CAGIRE a wield field NIR imager using the ALFA detector

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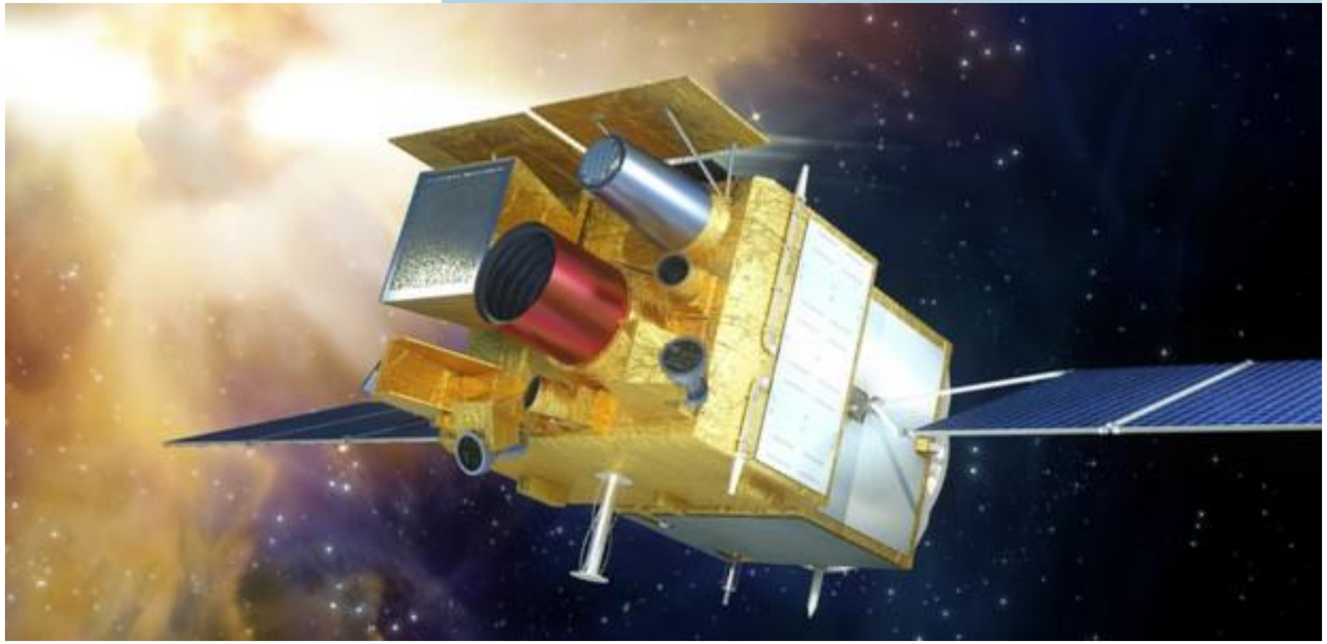
Supervised by J-L. Atteia, O. Gravrand,

Artist's view of the SVOM satellite (credit Svom.eu).



CONTEXT

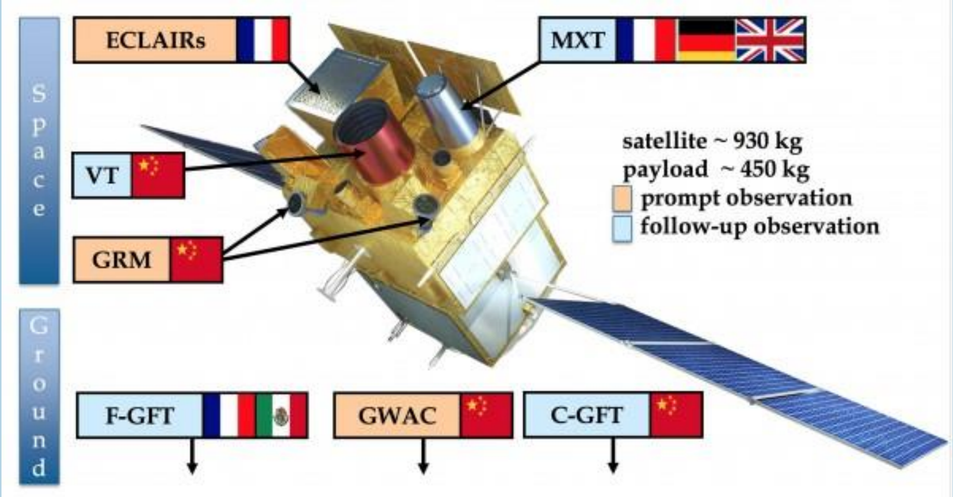
SVOM : SPACE BASED MULTI-BAND ASTRONOMICAL VARIABLE OBJECTS MONITOR

Study transient high energy sources such as Gamma Ray Bursts.

Gamma Ray Bursts (GRBs) :

Jet of particles and energy emitted because of the fusion of 2 compact objects or the collapse of a very massive star. The emission is short and very intense.

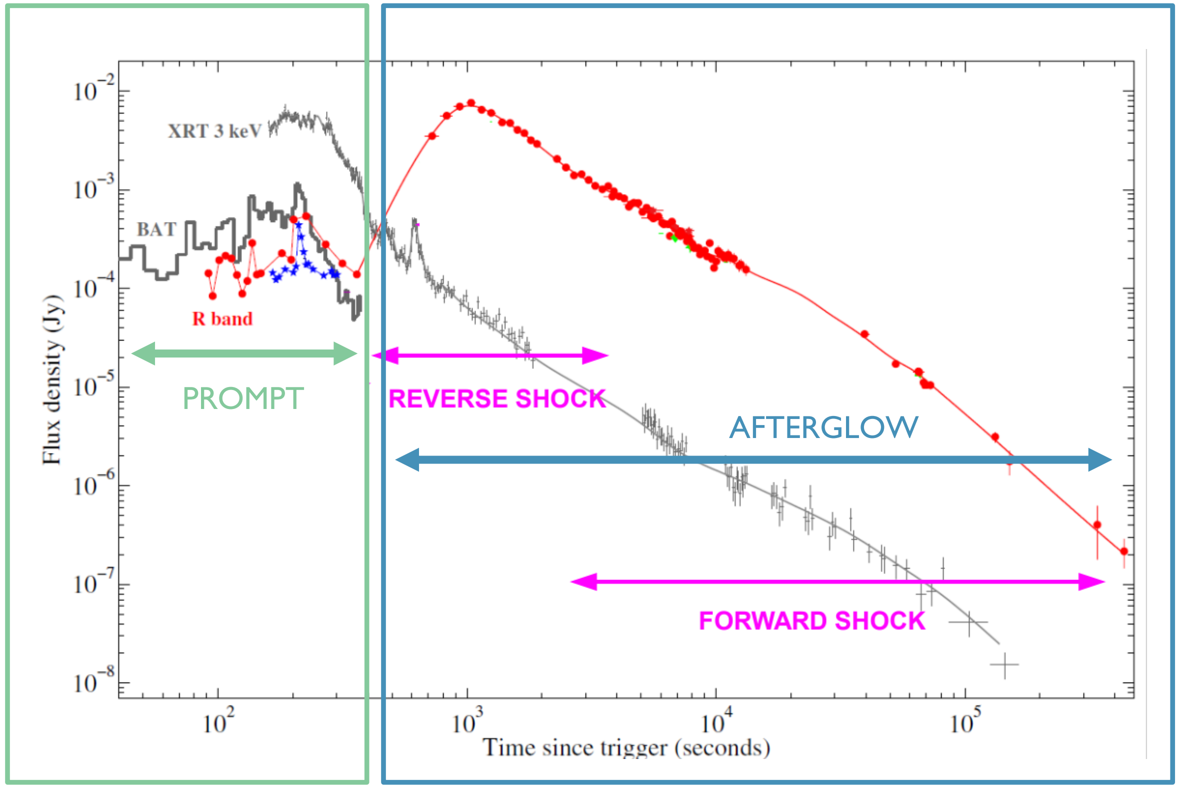
THE SVOM MISSION : SPACE AND GROUND SEGMENT



Svom instruments (ground and space) (credit : svom.eu)

Prompt emission (ɣ):

- ECLAIRs: localization of GRBs before stopped by the Earth's atmosphere.
- Information quickly transmitted to the ground.



Afterglow (X, visible, radio):

- Information received by Ground Follow-up telescopes (GFTs) within 1min.
- GFTs point the source and image the localized sky region.

COLIBRI & THE INFRARED

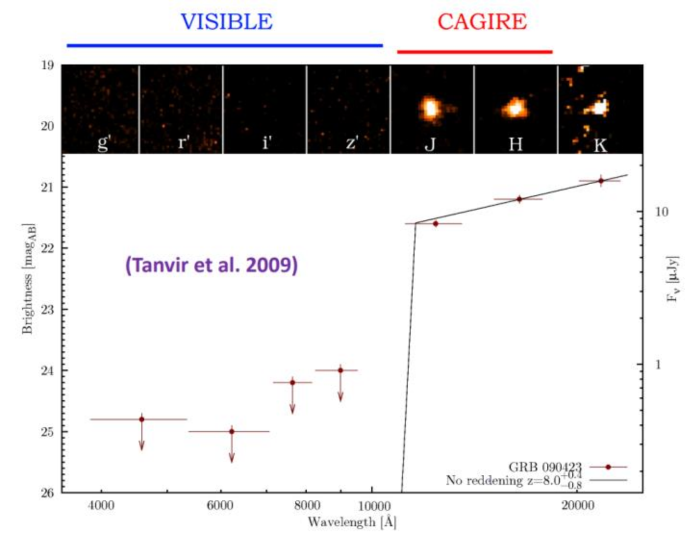
Why ground based telescopes?

