THESEUS
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

Lorenzo Amati (P.I)
(INAF – OAS Bologna)
on behalf of the THESEUS international collaboration

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)

Caltech | Department of Astronomy

X-ray Club Talk – November 23, 2020

Cosmology and multi-messenger astrophysics (and extreme physics) with Gamma-Ray Bursts

esa

European Space Agency

cosmic vision

theseus

transient high energy sky and early universe surveyor

ASI

Agenzia Spaziale Italiana

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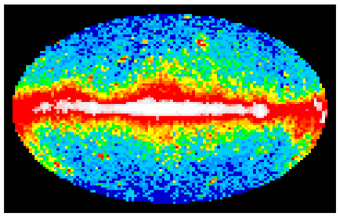
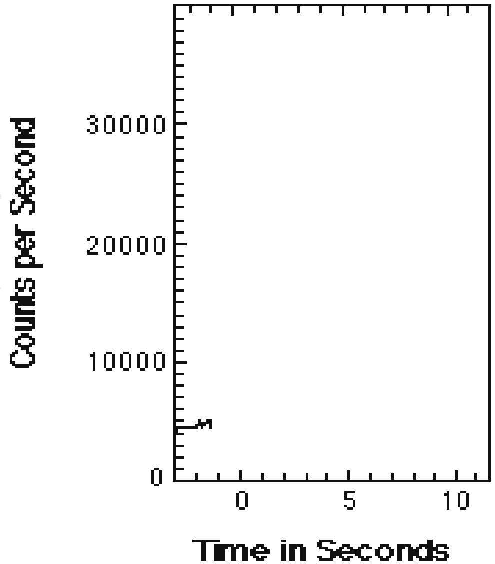
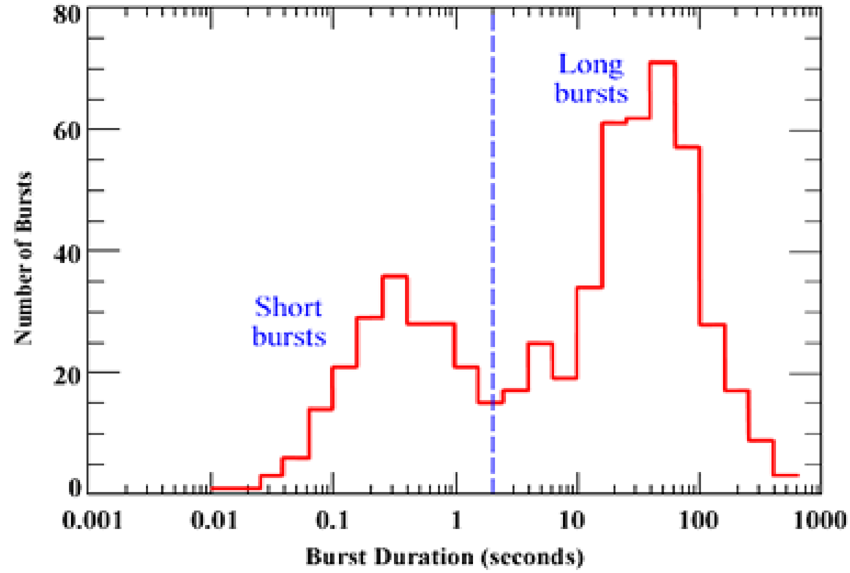
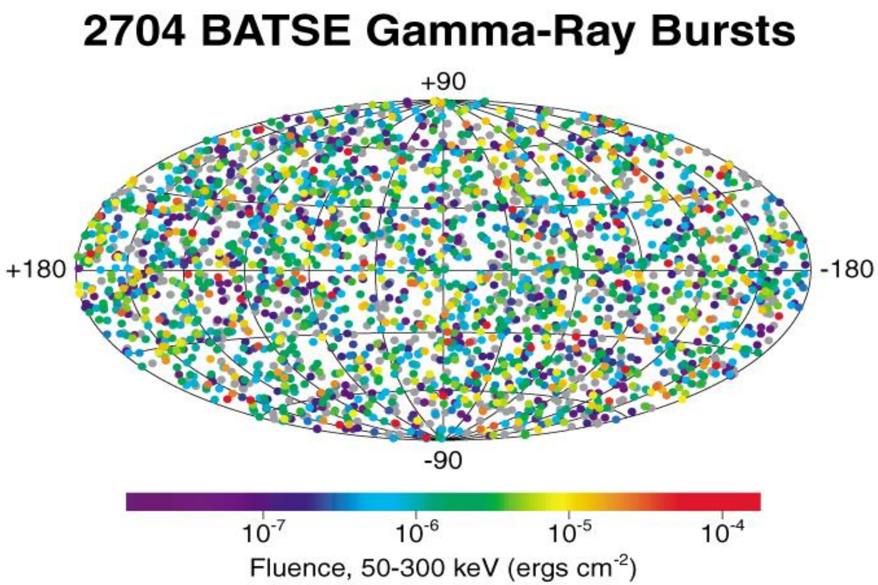
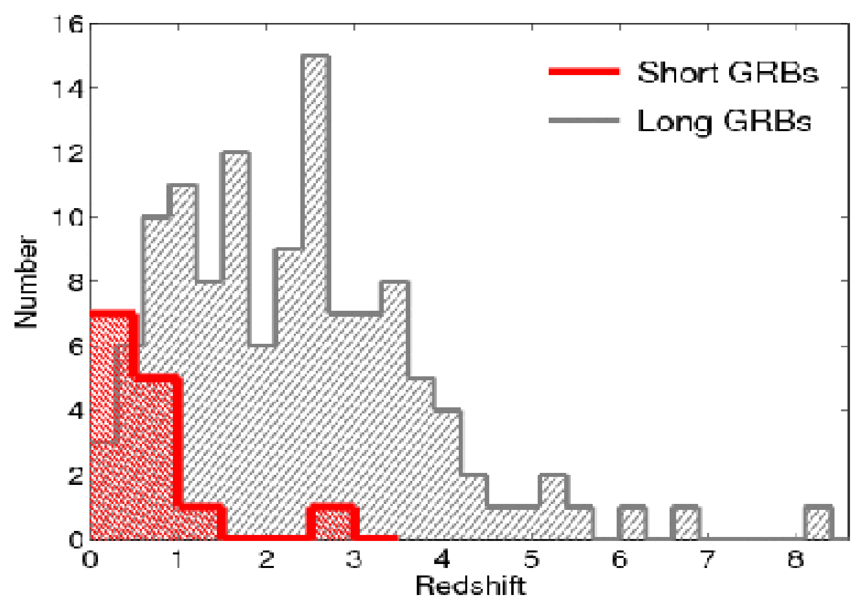
Gamma-Ray Bursts: the most extreme phenomenon in the Universe





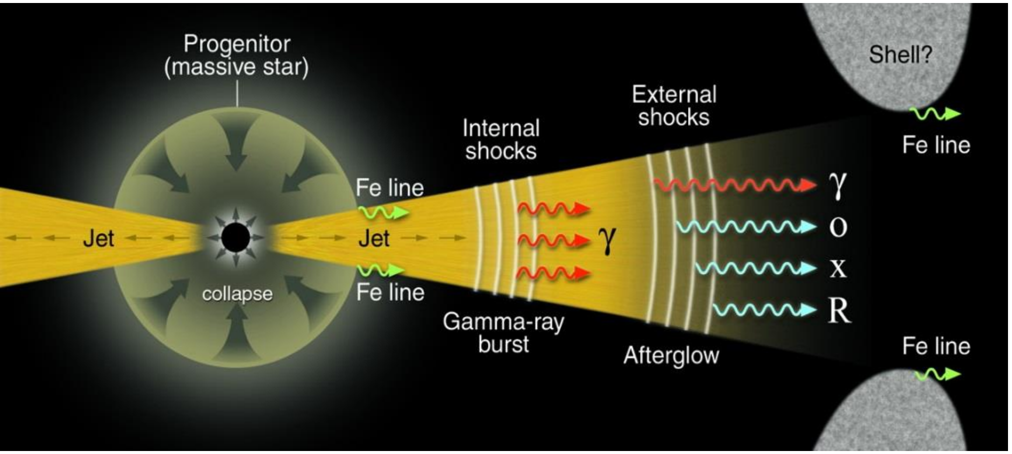






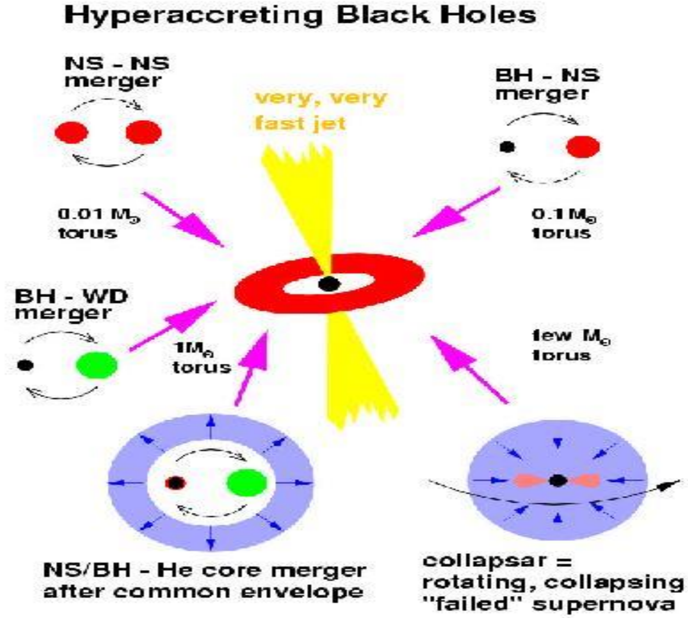
Standard scenarios for GRB progenitors

LONG



- energy budget up to >10^{54} erg
- long duration GRBs
- metal rich (Fe, Ni, Co) circum-burst environment
- GRBs occur in star forming regions
- GRBs are associated with SNe
- likely collimated emission

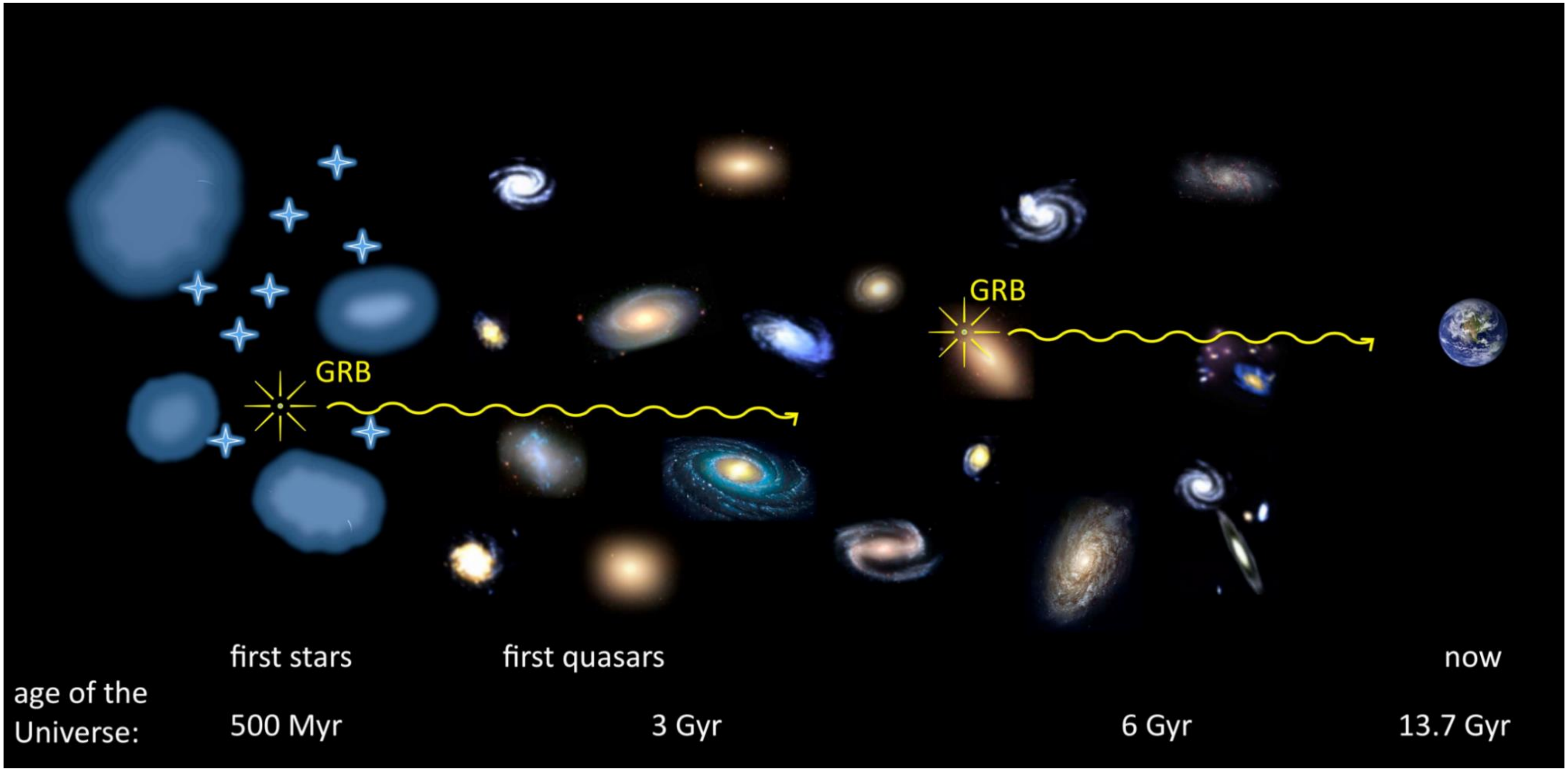
SHORT



- energy budget up to 10^{51} - 10^{52} erg
- short duration (< 5 s)
- clean circum-burst environment
- old stellar population

Long GRBs

- direct detection and accurate location of exploding stars (and their host galaxies) up to the Cosmic Dawn!!!
- cosmological «beacons»
- standardizable cosmological candles??



Long GRBs

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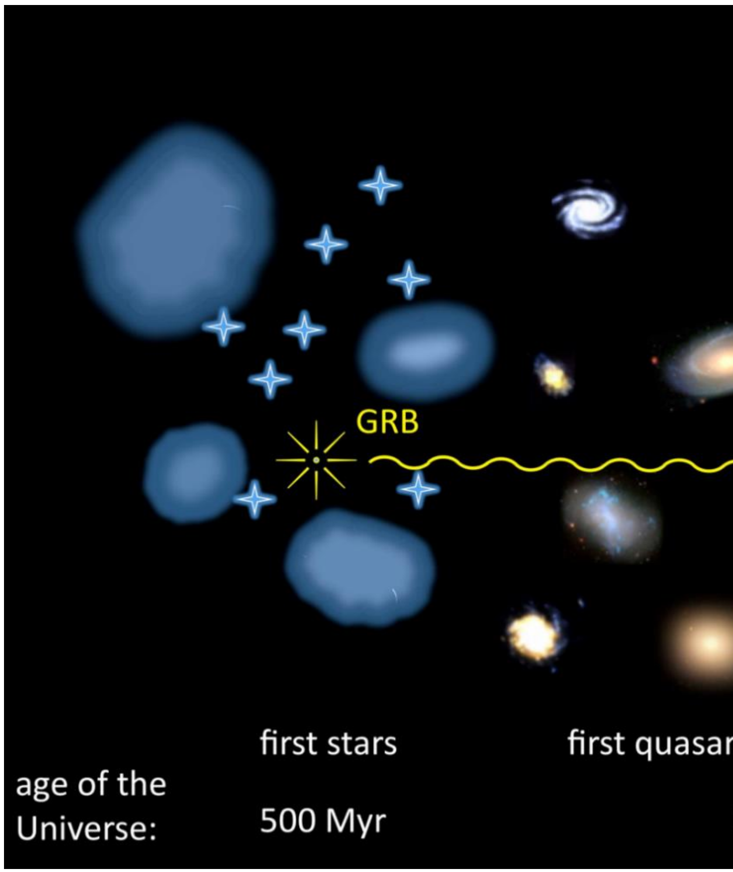
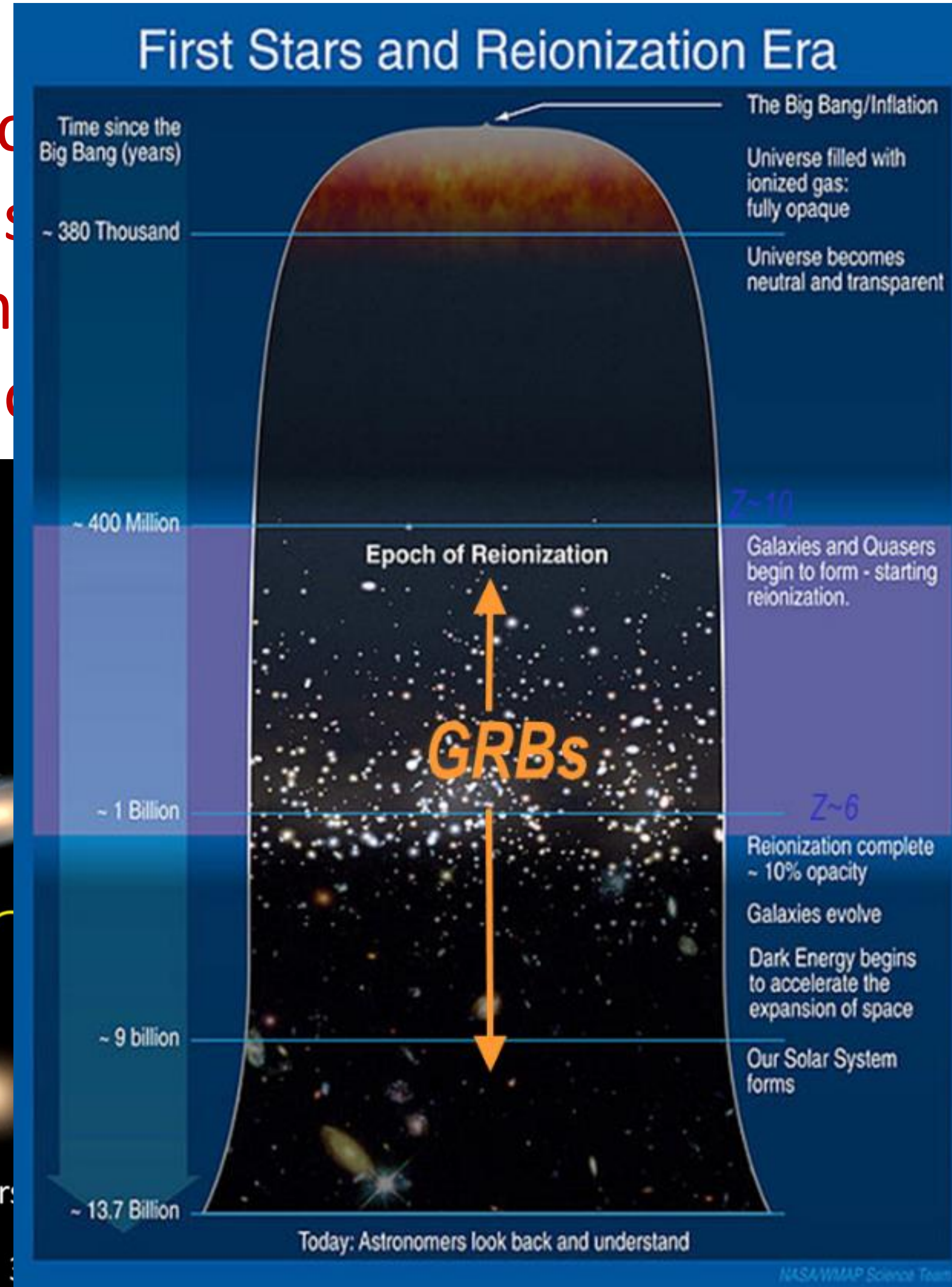
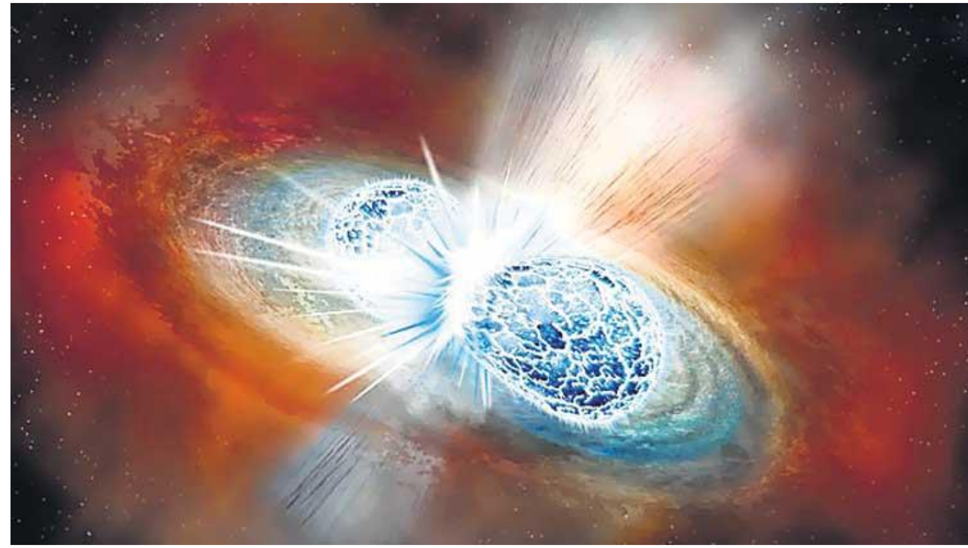
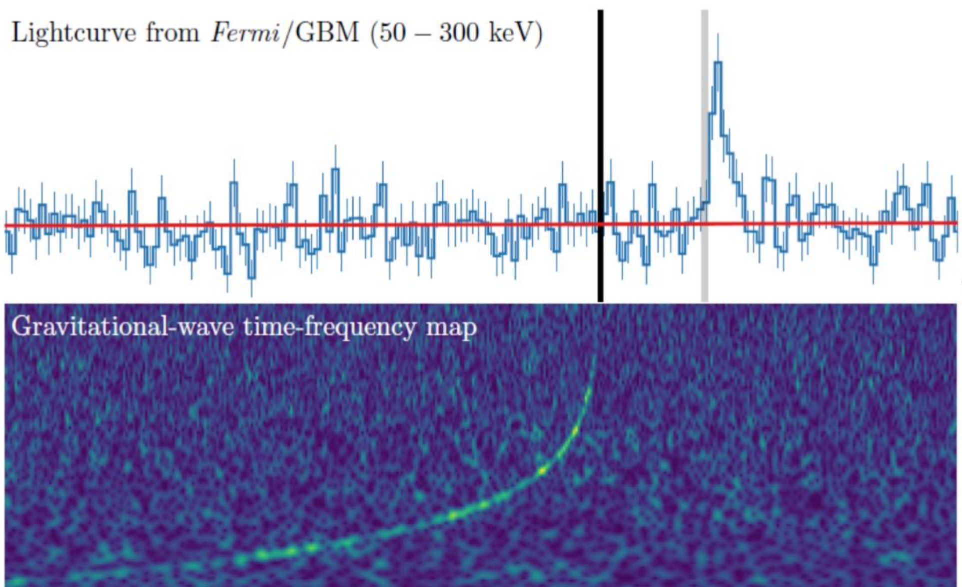


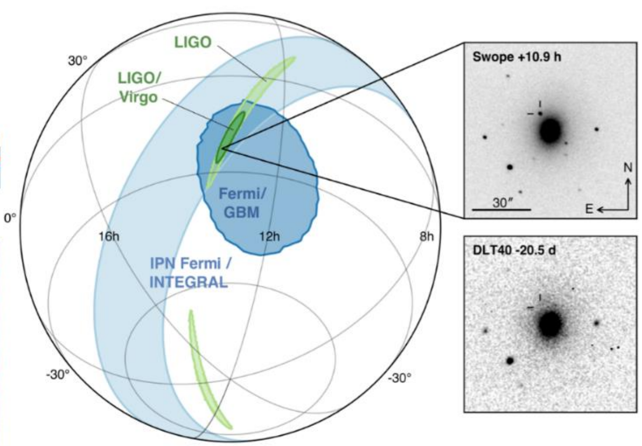


Short GRBs: e.m. counterparts of gravitational-waves sources!!!



