The International context

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NASA – ESA ties: lesson learned

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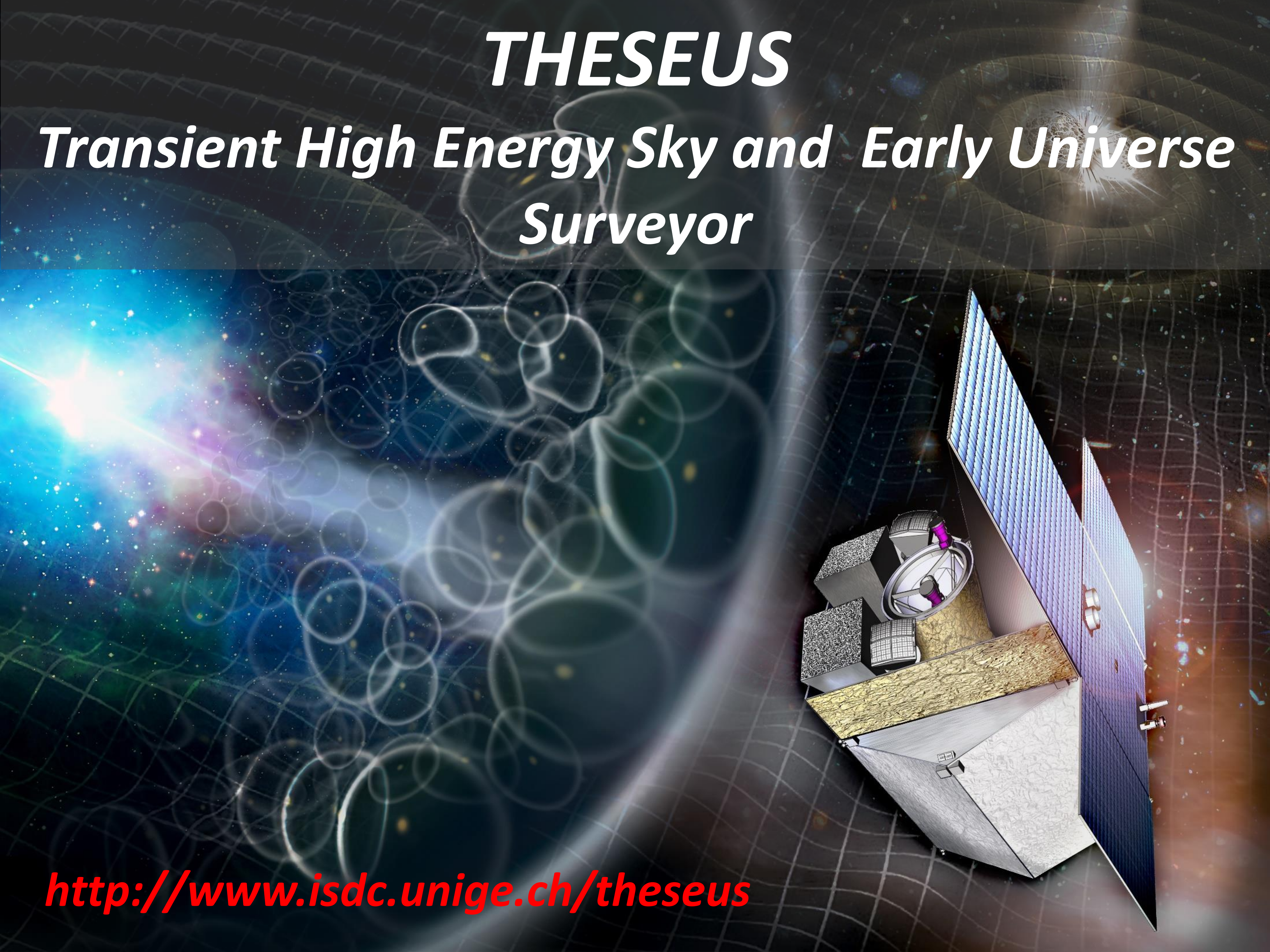
- ESA-NASA collaborations – summary of lesson learned:
  - International participation is (almost) always allowed in calls for missions but risks have to be costed
  - Different mission development phases: unmatched internal procedures (e.g. geo-return)
  - Back timing issues (e.g. THESEUS M7)
- Direct inter-agency exchanges leads to effective steps forward (e.g. Athena, LISA, ...)
- Direct EU member states participation into NASA-led projects can work efficiently (single I/F toward EU usually favoured)
  - Explorer schedule more challenging, SMEX & MIDEX easier (e.g. IXPE, Gamow)
  - (X-ray) Probes: STROBE-X, LEM

(LISTS NOT EXHAUSTIVE!)


