Future X-ray missions
(relevant to GRB science)

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HERMES-SP/TP 1ST SCIENTIFIC WORKSHOP
ASTROPHYSICS WITH CUBESATS

HERMES SP
SCIENTIFIC WORKSHOP
18 - 19 NOV. 2020

Future GRB missions: what is needed?

- ***Physic of prompt emission*, internal engine, progenitors** (es., sub-luminous, ultra-long, XRFs, NS vs. BH, jet structure and magnetization) -> extend sensitive mesurements to soft X-rays (< 10 keV), improved polarization and timing, …

- ***Early afterglow emission*:** -> internal engine, improve on prompt multi-wavelength measurements

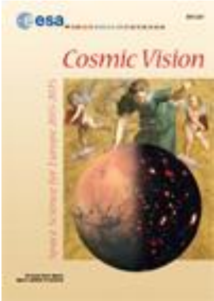
- ***GRB cosmology:*** use of long GRBs for early Universe (SFR, first stars and galaxies, cosmic re-ionization) and as possible «standardizable» candels -> improve on high-z GRBs

- **GRBs and multi-messenger astrophysics:** short GRBs as a key e.m. phenomenon for GW and neutrino astrophysics

- **GRBs and fundamental physics**: extreme physics, BH and NS properties, test of quantum-gravity /LI, etc. -> timing and z

- **Synergy with mw and mm large facilities**: large FOV + accurate source location + prompt dissemination + fast TOO

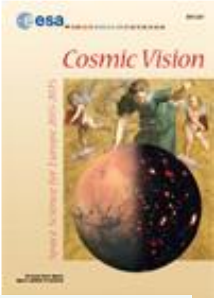
The ESA Cosmic Vision Programme



❖ Selected missions

- M1: Solar Orbiter (solar astrophysics, 2018)
- M2: Euclid (cosmology, 2021)
- L1: JUICE (exploration of Jupiter system, 2022)
- S1: CHEOPS (exoplanets, 2018)
- M3: PLATO (exoplanets, 2026)
- L2: ATHENA (X-ray observatory, cosmology, 2032)
- L3: LISA (gravitational wave observatory, 2034)
- M4: ARIEL (exoplanets, 2028)
- S2 (ESA-CAS): SMILE (solar wind <–> magneto/ionosphere)
- F1: COMET INTERCEPTOR (solar system origin, 2026)

The ESA Cosmic Vision Programme



Resonant keywords: cosmology (dark energy, dark matter, re-ionization, structures formation and evolution), **fundamental physics** (relativity, quantum gravity, QCD, gravitational wave universe), **life** (exoplanets formation + evolution + census, solar system exploration)

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Future GRB missions: synergies

- **Many next generation large observatories of the near** future (e.g., SKA, CTA, ATHENA, LSST, ELT, TMT, JWST) have GRB-related science in their core-science programmes

- **GRBs as key phenomenon for multi-messenger astrophysics** (GW, neutrinos): synergy with, e.g., advanced LIGO/VIRGO KAGRA, I-LIGO and, in perspective, 3G detectors (ET, CE) and possibly LISA.

- **NOTE:** further investigaiton of GRB impact on emergence and survivaility of life in the Universe may be of strong interst

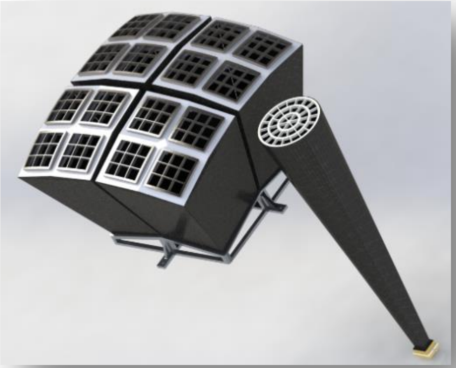
Future missions (early / mid ‘20s)

- **SVOM (2022-):** prompt emission down to 5 keV and up to MeVs, prompt follow-up with small X-ray and OUV telescopes, dedicated on-ground telescopes
- **Einstein Probe (2022-):** very good sensitivity, arcmin locaiton accuracy, operating only in the very soft X-ray energy band (0.3 - 5 keV), 1.4 sr FOV, follow-up in X-rays
- **GECAM (2020)**: all-sky FOV, 6 keV – few MeVs, source location a few degrees; **POLAR-2 (2024?):** improved polarimetry of prompt emission;
- **HERMES and other nano-satellite programs (2022-):** small detectors, energy band > 10 keV, potentially very good location accuracy for mid-bright GRBs, very good timing, depends on follow-up from ground
- **eXTP (2025?)** China-Europe, monitoring in 2-50 keV on 4-5 sr, X-ray followp-up spectroscopic and polarimetric very deep)

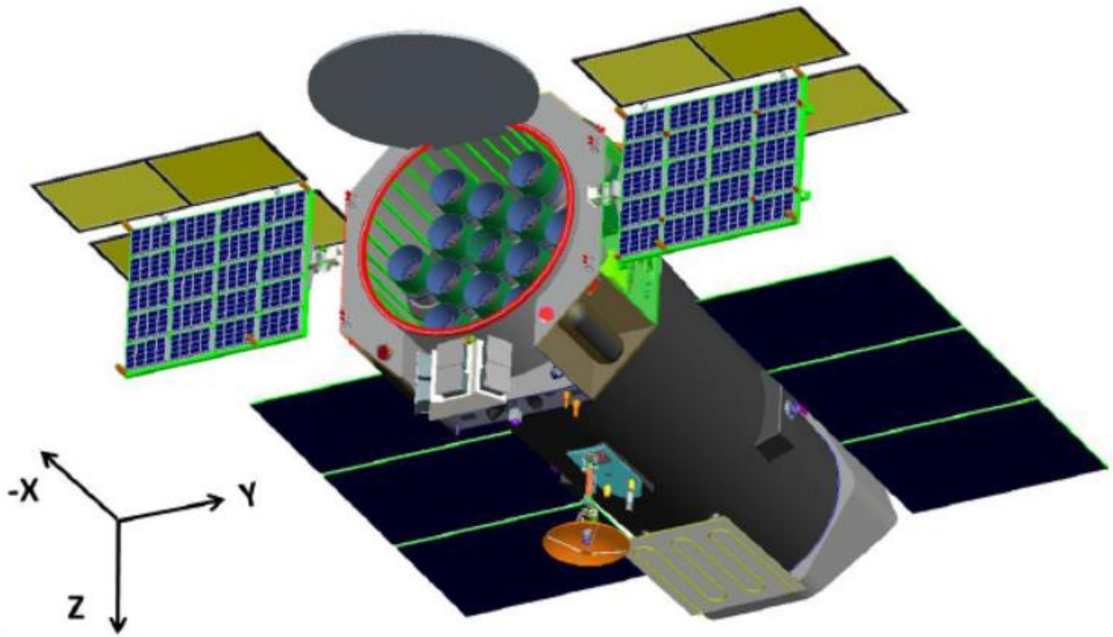
A Sino-French mission dedicated to
GRBs and HE transients
SVOM
cnes
CENTRE NATIONAL
D'ÉTUDES SPATIALES
CNSA
MXT
"The Micro-channel X-ray Telescope"
Narrow-field X-ray telescope
Spectral range : 0.2 keV – 10 keV
Localization accuracy < 1arcmin
ECLAIRs
« The trigger camera »
Wide-field X and Gamma rays telescope
Spectral range : 4 keV – 150 keV
Localization accuracy < 12arcmin
GRM
"The Gamma-Ray burst Monitor"
X-rays and Gamma-rays detectors
30 keV – 5 MeV
Localization accuracy < 5°
VT
"The Visible Telescope"
Narrow-field visible telescope
Ritchey Chretien Φ=400mm
Localization accuracy < 1arcsec
GFT-1
« Ground-based Follow-up Telescope »
Φ>1000mm
GWAC
« Ground Wide-Angle Cameras »
Φ=180mm
GFT-2
« Ground-based Follow-up Telescope »
VHF Alert Network
... and more !
Tracking antennas

Einstein Probe Mission Concept

- Payload
  - 12 x Wide-field X-ray telescope modules (WXT), each 348 sq. deg FOV – observe ~60% of sky several times per day using Lobster-eye technology + Chinese CMOS detectors
  - 2 x Follow-up X-ray telescope (FXT) – copy of eRosita telescopes with pnCCD
- Fast alerts data downlink (use BeiDOU + VHF)
- Rapid ToO uplink possible via BeiDOU for MM science
- Collaboration between CAS, ESA, MPE
- Orbit: 600-650km, i<30deg
- Mission life: 3 years
- Launch: Dec 2022



