THESEUS
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

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

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

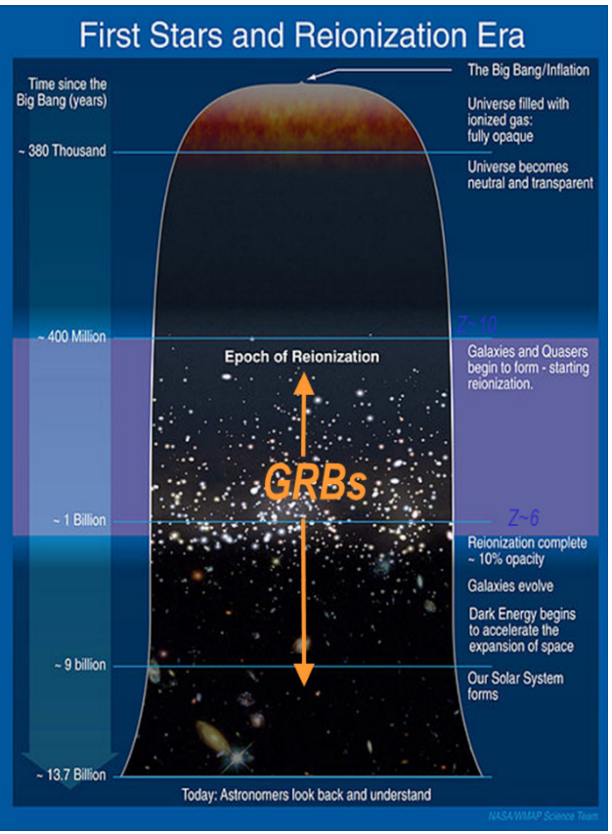
Amati et al. 2017 (Adv.Sp.Res., arXiv:1710.04638)
Stratta et al. 2017 (Adv.Sp.Res., arXiv:1712.08153)

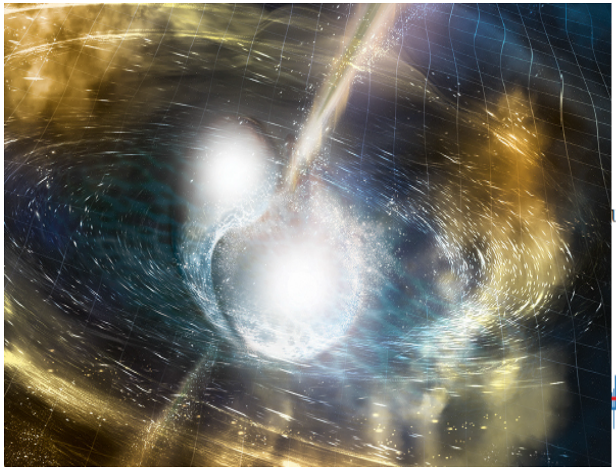
INAF OAS BOLOGNA

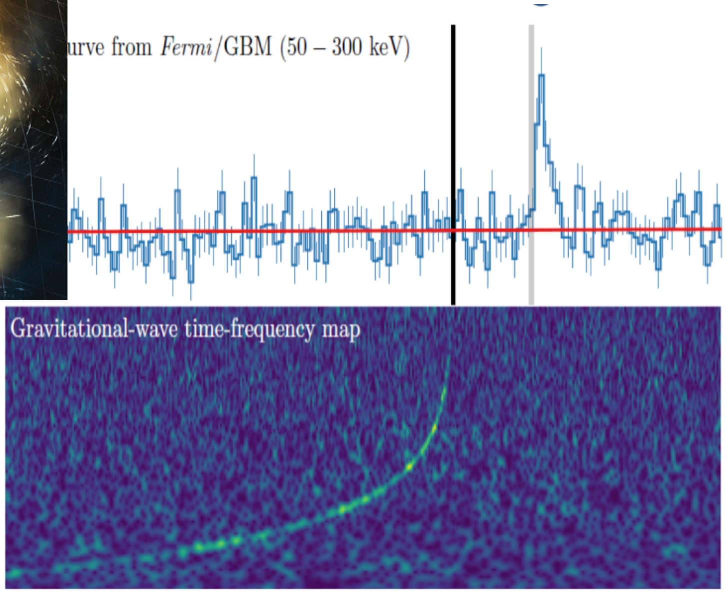
OAS Days - 18th December 2018

www.isdc.unige.ch/theseus/workshop2017-programme.html
Proceedings preprints on the arXiv in early February
(Mem.SAIt, Vol. 89 – N.1 - 2018)

Probing the Early Universe with GRBs
Multi-messenger and time domain Astrophysics
The transient high energy sky
Synergy with next generation large facilities (E-ELT, SKA, CTA, ATHENA, GW and neutrino detectors)







THESEUS

Transient High Energy Sky and Early Universe Surveyor

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

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

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

Interested international partners: USA, China, Brazil

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)

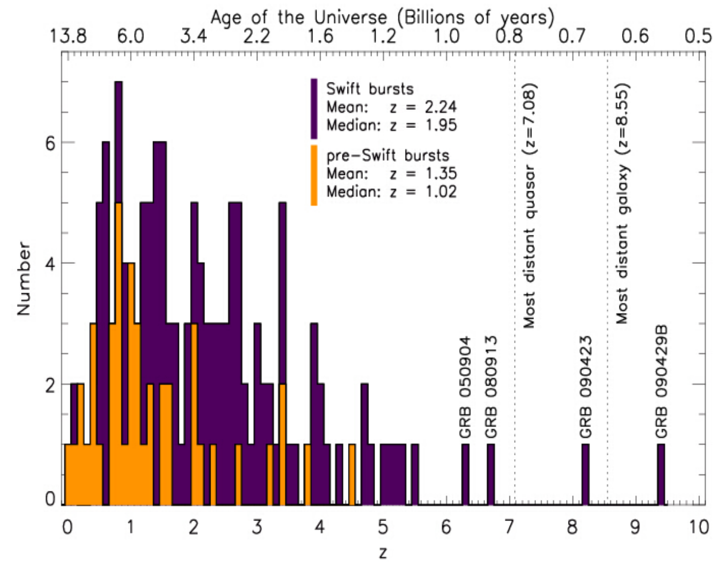
- Taking advantage of leadership in key enabling technologies based on R&D supported by ASI, INAF and INFN in the last years (e.g., silicon drift detectors + scintillators)

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

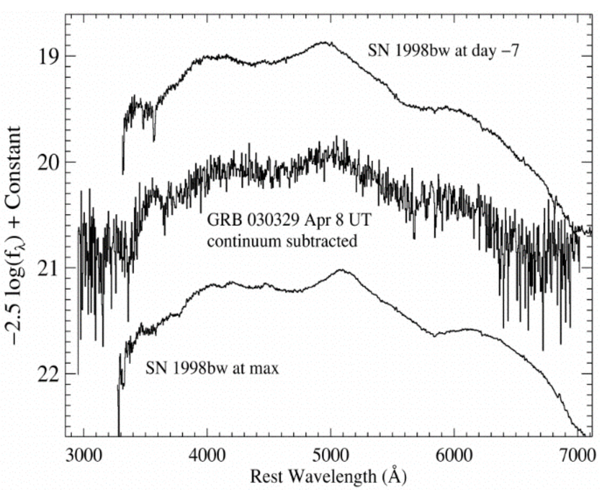
Activity	Date
Phase 0 kick-off	June 2018
Phase 0 completed (EnVision, SPICA and THESEUS)	End 2018
ITT for Phase A industrial studies	February 2019
Phase A industrial kick-off	June 2019
Mission Selection Review (technical and programmatic review for the three mission candidates)	Completed by June 2021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

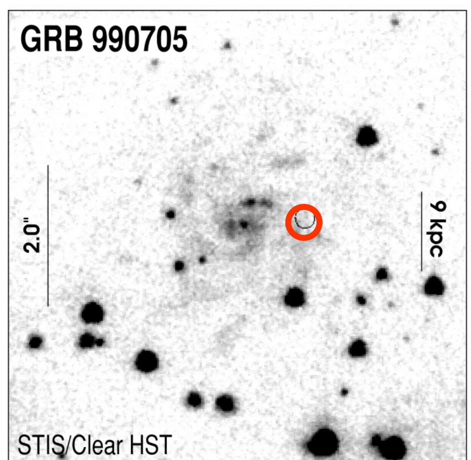
Shedding light on the early Universe with GRBs

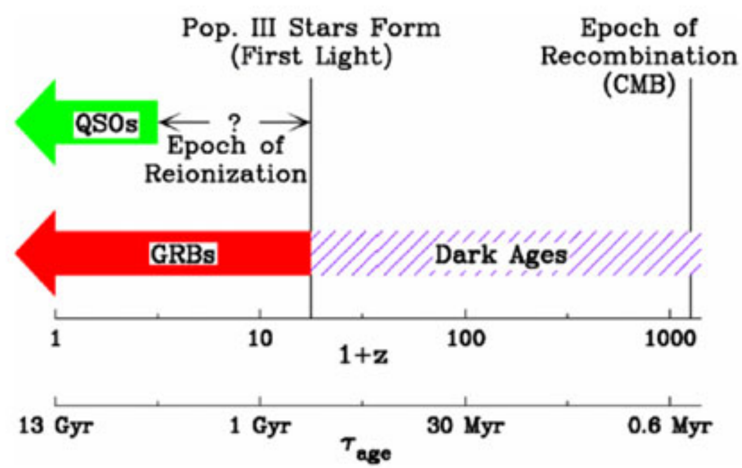
Because of their huge luminosities, mostly emitted in the X and gamma-rays, their redshift distribution extending at least to z ~9 and their association with explosive death of massive stars and star forming regions, GRBs are unique and powerful tools for investigating the early Universe: **SFR evolution,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



GRBs in Cosmological Context





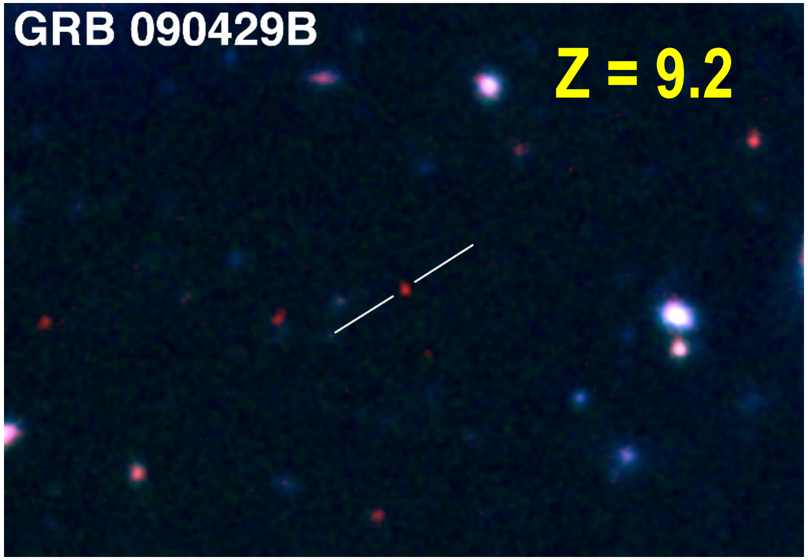


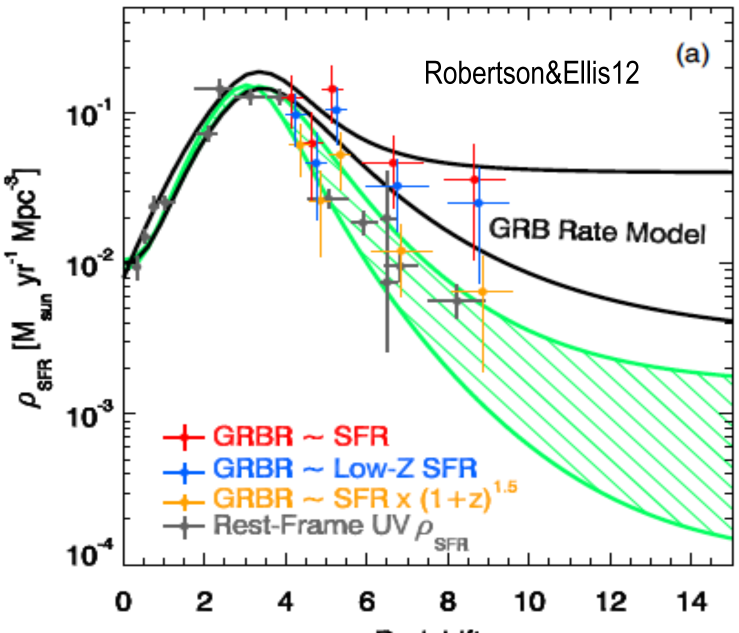
Lamb and Reichart (2000)

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

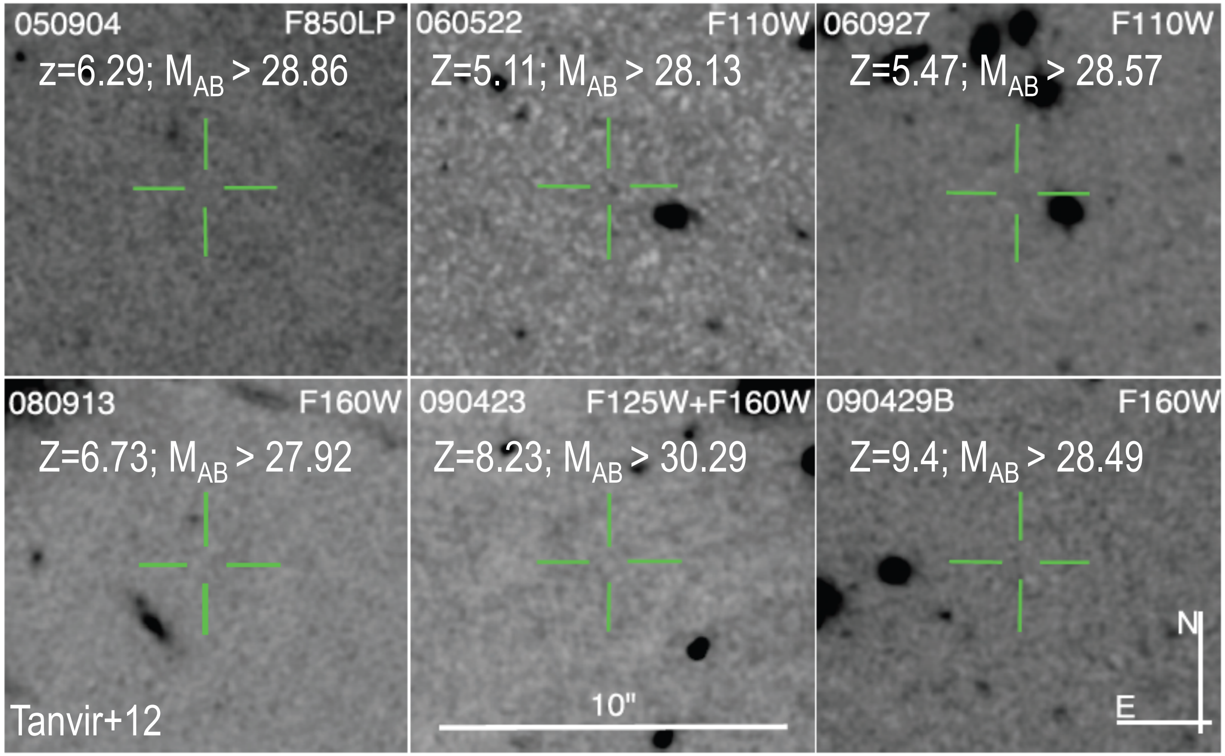
- measure independently the **cosmic star–formation rate**, even beyond the limits of current and future galaxy surveys

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





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

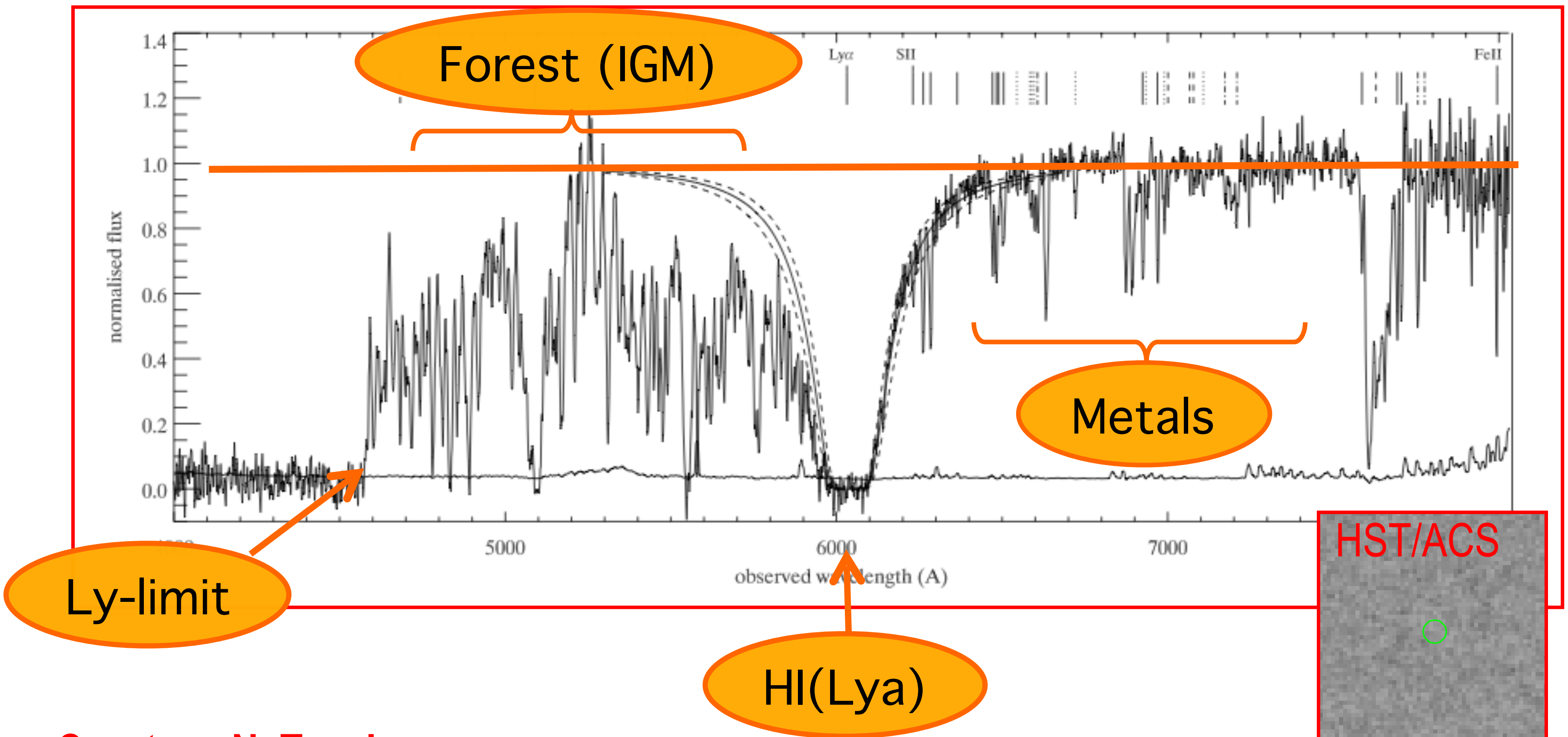


Robertson&Ellis12

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

- **the neutral hydrogen fraction**
- **the escape fraction of UV photons from high-z galaxies**
- **the early metallicity of the ISM and IGM and its evolution**

