Proton irradiation effects on a MWIR T2SL focal plane array in IDCA configuration

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Context

- determine the T2SL potentiality for space applications as a complementary IR technology to well-established ones
- Proton irradiation measurements generally carried out on single detectors
- First evaluation of the proton irradiation impact on a European T2SL commercial detector
- IRnova Dag MWIR detector : VGA T2SL detector, 15µm pitch, 80K in IDCA configuration

IRnova

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Proton radiation experiments

- UCL synchrotron facility
- 62MeV proton energy
- $\Phi = 10^8$ protons/(cm².s)
- FPA @ 80K but not biased during the proton irradiation
- Step by step test plan → determine degradation rates across the fluence range

covers most space missions

	Step 1	Step 2	Step 3	Step 4	Step 5
Cumulated fluence (p/cm^2)	1.10^{10}	5.10^{10}	1.10^{11}	2.10^{11}	5.10^{11}
Protons/pixel	$2,25.10^4$	1.10^5	$2,25.10^5$	$4,5.10^5$	1.10^6

1 order of magnitude > IR detectors protons fluence for most of space programs

Outline

1. EO test plan and test bench
2. Irradiation to Step 2 ($\Phi = 5.10^{10}$ protons/cm^2)

   Covering most space missions
3. Irradiation to Step 5 ($\Phi = 5.10^{11}$ protons/cm^2) and annealing effects
4. Comparison with published results
5. Conclusion and perspective

EO Test plan

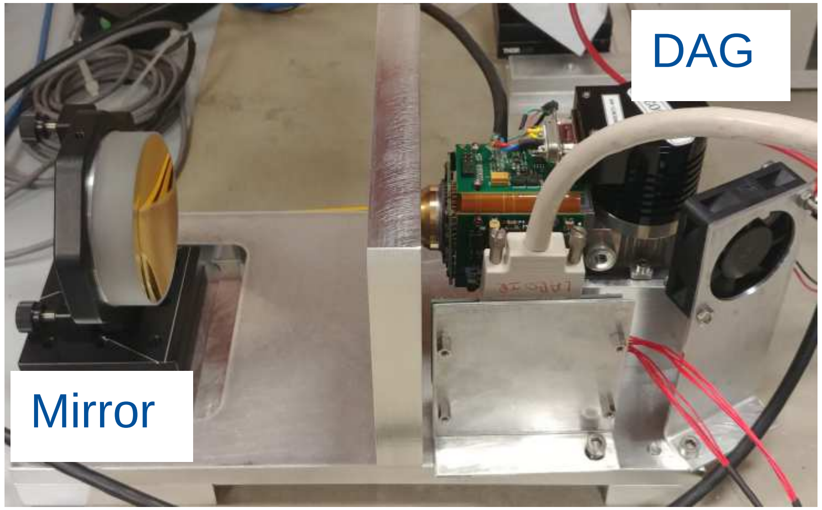
- 1st campaign on European COTS MWIR T2SL detector

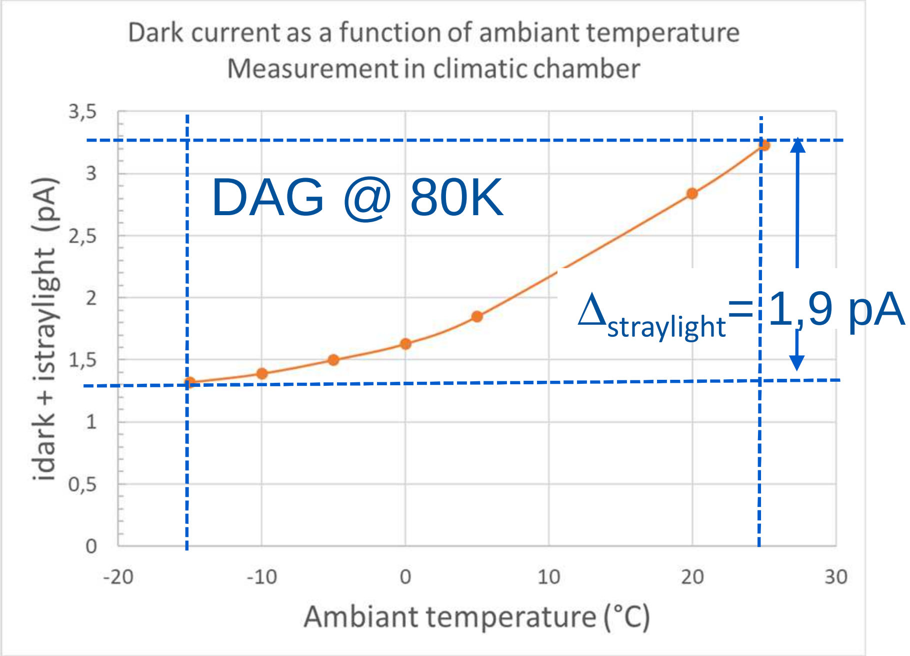
- Focus on first-rate merit factors :
  - Dark current
  - Photocurrent and QE
  - Operability
  - Temporal noise
  - Spectral response*

* Mesured only at Onera before and after irradiation campaign

Challenge: measuring dark current in an IDCA

- Usual i_{dark} measurement : closed cold shield within the dewar
- Narcissus effect :
  - ✓ Mirror placed in front of the dewar window
  - ✓ detector images itself => "sees" its own cryogenic temperature
- Main problem : parasitic flux
  - ✓ Zemax calculation to determine the mirror position minimizing straylight



