THESEUS
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

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(University of Geneva, Switzerland)
on behalf of the THESEUS consortium

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

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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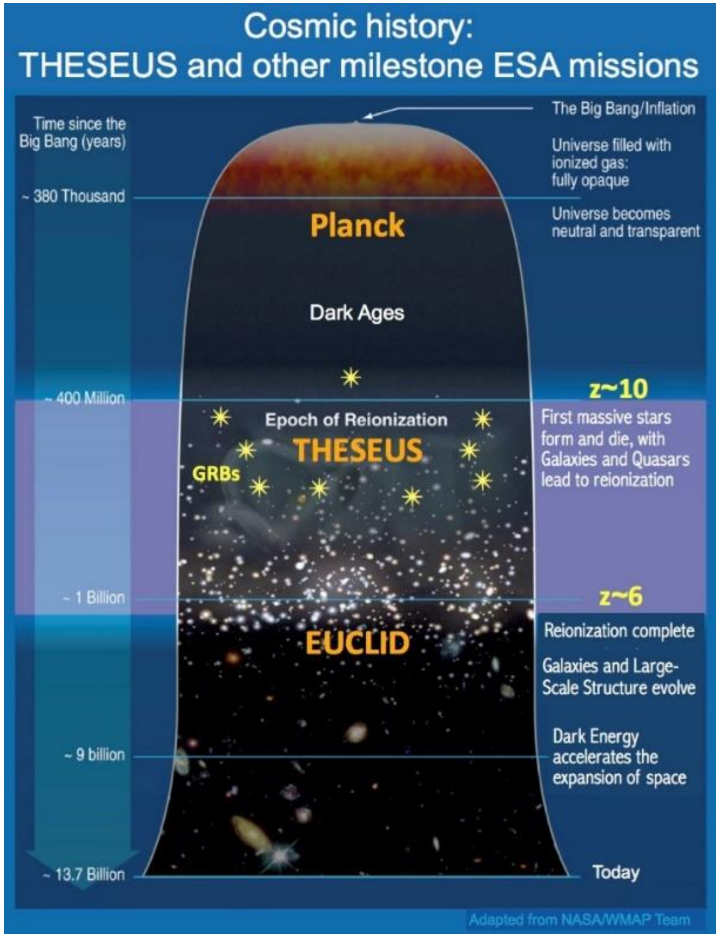
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

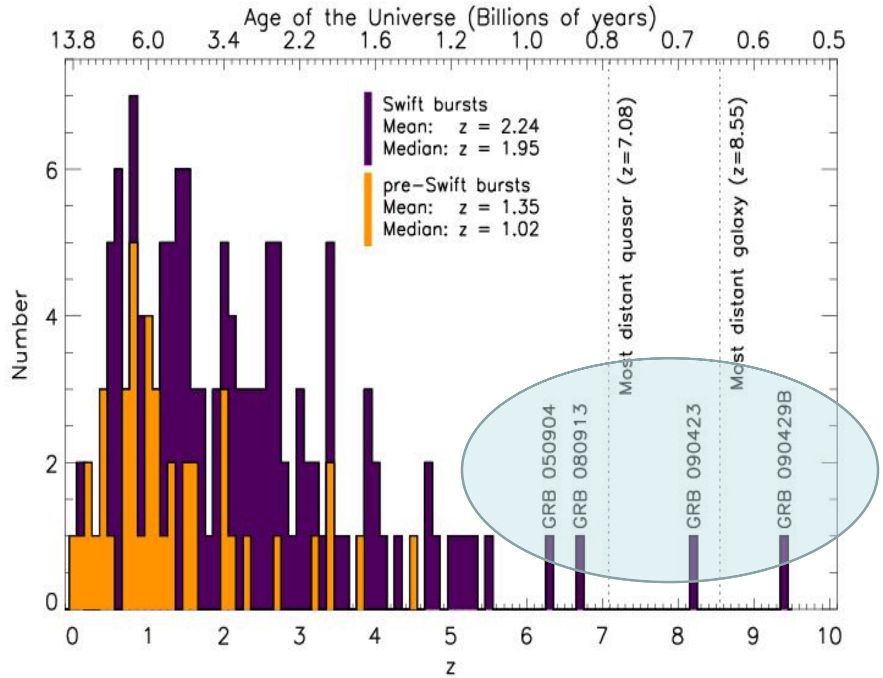
- ***THESEUS* Core Science is based on two pillars:**
  - probe the **physical properties of the early Universe**, by discovering and exploiting the population of high redshift GRBs.
  - provide an **unprecedented deep monitoring** of the soft X-ray transient Universe, providing a fundamental contribution 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).

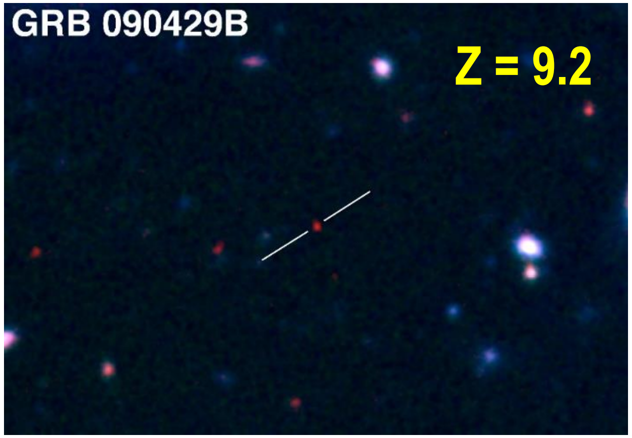
- ***THESEUS* Observatory Science includes:**
  - study of thousands of faint to bright X-ray sources by exploiting the **simultaneous availability of broad band X-ray and NIR observations**
  - provide a **flexible follow-up observatory** for fast transient events with multi-wavelength ToO capabilities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

Shedding light on the early Universe with GRBs

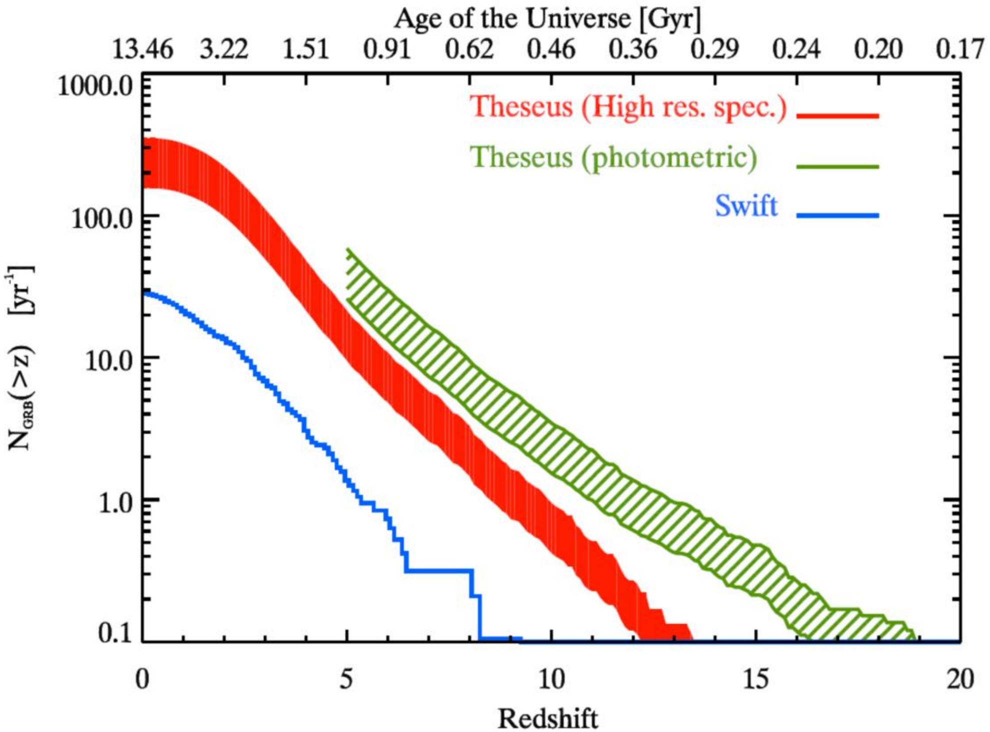
Because of their huge luminosities, mostly emitted in the X and gamma-rays, their redshift distribution extending at least to z ~9 and their association with explosive death of massive stars and star forming regions, GRBs are unique and powerful tools for investigating the early Universe: **SFR evolution, 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

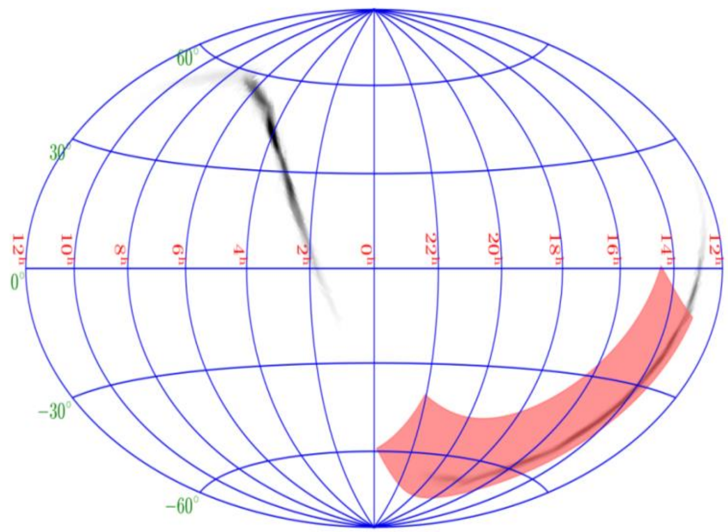


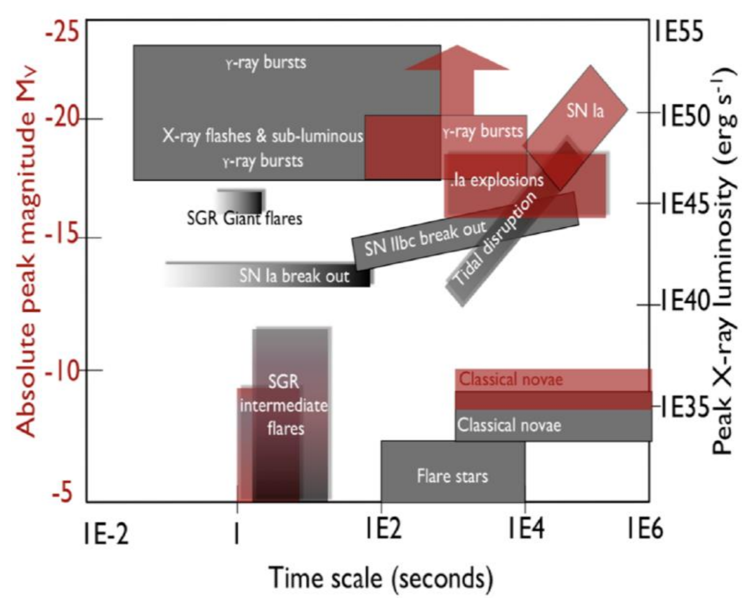
Exploring the multi-messenger transient sky