eXTP: enhanced X-ray Timing and Polarimetry Mission



Large eff. Area：
>3.5m²@6keV

High spectral res.:
FWHM <180eV@6keV

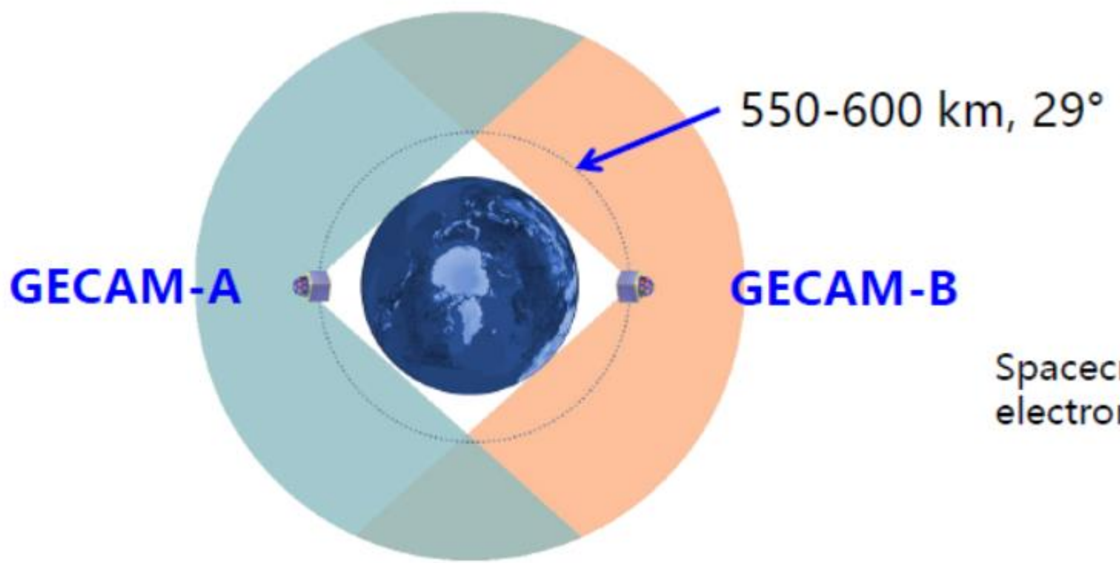
High throughput

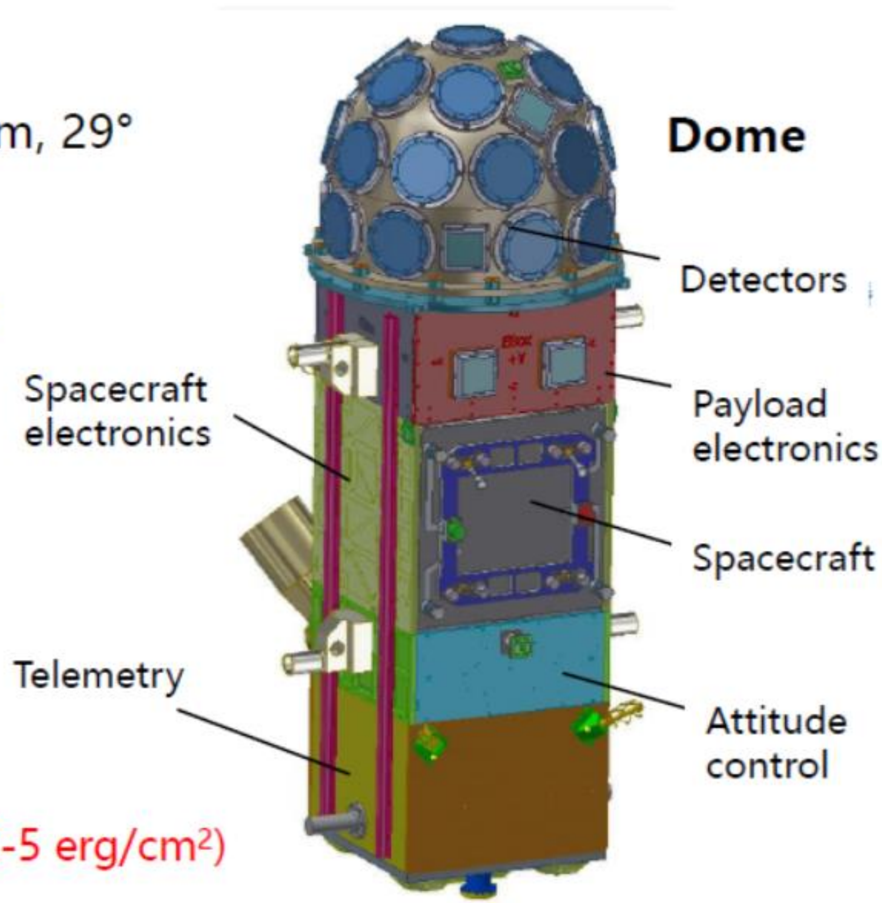
Payload	Configuration	Eff. area (m²)	Timing res. (μs)
Spectroscopic Focusing Array (SFA)	9 telescopes	0.54m²@1keV	10
Large Area Detector (LAD)	40 modules	>3.0 m²@6keV	10
Polarimetry Focusing Array (PFA)	4 telescopes	≥ 380cm²@3keV	500
Wide Field Monitor (WFM)	6 cameras	≥ 3 Sr （FOV）	10
Gamma Ray Burst Monitor (GRM) (optional)	3 units		

Launch date	~ 2025

GECAM

Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor





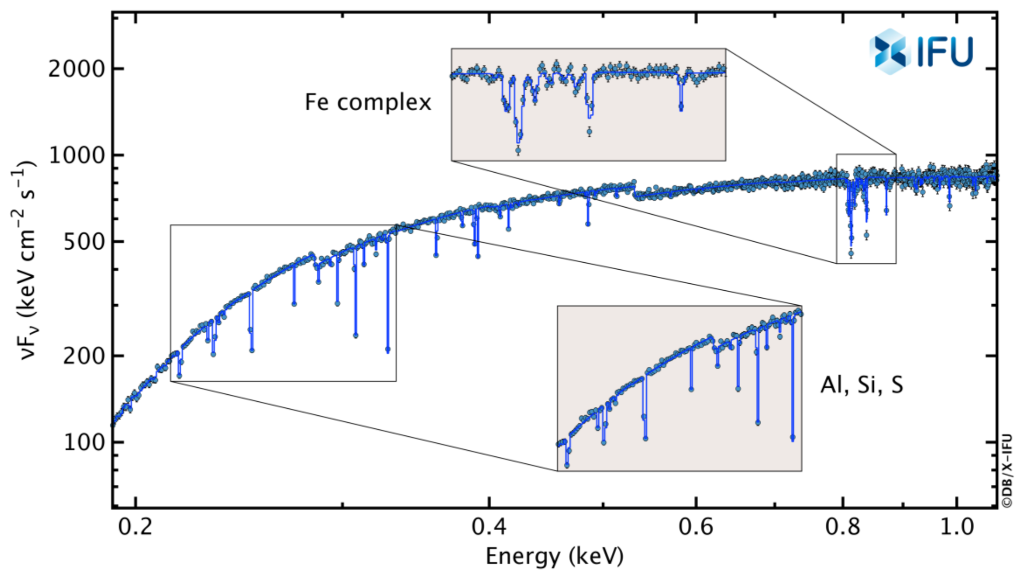
GECAM satellite (~140 kg for each)

- **Characteristics**
  - **FOV:** 100% all-sky
  - **Sensitivity:** ~2E-8 erg/cm^2/s
  - **Localization:** ~1 deg (1-σ stat., 1E-5 erg/cm^2)
  - **Energy band:** 6 keV – 5 MeV
- **Planned to launch by the end of 2020**
  - since LIGO will reach the design sensitivity around 2020 to 2021

Future missions (late‘20s and beyond)

- **THESEUS (ESA Cosmic Vision / M5, decision on June 2021, launch in 2032), HiZ-GUNDAM (JAXA, under study), launch: mid-20s?), TAP (under study for NASA decadal survey), Gamow Explorer (under study for MIDEX):** prompt emission from soft X-rays to MeVs, source location accuracy of arcmin, prompt follow-up with NIR telescope, on-board REDSHIFT

- **ATHENA (ESA L2, 2032):** GRBs as cosmic beacons (e.g., WHIM) and tracers of pop-III stars -> needs GRB trigger, accurate location and redshift



theseus

TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

esa

European Space Agency

cosmic vision

theseus

transient high energy sky and early universe surveyor

ASI

Agenzia Spaziale Italiana

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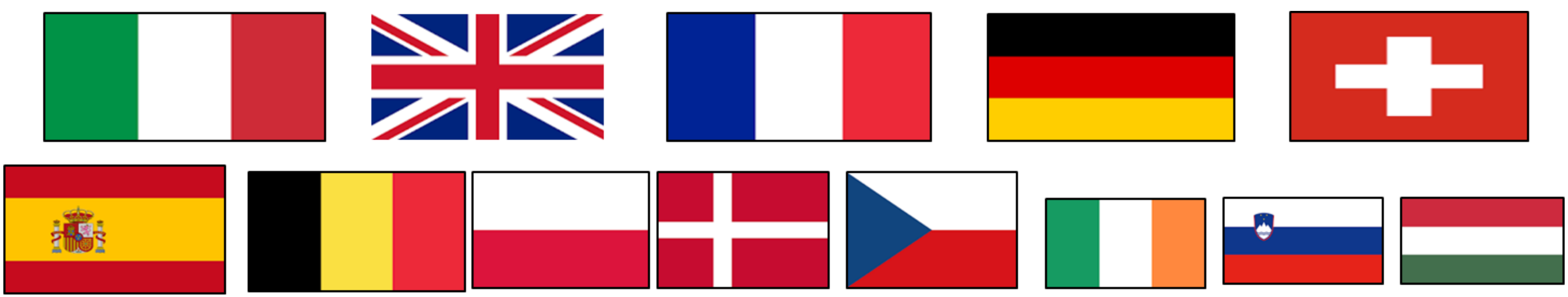

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ASI
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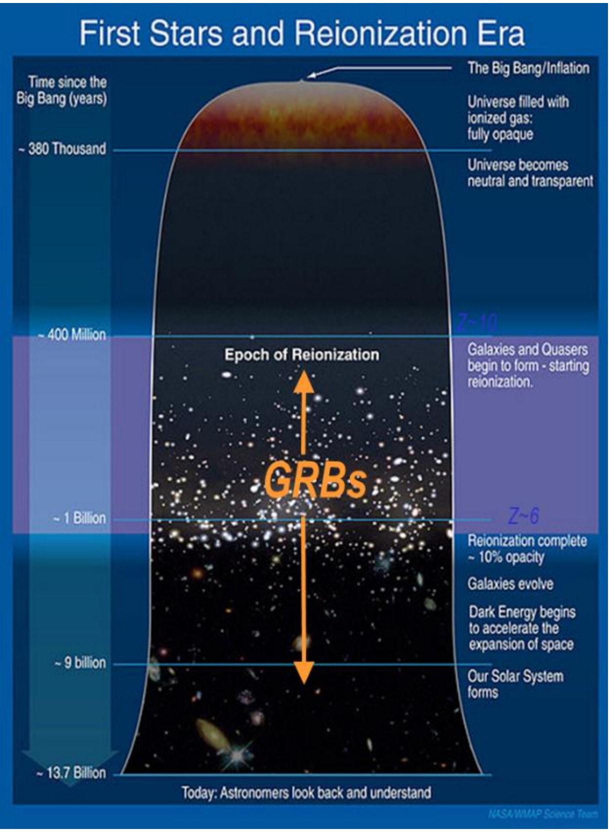
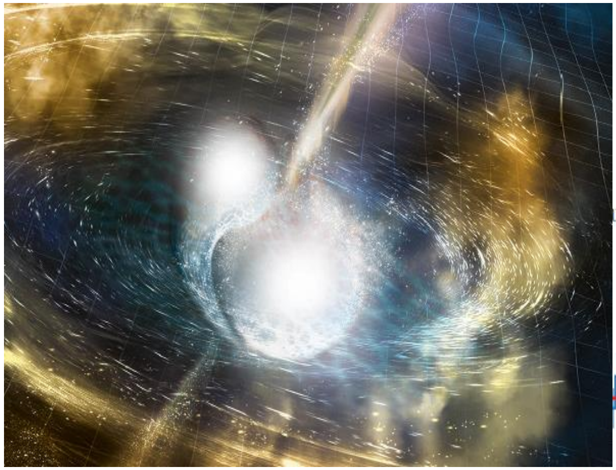
INAF ISTITUTO NAZIONALE DI ASTROFISICA

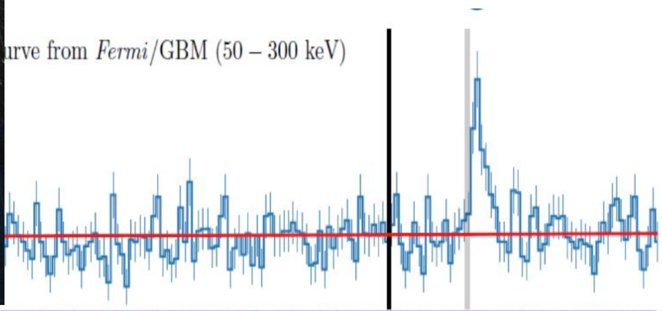
http://www.isdc.unige.ch/theseus/

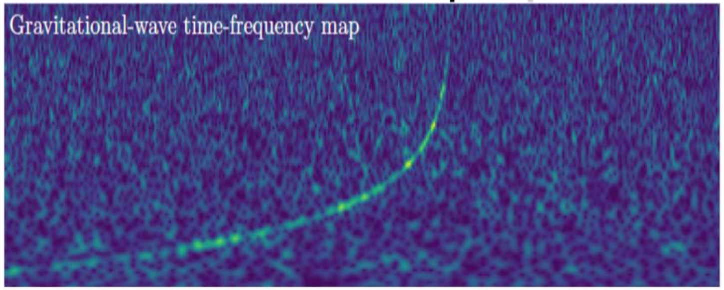
Amati et al. 2018 (Adv.Sp.Res., arXiv:1710.04638)
Stratta et al. 2018 (Adv.Sp.Res., arXiv:1712.08153)

Probing the Early Universe with GRBs
Multi-messenger and time domain Astrophysics
The transient high energy sky
Synergy with next generation large facilities (E-ELT, SKA, CTA, ATHENA, GW and neutrino detectors)









THESEUS

Transient High Energy Sky and Early Universe Surveyor

Lead Proposer (ESA/M5): Lorenzo Amati (INAF – OAS Bologna, Italy)

Coordinators (ESA/M5): Lorenzo Amati, Paul O'Brien (Univ. Leicester, UK), Diego Gotz (CEA-Paris, France), A. Santangelo (Univ. Tuebingen, D), E. Bozzo (Univ. Genève, CH)

