theseus
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

The Infra-Red Telescope on board THESEUS

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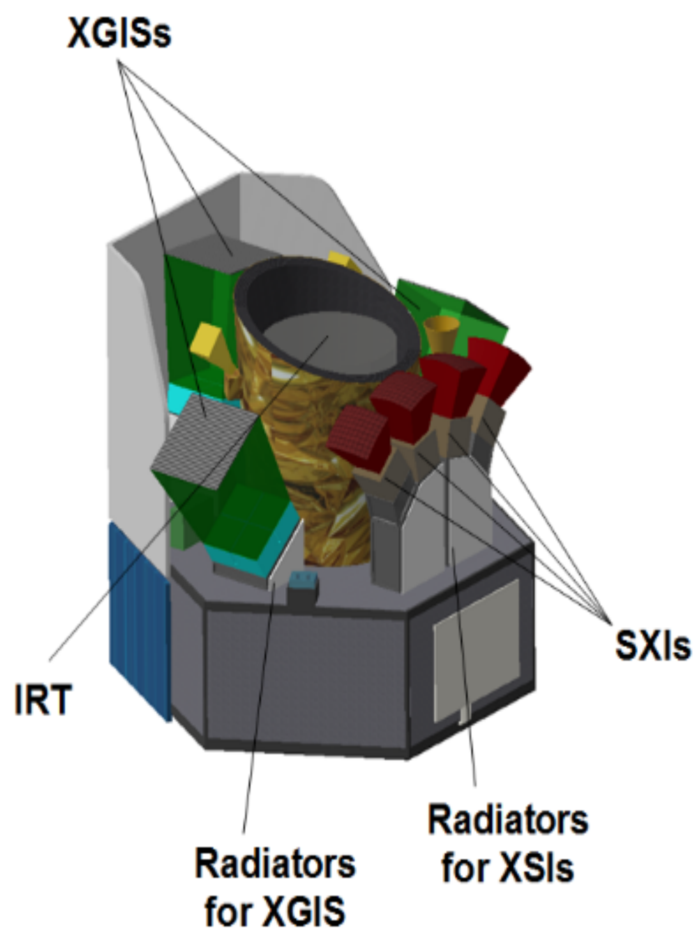
On behalf of the IRT Consortium (F, CH, D, PL)

Presentation Plan

- The IRT System
  - Observation Sequence
- The IRT Hardware
  - Cooling Solutions
  - The IRT detector options
- The IRT Consortium
- Conclusions



The IRT on board THESEUS

The scientific goals of THESEUS require the following **on-board** capabilities for an optical/near IR telescope (IRT) to follow-up GRBs after a demanded spacecraft slew:

1. **Identify and localize** the GRBs found by the SXI and XGS to arcsecond accuracy in the visible and near IR domain (0.5-2.0 μ);

2. **Autonomously determine the photometric redshift** of GRBs for z>4 and provide redshift upper limits for those at lower redshift;

3. Provide spectra to **accurately measure the redshift**, and possibly quantify the intrinsic N_H and metallicity for the majority of GRBs, and in particular those at z >4;

IRT Telescope Design

Telescope: *0.7 m aperture Cassegrain* space borne NIR telescope (with a 0.23 m secondary mirror)

