Study of a compact transient events detector as auxiliary payload for the Einstein Probe mission

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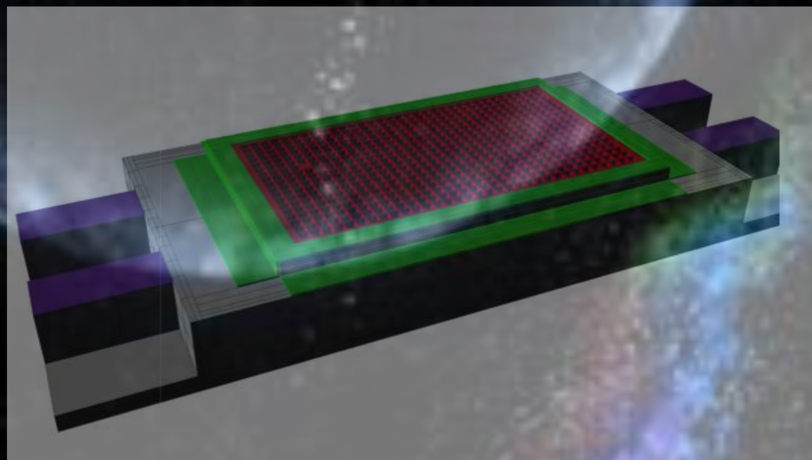
Thanks: L. Piro, J.E. Grindlay, S. Lotti, P. Bastia

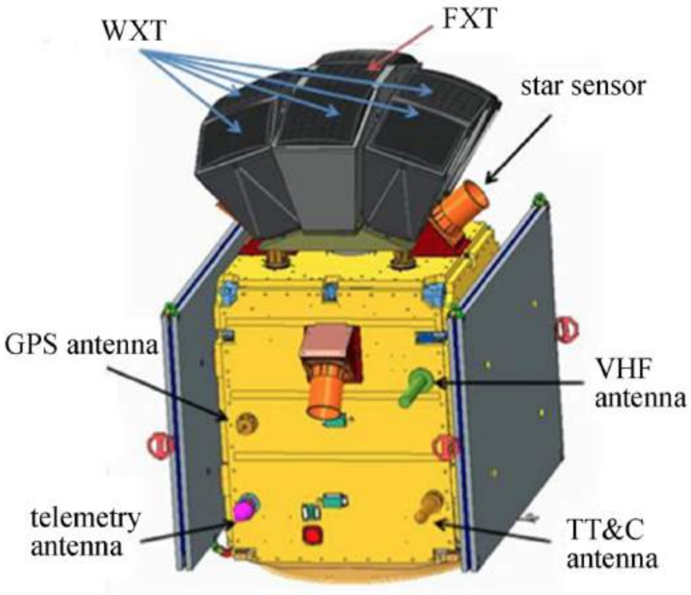


Background Image: EPA/Nasa

Motivation

- Lobster eye technology opens a new venue for all sky monitoring with transformation step in sensitivity
- It delivers the 2-years ROSAT all-sky sensitivity in ~2 days!
- Strategic roadmap for the next decade, putting X-ray astronomy à la pair with others (LSST, SKA etc)
- The Einstein Probe mission (launch in ~2021) is the first mission to fly a Lobster eye optics
- A call for Mission of Opportunity by ESA is expected towards EP
- Our contribution delivers a focused improvement, with limited resources and high TRL
- It continues the Italian heritage in the field (study of transients, GRBs, multi-messenger) and ensures a clear role of Italy in EP

Einstein Probe in a nutshell



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- Mission selected in the Space Science Program of the Chinese Academy of Sciences
- PI Weimin Yuan (NAOC)
- Main Institutes: NAOC+IHEP
- Launch date ~2021

	WXT	FXT
field of view	$60° \times 60°$	$1° \times 1°$
focal length	375 mm	1400 mm
energy band	0.5~4 keV	0.5~4 keV
effective area	$3\,\mathrm{cm}^2$ at 0.7 keV (central spot)	$60\,\mathrm{cm}^2$ (1 keV)
angular resolution	$< 5'$	$< 5'$
sensitivity (at 1 ks)	about $1 \times 10^{-11}\,\mathrm{erg{\cdot}s^{-1}{\cdot}cm^{-2}}$	about $3 \times 10^{-12}\,\mathrm{erg{\cdot}s^{-1}{\cdot}cm^{-2}}$
timing resolution	100 μs	1 s
energy resolution	50% at 4 keV	100 eV at 1 keV