- To look for afterglows
- To localize more precisely the burst
- To measure redshift

Colibri at OHP

Colibri :

- 1.3 m diameter
- Fast to point a source (< 30s)
- Two visible cameras
- One Near Infra Red (NIR) camera : CAGIRE

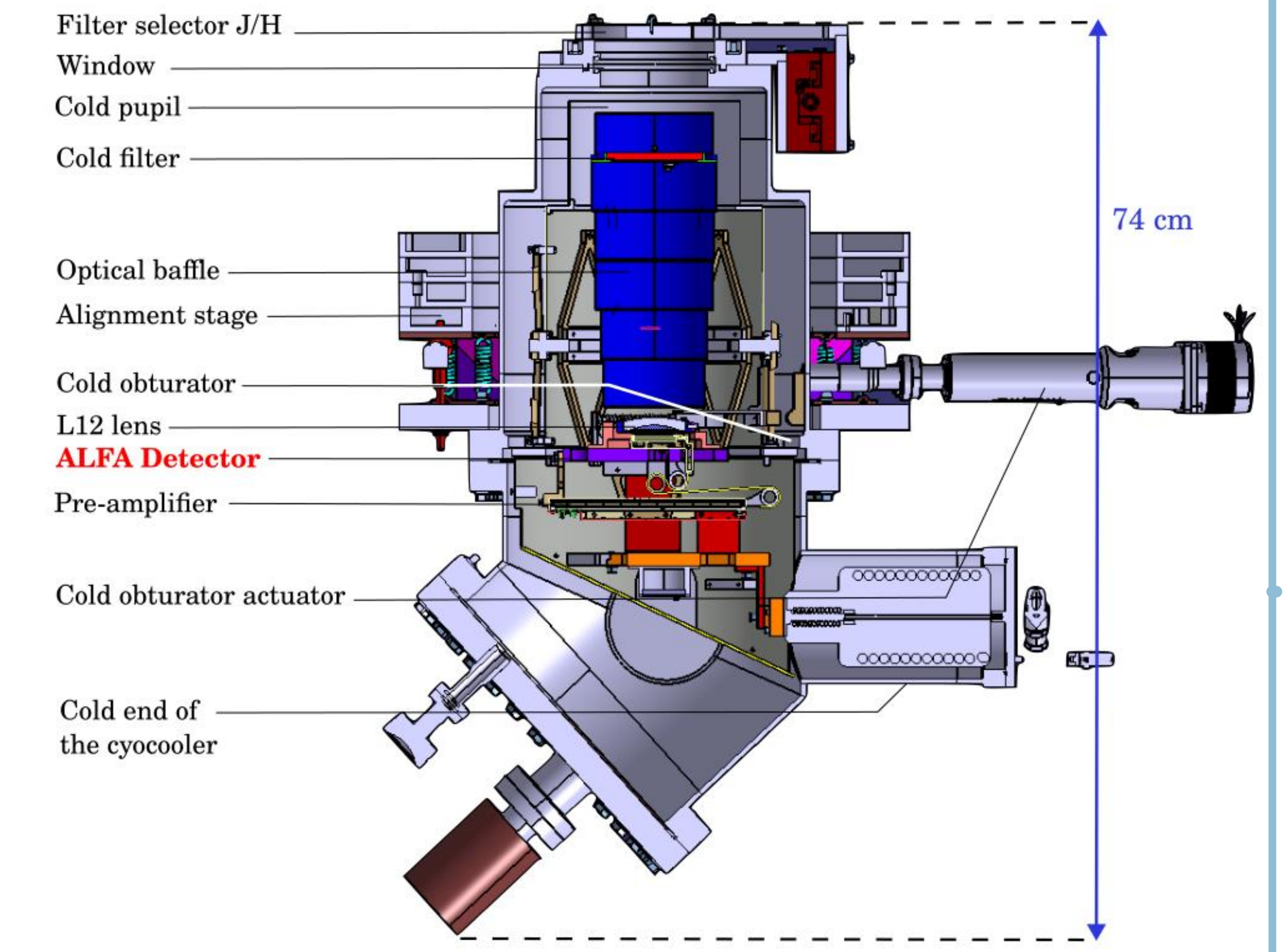


Why do we need the infrared ?

- Emission of X, visible & radio waves in the afterglow
- Expansion of the universe involves an increase of the apparent wavelength, which is shifted to the red = Redshift

⟶ Afterglow of GRBs with a redshift > 7.4 only detectable with infrared camera, due to UV absorption by hydrogen in the host galaxy.

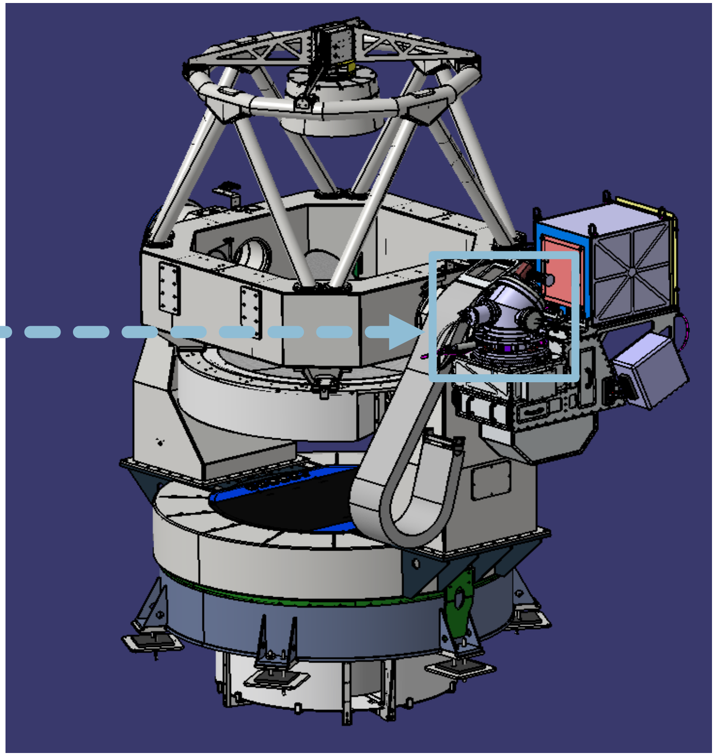
CAGIRE : CAPTURING GRB INFRARED EMISSION



Pixel sky resolution : 0.64”

Sky background : J ≈ 160 ; H ≈ 1250 e-/s/pix

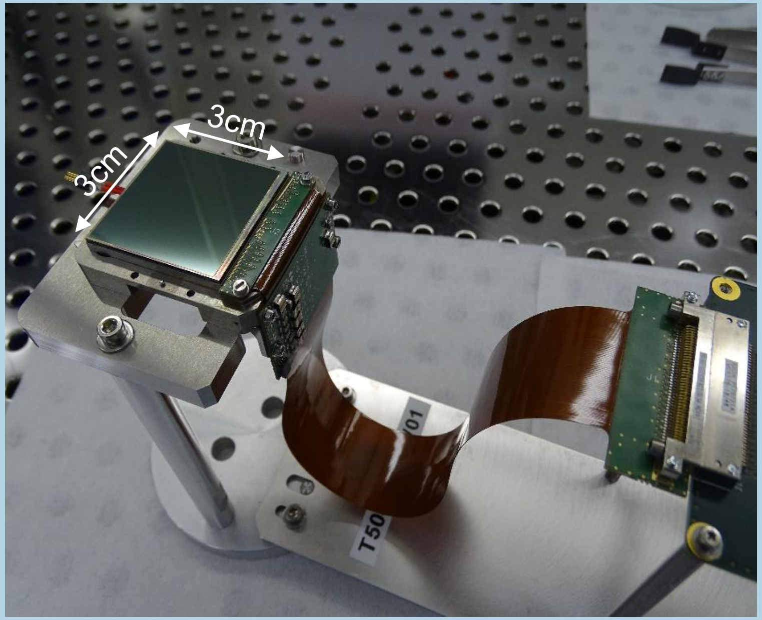
Wavelength: J [1.17-1.33] μm or H [1.49-1.78] μm



Controller: 60 cm

THE ALFA SENSOR

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

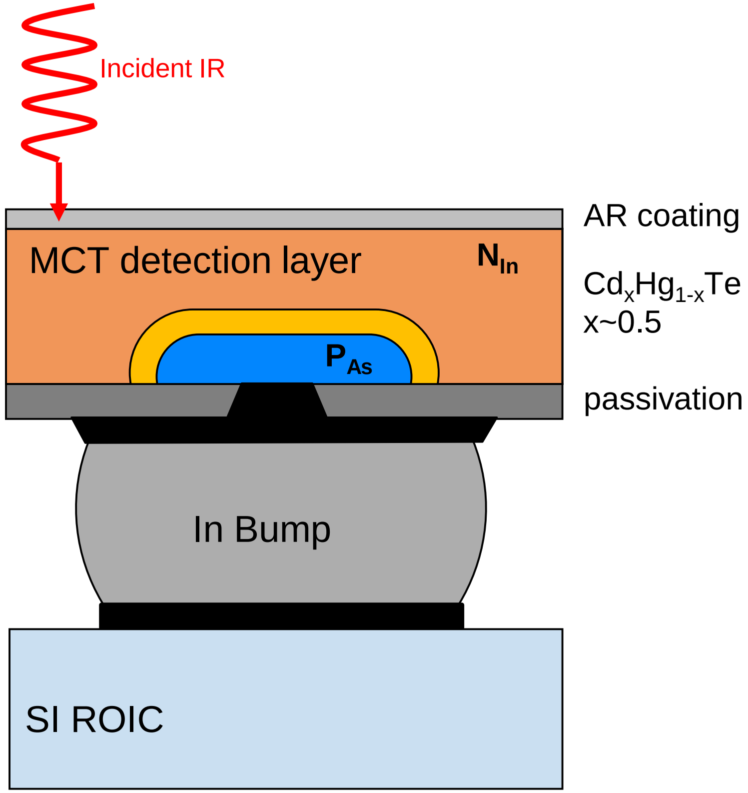


ALFA Sensor

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

Characteristics :

