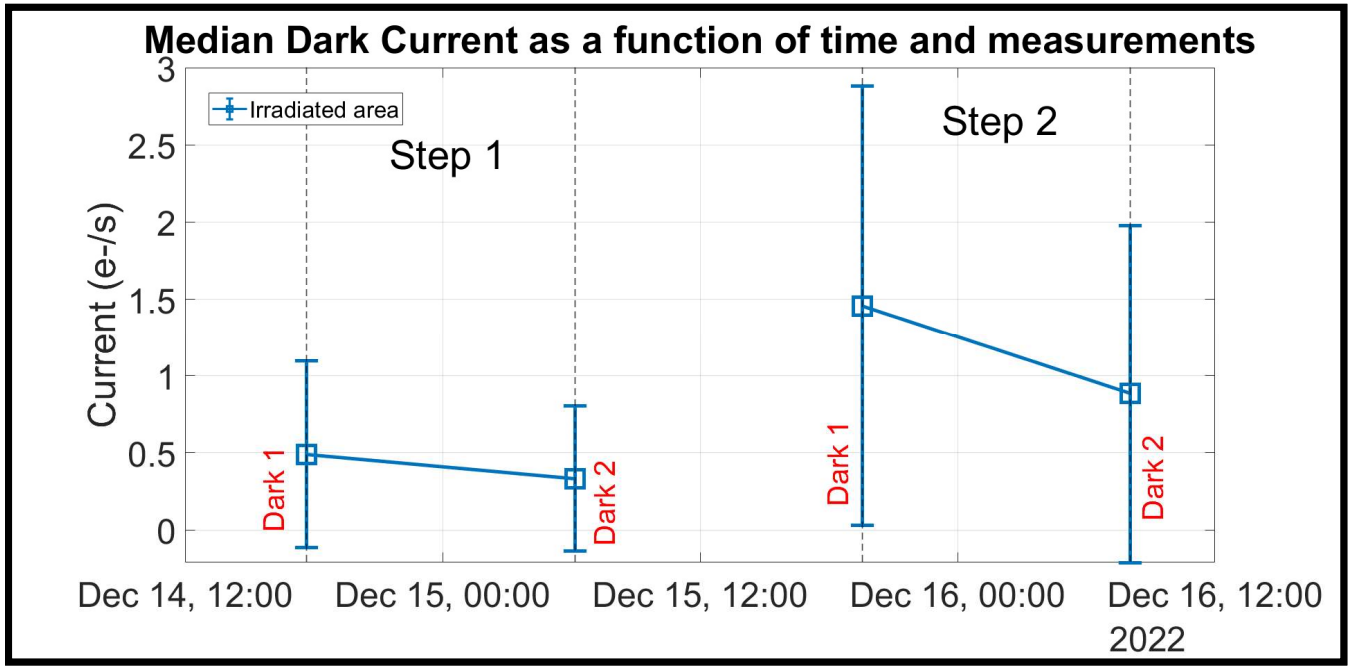


Fig 14. Representation of the areas of interest

Dark current results (with time)



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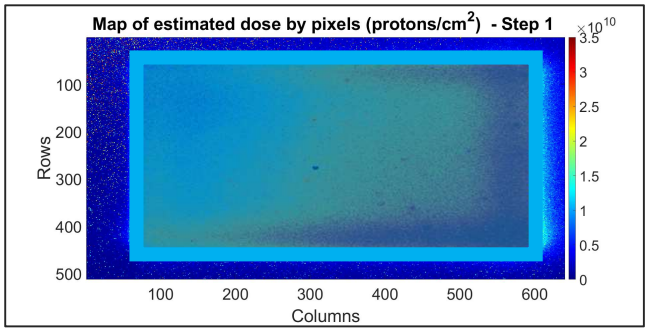

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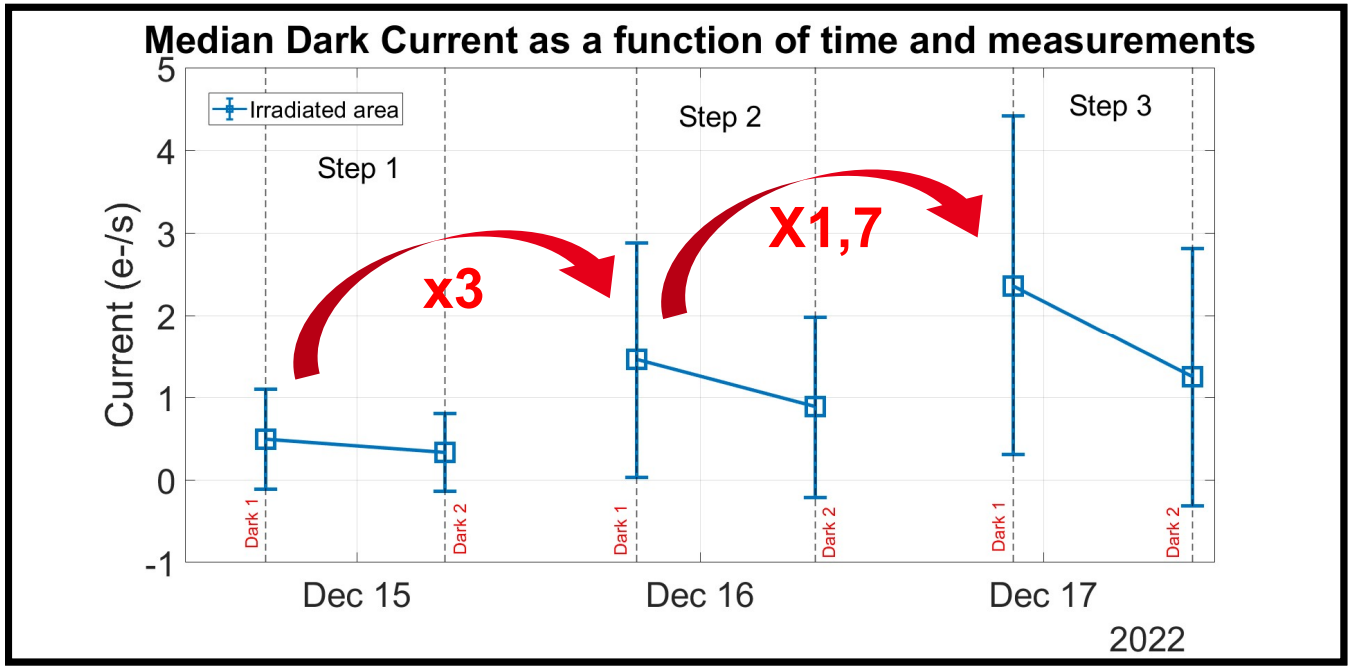


