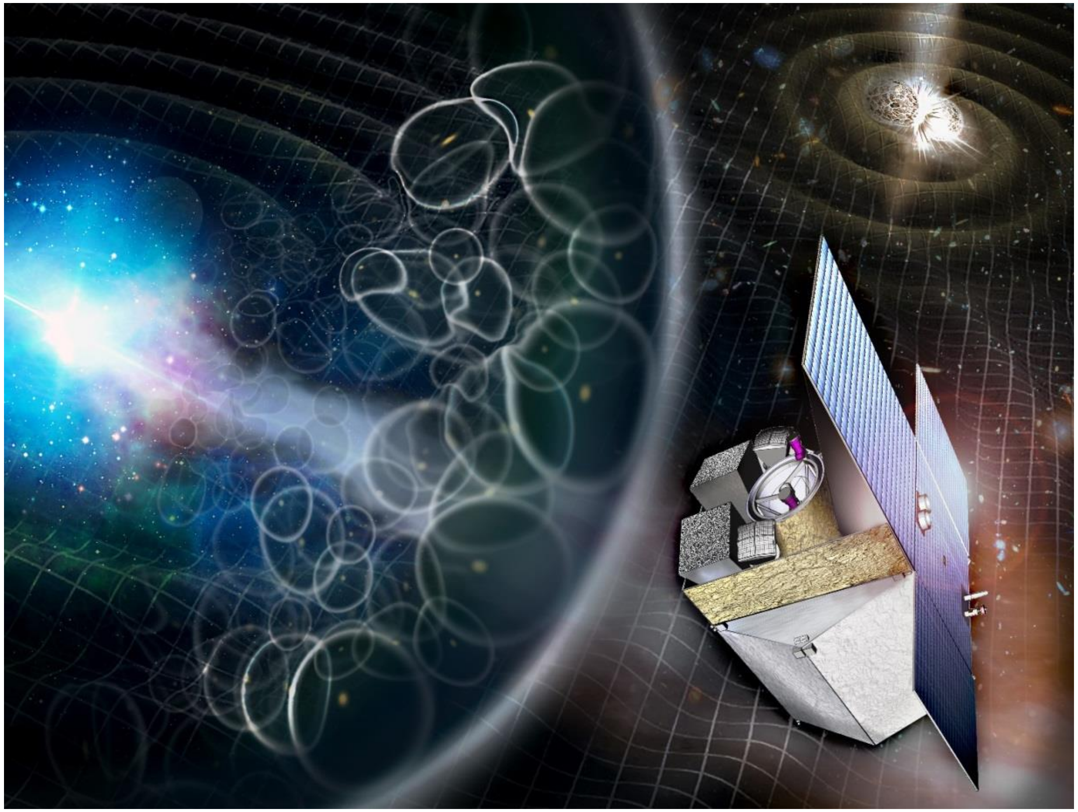
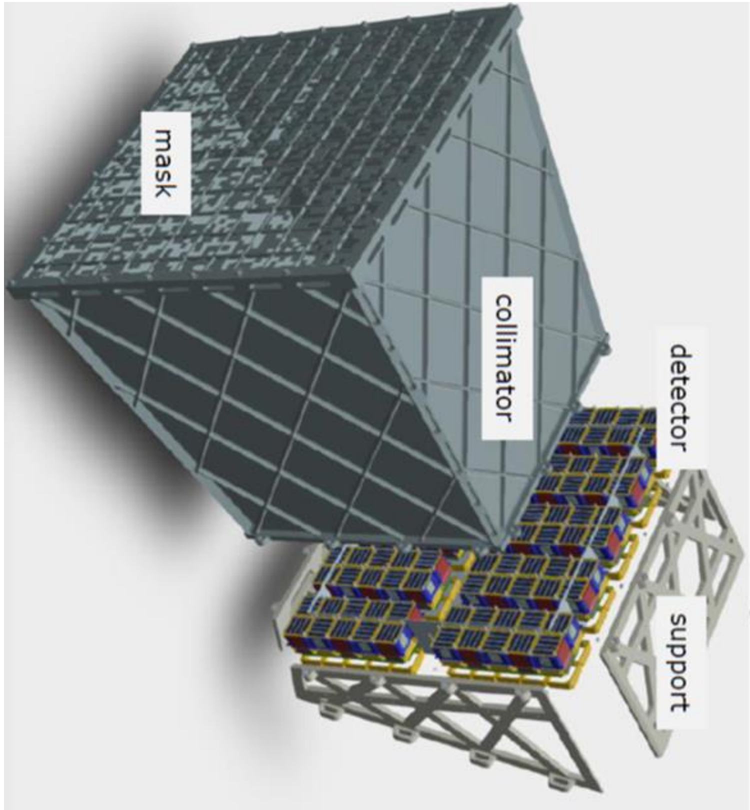
The THESEUS mission and the XGIS instrument

Transient High-Energy Sky and Early Universe Surveyor





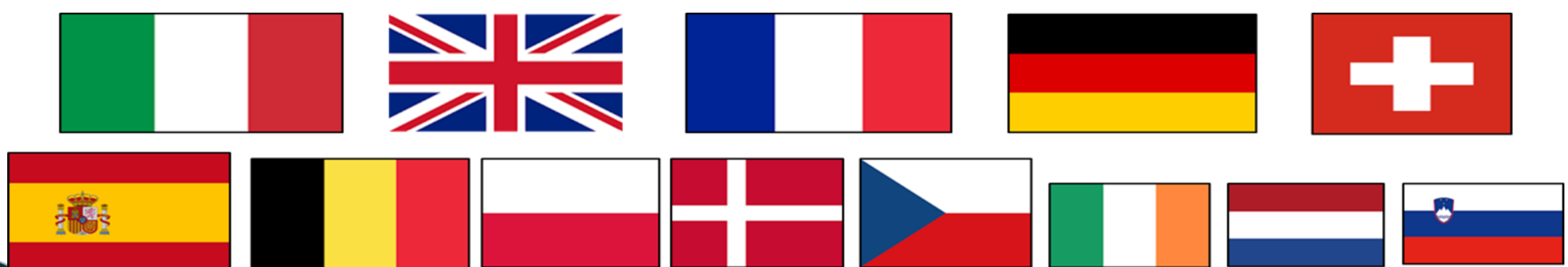
L. Amati & C. Labanti (INAF – OAS Bologna) on behalf of the Italian THESEUS Collaboration– INAF RSN5, May 17th 2021)

THESEUS FOR ESA/M5 (COSMIC VISION)

Lead Proposer: L. Amati (INAF Bologna, Italy)

Coordinators: P. O'Brien (Univ. Leicester, UK), D. Gotz (CEA-Paris, France), A. Santangelo (Univ. Tuebingen, D), E. Bozzo (Univ. Genève, CH)

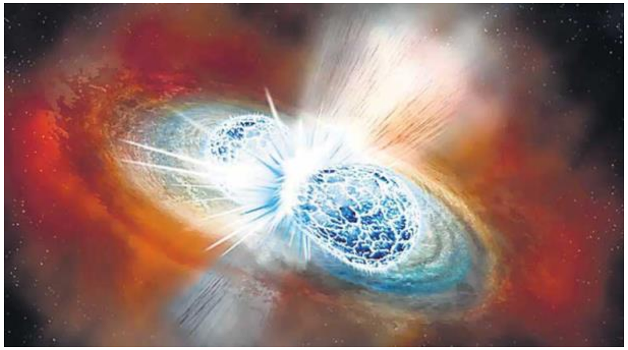
Payload consortium: Italy, UK, France, Germany, Switzerland, Spain, Poland, Denmark, Belgium, Czech Republic, Slovenia, Ireland, The Netherlands



THESEUS CORE SCIENCE GOALS

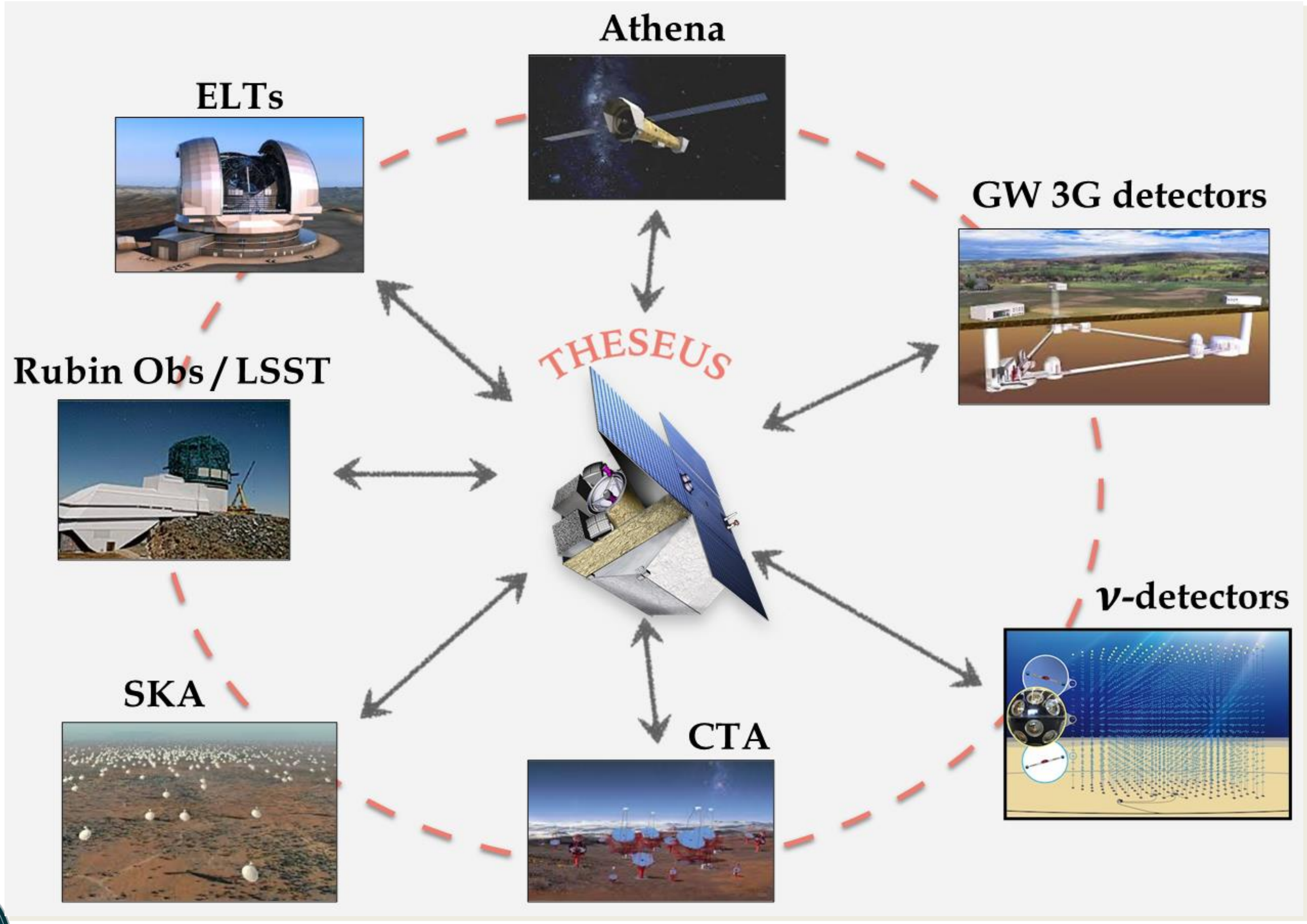
THESEUS will open a new window on the early Universe through **high-redshift** Gamma-Ray Bursts

THESEUS will be a cornerstone of **multi-messenger and time domain** astrophysics

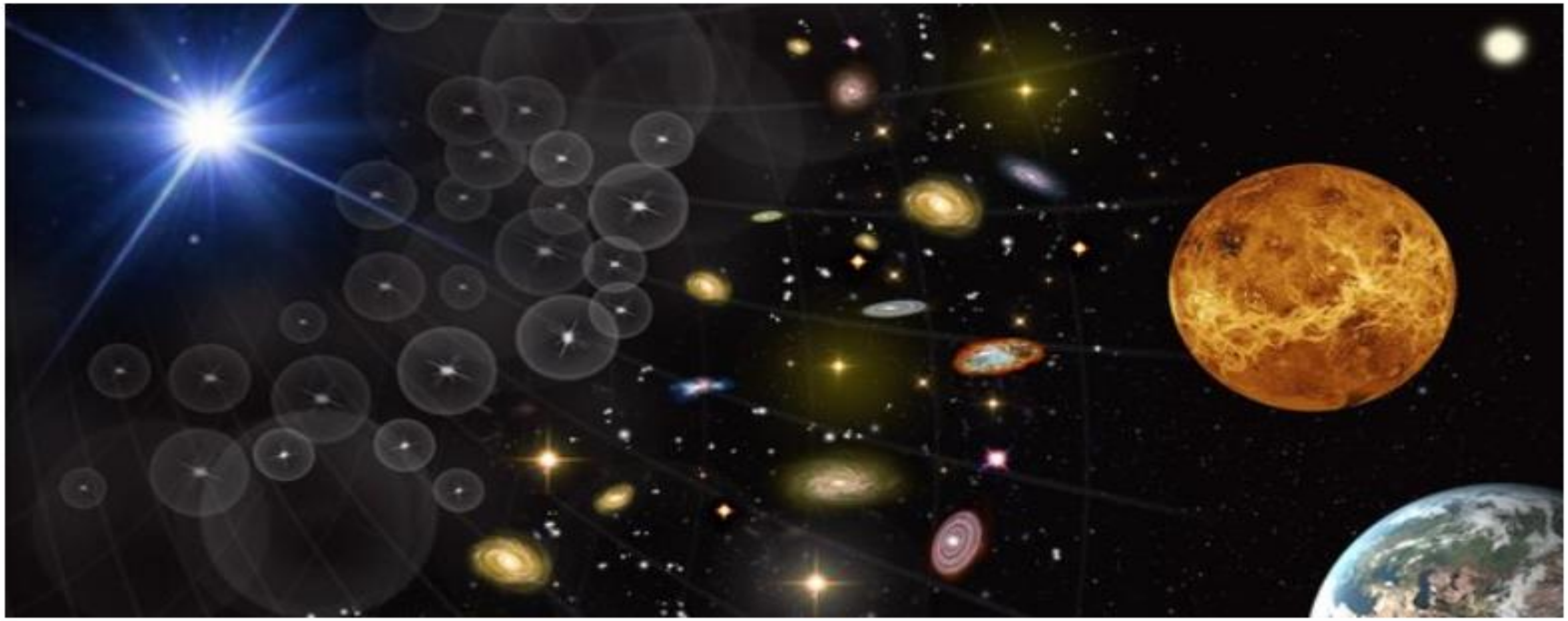


Amati et al. 2018 (Adv.Sp.Res., arXiv:1710.04638)
Stratta et al. 2018 (Adv.Sp.Res., arXiv:1712.08153)
Articles for SPIE 2020 and Epxerim.Astr. (all on arXiv)
http://www.isdc.unige.ch/theseus