Einstein Probe in a nutshell

Science
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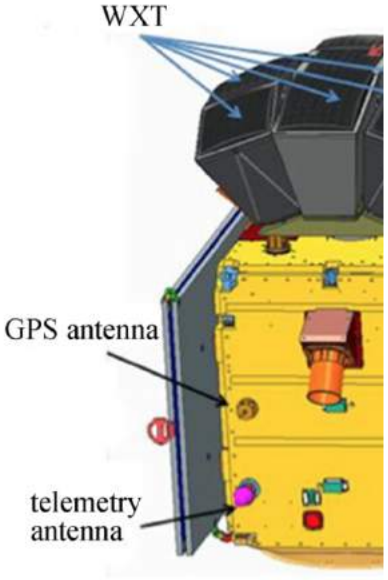

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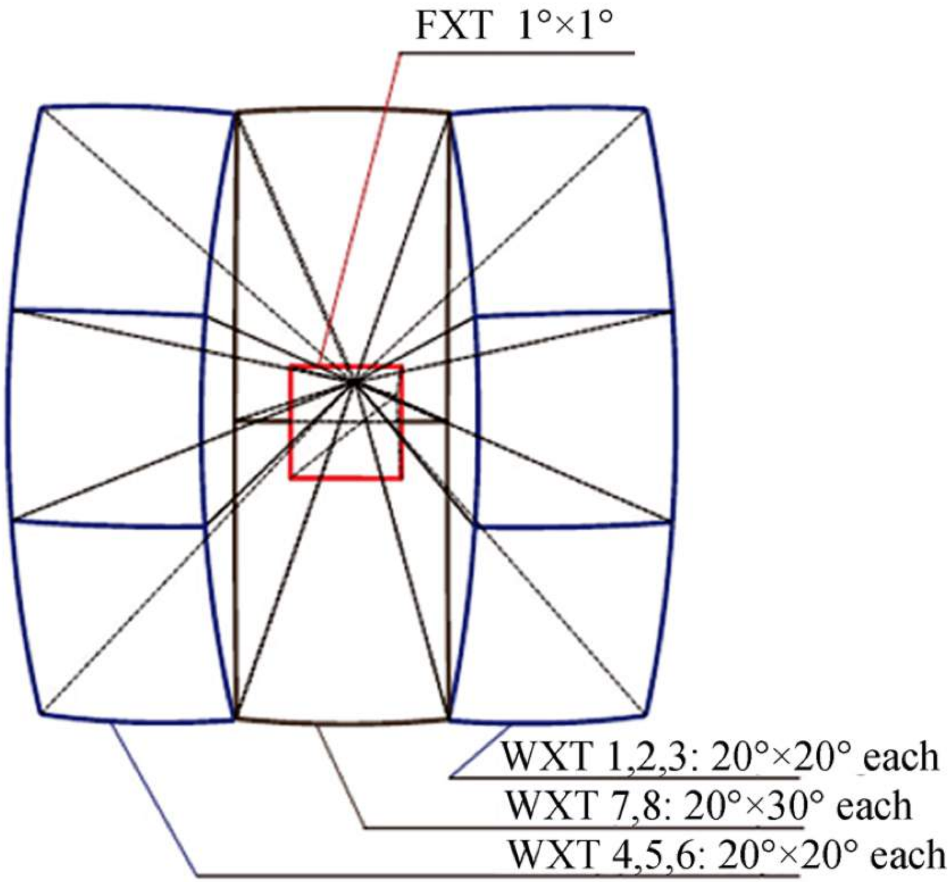

FXT
$1^\circ \times 1^\circ$
1400 mm
0.5~4 keV
$60\,cm^2$ (1 keV)
$< 5'$
about $3 \times 10^{-12}\,erg \cdot s^{-1} \cdot cm^{-2}$
1 s
100 eV at 1 keV

Einstein Probe science objectives (abridged)

