Exploring high-redshift GRBs with CAGIRE

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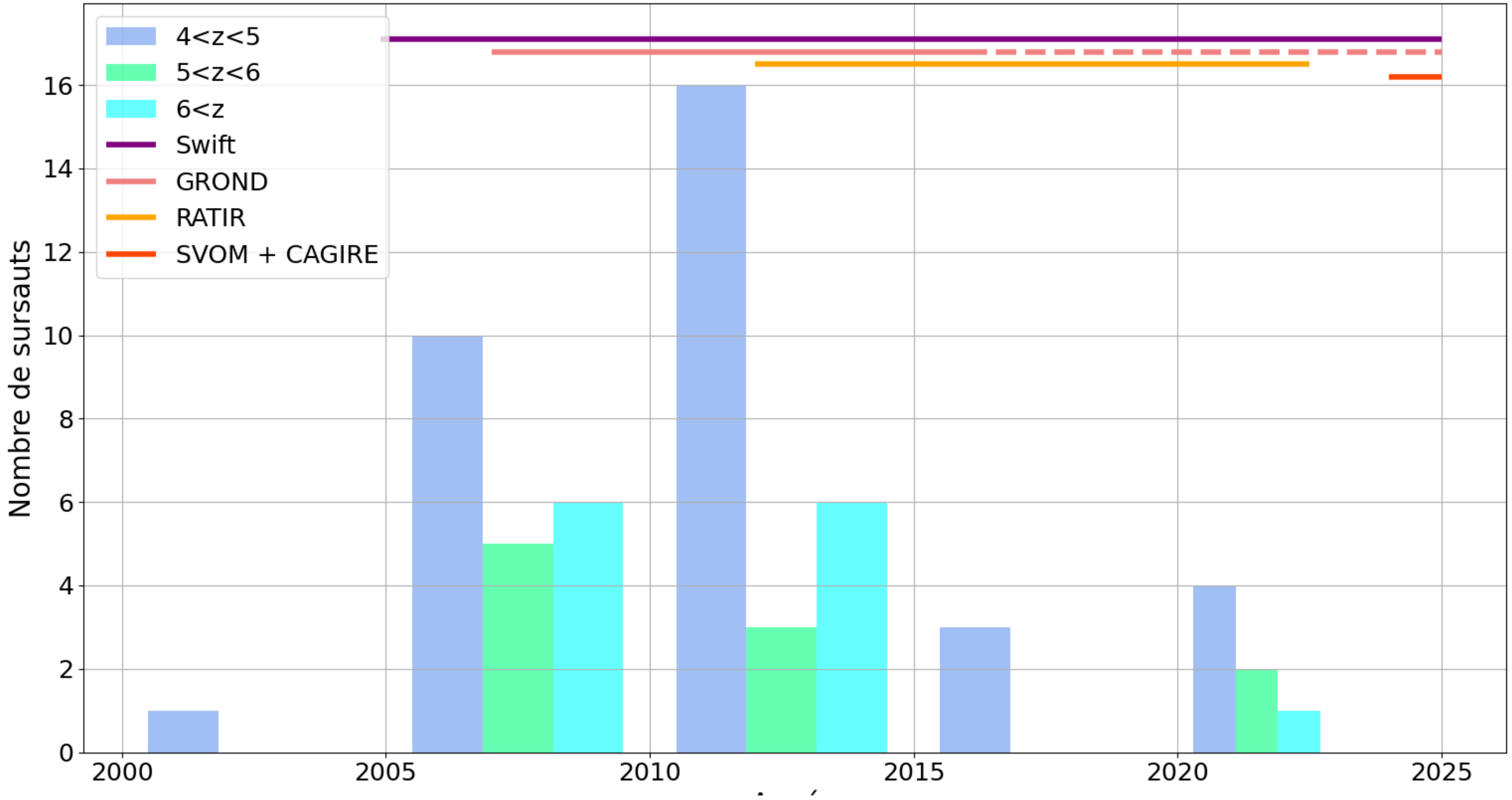
Difficulties to study high-redshift GRBs

- The redshifts of 609 GRBs were measured over the 2424 GRBs detected since 1997
- Scarcity of high-redshift GRBs: only 13 GRBs (2,1%) detected with z>6, since 1997

- 4 < z < 5 : 34 GRBs
- 5 < z < 6 : 10 GRBs
- 6 < z : 13 GRBs



SCIENTIFIC OBJECTIVES

→ Explore distant galaxies

→ Constrain the GRB formation rate

→ Study Pop III stars ?

