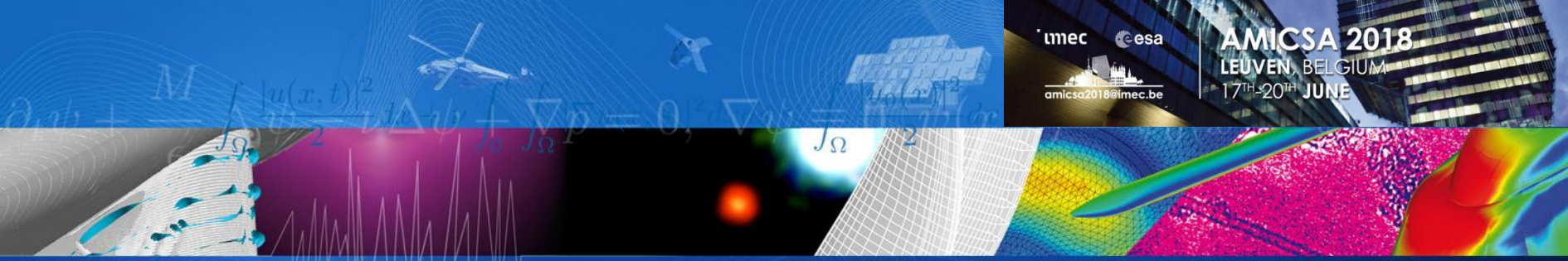

Radiation Single Event Effects Analysis in ReadOut Integrated Circuits at Cryogenic Temperatures

L. Artola[1], S. Ducret[2], A; AL Youssef[1,2], R. Buiron[2], F. Perrier[2], G. Hubert[1], and C. Poivey [3]

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[2] Sofradir, Veurey Voroize, France
[3] European Space Agency ESTEC, Netherlands

ONERA
THE FRENCH AEROSPACE LAB

retour sur innovation

SOFRADIR

Context of the work

- CMOS technology is relevant for integrate electronic functions in image sensors (row decoders, registers, Flip-Flops)

- For performance reasons, the infrared image sensors developed by Sofradir work at very low temperatures down to 50K

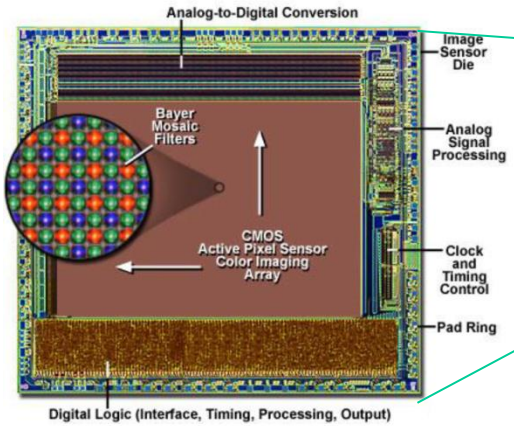
- The Single Event Upset can occurs in DFF for this temperature range. The temperature impact on the SEU occurrence is limited. (L. Artola et al, IEEE TNS. 2015)

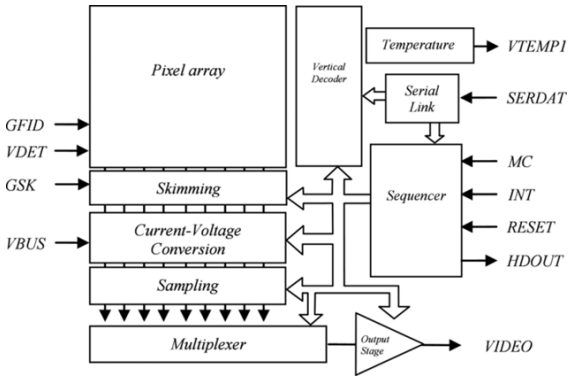
→ What about the occurrence of Single Event Transient and Functional Interrupt in ReadOut Integrated Circuit of Infrared image sensors?

Purpose of this work (1/2)

Single Event Effect analysis of heavy ion tests on Readout Integrated circuit

- **SEE measurements** → Trames analysis → Identify the SEE signatures →Determine the SEE origins





