Draft version June 30, 2025
Typeset using LaTeX **twocolumn** style in AASTeX7

The Necessity of an Additional High-Energy Transient Monitoring Mission

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ABSTRACT

Keywords: High Energy Astrophysics (739) – Gamma-Ray Astronomy (628) — Gamma-ray Telescope (634) — Very Long Baseline Interferometry (1769)

1. INTRODUCTION

High-energy astrophysics has very important mysteries to unfold yet. Since the discovery of the first high-energy radiation coming from space during the cold war, Gamma-ray bursts, actually unintentional, there have been 50 years full of discoveries. High-energy astrophysics, i.e. the astrophysics of the high-end of the electromagnetic spectrum: γ-ray and X-ray, is the sector of the Universe where the physical limits are reached. Black holes, Gamma-ray bursts, pulsars and magnetars, etc.

Despite the intense study of these high-energy phenomena (C. MISSING 2030), there are many more physics to discover: the nature of high-energy transients (B. P. Gompertz et al. 2023) (M. E. Ravasio et al. 2024), the equation of state (EOS) of compact objects ((Z. Ji & J. Chen 2025), (W.-Z. Qiumu et al. 2025), particle acceleration mechanisms (L. Miroshnichenko & W. Gan 2012), among many other interrogations including high-energy events as cosmic probes (E. Abdalla et al. 2022), (M. Dainotti et al. 2023). Furthermore, high-energy events are key for multi-messenger astronomy, i.e. finding counterpart observations of gravitational waves (GW) (C. MISSING 2030) and neutrino (ν) radiation (C. MISSING 2030). Thus, γ-ray and X-rays play a central role in this exploration, enabling the study of the Universe is all its aspects.

Neither γ-ray nor X-ray radiation do penetrate Earth's atmosphere (V. Schönfelder 2013) (L. Spitzer Jr 1946), thus making high-energy astrophysics only feasible via space-based telescopes, which need to provide complete datasets, including prompt and afterglow observations (D. Miceli & L. Nava 2022). It is true that very high-energy (VHE) γ-ray and ultra high-energy (UHE) cosmic rays (CR, ionic particles) can be detected using ground-based Cherenkov Telescopes, which observe the Cherenkov light emitted from relativistic particles from particle showers (C. MISSING 2030). However, the electromagnetic radiation emitted by high-energy astrophysical transients does not fall within this energy range.

In this paper, after reviewing the current status of high-energy transient observational capabilities, I present the rainforest mission. Focusing on its goals and capabilities which complement with the already planned missions. Furthermore, ... Finally, I reflect on the next steps for this mission and the timeline.

2. THE CURRENT STATUS OF HIGH-ENERGY OBSERVATORIES

Since the early 2000s there are two major missions still active: the Neil Gehrels Swift X-ray Observatory (C. MISSING 2030) and FERMI Gamma-ray Telescope (C. MISSING 2030). Both having transient monitoring instruments covering relatively wide energy ranges. During the 2010s only NICER (C. MISSING 2030) was launched inn the X-ray realm, observing only soft X-ray transients. And after 2020 there was a boom in X-ray telescope mission, with the launch of XRISM (C. MISSING 2030), Einstein Probe (C. MISSING 2030), SVOM (C. MISSING 2030) and the HERMES missions (C. MISSING 2030).

Until 2025 there were 3 big observatories covering the γ-ray regime: ESA's INTEGRAL and NASA's Swift and FERMI, However, INTEGRAL was shut down in March 2025, finalizing its mission near 23 years after launch. While Swift and Fermi, launched 2004 and 2008 respectively, are or will soon face aging and financial issues, continued high-quality observations are not granted.

In this context, space agencies and scientific institutions have taken action, with new missions in the X-ray range having been launched recently and future missions proposed, as seen in table 3.

