MINICOR - A COST-EFFECTIVE 12U CUBESAT CORONAGRAPH FOR THE STUDY OF SOLAR ERUPTIONS

Gabriel Gutierrez (1), Giorgia Casadei (1), Ludovica Bozzoli (1), Miguel Pereira (1), Corbett Hoenninger (1), Robert Mertes (1), Angelos Vourlidas (2), Aaron Magner (2), Edward Reynolds (2), Arnaud Thernisien (3), Clarence Korendyke (4)

(1) Argotec Inc, 180 McCormick Drive, Suite 350, Largo, Maryland 20774.
gabriel.gutierrez@argotecgroup.com
(2) The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd, Laurel, Maryland 20723
(3) Naval Research Laboratory, 4555 Overlook Av. SW, Washington, DC 20375
(4) Space Science Research Corporation, 2000 Duke St., #300, Alexandria, Va 22314

The study of solar activity is essential in not only unravelling the mysteries of the Sun's behaviour but also in advancing our understanding of its effects on the planets and human space exploration. As the sophistication of smallsats continues to grow across various space missions, their importance as solar observing platforms is increasing rapidly. The Miniature CORonagraph (MiniCOR) mission represents a pioneering 12U CubeSat coronagraph designed to address not only the technical challenges associated with smallsat missions, but also to contribute significantly to solar research. The understanding of the intricacies of solar eruptions, especially the kinematics of Coronal Mass Ejections (CMEs) is imperative to prevent and mitigate potential space weather impacts on Earth.

MiniCOR, designed as a cost-effective solution, seeks to demonstrate its capabilities by capturing high-cadence, high-quality solar imagery with equal or superior sensitivity to existing solar coronagraphs. In contrast to conventional large-scale instruments like the Solar and Heliospheric Observatory (SOHO) Large Angle and Spectrometric Coronagraphs (LASCO), MiniCOR’s compact size and efficient design allow for swift assembly, testing, and deployment. The mission’s primary purpose is to demonstrate that miniaturized optical instruments can perform equally well and even outclass conventional designs, whether operational (e.g., Compact CORonagraph; CCOR) or science-grade (e.g., Narrow Field Imager (NFI) of the PUNCH spacecraft). A successful demonstration of MiniCOR will pave the way for constellations of low-cost coronagraphs at optimal viewing points, such as the Sun-Earth Lagrange points, out-of-the ecliptic, or cis-lunar orbits.

MiniCOR leverages three key developments: the miniaturization of spacecraft systems for CubeSat applications, advancements in large-format scientific Active Pixel Sensor (APS) detectors, and the experience gained from developing imaging systems for volume- and mass-constrained missions such as Solar Orbiter and Parker Solar Probe. MiniCOR will capture slow solar wind, coronal mass ejections, and shocks in the inner corona (2.5-20 Rs) with a 4-minute cadence, outperforming existing missions like SOHO and STEREO (Solar TErrestrial RElations Observatory). The expected 6 months of operations provide ample opportunity to achieve technical objectives and to address broader scientific goals, finding among the foremost ones the understanding of small-scale structures in the corona and improving understanding of CME kinematics.

The collaborative effort behind MiniCOR Phase A, in development under the NASA Heliophysics Flight Opportunities for Research and Technology (H-FORT) program, involves the Johns Hopkins University Applied Physics Laboratory (APL) with a significant heritage in challenging space instrumentation and mission development, the Naval Research Laboratory (NRL) contributing expertise in coronagraph development, and Argotec Inc., a leader in CubeSat systems, responsible for developing, manufacturing, and operating the spacecraft. In fact, the spacecraft is based on Argotec's HAWK platform, successfully implemented in LICIACube and ArgoMoon deep space missions. APL and NRL will jointly analyse the data and publish results, further solidifying MiniCOR's impact in advancing solar research. The combined expertise of these institutions provides excellent premises for the future success of the mission, offering new insights into solar phenomena and further solidifying smallsats impact in advancing solar research.

1 INTRODUCTION

The study of solar activity occupies a prominent place within the missions carried out over the past decades by NASA (National Aeronautics and Space Administration) and NOAA (National Oceanic and Atmospheric Administration) programs. Coronagraphic missions, in particular, have contributed greatly in understanding the variability of our nearest star.

These instruments allow us to study the extended solar corona and its short- and long-term activity, especially the Coronal Mass Ejections (CMEs) phenomena, which are massive bursts of solar wind and magnetic fields rising above the solar corona. Coronagraphs are the only devices capable of capturing their development and propagation in the near Sun region and, for this reason, are one of the main players in enabling space weather forecasting programs.

Because of this strategic importance, the need to continue space-based coronagraphic observations beyond current missions' lifetimes has been recognized in the latest National Research Council (NRC) Heliophysics Decadal Survey and in the Promoting Research and Operations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act.

It is within this scenario that MiniCOR takes its place. The satellite a is twelve-unit (12U) CubeSat provided with a miniaturized coronagraph, planned to launch in 2027 in Dawn-to-Dusk Low Earth Orbit and operate for at least 6 months. It will observe the CME's kinematics and shocks in the middle corona (2.5-20 Rs) as well as the slow solar wind.