Detection of the faint hosts galaxies of very distant GRB

GRBs are great tools and allow to:

- Lighten the surrounding environment and reveal and probe their host galaxy (including faint hosts)
- Measure redshift
- Convey information about the gas/dust properties of their host galaxies through a detailed spectroscopy of the afterglow (chemical content, dynamics, hydrogen column density, sate of the IGN…)

As example the detection of *GRB 210905A* and its host galaxy at z~6.3 by SWIFT :

Low metallicity, moderate dust depletion, observation of low-ionization gas clouds far from the GRB, detection of 4 objects close to the host galaxy.

- JWST spectroscopy could help to complete the absorption measurement done by GRBs afterglow's observations (metallicity, dynamics) with emission observation (luminosity, SFR) .

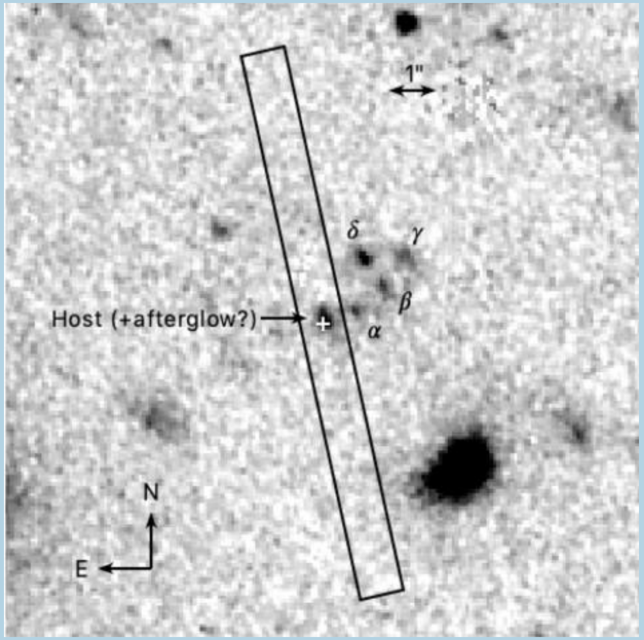
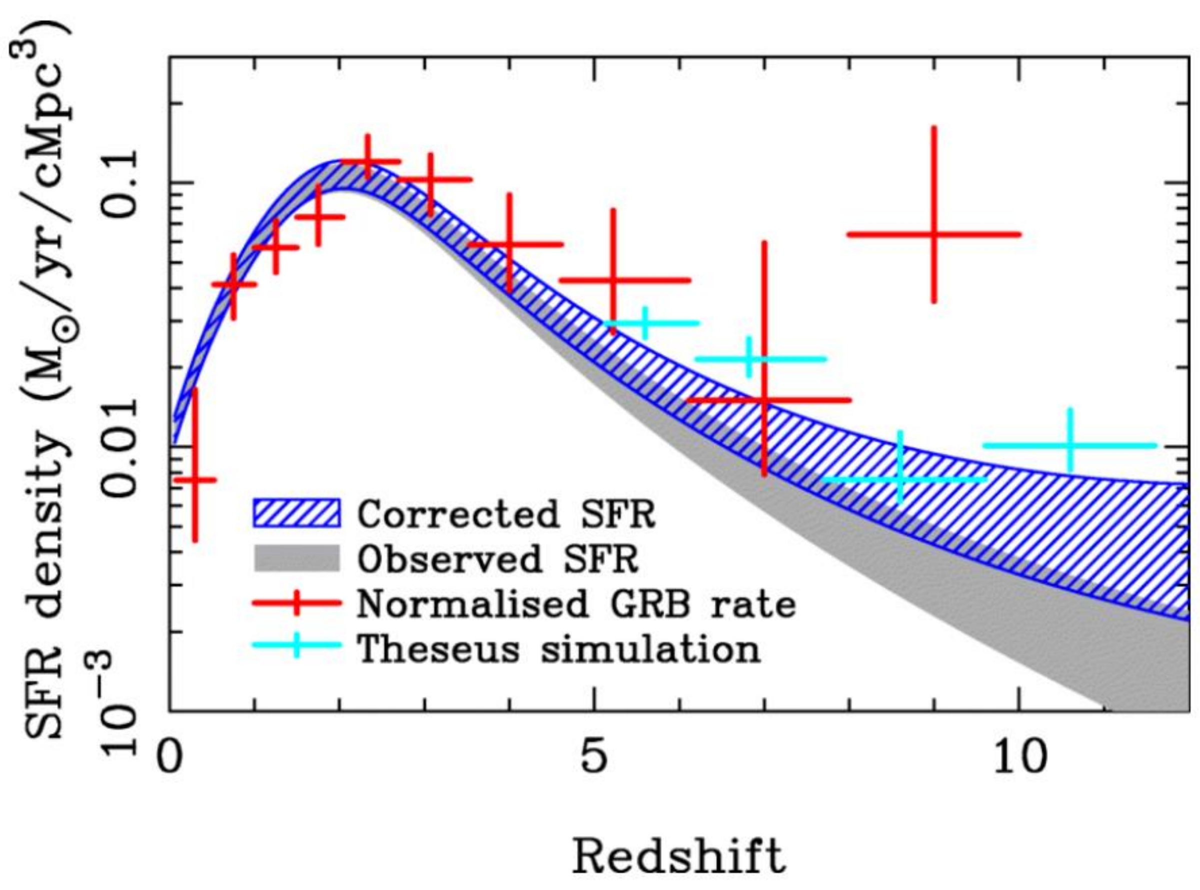


