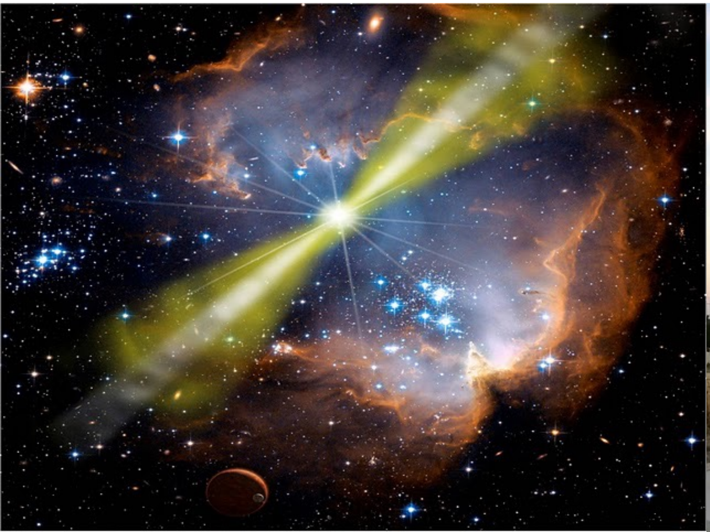
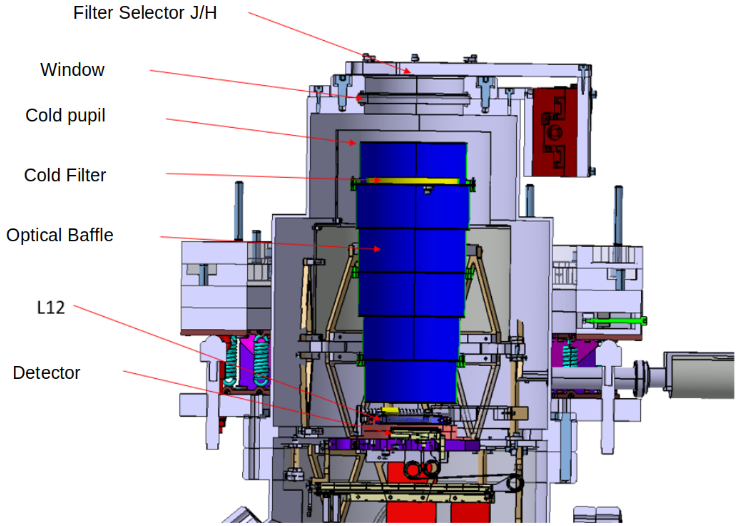
CAGIRE

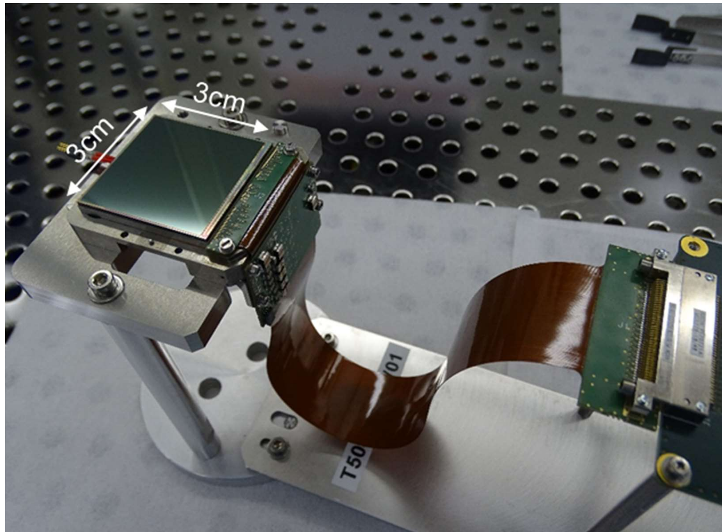
A NIR camera at the focus of the COLIBRÍ Ground Follow up Telescope

to quickly observe SVOM and multi-messengers alerts

J.L. Atteia – IRAP (Toulouse) – For the CAGIRE team







Outline

- *SVOM* & Colibrí
- The instrument (1)
- The sensor
- The instrument (2)
- Conclusions

SVOM & Colibrí

The *SVOM* mission

SVOM Science Goals

- **HE transient Astrophysics addresses major questions**
  - Stellar explosions – BNS mergers and the origin of heavy elements – BH astrophysics – Origin of magnetar activity...
  - Physics of relativistic jets, their role in VHE cosmic rays production
  - The high-z universe (with GRBs): IGM, first stars...
  - Tests of Lorentz Invariance

- **Diverse sources require diverse observing strategies**
  - Gamma-ray bursts (of all types)
  - Mergers of compact objects
  - Active Galactic Nuclei & Relativistic Tidal Disruption Events
  - Galactic transients & Magnetars
  - Fast Radio Bursts?

- **The study of astronomical transients will benefit from a rich astronomical panorama in the 2020's:**
  - Radio: SKA precursors & FRB detectors
  - Visible: Pan-STARRS – ZTF – VRO (LSST)
  - VHE γ-rays: CTA, HAWC, LHAASO
  - GWs: LIGO – VIRGO – KAGRA
  - Neutrinos: KM3NeT – ICECUBE

  This is a non-comprehensive list...

