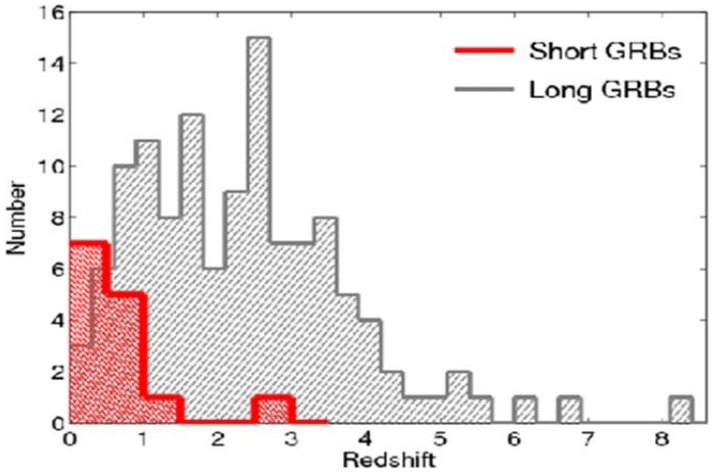
Cosmology & Multi-Messenger Astrophysics with next-generation GRB missions

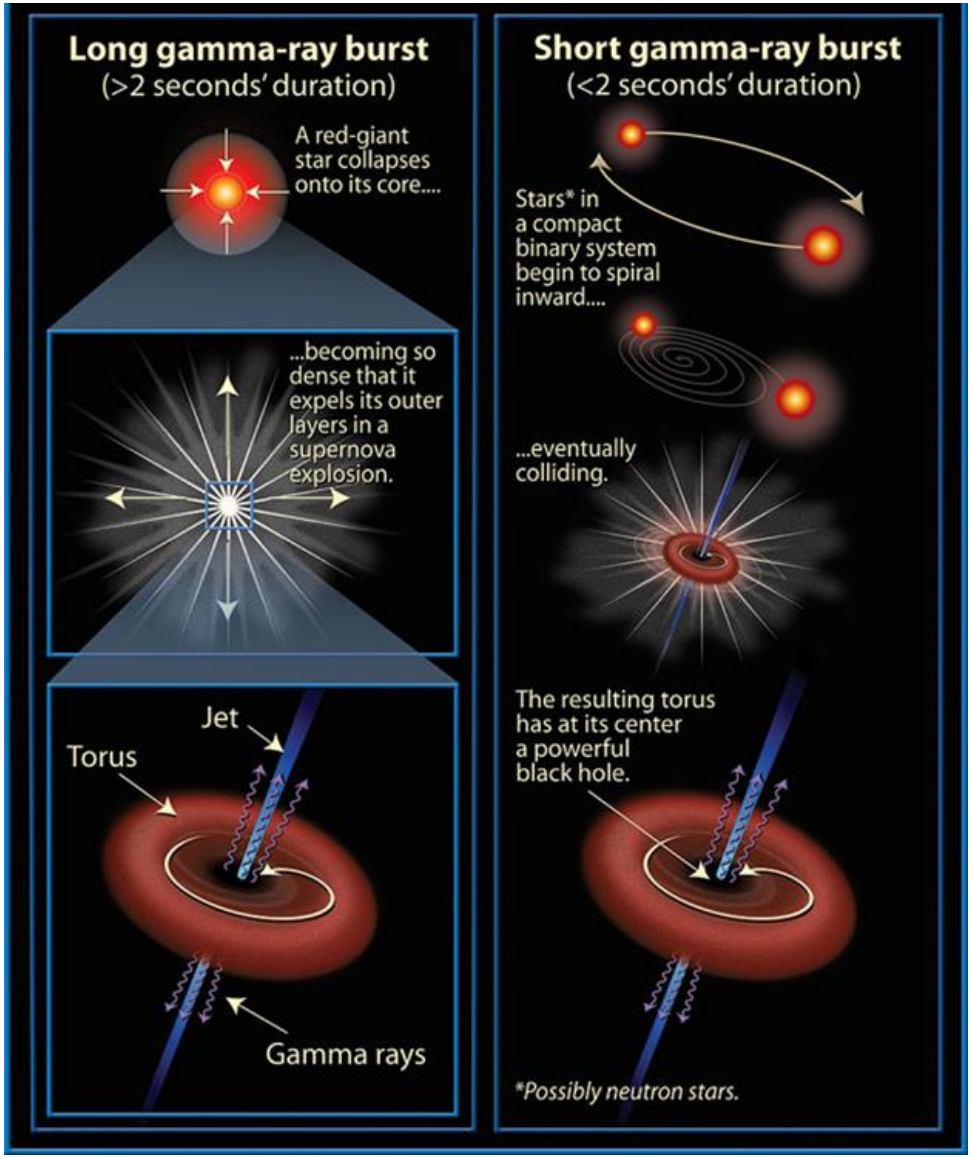
Lorenzo Amati
(INAF – OAS Bologna)
(18 May 2023)

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



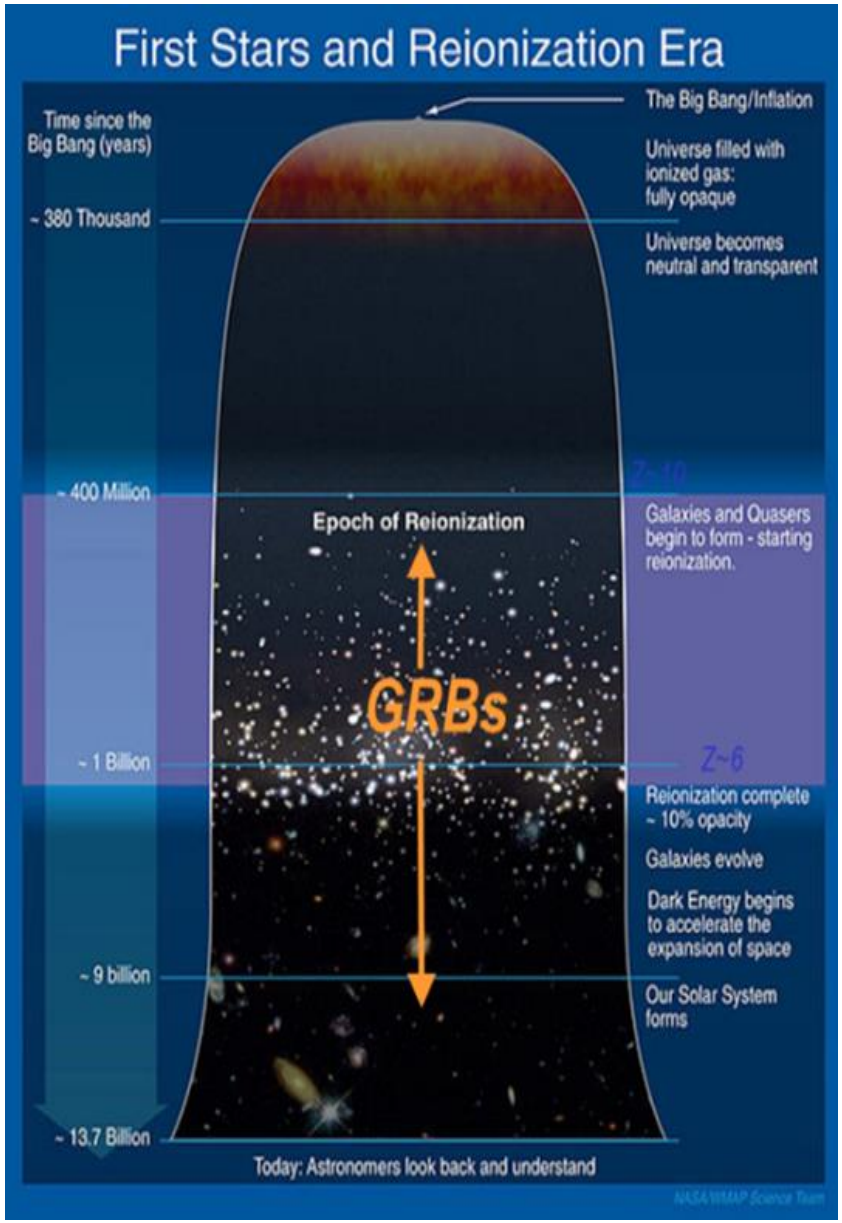
Long GRBs: core collapse of pecular massive stars, **association with SN**

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



Shedding light on the early Universe with GRBs

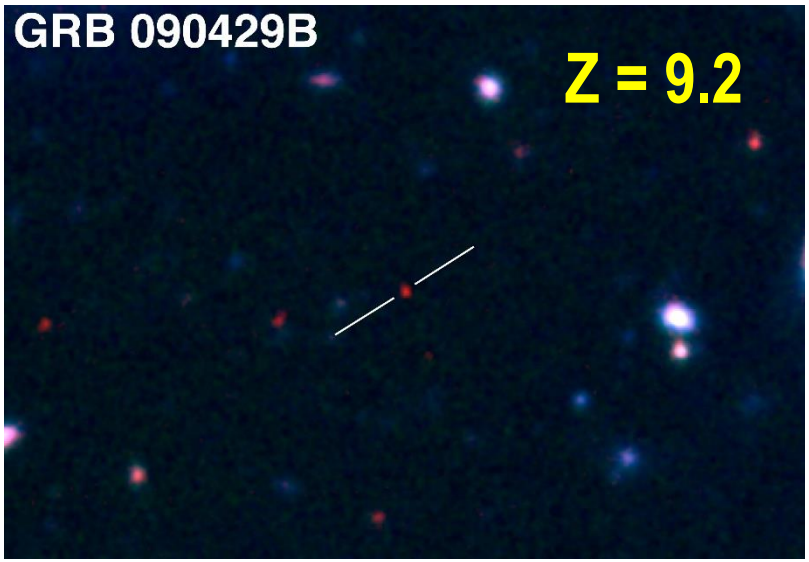
- **Long GRBs:** huge luminosities, mostly emitted in the X and gamma-rays
- **Redshift distribution** extending at least to z ~9 and association with exploding massive stars
- **Powerful tools for cosmology:** SFR evolution, physics of re-ionization, high-z low luminosity galaxies, pop III stars

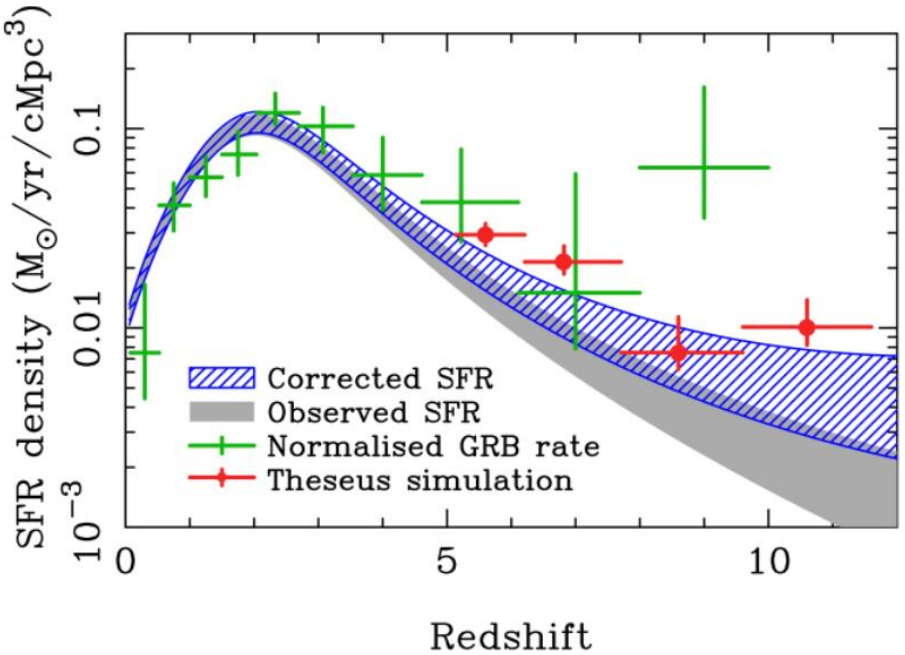


Shedding light on the early Universe with GRBs

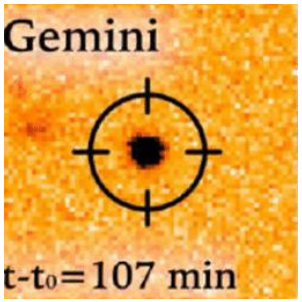
A statistical sample of high–z GRBs can provide fundamental information:

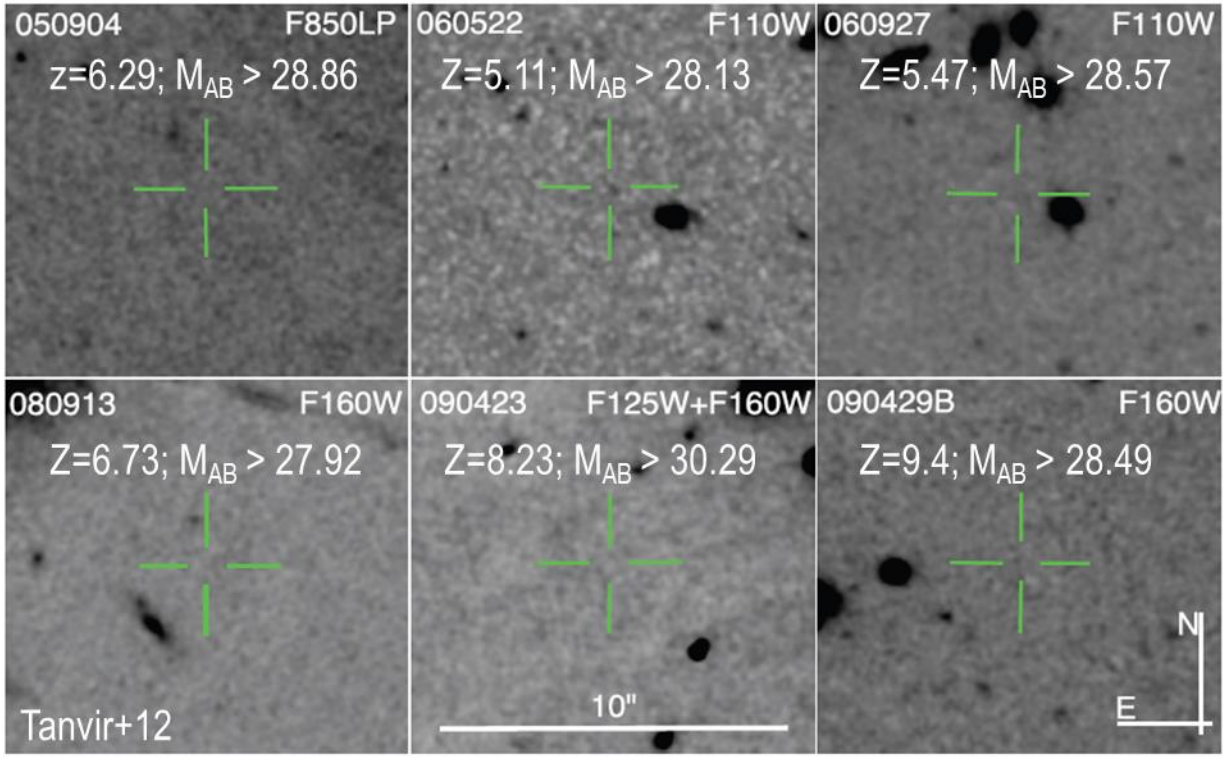
- measure independently the **cosmic star–formation rate**, even beyond the limits of current and future galaxy surveys
- directly (or indirectly) detect the **first population of stars (pop III)**





Detecting and studying primordial invisible galaxies

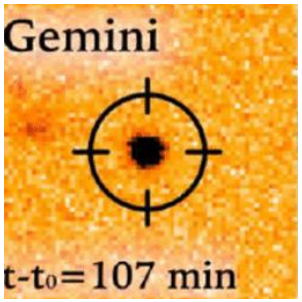


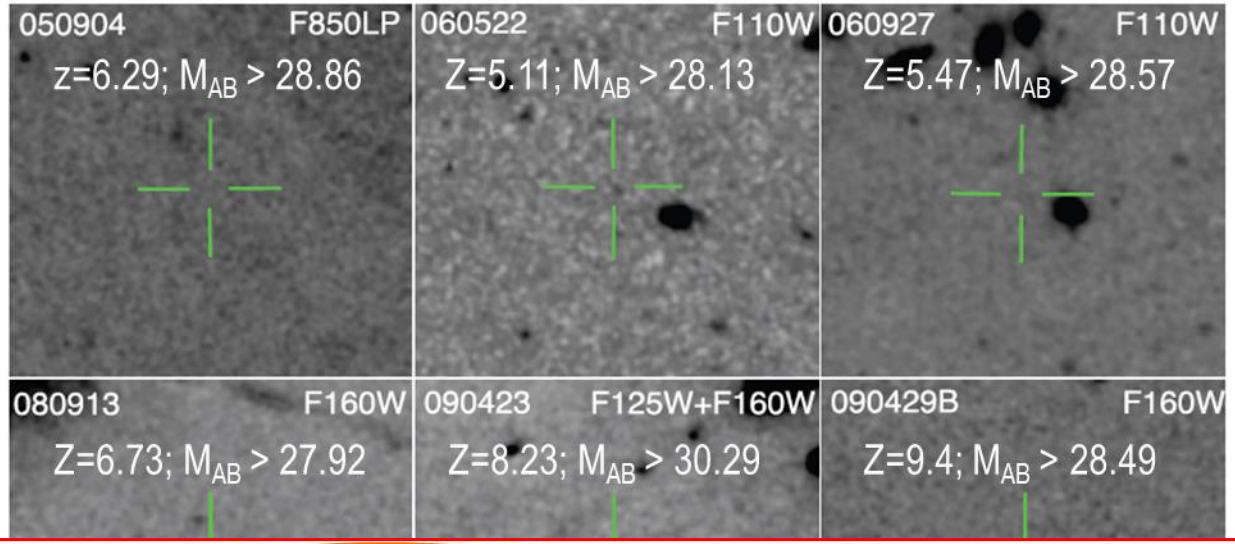


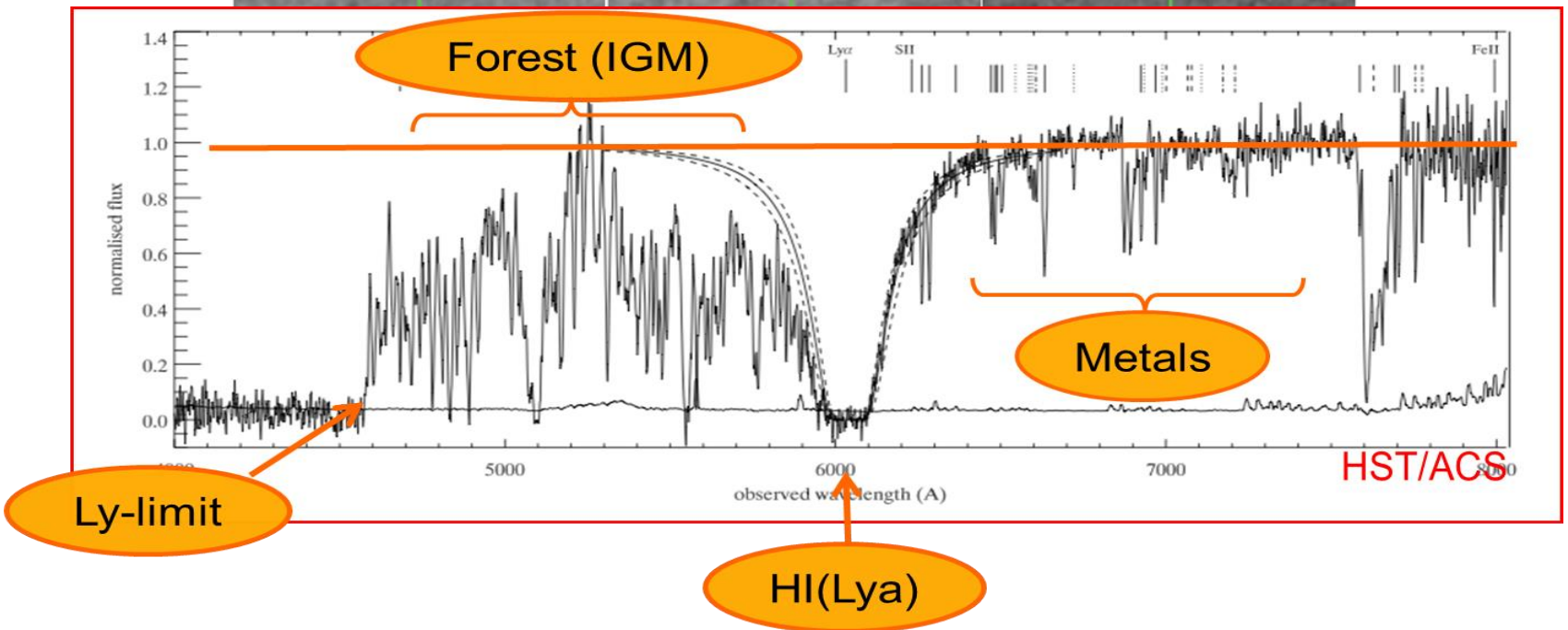
Robertson&Ellis12

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)

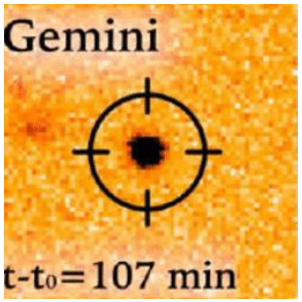
Detecting and studying primordial invisible galaxies