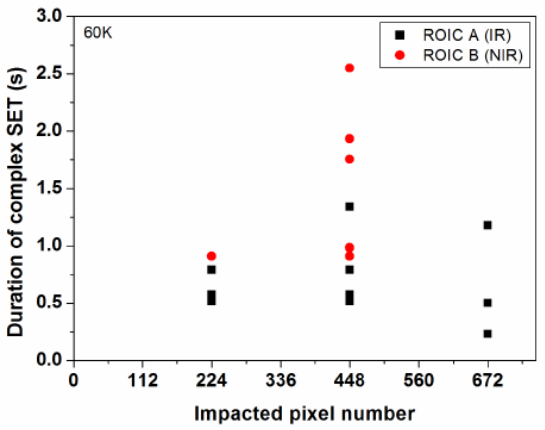
SEE measurements

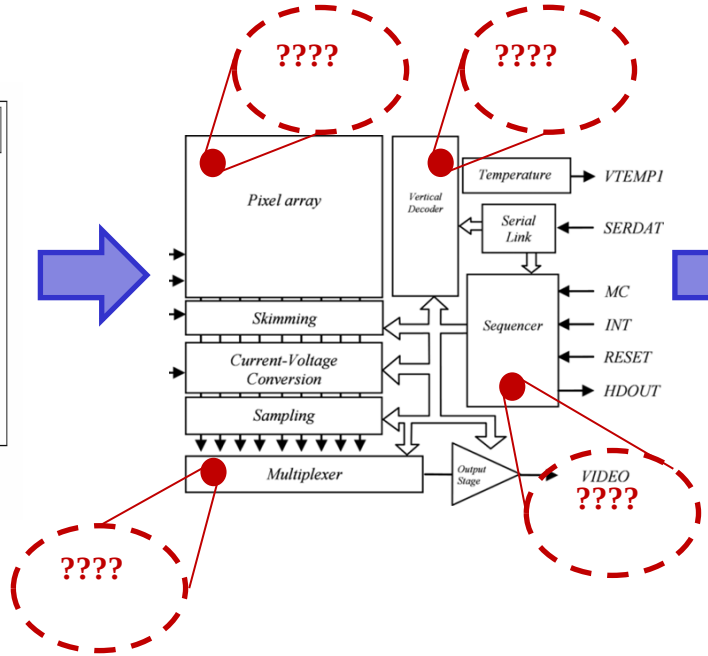
Purpose of this work (2/2)

Single Event Effect analysis of heavy ion tests on Readout Integrated circuit

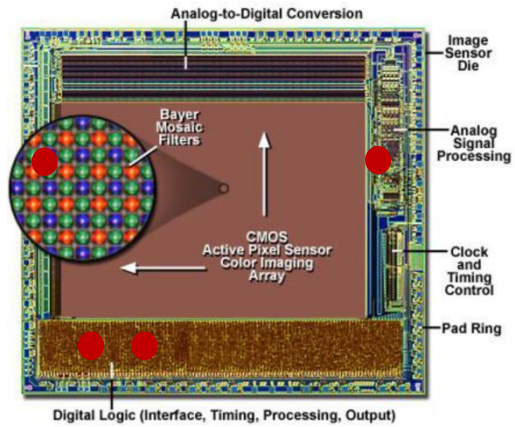
- SEE measurements → Trames analysis → Identify the SEE signatures →**Determine the SEE origins**

Identify the SEE signatures





Determine the SEE origins



Determine the SEE origin in ROICs / Evaluate the cryogenic temperature dependence of the SEFI occurrence

Outline of the presentation

- Presentation of DUT and experimental measurements under heavy ion beam
  - Device under test: ReadOut Integrated Circuit
  - Single Event Transient and Functional Interrupt measurements
- Single Event Transients in ReadOut Integrated Circuit
  - Simple Single Event Transients in pixel table
  - Complex Single Event Transients
  - Impact of cryogenic temperatures on SET occurrences
- Single Event Functional Interrupt in ReadOut Integrated Circuit
  - SEFI in video signals
  - SEFI in multiplexing functions
  - Impact of cryogenic temperatures on SEFI occurrences
- Conclusions and outlooks for radiation hardness assurance applications

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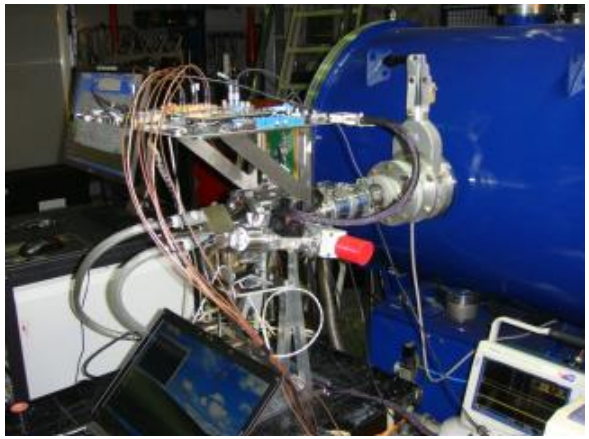
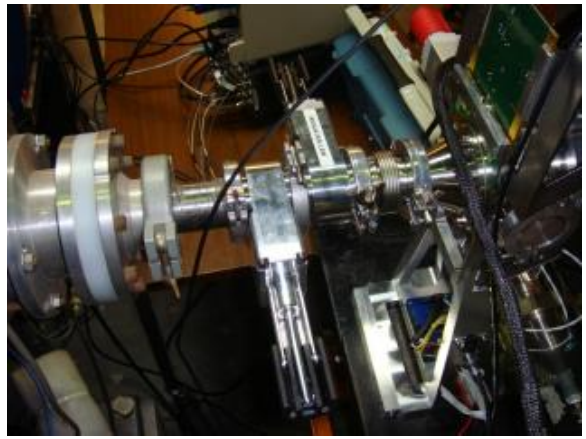
Experimental irradiation setup

- UCL facility has been used for the heavy ions characterization
- Temperature regulation from 50K up to 300K



