THE J2050 STUDENT POCKETQUBE FOR SPACE DEBRIS INVESTIGATION AND OPTICAL OBSERVATION TECHNOLOGY DEVELOPMENT

Federico Toson[1a], Giacomo Porcarelli[2b], Greta Rosa[3b], Lorenzo Olivieri[4c], Giacomo Colombatti[5c]

[a]CISAS "G. Colombo", University of Padova, Via Venezia 15, 35131 Padova, Italy
[b]University of Padova, Via VIII febbraio, 35122 Padova, Italy
[c] DII, University of Padova, Via Venezia 1, 35131 Padova, Italy

[1]0498276823, federico.toson@phd.unipd.it, [2]giacomo.porcarelli@studenti.unipd.it,
[3]greta.rosa@studenti.unipd.it, [4]lorenzo.olivieri@unipd.it,
[5]giacomo.colombatti@phd.unipd.it

ABSTRACT

Among the main trends of the new space economy, miniaturisation makes it possible to build mass-produced or customised spacecraft at a reduced price compared to older technologies; it encourages technological innovation, as in-space technology demonstrations are easier in cost, design, and legal and compliance aspects.

In this context, the J2050 project has been selected by the European Space Agency to develop and launch their 2p PocketQube in the framework of the 4th cycle of the hands-on "Fly Your Satellite!" programme; this is the first cycle that included the possibility to launch fractions of CubeSats. The current PocketQube configuration includes three main payloads: a miniaturised debris detector, an optical dimming system for cameras and telescopes, and a system for attitude determination and pointing consisting of LEDs and photodiodes. The three payloads will be integrated on board a platform fully designed and produced by the students, from electronic boards to the software and mechanical interfaces. This will also enable the team to achieve its main educational goal, preparing the next generation of space engineers.

In this paper, the specifics of the PocketQube, the design process, the resource management aspect, manufacturing, integration, testing, and outreach activities undertaken by the team will be described.

1 INTRODUCTION

With the new space economy trend, miniaturization turns out to be a key tool to reduce the mission failure, cost and pollution impact (on Earth and in orbit) of a satellite. For this reason, year after year, there are more and more constellations of small and medium-sized satellites, cooperating and non-cooperating, with objectives ranging from collection to information exchange with a marked improvement in safety, environmental management, and the orbiting technology network [1-2].

In this context, access to space has also been made possible by small and medium-sized investors but, above all, by researchers and students. In fact, space agencies, such as the ESA (European Space Agency), rely heavily on interdisciplinary training in space, and, with so-called "Hands-on" activities, bring students and young researchers to design and implement small space missions.

In general, the involvement of educational institutions has resulted in the growth of the space community and the emergence of many student teams with ambitions related to putting innovative technologies into orbit.

As mentioned above, the trend in the new space economy is increasingly moving towards smaller satellites that can be rapidly developed and launched. PocketQubes, due to their small size (5 x 5 x 5 cm per unit), align with this trend and offer cost-effective opportunities for training and technology validation. They have lower costs for development, production, launch, and operations [1]. PocketQubes are effective demonstrators of new technologies and payloads that can later be implemented in larger, more complex satellites. The small size of PocketQubes encourages innovation and experimentation in satellite design and mission concepts; while simplifications make it possible to design and produce a workable satellite at low cost [2].

It was from this very premise that J2050, a team from the University of Padova, was born, with the primary goal of growing and educating the students through the construction of a PocketQube, a 5 x 5 x 10 cm satellite.

The team is currently composed of students from different departments, at different levels of education (bachelor, master, PhD) and it is supported by professionals, researchers, and professors of the Department of Industrial Engineering. This project aims to include students from other faculties and institutions or early-career professionals to build a variegated and interdisciplinary team. J2050 wants to be the first student team from the University of Padova to launch a satellite into orbit.

The picosatellite is named "RedPill" (for its tiny size and the university's pantone colour, red), and after only five months of work, it was selected as one of three European teams for ESA's "Fly Your Satellite! 4" programme. RedPill aims to demonstrate three different technologies, with the following main objectives:

1. study the feasibility of non-mechanical space telescope covers.
2. collect in-situ measurements of the sub-mm space debris environment in LEO (Low Earth Orbits).
3. assess satellite tracking and attitude determination methods through observations of LEDs from ground and with on-board photodiodes data.

For each objective, the spacecraft will include a dedicated payload: CRYSTALS (ChRomatic, Yielding, and Smart Technologies for Anti-Light Shielding), CLOUD (CLassifying Orbital Undetectable Debris) and CLEAR (Compact LEDs and Attitude Reconstruction). These three payloads are the result of students' ideas, which in some cases are inspired by the heritage of the University of Padova’s research groups.

