Radiation effects in a modern CMOS Image Sensor

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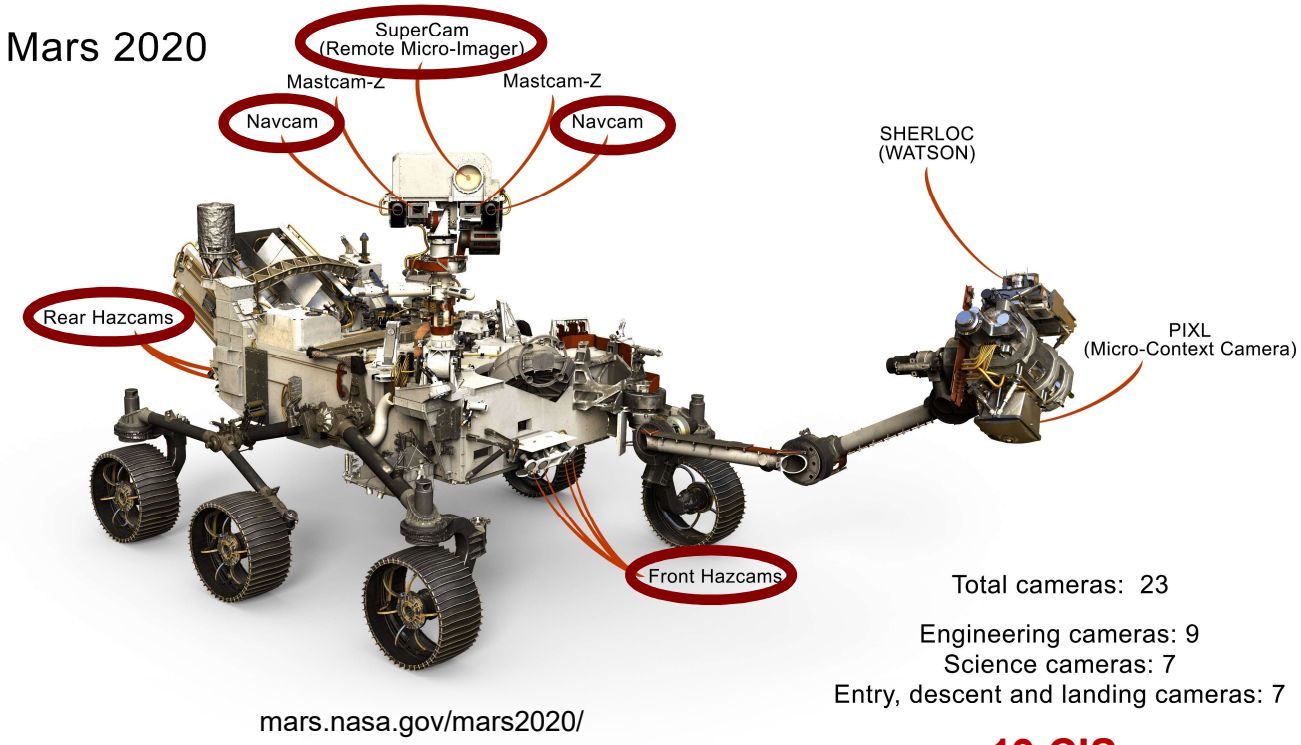
mars.nasa.gov/mars2020/

CMOS Image Sensors for space missions



mars.nasa.gov/mars2020/

Total cameras: 23

Engineering cameras: 9
Science cameras: 7
Entry, descent and landing cameras: 7

19 CIS

Commercial CIS in the Mars 2020 mission

Perseverance Engineering cameras:
ams CMV20000 *9

Perseverance Science cameras:
ams CMV4000

Entry Descent Landing system:
Onsemi P1300 *5
Onsemi P5000
Sony IMX265

Ingenuity:
Sony IMX214
Omnivision OV7251

Radiation Effects in CIS

Need to assess Radiation Hardness of recent CIS technologies to unlock the best performances and latest features

Single Event Effects (SEE)

- Transient charge collection

Ionizing Dose (TID)

- Si/SiO2 Interface States
- Oxide trapped charges
- Homogeneous degradation

Displacement Damage Dose (DDD)

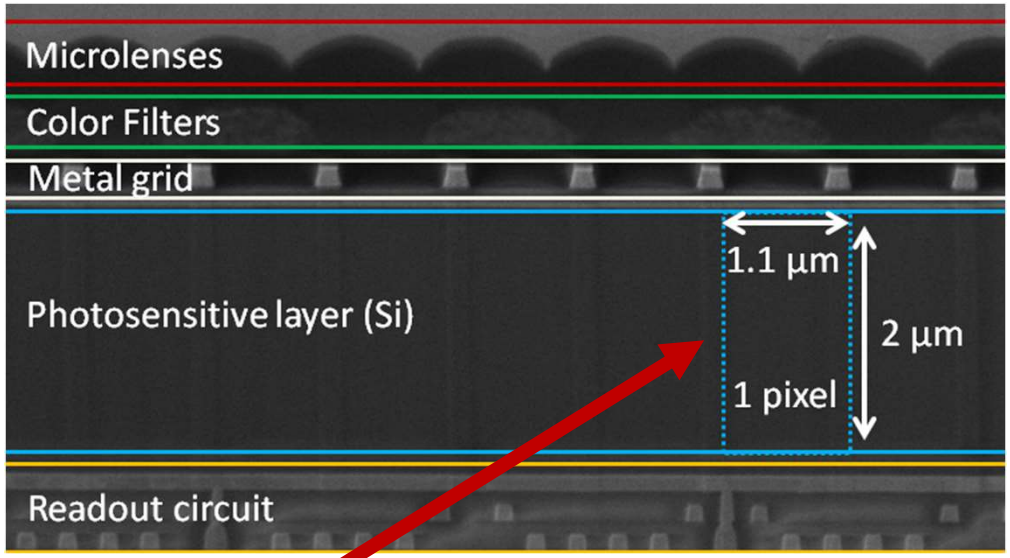
- Bulk defects
- Exponential tail of hot pixels