- **Multi-wavelength and multi-messenger astrophysics need High Energy observatories**

➔ **Monitoring the High-Energy sky will be more needed than ever in the coming years.**

➔ ***SVOM* brings some new capabilities.**

The *SVOM* Collaboration

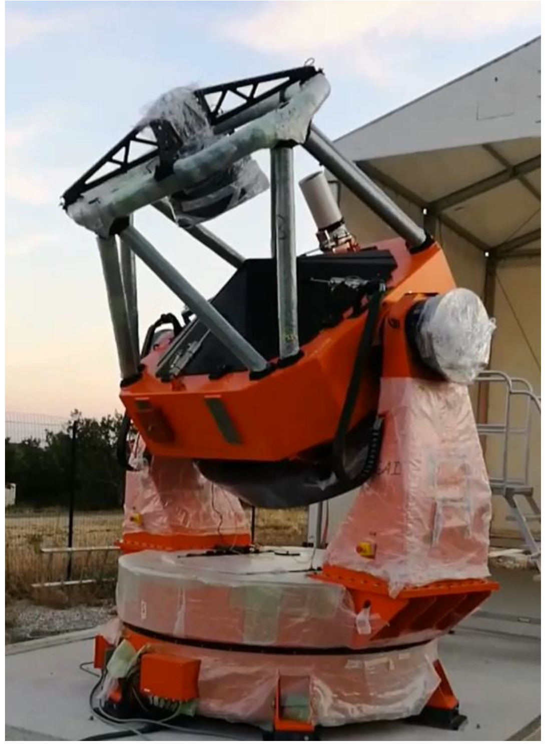
- **China (PI J. Wei)**
  - SECM Shanghai
  - Beijing Normal University
  - Central China University Wuhan
  - Guangxi University Nanning
  - IHEP Beijing
  - KIAA Peking University
  - Nanjing University
  - NAOC Beijing
  - National Astronomical Observatories
  - Purple Mountain Observatory Nanjing
  - Shanghai Astronomical Observatory
  - Tsinghua University Beijing
- **Mexico** UNAM Mexico
- **France (PI B. Cordier)**
  - CNES Toulouse
  - APC Paris
  - CEA Saclay
  - CPPM Marseille
  - GEPI Meudon
  - IAP Paris
  - IRAP Toulouse
  - LAL Orsay
  - LAM Marseille
  - LUPM Montpellier
  - OAS Strasbourg
- **UK** University of Leicester
- **Germany**
  - MPE Garching
  - IAAT Tübingen

The Colibrí robotic telescope...

... will be installed at the Mexican National Observatory in San Pedro Mártir

... has the following characteristics:

- Primary diameter: 1.3 m
- Fast pointing speed: ≈20 sec
- Pointing accuracy: 2.5”
- 2 Nasmyth ports
  - Nasmyth 1: three imaging instruments
    - Field of view: 26’ (21’ for CAGIRE)
    - Filters: g /r/ i – y/z – J/H
  - Nasmyth 2: medium resolution spectrograph



CAGIRE, the NIR camera of Colibrí

- CAGIRE is developed in the context of the *SVOM* mission (https://www.svom.eu/)

- CAGIRE is funded by CNES, CNRS (IRAP), and the LabEx FOCUS. CAGIRE involves several partners:
  - Lynred & CEA-LETI
  - LabEx FOCUS
  - CEA-IRFU / CPPM / IRAP / LAM

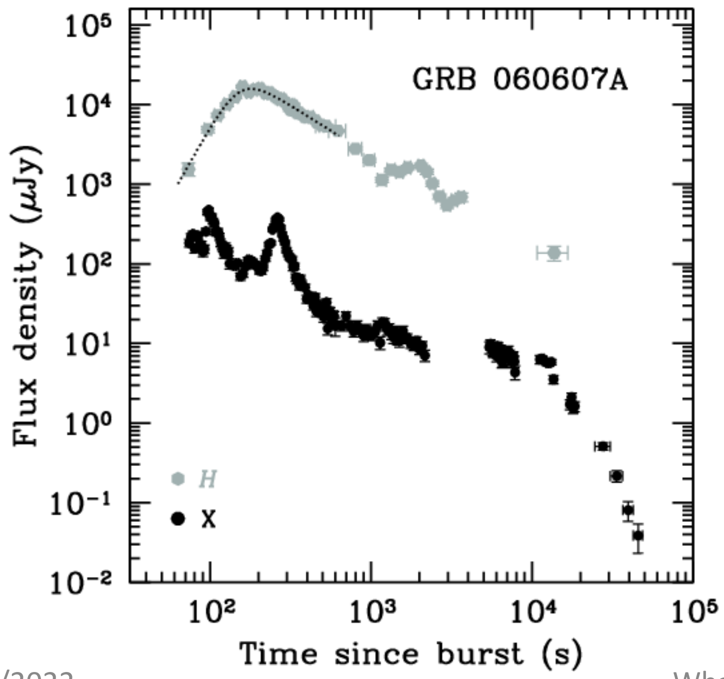
- Responsibilities:
  - CAGIRE is built under the responsibility of IRAP.
  - Coordination between the different partners is made by CNES.
  - The detector will be characterized by CEA and CPPM before its integration in CAGIRE.
  - Coordination with Colibrí is made by the project team at LAM.

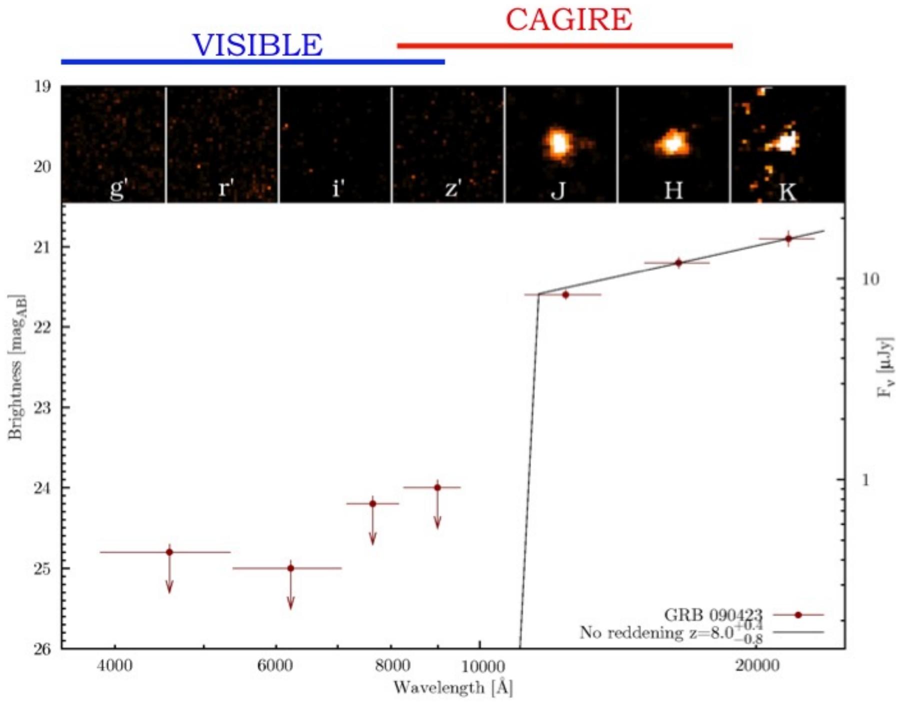
- CAGIRE will be delivered at OAN SPM in (spring) 2024.

