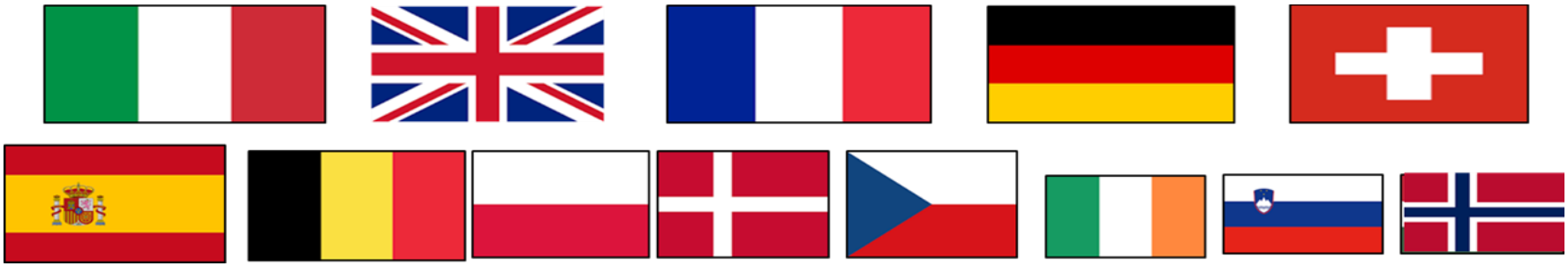
The THESEUS space mission concept

Transient High-Energy Sky and Early Universe Surveyor

Enrico Bozzo
University of Geneva (Switzerland)
on behalf of the THESEUS Consortium

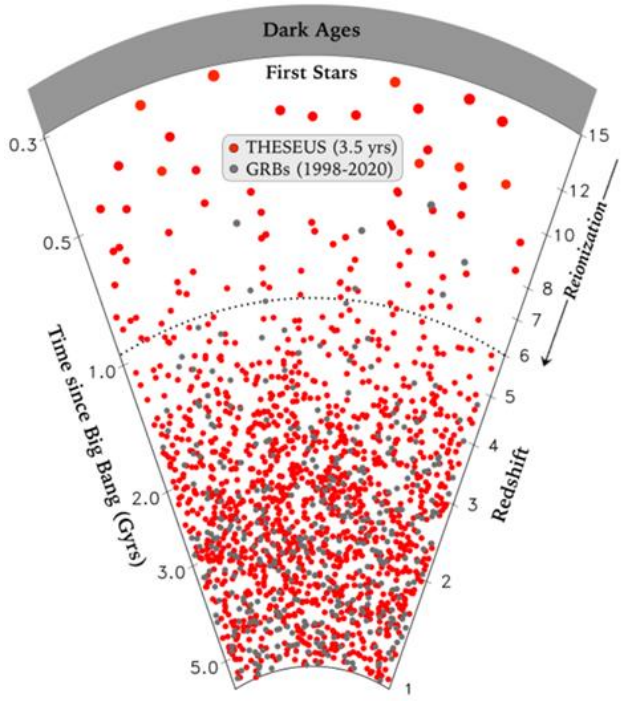


XMM2Athena Conference
28th February 2024 – Toulouse (France)

THESEUS Science Case

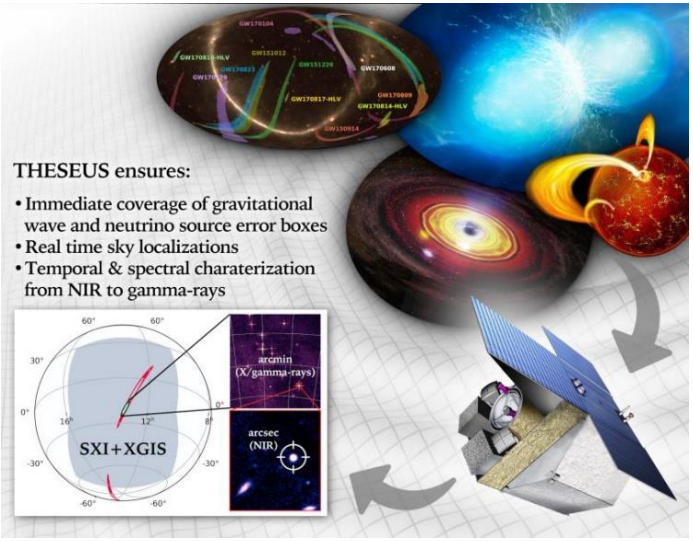
Core Science pillars:

- Probe the **early Universe (first stars, first galaxies, cosmic reionization)**, by unveiling and exploiting the population of high redshift Gamma-Ray Bursts (GRB)
- Provide a **fundamental contribution to multi-messenger time domain astrophysics** through short GRB and other transients



Observatory Science includes:

- Study of thousands of faint to bright X-ray sources by exploiting the **simultaneous broad band X-ray and NIR observations**
- Provide a **flexible follow-up observatory** for fast transient events with multi-wavelength ToO capabilities and **GO programmes**



- 2018-2021: ESA PHASE A STUDY (2018-2021) AS M5 CANDIDATE
- 2022: SELECTED FOR ESA PHASE-0 STUDY IN M7 SELECTION PROCESS
- M7 TIMELINE: PHASE-0/A (2023-2026), LAUNCH 2037

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

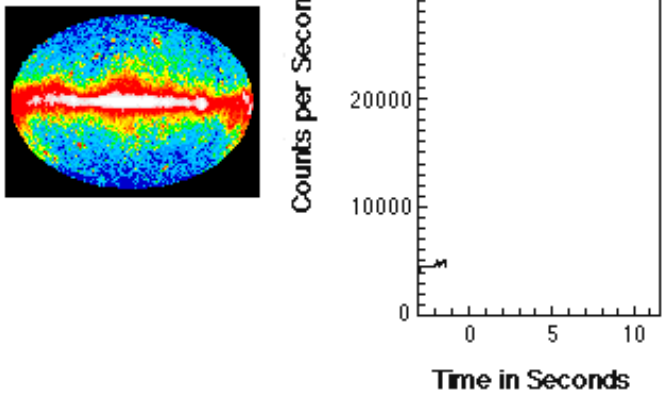
Leads: L. Amati (INAF – OAS Bologna, Italy, lead proposer), P. O'Brien (Un. Leicester, UK), D. Gotz (CEA-Paris, France), A. Santangelo (Un. Tuebingen, D), E. Bozzo (Un. Genève, CH)

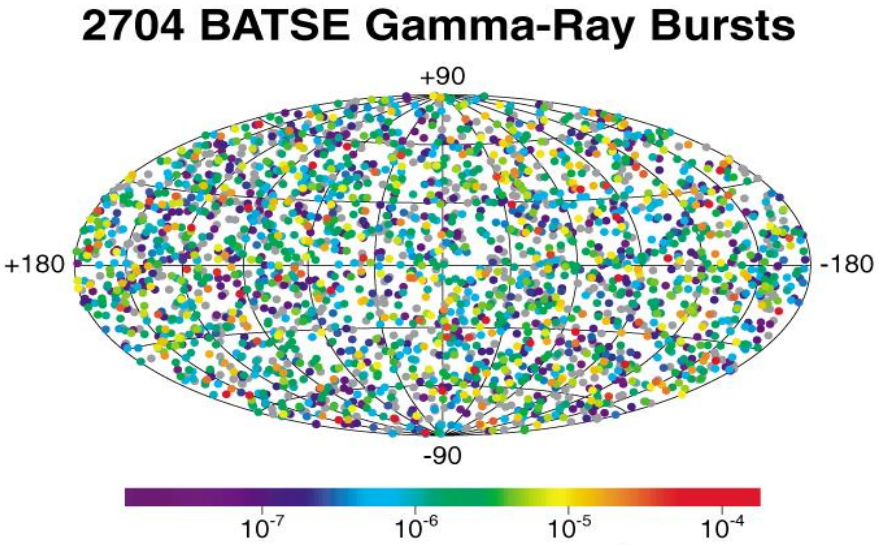
Amati et al. 2018 (Adv.Sp.Res., arXiv:1710.04638)
Stratta et al. 2018 (Adv.Sp.Res., arXiv:1712.08153)
Articles for SPIE 2020 and Exp..Astr. (all on arXiv)
https://www.isdc.unige.ch/theseus

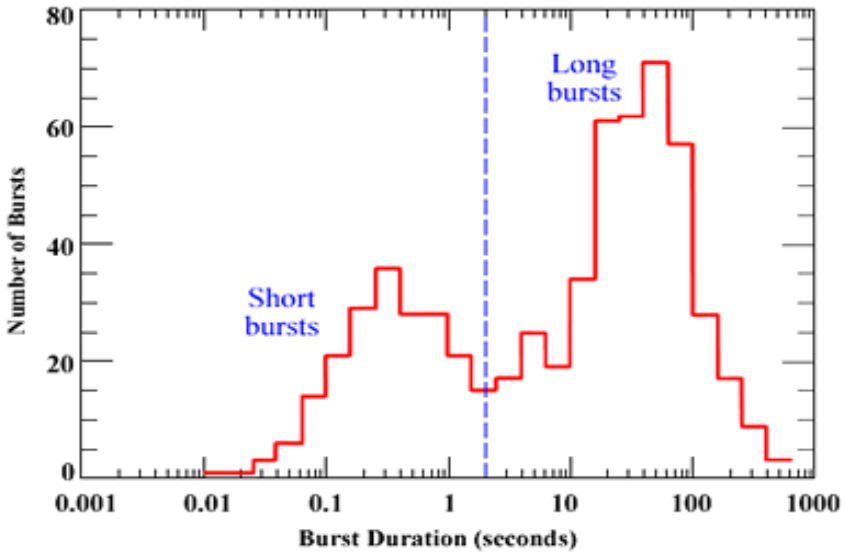
The ESA Cosmic Vision Programme

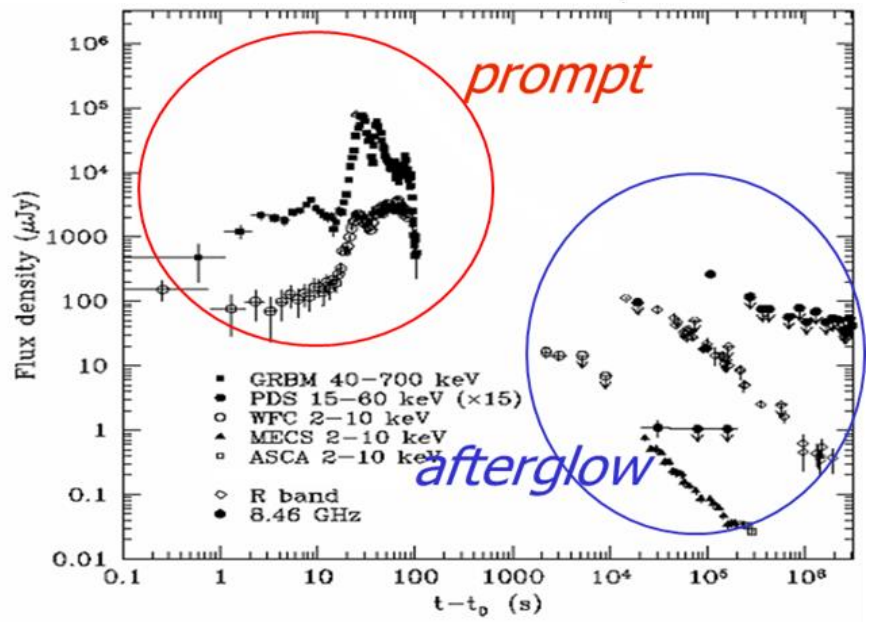
- S1: CHEOPS (exoplanets, 2019)
- M1: Solar Orbiter (solar astrophysics, 2020)
- M2: Euclid (cosmology, 2023)
- L1: JUICE (exploration of Jupiter system, 2023)
- S2: SMILE (solar wind-magneto/ionosphere, 2025)
- M3: PLATO (exoplanets, 2026)
- F1: COMET INTERCEPTOR (solar system origin, 2026)
- M4: ARIEL (exoplanets, 2028)
- F2: ARRAKIHS (cosmology & faint galaxies, 2030)
- M5: ENVISION (exploration of Venus, 2032)
- L2: NewATHENA (X-ray observatory, 2035)
- L3: LISA (gravitational wave observatory, 2037)