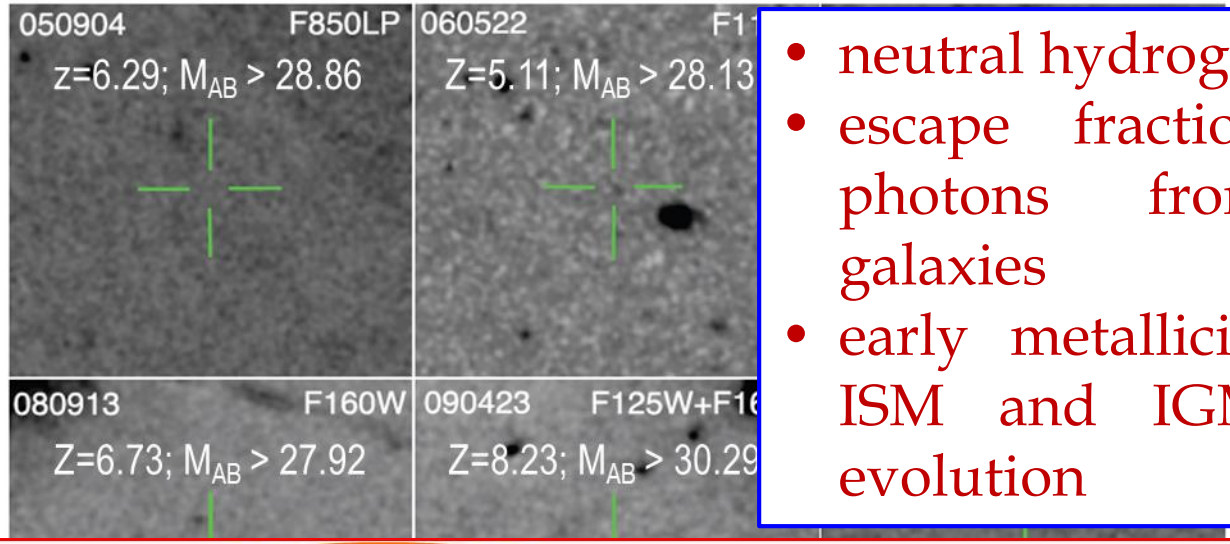




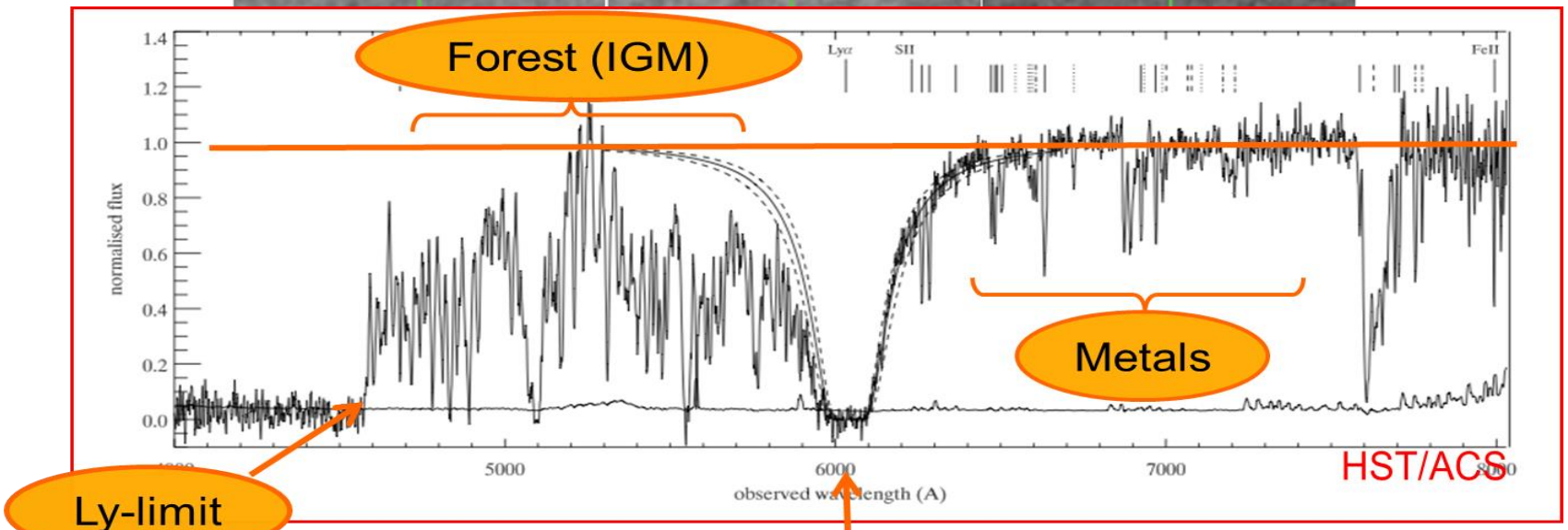


Detecting and studying primordial invisible galaxies

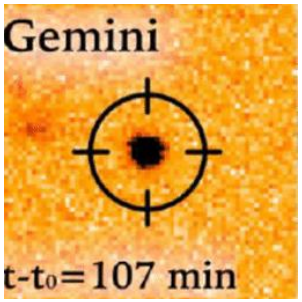


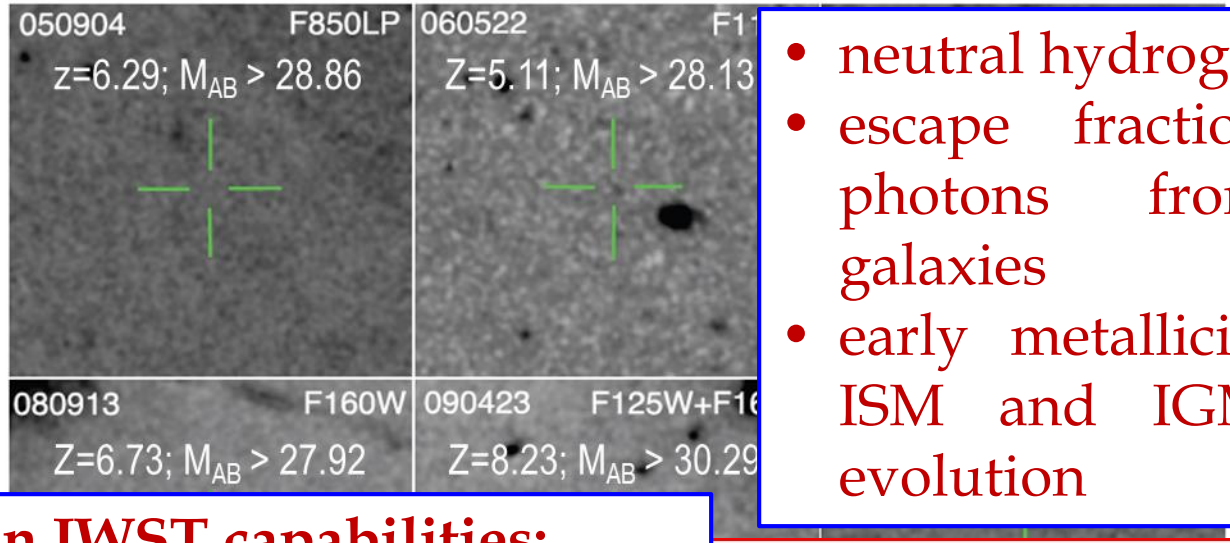


- neutral hydrogen fraction
- escape fraction of UV photons from high-z galaxies
- early metallicity of the ISM and IGM and its evolution



Detecting and studying primordial invisible galaxies

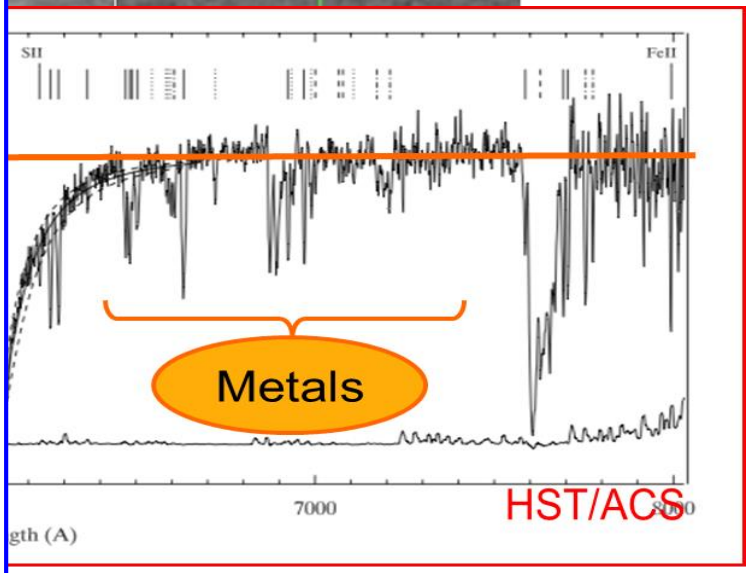




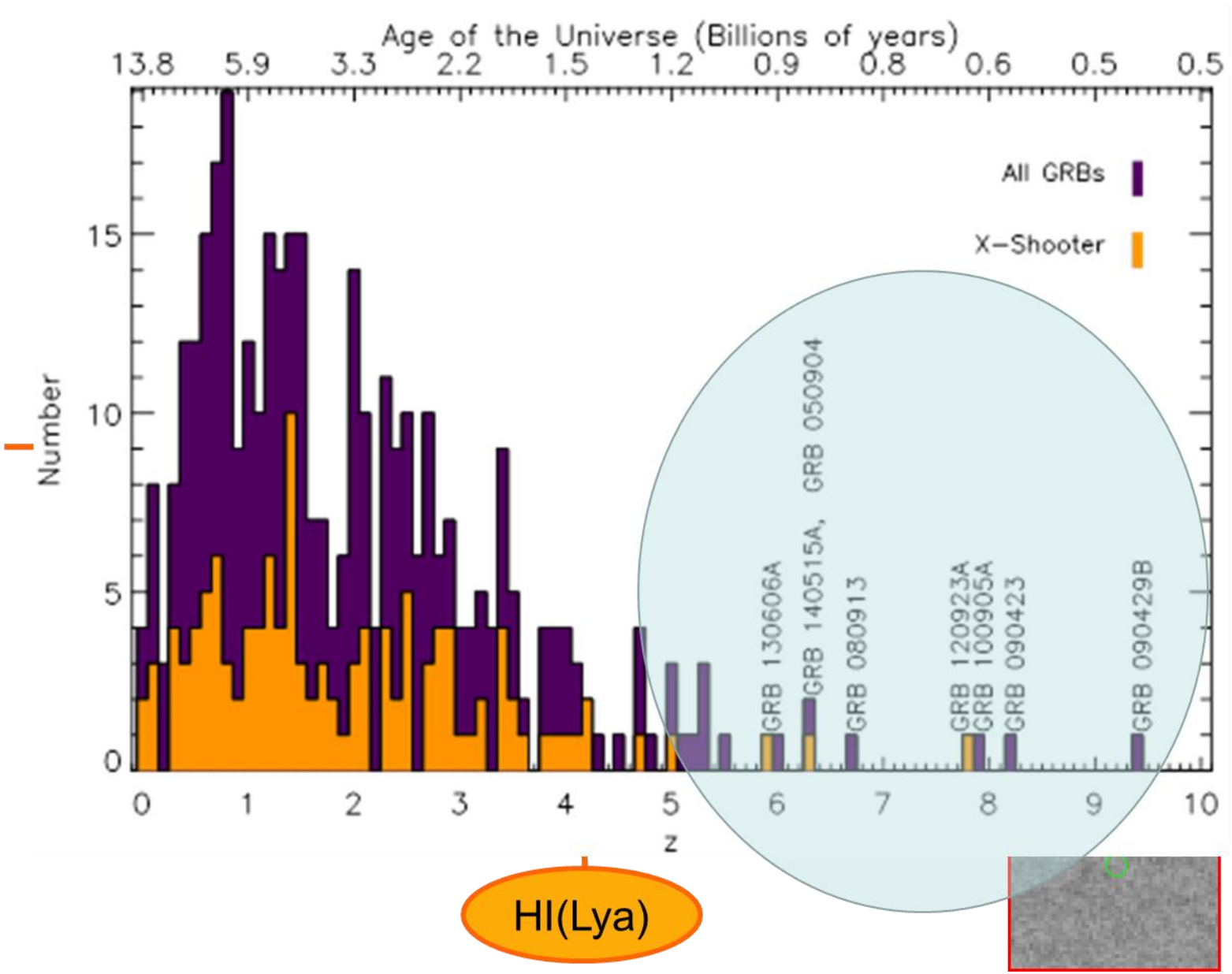
- neutral hydrogen fraction
- escape fraction of UV photons from high-z galaxies
- early metallicity of the ISM and IGM and its evolution

Beyond even JWST capabilities:

- Primordial galaxies detection and characterization Independent on mass and luminosity
- Allow absorption spectroscopy (needed because most metals are in neutral gas and and for dust ratio)
- Properties of primordial IGM
- Targets for JWST

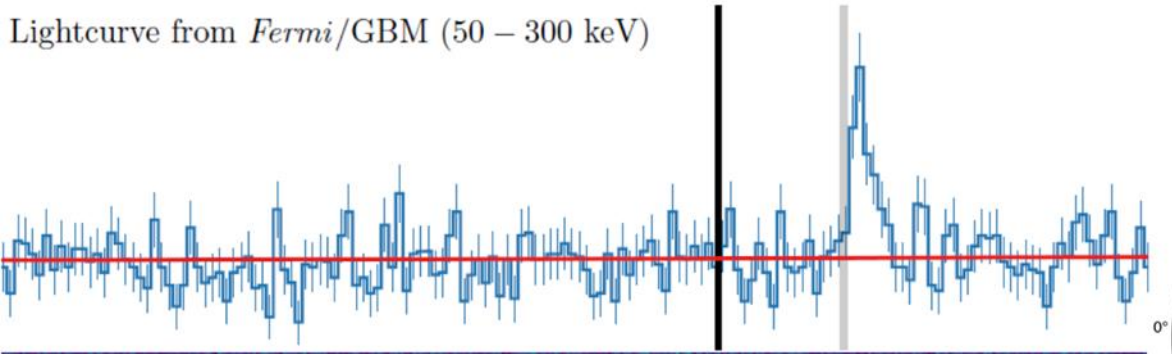


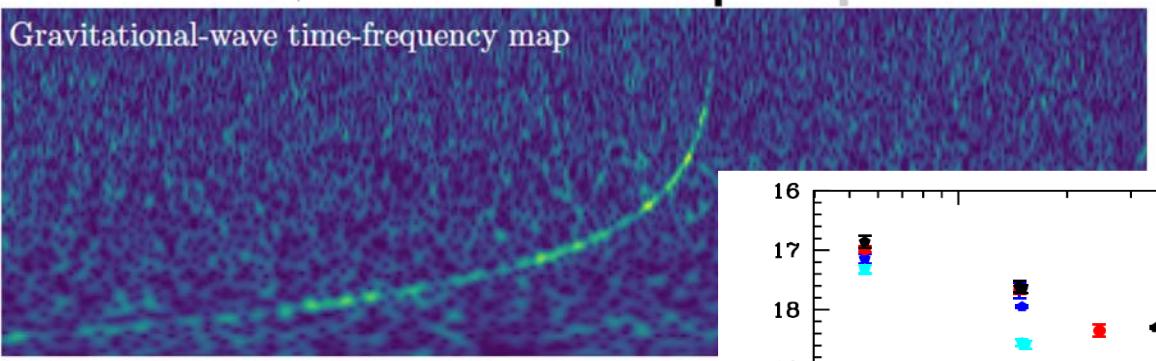
Shedding light on the early Universe with GRBs

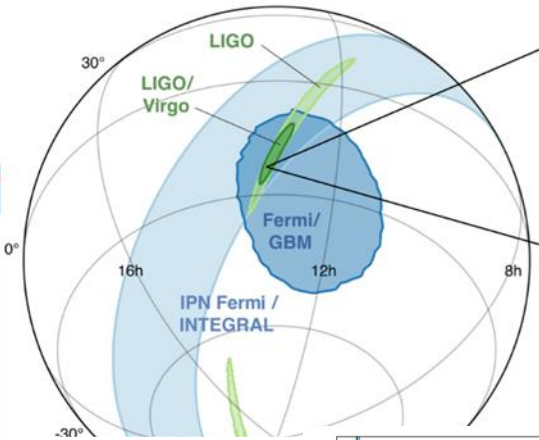


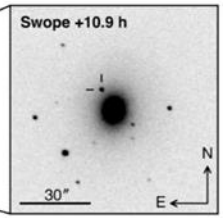
Short GRBs and multi-messenger astrophysics

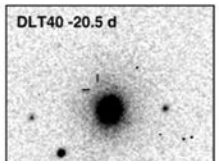
GW170817 + SHORT GRB 170817A + KN AT2017GFO (~40 Mpc):
the birth of multi-.messenger astrophysics

