Collaboration for the Analysis of Photonic and Ionic Bursts and Radiation from Barcelona (CAPIBARA): Preliminary Report for the SPARK Program

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Abstract

This report presents the preliminary concept for a satellite mission developed by the CAPIBARA Collaboration to detect, observe, and study high-energy astrophysics in both ionic and photonic states. The missions aim to advance research in these fields while providing young students first-hand experience in cutting-edge science and engineering. We discuss the mission's objectives, justification, scientific rationale, instrument design, and future plans, and introduce the collaboration team.

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Contents

1 Introduction

Cosmic Rays (CRs) or cosmic radiation are charged particles coming from the Universe at high energy due to their high velocities (Lerner, 2024). These particles are mainly protons (87%) and Helium nuclei (10%) (de Espectroscopía Gamma y de neutrones, 2014), see table 1 for a complete composition. We refer to these particles as Primary Cosmic Rays (PCRs).

Type	Percentage
Protons	$\sim 87\%$
α particles	$\sim 10\%$
Electrons	$\sim 2\%$
Light elements (Li, Be, B, ...)	$\sim 0.25\%$
Antimatter	$\sim 0.01\%$

Table 1: Composition of primary cosmic rays from de Espectroscopía Gamma y de neutrones (2014).

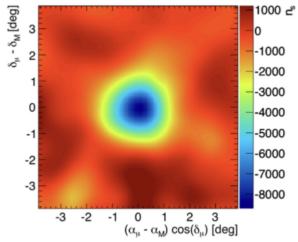


Figure 1: Contour plot of the muon deficit as measured by IceCube in the region around the Moon's position, the so-called on-source region (credit: IceCube Collaboration)

When these particles interact with a medium, they decay into lighter particles, called Secondary Cosmic Rays (SCRs). For instance, SCRs are produced as a consequence of PCRs decaying when hitting molecules in Earth's upper atmosphere. As a result, protons, alpha particles, pions, kaons, muons, electrons, and neutrinos are created (Morison, 2008), becoming a way of indirect detection (see Figure 1).

Furthermore, there is another radiation that helps trace CRs. However, it can not be categorized as cosmic rays due to its lack of electric charge. The interaction of both PCRs and SCRs emits light, for instance in accretion disks, nebulae, interstellar dust, quantum decays, and atmospheres, among others. This type of light reaches us in high-energy wavelengths, mostly in X-rays and γ-rays, but also in the ultraviolet (UV) and infrared (IR) spectrum. These photons have different properties compared to fermions and hadrons, meaning a different way to study the Universe.

Furthermore, CRs can also be divided by origin, which enables differentiation between galactic and extragalactic CRs. Galactic CRs emerge mainly from the sun, other nearby stars, or other objects such as neutron stars (NSs). This category may be estimated by the source coordinates, where low latitudes more likely correspond to the position in the galactic plane, whereas high latitudes likely come from other galaxies. Knowing the distance to the source is also a useful tool for estimating the origin[1].

Although CRs are known to come from outside of Earth (Hess, 1912), we do not know specific sources of CRs. As these are charged particles, they interact with magnetic fields through their way to Earth. Therefore, when we detect cosmic rays, we cannot determine their provenance. However, there are probable sources of CRs discussed: supernovae explosions (SNe) and remnants (SNRs), neutron stars (NSs), microquasars (Quasi Stellar Object, QSO), active galactic nuclei (AGNs), and gamma-ray bursts (GRBs).

2 Mission Objectives

Our objective is to explore high-energy phenomena, both in the form of light (photons) and particles (mainly protons and alpha particles). In this section, the mission objectives and technological requirements of the mission are described. For further details on the experiment design, i.e. how we aim to accomplish these goals, see section 5.

2.1 Primary CRs Detection

As explained before (see table 1), CRs mainly consist of protons (p^+) and α-particles, i.e. Helium nuclei, (α, α^{2+}, or He^{2+}); summing up to 97%. In order to explore the high-energy particles, providing useful data for the study of CRs, solar wind, astroparticle physics, and further topics of research, we aim to detect these particles using a variety of detectors. Each of the types of detectors, outlined in section 5 are capable of detecting a different property of these particles (e.g. velocity, energy, etc.). Therefore, all of them are needed to provide complete and reliable datasets.

[1]This technique is only applicable to electromagnetic radiation, as charged particles interact with magnetic fields, therefore making their direction an unreliable source of origin information.

2.2 Photonic Detection

Moreover, we want to accomplish the observation of electromagnetic radiation emitted by CR interactions, as they give us different information about CR sources and the physical processes of their interactions due to the difference in the nature of light. To do so, we have to be capable of detecting photons in the X-ray and γ-ray range of the spectrum, as high-energies are where CRs are expected to emit on account of their initial energy and velocity.

A Cosmic X-ray Background (CXB) was claimed with the launch of the first X-ray telescopes (e.g. ROSAT) in the late 20th century. Gilli (2013) showed a collection of different CXB measurements. However, more modern space telescopes have resolved the vast majority of this background into discrete, faint sources. As a consequence, with enough resolution, this 'background' radiation is negligible. For reference, see Figure 7 of Tozzi et al. (2001), where high-energies are expected to be filled by dust-obscured AGNs (Schneider, 2006).