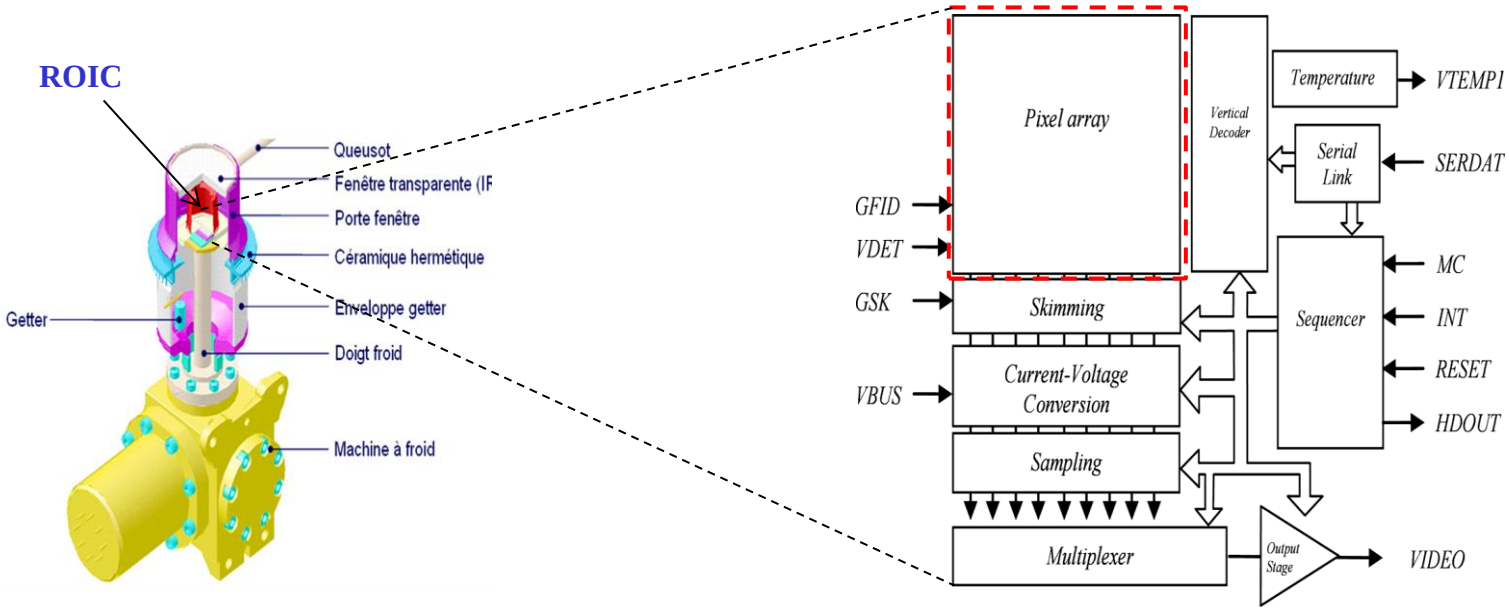


- SET, SEFI and SEL events are monitored during the irradiation runs
  → No SEL have been observed

Device Under Test: ROIC

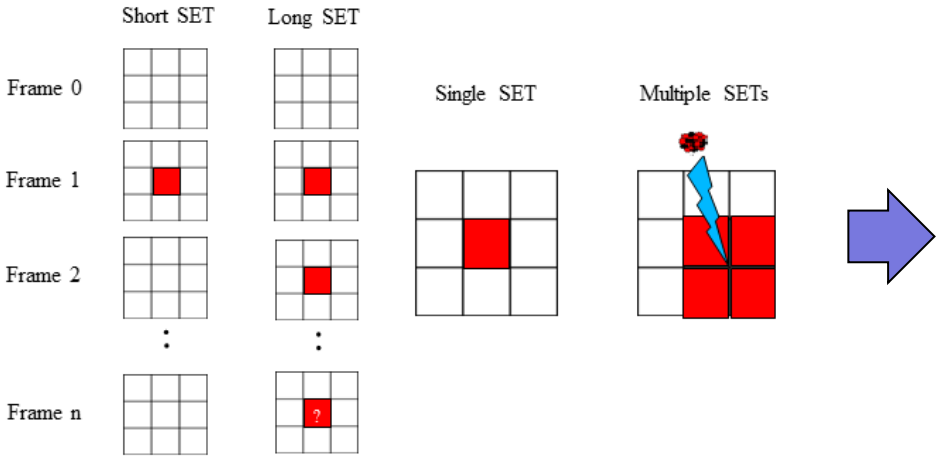
- 2 ROIC designs in silicon without the hybridation of the MCT circuit are investigated under heavy ions beams:

DUT	Sample number	Supply voltage	Total number of pixel	DUT
ROIC A (IR)	Sample A1 Sample A2 Sample A3	5V	2768	ROIC A (IR)
ROIC B (NIR)	Sample B1 Sample B2 Sample B3	5V	2768	ROIC B (NIR)

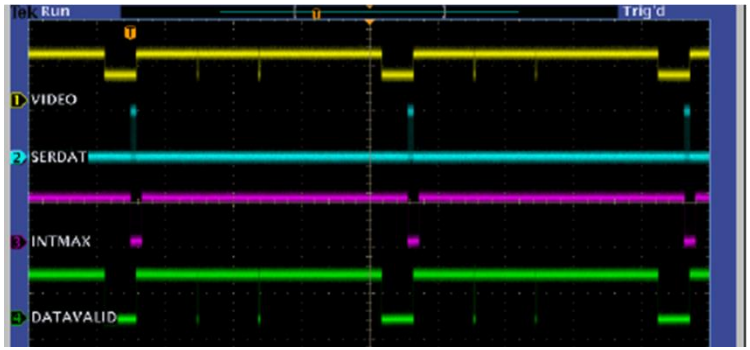


Single Event Effects detection

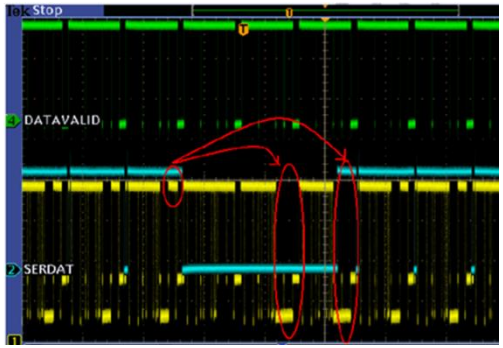
- SET and SEFI signatures have been observed



