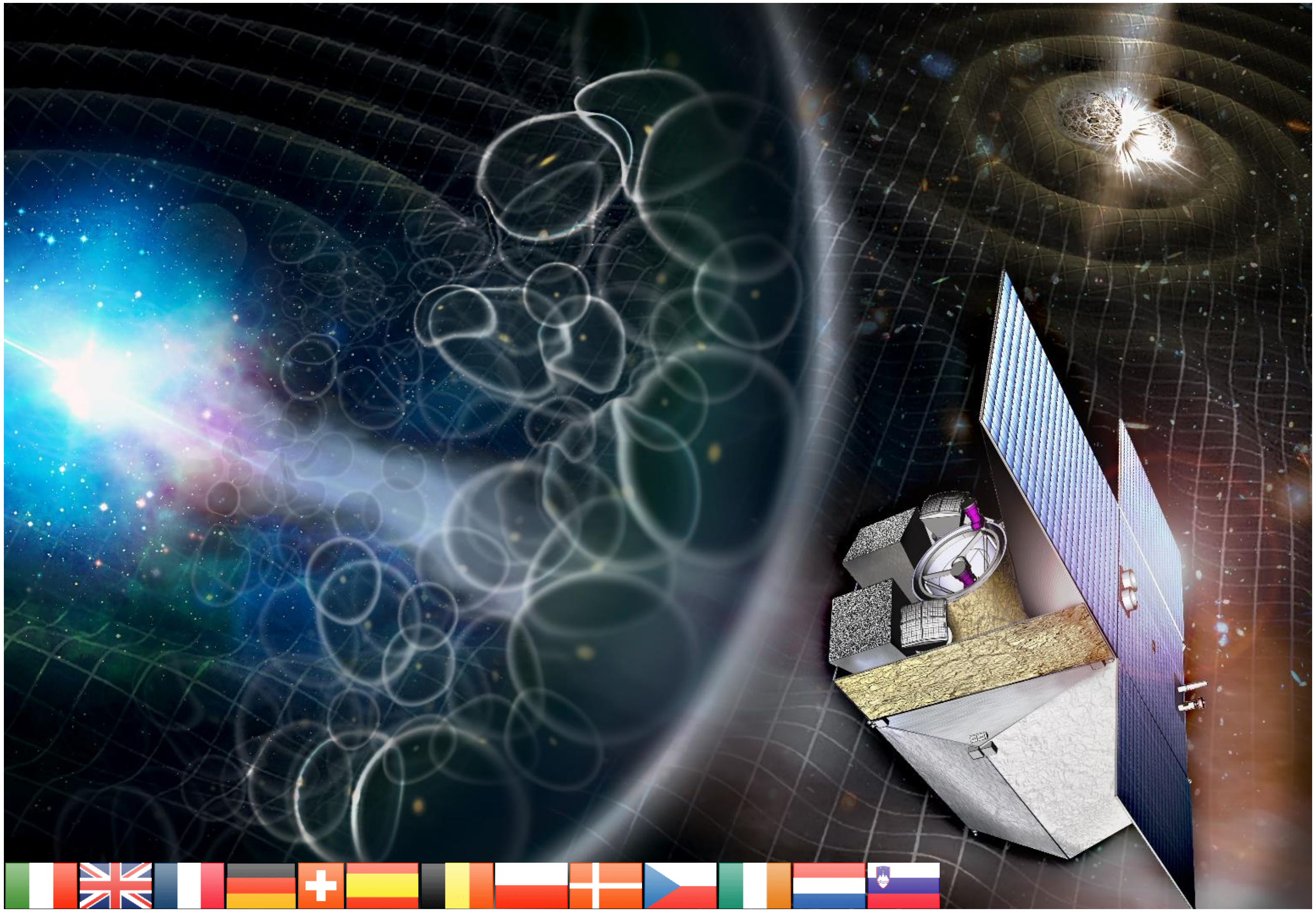
THESEUS

Transient High-Energy Sky and Early Universe Surveyor



L. Amati (INAF – OAS Bologna) on behalf of THESEUS Consortium and SST

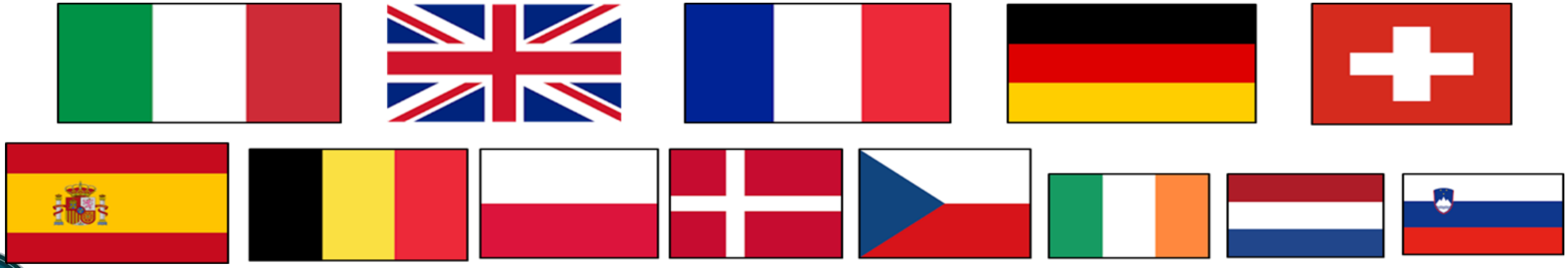
(Joint Astrophysical Colloquium – Bologna, May 13th 2021)

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)

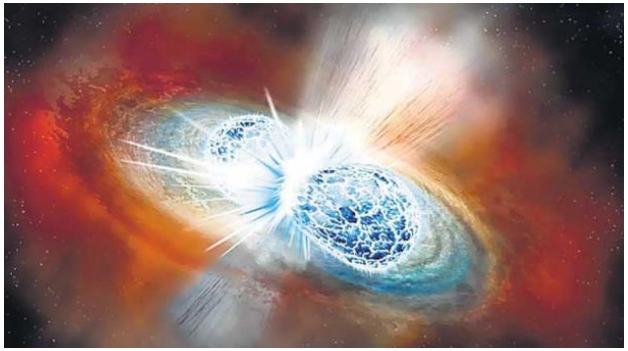
Payload consortium: Italy, UK, France, Germany, Switzerland, Spain, Poland, Denmark, Belgium, Czech Republic, Slovenia, Ireland, The Netherlands



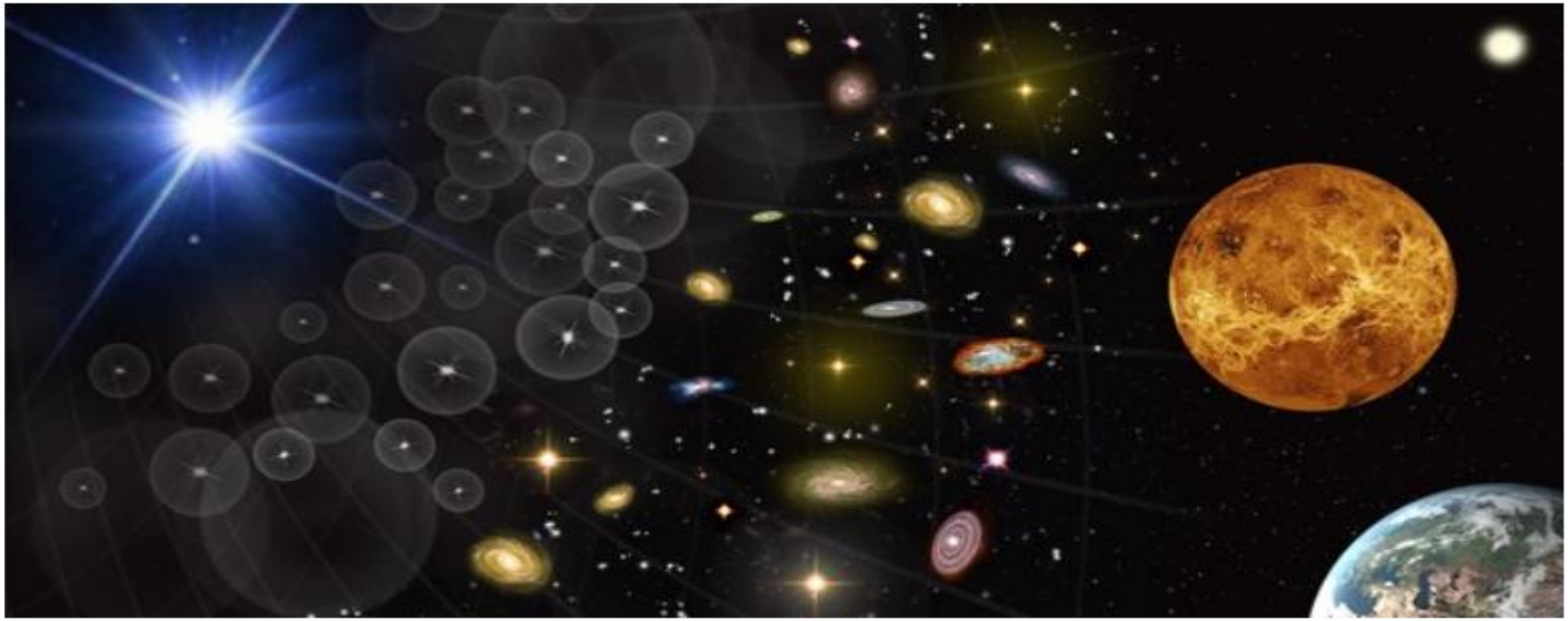
THESEUS CORE SCIENCE GOALS

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



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

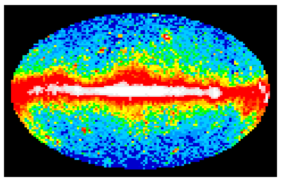
7 May 2018 A high-energy survey of the early Universe, an infrared observatory to study the formation of stars, planets and galaxies, and a Venus orbiter are to be considered for ESA's fifth medium class mission in its Cosmic Vision science programme, with a planned launch date in 2032.

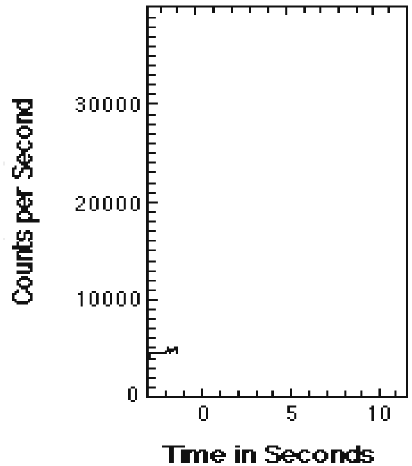
The three candidates, the Transient High Energy Sky and Early Universe Surveyor (Theseus), the SPace

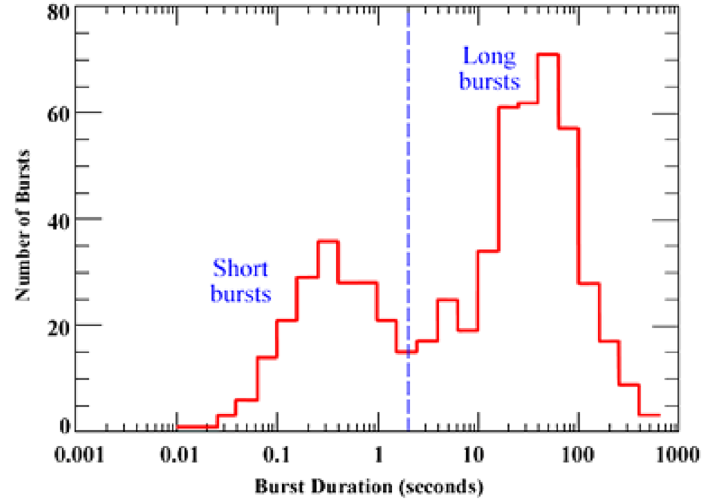
ESA milestones for M5

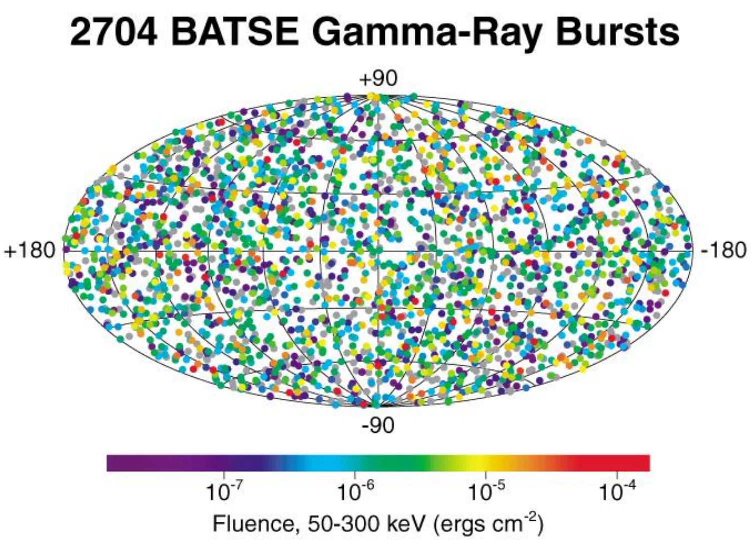
Activity	Date
Phase 0 kick-off	June 2018
Phase 0 completed (EnVision, SPICA and THESEUS)	End 2018
ITT for Phase A industrial studies	February 2019
Phase A industrial kick-off	June 2019
Mission Selection Review (technical and programmatic review for the three mission candidates)	Completed by May 2021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

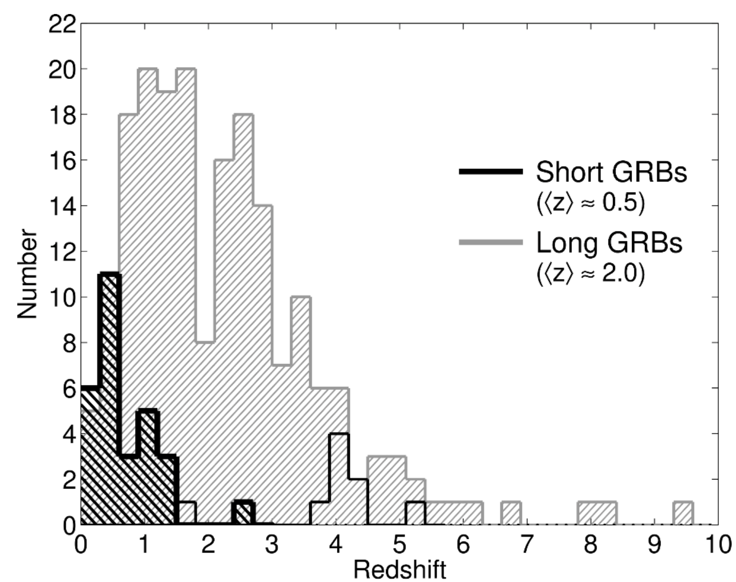
Gamma-Ray Bursts: the most extreme phenomena in the Universe







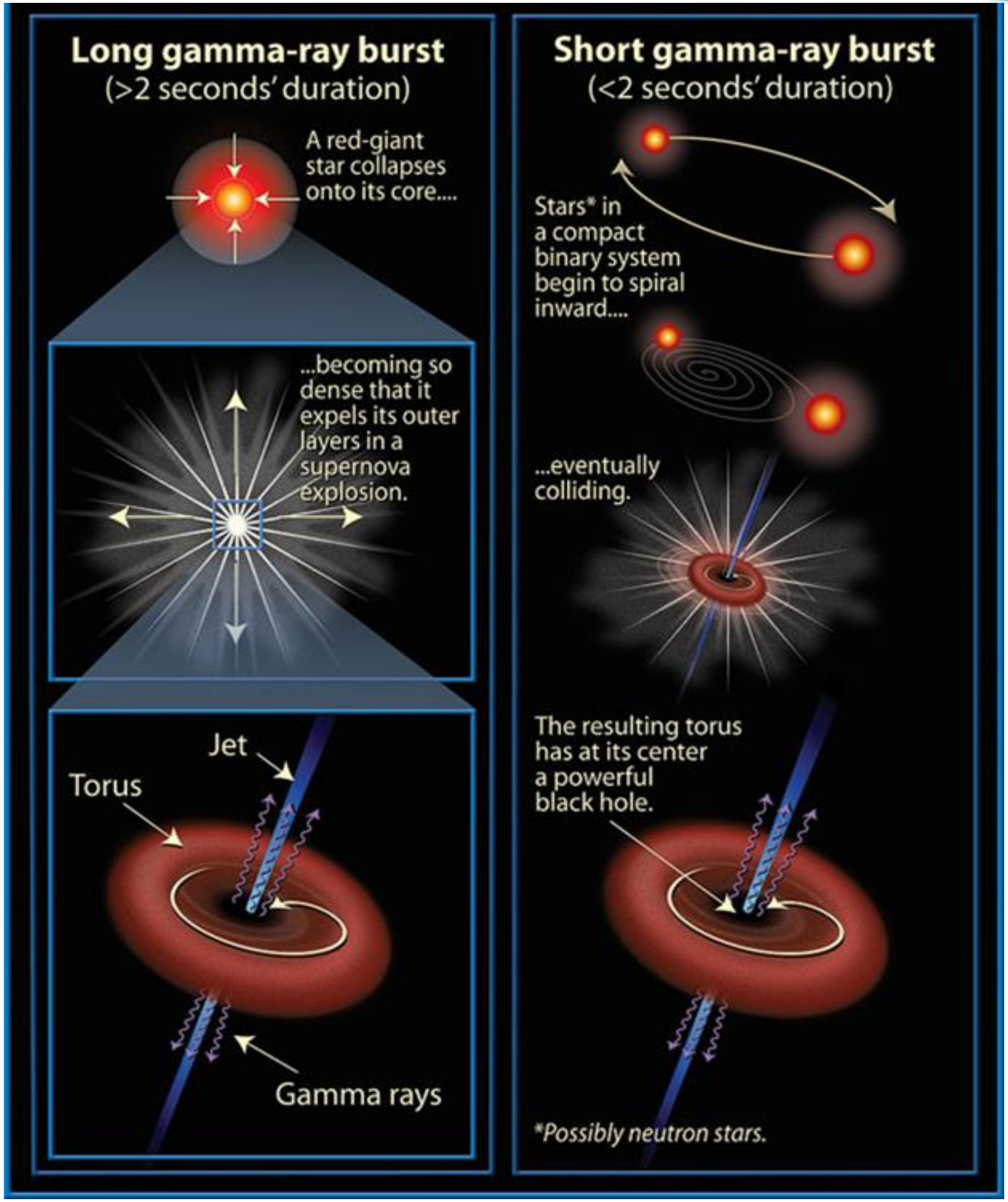




Standard scenarios for GRB progenitos

Long GRBs: core collapse of pecular massive stars, **association with SN**

Short GRBs: NS-NS or NS-BH mergers, **association with GW sources**

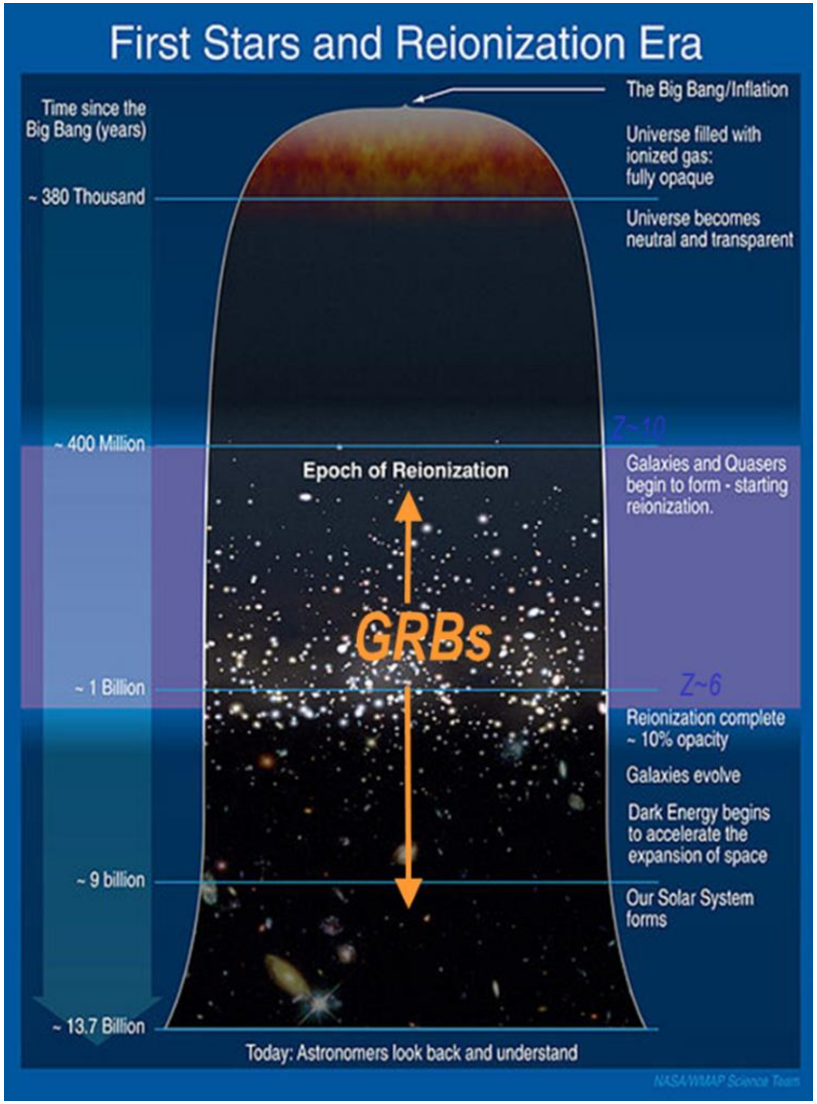


Shedding light on the early Universe with long GRBs

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

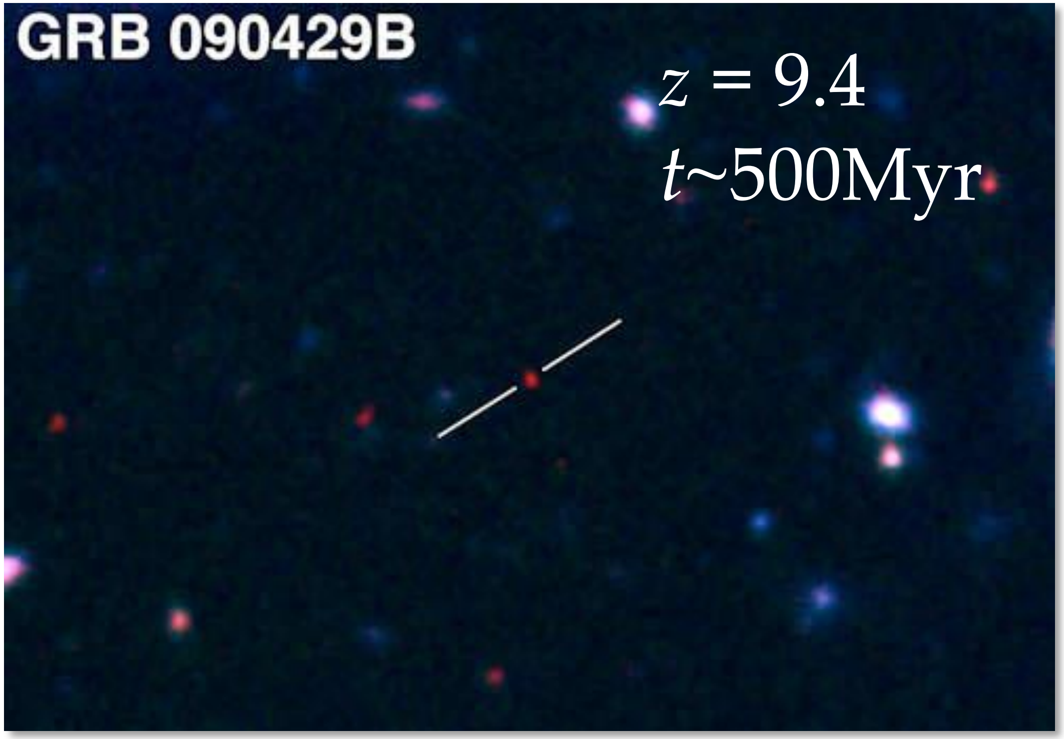
SFR evolution, cosmic re-ionization, high-z low luminosity galaxies, pop III stars



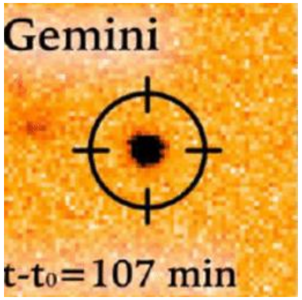
Direct detection of exploding stars at a few hundreds million years after the Big Bang