THESEUS
Transient High Energy Sky and Early Universe Surveyor
http://www.isdc.unige.ch/theseus

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, 2037?)
- L3: LISA (gravitational wave observatory, 2037?)
- M4: ARIEL (exoplanets, 2028)
- S2: SMILE (solar wind <–> magneto/ionosphere)
- F1: Comet Interceptor
- M5: Envision (THESEUS M5 not down-selected in 2021)
- M7: THESEUS, M-Matisse, Plasma Observatory (down selection in 2026)

Event	Date or duration	Note
Start of phase 0	Q1 2023	
Mission selection	2026	At the end of the Phase A
Mission adoption	2029	At the end of the Phase B1
Launch	By 2037	Will depend on the mission
Nominal in-orbit operations	Typically ~3 years	Operation costs must be included in the ESA CaC

Programmatics

- THESEUS first proposed for the M5 call in 2017, successfully completed a phase 0/A study but not down-selected in 2022 (Vs. EnVision), although declared compelling and fully feasible within available boundaries.

- THESEUS was reproposed for the M7 call in 2021 and currently in phase A. NASA participation for this call originally explored.

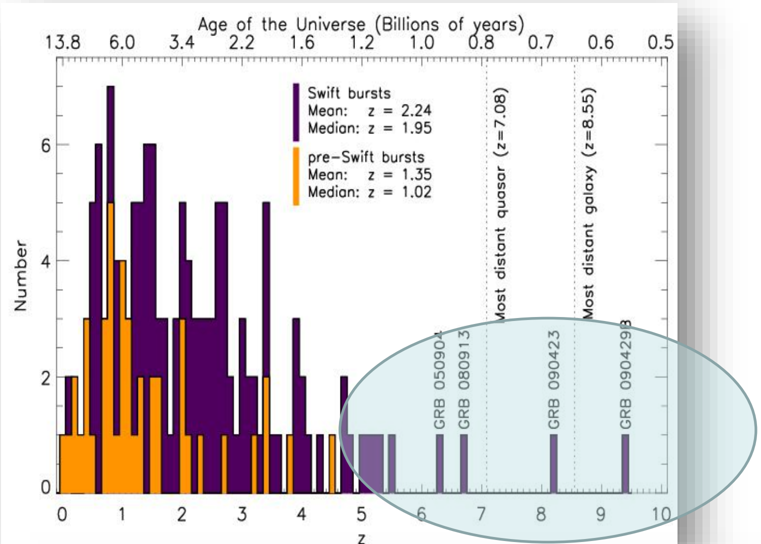
- THESEUS remains largely unchanged compared to the consolidated M5 design, with rearranged and extended contributions to several ESA member states.

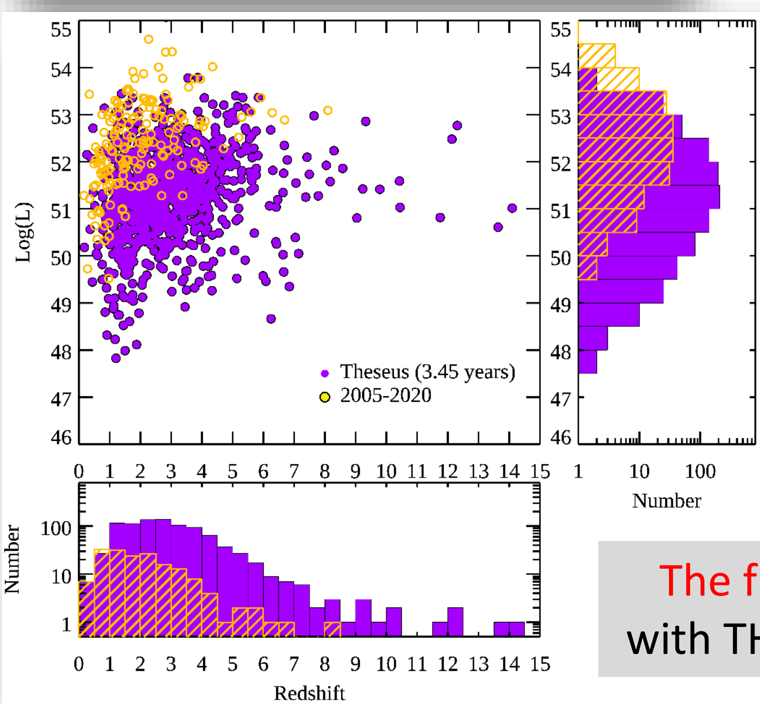
THESEUS
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

- ***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 >2030s (synergy with aLIGO/aVirgo, eLISA, ET, Km3NET and EM facilities e.g., LSST, E-ELT, SKA, CTA, ATHENA).