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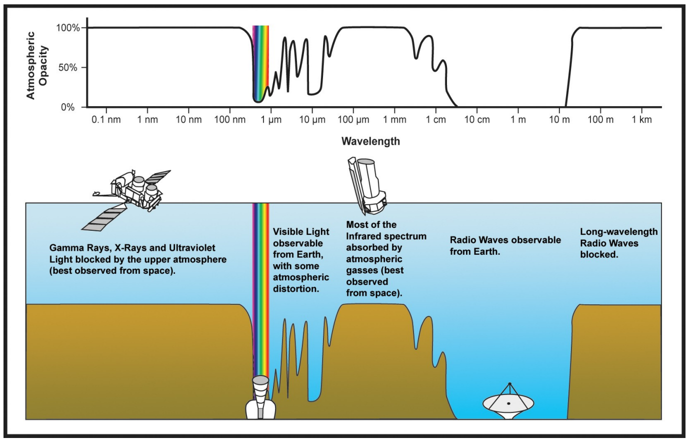

Figure 1. Atmospheric opacity by wavelength (credit: NASA, Public Domain via Commons)

2.1. *Recenlty Launched Missions*

2.1.1. *SVOM*

The Space-based multi-band astronomical Variable Objects Monitor (SVOM) mission is a Franco-Chinese space mission launch on June 22, 2024 with the aim to study the most distant explosions of stars, Gamma-ray Bursts (GRBs) (SVOM 2024). It features four instruments three X-ray to γ-ray instruments, to detect GRBs along the high-energy spectrum: ECLAIRs for GRB localisation (4-250KeV), MXT for Mmicrochannel X-ray observations (0.2-10keV) and GRM to measure the spectrum of GRBs (15keV1MeV); and a visible telescope to observe the immediate afterglow. Space-based observations are also supported with two optical, ground-based telescopes to accurately measure GRB coordinates and to detect the visible part of the GRB radiation. SVOM is the result of a collaboration between China National Space Administration (CNSA) and Centre National d'Éstudes Spatiales (CNES), as well as the Institute of Research into the Fundamental Laws of the Universe (IRFU), the Research Institute of Astrophysics and Planetology (IRAP), the National Astronomical Observatory (NAO) and the Beiking High Energy Institute (IHEP).

2.1.2. *Einstein Probe*

2.1.3. *HERMES*

HERMES-SP (High Energy Rapid Modular Ensemble of Satellites – Scientific Pathfinder) is a mission concept based on a constellation of nano-satellites in low Earth orbit (LEO), hosting new miniaturized detectors to probe the X-ray temporal emission of bright high-energy transients such as Gamma-Ray Bursts (GRB) and the electromagnetic counterparts of Gravitational Wave Events (GWE) – hence playing a pivotal role in multi-messenger Astrophysics of the next decade.

HERMES-SP goal is to design and implement the first Gamma-Ray Burst localisation experiment through a distributed space architecture realized by a 3+3 CubeSat federation. Each CubeSat will be equipped with a novel miniaturised detector to gain a wide deep space coverage, and demonstrate capabilities in precisely localising GRB events in space.

11 partners from 5 European countries form the HERMES-SP Consortium, under the scientific coordination of Dr. Fabrizio Fiore. HERMES-SP has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 821896, and exploits synergies with an ongoing project funded by Agenzia Spaziale Italiana (ASI).
[2] [3]

2.2. *Proposed Future Missions*

2.2.1. *COSI*

The COSI (Compton Spectrometer and Imager) mission is a γ-ray survey telescope designed to probe the origins of Galactic positrons, uncover the sites of nucleosynthesis in the Galaxy, perform pioneering studies of γ-ray polarization, and find couterparts to multi-messenger sources (T. COSI 2025). It will cover the soft γ-ray range between 0.2 MeV and 5 MeV. COSI combines improvements in sensitivity, spectral resolution, angular resolution, and sky coverage to contribute to the γ-ray astrophysics field. The space telescope is currently scheduled for launch in 2027. The COSI mission is developed by the University of California, Berkeley's Space Sciences Laboratory; the University of California, San Diego; the Naval Research Laboratory, NASA's Goddard Space Flight Center, and Northrop Grumman.

[2] 15–150 keV (BAT), 0.3–10 keV (XRT), 170–650 nm (UVOT)

[3] 4–150 keV (ECLAIRs), 15–5000 keV (GRM), 0.2–10 keV (MXT), 400–950 nm (VT)

Table 1. Current status of high-energy transient monitoring space missions. Note that INTEGRAL isn't included since it terminated its mission in February 2025 (M. R. ESA 2025). Take also into account that this is a list of transient observing high-energy telescopes, not all high-energy telescopes.