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



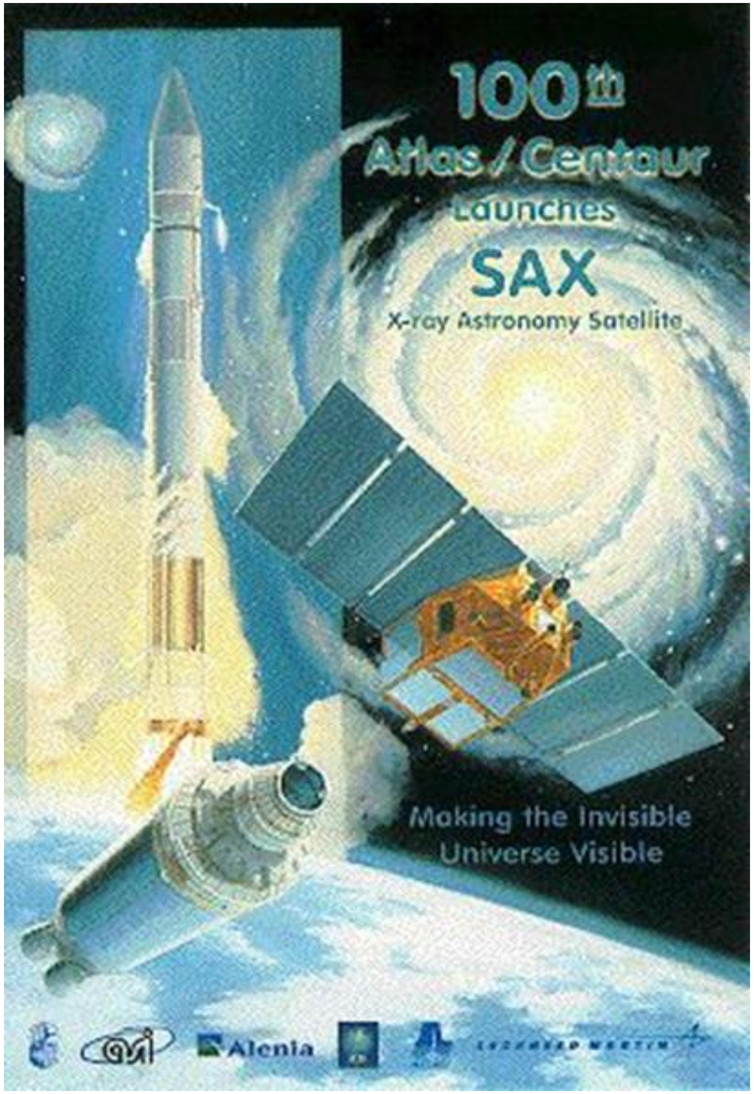


The BeppoSAX revolution and heritage (1996 – 2002)

- Italian (ASI) satellite with contributions by NL; key role of CNR (now INAF) space astrophysics institutes in Milano, Bologna, Roma and Palermo

- First systematic accurate (arcmin) locations of GRBs and discovery of “afterglow emission”, unveiling their cosmological distance scale

- First direct evidence of association of long GRBs with peculiar core-collapse SNe



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

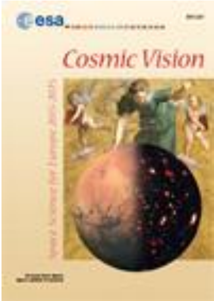
- ***GRB cosmology:*** use of long GRBs for early Universe (SFR, first stars and galaxies, cosmic re-ionization) and as possible «standardizable» candels -> improve on high-z GRBs

- **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

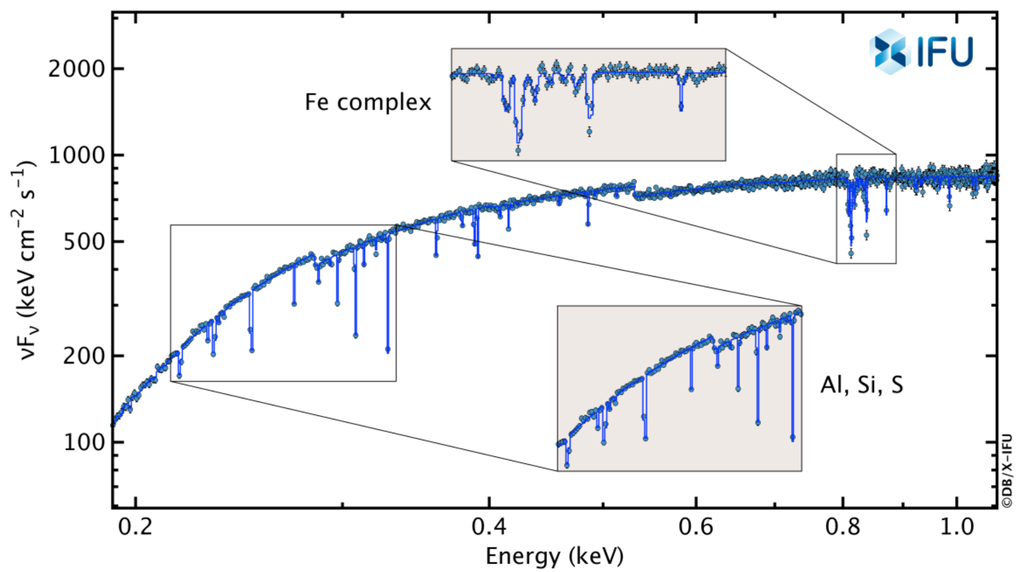
Future missions (early / mid '20s)

- **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)

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

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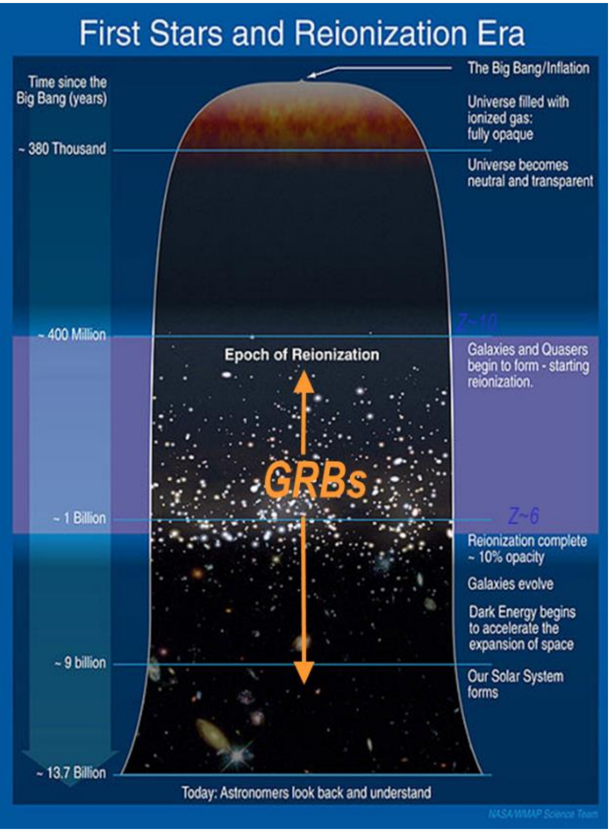
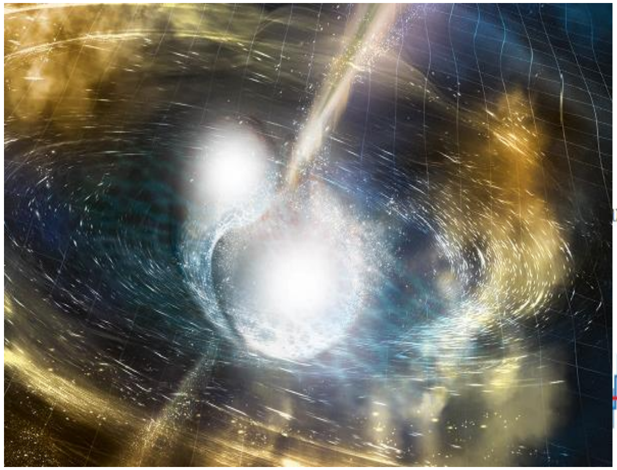
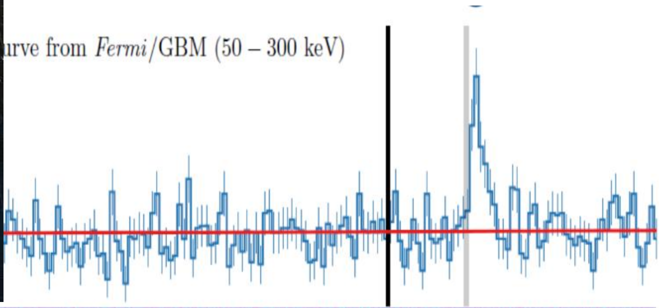
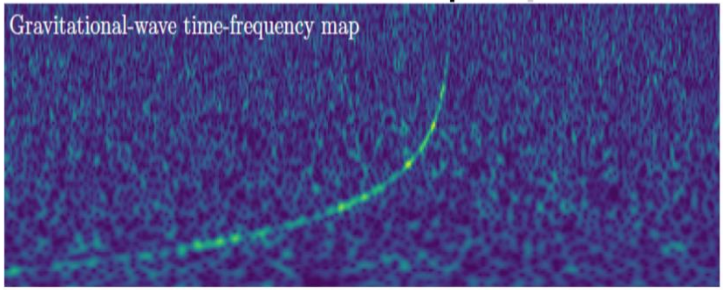
Probing the Early Universe with GRBs
Multi-messenger and time domain Astrophysics
The transient high energy sky
Synergy with next generation large facilities (E-ELT, SKA, CTA, ATHENA, GW and neutrino detectors)









THESEUS

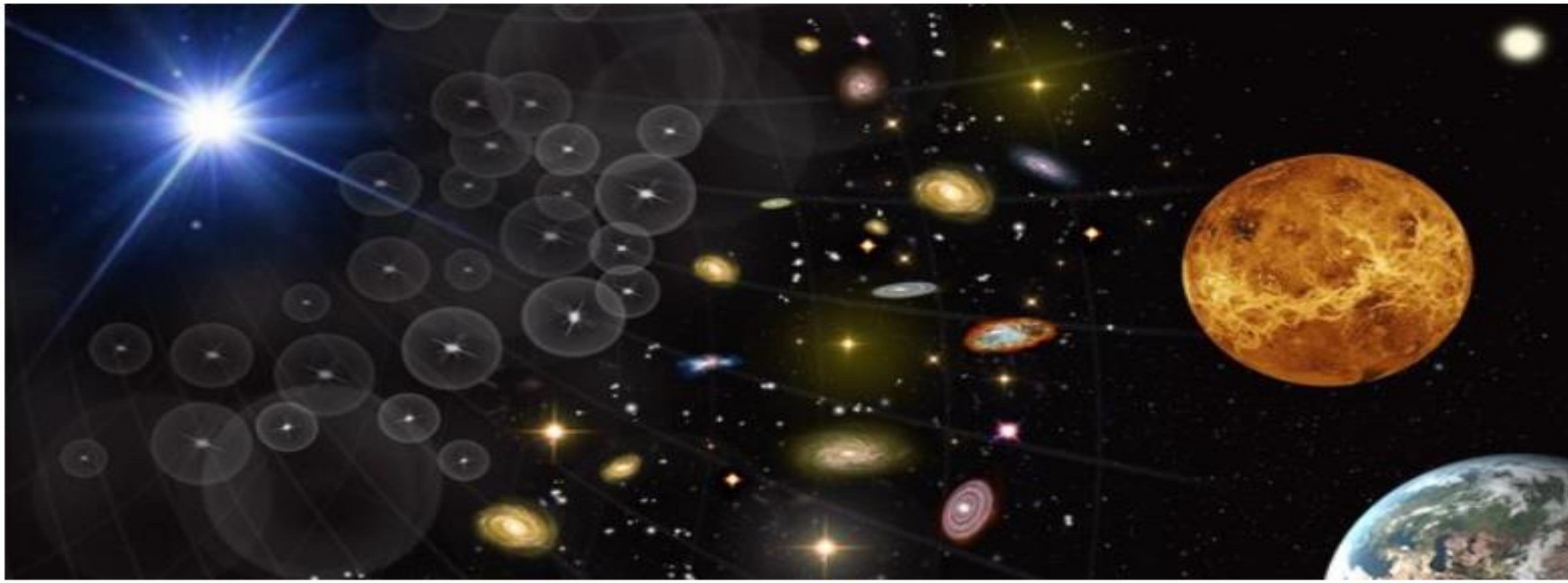
Transient High Energy Sky and Early Universe Surveyor

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)



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.

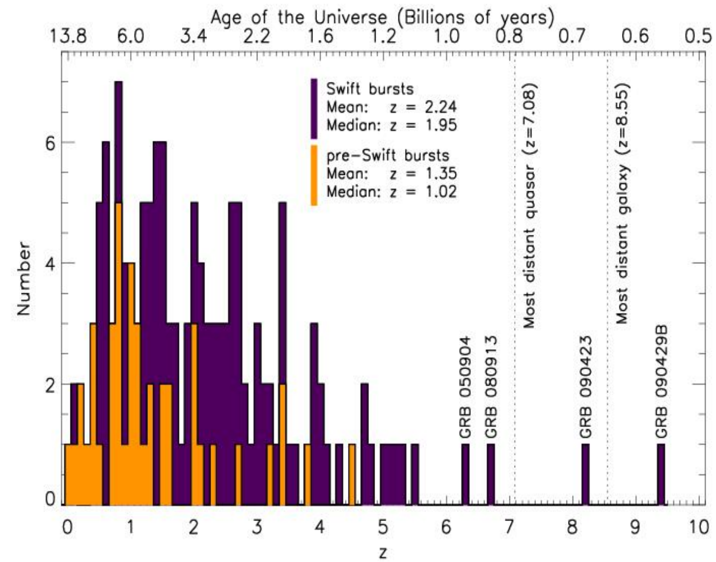
The three candidates, the Transient High Energy Sky and Early Universe Surveyor (Theseus), the SPace Infrared telescope for Cosmology and Astrophysics (Spica), and the EnVision mission to Venus were

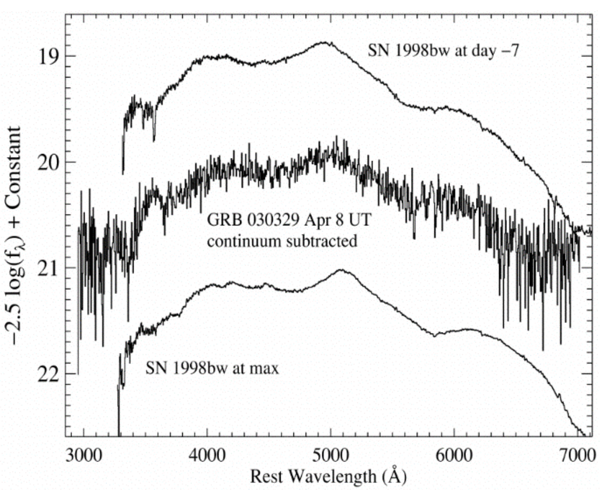
ESA timeline for M5

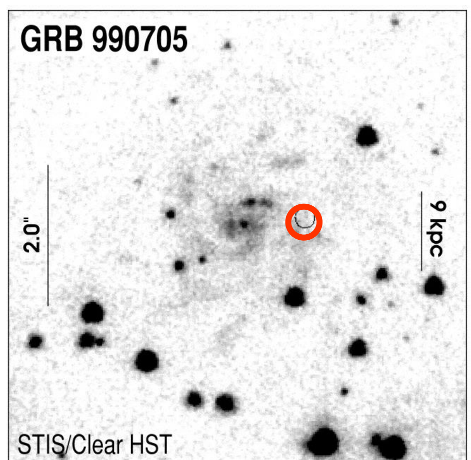
Activity	Date
Phase 0 kick-off	June 2018
Phase 0 completed (EnVision, SPICA and THESEUS)	End 2018
ITT for Phase A industrial studies	February 2019
Phase A industrial kick-off	June 2019
Mission Selection Review (technical and programmatic review for the three mission candidates)	Completed by June 2021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

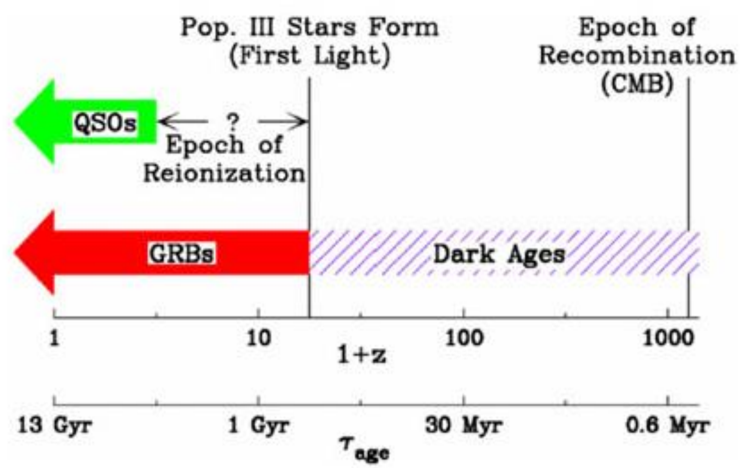
Because of their huge luminosities, mostly emitted in the X and gamma-rays, their redshift distribution extending at least to z ~9 and their association with explosive death of massive stars and star forming regions, GRBs are unique and powerful tools for investigating the early Universe: **SFR evolution,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







GRBs in Cosmological Context

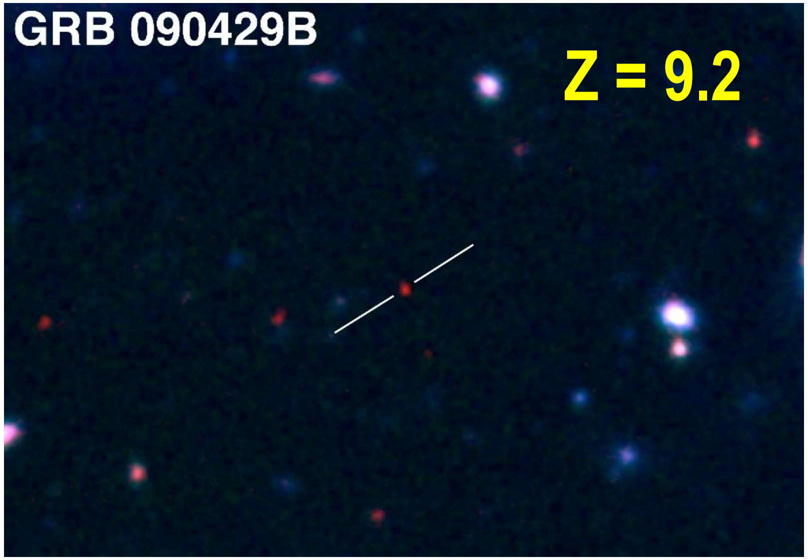


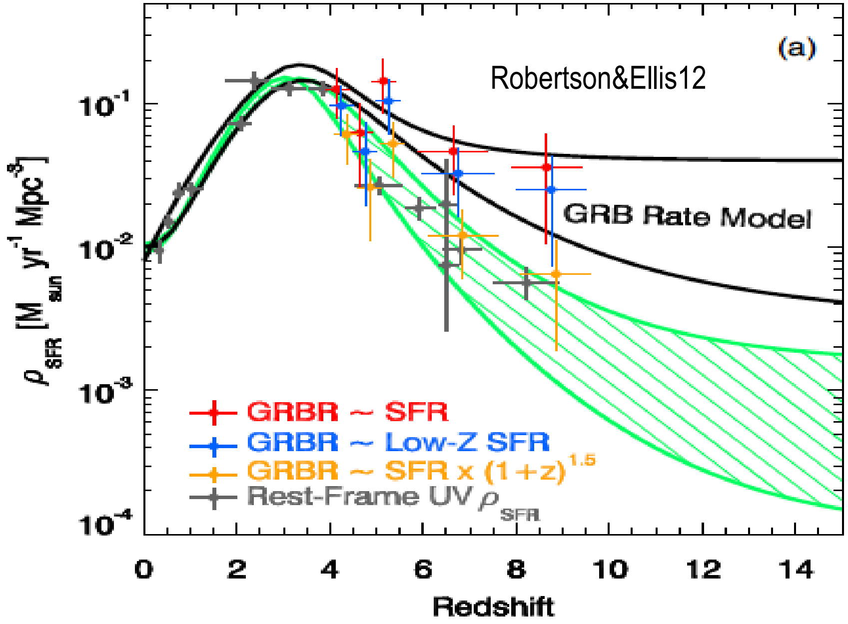
Lamb and Reichart (2000)

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

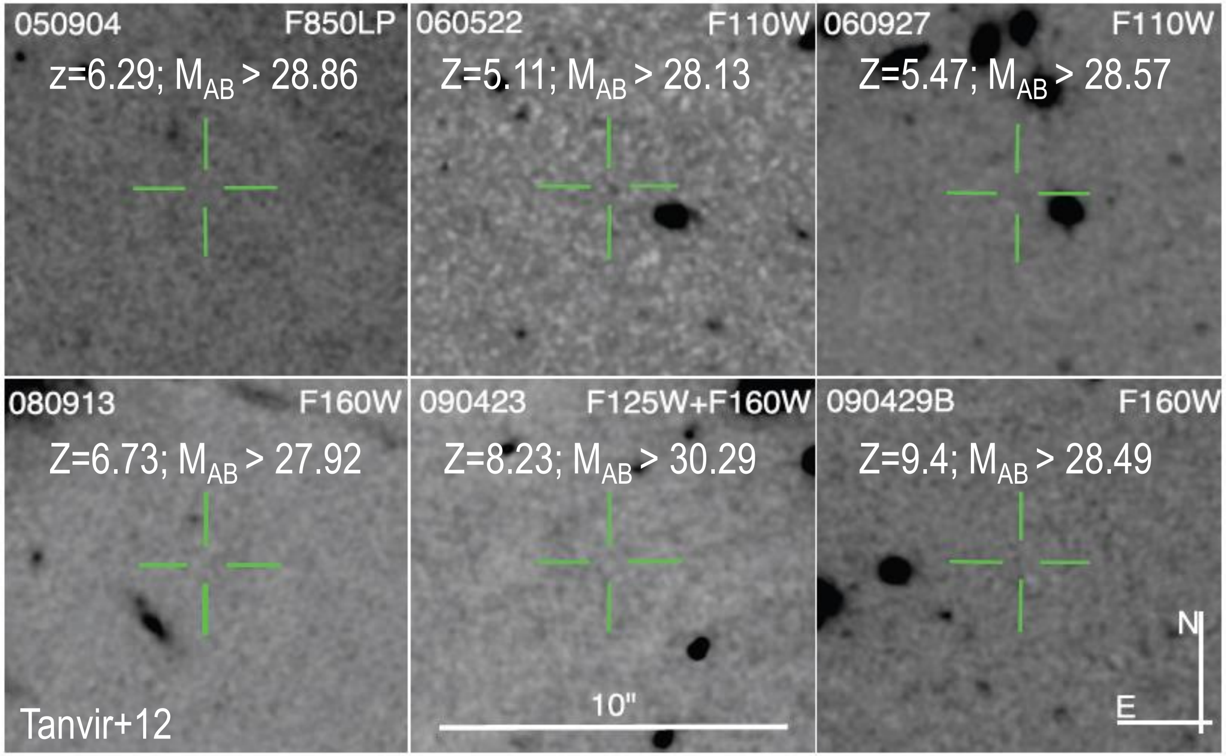
- measure independently the **cosmic star–formation rate**, even beyond the limits of current and future galaxy surveys