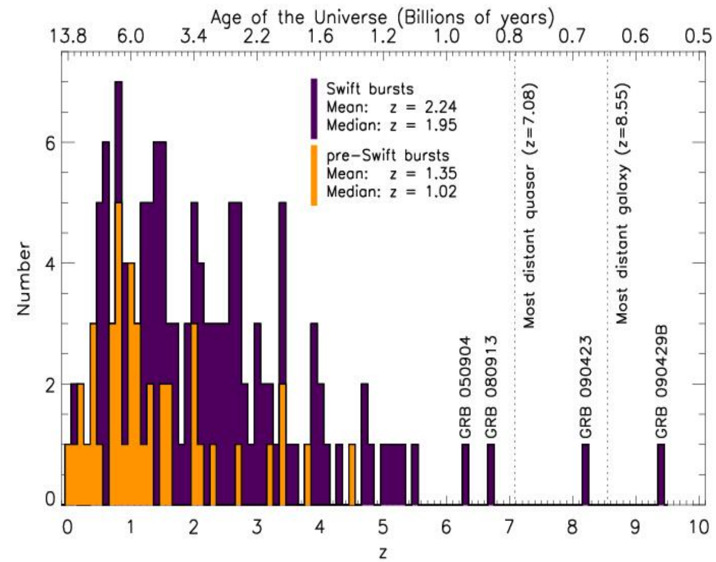
Payload consortium: Italy, UK, France, Germany, Switzerland, Spain, Poland, Denmark, Belgium, Czech Republic, Slovenia, ESA

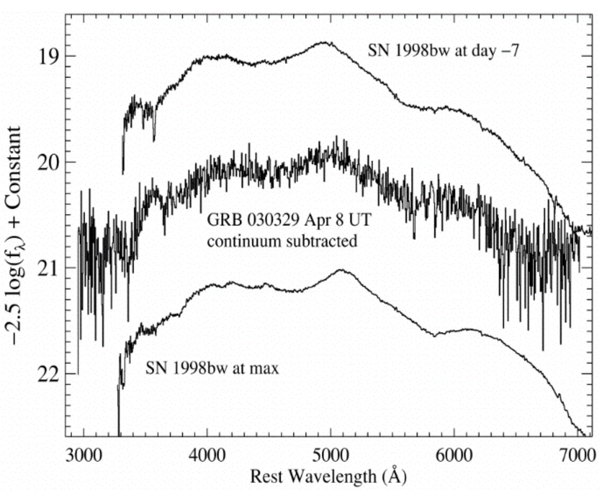
May 2018: THESEUS selected by ESA for Phase 0/A study
(with SPICA and ENVISION)

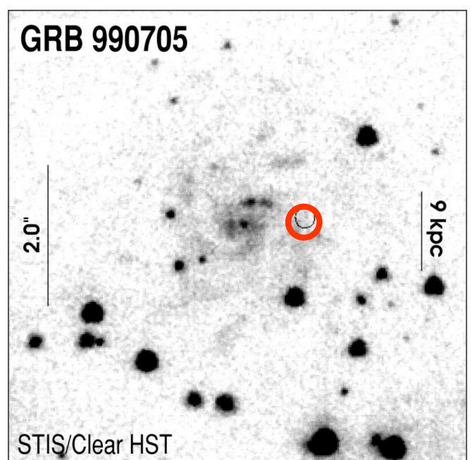
Activity	Date
Phase 0 kick-off	June 2018
Phase 0 completed (EnVision, SPICA and THESEUS)	End 2018
ITT for Phase A industrial studies	February 2019
Phase A industrial kick-off	June 2019
Mission Selection Review (technical and programmatic review for the three mission candidates)	Completed by June 2021
SPC selection of M5 mission	June 2021
Phase B1 kick-off for the selected M5 mission	December 2021
Mission Adoption Review (for the selected M5 mission)	March 2024
SPC adoption of M5 mission	June 2024
Phase B2/C/D kick-off	Q1 2025
Launch	2032

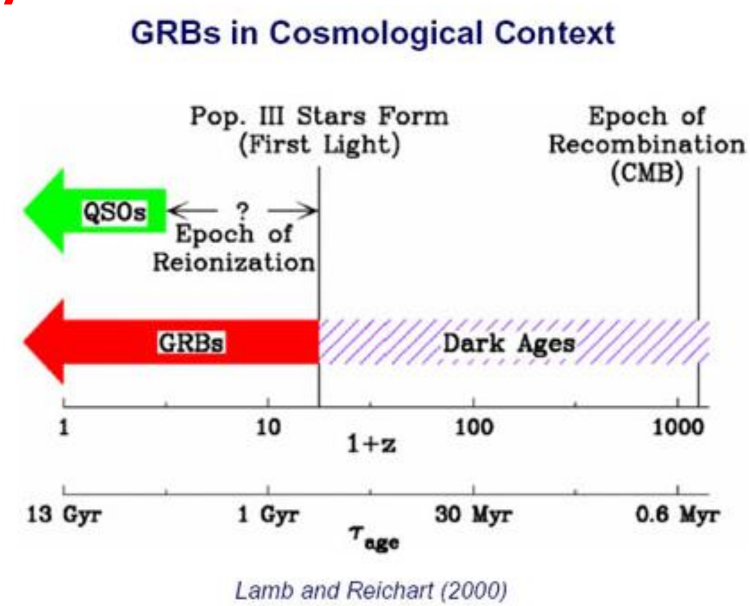
Shedding light on the early Universe with GRBs

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





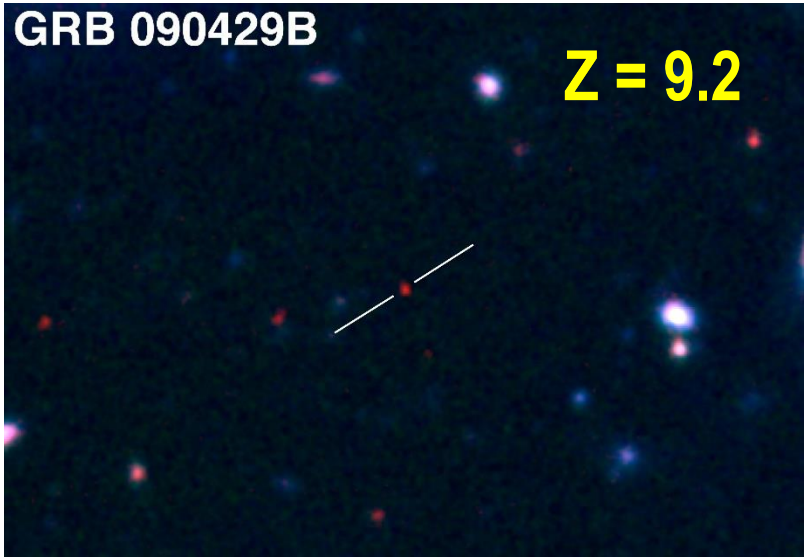


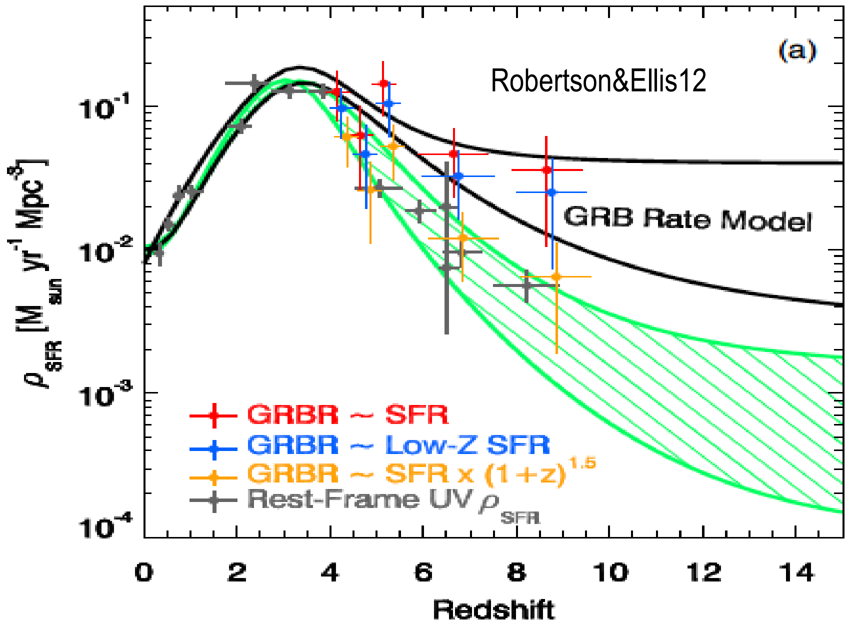


A statistical sample of high–z GRBs can provide fundamental information:

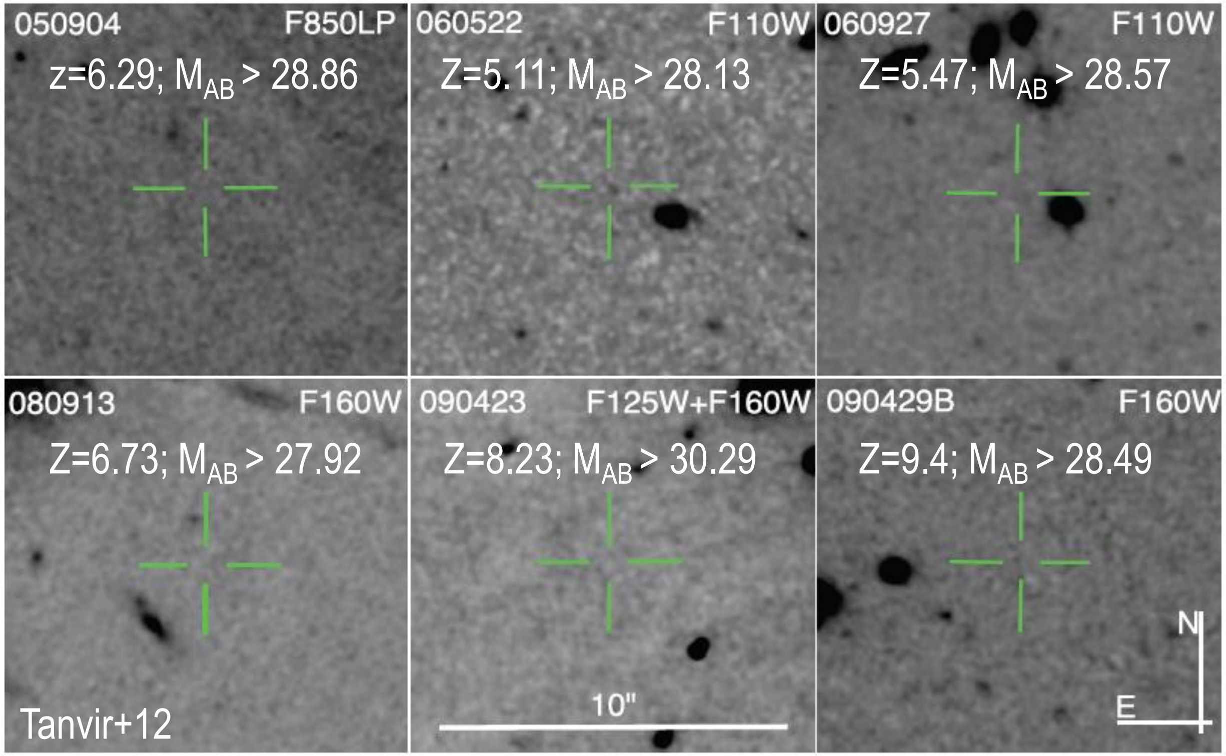
- measure independently the **cosmic star–formation rate**, even beyond the limits of current and future galaxy surveys