- Detect a population of quiescent BHs through detection of X-ray flares (e.g. tidaldisruption events)
- Discover and locate precisely the EM counterparts of gravitational wave source
- Systematic surveys of high energy transients, including high-Z GRBs and other classes of transients including faint ones
- Emphasis on the EP capability to discover and study transients since their onset phases

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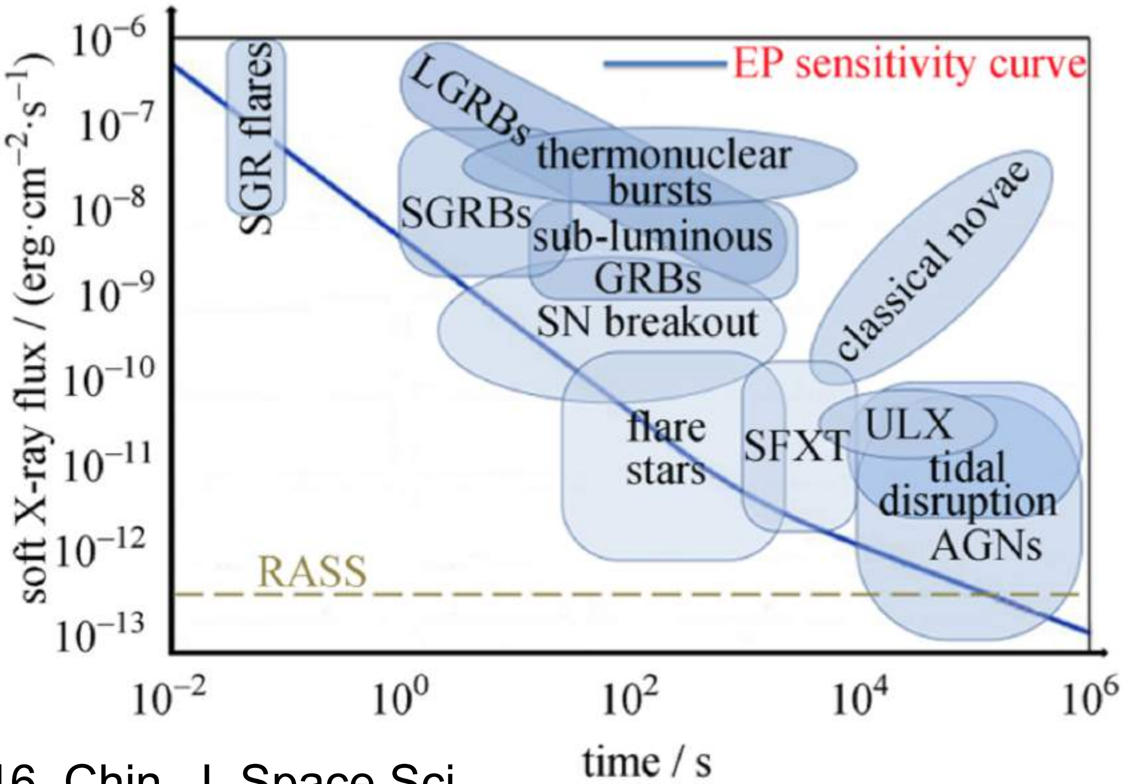

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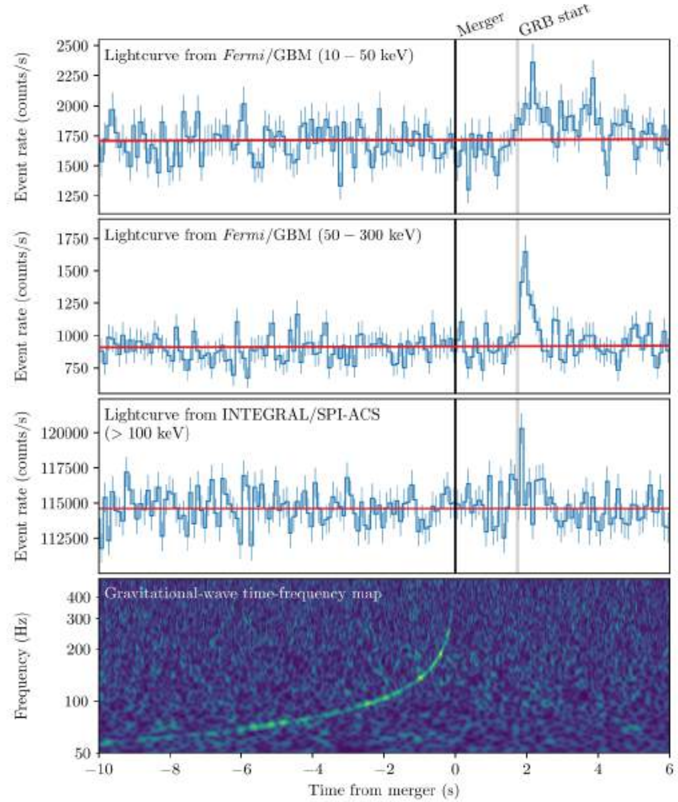
Focus of this proposal