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



ALFA Sensor diagram

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

THE ALFA SENSOR FOR CAGIRE : SPECIFICITIES

- Advantages :

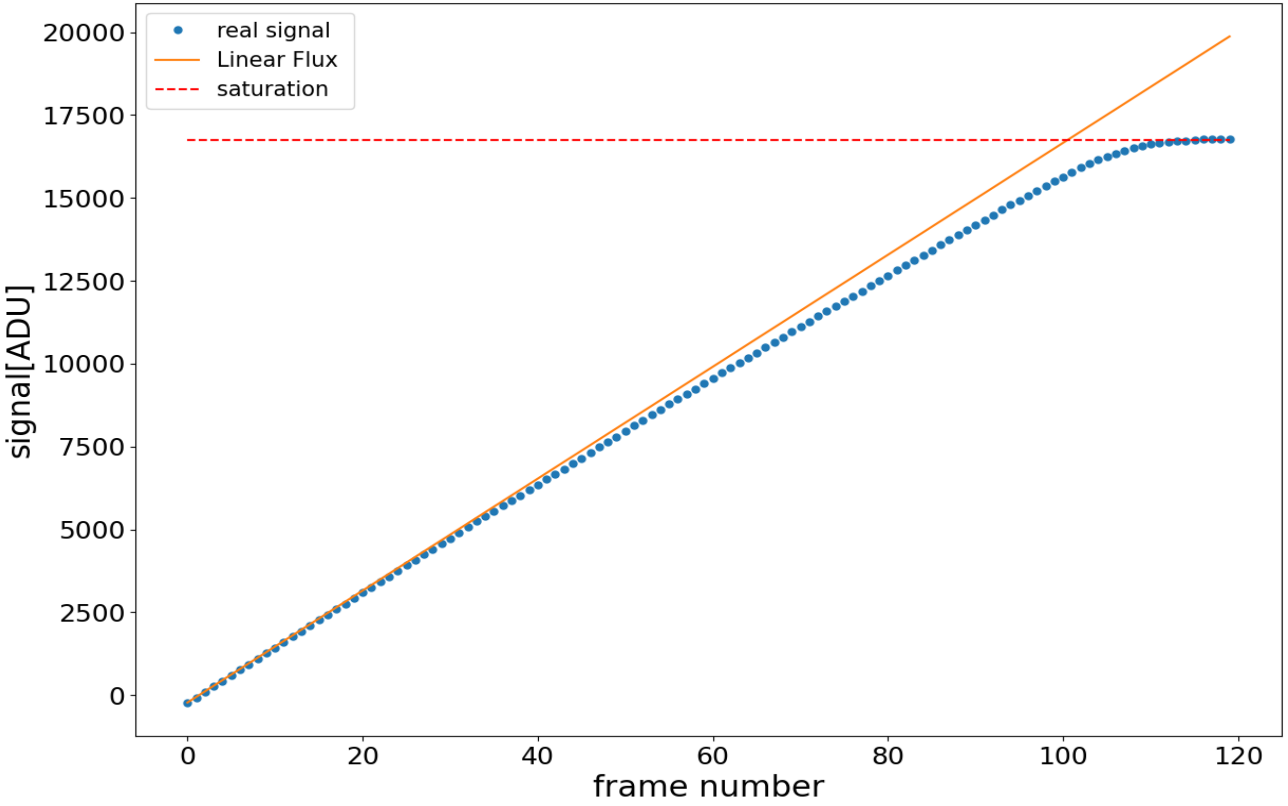
→ Dark current well below sky background

→ Low light level detection

→ Few non-operable pixels

→ Can work in "Up the ramp" mode :

Able to read while accumulating charges.



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

CHARACTERIZATION STRATEGY

16.01.2023 | November 2023 | May 2024

Characterization at CEA-IRFU → Characterization at CPPM → Characterization at IRAP → Delivery in Mexico

June 2023 : Cryostat delivery at IRAP

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
- Choice of the detector

Characterization of CAGIRE detection chain and operations

CPPM : Reference for the detector performances

- Performances with CAGIRE operating parameters

IRAP

- Tests with the engineering chain

Characterization of the camera CAGIRE

IRAP :

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

SIMULATIONS

Use the characterization of the detector to adapt a telescope simulator developed by David Corre to CAGIRE and ALFA specificities.

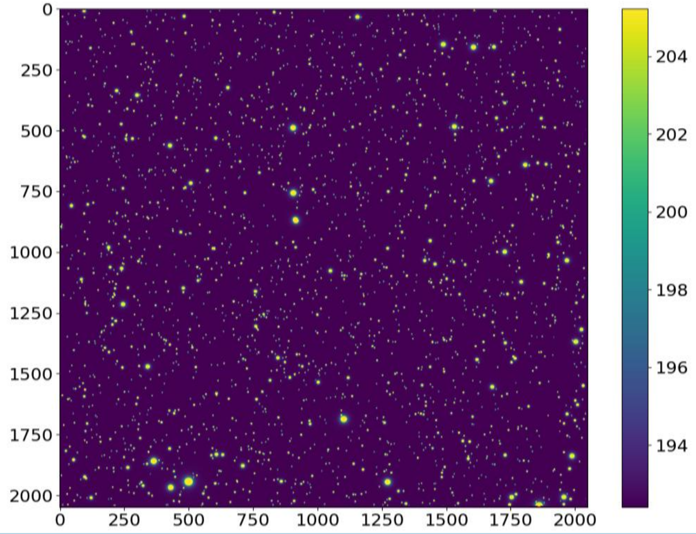
Goals :

- To evaluate performances of the camera and particularly for GRBs at high redshift
- To test and validate our pre-processing pipeline with these simulations
- To optimize observation strategies (ex : dithering)

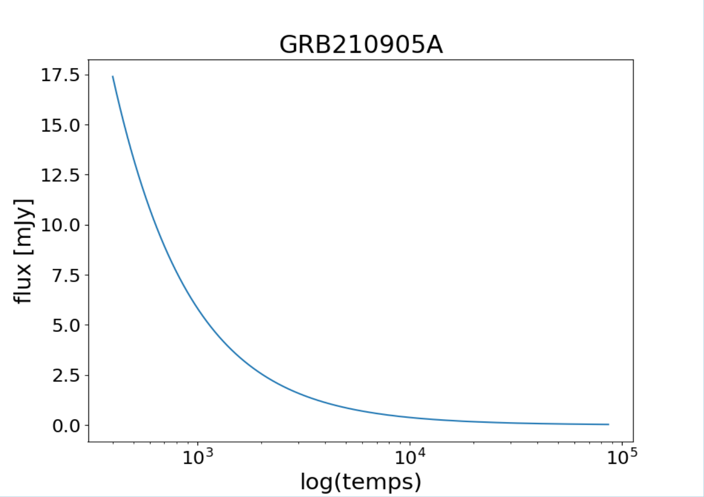
EFFECTS TO SIMULATE : SKY

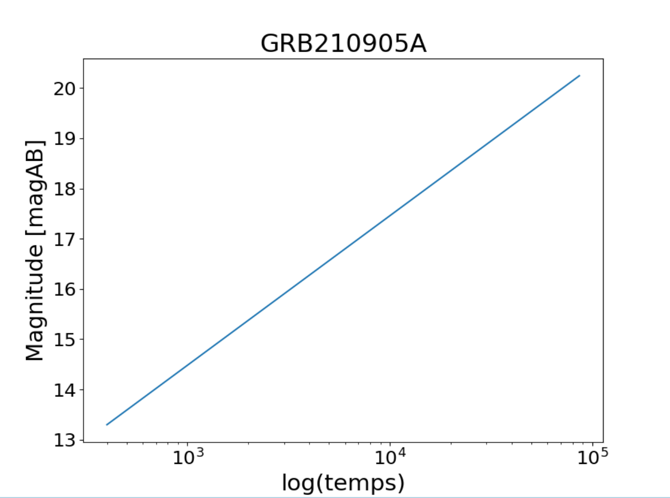
- Sky characteristics
  - → Photometric band to observe (J or H) for sky background.
  - → Acquisition duration
  - → Sky region to observe

Example of sky region + sky background without telescope effects.