- directly (or indirectly) detect the **first population of stars (pop III)**





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

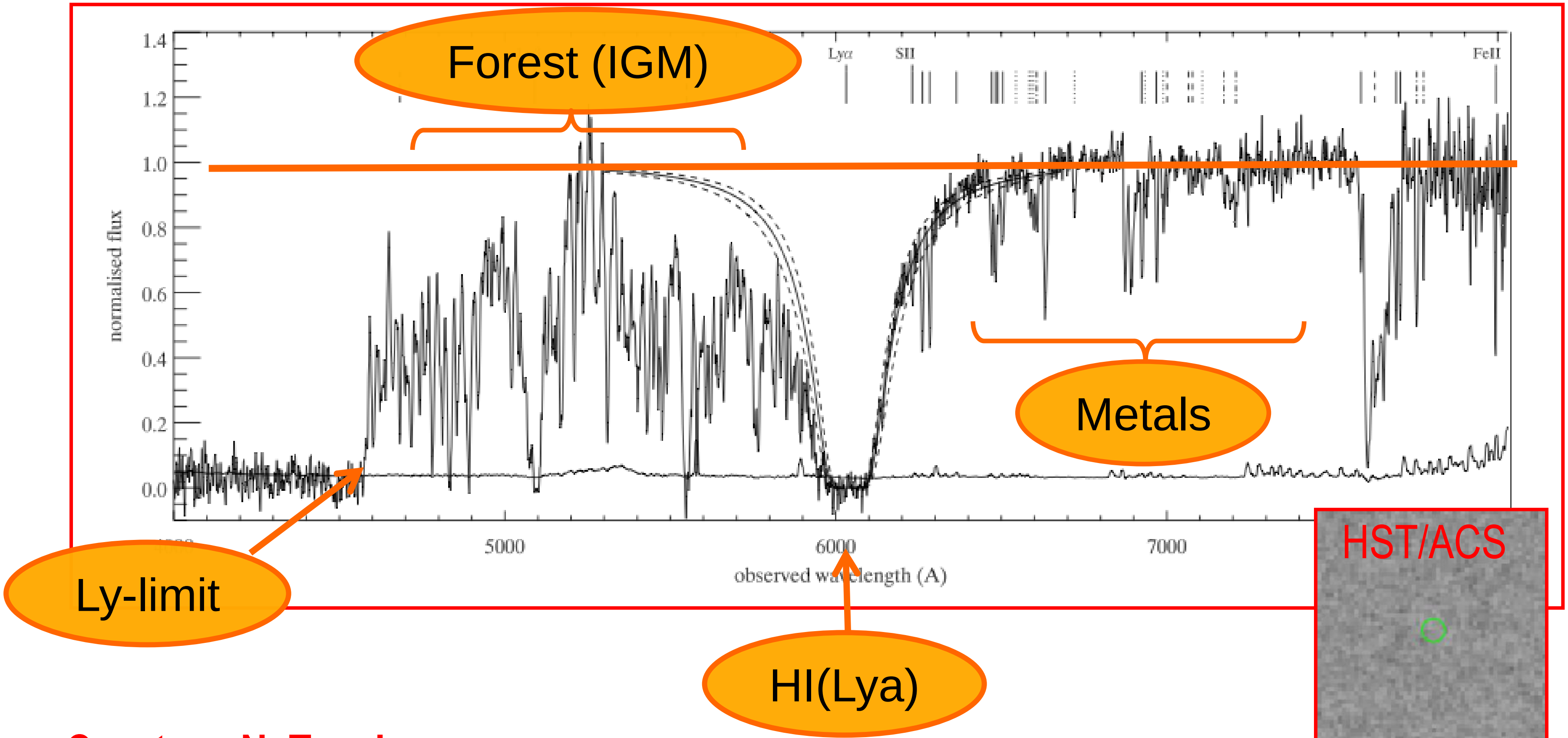


Robertson&Ellis12

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

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

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



Courtesy N. Tanvir

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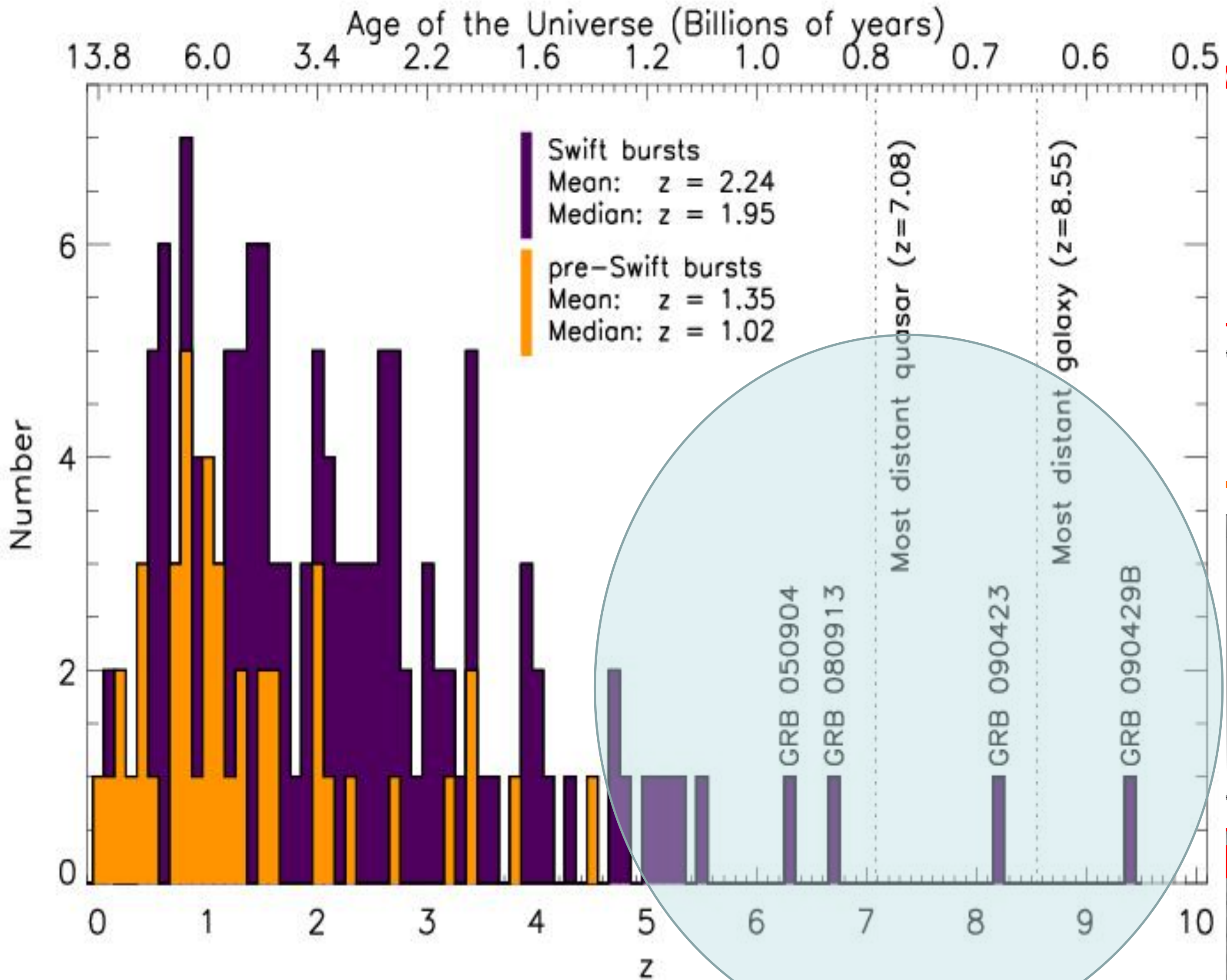

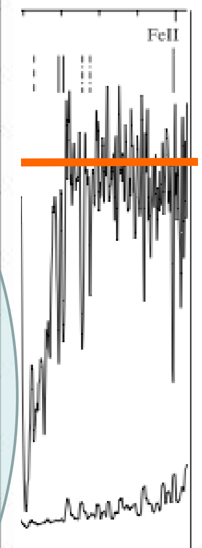

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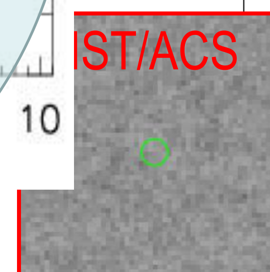
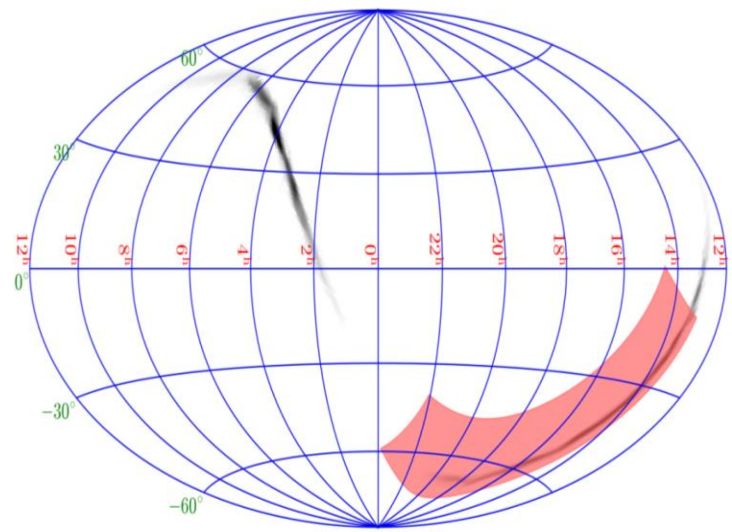


Courtesy N. Tanvir

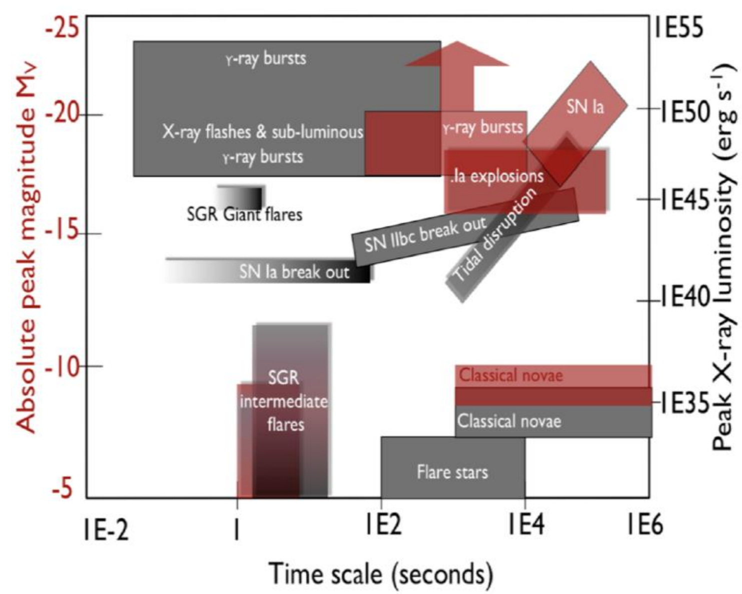
Exploring the multi-messenger transient sky

