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 (arXiv:1710.04638)
Stratta et al. 2017 (arXiv:1712.08153)

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

Proceedings preprints on the arXiv in early February

(Mem.SAIt, Vol. 89 – N.1 - 2018)

THESEUS

Transient High Energy Sky and Early Universe Surveyor

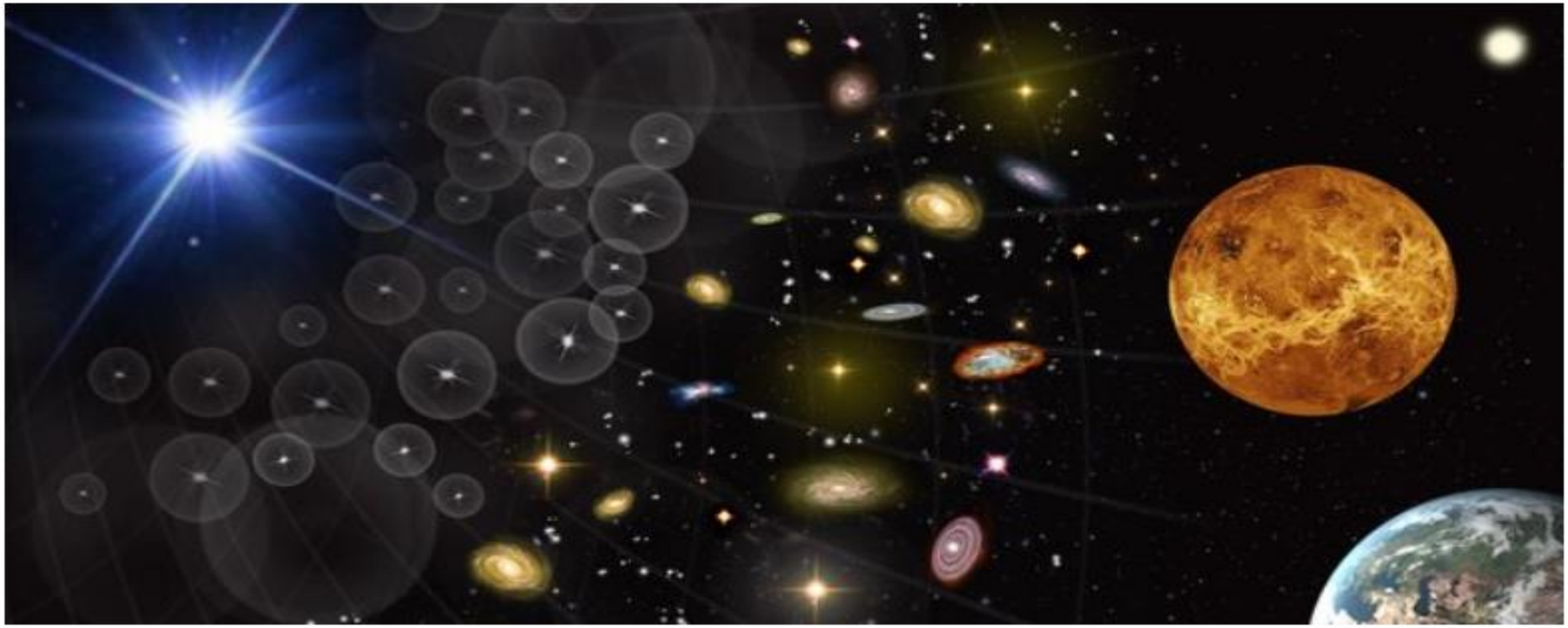
Lead Proposer (ESA/M5): Lorenzo Amati (INAF – IASF Bologna, Italy)

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

THESEUS selected by ESA for Phase 0/A study !!!!! (2018-2021)



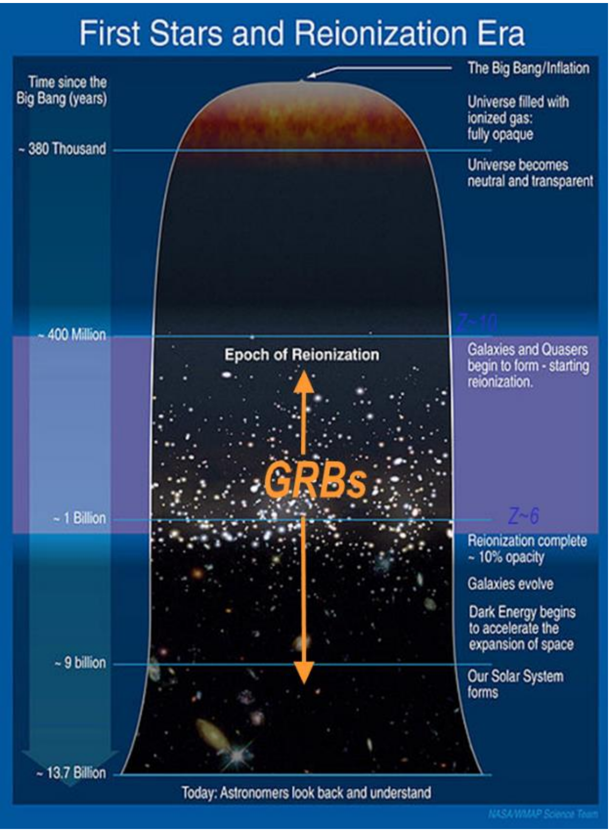
M5 mission themes

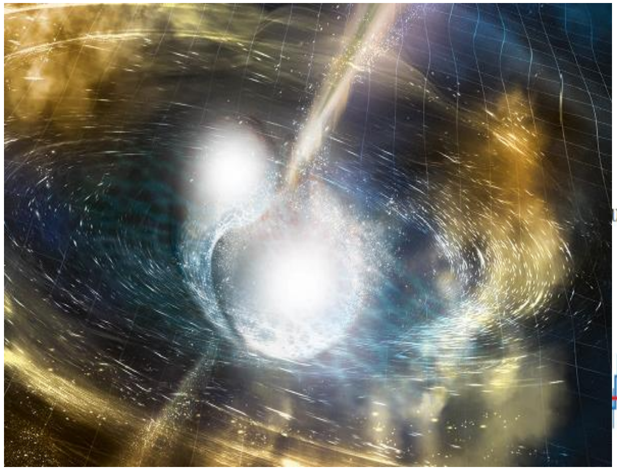
ESA SELECTS THREE NEW MISSION CONCEPTS FOR STUDY

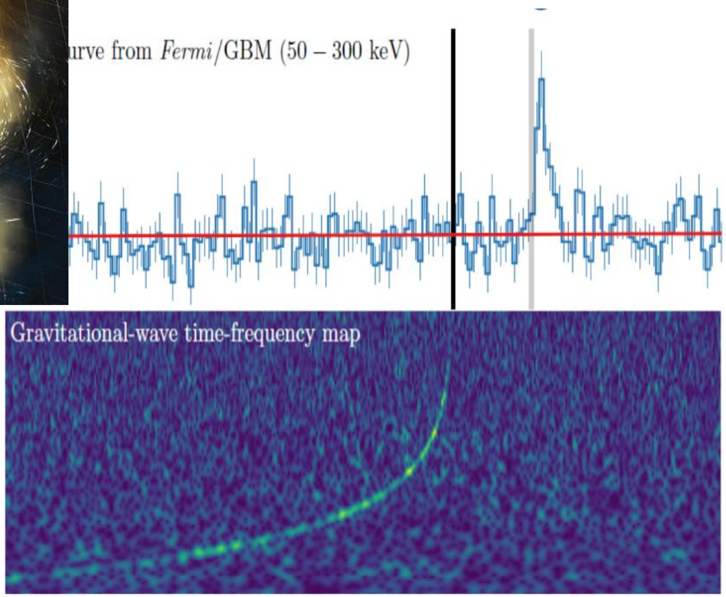
7 May 2018 A high-energy survey of the early Universe, an infrared observatory to study the formation of stars, planets and galaxies, and a Venus orbiter are to be considered for ESA's fifth medium class mission in its Cosmic Vision science programme, with a planned launch date in 2032.

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

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)

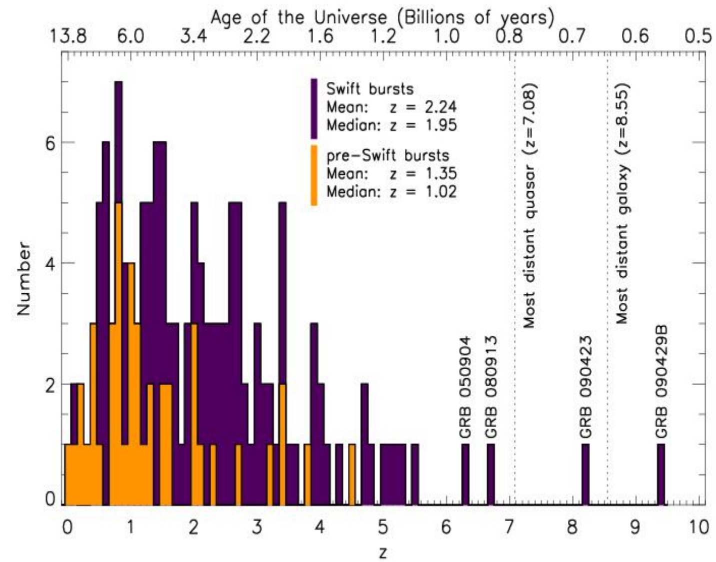




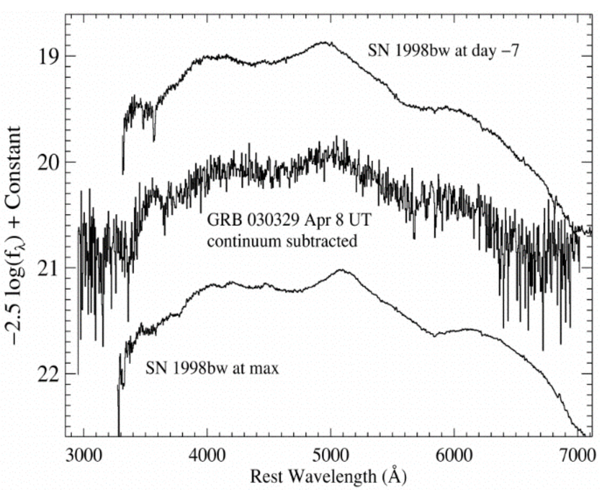


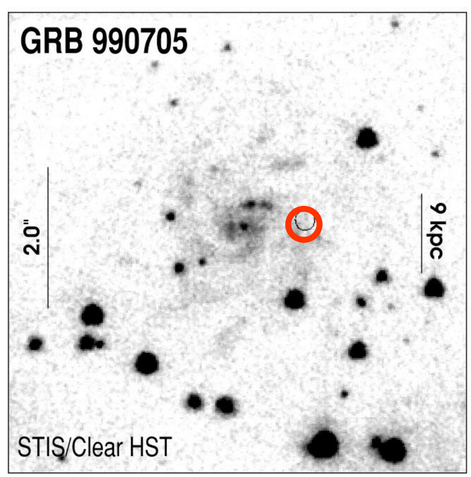
Shedding light on the early Universe with GRBs

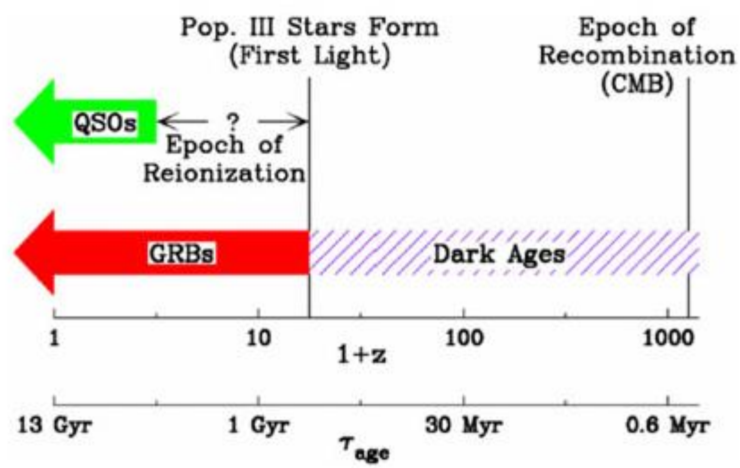
Because of their huge luminosities, mostly emitted in the X and gamma-rays, their redshift distribution extending at least to z ~9 and their association with explosive death of massive stars and star forming regions, GRBs are unique and powerful tools for investigating the early Universe: **SFR evolution,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



GRBs in Cosmological Context





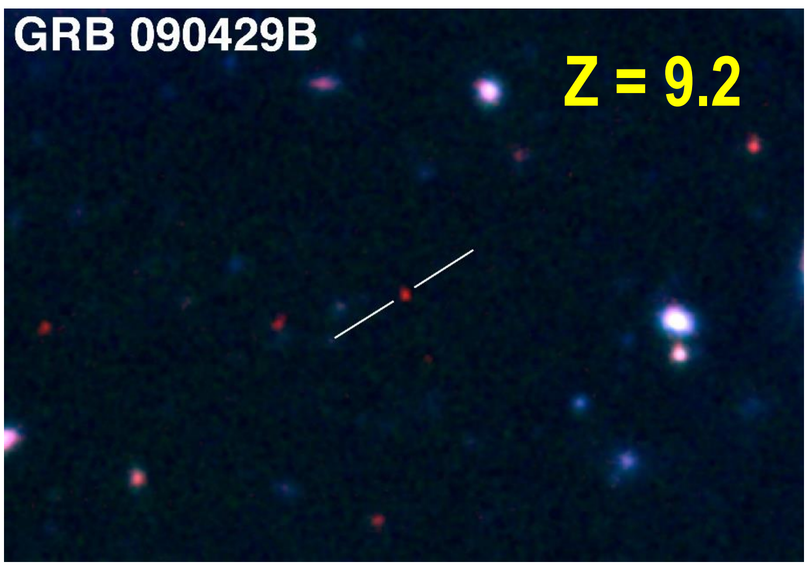


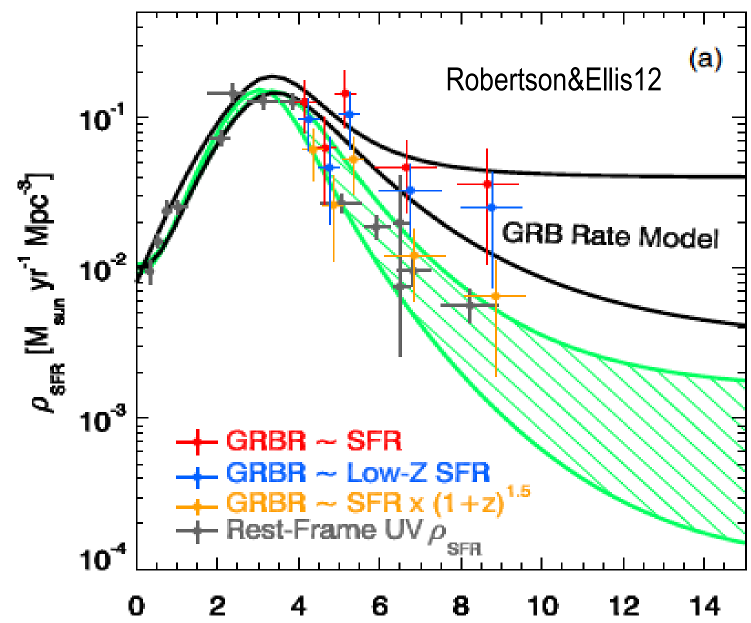
Lamb and Reichart (2000)

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

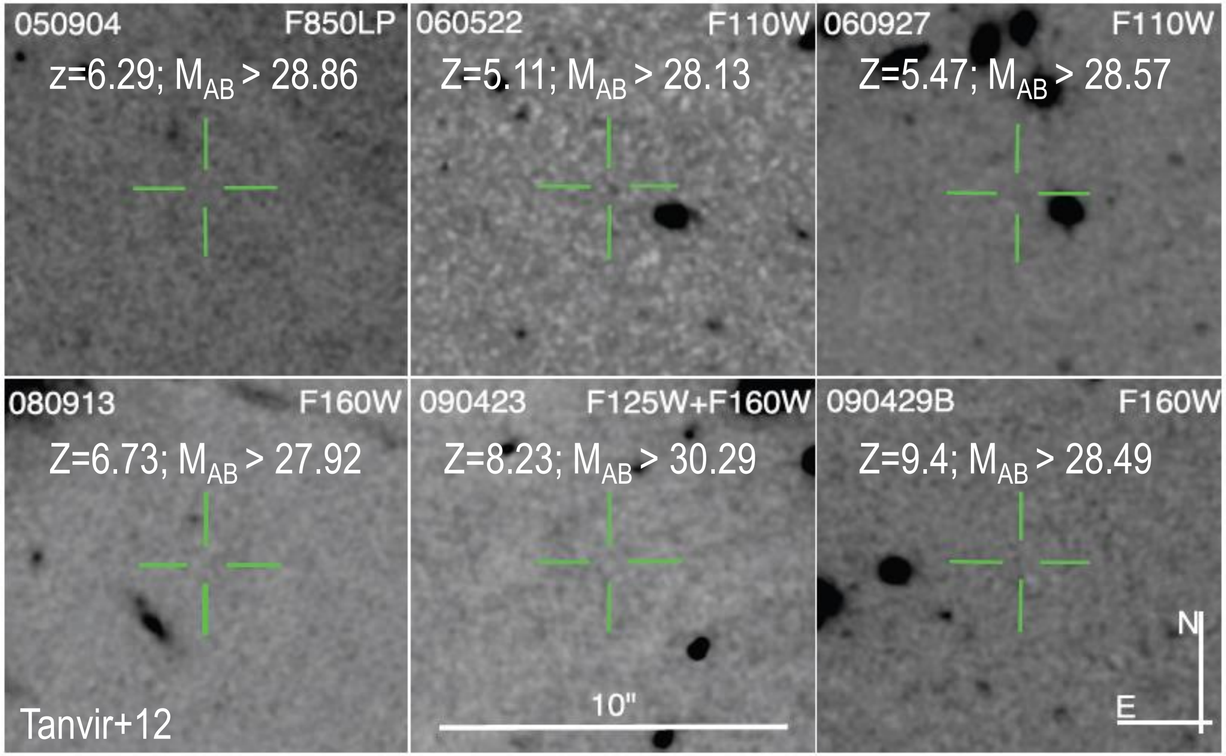
- measure independently the **cosmic star–formation rate**, even beyond the limits of current and future galaxy surveys

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





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

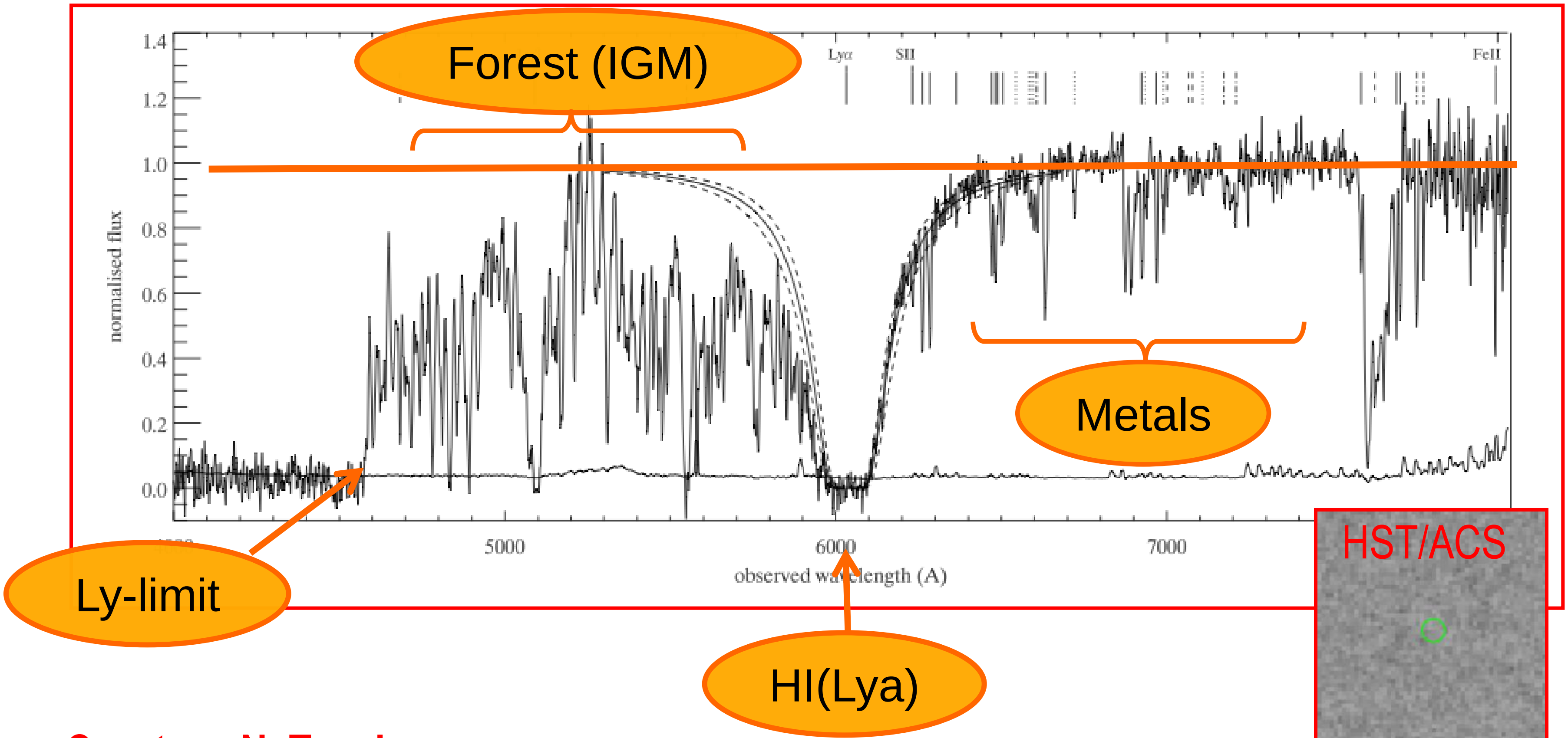


Robertson&Ellis12

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

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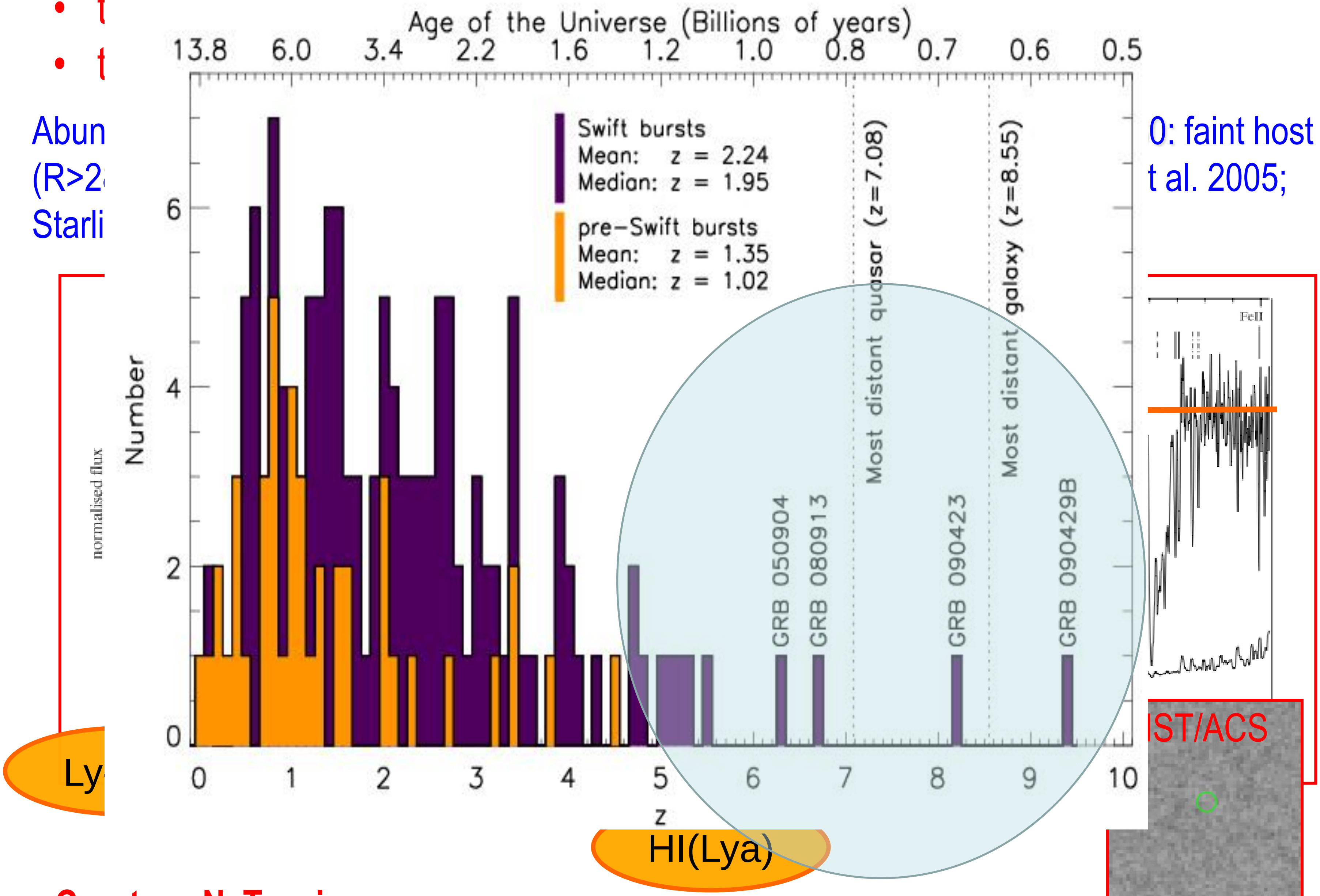
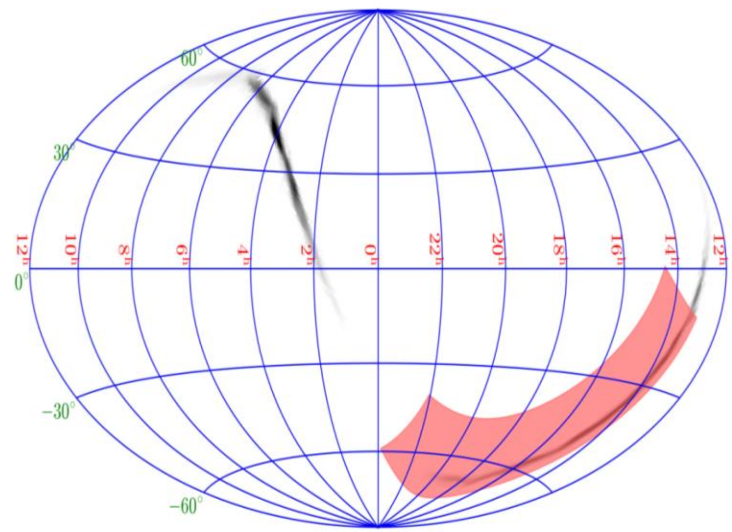


Courtesy N. Tanvir

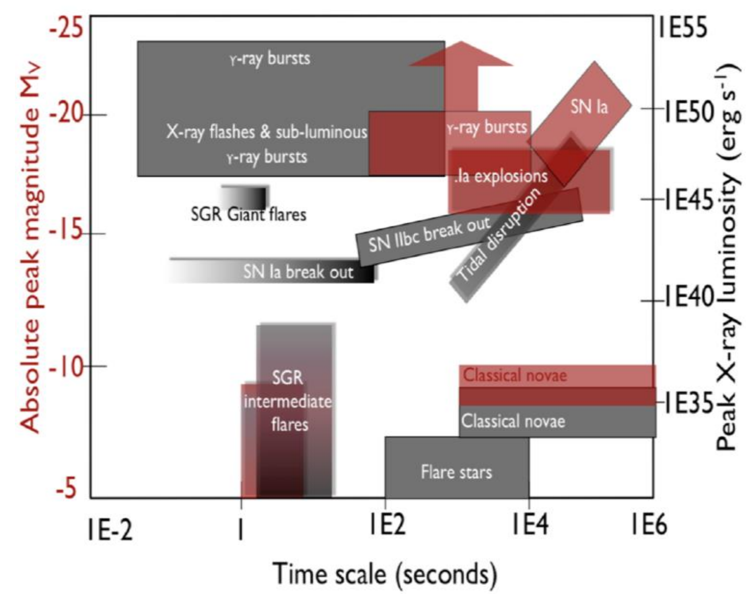
Monitoring the multi-messenger transient sky

- **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;**

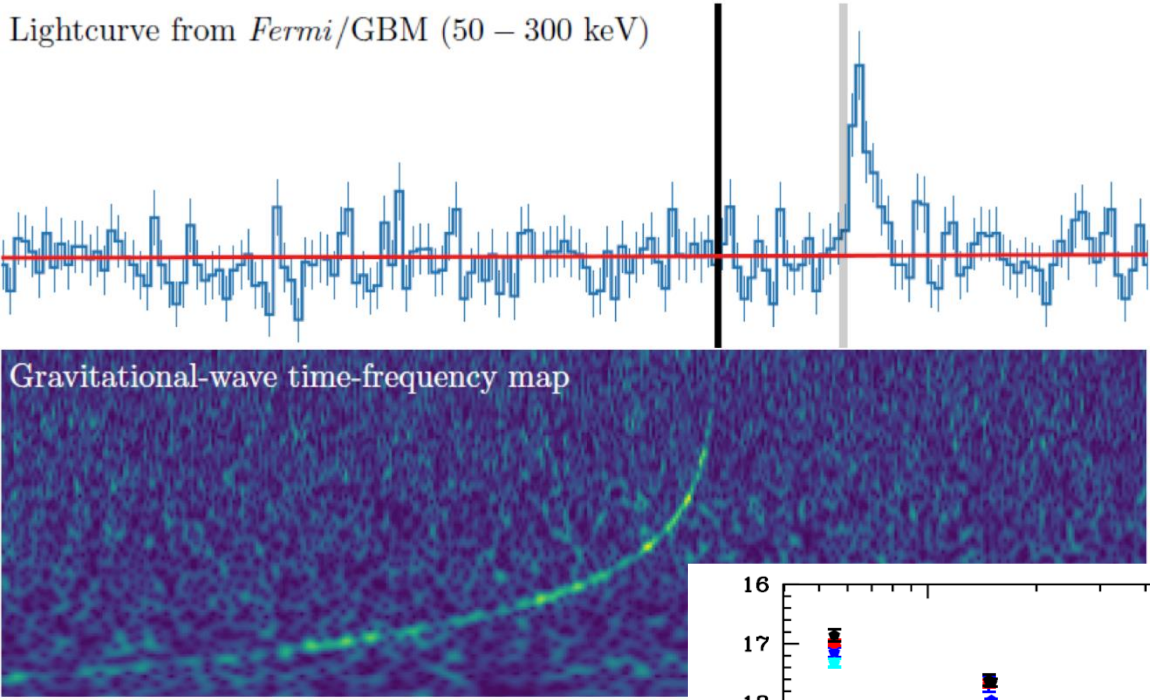


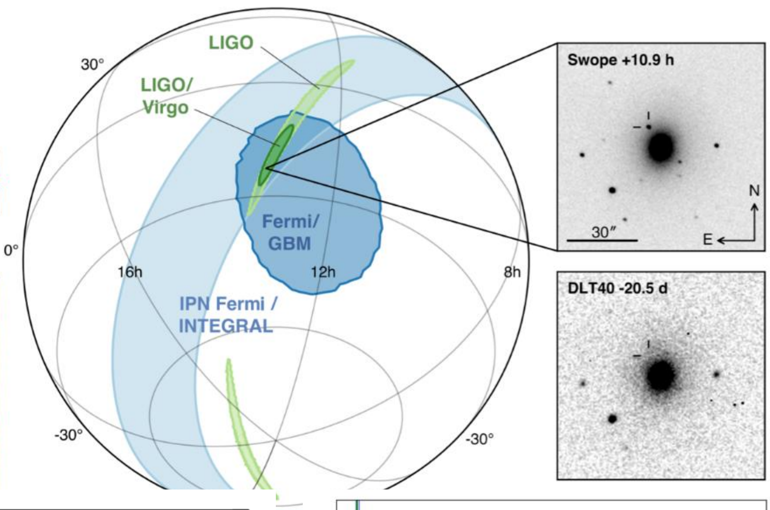
- Provide real-time triggers and accurate (~1 arcmin within a few seconds; ~1" within a few minutes) **high-energy transients for follow-up with next-generation optical-NIR (E-ELT, JWST if still operating), radio (SKA), X-rays (ATHENA), TeV (CTA) telescopes; synergy with LSST**