SEE type	Duration 1 frame	Duration >1 frames	Location	On/off cycle Needed
Simple SET	X	X	Pixel table	-
Complex SET	-	X	Pixel table / decoders	-
SEFI type 1	-	X	MUX / registers	X
SEFI type 2	-	X	Registers/adjacent control cells of video signal	X



Reference Level



SEFI occurrence

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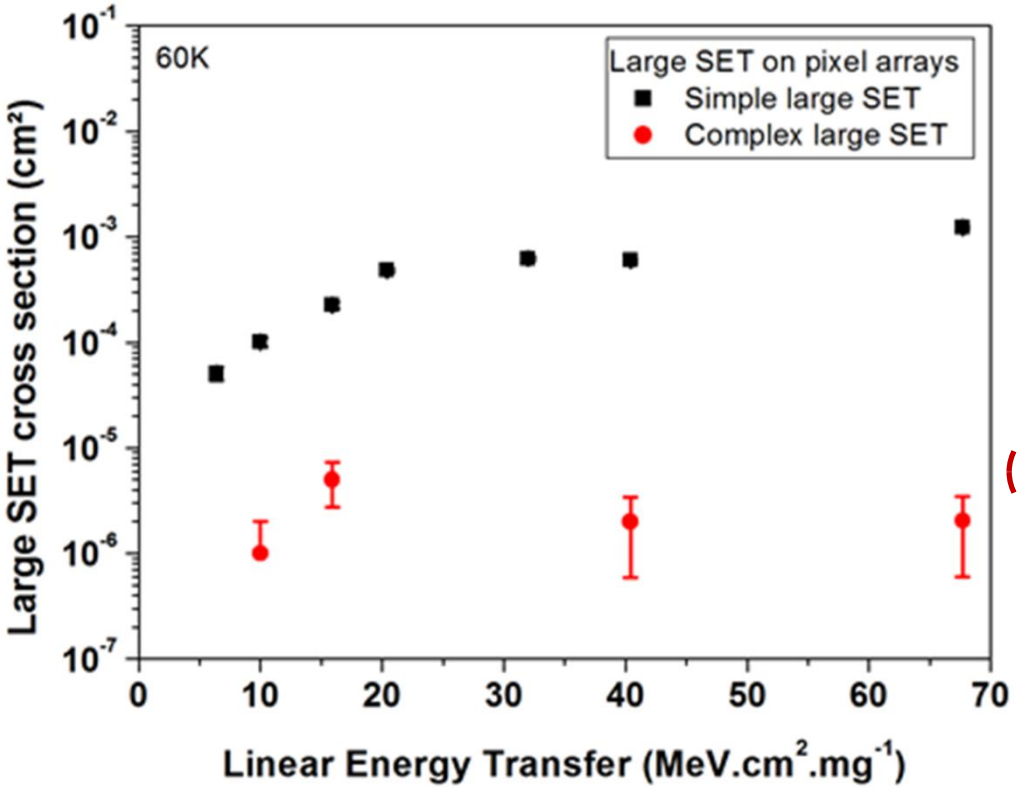
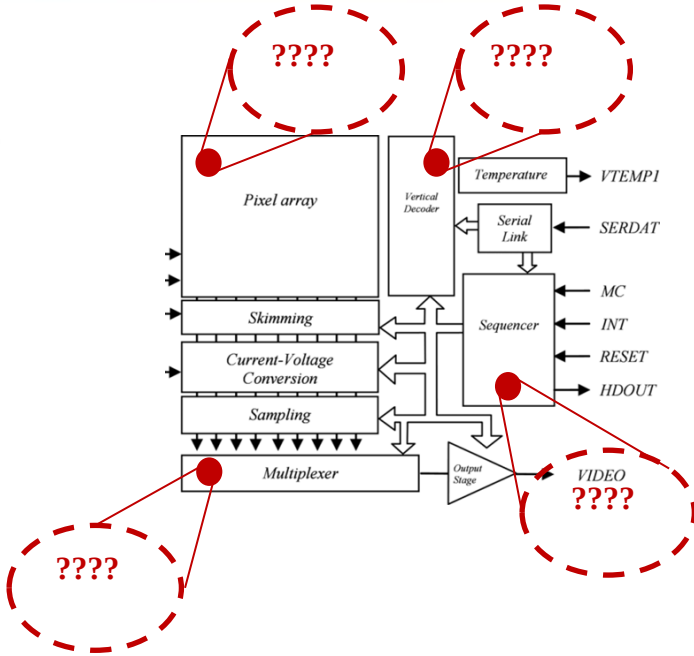
Single Event Transients in ROIC

- Simple versus complex SETs in ROIC





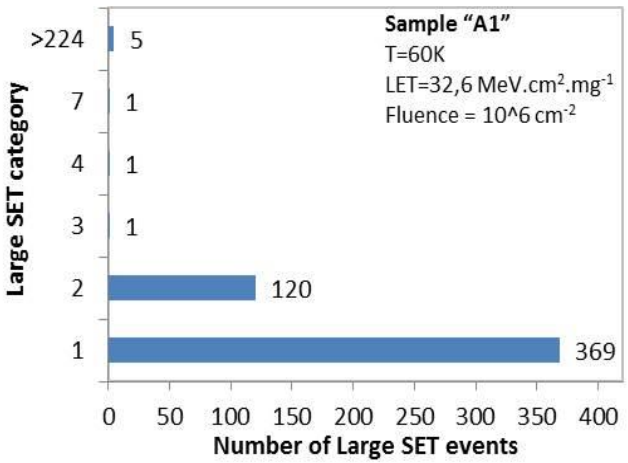
Video signal recovers its reference level without any on/off cycle

