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Proton and Gamma Radiation Effects on MWIR HgCdTe Detectors

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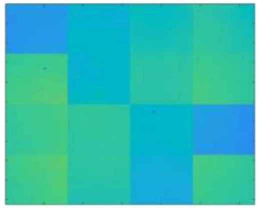
HgCdTe detectors : Devices Under Test

Tested Devices

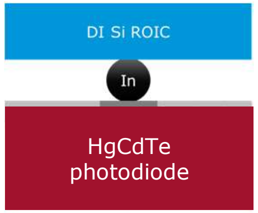
- Hybrid Focal Plane Array (FPA) n/p with variable n-type implantation diameters. TV format (640*512 pixels), 15 µm pixel pitch
- Single HgCdTe photodiodes n/p with variable n-type implantation diameters
- p-type Metal Insulator Semiconductor (MIS)

All devices originate from same wafer

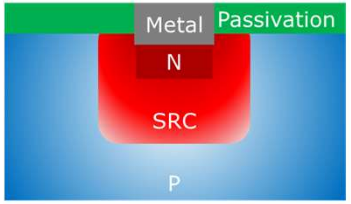
- MWIR (5.2 µm at 78 K, bandgap 220 meV)
- VHg doped
- CEA-Leti made
- Operated at cryogenic temperatures



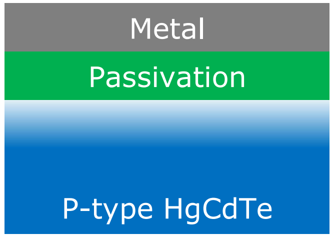
CEA FPA image showing the different diode sizes



Hybrid FPA



Schematic cut view of n/p HgCdTe photodiode



Schematic cut view of p-type MIS device

Recreating the Space Environment through Radiation Testing

Typical Earth Observation space mission proton fluence :

~ a few 10^{10} protons/cm²

HgCdTe material considered resisting well against radiations

x10

Proton test:
- 63 MeV at UCL
- Fluence up to 8×10^{11} protons/cm²

Gamma test:
- Co60 at ARC-Nucleart
- Dose up to 80 krad(Si)

Test Sequence Measurements:

- **Before irradiation**
- **After irradiation at cryogenic temperature**
- **After irradiation and a thermal cycle (cryo T° → room T° → cryo T°)**

Radiation effects on HgCdTe photodiodes

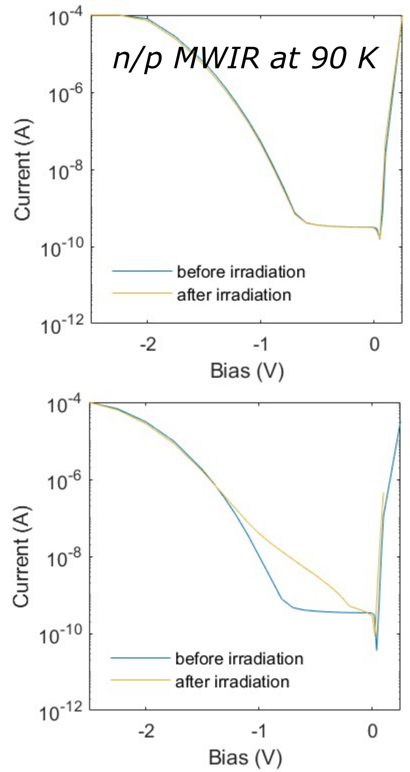
- **Total Ionising Dose (TID)** → Gamma test

  → No degradation on the HgCdTe photodiodes was visible **at the doses reached**

- **Displacement Damage Dose (DDD)** → Proton test

  → Induced degradation on HgCdTe photodiodes

→ **Main proton induced degradation on HgCdTe photodiodes is linked to DDD**



Current - Voltage characteristics of n/p MWIR HgCdTe photodiodes at 90 K

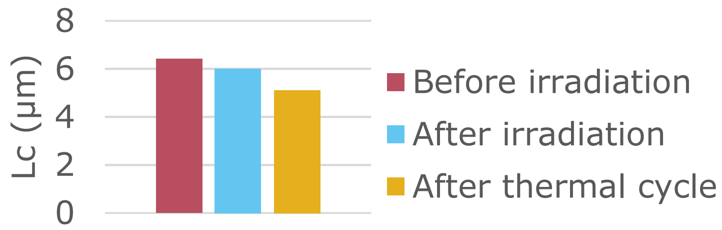
Estimating QE Evolution with DDD

Single photodiodes with variable diameters $\emptyset_d$

$$J_d = \frac{I_d}{\pi\left(\frac{\emptyset_d}{2}+L_c\right)^2} \text{ (A/cm}^2\text{)}$$