Mission	Launch	Energy Range	Estimated Lifetime	Key Capabilities
X-ray				
Swift	Nov 2004	footnote (2)	since 2004	Rapid GRB detection & multi-wavelength follow-up
NICER	Jun 2017	0.2–12 keV	since 2017	Soft X-ray timing and spectroscopy, focusing on neutron stars.
EP	Jan 2024	0.5–10 keV	3 years (extendable to 5)	Wide-field X-ray monitoring with lobster-eye optics
SVOM	Jun 2024	footnote (3)	TBD	Multi-wavelength observations of GRBs and other transients.
Gamma-ray				
Fermi	Jun 2008	8 keV–300 GeV	since 2008	All-sky gamma-ray monitoring
HERMES	March 2025	2 keV–2 MeV	2 years	NanoSat constellation for HE transient detection

2.2.2. *THESEUS*

The Transient High Energy Sky and Early Universe Surveyor (THESEUS) is a mission concept selected by ESA for launch in 2032. It is designed to increase the discovery space of the high energy transient phenomena over the cosmic history. Addressing open questions about the Early Universe and multi-messenger interferometry. It's main goals are deep sky monitoring in a broad energy band (0.3keV - 20 MeV), leveraging focusing capabilities and high angular resolution in the soft X-ray band, and on board near-IR capabilities for immediate transient identification and redshift determination. (L. Amati et al. 2018) (L. Amati et al. 2021). THESEUS is a mission coordinated by the Istituto Nazionale di Astrofisica (INAF-OAS) at Bologna, Leicester University, Commissariat à l'énergie atomique at the University of Saclay, the Institut für Astronomie und Astrophysik Tübingen, and the University of Geneva. It is very important to emphasize, what missions are ready for launch/tuning in soon, or are concepts studied for launch in the ¿2030 era

2.2.3. *HiZ-GUNDAM*

The High-z Gamma-ray bursts for Unraveling the Dark Ages Mission (HiZ-GUNDAM) is a mission that will search for evidence of the first generation of stars (also population I stars) through the detection of gamma-ray burst (GRB) afterglows in the ancient Universe ($z > 7$). The mission will also contribute to multi-messenger astronomy comparing the X-ray and Infrared (IR) observations of neutron star (NS) mergers with gravitational wave data (w. g. HiZ-GUNDAM ????). HiZ-GUNDAM will feature a wide-field X-ray detector to capture GRB phenomena as well as an infrared telescope to quickly observe the afterglow and measure the redshift of the corresponding celestial body. The wide-field X-ray detector of HiZ-GUNDAM should cover an energy range between 0.1 and 150 keV HiZ-GUNDAM the Japanese Aerospace Exploration Agency (JAXA) and the Institute of Space and Astronautical Science (ISAS).

2.2.4. *Comments*

This is good, as they will provide a very comprehensive all-sky transient coverage in the optical and infrared ranges. However, the high-energy range of the is less curated. The major γ-ray telescopes have more than 15 years, as with the X-ray telescopes, as some of them have 20+ years and are facing funding issues (see table **??**. The increases in age poses also increases in the risk of instrument malfunction and decreases in data qual-

Table 2. Overview of Upcoming High-Energy Missions

Mission	**Agency / Lead**	**Launch Date (Planned)**	**Energy Range**	**Key Capabilities**
Daksha	ISRO	TBD	1 keV – 1 MeV	Comprises two satellites for all-sky monitoring; aims to detect electromagnetic counterparts to gravitational wave events and study gamma-ray bursts (GRBs).
MoonBEAM	NASA	TBD	Gamma-ray (specific range TBD)	A 3-year mission in cislunar orbit designed for high-sensitivity all-sky monitoring of high-energy transients, including GRBs and magnetar flares.
CATCH	International Consortium	TBD	X-ray (specific range TBD)	Proposes a constellation of over 100 small satellites to monitor X-ray transients across the sky.
GECAM-C	CAS	TBD	6 keV – 5 MeV	Successor to GECAM-A/B missions; aims to detect and localize high-energy transients like GRBs.
HiZ-GUNDAM	JAXA	Late 2020s (proposed)	X-ray and Near-Infrared (specific ranges TBD)	Designed to detect high-redshift GRBs to study the early universe; equipped with wide-field X-ray detectors and a near-infrared telescope.
THESEUS	ESA	Early 2030s (proposed)	0.3 keV – 20 MeV	Aims to detect and characterize GRBs across cosmic history, contributing to multi-messenger and time-domain astrophysics.
STAR-X	July 2028	footnote[a]	TBD	Time-domain surveys and transient event rapid response
THESEUS	2032	0.3 keV–10 MeV	TBD	Detection and characterization of high-energy transients

[a] 0.2–6 keV (XRT), 165–300 nm (UVT)

ity[4]. In the future, this will create an observational gap, not satisfying the demand of high-energy astrophysics observations required for multi-wavelength and multi-messenger astrophysics.

