PERFORMANCES OF CAGIRE

ALIX NOUVEL DE LA FLÈCHE

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cnes
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LYNRED
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irap
astrophysique & planétologie

OUTLINE

- Context :
  - Scientific context
  - Detector specificities and CAGIRE requirements
  - Detector development and characterization strategies

- Performances of the 4^{th} detector :
  - Readout noise
    - Measurement of the noise
    - Correction strategies
  - Flux estimation
    - Method
    - Linearity computation

CONTEXT

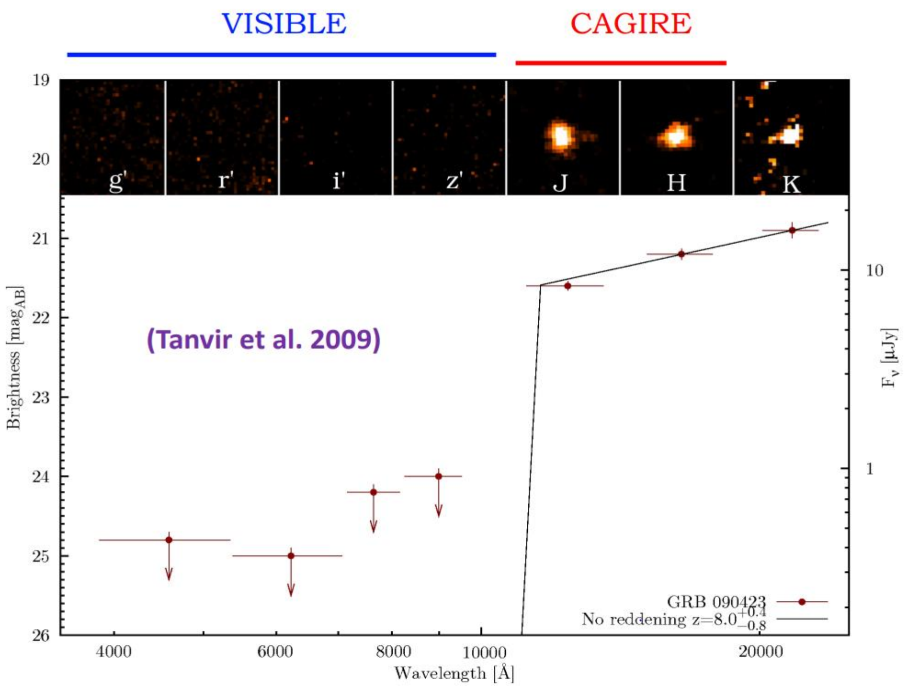
SCIENTIFIC CONTEXT

Need for the infrared

- Lyman limit = 91.2 nm : wavelength below which a photon has enough energy to ionize hydrogen atoms. This photons does not escape from the host galaxy.
- Distant observer sees only wavelengths greater than 91,2 nm (Source reference frame)
- Redshift : because of universe extension :

$$z = \frac{\lambda_{obs} - \lambda_0}{\lambda_0}$$

- The afterglow of a gamma rays burst (GRB) with a redshift >6 is detectable in near infra red only.
- Some bursts are attenuated by dust at visible wavelengths but detectable in the infrared.



Ex : Light emitted at λ_0 = 91,2 nm and received at λ_{obs} = 1,1 μm
→ Redshift z = 11 and invisible below J

