theseus

TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

Lorenzo Amati

(INAF – OAS Bologna)

on behalf of the THESEUS Consortium

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

Amati et al. 2018 (Adv.Sp.Res., arXiv:1710.04638)
Stratta et al. 2018 (Adv.Sp.Res., arXiv:1712.08153)

Coimbra AHEAD2020 Progress Meeting on Space Experiments for HE Astrophysics & Multi-messenger Astronomy

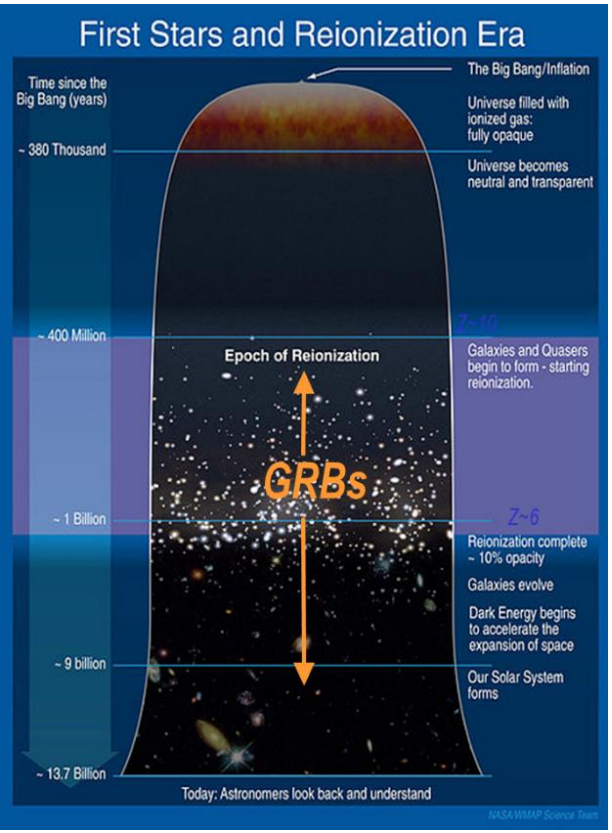
AHEAD 2020

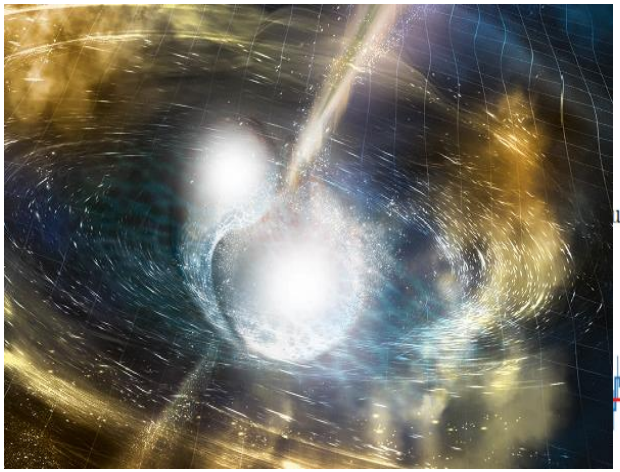
INTEGRATED ACTIVITIES FOR THE HIGH-ENERGY ASTROPHYSICS DOMAIN

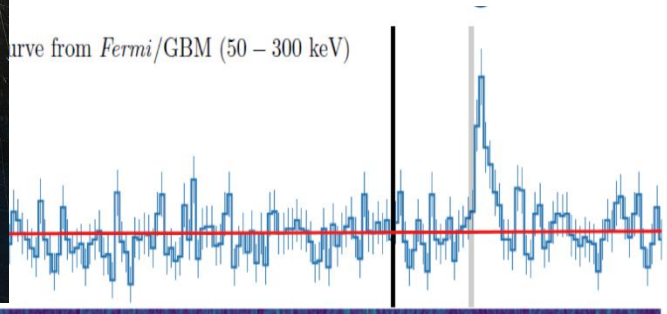
Funded by the Horizon 2020 Framework Programme of the European Union Grant Agreement No. 871158

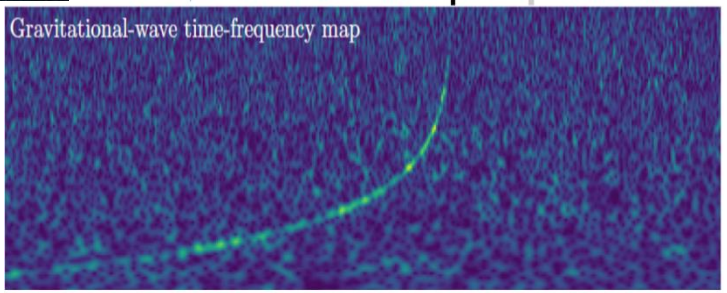
hosted by:

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)









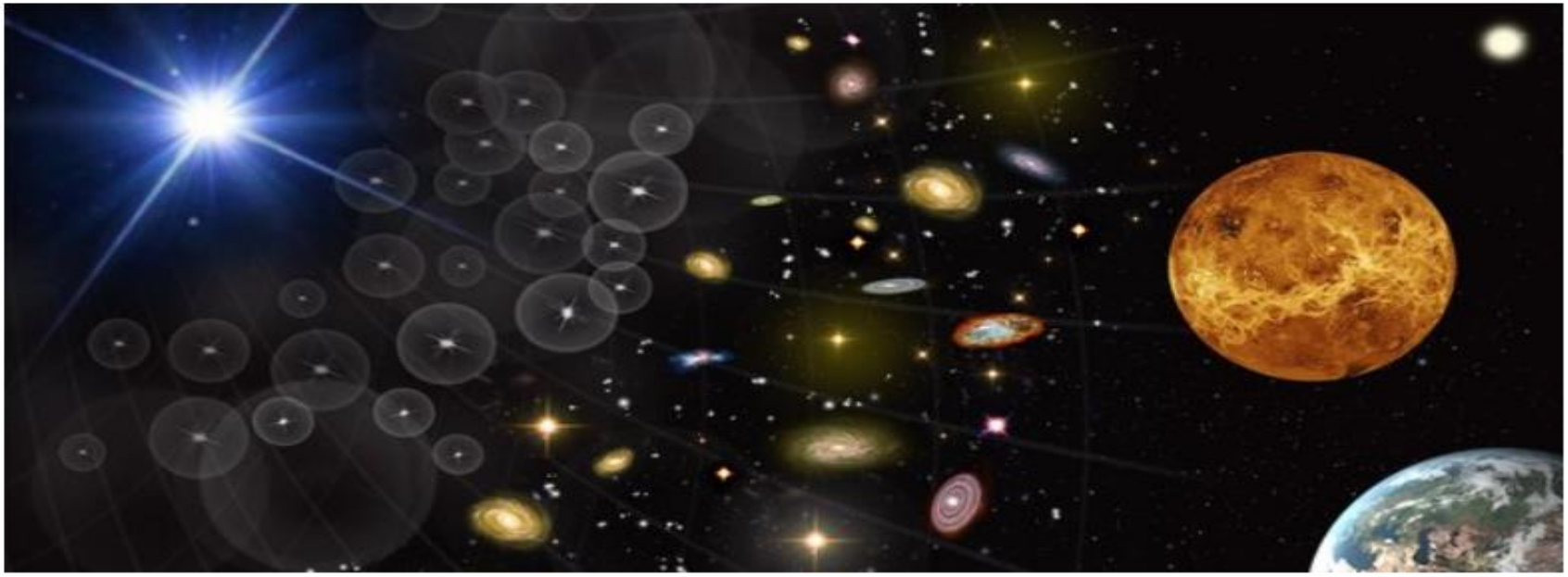
THESEUS
Transient High Energy Sky and Early Universe Surveyor

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, ESA

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



M5 mission themes

ESA SELECTS THREE NEW MISSION CONCEPTS FOR STUDY

7 May 2018 A high-energy survey of the early Universe, an infrared observatory to study the formation of stars, planets and galaxies, and a Venus orbiter are to be considered for ESA's fifth medium class mission in its Cosmic Vision science programme, with a planned launch date in 2032.

The three candidates, the Transient High Energy Sky and Early Universe Surveyor (Theseus), the SPace Infrared telescope for Cosmology and Astrophysics (Spica), and the EnVision mission to Venus were

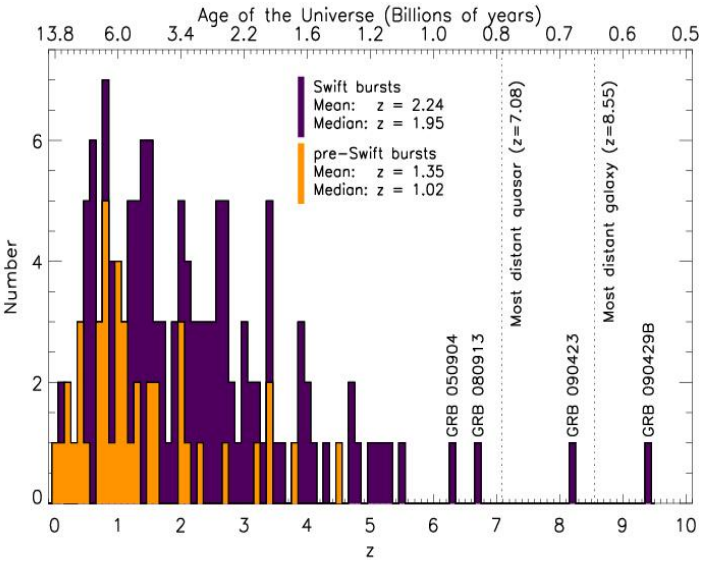
ESA timeline for M5 Phase 0/A study

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

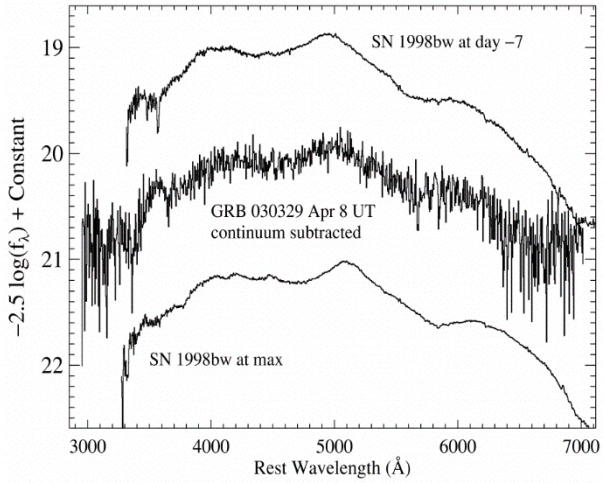
- THESEUS and ATHENA operations may overlap for several years

