The CRD Instrument and the COSMOS Mission Concept

Joan Alcaide-Núñez[1], *Lluc Soler Manich*[2], *Martina Solano Soto*[3], *Alessandro Sabia*[4], *Carles Fonseca Mauri*[5]

Abstract

The world of astrophysics is constantly in evolution. The detection of the first gravitational-wave signal 10 years ago opened a new way of detecting the universe, making many open questions regarding the behaviour of gravity and high-energy, compact objects possible to investigate. The Collaboration for the Analysis of Photonic and Ionic Bursts and Radiation (CAPIBARA Collaboration) is a group of ambitious young students (from high school to university) proposing and working on two projects to observe this side of the cosmos. Our Cosmic Ray Detector (CRD) project is our first step in attempting to enter the field of space exploration. We are designing a cosmic ray detector that will fly to space thanks to commercial partnership with Orbital Boost Aerospace and PLD Space. Our long-term plan is to develop a Constellation of Student-Made Observing CubeSats (COSMOS), which has the goal of monitoring the sky for high-energy, transient phenomena. These observations are crucial for multi-messenger efforts complementing observations by gravitational-wave and electromagnetic observatories. With our modular approach using CubeSats we aim to enable a pathfinder to demonstrate time-delay localization of these transients and provide a sustainable mission design, while leveraging already flown X-ray and gamma-ray detector technology. Additionally, the CAPIBARA Collaboration is entirely formed by students from high school to university level from different countries, making this project not only scientifically interesting, but also with a major educational impact and serving as an opportunity for young students to experiment and learn about aerospace engineering and astrophysics.

Keywords

Student CubeSat Missions, Multi-Messenger Astronomy, Cosmic Rays

[1] Corresponding author: Ludwig-Maximilians-Universität München (LMU), Germany, joan.alcaide@campus.lmu.de
[2] Universitat Politècnica de Catalunya (UPC), Spain
[3] La Salle Girona, Spain
[4] Liceo Statale "Angelico Aprosio", Italy
[5] University of California – Los Angeles (UCLA), USA

Acronyms/Abbreviations

ESA *European Space Agency*

FYS! *Flight Your Satellite!*

CAPIBARA *Collaboration for the Analysis of Photonic and Ionic Bursts and Radiation*

ET *Einstein Telescope*

LISA *Laser Interferometer Space Antenna*

GW *Gravitational Wave*

CRD *Cosmic Ray Detector*

COSMOS *Constellation of Student-Made Observing CubeSats*

CR *Cosmic Rays*

OBA *Orbital Boost Aerospace*

SiPM *Silicon Photomultiplier*

GRB *Gamma-Ray Burst*

SVOM *Space Variable Objects Monitor*

HERMES *High Energy Rapid Modular Ensemble of Satellites*

GCN *General Coordinates Network*

EIRSAT-1 *Educational Irish Research Satellites*

THESEUS *Transient High-Energy Sky and Early Universe Surveyor*

1. Introduction

The landscape of modern space exploration is shifting toward more inclusive, decentralized models, where student-led missions play vital roles in both technical innovation and the cultivation of the next generation of space professionals. The rise of CubeSats over the past decade has democratized space access, enabling students to gain early experience in space engineering and fostering new talents. For instance, 14 CubeSats have been launched by students through European Space Agency's FlyYourSatellite! (ESA FYS!) Program, demonstrating the viability of student-developed space hardware.

The Collaboration for the Analysis of Photonic and Ionic Bursts and Radiation (CAPIBARA Collaboration) is an international student-led initiative founded in summer 2024 with the goal of exploring the high-energy universe. Our members are high school and undergraduate students, creating a unique educational environment where participants can test their interests and skills while contributing to the project. With students at the center, we are seeking advisors across academia and industry to provide mentorship and guidance regarding the planning, building and operation of the instruments.

In August 2017, the detection of GW170817 demonstrated the transformative potential of coordinated gravitational wave and electromagnetic observations [1]. Next-generation facilities like Einstein Telescope (ET) will detect hundreds to thousands of gravitational wave (GW) events annually [2], creating an unprecedented demand for rapid electromagnetic counterpart identification. Presently, high-energy monitoring capabilities rely on assets like *Fermi* and *Swift, which were launched more than 20 years ago and perform sub-optimal observations. Thus, an observation gap emerges in the early 2030s coinciding with the start of missions such as THESEUS and ET*.

To address both this scientific need and our educational mission, CAPIBARA pursues two complementary programs: a Cosmic Ray Detector (CRD) for particle physics, and the Constellation of Student-Made Observing CubeSats (COSMOS) for transient astronomy. This dual approach allows students to progress from simpler instrumentation to increasingly complex space missions, building expertise incrementally while addressing both scientific and educational impact.

2. Cosmic Ray Detector

The goal of the Cosmic Ray Detector (CRD) is to detect and study the flux and energy spectrum of primary cosmic rays (CRs): charged, highly energetic particles with relativistic speeds coming from outer space or the Sun. These rays get blocked by Earth's atmosphere. Therefore, to overcome this limitation, we aim to insert our CR detector into orbit.

An ambitious goal that we plan to achieve thanks to the partnership with OBA Space, which will deploy our instrument as a payload on the OAB FARADAY satellite.

Given that the detector will be hosted in a CubeSat, we have optimized it for a small space. It consists of a 60 mm cube that has three compartments. The top one will host the plastic scintillator, which is connected to the silicon photomultiplier (SiPM), the central compartment will hold the electrical circuit. Lastly, in the bottom compartment, we will keep the batteries and the memory storage needed.