Science goals of CAGIRE - 1

- Extend towards the NIR the frequency range of GFT/Colibrí:
  - To detect highly redshifted and extinct sources.
  - To expand the photometry of optical transients and of permanent sources into the NIR: Photo-z, Dust properties, etc.
- The early afterglow (<1000 s) of GRBs is poorly observed in the NIR.
- Soon after the GRB, NIR afterglows can be very bright...

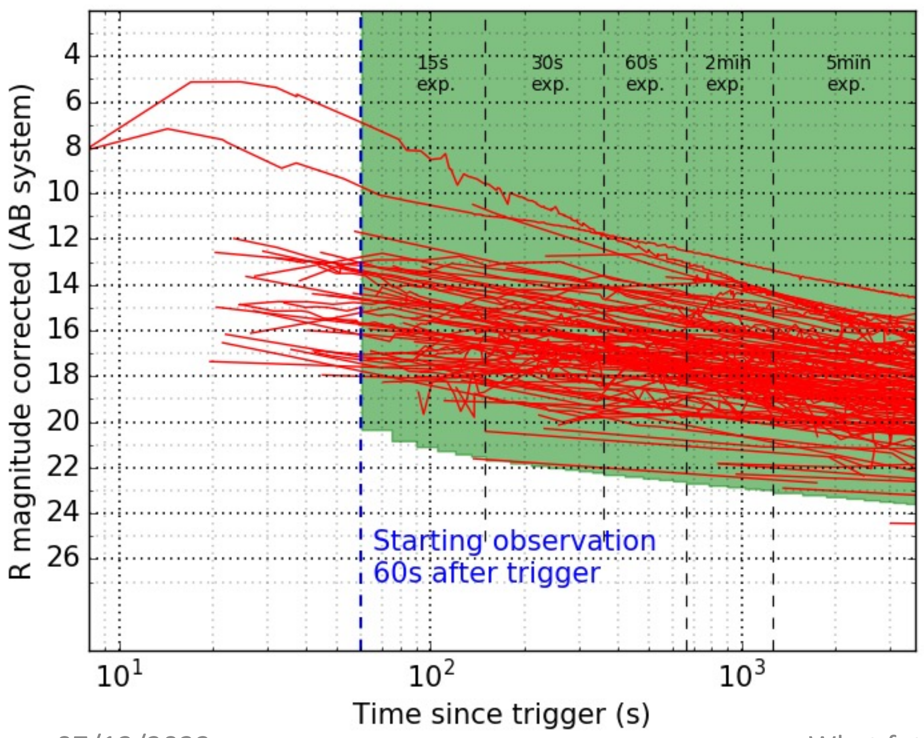
(Molinari et al. 2007 – REM-IR)