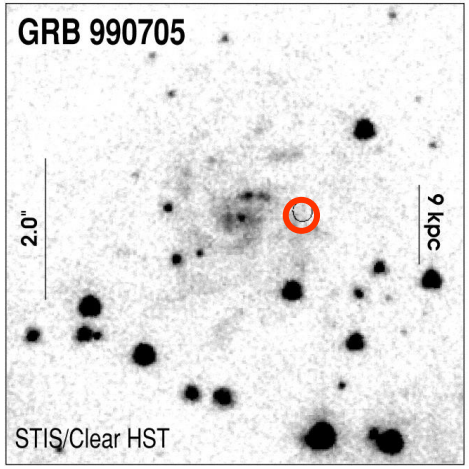
Shedding light on the early Universe with GRBs

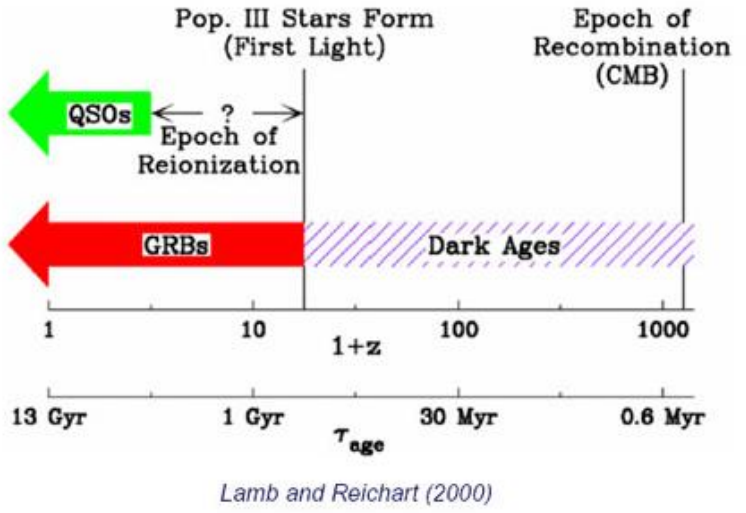
Because of their huge luminosities, mostly emitted in the X and gamma-rays, their redshift distribution extending at least to z ~9 and their association with explosive death of massive stars and star forming regions, GRBs are unique and powerful tools for investigating the early Universe: **SFR evolution,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



GRBs in Cosmological Context



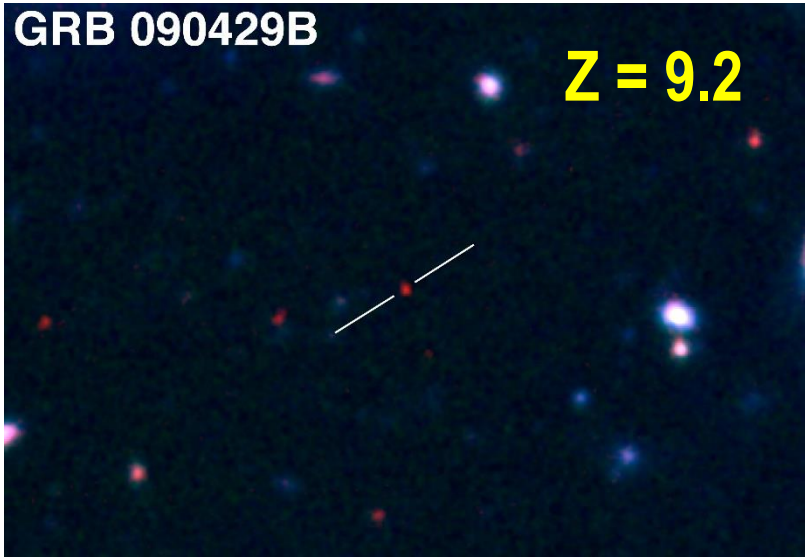


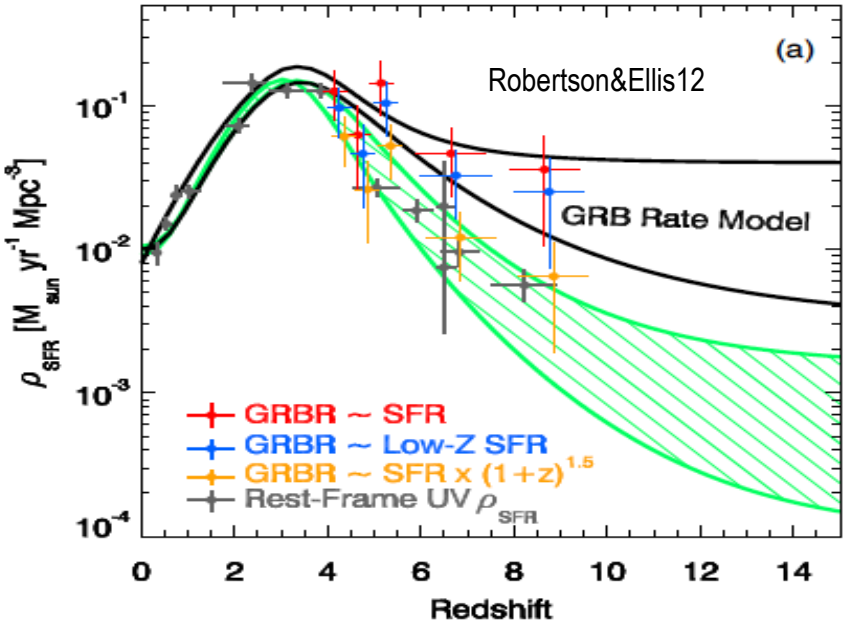


Lamb and Reichart (2000)

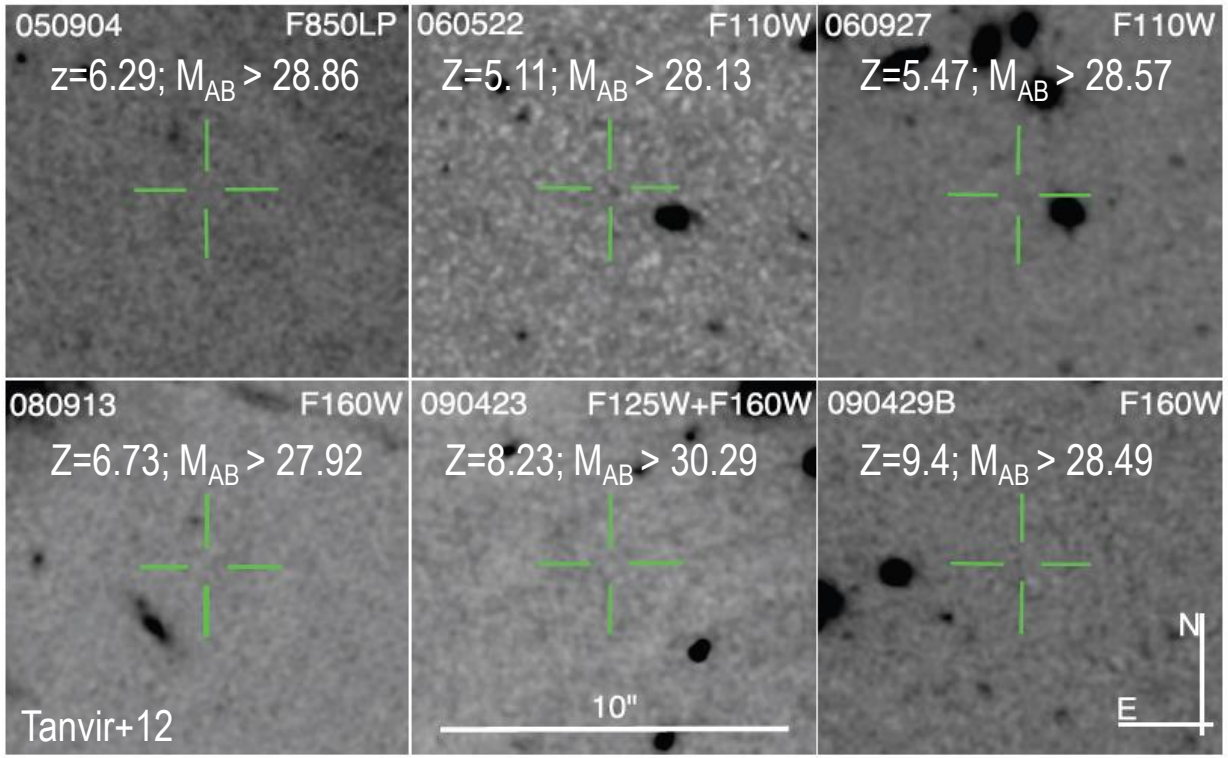
A statistical sample of high–z GRBs can provide fundamental information:

- 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)**





- the number density and properties of **low-mass galaxies**

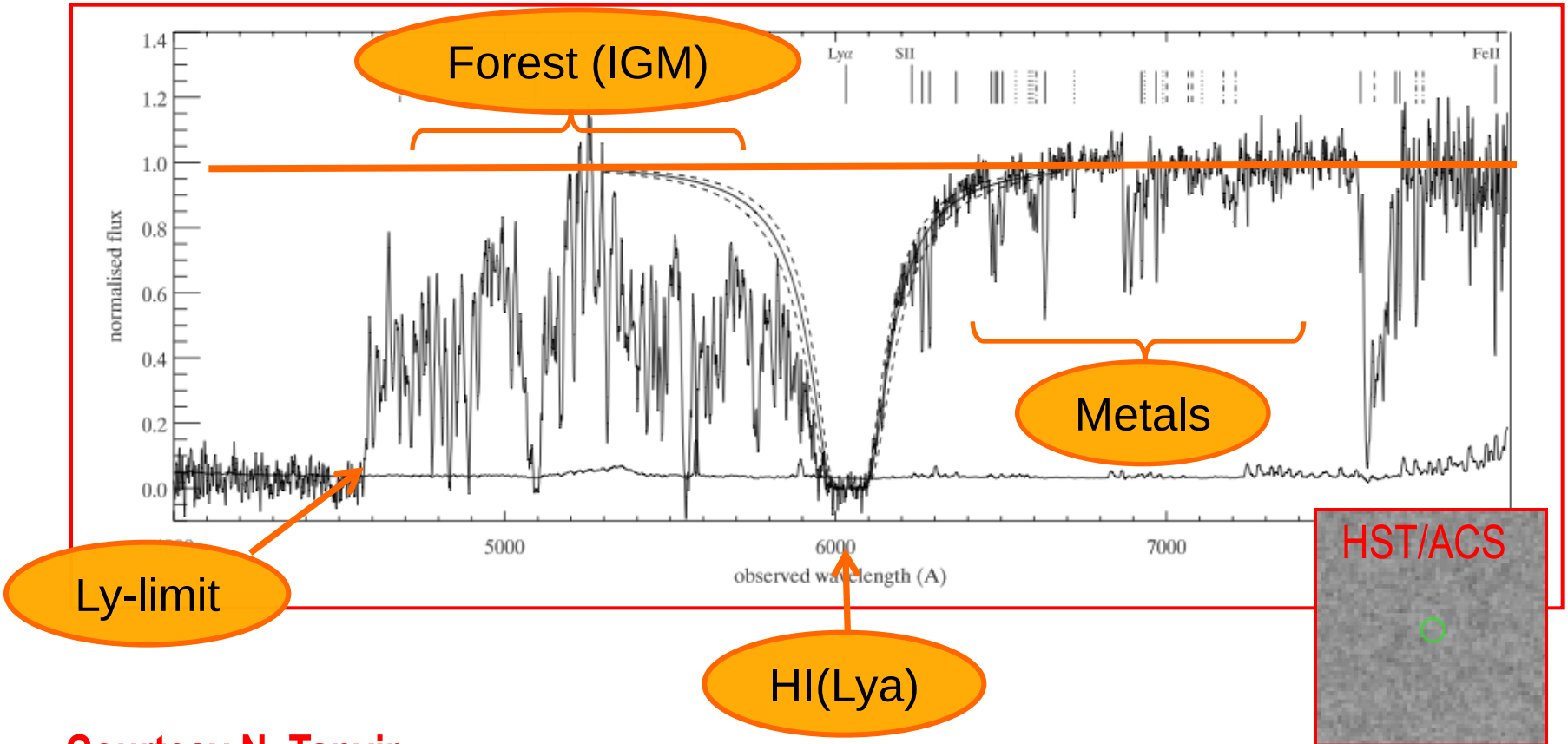


Robertson&Ellis12

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)

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

Abundances, HI, dust, dynamics etc. even for very faint hosts. E.g. GRB 050730: faint host (R>28.5), but z=3.97, [Fe/H]=-2 and low dust, from afterglow spectrum (Chen et al. 2005; Starling et al. 2005).