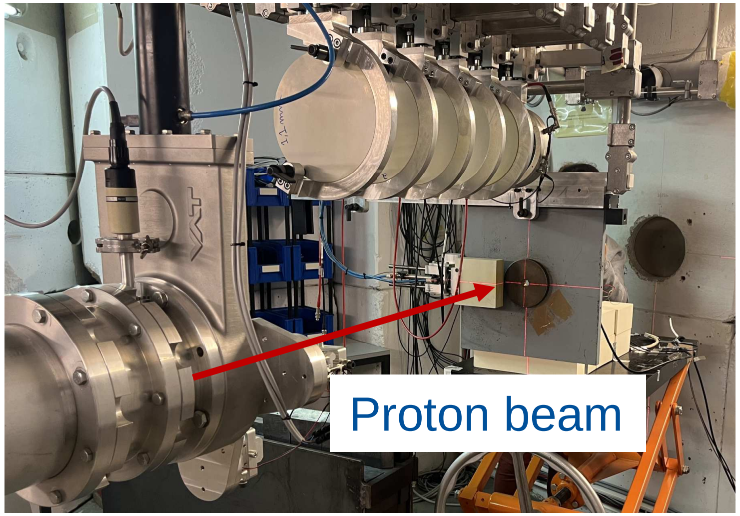


Measured current will be corrected from $i_{parasitic}$ according to T_{amb}

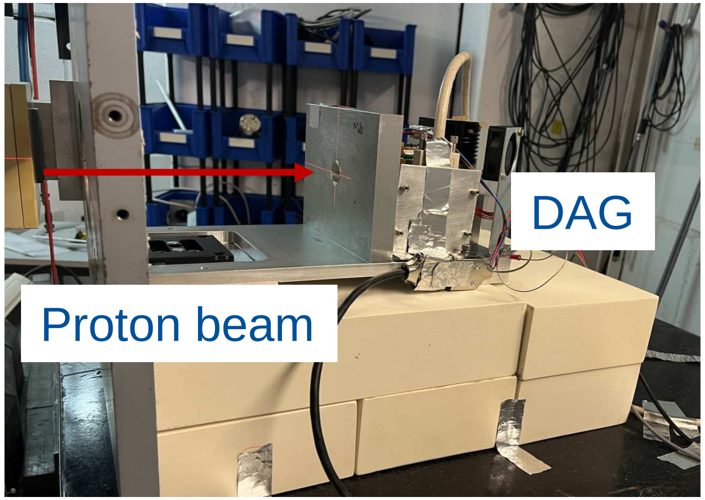
Irradiation and EO test benches

Modular test bench for easy and reproducible characterization at UCL facility

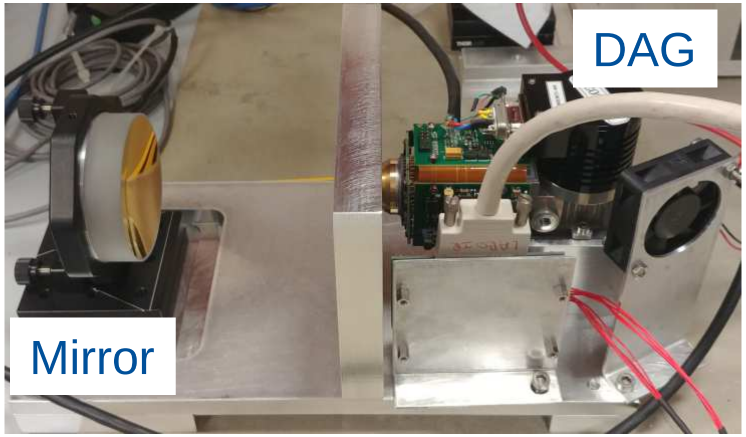
UCL proton beam overview



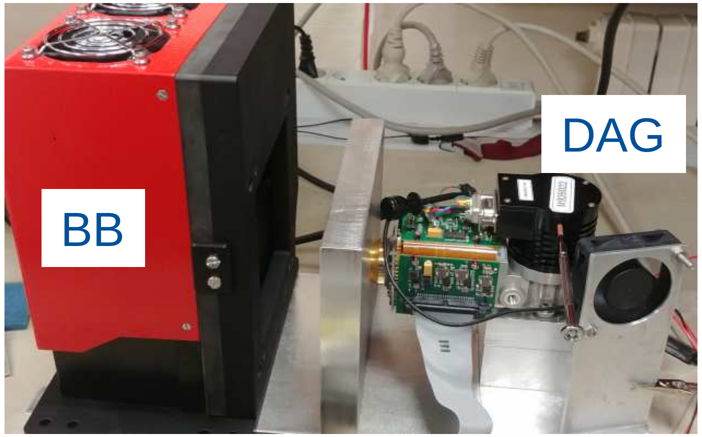
Irradiation config



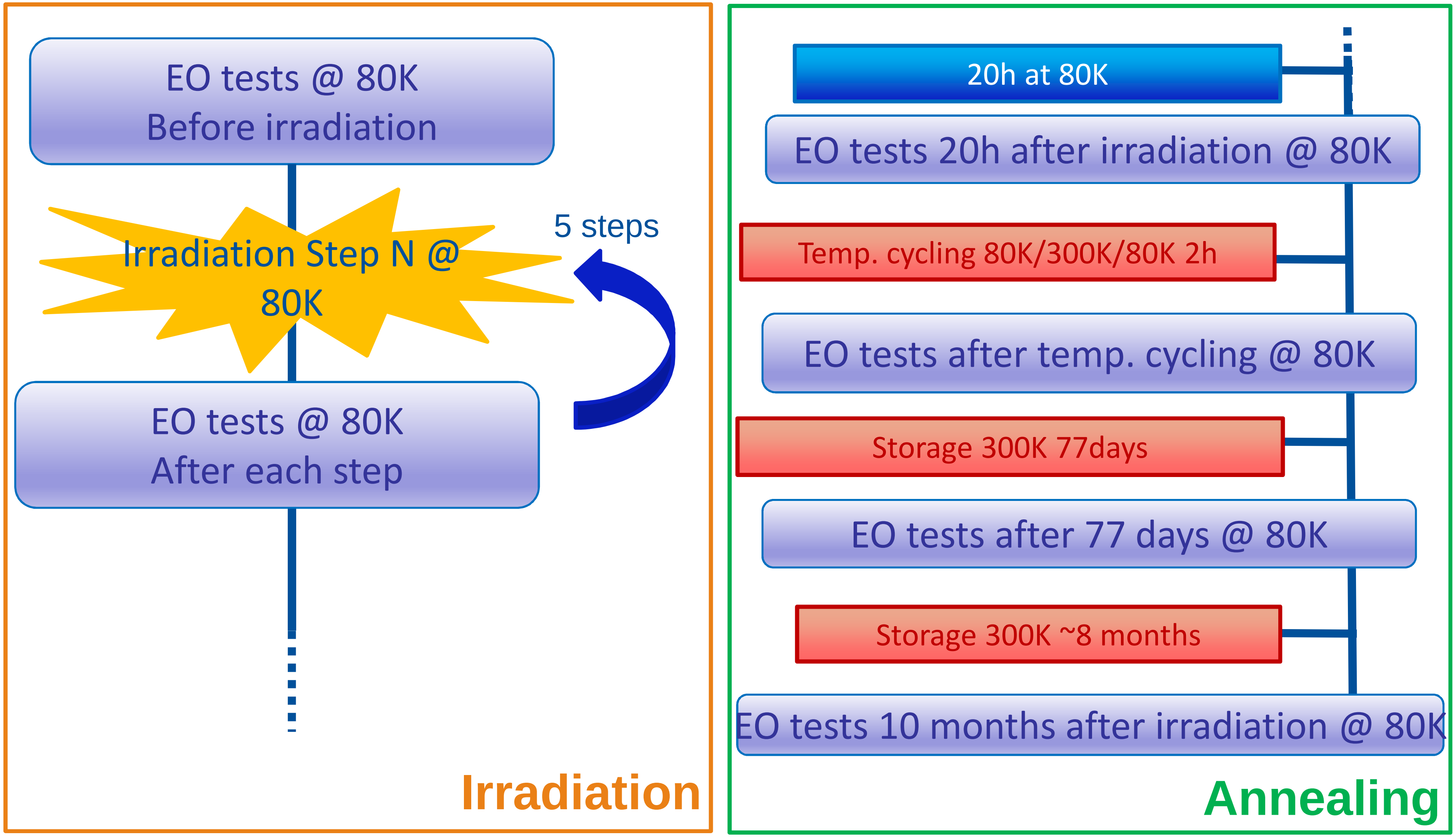
Dark current config



Photocurrent config



Irradiation and annealing test procedure



2. Irradiation to Step 2 ($\Phi = 5.10^{10}$ p/cm^2)

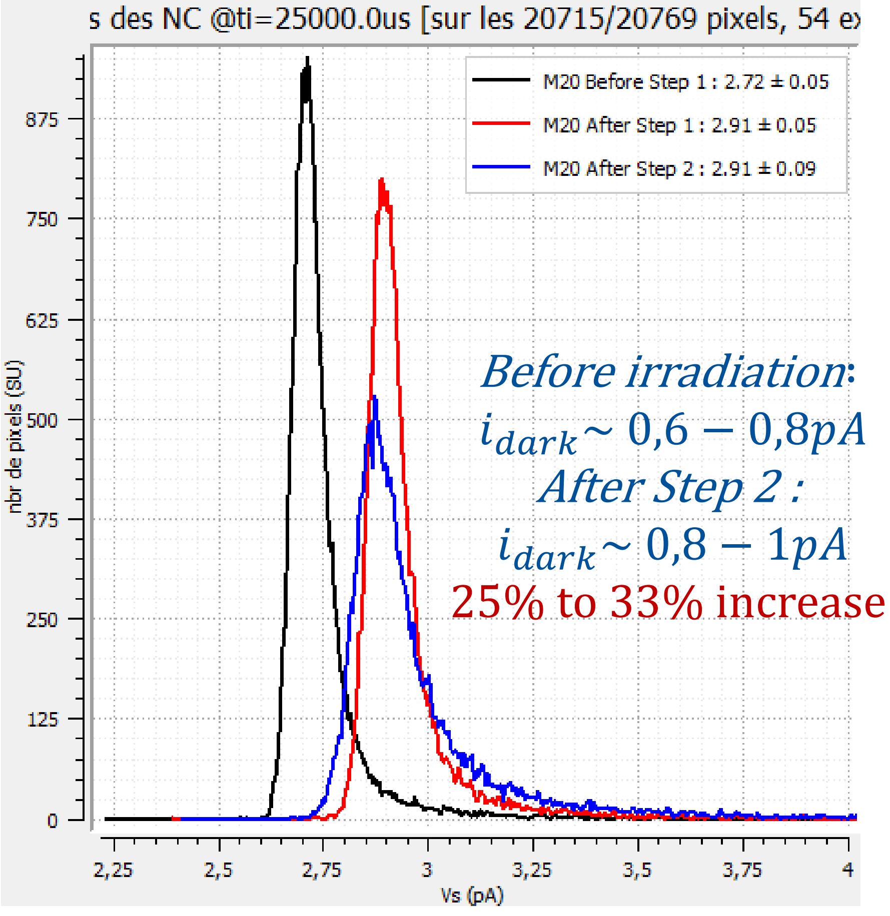
