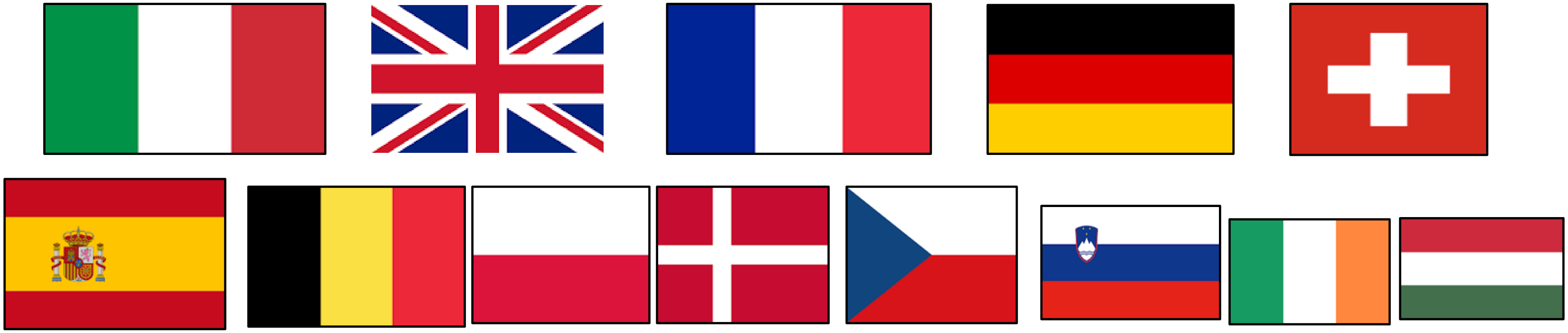
theseus

TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

Scientific WGs (video)conference

L. Amati - 3 June 2020



Agenda

WEDNESDAY JUNE 3

9:30 - 10:15: Welcome, overview and most recent updates (Amati with O'Brien and Gotz)
10:15 - 10:30: ESA/M5 process (McNamara)
10:30 - 10:50: Theseus study status (Saavedra)
10:50 - 11:10: Yellow Book preparation (Guainazzi)

11:10 - 11:30: Coffee break

11:30 - 12:00: Mission observation concept and simulator (Bozzo)
12:00 - 12:30: Theseus ground segment (ESA / Bozzo)

12:30 - 13:15: **WG1** - Early Universe with GRBs (Tanvir, Christensen, Ferrara, Le Floch)

Agenda

THURSDAY JUNE 4

09:30 - 10:15: **WG2** - Multi-messenger astrophysics (Stratta, Ciolfi, Rezzolla, Paltani)

10:15 - 11:00: **WG3** - Time-domain astronomy (Osborne, Mereghetti, Hanlon, Caballero-garcia)

11:00 - 11:15: Coffee break

11:15 - 12:00: **WG4** - Theseus GRB population synthesis model (Ghirlanda, Salvaterra, Mereghetti)

12:00 - 13:10: **WG5** - Synergies (Basa, Branchesi, Rosati and sub-WG coordinators)

13:10 - 13:50: **WG6** - Theseus as an Observatory (Blain, Castro-Tirado, De Rosa, Burderi)

13:50 - 14:00: Final remarks and adjourn

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

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

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

THESEUS
Transient High Energy Sky and Early Universe Surveyor

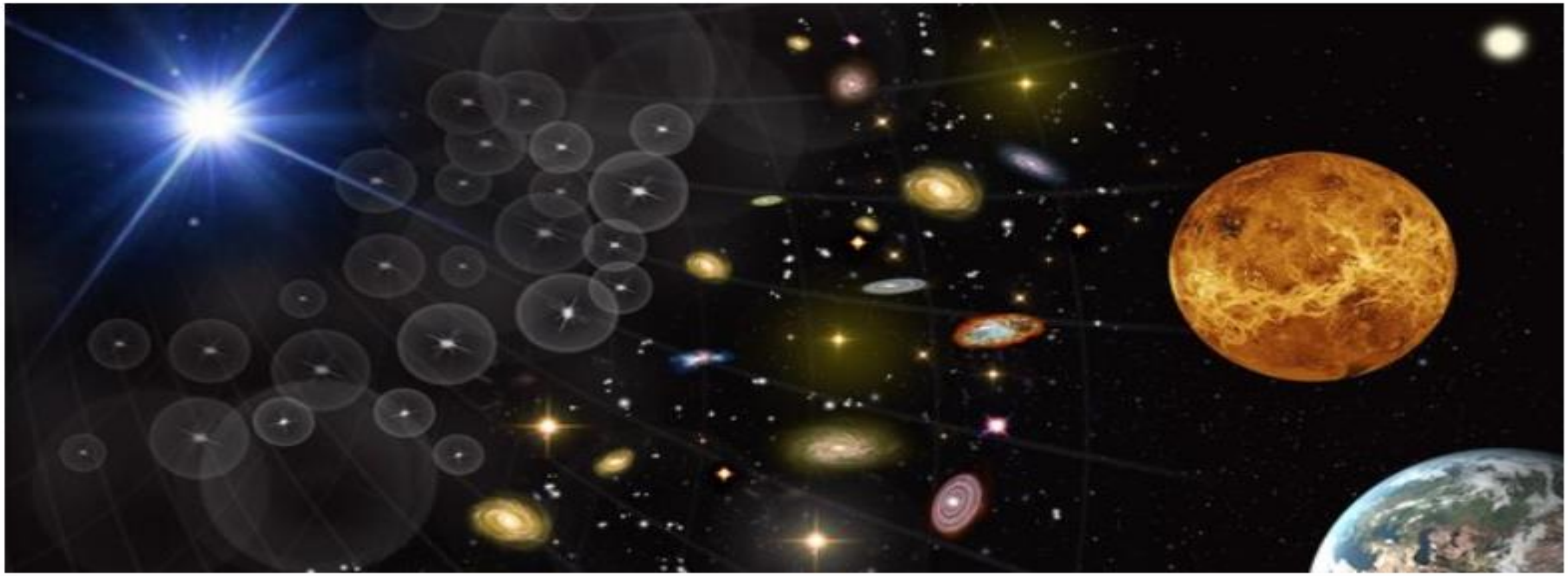
Lead Proposer (ESA/M5): Lorenzo Amati (INAF – OAS Bologna, Italy)

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

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

Interested international partners: USA, China, Brazil

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



M5 mission themes

ESA SELECTS THREE NEW MISSION CONCEPTS FOR STUDY

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

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

Updated ESA timeline for M5 Phase 0/A study

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

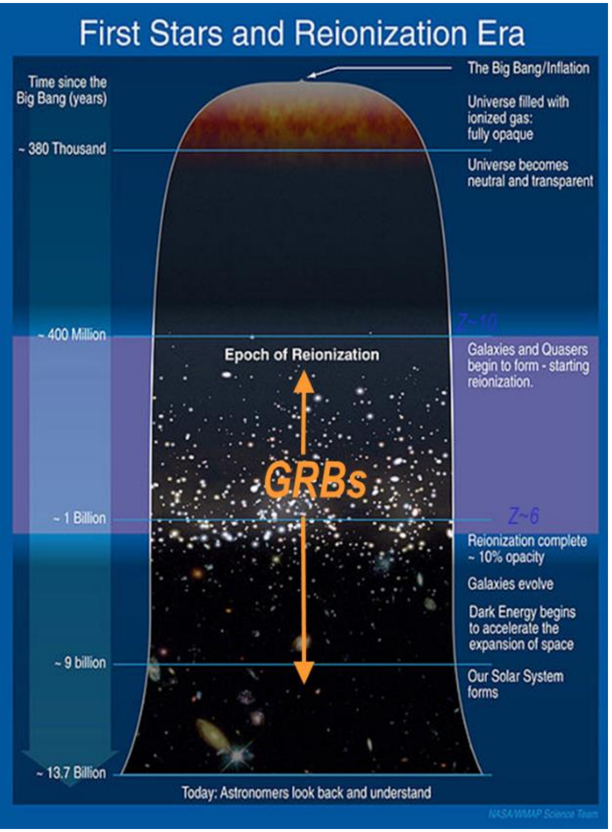
- **Smooth CDF study, successful MDR -> Phase A**
- Efficient and positive interaction between ESA and consortium

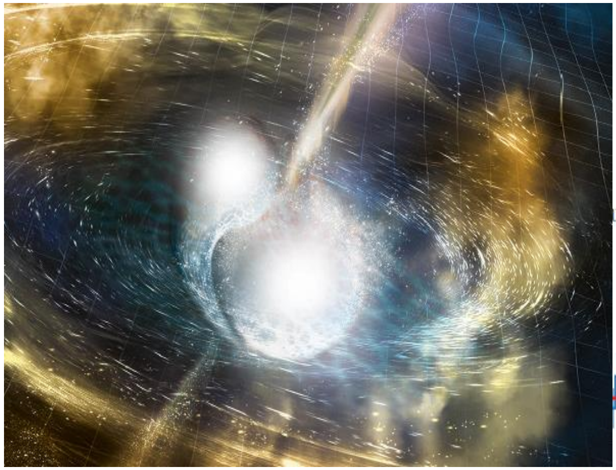
Probing the Early Universe with GRBs

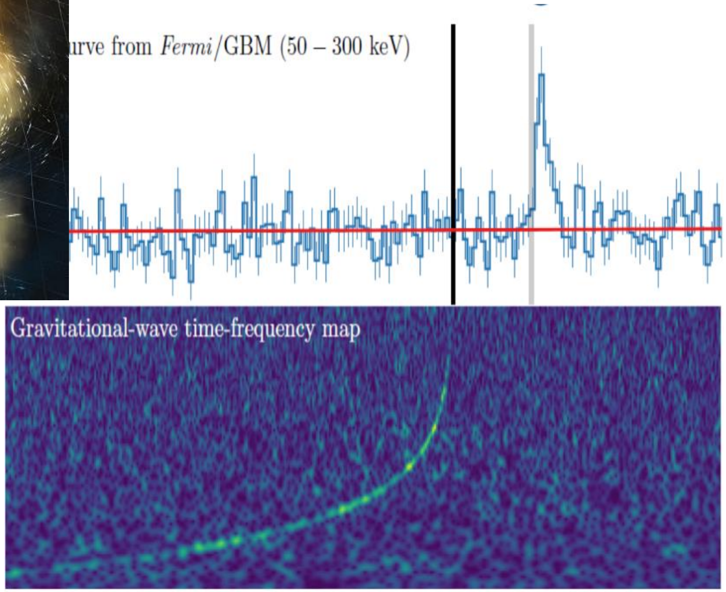
Multi-messenger and time domain Astrophysics

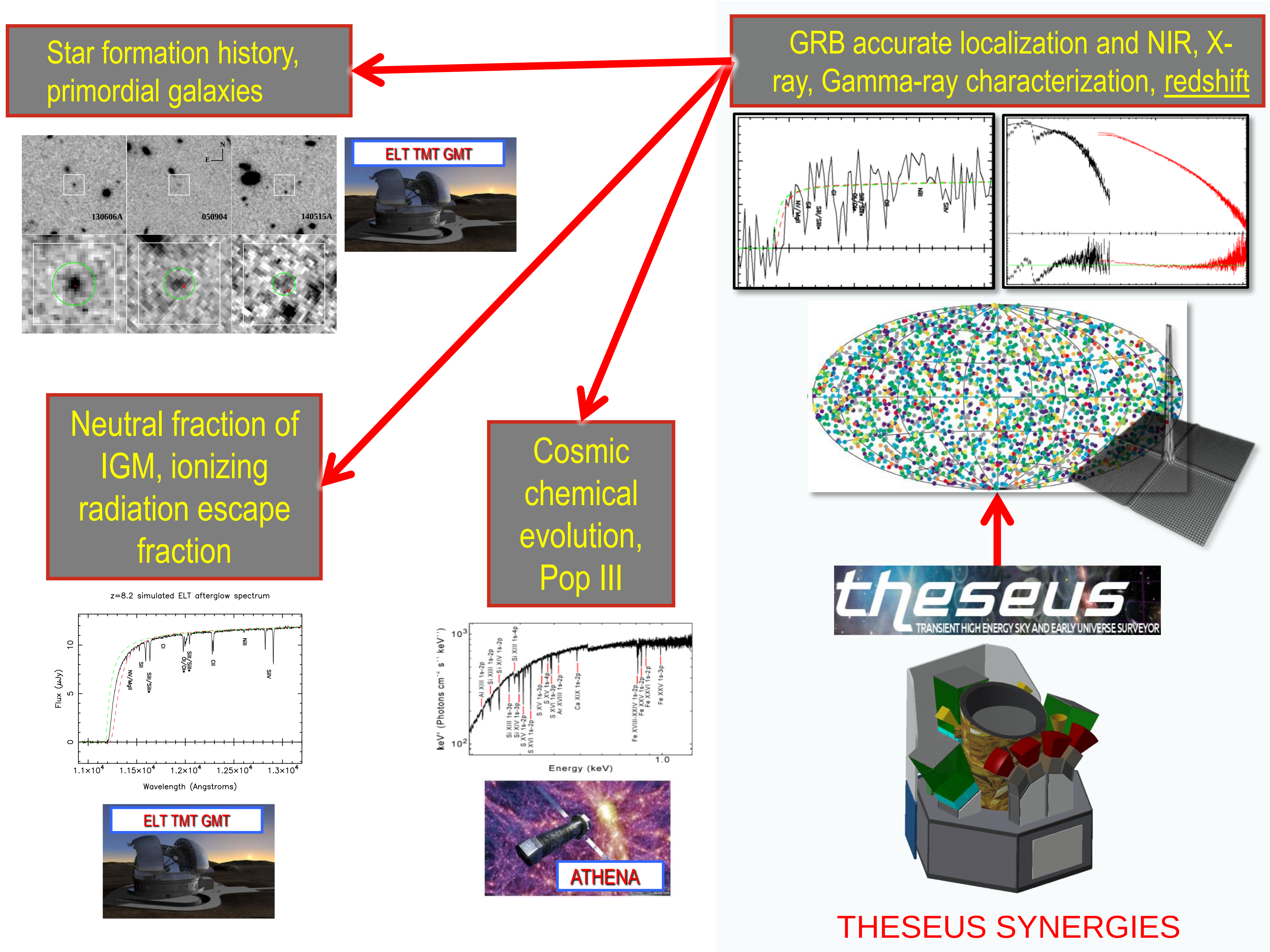
The transient high energy sky

Synergy with next generation large facilities (E-ELT, SKA, CTA, ATHENA, GW and neutrino detectors)








Star formation history, primordial galaxies
GRB accurate localization and NIR, X-ray, Gamma-ray characterization, redshift
130606A
050904
140515A
N
E
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)
1.1×10^4
1.15×10^4
1.2×10^4
1.25×10^4
1.3×10^4
NV/MgII
SiII
SiII/SiII*
CI
OI/OI*
SiII/SiII*
CII
NIII
SIV
keV² (Photons cm⁻² s⁻¹ keV⁻¹)
Energy (keV)
1.0
Al XIII 1s-2p
Si XIII 1s-2p
Si XIV 1s-2p
Si XIII 1s-4p
Si XIII 1s-3p
Si XIV 1s-3p
S XV 1s-2p
S XVI 1s-2p
S XV 1s-3p
S XVI 1s-4p
S XVI 1s-3p
Ar XVIII 1s-2p
Ca XIX 1s-2p
Fe XVIII-XXIV 1s-2p
Fe XXV 1s-2p
Fe XXVI 1s-2p
Fe XXV 1s-3p
ATHENA
ELT TMT GMT
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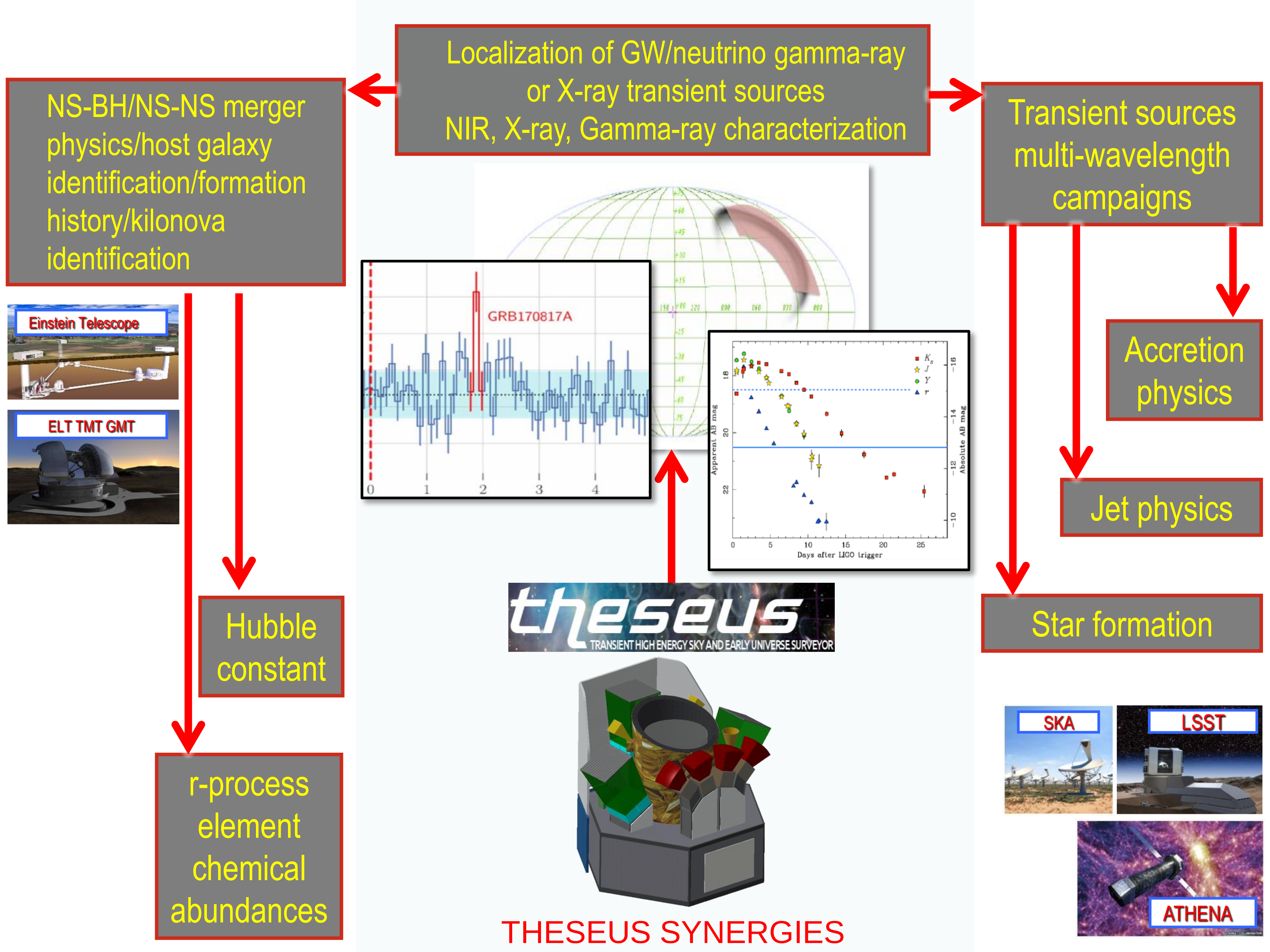
THESEUS SYNERGIES