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



Courtesy N. Tanvir

- the neutral hydrogen fraction
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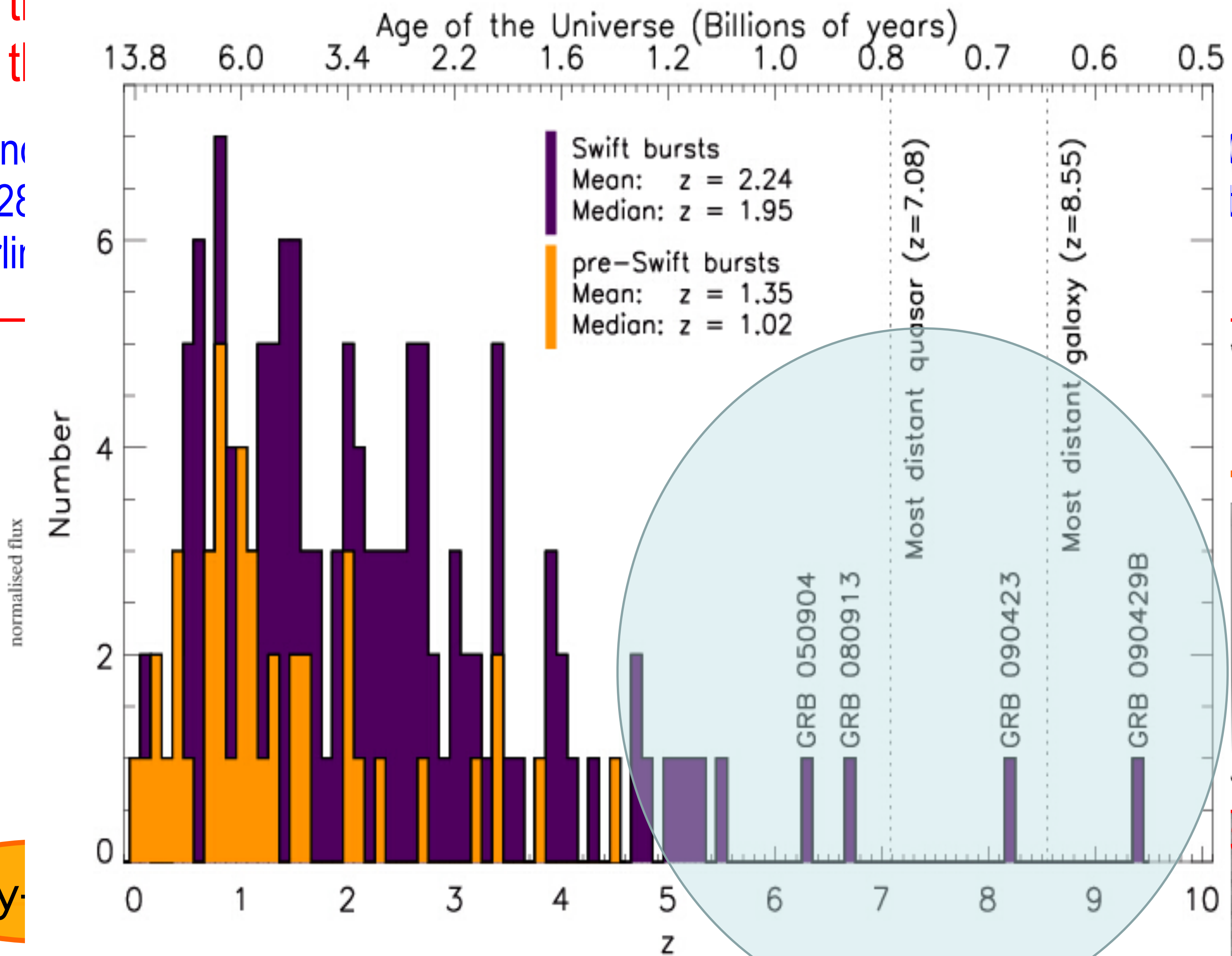
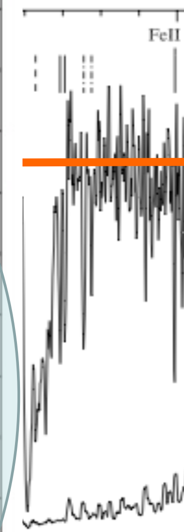
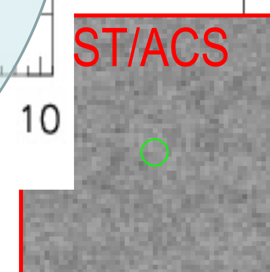
Abun 0: faint host
(R>28 t al. 2005;
Starli





Ly-

HI(Lya)



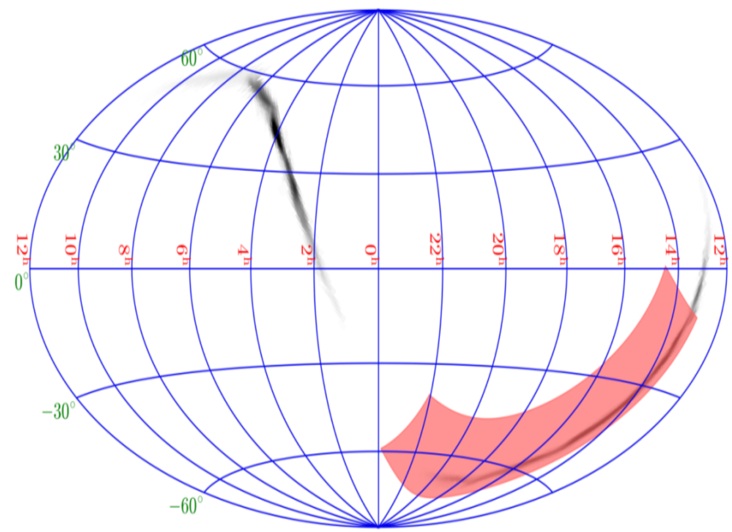
Courtesy N. Tanvir

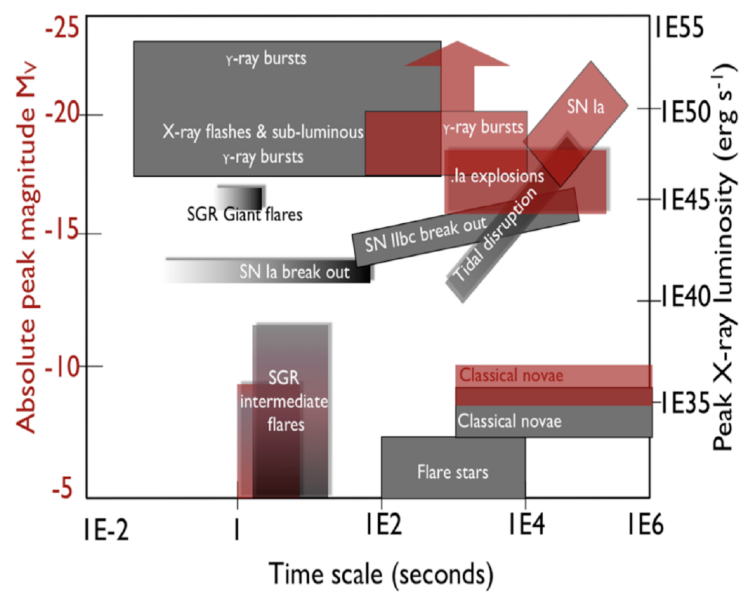
Exploring the multi-messenger transient sky

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

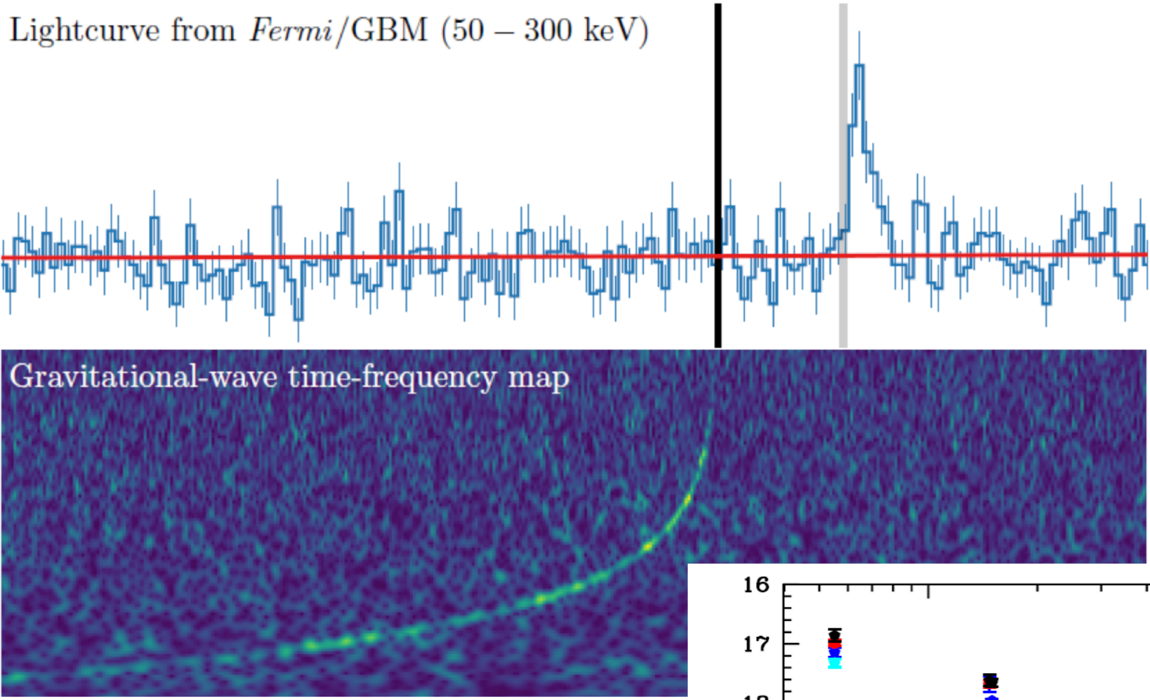
- Provide real-time triggers and accurate (~1 arcmin within a few seconds; ~1'' within a few minutes) **high-energy transients for follow-up with next-generation optical-NIR (E-ELT, JWST if still operating), radio (SKA), X-rays (ATHENA), TeV (CTA) telescopes; synergy with LSST**

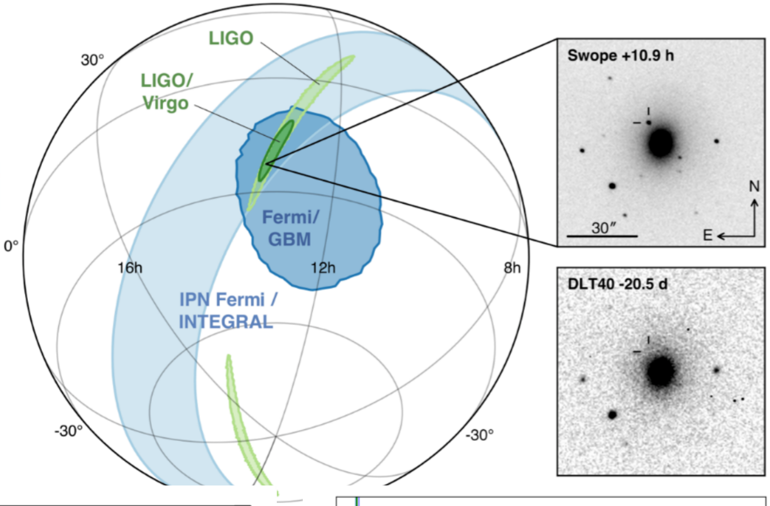
- Provide a fundamental step forward in the comprehension of the physics of various classes of transients and **fill the present gap in the discovery space of new classes of transients events**

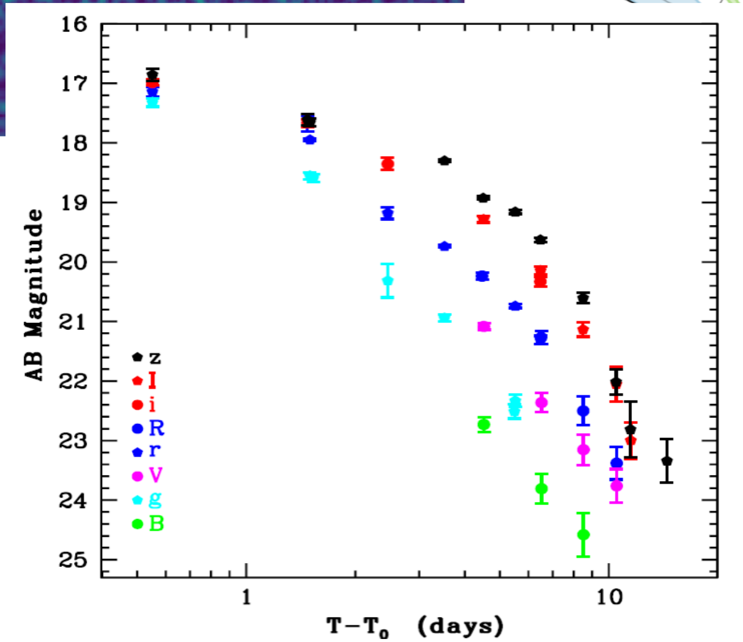


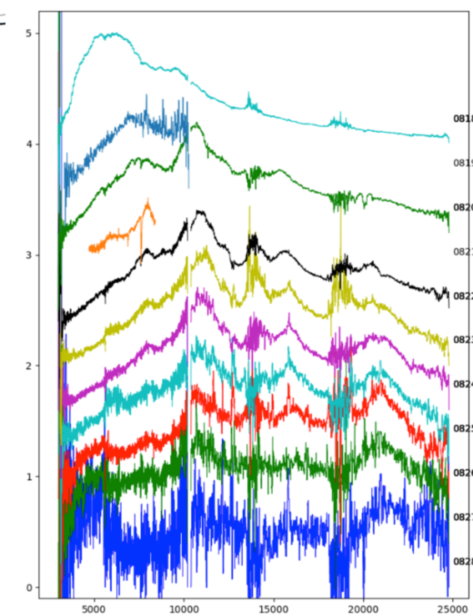


LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars



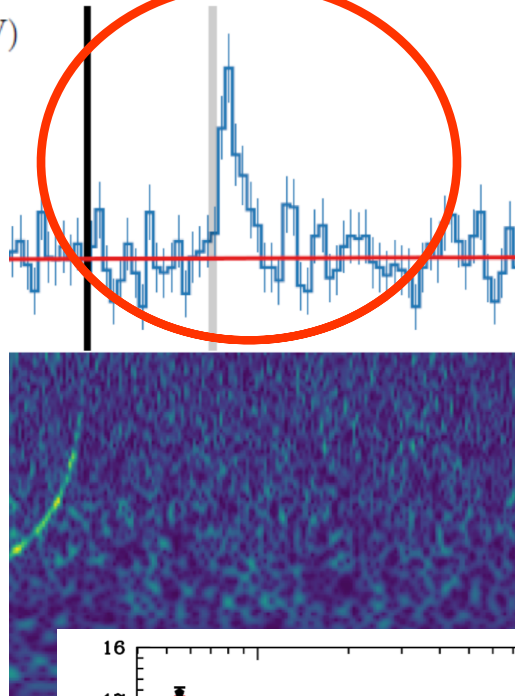






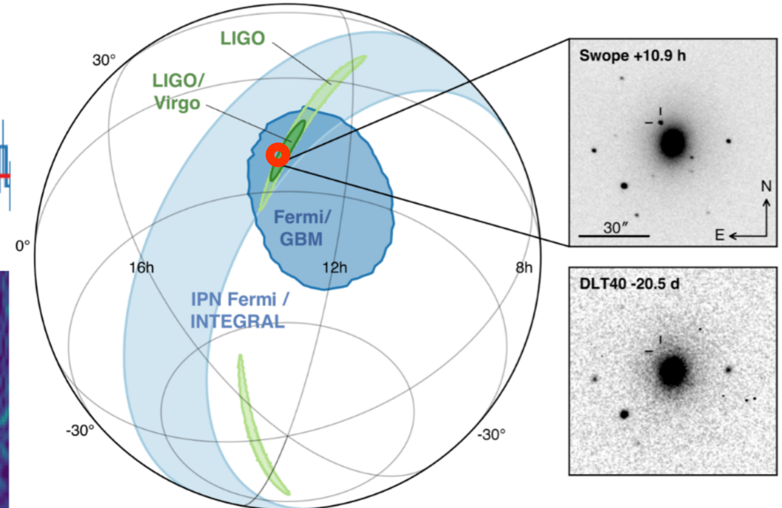
LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars

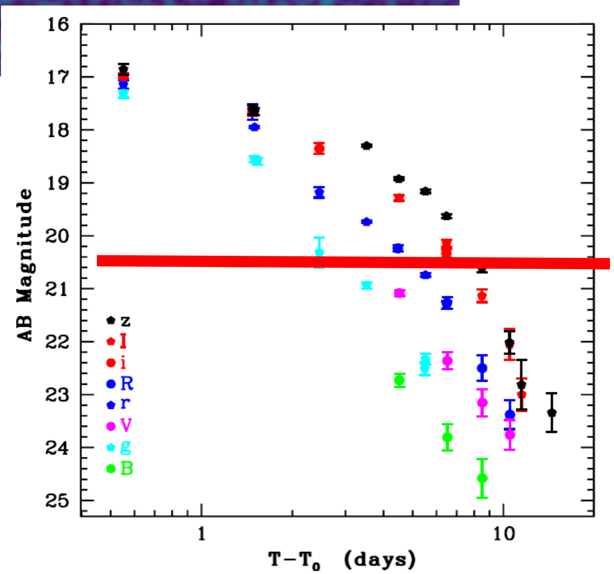
Lightcurve from *Fermi*/GBM (50 – 300 keV)

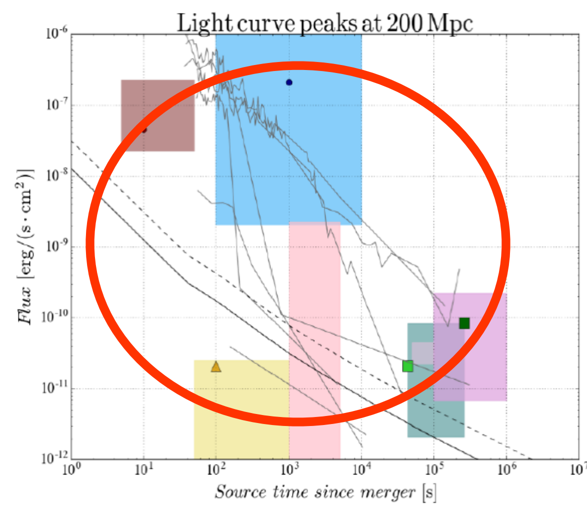


THESEUS:

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

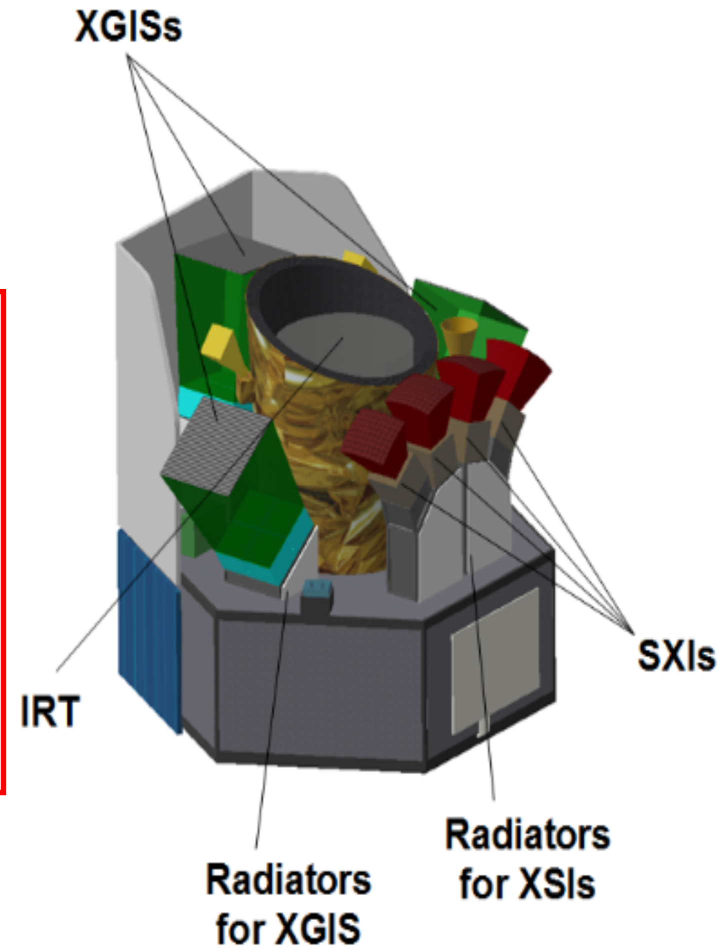




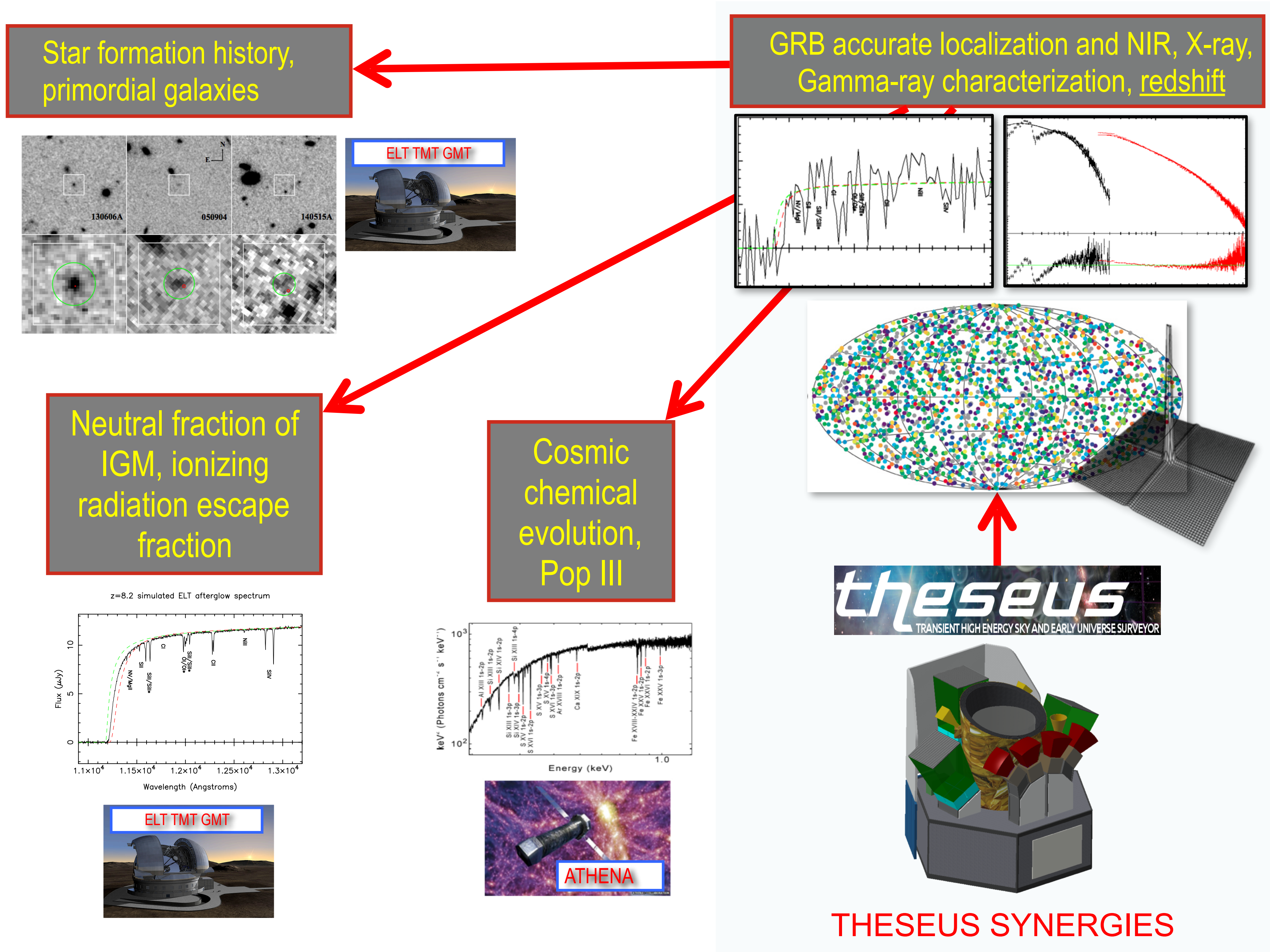


THESEUS mission concept

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



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


Star formation history, primordial galaxies
130606A
050904
140515A
ELT TMT GMT
GRB accurate localization and NIR, X-ray, Gamma-ray characterization, redshift
Neutral fraction of IGM, ionizing radiation escape fraction
Cosmic chemical evolution, Pop III
z=8.2 simulated ELT afterglow spectrum
Flux (μJy)
Wavelength (Angstroms)
ELT TMT GMT
Energy (keV)
ATHENA
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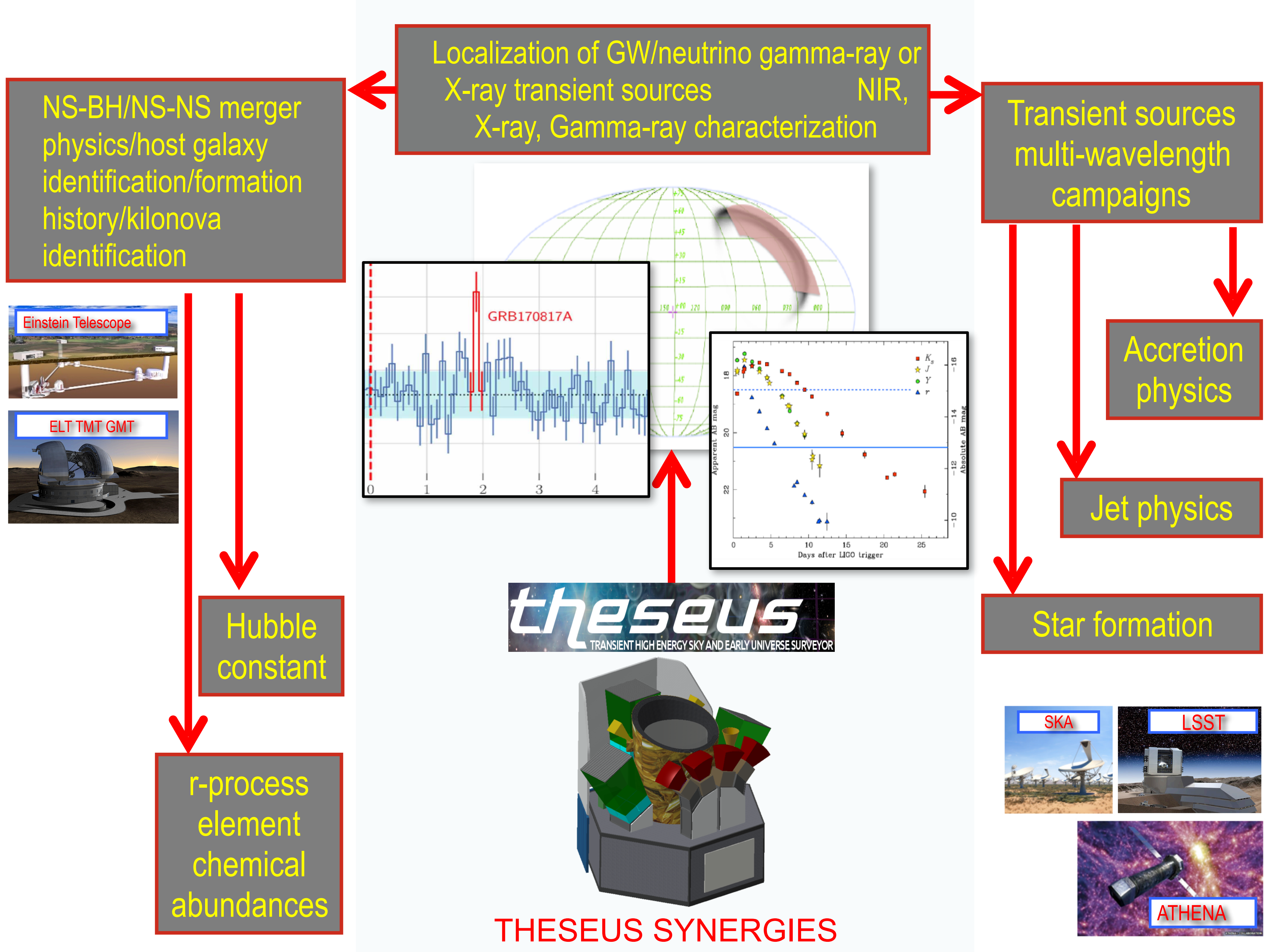
THESEUS SYNERGIES



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
Days after LIGO trigger
Apparent AB mag
Absolute AB mag
Accretion physics
Jet physics
Hubble constant
Star formation
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r-process element chemical abundances
SKA
LSST
ATHENA
THESEUS SYNERGIES

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

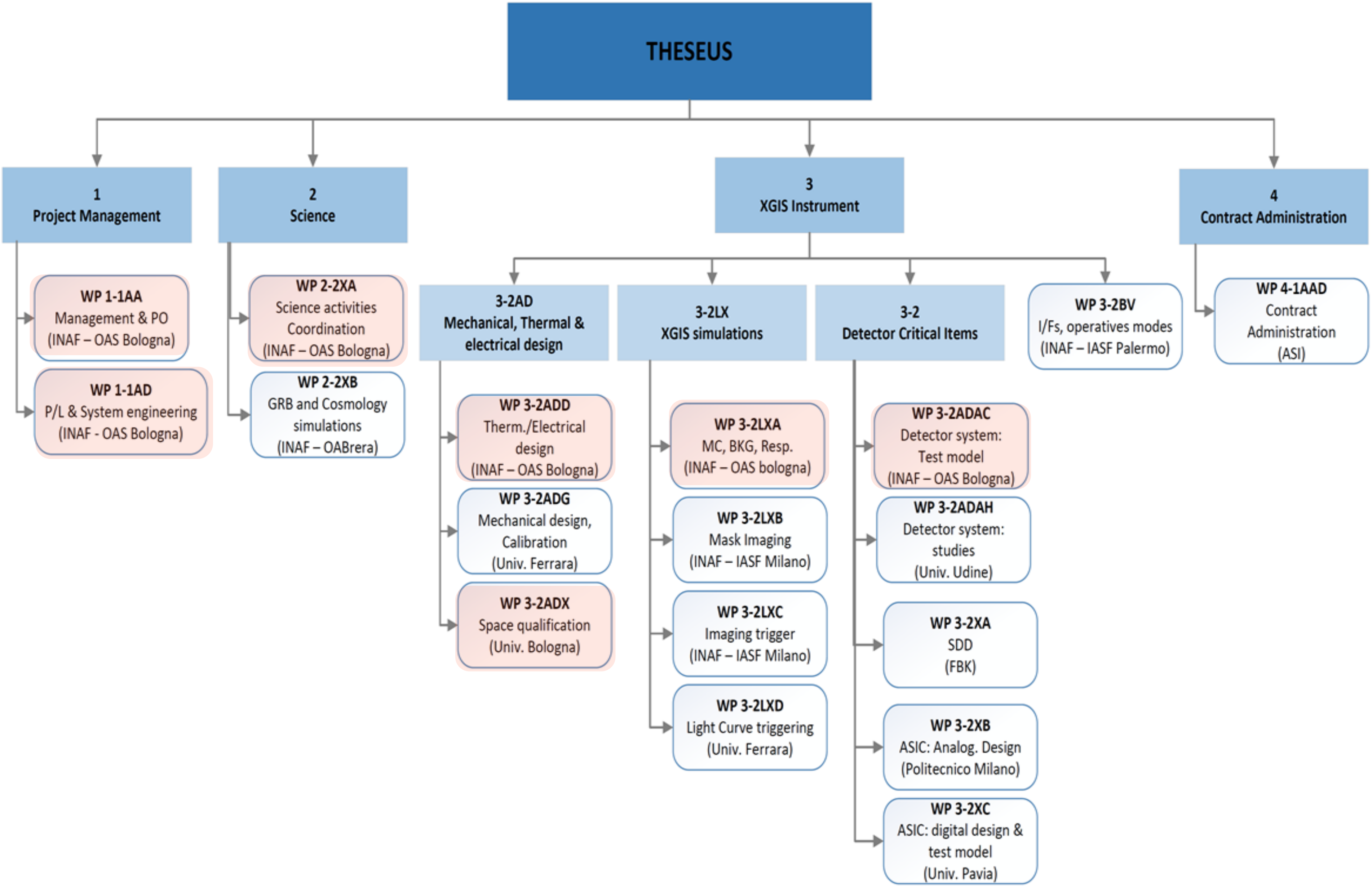
- ***THESEUS*** **Observatory Science includes:**
  - study of thousands of faint to bright X-ray sources by exploiting the **unique simultaneous availability of broad band X-ray and NIR observations**
  - provide a **flexible follow-up observatory** for fast transient events with multi-wavelength ToO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

The Italian contribution to THESEUS

- **Theseus consortium coordination: INAF** (Lead Proposer, project office)
- **Science: INAF** (Lead Scientist; OAS, IASF-MI, Oss. Brera, IAPS, IASF-PA, Oss. Napoli, Oss. Roma, …), **Universities** (e.g., Univ. Ferrara, Pol. Milano, SNS Pisa, Univ. Federico II Napoli, Univ. Urbino, …)
- **XGIS** (including radiation monitor): **INAF** (PIship; OAS, IASF-MI, IAPS, IASF-PA, …), **Universities** (Politecnico Milano, Univ. Pavia, Univ. Ferrara, Univ. Udine, **FBK** Trento
- **TBU** (Trigger Broadcasting Unit): **INAF**
- **Malindi ground station: ASI (**in-kind contribution)
- **Industries:** involvement already in Phase A (contrib. XGIS and TBU studies)

ASI funding for Phase A study: 500 KEuro (2019-2020)
Co-funding from INAF + Universities: 600 KEuro

Italian contribution: the key role of INAF-OAS



Theseus: OAS main contributors

Lorenzo Amati (Consortium PI, ESA Lead Scientist, XGIS Project Manager)

Claudio Labanti (XGIS System Manager, ESA System Engineering Working Group)

Filippo Frontera (project key person, ESA System Engineering Working Group)

Riccardo Campana, Fabio Fuschino, Mauro Orlandini (XGIS key persons)

Giulia Stratta (ESA Science Study Team)

Francesca Sortino and Natalia Auricchio (project management key persons)

Chris Butler, Adriano De Rosa, Gianluca Morgante, Luca Terenzi, Valentina Fioretti, Andrea Bulgarelli (XGIS technical support)

Elisabetta Maiorano, Andrea Rossi, Elena Pian, Eliana Palazzi, Luciano Nicastro, Nicola Masetti (scientific support)

Fabio Finelli, Eros Vanzella, Andrea Comastri, Stefano Ettori, Vito Sguera, Alessandro Gruppuso, et al. (interested / contributing scientists)

THESEUS consortium: science: 6 WGs, > 200 contributing scientists

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

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

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

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

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

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

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

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ADVANCES IN SPACE RESEARCH (a COSPAR publication)
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The THESEUS space mission concept: science case, design and expected performances

L. Amati [a,*], P. O'Brien [b], D. Götz [c], E. Bozzo [d], C. Tenzer [e], F. Frontera [f,g], G. Ghirlanda [h], C. Labanti [a], J.P. Osborne [b], G. Stratta [i], N. Tanvir [j], R. Willingale [b], P. Attina [k], R. Campana [l], A.J. Castro-Tirado [m], C. Contini [n], F. Fuschino [a], A. Gomboc [o], R. Hudec [p,q], P. Orleanski [r], E. Renotte [s], T. Rodic [t], Z. Bagoly [u], A. Blain [b], P. Callanan [v], S. Covino [w], A. Ferrara [x,y], E. Le Floch [z], M. Marisaldi [aa], S. Mereghetti [ab], P. Rosati [ac], A. Vacchi [ad], P. D'Avanzo [h], P. Giommi [ae], S. Piranomonte [af], L. Piro [ag], V. Reglero [ah], A. Rossi [a], A. Santangelo [e], R. Salvaterra [ai], G. Tagliaferri [h], S. Vergani [aj,ak], S. Vinciguerra [al], M. Briggs [am], E. Campolongo [n], R. Ciolfi [an,ao], V. Connaughton [ap], B. Cordier [c], B. Morelli [n], M. Orlandini [aq], C. Adami [ar], A. Argan [ag], J.-L. Atteia [as], N. Auricchio [a], L. Balazs [at], G. Baldazzi [au,av], S. Basa [ar], R. Basak [aw,ax], P. Bellutti [ay], M.G. Bernardini [h], G. Bertuccio [az,ba], J. Braga [bb], M. Branchesi [bc,bd], S. Brandt [be], E. Brocato [bf], C. Budtz-Jorgensen [be], A. Bulgarelli [bg], L. Burderi [bh], J. Camp [bi], S. Capozziello [bj], J. Caruana [bk,bl], P. Casella [af], B. Cenko [bm,bn], P. Chardonnet [bo,bp], B. Ciardi [bq], S. Colafrancesco [br], M.G. Dainotti [bs,bt,bu], V. D'Elia [bv,af], D. De Martino [bw], M. De Pasquale [bx], E. Del Monte [ag], M. Della Valle [by,bz], A. Drago [ca], Y. Evangelista [ag], M. Feroci [ag], F. Finelli [a], M. Fiorini [cb], J. Fynbo [cc], A. Gal-Yam [cd], B. Gendre [ce,cf], G. Ghisellini [h], A. Grado [bw], C. Guidorzi [f], M. Hafizi [cg], L. Hanlon [ch], J. Hjorth [cc], L. Izzo [ci], L. Kiss [cj], P. Kumar [ck], I. Kuvvetli [be], M. Lavagna [cl], T. Li [cm], F. Longo [cn,ad], M. Lyutikov [co,cp], U. Maio [cq,cr], E. Maiorano [aa], P. Malcovati [cs], D. Malesani [cc], R. Margutti [ct], A. Martin-Carrillo [ch], N. Masetti [aq,cu], S. McBreen [cv], R. Mignani [ai,cw], G. Morgante [aq], C. Mundell [cx], H.U. Nargaard-Nielsen [be], L. Nicastro [cy], E. Palazzi [aq], S. Paltani [d], F. Panessa [ag], G. Pareschi [h], A. Pe'er [v], A.V. Penacchioni [cz,da,db], E. Pian [x], E. Piedipalumbo [dc,dd], T. Piran [de], G. Rauw [df], M. Razzano [dg], A. Read [b], L. Rezzolla [dh,di], P. Romano [dj], R. Ruffini [dk,dl], S. Savaglio [dm], V. Sguera [a], P. Schady [dn], W. Skidmore [do], L. Song [dp], E. Stanway [dq], R. Starling [j], M. Topinka [dr], E. Troja [ds,dt], M. van Putten [du], E. Vanzella [dv], S. Vercellone [dw], C. Wilson-Hodge [dx], D. Yonetoku [dy], G. Zampa [ad], N. Zampa [ad], B. Zhang [dz], B.B. Zhang [m], S. Zhang [ea], S.-N. Zhang [ea], A. Antonelli [eb], F. Bianco [ec], S. Boci [cg], M. Boer [ed], M.T. Botticella [bw], O. Boulade [z], C. Butler [a], S. Campana [h], F. Capitanio [ag], A. Celotti [ee,ef,eg], Y. Chen [ea], M. Colpi [eh,ei], A. Comastri [ej], J.-G. Cuby [ek], M. Dadina [a], A. De Luca [cb], Y.-W. Dong [ea], S. Ettori [ej,el], P. Gandhi [em], E. Geza [en], J. Greiner [bq], S. Guiriec [eo,ep,eq,er], J. Harms [es], M. Hernanz [et], A. Hornstrup [be], I. Hutchinson [b], G. Israel [af], P. Jonker [eu,ev], Y. Kaneko [ew], N. Kawai [ex], K. Wiersema [b], S. Korpela [ey], V. Lebrun [ek], F. Lu [ea], A. MacFadyen [ez], G. Malaguti [aa], L. Maraschi [h], A. Melandri [fa], M. Modjaz [fb], D. Morris [fc,fd], N. Omodei [fe], A. Paizis [ff], P. Páta [fg],

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THESEUS: A key space mission concept for Multi-Messenger Astrophysics

G. Stratta [a,b,l,*], R. Ciolfi [c,d], L. Amati [b], E. Bozzo [e], G. Ghirlanda [f], E. Maiorano [b], L. Nicastro [b], A. Rossi [b], S. Vinciguerra [g], F. Frontera [h,b], D. Götz [i], C. Guidorzi [h], P. O'Brien [j], J.P. Osborne [j], N. Tanvir [k], M. Branchesi [m,l], E. Brocato [x], M.G. Dainotti [n,b,aw], M. De Pasquale [o], A. Grado [p], J. Greiner [q], F. Longo [r,s], U. Maio [t,u], D. Mereghetti [v], R. Mignani [v,w], S. Piranomonte [x], L. Rezzolla [y,z], R. Salvaterra [v], R. Starling [j], R. Willingale [j], M. Böer [aa], A. Bulgarelli [b], J. Caruana [ab], S. Colafrancesco [ac], M. Colpi [ad], S. Covino [f], P. D'Avanzo [f], V. D'Elia [ae,x], A. Drago [h], F. Fuschino [b], B. Gendre [ag,ah,af], R. Hudec [ai,aj], P. Jonker [ak,al], C. Labanti [b], D. Malesani [am], C.G. Mundell [an], E. Palazzi [b], B. Patricelli [ao], M. Razzano [ao], R. Campana [b], P. Rosati [h], T. Rodic [ap], D. Szécsi [aq,ar], A. Stamerra [ao], M. van Putten [as], S. Vergani [at,f], B. Zhang [au], M. Bernardini [av]

[a] Università degli Studi di Urbino, Dipartimento Scienze Pure e Applicate, via S. Chiara 27, 61029, Urbino, Italy
[b] INAF - OAS Bologna, via P. Gobetti 93/3, Bologna, Italy
[c] INAF, Osservatorio Astronomico di Padova, Vicolo dell' Osservatorio 5, I-35122 Padova, Italy
[d] INFN-TIFPA, Trento Institute for Fundamental Physics and Applications, via Sommarive 14, I-38123 Trento, Italy
[e] Department of Astronomy, University of Geneva, ch. d'Écogia 16, CH-1290 Versoix, Switzerland
[f] INAF - Osservatorio astronomico di Brera, Via E. Bianchi 46, Merate, LC I-23807, Italy
[g] Institute of Gravitational Wave Astronomy & School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, United Kingdom
[h] Department of Physics and Earth Sciences, University of Ferrara, Via Saragat 1, I-44122 Ferrara, Italy
[i] IRFU/Département d'Astrophysique, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
[j] Department of Physics and Astronomy, University of Leicester, Leicester LE1 7RH, United Kingdom
[k] University of Leicester, Department of Physics and Astronomy and Leicester Institute of Space & Earth Observation, University Road, Leicester LE1 7RH, United Kingdom
[l] INFN, Sezione di Firenze, via G. Sansone 1, 50019 Sesto Fiorentino, Italy
[m] Gran Sasso Science Institute (GSSI), Viale Francesco Crispi, 7, I-67100 L'Aquila, Italy
[n] Department of Physics & Astronomy, Stanford University, Via Pueblo Mall 382, Stanford, CA 94305-4060, USA
[o] Department of Astronomy and Space Sciences, Istanbul University, Beyazit, 34119 Istanbul, Turkey
[p] INAF-Capodimonte Astronomical observatory Naples, Via Moiariello 16, I-80131 Naples, Italy
[q] Max Planck Institute for Astrophysics, Karl-Schwarzschild-Str. 1, 85741 Garching, Germany
[r] Department of Physics, University of Trieste, via Valerio 2, Trieste, Italy
[s] INFN Trieste, via Valerio 2, Trieste, Italy
[t] Leibniz Institut for Astrophysics, An der Sternwarte 16, 14482 Potsdam, Germany
[u] INAF-Osservatorio Astronomico di Trieste, via G. Tiepolo 11, 34131 Trieste, Italy
[v] INAF - Istituto di Astrofisica Spaziale e Fisica Cosmica Milano, via E. Bassini 15, 20133 Milano, Italy
[w] Janusz Gil Institute of Astronomy, University of Zielona Góra, Lubuska 2, 65-265 Zielona Góra, Poland
[x] INAF-Osservatorio Astronomico di Roma, Via Frascati 33, I-00040 Monte Porzio Catone, Italy
[y] Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, Max-von-Laue-Straße 1, 60438 Frankfurt, Germany
[z] Frankfurt Institute for Advanced Studies, Ruth-Moufang-Straße 1, 60438 Frankfurt, Germany
[aa] ARTEMIS, CNRS UMR 5270, Université Côte d'Azur, Observatoire de la Côte d'Azur, boulevard de l'Observatoire, CS 34229, F-06304 Nice Cedex 04, France
[ab] Department of Physics & Institute of Space Sciences & Astronomy, University of Malta, Msida MSD 2080, Malta
[ac] School of Physics, University of Witwatersrand, Private Bag 3, Wits-2050, Johannesburg, South Africa

* Corresponding author at: Università degli Studi di Urbino, Dipartimento Scienze Pure e Applicate, via S. Chiara 27, 61029, Urbino, Italy.
E-mail address: giulia.stratta@uniurb.it (G. Stratta).