Image of the host 250 days after the trigger .
A. Saccardi et al. 2023

Sources : A. Saccardi et al. 2023, Mc Guire et al. 2018

Constrain the SFR above z~5-6

- Majority of star formation takes place in faint galaxies: difficulties to detect them.
- Long GRBs are associated with star forming regions.
- But Star Formation Rate (SFR) ≠ GRB formation rate (GRB rate seems to decrease more slowly than SFR.)
- Strong rise in the efficiency of producing GRBs with redshift ?
- Uncertainties (and contradictions?) => importance to study the SFR at high z.
- SFR is important to understand the contribution of massive stars to the reionisation of the universe.



Comoving Star Formation Rate density versus redshift.

Tanvir et al. 2021.

Source: Kistler et al. 2018, Bromm and Loeb 2006, Daigne et al. 2018, Tanvir et al. 2021.

Detection of GRB associated with the explosion of population III stars.

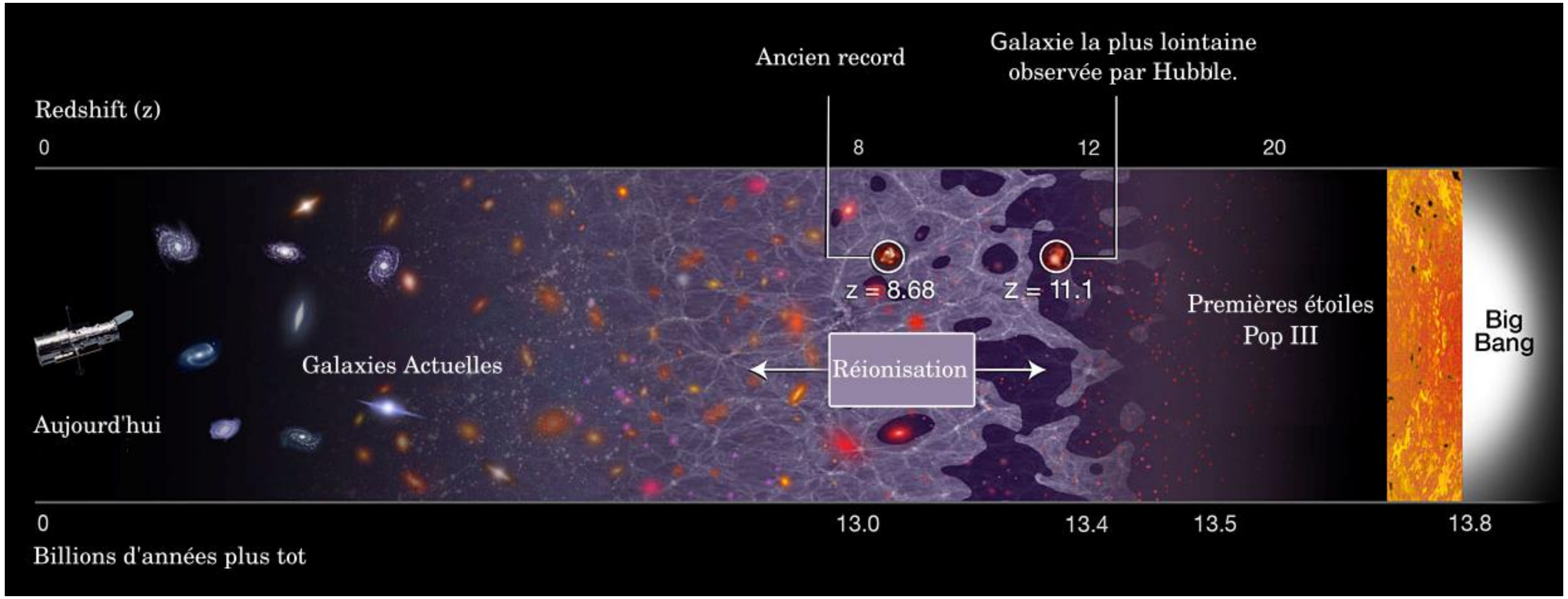
GRB from Pop III stars could help to

- Learn more about the history of star formation and about the transition between :

(1) The early universe: simple, homogeneous , populated with massive stars (pop III)

(2) The actual universe: more complex, populated with solar size stars (pop I & II)

- Learn more about the cosmic re-ionisation of the Inter Galactic Medium (IGM)



Sources:
NASA, Salvaterra et al. 2015

Detection of GRBs associated with the explosion of population III stars.

- Pop III stars could explain the reionisation and IGM promptly enrichment with heavy elements. They should be :

(1) Be (very) massive

(2) Have a high surface temperature: efficient sources of ionizing photons

(3) Present a short stellar evolution (10^6 years)

- Pop III stars with a close binary companion could be GRB progenitors. Pop III originated GRB should present:

(1) An afterglow free from metallic element: difficult to observe without very high signal to noise ratio

(2) Long and highly energetic because of the mass of the stars

Until today only Pop I/II stars have been observed even at redshift z>7, in massive galaxies, because of the rapid IGM enrichment with the first supernovae.

Sources: Toma et al. 2011, Bromm and Loeb 2006

Requirements to use GRBs as probes of the distant universe.

SVOM + ECLAIRs

- Science : Study and characterize the GRB
- + GRB position

COLIBRI
+ **CAGIRE** & DDRAGO

- Science : Multi-wavelength observation + afterglow photometric evolution
- + Quick and precise localisation + Redshift estimation

Large telescopes
(ALMA, ELT,VLT…)

- Science : High resolution spectroscopy + Imaging
  + Study high-redshift afterglows (z>6)