3. THE rainforest MISSION

The SVOM satellite weighs a total of 930 kg for a payload of 450 kg. It will be placed in a low earth orbit with an inclination of 30 degrees, an altitude of 625 km and an orbital period of 96 min.

In summary, although the current γ-ray space telescopes are getting older, new missions and ideas arise to fill in those observation gaps. In the X-ray regime, observatories have launched in recent years, however, there are also promising mission scheduled for the next decade. However, the high-energy range will not be completely observable.

As seen in fig. 2, once the new generation of high-energy telescopes (outlined in section ??), there will remain an observation gap between approximately 10^4 and 5×10^7 keV. This is now covered by the INTEGRAL and FERMI space telescopes. However, in the coming years they will, if not terminate their missions, become unprecise compared with new observation from HERD or COSI. That range should be observed by the CAPIBARA missionγ-ray instrument.

CAPIBARA (Collaboration for the Analysis of Photonic and Ionic Bursts and Radiation from Barcelona) (CAPIBARA Collaboration ????) is a group of high-school students, support by different institutions, aiming to launch a satellite for the high-energy cosmos. We

[4] Comparing the once launched instruments with today's technological possibilities

Telescope Name	Observation Range (keV)	science goals
CAPIBARA	$1 - 10,000\ MeV$	GRB, AGN, SNR
HERD	$1,000,000 - 1000,000,000\ MeV$	DM, CRs
COSI	$0.2 - 5\ MeV$	Galactic positrons, nucleosynthesis, γ-ray polarization, multi-messenger
THESEUS		
HiZ-GUNDAM	$0.1 - 150\ keV$	Population I stars, GRB afterglows, multi-messenger
AXIS	$0.3 - 10\ keV$	SMBH evolution, galactic feedback, AGN, stellar activity, SNe progetinors and rer
NewAthena	$0.1 - 12\ keV$	SMBH-galaxies, NS, intergalactic plasma large-scale structure, metals, star-pla
HERMES (INAF)		

Table 3. Summary of the current state of high-energy space telescopes.

