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TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

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on behalf of the THESEUS consortium

http://www.isdc.unige.ch/theseus

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transient high energy sky and early universe surveyor

THESEUS

Transient High Energy Sky and Early Universe Surveyor

Lead Proposer (ESA/M5): Lorenzo Amati (INAF – OAS Bologna, Italy)

Coordinators (ESA/M5): Lorenzo Amati, Paul O'Brien (Univ. Leicester, UK), Diego Gotz (CEA-Paris, France), C. Tenzer (Univ. Tuebingen, D), E. Bozzo (Univ. Genève, CH)

Payload consortium: Italy, UK, France, Germany, Switzerland, Spain, Poland, Czech Republic, Ireland, Hungary, Slovenia, ESA

The ESA Cosmic Vision Programme

- M1: Solar Orbiter (solar astrophysics, 2018)
- M2: Euclid (cosmology, 2021)
- L1: JUICE (exploration of Jupiter system, 2022)
- S1: CHEOPS (exoplanets, 2018)
- M3: PLATO (exoplanets, 2026)
- L2: ATHENA (X-ray observatory, cosmology, 2028)
- L3: LISA (gravitational wave observatory, 2034)
- M4: ARIEL (exoplanets, 2028)
- S2: SMILE (solar wind <–> magneto/ionosphere)
- F: new “fast” channel for small missions
- M5: ?

THE ESA/M5 Call

Activity	Date
Phase 0 kick-off	June 2018
Phase 0 completed (EnVision, SPICA and THESEUS)	End 2018
ITT for Phase A industrial studies	February 2019
Phase A industrial kick-off	June 2019
Mission Selection Review (technical and programmatic review for the three mission candidates)	Completed by June 2021
SPC selection of M5 mission	November 2021
Phase B1 kick-off for the selected M5 mission	December 2021
Mission Adoption Review (for the selected M5 mission)	March 2024
SPC adoption of M5 mission	June 2024
Phase B2/C/D kick-off	Q1 2025
Launch	2032

Launch in 2032
ESA budget 550 MEuro

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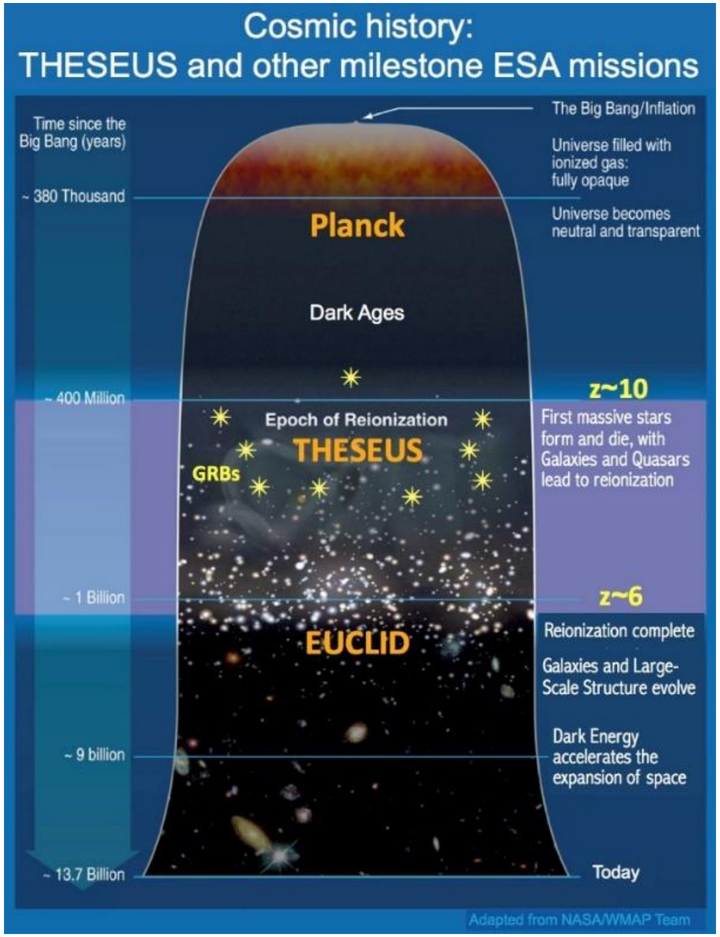
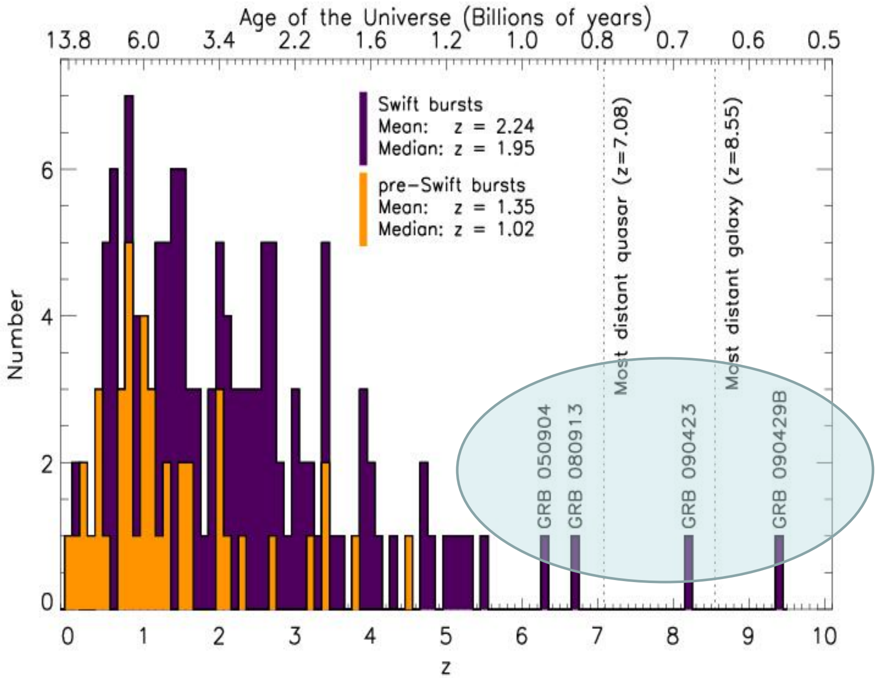
- ***THESEUS* Core Science is based on two pillars:**
  - probe the **physical properties of the early Universe**, by discovering and exploiting the population of high redshift GRBs.
  - provide an **unprecedented deep monitoring** of the soft X-ray transient Universe, providing a fundamental contribution to multi-messenger and time domain astrophysics in the early 2030s (synergy with aLIGO/aVirgo, eLISA, ET, Km3NET and EM facilities e.g., LSST, E-ELT, SKA, CTA, ATHENA).

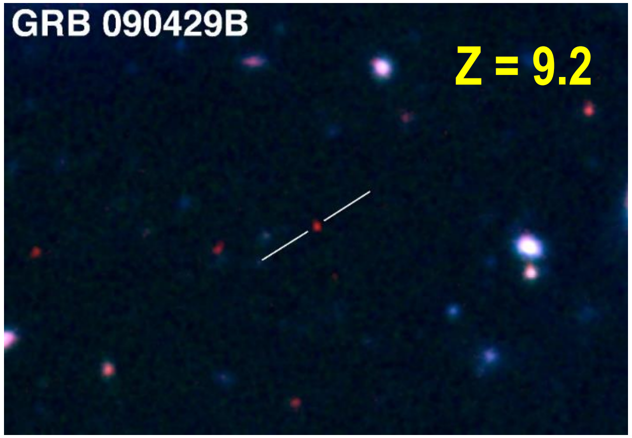
- ***THESEUS* Observatory Science includes:**
  - study of thousands of faint to bright X-ray sources by exploiting the **simultaneous availability of broad band X-ray and NIR observations**
  - provide a **flexible follow-up observatory** for fast transient events with multi-wavelength ToO capabilities and **guest-observer programmes**.

Shedding light on the early Universe with GRBs

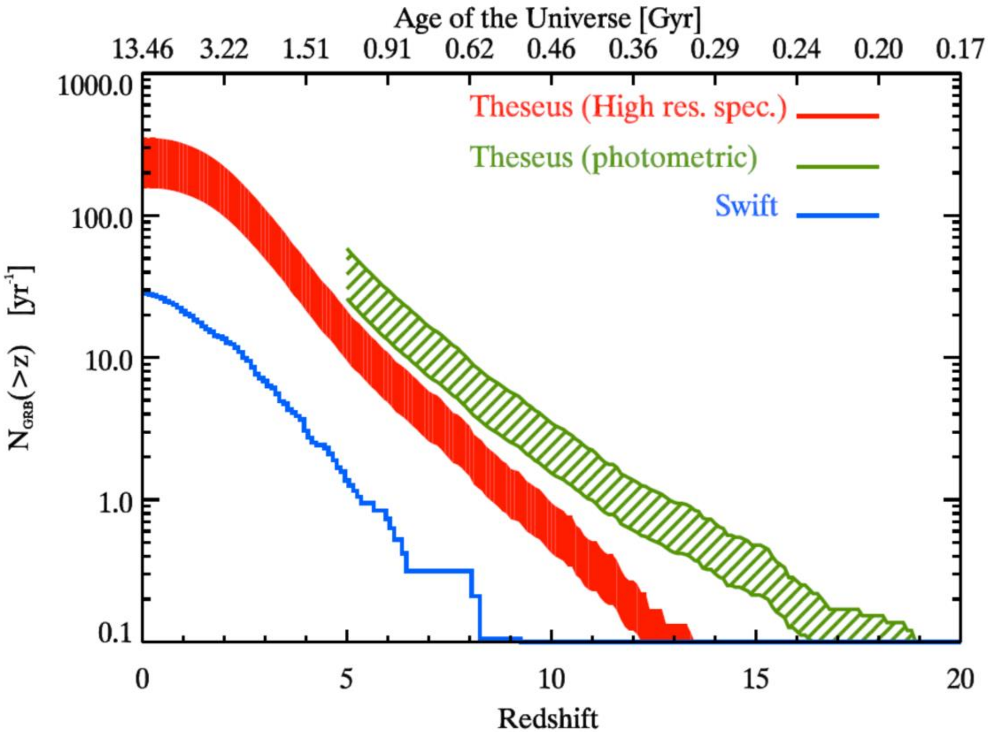
Because of their huge luminosities, mostly emitted in the X and gamma-rays, their redshift distribution extending at least to z ~9 and their association with explosive death of massive stars and star forming regions, GRBs are unique and powerful tools for investigating the early Universe: **SFR evolution, physics of re-ionization, galaxies metallicity evolution and luminosity function, first generation (pop III) stars**