- 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;**

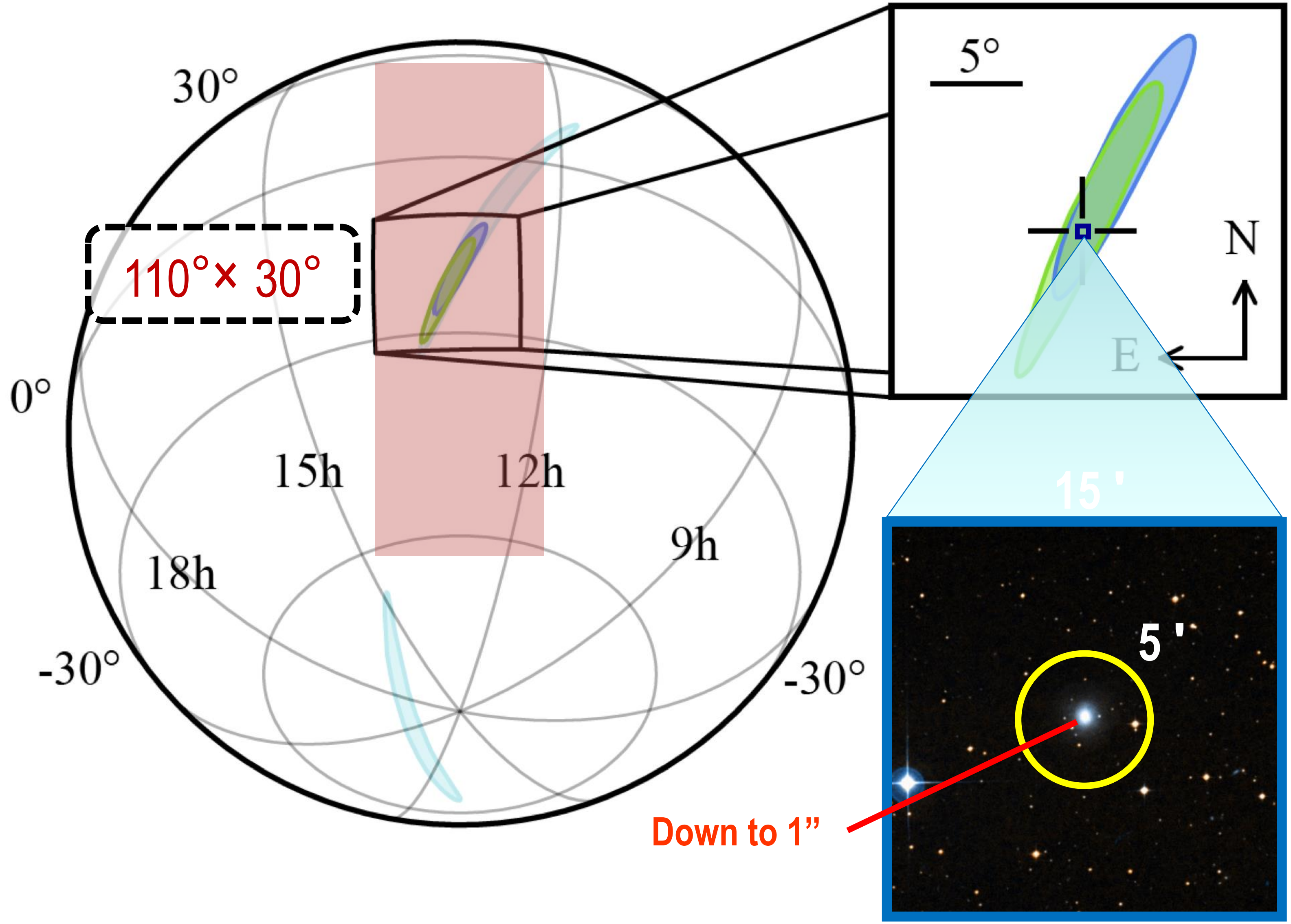
- Provide real-time triggers and accurate (~1 arcmin within a few seconds; ~1’’ within a few minutes) high-energy transients for follow-up with next-generation optical-NIR (**E-ELT, JWST** if still operating), radio (**SKA**), X-rays (**ATHENA**), TeV (**CTA**) telescopes; synergy with **LSST**