DETECTOR SPECIFICITIES AND CAGIRE REQUIREMENTS

Cagire and Colibrí

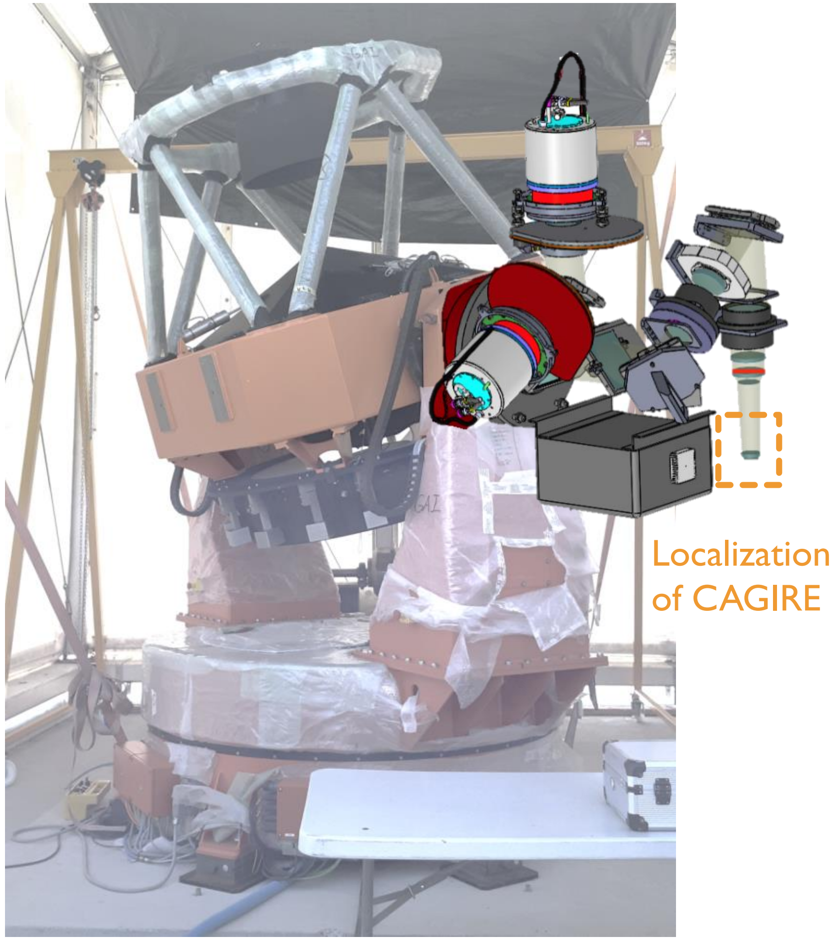
Colibri at OHP

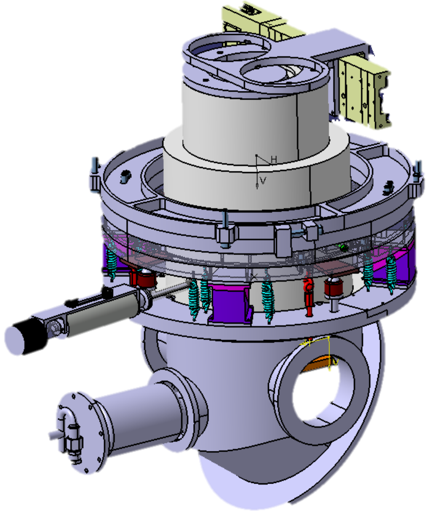
CAGIRE (CApturing GRB InfraRed Emission) :

- Located at one of the Nasmyth foci of COLIBRÍ
- Wavelengths between 1.1 and 1.8 μm → J & H bands
- Motivation : detect and monitor GRB afterglows including high redshift candidates ($z > 6$)
- Equipped with a 2k × 2k detector (Lynred) into a cryostat.

DETECTOR SPECIFICITIES AND CAGIRE REQUIREMENTS

Main constraints of operability for the telescope





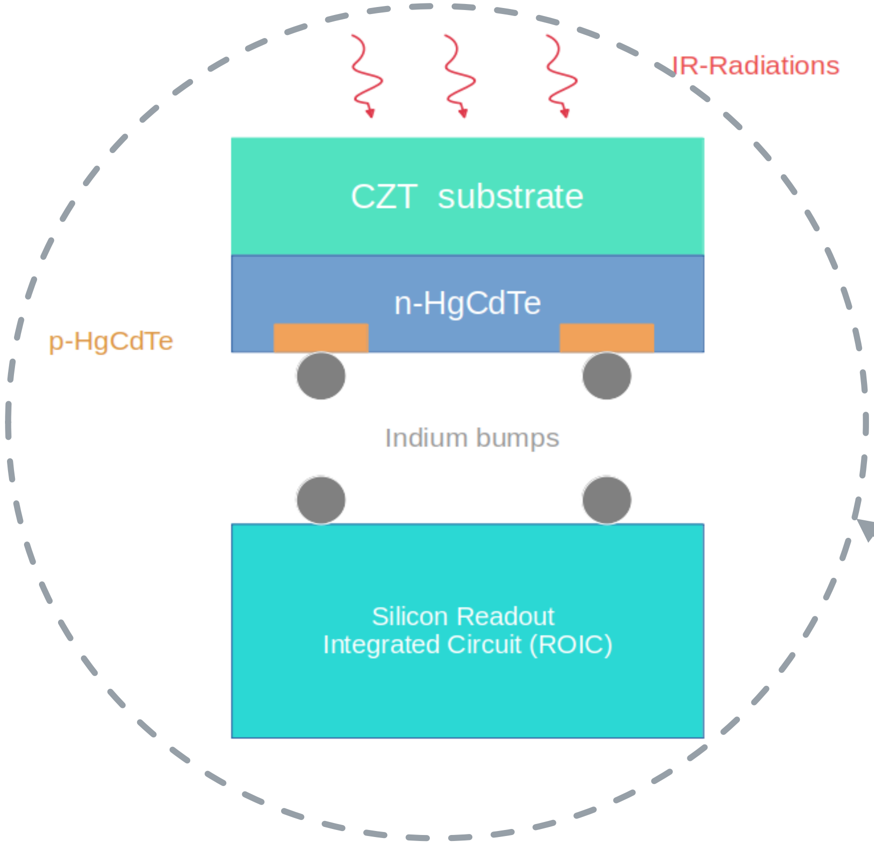
- Detector needs to operate at a stable temperature of 100K : The detector and the preamplifier are located in a cryostat.

- CAGIRE is located at the focus of COLIBRÍ, a Robotic Telescope :
    - The cryostat will be under rotation during the observations
    - Cryogenic vacuum is needed for at least 6 months (can't be under pumping)

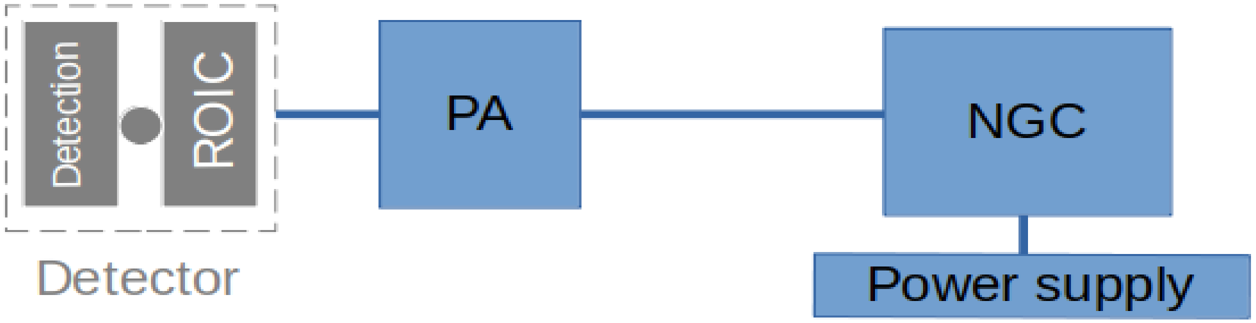
DETECTOR SPECIFICITIES AND CAGIRE REQUIREMENTS

Detection chain and detector architecture

- Detector ALFA : Astronomical Large Format Array.
- Composed of a detection layer hybridized on a readout layer (ROIC).

