DE LA RECHERCHE À L'INDUSTRIE

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Development at Lynred and CEA of very low flux SWIR detectors for astrophysics and space applications: final status of ALFA and ASTEROID programs

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    1. General context
    2. ALFA requirements
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    1. Dark current
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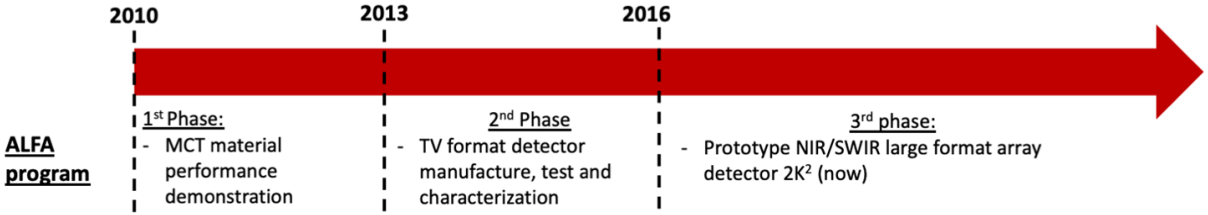
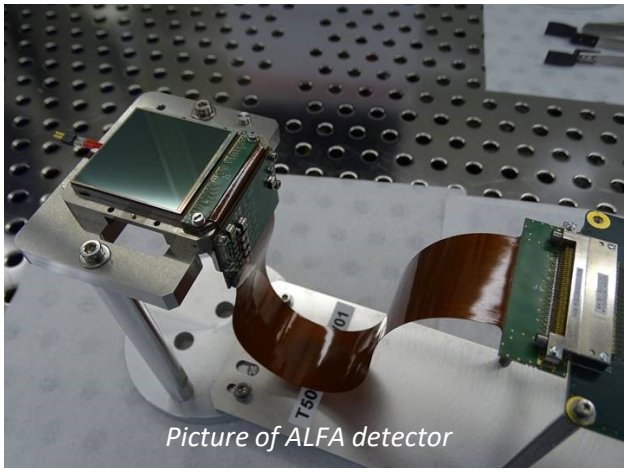
    3. General comments on ROIC problems
4. Persistence
5. ASTEROID program: Lynred SWIR PV layers
6. Final conclusions

Goal: equip Europe with high performance large format IR detectors for space applications and astrophysics

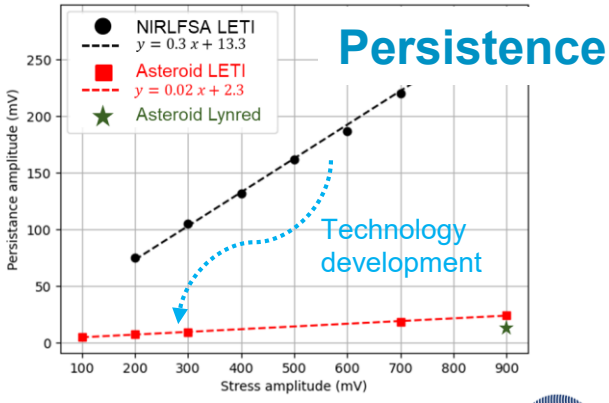



Picture of ALFA detector

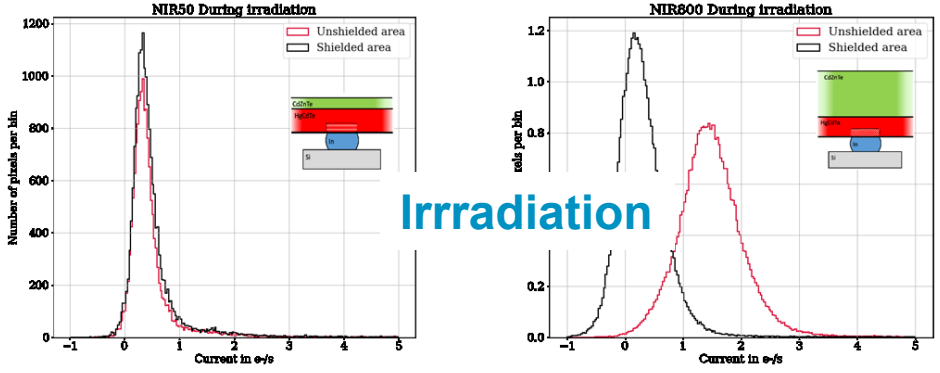
- **ALFA Development:** Lynred (ROIC + Hybridization) + CEA-Leti (PV)
- **Characterisation:** Astrophysics Department, CEA
- **Funding:** ESA, FOCUS

➔ TV format detectors of phase 2 have been extensively studied.

Persistence:
Persistence amplitude as a function of electrical stress amplitude measured on detector from different phases.



Irradiation: influence of the remaining substrate on the measured dark current under proton irradiation



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ALFA detector specifications: very similar to H2RG.

Parameter	Value
Dimension	
Number of pixels	*2048x2048*
Pixel pitch	*15x15 µm*
Number of outputs	*32 (Readout available through 1, 2, 4, 8, 16, 32)*
Reference Output	*1*
Performance	
Charge handling capacity	*≥ 60ke-*
Cutoff wavelength	*2.1 ± 0.05 µm*
QE	*> 70%*
Dark Current	*< 0.1 e-/s/pix at 100 K*
CDS readout noise	*18 e-*
Operation	
Reset	*Line by line, pixel by pixel, global reset, single pixel reset*
Readout rate	*Science: 100 kHz (pixel readout per channel)* *Fast mode: 5 MHz (pixel readout per channel)*

In total **4 detectors** were fabricated:

- 4 are operable
- 2 have good PV layer → The best one will be used inside the CAGIRE instrument (see A. Nouvel de la Fleche presentation on Friday)

→ Today's presentation will focus on this detector.