- 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**

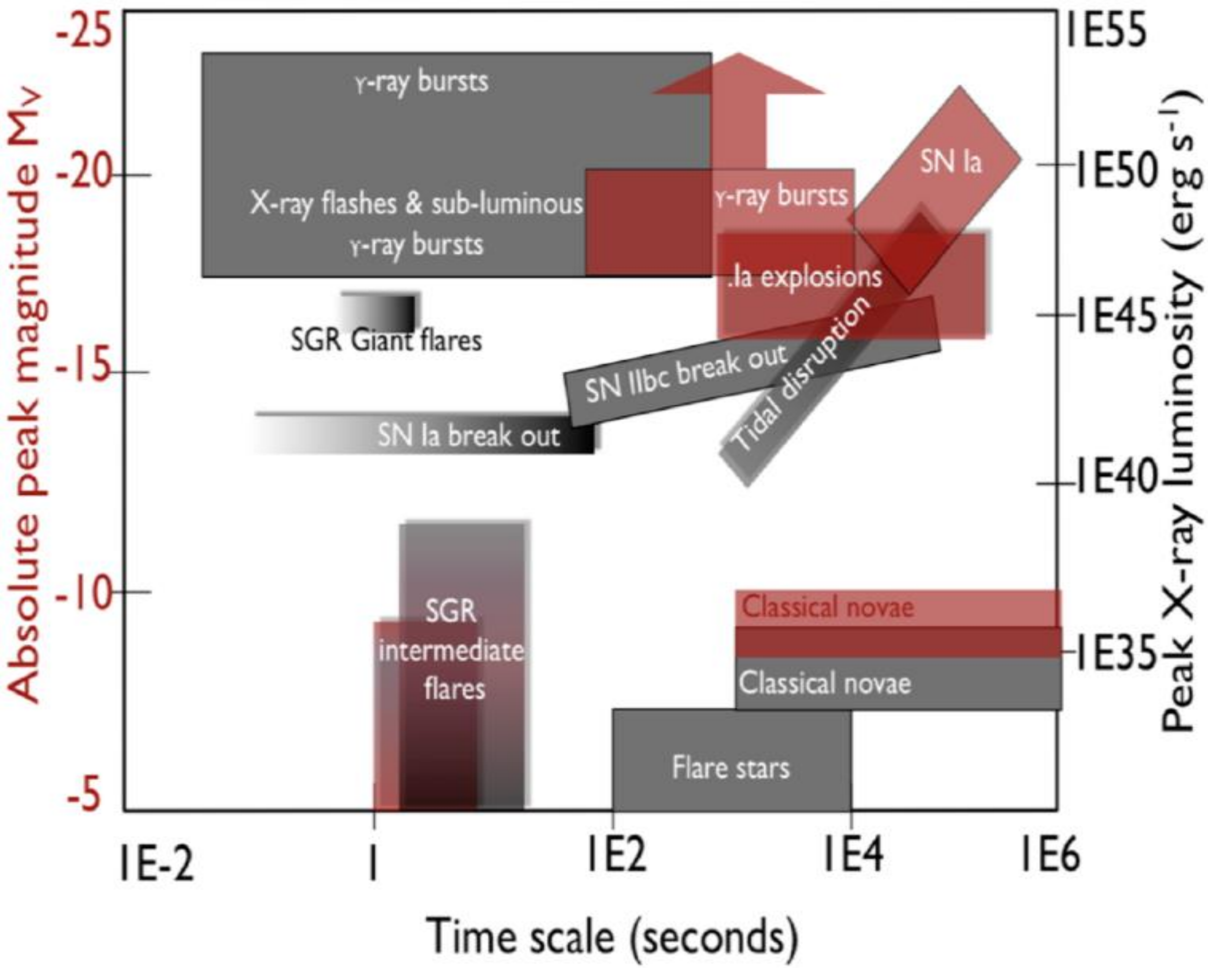




Promptly and accurately localizing transients with THESEUS

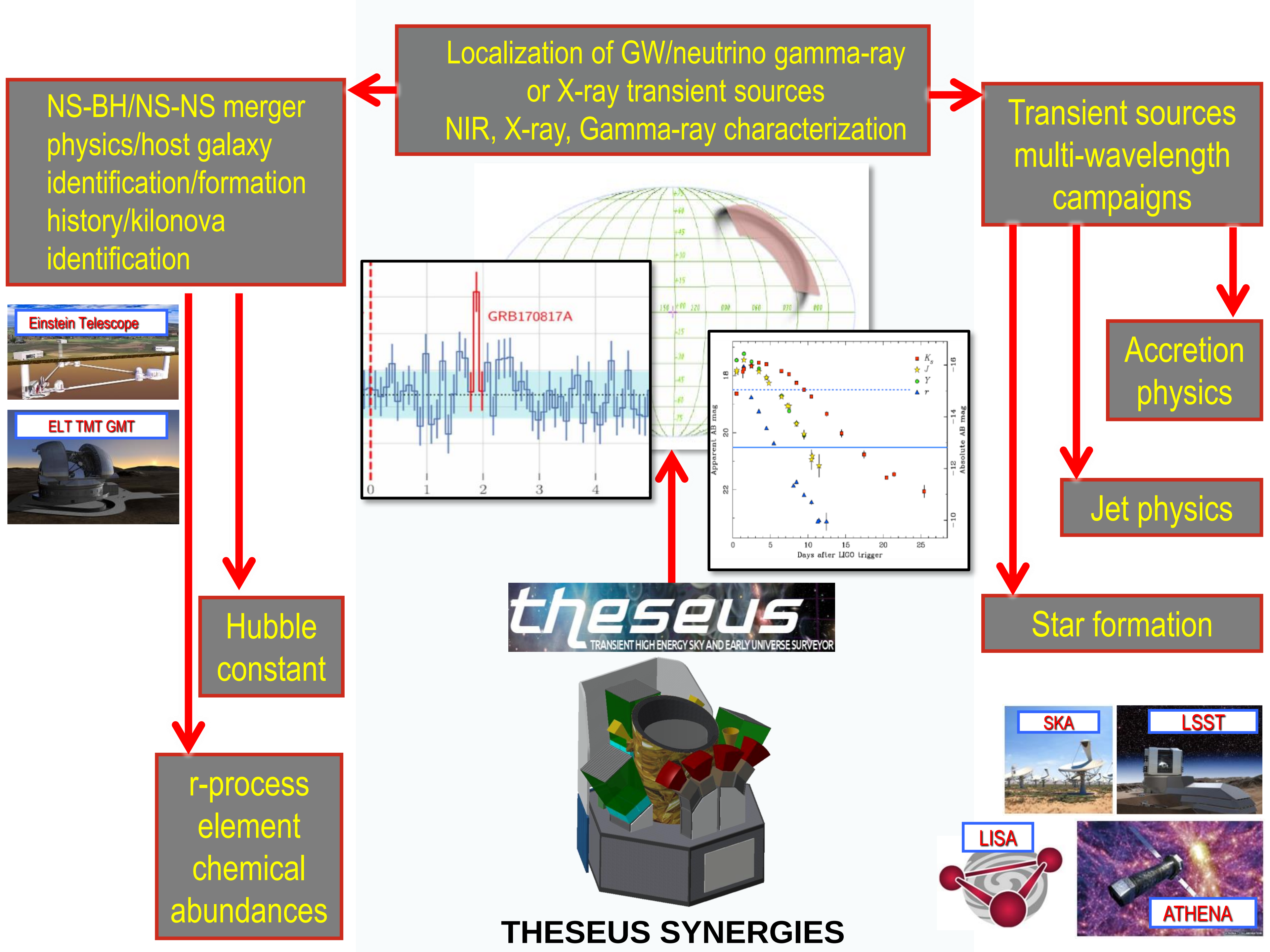


A powerful and flexible observatory



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
Accretion physics
Jet physics
Apparent AB mag
Absolute AB mag
Days after LIGO trigger
Hubble constant
Star formation
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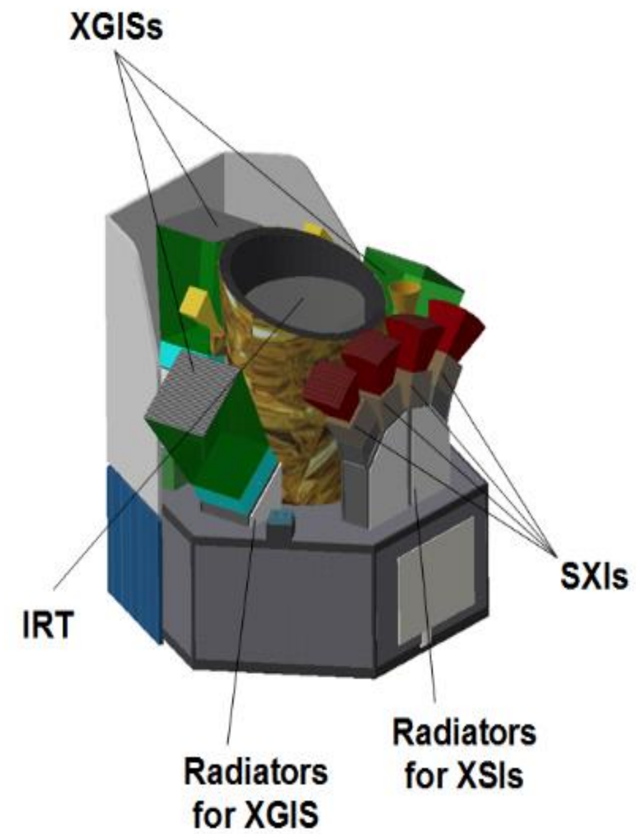
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR
SKA
LSST
LISA
ATHENA
r-process element chemical abundances
THESEUS SYNERGIES

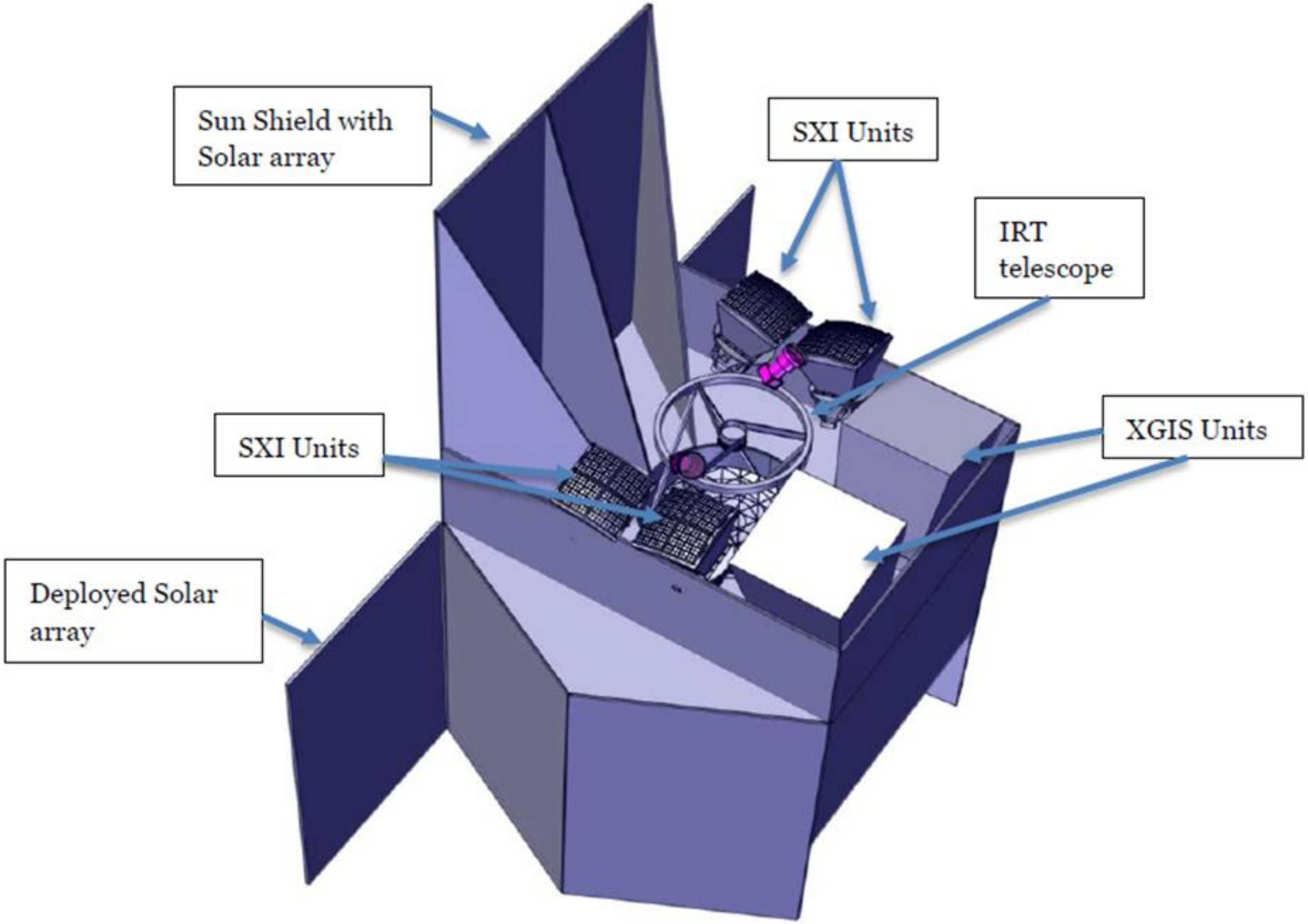
THESEUS mission concept

- **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)



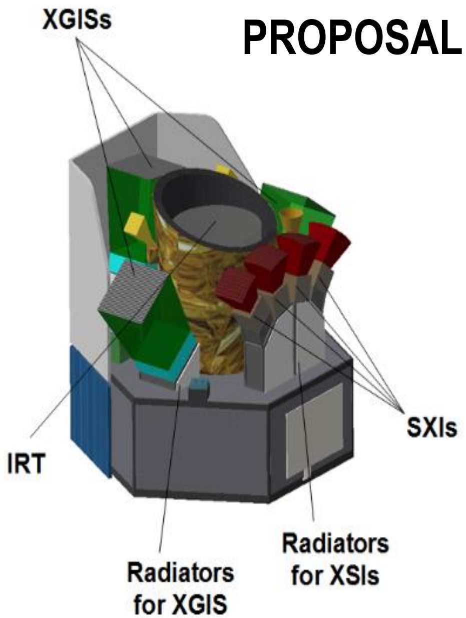
LEO (< 5°, ~600 km)
Autonomous slewing
Prompt downlink