Covering most space missions

Irradiations effect on dark current

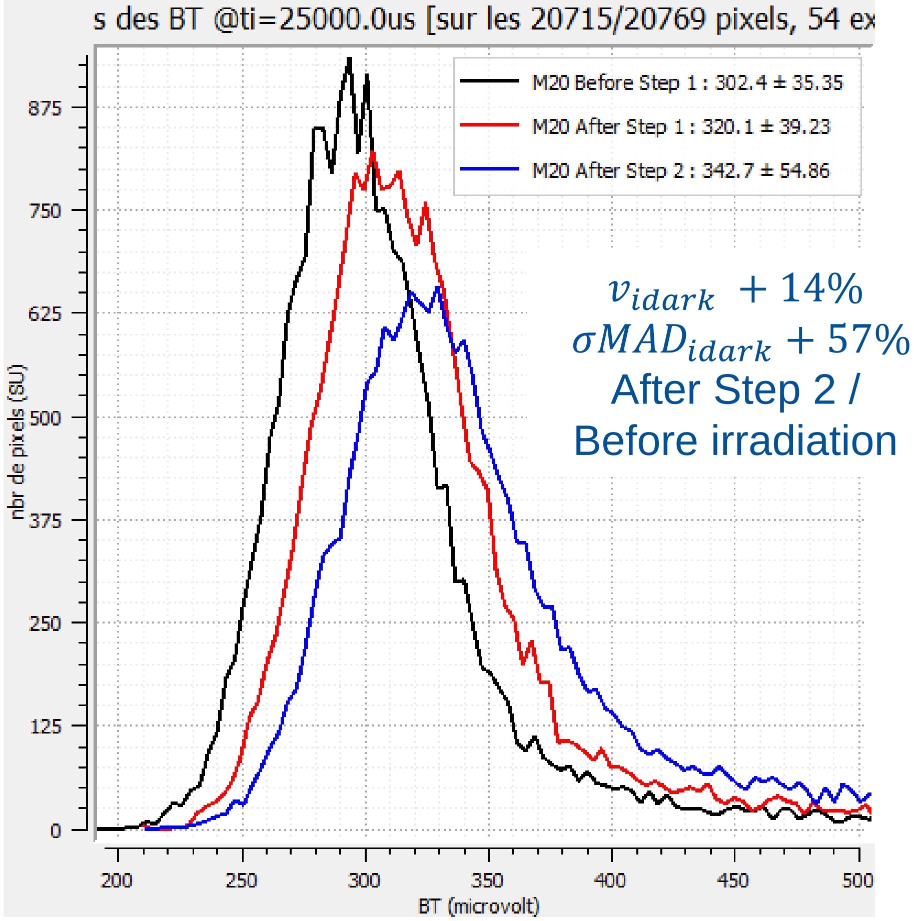
UP TO STEP 2 :
5.10^{10} protons/cm^2

Dark current spatial dispersion (ti = 25 ms)

Hyp : $i_{parasitic} \sim 2pA$ +/− $0{,}1pA$



Dark noise spatial dispersion (ti = 25ms)

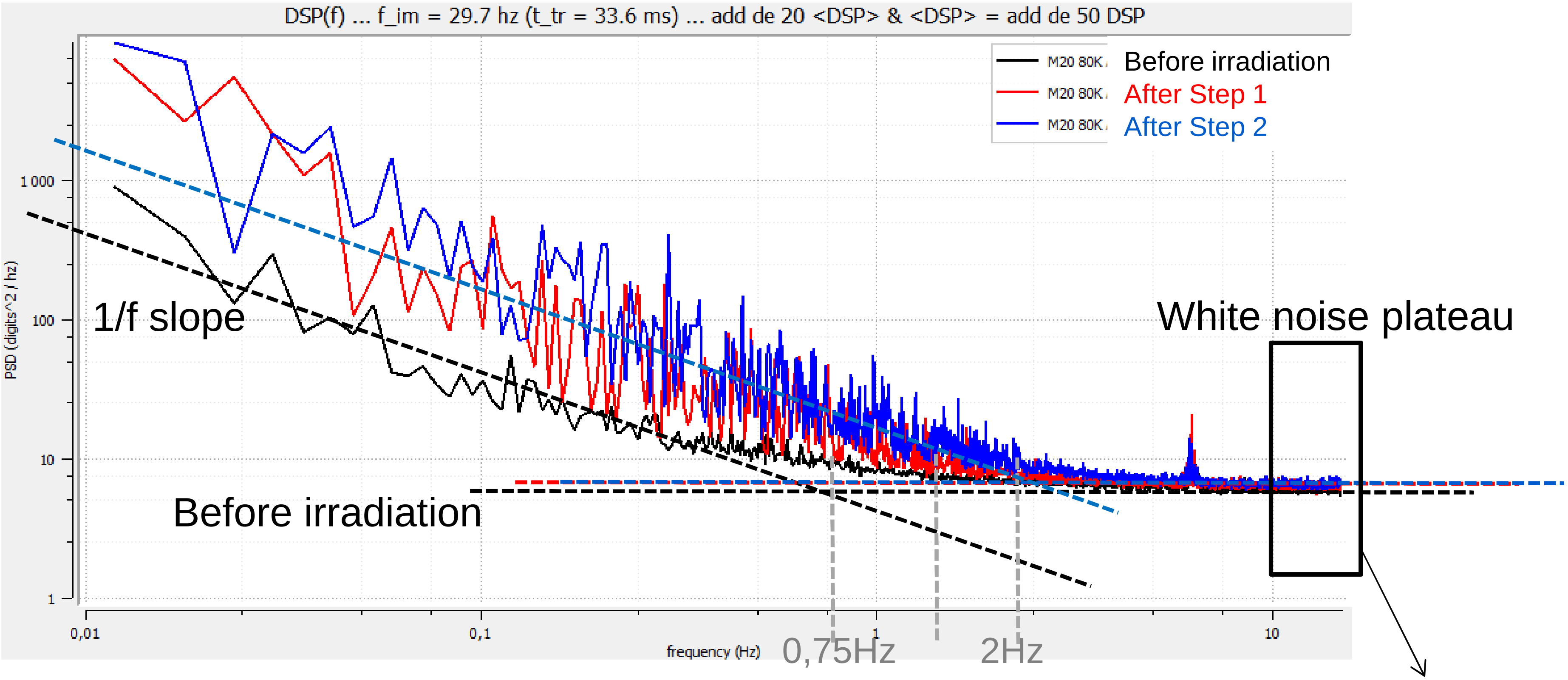


Measurement area 160x130 pixels

Dark current noise

UP TO STEP 2 :
5.10^{10} protons/cm^2

Power spectral density calculated from data cubes of 5000 images



	Total noise (µV)	Noise plateau (µV)
Before irradiation	385	323
After Step 1 : 1.10^{10} p/cm^2	931	329
After Step 2 : 5.10^{10} p/cm^2	816	335