Complex SETs are rare but critical for the ROIC reliability

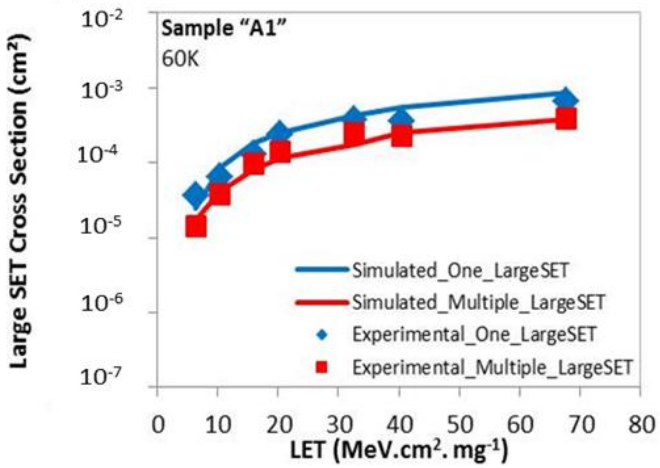
Single Event Transients in ROIC

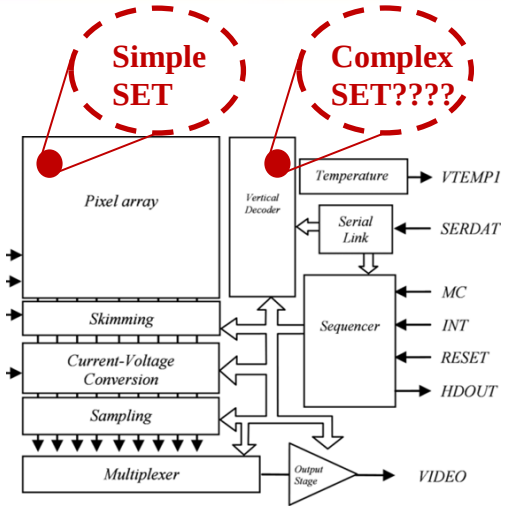
- Multiplicity of simple SETs in ROIC

Experimental analysis
SET histogram



Simulations of SET

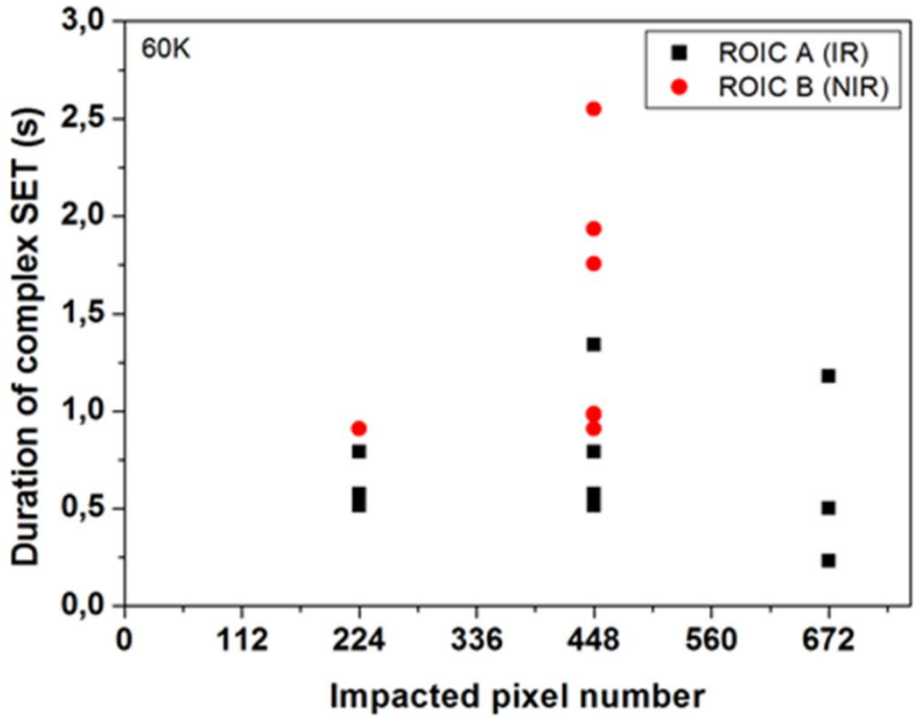


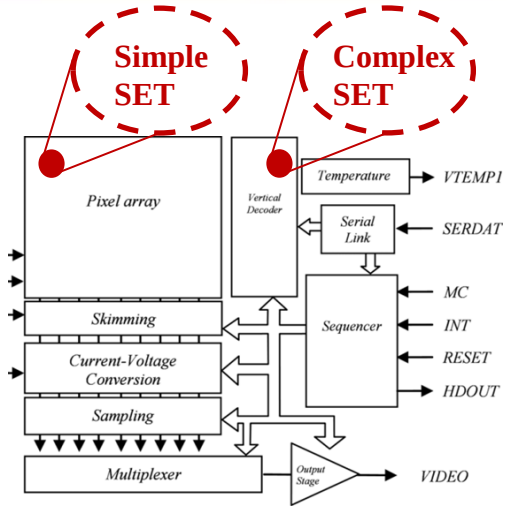


- SETs with a multiplicity up to 2 pixels represent the main contribution
- Simulations of SET in pixel array confirm the origin of simple and double SET
- Complex SET (multiplicity > 224) should be issued from other digital modules of the ROIC