Find optimal lateral collection length Lc of minority carriers for the photodiode set

→ Decreased lateral collection length after irradiation

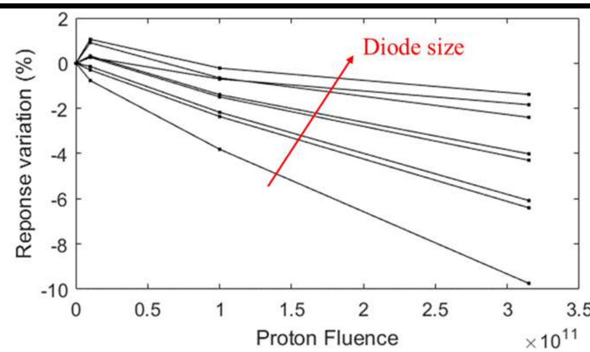


Evolution of lateral collection length with proton irradiation and following thermal cycle

Focal Plane Array photocurrent measurements in front of a blackbody (BB)

$$Response = \frac{\Delta I_{ph}}{\Delta T_{BB}} \text{ [A/K]}$$

→ Small diodes more impacted by blackbody response decrease (-10%) than larger diodes (-2%)



Evolution of response with proton fluence depending on the diode size

→ Shows a small degradation in quantum efficiency

Radiation-induced Dark current distribution in FPA

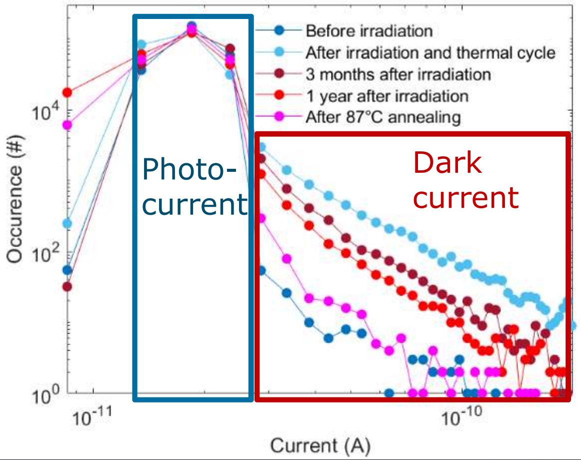
Analysis with a large number of pixels:

→ Increase of dark current with DDD: low mean increase but appearance of high excess current (hot) pixels

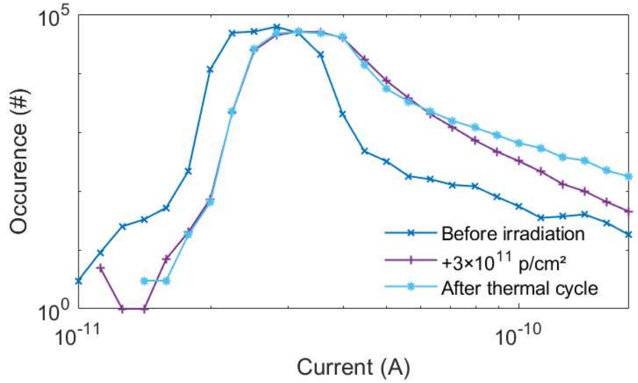
→ Thermal cycle effect on hot pixels

→ Annealing with time and high temperature (87°C during 3h)

Current distribution of FPA in standard biasing conditions (Vpol = 0,8 V) and at 90 K

