theseus
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

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

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

June 27, 2017

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

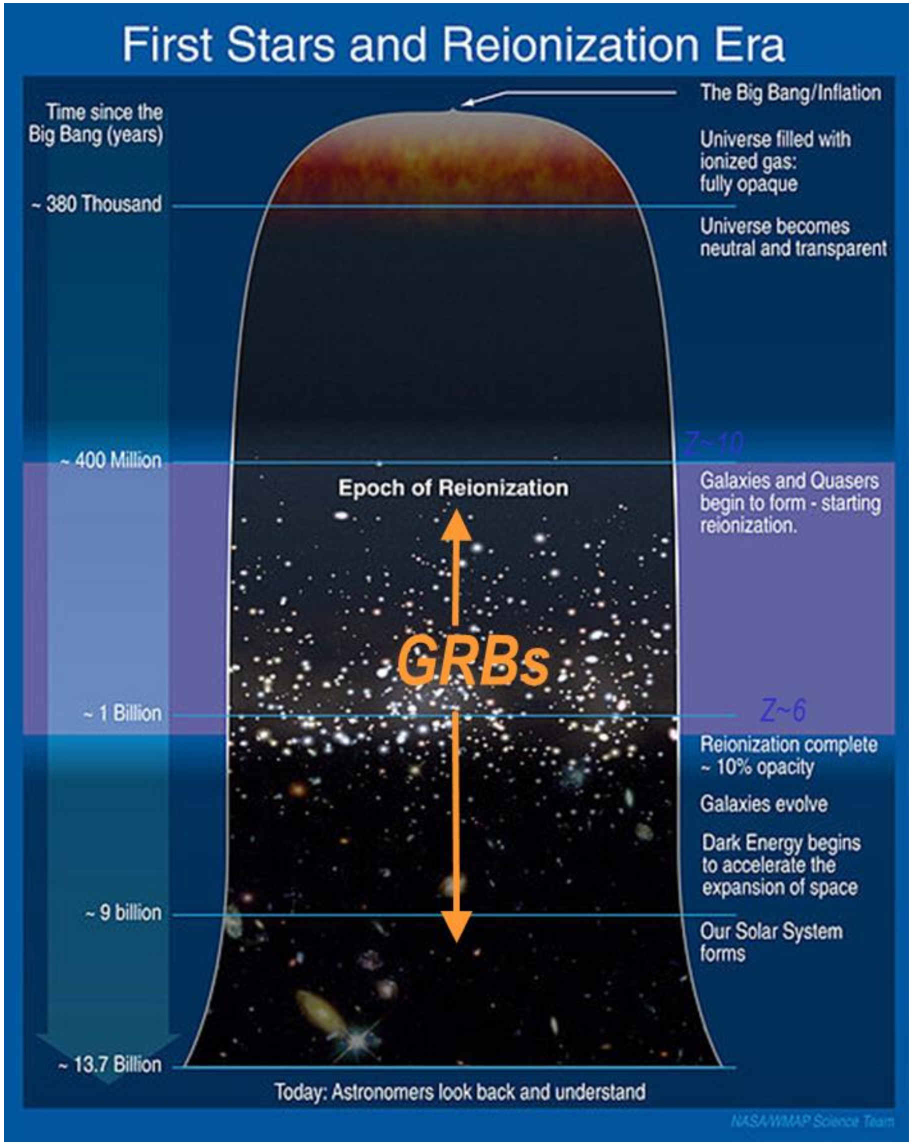
Interested international partners: USA, China, Brazil

THESEUS: 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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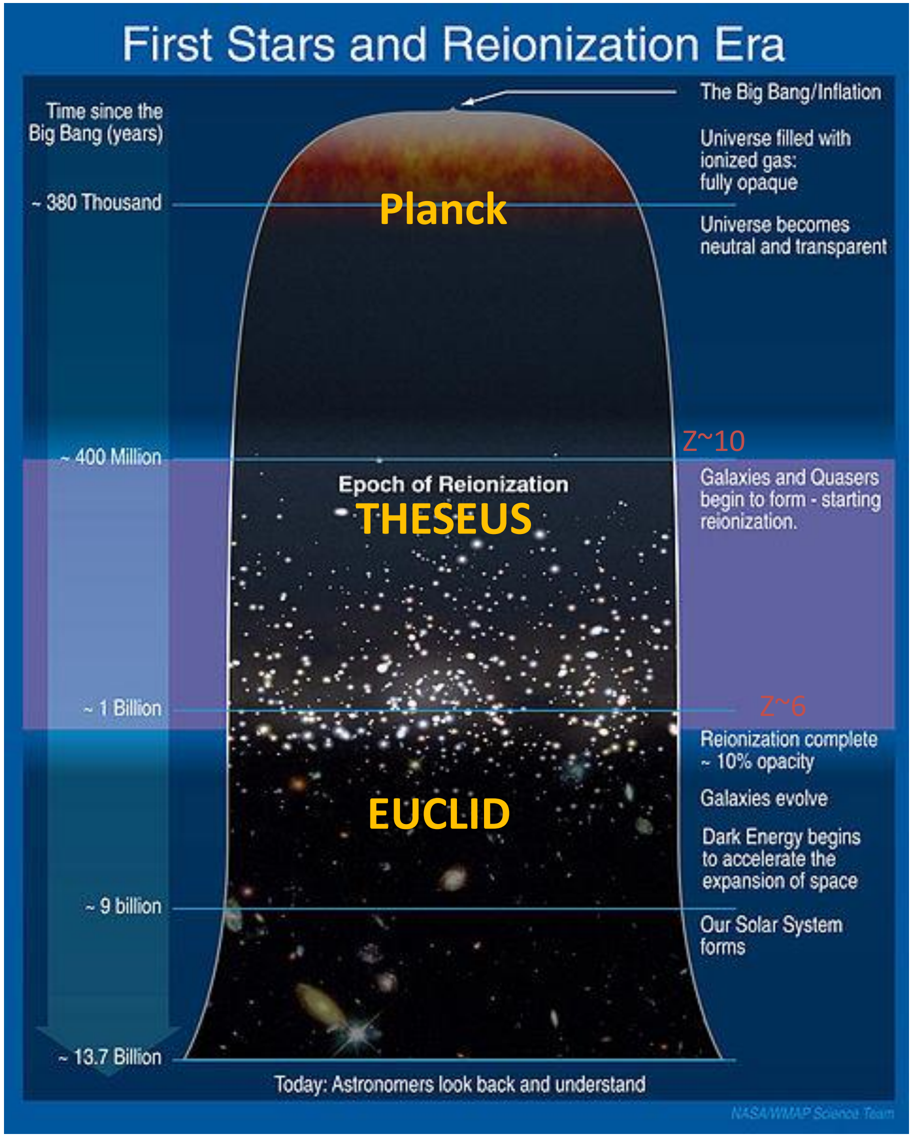
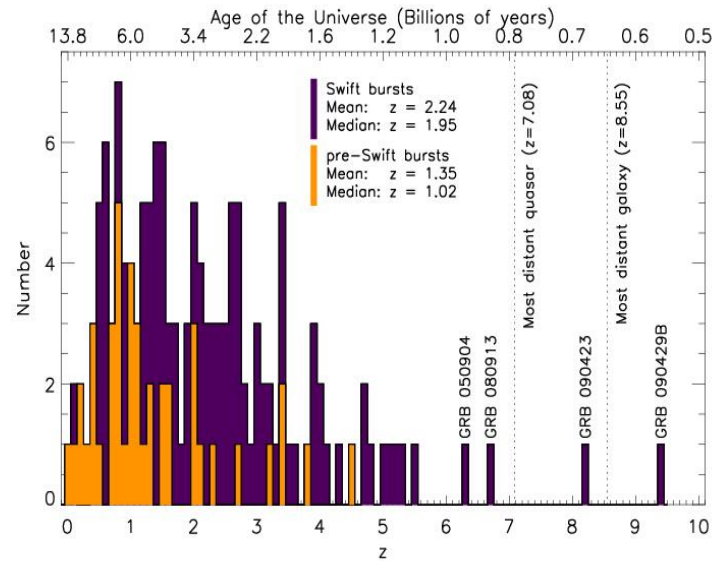
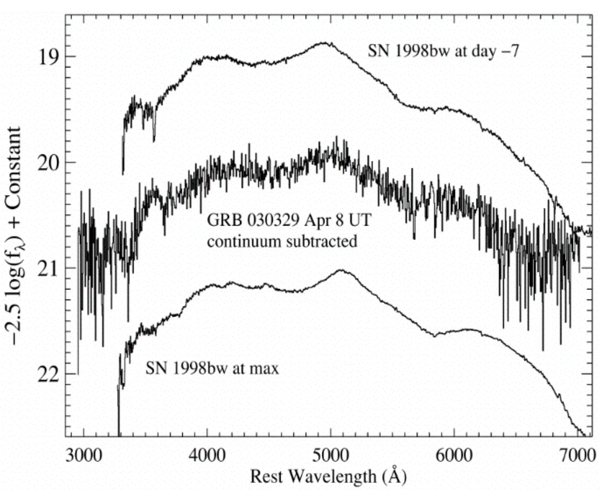


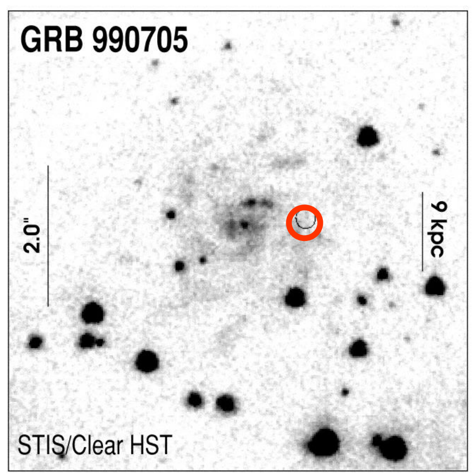
Shedding light on the early Universe with GRBs

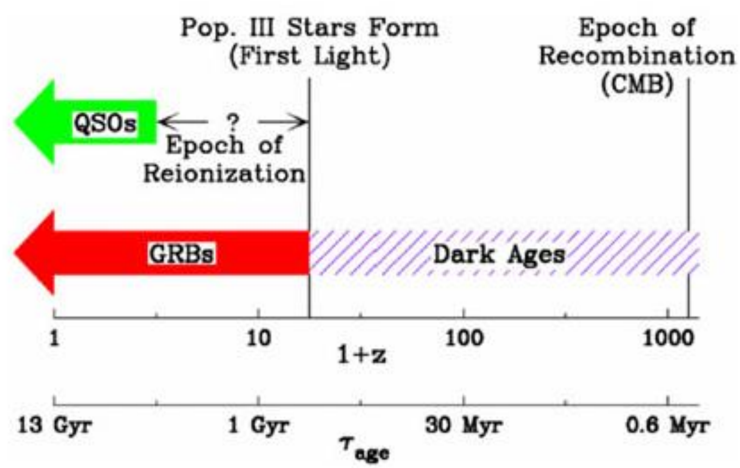
Because of their huge luminosities, mostly emitted in the X and gamma-rays, their redshift distribution extending at least to z ~9 and their association with explosive death of massive stars and star forming regions, GRBs are unique and powerful tools for investigating the early Universe: **SFR evolution,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



GRBs in Cosmological Context





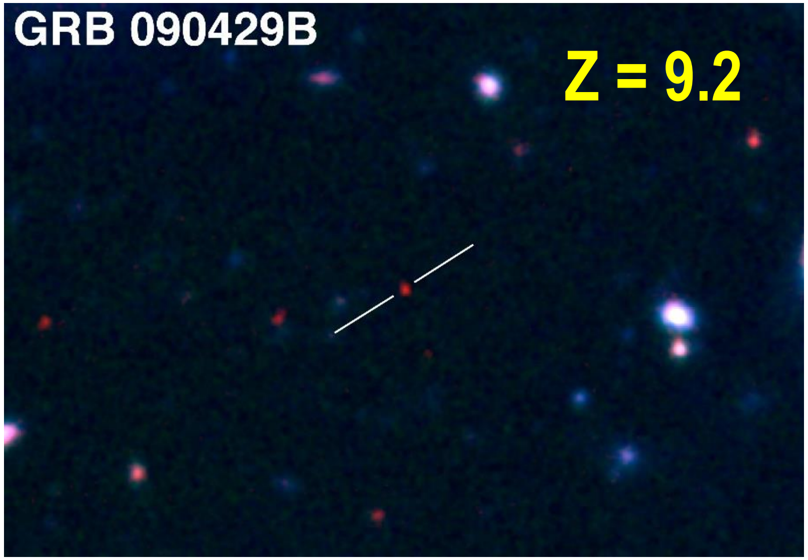


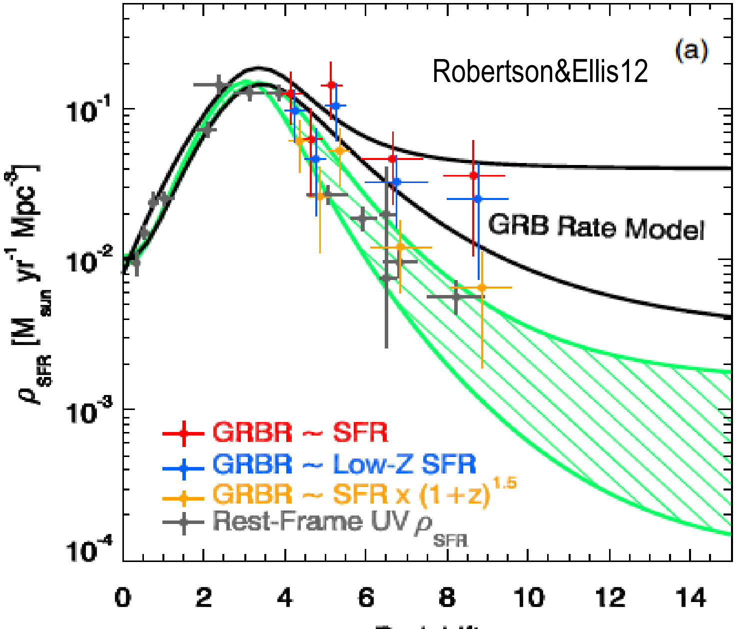
Lamb and Reichart (2000)

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

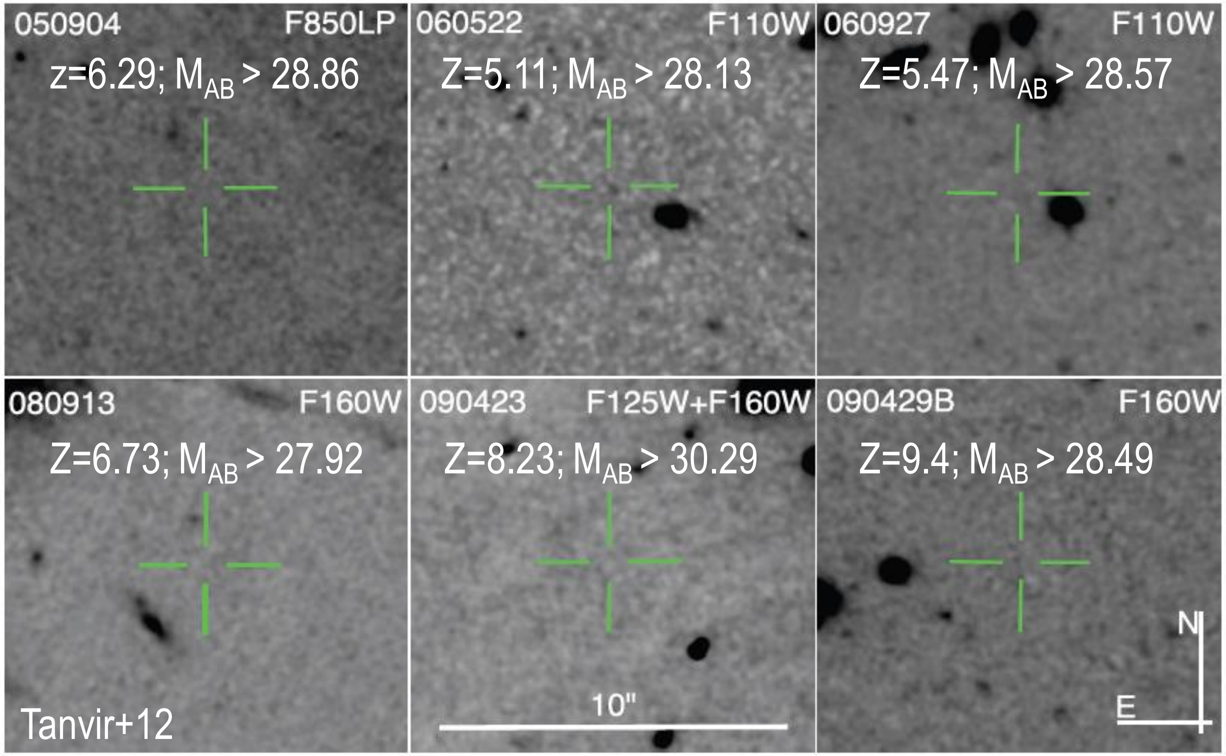
- measure independently the **cosmic star–formation rate**, even beyond the limits of current and future galaxy surveys

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





- the number density and properties of low-mass galaxies

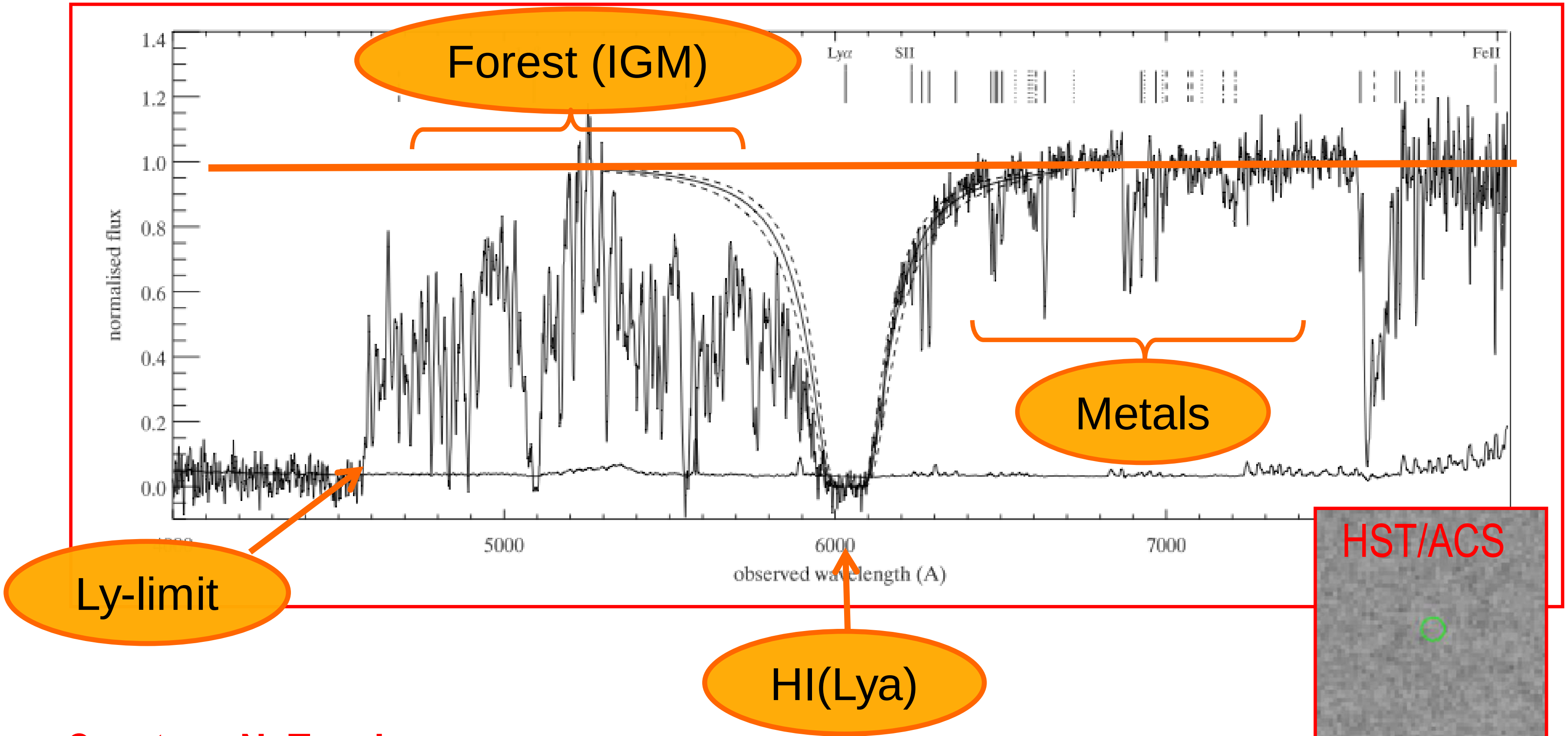


Robertson&Ellis12

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

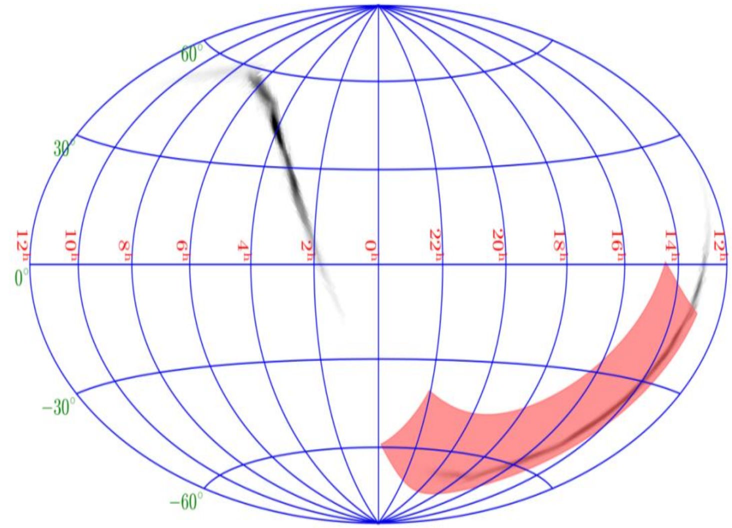
Abundances, HI, dust, dynamics etc. even for very faint hosts. E.g. GRB 050730: faint host (R>28.5), but z=3.97, [Fe/H]=-2 and low dust, from afterglow spectrum (Chen et al. 2005; Starling et al. 2005).