THESEUS CRUCIAL SYNERGIES



THESEUS 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

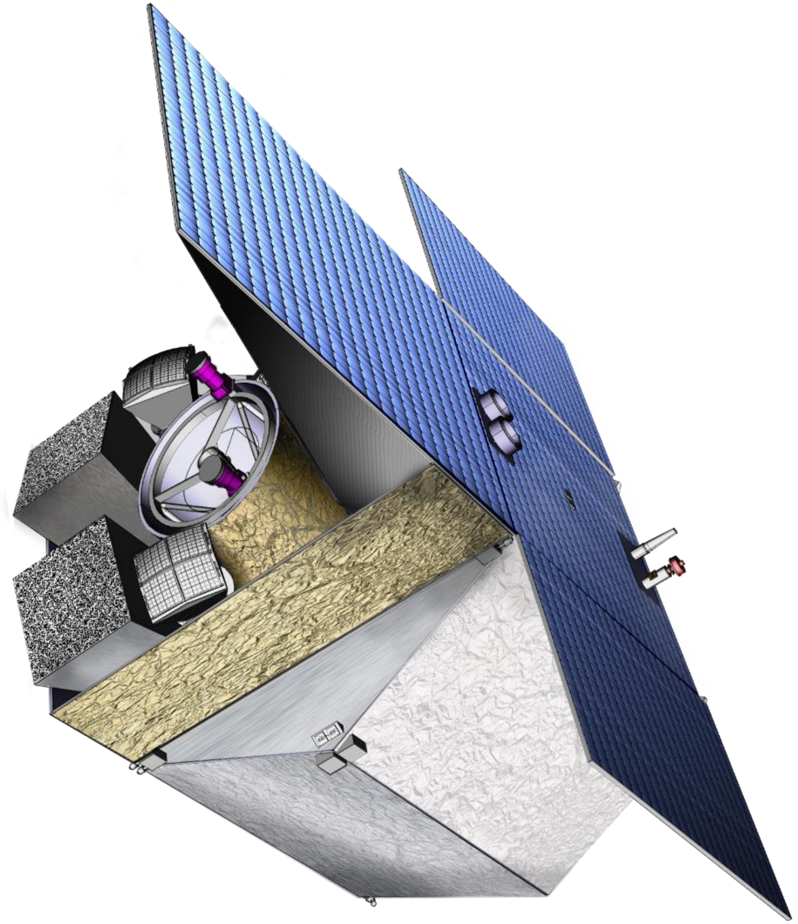
ESA milestones for M5

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 May 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)	October 2023
SPC adoption of M5 mission	January 2024
Phase B2/C/D kick-off	June 2025
Launch	2032

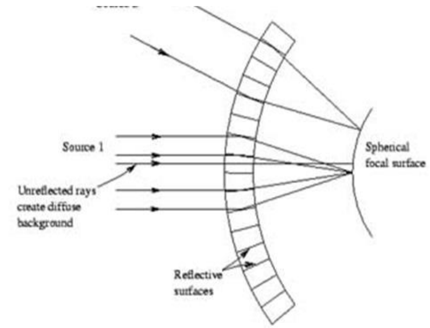
THIS BREAKTHROUGH WILL BE ACHIEVED BY A MISSION CONCEPT OVERCOMING MAIN LIMITATIONS OF CURRENT FACILITIES

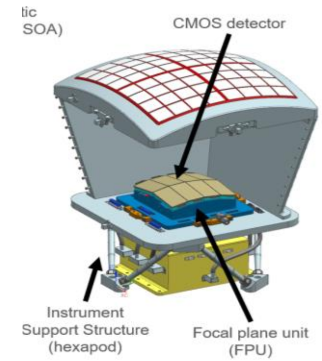
Set of innovative wide-field monitors with **unprecedented combination of broad energy range, sensitivity, FOV and localization accuracy**

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

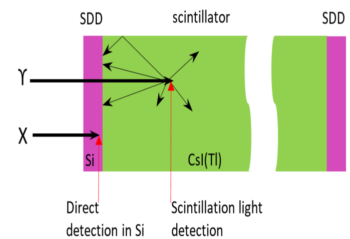


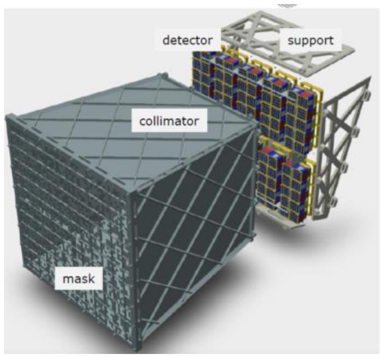
- **Soft X-ray Imager (SXI):** a set of two sensitive lobster-eye telescopes observing in 0.3 - 5 keV band, total FOV of ~0.5sr with source location accuracy <2′



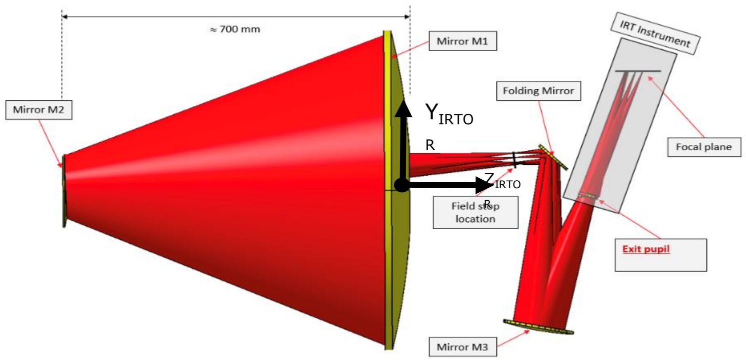


- **X-Gamma rays Imaging Spectrometer (XGIS):** 2 coded-mask X-gamma ray cameras using Silicon drift detectors coupled with CsI crystal scintillator bars observing in 2 keV – 10 MeV band, a FOV of >2 sr, overlapping the SXI, with <15′ GRB location accuracy



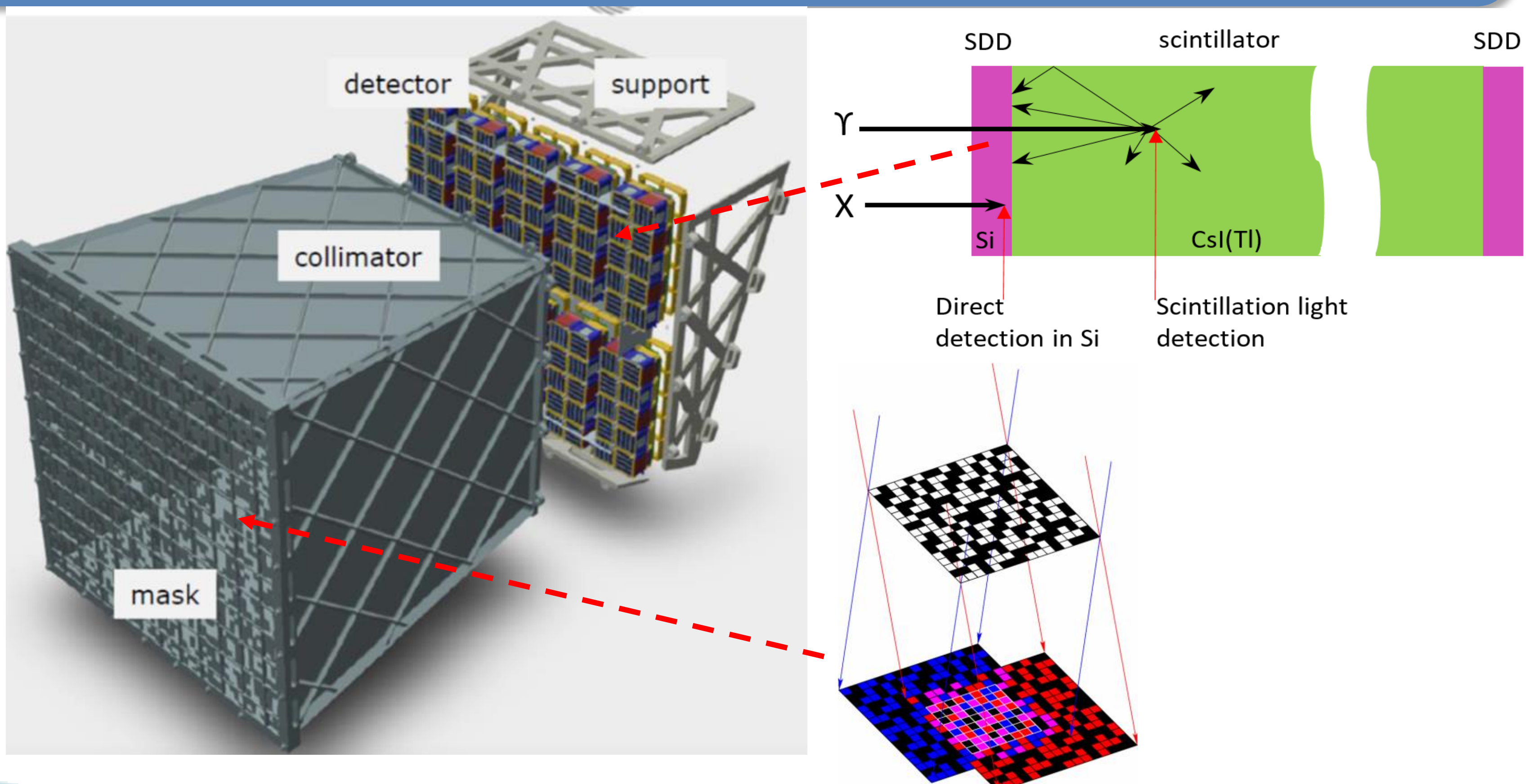


- **InfraRed Telescope (IRT):** a 0.7m class IR telescope observing in the 0.7 – 1.8 μm band, providing a 15′x15′ FOV, with both imaging and moderate resolution spectroscopy capabilities



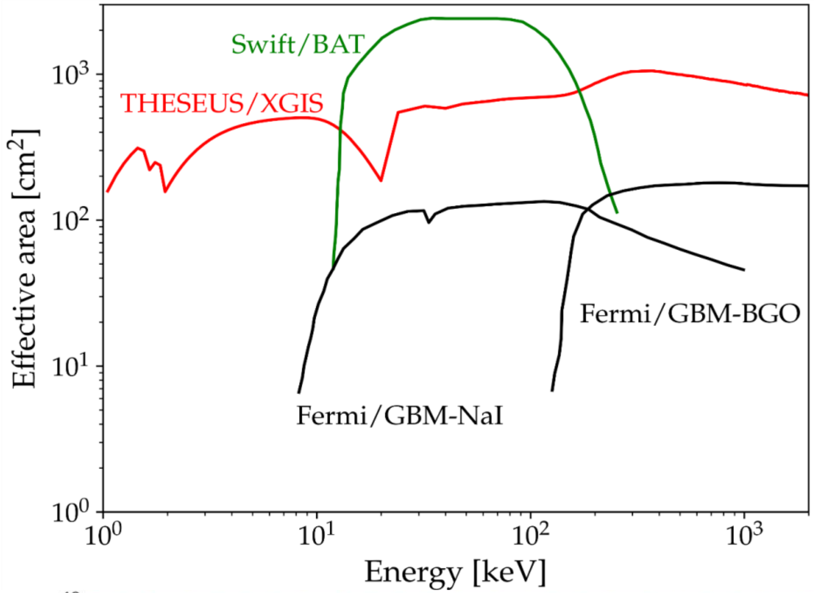
The X-Gamma Ray Imaging Spectrometer (XGIS)

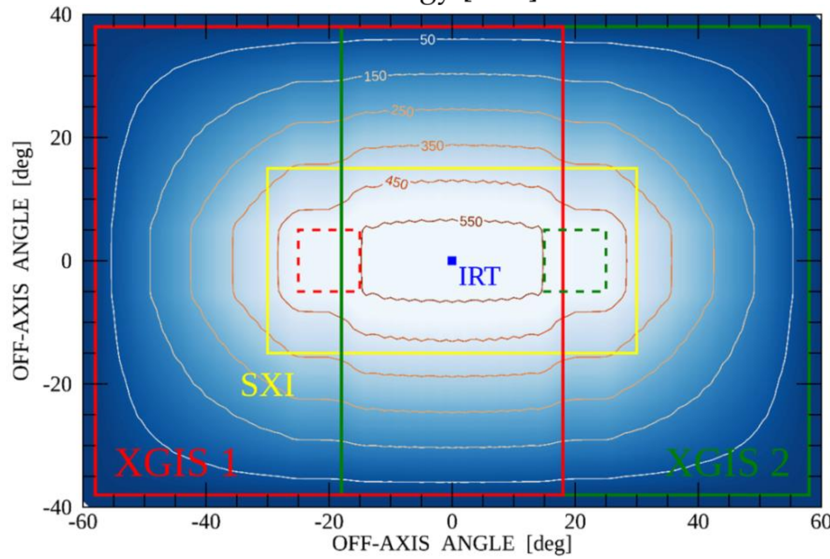
Two coded-mask X-gamma ray cameras using innovative coupling between Silicon drift detectors (2-30 keV) and CsI crystal scintillator bars (20 keV–10 MeV)