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

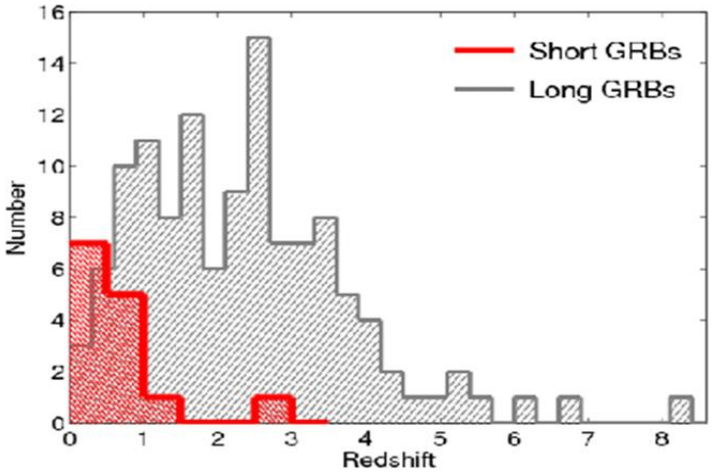






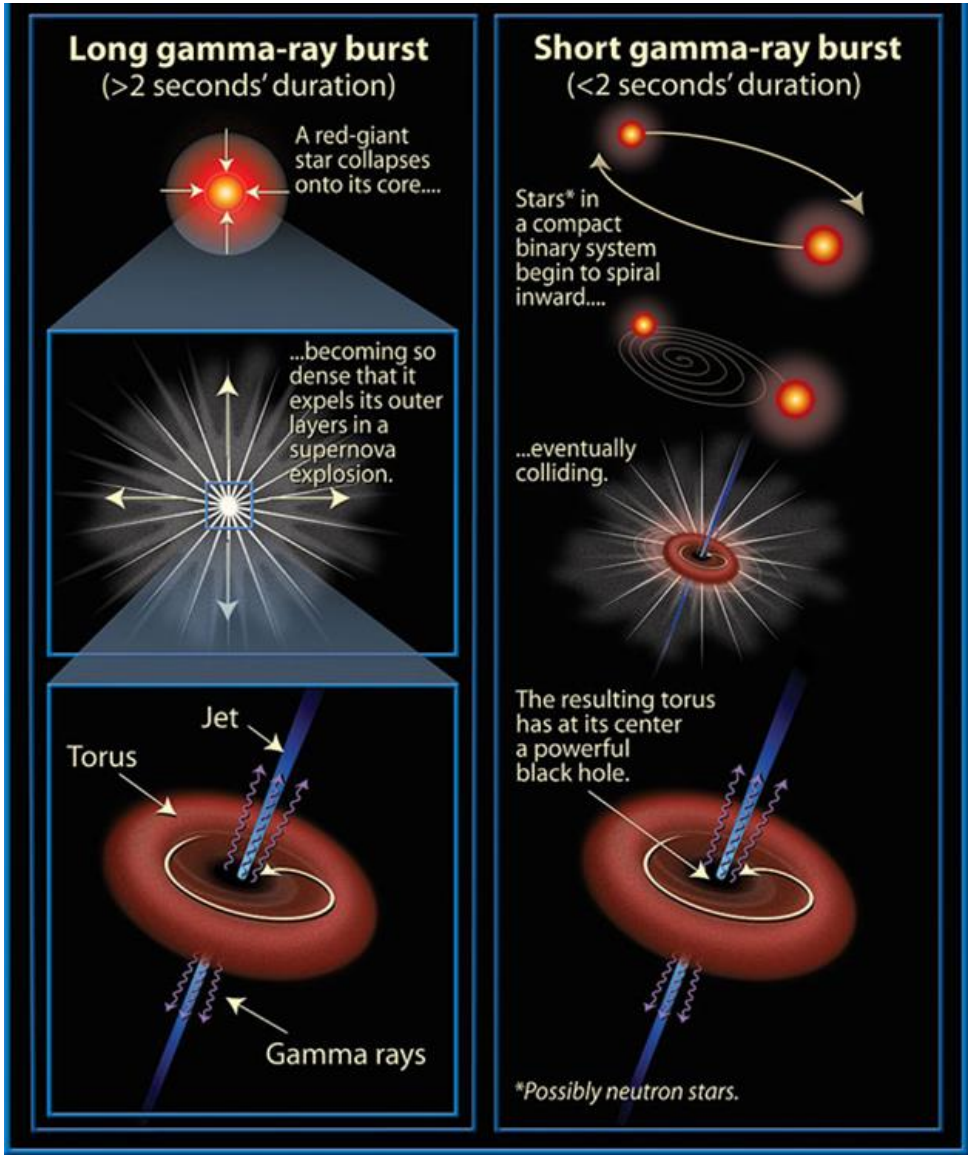


Gamma-Ray Bursts: the most extreme phenomena in the Universe



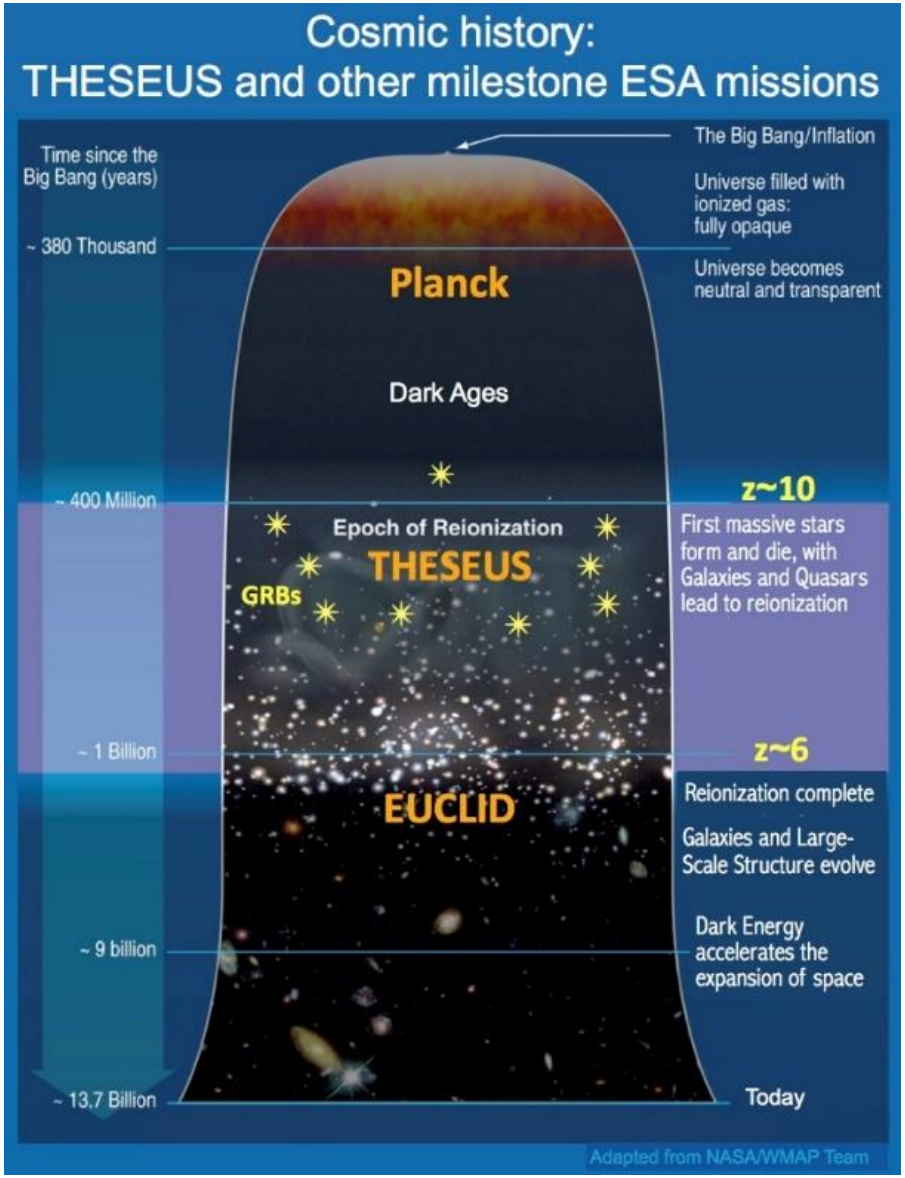
Long GRBs: core collapse of pecular massive stars, **association with SN**

