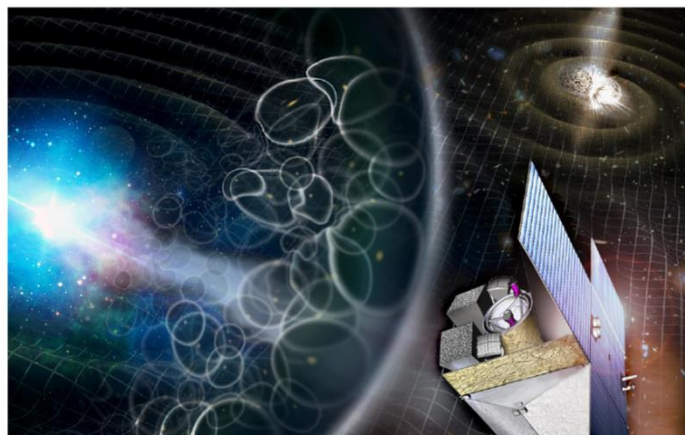


theseus

TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

The THESEUS Mission concept

L. Amati (INAF) on behalf of the THESEUS Consortium



Ninth International Fermi Symposium

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), A. Santangelo (Univ. Tuebingen, D), E. Bozzo (Univ. Genève, CH)

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



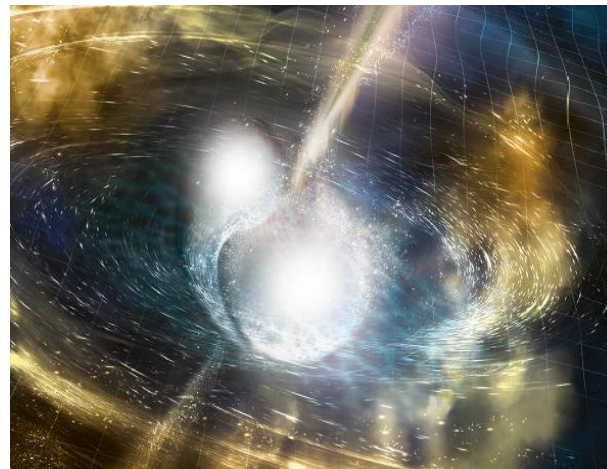
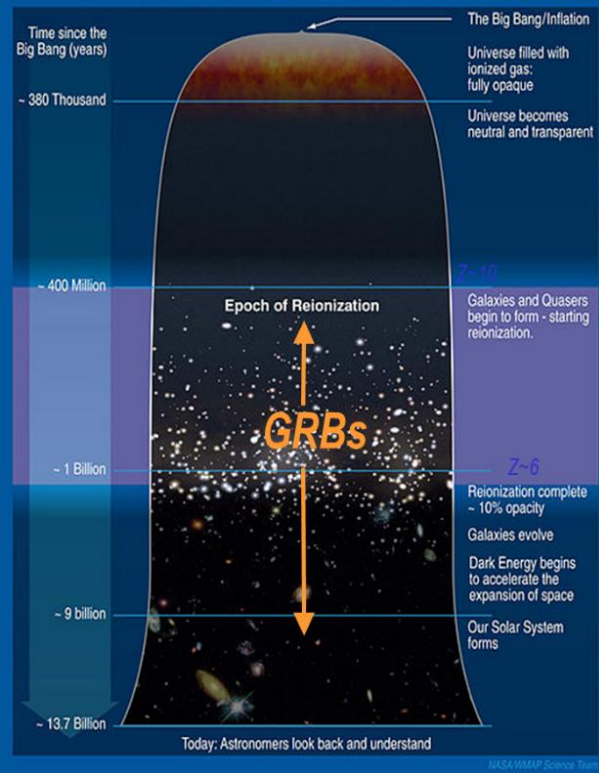
Probing the Early Universe with GRBs

Multi-messenger and time domain Astrophysics

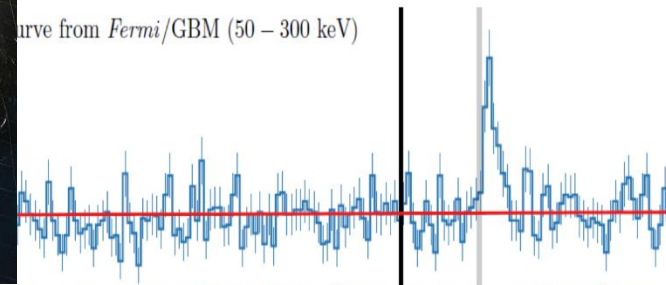
The transient high energy sky

Synergy with next generation large facilities (E-ELT, SKA, CTA, ATHENA, GW and neutrino detectors)

First Stars and Reionization Era



Curve from *Fermi*/GBM (50 – 300 keV)



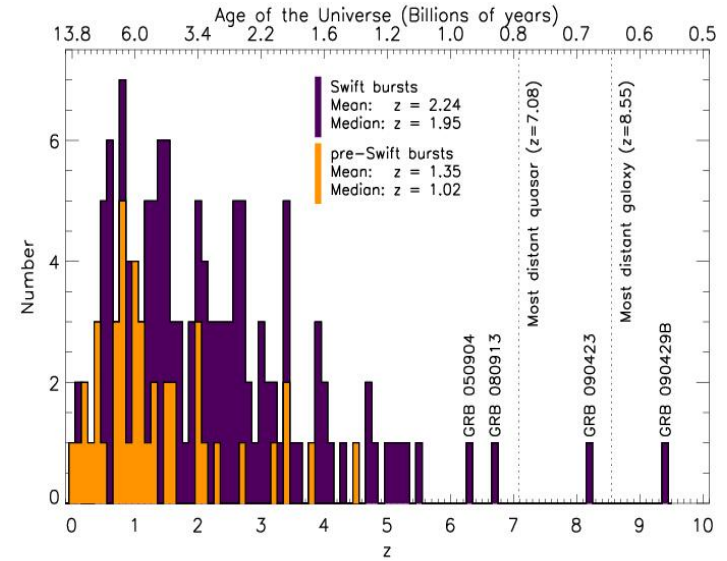
Gravitational-wave time-frequency map

May 2018: THESEUS selected by ESA for Phase 0/A study (with SPICA and ENVISION)

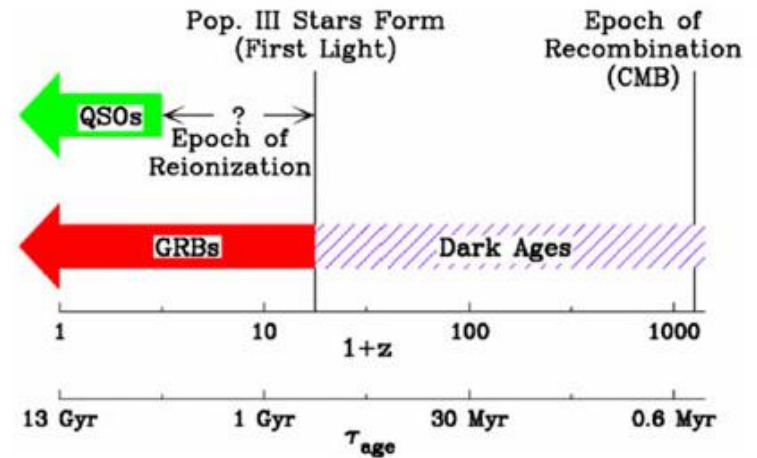
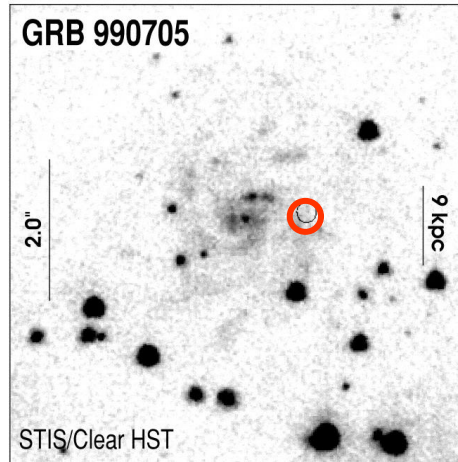
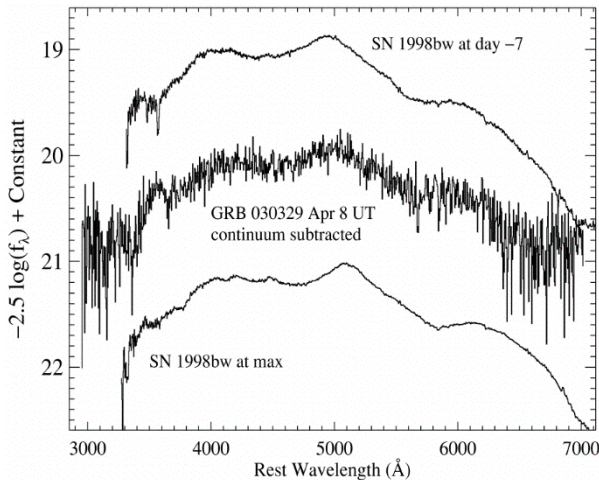
Activity	Date
Phase 0 kick-off	June 2018
Phase 0 completed (EnVision, SPICA and THESEUS)	End 2018
ITT for Phase A industrial studies	February 2019
Phase A industrial kick-off	June 2019
Mission Selection Review (technical and programmatic review for the three mission candidates)	Completed by June 2021
SPC selection of M5 mission	June 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

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 $z \sim 9$ and association with exploding massive stars
- ❑ **Powerful tools for cosmology:** SFR evolution, physics of re-ionization, high- z low luminosity galaxies, pop III stars



GRBs in Cosmological Context

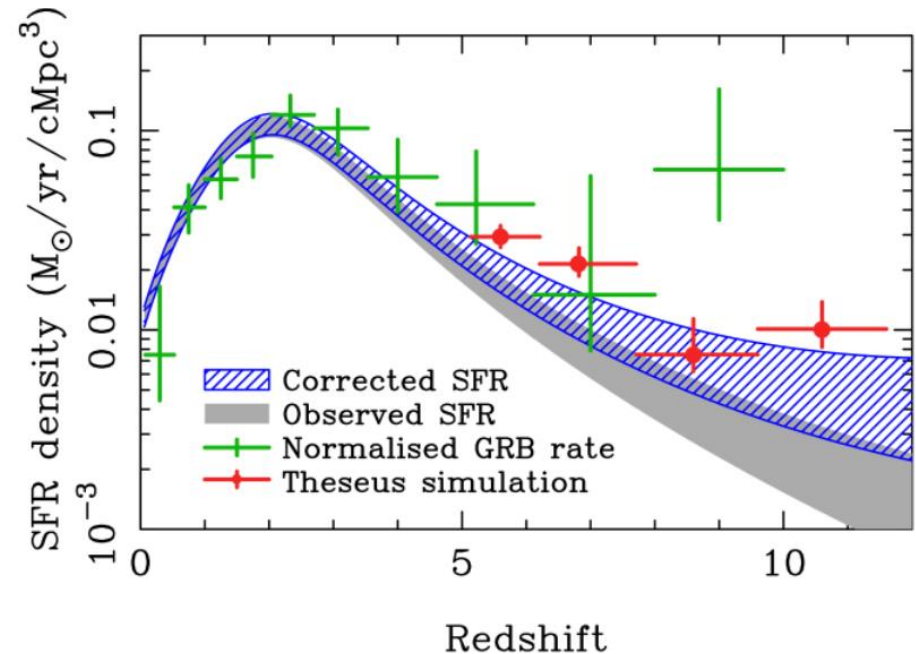


Lamb and Reichart (2000)