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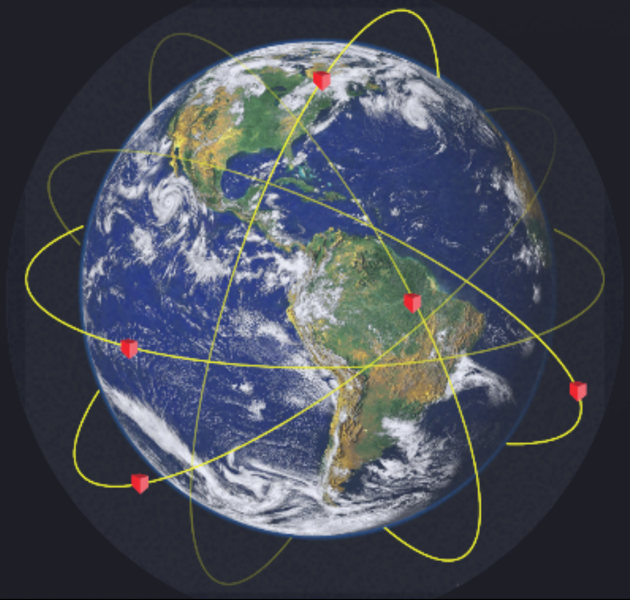
HermeS

High Energy Rapid Modular Ensemble of Satellites



HERMES: a constellation of nano-satellites for high energy astrophysics and fundamental physics research

http://hermes.dsf.unica.it/

INAF OAS BOLOGNA

OAS Days - 18th December 2018

Mission concept

Disruptive technologies: cheap, underperforming, but producing high impact. Distributed instrument, tens/hundreds of simple units

HERMES constellation of cubesat

2016: ASI funds for detector R&D
2018: MIUR funds for pathfinder (Progetti premiali 2015)
2018 H2020 Space-SCI-20 project

2018 ASI internal proposal

HERMES main goals

How to *promptly* localise a GRB *prompt* event?

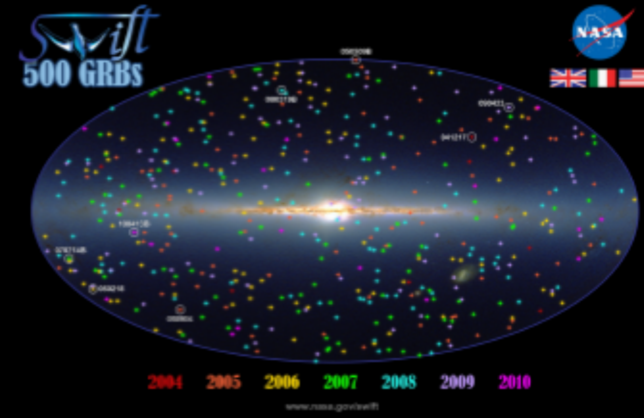
GW/ Multi-messenger astrophysics

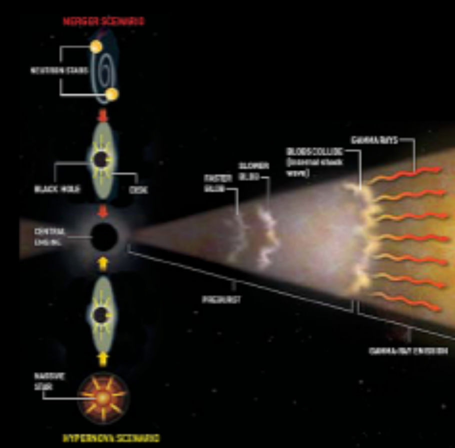
How to construct a GRB engine?

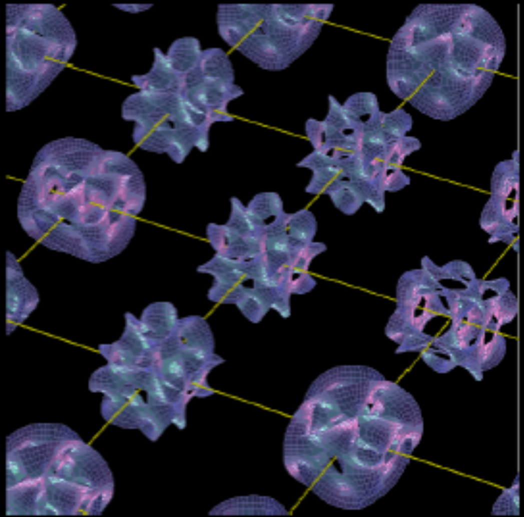
Jet / BH / NS physics, GRB progenitors

Which is the ultimate granular structure of space-time?

Fundamental physics, quantum gravity

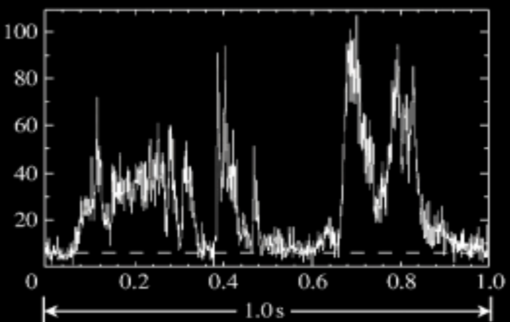






1. Measure GRB positions through delays between photons arrival times:

$\sigma_{Pos} = \sigma_{CCF}$ x c / <B> / (Nx(N –1– 2)$^{1/2}$



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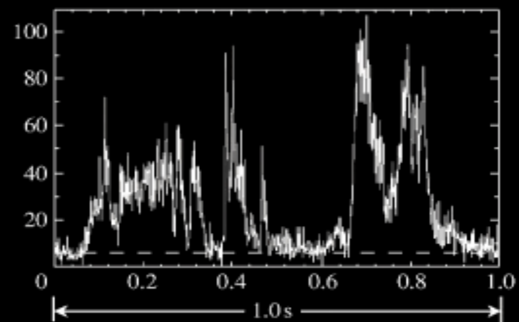

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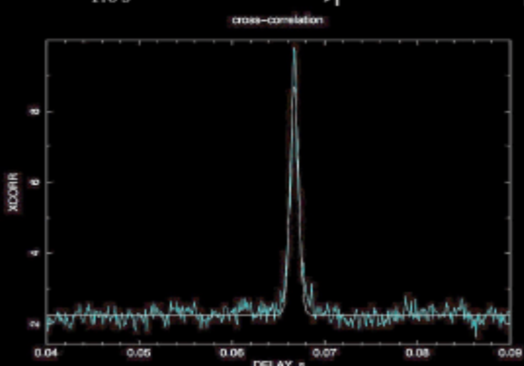
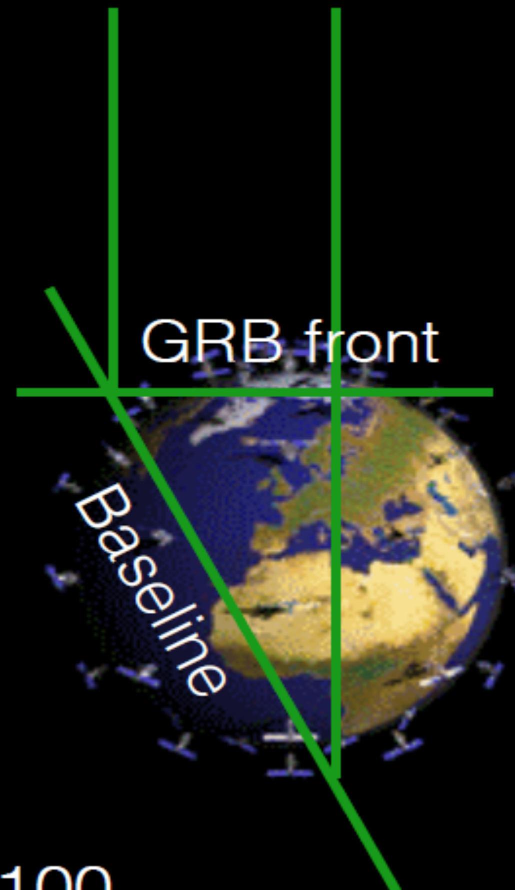


$\sigma_{CCF} \sim 10\mu s$

$\sigma_{Pos} \sim 10$arcsec

if <B>~7000km, N~100



Arcmin-arcsec positions of ~a few dozen GRB/yr

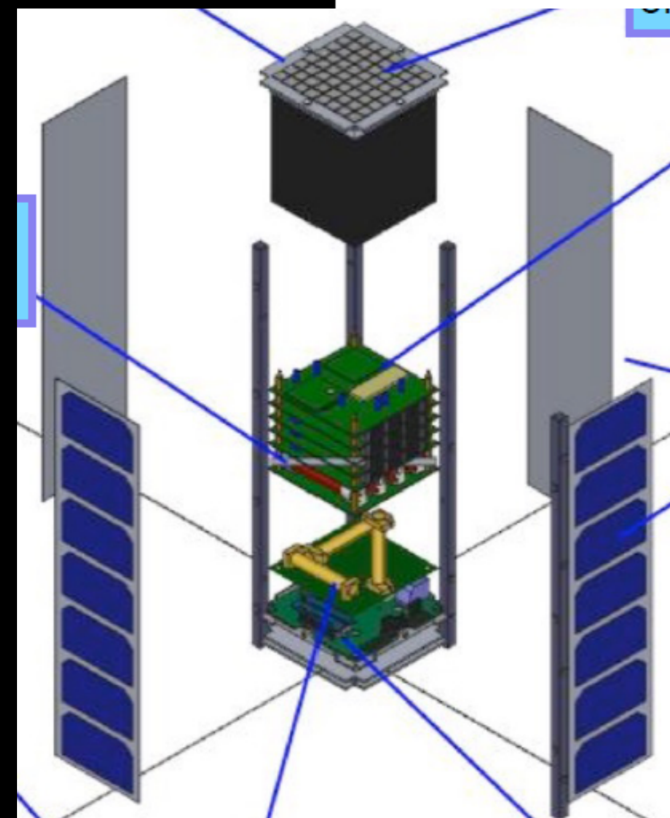
Prompt(minute) localisation

μs timing

$\Delta t/\Delta E \sim 3\mu s/100keV\ 30\mu s/1MeV \longrightarrow M_{QG} \sim M_{Planck}$

HERMES performances

$$\sigma_{Pos} = 2.4°[(\sigma_{CCF}{}^2 + \sigma_{sys}{}^2)/(N-3)]^{0.5}$$



<B>~7000km

N(pathfinder)~6-8, active simultaneously 4-6

N(final constellation) ~100, active 50

$\sigma_{Pos(pathfinder)}$ ~ 1 arcmin if σ_{CCF}, σ_{sys}~10usec

$\sigma_{Pos(FC)}$ <1arcsec if σ_{CCF}, σ_{sys}~10usec

Bright GRBs with msec structure

$\sigma_{Pos(pathfinder)}$ ~ 2.4 deg if σ_{CCF},σ_{sys}~0.001s

$\sigma_{Pos(FC)}$ ~ 3 arcmin if σ_{CCF},σ_{sys}~0.001s

Short GRBs without substructure, risetime fraction of second.

HERMES Institutes

- INAF, ASI, PoliMi, UniCagliari, UniPalermo, UniUdine, UniTrieste, UniPavia, UniFedericoII, UniFerrara, FBK, FPM

HERMES is open to ideas and collaboration

Want to be involved? Send an e-mail

fabrizio.fiore@inaf.it

burderi@dsf.unica.it

HERMES: OAS main contributors

Claudio Labanti (responsabile payload development)

Riccardo Campana and Fabio Fuschino (payload development key persons)

Gianluca Morgante, Luca Terenzi, Mauro Orlandini, Alessandro Mauri (payload development support)

Lorenzo Amati, Filippo Frontera (scientific support)

THESEUS – HERMES - ASTENA Synergies

- **HERMES** can be considered a technological (and partly scientific) pathfinder to **THESEUS/XGIS**
- The **ASTENA WFM** is a further application and development of the detection system concept behind **THESEUS/XGIS** and **HERMES** (and GRBs also in the cores science of **ASTENA**)
- The R&D, including simulations, for **HERMES** and **ASTENA/WFM** will contribute to enhancing **THESEUS/XGIS** TRL at the end of Phase-A
- Current proposed organization for the **AHEAD-2** proposal includes a WP on Instrumentation for GRB & multi-messenger astrophysics, coordinated by L. Hanlon and L. Amati and including support to **HERMES, THESEUS and ASTENA**

HERMES and THESEUS

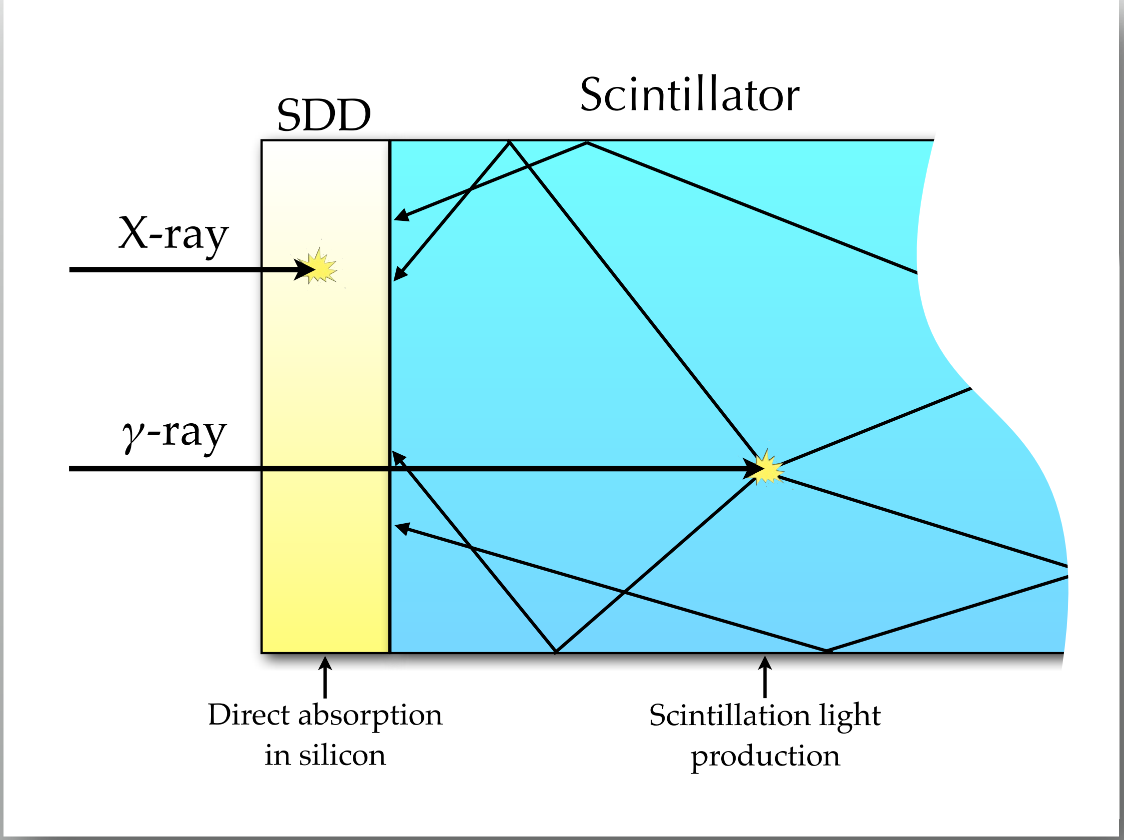
Synergies and technology towards a development path

Riccardo Campana

OAS Days 17–18 December 2018

The *siswich* architecture

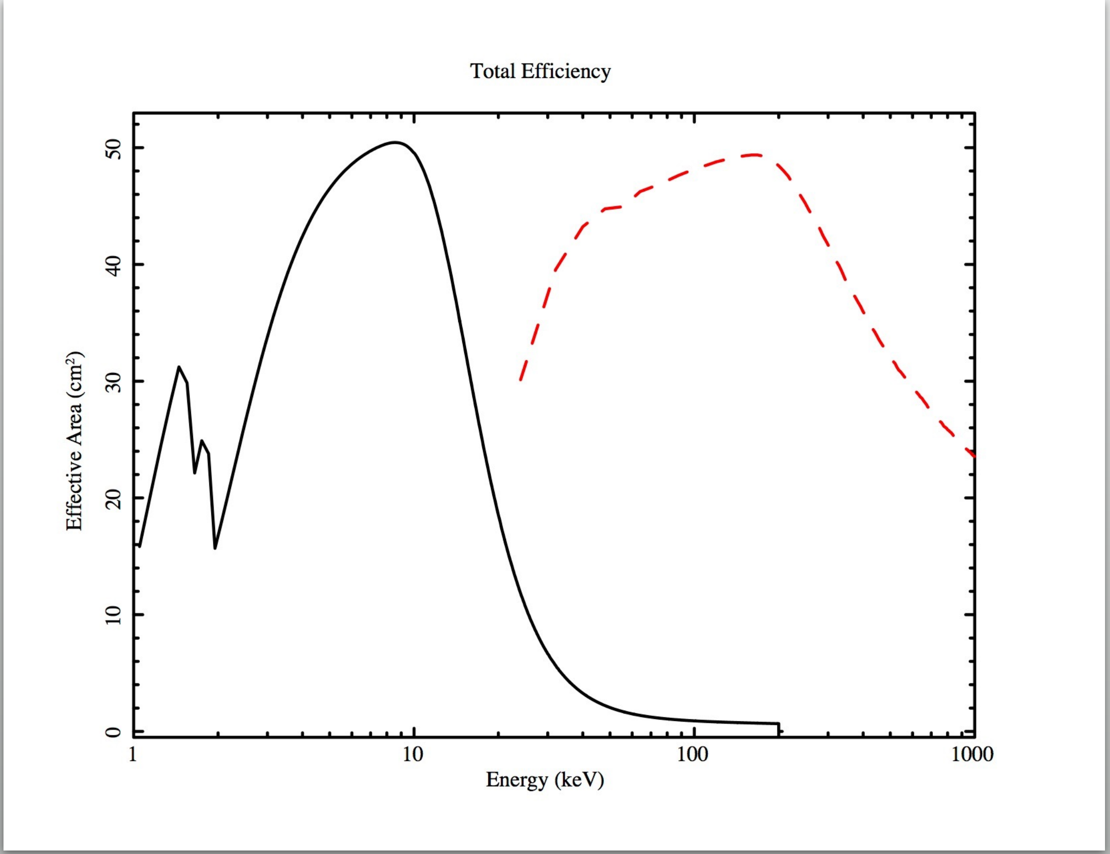
The **key** to both HERMES and THESEUS:
coupling of **Silicon Drift Detectors** (SDDs) and **scintillators**.
SDDs are sensitive to both X-rays and optical (scintillation) photons



Marisaldi+04
Labanti+05
Labanti+08
Campana+16

A huge sensitivity band

This allows for a monolithic detector with a **huge** sensitivity band,
from ~1–2 keV to several tens of MeV



Campana+16
Fuschino+16
Campana+18
Fuschino+18

HERMES

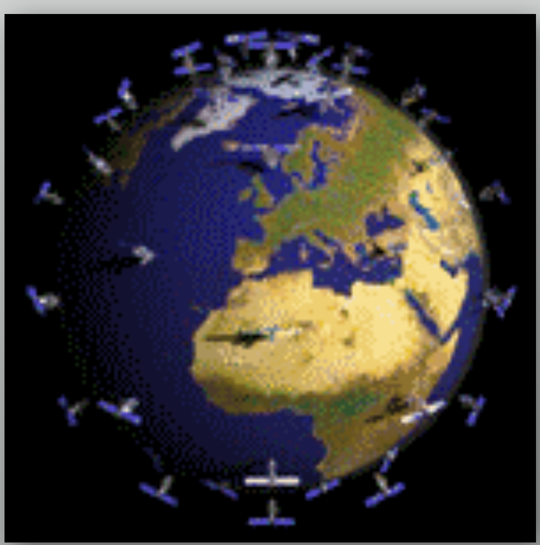
2015: **ASI tecnological project** (R&D on detectors and architecture)
2017: MIUR **Progetto Premiale**, led by ASI: *HERMES Technological Pathfinder*
2018: **H2020** project: *HERMES Scientific Pathfinder*

Disruptive technologies: **cheap**, **underperforming**, **but** producing **high impact**.