Order of magnitude improvement compared to Swift in the number of GRBs as a function of redshift

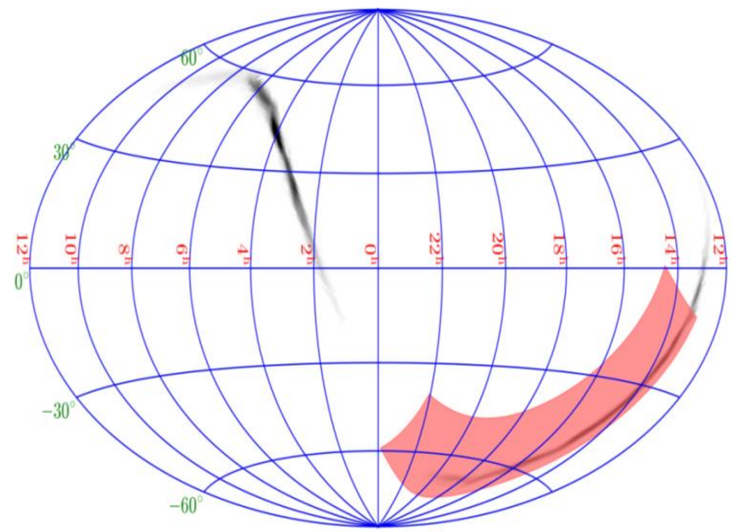


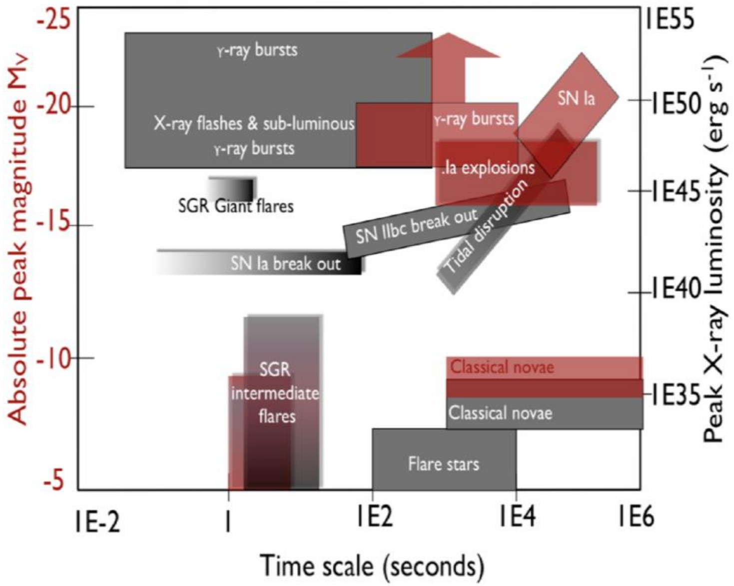
Exploring the multi-messenger transient sky

- ❑ Locate and identify the electromagnetic counterparts to sources of gravitational radiation and neutrinos, routinely detected in the late '20s / early '30s by **aLIGO/aVirgo, eLISA, ET, or Km3NET;**

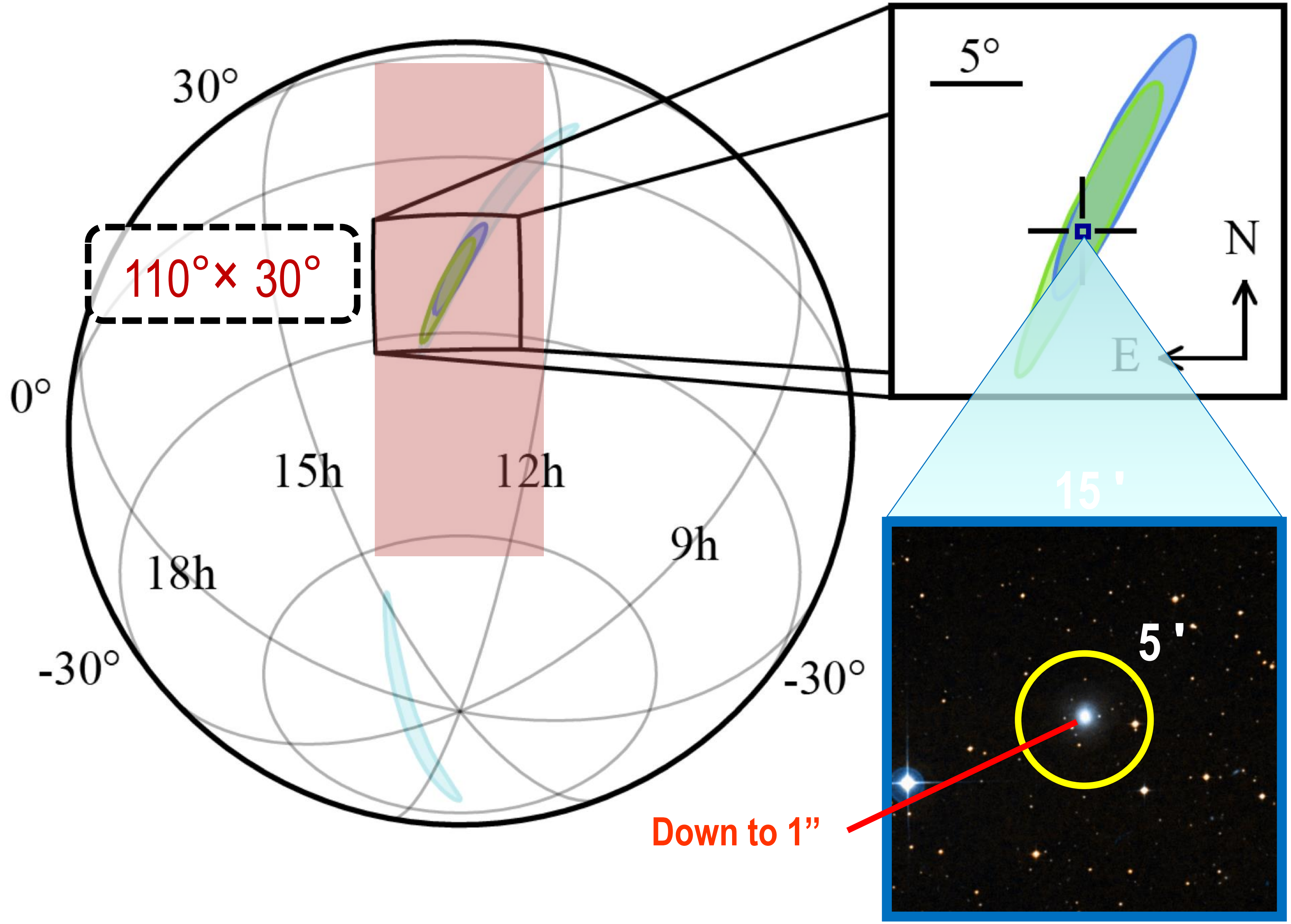
- ❑ Provide real-time triggers and accurate (~1 arcmin within a few seconds; ~1'' within a few minutes) high-energy transients for follow-up with next-generation optical-NIR (**E-ELT, JWST** if still operating), radio (**SKA**), X-rays (**ATHENA**), TeV (**CTA**) telescopes; synergy with **LSST**

- ❑ Provide a fundamental step forward in the comprehension of the physics of various classes of transients and **fill the present gap in the discovery space of new classes of transients events**