Example GRB210905A magnitude and flux curves





- GRB simulation from database
  - → magnitude variation
  - → Position

EFFECTS TO SIMULATE : DETECTOR

- Sensor Characteristics :

Electrons

→ Flatfield map

→ Dark current value

→ Hot pixels map and their flux

→ Dead pixels map (0 where pixels are dead)

→ Cross talk matrix

→ Non linearity map

→ Readout noise

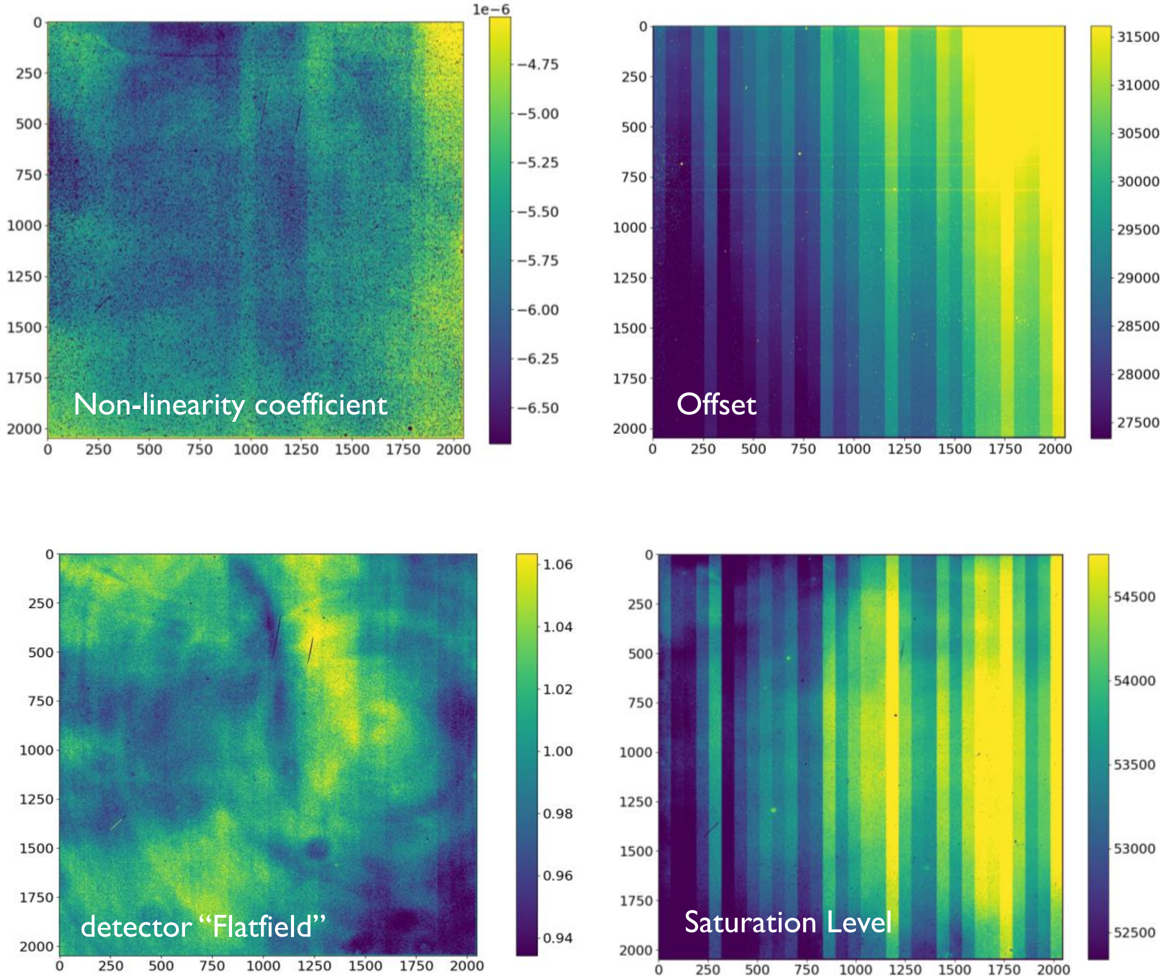
→ Persistence constant maps

→ Gain (electrons/ADU) value

ADU

→ Offset map

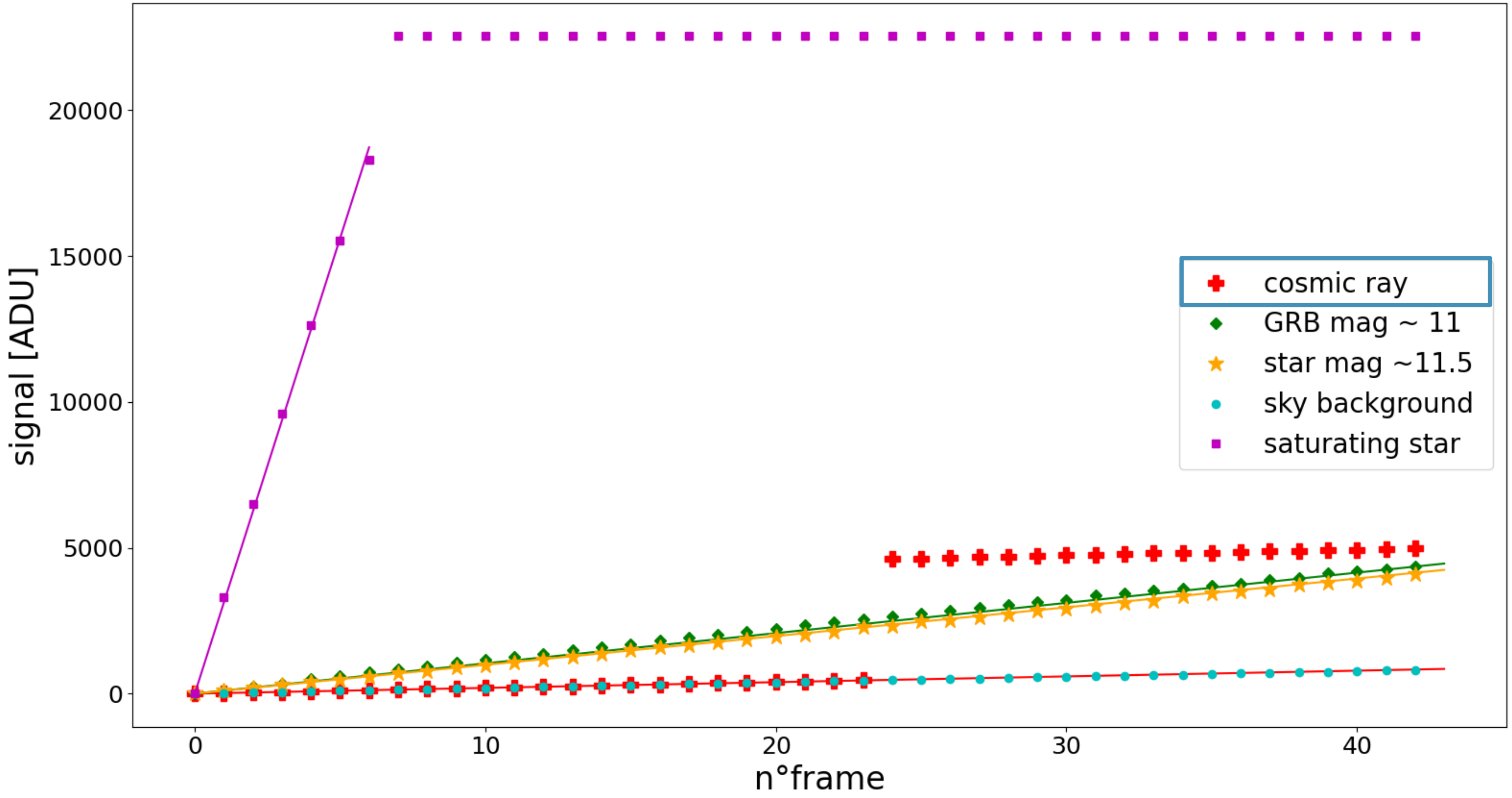
→ Saturation level map



Example of input maps

EFFECTS TO SIMULATE : ENVIRONEMENT

→ **Cosmic ray** position, energy and time of impact

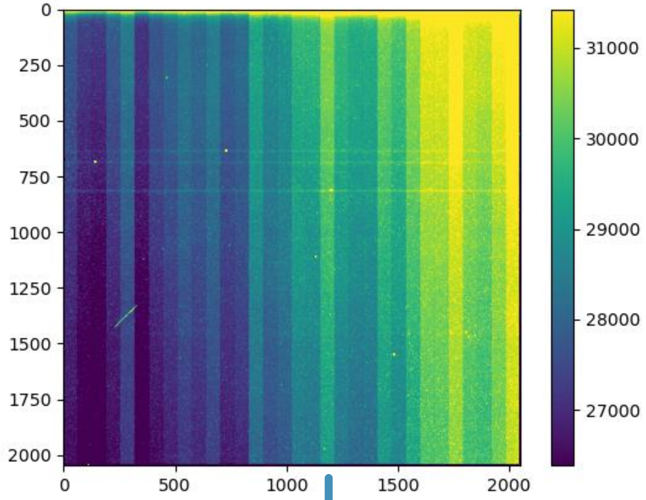


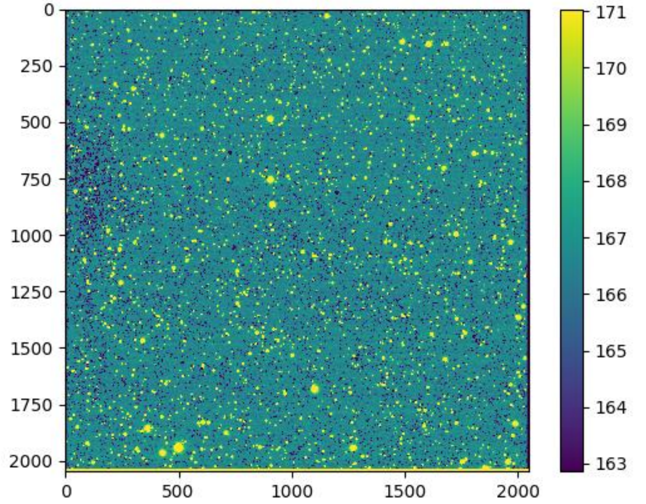
PRE-PROCESSING OF IMAGES

- Pre-processing pipeline : correct ramps from detector and environment effects to create relevant images for the astronomy pipeline.

