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PLATO FPA. Focal Plane Assembly of PLATO Instrument

J. Moreno*[1], E. Vielba[1], A. Manjón[1], A. Motos[1], E. Vázquez[1], E. Rodríguez[1], D. Saez[1], M. Sengl[1], J. Fernández[1], G. Campos[1]; D. Muñoz[1];
M. Mas[2] A. Balado[2], G. Ramos[2], C. Cerruti[2], M. Pajas[2], I. Catalán[2], M. A. Alcacera[2], A. Valverde[2], P. Pflueger[2], I. Vera[2]
[1]LIDAX, c/ Antonio Alonso Martín 1, 28860 Paracuellos de Jarama (Madrid), Spain
[2]INTA, Carretera de Ajalvir, Km. 4, 28850 Torrejón de Ardoz (Madrid), Spain

ABSTRACT

This paper describes the thermo-mechanical design of the Focal Plane Assembly (FPA) of the PLAnetary Transits and Oscillations of stars (PLATO) Instrument, developed by INTA and LIDAX. This is an ESA program with OHB as industry prime. In terms of assembly, alignment, and operational stability very demanding needs are required by a huge focal plane composed of four CCDs to assure the proper performance. This is translated into a complex thermo-mechanical design which shall be also focused on the correct production approach of the main parts involved, including several processes, and taking into account the number of cameras, and therefore Focal Plane Assemblies, to be produced (26). Part of these challenges, and their associated risks, are mitigated by means of the development of a totally representative prototype, which is currently finishing the integration phase and facing the test campaign.

Keywords: FPA, thermo-mechanical design, flexible thermal link, bipod, industrialization, concurrent, processes optimization, co-engineering phase, budget objectives

1. INTRODUCTION

The PLATO mission is a medium class mission part of the Cosmic Vision 2015-2025 program for a launch in 2024.

The Focal Plane Assembly (FPA) is a part of each Camera of PLATO mission, which is formed by 24 Normal Cameras and 2 Fast ones. The difference between the two camera types lies in the CCD working mode. The PLATO instrument's purpose is to find and study a large number of extra solar planetary systems, with emphasis on the properties of terrestrial planets in the habitable zone around solar-like stars. PLATO has also been designed to investigate seismic activity in stars, enabling the precise characterization of the planet host star, including its age.

The FPA gives support to four identical CCDs, which compose a common focal plane, providing sensing of the incoming light through the telescope. It is attached to the Telescope, and electrically connected to the proximity electronics by means of the CCD Flexi Cables. INTA is the final responsible for the PLATO FPA project design, development and integration.

The PLATO Camera is shown in Figure 1; it is divided into three main components:

- Telescope Optical Unit (TOU), developed by INAF and formed by the baffle and optical lenses.
- Focal Plane Assembly, developed by INTA/LIDAX. It is the structure that gives support to the 4 CCDs, providing attachment to the TOU. Thermal coupling is provided between CCDs and TOU, by means of 4 Thermal Straps (Flexible Thermal Links). Also, stray light protection is implemented.
- Front End Electronics (FEE), developed by MSSL (FEE for Normal Camera) & DLR (FEE for Fast Camera). It is the electronic box connected to the CCD Flexi Cables.

*morenofj@lidax.com; phone +34 91 678 08 05; www.lidax.com

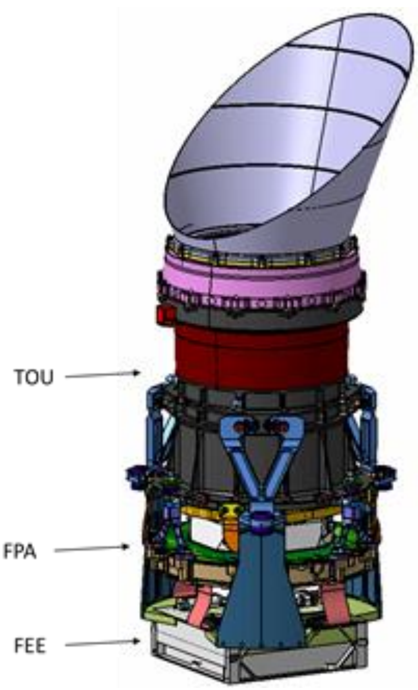

Figure 1: PLATO Camera 3D Model

The Focal Plane Assembly is the thermo-structural element which holds the four detectors together. There are 2 different types of CCDs, both developed by e2V: Full Frame CCDs for the Normal Cameras and Frame Transfer CCDs for the Fast cameras. Three bipods provide the required isostatic mounting to the TOU, and protection against Stray Light is given by means of a dedicated Mask.