~x2,5

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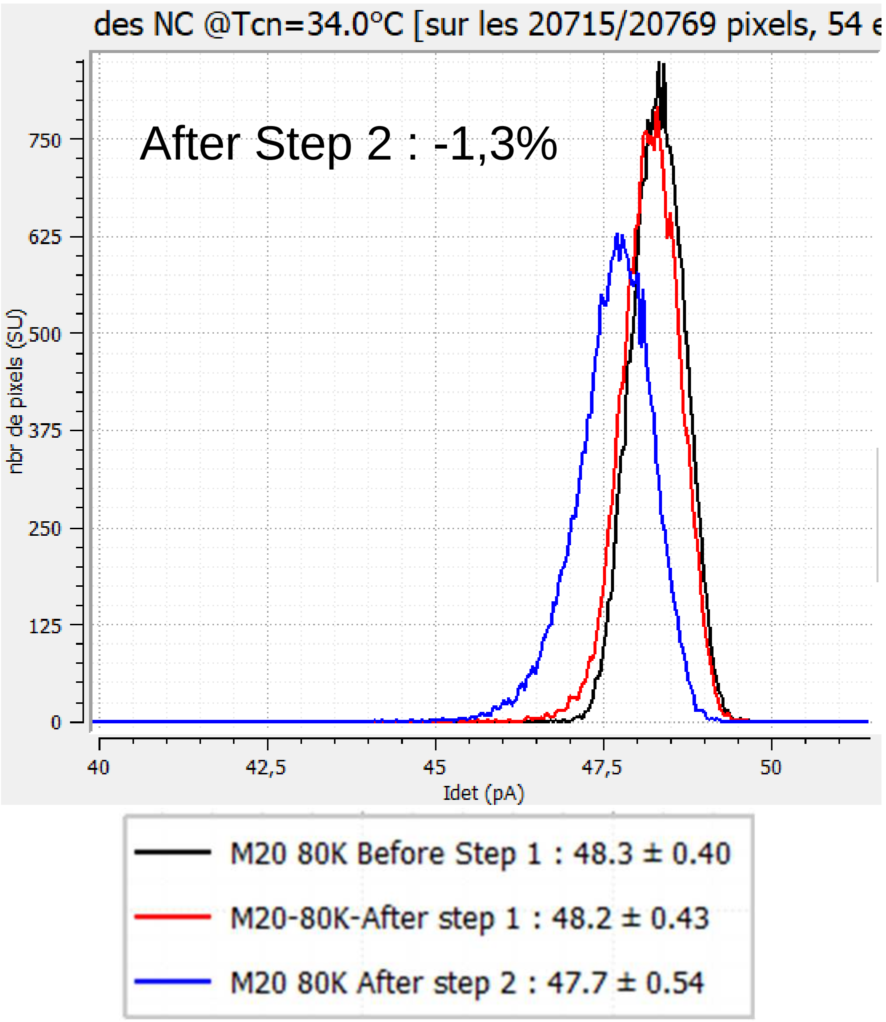
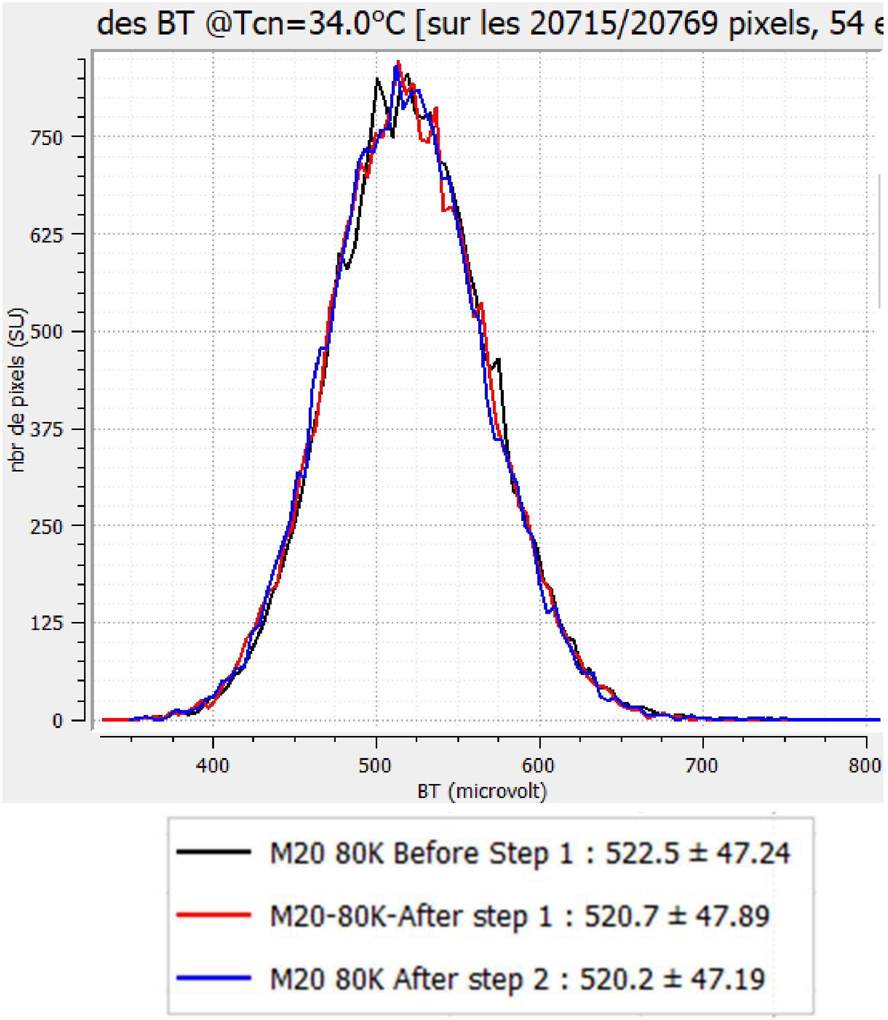
Irradiation effect on photocurrent