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

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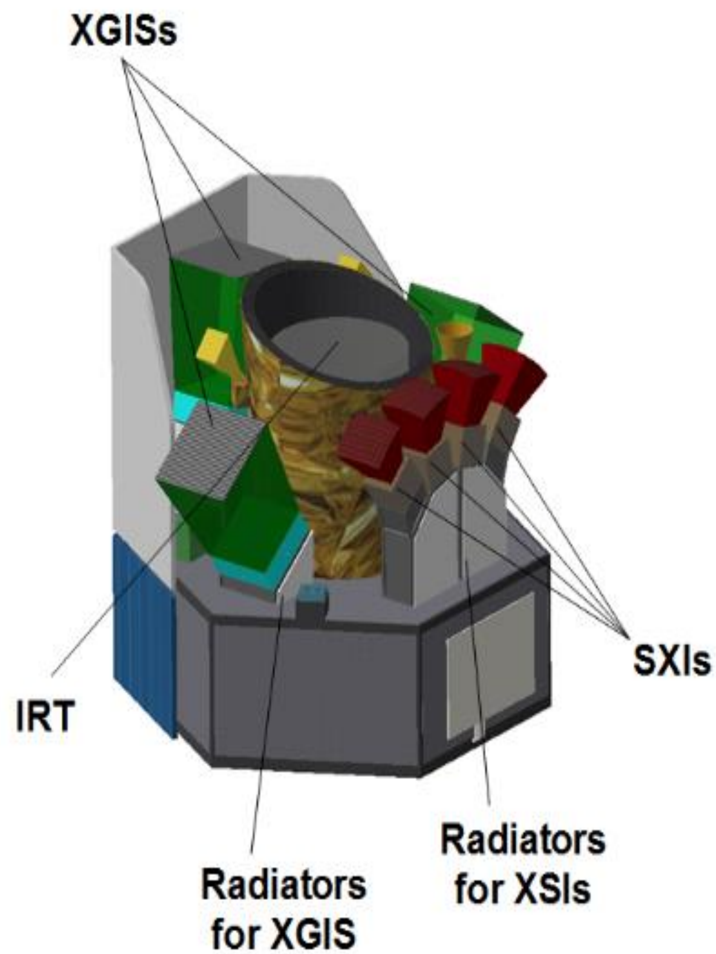
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

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

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

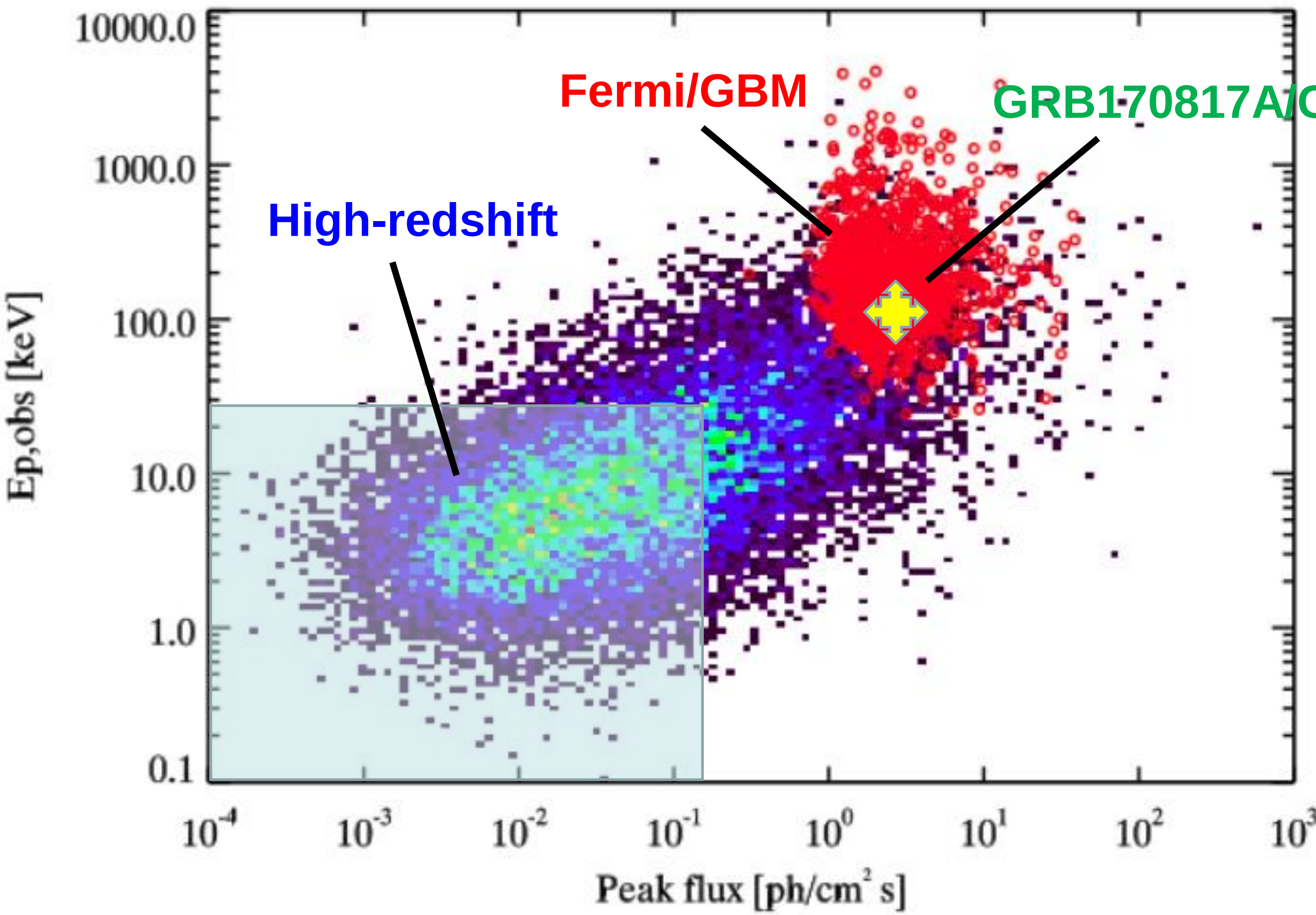
THESEUS mission concept

- **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' GRB location accuracy** in 2-30 (150) keV
- **InfraRed Telescope (IRT)**: a 0.7m class IR telescope observing in the **0.7 – 1.8 µm band, providing a 10'x10' FOV, with both imaging and moderate resolution spectroscopy capabilities (-> redshift)**

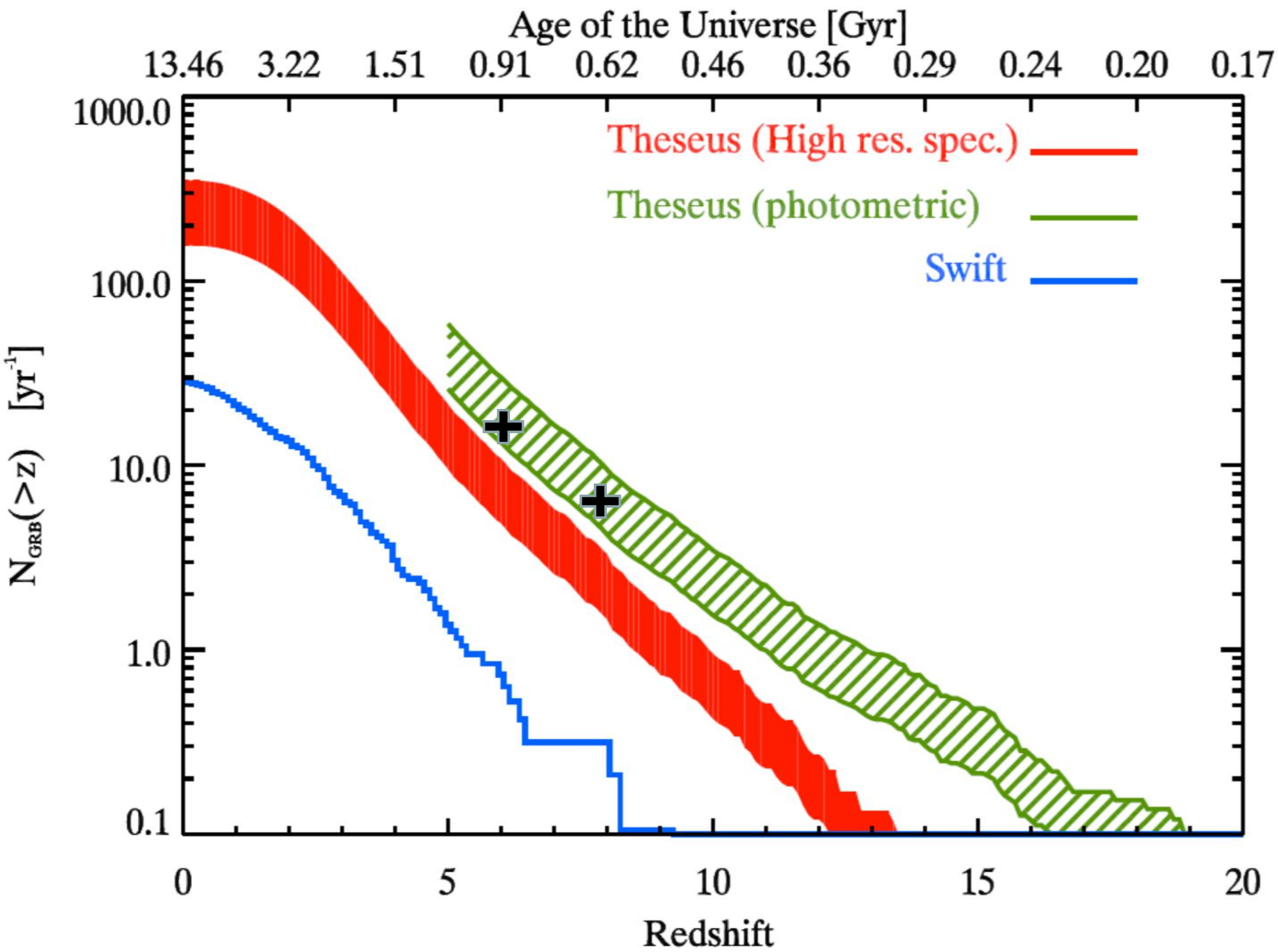


LEO (< 5°, ~600 km)
Rapid slewing bus
Prompt downlink

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

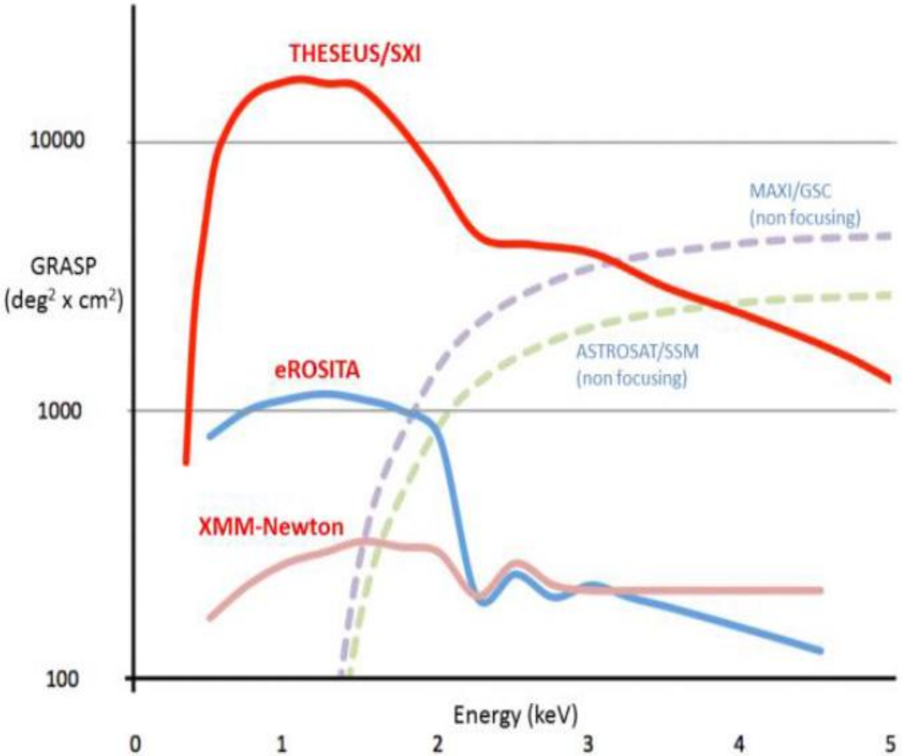


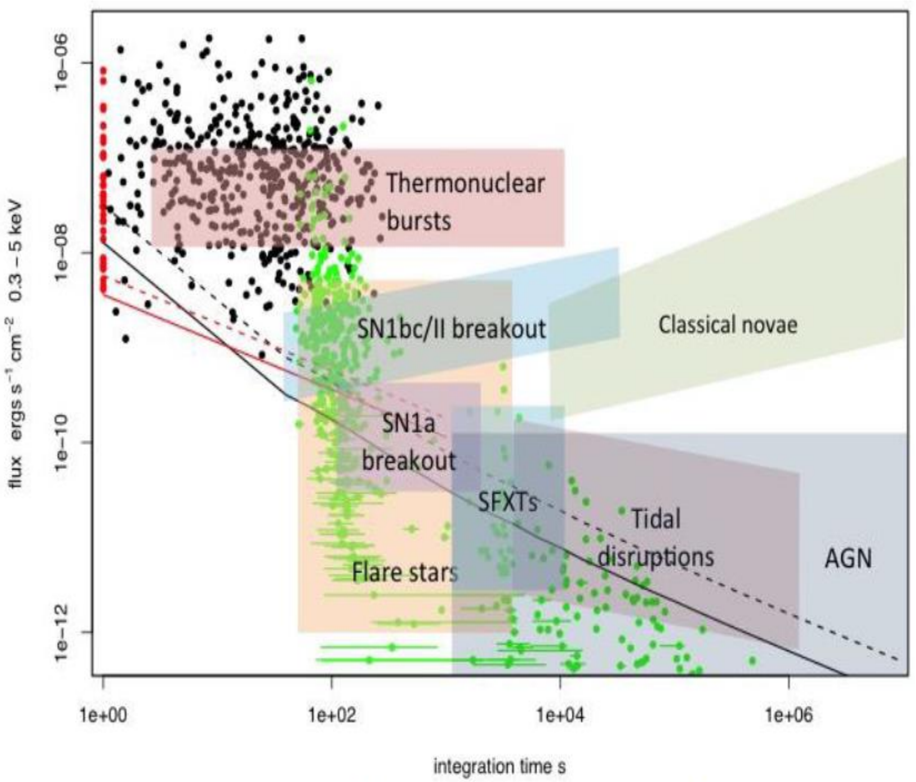
❑ Shedding light on the early Universe with GRBs



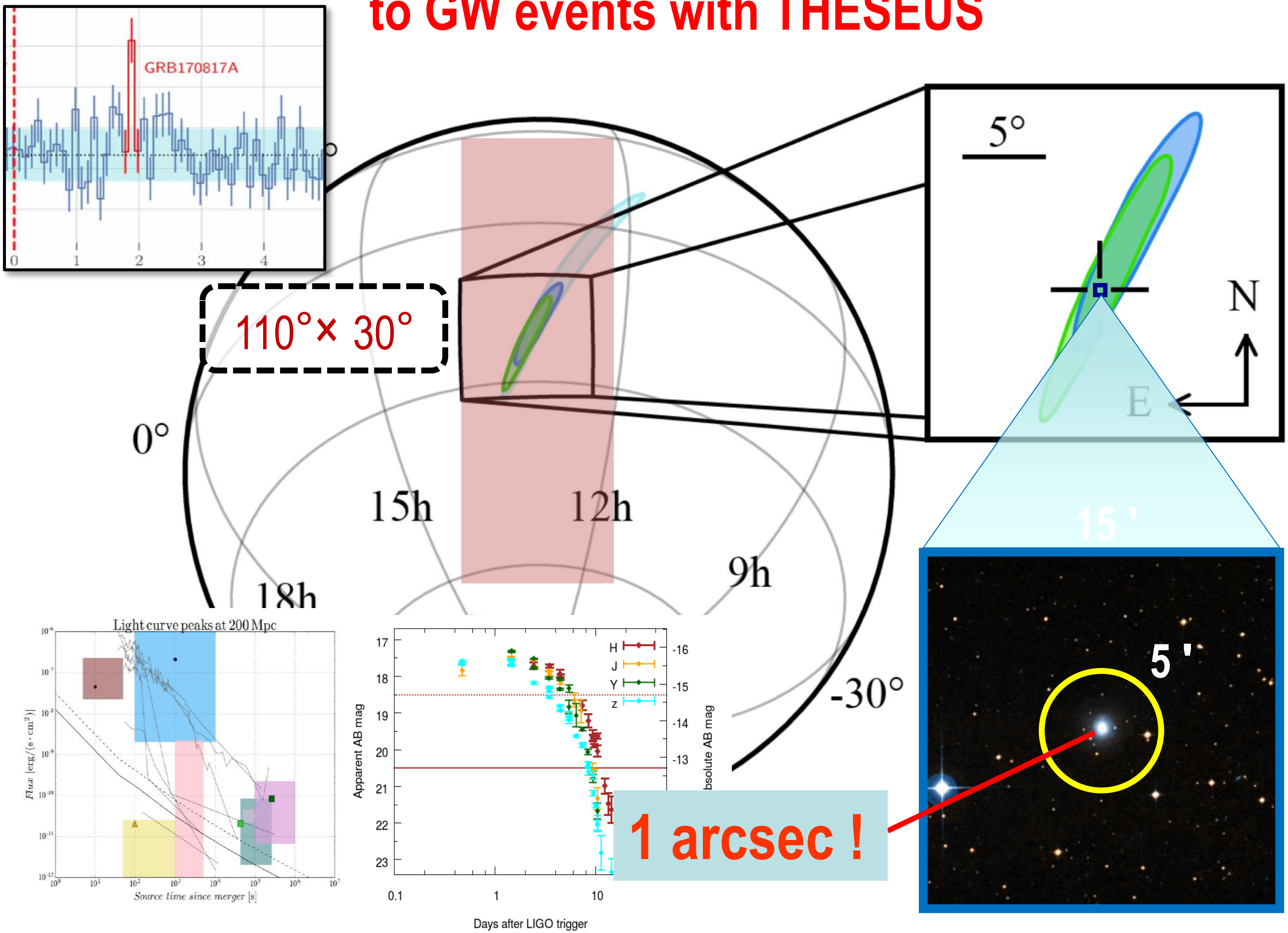
❑ THESEUS will also detect and localize down to 0.5-1 arcmin the soft X-ray short/long GRB afterglows, of NS-NS mergers and of many classes of galactic and extra-galactic transients

