THESEUS
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

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

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

Amati et al. 2017 (Adv.Sp.Res., arXiv:1710.04638)
Stratta et al. 2017 (Adv.Sp.Res., arXiv:1712.08153)

The II National Workshop of SKA science and technology

Bologna, 4 December 2018

www.isdc.unige.ch/theseus/workshop2017-programme.html

Proceedings preprints on the arXiv in early February

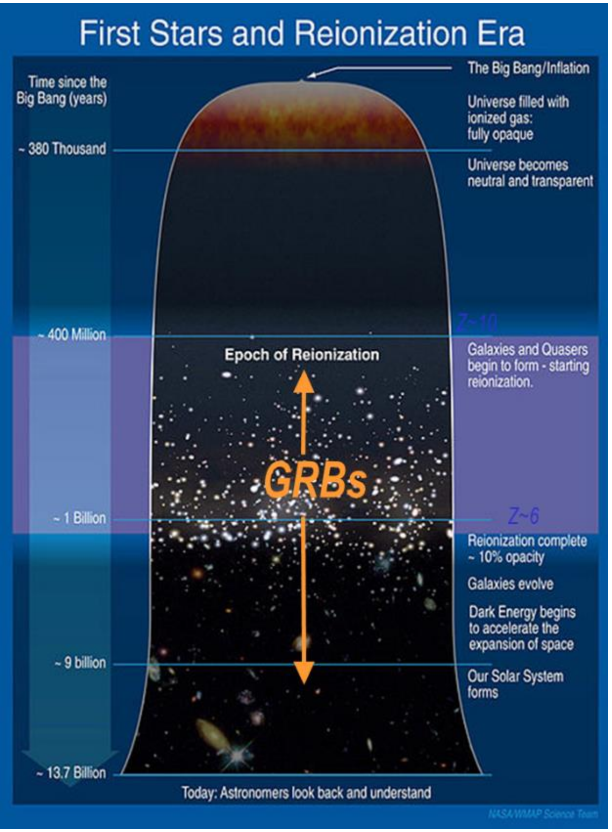
(Mem.SAIt, Vol. 89 – N.1 - 2018)

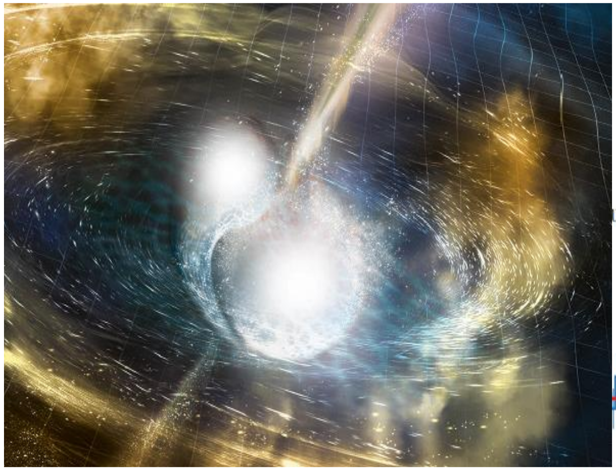
Probing the Early Universe with GRBs

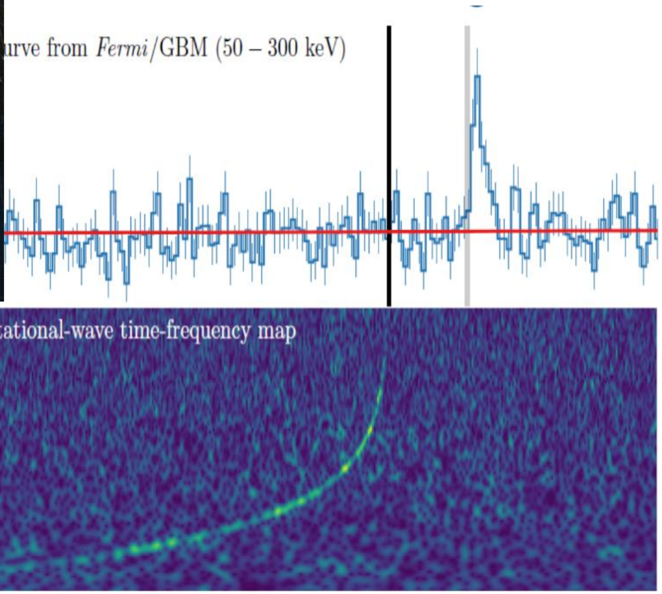
Multi-messenger and time domain Astrophysics

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), C. Tenzer (Univ. Tuebingen, D), E. Bozzo (Univ. Genève, CH)

Payload consortium: Italy, UK, France, Germany, Switzerland, Spain, Poland, Czech Republic, Ireland, Hungary, Slovenia , ESA

Interested international partners: USA, China, Brazil

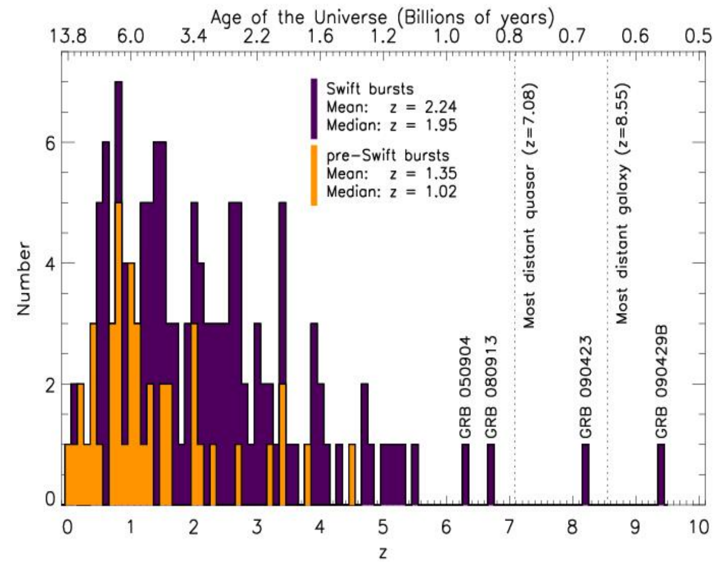
May 2018: THESEUS selected by ESA for M5 Phase 0/A study

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	November 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

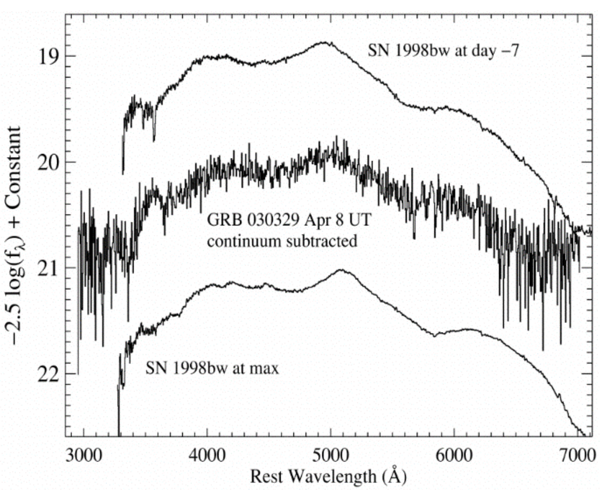
❑ **THESEUS and full SKA operative in the same years**

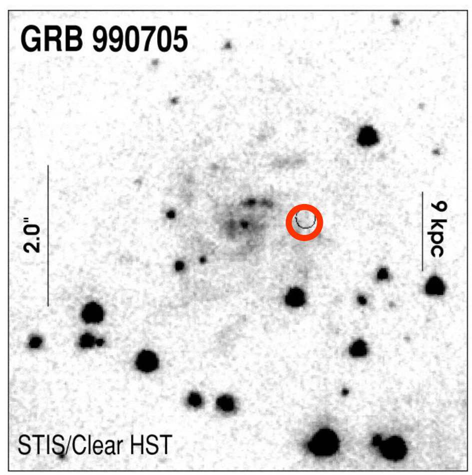
Shedding light on the early Universe with GRBs

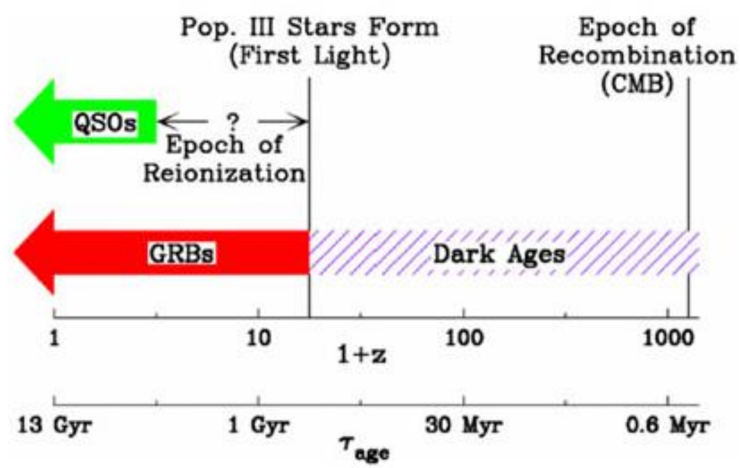
Because of their huge luminosities, mostly emitted in the X and gamma-rays, their redshift distribution extending at least to z ~9 and their association with explosive death of massive stars and star forming regions, GRBs are unique and powerful tools for investigating the early Universe: **SFR evolution,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



GRBs in Cosmological Context





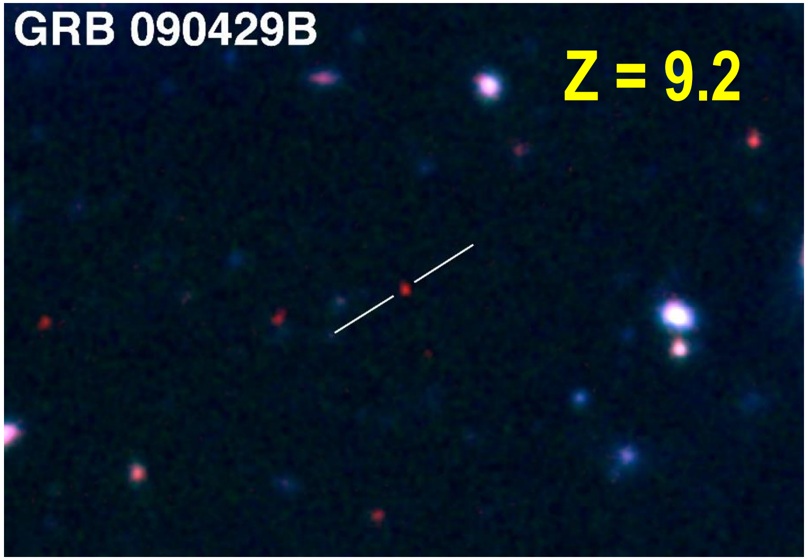


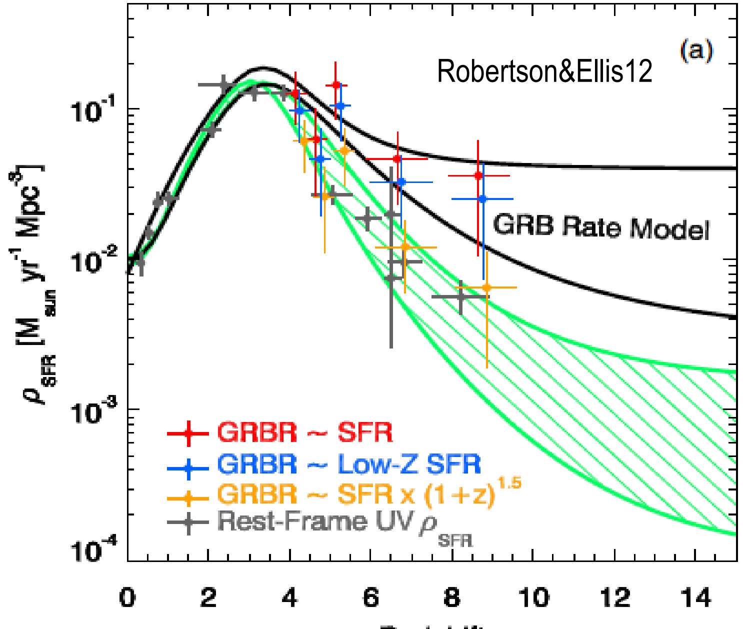
Lamb and Reichart (2000)

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

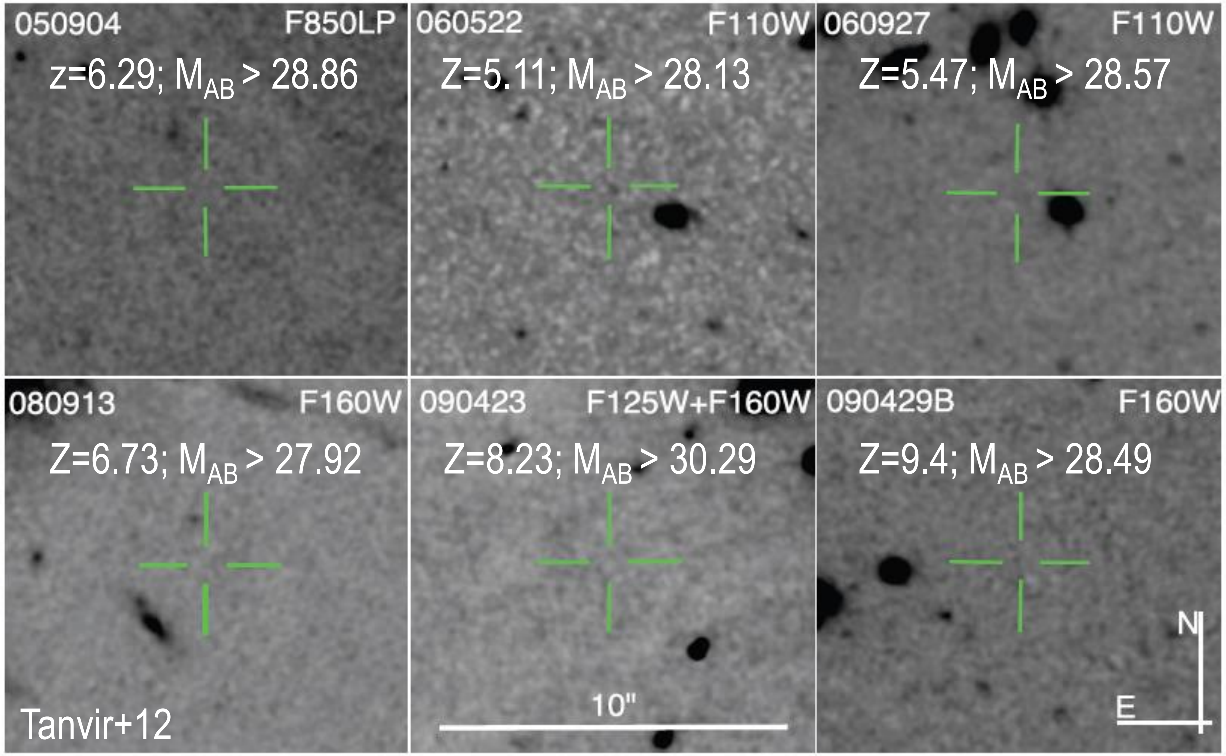
- measure independently the **cosmic star–formation rate**, even beyond the limits of current and future galaxy surveys

