Flux reconstruction for the NIR camera CAGIRE at the focus of the telescope Colibri

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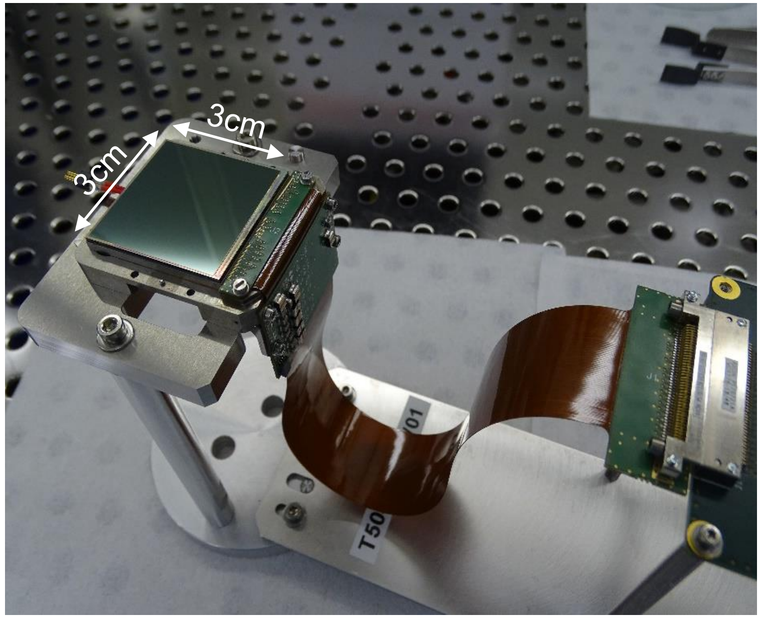
Supervised by Jean-Luc Atteia & Olivier Gravrand

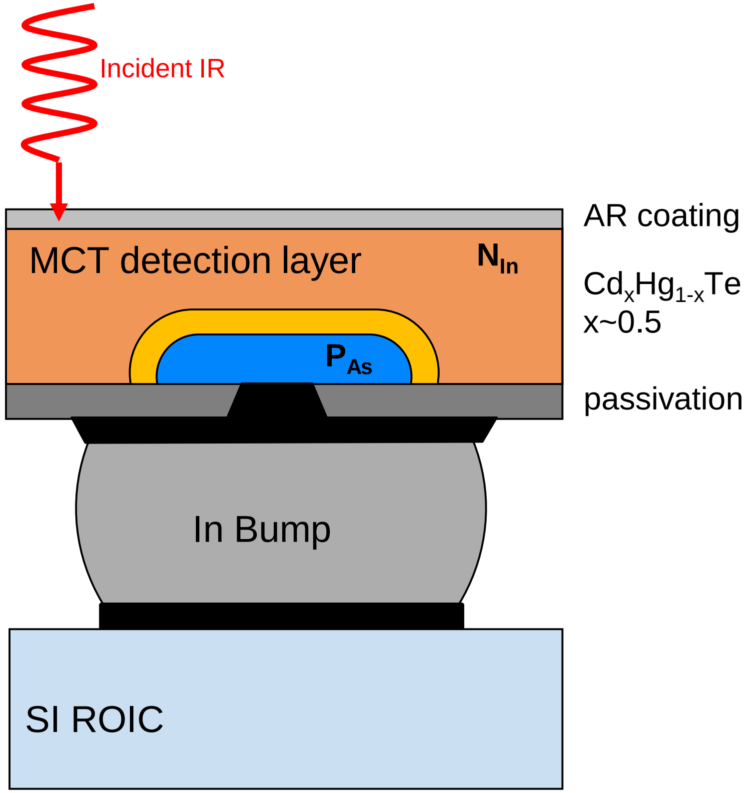
THE ALFA SENSOR

- ALFA : Astronomical Large Format Array developed by CEA-LETI and Lynred.
- Characterized by CEA-IRFU



Characteristics :

- Material : HgCdTe (MCT)
- Number of pixels : 2048 × 2048
- Pixel size : 15µm
- Cutoff : 2.1µm
- Operating temperature : 100K



Source : *Fabrication and characterization of a high performance NIE 2k×2k MCT array at CEA and Lynred for astronomy applications*, O.Gravrand et al.

THE ALFA SENSOR FOR CAGIRE : SPECIFICITIES

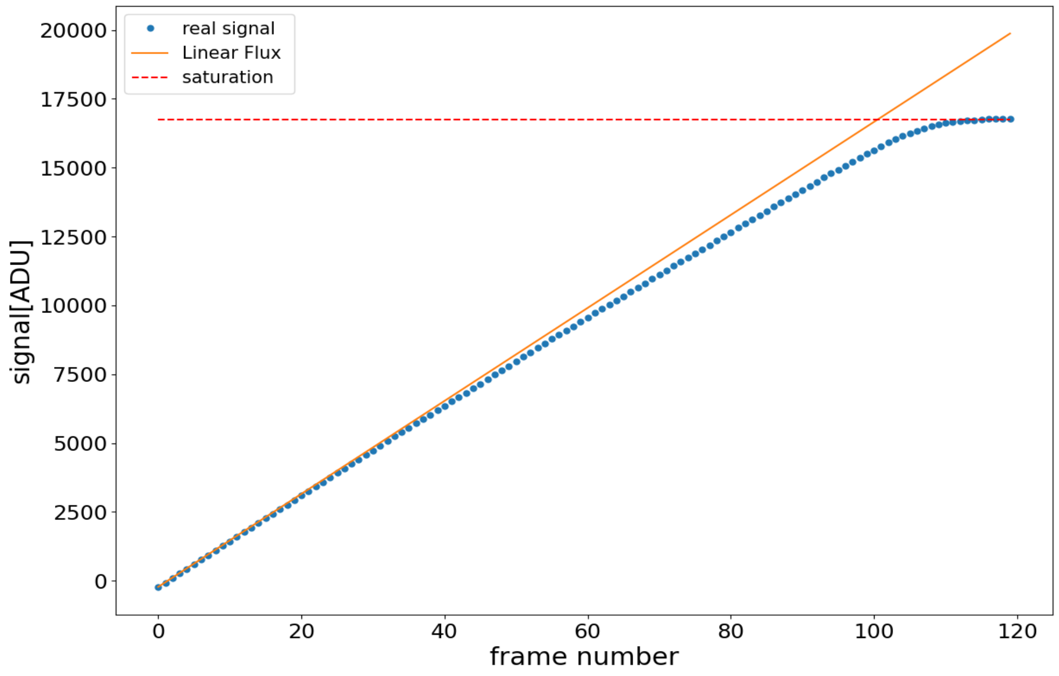
- Advantages :