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





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

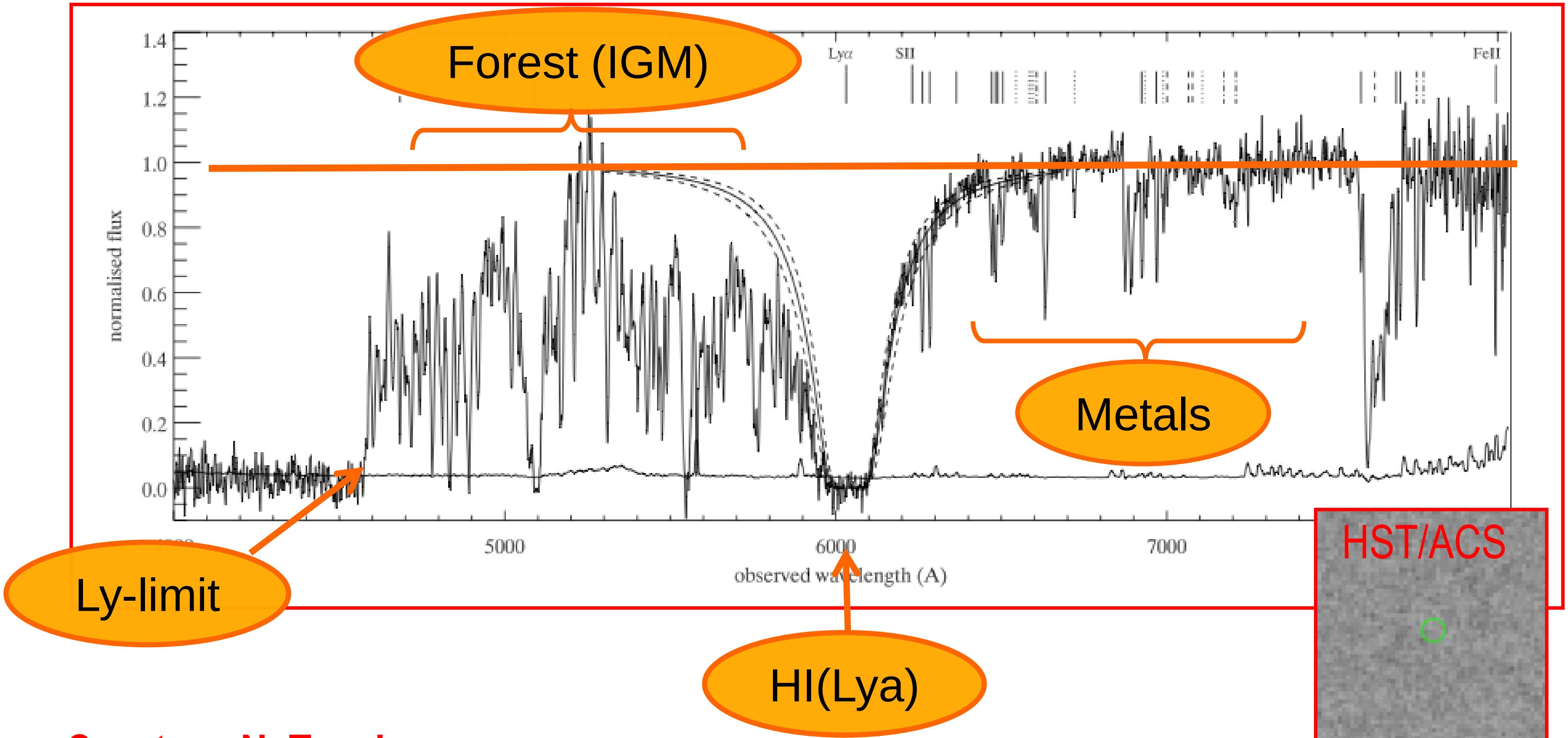


Robertson&Ellis12

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**

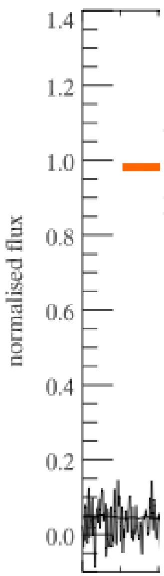
Abundances, HI, dust, dynamics etc. even for very faint hosts. E.g. GRB 050730: faint host (R>28.5), but z=3.97, [Fe/H]=-2 and low dust, from afterglow spectrum (Chen et al. 2005; Starling et al. 2005).

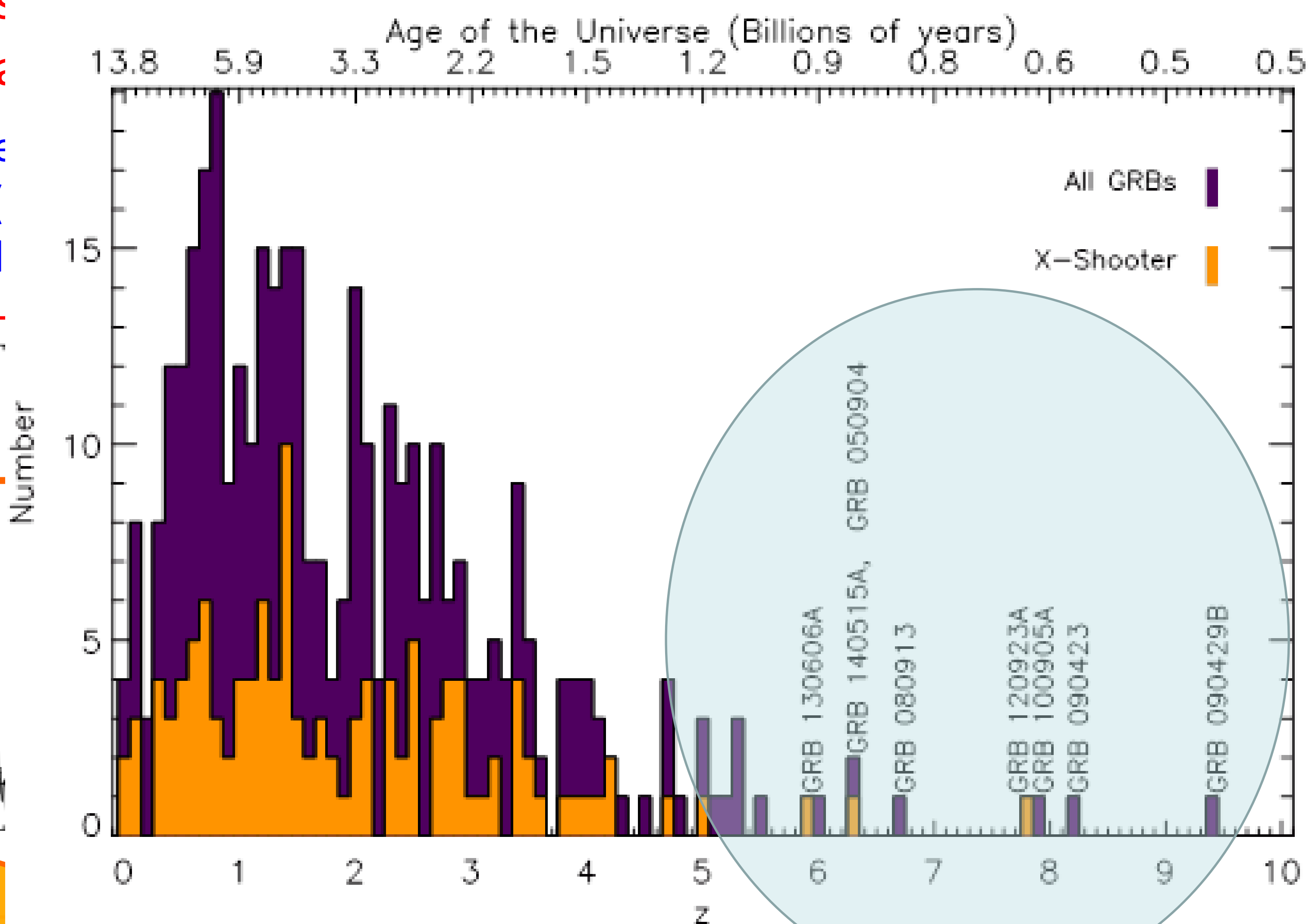


Courtesy N. Tanvir

- the neutral hydrogen fraction
- the es
- the ea

Abundance
faint host (
(Chen et al





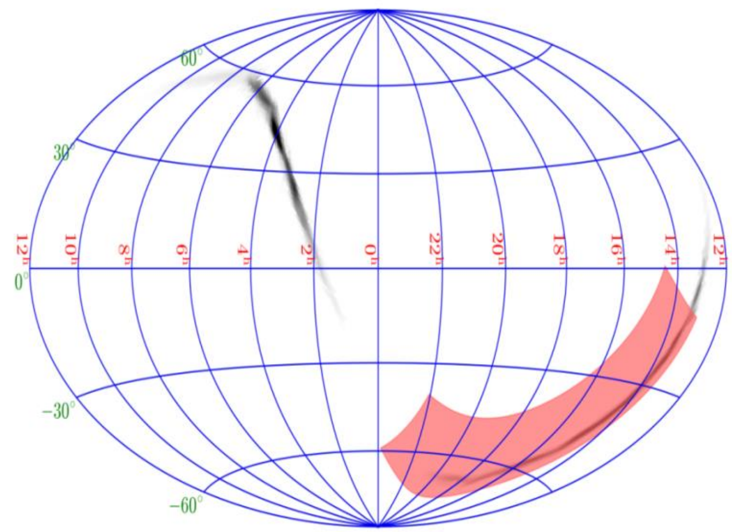
Ly-limit

HI(Lya)

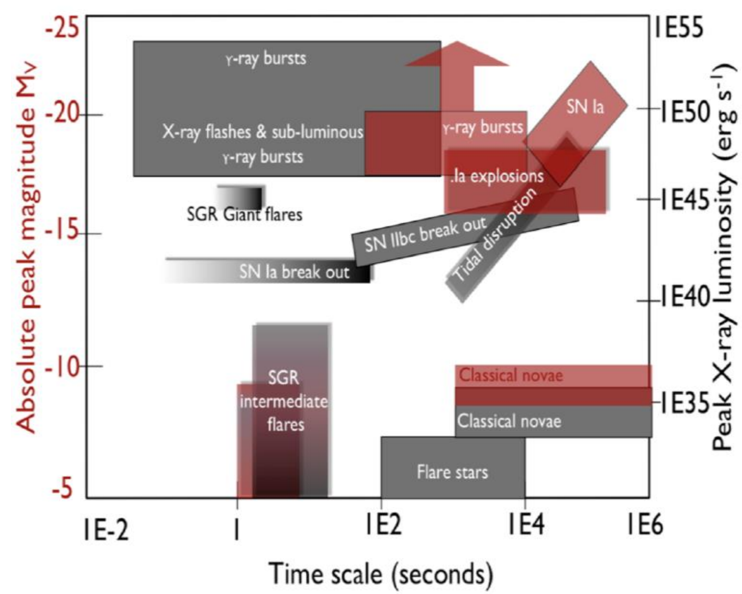
Courtesy N. Tanvir

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;**

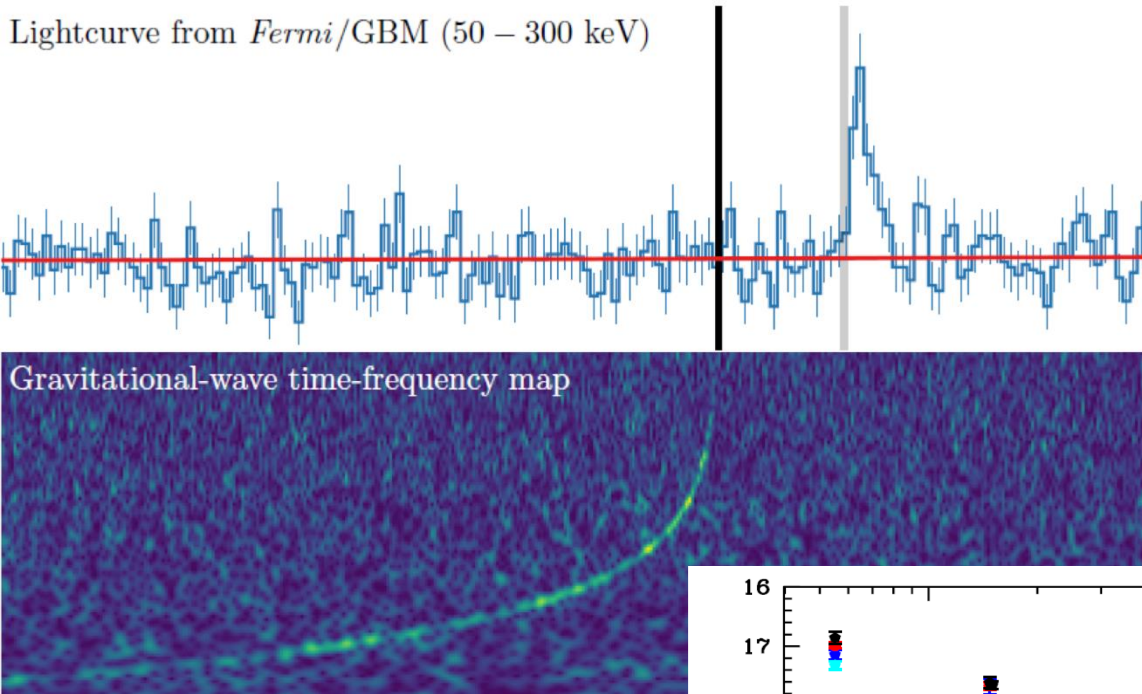


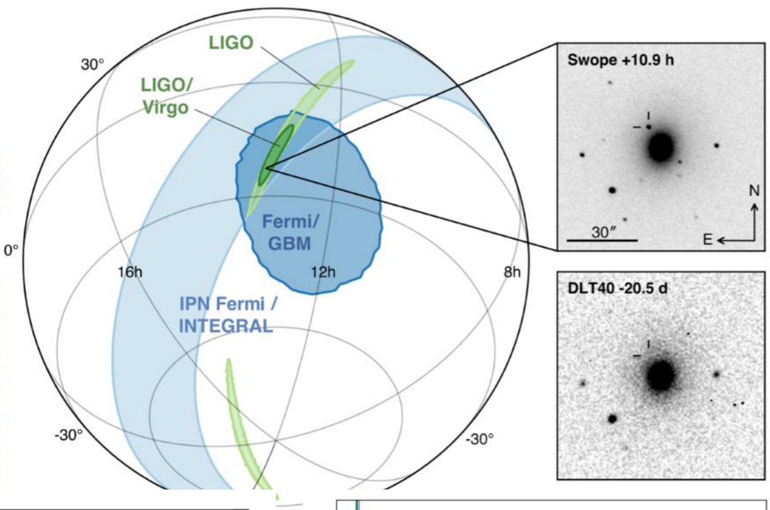
- Provide real-time triggers and accurate (~1 arcmin within a few seconds; ~1'' within a few minutes) **high-energy transients for follow-up with next-generation optical-NIR (E-ELT, JWST if still operating), radio (SKA), X-rays (ATHENA), TeV (CTA) telescopes; synergy with LSST**

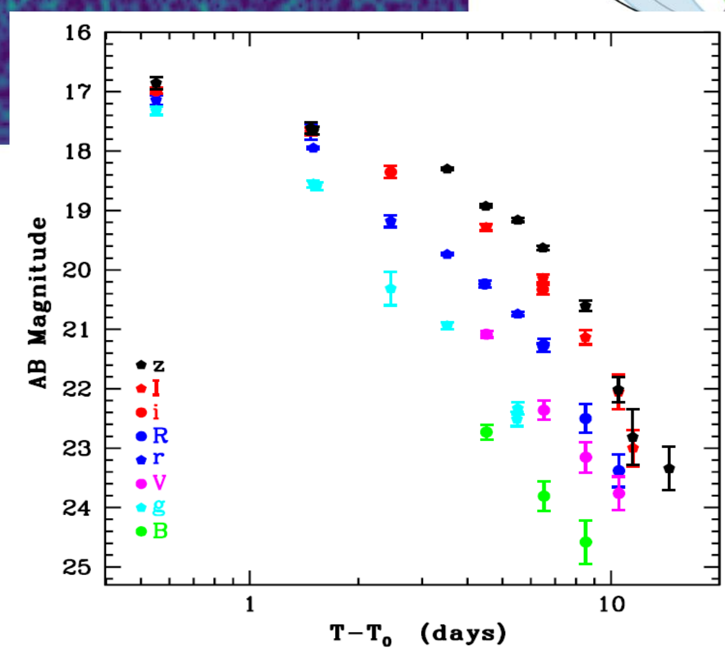


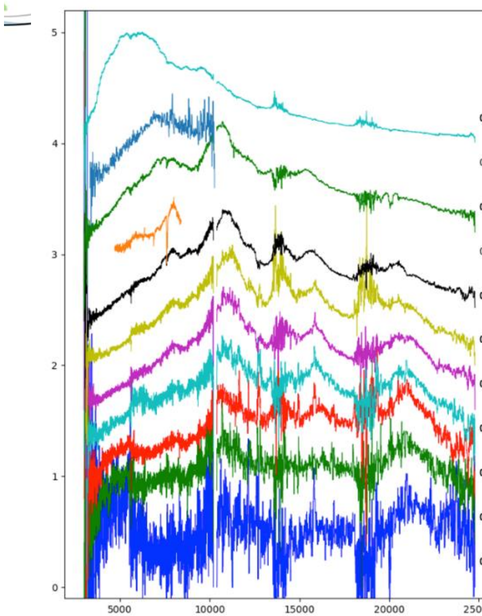
- Provide a fundamental step forward in the comprehension of the physics of various classes of transients and **fill the present gap in the discovery space of new classes of transients events**

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









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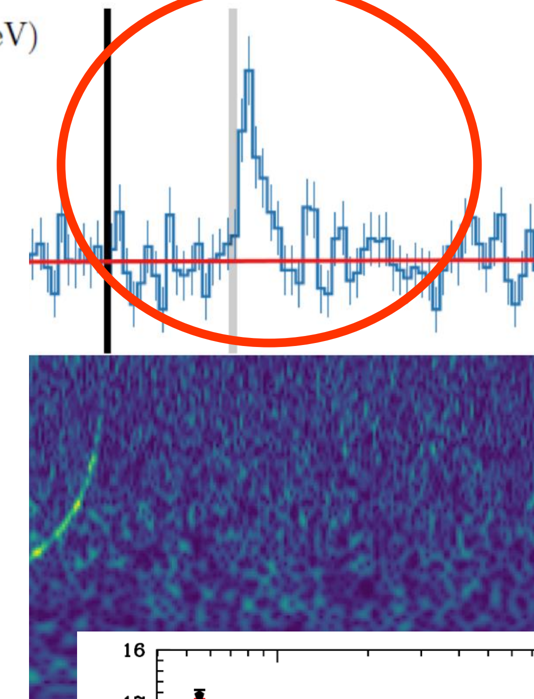
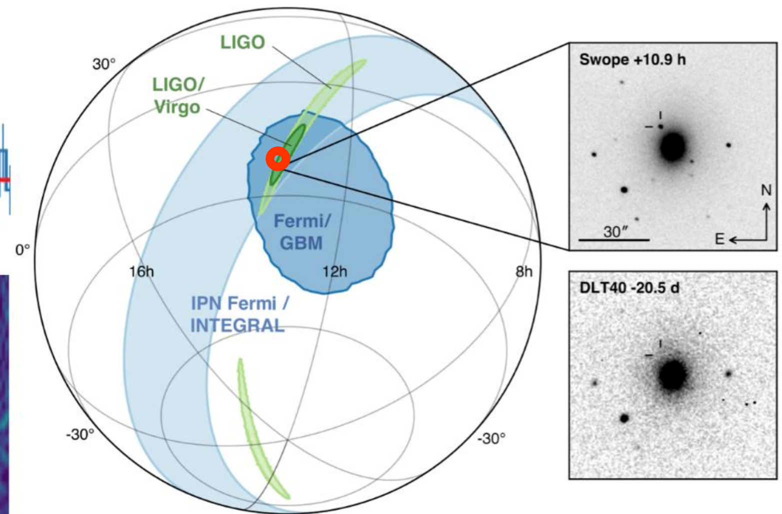
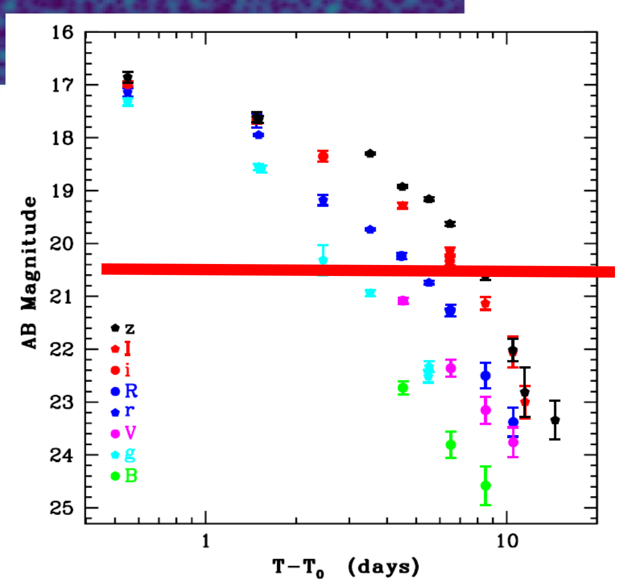
Lightcurve from *Fermi*/GBM (50 – 300 keV)

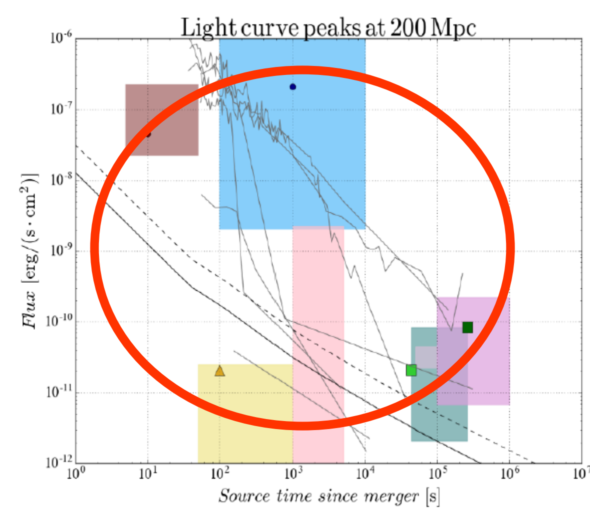


THESEUS:

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

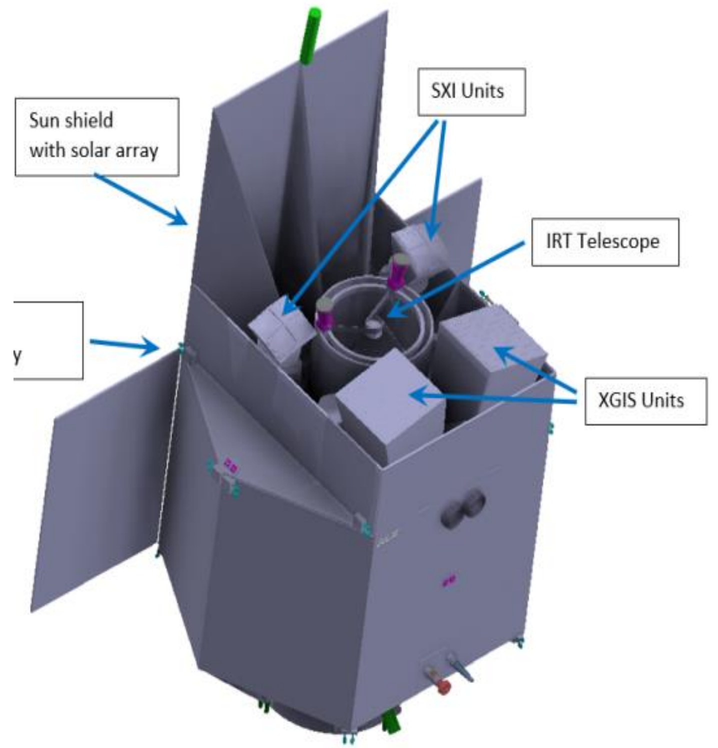






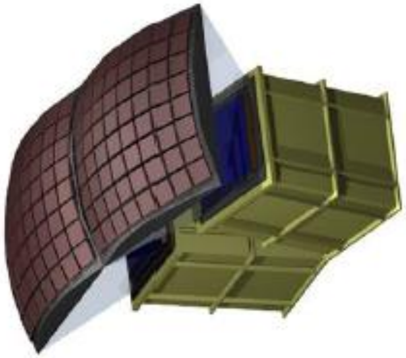
THESEUS mission concept

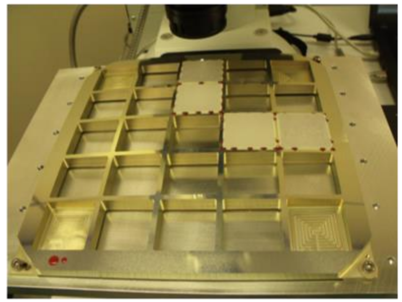
- **Soft X-ray Imager (SXI):** a set of two sensitive lobster-eye telescopes observing in **0.3 - 5 keV band, total FOV of ~0.5sr with source location accuracy <2';**
- **X-Gamma rays Imaging Spectrometer (XGIS,)**: 2 coded-mask X-gamma ray cameras using Silicon drift detectors coupled with CsI crystal 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)**