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





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

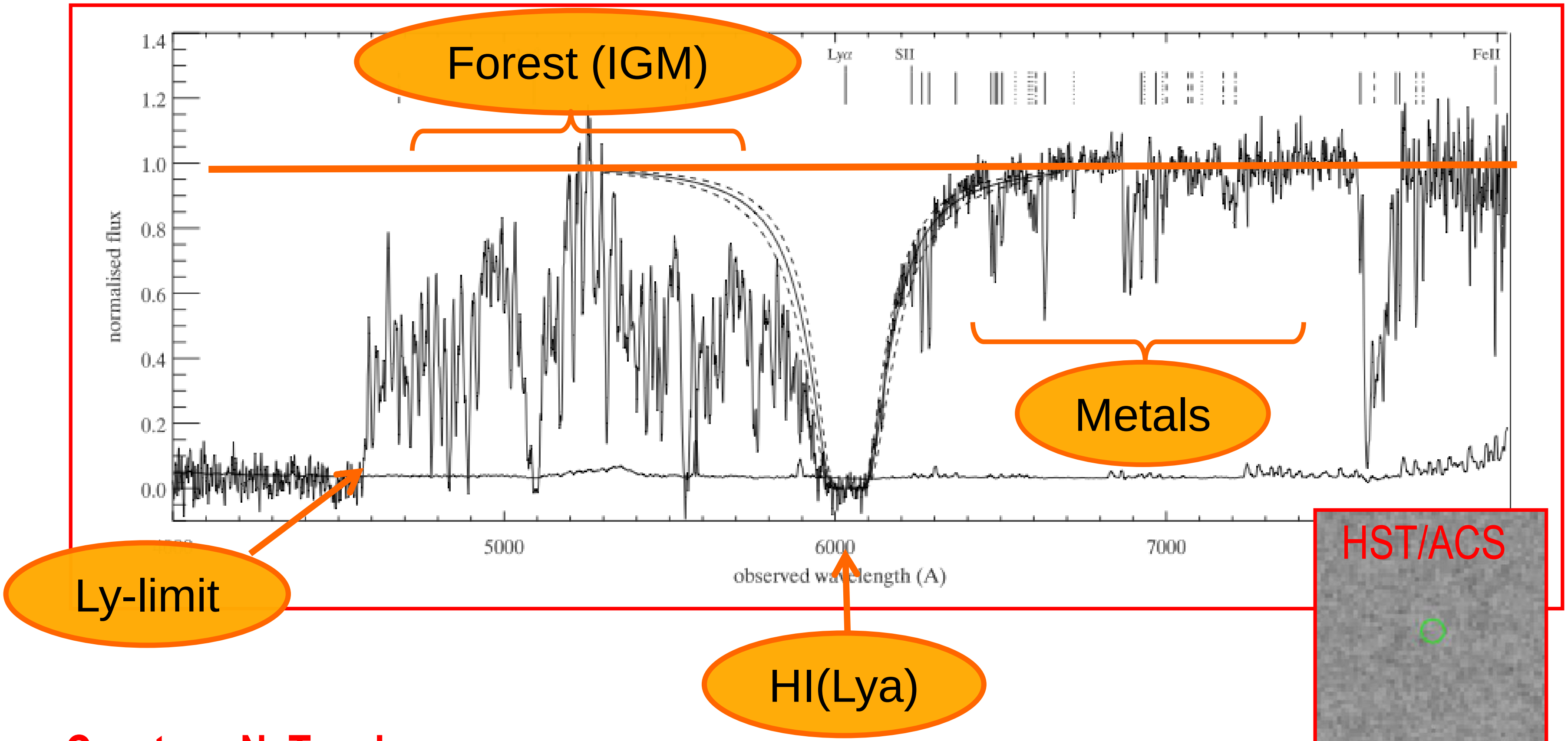


Robertson&Ellis12

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
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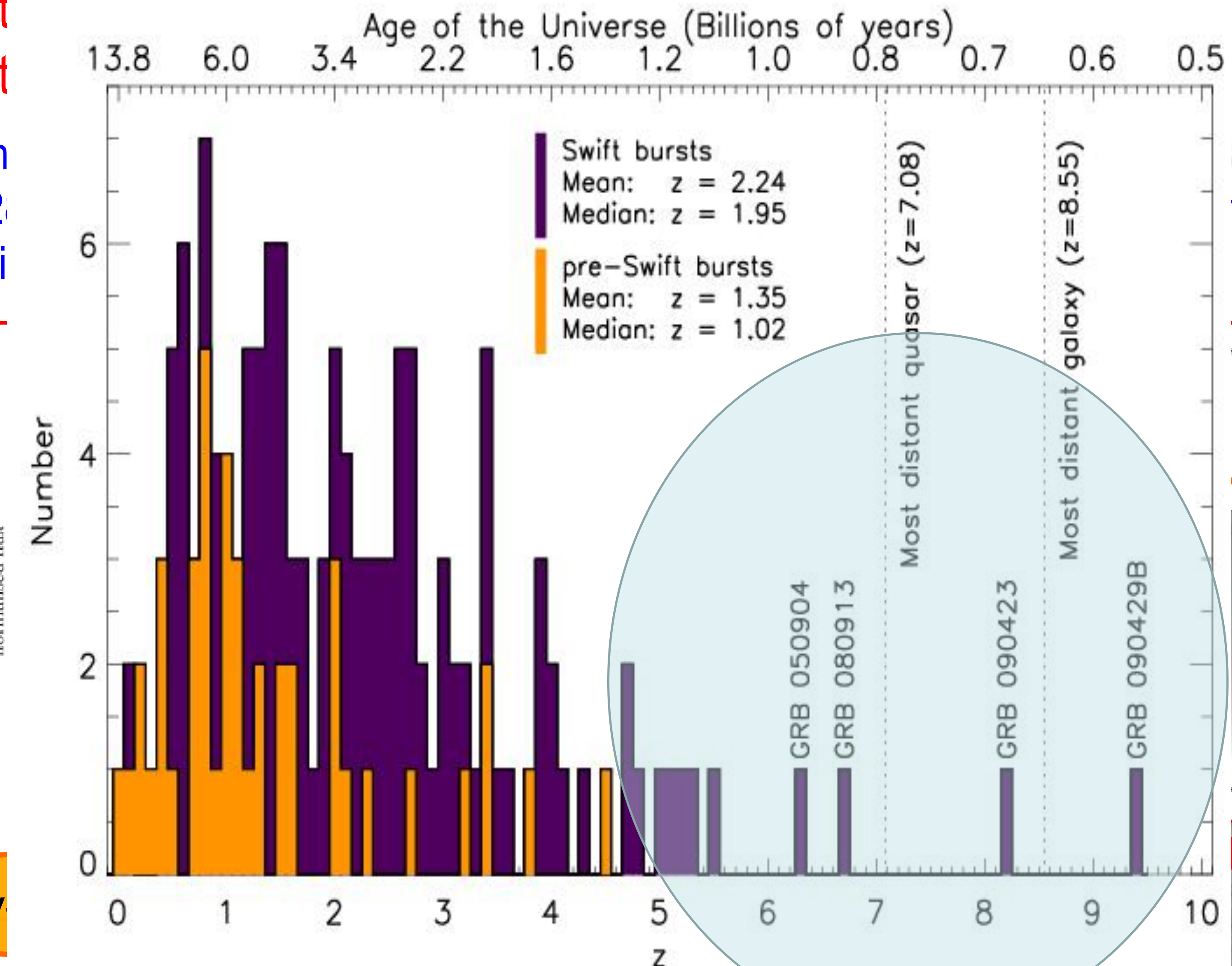

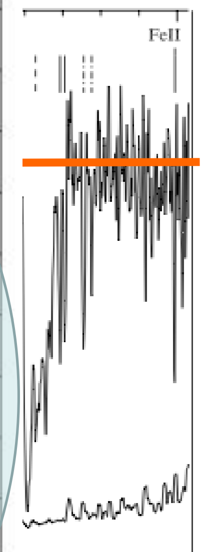

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HI(Lya)

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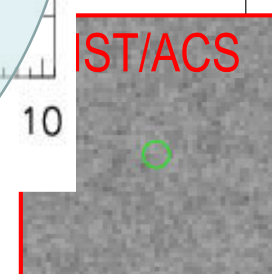
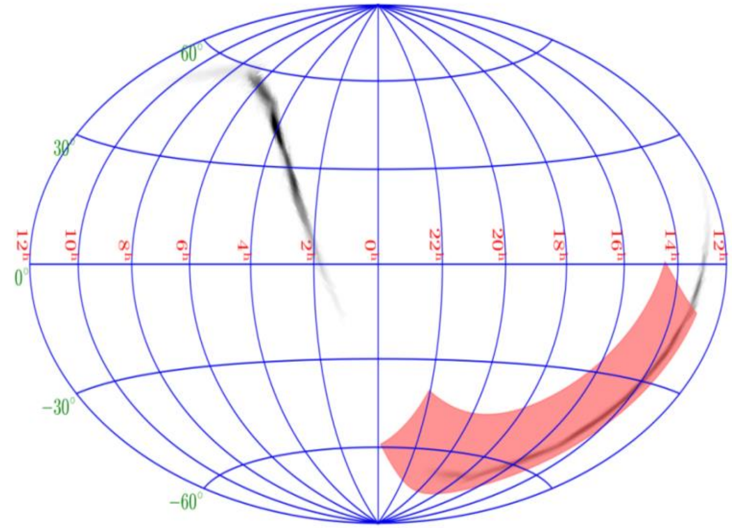


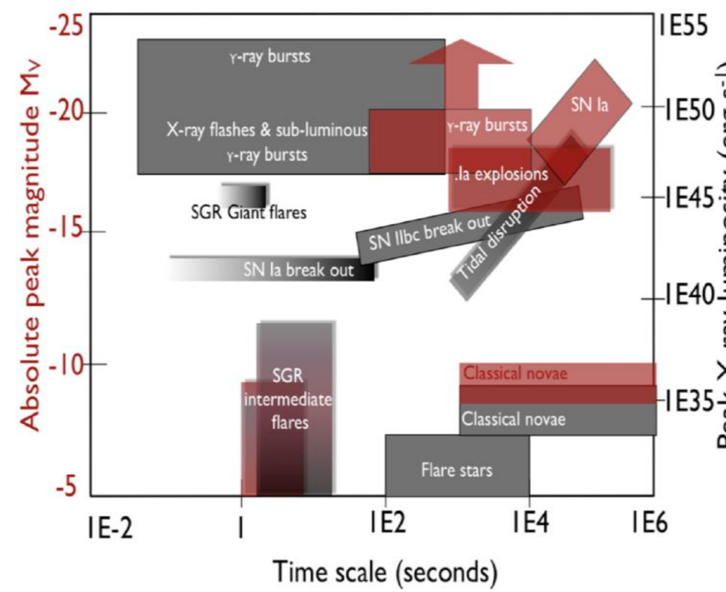
Courtesy N. Tanvir

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;**

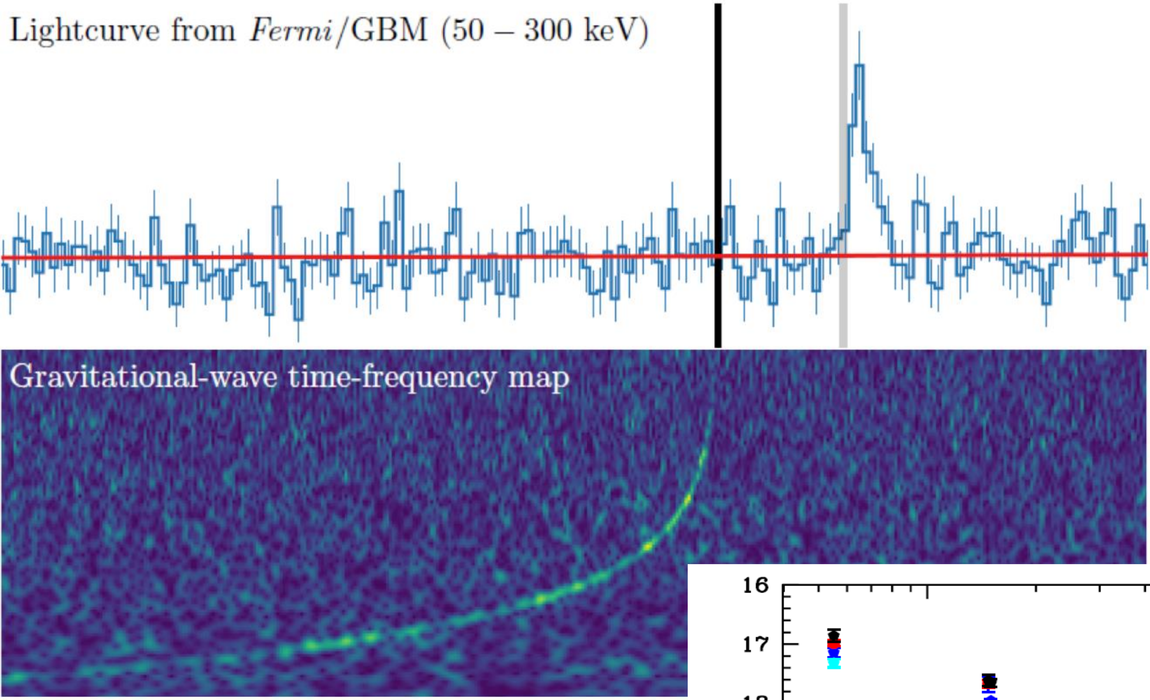


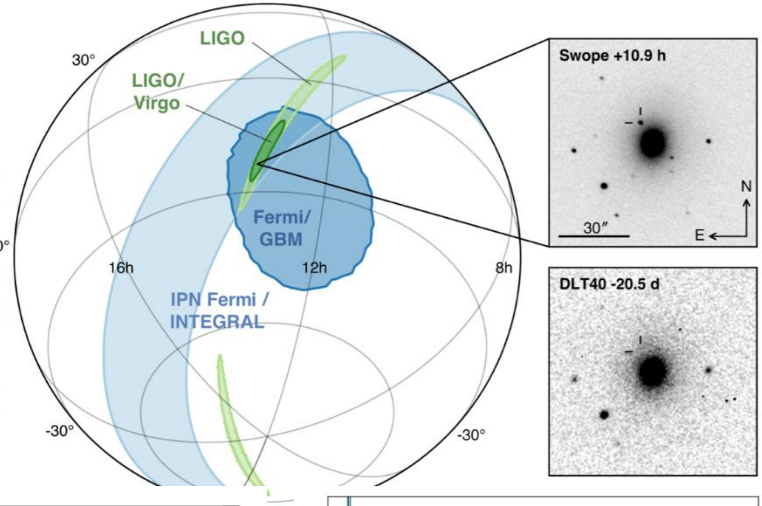
- Provide real-time triggers and accurate (~1 arcmin within a few seconds; ~1'' within a few minutes) **high-energy transients for follow-up with next-generation optical-NIR (E-ELT, JWST if still operating), radio (SKA), X-rays (ATHENA), TeV (CTA) telescopes; synergy with LSST**

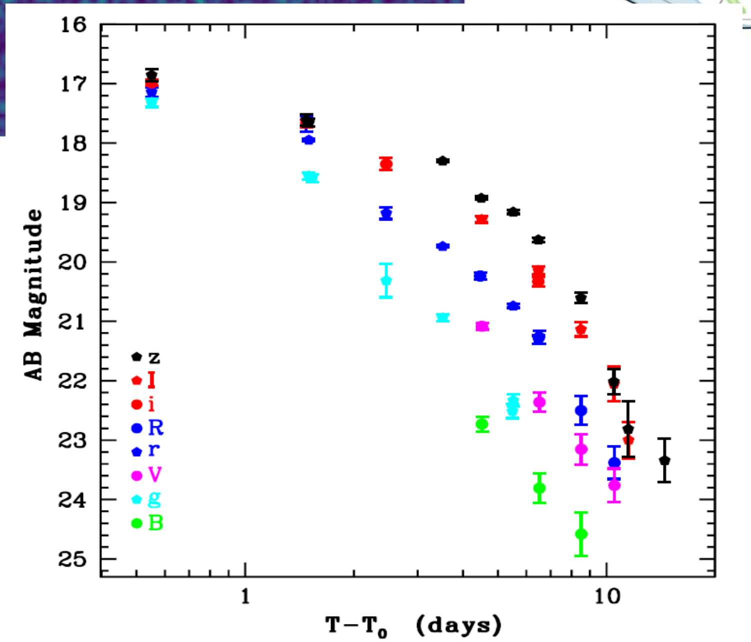


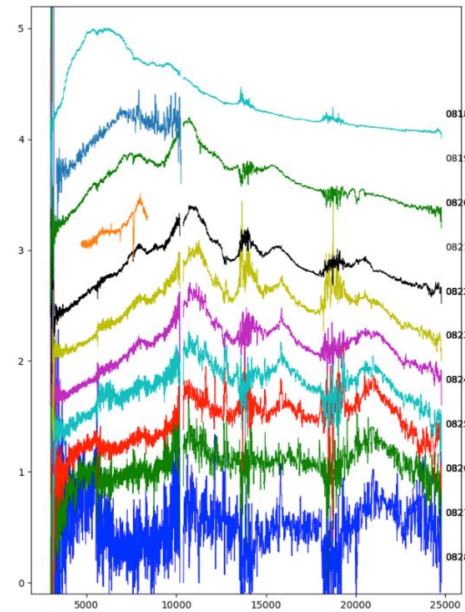
- Provide a fundamental step forward in the comprehension of the physics of various classes of transients and **fill the present gap in the discovery space of new classes of transients events**