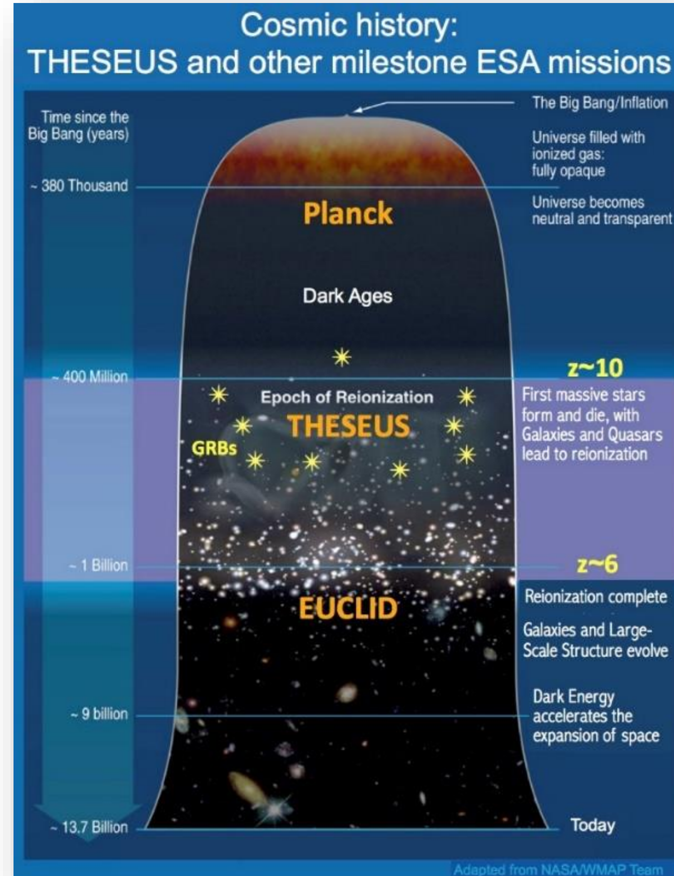
- ***THESEUS* Observatory Science includes:**
  - study of thousands of faint to bright X-ray sources by exploiting the **simultaneous availability of broad band X-ray and NIR observations**
  - provide a **flexible follow-up observatory** for fast transient events with multi-wavelength ToO capabilities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