The unit has very demanding alignment and stability requirements to assure CCDs stability with respect to the incoming light from the Telescope.

Also, the equipment shall withstand operational temperatures between -90ºC and +35ºC, assuring a maximum temperature difference between CCDs and TOU of 7K. Flexible conductive links (thermal straps) are implemented to achieve this goal.

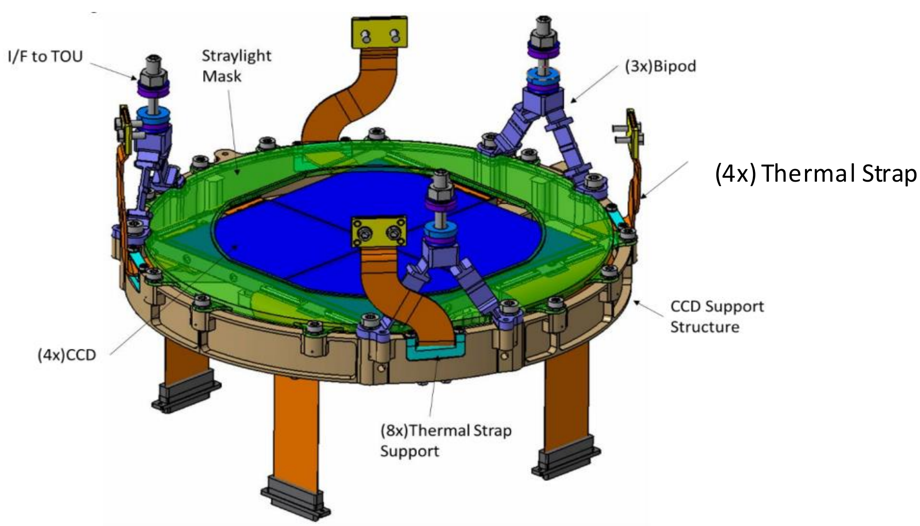

Figure 2: PLATO FPA 3D Model

Thermo-mechanical design of the PLATO FPA, including main functionalities and stability analysis, as well as the first results obtained on the Prototype Model and the different challenges to overcome, are described in the following chapters.

2. MODELS AND PROJECT STATUS

The PLATO Mission is composed of a unique spacecraft where the Payload Module consists of a total of 26 Cameras:

- 24 Normal Cameras
- 2 Fast Cameras

The program is currently going through phase B (Preliminary Design); Instrument PDR is foreseen by mid-October 2018 while the FPA PDR will take place early next year. Apart from the flight models (26 Cameras, so 26 FPAs), a model philosophy to be confident on the FPA flight model design and development, is being discussed. A classical philosophy approach at camera level is needed with STM, EM and QM models, but also other models are needed for the spacecraft qualification; 26 FPA MTD (Mass Thermal Dummies) units representative in mass and thermal properties are needed to be used for the Platform STM.

During the Phase B an FPA Prototype (PRT) model is being developed; this model is fully representative in mechanical and thermal aspects of the PDR design, but with limited electro-optical performance (no functional CCDs). It is specifically created to mitigate risks and consolidate the preliminary design, to face the phase C of the project with all guaranties. The very complex manufacturing and associated processes, integration and alignment activities, and general thermo-mechanical approach are checked and tested in this model. In addition, this model is used for tuning-up all process and methodologies needed for facing the production, assembly and testing of the 26 FPA FMs required.

The PRT has been already manufactured and the Assembly and Integration phase is being finished at the same time this paper is being written. PRT test campaign will take place during September and October 2018.

