**BIRDY: an interplanetary CubeSat to collect radiation data on the way to Mars and back to prepare the future manned missions**

Boria Segret (1),Parisa Segret (1,2), Jordan Yenni-Marti (3), Marco Aragón (4, 5), Audrey Panjait (4, 5), Gusamma Sinha (4, 5), Florent Daffara (4, 5), Jian-Hui Mao (4, 5), Jyh-Chang Joung (4, 5), Kaili Wang (4, 5)

**1)** Laboratoire d’Études Spatiales et d’Instrumentation en Astrophysique (LESIA), Observatoire de Paris, Muséum, France.

**2)** National Cheng Kung University, Department of Aeronautics and Astronautics, Taiwan.

**3)** National Cheng Kung University, Department of Electrical Engineering, Taiwan, Taiwan.

**4)** Institut de Mecanique Celeste et de Calcul des Ephemerides (IMCCE) Observatoire de Paris, Paris, France.

**5)** Centre National de la Recherche Scientifique (CNRS), France.

**6)** Université Pierre et Marie Curie, Paris, France.

**7)** National Cheng Kung University, Institute of Space and Plasma Sciences, Taiwan, Taiwan.

**Space weather in interplanetary medium**

Space weather measurements from multiple locations in the solar system are mandatory to improve the knowledge in space weather.

**BIRDY (Bipolar Interplanetary Radiation Determination Experiment),** a specialised 3-Unit CubeSat (10×10×30 cm3, 3.4 kg), is a small and cheap solution to take part in this global effort.

This science case is to take advantage of an Earth-Mars-Earth journey to participate in the space weather understanding by gathering observational data useful to improve the current models of radiations due to the solar wind, the OCB (Galactic Cosmic Rays) and their mutual interactions. BIRDY would demonstrate the possibility of doing interplanetary space science with a small minimised instrument payload onboard a CubeSat platform.

**BIRDY scientific and engineering objectives**

1. Characterize the energetic particle spectrum in the energy range from 15 MeV/nucleon to 1 GeV/nucleon in interplanetary medium between Earth and Mars’ orbits, and Venus’ orbit eventually.
2. To probe the arrival directions in and out of the ecliptic plane, and to measure the arrival directions and velocities of the energetic particles of interest.
3. To obtain the data in the design, to add prior gravity to the potential hazards produced by the solar wind.
4. To collect and keep the data for a duration as long as an Earth/Mars-Earth free-return trajectory, and to upload these data to a Martian ortricer and to ground stations when back near the Earth.
5. To autonomously estimate its own position with a Planet Tracker and to adjust its trajectory with an onboard small electric propulsion to allow a free return to Earth.

**BIRDY radiations payload**

In 2011-2012, during the Earth-Mars cruise of the MSX (Mars Science Laboratory) Curiosity mission, the instrument RAD (Radiation Assessment Detector, P.D. Hasler) provided the first radiation observation data on an Earth-Mars trajectory. But BA was only optimised for measures on the Martian surface, not from the interplanetary space. For BIRDY, the RAD (2×0×110 km) and 1.6 kg) is considered as a technical inspiration for a new, miniaturized and specialized instrument (1×1×10 km3 and max. 1.5 kg) to fit into the CubeSat.

BIRDY will focus on radiations due to GCR and SPE (Solar Particle Events). The SPE particles get through interplanetary medium along the IMF (Interplanetary Magnetic Field). The typical angle between the IMF lines and Sun’s direction is the scientific factor driving the observation capability of the payload. Preliminary studies show that BIRDY will be able to accurately observe incoming particles of the solar wind with velocities comprised between 300 km/sec and 500 km/sec. BIRDY could verify the Hollmann-Hohmann Parker effect, which defines that a spacecraft traveling on an Earth-Mars Hollmann Parker trajectory is magnificently compressioned by the same IMF lines either coming from Earth, or going to Mars. If so, the same SPE flux detected by a space probe could be also detected a few hours earlier near the Earth and/or later nearby Mars by other probes. Such a confirmation with BIRDY would be a bonus to contribute in space weather awareness. The secondary particles produced due to the CubeSat structure or detector may be mistakenly counted as primary particles with a lower energy than the actual primary particles. It would result in some contamination and this issue is still under investigation.

An international call of opportunity will offer a collaboration to a research laboratory for this payload.

**Navigation**

After jettisoning from the host mission, the CubeSat is fully autonomous. An optical system provides the location of the planets in front of the sky by determining their coordinates (longitude, latitude) and comparing them with the predicted ones (US: K0). The “planet tracker” consists in estimating the CubeSat’s position close to a previously computed orbiting trajectory, by comparing the angular distances between planets and stars with the expected ones that are stored in the CubeSat’s memory to calculate the needed attitude and trajectory corrections.