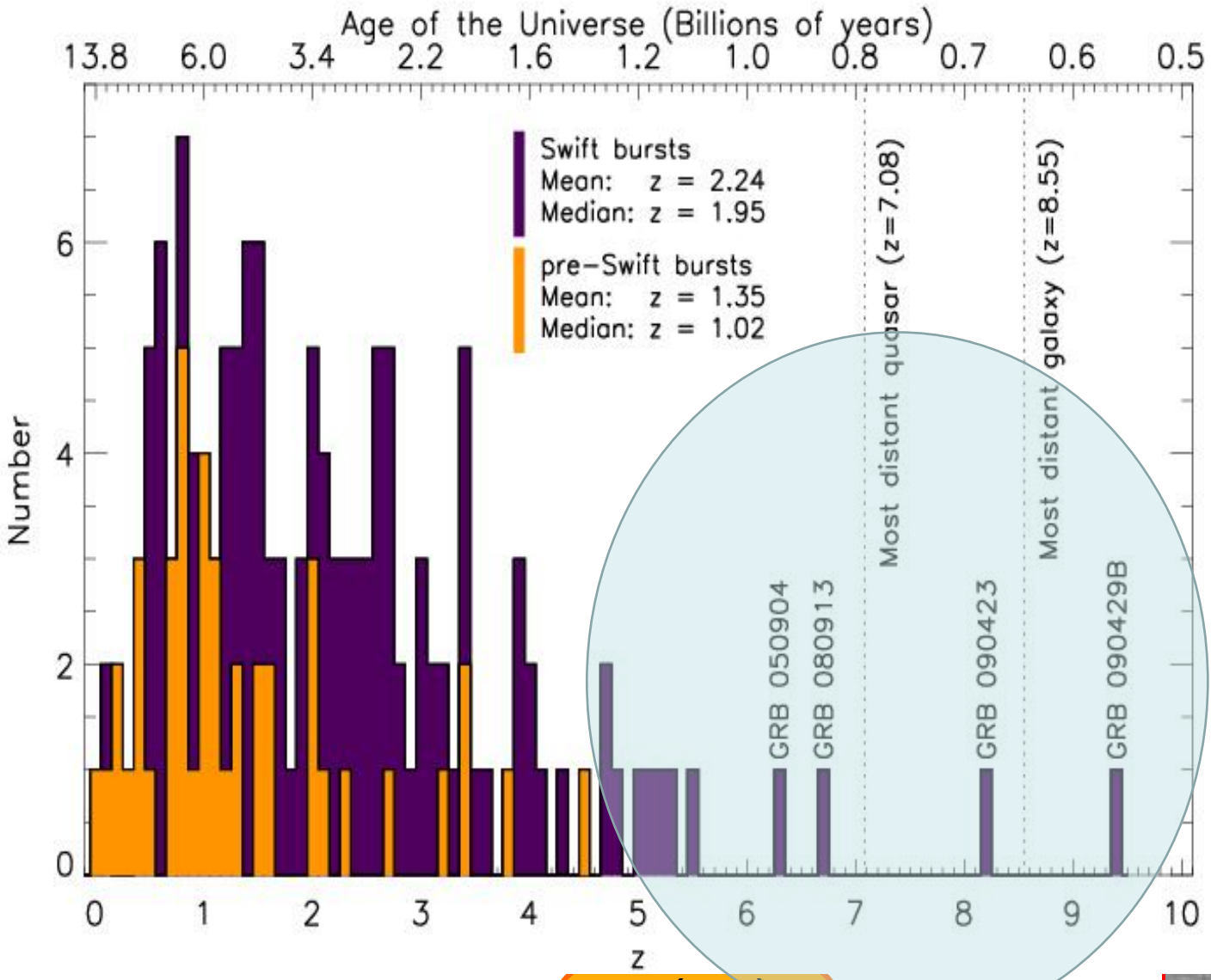
Courtesy N. Tanvir

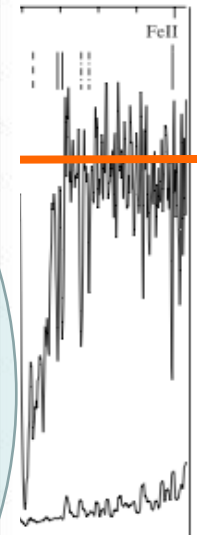
- the neutral hydrogen fraction
- t
- t

Abur
faint
(Che

on

050730:
spectrum





normalised flux

Ly

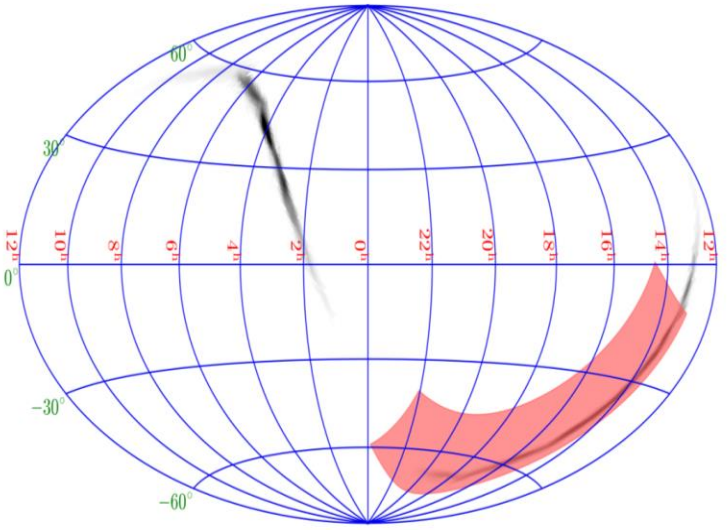
HI(Lya)

ST/ACS

Courtesy N. Tanvir

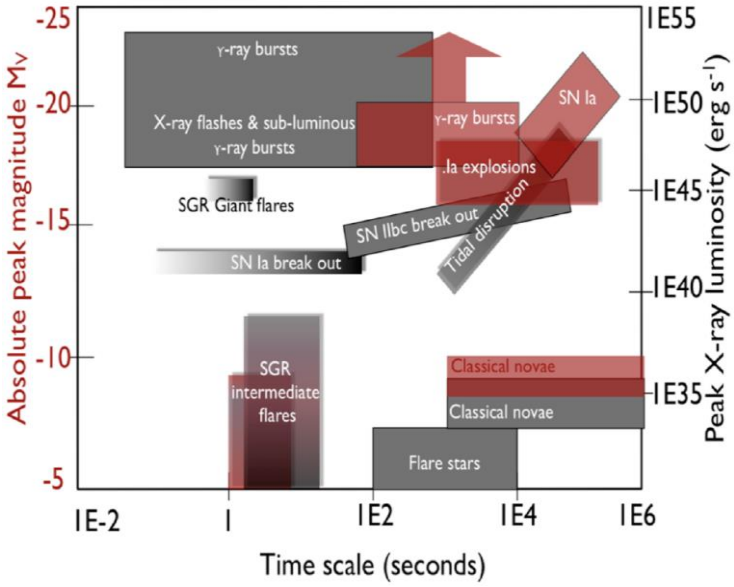
Exploring the multi-messenger transient sky

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

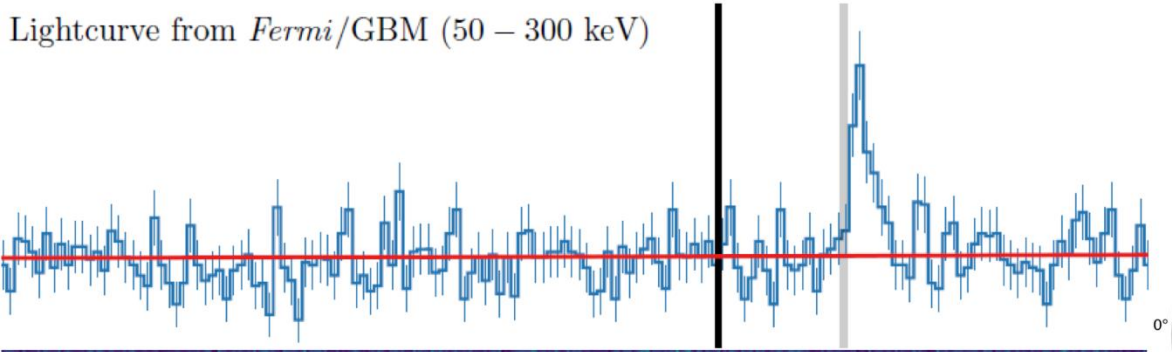


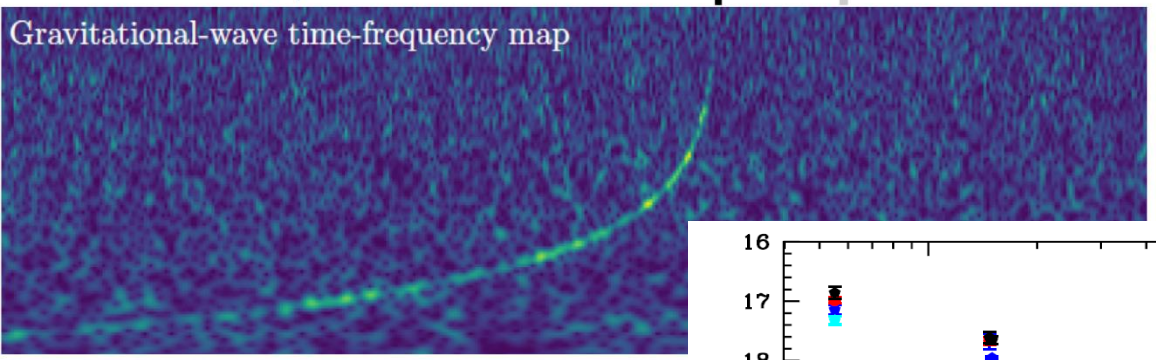
- Provide real-time triggers and accurate (~1 arcmin within a few seconds; ~1'' within a few minutes) **high-energy transients for follow-up with next-generation optical-NIR (E-ELT, JWST if still operating), radio (SKA), X-rays (ATHENA), TeV (CTA) telescopes; synergy with LSST**