3. MAIN REQUIREMENTS AND DESIGN DRIVERS

The main objective of the FPA thermo-mechanical design is to provide the four CCDs with an appropriate support able to guarantee the required position and stability on the image plane. This entails the following tasks:

- to avoid any distortion produced by possible thermo-elastic effects due to the CTE difference between the CCDs package and the CCDs Support Structure
- to evacuate the power dissipated by the CCDs during their operation, assuring thermal stability along the focal plane
- to provide the whole structure with enough stiffness to overcome launch loads assuring the correct position of the image plane

Additionally, some critical requirements are derived from the fact that the image plane is composed by four identical and independent CCDs, which means that the positioning and alignment of the four devices shall be almost perfect to create a huge common and unique focal plane, as required by the mission. Such a focal plane configuration forces to consider how to mount, position and align the four CCDs from the very beginning of the design, carrying out in parallel the design of the FPA itself and the associated integration and alignment MGSEs.

All these needs are translated in the following driving requirements:

- Science Operational Temperature range (-90ºC, -63ºC)
- Non- Science Operational Temperature range (-90ºC, +35ºC)

- Maximum temperature difference between FPA and TOU during observation phase ≤ 7ºC. This value shall be obtained by means of passive ways, taking care of the whole thermal path between FPA and TOU and providing high conductance FTLs (Flexible Thermal Links) to evacuate the CCDs power dissipation
- The FPA shall protect the CCDs from light coming from all directions except from the TOU FoV
- The top mounting surfaces of all bipods shall be contained in a common plane with flatness better than 30µm. This is a challenging requirement from both the manufacturing and integration point of view since the Bipods are three independent parts
- The FPA shall be designed in such a way that the common plane composed by the sensitive areas of the four CCDs is practically not shifted or tilted during the cooling down from RT to the minimum science operational temperature
- In the same way, the FPA design shall guarantee almost no movement of the CCDs due to the gravity release effect
- The initial alignment and position of the CCDs shall be maintained during the whole mission

On the other hand, some critical requirements, not directly present in the technical specifications, are intrinsic to the mission; a complete PLATO model is composed of 26 cameras, therefore 26 FPAs.

The total number of units for the whole project, probably quite a bit more than 27, and specially, the number of FMs needed for a unique and complete PLATO Payload Module FM, 26, make this development unique and critical from the programmatic and production point of view. This way, this project is placed in a complex position, halfway between the "Traditional Space", due to the highest levels of quality, reliability and performances required, and the "New Space", because of the absolutely mandatory need for the optimization of the supply chain, production, process and methodologies, and tests execution and coordination.

In order to succeed in the programme development INTA and LIDAX are changing their standard practices, strengthening the following skills to achieve the instrument performance while maintaining the budget objectives:

- Identification, and optimization, of recurrent manufacturing, assembly and testing activities
- Co-engineering with key partners and suppliers
- Organizational and industrialization capabilities. A specific Industrialization Plan is being elaborated including, among others, the following aspects:
    - Procurement Strategy (batch size, supply chain optimization…)
    - Production activities planification and fitting within the Project Schedule requirements
    - Production resources planification
    - AIT activities planification and necessary resources
    - Inventory management: Storage and control needs
    - Flux of goods and assemblies (among different facilities)
    - Suppliers management

4. THERMO-MECHANICAL DESIGN

The thermo-mechanical design of the PLATO FPA is focused on fulfilling the requirements and issues shown in the previous chapter, providing at the same time the following main functions:

- Mechanical Support to the four CCD detectors
- Thermo-mechanical interface with Telescope Optical Unit (TOU), fulfilling the high mechanical, alignment and stability requirements
- Electrical interface to the Front End Electronic (FEE) box
- Stray light (partial) protection of detectors

The four CCD Detectors together with their corresponding flex cables are mounted on a single integral part made from Ti6Al4V, the CCD Support Structure, which is provided with enough flexibility at the I/Fs with the CCDs to absorb the CTE difference with the CCDs package, made from SiC. Material selection for this critical part is the result of extensive trade-offs where mechanical strength, CTE, thermal conductivity, machining ease, coating possibilities, and cost and production time, are considered.