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



Shedding light on the early Universe with GRBs

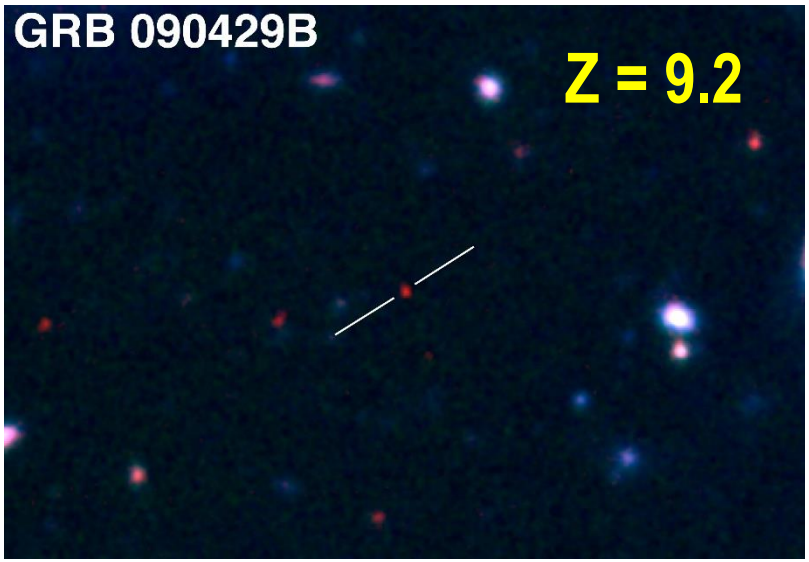
- **Long GRBs:** huge luminosities, mostly emitted in the X and gamma-rays
- **Redshift distribution** extending at least to z ~9 and association with exploding massive stars
- **Powerful tools for cosmology:** SFR evolution, physics of re-ionization, high-z low luminosity galaxies, pop III stars

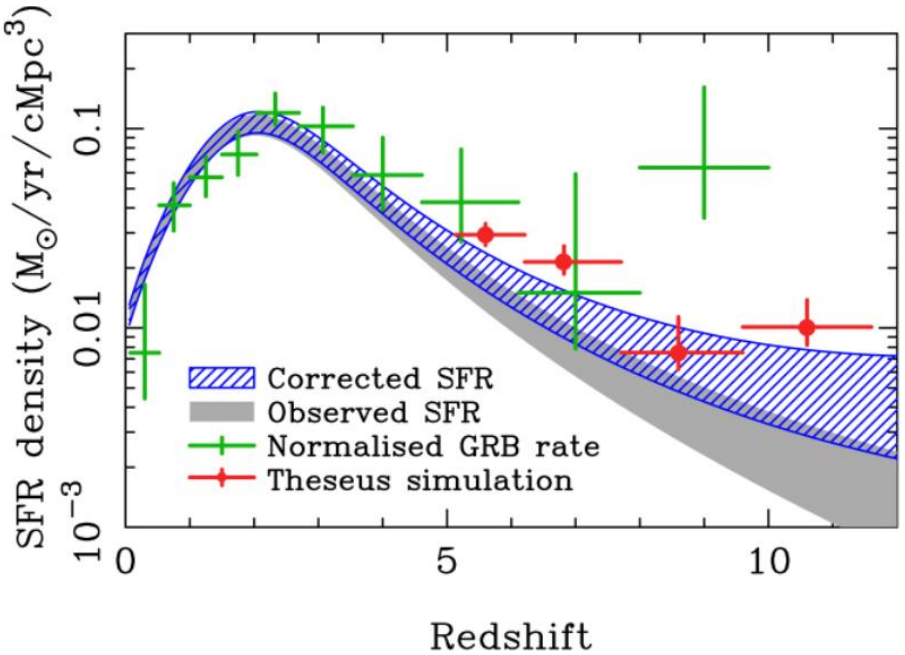


Shedding light on the early Universe with GRBs

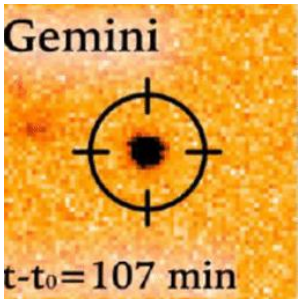
A statistical sample of high–z GRBs can provide fundamental information:

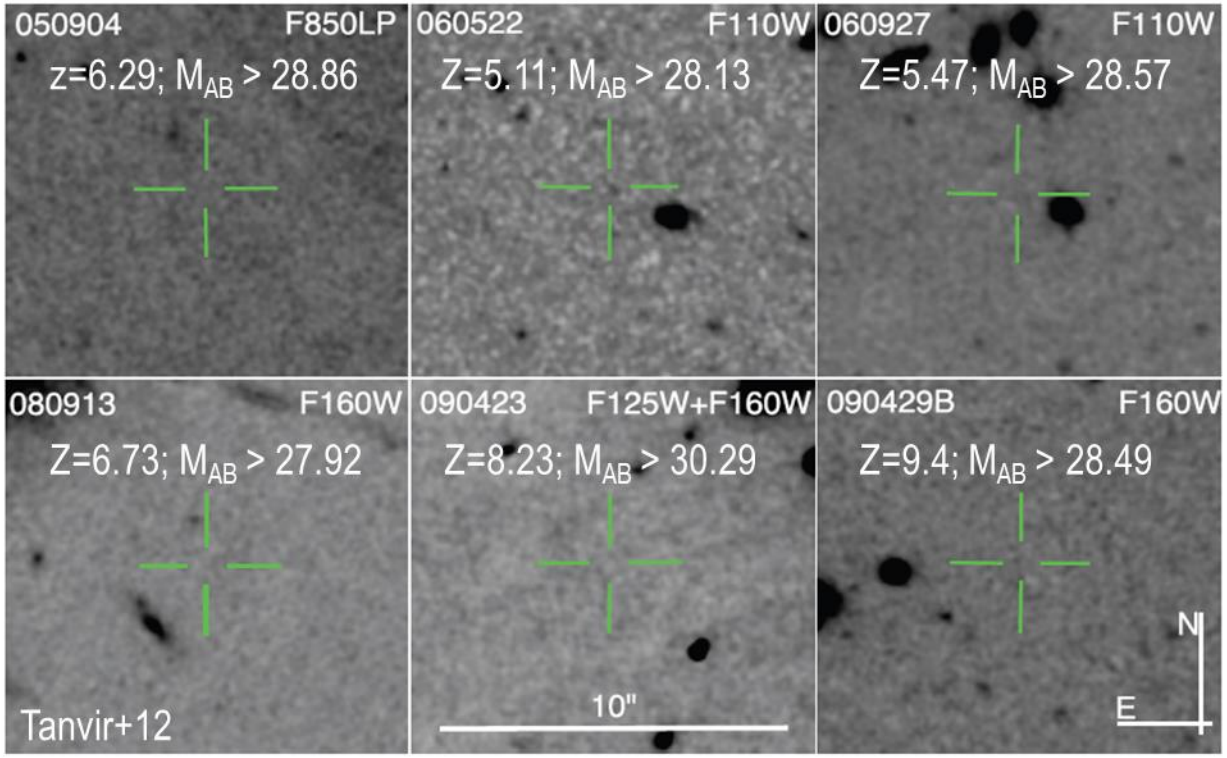
- measure independently the **cosmic star–formation rate**, even beyond the limits of current and future galaxy surveys
- directly (or indirectly) detect the **first population of stars (pop III)**





Detecting and studying primordial invisible galaxies

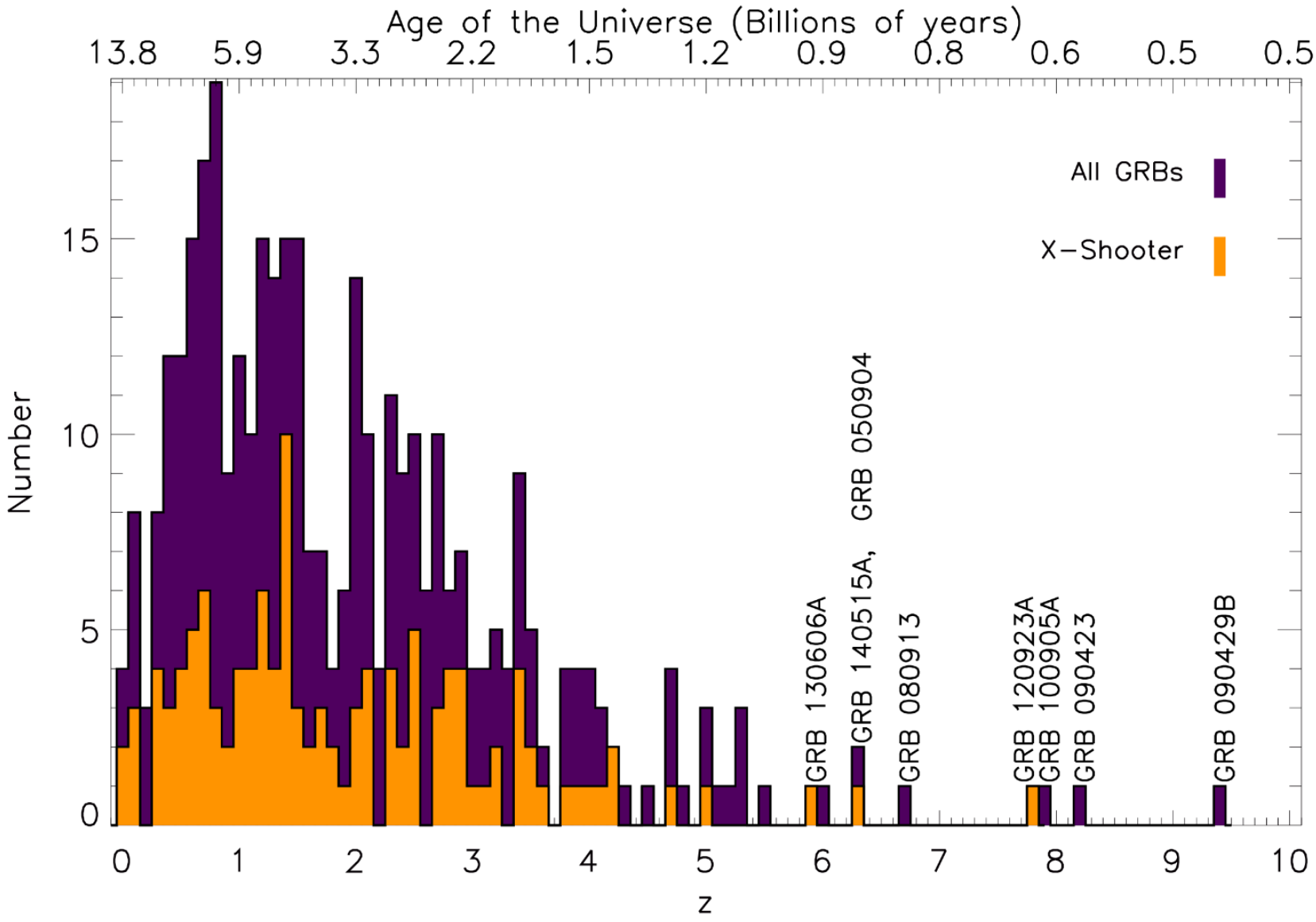




Robertson&Ellis12

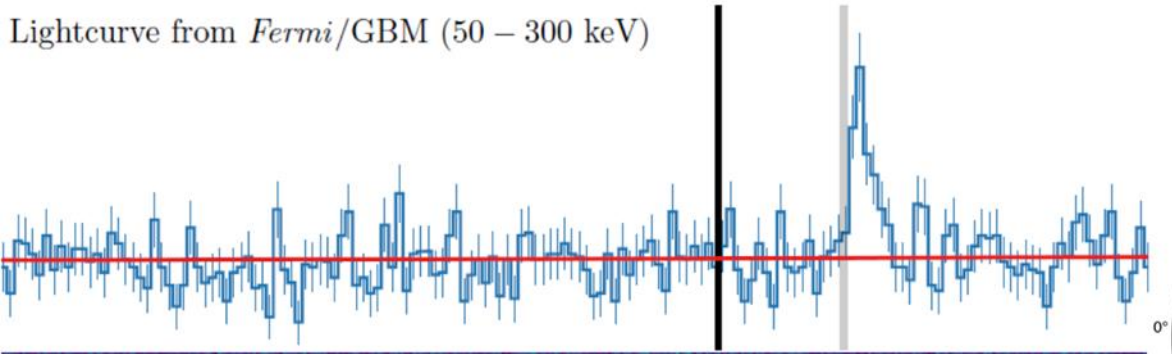
Even JWST and ELTs surveys will be not able to probe the faint end of the galaxy Luminosity Function at high redshifts (z>6-8)

