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PicSat: a Cubesat mission for exoplanetary transit detection in 2017

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ABSTRACT

The PicSat mission is based on a 3U Cubesat architecture, with a payload specifically designed for high precision stellar photometry. The satellite is planned to be launched in September 2017. The main objective of the mission is the continuous monitoring of the brightness of Beta Pictoris.

The Hill Sphere of planet Beta Pictoris b shall pass in front of its host during this period (from April 2017 to February 2018). To be ready on time for this rendez-vous, our philosophy was to focus our resources on the development of the payload and the flight software, where we have the expertise. We subcontracted the design and the realization of the platform and of the Attitude and Determination Control System.

The payload is designed with a 37mm effective aperture and a single pixel avalanche photodiode. A single-mode fiber is used to guide the stellar light from the focal plane to the photodiode. To guarantee photometric precision and payload stabilization, the residual jitter of the three-axis ADCS is complemented with a two-axis piezoelectric actuation system that locks the position of the fiber on the center of the star. The flight software is based on a "L0/L1" dual-level architecture, making use of Gericos, an active object framework developed in-house.

INTRODUCTION

The idea of PicSat was born while looking for a first conceptual step toward doing interferometry with Cubesat. We are developing integrated optics component, and we aim to make a space interferometer based on these components. The interferometer was too challenging for a first mission, and the prerequisite is to inject stellar light into single-mode fiber. The idea of a high precision photometer to tackle this technical challenge joined with the unique opportunity to observe the transit of the exoplanet Beta Pictoris b, made the PicSat mission (**Pic**toris **Sat**ellite).

But there was less than 3 years, between this idea (end 2014), and the transit of the planet. We had to build a team, learn how to do a Cubesat, design the payload, develop the software and convince people ... a lot of things to do within this short delay. As it is not something we are used to, we subcontracted the realization of the plateform. Something not usual for a Cubesat, it is not a student project. The core of the team is composed by engineers with some students around.

BETA PICTORIS

Beta Pictoris is a bright star (A6V star of V magnitude 3.86) which, due to its proximity (63 light years from the Earth) and young age, has always been a most promising target for the study of circumstellar environment and planetary systems. In 2003, β Pictoris b, a young Jupiter like giant exoplanet, was directly imaged around this star.[1] Its orbit was latter characterized using multiple astrometric position measurements acquired since 2009, is compatible with a transiting planet.[2] It is now strongly suspected that its environment will transit during the third or fourth quarters of 2017.[3] Because of its orbital period of 17 years, this represents a rare opportunity to finely characterize a young giant exoplanet and its close environment (Hill sphere) in front of a bright star.

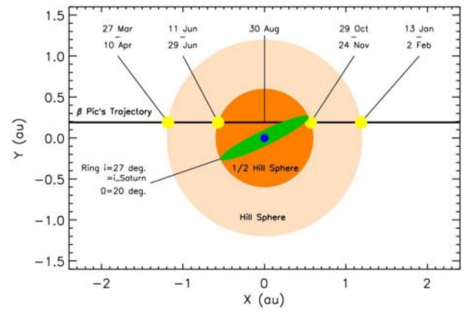

Figure 1 : transit prediction (Wang et al 2016)

Beta Pictoris b is an important planet in the context of exoplanet formation. It is due to the fact that it is extremely close (~20pc, hence prone for observation), and young (~20Myr, still in its infancy). The Hill

Sphere is the zone within which the gravitational field of the planet dominates over that of the star. Within this gravitation sphere of influence, smaller bodies like moons or rings can exist.

We plan to follow the photometry of the star during its passage behind the Hill Sphere of the planet. The goal is to have constant, uninterrupted monitoring. This is the only way to reconstruct the close environment of the planetary body.

This photometric follow-up of this star for several months will also be a unique opportunity to study the fine structure of the dust disc, and the orbiting exo-comets continuously over such a long period.

PAYLOAD

The principle of the payload is to track the star by moving a single mode fiber head in the focal plane. The fiber is mounted on a 2 axes piezo stage that modulates the position around the star with a 100Hz frequency. The Avalanche Photo Diode signal is demodulated at the Piezo modulation frequency to deduce the displacement of the star. The photometric signal is also used to measure the star flux at a lower frequency (1 measurement per minute). We expect 100 ppm/hr photometric precision on stars with Mv < 5.[4]