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

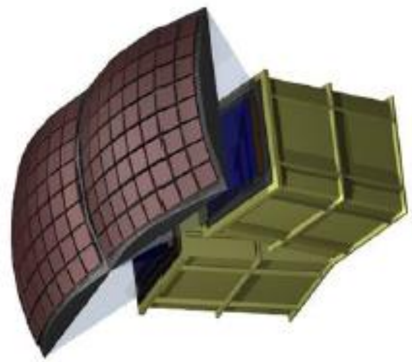


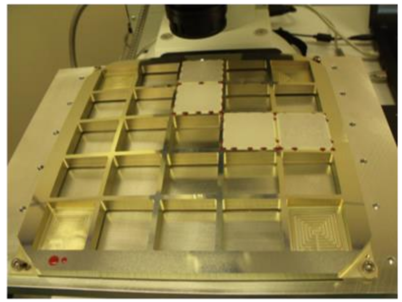


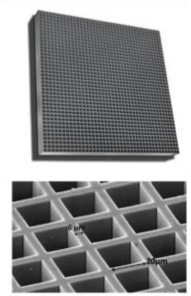
❑ Promptly and accurately localizing e.m. counterparts to GW events with THESEUS

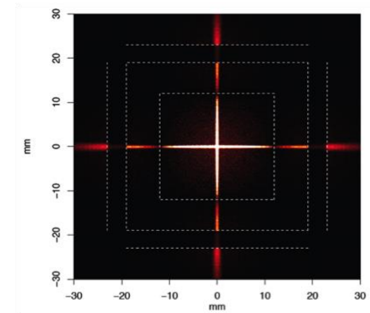


The Soft X-ray Imager (SXI)









4 DUs, each has a 31 x 26 degree FoV

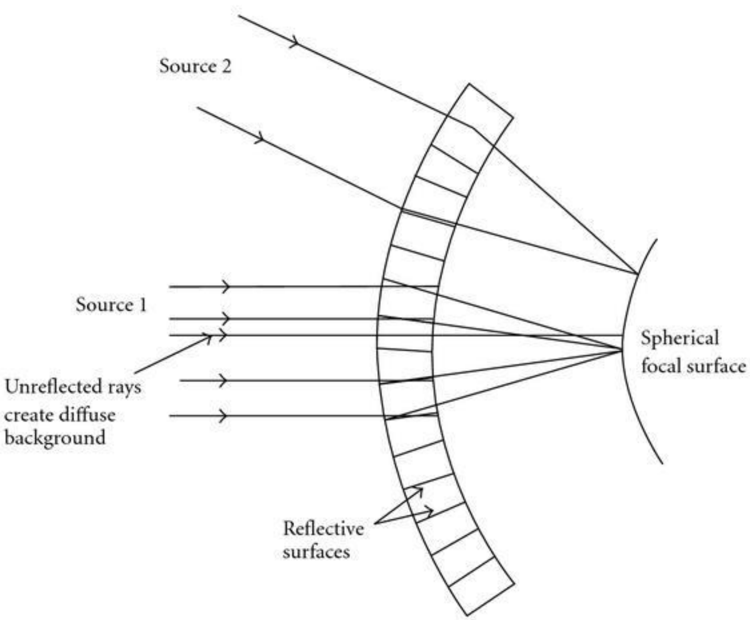
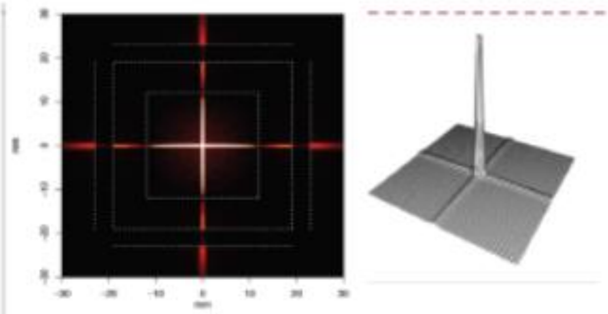


Table 4 : : SXI detector unit main physical characteristics

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

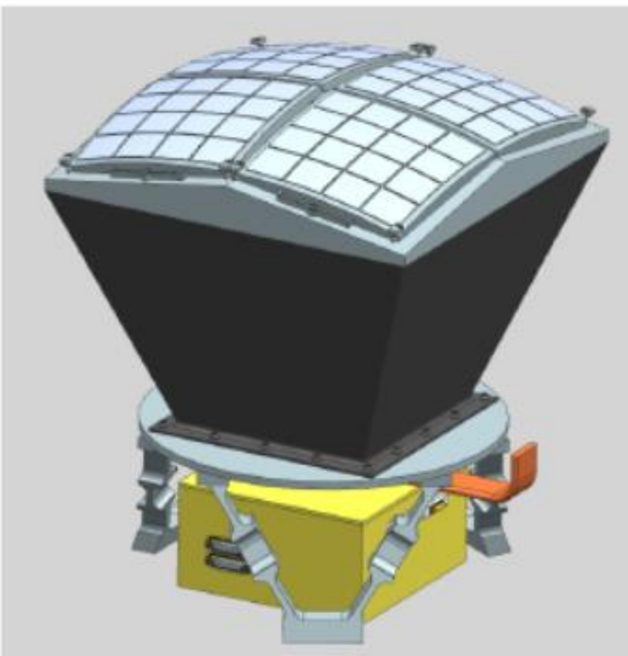
THESEUS SXI



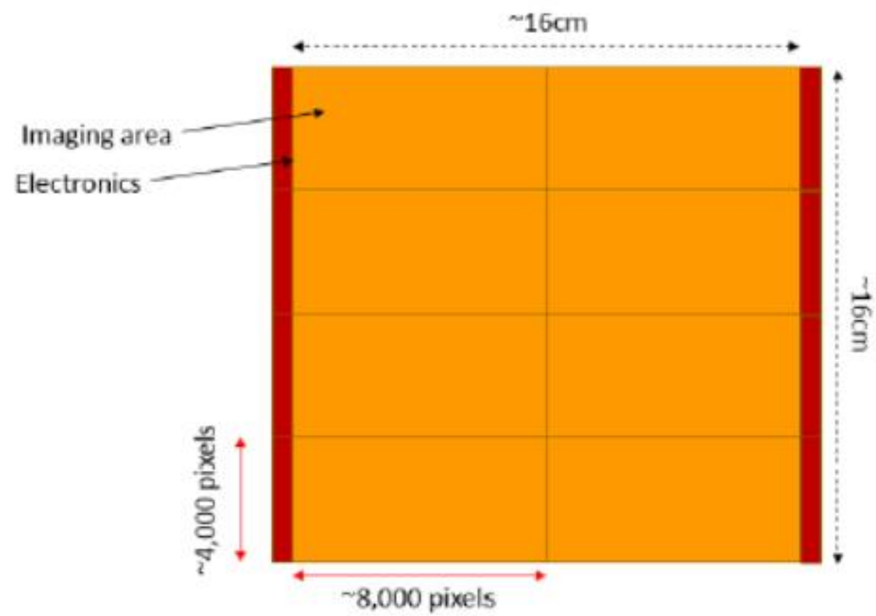
4 identical modules observing in 0.3-5 keV band

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

Each module uses 64 MPOs and 8 large format CMOS detectors

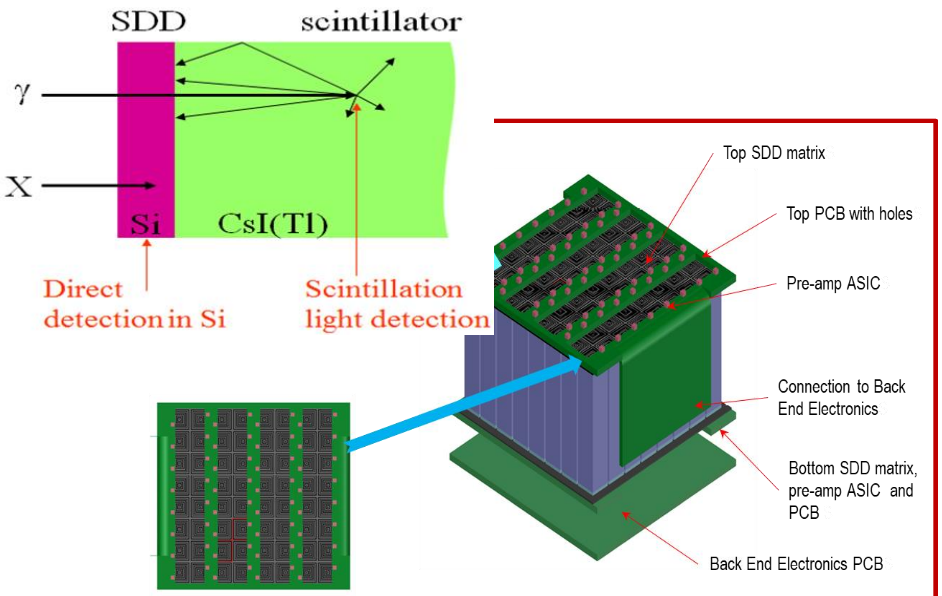


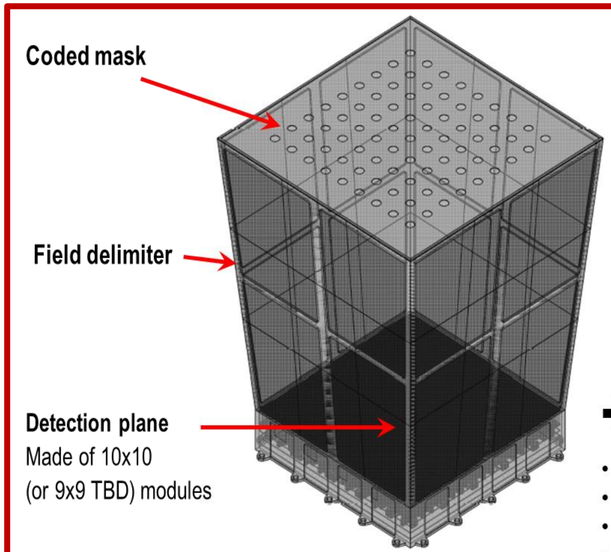
Single optics frame illuminates a curved focal plane



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

The X-Gamma-ray imaging spectrometer





+

- DHU (Data Handling Unit)
- Instr. Specific SW
- Harness
- Particle monitor
- .....

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

Extending the XGIS imaging to 150 keV

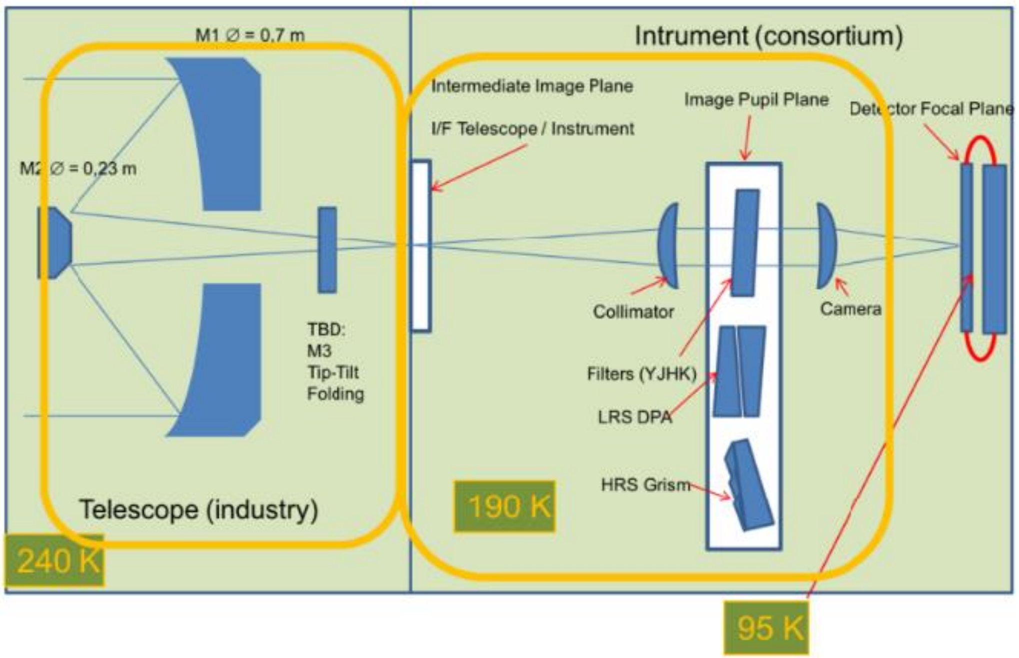
Table 6: XGIS unit characteristics vs energy range

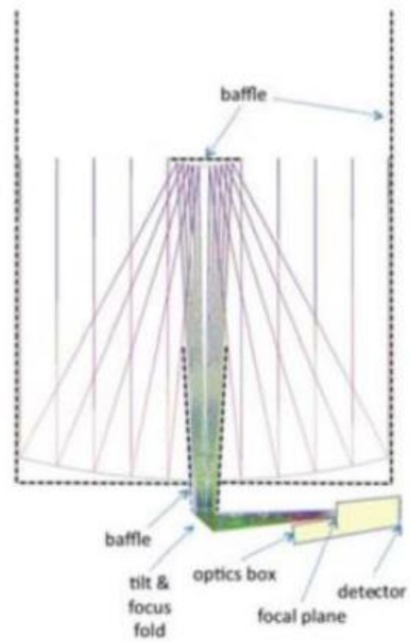
	2-30 keV	30-150 keV	>150 keV
Fully coded FOV	9 x 9 deg^2		
Half sens. FOV	50 x 50 deg^2	50 x 50 deg^2 (FWHM)	
Total FOV	64 x 64 deg^2	85 x 85 deg^2 (FWZR)	2π sr
Ang. res	25 arcmin		
Source location accuracy	~5 arcmin (for >6 σ source)		
Energy res	200 eV FWHM @ 6 keV	18 % FWHM @ 60 keV	6 % FWHM @ 500 keV
Timing res.	1 μsec	1 μsec	1 μsec
On axis useful area	512 <cm^2	1024 cm^2	1024 cm^2

- **Improve significantly the XGIS location capability for GRB and other transients**

- **Particulary important for short GRBs, showing a harder spectrum below Ep w/r to long ones -> optimization for multi-messenger astrophysics**

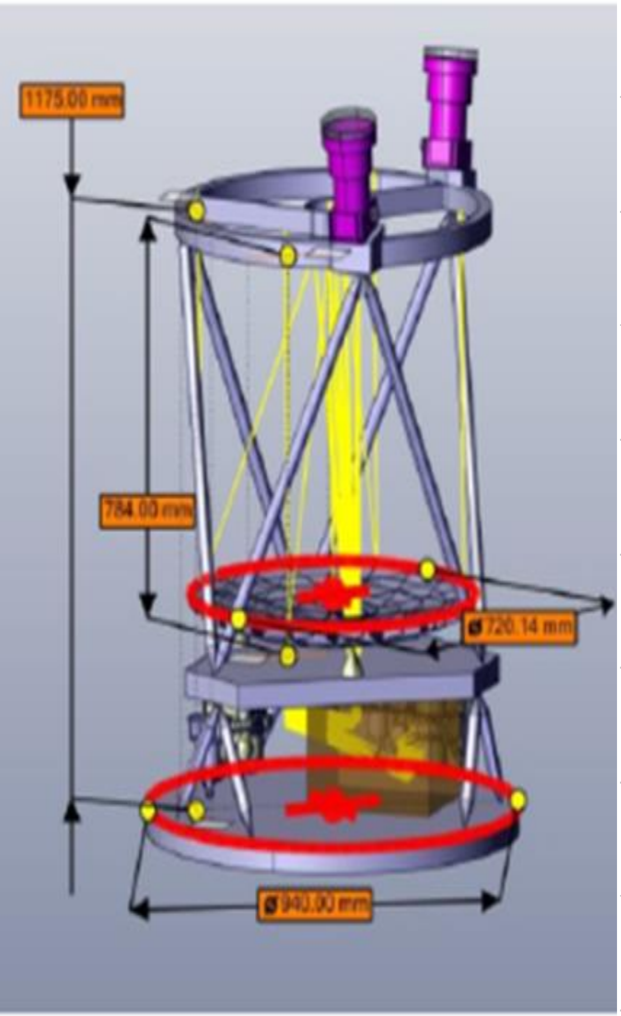
The InfraRed Telescope (IRT)





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		

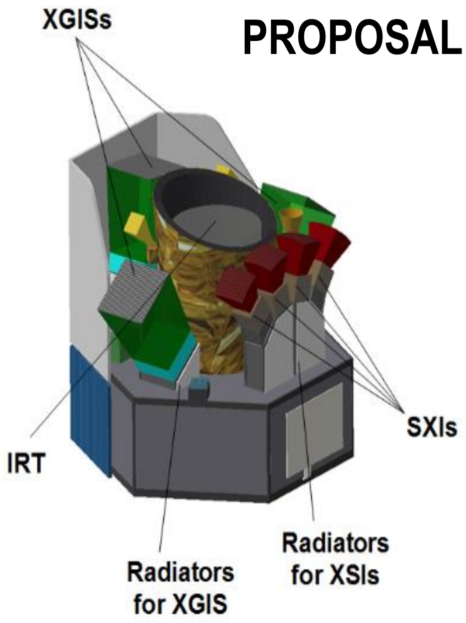
The InfraRed Telescope (IRT)



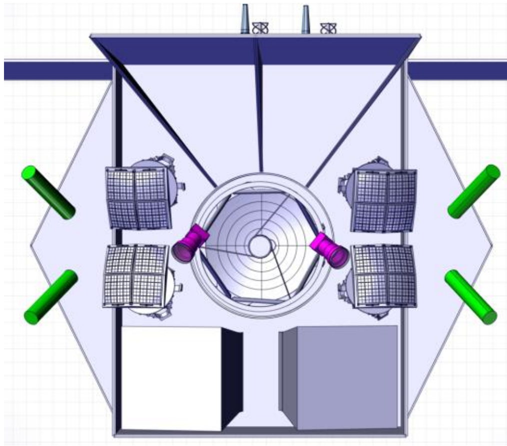
Telescope type:	Off-axis Korsch		
Primary & Secondary size:	700 mm & 230 mm		
Material:	SiC (for both optics and optical tube assembly) or Zerodur+CFRP, or other combination of materials satisfying requirements.		
Detector type:	European ALFA 2048x2048 pixels detector (15 µm pixels) or Teledyne Hawaii-2RG 2048 x 2048 pixels (18 µm each)		
Imaging plate scale	0".45-0.7"/pixel (depending on the S/C jitter/drift)		
Field of view:	15' x 15'	15' x 15'	5' x 5' (2' x 2' goal)
Resolution (λ/Δλ):	2-3 (imaging)	20 (low-res)	500 (high-res)
Sensitivity (AB mag):	H = 20.6 (300s)	H = 18.5 (300s)	H = 17.5 (1800 s)
Filters:	ZYJH	Prism	VPH grating
Wavelength range (µm):	0.7-1.8 (imaging)	0.8-1.6 (low-res)	0.8-1.6 (high-res, TBC)