Courtesy N. Tanvir

B) Perform an unprecedented deep monitoring of the soft X-ray transient Universe in order to:

- **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**

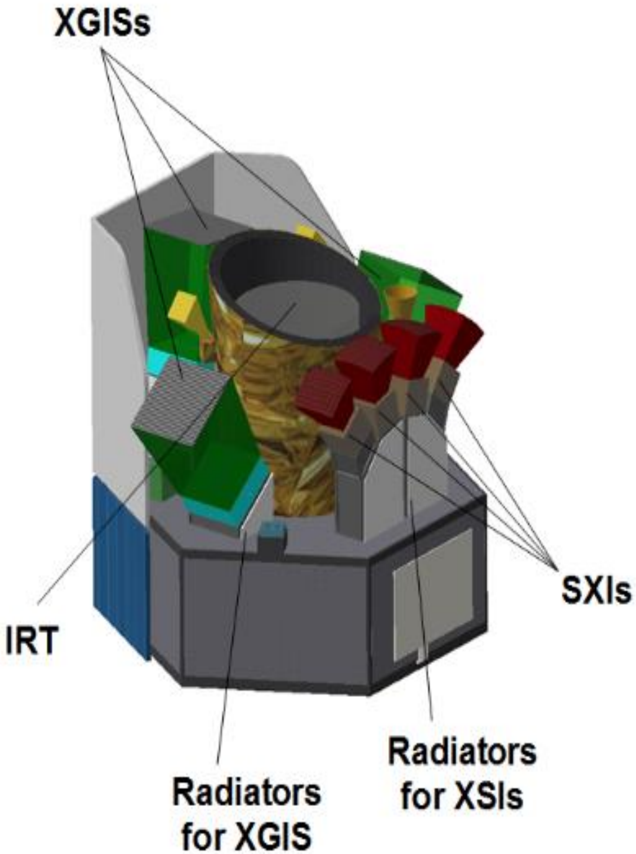
- Provide a fundamental step forward in the comprehension of the physics of various classes of transients and **fill the present gap in the discovery space of new classes of transients events**

Transient type	SXI Rate
GW sources	0.03-33 yr^{-1}
SN shock breakout	4 yr^{-1}
Tidal Disruptions Events	50 yr^{-1}
Thermonuclear bursts	35 day^{-1}
Novae	250 yr^{-1}
Dwarf novae	30 day^{-1}
Stellar flares	400 yr^{-1}
Stellar super flares	200 yr^{-1}

probe GRB physics

THESEUS payload

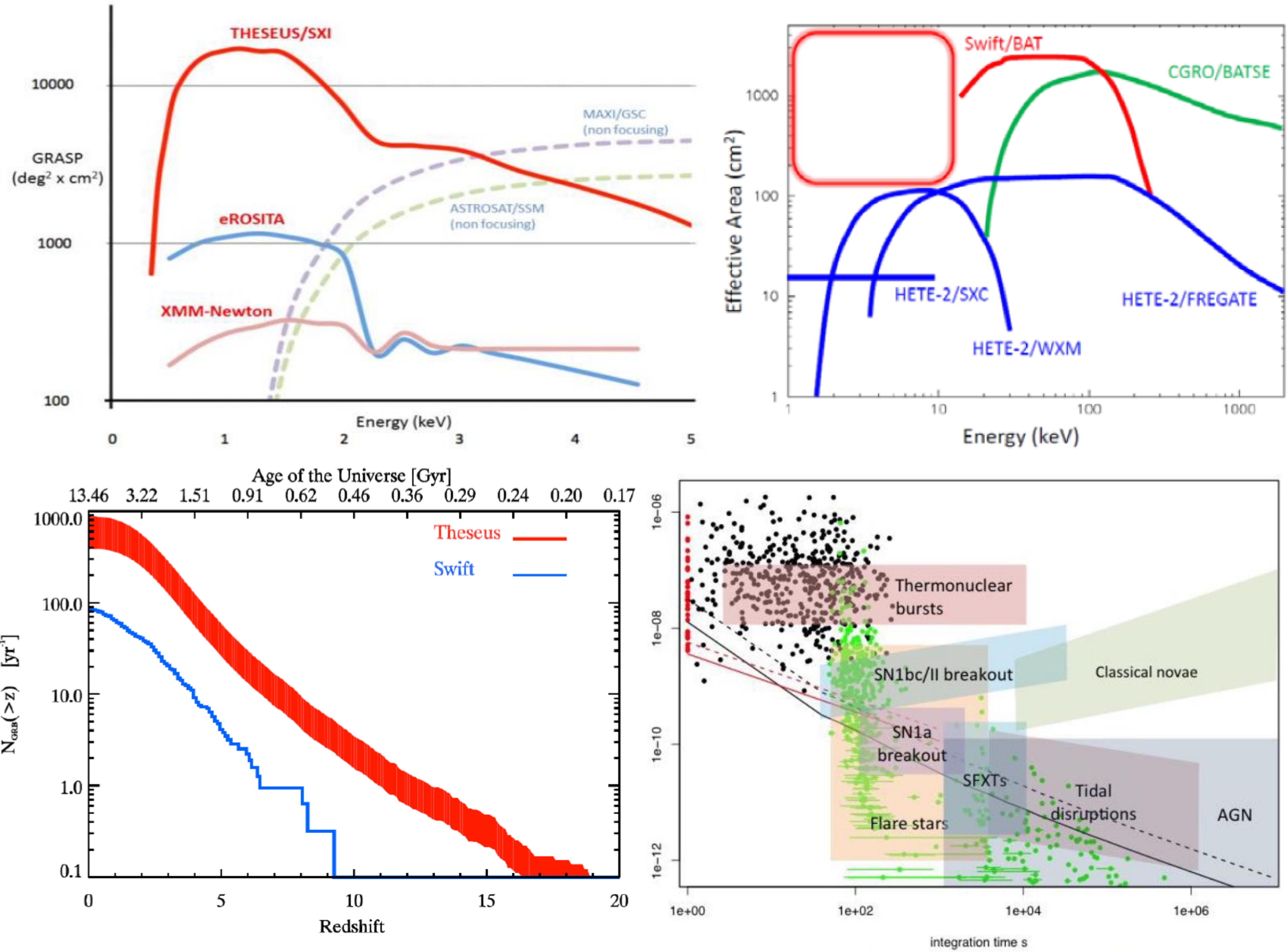
- **Soft X-ray Imager (SXI):** a set of four sensitive lobster-eye telescopes observing in 0.3 - 5 keV band, total FOV of ~1sr with source location accuracy < 1-2’;
- **X-Gamma rays Imaging Spectrometer (XGIS,)**: 3 coded-mask X-gamma ray cameras using bars of Silicon diodes coupled with CsI crystal scintillators observing in 2 keV – 10 MeV band, a FOV of ~1sr, 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



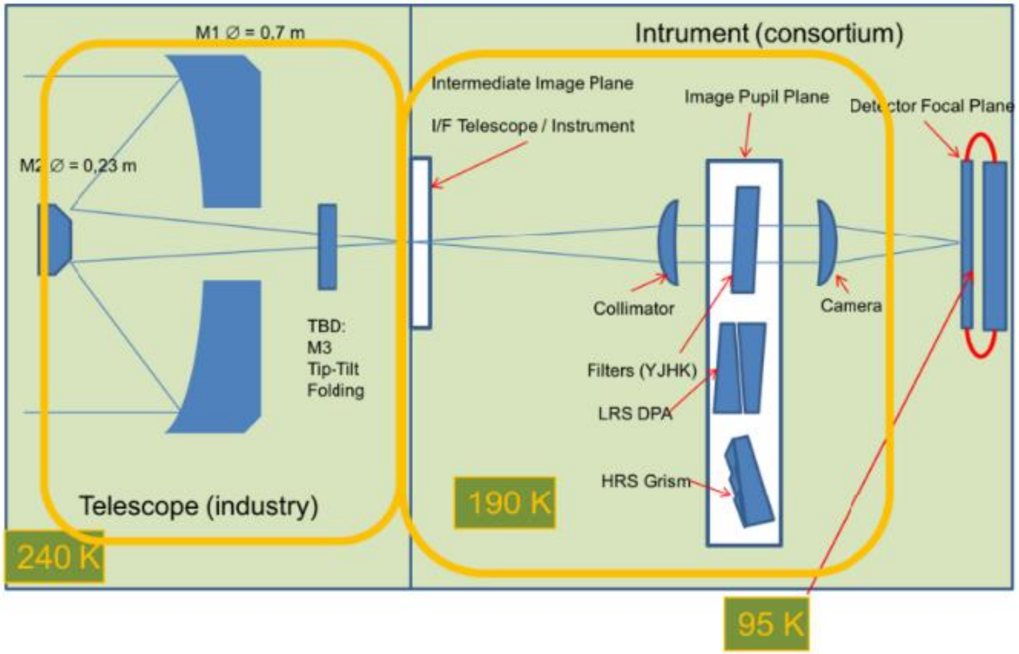
LEO (< 5°, ~600 km)
Rapid slewing bus
Prompt downlink

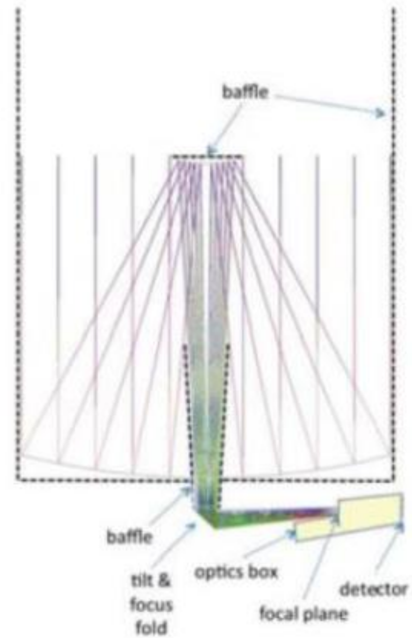
	Energy Band	FOV	Energy resolution	Peak eff. area	Source location	Operation
CGRO/BATSE	20–2000 keV	open	10 keV (100 keV)	~1700 cm^2	>1.7 deg	ended
Swift	15–150 keV	1.4 sr	7 keV (60 keV)	~2000 cm^2	1–4 arcmin	active
Fermi/GBM	8 keV – 40 MeV	open	10 keV (100 keV)	126 cm^2	>3 deg	active
Konus–WIND	20 keV – 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 !!!


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

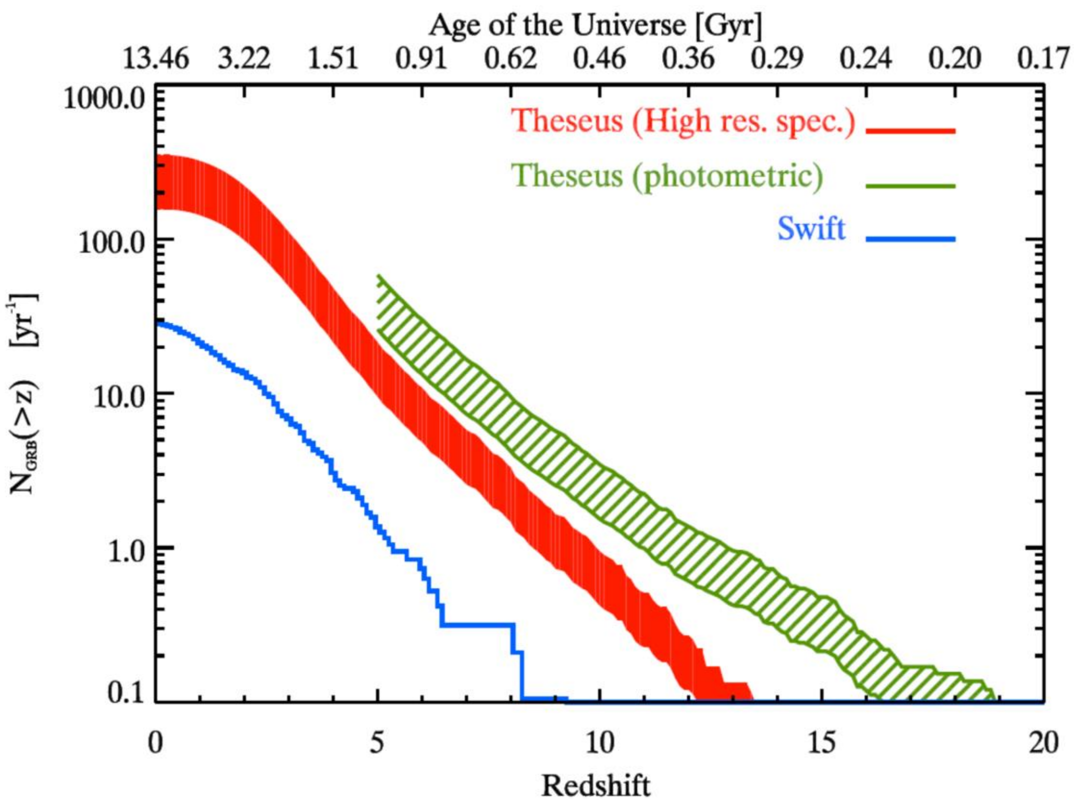
The InfraRed Telescope (IRT)





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		

❑ 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

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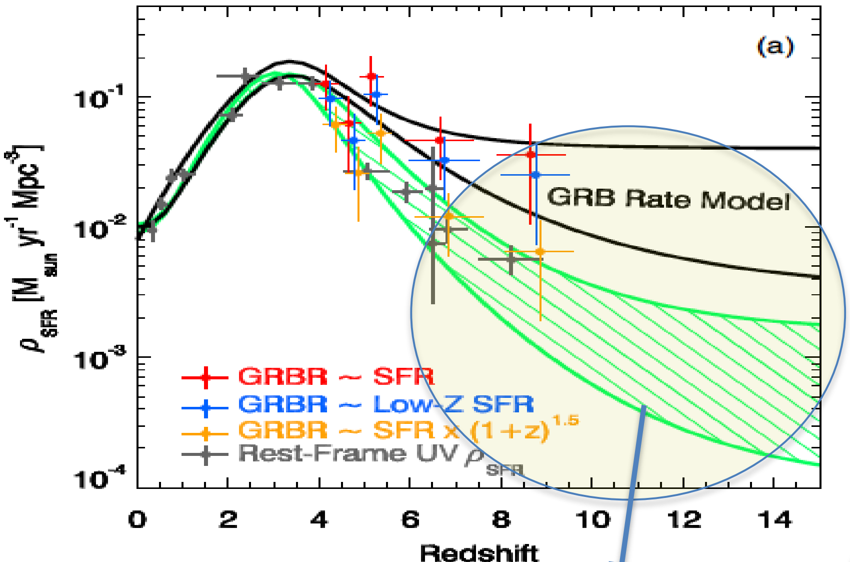
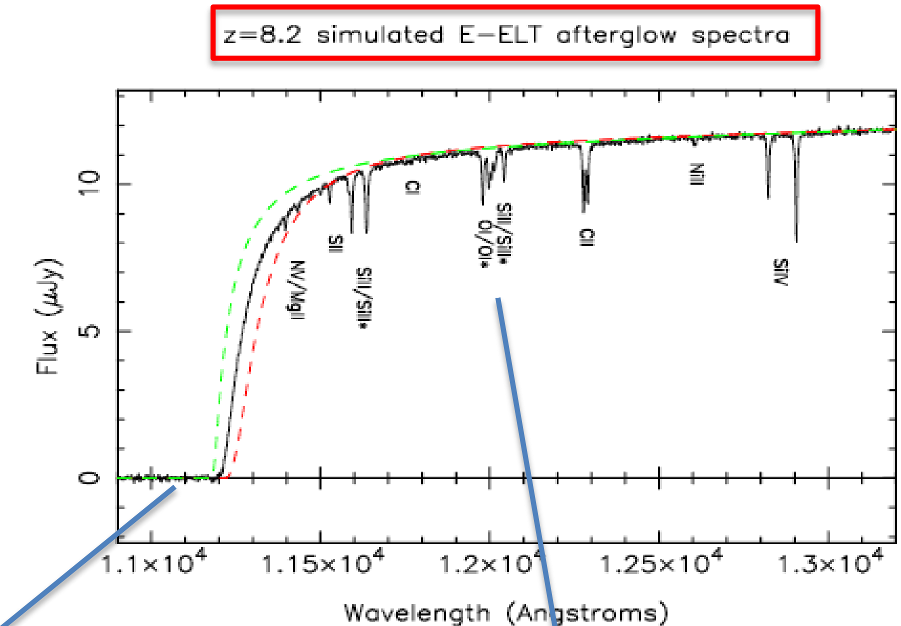
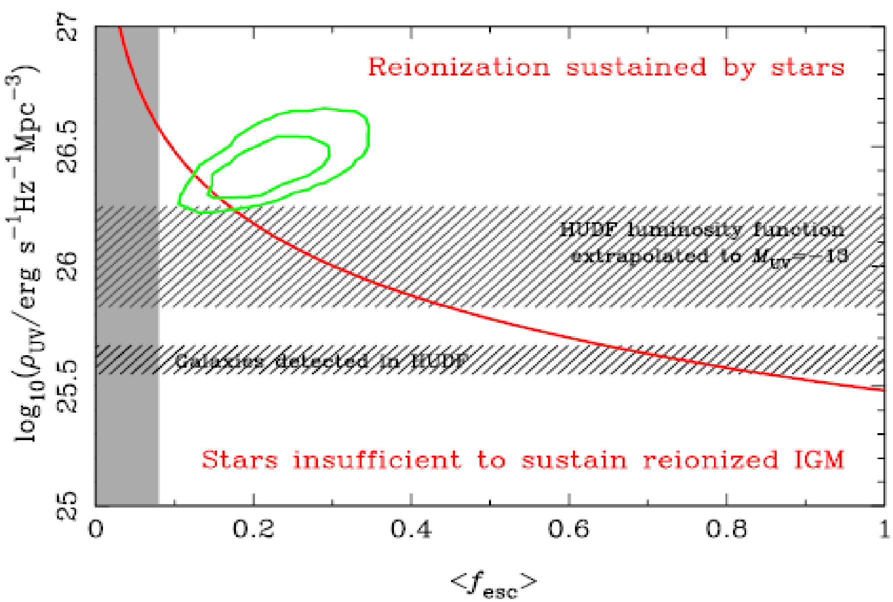
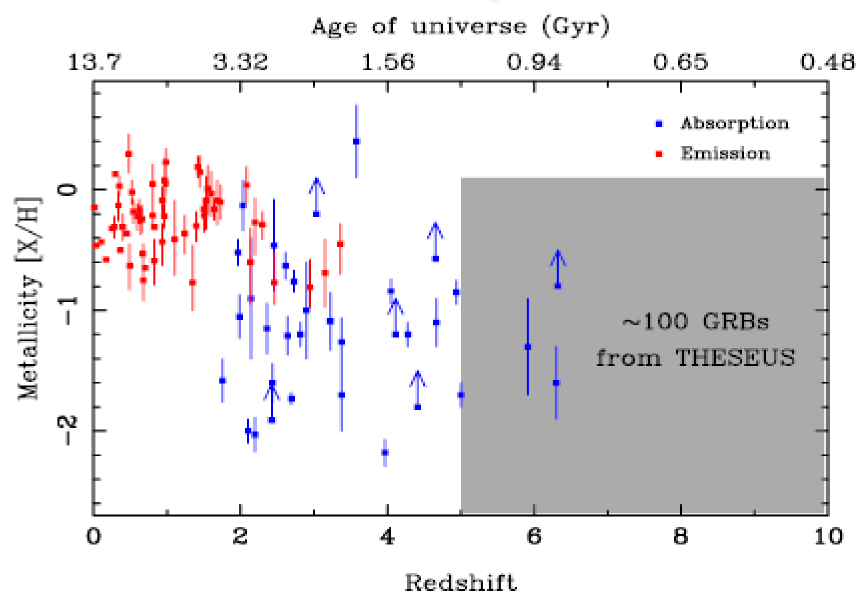