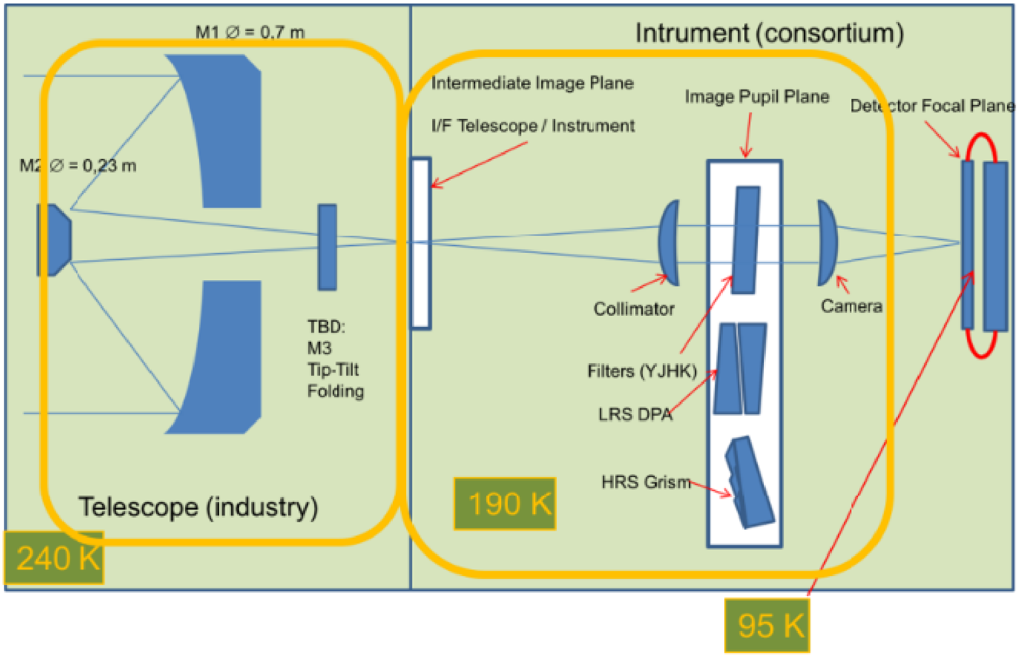
Detector: Teledyne *Hawaii*-2RG 2048x2048 pixels detector (18 μ pixels) -> results in 0.6 arc sec angular resolution (baseline, high TRL, but other options can be considered)

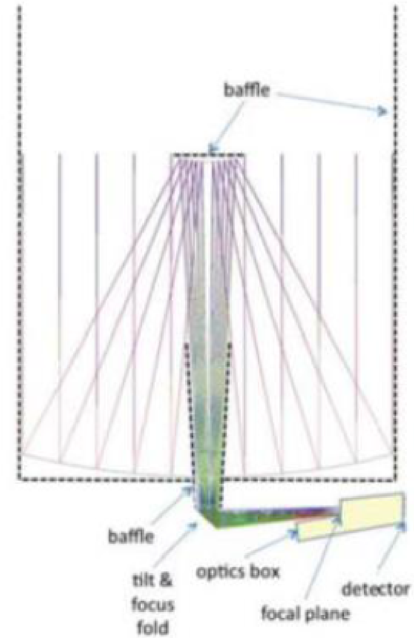
-> implying 22 pixel below the PSF

-> for a 22.5 (H) point like source in a single 300 s exposure one could expect a SNR of ~6. But due to satellite jitter (about 1 arc sec) in LEO this sensitivity is reduced to 20.6 (H) using 1-10 sec exposures.

In order to achieve such performances

- *the telescope needs to be cooled at 240 K*
- *the camera optics to 190 K.*
- *the detector itself needs to be cooled at 80-100 K* (to keep the dark current at an acceptable level)





Telescope type:	Cassegrain		
Primary & Secondary size:	700 mm & 230 mm		
Material:	SiC (for both optics and optical tube assembly)		
Detector type:	Teledyne Hawaii-2RG 2048 x 2048 pixels (18 µm each)		
Imaging plate scale	0".3/pixel		
Field of view:	10' x 10'	10' x 10'	5' x 5'
Resolution (λ/Δλ):	2-3 (imaging)	20 (low-res)	500 (high-res), goal 1000
Sensitivity (AB mag):	H = 20.6 (300s)	H = 18.5 (300s)	H = 17.5 (1800s)
Filters:	ZYJH	Prism	VPH grating
Wavelength range (µm):	0.7-1.8 (imaging)	0.7-1.8 (low-res)	0.7-1.8 (high-res, TBC)
Total envelope size (mm):	800 Ø x 1800		
Power (W):	115 (50 W for thermal control)		
Mass (kg):	112.6		

IRT Observing sequence

1) The IRT will observe the GRB error box in imaging mode as soon as the satellite is stabilized within 1 arc sec. Three initial frames in the ZJH-bands will be taken (10s each, goal 19 AB 5 σ sensitivity limit in H) to establish the astrometry and determine the detected sources colours.

2) IRT will enter the spectroscopy mode (Low Resolution Spectra, LRS, R~20) for a total integration time of 5 minutes (expected 5 σ sensitivity limit in H 18.5 (AB)).