Shedding light on the early Universe with GRBs





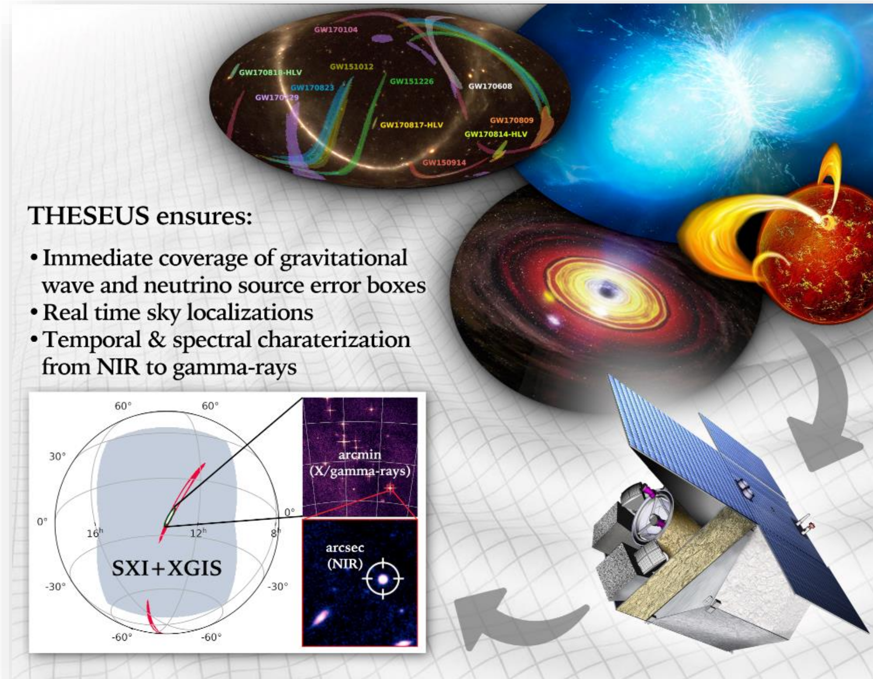
The future
with THESEUS

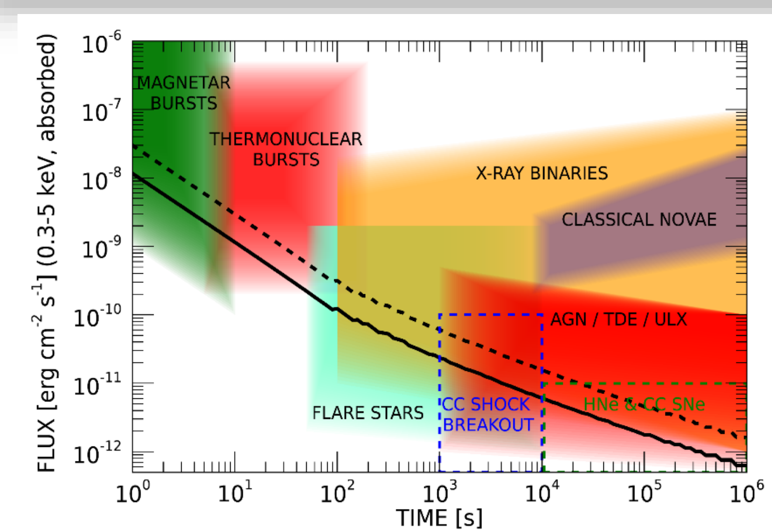


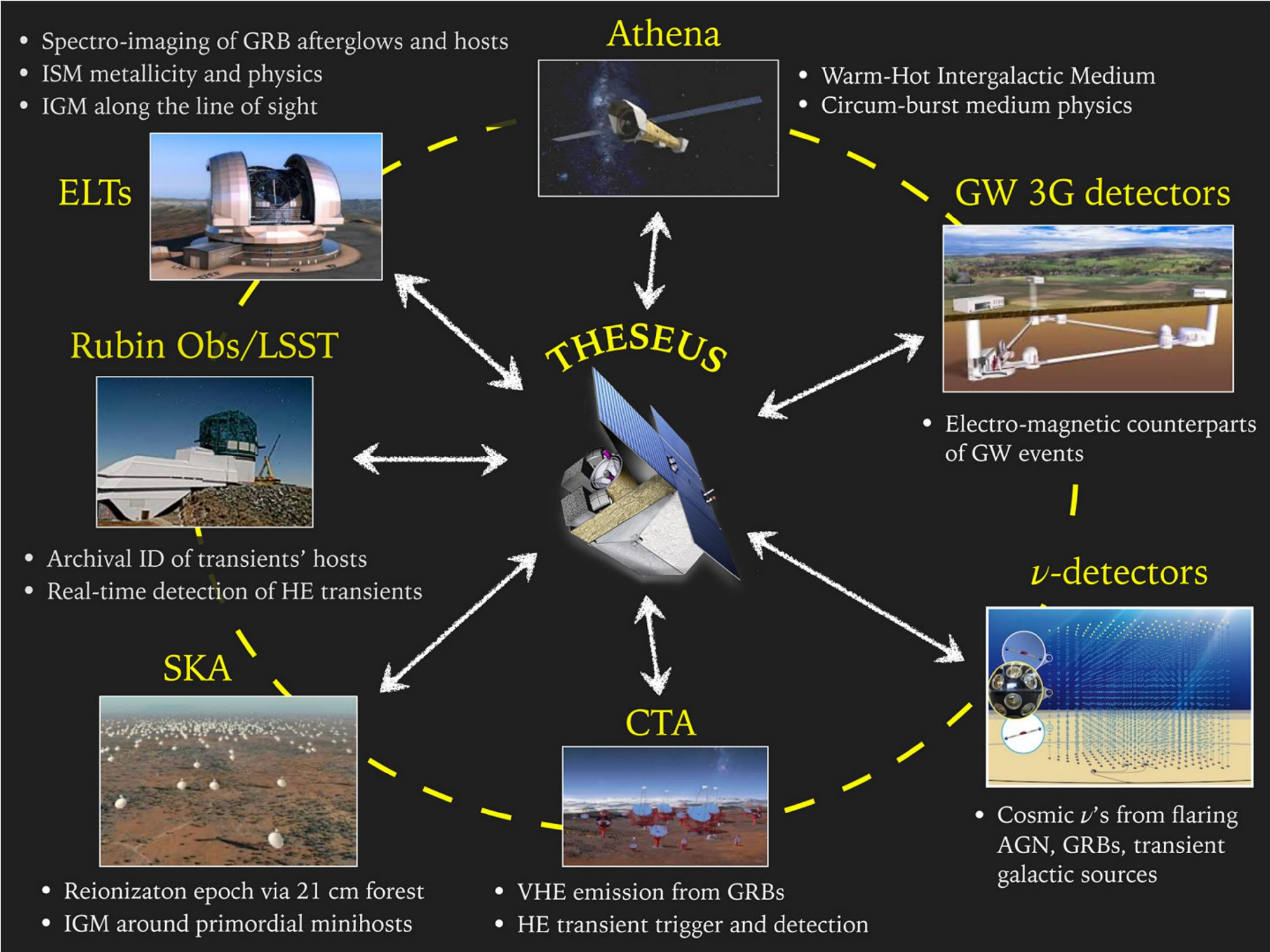
GRBs are unique and powerful tools for investigating the early Universe. They can be found at very high redshifts (>9-10) and provide multiple powerful probes of **early star formation, metal-enrichment and galaxy evolution, and the reionization history of the IGM**.

Exploring the multi-messenger transient sky

- Locate and identify the electromagnetic counterparts to sources of gravitational radiation and neutrinos, routinely detected in the '30s by **aLIGO/aVirgo, eLISA, ET, or Km3NET;**
- Provide accurate (~1'') 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**