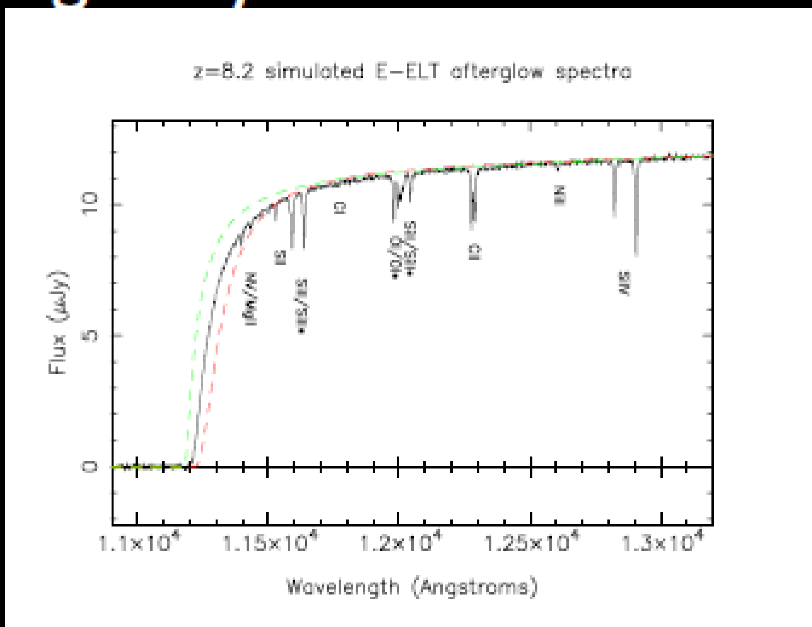


ATHENA+

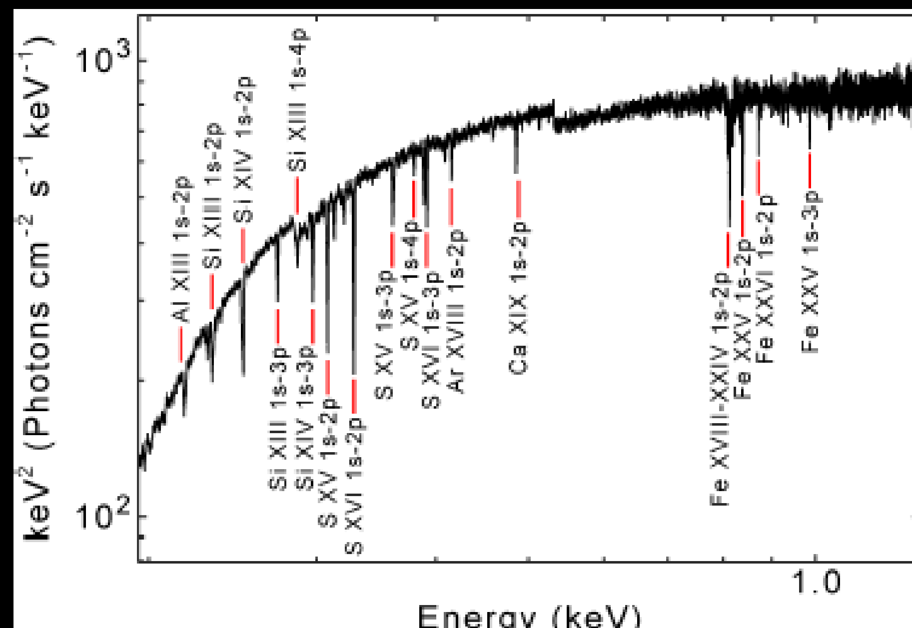
Follow-up of high-z GRB with large facilities

- Optical/IR abs. spectroscopy of the host galaxy

X-ray spectroscopy of the progenitor environme

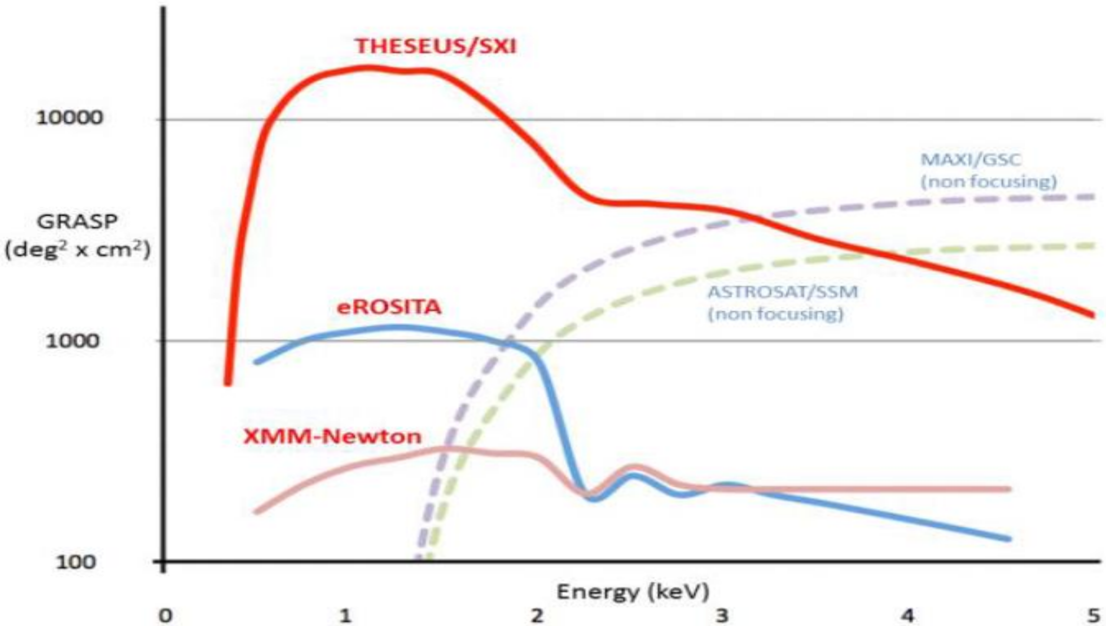


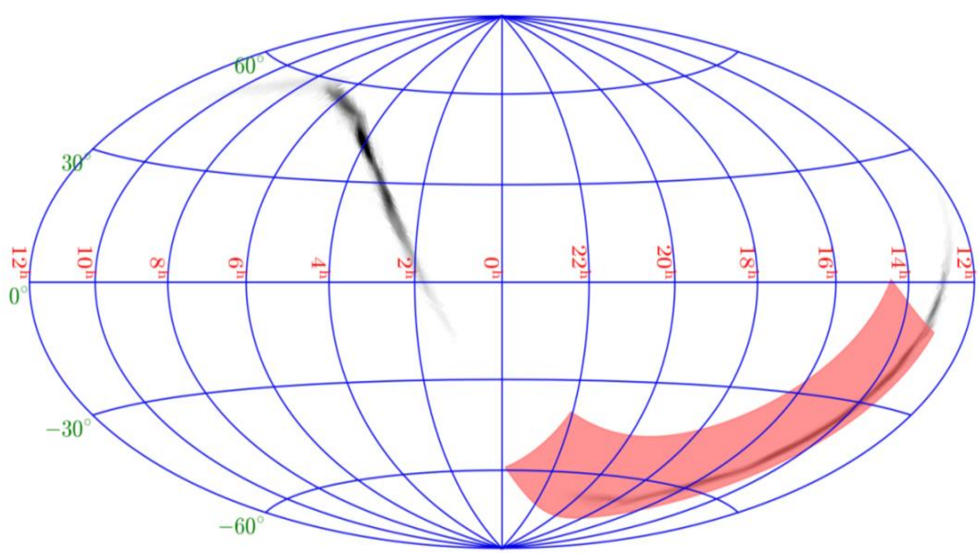
30+ m class ELTs



ESA L2 X-ray Observatory

❑ GW/multi-messenger and time-domain astrophysics





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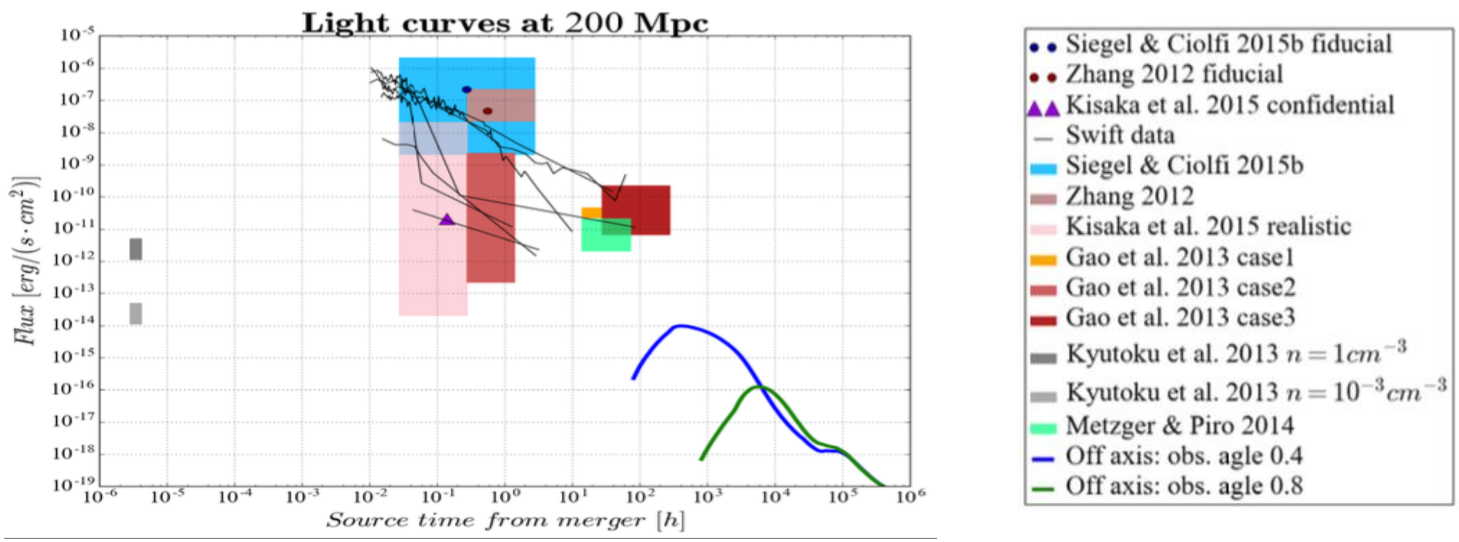
probe GRB physics

❑ GW/multi-messenger and time-domain astrophysics

Among the **GW transient sources that will be monitored by THESEUS** there are:

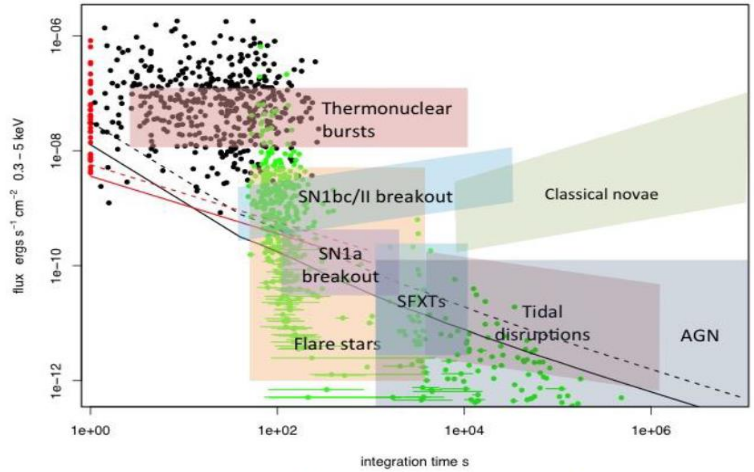
- ❑ NS-NS / NS-BH mergers:
  - ❑ **collimated** EM emission from short GRBs and their afterglows (rate of ≤ 1/yr for 2G GW detectors but up to 20/yr for 3G GW detectors as Einstein Telescope)
  - ❑ Optical/NIR and soft X-ray **isotropic** emissions from macronovae, off-axis afterglows and, for NS-NS, 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)

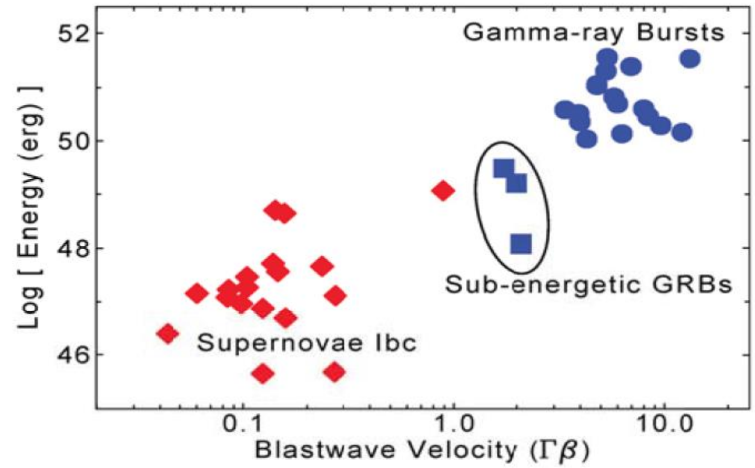


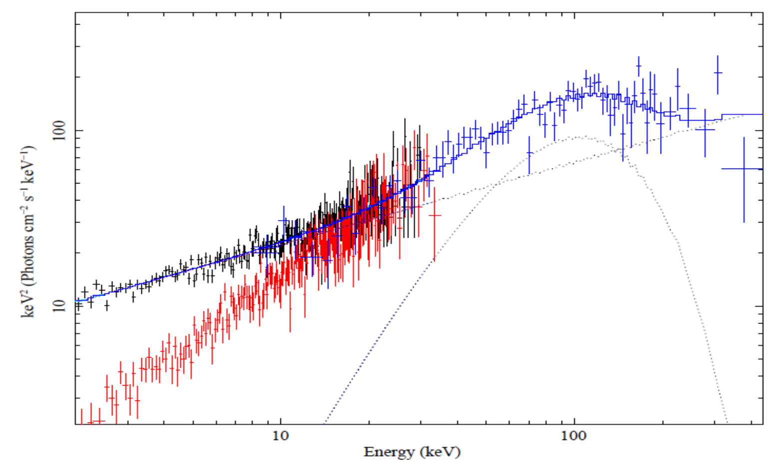
Credit: S. Vinciguerra

❑ 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;
- IR survey and guest observer possibilities, thus allowing an even stronger community involvement







Conclusions

- THESEUS (submitted to ESA/M5 by an Italy-led European collaboration, with interest of USA, China, Brazil) 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 perform a deep wide field monitoring of the high-energy sky from X-rays (0.3 keV) to gamma-rays (tens of MeV) with unprecedented combination of sensitivity, FOV and source location accuracy in the soft X-rays, coupled with extension up to several MeVs

- THESEUS will also play a fundamental role for GW/multi-messenger and time domain astrophysics at the end of next decade, operating in perfect synergy with next generation multi messenger (aLIGO/aVirgo, eLISA, ET, or Km3NET;) and e.m. facilities (e.g., LSST, E-ELT, SKA, CTA, ATHENA)

- THESEUS passed the ESA/M5 technical-programmatic evaluation, and will undergo the scientific evaluation in late 2017; provide your interest / support to amati@iasfbo.inaf.it or http://www.isdc.unige.ch/theseus/

- THESEUS white paper on arXiv within mid-July; “THESEUS WORKSHOP 2017” to be held in Naples on October 5-6

BACK-UP SLIDES

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

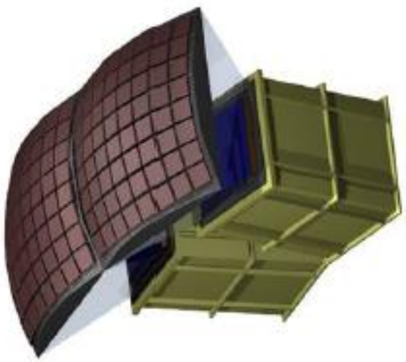
FUNCTIONAL SUBSYSTEMS	Nominal Avg Power (Watt)	Margin (%)	Margin (Watt)	Current Avg Power (Watt)
SERVICE MODULE				
AOCS	*79*	*10%*	*8*	*87*
DATA HANDLING	*37*	*10%*	*4*	*41*
EPS	*39*	*10%*	*4*	*43*
PROPULSION	*1*	*10%*	*0*	*1*
THERMAL CONTROL (incl. PLM)	*83*	*20%*	*17*	*100*
PDHU + X BAND	*42*	*10%*	*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*

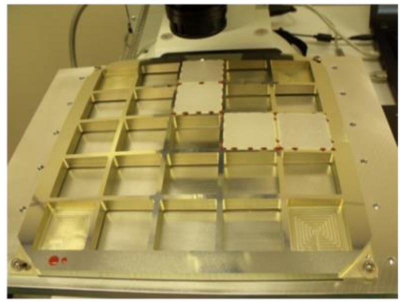
Satellite Nominal Power (W)	
Service Module	282
Payload Module	381
20% System Margin	132
Harness Loss	18
Total power with losses and margin	813

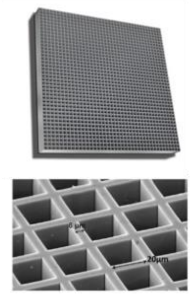
THESEUS payload consortium (M5)

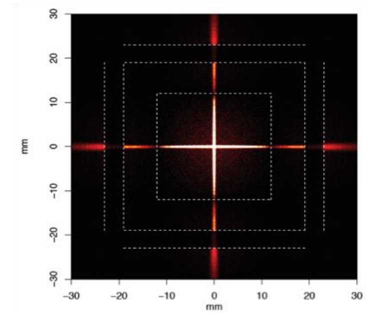
- **ITALY -** L.P. / project office, XGIS, Malindi antenna
- **UK -** SXI (optics + detectors + calibration) + S/W (SXI pipeline and remote contribution to SDC)
- **France -** IRT (coordination and IR camera, including cooler) **, ESA -** IRT optics + SXI CCDs
- **Germany, Poland** - Data Processing 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 Soft X-ray Imager (SXI)