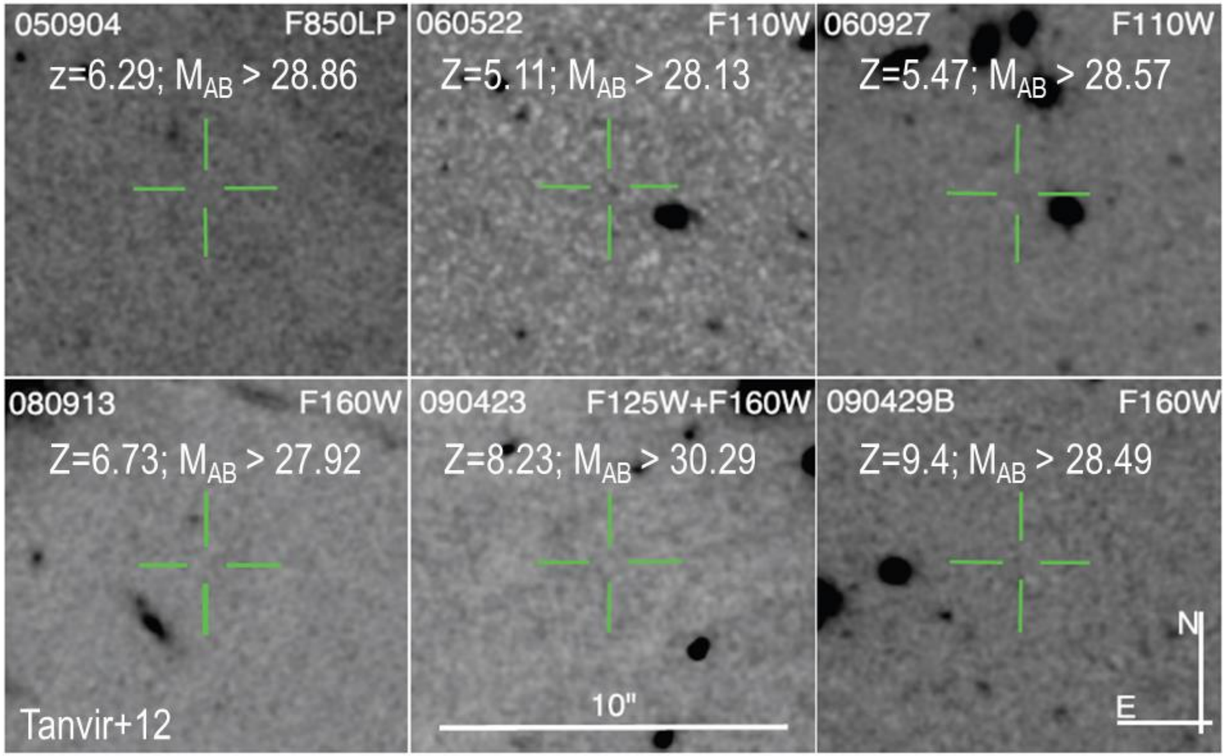
Measure independently the cosmic star-formation rate

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



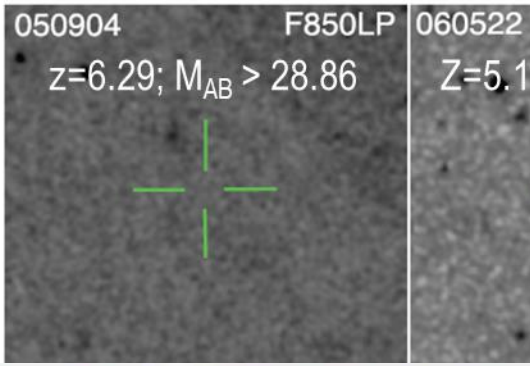
Detecting and studying primordial invisible galaxies through high-z GRBs



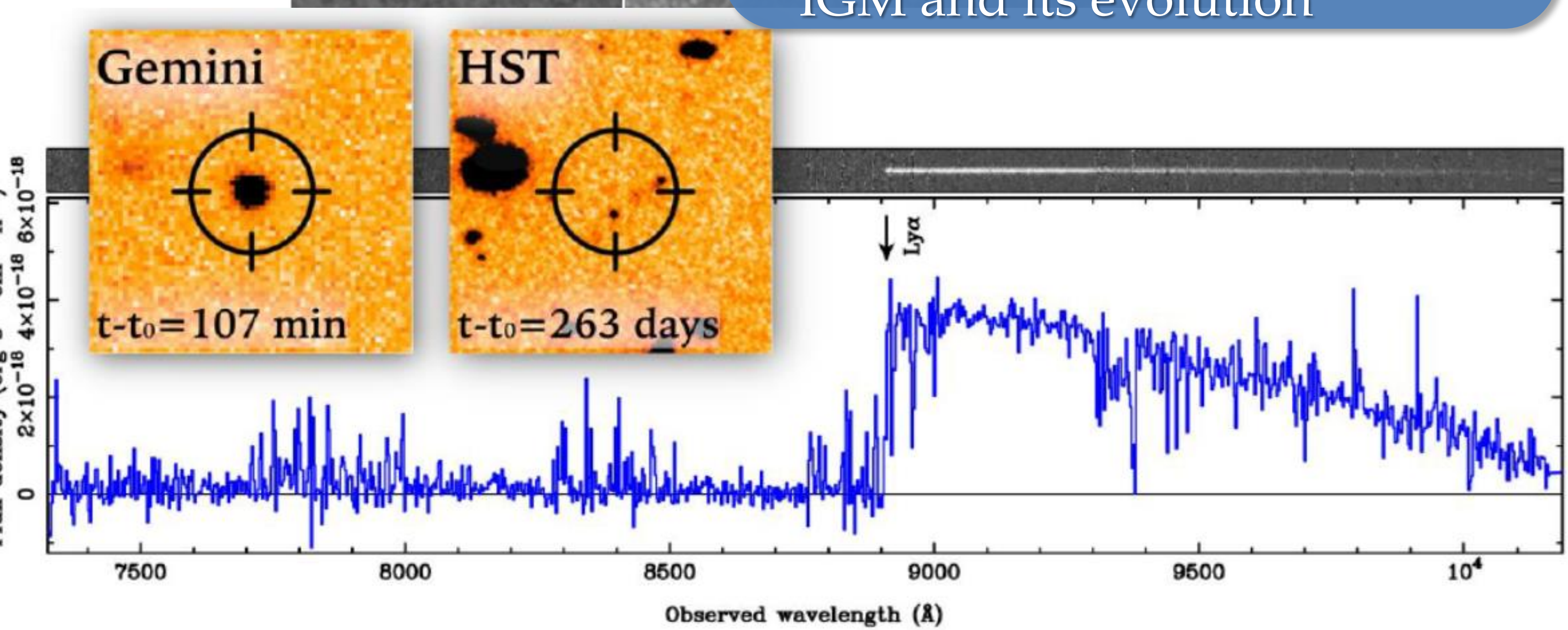


Even JWST and ELTs surveys will be not able to probe the faint end of the galaxy Luminosity Function at high redshifts ($z>6-8$)

Detecting and studying primordial invisible galaxies through high-z GRBs

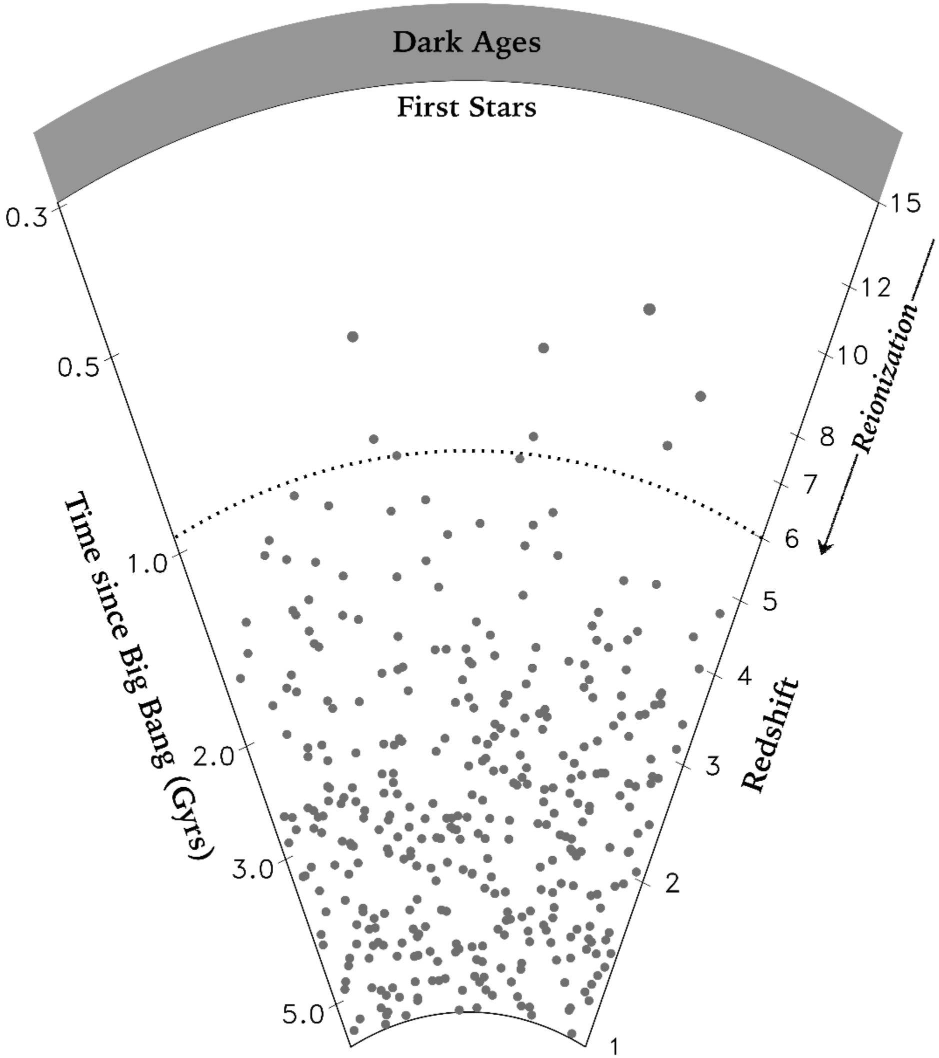


- neutral hydrogen fraction
- escape fraction of UV photons from high-z galaxies
- early metallicity of the ISM and IGM and its evolution



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



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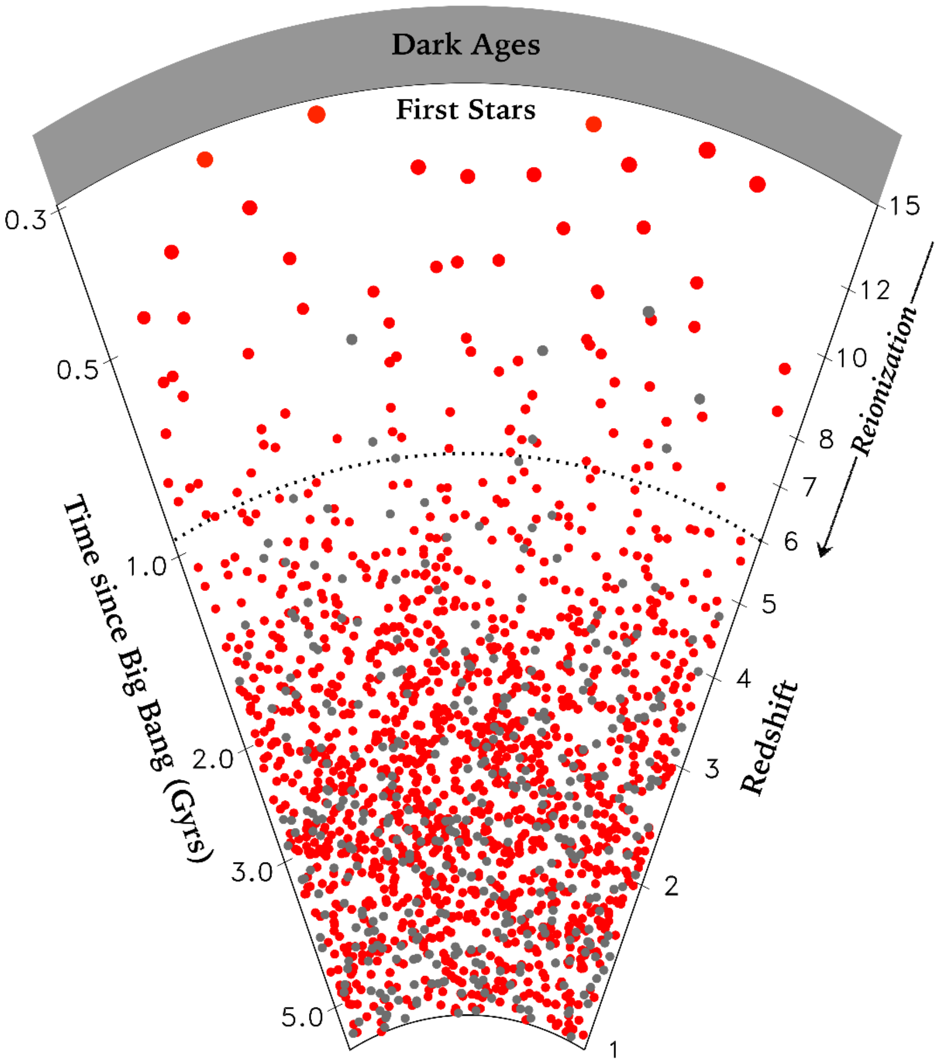
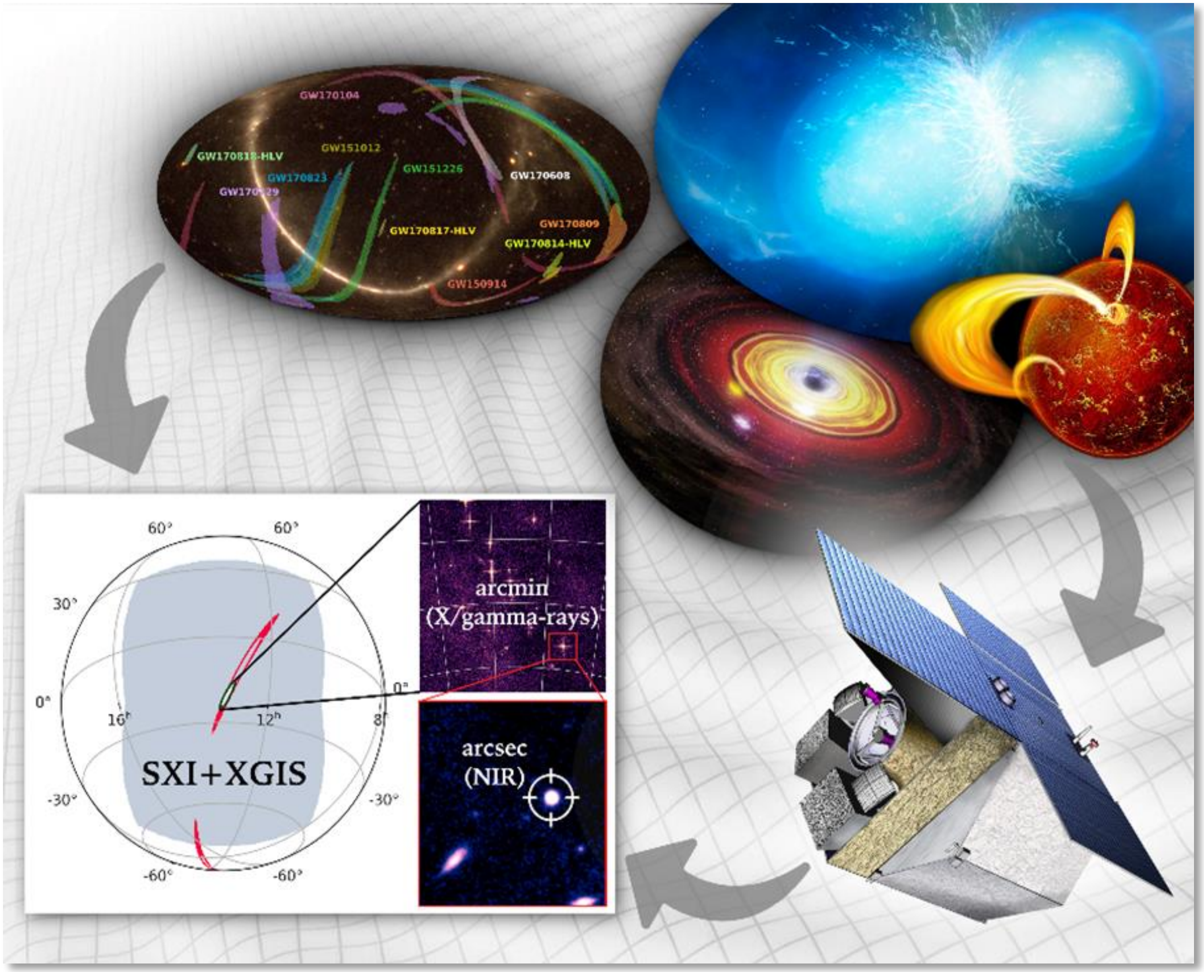
Past and current space and ground facilities in last 20 years

THESEUS in 3.5 years of scientific operations

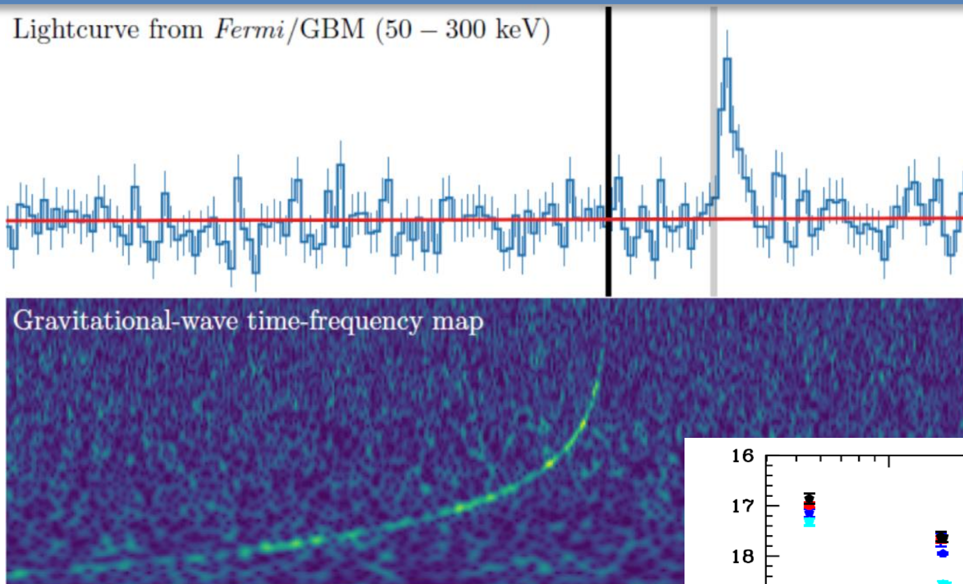


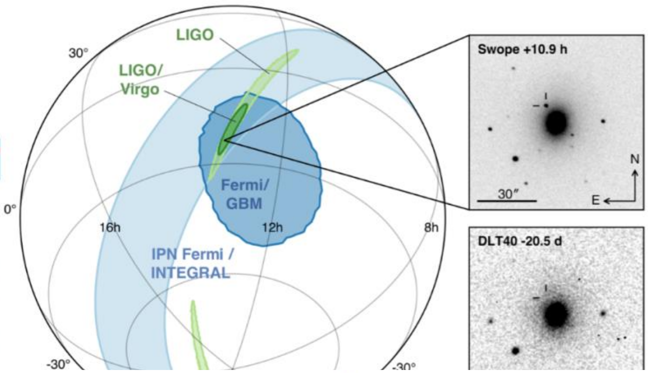
UNPRECEDENTED SURVEY OF THE X/GAMMA-RAY SKY COMBINED WITH AUTONOMOUS NIR FOLLOW-UP CAPABILITY

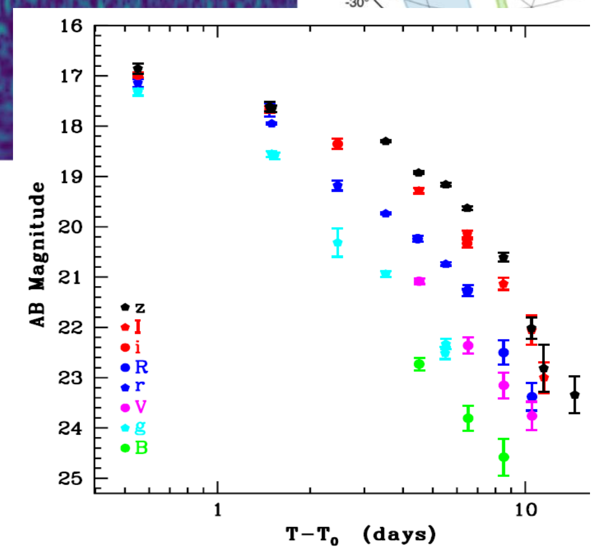


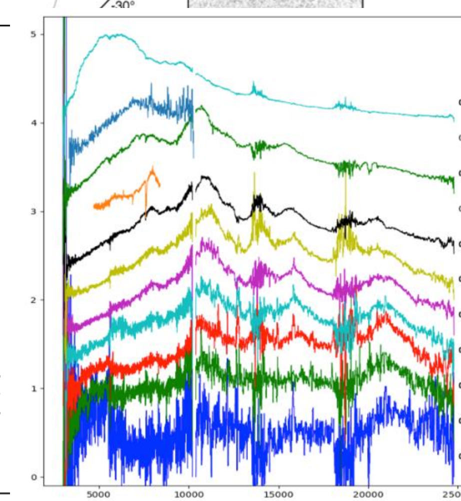
THESEUS AND MULTI-MESSENGER ASTROPHYSICS

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









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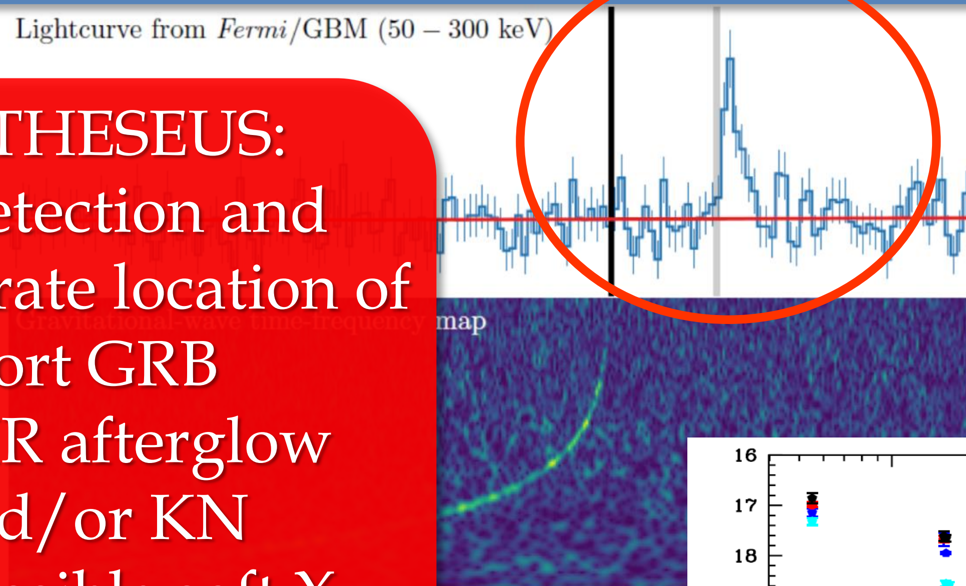
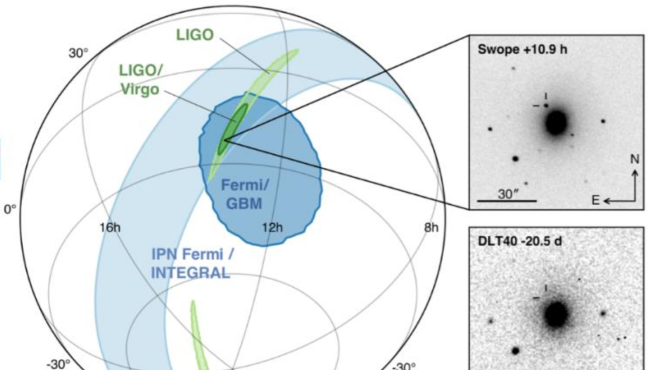
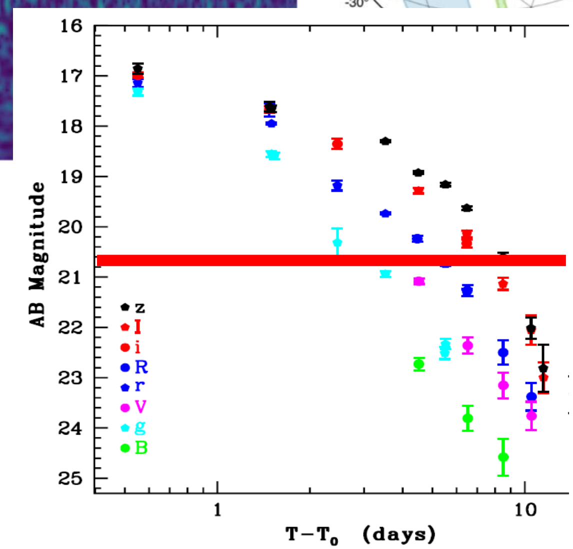
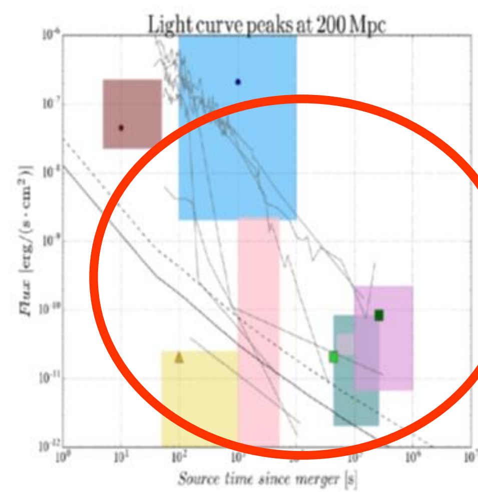