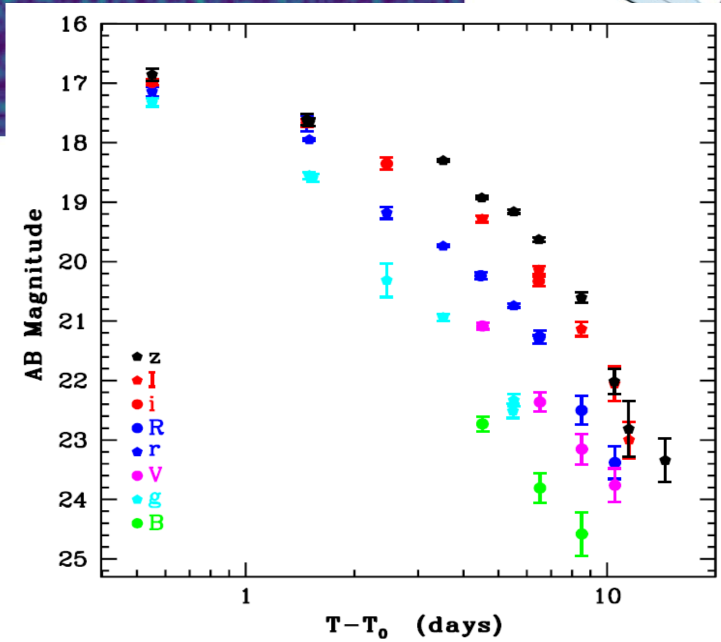
- Provide a fundamental step forward in the comprehension of the physics of various classes of transients and **fill the present gap in the discovery space of new classes of transients events**

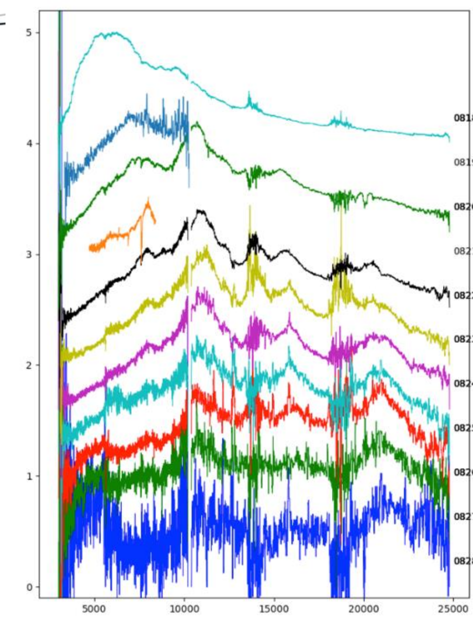


LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars



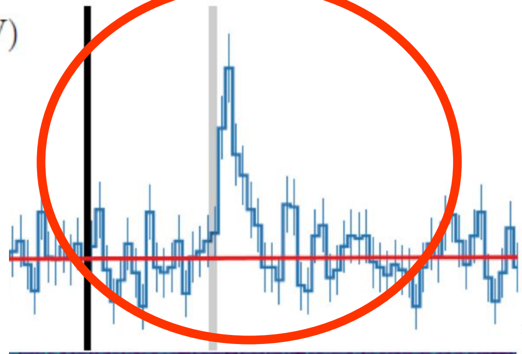


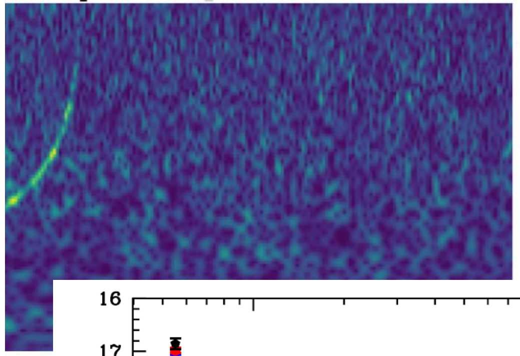


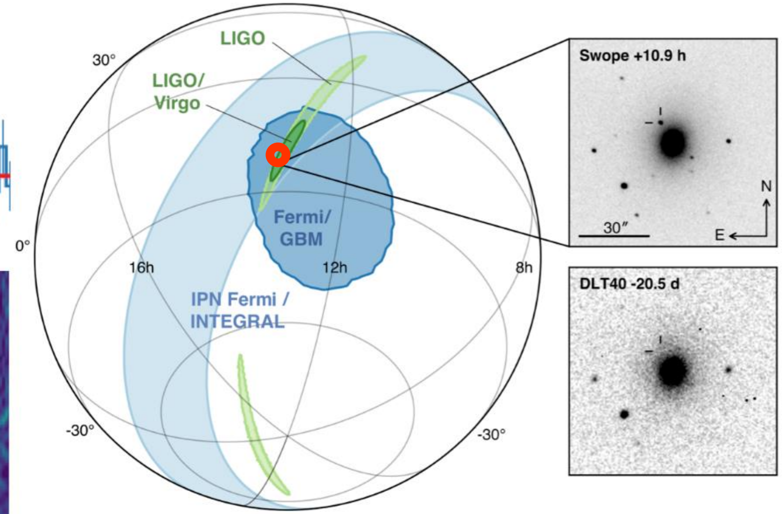


LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars

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

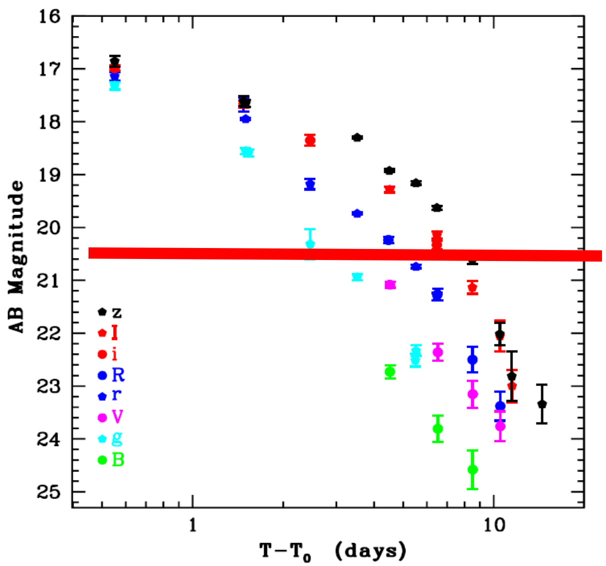


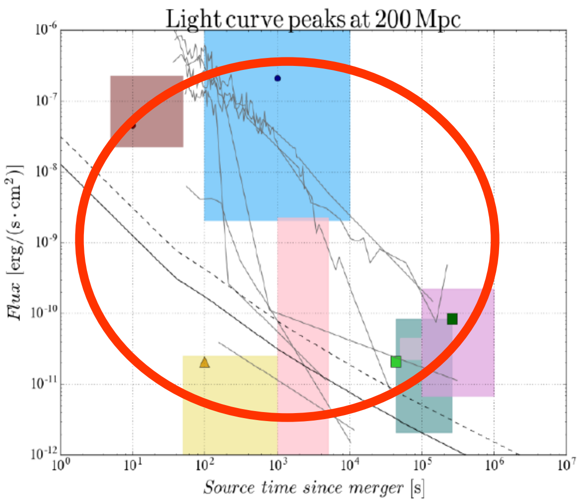




THESEUS:

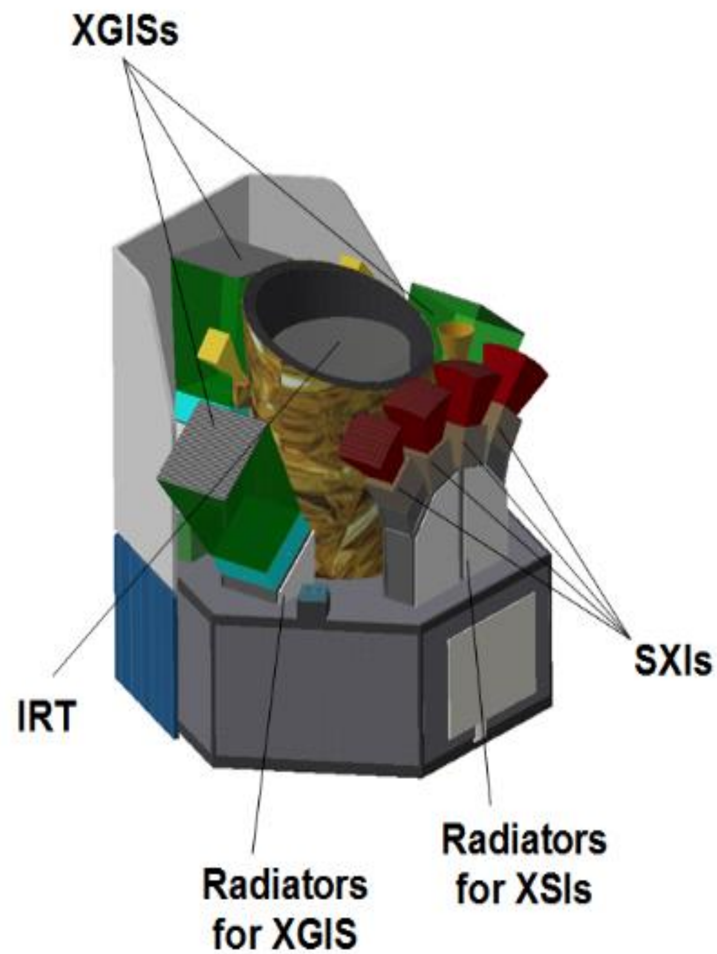
- ✓ short GRB detection over large FOV with arcmin localization
- ✓ Kilonova detection, arcsec localization and characterization
- ✓ Possible detection of weaker isotropic X-ray emission





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)**

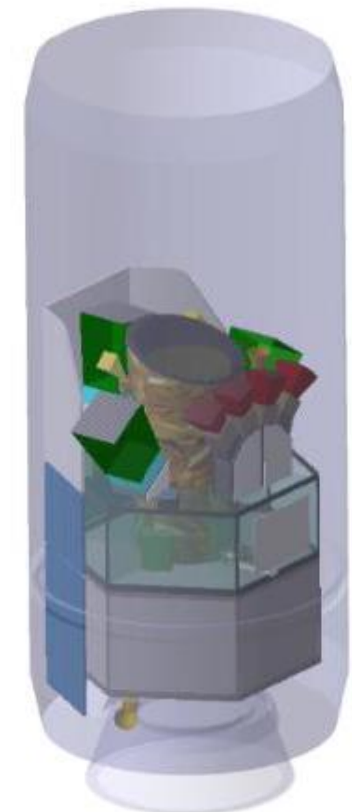


LEO (< 5°, ~600 km)
Rapid slewing bus
Prompt downlink

Mission profile and budgets

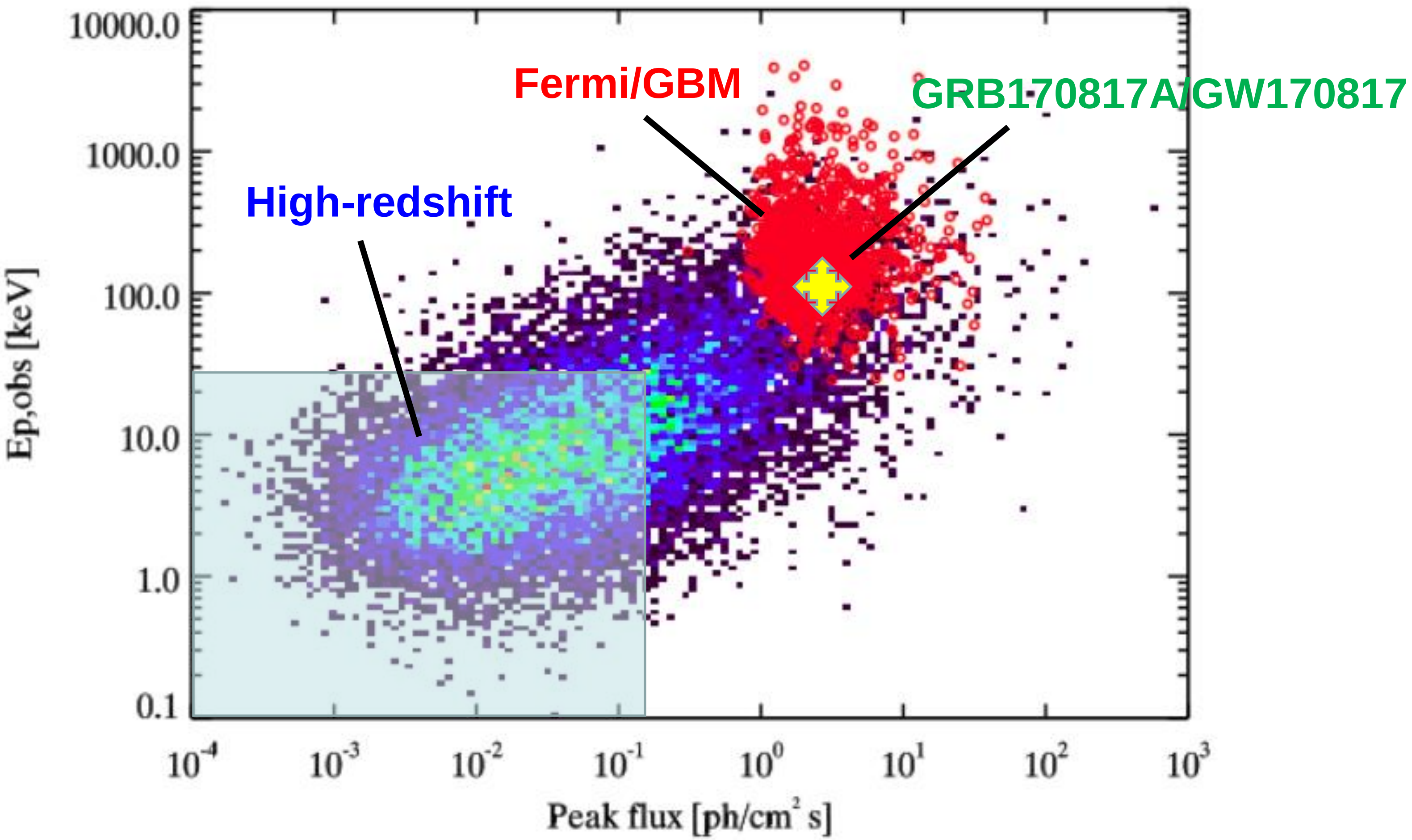
FUNCTIONAL SUBSYSTEMS	Basic Mass (kg)	Margin (%)	Margin (kg)	Current Mass (Kg)
SERVICE MODULE				
AOCS (gyro, RW, SAS, ST)	115,1	10%	11,5	126,6
PDHU + X BAND	31,4	10%	3,1	34,5
DATA HANDLING	24,4	5%	1,2	25,6
EPS (PCU, Battery, SA)	85,1	10%	8,5	93,6
SYSTEM STRUCTURE	129,1	10%	12,9	142,0
PROPULSION	17,0	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**



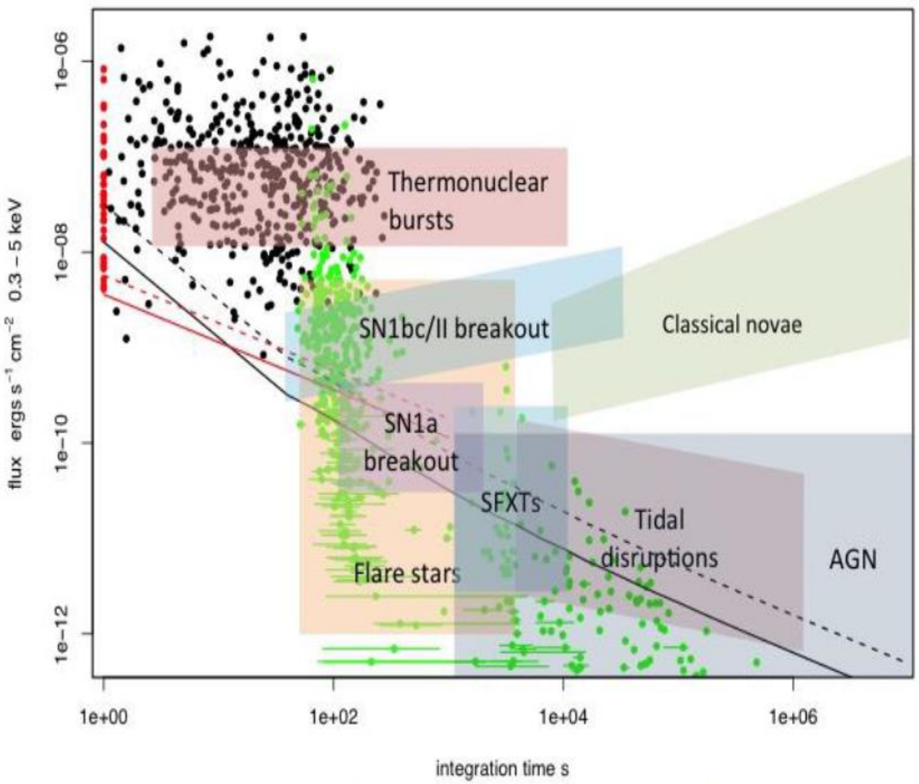
- Launch with VEGA-C into LEO (< 5°, ~600 km)
- **Spacecraft slewing capabilities (30° < 5 min)**
- **Prompt downlink options : WHF network (options: IRIDIUM network, ORBCOMM, NASA/TDRSS, ESA/EDRS)**

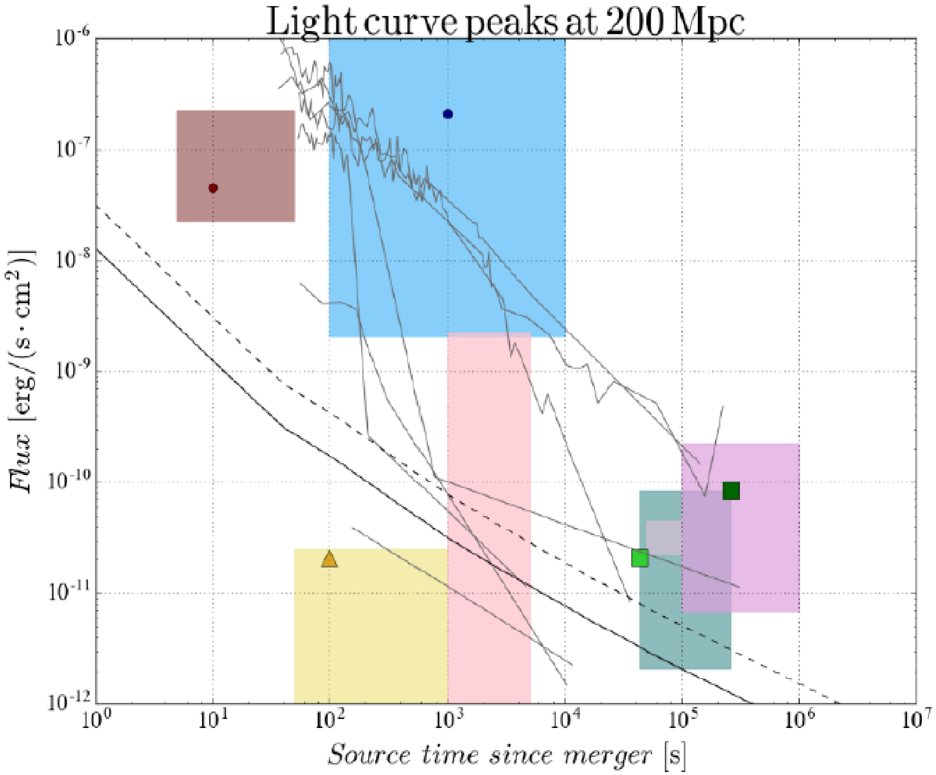
❑ THESEUS will have the ideal combination of instrumentation and mission profile for detecting all types of GRBs (long, short/hard, weak/soft, high-redshift), localizing them from a few arcmin down to arsec and measure the redshift for a large fraction of them



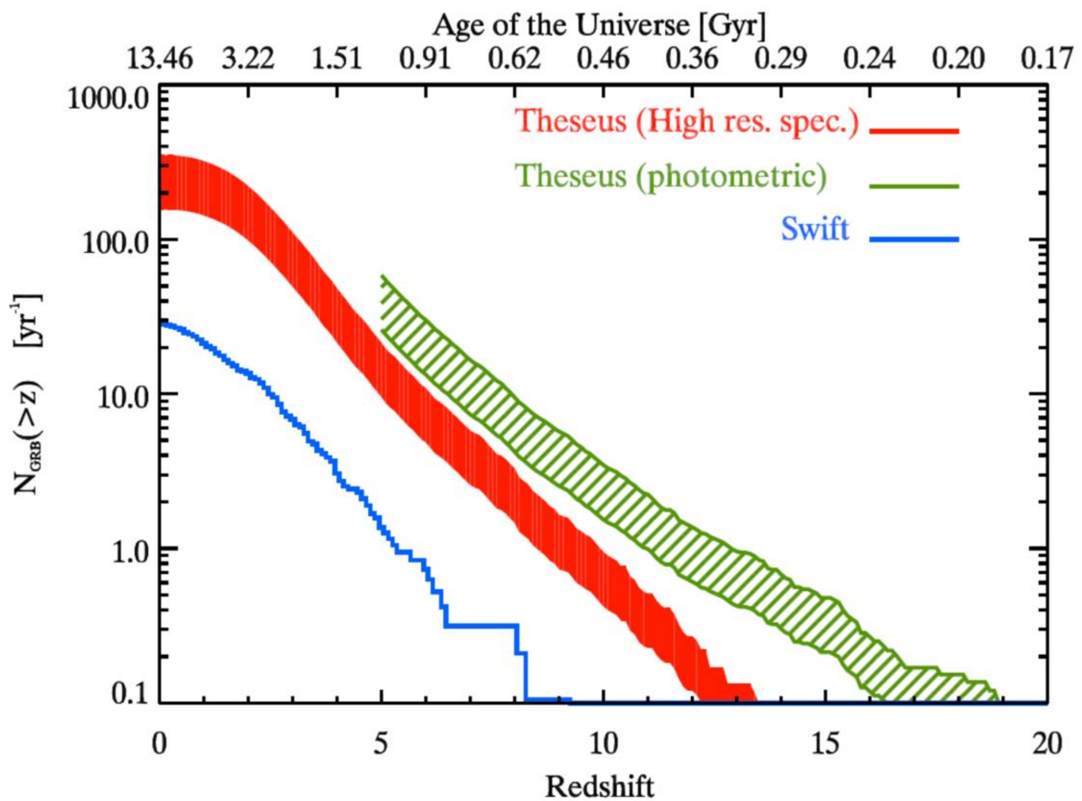
- THESEUS will also detect and localize down to 0.5-1 arcmin the soft X-ray short/long GRB afterglows, of NS-NS (BH) mergers and of many classes of galactic and extra-galactic transients

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





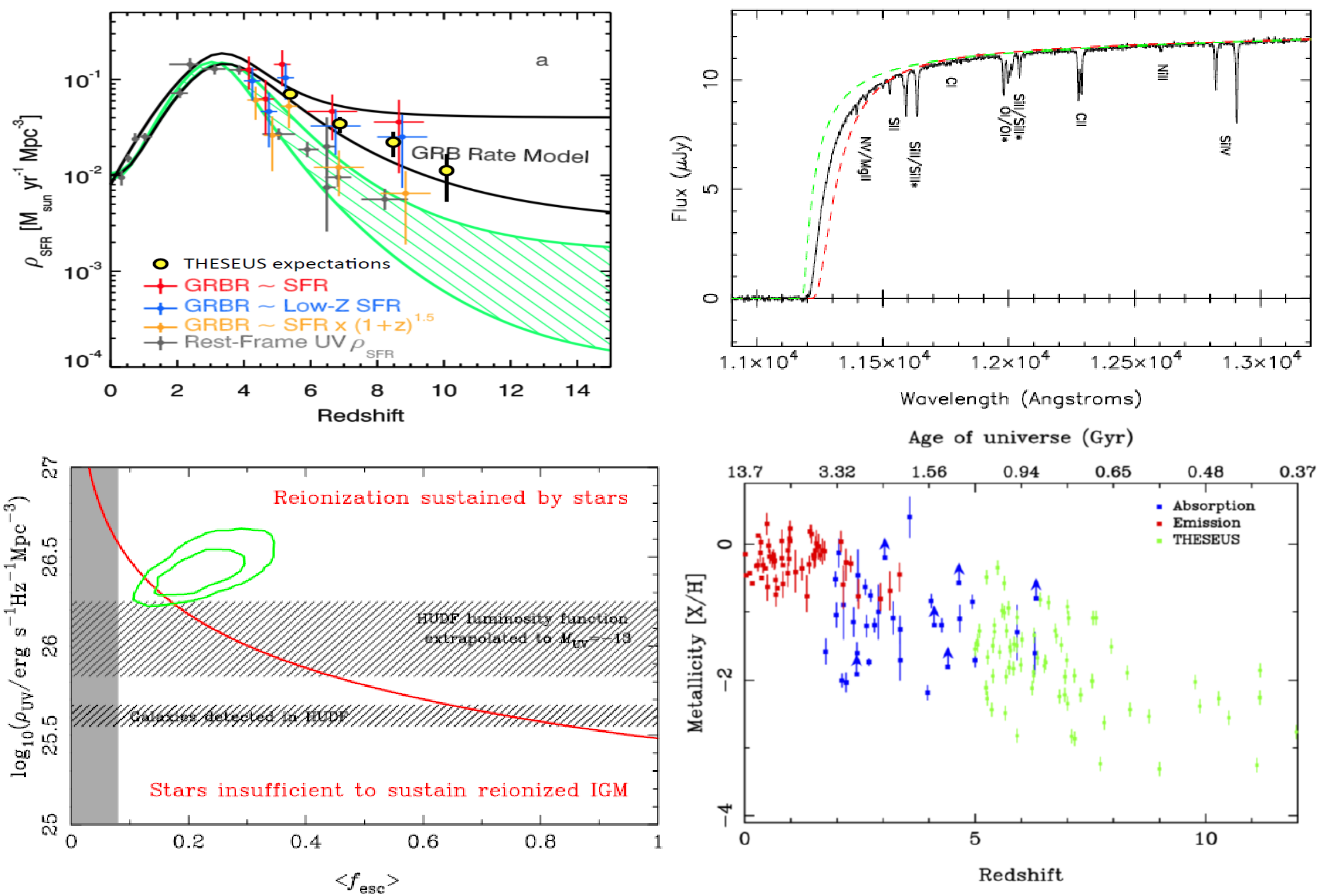
❑ Shedding light on the early Universe with GRBs

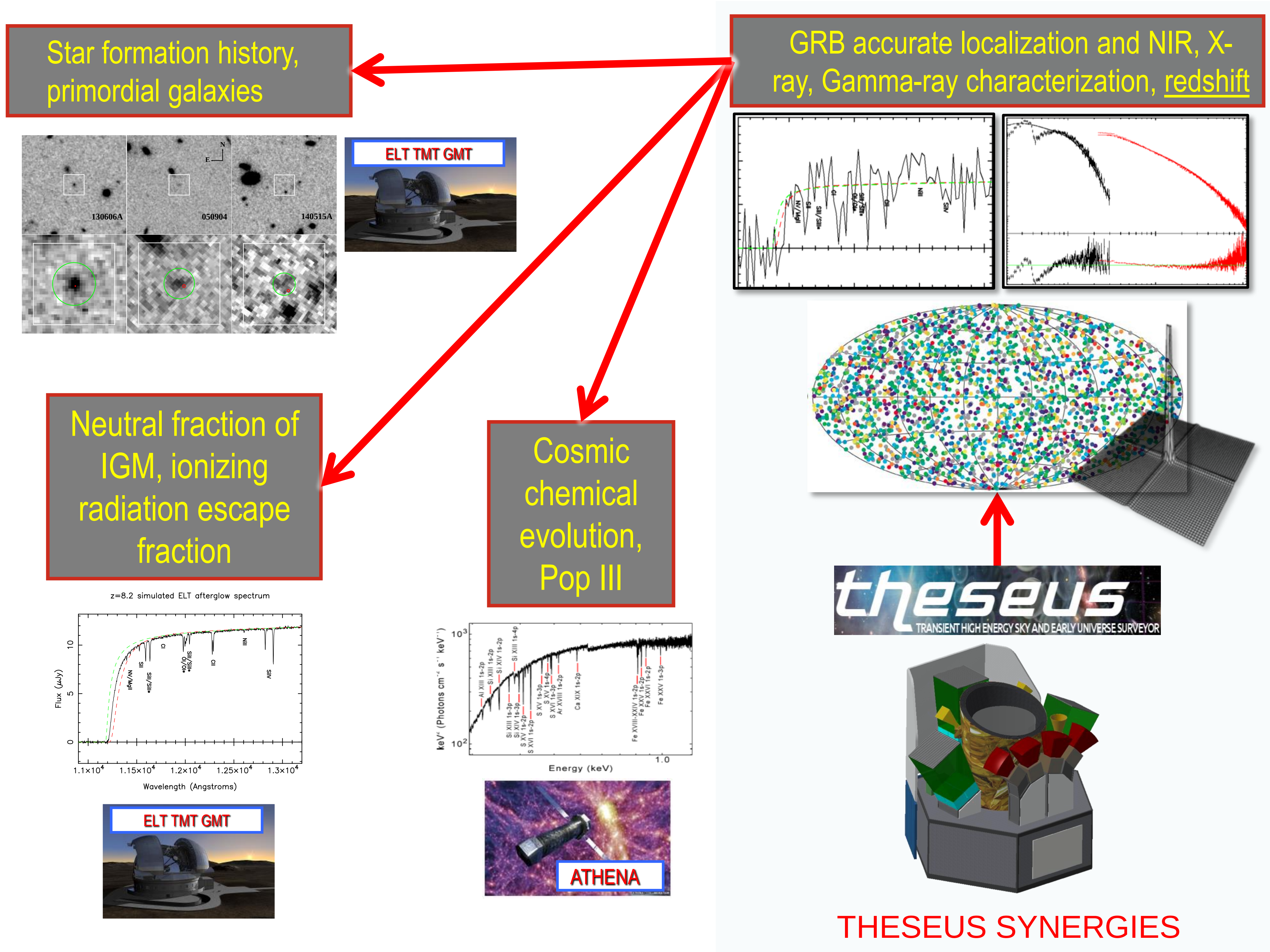


THESEUS GRB#/yr	All	z > 5	z > 8	z > 10
Detections	387 - 870	25 – 60	4 – 10	2 - 4
Photometric z		25 – 60	4 – 10	2 - 4
Spectroscopic z	156 - 350	10 - 20	1 - 3	0.5 - 1