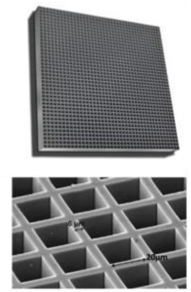


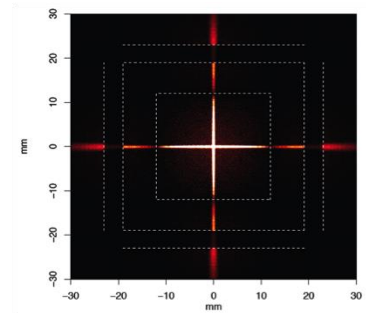
LEO (< 5°, ~600 km)
Rapid slewing bus
Prompt downlink

The Soft X-ray Imager (SXI) – led by UK









2 DUs, each has a 31 x 26 degree FoV

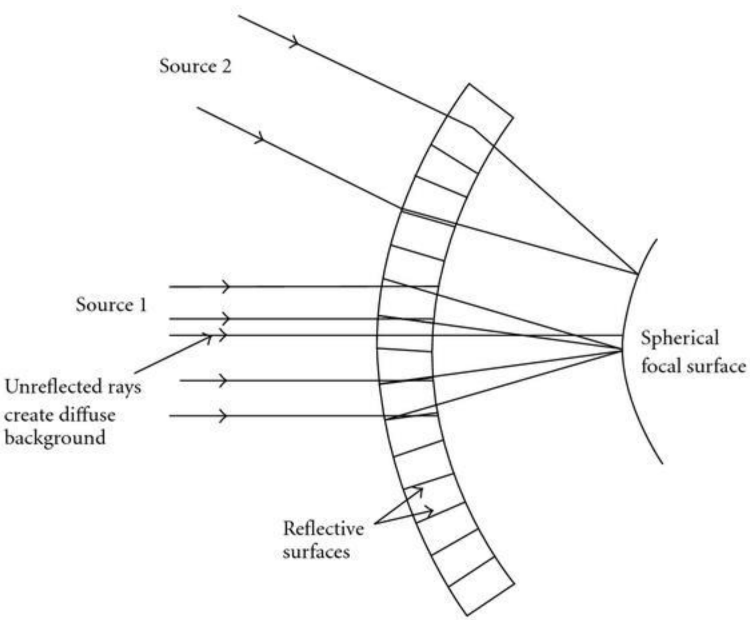
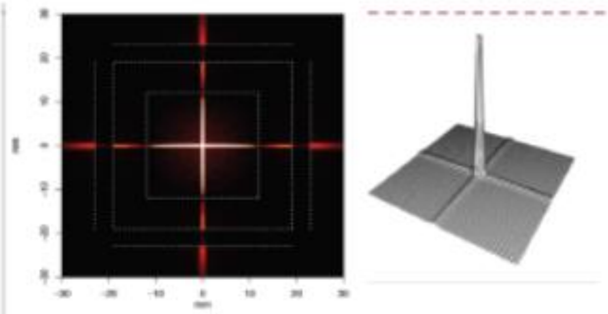


Table 4 : : SXI detector unit main physical characteristics

Energy band (keV)	0.3-5
Telescope type:	Lobster eye
Optics aperture (mm2)	320x320
Optics configuration	8x8 square pore MCPs
MCP size (mm2)	40x40
Focal length (mm)	300
Focal plane shape	spherical
Focal plane detectors	CCD array
Size of each CCD (mm2)	81.2x67.7
Pixel size (µm)	18
Pixel Number	4510 x 3758 per CCD
Number of CCDs	4
Field of View (square deg)	~1sr
Angular accuracy (best, worst) (arcsec)	(<10, 105)
Power [W]	27,8
Mass [kg]	40

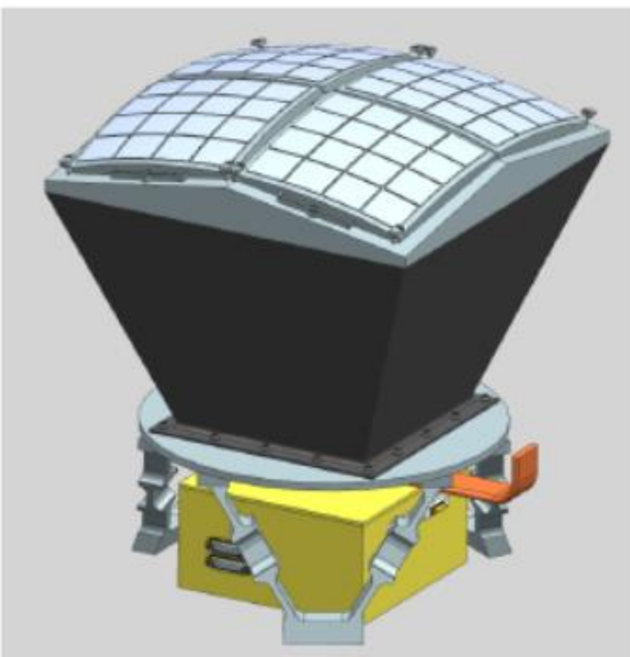
THESEUS SXI



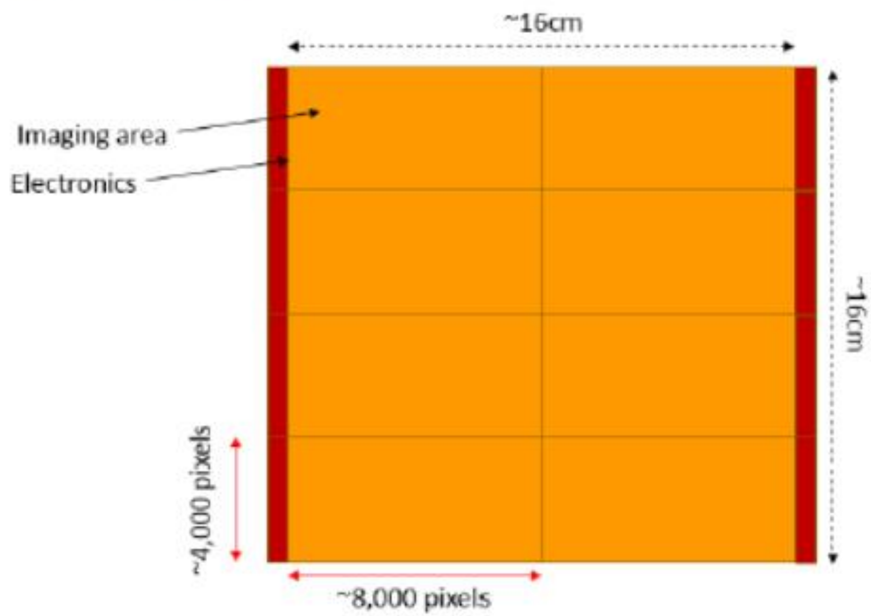
4 identical modules observing in 0.3-5 keV band

Module FoV ~31 x 31 degree
(~1 sr total: ~61 x 61 degree)

Each module uses 64 MPOs and 8 large format CMOS detectors

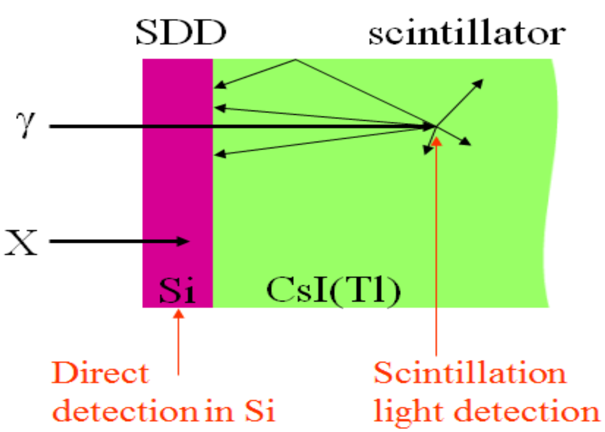


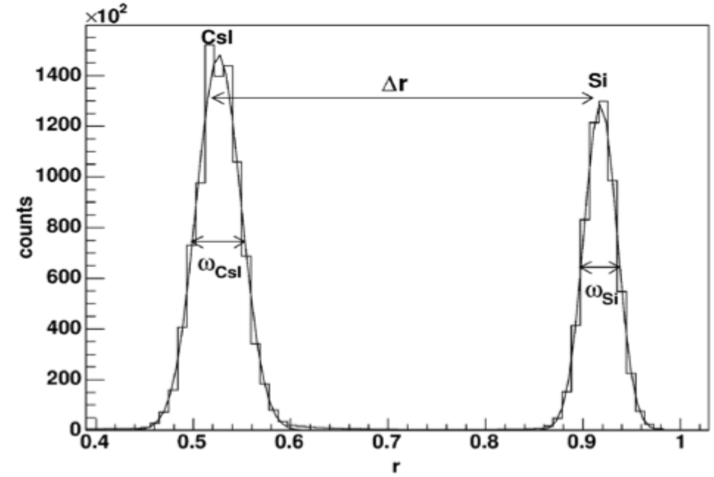
Single optics frame illuminates a curved focal plane

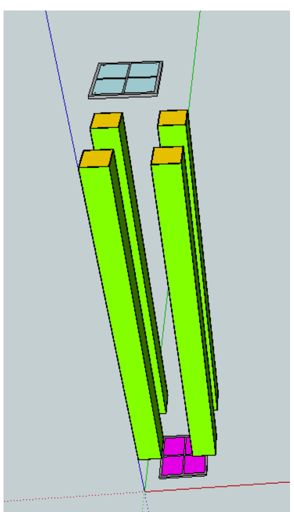


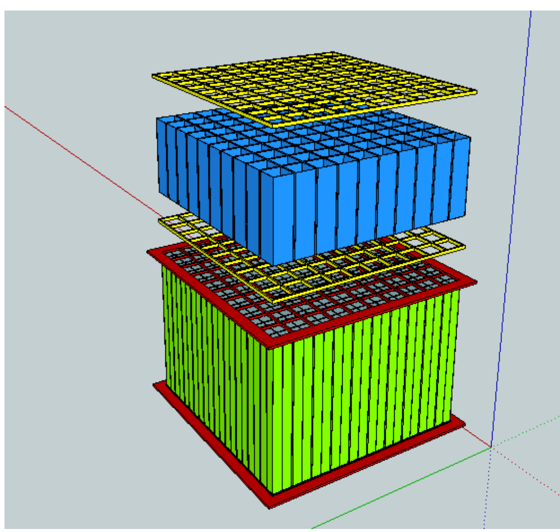
Phase A work to increase pixel size (10->40 microns to reduce to 2k x 1k pixels per CMOS)

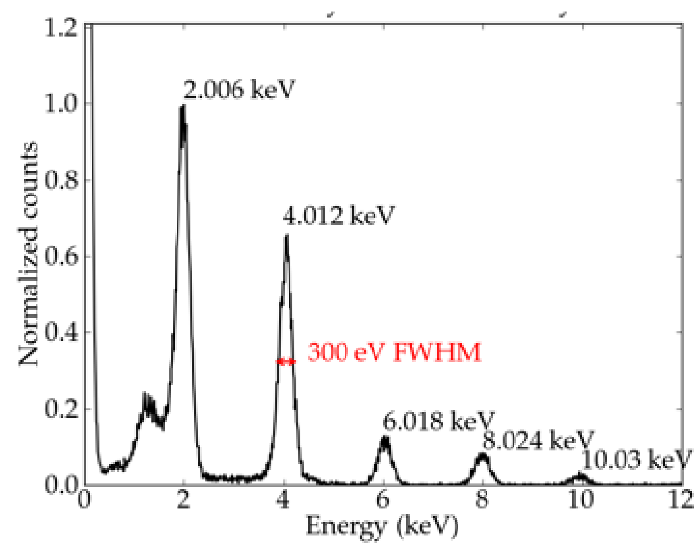
The X-Gamma-ray imaging spectrometer (led by Italy)

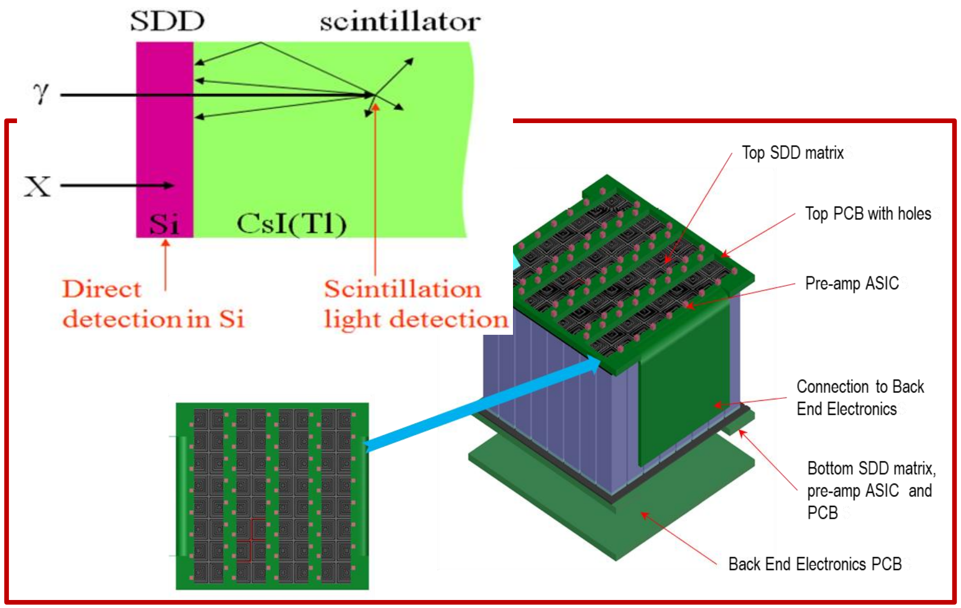


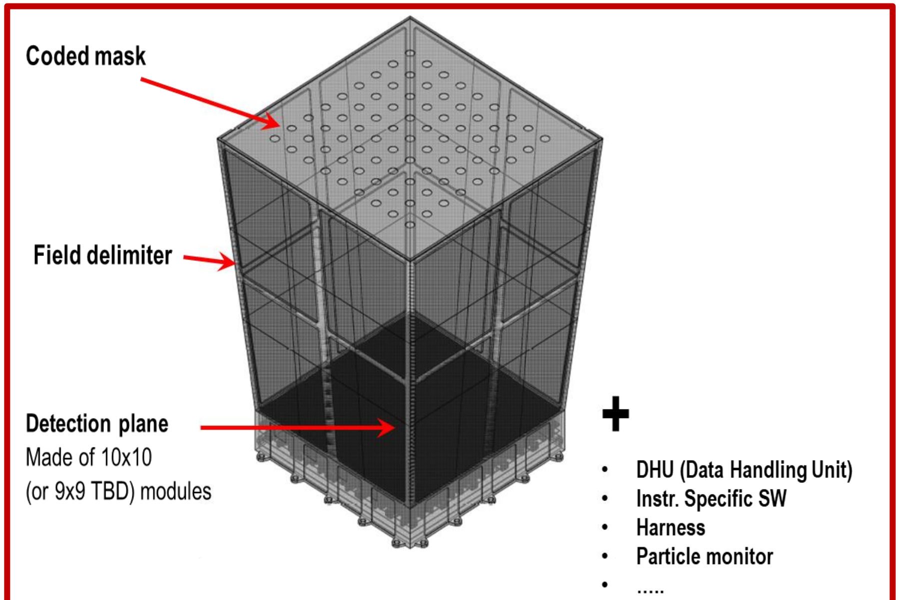






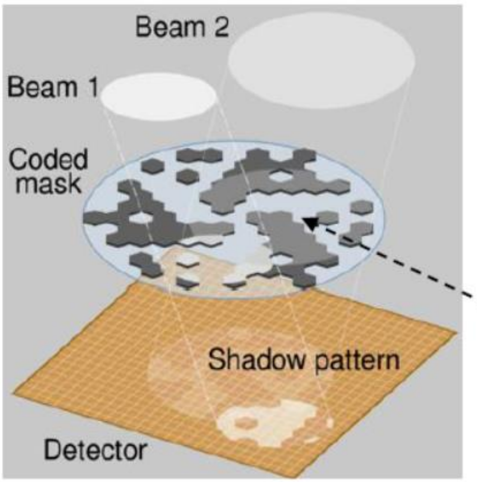




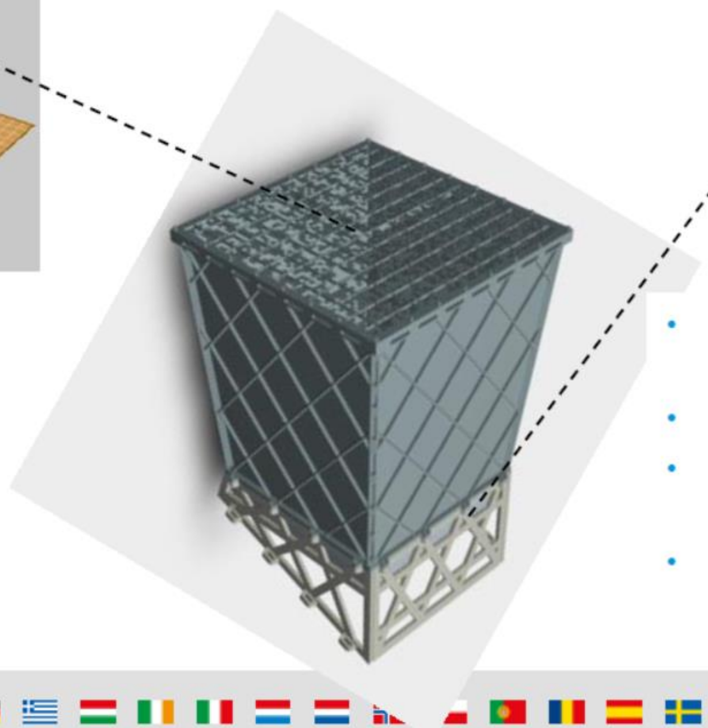


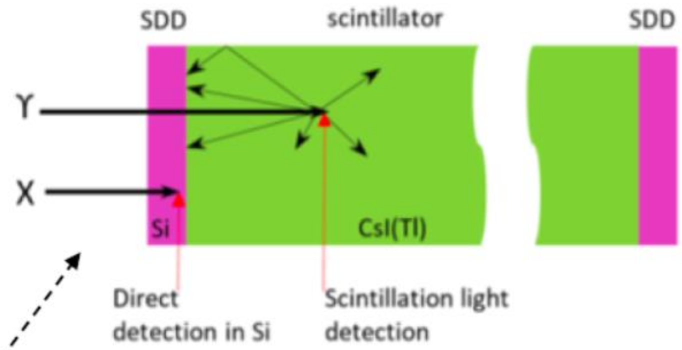
- *Siswich* detector (SDD+CsI:Tl scintillator): large sensitivity band, from 2 keV up to 10–20 MeV
- Coded-mask imaging up to 150 keV
- Modular detection plane: 10×10 modules, 6400 pixels. Each pixel consists in a 4.5×4.5×30 mm CsI:Tl scintillator bar, read at both ends by a SDD cell → 3D event reconstruction
- 2 units, offset of 20°
- Total FoV of 77°×118° (overlapping SXI FoV of 51°×61°)

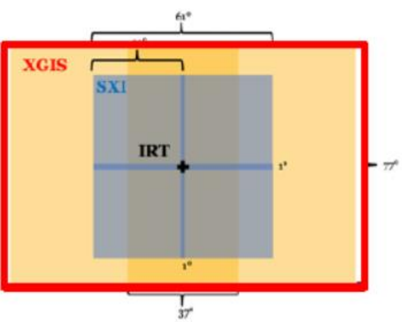
XGIS: X- and Gamma Imaging Spectrometer



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



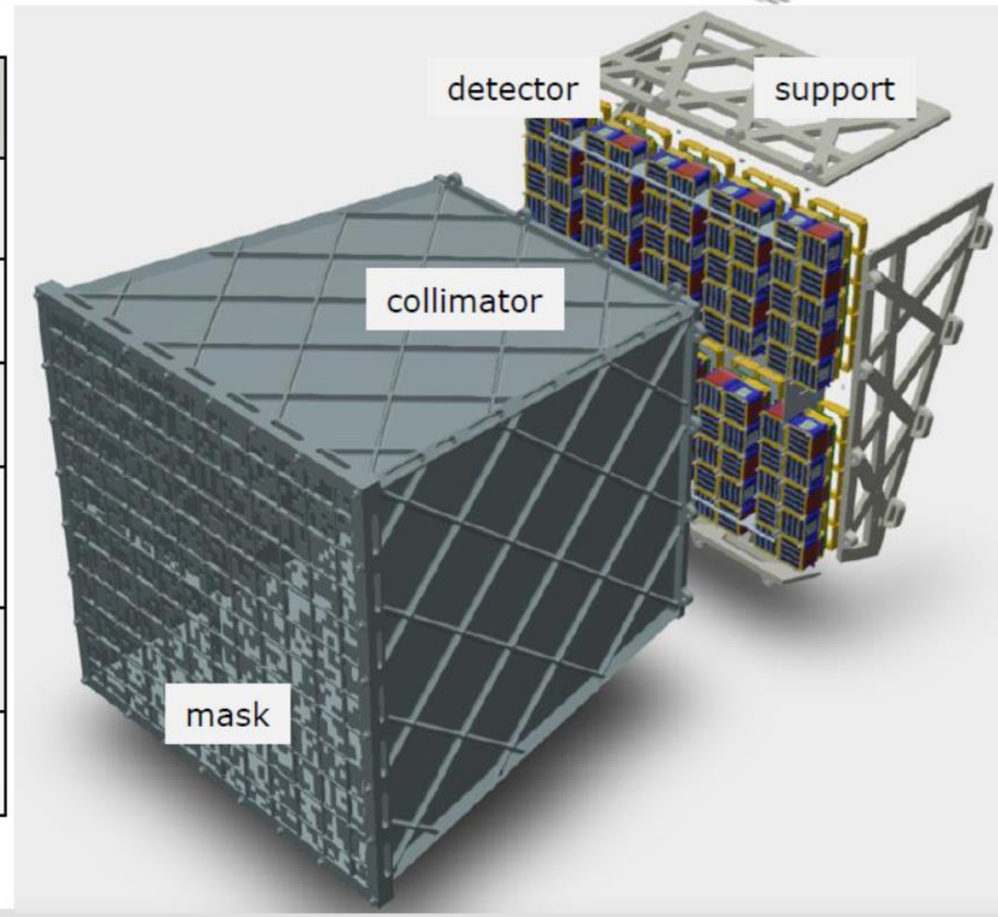




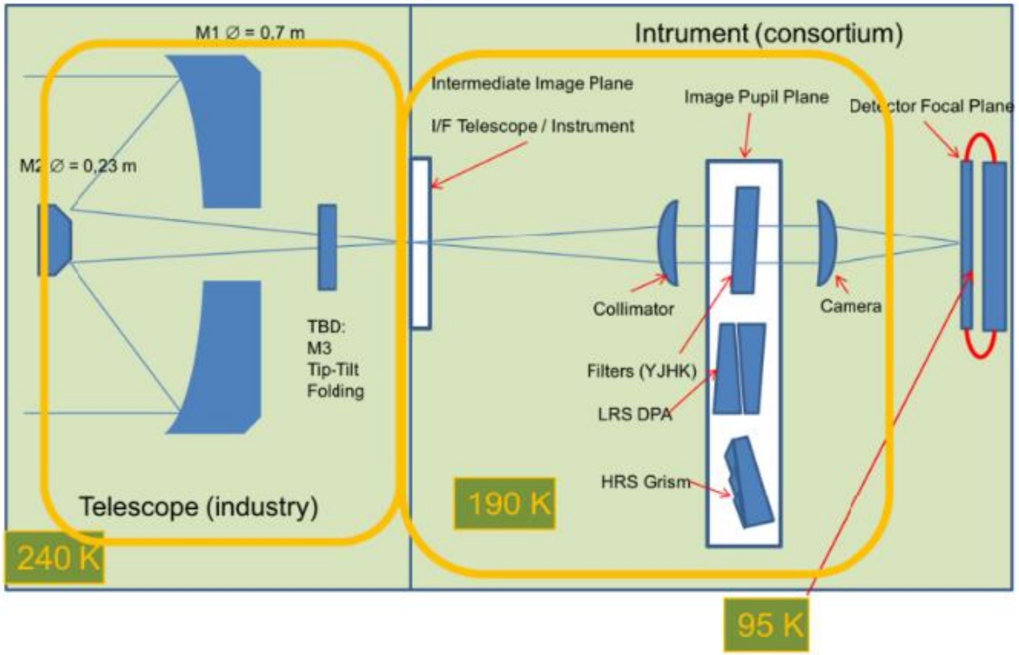
- Coded mask telescopes with scintillator crystal and silicon drift detectors
- 2 keV–10 MeV
- 2 sr imaging FoV: 2 keV-150 keV with <15′ source location accuracy
- 4 sr spectrometer FoV above 150 keV