4 DUs, each has a 31 x 26 degree FoV

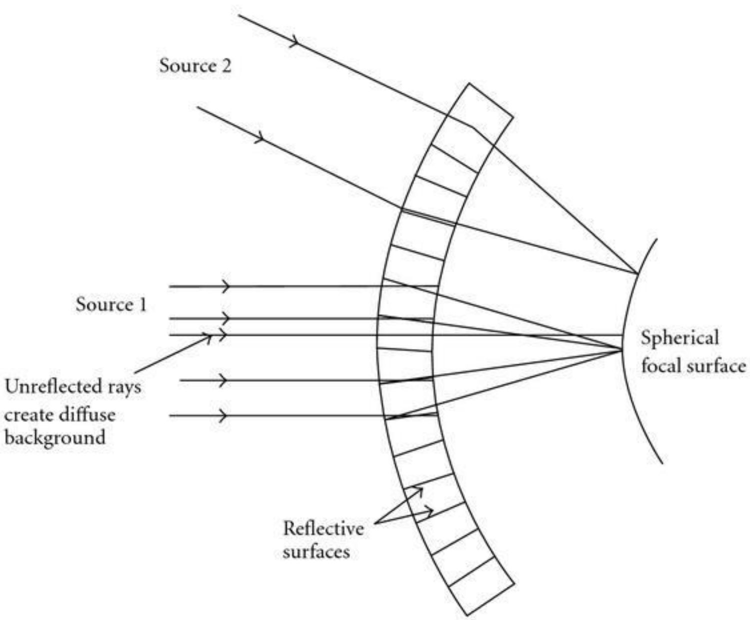
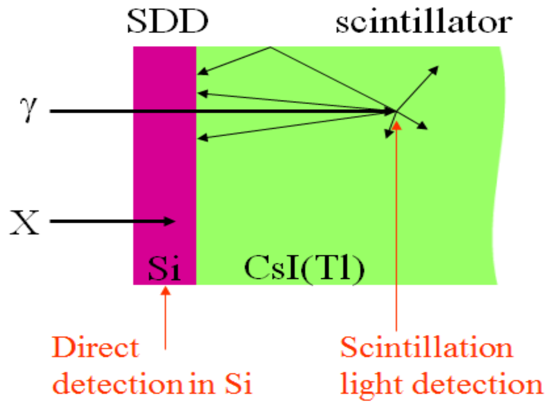
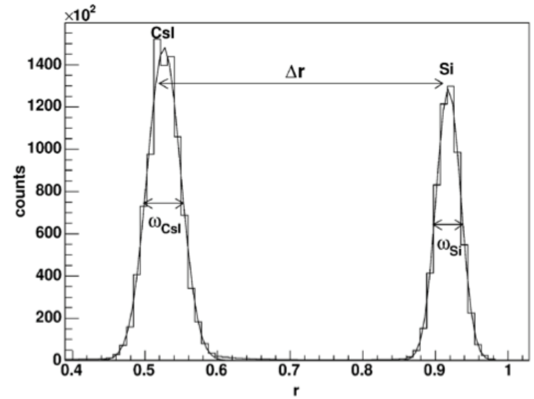


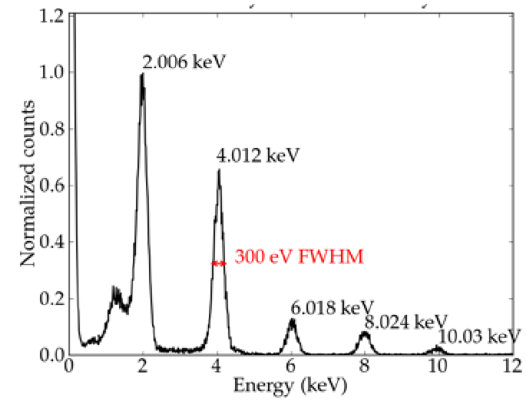
Table 4 : : SXI detector unit main physical characteristics

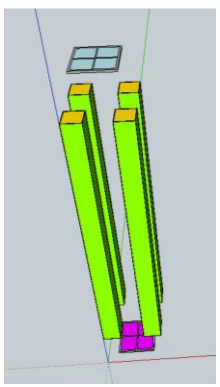
Energy band (keV)	0.3-5
Telescope type:	Lobster eye
Optics aperture (mm2)	320x320
Optics configuration	8x8 square pore MCPs
MCP size (mm2)	40x40
Focal length (mm)	300
Focal plane shape	spherical
Focal plane detectors	CCD array
Size of each CCD (mm2)	81.2x67.7
Pixel size (μm)	18
Pixel Number	4510 x 3758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

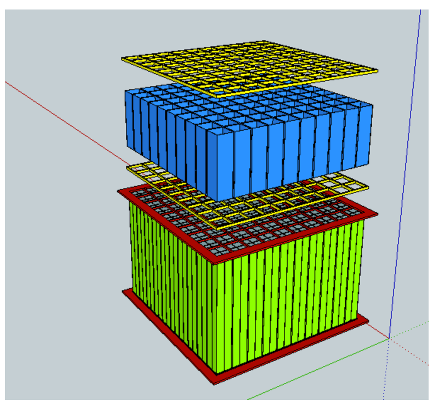
The X-Gamma-rays spectrometer (XGS)

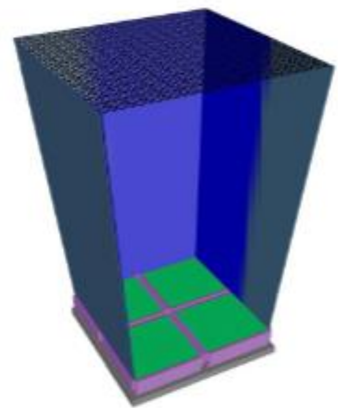












Energy band	*2 keV – 20 MeV*
# detection plane modules	*4*
# of detector pixel / module	*32x32*
pixel size (= mask element size)	*5x5 mm*
Low-energy detector (2-30 keV)	*Silicon Drift Detector 450 μm thick*
High energy detector (> 30 keV)	*CsI(Tl) (3 cm thick)*
Discrimination Si/CsI(Tl) detection	*Pulse 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

❑ Shedding light on the early Universe with GRBs

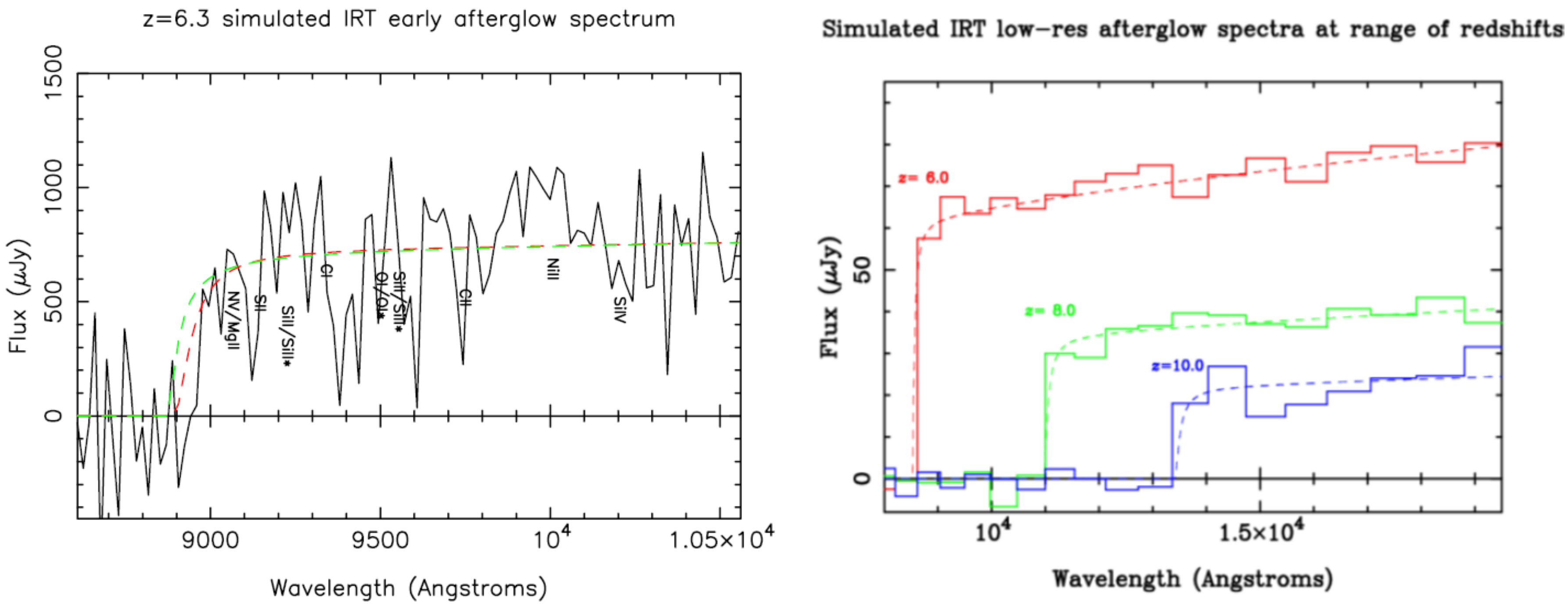


Figure 11: Left: a simulated IRT high resolution (R=500) spectrum for a GRB at z=6.3 observed at 1 hour post trigger assuming a GRB similar to GRB 050904. The spectrum has host log(NH)=21 and neutral fraction Fx=0.5 (and metallicity 0.1solar). The two models are: Red: log(NH)=21.3, Fx=0 Green: log(NH)=20.3, Fx=1. The IRT spectra provide accurate redshifts. Right: simulated IRT low resolution (R=20) spectra as a function of redshift for a GRB at the limiting magnitude AB mag 20.8 at z=10, and by assuming a 20 minute exposure.The underlying (noise-free) model spectra in each case are shown as smooth, dashed lines. Even for difficult cases the low-res spectroscopy should provide redshifts to a few percent precision or better. For many applications this is fine - e.g. star formation rate evolution.

Italian contributions to THESEUS (M5)

- **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, …)

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

- **Malindi ground station: ASI**

- **Industrial support for M5 proposal: CGS, GPAP**

- **Requested support to ASI:** industrial costs and procurement related to the XGIS instrument, support to scientific and industrial activities within Italian Institutions (details delivered to ASI)

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.)

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)**

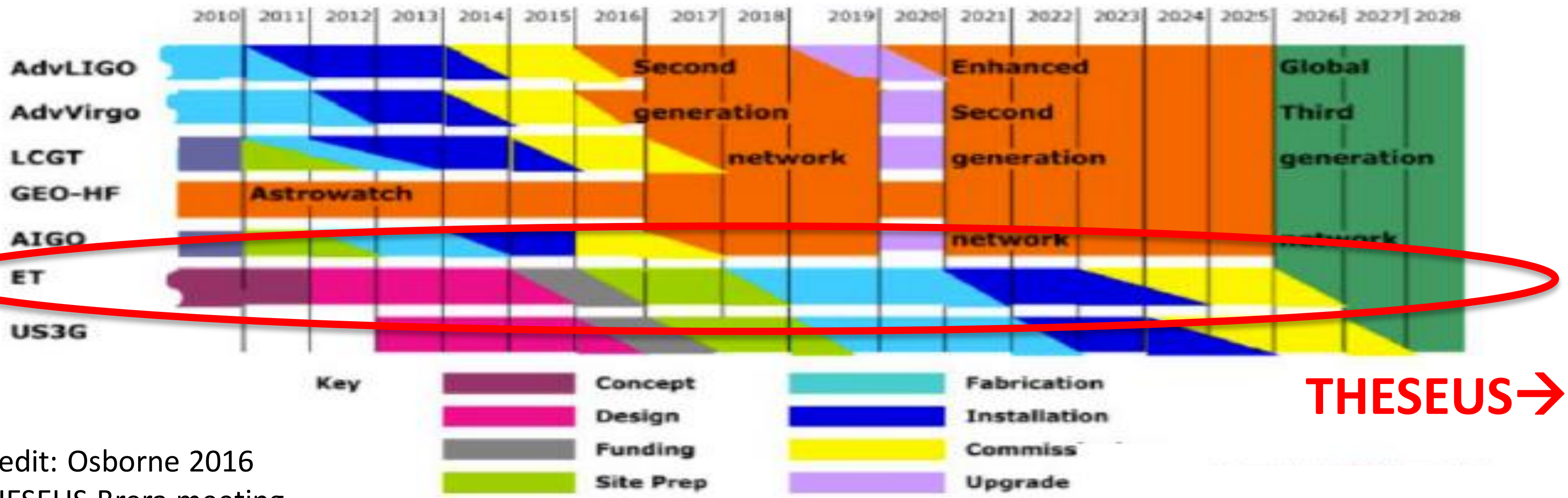
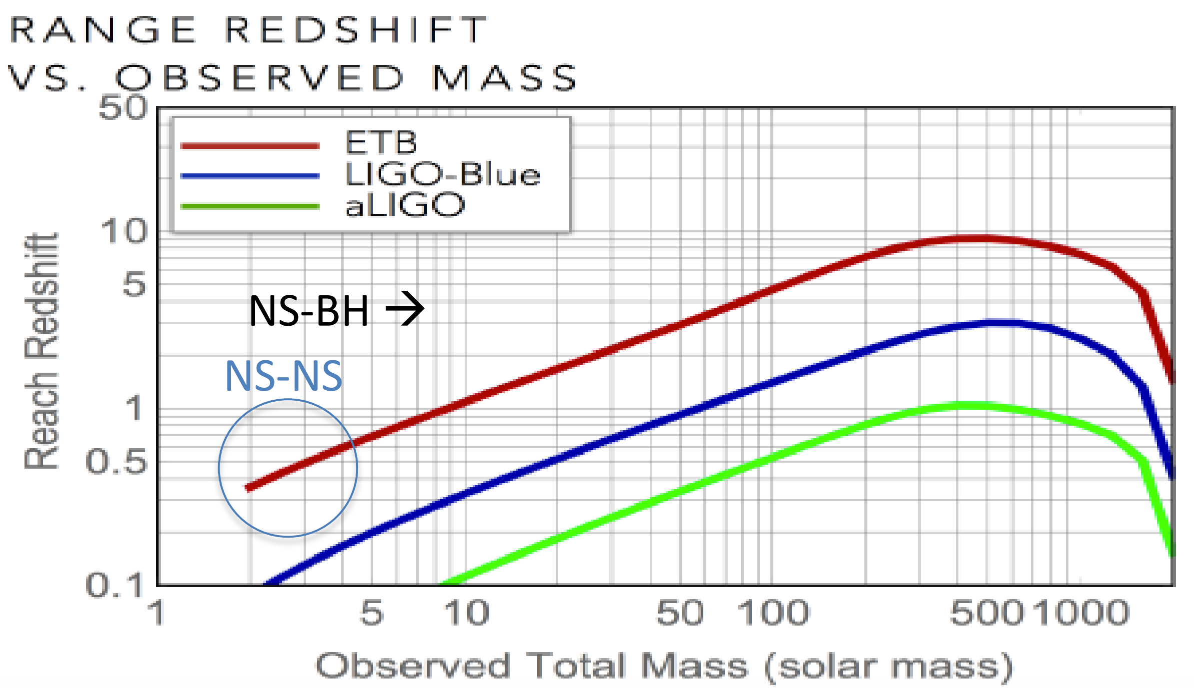


Fig. 5.1 – Time-line for ground based detector developments

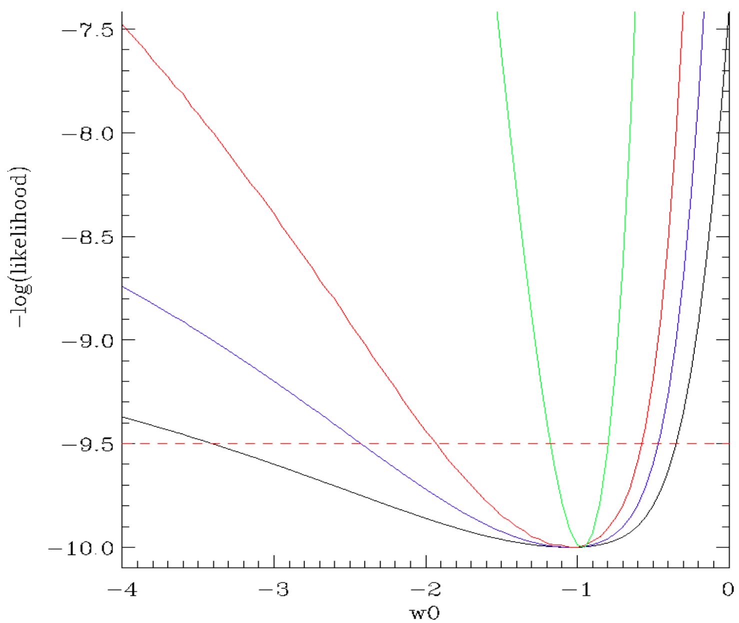
Credit: Osborne 2016
THESEUS Brera meeting

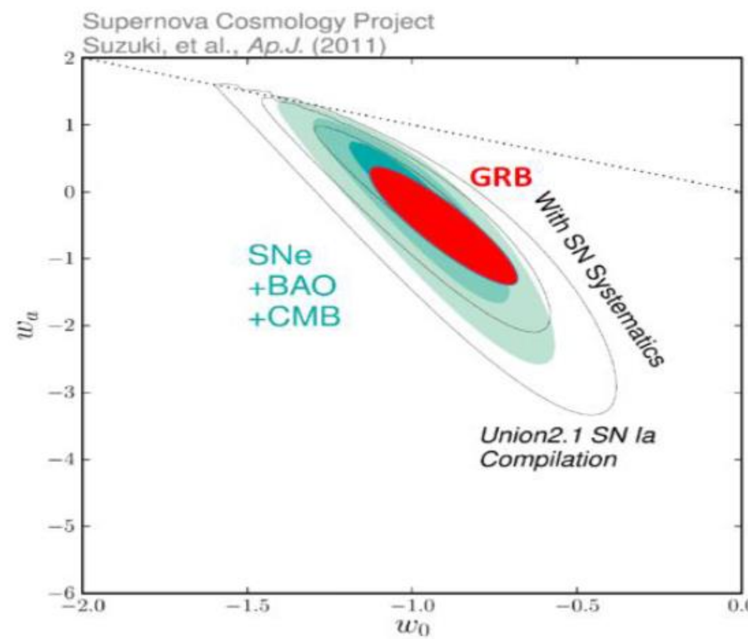


Credit:
Sathyaprakash 2016
7° ET Symposium

❑ Shedding light on the dark energy with GRBs

GRB #	Ω_M (flat)	w_0 (flat,Ω_M=0.3,w_a=0.5)
70 (real) GRBs (Amati+ 08)	$0.27^{+0.38}_{-0.18}$	<-0.3 (90%)
156 (real) GRBs (Amati+ 13)	$0.29^{+0.28}_{-0.15}$	$-0.9^{+0.4}_{-1.5}$
250 (156 real + 94 simulated) GRBs	$0.29^{+0.16}_{-0.12}$	$-0.9^{+0.3}_{-1.1}$
500 (156 real + 344 simulated) GRBs	$0.29^{+0.10}_{-0.09}$	$-0.9^{+0.2}_{-0.8}$
156 (real) GRBs, calibration	$0.30^{+0.06}_{-0.06}$	$-1.1^{+0.25}_{-0.30}$
250 (156 real + 94 simulated) GRBs, calibration	$0.30^{+0.04}_{-0.05}$	$-1.1^{+0.20}_{-0.20}$
500 (156 real + 344 simulated) GRBs, calibration	$0.30^{+0.03}_{-0.03}$	$-1.1^{+0.12}_{-0.15}$





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.