THESEUS: detection and accurate location of

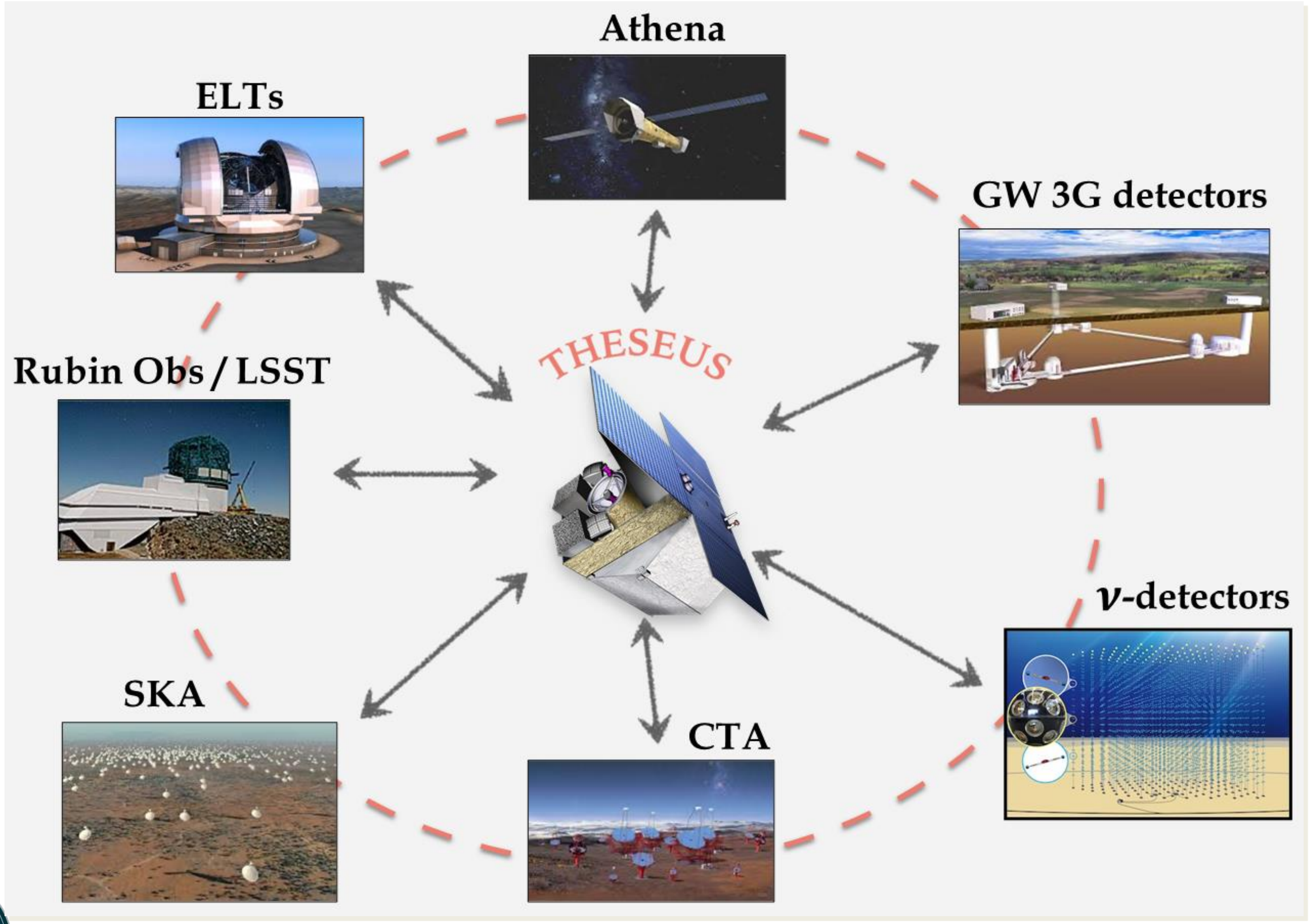
- short GRB
- NIR afterglow and/or KN
- possible soft X-ray emission



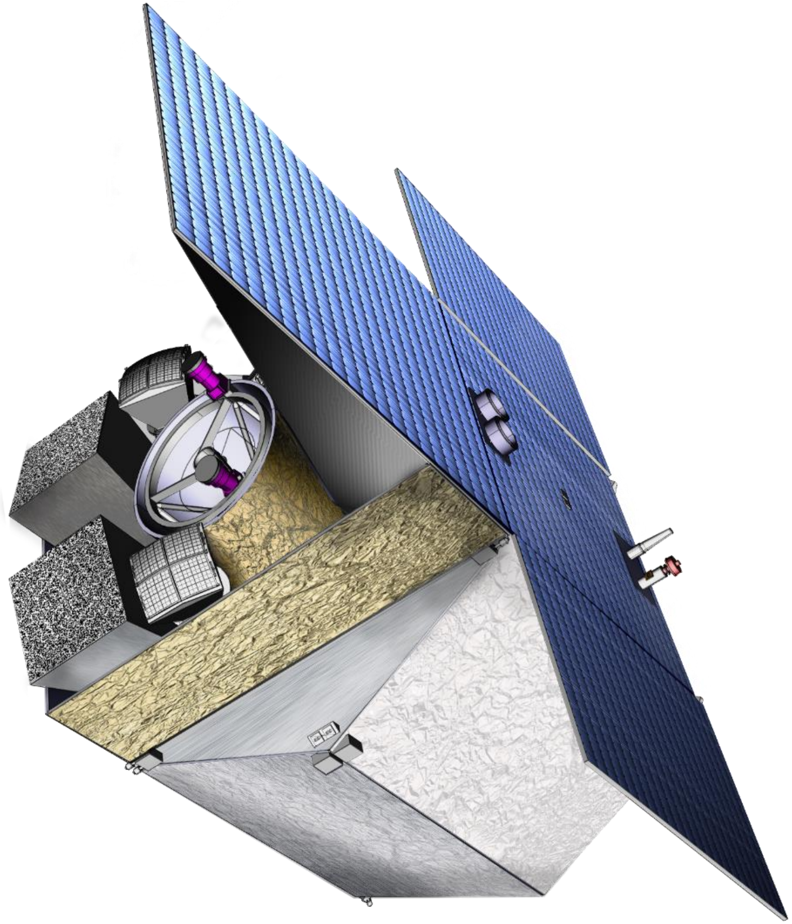




THESEUS CRUCIAL SYNERGIES

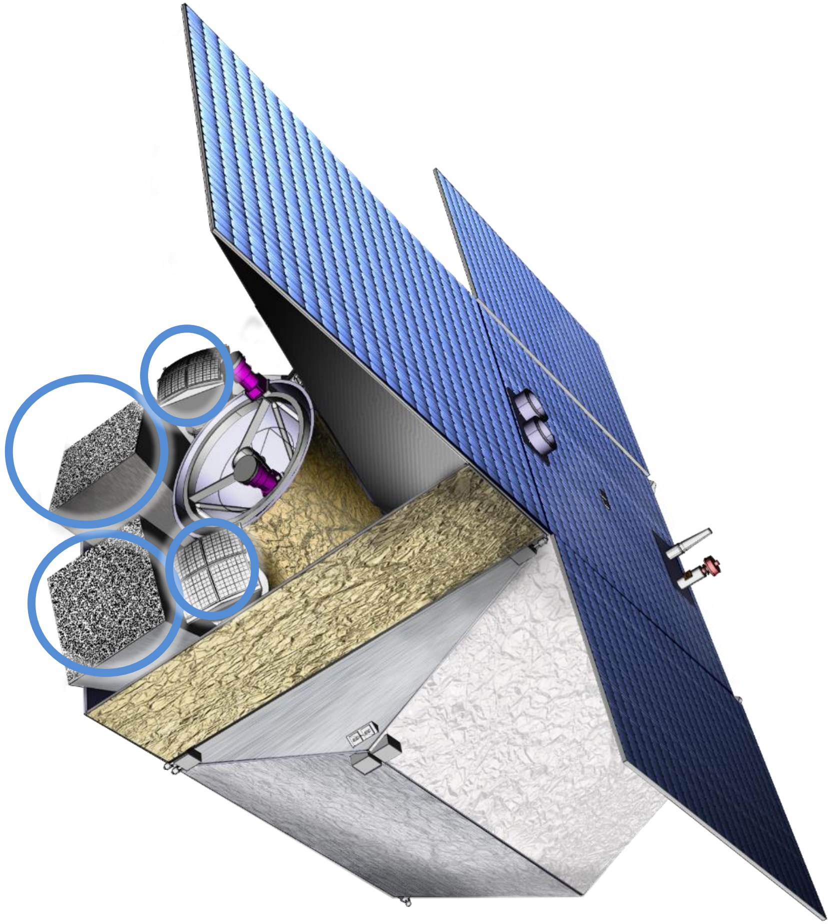


THIS BREAKTHROUGH WILL BE ACHIEVED BY A MISSION CONCEPT OVERCOMING MAIN LIMITATIONS OF CURRENT FACILITIES



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**



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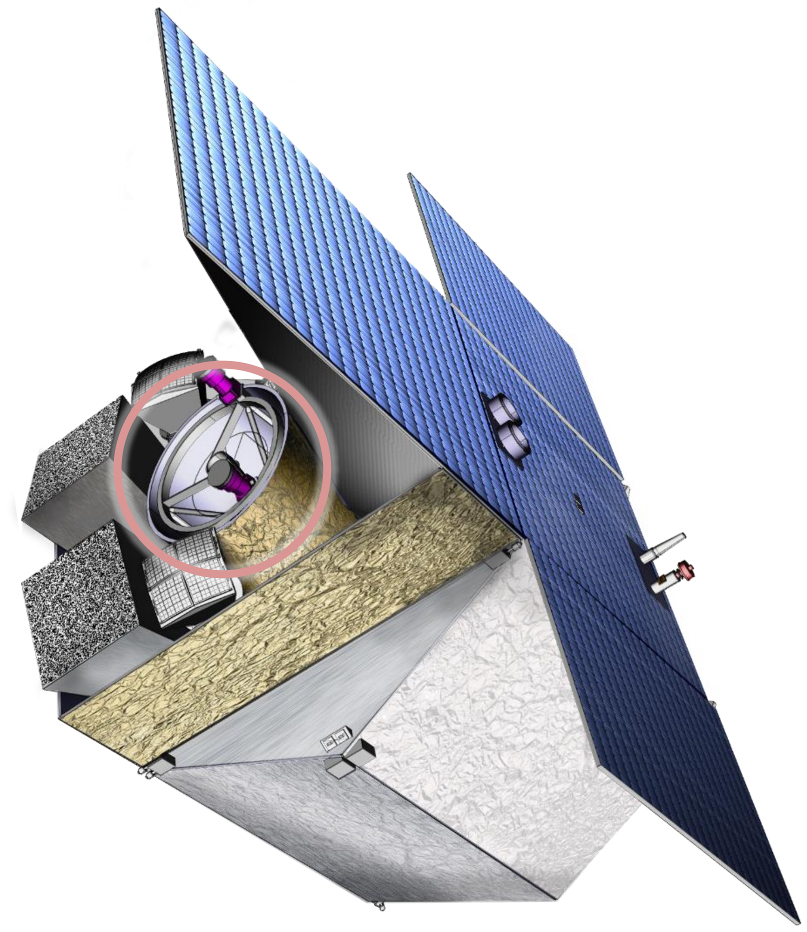
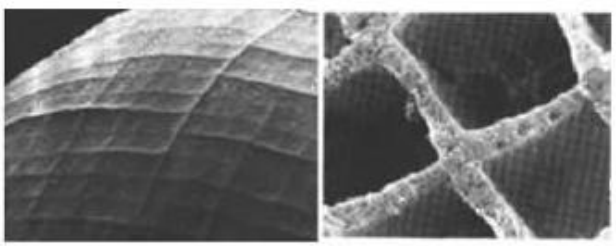
Set of innovative wide-field monitors with **unprecedented combination of broad energy range, sensitivity, FOV and localization accuracy**

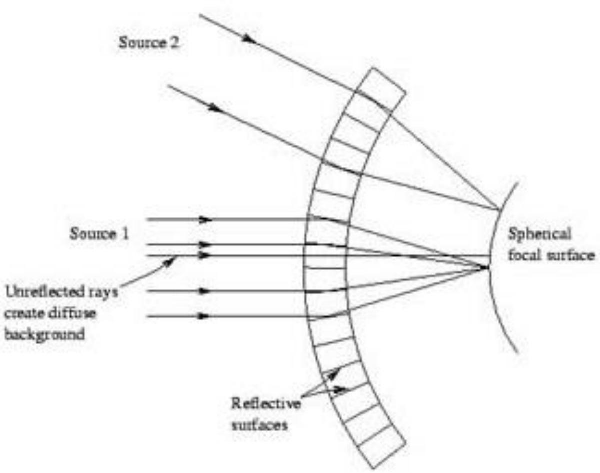
On-board **autonomous fast follow-up** in optical/NIR, arcsec location and **redshift measurement** of detected GRB/transients



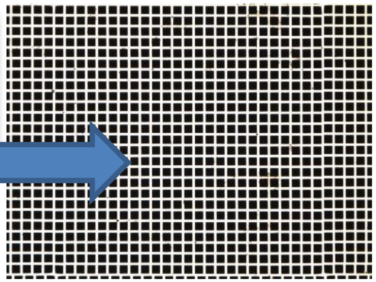
The Soft X-Ray Imager (SXI)

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′



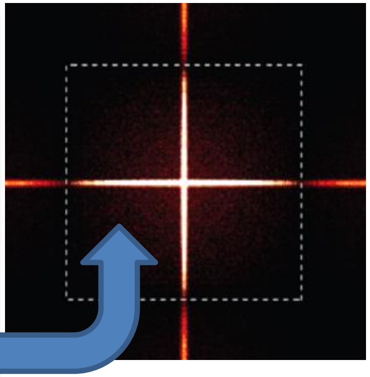


Mimic a lobster-eye using curved, square-pore MPOs



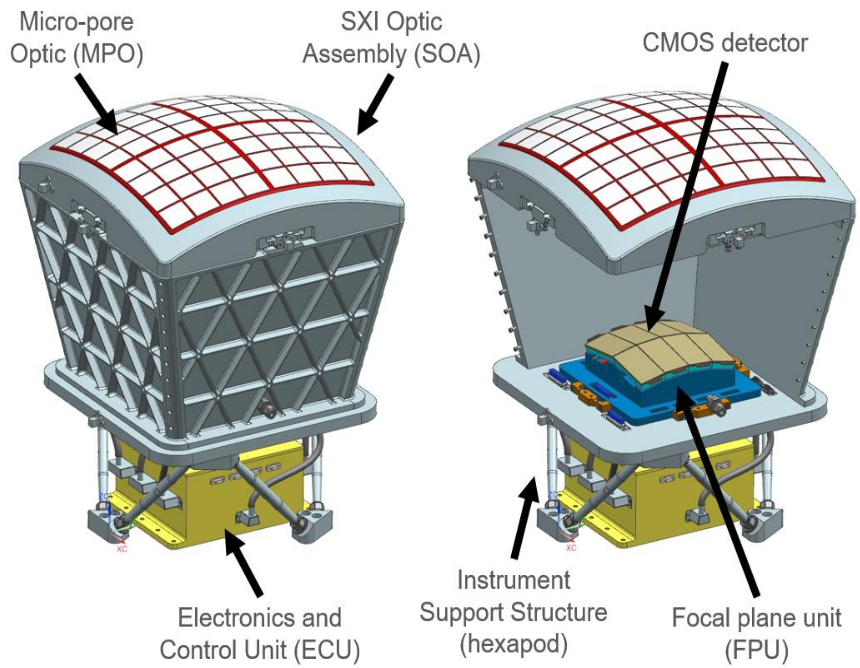
No single optical axis: get a wide field of view plus focusing with constant effective area

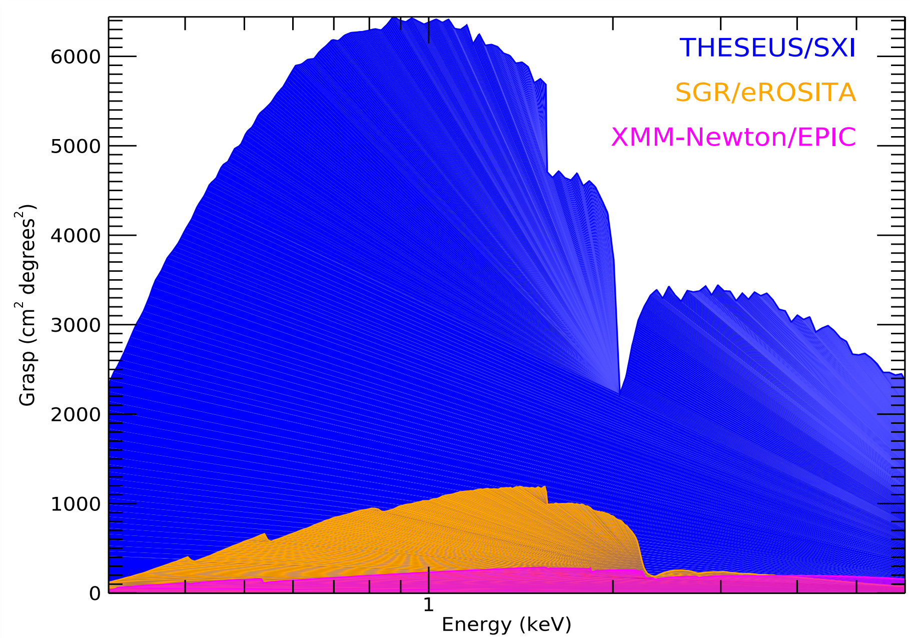
Spot (double reflection)
Lines (single reflections)



The Soft X-Ray Imager (SXI)

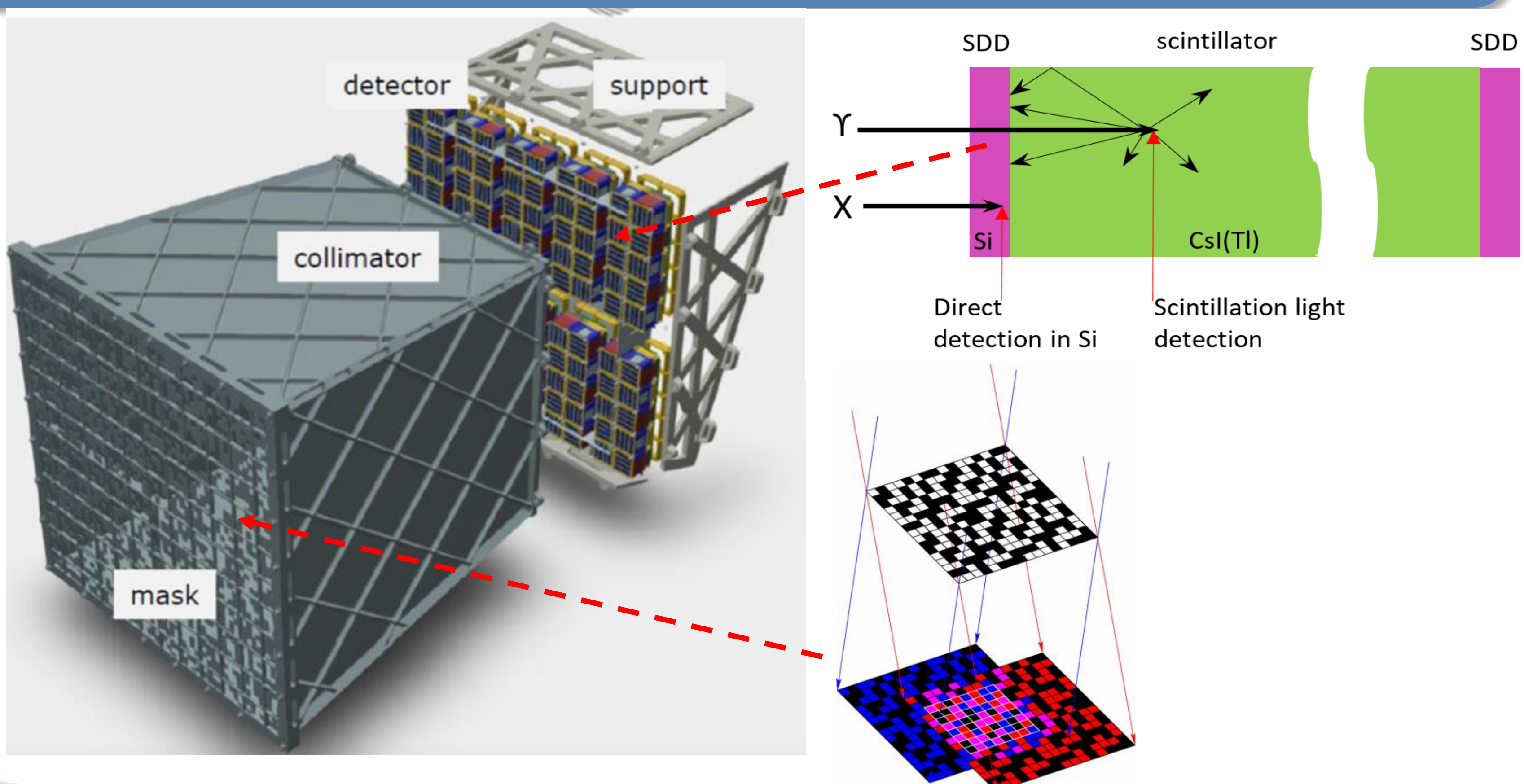
SXI will show a unique combination of FOV and effective area (GRASP), enabling simulatneous detection and localization of many transients in parallel.





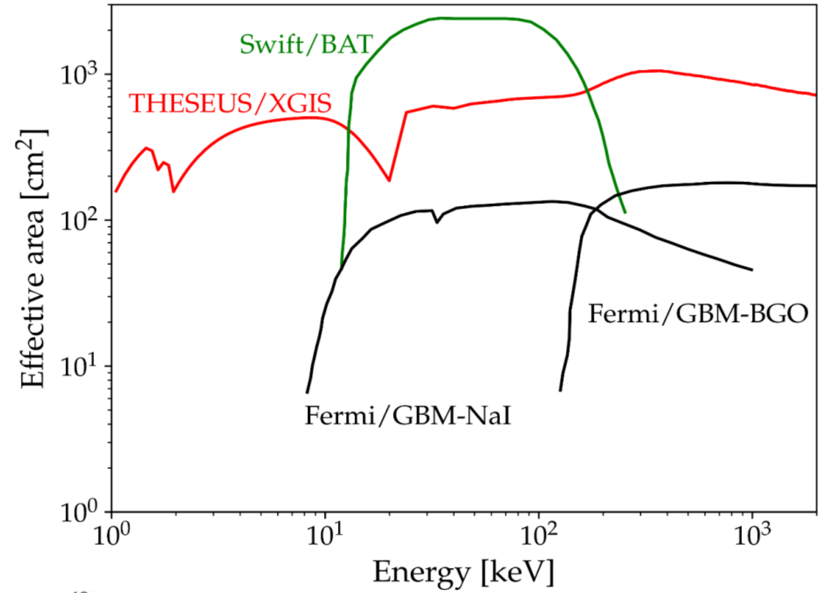
The X-Gamma Ray Imaging Spectrometer (XGIS)

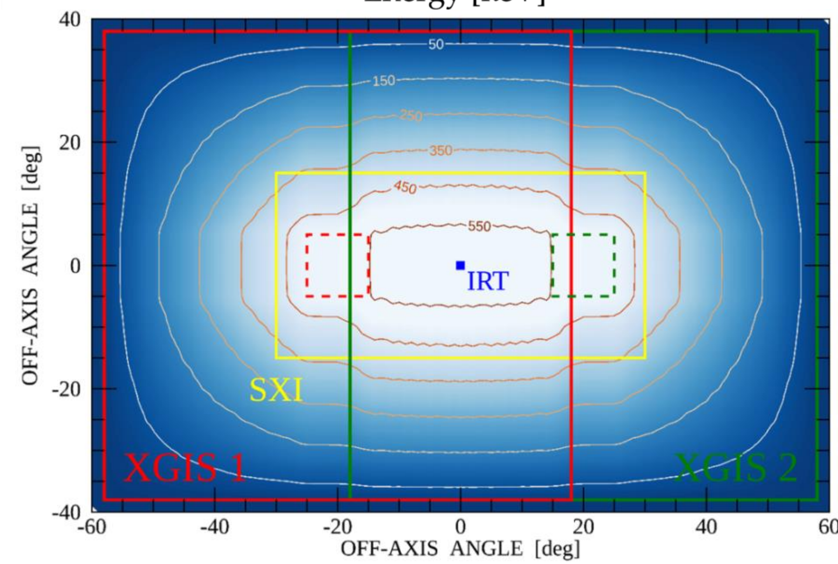
Two coded-mask X-gamma ray cameras using innovative coupling between Silicon drift detectors (2-30 keV) and CsI crystal scintillator bars (20 keV–10 MeV)



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)





