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

http://www.isdc.unige.ch/theseus/
www.isdc.unige.ch/theseus/workshop2017-programme.html
Proceedings preprints on the arXiv in early February
(Mem.SAlt, Vol. 89 – N.1 - 2018)
Probing the Early Universe with GRBs
Multi-messenger and time domain Astrophysics
The transient high energy sky
Synergy with next generation large facilities (E-ELT, SKA, CTA, ATHENA, GW and neutrino detectors)
THESEUS
Transient High Energy Sky and Early Universe Surveyor

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

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

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

Interested international partners: USA, China, Brazil
May 2018: THESEUS selected by ESA for M5 Phase 0/A study

<table>
<thead>
<tr>
<th>Activity</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 0 kick-off</td>
<td>June 2018</td>
</tr>
<tr>
<td>Phase 0 completed (EnVision, SPICA and THESEUS)</td>
<td>End 2018</td>
</tr>
<tr>
<td>ITT for Phase A industrial studies</td>
<td>February 2019</td>
</tr>
<tr>
<td>Phase A industrial kick-off</td>
<td>June 2019</td>
</tr>
<tr>
<td>Mission Selection Review (technical and programmatic review for the three mission candidates)</td>
<td>Completed by June 2021</td>
</tr>
<tr>
<td>SPC selection of M5 mission</td>
<td>November 2021</td>
</tr>
<tr>
<td>Phase B1 kick-off for the selected M5 mission</td>
<td>December 2021</td>
</tr>
<tr>
<td>Mission Adoption Review (for the selected M5 mission)</td>
<td>March 2024</td>
</tr>
<tr>
<td>SPC adoption of M5 mission</td>
<td>June 2024</td>
</tr>
<tr>
<td>Phase B2/C/D kick-off</td>
<td>Q1 2025</td>
</tr>
<tr>
<td>Launch</td>
<td>2032</td>
</tr>
</tbody>
</table>
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 $z \sim 9$ 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.
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

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

- 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

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

- 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

Courtesy N. Tanvir
Exploring the multi-messenger transient sky

- Locate and identify the electromagnetic counterparts to sources of gravitational radiation and neutrinos, which may be routinely detected in the late ‘20s / early ‘30s by next generation facilities like aLIGO/aVirgo, eLISA, ET, or Km3NET;

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

- Provide a fundamental step forward in the comprehension of the physics of various classes of transients and fill the present gap in the discovery space of new classes of transients events
LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars

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

Gravitational-wave time-frequency map
LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars

Lightcurve from Fermi/GBM (50 – 300 keV)

**THESEUS:**

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

- **Soft X-ray Imager (SXI):** a set of four sensitive lobster-eye telescopes observing in 0.3 - 5 keV band, total FOV of ~1sr with source location accuracy 0.5-1’;

- **X-Gamma rays Imaging Spectrometer (XGIS):** 3 coded-mask X-gamma ray cameras using bars of Silicon diodes coupled with CsI crystal scintillators observing in 2 keV – 10 MeV band, a FOV of ~2-4 sr, overlapping the SXI, with ~5’ source location accuracy;

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

LEO (< 5°, ~600 km)
Rapid slewing bus
Prompt downlink
THESEUS will have the ideal combination of instrumentation and mission profile for detecting all types of GRBs (long, short/hard, weak/soft, high-redshift), localizing them from a few arcmin down to arcsec and measure the redshift for a large fraction of them.
THESEUS will also detect and localize down to 0.5-1 arcmin the soft X-ray short/long GRB afterglows, of NS-NS (BH) mergers and of many classes of galactic and extra-galactic transients.