CAGIRE

CAPTURING GAMMA RAY BURST INFRA-RED EMMISSION

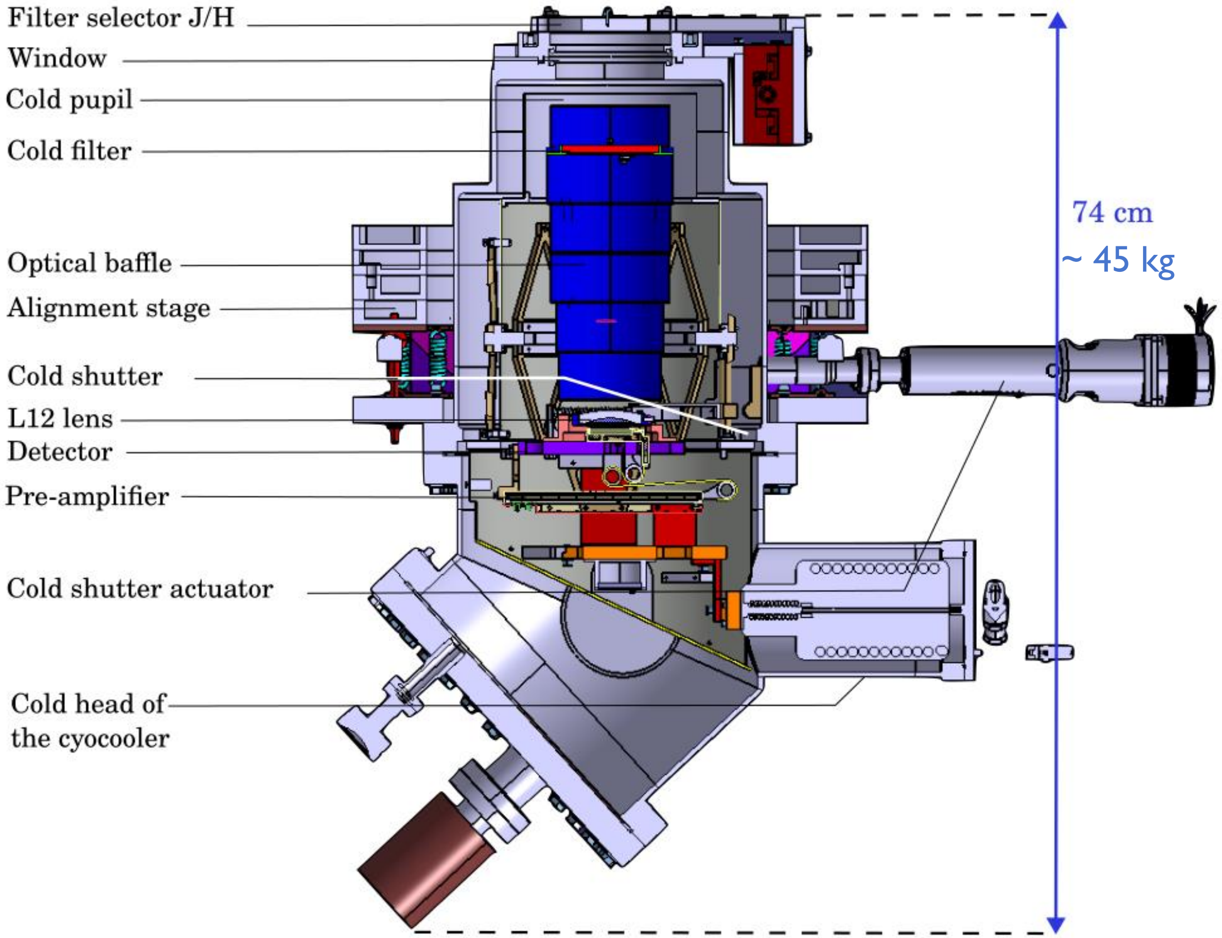
Study the IR counterpart of the afterglows of SVOM GRBs.

CAGIRE aims to:

- Study high redshift candidates
- Localize more precisely the bursts
- Combined with DDRAGO: measure the photometric redshift