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



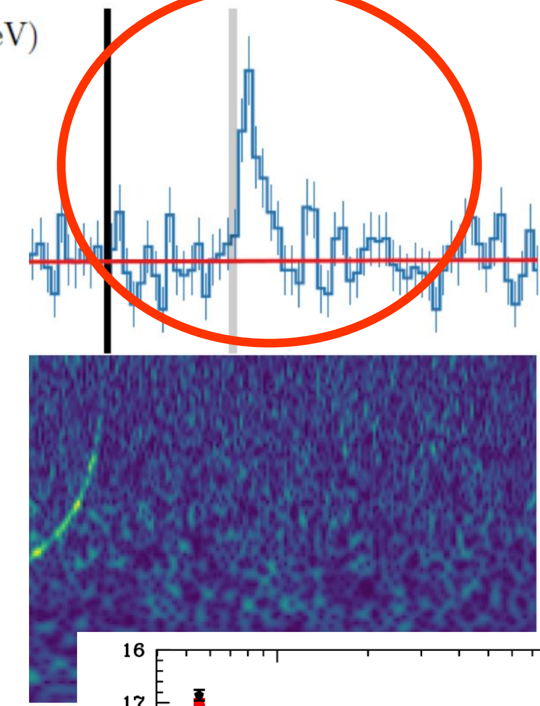






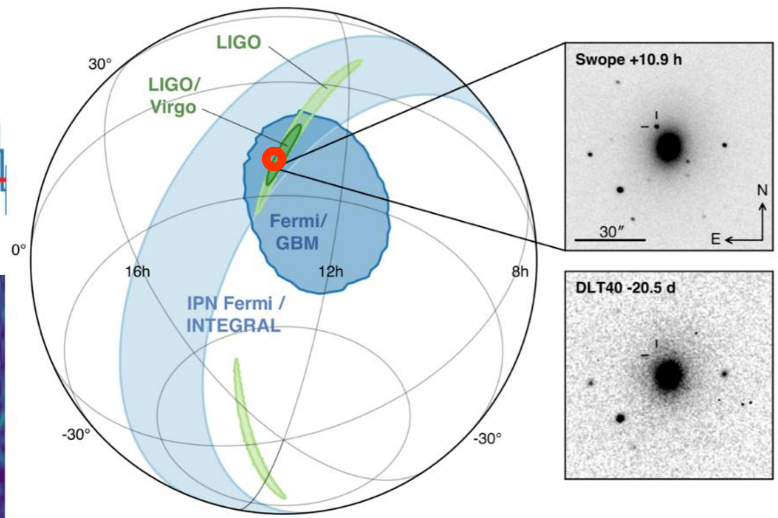
LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars

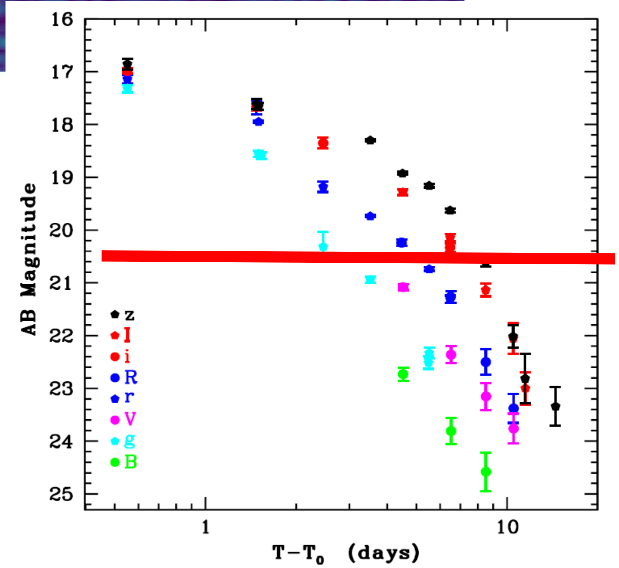
Lightcurve from *Fermi*/GBM (50 – 300 keV)

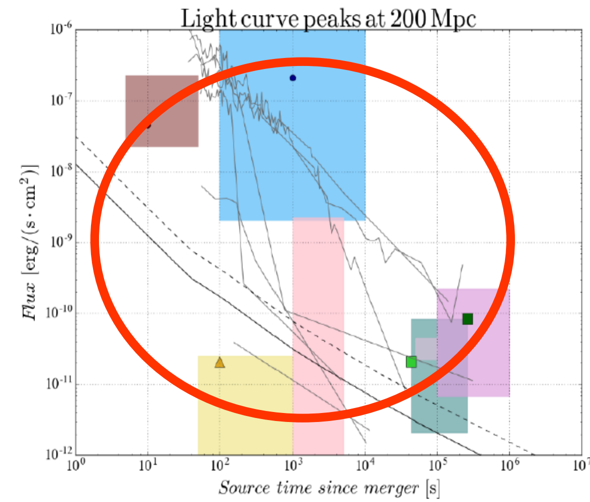


THESEUS:

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

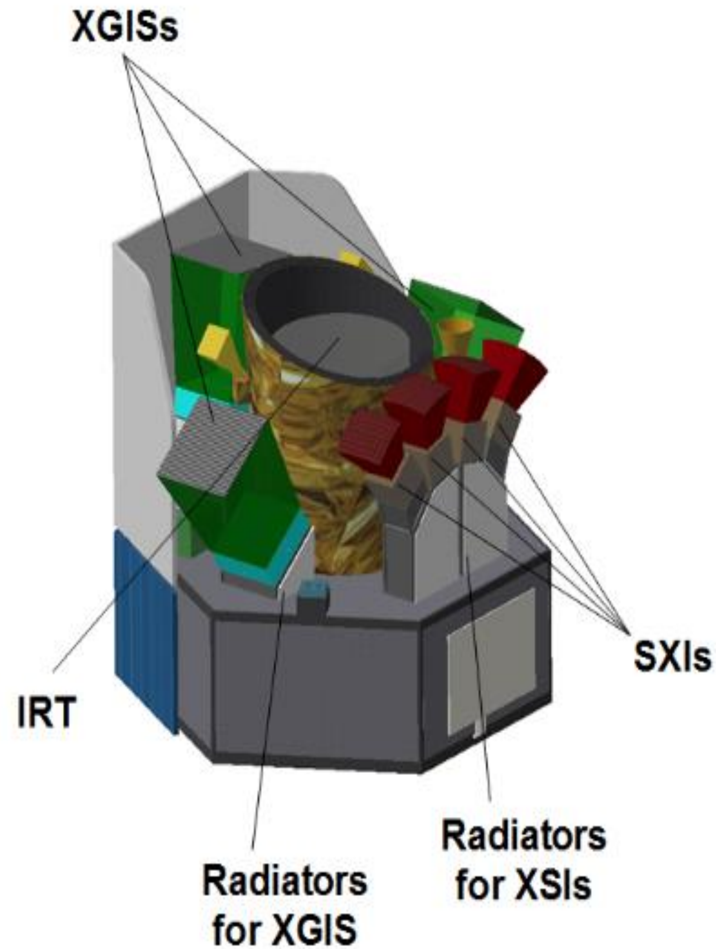






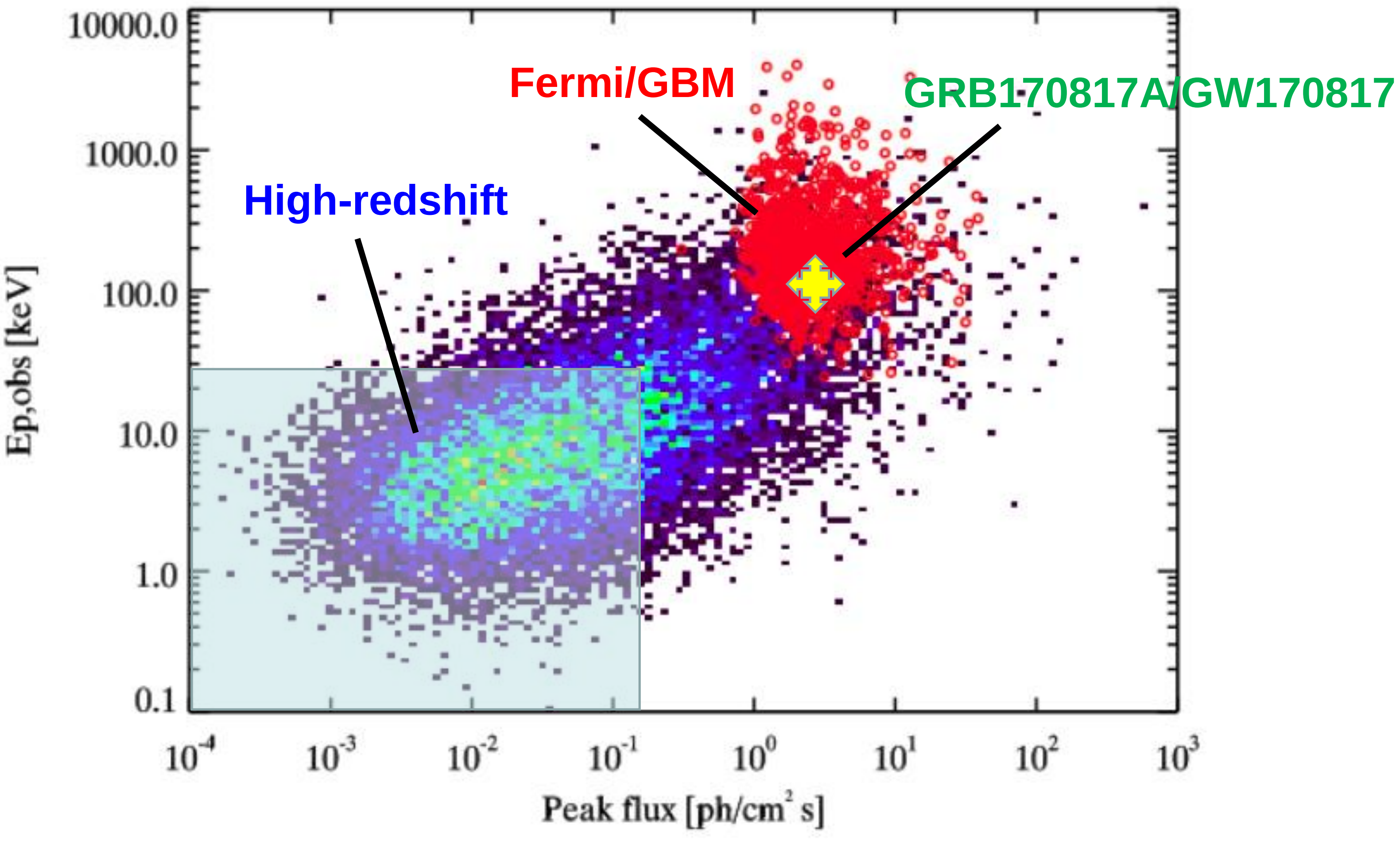
THESEUS mission concept

- **Soft X-ray Imager (SXI):** a set of four sensitive lobster-eye telescopes observing in **0.3 - 5 keV band, total FOV of ~1sr with source location accuracy 0.5-1';**
- **X-Gamma rays Imaging Spectrometer (XGIS,)**: 3 coded-mask X-gamma ray cameras using bars of Silicon diodes coupled with CsI crystal scintillators observing in **2 keV – 10 MeV band, a FOV of ~2-4 sr, overlapping the SXI, with ~5' source location accuracy**;
- **InfraRed Telescope (IRT)**: a 0.7m class IR telescope observing in the **0.7 – 1.8 μm band, providing a 10'x10' FOV, with both imaging and moderate resolution spectroscopy capabilities (-> redshift)**



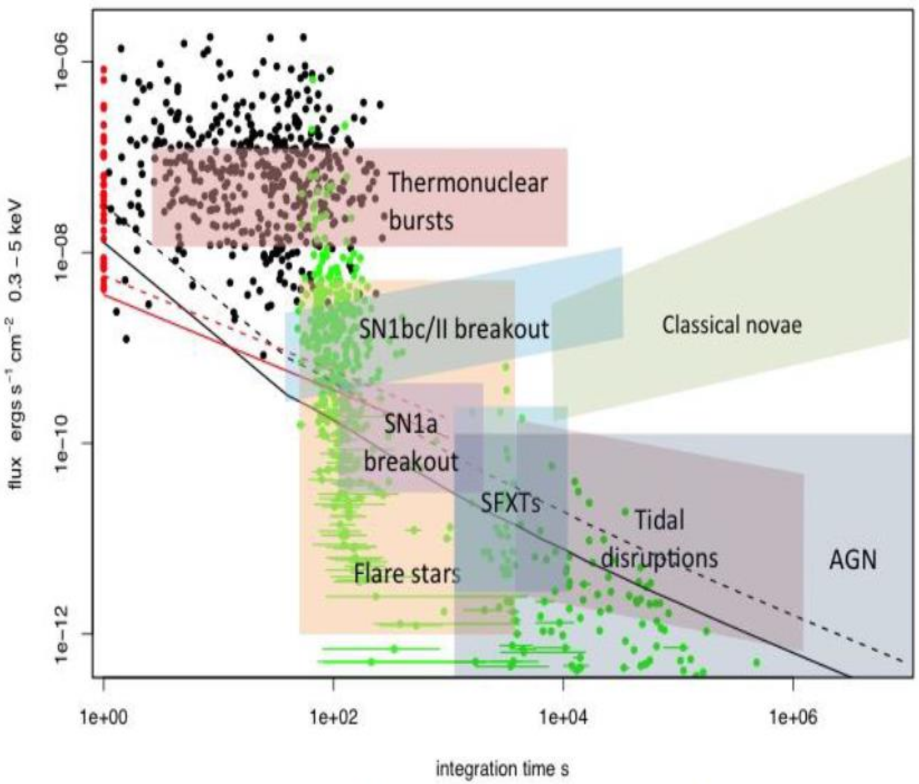
LEO (< 5°, ~600 km)
Rapid slewing bus
Prompt downlink

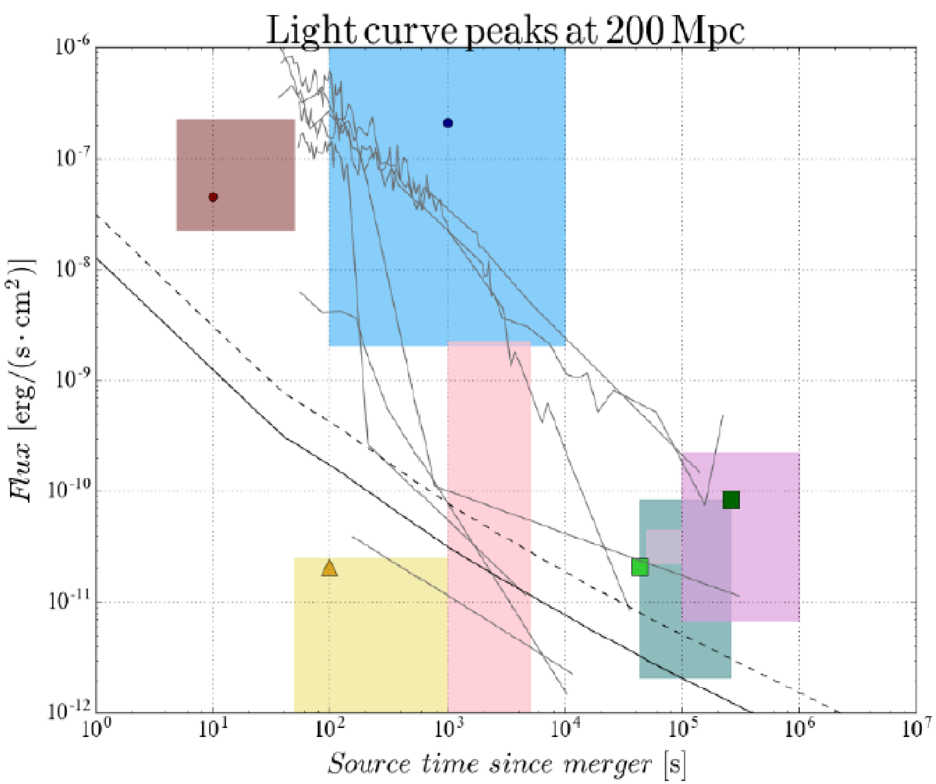
❑ THESEUS will have the ideal combination of instrumentation and mission profile for detecting all types of GRBs (long, short/hard, weak/soft, high-redshift), localizing them from a few arcmin down to arsec and measure the redshift for a large fraction of them