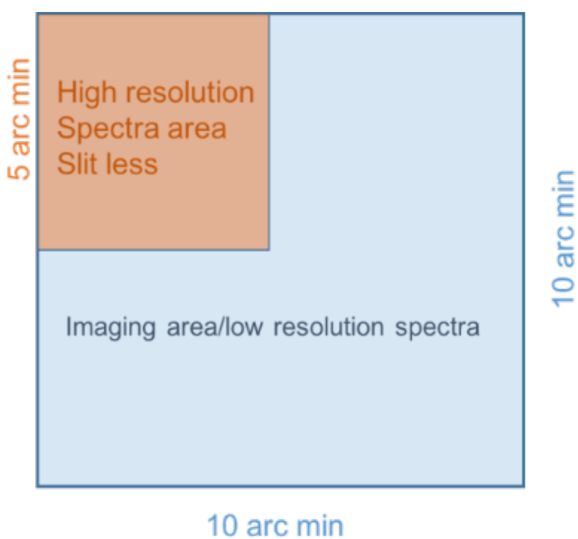
3) Sources with peculiar colours and/or variability (such as GRB afterglows) should have been pinpointed while the low-res spectra were obtained and IRT will take a deeper (20 mag sensitivity limit (AB)) H-band image for a total of 60 s. These images will be then added/subtracted on board in order to identify bright variable sources with one of them possibly matching one of the peculiar colour ones. NIR catalogues will also be used in order to exclude known sources from the GRB candidates.

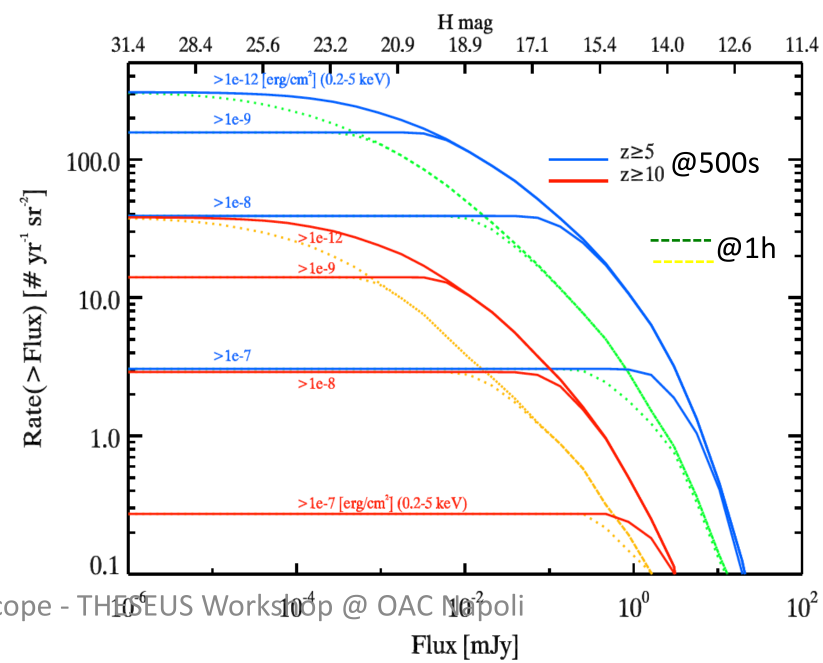
IRT Observing sequence

In case a peculiar colour source or/and bright (< 17.5 H (AB)) variable source is found in the imaging step, the IRT computes its redshift (a numerical value if 5<z<10 or an upper limit z<5) from the low resolution spectra obtained at point 1) and determines its accurate position.