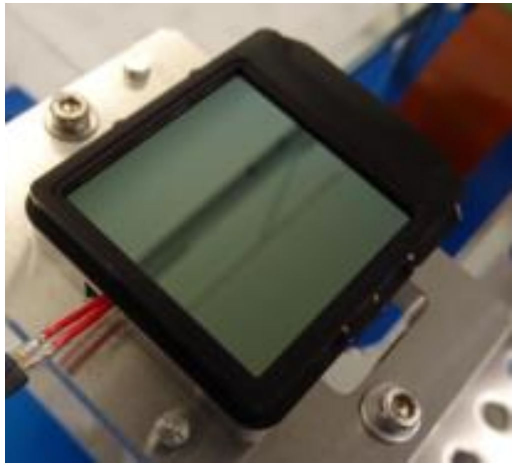


- Detection Chain composed of :
  - → The detector
  - → A Pre-Amplifier (PA)
  - → A New Generation Controller (NGC)

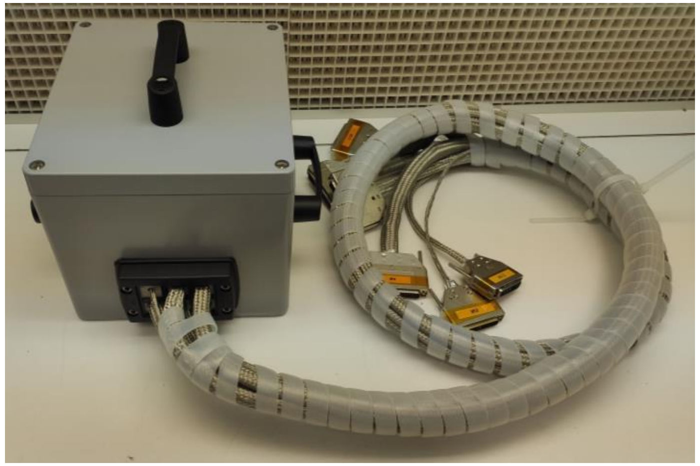


DETECTOR SPECIFICITIES AND CAGIRE REQUIREMENTS

Detection chain and detector architecture



→ Detection layer



→ ROIC + PA

→ ESO NGC

Credit : CEA (O. Boulade), IRAP (J. Boy)

PROJECT CONTEXT SUM UP

Choice of the detector ALFA by Lynred

- Lynred and CEA developed an IR Large Array detector
  - → To meet the need for the infrared technology for European project such as CAGIRE on COLIBRI
  - → To support French industry

- 4 detectors were provided by Lynred and CEA : 2 “engineering-grade” and 2 “science-grade”. One of the scientific will be lent to CAGIRE and its performances are under test.

- The characterization strategy is conducted by CEA, CPPM, IRAP and LAM

CHARACTERIZATION STRATEGIES

- March 2022
- Oct 2022
- Apr 2023
- Detector at CEA
- Tests at CPPM
- Characterization at IRAP
- Delivery in Mexico
- WOB at OAN
- Fev 2023

Detailed Characterization of ALFA detectors

CEA : Approval of the detection chain.

- According to ESA specifications

CPPM and IRAP

- Working on CEA data
- Tests with an engineering chain

Characterization of the performances of the detection chain for CAGIRE

CPPM : Reference for the detector performances

- Performances with the operating parameters

IRAP

- Test with the engineering chain

Characterization of the camera CAGIRE

IRAP :

- Integration of the camera
- Characterization of the complete camera.

PERFORMANCES ON THE 4TH DETECTOR

Detector n° 4 : CH329505 (lot n°3)

DATA UNDER STUDY

Origin of the data

- CEA : with the whole detection chain

Name	Det n°	Illumination ?	Reset type	Nb of frames	Exposure time
test_dark_100K_pixel_reset_tint_360.fits	4	Dark	Pixel	200	360s
linearity_100K_BB390K_row_reset.fits	4	Illumination	Line	200	UTR (every 1,3s)
linearity_100K_BB390K_pixel_reset_option2 .fits	4	Illumination	Pixel	200	UTR (every 1,3s)