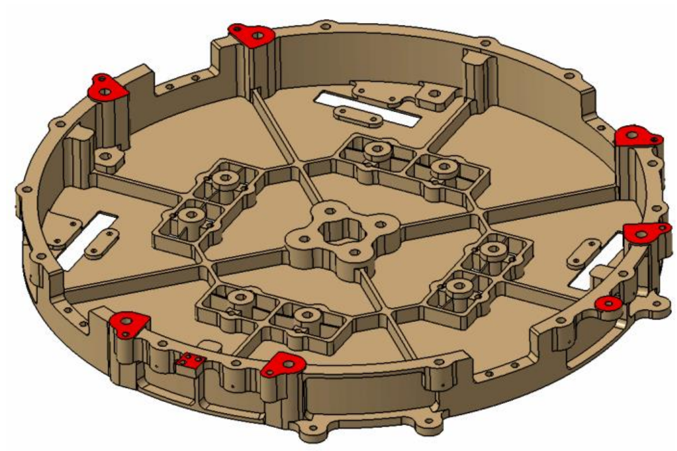

Figure 3: CCD Support Structure design

The previous part is connected to the TOU by means of three Bipods, also made from Ti6Al4V, which are designed in such a way to provide flexibility enough and to absorb the deformation of the CCD Support Structure. Also, a design driver for this part is to achieve good performance results under thermo-elastic loads as well as to reduce the CCDs IF (Interface) forces under Quasi-Static and Dynamic loads.

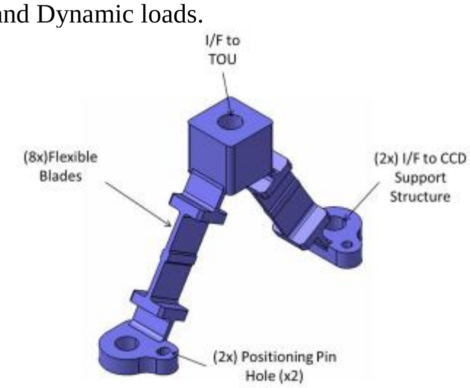

Figure 4: Bipods design

The Stray Light Mask is attached to the CCD Support Structure and protects the CCDs from parasitic stray light. It is a complex part due to the required slenderness to minimize the mass impact. It is provided with an external ring that avoids lateral rays to reach the CCDs sensitive area. Material is also black coated Ti6Al4V.

Finally, the CCDs are maintained at the desired temperature by means of dedicated FTLs (Flexible Thermal Links), which conductively connect each one of the CCD packages with the TOU structure. The TOU structure acts as heatsink, and the FTLs are dimensioned to assure a maximum temperature drop of 7K between the TOU and the CCDs. These FTLs are based on LIDAX's flight qualified units, used in other projects such as CAS ATLID for the EarthCare mission, and are made up of thin copper sheets fixed by copper terminals at the IFs. All parts are gold coated for corrosion protection and to minimize the radiative interchanges.

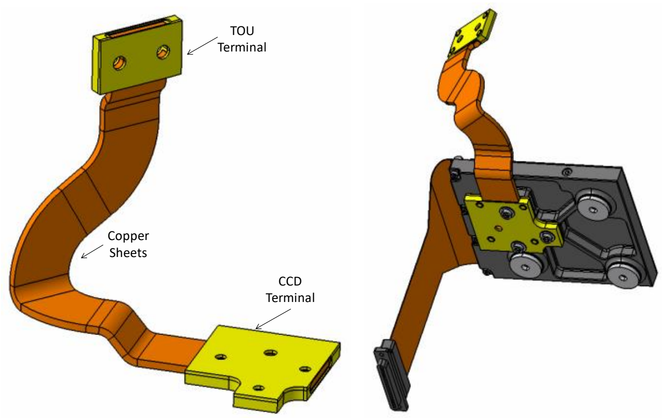

Figure 5: FTLs design

5. FPA PROTOTYPE

As already commented, the FPA Prototype objective is to reduce the FPA development risk and to gain confidence in the current FPA design. In addition, all methodologies, processes, and procedures necessary to correctly build a compliant FPA for the PLATO mission will be created and optimized to allow a smooth production and delivery of the final 26 FPA FMs. The FPA prototype will provide info on:

- Manufacturability: Demonstrate that the FPA design is manufacturable with flight materials and obtain manufacturing tolerances
- Mass budget confirmation
- CCD/FPA Interface: Interfaces agreed with ESA tested
- Integration and Alignment requirements feasibility
- Analysis correlation: A complete Mechanical/thermal test campaign to correlate the thermal/mechanical analysis
- Requirements: Non-compliance requirements assessment
- Schedule: Information about the processes & tests timing

The PLATO FPA PRT is totally representative of the FM design, which is at this moment facing the PDR milestone. The only differences are:

- TOU/FPA Interface is different to the Flight Model
- FTLs coating (Nickel instead of Gold); this deviation does not affect the thermal performance of the Flexible Thermal Links
- CCD Support Structure, Bipods, and Stray Light Mask are not black coated
- Non-Functional CCDs → Electrical precautions are not needed during integration

Manufacturing, Integration and Alignment

Main difficulties found during the PRT manufacturing are related to the CCD Support Structure and the Bipods. These are very complex parts whose tolerances shall be carefully combined to provide the CCDs with the required position and stability. It is necessary to combine several different machining processes and treatments, which have been optimized and described in specific manufacturing procedures and processes specifications. In that sense, the concurrent manufacturing engineering performed together with LIDAX's machining partner has been key, to clearly define and to optimize all the steps of the production for these parts. The PRT CCD Support Structure and Bipods are shown in Figure 6.

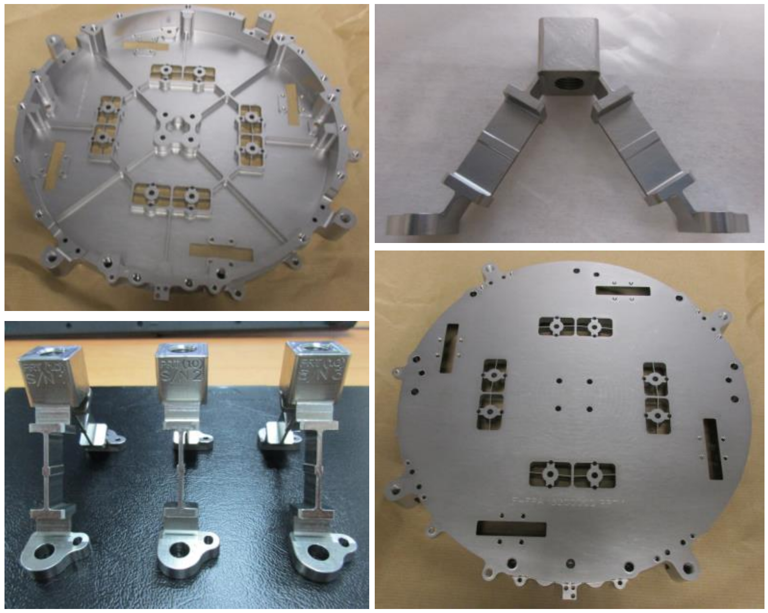

Figure 6: PRT CCD Support Structure and Bipods

Based on the tolerances obtained for the different parts, the Prototype is also serving to verify and optimize AIT techniques, such as shimming for improving the FPA alignment. Results have been satisfactory with good repeatability. For future models, manufacturing processes will improve to reduce to the minimum such time/effort related to AIT activities.

Another critical point is the CCDs/FPA IF, since the CCDs have quite limited tensile strength while they suffer high lateral forces at their IFs during vibrations, which at the end is translated into a narrow margin for preload scatter. This issue is solved introducing a specific stack of disc spring washers in the CCDs- CCD Support Structure joint and characterizing their deflection. The solution has been found in close collaboration with ESA, with very good results translated into a robust integration procedure which provides a maximum preload scatter of less than 60N.