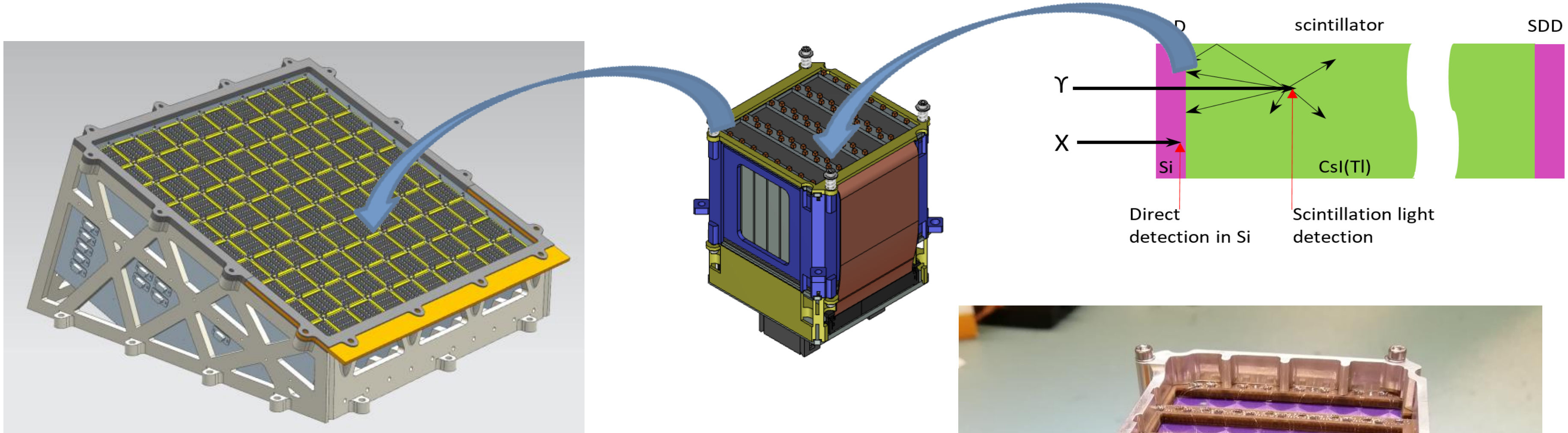
The X-Gamma Ray Imaging Spectrometer (XGIS)

- 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)

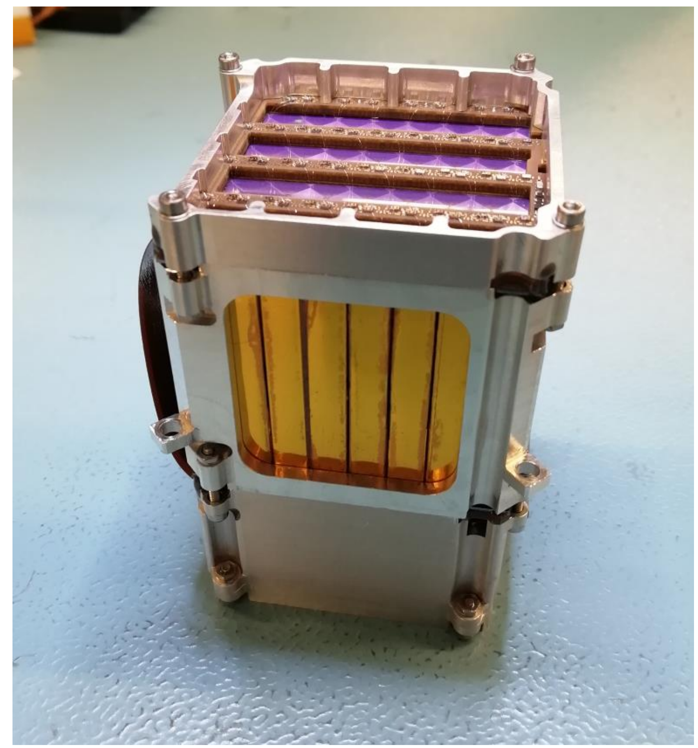




The X-Gamma Ray Imaging Spectrometer (XGIS)



XGIS Phase A study: detection module prototype (ESA-OHB–INAF/OAS +ASI-INAF partners)

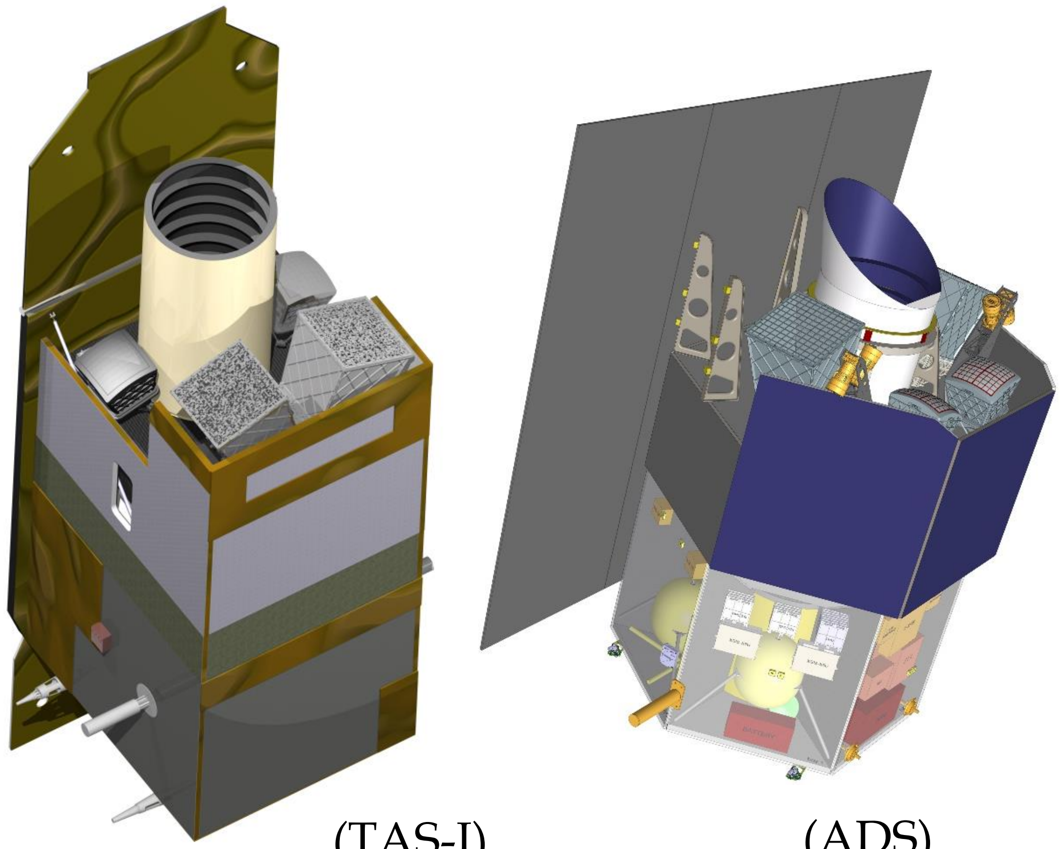


THE SPACECRAFT DESIGN, LAUNCH, AND ORBIT

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

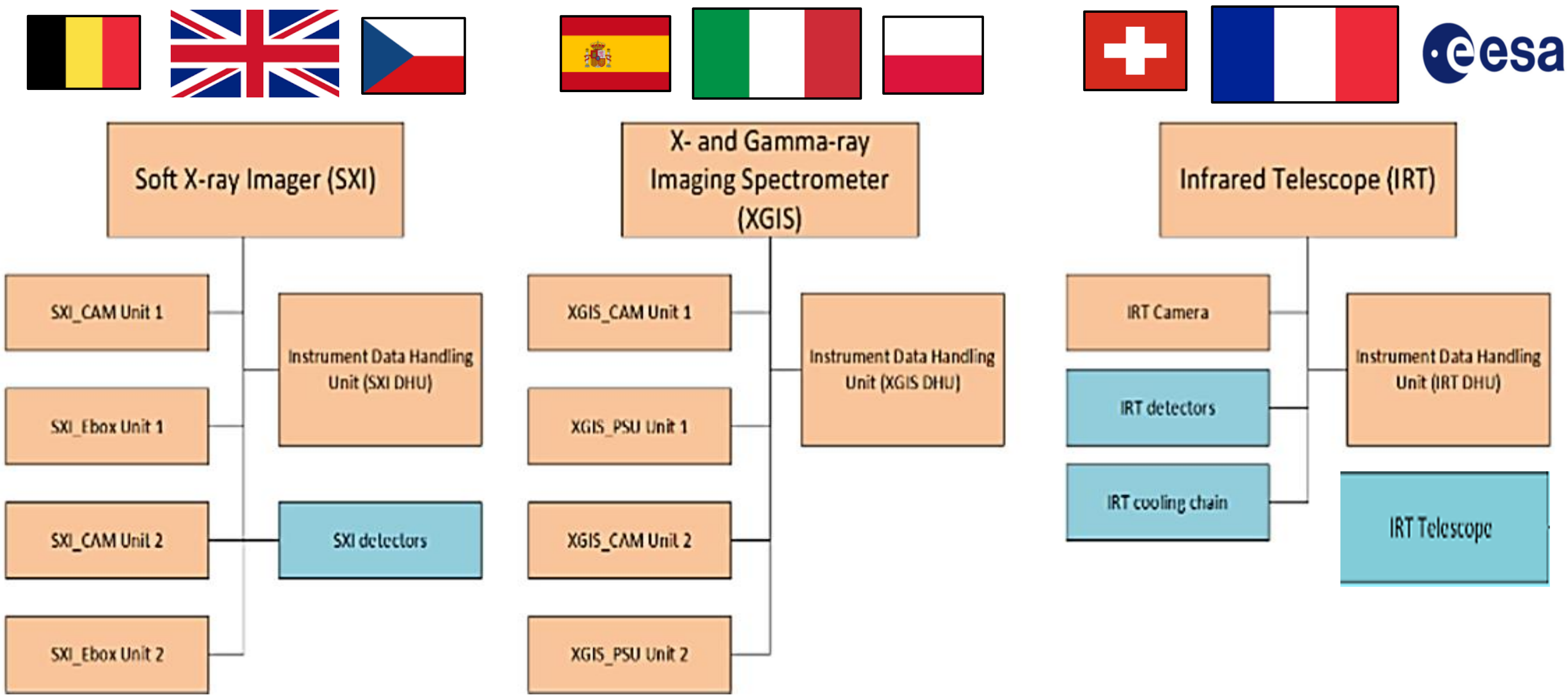
Low-Earth Orbit (LEO), with about 4° inclination and 550-640 km altitude

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



(TAS-I) (ADS)

THESEUS consortium responsibilities (Lead: ITALY)

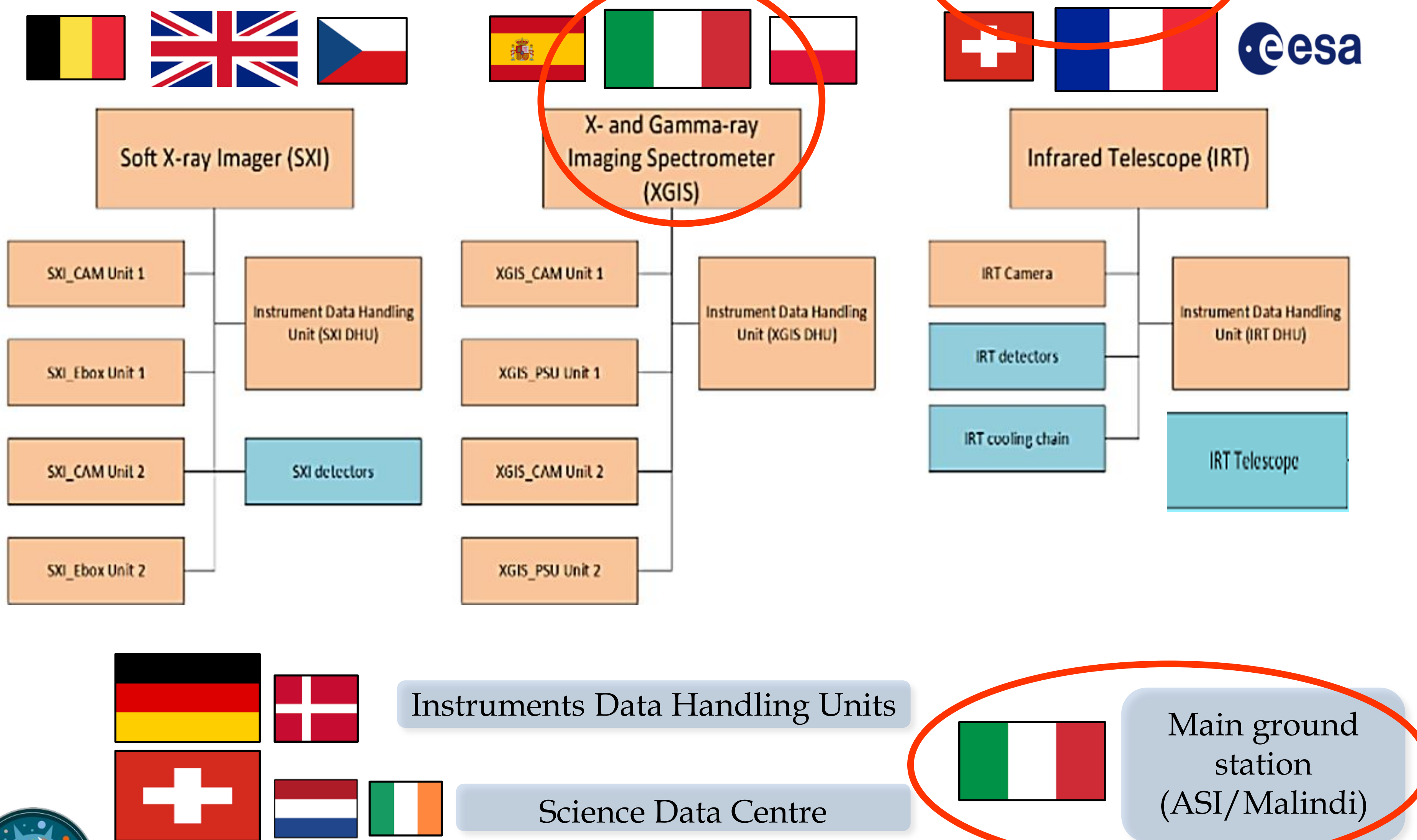


Instruments Data Handling Units

Science Data Centre

Main ground station (ASI/Malindi)

THESEUS consortium responsibilities (Lead: ITALY)



The THESEUS scientific community
(http://www.isdc.unige.ch/theseus)

The THESEUS Consortium includes nearly 500 contributing scientists from worldwide, organized in six Scientific WGs including synergies and GO science

Coordinators and member of WG include also key scientists and coordinators of external facilities with great synergies with THESEUS

Involvement of the community through THESEUS Conferences and the many articles illustrating the THESEUS mission (e.g, SPIE) and the great expected science (e.g., Experimental Astornomy)

The Italian contribution to THESEUS

Supported by ASI & INAF (+ AHEAD2020, ESA/NPMC)

Coordination of the International Consortium
(Lead proposer: L. Amati @ INAF – OAS Bologna)

Responsibility of the XGIS instrument
(L. Amati, C. Labanti @ INAF – OAS Bologna)

Main ground station (ASI/Malindi) and Trigger Broadcasting Unit

Key roles in ESA Science Study Team and Scientific WGs

Institutions (INAF, Universities, FBK) + Industries (OHB, GPAP)