  → Low light level detection

  → Readout noise < Photon noise

  → Very few non-operable pixels

  → Can work in "Up the ramp" mode



Ramp of detector CH329505 illuminated by a blackbody at 390K.

PRE-PROCESSING PIPELINE

→ Provide a reliable input for the astronomy pipeline.

→ Fast : finish the process before starting the next acquisition

→ Take into account the specificities of each pixel

IMAGE PROCCESSING PLAN

Raw ramps

↓

Pre-Processing Pipeline

Detector / Environment correction
+
Flux computation

↓

Astronomy Pipeline

Flat Field correction

↓

Dithering strategy to compute images

↓

Star extraction
+
Magnitude computation

GOALS OF THE PRE-PROCESSING PIPELINE

Need to :

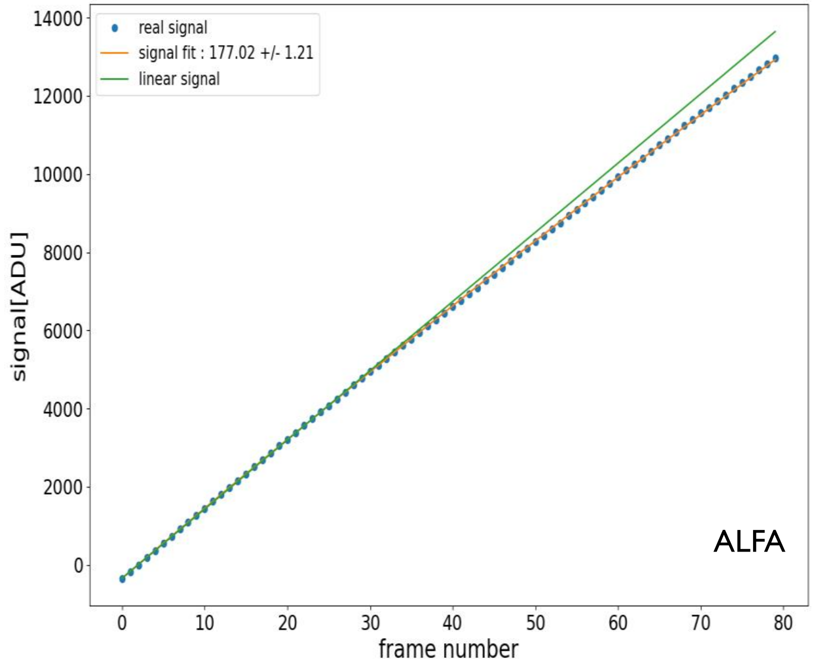
- Provide a reliable input for the astronomy pipeline
- Be fast : to finish to process ramps before the next acquisition
- Take into account the specificities of each pixel independently

Are not corrected :

- The persistence : the pre-processing do not consider the detector historic, but dithering should help to correct it.
- The cross talk.
- The uniformity of the detector : a flatfield acquired with the camera below the telescope is used in the astronomy pipeline.

GOALS OF THE PRE-PROCESSING PIPELINE

- Correct flux maps from detector effects:
  - Common mode noise and bias
  - Non linearities from flux and from capacitive effects
  - Saturation
  - First frame impact
- Correct flux maps from environment effects: Cosmic Rays



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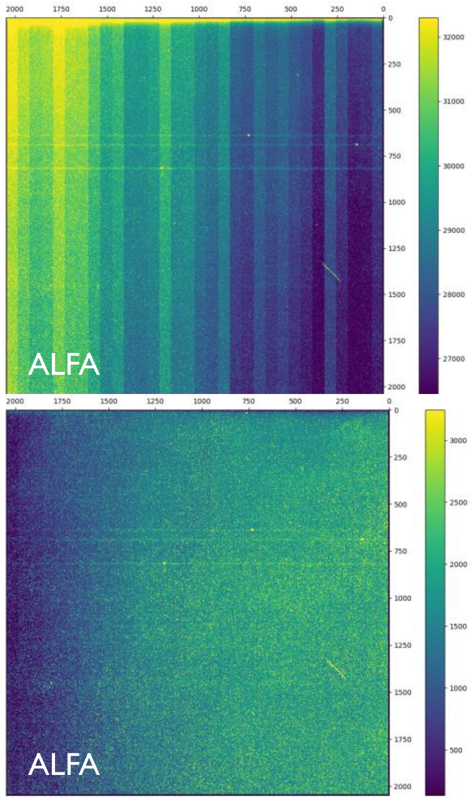
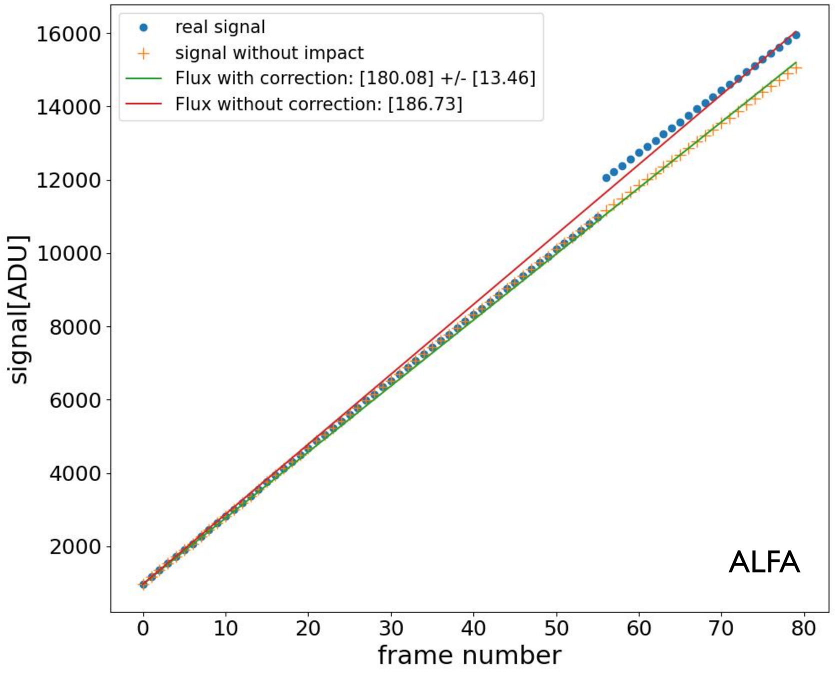