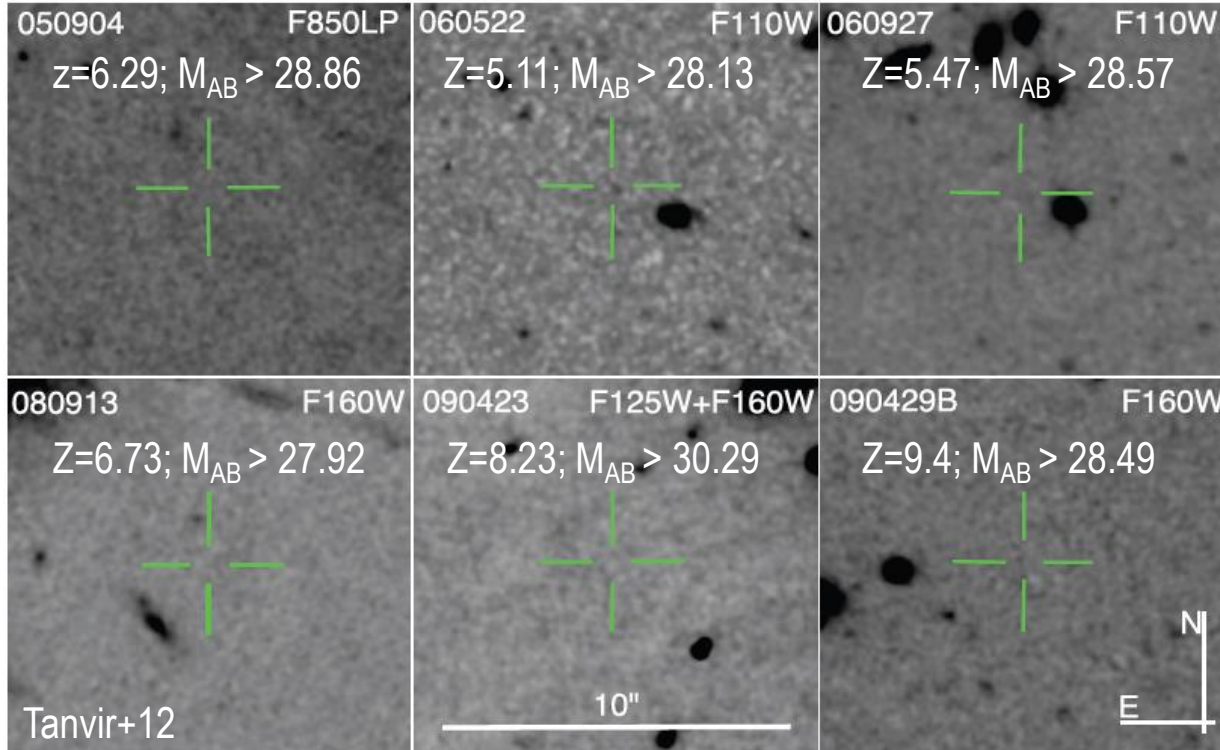
Shedding light on the early Universe with GRBs

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)**



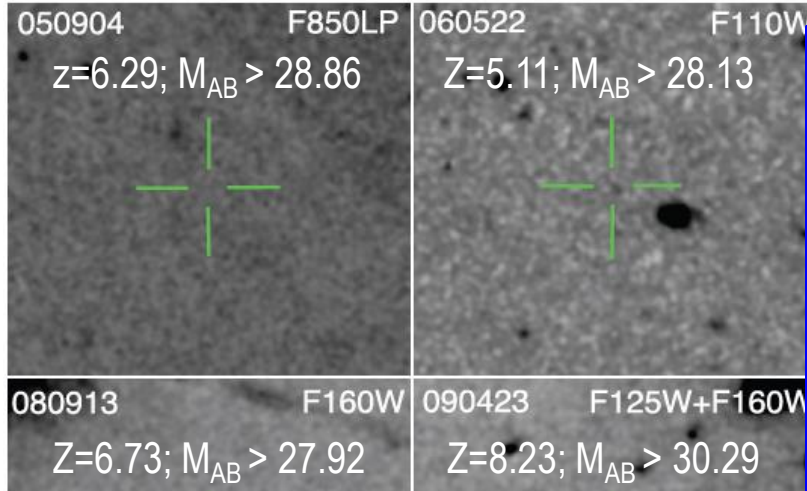
- **Detecting and studying primordial invisible galaxies**



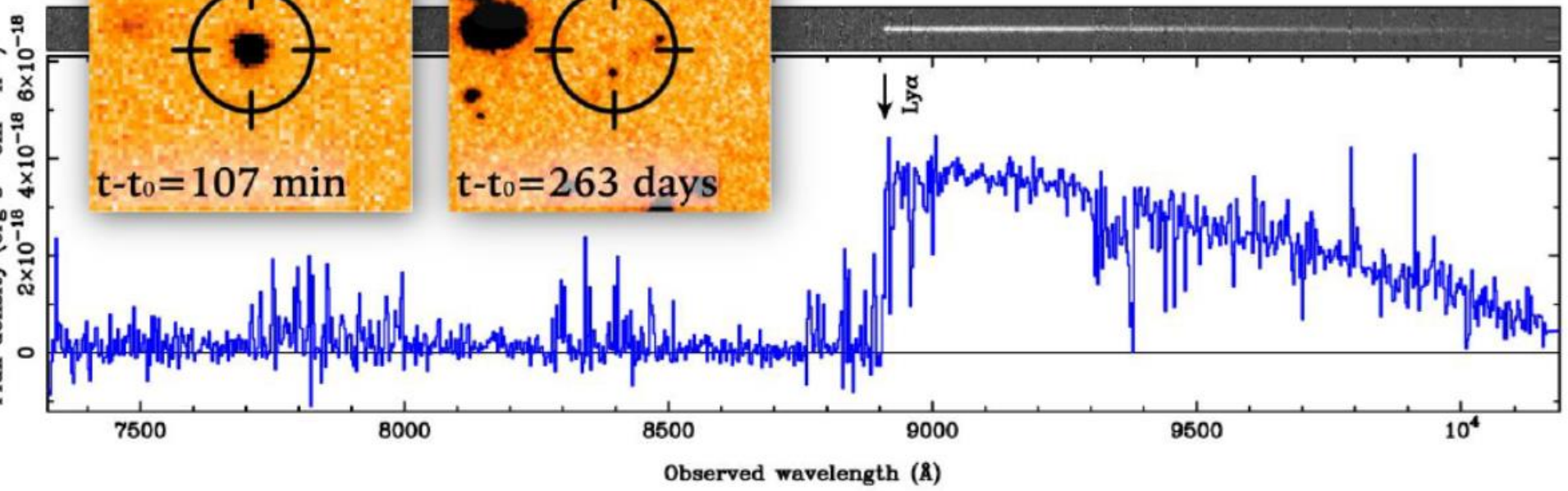
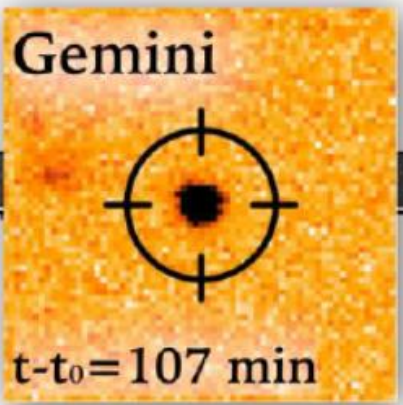
Robertson&Ellis12

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

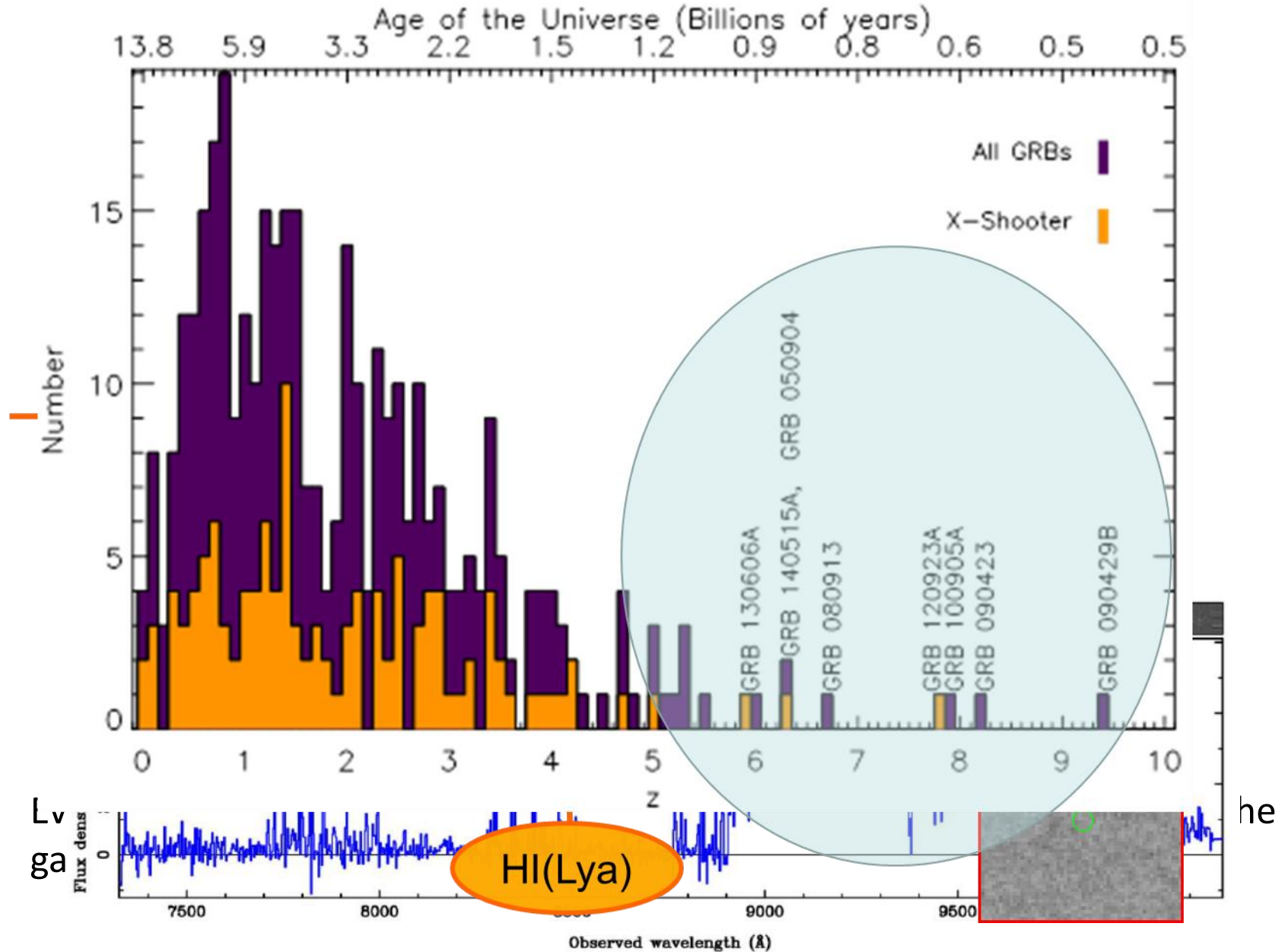
• Detecting and studying primordial invisible galaxies