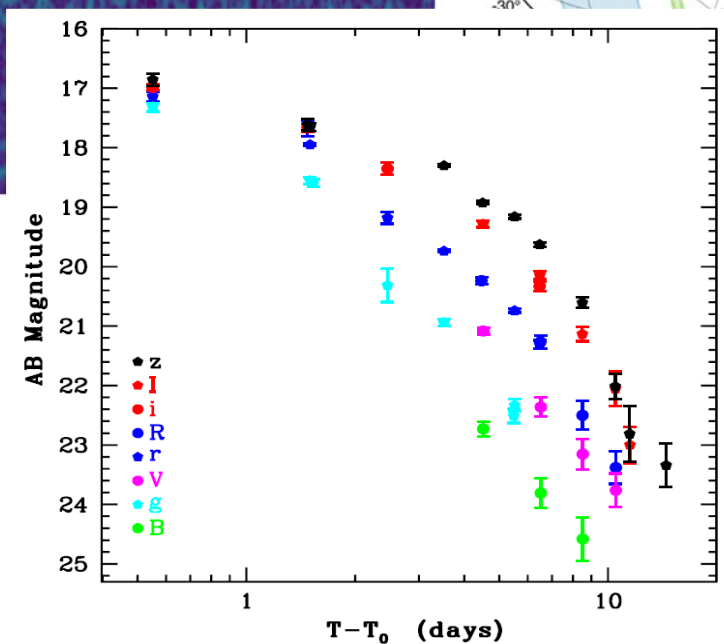


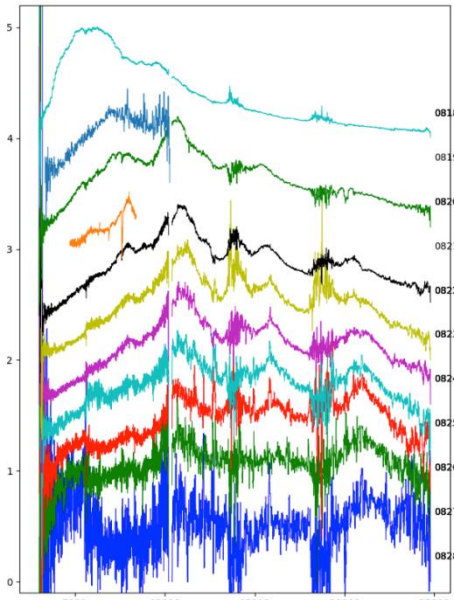






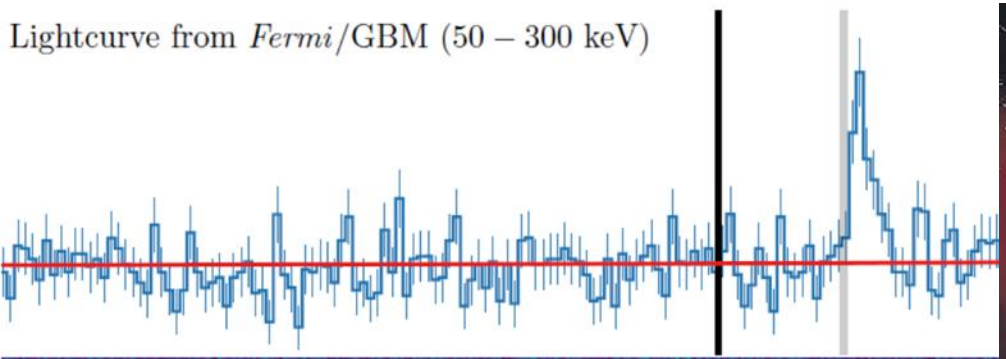


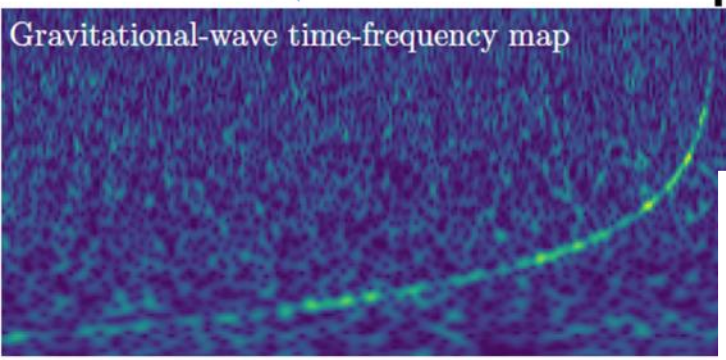


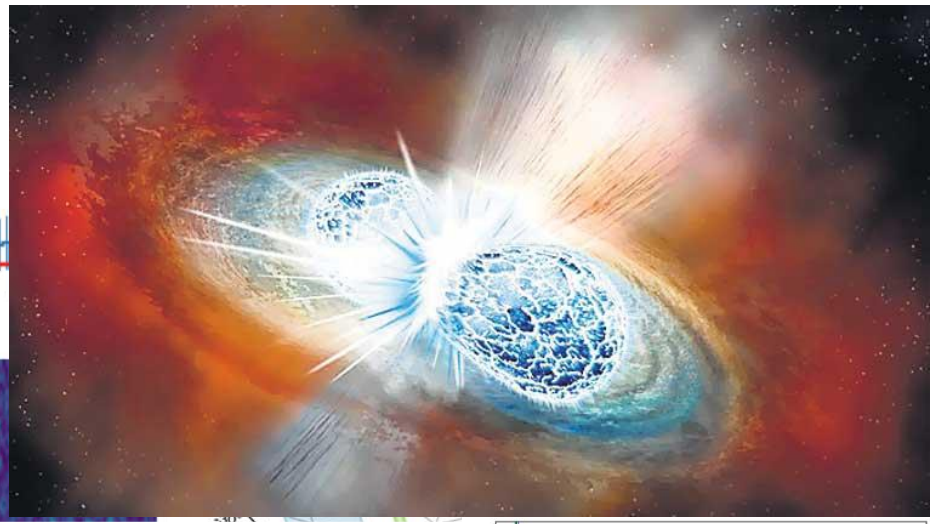


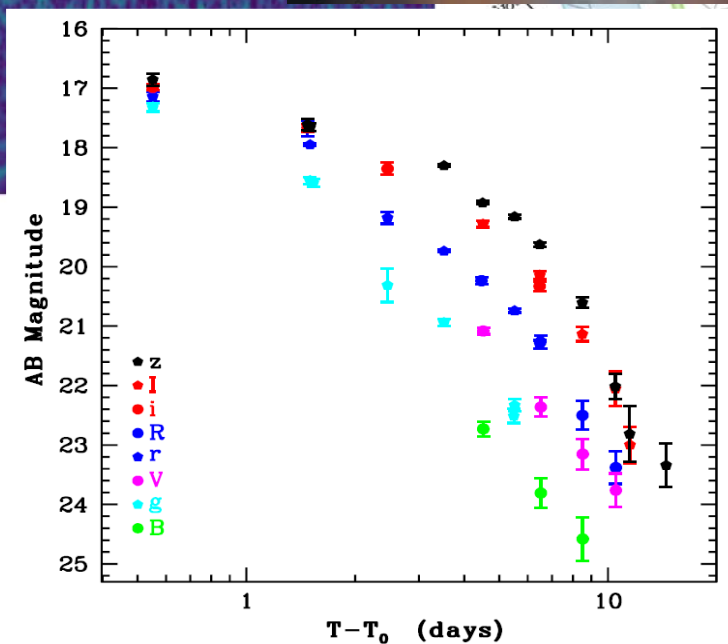
Short GRBs and multi-messenger astrophysics

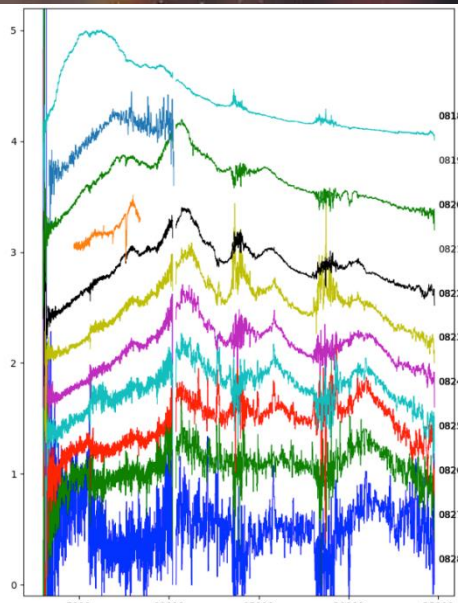
GW170817 + SHORT GRB 170817A + KN AT2017GFO (~40 Mpc):
the birth of multi-.messenger astrophysics







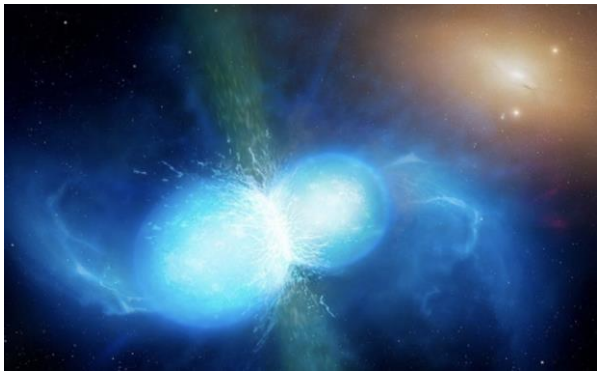




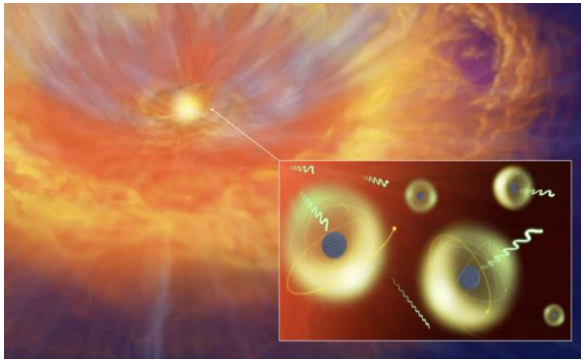
GRB: a key phenomenon for multi-messenger astrophysics (and cosmology)

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

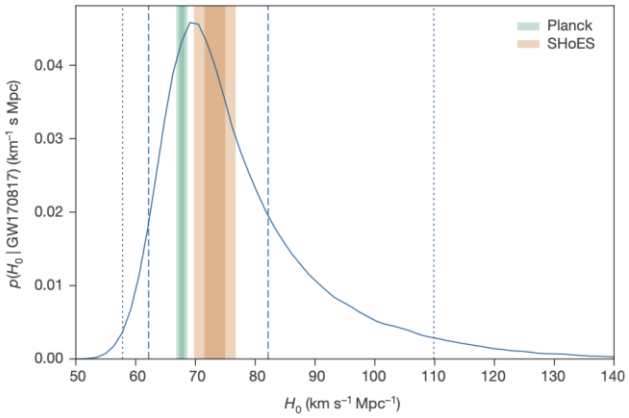
Relativistic jet formation, equation of state, fundamental physics



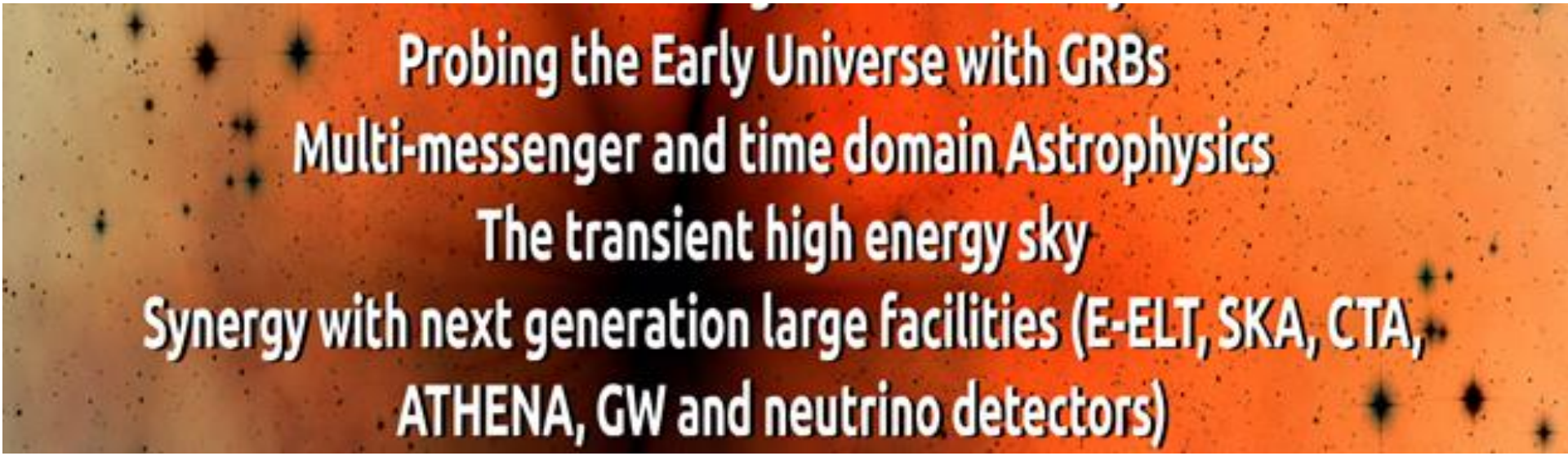
Cosmic sites of r-process nucleosynthesis