Figure 1. MiniCOR Spacecraft

One of its most notable features of CCOR is the capture of images at higher cadence and with equal or better sensitivity than those from the currently operating space coronagraphs SOHO/LASCO and with a factor of 2.9 improvement in light gathering power over SOHO. This will be possible on a low budget and rapid timescale thanks to three key developments:

- Recent technology miniaturization of CubeSat systems, capable to meet science-grade telescope requirements.
- Electronic advances in Active Pixel Sensors (APS).
- New imaging systems developed, and lessons-learned from Solar Orbiter and Parker Solar Probe missions.

With its quasi-continuous data collection and high signal-to-noise ratio (SNR) instrumentation, MiniCOR will play a crucial role in opening new windows into our understanding of the inner heliosphere, providing support and complementary data to ones given by Parker Solar Probe (PSP) and Solar Orbiter (SO) missions.

The team that will collaborate on the project combines the necessary expertise for the successful outcome of MiniCOR mission. The APL team, with a long history in coronagraph science and instrument development, is supported by the NRL, a premier institution for space coronagraph development, and Argotec, a major player in the CubeSat market with expertise in CubeSat systems such as LICIACube, ArgoMoon, LUMIO and HENON Deep Space Missions. The collaboration aims to analyse data jointly and publish results.

1.1 Scientific Relevance of the MiniCOR mission

The MiniCOR field of view (FOV) spans from 2.5 Rs to 20 Rs, covering the region where coronal mass ejections undergo acceleration to their terminal speed as they depart from the Sun. During this phase, the morphology of CMEs evolves to a stage where it can be possible to identify Earth-directed CME, also called “Halo CME” for their characteristic halo appearance. The derived morphology and kinematics of CMEs from MiniCOR images provide essential inputs for operational models of solar wind disturbance propagation, such as ENLIL, with the model's inner boundary closely matching the MiniCOR FOV at 21.5 Rs.

The high cadence (about 4 minutes) and high signal-to-noise ratio (SNR) of MiniCOR observations allow for the measurements of small variations in CME speed and acceleration up to 20 Rs, shedding some light in the role of post-flare reconnection in CME kinematics and enhancing the accuracy of CME propagation models. Even the fastest CME ever observed at 3,000 km/s would take an hour to traverse the MiniCOR FOV and easily be observed by the coronagraph, even if the occurrence of such event in the 4 months of operations is highly improbable.

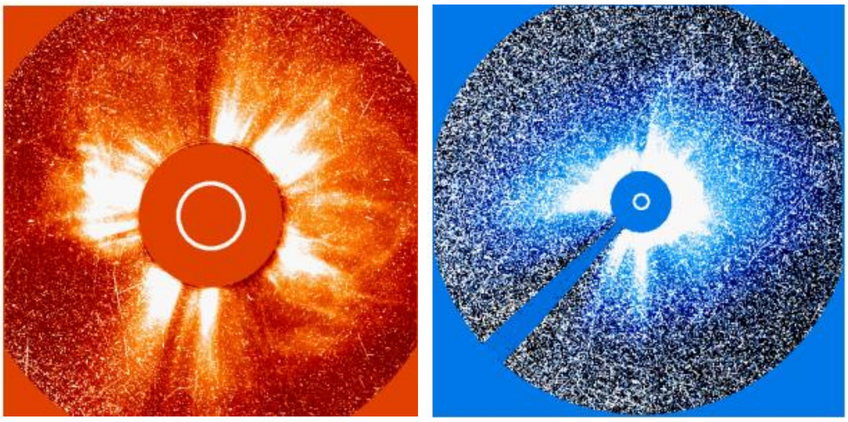

Figure 2. Particles accelerated during a CME event captured by LASCO C2 (left panel, 11:06 UT) and C3 (right panel, 11:18 UT)

MiniCOR unique configuration aims to outperform existing coronagraphs in cadence and coverage, demonstrating that a low-cost, miniaturized CubeSat coronagraph can produce scientific data of comparable quality to the currently operational conventional SOHO/LASCO and STEREO/SECCHI coronagraphs. In its stowed configuration, MiniCOR coronagraph occupies approximately 3U, significantly less than the combined volume of LASCO C2 and C3 one, which totals 73.4U. The projected mass of the MiniCOR instrument is less than 3.6 kg, including the boom, structure, and contingency, in comparison to the 13 kg mass of the STEREO/COR2 coronagraph and the 18 kg mass of CCOR-2.

The upcoming years present an excellent opportunity to launch and test MiniCOR. The CCOR coronagraphs on the GOES and SWFO-L1 (Space Weather Follow On-Lagrange 1) observatories will serve as a unique resource for cross-calibrating and assessing the performance of a coronagraph along the Sun-Earth line. If still operational, STEREO-A/COR2 will be in quadrature, providing support for 3D reconstruction of CMEs in the lower corona (in the region under 4 Rs), which is inaccessible to CCOR or PUNCH. Due to MiniCOR's improved resource requirements compared to CCOR, it represents a significant next step for both research and operational coronagraphs.