- Note : Each pixel is processed individually

- Main steps :
  - Find the linear range of the ramp for each pixel
  - Find saturated pixels
  - Correction of common modes noise (with reference pixels)
  - Compute a differential ramp
  - Localize pixels impacted by cosmic rays and correct their signal
  - Compute signal and associated error.





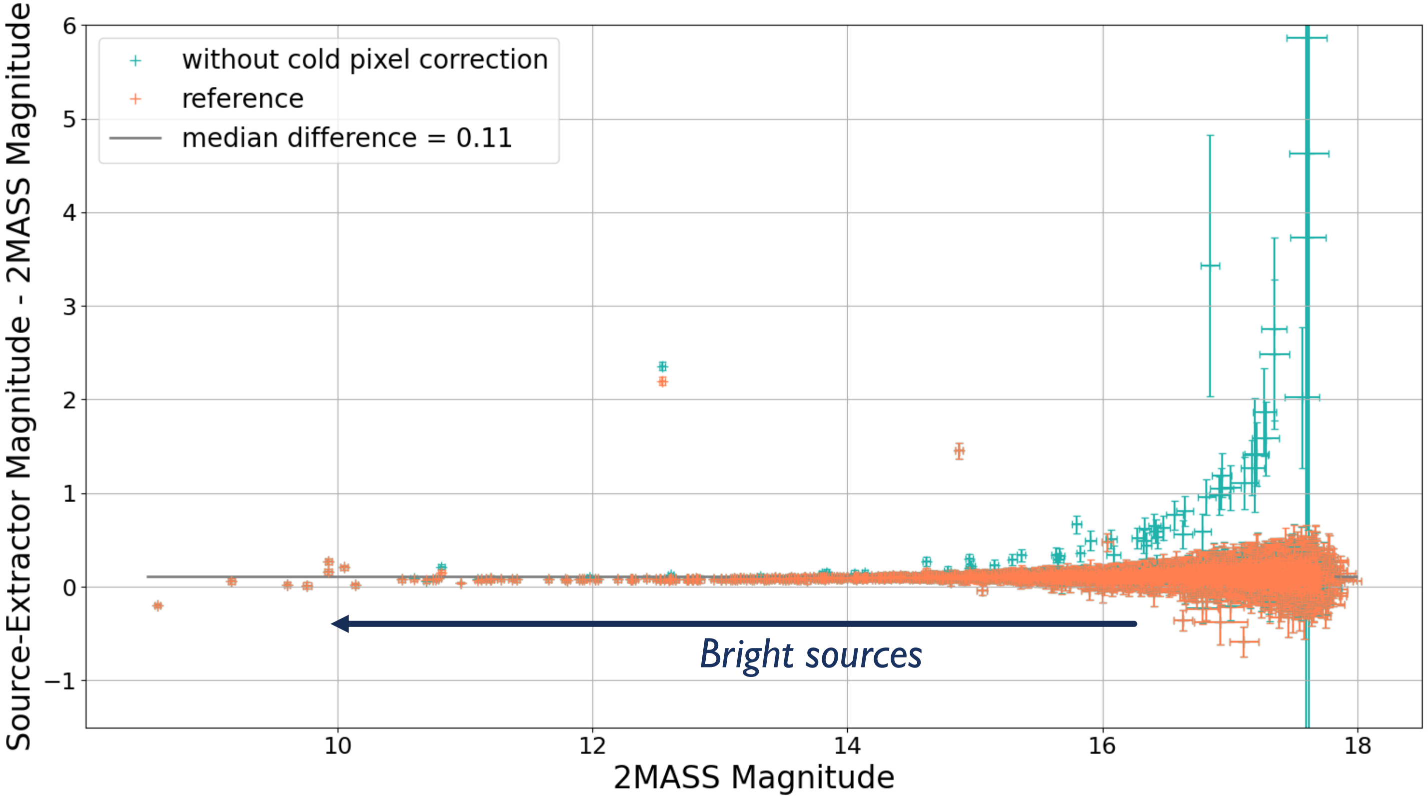
Example of a frame before correction and final flux computed by the pre-processing pipeline, corrected from flatfield.

CAGIRE SIMULATION AND PRE-PROCESSING RESULTS

Test and validation of the pipeline :

- Pre-processed images well calibrated
- Detection of uncatalogued sources

1. Correction of the signal map by the flatfield map.
2. Correction of cold pixels
3. Extraction of sources (Source-Extractor) & cross-match with 2MASS.



(Measured – 2MASS) magnitude versus 2MASS magnitude

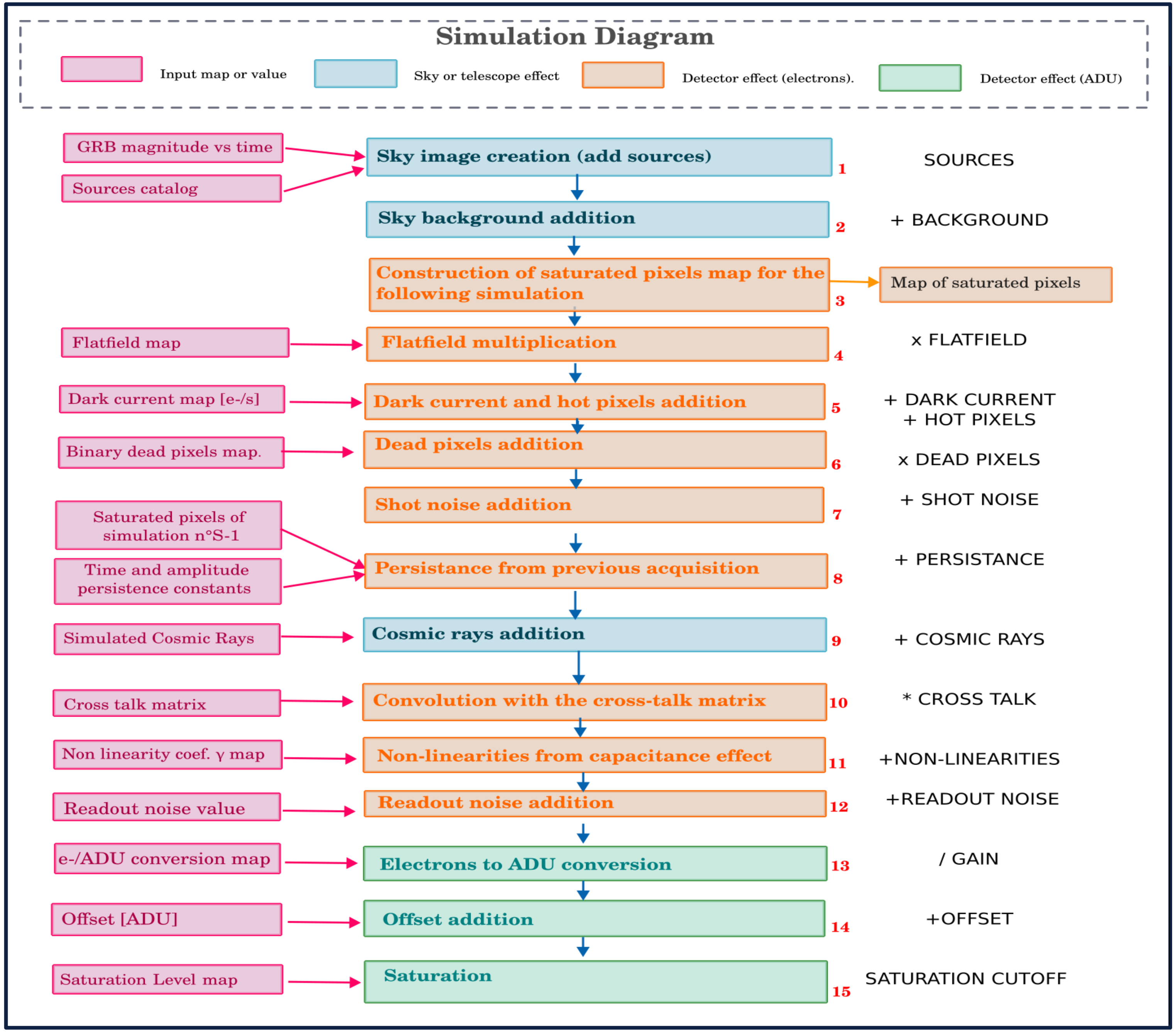
CONCLUSION

- We are able to simulate ramps acquired with the CAGIRE camera, considering detector effects, telescope impact and environment contributions.
- We can simulate GRB generated from database parameters on these maps.
- It allowed us to test our preprocessing pipeline
- We showed that we found results adapted to the astronomy pipeline

Perspectives :