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**

THESEUS: scientific background

- Because of their huge luminosities, redshift distribution extending at least to z ~10, connection with peculiar type Ibc SNE (long GRBs) and NS-NS (BH) mergers (short GRBs), GRBS are of high interest for several field of astrophysics, for cosmology and for fundamental physics

- The European community played a fundamental role in the enormous progress in the field of the last 15 years (BeppoSAX, HETE-2, Swift, AGILE, Fermi + enormous efforts in optical IR and radio follow-up)

- In 2012, two European proposals for ESA Call for Small mission dedicated to GRBs and all-sky monitoring: GAME (led by Italy, SDD-based cameras + scintillator base detectors) and A-STAR (led by UK, lobster-eye telescopes + CdTe detectors)

- The White Paper on GRBs as probes of the early Universe submitted in response to ESA Call for science theme for next L2/L3 missions (Amati, Tanvir, et al., arXiv:1306.5259) was very well considered by ESA

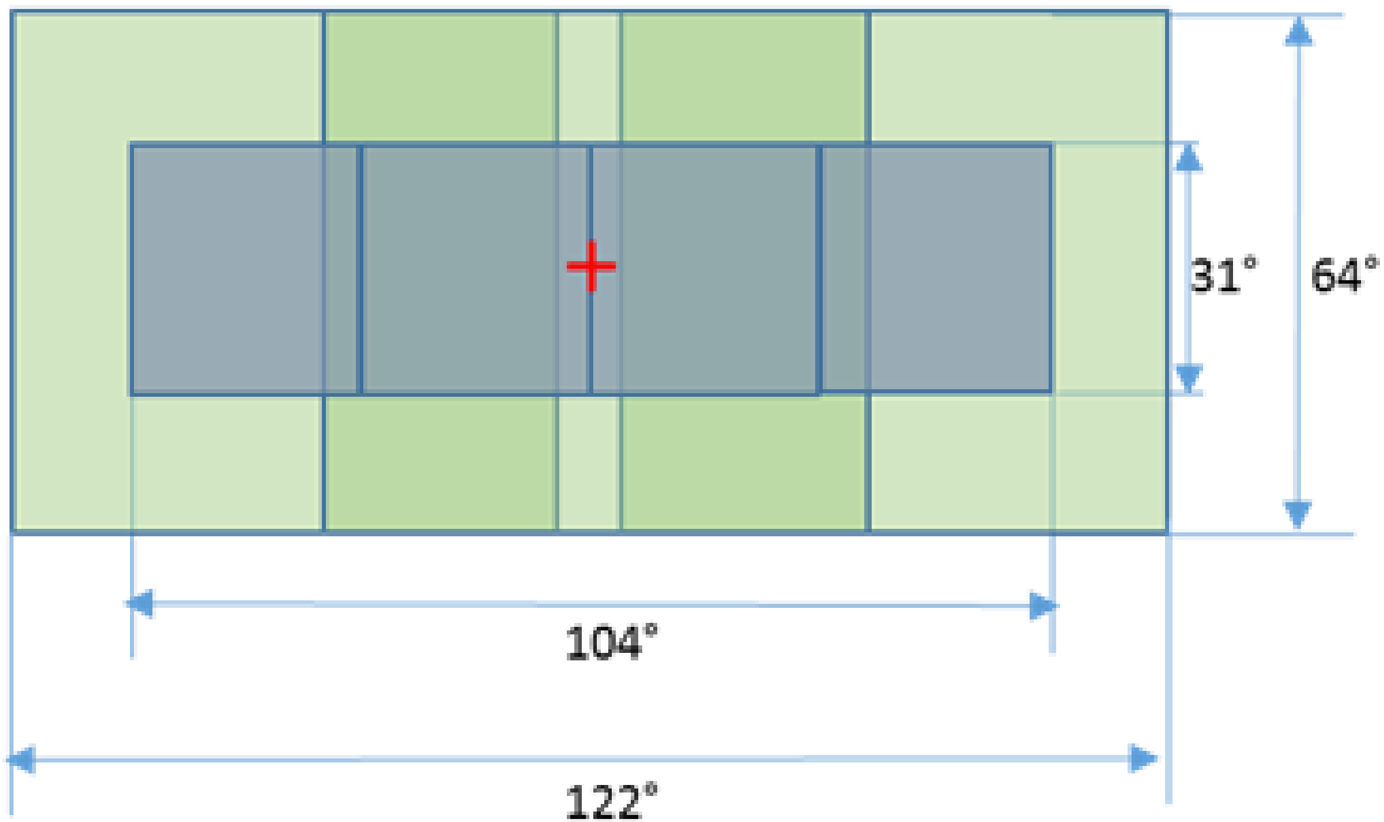
- European community at the frontiers of time-domain and multi-messenger astrophysics (e.g., EGO / Virgo)

Field of view

XGIS

SXI

IRT



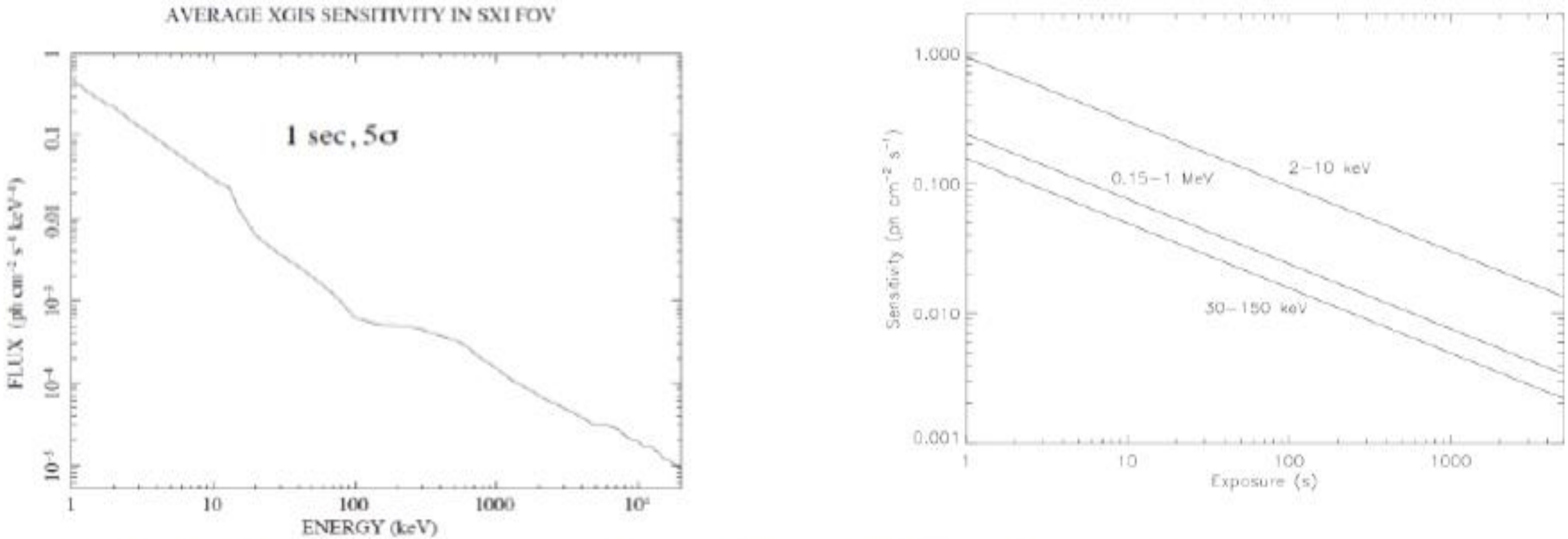
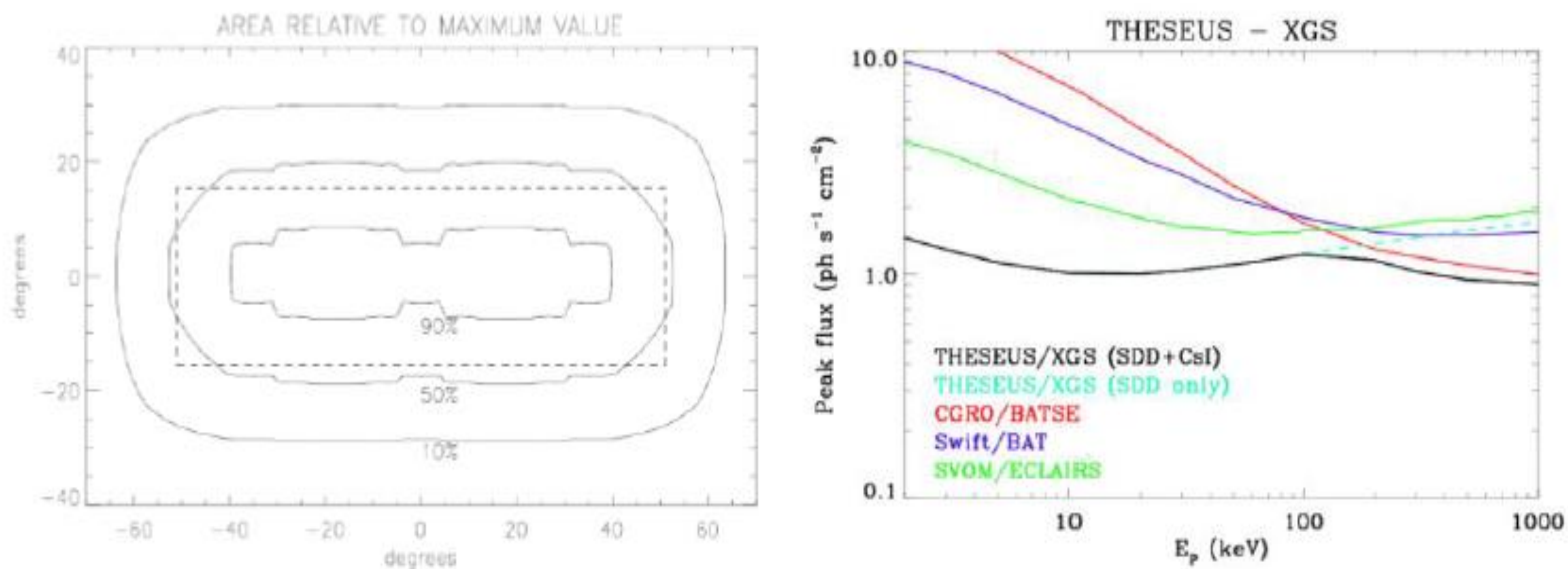


Figure 5: Left: XGIS sensitivity vs. energy in 1 second. Right: XGIS sensitivity as a function of exposure time in diffe
bands.



Subject: Letter of Endorsement for the THESUES M5 mission candidate

Dr Lorenzo Amati
INAF – Istituto di Fisica Spaziale e Fisica Cosmica di Bologna (IASF-Bo)
Via P. Gobetti 101, 40129 – Bologna (ITALY)
Telephone: (+39) 0516398745
Fax: (+39) 0516398723
e-mail: amati@iasfbo.inaf.it

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

Participants from Italian Institutions

Lead Proposer

Amati Lorenzo	INAF-IASF Bologna

Members of Payload Core Team

Bellutti Pierluigi	Fondazione Bruno Kessler (FBK), Trento
Bertuccio Giuseppe	Politecnico di Milano
Campana Riccardo	INAF-IASF-Bologna
Fiorini Mauro	INAF-IASF Milano
Frontera Filippo	University of Ferrara and INAF-IASF Bologna
Fuschino Fabio	INAF-IASF Bologna
Labanti Claudio	IASF-IASF Bologna
Malcovati Piero	University of Pavia
Marisaldi Martino	INAF-IASF Bologna
Mereghetti Sandro	INAF-IASF Milano
Morgante Gianluca	INAF-IASF Bologna
Orlandini Mauro	INAF-IASF Bologna
Vacchi Andrea	INFN-Sezione di Trieste
Zampa Gianluigi	INFN-Sezione di Trieste
Zampa Nicola	INFN-Sezione di Trieste

Industrial support

Attinà Primo	GP Advanced Projects, Brescia
Contini Cristiano	CGS/OHB Roma
Lorenzi Paolo	CGS/OHB Milano
Morelli Barbara	CGS/OHB Roma

Members of Science Core Team

+ ~40 contrib. Scientists from INAF, INFN, Universities

Capozziello Salvatore	University Federico II of Napoli and INFN-Sezione di Napoli
Casella Piergiorgio	INAF-Osservatorio Astronomico di Roma
Covino Stefano	INAF-Osservatorio Astronomico di Brera
D'Avanzo Paolo	INAF-Osservatorio Astronomico di Brera
De Martino Domitilla	INAF-Osservatorio Astronomico di Capodimonte
Della Valle Massimo	INAF-Osservatorio Astronomico di Capodimonte
Ferrara Andrea	Scuola Normale Superiore di Pisa
Ghirlanda Giancarlo	INAF-Osservatorio Astronomico di Brera
Guidorzi Cristiano	University of Ferrara
Maio Umberto	Osservatorio Astronomico di Trieste
Melandri Andrea	INAF-Osservatorio Astronomico di Brera
Mignani Roberto	INAF-IASF milano
Nicastro Luciano	INAF-IASF Bologna
Palazzi Eliana	INAF-IASF Bologna
Pian Elena	INAF-IASF Bologna
Piranomonte Silvia	INAF-Osservatorio Astronomico di Roma
Piro Luigi	INAF-IAPS
Romano Patrizia	INAF-Osservatorio Astronomico di Brera
Rosati Piero	University of Ferrara
Rossi Andrea	INAF-IASF Bologna
Ruffini Remo	ICRANet Pescara
Salvaterra Ruben	INAF-IASF Milano
Savaglio Sandra	University of Calabria
Stratta Giulia	University of Urbino
Tagliaferri Gianpiero	INAF-Osservatorio Astronomico di Brera
Vanzella Eros	INAF-Oservatorio Astronomico di Bologna

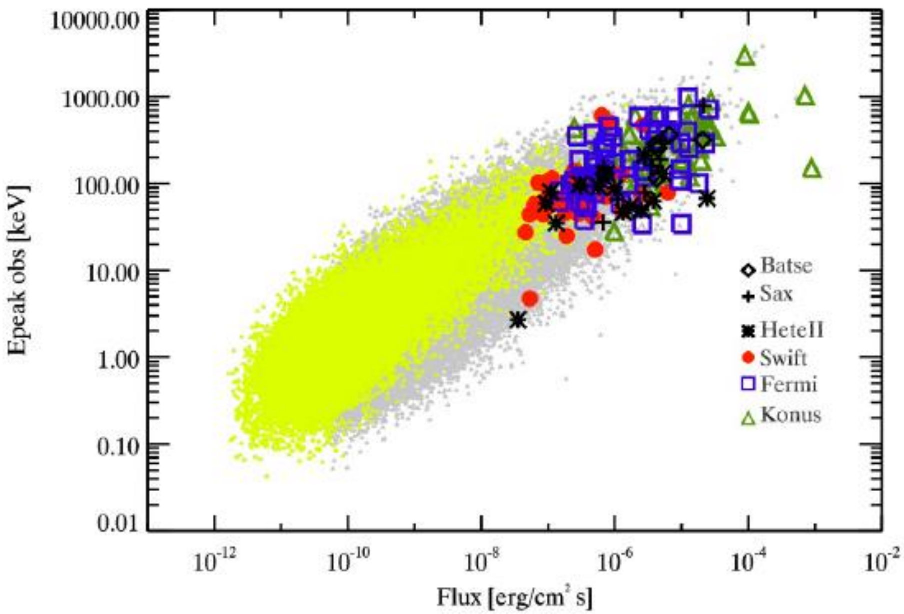
THESEUS Requirements I

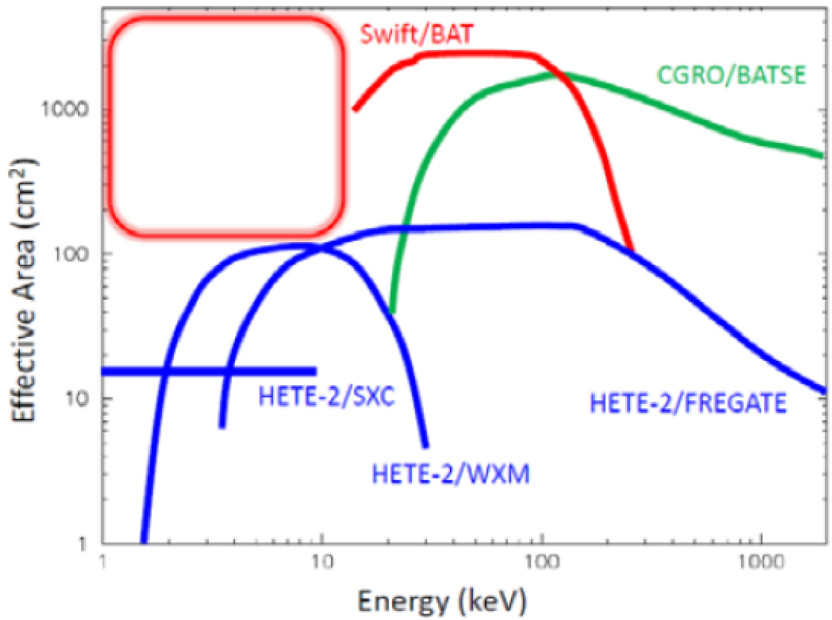
- A full exploration of the early Universe requires the detection of a factor 10 more GRBs (about 80-100) than currently available at z>6

- As supported by intensive simulation efforts (e.g. Ghirlanda+15 MNRAS) a high detection rate of high redshift GRBs requires a *soft* **and** *sensitive* (down to 10^{-9} erg/cm^2/s) *wide field* high-energy trigger, with precise and reliable localization techniques (< 2 arc min)

- In order to efficiently classify and filter the trigger a broad band spectral coverage is needed at high energies (+ GRB physics and additional cosmology)

Ghirlanda et al. 2015





Yonetoku et al. 2014

THESEUS Requirements II

- In order to *identify, classify and study* the high-z GRB counterparts, an near-infrared (due to cosmological Ly-alpha suppression) telescope is needed on board. It will provide accurate positions, GRB redshifts, and GRB afterglows *spectra* (R~1000).

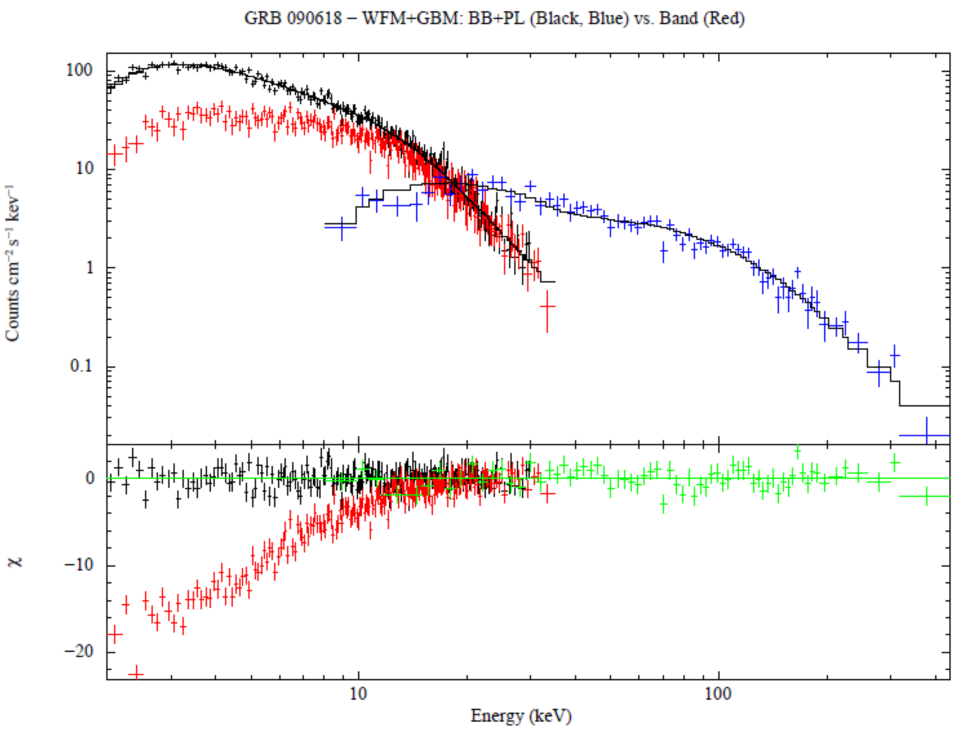
- The telescope shall be of the 0.5-1 m class in order to be able to detect the sources with the expected flux.