With CRYSTALS, J2050 aims to develop non-mechanical covers for space telescopes. Current technologies for protecting space telescopes involve mechanical covers, which present several challenges and risk of failures during operations [3-4]. One of the main problems with these mechanisms is deployment and folding. Space telescopes are often launched folded and must deploy their covers once in space. The unfolding mechanism must be reliable and precise to ensure the cover unfolds as planned without a hitch [5]. Folding the cover for deployment and ensuring it's stowed compactly is also challenging.

In short, this new technology involves a device that uses an electrolyte that can darken and then become transparent again, thanks to a chemical reduction process when a voltage is applied. In this way, the telescope can be protected from solar rays when CRYSTALS is in dark mode and can observe space when the electrolyte is transparent during observation mode. This new telescope cover concept aims to have much lower failure rates than the mechanical telescope covers on the market today and those currently used in orbiting telescopes. Deployment-related failure is practically non-existent as the system will be already integrated into its final configuration before launch. Therefore, it does not require mechanical folding and unfolding during telescope operations, eliminating additional failure risks during the system's operational life. At the same time, it will offer all the properties and characteristics that space telescope

covers must have. To ensure the device is functioning correctly, both a camera and photodiode will be integrated behind CRYSTALS to measure its performance.
As for CLOUD, Space debris represent a critical hazard for space missions [6]; while ground tracking allows the continuous monitoring of objects larger than 1 cm in LEO [7]. However, since the population of small debris is not observable from the ground, it is essential to carry out in-situ measurements [8] to validate the debris environment models [9]. For this reason, the payload consists of a debris sensor mounted on board of the PocketQube. Its objective is to measure the number of impacts with small debris (sub-mm size range). To achieve this, the team is working alongside the Alba CubeSat university team [10-12] to develop and manufacture a miniaturised impact sensor suitable for 2P picosatellites that will be placed on the +Y and -Y face of the satellite (where solar panels do not cover the surface). In addition to the scientific outcome, this payload will allow validating the sensor technology and increasing its TRL (Technology Readiness Level), with the final goal of obtaining a sensor board that could be easily scaled and adapted to a large number of space missions.
CLEAR is payload born from the necessity to better track nano and picosatellites in space. The increasing number of small satellite cluster launches [13] leads to a greater risk of confusion and collision after deployment [14]. This calls for further enhancement of space surveillance capabilities. The team's main aim is to develop and launch a PocketQube equipped with LEDs for optical tracking with ground-based telescopes [15]. By having LEDs as an on-board payload to actively illuminate the satellite the number of passes in which the satellite is visible with ground-based telescopes is higher. Thus, it is possible to increase the accuracy and the precision of tracking objects in LEO (Low Earth Orbit), as already demonstrated by the LEDSAT CubeSat team of the University of Roma "La Sapienza" [16]. On the satellite, the utilisation of different colours and pulse periods with the LEDs on the spacecraft faces will allow the determination of its attitude during the observation and, in case of tumbling, its rotation rate. In addition, photodiodes will be installed on the spacecraft to determine the direction of solar and/or albedo radiation, to evaluate the possibility to reconstruct the spacecraft attitude with such low-cost sensors [17-18]. While on-board attitude determination will not be used to determine which LEDs to switch on, it is expected to employ such information to validate ground observations.
The data collected by the technical experiments performed during the mission will contribute to the technology development of space payloads; in addition, it will enrich the current knowledge of the space environment and will support research activities currently carried out within the University of Padova. The data produced by a successful mission will vary for each payload.
In addition to the achievement of these mission objectives, it will also be considered successful and worth of producing technical advancements and academic return:

1. The proper functioning of the PocketQube during the operational period.
2. The correct attitude achieved by the permanent magnets on board the satellite.
3. The successful communication with the ground station to perform uplink and downlink with the LoRa technology.
4. The re-entry within the timeframe envisaged by calculations and compatibility with the ESA Space Debris Mitigation Requirements.

A secondary technical objective of the J2050 project is to validate the design of a PocketQube bus for future mission launches using the acquired heritage. The aim is to validate the self-developed design, specifically for the OBC (On-Board Computer), EPS (Electric and Power System), and other subsystems, which occupy less than one unit of the two used without the Payloads. This will provide other possible PocketQubes, not only from the University of

Padova but also from other universities, with access to a tested and qualified design at a low cost.
In the remainder of this paper, the technical features of RedPill and its potential will be described in detail, starting with the satellite's layout and mission objectives, and ending with the team's technical and educational return.

