The THESEUS space mission concept

Transient High-Energy Sky and Early Universe Surveyor

L. Amati & S. Covino

on behalf of the THESEUS Consortium

theseus

TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

- 2018-2021: ESA Phase-A study (2018-2021) as M5 candidate
- 2022: Selected for Phase 0 study (2023) within M7 process
- 2023: Selected for Phase-A study (2024-2026) as M7 candidate
- M7 timeline: Phase-A (2024-2026), adoption 2028, launch 2037

Payload consortium: Italy, Germany, UK, France, Switzerland, Spain, Poland, Denmark, Belgium, Czech Republic, The Netherlands, Norway, Slovenia, Ireland (+ Hungary?)

Leads: L. Amati (INAF – OAS Bologna, Italy, lead proposer), A. Santangelo (Un. Tuebingen, D), P. O'Brien (Un. Leicester, UK), D. Gotz (CEA-Paris, France), E. Bozzo (Un. Genève, CH)

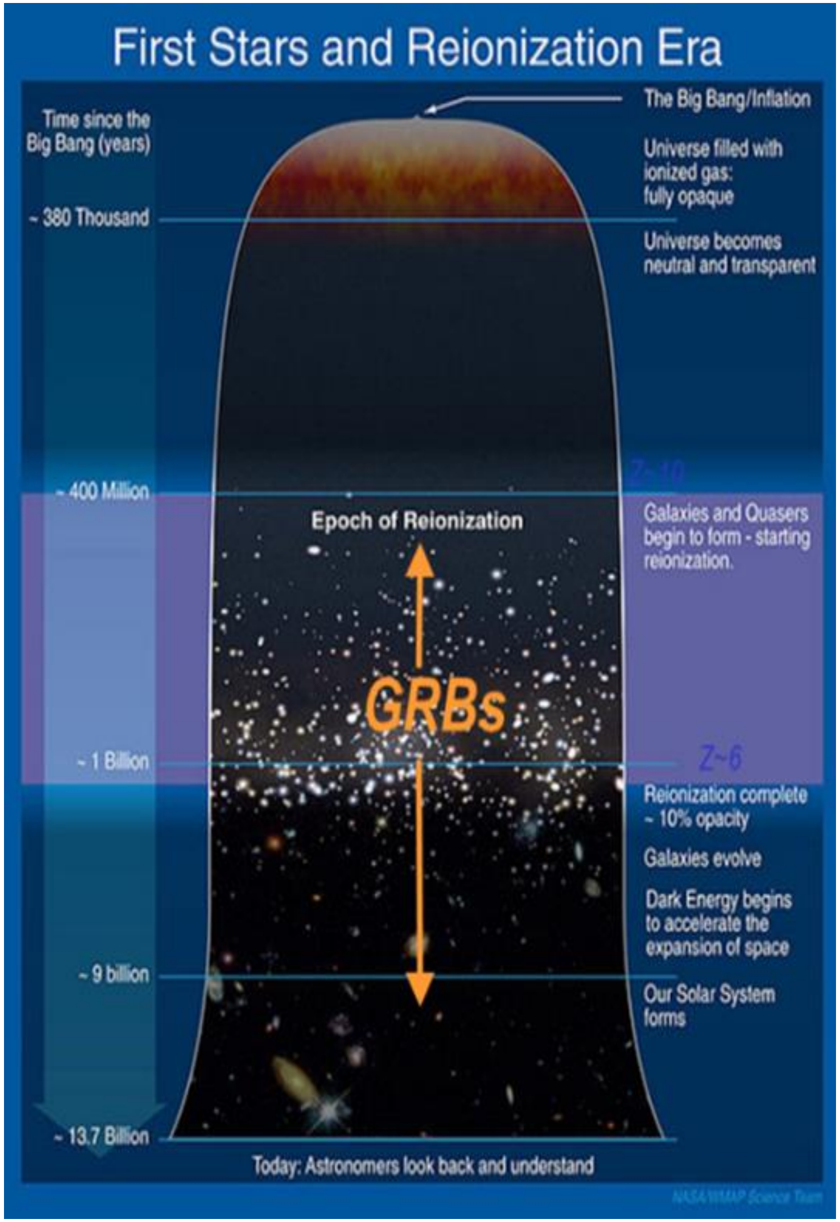
Amati et al. 2018 (Adv.Sp.Res., arXiv:1710.04638)
Stratta et al. 2018 (Adv.Sp.Res., arXiv:1712.08153)
Articles for SPIE 2020 and Exp..Astr. (all on arXiv)
http://www.isdc.unige.ch/theseus

Shedding light on the early Universe with GRBs

- **Long GRBs:** huge luminosities, mostly emitted in the X and gamma-rays

- **Redshift distribution** extending at least to z ~9 and association with exploding massive stars

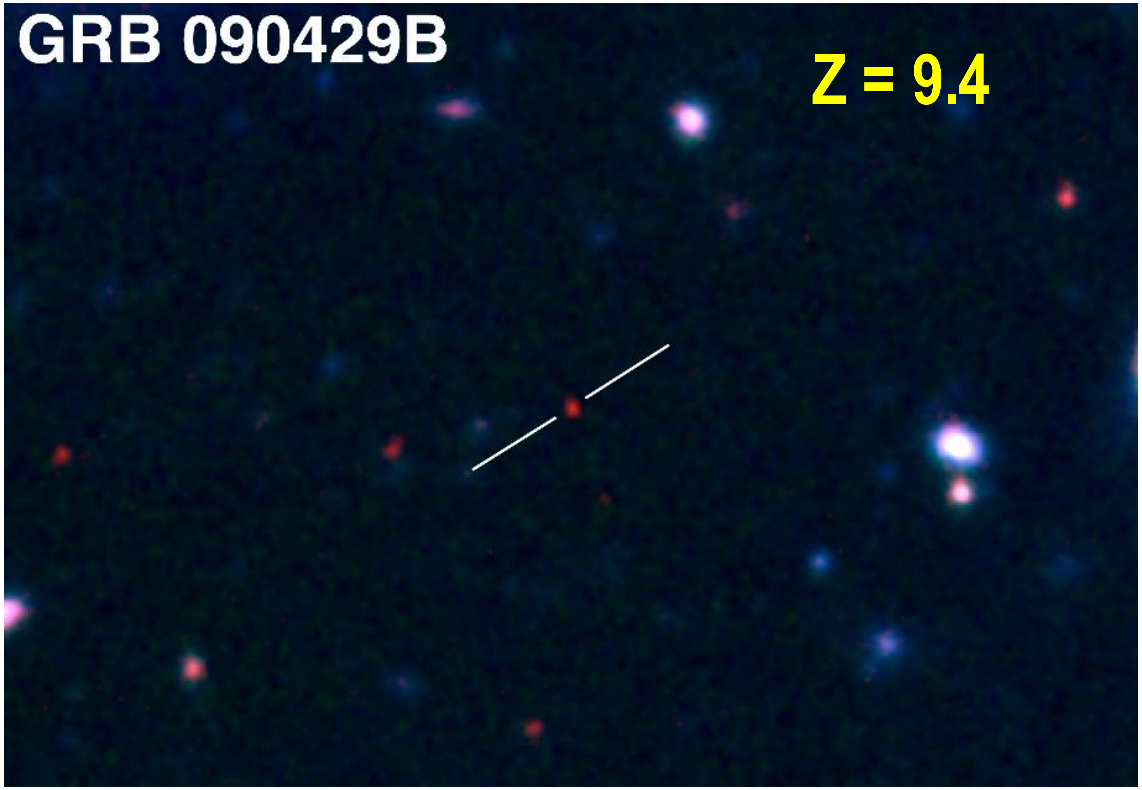
- **Powerful tools for cosmology:** SFR evolution, physics of re-ionization, high-z low luminosity galaxies, pop III stars



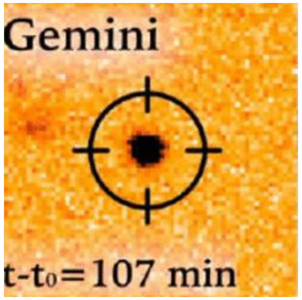
Shedding light on the early Universe with GRBs

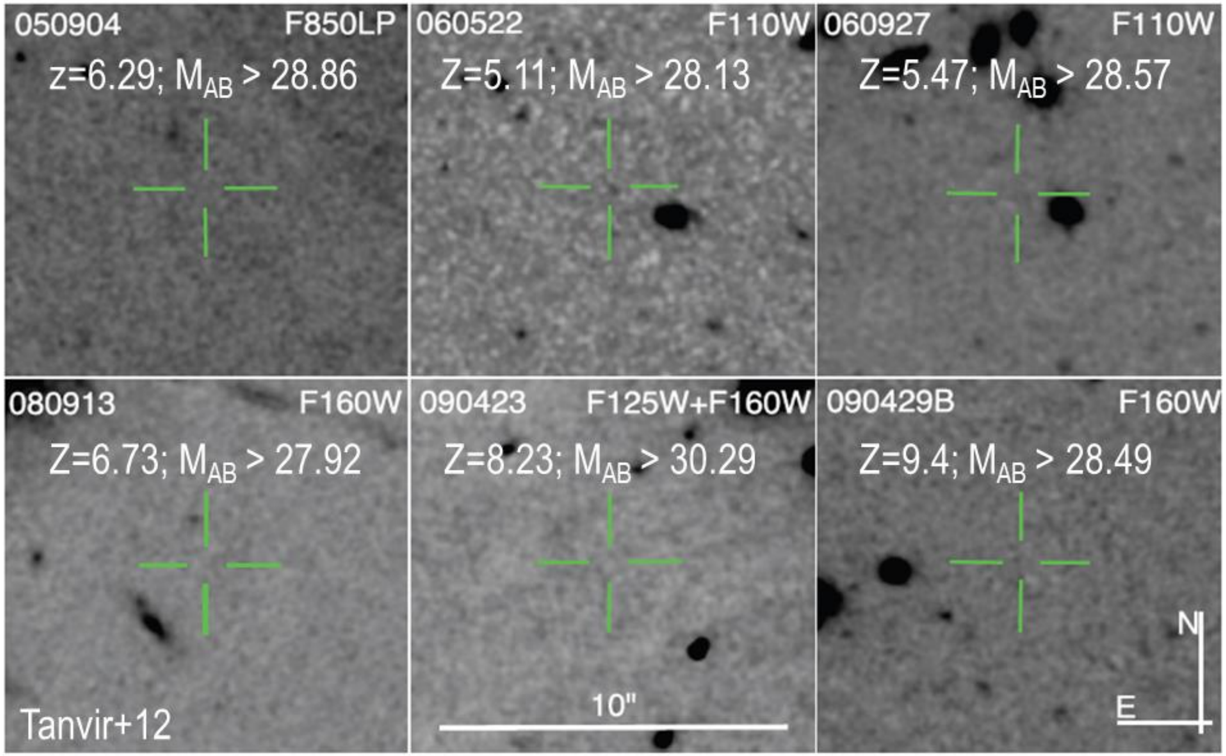
A statistical sample of high–z GRBs can provide fundamental information:

- measure independently the **cosmic star–formation rate**, even beyond the limits of current and future galaxy surveys
- directly (or indirectly) detect the **first population of stars (pop III)**



Detecting and studying primordial invisible galaxies

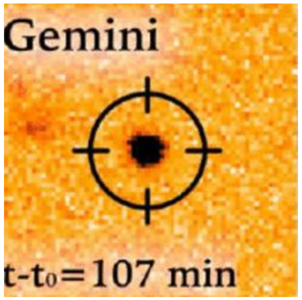


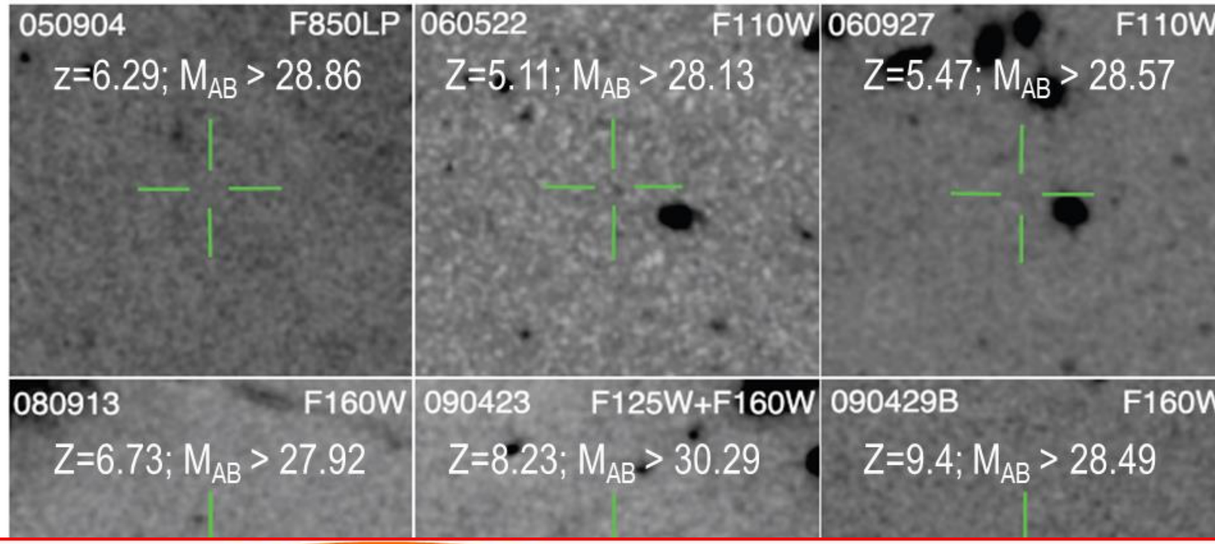


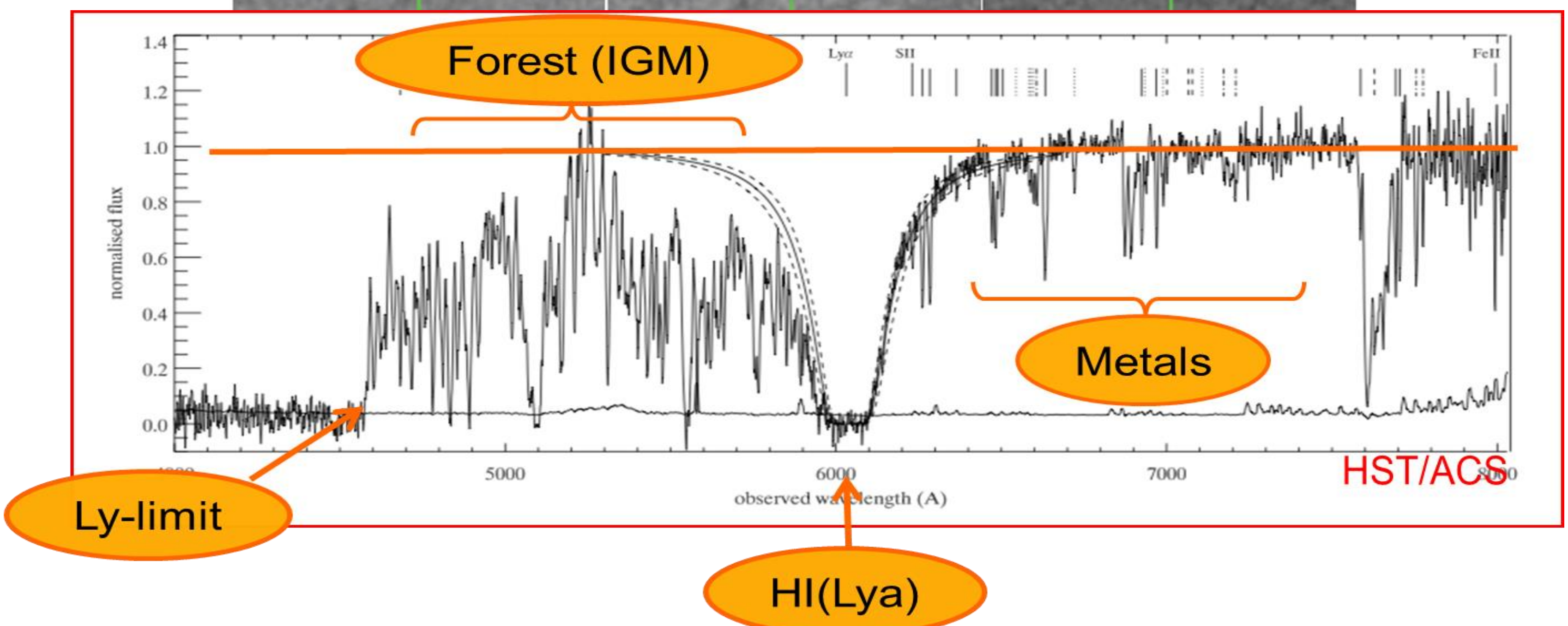
Robertson&Ellis12

Even JWST and ELTs surveys will be not able to probe the faint end of the galaxy Luminosity Function at high redshifts (z>6-8)

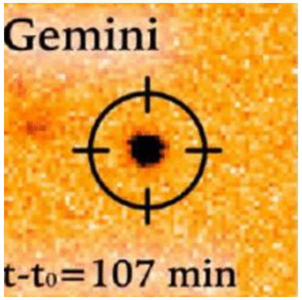
Detecting and studying primordial invisible galaxies