Frame of detector CH329505 illuminated by a blackbody at 390K before and after common mode noise correction.

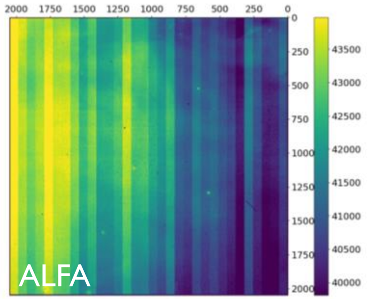


Ramp of detector CH329505 illuminated by a blackbody at 390K.

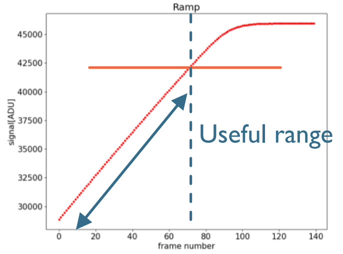
PRE-PROCESSING PIPELINE

1) Determination of the linear useful range of the ramp before saturation for each pixel.

+ Find saturated pixels.



Saturation map



Ramp of one pixel

PRE-PROCESSING PIPELINE

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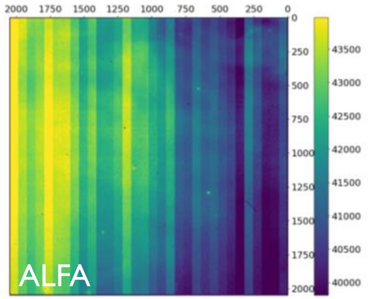
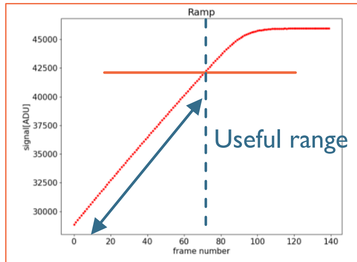
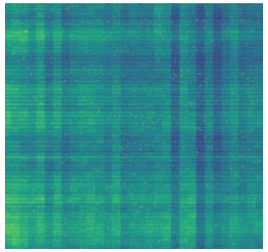


Saturation map



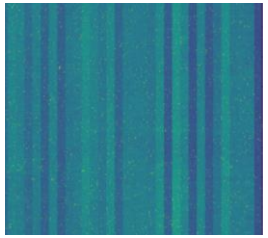
Ramp of one pixel

2) Correction of offsets and common modes thanks to reference pixels



Noise before correction

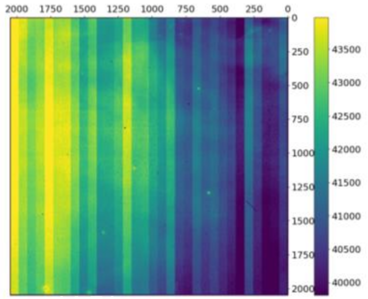
Noise after correction



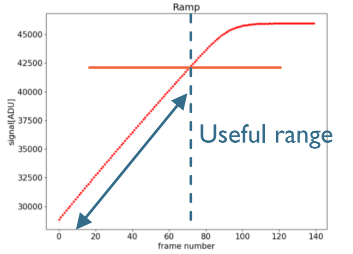
PRE-PROCESSING PIPELINE

1) Determination of the linear useful range of the ramp before saturation for each pixel. → 2) Correction of offsets and common modes thanks to reference pixels → 3) Construction of a differential ramp = subtraction of 2 consecutive frames

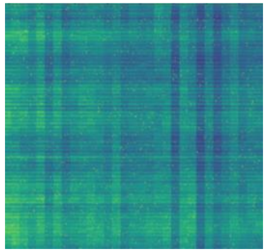
+ Find saturated pixels.