The existence of a Cosmic γ-Ray Background (CGRB) has been studied by the FERMI-LAT instrument in detail. It is believed that this radiation emerges from unresolved sources (e.g. SNe, pulsars, or AGNs) and possible exotic processes like dark matter (DM) annihilation or decay. The background is far from negligible and must be accounted for in γ-ray data analysis. Common techniques to consider this radiation are image background subtraction (both instrumental background and template fitting), background modeling, and likelihood analysis (e.g. Markov Chain Monte Carlo (MCMC)).

Technical requirements to consider are that we expect to perform both photometric and spectroscopic analysis of observations. This is especially important, as both approaches provide different information and data about the phenomena, complementing each other.

Furthermore, light observations require the capability of pointing in the sky to localize sources. We intend to use a wide-field γ-ray camera to monitor events, this does not need a more precise accuracy than to localize sources in $5''$ to $1''$ (arcseconds). While a narrower field of view (FoV), should have a pointing accuracy between $0.5''$ and $1''$.

2.3 Deorbitation & Sustainability

A crucial aspect of modern space missions is ensuring they adhere to sustainability guidelines, including proper end-of-life procedures for deorbitation. Space debris represents a danger to space traffic and human spaceflight, as well as posing a threat to Earth and Space-based astronomical observations. Therefore, we want our mission to incorporate a well-defined deorbitation plan to ensure that the satellite does not contribute to this growing problem, following international space mitigation standards. Applicable measures include orbital decay monitoring, end-of-mission deorbit burn, sustainability compliance, and post-mission disposal.

Given that our satellite will operate in a Sun-Synchronous Orbit (SSO), as given by the Spark program, we aim to perform a controlled deorbitation maneuver at the end of the mission's operational lifetime. While natural orbital decay due to atmospheric is slower at the higher altitudes typical of SSO, we plan to initiate a controlled deorbitation sequence. This will involve reducing the satellite's altitude through propulsion-based maneuvers, eventually leading to a final deorbit burn. The objective is to ensure that the satellite safely reenters Earth's atmosphere, where it will burn up, minimizing the risk of debris surviving re-entry and reaching the surface.

3 Justification

3.1 Atmospheric Opacity

The radiation we aim to detect, which consists of both particles and light, is not possible to study from the Earth's surface.

PCRs interact with Earth's upper atmosphere, creating particle showers, which are detectable from Earth, and so-called SCRs. However, the particles resulting from these interactions have lost part of the information inferable from PCR detections. Furthermore, Earth's magnetic field also shapes how SCRs are detected. Therefore, the effect of magnetic paths should be smaller using space-based detectors.

Additionally, neither X-ray nor γ-ray radiation do penetrate Earth's atmosphere (see Figure 2), which means that their detections are only possible with space-based telescopes (Brandt et al., 1992). Therefore, the observation of this type of emission is of huge importance, as it is the only way to study high-energy phenomena (Lyman Spitzer, 1990).

All in all, high-energy particles and light with cosmic origin do not reach Earth's surface, meaning the development of space-based detection missions is crucial for the study of these phenomena.

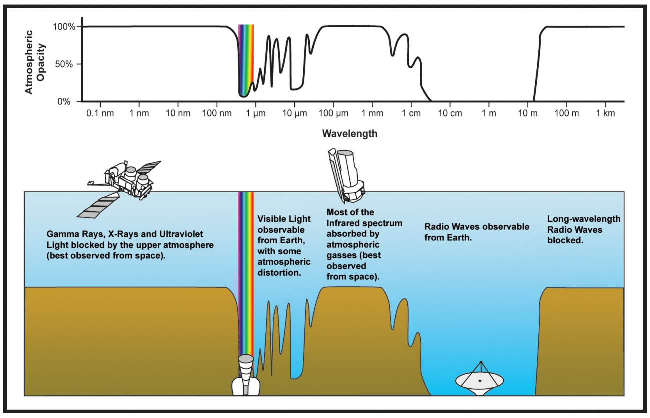


Figure 2: Atmospheric electromagnetic opacity by wavelength. (credit: NASA)

3.2 Application

Furthermore, the fundamental research in cosmic rays has wide applications. The most obvious are particle physics, nuclear and atomic physics, as well as astronomy and astrophysics.

However, also geophysics and climate studies benefit, as CRs can help us study the formation of clouds, monitor the atmosphere (Kuwabara et al., 2006), and develop techniques for geologic dating (Blard et al., 2006). What is more, medicine benefits from both the best medical imaging methods, e.g. positron emission (PET); as of radiotherapy, the research of radiation for the development of medical treatments (Royon et al., 2019).

The improvement and development of new imaging techniques inspired by cosmic ray detection help to study the strength and durability of objects and substances, advancing material science. Likewise, imaging methods allow the study of the interior of pyramids, caves, volcanoes, and other structures.

In addition, living beings in space suffer from the impact of radiation against their bodies, therefore, studying the nature of cosmic rays would help us innovate in potential solutions for the protection against such radiation, which would allow very long duration crewed missions (Saganti et al., 2004).