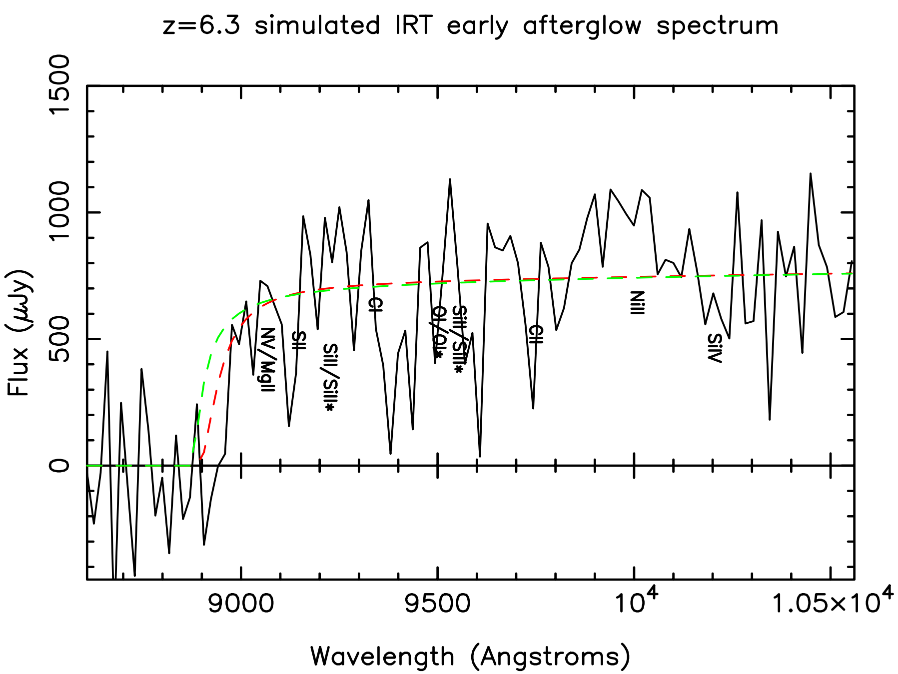
Both the position and redshift estimate will be sent to ground for follow-up observations.

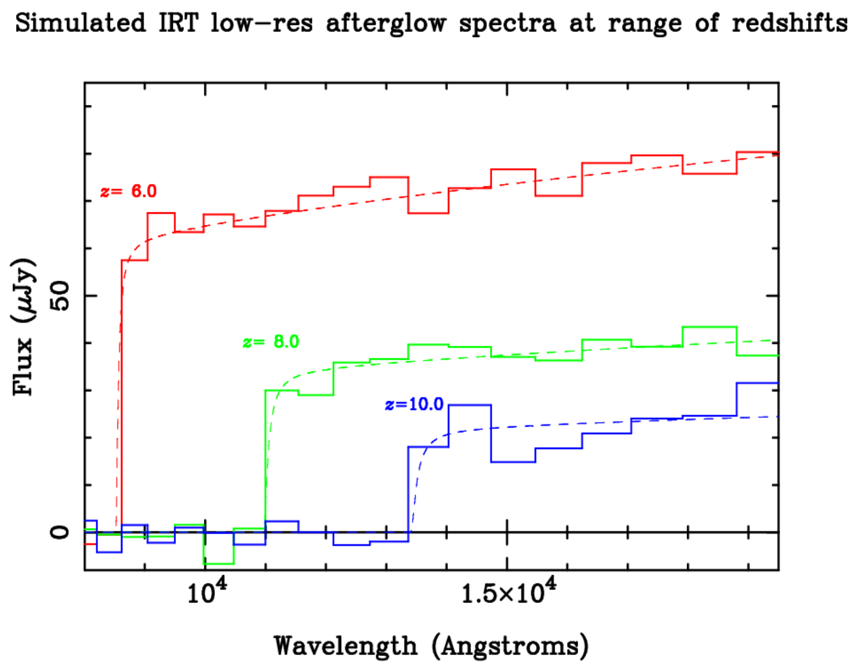
The derived position will then be used in order to ask the satellite to slew to it so that the source is places in the in the high resolution part of the detector plane (see below) where the slit-less high resolution (R~500) mode spectra are acquired (analogous to HST WFPC3). This strategy is driven by the satellite absolute pointing accuracy of 2 arc min in LEO.