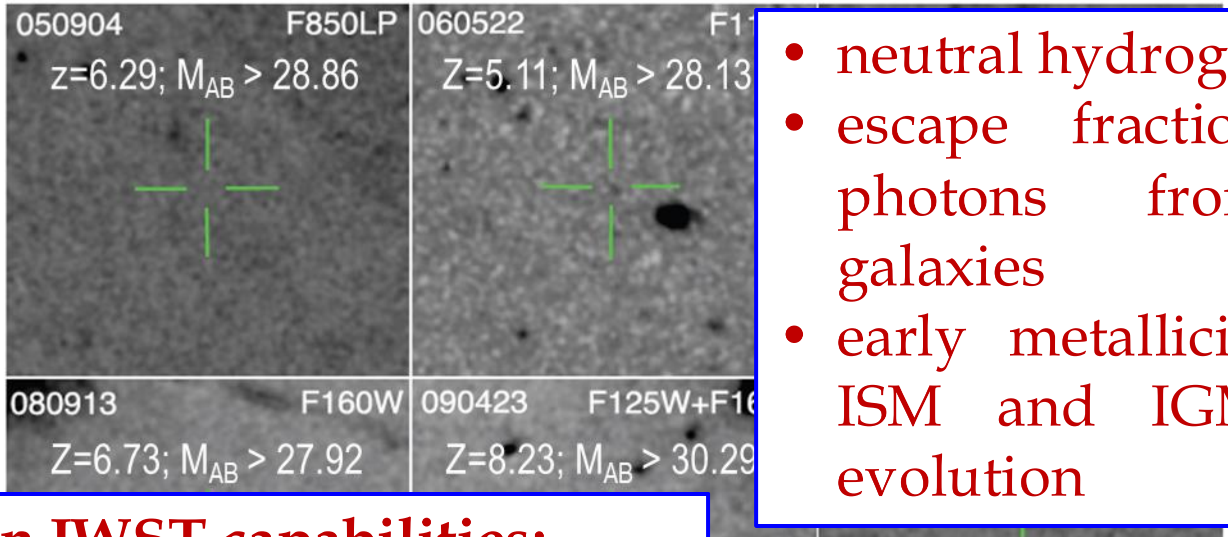






Detecting and studying primordial invisible galaxies

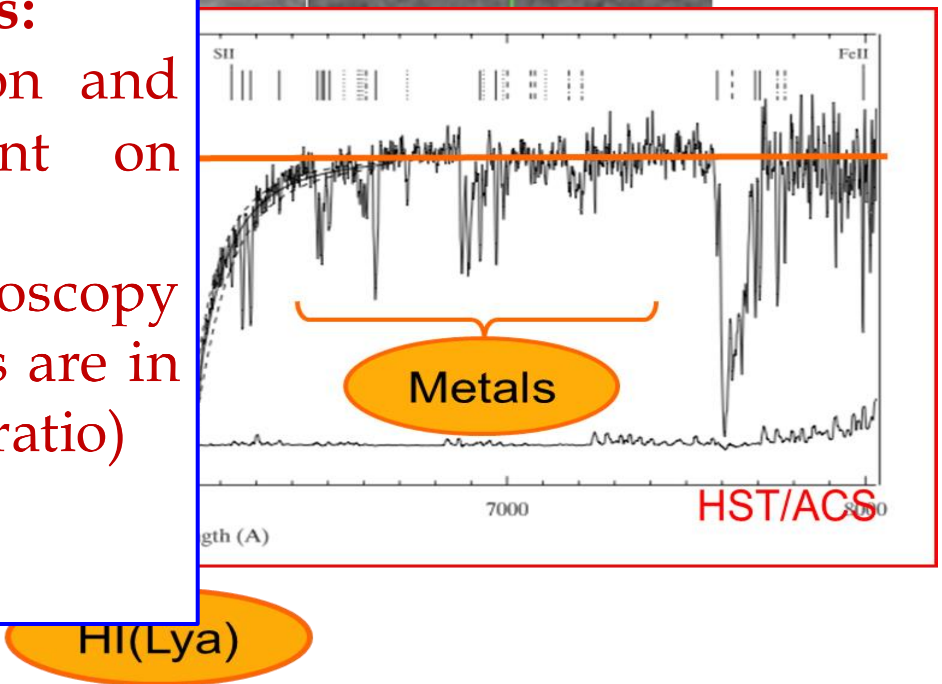




- neutral hydrogen fraction
- escape fraction of UV photons from high-z galaxies
- early metallicity of the ISM and IGM and its evolution

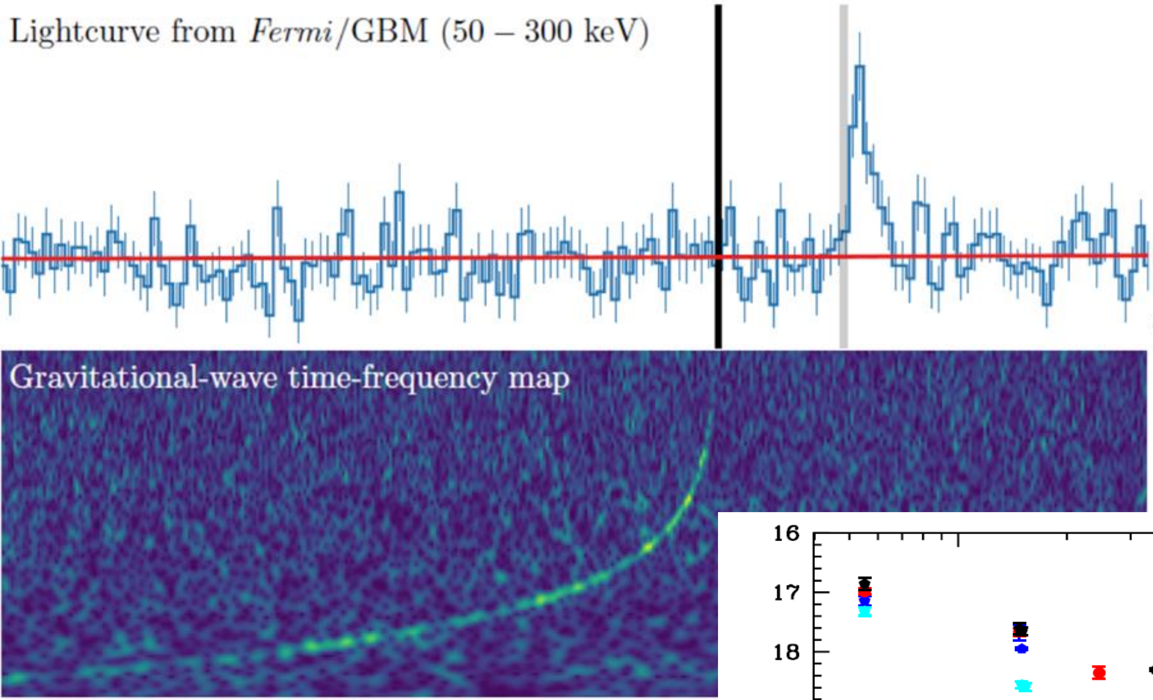
Beyond even JWST capabilities:

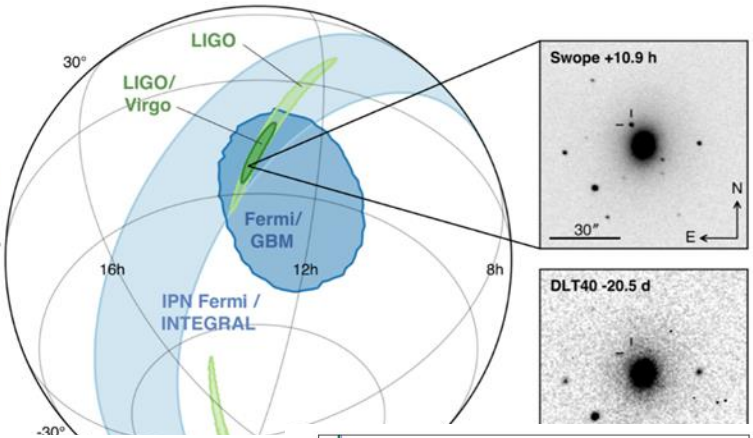
- Primordial galaxies detection and characterization Independent on mass and luminosity
- Allow absorption spectroscopy (needed because most metals are in neutral gas and and for dust ratio)
- Properties of primordial IGM
- Targets for JWST

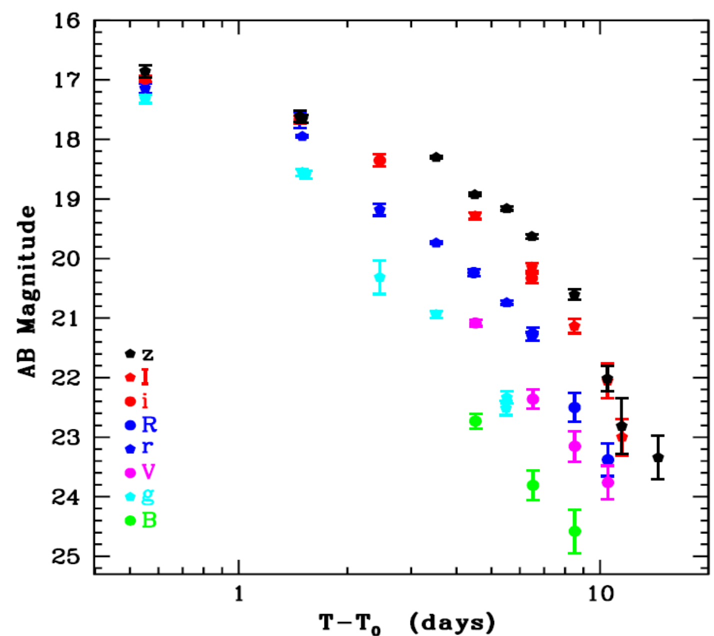


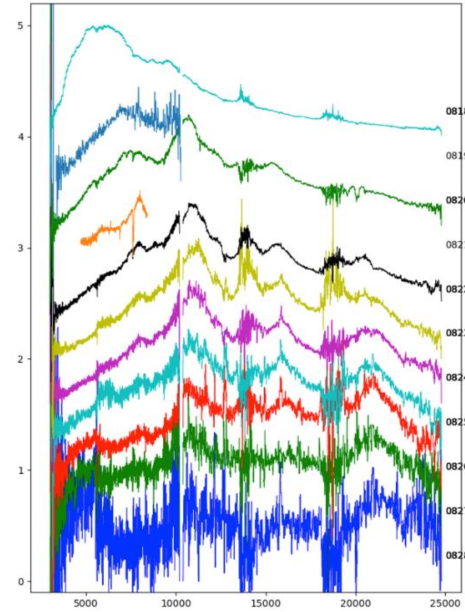
Short GRBs and multi-messenger astrophysics

GW170817 + SHORT GRB 170817A + KN AT2017GFO (~40 Mpc):





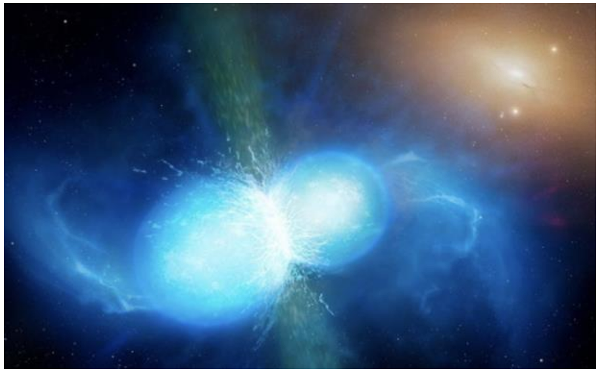




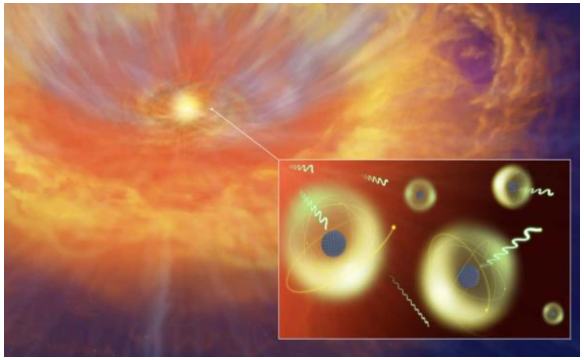
GRB: a key phenomenon for multi-messenger astrophysics (and cosmology)