❑ Shedding light on the early Universe with GRBs

z=8.2 simulated E−ELT afterglow spectra





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
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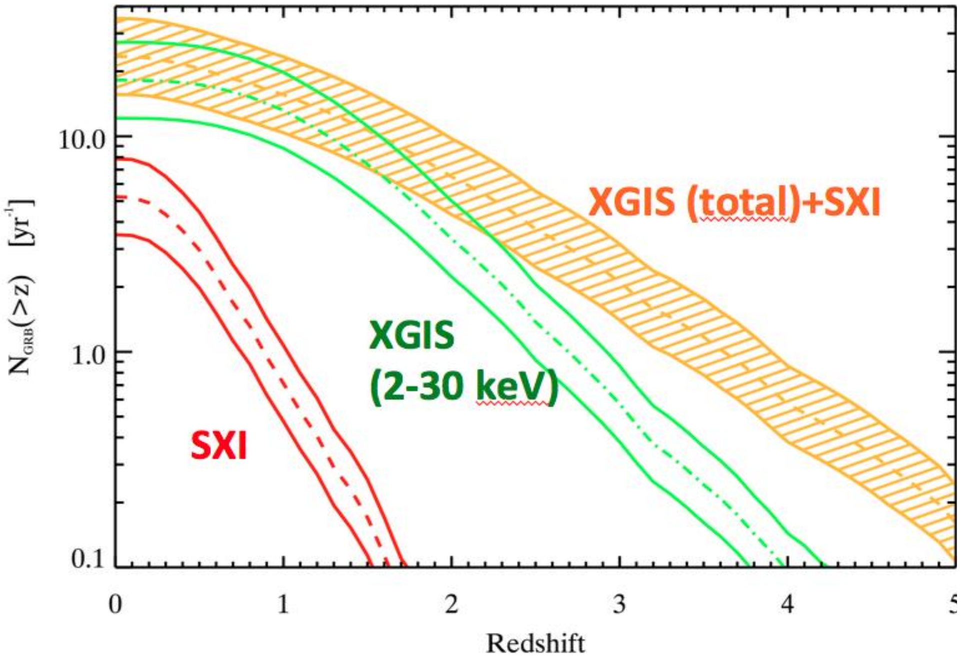
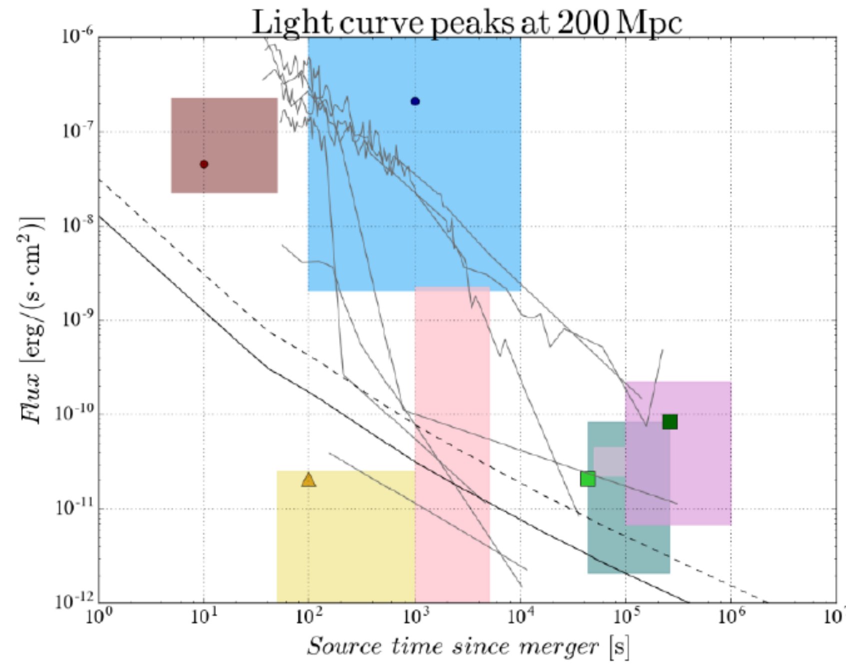
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR
THESEUS SYNERGIES

❑ GW/multi-messenger time-domain astrophysics

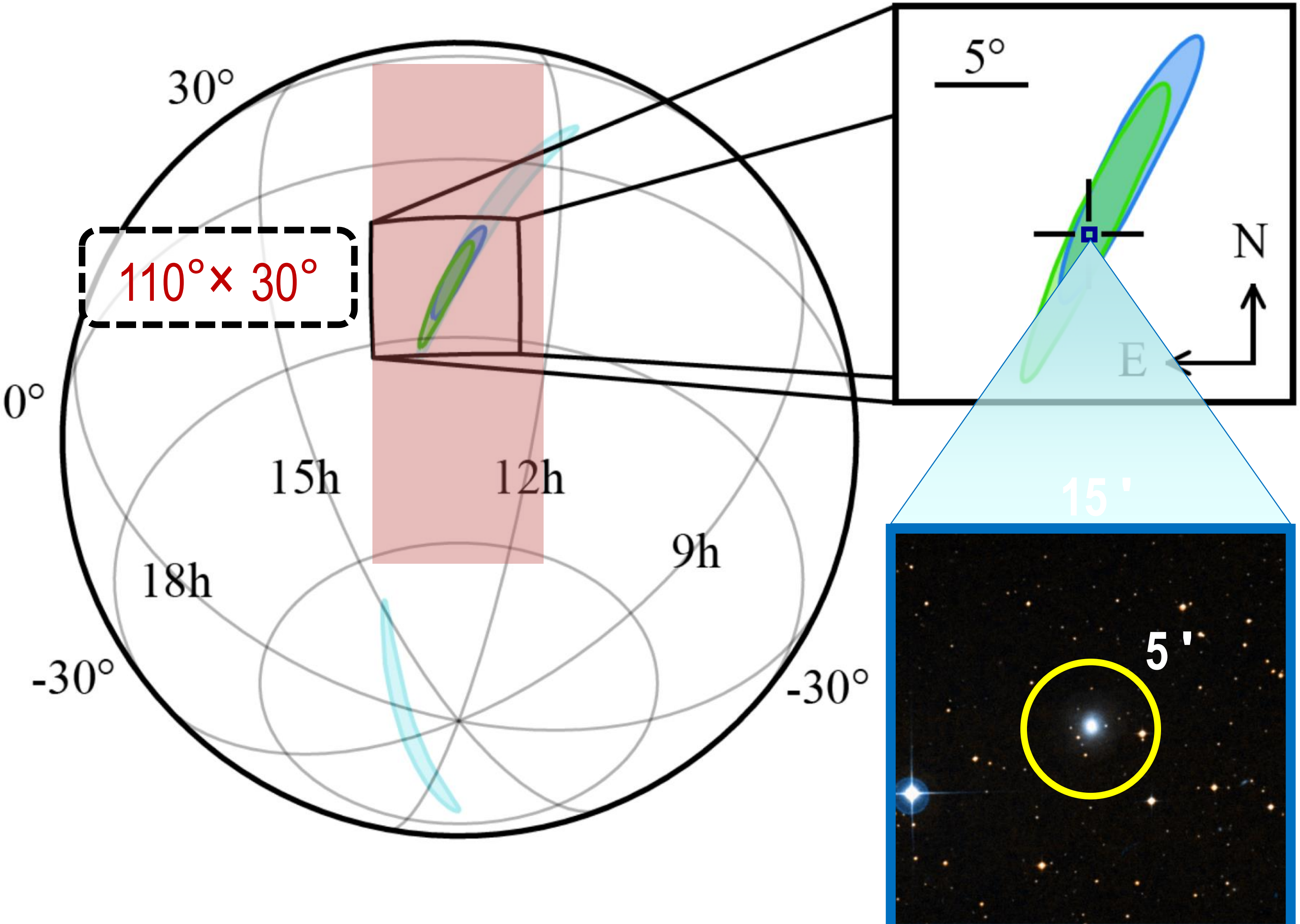
GW transient sources that will be monitored by THESEUS include **NS-NS / NS-BH mergers**:

- ❑ **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

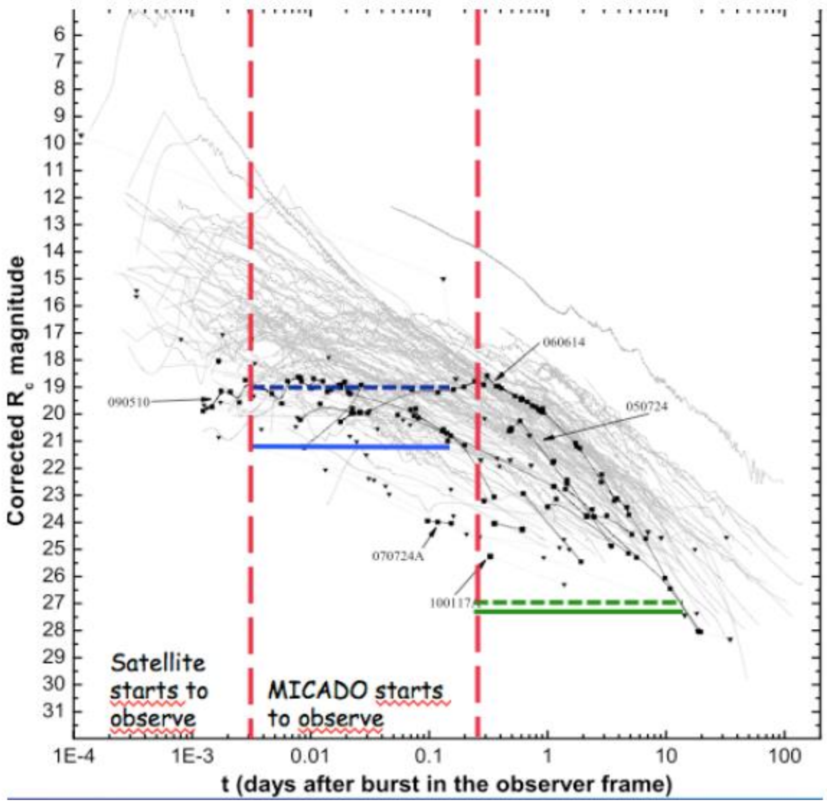


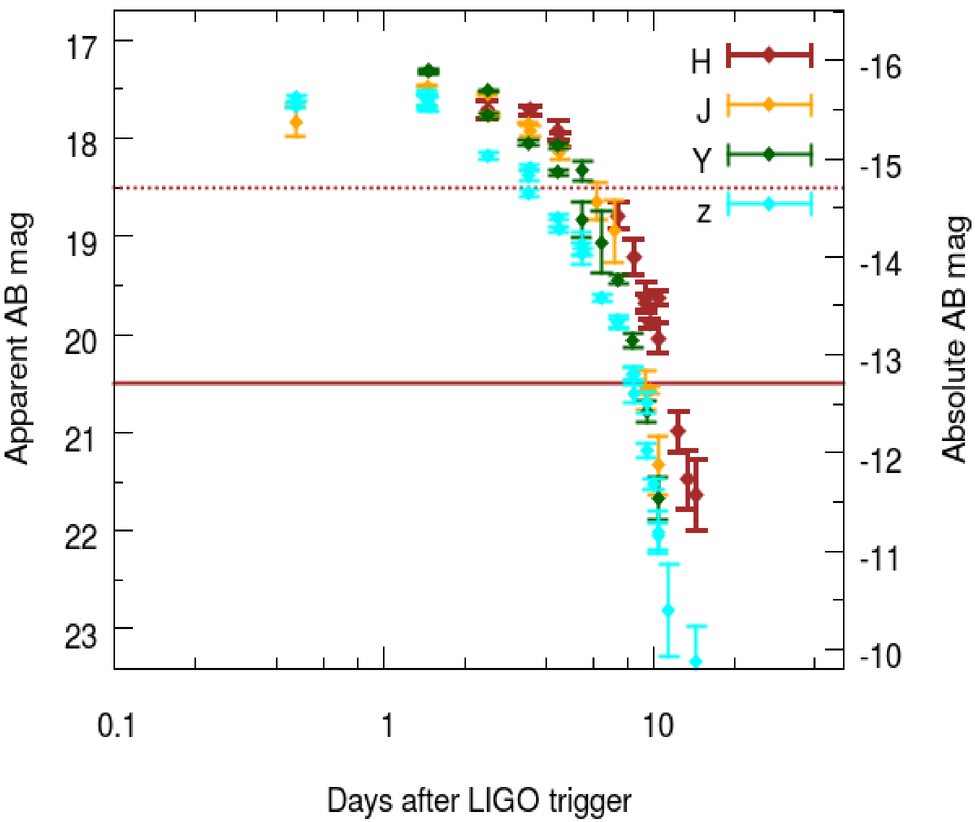


❑ Promptly and accurately localizing e.m. counterparts to GW events with THESEUS



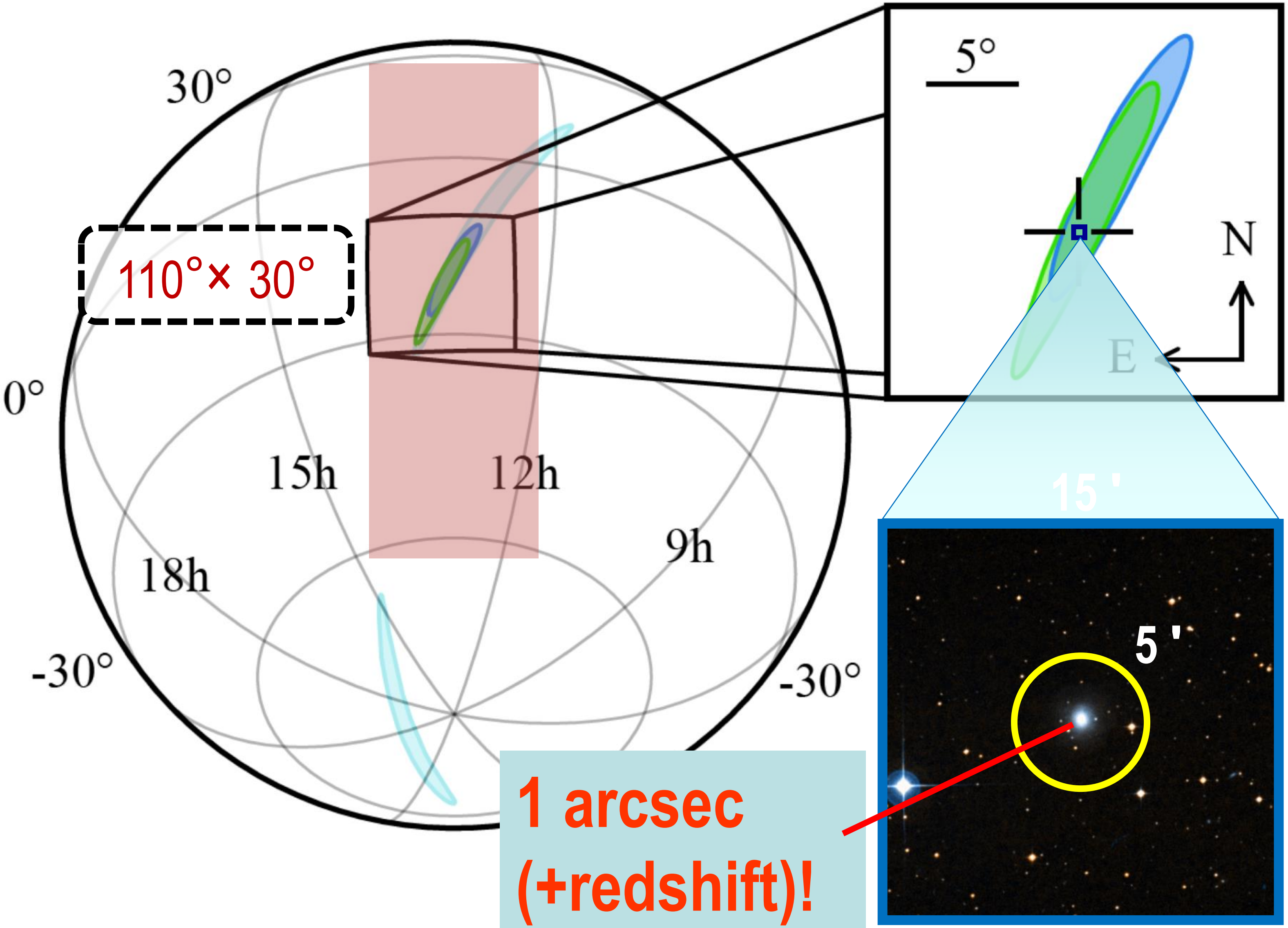
- Detection, study, arcsecond localization and redshift of afterglow and kilonova emission from shortGRB/GW events with THESEUS/IRT

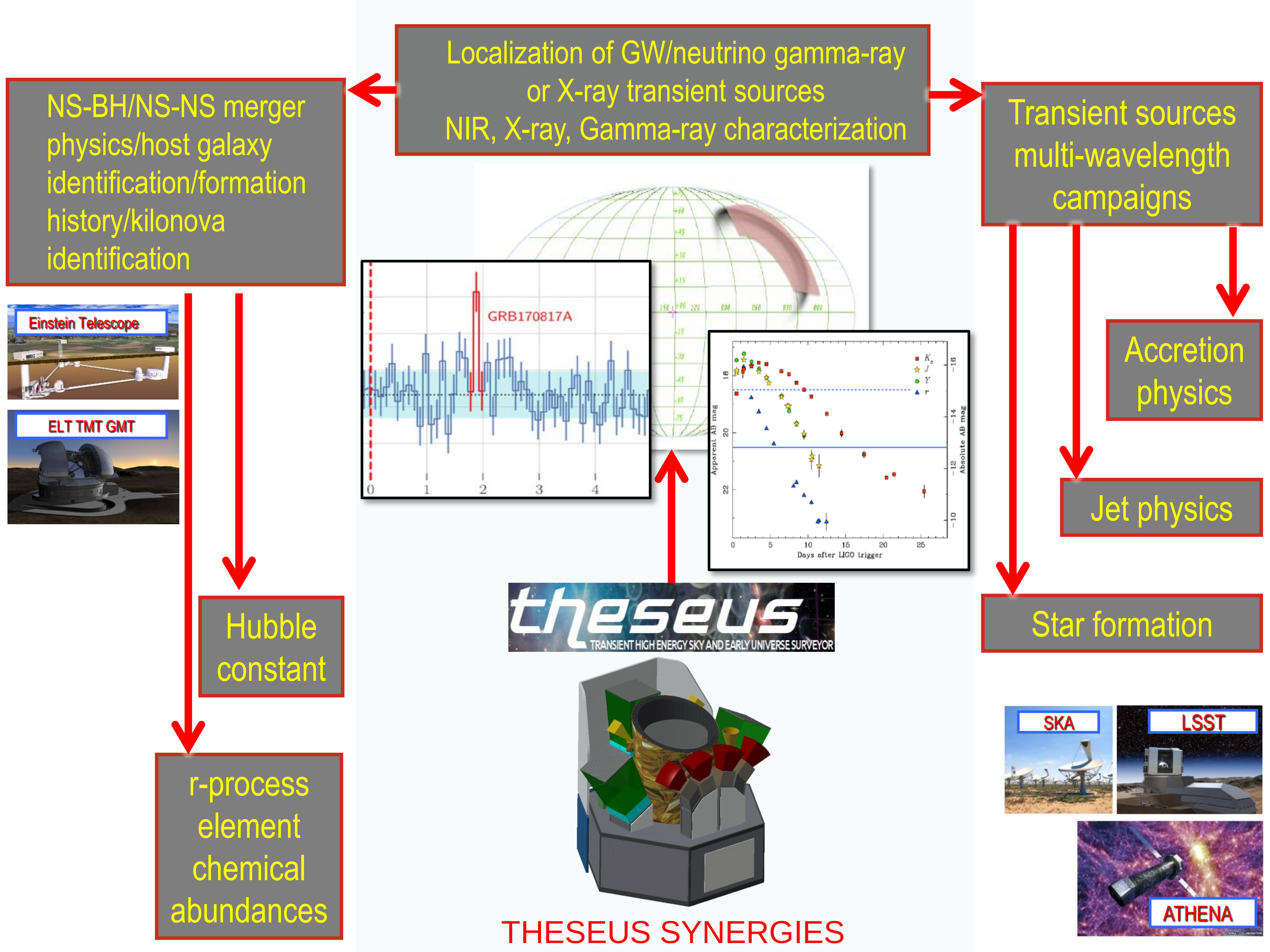




Precise localization is mandatory to activate large ground-based telescopes as VLT or ELT from which detailed spectral analysis will reveal the intrinsic nature of these newly discovered phenomena

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





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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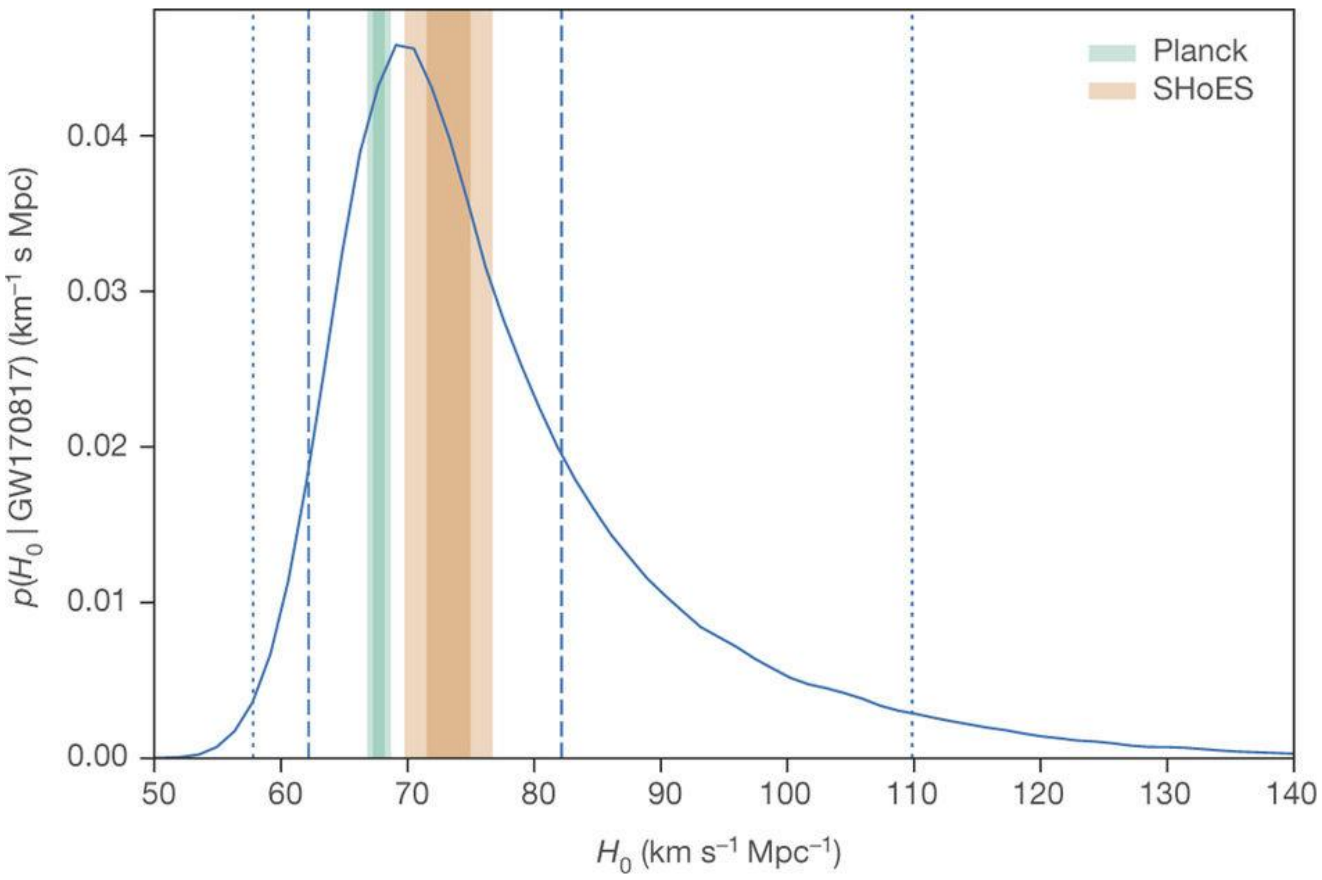
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR
r-process
element
chemical
abundances
SKA
LSST
ATHENA
THESEUS SYNERGIES

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



Estimating H0 with GW170817A

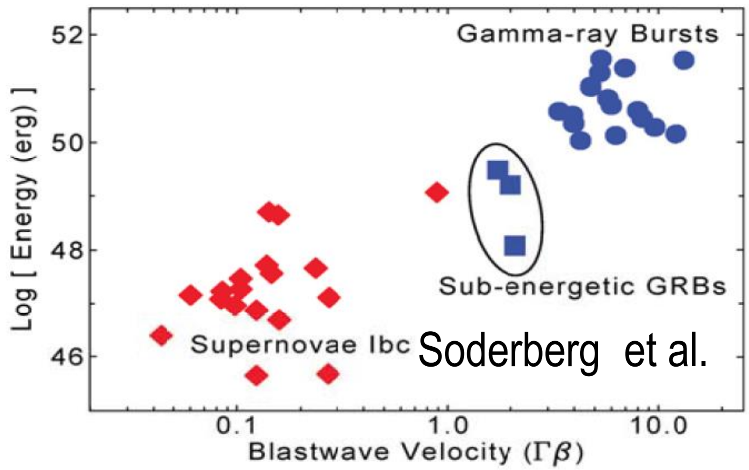
❑ Time-domain astronomy and GRB physics

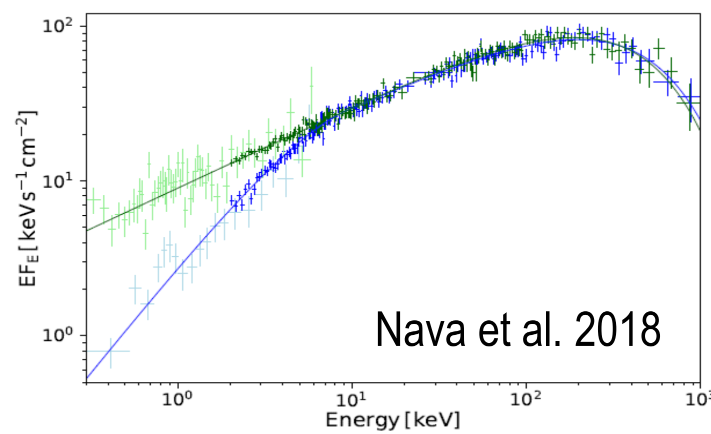
- survey capabilities of transient phenomena similar to the Large Synoptic Survey Telescope (LSST) in the optical: a remarkable scientific sinergy can be anticipated.

- 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}





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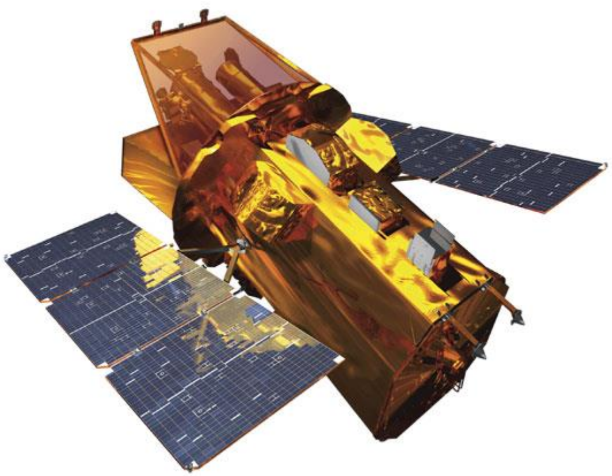
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

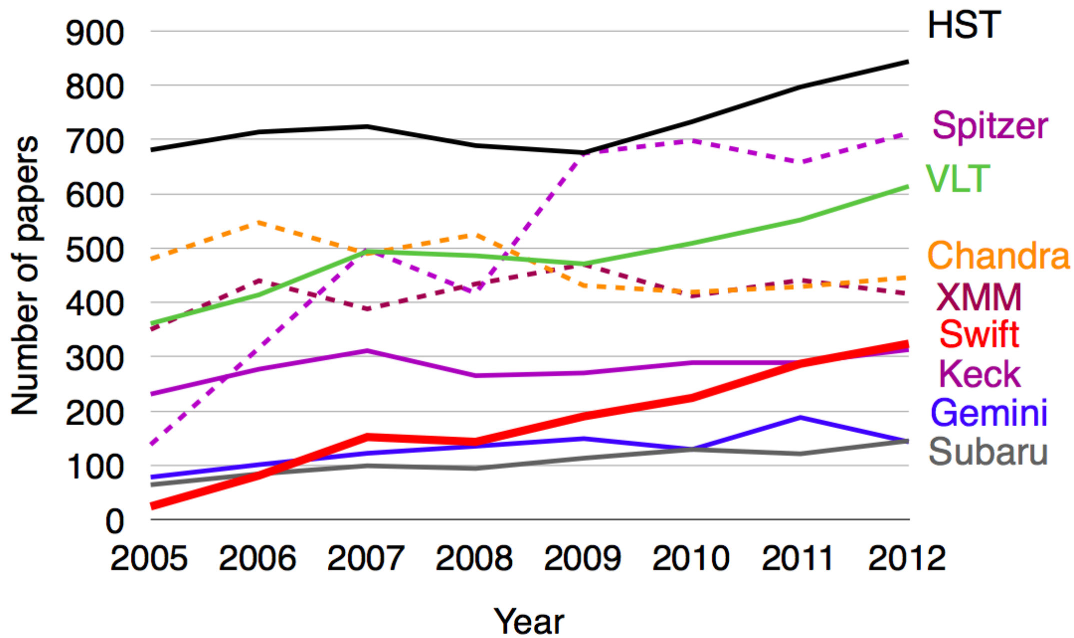
- ***THESEUS* Core Science is based on two pillars:**
  - probe the **physical properties of the early Universe**, by discovering and exploiting the population of high redshift GRBs.
  - provide an **unprecedented deep monitoring** of the soft X-ray transient Universe, providing a fundamental contribution 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**.

The Swift experience

- A flexible, rapid-slewing, multi-wavelength observatory has proven a very powerful facility.
- New, frequently unanticipated, discoveries throughout mission.
- High publication rate, particularly of high impact papers (e.g. >50 Nature papers)





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 and Italian leadership in time-domain and multi-messenger astrophysics and in key-enabling technologies (lobster-eye telescopes, SDD by INAF, INFN, FBK, Un.)