- Studies of GW170817 and its EM counterpart provide the first direct link between gravitational wave sources and GRBs
- The role of Fermi and INTEGRAL has been crucial to confirm the EM counterpart as a binary compact merger
- EP telescopes are quite limited in bandwith (~0.5-5 keV) and for their high sensitivity, they will have to deal with many spurious triggers
- A compact hard X-ray/soft γ-ray detector can extend the energy band towards E_{peak} of GRBs and improve the mission science, without the need for imaging capability

Gravitational Waves and Gamma-Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A

LIGO Scientific Collaboration and Virgo Collaboration, *Fermi* Gamma-ray Burst Monitor, and INTEGRAL



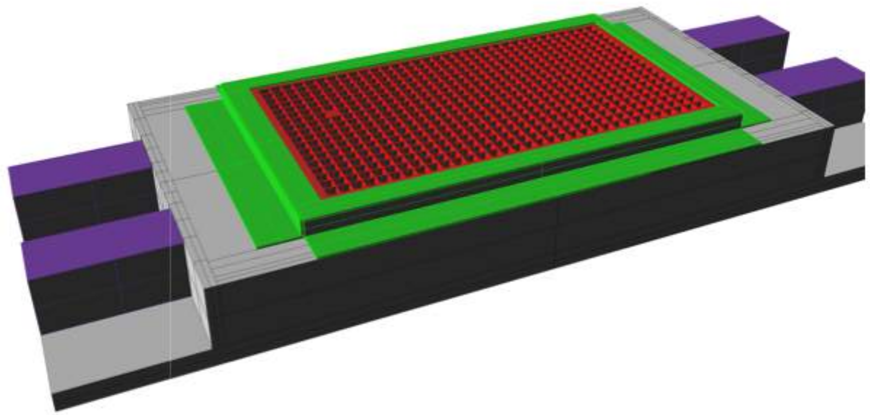
Our approach

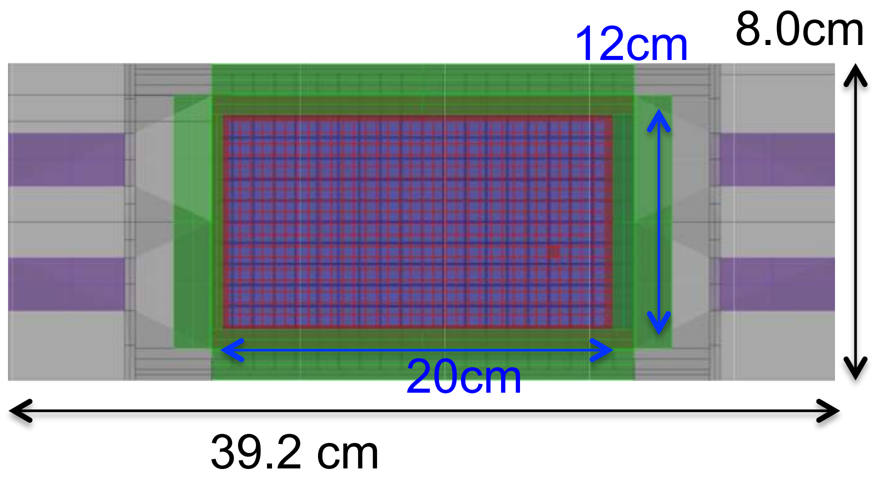
- A compact instrument based on scintillator type technology may be well suited as complementary payload to the Lobster optics telescopes
- It can be used to cover the WXT FOV, providing autonomous trigger capability
- It can also be used to observe directions out of the Lobster FOV and provide additional triggers (e.g. bright GRBs)
- In the latter case, a combination of modules with tilted pointing directions can provide a coarse position with error matching the FOV of the Wide Field Telescope.
- In both cases, no true imaging capability is needed, which would considerably reduce the detection sensitivity as in the case of a coded mask instrument
- The above solution(s) will allow to increase the scientific impact of EP using a cost-effective, realistic (high-TRL) approach