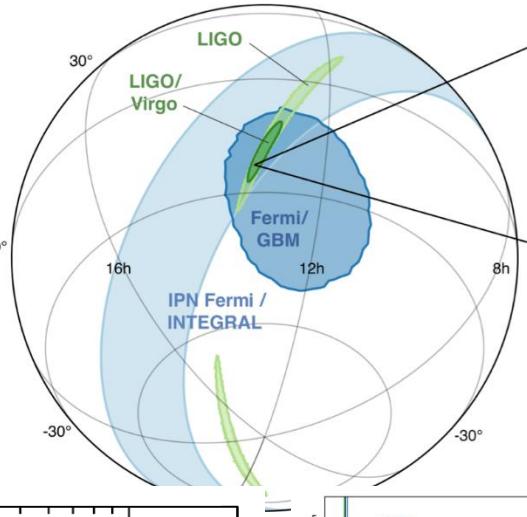
- Provide a fundamental step forward in the comprehension of the physics of various classes of transients and **fill the present gap in the discovery space of new classes of transients events**

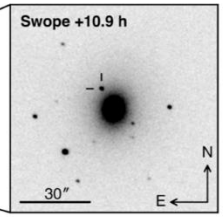


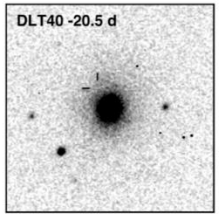
LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars

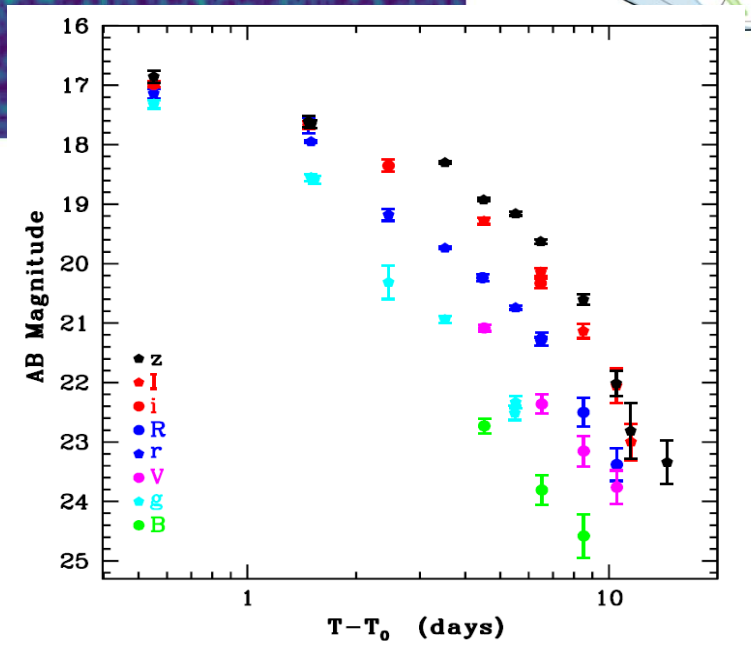


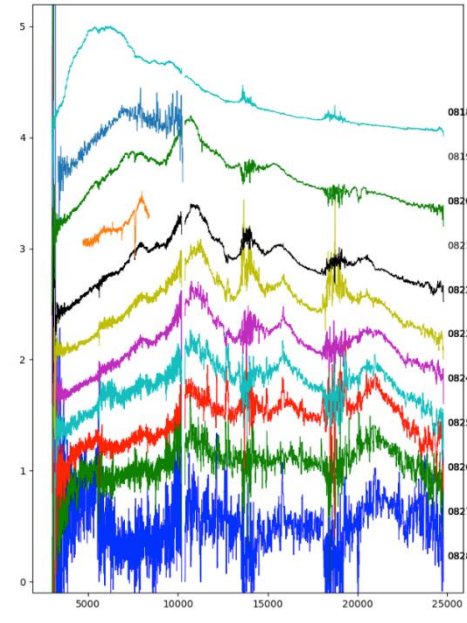




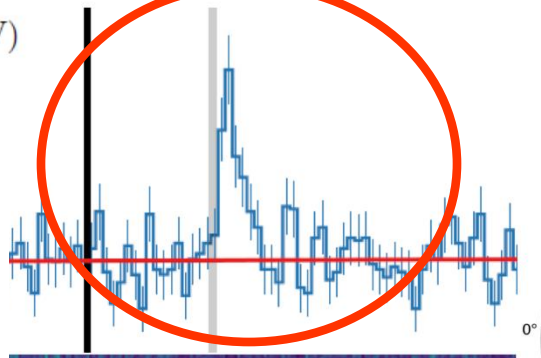






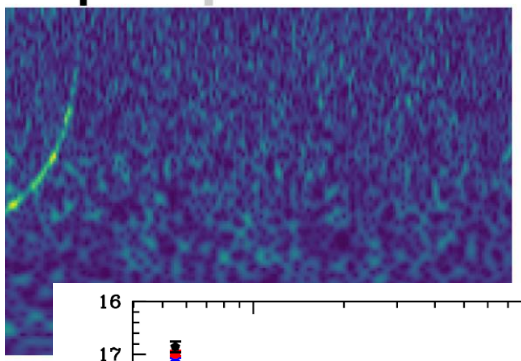


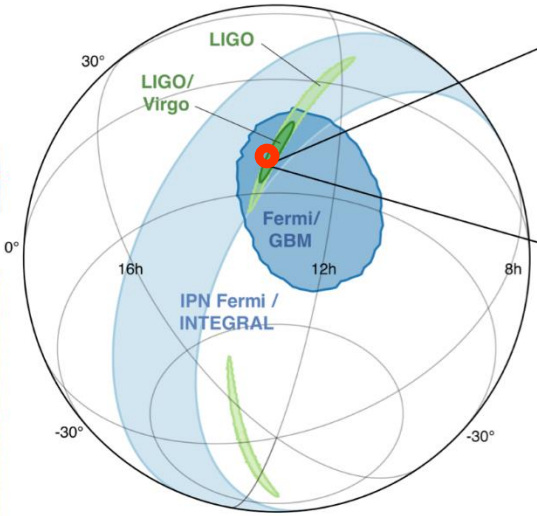
LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars

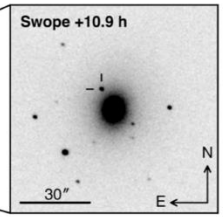


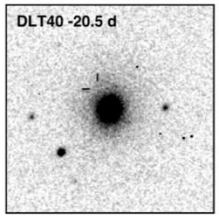
THESEUS:

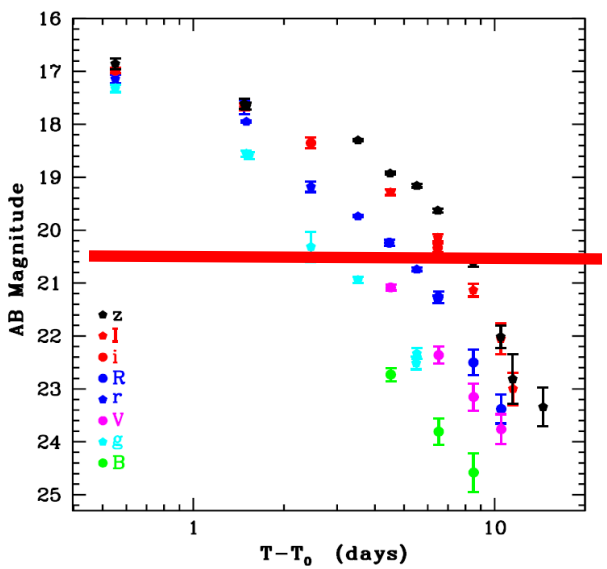
- ✓ **short GRB detection over large FOV with arcmin localization**
- ✓ **Kilonova detection, arcsec localization and characterization**
- ✓ **Possible detection of weaker isotropic X-ray emission**