UP TO STEP 2 :
5.10^{10} protons/cm^2

For a fixed Tblackbody : 34° C : $\Phi = 3.10^8$ ph/s/pixel

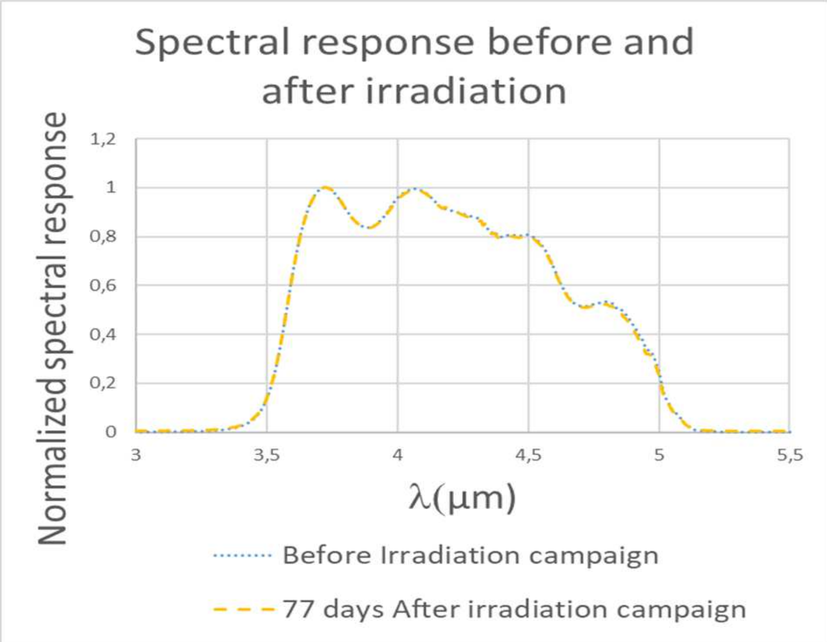




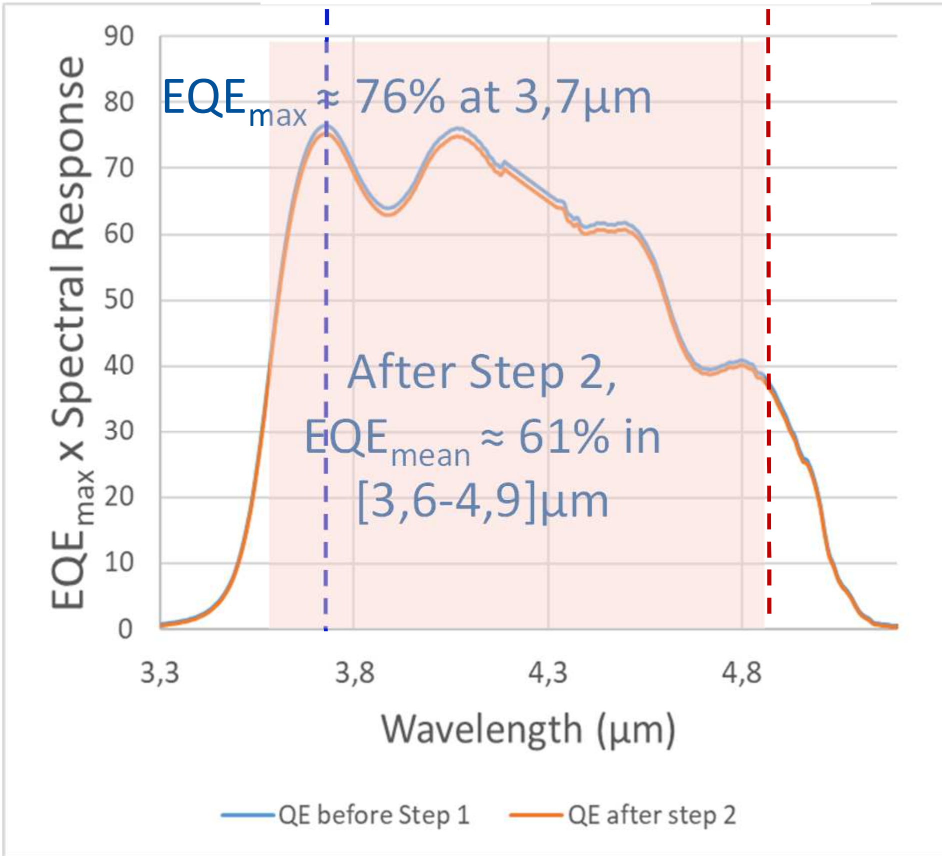
Measurement area 160x130 pixels : central area => not disturbed by cos4 dependence decay

External Quantum Efficiency (QExFFxTopt)

UP TO STEP 2 :
5.10^{10} p/cm^2



After Step 2 : -1,3%



Slope of the signal as a function of IR flux

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Irradiation effect on operability