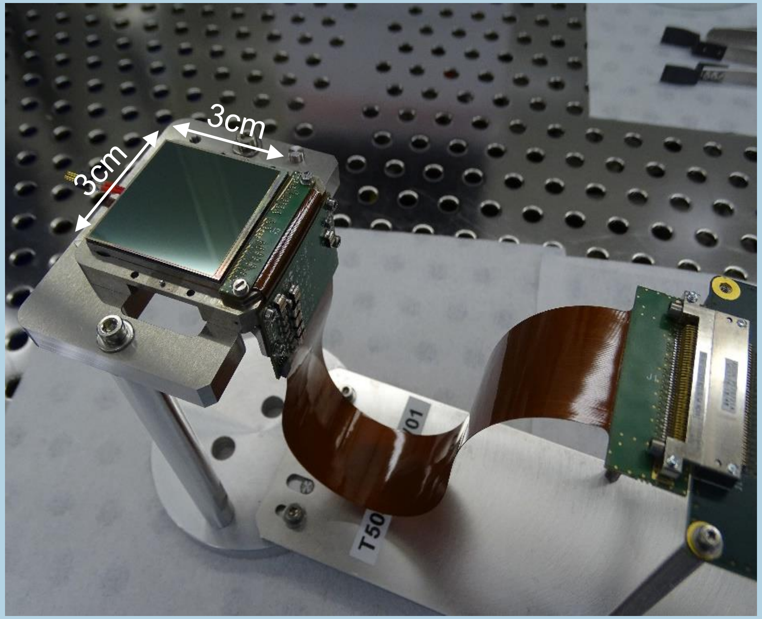
CAGIRE

CAGIRE Parameters	
Field of view	21.7 ‘
Sky pixel size	0,65”
Wavelength range Photometric channels	1.1 – 1.8 µm J & H
Sky background expected	160 e-/s/pix (J) 1250 e-/s/pix (H)
Attainable redshift	Up to z~11
Vacuum autonomy	> 6 months
Detector	ALFA
Number of pixels	2048 × 2048