Fig 13. Median Dark Current as a function of the time and the measure

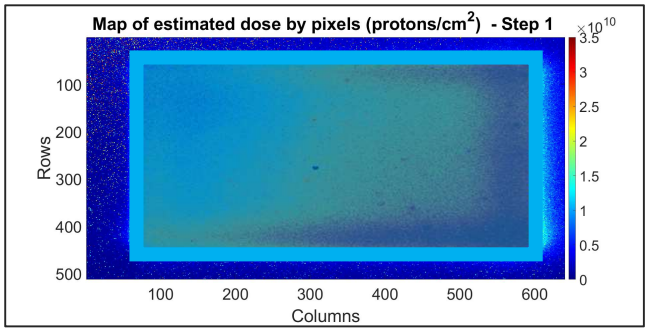


Fig 14. Representation of the areas of interest

- Increase with irradiation
- Decrease with time after the irradiation

Dark current results (with time)

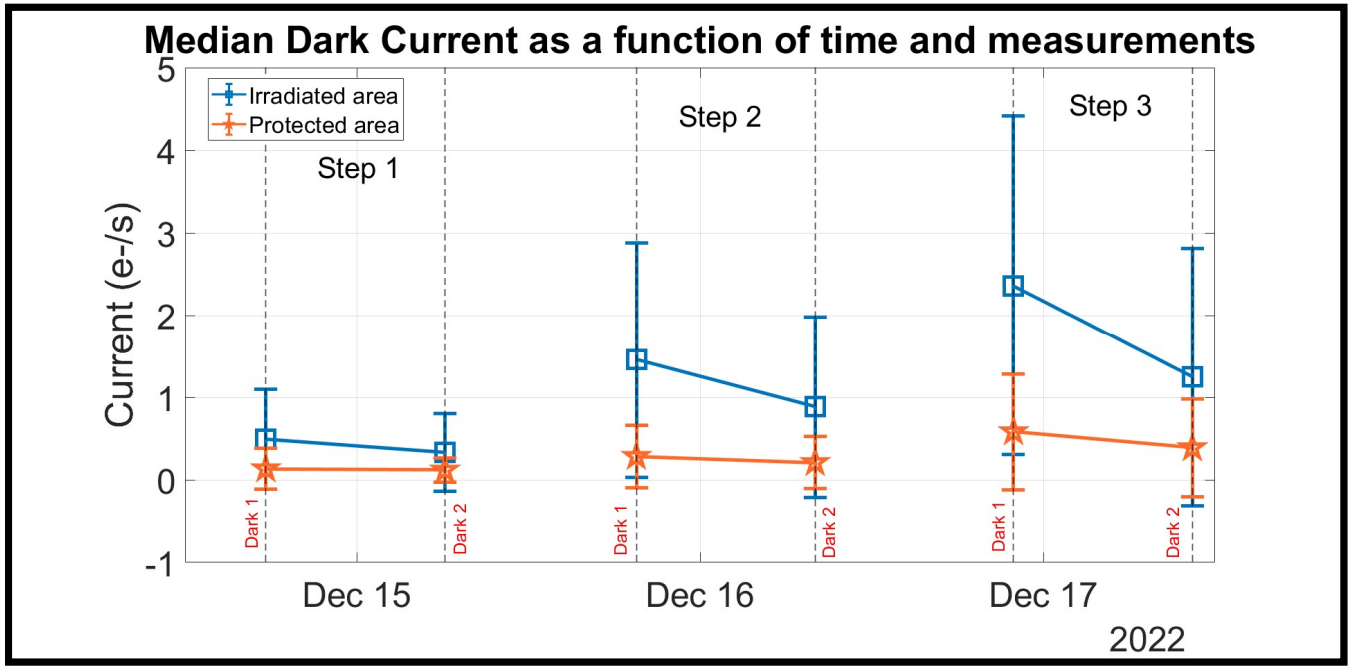


Fig 13. Median Dark Current as a function of the time and the measure

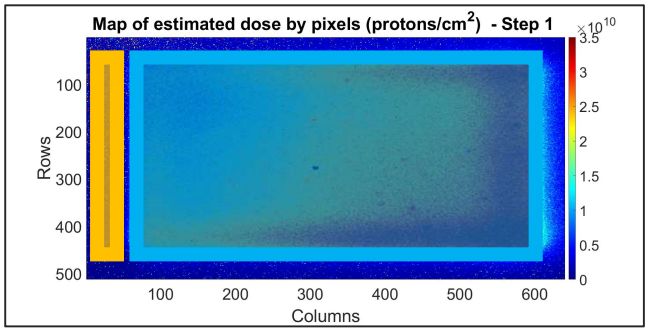


Fig 14. Representation of the areas of interest

- Increase with irradiation
- Decrease with time after the irradiation

Dark current results (with time)