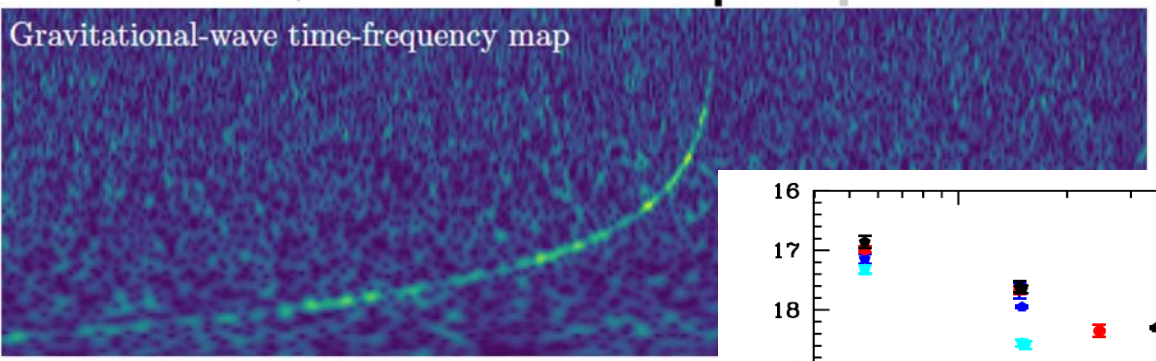
Shedding light on the early Universe with GRBs

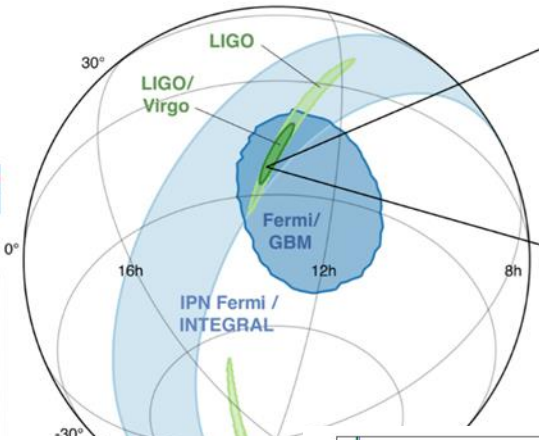


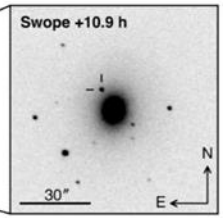
Short GRBs and multi-messenger astrophysics

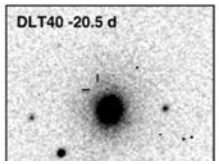
GW170817 + SHORT GRB 170817A + KN AT2017GFO (~40 Mpc):
the birth of multi-messenger astrophysics

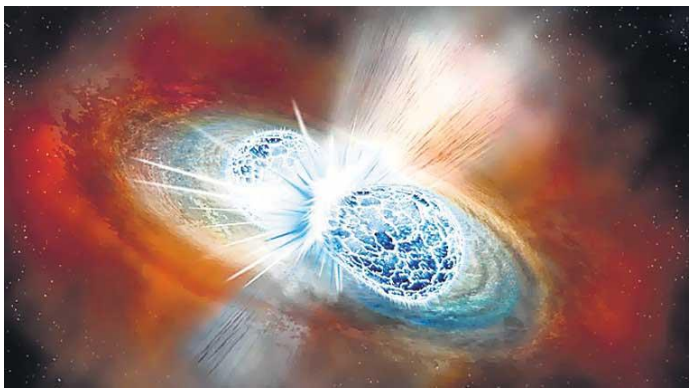


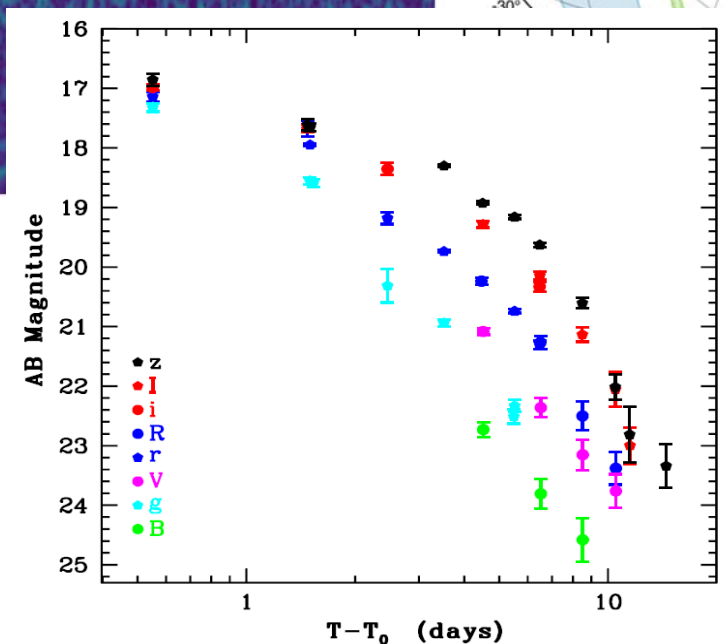


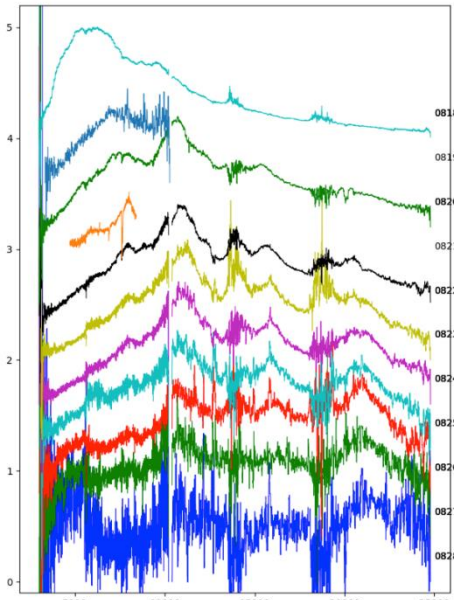










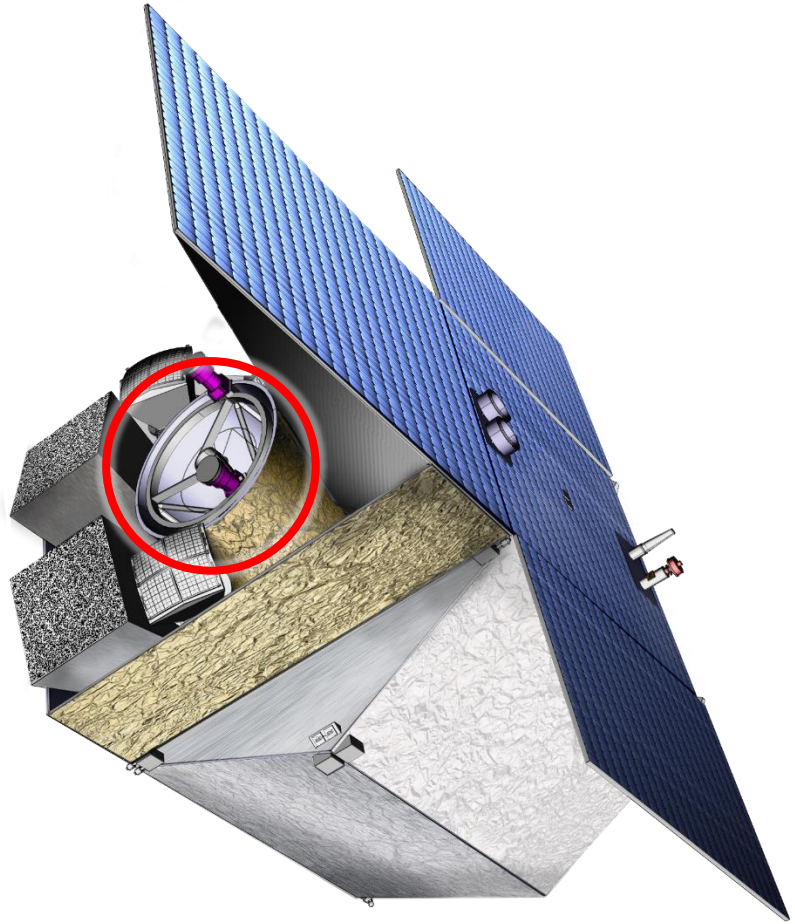


THESEUS Mission Concept

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

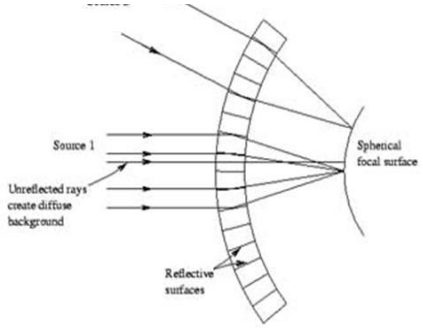
Set of innovative wide-field monitors with **unprecedented combination of broad energy range from gamma-rays down to soft X-rays, FOV and localization accuracy**

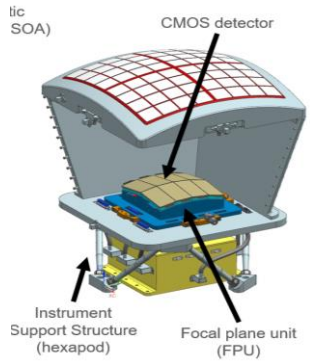
On-board **autonomous fast follow-up in optical/NIR**, arcsec location and **redshift measurement** of detected GRB/transients