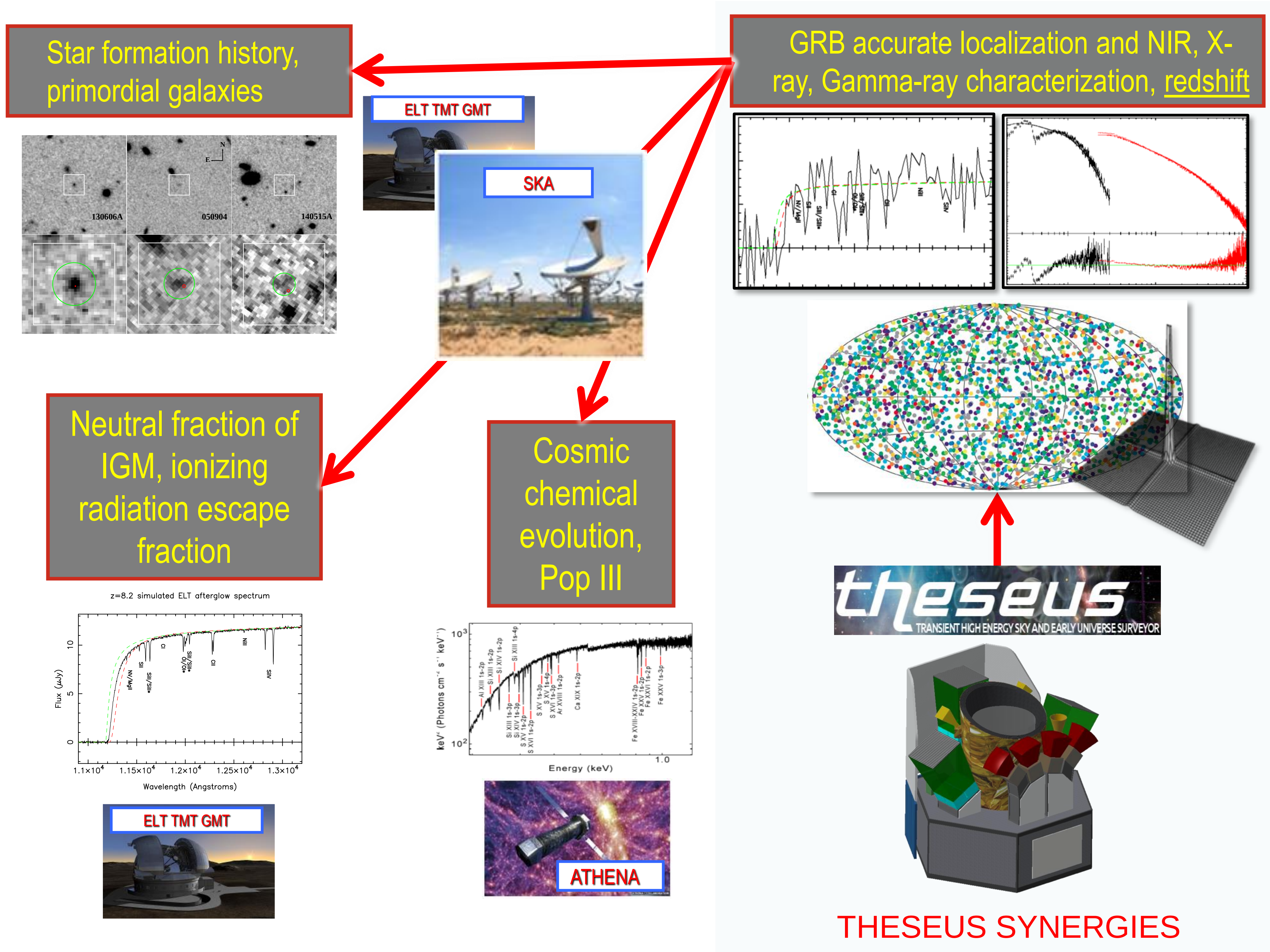


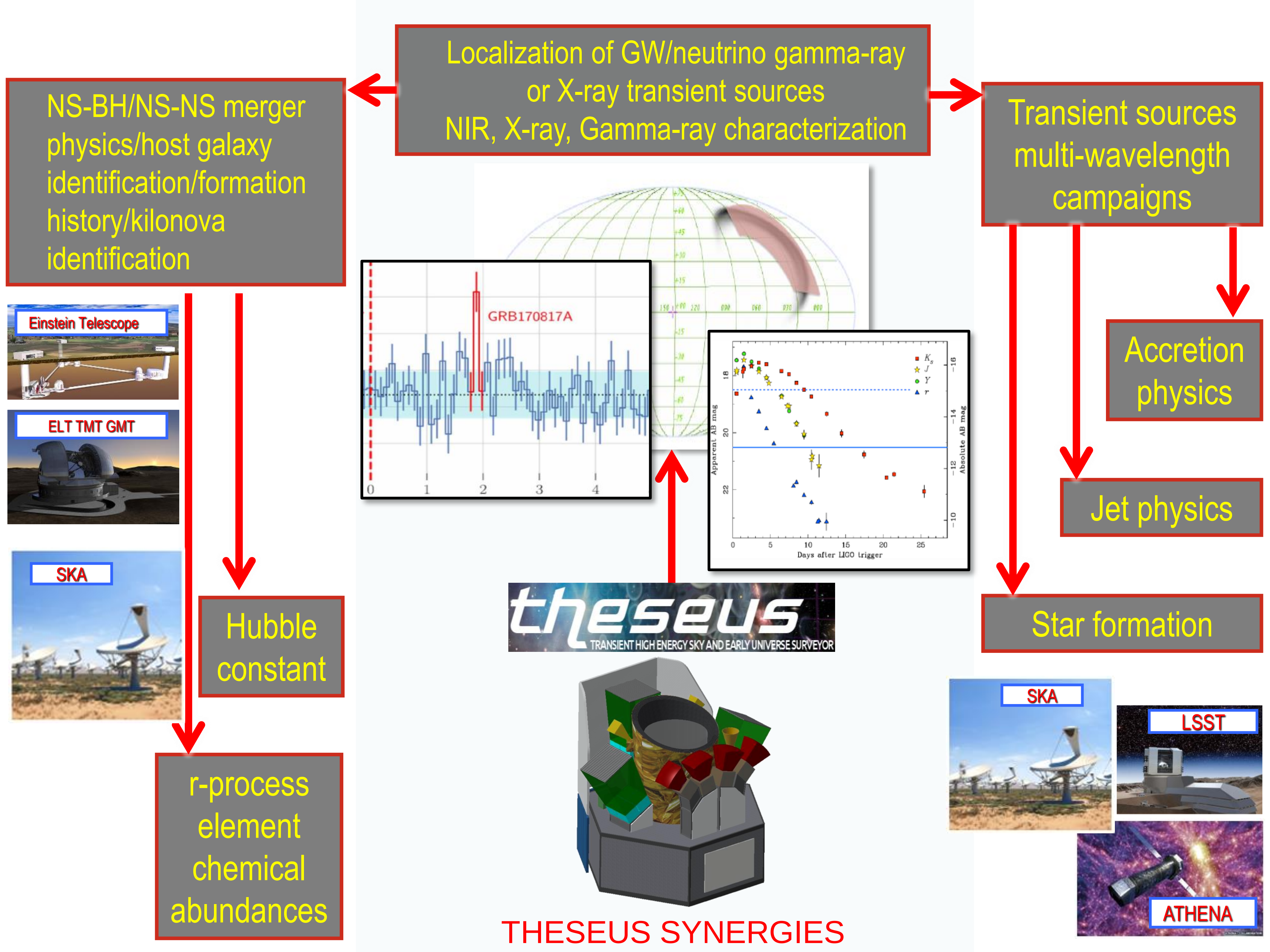
❑ THESEUS will also detect and localize down to 0.5-1 arcmin the soft X-ray short/long GRB afterglows, of NS-NS (BH) mergers and of many classes of galactic and extra-galactic transients

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






Star formation history, primordial galaxies
130606A
050904
140515A
ELT TMT GMT
SKA
GRB accurate localization and NIR, X-ray, Gamma-ray characterization, redshift
Neutral fraction of IGM, ionizing radiation escape fraction
Cosmic chemical evolution, Pop III
z=8.2 simulated ELT afterglow spectrum
Flux (μJy)
Wavelength (Angstroms)
Energy (keV)
ELT TMT GMT
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
SKA
Hubble constant
r-process element chemical abundances
GRB170817A
Apparent AB mag
Absolute AB mag
Days after LIGO trigger
Accretion physics
Jet physics
Star formation
theseus
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR
SKA
LSST
ATHENA
THESEUS SYNERGIES

THESEUS: straightforward synergies with SKA

- **High complementarity in the study of the early Universe**

(1) Pop-III stars and SFR evolution up cosmic dawn
(2) History, topology and physics of cosmic re-ionization
(3) Population, properties and evolution of weak/low-lum first galaxies

- **THESEUS will be the perfect GRB and transients machine for allowing SKA to fully exploit its capabilities for time-domain and multi-messenger astrophysics:**

(1) Short GRBs and soft X-ray transients as e.m. counterparts of GW emitters (NS-NS, NS-BH)
(2) GRBs: physics / geometry of the emission, population studies, cosmology
(3) Long GRBs – SNe-Ib/c - neutrinos
(4) Many other transients found by THESEUS (e.g., TDEs, magnetars, …) will also be high-value targets for SKA

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 consortium science: 6 WGs, > 200 contributing scientists

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

1. Exploring the Early Universe with GRBs		
Surname and Name	**Country**	**Institute**
Tanvir Nial	United Kingdom	University of Leicester

2. Gravitational waves and multi-messanger Astrophysics		
Surname and Name	**Country**	**Institute**
Stratta Giulia	Italy	Urbino University

3. Exploring the time domain Universe		
Surname and Name	**Country**	**Institute**
Osborne Julian	United Kingdom	University of Leicester

4. Sinergy with other electromagnetic facilities (including LSST)		
Surname and Name	**Country**	**Institute**
Rosati Piero	Italy	University of Ferrara

5. Scientific requirements		
Surname and Name	**Country**	**Institute**
Ghirlanda Giancarlo	Italy	INAF-OA Brera

6. The IRT as a flexible Guest Observer IR observatory		
Surname and Name	**Country**	**Institute**
Blain Andrew	United Kingdom	University of Leicester

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Società Astronomica Italiana

Synergies of THESEUS with the SKA: a brief report

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Abstract. We present a short report on the main synergies between Theseus and SKA in the study of high-redshift transients and we summarize a few more aspects where Theseus and SKA can contribute to explore fundamental physics in the universe.

Key words. Cosmology: early Universe Galaxies: high-redshift, Transients

1. Introduction

The Transient High Energy Sky and Early Universe Surveyor (THESEUS) is a space mission concept whose core science goals of THESEUS comprise the exploration of the cosmic dawn and re-ionization era through the prompt detection and characterization of transients up to high redshifts.

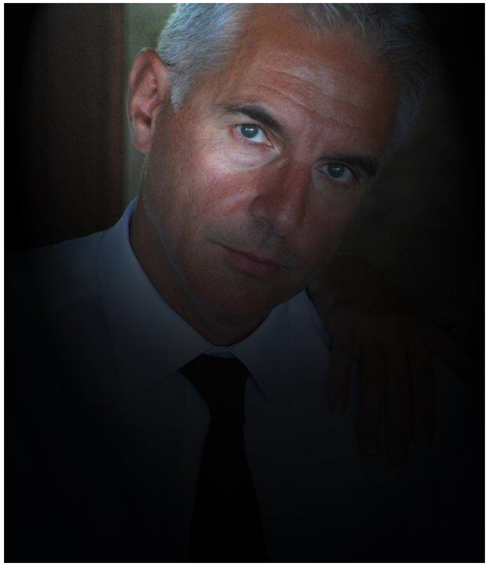
The Square Kilometer Array (SKA) has similar key science programs working in the very-low (70-350 MHz) to mid- (0.4-10 GHz) radio frequency range (for a comprehensive illustration of the SKA science topics and

1.1. Blob-ology

This is mainly the case of the GRB (radio afterglows) population study.

The first moral we can get from this study is that the sensitivity of the SKA will allow to observe almost the complete population of GRBs, provided that a X/g-ray instrument (more sensitive than Swift) will be operational in the SKA era (e.g., Theseus) and provided a GRB localisation to a few arcsec resolution Burlon et al. (2015).

The second moral we can get is that once you have a relatively large sample of sparks



In summary

- THESEUS, under study by ESA and 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 (lobster-eye telescopes, SDD by INAF, INFN, FBK, Un.)

- THESEUS will enhance importantly the scientific return of next generation facilities in the multi messenger (aLIGO/aVirgo, LISA, ET, or Km3NET) and e.m. (e.g., LSST, E-ELT, SKA, CTA, ATHENA) domain

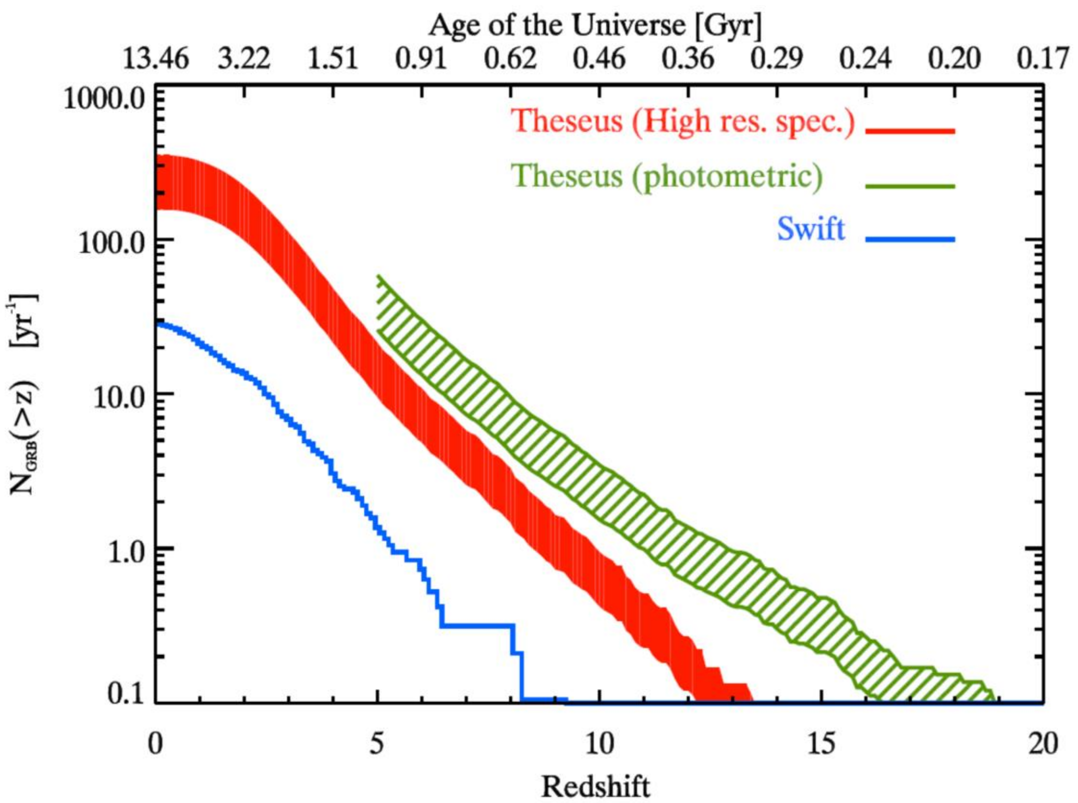
- Strong synergy with SKA: early Universe cosmology (pop III stars, re-ionization, first galaxies), GRBs, transients and multi-messenger astrophysics (Lorenzo.amati@inaf.it , https://www.isdc.unige.ch/theseus/)

- *ESA L2/L3 review:* “The SSC strongly endorses the need to continue pursuing in the future the discovery of GRBs”

- THESEUS will be a really unique and superbly capable facility, one that will do amazing science on its own, but also will add huge value to the currently planned new photon and multi-messenger astrophysics infrastructures in the 2020s to > 2030s.