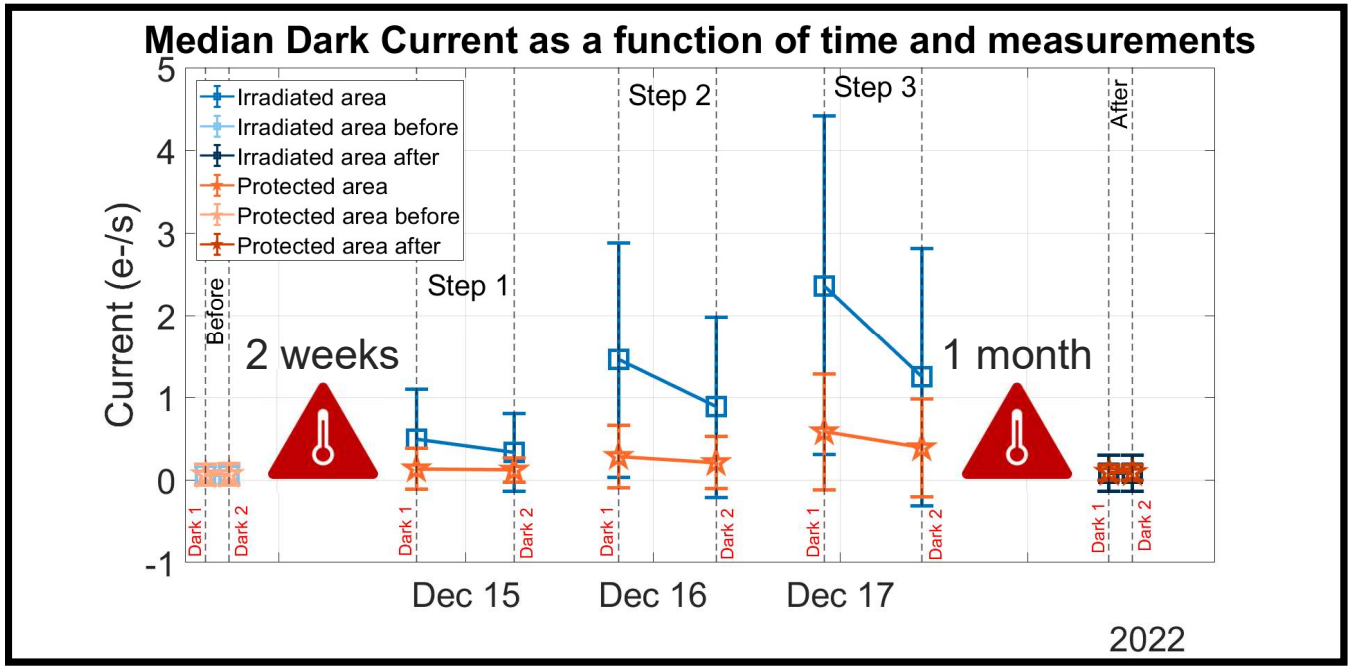


Fig 13. Median Dark Current as a function of the time and the measure

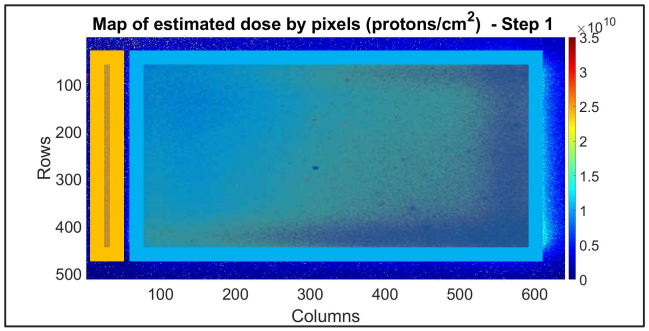


Fig 14. Representation of the areas of interest

- Increase with irradiation
  - From < 0,1 to >2 e-/s
- Decrease with times after the irradiation
- Dark Current recover nearly to its initial value (from 0,06 to 0,08 e-/s)

Dark current results (with number of protons)

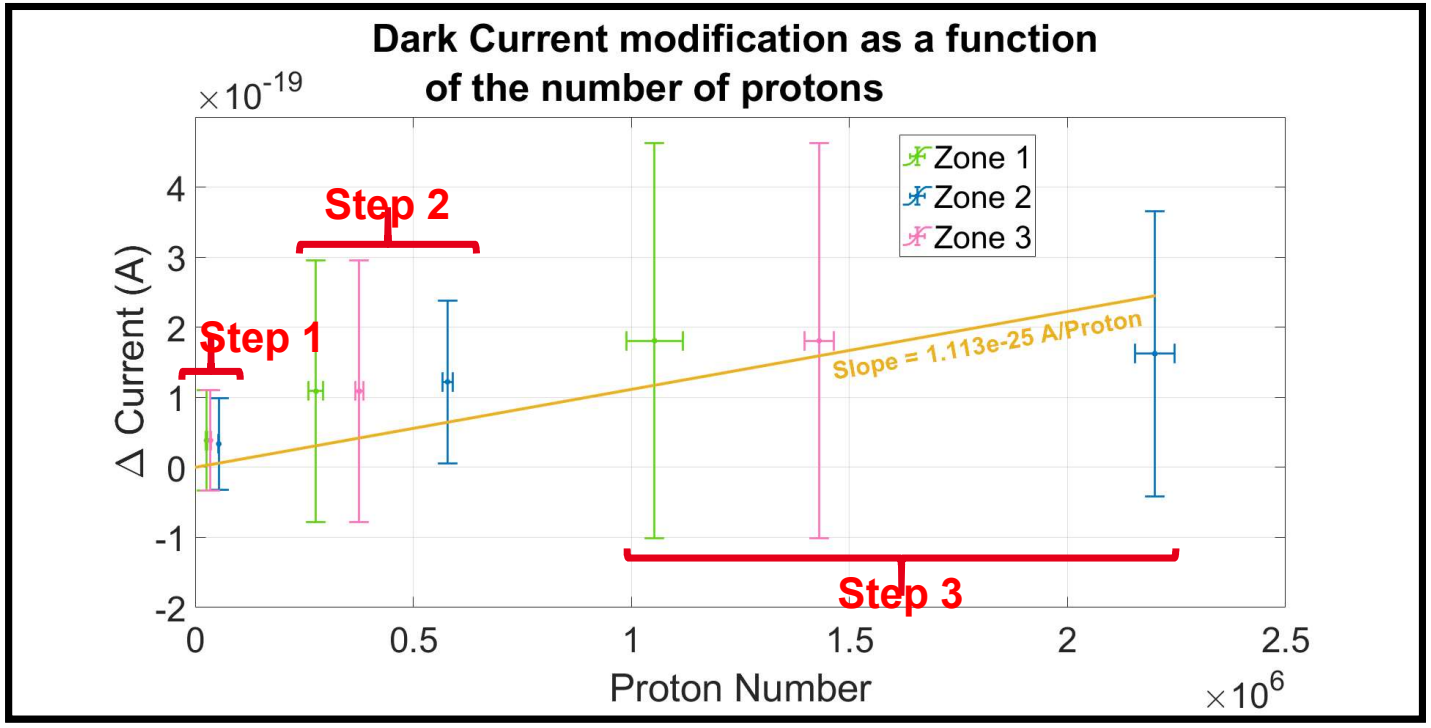


Fig 16. Median Dark Current as a function of the dose

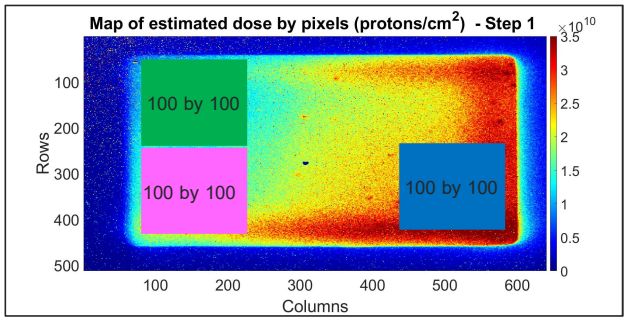


Fig 15. Representation of the areas of interest

- Increase in Dark Current with the dose
- Again, dispersion also increase with the dose
- Damage factor of $\sim 10^{-25} A/proton$ $\sim 10^{-6} e/s\ /proton$