2 MINICOR’S MISSION ANALYSIS AND DESIGN

The design of the project concerning the planning and development was initially approached in two steps, through which a strategy to achieve efficiently the set objectives was developed:

- Mission Analysis: a thorough review of the mission's objectives, needs, and constraints to underline the scientific, technical, and logistical elements and pinpoint potential issues. This ensures a full grasp of the mission's extent and aims.

- Mission Design: a comprehensive strategy for the mission is formulated, outlining precise activities, roles, and responsibilities for each segment, including spacecraft or ground operations. This integrated approach marries scientific objectives with engineering and operational considerations to guarantee a mission that is not only successful but also efficiently managed across technical, economic, and logistical hurdles.

2.1 MiniCOR Objectives, goals, and needs

Based on the importance of coronographic studies defined in the previous chapter, and the stakeholder needs, the MiniCOR mission objectives are:

- Unravel the small-scale nature of the slow solar wind.
- Delineate the kinematic behavior of Coronal Mass Ejections (CMEs) in the middle corona, ranging from 2.5 to 20 solar radii.
- Leverage cost-effective technologies to provide high-quality data that matches or surpasses that of larger-scale coronagraphs.

From these, a set of goals are written to better elaborate and explain how the needs will be fulfilled in term of system performance:

- The mission will capture detailed images within the middle corona range of 2.5 to 20 solar radii (Rs) targeting CMEs and the dynamics of the slow solar wind. By scheduled the launch within the end of the solar maximum cycle, the project plans to collect crucial data over an initial four-month period, with an option to extend for an additional year.
- In order to equal or exceed the capabilities of existing missions like SOHO/LASCO, STEREO, and SECCHI the mission needs to offer data with a duty cycle (exposure/cadence) equal to 8%, provide sensitivity and quality improvement, and obtain a signal-to-noise ratio of 5. This improvement in data quality and frequency aims to provide more detailed and reliable solar observations.
- Additionally, the mission intends to showcase the effectiveness of small satellite technologies, such as the utilization of miniaturized detectors on a CubeSat platform. This approach seeks to prove that advanced scientific missions can be conducted efficiently and cost-effectively using compact satellite systems.

Based on these considerations, we flow down a set of mission top-level requirements summarized in Table 1 that drive the mission design. If the requirements are not met, then the mission may be at risk of not fulfilling its science objectives.

Table 1 MiniCOR Top-Level Mission Requirements

Mission Parameter	Requirement
Mission Duration	≥ 4 months of scientific operations
Orbit	Altitude <580 km; Inclination >35°
Pointing	Accuracy < 60” Stability 20”/20 sec Knowledge < 60”
Downlink	≥ 430 MB/day
Platform	6U- 12U CubeSat
Operations	No special maneuvers; no target selection; no special observing programs

The mission design process is then continued with the functional analysis that, from the mission's goals and constraints, identifies and delineates the core functions that must be executed by the spacecraft and other mission elements. This phase is pivotal for grasping the logical breakdown of these functions, allowing for a thorough assessment of each mission scenario to unravel the complexities of a space system. Such analysis enables the assignment of specific functions to subsystems or components, thereby enhancing the clarity in the development of a system's architecture, the groundwork for defining system requirements, interface definitions, and setting verification and validation standards.

During this analysis, besides the launch, operational and disposal scenario even the protoqualification and test environment ones were considered. The analysis involved the development of Functional Tree, Functional Flow Block Diagram (FFBD), Function/Devices Matrix, Connection Matrix and Product Tree.

2.2 System Work Philosophy

Throughout the duration of the project, continuous engagement with stakeholders and clients is envisioned to facilitate the gathering of diverse requests that will shape the mission and the design of the system, including its platform and payloads. These requests are transformed through the system engineering process into concrete system requirements.

Requirement generation is part of a cyclical and iterative methodology designed to capture and define all relevant inputs, outputs, their interrelationships, constraints, and how the system will interact with the technical team responsible for its operation and with other systems.

The iterative process begins with defining mission objectives and identifying mission design drivers, such as programmatic factors, cost, schedule, and other limitations. After establishing the baseline concept of operations, supported by mission analysis results, an initial set of mission requirements is agreed. The system functional requirements are instead developed from the functional tree and further improved by the function/device matrix together with the connection matrix to outline equipment interrelationships and preliminary interface requirements.

If then, after writing the system requirements, the product tree and the preliminary functional and physical system architecture meet the Concept of Operations (ConOps) and mission requirements, the process advances to subsystem level analysis. At every discrepancy and open point, the process iterates to find a new solution. Following this method, the MiniCOR mission will guarantee a complete and sound process for the definition of both technical and programmatic constraints, while guaranteeing the satisfaction of the stakeholders. This iterative process is shown in Figure 3.

Furthermore, the MiniCOR technical and programmatic development will be aided by an Agile philosophy, where the team members will work using the Scrum methodology in fixed time sprints. These sprints will be defined by achievable and well-defined tasks and goals, ensuring that at the end of this timeframe a concrete increment is met. This method includes in the iterations loop the management, the client, and other stakeholders, guaranteeing the alignment of all the different players, the achievement of results and the planning for the next sprints to be in line with expectations.