THE ALFA SENSOR

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

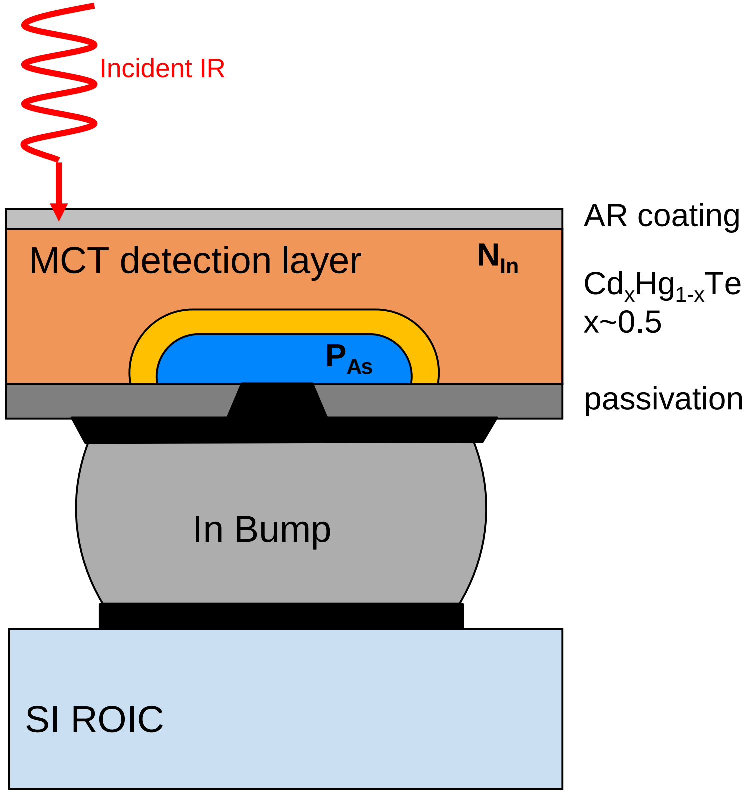


ALFA Sensor

Source : *Fabrication and characterization of a high performance NIE 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