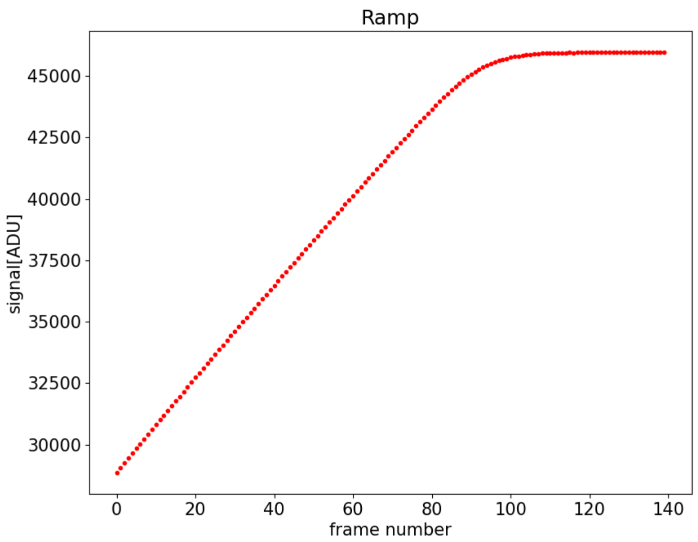
- CPPM : without the detection layer

Name	Det n°	Illumination ?	Reset type	Nb of frames	Exposure time
ngc_100K_11.fits	NA	Without detector	Pixel	100	UTR (every 1,3s)

DETECTOR OPERATION

Ramp mode

- Observation with CAGIRE = series of short exposures (1-2 minutes) during which pixels are read every 1,3s.
- The detector continuously accumulate charges proportionally to the flux received creating a ramp of the output signal : ramp mode.



- The ramps are measured in ADU and can be converted to electrons thanks to $g_{e-/ADU}$ = 7,5 e- / ADU

READOUT NOISE

Origin of the noise

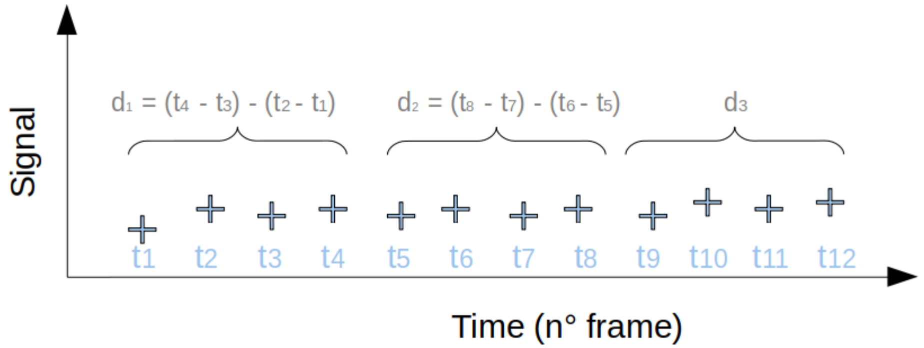
What is the readout noise ?

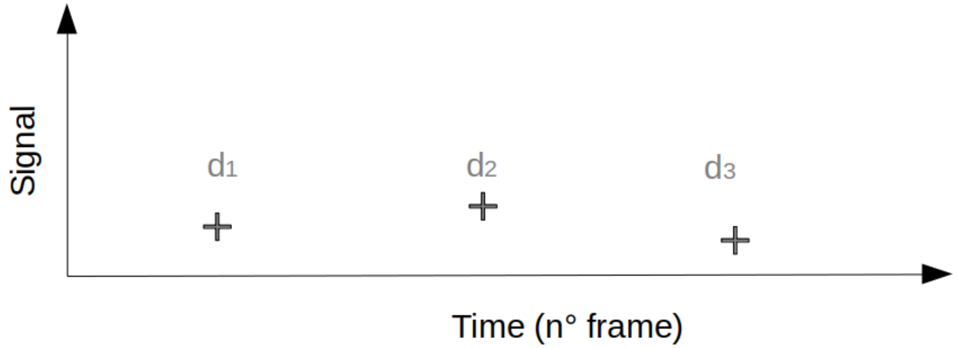
- Readout noise mainly comes from the transistors used to read the detector.
- The readout noise is generated :
  - at the pixel level (independent sources of noise).
  - at the readout channel level where polarization and clocks are common to several pixels = common modes (correlated noise).
- The readout noise is measured looking at the signal delivered by pixels in the dark and their fluctuations.