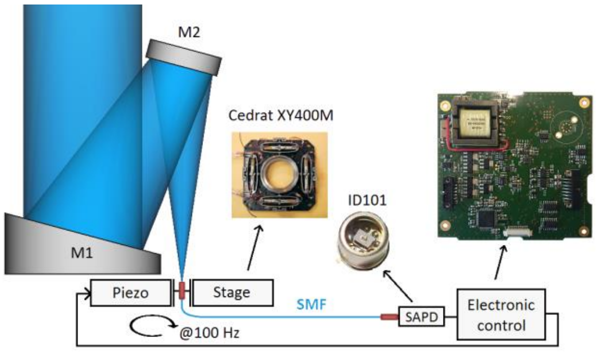

Figure 2 : Payload control loop

The optical part is composed by an off axis aluminum parabola with a pupil of 37 mm and an aperture of f/4 adapted to the single-mode fiber (a pure silica core Nufern S405-XP). The optical path is folded via a plan mirror.

The piezo sage is an XY400M based on the space qualified XY200M model of Cedra Technologies. The amplified piezoelectric actuators (APA400M) mounted in this model offer a range of 450 µm. This corresponds to a field of view of 0.2°. The single mode fiber is directly connected to the moving part of the stage.

The other end of the fiber is mounted on a detector designed by IdQuantic. It is a single photon avalanche diode (ID101-SMF20). It consists of a CMOS silicon chip mounted on a thermoelectric cooler. The quantum efficiency of this APD in the effective range (400-680 nm) is above 30%.

The last part of the payload is the electronic board designed for this application following the PC104 standard. It is in charge of the readout of the photodiode, and the control of the piezo stage (150 V). A microcontroller (STM32 F3 with a CortexM4) controls the loop and does the tracking of the star as soon as it is in the field of view of 0.2°. To maintain the optical quality, the star has to stay as close as possible to the optimal focal position (0.01°). The payload relies on the ADCS to bring the star within the field of view and stable within the optimal focal position.

The full payload (optomecanics and electronics) fills half of the volume of the 3U Cubesat. It weighs less than 1.4 kg and its power consumption is lower than 2W.[5]

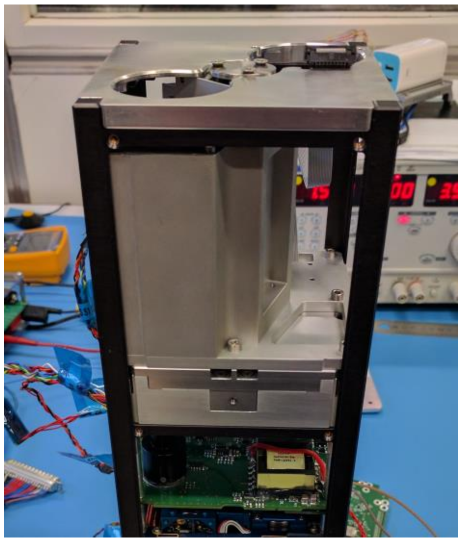

Figure 3 : Payload qualification model. From bottom to top: electronic, piezo-stage and telescope.

PLATFORM

The platform, including the bus and the ADCS, has been subcontracted as our philosophy was to focus on the design and the realization of the payload. The first step was to select the ADCS as the pointing performances is a key point of our mission. Then the 3U bus has been designed given the constraints of the payload and the ADCS.

ADCS

The ADCS selected for the PicSat mission is the iADCS100 provided by Hyperion Technologies. The role of the ADCS will be to point the instrument to Beta Pictoris within accuracy and stability of 30 arcsec.

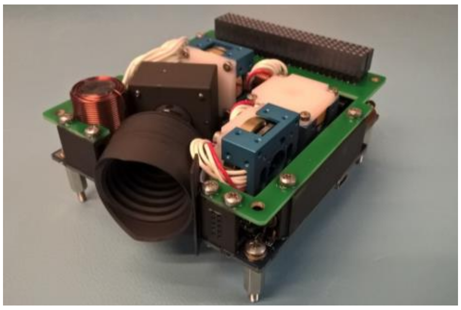

Figure 4 : ADCS system

The iADCS100 matches the ST200 star tracker with Hyperion's RW200-series of reaction wheels, as well as the MTQ200 series of magnetorquers. Combined with Berlin Space Technologies' flight-proven control algorithms, it offers an entirely autonomous attitude control system, in the space of two standard CubeSat PCB's. With the help of the RW200-series of reaction wheels, it is capable of precisely pointing and slewing 3U CubeSat.

It features a host of operating modes, chief among which is the tracking mode, which allows users to enter target quaternion, after which the system will orient a pre-defined instrument-side towards that target, following it until it has passed the local horizon.

The iADCS100 is also stack-through and is stacked with the payload electronic.