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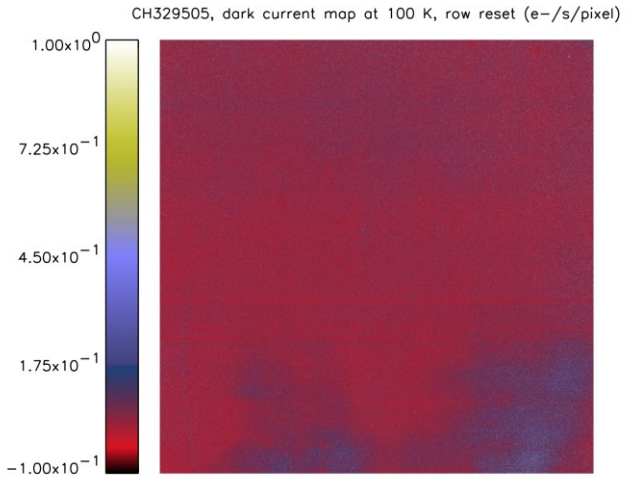
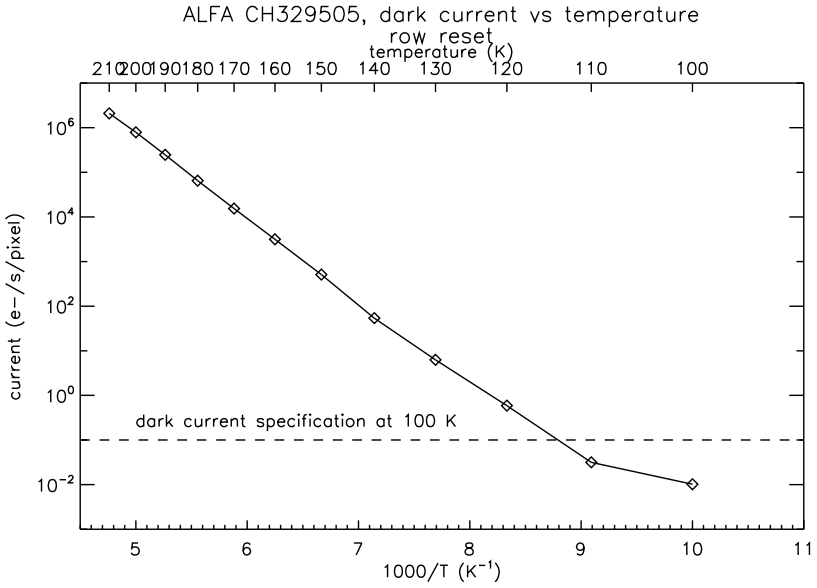
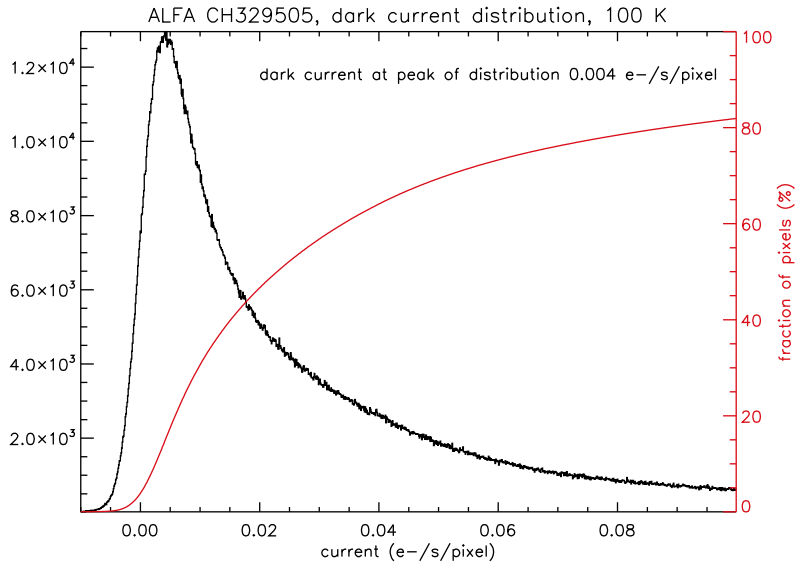
Dark current measurement:

- Dark current measurement at 100K is 20h long
- Peak of the distribution is equal to **0.004 e-/s/pix**
- Operability at dark at 100 K is equal to 95% (dark current < than 0.5 e-/s/pix)