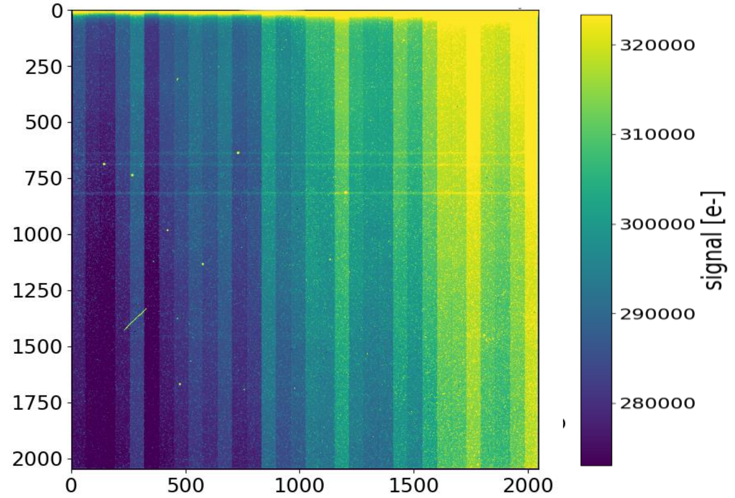
ALFA Sensor diagram

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

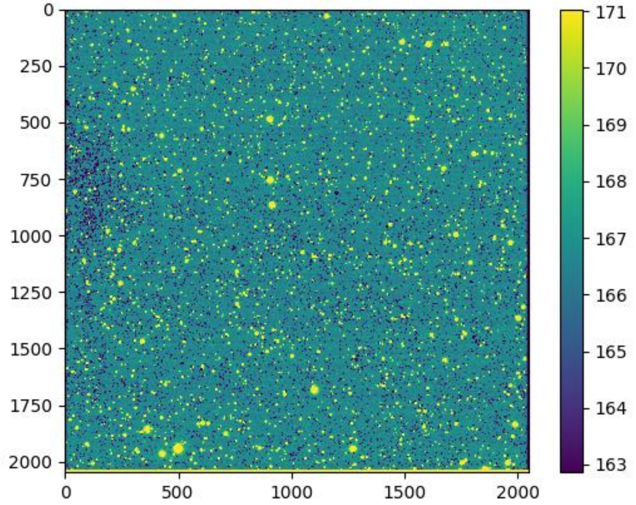
- Characterization by CEA-IRFU allowed to simulate the camera

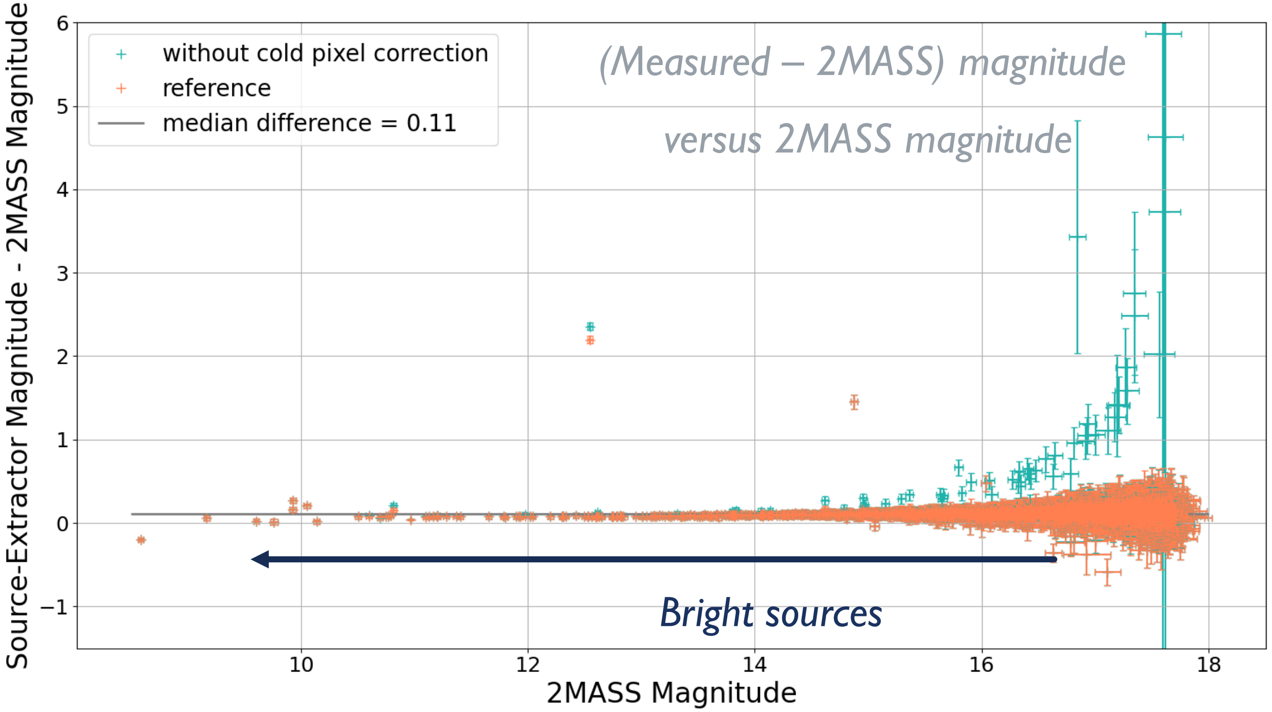
CAGIRE SIMULATION

- Efficiency of CAGIRE pre-processing pipeline to provide relevant signal maps for astrophysics studies



Example of a final flux map corrected from flatfield





(Measured – 2MASS) magnitude

versus 2MASS magnitude

1. Pre-processing to compute the signal while correcting non linearities, saturated pixels, cosmic rays.
2. Flatfield correction of the signal map and correction of cold pixels
3. Extraction of sources (Source-Extractor) & cross-match with 2MASS.