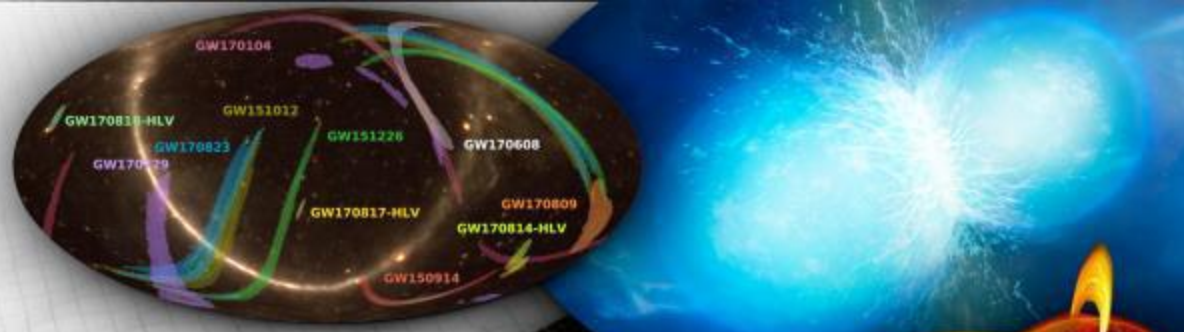
- neutral hydrogen fraction
- escape fraction of UV photons from high-z galaxies
- early metallicity of the ISM and IGM and its evolution



- **Detecting and studying primordial invisible galaxies**

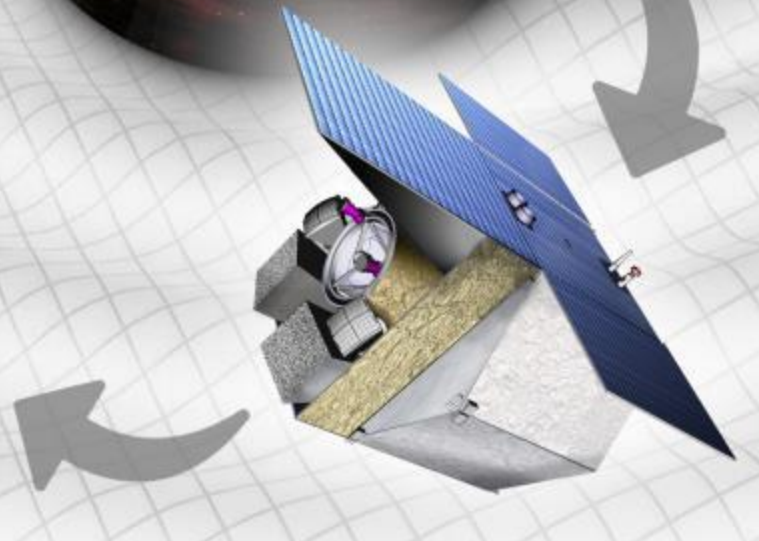
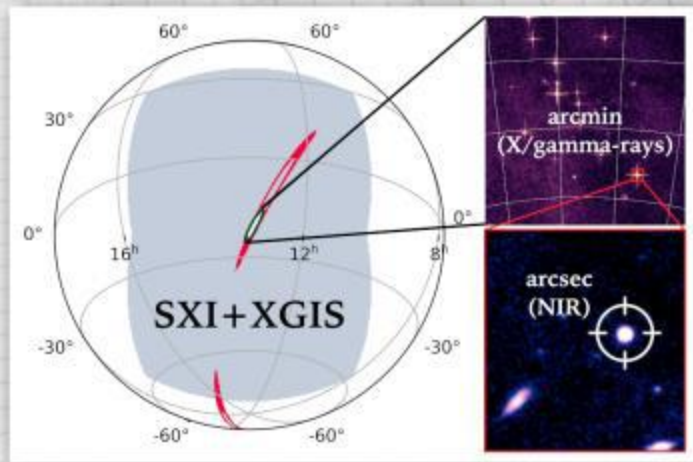


Exploring the multi-messenger transient sky



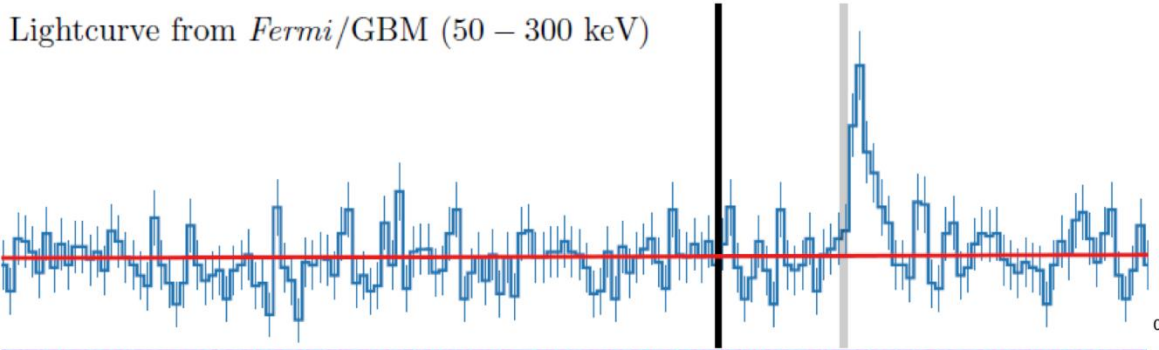
THESEUS ensures:

- Immediate coverage of gravitational wave and neutrino source error boxes
- Real time sky localizations
- Temporal & spectral characterization from NIR to gamma-rays

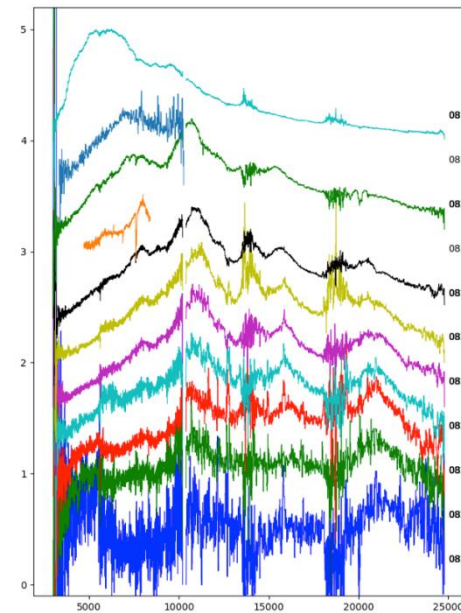
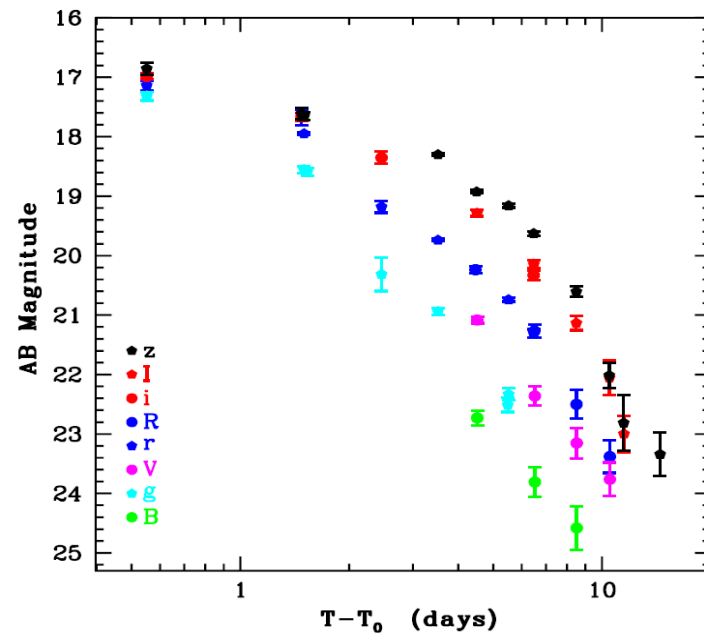
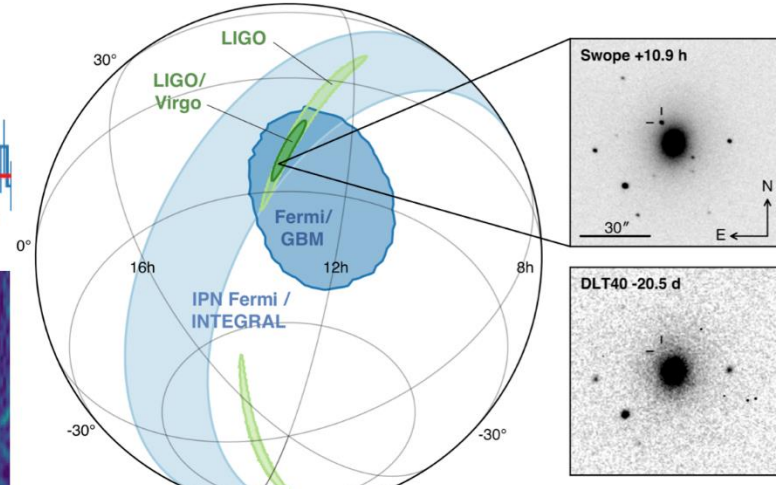
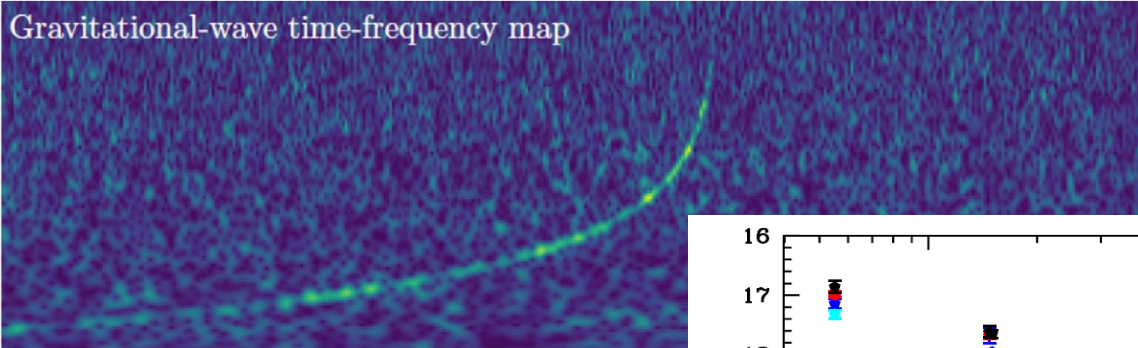


LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars

Lightcurve from *Fermi*/GBM (50 – 300 keV)



Gravitational-wave time-frequency map

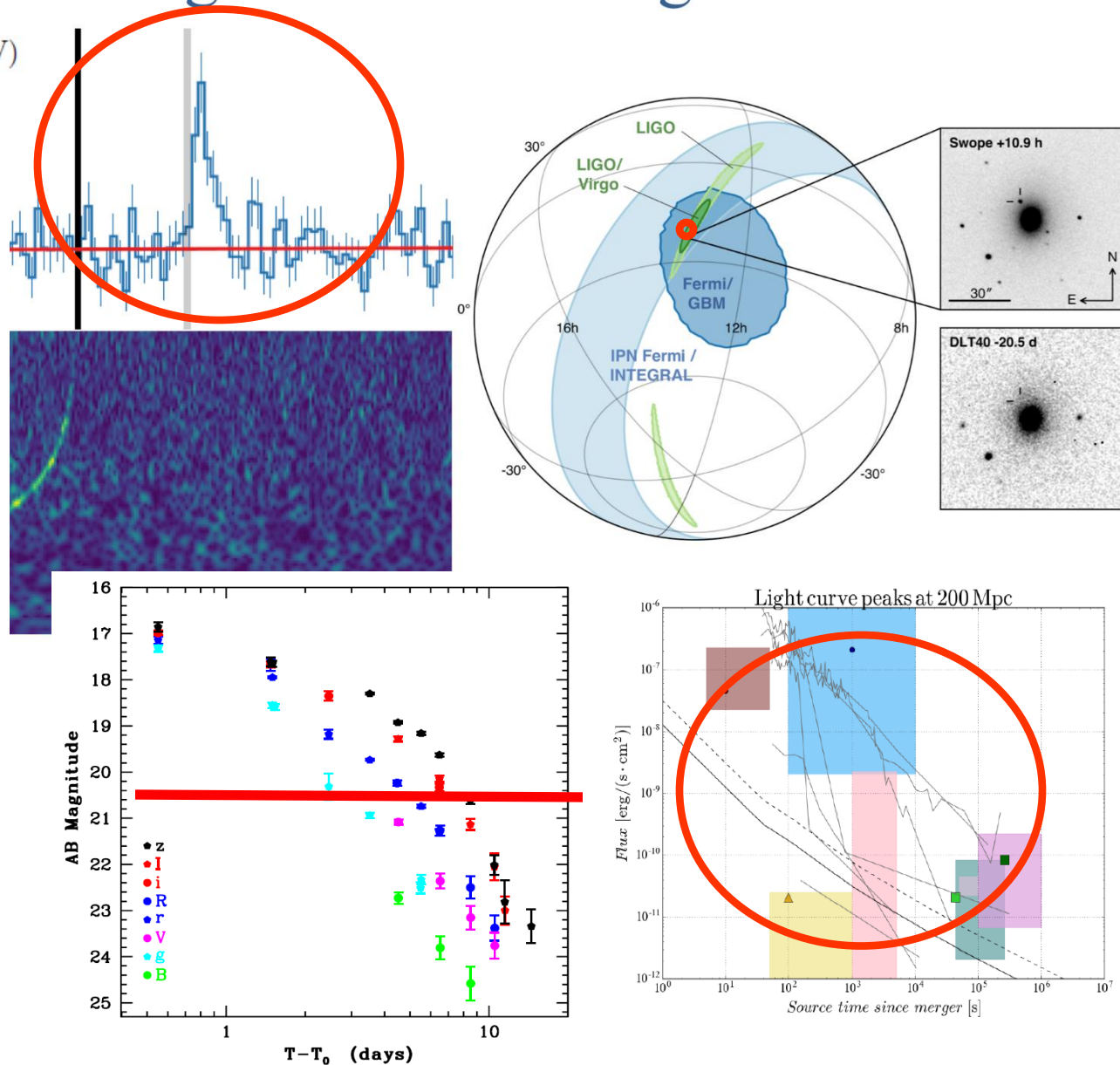


LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars

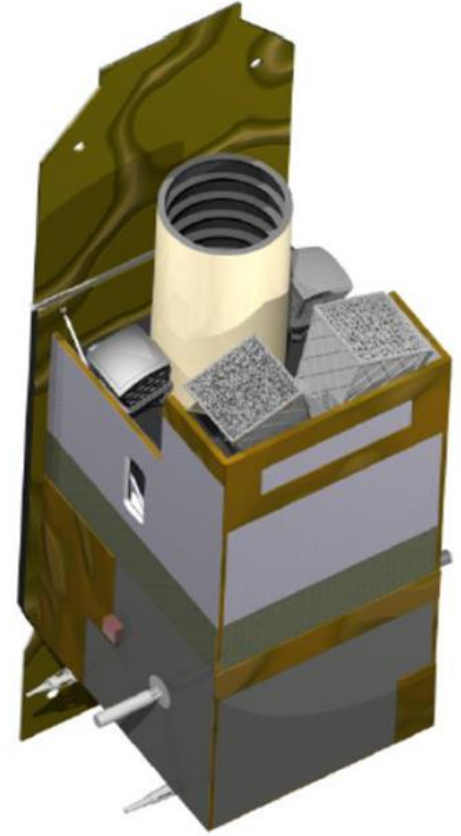
Lightcurve from *Fermi*/GBM (50 – 300 keV)

THESEUS:

- ✓ short GRB detection over large FOV with arcmin localization
- ✓ Kilonova detection, arcsec localization and characterization
- ✓ Possible detection of weaker isotropic X-ray emission

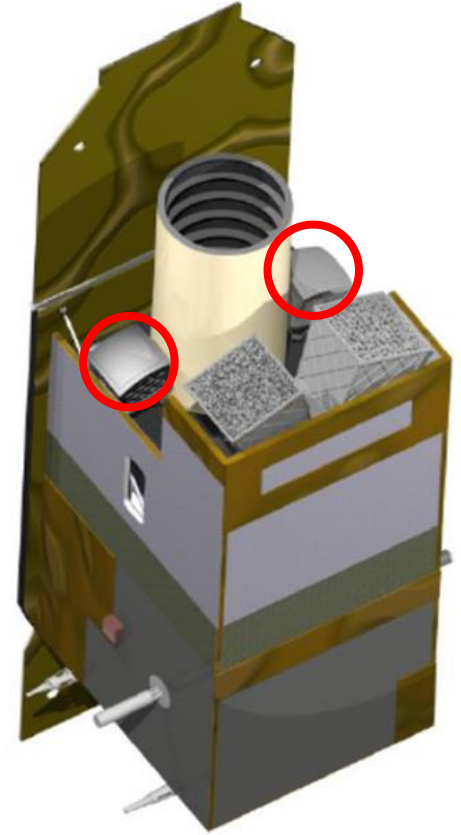


THESEUS mission concept



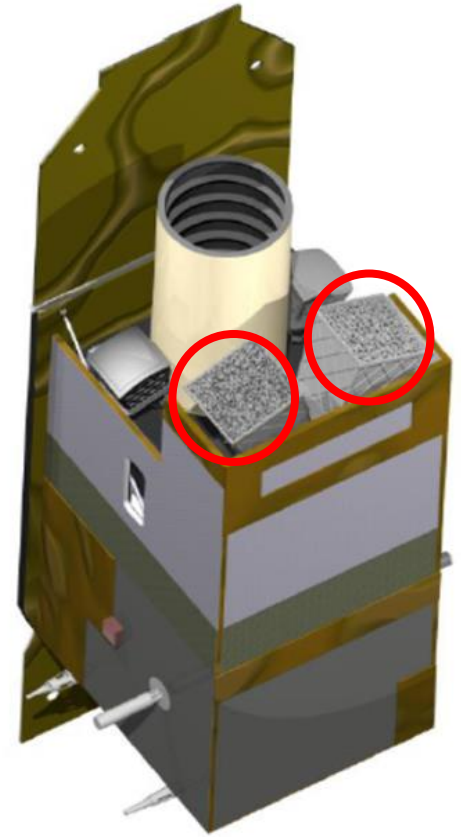
THESEUS mission concept

- **Soft X-ray Imager (SXI):** a set of two sensitive lobster-eye telescopes observing in **0.3 - 5 keV band**, total FOV of **$\sim 0.5\text{sr}$** with source location accuracy **$< 2'$** ;



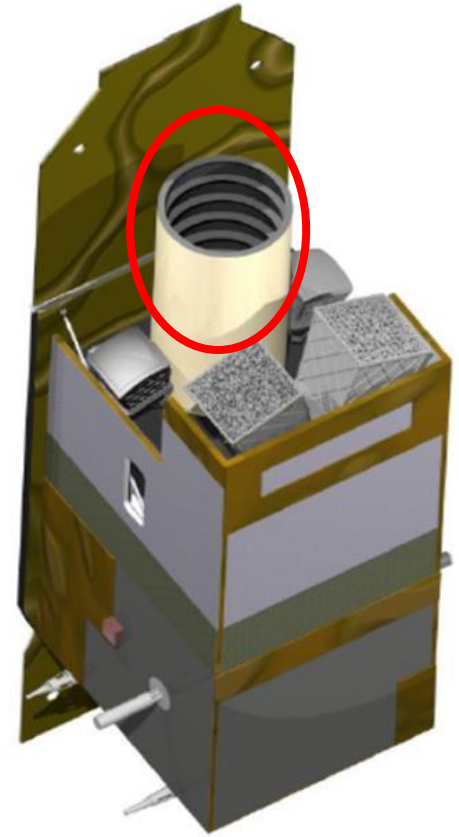
THESEUS mission concept

- ❑ **Soft X-ray Imager (SXI):** a set of two sensitive lobster-eye telescopes observing in **0.3 - 5 keV band**, total FOV of **~ 0.5 sr** 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 in 2-150 keV



