# 1 Introduction

Cosmic Rays (CRs) or cosmic radiation are charged particles coming from the Universe at high energy due to their high velocities. 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 | $\sim 87\%$ |
| $\alpha$ 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).

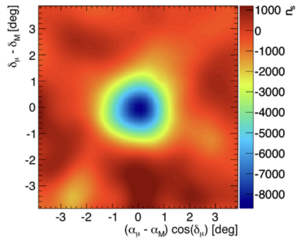



Figure 1: Contour plot of the muon deficit as measured by IceCube in the region around the Moon's position, the so-called on-source region (credit: IceCube Collaboration)

When these particles interact with a medium, they decay in 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 which helps trace CRs. However, it can not been 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, atmospheres, among others. This type of light reaches us in high-energy wavelengths, mostly in X-rays and $\gamma$-rays, but also in the ultraviolet (UV) and infrared (IR) spectrum. These photons have different properties as compared with fermions and hadrons, meaning a totally 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 $\alpha$-particles, i.e. Helium nuclei, ($\alpha$, $\alpha^{2+}$, 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 CRs interactions, as they give us different information about CR sources and physical processes of their interactions due to the difference in nature of light. To do so, we have to be capable to detect photons in the X-ray and $\gamma$-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 alte 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 $\gamma$-ray background (CGRB) has been studied by the FERMI-LAT instrument in detail. It is believed that this radiation emerges from unresolved source (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 in $\gamma$-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 $\gamma$-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 mission 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 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 derobit 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 PCRs 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 $\gamma$-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 mission is crucial for the study of these phenomena.

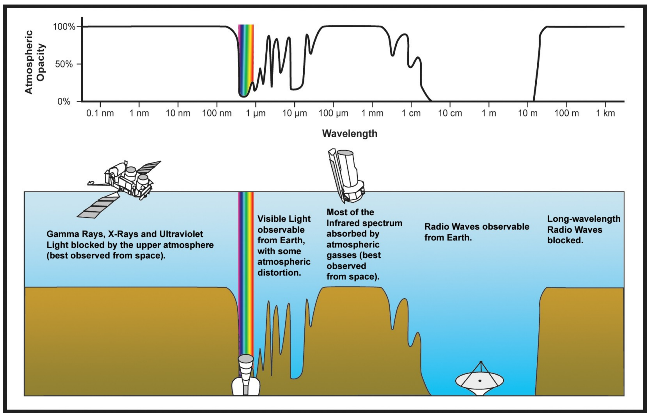



Figure 2: Atmospheric electromagnetic opacity by wavelength. (credit: NASA)

### 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 in 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 solution 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 landspace 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).

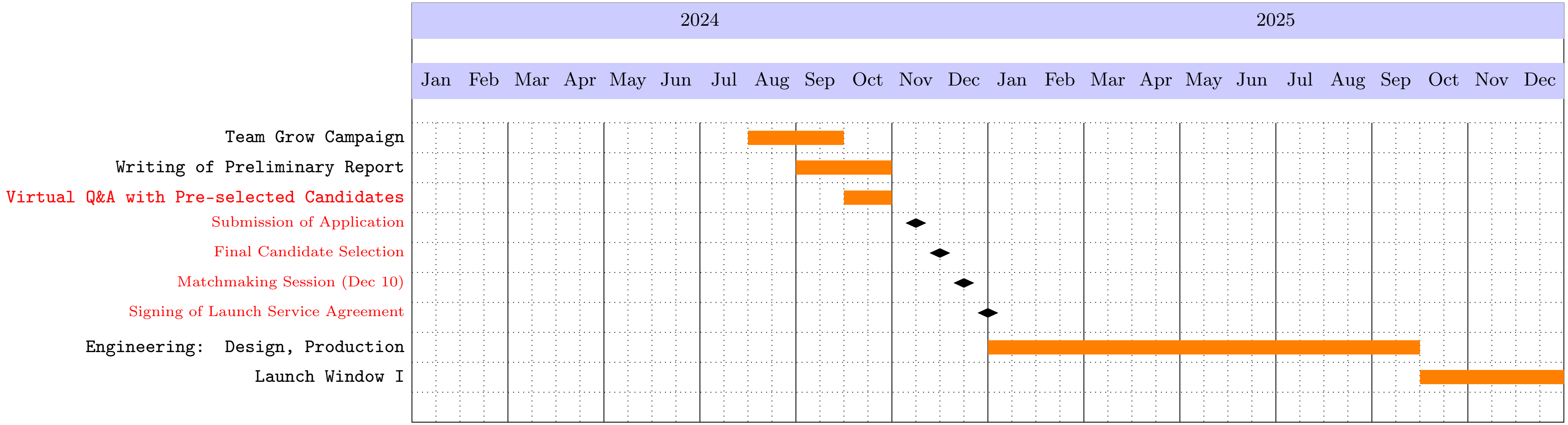
Furthermore, two of NASA's Great Observatories[2] were once dedicated to high-energies, Compton (CGRO) and Chandra (CXO). However, the Compton Observatory was deorbited in 2000, and the Chandra Observatory is going to be decommissioned soon without direct replacements[3]. Other $\gamma$-ray telescopes such as SWIFT (launched 2004) or FERMI (launched 2008) are also turning old.

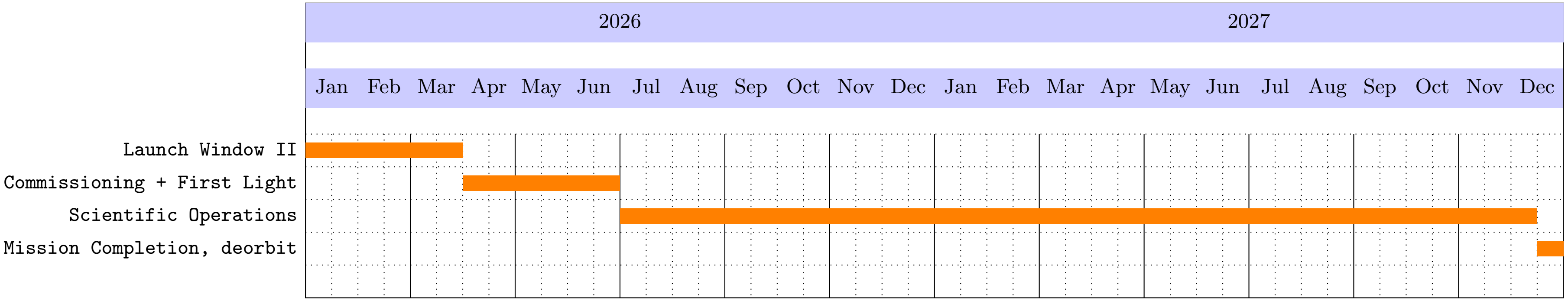
Therefore, our objective of exploring the high-energy range by observing light as well as particles (CRs) align with the current gap in observational capabilities, which develops a gap in research.

All in all, these factors highlight a limitation in observational capabilities that develops a research gap, which we intend to address with our mission by exploring the high-energy range through the observation of both light and cosmic rays.

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

# 7 Project Timeline




Red text indicates deadline established by PLDSpace (from Application Stages). Also, note that the duration of the scientific operations is not yet decided. (last checked Aug 24, 2024).