Distributed instrument: tens/hundreds of simple units

HERMES is a constellation of CubeSats

*(**H**igh **E**nergy **R**apid **M**odular **E**nsemble of **S**atellites)*



Modularity

- Avoid single point failures, improve hardware
- Pathfinder

Limited cost and quick development

- COTS and in-house components
- Cost reduction of manifacturing: direct launch of QM

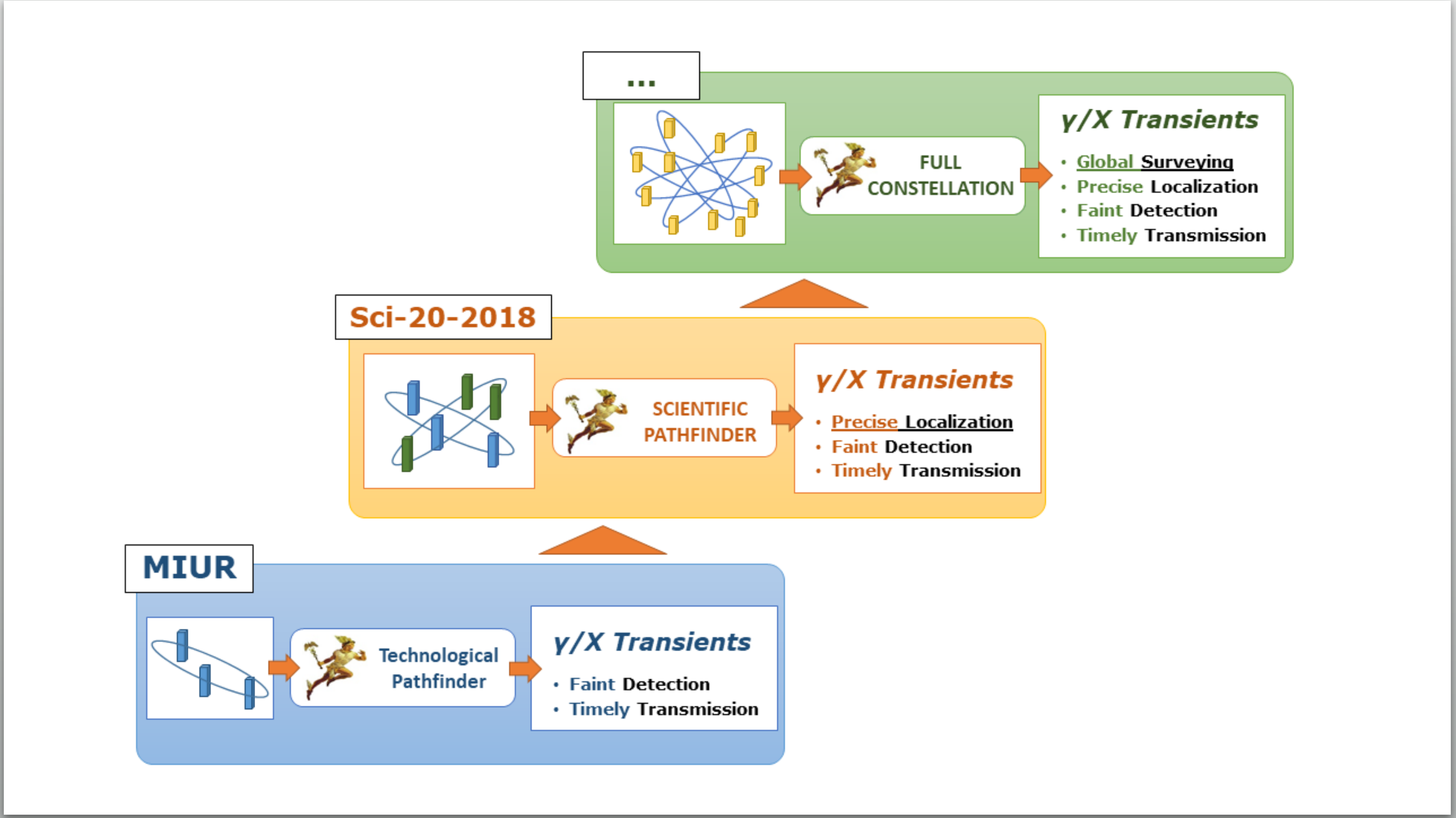
HERMES will open the submillisecond time window for GRB science

- Accurate positions
- Quantum gravity tests

Why now? Breakthrough scientific case: electromagnetic counterparts of gravitational wave events

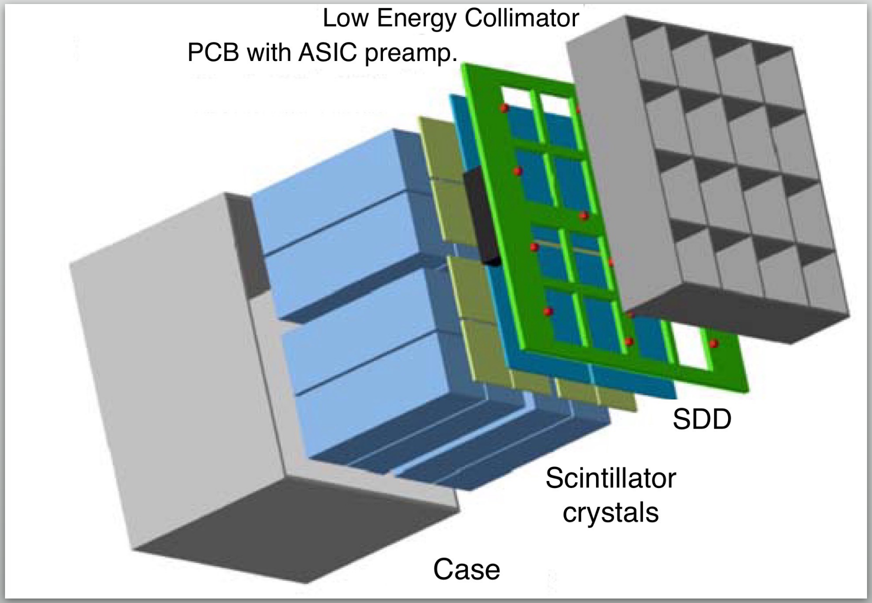
HERMES

2015: **ASI tecnological project** (R&D on detectors and architecture)
2017: MIUR **Progetto Premiale**, led by ASI: *HERMES* ***Technological*** *Pathfinder*
2018: **H2020** project: *HERMES* ***Scientific*** *Pathfinder*

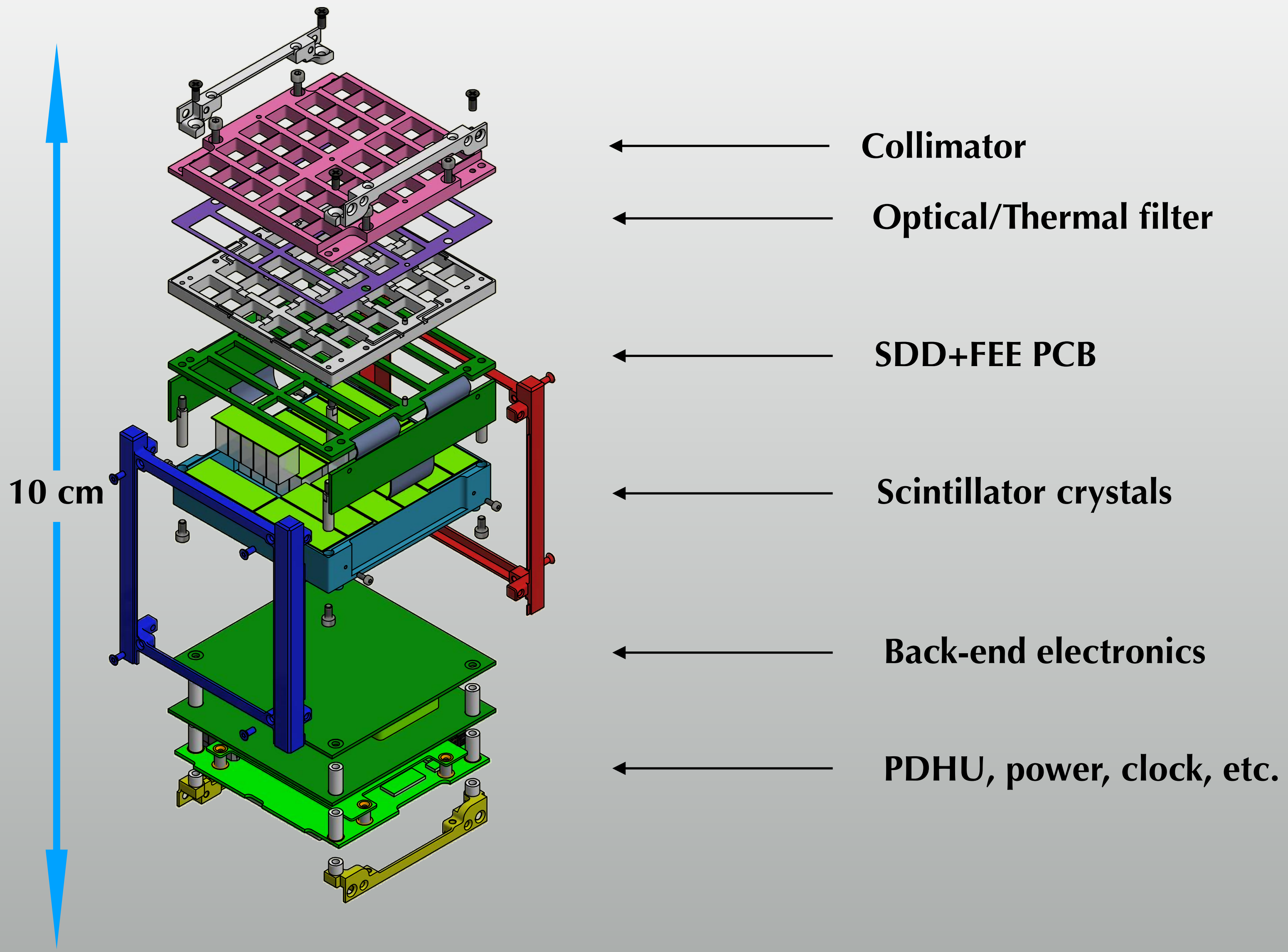


HERMES

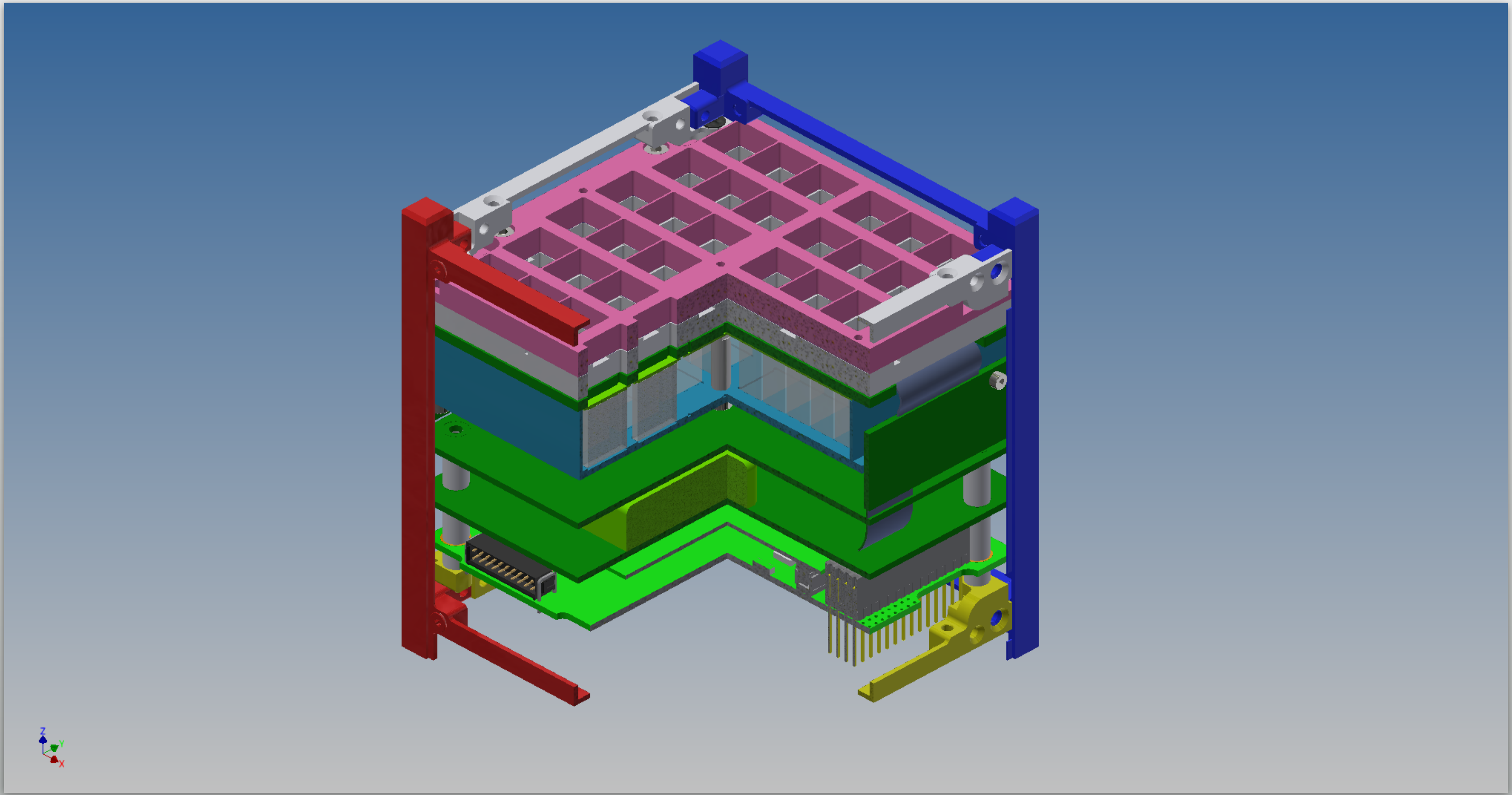
- A huge sensitivity band in a modular instrument within 10×10×10 cm^3
- "**Siswich**" architecture: Silicon Drift Detector + scintillator. SDD acts **both** as direct X-ray instrument and as photodiode for scintillator light readout
- Scintillator cristal: GAGG:Ce
- 5–300 keV main scientific band
- Sensitive in **2–2000 keV**
- ~50 cm^2 collecting area
- A few sr FOV at low energies
- Temporal resolution 100 ns
- **~1.5 kg**
- less than **4 W** power consumption



A complex detector in 1 liter volume



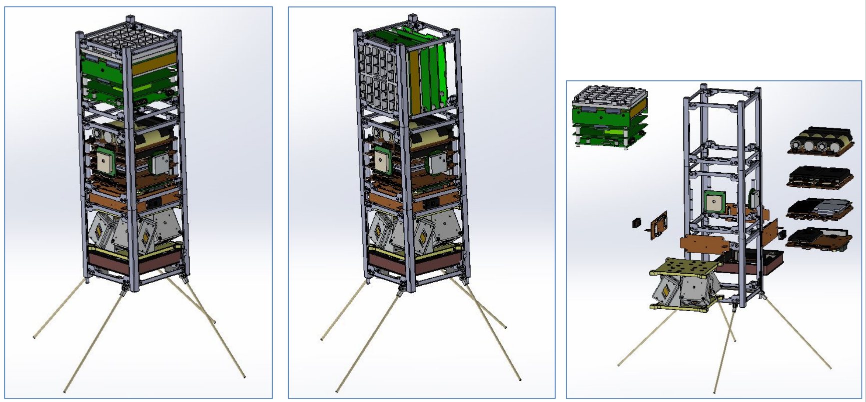
HERMES payload preliminary design



Ongoing mission studies

The HERMES consortium, with the **full involvement of the INAF/OAS team**, is now performing detailed mission studies in various scenarios

WP3 DESIGN REVIEW: state of the art – Space segment options



Detector allocation
CubeSat avionics
Telemetry and ground stations
Pointing strategy

Constellation configuration
Optimization of the scientific return
Thermal studies
Radiation damage
Launch opportunities

WP3 DESIGN REVIEW: state of the art – option example

3 sats 550km SSO

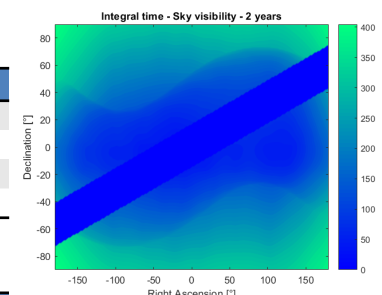
Absolute Orbits

Orbit SSO 550 km	
h [km]	550
e [-]	0
i [°]	97.6
Ω [°]	281.3

Injection

Orbit	Direction	Δv [m/s]
SSO 550km	+V-bar	1
SSO 550km	-V-bar	1
SSO 550km	+H-bar	1

Sky Visibility



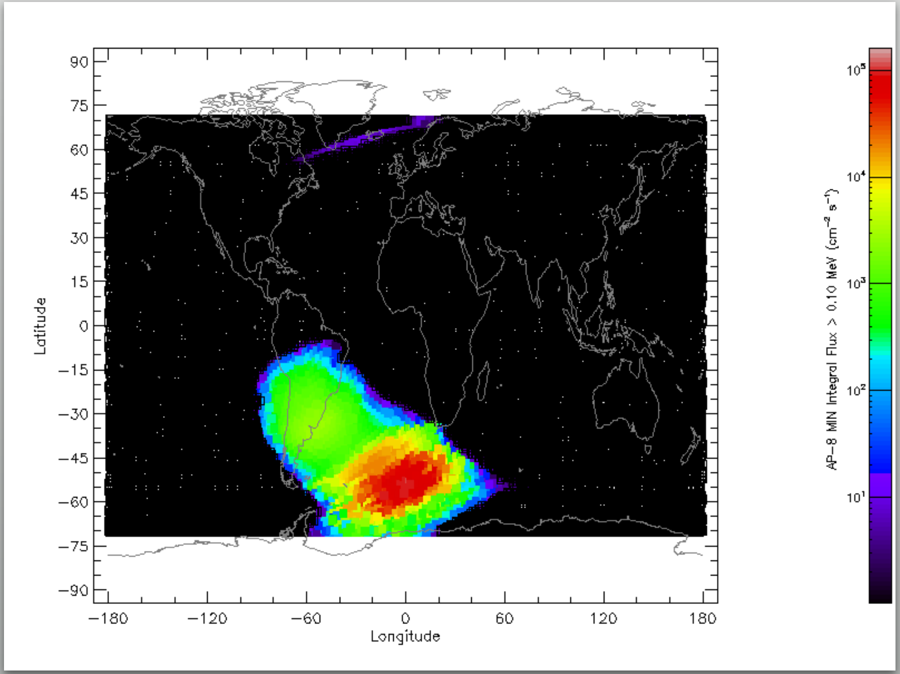
- Max Integral: **412.7 days** (fixed inertial direction)
- Weekly-maneuver: **503.3 days** (each week maximum inertial direction pointing)

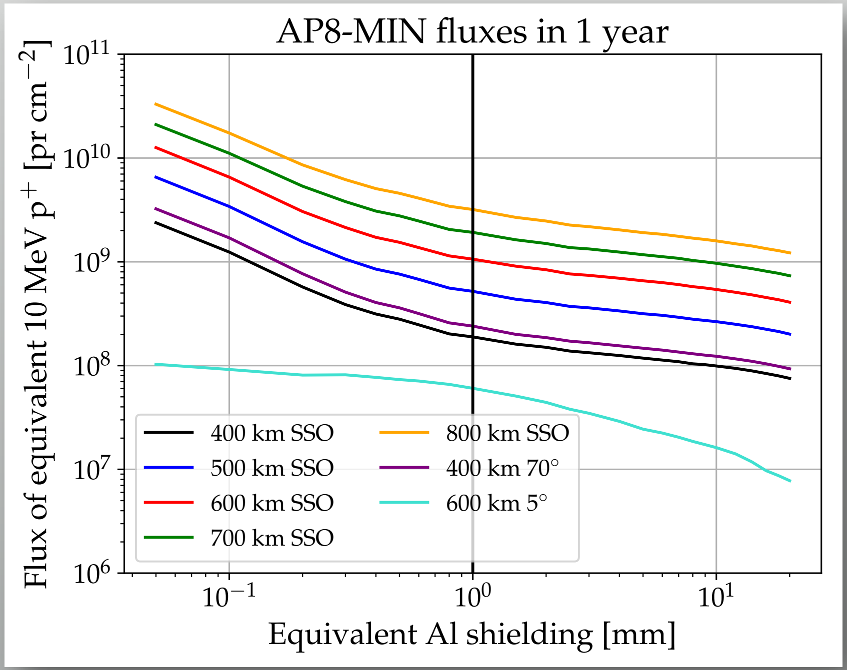
Sky visibility computed meeting the following requirements:
- Sun avoidance (50°)
- Earth (Earth radius + 120 km Atmosphere)
- Galactic equator (+/- 15°)
- Projected Baseline (>1000 km)