Back-up slides

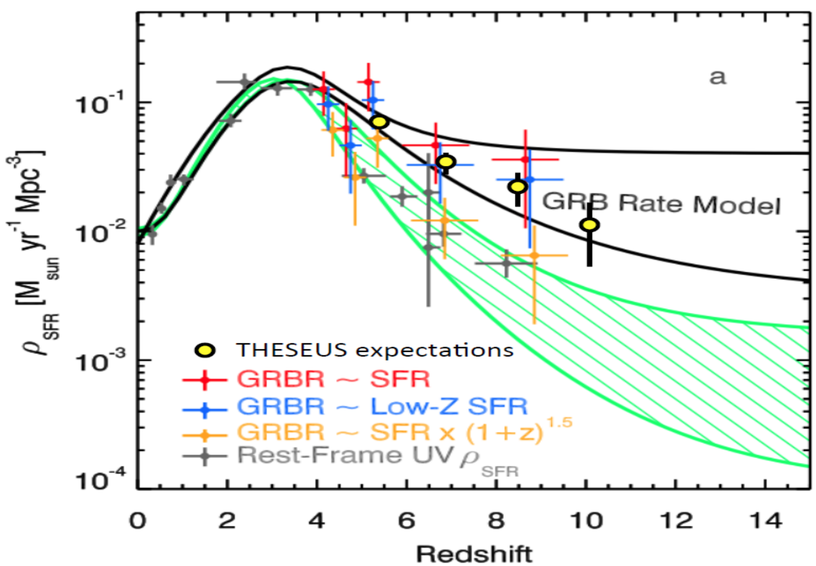
❑ Shedding light on the early Universe with GRBs

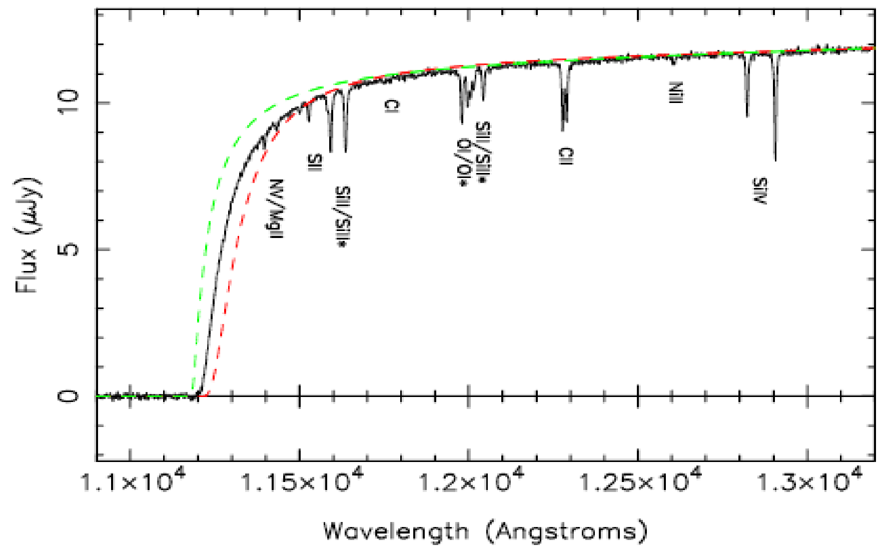


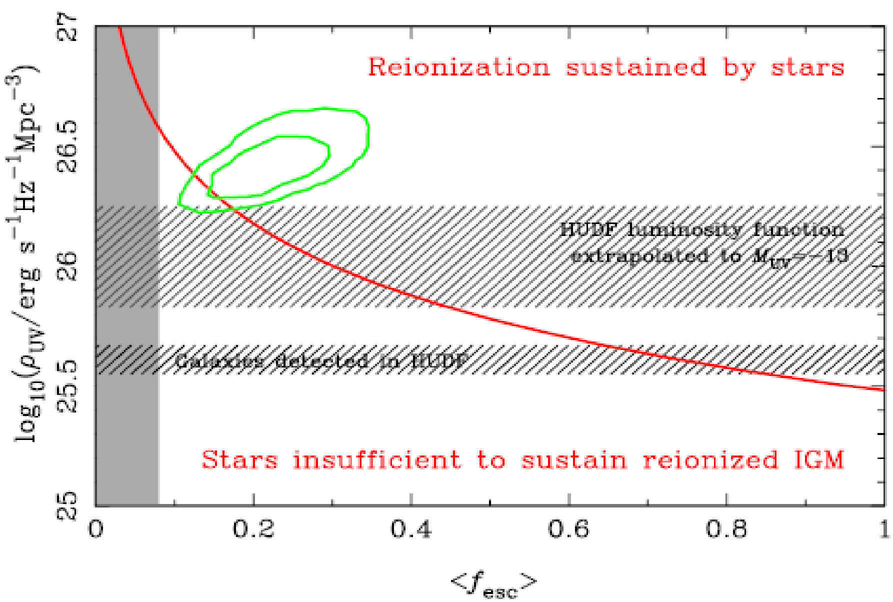
THESEUS GRB#/yr	All	z > 5	z > 8	z > 10
Detections	387 - 870	25 – 60	4 – 10	2 - 4
Photometric z		25 – 60	4 – 10	2 - 4
Spectroscopic z	156 - 350	10 - 20	1 - 3	0.5 - 1

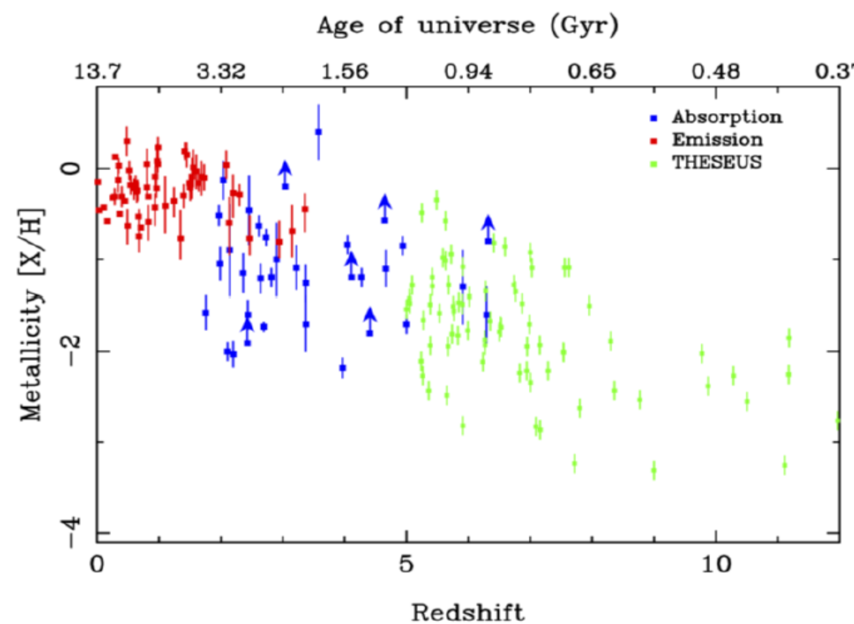
❑ Shedding light on the early Universe with GRBs

z=8.2 simulated E−ELT afterglow spectra





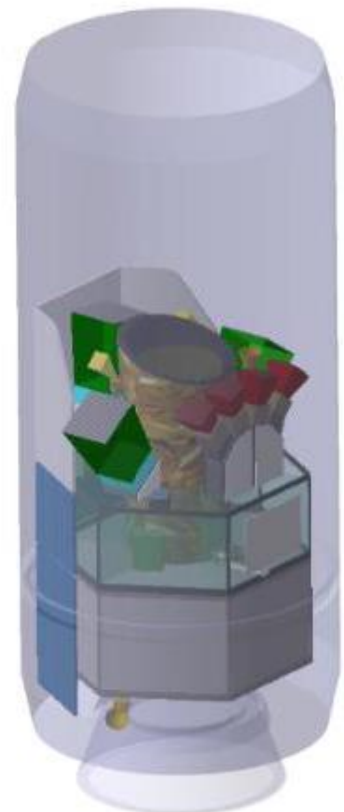




Mission profile and budgets

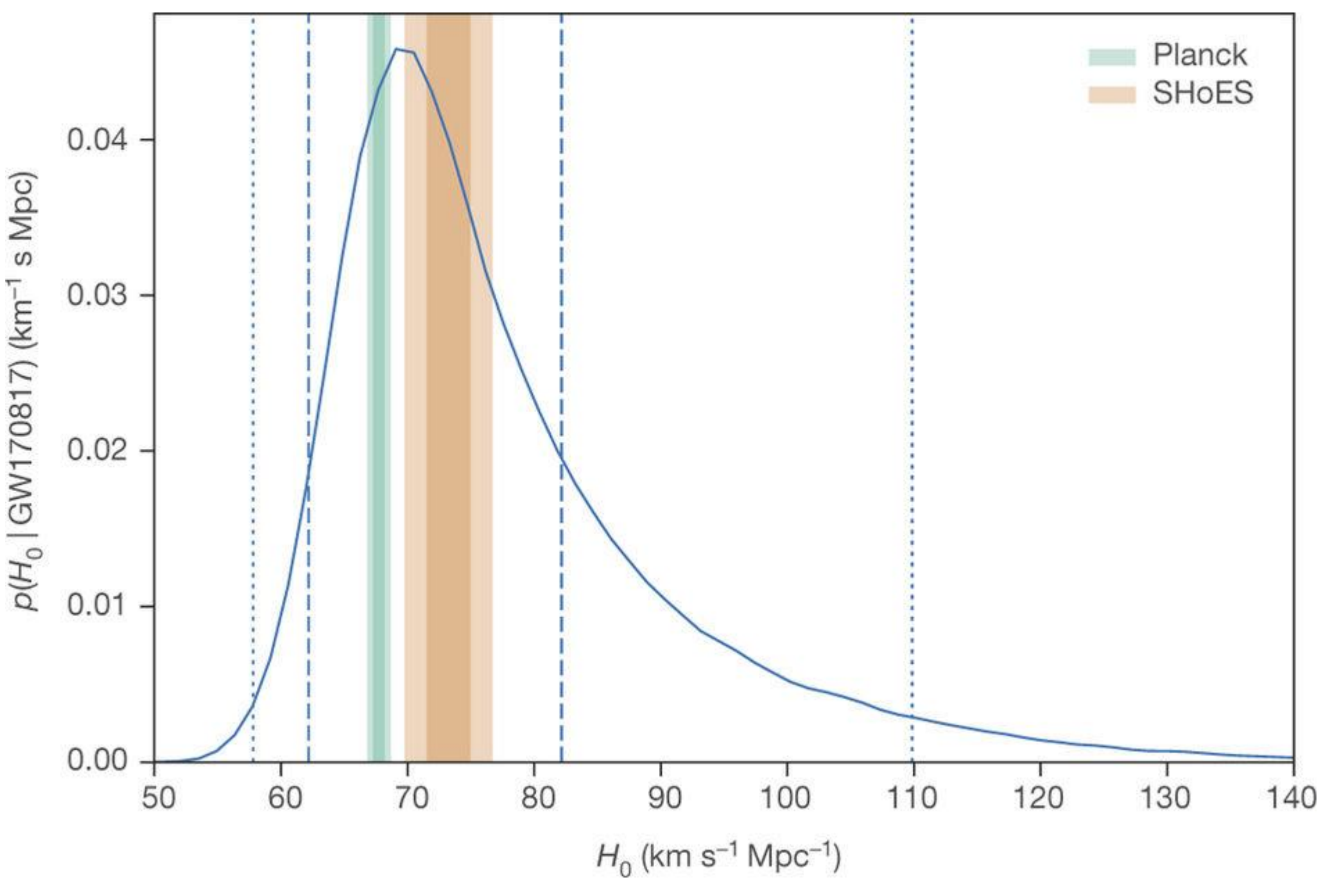
FUNCTIONAL SUBSYSTEMS	Basic Mass (kg)	Margin (%)	Margin (kg)	Current Mass (Kg)
SERVICE MODULE				
AOCS (gyro, RW, SAS, ST)	115,1	10%	11,5	126,6
PDHU + X BAND	31,4	10%	3,1	34,5
DATA HANDLING	24,4	5%	1,2	25,6
EPS (PCU, Battery, SA)	85,1	10%	8,5	93,6
SYSTEM STRUCTURE	129,1	10%	12,9	142,0
PROPULSION	17,0	15%	2,5	19,5
THERMAL CONTROL (heaters+blankets)	14,2	10%	1,4	15,6
HARNESS	46,0	20%	9,2	55,2
Total Service Module Mass	462,3	11%	50,5	512,8
PAYLOAD MODULE				
SXI	100,0	20%	20,0	120,0
XGIS	93,0	20%	18,6	111,6
IRT	94,2	20%	18,8	116,0
i-DHU + i-DU + NGRM + TBU + harness (TBC)	23,1	20%	4,6	27,7
Total P/L Module Mass	310,3		62,1	375,3

Total Service Module Mass (kg)	512,8
Total Payload Module Mass (kg)	375,3
System level margin (20%)	177,6
Dry Mass at launch (kg)	**1065,6**
Propellant	100,0
Launcher adapter	31,7
Total mass at launch (kg)	**1197,3**



- Launch with VEGA-C into LEO (< 5°, ~600 km)
- **Spacecraft slewing capabilities (30° < 5 min)**
- **Prompt downlink options : WHF network (options: IRIDIUM network, ORBCOMM, NASA/TDRSS, ESA/EDRS)**

- 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

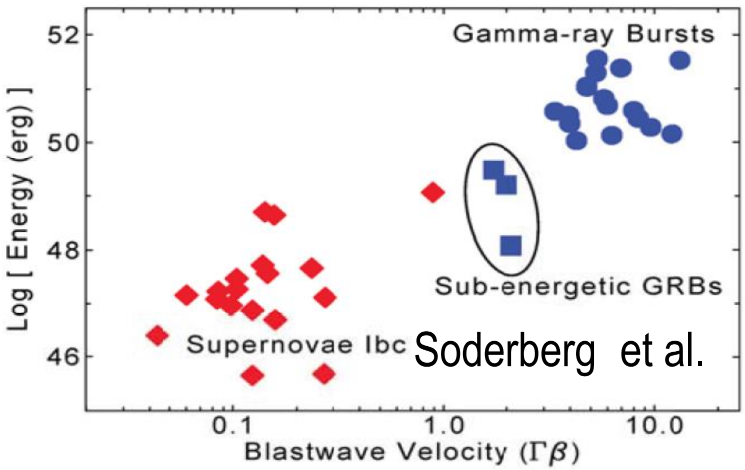
❑ Time-domain astronomy and GRB physics

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

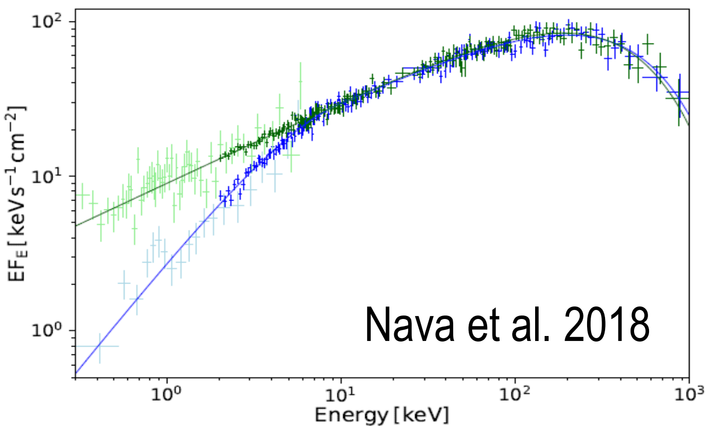
- substantially increased detection rate and characterization of sub-energetic GRBs and X-Ray Flashes;

- 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}



Soderberg et al.