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

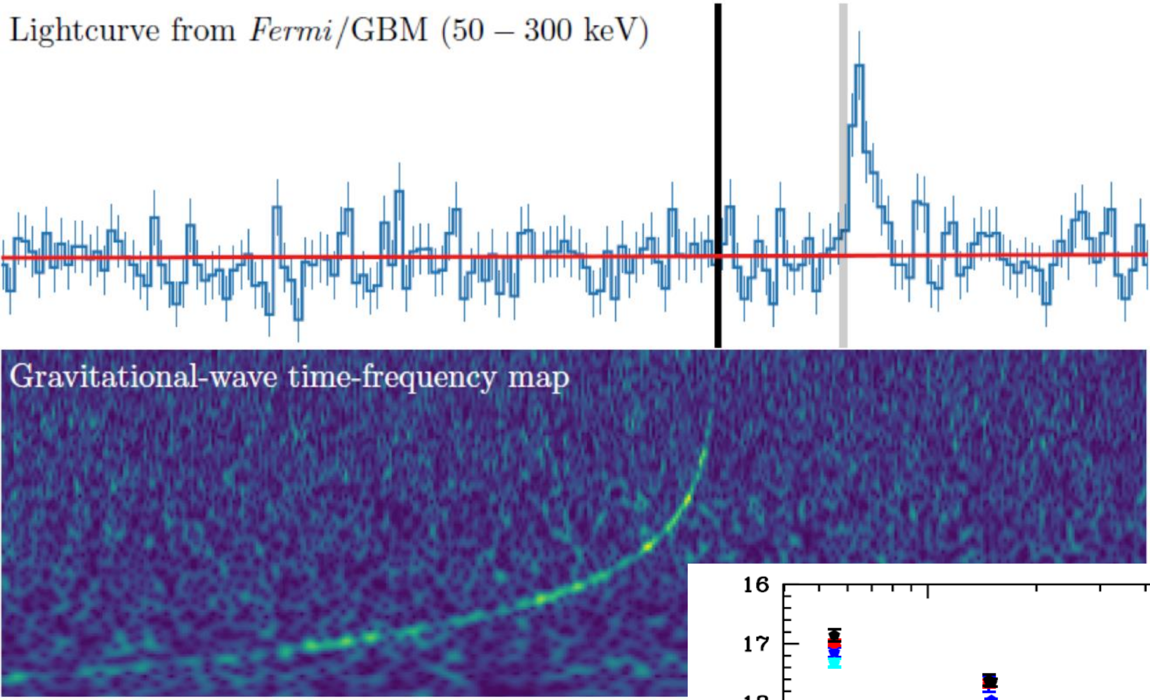


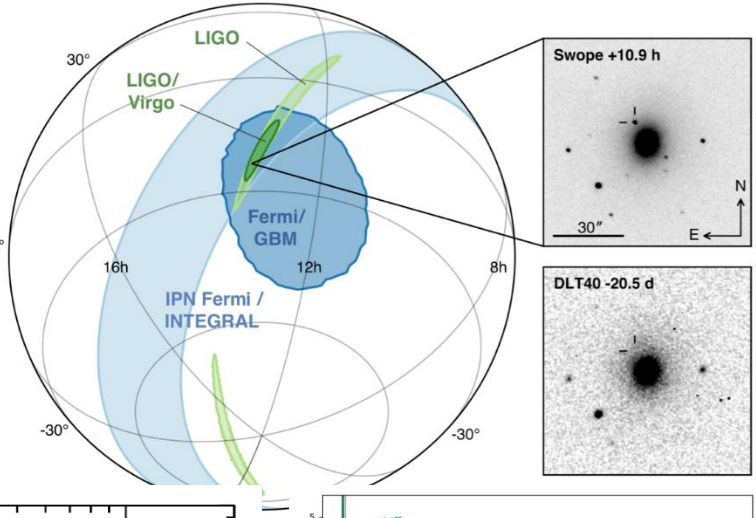
- Provide real-time triggers and accurate (~1 arcmin within a few seconds; ~1'' within a few minutes) **high-energy transients for follow-up with next-generation optical-NIR (E-ELT, JWST if still operating), radio (SKA), X-rays (ATHENA), TeV (CTA) telescopes; synergy with LSST**

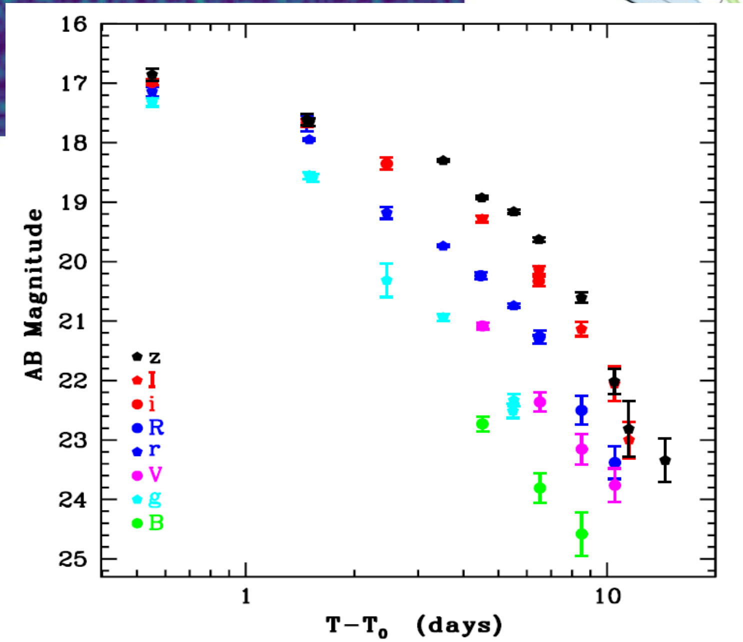
- Provide a fundamental step forward in the comprehension of the physics of various classes of transients and **fill the present gap in the discovery space of new classes of transients events**

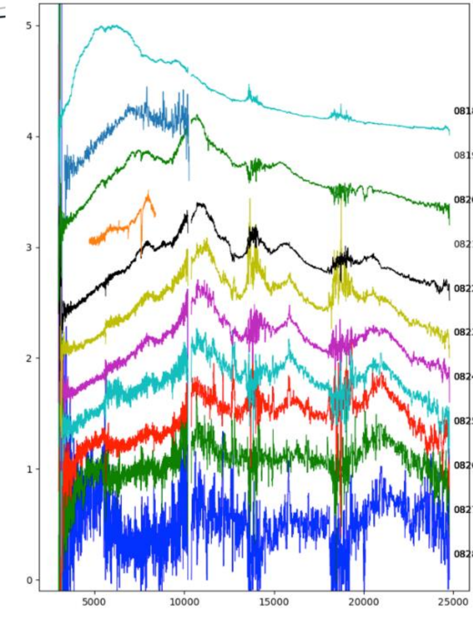


LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars









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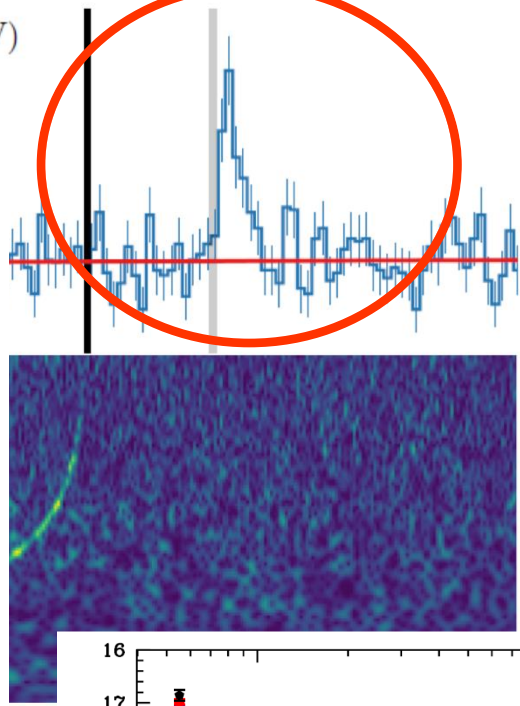
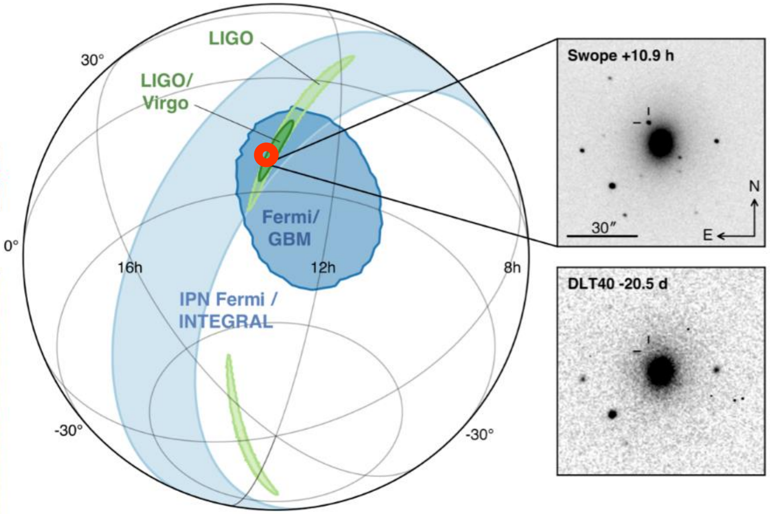
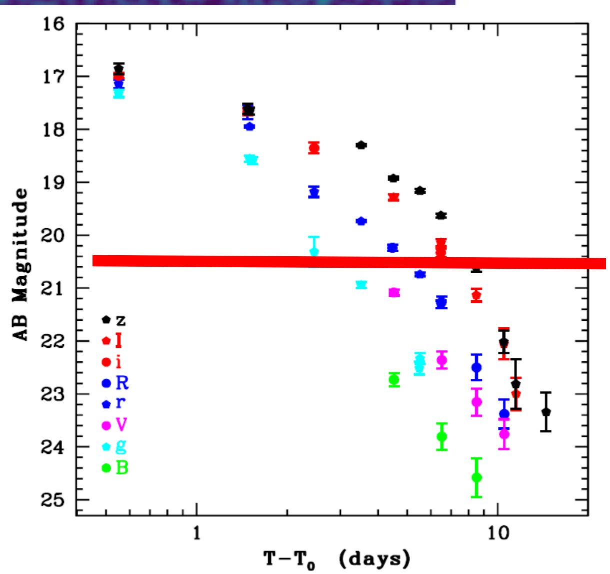
Lightcurve from *Fermi*/GBM (50 – 300 keV)

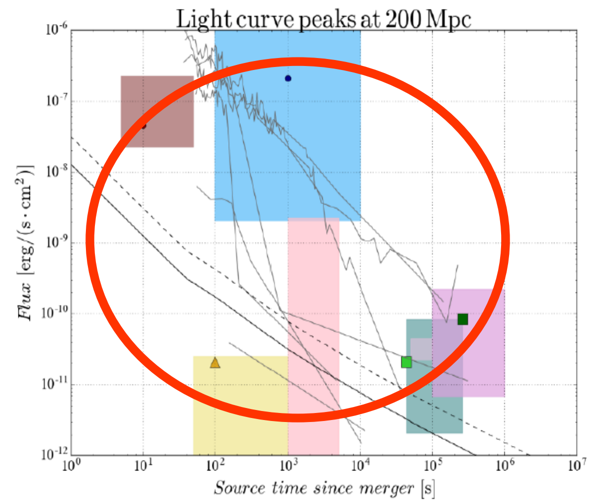


THESEUS:

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

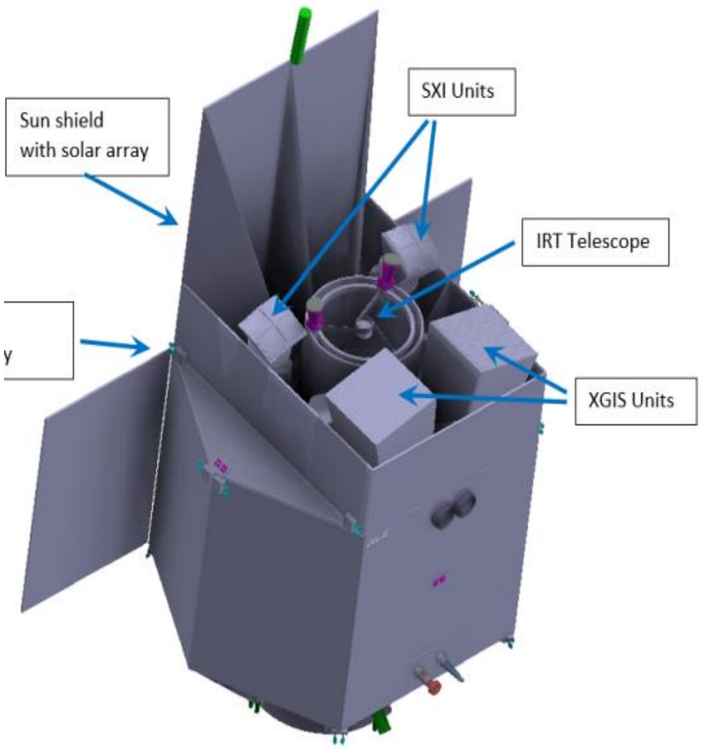






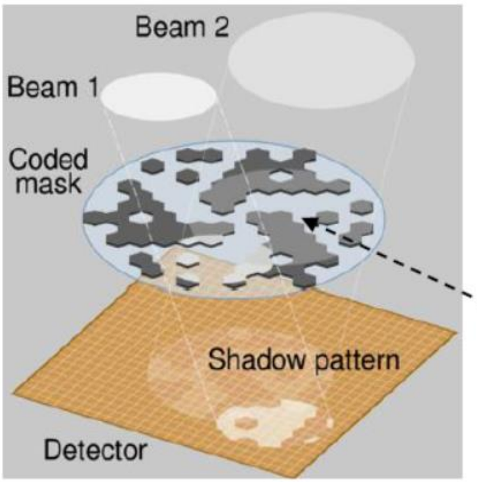
THESEUS mission concept

- **Soft X-ray Imager (SXI):** a set of two sensitive lobster-eye telescopes observing in **0.3 - 5 keV band, total FOV of ~0.5sr with source location accuracy <2';**
- **X-Gamma rays Imaging Spectrometer (XGIS,):** 2 coded-mask X-gamma ray cameras using 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** in 2-150 keV
- **InfraRed Telescope (IRT):** a 0.7m class IR telescope observing in the **0.7 – 1.8 μm band, providing a 15'x15' FOV, with both imaging and moderate resolution spectroscopy capabilities (-> redshift)**