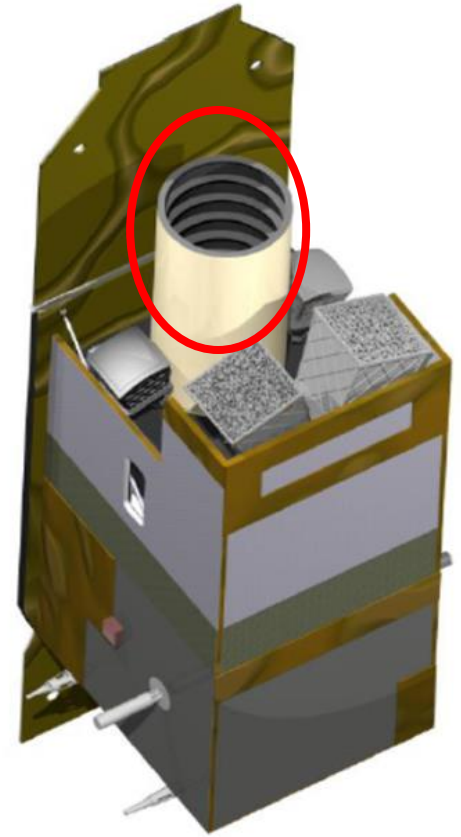
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- ❑ **InfraRed Telescope (IRT):** a 0.7m class IR telescope observing in the **0.7 – 1.8 μm** band, providing a **15'x15'** FOV, with both imaging and moderate resolution spectroscopy capabilities (**-> redshift**)



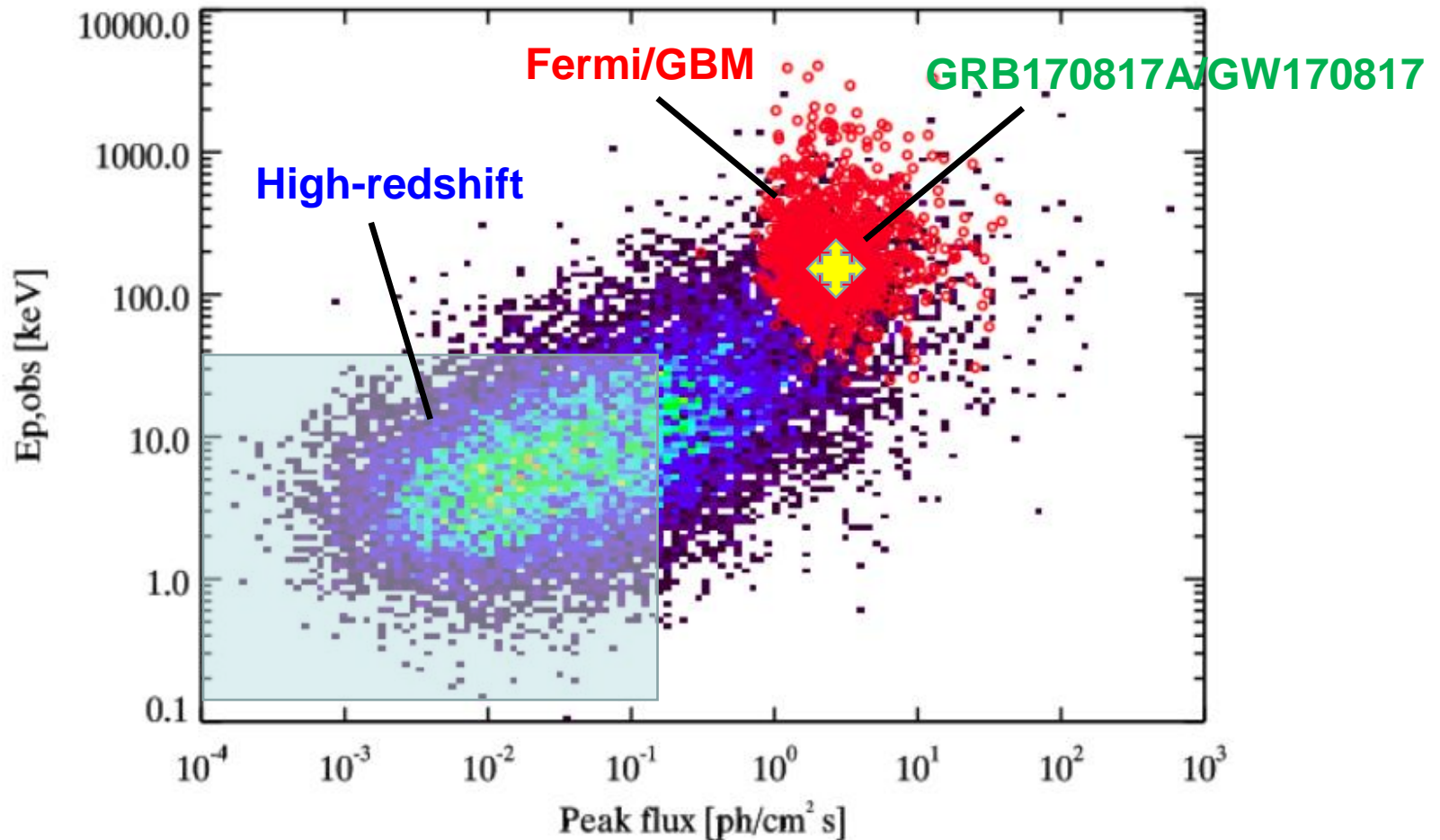
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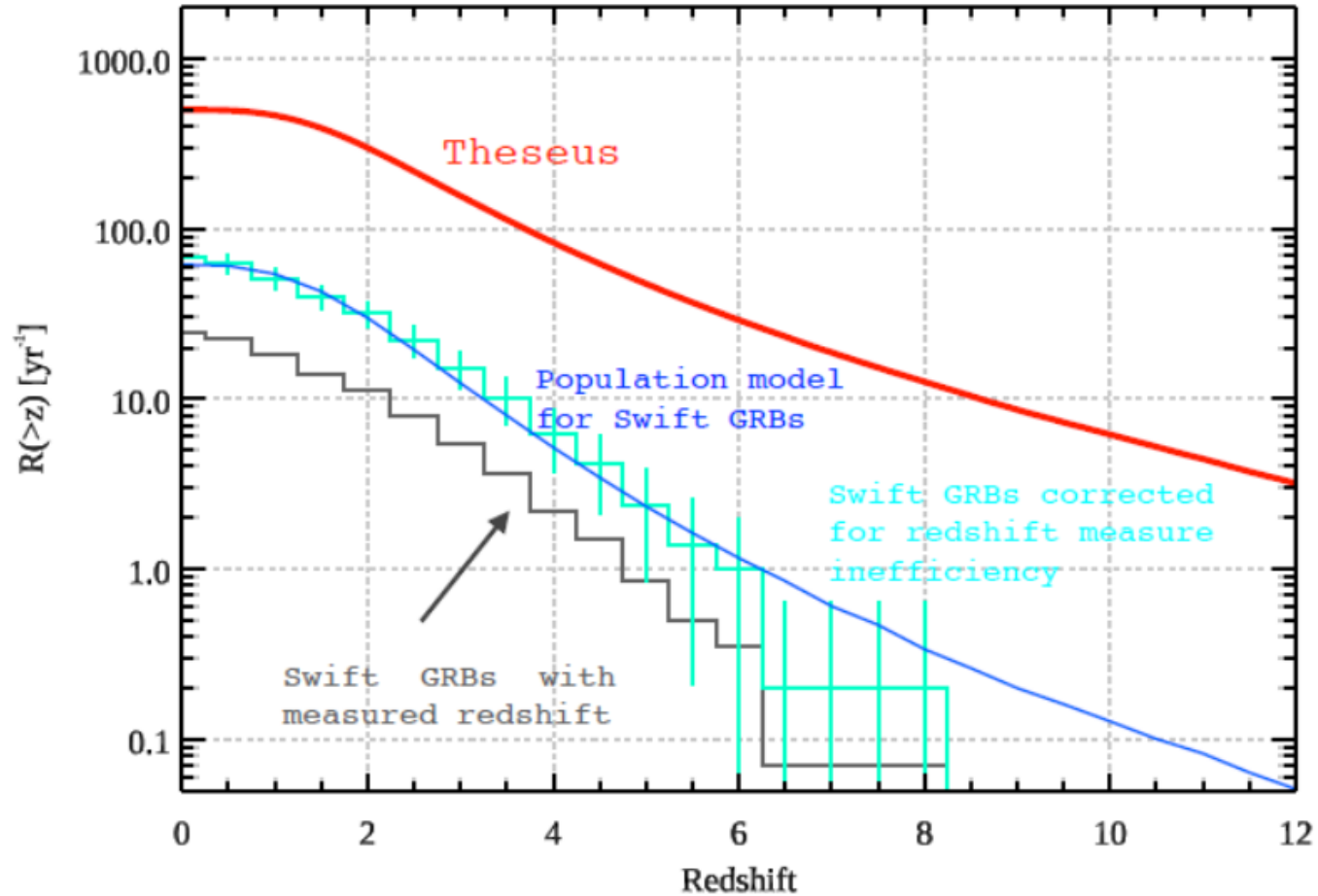


- **Low Earth Orbit**
(**$< 5^\circ$, ~ 600 km**)
- **Autonomously rapid slewing bus**
- **4-years nominal**

