STUDY AND CHARACTERIZATION OF PERSISTENCE ON HGCDTE INFRARED DETECTORS FOR ASTRONOMY APPLICATION

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OUTLOOK

- **Introduction**
- **Instrumentation & protocoles**
  - Cryostat with cold integration sphère and IR LED
  - Protocoles definition (optical, electrical, flash, ramp)
- **Analysis**
  - Influence of test parameters
  - Comparison of optical flash & electrical stress
  - Comparison of optical ramp & flash illumination
- **Persistence : a tool to probe technology quality**
  - Additionnal information obtained with persistence
  - Persistence study on detectors with technological flavors
- **Conclusion**

INTRODUCTION

VGA Test Detectors

In house HgCdTe SWIR (2.1 and 2.5µm)
15µm pitch, P/N diodes
Preliminary batches from ALFA

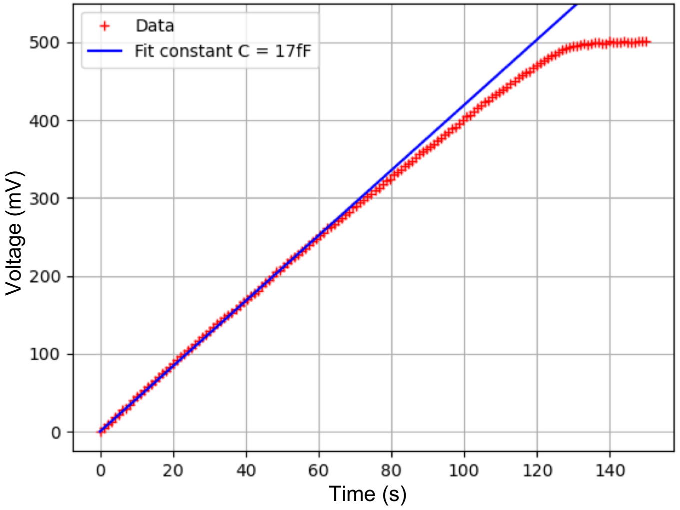
Low flux detectors for astronomy

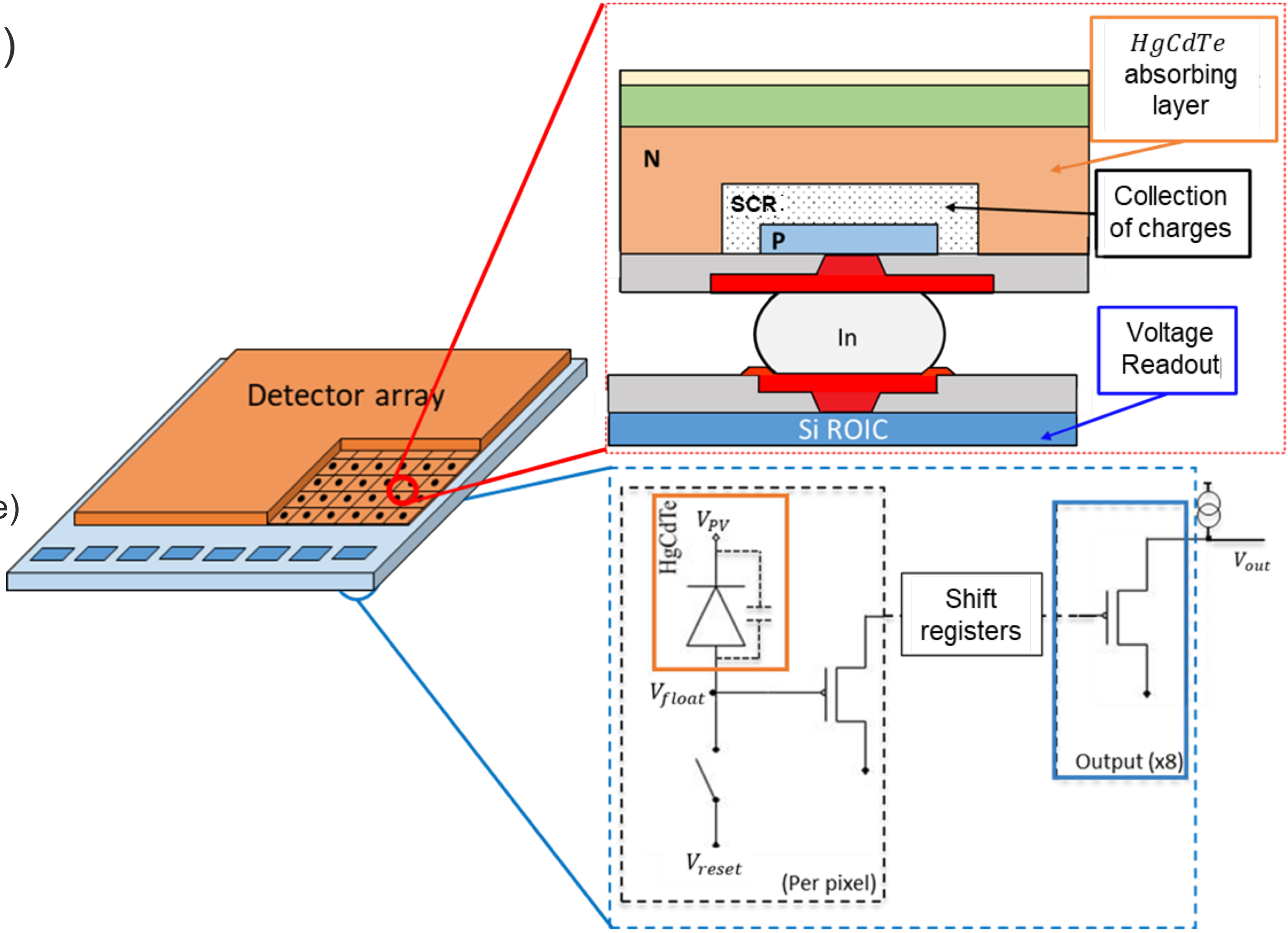
Flux ~1ph/s

SFD ROIC

Non destructive readout
High conversion gain
But non linear (no additionnal capacitance)

Integration ramp on a SFD pixel under constant flux

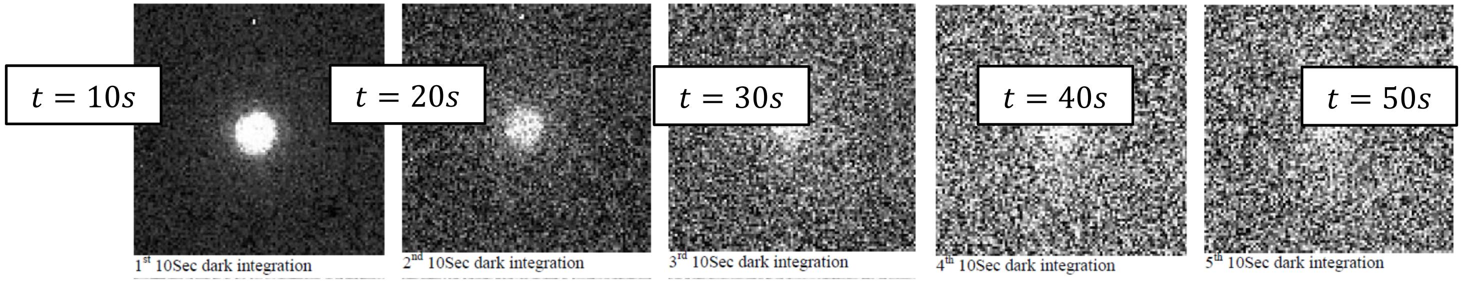




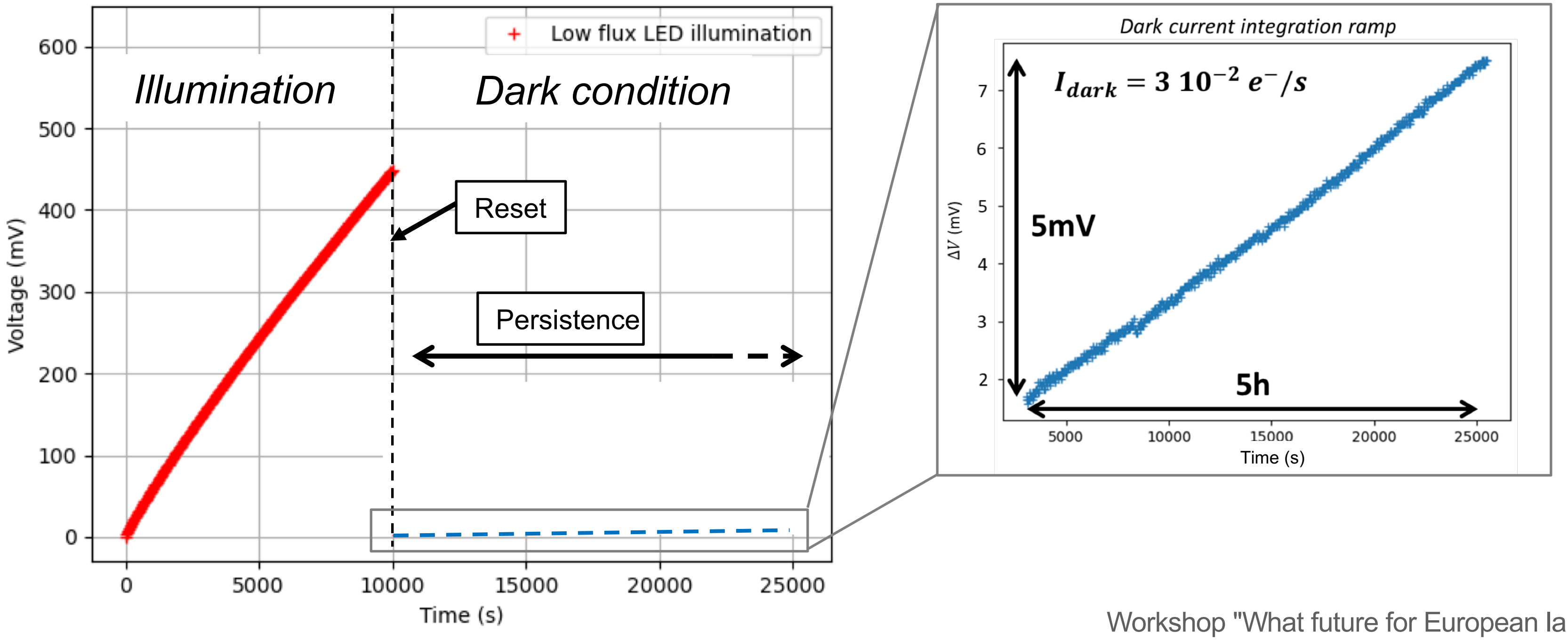
DESCRIPTION OF PERSISTENCE AND ITS PROBLEMATIC

Persistence

= influence of all previous acquisition



[1] N. Besawada (2004)



Calibration ?