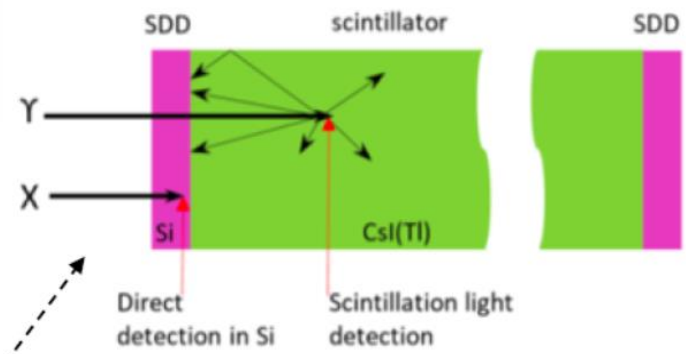


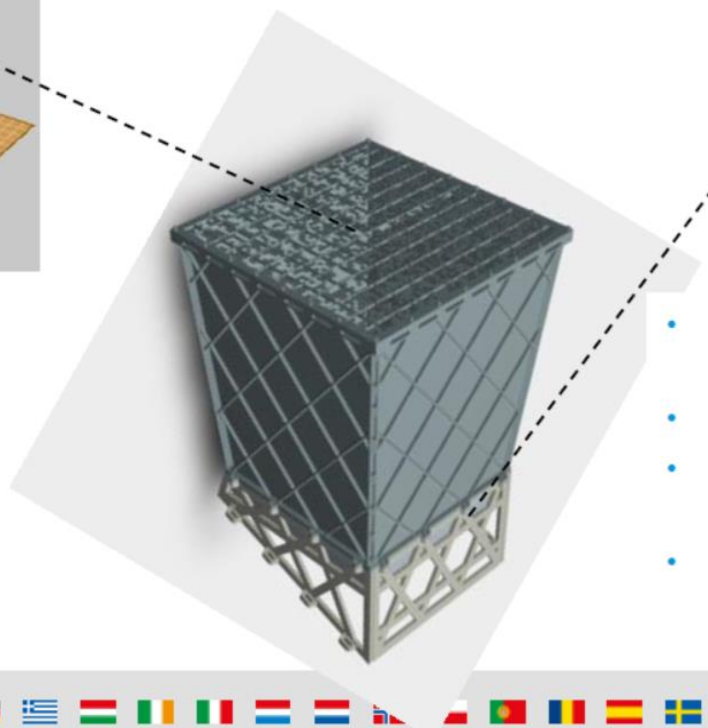
LEO (< 5°, ~600 km)
Rapid slewing bus
Prompt downlink

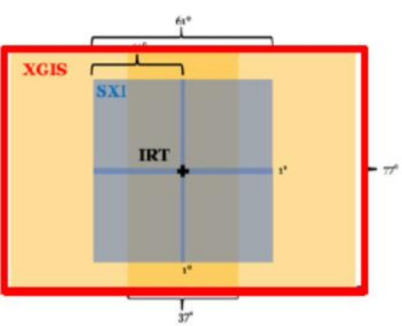
XGIS: X- and Gamma Imaging Spectrometer



Targets: long (hi-z) and short (black-hole mergers/GW counterparts) GRBs







- Coded mask telescopes with scintillator crystal and silicon drift detectors
- 2 keV–10 MeV
- 2 sr imaging FoV: 2 keV-150 keV with <15′ source location accuracy
- 4 sr spectrometer FoV above 150 keV

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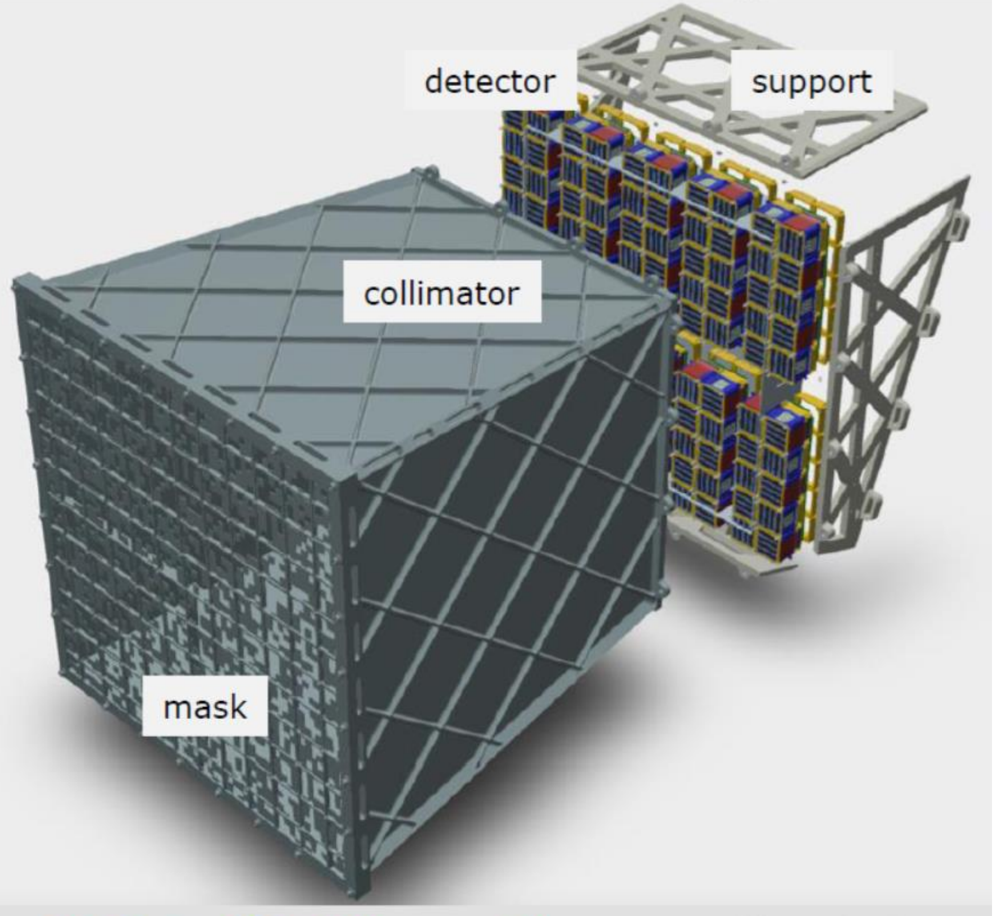
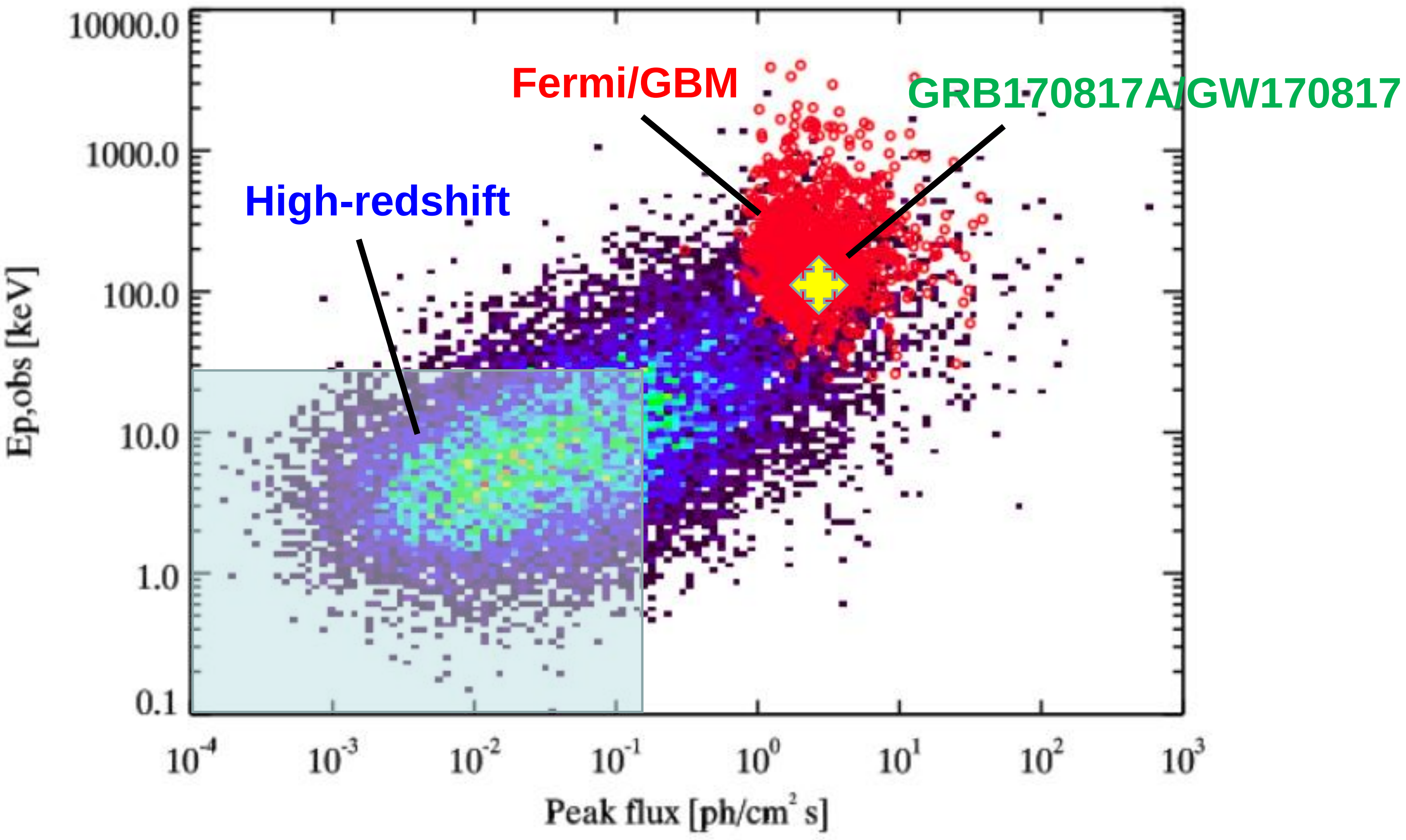
XGIS: key numbers & elements