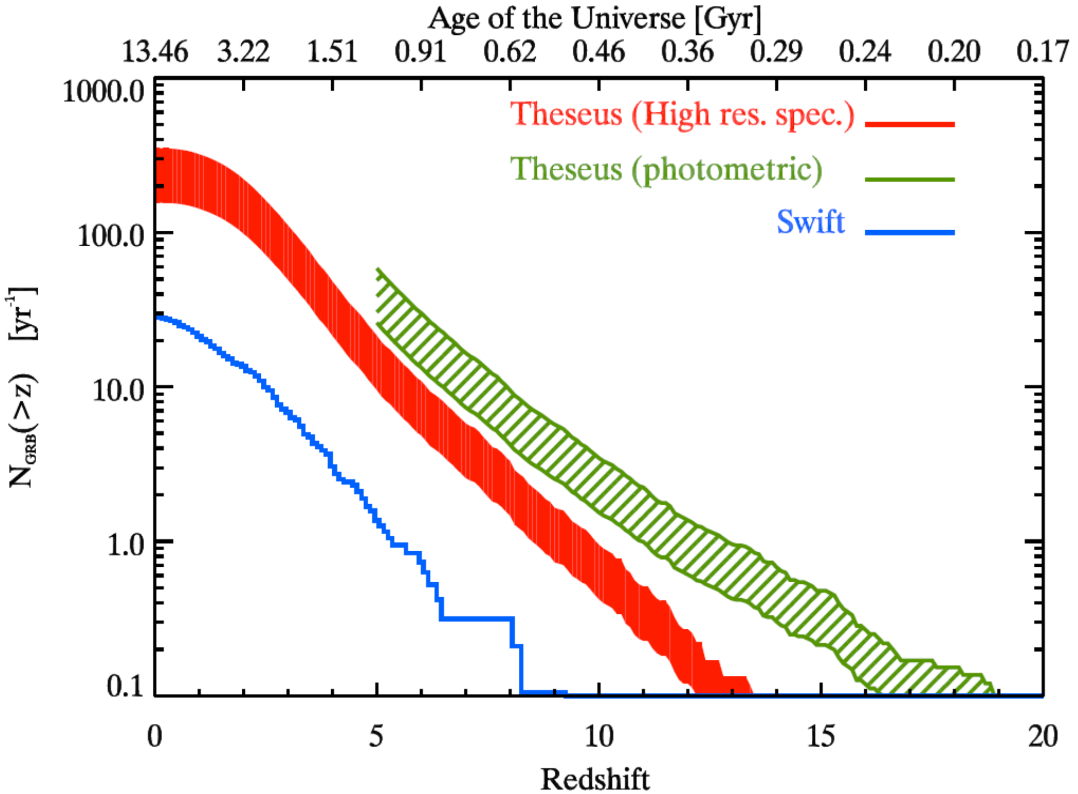
High and low resolution spectra





1 hour after trigger

Shedding light on the early Universe with GRBs



THESEUS GRB#/yr	All	z > 5	z > 8	z > 10
Detections	387 - 870	25 – 60	4 – 10	2 - 4
Photometric z		25 – 60	4 – 10	2 - 4
Spectroscopic z	156 - 350	10 - 20	1 - 3	0.5 - 1

RESEARCH

Gravitational waves

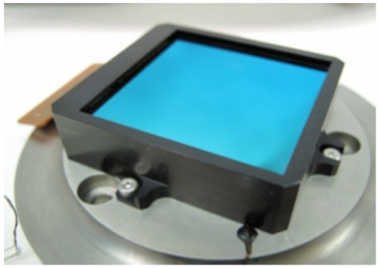
Many of the world's best telescopes were turned to a little-known galaxy called NGC 4993 from 17 August, after an alert about a potential gravitational-wave detection in the region. Rumours abounded that the US-based Laser Interferometer Gravitational-wave Observatory (LIGO), possibly aided for the first time by the Virgo interferometer in Pisa, Italy, had picked up the signature of two neutron stars colliding in the galaxy. NASA's Fermi Gamma-ray Space Telescope detected a burst of γ-rays in roughly the same region of the sky as NGC 4993, which may indicate the aftermath of a neutron-star collision there, but which could instead come from an unrelated event. It would be a historic first for astronomy if telescopes saw signatures of the collision at the same time as interferometers 'heard' the event through vibrations in space-time. See go.nature.com/2w46ja8 for more.

Nature, 548, 504, 2017

THESEUS and GWs

- According to rumours, X/gamma and optical/NIR counterparts to GW sources exist (double NS mergers)
- THESEUS is particularly suited for prompt detection and/or follow-up of GW alerts
- SXI is able to detect and localize the prompt emission and early X-ray afterglow (if any)
- The XGIS is suited to detect (and precisely localize) the prompt gamma-ray emission of short GRBs
- *If a counterpart is identified the IRT can acquire NIR spectra/images, enabling to identify a potential "macronova" (isotropic) component*

The InfraRed Detector: The ALFA project



The baseline detector option is *Teledyne Hawaii-2RG*.