RTS results

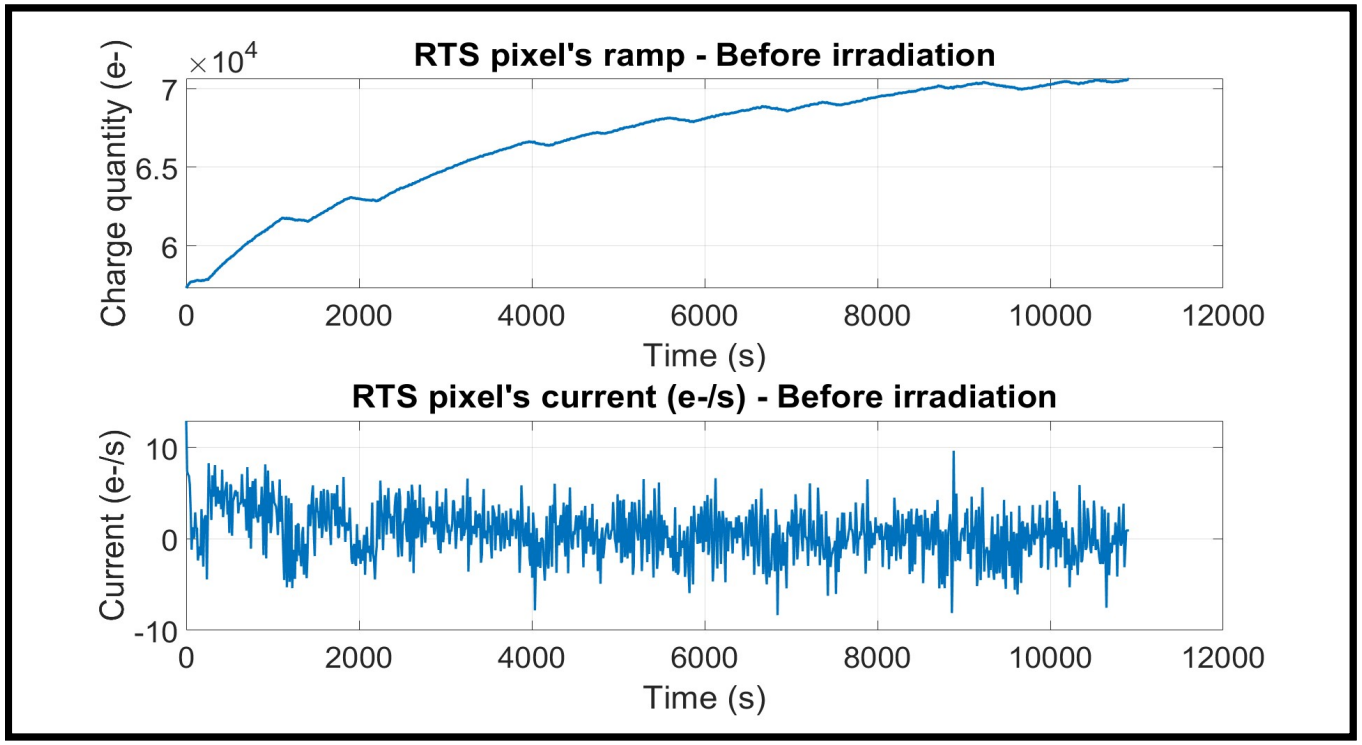


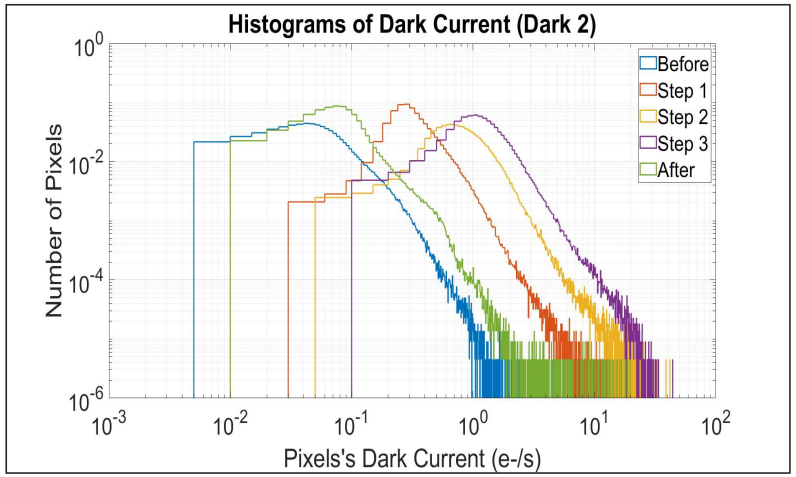
Fig 18. Example of a pixel showing a RTS behavoir

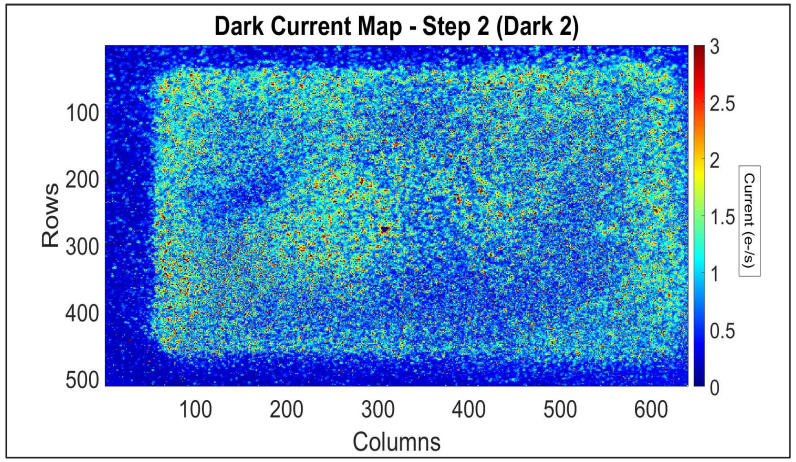
- Very low Dark Current → difficult to detect RTS behavior
  - If we can't detect them, they are less critical

4. Conclusion

Conclusion

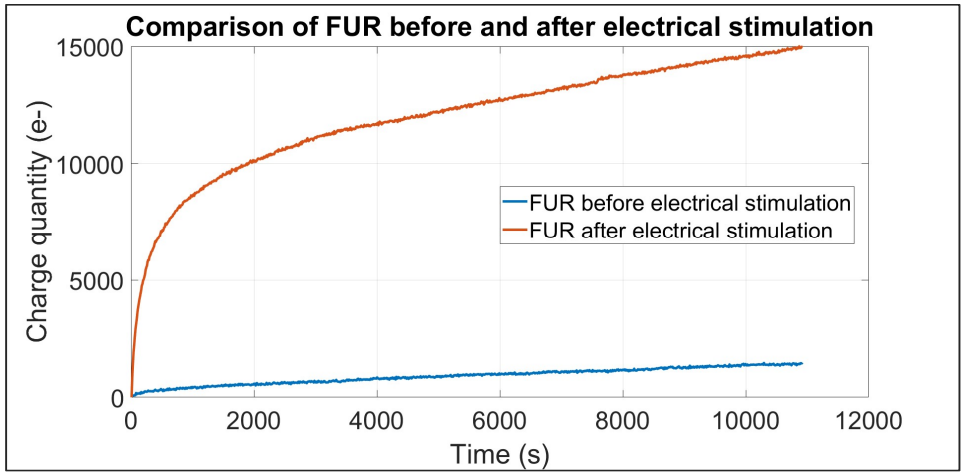
- **Dark Current study were performed on an irradiated SWIR MCT detector at cryogenic temperature**
- **Dose was spatially estimated**
- Increase of the Dark Current after irradiation **(from < 0,1 e/s to > 2 e/s)**
  - **Limited increase in comparison to the dose ($4,73.10^{11}\ p+/cm^2$)**
  - **Low damage factor (~$10^{-25} A/p+$)**
  - **Permanent damage of the sensor ($+\ 0,02\ e/s$)**
- Very low number of RTS pixels detected