- THESEUS observations will impact on several fields of astrophysics, cosmology and even 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)

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

Amati et al. 2017 (arXiv:1710.04638)
Stratta et al. 2017 (arXiv:1712.08153)

- *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

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

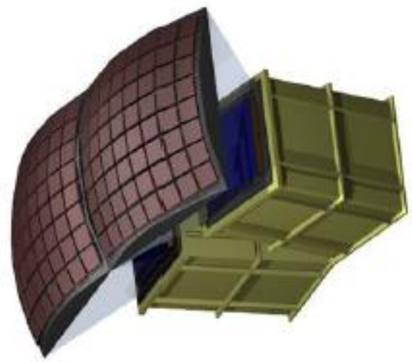
- **Concept and earliest testing of SDD+CsI (“siswich”)** (e.g., Marisaldi et al. 2005)

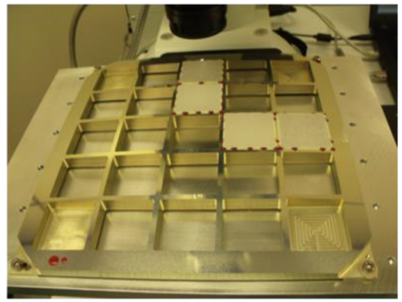
- **Concept studies of next generation GRB Monitors for future opportunities:** supported by ASI-INAF contract during 2006-2011 (p.i. L. Amati)

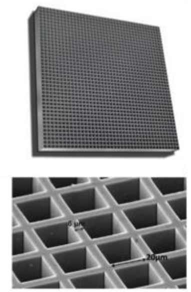
- **Innovation:** SDD+CsI detection system, ASIC

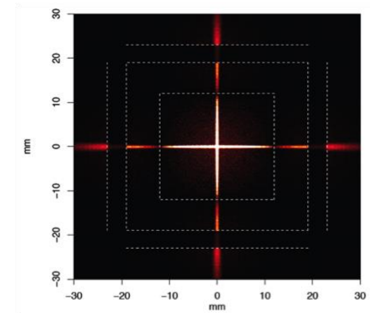
- **Development and testing of an XGIS module prototype is supported by TECNO INAF 2014 (P.I. L. Amati, INAF – IASF Bologna)**

The Soft X-ray Imager (SXI)









4 DUs, each has a 31 x 26 degree FoV

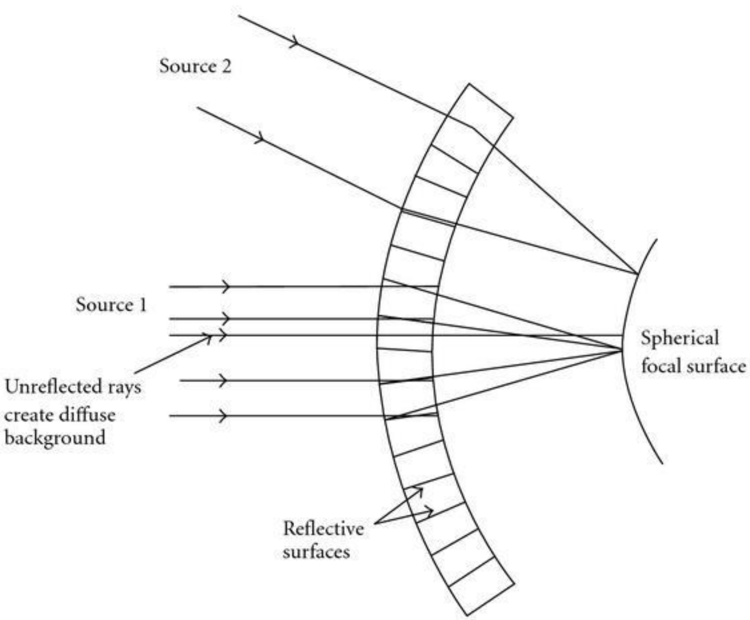
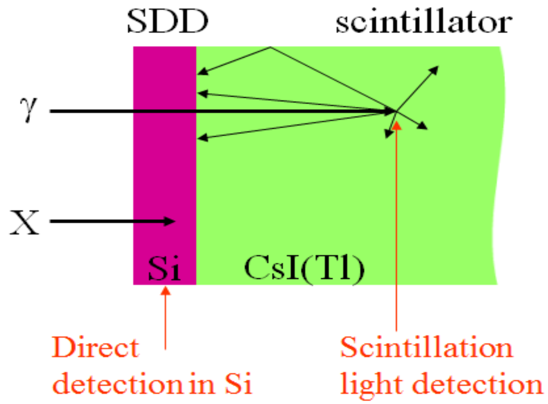
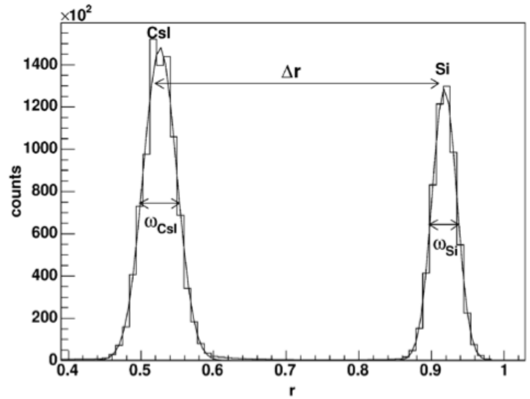


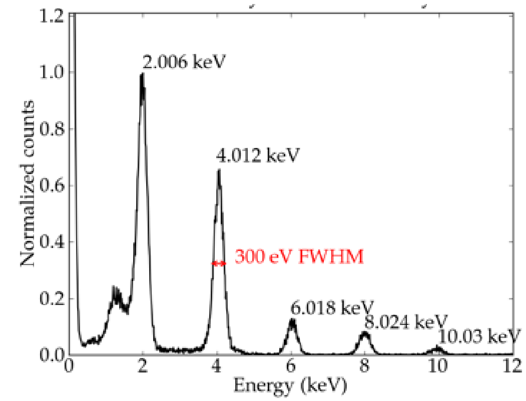
Table 4 : : SXI detector unit main physical characteristics

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

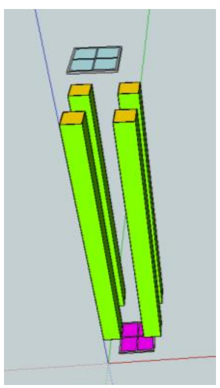
The X-Gamma-rays spectrometer (XGS)

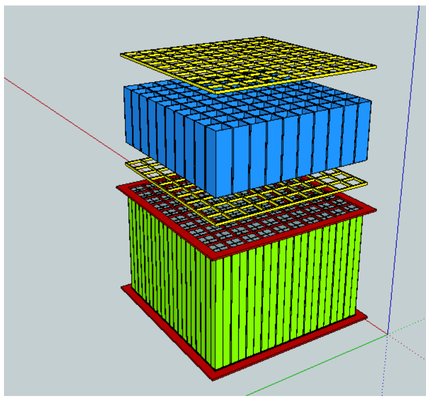


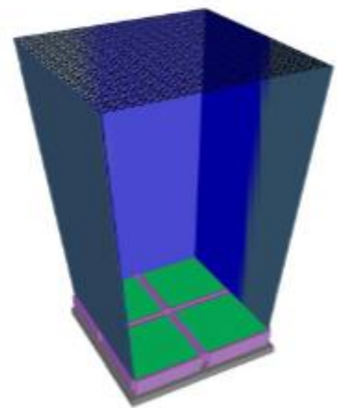




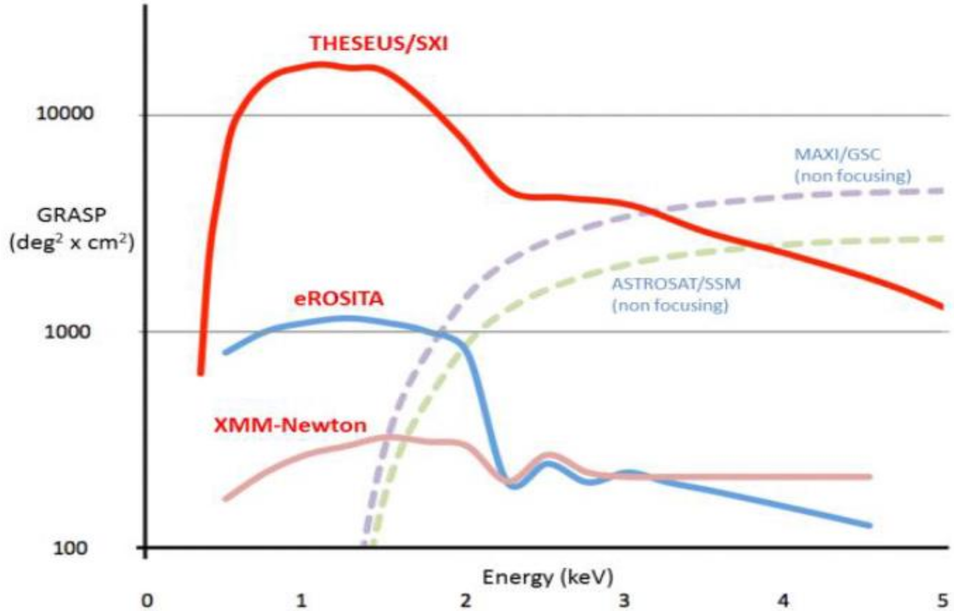
Energy band	2 keV – 20 MeV
# detection plane modules	4
# of detector pixel / module	32x32
pixel size (= mask element size)	5x5 mm
Low-energy detector (2-30 keV)	Silicon Drift Detector 450 μm thick
High energy detector (> 30 keV)	CsI(Tl) (3 cm thick)
Discrimination Si/CsI(Tl) detection	Pulse shape analysis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

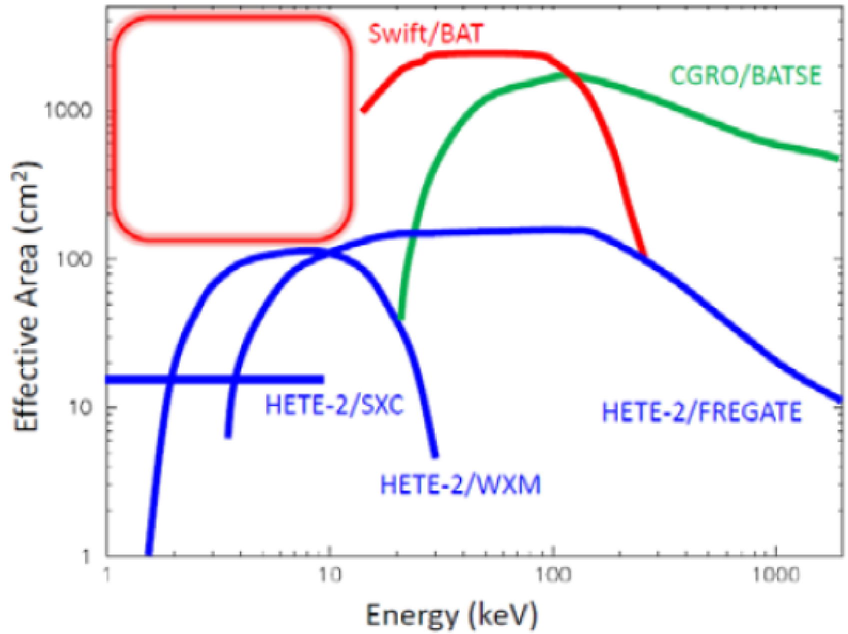






	2-30 keV	30-150 keV	>150 keV
Fully coded FOV	9 x 9 deg²		
Half sens. FOV	50 x 50 deg²	50 x 50 deg² (FWHM)	
Total FOV	64 x 64 deg²	85 x 85 deg² (FWZR)	2π sr
Ang. res	25 arcmin		
Source location accuracy	~5 arcmin (for >6 σ source)		
Energy res	200 eV FWHM @ 6 keV	18 % FWHM @ 60 keV	6 % FWHM @ 500 keV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

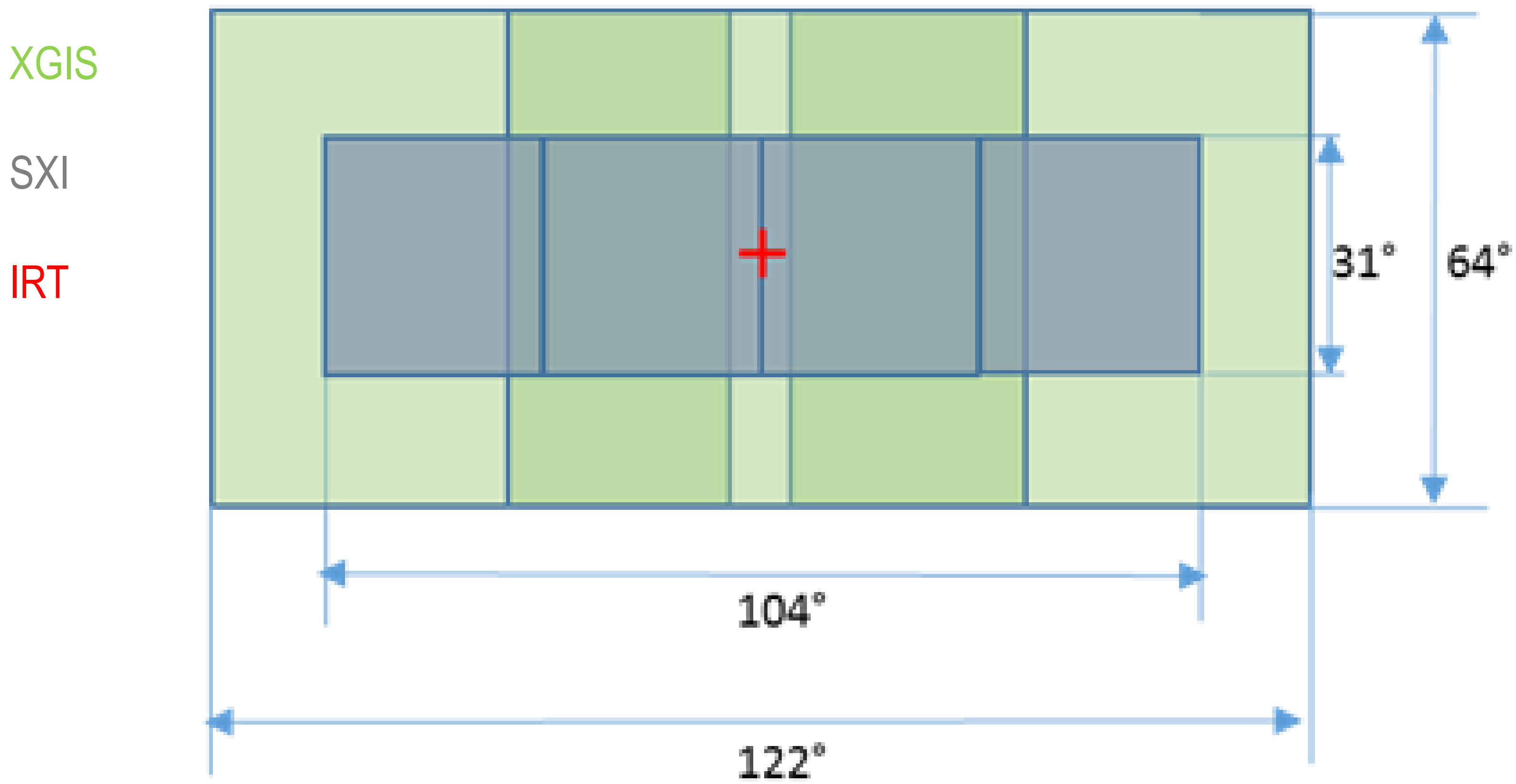




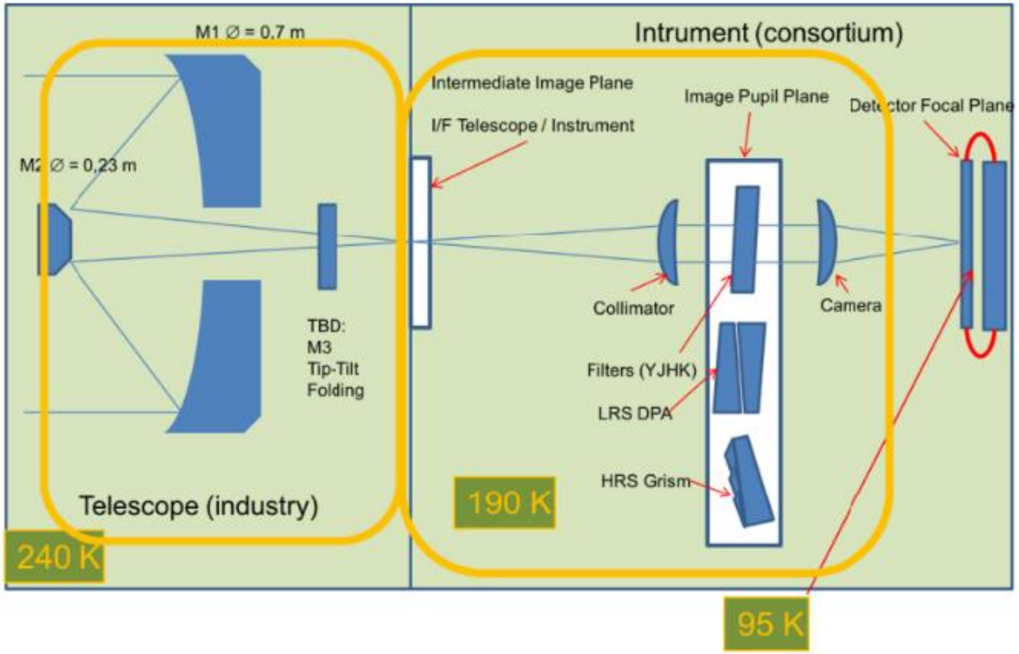
	Energy Band	FOV	Energy resolution	Peak eff. area	Source location	2022 Operation
CGRO/BATSE	20–2000 keV	open	10 keV (100 keV)	~1700 cm^2	>1.7 deg	ended
Swift	15–150 keV	1.4 sr	7 keV (60 keV)	~2000 cm^2	1–4 arcmin	active
Fermi/GBM	8 keV – 40 MeV	open	10 keV (100 keV)	126 cm^2	>3 deg	active
Konus–WIND	20 keV – 15 MeV	open	10 keV at 100 keV	120 cm^2	–	active
BeppoSAX/WFC	2–28 keV	0.25 sr	1.2 keV (6 keV)	140cm^2	1 arcmin	ended
HETE-2/WXM	2–25 keV	0.8 sr	1.7 keV (6 keV)	350cm^2	1–3 arcmin	ended
THESEUS	0.3–20000 keV	1 - 1.4 sr	300 eV (6 keV)	1500 cm^2	0.5–1 arcmin	2025–2028 ?
SVOM	4 keV – 5 MeV	1.5 sr	2 keV (60 keV)	1000 cm^2	2–10 arcmin	2018-2022 ?

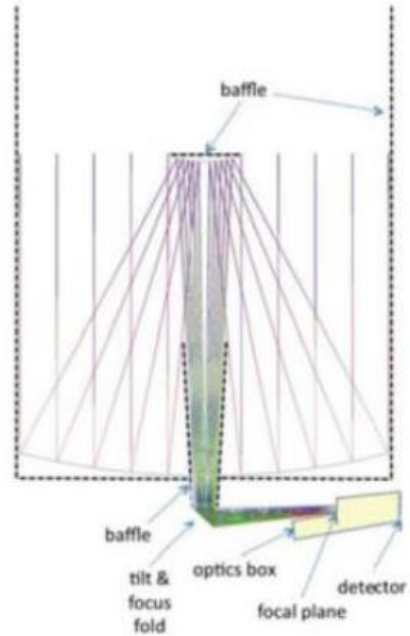
+ Infrared telescope and fast slewing !!!

Field of view

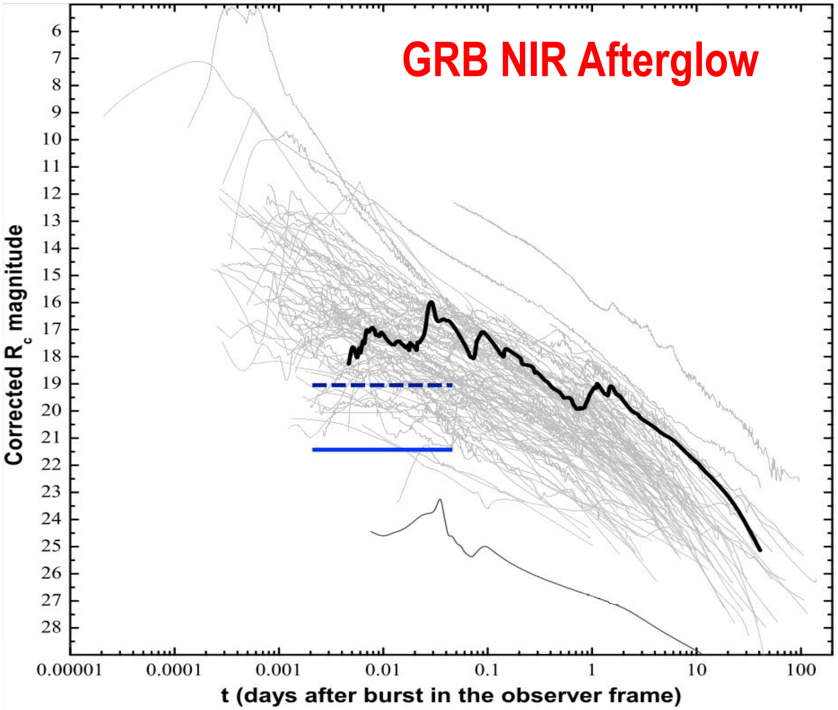


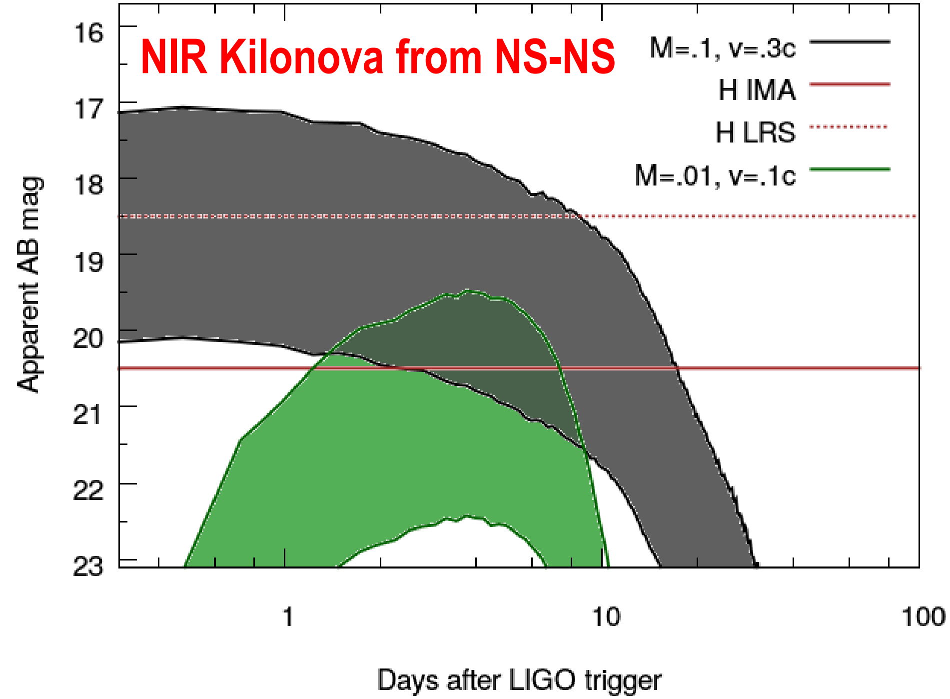
The InfraRed Telescope (IRT)





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
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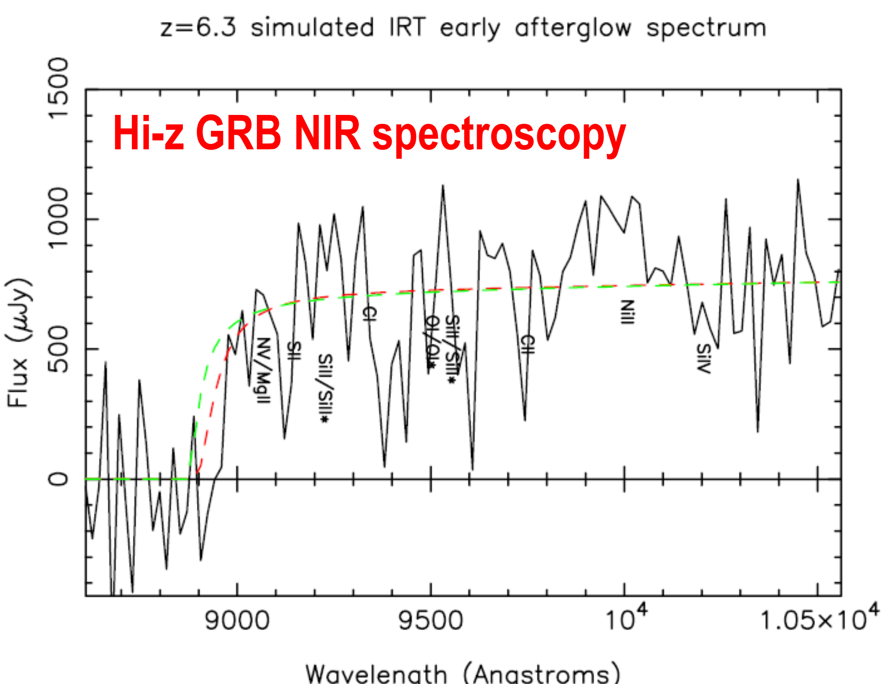
M=.01, v=.1c
Apparent AB mag
Days after LIGO trigger
1
10
100


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*
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CII
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SiIV
9000
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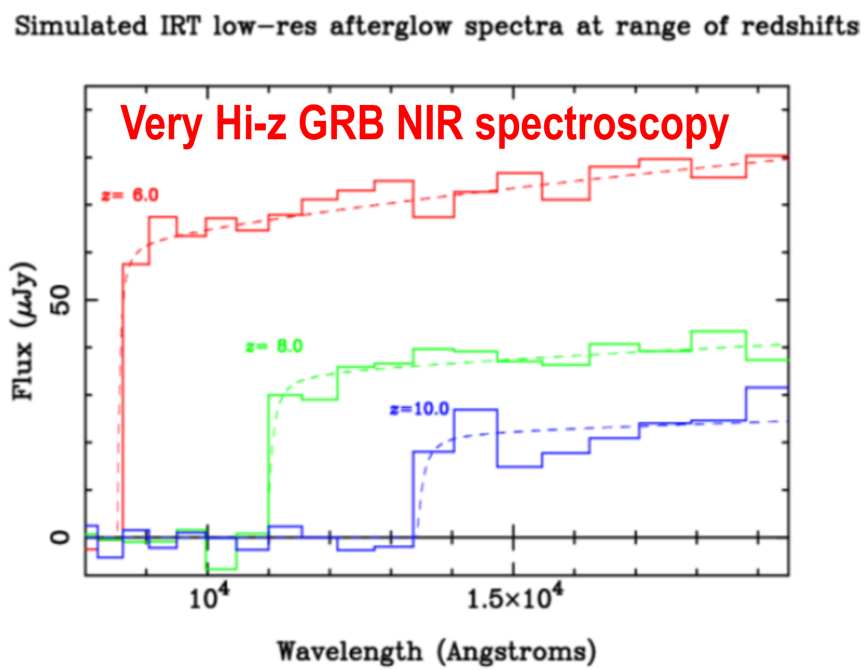
10^4
1.05×10^4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z= 6.0
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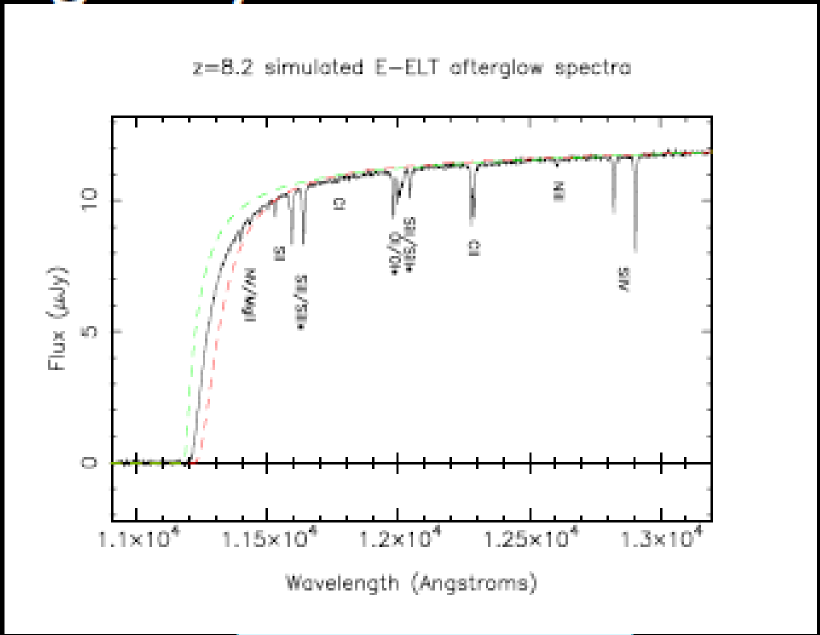
z=10.0
Flux (μJy)
Wavelength (Angstroms)
10^4
1.5×10^4

ATHENA+

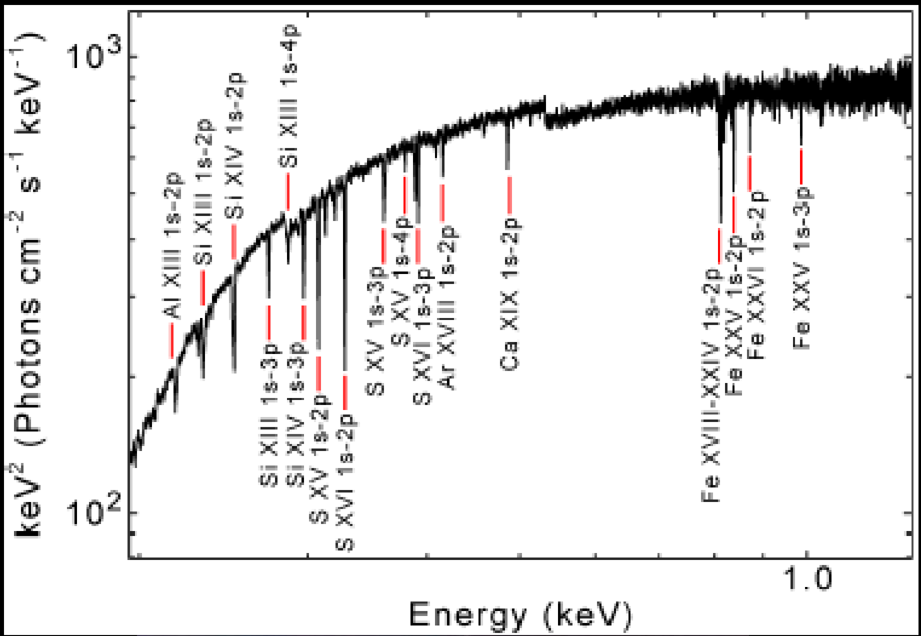
Follow-up of high-z GRB with large facilities

- Optical/IR abs. spectroscopy of the host galaxy

X-ray spectroscopy of the progenitor environme



30+ m class ELTs



ESA L2 X-ray Observatory

Table 2: Number of NS-NS (BNS) mergers expected to be detected in the next years by second- (2020+) and third- (2030+) generation GW detectors and the expected detection number of electromagnetic counterparts as short GRBs (collimated) and X-ray isotropic emitting counterparts (see §3.1 and 3.2) with THESEUS SXI and XGIS (see text for more details). BNS rate is a realistic estimate from Abadie et al. 2010 and Sathyaprakash et al. 2012 and the BNS range indicates the sky- and orbital inclination-averaged distance up to which GW detectors can detect a BNS with $SNR = 8$.