Complex Single Event Transients in ROIC

- Characteristics of complex SETs in ROIC





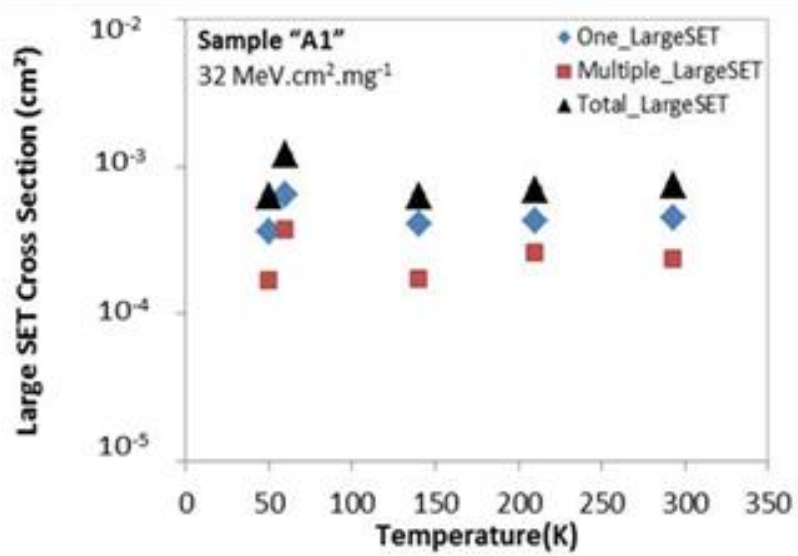
Multiplicity of complex SETs correspond to the number of lines of pixel arrays in the ROIC→ Complex SETs occur on row decoders of pixel array

Complex SETs can induce very long durations of video signal inoperability

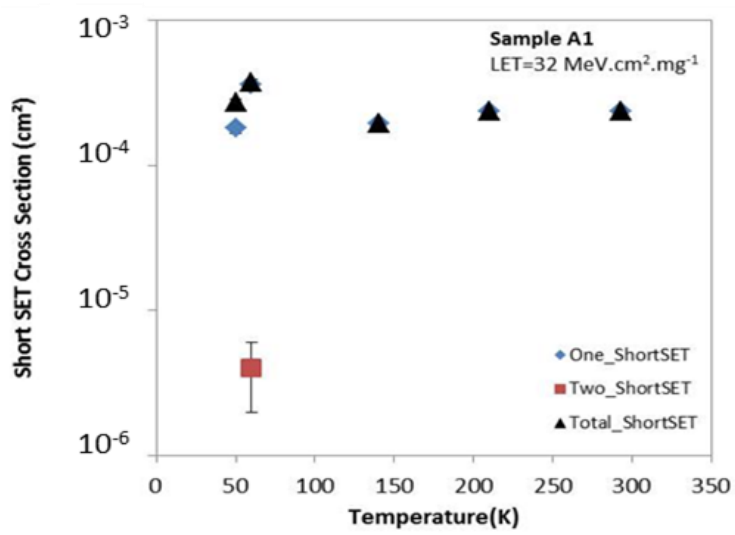
Single Event Transients in ROIC

- Impact of cryogenic temperatures on SETs in ROIC

Large SET



Short SET



No impact of cryogenic temperature on SET what ever the duration

Same trend for IR and NIR ROIC ("sample A" and "sample B")

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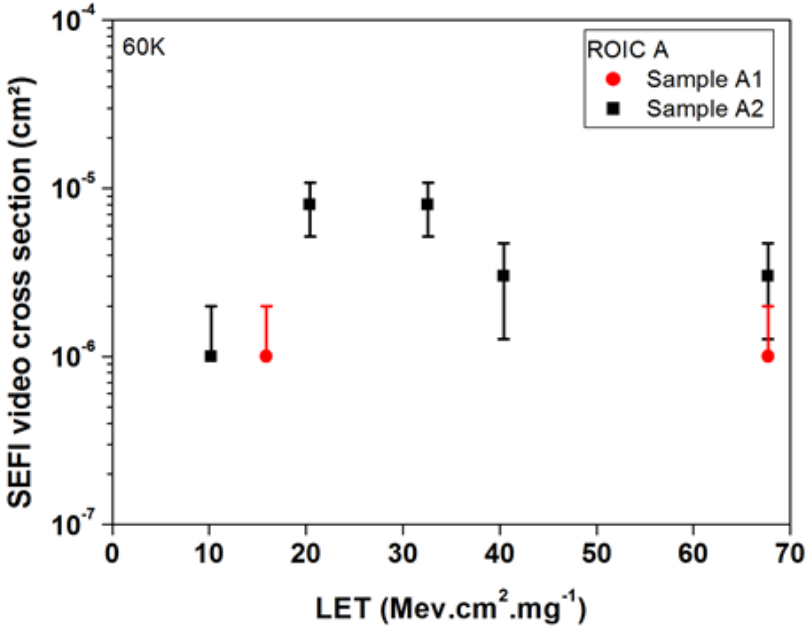
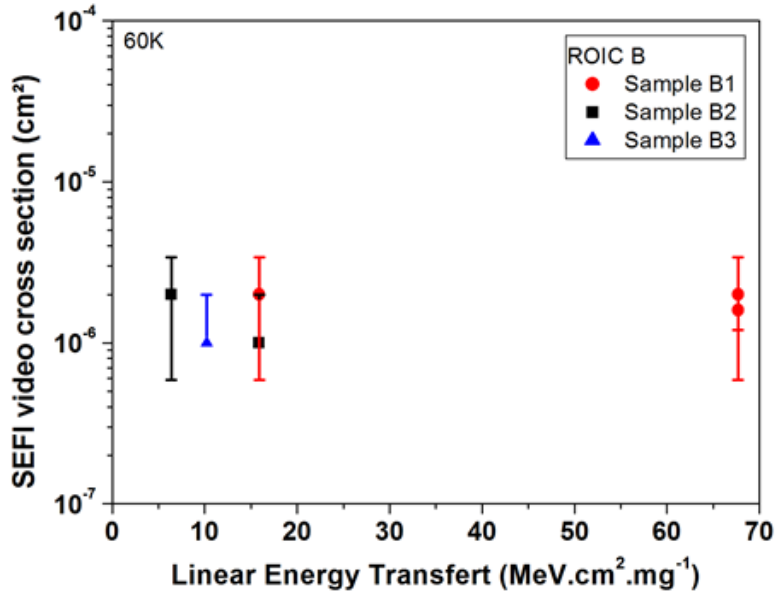
SEFI occurrence in ROIC (1/3)