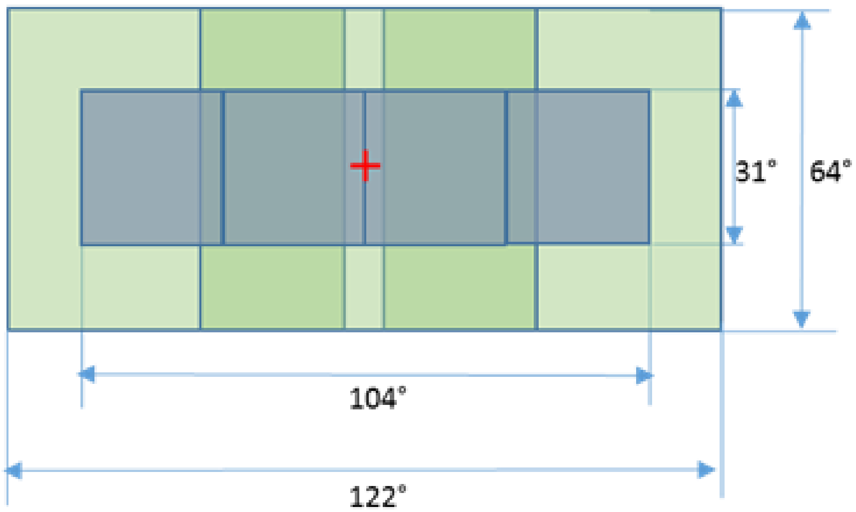
THESEUS mission concept: ESA study

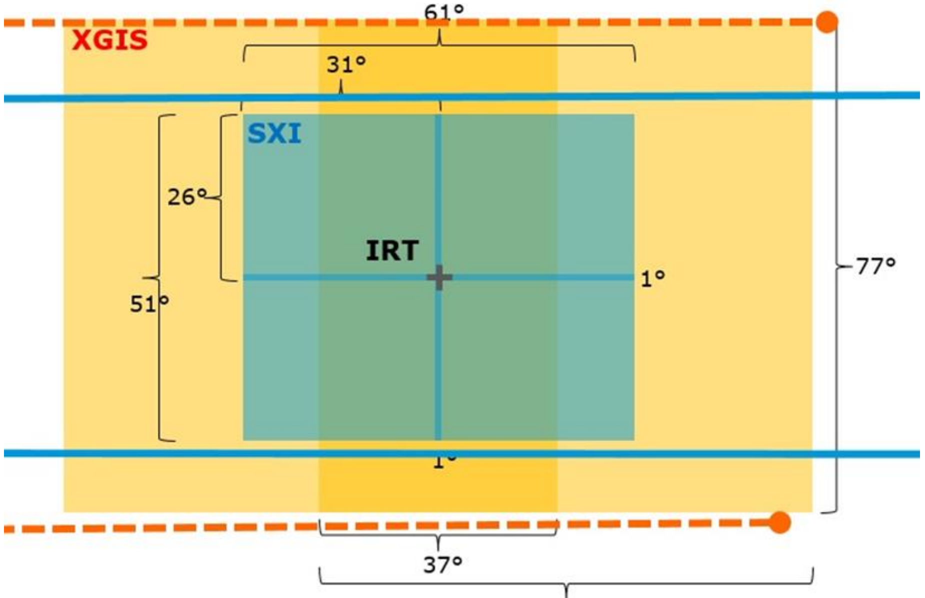
PROPOSAL



CDF STUDY

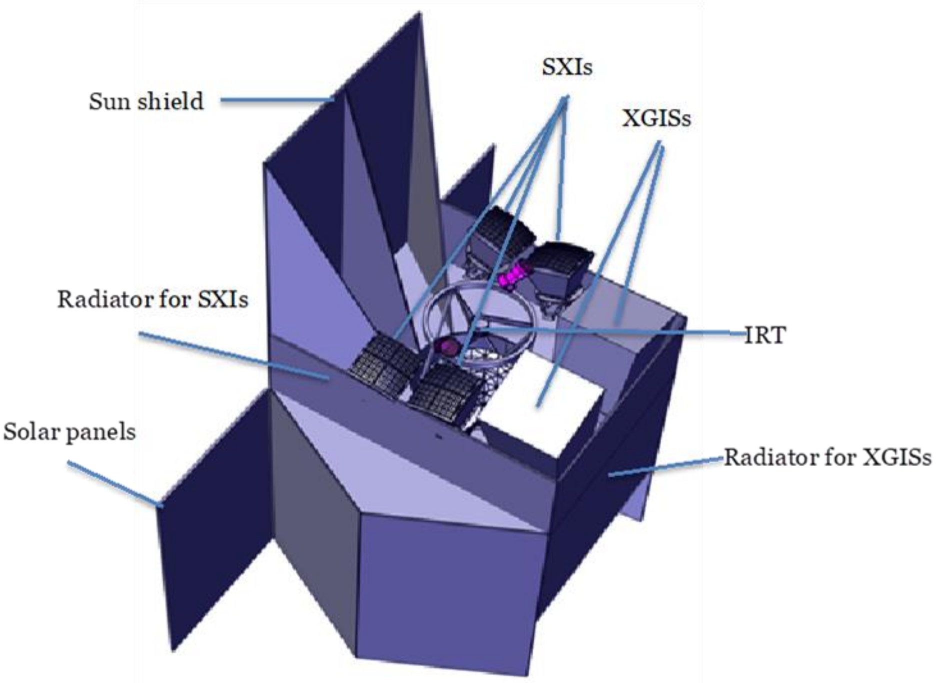


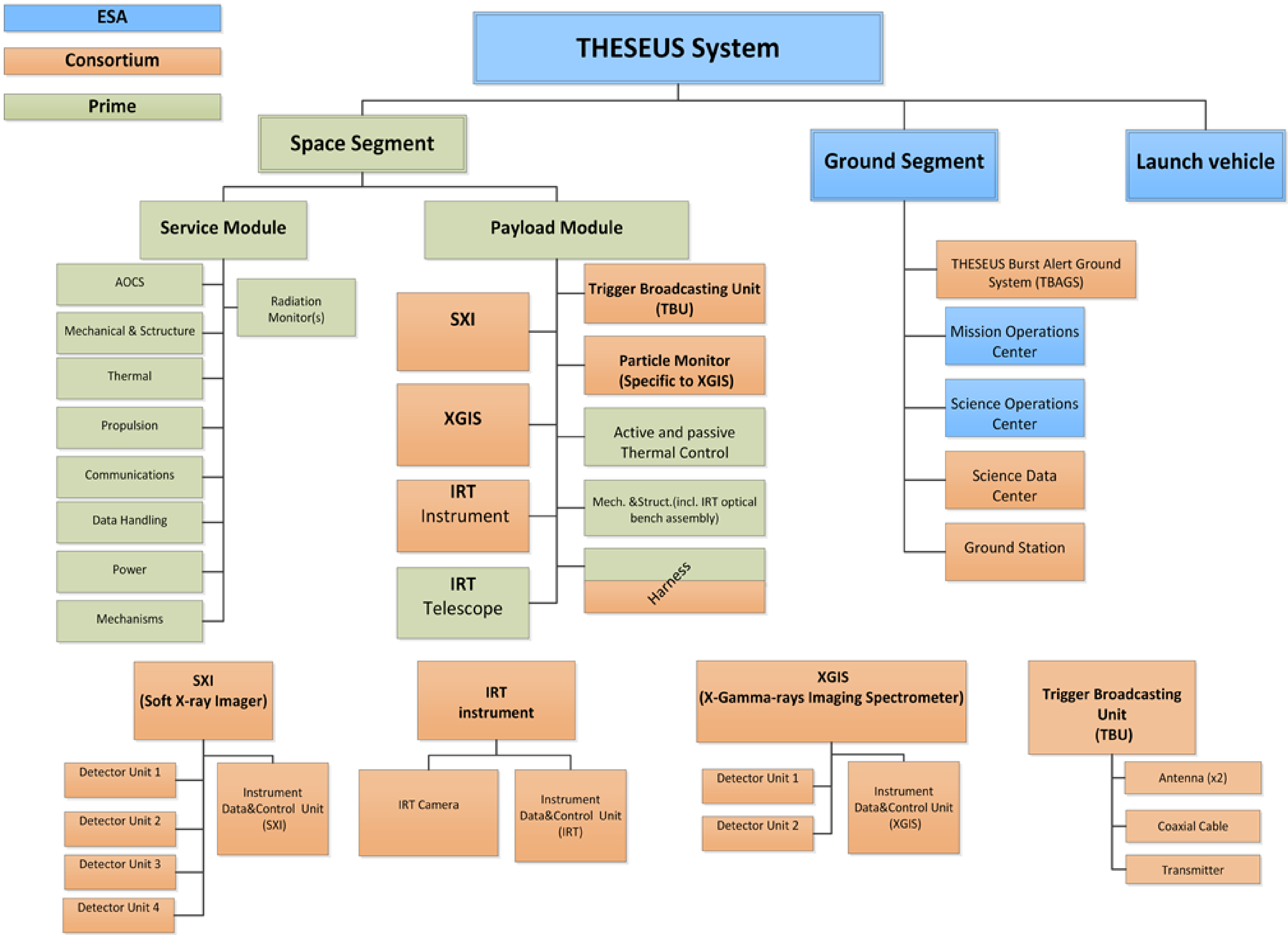




Mission profile and budgets

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





ESA
Consortium
Prime
THESEUS System
Space Segment
Ground Segment
Launch vehicle
Service Module
Payload Module
AOCS
Radiation Monitor(s)
Mechanical & Sctructure
Thermal
Propulsion
Communications
Data Handling
Power
Mechanisms
SXI
XGIS
IRT Instrument
IRT Telescope
Trigger Broadcasting Unit (TBU)
Particle Monitor (Specific to XGIS)
Active and passive Thermal Control
Mech. &Struct.(incl. IRT optical bench assembly)
Harness
THESEUS Burst Alert Ground System (TBAGS)
Mission Operations Center
Science Operations Center
Science Data Center
Ground Station
SXI (Soft X-ray Imager)
Detector Unit 1
Detector Unit 2
Detector Unit 3
Detector Unit 4
Instrument Data&Control Unit (SXI)
IRT instrument
IRT Camera
Instrument Data&Control Unit (IRT)
XGIS (X-Gamma-rays Imaging Spectrometer)
Detector Unit 1
Detector Unit 2
Instrument Data&Control Unit (XGIS)
Trigger Broadcasting Unit (TBU)
Antenna (x2)
Coaxial Cable
Transmitter

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

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

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

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

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

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

Denmark: specific responsibility of XGIS DHU hardware and software.

Poland : XGIS power-supply units.

Belgium: contribution to SXI integration and tests.

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

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

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

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

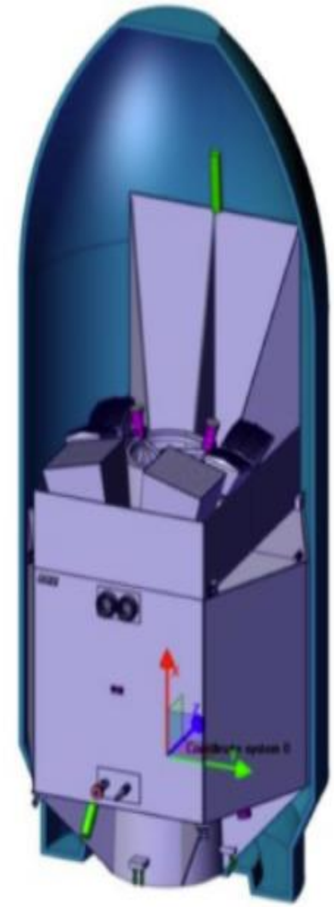
THESEUS ESA study: timeline, organization and status

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

- ❑ **Smooth CDF study, successful MDR -> Phase A**
- ❑ Efficient and positive interaction between ESA and consortium

THESEUS Phase A Industrial studies (milestones)

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



THESEUS Phase A Industrial studies (milestones)

- ITT release to Industry: March 2019
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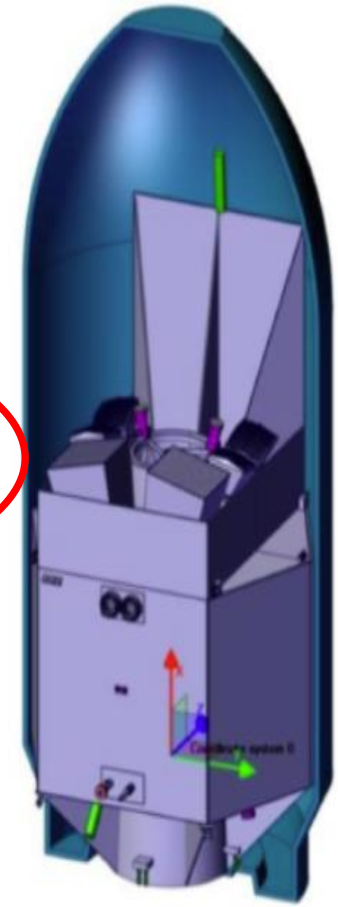
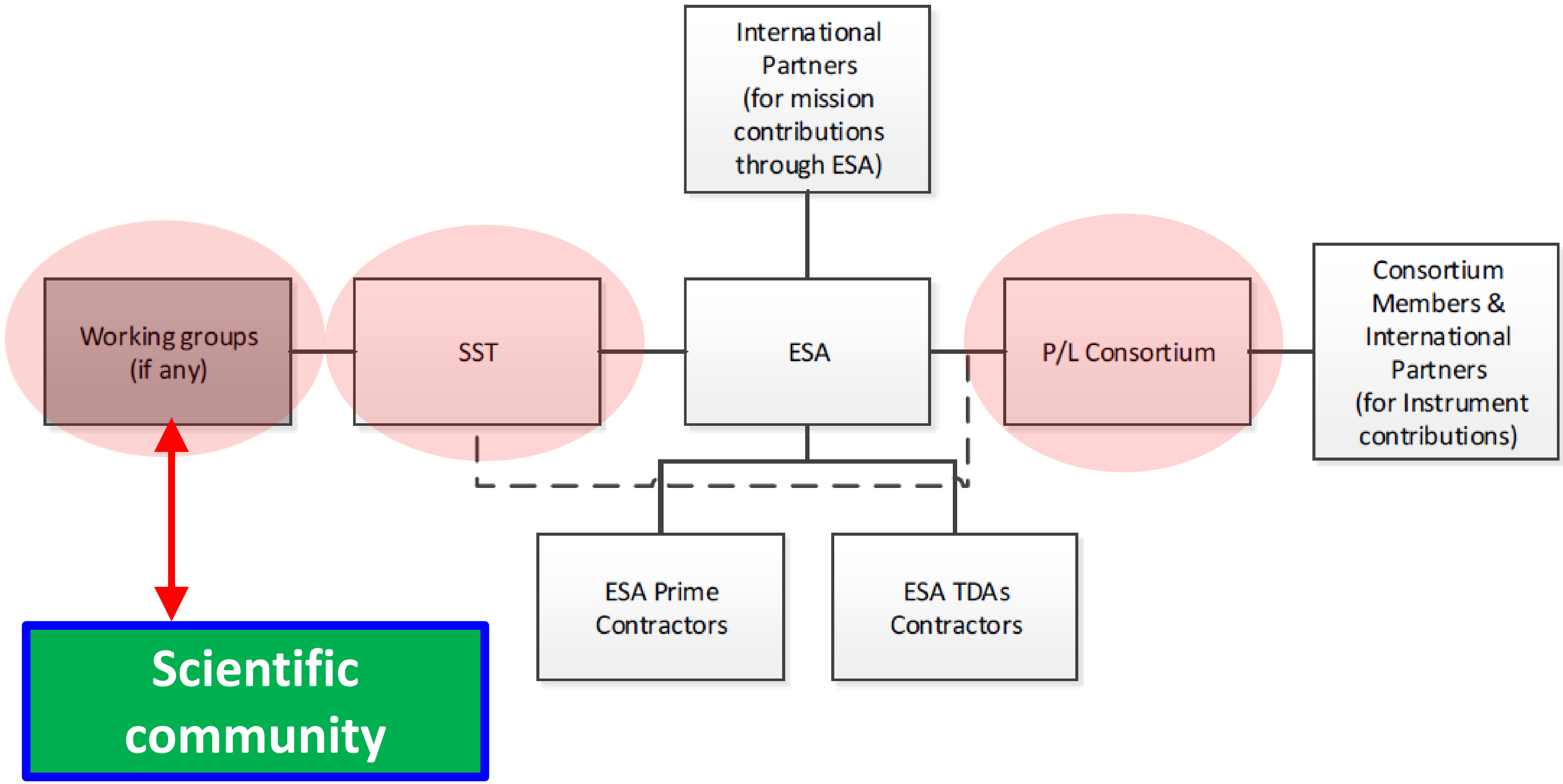


THESEUS Phase A Industrial studies (milestones)

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

Phase A study organization



THESEUS ESA Teams

L. Colangeli, P. McNamara (Science Coordination Office), P. Falkner (Mission Studies Office)

ESA study team

Name and Surname	Role	Institute	Country
Philippe Gondoin	(former) Study manager	ESA/ESTEC	Netherlands
Gonzalo Saavedra	Study manager	ESA/ESTEC	Netherlands
Jonan Larranaga	System engineer	ESA/ESTEC	Netherlands
Thibaut Prod'homme	Payload manager	ESA/ESTEC	Netherlands
Tim Oosterbroek	Payload system engineer	ESA/ESAC	Spain
Matteo Guainazzi	Study scientist	ESA/ESTEC	Netherlands
Isabel Escudero Sanz	Optics expert	ESA/ESTEC	Netherlands
Guillaume Belanger	Operations expert	ESA/ESAC	Spain

THESEUS Science Study Team

Author	Country	Institute
Amati Lorenzo (Lead scientist)	Italy	INAF - OAS Bologna
Basa Stephane	France	LAM
Caballero-Garcia Maria Dolores	Spain	IAA-CSIC
Christensen Lise	Denmark	University of Copenhagen
Götz Diego	France	CEA - Saclay / Irfu / SAp
Hanlon Lorraine	Ireland	UCD
O'Brien Paul	United Kingdom	University of Leicester
Paltani Stephane	Switzerland	University of Geneva
Santangelo Andrea	Germany	IAAT, University of Tuebingen
Stratta Giulia	Italy	INAF - OAS Bologna
Tanvir Nial	United Kingdom	University of Leicester