Influence of stress amplitude, duration, operating temperature …

→ Time consuming

Persistence comparison between detectors ?

Needs of a reproducible protocole and controled environment

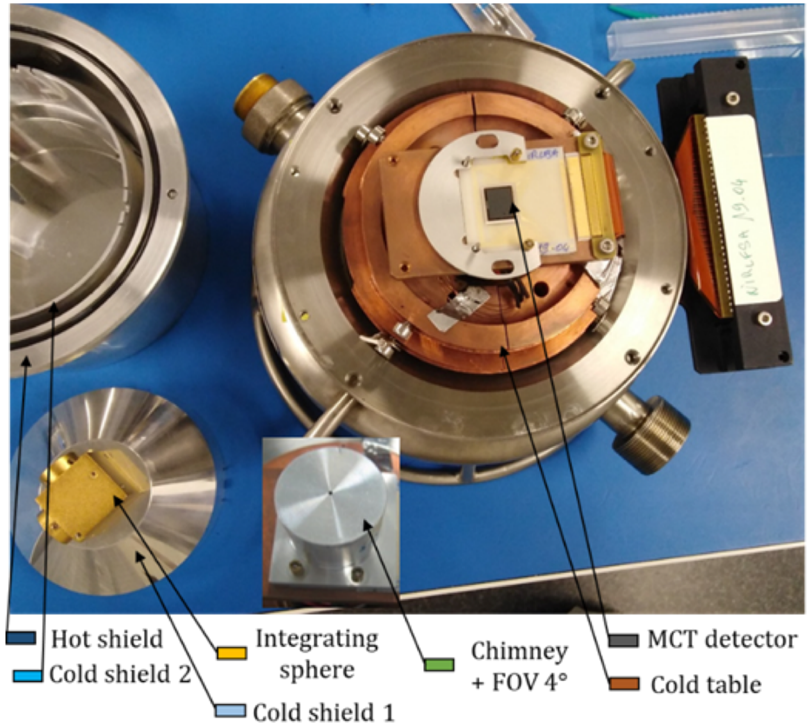
INSTRUMENTATION – CRYOSTAT WITH COOLED IR LED

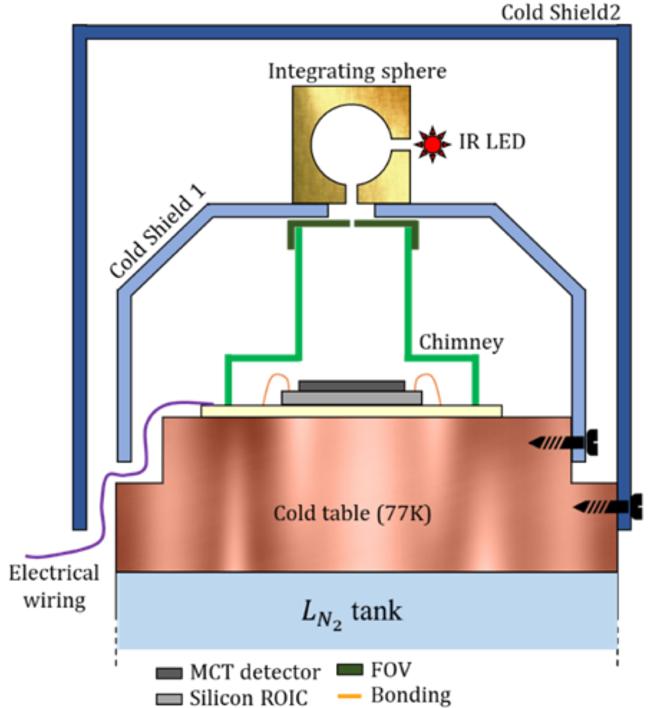
Cryostat

Liquid nitrogen + regulation T° from 90 to 150K
Shielding : measured obscurity < $0{,}003\ ph/s$
Integrating sphere : FOCUS

IR LED

LED (@1,55µm) flux : $4\ 10^6\ ph/s$ to 4 ph/s
→ Pulsed operation : repetition of 1µs flash → 4 ph/pulse





PROTOCOLES DEFINITION

Protocoles inspired from the litterature

Measurement type:

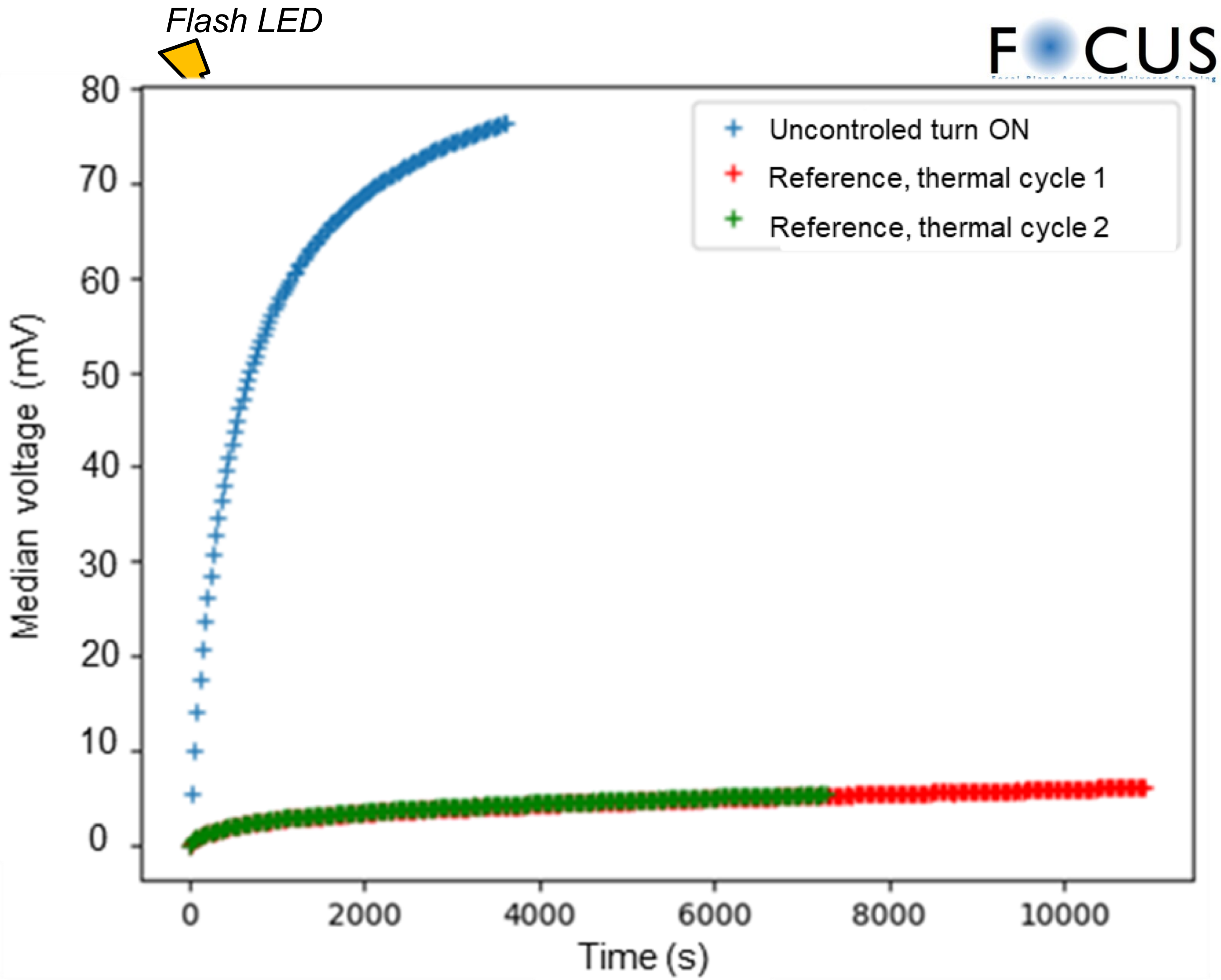
- Reproducible reference
- LED flash
- Illumination ramp
- Electrical stress

Test parameter

- Stress amplitude :nbr of photons or ΔV
- Soak time

Persistence parameters

- Amplitude
- Time constant
- Current decay



[2] T. Le Goff (JEM, en cours de publication 2022)

PERSISTENCE ANALYSIS

Multi-exponential fitting:

- Cumulative persistence
- Free parameters : V_i and τ_i

$$V(t) = V_1\left(1-e^{-\frac{t}{\tau_1}}\right) + V_2\left(1-e^{-\frac{t}{\tau_2}}\right) + V_3\left(1-e^{-\frac{t}{\tau_3}}\right) + \frac{I_{dark}}{C}t$$