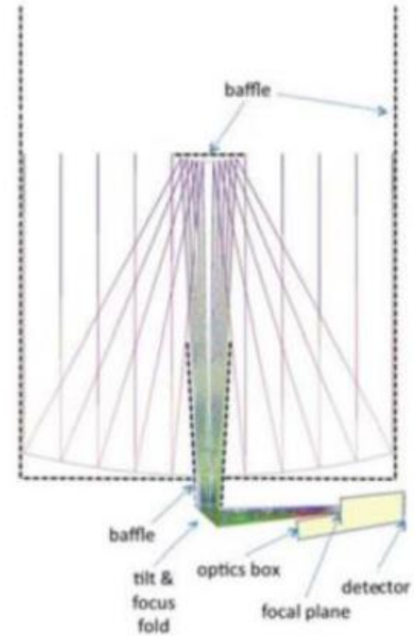
XGIS: key numbers & elements

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	



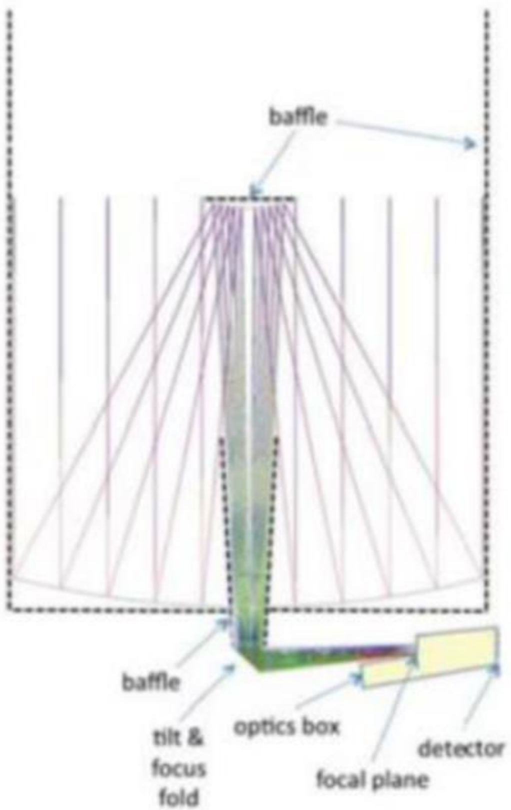
The InfraRed Telescope (IRT) – led by FR

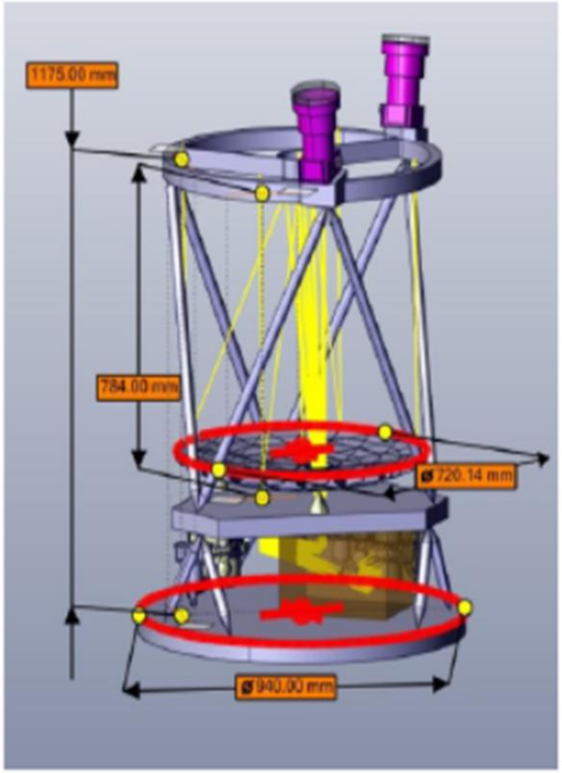




Telescope type:	Cassegrain		
Primary & Secondary size:	700 mm & 230 mm		
Material:	SiC (for both optics and optical tube assembly)		
Detector type:	Teledyne Hawaii-2RG 2048 x 2048 pixels (18 µm each)		
Imaging plate scale	0".3/pixel		
Field of view:	10' x 10'	10' x 10'	5' x 5'
Resolution (λ/Δλ):	2-3 (imaging)	20 (low-res)	500 (high-res), goal 1000
Sensitivity (AB mag):	H = 20.6 (300s)	H = 18.5 (300s)	H = 17.5 (1800s)
Filters:	ZYJH	Prism	VPH grating
Wavelength range (µm):	0.7-1.8 (imaging)	0.7-1.8 (low-res)	0.7-1.8 (high-res, TBC)
Total envelope size (mm):	800 Ø x 1800		
Power (W):	115 (50 W for thermal control)		
Mass (kg):	112.6		

IRT – Telescope ESA Study



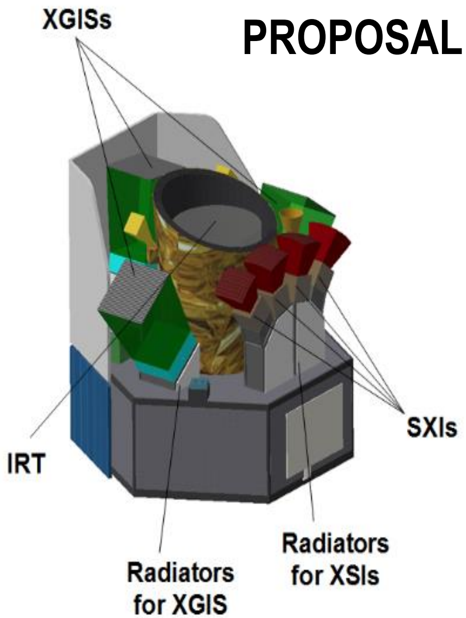


- **Korsch FoV off-axis** telescope
- Telescope mass compatible with Zerodur/CFRP or SiC
- **M2 focus mechanism**
- **Spider** supporting structures for M2 assembly
- **2x** XGIS units
- **Squared** combined FoV for SXI
- **Active** thermal control with **LHP (Propylene)**
- **Coarse** star Trackers

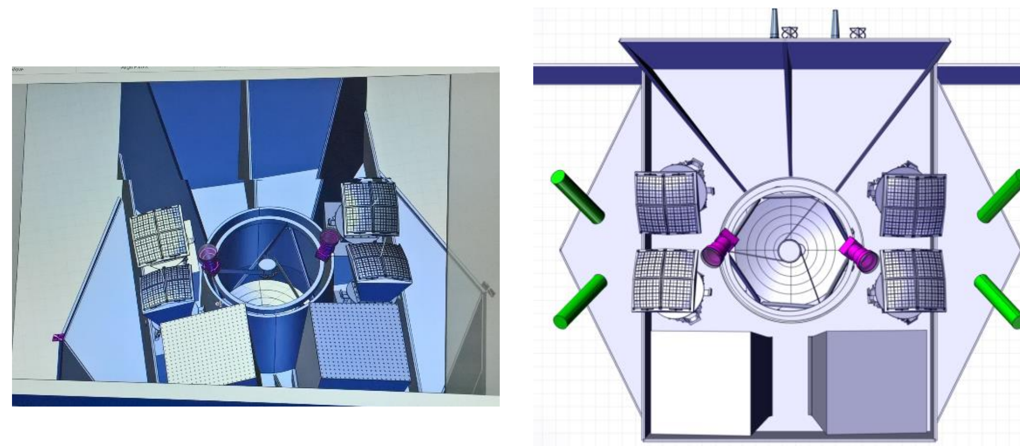
A **Korsch telescope** is corrected for spherical aberration, coma, astigmatism, and field curvature and can have a wide field of view while ensuring that there is little stray light in the focal plane.

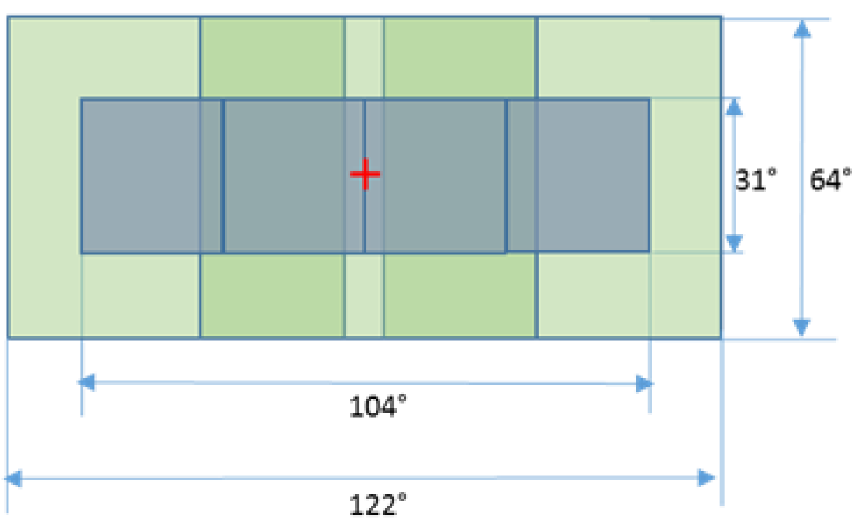
THESEUS mission concept: ESA study

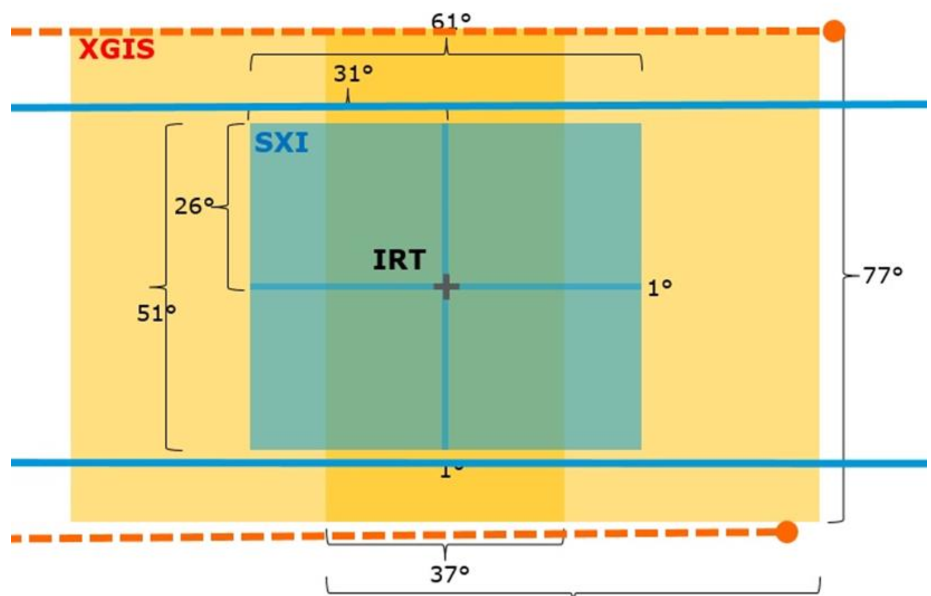
PROPOSAL



CDF STUDY

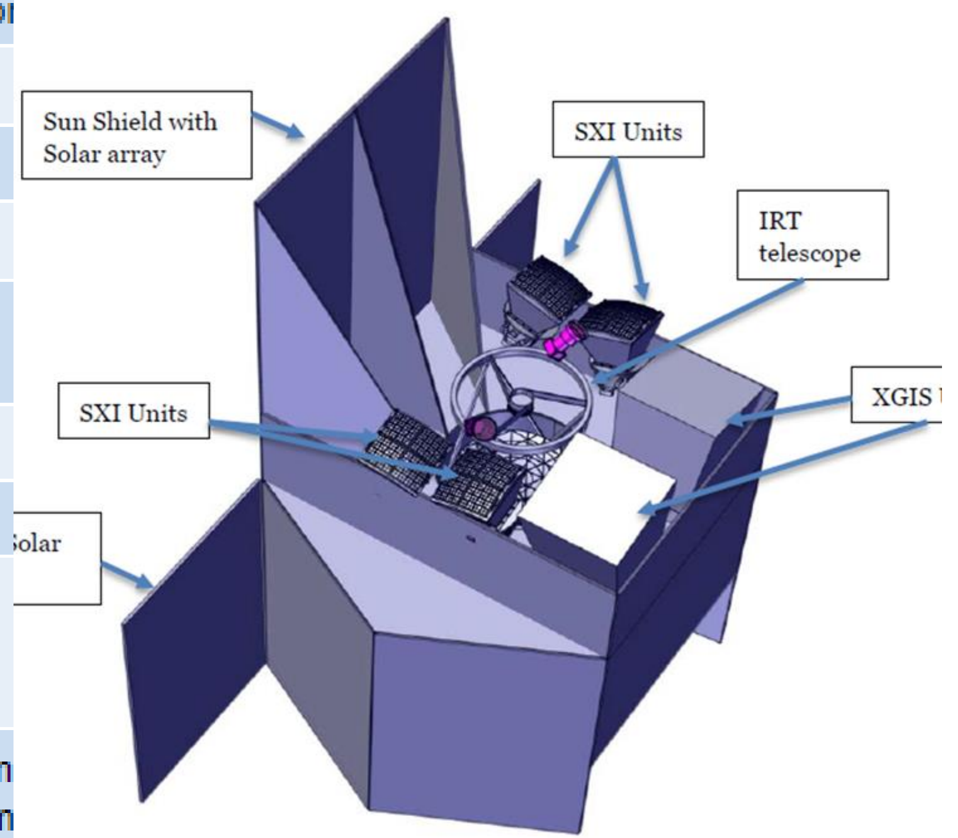






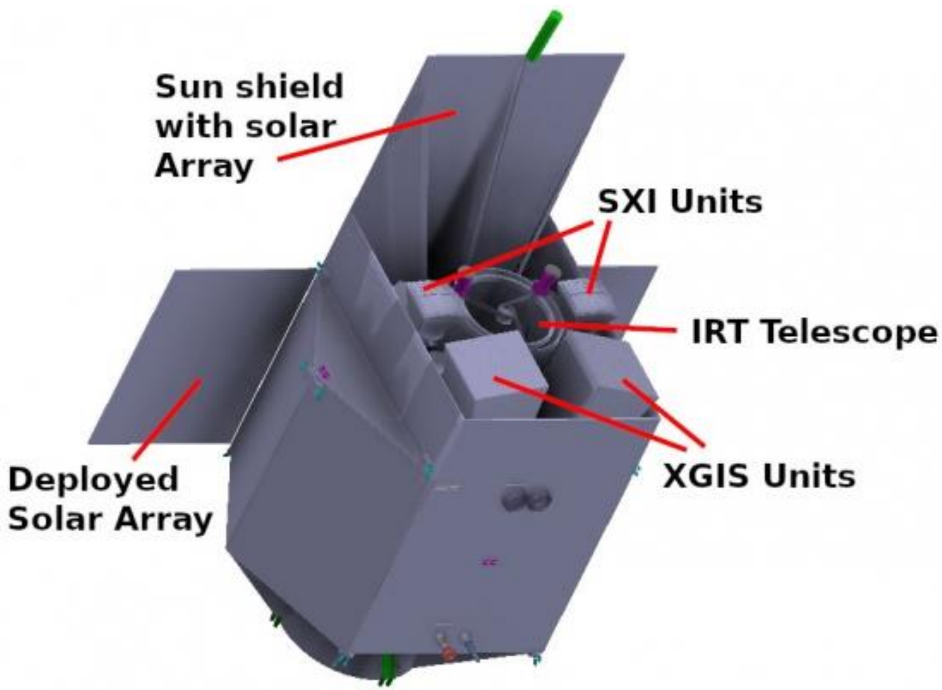
Mission profile and budgets (ESA CDF)

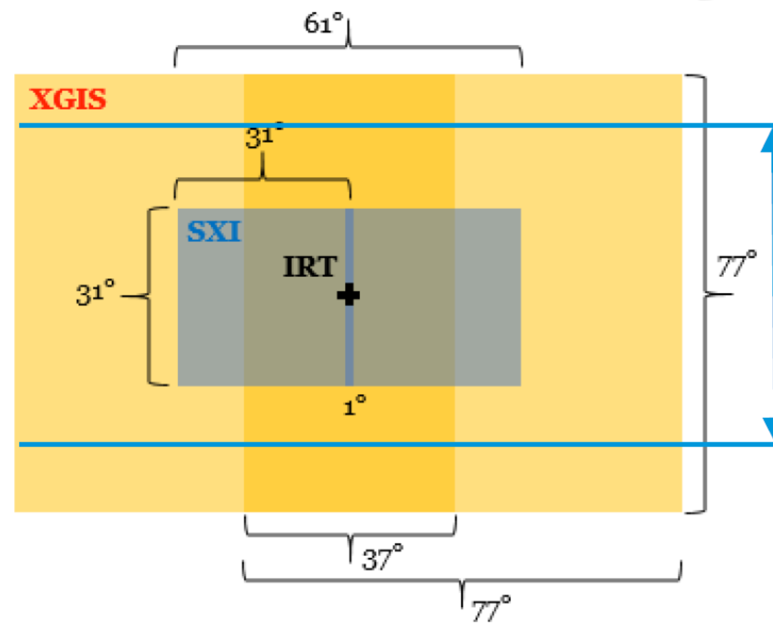
Launch vehicle	VEGA-C (backup Ariane62)
Launch date	2032 (night launch)
Lifetime	Nominal 3 years (consumables fo
Orbit	Circular LEO
Altitude	600 km
Inclination	5.4°
Ground stations	Malindi (backup Kourou) VHF SVOM network
Delta-V	225.8 m/s
Re-entry	Controlled re-entry (4 burns)
Mass	Dry mass w/ margin 1504 kg Wet mass 1702 kg Total (wet + adapter) 1697 kg
Dimensions	Launch conf.: 4.23 m x 3.02 m Deployed conf.: 4.23 m x 4.40 m
Payload	1x InfraRed Telescope (IRT) 2x X-Gamma-rays Imaging Spect 4x Soft X-ray Imager (SXI) 2x Radiation monitors