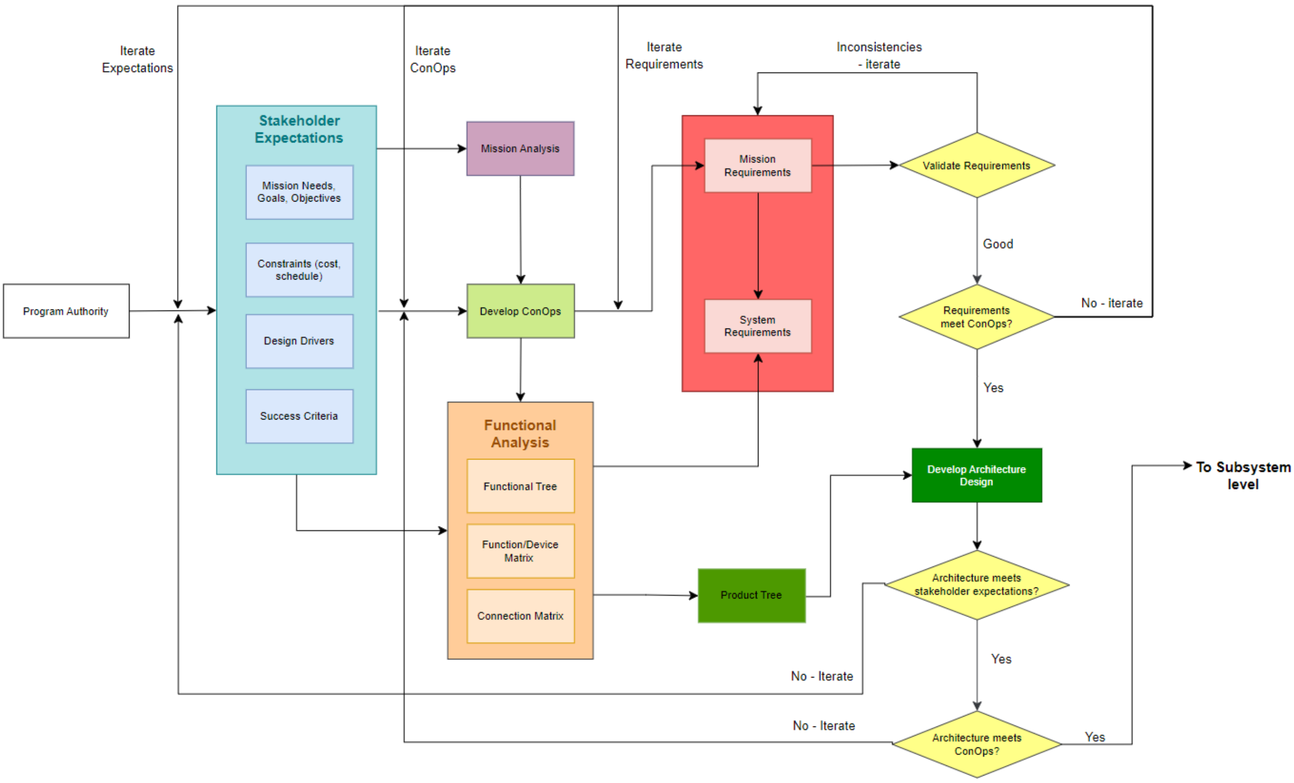

Figure 3. System Design Process

3 CONCEPT OF OPERATIONS

From the mission goals and constraints and through the mission analysis, a Concept of Operations (ConOps) was elaborated to further investigate the feasibility of the developed project ideas, describing the mission architecture and how those elements cooperate to achieve the identified objectives (with particular focus on temporal and operational standpoints), the set of operations to be carried out during the operational and non-operational life of the satellite, and the various application scenarios of the platform from an user point of view. This procedure is highly iterative, as each new concept can reveal previously overlooked aspects and requirements. Consequently, the ConOps will develop concurrently with the system definition and development stages.

The baseline MiniCOR mission aims to capture images of the solar corona with improved sensitivity, frequency, and clarity. To achieve this, the satellite is fitted with a 3U coronagraph and a sophisticated optical sensor capable of identifying fine solar structures. Operating from a Low Earth Orbit (LEO) or SSO depending on launcher availability, the mission benefits from multiple ground stations capable of S-band communication (e.g., commercial providers, specially over the Svalbard Islands) for data and telemetry transmission and reception, that need to be evaluated to ensure enough communications window for the downlink. The mission operations will be managed internally by the consortium, where Argotec will oversee spacecraft operations and APL and NRL will manage the data analysis and distribution. The Launch segment that provides the best piggyback launch opportunity in relation to the timeframe and other constraints of the project is under the NASA's CubeSat Launch initiative (CSLI).