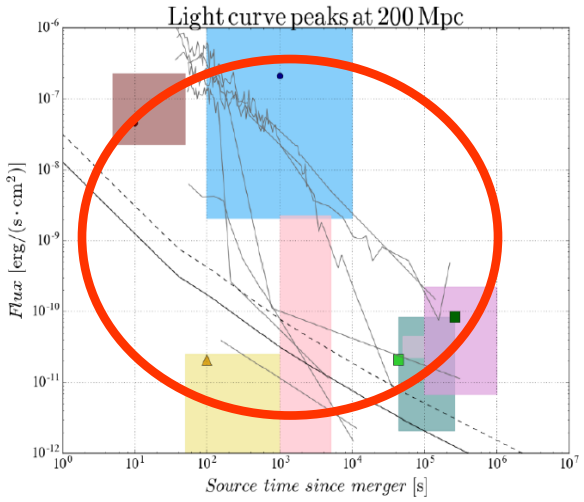






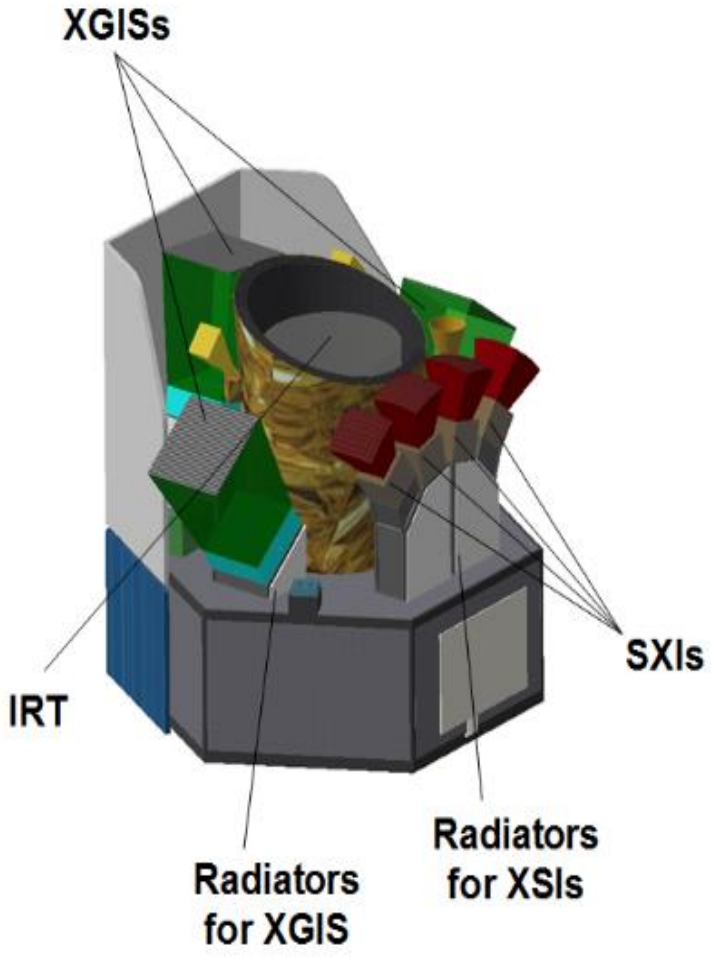






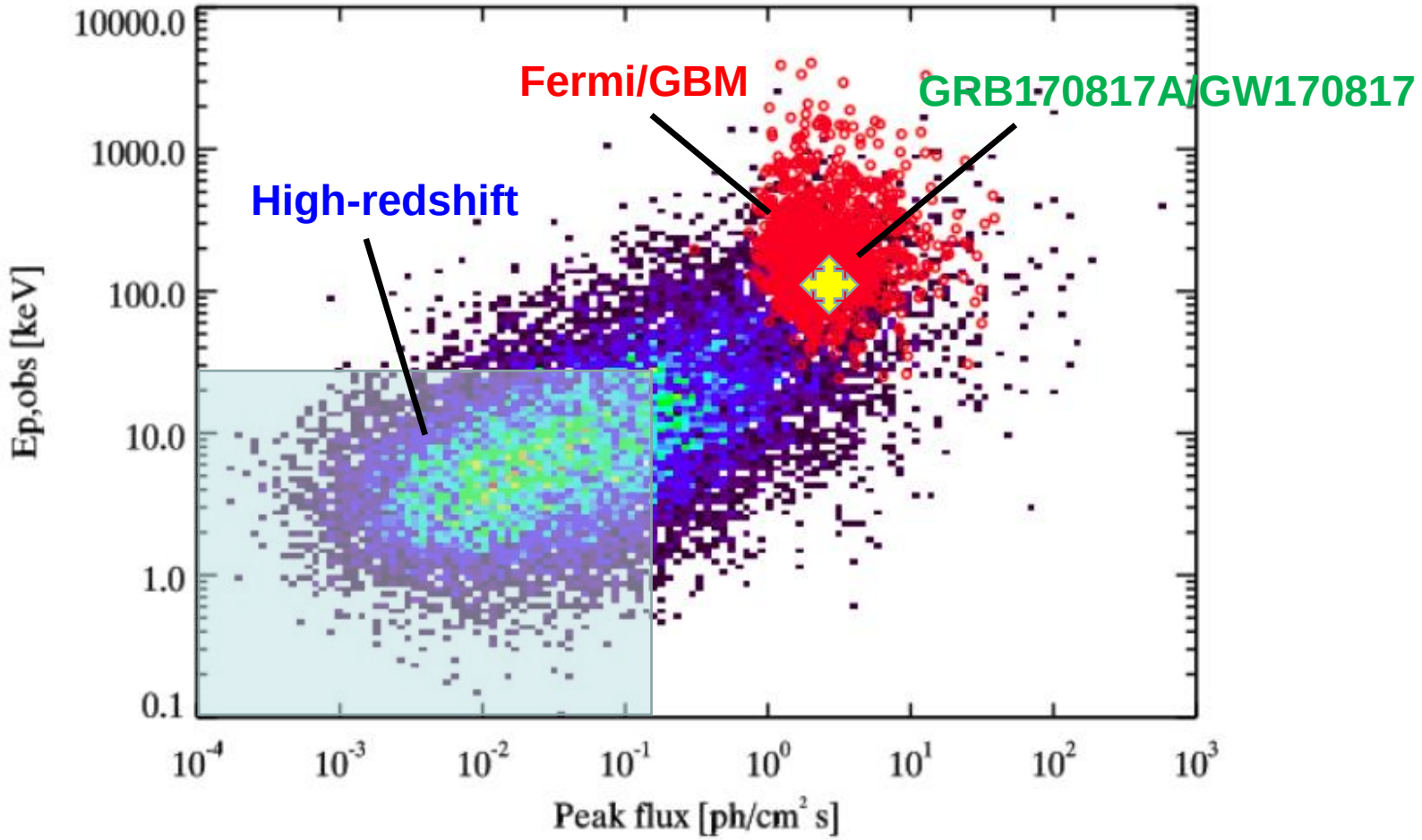
THESEUS mission concept

- **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 bars of Silicon diodes coupled with CsI crystal scintillators observing in **2 keV – 10 MeV band, a FOV of >2 sr, overlapping the SXI, with <15' GRB location accuracy** in 2-150 keV
- **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)**

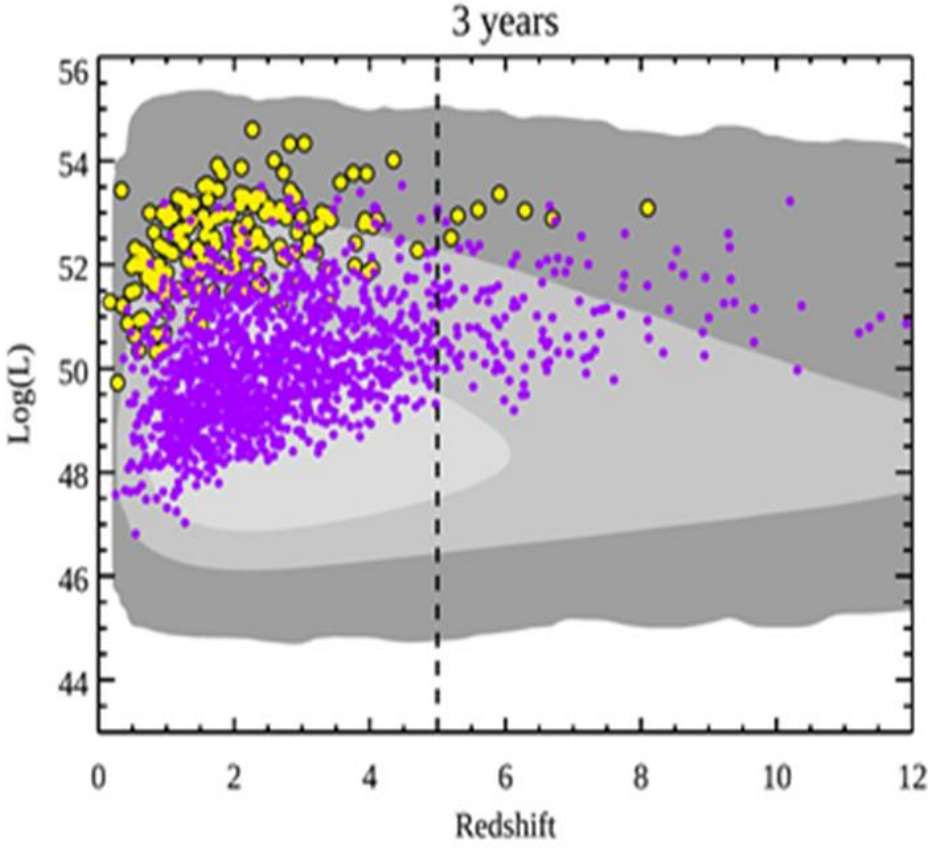


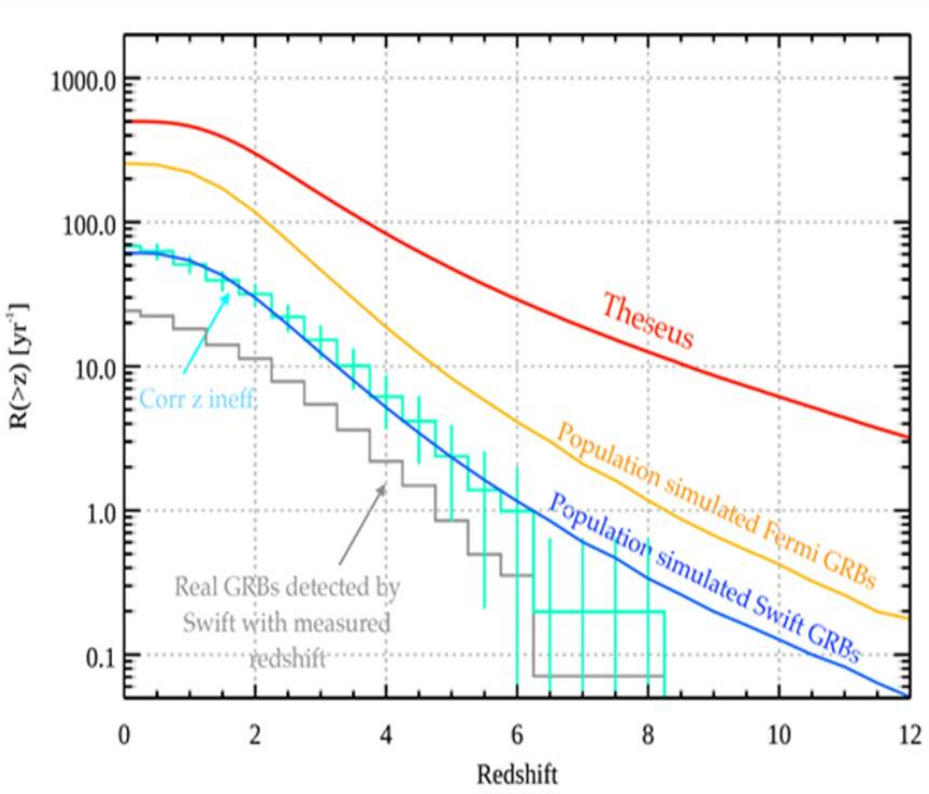
LEO (< 5°, ~600 km)
Rapid slewing bus
Prompt downlink