Time to first potential triangularization: **~3.97 days**

Trade-off studies at OAS

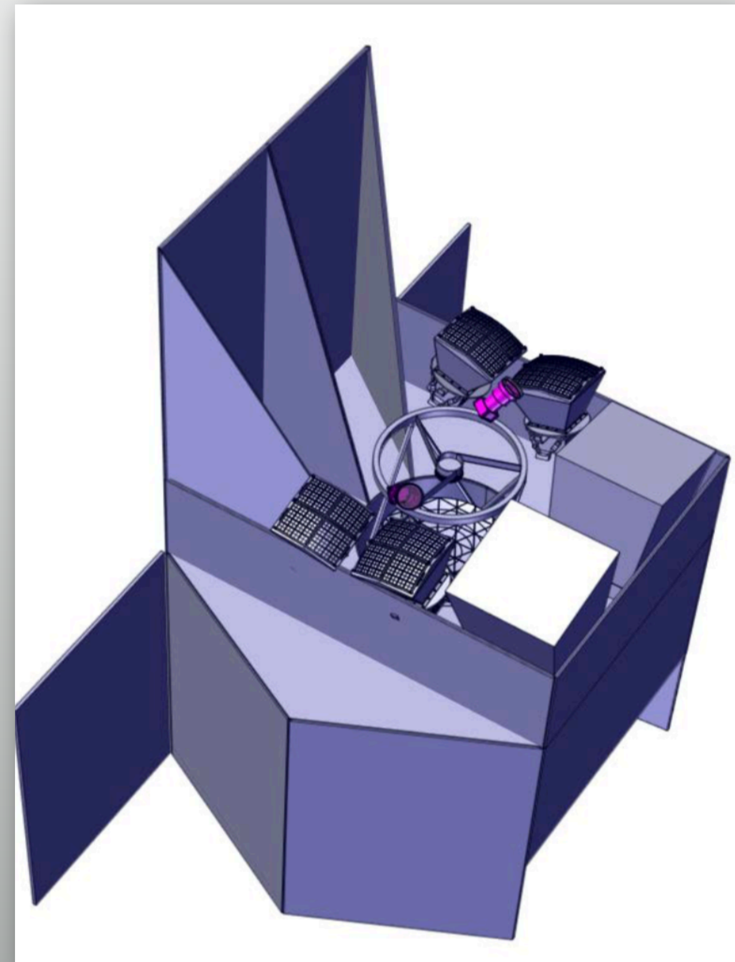
HERMES cubesats are a *secondary* payload, therefore we do not have much choice for the final satellite orbits... **Radiation damage** (due to high-energy proton space environment) and **orbital decay** will limit the useful lifetime.
For the first launches the orbit will likely be sun-synchronous, high inclination, 500–600 km altitude, ~circular (TBC)
Equatorial low altitude orbits are preferred from a radiation damage standpoint ...but also for their lower background! (**Geant-4 simulations**)





THESEUS

Transient High Energy Sky and Extreme Universe Surveyor
A **ESA-M5** mission candidate, currently in **Phase A**



Three main instruments:
SXI (Soft X-ray Imager) led by UK
IRT (InfraRed Telescope) led by France
XGIS (X and Gamma Imaging Spectrometer) led by Italy

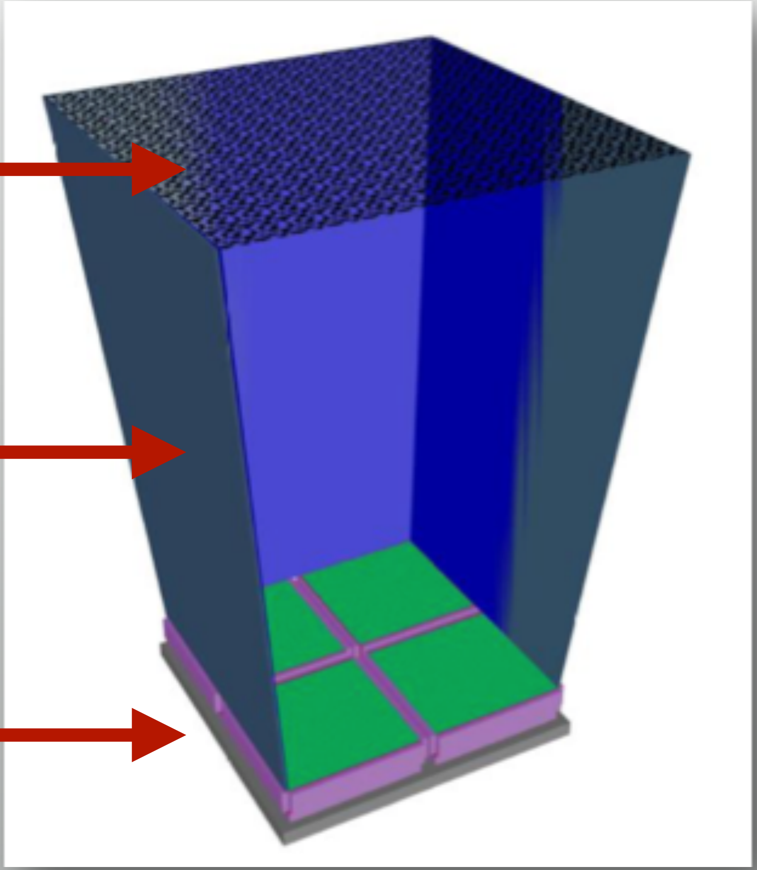
The XGIS instrument

At a glance – One unit

Coded mask
Provides imaging capabilites
below ~30 keV

Collimator
Shields the FoV
below ~150 keV

Detector plane
9x9 modules with
SDD and CsI(Tl) scintillator



The XGIS instrument

At a glance – One unit

Energy band	2 keV – 20 MeV
# of detection plane modules	100 (10×10)
# of detector pixels per module	64 (8×8)
Low Energy detector (2–30 keV)	SDD (450 μm thick)
High Energy detector (30 keV – 20 MeV)	CsI(Tl) (3 cm thick)
Discrimination LE/HE modes	Pulse shape analysis
Dimensions	63×63×80 cm^3
Weight	81 kg

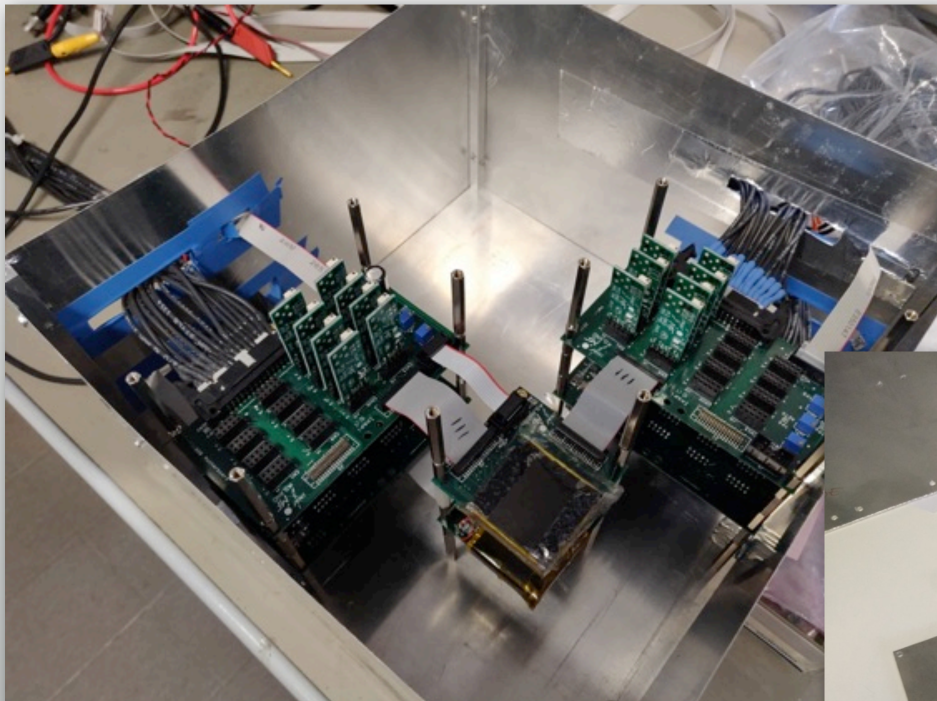
The XGIS instrument

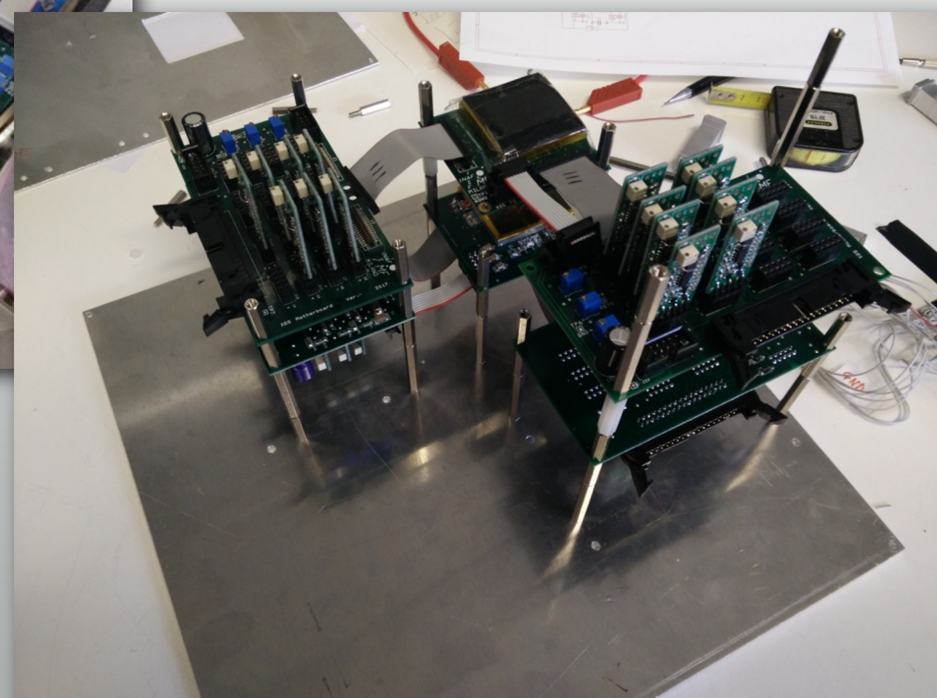
At a glance – One unit

Energy band	2–30 keV	30–150 keV	>150 keV
Half sensitivity FoV	60° × 60°	60° × 60° (FWHM)	–
Total FoV	77° × 77°	~100° × 100° (FWZR)	2π sr
Angular resolution	~ 5' at 6 sigma	–	–
Energy resolution	200 eV FWHM at 6 keV	18% FWHM at 60 keV	6% FWHM at 600 keV
Timing resolution	1 μs	1 μs	1 μs
On-axis useful area	518 cm^2	1296 cm^2	1296 cm^2

Ongoing mission studies at OAS

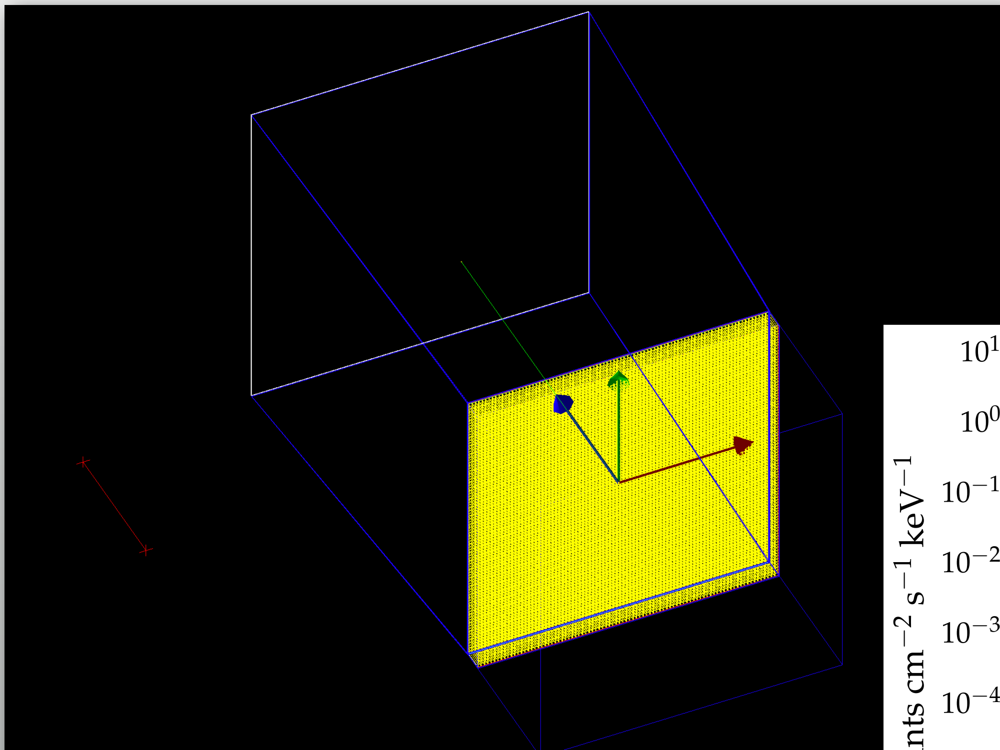
Prototyping activity in the Gamma Laboratory

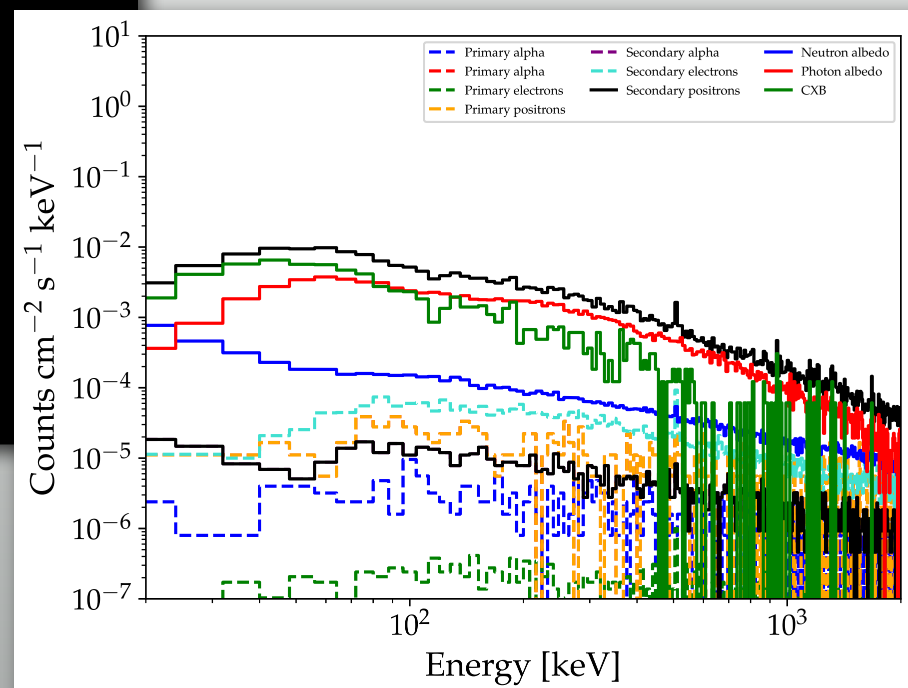




Ongoing mission studies at OAS

Geant4 based MonteCarlo **simulator** for XGIS and **background** studies





The XGIS instrument

THESEUS Phase A (2019–2021)

next steps at OAS

(1–2 AdR positions will be available in 2019 on THESEUS simulations and technology)

1. Development of a **consolidated XGIS design**
   i) *Detector plane with FEE, BEE and PDHU*
   ii) *Coded mask imaging system*
2. **Scientific simulations** and performance optimization
3. **Monte Carlo Geant-4 simulations**, response matrices and background studies
4. **Laboratory prototypes** of a fully integrated detection module

X & Gamma Silicon Detectors for Space Applications

F. Fuschino on behalf
of the OAS Group

Main actors

Claudio Labanti
(Coordinator)

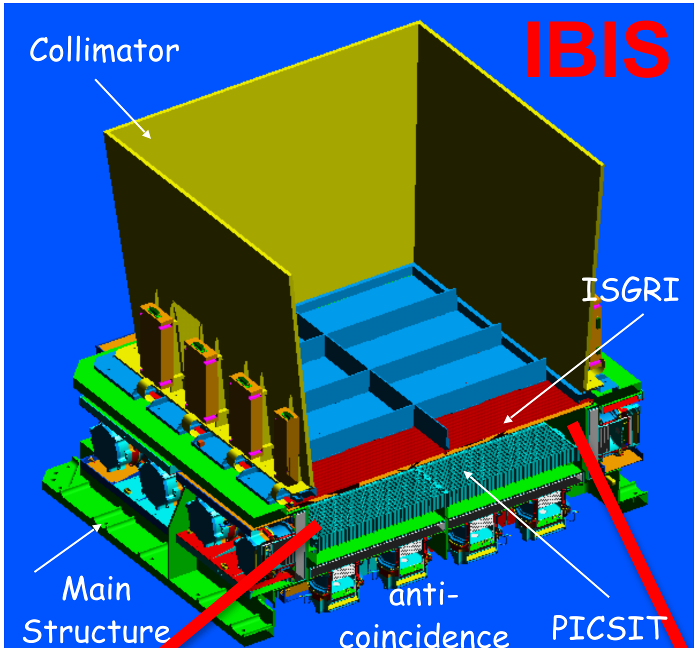
Riccardo Campana

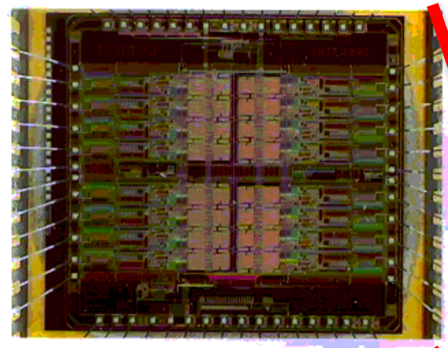
Fabio Fuschino

Alessandro Mauri
(Associato)

PiCsIT on board INTEGRAL

Responsible: C. Labanti

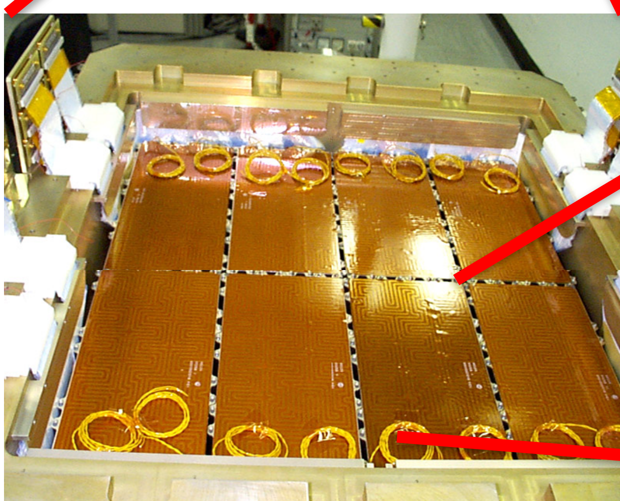


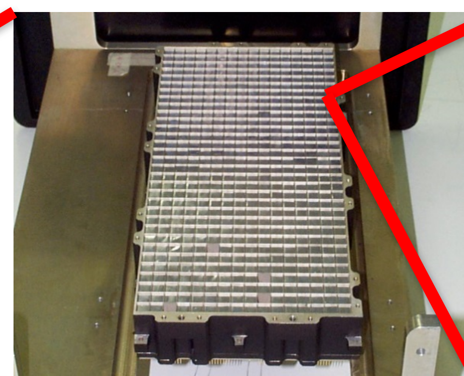


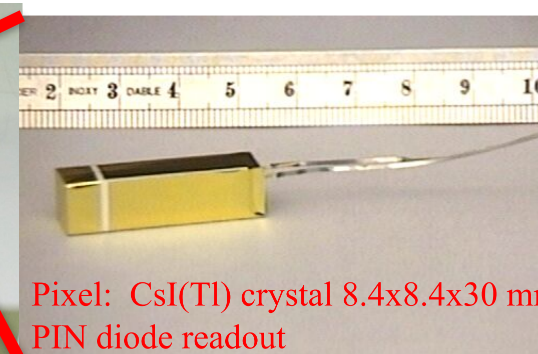
ICARUS ASIC

INTEGRAL overall weight ~ 4000 kg

PICsIT
4096 Pixel
Sensitive Area 2890 cm²
Range 180 keV – 20 MeV



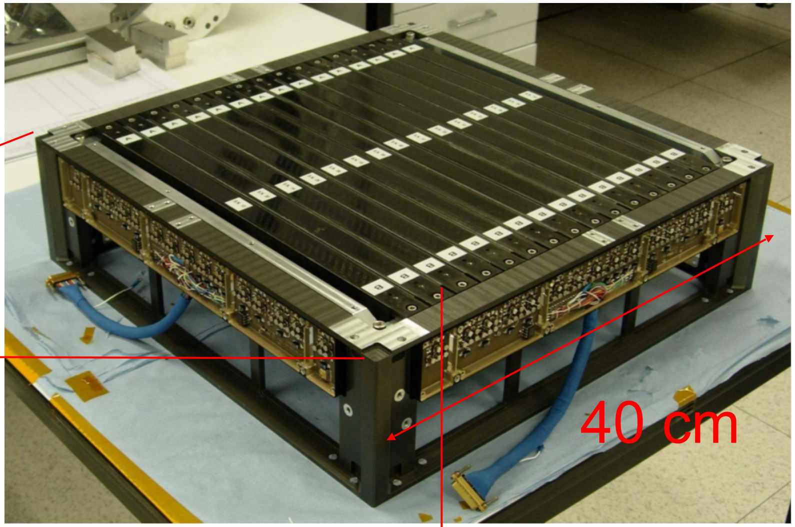


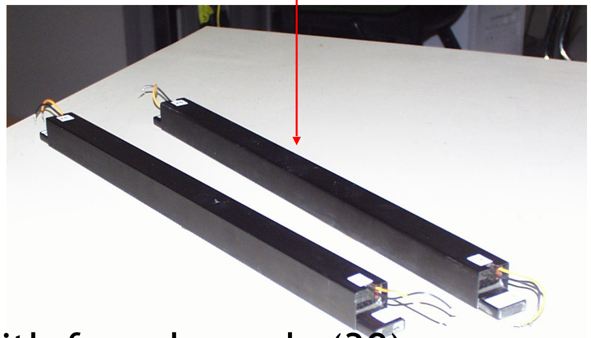


MCAL on board AGILE

Responsible: C. Labanti

AGILE overall weight ~ 350 kg

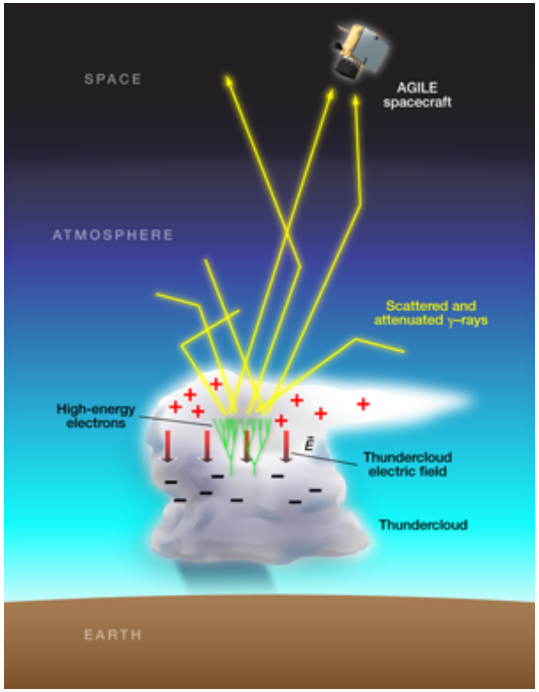




Constraints:
- Low weight
- Low power → few channels / solid state readout
- Low telemetry budget → on-board trigger logic