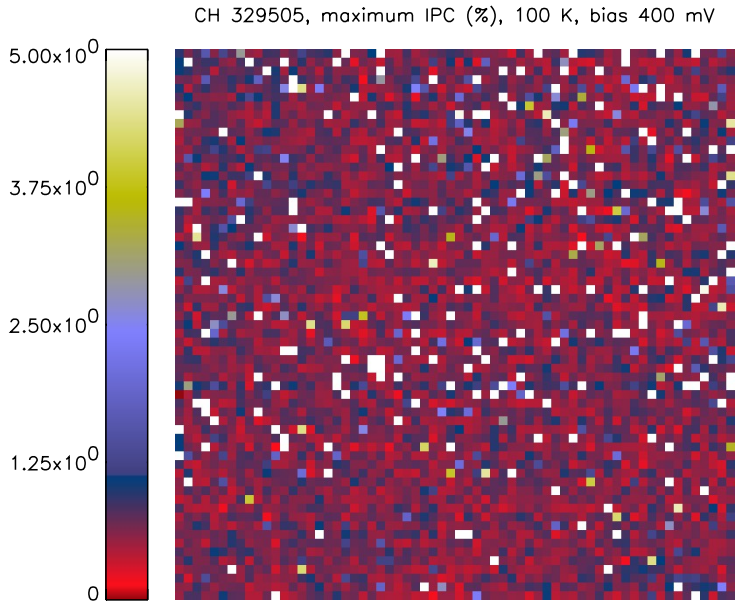


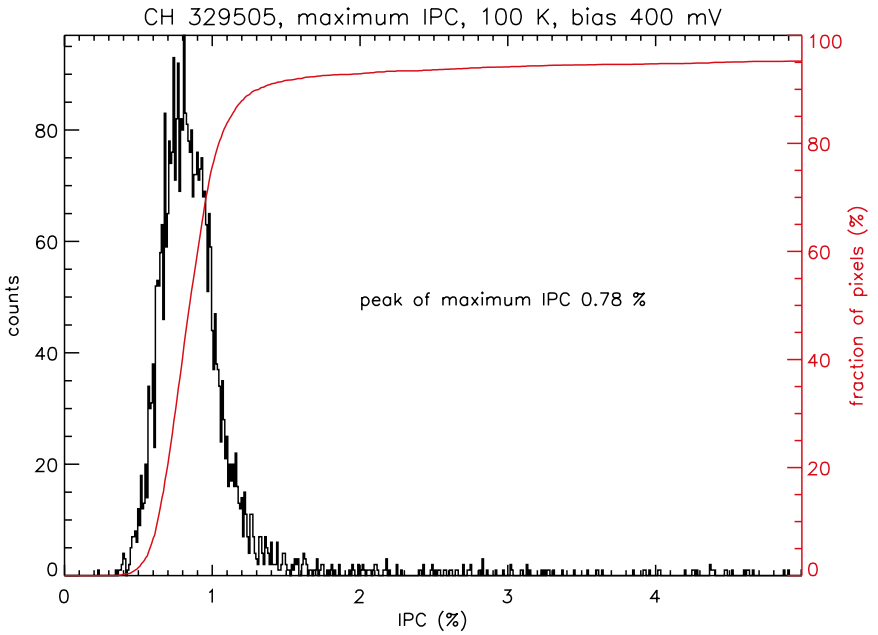


Crosstalk

- IPC measured for ALFA device, using 4096 IPC pixels (using of a dedicated mode the ROIC)
- IPC is equal to 0.8% for CH329505. The IPC is very good

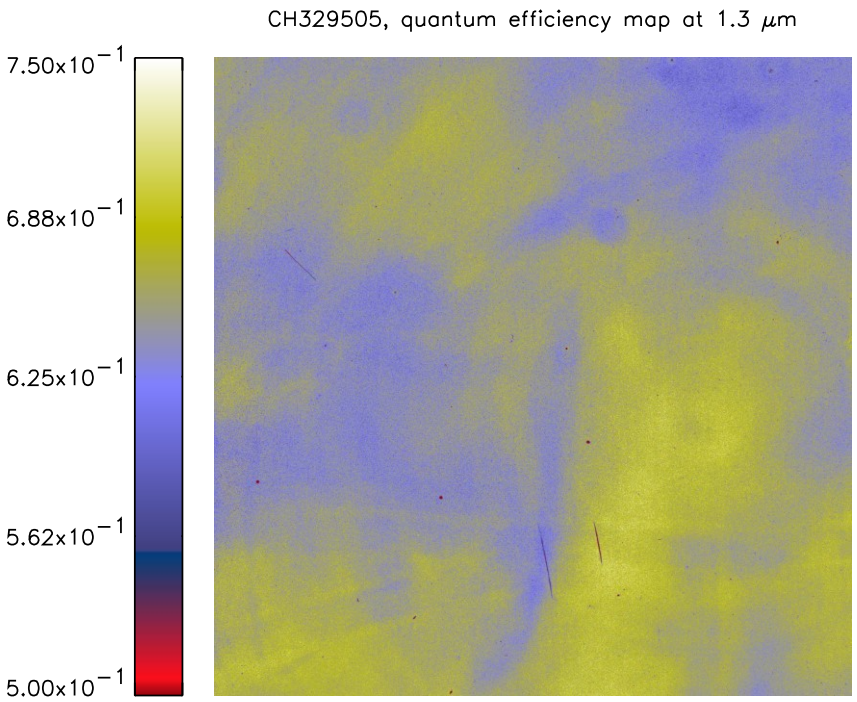
⇒Average corrected total capacitances is 67.1 fF for CAGIRE detector.





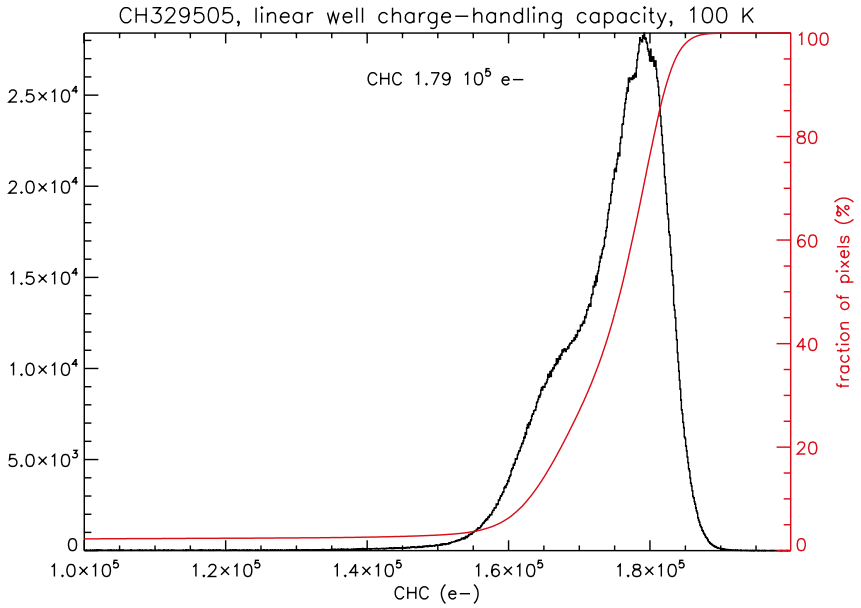
Pixel response non uniformity:

- At 1.3 µm, the PRNU is 5.3%.
- Close to the cutoff wavelength, the QE map changes. The PRNU at 2.05 µm is 6.7%.
- Operability under flux is 99%

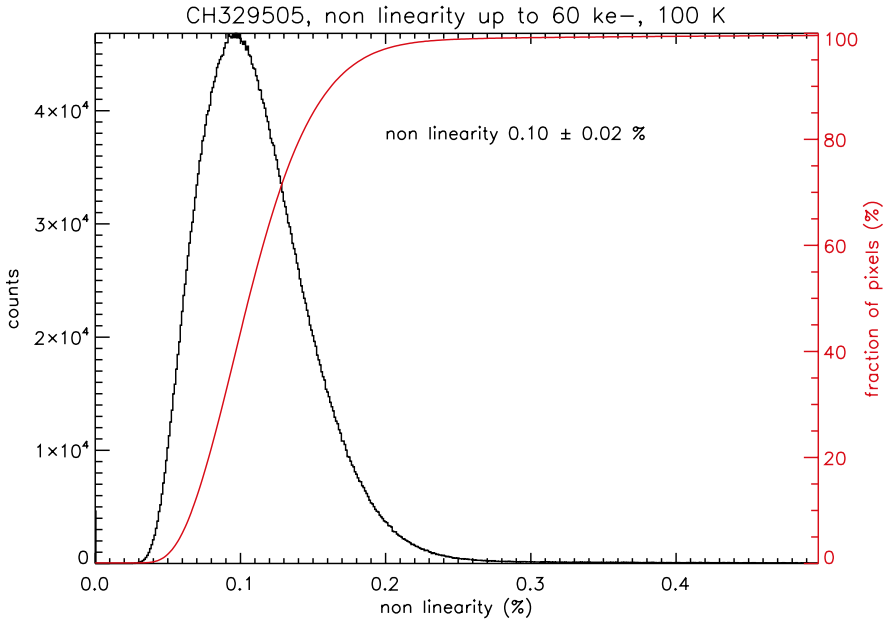


Detector demonstrates very good linearity:

- Charge handling capacity is equal to **179 000 e-**. Defined as the signal level where non linearity exceeds 3%.
- Non linearity is equal to 0.1% at 60 ke-.



Full well requirement



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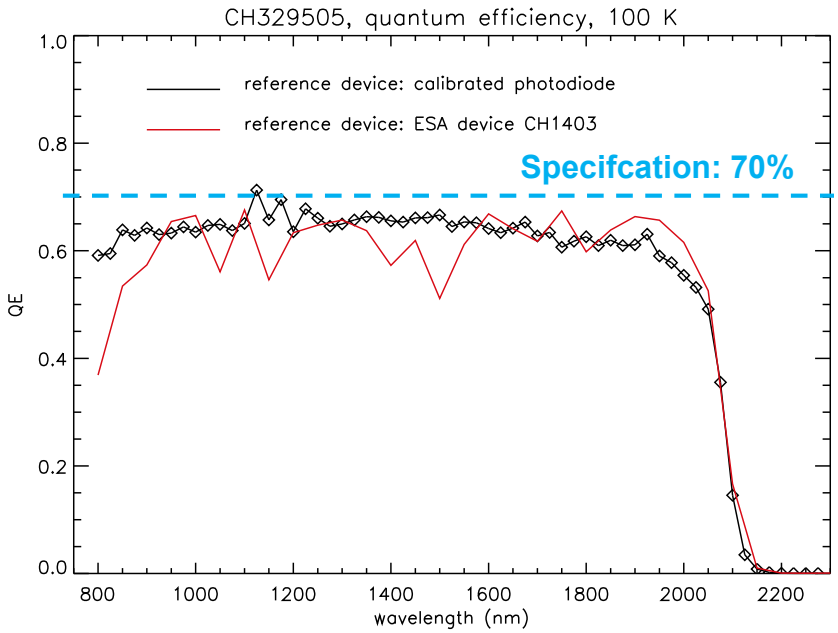
3. WHAT DOES NOT WORK SO WELL
1. QUANTUM EFFICIENCY

The **Quantum Efficiency (QE)** of the detector has been measured on Quantix test bench, with two methods:

1. With the calibrated photodiode (FOCUS, CEA/LETI)
2. With the ESA reference device 1403 (manufactured by CEA/LETI)



<u>QE measurement results:</u>

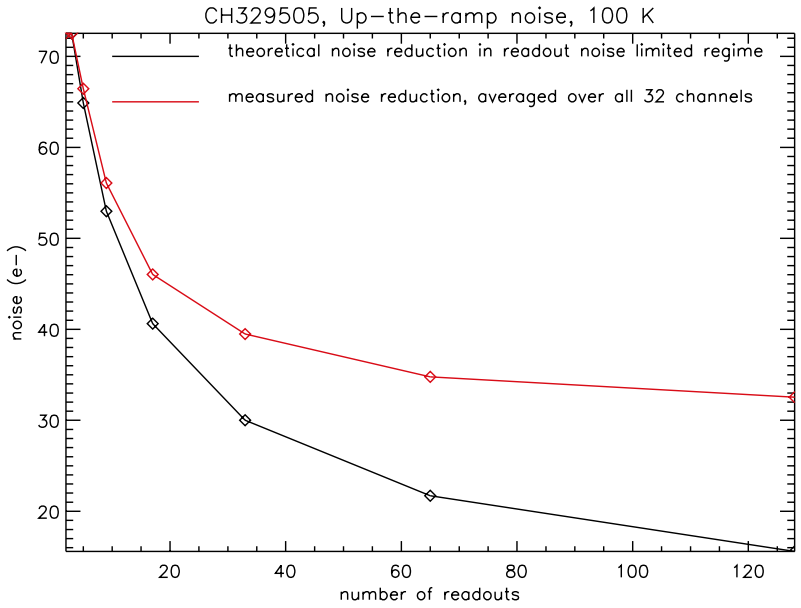
- QE is flat around 60%
- Cut off wavelength: **2.075 µm**
- 12 % uncertaintity on QE measurements (dominated by measurements of the photodiode current)

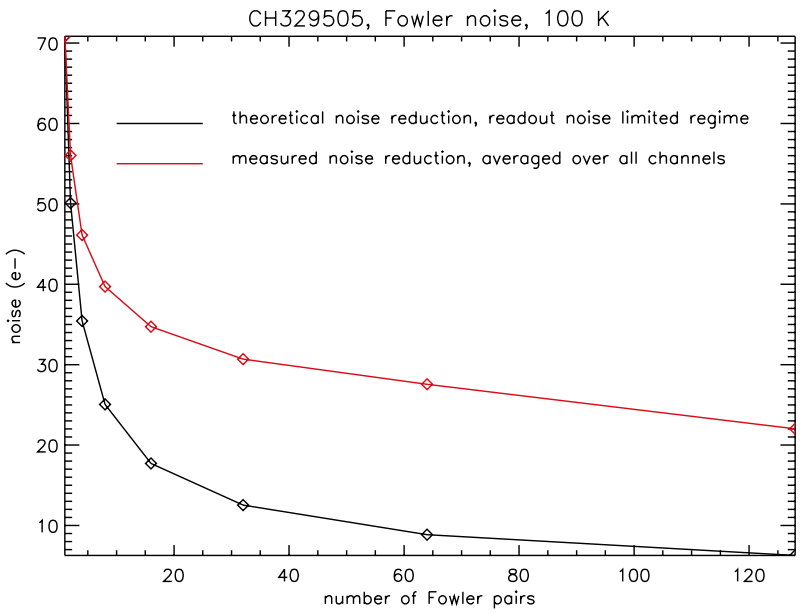
Readout noise

- 100 CDS images acquired
- CDS noise of the detector alone is equal of 60 electrons (**ALFA specification 18 e-**)
- Total CDS noise (detector + acquisition chain) is equal to 72 electrons

FUR noise reduction and Fowler reduction.

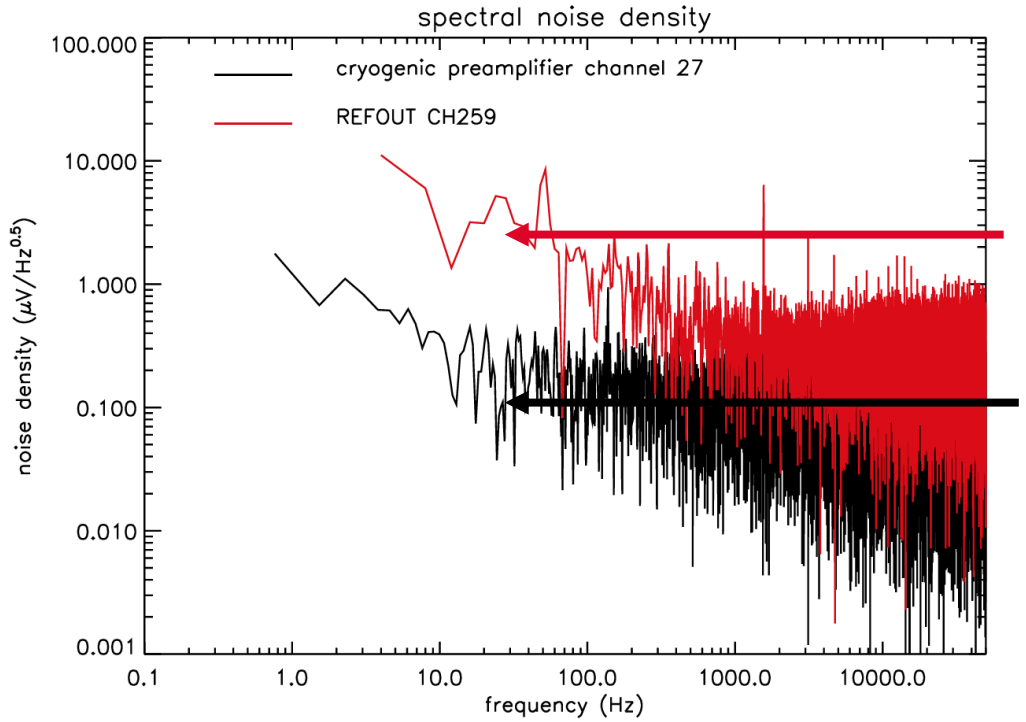
- 100 ramps acquired with 256 images under dark conditions (readout noise limited regime)





Noise spectral density

- Strong 1/f noise is visible
- Different tests have been performed with no effect such as: use external current source, use of very low noise power supply instead of NGC ones, improve grounding, filtering biases.
- The noise has been studied as a function of the two bias voltages used to drive the two stages of source followers. No significant variation has been observed.