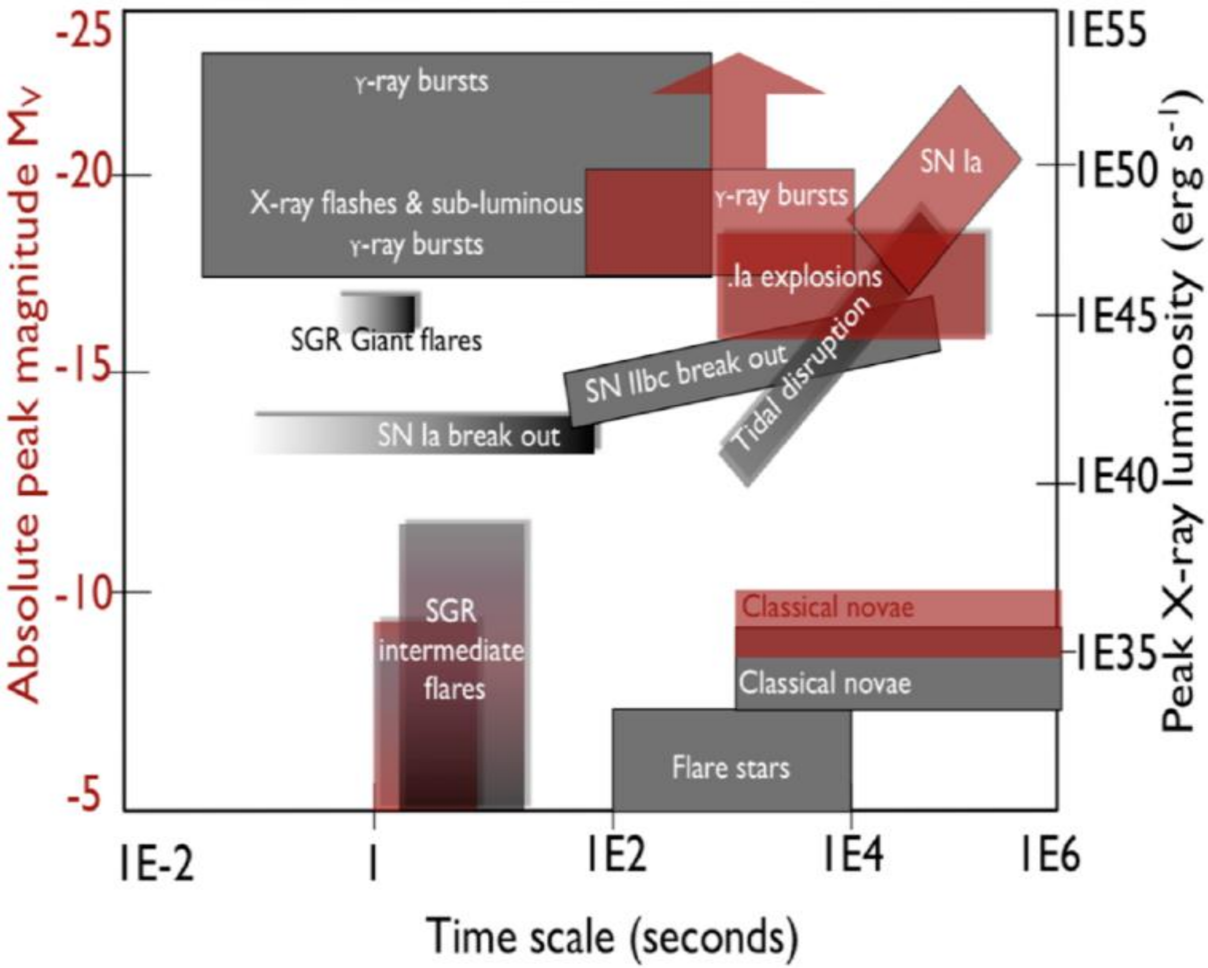




Promptly and accurately localizing transients with THESEUS

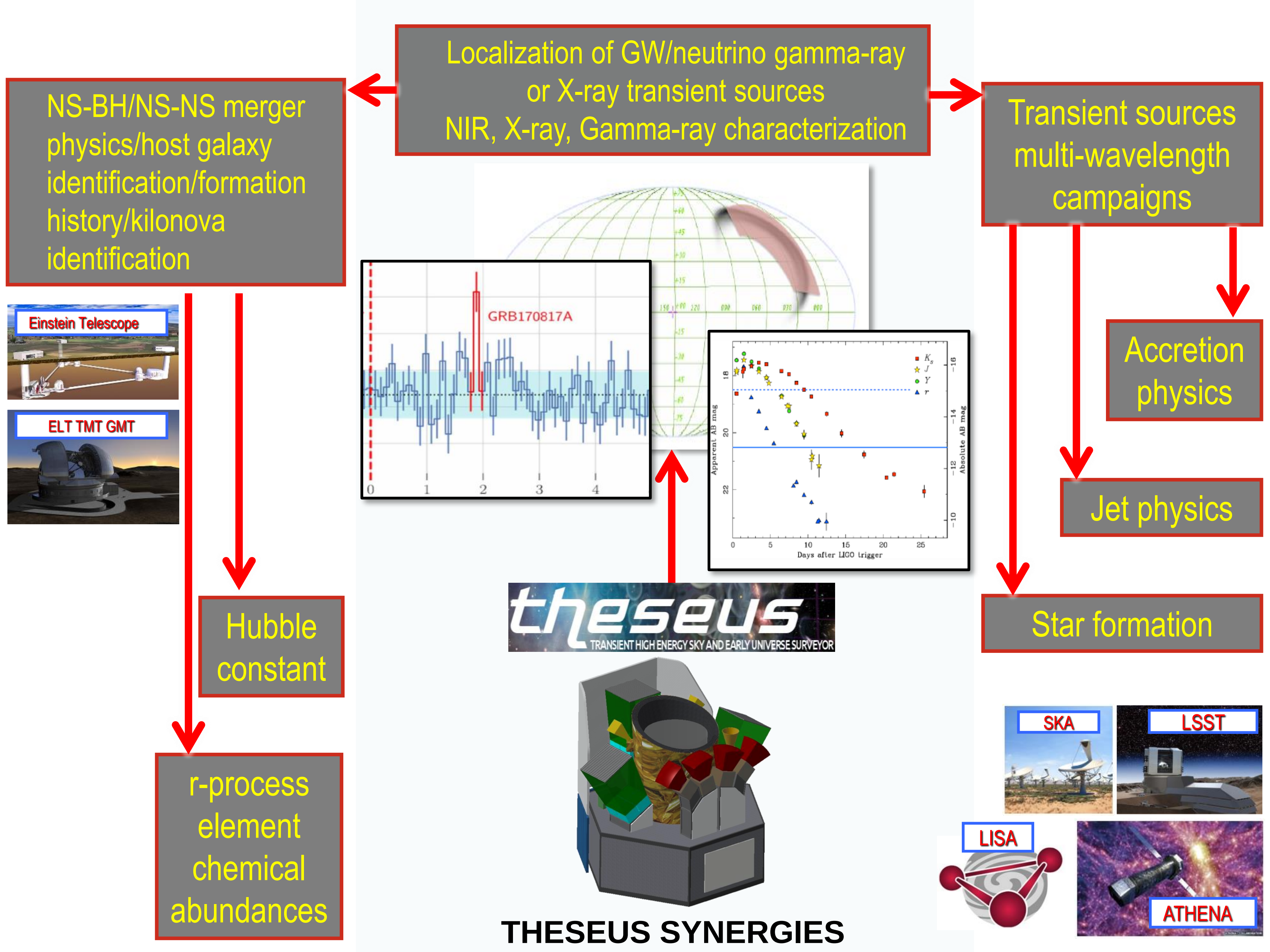


A powerful and flexible observatory



Transient type	SXI rate
Magnetars	40 day^{-1}
SN shock breakout	4 yr^{-1}
TDE	50 yr^{-1}
AGN+Blazars	350 yr^{-1}
Thermonuclear bursts	35 day^{-1}
Novae	250 yr^{-1}
Dwarf novae	30 day^{-1}
SFXTs	1000 yr^{-1}
Stellar flares	400 yr^{-1}
Stellar super flares	200 yr^{-1}

Provide a **flexible follow-up observatory** for fast transient events with multi-wavelength ToO capabilities and **guest-observer programmes**



Localization of GW/neutrino gamma-ray
or X-ray transient sources
NIR, X-ray, Gamma-ray characterization
NS-BH/NS-NS merger physics/host galaxy identification/formation history/kilonova identification
Transient sources multi-wavelength campaigns
Einstein Telescope
ELT TMT GMT
GRB170817A
Apparent AB mag
Absolute AB mag
Days after LIGO trigger
Accretion physics
Jet physics
Star formation
Hubble constant
r-process element chemical abundances
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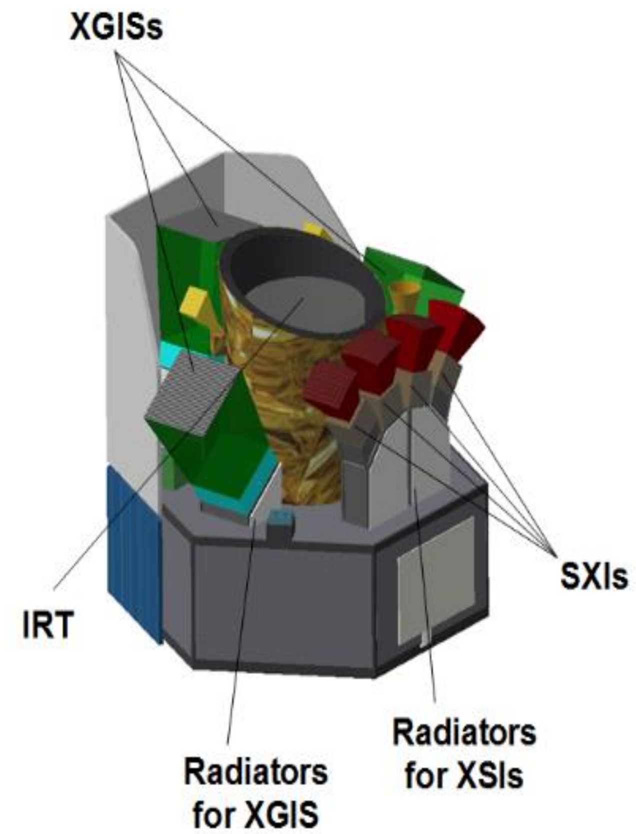
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR
SKA
LSST
LISA
ATHENA
THESEUS SYNERGIES