- SEFI video in IR and NIR ROICs at cryogenic temperatures

IR ROIC



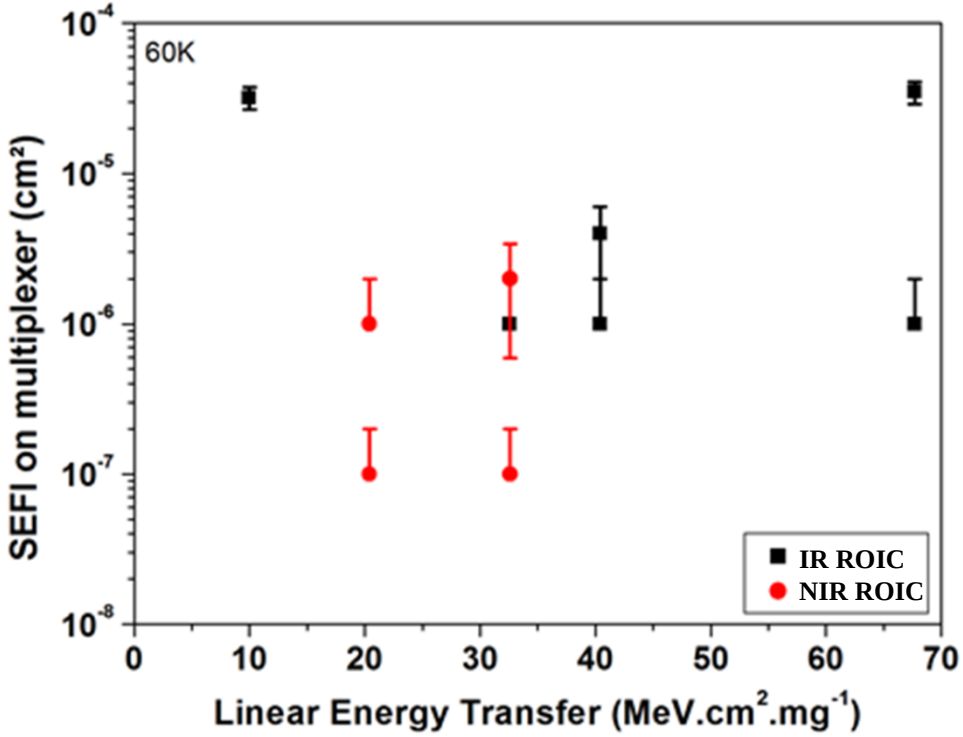
NIR ROIC

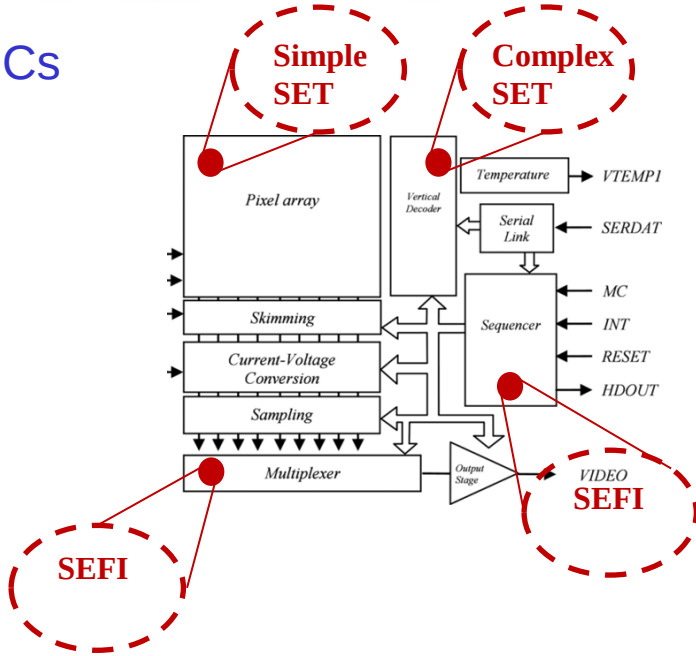


- Strong SEFI robustness
- Low sample to sample variability of the SEFI sensitivity for the two ROIC designs
- Very similar SEFI sensitivity for the two ROICs: IR and NIR

SEFI occurrence in ROIC (2/3)