Device under test

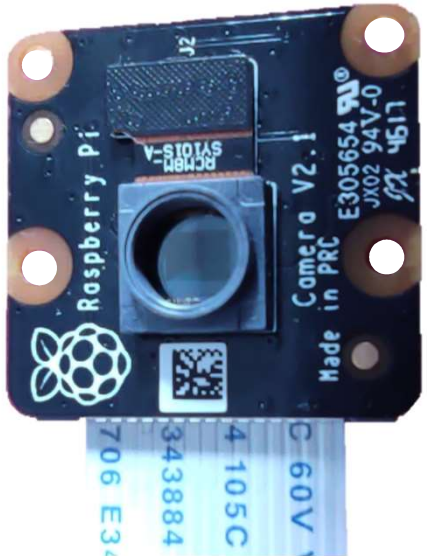
Sony IMX219:

- 8 Mpix
- 1.1 µm pitch
- 1.5 transistor/pixel
- Backside Illuminated
- Operated using a Raspberry Pi

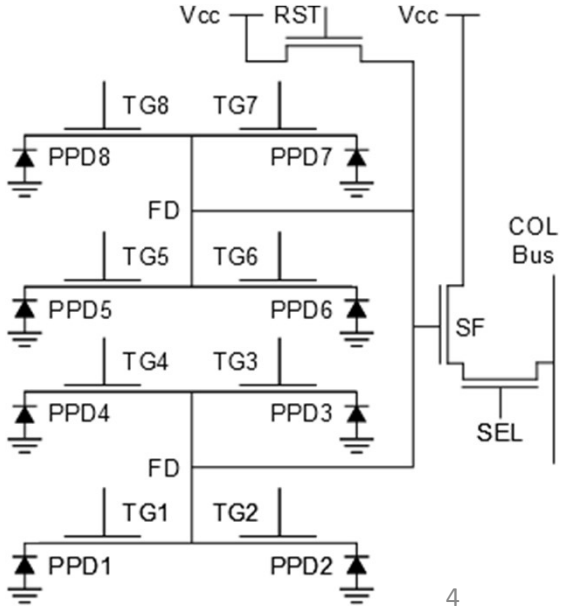
IMX219 pixel cross section



Vertically pinned PD



IMX219 pixel electrical layout



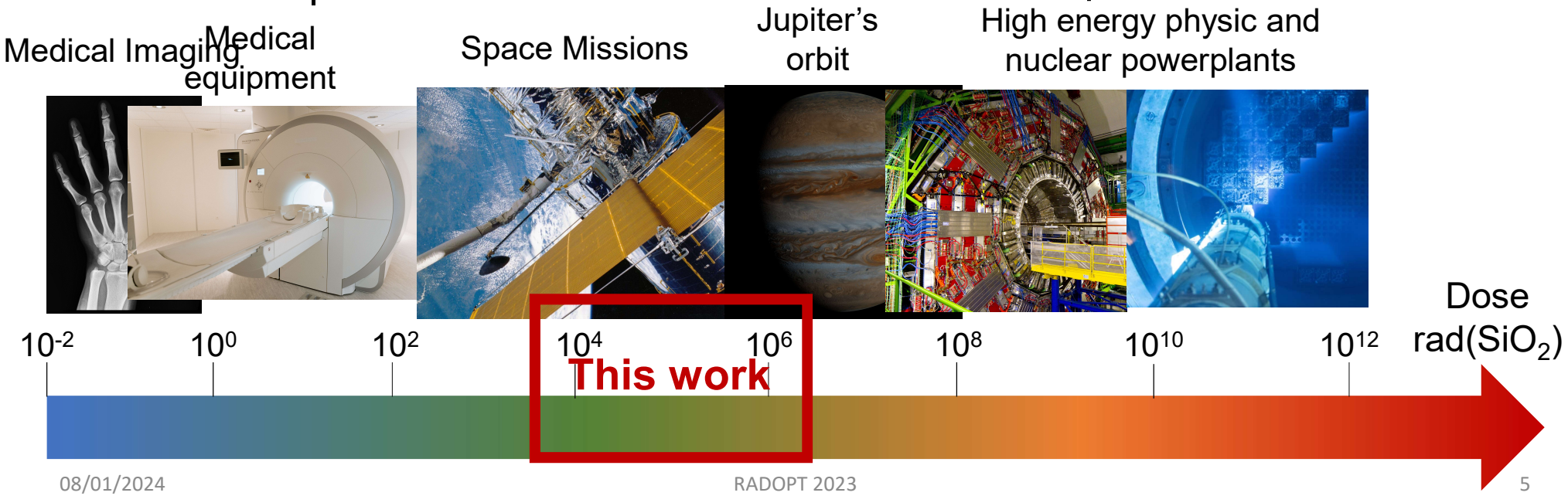
Irradiations

Ionizing Dose (TID)