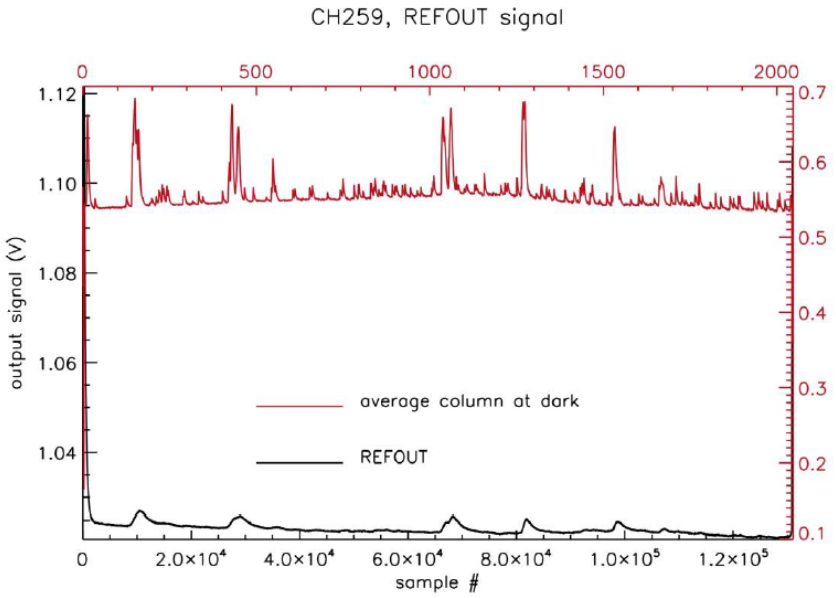
Integral of noise spectral density:
98μV for the reference output

Integral of noise spectral density:
28μV for acquisition chain (lowest value).
The mean acquisition chain noise is equal to 58.4μV (calculated over 32 channels).

There are multiple issues identified with the ROIC:

1. Some of them can be solved with metal fix
2. Some of them require a 2nd version of the ROIC

Example: Separate reference output signal is correlated with sensitive pixel signal.



Example: Dark current map depending on the reset pattern.

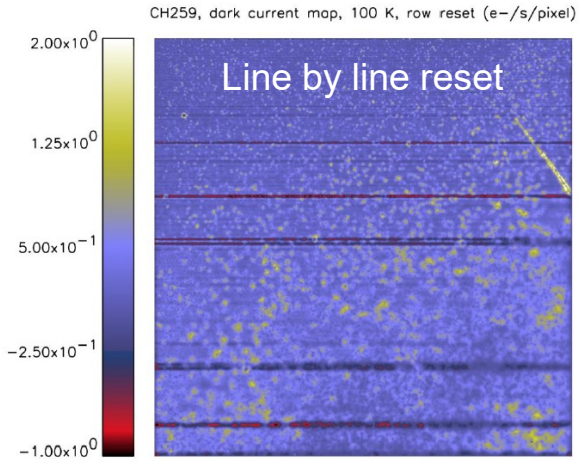


Figure 21 Dark current map of device CH259 at 100 K. row reset

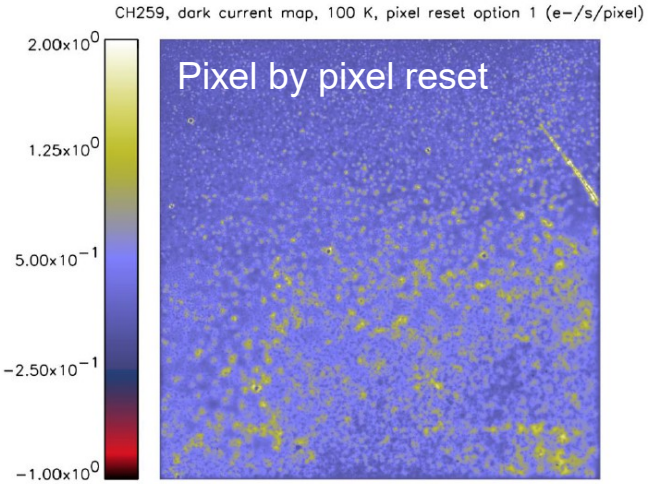


Figure 22 Dark current map of device CH259 at 100 K, pixel reset option 1

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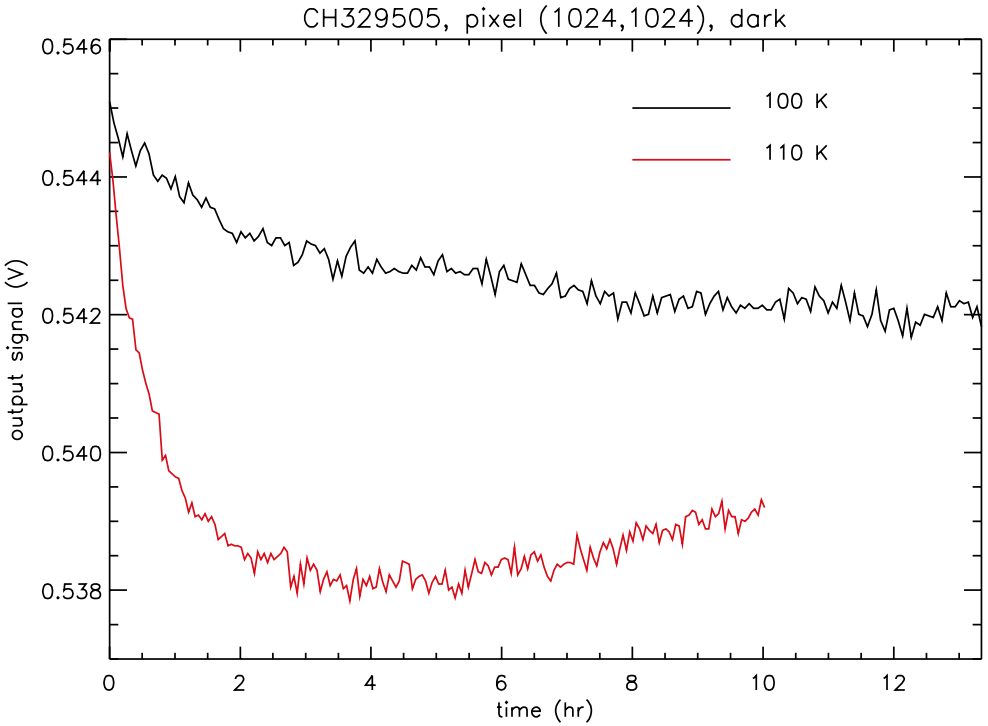
Electrically stimulated persistence induced by reset