GW170817 + SHORT GRB 170817A + KN AT2017GFO

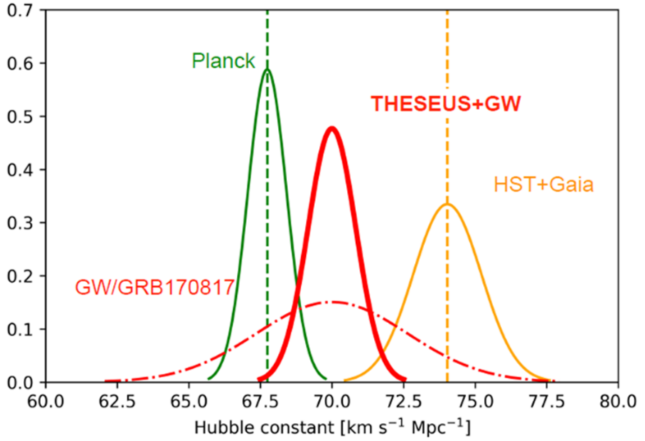
Relativistic jet formation, equation of state, fundamental physics



Cosmic sites of r-process nucleosynthesis



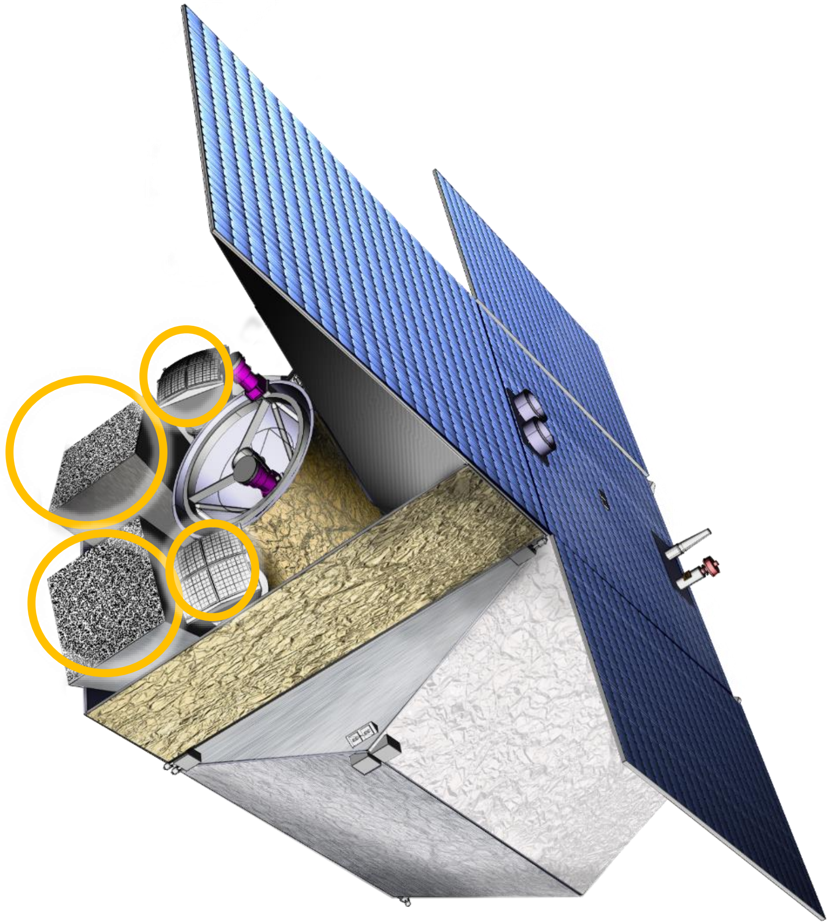
New independent route to measure cosmological parameters



THESEUS Mission Concept

THIS BREAKTHROUGH WILL BE ACHIEVED BY A MISSION CONCEPT OVERCOMING MAIN LIMITATIONS OF CURRENT FACILITIES

Set of innovative wide-field monitors with **unprecedented combination of broad energy range from gamma-rays down to soft X-rays, FOV and localization accuracy**



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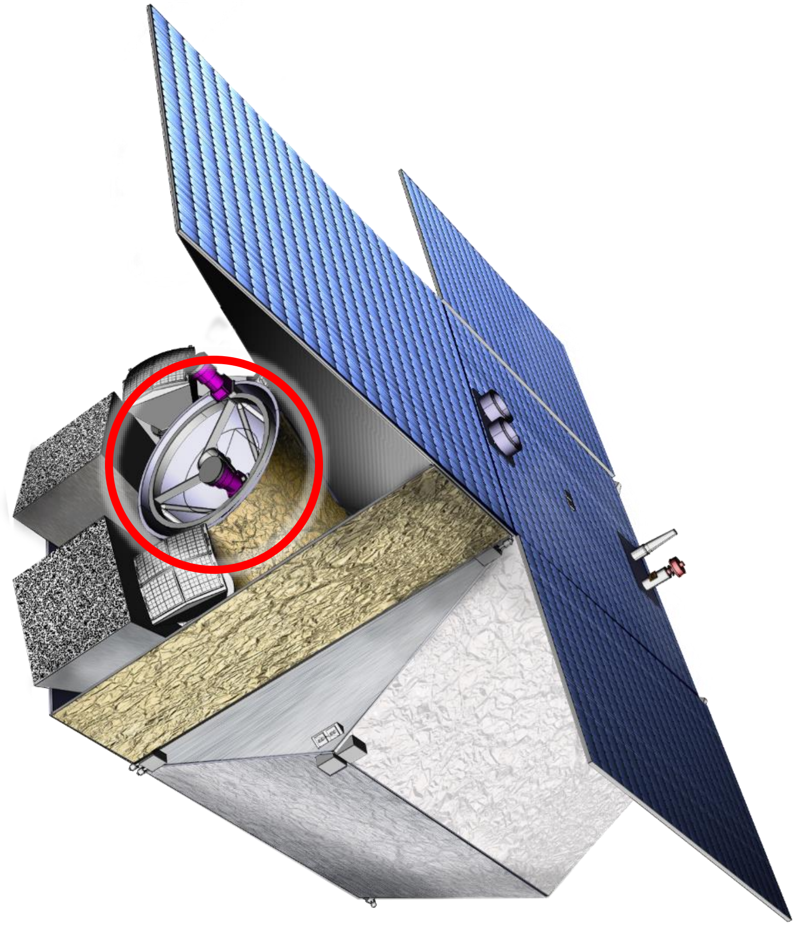
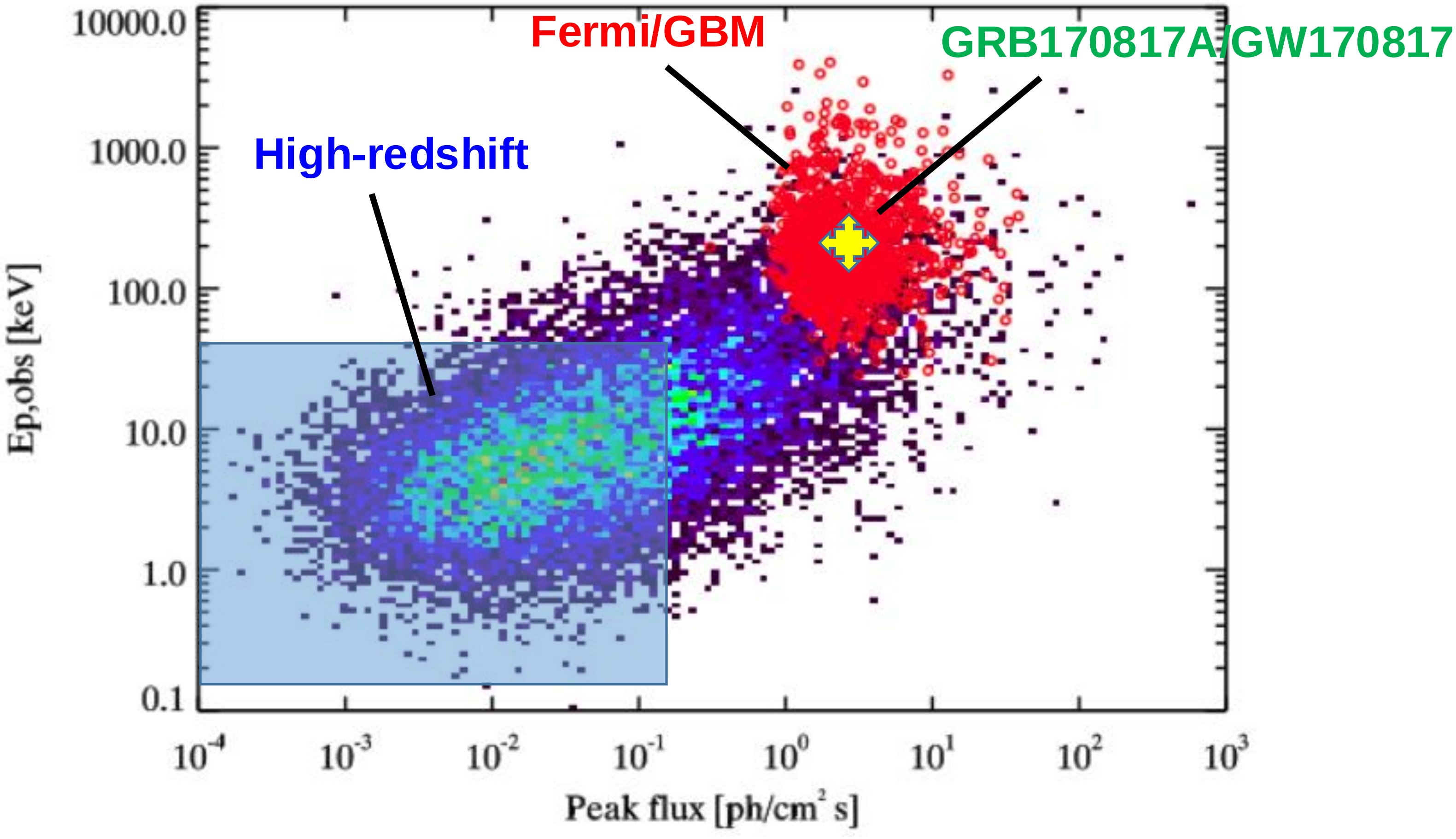
Set of innovative wide-field monitors with **unprecedented combination of broad energy range from gamma-rays down to soft X-rays, FOV and localization accuracy**