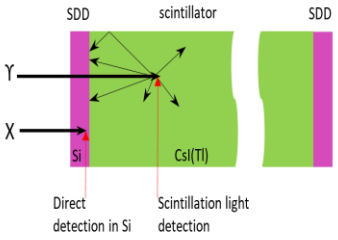
THESEUS Mission Concept

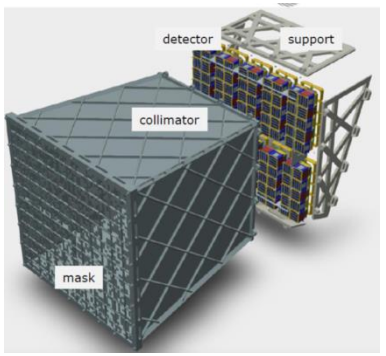
- **Soft X-ray Imager (SXI):** a set of two sensitive lobster-eye telescopes observing in 0.3 - 5 keV band, total FOV of ~0.5sr with source location accuracy <2’



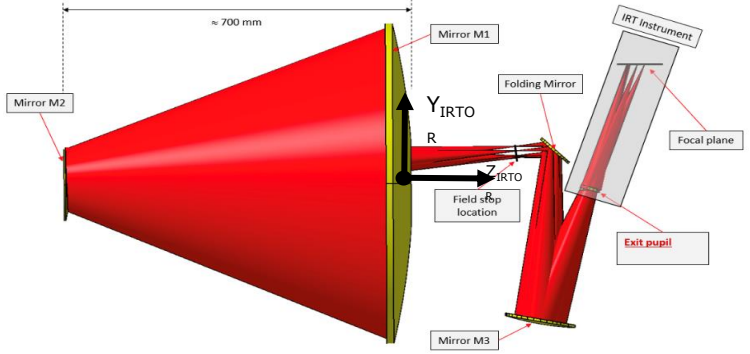


- **X-Gamma rays Imaging Spectrometer (XGIS):** 2 coded-mask X-gamma ray cameras using Silicon drift detectors coupled with CsI crystal scintillator bars observing in 2 keV – 10 MeV band, a FOV of >2 sr, overlapping the SXI, with <15’ GRB location accuracy



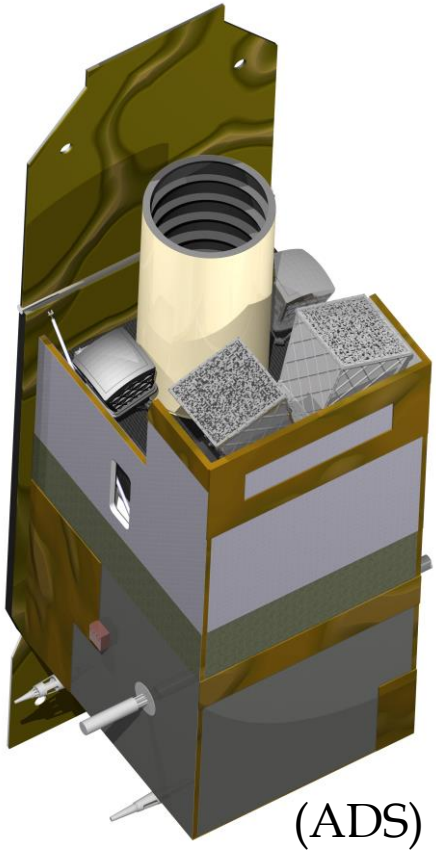


- **InfraRed Telescope (IRT):** a 0.7m class IR telescope observing in the 0.7 – 1.8 μm band, providing a 15’x15’ FOV, with both imaging and moderate resolution spectroscopy capabilities

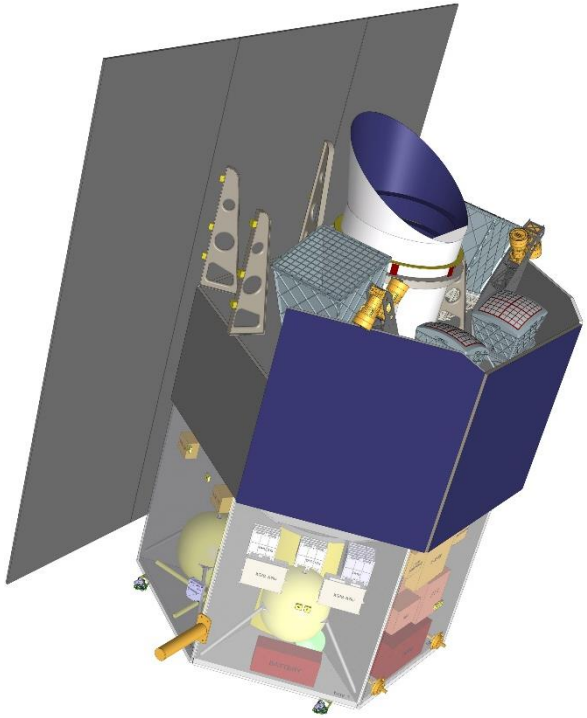


THESEUS Mission Concept

- **Fast slewing capability** (>10°/min), granting prompt NIR follow-up of GRBs and transients
- **Low-Earth Orbit (LEO),** with about 4° inclination and 550-640 km altitude, granting low and stable BKG for the monitors
- The weight (about 2.3 tons) and dimensions are suitable for **launch with VEGA-E**

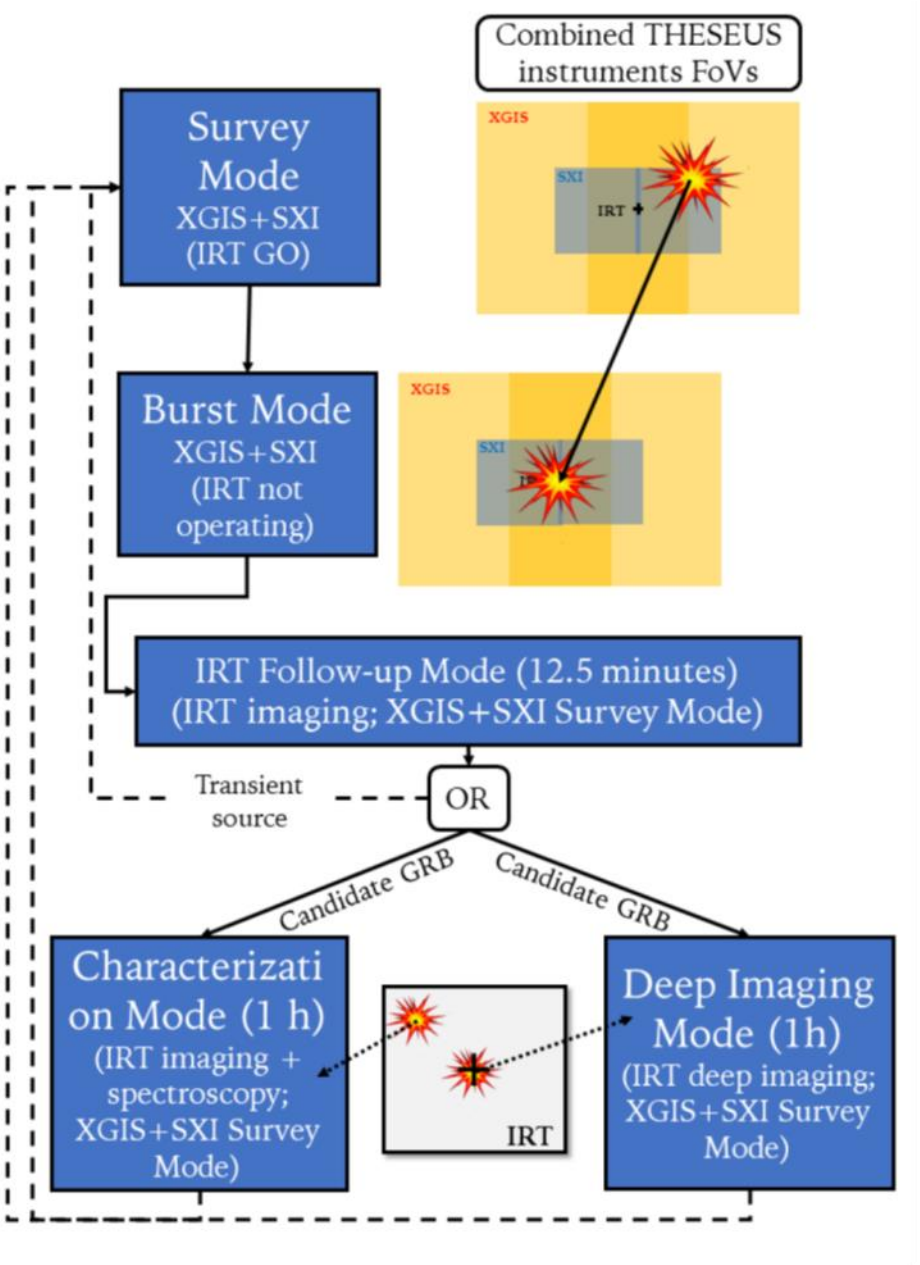


(ADS)