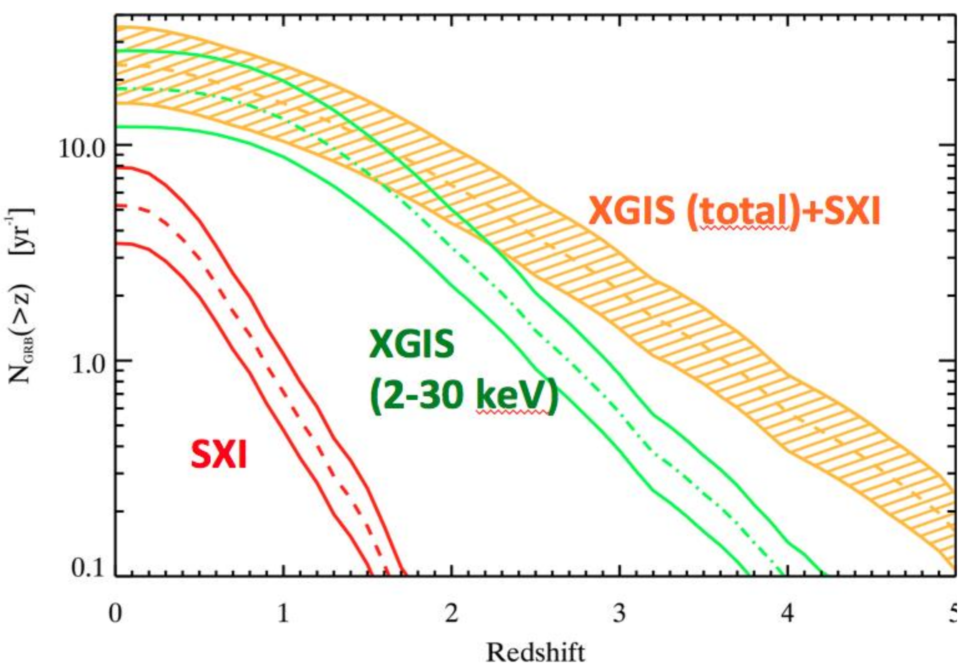


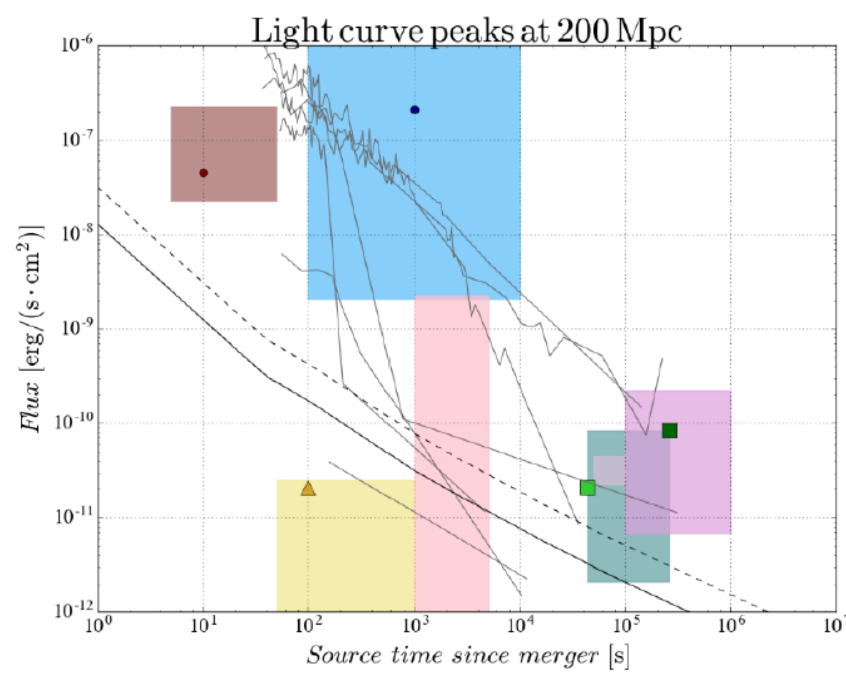
Nava et al. 2018

❑ GW/multi-messenger time-domain astrophysics

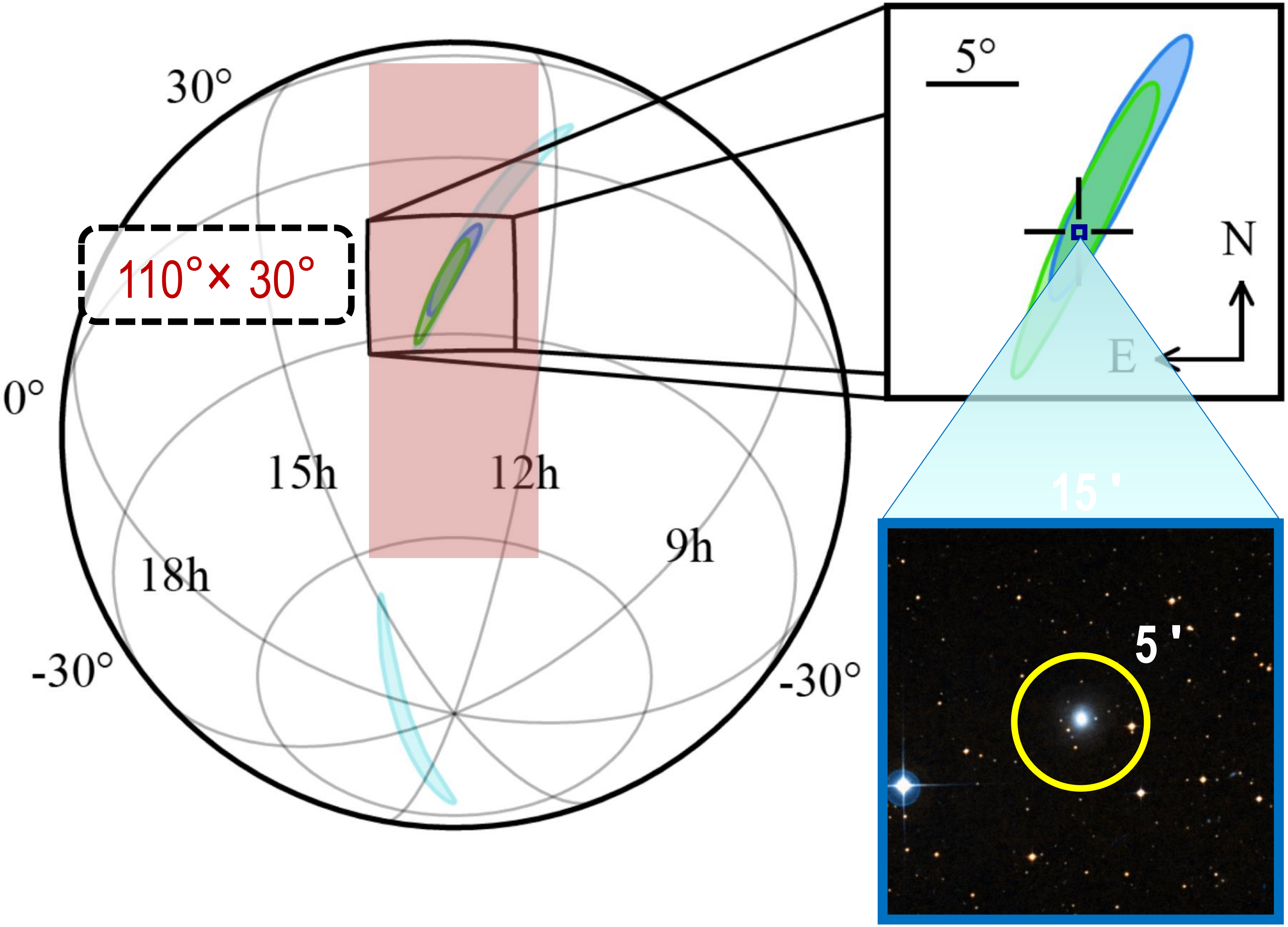
GW transient sources that will be monitored by THESEUS include **NS-NS / NS-BH mergers**:

- ❑ **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

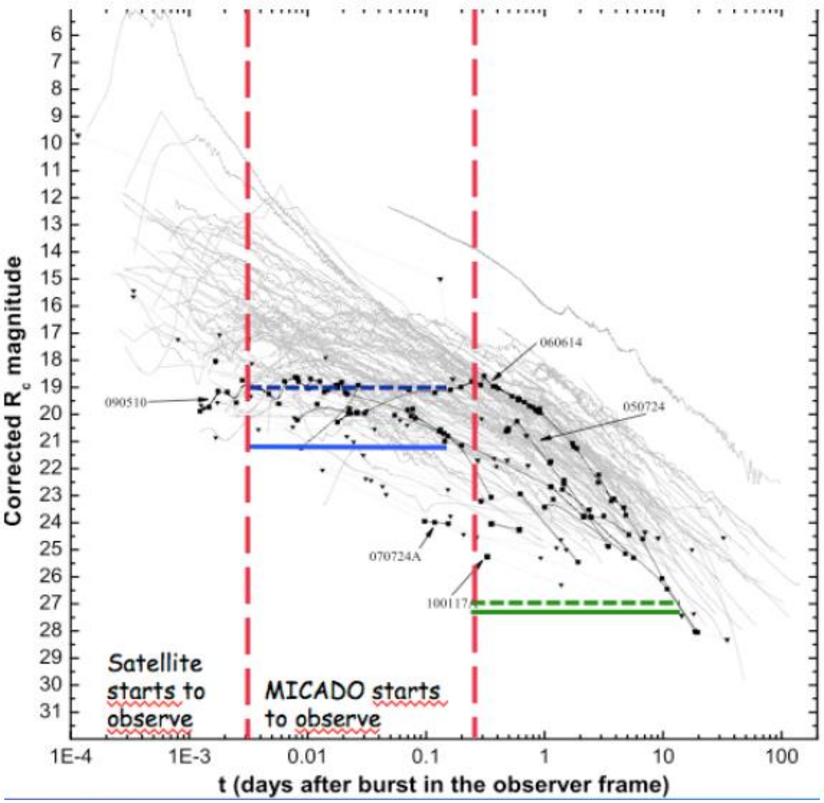


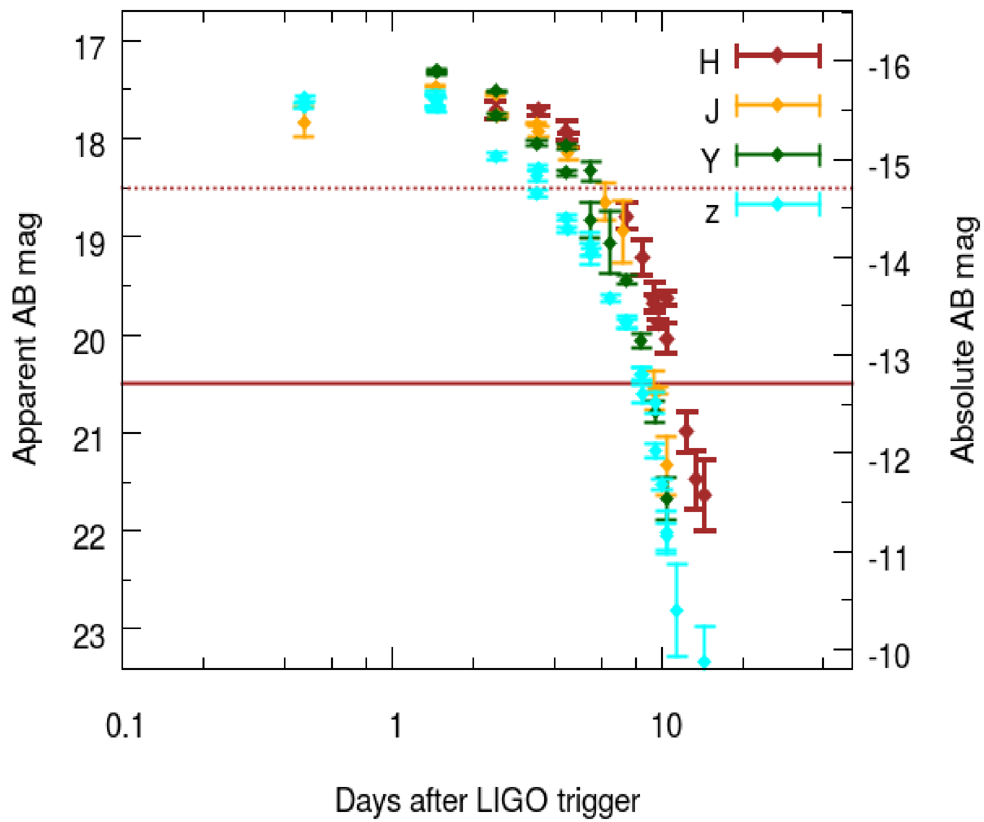


❑ Promptly and accurately localizing e.m. counterparts to GW events with THESEUS



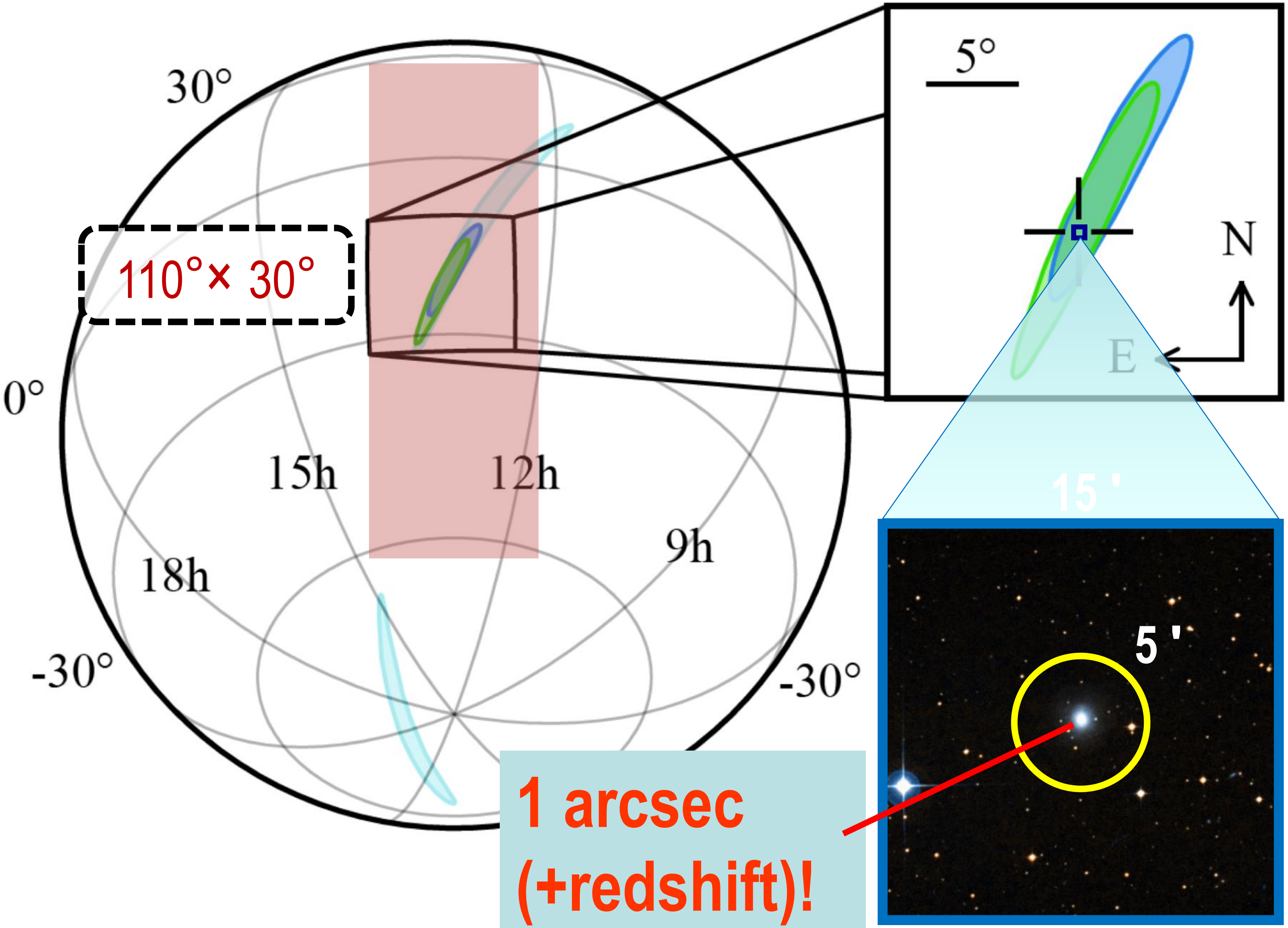
❑ **Detection, study, arcsecond localization and redshift of afterglow and kilonova emission from shortGRB/GW events with THESEUS/IRT**





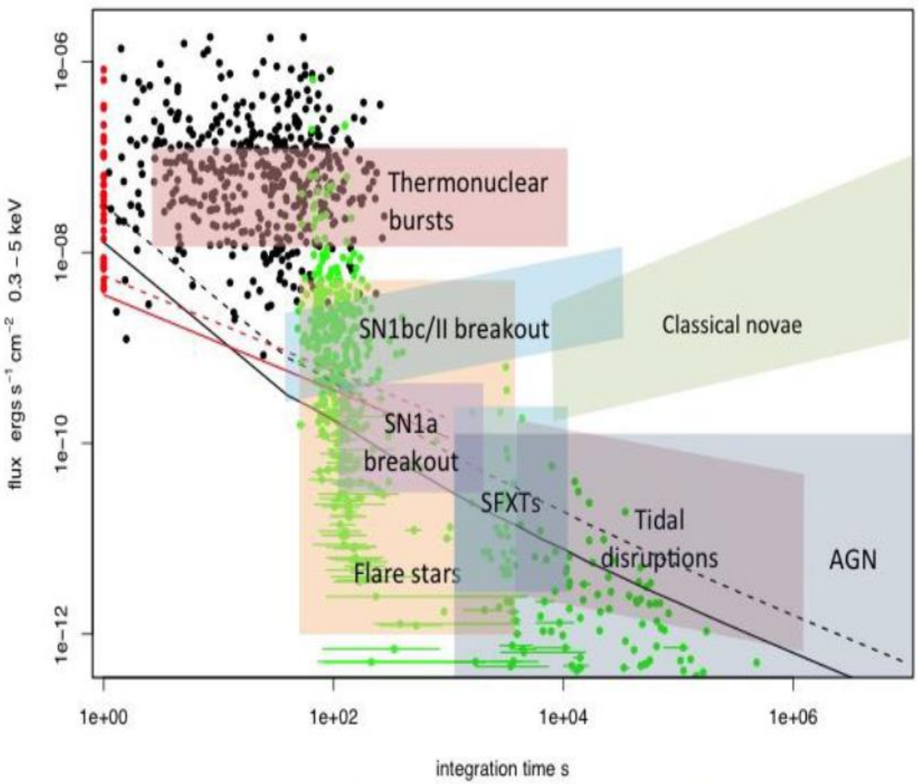
Precise localization is mandatory to activate large ground-based telescopes as VLT or ELT from which detailed spectral analysis will reveal the intrinsic nature of these newly discovered phenomena