- Or fixed τ

$$V(t) = \frac{I_{dark}}{C}t + \sum_{i=0}^{n=6} V_i\left(1-e^{-\frac{t}{10^i}}\right)$$

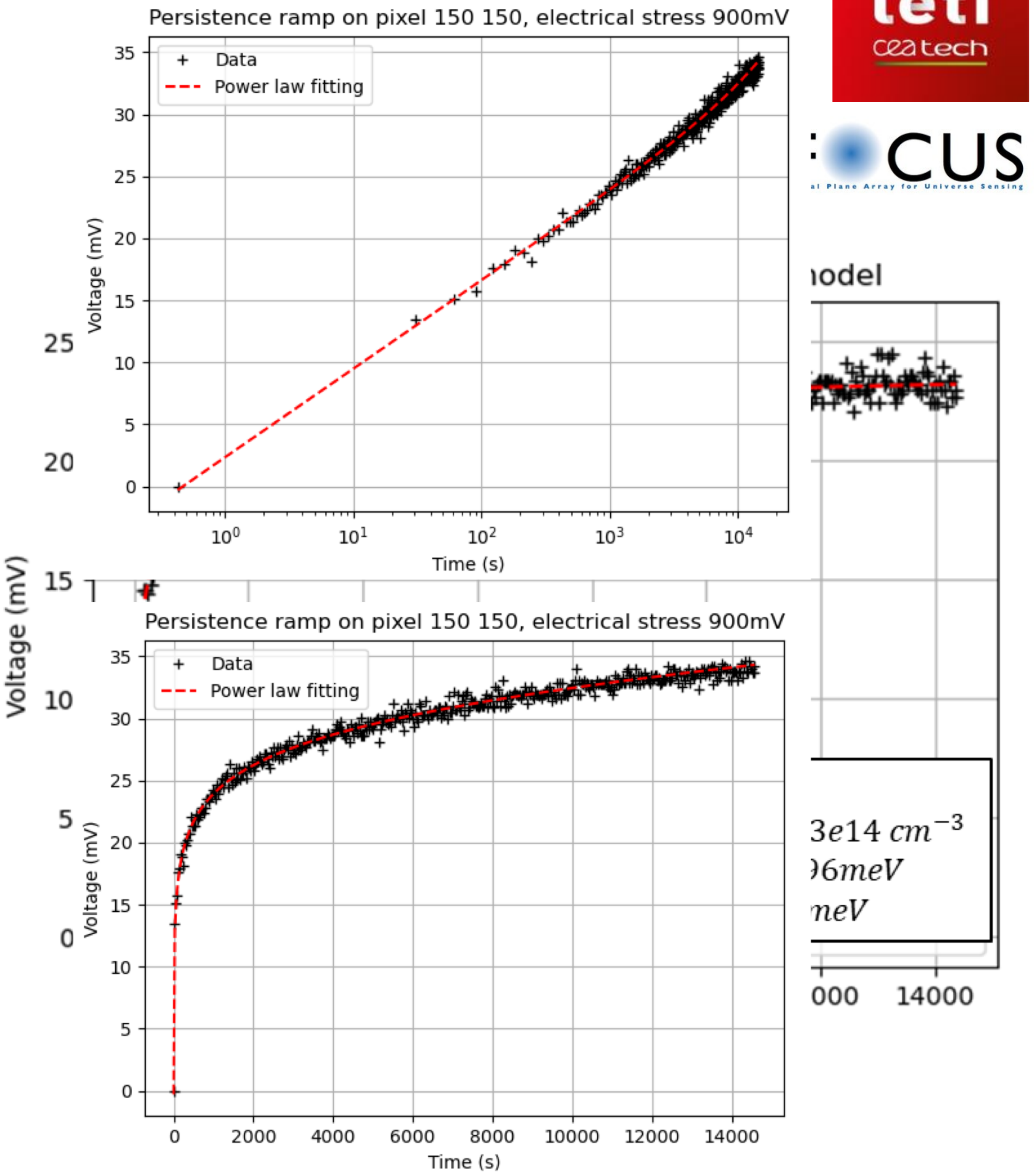
Power law fitting:

- Faster than multi-exponential fitting
- Less robust (I_{dark} must be well estimated)

$$V(t) = V_0\, t^{\gamma}$$

Semi-analytic model[2] :

- Based on emission of traps in the SCR



[2] T. Le Goff (JEM, 2022)

CHARACTERIZATION PROTOCOLS COMPARISON

LED flash ($4\ 10^6 ph/s$) and illumination ramp ($10 ph/s$)

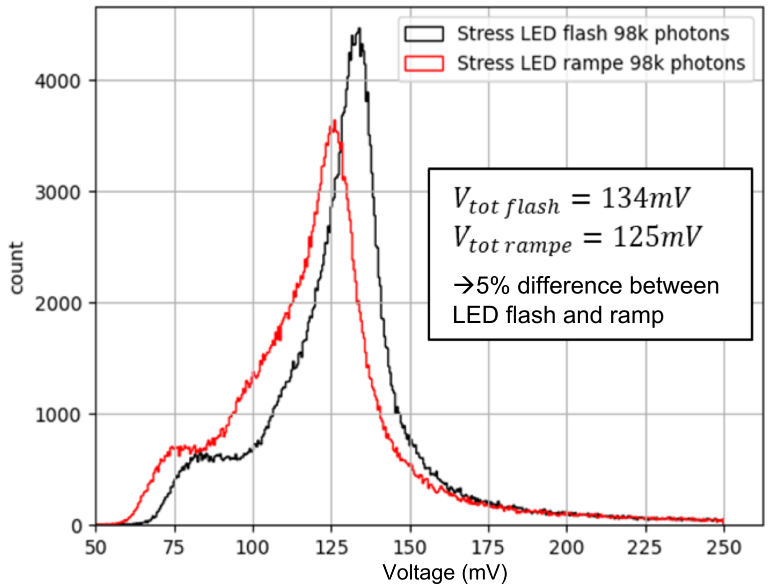
Difference between stress flash & ramp :
Amplitude is lower and time constant is shorter with the ramp illumination
Persistence takes time to charge
→ **Measured flux appears lower thant the true flux**

t_{soak}

Reset

Persistence

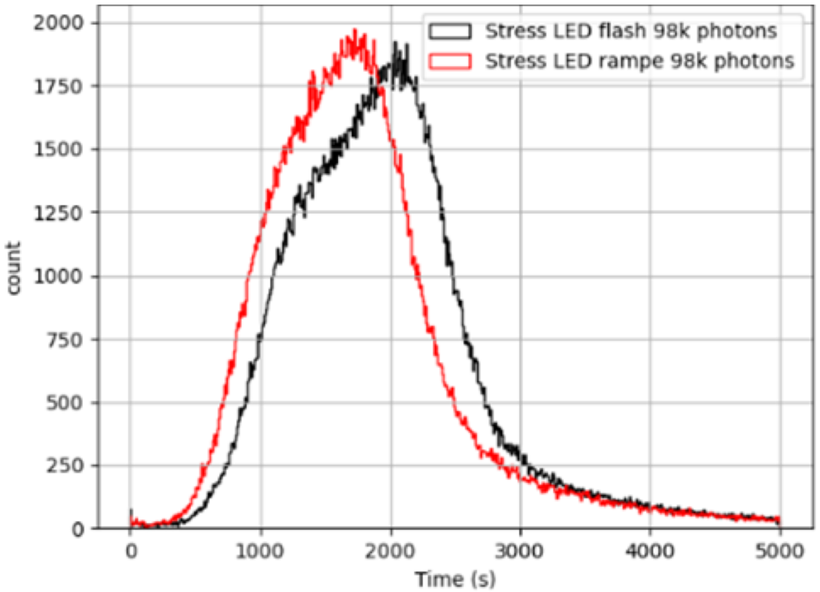
Persistence amplitude



$V_{tot\ flash} = 134mV$
$V_{tot\ rampe} = 125mV$

→5% difference between LED flash and ramp

Persistence time constant



CHARACTERIZATION PROTOCOLS COMPARISON

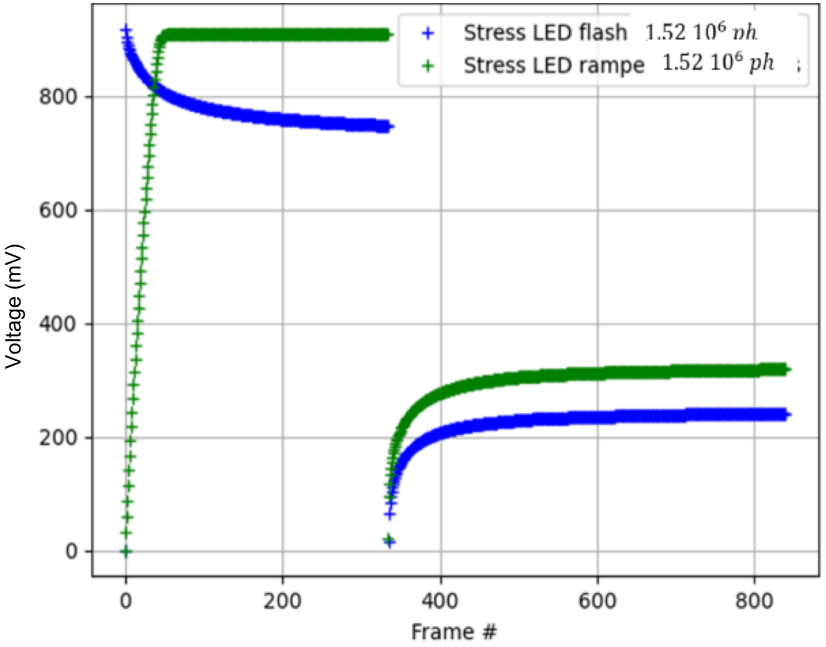
LED flash and illumination ramp, effect of saturation regime