3.3 Observational and Research Gap

Finally, given the current landscape in space observation, the study of cosmic rays and high-energy phenomena seemed particularly compelling. Although these topics are at the forefront of modern astrophysics, representing relatively new areas, many modern telescopes, such as the James Webb Space Telescope (JWST), Euclid, the Vera C. Rubin Observatory (LSST), or the Nancy Grace Roman Space Telescope (WFIRST), focus primarily on electromagnetic radiation in wavelengths close to the optical range (partially covering the UV and IR).

Furthermore, two of NASA's Great Observatories[2] were once dedicated to high-energies, Compton (CGRO) and Chandra (CXO). However, the Compton Observatory was deorbited in 2000, and the Chandra Observatory is facing funding issues without current plans for replacements[3]. Other γ-ray telescopes such as SWIFT (launched 2004) or FERMI (launched 2008) are also turning old.

Our mission aims to address a critical research gap by exploring the high-energy range through the observation of both light and cosmic rays (CRs), aligning with the current limitations in observational capabilities that restrict advancements in this area.

[2]Spitzer (IR), Hubble (NIR, Optical & UV), Chandra (X-ray), and Compton (γ-ray)
[3]Chandra Decommissioning

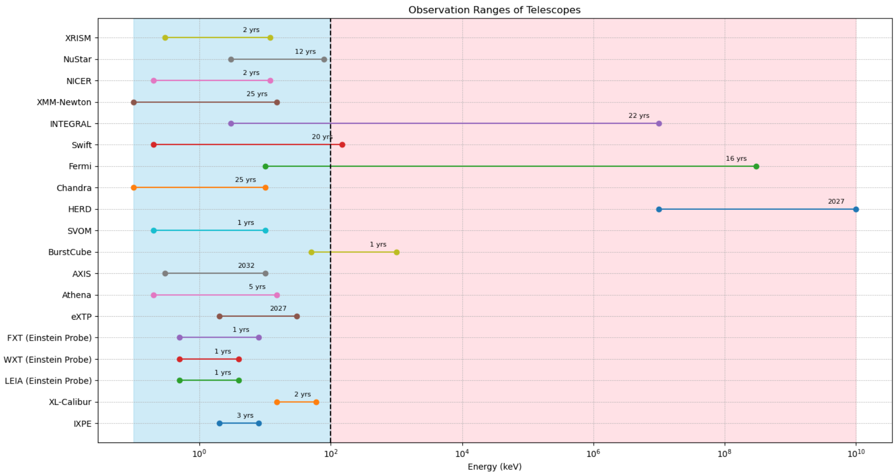


Figure 3: Figure showing the observational coverage of the high-energy range of the electromagnetic spectrum. Shaded in blue is the X-ray range, and in red the γ-ray one. Telescopes' observational capabilities are plotted along with their age or predicted launch date. It can be seen that there is an observational gap in the γ-ray part of the spectrum and that the X-ray part is more crowded, though the majority are old (<20 yrs) or short-mission telescopes.

4 Scientific Research

4.1 Gamma-Ray Burst Cosmology

- Author: Joan Alcaide-Núñez
- Field: Cosmology and Extragalactic Astrophysics
- Context: The Hubble-Lemaître constant (Hubble, 1929) (Lemaître, 1927) represents the local expansion rate of the Universe, sets its overall scale, and enables determination of its age and history. It is a fundamental measure in cosmology and a keystone for cosmological models of the Universe (Freedman et al., 2010). Since its first derivation in the 1920s, it has been recomputed multiple times (Freedman, 2021) (Valentino et al., 2021). However, its exact value is not yet known, as different methods result in different values (Freedman et al., 2010) (Aghanim et al., 2020) (245 et al., 2017). Not only that, but as techniques and instrumentation have become more precise, the discrepancy has gotten stronger (Riess et al., 2024a) (Valentino et al., 2019) (Freedman, 2021). This problem is called the Hubble Tension, often also referred to as the Crisis in Cosmology.

  For reference, see the latest measurements for each method in Figure 4; Local Distance Ladder (Freedman et al., 2024)[4] (Riess et al., 2024b)[5]; CMB (Aghanim et al., 2020)[6]; BAO (Collaboration et al., 2024)[7]; and Gravitational Waves (245 et al., 2017)[8].

[4] JAGB (J-region Asymptotic Giant Branch), TRGB (Tip of the Red Giant Branch), Cepheids, and Ia SNe (Type Ia Supernovae)
[5] Different Ia SNe catalogs
[6] Cosmic Microwave Background
[7] Baryonic Acoustic Oscillations
[8] Standard Siren method