On-board **autonomous fast follow-up in optical/NIR**, arcsec location and **redshift measurement** of detected GRB/transients

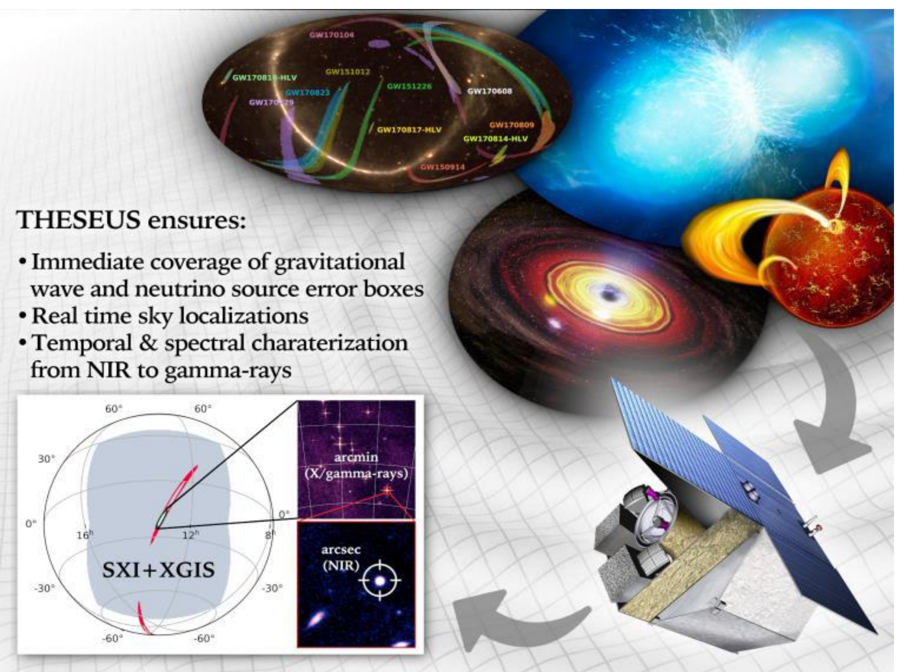


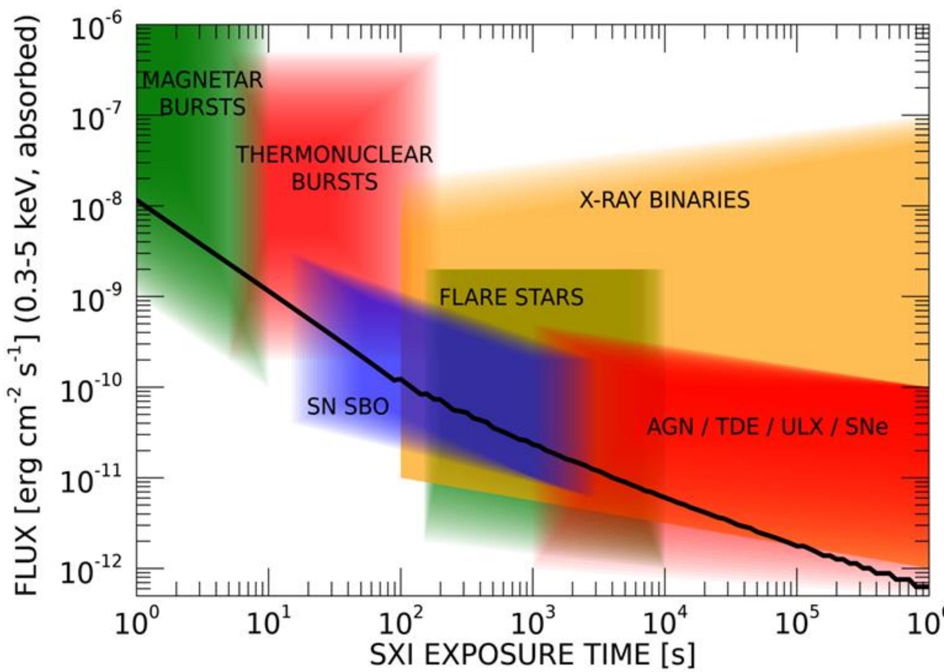
THESEUS will have a combination of instrumentation and mission profile allowing the detection of all types of GRBs (long, short/hard, weak/soft, high-redshift) and provide accurate location and redshift measurement for a large fraction of them



Exploring the transient sky

- **GRBs extreme emission physics**, central engine, sub-classes & progenitors, **cosmological parameters & fundamental physics**
- Study of **many classes of X-ray sources** by exploiting the **simultaneous 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**



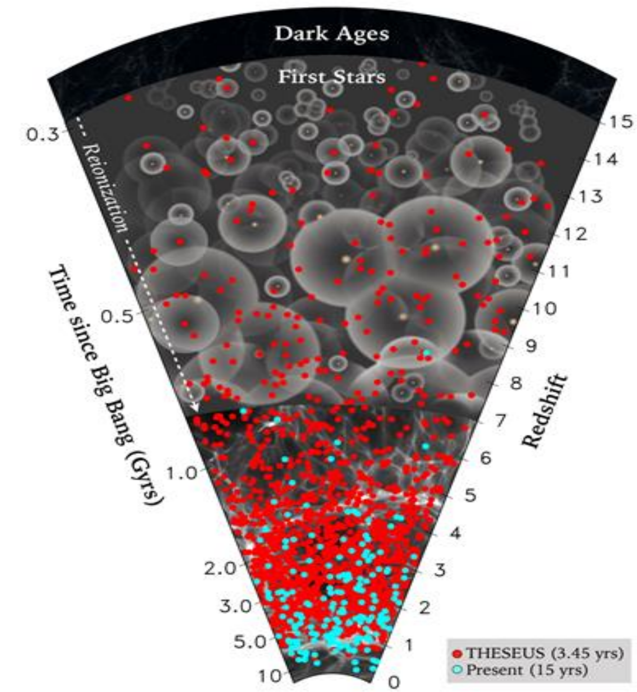


THESEUS Science Case

Core Science pillars:

- Probe the **early Universe (first stars, first galaxies, cosmic reionization)**, by unveiling and exploiting the population of high redshift Gamma-Ray Bursts (GRB)

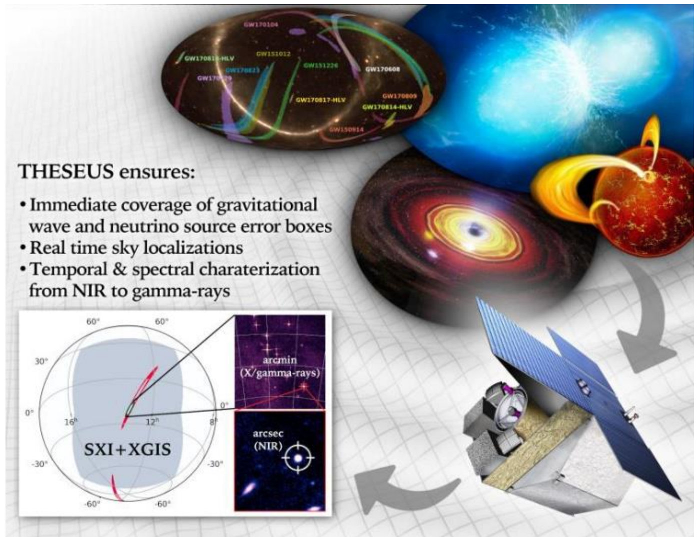
- Provide a **fundamental contribution to multi-messenger time domain astrophysics** through short GRB and other transients