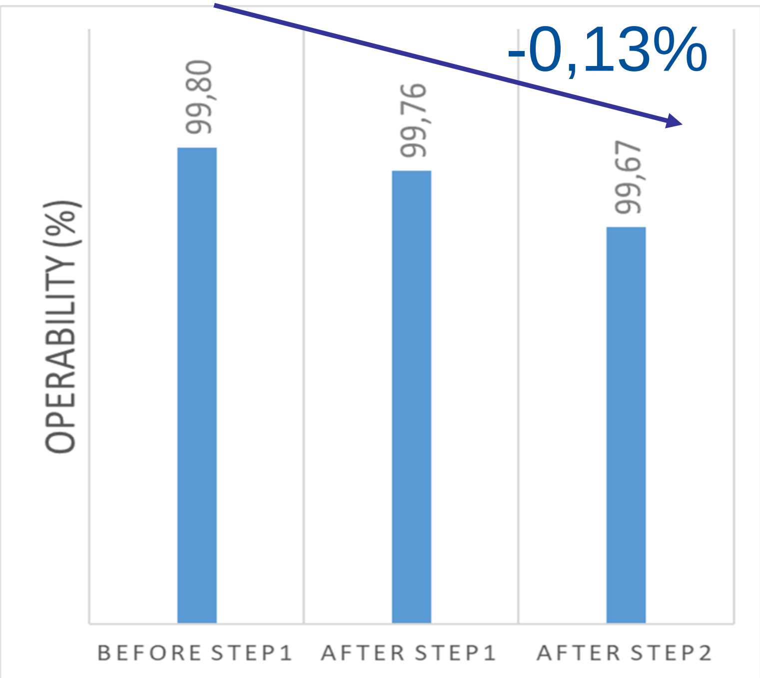
UP TO STEP 2 :
5.10^{10} protons/cm^2

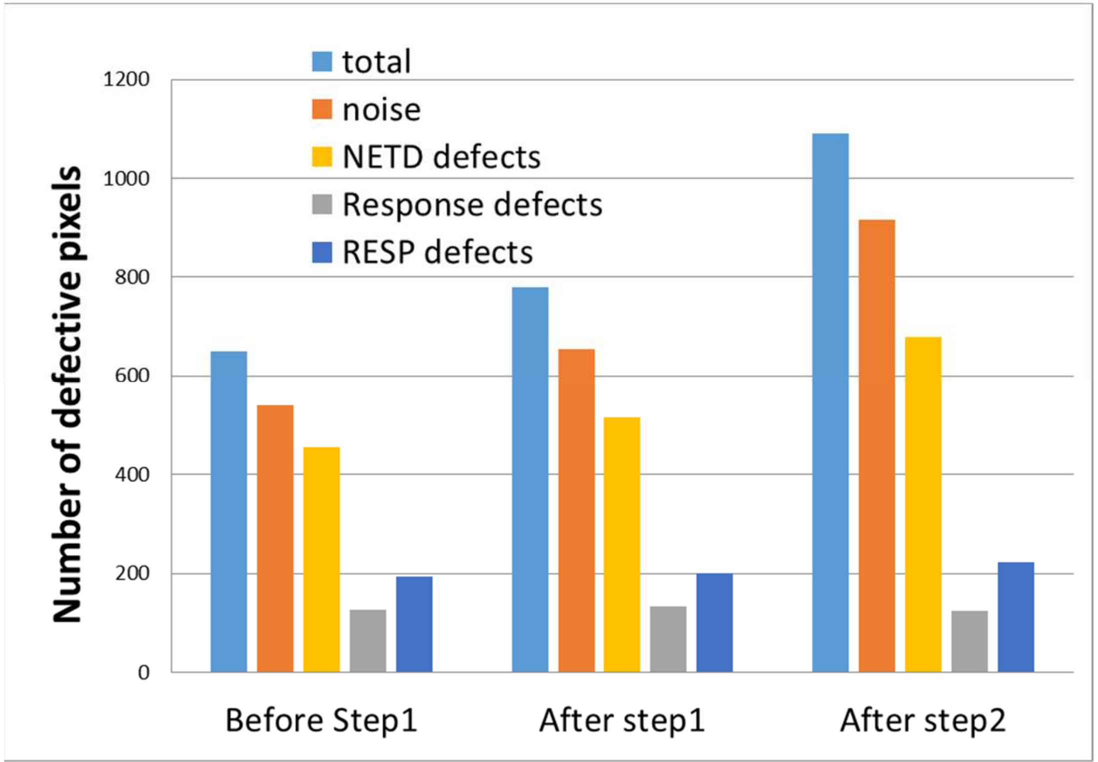
Onera's Criteria

- Signal output +/-30%
- Temporal noise +/- 50%
- Responsivity +/- 30%
- NETD +/- 100%