The backup option is to use the ESA funded NIR chip development performed in France (CEA/Sofradir/FOCUS);

- Final goal: a flight quality 2kx2k large format NIR detector « European made »
- ESA launched - a first activity aimed to develop a hybridized prototype with 2kx2k pixels
- The activity named ALFA, for Astronomy Large Focal plane Array, is performed in collaboration among Sofradir, CEA-LETI and CEA-DAp
  - Sofradir manages the overall study and is in charge of the ROIC development and the packaging
  - CEA LETI in in charge of the photo-sensitive diode array technology, in particular aiming at low-noise, very low dark current, high QE
  - CEA DAp performs the tests and validates the performances

Main detector requirements

Number of pixels	2048 x 2048
Dimension of the pixels	15 x 15 µm
Spectral range	0.8 – 2.1 µm
Dark Current	<0.1 e^-/pixel/s@100 K
Operating temperature	100 K
Readout noise	<18 e^- rms in CDS mode
Full frame readout time	<1.31 s
Quantum Efficiency	>70% over the entire spectral range

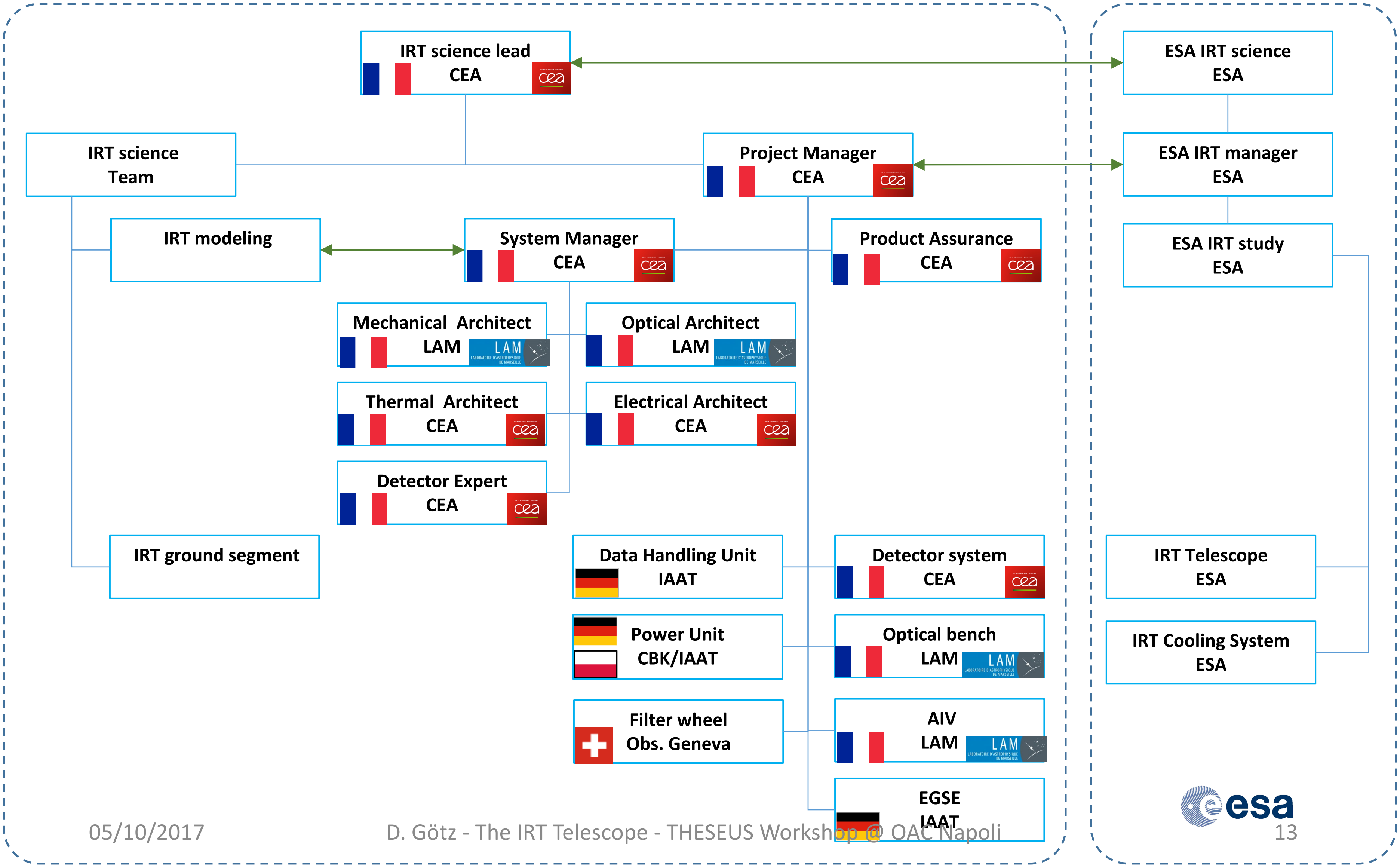
ALFA project Key Dates

- the goal is to have a TRL 4 NIR 2k x 2k by 2019.
  - A « non-spatial » prototype will be used at the focus of the SVOM French Ground Follow-up Telescope in the CAGIRE instrument