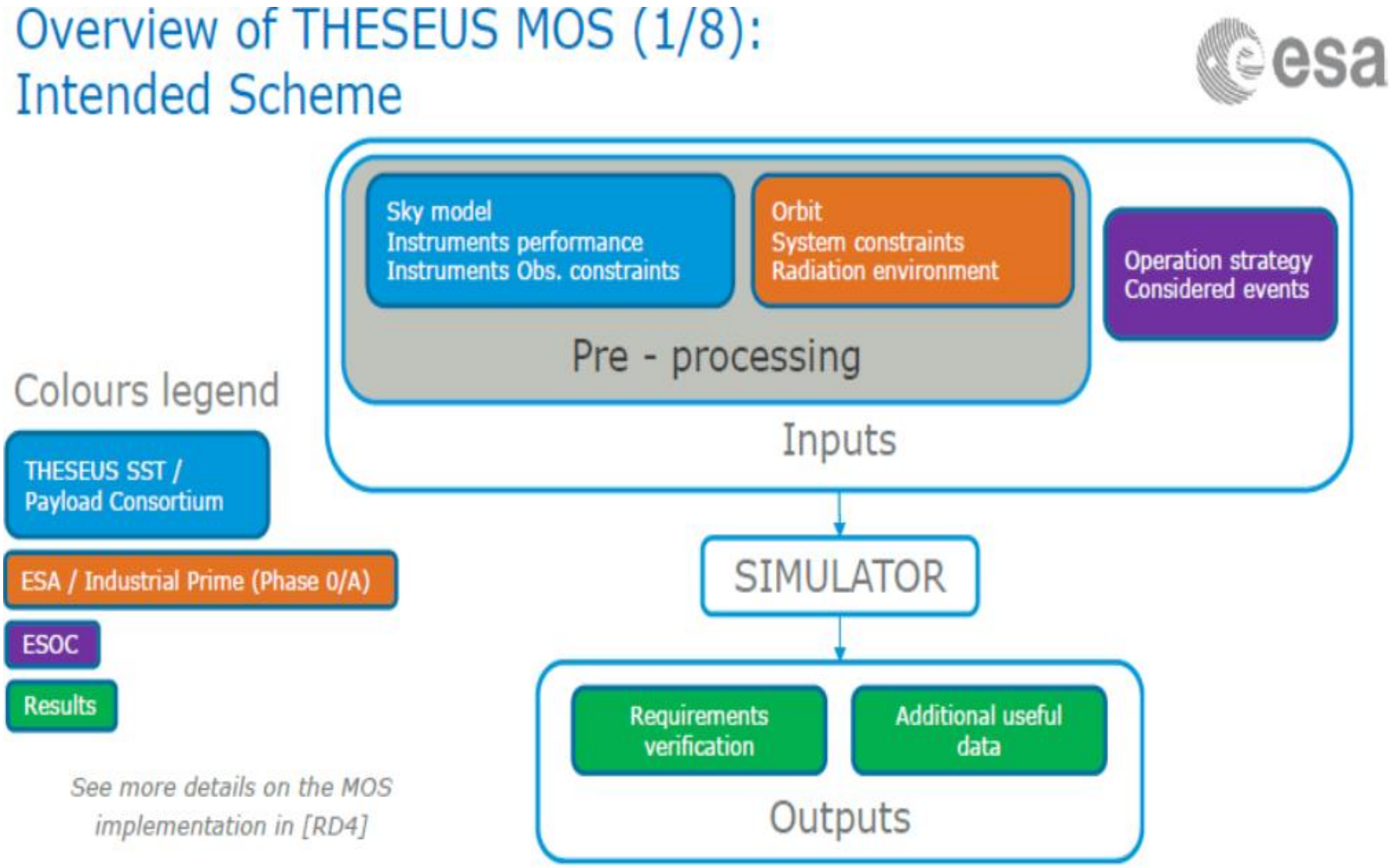


(THALES)

Mission Operation Concept (MOC)



Mission Observation Simulator (MOS)

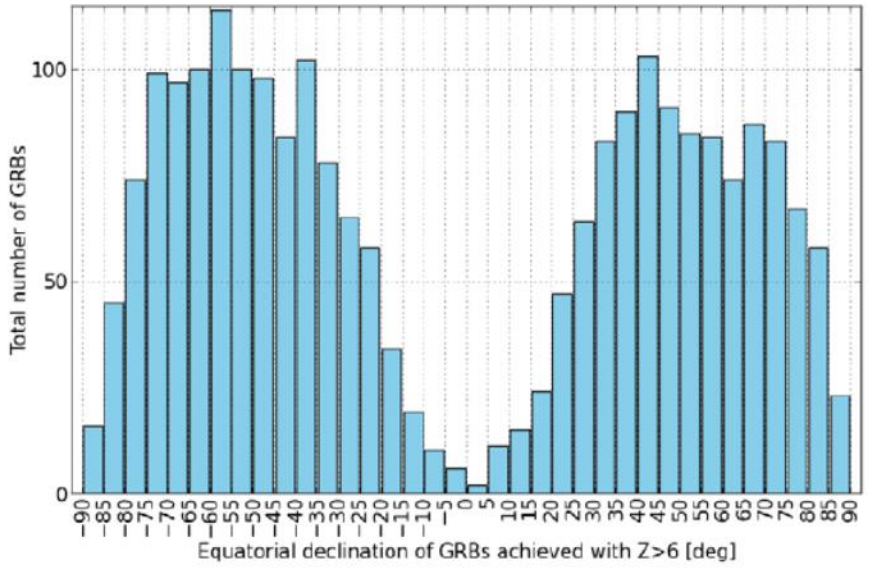


MOS: pointing strategies trade-offs

- Optimize for follow-up from on-ground large telescopes (e.g., ELT, TMT) -> lower latitudes

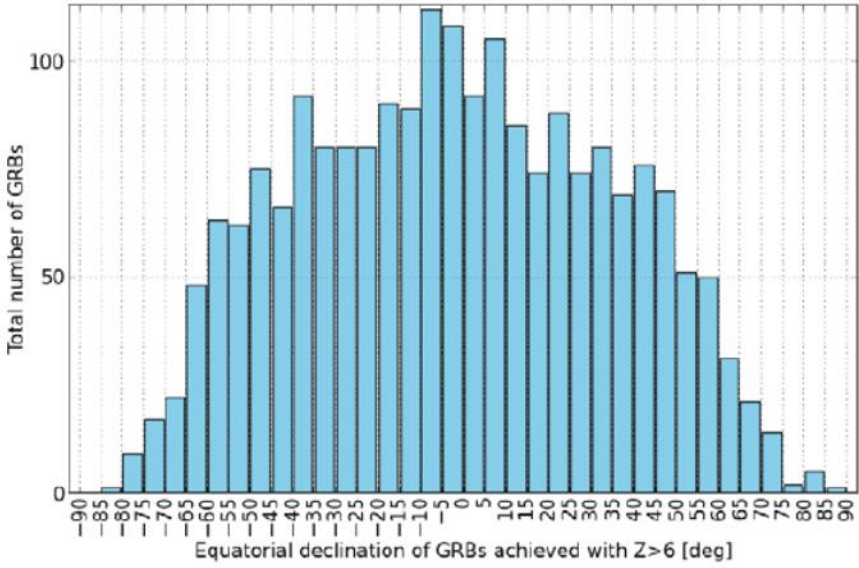
30 deg tilt (2/2)

Declination range (absolute)	Fraction of achieved GRBs z>6
0-30	15.5%
30-55	39.9%
55-75	32.2%
75-90	12.4%

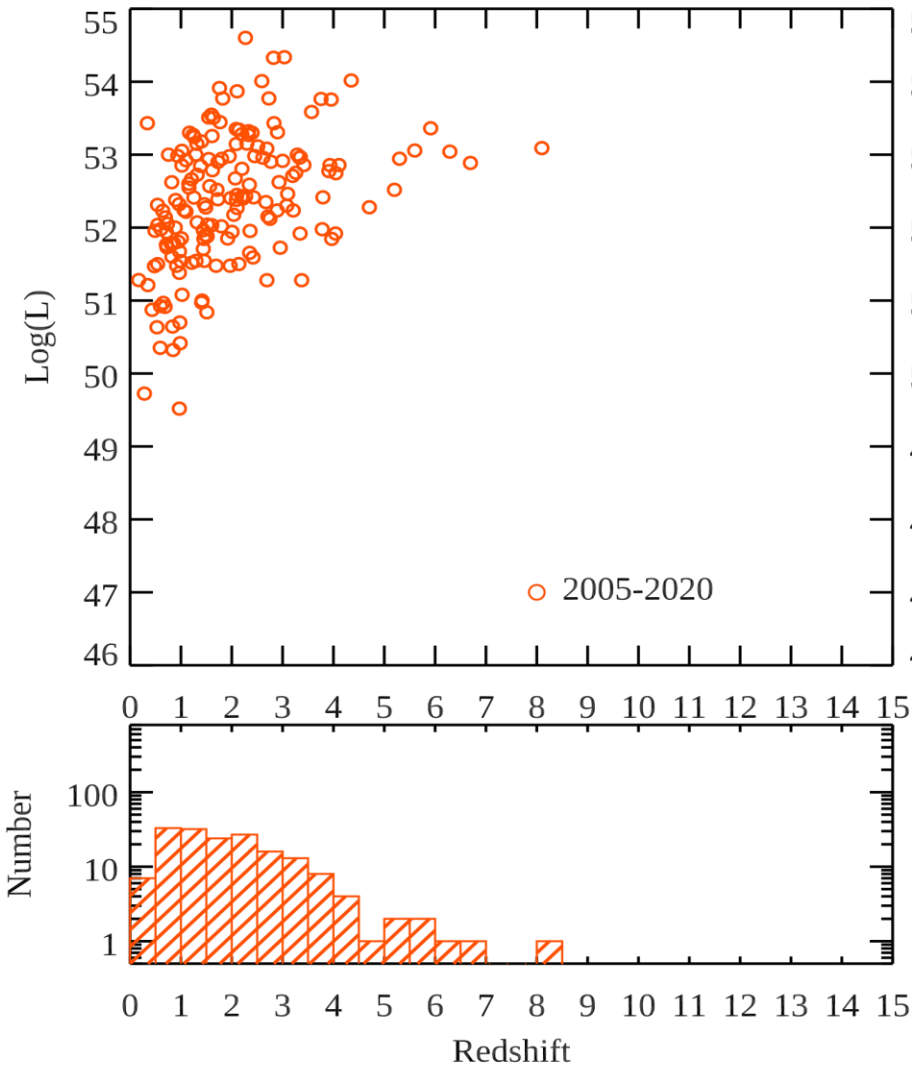


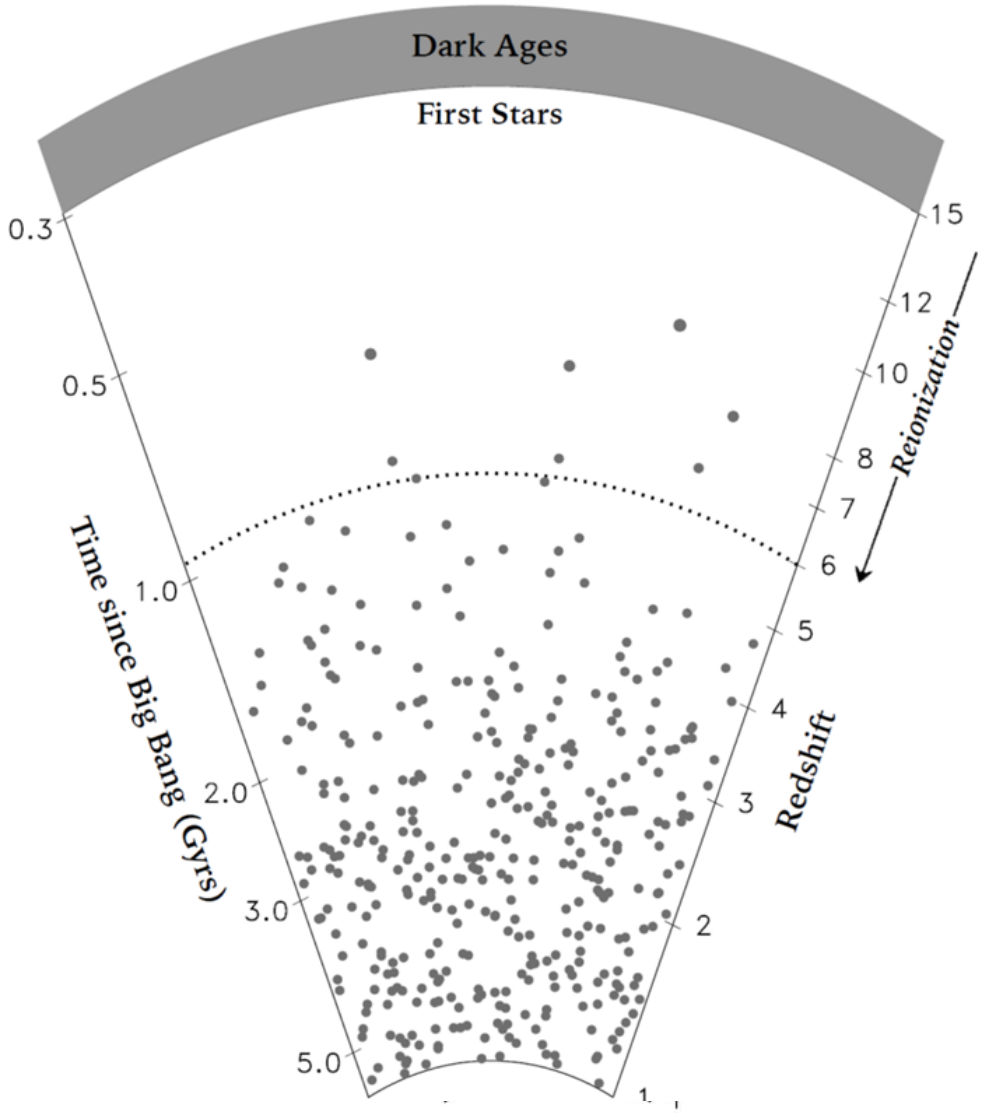
60 deg tilt (2/2)

