

CCD Detector Handling for the PLATO Focal Plane Assembly at INTA

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ABSTRACT

PLATO (PLANetary Transits and Oscillations of stars) is a European Space Agency (ESA) mission for detecting and characterizing extrasolar planetary systems, with particular emphasis on Earth-like rocky planets orbiting Sun-like stars within their habitable zones. Scheduled for launch in 2027, the mission will advance our understanding of planetary system formation and evolution through high-precision photometry and asteroseismology [1].

The PLATO payload consists of 26 cameras mounted on a common optical bench, providing a very large field of view. Each camera comprises a Telescope Optical Unit (TOU), a Focal Plane Assembly (FPA), and a Front-End Electronics (FEE) unit.

This paper focuses on the FPA detectors. The PLATO CCD is a large-format, back-illuminated device (8 x 8 cm, 4510 x 4510 pixels, 18 μm pitch), designed and manufactured by Teledyne e2v. Two types are used: Normal CCDs, optimized for science observations with images acquired every 25 seconds, and Fast CCDs, dedicated to bright targets, fine guidance and navigation, with images every 2.5 seconds.

Each FPA houses four CCDs that must operate as a single sensitive area, imposing stringent coplanarity and alignment requirements. The scale of the mission has required an unusually high level of serial manufacturing for space instrumentation, posing significant challenges in consistency, reliability and quality assurance [4].

In total, 26 flight FPAs (plus 3 spares) integrating 116 CCDs have been produced. Ensuring consistent performance requires strict control of handling, integration and verification throughout production at INTA. The methodologies developed for safe handling such as contamination control, ESD mitigation, and electrical verification are presented, demonstrating the feasibility of large-scale, high-reliability CCD handling for future space missions with similar requirements.

Keywords: Exoplanets, PLATO, handling, contamination control, ESD, AIVT, FPA, CCD.

1. INTRODUCTION

The PLATO mission requires exceptional photometric stability and optical performance from its focal plane detectors. The scientific return of the mission (the detection of small, long-period transits of Earth-like planets and the characterization of stellar oscillations) depends directly on the quality, cleanliness and structural integrity of the flight CCD detectors that populate the 26 flight Focal Plane Assemblies (FPAs).

PLATO requires an unusually high level of serial manufacturing, assembly, integration and verification (AIVT) activity for space-qualified hardware. Each of the 26 flight cameras must reach comparable optical and electrical performance, which requires that the handling procedures applied to every CCD and every FPA be repeatable, traceable and robust against operator variability.

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Prior to the start of flight production, the FPA design was validated through a dedicated model philosophy (including prototype, structural/thermal, engineering and qualification models) that consolidated the manufacturing, assembly and verification processes ahead of the serial flight production [3].

This paper describes the methodologies developed and implemented at INTA for the safe handling of the PLATO CCD detectors throughout their production lifecycle: incoming inspection and storage, integration into the FPA, testing [8][12], intermediate and final verification, cleaning, and packing for delivery. Particular attention is given to three areas that dominate the greatest risk of damage or performance degradation: contamination, electrostatic discharge (ESD) and electrical verification.

2. THE PLATO PAYLOAD AND THE FOCAL PLANE ASSEMBLY

The PLATO payload is composed of an array of 26 cameras mounted on a common optical bench. Each camera comprises a Telescope Optical Unit (TOU), a Focal Plane Assembly (FPA) and a Front-End Electronics (FEE) unit. This multi-camera architecture gives PLATO its very large field of view, which is essential to monitor a sufficiently large number of bright stars simultaneously.

The FPA [9] is the part of the camera that holds the detectors. Each FPA accommodates four CCDs that must behave as a single, coplanar sensitive area; this imposes stringent requirements on the alignment and coplanarity between the four detectors, and consequently on every handling and integration operation performed on them.