- A TRL 6 solution shall be available by 2021 (THESEUS mission adoption)

Current IRT Consortium

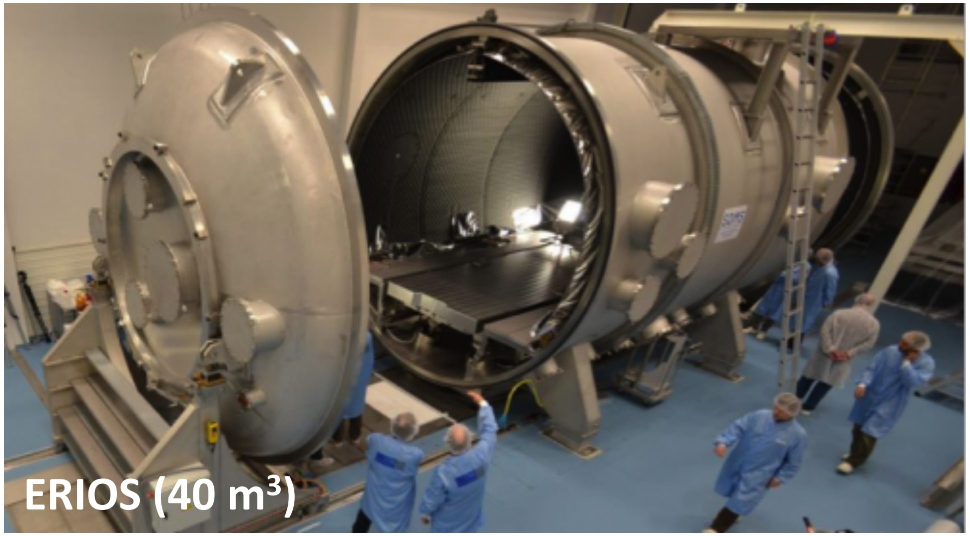
The IRT development will be lead by France with CEA Saclay and LAM Marseille deeply involved (but other labs may contribute). Other identified contributors are IAAT Tübingen, ISDC/Obs. de Genève, CBK Warsaw.



Integration and test facilities at LAM Marseille

LAM owns several facilities for (EUCLID heritage) :

- **Assembly** : mechanical facilities, 3D metrology.
- **Integration** : clean rooms (940 m^2), electronic instrumentation.
- **Tests/Qualification** : optical metrology, transmission and reflection measurements vibration facilities, vacuum chambers (cryogenic, optical table.
- **Calibration** : optical benches (0.8, 6 and 40 m^3), infrared spectroscopy.



ERIOS (40 m^3)

Pot vibrant

Detector test facilities at CEA

- Two cryostats optimised for the measurement of dark current
  - Light tight, very stable in temperature (1mK rms for days)
  - Dark currents below 0.1 e-/s/pixel have been already measured
  - Q.E. measurements, response linearity, noise, cross-talk measurements by an internal black body source and external monochromator
  - Already used in the framework of several ESA/CNES activities of detector characterisations

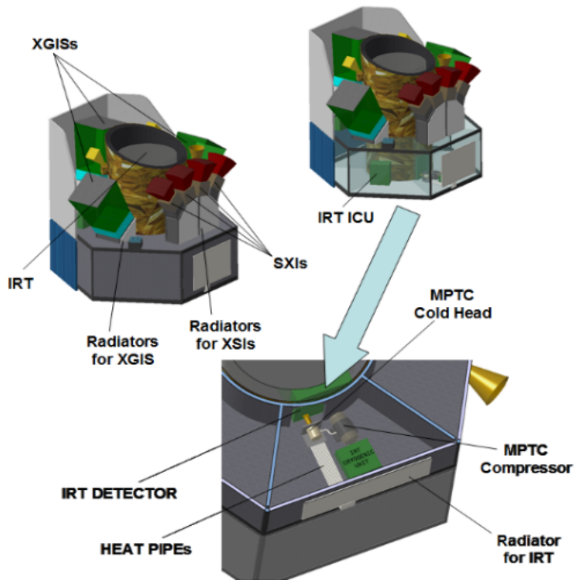
- Two test benches being developed
  - Spectral Q.E. and persistence measurements up to 2.3μm (2.5μm TBC) starting 2018
  - Expected accuracy +/- 5%
  - Intra-pixel response measurement and its variation over the entire detector starting from mid 2018
    - 1/10th de pixel resolution; expected accuracy 10%