Previous study for a Lobster mission

- The GABI instrument preliminary design was the outcome of a previous study for the *Lobster* mission proposed to NASA (PI Neil Gehrels)
- Proposed Italian contribution (as pre-phase A study)
- It is based on a combination of compact, low power, non-position sensitive soft γ-ray detectors with an energy coverage ~8-1000 keV
- 3 NaI(Tl) scintillator modules for excellent light collection efficiency and broadband continuum spectroscopy
- Geometry of modules matching the FOV (~1 steradian) of the Lobster telescopes
- Autonomous trigger capability

One GABI module



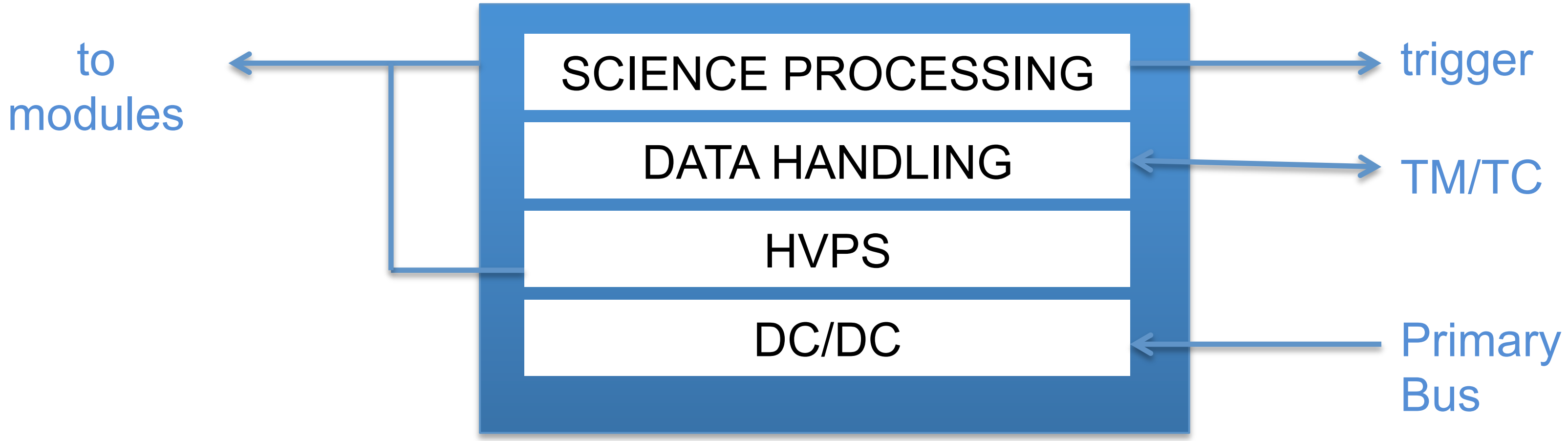


- built around a single NaI(Tl) crystal of size 12x20cm^2, 1cm thick, with Al housing and thin Al entrance window
- readout by 4 PMTs, Hamamatsu R8900U-100, 5.5 cm^2 entrance window
- slat collimator on top of crystal, square 30.4 deg FWHM (walls: 0.4mm tungsten or equivalent)
- CFRP mechanical structure with internal support grid for crystal
- Total Mass: 3.2kg

(Natalucci+12)