New independent route to measure cosmological parameters



Next generation GRB missions ('30s)



- **THESEUS** (studied for ESA Cosmic Vision / M5), **HiZ-GUNDAM** (JAXA, under study), **Gamow Explorer** (proposal for NASA MIDEX**): prompt emission down to soft X-rays, source location accuracy of few arcmin, prompt follow-up with NIR telescope, on-board REDSHIFT**

theseus

TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

- 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

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

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

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

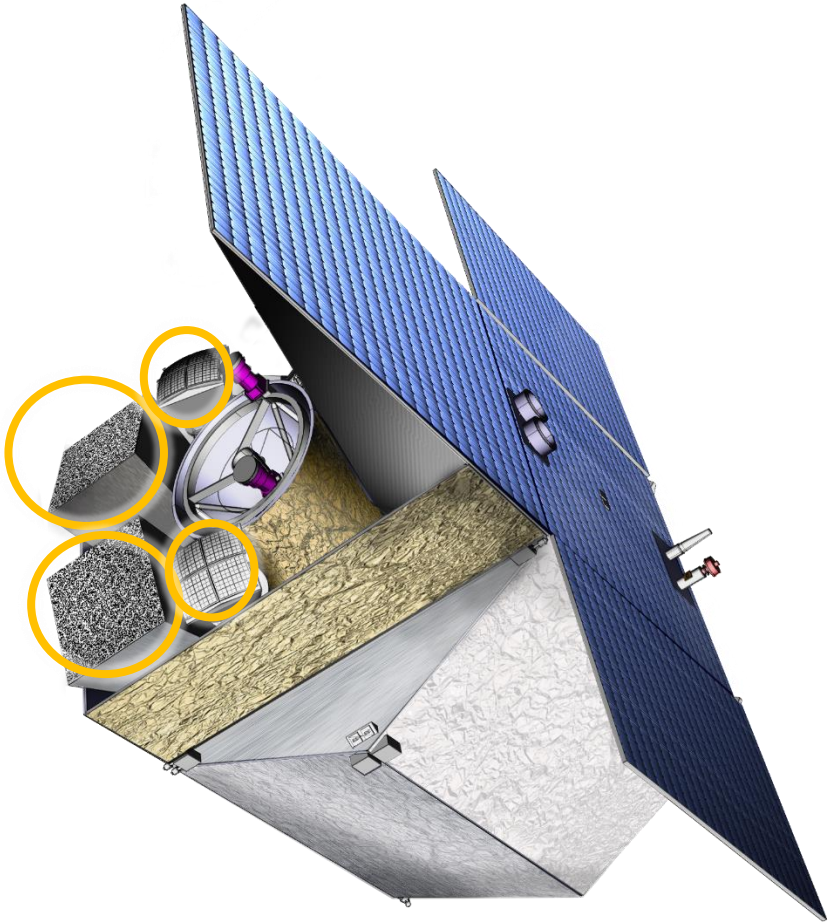
Amati et al. 2018 (Adv.Sp.Res., arXiv:1710.04638)
Stratta et al. 2018 (Adv.Sp.Res., arXiv:1712.08153)
Articles for SPIE 2020 and Exp..Astr. (all on arXiv)

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

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**

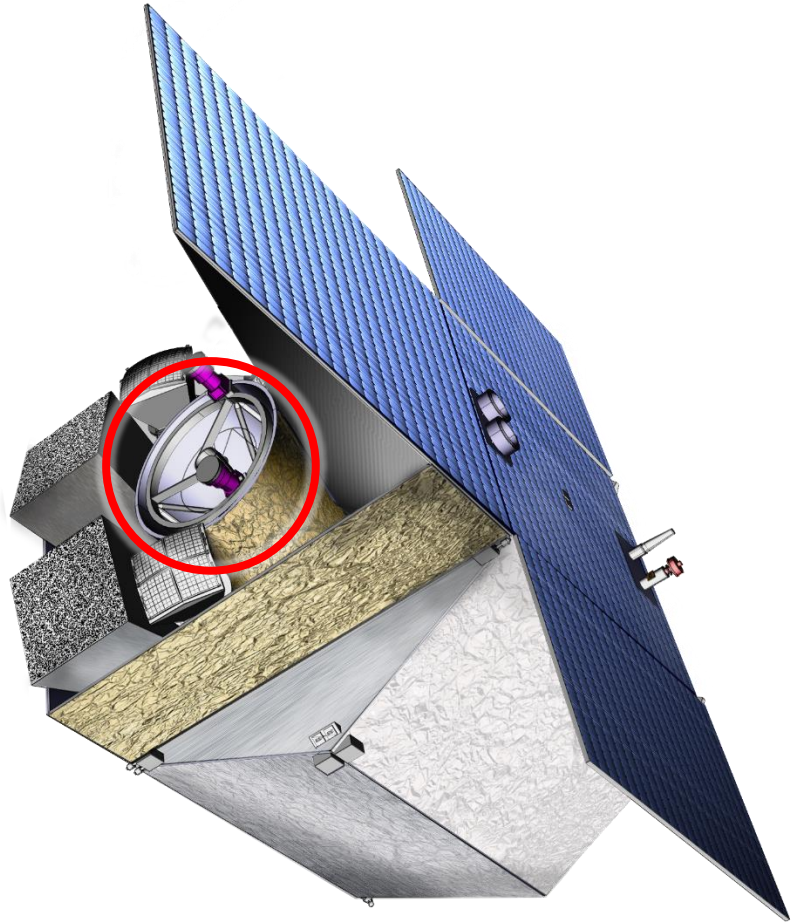


THESEUS Mission Concept

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

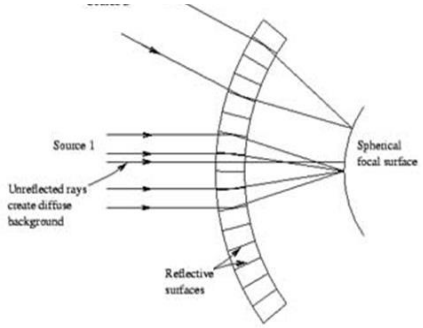
Set of innovative wide-field monitors with **unprecedented combination of broad energy range from gamma-rays down to soft X-rays, FOV and localization accuracy**

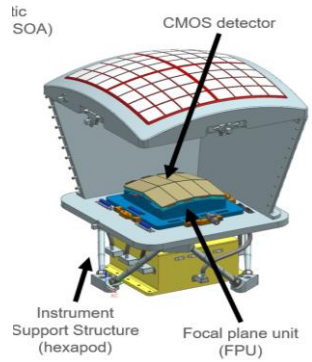
On-board **autonomous fast follow-up in optical/NIR**, arcsec location and **redshift measurement** of detected GRB/transients



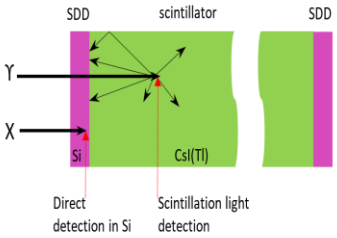
THESEUS Mission Concept

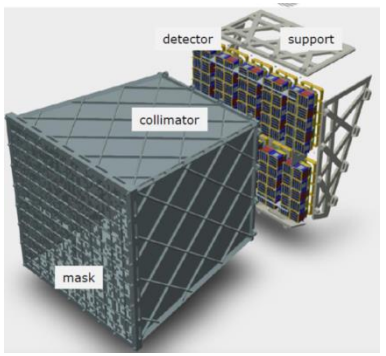
- **Soft X-ray Imager (SXI):** a set of two sensitive lobster-eye telescopes observing in 0.3 - 5 keV band, total FOV of ~0.5sr with source location accuracy <2’



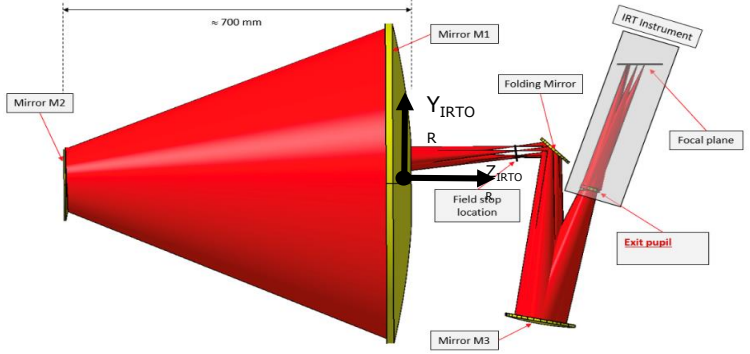


- **X-Gamma rays Imaging Spectrometer (XGIS):** 2 coded-mask X-gamma ray cameras using Silicon drift detectors coupled with CsI crystal scintillator bars observing in 2 keV – 10 MeV band, a FOV of >2 sr, overlapping the SXI, with <15’ GRB location accuracy





- **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

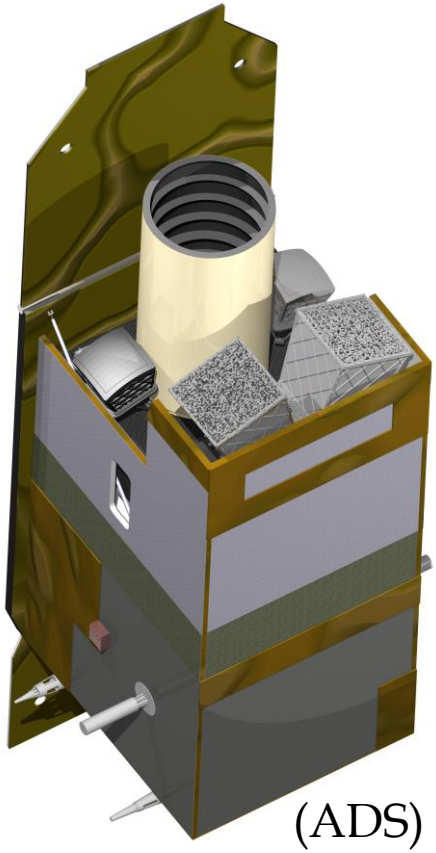


THESEUS Mission Concept

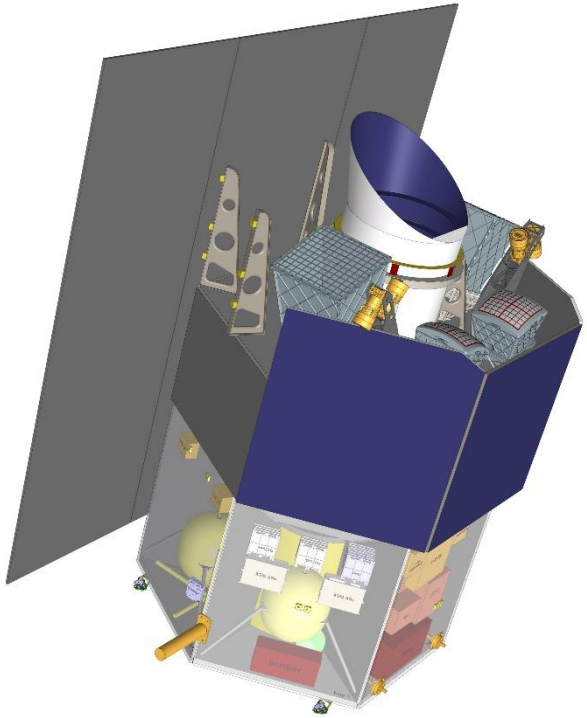
- **Fast slewing capability** (>10°/min), granting prompt NIR follow-up of GRBs and transients