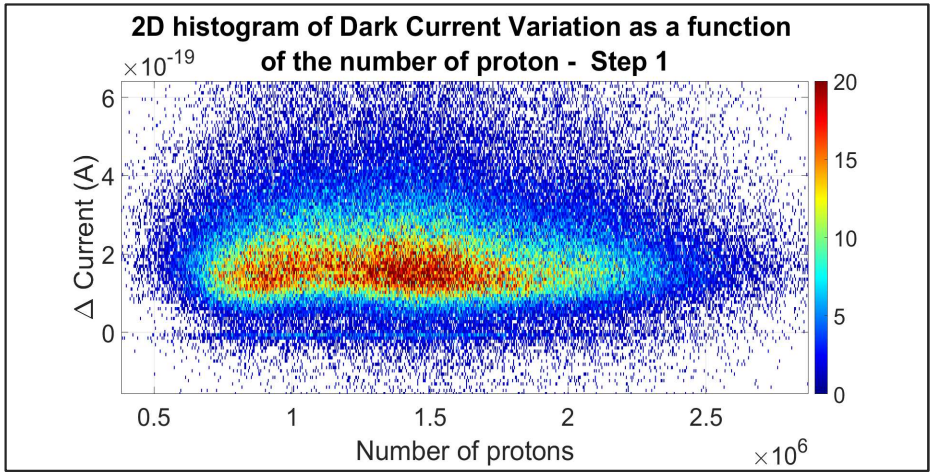




Perspectives

- Persistence phenomenon analysis
- Investigation on the supposed non linearity of the damage factor
  - Study of the correlation between Dark Current degradation and dose





Thank you for your attention

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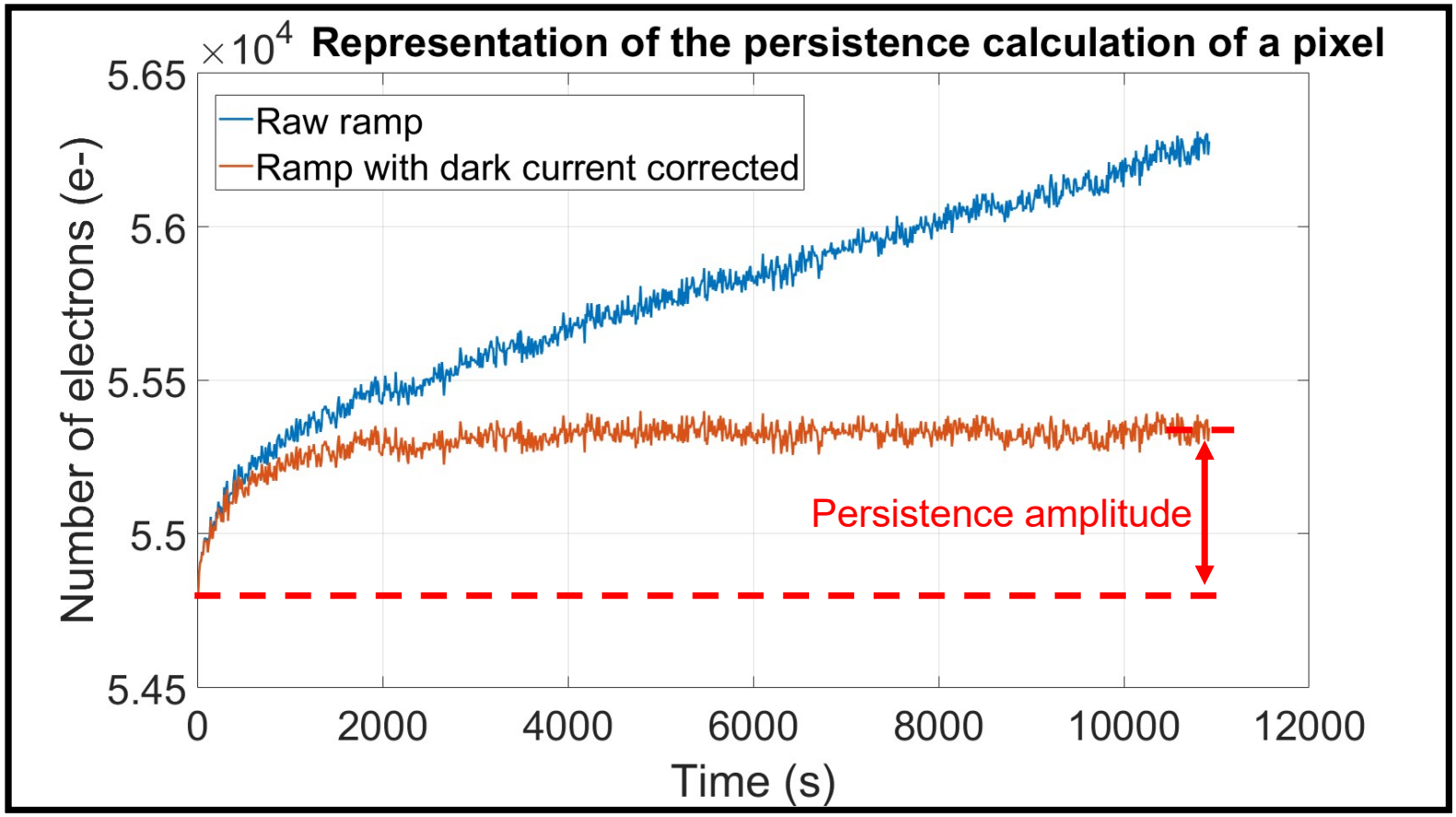
Annexes

Persistence you say?