- Simulate different GRBs and look at how we detect them with CAGIRE

BACK UP

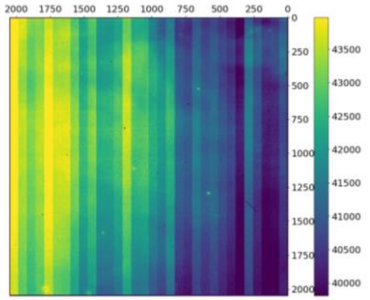


Simulation Diagram
Input map or value
Sky or telescope effect
Detector effect (electrons).
Detector effect (ADU)
GRB magnitude vs time
Sources catalog
Sky image creation (add sources)
1
SOURCES
Sky background addition
2
+ BACKGROUND
Construction of saturated pixels map for the following simulation
3
Map of saturated pixels
Flatfield map
Flatfield multiplication
4
x FLATFIELD
Dark current map [e-/s]
Dark current and hot pixels addition
5
+ DARK CURRENT
+ HOT PIXELS
Binary dead pixels map.
Dead pixels addition
6
x DEAD PIXELS
Shot noise addition
7
+ SHOT NOISE
Saturated pixels of simulation n°S-1
Time and amplitude persistence constants
Persistance from previous acquisition
8
+ PERSISTANCE
Simulated Cosmic Rays
Cosmic rays addition
9
+ COSMIC RAYS
Cross talk matrix
Convolution with the cross-talk matrix
10
* CROSS TALK
Non linearity coef. γ map
Non-linearities from capacitance effect
11
+NON-LINEARITIES
Readout noise value
Readout noise addition
12
+READOUT NOISE
e-/ADU conversion map
Electrons to ADU conversion
13
/ GAIN
Offset [ADU]
Offset addition
14
+OFFSET
Saturation Level map
Saturation
15
SATURATION CUTOFF

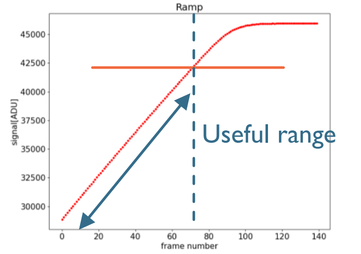
PRE-PROCESSING PIPELINE

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

+ Find saturated pixels.

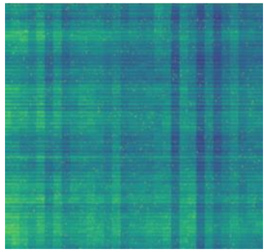


Saturation map

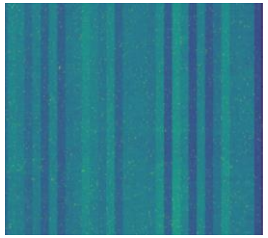


Ramp of one pixel

2) Correction of the common modes thanks to reference pixels

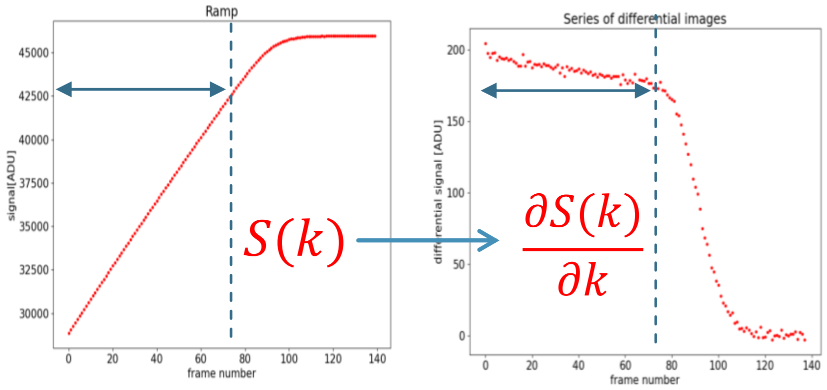


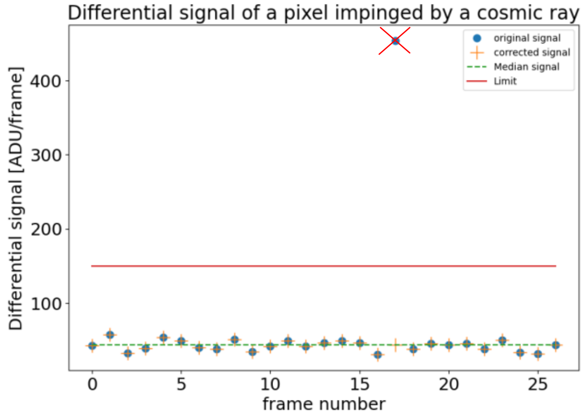
Noise before correction



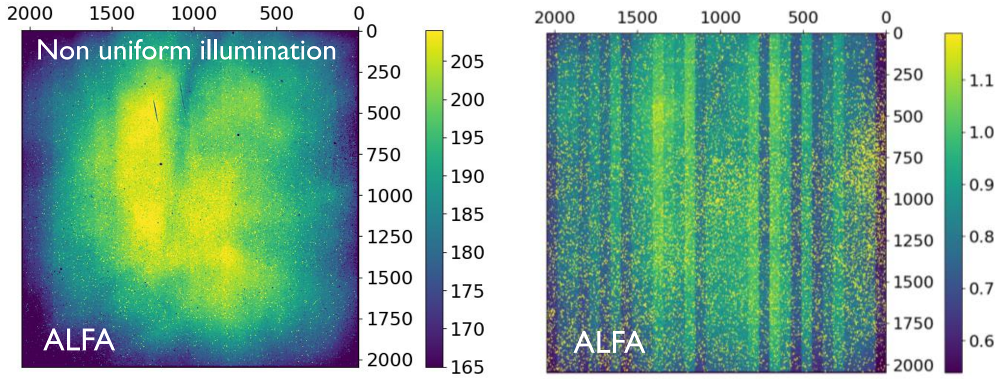
Noise after correction

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





4) Flag cosmic rays and correction of their signal

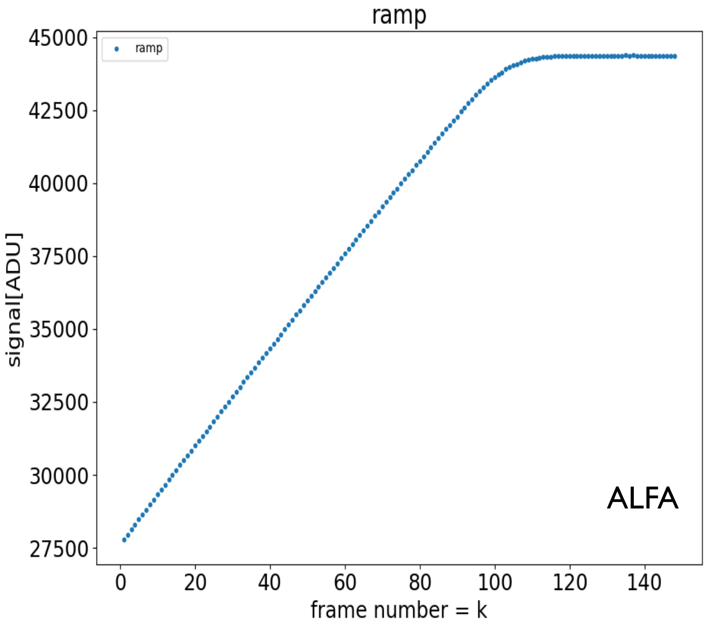


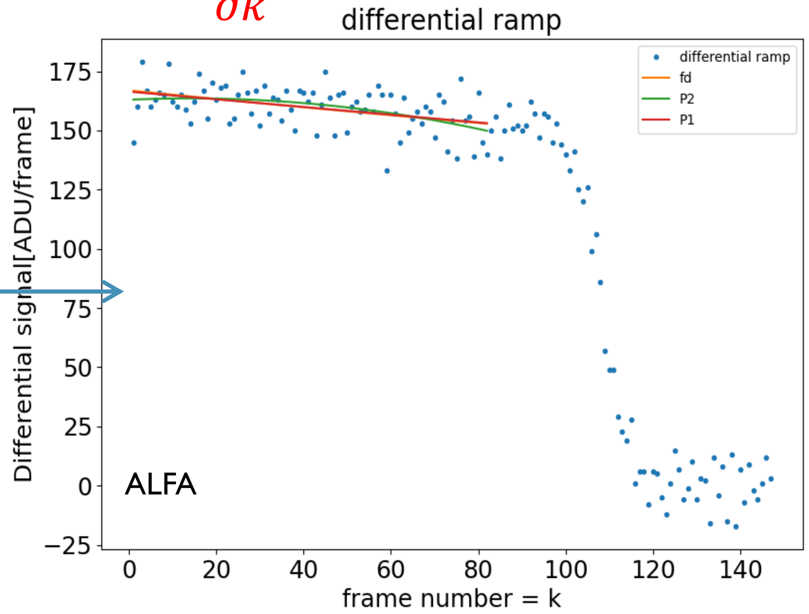
5) Flux and associated error estimation on images corrected from noise and cosmic rays.