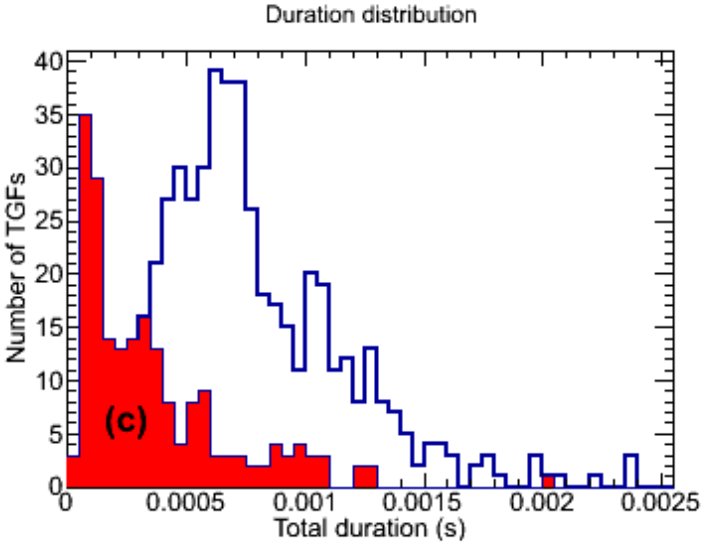
Design choices:
- Hodoscopic architecture → position reconstruction with few channels (30)
- PD readout: 350 keV threshold → energy range extended up to 100 MeV
- Trigger logic → very short time scales (300 μs, 1 ms) + photon-by-photon data + GPS

Terrestrial Gamma Flashes (TGFs)

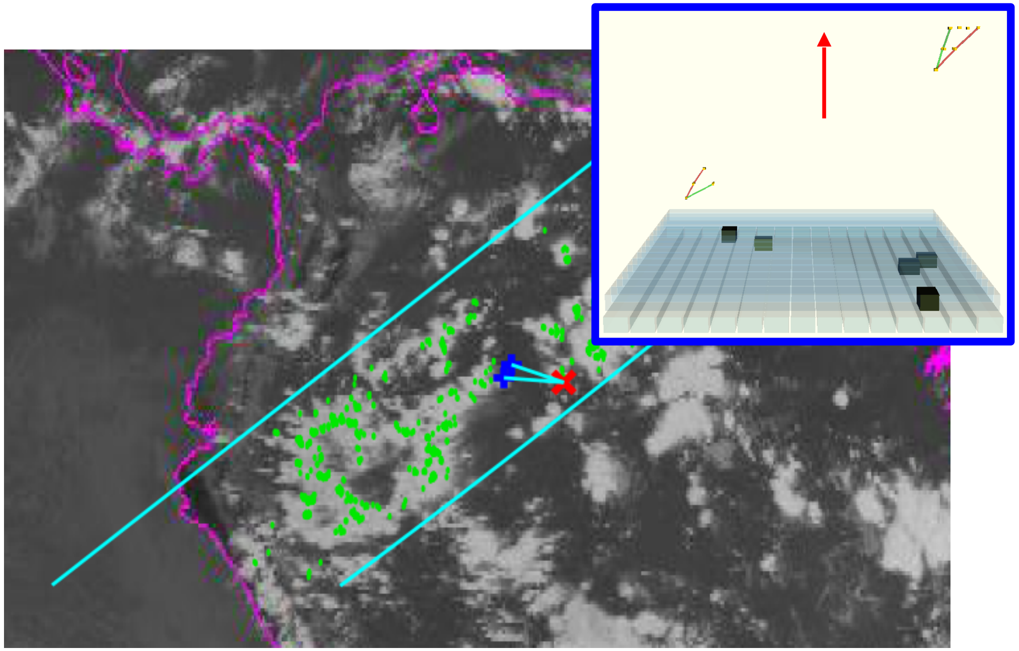


Credit: Alan Stonebraker

Enhanced TGFs detection capability
Marisaldi+2015

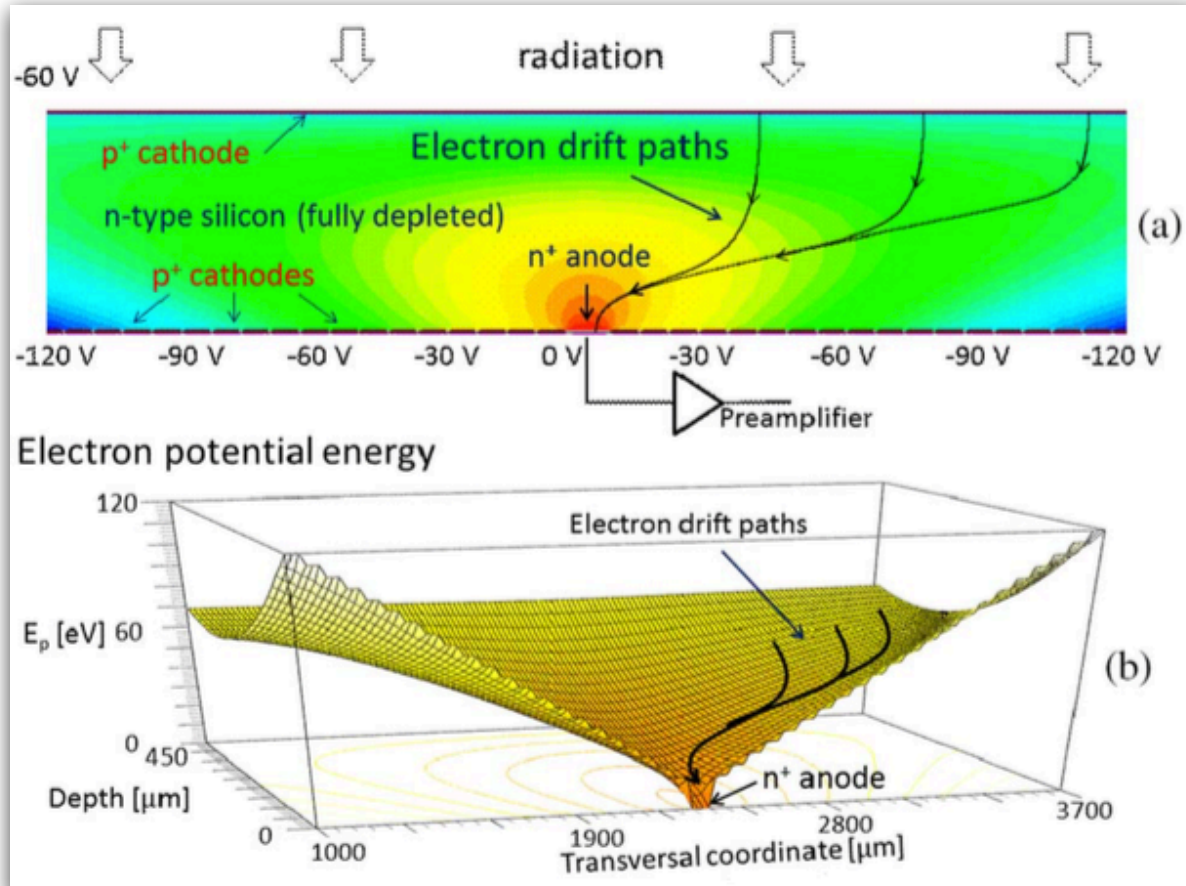


First TGFs localization
Marisaldi+2010



Basic Principle of SDD Silicon Drift Detector

Anode Capacitance: as small as possible



Credits: Bertuccio+16

Gatti+1984

The redSox Collaboration

RESEARCH DRIFT FOR SOFT X-RAYS

Funded by INFN - P.I. Prof.A.Vacchi

FONDAZIONE BRUNO KESSLER

CMM CENTER FOR MATERIALS AND MICROSYSTEMS

INFN Istituto Nazionale di Fisica Nucleare

UNIVERSITAS STUDIORUM UTINENSIS

Design, production & costs funding

POLITECNICO MILANO

ALMA TICINENSIS UNIVERSITAS

Extremely Low Noise Front End Electronics Design and production

INFN Istituto Nazionale di Fisica Nucleare

IMM Istituto per la Microelettronica e Microsistemi

Integration SDD & FEE

Nuclear Physics and Synchrotron light applications

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

SESAME

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA A.D. 1088

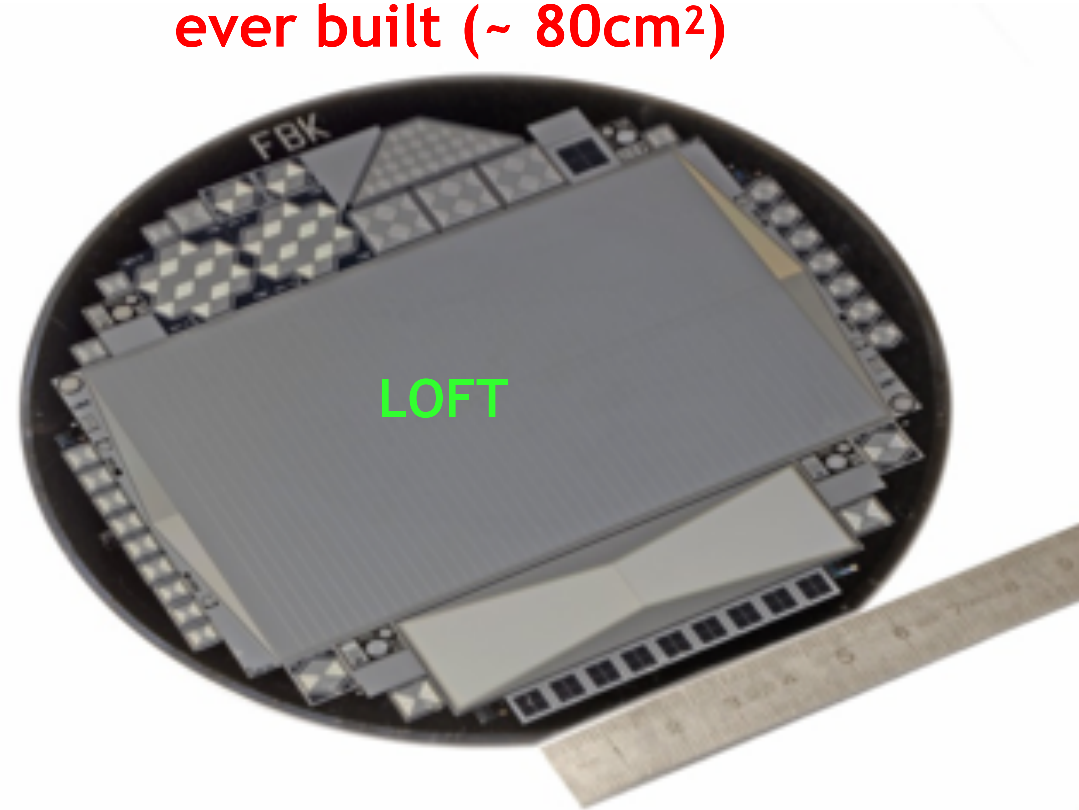
iaps

High Energy Astrophysics applications

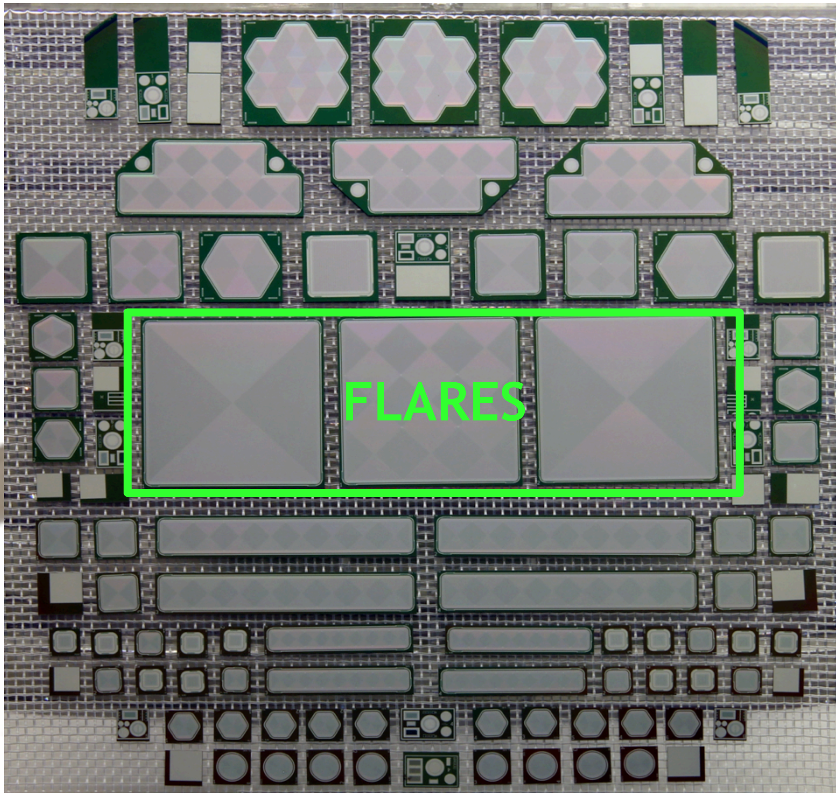
SDD within RESEARCH DRIFT FOR SOFT X-RAYS redSox Collaboration

6'' Silicon wafers

Largest SDD ever built (~ 80cm^2)



Single cell SDD with 900 mm^2 sensitive area

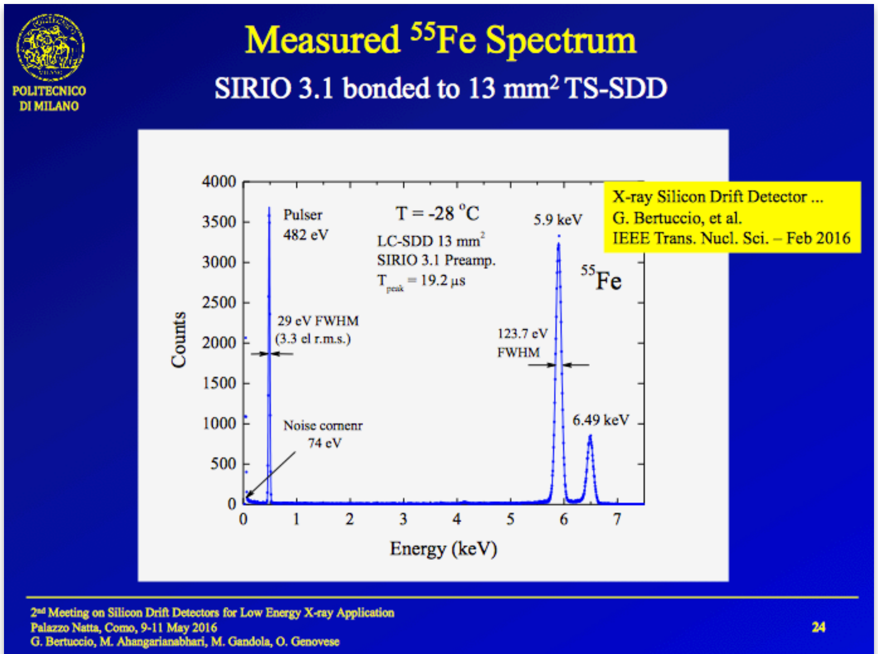


Low anode capacitance (few tens of fF)

Low leakage current (tens of pA/cm^2)

SDD Quantum Efficiency (QE) > 80%

State-of-the-art FEE performances



Extremely Low noise

Low power consumption

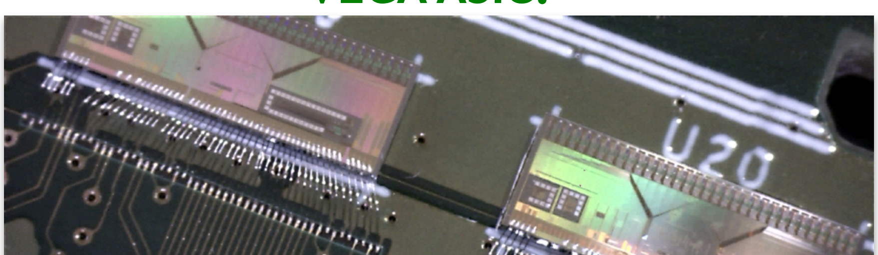
Low anode capacitance (SDD)

SIRIO Preamp (1 ch)

~ 10 mW / ch

ENC ~ 1.3 e- r.m.s.

VEGA ASIC:



32 parallel channels

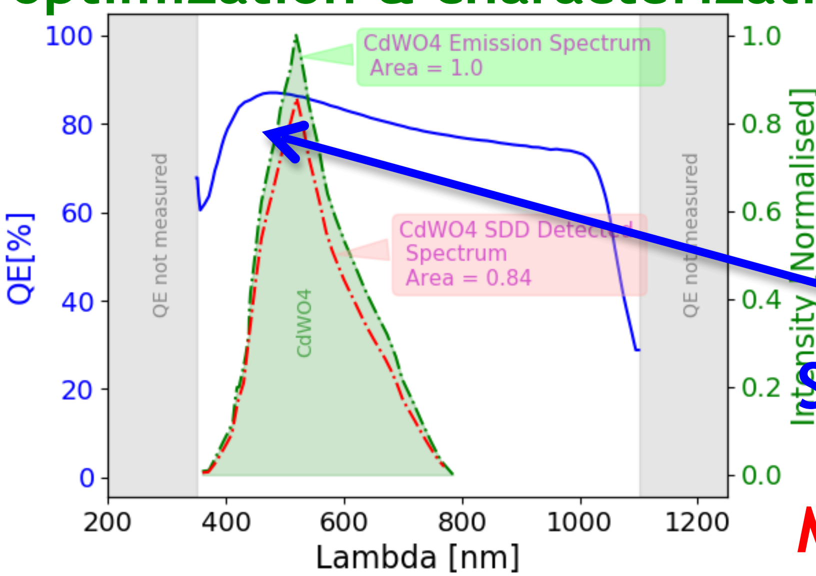
~ 0.5 mW / channel

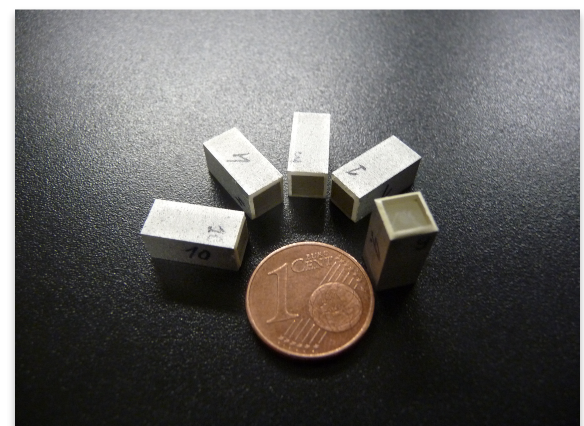
ENC ~ 15 e- r.m.s.