2 SATELLITE LAYOUT AND MISSION PROFILE

For the satellite, the team chose a 2P form factor PocketQube (5 x 5 x 10 cm). The PocketQube's layout is designed to optimize efficiency, compactness, and functionality within the constraints of its small form factor, enabling a wide range of space missions despite limited size and resources. The RedPill PocketQube is built using mostly COTS components for the bus and the three on-board payloads, and the architecture of the standard 2P platform includes all necessary subsystems. The bus is based on the design in Figure 1; its main functional tasks are summarized in the following list:

1) Supporting payloads in terms of structural rigidity, power, and data handling.
2) To power the satellite subsystems through solar panels and batteries.
3) To collect payload data, such as the conditions of the stripes that compose the space debris sensors, photodiode data, and CRYSTALS data.
4) To transmit the temperatures of the batteries and the external surfaces of the PocketQube.
5) To accomplish autonomously simple task to prevent system failure (ex. thermal control and power distribution).

The bus is provided with AOCS (Attitude and Orbit Control System), EPS, OBDH (On Board Data Handling), a dedicated OBSW (On-Board Software), the Telemetry, TT&C (Tracking and Command) and thermal control. A propulsion system is not required to fulfil the mission goals.

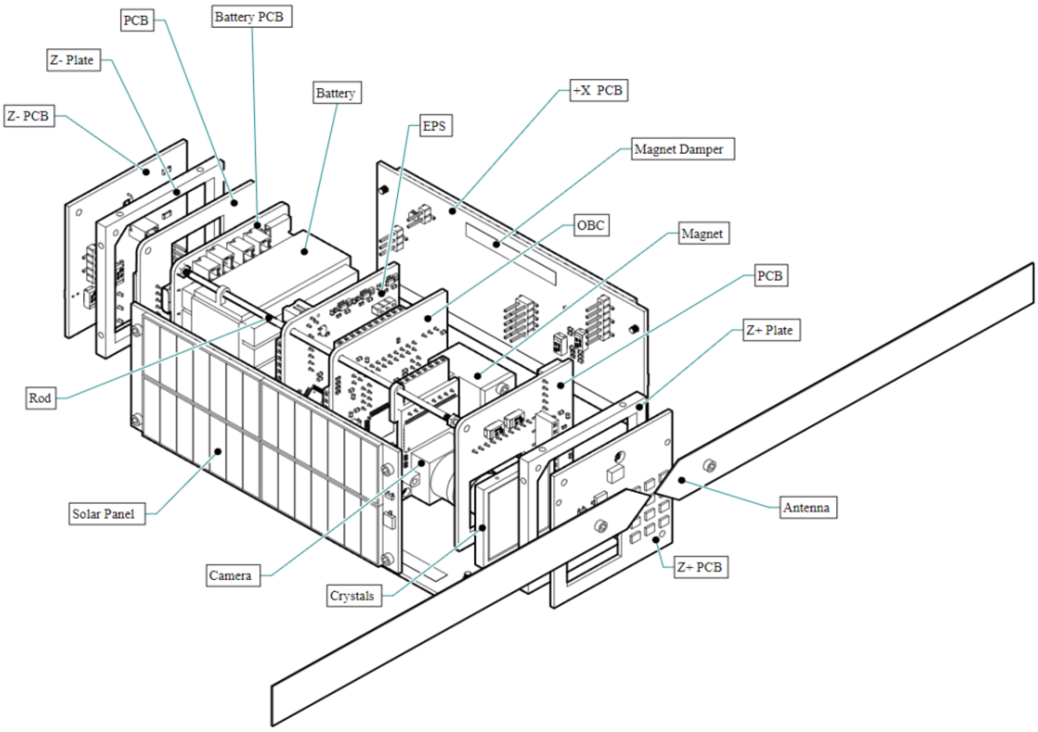

Figure 1: global overview of RedPill satellite.

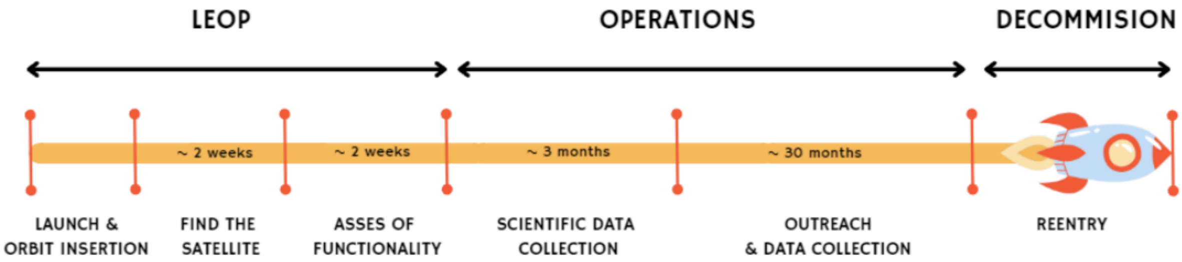

Figure 2: workflow schedule of the mission phases.