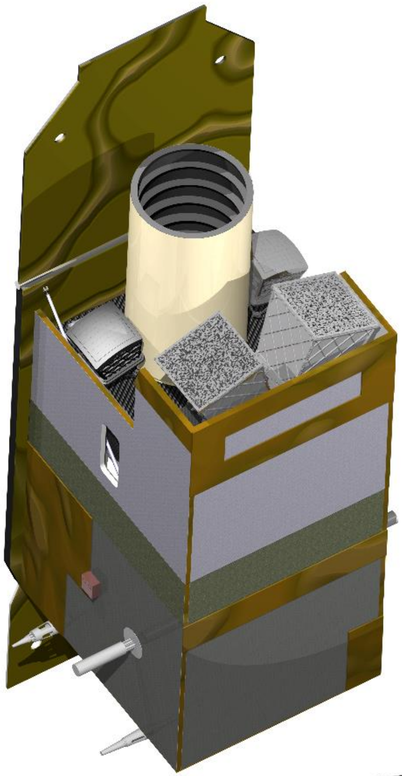




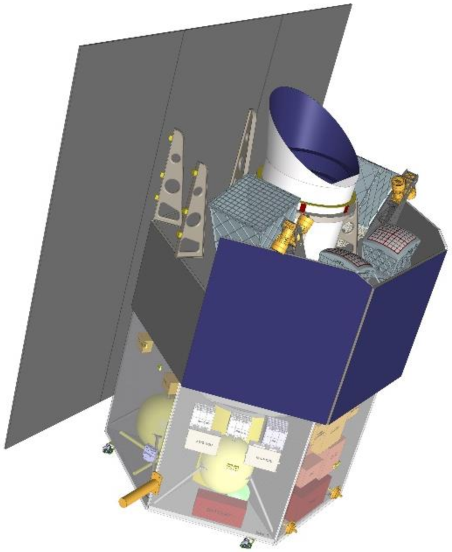


Athena
• Spectro-imaging of GRB afterglows and hosts
• ISM metallicity and physics
• IGM along the line of sight
• Warm-Hot Intergalactic Medium
• Circum-burst medium physics
ELTs
GW 3G detectors
THESEUS
Rubin Obs/LSST
• Electro-magnetic counterparts of GW events
• Archival ID of transients' hosts
• Real-time detection of HE transients
ν-detectors
SKA
CTA
• Cosmic ν's from flaring AGN, GRBs, transient galactic sources
• Reionizaton epoch via 21 cm forest
• IGM around primordial minihosts
• VHE emission from GRBs
• HE transient trigger and detection

THESEUS mission concept

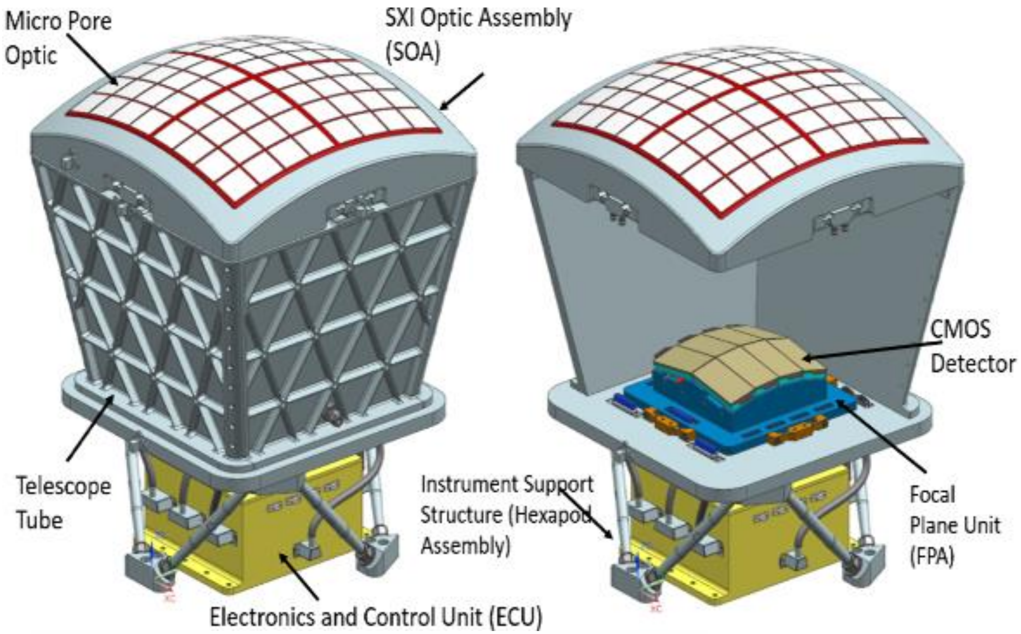


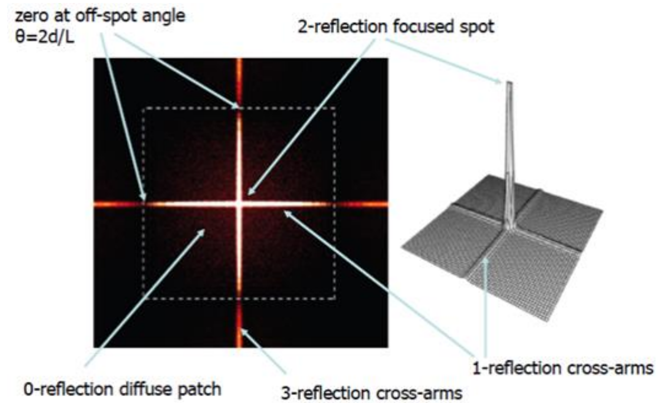
- **Soft X-ray Imager (SXI):** a set of 2 lobster-eye telescopes (**0.3 - 5 keV band, total FOV of ~1sr with source location accuracy <1'**)
- **X-Gamma rays Imaging Spectrometer** (**XGIS**): 2 coded-mask X-gamma ray cameras using bars of Silicon diodes coupled with CsI crystal scintillators observing in (**2 keV – 10 MeV band, FOV of ~2-4 sr overlapping the SXI, <15' source location accuracy**)
- **InfraRed Telescope (IRT)**: a 0.7m class IR telescope (**0.7 – 1.8 μm**, **15'x15' FOV**) **for imaging and moderate resolution spectroscopy capabilities** (R~400)