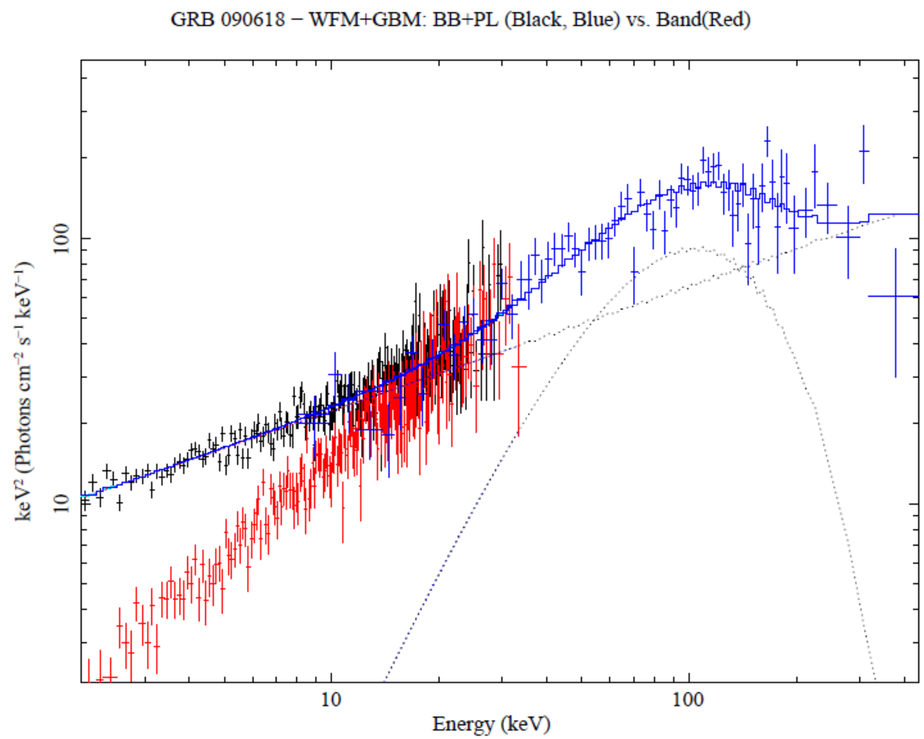
  Note that any ground based facility will not have the same efficiency and/or sensitivity in following-up 1000 bursts per year that are needed in order to have a few tens of GRBs beyond z=8.

- An agile and autonomous platform (Swift-like) is required in order to point at the GRB position *quickly (within 5-10 min);* also, in order to allow slit spectroscopy, *the poiting stability should be better than 0.5 arcsec*

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

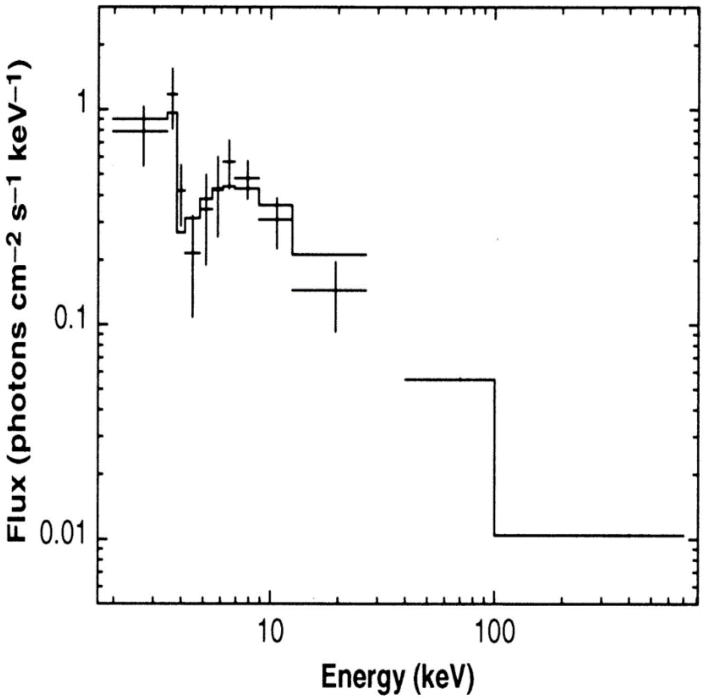
THESEUS/XGS will be capable of discriminating among Band and BB+PL thanks to its energy band extending below 10 keV

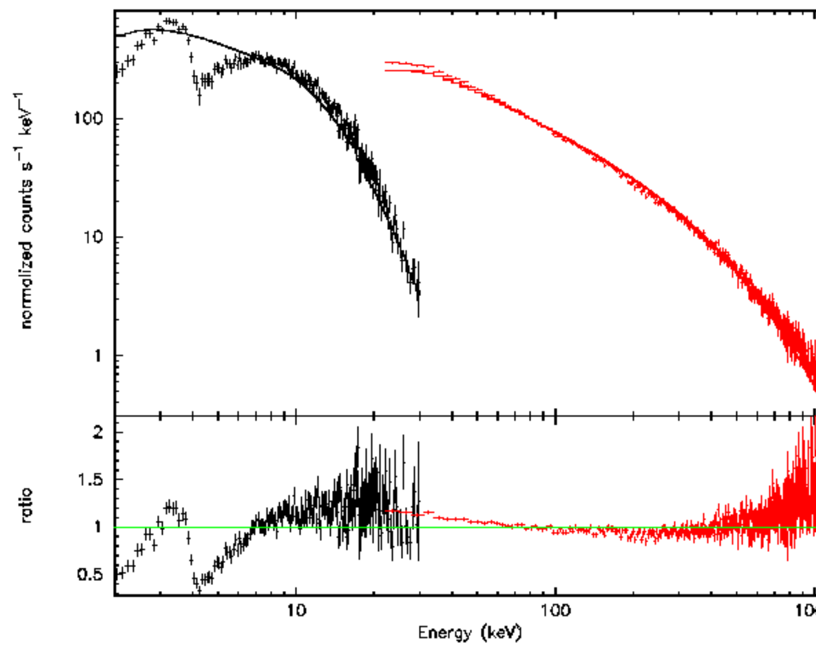




Fermi/GBM   THESEUS/XGS (BB+PL)   THESEUS /XGS (Band model)

❑ 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

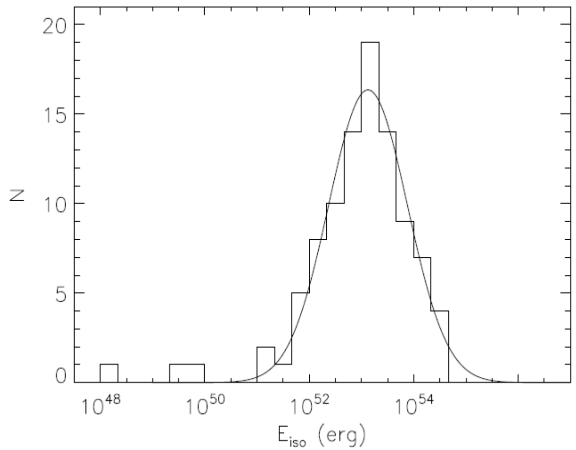


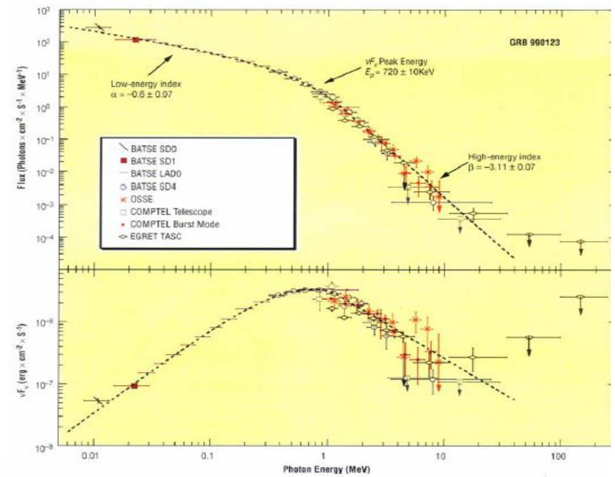


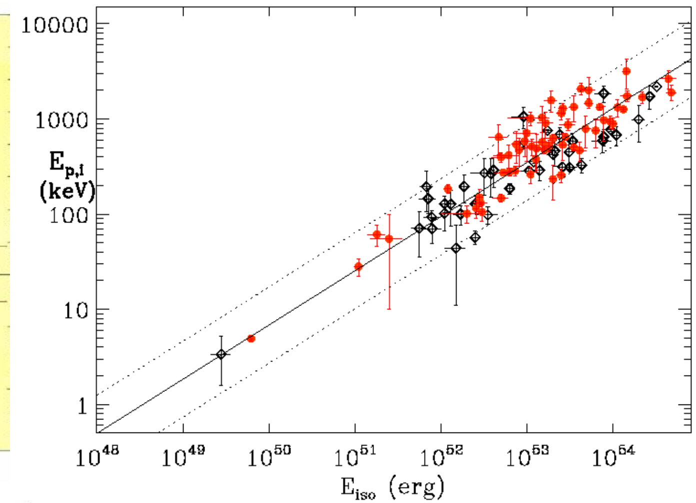
BeppoSAX WFC + GRBM

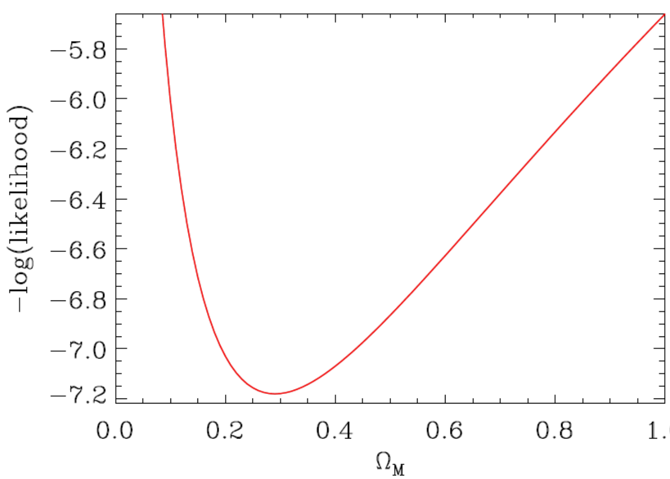
THESEUS XGS

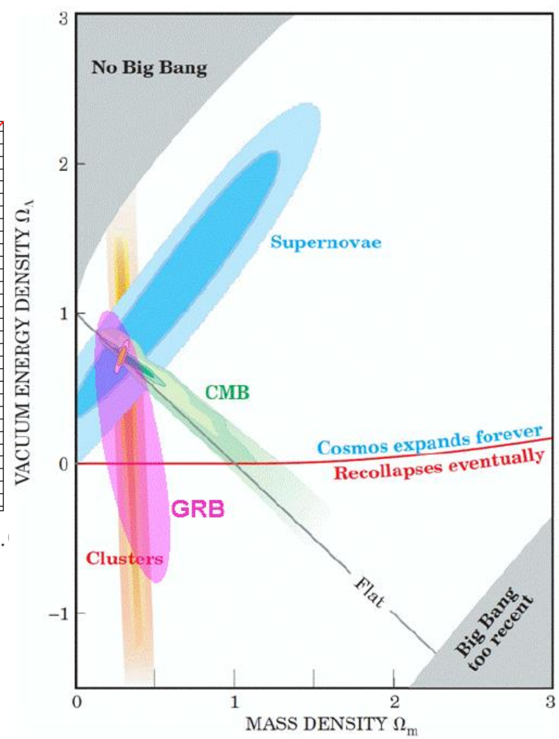
❑ measuring cosmological parameters with GRBs

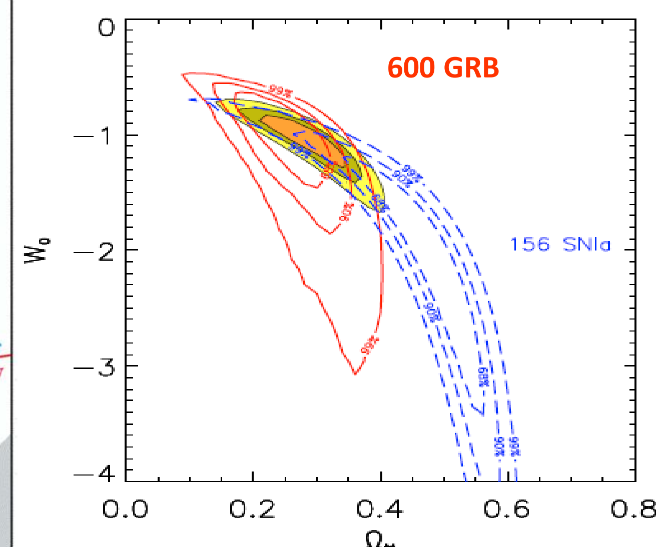






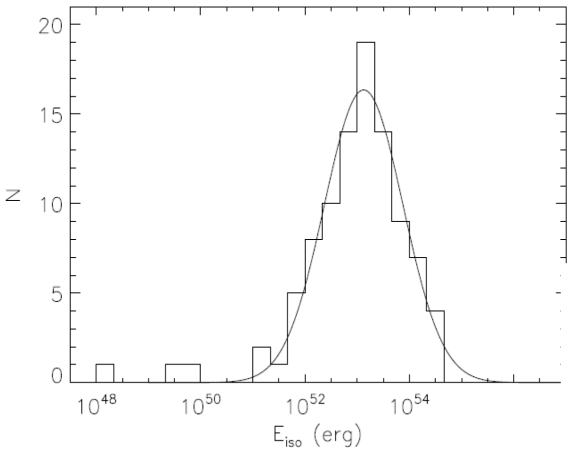


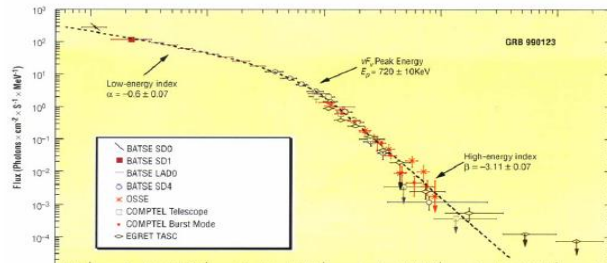


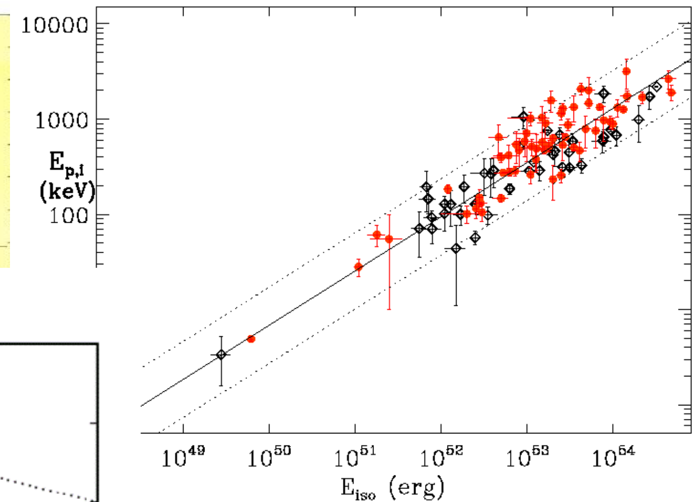


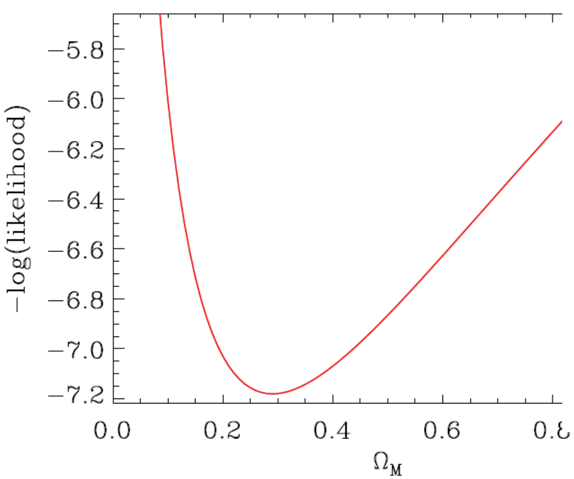
$$w(z) = w_0 + \frac{w_a z}{1+z}$$

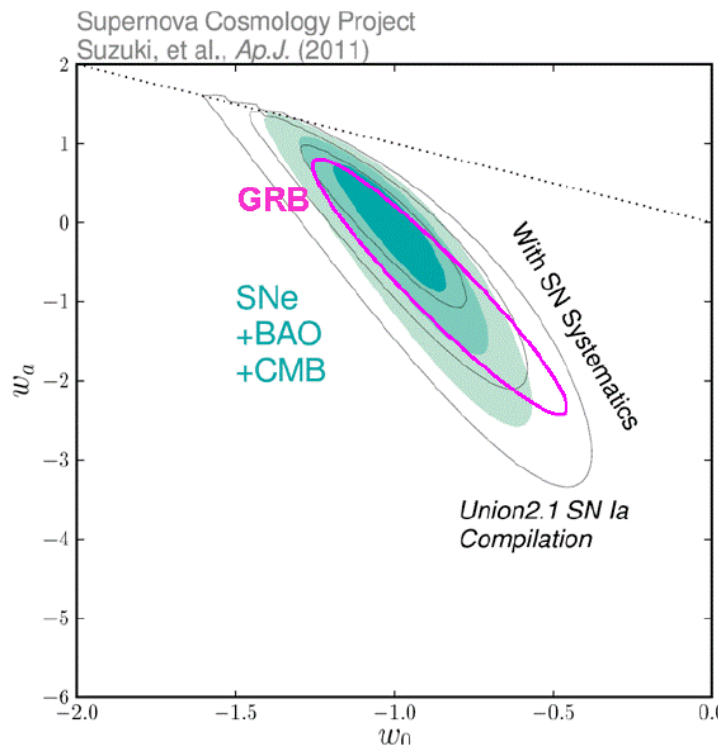
❑ measuring cosmological parameters with GRBs

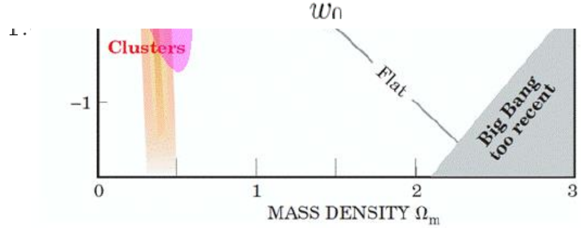


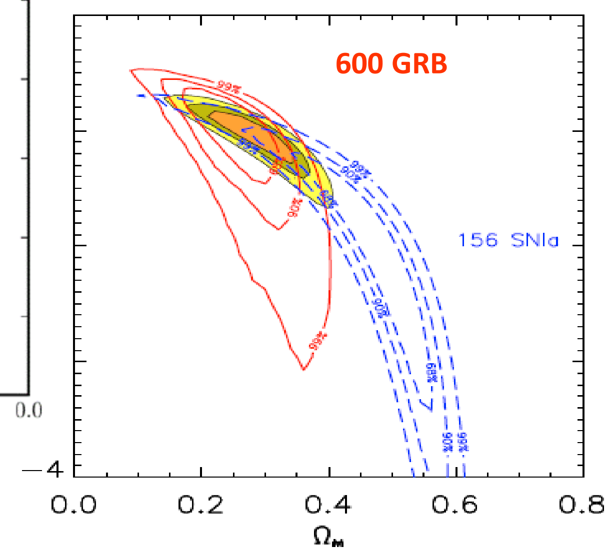












$$w(z) = w_0 + \frac{w_a z}{1+z}$$

GRBs within Cosmic Vision

- The European community played a fundamental role in the enormous progress in the field of the last 15 - 20 years (BeppoSAX, HETE-2, Swift, AGILE, Fermi + enormous efforts in optical IR and radio follow-up)

- In 2012, two European proposals for ESA Call for Small mission dedicated to GRBs and all-sky monitoring: **GAME** (led by Italy, SDD-based cameras + CZT-based camera + scintillator based detectors) and **A-STAR** (led by UK, lobster-eye telescopes + CdTe detectors)

- The **White Paper on GRBs** as probes of the early Universe submitted in response to ESA Call for science theme for next L2/L3 missions (Amati, Tanvir, et al., arXiv:1306.5259) was very well considered by ESA

- ATHENA (ESA/L2, 2028): very high spectral resolution spectroscopic observations of high redshift gamma-ray bursts (GRBs) to study metal enrichment in the early Universe

SXI (4 units)	400 MCPs	4.0	Quotation Photonis	Mass production	UK, , Czech Republic, Belgium, Germany, ESA (contribution of the CCDs)
	20 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, Spain
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IRT	Telescope Mirror	100	Quotation		ESA (telescope and overall cooling system, including MPTC), France, Switzerland, Hungary
	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	
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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€)**			

THESEUS: Italian contribution (ASI support)

- **XGIS -** 3 FM units + 1 spare unit, each one including 4 X-gamma ray detector modules, electronics, instr. spec. S/W, EGSE, MGSE and calibrations: ~15 - 17 ME
- **XGIS instrument specific S/W** for I-DHU: ~1 - 1.5 ME
- **Ground segment-** Malindi antenna: ~ 2 ME
- **Trigger Broadcasting Unit** (VHF transmitter): ~0.7 ME
- **Support to industrial and scientific activities in Italy** : ~2 - 2.5 ME
- **Total: ~20 – 23 ME**

❑ GW/multi-messenger and time-domain astrophysics

- ❑ Several high energy sources that THESEUS will monitor are also thought to be strong neutrino emitters, in particular SNe and GRBs.