THESEUS mission concept: ESA study

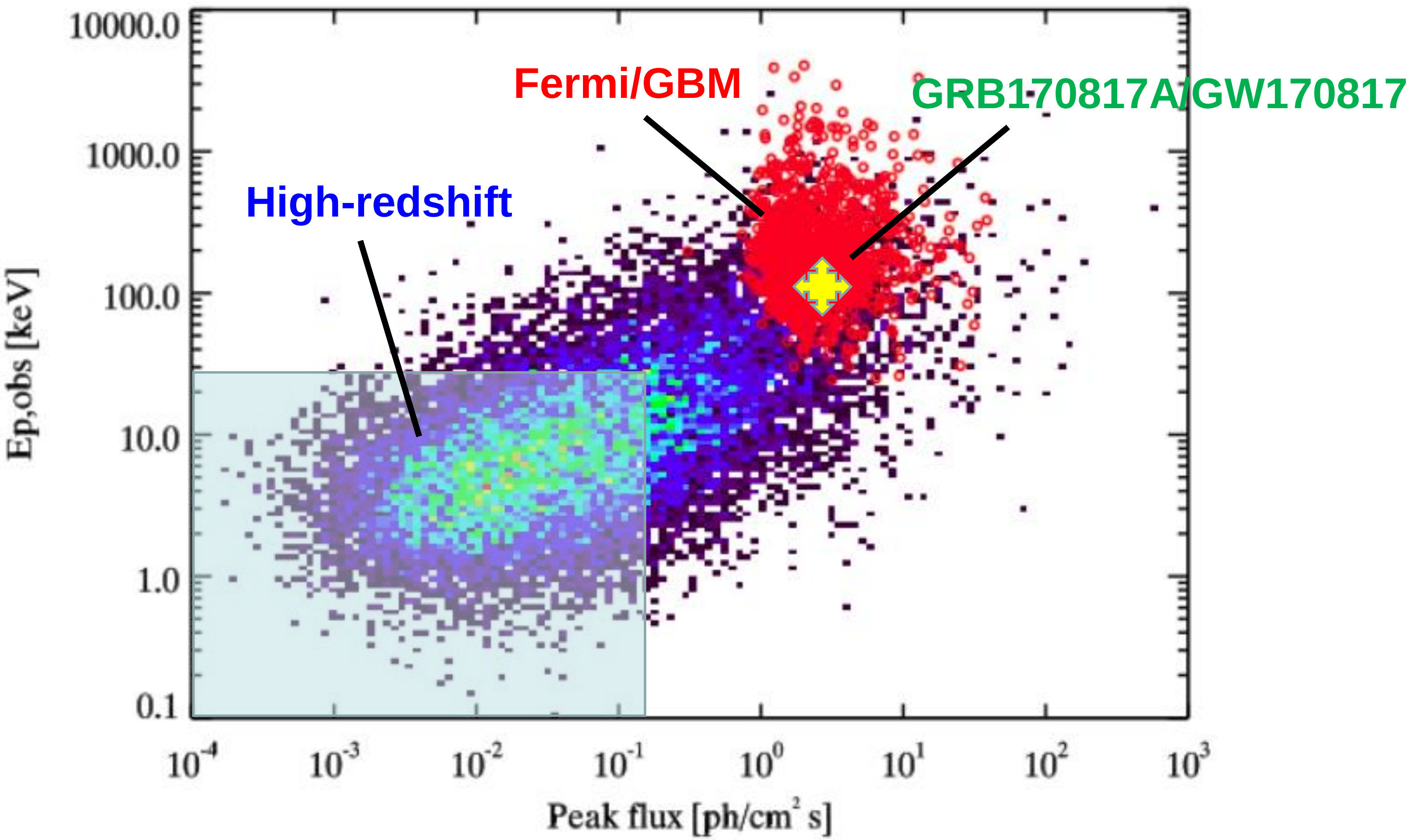
Mission Consolidation Review



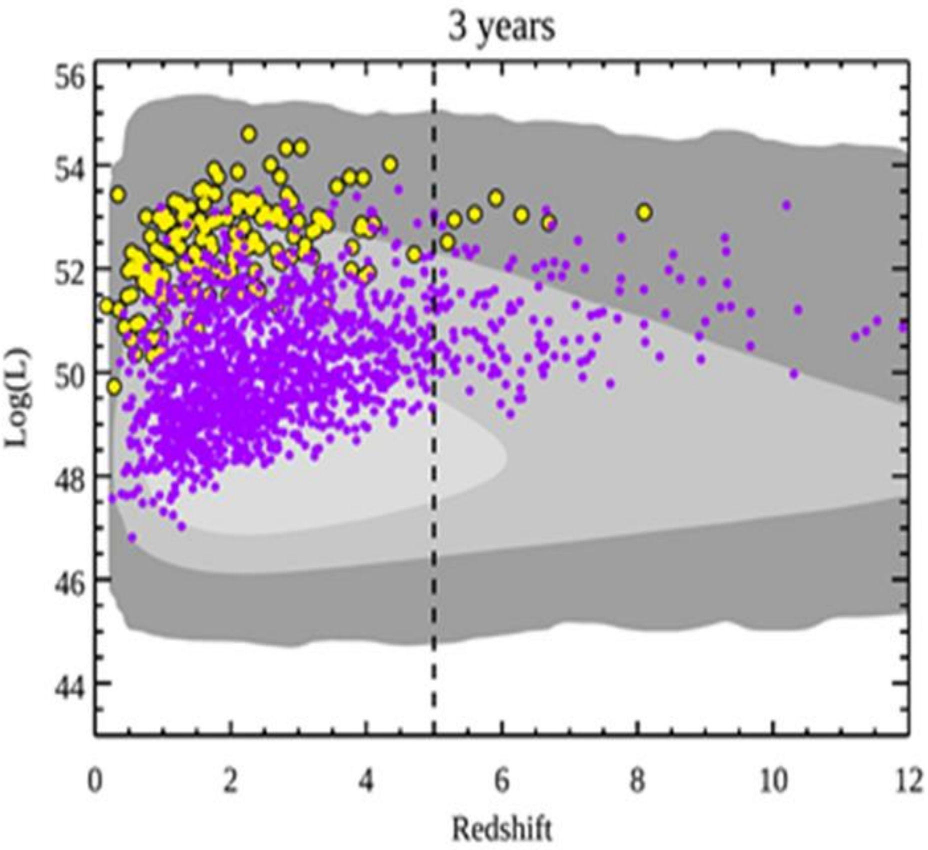


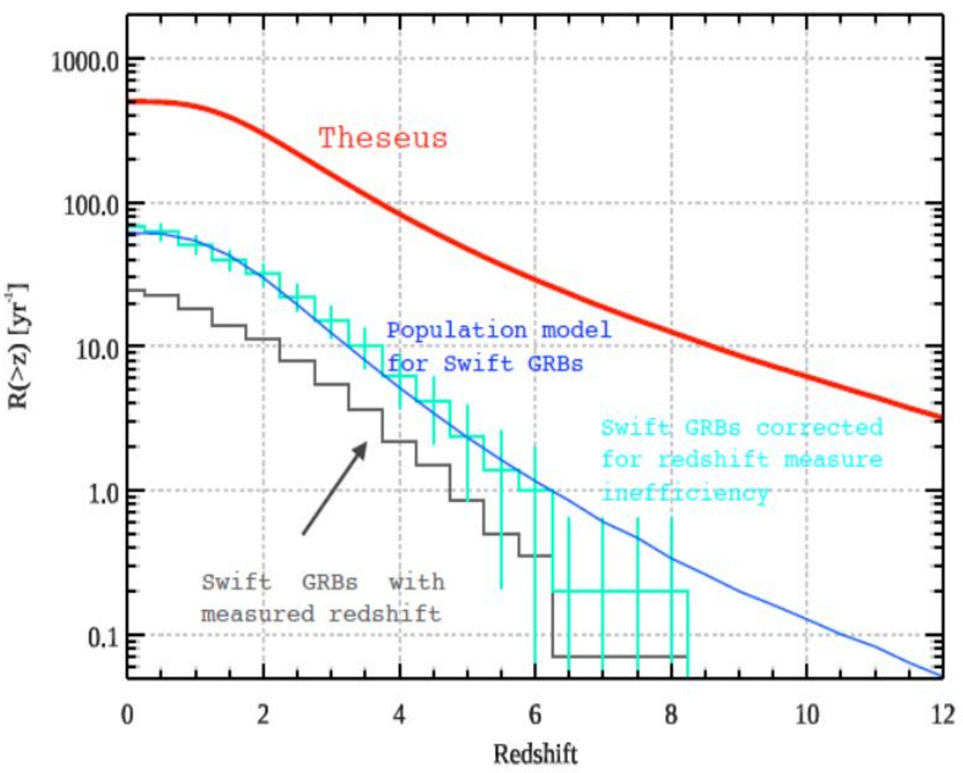
- **Nominal mission duration extended to from 3 to 4 years**
- **Much more robust and lower risk** (i.e., much better shape for final Mission Selection Review) mission profile, with minor impact on expected science

❑ **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**



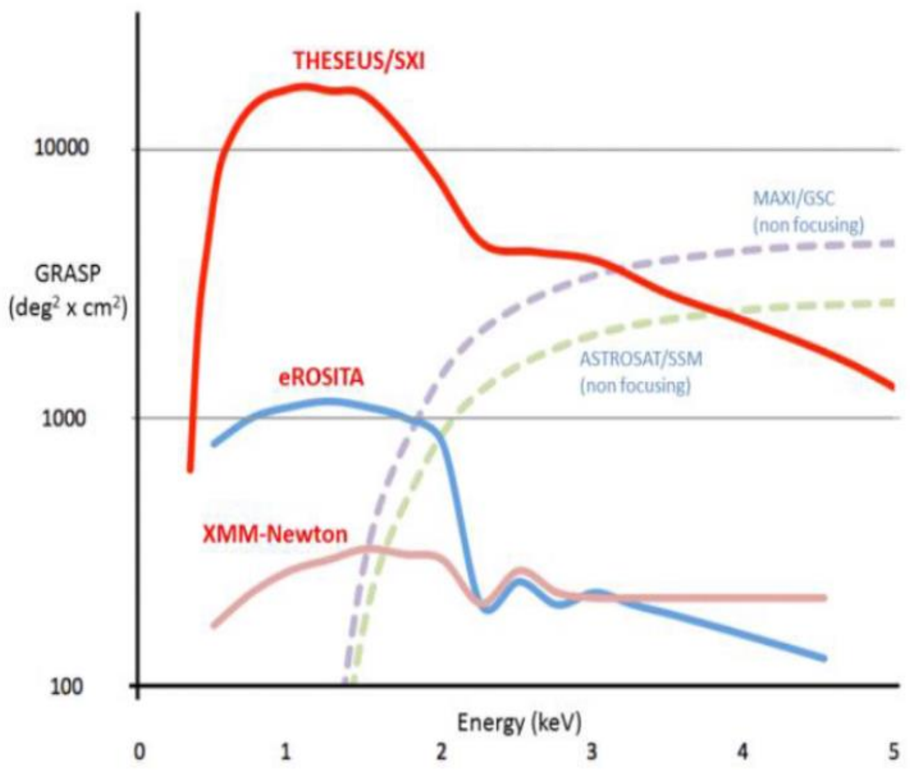
❑ Shedding light on the early Universe with GRBs

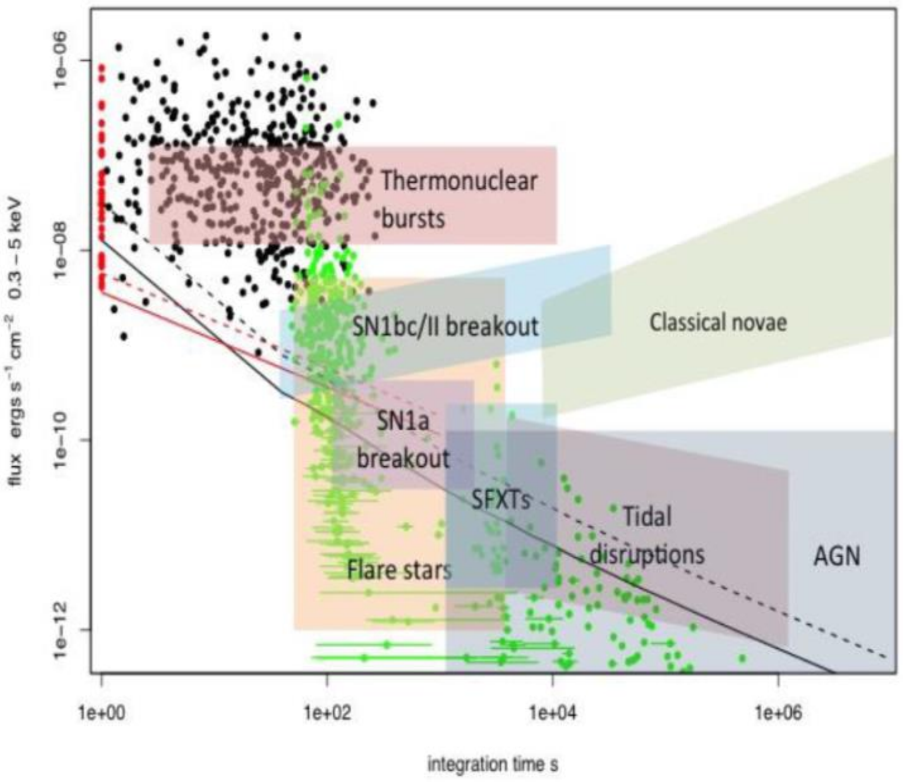




❑ **THESEUS will also detect and localize down to 0.5-1 arcmin the soft X-ray short/long GRB afterglows, of NS-NS mergers and of many classes of galactic and extra-galactic transients**

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

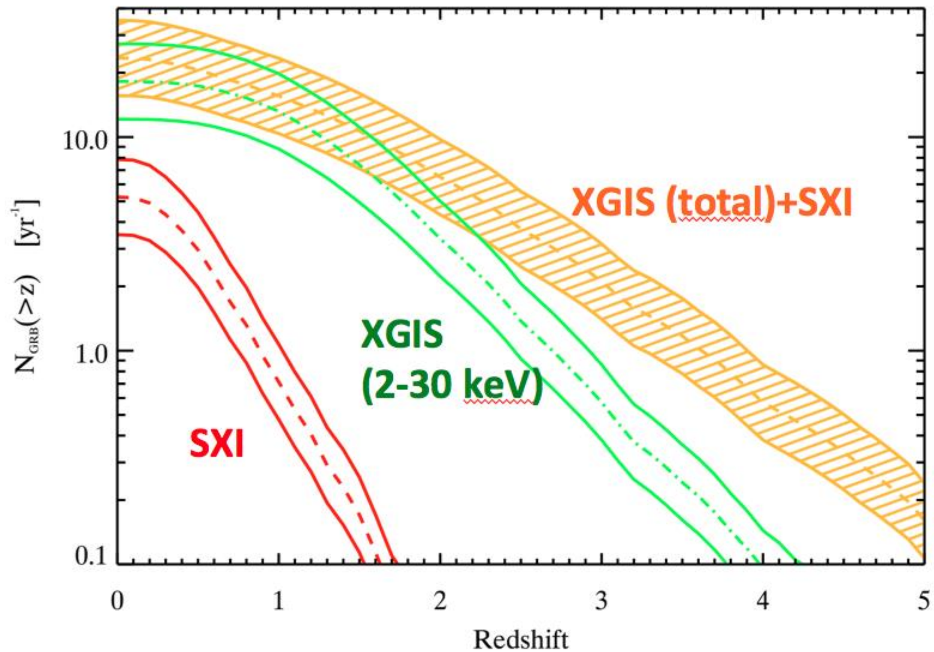


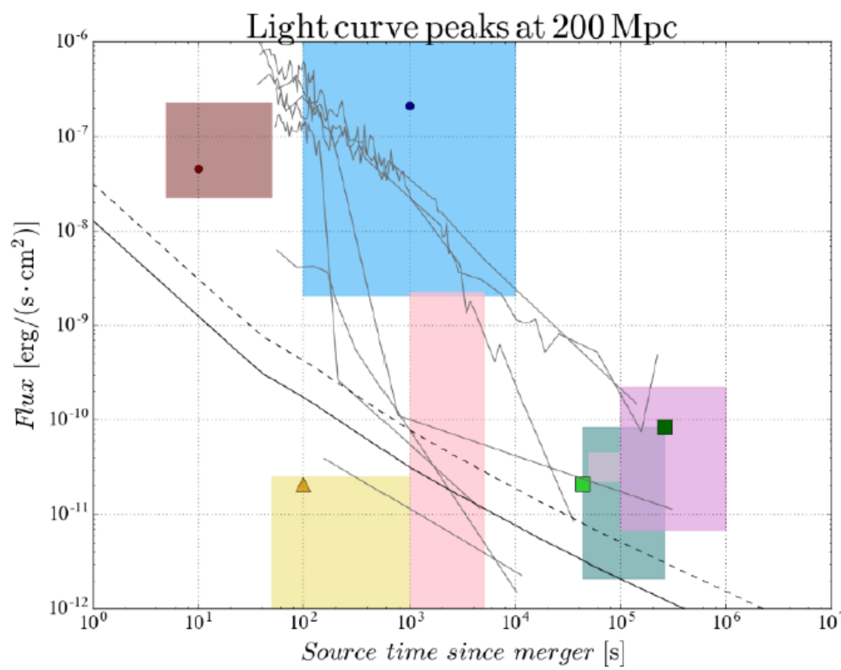


❑ GW/multi-messenger and time-domain astrophysics

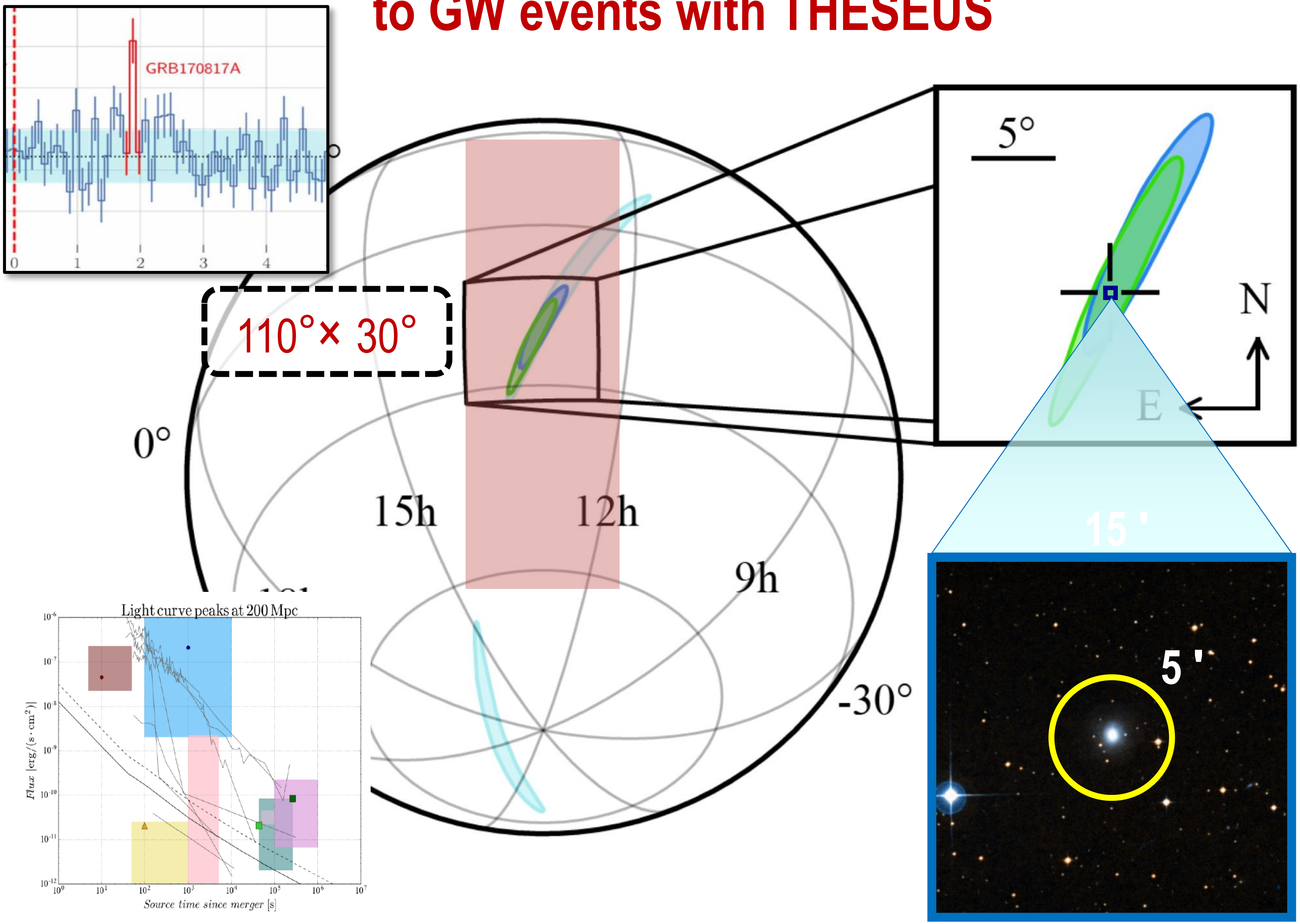
GW transient sources that will be monitored by THESEUS include **NS-NS / NS-BH mergers**:

- ❑ **collimated** on-axis and off-axis prompt gamma-ray emission from short GRBs
- ❑ Optical/NIR and soft X-ray **isotropic** emissions from kilonovae, off-axis afterglows and, for NS-NS, from newly born ms magnetar spindown

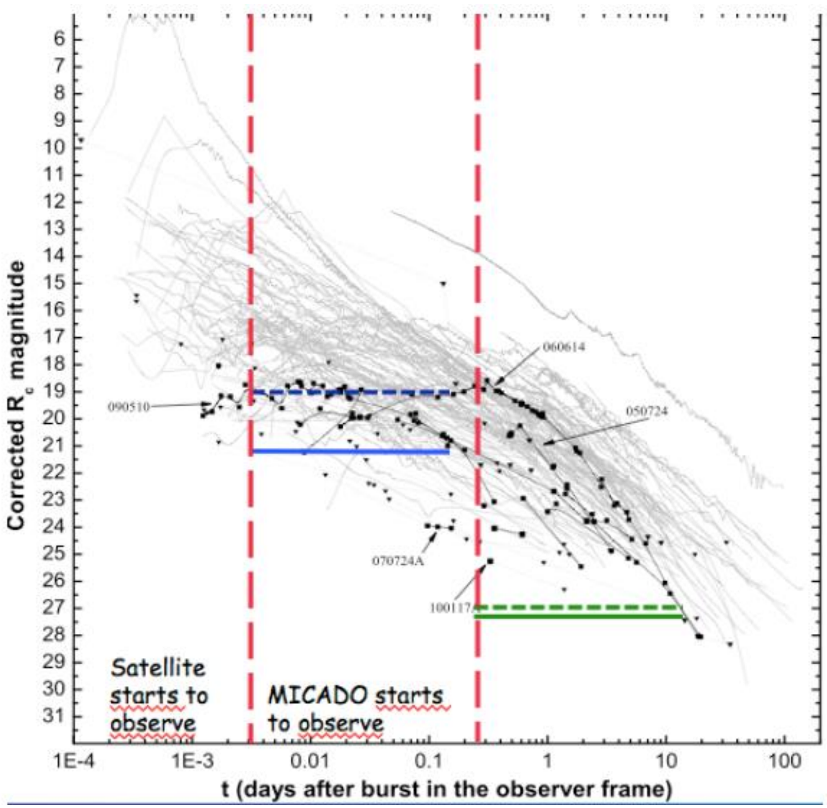


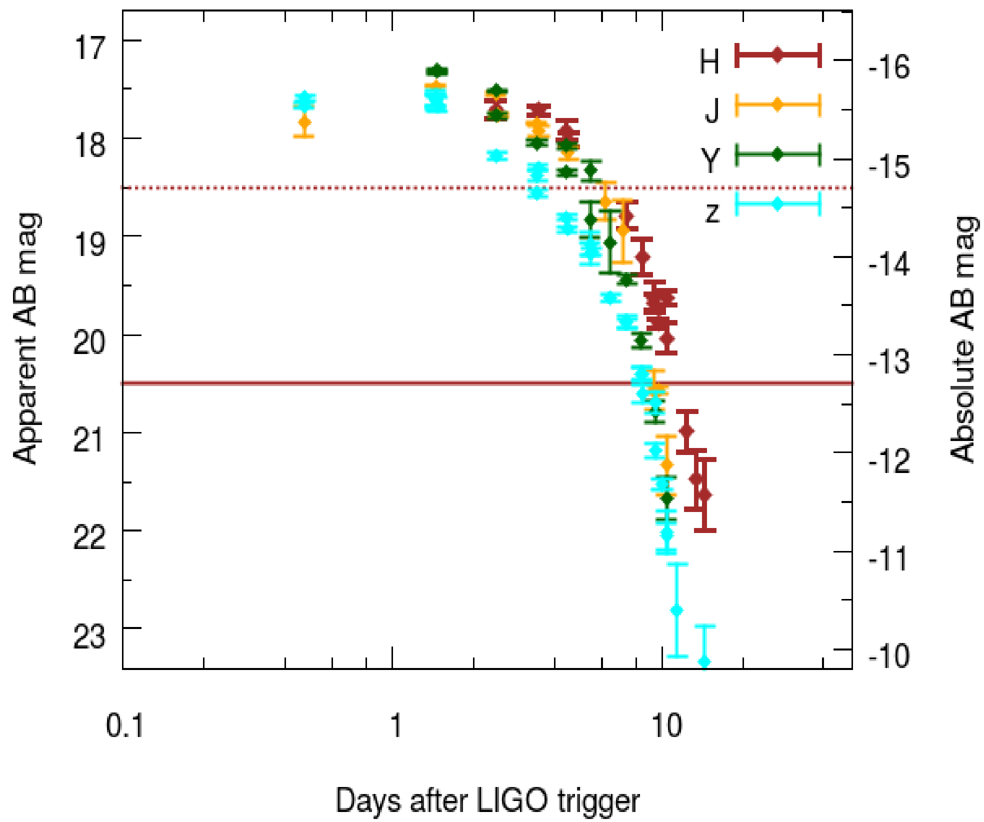


❑ Promptly and accurately localizing e.m. counterparts to GW events with THESEUS



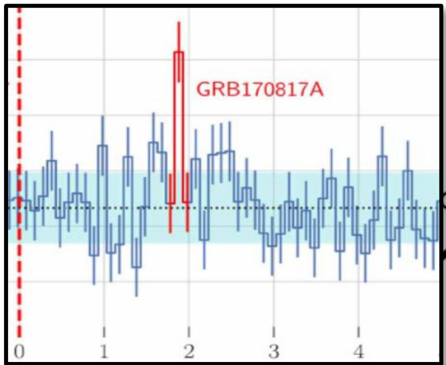
❑ Detection, study and arcsecond localization of afterglow and kilonova emission from shortGRB/GW events with THESEUS/IRT