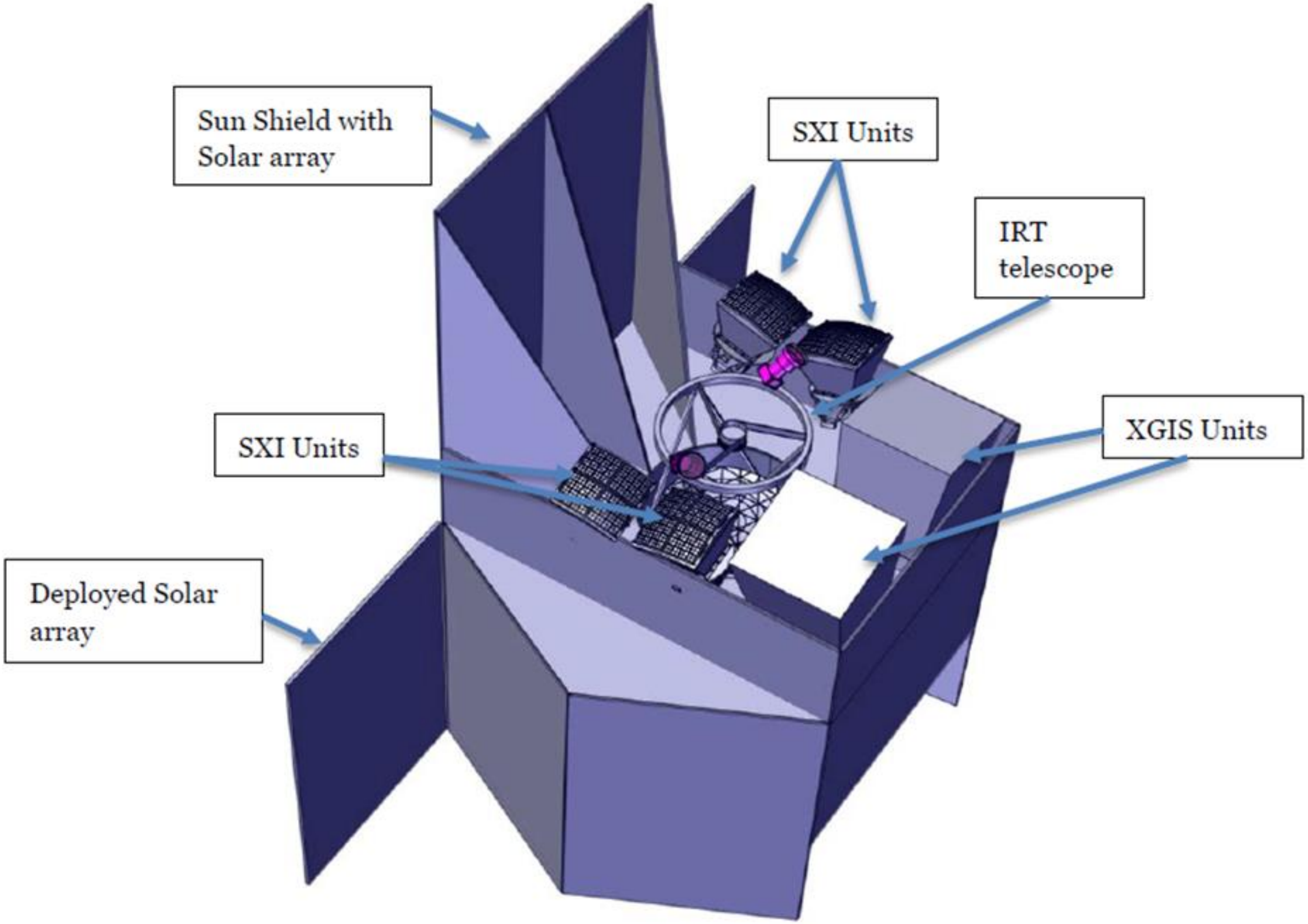
THESEUS mission concept

- **Soft X-ray Imager (SXI):** a set of 4 lobster-eye telescopes (**0.3 - 5 keV band, total FOV of ~1sr with source location accuracy 0.5-1'**)
- **X-Gamma rays Imaging Spectrometer** (**XGIS**): 2 coded-mask X-gamma ray cameras using bars of Silicon diodes coupled with CsI crystal scintillators observing in (**2 keV – 10 MeV band, FOV of ~2-4 sr overlapping the SXI, ~5' source location accuracy**)
- **InfraRed Telescope (IRT)**: a 0.7m class IR telescope (**0.7 – 1.8 µm**, **10'x10' FOV**) **for imaging and moderate resolution spectroscopy capabilities** (-> redshift)



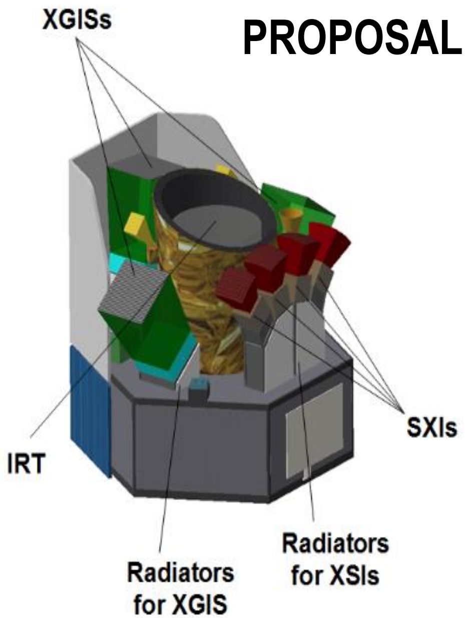
LEO (< 5°, ~600 km)
Autonomous slewing
Prompt downlink