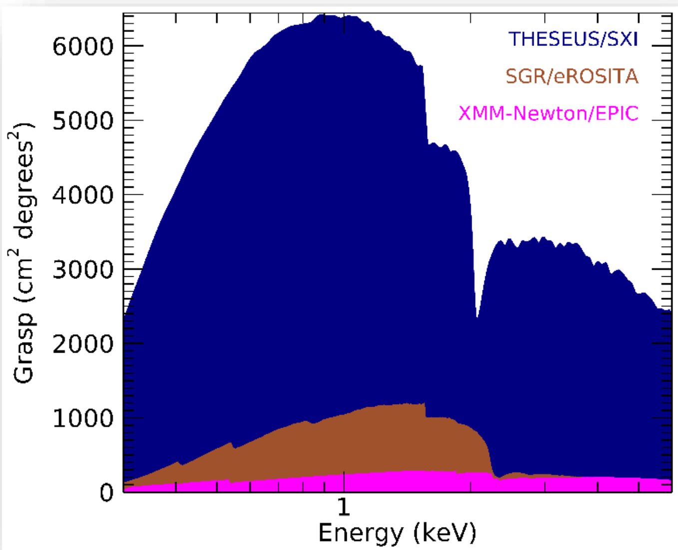
LEO (< 5°, ~600 km)
Autonomous slewing

The Soft X-ray Imager (SXI)



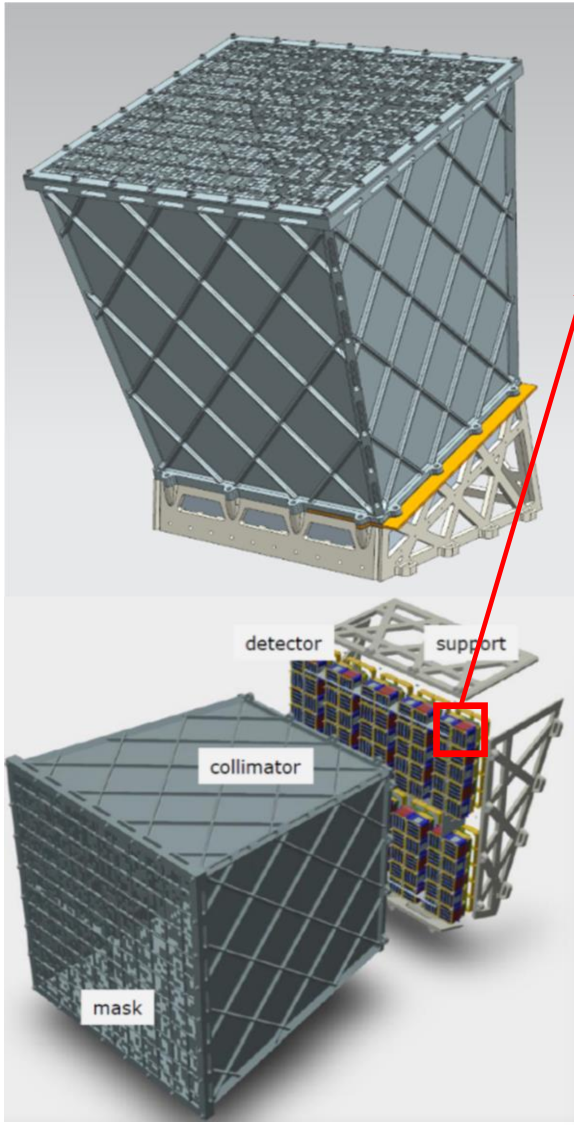


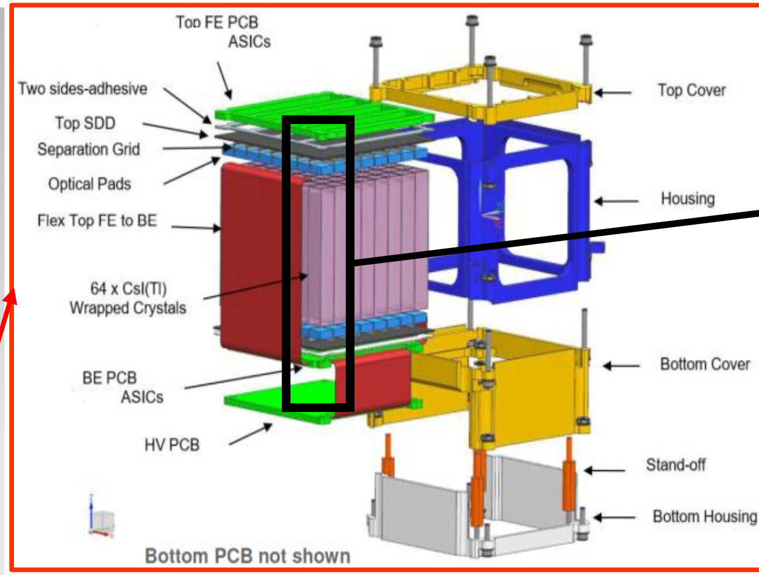
Energy band (keV)	**0.3-5**
Optics configuration	8x8 square pore MPOs
MPO size (mm^2)	40x40
Focal length (mm)	300
Focal plane detectors	CMOS array
CMOS size (mm^2)	80x40
CMOS pixel size (μm)	40
CMOS pixel Number	2000x1000
Number of CMOS	8
Module Field of View (sr)	0.25
Centroiding accuracy (best, worst) (arcsec)	(<30, 180)