Secondary particles impacts

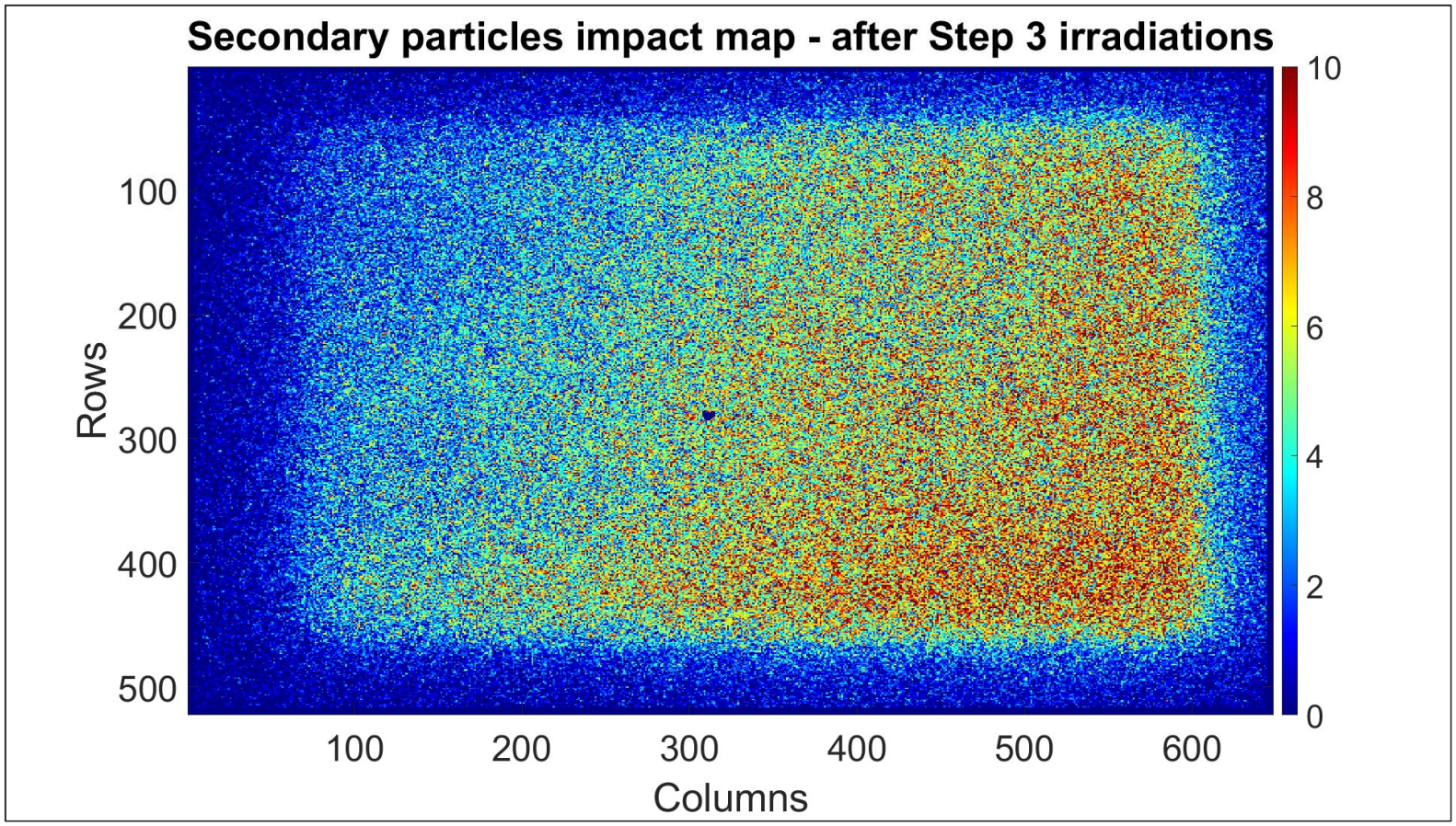


Fig 7. Secondary particles impact map – after Step 3 irradiations

Dark current results (with cumulative fluence)