THESEUS mission concept: ESA study

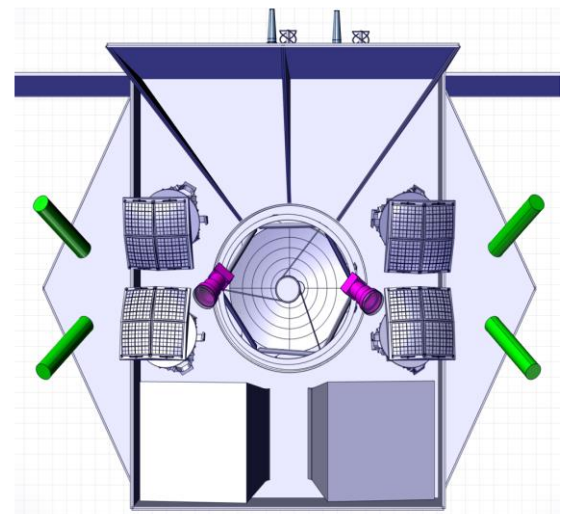


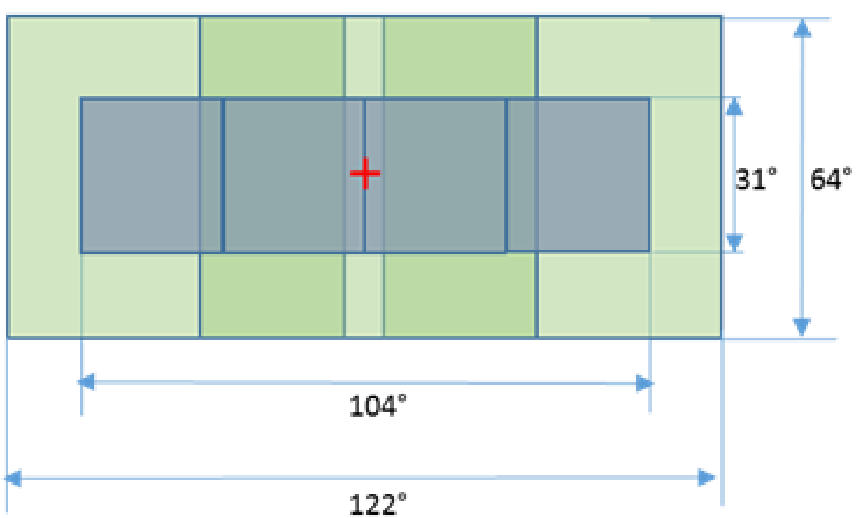
THESEUS mission concept: ESA study

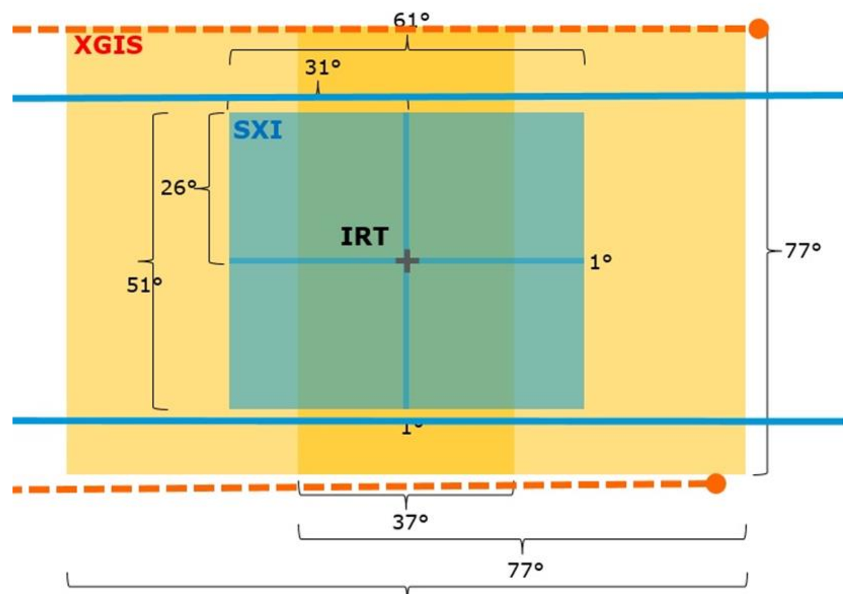
PROPOSAL



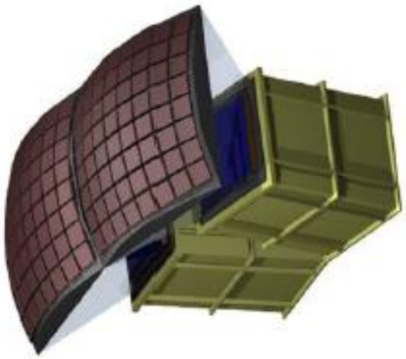
CDF STUDY

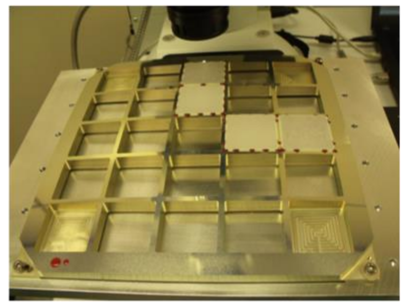


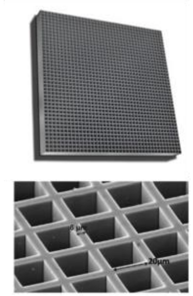


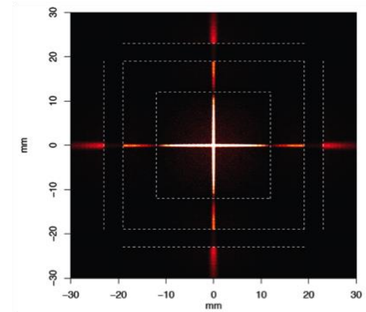


The Soft X-ray Imager (SXI)









4 DUs, each has a 31 x 26 degree FoV

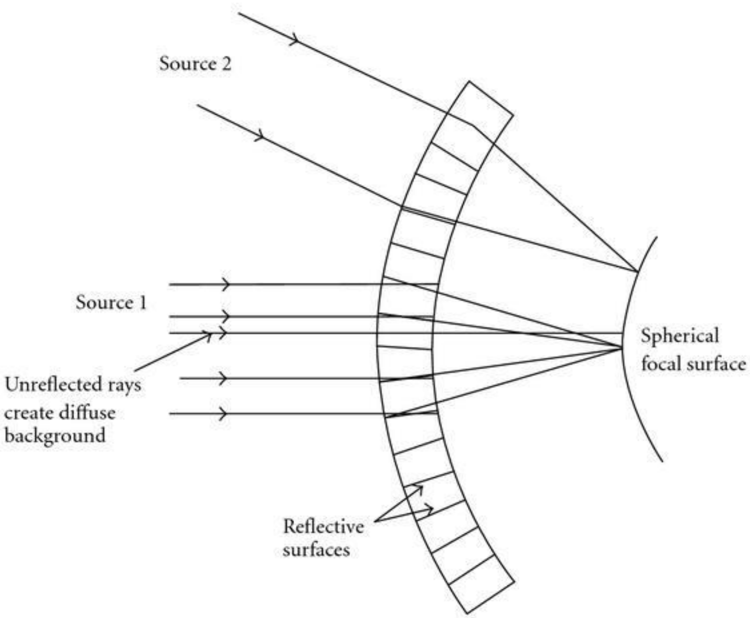
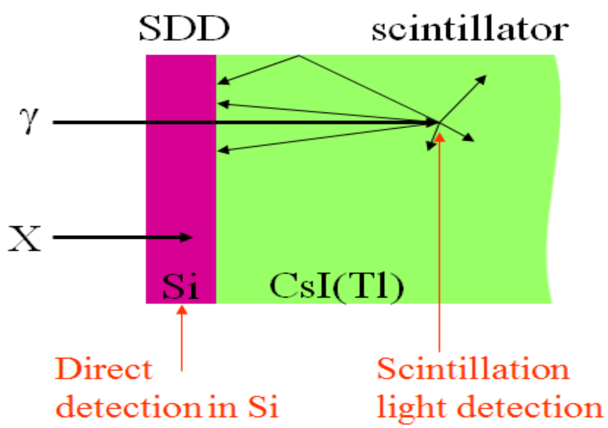
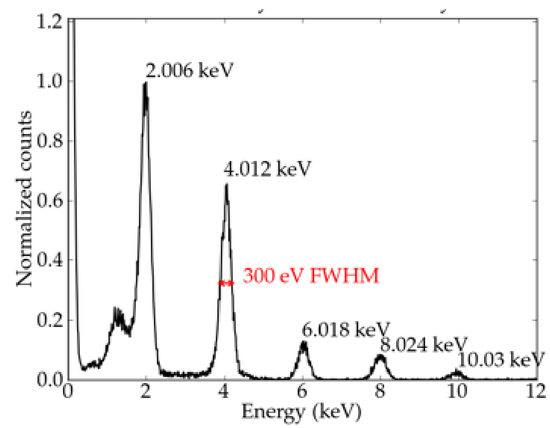


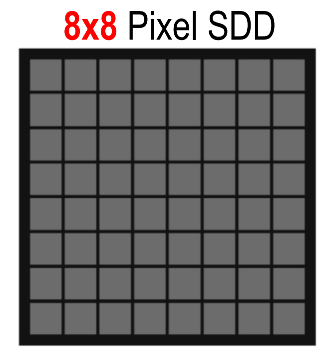
Table 4 : : SXI detector unit main physical characteristics

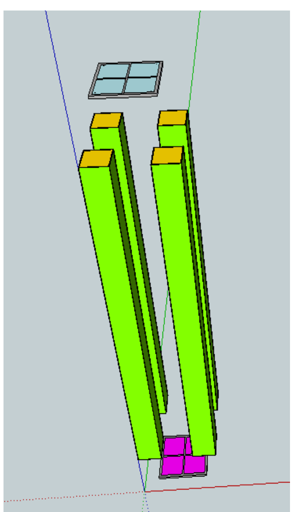
Energy band (keV)	0.3-5
Telescope type:	Lobster eye
Optics aperture (mm2)	320x320
Optics configuration	8x8 square pore MCPs
MCP size (mm2)	40x40
Focal length (mm)	300
Focal plane shape	spherical
Focal plane detectors	CCD array
Size of each CCD (mm2)	81.2x67.7
Pixel size (μm)	18
Pixel Number	4510 x 3758 per CCD
Number of CCDs	4
Field of View (square deg)	~1sr
Angular accuracy (best, worst) (arcsec)	(<10, 105)
Power [W]	27,8
Mass [kg]	40