Saturation map



Ramp of one pixel



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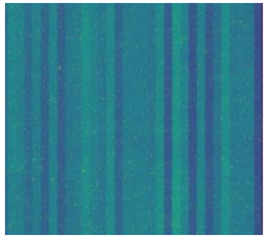

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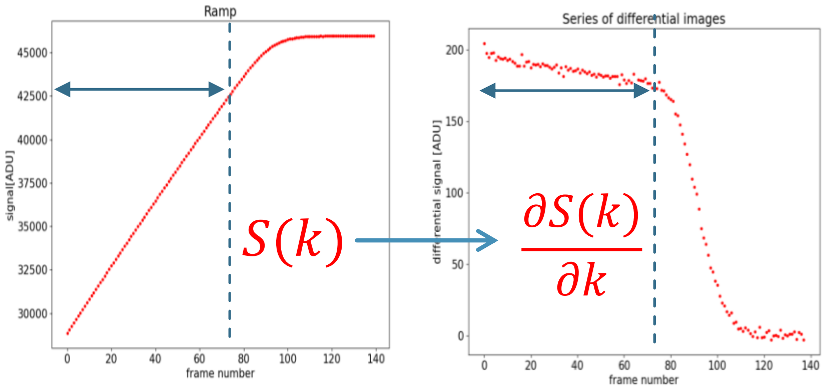

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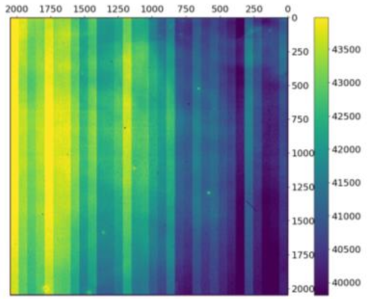
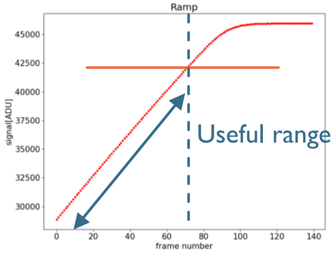


Saturation map



Ramp of one pixel

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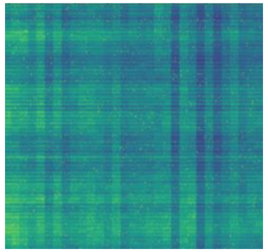
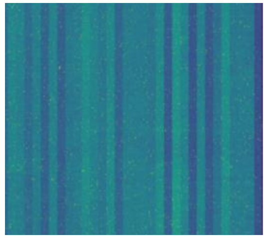
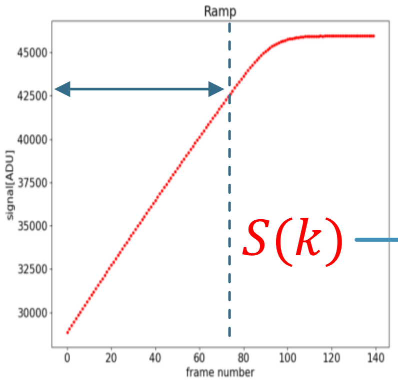


Noise before correction

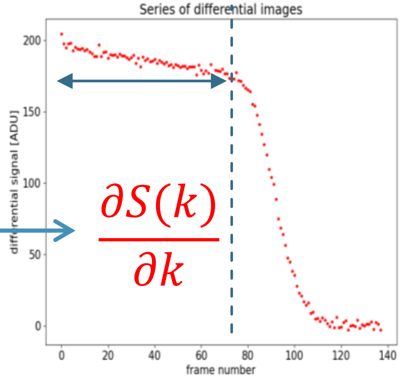


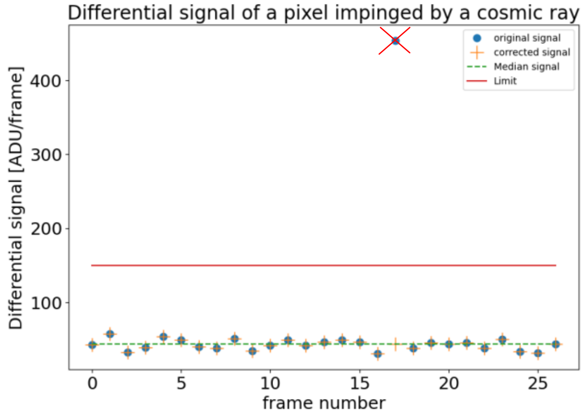
Noise after correction

3) Construction of a differential ramp = subtraction of 2 consecutive frames



$S(k)$ → $\frac{\partial S(k)}{\partial k}$





4) Flag cosmic rays and correction of their signal

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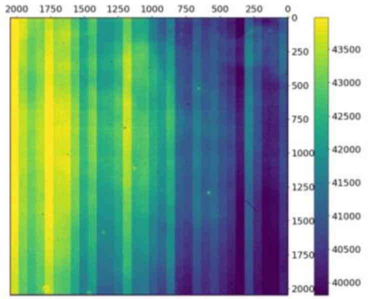
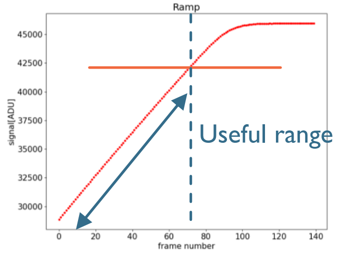


Saturation map



Ramp of one pixel

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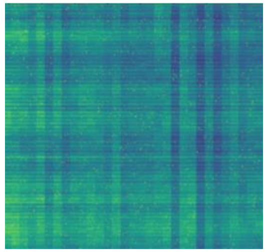
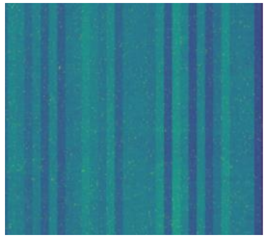


Noise before correction



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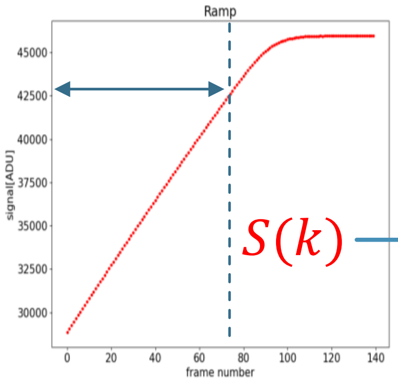