- SEFI on multiplexing functions of IR and NIR ROICs



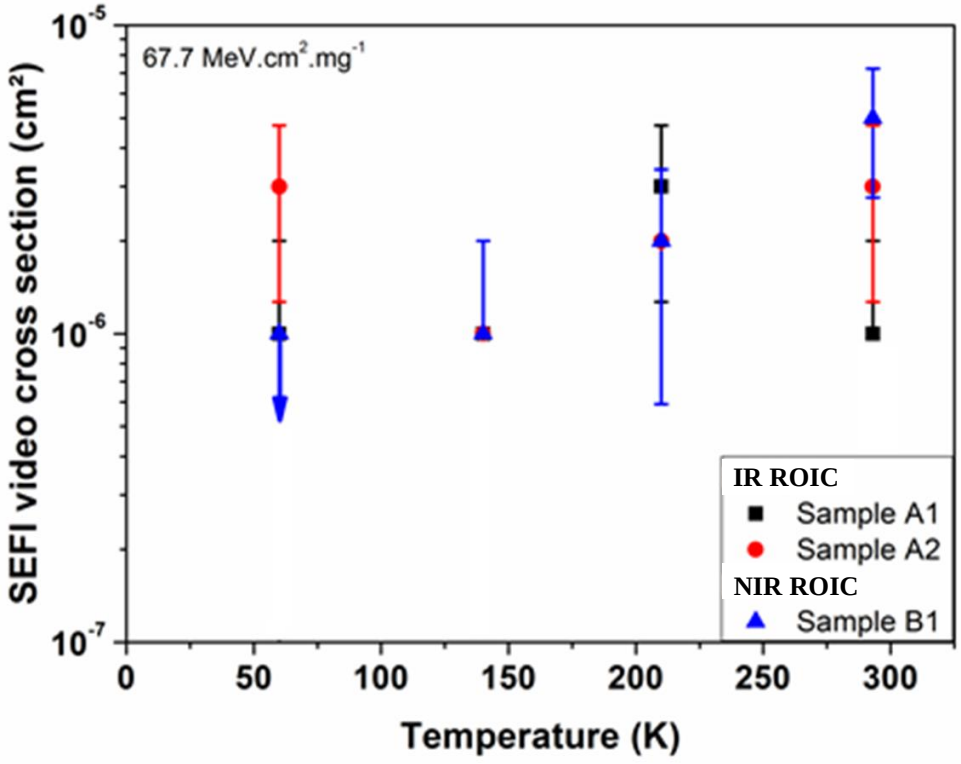


Design of NIR ROIC is quite lower sensitive to SEFI than the design of IR ROIC

Effect of the frequency ? Design ?

SEFI occurrence in ROIC (3/3)

- Cryogenic temperature impact on SEFI video occurrences



Low temperature dependence of the SEFI occurrence at cryogenic range (as observed for SEU for DFF [2]

[2] L. Artola et al, IEEE Trans, Nucl. Sci,, vol. 62, no. 6, pp. 2979 – 2987, Dec. 2015

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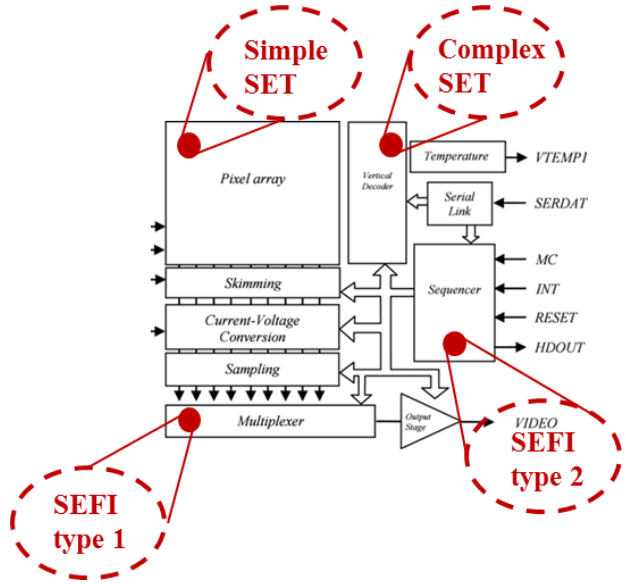
Conclusions

- The SEE (SET/SEU/SEFI) robustness of Sofradir ROICs is compliant with the ESA project
- The Multiplicity of SET is many due to the location of the event:
  - [1-2]: Pixel arrays (up to 4 as a function of pixel pitch)
  - >hundred: ROIC's logics such as row decoder
- Complex SETs can induce very long durations of video signal inoperability
- Low temperature dependence of SET and SEFI occurrence → Relevant with previous works dedicated on SEU analysis in DFF [1][2][3]



→ Potential update in SEE radiation hardness assurance for cooled infrared systems ?

[1] L. Artola, et al, IEEE Trans, Nucl. Sci,, vol. 62, no. 6, pp. 2979 – 2987, Dec. 2015
[2] A. Al Youssef, et al, IEEE Trans. Nucl. Sci., vol. 65, no. 1, pp,119 – 215, Jan. 2018
[3] L. Artola, et al, IEEE Trans. Nucl. Sci., vol, 65, Early Access

Outlooks: SEE RHA update for IR device ?

- **SEE Radiation tests** (proton/heavy ions) of IR sensors/ROIC are done at functional temperatures [50-100K] as mandatory by ECSS basic specification No 25100

- **Tests and measurements of cryogenic temperatures** require complex equipment and induce strong constraints →**Cost and timing consuming** for the space ROIC development project

Works done since 2013:

→ **Measurements** on several designs of ROIC, and several designs of Flip-flops test-chips showed the **limited impact of cryogenic temperature on SEE sensitivity**

→ **Simulations** with Monte-Carlo radiation tool (MUSCA SEP3) coupled with Transient ERRor injection Framework for Integrated CMOS (TERRIFIC) confirm the same effect at gate and system level

→ Future SEE test of ROIC of IR sensors could be done at room temperature