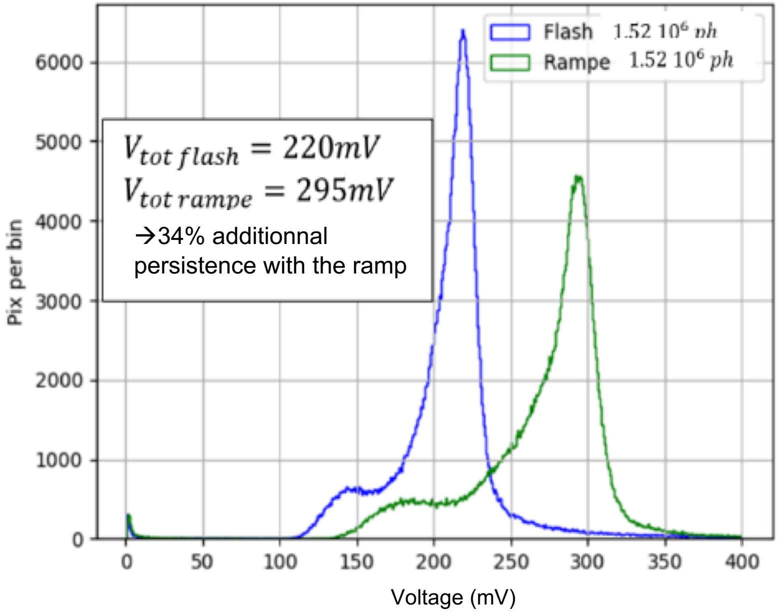
Stress up to 10x full well

Ramp persistence amplitude > flash

→ Time spent at saturation is crutial

LED flash cannot calibrate this regime





$V_{tot\ flash} = 220mV$

$V_{tot\ rampe} = 295mV$

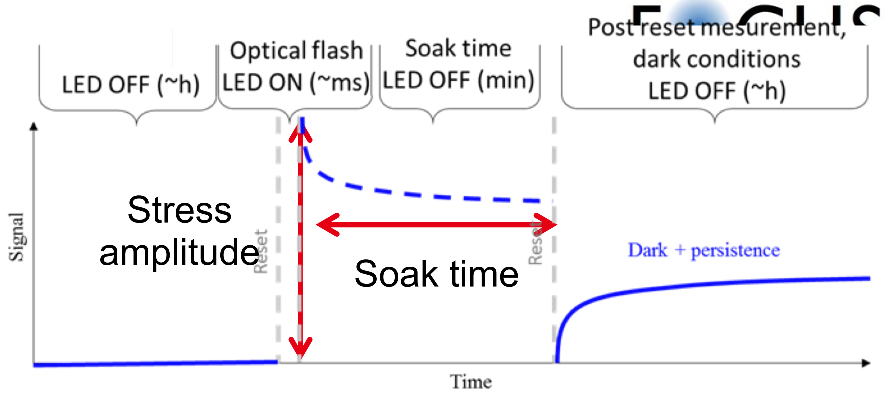
→34% additionnal persistence with the ramp

CHARACTERIZATION PROTOCOLS COMPARISON

Flash LED and electrical stress

Persistence amplitude with soak time : power law

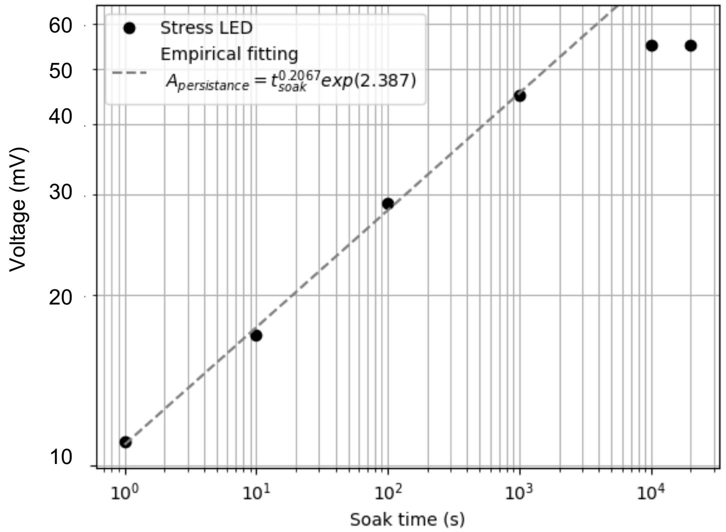
Persistence with stress amplitude : linear relation up to FW