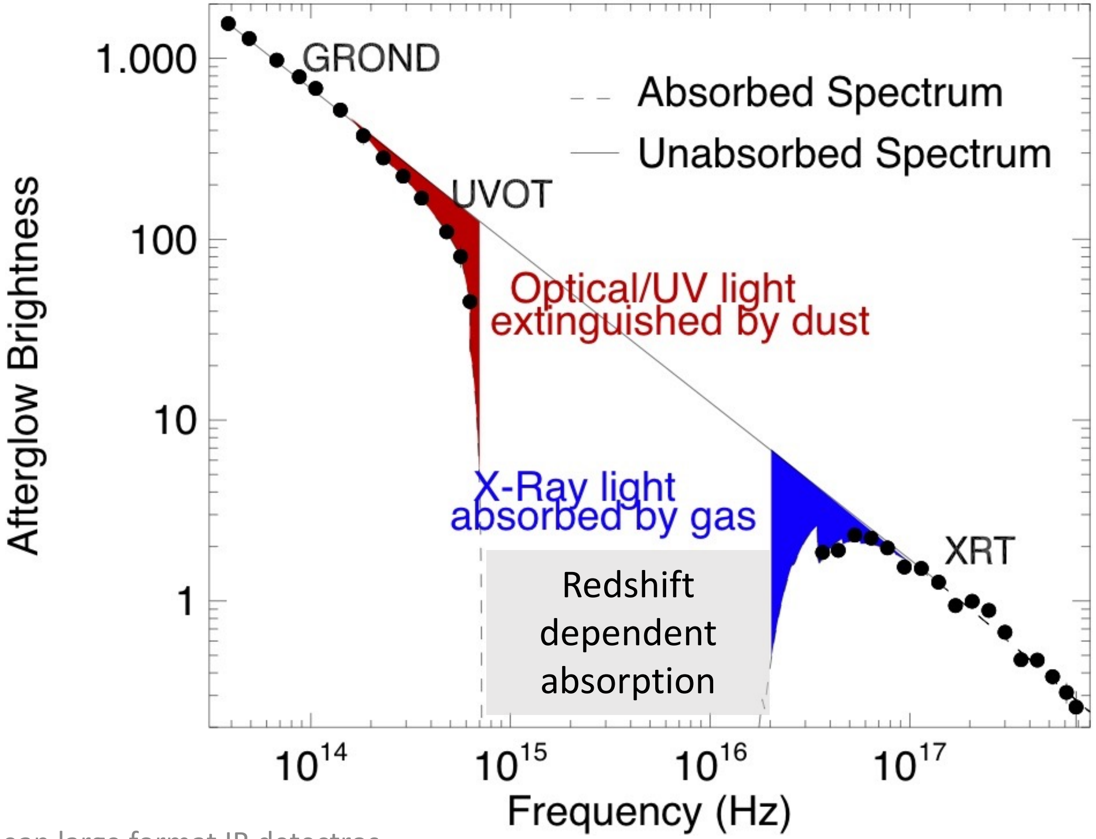


Science goals of CAGIRE - 2

- Extend towards the NIR the frequency range of GFT/Colibrí:
    - To detect highly redshifted and extinct sources.
    - To expand the photometry of optical transients and of permanent sources into the NIR: Photo-z, Dust properties, etc.
- The early afterglow (<1000 s) of GRBs is poorly observed in the NIR.
- Soon after the GRB, NIR afterglows can be very bright...



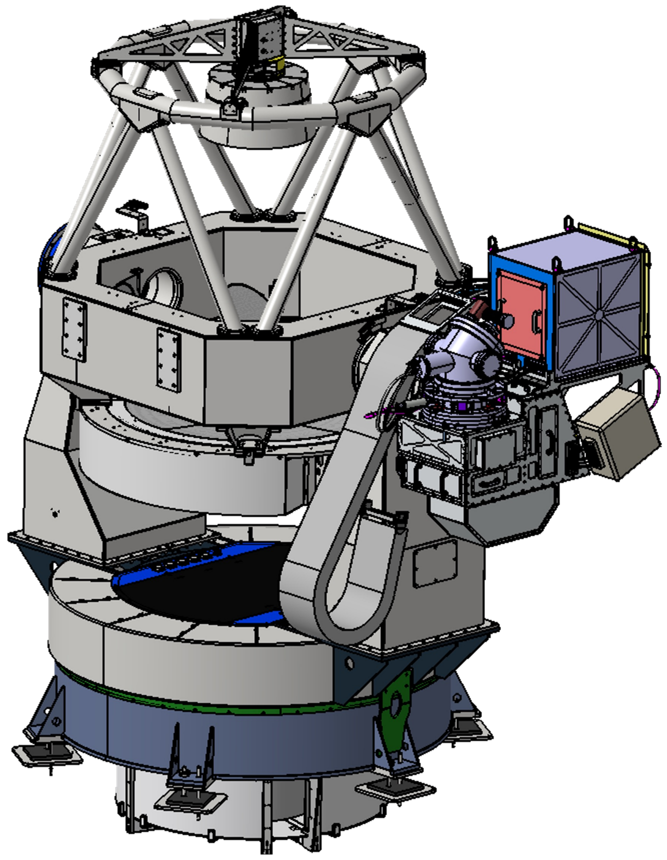
(Credit: P. Schady)