For these reasons, an electrical propulsion system is integrated in BIRDY: a system of liquid micro-pumped plasma thrusters that is close to space qualification (LPPS-WP, http://www.iaspp.eu, developed by Europe’s FP7 program and member of BIRDY consortium).

**Deployment Plan**

BIRDY is a “project” that will set up a new approach in engineering that is inspired from the AGILE principles practiced in the software industry and specifically adapted to the development of CubeSats. Care has been taken to develop the prototype of the project. The development plan is (1) set up Phase (Up), Short Term Phase (STP), Medium Term Phase (MTP), Long Term Phase (LTP). This approach is preferred (1) if a typical space project approach ( phase A, C, D, E, )

- STP (2012Q2 – 2012Q4): Mission pre-staging and feasibility science advisory group set-up, STM (Structural and Thermal Model) student team hired, specification of needed scientific payloads, internships at Esa KUL/IMCCE and LESIA.

- MTP (2012Q5 – 2013Q2): During this phase the BIRDY preliminary conceptual design is achieved and a PDR (Preliminary Design Review) will take place. This phase will target the most defining tests and flight and BIRDY STM (Structural and Thermal Model).

- LTP (2013Q4 – 2013Q2): The phase during this phase the BIRDY flight model is fabricated and ready to participate to a precision flight test in the following semester. The CubeSat is benchmarked as a platform for a specialized host mission. Research on the European Technology Transfer (OTR) and flight box near the Earth in the next year will be funded by JSEP (Joint Space Exploration Project) and performed during several bio-geo tests depending on the electrical propulsion performances.

- TDR (2012Q3 – 2013Q2): During this phase the BIRDY FM (flight model) is manufactured according to the lessons learned from the precursor flight and as far as possible towards Mars.

- Overall project: valuable technologies and techniques for CubeSat-based CubeSat (autonomous navigation, complex onboard processing, inter-satellite communication, electrical propulsion) and new engineering methods will be acquired for CubeSats in a new educational and international context.

**Reference Trajectory**

A reference trajectory of BIRDY is planned according to the CRN (Cruise Reference Node) which outlines the relocation of the radiation data of the CubeSat to ensure a coming back to the Earth. Indeed each radiating object has an attitude of which the CubeSat will cross the Earth orbital plane. Several hypothesis must be taken into account during the trajectory flight because the movement control is a key point. As an example, the Earth is the central body in the numerical integration, the 2 non-Keplerian parameters of the Earth, Mars and the Sun should be considered but also the radiation pressure and the influences of external bodies. The mission preparation tool belongs to the ground segment and should be available early enough to properly locate the CubeSat and benefit BIRDY (EUSC2016, M2L2016, EUSC2017) taking the last update of 3-120 days. The reference trajectory data will have to be stored in the flight navigation software.

**Mars Flyby**

The numerical integration of the CubeSat for 2 initial velocity vectors reveals that a small altitude apogee on the trajectory of the CubeSat can have an important impact on the change of inclination of the orbital plane, close to the minimum distance to Mars. A trial of torques only applied 1100 km from the center of the Earth changed the inclination from 0.86° to 4.42°.

On the other hand, the orbit inclination inclination makes the impact onto the Earth significantly less safe than previously thought when it is less than 0.4°. The flyby will not be decided for a possible return of the CubeSat to the Earth. Moreover, the latest sensitivity of Mars has been taken into account for the numerical integration.

The flyby inclination was set to 4.42° by the team in charge of the CubeSat design. In addition, the team in charge of the CubeSat design made sure that the mission satisfies the minimum requirements for a future manned mission to Mars, specifically.

**Communication (TT&C)**

BIRDY is not able to do interplanetary communications. The scientific and housekeeping data recorded on the way to Mars have to be sent to an orbiter in Mars' orbit.

The orbit inclination then allows one to adjust the trajectory and to store the orbit inclination in the receiver, according to the CDSOS protocol. In fact, the mission data volume (proximal orbit, TT&CD depending on the maximum light time) is so small that there is no need to have a delay due to the receiver.

The season will be monitored by the Very-Large Baseline Interferometer (VLBI) for BIRDY’s tracking and basic housekeeping data.

---

**Communication (TT&C)**

BIRDY is not able to do interplanetary communications. The scientific and housekeeping data recorded on the way to Mars have to be sent to an orbiter in Mars’ orbit. The orbit inclination then allows one to adjust the trajectory and to store the orbit inclination in the receiver, according to the CDSOS protocol. In fact, the mission data volume (proximal orbit, TT&CD depending on the maximum light time) is so small that there is no need to have a delay due to the receiver. The season will be monitored by the Very Large Baseline Interferometer (VLBI) for BIRDY’s tracking and basic housekeeping data.