With respect to the payloads, their main characteristics are listed below. CRYSTALS is a prototype of a device that functions as a non-mechanical space telescope cover. The design was completely developed in-house and will be manufactured in the chemistry laboratories of the DII (Department of Industrial Engineering). CLOUD is an impact sensor that will be placed on one of the outer faces of the satellite. It will count the number of debris impacting the spacecraft. The University of Padova has a strong background in this field, with several impact sensor prototypes already evaluated and under calibration in the CISAS hypervelocity impact laboratory. Last, CLEAR consists of several COTS LEDs placed on the faces of the PocketQube. These LEDs are used to collect data on the satellite's position and attitude with ground telescopes. Photodiodes will also be strategically placed to on board assess the satellite's attitude and cross-validate the ground reconstruction. For the CLEAR payload, a site for ground-based observations has been preliminarily identified in the Asiago Observatory.
Chapter 3 will cover the detailed design of the satellite and its payloads.
As shown in Figure 2 the team has identified 3 mission phases: Launch and Early Orbit Phase (LEOP), Operations and Decommission.

2.1 LEOP

During the LEOP phase, the spacecraft will be commissioned into orbit, and it will be prepared for nominal operations. The phase is further subdivided in sub-phases, tracing the development of the mission.

- Launch
  This procedure is expected to last for some hours (TBC); during this phase all the satellite subsystems shall be turned off.
- Orbit Insertion
  After the in-orbit delivery, the OBC and EPS subsystems are activated, and start the boot-up sequence. In addition, the passive AOCS starts the detumbling process to lower the rotational rate of the PocketQube. Payloads are not active during this phase. After a little over 30 minutes the antenna is deployed and after 45 minutes radio communications in the form of a beacon begin.
- Find the Satellite
  PQ (PocketQube) tracking is determined by TinyGS network [19], vital values are assessed from received beacons.
- Asses of Functionality
  After the satellite's actual orbit is assessed and first communications with the GS UniPD (University of Padova) are established, a series of extensive tests are done to further validate PQ status and detumbling status. After that payloads will be activated to reach operation readiness.

2.2 Operations

This phase will be initiated once all the subphases of LEOP are successfully completed. During the Operations phase, the spacecraft will be fully operational into orbit performing its main mission tasks. It will collect scientific data, activate, and run the payloads and perform PDTs (Payload Data Transfer). The phase is further subdivided in sub-phases, to accomplish the objective of the mission:

- Scientific Data Collection
  During this phase, all the functional and performance requirements of the payloads will be executed. All data collected will be downloaded and analysed by the GS UniPD at the University of Padova.
- Outreach and Scientific Data Collection
  Once enough data has been collected for the scientific purpose of the mission, the Outreach phase commences. It is noteworthy that scientific experiments are planned to be conducted during this phase as well, aiming to fulfil the performance requirements of CLOUD and validate the PQ Bus by assessing its behaviour over an extended orbit time.

2.3 Decommission

During this phase all payloads and instruments of the satellite will be switched off and the ability of the battery to recharge via solar cell will be inhibited thus leading to battery depletion. The programmed duration of the mission is 1.5 years. J2050, thanks to the support of the University of Padova, doesn't rule out investing more effort and resources in prolonging the mission (and thus further developing the outreach purpose and CLOUD performance) until re-entry.

More precisely, the mission is designed through operational phases and follows a series of steps to ensure that the mission tasks are performed correctly. During LEOP, the satellite follows the start-up procedures and remains under observation for two weeks without performing any major activities. The system's vital values are verified and, thanks to the TinyGS network, the satellite's position in its current orbit is estimated; the time parameters on board are also synchronized with GS (Ground Station) UniPD. The next LEOP phase, which will also last two weeks, will verify the values of on-board thermal sensors and accelerometers, carry out preliminary tests to ensure the collection of data during payload operations, analyse the performance of the infrastructure and verify the status of detumbling. Payload tasks are performed in the Operations phase by means of GS commands. Satellite activities are managed by “operational states”. The operational states, battery management and software architecture are managed autonomously by the OBSW, leaving the payload executions to be activated by a software alias sent by the GS UniPD.

In order to study the orbital behaviour of the mission and select the most suitable orbits to achieve the mission objectives, a MATLAB script has been developed and specific software has been used. The MATLAB scripts use the GMAT API to simulate multiple orbits (iterating on the orbital elements) and output the average data exchanged with the GS UniPD. In future development, this MATLAB will be integrated with the AOCS simulation to evaluate the performance of passive magnetic attitude determination in the chosen orbit. The de-orbiting time is assessed using the DAS software. Airbus SYSTEMA was also used to evaluate the performance of CLOUD on several orbits and all the results were taken into account in the analysis.

3 SATELLITE DESIGN

The design phase involved several students from the J2050 team who had the chance to apply what they learned during their years of study The main design philosophy was to create a versatile and sufficiently reliable bus that, once validated through the RedPill mission, can be reused to carry other payloads into orbit at a relatively low cost, thus facilitating access to space for innovative payloads and technologies.