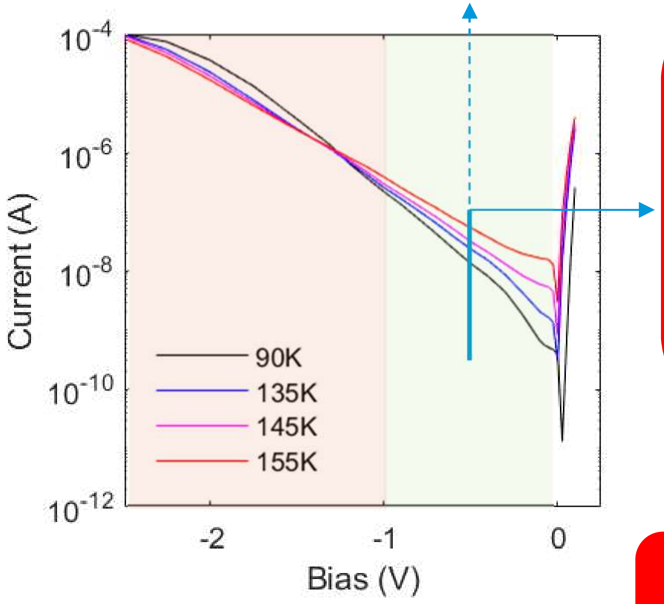


Dark current distribution of FPA in standard biasing conditions (Vpol = 0,8 V) and at 135 K

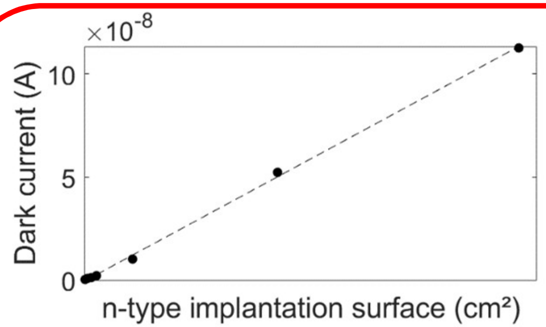


Evolution of Dark Current with Temperature

Activation Energy (-0.5V) = 73 meV → **Decreased dark current activation energy** indicates dark current is no longer dominated by diffusion



After Thermal cycle

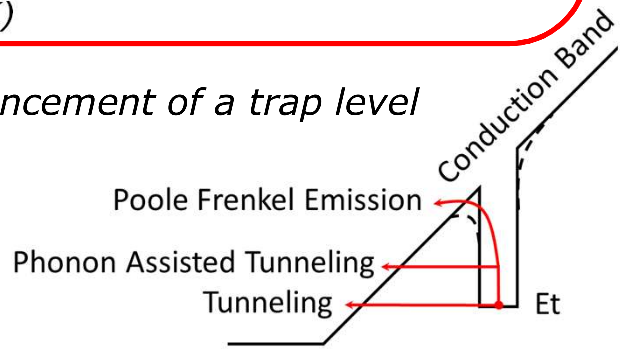


Dark current after post irradiation thermal cycle (-0.5 V bias at 155 K)

- → Dark current ∝ to the photodiode surface
- → Suggests defects responsible for dark current are located **in the Space Charge Region**

→ Electric Field Enhanced SRH centers as radiation induced dark current contribution

Electric Field Enhancement of a trap level



Thermal cycle (TC) and Passivation

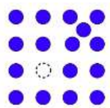
- Most frequent partial recovery of DC with TC, except in *[X. Sun et al., "Proton Radiation Effects on HgCdTe Avalanche Photodiode Detectors," IEEE Trans. Nucl. Sci., vol. 68, nº 1, pp. 27-35, Jan. 2021].*

- Change in MIS flatband voltage after TC indicates positive charges trapped in the passivation

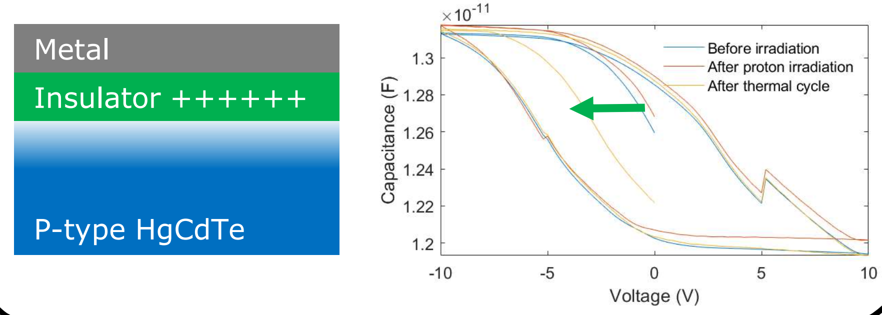
→ Possible SCR extension at the interface