Scintillator readout with SDD

LaBr$_3$(Ce)

Optical properties optimization & characterization





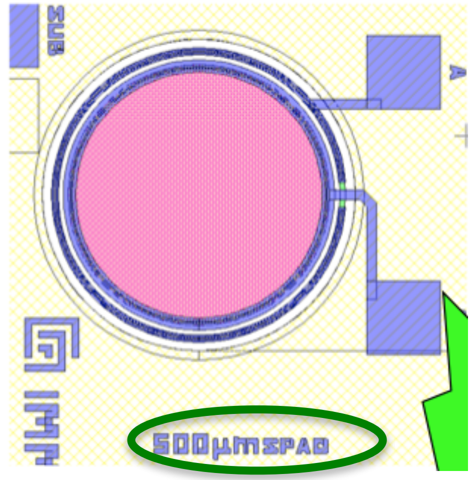
SDD QE > 80%

Max PMT QE < 40%

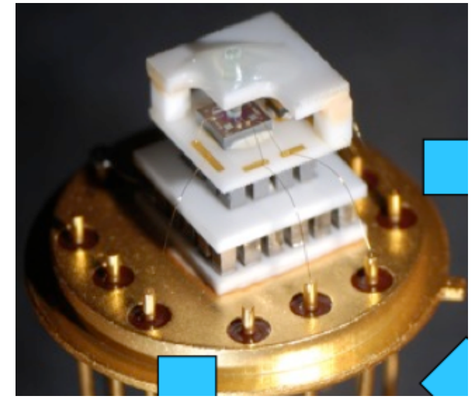
Other Silicon devices

SPAD
custom design & production
CNR/IMM Bologna
(FEE PoliMI)

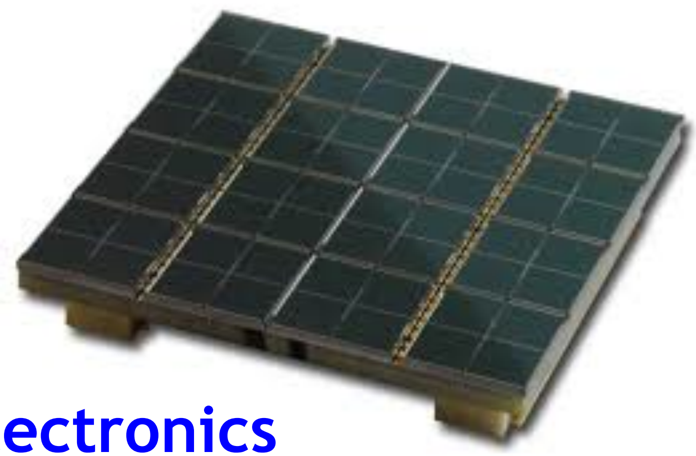
Sensor



Assembly



SiPM
(available on the market)



Equipped with fast readout electronics

Towards prototypes

- **Design of innovative architectures**
- **Sensors & FEE integration (bonds, etc.)**
- **Back End Electronics requirements (construction)**
- **Prototype Assembly**
- **Test Equipment**
- **Prototype tests & characterizations**

Space Missions

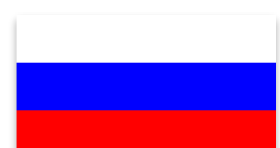
- LOFT (ESA Calls M3-M4-M5) → LAD & WFM
- NHXM → WFM
- THESEUS (ESA Calls M4-M5) → XGIS
- ASTROGAM (ESA Calls M4-M5) → Calorimeter
- PANGEA (ESA Earth Explorer Call EE9) → 3DCAL
- HERMES (MIUR, H2020Space)

LOFT today is :

eXTP

Strobe-X

MVN-M2



Enhancing the TRL with funded projects

INFN

XDXL	(SDD)	2008
ReDSoX	(SDD)	2012
ReDSoX2	(SDD)	2016
FLARES	(SDD+Cryo-cooling)	2014
FAMU	(PMT+$LaBr_3$:Ce+Cryo-cooling)	2014

INAF

WFM (Feroci)	(SDD)	2009
PICO (Marisaldi)	(SPAD)	2011
SDD + scintillatori (Labanti)	(SDD)	2011
XGS (Amati)	(SDD)	2015
Pixel drift (Feroci)	(SDD)	2015
COMPASS (Del Monte)	(SiPM)	2014

ASI

All sky Monitor (Feroci)	(SDD)	2007
LOFT (Stella/Feroci)	(SDD)	2008
Compton camera (Labanti)	(SDD)	2008
FiberSPAD (Marisaldi)	(SPAD)	2009
WFM (Piro/Feroci)	(SDD)	2014
PiXDD (Feroci)	(SDD)	2016
HERMES (Burderi)	(SiPM+SDD)	2016

Back-up slides

1.2. List of Beneficiaries

Project Number [1]	821896	Project Acronym [2]	HERMES-SP

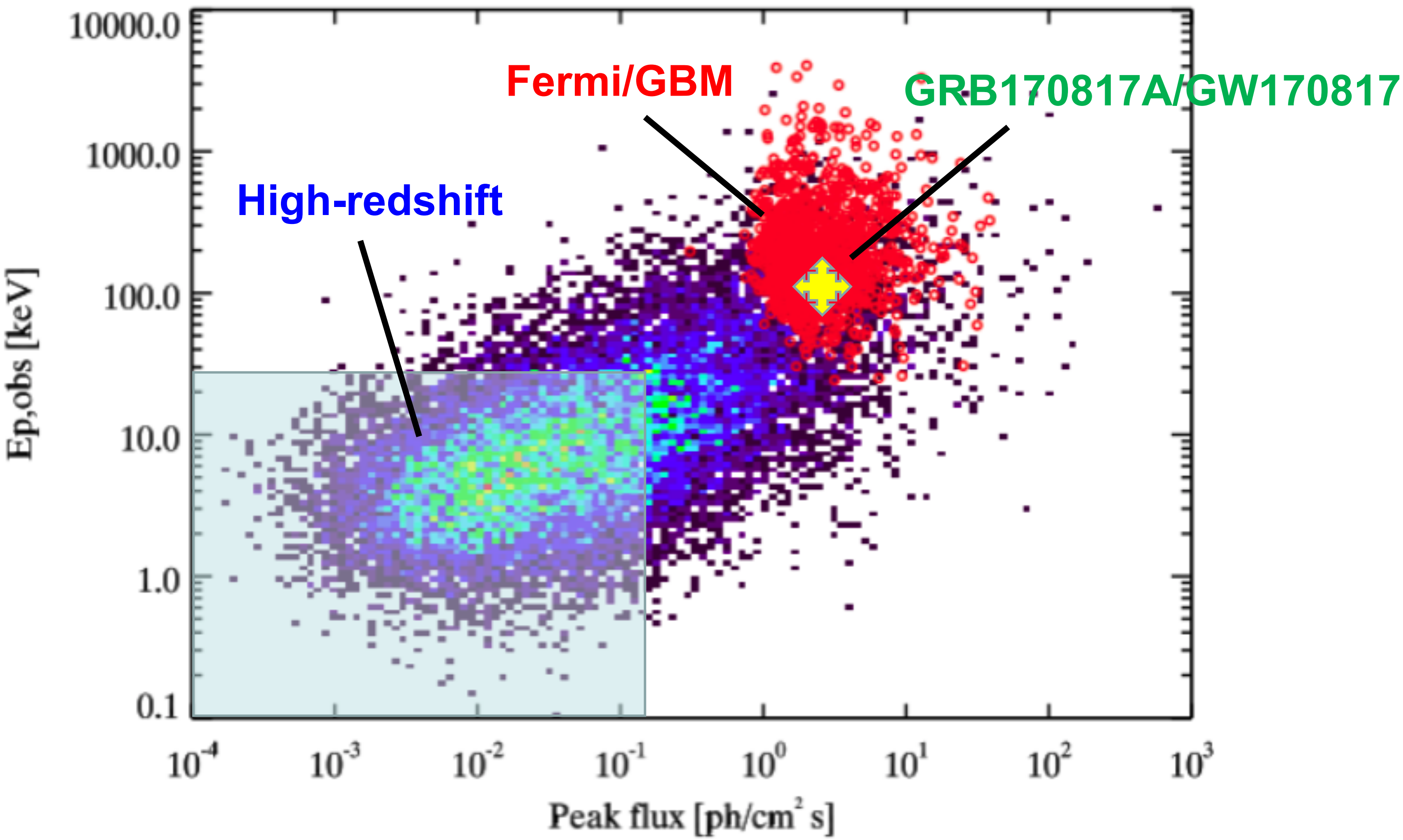
List of Beneficiaries

No	Name	Short name	Country	Project entry month[8]	Project exit month
1	ISTITUTO NAZIONALE DI ASTROFISICA	INAF	Italy	1	36
2	UNIVERZA V NOVI GORICI	UNG	Slovenia	1	36
3	POLITECNICO DI MILANO	POLIMI	Italy	1	36
4	SKYLABS VESOLJSKE TECHNOLOGIJE DOO	SkyLabs	Slovenia	1	36
5	UNIVERSITA DEGLI STUDI DI CAGLIARI	UNICA	Italy	1	36
6	DEIMOS SPACE SOCIEDAD LIMITADA UNIPERSONAL	DEIMOS	Spain	1	36
7	AALTA LAB, RAZVOJ ZMOGLJIVE PROGRAMSKE OPREME D.O.O.	Aalta	Slovenia	1	36
8	FONDAZIONE POLITECNICO DI MILANO	FPM	Italy	1	36
9	EBERHARD KARLS UNIVERSITAET TUEBINGEN	EKUT	Germany	1	36
10	EOTVOS LORAND TUDOMANYEGYETEM	ELTE	Hungary	1	36
11	C3S ELEKTRONIKAI FEJLESZTO KFT.	C3S	Hungary	1	36

THESEUS payload consortium: contributions

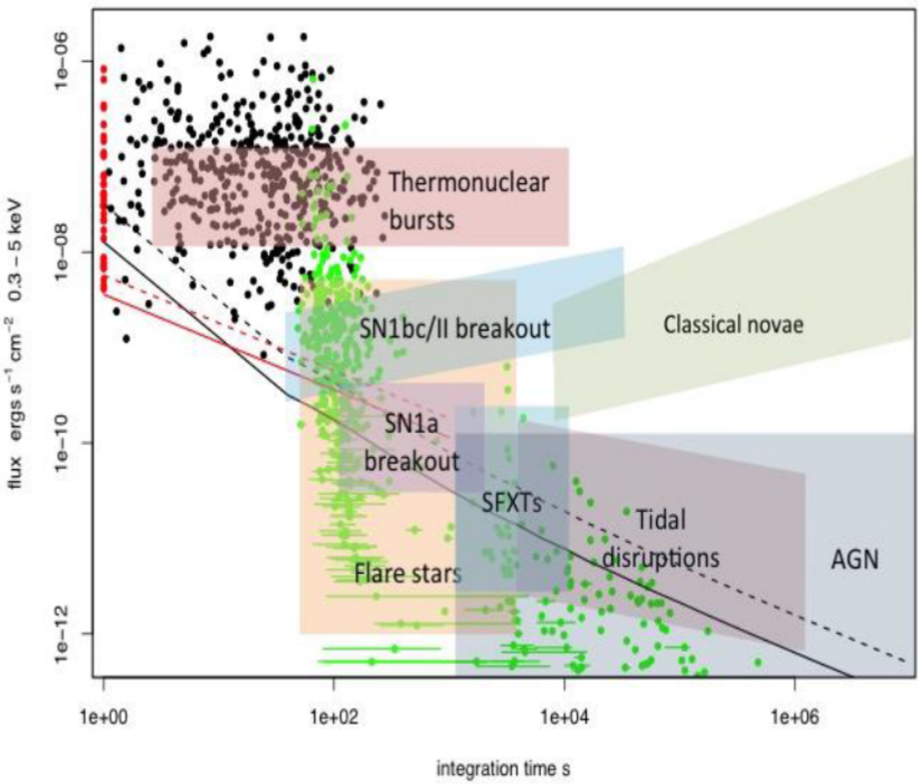
- **ITALY -** L.P. / project office, XGIS, Malindi ground station, Trigger Broadcasting Unit (TBU)
- **UK -** SXI (optics + detectors + calibration) + S/W (SXI pipeline and remote contribution to SDC)
- **France -** IRT (coordination and IR camera), Theseus Burst Alert Ground Segment (TBAGS)
- **Germany (with Poland and Denmark)** - I-DHUs and Power Supply Units (PSU)
- **Switzerland**: SDC (s/w, data processing, pipelines, quick-look) + IRT filter wheel
- **ESA P/L contribution:** IRT telescope (including cooler) + SXI CCDs
- **Other contributions: Spain** (XGIS coded mask, IRT), **Belgium** (SXI integration and tests), **Czech Rep.** (mechanical structures and thermal control of SXI)
- **Possible minor contributions: Ireland** (XGIS detectors, IRT on-board s/w), **Hungary** (spacecraft interface simulator, PDHU, IRT calib.), **Slovenia** (X-band transponder, mobile ground station)

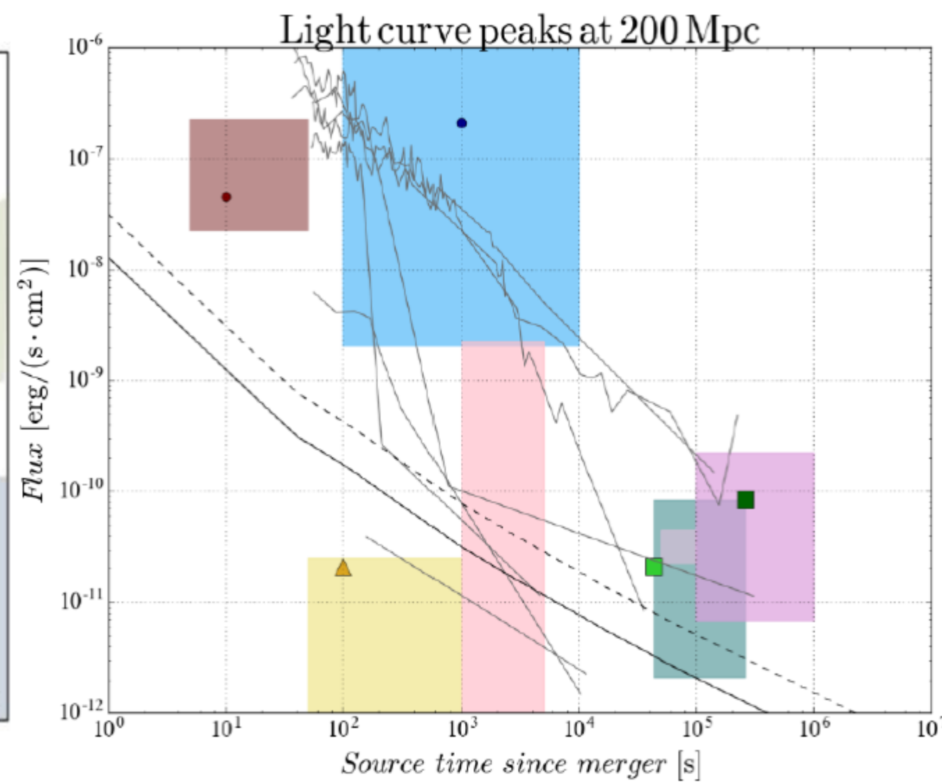
- THESEUS will have the ideal combination of instrumentation and mission profile for detecting all types of GRBs (long, short/hard, weak/soft, high-redshift), localizing them from a few arcmin down to arsec and measure the redshift for a large fraction of them



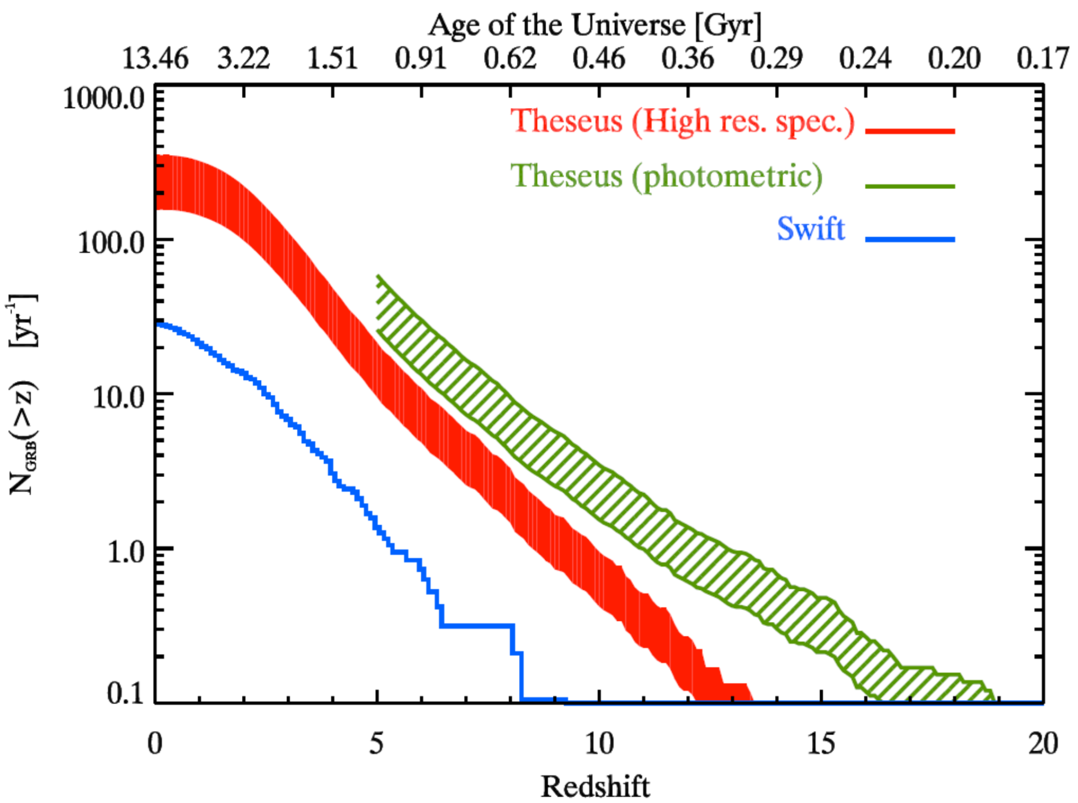
- **THESEUS will also detect and localize down to 0.5-1 arcmin the soft X-ray short/long GRB afterglows, of NS-NS (BH) mergers and of many classes of galactic and extra-galactic transients**

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



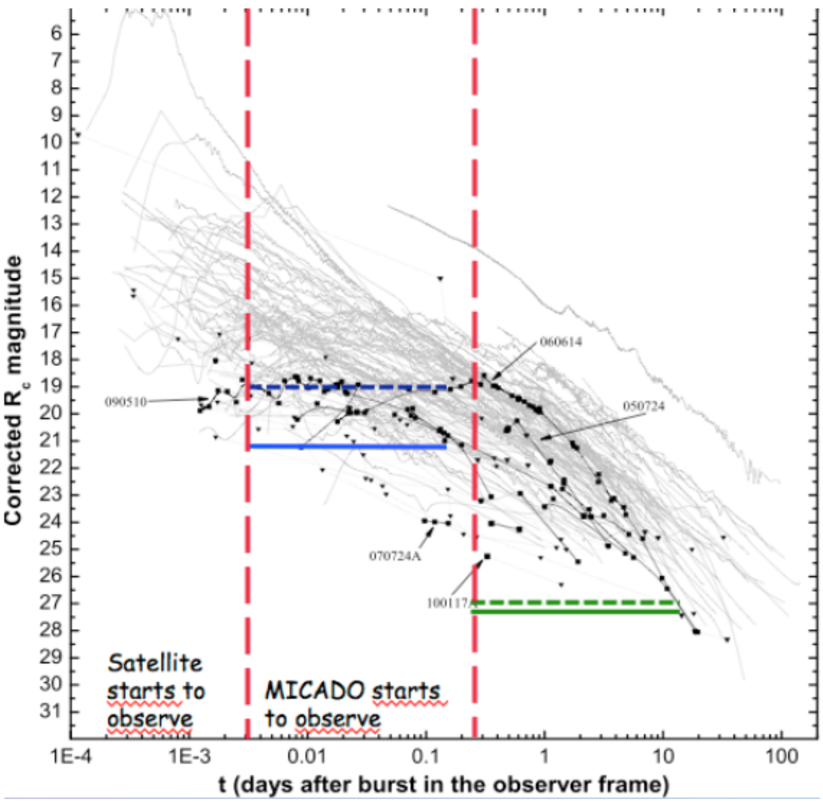


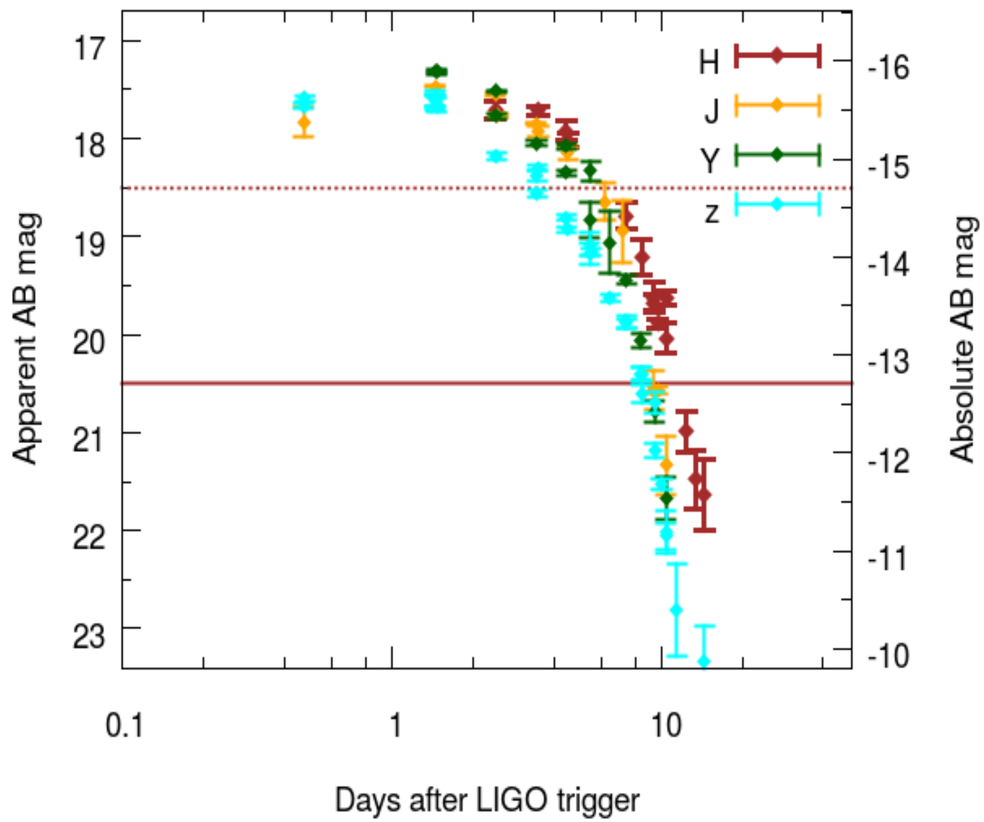
❑ Shedding light on the early Universe with GRBs



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

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





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

- *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.