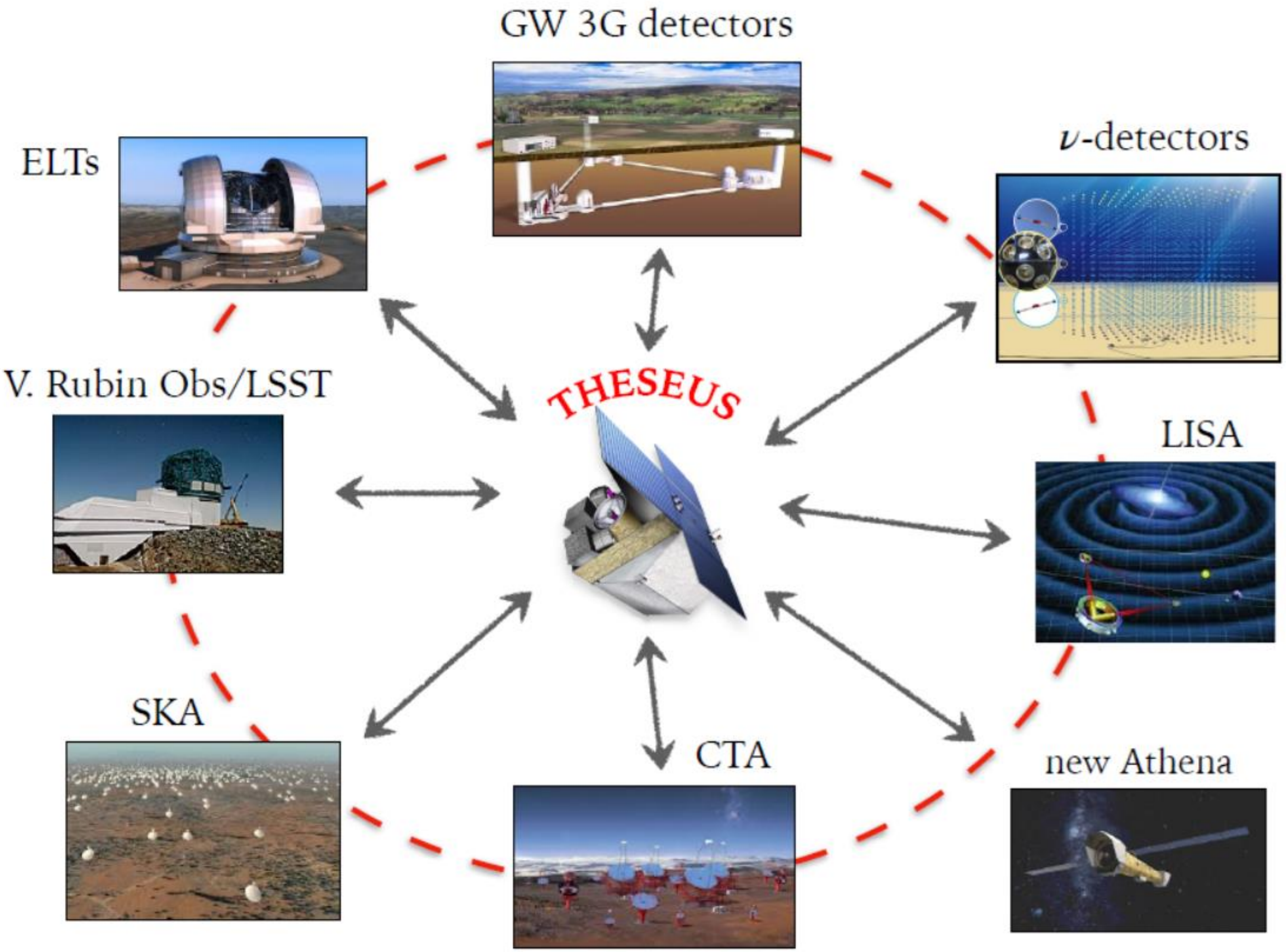
Observatory Science includes:

- Study of thousands of faint to bright X-ray sources by exploiting the **simultaneous broad band X-ray and NIR observations**

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



THESEUS: crucial synergies in the late ‘30s



The «**M7**» **timeline** will allow to **widely broaden the mission scientific impact** by taking advantage of the **perfectly matched synergies** with major facilities coming fully operative in the 2030s **(e.g., 3G GW detectors)**

In summary

- GRBs are a key phenomenon for **cosmology**, **multi-messenger astrophysics** and **fundamental physics**

- Next generation GRB missions, like **THESEUS**, developed by a large European collaboration, studied (M5 Phase A) and re-selected (M7 Phase-0) by ESA **will fully exploit these potentialities and also provide unprecedented clues to GRB physics and a substantial contribution to time-domain astronomy**

- The "M7" timeline will allow an **unprecedented great synergy with future very large observing** facilities in the e.m. and multi messenger domains, **enhancing their scientific return and fully exploiting the European leadership and investments put in them**.

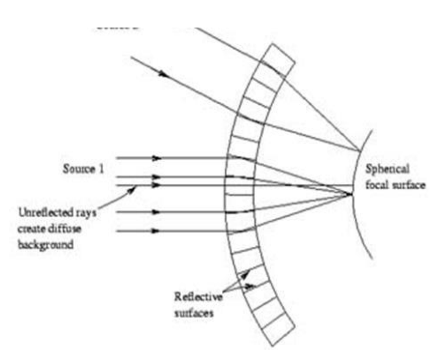
- Because of the wide scope of its science goals, the great synergies and timeline and a **guest-observer programme**, **THESEUS scientific return will involve an unprecedented wide scientific community.**

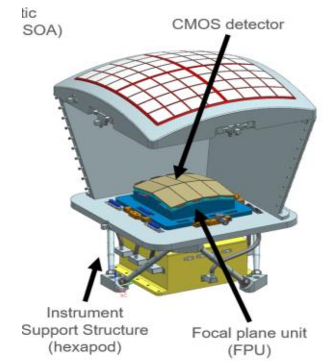
- **THESEUS: ESA/M5 Phase A study and selected for M7 Phase 0 (->2037)**
SPIE articles on instruments, Adv.Sp.Res. & Exp.Astr. articles on science
http://www.isdc.unige.ch/theseus/

Back-up slides

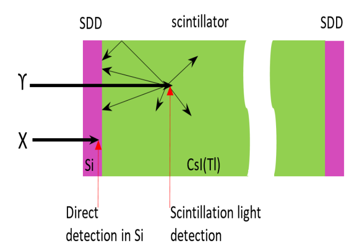
THESEUS Mission Concept

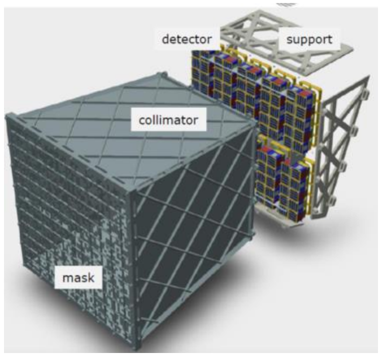
- **Soft X-ray Imager (SXI):** a set of two sensitive lobster-eye telescopes observing in 0.3 - 5 keV band, total FOV of ~0.5sr with source location accuracy <2′



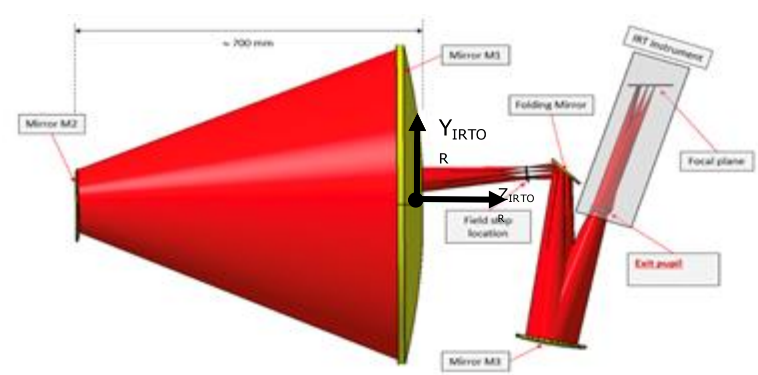


- **X-Gamma rays Imaging Spectrometer (XGIS):** 2 coded-mask X-gamma ray cameras using Silicon drift detectors coupled with CsI crystal scintillator bars observing in 2 keV – 10 MeV band, a FOV of >2 sr, overlapping the SXI, with <15′ GRB location accuracy





- **InfraRed Telescope (IRT):** a 0.7m class IR telescope observing in the 0.7 – 1.8 μm band, providing a 15′x15′ FOV, with both imaging and moderate resolution spectroscopy capabilities

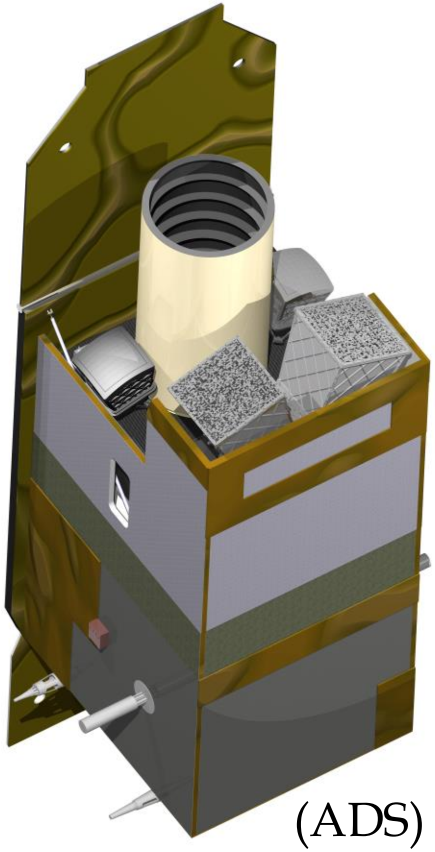


THESEUS Mission Concept

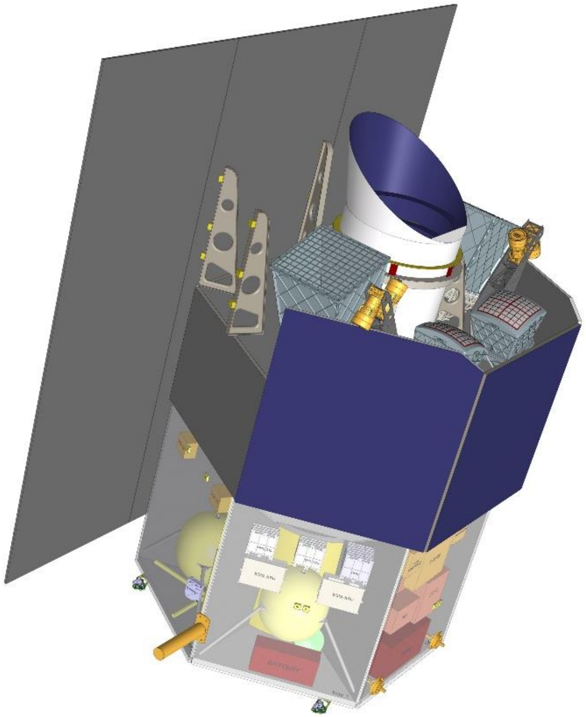
- **Fast slewing capability** (>10°/min), granting prompt NIR follow-up of GRBs and transients