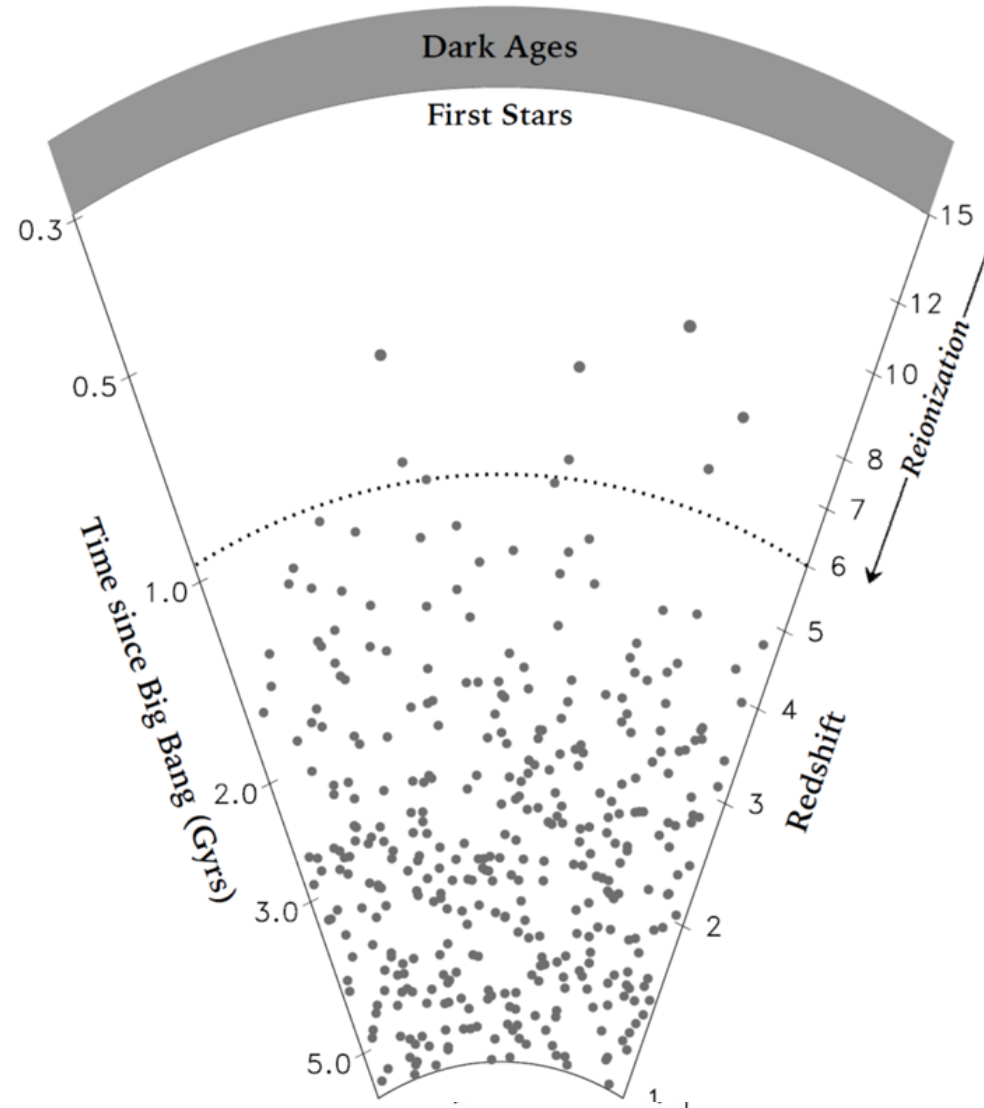
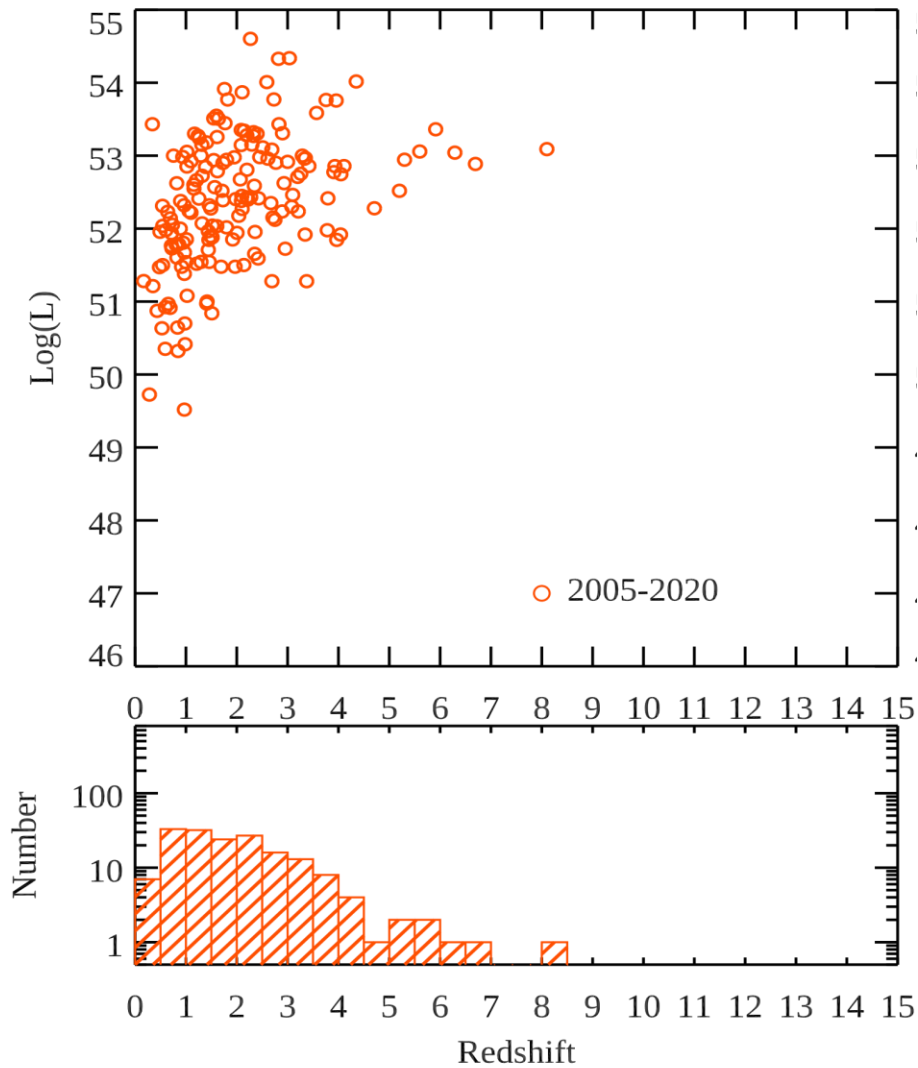
THESEUS will have the ideal combination of instrumentation and mission profile for detecting all types of GRBs (long, short/hard, weak/soft, high-redshift), providing accurate location and redshift for a large fraction of them



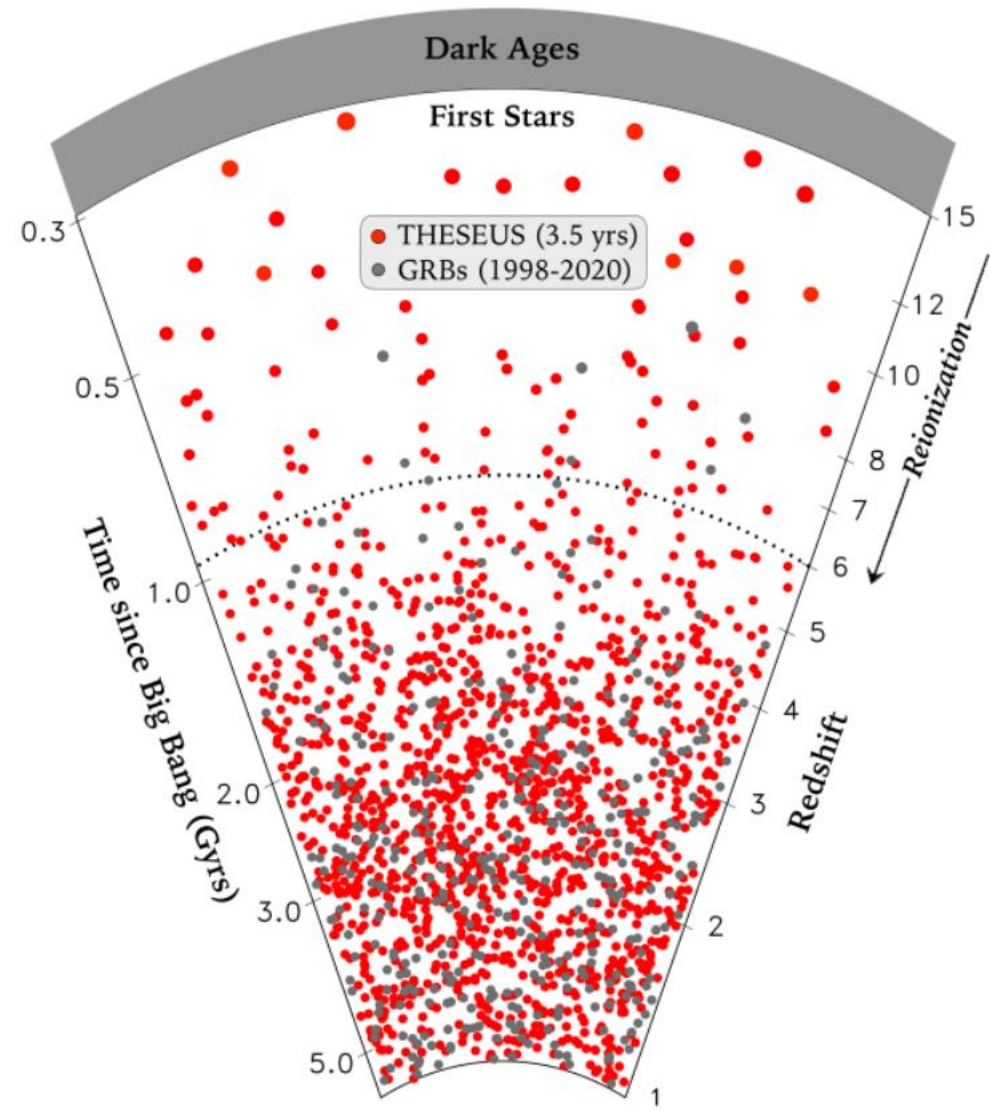
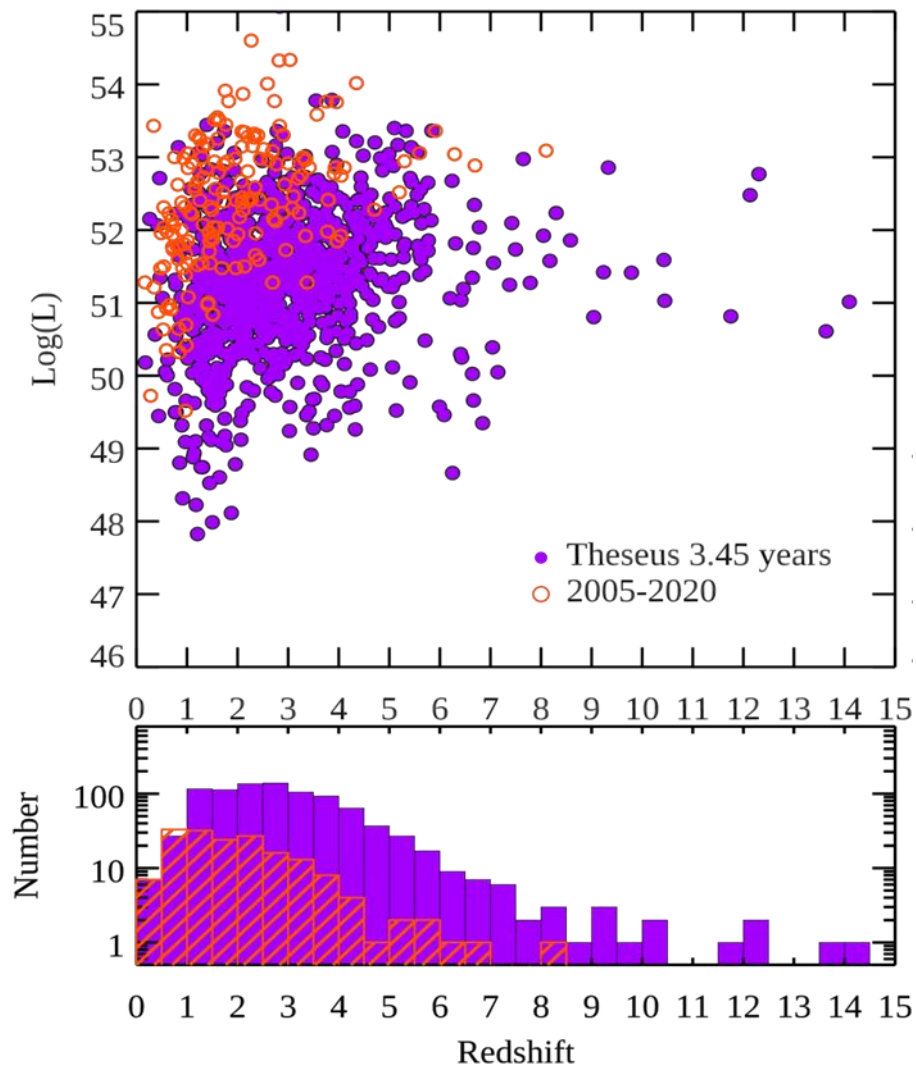
Shedding light on the early Universe with GRBs