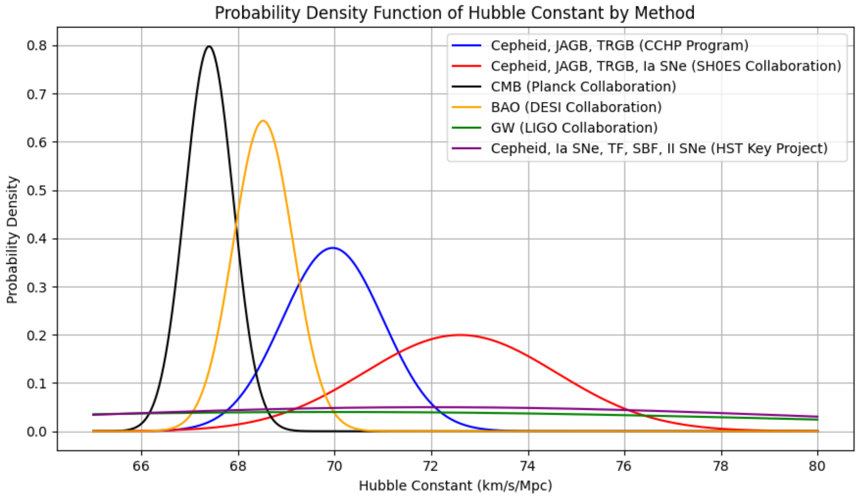


Figure 4: Probability Density Function diagram for different measurements of the Hubble Constant. Data from: Freedman et al. (2024) (blue), Riess et al. (2024b) (red), Aghanim et al. (2020) (black), Collaboration et al. (2024) (orange), 245 et al. (2017) (green), Freedman et al. (2001) (purple).

Furthermore, relatively recently it was discovered that the expansion rate of the Universe is accelerating (Riess et al., 1998), this discovery having very important implications in our understanding of the Universe and the crafting of the ΛCDM model[9] (Peebles et al., 2003) To do so, it was required to observe SNe in very distant galaxies. This has additional difficulties due to the reduction of spatial resolution (crowding effect (Freedman et al., 2024)) and the diminishing luminosity. However, only at this greater distance, the effects of an accelerating, neutral, or decelerating expansion rate are observable. More recently, some research has posed that dark energy, the substance responsible for accelerating the expansion, is evolving in the function of time (Efstathiou, 2024)(DESI Collaboration et al., 2024). If true, this could be the first hint about the nature of dark energy since its discovery.

- Goals: Our aim is to use Gamma-Ray Bursts (GRBs) as cosmological distance indicators. GRBs are the most energetic events in the Universe, releasing in just a few seconds more energy than the Sun emits over its entire lifetime. Hence, they can be observed at great distances. For reference, GRBs have been observed up to $z > 8$, while the more distant Ia SN is at $z < 2$. The standardization of their high luminosity and the use of GRBs as cosmological distance indicators will provide very valuable data for the study of the Hubble Tension, the nature of dark energy, and thus the validation of ΛCDM. Furthermore, the impact on the field is considerable, as greater distances will enable more precise fitting of cosmological parameters to the data, and new measurements.
- Methods: γ-ray photometric and X-ray photometric and spectroscopic analysis; identification of GRBs; study of new methods for the standardization of GRBs cosmological distances; cross-check with external databases for redshift data.

4.2 Exoplanet Research from CR Interaction Radiation

- Author: Joan Alcaide-Núñez
- Field: Earth and Planetary Sciences
- Context: Since the discovery of the first exoplanet in 1992 (Wolszczan et al., 1992) and the discovery of the first exoplanet around a star in 1995 (Mayor et al., 1995), the observation of new exoplanets has grown exponentially, as has the field (Editorial, 2024). In 2001 the first exoplanetary atmosphere was confirmed via spectroscopy during planetary transits[10] (Charbonneau et al., 2002). The first direct of an exoplanet was achieved by the VLT[11] (ESO)[12] in 2006 (Song et al., 2006).

  Moreover, Secondary Cosmic Rays (SCRs) can be detected on Earth's surface (including at sea level) due to the decay of PCRs as they hit molecules in the upper atmosphere (). This event is also known

[9] A cosmological model for a Universe with dark energy (Λ) and Cold Dark Matter (CDM).
[10] A planetary transit happens when a planet passes between its host star and the observer.
[11] Very Large Telescope
[12] European Southern Observatory

as particle shower, an example being shown in figure 5. Exoplanets in the atmosphere are expected to express the same or similar γ-ray signatures based on these processes. The strength of this emission will depend on the source's characteristics, the atmospheric composition, and the distance to the exoplanet.

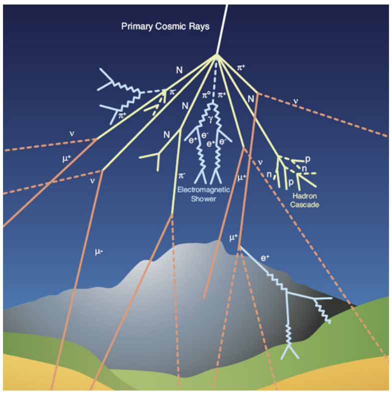


Figure 5: Cosmic ray air shower scheme by the European Council for Nuclear Research (CERN, acronym in French). It is an example of the particles resulting from the decay of PCRs in Earth's atmosphere.