Exploiting the great heritage and leadership in the main scientific fields and key enabling technologies

The key role of Italy in THESEUS

Unique heritage in GRB and transients detectors and science (BeppoSAX, HETE-2, Swift, INTEGRAL, AGILE, Fermi, optical/NIR follow-up)

Fundamental contribution to the birth of gravitational waves and multi-messenger astrophysics (EGO-Virgo, EM follow-up with major facilities like VLT)

Leadership in key enabling technologies based on R&D supported by ASI, INAF and INFN in the last years (e.g., silicon drift detectors + scintillators)

The XGIS instrument: heritage and synergies

Design, development and operation of space experiments: BeppoSAX/GRBM, INTEGRAL/PiCsIT, AGILE/MCAL

Science case, requirements and concept design of next generation GRB experiments, supported, e.g., by ASI-INAF "Studio di Astrofisica delle Alte Energie (2007-2010), Tecno-INAF (2014-2016)

R&D on Silicon Drift Detectors within REDSOX collaboration (>2010, INFN, INAF, FBK); R&D on crystal scintillators and SDD+CsI (INAF)

Synergies: HERMES, eXTP, ADAM

Italian contribution to M5 Phase-A: organization and funding

Mostly funded through agreement ASI-INAF n. 2018-29-HH.0 (500 KE from ASI, 600 KE co-finding from INAF and partners)

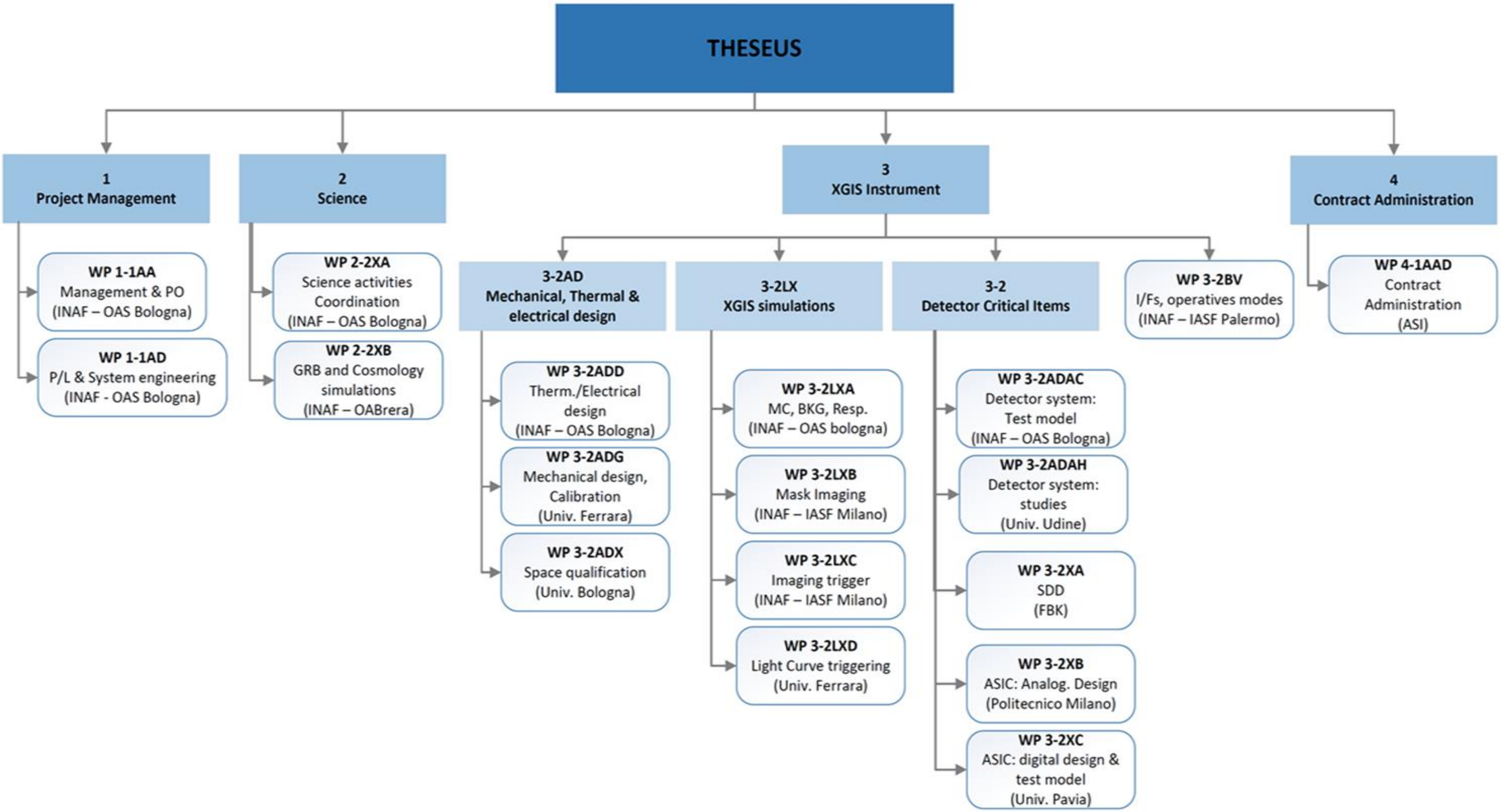
Formal participants: INAF (OAS Bologna, IASF Milano, Oss. Brera in Milano, IASF Palermo), FBK (Trento), Univ. Bologna, Univ. Ferrara, Univ. Udine, Univ. Pavia, Politecnico Milano

Additional funding for XGIS detection module prototype from ESA M5 NPMC (460 KE, OHB-I + INAF/OAS Bologna as partner)

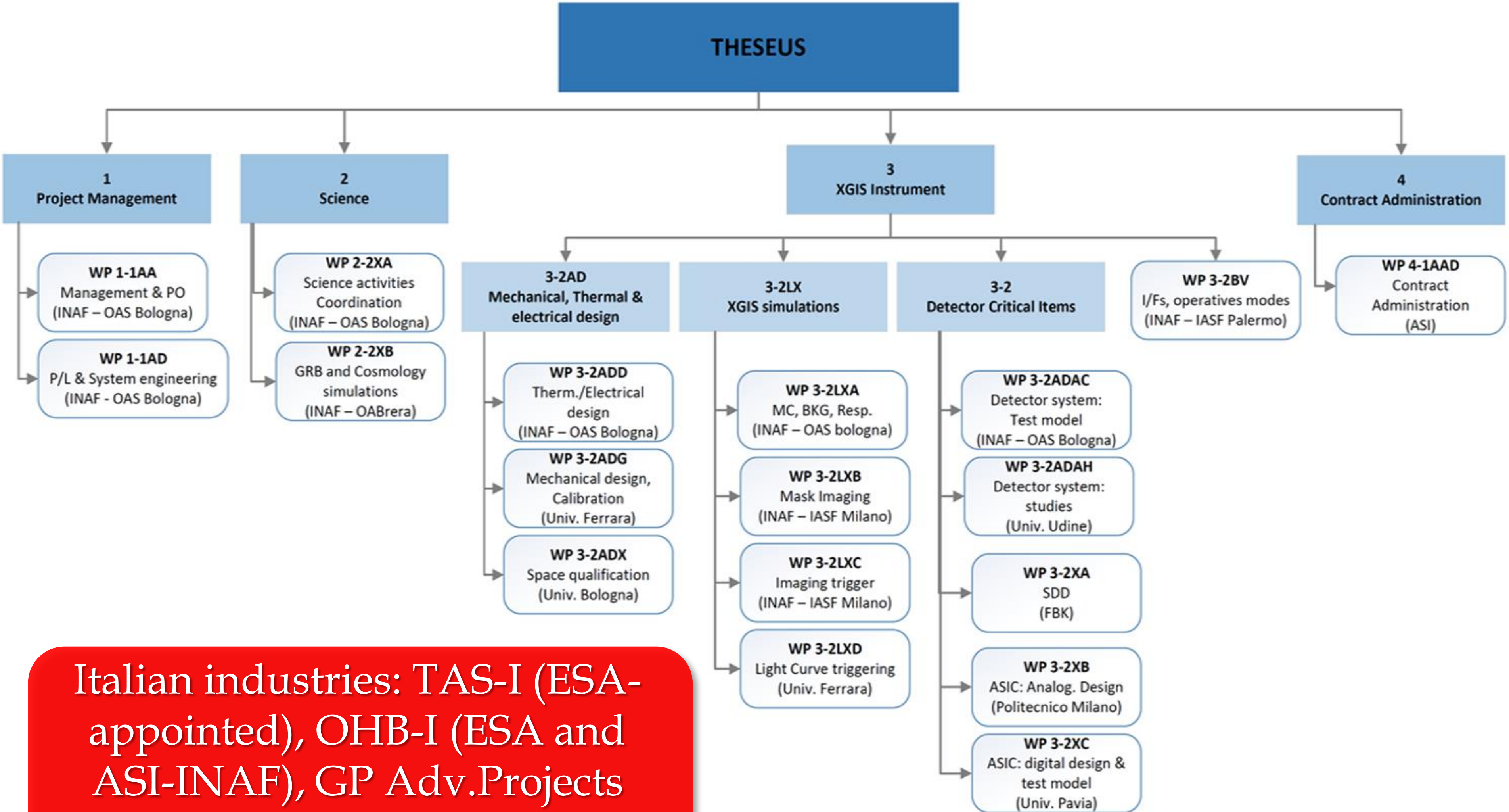
Further support from AHEAD2 H2020/INFRAIA (120 KE)

Contributions to scientific activities by tens of scientists from further INAF institutes and Universities; interest and in-kind conribuitions by INFN scientists and technologists

Italian contribution to M5 Phase-A: organization and funding



Italian contribution to M5 Phase-A: organization and funding



Italian industries: TAS-I (ESA-appointed), OHB-I (ESA and ASI-INAF), GP Adv.Projects (ASI-INAF)

Italian contribution to M5 Phase-A: technology

XGIS: instrument concept and description consolidation, mechanical, electrical and thermal design and models, structural, thermal and radiation analyses, MC model and simulations

XGIS: R&D on critical technologies (SDD, SDD+CsI, ASICs) for reaching TRL 4 and demonstrate path to TRL6 at Mission Adoption

XGIS: design, development and testing of detection module prototype (path to TRL 6 at asoption)

Trigger Broadcasting Unit (TBU): concept design, models, analyses, expected performances, trade-offs between VHF and other systems

Production of the large amount of documents requested by ESA and of papers for SPIE

Italian contribution to M5 Phase-A: science and management

Key roles in THESEUS Science Study Team (ESA appointed) and Consortium scientific Working Groups

Scientific requirements assessment, trade-offs, interface with scientific community, organization of THESEUS meetings and conferences, presentation of THESEUS at main conferences, Fundamental contributions to Assessment Study Report ("Yellow Book") and artcles on expected scientific performances

Fundamental contributions to Mission Operations Simulator (MOS) developed by ESA: GRB sky model, XGIS scientific simulation tools, definition of mission operation concept

Consortium project office and p/l system engineering team; main reference for ESA; organization of consortium meetings

The Phase A study of THESEUS: a source of pride for INAF

THESEUS passed successfully the CDF anaysis and Mission Definition Review (MDR) in November 2018

TEHSEUS passed successfully the Mission Consolidation Review (MCR) in Spring 2020

THESEUS passed successfully the Mission Selection Review (MSR) and Science Assessment Recommendation (SAR) in Spring 2021

ESA technological, programmatic and scientific panels, as well as ESA management, congratulated to THESEUS consortium for unprecedently detailed and high-level Phase A study

Great advancement in the design, modelization, analyses, R&D, prototyping, simulation of XGIS instrument

Planning and resources: selection by ESA as M5 mission

Selection by ESA/SPC on June 9-10
Phase B1: Jul. 2021 – Dec. 2023
Mission Adoption: Jan. 2024
Phase B2: Oct. 2024 – Jun. 2026
Phase C+D: Jul. 2026 – Dec. 2031
Operations: 2032-2036 (nominal + 2yrs possible extension)

ASI support: 25-27 ME for all mission phases;
Phase B1: 1.5 ME (750 KE/yr) for ASI-INAF agreement budgeted,
further 800 KE (contract with industry) requested
Further support for Phase B1: AHEAD2020, ESA/NPMC?

Priority Phase B1 activities on XGIS for de-risking schedule and TRL. Further R&D on SDD, ASICs, second detection module prototype, super-module assembly and testing

Planning and resources: non selection by ESA

Capitalize the large and great work done for THESEUS Phase A study as ESA/M5 candidate

Science case and requirements for next generation missions for GRB, time-domain and multi-messenger astrophysics, further development of the XGIS instrument for future mission opportunities

Priority activities on XGIS as for ESA/M5 Phase B1; funding until end of 2021 based on residuals of ASI-INAF agreement for Phase A, ESA/NPMC contract, AHEAD2020; for next years we rely on possible support from "bandi tecnologici" ASI and INAF, funding opportunities by MUR and UE

Crticalities

In view for next M5 Phases, or in anycase for further development of the project, the acquisition of the following resources should be considered by INAF, which would also be very useful for other space mission projects in which INAF is heavily involved:

- mechanical engineer expert in mechanical / structural analysis;
- project management expert / engineer;
- system engineering expert.