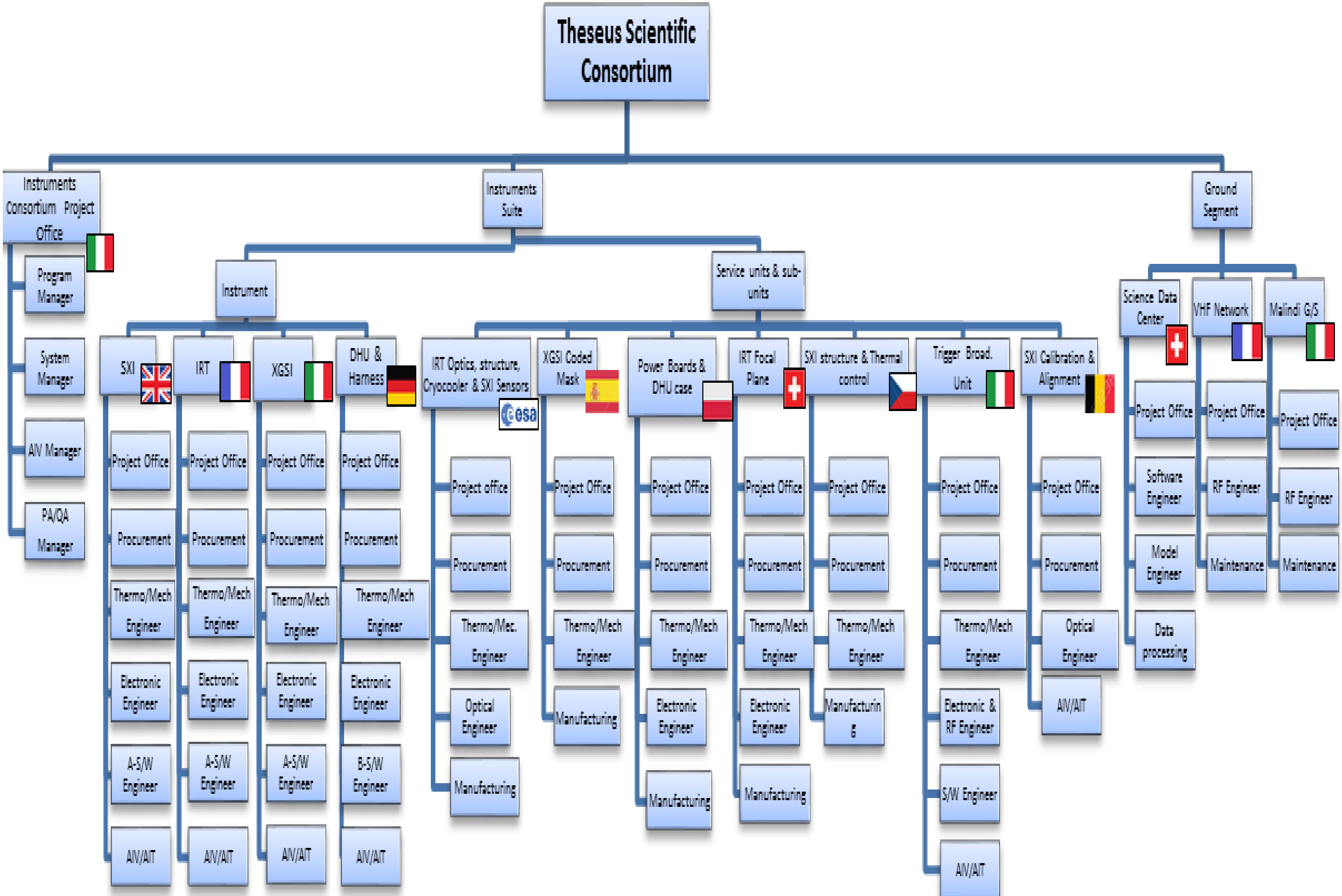
  - ❑ High energy neutrinos (>10^5 GeV): ultra-relativistic jets produce shock-accelerated protons that, interacting with high energy photons, originate high energy neutrinos via charged pions decay (e.g. Waxman & Bachall 1997).

  - ❑ Pulsed of low energy neutrinos (< 10 MeV) are expected during CC-Sne. Low energy neutrinos has been detected from SN 1987 A at 50 kpc.

- ❑ GW and neutrino emissions provide important information from the innermost regions (e.g. as the degree of asymmetry in the matter distribution, the rotation rate and strenght of magnetic fields)

- ❑ Future Megatons detectors as Deep-TITAND are expected to work during the 3G GW detectors, will reach distance up to 8 Mpc thus guaranteeing simultaneous GW/neutrino and EM detections of 1 SN/yr.

- ❑ Very promising for such multi-messenger sutdies are the LLGRBs given their expected larger rate than for standard LGRBs (up to 1000 higher) and their proximity.



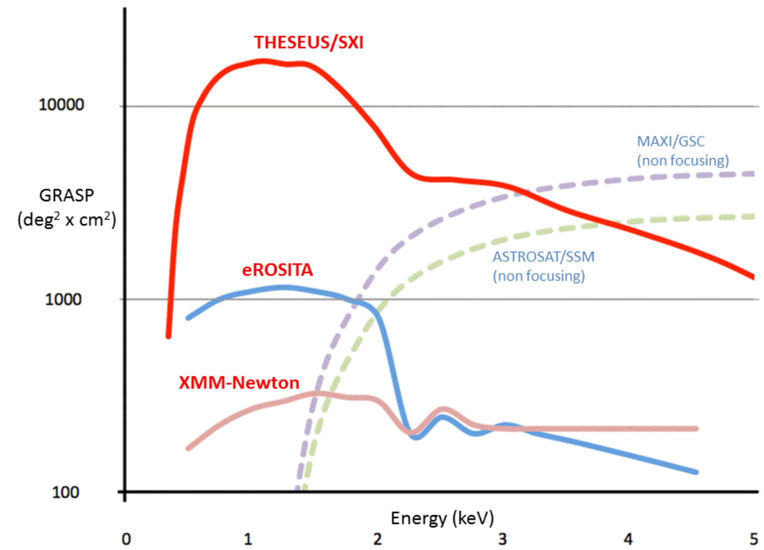
A-SW = Applicative Software
B-SW= Basic Software

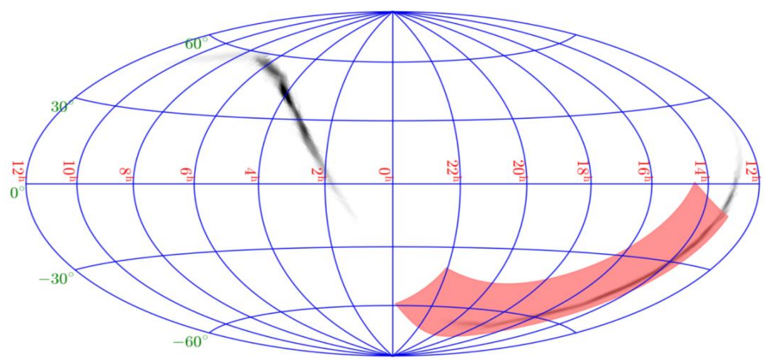
❑ GW/multi-messenger and time-domain astrophysics

- ❑ 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) locations of (long/short) GRBs and 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;

- ❑ Provide a fundamental step forward in the comprehension of the physics of various classes of Galactic and extra-Galactic transients, e.g. tidal disruption events (TDE), magnetars /SGRs, SN shock break-outs, Soft X-ray Transients SFXTS, thermonuclear bursts from accreting neutron stars, Novae, dwarf novae, stellar flares, AGNs and Blazars





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)

Subject: Letter of Endorsement for the THESUES M5 mission candidate

Dr Lorenzo Amati
INAF – Istituto di Fisica Spaziale e Fisica Cosmica di Bologna (IASF-Bo)
Via P. Gobetti 101, 40129 – Bologna (ITALY)
Telephone: (+39) 0516398745
Fax: (+39) 0516398723
e-mail: amati@iasfbo.inaf.it

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

					Co-Is
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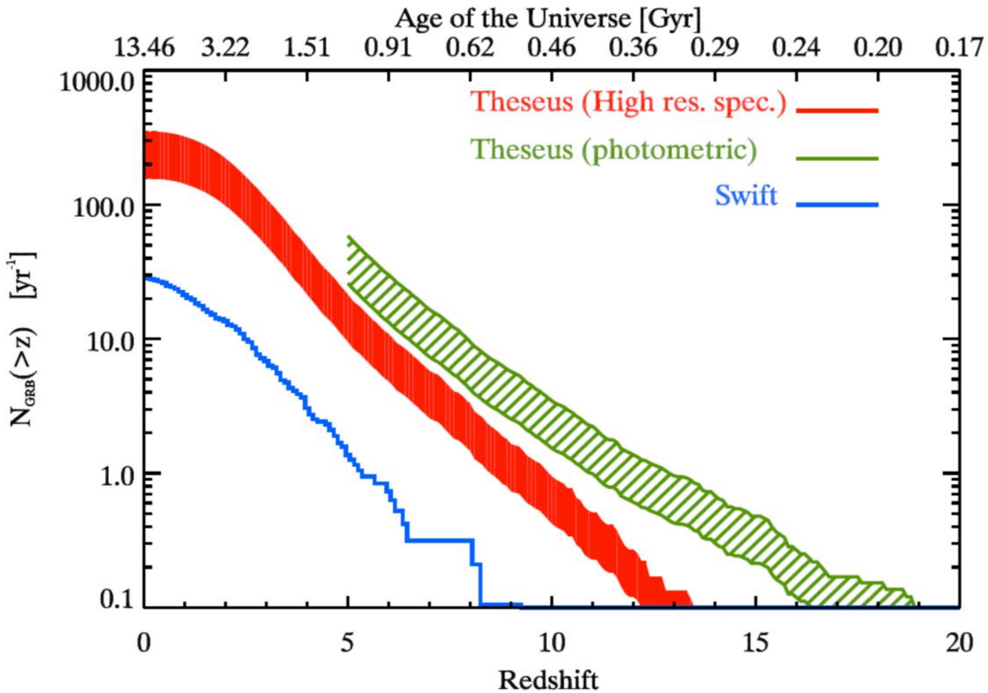
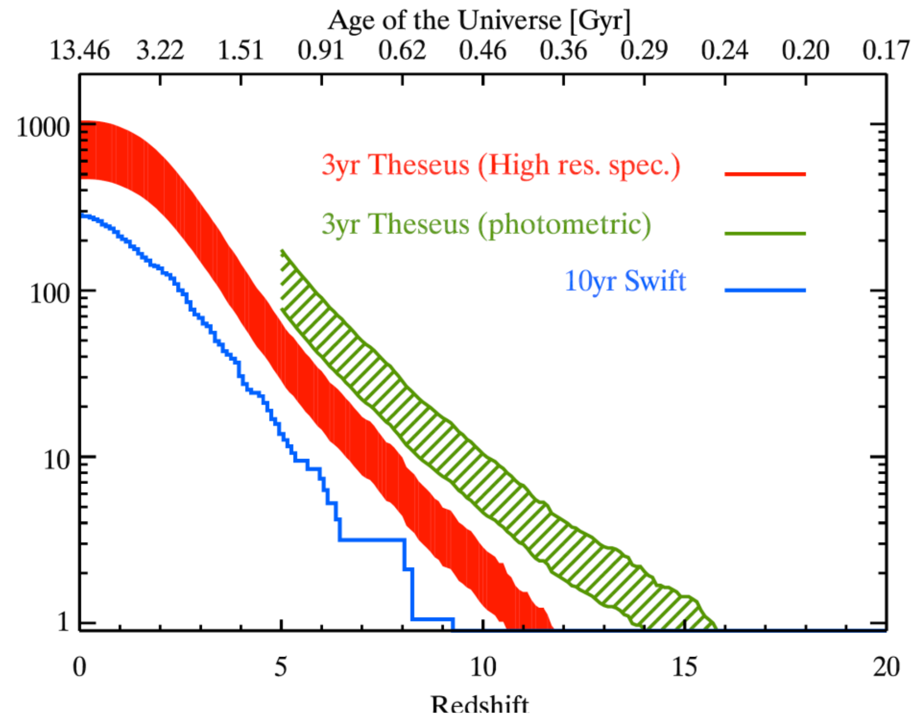
Instrument Operations Centers (one per instrument)		10	Past experience with flown missions & extended expertize from the UoG on past and running missions		All
Operational support		10	Past experience		All
Total		**273.1 (without ESA 153.1)**			

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 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

	Energy Band	FOV	Energy resolution	Peak eff. area	Source location	Operation
CGRO/BATSE	20–2000 keV	open	10 keV (100 keV)	$\sim$1700 cm^2	>1.7 deg	ended
Swift	15–150 keV	1.4 sr	7 keV (60 keV)	$\sim$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 ?
UFFO–p	5–100 keV	1.5 sr	2 keV (60 keV)	191 cm^2	5–10 arcmin	2014–2018 ?
CALET/GBM	7 keV – 20 MeV	3 sr	5 keV (60 keV)	68 cm^2	–	2014–2018 ?

Table 2: Characteristics of the THESEUS X/gamma-ray instruments compared with the main past and present GRB–dedicated instruments (CGRO/BATSE, Swift, Fermi/GBM, Konus–WIND), the two main instruments capable of measuring GRB prompt emission down to 2 keV (BeppoSAX/WFC and HETE–2/WXM), and next future GRB experiments under development or advanced study (SVOM, Lomonosov/UFFO–p, CALET/GBM).

+ Infrared telescope and fast slewing !!!

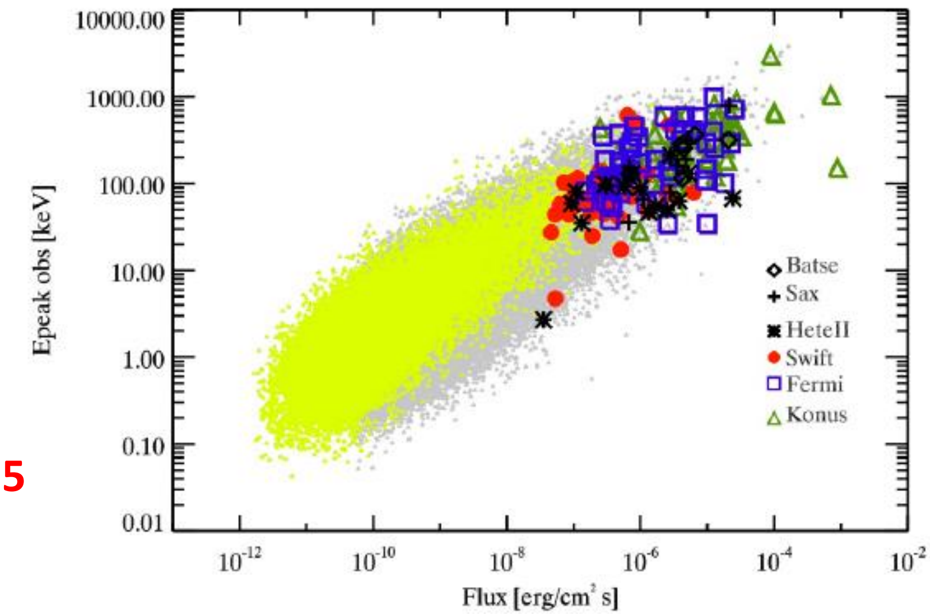
THESEUS Requirements I

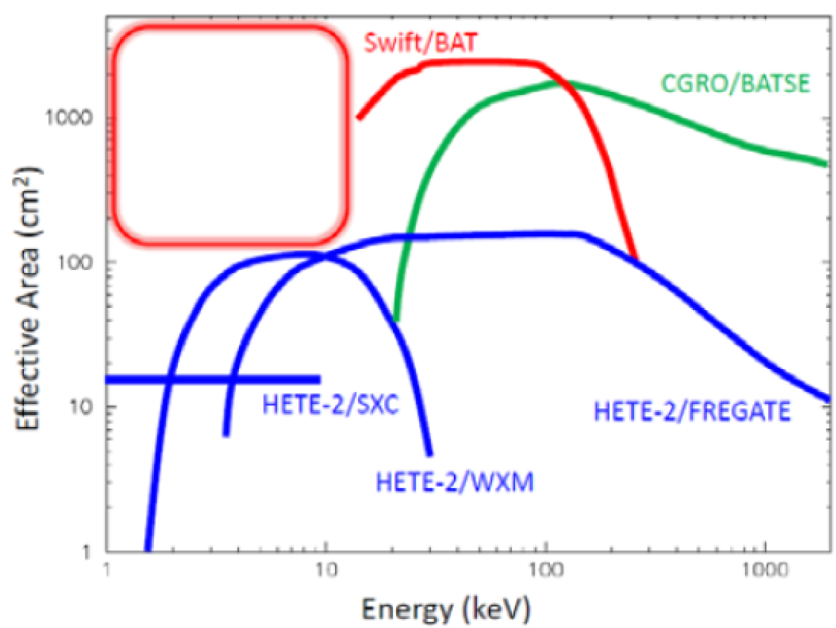
- A full exploration of the early Universe requires the detection of a factor 10 more GRBs (about 80-100) than currently available at $z>6$

- As supported by intensive simulation efforts (e.g. Ghirlanda+15 MNRAS) a high detection rate of high redshift GRBs requires a *soft* **and** *sensitive* (down to 10^{-9} erg/cm^2/s) *wide field* high-energy trigger, with precise and reliable localization techniques (< 2 arc min)

- In order to efficiently classify and filter the trigger a broad band spectral coverage is needed at high energies (+ GRB physics and additional cosmology)

Ghirlanda et al. 2015





Yonetoku et al. 2014

THESEUS Requirements II

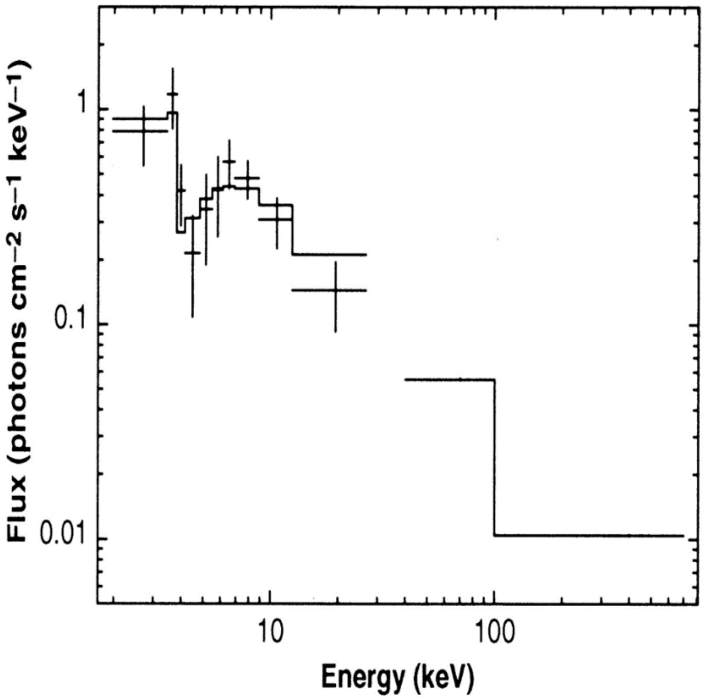
- In order to *identify, classify and study* the high-z GRB counterparts, an near-infrared (due to cosmological Ly-alpha suppression) telescope is needed on board. It will provide accurate positions, GRB redshifts, and GRB afterglows *spectra* (R~1000).