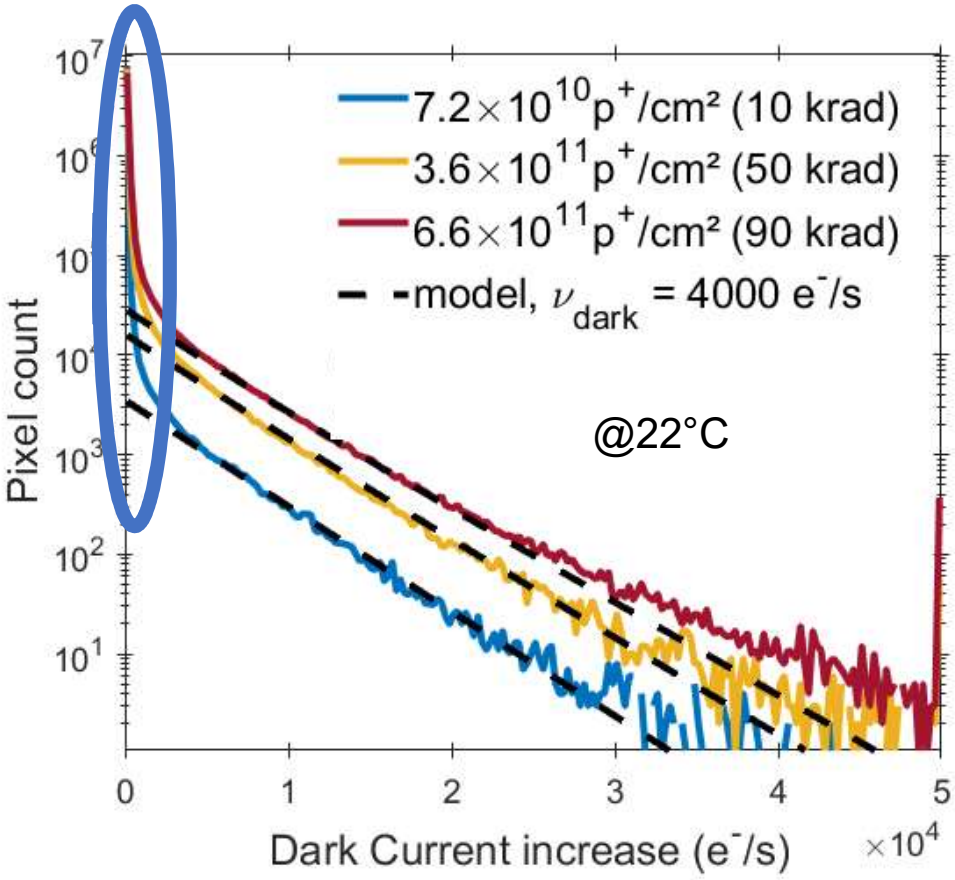
- 1.2 MeV gamma rays
- Radiation Effects Facility, NASA GSFC, USA
- Biased/Grounded
- Room temperature

Displacement Damage Dose (DDD)

- 62 MeV protons
- Catholic University of Louvain, Belgium
- Grounded
- Room temperature



Proton irradiation – Dark current increase



DDD induced exponential tail of hot pixels

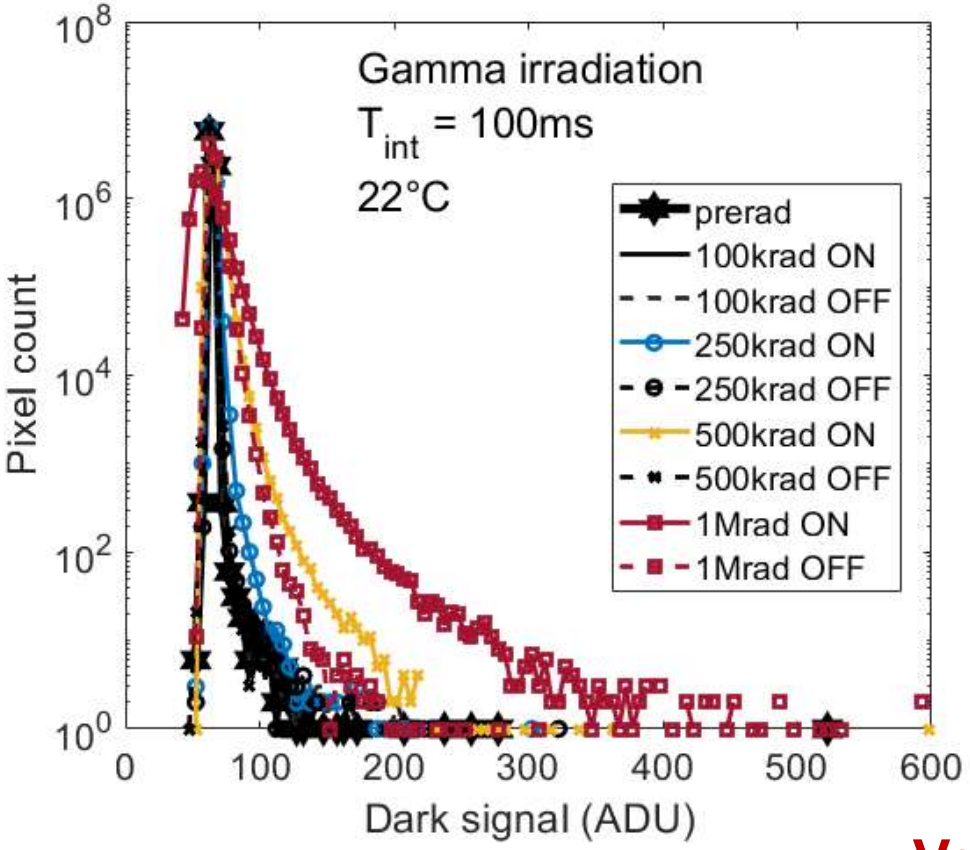
Follows typical trend and empirical model for CIS…

$$f(\Delta I_{dark}) = \frac{1}{\nu_{dark}} \exp(-\frac{\Delta I_{dark}}{\nu_{dark}})$$

… with 10 to 100 times smaller silicon volumes!