GW observations			THESEUS XGIS/SXI joint GW+EM observations		
Epoch	GW detector	BNS range	BNS rate (yr^{-1})	XGIS/sGRB rate (yr^{-1})	SXI/X-ray isotropic counterpart rate (yr^{-1})
2020+	Second-generation (advanced LIGO, Advanced Virgo, India-LIGO, KAGRA)	~200 Mpc	~40*	~5-15	~1-3 (simultaneous) ~6-12 (+follow-up)
2030+	Second + Third-generation (e.g. ET, Cosmic Explorer)	~15-20 Gpc	>10000	~15-35	$\gtrsim$100

* from Abadie et al. 2010a

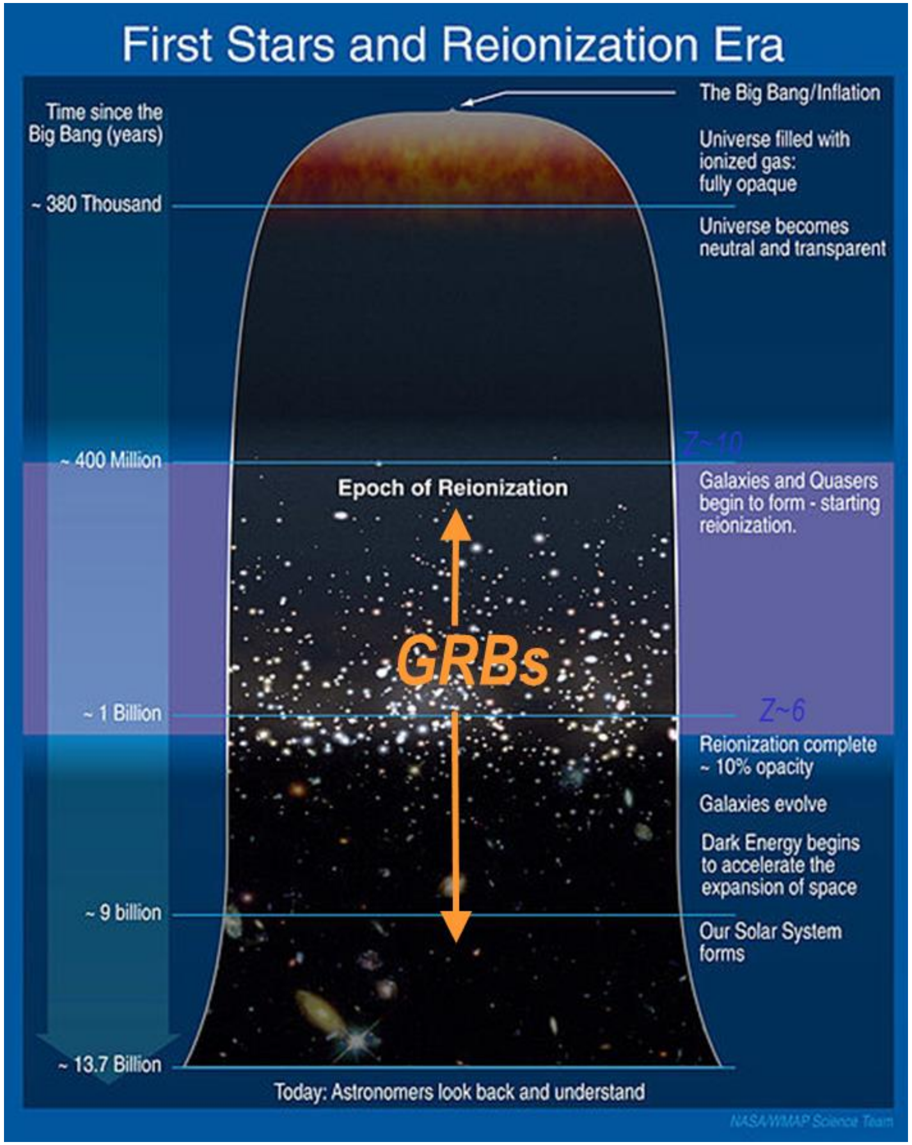
❑ GW/multi-messenger and time-domain astrophysics

GW transient sources that will be monitored by THESEUS include:

- ❑ NS-NS / NS-BH mergers:
  - ❑ **collimated** EM emission from short GRBs and their afterglows (rate of ≤ 1/yr for 2G GW detectors but up to 20/yr for 3G GW detectors as Einstein Telescope)
  - ❑ Optical/NIR and soft X-ray **isotropic** emissions from **macronovae, off-axis afterglows** and, for NS-NS, from newly born ms magnetar spindown (rate of GW detectable NS-NS or NS-BH systems, i.e. dozens-hundreds/yr)
- ❑ Core collapse of massive stars: Long GRBs, LLGRBs, ccSNe (much more uncertain predictions in GW energy output, possible rate of ~1/yr)
- ❑ Flares from isolated NSs: Soft Gamma Repeaters (although GW energy content is ~0.01%-1% of EM counterpart)

THESEUS: Main scientific goals

A) Exploring the Early Universe (cosmic dawn and reionization era) by unveiling the Gamma-Ray Burst (GRBs) population in the first billion years



The study of the Universe before and during the epoch of reionization represents one of the major themes for the next generation of space and ground–based observational facilities. Many questions about the first phases of structure formation in the early Universe will still be open in the late 2020s:

- *When and how did first stars/galaxies form?*
- *What are their properties? When and how fast was the Universe enriched with metals?*
- *How did reionization proceed?*

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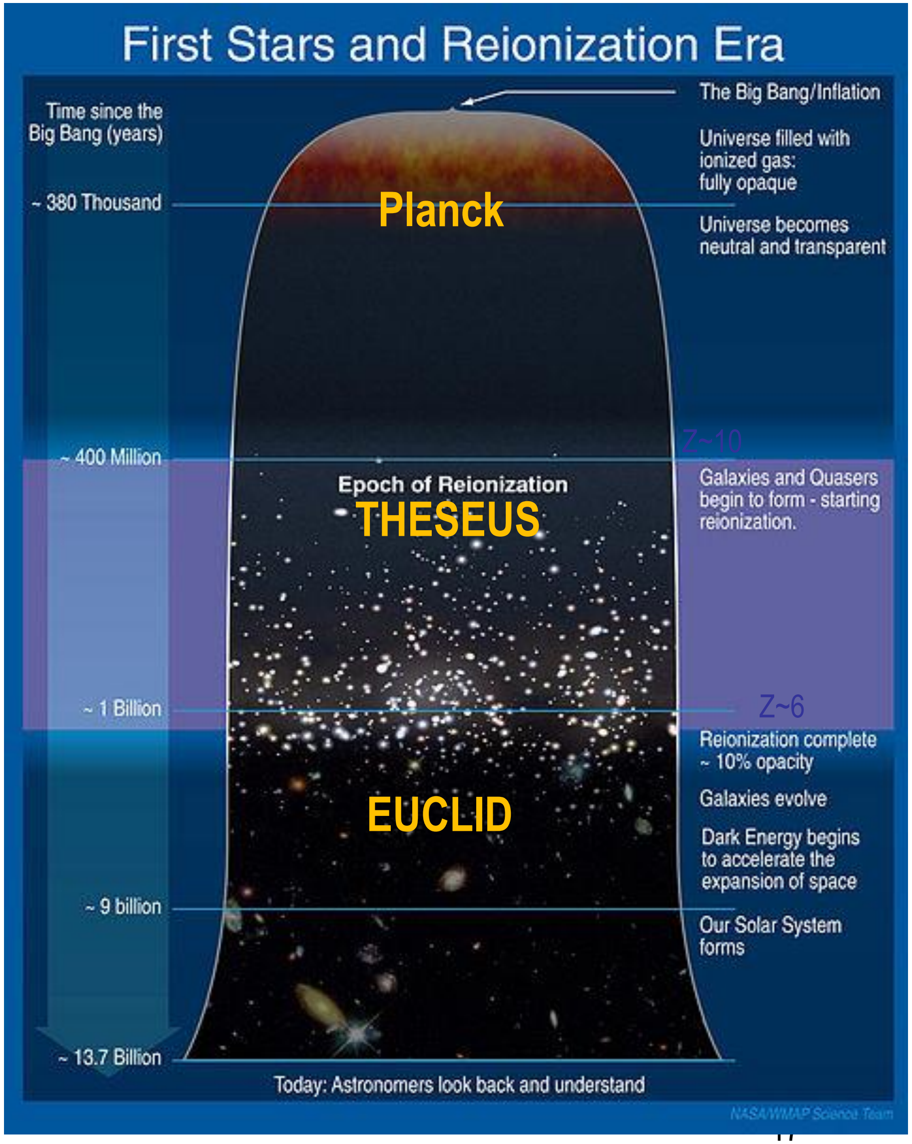
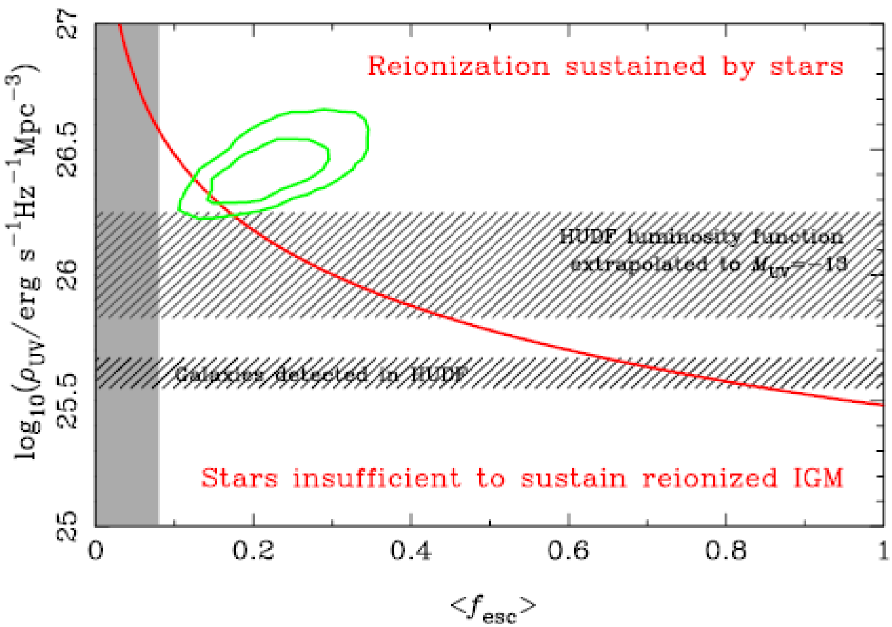
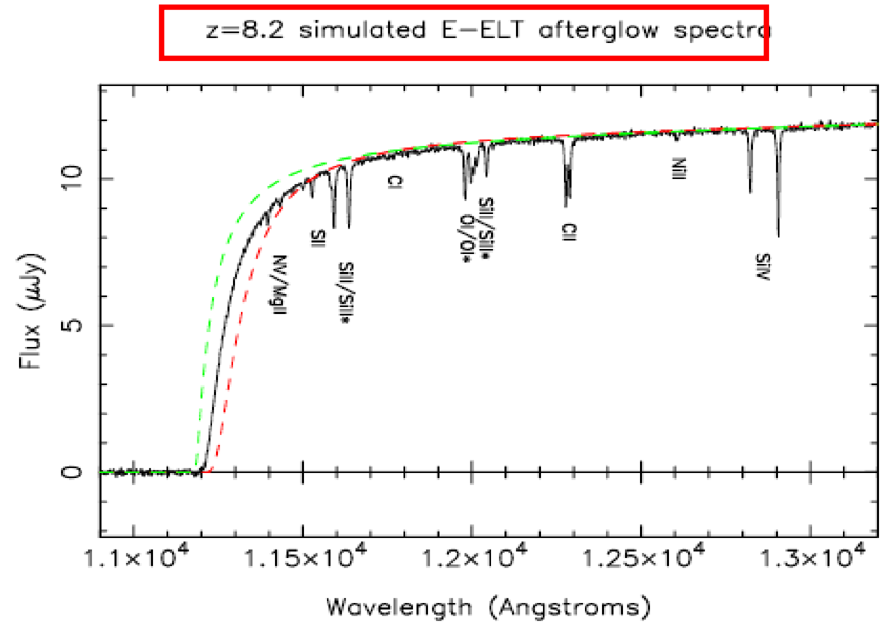
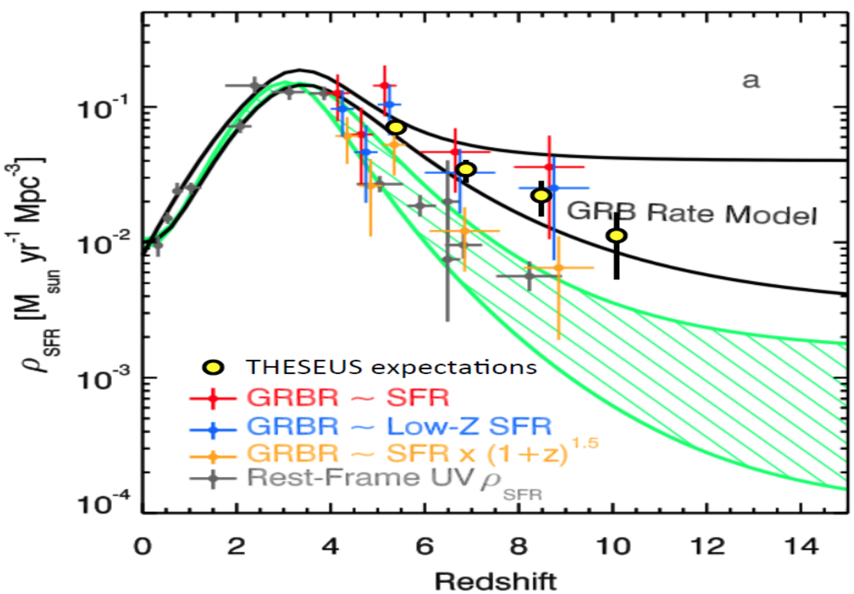
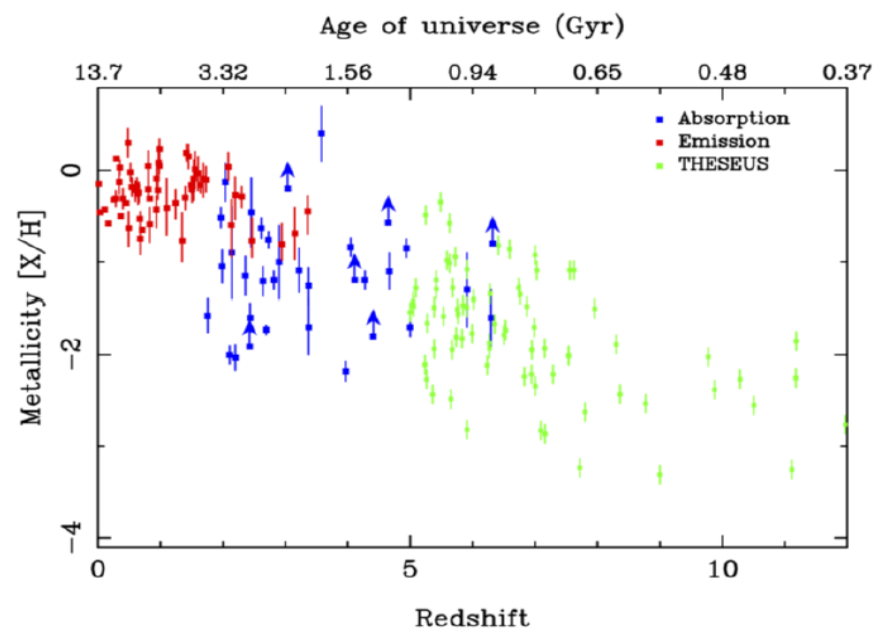


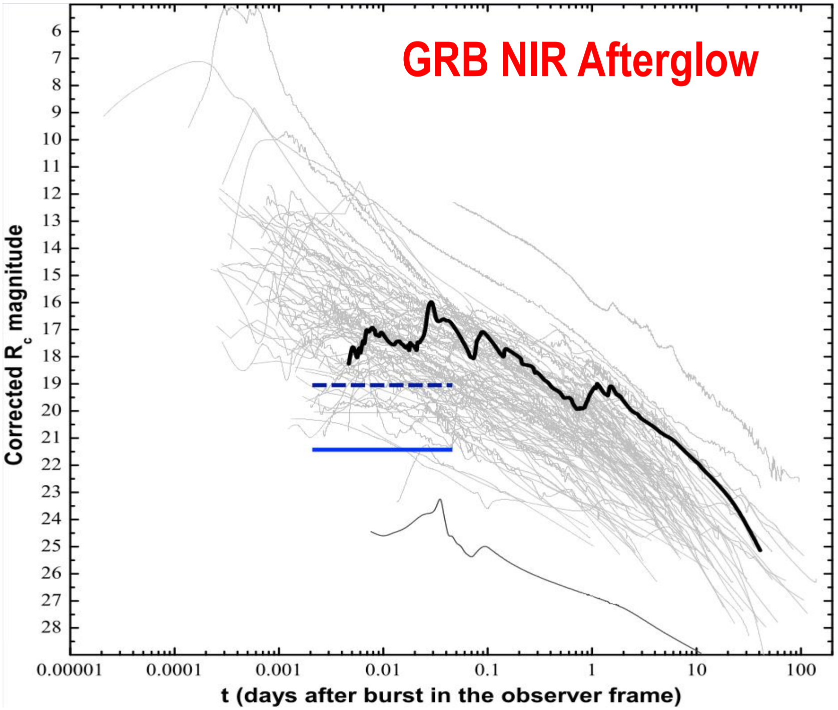
❑ Shedding light on the early Universe with GRBs







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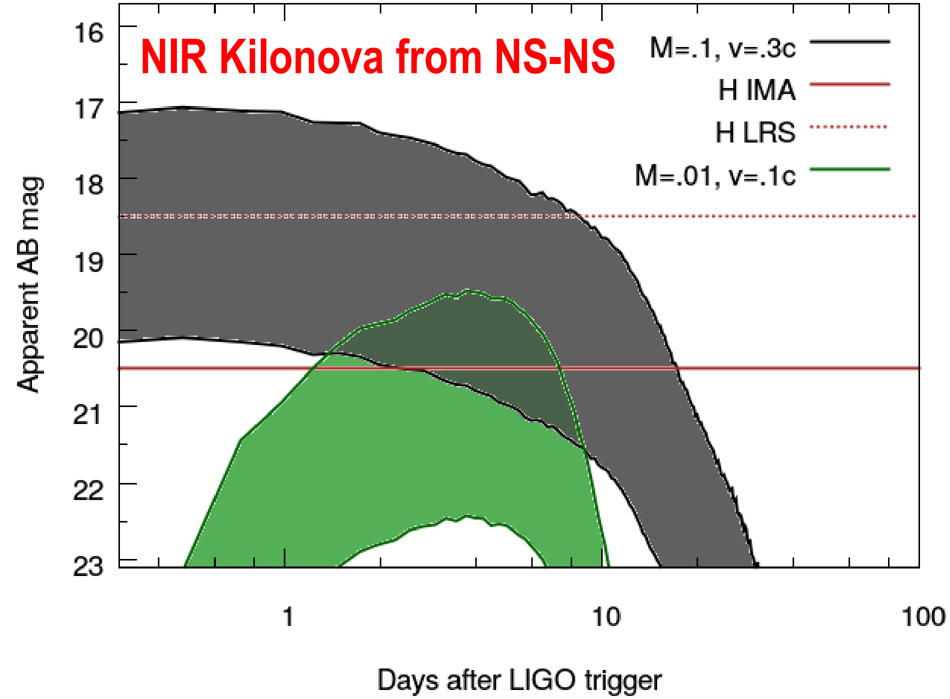
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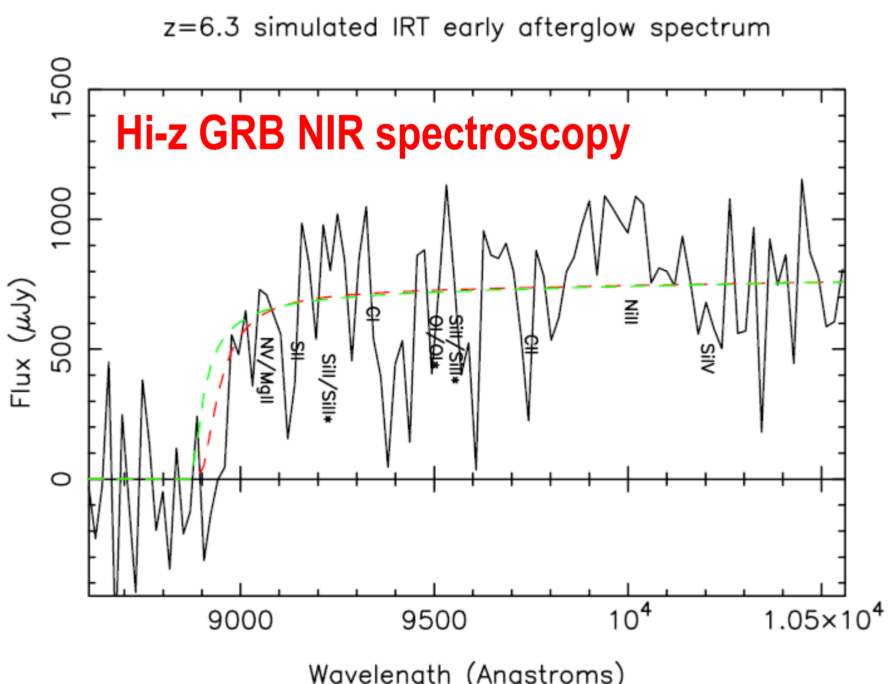
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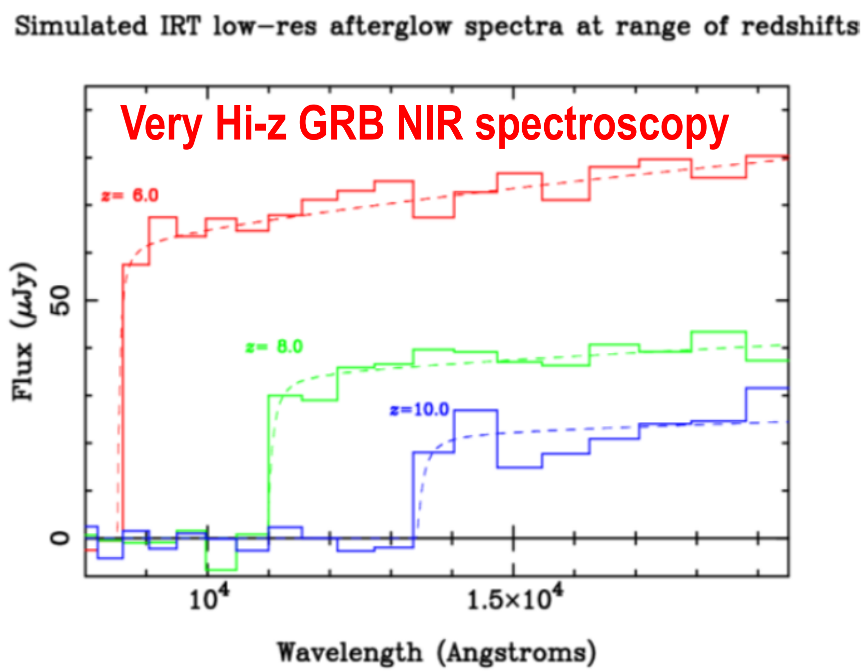
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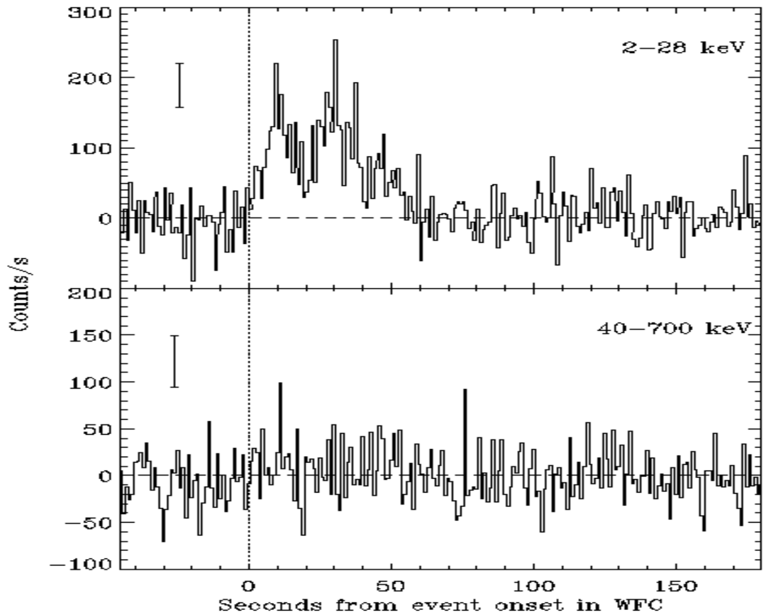
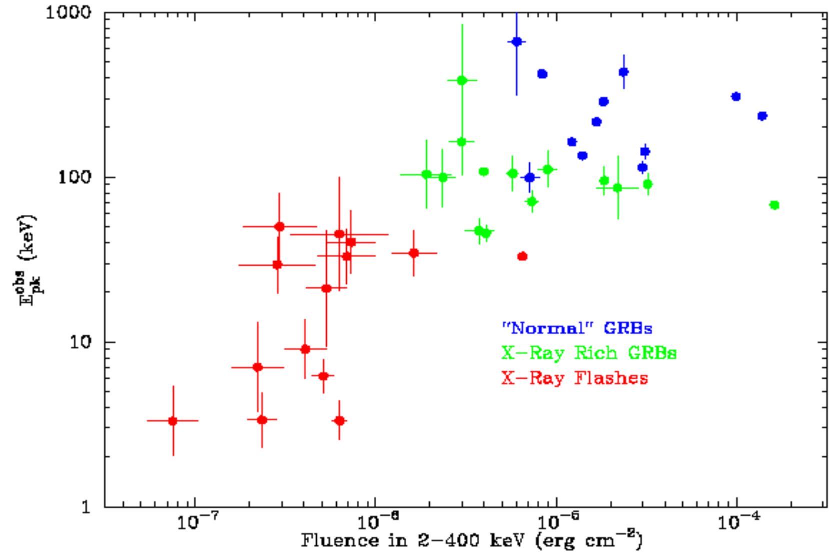
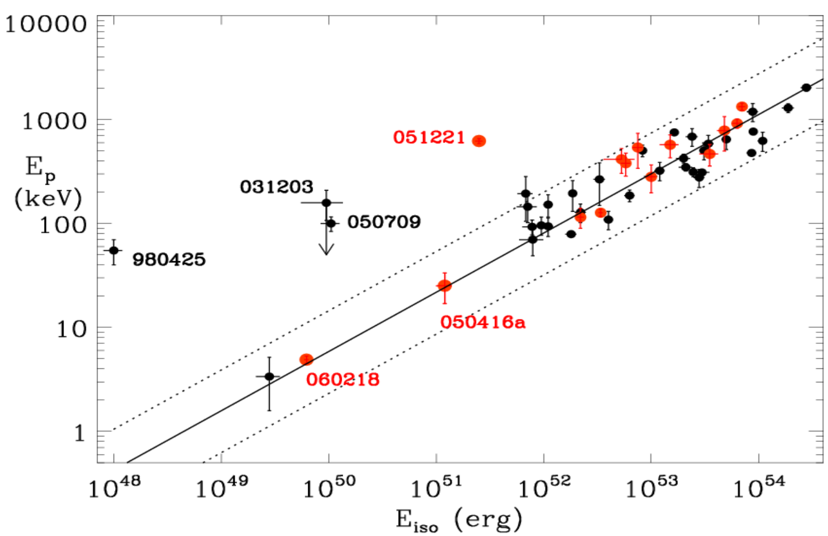
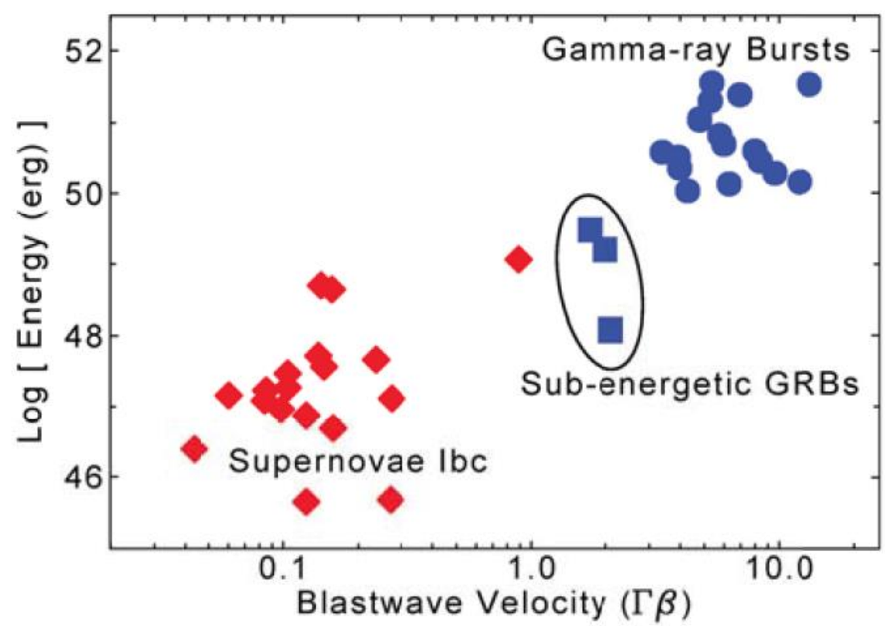
THESEUS synergy with next generation large observatories

❑ X-Ray flashes and subluminous GRBs









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Subject: Letter of Endorsement for the THESUES M5 mission candidate

Dr Lorenzo Amati
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Dear Dr Amati,

We have received a description of the THESEUS mission that will be proposed to the European Space Agency (ESA) for consideration as a Cosmic Vision M5 mission.

The mission's science objectives are of strong interest for the multi-messenger astronomy, including the gravitational waves. The astrophysical sources that THESEUS will observe are expected to be detectable by ground based gravitational wave detectors (10-1000 Hz). The simultaneous multi-wavelength electromagnetic and gravitational wave observations maximize the scientific return of each detection.

The Virgo Collaboration and the European Gravitational Wave Observatory (EGO) strongly support the THESEUS proposal and express interest to collaborate on the exploitation of scientific data in a multi-messenger context.