❑ **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**



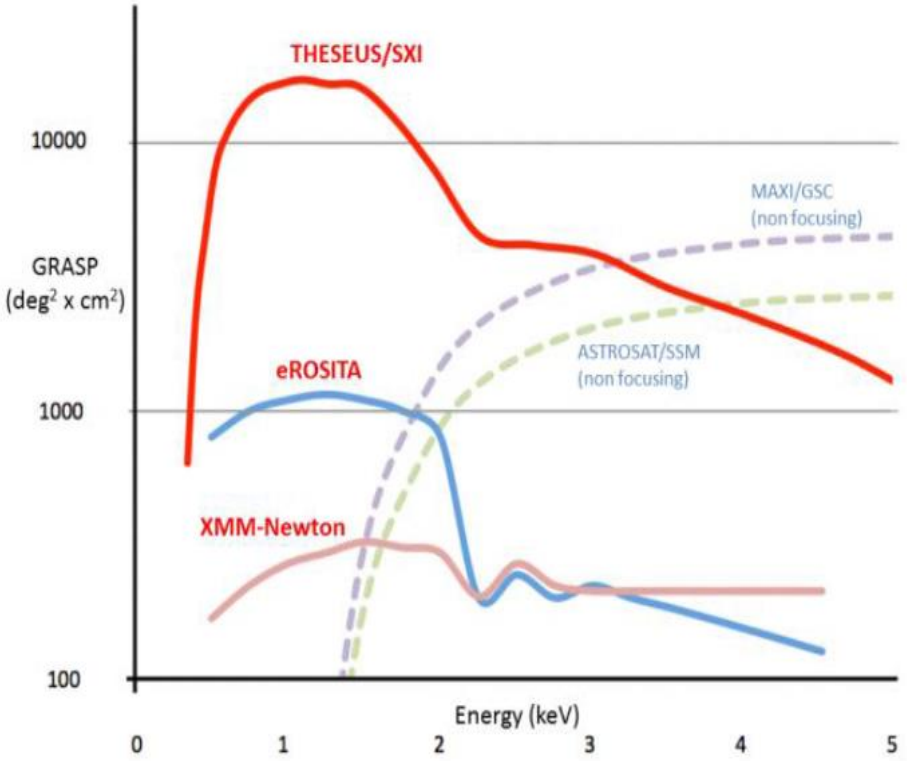
❑ Shedding light on the early Universe with GRBs

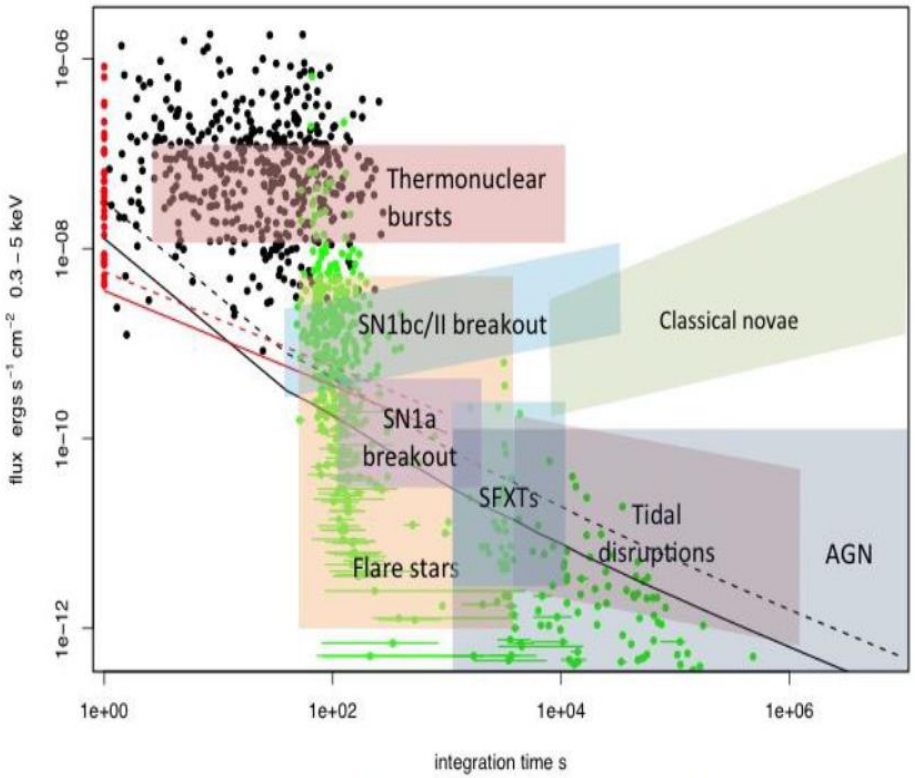




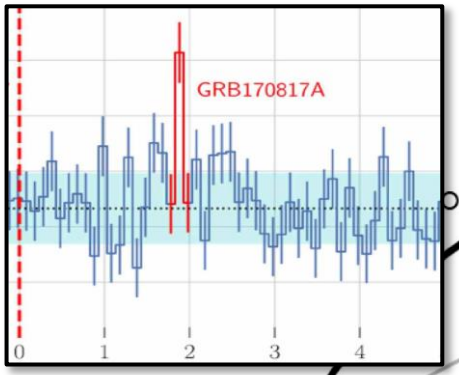
❑ **THESEUS will also detect and localize down to 0.5-1 arcmin the soft X-ray short/long GRB afterglows, of NS-NS mergers and of many classes of galactic and extra-galactic transients**

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

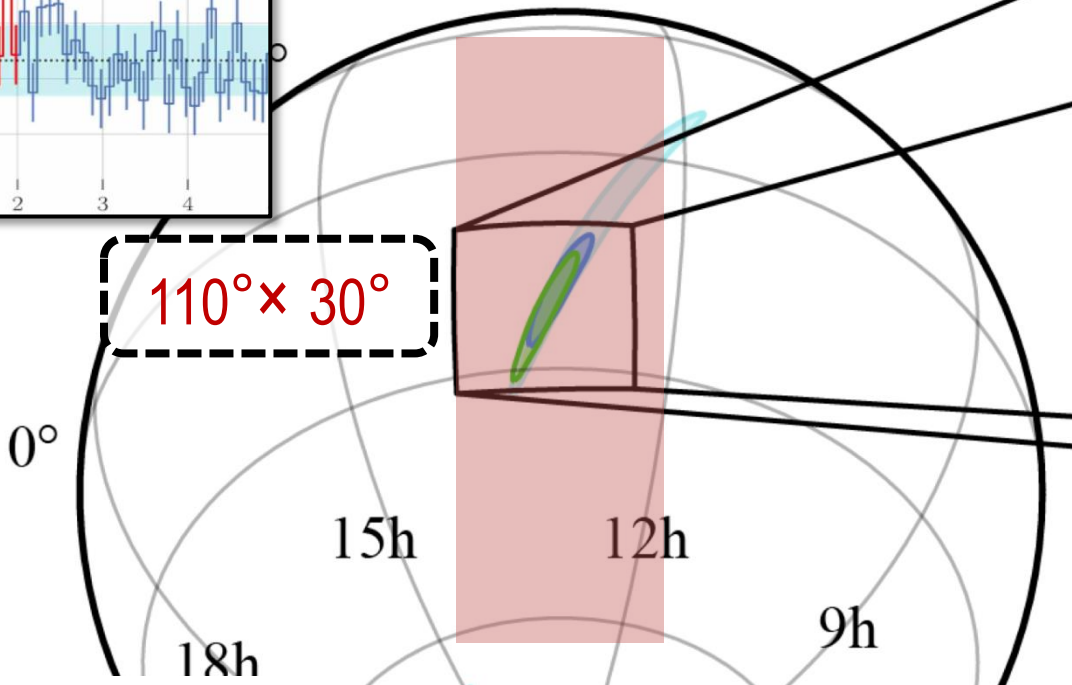


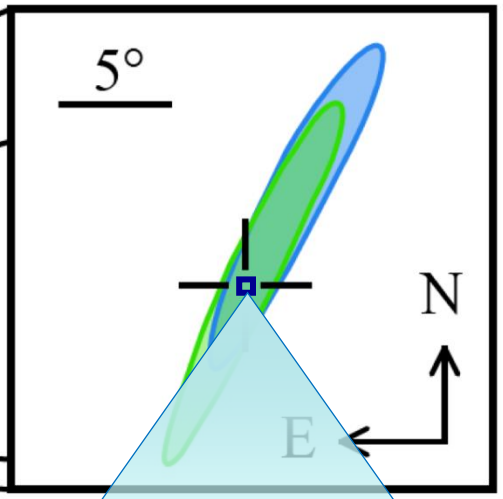


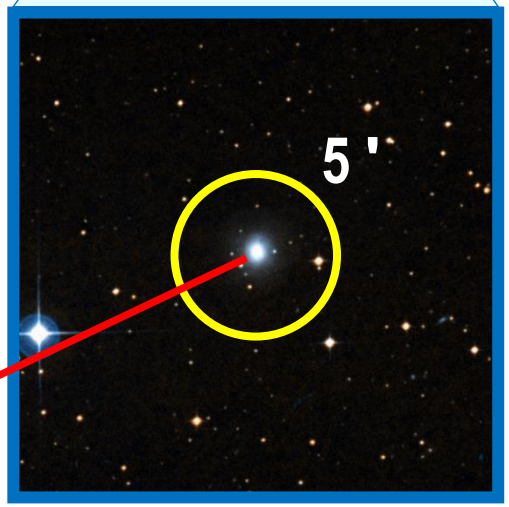
❑ Promptly and accurately localizing e.m. counterparts to GW events with THESEUS

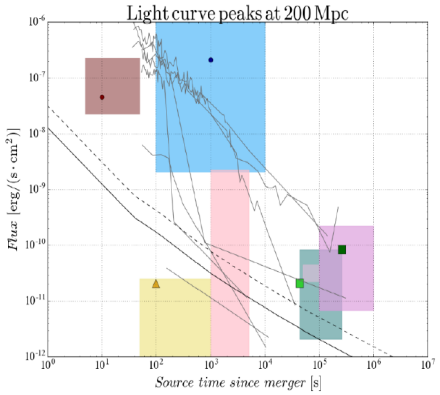


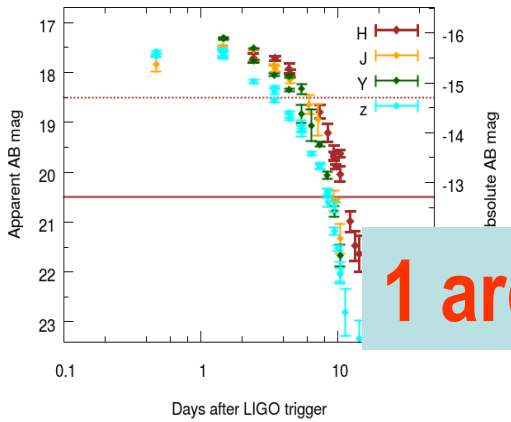
110°× 30°





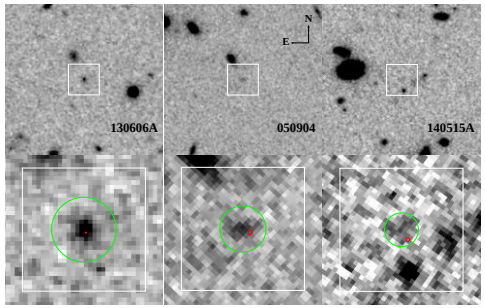




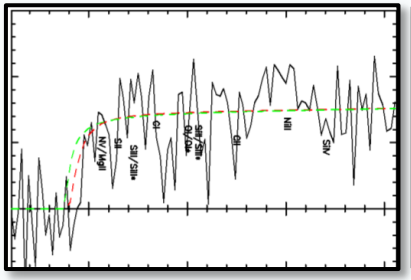


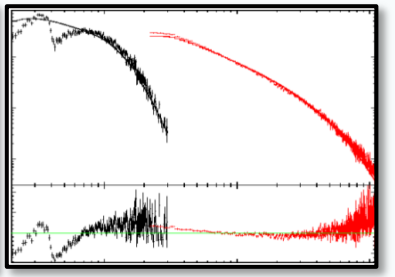
1 arcsec !