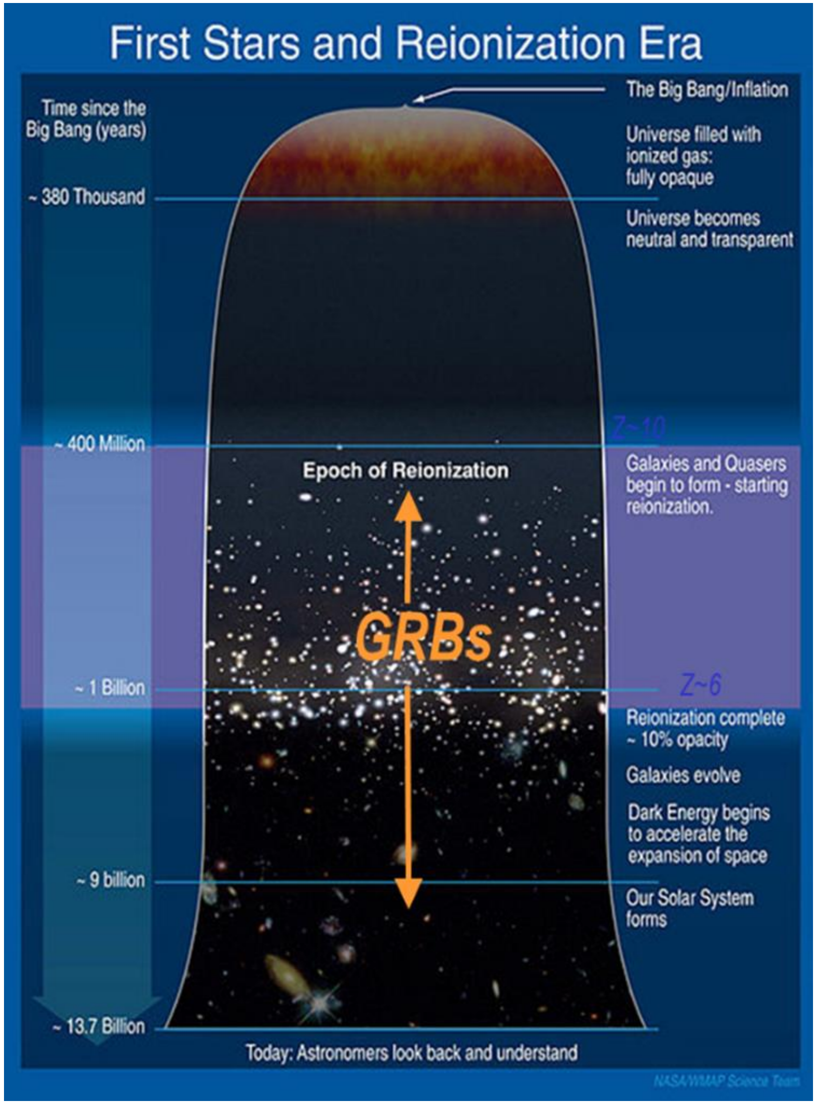
Back-up slides

Shedding light on the early Universe with long GRBs

Huge luminosities, mostly emitted in the X and gamma-rays

Association with exploding massive stars and redshift distribution extending at least up to z ~10

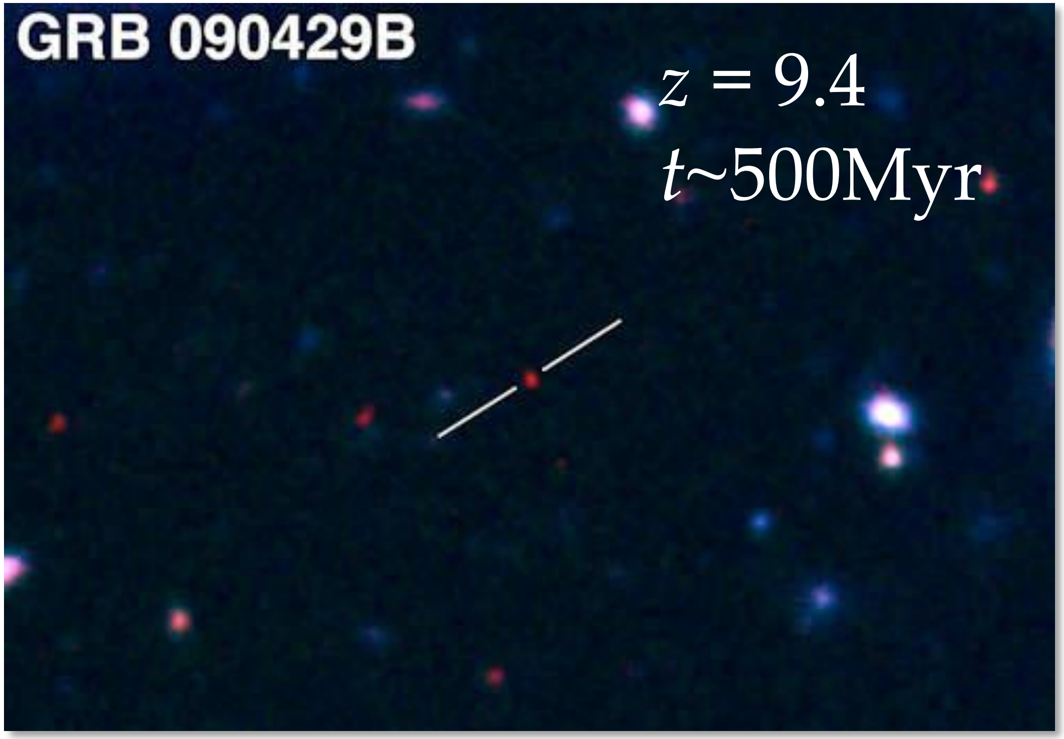
SFR evolution, cosmic re-ionization, high-z low luminosity galaxies, pop III stars



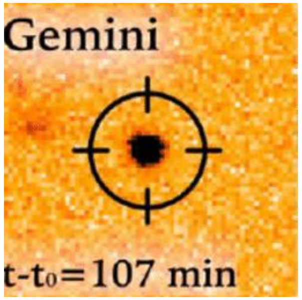
Direct detection of exploding stars at a few hundreds million years after the Big Bang

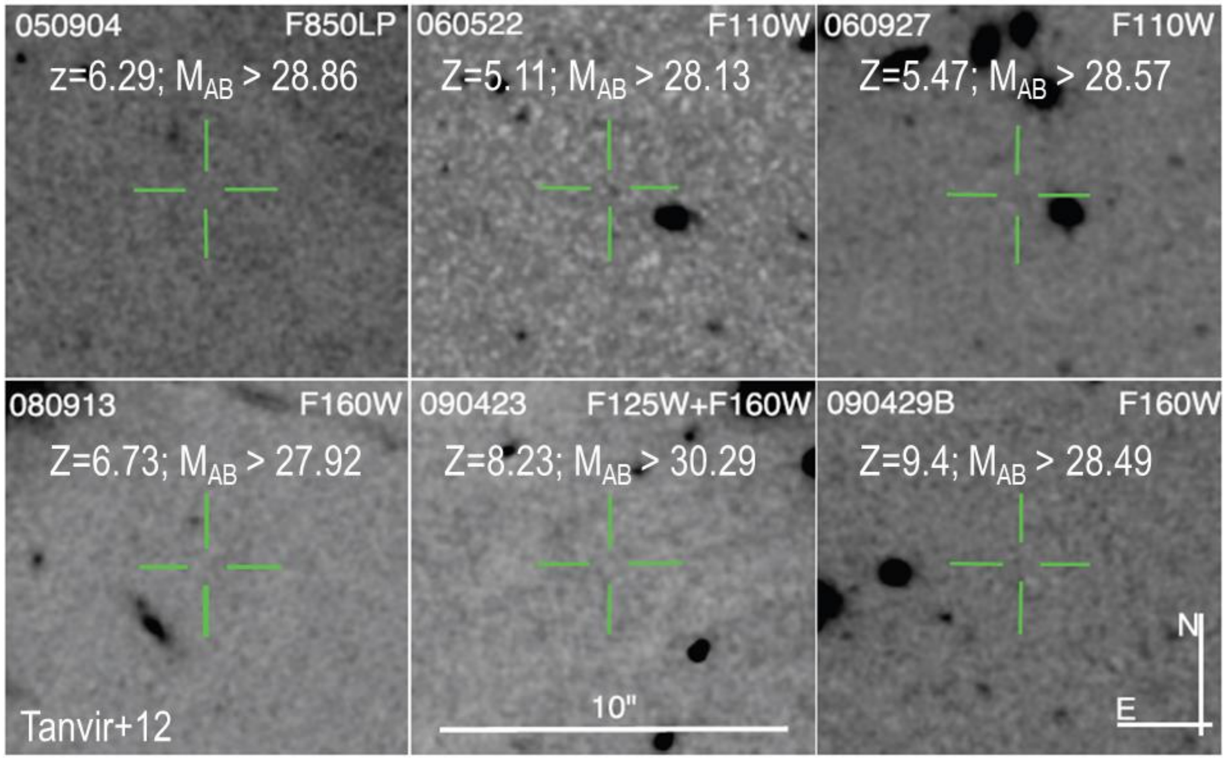
Measure independently the cosmic star-formation rate

Directly (or indirectly) detect first population of stars (pop III)



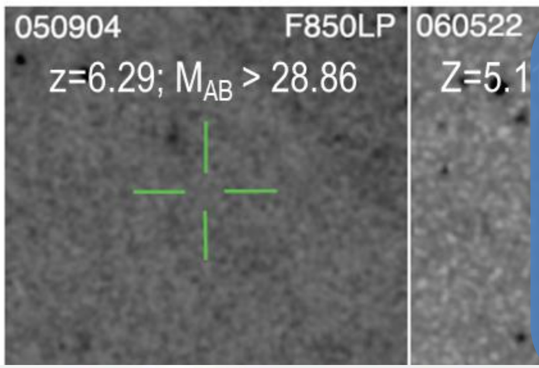
Detecting and studying primordial invisible galaxies through high-z GRBs



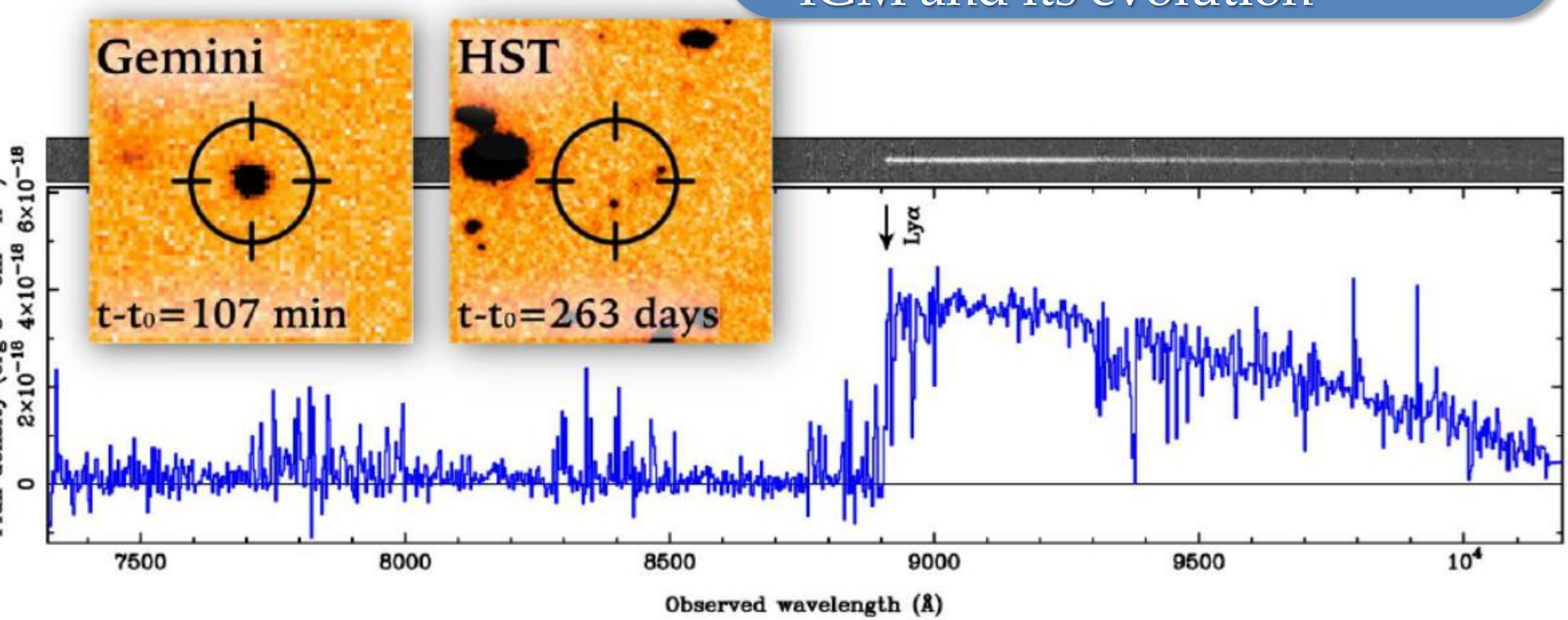


Even JWST and ELTs surveys will be not able to probe the faint end of the galaxy Luminosity Function at high redshifts (z>6-8)

Detecting and studying primordial invisible galaxies through high-z GRBs

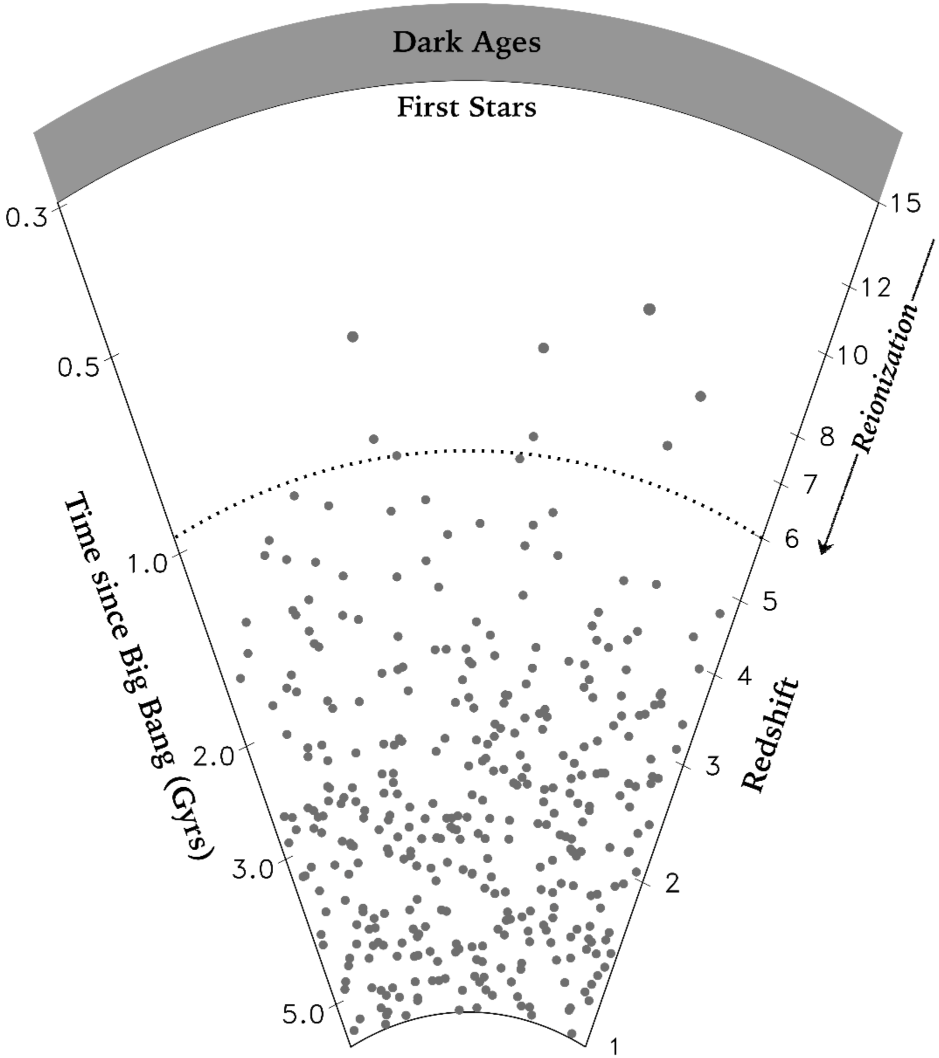


- neutral hydrogen fraction
- escape fraction of UV photons from high-z galaxies
- early metallicity of the ISM and IGM and its evolution