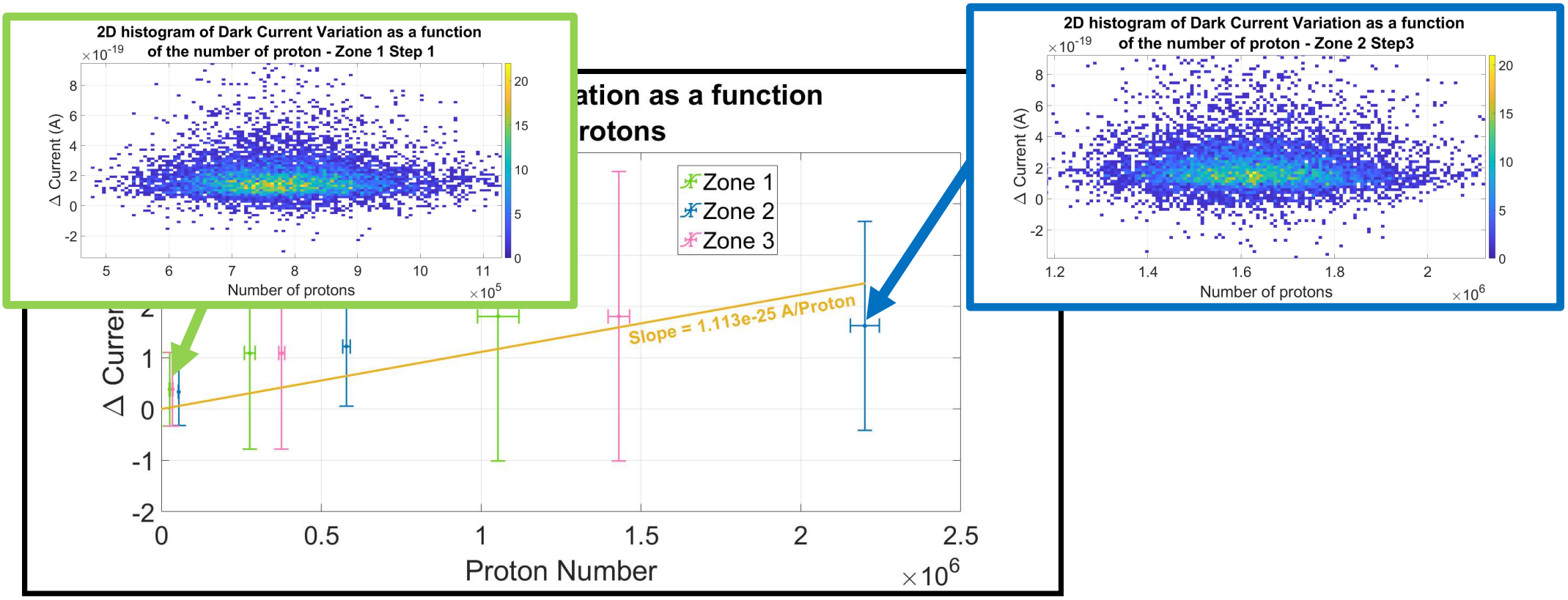
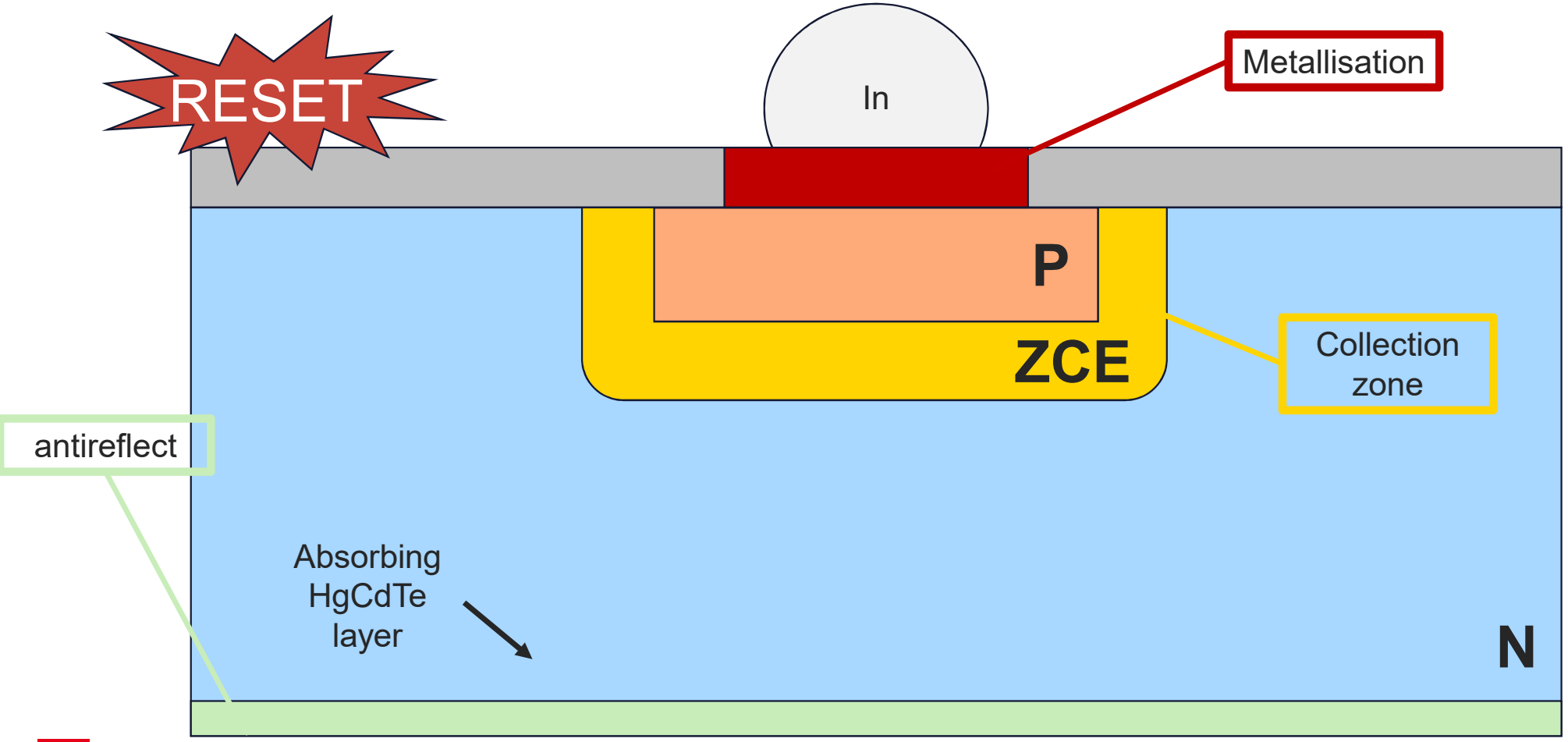
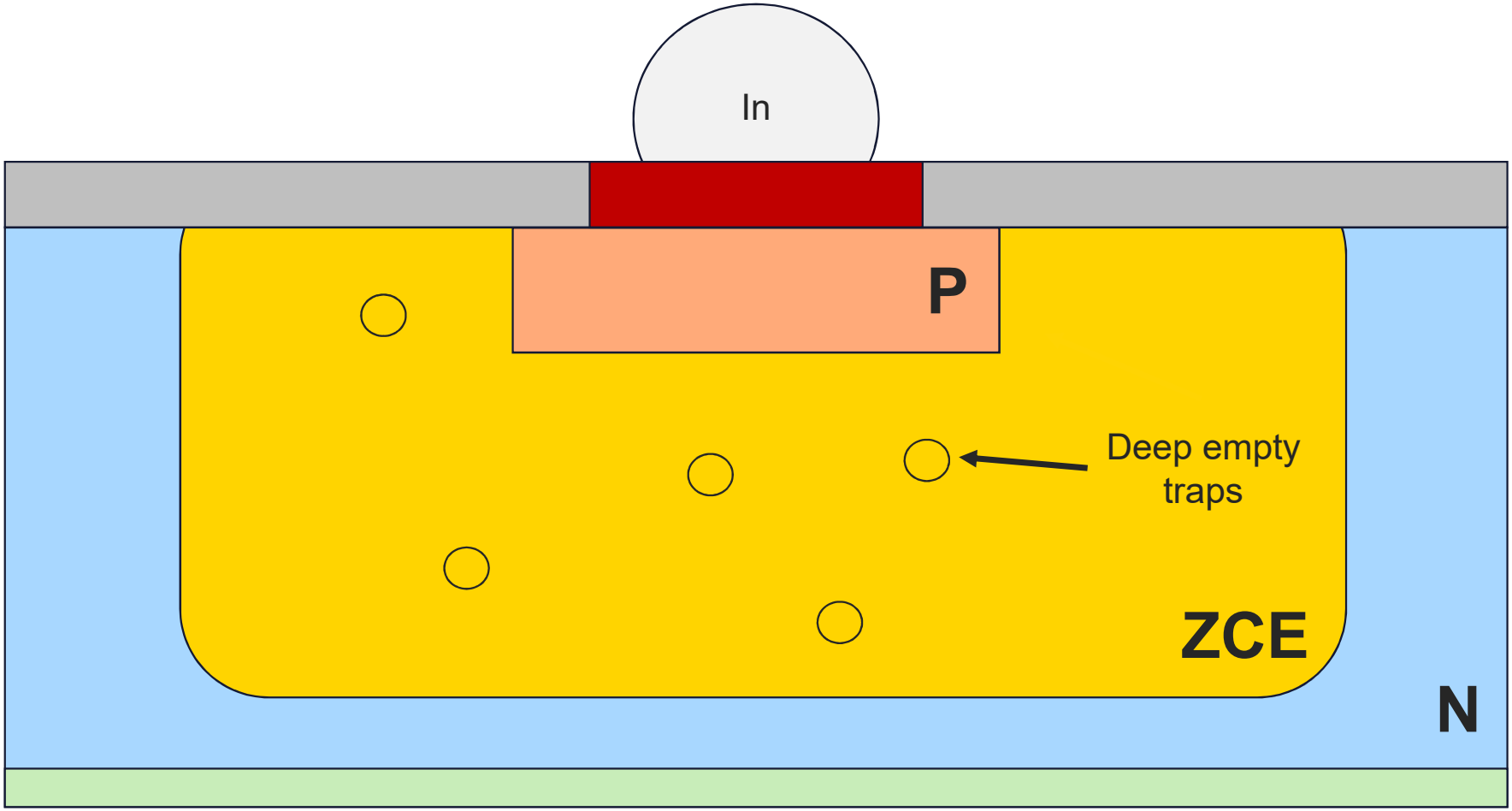


Fig 16. Median Dark Current as a function of the dose

Persistence you say?



Persistence you say?