The ST200 star tracker is deported on the payload stack to have the same LOS (line of sight) with the telescope and a baffle was specially designed for the mission.

Bus

The bus, including the 3U structure, the communication, the command and data handling, and the power management, has been design by ISIS.

The structure is a standard 3U structure that respects the CubeSat form factor. The structure has been slightly adapted to accommodate the payload.

The communication is performed with the ISIS TRxVU transceiver. It transmits in UHF (435.525 MHz), and receives in VHF (145.910 MHz). We are allowed to use the radio-ham bands thank to a collaboration with the French radioamateur association (REF). This transceiver also includes a transponder that can be activated when the power budget is positive for the radio-ham. The two pairs of antennas are deployable with the Hold Down and Release Mechanism (HDRM) of ISIS.

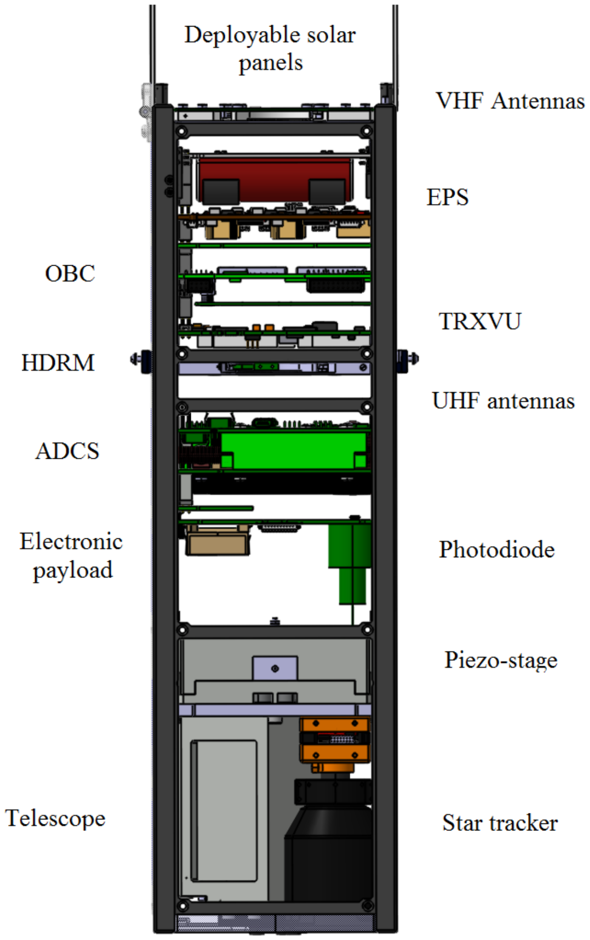

Figure 5 : Detailed view of the full satellite

The on-board computer is the ISIS OBC. It is based around an ARM9 processor with a custom pluggable daughter to fit our needs. The OBC is equipped with two SD card (32GB each) to store the payload data.

The power unit is the EPS GomSpace P31U and the battery pack GomSpace BP4 with a total capacity 37.4Wh.

The energy is produced by a total of 32 solar cells. But 8 of them are mounted on two deployable panels to give additional power.

SOFTWARE

The software is something that we developed in-house, as it is a key investment for future mission.

Flight software

The general architecture and real time aspects are based on the Gericos framework. This framework has been created at LESIA for the development of the software of an instrument onboard Solar Orbiter. It is based on a Real Time Operating System (RTOS), namely FreeRTOS, which is used to share processor time between different high-level tasks. Gericos implements an Active Objects (AO) design pattern, in which different tasks corresponds to different "active objects". The processor time is shared between the different tasks by the RTOS. The framework, initially developed for LEON architectures, has then been ported for other family of microcontroller. The porting of Gericos has been done for the AT91SAM9G20 processor (on which the ISIS on-board computer is based) and STM32F303 (which is on the payload electronics).

Table 1: Tasks managed by the on-board computer software

Tasks	Description
ModeManager	Highest priority task, manages the state machine, process events.
EPSManager	Interface class with the electrical power system.
ComManager	Interface class with the communications systems. Receive and transmits telemetry and telecommands
ADCSManager	Interface class with the ADCS.
PlManager	Interface class with the payload. Synchronize the payload modes with the OBC modes.
HouseKeeper	Collect house keepings, stores high frequency HK in a buffer.
DataRed	Lowest priority task, collect and process data from the payload.

The flight software of the on-board computer is split into two levels. The level 0 (L0) has to be fully stable and contains the vital tasks (EPSManager, EPSManager, ComManager), while the level 1 takes care of higher tasks (ADCSManager, PIManager, DataRed, Mode Manager). The L1 software can be updated remotely during the mission.