Specific tools and MGSEs have been designed and produced to mount and correctly align the four Detectors; instrumentation such as theodolites and LIDAX's ISO 7 CMM have been utilized during the process:

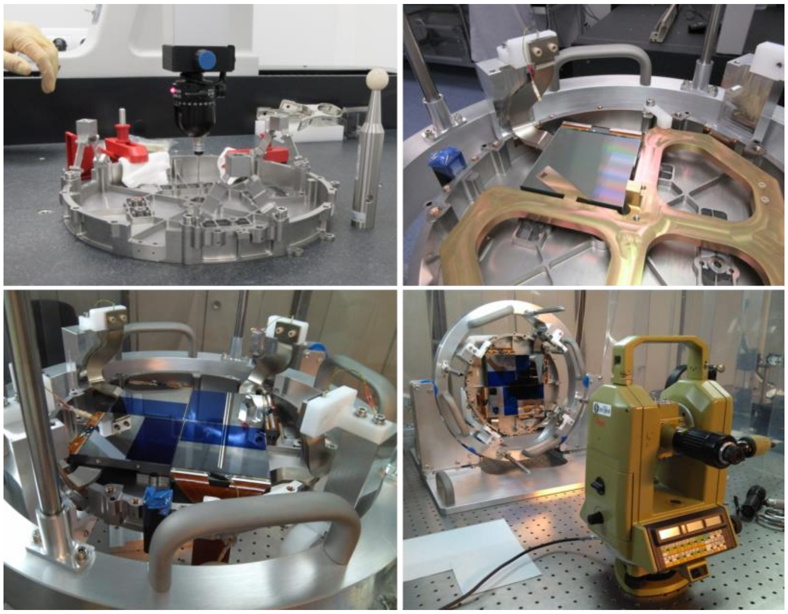

Figure 7: PRT assembly and alignment activities

Test Campaign

The FPA PRT is going to be submitted to a full test campaign as per the following sequence:

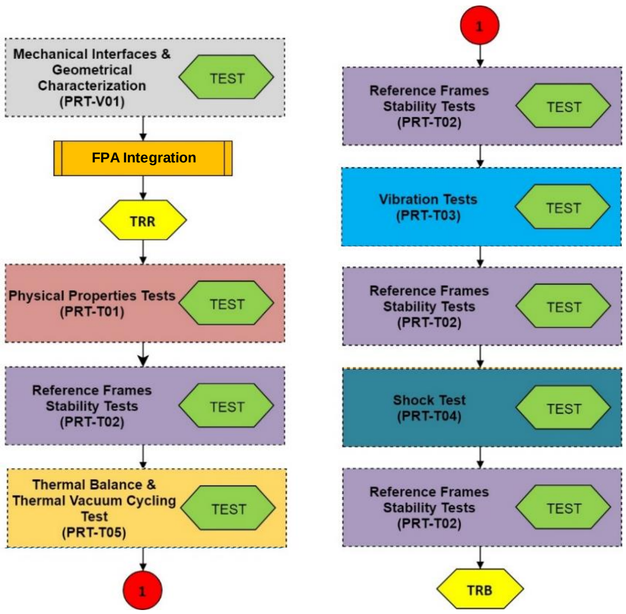

Figure 8: PRT Test Campaign Sequence

Special importance is given to test PRT-02, which is focused on measuring the stability of the CCDs and the different reference frames of the FPA, and will be carried out before and after each thermal and mechanical test.

This campaign will help to tune up all the procedures and test methodologies before PDR, it will allow mechanical and thermal models correlation, and will provide crucial information on the requirements compliance, timing and effort needed, to properly face the detailed design and FMs production and testing phases.

6. CONCLUSIONS

PLATO FPA demands, on one hand, a complex design to fulfill very high-performance requirements, and on the other hand, it entails a challenge in terms of production, assembly and testing, to assure the correct delivery of 26 FMs on time and within a reasonable budget. This involves changing the standard practices, and to optimize every step in the project development to guarantee the feasibility in terms of costs and Schedule, while maintaining the highest level of quality and excellence.

A powerful preliminary design, supported by a specific model, the PRT, is on going to mitigate risks and to tune up all the process and methodologies, as well as to create the required industrial organization, needed to complete the production and delivery of the 26 PLATO FPA FMs successfully.

The PRT Test Campaign will take place during autumn 2018 and the FPA PDR will take place early next year.

7. ACKNOWLEDGEMENTS

The design and activities described in this paper and the overall advances in the PLATO FPA development are fruit of the joint effort between LIDAX and INTA, as well as the support of OHB-System AG, and the European Space Agency.

Special thanks to all LIDAX PLATO Team, who is doing a great job for a very demanding and challenging project.