Shedding light on the early Universe with GRBs



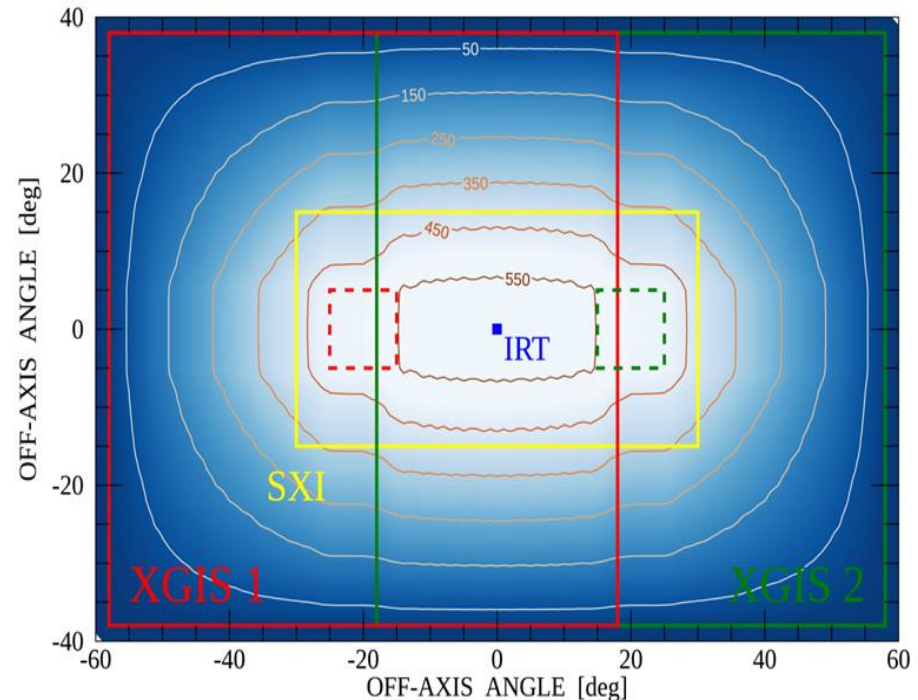
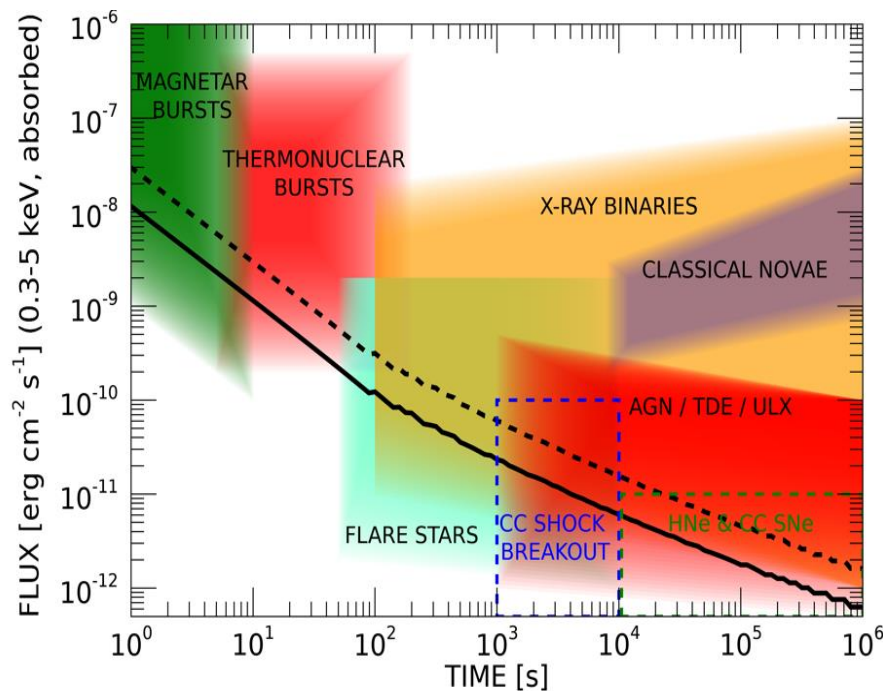
Shedding light on the early Universe with GRBs



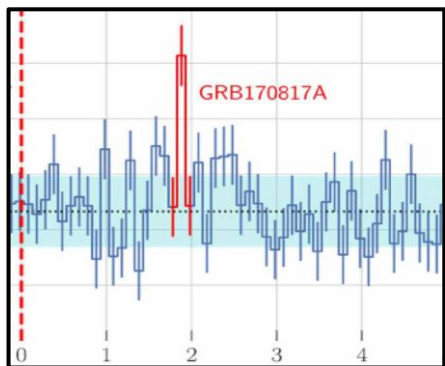
Exploring the multi-messenger transient sky

☐ THESEUS will detect and localize down to 0.5-1 arcmin the soft X-ray short/long GRB afterglows, of NS-NS mergers and of many classes of galactic and extra-galactic transients

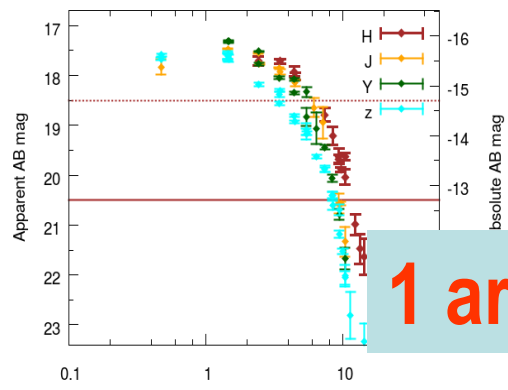
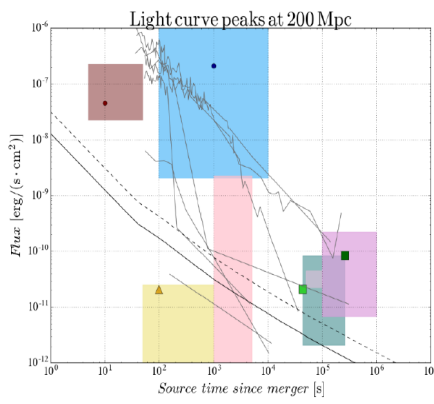
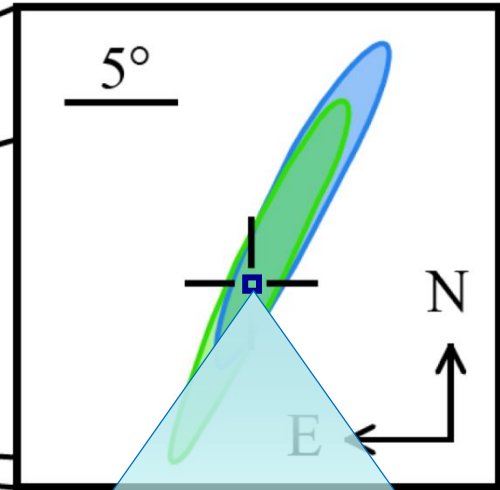
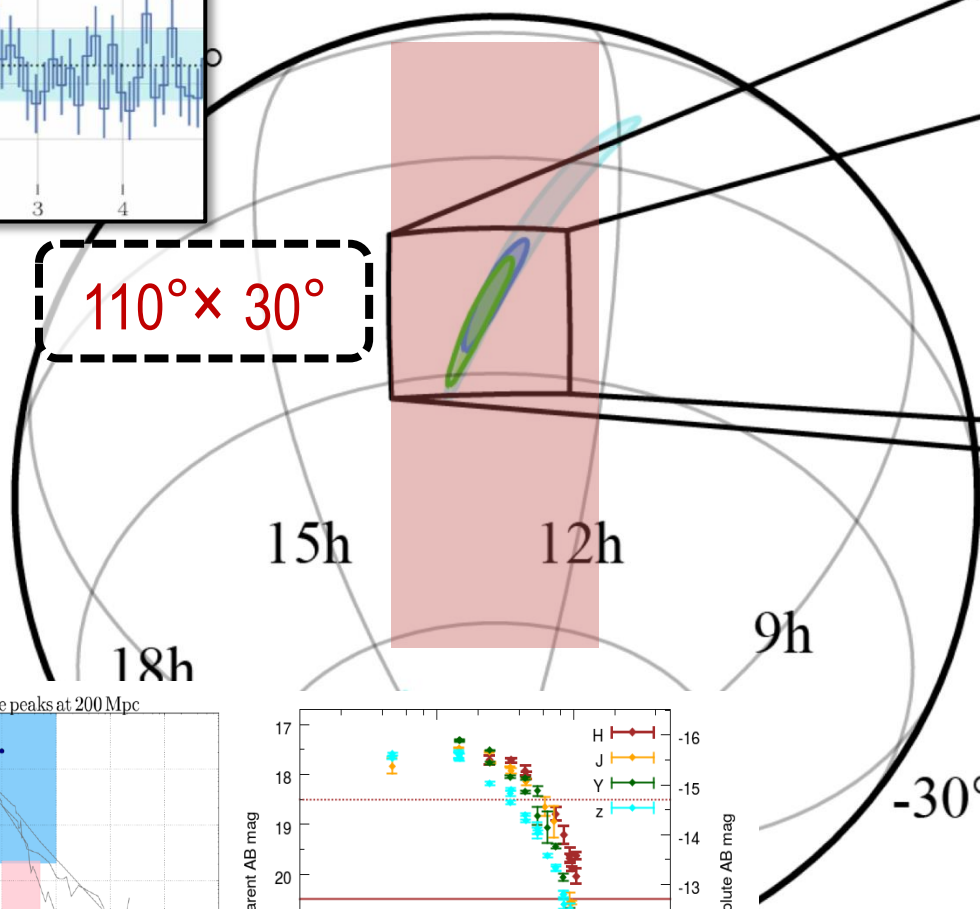
☐ For several of these sources, THESEUS/IRT may provide detection and study of associated NIR emission, location within 1 arcsec and redshift