- Goals: We aim to detect exoplanet SCR signatures coming from the interaction of PCRs with the exoplanetary atmospheres.
- Methods: Transit observations, X-ray & γ-ray astronomy (photometry and spectroscopy), exoplanets, host stars

4.3 Characterization of PCR Radiation from Solar Origin

- Author: Martí Delgado Farriol
- Field: Solar and Stellar Astrophysics, Earth and Planetary Sciences
- Context: Primary Cosmic Rays (PCRs) are thought to come from high-energy phenomena (Lerner, 2024). Nevertheless, we also know about stellar (and/or solar) wind, which is a flow of charged particles ejected from the Sun's atmosphere the corona) (ESA). These charged particles can pose a danger to satellites (e.g. weather monitoring, communications, and GPS satellites) and human space flight.
- Goals: Our goal is to differentiate between solar PCRs and those coming from outside the solar system. We aim to characterize the sun's radiation and understand the physical background phenomena of PCR sources by differentiating particle radiation (mainly protons) during orbiting Earth's day, in which solar radiation will be present. We expect solar PCRs to have slower velocities and lower energies. Furthermore, their interaction with magnetic fields should be easy to track due to the short distance. The understanding of CRs within the solar system is key to developing practical applications to protect long-duration missions.
- Methods: Particle detection, magnetic fields, orbit trajectories.

4.4 Observation of Supernova Remnants

- Author: Hongda Zheng
- Field: Supernova Remnants
- Context: Supernova Remnants (SNRs) are the material leftover from a supernova explosion (SNe). There are two criteria for the classification of SNe which originates from different subtypes:
  - Core Collapse (Type II SNe): They are the result of massive stars rich in iron that ran out of material to fusion since no energy can be gained from nuclear fusion of iron. Then they collapse into neutrons stars (NSs) or black holes (BHs) depending on the initial mass.
  - Thermonuclear explosion (Type I SNe): They are thought to be the explosion of Carbon/Oxygen White Dwarfs stars (no massive stars) that generate explosive nuclear burning. In both cases, the explosion leaves behind its nucleus and produces an explosion and the ejection of stellar materials such as gas or dust. Those rests are the SNR (GSFC, 2021). The SNR consists of the core and the materials around it, which are in constant expansion.

SNRs are very interesting astronomical phenomena since they allow us to study the creation of various chemical elements in the stars and what composition they have. In addition, there is an ejection of heavy metals that contribute to the formation of new stars. SNRs also emit energy in different forms, such as X-ray synchrotron energy, which allows us to know if there is or not a neutron star in it (Ishikawa, 2019).

Even with this classification of SNe, the supernova origin of SNRs is often difficult to establish. Because of that, SNRs have a classification of their own, which is based on their morphology. This classification recognizes three different classes:

  – Shell type SNRs: As the blast wave sweeps through the interstellar medium. The shockwave from the supernova explosion that plows through space, heats and stirs up any interstellar material it encounters, and produces a big shell of hot material in space. As the blast wave sweeps through the interstellar medium.
  – Crab-type SNR or plerions: in this case, the nebulae are filled with high-energy electrons that are flung out from a pulsar in the middle, producing a blob form.
  – Composite SNRs: they are the cross between the shell-type remnants and crab-like remnants.

- Goals: Our aim is to determine the category of a candidate of SNR and what its magnetic field strength is by analyzing which kinds and levels of radiation it emits and how they affect shock waves.
- Methods: X-ray Synchrotron Radiation Detection and Spectroscopic Analysis.

4.5 AGN Jet Dynamics and Cosmic Ray Interactions

- Author: Carles Fonseca Maurí
- Field: Active Galactic Nuclei
- Context: Active Galactic Nuclei (AGN) are among the most energetic astrophysical phenomena, with relativistic jets originating from their central supermassive black holes (SMBHs), Blandford et al. (1977). These jets are capable of injecting vast amounts of energy into the interstellar and intergalactic medium, impacting gas dynamics, star formation rates, and the broader evolution of galaxy clusters. Understanding the precise influence of AGN jets, particularly their role in quenching star formation and generating cosmic rays (CRs), remains an active research area. The CAPIBARA mission provides a novel opportunity to study these high-energy processes.
- Goals: We aim to compare the simulated high-energy outputs and particle distributions from AGN jets using the SWIFT simulation code (Schaller et al. (2024)) to CAPIBARA's expected observational data on CRs and associated photon emissions. Through these simulations, AGN jets are analyzed in terms of their jet power, spin dynamics, and interactions with the surrounding medium, with special attention to shock-induced CR production and X-ray cavity formation.
- Methods: This study employs SWIFT-based simulations of AGN jets, mirroring setups similar to those used by Huško et al (e.g. Huško et al. (2024)) to model jet feedback and black hole spin dynamics in galaxy groups and clusters.

  By drawing comparisons between the simulated jet energetics and CAPIBARA's CR observations, this study aims to enhance our understanding of how AGNs contribute to the CR population and high-energy photon background. Furthermore, this context allows us to explore how AGN feedback mechanisms shape the evolution of galaxy clusters, offering theoretical support for CAPIBARA's objectives in mapping high-energy cosmic processes.

5 Experiment Design

5.1 Primary Cosmic Ray Detector

This experiment must be capable of detecting CR protons and, if possible, α-particles. The two most frequent CR particles (see 1).