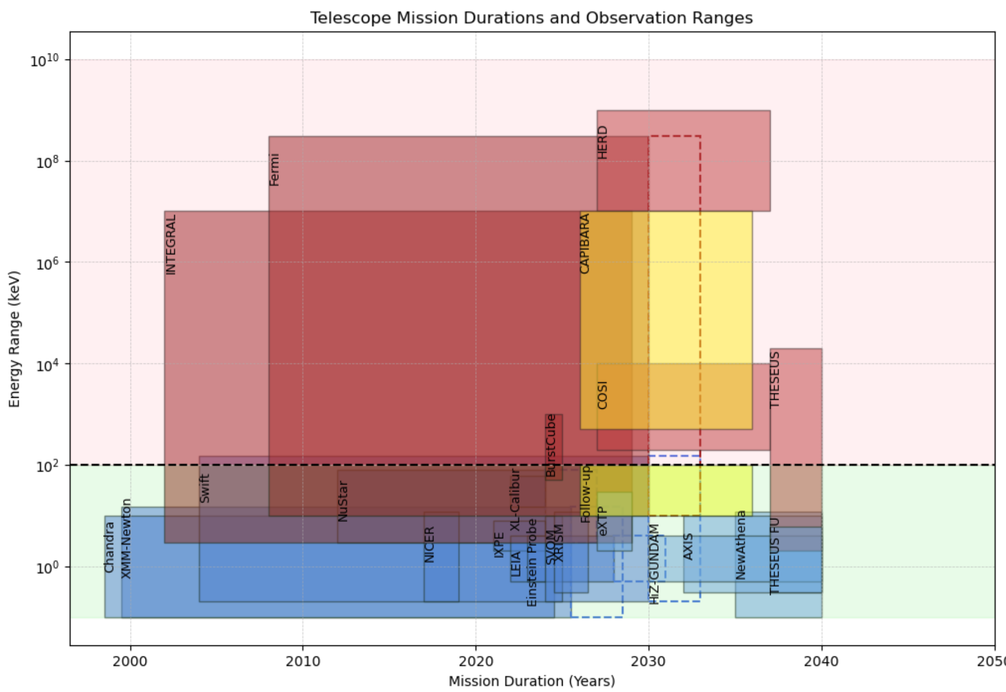

Figure 2. Time (years) - Energy (keV) plot of current and future X-ray and γ-ray telescopes. The color-code is blue for mainly X-ray telescopes, and red for mainly γ-ray telescopes. Additionally, the X-ray range is colored green and the γ-ray on red. Highlighted in yellow are the observational ranges of the CAPIBARA missions. Note that timelines in the future are all set to 10 years of mission duration up to 2040. Possible mission extensions are represented by dashed lines.

want to explore the high energies in both its ionic (cosmic rays) states and photonic (γ-ray and X-ray).

Inside the collaboration, our focus will be in the standardization of gamma-ray bursts (GRBs) for cosmology, the study of γ-ray and X-ray emissions in supernova remnants (SNR) and active galactic nuclei (AGN), and solar cosmic rays. However, we wlil make all of our data and observationa publicly available for anyone to conduct their research. Furthermore, transient detections will be notified in real time through the General Coordinates Network (GCN) (General Coordinates Network GCN ????), (V. Sharma & GCN Team 2024). CAPIBARA will observe in an energy range of 10^4 to 10^8 keV as well as between $0.X$ to 10^2 keV for afterglow and lower energy transients observations (currently covered by the 26-year-old SWIFT observatory).

The CAPIBARA mission will contribute to the decadal survey's goals to promote multi-wavelength and multi-messenger astrophysics (E. National Academies of Sciences & Medicine 2023). Multi-wavelength because it will observe a precise, neglected, energy range in the γ-ray spectra, filling the observational gap and providing complementing observations with those of other high-energy and lower energy telescopes. Multi-messenger because it will observe the light of very high energy astrophysical phenomena, which also generate gravitational waves. Providing electromagnetic observations for events detected by LIGO, VIRGO, KAGRA, and LISA.

In Addition, the CAPIBARA missions will enable γ-ray space interferometry. γ-ray are a highly penetrating radiation and cannot be focused using conventional mirrors or telescopic techniques. In the last decades there have been multiple techniques developed to pinpoint the origin of observed γ-ray like Compton detectors or Pair Production detectors (D. J. Thompson & A. A. Moiseev 2022). However, the most precise method for source localization is intensity interferometry. This technique uses time-of-arrival (ToA) differences for different telescopes to have better angular resolution (up to nanoarcsecond resolution). As wavefront normalization is not feasible for γ-ray , due to their extremely short wavelength, we employ energy intensity (flux) to compare the ToA differences for different observatories and thus compute localize the gamma-ray source with angular resolution in the order to nanoarcseconds.

4. GOALS AND CAPABILITIES

- goals
- detector types, sensitivity, FoV, ...
- future work: timing accuracy, polarization analysis, ultra-fast transient alert notification
- the broader status of high-energy astronomical observations

γ-ray , and also X-ray to a lesser extent, are extremely hard to focus. *Intensity interferometry* comes across as a method to combine the observed information from various telescopes (i.e. various satellites) to contraint the sky coordinates of GRBs. This is done by comparing the different times of arrival (ToA) of a transient signal of a given intensity among different telescopes placed at a baseline distance D. The angular resolution of the computed transient coordinates θ can be approximated by:

$$\theta \approx \frac{c\delta t}{D} \tag{1}$$

Where δt is the differential between ToA and c the light speed. This method not only enable preciser source localization, but also easier host galaxy identification and hence further host environment studies and redshift measurements. In order to employ intensity interferomtry a fleet of γ-ray /X-ray telescope is needed online, strategically covering different ranges of the high-energy spectrum.

5. CONCLUSION

ACKNOWLEDGEMENTS

This paper is part of the study of concept and elaboration of a high-energy mission by the Collaboration for the Analysis of Photonic and Ionic Bursts and Radiation from Barcelona (CAPIBARA)[5], a research and engineering collaboration lead by high school students.

AUTHOR CONTRIBUTIONS

Software:

[5] capibara3.github.io

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