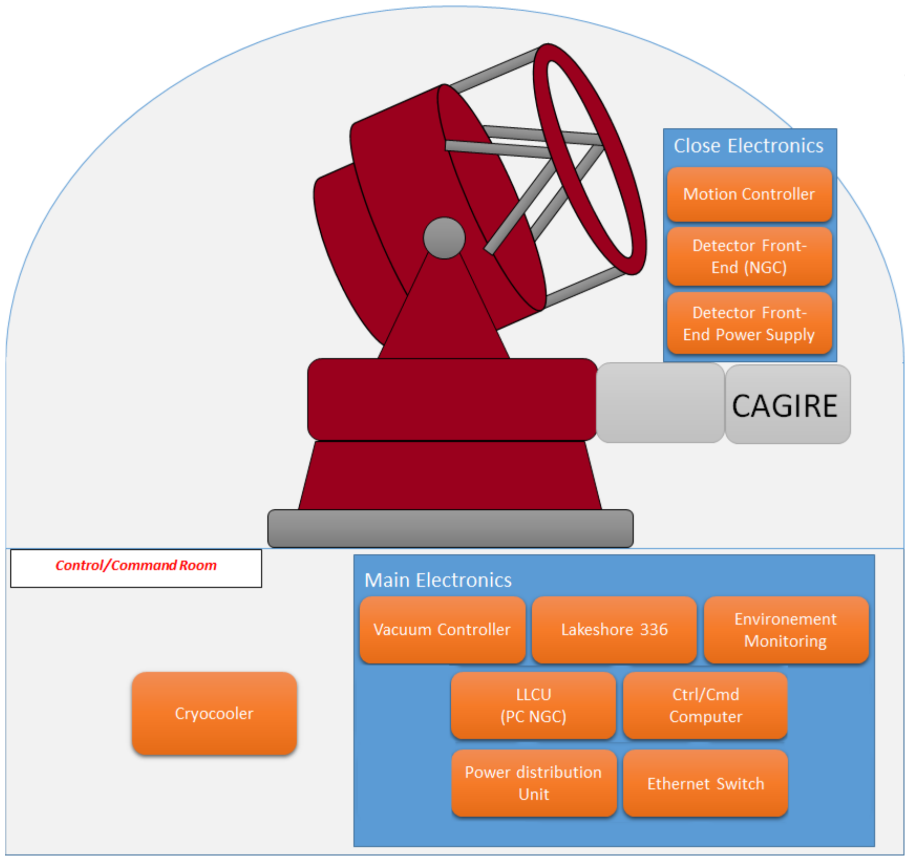


The instrument - 1

Three subsystems…

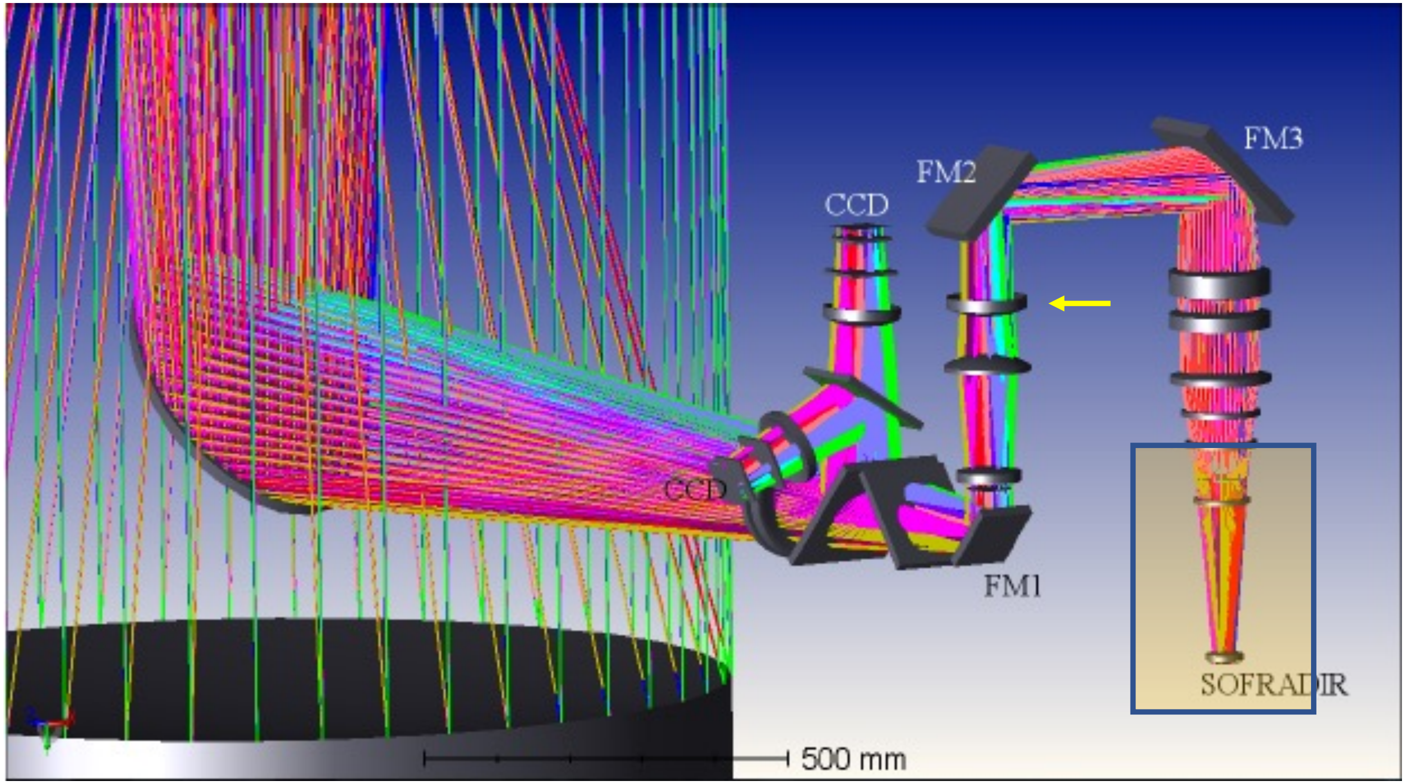
- CAGIRE encompasses three sub-systems:
  - Cryostat
  - On-board (close) electronics
  - Remote (main) electronics
- Some consequences:
  - Rotating instrument and controller.
  - Cryogenic vacuum.
  - Cable paths from the control room to the instrument.

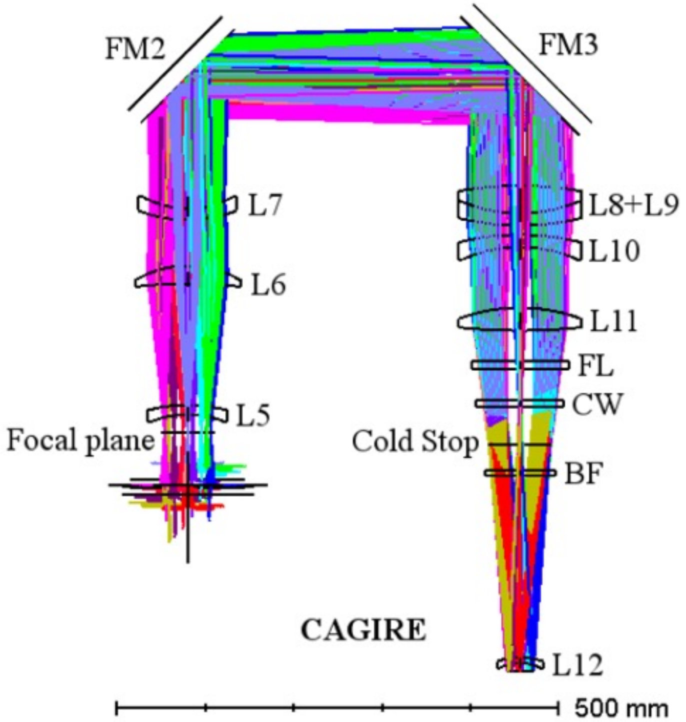




Optical design

- The optical design has been made by UNAM.





A NIR camera on a fully robotic telescope

Design trade-offs

- Outside the cryostat, warm optics:
  - VIS vs NIR separation at 1.1 µm.
  - Focus done by moving L7.
  - Warm shutter
  - J & H filters: [1.17 – 1.33] & [1.49 – 1.78] µm
- Inside the cryostat:
  - Cold pupil.
  - Blocking filter for wavelengths >1.78 µm.
  - 1 ALFA detector from the Lynred company.