When considering direct measurements, as this is the case, combining different detectors is essential to obtain a full characterization of the particles (Piera, 2012). Therefore, the detector should be "layer" built, basically stacking the detectors together and obtaining a relatively compact device (taking into consideration the distance between detectors needed to perform some detections). There are three types of measurements which need separate devices, which are the following:

- **Time-of-Flight (TOF):** Time-of-flight detectors work in pairs, and they trigger a clock when a particle hits the first one, which is stopped when the second one is hit. Then, through a series of calculations, the particle velocity can be obtained. In our case, and as many other satellites CR detectors (i.e. PAMELA[13], AMS[14]), scintillators can be used. Scintillators are materials that exhibit scintillation, which is the physical process through which a material emits a flash of light when it is hit by a charged particle, for instance, protons or α particles (Maddalena F, 2019). This light is then detected with photo-multipliers which are part of an electrical circuit that can recognize a difference in the voltage. The main disadvantage of scintillators is that the light produced is not linear, which means that the energy can not be inferred (Zeitlin, 2012).

- **Charge Detector:** Essentially, this detector determines whether the charge is positive or negative and the value itself. Among the available options, one that is fairly used in other detectors, are Silicon Detectors. They work as diodes to which a voltage is applied, acting as a parallel-plate ionization chamber, that is, when a charged particle passes through it generates a current (Zeitlin, 2012).

- **Energy Detector:** The principal function of this apparatus is to establish the total energy of the particle. In this case, an electromagnetic calorimeter is required. It works by the principle of "destruction", which means a particle loses all its energy passing through the detector, which is converted into a signal (Masciocchi, 2017).

5.2 X-ray Observatory

Electromagnetic detection in the X-ray range with a pointing accuracy of about $5''$ and $0.5''$ in both right ascension (RA) and declination (DEC) coordinates.

In astronomy, many X-ray detection methods have been discovered and evaluated, and one that has been widely applied within scientific purposes are Charged-Coupled Devices (CCDs), which are arrays of linked capacitors (Grant, 2011). This device converts the photons into photoelectrons and moves an electrical charge. This is negative and can be shifted along the sensor to the readout register where is converted into a digital signal (a process known as charge transfer, see figure 6. For a better understanding of their principle of working see (Teledyne, 2024a)). When these photons pass through the CCDs, they lose energy through different effects, i.e. Compton scattering, fluorescence or photoelectric effect (Teledyne, 2024b), generating electron-hole pairs[15]. Considering a silicon substrate, an average ionization energy of $3.65eV$ is required. Therefore, we can estimate the energy of the X-ray with the following formula $N_e = E_x/w$. Where N_e is the number of electrons, E_x is the energy of the X-ray photon and w is the ionization energy ($3.65eV$).

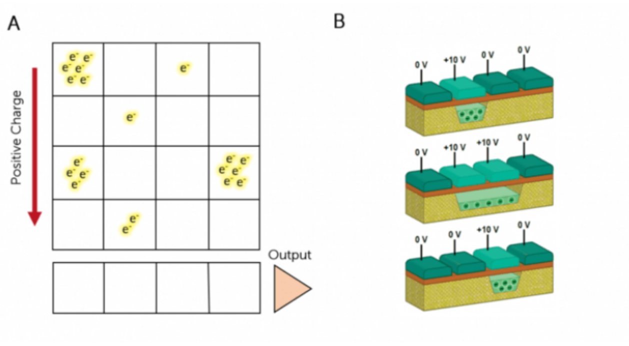


Figure 6: Charge transfer process (credit: (Teledyne, 2024a))

The detector would work as a photon-counter, which basically means that it makes a recount of all the photons detected. To ensure high-quality measurements, each photon should be collected within only one pixel. Nevertheless, one photon may interact with two, or more, different pixels. To address this situation, an intensity-threshold is used to distinguish between single-pixel and multiple-pixel events. A grading system is used in X-ray telescopes with this technology, such as ASCA, which stands for Advanced Satellite for Cosmology and Astrophysics (see figure 7), to discriminate between X-ray and cosmic rays [16] (Grant, 2011) .

[13] https://pamela.roma2.infn.it/

[14] https://ams02.space/

[15] Electron-hole pairs refer to the excitation in a semiconductor where an electron is excited from the valence band to the conduction band, leaving behind a positively charged hole (Luiz H.G. Tizei, 2017).

[16] These grade codes were used in the ASCA mission to discriminate between X-ray and cosmic ray events. Generally, X-rays tend to be simpler events than other cosmic ray events, therefore, they can be differentiated. It is further explained in (Grant, 2011).