- **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**

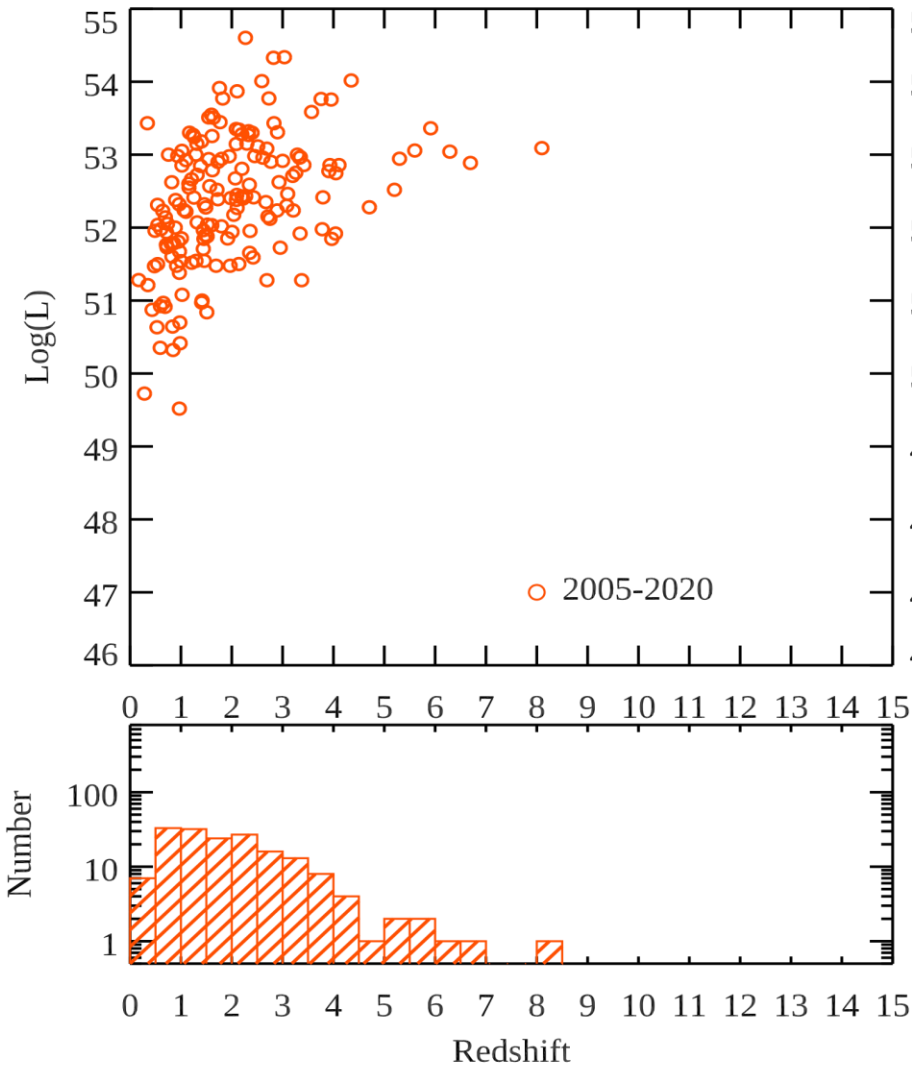


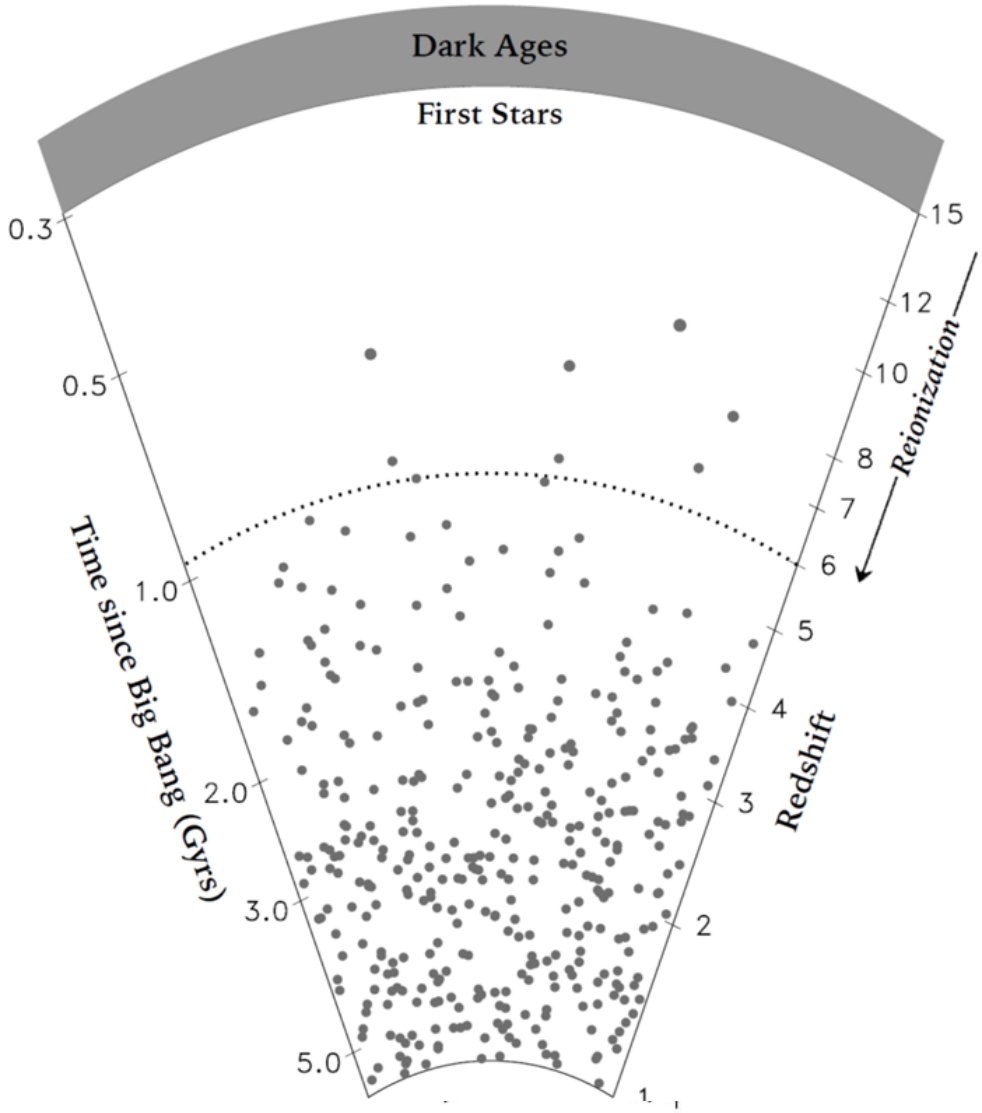
(ADS)



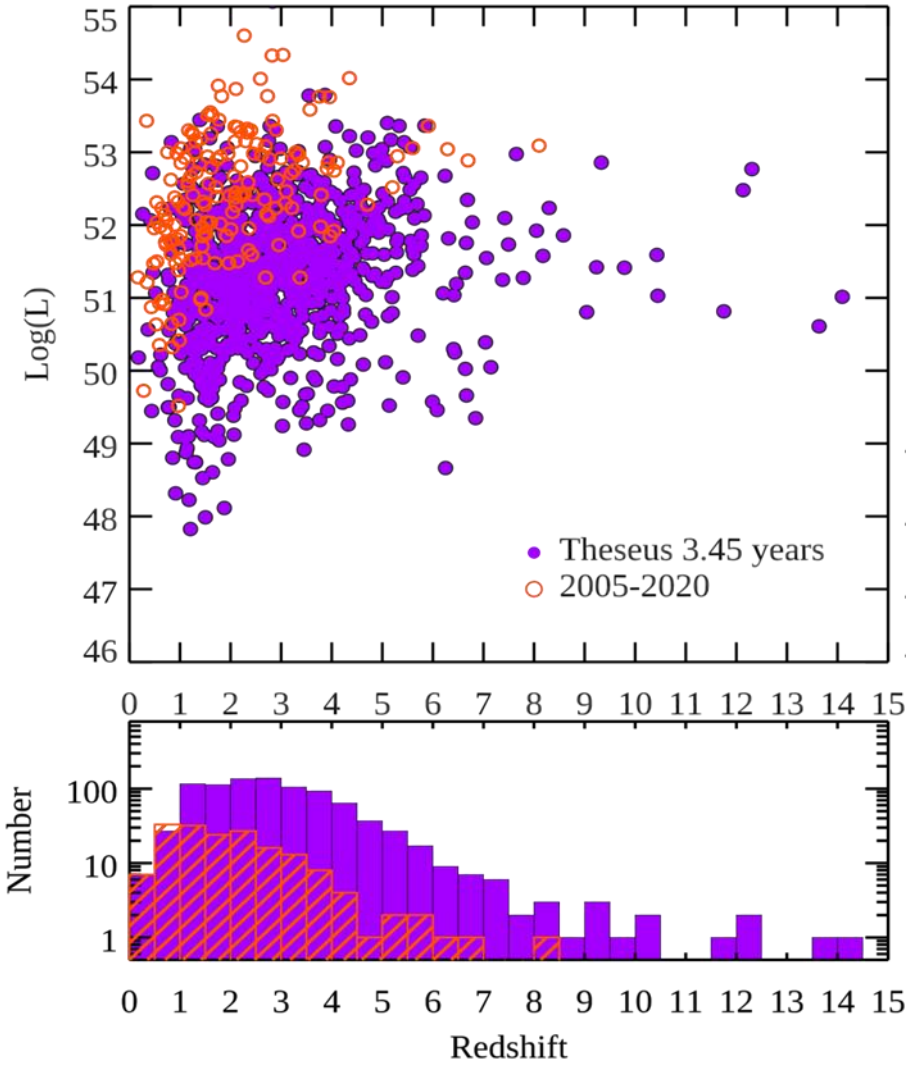
(THALES)