THESEUS Consortium

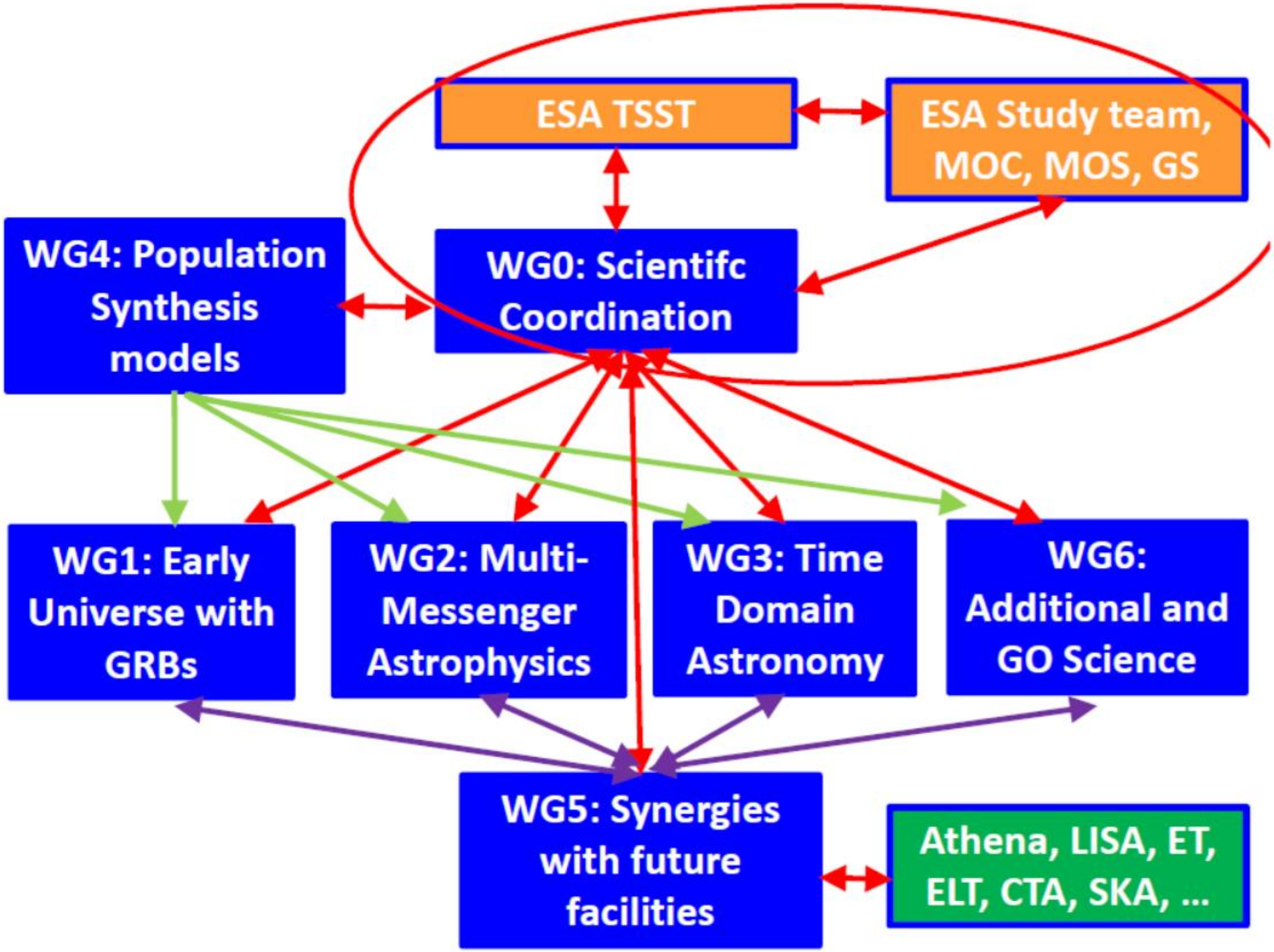
Coordination team

Name and Surname	Country	Institute
Lorenzo Amati (Mission PI, lead Scientist)	Italy	INAF-OAS Bologna
Paul O'Brien	United Kingdom	Leicester University
Diego Goetz	France	CEA/Saclay
Andrea Santangelo	Germany	IAAT
Enrico Bozzo (Project configuration control)	Switzerland	University of Geneva

Payload and science data center

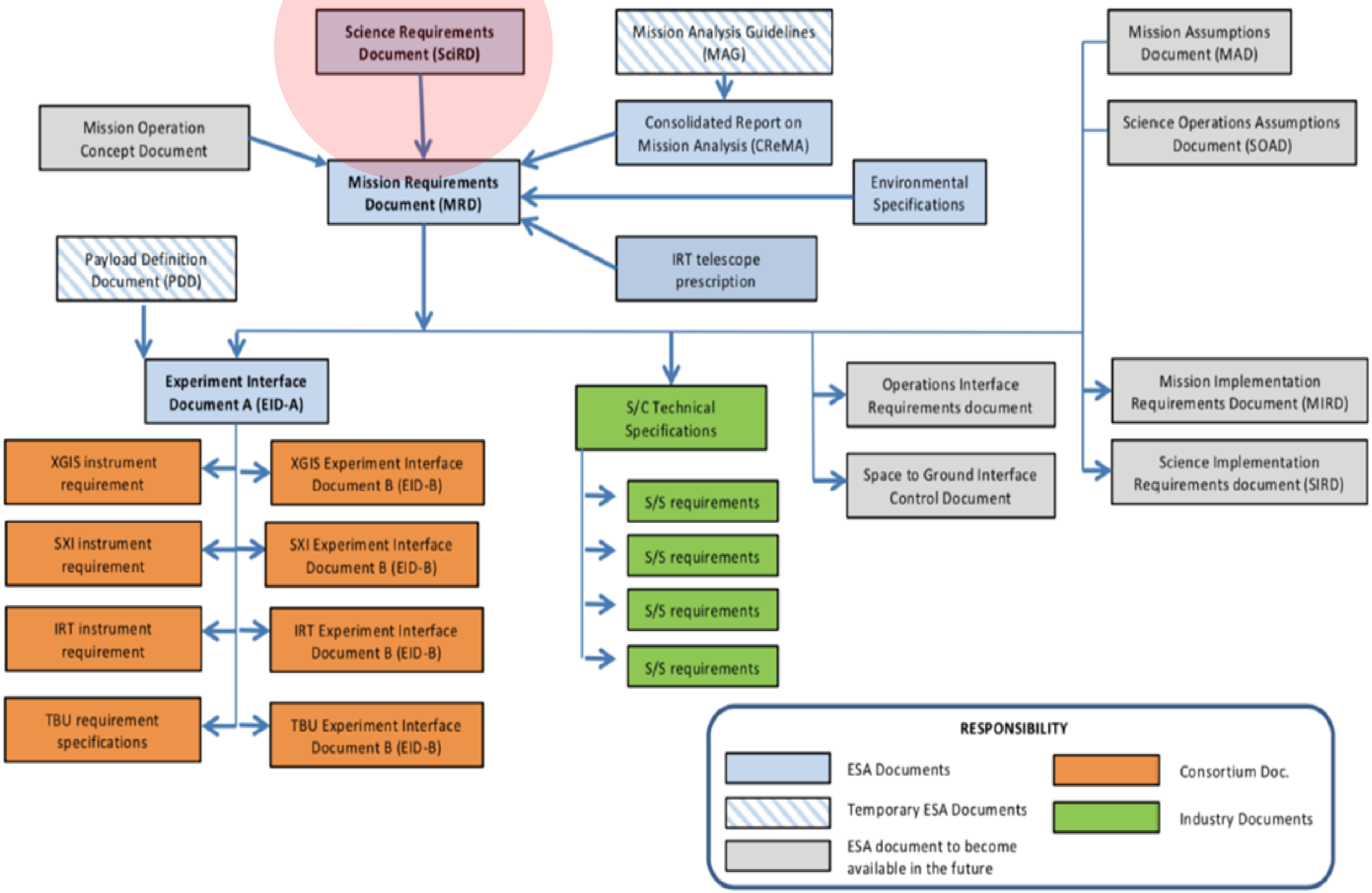
Element	Name and Surname	Institute	Country
SXI	Paul O'Brien and Ian Hutchinson	University of Leicester	United Kingdom
XGIS	Lorenzo Amati and Claudio Labanti	INAF-OAS Bologna	Italy
IRT	Diego Goetz and Stephane Basa	CEA, Saclay	France
I-DHU	Andrea Santangelo and Chris Tenzer	IAAT, Tuebingen	Germany
TBU	Guido Parissenti & Romeo Casesa	INAF & GP Advanced Project	Italy
SDC	Stephane Paltani and Enrico Bozzo	University of Geneva	Switzerland

THESEUS Consortium scientific WGs



Scientific Requirements Document (SciRD)

THESEUS Document Requirement Tree



Theseus Requirements Levels

Level	Topic	Location
0	Science Objectives	SciRD
1	Science Requirements	SciRD
2	Mission Implementation	SciRD/MRD
3	S/C – Payload – GS	MRD/EIDA

- **The Mission Observation Simulator** (MOS) verifies level 2 compliance with level 1.
- **The System Performance Budget** justifies the flow-down of requirements from level 2 to level 3.
- **The Instrument Performance Budgets** justify the in-orbit end of life instrument performance requirement flow-down below level 2.

Level 0

THS-SCI-R-010	**Exploring the early Universe with GRB**			
Definition	THESEUS shall achieve a complete census and characterization of GRB in the first billion years of the Universe.			
Synopsis	*Value*	*Units*	*Condition*	*Parent Requirements*
	N/A	N/A	N/A	See [RD5]

Comment: a "complete census" is a sample that is representative of the parent population on a given redshift range within a certain confidence level. In the context of this document "characterization" implies the capability by THESEUS mission to measure images (IR), spectra and light curves (IR, X-ray, and γ-rays) of a target source.

THS-SCI-R-020	**Multi-messenger astrophysics via time-domain X-rays exploration**			
Definition	THESEUS shall identify (i.e. detect and localize) and study the electromagnetic counterparts of GW and cosmic neutrino astrophysical sources through an unprecedented exploration of the time-domain Universe in X-rays and soft γ-rays.			
Synopsis	*Value*	*Units*	*Condition*	*Parent Requirements*
	N/A	N/A	N/A	See [RD5]

Level 1

THS-SCI-R-101	**Number of long GRB (very high-redshift)** N.B.: the goal is 100			
Definition	THESEUS shall provide detection, accurate location, and redshift measurement for at least 50 GRBs at $z \geq 6$ (corresponding to approximately the first billion years of the Universe in the standard ΛCDM cosmology) over the in-orbit nominal mission lifetime at the 99% confidence level.			
Synopsis	*Value*	*Units*	*Condition or Instrument*	*Parent Requirements*
	≥50	-		THS-SCI-R-010

THS-SCI-R-103	**Number of short GRB**			
Definition	THESEUS shall provide detection and localization of at least 30 short GRB over the in-orbit nominal mission lifetime			
Synopsis	*Value*	*Units*	*Condition or Instrument*	*Parent Requirements*
	≥30			THS-SCI-R-020

THESEUS science requirements: L0

THS-SCI-R-010	**Exploring the early Universe with GRB**			
Definition	THESEUS shall achieve a complete census and characterization of GRB in the first billion years of the Universe.			
Synopsis	*Value*	*Units*	*Condition*	*Parent Requirements*
	N/A	N/A	N/A	See [RD5]

Comment: a "complete census" is a sample that is representative of the parent population on a given redshift range within a certain confidence level. In the context of this document "characterization" implies the capability by THESEUS mission to measure images (IR), spectra and light curves (IR, X-ray, and γ-rays) of a target source.

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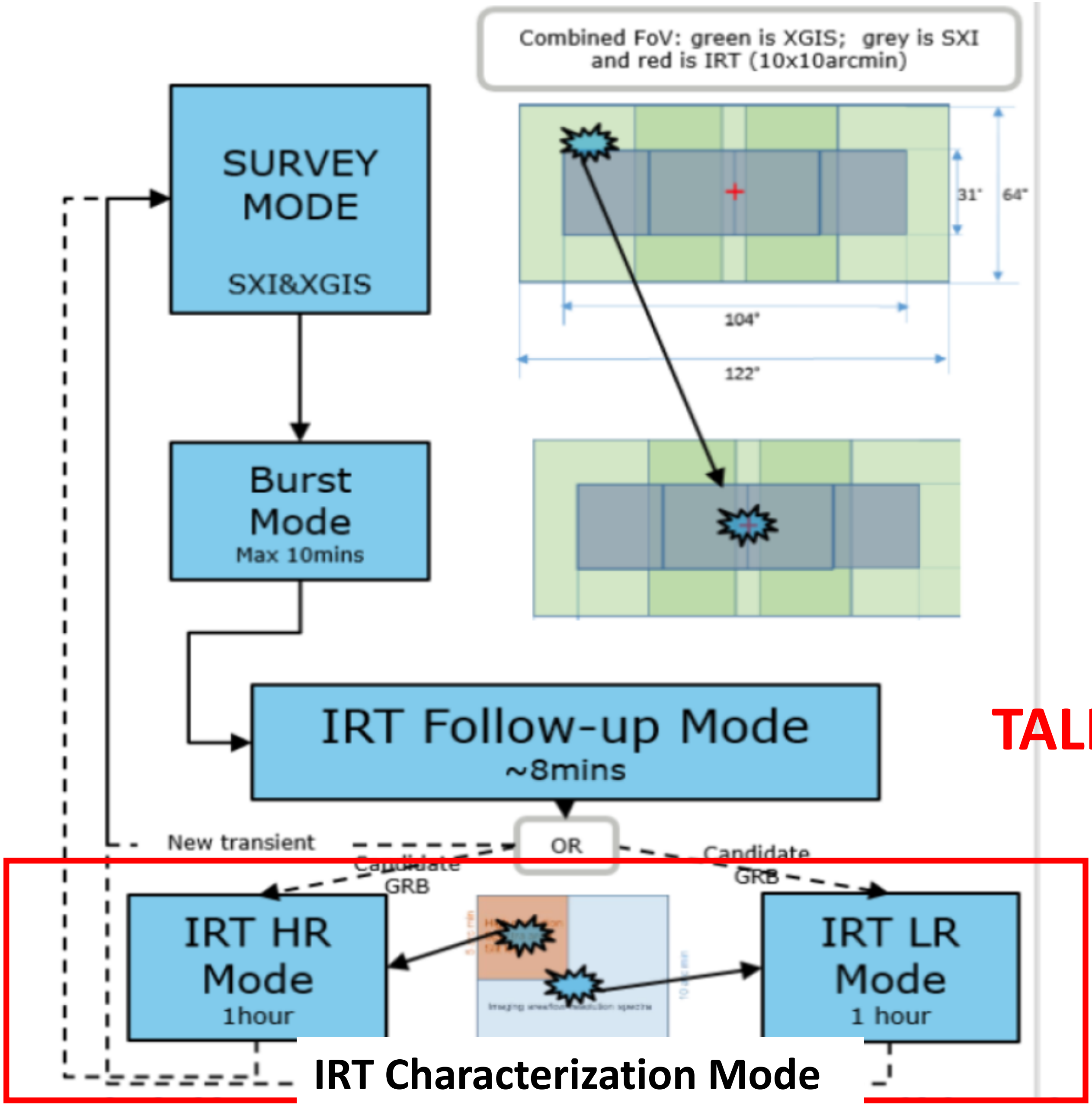
Synopsis	*Value*	*Units*	*Condition*	*Parent Requirements*
	N/A	N/A	N/A	See [RD5]

NEW:

THS-SCI-R-030	**Observatory science**				
Definition	THESEUS shall have the capability to offer opportunities for observatory science, while THS-SCI-R-010 and THS-SCI-R-020 are pursued, and provided that THS-SCI-R-010 and THS-SCI-R-020 are fulfilled according to the conditions laid out in these requirements.				
Synopsis	*Value*	*Units*	*Condition*	*Owner*	*Parent Requirements*
	N/A	N/A	THS-SCI-R-101, and -103 fulfilled	ESA	See [RD5]

Commens: former THS-SCI-R-290

Mission Operation Concept (MOC)



TALK by Bozzo

Mission Operation Concept (MOC)

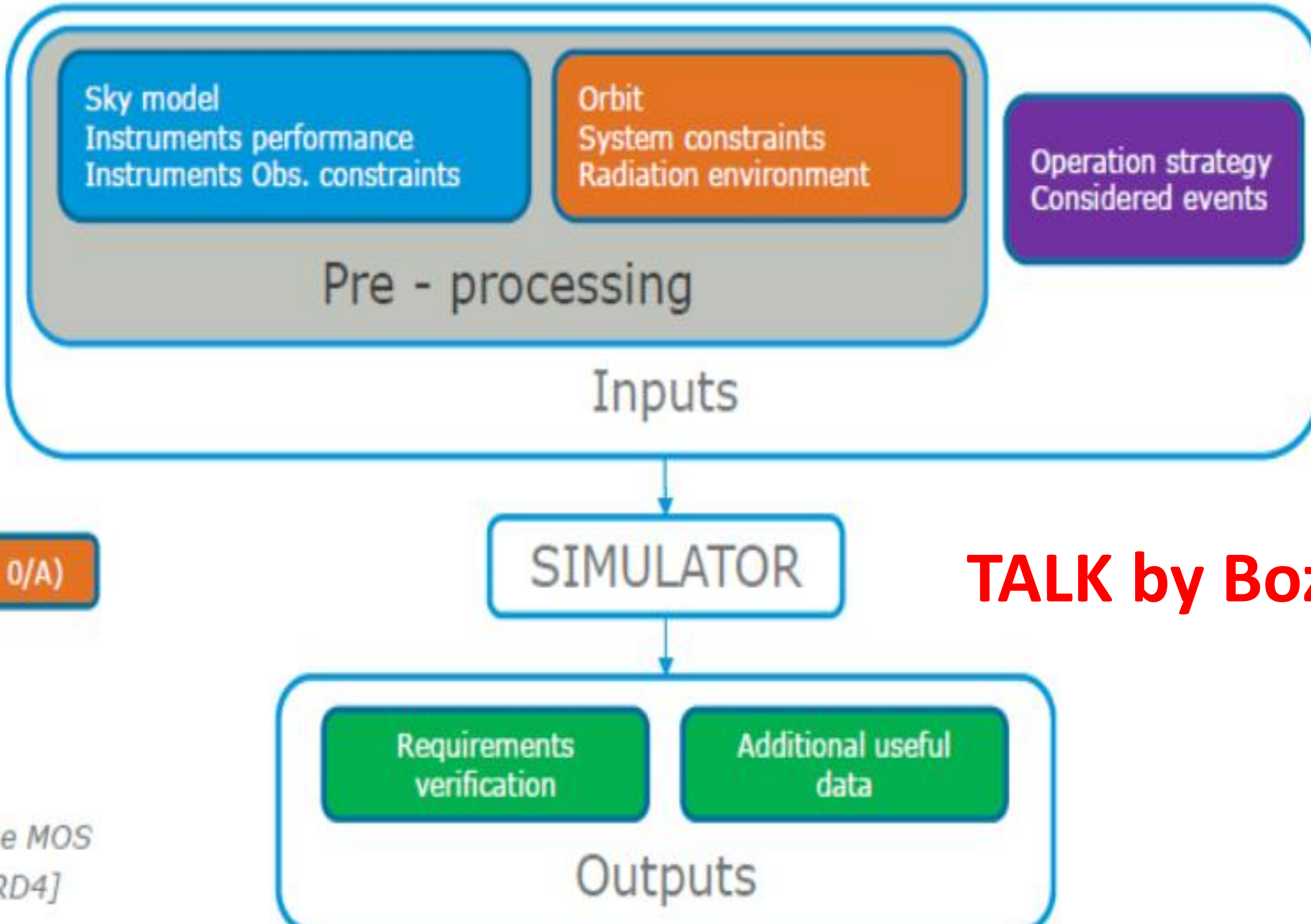
External trigger (TOO)

- 3 per month dedicated to core science are granted (SciRD); more / additional science -> GO programme;
- reaction times: 12 hr (goal 4hr) during working days (due to mission operation control, despite high level of spacecraft agility and autonomy)

- **Guest Observer**
- small deviations (< few deg) from nominal pointing strategy during survey mode to observe sources of interest selected through a GO programme is in mission baseline;
- GO observations (including TOOs) requiring larger deviations / resources are an option subject to achievement of core science objectives.