- **Low-Earth Orbit (LEO),** with about 4° inclination and 550-640 km altitude, granting low and stable BKG for the monitors

- The weight (about 2.3 tons) and dimensions are suitable for **launch with VEGA-E**



(ADS)



(THALES)

Expected progress in the near future ('20s)

- **Continuing operations of current main GRB / related missions** (Swift, Fermi, Konus-WIND, GECAM, HXMT, MAXI, GRBalpha, …)

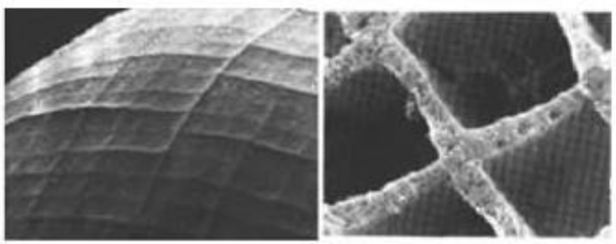
- **New / near future GRB / related missions** (EP, SVOM, POLAR-2, COSI, …) and **cubesats networks** (e.g., HERMES)

- **Synergies with new / growing on-ground very large facilities** (late '20s): JWST, ELT, LSST, CTA, SKA, upgraded 2nd generation GW and neutrino detectors

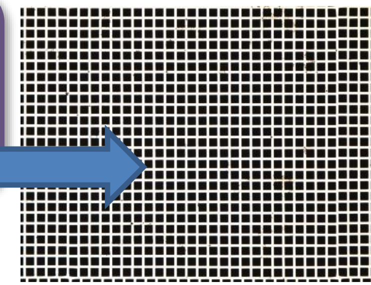
- **Main improvements on GRB physics, incremental progress in GRB cosmology, likely little progress in multi-messenger astrophysics (mostly limited by capabilities of 2G detectors)**

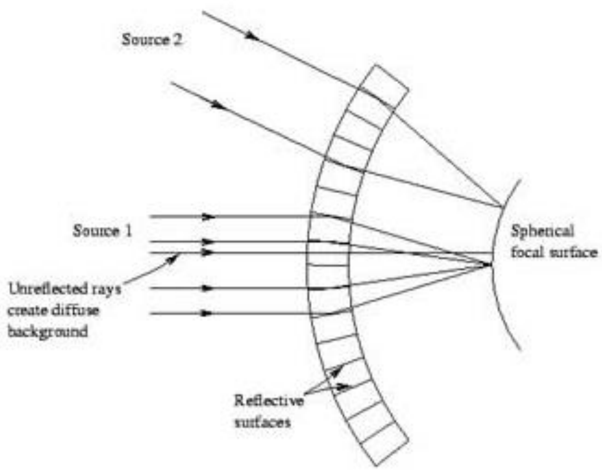
The Soft X-Ray Imager (SXI)

Two sensitive "lobster-eye" X-ray telescopes (0.3 - 5 keV); total FOV of 0.5sr (>1000 × conventional X-ray telescopes); 100ms photon timing; source location accuracy <2′



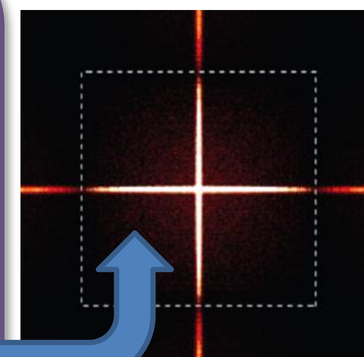
Mimic a lobster-eye using curved, square-pore MPOs





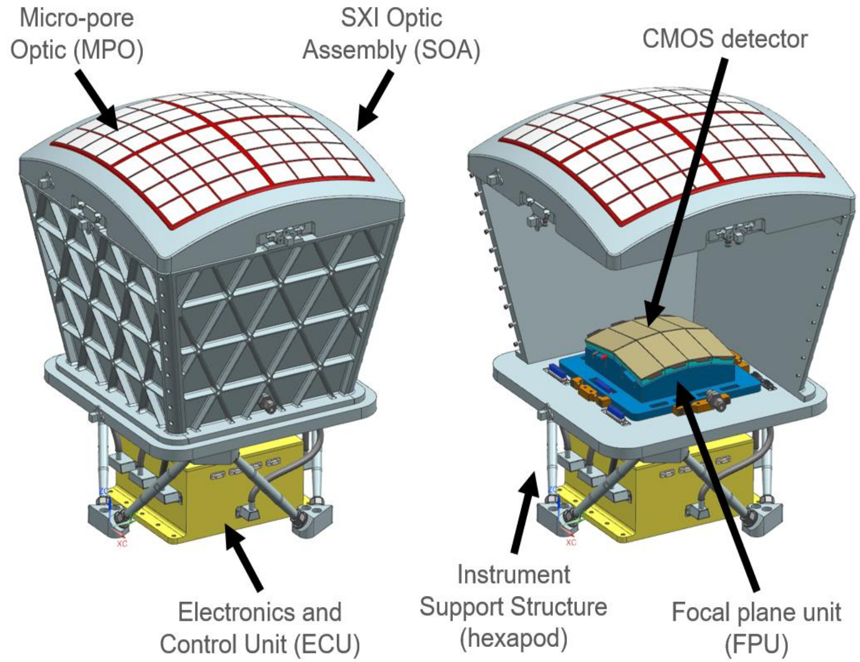
No single optical axis: get a wide field of view plus focusing with constant effective area

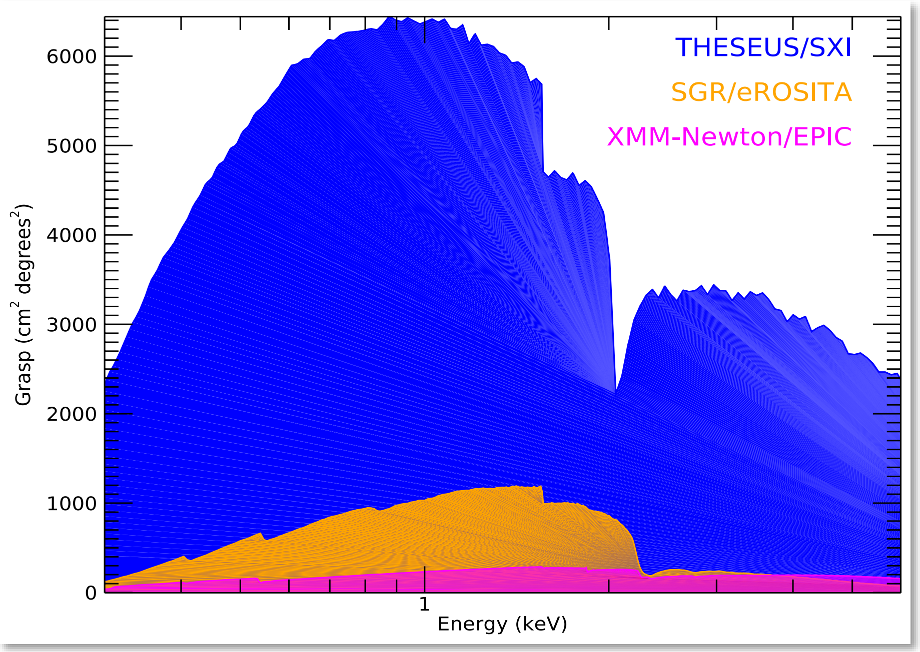
Spot (double reflection)
Lines (single reflections)



The Soft X-Ray Imager (SXI)