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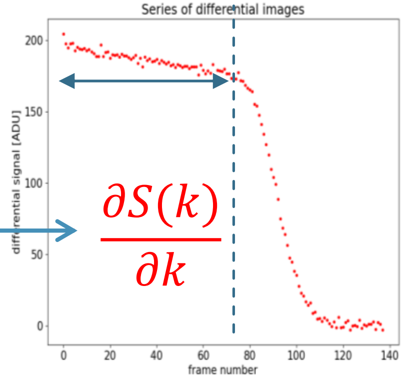

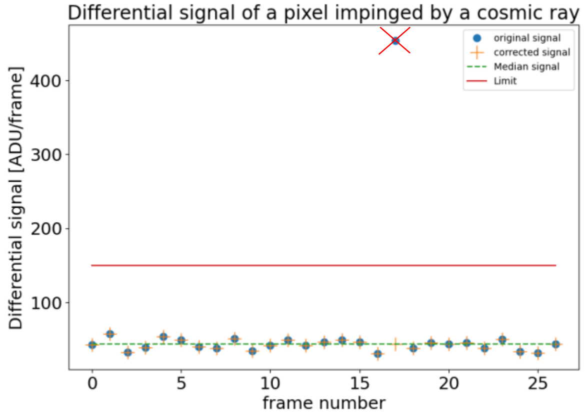

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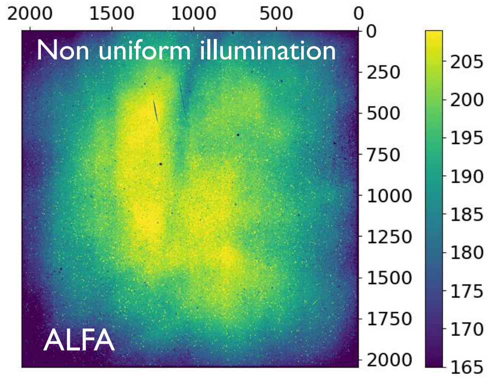
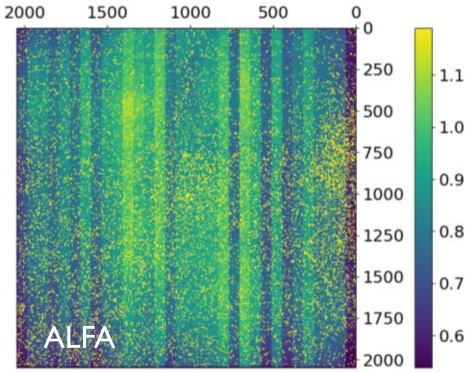


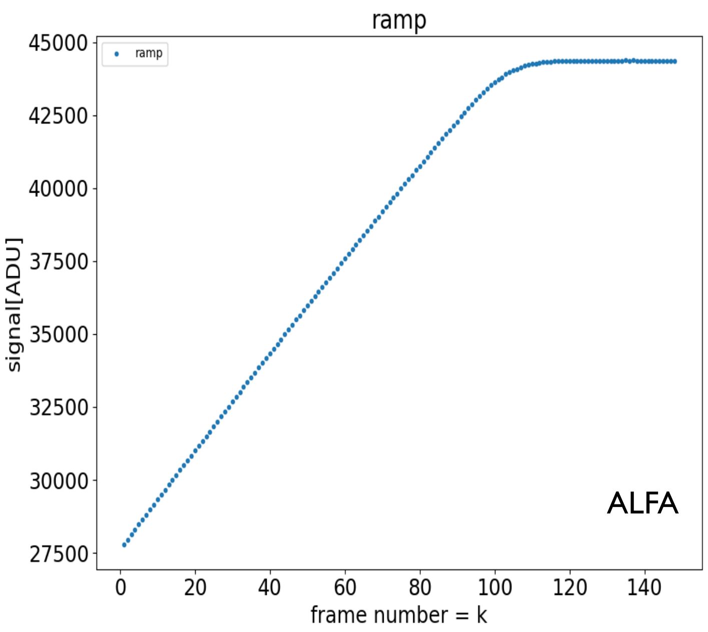


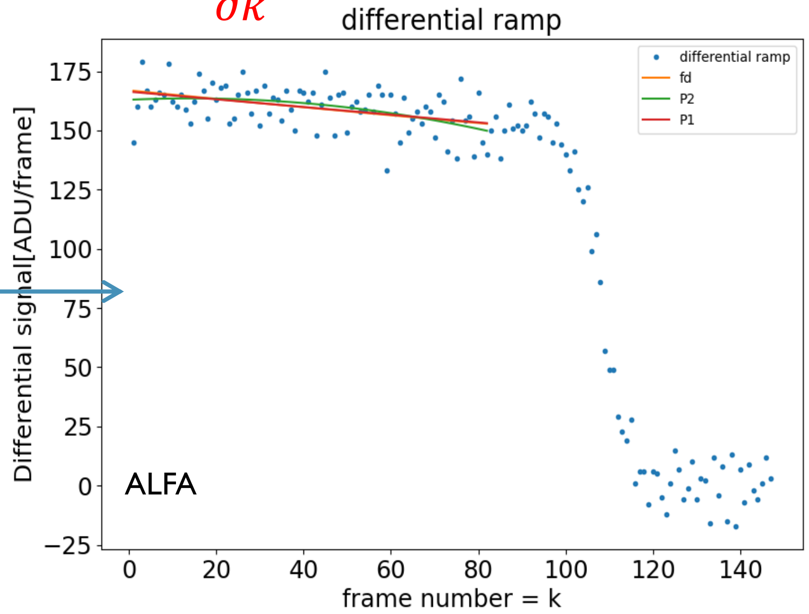
5) Flux and associated error estimation on images corrected from noise and cosmic rays.

DIFFERENTIAL RAMPS

3) Construction of a differential ramp = subtraction of 2 consecutive frames

$$S(k) \longrightarrow \frac{\partial S(k)}{\partial k}$$





Advantages :

- 1 less parameter to fit
- Same noise on each point, no need for ponderation.