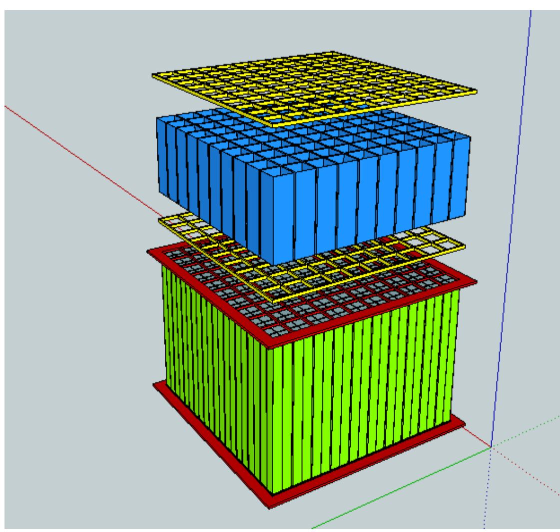
The X-Gamma-ray imaging spectrometer

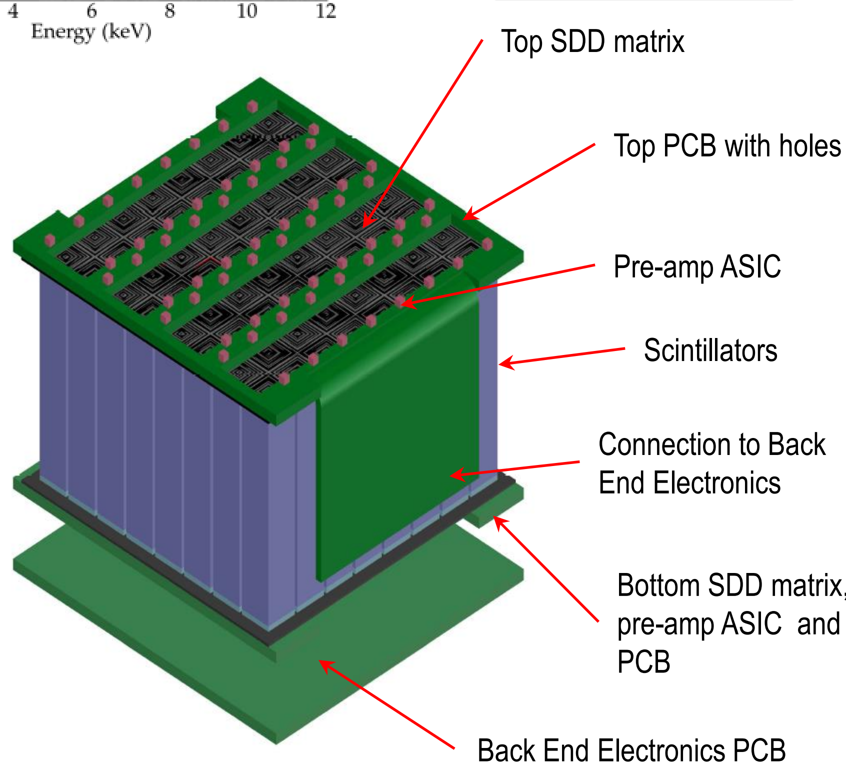












The X-Gamma-ray imaging spectrometer

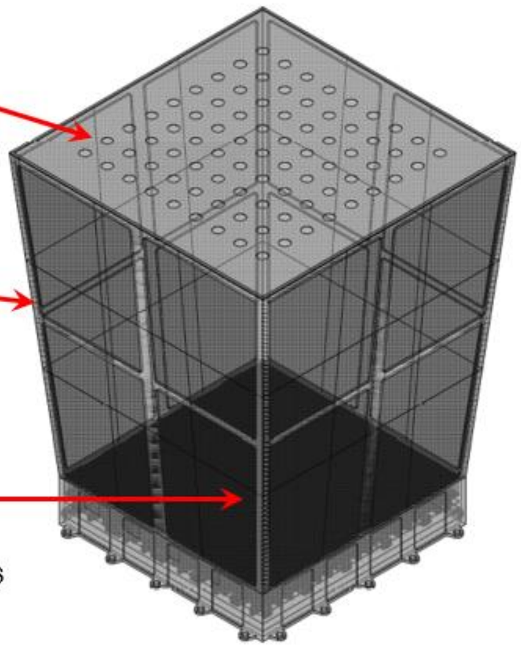


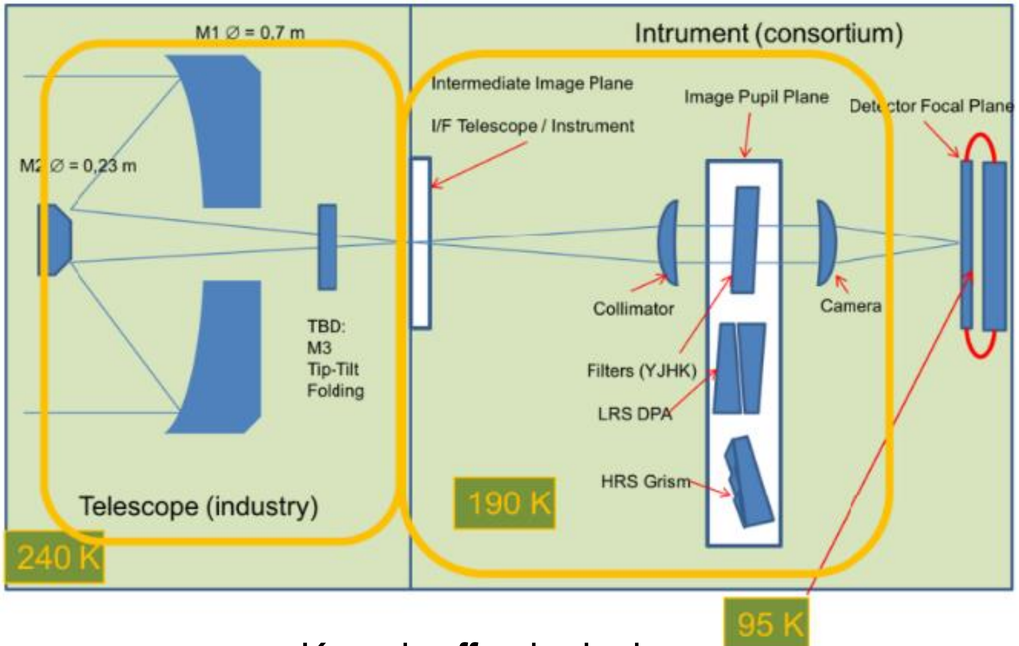
Table 5: XGIS detector unit main physical characteristics

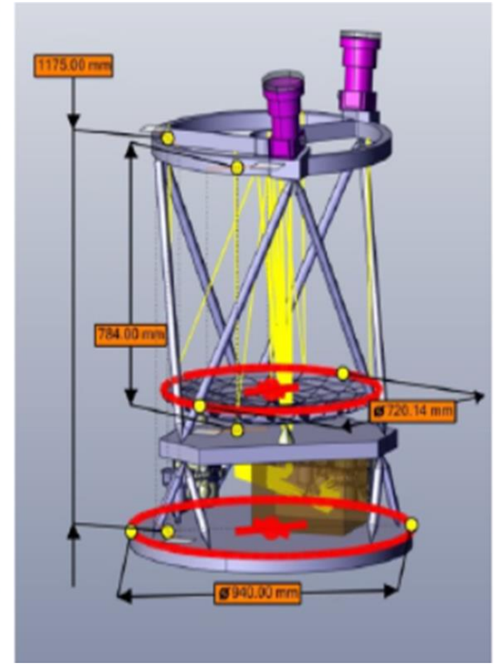
Energy band	2 keV – 20 MeV
# detection plane modules	4
# of detector pixel / module	32x32
pixel size (= mask element size)	5x5 mm
Low-energy detector (2-30 keV)	Silicon Drift Detector 450 μm thick
High energy detector (> 30 keV)	CsI(Tl) (3 cm thick)
Discrimination Si/CsI(Tl) detection	Pulse shape analysis
Dimension [cm]	50x50x85
Power [W]	30,0
Mass [kg]	37.3

Table 6: XGIS unit characteristics vs energy range

	2-30 keV	30-150 keV	>150 keV
Fully coded FOV	9 x 9 deg²		
Half sens. FOV	50 x 50 deg²	50 x 50 deg² (FWHM)	
Total FOV	64 x 64 deg²	85 x 85 deg² (FWZR)	2π sr
Ang. res	25 arcmin		
Source location accuracy	~5 arcmin (for >6 σ source)		
Energy res	200 eV FWHM @ 6 keV	18 % FWHM @ 60 keV	6 % FWHM @ 500 keV
Timing res.	1 μsec	1 μsec	1 μsec
On axis useful area	512 <cm²	1024 cm²	1024 cm²

The InfraRed Telescope (IRT)





Korsch off axis design

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 ($\lambda/\Delta\lambda$):	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		

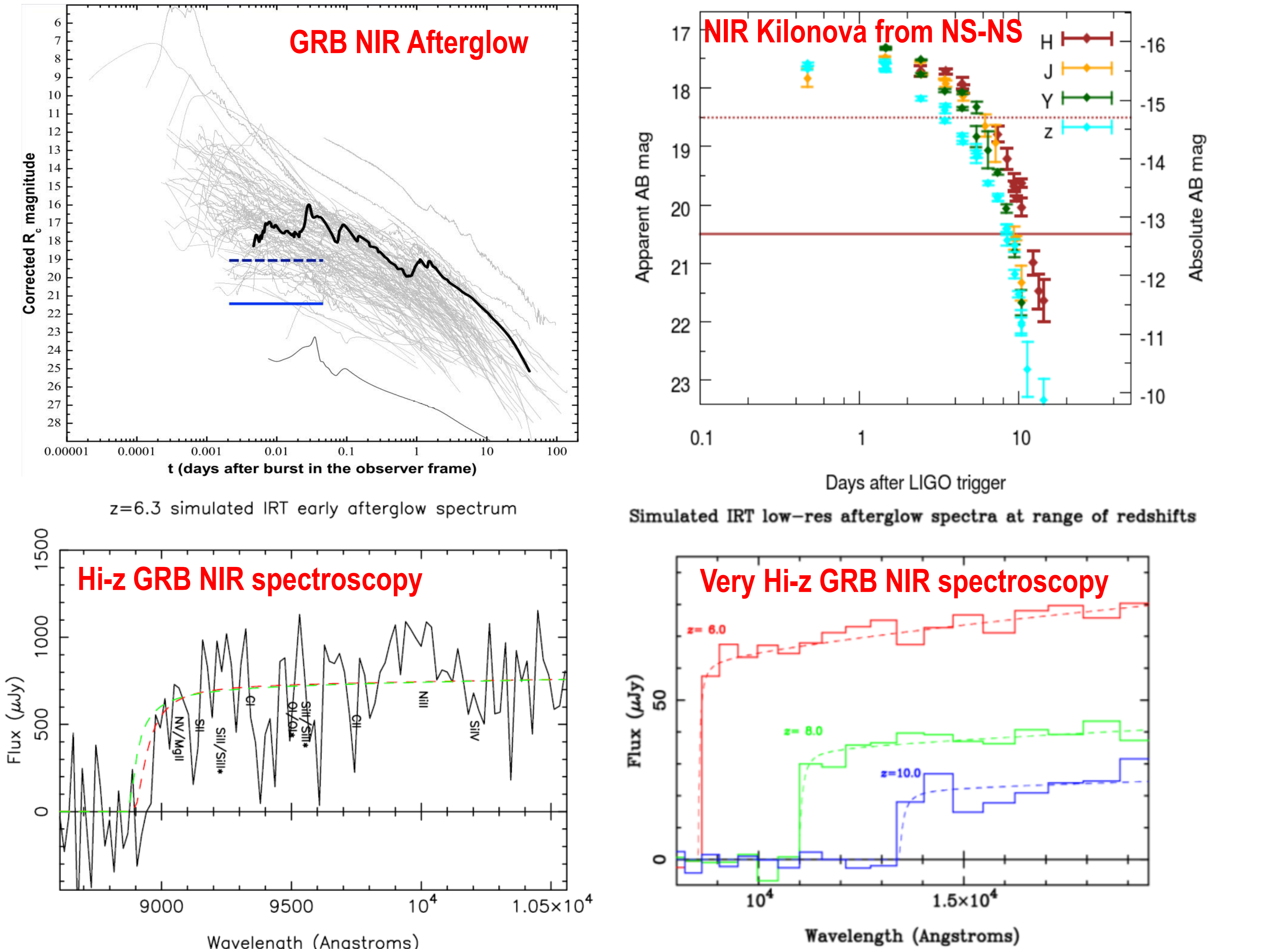
Status and near future

- Study at ESA has identified a solid mission baseline. Complex and conservative S/C simulator developed in collaboration with ESA confirms the feasibility of the science goals of THESEUS with significant margins.