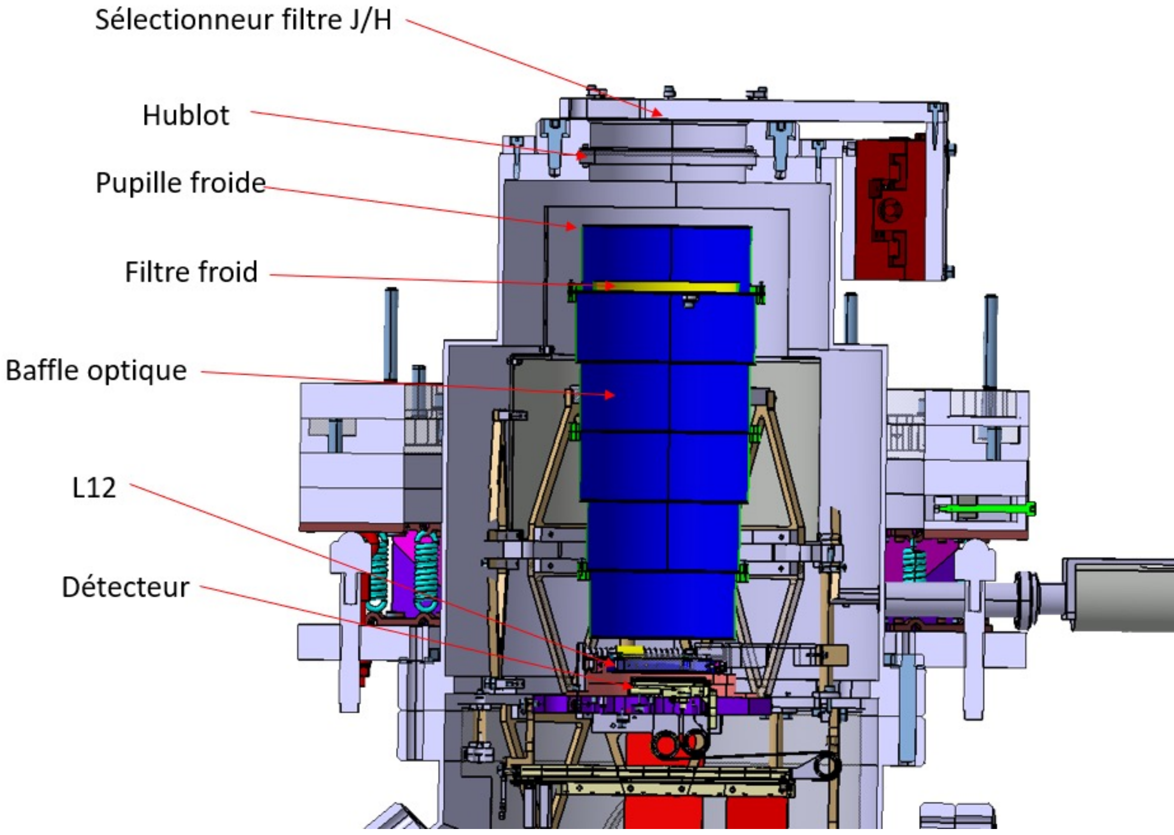
  - No cryogenic mechanism in normal operation.
  - Can use a moveable cold shutter to put the detector in darkness, during engineering periods.

- The sensor is readout with the New General Controller from ESO.
- All observations made in Up The Ramp mode (UTR).

- No dithering at instrument level.
- No correction for atmospheric dispersion.
- Fast inline data analysis.

The cryostat

- The cryostat maintains the detector cold, under vacuum.
- Few optical components inside the cryostat:
  - A cold pupil and an optical baffle.
  - A cold filter blocking wavelengths longer than 1.8 µm.
  - A field lens, just in front of the detector.
- In normal operations there is a single mechanism: the warm J/H filter slide.
- A motorized cold shutter permits to put the detector in darkness for calibration purposes. It will be used during special engineering sessions.
- The construction of the cryostat has been awarded to the SDMS company.



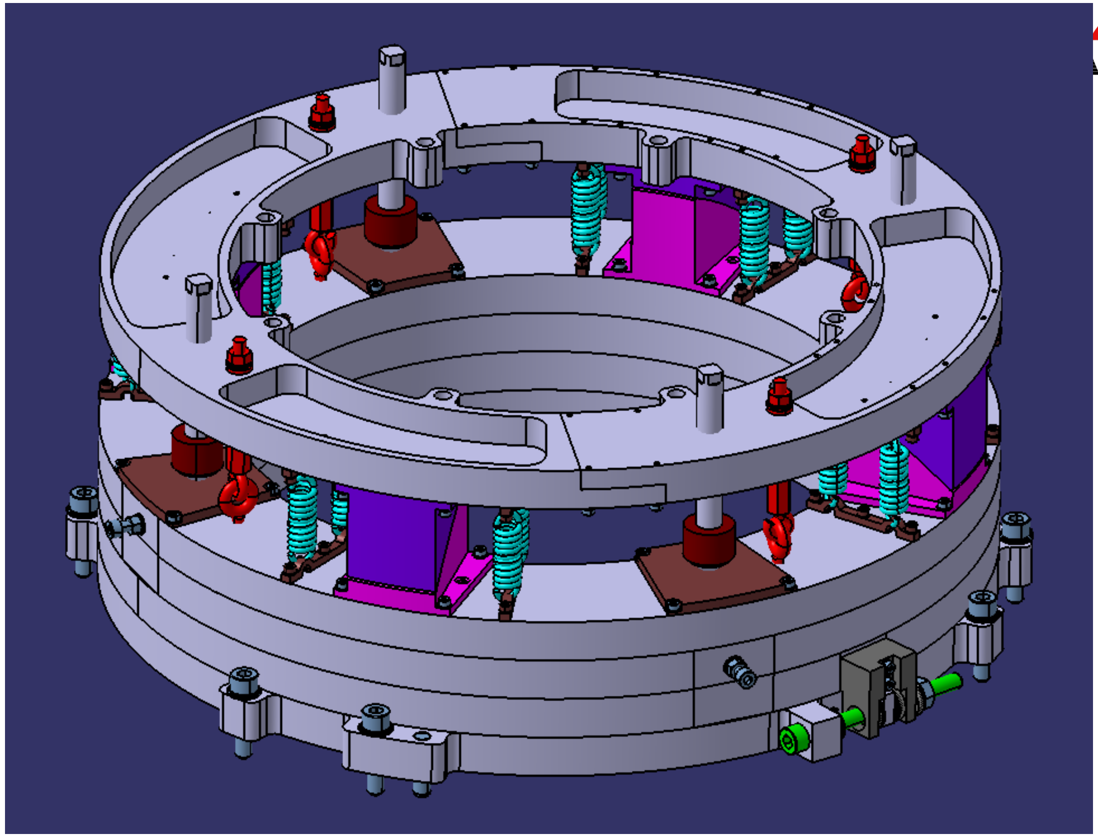
Electronics

- The electronics controls:
  - The detector: preamplifier, NGC
  - The cryostat: temperature regulation, pressure control
  - The cryocooler
  - The filters (J/H)
  - The cold shutter (open/close)