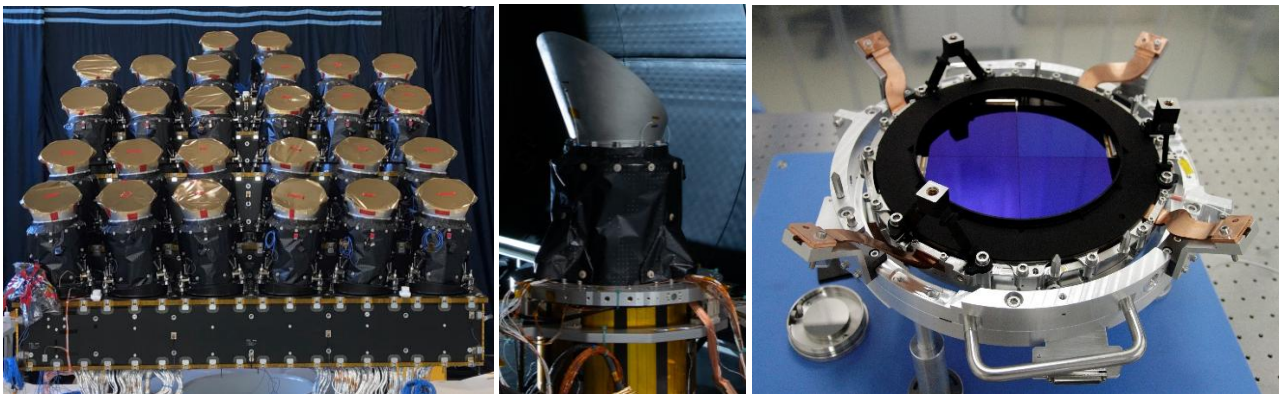


Figure 1. From left to right: PLATO satellite; PLATO camera; PLATO FPA.

2.1 CCD detector description [2]

The PLATO CCD (CCD270, also referred to as CCD-BRUYERES) has been designed and manufactured for the mission by Teledyne e2v. It is a large-format, back-illuminated device of approximately 8×8 cm, with 4510×4510 pixels at an $18 \mu\text{m}$ pitch, producing an image of 20 megapixels. Two variants are used on each FPA: Normal CCDs (full frame), optimized for science observations with images acquired every 25 seconds, and Fast CCDs (where only one half of the CCD collects photons while the other covered half acts as a storage area for rapid charge transfer) dedicated to bright-target monitoring, fine guidance and navigation, with images acquired every 2.5 seconds. In operation, the detectors are cooled below -65°C to maximize their sensitivity.

The CCD package includes several parts manufactured in Invar, namely M4 and M3 threaded inserts, M3 threaded insert caps and bodies, flex cable clamps and shims. These are the most delicate parts from a corrosion point of view, as discussed in Section 3.

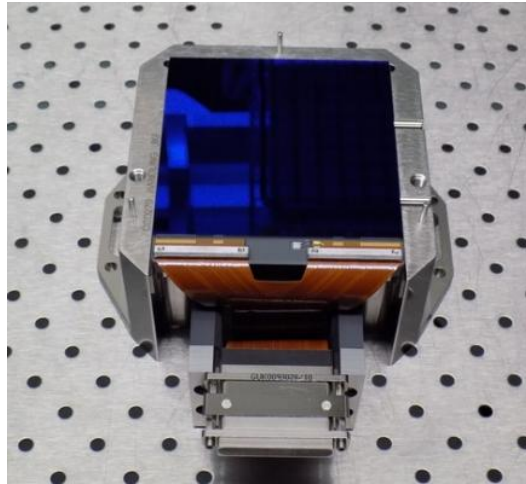


Figure 2. PLATO CCD Normal (Full frame).

3. CCD HANDLING PRECAUTIONS

The handling flow covers incoming inspection and storage of the CCDs, their integration into the FPA, testing, intermediate and final inspection, and packing. Across all these stages, four risk drivers govern the applicable precautions: electrostatic sensitivity, susceptibility of the Invar parts to corrosion, the mechanical fragility of the SiC package and wire bonds and contamination.