Simplest one

$$P_1(k) = a_1 \times k + a_0$$

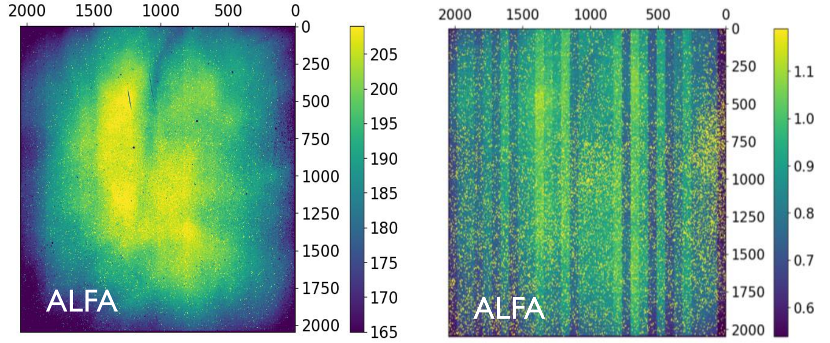
$$P_2(k) = a_2 \times k^2 + a_1 \times k + a_0$$

$$F_\delta(k) = \frac{a_0}{(1 - \delta \times a_0 \times k)^2}$$

	1st order	2nd order	F_δ
Reduced χ^2 of the ramp fit (median value)	0,94	0,95	0,94

→ Flux computed with 1st order polynomial fit on the differential ramp =2nd order polynomial fit on the initial ramp

SIGNAL ESTIMATION



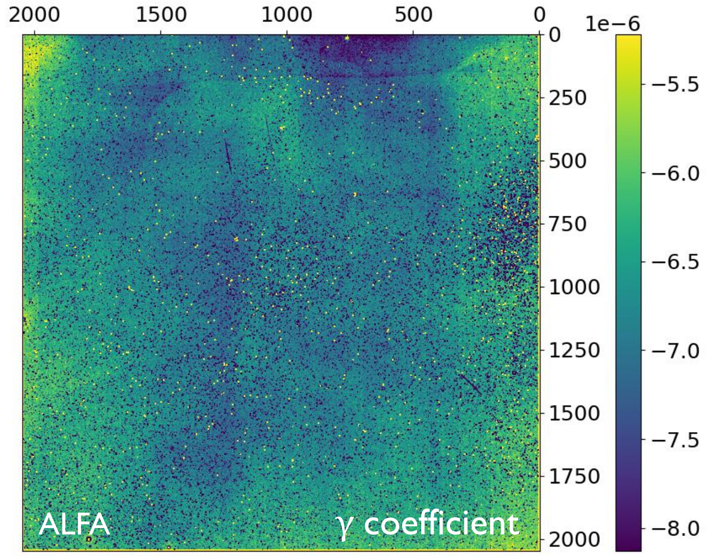
5) Flux and associated error estimation on images corrected from noise and cosmic rays

- Linear fit of the differential ramp :

$$d_k = a_0 + a_1 \times k \quad (1)$$

- We define a coefficient of nonlinearity independent of the flux

$$\gamma = \frac{a_1}{a_0^2} \sim -6 \times 10^{-6} \text{ADU}^{-1}$$



- Using γ equation (1) becomes :

$$d_k = a_0 + a_0{}^2 \times \gamma \times k$$

- The signal a_0 [ADU/frame] is found by solving this equation for each pixel
- The Flux will be extracted from a_0 versus flux illumination curves computed during calibration tests

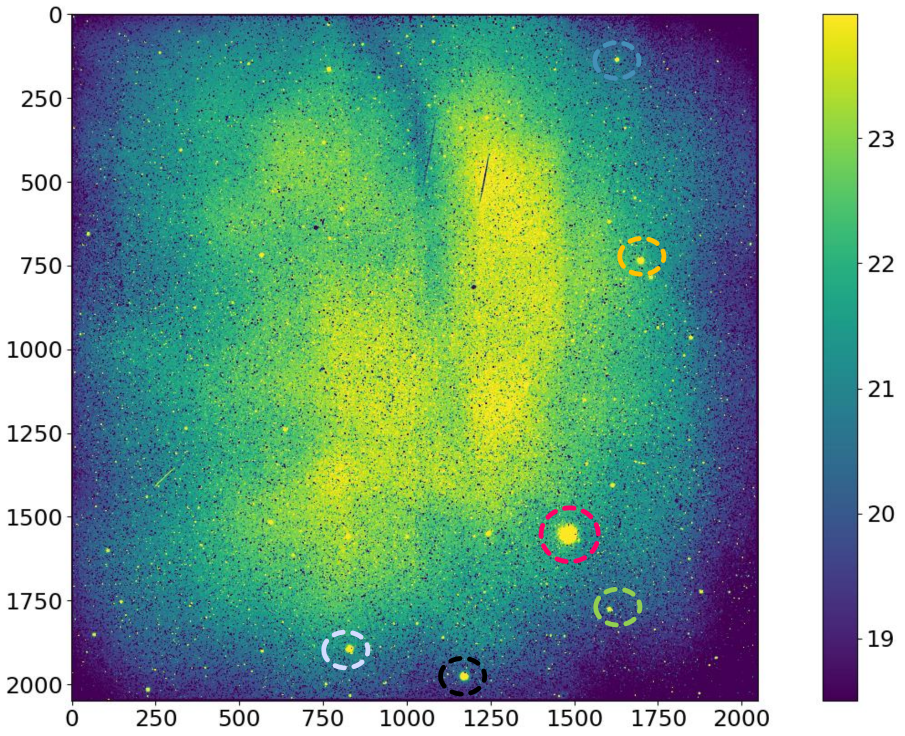
PIPELINE PERFORMANCES

Number of frames considered	7	20	46	90
Exposure duration [s]	9	27	60	120
Finding saturated pixels [s]	0.008	0.008	0.008	0.02
Computing the limit of the fit [s]	0.3	0.7	2	6
Correction by reference pixels [s]	0.8	2.3	5	9.7
Creation of the differential ramp [s]	0.2	0.8	2.0	3.6
Computing output variables (Flux, Error, Cosmic-rays hits)[s]	1.5	2.5	5.6	19.4
Duration of the preprocessing	**6**	**9**	**18**	**54**