  - The close cabinet environment (T, humidity)
  - The power distribution

Mechanics

- It provides the mean to align the optical axis of the camera with the optical axis of the telescope, with 5 degrees of freedom.
- The mechanics ensures the rigidity of the camera during the movements of the telescope.
- Being on the derotator, the cryostat and the close electronics have strict weight and CoG constraints.



Operations & software

- CAGIRE is essentially a passive instrument, executing ramp observations upon request, and sending back NIR images for the Astronomy pipeline, in typically less than 60 s.

- The instrument configuration parameters are minimal:
  - Filter: J or H
  - Ramp duration

- The detector is permanently under reset waiting a msg from the Telescope Control System (TCS) to start a ramp.
  - When the ramp is finished, it is automatically processed within seconds.
  - As soon as it is available, the flux map is made available to the Astronomy pipeline.
  - Ramps can be interrupted at any time by the TCS.

==> Alix presentation

The sensor

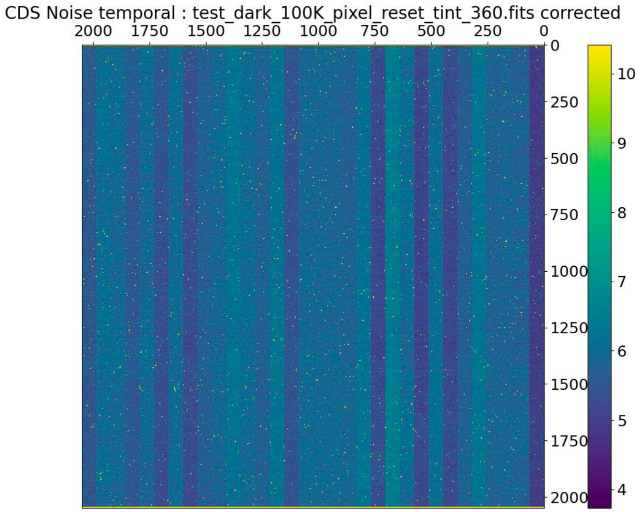
ALFA CH 329505

The Sensor

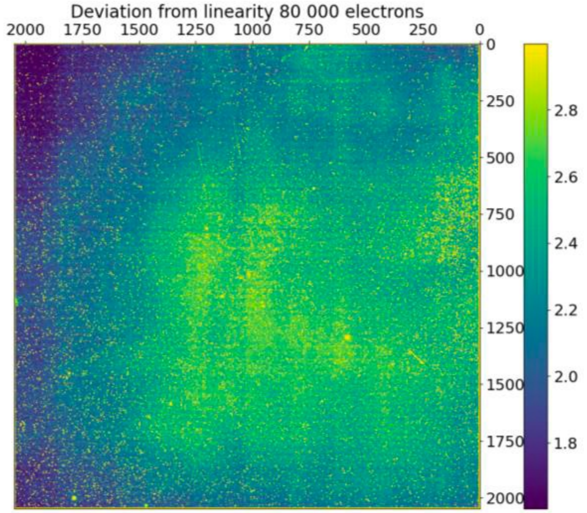
- ALFA (Astronomy Large Focal plane Array) is a 2k x 2k NIR detector jointly developed by CEA-LETI and the Lynred company.
- CEA-IRFU has performed the detailed characterization of various ALFA detectors: dark current, CDS noise, dynamic range, linearity, cosmetics, quantum efficiency, persistence, etc.
- These tests have shown that the performance of CH 329505 is perfectly adapted to CAGIRE needs. ESA has accepted to lend it to CAGIRE, and the FOCUS <-> ESA contract has been signed very recently.

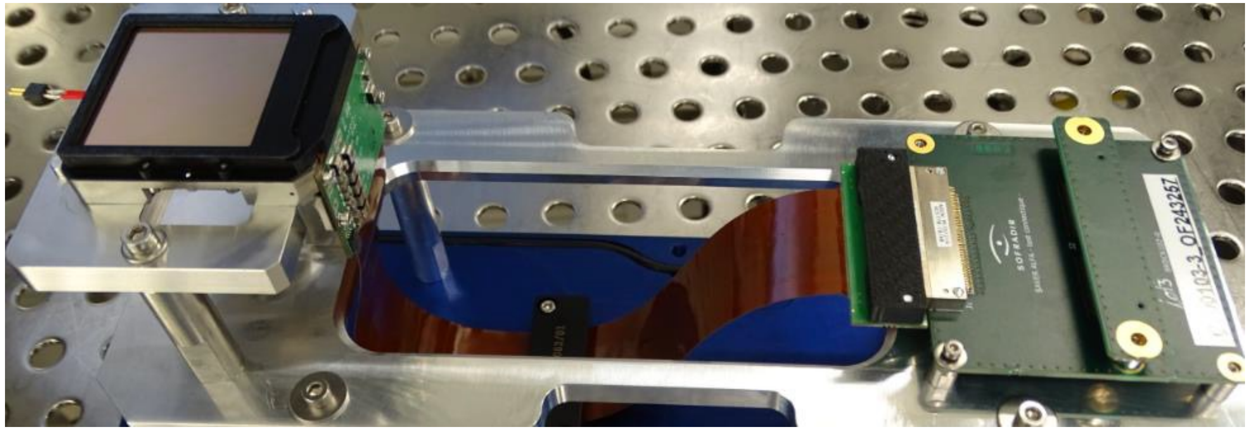
Great Thanks!