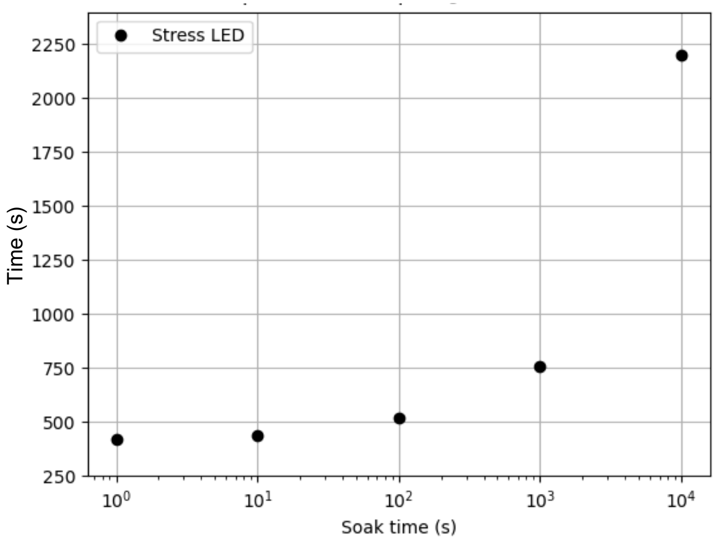
Persistence function of soak time

Persistence function of stress amplitude

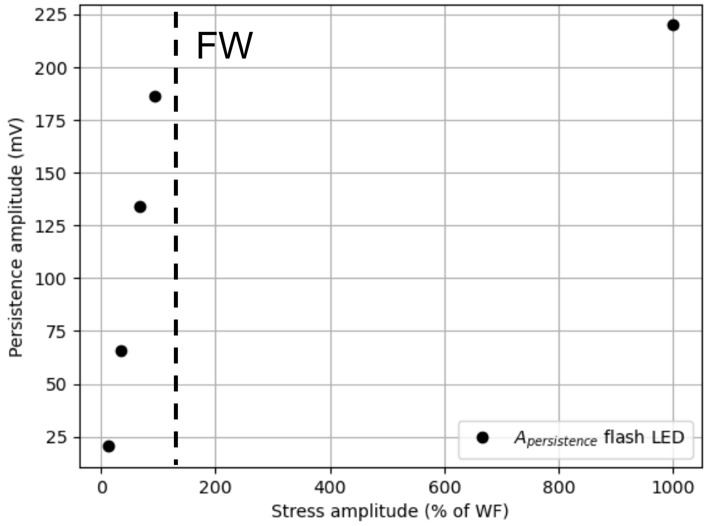
Persistence amplitude



Persistence time constant



Persistence amplitude



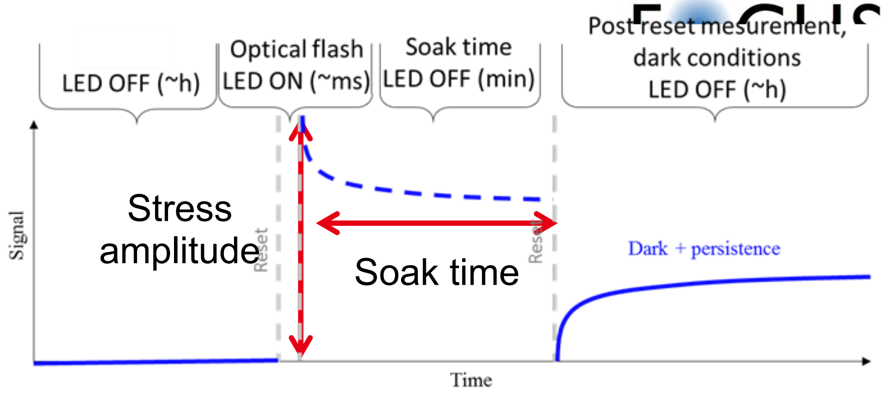
MAIN RESULTS

Flash LED and electrical stress

Comparison with electrical stress

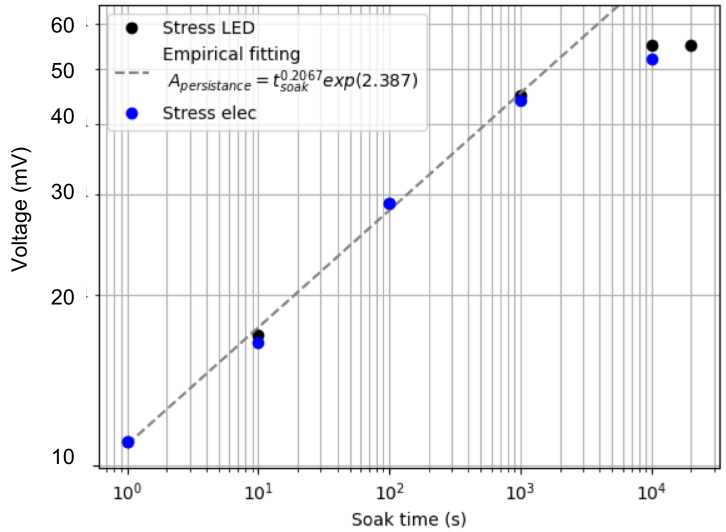
Similar results

➔ Equivalence of both protocoles

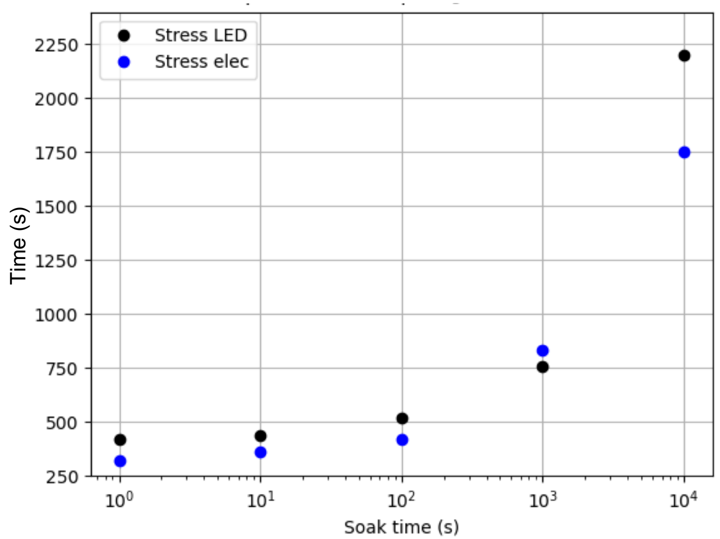


Persistence function of soak time

Persistence amplitude

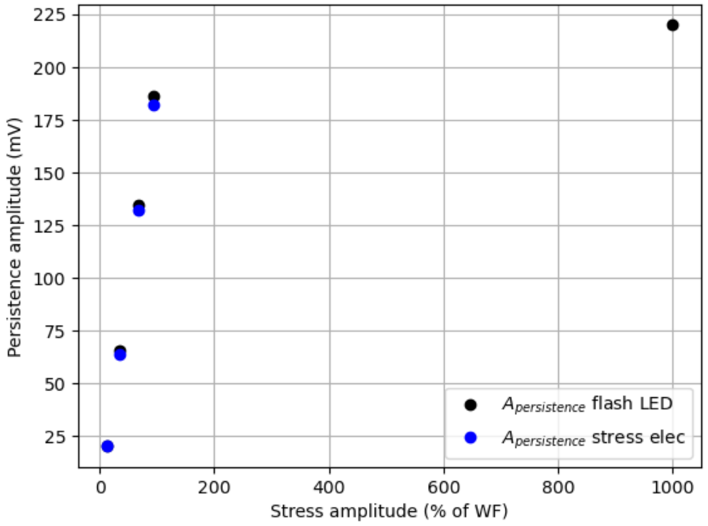


Persistence time constant



Persistence function of stress amplitude

Persistence amplitude



CHARACTERIZATION PROTOCOLS COMPARISON

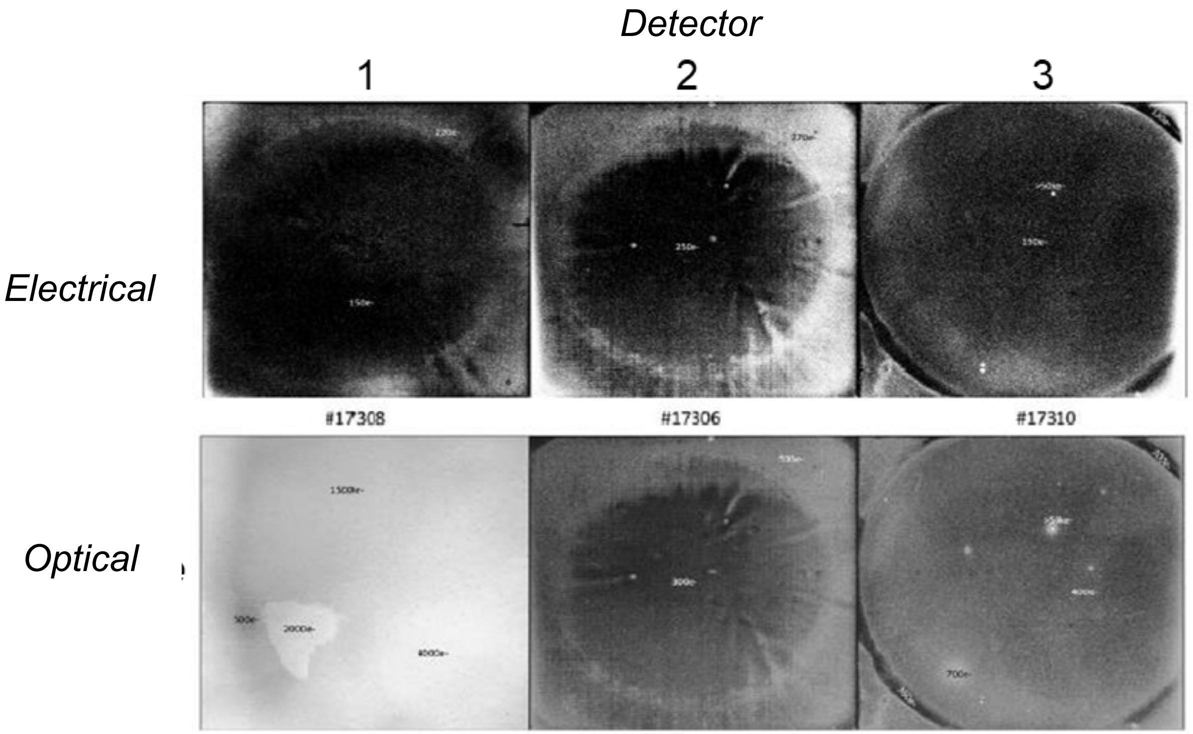
Flash LED and electrical stress

Comparison with electrical stress

Similar results

➔ Equivalence of both protocoles

But can differ on some detectors [3]. Epoxy void contribution ?



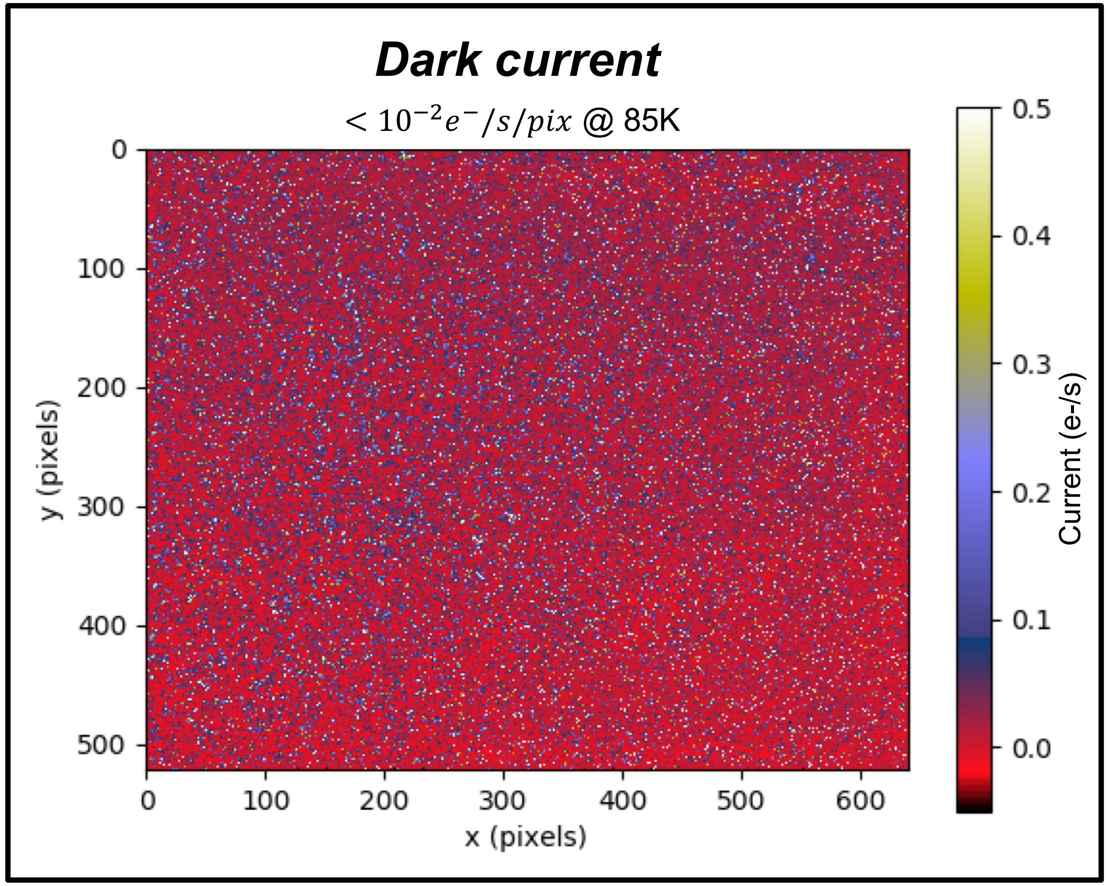
[3] S. Tulloch (2018)