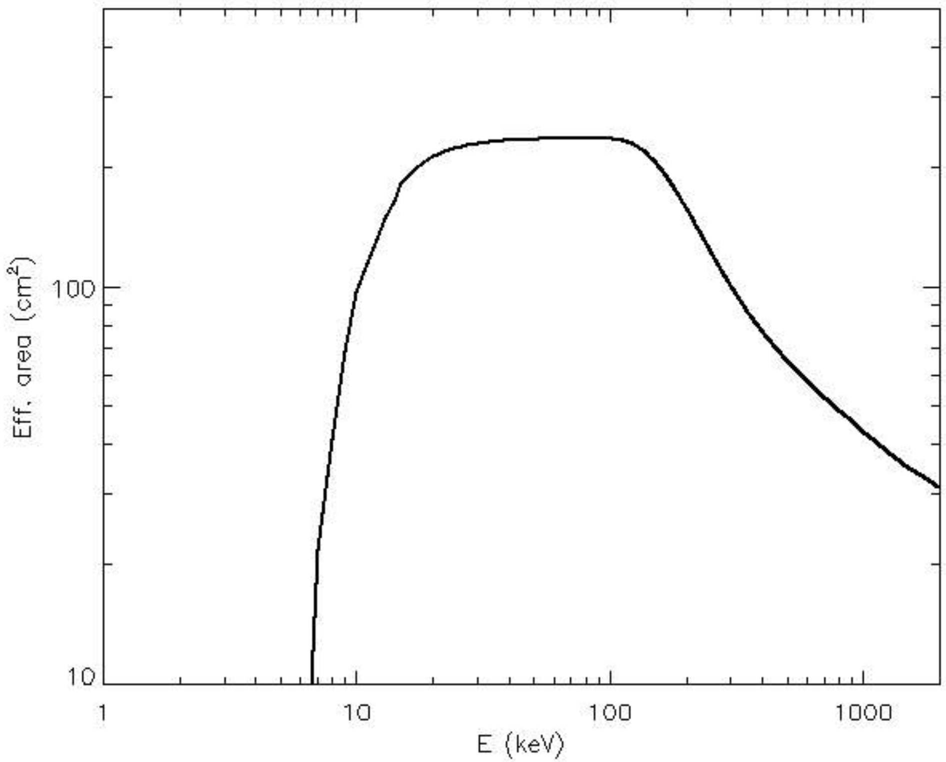
Multi-module scheme

❑ A single **Gabi Control Box** (GCB) is devoted to command and receive analog signals from a set of modules PMTs. The GCB controls and distributes the power to the units and perform digital HV adjustment and gain control.



❑ As baseline the Science Processing Unit is based on FPGA and generate trigger flag for the Lobster control unit. The data in normal (non-trigger) operations is organized in low rate science TLM (integrated spectra/timing).

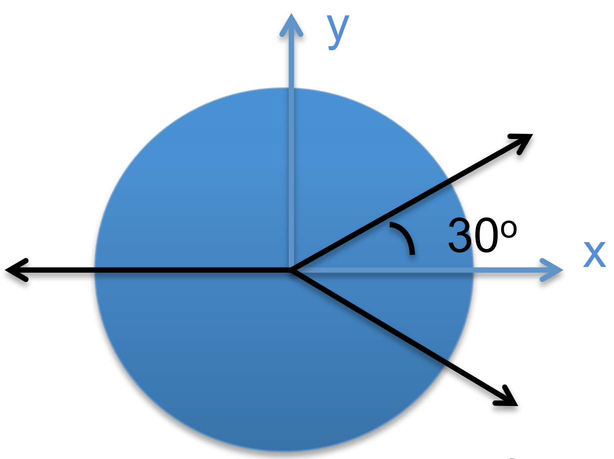
GABI Effective area and rates (1 module)