When a charged particle passes through the scintillator, its atoms are excited; as they return to normal state, some photons are emitted. The photons will then be collected by a SiPM, which will transform the collection into a peak of voltage to allow us to detect the event. We do not have any control over the direction of photons emitted by the scintillator; therefore, we need to redirect them to the SiPM, by making the chamber fully reflective, we allow the photons to bounce off the walls until they get collected by it. To achieve this the detector will be built of metal (likely aluminum).

Initially, the detector will focus on photon count, i.e., we won't address the energy or the charge of the CRs yet. This helps us to understand how different orientations affect the CR ratio of detection. Moreover, we intend to send two identical detectors, which will be aligned with some separation between them. This will allow us to better determine the direction from which the CRs come and the speed at which these CRs travel, as we will know the distance between detectors and the difference in detection time.

Currently we are working on the detector 3D model[6] with guidance and technical support from PLD Space's SPARK program alongside OBA Space.

3. Constellation of Student-Made Observing CubeSats (COSMOS)

The COSMOS program represents CAPIBARA's long-term strategic vision, aiming to bridge a critical observational gap in high-energy astrophysics throughout the 2030s. The scientific rationale centres on detecting and rapidly localizing high-energy transient events, particularly gamma-ray bursts (GRBs) and electromagnetic counterparts to GW sources.

3.1. Scientific Motivation

Next-generation gravitational wave observatories (ET, Laser Interferometer Space Antenna (LISA), Cosmic Explorer) will detect hundreds to thousands of events annually, but localizing these sources requires electromagnetic counterparts. High-energy transients like GRBs provide crucial early detection, as they begin with brief gamma-ray/X-ray emission before evolving to longer wavelengths. Rapid, precise localization enables follow-up observations for host galaxy identification (essential for redshift measurements), jet physics studies, and multi-messenger correlation.

Current capabilities face a coverage gap: *Swift* and *Fermi* are starting to become obsolete, and while missions like Space Variable Objects Monitor (SVOM) [3] and High Energy Rapid Modular Ensemble of Satellites (HERMES) [4] provide some coverage, no existing or firmly planned mission combines continuous all-sky monitoring with arcminute-level localization and a scalable, sustainable architecture for the 2030s.

3.2. Phased Mission Architecture

COSMOS follows a three-phase development strategy.

Phase 0 (2024-2026) focuses on collaboration infrastructure, field study, and documentation, culminating in our SSEA 2026 presentation, Mission Concept Document and the formation of an advisory board.

Phase 1: COSMOS-Twin (2026-2032) deploys two 3-6U CubeSats to demonstrate time-delay localization. Using GPS-synchronized clocks (~ 100 ns accuracy), the satellites detect the same transient and compare arrival times to constrain source position along a hyperbolic region on the celestial sphere. Twin is expected to measure ~ 10 bright GRBs, validating the localization technique and building flight experience. For the launch, we expect to be able to participate in a public or commercial rideshare program like ESA's FYS!.

Phase 2: COSMOS-Net (2031-2040) scales to 6-8 satellites in constellation, enabling true triangulation for arcminute-level localization. With three or more satellites detecting an event, time-delay measurements yield precise sky coordinates. The modular design allows satellites to be replaced as they age, ensuring sustained operations in the long-term run. COSMOS-Net would integrate into the broader multi-messenger alert network via the General Coordinates Network (GCN), providing rapid public alerts for community follow-up. In this position, COSMOS-Net would play the role of monitoring and alerting other flagship observatories when a potential transient is detected.

3.3. Technical Approach

[6] https://cad.onshape.com/documents/3e1c7ca1bc19bf5ab525e65e/w/cadc6ff12fdf242ef4cfd395/e/52b1a09b4bb121e927d4dd17

COSMOS leverages flight-proven detector technology from the Education Irish Research Satellite (EIRSAT-1) [5], GRBAlpha [6], HERMES [4], and BurstCube [7], using CsI or GAGG(Ce) scintillators with SiPM or CZT readout covering the 10-2000 keV energy range, which corresponds to the transition phase between X-rays and gamma-rays. By building on existing heritage rather than developing novel detectors, we reduce risk and focus innovation on constellation coordination, autonomous transient recognition, and time-delay localization efforts. The identical-satellite approach for Twin halves design burden and enables cross-validation.

Key technical challenges include GPS-based timekeeping for precise synchronization, inter-satellite communication for rapid cross-validation, and constellation orbit maintenance. Additionally, transient trigger algorithms to autonomously recognize when a transient is observed to send a GCN alert also need to be developed. The experience and observations obtain with COSMOS-Twin will serve us well for this purpose.

Moreover, our advisory board will provide structured mentorship and advice to approach these challenges, making COSMOS a valuable training group for students. This advisory board is currently in the process of being established.

4. Discussion

The two-mission approach provides a structured pathway for technical capability building. The CRD validates core detector and data acquisition technologies and enables us to gain experience in the field. COSMOS-Twin then demonstrates time-delay localization and constellation operations using two satellites, targeting ~10 bright GRBs to measure localization precision versus baseline distance.

COSMOS-Net's role is providing continuous all-sky monitoring during the 2030s era of advanced gravitational wave observatories. Generating a sample of high-energy transients and aiding multi-messenger correlation studies. The modular design allows incremental deployment and technology evolution, adapting to our educational approach and supporting a 15-year operational timeline across distributed university partnerships.

5. Conclusions

While leveraging proven detector technologies from EIRSAT-1, HERMES, GRBAlpha and BurstCube, CAPIBARA pursues two complementary missions to address a need to learn about the high-energy universe: CRD gives us experience and validates our approach, COSMOS-Twin demonstrates time-delay localization, and COSMOS-Net provides systematic transient monitoring supporting flagship observatories like ET, LISA, Transient High-Energy Sky and Early Universe Surveyor (THESEUS) and more. We are looking forward to continuing developing these projects and engaging with the space exploration community, in part by starting our advisory board.

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