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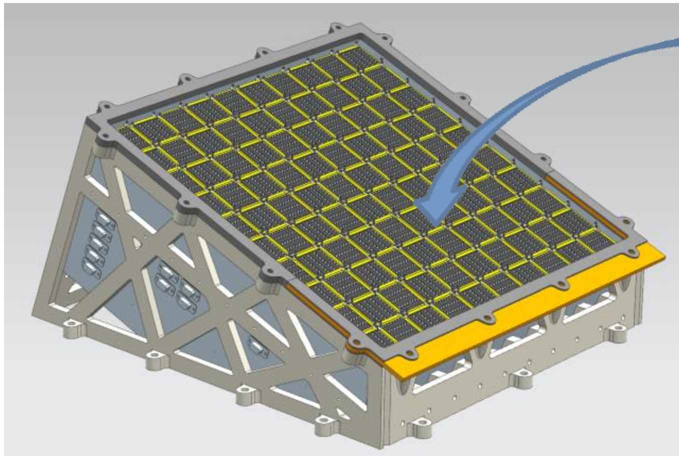
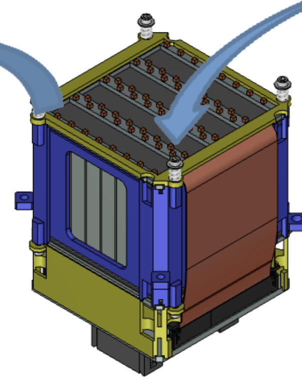
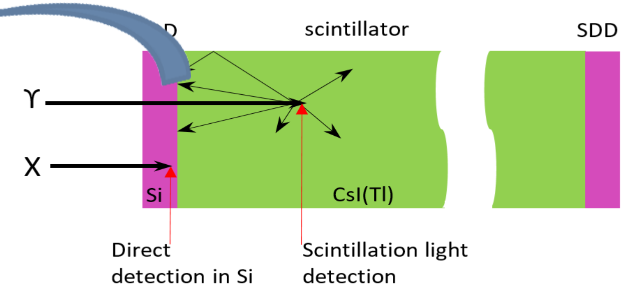
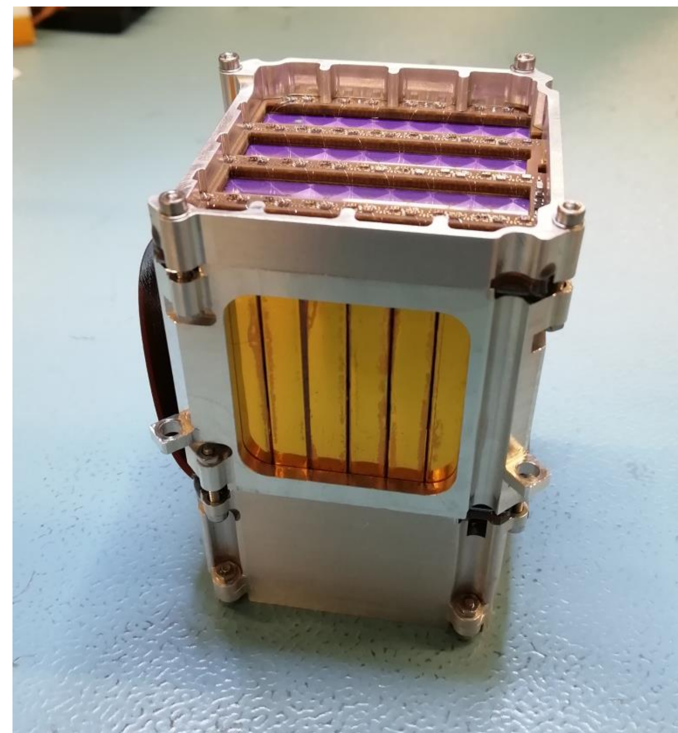






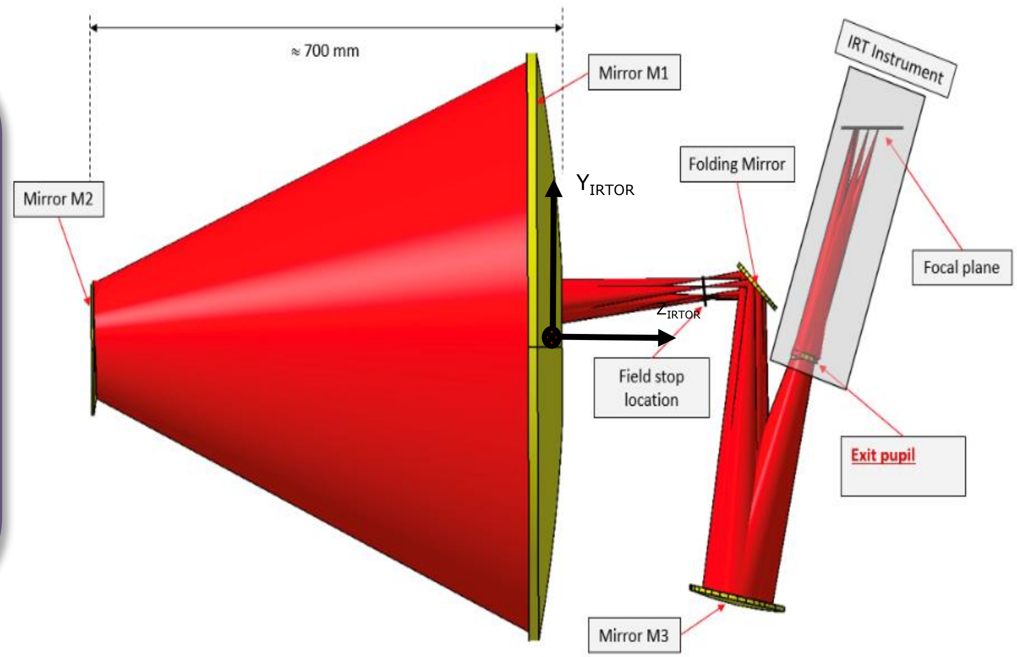
XGIS Phase A study: detection module prototype (ESA-OHB-ESA –INAF/OAS +ASI-INAF partners)



The Infra-Red Telescope (IRT)

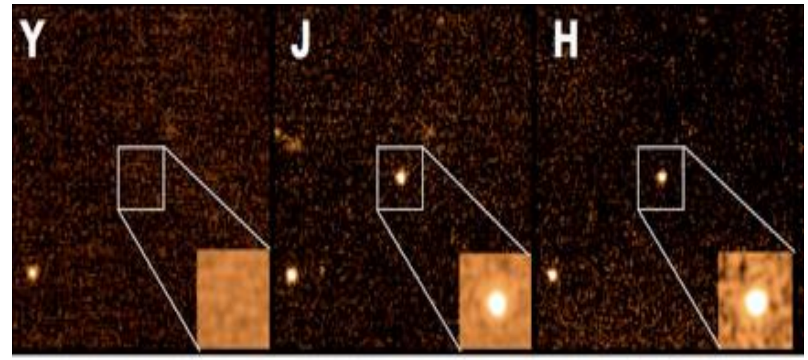
A 0.7 m class telescope with an off-axis Korsch optical design allowing for a large field of view (15′x15′) with imaging and moderate (R~400) spectroscopic capabilities

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

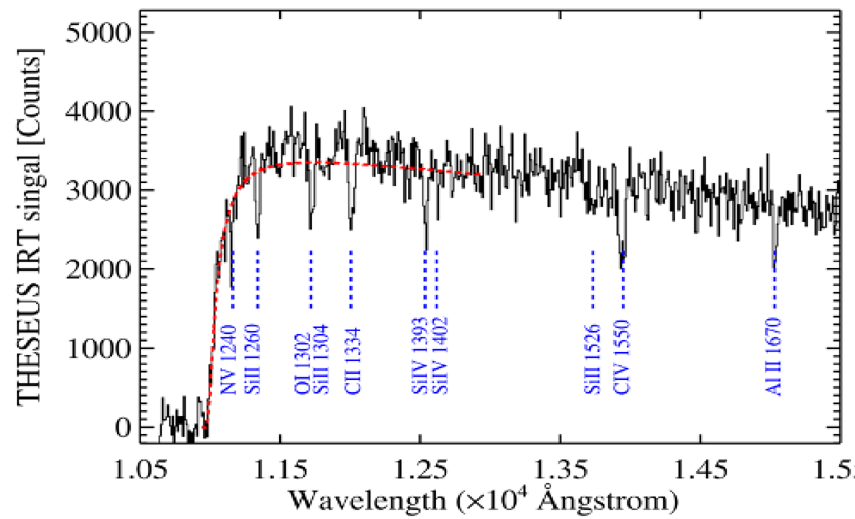


The Infra-Red Telescope (IRT)

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



On-board sensitive absorption spectrosocpy for medium-bright events

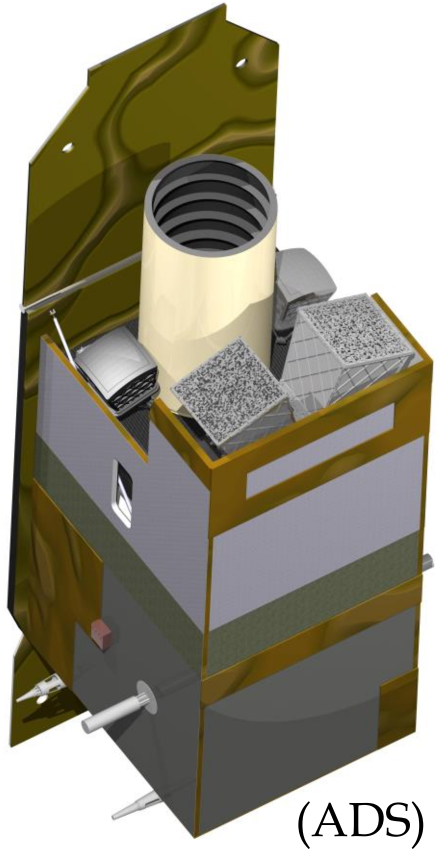


THE SPACECRAFT DESIGN, LAUNCH, AND ORBIT

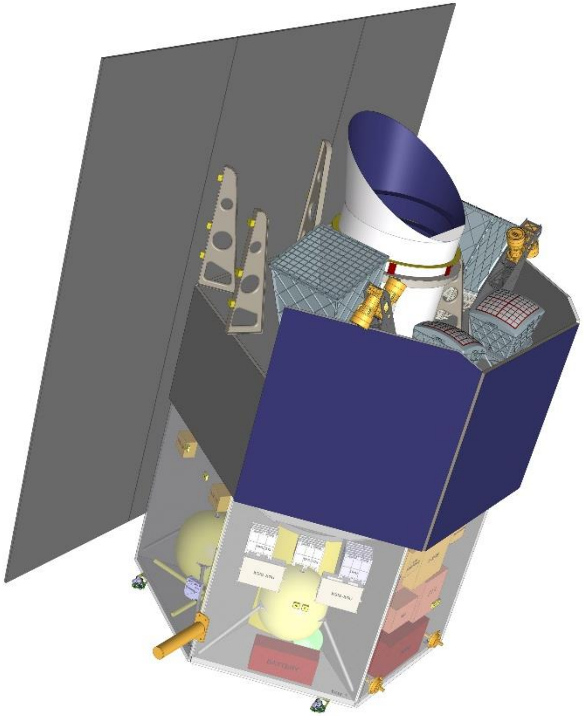
Fast slewing capability (>10°/min), granting prompt NIR follow-up of GRBs and transients

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

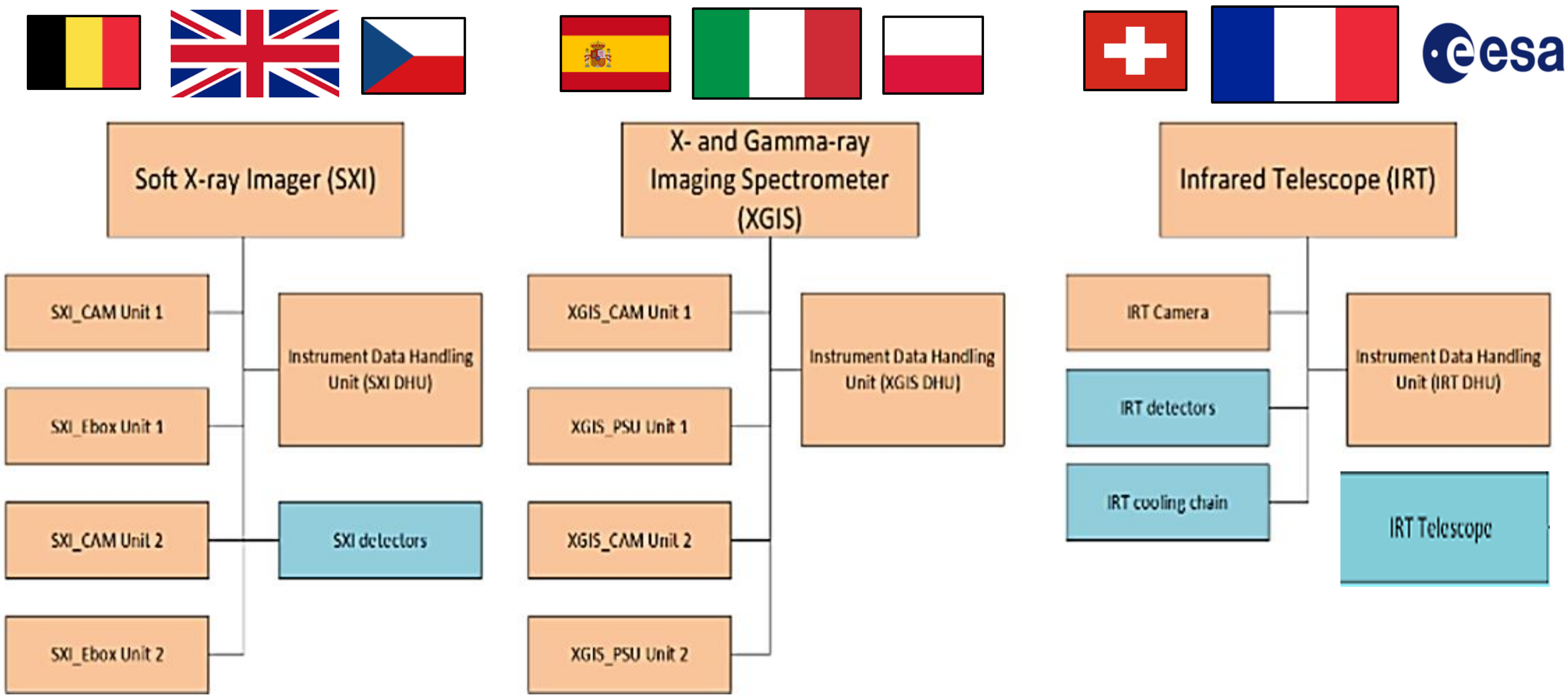


(ADS)



(THALES)

THESEUS consortium responsibilities (Lead: ITALY)

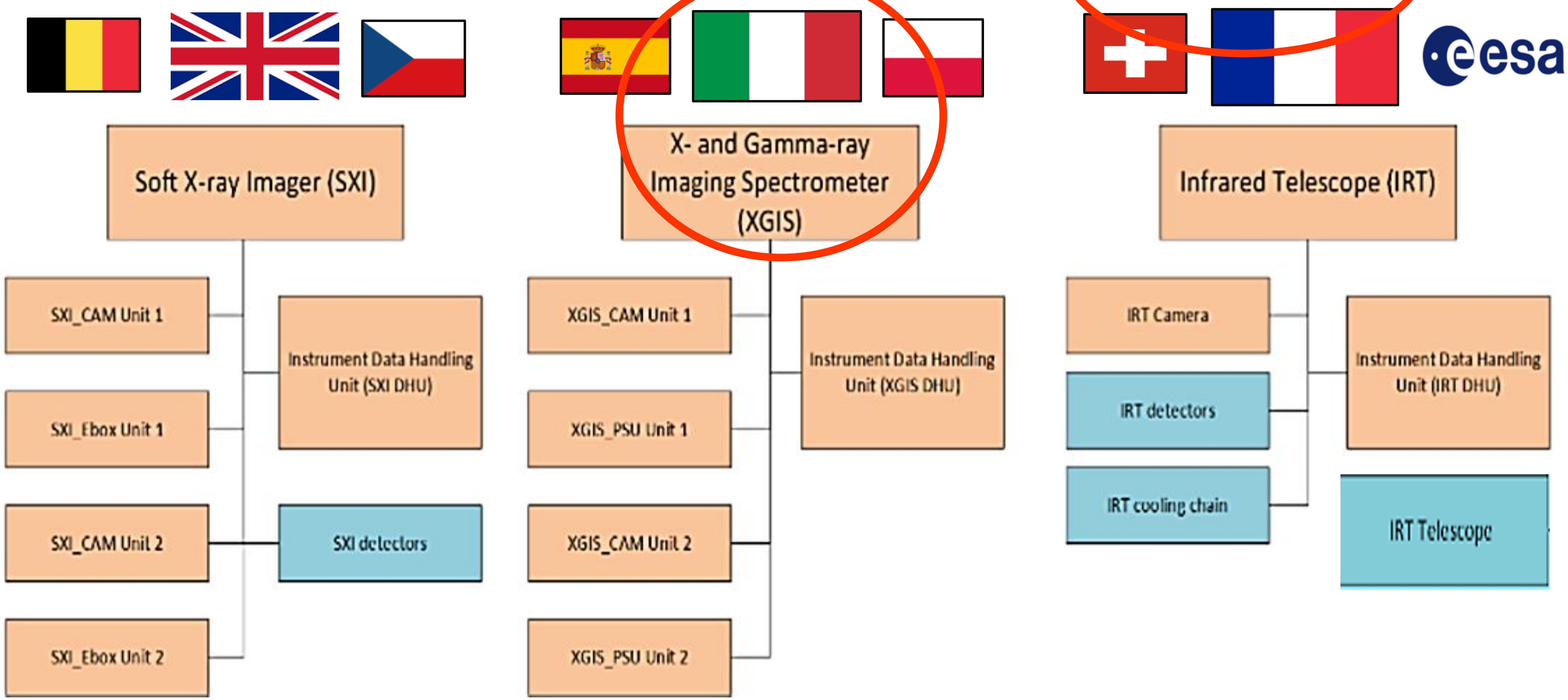


Instruments Data Handling Units

Science Data Centre

Main ground station (ASI/Malindi)

THESEUS consortium responsibilities (Lead: ITALY)

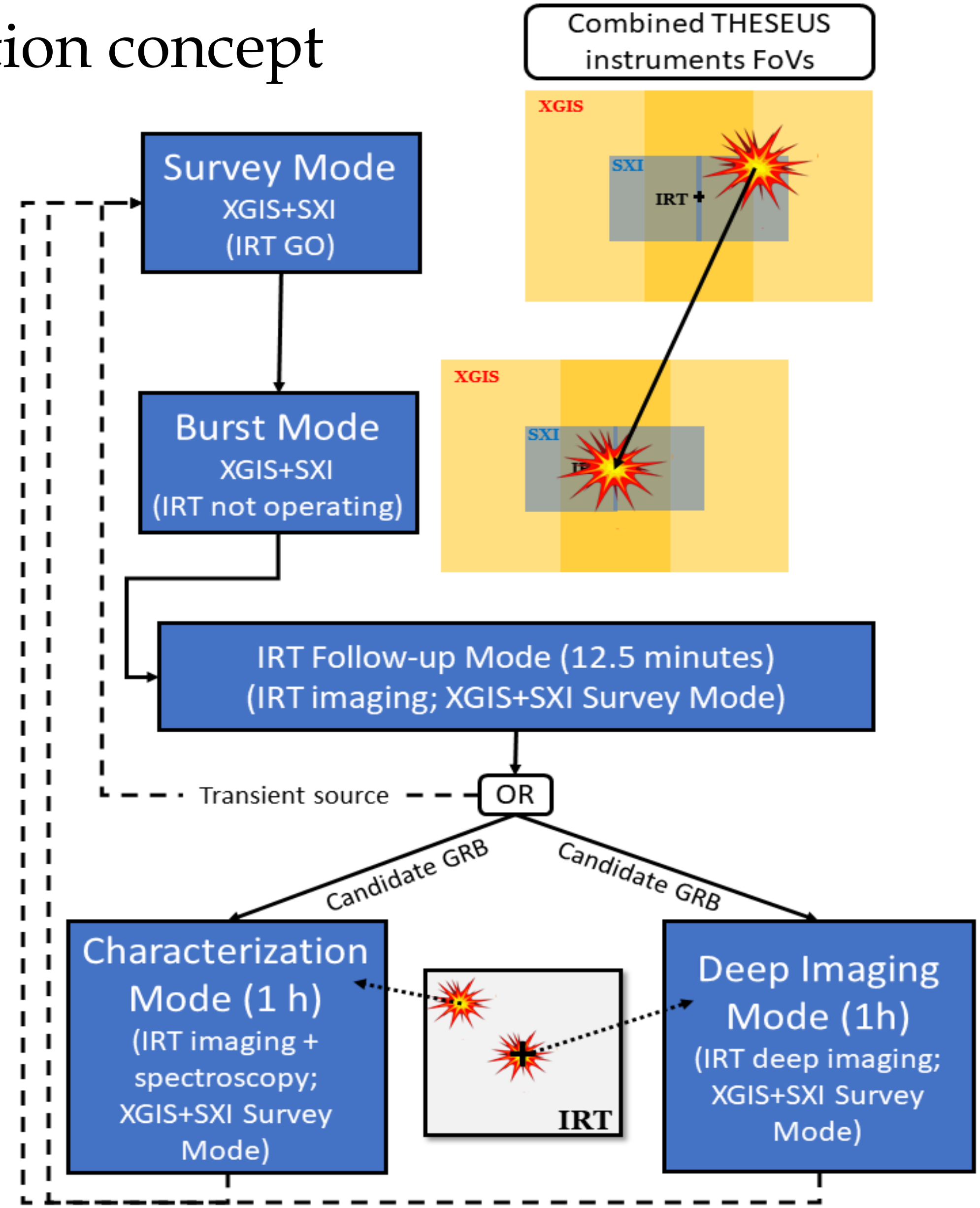


Instruments Data Handling Units

Science Data Centre

Main ground station (ASI/Malindi)

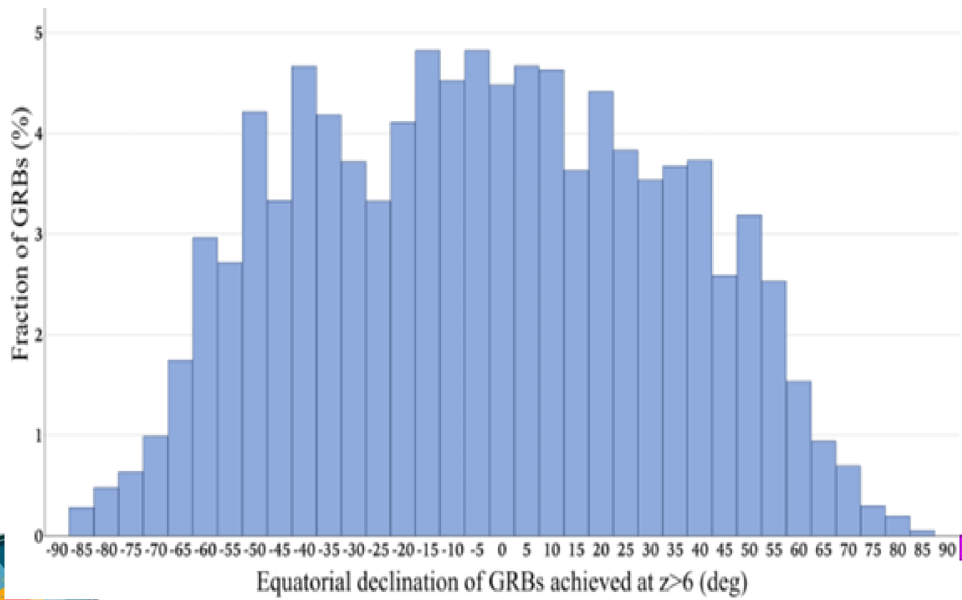
Mission operation concept

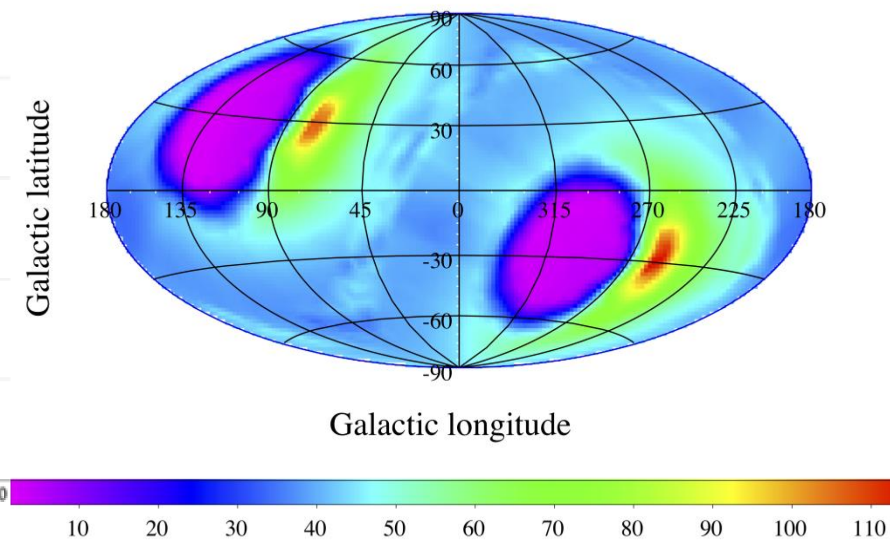


THESEUS pointing strategy in survey (GRB hunting) mode

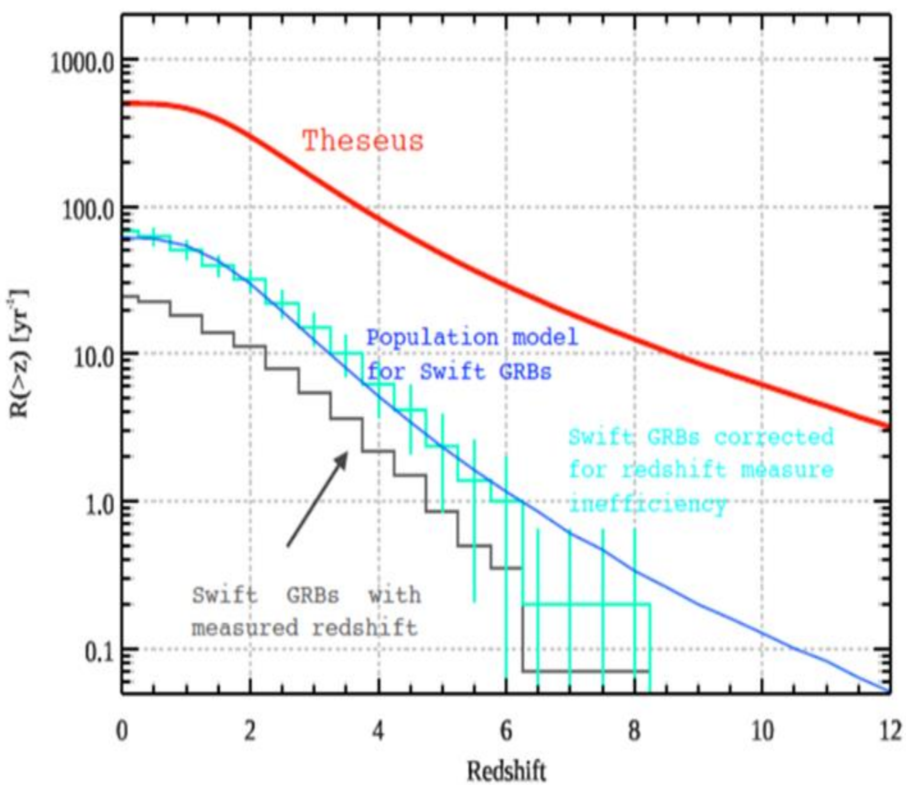
Different pointing strategies investigated through sophisticated Mission Observation Simulator