The software receives and transmits packet based on the CCSDS standard from ESA.

Ground segment

The ground segment is the hardware (UHF and VHF antenna, transceiver …) and the piece of software that send telecommands to the satellite through the radio hardware, and archive all the receive telemetries into the database.

The software of the ground segment has been developed in python. It is able to handle the CCSDS standard and is composed by 4 processes interacting with each other. The "listen" process catches all the information that transits onto the uplink and downlink ports. The "watch" process shows to the user the received telemetries (TM) and sent telecommands (TC) with their status and acknowledgments. The "control" allows the user to send the telecommands. And the "save" process archives all the information (TC, TM) into the database.

Thanks to python, all the interaction with the ground segment can be scripted to do complex communication with the satellite, including flight software patch.

A web interface with the amateur radio community is also in place where they can upload the data that they could have received. It is possible also to see there the last status and data of the mission (see picsat.obspm.fr).

READY FOR FLIGHT

Design, realization, qualification, and tests of the payload are achieved now. Integration and test has been done on an engineering satellite. The flight model ADCS has been delivered as well as the flight model platform. We are now integrating the full satellite, and we still need to do some test to be ready for flight.

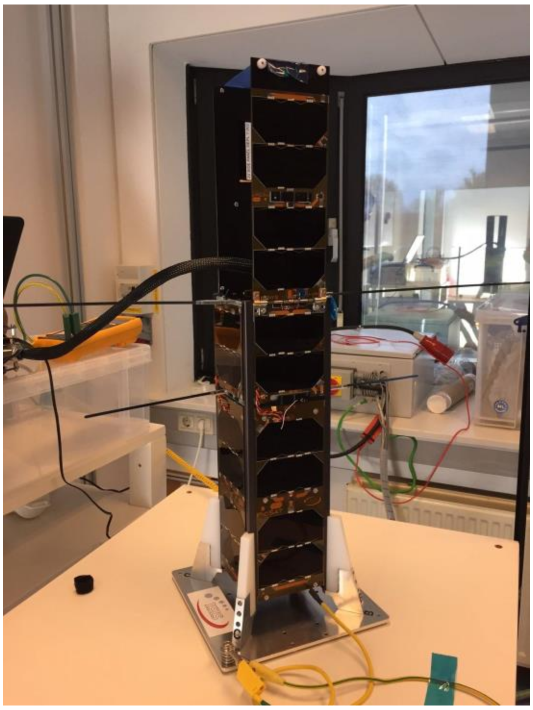

Figure 6 : Flight model of PicSat, antennas and solar panels deployed

The launch has been contracted with ISIS/ISL and planned for September. Just on time to observe the second part of the transit of the Hill sphere.

The operations will last 1 year. We expect a lot of feedback on the performances of the pointing for such platform, as well as the quality of the injection into a single mode fiber. And of course, the scientific return is awaited: on Beta Pictoris b for the beginning of the mission, on exo-comets detection, and why not on other stars measurement.

Acknowledgments

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References

1. Lagrange, A.-M., Gratadour, D., Chauvin, G., Fusco, T., Ehrenreich, D., Mouillet, D., Rousset, G., Rouan, D., Allard, F., Gendron, É., Charton, J., Mugnier, L., Rabou, P., Montri, J., and Lacombe, F., “A probable giant planet imaged in the β Pictoris disk. VLT/NaCo deep L’-band imaging,” A&A 493, L21–L25, Jan.2009
2. Lecavelier des Etangs, A. and Vidal-Madjar, A., The orbit of beta Pictoris b as a transiting planet," A&A 588, A60 (Apr. 2016)
3. Wang, J. J. et all., “The Orbit and Transit Prospects for β Pictoris b Constrained with One Milliarcsecond Astrometry,” The Astronomical Journal, Volume 152, 2016
4. Nowak, M., Lacour, S., Lapeyrère, V., David, L., Crouzier, A., Dufoing, C., Faiz, H., Lemoult, T., Trébuchet, P., “Reaching sub-milimag photometric precision on Beta Pictoris with a nanosat: the PicSat mission,” Proceedings of the SPIE, Volume 9904, id. 99044L 7 pp., 2016
5. M. Nowak, S. Lacour, V. Lapeyrère, L. David, A. Crouzier, G. Schworer, P. Perrot, S. Rayane, “A Compact and Lightweight Fibered Photometer for the PicSat Mission”, SSC17-VI-01, 2017