CDS NOISE

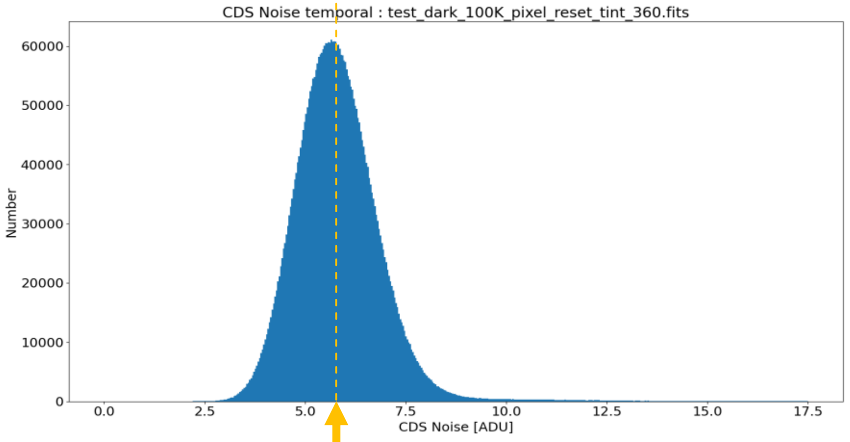
Temporal measurement of noise

For one pixel



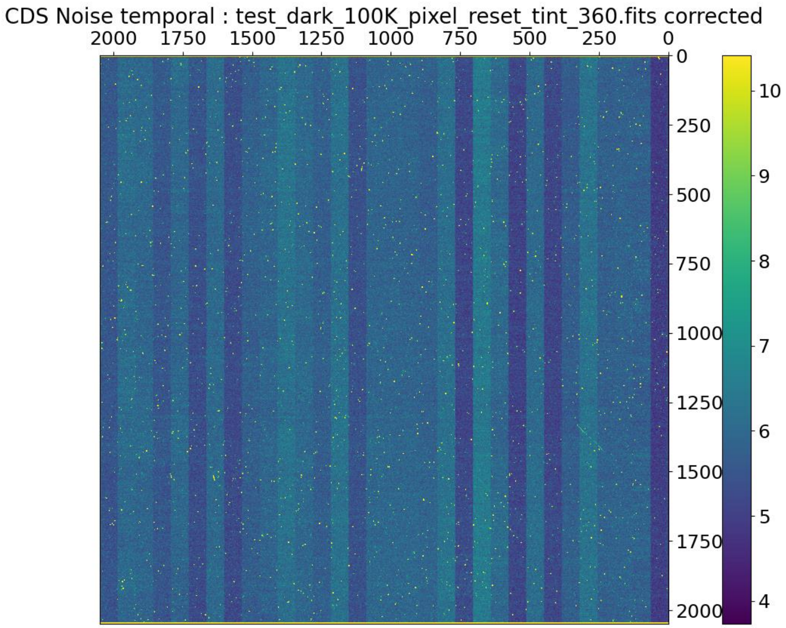


$$\text{Noise}_{\text{temporal}}(1\text{pixel}) = \frac{1}{\sqrt{2}}\text{Std}\left(d_1, d_2, d_3, \dots, d_n\right)$$



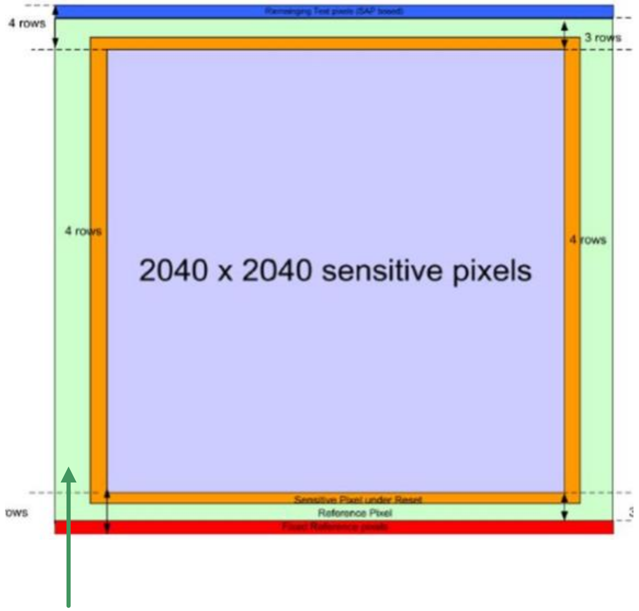
noise = 5,7 ADU

Noise by pixel and histogram associated



CDS NOISE

Reference pixels and how to correct the readout noise



Reference pixels.

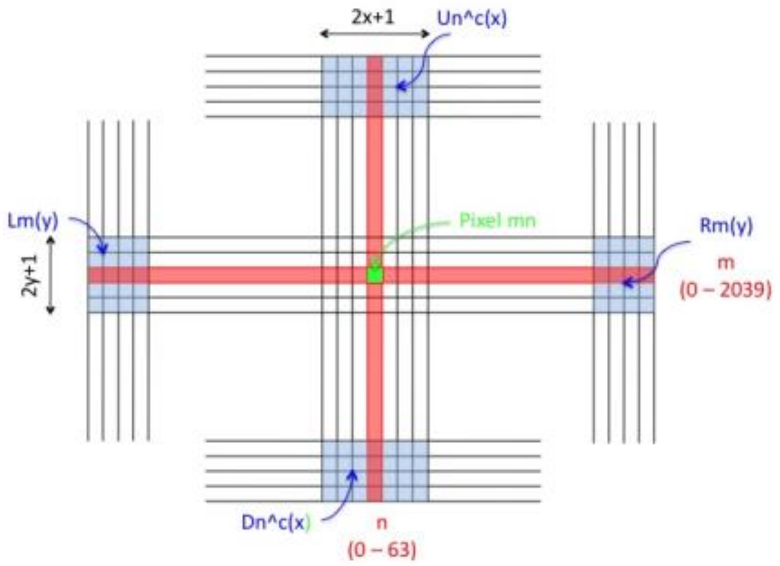
- Objectives : We want to reduce the noise from the common modes of the ROIC.
- We relied on the article " *Impact of common modes correlations and time sampling on the total noise of H2RG near-IR detector*" by B. Kubik et al.
- <u>Reference pixels</u> : pixels with the same electronics as active ones but not sensitive to light.

- We select all the reference pixels of the output of the pixel to correct, we compute their mean and subtract it to the pixel to correct.
- We select 9 lines of reference pixels around the pixel to correct (4 above and 4 below), we compute their mean and subtract it to the pixel to correct.