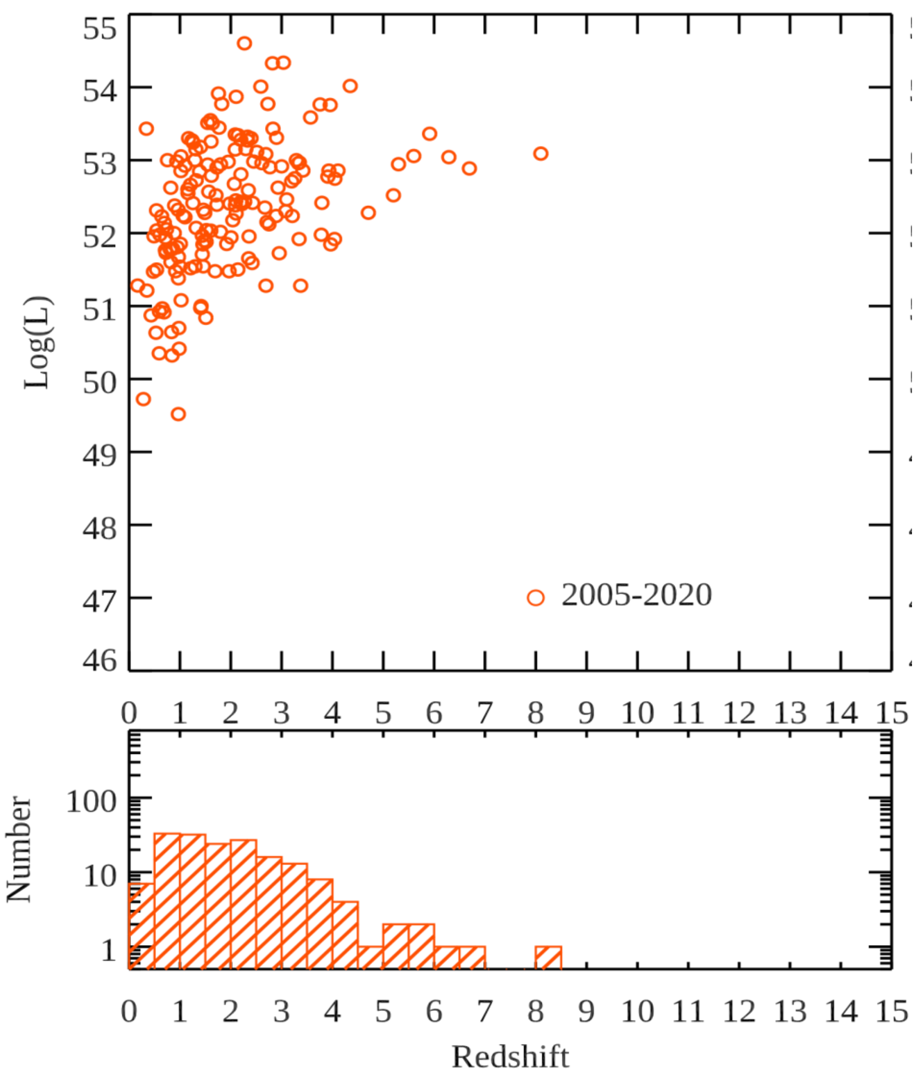
Optimization of combined SXI+XGIS+IRT detection efficiency, sky exposure, follow-up from ground





Shedding light on the early Universe with THESEUS





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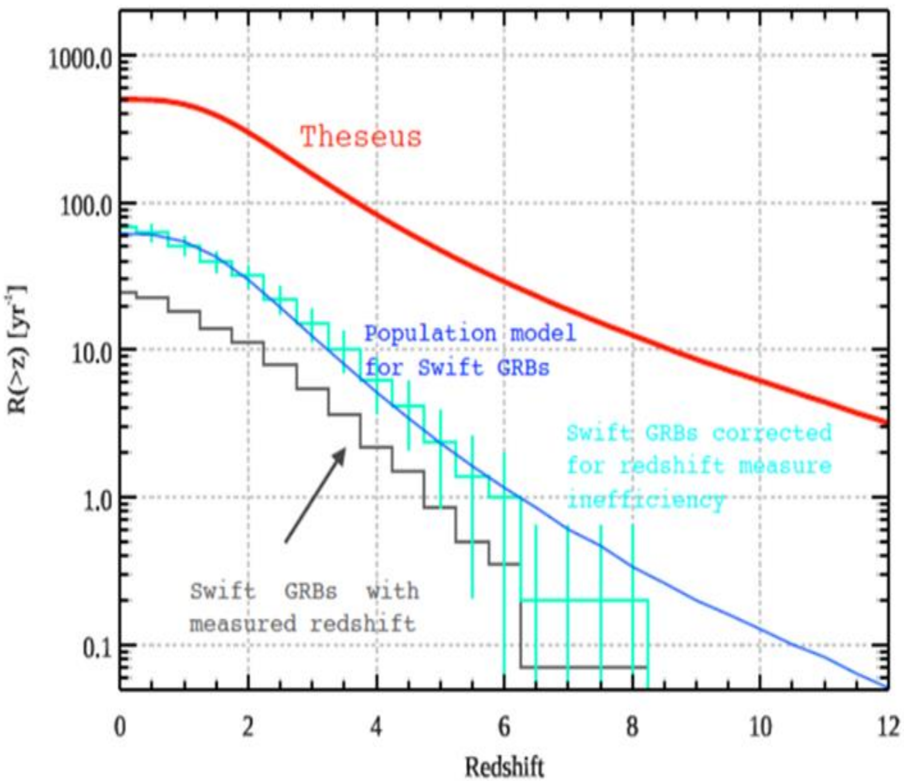
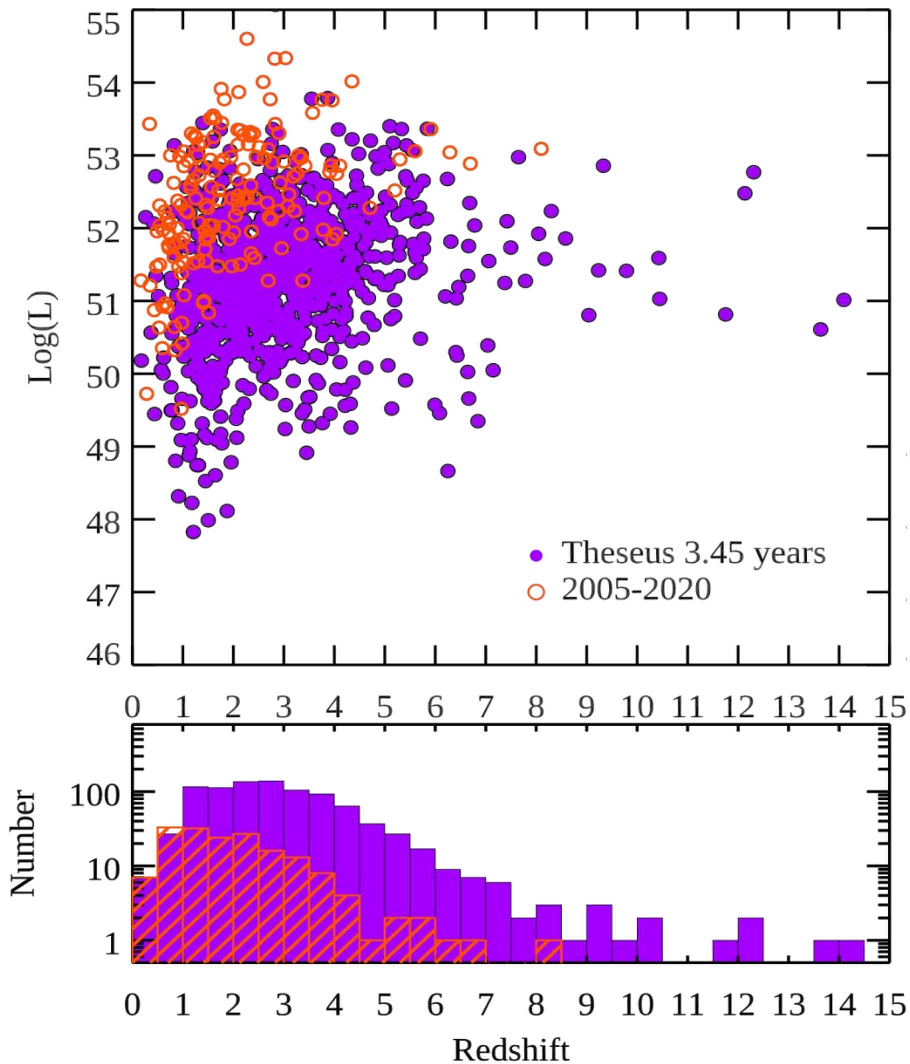
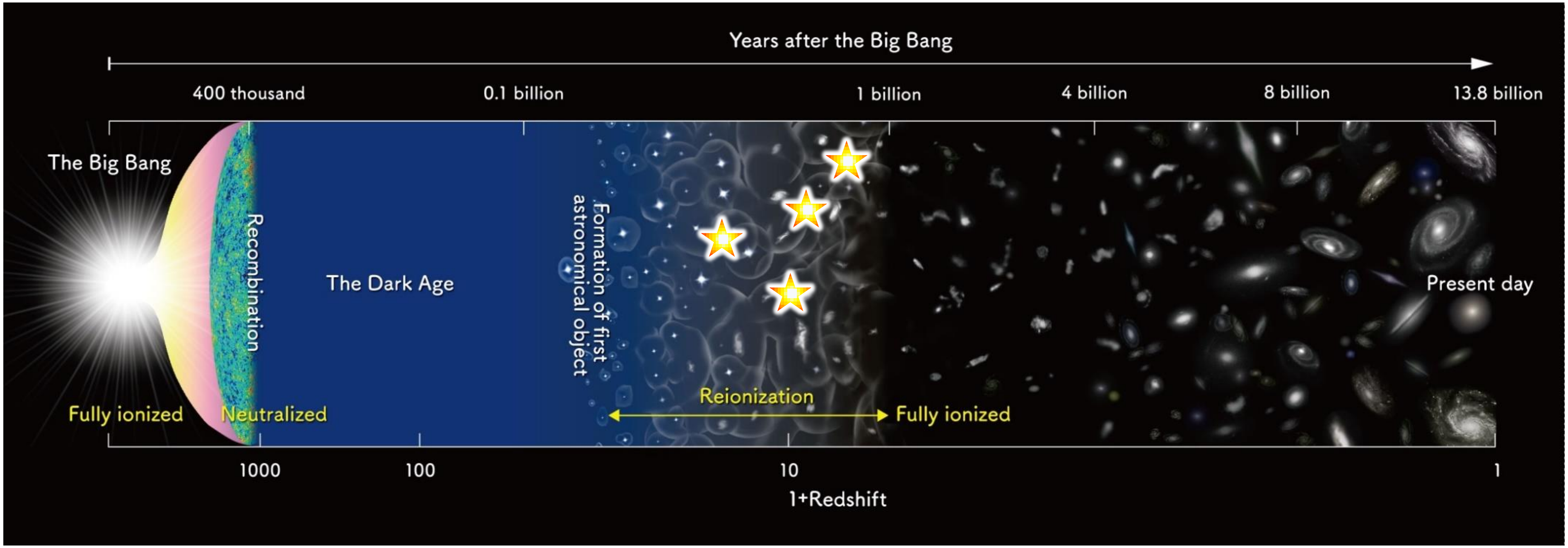


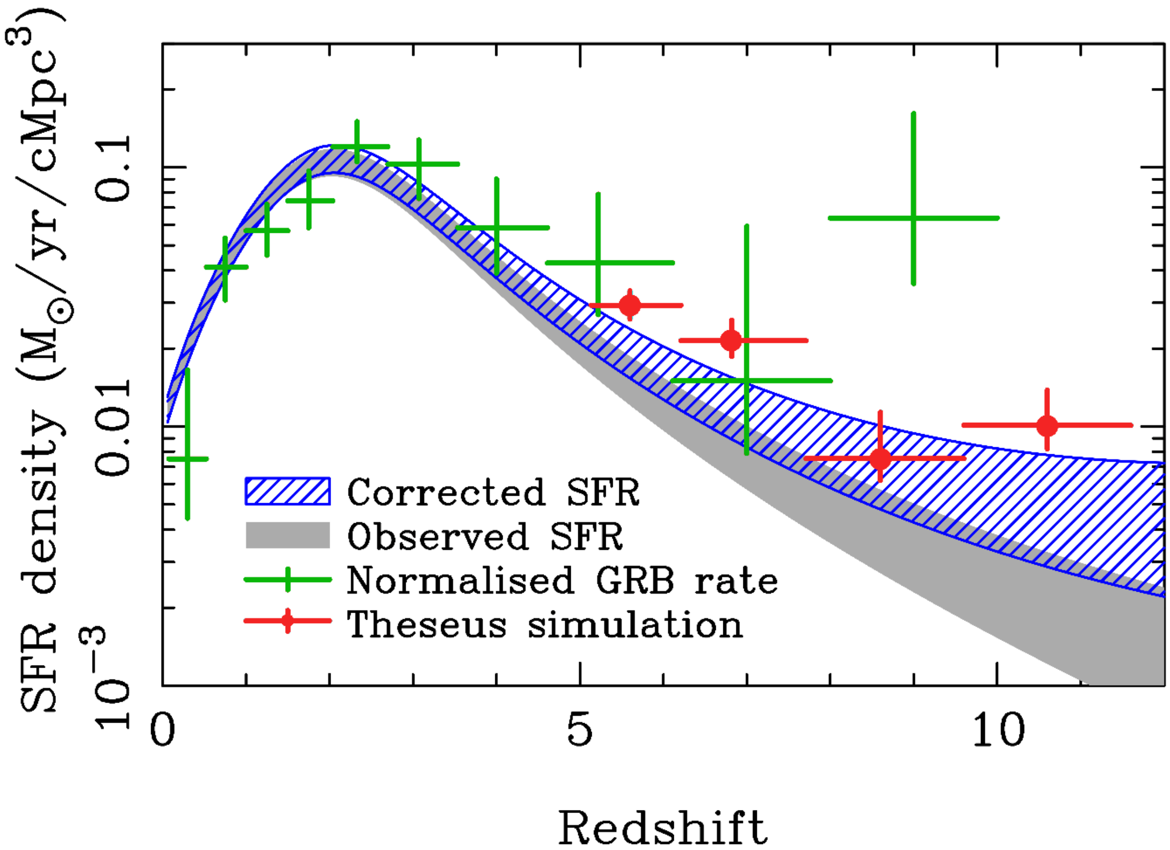


Investigating the first collapsed cosmic objects - primordial stars and galaxies – in the early Universe with long-GRBs



GRBs: pinpoint the locations of massive star formation back to cosmic dawn, allowing detailed spectroscopic studies of even very faint galaxies

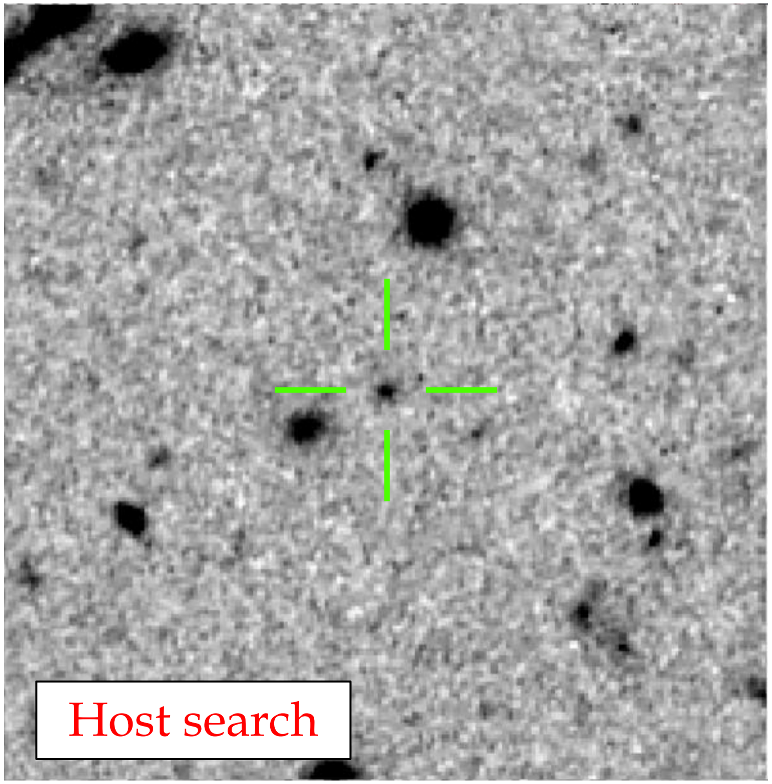
INDEPENDENT MEASURE OF COSMIC STAR FORMATION RATE



A statistical sample of high–z GRBs will give access to star formation in the faintest galaxies, overcoming limits of current and future galaxy surveys

DETECTING AND STUDYING PRIMORDIAL INVISIBLE GALAXIES THROUGH HIGH-Z GRBS

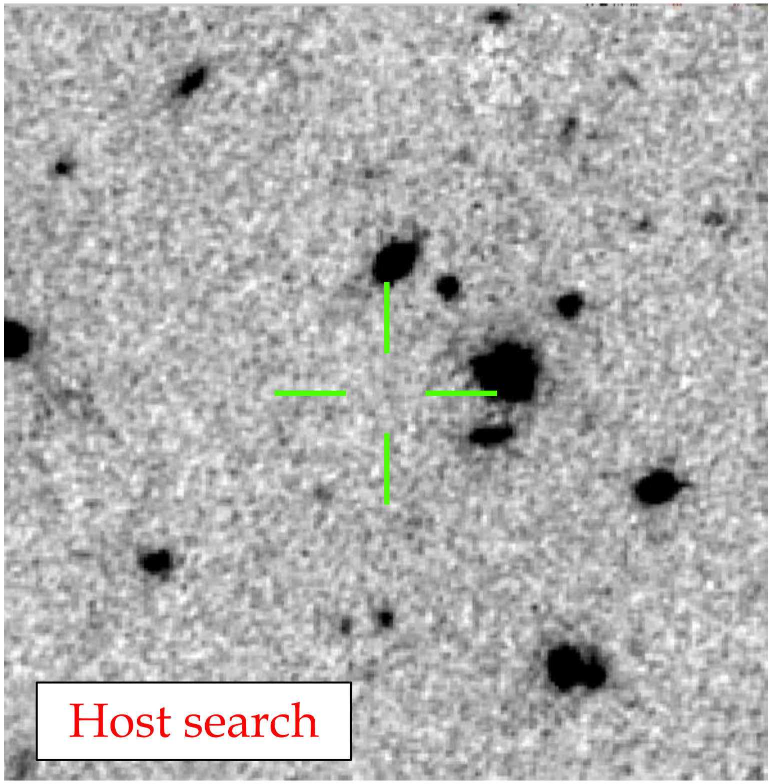
GRB 130606A



In some cases, deep HST follow-up has revealed faint hosts at z ~ 6

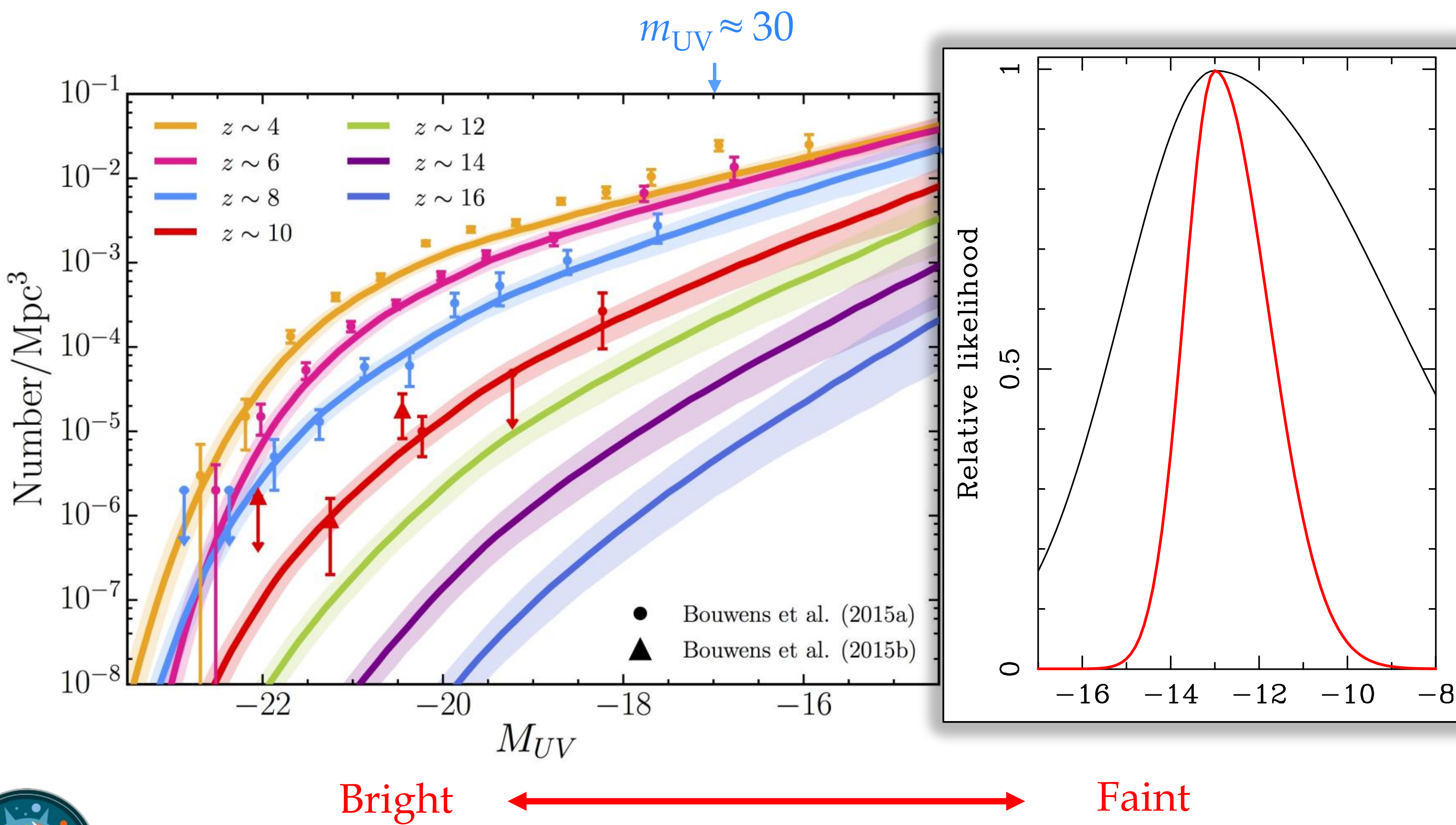
DETECTING AND STUDYING PRIMORDIAL INVISIBLE GALAXIES THROUGH HIGH-Z GRBS

GRB 120521C



But majority of z > 6 hosts remain undetected, confirming that most star formation is in intrinsically faint primordial galaxies in that era

The proportion of GRB hosts below a given detection limit provides an estimate of the fraction of star formation "hidden" in such faint galaxies