For several of these sources, THESEUS/IRT will provide detection and study of associated NIR emission, location within 1 arcsec and redshift.
Star formation history, primordial galaxies

Neutral fraction of IGM, ionizing radiation escape fraction

Cosmic chemical evolution, Pop III

GRB accurate localization and NIR, X-ray, Gamma-ray characterization, redshift
Localization of GW/neutrino gamma-ray or X-ray transient sources
NIR, X-ray, Gamma-ray characterization

Transient sources multi-wavelength campaigns

Accretion physics
Jet physics
Star formation

Hubble constant

r-process element chemical abundances

NS-BH/NS-NS merger physics/host galaxy identification/formation history/kilonova identification

THESEUS SYNERGIES
THESEUS: straightforward synergies with SKA

- High complementarity in the study of the early Universe
  1. Pop-III stars and SFR evolution up cosmic dawn
  2. History, topology and physics of cosmic re-ionization
  3. Population, properties and evolution of weak/low-lum first galaxies

- THESEUS will be the perfect GRB and transients machine for allowing SKA to fully exploit its capabilities for time-domain and multi-messenger astrophysics:
  1. Short GRBs and soft X-ray transients as e.m. counterparts of GW emitters (NS-NS, NS-BH)
  2. GRBs: physics / geometry of the emission, population studies, cosmology
  3. Long GRBs – SNe-Ib/c - neutrinos
  4. Many other transients found by THESEUS (e.g., TDEs, magnetars, …) will also be high-value targets for SKA
• **THESEUS Core Science** is based on two pillars:
  o probe the **physical properties of the early Universe**, by discovering and exploiting the population of high redshift GRBs.
  o 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:
  o study of thousands of faint to bright X-ray sources by exploiting the **unique simultaneous availability of broad band X-ray and NIR observations**
  o provide a **flexible follow-up observatory** for fast transient events with multi-wavelength ToO capabilities and **guest-observer programmes**.
THESEUS consortium science: 6 WGs, > 200 contributing scientists

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

<table>
<thead>
<tr>
<th>1. Exploring the Early Universe with GRBs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surname and Name</strong></td>
</tr>
<tr>
<td>Tanvir Nial</td>
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</table>

<table>
<thead>
<tr>
<th>2. Gravitational waves and multi-messenger Astrophysics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surname and Name</strong></td>
</tr>
<tr>
<td>Stratta Giulia</td>
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<table>
<thead>
<tr>
<th>3. Exploring the time domain Universe</th>
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<tbody>
<tr>
<td><strong>Surname and Name</strong></td>
</tr>
<tr>
<td>Osborne Julian</td>
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</table>

<table>
<thead>
<tr>
<th>4. Synergy with other electromagnetic facilities (including LSST)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surname and Name</strong></td>
</tr>
<tr>
<td>Rosati Pero</td>
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<table>
<thead>
<tr>
<th>5. Scientific requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surname and Name</strong></td>
</tr>
<tr>
<td>Ghirlanda Giancarlo</td>
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<table>
<thead>
<tr>
<th>6. The IRT as a flexible Guest Observer IR observatory</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surname and Name</strong></td>
</tr>
<tr>
<td>Blain Andrew</td>
</tr>
</tbody>
</table>
In summary

- **THESEUS**, under study by ESA and a large European collaboration with strong interest by international partners (e.g., US) will fully exploit GRBs as powerful and unique tools to investigate the early Universe and will provide us with unprecedented clues to GRB physics and sub-classes.

- **THESEUS** will also play a fundamental role for GW/multi-messenger and time domain astrophysics at the end of next decade, also by providing a flexible follow-up observatory for fast transient events with multi-wavelength ToO capabilities and guest-observer programmes.

- **THESEUS** is a unique occasion for fully exploiting the European leadership in time-domain and multi-messenger astrophysics and in key-enabling technologies (lobster-eye telescopes, SDD by INAF, INFN, FBK, Un.)