No clear TID impact

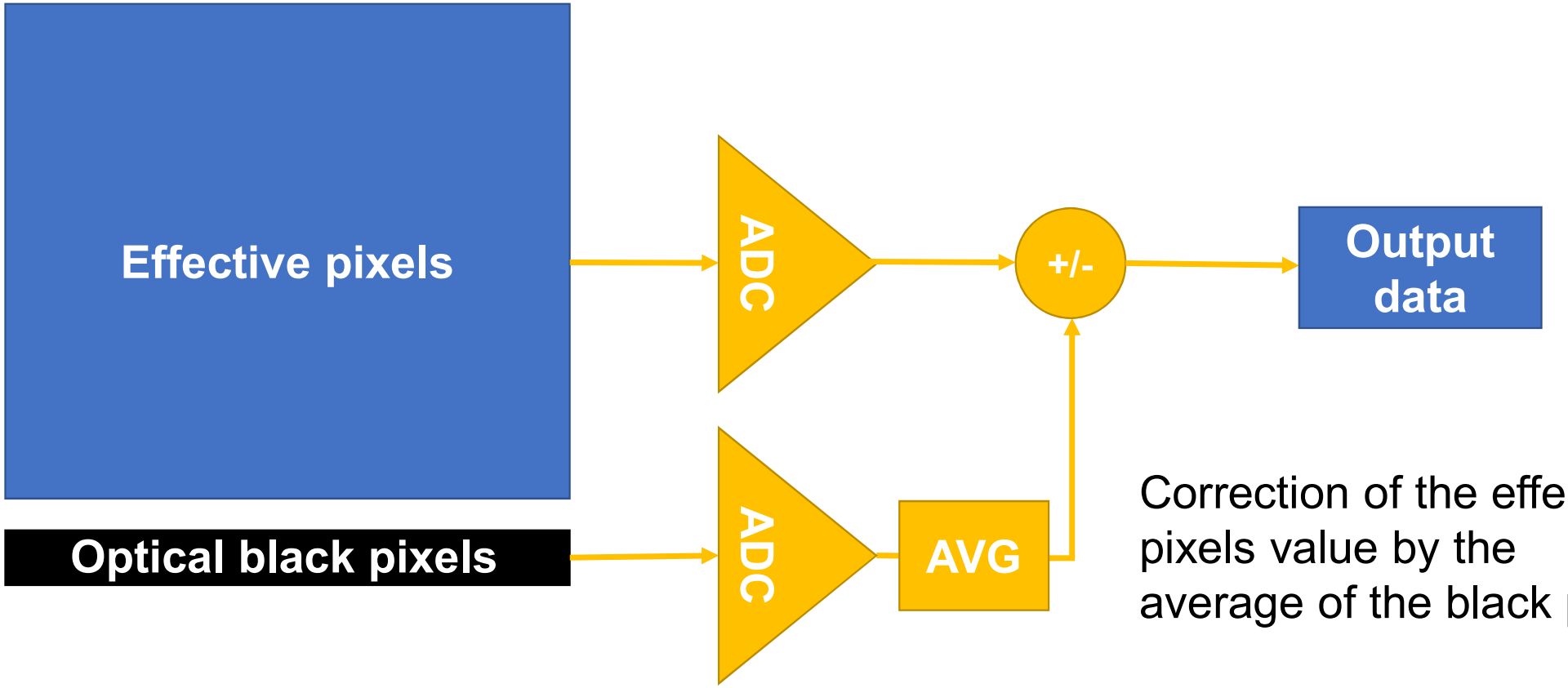
Gamma irradiation – Dark signal increase



- Strong bias impact on the degradation
- No change in the dark signal histogram up to 100 krad(SiO_2) when biased and up to 500 krad(SiO_2) when grounded
- Histogram widening but no increase of the mean value => effect of on chip black clamping

Very good TID tolerance up to 250 krad(SiO_2)