Following a literature review of the state of the art of PocketQubes, a stack design with 2 M3 bars and supports in the Z+ and Z- faces was chosen to ensure a sturdy structure. All faces of the PQ and internal layers are made of in-house designed PCB (FR4 material) mounted on the aforementioned structure. Vibrational and stress analyses were conducted to ensure that the satellite could withstand launch loads. Shake tests are also planned.

Regarding energy management, the PQ is equipped with a LiPo battery accumulator that has a capacity of up to 15 Wh. The accumulator is recharged by solar panels, which are widely available. These decreases lead times and speeds up the prototyping process. The solar panels can nominally recharge 400 mWh per orbit. This production is suitable for the RedPill mission because it allows for a positive energy balance over several orbits, even when considering the power consumption of various subsystems with safety margin.

In future missions, power generation can be increased by adding solar panels to the faces currently occupied by CLOUD or by purchasing solar panels with higher efficiency and longer lead times.

Regarding the OBC and EPS, which are the two processors on board the PQ, microprocessors with flight heritage and low power consumption were chosen: in particular, the STM32L5 processor was chosen for the OBC and the STM32L1 processor for the EPS.

For the digital communication between the various subsystems, SPI (serial peripheral interface) was chosen as the communication protocol since, according to a literature study, it proved to be the most reliable and requires the least power.

These two boards have been equipped with several features: the EPS is able to manage the battery charge and monitor all the battery parameters, sending warnings about the status of the bacteria to the OBC when necessary. the OBC collects data from all the payloads and manages the power distribution within the satellite. it is also equipped with an IMU and can read different analogue signals, which makes it very versatile.

3.1 CLOUD

The aim of the CLOUD payload (Figure 3) is to validate the sub-mm debris environment models in LEO orbits [20]. A different version of the sensor has been first developed by Alba CubeSat UniPD [10-12], a student project based in the University of Padova, to be hosted on a CubeSat 2U. The same payload idea will be modified to be integrated in the 2P PocketQube. As of now the design of the debris sensor is at TRL 4 level thanks to the technology heritage inherited by AlbaCube Sat.

The experimental concept consists of 16 copper stripes integrated in the PCB schematics that, if struck by debris, could be ruptured. This rupture will be detected by the ADC (Analog to Digital Converter) and communicated via SPI to the OBC. It follows that the maximum number of detected impacts is 16 (one for every stripe). Stripes are designed to be 0.080 mm wide (as tight as possible for the PCB manufacturing process) spaced 0.2 mm between each other and arranged in a spiral configuration to ensure minimum sensible area loss after a stipe breach.

Two CLOUD devices are placed in the +Y e -Y faces of the PQ, the total sensible area is 2400 mm2 on the +Y face and 3500 mm2 on the -Y face.

Figure 3: photo of CLOUD payload PCB.

3.2 CLEAR

The CLEAR payload (Figure 4) is composed by LEDs mounted on the satellite (whose task is to make the system visible from Earth and to help reconstruct the attitude) organised in two, 12-LEDs arrays placed on the +Z, -Z faces of the satellite (i.e. the faces pointing towards the Earth). Since the LEDs must perform a particular application which imposed high-efficiency, high-power requirements, the choice fell to LUXEON 2835 Colour Line LEDs. Concerning attitude determination through photodiodes, a method whose effectiveness has been widely proved in literature has been selected [18]. One photodiode has been installed on each PQ's face. Since photodiodes generate a current proportional to the light incident angle's cosine, by collecting the current signals from every face it is possible to estimate the precise orientation of the PocketQube relative to the Sun. Thus, a transimpedance amplifier is required to manipulate the analog signal to be read by the 10-bit µC OBC ADC with the correct accuracy. Additionally, a voltage buffer is in series with the transimpedance amplifier. The analog circuit was designed using 1800 W/m^2 as the peak light intensity (obtained using a safety factor on the solar peak light intensity and Earth albedo). The following steps consist of developing a Kalman filter to elaborate the collected data, especially to filter the Earth albedo disturbance.
The CLEAR payload will also be crucial in attitude determination and in investigatinf the efficiency of the passive method for PocketQubes attitude control. Not an easy challenge that fortunately has varied analyses in the literature [21-28].