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

- Strong synergy with SKA: early Universe cosmology (pop III stars, re-ionization, first galaxies), GRBs, transients and multi-messenger astrophysics (Lorenzo.amati@inaf.it, https://www.isdc.unige.ch/theseus/)
• **ESA L2/L3 review:** “The SSC strongly endorses the need to continue pursuing in the future the discovery of GRBs”

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

<table>
<thead>
<tr>
<th>THESEUS GRB#/yr</th>
<th>All</th>
<th>$z &gt; 5$</th>
<th>$z &gt; 8$</th>
<th>$z &gt; 10$</th>
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<tbody>
<tr>
<td>Detections</td>
<td>387 - 870</td>
<td>25 - 60</td>
<td>4 - 10</td>
<td>2 - 4</td>
</tr>
<tr>
<td>Photometric z</td>
<td>25 - 60</td>
<td>4 - 10</td>
<td>2 - 4</td>
<td></td>
</tr>
<tr>
<td>Spectroscopic z</td>
<td>156 - 350</td>
<td>10 - 20</td>
<td>1 - 3</td>
<td>0.5 - 1</td>
</tr>
</tbody>
</table>
Shedding light on the early Universe with GRBs

- **z=8.2 simulated E-ELT afterglow spectra**
- **Reionization sustained by stars**
- **Stars insufficient to sustain reionized IGM**
Mission profile and budgets

- Launch with VEGA-C into LEO (< 5°, ~600 km)
- Spacecraft slewing capabilities (30° < 5 min)
- Prompt downlink options: WHF network (options: IRIDIUM network, ORBCOMM, NASA/TDRSS, ESA/EDRS)
THESEUS measurements + sinergy with large e.m. facilities -> substantial improvement of redshift estimate for e.m. counterparts of GW sources -> cosmology

Estimating $H_0$ with GW170817A
Time-domain astronomy and GRB physics

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

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

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

<table>
<thead>
<tr>
<th>Transient type</th>
<th>SXI rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetars</td>
<td>40 day(^{-1})</td>
</tr>
<tr>
<td>SN shock breakout</td>
<td>4 yr(^{-1})</td>
</tr>
<tr>
<td>TDE</td>
<td>50 yr(^{-1})</td>
</tr>
<tr>
<td>AGN+Blazars</td>
<td>350 yr(^{-1})</td>
</tr>
<tr>
<td>Thermonuclear bursts</td>
<td>35 day(^{-1})</td>
</tr>
<tr>
<td>Novae</td>
<td>250 yr(^{-1})</td>
</tr>
<tr>
<td>Dwarf novae</td>
<td>30 day(^{-1})</td>
</tr>
<tr>
<td>SFXTs</td>
<td>1000 yr(^{-1})</td>
</tr>
<tr>
<td>Stellar flares</td>
<td>400 yr(^{-1})</td>
</tr>
<tr>
<td>Stellar super flares</td>
<td>200 yr(^{-1})</td>
</tr>
</tbody>
</table>

Soderberg et al.

Nava et al. 2018
GW/multi-messenger time-domain astrophysics

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

- **collimated** on-axis and off-axis prompt gamma-ray emission from short GRBs
- Optical/NIR and soft X-ray **isotropic** emissions from kilonovae, off-axis afterglows and, for NS-NS, from newly born ms magnetar spindown
Promptly and accurately localizing e.m. counterparts to GW events with THESEUS
Detection, study, arcsecond localization and redshift of afterglow and kilonova emission from short GRB/GW events with THESEUS/IRT.

Precise localization is mandatory to activate large ground-based telescopes as VLT or ELT from which detailed spectral analysis will reveal the intrinsic nature of these newly discovered phenomena.
Promptly and accurately localizing e.m. counterparts to GW events with THESEUS
THESEUS will also detect and localize down to 0.5-1 arcmin the soft X-ray short/long GRB afterglows, of NS-NS (BH) mergers and of many classes of galactic and extra-galactic transients.