Conclusions

- *France (DAp, LAM,…) leads the IRT consortium. The IRT design phase 0 design is based on the EUCLID one; but IRT is simpler and the telescope smaller wrt. e.g. EUCLID. The thermal constraints are similar (mirrors cooled at 270 K, detector at 80-100 K (0.1 e^-/s/pixel of DC)), but the final orbit will probably be different (LEO vs. L2) and requires the presence of an active cooling system (a possible solution Micro Pulse Tube Cooler from Air Liquide)*
  - *Phase 0 studies indicate that the thermal control is feasible, but the addition of another cooling stage needs to be evaluated in phase A*
- *Due to the orbit and the frequent pointing changes thermo-elastic deformations of the telescope may be important → additional design and possibly mission scenario constraints*
- *The absolute pointing accuracy and stability (especially for the spectroscopic mode) is the most critical impact point on the scientific performance*
  - *The satellite jitter requires a rapid detector readout (1-10 s, to limit the image blurring) increasing the overall noise (ROIC dominates! 7 e^- rms used for simulation), a more complicated on-board s/w, and increased telemetry.*
  - *The absolute pointing accuracy does not allow for the use of a slit (source contamination, sensitivity loss) and requires a larger detector/detector area dedicated to spectroscopy*

BACKUP SLIDES

The IRT thermal system



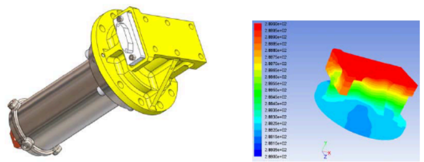


Figure 4: Warm End thermal interface (60x30mm) and the associated Termal Analysis [K]

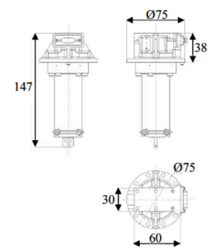
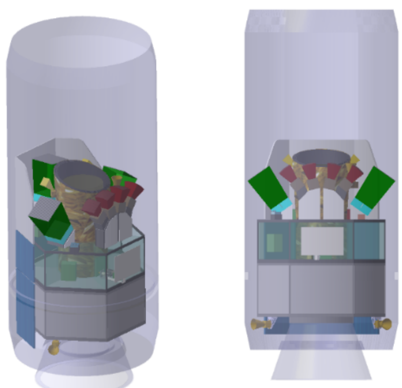


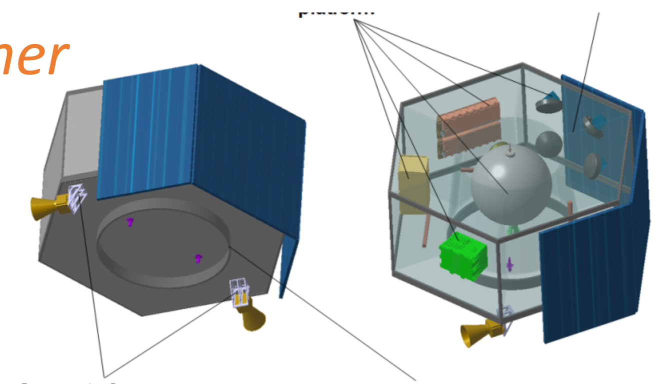
Figure 5: Cold Finger Assembly layout

MPTC by Air Liquide
Currently TRL 5
(MICROCARB)
TRL 8 expected in2018

The platform (stability) and the launcher



Vega fairing



Pitch & yaw [roll]	SXI	XGIS	IRT
APE (3 sigma, arcsec)	120 [270]	120 [270]	120 [270]
AMA (3 sigma, arcsec)	3 [90]	3 [90]	3 [90]
APD (3 sigma, arcsec) on observation time of 30 minutes	N.A.	N.A.	10 (TBC)
RPE/Jitter(3 sigma, arcsec) on exposure time of 10 seconds	N.A.	N.A.	1 [1]