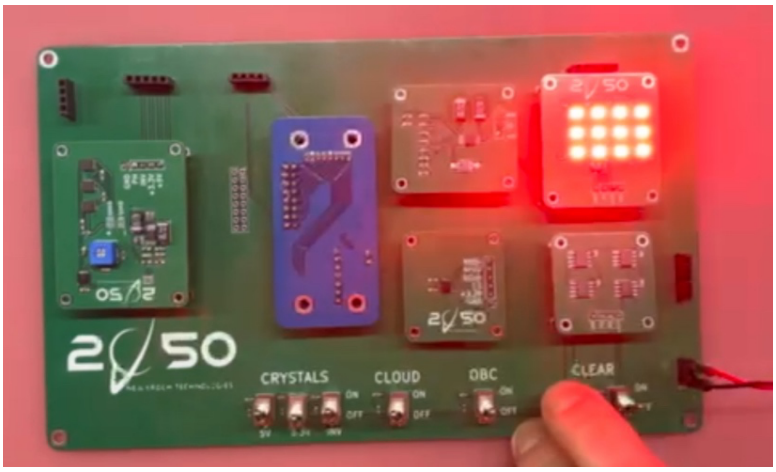

Figure 4: CLEAR payload LEDs in function on the FlatSat model.

3.3 CRYSTALS

CRYSTALS, as mentioned before is an innovative alternative to current telescope dimming mechanisms. The design of this instrument was among the most complex of the PocketQube being something that has never been done in the space environment and especially in such a small size. Taking a cue from the literature [29-31], several design solutions were tested, all involving ITO (Indium Tin Oxide) glass, i.e. conductive glass, an electrolyte (gelatinous and colourless, with metal salts dissolved in it) and an electrode.

The operating principle involves darkening and brightening of the ITO glass due to the deposition of dissolved metallic material in the electrolyte gel. This is possible by placing the gel between the ITO glass and the electrode; by applying a positive and negative potential difference between them, metal deposition or its solubilization in the gel is possible. Different recipes are still being tested as electrolytes and will be described in forthcoming work; for this reason, no gel preparation information is presented in this article. Depending on the direction of the potential difference, it is possible to control the darkening and brightening of the glass. The latest version (shown in Figure 6) uitilises two ITO glasses on either side of the device, which act as the outermost layer of a 'sandwich' that has two PCBs inside, which enable the ITO glasses to be energised and which distance and insulate them from the electrode, which is in the inner layer. The whole device is filled with electrolyte gel. The device is watertight because both for bonding where there is electrical conduction and for other fixings, space-age epoxy glues (such as silver epoxy) are used. The points from which the current flows are the screws, which, being through all thickness of CRYSTALS, give current to both the internal electrode and the two ITO glasses. In this way, the design is truly compact and manageable, simple to integrate and put into operation.

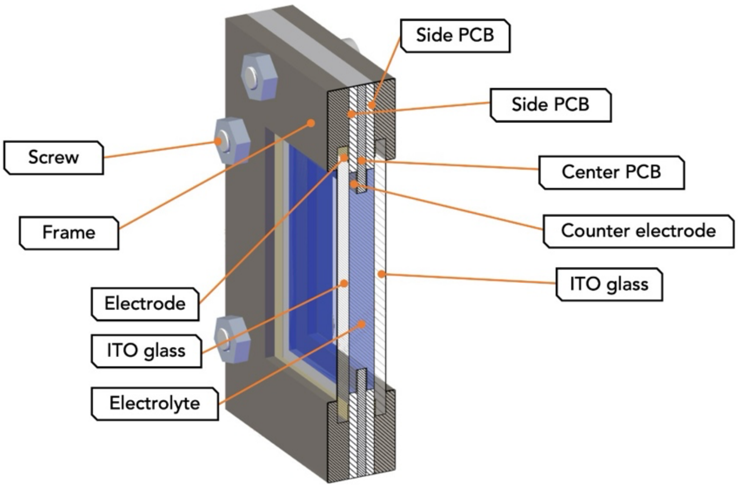

Figure 6: CRYSTALS 3D section with components overview.

The RedPill mission requires control of orbital positioning to ensure that the system, consisting of CRYSTALS and the camera, is pointing towards Earth. However, it is not necessary for the system to always be directed towards a specific point. The AOCS will only provide the required pointing accuracy and stability to ensure that, once the system is stabilised, the camera points towards Earth during different mission phases, and that the TT&C subsystem can receive and transmit data. Attitude control will be required for the satellite to detumble after deployment and for potential impact with space debris. Environmental torques acting on the satellite are estimated to be in the order of magnitude of 10-4 Nm, considering worst cases relative to the gravity gradient, magnetic, solar radiation, and aerodynamic effects. This estimation is valid at