Mission Observation Simulator (MOS)

Overview of THESEUS MOS (1/8): Intended Scheme



Colours legend

- THESEUS SST / Payload Consortium
- ESA / Industrial Prime (Phase 0/A)
- ESOC
- Results

TALK by Bozzo

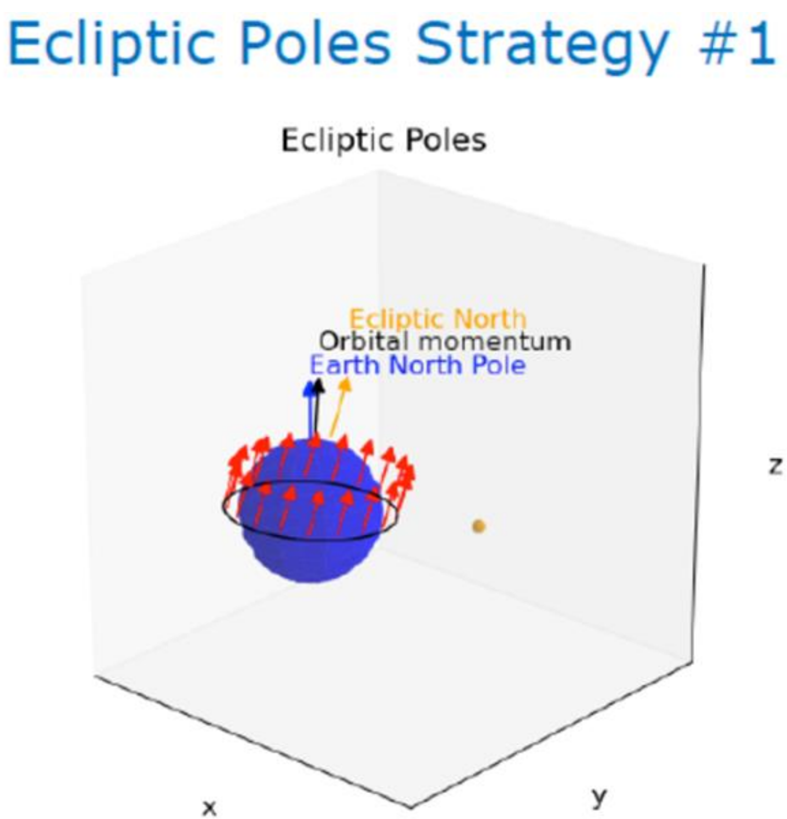
See more details on the MOS implementation in [RD4]

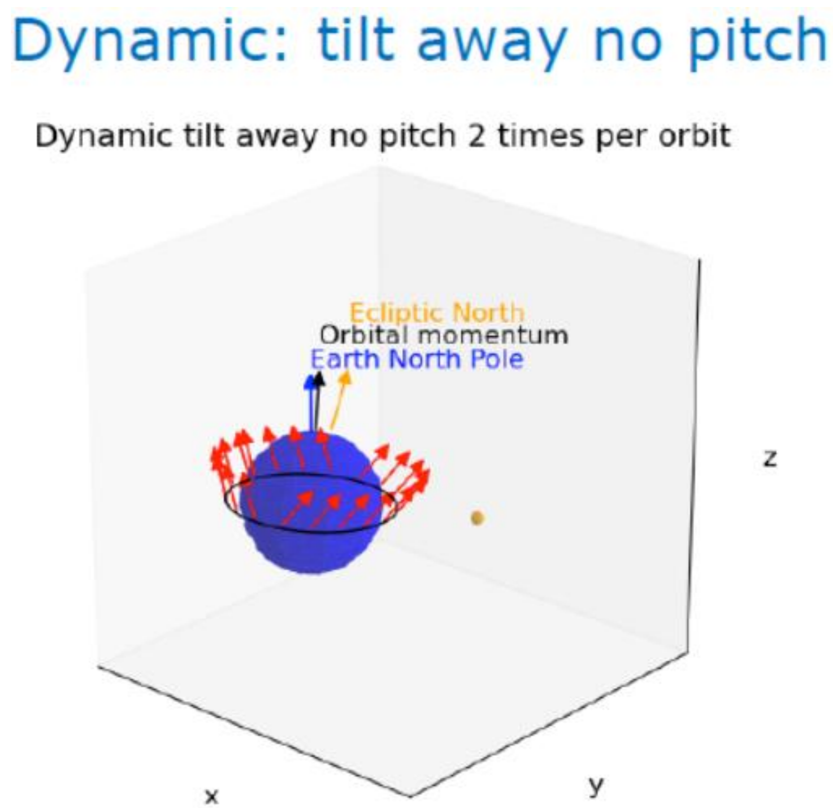
Most updated rates from MOS

Main results	Average per science year	
	Absolute	Variation w.r.t. EP [%]
Detected target sources (false triggers excluded)	523.6	6.7%
detected only by SXI	218.0	2.2%
detected only by XGIS	124.6	16.3%
detected by both SXI and XGIS	181.0	6.4%
IRT follow-up mode executed (7 min continuous exposure out of 20/100 min, false triggers excluded)	438.9	6.2%
Detected by IRT (flux above 0.02 mJy)	282.6	4.8%
Further IRT characterisation performed (1 hour exposure)	282.4	4.8%
flux between 0.02 and 0.14 mJy	115.8	5.6%
flux between 0.14 and 0.36 mJy (LR mode)	49.0	4.9%
flux above 0.36 mJy (HR mode)	117.6	4.0%
Achieved required GRBs z>6	19.4	2.1%
Achieved required GRBs z>8	8.9	8.5%
Achieved short GRBs	11.7	10.4%

Pointing strategies trade-offs

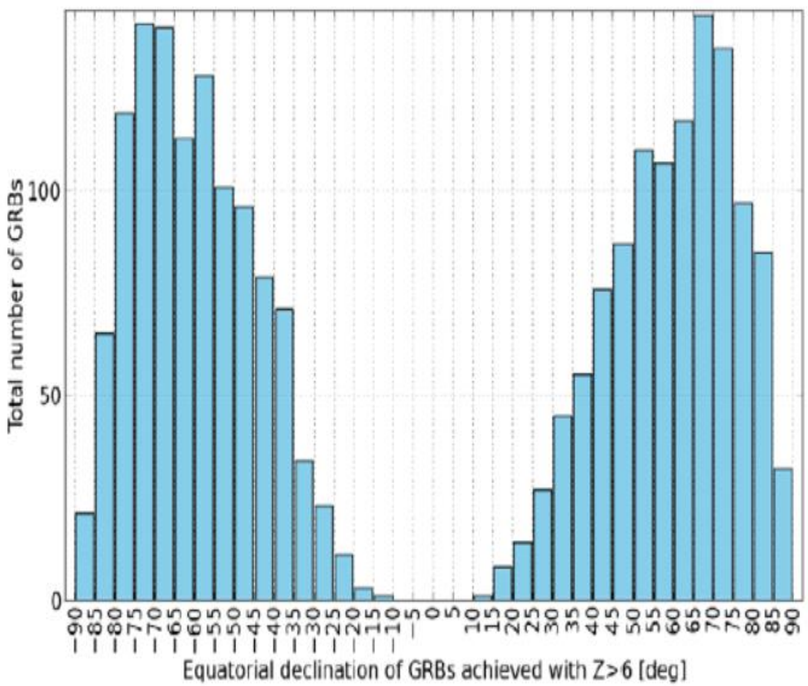
- Minimize Earth in FOV of SXI (and XGIS imaging FOV)
- Optimize for follow-up from on-ground large telescopes (e.g., ELT, TMT) -> lower latitudes
- Optimize sky exposure of the monitors e.g.,





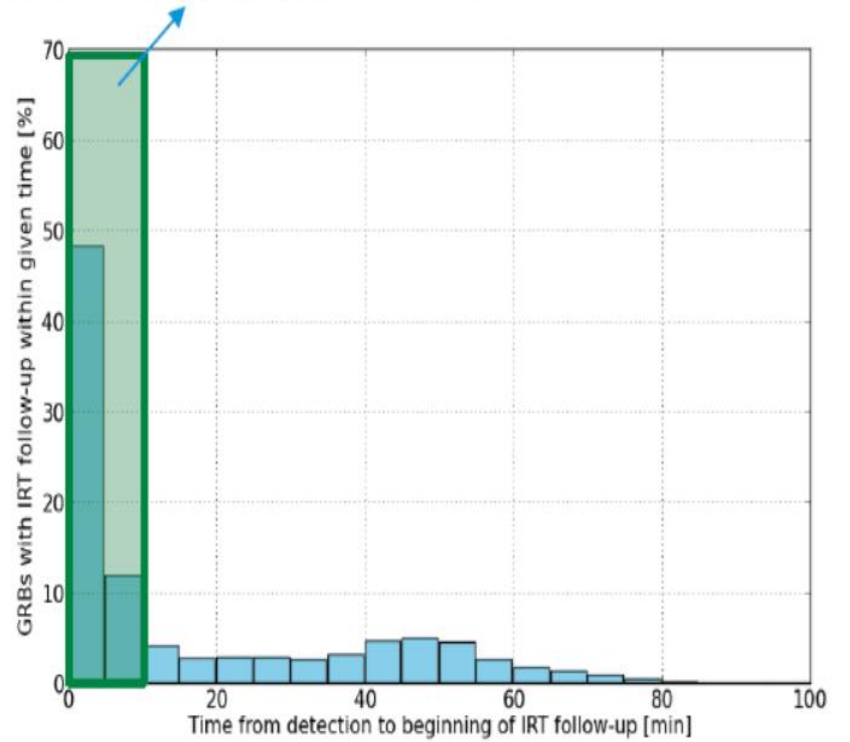
Baseline Ecliptic Poles (2/2)

Declination range (absolute)	Fraction of achieved GRBs z>6
0-30	3.9 %
30-55	33.0 %
55-75	44.8 %
75-90	18.3 %



THS-SCI-R-260-Alert response time:

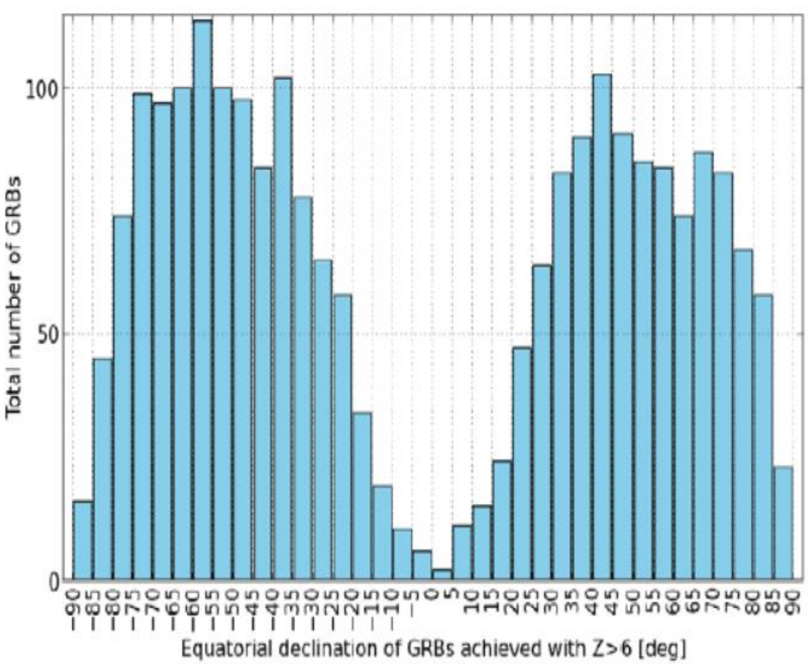
The THESEUS spacecraft shall be able to start optical/IR follow-up observations within 10 minutes after Burst/Transient detection.
(See note below also applicable for all strategies)

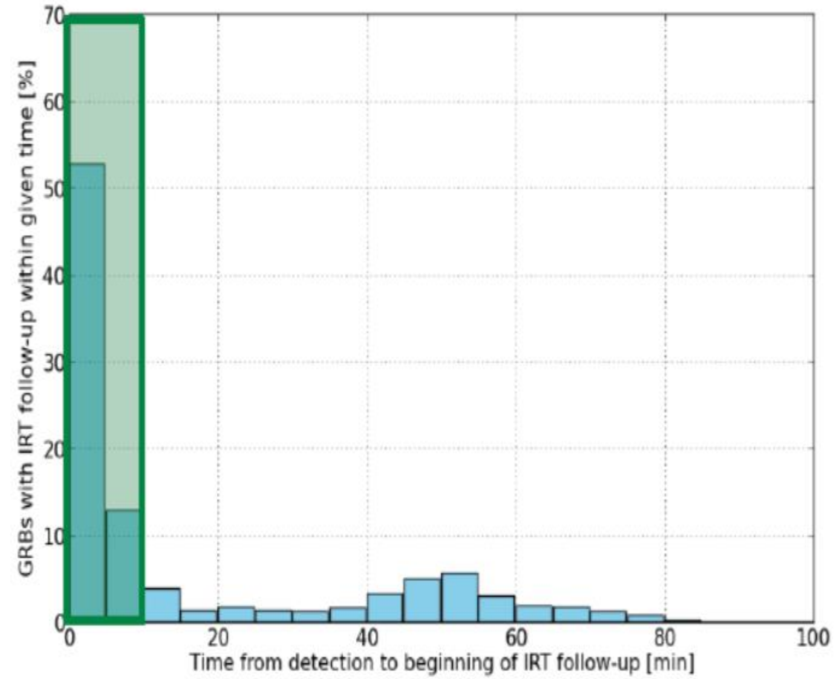


Note: Above results are not driven only by the SC agility model that provides a SC response time "average slew time" of 210sec but also due to the follow-up definition a.k.a condition of finding a window of 7mins continuous exposure time. Even with a goal requirement in the SciRD/MRD of SC agility of 3 mins the compliance to this requirement for 100% of triggers is not believed to be feasible.

Menu Option 2: Dyn. 2 slews per orbit, 30 deg tilt (2/2)

Declination range (absolute)	Fraction of achieved GRBs z>6
0-30	15.5%
30-55	39.9%
55-75	32.2%
75-90	12.4%





Strategy Name	Strategy ID	Strategy	SXI instrument	South Atlantic anomaly	Earth Occultation while out of SAA		Trade-off parameters			
		Available time substracting slew time	Average active quadrants	Time out of SAA	SXI FoV active (free from Earth occultation and including quadrant condition)	SXI FoV free from Earth occultations	Efficiency Factor		Estimated triggers/day increase w.r.t. #1	
							With quadrant condition	Without quadrant condition	SXI	XGIS (approx.)
Ideal theoretical reference case	refA	100.0%	4.0	100.0%	100.0%	100.0%	100.0%	100.0%	79.3%	38.7%
Ideal accounting for SAA passages	refB	100.0%	4.0	83.9%	100.0%	100.0%	83.9%	83.9%	50.4%	16.3%
Ecliptic Poles Pointing (EP)	#1	100.0%	2.4	83.9%	66.5%	86.0%	55.8%	72.1%	0.0%	0.0%
Celestial Poles Pointing	#2	100.0%	2.2	83.9%	62.4%	92.2%	52.3%	77.3%	-6.2%	7.3%
Celestial Pointing with 25% reduced FoV to reduce Earth occultation	#2b	100.0%	2.7	83.9%	72.0%	95.7%	43.2%	57.4%	-22.6%	-20.4%
Orbital Momentum Pointing	#3	100.0%	2.2	83.9%	61.6%	92.6%	51.7%	77.6%	-7.4%	7.7%
Dynamic pointing: 360 deg rotation around Sun direction	#4	70.0%	3.7	83.9%	94.4%	99.5%	55.4%	58.4%	-0.7%	-18.9%
Dynamic pointing: tilt away from Earth but no pitch 2 times per orbit	#5b	89.8%	3.4	83.9%	86.5%	96.2%	65.2%	72.5%	16.9%	0.5%
Dynamic pointing: tilt away from Earth with 10 deg margin but no pitch 2 times per orbit	#5c	86.0%	3.5	83.9%	90.4%	97.4%	65.2%	70.3%	17.0%	-2.6%
Dynamic pointing: tilt away from Earth with 20 deg margin but no pitch 2 times per orbit	#5d	86.1%	3.7	83.9%	92.7%	98.2%	66.9%	71.0%	20.0%	-1.6%
Celestial Poles Projection Pointing	#6	100.0%	2.3	83.9%	64.9%	89.0%	54.4%	74.7%	-2.4%	3.6%

- **Remark: different pointing strategies will be feasible with Theseus,** some of them not impacting significantly the main goals but optimizing different aspects of the scientific return

- **Pointing strategy may be changed during the mission** based on the scientific return, evolution of the scientific scenario, emergency of new science cases, etc.