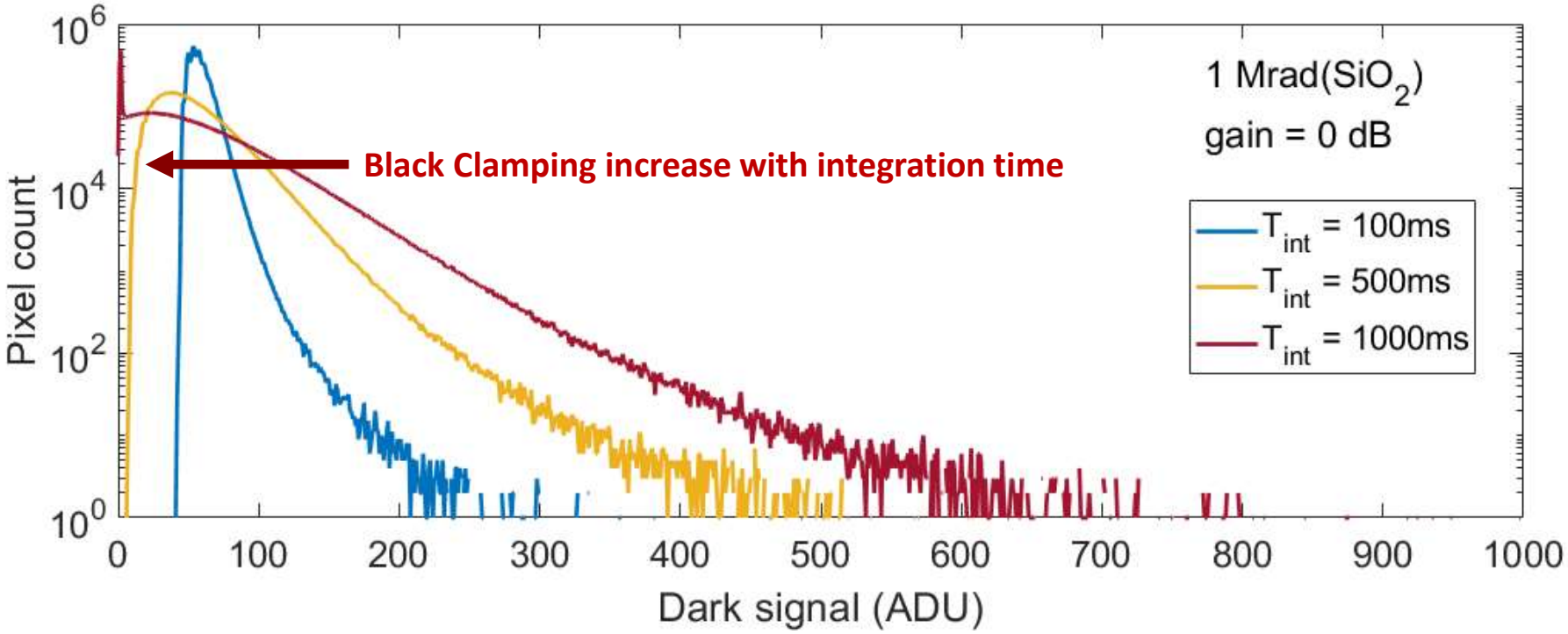
Black-clamping – basic principle



Correction of the effective pixels value by the average of the black pixels

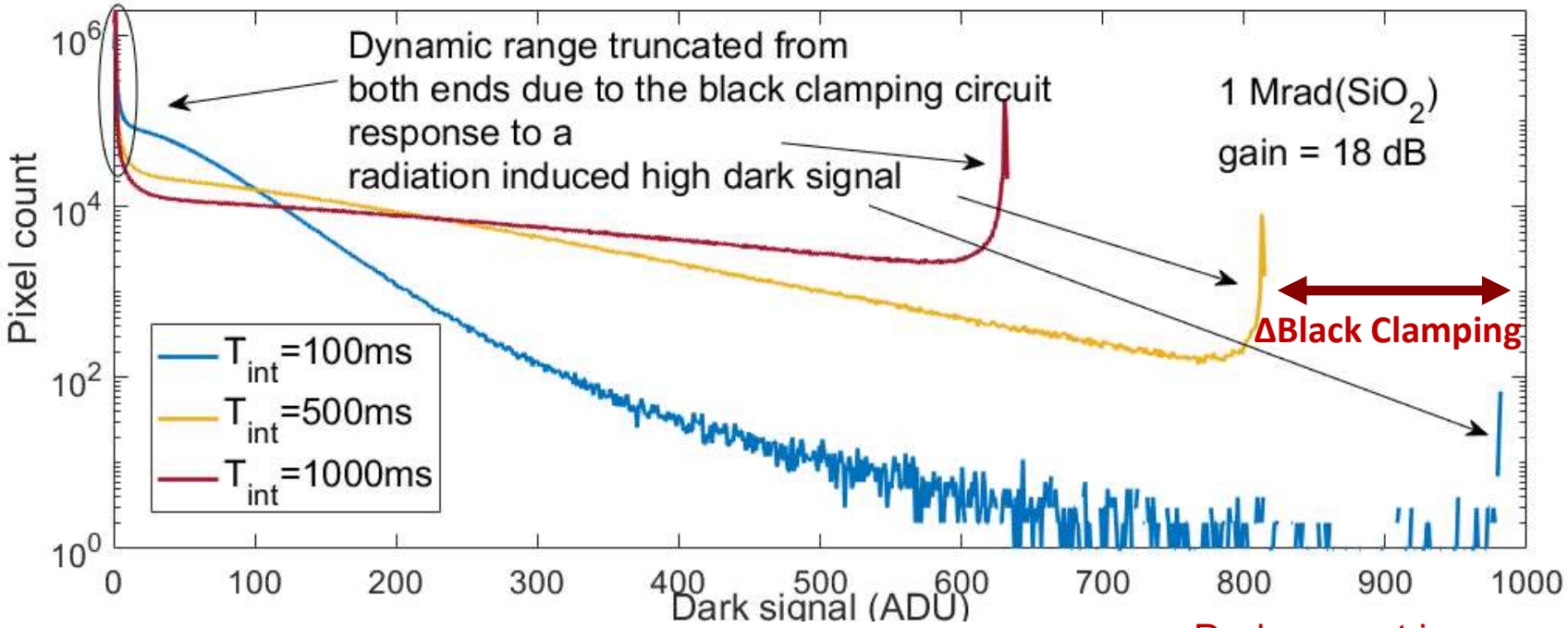
Black-clamping – effects

Makes it hard to evaluate dark current by increasing the integration time
=> The black clamping correction changes and is unknown