450 km of altitude, and lower disturbances have been found for higher altitudes. Throughout the mission requirement definition and analysis phase, various AOCS solutions were compared based on their performance, compliance with requirements, and their mass, power, and envelope budgets. The AOCS will adopt a passive configuration, with the AOCS unit utilising COTS components, featuring a set of three stacked permanent magnets positioned along the X axis. The AOCS comprises three permanent neodymium magnets, N45 graded, stacked on top of each other. These magnets will be positioned inside the PocketQube so that their magnetic field is aligned parallel to the Earth's magnetic field (in the magnet's reference system, this will be the X direction). The satellite's internal walls on the +X/-X faces will be equipped with ferromagnetic hysteresis bars perpendicular to the permanent magnets' axis along the longitudinal Z direction. These bars aim to dampen oscillatory motions that may occur due to rotation in the geomagnetic field. The kinetic energy of the satellite is transformed into hysteresis losses through magnetization changes in the bars. A trade-off analysis was conducted, taking into account all potential disturbances affecting the satellite at various altitudes. It was found that the only significant disturbance was the magnetic torque caused by the Earth's magnetic field. Commercially available solutions for both permanent magnets and soft-magnetic hysteresis components were considered. Due to the limited space available inside the PocketQube and the restrictions imposed by other payloads and power systems, the optimal solution was found to be the use of flat, rectangular cross-section permanent magnets placed sideways to the camera, near the face pointing towards the Earth. Various materials and geometries for the soft-magnetic bars were reviewed, as these factors may significantly influence the damping effect. The optimal solution involves using elongated, rectangular, and extremely flat strips made of mu-metal. Although innovative materials such as amorphous Fe-B-Si have shown promise, a more reliable and commonly used material has been selected to minimise risks and avoid in-house production. In future works, the aim is to develop a mathematical model of the hysteresis strips to optimise their positioning. An excessively short distance between them may result in excessive energy losses. Simulations in MATLAB/GMAT/Simulink will be performed to test the system performance.

4 APPROACH TO SATELLITE MAIT

In this section the manufacturing, assembly, integration, and testing process for RedPill is presented. The model philosophy that will be followed during the PocketQube implementation includes three different models: Development Model (DM), Engineering Model (EM), ProtoFlight Model (PFM). This approach allows to keep development and manufacturing costs low and to have relatively fast mission development. The latter is related to the need for the mission to be ready for the upcoming integration and launch opportunities with ESA. The DM+EM+PFM is used for all the subsystems.

For the DM, the AIV focuses on reaching TRL 4 for most components in order to meet functional requirements and subsequent assembly (this starts with Payloads such as CRYSTALS and goes up to entire subsystems such as EPS).

Having reached this level of technology, the second step of AIV of the DM involves testing different configurations to understand how they meet performance requirements.

As far as EM is concerned, on the other hand, the AIV also plans to meet dimensional and design requirements, but always in FlatSat format (Figure 6).

After an initial verification step, the functional and performance requirements are again verified to export the model and transform it into the final stack version (PFM).

For all Payloads, the tests and procedures are being developed with the exception of CRYSTALS, which, being an innovative idea within the team, required additional preliminary testing to bring the technology to TRL 4 before Design confirmation.

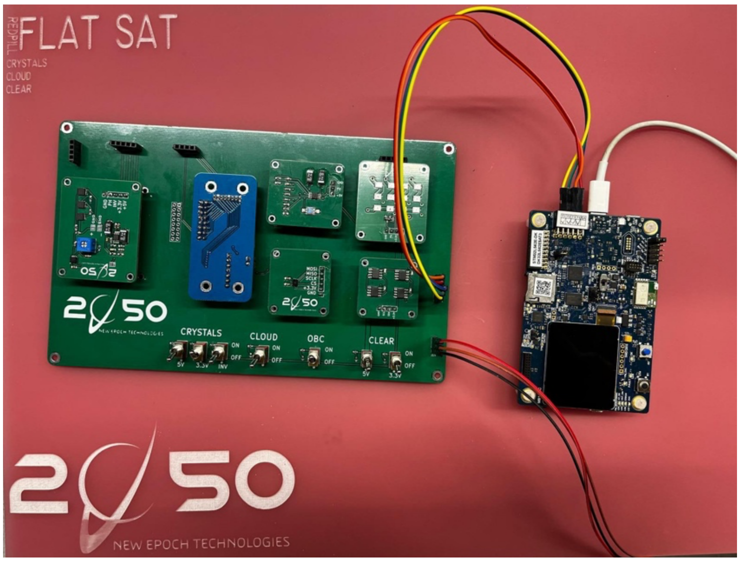

Figure 6: FlatSat after first integration.

A brief description of the procedures used for CRYSTALS can be found at the end of this Section.

Finally, the PFM is to all intents and purposes a flight version of the satellite, but, as mentioned earlier the team evaluates the possibility, if the low production cost is confirmed, to add an FM that will undergo less intensive functional testing.

The various qualification tests will be carried out at the laboratories of CISAS G. Colombo (University Centre for Space Studies), which is equipped with thermo-vacuum chambers (example in Figure 7), electrodynamic shakers, and clean rooms.

Figure 7: CISAS's thermo-vacuum chamber with window for exposition to the solar simulator.