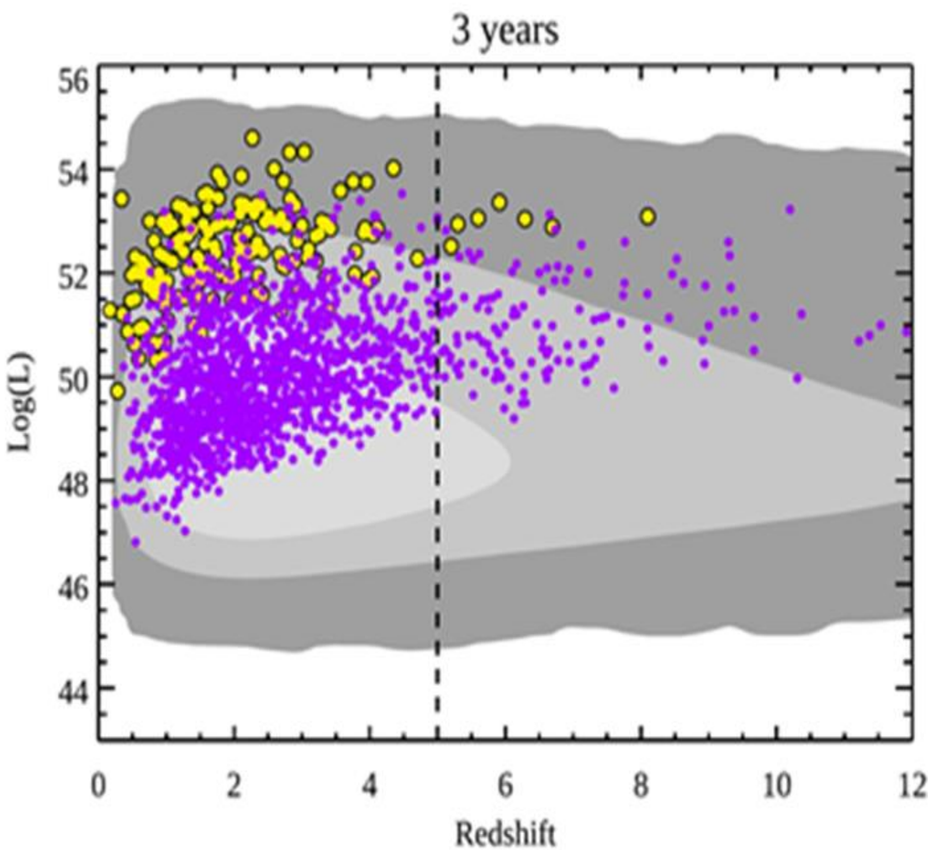
XGIS	Lead: INAF Bologna, IT		2x units
Budgets (total)	158 kg	211 W	25 Gbit/day
Dimensions/ unit (mm)	740 (h) x 600x600 (@ mask) 490x490 (@ detector)		
Energy ranges	2-30 keV	30 – 150 keV	150 keV- 10 MeV
Detector technologies	Silicon drift detectors (SDD)	CsI(Tl) scintillating crystal + SDD	
Imaging capability	<15′ loc. accuracy FoV 2 sr		None, 4 sr
Energy resolutions	20% @ 6keV	6% @ 600 KeV	

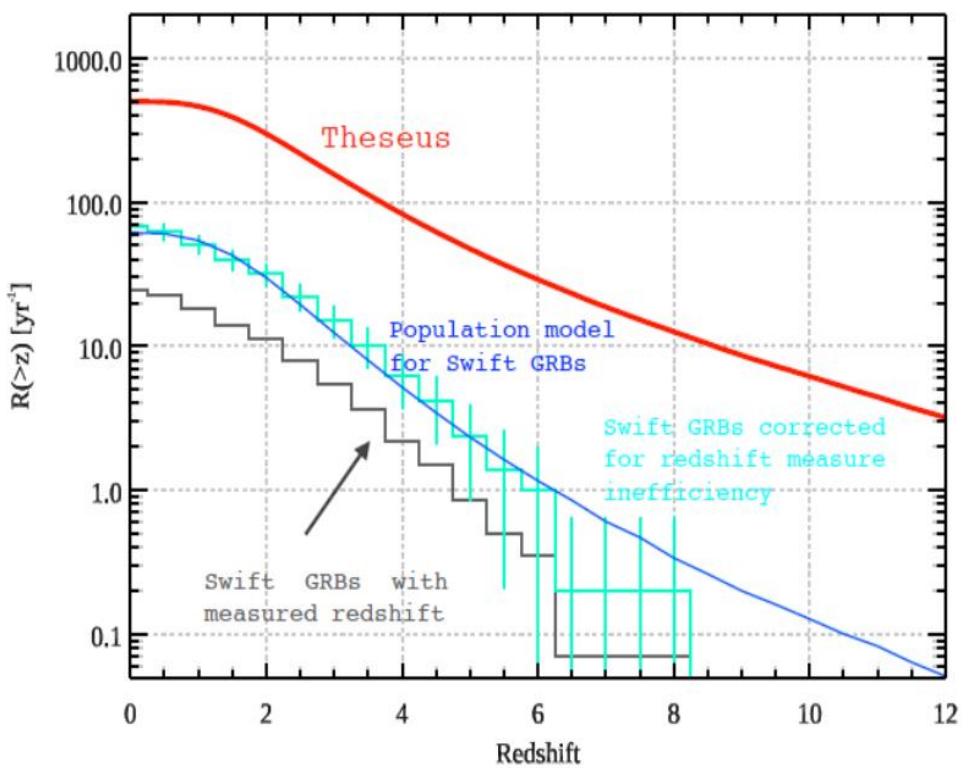


- THESEUS will have the ideal combination of instrumentation and mission profile for detecting all types of GRBs (long, short/hard, weak/soft, high-redshift), localizing them from a few arcmin down to arsec and measure the redshift for a large fraction of them



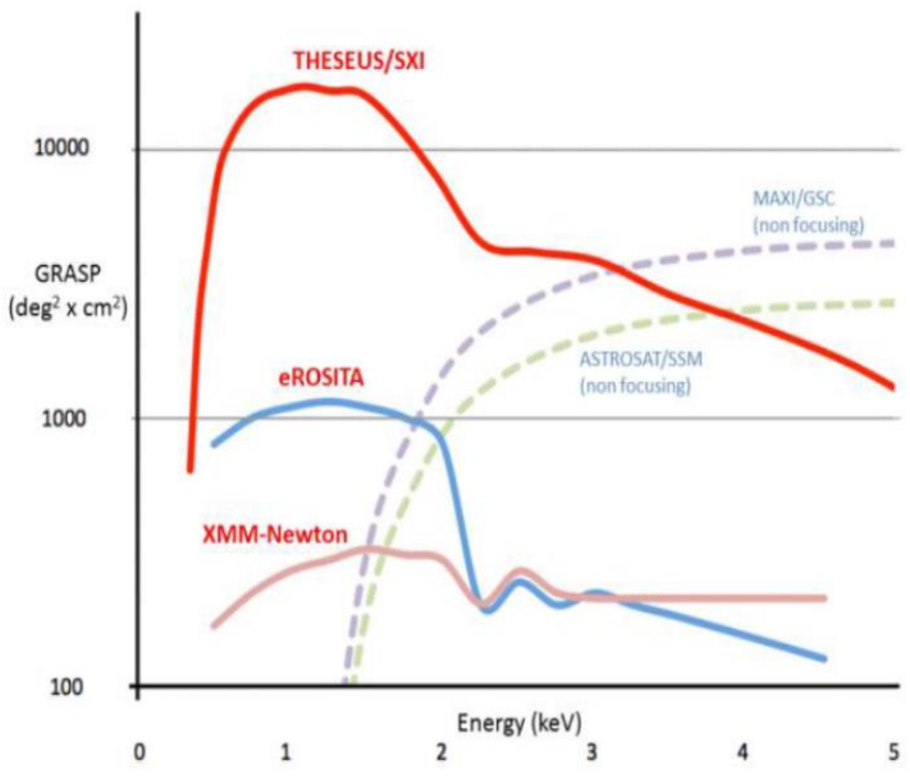
❑ Shedding light on the early Universe with GRBs

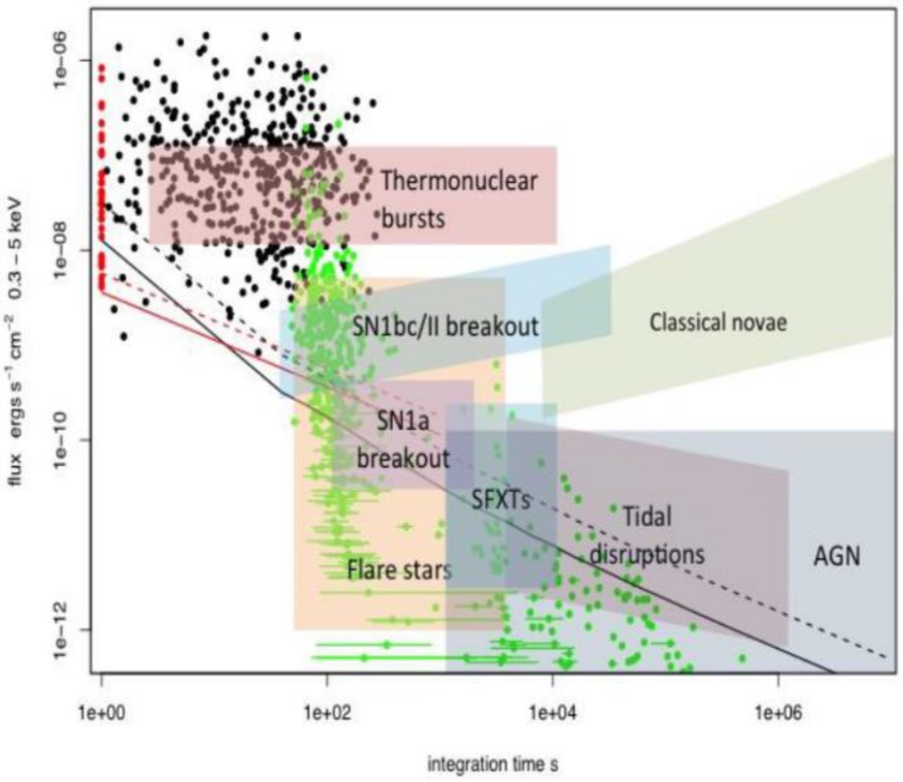




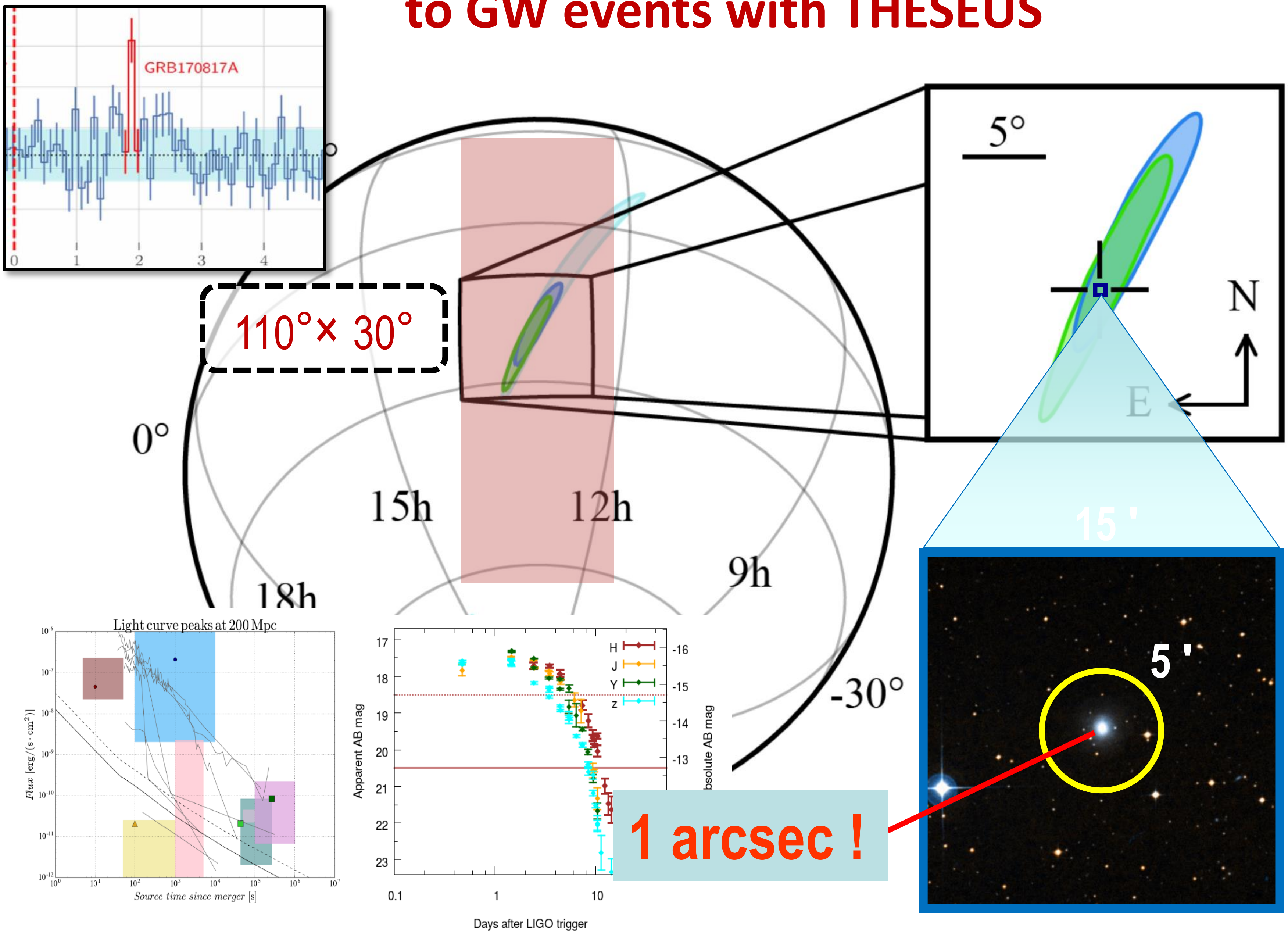
❑ THESEUS will also detect and localize down to 0.5-1 arcmin the soft X-ray short/long GRB afterglows, of NS-NS mergers and of many classes of galactic and extra-galactic transients