CDS noise : 43 e-



Median deviation from linearity
2.3% (at 80 ke-)





A sensor for CAGIRE

- The design of CAGIRE explains why some characteristics are more important than others:

  - CAGIRE observes a large field of view...
    - With 'only' 4 10^6 pixels. It has large sky pixels, 0.65" on a side, resulting in a **high sky background** ≈100-1000 e-/s/pix in the J & H channels respectively. The dark current is completely negligible, and the readout noise is sub-dominant except for very short exposures.
    - The field of view will always contain 10's to 100's **saturating stars** (J,H ≤11). It is thus important to have a large dynamic range in flux and little persistence.

  - We don't know the GRB position in the field of view, hence we cannot favour a 'better' part of the detector. It is important to have a spatially uniform detector.

A crude (personal) summary after IRFU characterization

	CH 329505
More important characteristics:	
Dynamic range & linearity	++
Spatial homogeneity	++
Quantum efficiency	=
Persistence	+
Cross-talk	+
Cosmetics	++
Less important characteristics:	
Dark current	+
Noise	-

Sensor characterization strategy

The characterization of the ALFA sensor for CAGIRE goes through 3 steps:

@IRFU, full characterization under ESA contract, including RQE

➔**Done, for CH 329505**

@CPPM, CAGIRE oriented characterization: settings and operations identical to CAGIRE. These characterizations will permit measuring several parameters relevant for CAGIRE observations: saturation level, non-linearity, response to light, dark signal, cosmetic, etc. for all the pixels.

➔ **Starting soon**

@IRAP, characterization of the whole CAGIRE instrument: with realistic electrical and thermal environment (and simulated point sources)

➔**Fall 2023**

The instrument - 2

Instrument status (Dec. 2022)

- PDR passed in June 2020. CDR passed in June 2021.
- The I/Fs with Colibrí are fully defined: optical – mechanical – electrical – software.

- Two warm electronic chains (ROIC + preAmp + NGC) are available at IRAP and CPPM. They are used to prepare all the AIT/AIV activities before we get the real sensor.

- The contract for the cryostat has been awarded to the SDMS company. The cryostat will be delivered to IRAP before June 2023.
- The contract between ESA and UGA (FOCUS) has been signed recently, allowing CH 329505 to go to CPPM.
- We expect the sensor to be delivered to CPPM before the end of the year and the characterizations at CPPM to start in January 2023.

- We are currently revising the AIT plan @IRAP to shorten (reasonably) the duration of the tests of the instrument.
- We expect to have CAGIRE installed @OAN SPM by mid-2024. A mass model of CAGIRE will be sent to Mexico, along with the telescope, to allow using the visible channels before the delivery of CAGIRE.

Sensitivity

- CAGIRE provides 0.65" pixels on the sky, giving an expected sky signal of 150 and 1250 e-/s/pix in J & H respectively (4.6 and 37.5 ke- in a 30 s exposure). Except for very short exposures, the sensitivity will be limited by the fluctuations of the sky signal. The sensitivity of CAGIRE is thus sky-limited.

- The sensitivity of CAGIRE has been computed in the document "Colibrí expected performance" (GFT-AN-A3135-046-UNAM): for an exposure of 240 s (8 exposures of 30 s), the limiting magnitudes are J_{AB} = 19.7 and H_{AB} = 18.8, complying with the science requirements.

Simulation of the detector

- Alix and David Corre are doing a significant amount of work to simulate realistic sky images with CAGIRE, that include the sky and telescope and detector effects.

- This is a very useful tool, to test the observing strategy, the preprocessing, and the impact of detector performance on the instrument sensitivity.

- Contribution to the construction of an Exposure Time Calculator and Image Simulator for Colibrí.

- Will permit to include CAGIRE in the complete simulation chain of *SVOM*.

Conclusions

- Studying the first minutes of GRB emission and multi-messenger transients at NIR wavelengths remains a crucial objective in the coming years.

- After a successful critical definition review, CAGIRE is now in the realization phase.

- CAGIRE relies on the close collaboration of several partners:
  - FOCUS has attributed one ALFA detector → **Many Thanks!**
  - ESA has accepted to loan the best sensor to FOCUS for CAGIRE → **Many Thanks!**
  - CEA-IRFU and CPPM are key partners, they experience is crucial to get the best from the sensor.

- The instrument teams are working hard to get CAGIRE looking at the NIR sky in the summer of 2024.

CAGIRE science requirements

Criterion	Parameter	Value	Comment
S02[a]	Spectral range	Must cover J & H photometric channels ([1.1 – 1.8] µm)	
S07	Detector readout mode	Up The Ramp	Science mode @ 100 kHz
S08	Time to start a new observation	≤ 5 s	
S09	Time resolution	≤ 2 s	
S10	Timing accuracy	100 ms	
A01	Number of outputs	32	
A02	Readout time	1.33 s	
A03	Linear well CHC	≥ 80 ke-	Linearity better than 5% at 80 ke-
A04	CDS Noise	≤ 55 e- rms	Decrease of mag. limit ≤ 0.15 wrt 20 e- rms
A05	QE @ 100K	≥ 0.7	Measured at 1.3 & 1.7 µm Cf. doc "GFT expected performance"
A06	Dark current	≤ 1 e-/pix/s	Not critical, considering the sky background
A07	Pixel operability	≥ 95% (TBC)	A pixel is operable if the following parameters are in their acceptable range: CDS Noise – Dark current – Linear well – QE – Persistence – Light response
A08	Cross-talk (total)	≤ 5%	Measured at 50% of full well
A09	Persistence	≤ 25 e-/s/pix (TBC)	Measured during 60 s after a 60 s saturated exposure. Cf. doc about persistence