Declination range (absolute)	Fraction of achieved GR
0-30	51.7%
30-55	34.6%
55-75	12.8%
75-90	0.9%



Expected performances: early Universe





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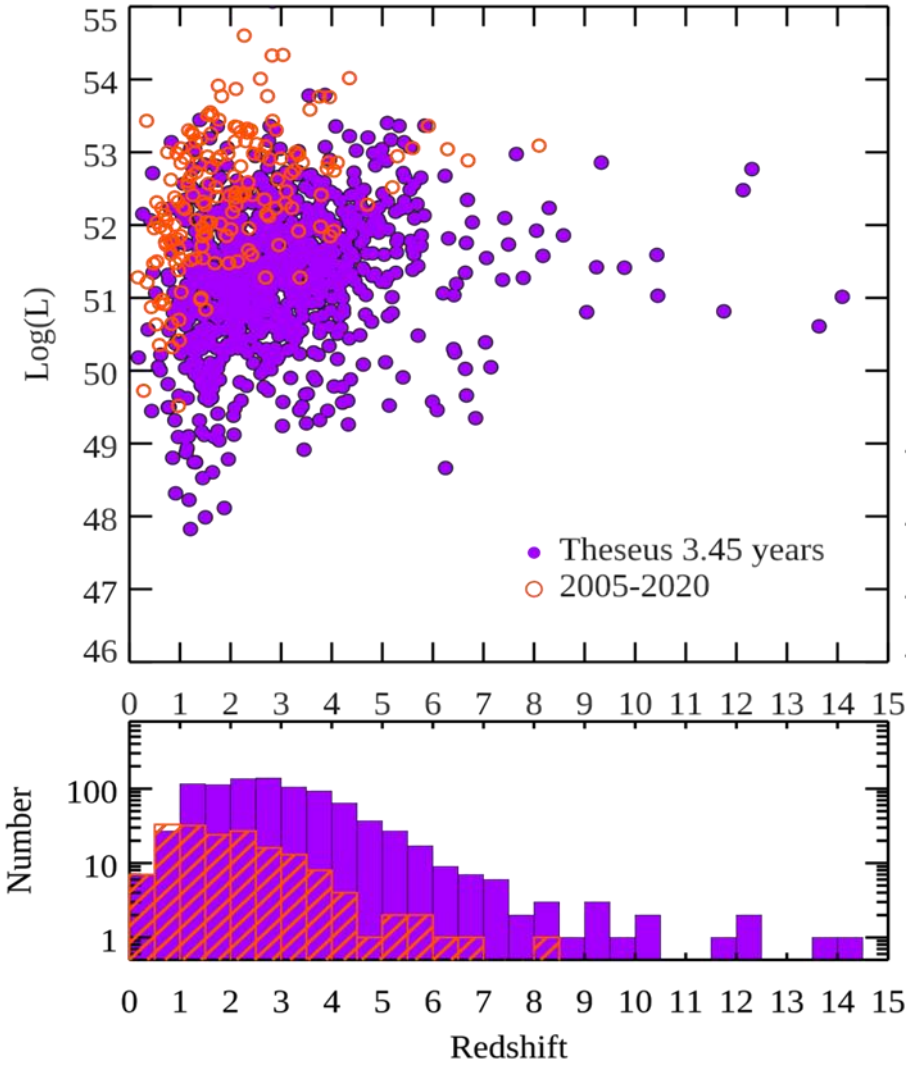
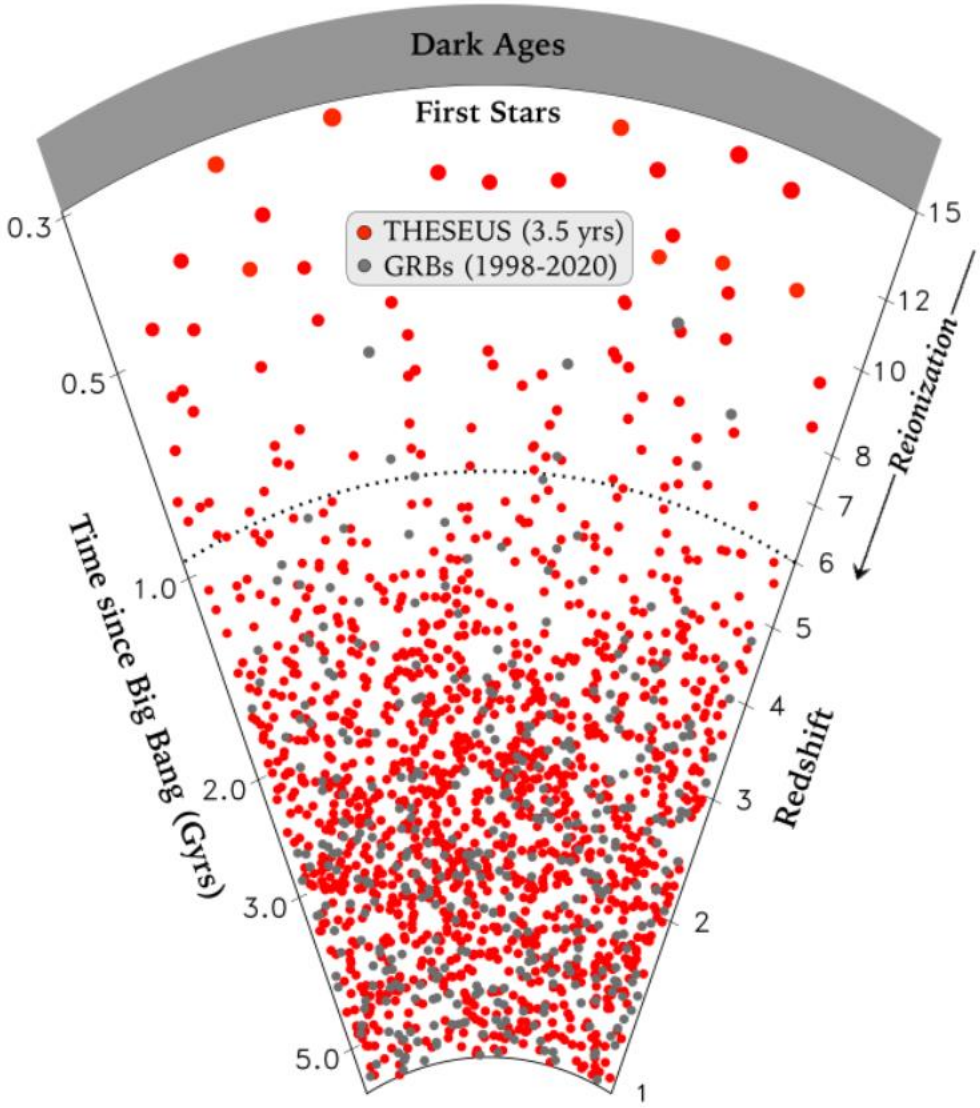
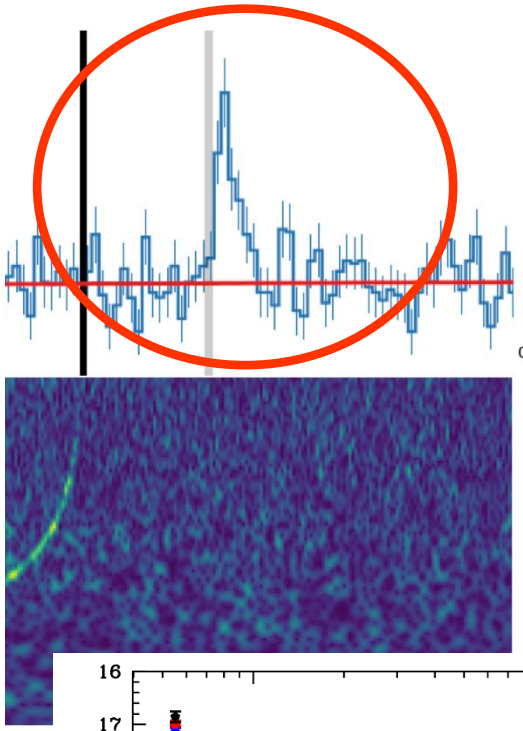


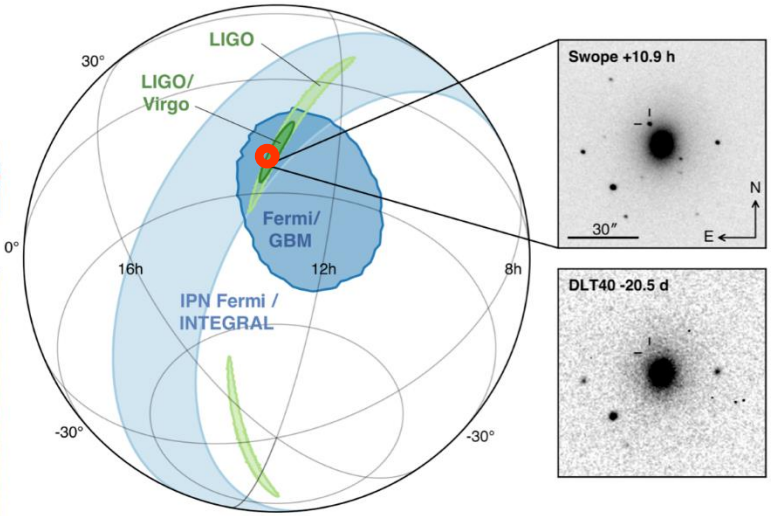


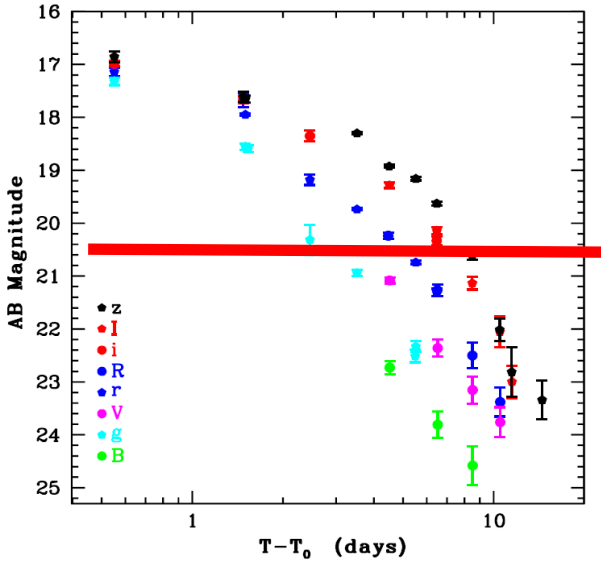
Expected performances: multi-messenger astr.