THESEUS mission concept: ESA study

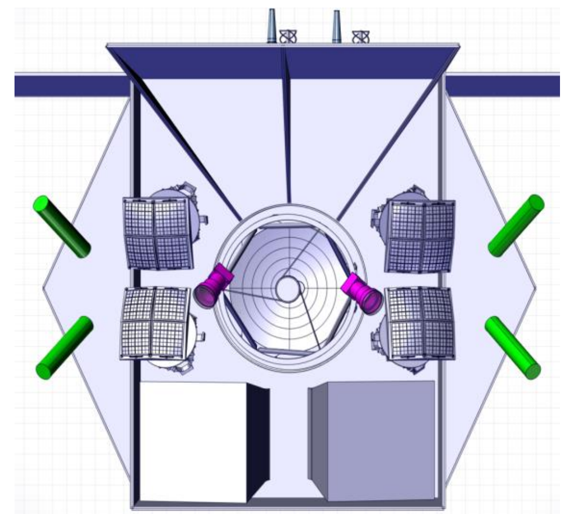


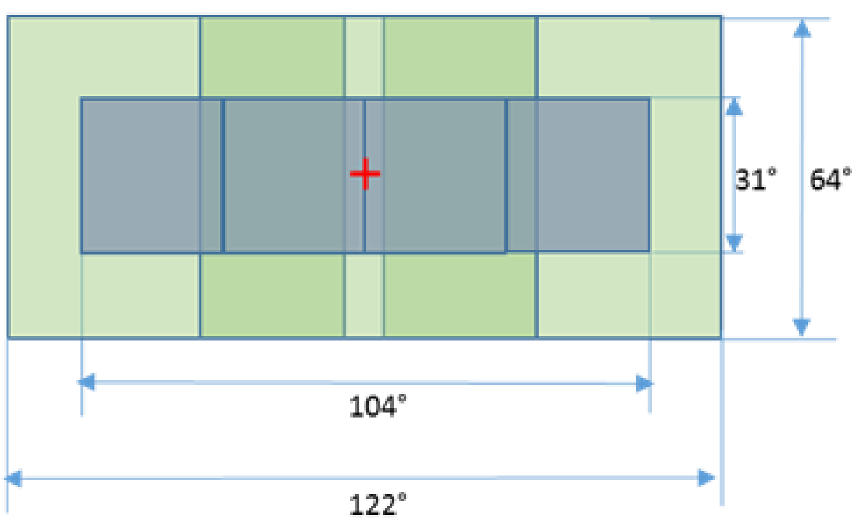
THESEUS mission concept: ESA study

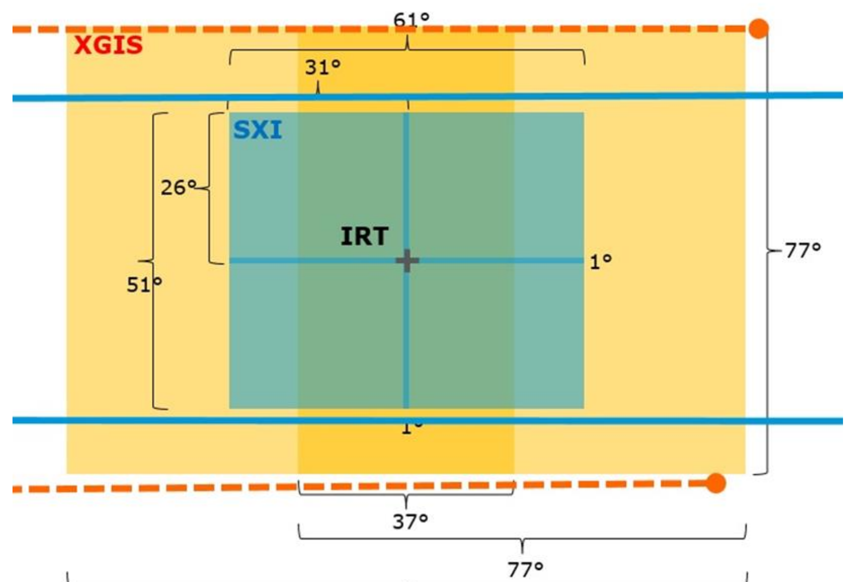
PROPOSAL



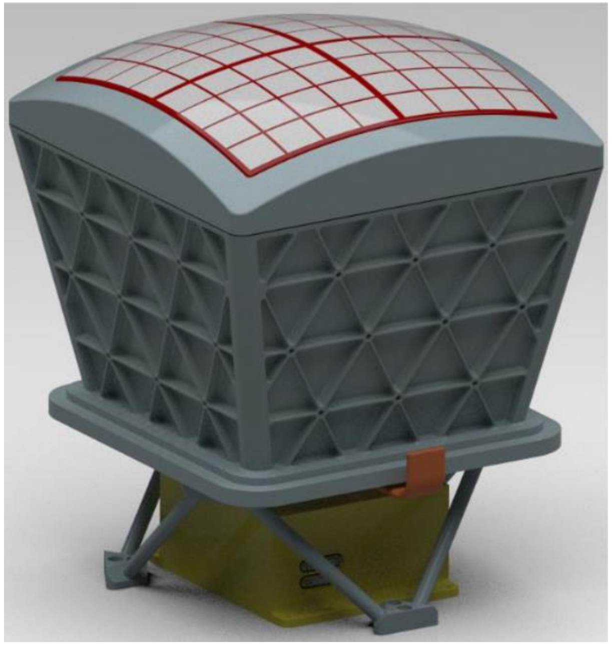
CDF STUDY

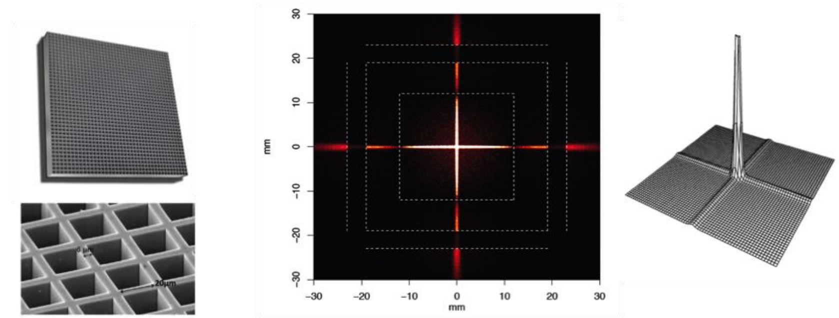






The Soft X-ray Imager (SXI)





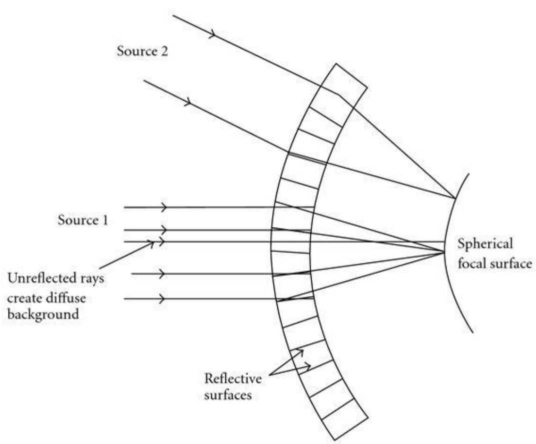
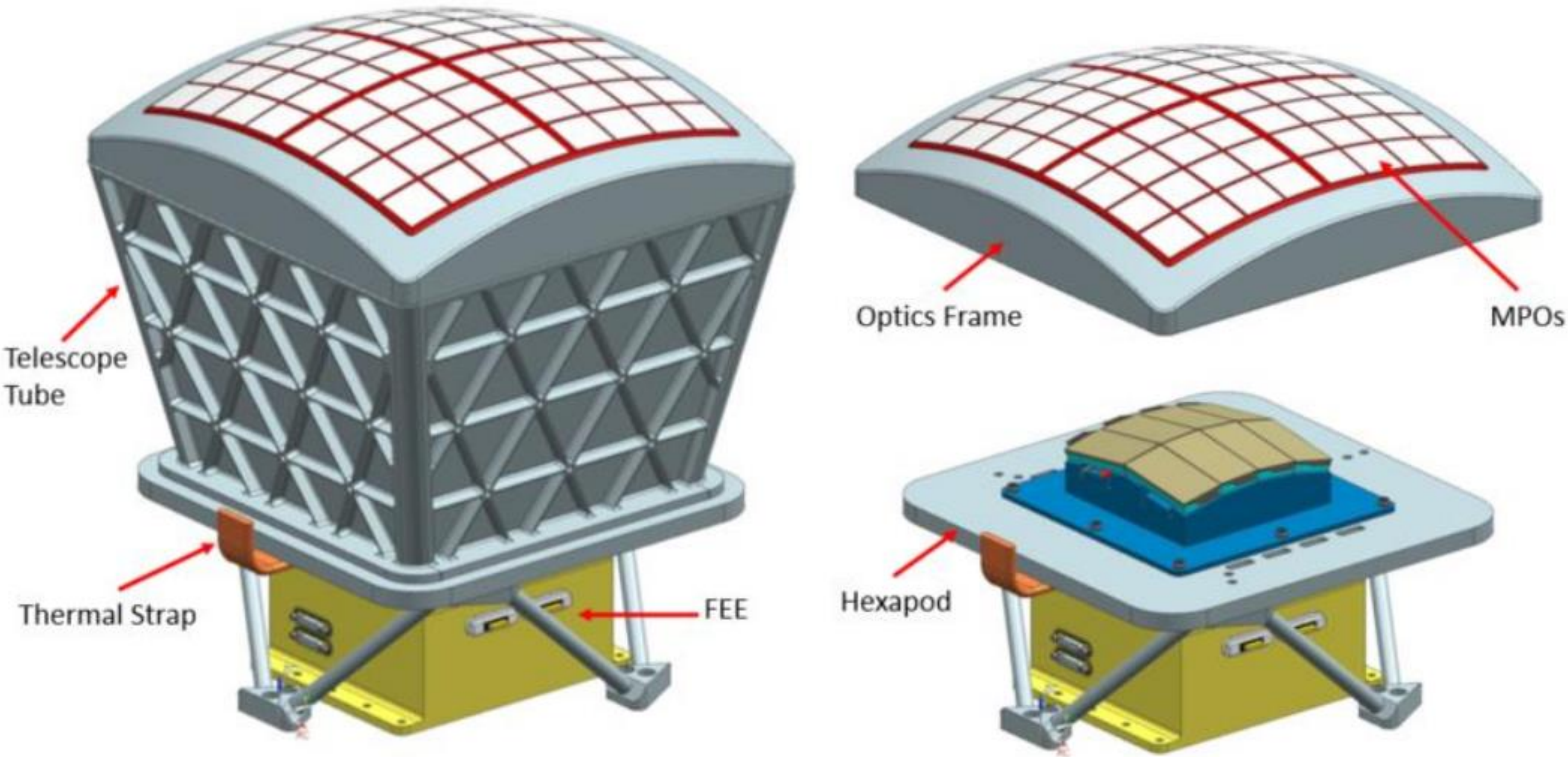


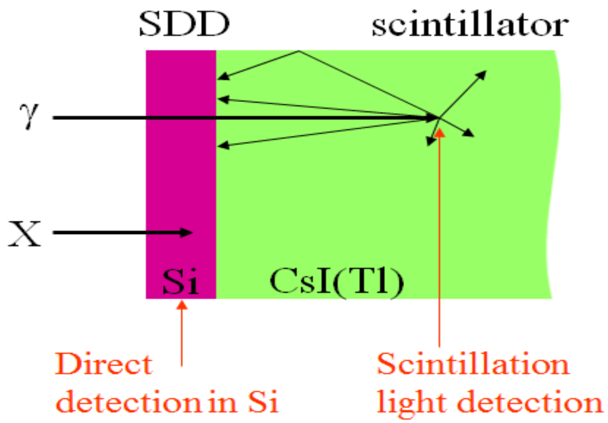
Table 4 : : SXI detector unit main physical characteristics

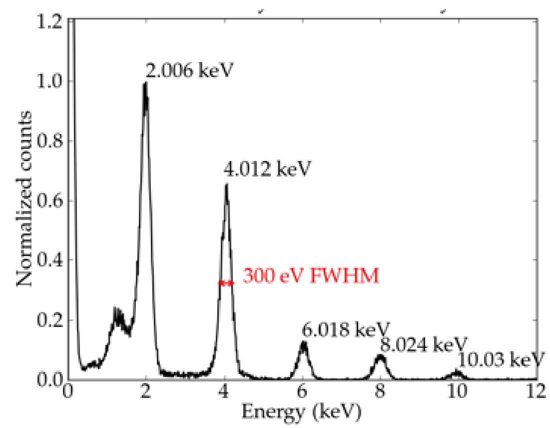
Energy band (keV)	0.3-5
Telescope type:	Lobster eye
Optics aperture (mm2)	320x320
Optics configuration	8x8 square pore MCPs
MCP size (mm2)	40x40
Focal length (mm)	300
Focal plane shape	spherical
Focal plane detectors	CCD array
Size of each CCD (mm2)	81.2x67.7
Pixel size (µm)	18
Pixel Number	4510 x 3758 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

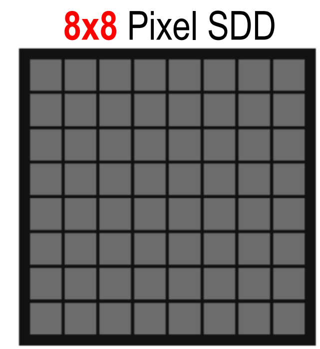
The Soft X-ray Imager (SXI)