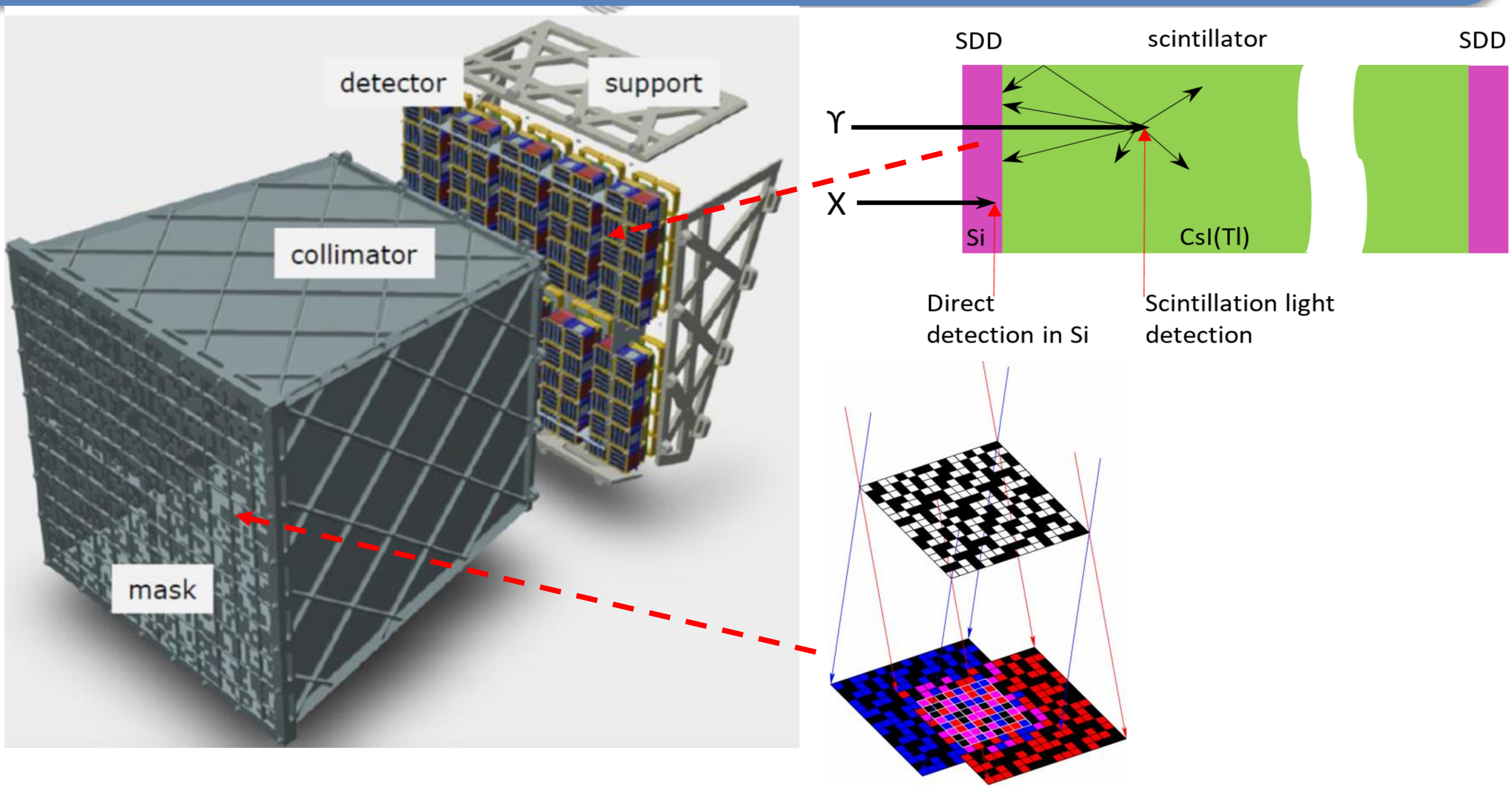
SXI will show a unique combination of FOV and effective area (GRASP), enabling simulatneous detection and localization of many transients in parallel.





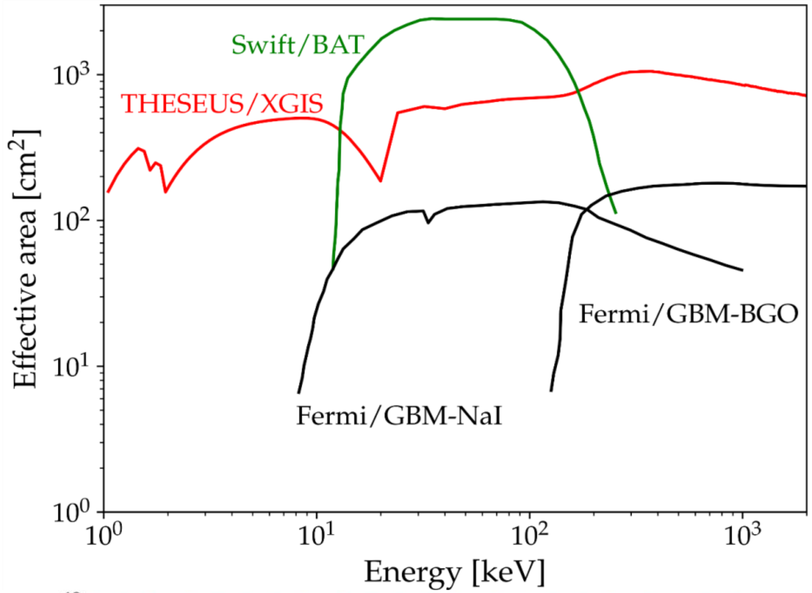
The X-Gamma Ray Imaging Spectrometer (XGIS)

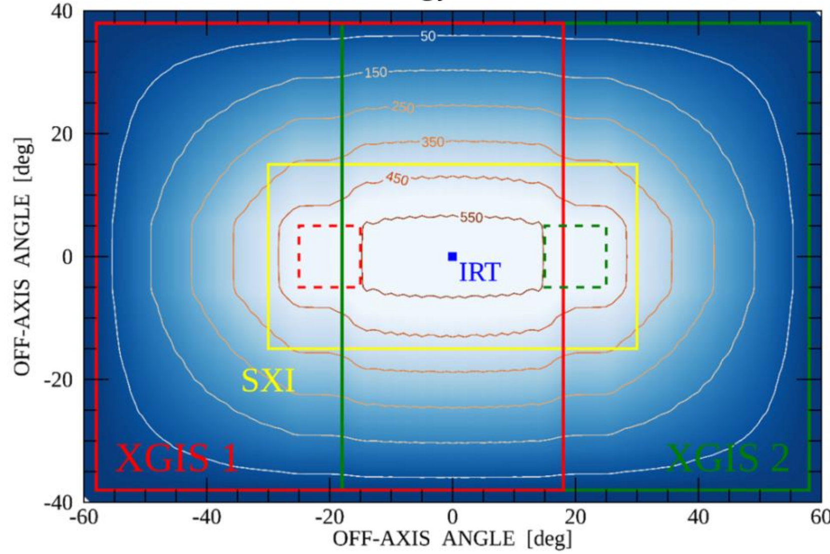
Two coded-mask X-gamma ray cameras using innovative coupling between Silicon drift detectors (2-30 keV) and CsI crystal scintillator bars (20 keV–10 MeV)



The X-Gamma Ray Imaging Spectrometer (XGIS)

- Unprecedented energy band (2 keV – 10 MeV)
- Large effective area down to 2 keV
- FOV >2 sr overlapping the SXI one
- GRB location accuracy <15′ in 2-150 keV
- Excellent timing (< a few μs)

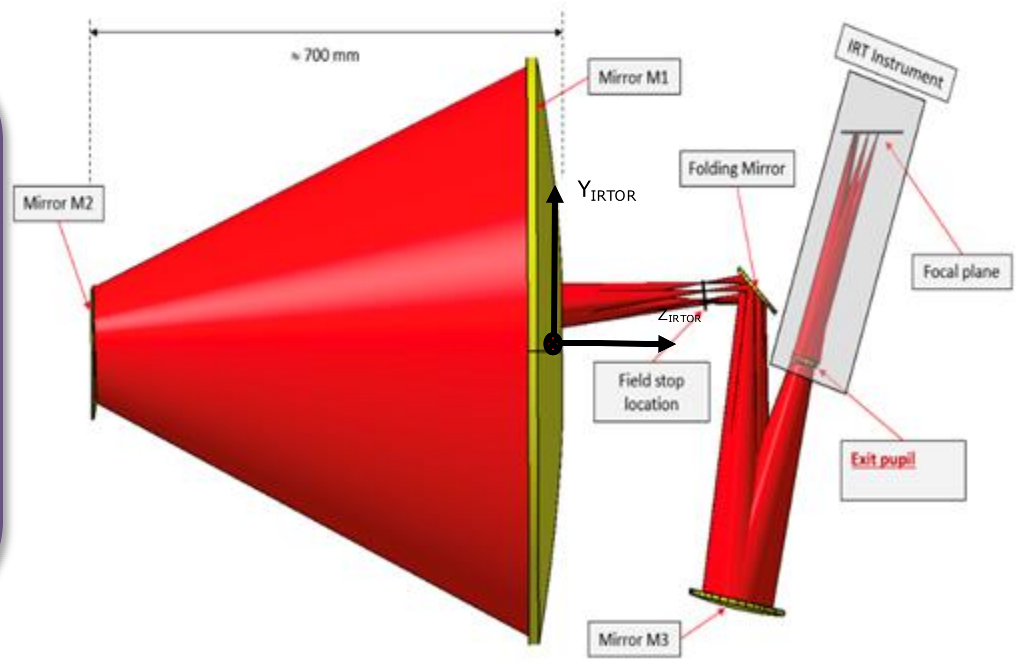




The Infra-Red Telescope (IRT)

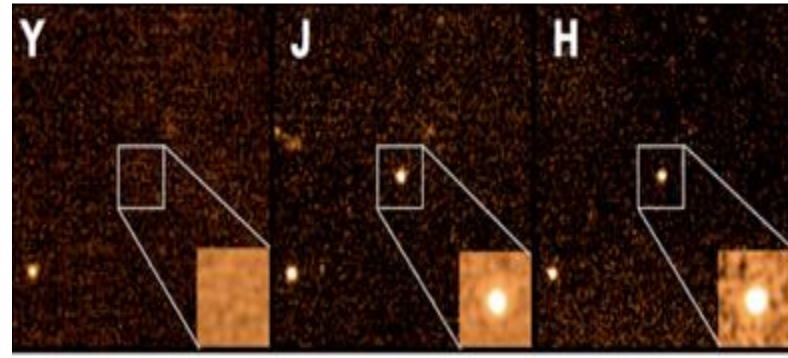
A 0.7 m class telescope with an off-axis Korsch optical design allowing for a large field of view (15′x15′) with imaging and moderate (R~400) spectroscopic capabilities

Teledyne H2RG sensitive in 0.7-1.8 microns
Expected sensitivity per filter (over 150 s): 20.9 (I), 20.7 (Z), 20.4 (Y), 21.1 (J), 21.1(H).
Spectral sensitivity limit (over 1800 s), about 17.5 (H) over the 0.8-1.6 microns



The Infra-Red Telescope (IRT)

On-board photometric redshift for >90% detected GRB afterglows



On-board sensitive absorption spectrosocpy for medium-bright events