THESEUS WILL PROVIDE A SUBSTANTIAL IMPROVEMENT IN THE DETECTION AND IDENTIFICATION OF GRBS AT Z>6

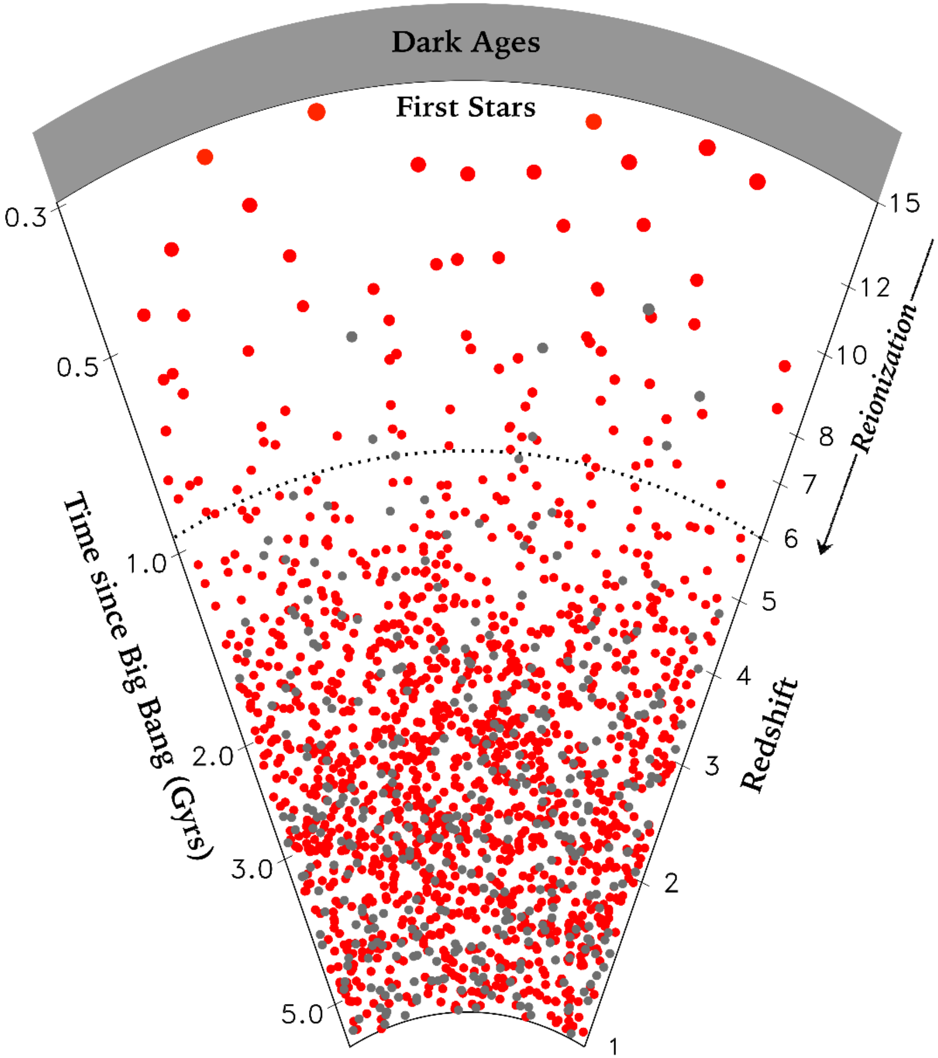
Past and current space and ground facilities in last 20 years



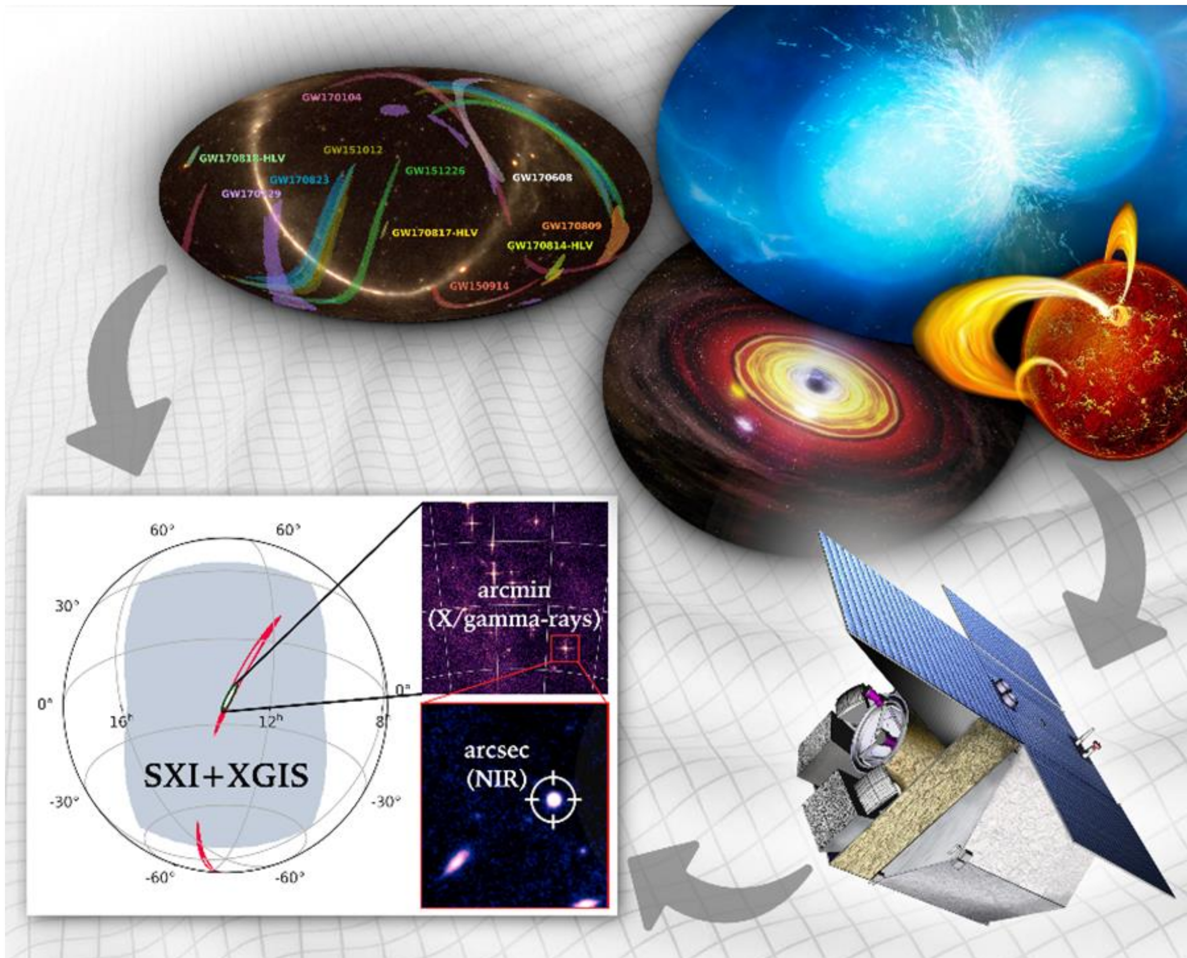
THESEUS WILL PROVIDE A SUBSTANTIAL IMPROVEMENT IN THE DETECTION AND IDENTIFICATION OF GRBS AT Z>6

Past and current space and ground facilities in last 20 years

THESEUS in 3.5 years of scientific operations

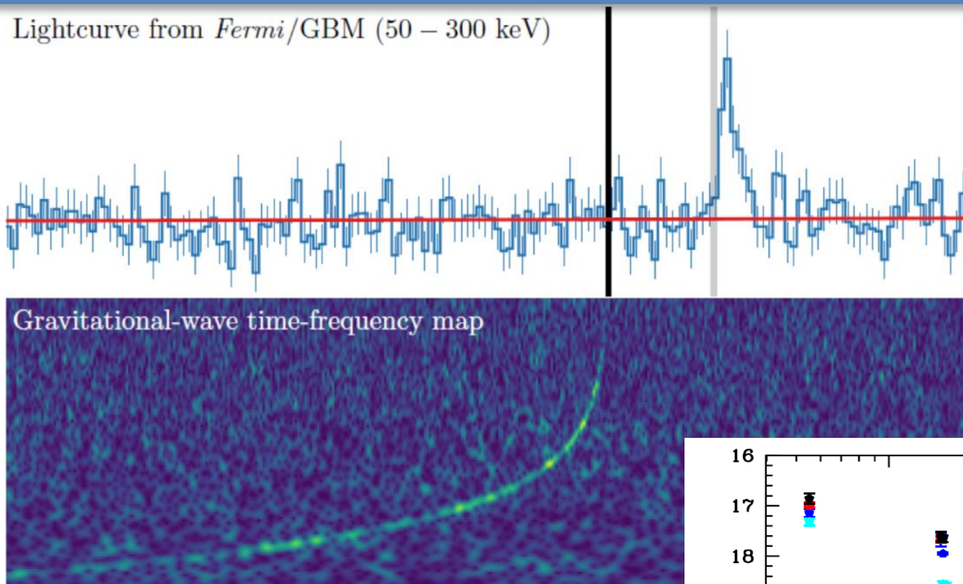


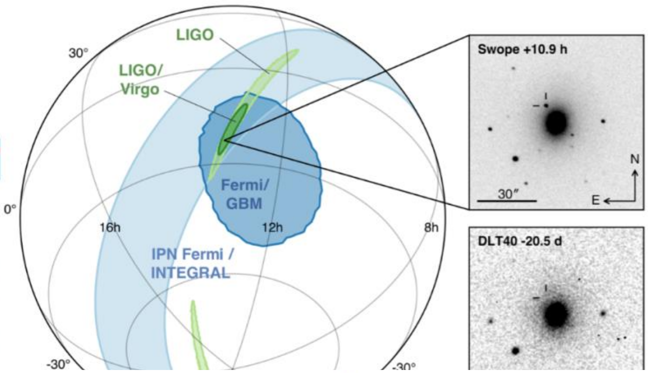
UNPRECEDENTED SURVEY OF THE X/GAMMA-RAY SKY COMBINED WITH AUTONOMOUS NIR FOLLOW-UP CAPABILITY

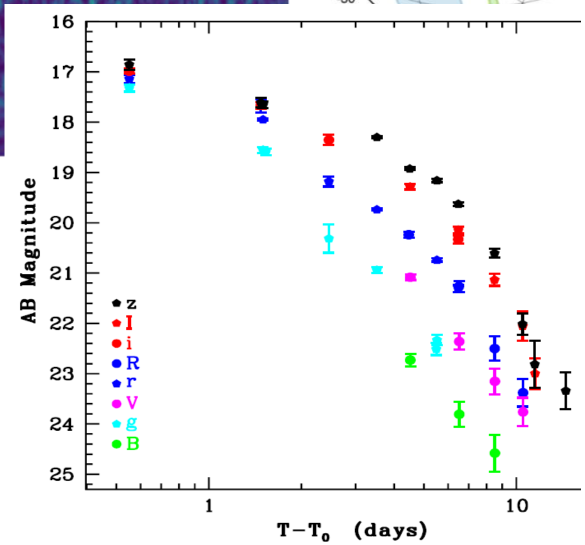


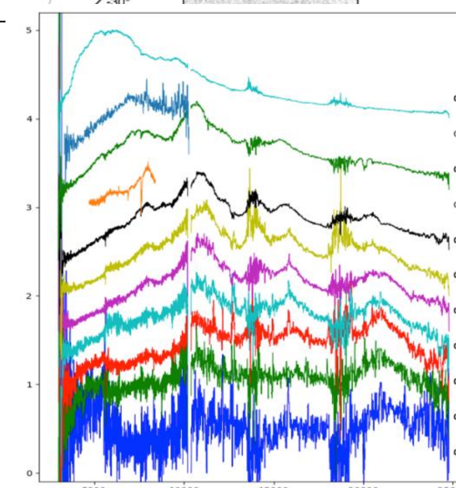
THESEUS AND MULTI-MESSENGER ASTROPHYSICS

The 2017 breakthrough: LIGO, Virgo and partners make first detection of GW and light from colliding neutron stars





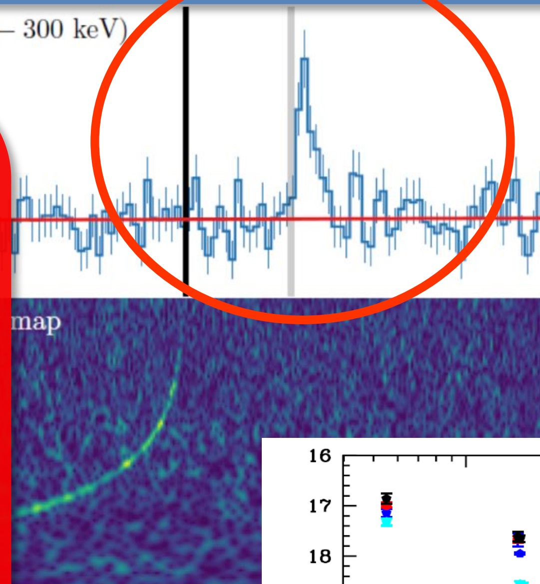


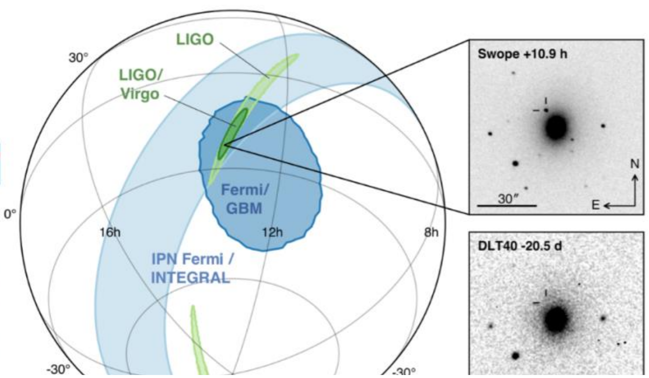


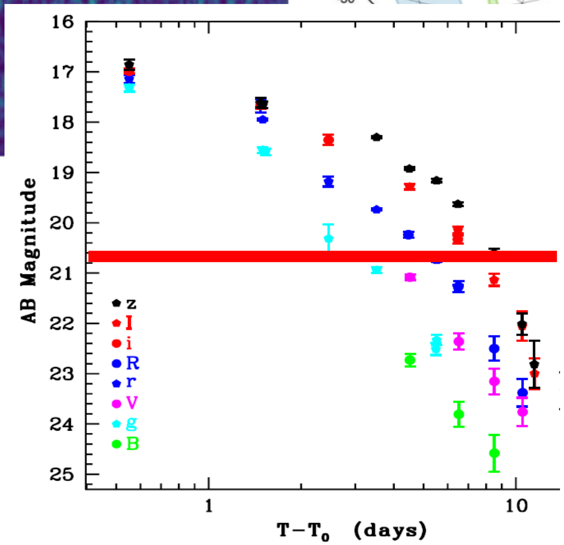
THESEUS AND MULTI-MESSENGER ASTROPHYSICS