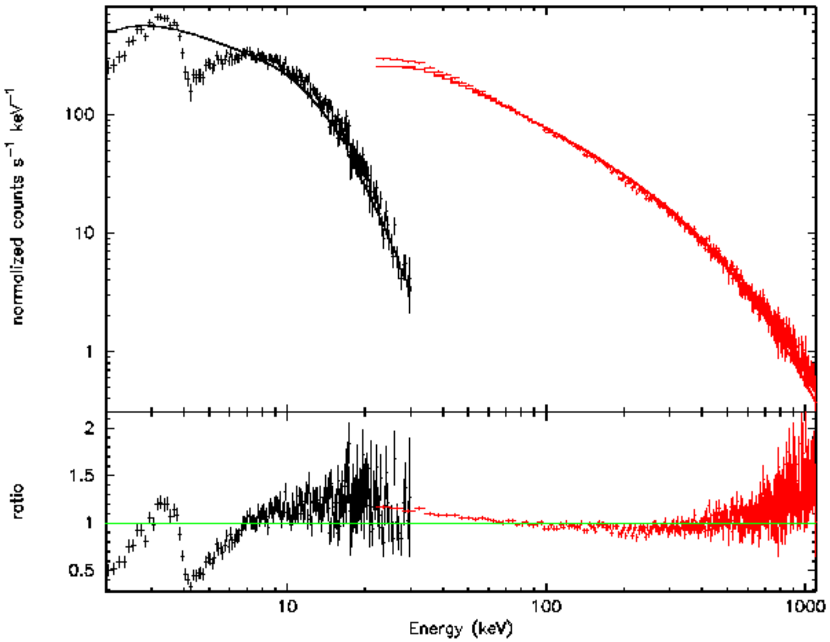
- The telescope shall be of the 0.5-1 m class in order to be able to detect the sources with the expected flux.

  Note that any ground based facility will not have the same efficiency and/or sensitivity in following-up 1000 bursts per year that are needed in order to have a few tens of GRBs beyond z=8.

- An agile and autonomous platform (Swift-like) is required in order to point at the GRB position *quickly (within 5-10 min);* also, in order to allow slit spectroscopy, *the poiting stability should be better than 0.5 arcsec*

❑ 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

GRBs within Cosmic Vision

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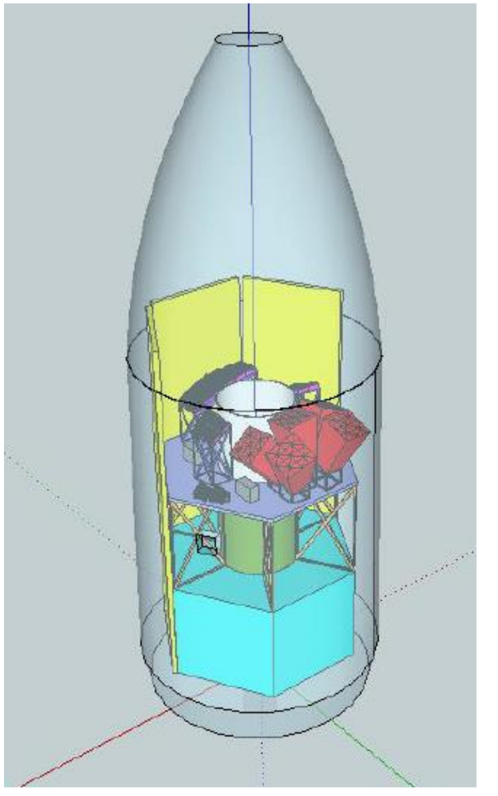
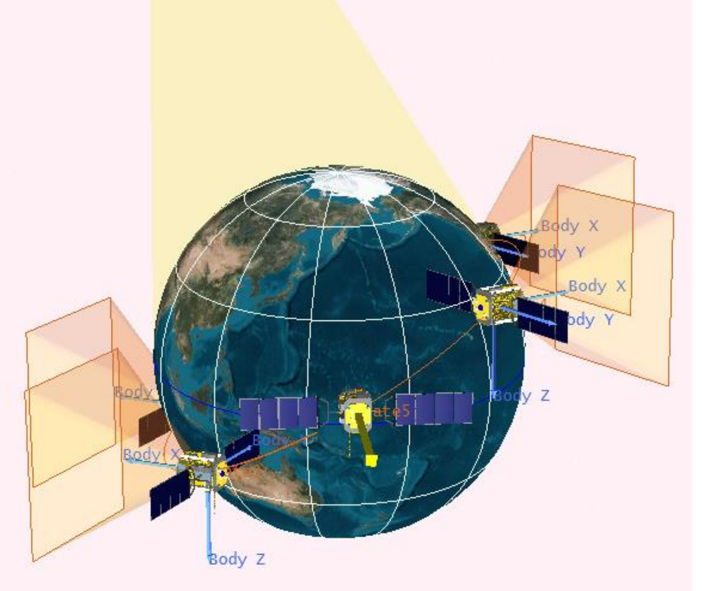
- ATHENA (ESA/L2, 2028): very high spectral resolution spectroscopic observations of high redshift gamma-ray bursts (GRBs) to study metal enrichment in the early Universe

- **ESA/M4: THESEUS** (Early Universe through high-redshift GRBs + GRB physics, sub-classes, etc.), LOFT (M3 assessment study, GRBs as part of observatory science), ASTROGAM (GRB jet physics in the MeV and testing LI with GRBs as part of many science topics), XIPE, …

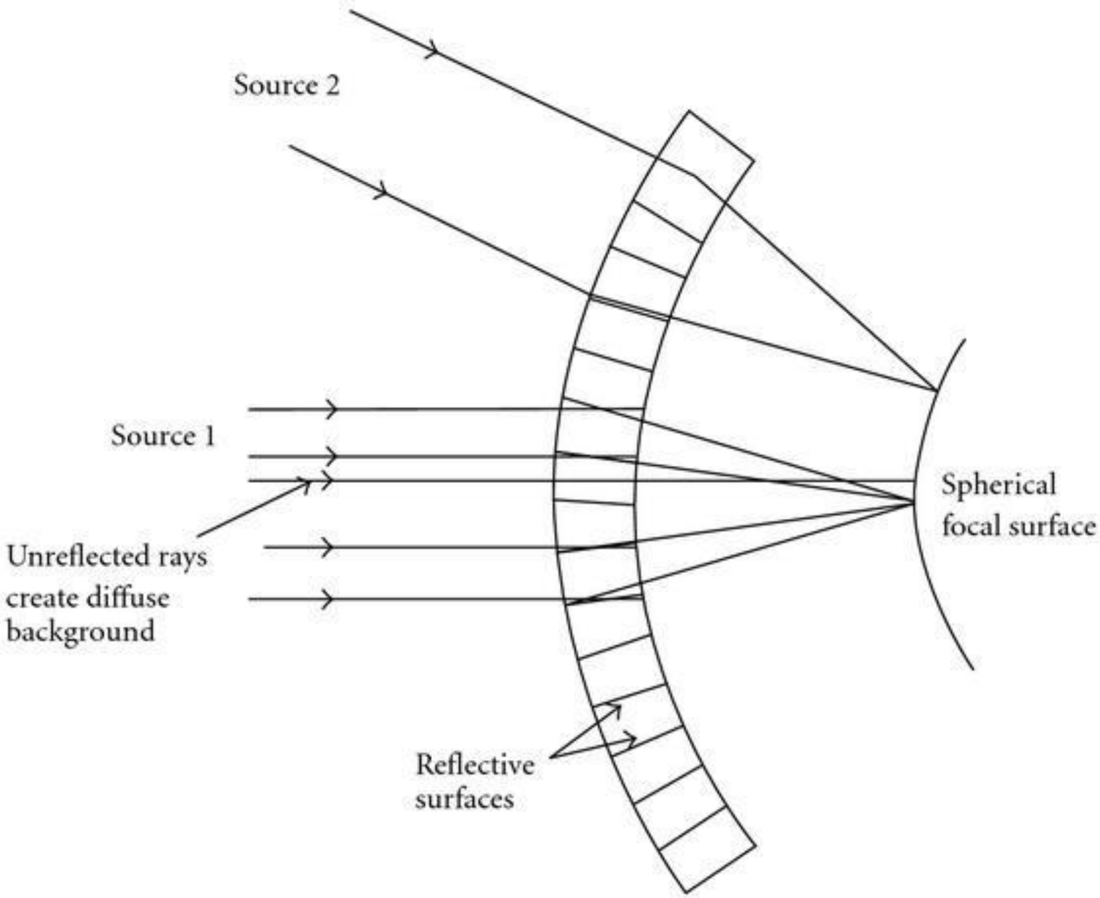
Mission profile

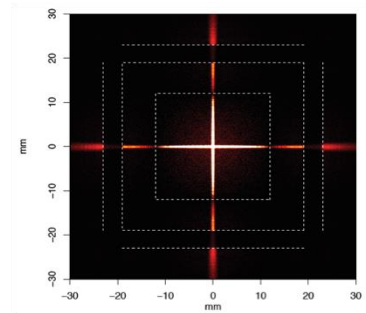


- Launch with VEGA into LEO (< 5°, ~600 km)
- **Spacecraft slewing capabilities (30° < 4 min)**
- Pointing anti-sun + ~polar
- Malindi antenna (+ Alcantara ?)
- **Prompt downlink options : NASA/TDRSS, ESA/EDRS, WHF network, IRIDIUM network, ORBCOMM**
- MOC, SOC -> ESA
- SDC -> ASDC (+FSC)



The Soft X-ray Imager (SXI)





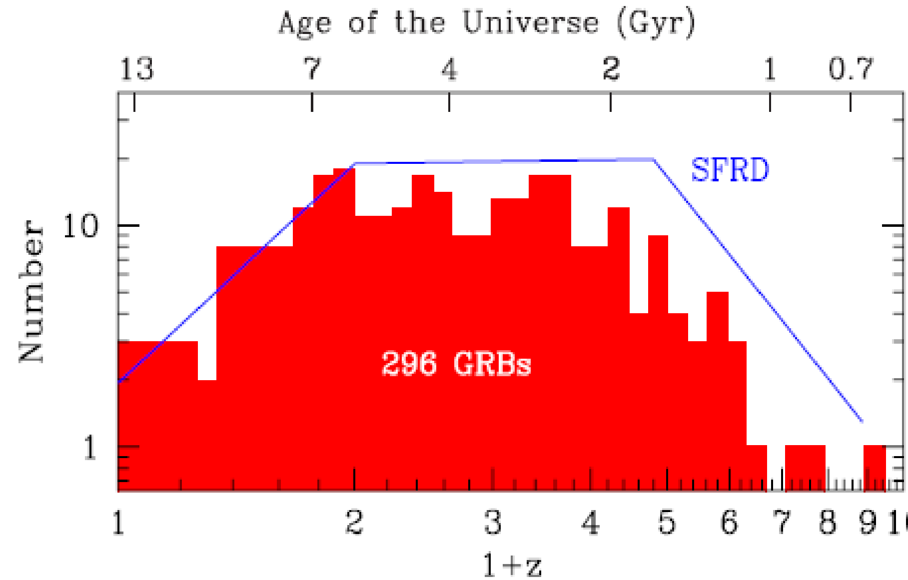
	ter eye
	290
	quare pore MCPs
	0
	rical
	array
	1
Pixel Number	1024 x 1024
Number of CCDs	4
Field of View (square deg)	542.8
Angular accuracy (best, worst) (arcsec)	(<10, 105)

Table 3.1 – Specifications of each SXI module

THESEUS payload consortium (M5)

- **ITALY -** XGS + SDC + 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
- **Germany (+ Denmark ?)** - 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: 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), **Spain ?** (cal.)
- **International optional contributions: USA:** (TDRSS, contrib. to XGS and IRT detector ?), **Brazil:** Alcantara antenna (+ …. ?), **Japan** (TBD) ?
- **Industrial partner:** CGS (OHB group), GPAP

GRB White paper for ESA/L2-L3



➢ **Time frame**: next decade

➢ **Collaboration**: D, UK, Fr, It, Ir, Dm, ..

➢ **Status**: theme for ESA/L2-3

➢ **Goals**: detect 1000 GRB/year for substantial increase of high-z GRBs (50 at z >9) -> GRBs as probes of Pop III stars, metal enrichment and reionization of the Universe, IGM,SFR evolution up to early Universe ; provide trigger and e.m. counterpart for next generation grav. wave and neutrino detectors; GRB polarisation

➢ **Payload**: different solutions proposed, e.g., multi-BAT or Compton Telescope or Lobster-eye telescope + X-ray telescope +NIR telescope; L2 orbit prefarable

Table 1: Scientific requirements for a future GRB mission with assumed 5 yr lifetime.

Requirement	Goal	Detector ability
1. Detect 1000 GRBs/yr	obtain 50 (5) GRBs at $z > 10(20)$	large FOV, soft response
2. Rapid transmission to ground	allow timely follow-up observations	communication network
3. Rapid localization to few $''$	opt/NIR identification of 1000 GRBs/yr	slewing X-ray or opt/NIR telescope
4. Provide z-indication	allow selection of high-z objects	multi-filter or spectroscopic capability

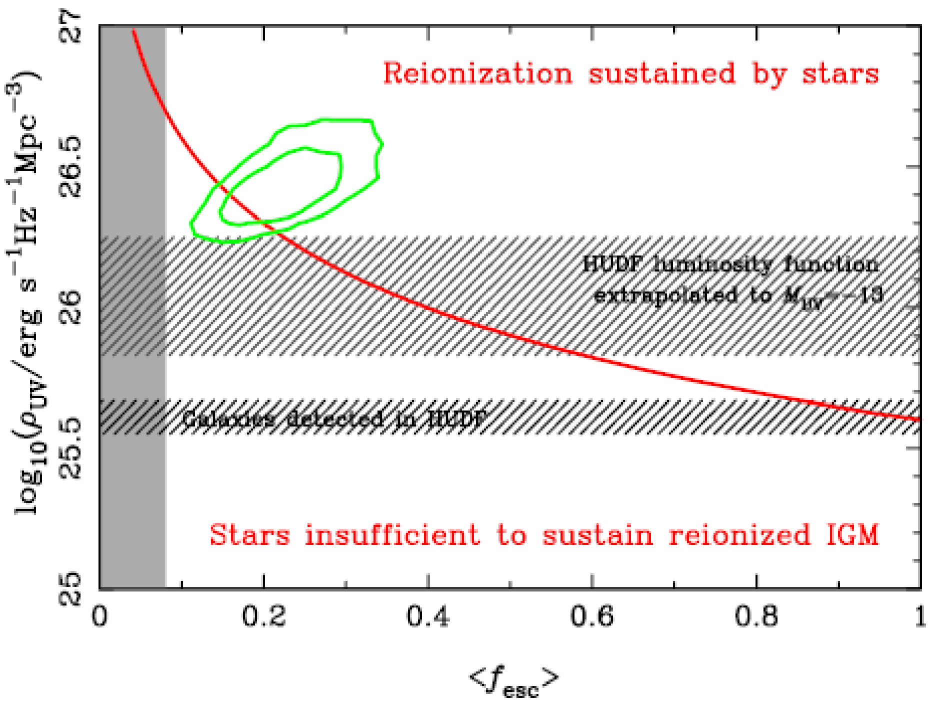


Fig. 1.3: The UV luminosity density from stars at z~8 and average escape fraction $<f_{esc}>$ are insufficient to sustain reionization unless the galaxy luminosity function steepens to magnitudes fainter than M_{UV}=-13 (grey hatched region), and/or $<f_{esc}>$ is much higher than that typically found at z~3 (grey shaded region). Even in the late 2020s, $<f_{esc}>$ at these redshifts will be largely unconstrained by direct observations. The green contours show the 1- 2-σ expectations for a sample of 30 GRBs at z~8 for which deep spectroscopy provides the host neutral column and deep imaging constrains the fraction of star formation occurring in hosts below the JWST limit (Robertson et al. 2013 ApJ 768 71). The input parameters were $\log_{10}(\rho_{UV})$=26.44 *and $<f_{esc}>$=0.23, close to the (red) borderline for reionization by stars*

N. Tanvir

❑ Shedding light on the early Universe with GRBs

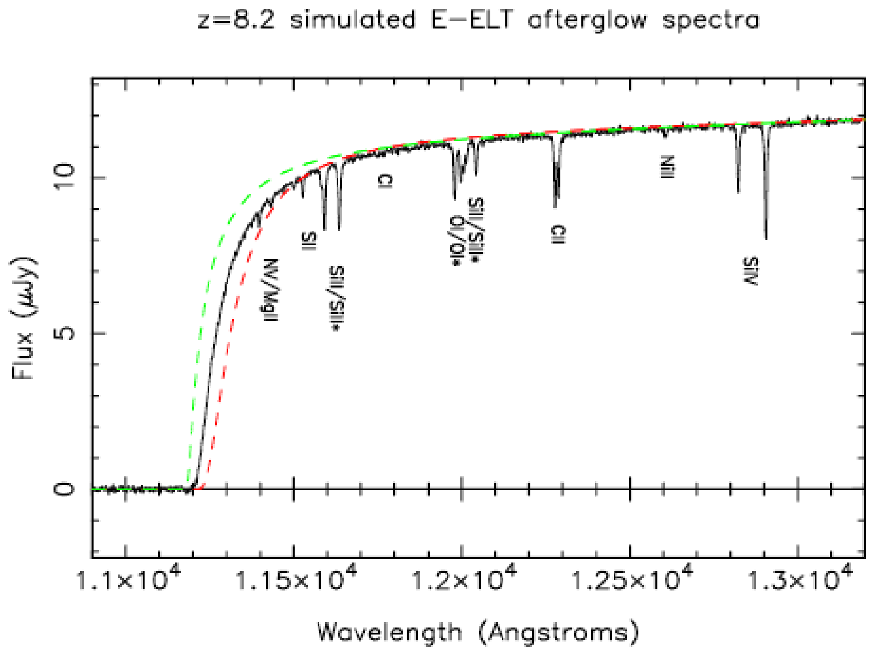


Fig. 1.4: simulated E-ELT 30 min spectrum of a faint GRB afterglow observed after ~1 day. The S/N provides exquisite abundance determinations while fitting the Ly-a damping wing simultaneously fixes the IGM neutral fraction and the host HI column density, as illustrated by the two extreme models, a pure 100% neutral IGM (green,) and best-fit host absorption with a fully ionized IGM