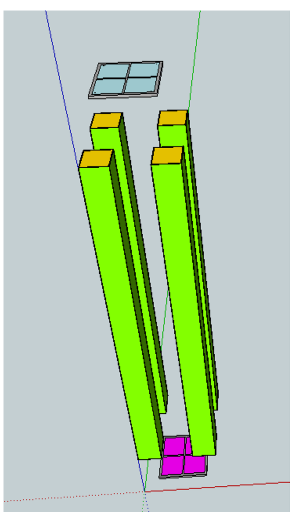


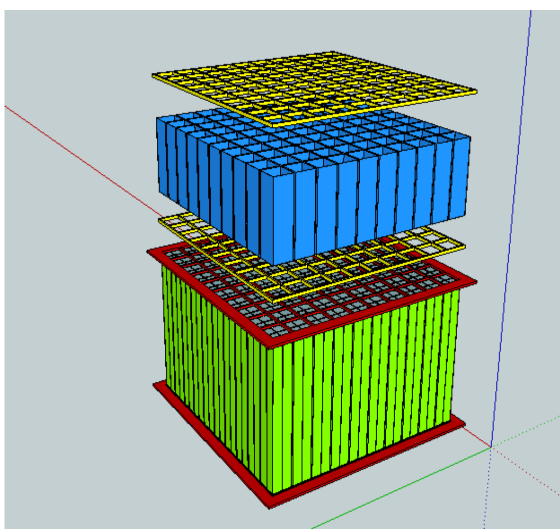
The X-Gamma-ray imaging spectrometer

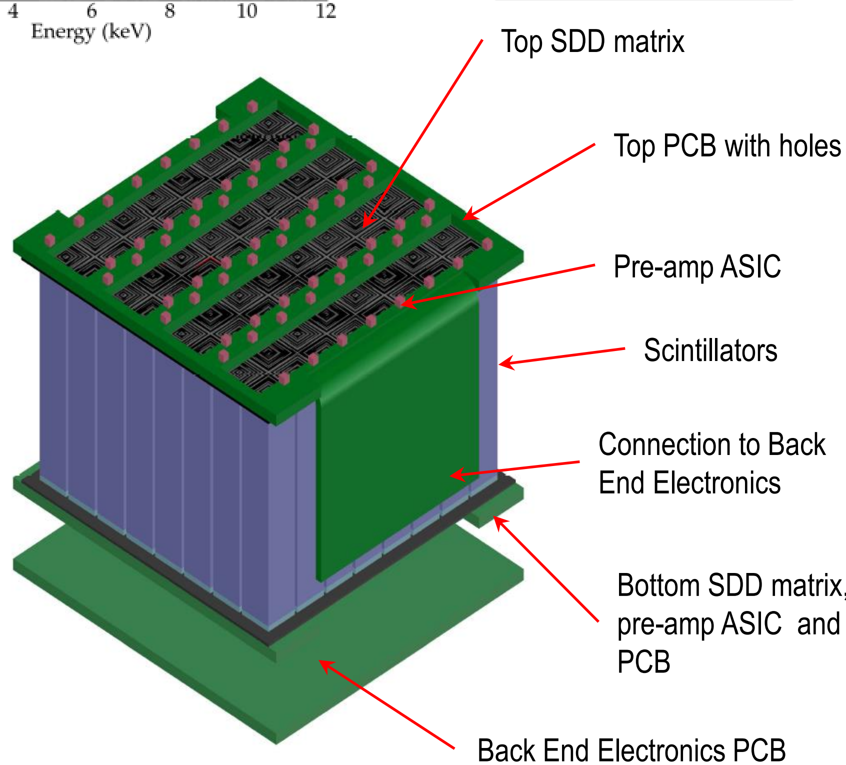




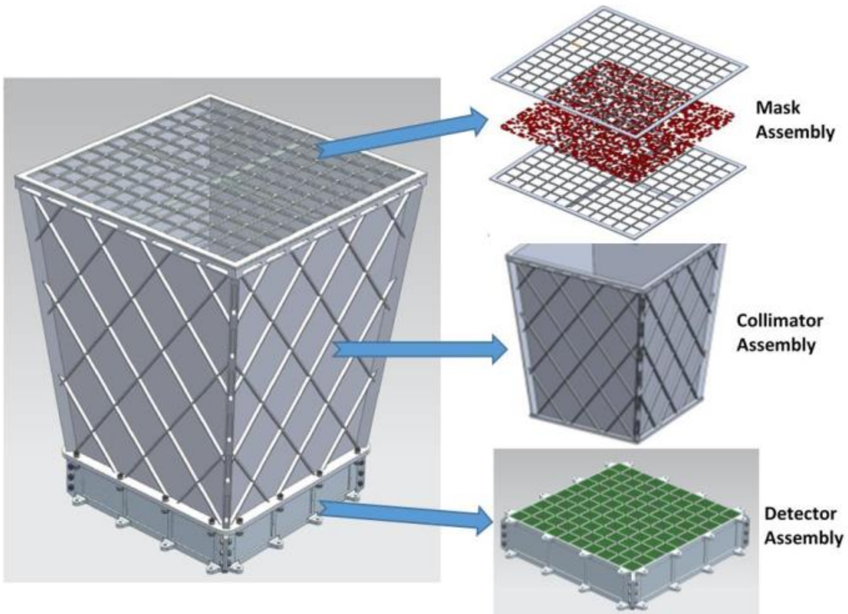


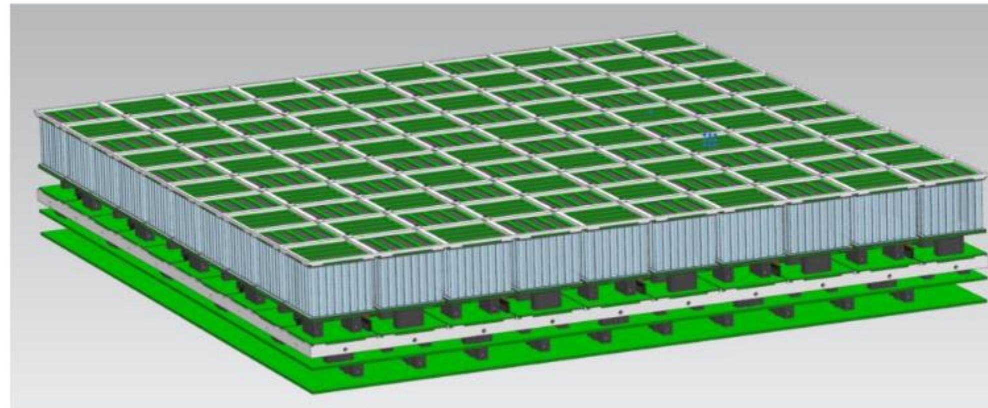


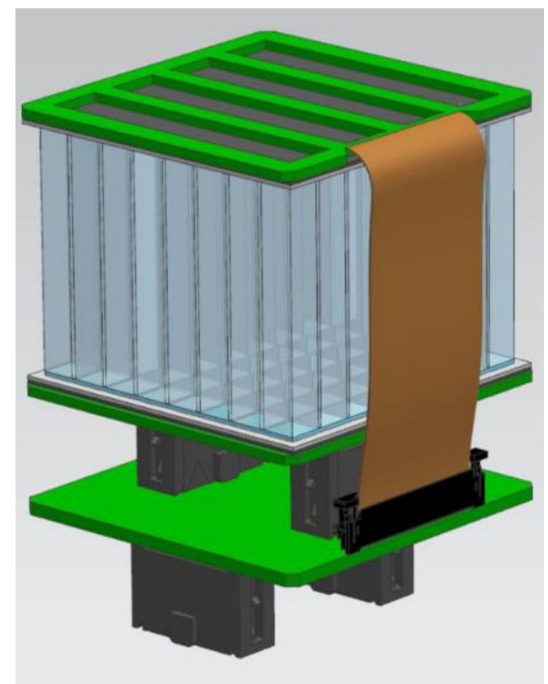




The X-Gamma-rav imaging spectrometer

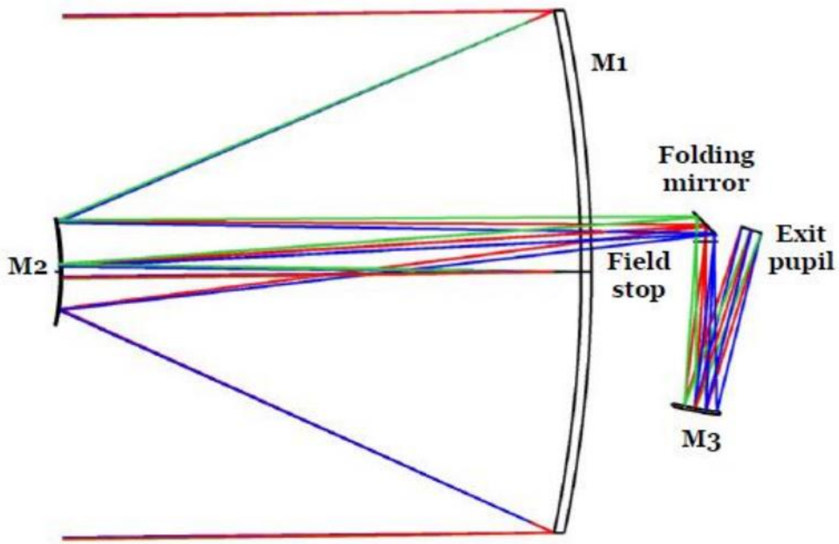


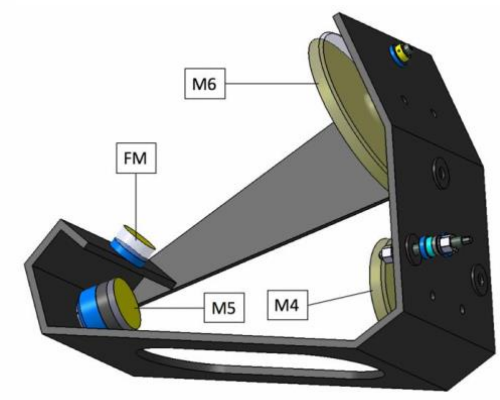




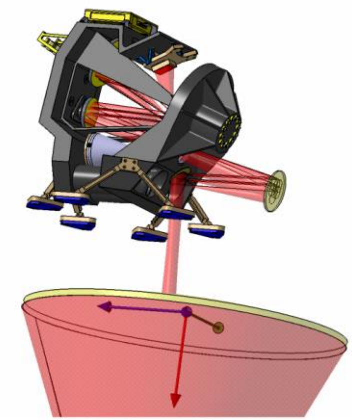
	3-150 keV	>150 keV
Fully coded FOV	10.5 x 10.5 deg^2	
Partially Coded FOV	77 x 77 deg^2	4 sr
Ang. res (1.1 cm mask elements)	60 arcmin	
Source location accuracy	≤ 10 arcmin (for >10 σ source) (TBC)	
Energy res	200 eV FWHM @ 6 keV	6 % FWHM @ 500 keV
Timing res.	1 µsec	1 µsec
On axis useful area	518 cm^2 assuning a mask open fraction of 50% and hole size on top PCB	1296 cm^2

The InfraRed Telescope (IRT)