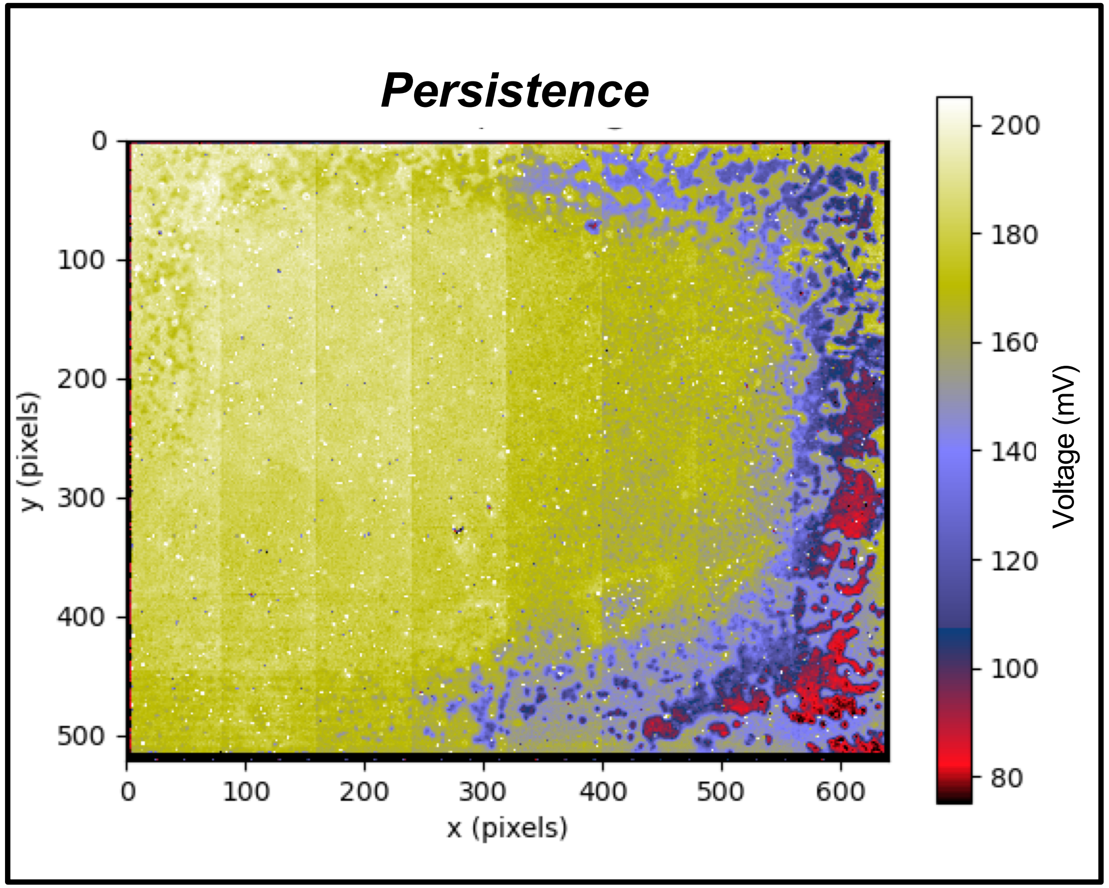
INFLUENCE OF A DETECTOR TECHNOLOGY ON PERSISTENCE

Manufacturing interest:

Persistence patterns on a detector differs from dark current

→ Additionnal information thanks to persistence

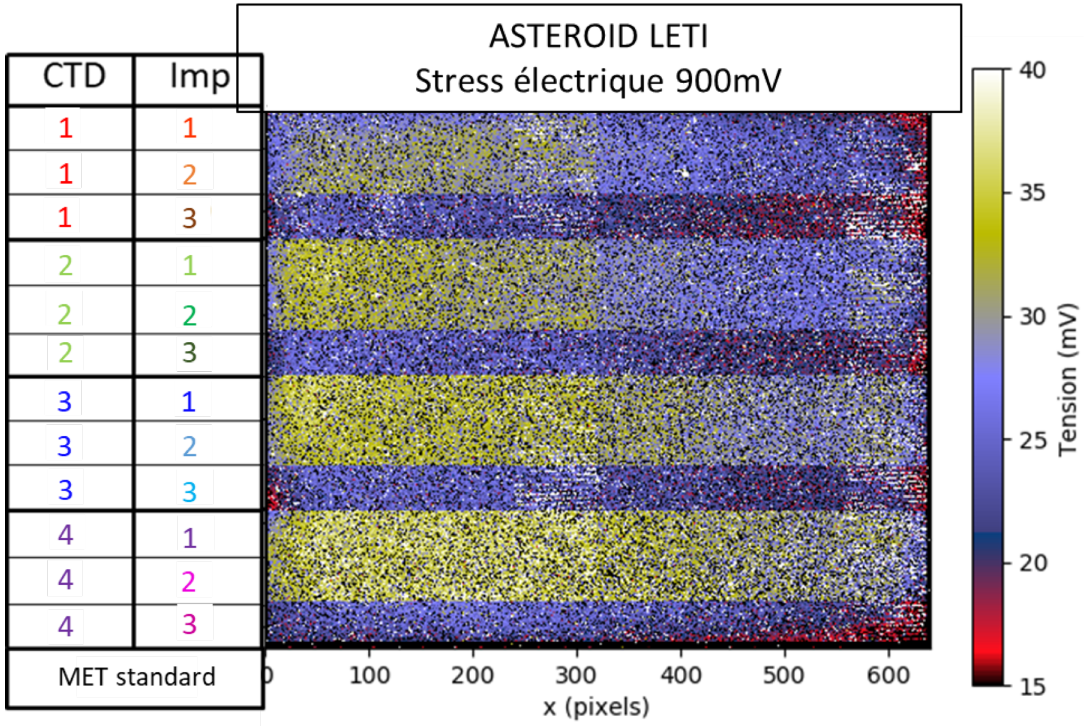




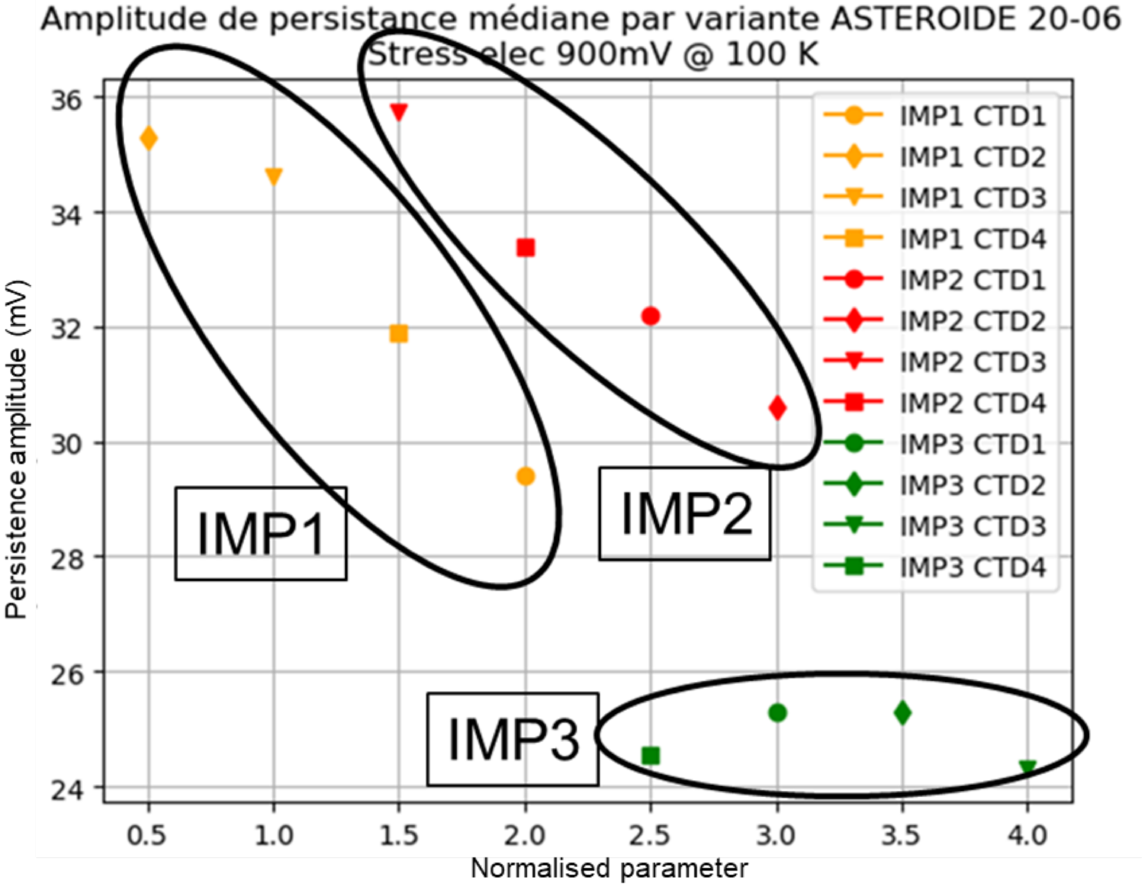
INFLUENCE OF A DETECTOR TECHNOLOGY ON PERSISTENCE