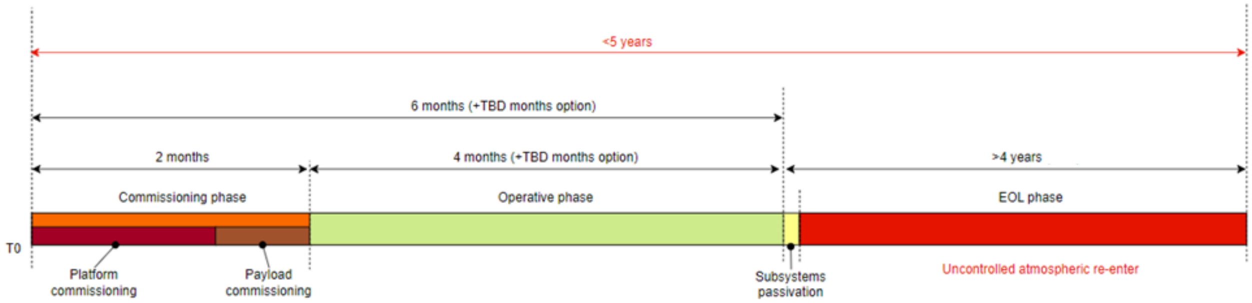

Figure 4: Mission Phases

After the launch and commissioning phase, the mission embarks on its science phase, during which the spacecraft is tasked with achieving the mission's objectives. This phase is set to last for 4 months after which it will transition to the End-of-life Phase. During those months, the spacecraft will continuously capture images of the Sun's corona during the Acquisition Mode, while in Communication Mode it will transmit telemetry and payload data to ground stations, alongside a transmission exchange to monitor system health and receive telecommands. Other activities include battery recharging in Sun Pointing Mode, using magnetorquers to desaturate the reaction wheels, and entering power-saving mode during eclipses (Eclipse Mode). The payload acquisition is constant in sunlight and comprises of 20-80 sec exposure, depending on whether image summing is on, with a 4-minute cadence. The communication windows are set to be around one every three orbits with an average duration of 7 minutes. MiniCOR will provide around 350 images per day, with a total daily date volume of 367 MB and a daily data volume capability of 450 MB.

In accordance with the Space Debris Policy, all spacecraft must vacate Low Earth Orbit (LEO) within 5 years following mission completion. Given that MiniCOR lacks a propulsion system, it is crucial to conduct specific analyses to assess its decay timeline. These analyses include the evaluation of potential debris generation and collision risks after passivation, ensuring compliance with regulatory standards, even for a CubeSat mission.

4 SYSTEM DESIGN

The capability to meet outstanding performance of large-scale coronagraphs in a 3U volume is possible thanks to three factors: exceptional optical capabilities, a compact deployable boom measuring 60 cm, and a flight-proven APS detector. Leveraging the unique features of the APS electronic shutter, 16GB memory storage, and staggering spacecraft pointing capabilities, MiniCOR aims to gather coronagraphic data with unprecedented sensitivity and temporal resolution. The spacecraft platform and subsystems, provided within the Argotec’s HAWK 12U standardized LEO platform, as well as the payload from the NRL-APL team, which possesses world-class expertise in coronagraphic instrumentation and science, will be equipped with extensive heritage hardware derived from prior projects (PSP/WISPR, DART/LICIACube, Artemis 1/ArgoMoon), significantly mitigating program cost and schedule risks.