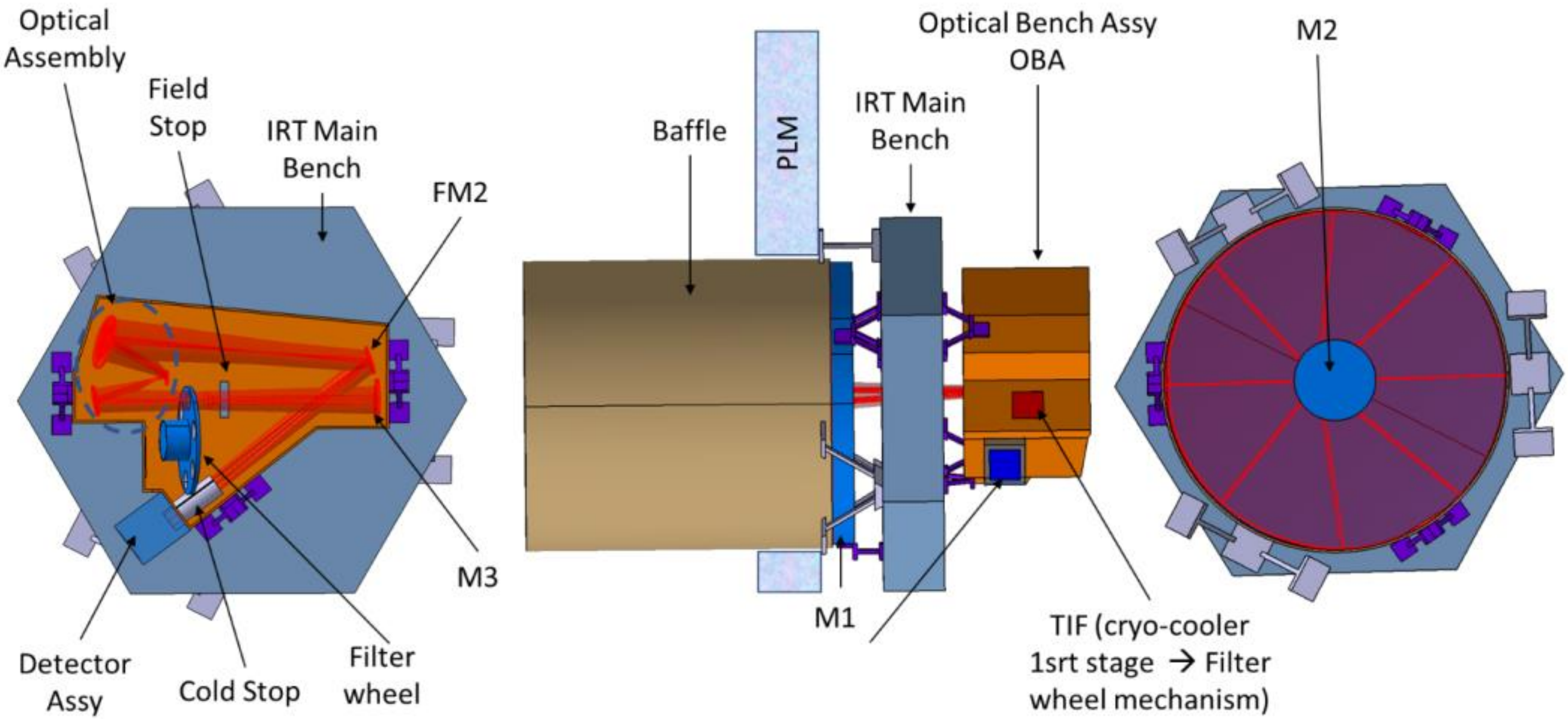


Telescope type	Off-axis Korsch
Primary & Secondary Size	>600 mm (goal 700 mm) & 214-250 mm
Detector type	Baseline: European ALFA detector (2048x2048 15 μ pixels) Back-up: Teledyne Hawaii 2-RG 2048x2048 18 μ pixels
Imaging plate scale	0.45 arcsec/pixel
Field of view	15x15 arc min in imaging and LRS modes, 5x5 arc min in HRS mode (TBC)
Rsolution (Δλ/λ)	20 in LRS mode; 500 in HRS mode
Sensitivity (H band)	20.6 (AB; 300 s) in imaging mode; 18.5 (AB; 300 s) in LRS mode; 17.5 (AB, 1800 s) in HRS mode
Wavelength range	0.7-1.8 μ in imaging mode; 0.8-1.6 μ in LRS and HRS modes



IRT telescope: off-axis three-mirror anastigmat afocal telescope. Diameter of the exit pupil: 30mm. IRT instrument is three-mirror off-axis system incorporating a folding mirror just before the detector.

The InfraRed Telescope (IRT)

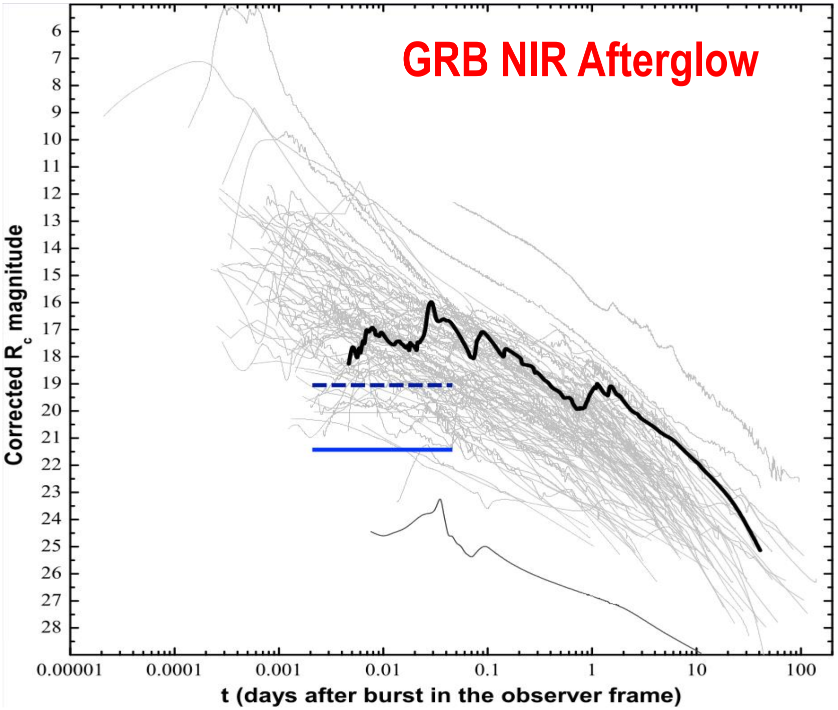


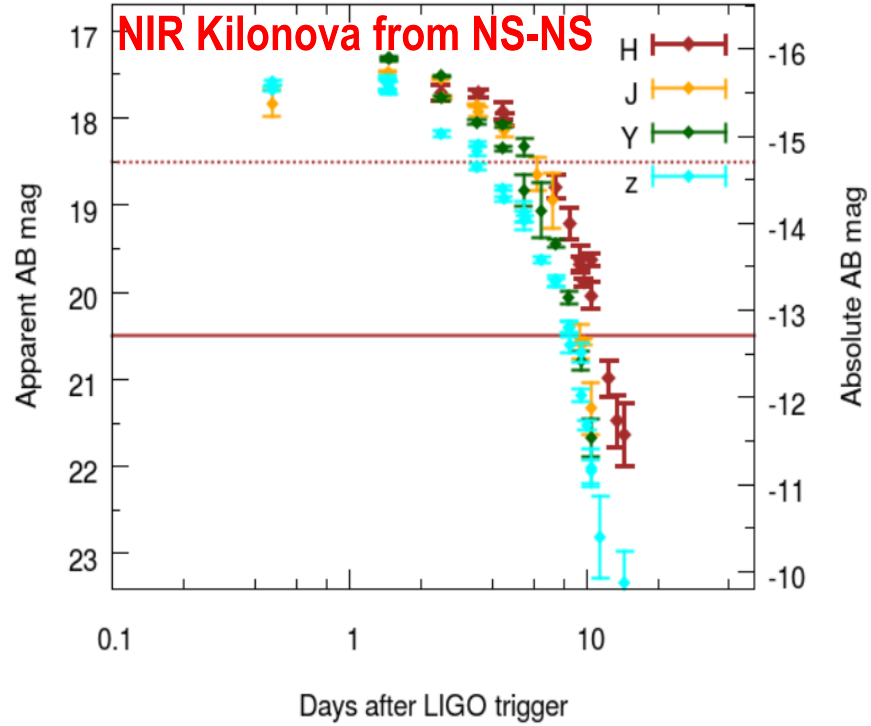
Status and near future

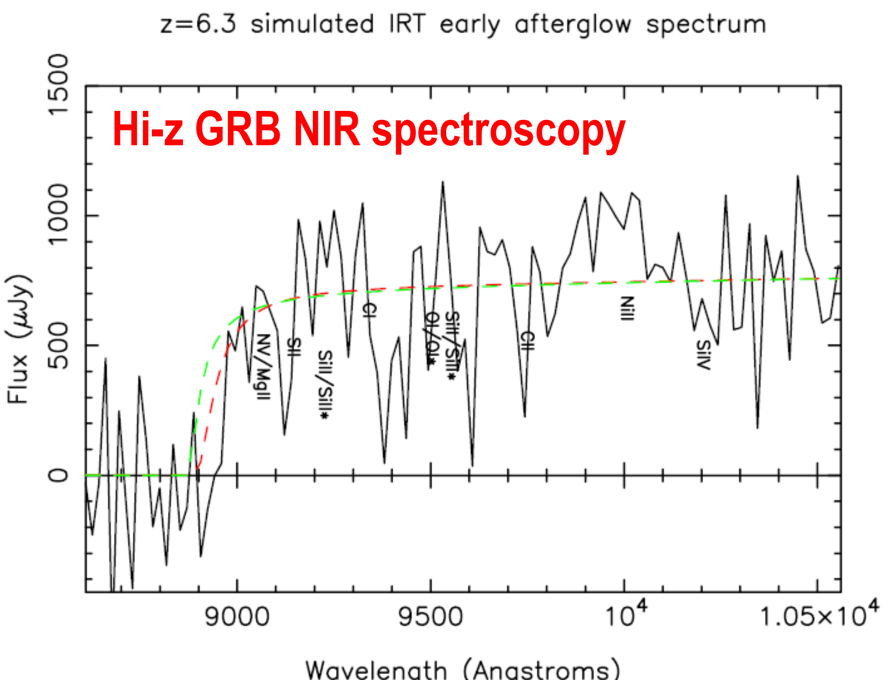
- Study at ESA has identified a solid mission baseline. Complex and conservative S/C simulator developed in collaboration with ESA confirms the feasibility of the science goals of THESEUS with significant margins.