Sincererly,

Prof. Fulvio Ricci
Virgo spokesperson

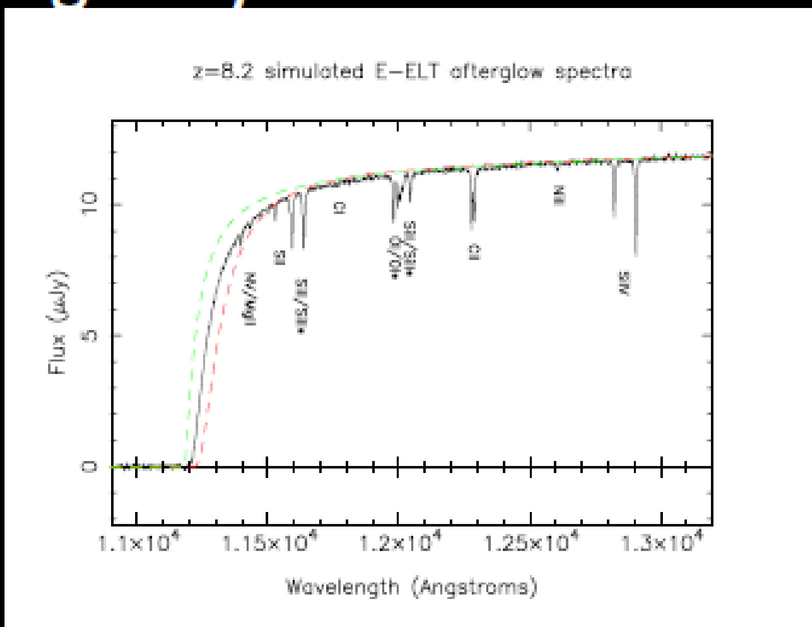
Prof. Federico Ferrini
EGO Director

ATHENA+

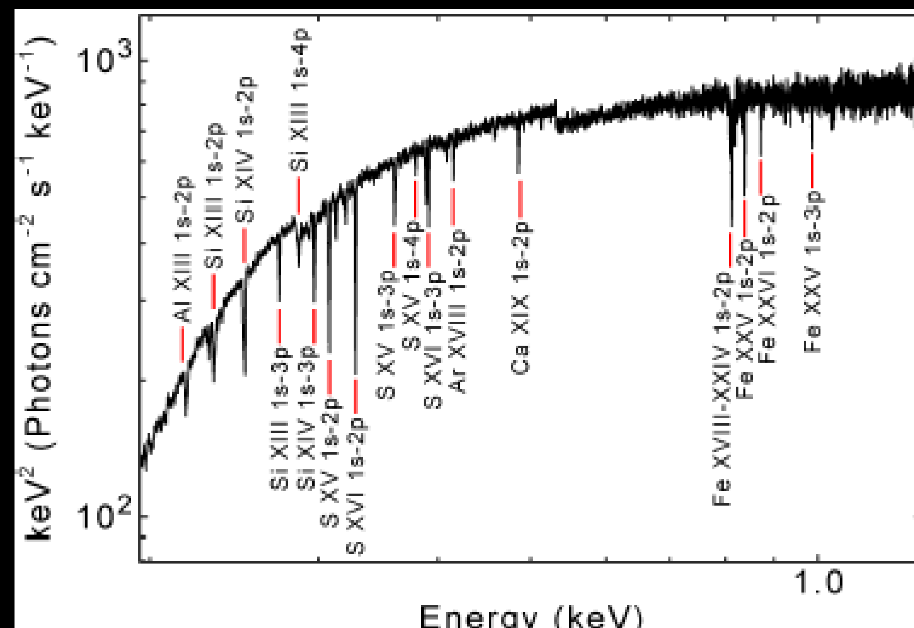
Follow-up of high-z GRB with large facilities

- Optical/IR abs. spectroscopy of the host galaxy

X-ray spectroscopy of the progenitor environme



30+ m class ELTs



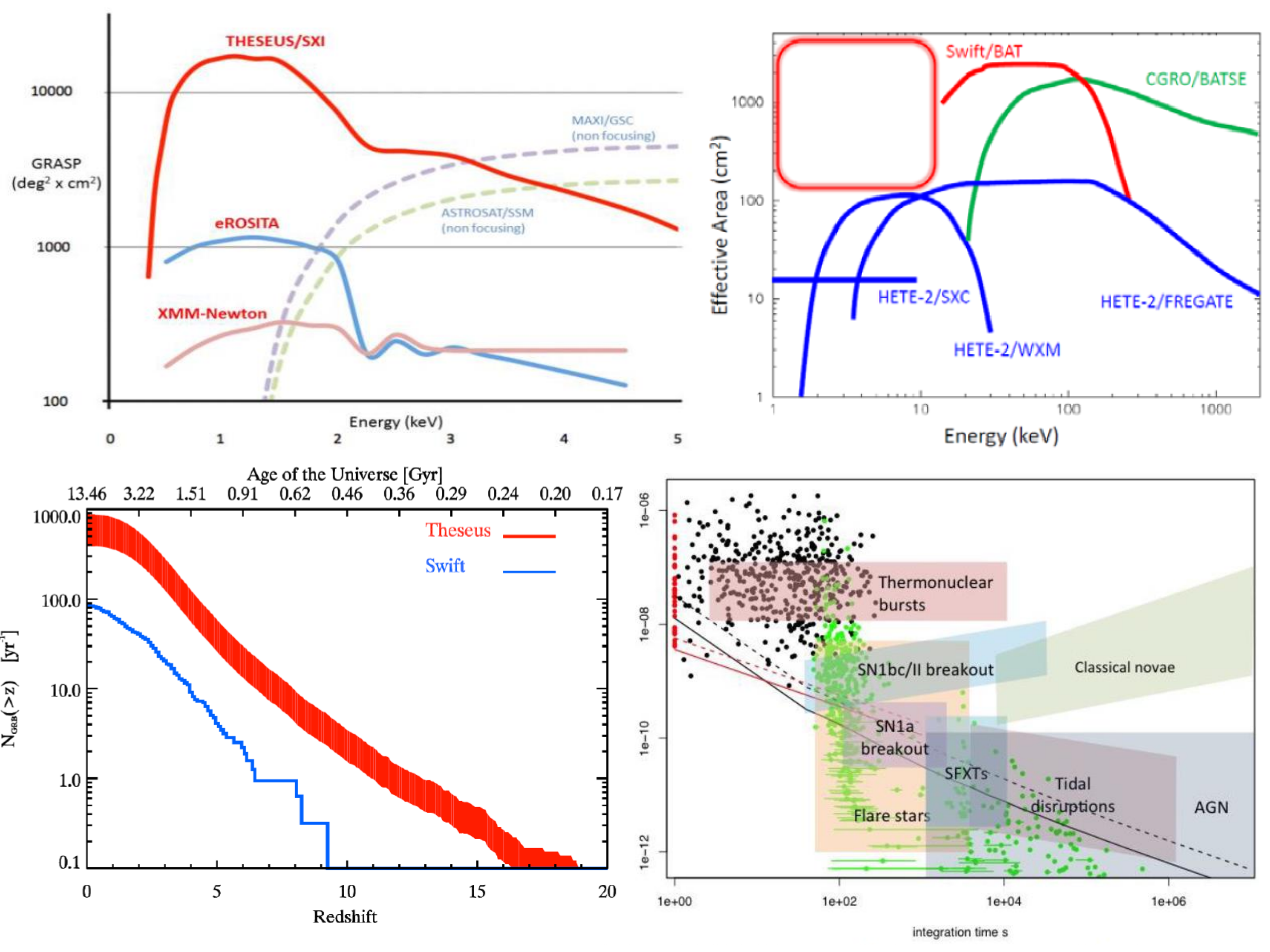
ESA L2 X-ray Observatory

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

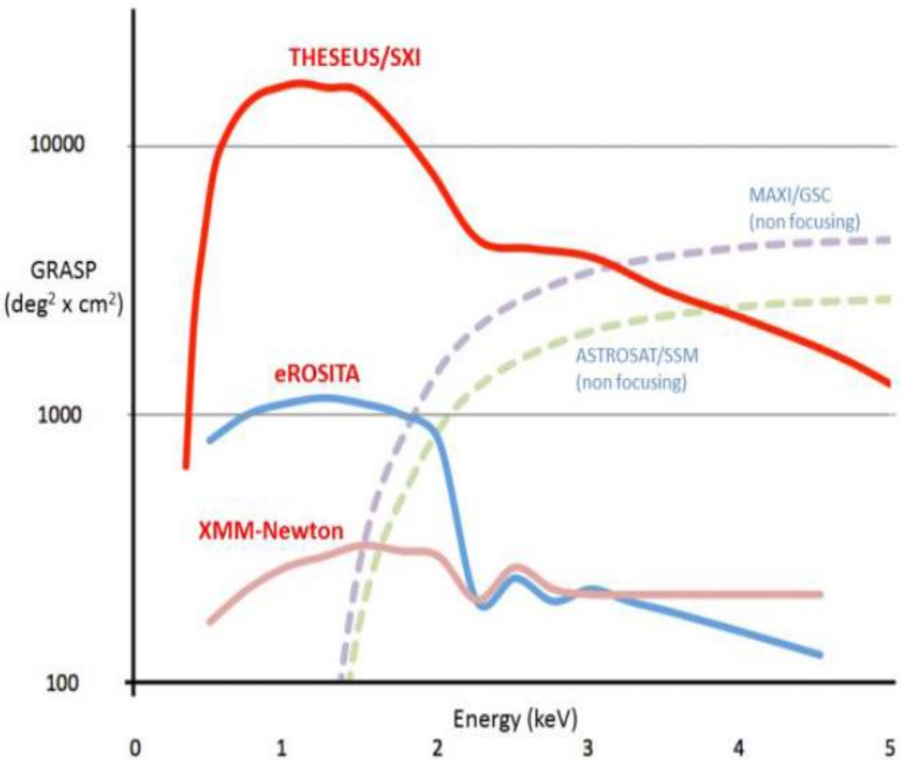
Activity	CAC (M€)
ESA Project Office	54
Satellite (incl. 20% contingency)	165
ESA contribution to P/L	120
Launch (VEGA)	45
Ground Segment & Operations	84
Contingency (15% of subtotal)	70
Total cost for ESA	538

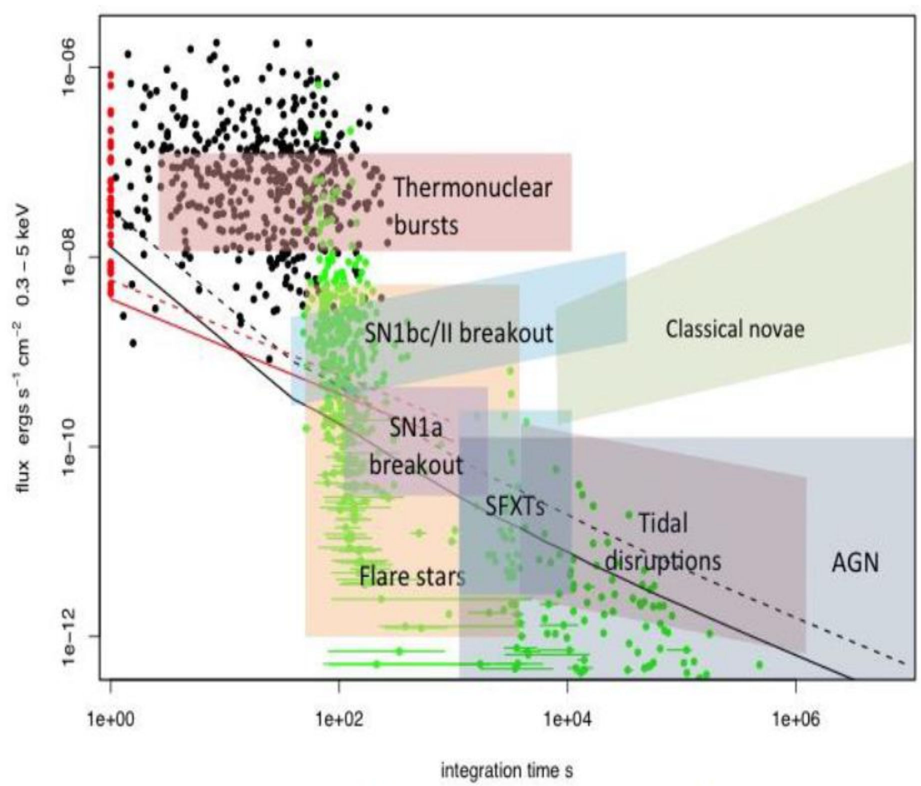


THESEUS/SXI
10000
GRASP
(deg² x cm²)
MAXI/GSC
(non focusing)
eROSITA
ASTROSAT/SSM
(non focusing)
1000
XMM-Newton
100
Energy (keV)
0
1
2
3
4
5
Swift/BAT
CGRO/BATSE
1000
100
10
1
Effective Area (cm²)
HETE-2/SXC
HETE-2/FREGATE
HETE-2/WXM
1
10
100
1000
Energy (keV)
Age of the Universe [Gyr]
13.46
3.22
1.51
0.91
0.62
0.46
0.36
0.29
0.24
0.20
0.17
1000.0
100.0
10.0
1.0
0.1
Theseus
Swift
N_GRB(>z) [yr⁻¹]
0
5
10
15
20
Redshift
1e-06
1e-08
1e-10
1e-12
Thermonuclear
bursts
SN1bc/II breakout
Classical novae
SN1a
breakout
SFXTs
Tidal
disruptions
AGN
Flare stars
1e+00
1e+02
1e+04
1e+06
integration time s

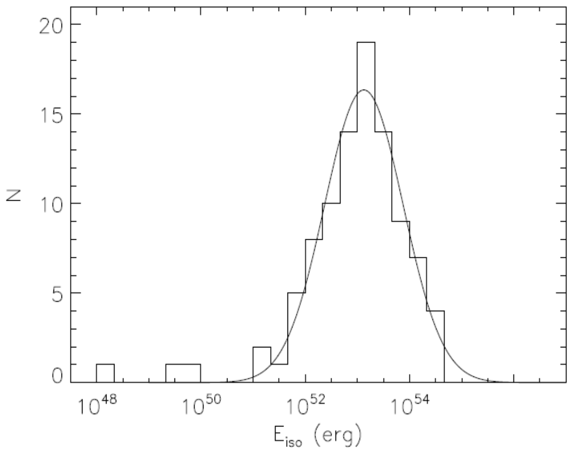
❑ THESEUS will also detect and localize down to 0.5-1 arcmin the soft X-ray short/long GRB afterglows, of NS-NS (BH) mergers and of many classes of galactic and extra-galactic transients

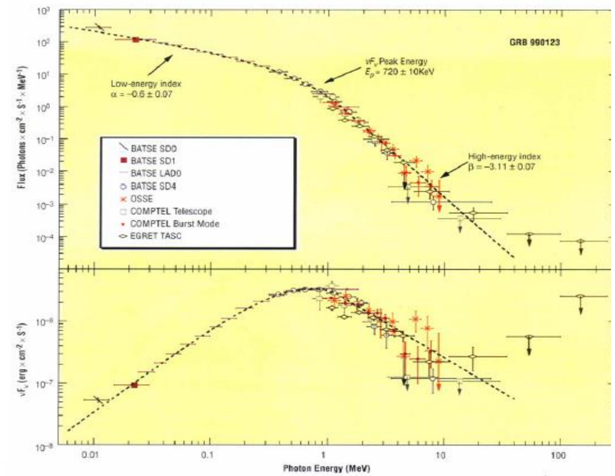
❑ For several of these sources, THESEUS/IRT may provide detection and study of associated NIR emission, location within 1 arcsec and redshift

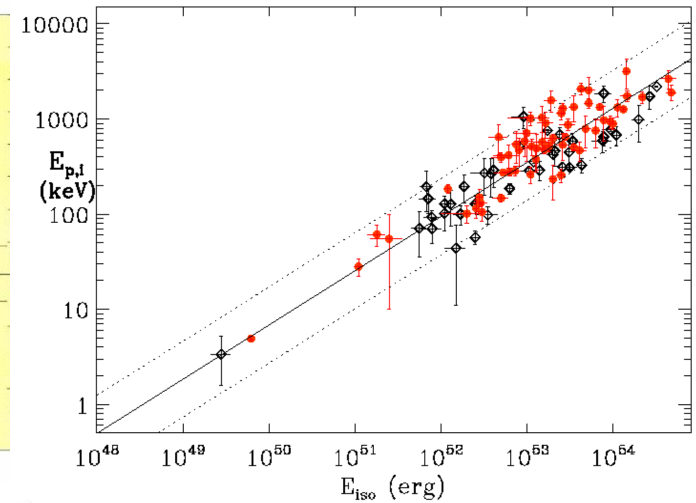


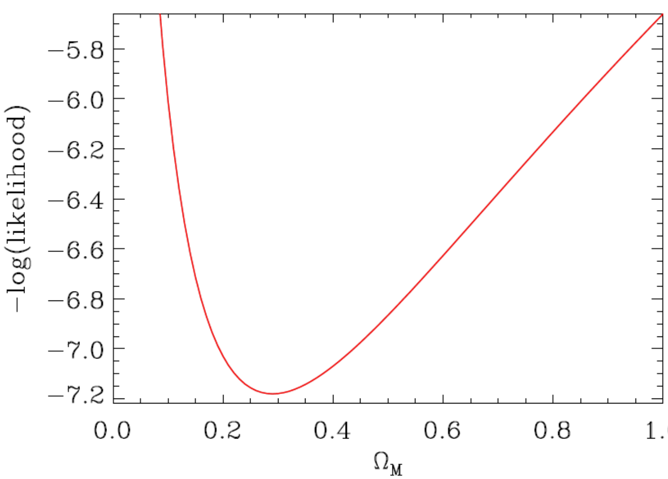


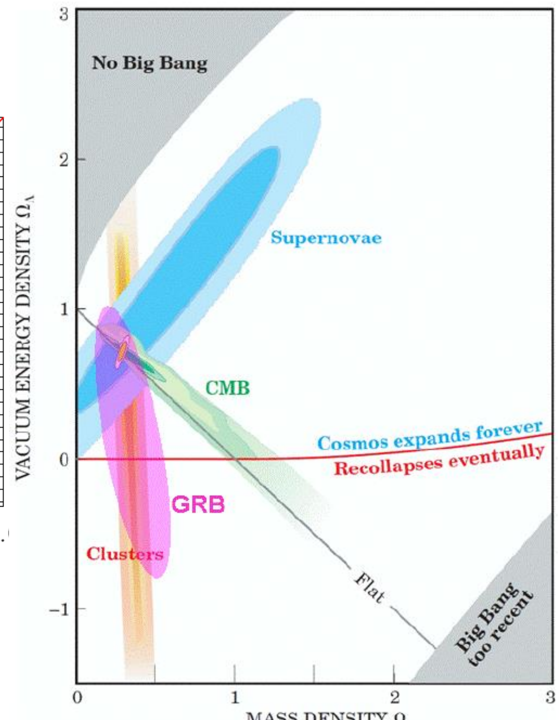
❑ measuring cosmological parameters with GRBs

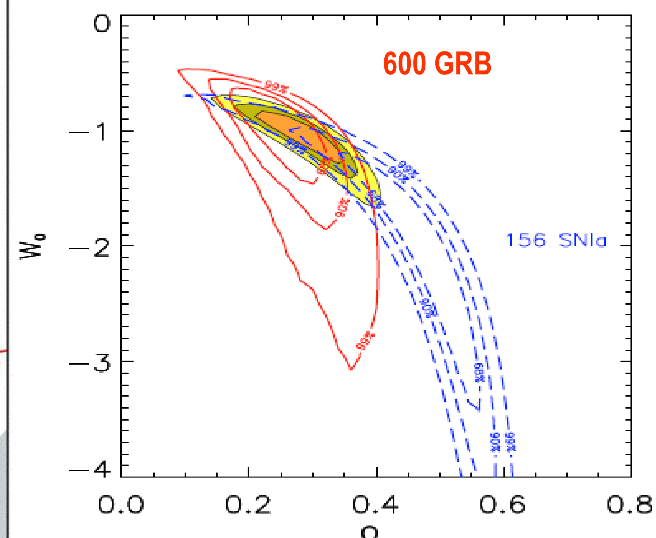






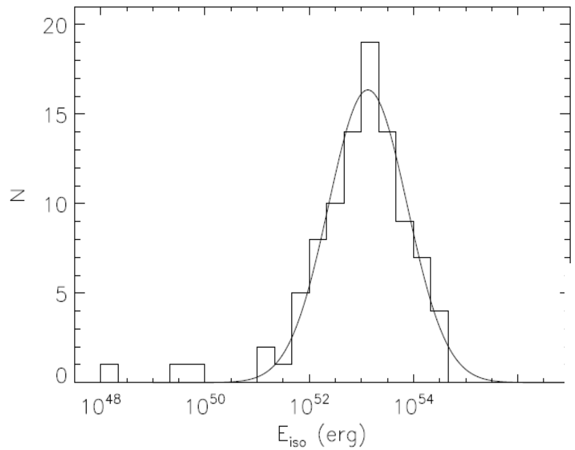


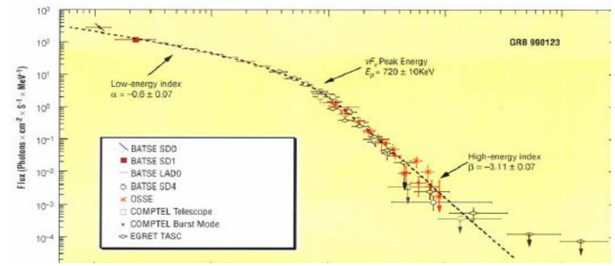


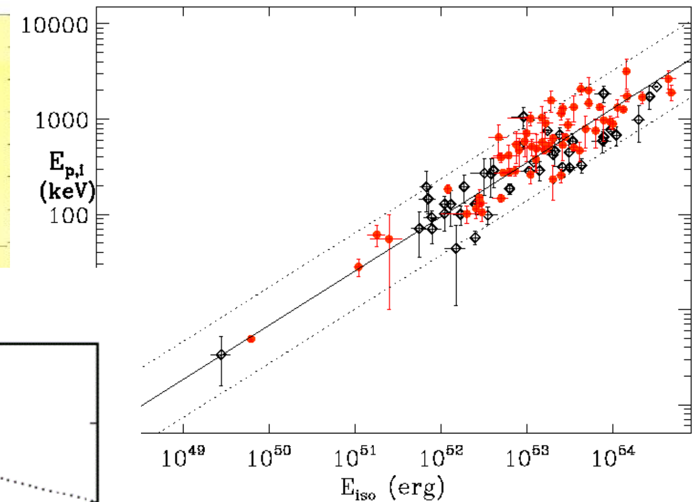


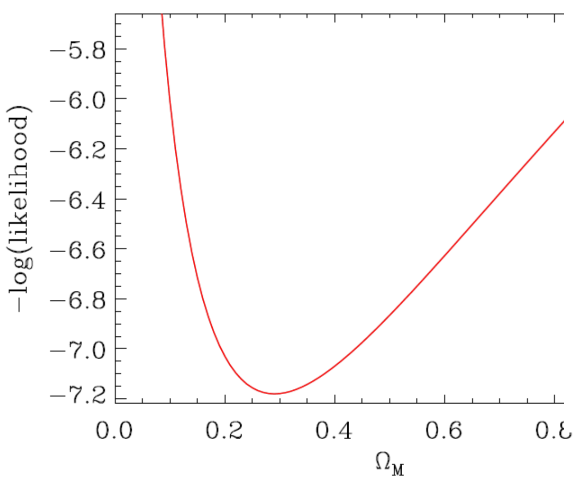
$$w(z) = w_0 + \frac{w_a z}{1+z}$$

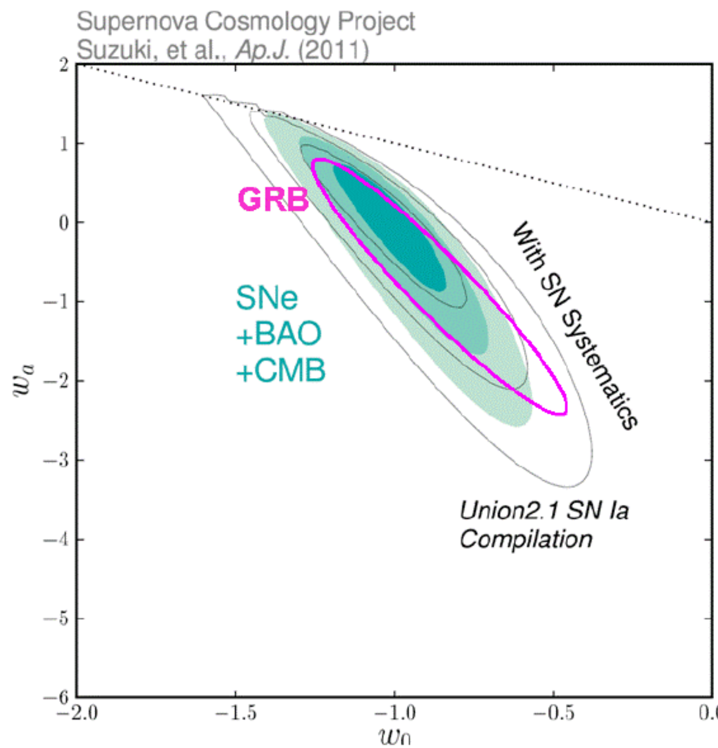
❑ measuring cosmological parameters with GRBs

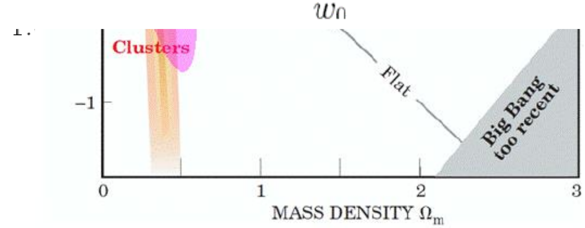


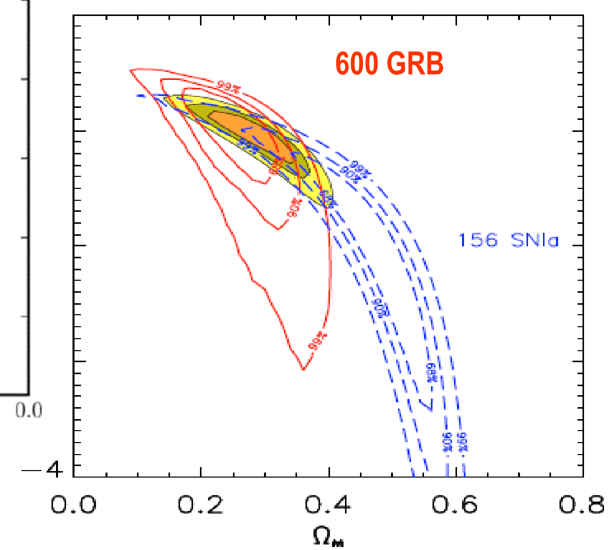






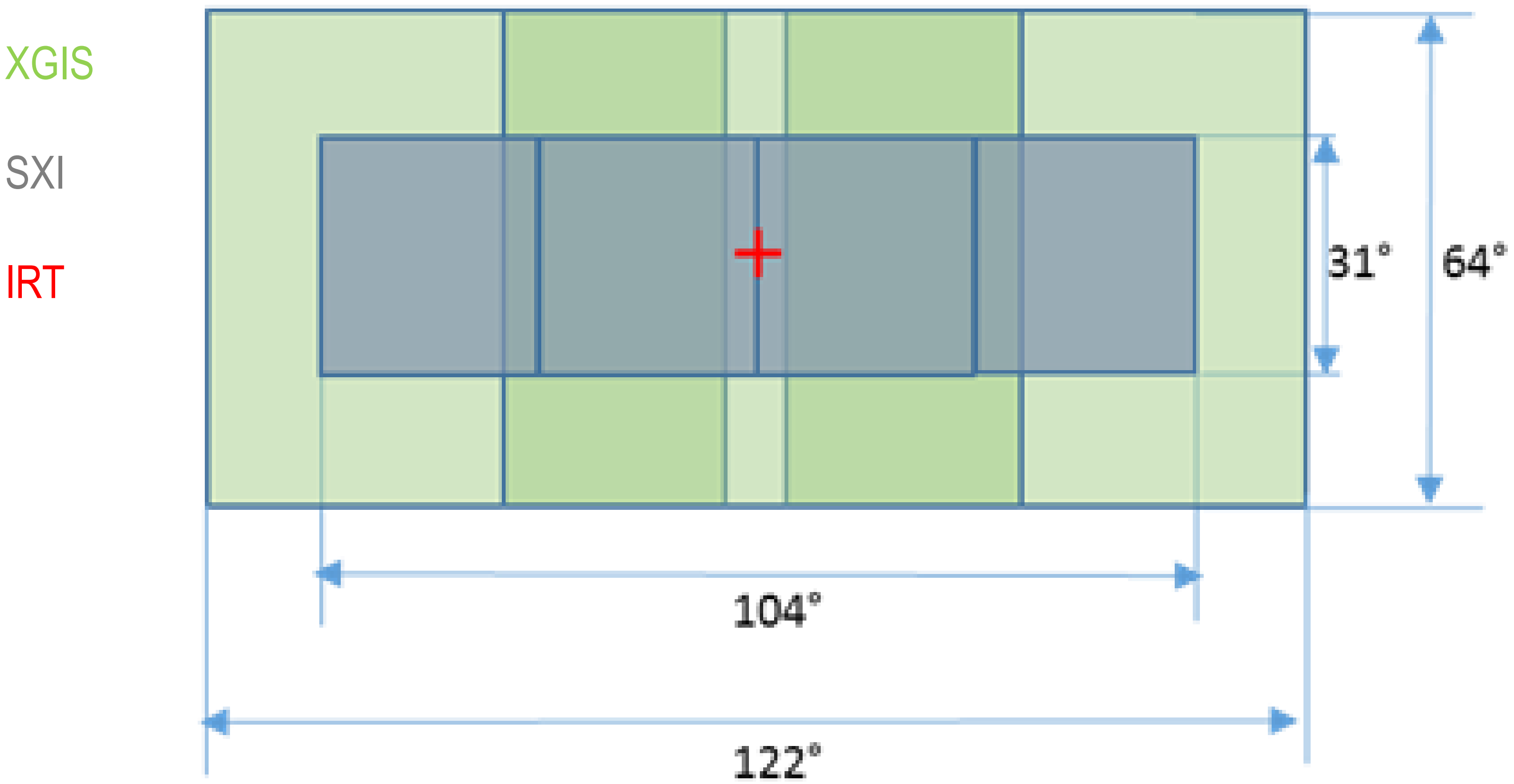




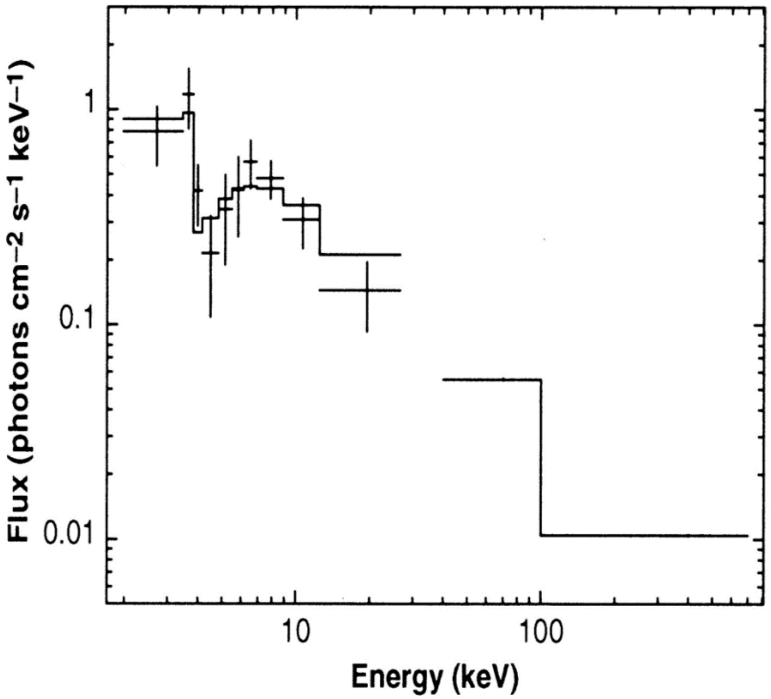


$$w(z) = w_0 + \frac{w_a z}{1+z}$$

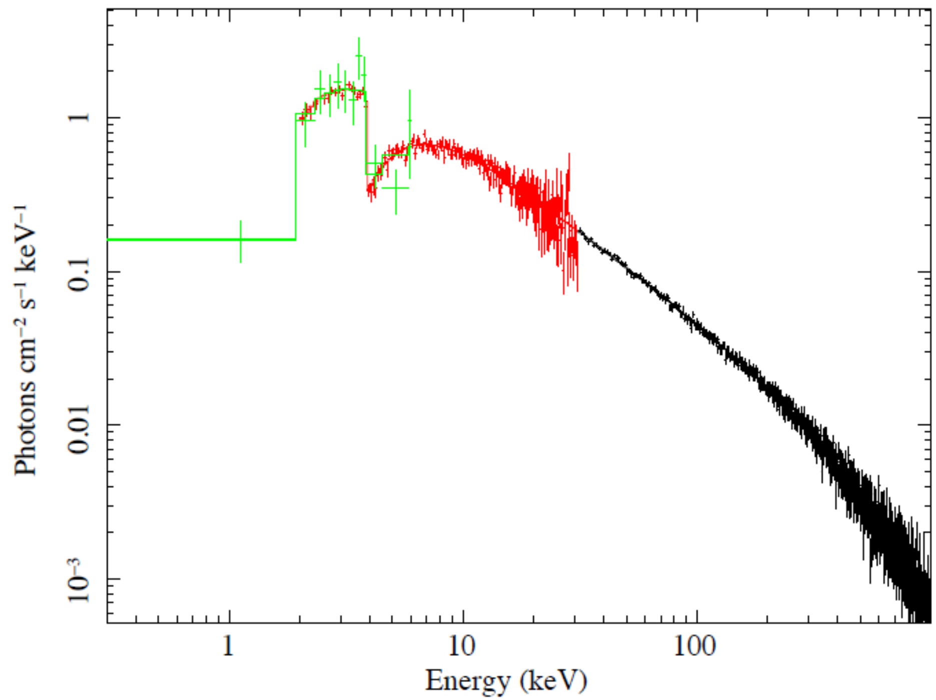
Field of view



❑ 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



BeppoSAX WFC + GRBM
(Amati et al. 2000)



THESEUS SXI + XGIS
(Nava et al. 2018)

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

	Energy Band	FOV	Energy resolution	Peak eff. area	Source location	Operation
CGRO/BATSE	20–2000 keV	open	10 keV (100 keV)	~1700 cm^2	>1.7 deg	ended
Swift	15–150 keV	1.4 sr	7 keV (60 keV)	~2000 cm^2	1–4 arcmin	active
Fermi/GBM	8 keV – 40 MeV	open	10 keV (100 keV)	126 cm^2	>3 deg	active
Konus–WIND	20 keV – 15 MeV	open	10 keV at 100 keV	120 cm^2	–	active
BeppoSAX/WFC	2–28 keV	0.25 sr	1.2 keV (6 keV)	140cm^2	1 arcmin	ended
HETE-2/WXM	2–25 keV	0.8 sr	1.7 keV (6 keV)	350cm^2	1–3 arcmin	ended
THESEUS	0.3–20000 keV	1 - 1.4 sr	300 eV (6 keV)	1500 cm^2	0.5–1 arcmin	2029-2030
SVOM	4 keV – 5 MeV	1.5 sr	2 keV (60 keV)	1000 cm^2	2–10 arcmin	2022

+ Infrared telescope and fast slewing !!!