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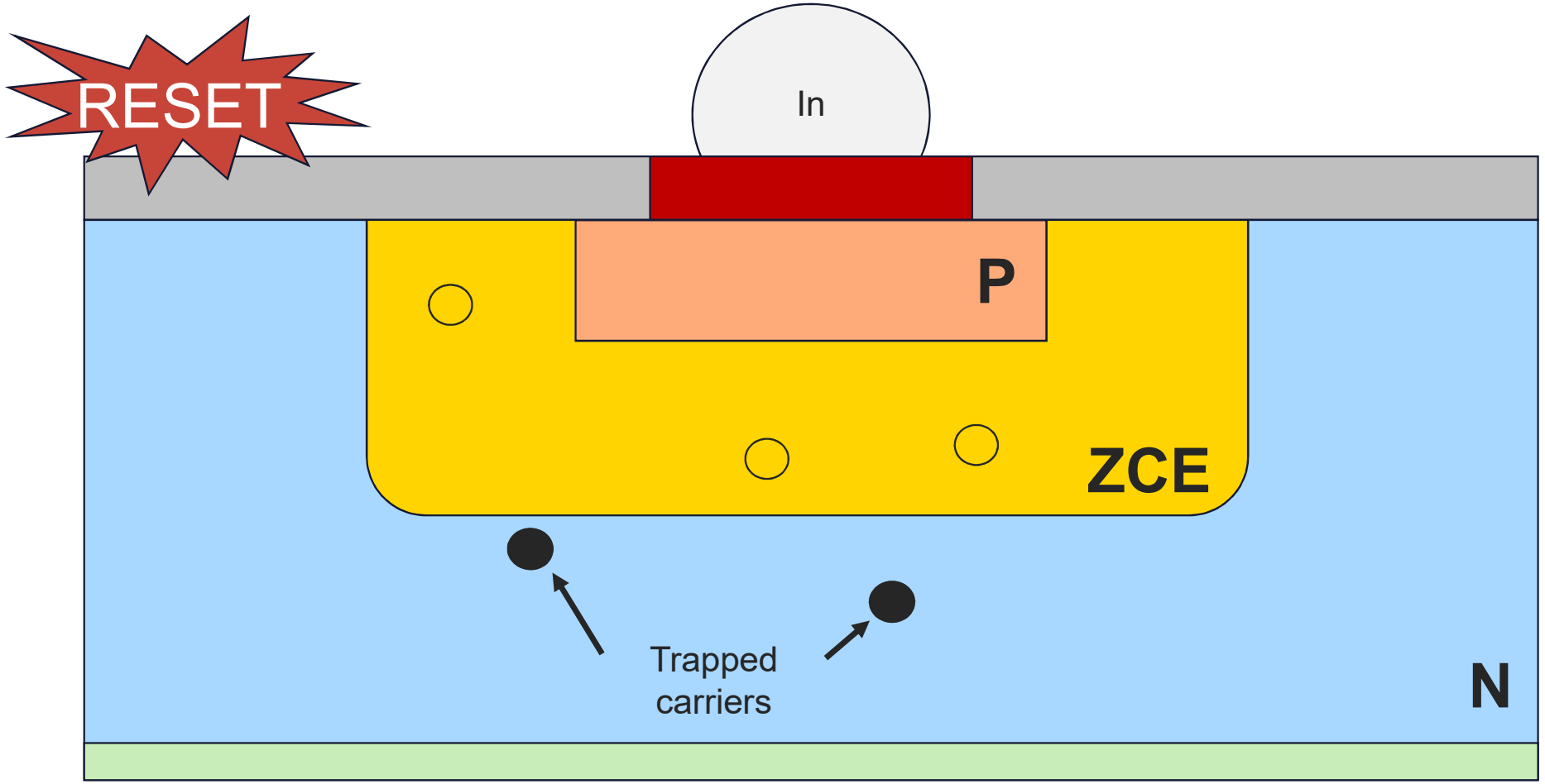

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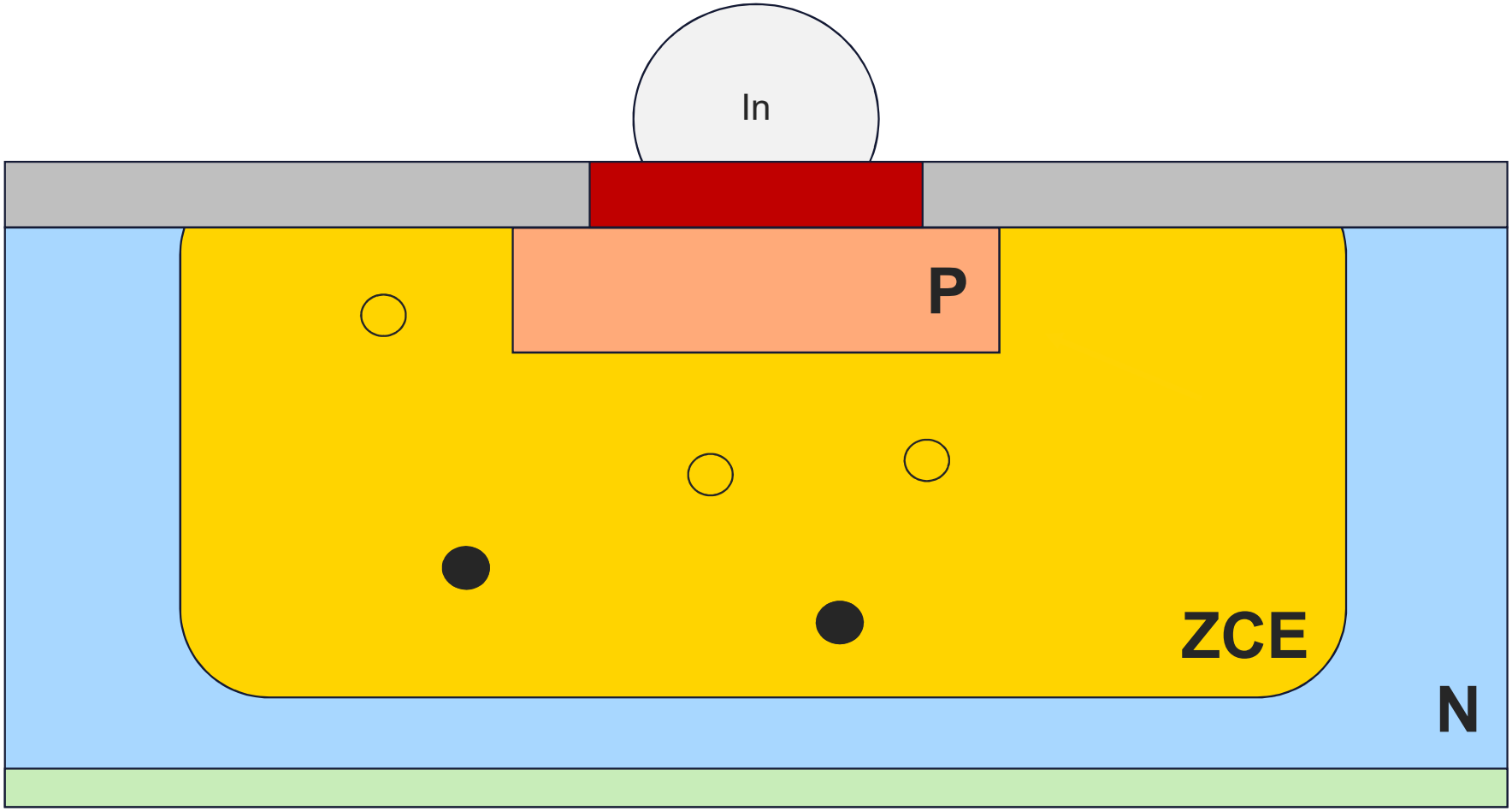

Persistence you say?