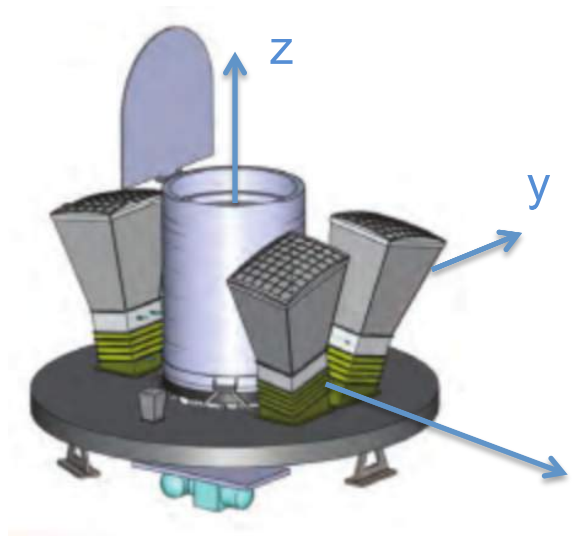


- Energy range (> 20% max. effective area): 8-1000 keV
- Expected background rate (LEO, full band): ~600 c/s
- Expected source rate (1 Crab, full band): ≈140 c/s

Studied configuration for NASA /*Lobster*

- We considered a geometry with 3 Gabi modules accomodated on the Lobster S/C
- The 3 modules cover the field of view of the WFI modules, with extended capability up to ~1 sr

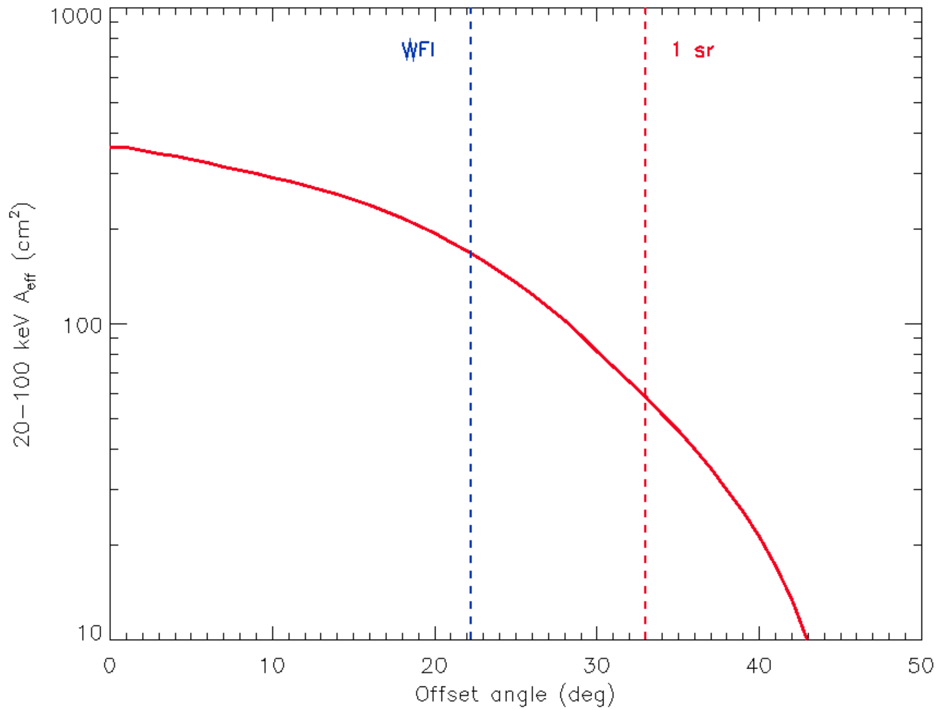




Assumed azimuth orientation of the 3 modules
Assumed Z-axis tilt angle =15^o

Sky coverage

Average effective area at given offset angle



- The instrument can be very effective for the detection of GRBs in the FoV of the WFI and up to ~1 sr.
- With this configuration, GRBs with T_{90}fluence greater than a few 10^{-7} would be amenable to study in combination with the WFI.

Summary Table for Lobster/Gabi configuration

Energy Range	8-1000 keV
Field of View	~1sr
Effective Area	>200 cm^2 within 0.5 sr
Energy resolution(FWHM@100 keV)	13%
Sensitivity (5σ, 100s transient)	~2x10^{-9} erg cm^{-2} s^{-1}
Total Mass	16 .5 kg incl. 20% cont.
Total Power	10W incl. 20% cont.