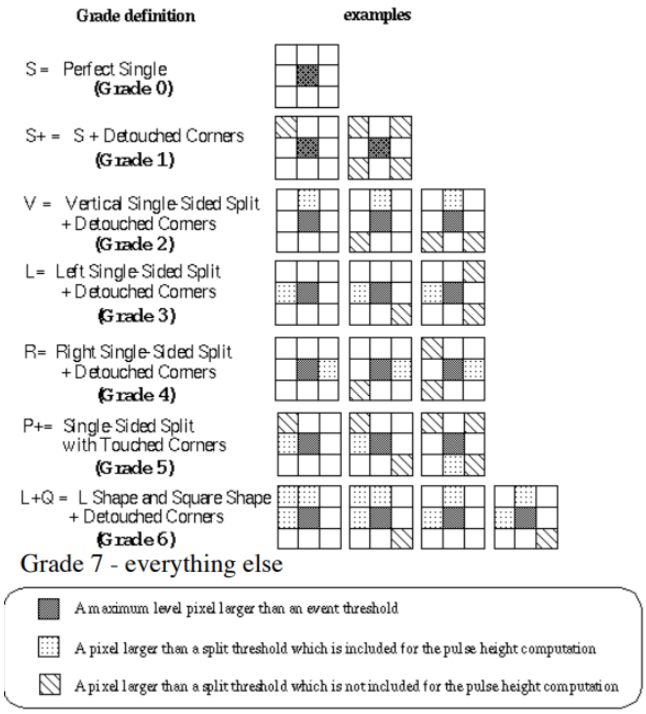


Figure 7: ASCA Grade Codes (credit: (Grant, 2011))

5.3 γ-ray Observatory

Wide-field camera for surveying γ-ray sources, less pointing capability will be required.

γ-ray detection can be divided into two categories. The first one includes what are called spectrometers or photometers in optical astronomy, which use scintillators or solid-state detectors. The second includes detectors that perform γ-ray imaging. This one relies on the processes that happen due to the nature of γ-rays, for example, Compton scattering (GSFC, 2018).

In the first case, the operation of scintillators or solid-state detectors is done in the same way it is done in X-ray astronomy, so in our case, these detectors would be very convenient. Nevertheless, a brief description of a specific γ-ray detector is provided:

- Compton Scattering Detectors: The so-called Compton Scattering is a phenomenon that occurs when a photon hits an electron and some of the photon energy is transferred to the charged particle, this is the basis of the detection. These telescopes have usually two levels of detectors (see figure 8). In the first layer, the γ-ray scatters off an electron, and then this scattered photon is absorbed by a second layer. With the help of phototubes, an approximation is made to determine the interaction points and the deposited energy (GSFC, 2018).

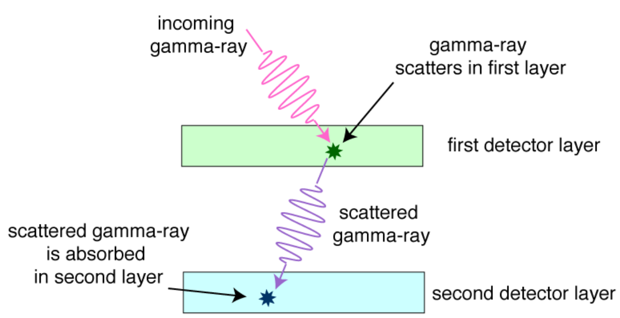


Figure 8: The structure of a two-level Compton detector (credit: (GSFC, 2018))

6 Data Management Plan

We expect to collect 8 different types of data: (1) CR particle count, (2) CR time-of-flight, (3) CR charge, (4) CR energy, (4, 5) photometric and (6, 7) spectroscopic data from X-ray and γ-ray cameras, and (8) environmental data from the satellite. This data will be collected by: (1) combined CR detectors, (2) time-of-flight detector, (3) charge detector, (4) energy detector, (4, 5) X-ray and γ-ray CCDs, (6, 7) X-ray and γ-ray spectrometers, and (8) specialized sensors on the satellite[17].

6.1 Onboard Data Processing

Onboard data processing is necessary, and as a consequence temporary onboard storage. Some high-energy phenomena only last for minutes or even seconds, therefore it is crucial to have onboard data processing to live monitor observations and identify and localize potential transient detections, as well as create and share alerts via the General Coordinates Network[18] (GCN) (Singer et al., 2023). Another consideration is to perform early-stage data reduction (e.g. instrumental background subtraction and image calibration) onboard, this way we would reduce the amount of data transmitted back to the ground.

Regarding ground data processing, an automated or semi-automated data reduction pipeline will be developed by the collaboration and made available publicly. Afterward, each research project will analyze the data at their convenience, focusing on their specific research requirements.

6.2 Data Publication

Data will be made public by steps, and differently depending on the data type. Firstly, regular observations will be reduced and made public internally in the collaboration as soon as possible. The data will be made public about 180 days (6 months) after the observation. The method for massive data publication is still to be determined.