CONCLUSION

- Hight redshift GRBs are difficult to localize and to observe
- Their detection could help to:

→ Explore distant galaxies

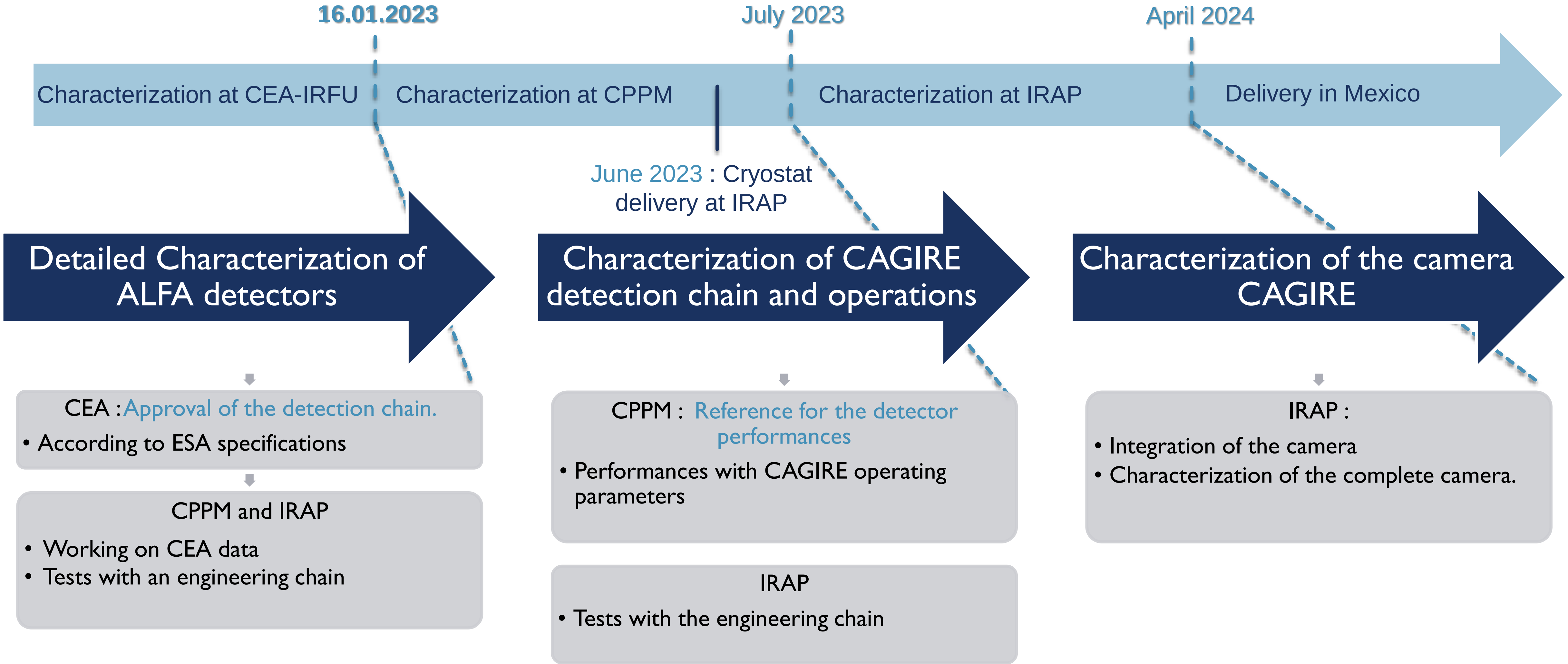
→ Constrain the GRB formation rate

→ Study Pop III stars ?

- CAGIRE at the focus of the robotic telescope COLIBRI : to study distant GRB thanks to its sensibility in the infra-red, targeting GRBs with a redshift z<11
- Efficiency of CAGIRE pre-processing pipeline to provide relevant signal maps for astrophysics studies

CHARACTERIZATION STRATEGY

- The detector is now at CPPM !



16.01.2023

July 2023

April 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

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.

PERSISTENCE CORRECTION

- Accumulated persistent signal : $P(t) = A_1\left[1 - exp\left(-\frac{t}{\tau_1}\right)\right] + A_2\left[1 - exp\left(-\frac{t}{\tau_2}\right)\right]$
- Correction with 2 maps : A1 and A2 (with τ1 and τ2 fixed beforehand)