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

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

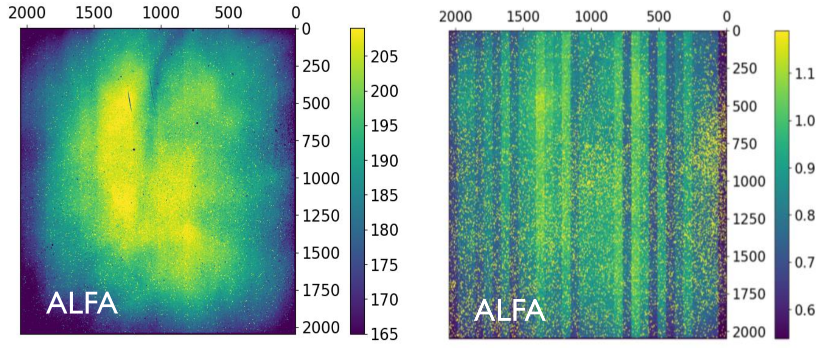
$$P_2(k) = a_2 \times k^2 + a_1 \times k + a_0$$

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

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

→ Flux computed with Ist 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 :

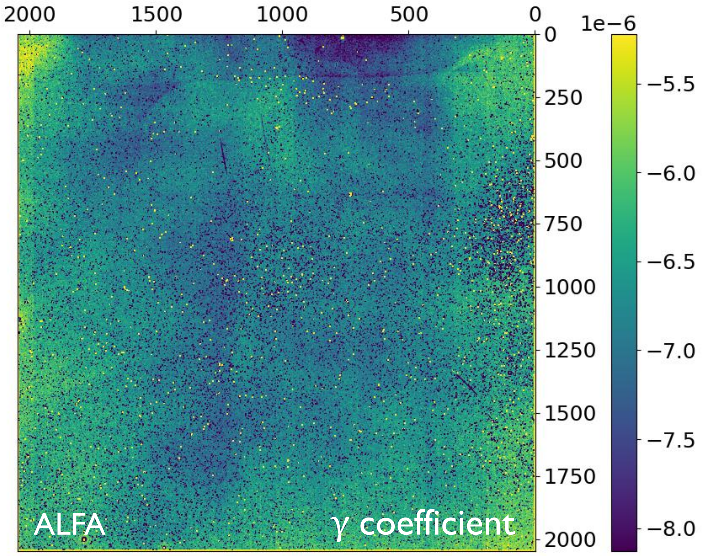
$$d_k = a_0 + a_1 \times k \quad (1)$$

- 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

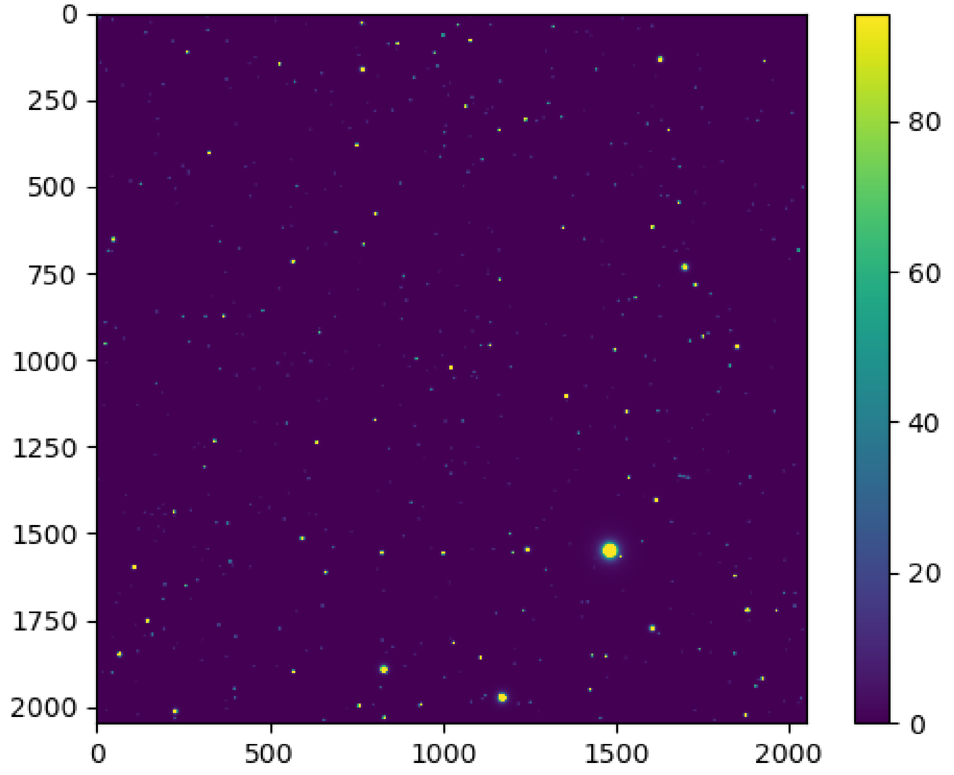
SIMULATION DIAGRAM

GRB mag vs time

T

Sources map creation :

- Source location + PSF
- Mag to e- conversion



T Time dependent

A Detector effect (electrons)

I Input map

D Detector effect (ADU)

E Environment effect

SIMULATION DIAGRAM

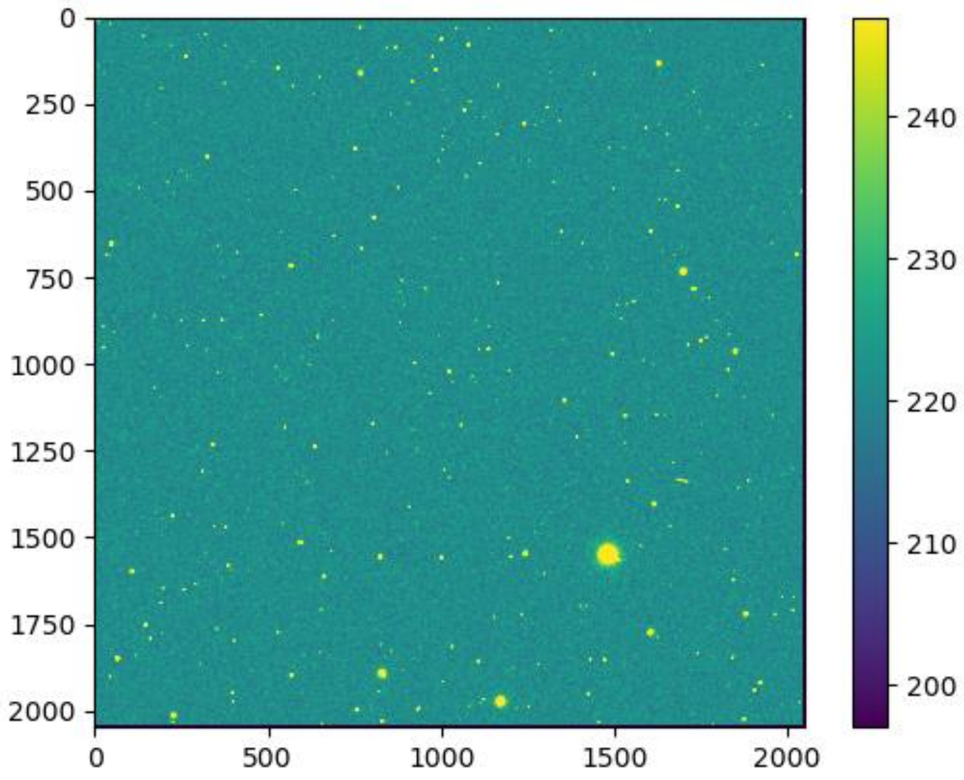
GRB mag vs time

T

Sources map creation :
- Source location + PSF
- Mag to e- conversion

J/H background

Add sky background



T Time dependent

A Detector effect (electrons)

I Input map

D Detector effect (ADU)

E Environment effect

SIMULATION DIAGRAM

GRB mag vs time

T

J/H background

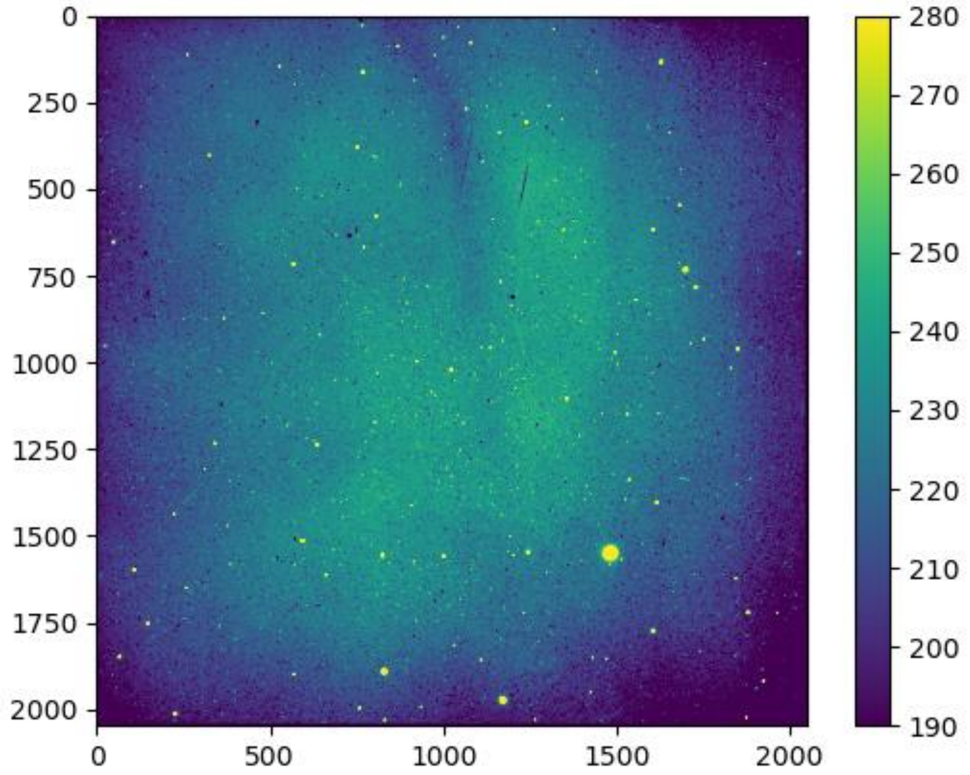
Flatfield map

Sources map creation :