From mean values @ WF = 50%

Mainly noise defects increase



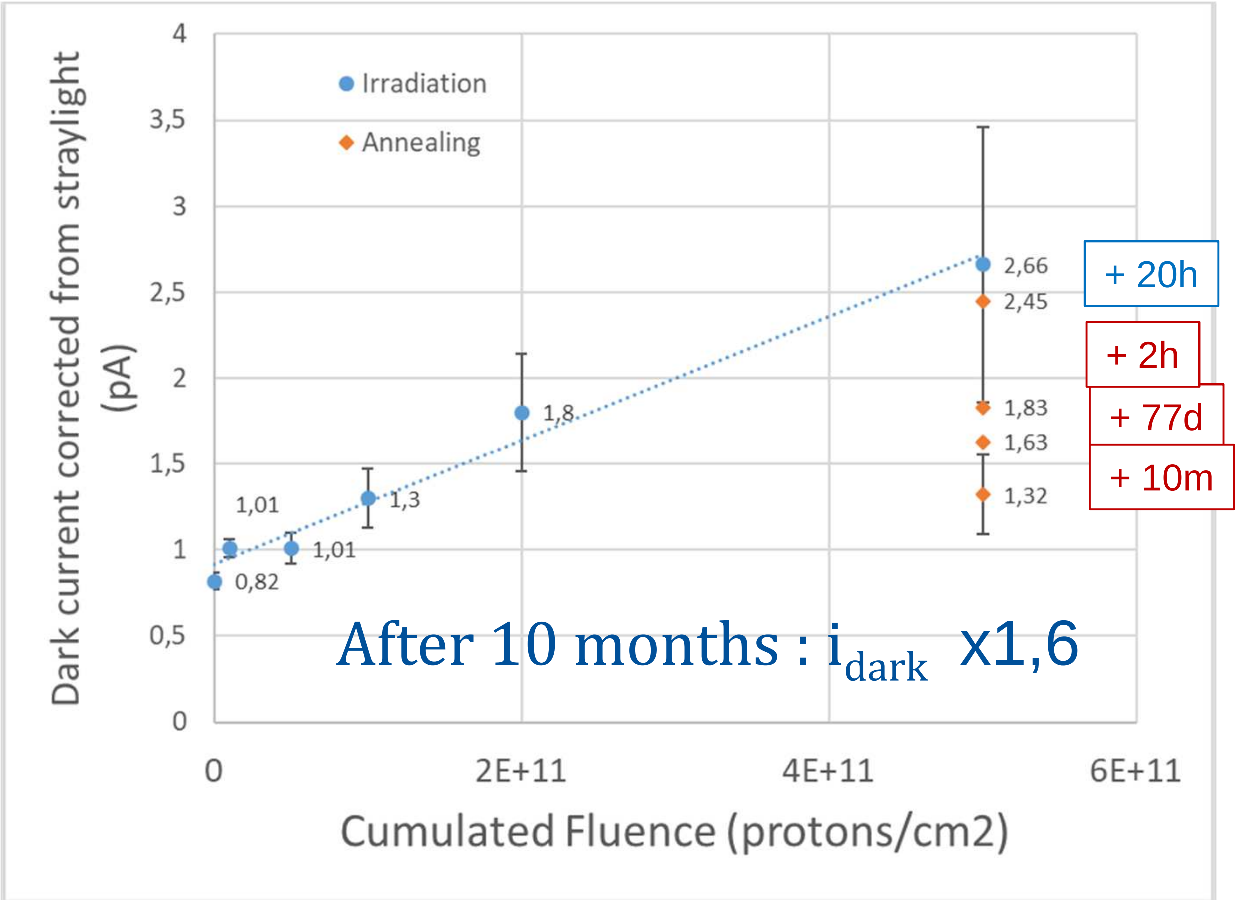


3. Irradiation to Step 5 ($\Phi = 5.10^{11}$ p/cm^2)

Highlight the radiation damage mechanisms

Effect of the annealing steps

Dark current degradation rates across fluence range and annealing effects

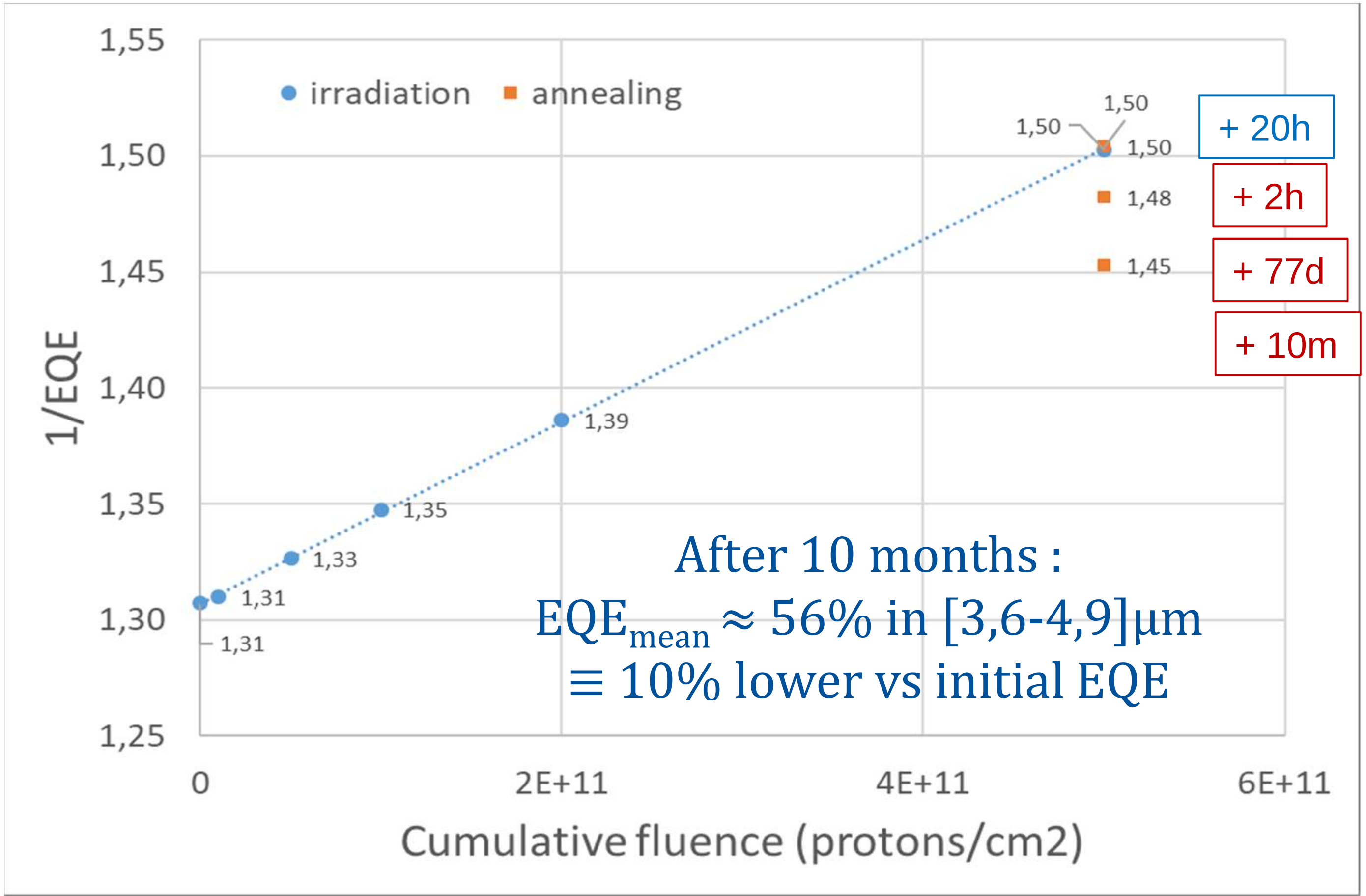


Linear behaviour with cumulated fluence

Annealing => Healing effect, whether the detector is maintained at 80K or heated to 300K

@300K @ 80K Error bars = Unbiased median absolute deviation

EQE degradation rates across fluence range and annealing effects

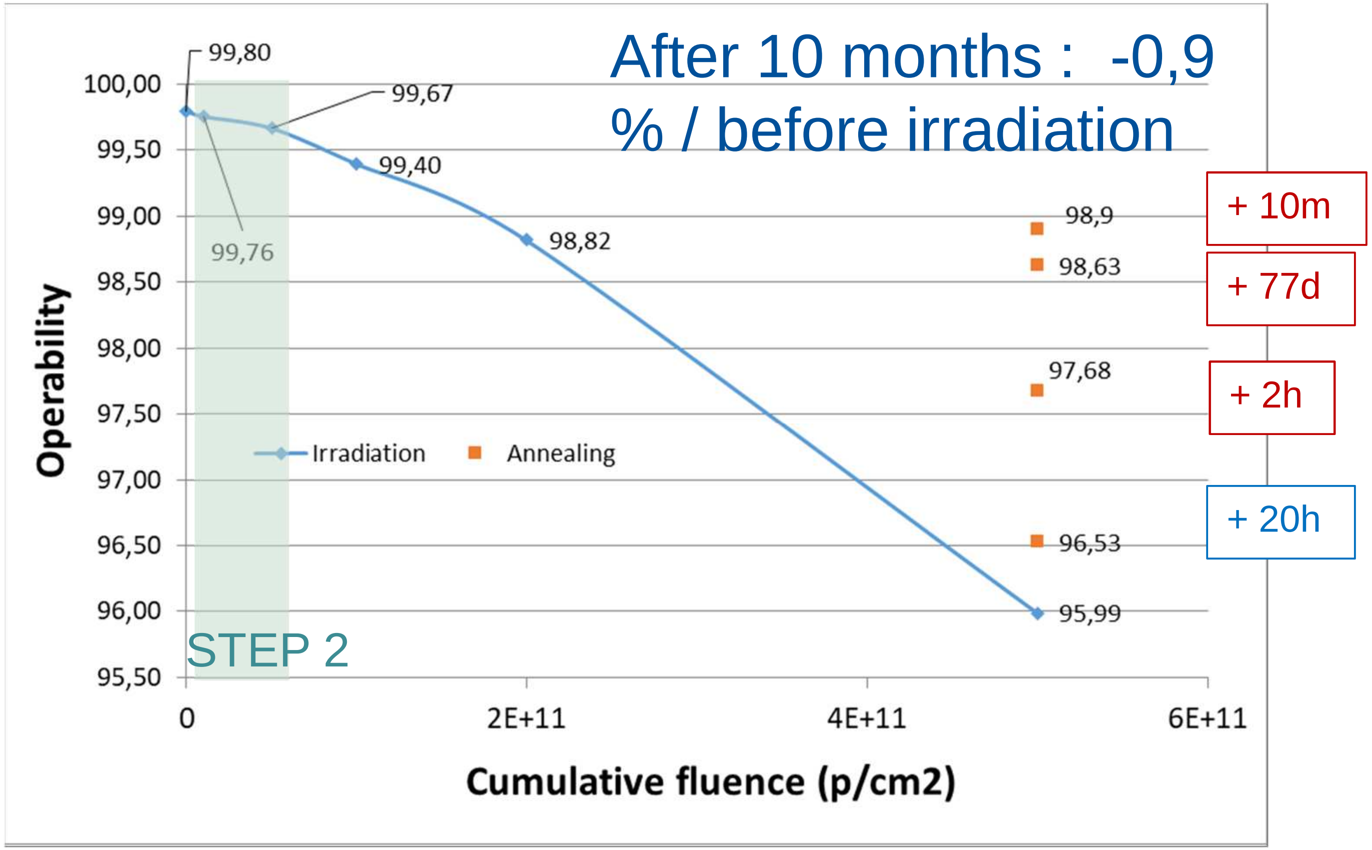


Linear behaviour with cumulated fluence

Annealing => Healing effect, whether the detector is maintained at 80K or heated to 300K