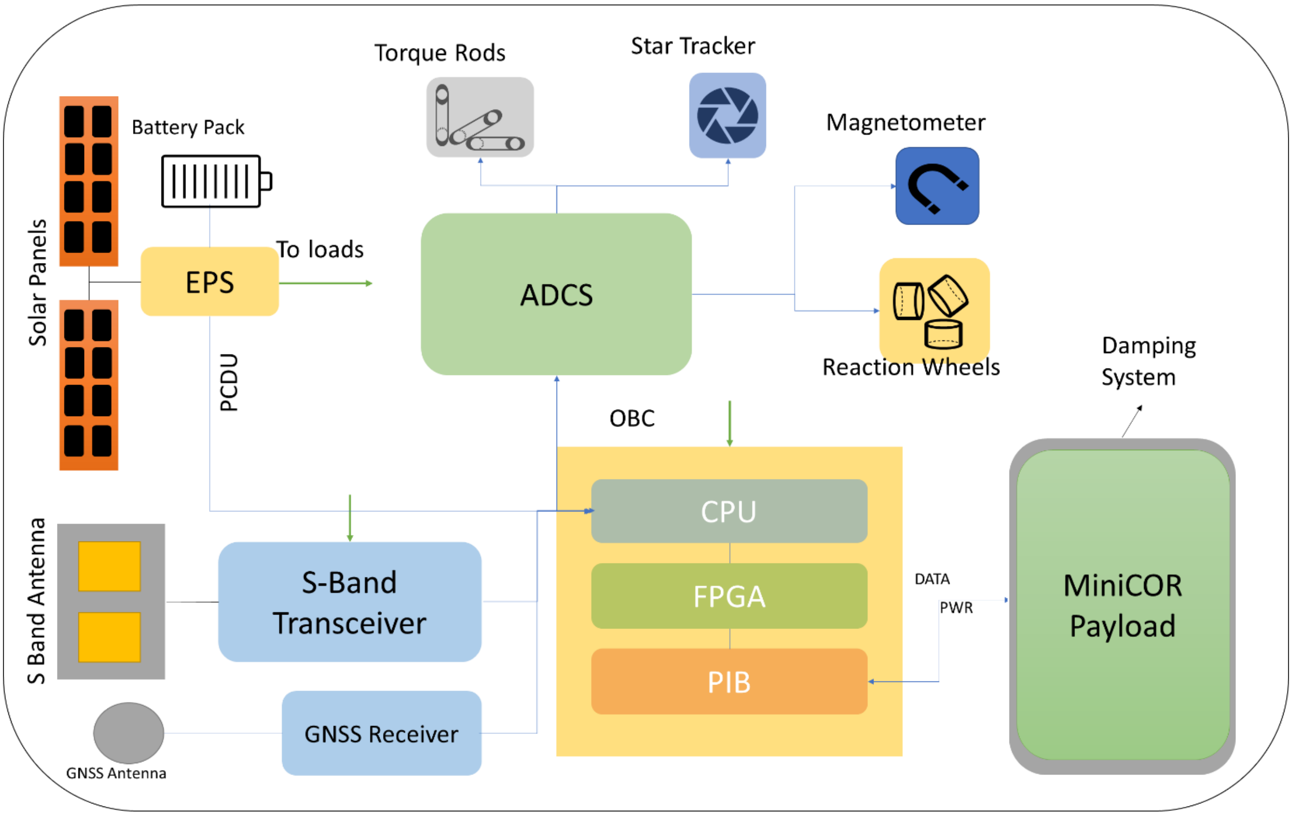

Figure 5. MiniCOR Spacecraft Architecture

4.1 Payload description

Coronagraphs are instruments used in astronomy to observe the Sun outer corona (and of other celestial bodies) by blocking out the direct light from the central disk, allowing fainter structure to be visible and otherwise overwhelmed by the intense brightness of the Sun. To block the direct light an occulting disk is usually used, placed in the optical path, but allowing light from the outer regions to pass through. MiniCOR adheres to the successful design principles employed in the development of previous coronagraphs, especially aligning with those of the SECCHI COR2. In fact, MiniCOR's field of view and distance to the external occulter closely mirror those of SECCHI COR2 together with the stray light performance, approximately ~$3x10^{-11}$ Mean Solar Brightness (MSB). Also, the image quality of 53 arcsec FWHM is comparable to CCOR and represents improvement over C3 120 arcsec. Because of the volume constraints, the coronagraph optical train is enveloped in a 90x180mm thanks to the use of two folding mirrors.

The deployable boom design follows the OSO-7/Solwind design. The release will be managed electronically by the spacecraft through a pin-pulling paraffin actuator. Each segment will be moved into its designated position using a constant force spring, and precision hardened steel locating pins will ensure the precise alignment of each stage, at a maximum extension of around 60 cm.

The MiniCOR payload design is characterized by its simplicity and its heritage, being a traditional externally occulted Lyot coronagraph and incorporates various apertures and stops to eliminate stray radiation sources, while leveraging past space missions' know-how and technologies. Operating in a Dawn to Dusk orbit, Earth eclipses occur for about three months per year, with most eclipses lasting less than 21 minutes, during which the acquisition phase operations will not be possible to be pursue. One of the main concerns is to manage and plan a launch date or orbit that minimizes Earth eclipses throughout the 4-month of the mission operations, otherwise the mission will be managed in a best-effort basis.

4.2 Spacecraft Bus description

Argotec is responsible for the platform development and for the operational phase of the mission. The spacecraft is based on the HAWK 6U bus, used on ArgoMoon and LICIACube deep space missions, and the HAWK for Earth Observation platform optimized for LEO. This 12U standardized platform will include both COTS and Argotec developed subsystems, leveraging both budget optimization and reliability. The following subsystems and equipment are envisioned:

- The **Structure** Subsystem provides the necessary physical support for the hardware and endures mechanical loads during launch, deployment, and operational phases. This is made to be compatible with different payloads and deployment systems, optimizing for different launch opportunities that might arise.

- The **Attitude Determination and Control System** (ADCS) focuses on determining and controlling the satellite's attitude, ensuring it is always properly oriented according to its intended pointing direction. The chosen ADCS architecture is comprised of: 3x Reaction Wheels, 3x Magnetorquers, 3-axis Magnetometer, 1x Star Tracker, 3x Sun Sensors, 1x IMU. The subsystem is considered critical because of the pointing stability constraints imposed for the acquisition phase, which are of 20 arcsec over 20 seconds towards the Sun. Only few COTS ADCS have enough jitter accuracy and are enough reliable to satisfy it. Because of the importance of this issue, in addition to the appropriate choice of subsystem and system level analysis, there are also other two mitigations strategies that could be implemented: vibration damping system and detailed jitter analysis and testing.

- The **On-Board Computer & Data Handling** (OBC&DH) subsystem enables communication among all subsystems to ensure proper interaction and executes the satellite's intended operations. The selected OBC is “FERMI”, developed by Argotec for deep space CubeSats employing high reliable components. This next generation OBC is characterized by a robust design, top class performances, compact form factor and low power consumption.
  The system is characterized by two main components: a CPU executing the software and handling the main data interfaces, and an FPGA acting as extension chipset and providing additional interfaces, mass memory, and hardware-acceleration capabilities, allowing real time image processing, storage and distribution capabilities.