Black-clamping – effects

High gain allows for a rough estimation of the mean dark current:
(underestimation due to pixels reaching saturation)



$$\overline{Id} \approx \frac{\Delta Black\ clamping}{gain \times CVF \times \Delta tint}$$

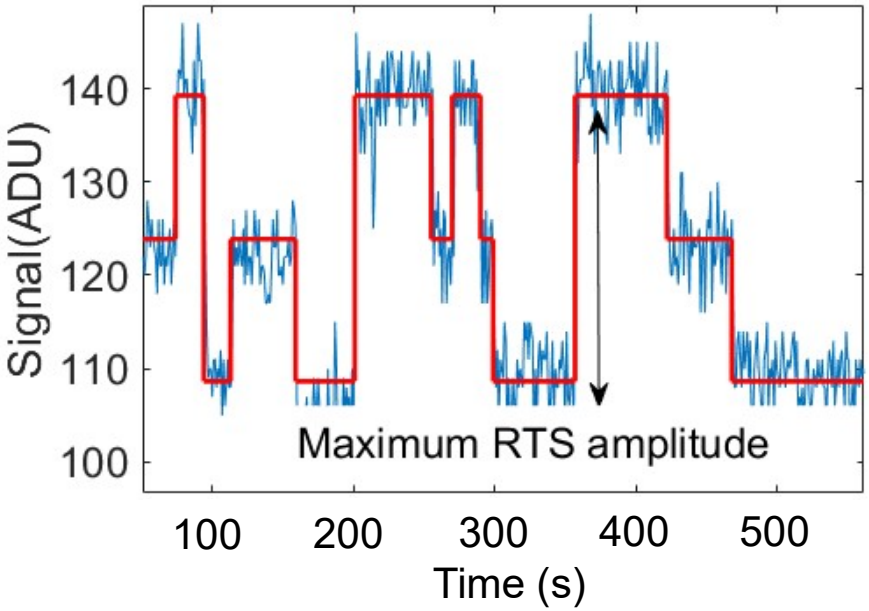
$$\overline{Id} \approx \frac{200}{8 \times 0{,}18 \times 0{,}5}$$

$$\overline{Id} \approx 277\ e^{-}/s$$

$$\overline{Id} \approx 3.7 \times 10^{3}\ pA/cm^{2}$$

Dark current increase comparable with RHBD 3T or recent p-type photogates (STm)

Random Telegraph Signal – Blinking pixels



10 000 x 100 ms @ 22°C, 1 FPS

SN-RTS

Metastable SRH Generation/Recombination centers in the sense node

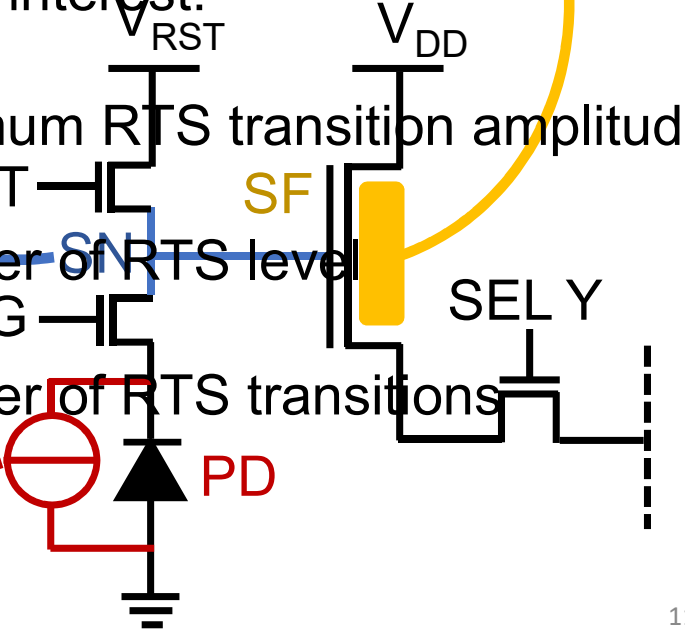
SF-RTS

Source-Follower channel conductance variation due to trapping/emission of single carriers

RTS extraction using edge detection

Parameters of interest:

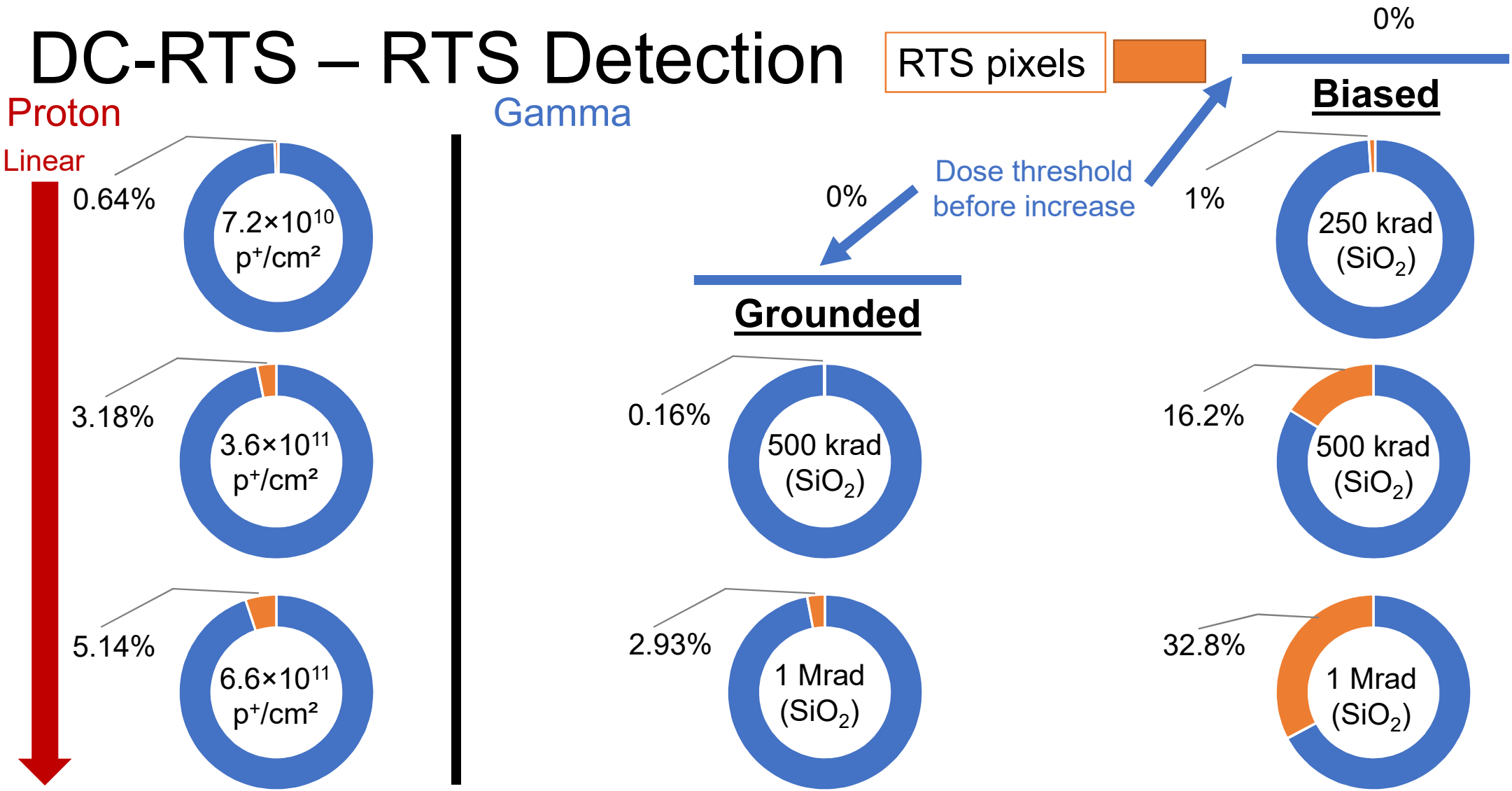
- Maximum RTS transition amplitude
- Number of RTS level
- Number of RTS transitions