Detection matrix view and reference pixels use

CDS NOISE

Reference pixels and how to correct the readout noise



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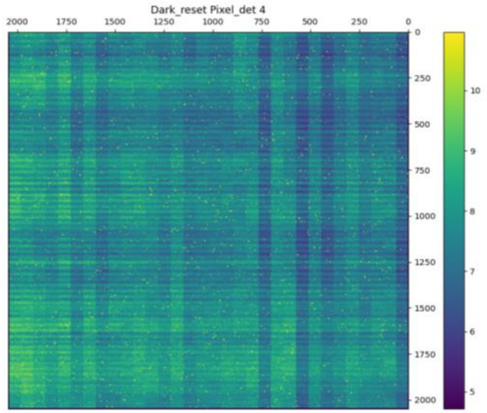
test_dark_100K_pixel_reset_tint_360.fits

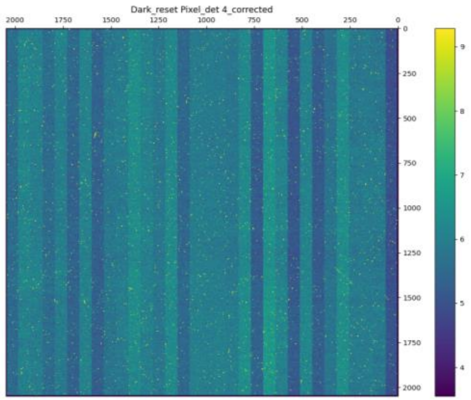
ngc_100K_11.fits

CDS NOISE

Summary on the file: test_dark_100K_pixel_reset_tint_360.fits

Noise (median on the detector)	**Science detector**		**ROIC**	
	Before correction	After correction	Before correction	After correction
CDS Noise [ADU]	7,59	5,80	5,14	3,81
CDS Noise [electrons]	56,9	43,5	24,2	17,98
Readout Noise [electrons]	40,23	30,75	17,11	12,71





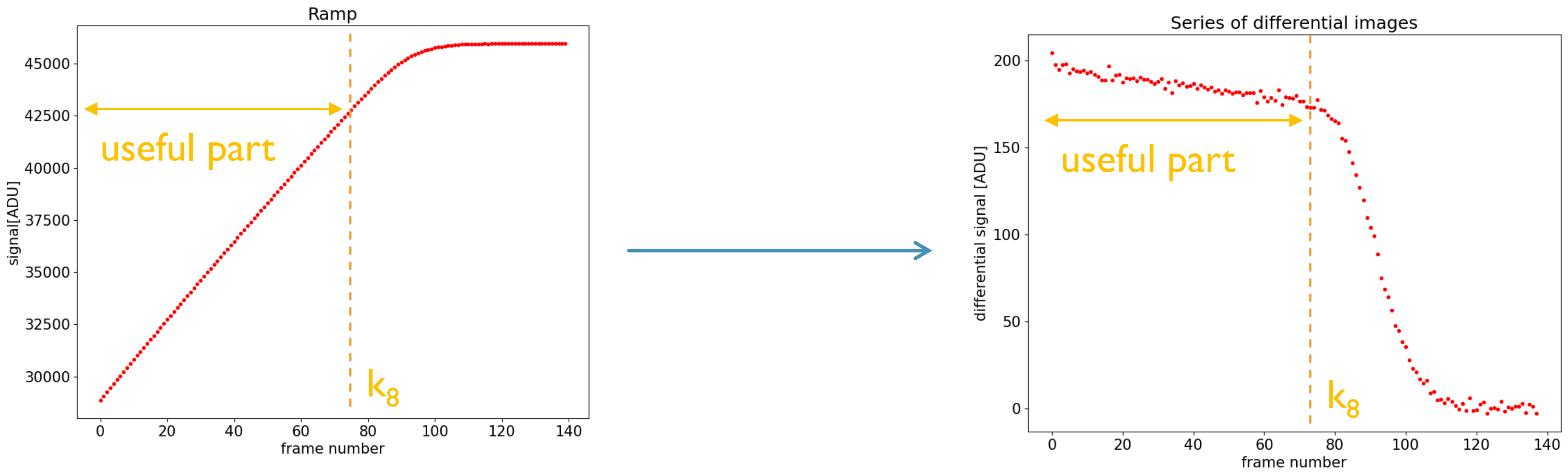
Temporal noise by pixel, before (left) and after (right) correction by the reference pixels for the Detection Layer file.

- The noise measured is significantly lower with the ROIC only than with the whole detection chain.
- However the measurement with the detection layer is not completely free of illumination.

FLUX ESTIMATION

Series of Differential images.

- Computation of the index value for 80% of the ramp before saturation (k_8) (TBC).
- Correction by the reference pixels
- Creation of a series of differential images from the ramps (difference between two consecutive frames)



Signal ramp to differential ramp

- Fit of the series of differential images.

Differential images are preferred because they permit to consider the experimental errors as constant when computing the fit .

FLUX ESTIMATION

Series of Differential images.