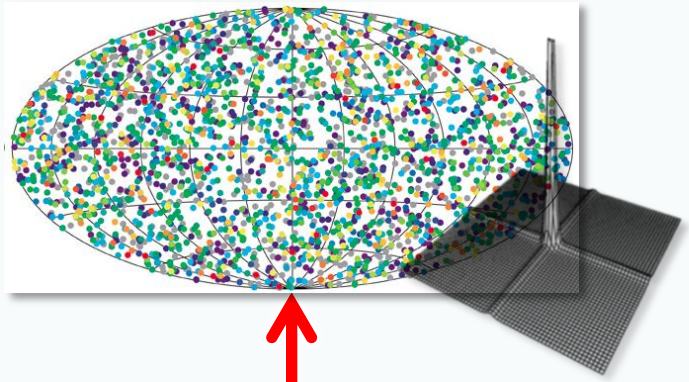
Star formation history, primordial galaxies



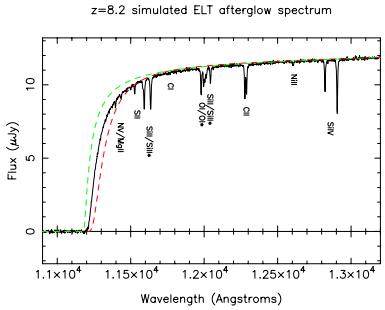
GRB accurate localization and NIR, X-ray, Gamma-ray characterization, redshift



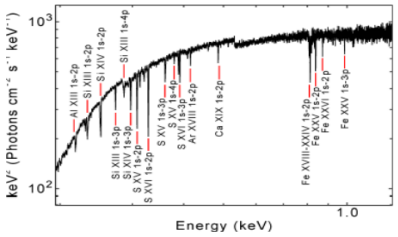




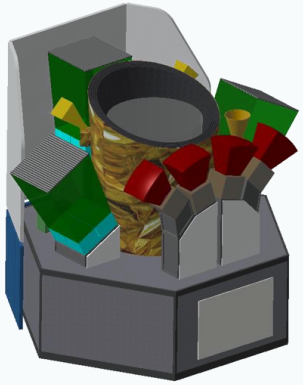
Neutral fraction of IGM, ionizing radiation escape fraction



Cosmic chemical evolution, Pop III



theseus
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

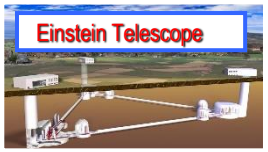


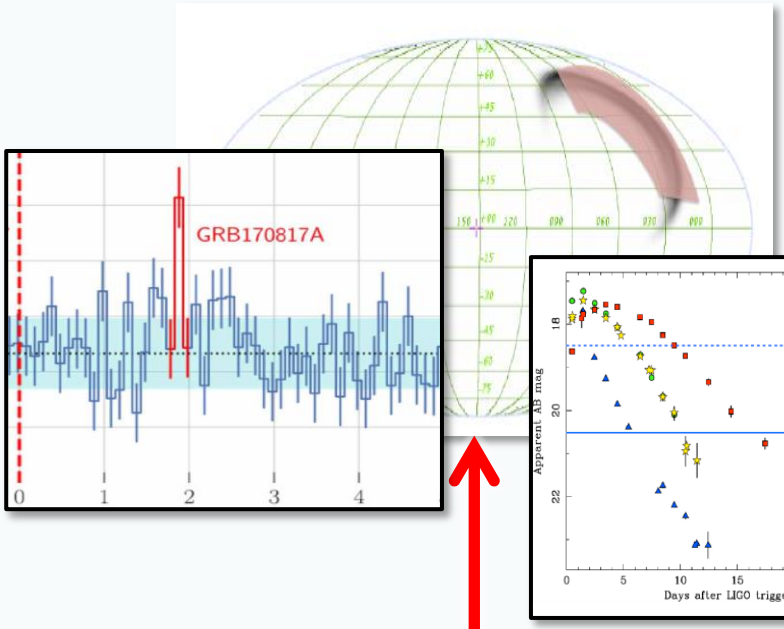
THESEUS SYNERGIES

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





Hubble constant

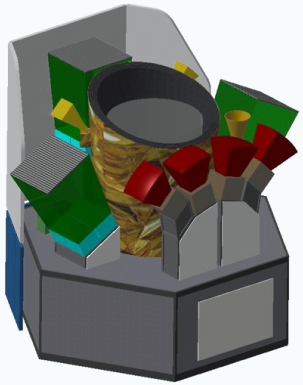
Accretion physics

Jet physics

Star formation

r-process element chemical abundances

theseus
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR



THESEUS SYNERGIES

- ***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**.

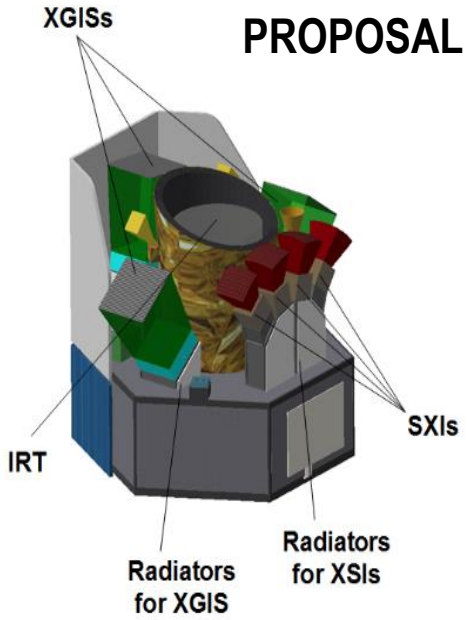
THESEUS ESA study: timeline and status

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

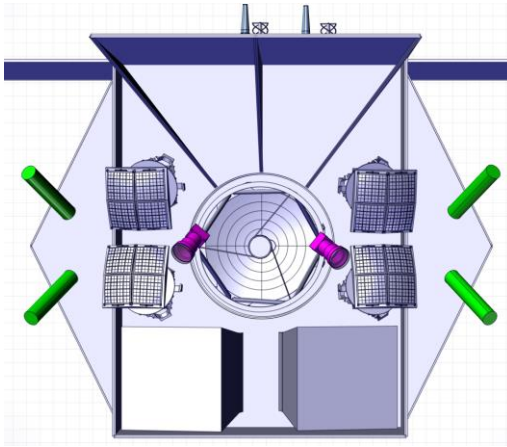
- **Smooth CDF study, successful MDR -> Phase A**
- Efficient and positive interaction between ESA and consortium