- Very long settling time at dark at Tdet ≤ 110K

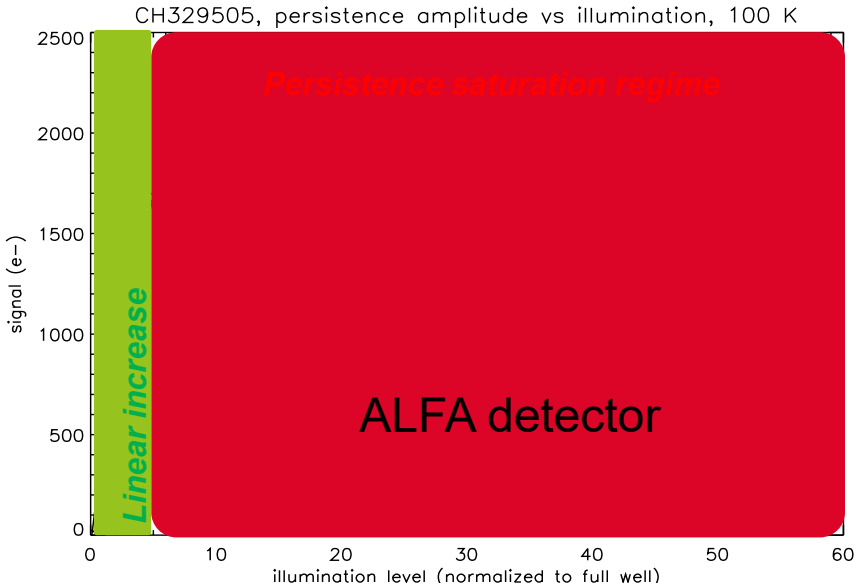
⇒ Duration of dark current measurement at 110 K > 10h, at 100 K > 20 h…



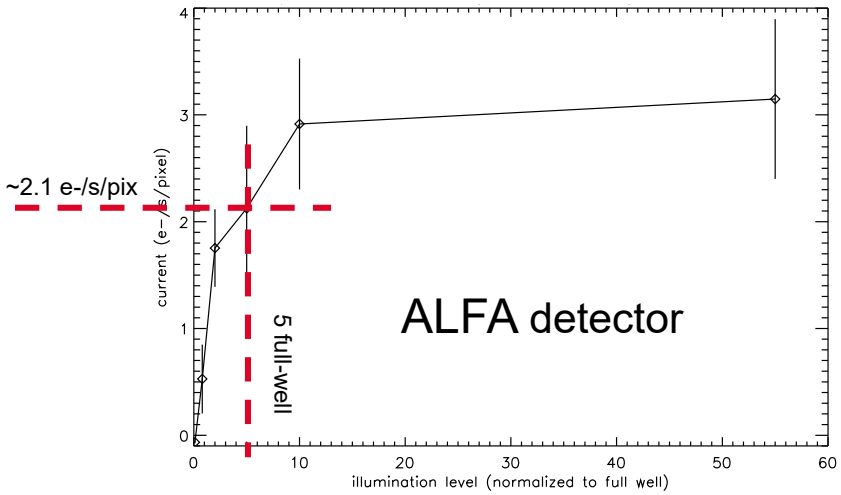
➔ The reset seems to be highly disturbing. It induces very long perturbations of the detector

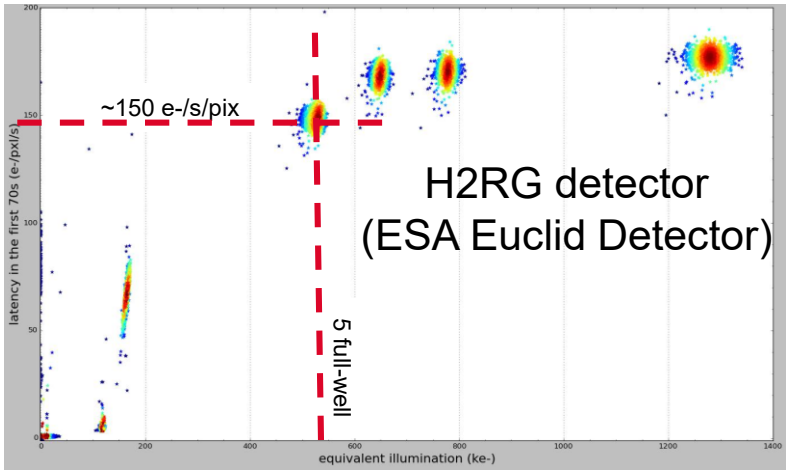
Optically stimulated persistence

- Persistence has been measured as a function of illumination level.
- Measurement protocol:
  1. Dark reference
  2. Optical flash
  3. Persistence measurement
- Analysis protocol
  - Fit with 3 exponentials with a dark current contribution