→ Increased number of interface defects in the SCR. Increased surface GR + strong EFE contribution after thermal cycle

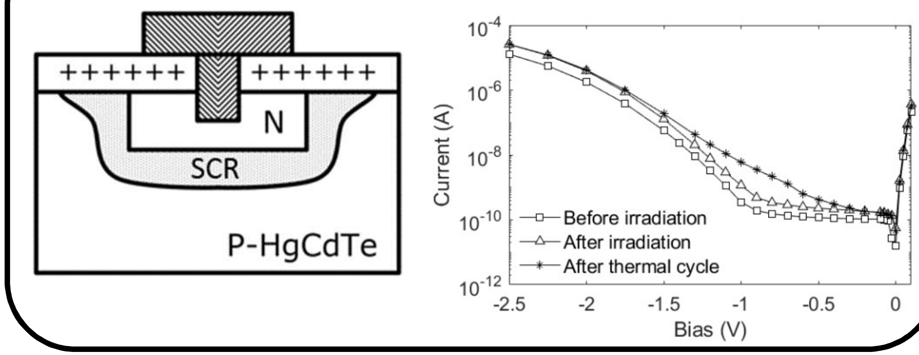
Mechanism to be identified
Frozen defect migration in the passivation to interface at cryogenic temperature ?



Proton irradiation on a p-type HgCdTe Metal – Insulator – Semiconductor *device*

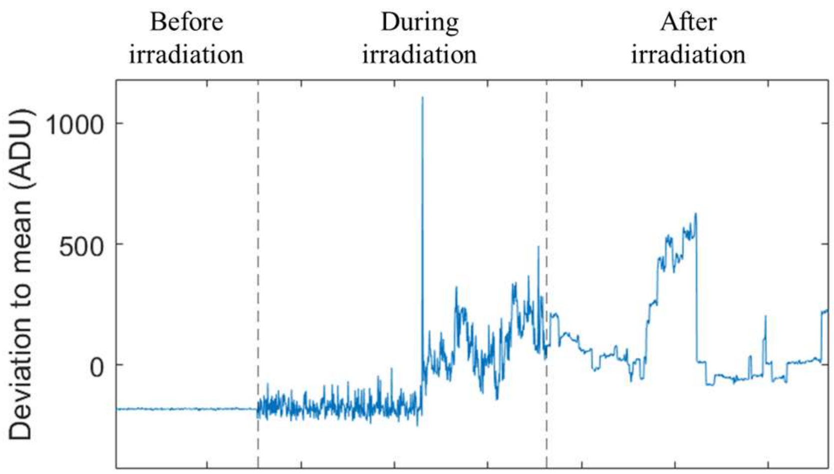


Proton irradiation on a single n/p MWIR HgCdTe photodiode

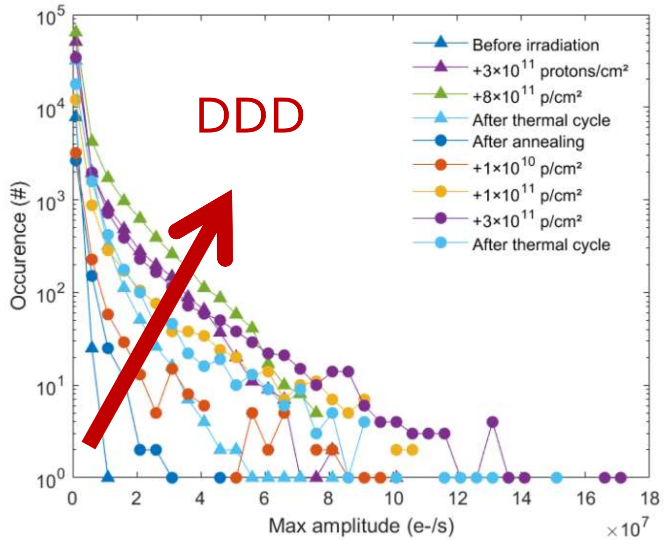


Formation and Dynamics of DDD Induced RTS

- RTS seems to be linked to a single proton interaction displacement damage event.
- Number of RTS pixels increases with DDD.