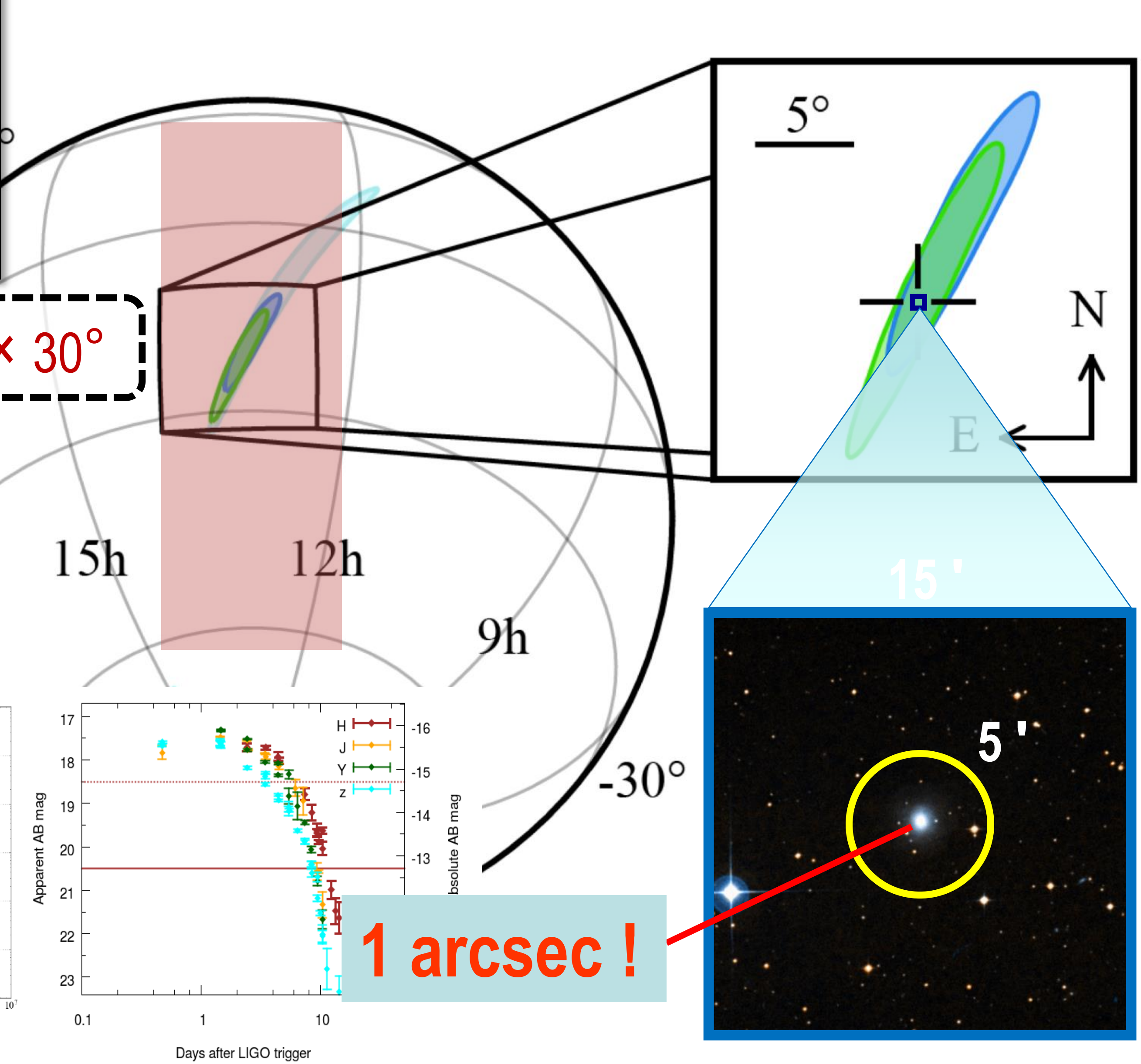




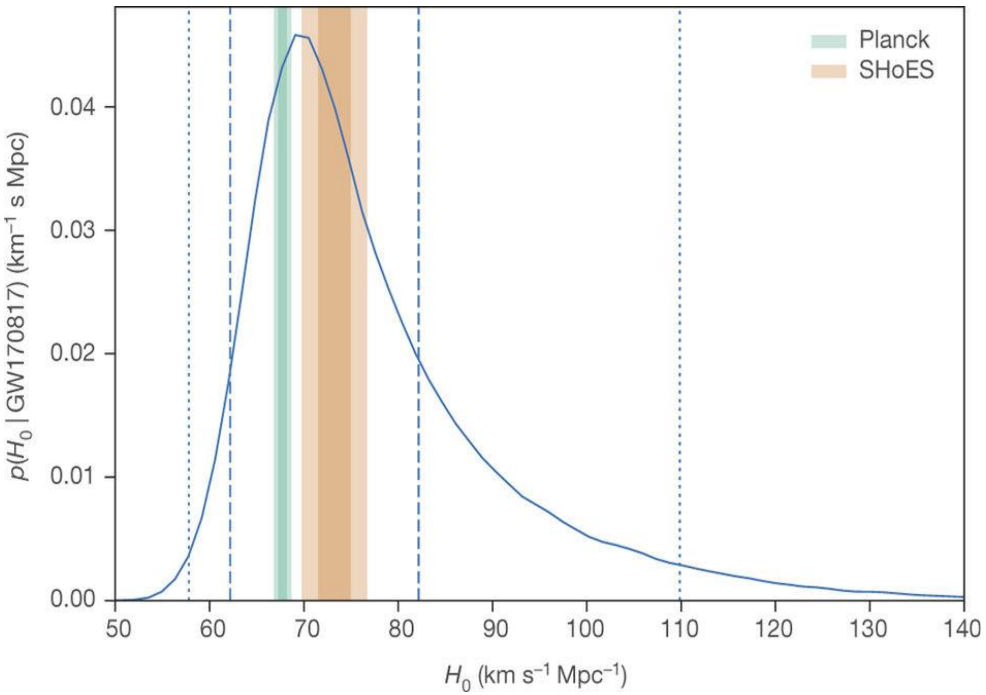
Precise localization is mandatory to activate large ground-based telescopes as VLT or ELT from which detailed spectral analysis will reveal the intrinsic nature of these newly discovered phenomena

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

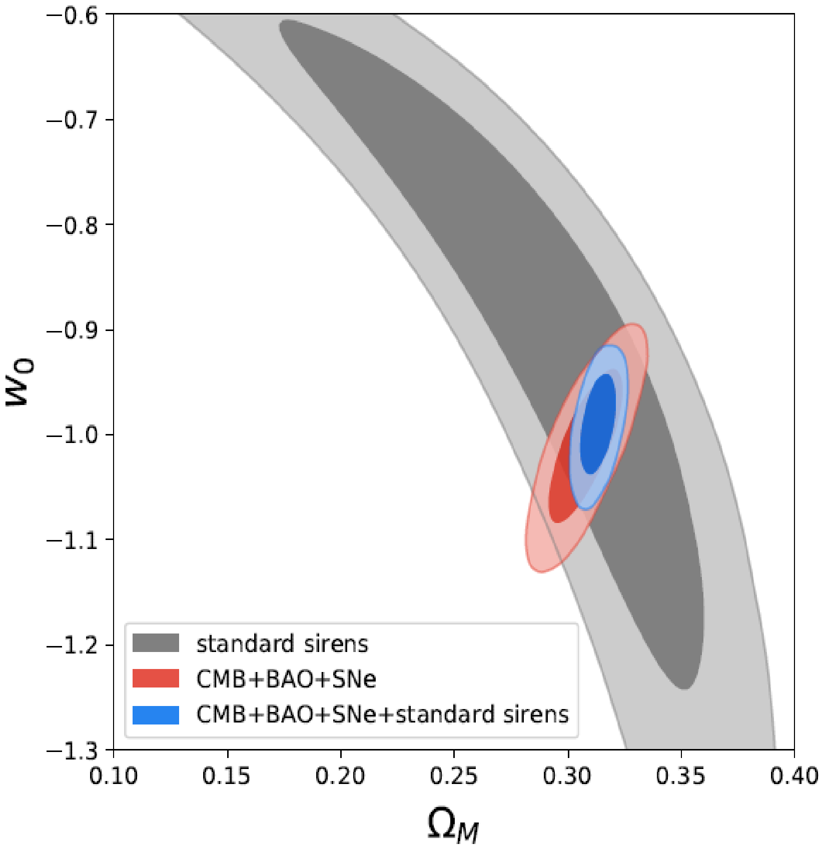




- THESEUS measurements + sinergy with large e.m. facilities -> substantial improvment of redshift estimate for e.m. counterparts of GW sources -> **cosmology**



Estimating H0 with GW170817A (LVC 2017)



Investigating dark energy with a statistical sample of GW + e.m. (Sathyaprakash et al. 2019)

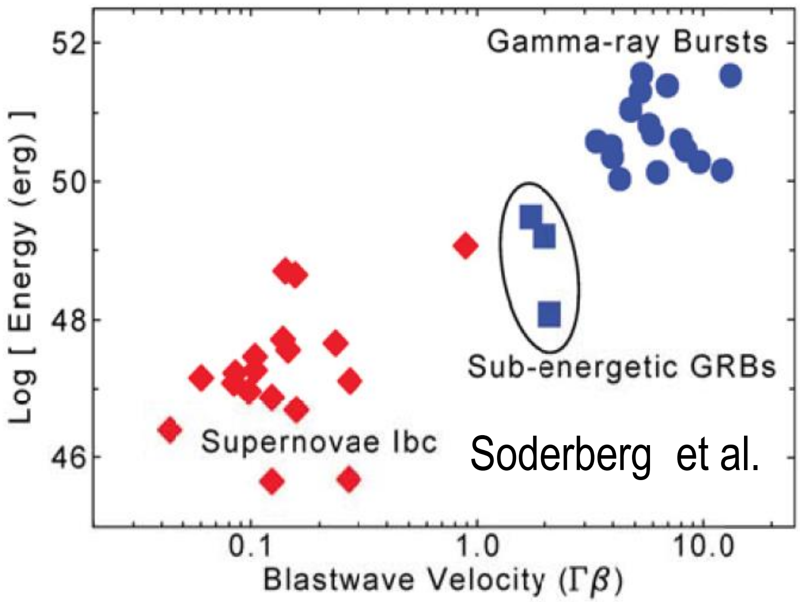
❑ Time-domain astronomy and GRB physics

- survey capabilities of transient phenomena similar to the Large Synoptic Survey Telescope (LSST) in the optical: a remarkable scientific sinergy can be anticipated.

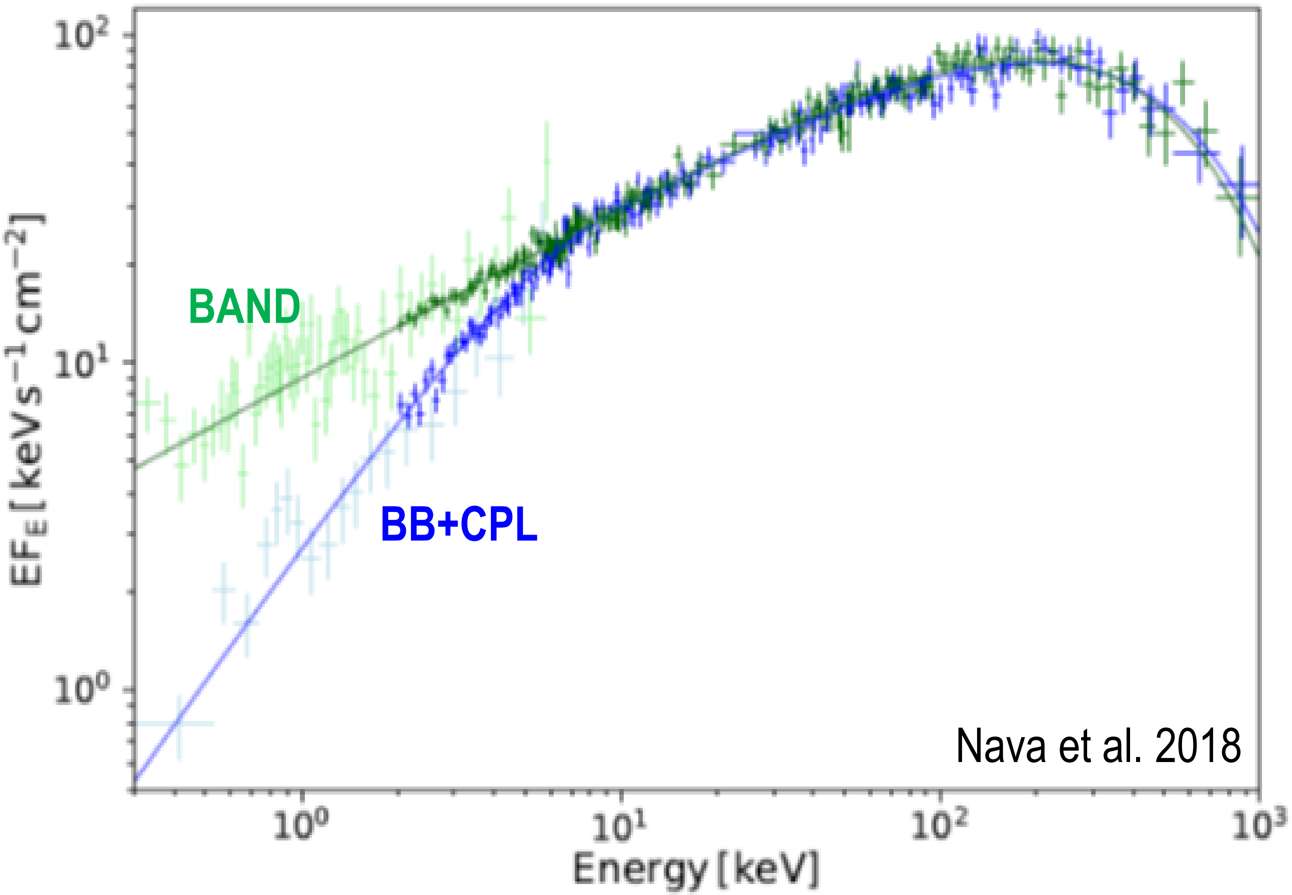
- substantially increased detection rate and characterization of sub-energetic GRBs and X-Ray Flashes;

- unprecedented insights in the physics and progenitors of GRBs and their connection with peculiar core-collapse Sne;

Transient type	SXI rate
Magnetars	40 day^{-1}
SN shock breakout	4 yr^{-1}
TDE	50 yr^{-1}
AGN+Blazars	350 yr^{-1}
Thermonuclear bursts	35 day^{-1}
Novae	250 yr^{-1}
Dwarf novae	30 day^{-1}
SFXTs	1000 yr^{-1}
Stellar flares	400 yr^{-1}
Stellar super flares	200 yr^{-1}

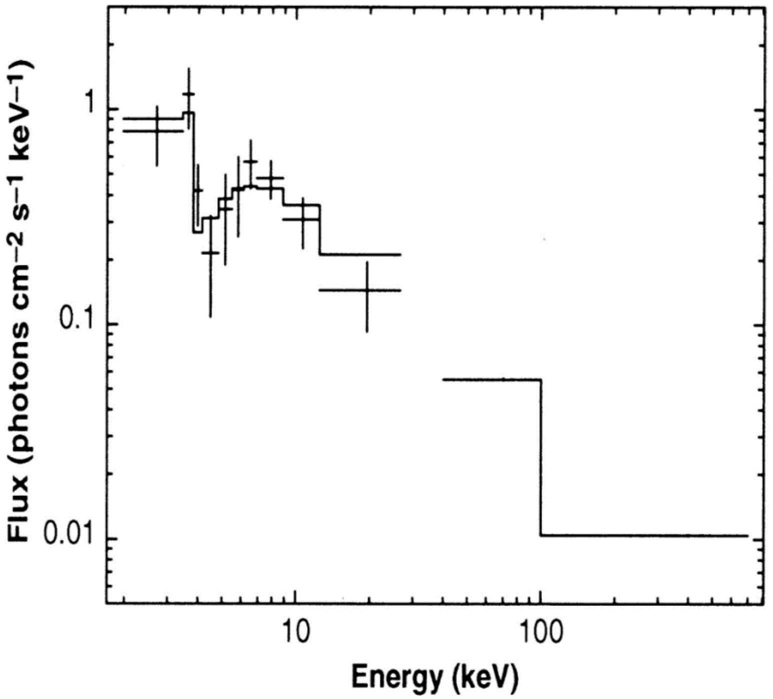


Discriminating GRB prompt emission models through unprecedented SXI+XGIS energy band (0.3 keV – 20 meV)

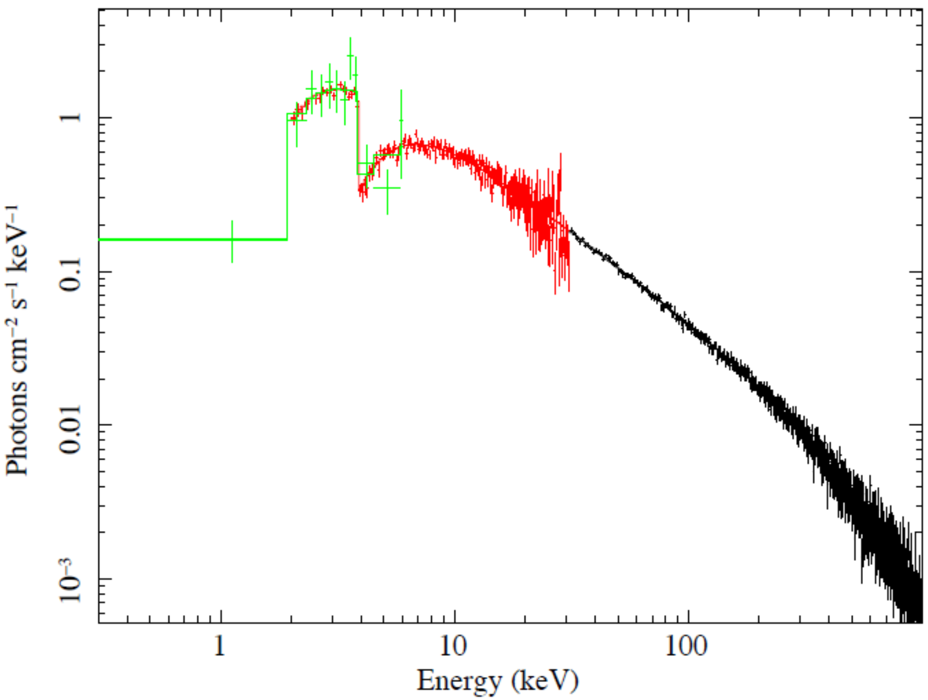


GRB spectrum measured simultaneously over 5 orders of magnitudes in energy!!!

❑ Absorption features: the case of GRB990705 (edge at 3.8 keV -> redshifted neutral iron k-edge -> z = 0.85 -> confirmed by host galaxy spectroscopy: **redshift estimate through X-ray spectroscopy (need energy resolution < ~1 keV in X-rays)**

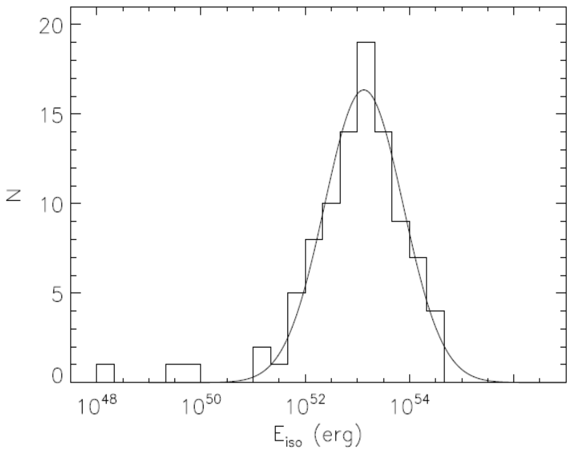


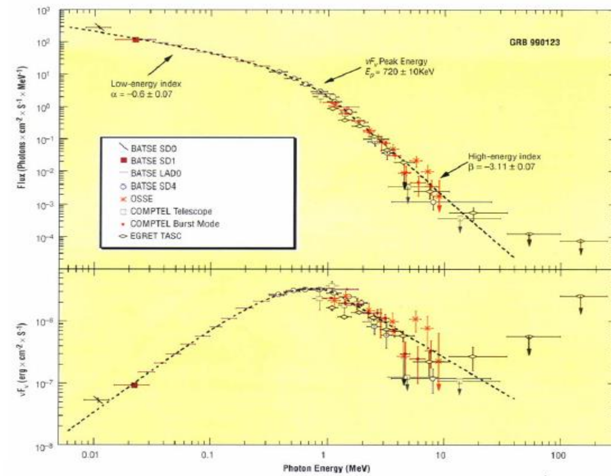
BeppoSAX WFC + GRBM
(Amati et al. 2000)

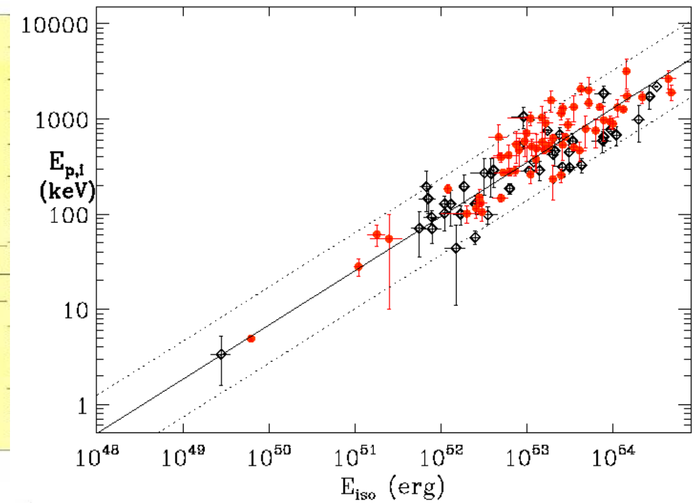


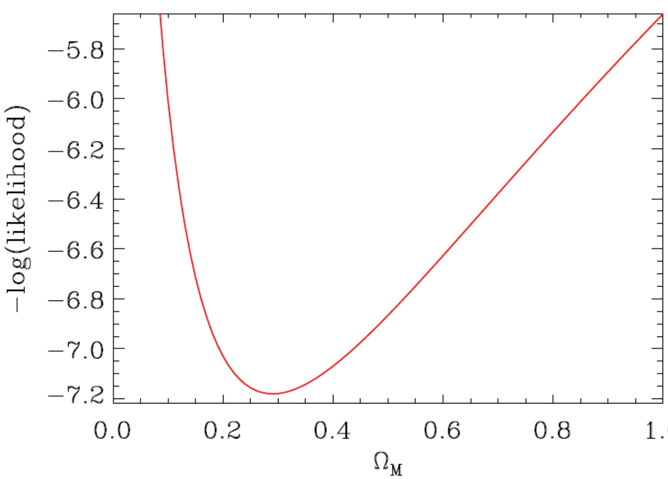
THESEUS SXI + XGIS
(Nava et al. 2018)

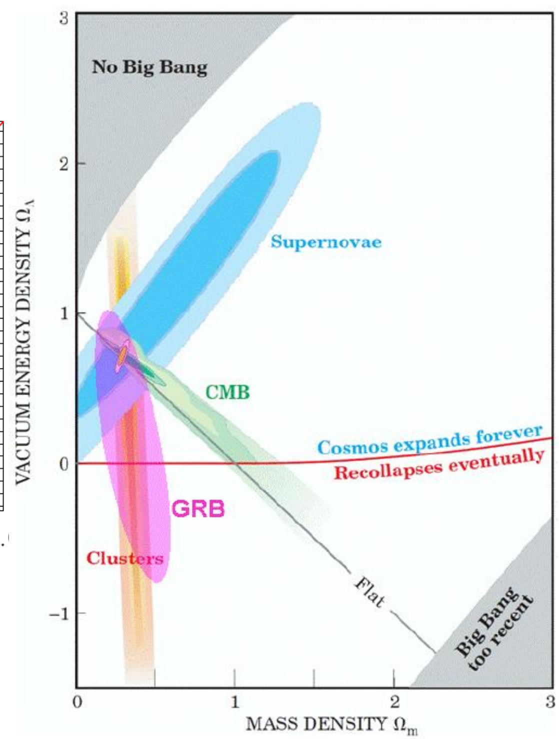
❑ measuring cosmological parameters with GRBs