Detector with technology flavors

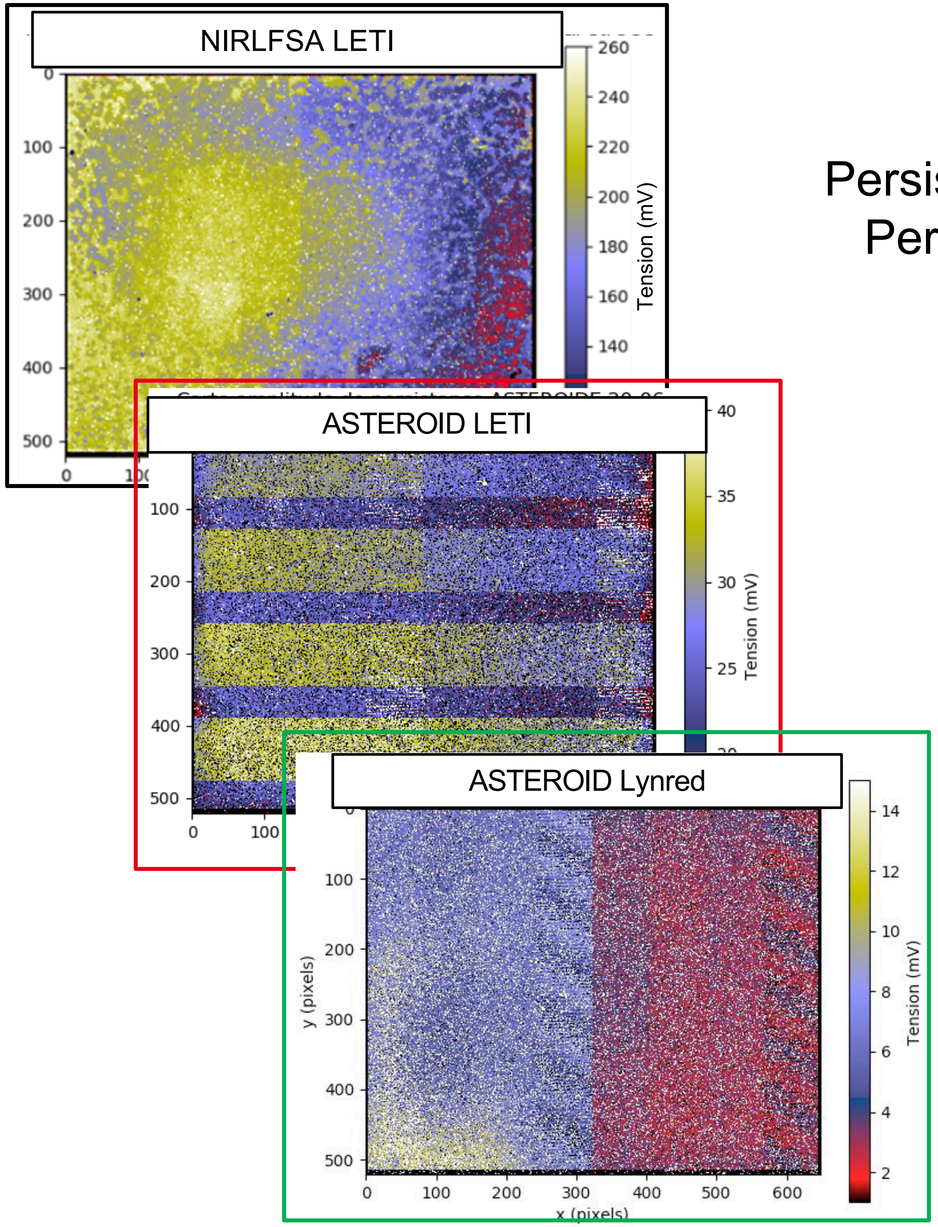
Mechanisms involved in persistence?



CTD	Imp
1	1
1	2
1	3
2	1
2	2
2	3
3	1
3	2
3	3
4	1
4	2
4	3
MET standard	



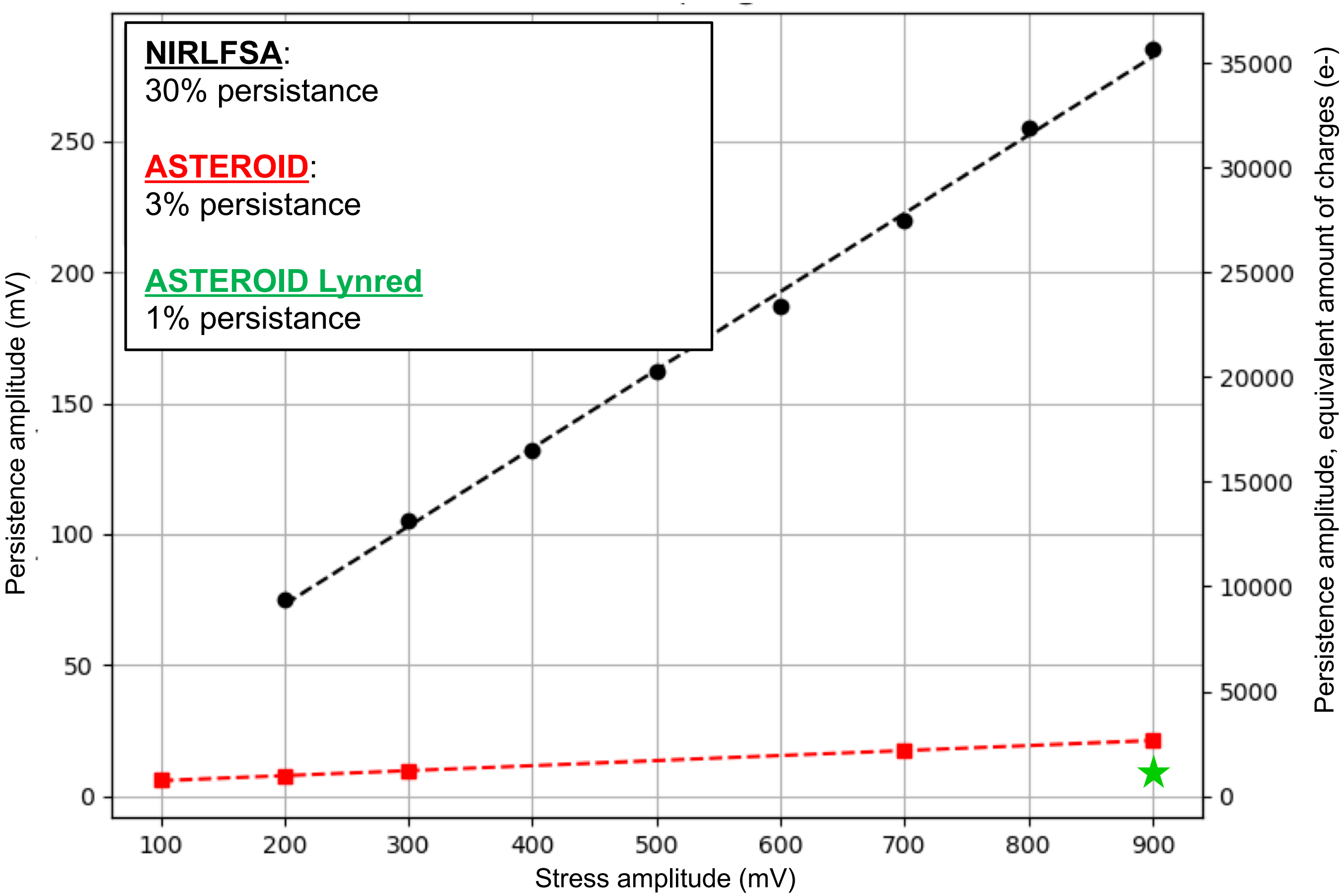
INFLUENCE OF A DETECTOR TECHNOLOGY ON PERSISTENCE



Test detectors

Persistence **depends largely** on the detectors technology

Persistence amplitude can be **reduced by a factor 10**


NIRLFSA:
30% persistance

ASTEROID:
3% persistance

ASTEROID Lynred
1% persistance

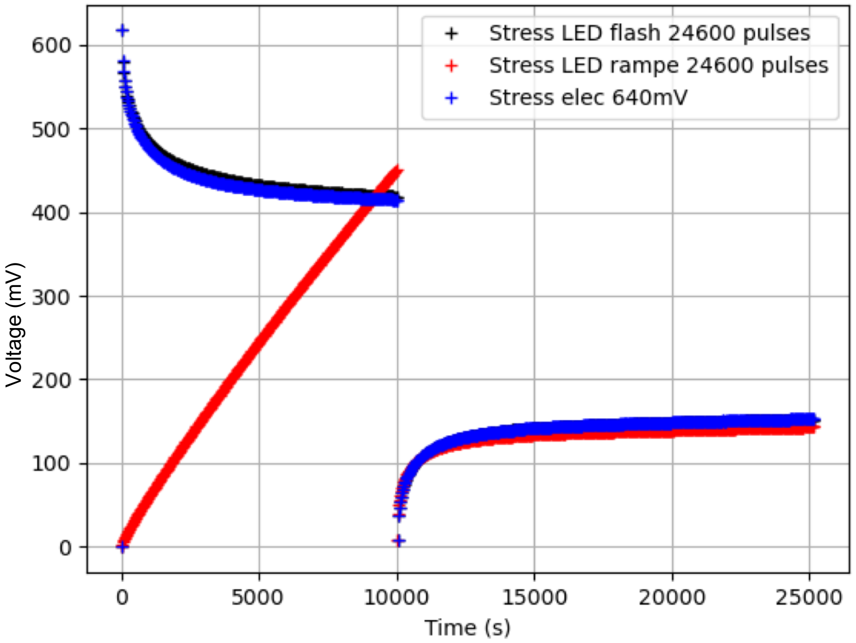
CONCLUSION

Protocoles comparison

LED flash ⬄ electrical stress

Needs to calibrate soak time

Importance of time spent at saturation



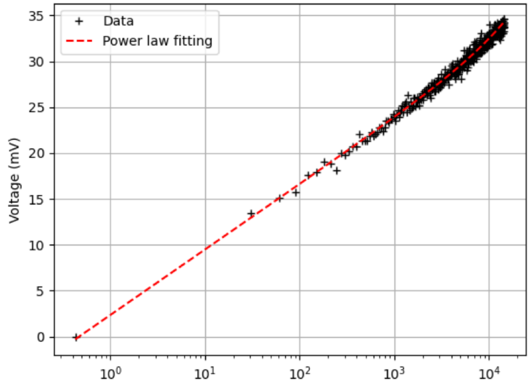
Analysis tools

Multi-exponential or power law

Semi-analytic model

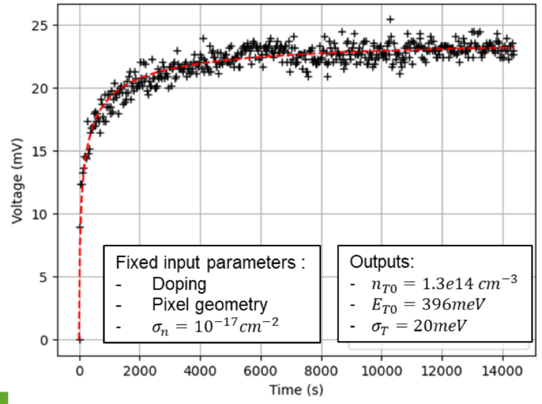
Considering charge phase of persistence?