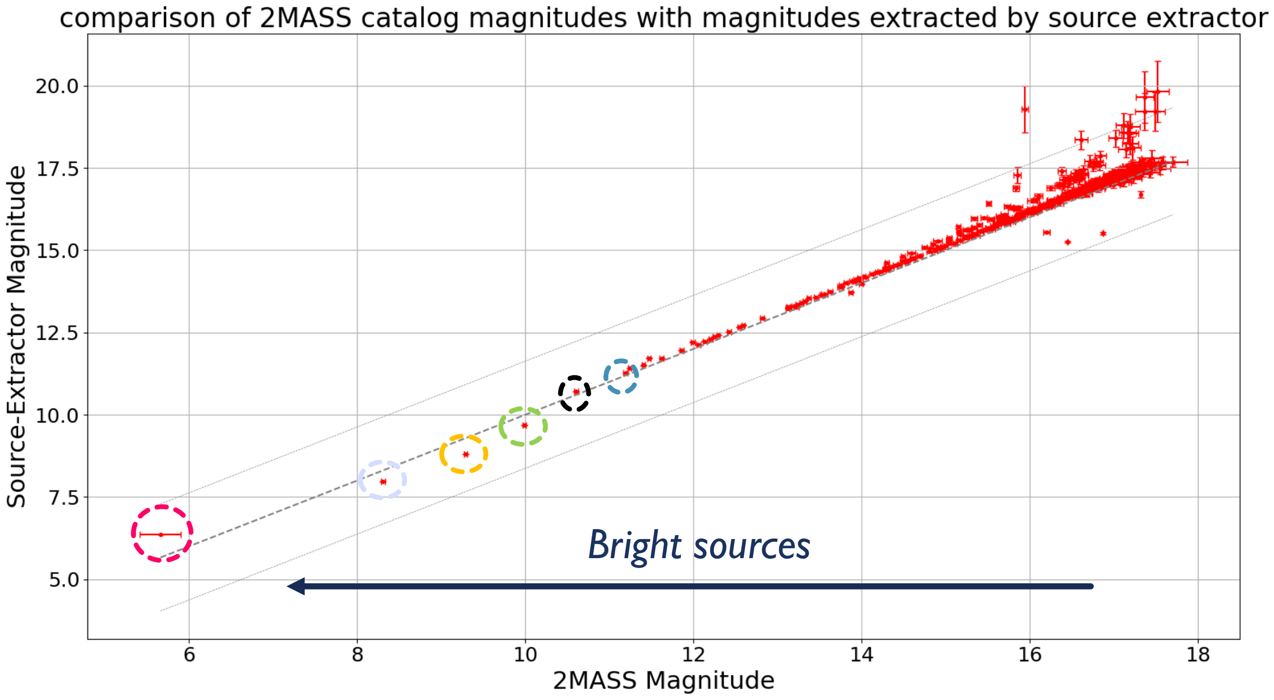
Table 2. Table of the characteristic processing time of the pipeline over the 4 millions of pixels

TESTS ON SIMULATED IMAGES

- Goal : show that we find coherent magnitudes, using "handmade" extraction of stars.



Example of a final flux map



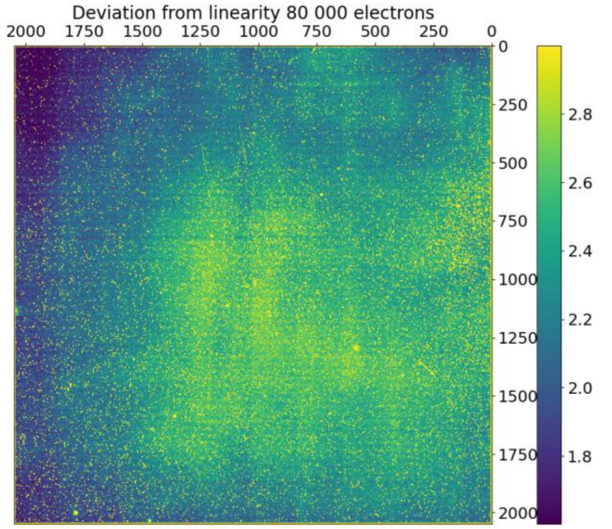
Comparison between measured magnitude and 2MASS magnitude

1. Correction of the flux map by the flatfield map.
2. Extraction of sources with Source-Extractor and cross-match with 2MASS.

CONCLUSION

- We confirmed that the ALFA detector fulfills CAGIRE requirements:
  - Very good dynamic and linearity
  - Few non-operable pixels
  - Good uniformity according to CEA characterizations