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**

The key role of Italy in THESEUS

- Building on the unique scientific heritage 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,)

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, 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

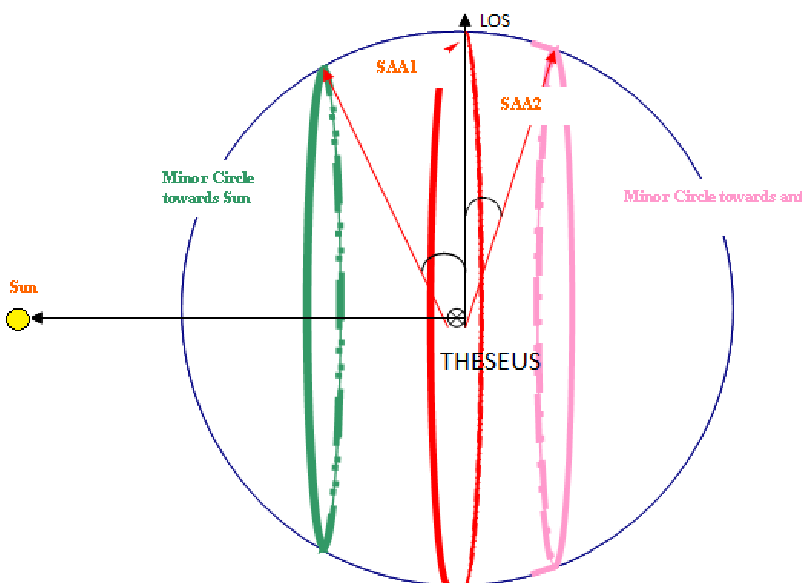
- **Development and testing of an XGIS module prototype is supported by TECNO INAF 2014 (P.I. L. Amati, INAF – IASF Bologna)**

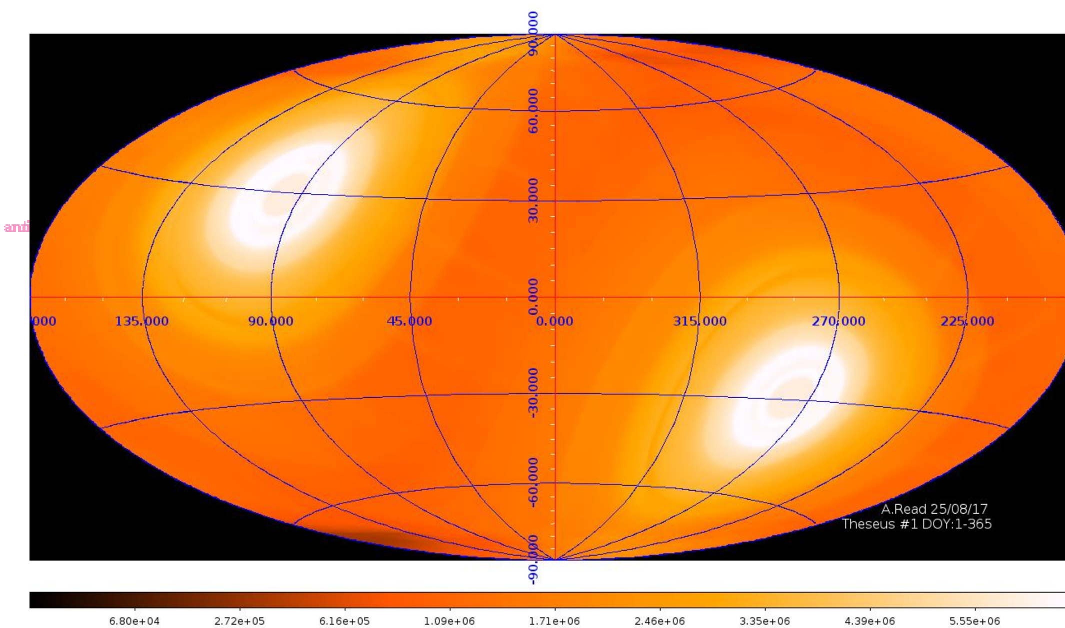
- *ESA L2/L3 review:* “The SSC strongly endorses the need to continue pursuing in the future the discovery of GRBs”

- 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.

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%





THESEUS after JWST and SKA

- **Even JWST and E-ELTs surveys, in the 2020s, will be not able to probe the faint end of the galaxy Luminosity Function at high redshifts (z>6-8).**

- The first, metal–free stars (the so–called **Pop III stars**) can result in powerful GRBs (e.g. Meszaros+10). GRBs offer a powerful route to directly identify such elusive objects (even JWST will not be able to detect them directly) and study the galaxies in which they are hosted. Even indirectly, the role of Pop III stars in **enriching the first galaxies** with metals can be studied by looking to the absorption features of Pop II GRBs blowing out in a medium enriched by the first Pop III supernovae (Wang+12).

- This is intimately connected to the reionization of the IGM and build up of global metallicity. The latter is very poorly constrained, and **even in the *JWST* era will rely on crude emission line diagnostics for only the brightest galaxies.**

- Regarding **reionization**, measurements of the Thomson scattering optical depth to the microwave background by the Planck satellite now suggest it substantially occurred in the redshift range $z \sim 7.8 - 8.8$ (e.g., Planck collaboration. 2016), whereas the observations of the Gunn-Peterson trough in the spectra of distant quasars and galaxies indicate it was largely finished by $z \sim 6.5$ (e.g., Schenker et al. 2014). Statistical measurements of the fluctuations in the redshifted 21 cm line of neutral hydrogen by experiments such as LOFAR and SKA are expected to soon provide further constraints on the time history (e.g, Patil et al. 2014). ***The central question, however, remains whether it was predominantly radiation from massive stars that both brought about and sustained this phase change, or whether more exotic mechanisms must be sought?*** With samples of several tens of GRBs at z > 7-8, we can begin to statistically investigate the average and variance of the reionization process as a function of redshift (e.g., McQuinn et al. 2008).

- Even though some constraints on fainter galaxies can be obtained through observations of lensing clusters (e.g. Atek et al. 2015 ApJ 7 814 69), which will be improved further by *JWST*, simulations **suggest star formation was likely occurring in considerably fainter systems still** (Liu et al. 2016).

THESEUS IRT Observatory Science

- Fielding an IR-specified spectrograph in space, THESEUS would provide a unique resource for understanding the evolution of large samples of obscured galaxies and AGN. With a rapid slewing capability, and substantial mission duration, the mission provides a very flexible opportunity to take efficient images and spectra of large samples of galaxies with minute-to-many-hour-long cumulative integrations

- The capability to cover the redshift range from $0.07<z<1.74$ for H-alpha and $0.44<z<2.29$ for H-beta enables Balmer decrement measurements of the extensive evolution of the AGN and galaxy luminosity functions at redshift ~0.5-1.5, a spectral region that simply cannot be covered from the ground. These key diagnostic rest-optical emission lines will be observed for galaxies in this substantial range of redshifts, reaching out towards the peak of AGN and galaxy formation activity, over a continuous redshift range where the bulge-blackhole mass relation is being built up and established, and the main sequence of star formation is well-studied. With excellent image quality, THESEUS~Rs R~500 grism can also provide spatially-resolved spectral information to highlight AGN emission, and identify galaxy asymmetries.

- The imaging sensitivity of THESEUS is about 6 magnitudes lower than for JWST in the same exposure time; nevertheless, its availability ensures that many important statistical samples of active and evolved galaxies, selected from a wide range of sources can be compiled and diagnosed in detail at these interesting redshifts. Samples can be drawn from the very large WISE- and Herschel-selected infrared samples of galaxies, from EUCLID~Rs 24-mag large-area near-infrared galaxy survey, augmented by near-infrared selection in surveys from UKIDSS (whose deepest field reaches approximately 1 mag deeper than EUCLID~Rs wide-area survey in the H band) and VISTA, and in the optical from LSST and SDSS.

- Spectra for rare and unusual galaxies and AGNs selected from wide-field imaging surveys can be obtained using the wide-field of THESEUS grism, thus building an extensive reference sample for studying the environments of the selected galaxies and AGNs, identifying large-scale structures and allowing overdensities to be measured.

A flexible and efficient use of the non-GRB THESEUS time with GO and ToO programs will enable to tackle a wide range of studies of variable and transients sources. The near-infrared bands are critical for Solar-system object tracking and multi-epoch variability studies. Cool stars, whose photon fluxes peak in the near-IR, are ideal targets for the detection and characterization of exoplanets using the transit technique, either in surveys or for follow-up
observations of individual sources (see, e.g., Clinton et al. 2012, PASP, 124, 700 and references therein). Simultaneous X-ray and NIR monitoring of samples of T-Tauri stars will shed light on the mechanisms responsible for the onset of the observed outbursts, and how the accretion rate of matter on these stars and the emission of jets can influence the formation of proto-planetary systems. Several open questions for low-mass X-ray binaries, hosting either neutron stars or stellar-mass black holes, require simultaneous IR and X-ray photometry (e.g. concerning the physics of jet emission from these sources; see, e.g., Migliari et al. 2010, ApJ, 710, 117; Russell et al. 2013, MNRAS, 429, 815). Recent studies have found that the peak luminosity of SNe Ia are genuine standard candles in the NIR (e.g. Krisciunas et al. 2004, ApJ 602 L81; Burns et al. 2014, ApJ 789 32). Considering also the reduced systematics in the NIR related to host-galaxy reddening, the IRT will represent an very efficient tool to construct a low-z sample of SNe Ia to be compared with the high-z samples that will be built by forthcoming IR facilities (e.g. JWST). In addition, gravitational time delays (a technique increasingly exploited in recent years for competitive H0 measurements) and AGN reverberation mapping variability projects will be particularly advantageous for THESEUS, where the cadence can be chosen more flexibly.

Possible THESEUS Data Policy

- In order to increase the follow-up from ground based facilities GRB positions and redshifts will be made immediately public
- GRB data will be owned by the consortium and made public after 1 year (TBC)
- X-ray survey alerts (i.e. non-GRB) will be made immediately public
- X-ray survey data will be owned by the consortium and made public within 1 year (TBC)
- THESEUS can be used as an observatory between one GRB follow-up and the other **a la Swift/XRT**

Table 17: Instruments TM summary

Instrument Suite	TM load (Gbit/orbit)
SXI	0.3
XGIS	2.4
IRT	2.2
Total P/L telemetry	4.5

Table 18: Summary of Instrument Suite temperatures

Instrument Element	Operative range (°C)	Cooling
SXI- structure/optics	-20 ÷ +20	passive
SXI- detectors	-65	active
XGIS-detectors	-20 ÷ +10	passive
IRT-structure	-30	active
IRT-optics	-83	active

SXI (4 units)	400 MCPs	4.0	Quotation Photonis	Mass production	UK, , Czech Republic, Germany, Belgium, ESA (contribution of the CCDs)
	30 CCDs	12	Quotation EEV	Mass production	
	Optics build test	10	100% FTE	Working time	
	Focal plane build test	11	100% FTE	Working time	
	Module structure/thermal/integration	11	100%FTE	Working time	
	Calibration 5 modules	2.0	100% FTE	Working time	
	Instrument controller into I-DHU	2.0	100%FTE	Working time and materials	
XGIS (3 units)	Man power for a) system management; b)electrical,mech & therm. des.; c) material procurement logistics; d) mass production (180 boards); e) AIV of the 26 modules; f) program management; g) Product assurance	9.0	Quotation	Mass production	Italy, Poland
	ASICs	1.0	Quotation	Mass production	
	SDD-PD units	2.4	Quotation	Mass Production	
	CsI bars	0.6	Quotation	Mass Production	
	Electronic board materials	1.3	Quotation	Mass production	
	Mechanical structure and collimators	1.5	Quotation	Mass production	
	Ground Support Equipment	0.2	Quotation	Working time	
	Spare materials	0.3	Quotation		
	Instrument Controller into I-DHU	1.25	100%FTE	Working time	
IRT	Telescope Mirror	100	Quotation		ESA (telescope and overall cooling system, including MPTC), France, Switzerland, Germany, Poland, Belgium
	Cost for a) management; b) System Engineering; c) Product Assurance; d) Camera optics and CCD e) Camera mechanical design; f) Camera thermal design; g) GSe; h) Camera Assembly, i) AIV/AIT.	22	Quotation (EUCLID experience)	Working time plus materials	
	Camera cooling system including MPTC	3,1	Quotation from AirLiquide	Material	
	IRT focal plane	5	Quotation	Production	
	Instrument Controller into I-DHU	1.25	100%FTE	Working time and materials	
I-DHU &Power	Costs for a)Management; b) Structure; c) I-DHU HW; d) DHU SW; e) Power f) I-DHU&Powe board AITV.	6.2	ASIM Experience		Poland
SDC	Starting 6yrs ahead of launch. 3yrs of operations plus 2yrs of post-operations)	10	Based on the extensive experience of the UoG		Switzerland, Italy, UK, Spain
Instrument Operations Centers (one per instrument)		10	Past experience with flown missions & extended expertize from the UoG on past and running missions		All
Operational support		10	Past experience		All
Total		**237.1 (without ESA 117.1) M€)**			

Objectives

Explore the early Universe with a complete census of GRBs in the 1st billion years

Identify and study GW and cosmic neutrino astrophysical sources through an unprecedented exploration of the time-domain Universe in X-rays

Approaches

High detection rate of high-redshift GRBs and high-cadence large area monitoring of the X-ray sky using sensitive widest-field telescopes in the optimal soft X-ray band

Broad X-ray spectral band-pass to distinguish source types and increase detection efficiency to short GRBs

Rapid autonomous re-pointing allows OIR redshift measurement & spectral study while transient is bright

Rapid down-link lto large space & ground facilities

Measurements

30 GRBs with measured z > 8

Hundreds of new transient / variable high energy sources per year

X-ray positions at <1′ (soft band) and at< 5′ (hard band)

Triggers: 0.3 keV - 10 MeV

Broad band high energy spectra

Opt/IR imaging & spectra: 0.7 – 1.8 μ

Transient light curves over seconds to months

Instrument requirements

Soft X-rays:

- 1 sr FOV
- 1000s sensitivity 1×10^{-10} cgs in 0.3-5 keV)
- PSF FWHM 4.5′
- 150 eV FWHM @ 6 keV
- On-board multi-timescale image trigger

Hard X-rays:

- 1.5 sr FOV
- 1s sensitivity 300 mCrab in 2-30 keV
- 300 eV FWHM @ 6 keV
- On-board multi-timescale image trigger

Optical-IR:

- Imaging, lo-res & hi-res spectra
- 10′x10′ FOV
- Positions <1″
- H = 20.6 in 300s @ SNR 5

Mission requirements

Low earth (500-600 km), low inclination orbit (<6°) for low background

Field of Regards > 60°

Prompt alert downlink

Pointing accuracy and stability: APE < 2.5′, jitter < 1.5′′ (10s)

On-board time management accuracy: < few μs

Rapid autonomous re-pointing (>5°/min)

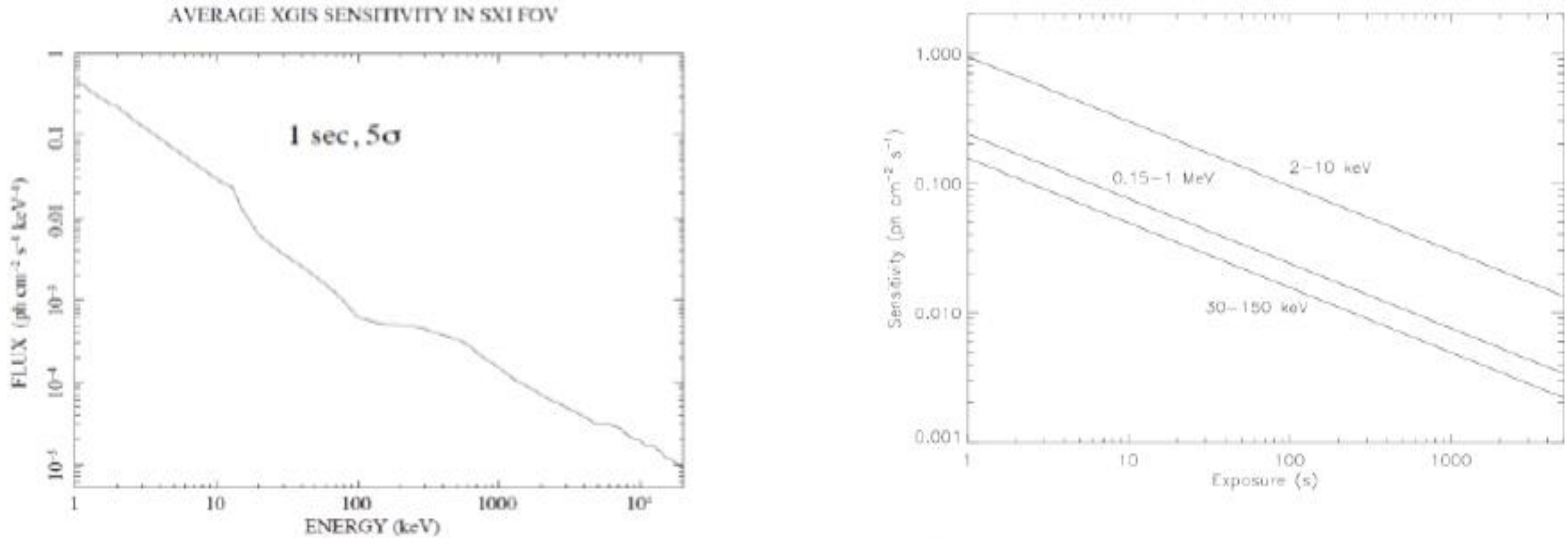
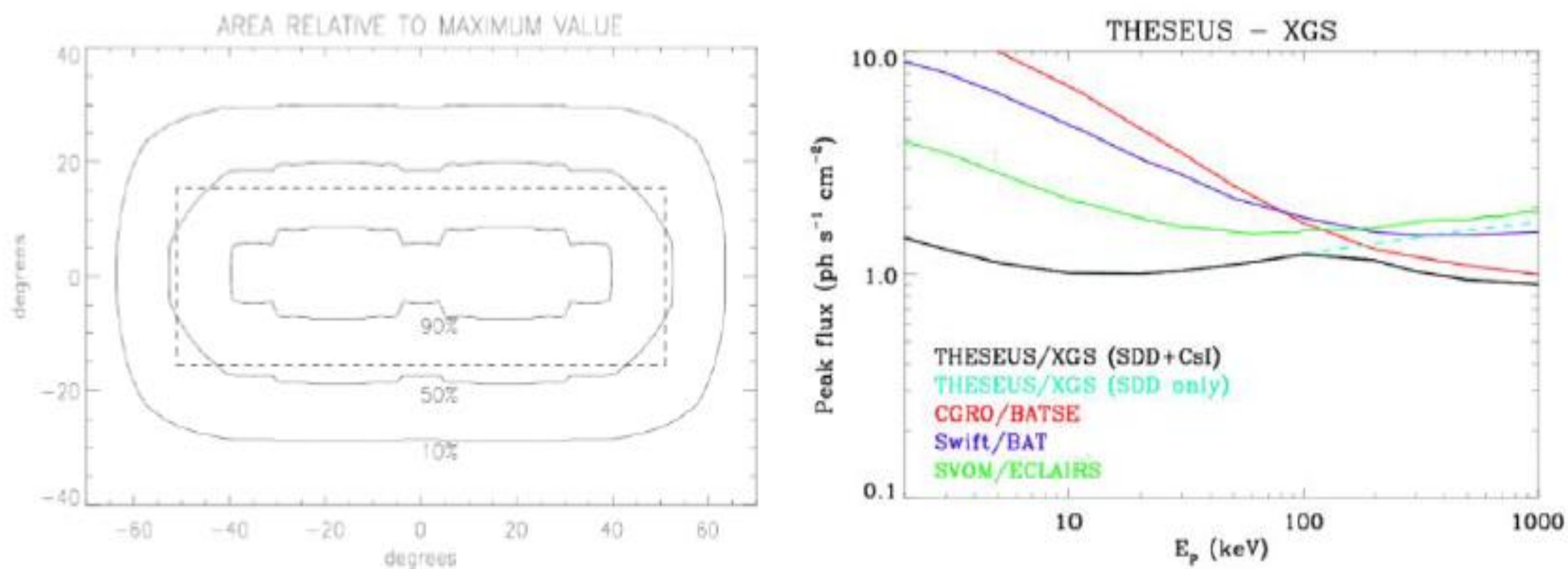
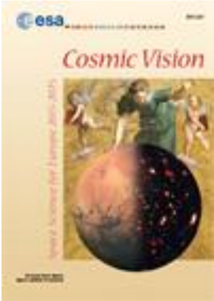


Figure 5: Left: XGIS sensitivity vs. energy in 1 second. Right: XGIS sensitivity as a function of exposure time in diffe bands.



The ESA Cosmic Vision Programme



❖ Selected missions

- M1: Solar Orbiter (solar astrophysics, 2017)
- M2: Euclid (cosmology, 2020)
- L1: JUICE (exploration of Jupiter system, 2022)
- S1: CHEOPS (exoplanets, 2017)
- M3: PLATO (exoplanets, 2024)
- L2: ATHENA (X-ray observatory, cosmology, 2028)
- L3: LISA (gravitational wave observatory, 2034)
- M4: TBD (2025) [XIPE (X-ray pol.), ARIEL (exoplanets), THOR (plasma, interaction star-planet)]
- M5: 2029-2030 launch (ESA budget 550Meuro) – phase A selection in June 2017

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**), **exoplanets** (planets formation + evolution + census **-> life**), **solar system exploration** (as for exoplanets)

THE ESA/M5 Call (for launch in ~2029)

Activity	Date
Release of Call for M5 mission	April 29, 2016
Letter of Intent submission deadline	June 6, 2016, 12:00 (noon) CEST
Briefing meeting (ESTEC)	June 24, 2016 (TBC)
Proposal submission deadline	October 5, 2016, 12:00 (noon) CEST
Letters of Endorsement deadline	February 8, 2017, 12:00 (noon) CET
Selection of missions for study	June 2017
Phase 0 completed	November 2017
Phase A kick-off	January 2018
Mission selection	November 2019
Mission adoption	November 2021

- **M5: launch in 2029-2030, ESA budget 550Meuro, final selection of 3 missions for phase 0/A by March 2018 (?)**
- **June 2017: THESEUS passed the technical-programmatic evaluation and was admitted to the final scientific evaluation**

Italian leadership and contribution to THESEUS: motivation and heritage

- **BeppoSAX (Italy, +NL contribution)** : X-ray afterglow emission -> optical counterparts and host galaxies -> cosmological distance scale, GRB-SN connection, X-ray flashes, Ep- Eiso ("Amati") correlation -> cosmological parameters and dark energy

- HETE-2 (USA; Italian contribution): deeper investigation of X-ray flashes

- Swift (USA, Italian contribution): early afterglow phenomenology, sub-energetic GRBs, ultra-long GRBs, soft long tail of short GRBs

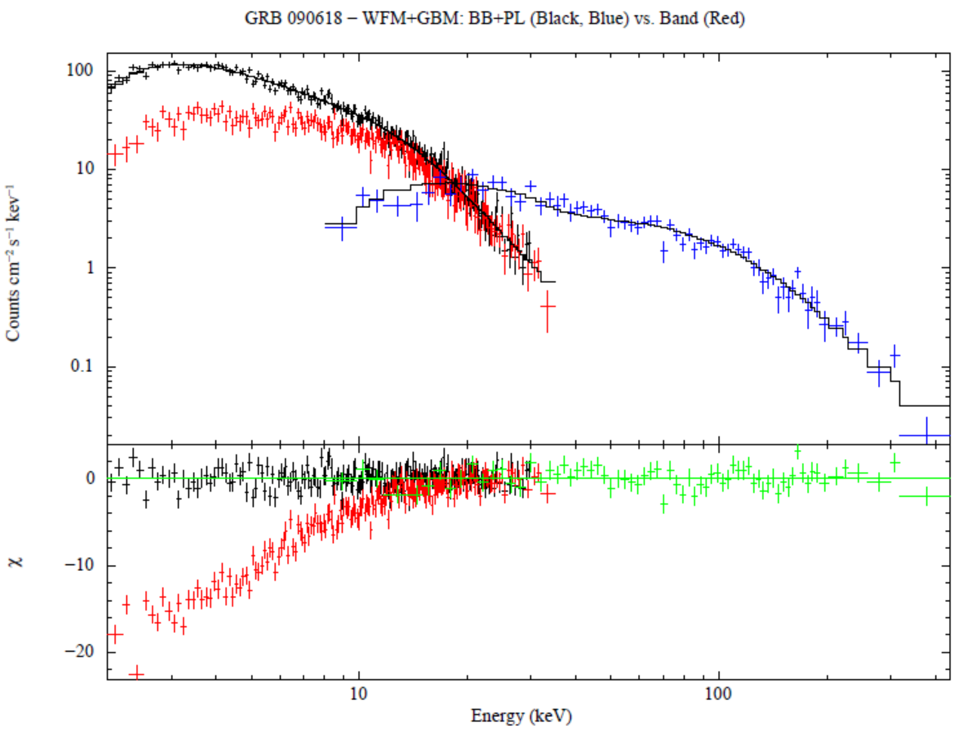
- AGILE (Italy): timing of prompt emission + X-ray detections

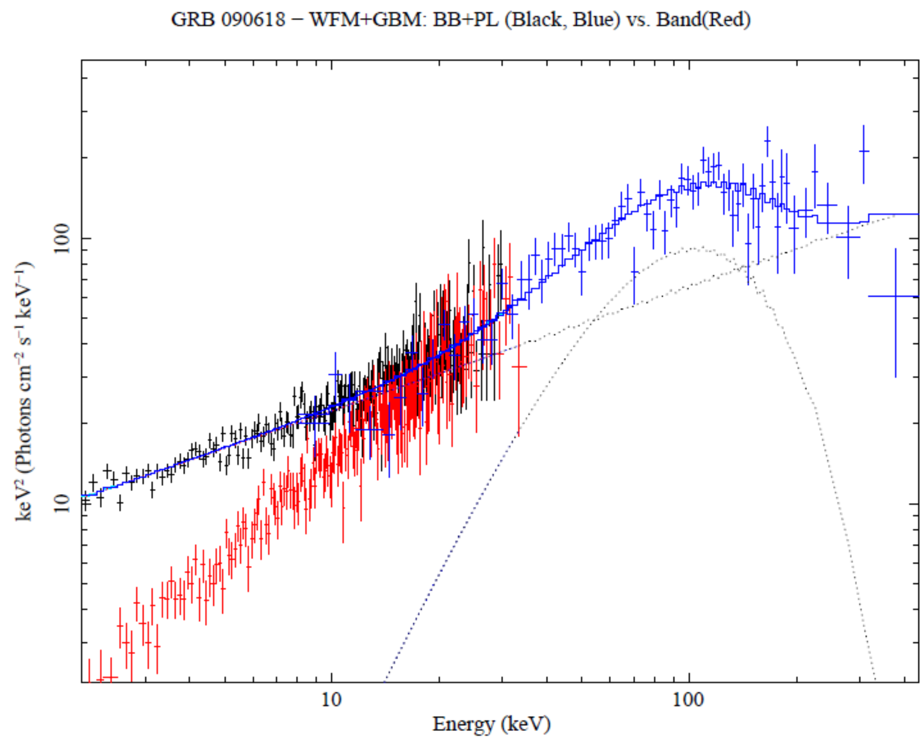
- Fermi (USA, Italian contribution): high energy emission, additional spectral features -> crucial tests for emission physics, engine (+ testing quantum gravity ?)

- Piship of large optical /NIR follow-up programmes (TNG, VLT, etc.)