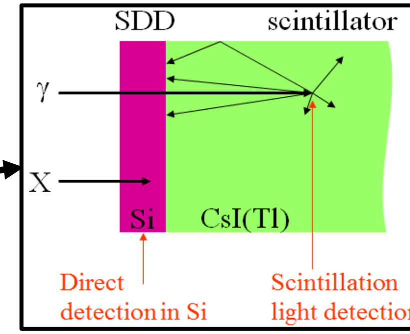


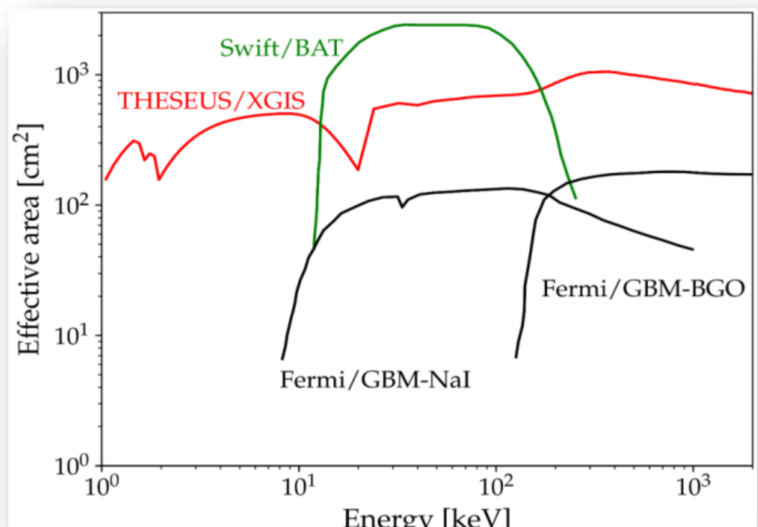
The SXI uses lobster eye wide-field (~0.5sr) focusing optics to increase the sensitivity to fast transients. The use of such optics provides uniform sensitivity across a very large field of view while maintaining arcminute localisation accuracy