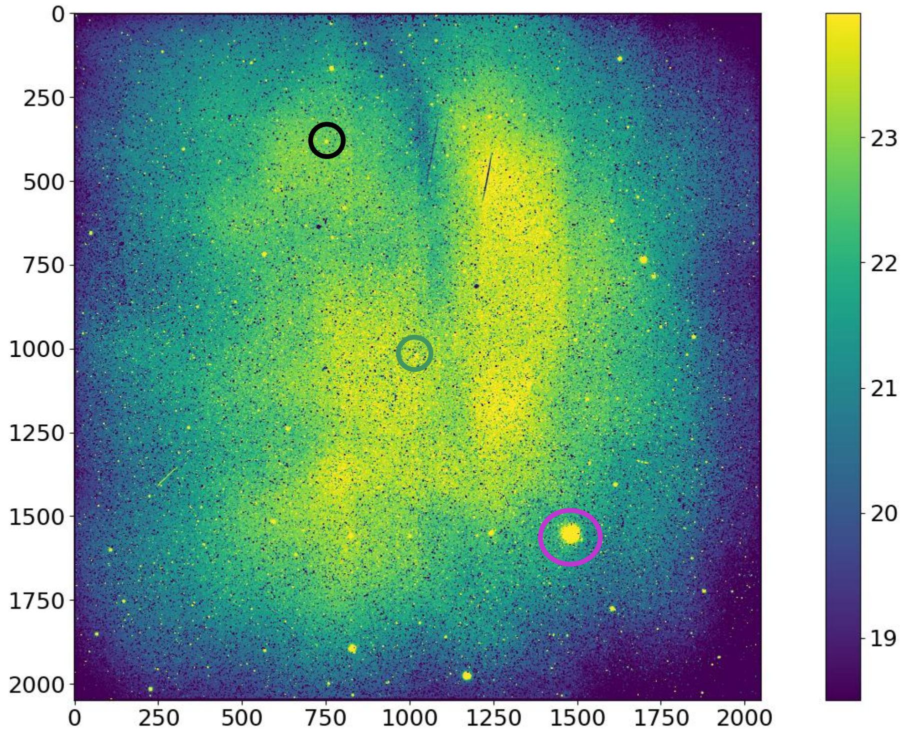
- We developed a pre-processing pipeline which is :
  - Able to provide a map of the flux received by the detector, with its errors
  - Adapted to each pixel (saturation level, non linearity)
  - Able to detect and correct the impact of cosmic rays
  - Fast and suitable for the astronomy pipeline

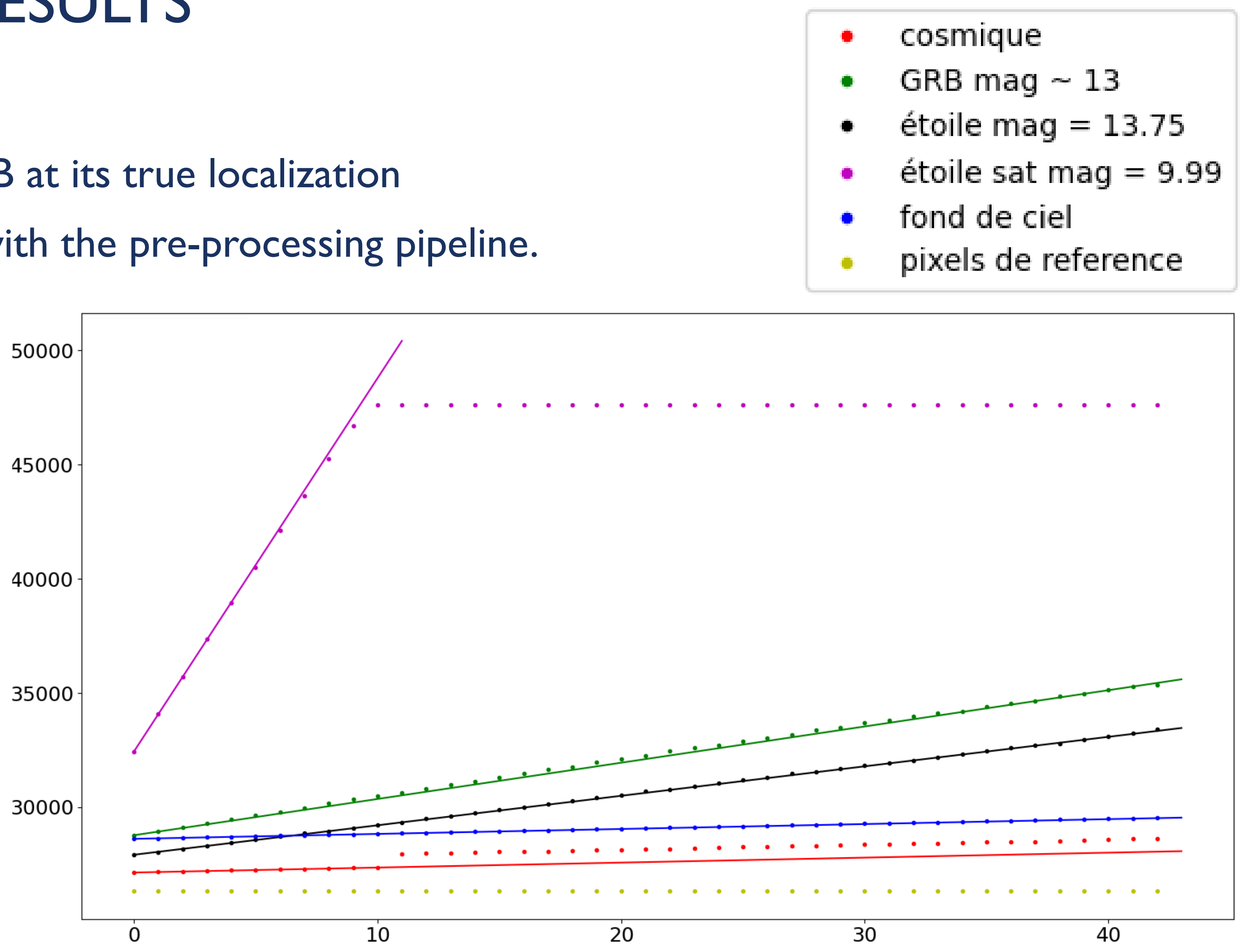


Deviation from linearity
at 80 000 electrons

COMPLETE SIMULATION RESULTS

- Example of GRB210905A
  - → Simulation of the sky map with GRB at its true localization
  - → Processing of the simulated ramp with the pre-processing pipeline.





Example of a final flux map and ramps of some particular pixels