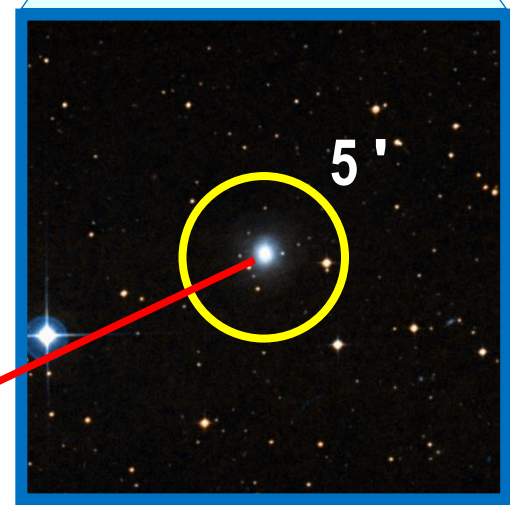
□ Promptly and accurately localizing e.m. counterparts to GW events with THESEUS



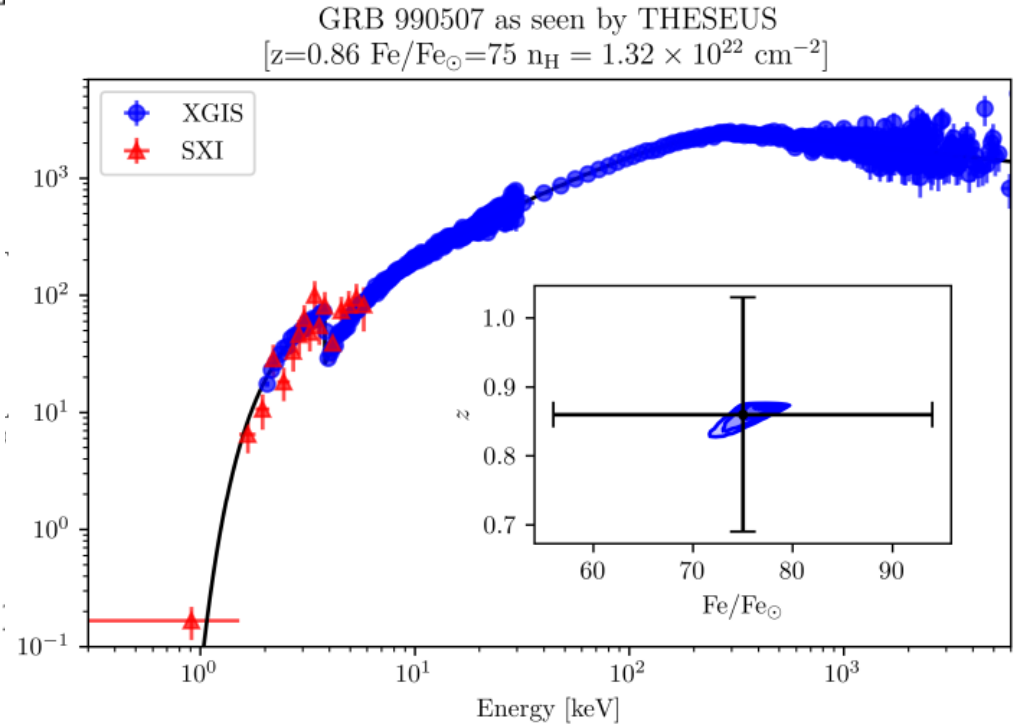
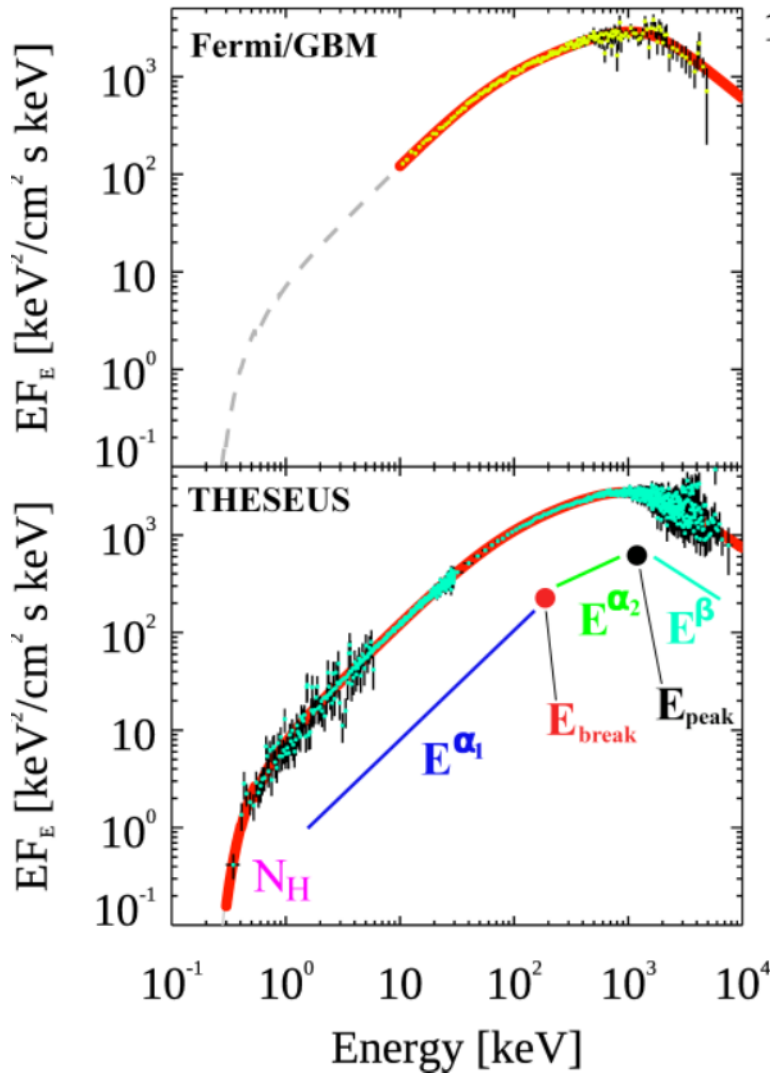
$110^\circ \times 30^\circ$



1 arcsec !



GRB prompt emission physics through unprecedented SXI+XGIS energy band (0.3 keV – 20 meV)



GRB spectrum measured simultaneously over 5 orders of magnitudes in energy!!!

THESEUS Synergies

- Spectro-imaging of GRB afterglows and hosts
- ISM metallicity and physics
- IGM along the line of sight

ELTs



Rubin Obs/LSST



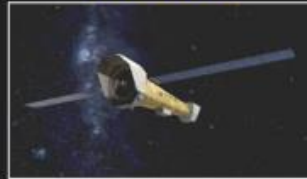
- Archival ID of transients' hosts
- Real-time detection of HE transients

SKA



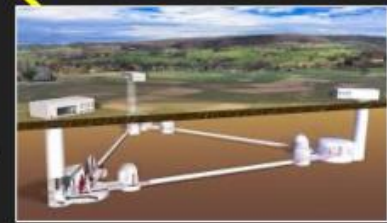
- Reionization epoch via 21 cm forest
- IGM around primordial minihosts

Athena



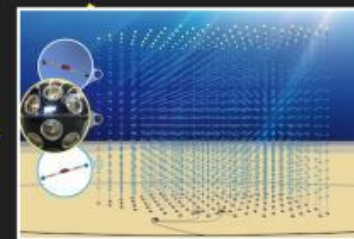
- Warm-Hot Intergalactic Medium
- Circum-burst medium physics

GW 3G detectors



- Electro-magnetic counterparts of GW events

ν -detectors



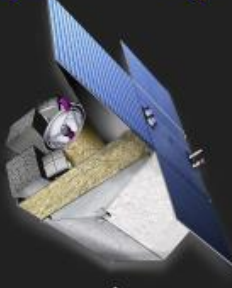
- Cosmic ν 's from flaring AGN, GRBs, transient galactic sources

CTA



- VHE emission from GRBs
- HE transient trigger and detection

THESEUS



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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 **unique 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**.

In summary

- ❖ THESEUS, submitted to ESA/M5 by a large European collaboration **will fully exploit GRBs as powerful and unique tools to investigate the early Universe and will provide us with unprecedented clues to GRB physics and subclasses.**
- ❖ THESEUS will also play a **fundamental role for GW/multi-messenger and time domain astrophysics** at the end of next decade, also by providing a **flexible follow-up observatory for fast transient events** with multi-wavelength ToO capabilities and guest-observer programmes
- ❖ THESEUS is a **unique occasion for fully exploiting the European leadership** in time-domain and multi-messenger astrophysics and in related **key-enabling technologies**
- ❖ THESEUS observations will impact on **several fields of astrophysics, cosmology and fundamental physics** and will enhance importantly the **scientific return of next generation multi messenger (aLIGO/aVirgo, LISA, ET, or Km3NET;) and e.m. facilities** (e.g., LSST, E-ELT, SKA, CTA, ATHENA)

- ❖ **Phase A will be concluded in Spring 2021; final selection on June**
SPIE articles on THESEUS already out. Science papers on Exp.Astr. coming.
<http://www.isdc.unige.ch/theseus/>