@300K @ 80K

Operability degradation rates across fluence range and annealing effects

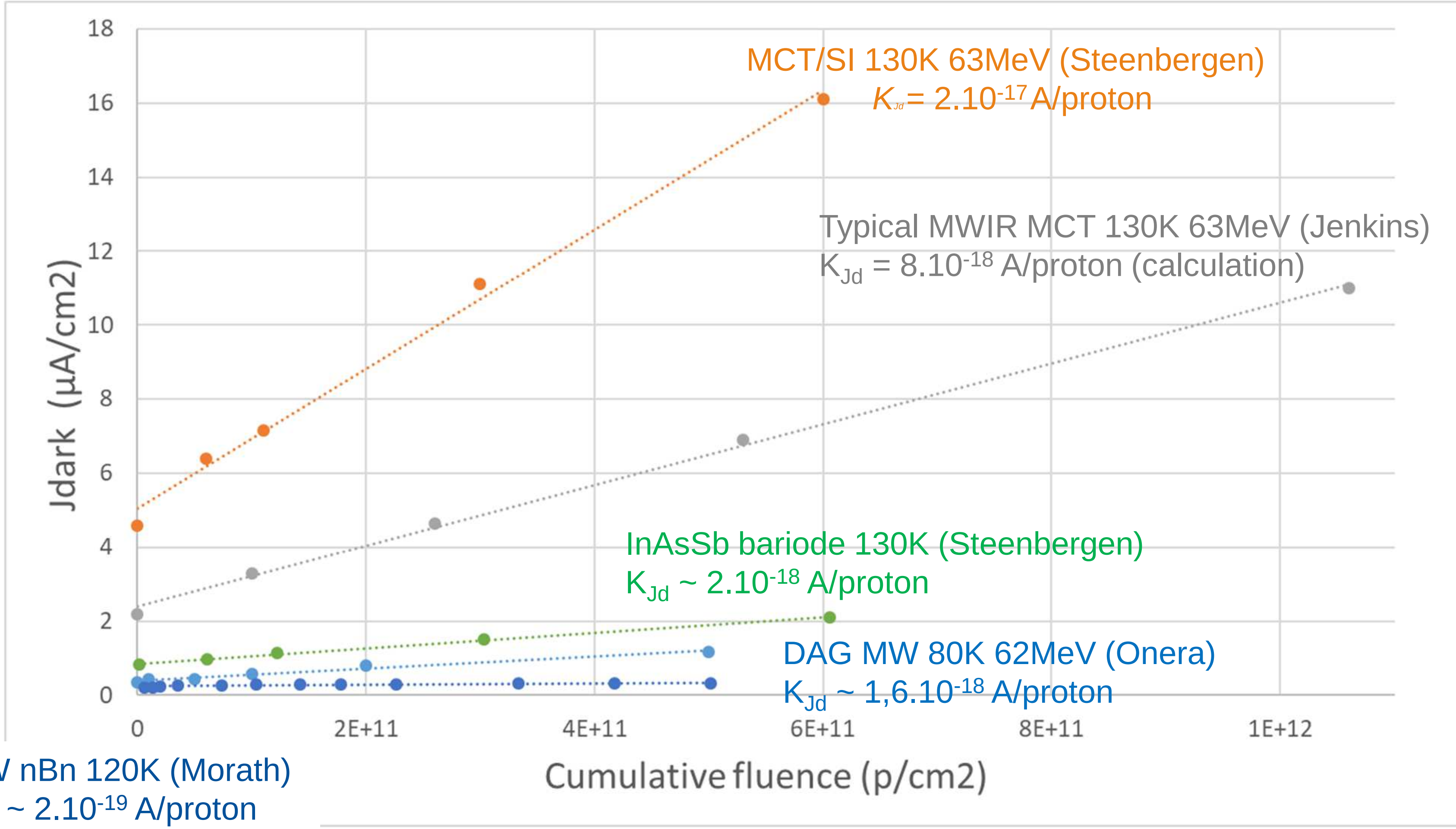


- No linear behaviour with cumulated fluence
- Acceleration of the degradation with fluence

4. Comparison with published results

Dark current density degradation with proton fluence

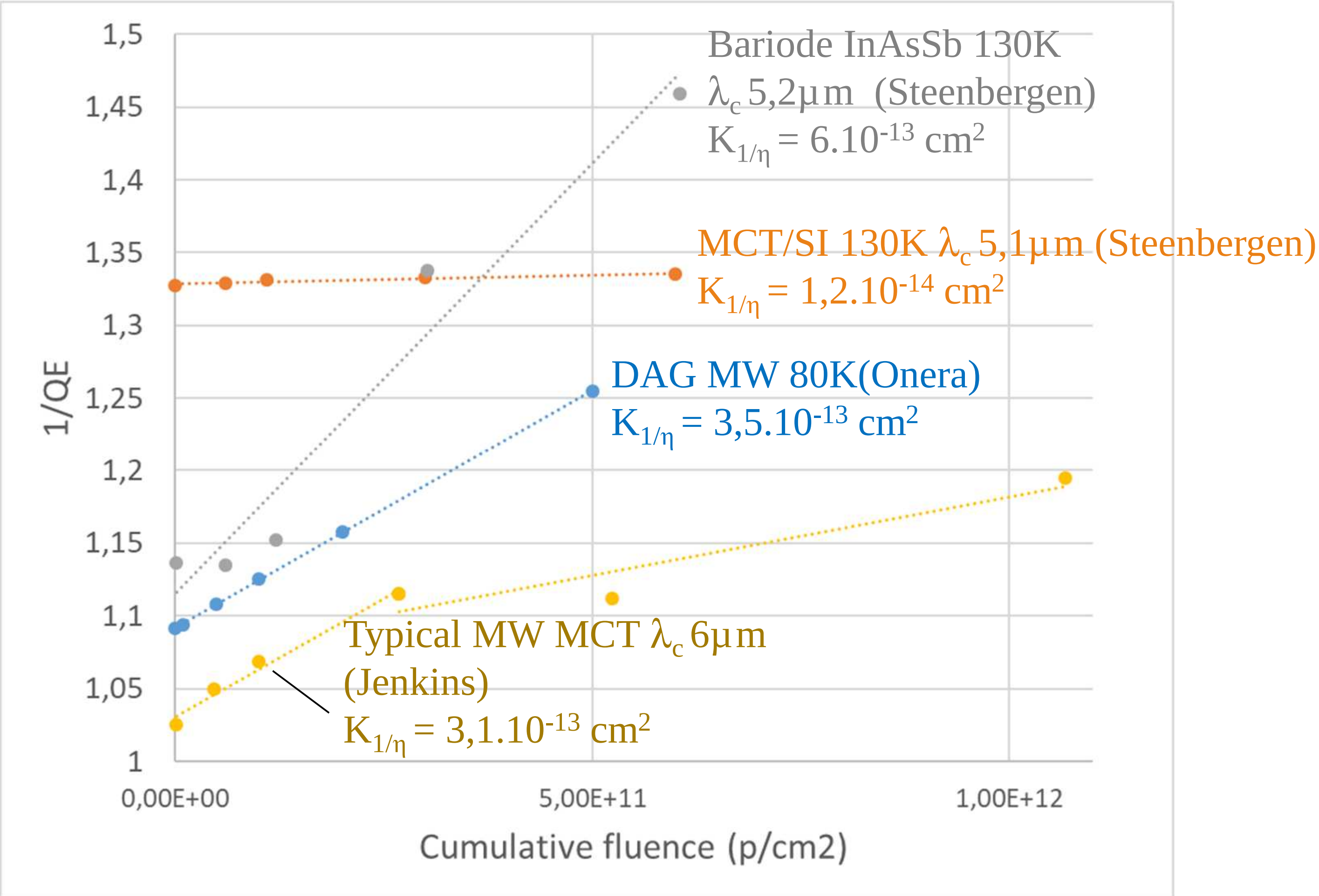
- ✓ Same linear behaviour => damage factor extraction
- ✓ Lack of published data concerning off-the-shelf detectors



G.D.JENKINS, Journal of ELECTRONIC MATERIALS, Vol. 46, No. 9, 2017
E. Steenbergen, Proc. SPIE 11002, Infrared Technology and Applications XLV, 110021B (May 2019)
C.P. Morath, Infrared Physics & Technology, Volume 97, 2019

QE degradation with proton fluence

- ✓ Same linear behaviour except for Jenkins when $\Phi > 5.10^{11}$ p/cm^2
  => damage factor extraction
- ✓ Lack of published data concerning off-the-shelf detectors



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E. Steenbergen, Proc. SPIE 11002, Infrared Technology and Applications XLV, 110021B (May 2019)
C.P. Morath, Infrared Physics & Technology, Volume 97, 2019

Conclusion and perspectives

	Impact	Dark current increase	EQE loss	Operability Loss
Step 2 ($\Phi = 5.10^{10}$ p/cm^2) *Covering most space missions*	Low	~30%	~1,3%	~0,13%
Step 5 ($\Phi = 5.10^{11}$ p/cm^2) *1 o. of magnitude > most space missions*	Moderate	X 3	~13%	~3,8%
Annealing after Step 5 *: After 10 months compared to values before irradiation*	Healing effect	X 1,6	~10%	~0,9%

- First evaluation of the impact of proton irradiation on European COTS MWIR T2SL detector :
  - ✓ focus on first-rate merit factors
  - ✓ suitable for most of space Earth Observation and Science missions in terms of radiation resistance

- A second test campaign is currently considered, in view of testing COTS HOT MWIR T2SL detectors (operating temperature in the 130 K range), with specific focus on the irradiation effect on RTS pixel statistics

Thank you for your attention