- The **Electrical Power System** (EPS) comprises the Power Conditioning & Distribution Unit (PCDU), the batteries, and the Solar Panel Array (SPA). It manages the supply, storage, and distribution of electrical power after converting it from the SPA. Argotec ZEUS is an all-in-one PCDU and is part of the selected EPS components. It is developed for microsatellite applications and possesses advanced capabilities for solar panels management, regulation during battery charging, and secondary power rails protection against latch-up incidents. The primary bus operates at a nominal voltage of 32V, while the combined power output of the secondary power rails can reach up to 150W. Despite the incorporation of radiation tollerant and space-qualified components, the unit maintains an exceptionally compact form factor with a total volume < 0.5 U and a mass < 0.6 kg. The batteries will also be provided by Argotec who designed the ELEKTRA battery pack, which will provide two strings with each total energy <180 Wh. In addition, the EPS includes two deployable solar panels wings, released with thermal knives through a spring and hinge mechanism, fixed at a specific angle to reduce straylight effects, which will contribute to a maximum power output of 80W.

- **TeleMetry & TeleCommand** (TMTC) allows the satellite to transmit data to the ground, including scientific acquisitions, and to receive commands from the ground. The communication system is comprised of an S-Band Transceiver paired with two dual-patch antennas for both transmission (TX) and reception (RX). The selected transceiver has an RF power of 2W, while having a frequency selection that adheres to the ITU regulations.

- **Thermal Control System** (TCS) is responsible for maintaining the components of all subsystems within their designated temperature ranges. Thermal control is essential to ensure the optimal functioning of the payload and to manage heat generated by the spacecraft avionics. Throughout the design phase, efforts will be directed towards identifying an optimal combination of surface finishes that produce consistent temperatures over the spacecraft: the ultimate goal is to achieve a fully passive thermal control design.

All these subsystems must be tailored to function even during off nominal and worst-case conditions to guarantee the spacecraft and mission survival. Furthermore, the onboard software (OSW) is based on Argotec’s software with heritage from previous missions, programmed with a suite of mission specific operative modes that tailor the spacecraft's subsystems for each phase of the mission, enhancing efficiency and survivability. Thus, MiniCOR journey begins with LEOP Mode, immediately post-deployment, activating critical systems like the OBC and ADCS to stabilize orientation and power management. The solar panels deploy autonomously, and the spacecraft positions itself to harness solar energy effectively and communicate with Earth.

Figure 6 shows a preliminary CAD of MiniCOR fully deployed. To reach this configuration, various things were considered:

- The payload takes up 30% of the volume and it is the major volume constraint driver of the mission. Due to the length of the telescope, the payload must be placed on the long side of the SC, constraining the solar panels and the remaining subsystems position.

- The solar panels extend from the short side of the spacecraft to always face the Sun. In the CAD it is not effectively pictured, but the panels are envisioned to have a slight tilt towards Z+ to reduce straylight effects on the payload due to reflections in the boom.

- The antennas are situated on the bottom side to always face the Earth (-X) and on the upper side (+X) to guarantee complete commandability in case of malfunctions or uncontrolled attitude.

- To locate the star tracker an analysis of the main attitude states is performed to avoid the Earth, Moon or Sun enter its FOV (which is of 10 deg tilted up). In this case, since there is only one attitude state (+Z pointing the Sun), the only feasible option is to put it on the +X side at anti-nadir.

- The GNSS antenna is also placed in the anti-nadir side, opposed to the Earth, for a better reception of the GNSS constellation.

- The sun sensors shall instead be positioned on the spacecraft faces where it is essential to know if the Sun is present. For this reason, the two-sun sensor will be positioned one on the +Z side where there is the payload, and one where all the sun-sensitive optics are, which is on the +X side. Extra sun sensors can be placed if deemed necessary.