Persistence ramp on pixel 150 150, electrical stress 900mV



Persistence ramp of one pixel

Fit with extended energy distribution model



Fixed input parameters :
- Doping
- Pixel geometry
- $\sigma_n = 10^{-17} cm^{-2}$

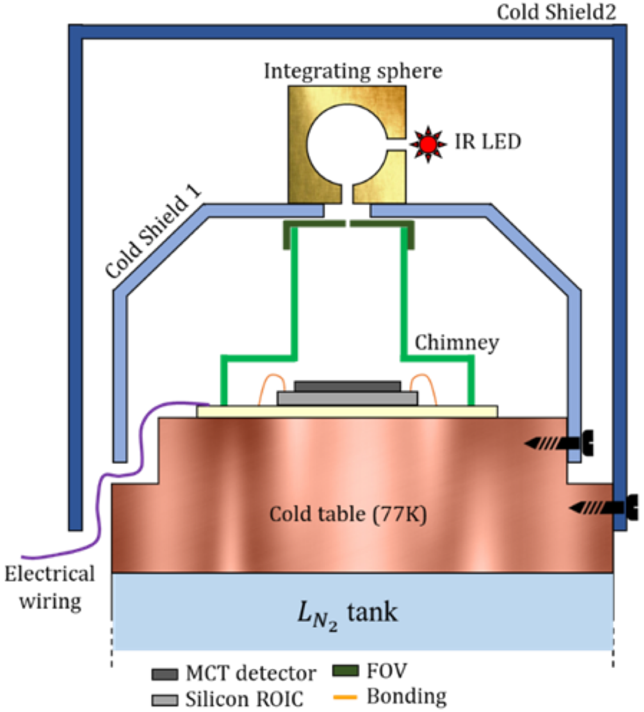
Outputs:
- $n_{T0} = 1.3e14\ cm^{-3}$
- $E_{T0} = 396 meV$
- $\sigma_T = 20 meV$

Perspectives

Persistence mitigation

PhD work ongoing : Hugo ROUSSET

(2021-2024)



Thank you !

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ANNEXE

Usual explanation [4]

Electrical stress : all traps are filled

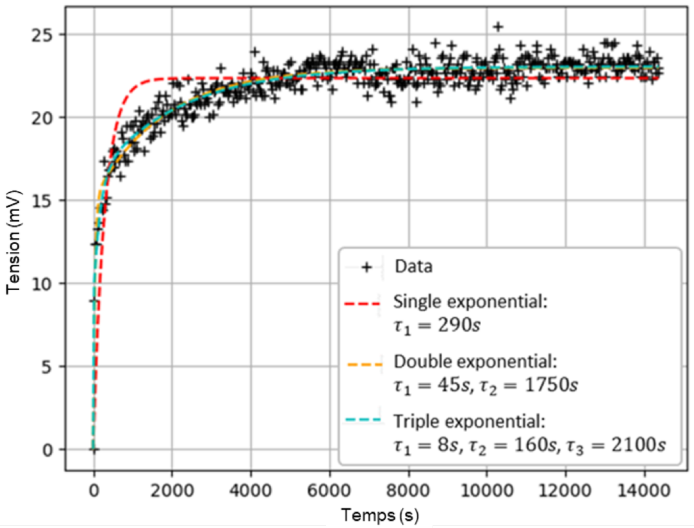
Trapping/emission processes from diode SCR with moving edges

Trap emission dynamics:

$$e_n(E_T) = \sigma_n v_{th} N_c \exp[-\frac{E_c - E_{T0}}{kT}]$$

And $\frac{dn}{dt} = e_n n_T(t)$ et $\frac{dn_T}{dt} = -e_n n_T(t)$

Rampe de persistance d'un pixel
Fit avec modèle multi-exponentiel



New hypothesis :

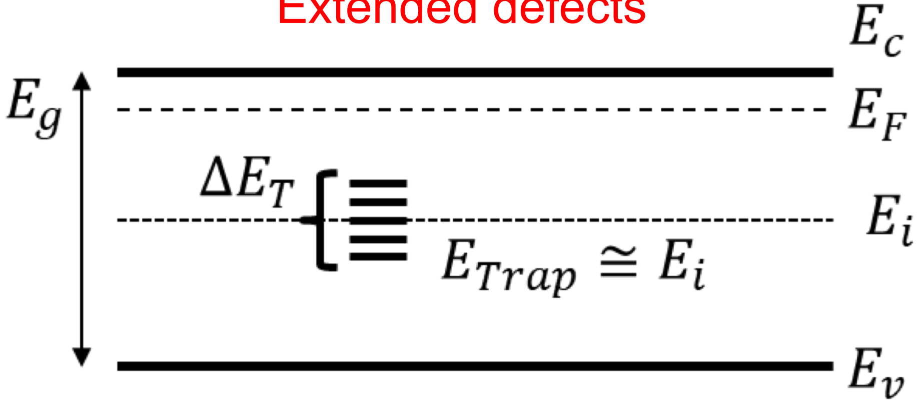
Defects with broad energy level distribution

[7] $n_T(t) = n_T(0) \int_0^\infty g(E_{Ti}) \exp[-e_n(E_{Ti})t]\, dE_{Ti}$

$$g(E_{Ti}) = \frac{1}{\sigma_T\sqrt{2\pi}} \exp\left[-\frac{(E_{T0}-E_{Ti})^2}{2\sigma_T^2}\right]$$

Defects in MCT [6]:

Alloy disorder
Extended defects



[7] W. Schröter, J. Kronewitz, U. Gnauert, F. Riedel and M. Seibt, Phys. Rev. B, vol 52 (1995)
[8] P. Omling, L. Samuelson, and H. G. Grimmeiss, Journal of Applied Physics 54, 5117 (1983)

ANNEXE

Persistence in a SFD pixel:

Current transient [8]

Non linear capacitance change

Capacitance:

$$C = \frac{A\epsilon}{W(t)};\ W(t) = \sqrt{\frac{2\epsilon_{MCT}}{q[\boldsymbol{N_D} - \boldsymbol{n_T(t)}]}\left[V_{bi} - \left(V_{stress} + V_{float}(t)\right)\right]}$$

Current:

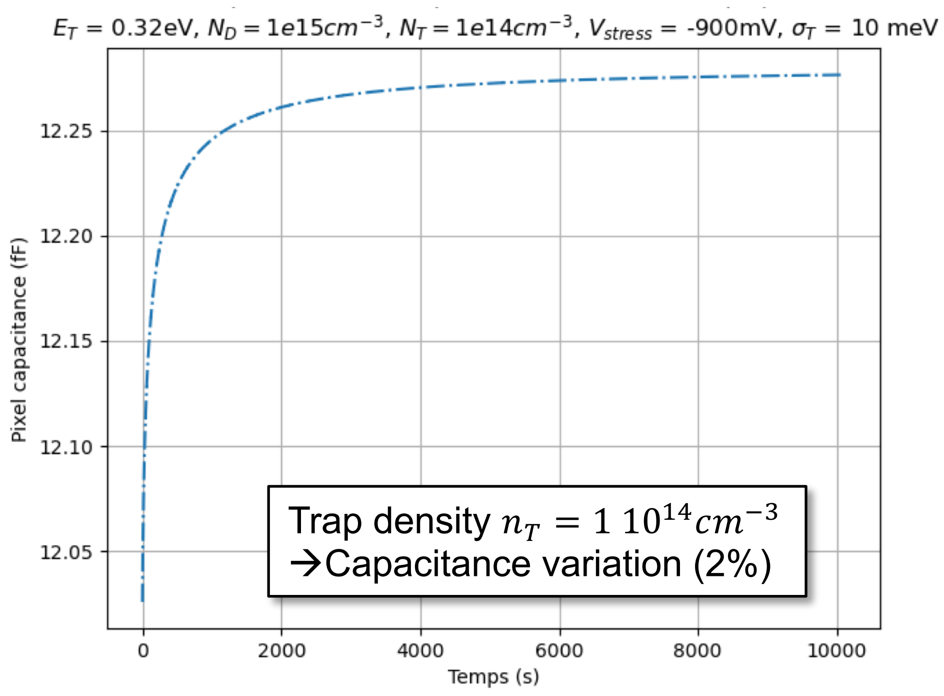
$$I = qA\left[W(t) - W_0 - \frac{W(t)^2 - W_0^2}{2W(t)}\right]\int_0^{\infty} g(E_T)e_n(E_T)n_T(0)\exp[-e_n(E_T)t]\,dE_T$$

Geometry

Electron emission

Displacement current

Trap distribution broadening



Trap density $n_T = 1\ 10^{14} cm^{-3}$

→Capacitance variation (2%)

[8] D. Schroder, ‘Semiconductor Material and Device Characterization: Third Edition’ (2005)

ANNEXE

Results

Reproduces the non linear dynamics
Persistence amplitude only depends on n_T
ASTEROID : $\boldsymbol{n_T}$ **= residual doping**

Limits

Persistence on 1st generation detectors:
Trap density ≅ doping
Compensated material ? Out of the scope of the model