The X-Gamma-ray imaging spectrometer



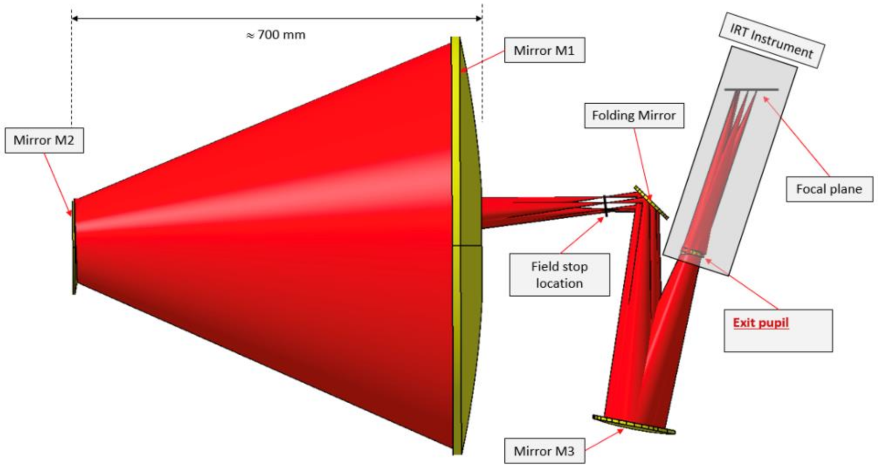


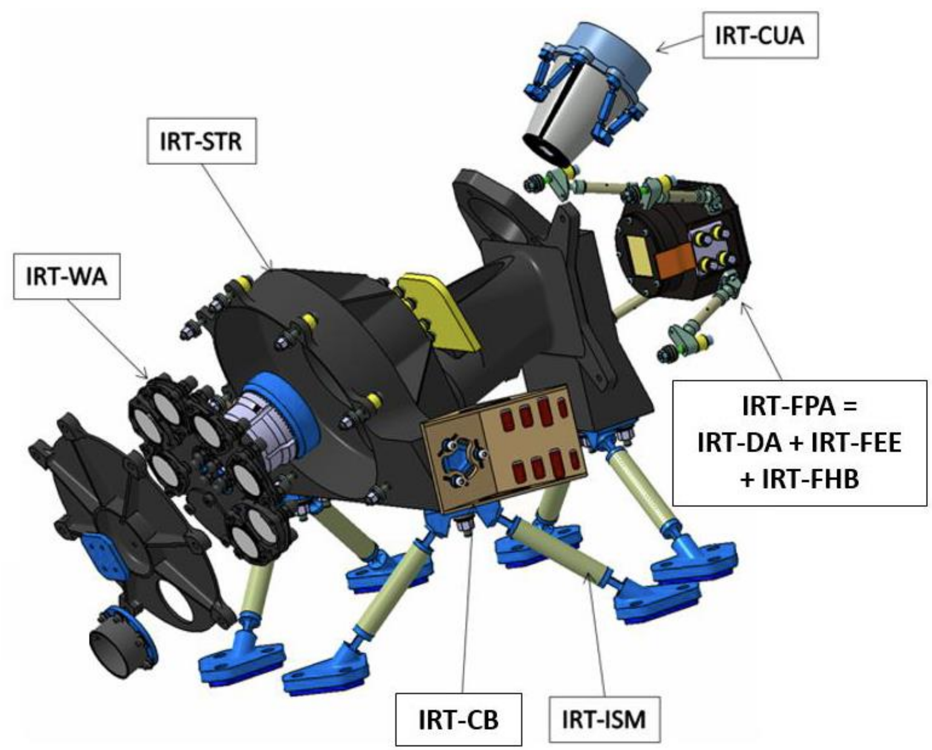




The XGIS is a GRB and transients monitor providing wide energy band (2 keV-10 MeV), imaging capabilities, location accuracy (<15), FoV up to 4π, good energy resolution up to 30 keV, and ms time resolution over the whole energy band.

The InfraRed Telescope (IRT)





IRT characteristic	Value
Photometric wavelength range	0.7-1.8 mm
Spectroscopic wavelength range	0.8-1.6 mm
Photometric field of view	15 x 15 arcmin (goal: 17’ x 20’)
Pixel size/scale	18 mm / 0.6 arcsec
Required Photometric sensitivity (AB, in150 s, SNR=5) for each implemented filter	I: 20.9 (goal: 21.3) Z: 20.7 (goal 21.2) Y: 20.4 (goal: 20.8) J: 20.7 (goal: 21.1) H: 20.8 (goal: 21.1)
Expected photo-z accuracy	< 10%
Astrometric accuracy	< 5 arcsec in near-real time < 1 arcsec after ground processing
Spectroscopic field of view	2 x 2 arcmin
Resolving Power at 1.1 mm	> 400
Required Spectroscopic sensitivity (AB, H filter, 1800 s, SNR=3 for each spectral bin)	17.5 (goal: 19)

The IRT detects, identifies and measures the redshift of GRB afterglows discovered by SXI and XGIS, especially those at high redshift (z>6).

It is a 70 cm Korsch telescope, implementing two separated fields of view, one for photometry (15’ x 15’) and one for spectroscopy (2’ x 2’).

Gamow

The Gamow Explorer: A gamma-ray burst observatory to study the high redshift universe and enable multi-messenger astrophysics

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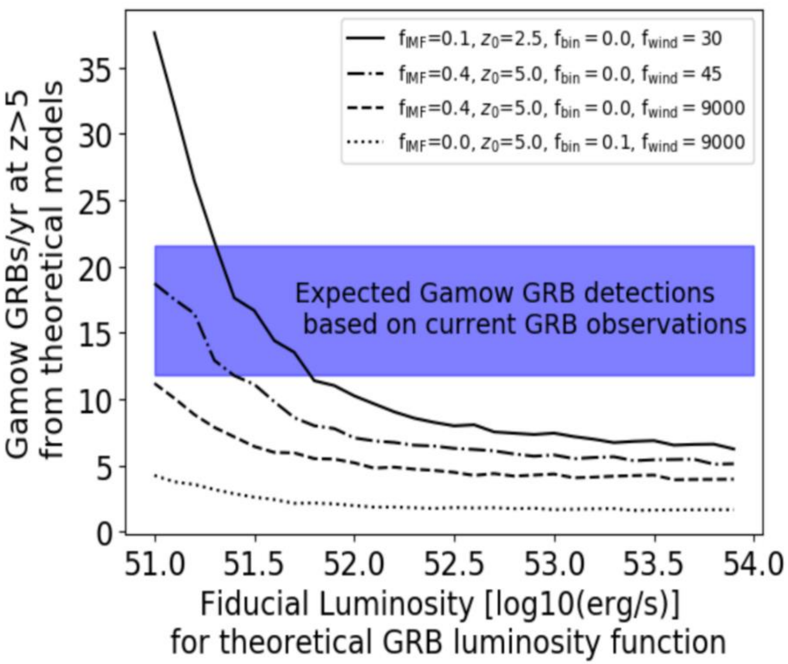

Two on-board instruments:

LEXT - Lobster Eye Telescope - for the detection and localization of (Cosmological) GRBs in the soft X-rays

PIRT - Photo-z InfraRed Telescope – for the on-board redshift determination (only photometry, spectra from the ground with large telescopes)

STROBE-X

- NASA Probe proposal submitted
- EU participation consolidated for the proposal stage within allowed boundaries.
- Feedback expected in February, but down-selection of 1 X-ray and 1 IR probe not earlier than 08.2024.