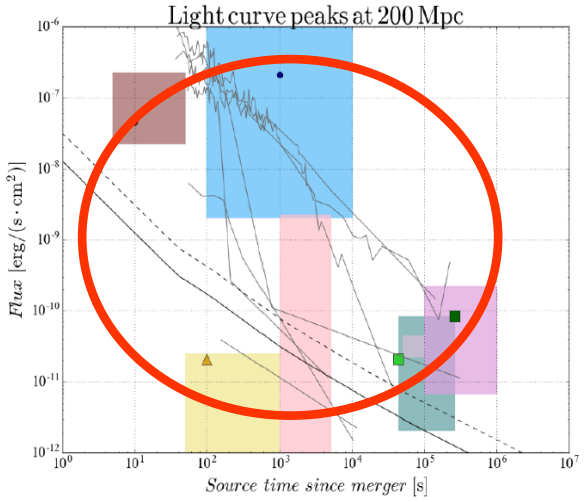
THESEUS:

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



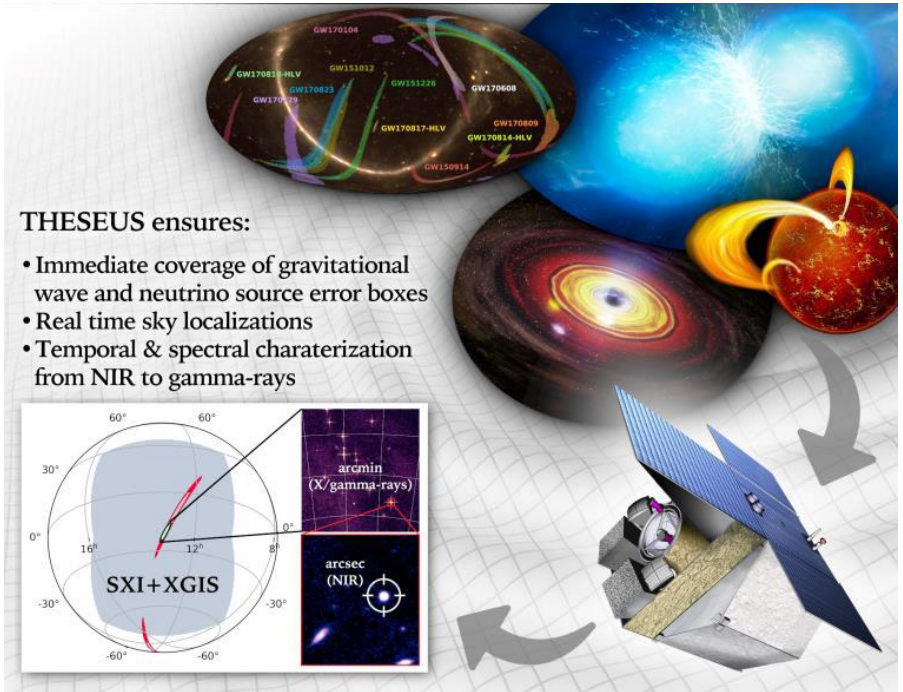


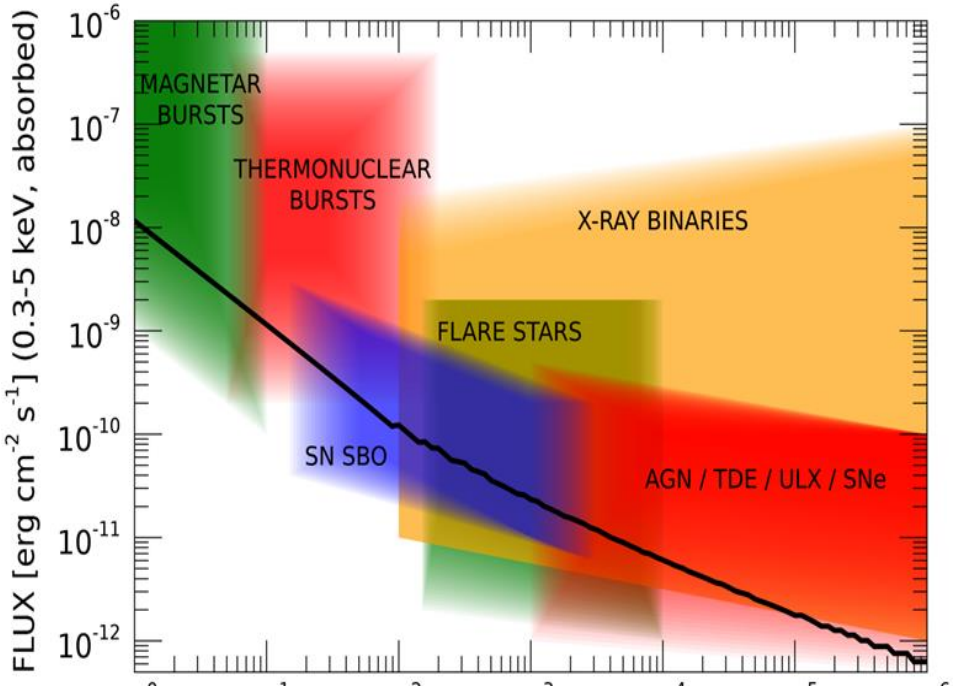




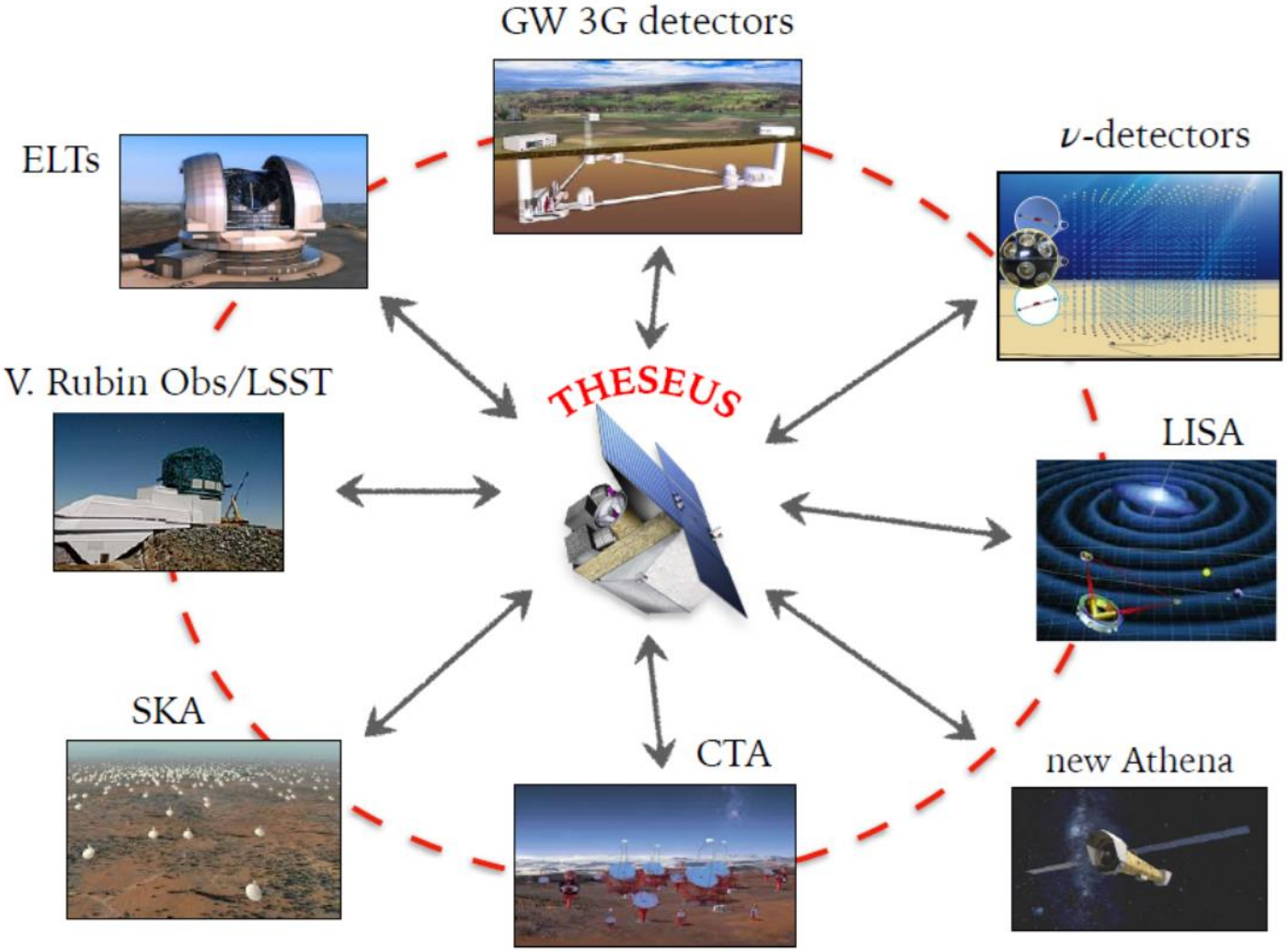
Exploring the transient sky

- **GRBs extreme emission physics**, central engine, sub-classes & progenitors, **cosmological parameters & fundamental physics**
- Study of **many classes of X-ray sources** by exploiting the **simultaneous broad band X-ray and NIR observations**
- Provide a **flexible follow-up observatory** for fast transient events with **multi-wavelength ToO capabilities** and **guest-observer programmes**





THESEUS: crucial synergies in the late '30s



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

In summary

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

- **THESEUS**, a mission concept developed by a large European collaboration led by Italy and under study by ESA (M7 Phase-A) **will fully exploit these potentialities**, providing a substantial contribution to extreme GRB physics and time-domain astronomy

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

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

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