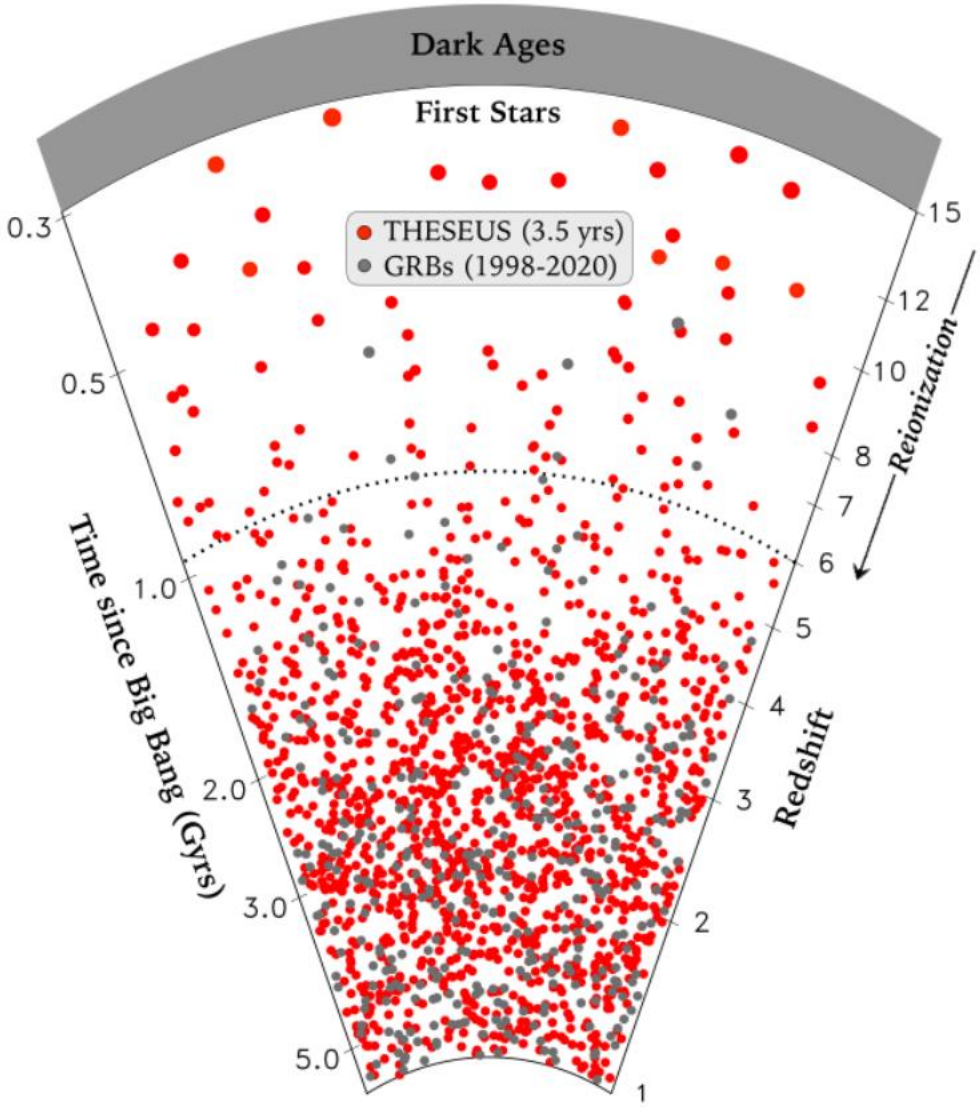
Expected performances: early Universe





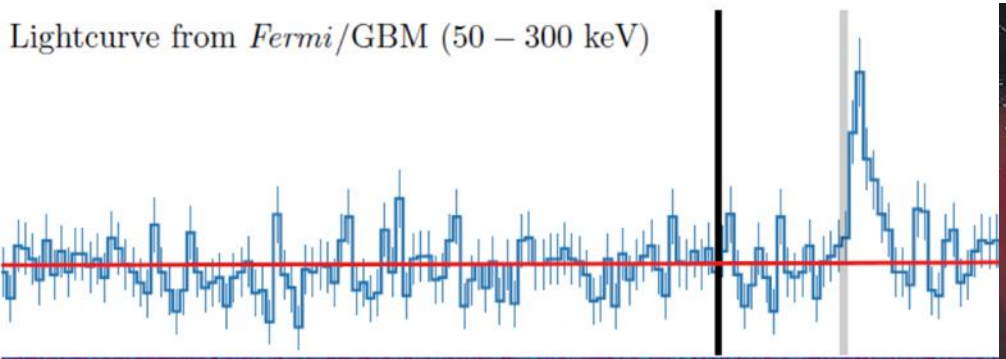
Expected performances: early Universe

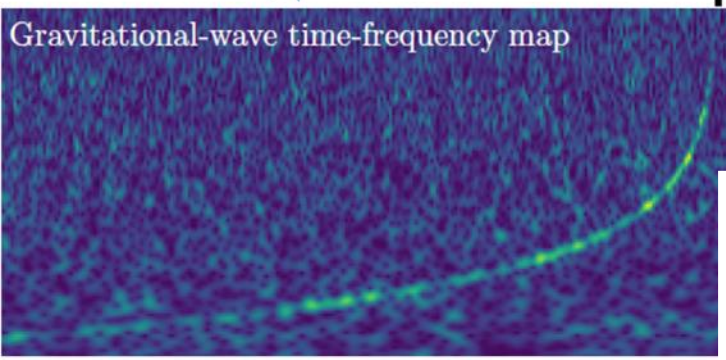


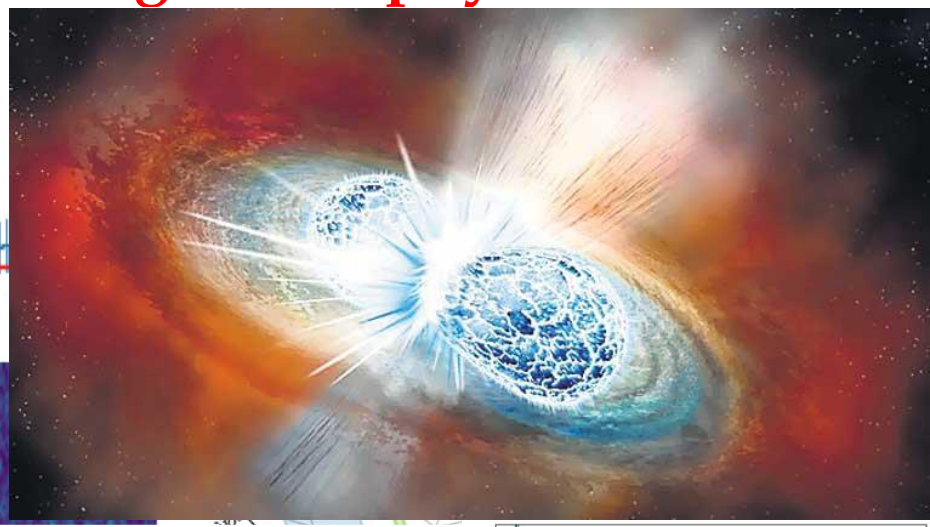


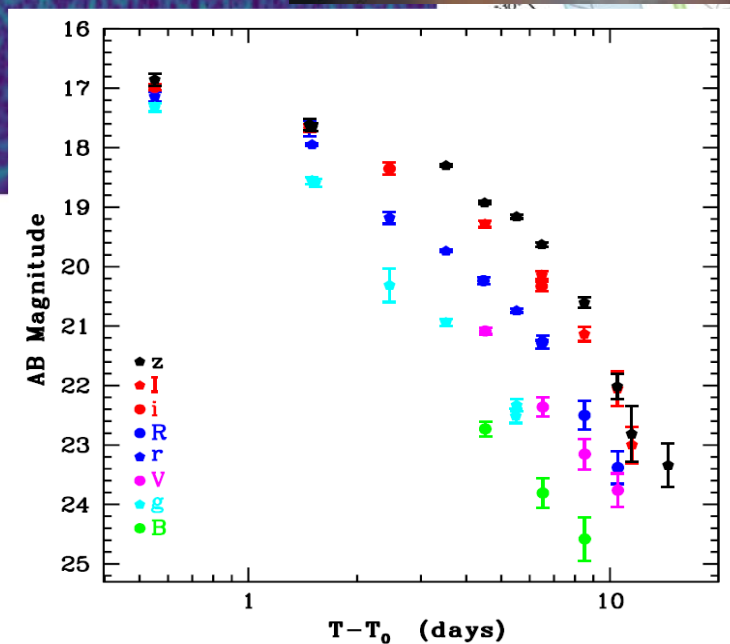
Expected performances: multi-messenger astr.

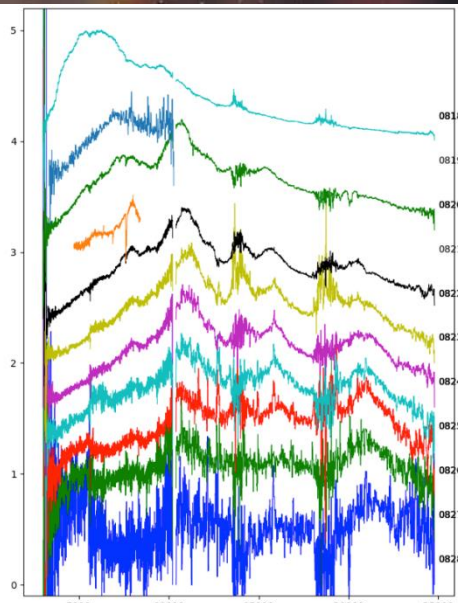
GW170817 + SHORT GRB 170817A + KN AT2017GFO (~40 Mpc):
the birth of multi-.messenger astrophysics



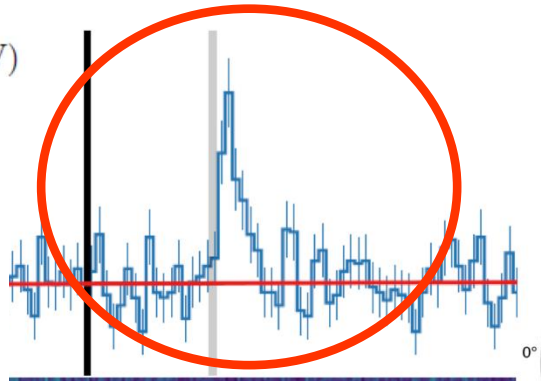






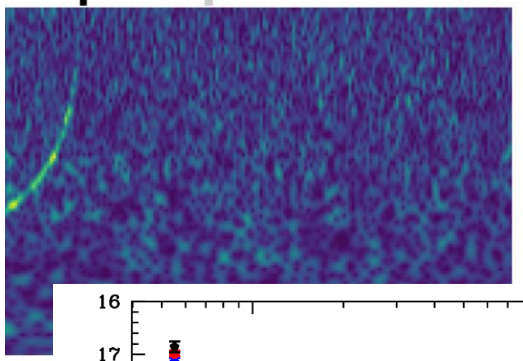


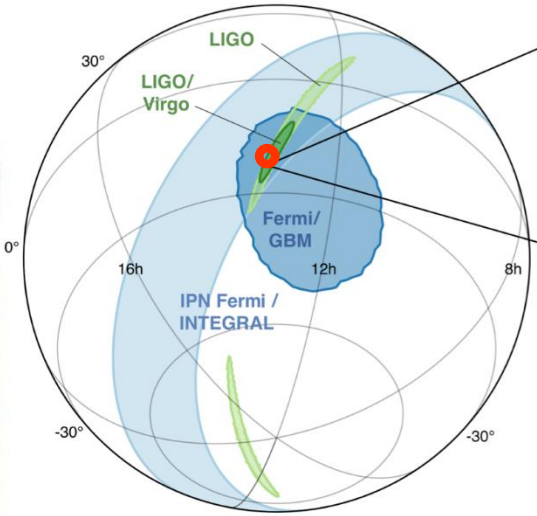
Expected performances: multi-messenger astr.

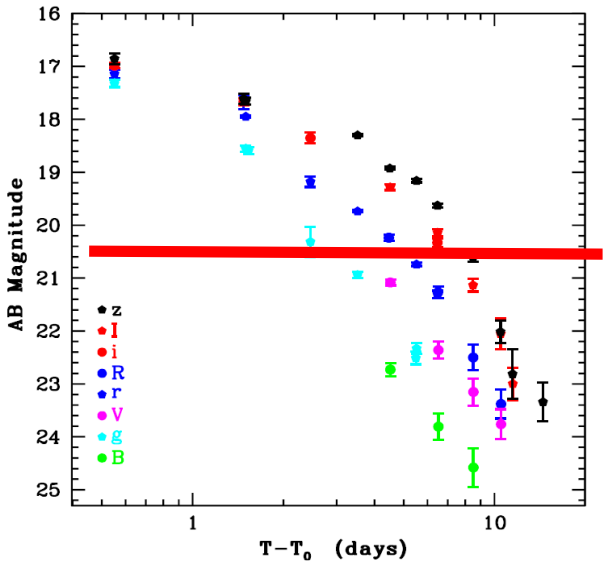


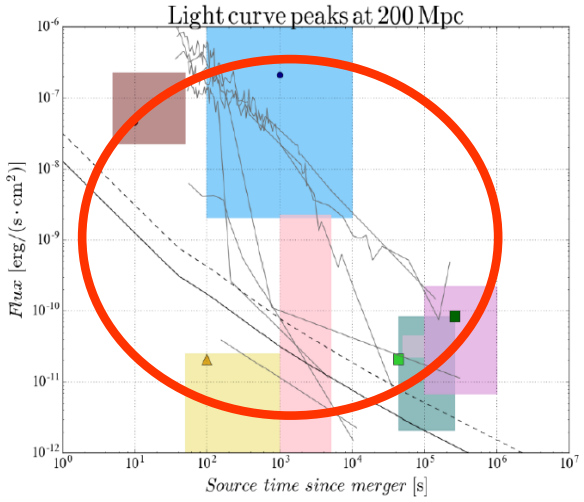
THESEUS:

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



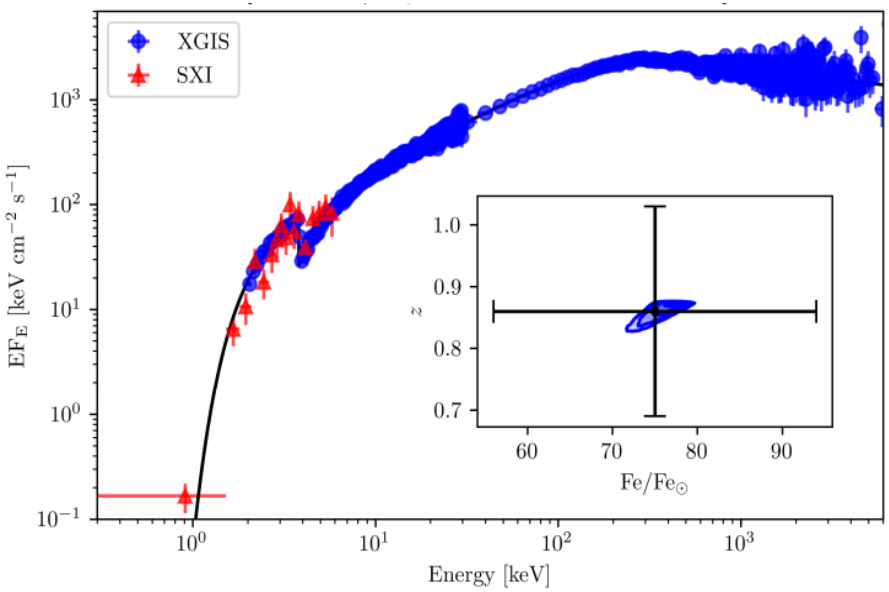


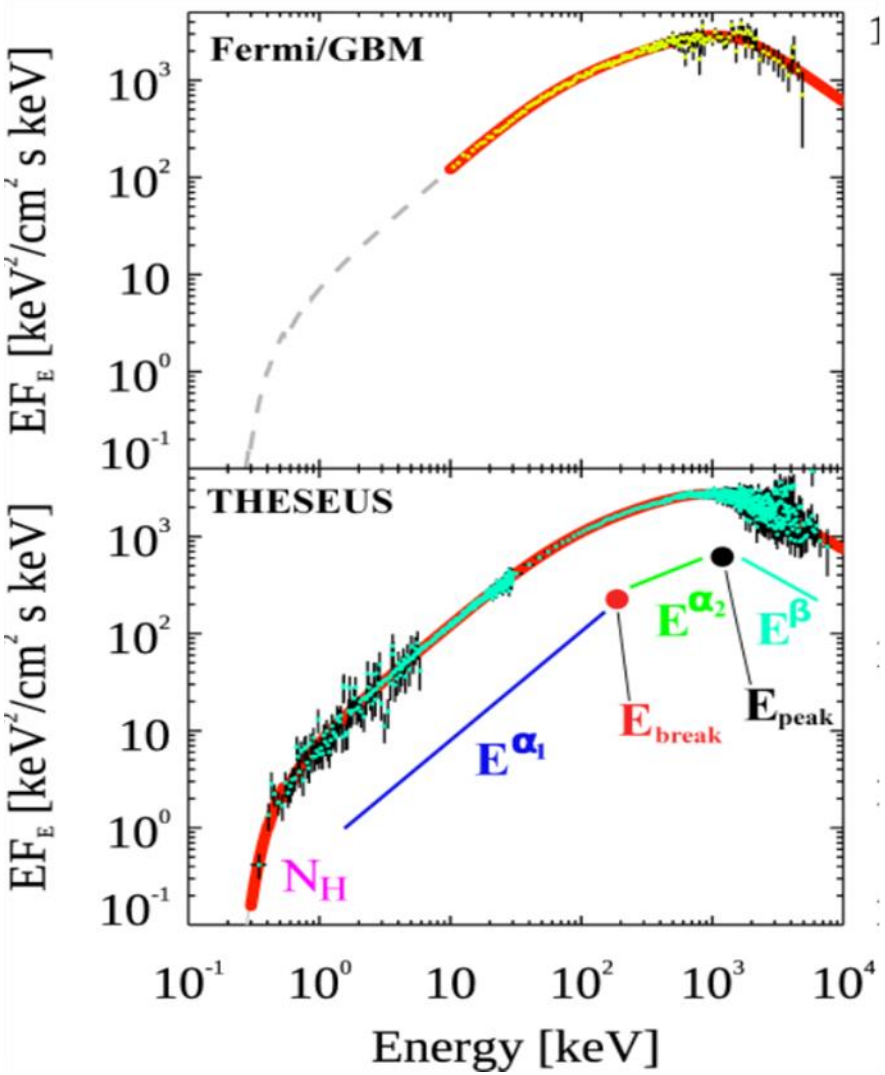




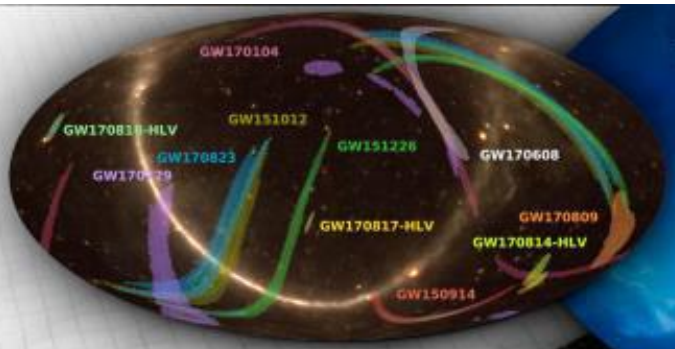
GRB science with THESEUS

- Extreme prompt emission physics & jet structure
- Central engine, sub-classes & progenitors,
- Cosmological parameters & fundamental physics



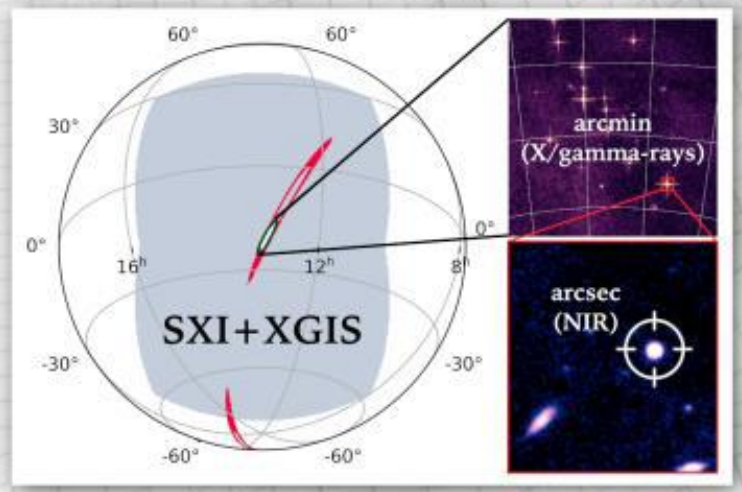


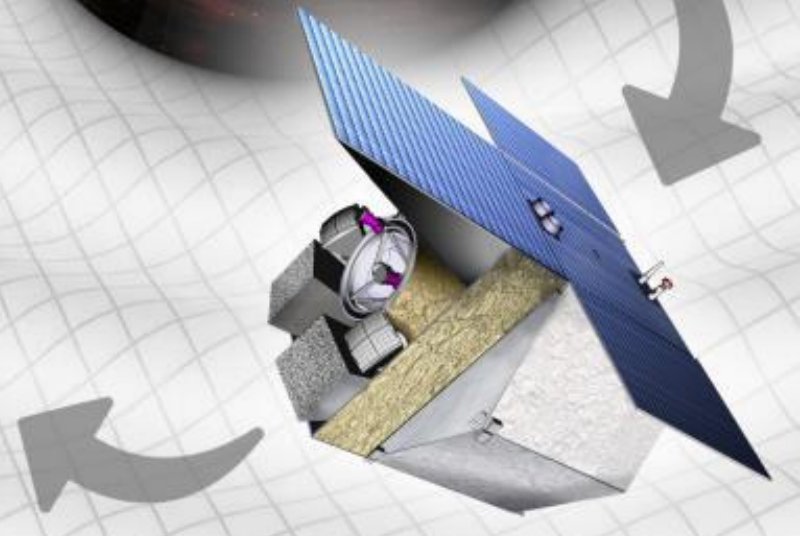
Exploring the transient sky



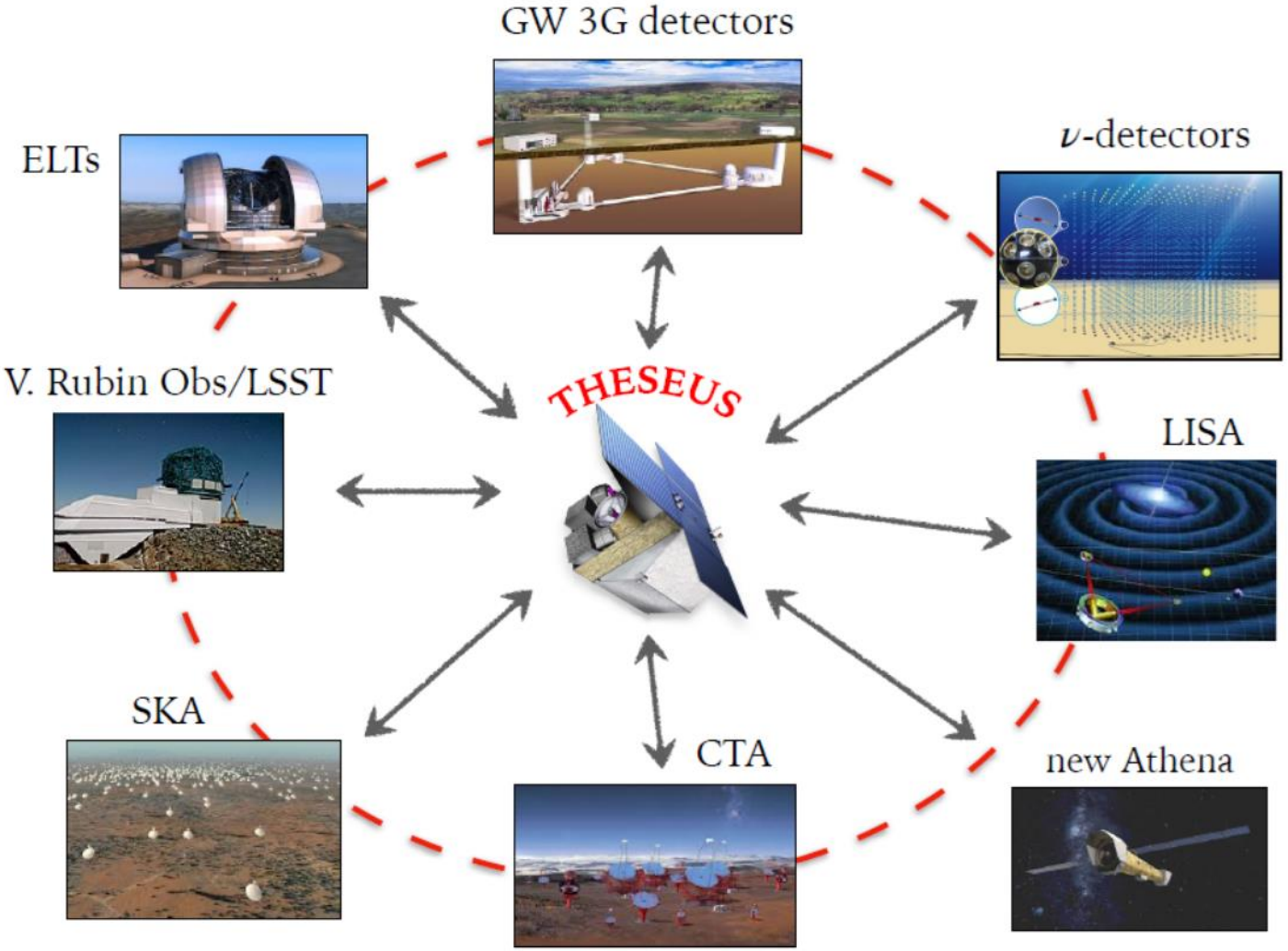
THESEUS ensures:

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



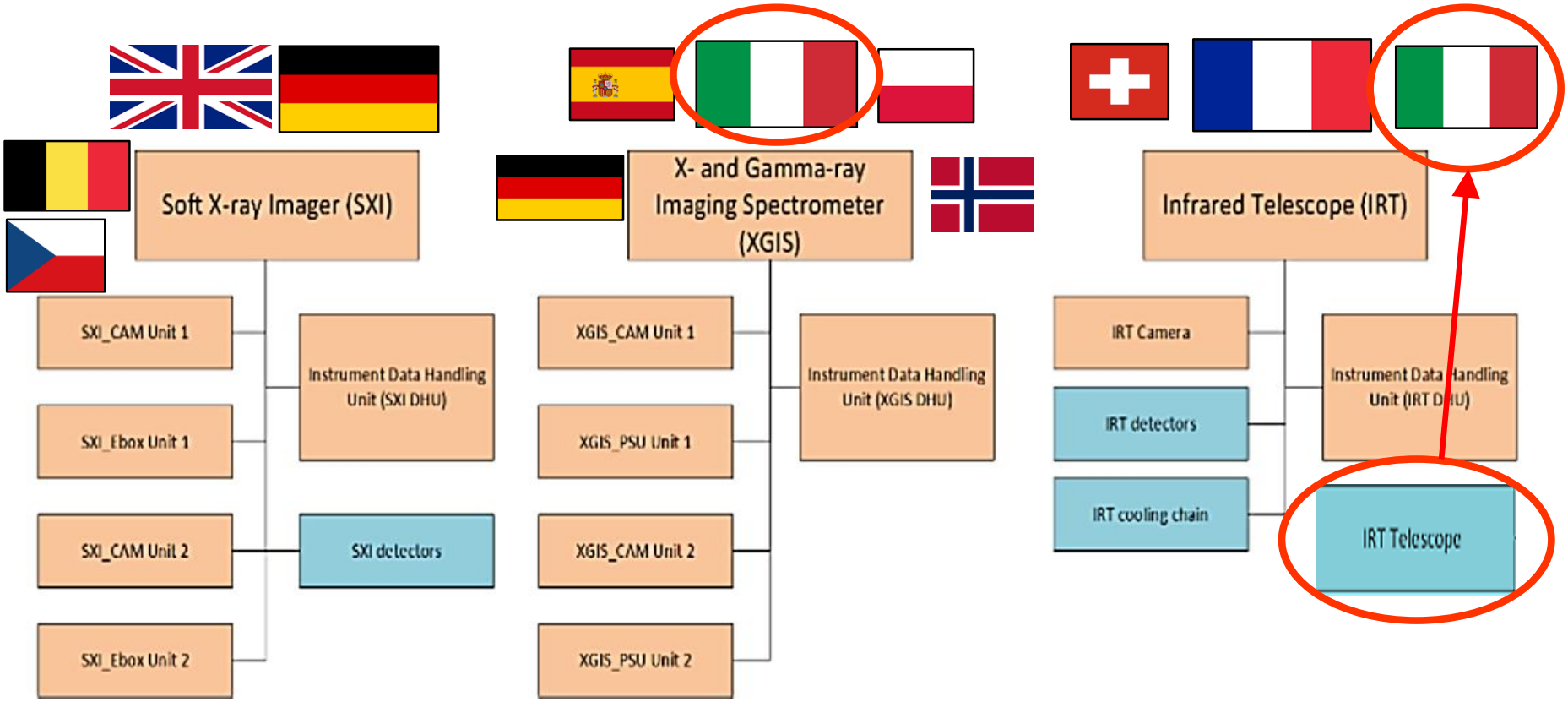


THESEUS: crucial synergies in the late '30s



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)**

THESEUS payload procurement scheme



Instruments Data Handling Units

Science Data Centre

Main ground station (ASI/Malindi)

In summary

- GRBs are a key phenomenon for **cosmology**, **multi-messenger astrophysics** and **fundamental physics**
- Next generation GRB missions, like **THESEUS**, developed by a large European collaboration, studied (M5 Phase A) and re-selected (M7 Phase-0) by ESA **will fully exploit these potentialities and also provide unprecedented clues to GRB physics and a substantial contribution to 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.**

- **THESEUS: ESA/M5 Phase A study and selected for M7 Phase 0 (->2037)**

SPIE articles on instruments, Adv.Sp.Res. & Exp.Astr. articles on science

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