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

Light curve peaks at 200 Mpc
The ESA Cosmic Vision Programme

- **Selected missions**
  - M1: Solar Orbiter (solar astrophysics, 2018)
  - M2: Euclid (cosmology, 2021)
  - L1: JUICE (exploration of Jupiter system, 2022)
  - S1: CHEOPS (exoplanets, 2018)
  - M3: PLATO (exoplanets, 2026)
  - L2: ATHENA (X-ray observatory, cosmology, 2028)
  - L3: LISA (gravitational wave observatory, 2034)
  - M4: ARIEL (exoplanets, 2028)
  - “S2” (ESA-CAS): SMILE (solar wind <-> magneto/ionosphere)
The ESA Cosmic Vision Programme

Resonant keywords: **cosmology** (dark energy, dark matter, re-ionization, structures formation and evolution), **fundamental physics** (relativity, quantum gravity, QCD, gravitational wave universe), **life** (exoplanets formation + evolution + census, solar system exploration)
THESEUS payload consortium (M5)

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

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

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

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

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

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

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

- **Industrial support for M5 proposal**: OHB-Italia, GPAP
Italian contribution: technological heritage

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

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

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

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

- Innovation: SDD+CsI detection system, ASIC

- Development and testing of an XGIS module prototype is supported by TECNO INAF 2014 (P.I. L. Amati, INAF – IASF Bologna)
The Soft X-ray Imager (SXI)

4 DUs, each has a 31 x 26 degree FoV

Table 4: SXI detector unit main physical characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy band (keV)</td>
<td>0.3-5</td>
</tr>
<tr>
<td>Telescope type</td>
<td>Lobster eye</td>
</tr>
<tr>
<td>Optics aperture (mm²)</td>
<td>320x320</td>
</tr>
<tr>
<td>Optics configuration</td>
<td>8x8 square pore MCPs</td>
</tr>
<tr>
<td>MCP size (mm²)</td>
<td>40x40</td>
</tr>
<tr>
<td>Focal length (mm)</td>
<td>300</td>
</tr>
<tr>
<td>Focal plane shape</td>
<td>spherical</td>
</tr>
<tr>
<td>Focal plane detectors</td>
<td>CCD array</td>
</tr>
<tr>
<td>Size of each CCD (mm²)</td>
<td>81.2x67.7</td>
</tr>
<tr>
<td>Pixel size (µm)</td>
<td>18</td>
</tr>
<tr>
<td>Pixel Number</td>
<td>4510 x 3758 per CCD</td>
</tr>
<tr>
<td>Number of CCDs</td>
<td>4</td>
</tr>
<tr>
<td>Field of View (square deg)</td>
<td>~1sr</td>
</tr>
<tr>
<td>Angular accuracy (best, worst) (arcsec)</td>
<td>(&lt;10, 105)</td>
</tr>
<tr>
<td>Power [W]</td>
<td>27.8</td>
</tr>
<tr>
<td>Mass [kg]</td>
<td>40</td>
</tr>
</tbody>
</table>
The X-Gamma-rays spectrometer (XGS)

- **Direct detection in Si**
- **Scintillation light detection**

**Energy band**: 2 keV – 20 MeV

<table>
<thead>
<tr>
<th># detection plane modules</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td># of detector pixel / module</td>
<td>32×32</td>
</tr>
<tr>
<td>Pixel size (= mask element size)</td>
<td>5×5 mm</td>
</tr>
<tr>
<td>Low-energy detector (2-30 keV)</td>
<td>Silicon Drift Detector 450 µm thick</td>
</tr>
<tr>
<td>High energy detector (&gt; 30 keV)</td>
<td>CsI(Tl) (3 cm thick)</td>
</tr>
<tr>
<td>Discrimination Si/CsI(Tl) detection</td>
<td>Pulse shape analysis</td>
</tr>
<tr>
<td>Dimension [cm]</td>
<td>50×50×85</td>
</tr>
<tr>
<td>Power [W]</td>
<td>30.0</td>
</tr>
<tr>
<td>Mass [kg]</td>
<td>37.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy range</th>
<th>2-30 keV</th>
<th>30-150 keV</th>
<th>&gt;150 keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully coded FOV</td>
<td>9 x 9 deg²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Half sens. FOV</td>
<td>50 x 50 deg²</td>
<td>50 x 50 deg² (FWHM)</td>
<td></td>
</tr>
<tr>
<td>Total FOV</td>
<td>64 x 64 deg²</td>
<td>85 x 85 deg² (FWZR)</td>
<td>2π sr</td>
</tr>
<tr>
<td>Ang. res</td>
<td>25 arcmin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source location accuracy</td>
<td>~5 arcmin (for &gt;6 σ source)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy res</td>
<td>200 eV FWHM @ 6 keV</td>
<td>18 % FWHM @ 60 keV</td>
<td>6 % FWHM @ 500 keV</td>
</tr>
<tr>
<td>Timing res.</td>
<td>1 µsec</td>
<td>1 µsec</td>
<td>1 µsec</td>
</tr>
</tbody>
</table>
Field of view