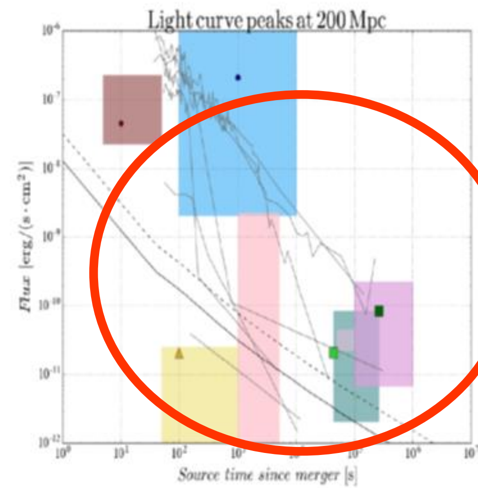
The 2017 breakthrough: LIGO, Virgo and partners make first detection of GW and light from colliding neutron stars

THESEUS: detection and accurate location of
- short GRB
- NIR afterglow and/or KN
- possible soft X-ray emission

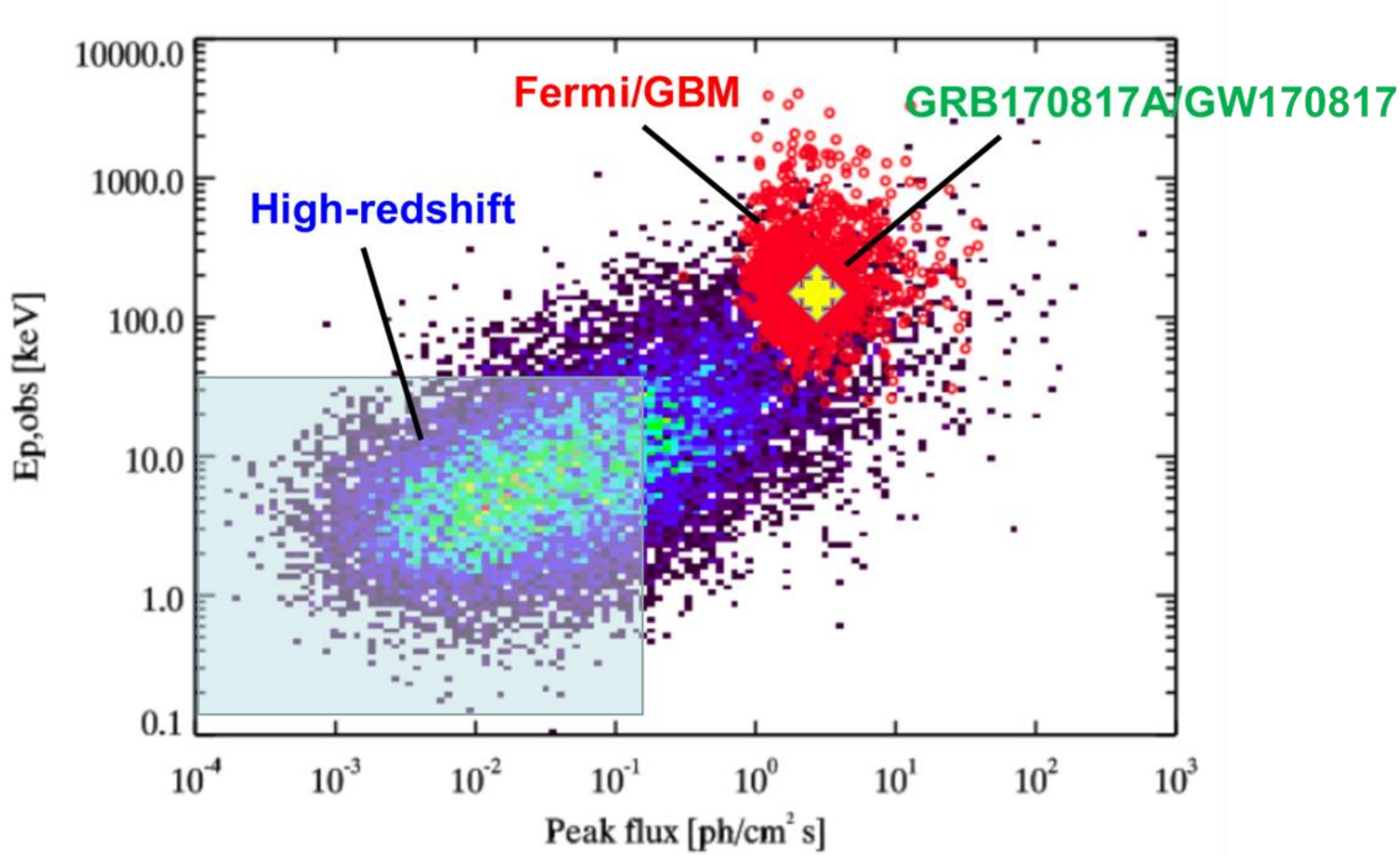








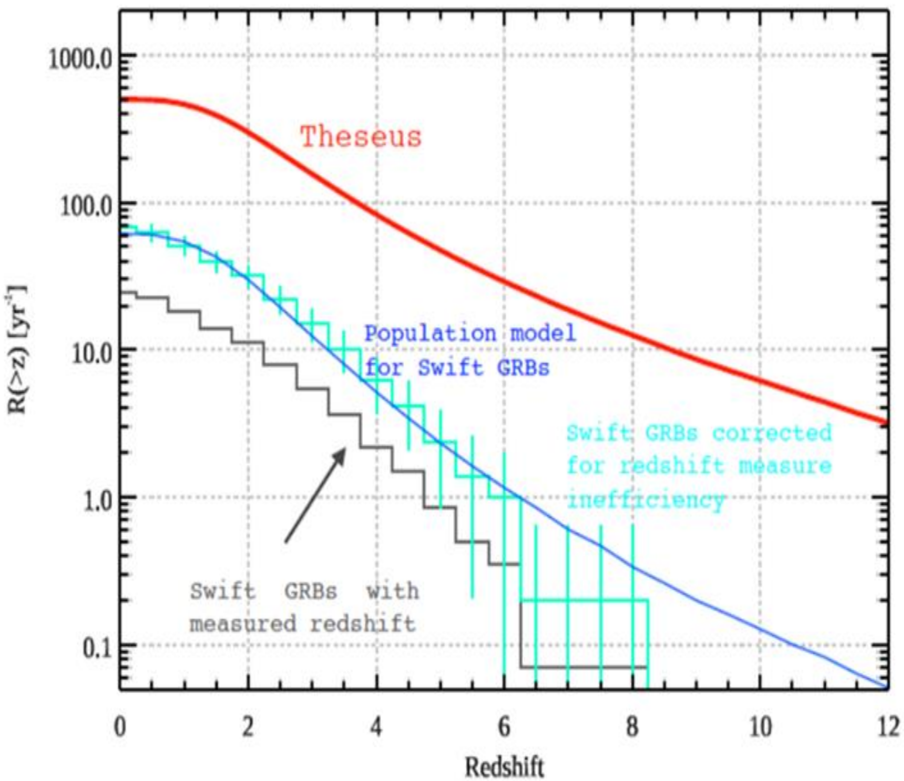
THESEUS WILL HAVE THE IDEAL COMBINATION OF INSTRUMENTATION AND MISSION PROFILE FOR DETECTING ALL TYPES OF GRBS PROVIDING ACCURATE LOCATION AND REDSHIFT FOR A LARGE FRACTION OF THEM

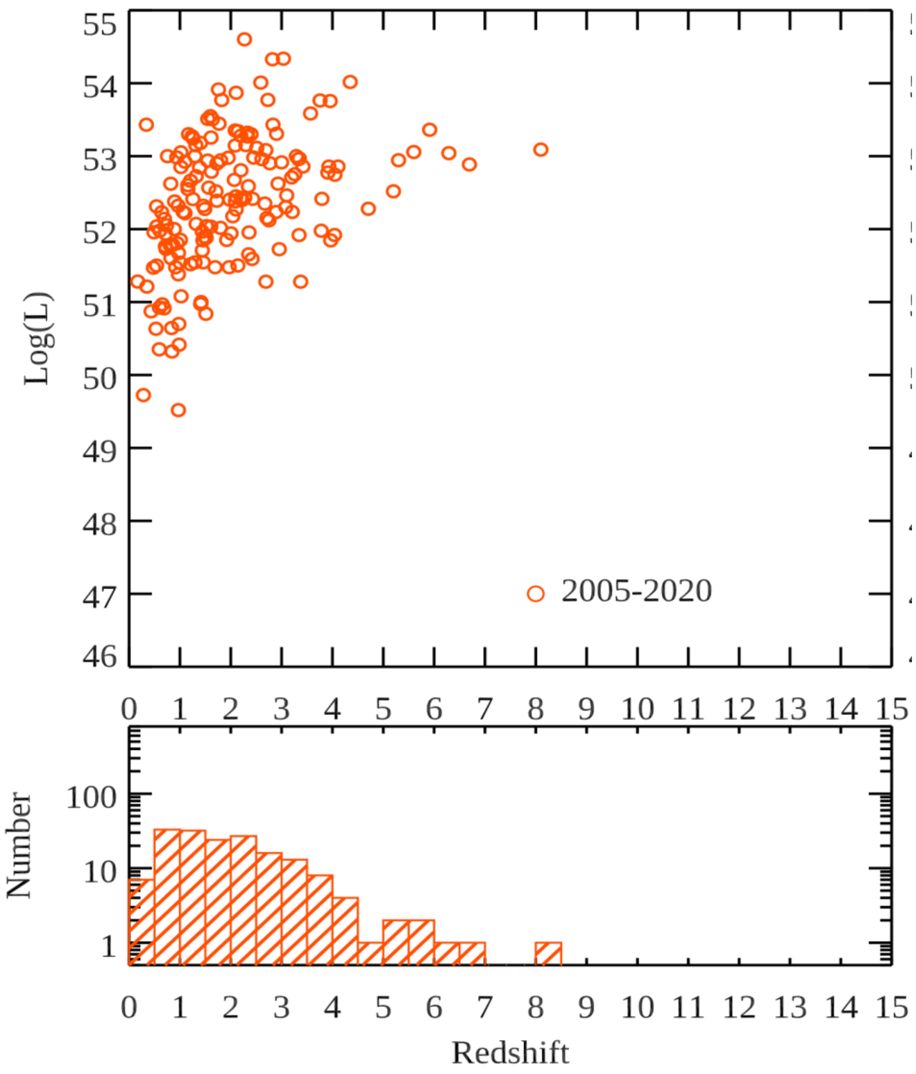


THIS BREAK-TRHOUGH WILL BE ACHIEVED BY A MISSION CONCEPT OVERCOMING MAIN LIMITATIONS OF CURRENT FACILITIES

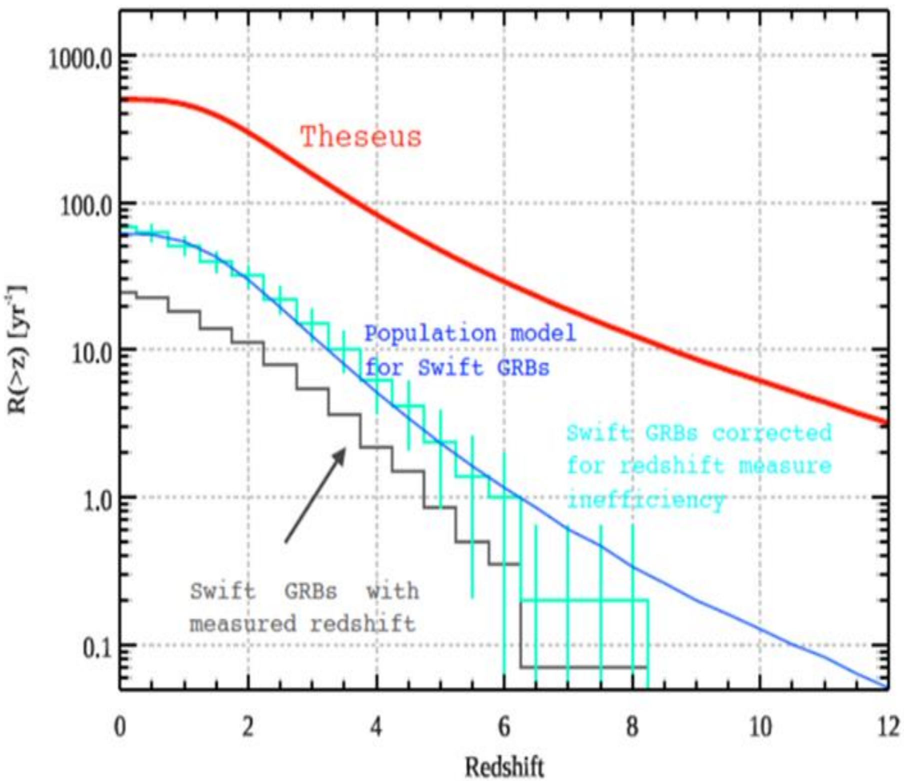
Mission	Autonomous rapid repointing	Arcsec localisation	Optical imaging	Near-IR imaging	Near-IR spectroscopy	On-board redshift	<10 keV X-ray coverage	>10 keV X-ray coverage	MeV γ-ray coverage
Swift	✓	✓	✓	✘	✘	✘	✓	✓	✘
Fermi/GRB	✘	✘	✘	✘	✘	✘	✘	✓	✓
Integral	✘	✘	✓	✘	✘	✘	✘	✓	✓
SVOM	✘	✘	✓	✘	✘	✘	✓	✓	✓
Einstein Probe	✓	✘	✘	✘	✘	✘	✓	✘	✘
eXTP	✓	✓	✘	✘	✘	✘	✓	✘	✘
THESEUS	✓	✓	✓	✓	✓	✓	✓	✓	✓