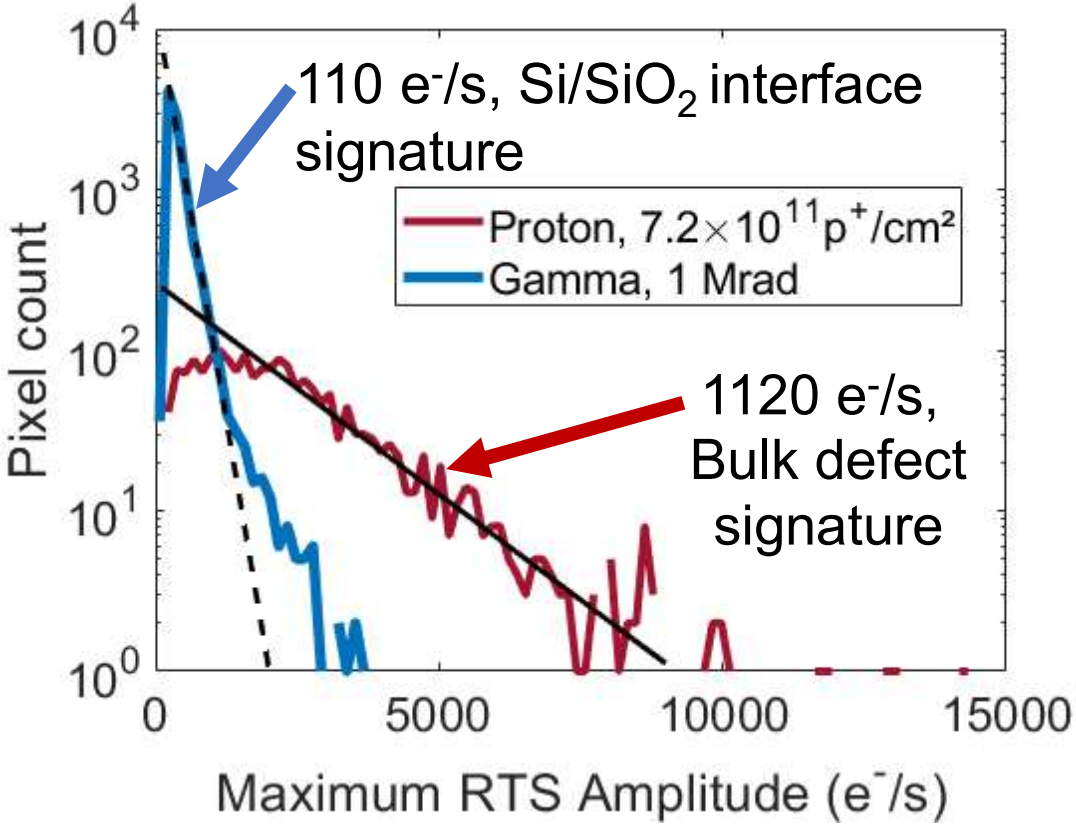
DC-RTS

Metastable SRH Generation/Recombination centers in the photdiode

DC-RTS – RTS Detection



Maximum RTS Transition Amplitude



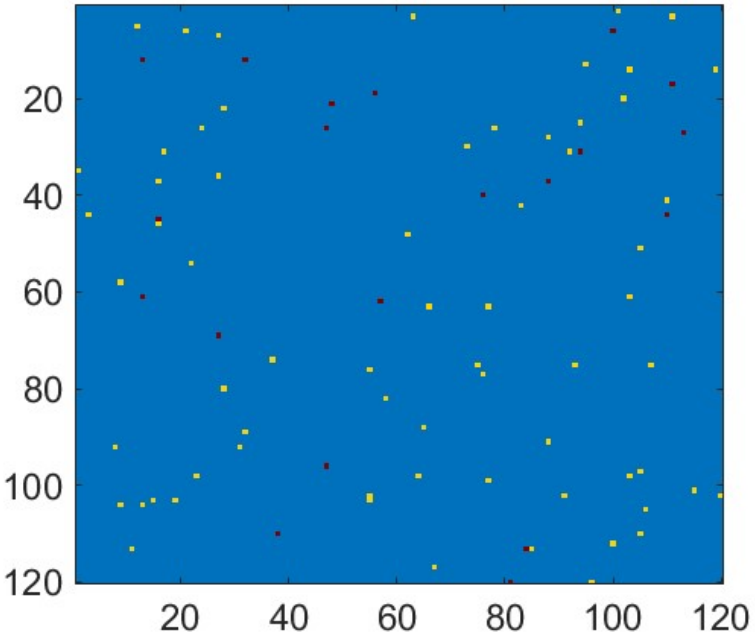
Both TID and DDD induced RTS distributions follow exponential laws

The mean RTS maximum transition amlitude is larger for DDD than for TID (1120 e^-/s vs 110 e^-/s)

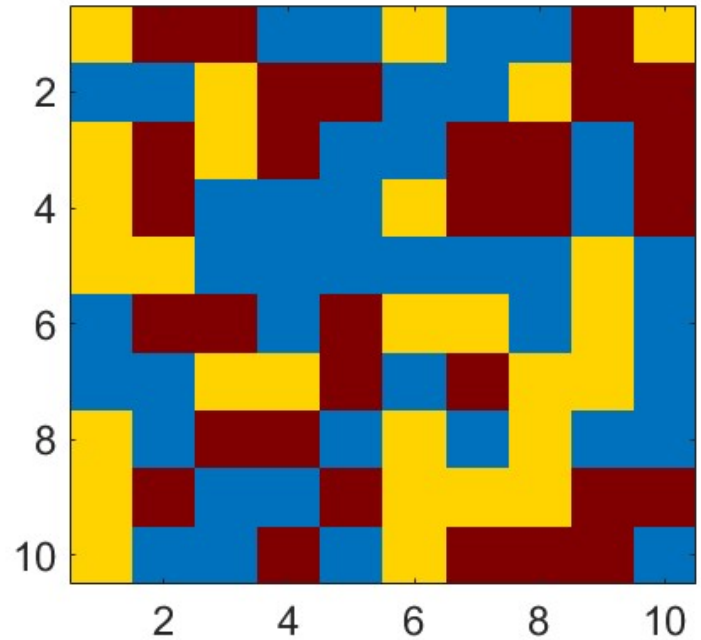
In line with state-of-the-art results for CMOS Image sensors despite:

- **smaller pixel pitch than previous work**
- **pixel design moving away from the planar PPD**

DDD - DC-RTS, scaling pixel volume



0.64%



39%

Mean number of RTS centers per pixel

$u_{RTS} = 0.01$

RTS pixels

$u_{RTS} = K \times V_{dep} \times DDD$

2-level

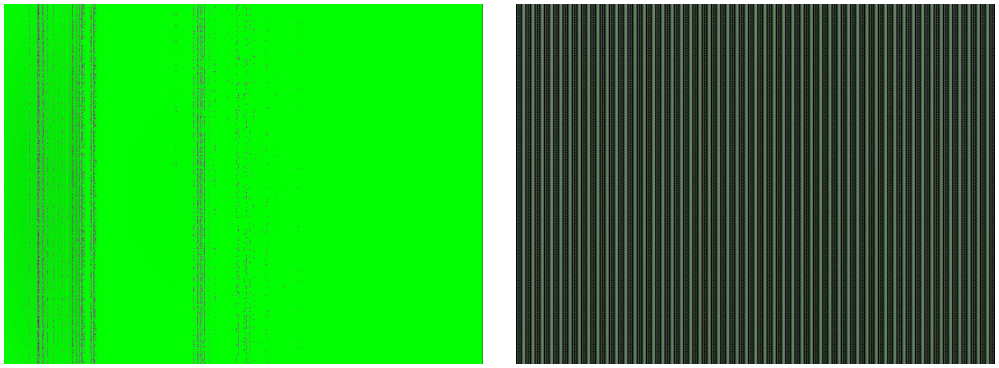
$u_{RTS} = 1.44$

multi-level

Conclusion

IMX219 follows universal CIS radiation induced degradation behavior for TID and DDD, despite small pixel pitch and pixel architecture

A good candidate as engineering camera for space mission considering tolerance to cumulative dose BUT …



Corrupted frames obtained during proton irradiation

could be Single Event Effect sensitive