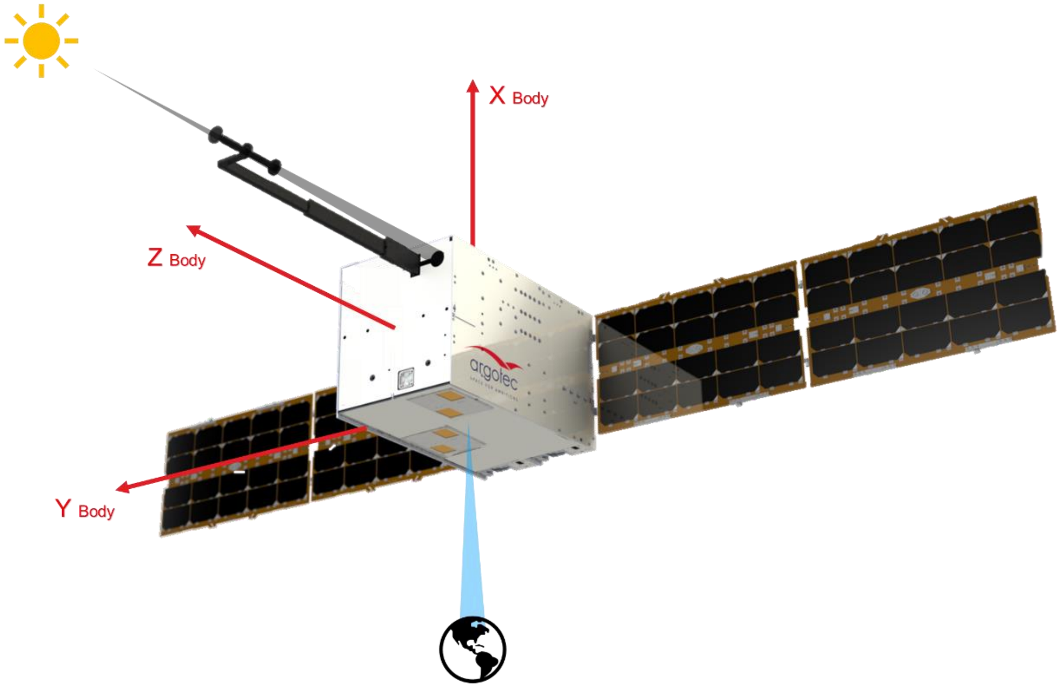

Figure 6. MiniCOR deployed configuration and axis.

As the mission progresses to the nominal operations, the Acquisition Mode points the spacecraft to the designated target, with the payload aligning to collect solar data. The ADCS ensures precise alignment, while onboard systems manage data storage and processing. To transfer the acquired data, the Communication Mode activates to perform data downlink and command uplink as orchestrated by mission control. It ensures the continuous exchange of data and instructions, vital for mission adaptability and scientific output. The Eclipse Mode sees the spacecraft through Earth’s shadow, reducing subsystem activities to essential operations only. This power-conserving stance is critical for maintaining core functions during periods of limited solar energy availability.

In the event of anomalies, Safe Mode prioritizes the spacecraft's preservation. It reduces operations to a bare minimum, focusing on the most crucial systems needed to regain full functionality. Lastly, Sun Pointing Mode focuses on recharging the spacecraft's batteries. It orients the solar arrays towards the Sun, ensuring that power levels are optimized for ongoing mission demands. Through these modes, the OSW harnesses the spacecraft's sophisticated architecture, ensuring each subsystem contributes to the overarching mission goals while prepared to face the dynamic environment of space.

As the operative modes of the OSW are established, providing a robust framework for mission execution. The MiniCOR team, as part of the Phase A of the mission, will also focus on the comprehensive power and energy analyses based on these operative modes, which are instrumental in ensuring the spacecraft's systems operate within their designed capacities throughout the mission's lifecycle. By employing the necessary margins and following best practices and standards, these analysis will define the operative capabilities of the spacecraft, while also highlighting possible risks into the mission design.

The transition from the theoretical to the tangible occurs as the time-sequenced operations are defined. This temporal map lays out when and how the spacecraft's various systems will engage, ensuring that each phase flows into the next with precision-engineered efficiency. It is within this context that the detailed power, energy mass, and link budgets are consolidated and validated against the ConOps. These budgets are vital in translating the spacecraft's capabilities into quantifiable parameters, ensuring that every subsystem not only performs optimally but also harmonizes with the spacecraft's overall mission profile.

The trade-offs and decisions based on this budgets and analyses emerge as the keystones that support the ambitious goals of the mission. They encapsulate the complexity and interdependence of the spacecraft's systems, while also framing the future discussions on resource allocation, risks, mission duration, and the ultimate feasibility of the mission objectives. The interplay between these factors and the operative modes previously outlined will guide the final stages of mission planning, propelling MiniCOR towards its ambitious goals.

5 CONCLUSIONS

The MiniCOR mission embodies a significant leap in coronagraphy and CubeSat technology, marking a pioneering improvement in our pursuit to understand coronal mass ejections (CMEs) and their implications for space weather. Thanks to its novel approach, which combines the agility of a CubeSat platform with the technological sophistication typically reserved for larger missions, MiniCOR challenges traditional assumptions about the capabilities of small-scale missions offering a compelling demonstration of how such missions can deliver high-quality scientific data, previously thought possible only through larger, more traditional space missions.

The consequences for NASA's future research and mission strategies could even be paradigm-shifting, enabling imaging telescopes to fit in various spacecraft platforms and allowing more cost-effective instruments developing, especially when the scientific goals don't require a huge improvement in spatial or temporal resolution. As a final result, MiniCOR's potential benefits could extend to mission concepts reliant on special viewpoints (e.g. Solar Polar Imaging, out of the ecliptic or missions to the L5 Lagrangian point), where instrument mass and power restrictions are crucial.

In essence, the MiniCOR project, while facing challenging obstacles, is a testament to the potential of collaborative innovation and strategic planning in the scientific community. With the right team and a steadfast commitment to addressing the challenges ahead, MiniCOR is poised to realize something extraordinary: a standardized, efficient, and accessible CubeSat platform that could revolutionize space missions, coronagraphy and our understanding of space weather.

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