- The M5 phase A will finish in mid-2021, and a down-selection to a single mission is expected around June 2021.

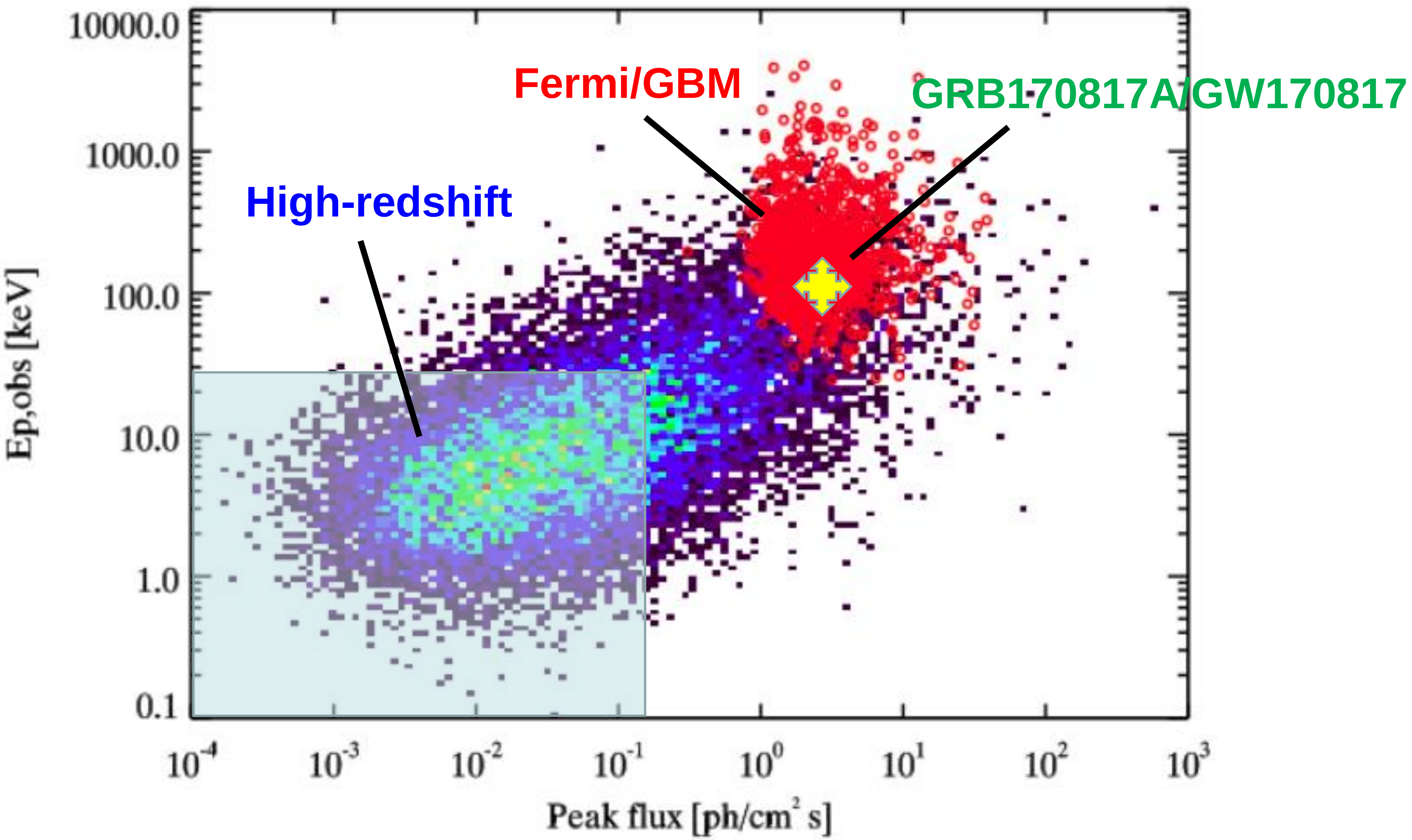
- The call to participate to the THESEUS Science Working Groups is still open! You are very welcome to apply! The final goal is the preparation of the mission Yellow Book.
  - https://www.isdc.unige.ch/theseus/wg-association-request.html

- Public international conference dedicated to THESEUS: Malaga, Spain, 12-15 May 2020
  - https://www.isdc.unige.ch/theseus/theseus-conference-2020.html

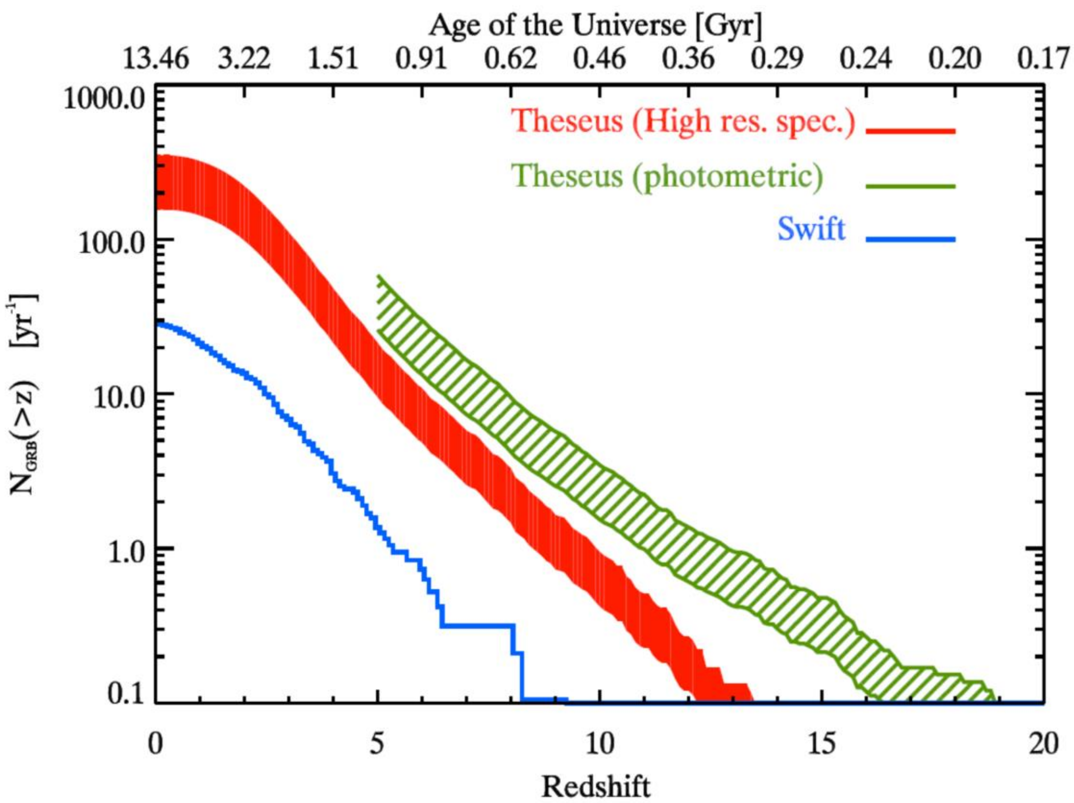


GRB NIR Afterglow
Corrected R_c magnitude
t (days after burst in the observer frame)
0.00001
0.0001
0.001
0.01
0.1
1
10
100
NIR Kilonova from NS-NS
H
J
Y
z
Apparent AB mag
Absolute AB mag
Days after LIGO trigger
0.1
1
10
z=6.3 simulated IRT early afterglow spectrum
Hi-z GRB NIR spectroscopy
Flux (μJy)
Wavelength (Angstroms)
NV/MgII
SII
SiII/SiII*
CI
OI/OI*
SiII/SiII*
CII
NiII
SiIV
Simulated IRT low−res afterglow spectra at range of redshifts
Very Hi-z GRB NIR spectroscopy
z= 6.0
z= 8.0
z=10.0
Flux (μJy)
Wavelength (Angstroms)

❑ **THESEUS will have the ideal combination of instrumentation and mission profile for detecting all types of GRBs (long, short/hard, weak/soft, high-redshift), localizing them from a few arcmin down to arsec and measure the redshift for a large fraction of them**