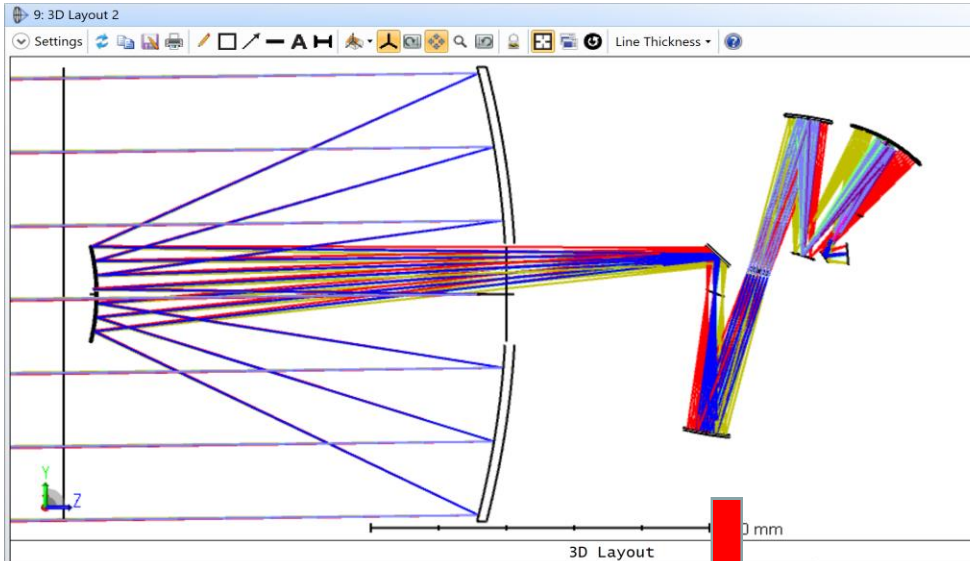
- **The sWGs** should provide first of all feedback, supported by as quantitative as possible simulations, **on the best pointing strategy for core science goals as well specific topics**

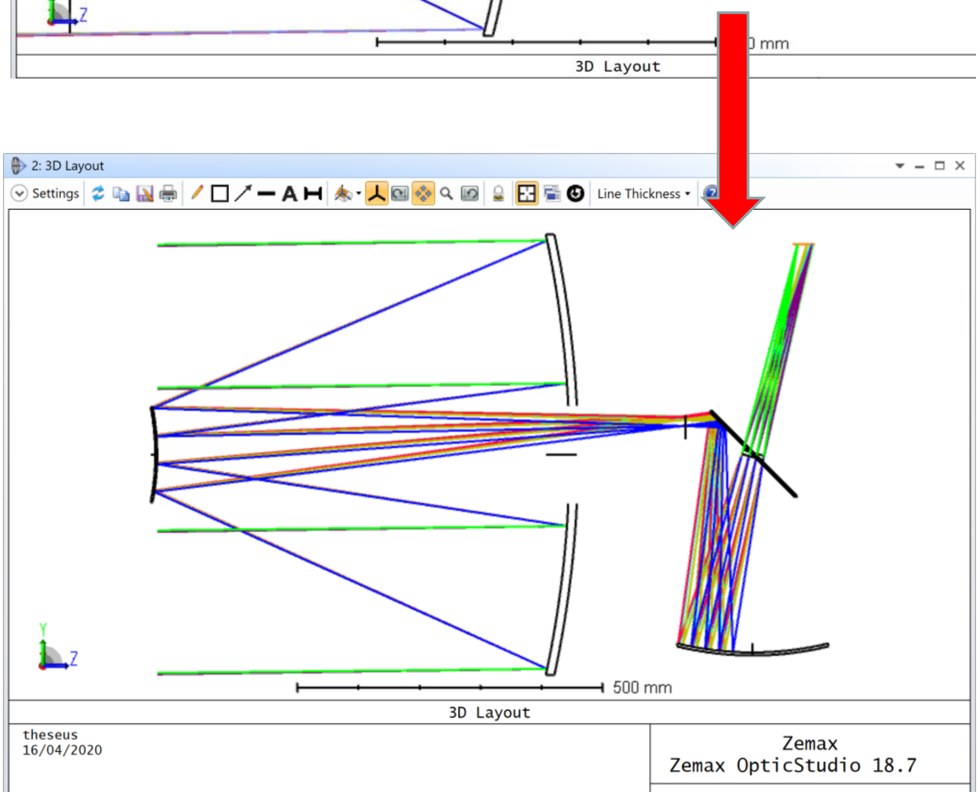
- **The sWGs** should also provide **justification and support for the minimum and possibly extended number of external triggers / TOOs.**

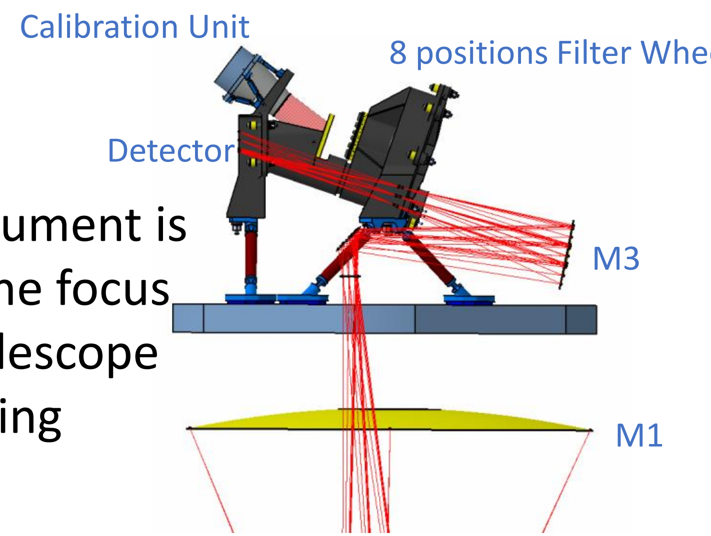
Main recent instrument updates: IRT (D.Gotz)

- A new optical design for the IRT telescope has been proposed by ESA and has been studied by the IRT Consortium during MCR
- The new design simplifies the optical interface with industry, the IRT instrument accommodation, and the IRT design. Also improves the global efficiency (less reflecting surfaces), slight performance increase expected.
- With the new design the low resolution spectral mode is hard to implement: this issue and the sensitivity considerations (see next slide) induced the suppression of the LR mode and just the photometric and HR mode are being considered
- The Resolution of the HR mode is being traded against the sensitivity. The current resolution trade-off interval is 300-500
- The detector trade-off has been concluded and the Teledyne H2RG is now the new baseline (allows more margins wrt. scientific requirements)

New Instrument Design







The instrument is now at the focus of the telescope (converging beam).

4 mirrors removed.

The Instrument requires a telescope simulator to be tested.

Updated IRT follow-up sequence

Old Sequence

- 3 X 10 s images (JHK) -> field astrometry and early spectral selection (19 mag requirement)
- 300 s LR mode (30 x 10 s) frames : (18.6 H mag requirement)
- 60 s (6x10s) -> sources variability
  - Total duration 390s~6.5 min The sequence was imagined during the proposal phase and based one early sensitivity estimations
- Now we have advanced in the telescope an instrument design and performance and we have started to (partially) re-think our follow-up strategy

The old follow-up sequence was a combination of imaging and LR spectroscopy, but the imaging depth was not enough to guarantee sufficient success in afterglow identification and redshift determination. Hence a new was proposed:

- We now better assessed the IRT sensitivity (including jitter, drift, detailed optical design, etc.) and we feel that the old sequence is not efficient. In addition we want to be conservative and have margins at this stage

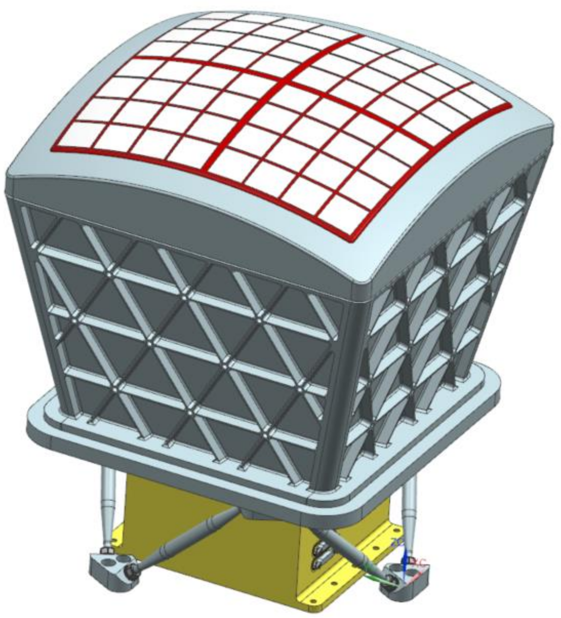
- We want to be sure to able to estimate photometric redshifts early for all GRBs at z >6.

- **In order to obtain that, 5 filter images (I,Z,Y,J,H) equally long exposures are implemented: 5 x 150 s (25 s frames) exposures in 5 filters (~0.02 mJy sensitivity) in order to obtain photometric redshifts.** As before the early sequence will be followed (as a function of the flux) by 1800 s in HR mode (60 s frames) for GRB characterization.

- Early simulations have assessed the efficiency of such strategy for redshift determination, but further (more sophisticated) simulations) will investigate possible degeneracies between high-redshift and dust-obscured GRBs

Main recent instrument updates: SXI (P. O'Brien)

- Instrument concept updates
- New Point Spread Function analysis
- Effective area improvement
- On-going development work

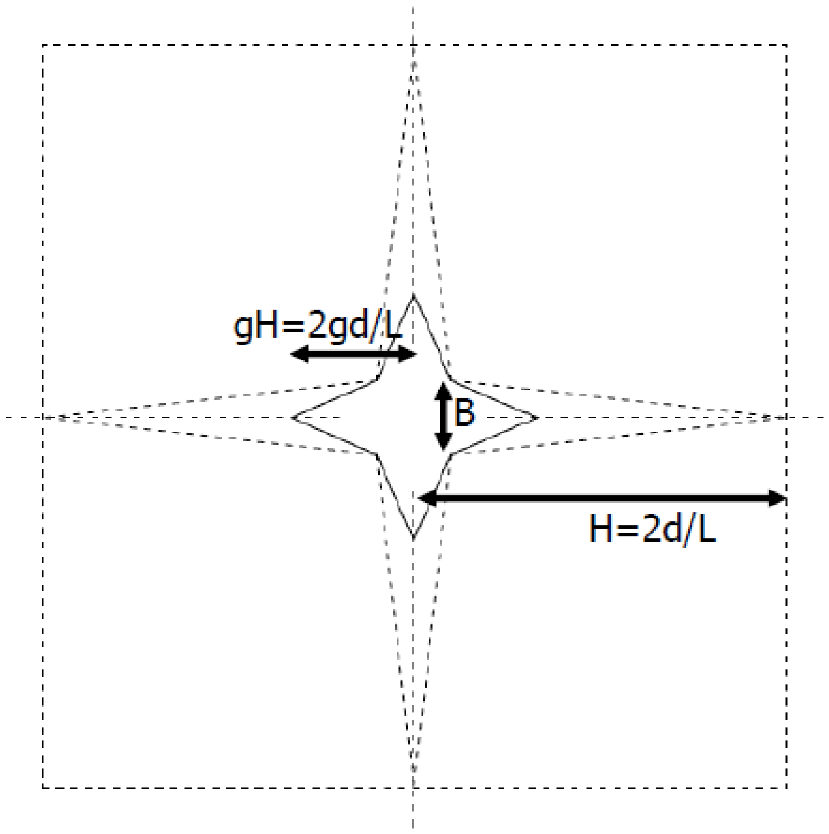


SXI module

Instrument concept updates

- Thermal design (spacecraft interface; detector baseplate analysis; effect of Earth pointing)
- Mechanical design (CAD model: updated instrument shape)
- Detector performance (X-ray characterisation and radiation sector analysis – EOL performance)
- Performance budget (optics performance: cross-beam analysis & PSF analysis; effect on sensitivity)

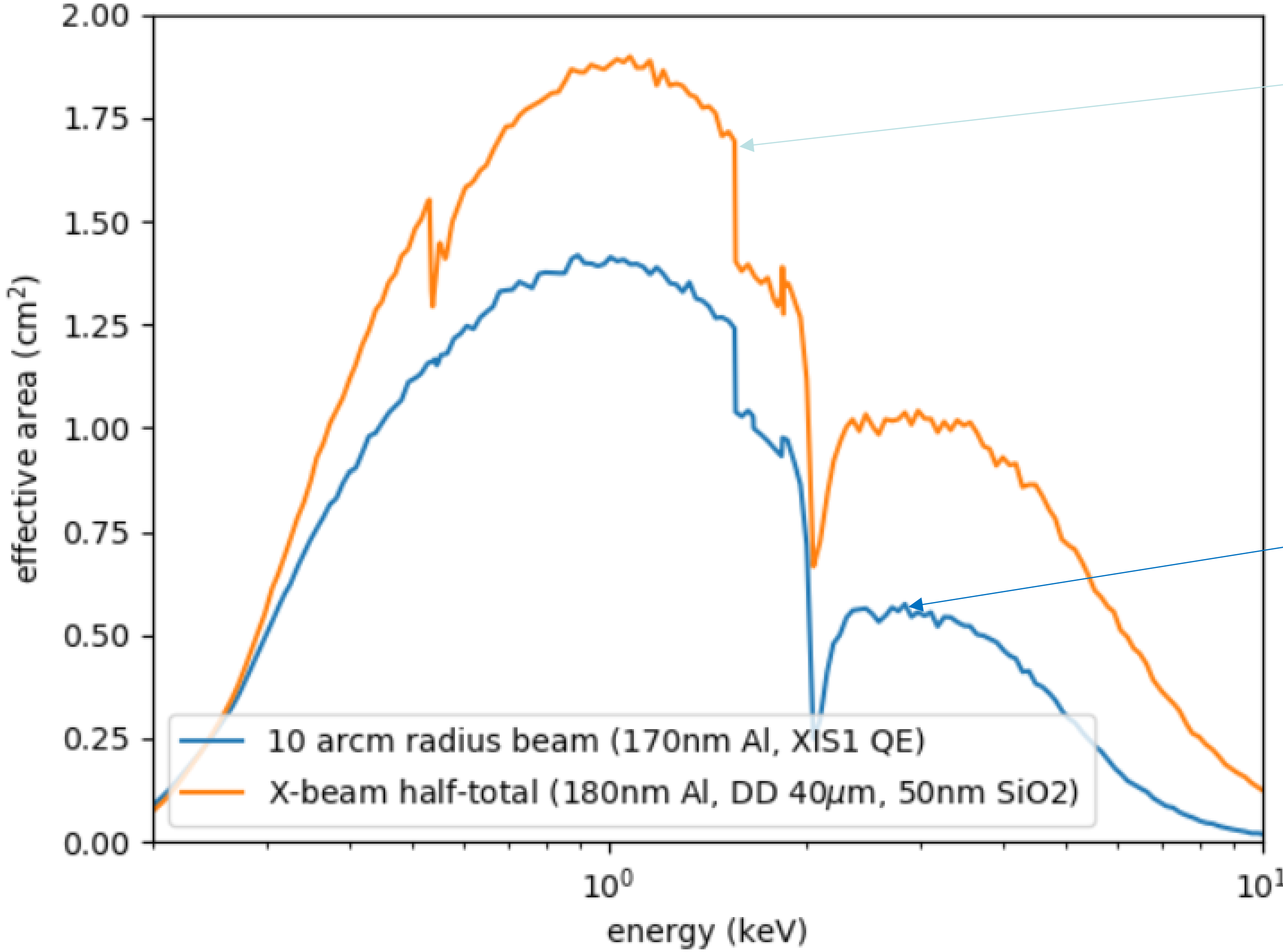
New method of defining the Point Spread Function



A conventional circular beam is not a good approximation to the PSF shape

- Instead we define a cross-beam:
- This provides a better match and is flexible – can adjust to exposure
- Current approach (for MOS run) is a single cross-beam using half the effective area for photons that suffer 1 or 2 reflections
- Next level is to adjust the PSF used as a function of trigger duration
- This would also be optimal for any source detection
- Also recalculated sky and particle background (lower on average)

Effective Area



New effective area:

- Cross-beam analysis;
- Deep depleted CMOS with SiO2 deadlayer QE;
- 180nm Al total filter (optical block)

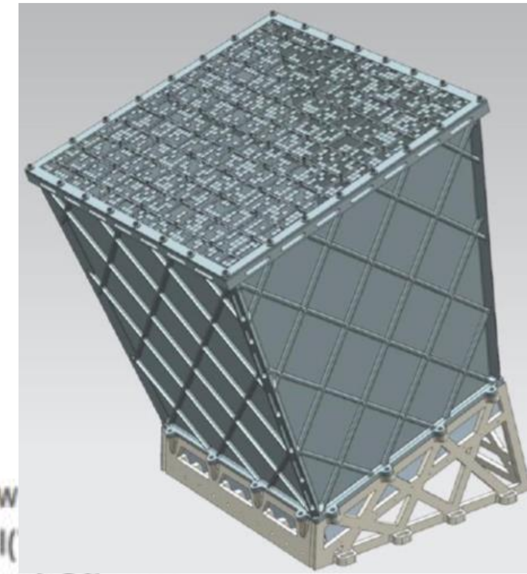
Old effective area (used in previous SXI sensitivity analyses & MOS runs):

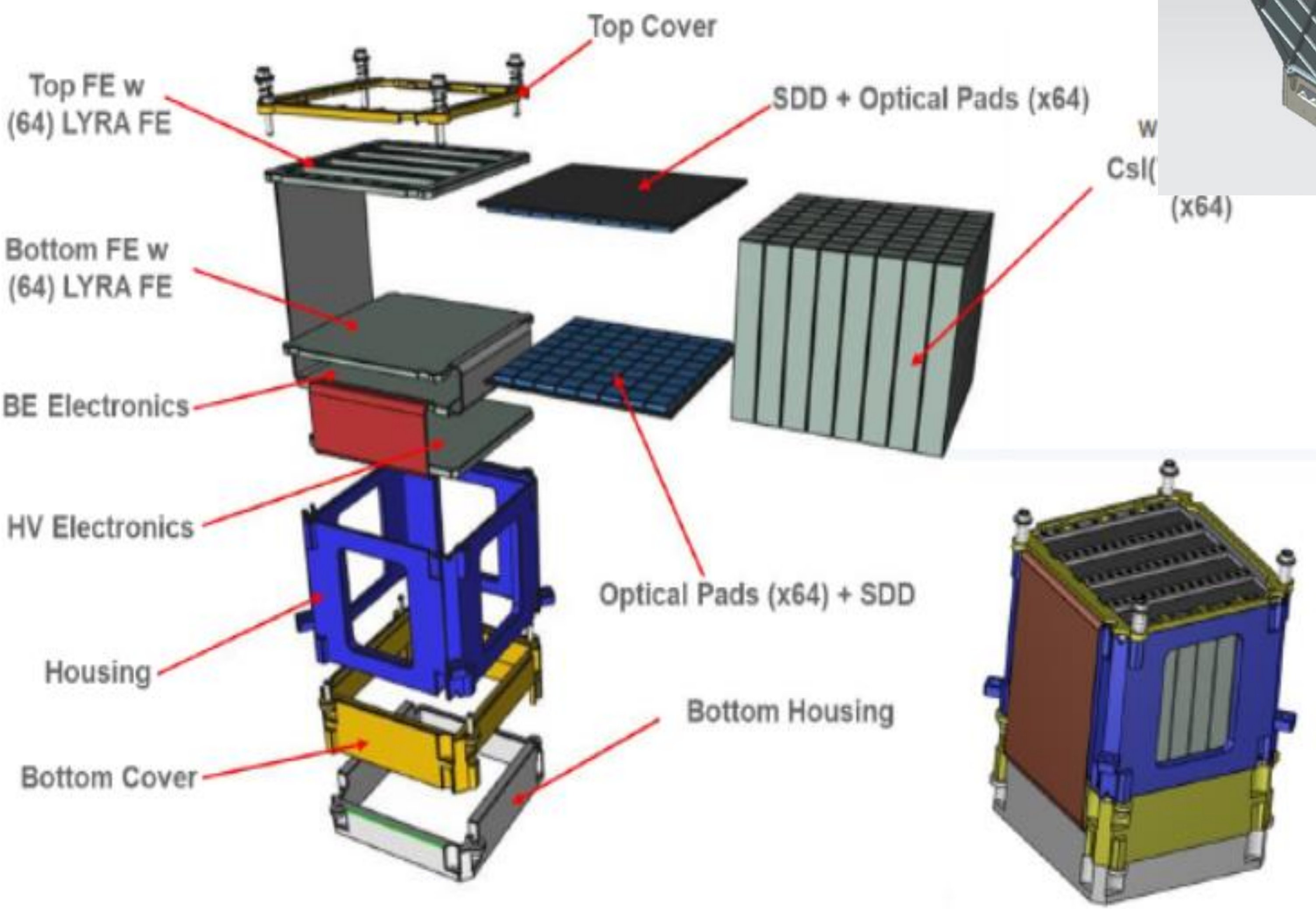
- Circular beam analysis;
- Suzaku CCD QE;
- 170nm Al total filter