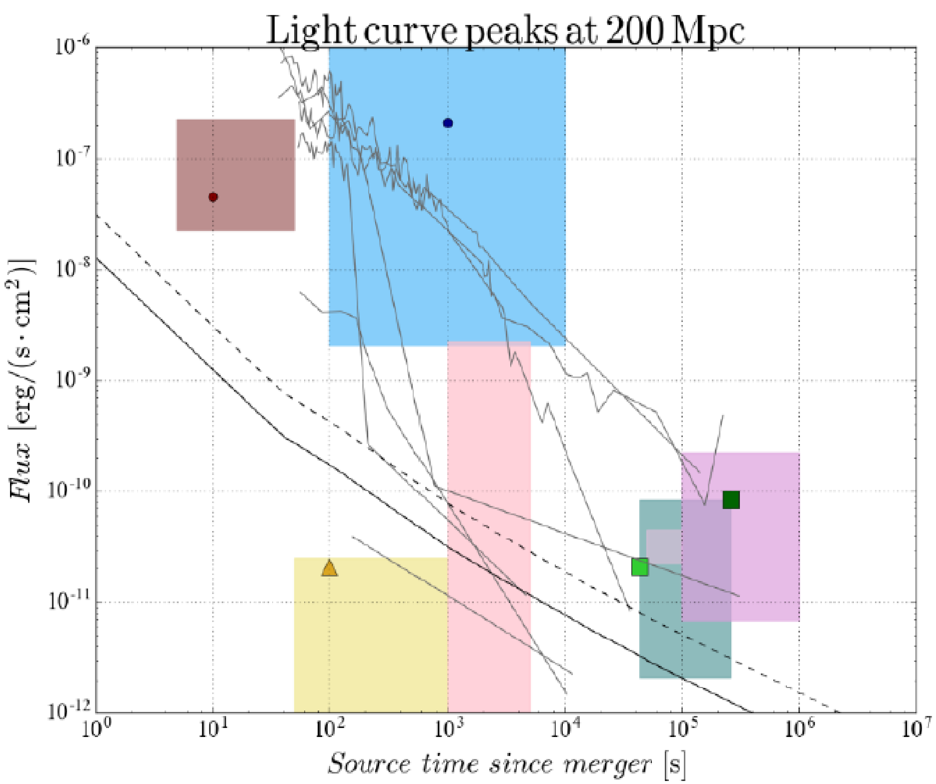
❑ Promptly and accurately localizing e.m. counterparts to GW events with THESEUS



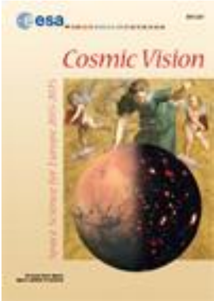
- THESEUS will also detect and localize down to 0.5-1 arcmin the soft X-ray short/long GRB afterglows, of NS-NS (BH) mergers and of many classes of galactic and extra-galactic transients

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





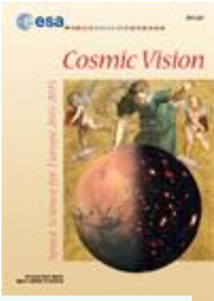
The ESA Cosmic Vision Programme



❖ 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, 2028)
- L3: LISA (gravitational wave observatory, 2034)
- M4: ARIEL (exoplanets, 2028)
- “S2” (ESA-CAS): SMILE (solar wind <–> magneto/ionosphere)

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)

THESEUS payload consortium (M5)

- **ITALY -** L.P. / project office, XGIS, Malindi antenna
- **UK -** SXI (optics + detectors + calibration) + S/W (SXI pipeline and remote contribution to SDC)
- **France -** IRT (coordination and IR camera, including cooler) **, ESA -** IRT optics + SXI CCDs
- **Germany, Poland** - Data Processing Units (DPU) for both SXI and XGS, Power Supply Units (PSU)
- **Switzerland**: SDC (data archiving, AOs, + pipelines) + IRT focal plane assembly
- **Other contributions: Spain** (XGIS collimators), **Belgium** (SXI integration and tests), **Czech Rep.** (mechanical structures and thermal control of SXI), **Ireland** (IRT focal plane)**, Hungary** (spacecraft interface simulator, PDHU, IRT calib.), **Slovenia** (X-band transponder, mobile ground station)
- **International optional contributions: USA:** (TDRSS, contrib. to XGS and IRT detectors), **Brazil:** Alcantara antenna, **China** (SXI, XGS), **Japan** ?
- **Industrial partners:** CGS (OHB group), GPAP

The key role of Italy in THESEUS

- Building on the unique heritage in GRB and transients science of the last 15-20 years (BeppoSAX, HETE-2, Swift, INTEGRAL, AGILE, Fermi, optical/NIR follow-up)

- Strengthening and exploiting the fundamental contribution to time domain and gravitational waves astrophysics (EGO-Virgo, EM follow-up with major facilities like VLT)

- Taking advantage of leadership in key enabling technologies based on R&D supported by INFN, INAF, ASI in the last years (e.g., silicon drift detectors + scintillators,)

The key role of Italy in THESEUS

- **Science: INAF** (Lead Proposer & coordination; IASF-BO, IASF-MI, Oss. Brera, IAPS, IASF-PA, Oss. Napoli, …), **Universities** (e.g., Univ. Ferrara, Pol. Milano, SNS Pisa, Univ. Federico II Napoli, Univ. Urbino, …), **INFN** (Trieste, Napoli, Bologna, …)

- **XGIS: INAF** (PI; IASF-BO, IASF-MI, IAPS, …), **INFN** (Trieste, Bologna, …), **Universities** (Politecnico Milano, Univ. Pavia, Univ. Ferrara, …), **FBK** Trento

- **Support for XGIS, Malindi ground station: ASI**

- **Industrial support for M5 proposal: OHB-Italia, GPAP**

Italian contribution: technological heritage

- **Scintillator-based detectors for high energy astrophysics:** BeppoSAX PDS & GRBM, INTEGRAL/PiCSIT, AGILE/MCAL (leading roles of INAF - IASF – Bologna) + R&D projects funded by ASI

- **SDD as detectors for high energy astrophysics and associated electronics (ASIC)**: R&D projects funded by INFN (e.g., REDSOX), ASI, INAF

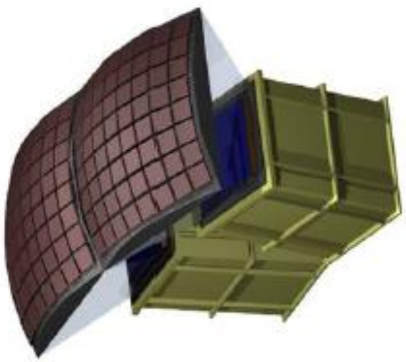
- **Concept and earliest testing of SDD+CsI ("siswich")** (e.g., Marisaldi et al. 2005)

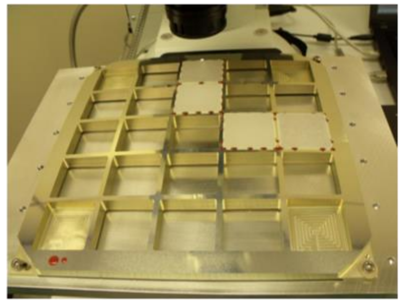
- **Concept studies of next generation GRB Monitors for future opportunities:** supported by ASI-INAF contract during 2006-2011 (p.i. L. Amati)

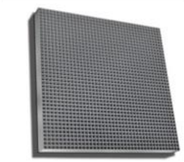
- **Innovation:** SDD+CsI detection system, ASIC

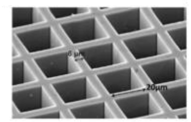
- **Development and testing of an XGIS module prototype is supported by TECNO INAF 2014 (P.I. L. Amati, INAF – IASF Bologna)**

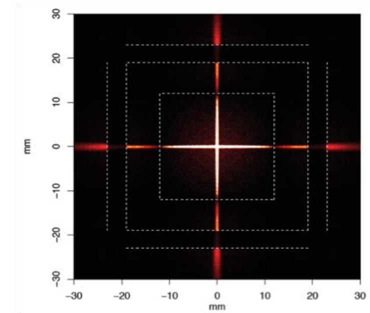
The Soft X-ray Imager (SXI)











4 DUs, each has a 31 x 26 degree FoV

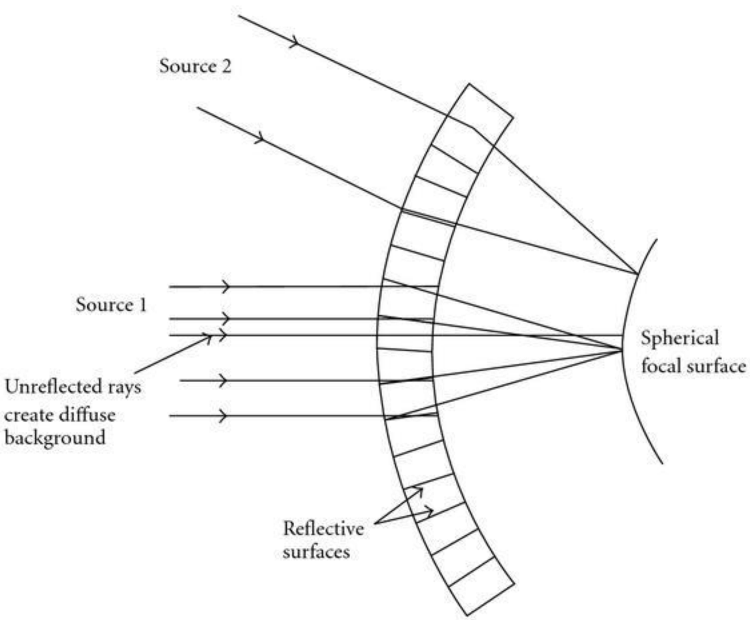
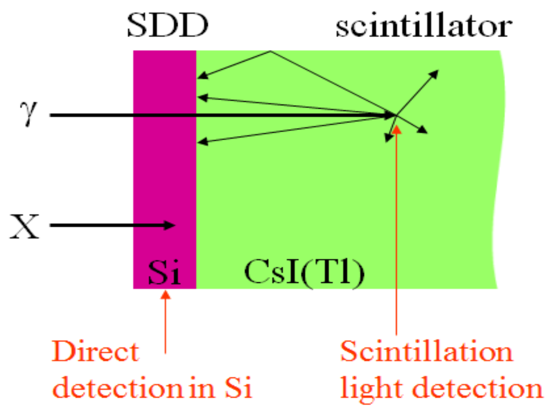
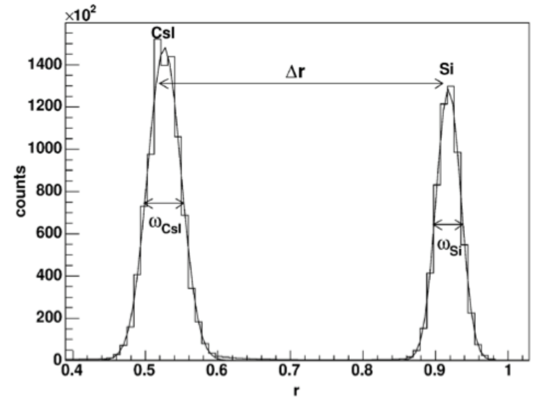


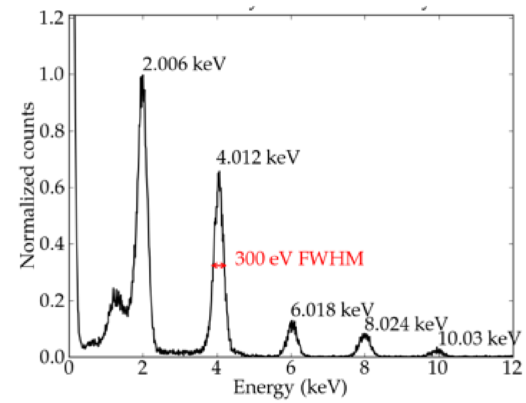
Table 4 : : SXI detector unit main physical characteristics

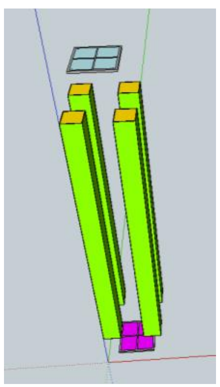
Energy band (keV)	0.3-5
Telescope type:	Lobster eye
Optics aperture (mm2)	320x320
Optics configuration	8x8 square pore MCPs
MCP size (mm2)	40x40
Focal length (mm)	300
Focal plane shape	spherical
Focal plane detectors	CCD array
Size of each CCD (mm2)	81.2x67.7
Pixel size (µm)	18
Pixel Number	4510 x 3758 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

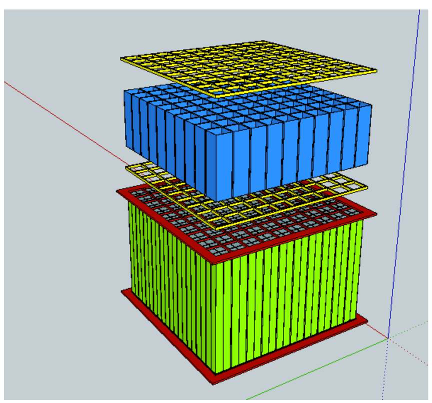
The X-Gamma-rays spectrometer (XGS)