❑ Discriminating among different models - The case of GRB 090618:

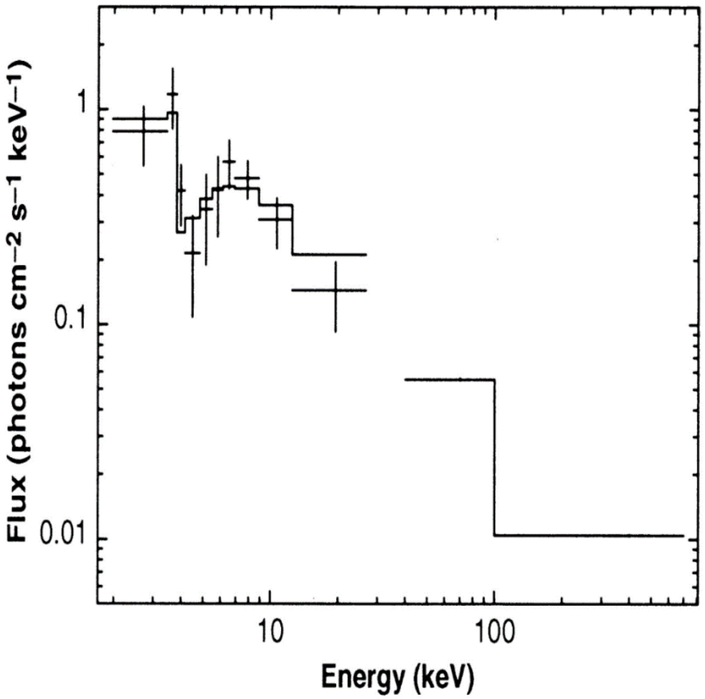
THESEUS/XGS will be capable of discriminating among Band and BB+PL thanks to its energy band extending below 10 keV

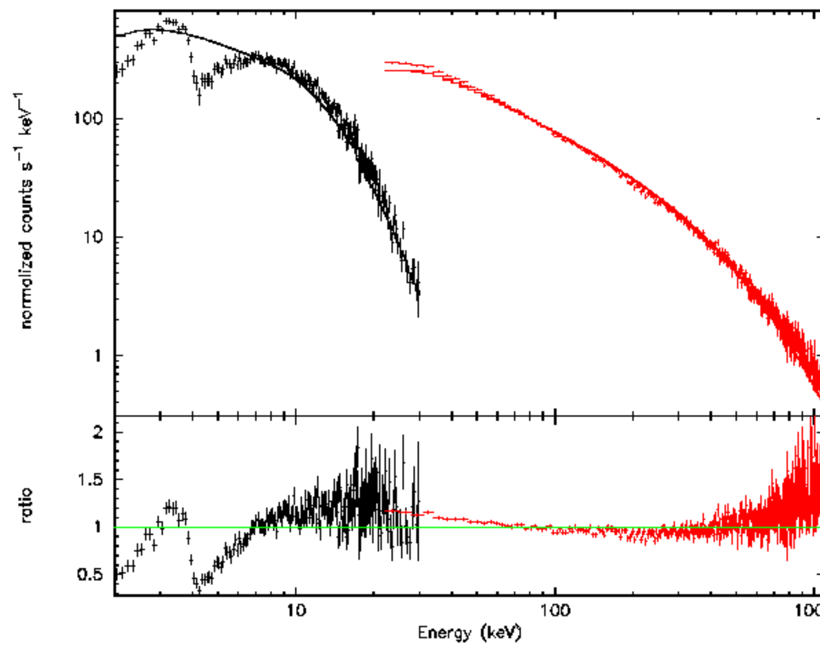




Fermi/GBM **THESEUS/XGS (BB+PL)** **THESEUS /XGS (Band model)**

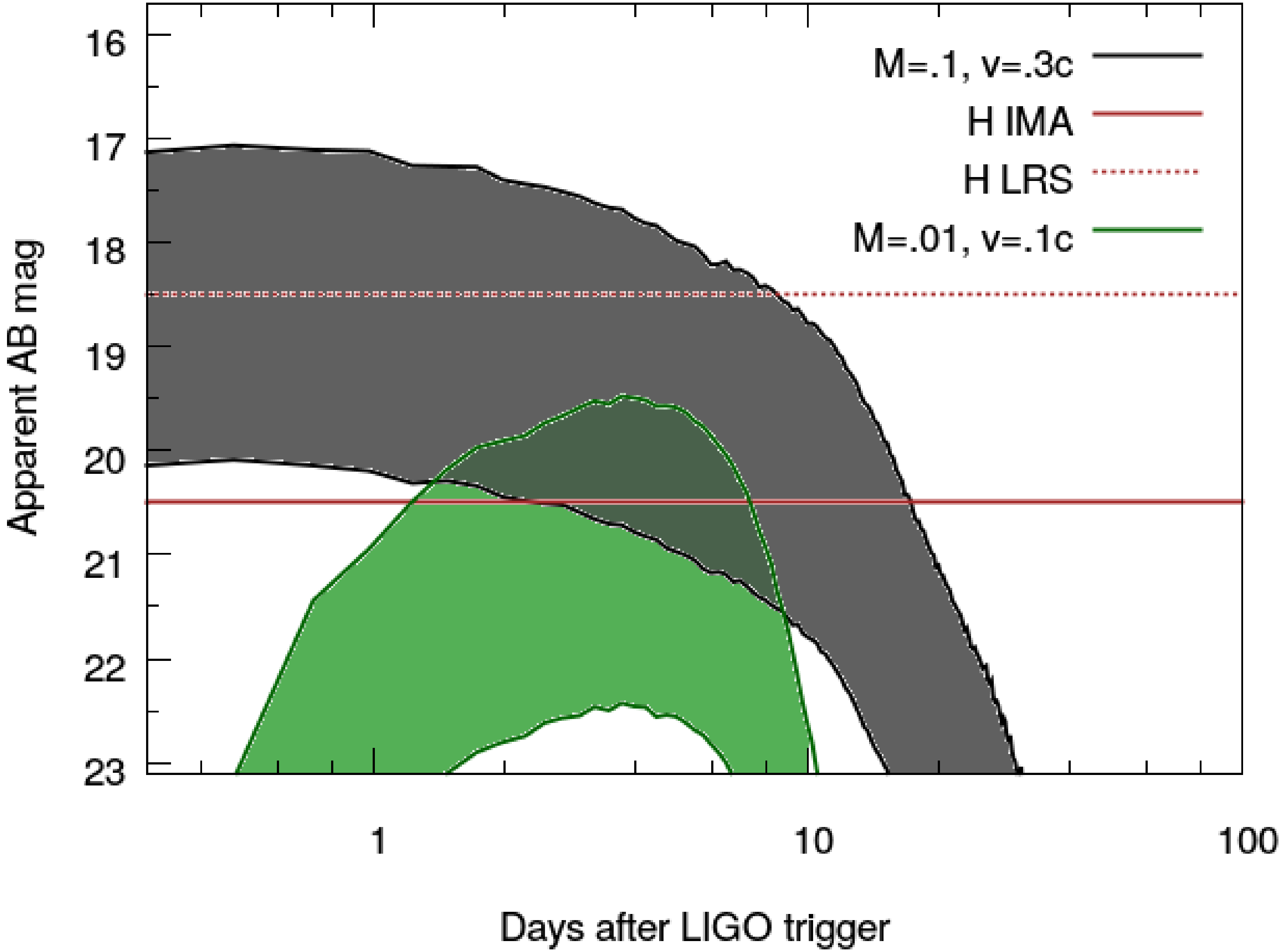
❑ Absorption features: the case of GRB990705 (edge at 3.8 keV -> redshifted neutral iron k-edge -> z = 0.85 -> confirmed by host galaxy spectroscopy: redshift estimate through X-ray spectroscopy





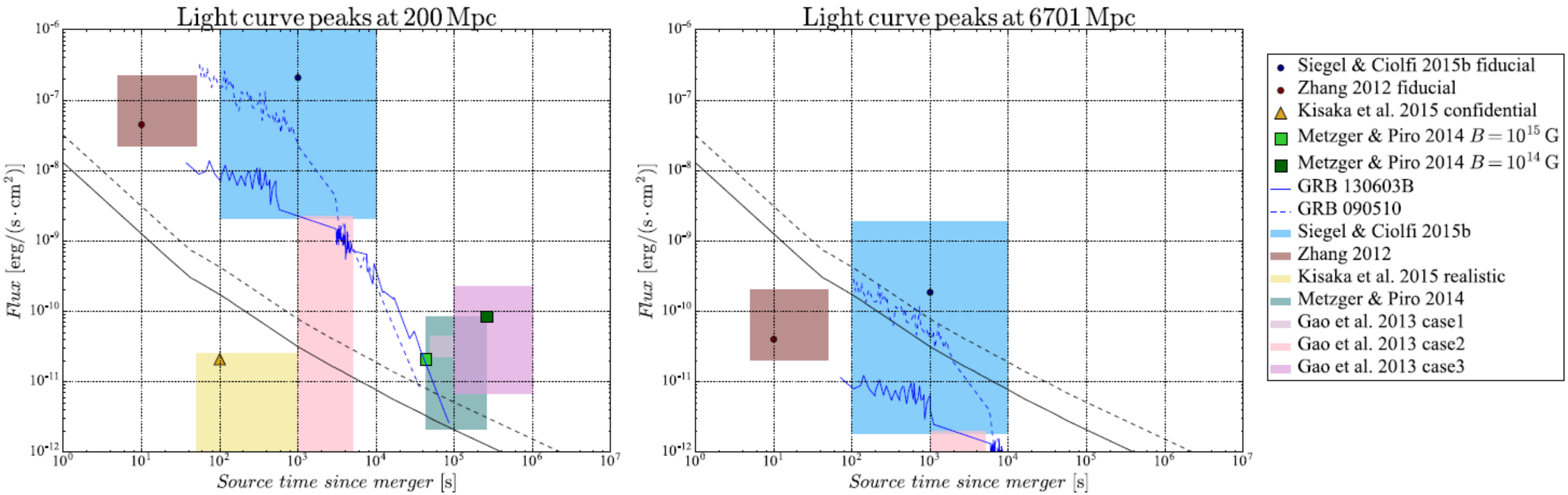
BeppoSAX WFC + GRBM

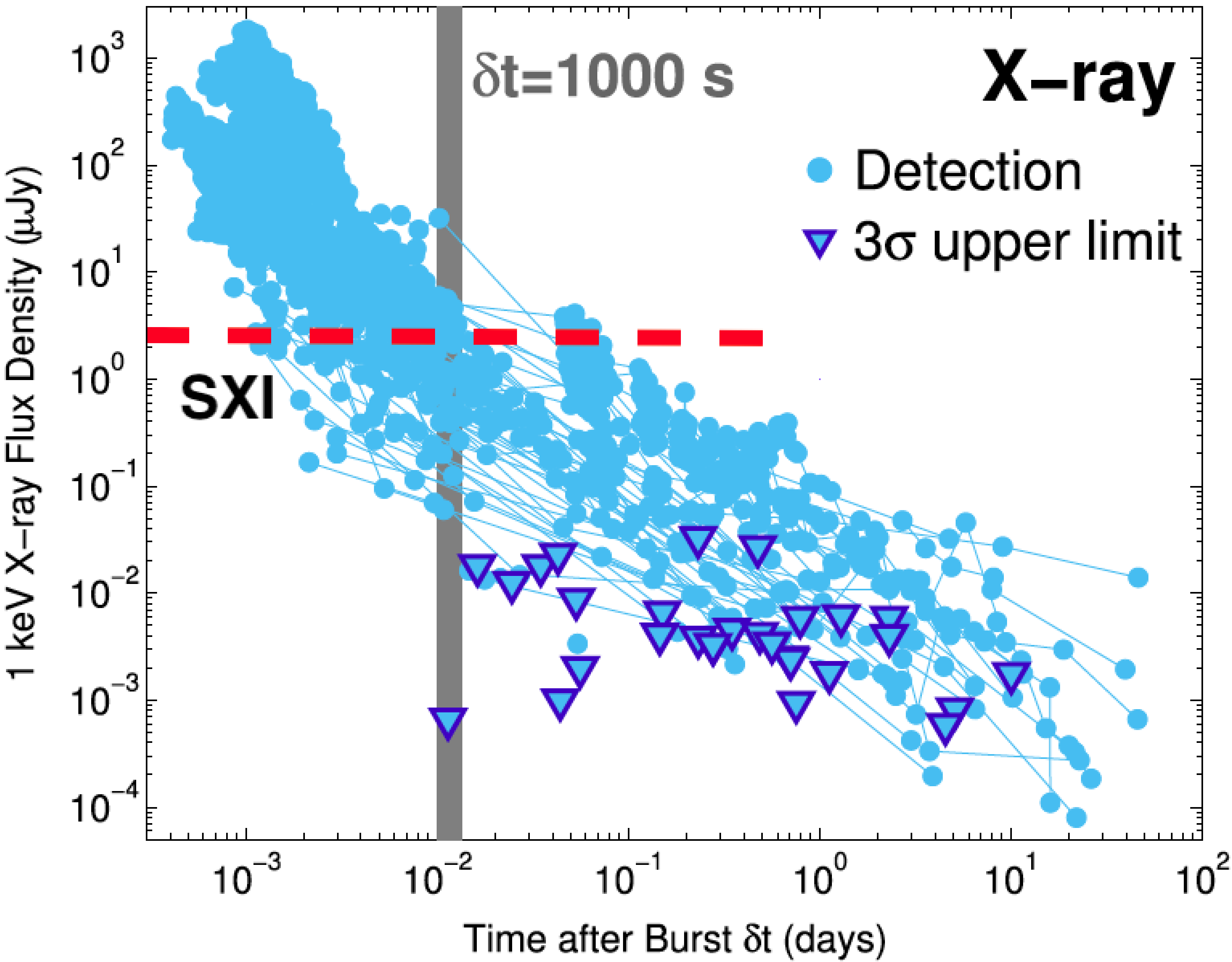
THESEUS XGS



Here we show theoretical H-band lightcurves of kilonova based on models from Barnes et al., 2016 (ApJ 829,110). The lightcurves are in observer frame for a source between 50 and 200 Mpc. Gray model is for the most optimistic case of a kilonova with $0.1 solar masses ejected with speed of 0.3,c. Green model is for a weaker emission, corresponding to $0.01 solar masses ejected with speed of 0.1 c.

GW observations				THESEUS XGIS/SXI joint GW+EM observations	
Epoch	GW detector	BNS horizon	BNS rate (yr^{-1})	XGIS/sGRB rate (yr^{-1})	SXI/X-ray isotropic counterpart rate (yr^{-1})
2020+	Second-generation (advanced LIGO, Advanced Virgo, India-LIGO, KAGRA)	~400 Mpc	~40	~5-15	~1-3 (simultaneous) ~6-18 (+follow-up)
2030+	Second + Third-generation (e.g. ET, Cosmic Explorer)	~15-20 Gpc	>10000	~15-25	$\gtrsim$100




δt=1000 s
X−ray
Detection
3σ upper limit
SXI
1 keV X−ray Flux Density (μJy)
Time after Burst δt (days)

Lorenzo Amati

(INAF – OAS Bologna)

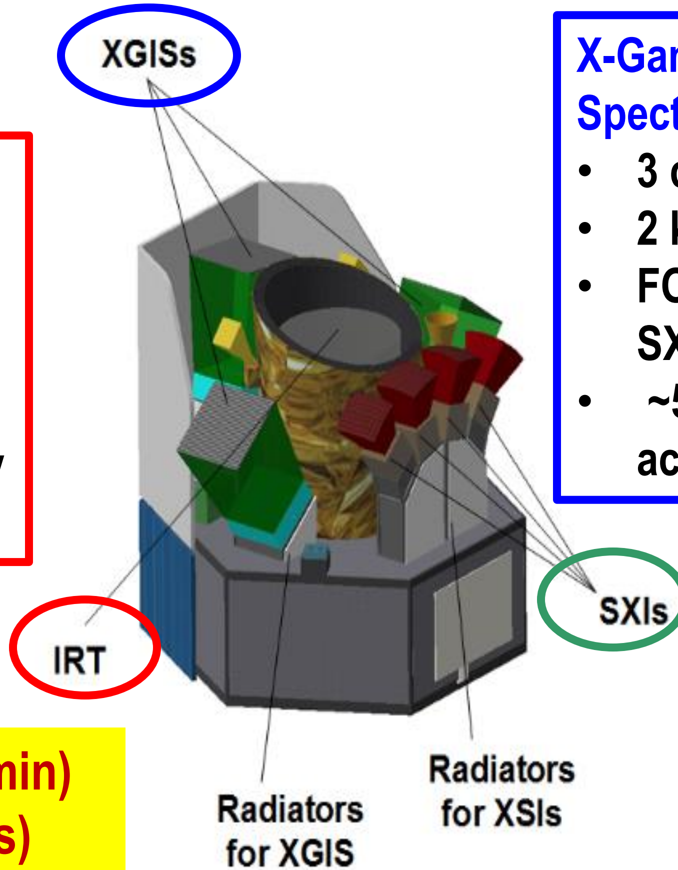
on behalf of the THESEUS international collaboration

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

Amati et al. 2017 (arXiv:1710.04638)
Stratta et al. 2017 (arXiv:1712.08153)

THESEUS mission concept

InfraRed Telescope (IRT)
- 0.7m class IR telescope
- 0.7 – 1.8 μm band
- 10’x10’ FOV
- Imaging + moderate resolution spectroscopy capabilities



X-Gamma rays Imaging Spectrometer (XGIS)
- 3 coded-mask X-γ ray cameras
- 2 keV – 10 MeV band
- FOV of ~2-4 sr, overlapping the SXI,
- ~5 arcmin source location accuracy

Soft X-ray Imager (SXI)
- set of 4 sensitive lobster-eye telescopes
- 0.3 - 5 keV band,
- FOV of ~1sr
- 0.5-1 arcmin source location accuracy

Rapid slewing bus (>10°/min)
Prompt downlink (< 10-20s)
64% sky coverage

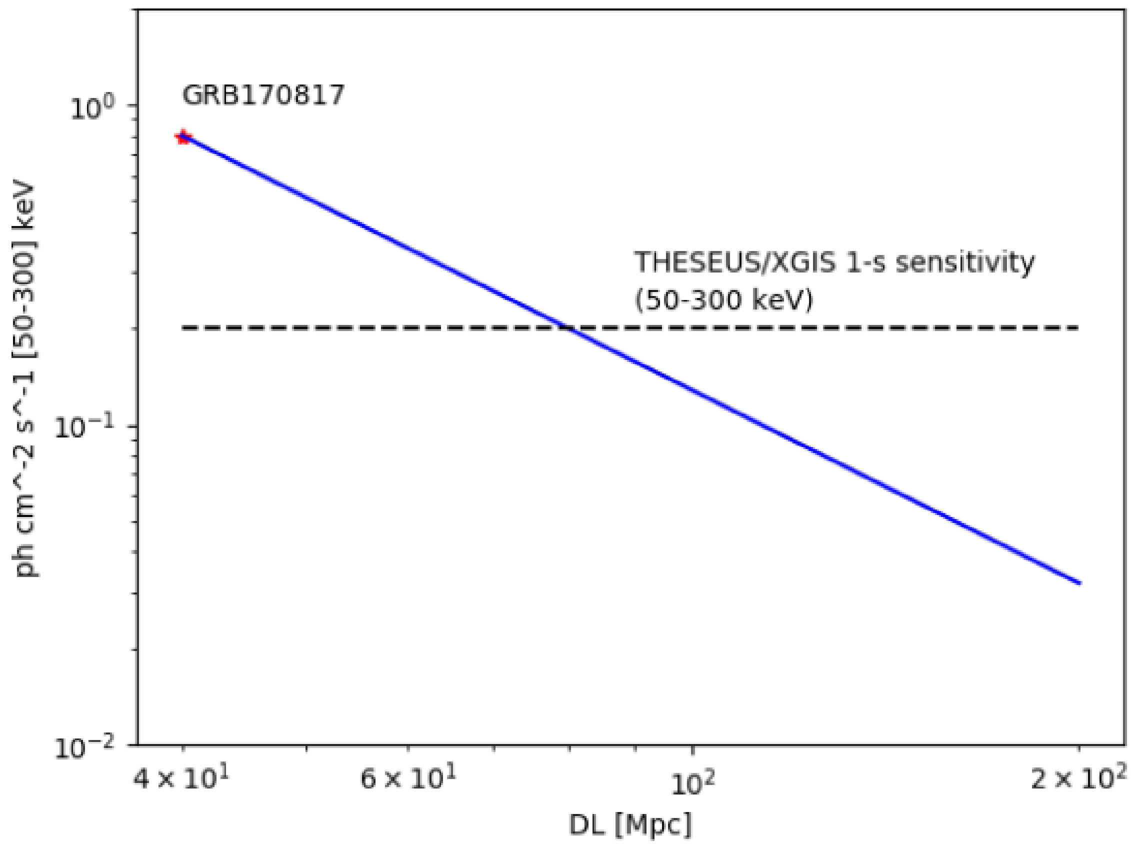
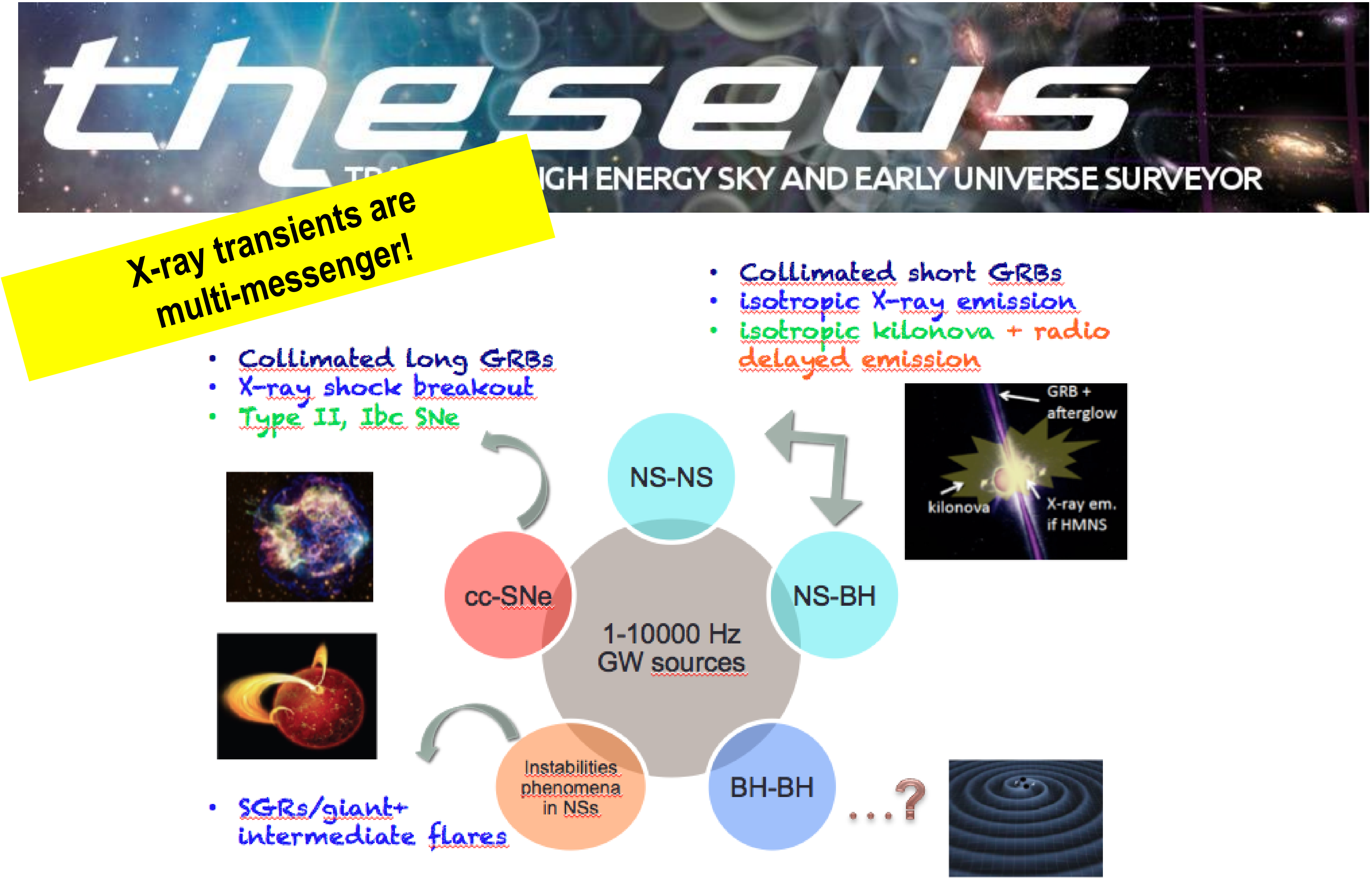
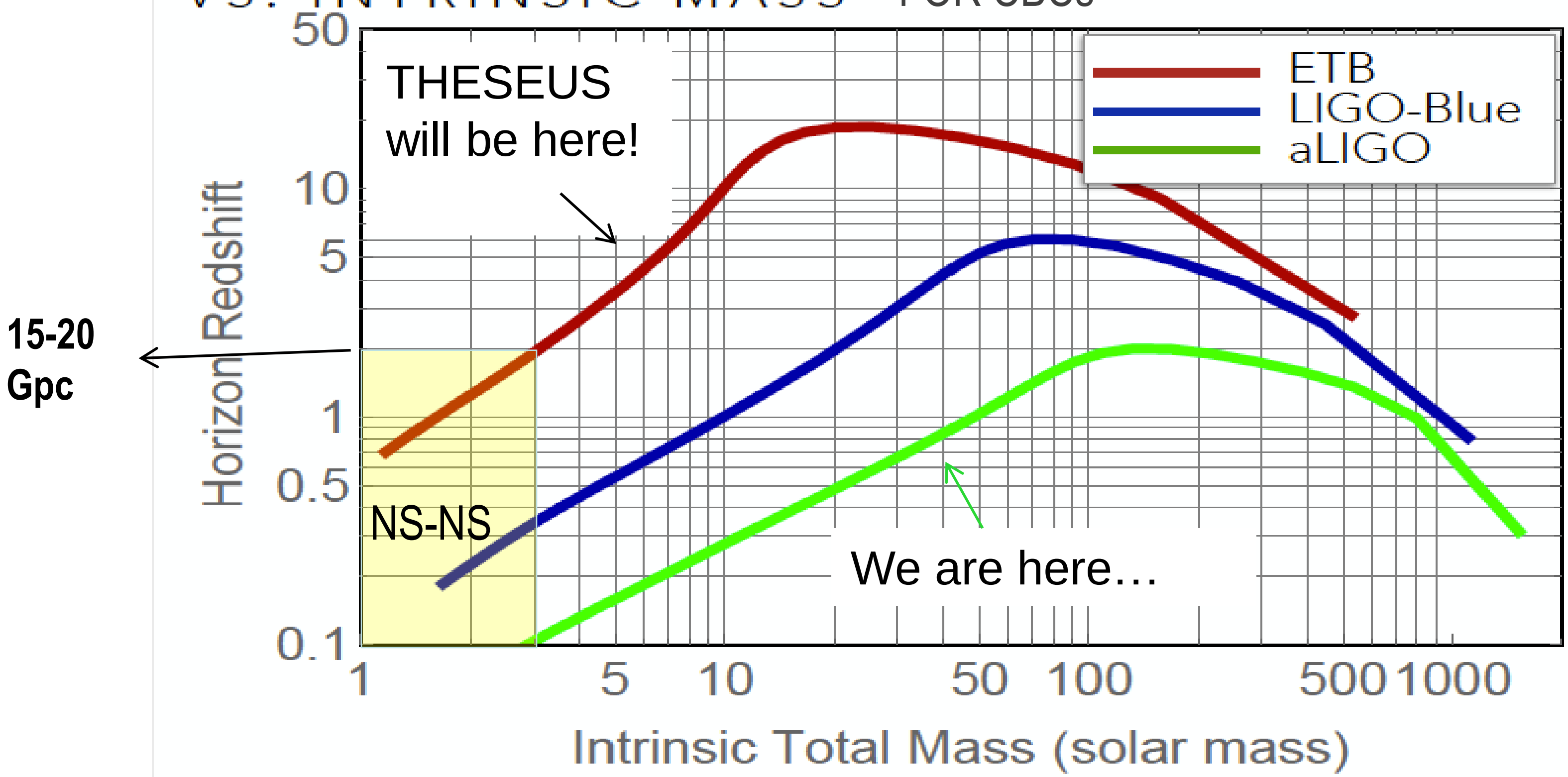


Figure 10: The Fermi/GBM peak photon flux of the short GW/GRB 170817 (red star, Goldstein et al. 2017) rescaled with the distance (blue line) and compared with THESEUS/XGIS 1-s sensitivity in the 50-300 keV energy range. Off-axis short GRB similar to GRB 170817 could had been detected with THESEUS/XGIS up to ~ 70 – 80 Mpc.

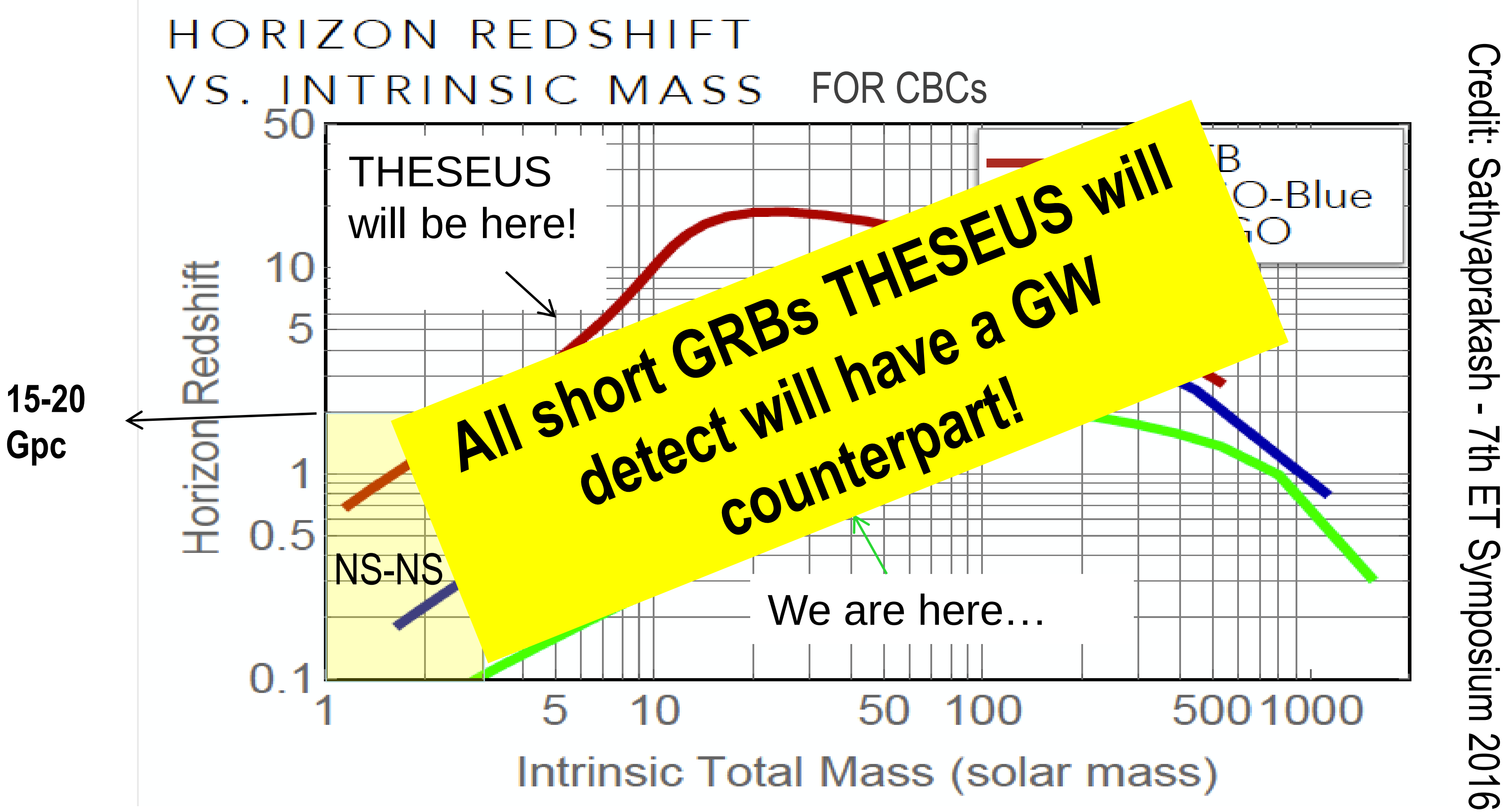


G. Stratta - LVC Town Hall Meeting, 2018,
April 12-13, Amsterdam

HORIZON REDSHIFT
VS. INTRINSIC MASS FOR CBCs



Credit: Sathyaprakash - 7th ET Symposium 2016



G. Stratta - LVC Town Hall Meeting, 2018,
April 12-13, Amsterdam