XGIS
SXI
IRT
## The InfraRed Telescope (IRT)

![Diagram of the InfraRed Telescope](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Telescope type:</strong></td>
<td>Cassegrain</td>
</tr>
<tr>
<td><strong>Primary &amp; Secondary size:</strong></td>
<td>700 mm &amp; 230 mm</td>
</tr>
<tr>
<td><strong>Material:</strong></td>
<td>SiC (for both optics and optical tube assembly)</td>
</tr>
<tr>
<td><strong>Detector type:</strong></td>
<td>Teledyne Hawaii-2RG 2048 x 2048 pixels (18 μm each)</td>
</tr>
<tr>
<td><strong>Imaging plate scale:</strong></td>
<td>0&quot;.3/pixel</td>
</tr>
<tr>
<td><strong>Field of view:</strong></td>
<td>10' x 10'</td>
</tr>
<tr>
<td><strong>Resolution (λ/Δλ):</strong></td>
<td>2-3 (imaging)</td>
</tr>
<tr>
<td><strong>Sensitivity (AB mag):</strong></td>
<td>H = 20.6 (300s)</td>
</tr>
<tr>
<td><strong>Filters:</strong></td>
<td>ZYJH</td>
</tr>
<tr>
<td><strong>Wavelength range (μm):</strong></td>
<td>0.7-1.8 (imaging)</td>
</tr>
<tr>
<td><strong>Total envelope size (mm):</strong></td>
<td>800 Ø x 1800</td>
</tr>
<tr>
<td><strong>Power (W):</strong></td>
<td>115 (50 W for thermal control)</td>
</tr>
<tr>
<td><strong>Mass (kg):</strong></td>
<td>112.6</td>
</tr>
</tbody>
</table>
GRB NIR Afterglow

NIR Kilonova from NS-NS

Simulated IRT low-res afterglow spectra at range of redshifts

Hi-z GRB NIR spectroscopy

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

<p>| Satellite Nominal Power (W)                    |                       |                |               |                      |
| Service Module                                 | 282                   |                |               |                      |
| Payload Module                                 | 381                   |                |               |                      |
| 20% System Margin                              | 132                   |                |               |                      |
| Harness Loss                                   | 18                    |                |               |                      |
| <strong>Total power with losses and margin</strong>         | 813                   |                |               |                      |</p>
<table>
<thead>
<tr>
<th>Activity</th>
<th>CAC (M€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESA Project Office</td>
<td>54</td>
</tr>
<tr>
<td>Satellite (incl. 20% contingency)</td>
<td>165</td>
</tr>
<tr>
<td>ESA contribution to P/L</td>
<td>120</td>
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<tr>
<td>Launch (VEGA)</td>
<td>45</td>
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<tr>
<td>Ground Segment &amp; Operations</td>
<td>84</td>
</tr>
<tr>
<td>Contingency (15% of subtotal)</td>
<td>70</td>
</tr>
<tr>
<td><strong>Total cost for ESA</strong></td>
<td><strong>538</strong></td>
</tr>
</tbody>
</table>
THESEUS mission profile

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