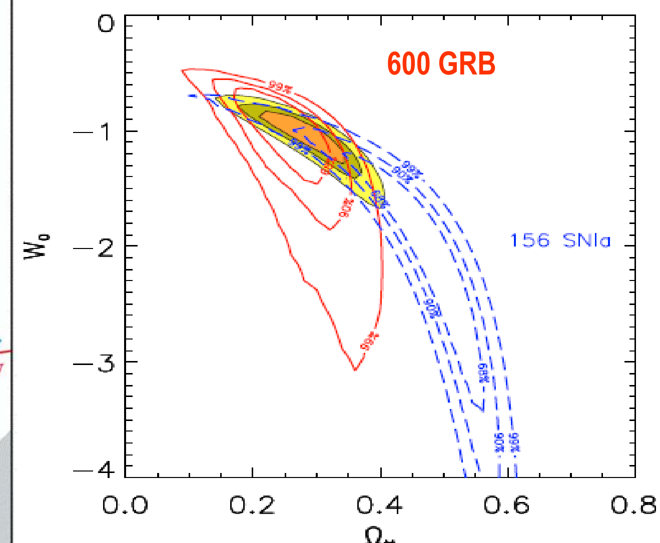




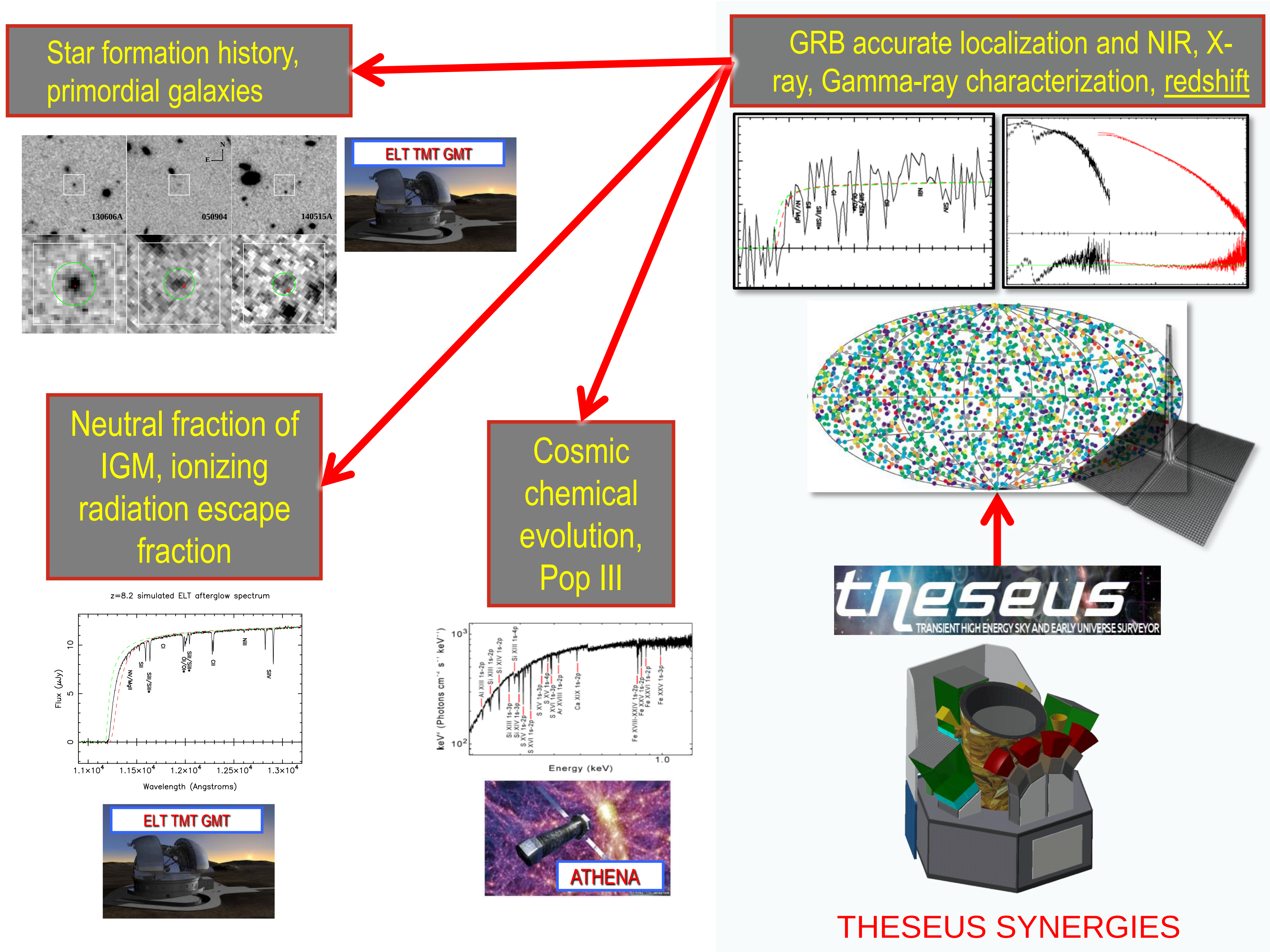




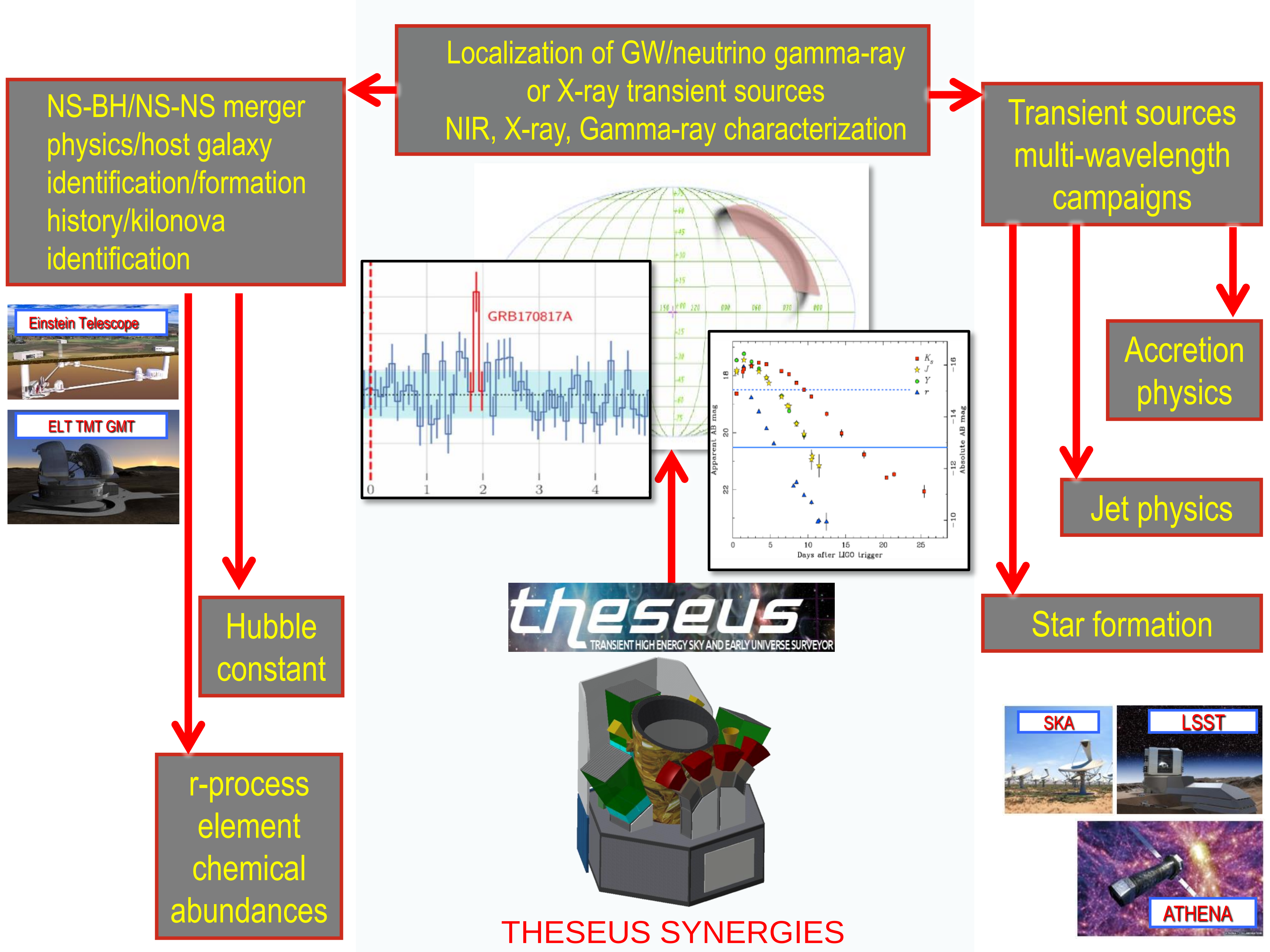




$$w(z) = w_0 + \frac{w_a z}{1+z}$$



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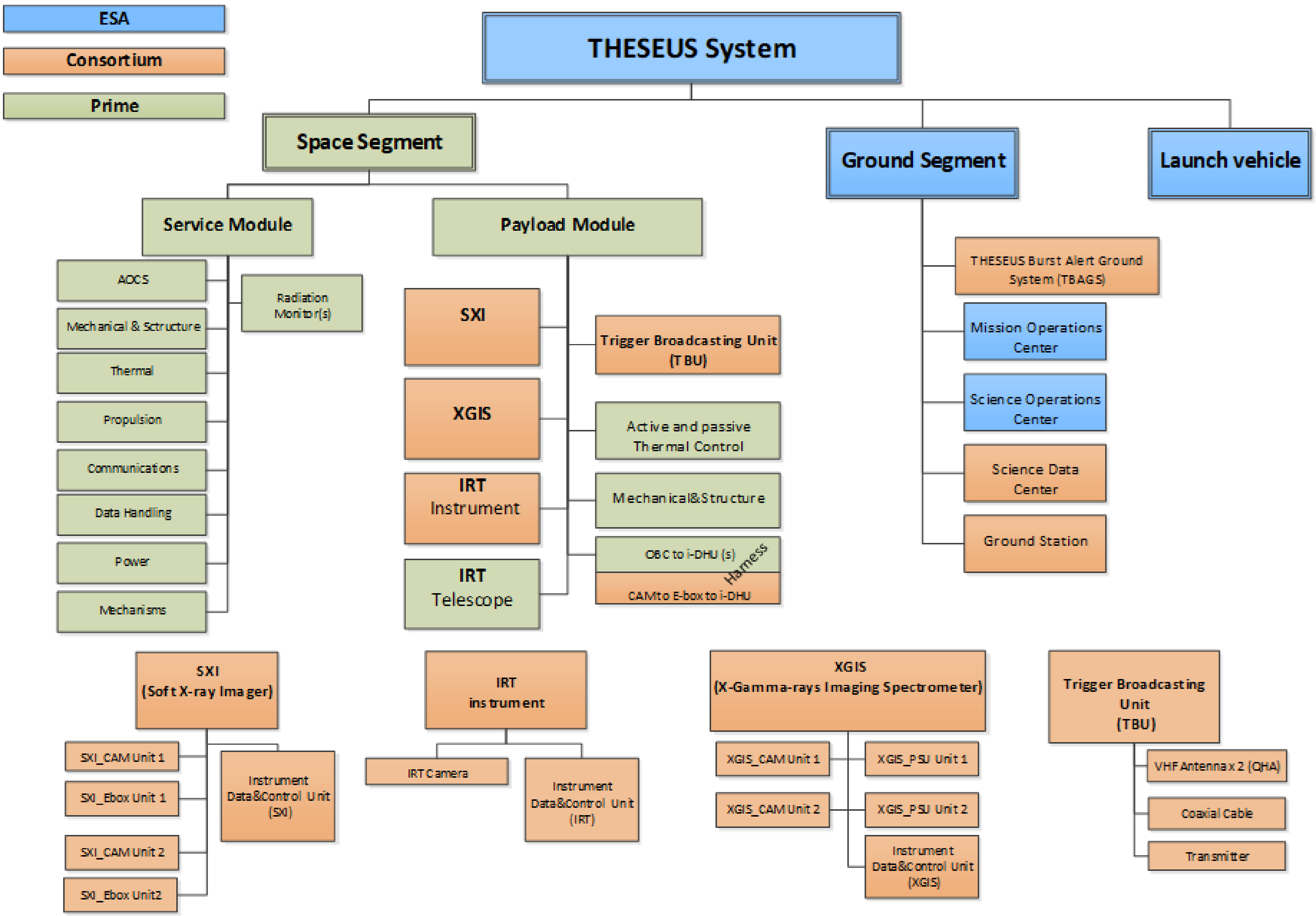
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR
r-process element chemical abundances
SKA
LSST
ATHENA
THESEUS SYNERGIES

THESEUS
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**.

Theseus: responsibilities break-down



THESEUS payload consortium

Italy: responsibility of XGIS (design, detection plane procurements and assembly, electronics, integration, testing, simulations, calibrations, s/w), responsibility of Trigger Broadcasting Unit (TBU), Malindi ground station (ASI inkind).

UK: responsibility of SXI (design, detection plane assembly, optics procurement and assembly (TBD), electronics, integration, testing, simulations, calibrations, s/w).

France: responsibility of IRT (optical design of the telescope; IRT instrument including the focal plane assembly, electronics, integration, testing, simulations, calibrations, s/w); Theseus Burst Alert Ground Segment (including the CNES VHF Network system and the Burst Alert Centre).

Germany: overall responsibility of instruments data handling (DHU) systems (design, hardware, software).

Switzerland: Science Data Center (s/w, data processing, pipelines, quick-look), IRT filter wheel.

ESA P/L contribution: IRT telescope & cooling system, IRT detectors, SXI detectors

Spain : XGIS coded mask and collimator, contribution to SXI focal plane assembly.

Denmark: specific responsibility of XGIS DHU hardware and software.

Poland : XGIS power-supply units.

Belgium: contribution to SXI integration and tests.

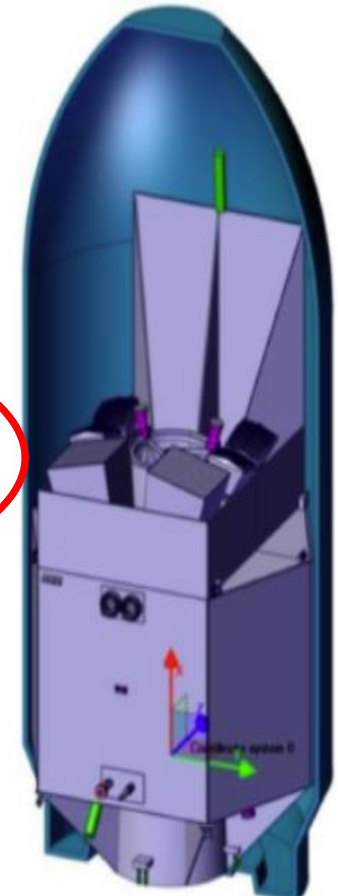
Czech Rep.: contribution to SXI echanical structures and thermal control.

Slovenia: investigation of optional X-band mobile ground stations.

Possible further contributions (TBD after Phase A): Ireland (contribution to XGIS detectors and IRT on-board s/w)**, Hungary** (contribution to spacecraft interface simulator, data-handling system, IRT calirations)

THESEUS Phase A Industrial studies (milestones)

- ITT release to Industry: March 2019
- KO of THESEUS TAS-I Industrial Study: June 2019
- KO of THESEUS Airbus Industrial Study: July 2019
- **Mission Consolidation Review (MCR)**
  - **Payload MCR KO: 15st February 2020**
  - **Spacecraft MCR KO: 15th March 2020**
- Mission Selection Review (MSR)
  - KO: 15th February 2021
  - Duration: 2 months

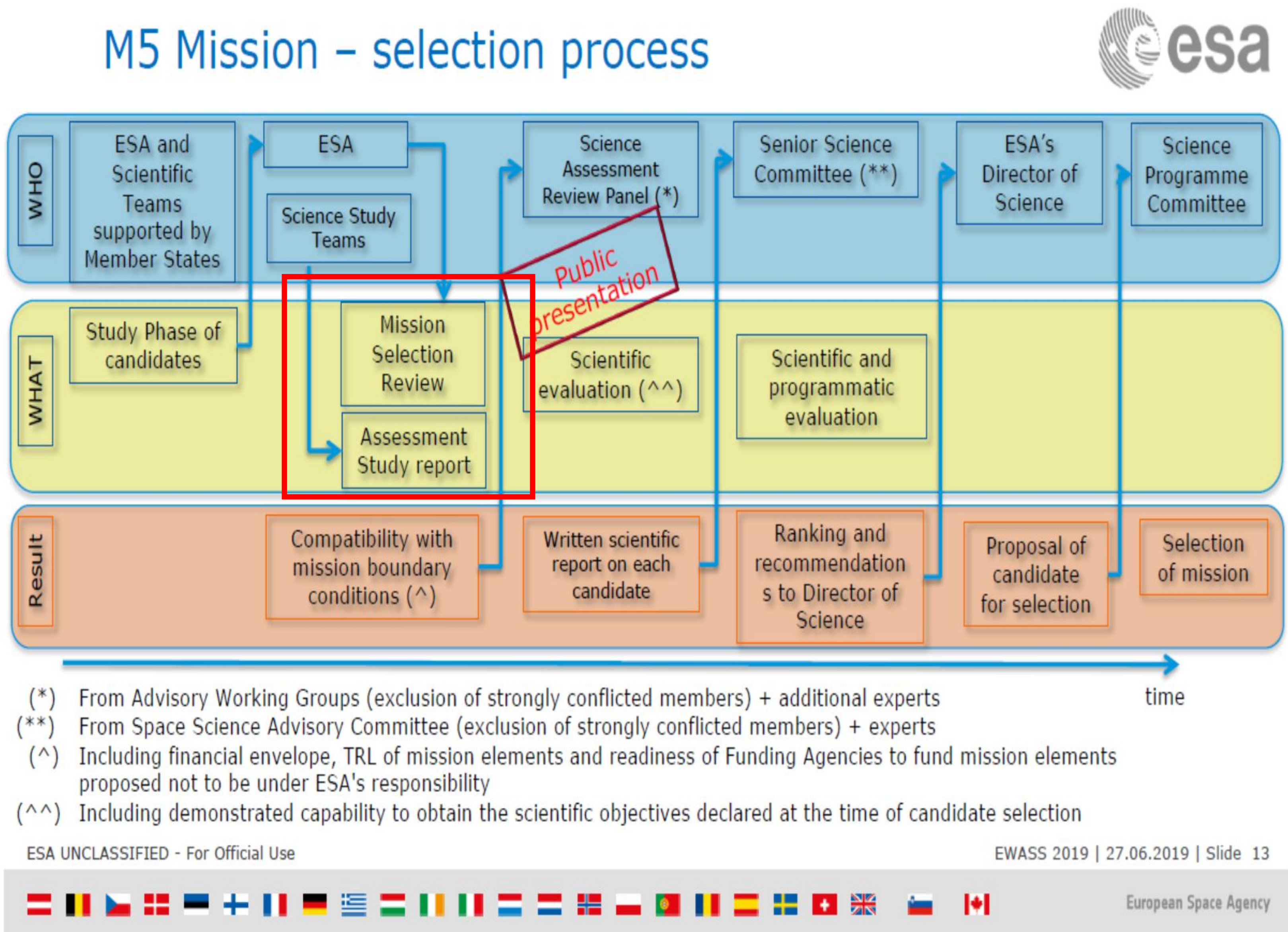


May 2020: THESEUS successfully passed the MCR, a main achievement of the study, thanks to the great efforts to the Consortium and ESA teams!

Study status – now in Phase A2

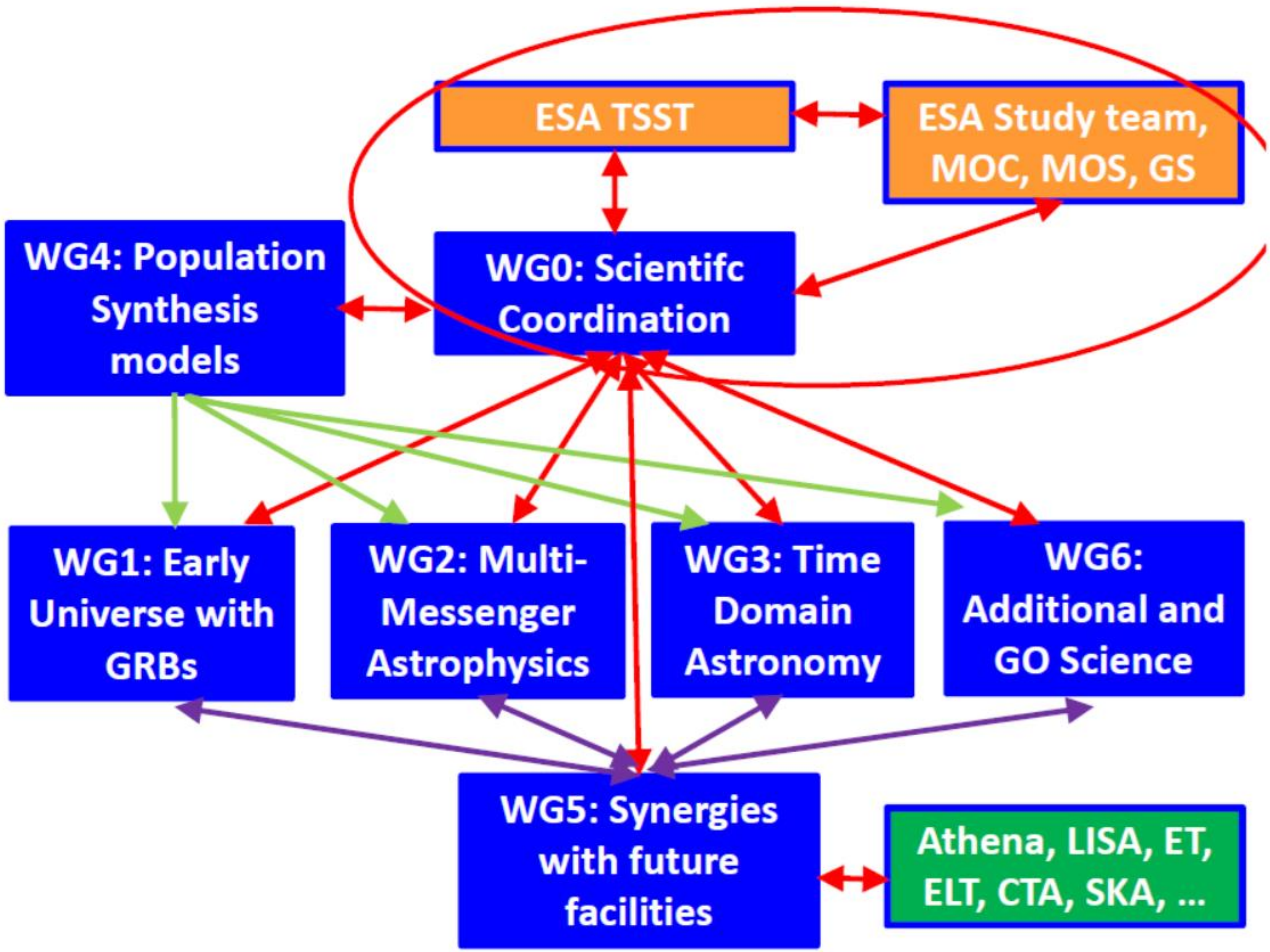
- ITT release to Industry: March 2019
- KO of THESEUS TAS-I Industrial Study: June 2019
- KO of THESEUS Airbus Industrial Study: July 2019
- Mission Consolidation Review (MCR)
- Consortium Prime I/F meetings
- **Mission Selection Review (MSR)**
    - PL MSR DP: **5 Feb. 2021**
    - PL panel starts earlier than system
    - Total Duration: 3 months
- M5 selection at June SPC

Towards M5 final candidate selection: MSR + YB



- **Theseus Editorial Board (TEB)** set-up (Guainazzi, Amati, O'Brien, Gotz, Tanvir, Stratta, Bozzo, Mereghetti, Osborne, Ghirlanda, Rosati, Blain) and KO in May 2020

THESEUS Consortium scientific WGs



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/