On-going development work

- Analysis of optimum trigger algorithm
- Technology development work on optics and detectors on-going (with some delays due to the virus…). Additional work on electronics soon to begin.
- Thermal and radiation analysis – reduce impact of cooling requirements on spacecraft
- Design of electron diverter
- Initial design of ground segment

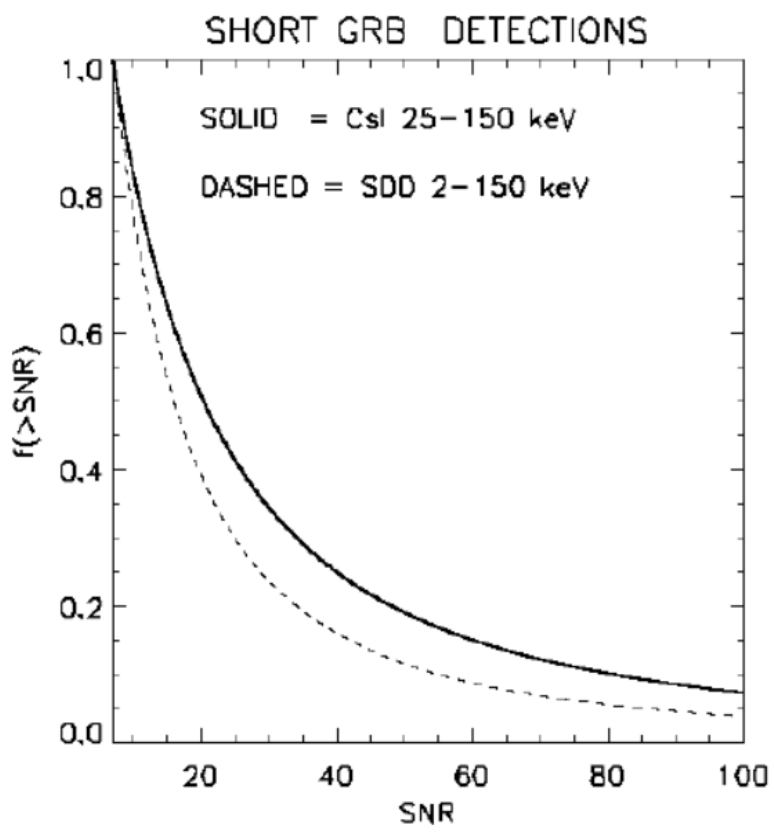
Main recent instrument updates: XGIS

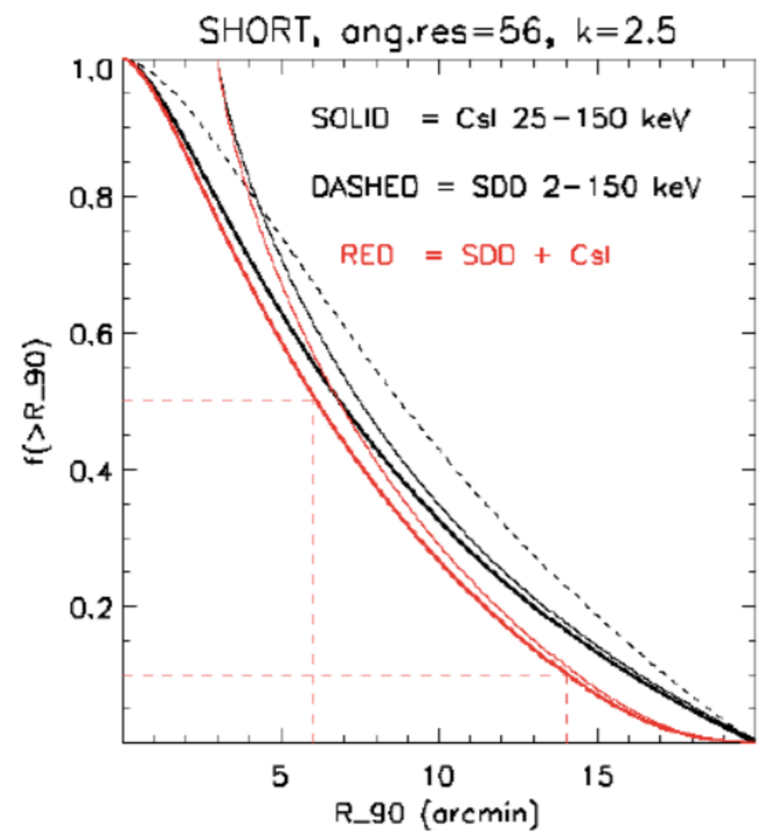




XGIS: updated source location accuracy and effect of extension to 150 keV of imaging

- Using the combination of CsI and SDD, we currently estimate that 90% of the short GRBs will have R90 <14 arcmin (and 50% R90 <6 arcmin).





Instrument design and R&D/TDA

- Inclusion of support structure into XGIS cameras -> updated mechanical design, impact on structural and thermal analysis, I/F with platform, etc. (must be taken into account in mass budget)

- Overall consolidation of budgets (mass, power) and clarifications

- Enhanced thermal design and analysis in progress following interactions with ESA engineers during las SEWG and MCR

- Detection plane: excellent feedback from TDA on detection module (OHB-I + INAF/OAS) to mechanical, thermal and electrical design

- Continuing progress on detectors and ASIC R&D activities

- MC simulations (GEANT4) for response and BKG, radiation and activation analysis in very good status and progress, thanks to significant heritage and further stimulated by MCR

Scientific WGs main aims

- Support TSST in further assessment and refinement of SciRD: e.g, formulation of requirement on high-z GRBs, re-assessment of req. on short GRBs, etc.
- Support TSST in main scientific trade-off and assessments: e,g, justification of IRT HR mode, pointing strategy vs. follow-up from ground, justification and needs of guest-observer and "external trigger" obs.
- Support TSST in further refinement of mission operation concept (e.g., IRT observing sequence) and inputs to the MOS (e.g., population models)
- Contribute to mission advertising and community involvement
- **Main task: provide fundamental contribution to the writing of the scientific sections of the "Yellow Book"**
- **Possible contributing / white papers**

Scientific WGs main aims

- Support TSST in further assessment and refinement of SciRD: e.g, formulation of requirement on high-z GRBs, re-assessment of req. on short GRBs, etc.

- Support TSST in main scientific trade-off and assessments: e,g, justification of IRT HR mode, pointing strategy vs. follow-up from ground, justification and needs of guest-observer and "external trigger" obs.

- Support TSST in further refinement of mission operation concept (e.g., IRT observing sequence) and inputs to the MOS (e.g., population models)

- Contribute to mission advertising and community involvement

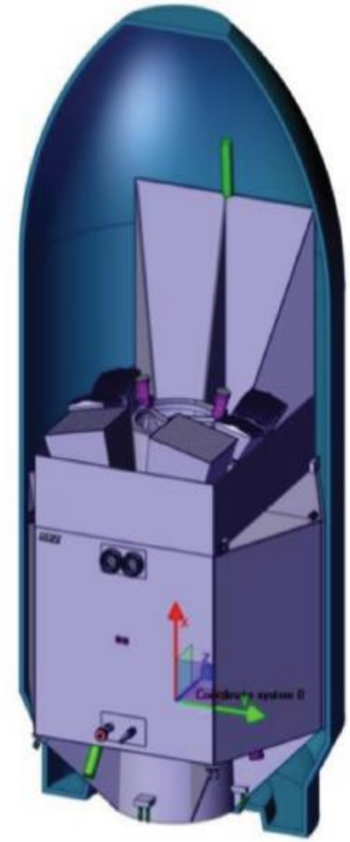
- **Main task: provide fundamental contribution to the writing of the scientific sections of the "Yellow Book"**

- **Possible contributing / white papers**

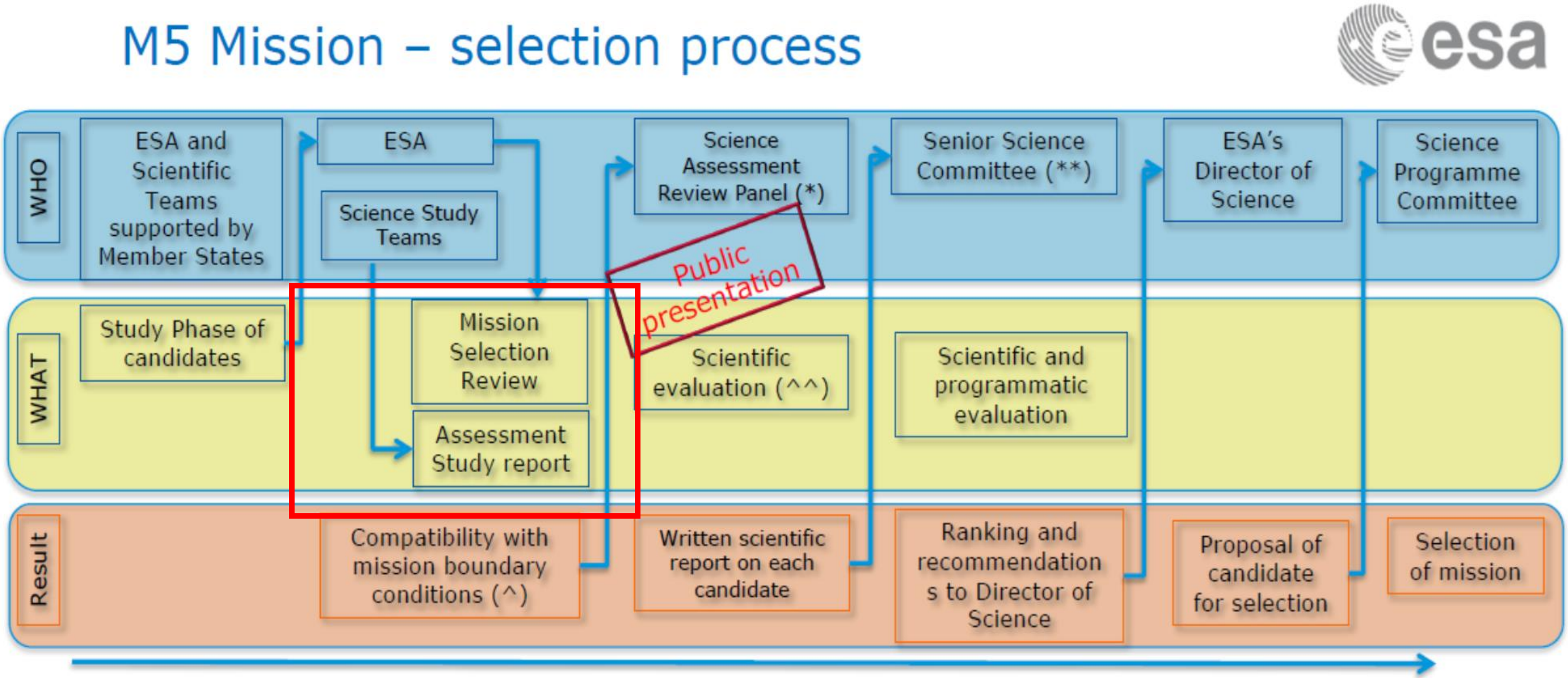
Main task: science sections of «Yellow Book»

THESEUS Phase A Milestones

- Phase A ITT release to Industry: February 2019
- **KO of Industrial Studies: June 2019**
- Mission Consolidation Review (MCR)
  - KO: 1st March 2020
- Mission Selection Review (MSR)
  - KO: 15th February 2021
  - Duration: 2 months



Main task: science sections of «Yellow Book»



(*) From Advisory Working Groups (exclusion of strongly conflicted members) + additional experts
(**) From Space Science Advisory Committee (exclusion of strongly conflicted members) + experts
(^) Including financial envelope, TRL of mission elements and readiness of Funding Agencies to fund mission elements proposed not to be under ESA's responsibility
(^^) Including demonstrated capability to obtain the scientific objectives declared at the time of candidate selection

"Yellow Book"

esa

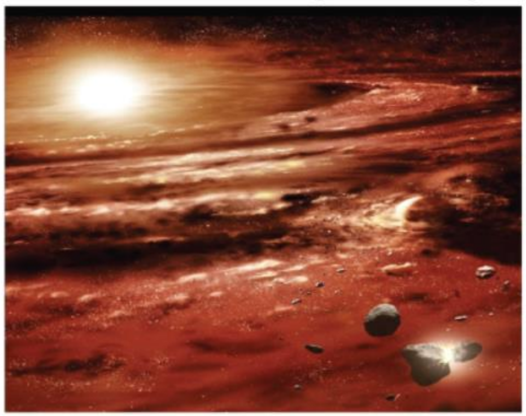
esa

ESA/SCI(2020)X
December 2020

Mission Name

Detailed name of mission

(image to be changed)



Assessment Study Report

Detailed template available

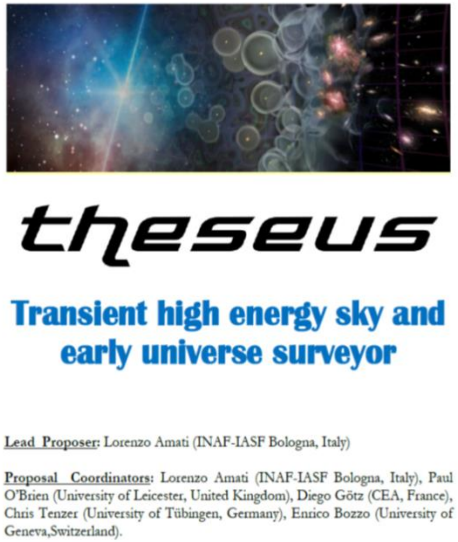
European Space Agency

- At MSR, THESEUS must submit an **Assessment Study Report** (a.k.a. *"Yellow Book"*)
- ESA Document, public (even if not selected!)
  - Main Editor is the Study Scientist (me)
  - Content is primary responsibility of the Consortium/Science Community
- Aiming at describing (primarily) the science, as well as various aspects of the mission implementation (see next slide)
- To be ready by **early 2021**.

TALK by Guainazzi

Tools for sWGs: main reference documents

- SciRD: formal reference for expected scientifc performances
- Theseus M5 proposal
- Theseus papers on Adv. Sp. Res. (general and MMS-specific) and Proc. of Theseus Workshop 2017
- Responses by Theseus consortium to questions posed by ESA scientific panels during proposal evaluation proces
- All available in the WGs repositories



- Note summarizing the priority tasks to be addressed by each sWG circulated by L. Amati on Dec. 17, following also discussions at KO meeting in Paris

theseus

TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

Priorities for the first months of activity of the re-newed THESEUS scientific Working Groups

(first preliminary draft by L. Amati, 17 December 2019; TBD with WG coord.s)

Tools for WGs: scientific simulations

- Accessible through UPDATED THESEUS website: simulations and testing by WG members; SXI and XGIS updated versions (same as input for the MOS) available; **updated description of instruments characteristics and performances on website**

- SXI FITS files for bkg, rmf, arf: assuming uniform response within FOV; updated response and background for a cross-beam extraction region (containing a sky area 675 arcmin^2); estimated BKG ncludes instrumental and diffuse X-ray background components (the latter estimated from the median over the ROSAT All Sky Survey data)

- XGIS FITS files for bkg, rmf, arf: effective area varies significantly within the FOV depending on off-axis; available FITS file for bkg (CXB + instrumental), response (rmf, arf) for some off-axis directions; different sets of files for SDD and CsI detecting elements.

Tools for WGs: scientific simulations

- IRT: Exposure Time Calculator (imaging, LR, HR for different filters); tools for simulations of spectra and images available through interaction with IRT team (TBC)

- Exposure maps: SXI and XGIS sky exposure maps for baseline and different pointing strategies are an outcome of the MOS; may be made available under request (but see later)

- Library of IR afterglow light curves for GRBs detectable by SXI

- **More refined simulations will require direct interaction with instruments teams**

Tools for WGs: MOS outputs

- Implemented for technical assessment of compliance of mission profile and instruments performance with main scientific requirements (e.g., #GRB@z>6)

- Additional (under request by TSST) trade-off between different pointing strategies (relevant, e.g., for follow-up from ground or survey uniformity)

- Most recent results provided to TSST on May 4

- List of useful outputs for WGs and TEB work (distributions, exposure maps, etc.) requested by Consortium and should be delivered soon

Tools for WGs: most recent MOS feedback

- Impact of new IRT follow-up sequence (-> photo-z measurement through imaging in 5 filters for a total of 12.5 min) on #GRB@z>6 is marginal (decrease by a few%)

- Because of new IRT follow-up sequence, distribution of start time of IRT observations inconsistent with requirement (50% within 10 min w/r to 90% required): no relevant impact (see above), but TSST may need to change req.

- Pointing strategies giving a "better" distribution of declinations for high-z GRBs are technically feasible and provide #GRB@z>6 in 3 years > 50 (as required)

- Slight improvement (2.5%) of #GRBs@z>6 (19/year) with updated SXI eff. Area and corrected BKG

- Impact of XGIS location accuracy on #GRBs@z>6 needs further assessment (but about 2/3 of only XGIS detected GRBs should have an IR counterpart within IRT FOV after pointing)

WGs timeline

- October 2019: Call to the community for joining renewed WGs and messages to WGs by coordinators: **more than 450 contrib. scientists**

- December 2019: KO meeting (Paris) of the sWGs (general information and updates, YB structure, main scientific trade-offs, priorities)

- Jan-Feb 2020: interactions within sWGs, managed by coordinators, to collect availabilities, organize the work, discussing piorities and doing first analyses and simulations

- March 2020: updated instrument description and performances sections and simulation tools on the website

- April 2020 Scientific WGs meeting In Leicester replaced by telecon among coordinators: presentation, discussion and planning of activities of each WG

- June 2020 : Theseus Conference 2020 in Malaga canceled and replaced by a telecon open to all WG members (this meeting)

WGs timeline: next milestones

- Activities of sWGs need to be synergic with those on YB preparation: schedule synchronized with that of TEB (Theseus Editorial Board for YB editing), see talk by Guainazzi)

- Theseus sWG meeting on October 2020: likely still videoconf; further inputs to TEB for final phase of YB writing

- Delivery of YB to ESA: 15 Jan 2021 (draft), 15 Feb. 2021 (final, for MSR)

- THESEUS Conference 2021: Malaga (Spain) on March 23-26

- Possible white papers: ready by March/April 2021

- Please, stay in touch with the coordinators of your WG(s) and refer to them for any clarifications, discussions, ideas, etc.