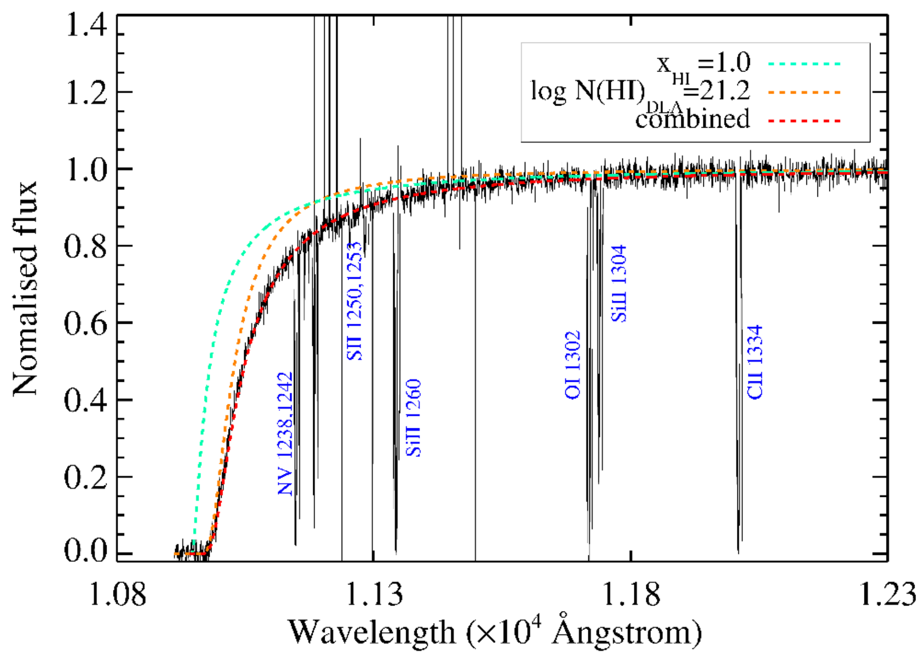


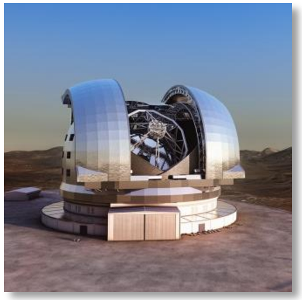
AFTERGLOW SPECTROSCOPY – THESEUS SAMPLES WILL REVEAL:

- Metallicity of the ISM and IGM ➞ cosmic chemical evolution
- Detailed abundance patterns ➞ signatures of earlier generations
- Time variability ➞ structure/depth of ISM along line of sight

Simulated ELT spectrum of $z = 8$ afterglow

Metals + HI column in host and IGM





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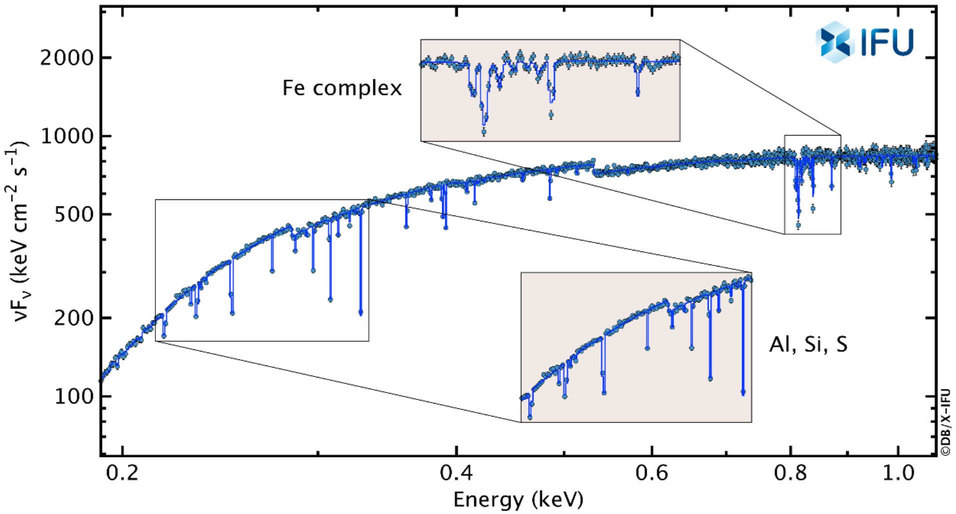
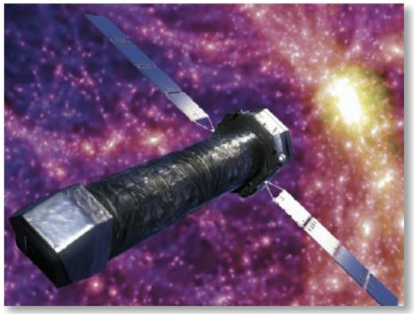


Athena-THESEUS synergy white paper
https://www.isdc.unige.ch/theseus/wp.pdf

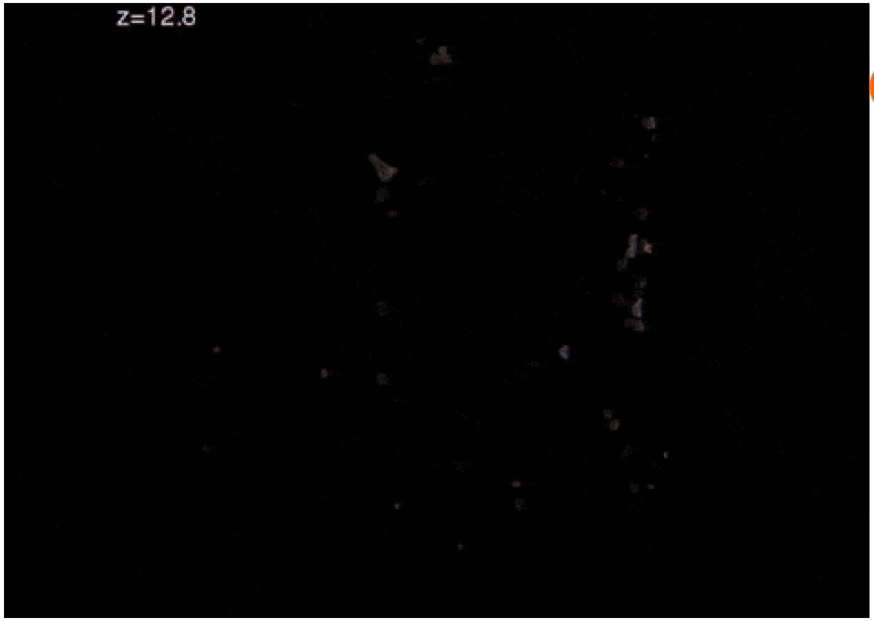


X-ray spectroscopy with Athena will reveal high ionization species e.g. gas proximate to the GRB

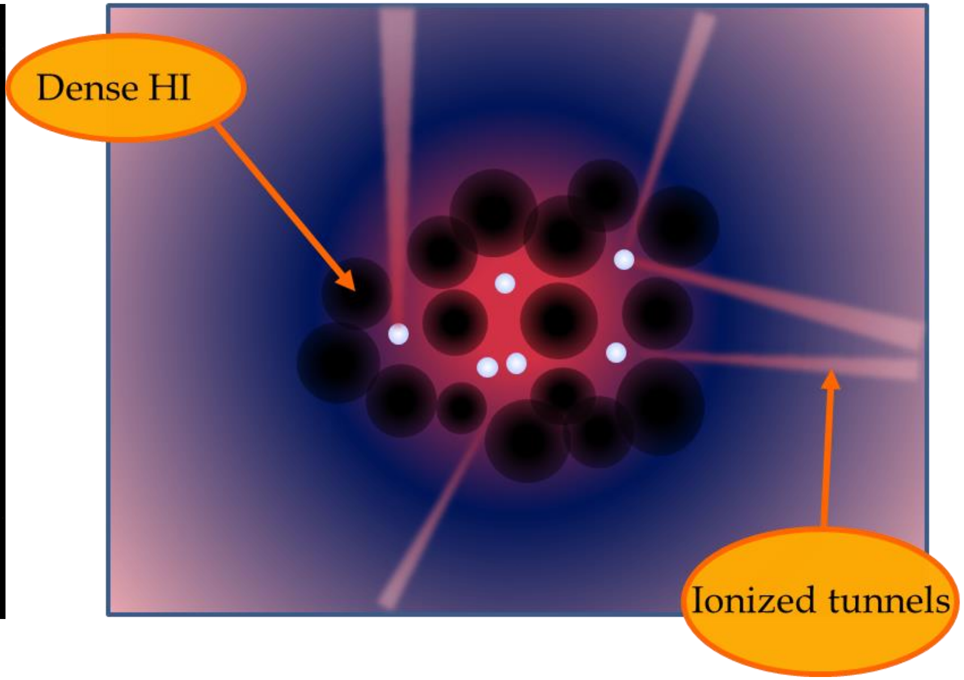
AFTERGLOW SPECTROSCOPY – THESEUS SAMPLES WILL REVEAL:

Distribution of neutral hydrogen fraction of intergalactic medium as a function of redshift, including estimation of sizes of any local ionized bubble

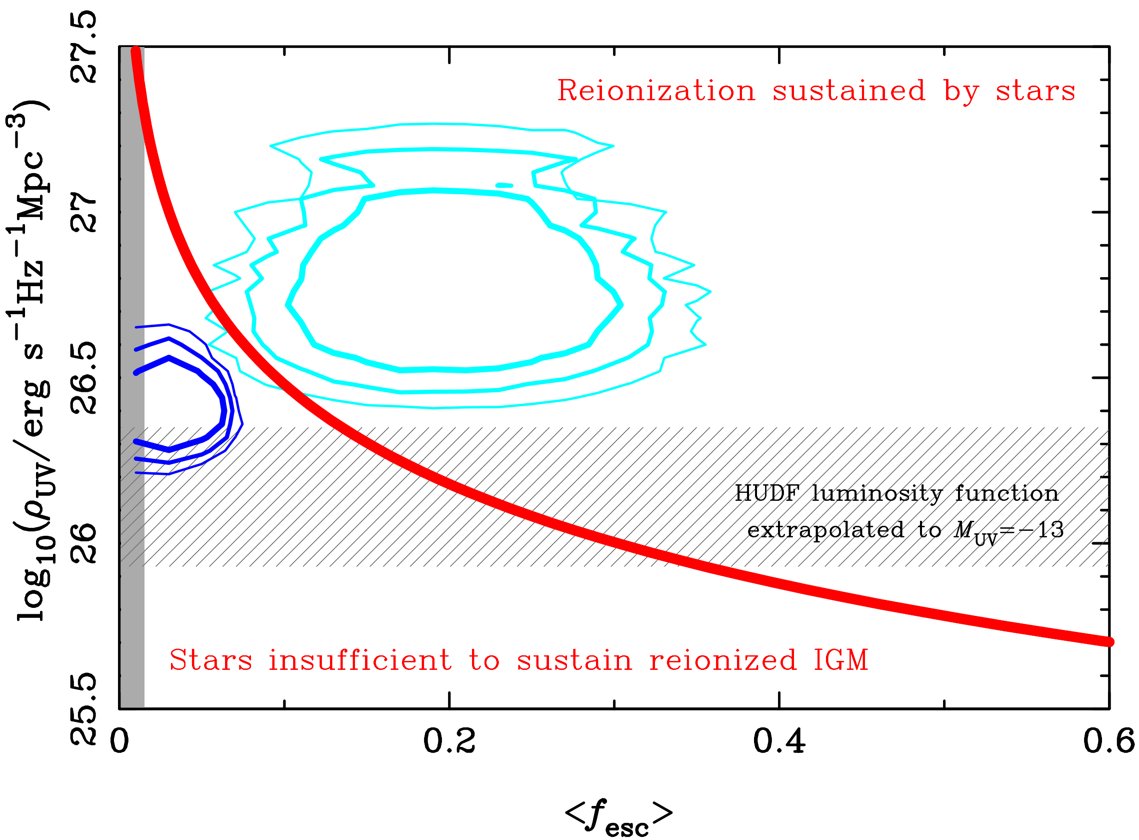
Opacity of host interstellar medium gas to ionizing radiation, average escape fraction of ionizing radiation



Alvarez et al.

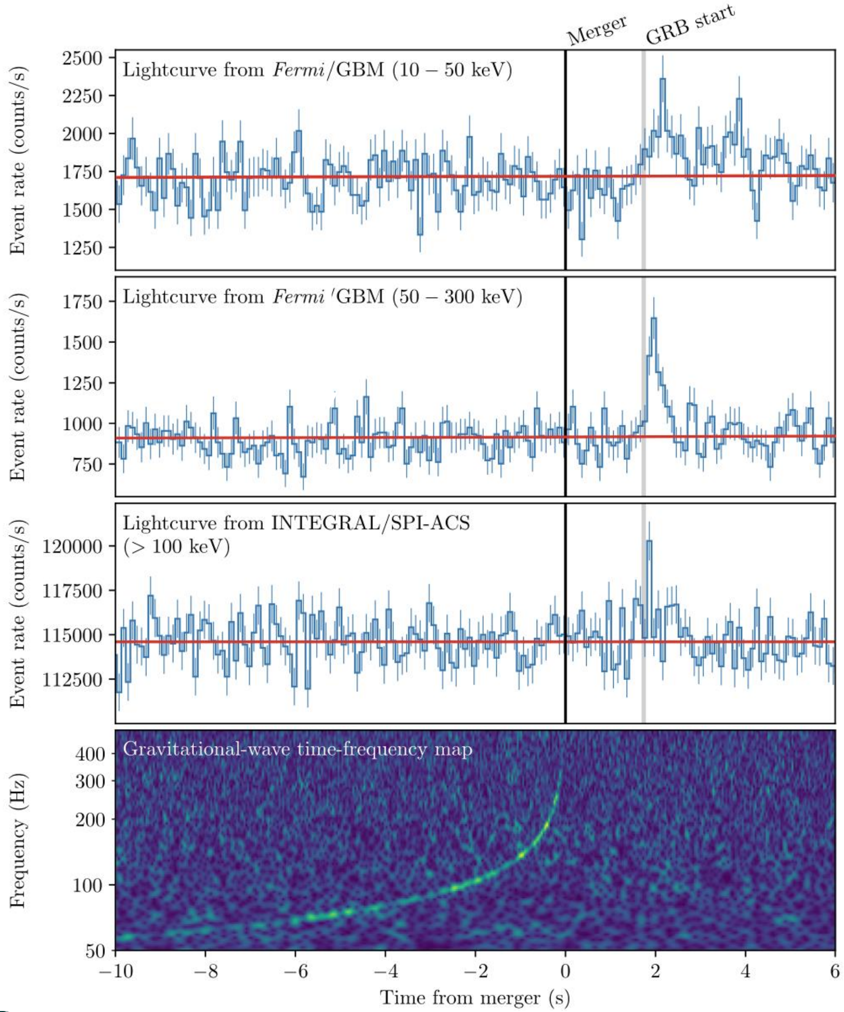


AFTERGLOW SPECTROSCOPY – THESEUS SAMPLES WILL REVEAL:



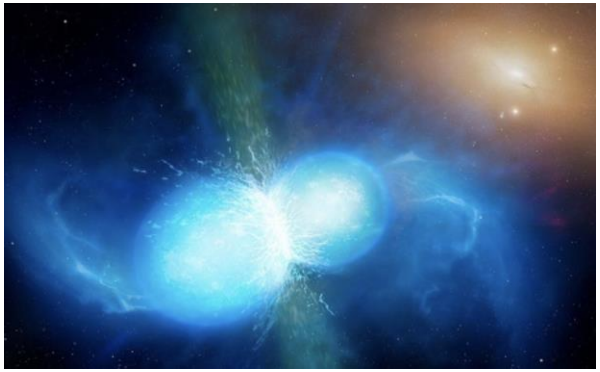
Combination of massive star formation rate and ionizing escape fraction will establish whether stellar radiation was sufficient to reionize the universe, and indicate the galaxy populations responsible

GW170817 + SHORT GRB 170817A + KN AT2017GFO
THE BIRTH OF MULTI-MESSENGER ASTROPHYSICS

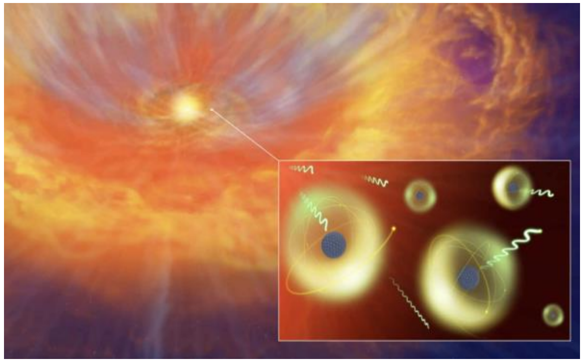


GW170817 + SHORT GRB 170817A + KN AT2017GFO
THE BIRTH OF MULTI-MESSENGER ASTROPHYSICS

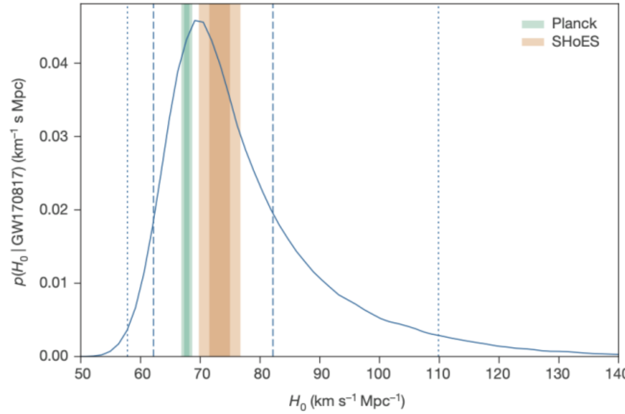
Relativistic jet formation, equation of state, fundamental physics



Cosmic sites of r-process nucleosynthesis

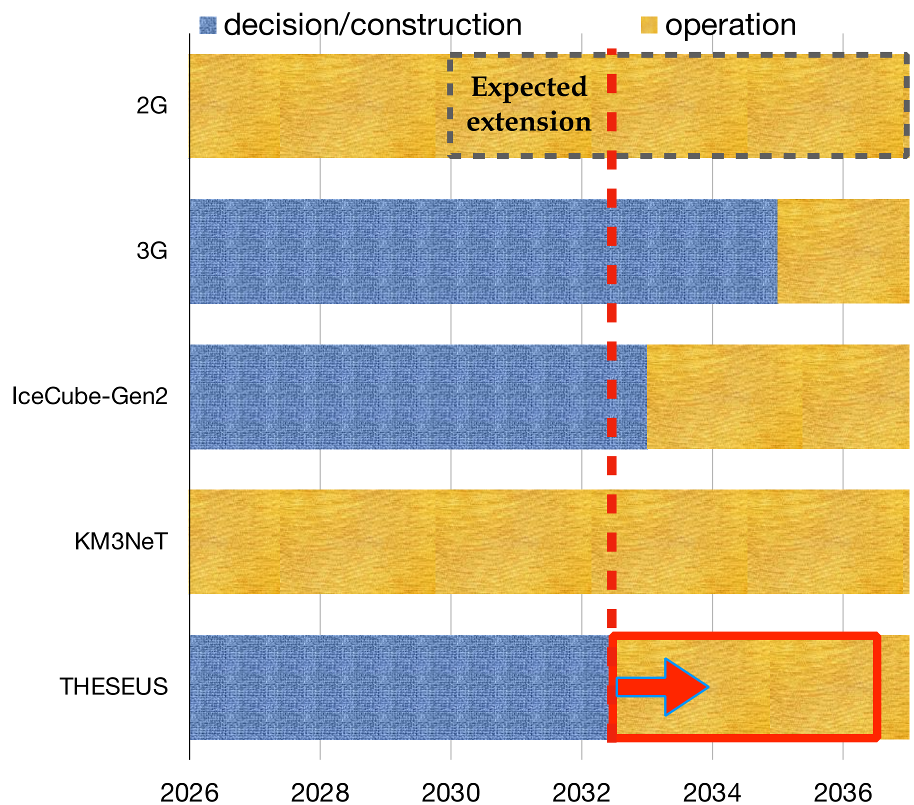


New independent route to measure cosmological parameters

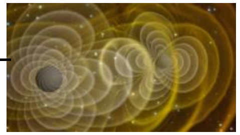


THESEUS IN THE GOLDEN ERA OF MULTI-MESSENGER ASTROPHYSICS

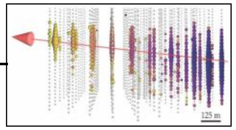
THESEUS synergy with future GW and neutrino facilities will enable transformational investigations of multi-messenger sources

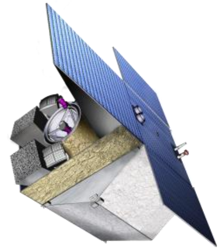


Gravitational waves



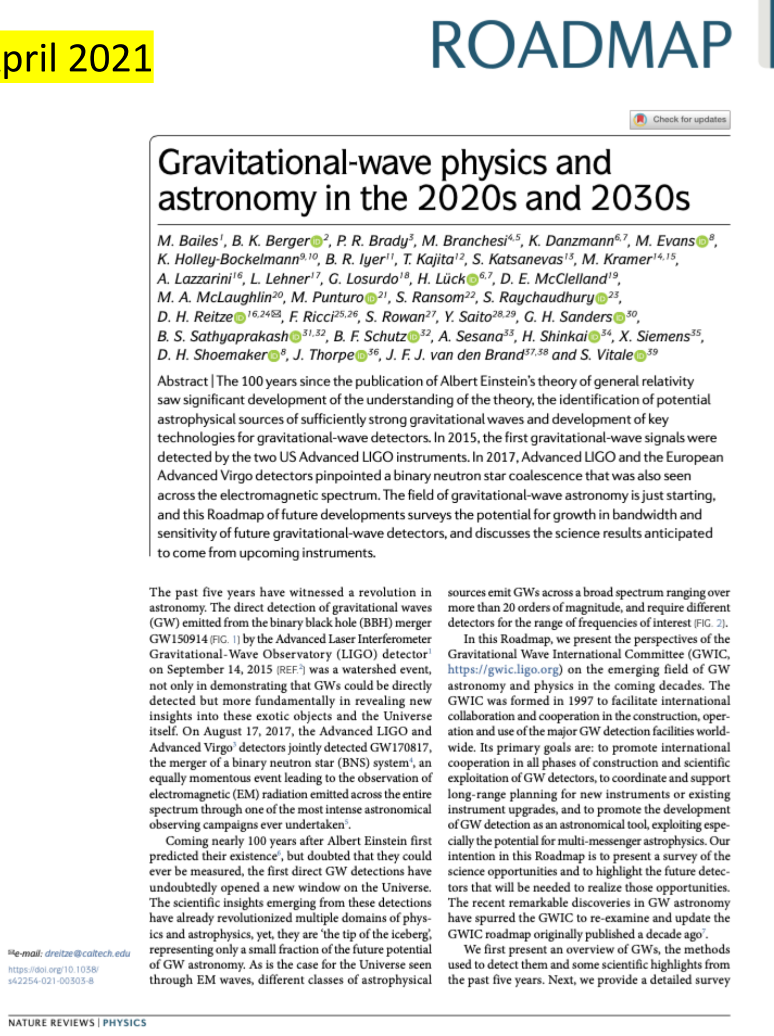
Neutrinos





https://www.nature.com/articles/s42254-021-00303-8

April 2021



ROADMAP

Check for updates

Gravitational-wave physics and astronomy in the 2020s and 2030s

M. Bailes[1], B. K. Berger[2], P. R. Brady[3], M. Branchesi[4,5], K. Danzmann[6,7], M. Evans[8], K. Holley-Bockelmann[9,10], B. R. Iyer[11], T. Kajita[12], S. Katsanevas[13], M. Kramer[14,15], A. Lazzarini[16], L. Lehner[17], G. Losurdo[18], H. Lück[6,7], D. E. McClelland[19], M. A. McLaughlin[20], M. Punturo[21], S. Ransom[22], S. Raychaudhury[23], D. H. Reitze[16,24]✉, F. Ricci[25,26], S. Rowan[27], Y. Saito[28,29], G. H. Sanders[30], B. S. Sathyaprakash[31,32], B. F. Schutz[32], A. Sesana[33], H. Shinkai[34], X. Siemens[35], D. H. Shoemaker[8], J. Thorpe[36], J. F. J. van den Brand[37,38] and S. Vitale[39]

Abstract | The 100 years since the publication of Albert Einstein's theory of general relativity saw significant development of the understanding of the theory, the identification of potential astrophysical sources of sufficiently strong gravitational waves and development of key technologies for gravitational-wave detectors. In 2015, the first gravitational-wave signals were detected by the two US Advanced LIGO instruments. In 2017, Advanced LIGO and the European Advanced Virgo detectors pinpointed a binary neutron star coalescence that was also seen across the electromagnetic spectrum. The field of gravitational-wave astronomy is just starting, and this Roadmap of future developments surveys the potential for growth in bandwidth and sensitivity of future gravitational-wave detectors, and discusses the science results anticipated to come from upcoming instruments.

The past five years have witnessed a revolution in astronomy. The direct detection of gravitational waves (GW) emitted from the binary black hole (BBH) merger GW150914 (FIG. 1) by the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) detector[1] on September 14, 2015 (REF.[2]) was a watershed event, not only in demonstrating that GWs could be directly detected but more fundamentally in revealing new insights into these exotic objects and the Universe itself. On August 17, 2017, the Advanced LIGO and Advanced Virgo[3] detectors jointly detected GW170817, the merger of a binary neutron star (BNS) system[4], an equally momentous event leading to the observation of electromagnetic (EM) radiation emitted across the entire spectrum through one of the most intense astronomical observing campaigns ever undertaken[5].