In real time formation and dynamics of RTS in proton irradiated HgCdTe pixel

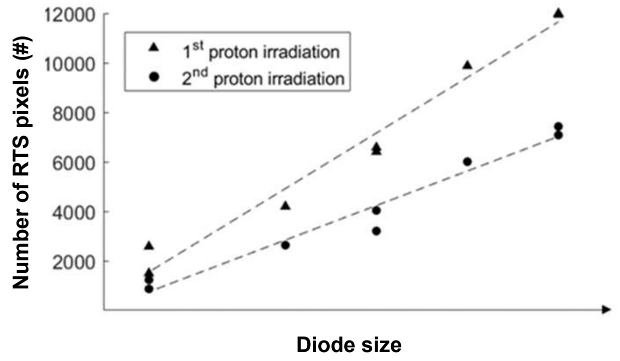


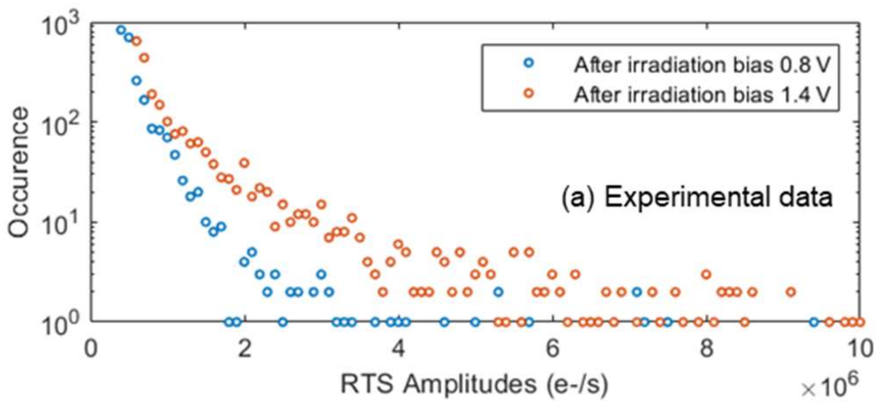
Proton-induced RTS maximal amplitude histograms in hybrid HgCdTe FPA pixels

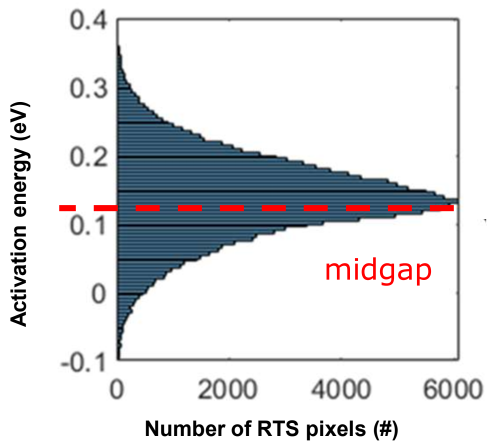
Formation and Dynamics of DDD Induced RTS

- RTS occurrence ∝ diode size
- Depends on electric field
- Amplitudes mean RTS Activation Energy ≈ ½ Eg