For the technical aspects of PFM verification, all tests in a critical environment will be carried out by means of connections between inside and outside the thermo-vacuum chamber, so as to supply power and communicate with the PocketQube in the event of malfunctions. The use of the solar simulator is carried out in combination with the thermo-vacuum chamber. The mechanical interfaces for vibration tests will be adapted and connected to accelerometers for testing vibration modes in the 3 axes with resonance and random vibration search. The function and performance tests of the payloads will be performed both at subsystems and system level. Tests will be mostly performed at the facilities provided by the University of Padova, inclusive of a shaker for mechanical loads and vibrations from a launch vehicle, a thermo-vacuum chamber for assessing the survivability to the thermal environment typical of low-Earth orbits.

5 EDUCATIONAL OUTCOME

The activities have enhanced the skills of the students involved. Additionally, education is another important aspect. As stated in the introduction, the objective is to educate students and develop their transversal skills. The training aims to equip participants with the ability to interact with each other, reference figures, and entities outside the university, such as companies or space agencies. This objective is shared with ESA and is one of the pillars of ESA Education and the 'FYS!' Program.

To accomplish this, the team has defined a precise team structure using a Work Breakdown Structure (WBS).

To accomplish this, we have defined a precise team structure using a Work Breakdown Structure (WBS). The WBS outlines the lines of work shared among the team, ensuring practical application. The project timeline is summarized in a GANTT chart. The J2050 Team is divided into sub-teams with different applications. This allows for the definition of roles, resulting in accountability of members and development of soft skills such as teamwork, positive interaction, and collaboration. Scheduling is used to transmit the cruciality and importance of deadlines, train students in problem-solving, and teach them to organize their time so as not to find themselves unprepared. The organization of work in general was done following ECSS guidelines, such as those related to management, which also allowed students to become familiar with these standards [32].

The effectiveness of this method became apparent early on. Within a few months, students were able to design, develop, and receive positive feedback for their work in the ESA's 'Fly Your Satellite! 4' programme.

Moreover, RedPill being almost entirely "new," the entire production was the result of the team's skills and the synergy established among the various sub-teams.

The students involved will have the opportunity to showcase their designs and developments in thesis papers, scientific reports, conferences, and scientific journals, highlighting their capabilities. This has implications for preparation for the world of work and research, which often relies heavily on young minds who have had the opportunity to experience what they have learned in their university studies.

Additionally, the Outreach sub-team has developed an important aspect of dissemination. Many schools will have the opportunity to interact with the RedPill project and J2050 in general through lectures, workshops, and satellite interactions. The Asiago Observatory, radio amateurs and other entities at the territorial level have offered their support to J2050 in its dissemination and education mission.

6 CONCLUSIONS

This paper presented the general overview of the RedPill PocketQube and the description of its bus and payloads. The satellite will provide a simple, functional, and low-cost solution to validate and verify in-orbit technologies for (1) non-mechanical space telescope covers, (2) in-situ sub-millimetric space debris detection, and (3) advanced satellite tracking and attitude reconstruction, both on board and from ground observatories. In addition, the J2050 team continues to pursue the goal of technical and educational training of participants. The team's achievements in both areas have been confirmed through its participation in ESA's 'Fly Your Satellite! 4' program. The team members are constantly developing their soft skills by learning to handle tight schedules, various problems, and relationships with stakeholders, supervisors, and external agencies and companies through their work on RedPill.

The design of the picosatellite is solid and will be refined in 2024, in preparation for a potential launch window as early as 2025. The team's strength lies in the originality and innovation of the payloads on board. They aim to continue testing innovative technologies in the future, not limiting themselves to producing only RedPill. Regarding CRYSTALS, the team plans to continue developing it as a dimming alternative for larger telescopes if the technology proves successful.

The experiment was successful in terms of broadcasting and school outreach, which proved to be an engaging and functional strategy for developing an aware, responsible, and growing scientific community.

ACKNOWLEDGEMENTS

The authors would like to thank all the students involved in the project: Alessandro Vignato, Marco Peviani, Francesco Miola, Giacomo Vedovato, Luca Dallago, Zoe Murgia, Mateo Loshi, Giovanni Pitacco, Andrea Zambon, Francesco Vesentini, Gregorio Poggi, Tommaso Fabrizi, Matteo Rango, Alex Scantamburlo, Nicola Destro, Stefano Grisotto, Lorenzo Franchini, Alessia Dorigatti, and Amanda Roman Navarro.

In addition, we thank: the University of Padua that has funded the J2050 project from the beginning, especially the Department of Industrial Engineering (DII) in the figures of the researchers and professors of the FLIGHTDS (Flight Mechanics and Space Systems) group of the University of Padua and the centre for Space Studies CISAS G. Colombo.

Finally, a special thanks to ESA, especially the ESA Education FYS! group for the opportunity to be part of this space adventure.

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