Coming nearly 100 years after Albert Einstein first predicted their existence[6], but doubted that they could ever be measured, the first direct GW detections have undoubtedly opened a new window on the Universe. The scientific insights emerging from these detections have already revolutionized multiple domains of physics and astrophysics, yet, they are 'the tip of the iceberg', representing only a small fraction of the future potential of GW astronomy. As is the case for the Universe seen through EM waves, different classes of astrophysical sources emit GWs across a broad spectrum ranging over more than 20 orders of magnitude, and require different detectors for the range of frequencies of interest (FIG. 2).

In this Roadmap, we present the perspectives of the Gravitational Wave International Committee (GWIC, https://gwic.ligo.org) on the emerging field of GW astronomy and physics in the coming decades. The GWIC was formed in 1997 to facilitate international collaboration and cooperation in the construction, operation and use of the major GW detection facilities worldwide. Its primary goals are: to promote international cooperation in all phases of construction and scientific exploitation of GW detectors, to coordinate and support long-range planning for new instruments or existing instrument upgrades, and to promote the development of GW detection as an astronomical tool, exploiting especially the potential for multi-messenger astrophysics. Our intention in this Roadmap is to present a survey of the science opportunities and to highlight the future detectors that will be needed to realize those opportunities. The recent remarkable discoveries in GW astronomy have spurred the GWIC to re-examine and update the GWIC roadmap originally published a decade ago[7].

We first present an overview of GWs, the methods used to detect them and some scientific highlights from the past five years. Next, we provide a detailed survey

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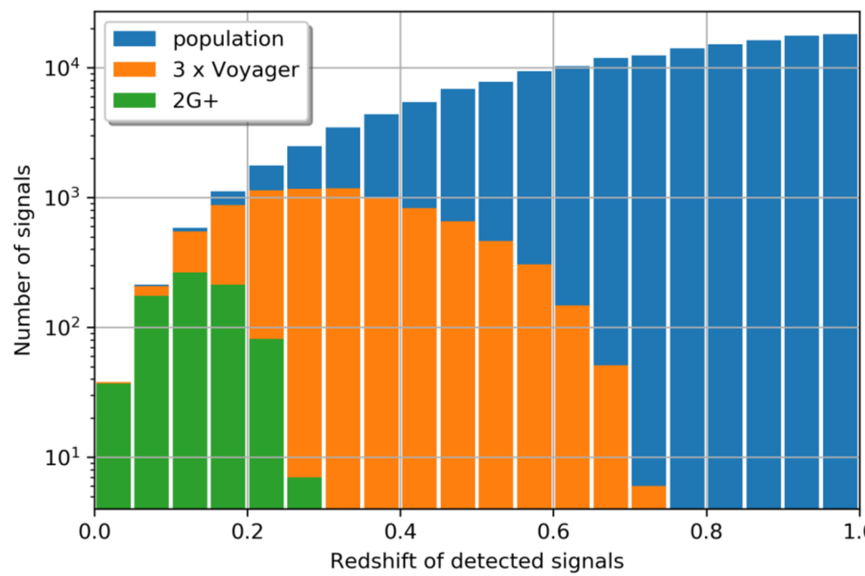
https://doi.org/10.1038/s42254-021-00303-8

GWIC Roadmap and Letter of Endorsement from EGO/virgo clearly mention further upgrades of 2G to bridge in the 3G era



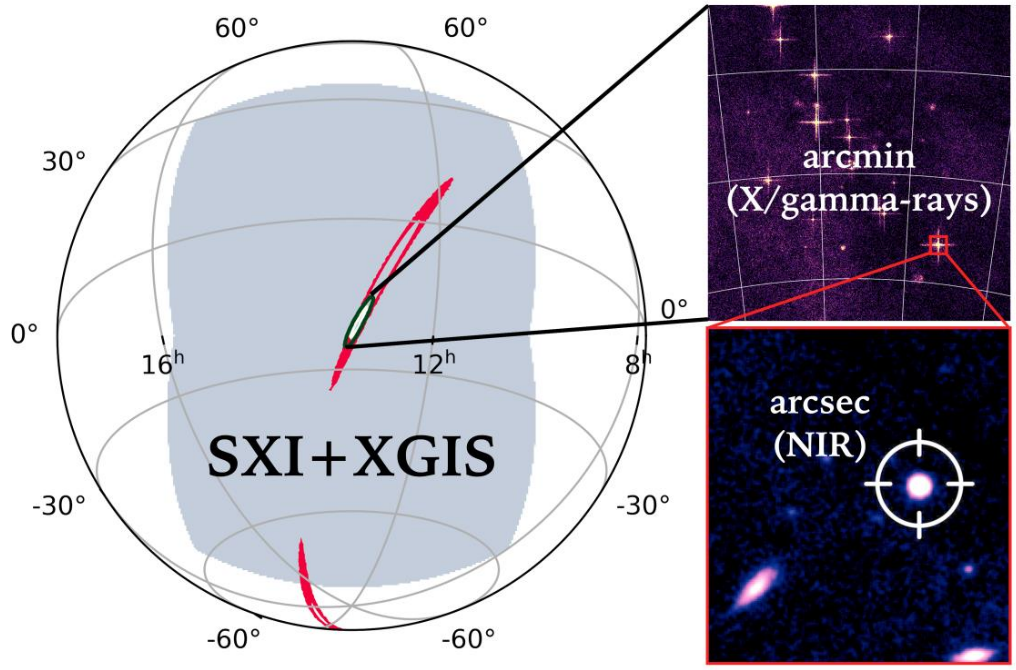
NS-NS merger detection efficiency with 2G and 2G++ will sensibly improve at z>0.1 with 2G++

MAIN THESEUS CAPABILITIES FOR MULTI-MESSENGER ASTRONOMY

Independent detection of the electromagnetic counterparts

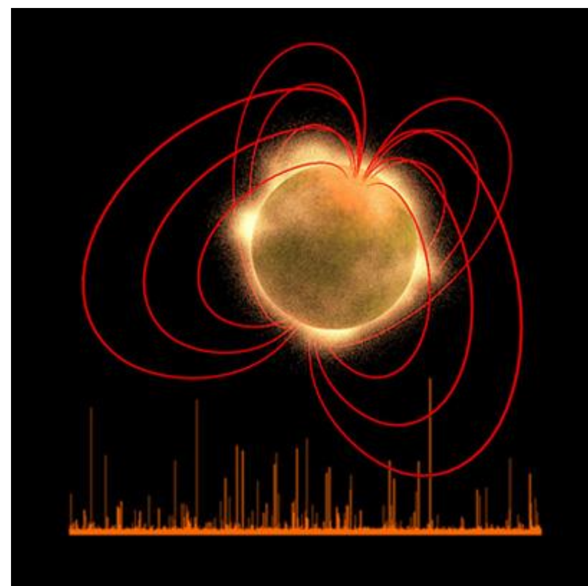
Autonomous source identification and characterization

Accurate sky coordinate dissemination – essential, given large GW error regions



MULTI-MESSENGER TARGETS FOR THESEUS

- **Short GRBs**
- Core-collapse stars
- Soft Gamma-ray Repeaters
- Unexpected transients…

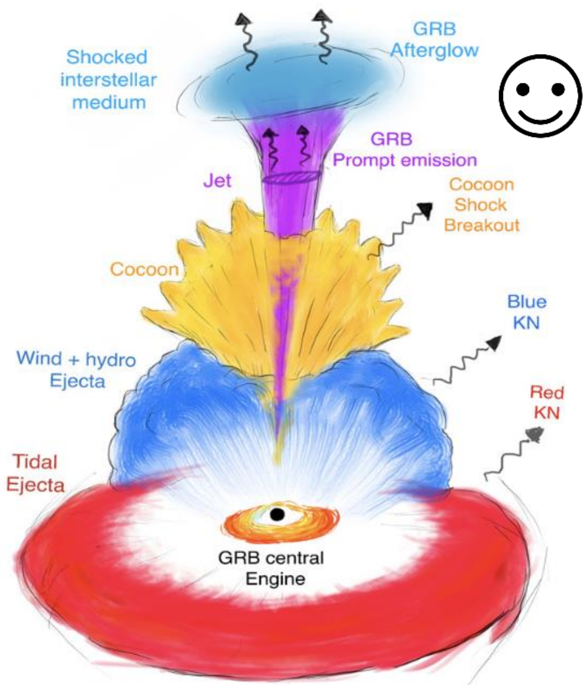


MAIN THESEUS CAPABILITIES FOR MULTI-MESSENGER ASTRONOMY: NS-NS (NS-BH) mergers

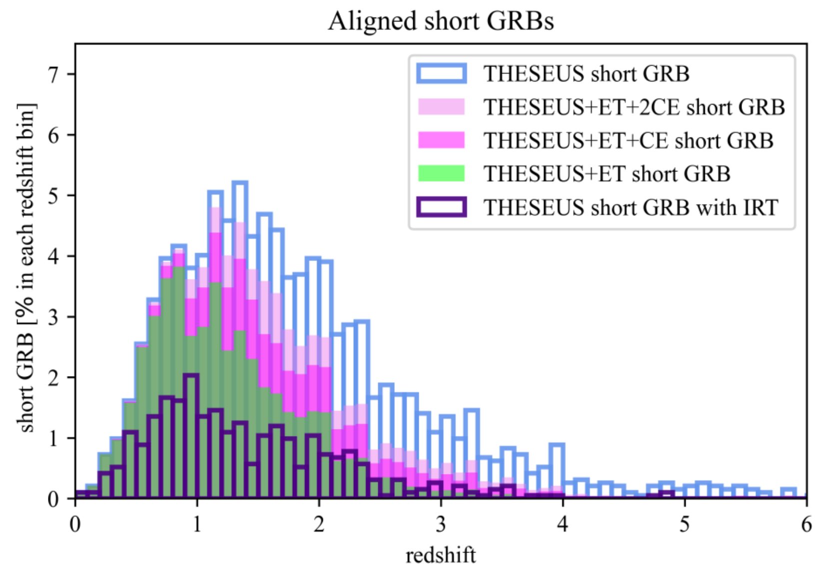
Collimated on-axis and off-axis prompt gamma-ray emission from short GRBs

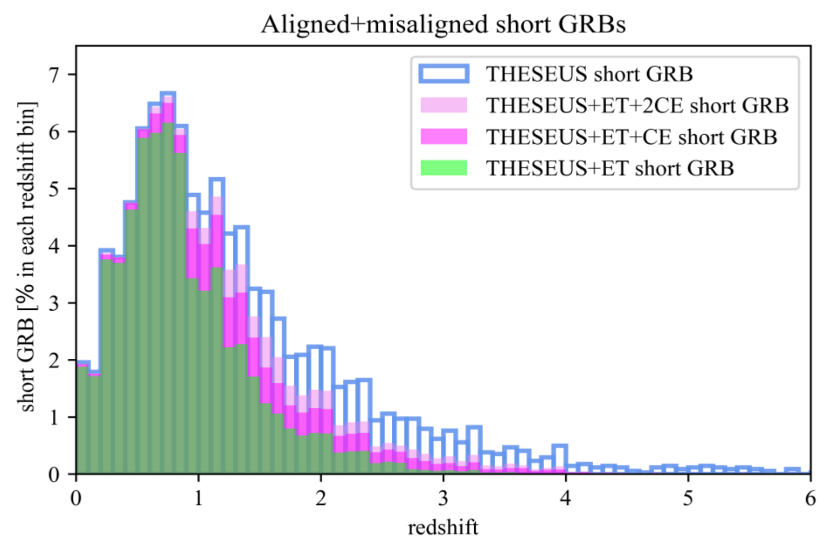
Aligned GRBs

Misaligned GRBs



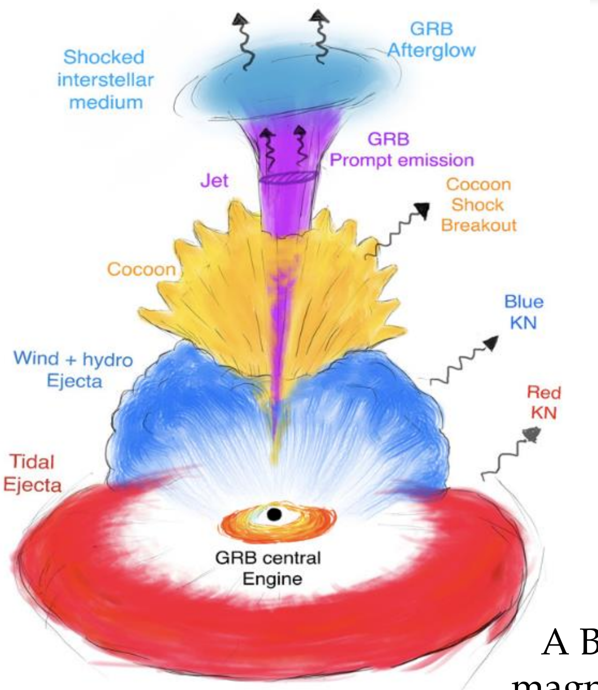
Ascenzi et al., 2021



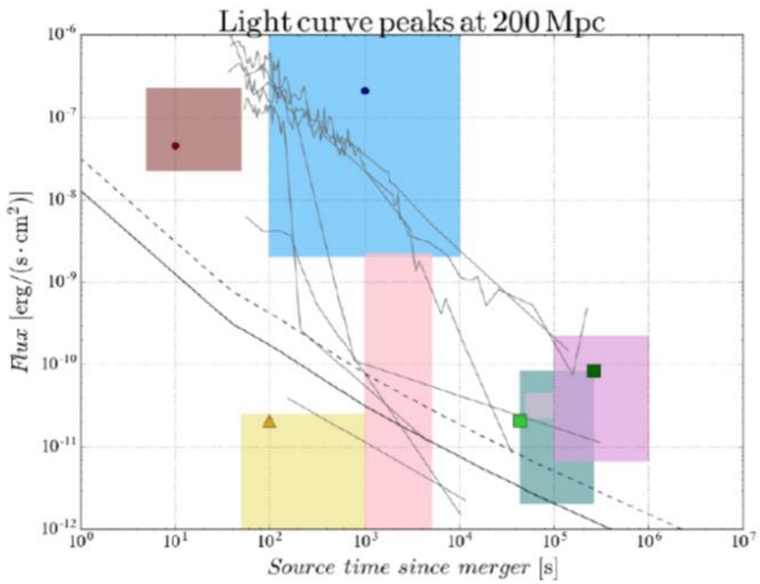


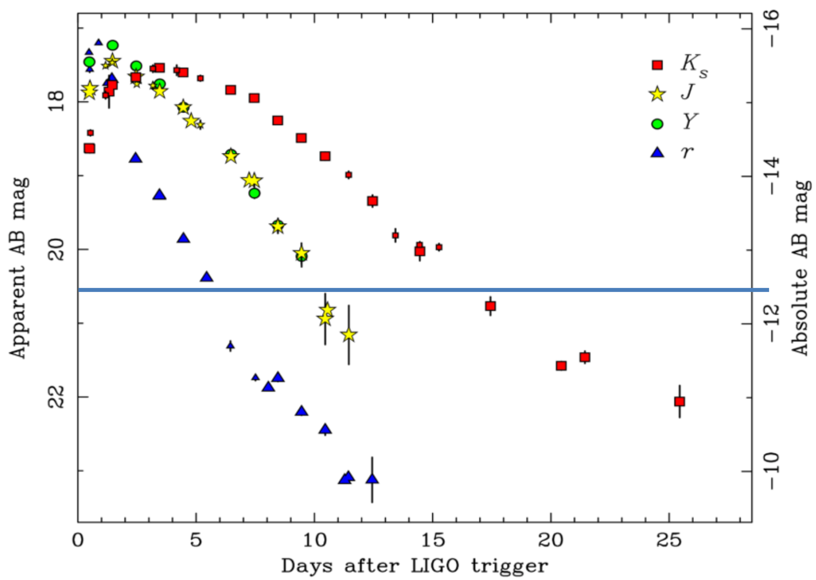
MAIN THESEUS CAPABILITIES FOR MULTI-MESSENGER ASTRONOMY: NS-NS (NS-BH) mergers

Optical/NIR and soft X-ray isotropic emissions from kilonovae, off-axis afterglows and, for NS-NS, from newly born ms magnetar spindown



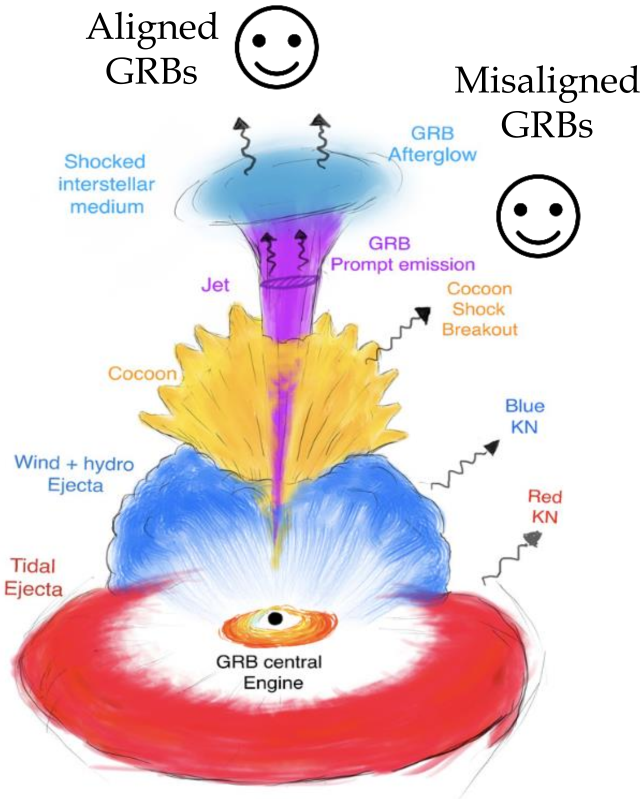
A BH or a long-lived ms magnetar can form after the merger of two NS





INDEPENDENT DETECTION & CHARACTERISATION OF THE MULTI-MESSENGER SOURCES

Lessons from GRB170817A



Expected rates:

THESEUS + 2G++:

- ~10 yr aligned+misaligned collimated short GRBs
- ~50/yr isotropic X-ray transients from possible NS-NS merger remnant

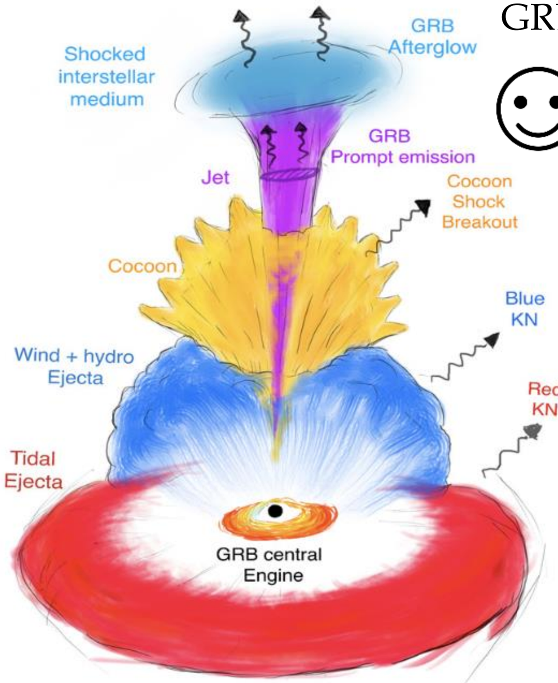
Low redshifts events: detailed study of kilonovae, jet structure, remnant nature

INDEPENDENT DETECTION & CHARACTERISATION OF THE MULTI-MESSENGER SOURCES

Lessons from GRB170817A

Aligned GRBs ☺

Misaligned GRBs ☺



Expected rates:

THESEUS + 3G:

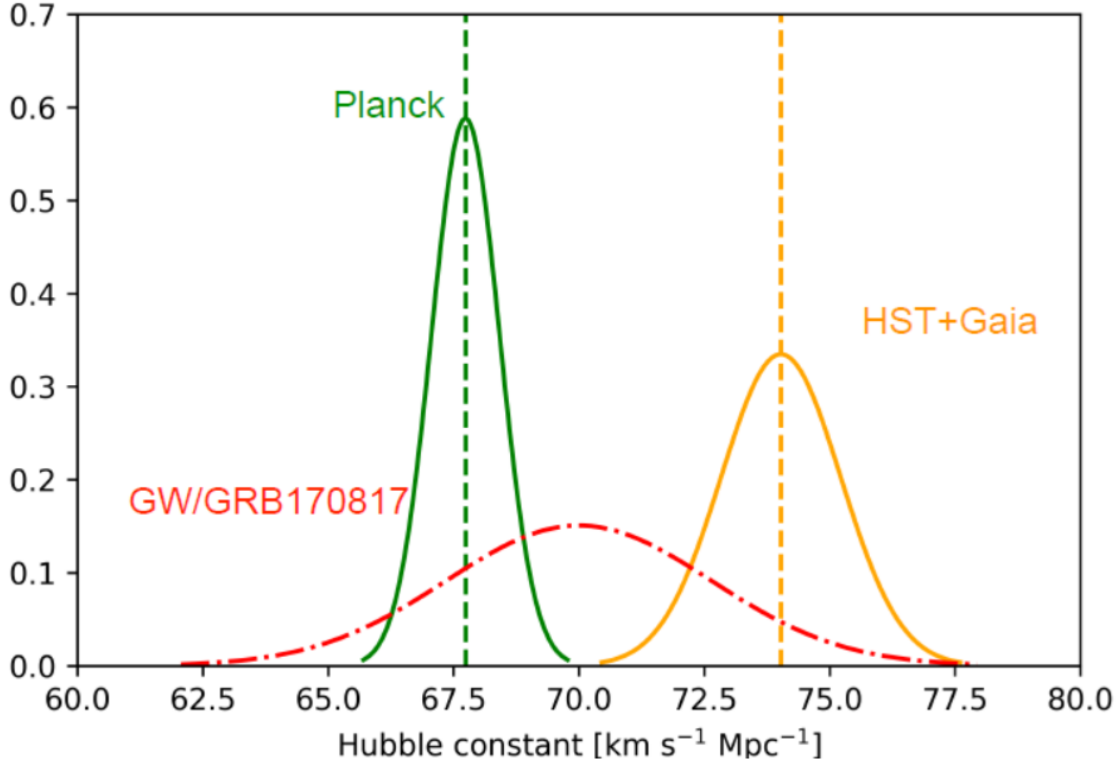
- ~50 aligned+misaligned short GRBs
- ~200 X-ray transients

Higher redshift events – X/γ is likely only route to EM detection: larger statistical studies including source evolution, probe of dark energy and test modified gravity on cosmological scales

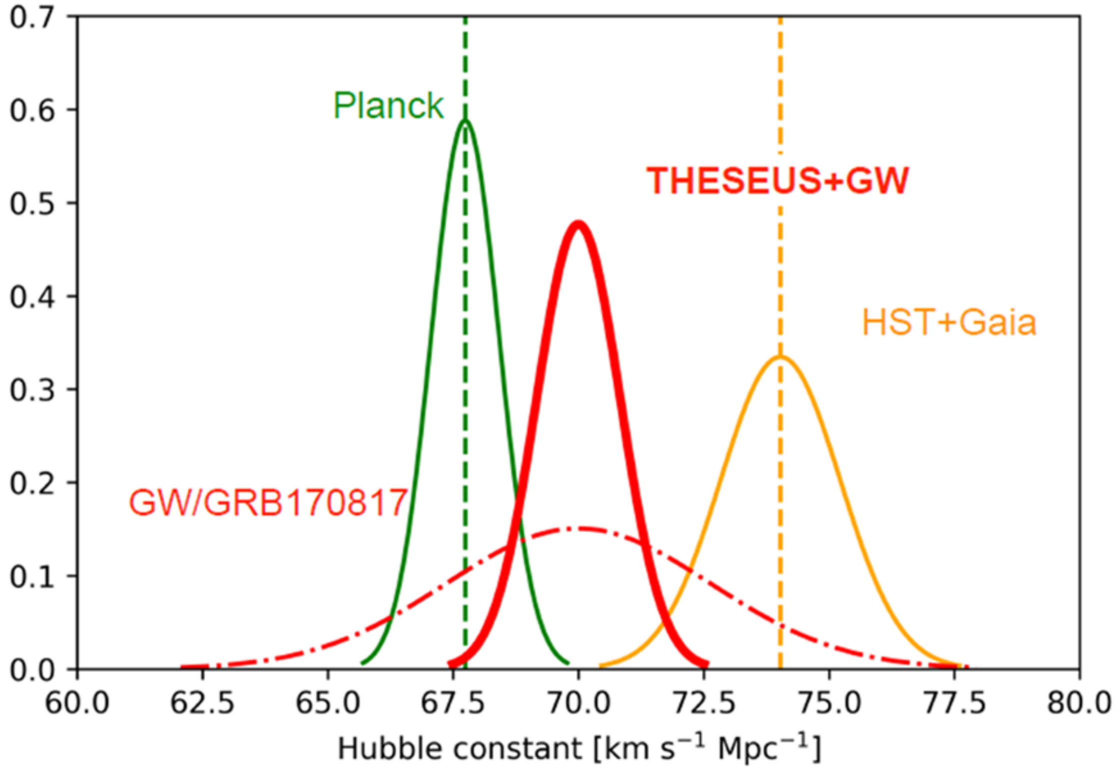
THESEUS & 2G++ SCIENCE

Main topics	THESEUS role	What will we learn?
Physics of compact binaries	short GRB+GW detection and localization	**relativistic jet formation mechanism/efficiency, remnant nature, NS EoS**
Relativistic plasma	accurate sky coordinates of GW events associated with misaligned afterglows	**Jet propagation, jet structure and its universality, NSBH vs NSNS**
Physics of kilonova	accurate sky coordinates of GW events	**Role of NS-NS/NSBH in r-process element nucleosynthesis**
Fundamental physics	Identify counterparts for events at z>0.3	**Tests of modified gravity theories**
Cosmology	accurate sky coordinates of GW events allowing redshift measurement	**Independent H_0 measure**