- Source location + PSF
- Mag to e- conversion

Add sky background

Flatfield multiplication



T Time dependent

A Detector effect (electrons)

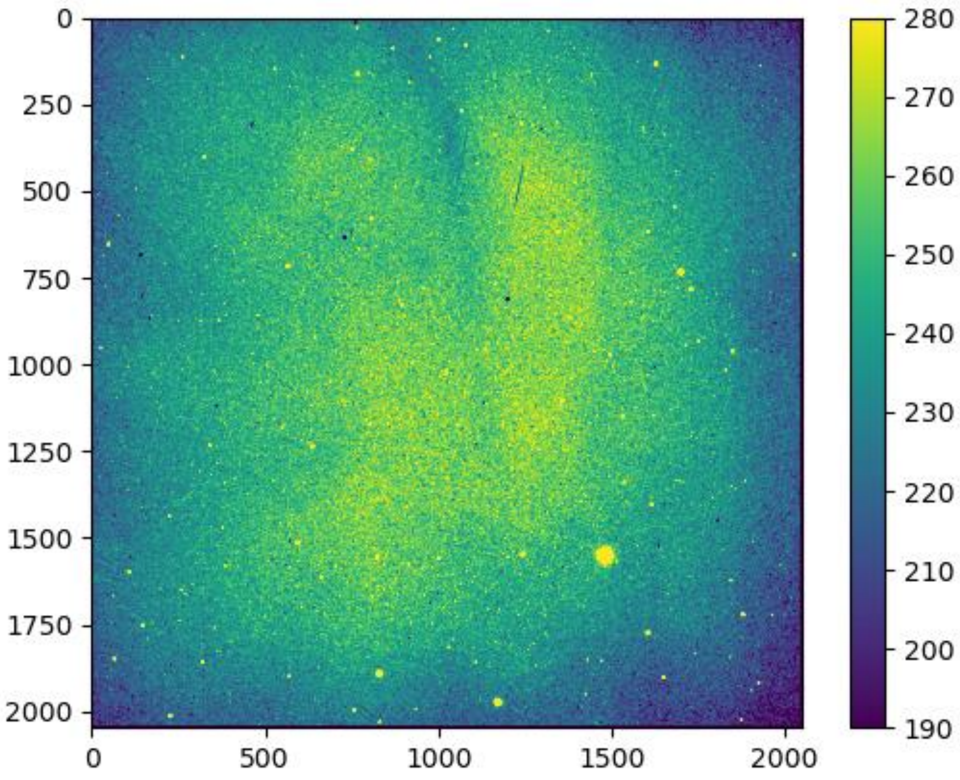
I Input map

D Detector effect (ADU)

E Environment effect

SIMULATION DIAGRAM

Input	Step
GRB mag vs time (T)	Sources map creation : • Source location + PSF • Mag to e- conversion
J/H background	Add sky background
Flatfield map	Flatfield multiplication
DC value	Add Dark Current (DC)
Dead pixel map	Add dead pixels
Hot pixels response map into dark	Add hot pixels
Cosmic rays map	Add cosmic rays
	Add shot noise
Cross Talk matrix	Add cross talk
Non linearity map	Add Non-Linearities
Readout noise value	Add readout noise



T Time dependent

A Detector effect (electrons)

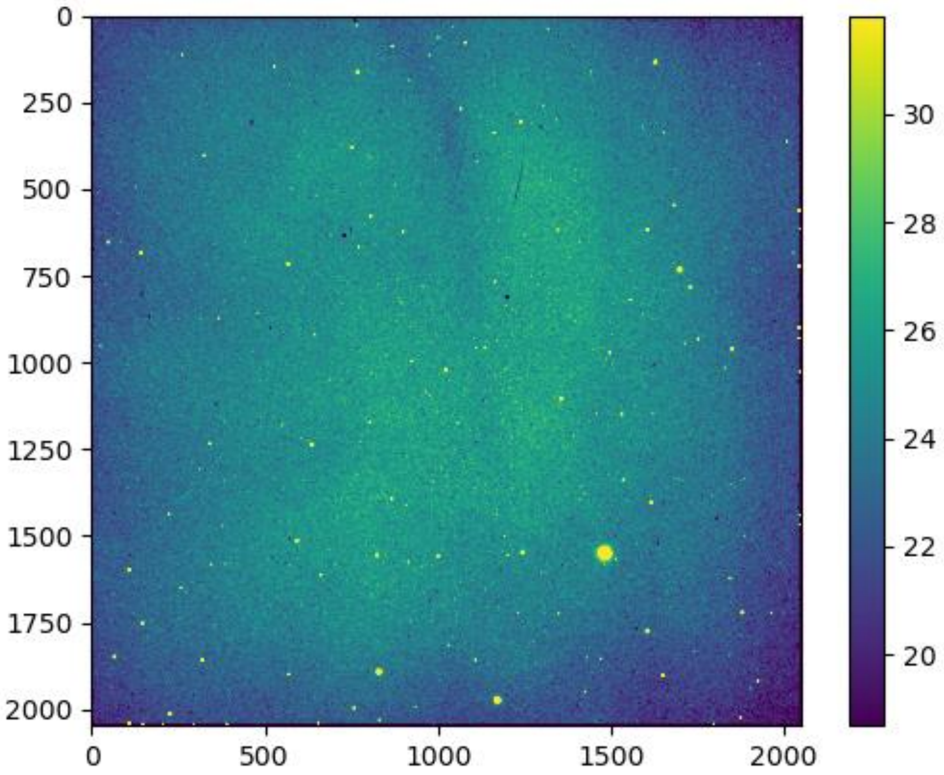
I Input map

D Detector effect (ADU)

E Environment effect

SIMULATION DIAGRAM

GRB mag vs time	T	Sources map creation : • Source location + PSF • Mag to e- conversion
J/H background		Add sky background
Flatfield map		Flatfield multiplication
DC value		Add Dark Current (DC)
Dead pixel map		Add dead pixels
Hot pixels response map into dark		Add hot pixels
Cosmic rays map		Add cosmic rays
		Add shot noise
Cross Talk matrix		Add cross talk
Non linearity map		Add Non-Linearities
Readout noise value		Add readout noise
Gain map		Electrons to ADU conversion



T Time dependent

A Detector effect (electrons)

I Input map

D Detector effect (ADU)

E Environment effect

SIMULATION DIAGRAM

GRB mag vs time (T)	Sources map creation : • Source location + PSF • Mag to e- conversion
J/H background	Add sky background
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DC value	Add Dark Current (DC)
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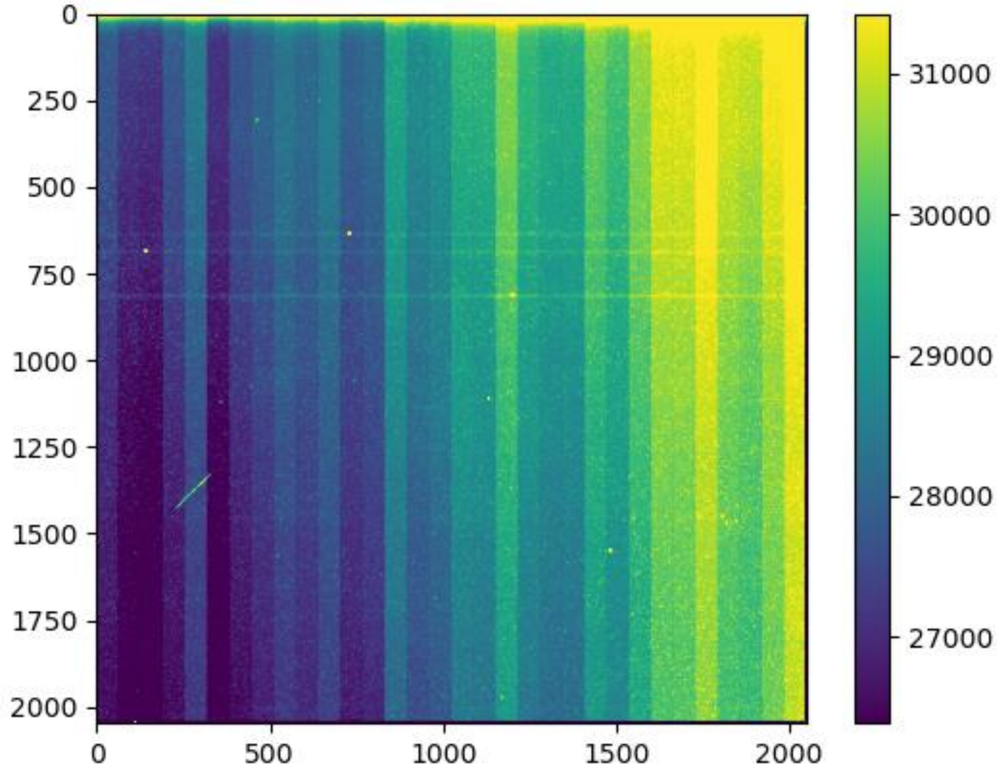
Hot pixels response map into dark	Add hot pixels
Cosmic rays map	Add cosmic rays
	Add shot noise
Cross Talk matrix	Add cross talk
Non linearity map	Add Non-Linearities
Readout noise value	Add readout noise
Gain map	Electrons to ADU conversion
Offset map	Add offset
Saturation map	Cut saturated values



- T — Time dependent
- I — Input map
- E — Environment effect
- A — Detector effect (electrons)
- D — Detector effect (ADU)