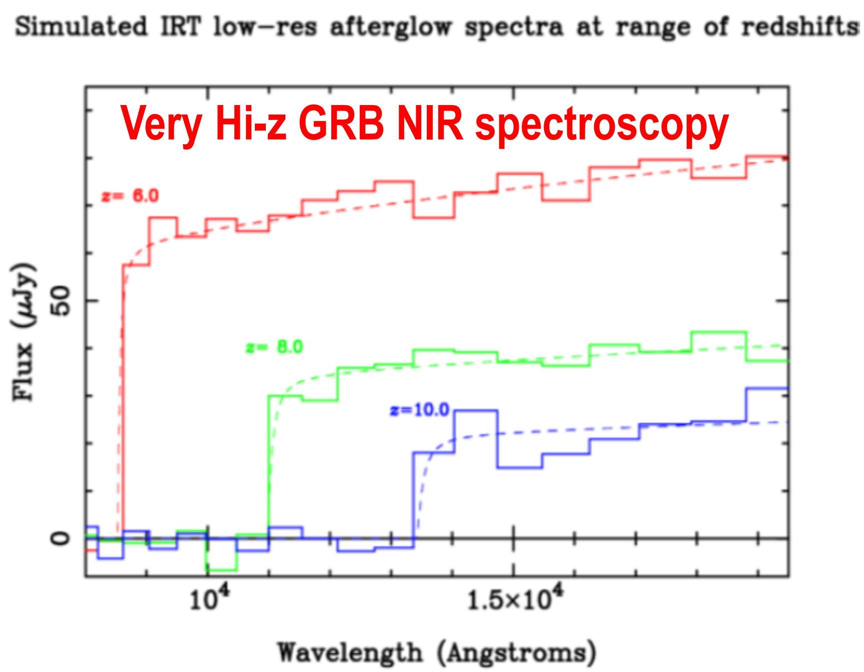
- Participation to the THESEUS Science Working Groups encouraged! The final goal is the preparation of the mission Yellow Book.
  - https://www.isdc.unige.ch/theseus/wg-association-request.html

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

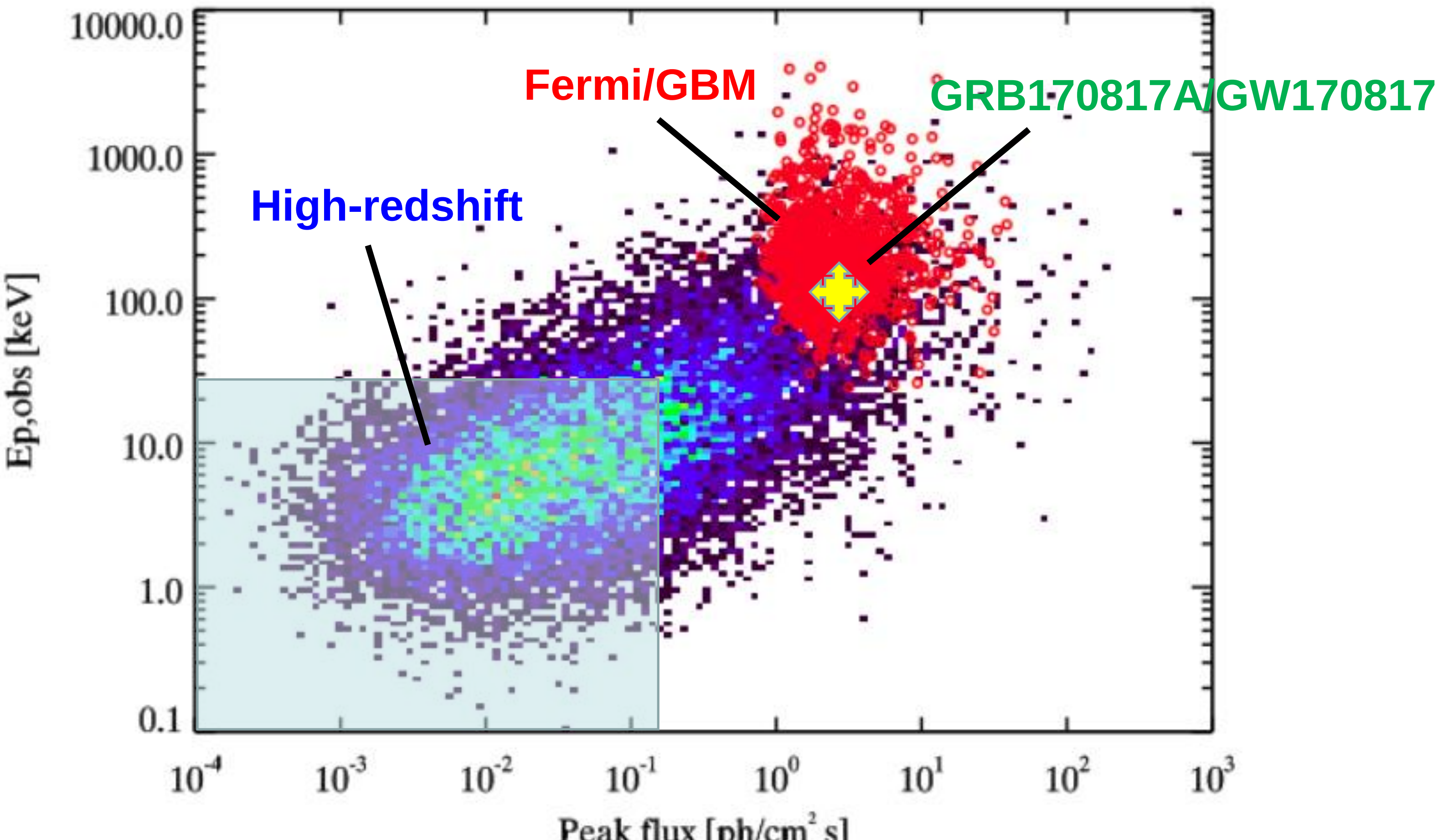

GRB NIR Afterglow
Corrected R_c magnitude
t (days after burst in the observer frame)


NIR Kilonova from NS-NS
H
J
Y
z
Apparent AB mag
Absolute AB mag
Days after LIGO trigger

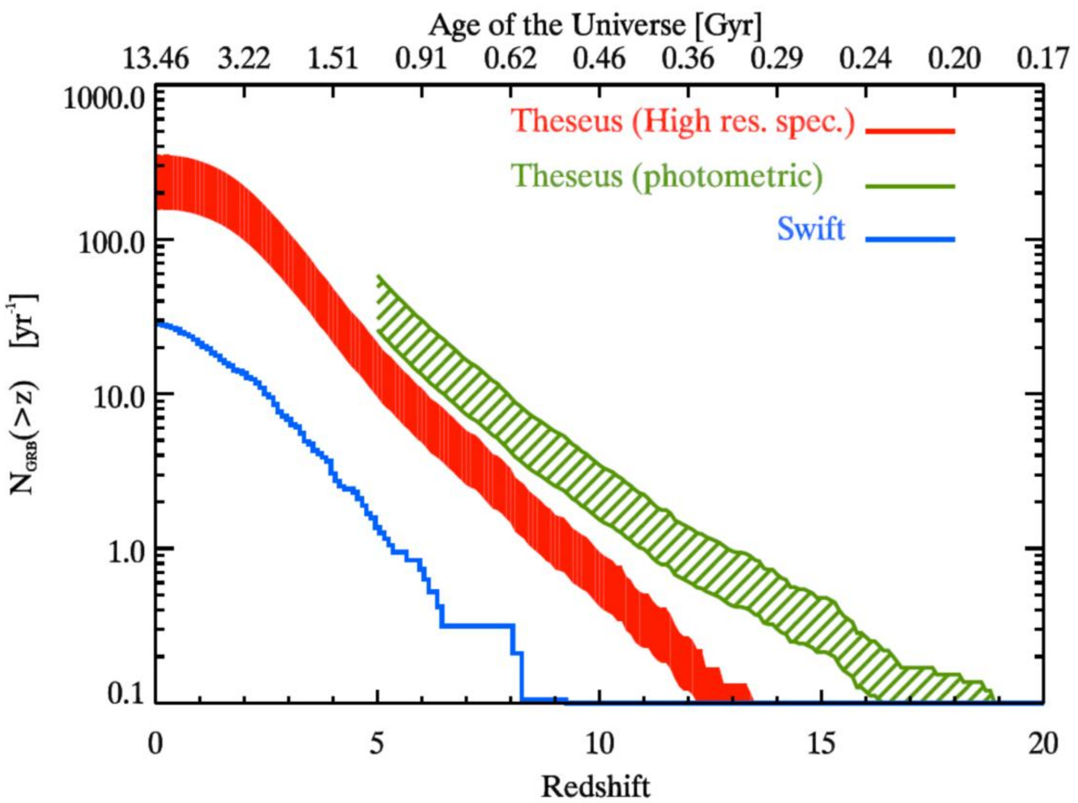

z=6.3 simulated IRT early afterglow spectrum
Hi-z GRB NIR spectroscopy
Flux (μJy)
Wavelength (Angstroms)
NV/MgII
SII
SiII/SiII*
CI
OI/OI*
SiII/SiII*
CII
NiII
SiIV


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



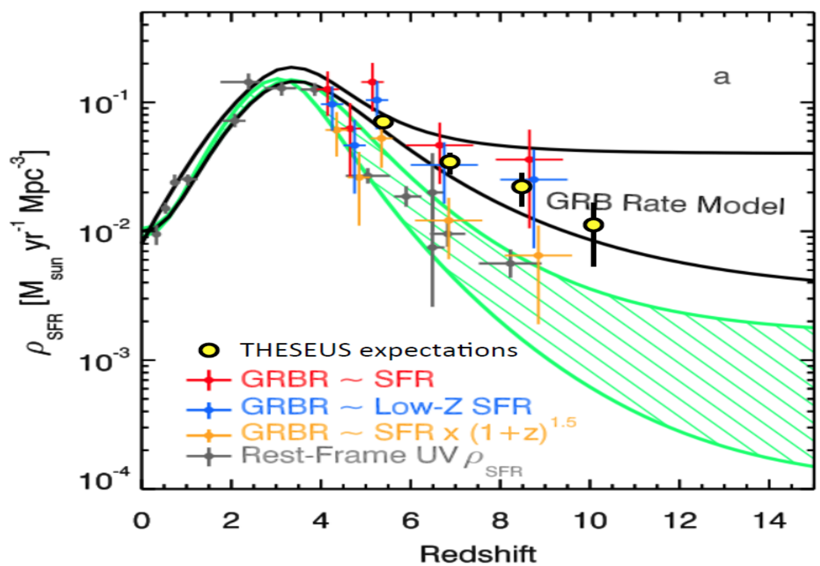
❑ Shedding light on the early Universe with GRBs