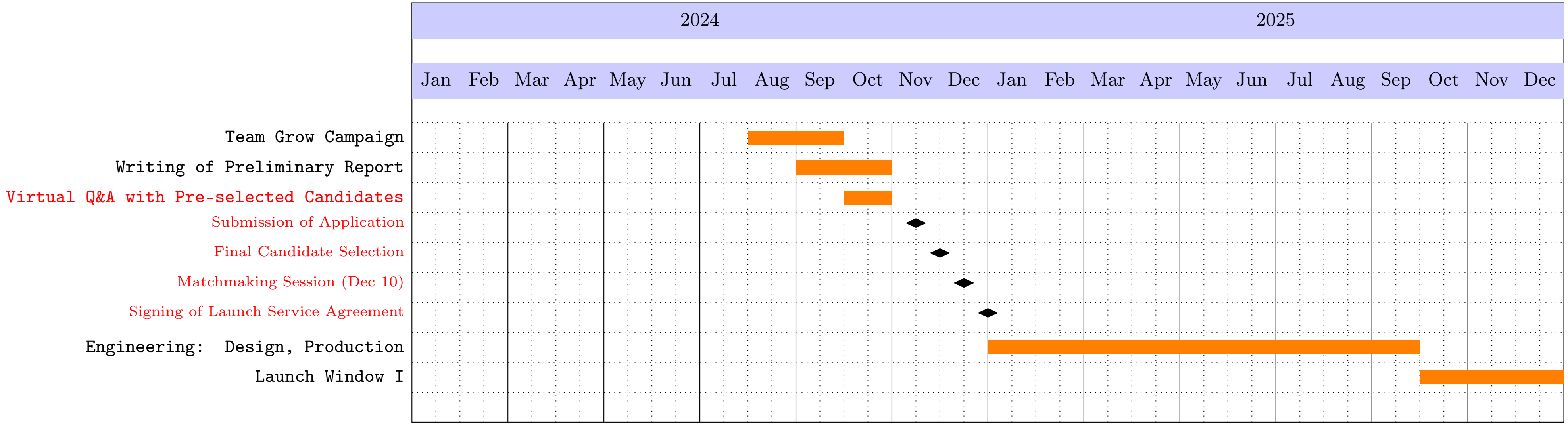
For transient events[19] data will follow the same path as regular data. However, due to the transient nature of these phenomena, some data will be shared via an alert through the GCN. These alerts enable quick follow-up observations with other telescopes and instruments covering diverse wavelengths, as well as cross-check observations.

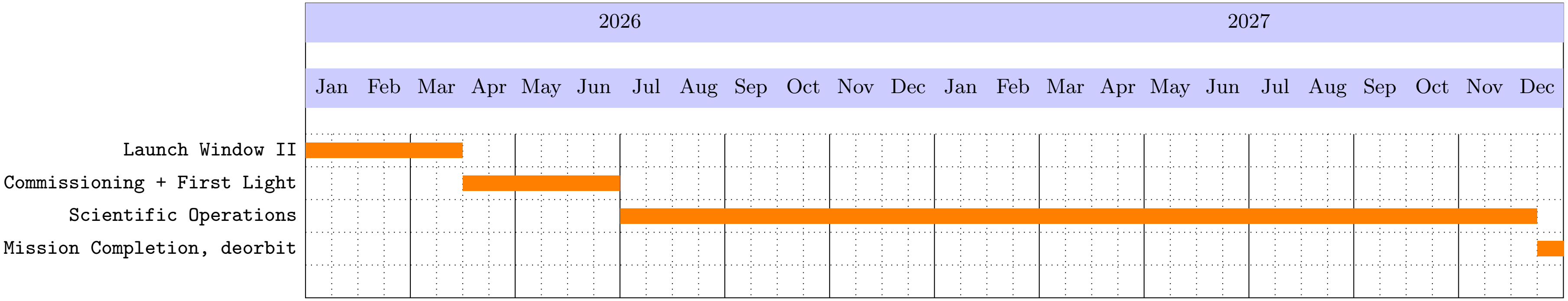
Additionally, we expect to publish a formal data release paper, where we will extensively explain the data reduction pipeline and data accessing procedure.

We are exploring various data-sharing options including collaborative repositories and public databases. Internal data-sharing protocols are still to be disused, with decisions on storage solutions, licensing, and cyber-security measures to be made as the project advances. Furthermore, storage capacity and data load expectations will be evaluated once the instrument specifications are finalized.

[17] Note that we do not have a plan for these sensors, but rely on the matchmaking for this aspect.
[18] https://gcn.nasa.gov
[19] As transient events we are considering SNe, GRBs, AGNs, TDEs, Kilonovae, Novae, M-dwarf flares, Variable stars, and transient CR phenomena.

7 Project Timeline





Red text indicates the deadline established by PLDSpace (from Application Stages). Also, note that the duration of the scientific operations is not yet decided. (last checked Nov 10, 2024).

8 Team Presentation

We are a group of students from various schools in the greater Barcelona metropolitan area, united by our interest in scientific research and space exploration. Motivated to participate in the Spark program by PLDSpace, we are excited to bring this project to life. Each team member has a unique background and area of expertise, contributing their knowledge and skills to the group. We are also grateful for the support of our science and technology teachers, who have guided us along the way. Below is a brief introduction to all participants. You can find more information about the project and our team on our website, capibara3.github.io.

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- Field of work: Astronomy & Astrophysics, Cosmology
- Experience: Joves i Ciència '23, Jugend Forscht '24, Explainers '22
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- Field of work: Astrophysics, Engineering (Aerospace)
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- Hobbies: Playing the piano, basketball, skiing, coding, reading.

9 Conclusion

In conclusion, we have presented a preliminary concept for our mission covering the central aspects for further development and participation in the Spark Program. Describe our scientific and technical objectives and outline the relevance of this mission. Additionally, we have shown potential applications and research within the collaboration, and present a preliminary instrument design plan, and future plans and timeline. We are confident that with continued refinement and support, this mission will create new opportunities for discovery and foster a collaborative research environment that bridges educational and scientific achievements, contributing to a deeper understanding of the Universe's most energetic phenomena.

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