MEASURING THE EXPANSION RATE AND GEOMETRY OF SPACE-TIME



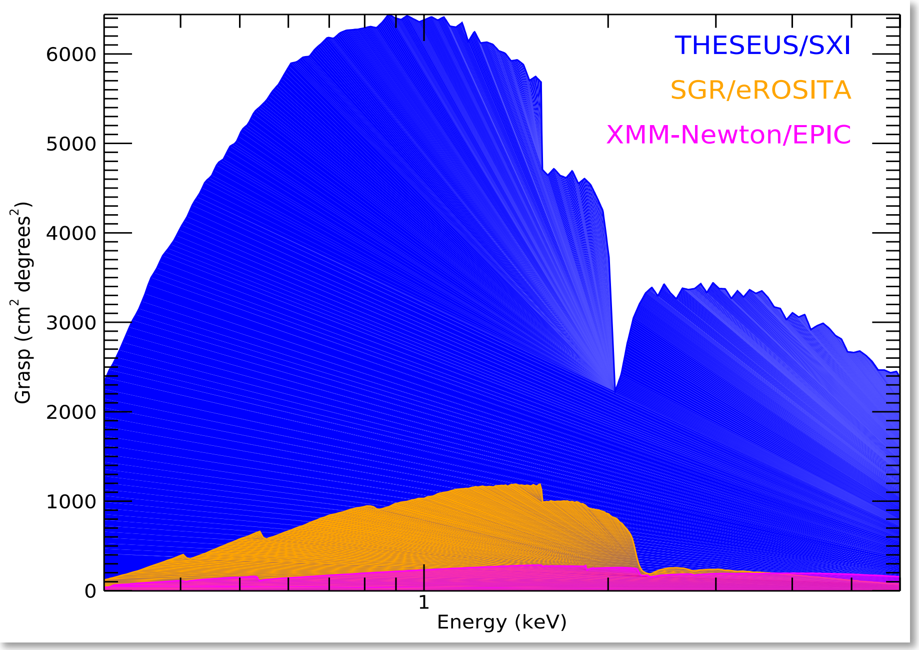
MEASURING THE EXPANSION RATE AND GEOMETRY OF SPACE-TIME

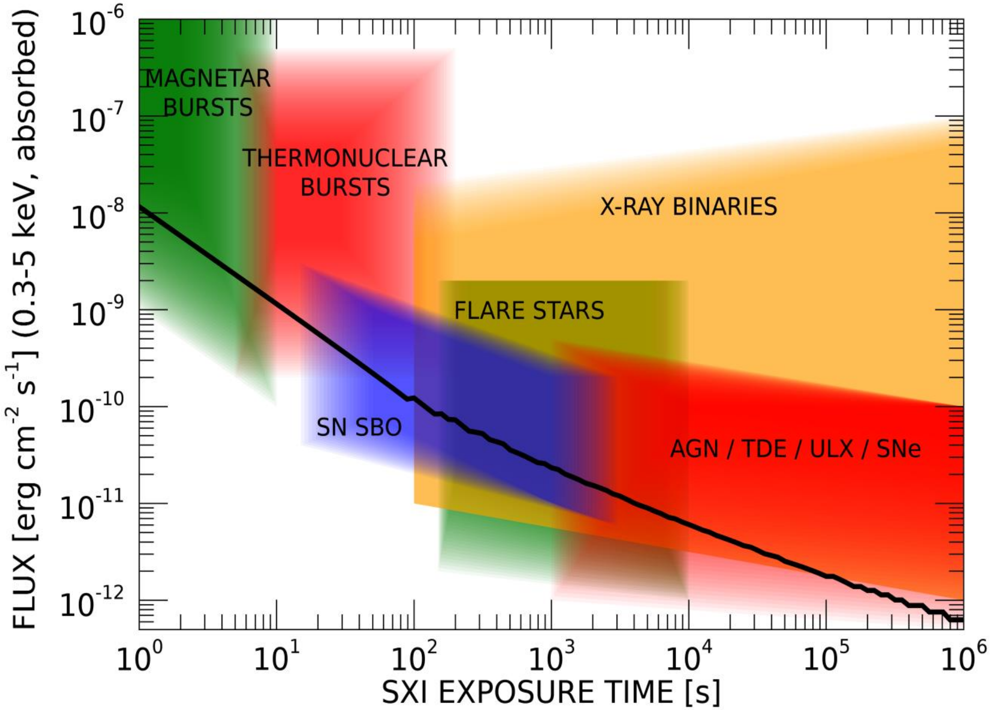


~20 joint THESEUS+GW events

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

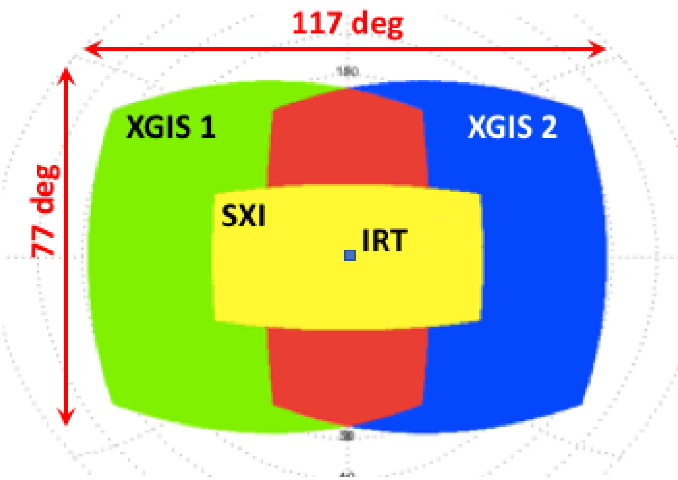


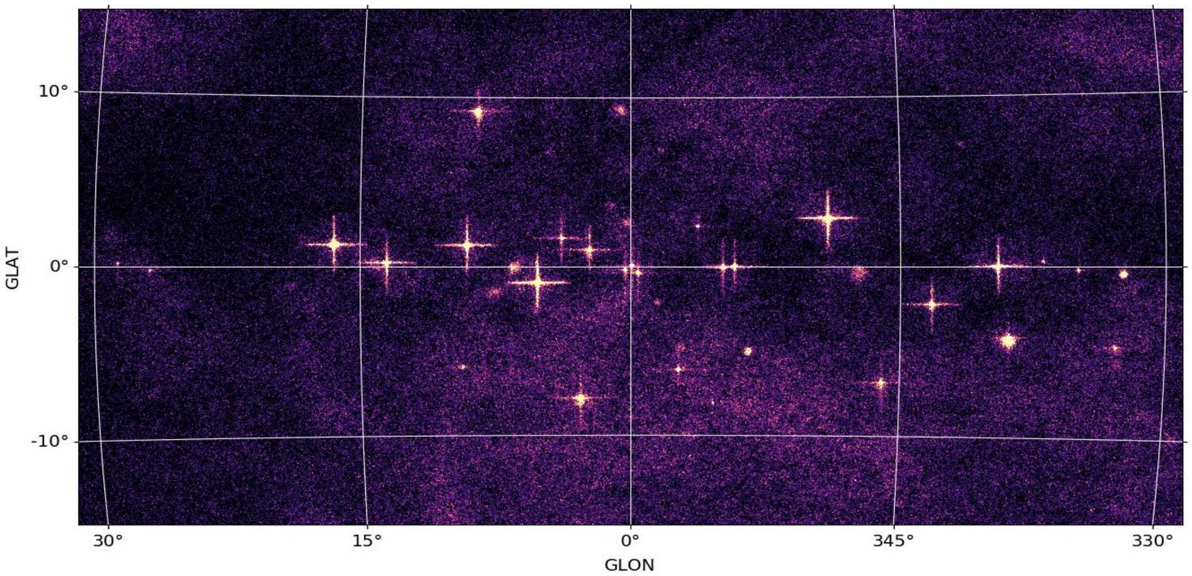


EXPLORING THE TRANSIENT SKY WITH THESEUS

THESEUS will find fast transients within a single orbit, while co-adding survey data will monitor longer timescale events

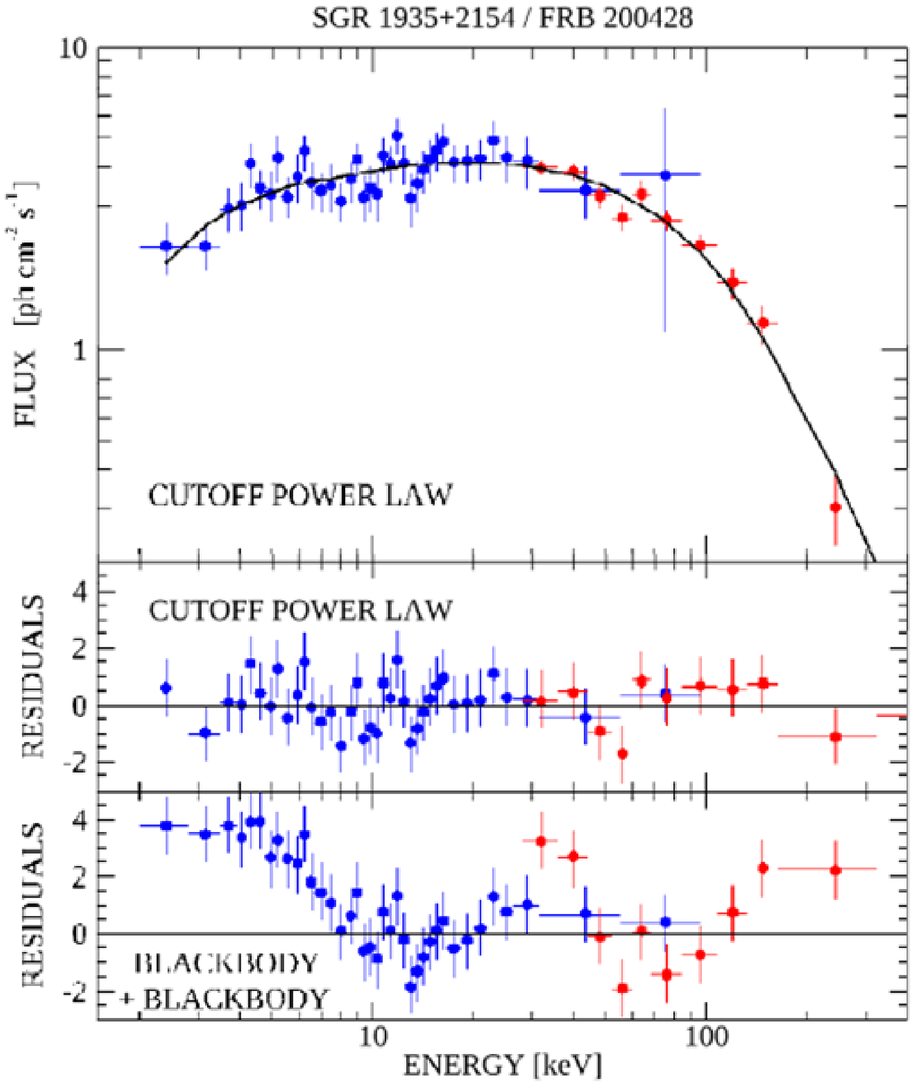
The IRT will observe sources (also selected through GO programme) in the monitors FOV, giving very broad-data spectral coverage for key object classes





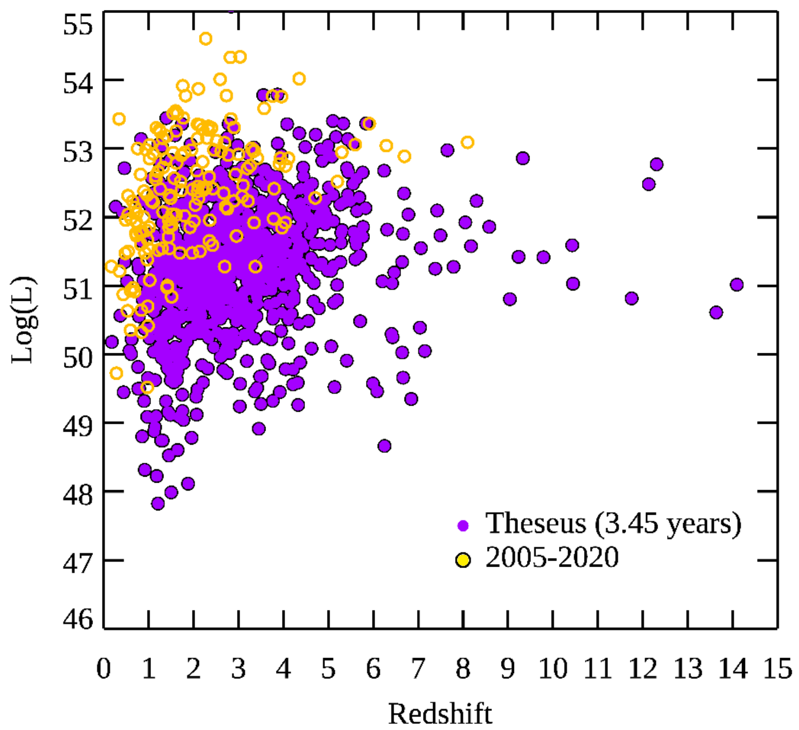
THESEUS capabilities for time domain astronomy

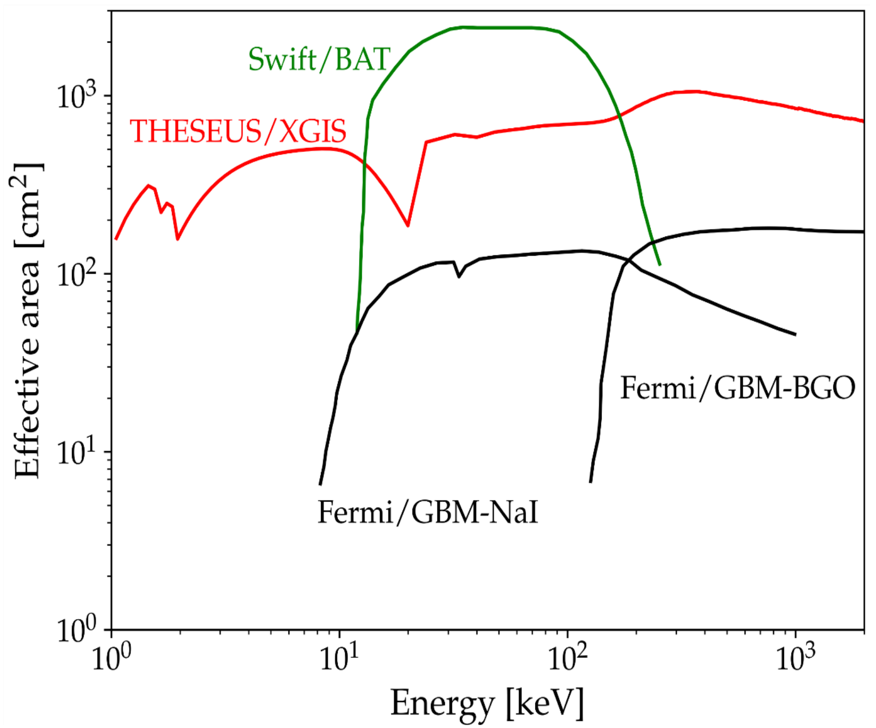
Outstanding example: investigating the Fast-Radio Burst – Soft Gamma Repeaters connection and physics



THESEUS capabilities for GRB SCIENCE

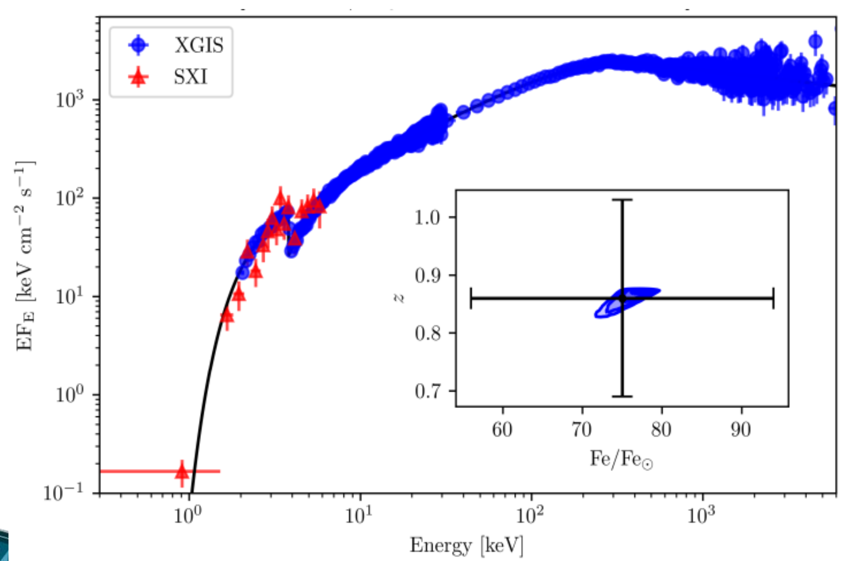
THESEUS will provide an unprecedented sample of many hundreds of GRBs with redshift, wide band X/gamma-ray spectroscopic and few ms timing characterization, NIR

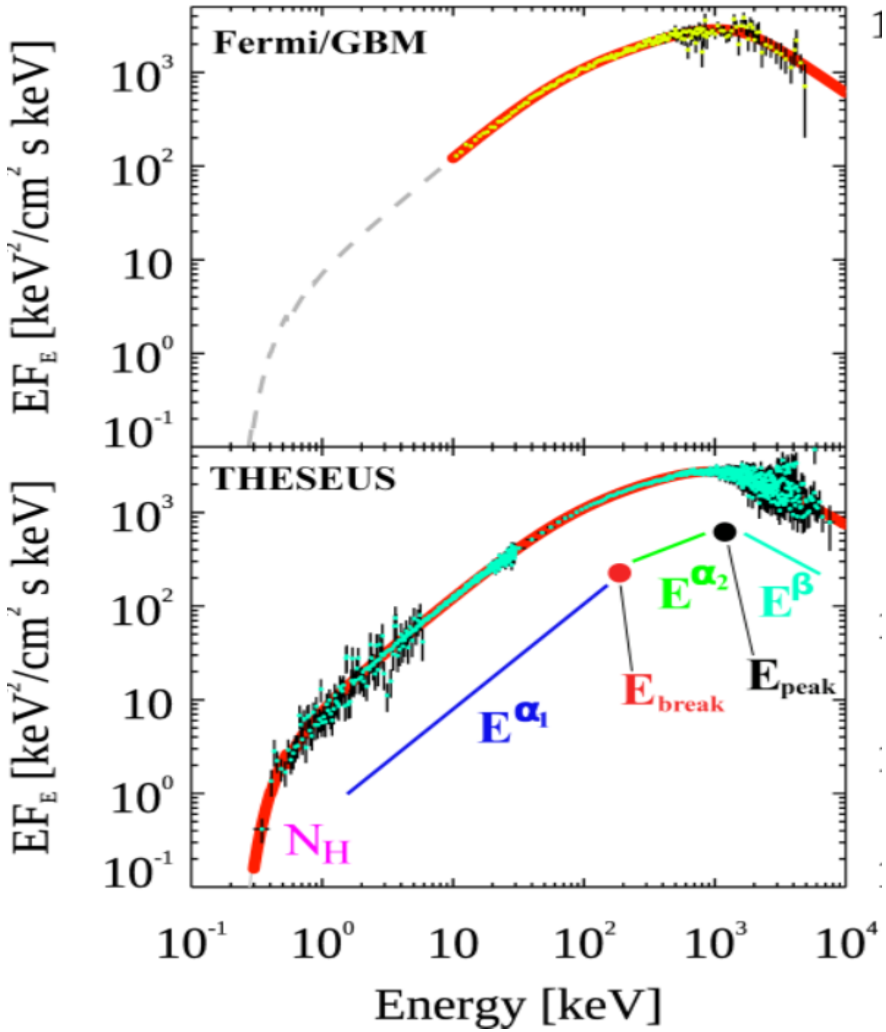




THESEUS capabilities for GRB SCIENCE

Extreme prompt emission physics, jet structure, central engine, circum-burst environment -> progenitors, weak/soft "local" GRBs, cosmological parameters, fundamental physics





THESEUS GUEST OBSERVER OPPORTUNITIES

THESEUS will provide the opportunity for agile **simultaneous** NIR and X-ray observations beyond its core science

Wide range of potential targets, from asteroids and exoplanets to SNe and distant AGNs

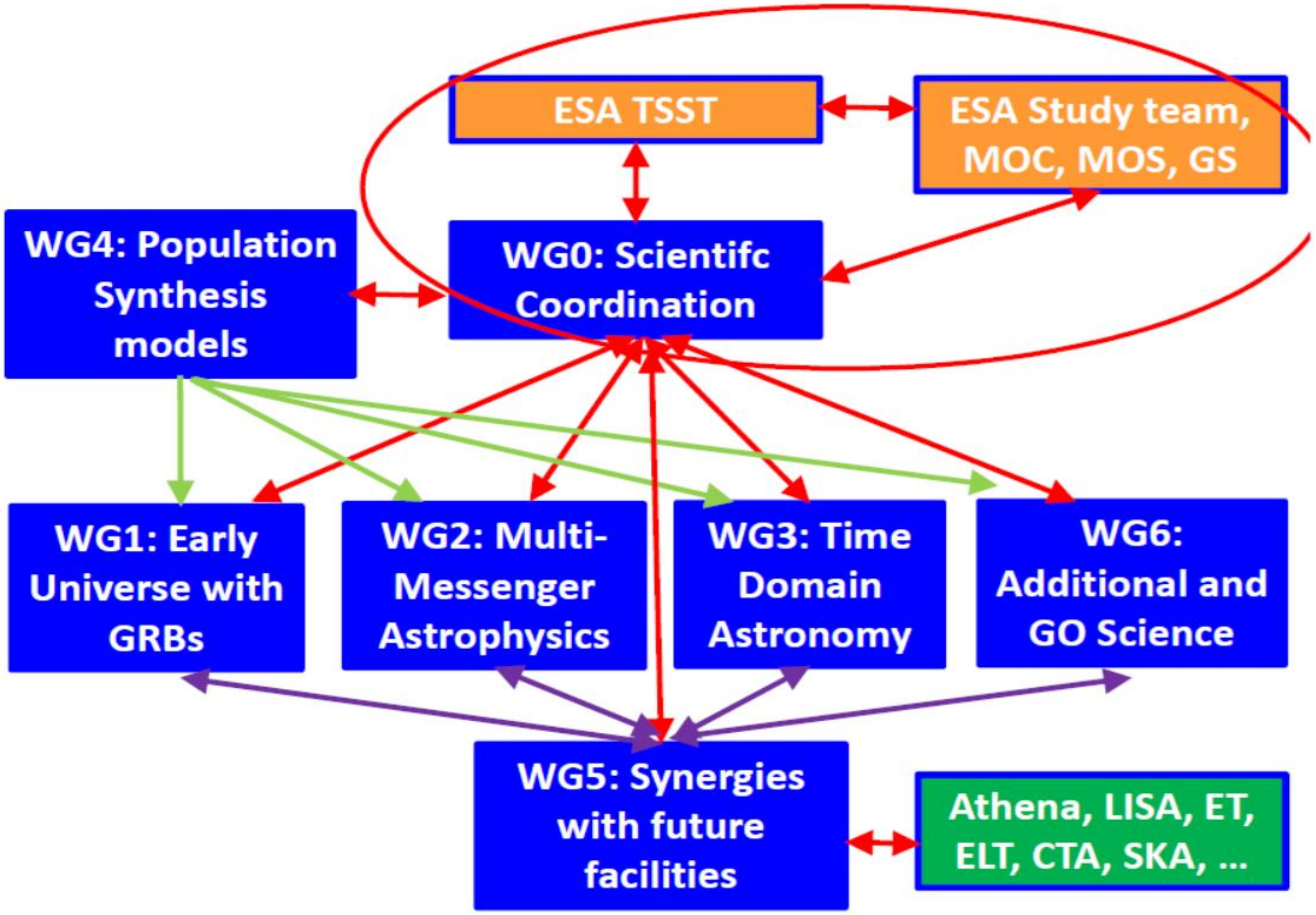
The THESEUS scientific community
(http://www.isdc.unige.ch/theseus)

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 the many articles illustrating the THESEUS mission (e.g, SPIE) and the great expected science (e.g., Experimental Astornomy)

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



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)

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 PROMISE OF THESEUS

THESEUS will open a new window on the Early Universe and will be a cornerstone of multi-messenger and time domain astrophysics of the '30s

THESEUS will impact a very broad range of research fields through its core science, wide synergies and GO opportunities

THESEUS is a unique occasion for fully exploiting the European leadership in time-domain and multi-messenger astrophysics and in related key enabling technologies

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

Back-up slides

THESEUS data policy

All data taken during the nominal mission operations 3.45 years) will be public as soon as they are processed (except for GO: reserved for 3 months)

The consortium will release regular XGIS and SXI survey products, and near real-time on-line data products will be available for monitoring many known transients and for alerting the community to new transients

In addition to early verification phases (first 3 months) some limited (few months) reserved access to GRB data (e.g., z>6 GRBs in the first 6 months) may be granted to consortium

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	✓	✓	✓	✓	✓	✓	✓	✓	✓