→ **RTS defects centers located in the SCR**







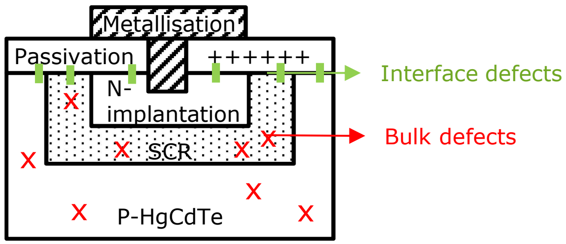
Conclusions

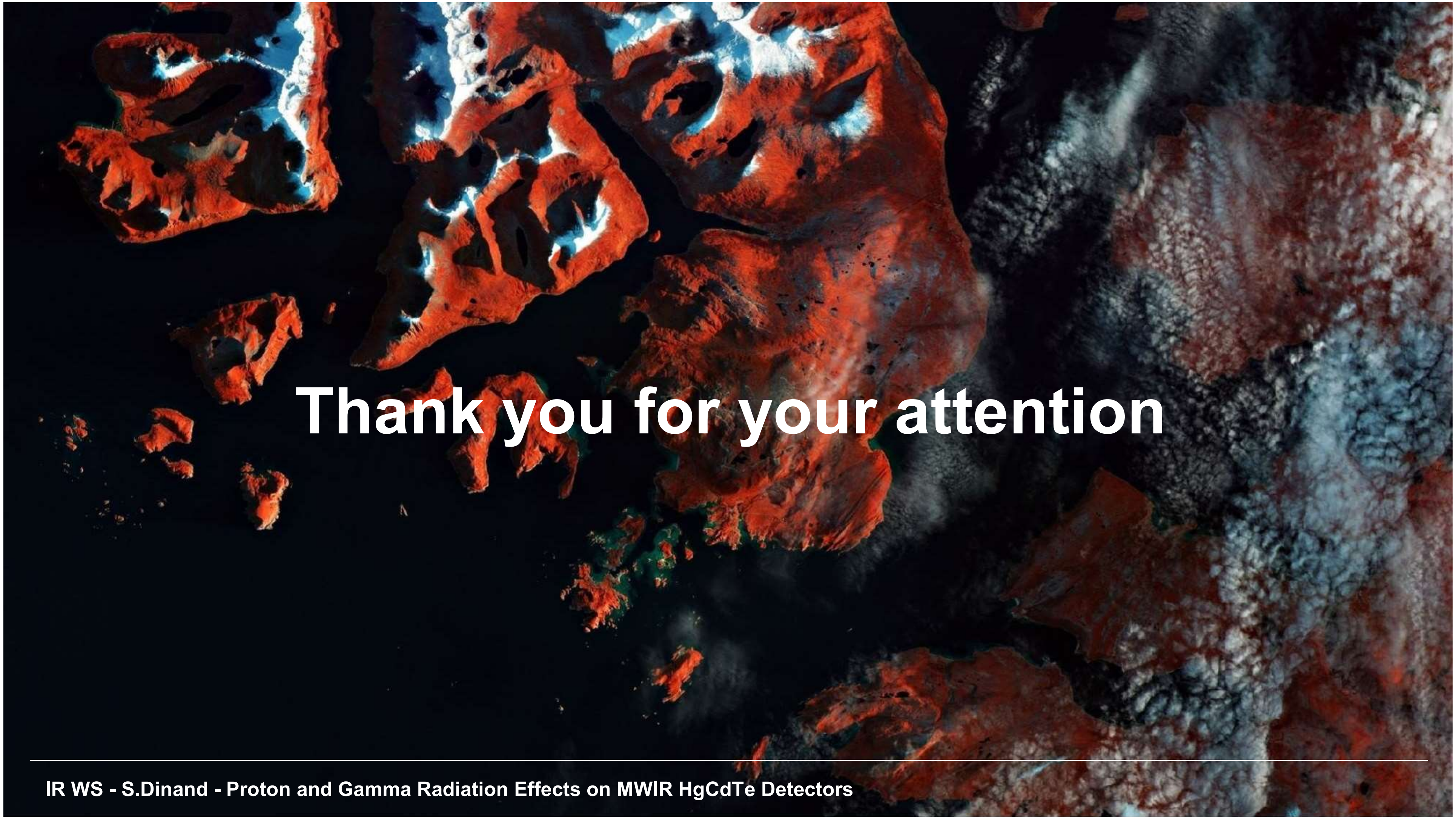
- Total Ionizing Dose does not impact HgCdTe photodiodes performances at doses at least up to 80 krad(Si).
- HgCdTe photodiodes are sensitive to Displacement Damage Dose:
  - Response degradation indicating a change in quantum efficiency
  - Increased Dark Current
  - Random Telegraph Signal

  All three effects are consistent with the introduction of defects throughout the photodiode.

  Radiation tolerance is a diode size trade off between quantum efficiency and dark current operability.

- The thermal cycle delays in this case the main dark curent degradation in HgCdTe. MIS devices indicate surface effects linked to the positive charging of the passivation layer





Thank you for your attention