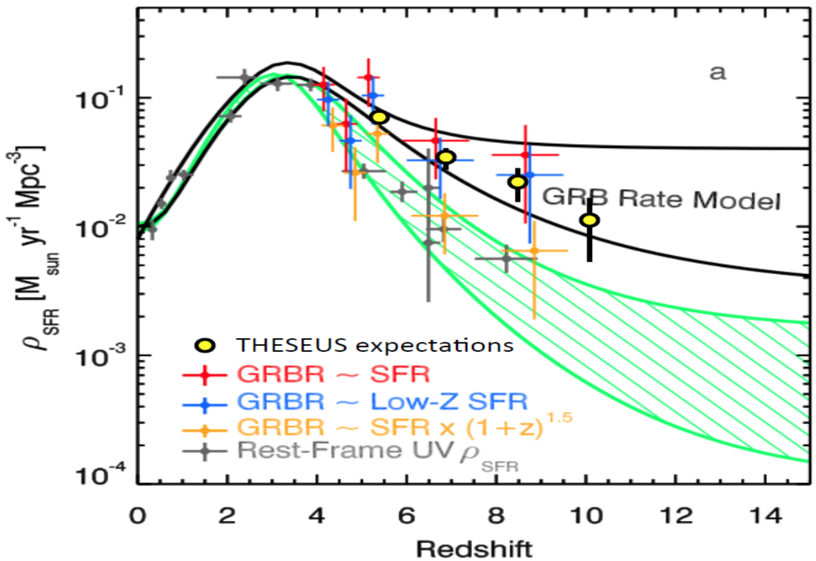


❑ Shedding light on the early Universe with GRBs

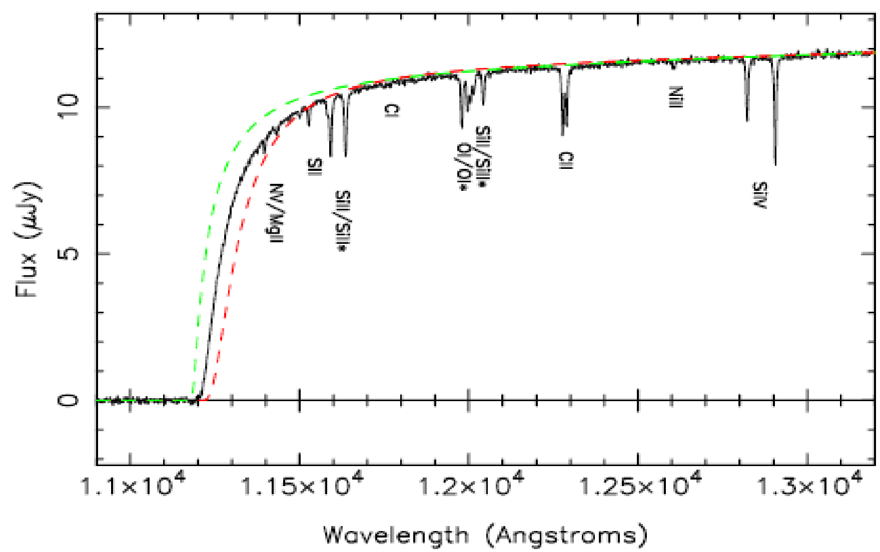


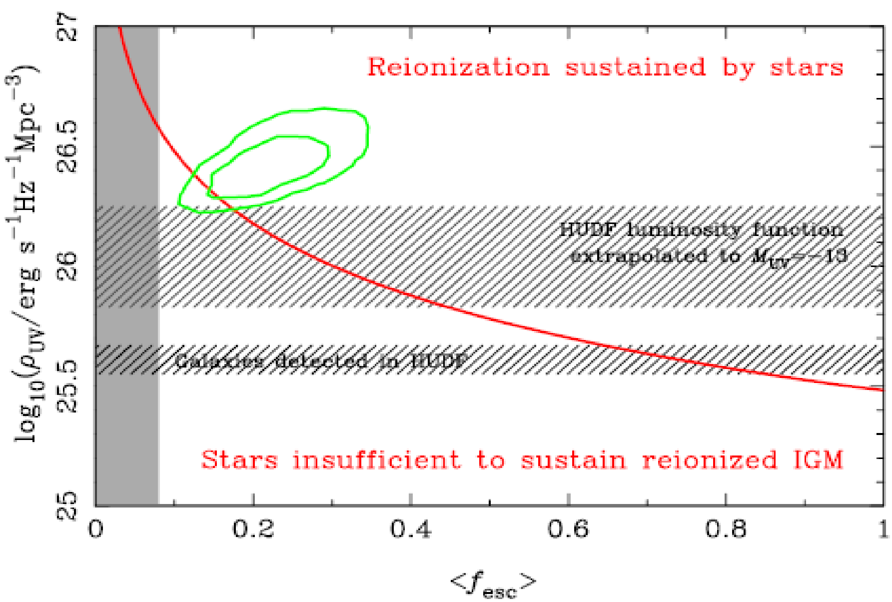
THESEUS GRB#/yr	All	z > 5	z > 8	z > 10
Detections	387 - 870	25 – 60	4 – 10	2 - 4
Photometric z		25 – 60	4 – 10	2 - 4
Spectroscopic z	156 - 350	10 - 20	1 - 3	0.5 - 1

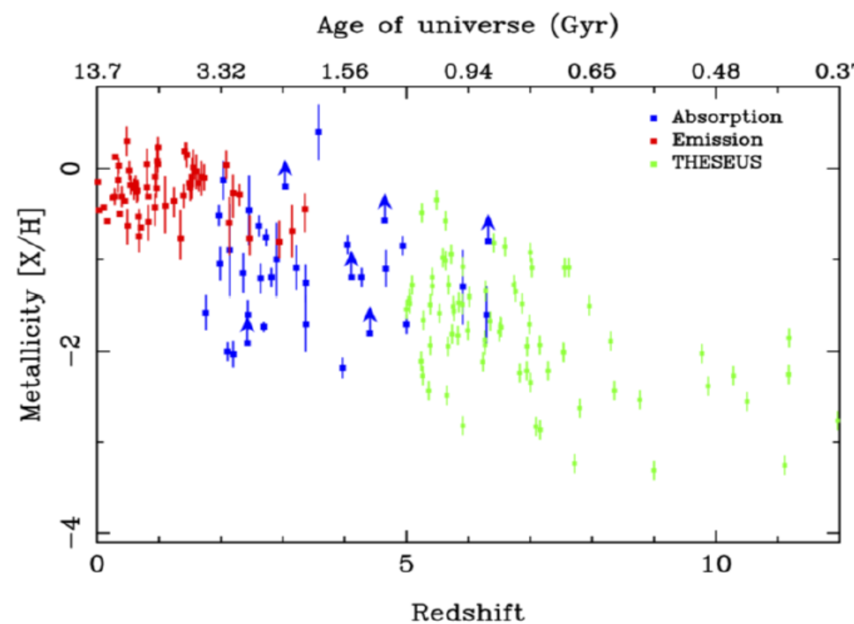
❑ Shedding light on the early Universe with GRBs



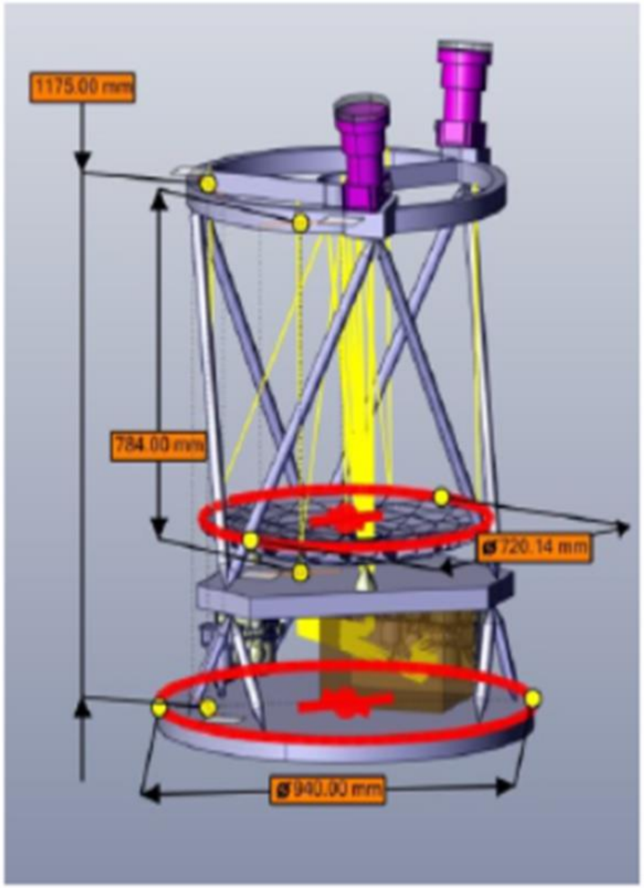
z=8.2 simulated E−ELT afterglow spectra







The InfraRed Telescope (IRT)



- **Korsch FoV off-axis** telescope
- Telescope mass compatible with Zerodur/CFRP or SiC
- **M2 focus mechanism**
- **Spider** supporting structures for M2 assembly
- **2x** XGIS units
- **Squared** combined FoV for SXI
- **Active** thermal control with **LHP (Propylene)**
- **Coarse** star Trackers

A **Korsch telescope** is corrected for spherical aberration, coma, astigmatism, and field curvature and can have a wide field of view while ensuring that there is little stray light in the focal plane.