- The models to fit the 80% of the dynamic range selected are 1st and a 2nd order polynomial. We use the χ^2 to fit our curves.

$$\chi^2_{dl} = \sum_i \frac{\left(f^k(x_i) - y_i\right)^2}{\sigma^2}$$

- σ the variance, is considered as constant for each differential image:

$$\sigma^2 = CDSNoise^2_{\mathrm{ADU}} + \frac{S_{\mathrm{ADU}}}{g}$$

- Choice of the model : by comparison thanks to the Akaike Information Criterium (AIC).
- The criterium to compare is the difference $\Delta\chi^2$ between the χ^2 of the two models to compare.

$$\Delta\chi^2 = \chi^2_2 - \chi^2_1$$

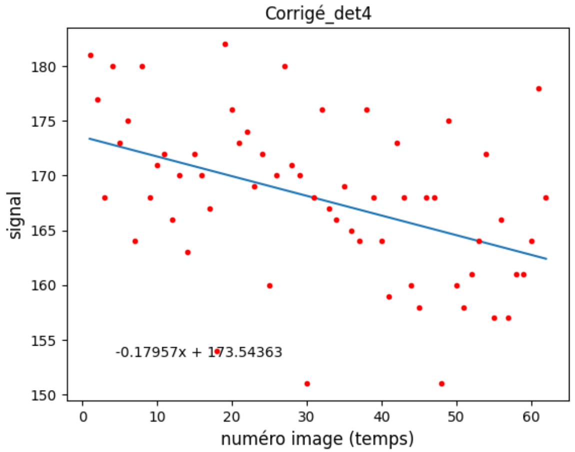
- The second order model is chosen if $\Delta\chi^2 < -2$.
- The Flux is estimated as the zero-th order coefficient of the model.

FLUX ESTIMATION

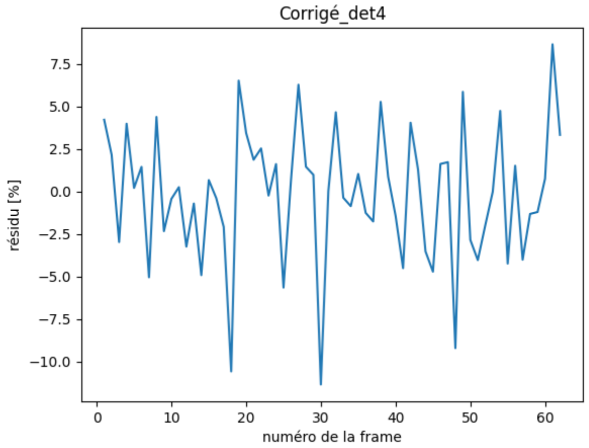
Series of Differential images : Results on the 4th detector.

	1st order polynomial	2nd order polynomial
Estimated flux (Median) [ADU/frame]	191,8	191,36
Variance on the flux parameter estimation [ADU²]	3,05	7,15
χ_r^2 (Median) : reduced χ^2	0,93	0,95
$\Delta\chi^2$ (Median) :	-0,35	

- 8,9% of the pixels have a $\Delta\chi^2 < -2$: the flux estimated on these pixels by the two models is similar at 3%.



$$D(k) = A_0 + A_1 \times k$$

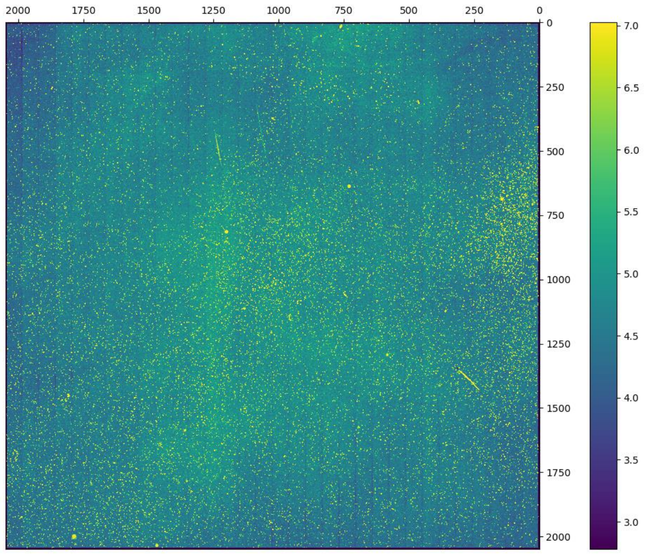


→ The flux will be computed as the Zero-th order coefficient of the 1st order polynomial fit.

LINEARITY

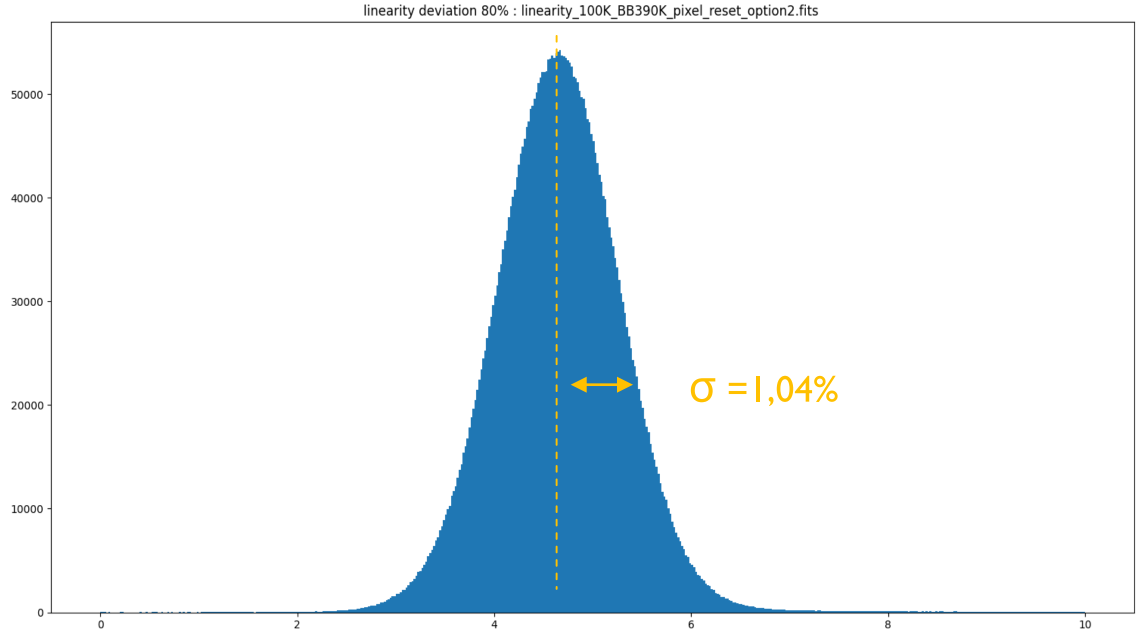
Deviation from linearity :