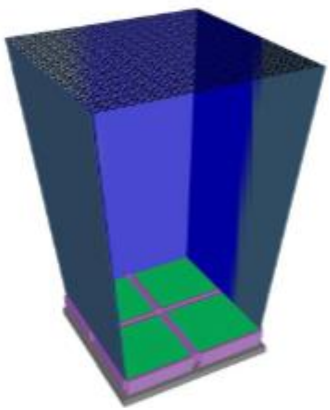








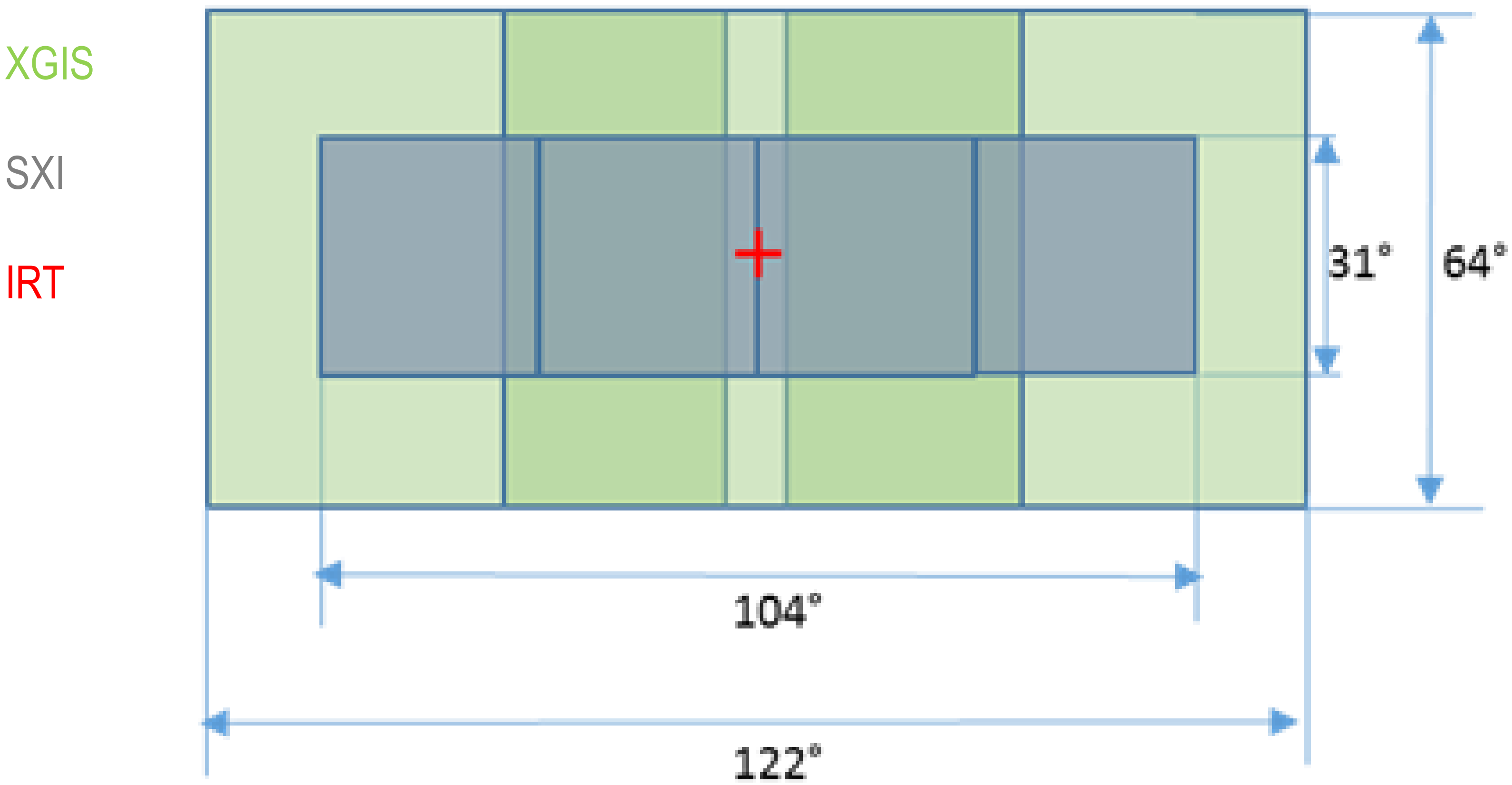




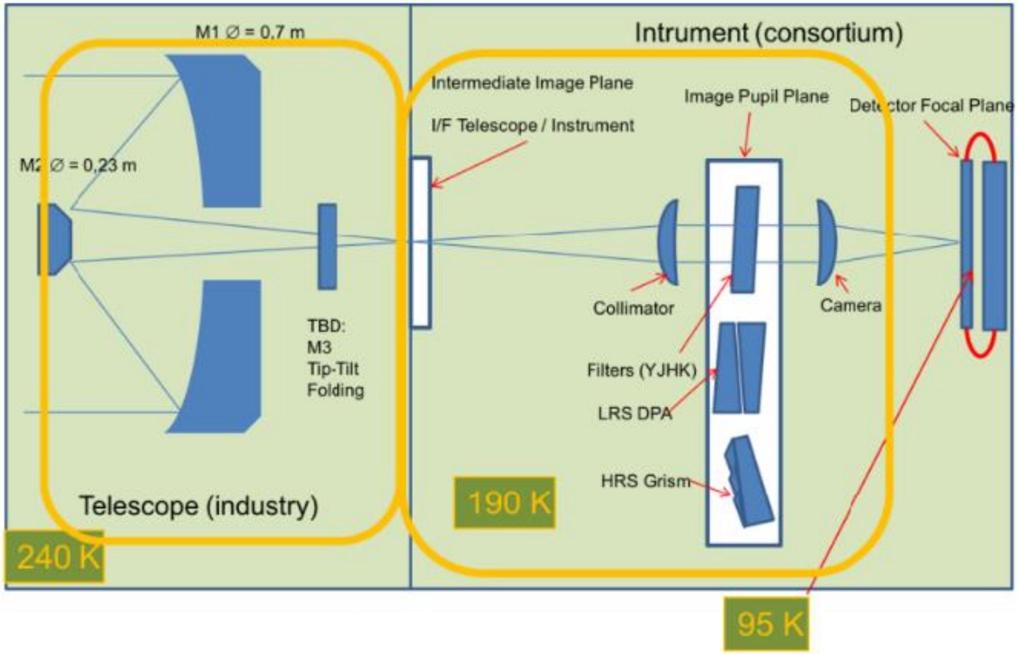
Energy band	*2 keV – 20 MeV*
# detection plane modules	*4*
# of detector pixel / module	*32x32*
pixel size (= mask element size)	*5x5 mm*
Low-energy detector (2-30 keV)	*Silicon Drift Detector 450 μm thick*
High energy detector (> 30 keV)	*CsI(Tl) (3 cm thick)*
Discrimination Si/CsI(Tl) detection	*Pulse shape analysis*
Dimension [cm]	*50x50x85*
Power [W]	*30,0*
Mass [kg]	*37.3*

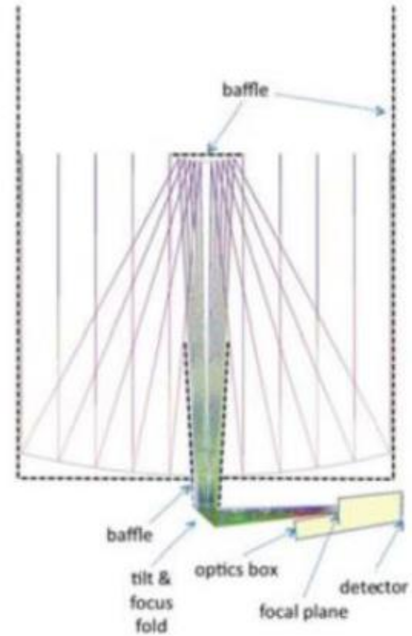
	2-30 keV	30-150 keV	>150 keV
Fully coded FOV	9 x 9 deg²		
Half sens. FOV	50 x 50 deg²	50 x 50 deg² (FWHM)	
Total FOV	64 x 64 deg²	85 x 85 deg² (FWZR)	2π sr
Ang. res	25 arcmin		
Source location accuracy	~5 arcmin (for >6 σ source)		
Energy res	200 eV FWHM @ 6 keV	18 % FWHM @ 60 keV	6 % FWHM @ 500 keV
Timing res.	1 μsec	1 μsec	1 μsec

Field of view

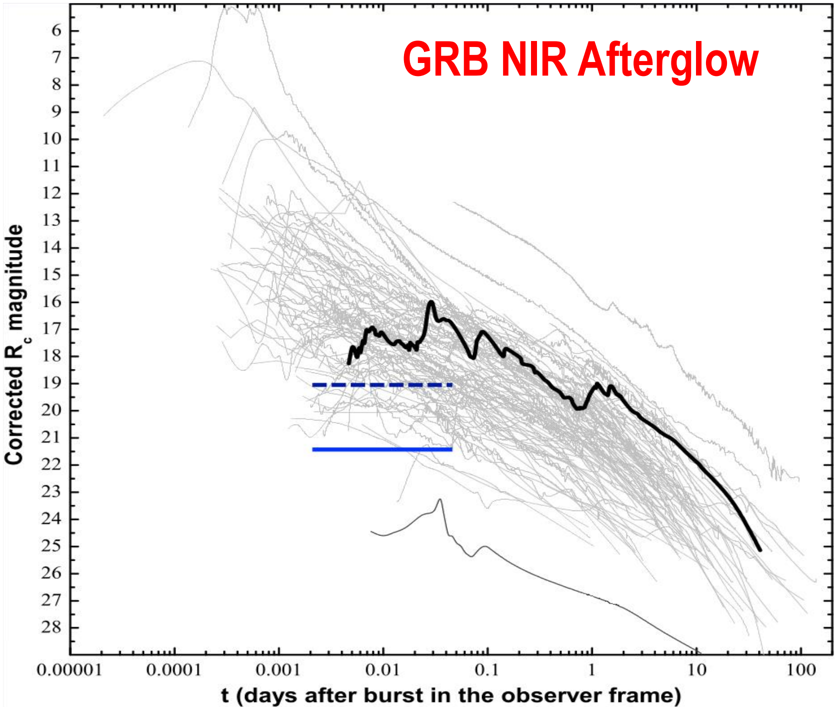


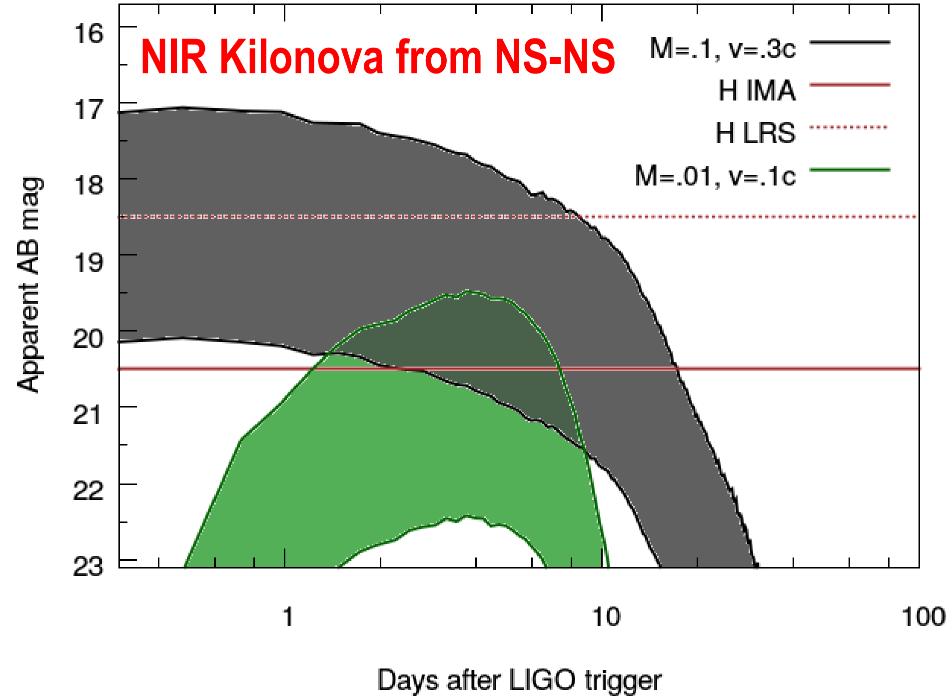
The InfraRed Telescope (IRT)

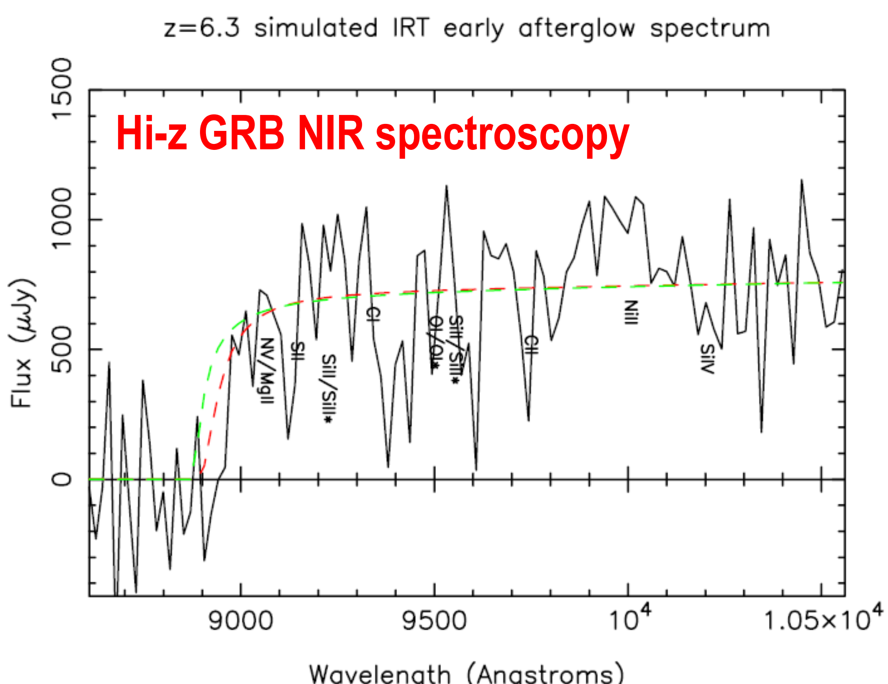


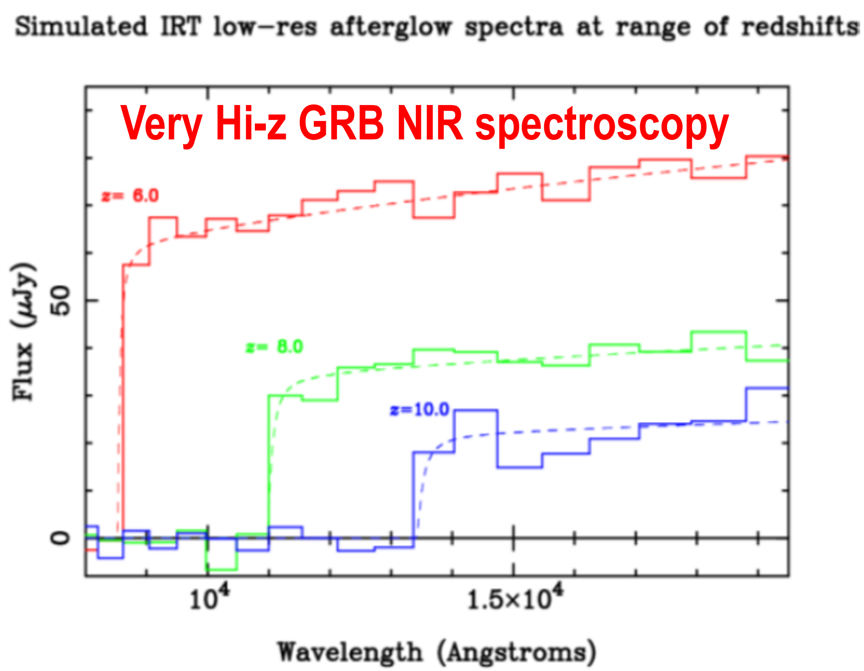


Telescope type:	Cassegrain		
Primary & Secondary size:	700 mm & 230 mm		
Material:	SiC (for both optics and optical tube assembly)		
Detector type:	Teledyne Hawaii-2RG 2048 x 2048 pixels (18 μm each)		
Imaging plate scale	0".3/pixel		
Field of view:	10' x 10'	10' x 10'	5' x 5'
Resolution (λ/Δλ):	2-3 (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		


GRB NIR Afterglow
Corrected R_c magnitude
t (days after burst in the observer frame)
0.00001
0.0001
0.001
0.01
0.1
1
10
100


NIR Kilonova from NS-NS
M=.1, v=.3c
H IMA
H LRS
M=.01, v=.1c
Apparent AB mag
Days after LIGO trigger
1
10
100


z=6.3 simulated IRT early afterglow spectrum
Hi-z GRB NIR spectroscopy
Flux (μJy)
Wavelength (Angstroms)
NV/MgII
SII
SiII/SiII*
CI
OI/OI*
SiII/SiII*
CII
NiII
SiIV
9000
9500
10^4
1.05×10^4


Simulated IRT low-res afterglow spectra at range of redshifts
Very Hi-z GRB NIR spectroscopy
z= 6.0
z= 8.0
z=10.0
Flux (μJy)
Wavelength (Angstroms)
10^4
1.5×10^4

FUNCTIONAL SUBSYSTEMS	Nominal Avg Power (Watt)	Margin (%)	Margin (Watt)	Current Avg Power (Watt)
SERVICE MODULE				
AOCS	79	10%	8	87
DATA HANDLING	37	10%	4	41
EPS	39	10%	4	43
PROPULSION	1	10%	0	1
THERMAL CONTROL (incl. PLM)	83	20%	17	100
PDHU + X BAND	42	10%	4	46
Total Service Module Power	282	13%	36	318
PAYLOAD MODULE				
SXI	93	20%	19	111
XGIS	75	20%	15	90
IRT	96	20%	19	115
NGRM+TBU	93	20%	19	111
I-DHU + i-DU (TBC)	25	20%	5	30
Total Payload Module Power	381	20%	76	457

Satellite Nominal Power (W)	
Service Module	282
Payload Module	381
20% System Margin	132
Harness Loss	18
Total power with losses and margin	813

Table 21: Cost Estimates to ESA

Activity	CAC (M€)
ESA Project Office	54
Satellite (incl. 20% contingency)	165
ESA contribution to P/L	120
Launch (VEGA)	45
Ground Segment & Operations	84
Contingency (15% of subtotal)	70
Total cost for ESA	538

THESEUS mission profile

- Low-Earth Orbit (LEO), (< 5°, ~600 km)
- Rapid slewing bus (>10°/min)
- Prompt downlink (< 10-20s)
- Sky fraction that can be observed: 64%