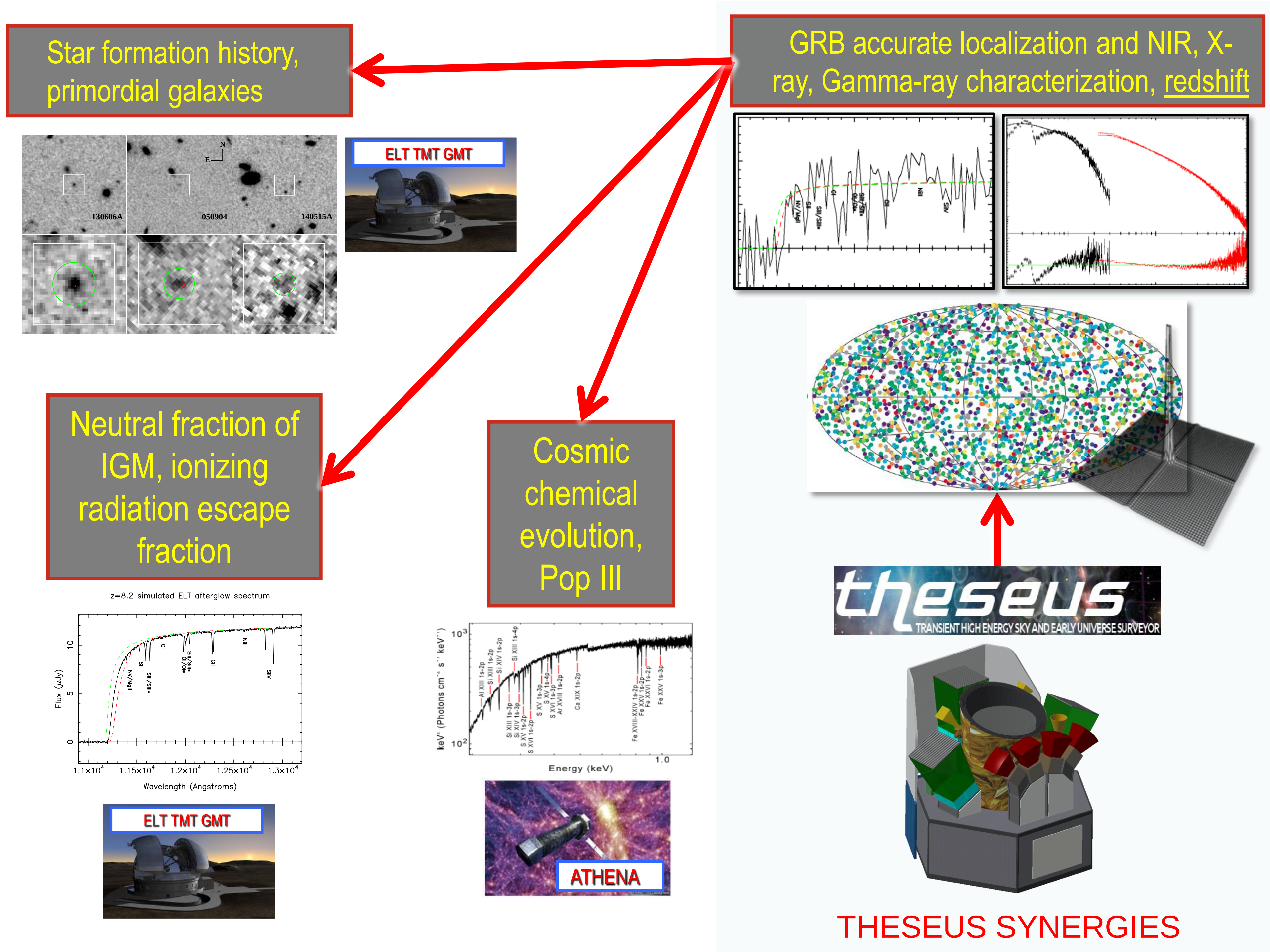
❑ For several of these sources, THESEUS/IRT may provide detection and study of associated NIR emission, location within 1 arcsec and redshift



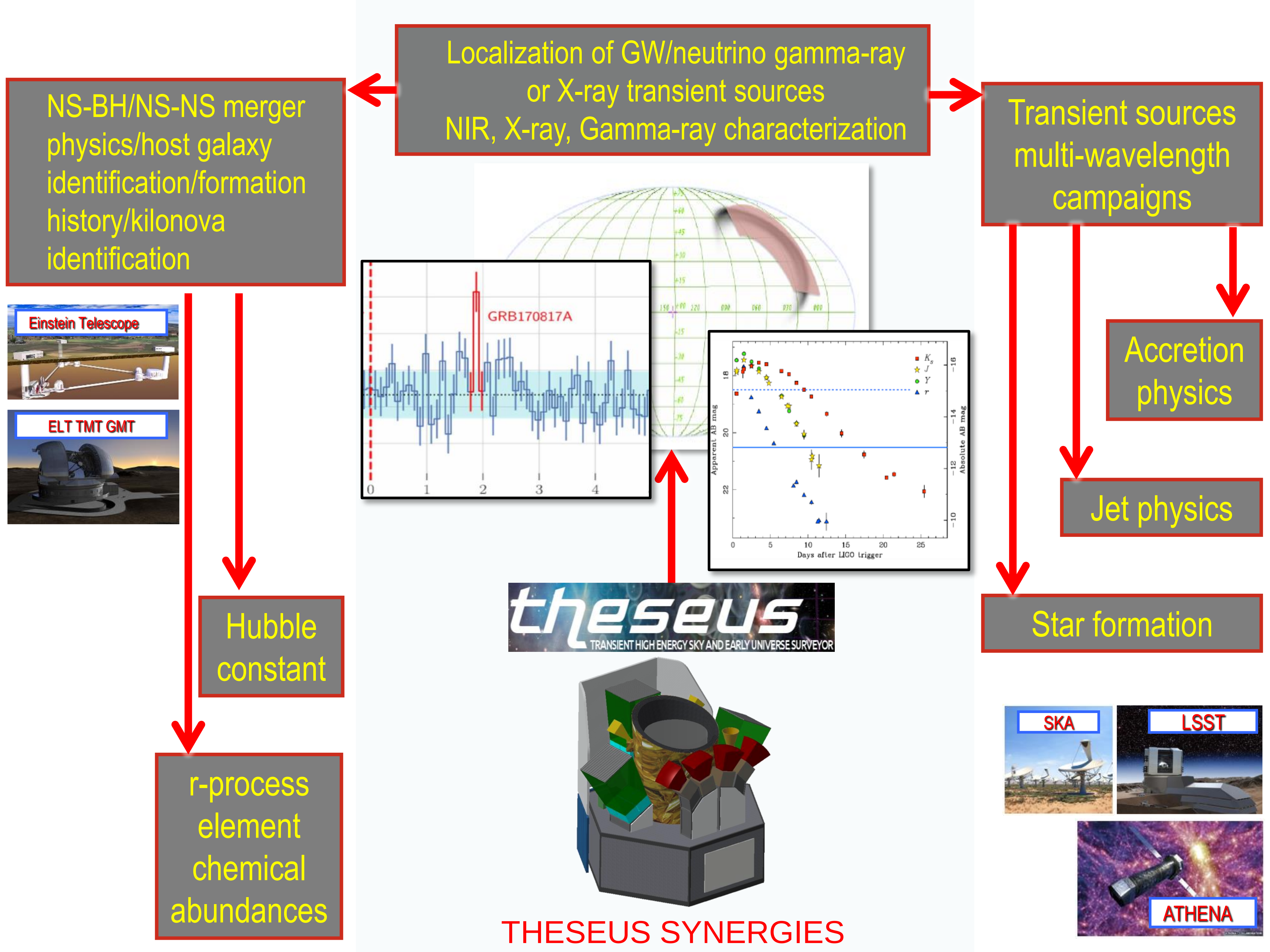


❑ Promptly and accurately localizing e.m. counterparts to GW events with THESEUS





Star formation history, primordial galaxies
GRB accurate localization and NIR, X-ray, Gamma-ray characterization, redshift
130606A
050904
140515A
ELT TMT GMT
Neutral fraction of IGM, ionizing radiation escape fraction
Cosmic chemical evolution, Pop III
z=8.2 simulated ELT afterglow spectrum
Flux (μJy)
Wavelength (Angstroms)
ELT TMT GMT
Energy (keV)
ATHENA
theseus
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR
THESEUS SYNERGIES


Localization of GW/neutrino gamma-ray
or X-ray transient sources
NIR, X-ray, Gamma-ray characterization
NS-BH/NS-NS merger physics/host galaxy identification/formation history/kilonova identification
Transient sources multi-wavelength campaigns
Einstein Telescope
ELT TMT GMT
GRB170817A
Apparent AB mag
Absolute AB mag
Days after LIGO trigger
Accretion physics
Jet physics
Star formation
Hubble constant
r-process element chemical abundances
theseus
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR
SKA
LSST
ATHENA
THESEUS SYNERGIES

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TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

- ***THESEUS* Core Science is based on two pillars:**
  - probe the **physical properties of the early Universe**, by discovering and exploiting the population of high redshift GRBs.
  - provide an **unprecedented deep monitoring** of the soft X-ray transient Universe, providing a fundamental contribution to multi-messenger and time domain astrophysics in the early 2030s (synergy with aLIGO/aVirgo, eLISA, ET, Km3NET and EM facilities e.g., LSST, E-ELT, SKA, CTA, ATHENA).

- ***THESEUS* Observatory Science includes:**
  - study of thousands of faint to bright X-ray sources by exploiting the **unique simultaneous availability of broad band X-ray and NIR observations**
  - provide a **flexible follow-up observatory** for fast transient events with multi-wavelength ToO capabilities and **guest-observer programmes**.

In summary

- THESEUS, submitted to ESA/M5 by a large European collaboration with strong interest by international partners (e.g., US) will fully exploit GRBs as powerful and unique tools to investigate the early Universe and will provide us with unprecedented clues to GRB physics and sub-classes.

- THESEUS will also play a fundamental role for GW/multi-messenger and time domain astrophysics at the end of next decade, also by providing a flexible follow-up observatory for fast transient events with multi-wavelength ToO capabilities and guest-observer programmes

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

- THESEUS observations will impact on several fields of astrophysics, cosmology and fundamental physics and will enhance importantly the scientific return of next generation multi messenger (aLIGO/aVirgo, LISA, ET, or Km3NET;) and e.m. facilities (e.g., LSST, E-ELT, SKA, CTA, ATHENA)

- Phase A will be concluded in Spring 2021; final selection on June

THESEUS International Conference in Malaga (or virtual) on Spring 2021

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