Difference between the ramp and the linear approximation at a level of 80% of the ramp before saturation. This quantity is normalized by the linear value.



Deviation from linearity at 80% of the ramp before saturation.

Deviation from linearity at 80% of the ramp before saturation.



median = 4,52 %

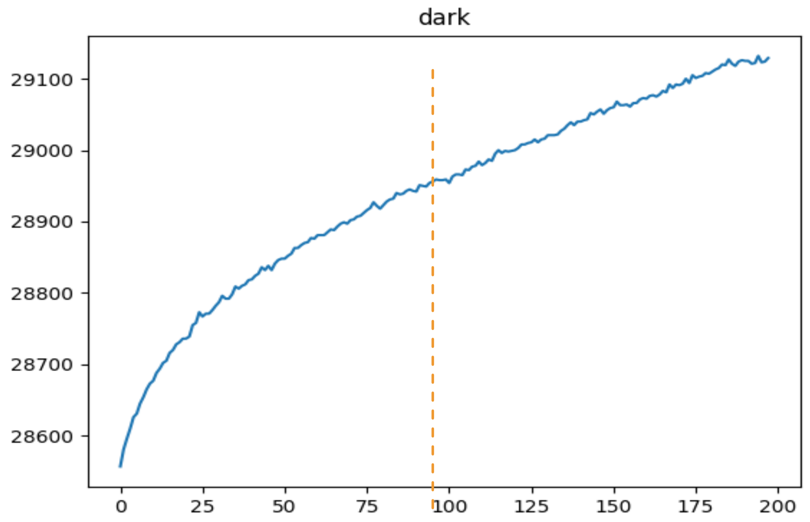
$$NL = \frac{A_1}{A_0} \times \frac{k_8}{2}$$

Good pixel : Deviation from linearity within 3σ

For detector n°4 we have 99,7 % of good pixels.

DARK CURRENT

- We measure the dark current by computing the flux on file : `test_dark_100K_pixel_reset_tint_360.fits`



- This file is impacted at by the persistence phenomenon. We thus compute the flux from the frame 90 to frame190 of the file.
- We find a median dark current of 0,84 ADU/frame.

  A frame lasts 361,32s and there is 7,5 electrons in one ADU : dark current = 0,017 electrons/s

RESULTS CONCLUSION

- The 4th detector has a low readout noise : 30 electrons after correction.
- We can estimate the flux as the 0^{th} order coefficient of the fit on 80% of the series of differential images.
- The detector has a good linearity : median deviation from linearity of 4,52%
- The dark current is estimated around 0,02 e-/s/pix

CONCLUSION

SOURCES

- *“Caractérisation du détecteur et de la chaine de détection de CAGIRE”*, IRAP-CPPM-IRFU 2020
- *“ Development of Astronomy Large Focal plane Array « ALFA » at Sofradir and CEA ”*, B.Fièque et al. 2019
- *“ Plan de test de la chaine de detection de CAGIRE au CPPM”*, J-L Atteia, J-C Clémens A. Secroun, 2020
- *“ Impact of common modes correlations and time sampling on the total noise of H2RG near-IR detector”* by B. Kubik et al., 2014.

NOISE COMPUTATION

$$S_{électrons} = S_{ADU} \times g \quad (2)$$

L'erreur sur le signal vaut :

$$\sigma^2_{ADU} = Bruit^2_{CDSADU} + \sigma^2_{SignalADU} \quad (3)$$

Or, comme nous sommes dans le cas ou le signal suit une loi de Poisson, nous avons :

$$\sigma^2_{Signalélectrons} = Var\left(S_{électrons}\right) = S_{électrons} \quad (4)$$

et donc :

$$\sigma^2_{SignalADU} = Var\left(S_{ADU}\right) = Var\left(\frac{S_{électrons}}{g}\right) = \frac{S_{électrons}}{g^2} = \frac{S_{ADU} \times g}{g^2} = \frac{S_{ADU}}{g} \quad (5)$$

Nous avons donc:

$$\sigma^2_{ADU} = Bruit^2_{CDSADU} + \frac{S_{ADU}}{g} \quad (6)$$

AKAIKE INFORMATION CRITERIUM (AIC)

Allows to compare 2 models without any preconception on the model to choose.
We then choose the model with the more accurate information.

$$AIC = 2k - 2ln(L)$$

L is the likelihood function, $ln(L) = Constante - \chi^2/2$

k is the number of parameters of the model to estimate, k=1

$$\Delta AIC = (2(k) - C + \chi^2_N) - (2(k-1) - C + \chi^2_{N-1}) = 2 + \Delta\chi^2$$

The model N is chosen if $\Delta AIC < 0$ so if $\Delta\chi^2 < -2$