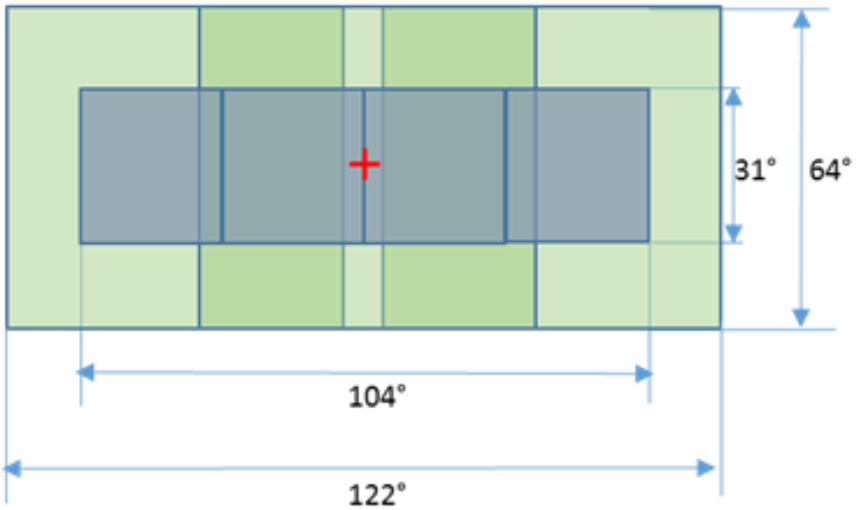
THESEUS mission concept: ESA study

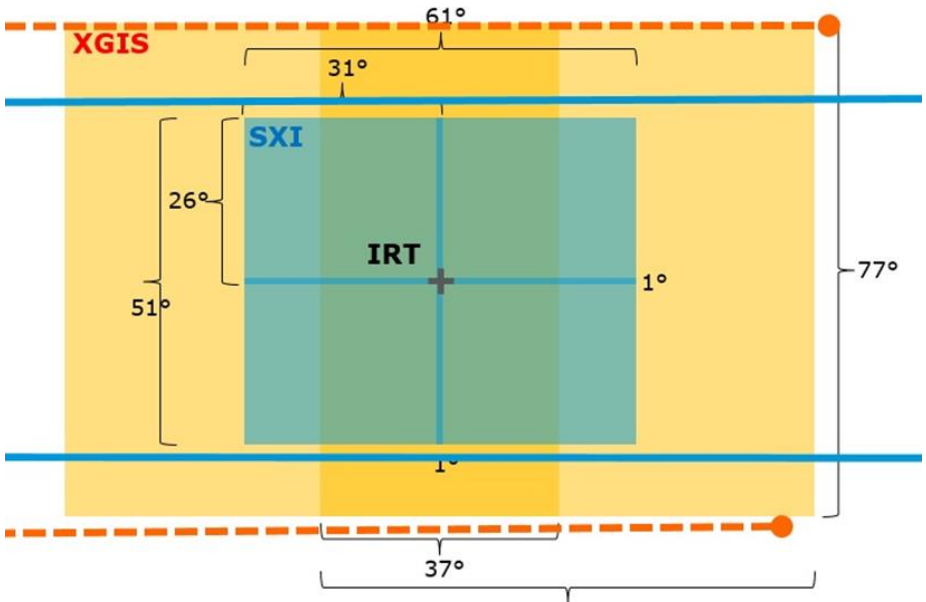
PROPOSAL



CDF STUDY

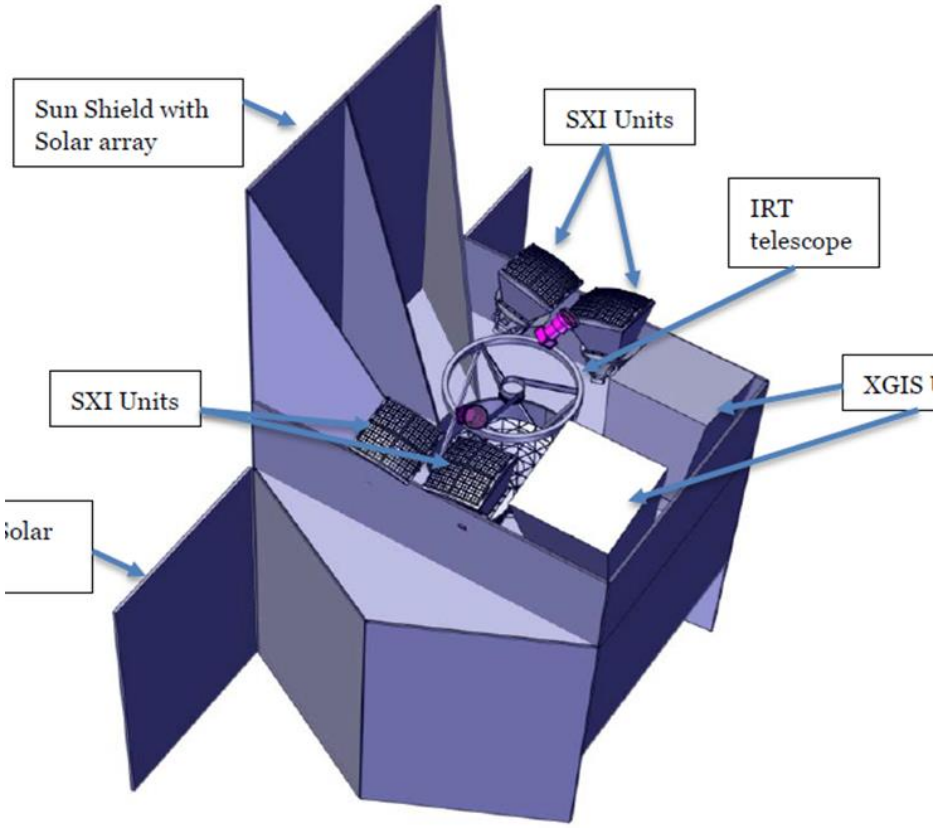






Mission profile and budgets: ESA study

Launch vehicle	VEGA-C (backup Ariane62)
Launch date	2032 (night launch)
Lifetime	Nominal 3 years (consumables fo
Orbit	Circular LEO
Altitude	600 km
Inclination	5.4°
Ground stations	Malindi (backup Kourou) VHF SVOM network
Delta-V	225.8 m/s
Re-entry	Controlled re-entry (4 burns)
Mass	Dry mass w/ margin 1504 kg Wet mass 1702 kg Total (wet + adapter) 1697 kg
Dimensions	Launch conf.: 4.23 m x 3.02 m Deployed conf.: 4.23 m x 4.40 m
Payload	1x InfraRed Telescope (IRT) 2x X-Gamma-rays Imaging Spectr 4x Soft X-ray Imager (SXI) 2x Radiation monitors



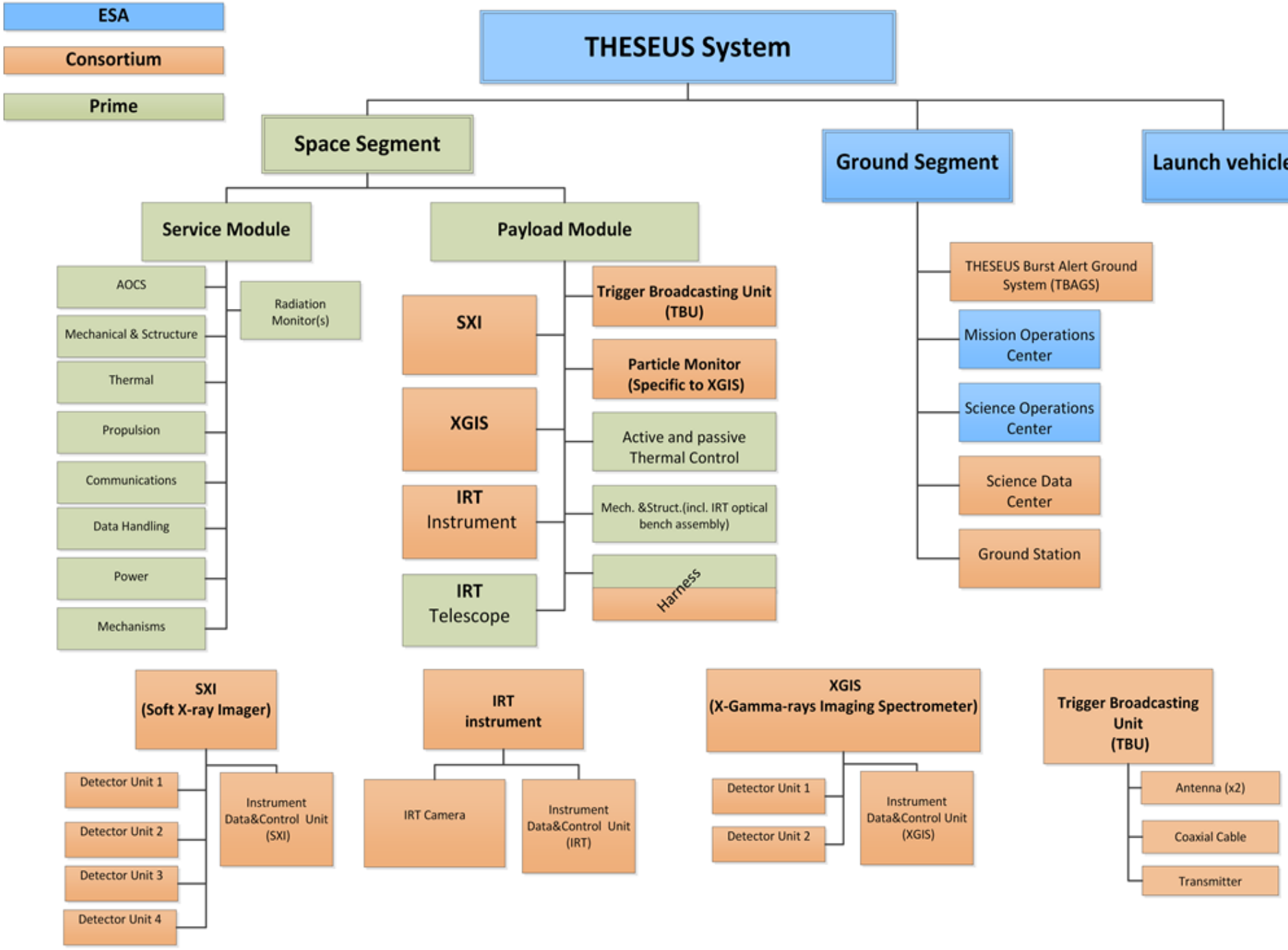
THESEUS Phase A Industrial studies (milestones)

- ITT release to Industry: March 2019
- KO of THESEUS TAS-I Industrial Study: June 2019
- KO of THESEUS Airbus Industrial Study: July 2019
- **Mission Consolidation Review (MCR)**
  - **Payload MCR KO: 15st February 2020**
  - **Spacecraft MCR KO: 15th March 2020**
- Mission Selection Review (MSR)
  - KO: 15th February 2021
  - Duration: 2 months

May 2020: THESEUS successfully passed the MCR, a main achievement of the study, thanks to the great efforts to the Consortium and ESA teams!

Study status – now in Phase A2

- ITT release to Industry: March 2019
- KO of THESEUS TAS-I Industrial Study: June 2019
- KO of THESEUS Airbus Industrial Study: July 2019
- Mission Consolidation Review (MCR)
- Consortium Prime I/F meetings
- **Mission Selection Review (MSR)**
  - PL MSR DP: TBD Jan. 2021
  - PL panel starts earlier than system
  - Total Duration: 3 months
- M5 selection at June SPC


ESA
Consortium
Prime
THESEUS System
Space Segment
Ground Segment
Launch vehicle
Service Module
Payload Module
AOCS
Mechanical & Sctructure
Thermal
Propulsion
Communications
Data Handling
Power
Mechanisms
Radiation Monitor(s)
SXI
XGIS
IRT Instrument
IRT Telescope
Trigger Broadcasting Unit (TBU)
Particle Monitor (Specific to XGIS)
Active and passive Thermal Control
Mech. &Struct.(incl. IRT optical bench assembly)
Harness
THESEUS Burst Alert Ground System (TBAGS)
Mission Operations Center
Science Operations Center
Science Data Center
Ground Station
SXI (Soft X-ray Imager)
Detector Unit 1
Detector Unit 2
Detector Unit 3
Detector Unit 4
Instrument Data&Control Unit (SXI)
IRT instrument
IRT Camera
Instrument Data&Control Unit (IRT)
XGIS (X-Gamma-rays Imaging Spectrometer)
Detector Unit 1
Detector Unit 2
Instrument Data&Control Unit (XGIS)
Trigger Broadcasting Unit (TBU)
Antenna (x2)
Coaxial Cable
Transmitter

THESEUS payload consortium

Italy: responsibility of XGIS (design, detection plane procurements and assembly, electronics, integration, testing, simulations, calibrations, s/w), responsibility of Trigger Broadcasting Unit (TBU), Malindi ground station (ASI inkind).

UK: responsibility of SXI (design, detection plane assembly, optics procurement and assembly (TBD), electronics, integration, testing, simulations, calibrations, s/w).

France: responsibility of IRT (optical design of the telescope; IRT instrument including the focal plane assembly, electronics, integration, testing, simulations, calibrations, s/w); Theseus Burst Alert Ground Segment (including the CNES VHF Network system and the Burst Alert Centre).

Germany: overall responsibility of instruments data handling (DHU) systems (design, hardware, software).

Switzerland: Science Data Center (s/w, data processing, pipelines, quick-look), IRT filter wheel.

ESA P/L contribution: IRT telescope & cooling system, IRT detectors, SXI detectors

Denmark: specific responsibility of XGIS DHU hardware and software.

Poland : XGIS power-supply units.

Belgium: contribution to SXI integration and tests.

Czech Rep.: contribution to SXI echanical structures and thermal control.

Slovenia: investigation of optional X-band mobile ground stations.

Possible further contributions (TBD after Phase A): Ireland (contribution to XGIS detectors ar
IRT on-board s/w), **Hungary** (contribution to spacecraft interface simulator, data-handling syst
IRT calirations)

In summary

- **THESEUS, submitted to ESA/M5 by a large European collaboration with strong interest by international partners (e.g., US) 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 sub-classes.**
- **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 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)**

- **AHEAD2020 support to THESEUS: WP11.4 / JRA3 «Future missions - beyond the baseline»** (e.g., XGIS & IRT calibrations, workshop) + **JRA2** (SXI optics, testing), **JRA6** (s/w for transients trigger and identification), etc. (talk by C. Labanti on AHEAD XGIS)