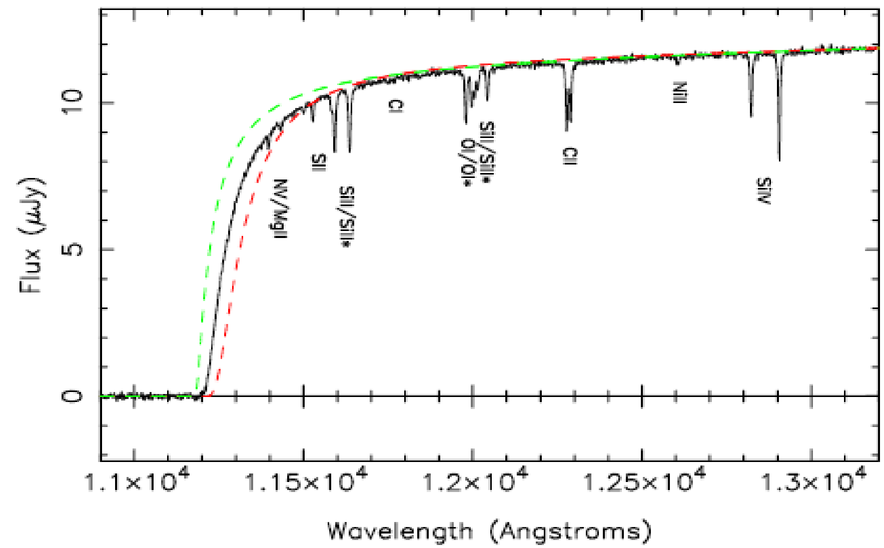


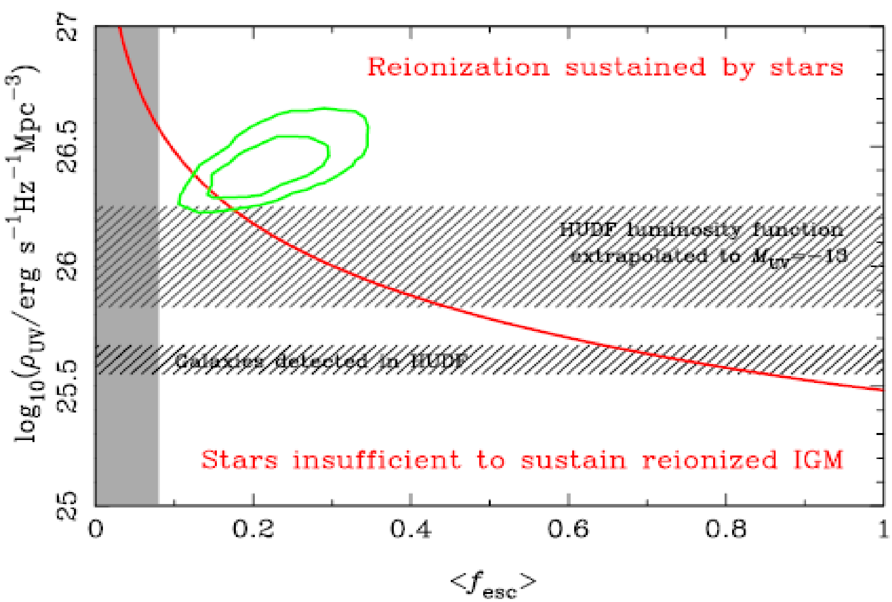
THESEUS GRB#/yr	All	z > 5	z > 8	z > 10
Detections	387 - 870	25 – 60	4 – 10	2 - 4
Photometric z		25 – 60	4 – 10	2 - 4
Spectroscopic z	156 - 350	10 - 20	1 - 3	0.5 - 1

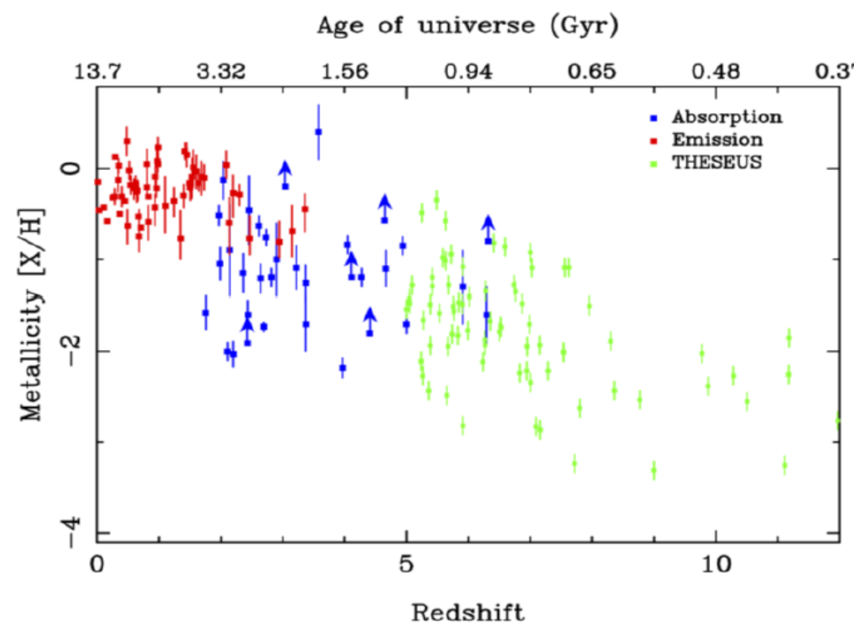
❑ Shedding light on the early Universe with GRBs

z=8.2 simulated E-ELT afterglow spectra

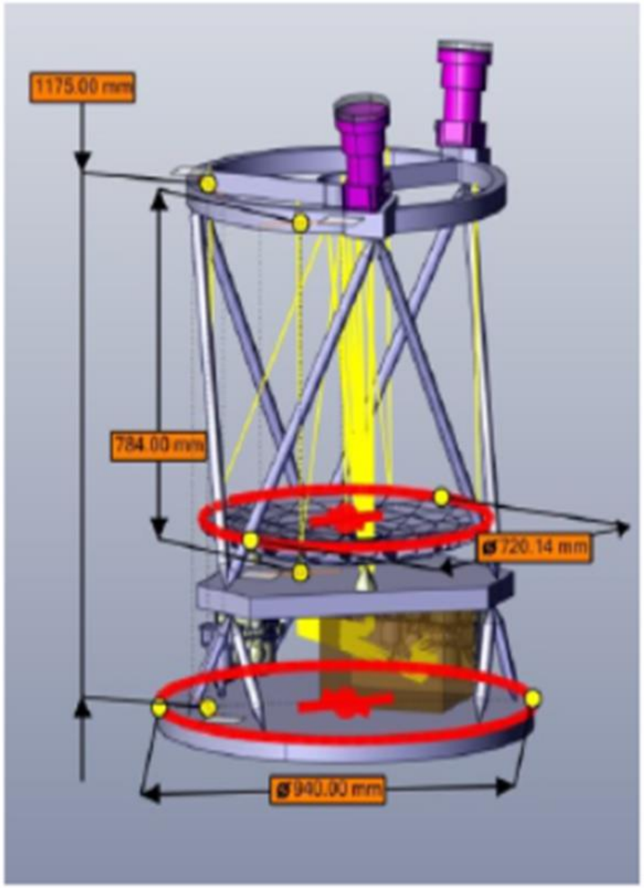








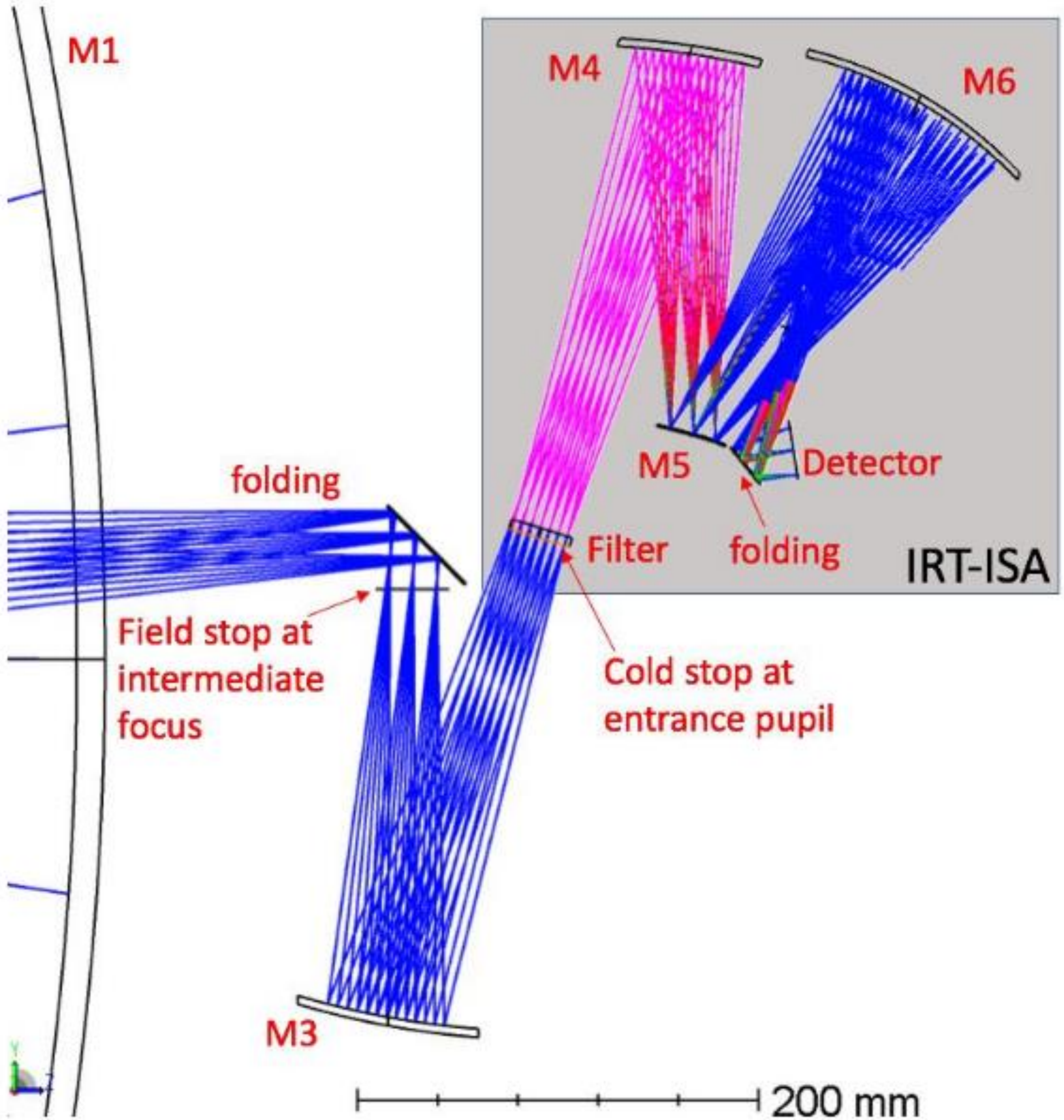
The InfraRed Telescope (IRT)



- **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.

The InfraRed Telescope (IRT)



The InfraRed Telescope (IRT)

Component	Characteristics
M4	Radius of curvature: RoC = 377.03mm (concave)
	Conic constant: k = -0.7355 (elongated ellipsoid)
	Off-axis distance: 80mm
	Clear aperture: CA = 60mm approx.
	Material: Zerodur
M5	Radius of curvature: RoC = 87.58mm (convex)
	Conic constant: k = -71.87 (hyperboloid)
	Off-axis distance: 12.5mm
	Clear aperture: CA = 35mm approx.
	Material: Zerodur
M6	Radius of curvature: RoC = 213.41mm (concave)
	Conic constant: k = -0.072 (elongated ellipsoid)
	Off-axis distance: 38mm
	Clear aperture: CA = 100mm approx.
	Material: Zerodur
FM	Flat
	Clear aperture: CA = 25mm approx.
	Material: Zerodur
Cold stop	Diameter: 30mm
	Position: just before the filter wheel

The InfraRed Telescope (IRT)

Component	Characteristics
Filters (photometric mode)	Plane-parallel plate
	Material: silica
	Thickness: 5mm
	Clear aperture: CA = 30mm approx.
Prism (LR mode)	Material: N-F2 / silica
	Thickness: 10mm
	Clear aperture: CA = 30mm approx.
Grism (HR mode)	Material: silica
	Thickness: 8mm
	Clear aperture: CA = 30mm approx.
	Grating: 30.8 lines/mm

The InfraRed Telescope (IRT)

Components	Distance
Telescope folding – Field stop	35mm
Telescope M3 – Cold stop	245.5mm
Cold stop – M4	249mm
M4 – M5	184.4mm
M5 – M6	196.3mm
M6 – Instrument folding	200mm
Instrument folding – Detector	27mm