Persistence current 70s after reset





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ASTEROID: **AST**ronomy **E**u**RO**pean **I**nfrared **D**etection

- **Funding** :
  - European Commission
- **Development**:
  - Lynred (PV, 1st SWIR PV layer dedicated to very low flux applications) and CEA-Leti (ROIC)
- **Characterisation :**
  - Astrophysics Department, CEA
- **ASTEROID Specifications:**
  - ALFA like technology, HgCdTe-based IR detectors
  - 640x512 with a pixel pitch of 15µm.
  - **Spectral domain 0.8µm to 2.1µm.**
  - **Dark <0.1 e-/s/pix at 100 K**

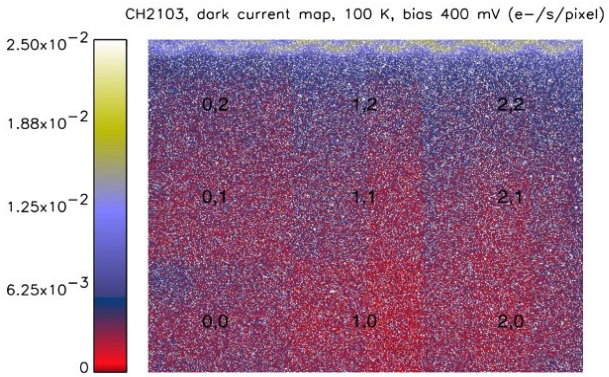
ref. LETI	Type	Characterized at DAP
21-09	Monovariante	

ref. LETI	General performance
21-03	Very good
21-08	Very good
21-09	Very good
21-02	Polluted by glow
21-04	Polluted by glow
21-06	Bad

9 detectors manufactured
→ 7 delivered at CEA-Dap
→ 6 characterized

6. ASTEROID PROGRAM: LYNRED SWIR PV LAYERS
6.1 DETECTOR 2108

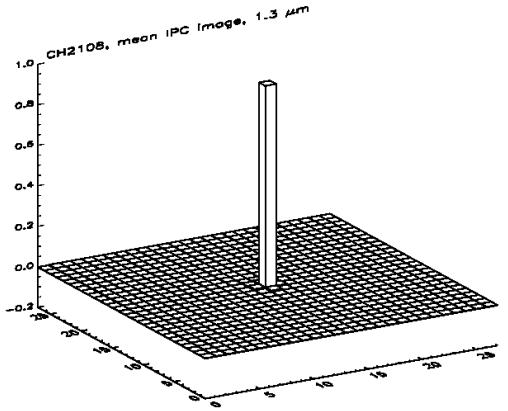
Dark current at 100 K



Median dark current < 0.005 e-/s/pix

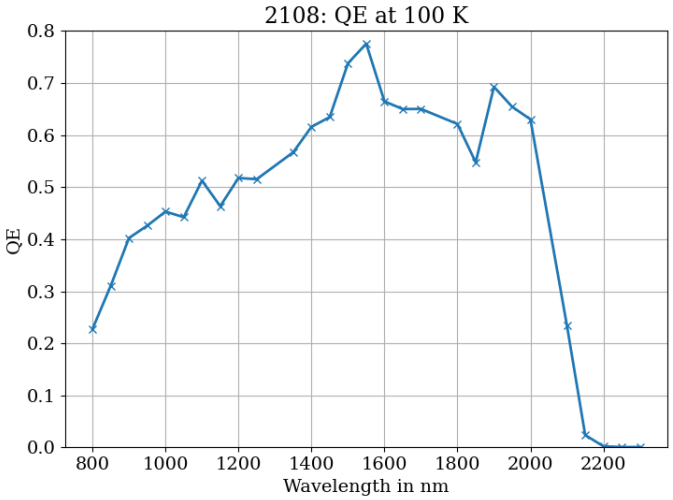
Despite glow mitigation protocol, glow of the output amplifier is still visible.

IPC kernel at 100K



Total IPC 2.3 %

Quantum efficiency at 100 K



- Cut off wavelength: **2.05 µm**
- 12 % uncertaintity on QE measurements (dominated by measurement of the photodiode current)

The **Pixel Response Non Uniformity (PRNU)** at 1.3 µm is very good, **around 2% for all diode technologies**: for each diode technology, the photonic current in each corresponding subarea of the array was normalized to its mean value.

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7. IN A NUTSHELL

Lynred and CEA-Leti demonstrate rather good PV layer manufacturing capability
…but lots of ROIC problems

Detector	EUCLID H2RG detector, 2.3 µm cutoff at 100K	CEA/LETI CH1403 (ESA ref for Quantix, 1st phase of ALFA program)	ASTEROID: Lynred CH2109	ASTEROID: Lynred CH2108 Detector with different diode geometries	ASTEROID: Lynred CH2103 Detector with different diode geometries	ALFA: CEA/LETI CH329505 (Detector CAGIRE)
IPC (%)	**2.1-2.6**	2.4	2.5	2.3	To be measured	2.3
QE	**~80 %**	~80 %	To be measured	max 75 %	To be measured	60 %
Dark current at 100 K in e-/s/pix	**0.0052 (Phd Serra B.)**	~1 (polluted by glow, to be remeasured)	0.004	0.003-0.006	0.002-0.005	0.004

The results are highly encouraging, but further improvement would require:

1. 2nd version of ROIC
2. Additionnal manufacturing of ALFA detectors to improve statistics