Compact devices with scintillators

- Our objective is to confirm the high TRL of scintillator based technology for more compact geometry than used in present or past GRB detectors
- Tradeoff studies will consider choice of crystal type and geometry, light collection efficiency, the need for large exposed area and background shielding, low threshold, QE of readout devices.
- Basic requirement for Lobster FOV coverage is Aeff > 200[80] cm^2 within 0.5[1] sr, which would allow the detection of ~100 GRBs/year
- Compared to Fermi/GBM, employing large (12.5 cm diameter entrance window) PMTs, different readout options will be considered, also including much smaller PMTs or the new SiPM technology
- The tradeoff studies will comprise Montecarlo simulations and build of a module prototype

Project organisation and work sharing

Work breakdown

1. Choice of instrument configuration to be studied (scintillator type, crystal tiling etc)
2. Design optimization (Monte Carlo simulation, including background assessment, light transport and generation of signal)
3. Prototype optical and mechanical mounting
4. Functional tests and characterization
5. Thermal cycle testing
6. Preliminary calibration and performance comparison with simulations
7. Accomodation study for the EP mission

Role of participants

- IAPS/ Project management, mass model and background simulation, instrument design, final tests (thermal, vibration) and preliminary calibration, accomodation study for the EP mission
- IASF/ (a) Bologna: crystal & PMT procurement, optical coupling & assembly of prototype, device testing; (b) Milano: procurement of readout electronics & associated equipment, mechanical mounting, device testing.

Resources already available to the project

- 3 INAF departments and associated laboratory equipments:
  IAPS-Rome, IASF-Milano and IASF-Bologna
- Coordinating RU: IAPS
- Appointed staff (effective manpower support) :
  7 researchers, 1 technologist, 4 engineers, 1 staff for admin support
- Other supporting staff: 4 postdoc researchers and 1 senior associated researcher
- Total Man-months: 54
- Consumables

Resources requested

- Post-doc grant (1 year) to be assigned to IAPS to work on instrument design and testing (including simulations) and preliminary calibration of prototype
- Travel grants for 6 team meetings and inter-laboratory activities; travel to 2 conference(s) e.g. SPIE +1 European
- Equipments: Crystal procurement, Optical coupling and readout, Electronics & I/F components, Mechanical Equipment, Calibration sources
- Overall request is ~150kEur. Equipment costs amount to ~65% of the overall cost

Facilities available

IAPS: Class 50,000 clean room, Test facilities (thermal testing, plasma chamber)

IASF-Milano: Mechanic's workshop, Laboratory for electronics development

IASF-Bologna: Class 100,000 clean room, Electronics Lab and shielded room for testing with radioactive sources

Heritage of the team

- The team has direct expertise in the design and operation of in flight instruments operating scintillator devices, as the IBIS VETO anticoincidence system, the PICsIT high energy detector and the AGILE mini-calorimeter.

Image credit: ESA

- The IBIS VETO system consists of 32 BGO modules fully operative since 15 years.
- Its functioning is generally stable with basically no change respect to their initial setting configuration.

Work Schedule

Milestones

KO meeting (T0)
Design Review (T0+8M)
Mid-Term Review (T0+12M)
Prototype functional tests and Characterization (T0+18M)
Thermal tests and Preliminary Calibration (T0+21M)
Final Review (T0+23M)

Deliverables after 1 year

- Report on instrument design study and baseline configuration description

Deliverables at the conclusion:

- Instrument assembly and functional test report
- Instrument thermal tests report
- Calibration and performance assessment report
- Report on accomodation study for the Einstein Probe mission

Conclusions

- E-Probe is a small type mission selected in the Space Science Program of the Chinese Academy of Sciences. It will fly in ~2021
- ~ 2 orders of magnitude step in sensitivity compared to the present most sensitive ASM
- By combining the WXT response with a HE transient event detector, it will be capable to firmly detect and characterise many HE transients, like GRBs associated to GW events that will be discovered by GW detectors with improved performance
- This study will pave the way towards a sound proposal for a forthcoming ESA MOO
- The participation to the E-Probe mission is a unique opportunity for the Italian community to keep the focus on key science objectives like GRBs and multi-messenger astronomy
- We have contacted the PI of the mission for possible collaboration and received positive feedback
- ASI has already expressed support for similar study oriented to a Lobster type mission proposed by NASA.