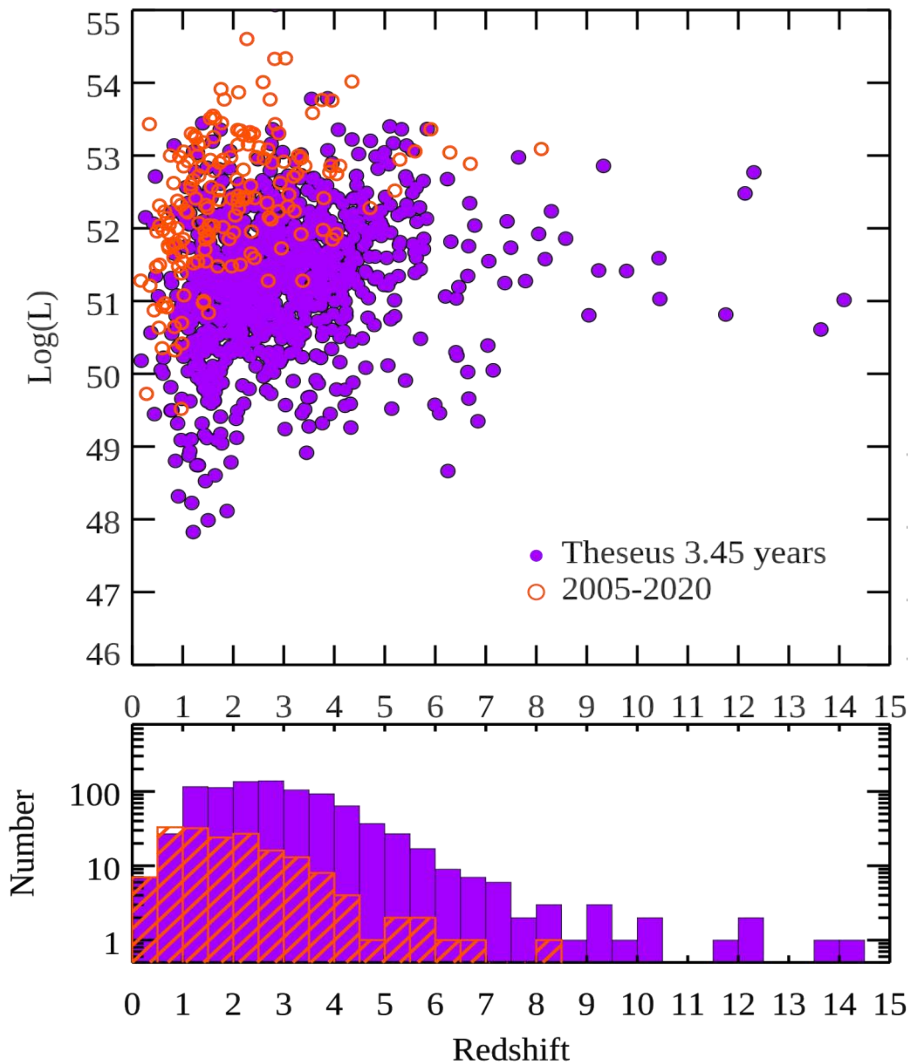
Shedding light on the early Universe with THESEUS





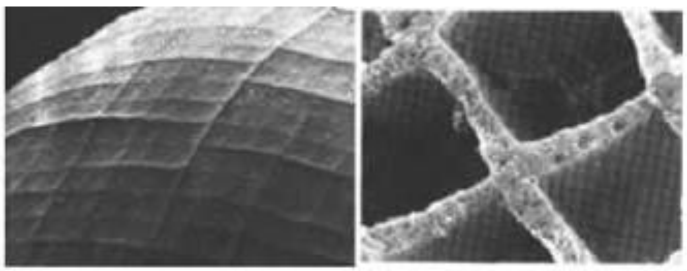
Shedding light on the early Universe with THESEUS



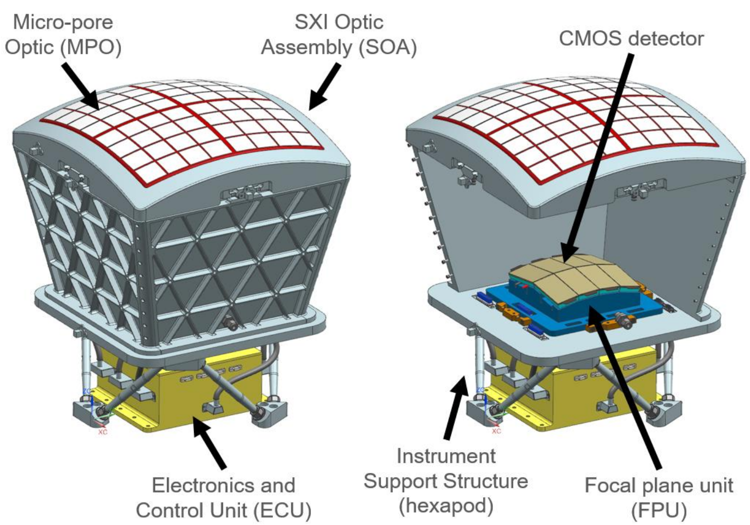


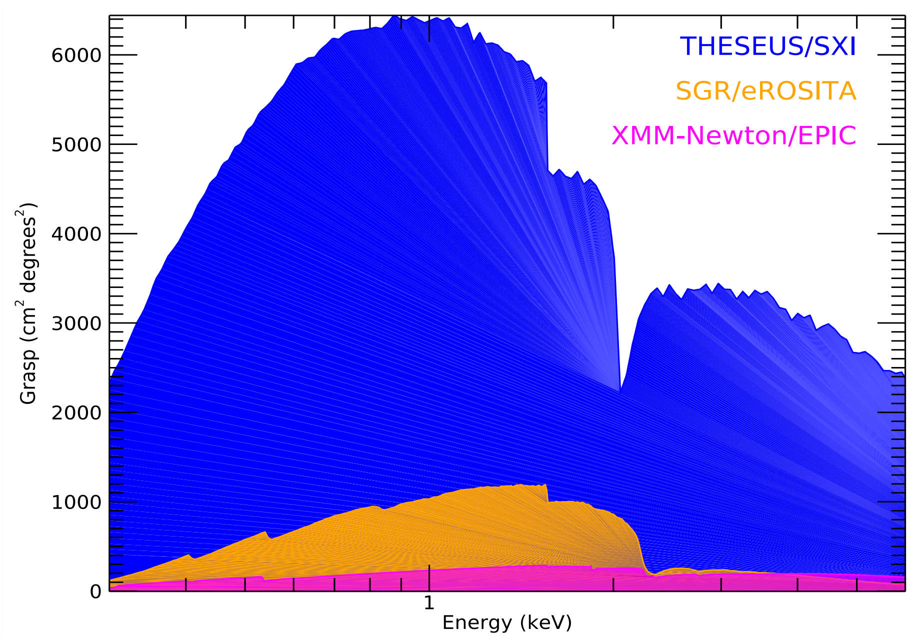
THE SOFT X-RAY IMAGER (SXI)

Two sensitive “lobster-eye” X-ray telescopes (0.3 - 5 keV)
Total FOV of 0.5sr (>1000 × conventional X-ray telescopes)



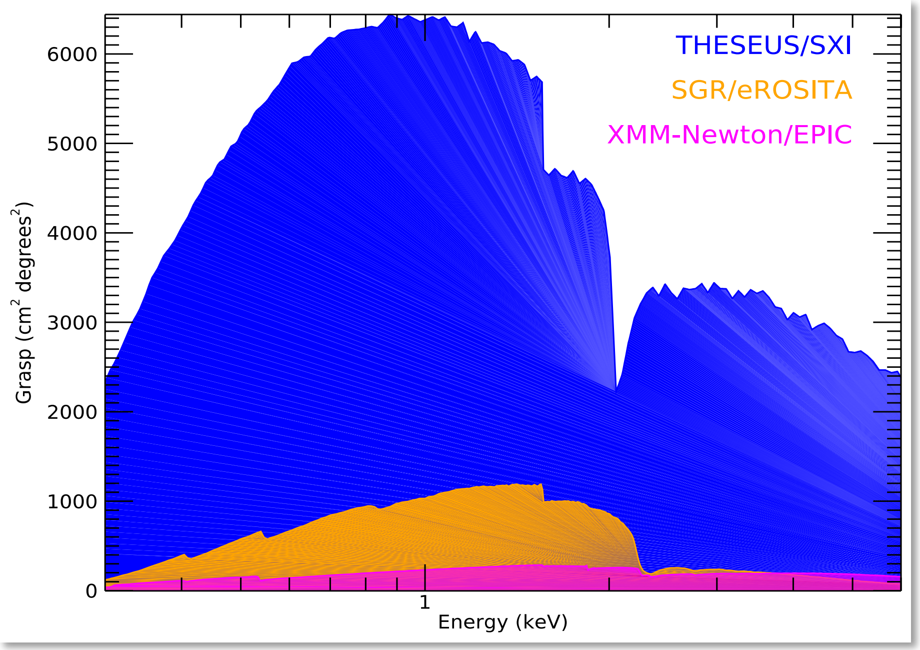
No single optical axis results in a focusing X-ray optic with a huge field of view and a large grasp

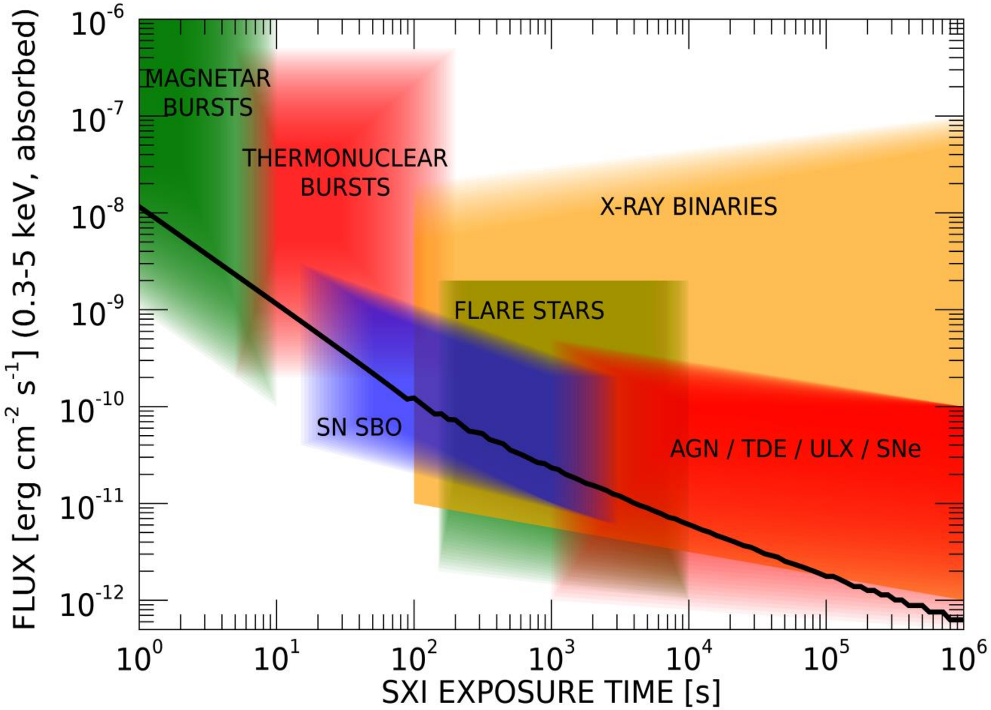




EXPLORING THE TRANSIENT SKY WITH THESEUS

THESEUS will have a unique combination of Field-Of-View, sensitivity and energy band, enabling simultaneous detection, accurate localization and characterization of many classes of transients in parallel

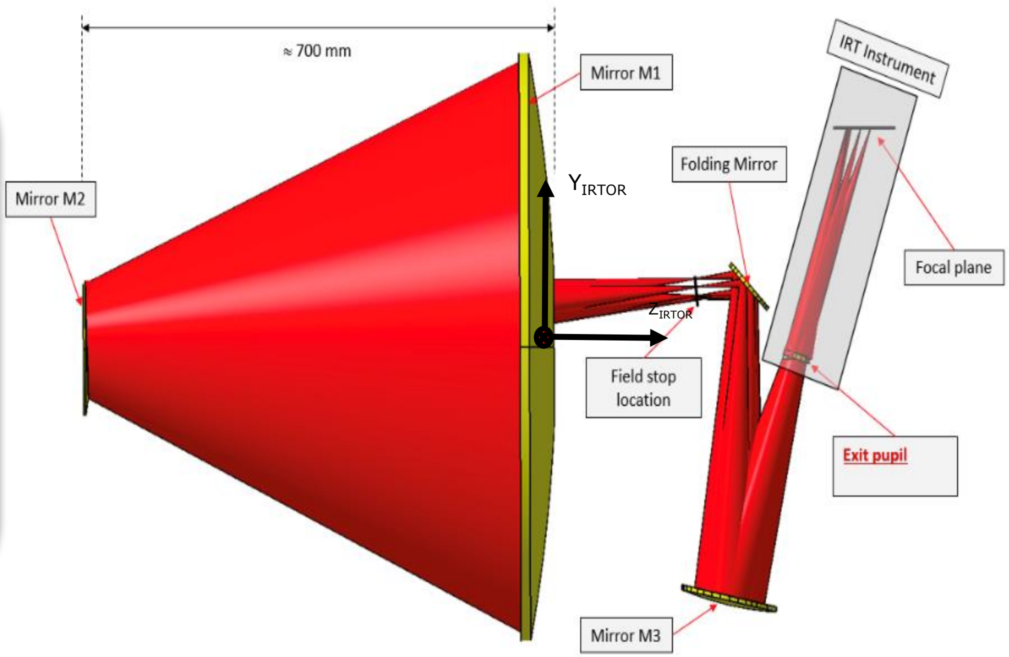




The Infra-Red Telescope (IRT)

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 INFRARED TELESCOPE (IRT)

0.7m off-axis Korsch telescope, large field of view (15′x15′), imaging and spectroscopic (R~400) capabilities