The first two risk drivers are directly linked to the relative humidity (RH) of the working environment, and pull in opposite directions: low RH increases the ESD risk, while high RH increases the corrosion risk of the Invar parts. Figure 3 summarizes how these two constraints combine to define the recommended operating range.

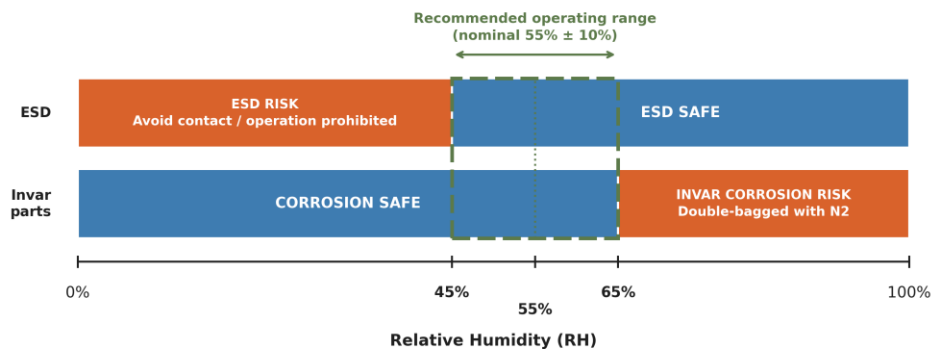


Figure 3. Relative humidity constraints affecting CCD/FPA handling. Low RH increases the ESD risk, while high RH increases the corrosion risk of the Invar parts; the 45–65% range (nominal 55% $\pm$ 10%) satisfies both constraints.

3.1 ESD precautions

The CCDs are highly sensitive to Electro-Static Discharge (ESD) events, and the applicable ESD control plan is enforced at every stage of handling. Upon arrival at INTA, the devices are kept double-bagged in their original protective metal transport box and are extracted only immediately prior to integration into the CCD support structure. All surfaces on which the CCD or its metal packing case rests are ESD-protected, with grounding through a minimum 1 M Ω resistor, and all material used within 30 cm of the CCD is static-dissipative.

Shorting connectors are fitted to the CCDs whenever possible to prevent ESD events, and are removed only for the duration of DC electrical tests. Personnel are grounded at all times through a wrist strap, and the use of antistatic garments is mandatory. Relative humidity is controlled to 55% $\pm$ 10%, and the FPA is kept grounded once the CCDs are assembled.

If relative humidity drops below 45% during any activity, the increased ESD risk requires that the activity be stopped and the Product Assurance (PA) manager be contacted.

For both internal and external transport, the FPA is double-bagged in antistatic bags.

For further information on ESD precautions in PLATO, see [10].

3.2 Corrosion control of Invar parts

The Invar parts (M4 and M3 threaded inserts, clamps and shims) described in Section 2.1 have no corrosion protection, and only the flexi clamps and shims remain accessible for inspection once the device is integrated. Their environmental exposure must therefore be tightly controlled throughout the handling flow to manage the corrosion risk: storage in an ISO class 6 cleanroom or better, and a maximum relative humidity of 65%. Because the lower bound of acceptable humidity is itself constrained by ESD considerations, the best protection against corrosion during storage and transport is a nitrogen atmosphere; where this is not achievable, dry air obtained through sufficient desiccant enclosed between the inner and outer bags is used instead.

CCD transport boxes are not opened until the CCD is due for integration, and the devices remain stored inside their sealed boxes until that moment. During integration, test and prior to FPA packaging, the same ISO 6 / 65% maximum RH environmental envelope applies. Any sign of corrosion on the shims observed at reception triggers a Non-Conformance Review Board (NRB).

3.3 SiC package and wire bonding

The CCD package is manufactured in Silicon Carbide (SiC), a very brittle material, so careful handling is required throughout both CCD handling and FPA integration to avoid structural damage or breakage. During transport and storage, the CCD active area is protected by a transparent lid; once this lid is removed for integration, the device, and in particular its wire bonds, becomes highly exposed and vulnerable, and extreme care is required when performing this operation.

3.4 Cleanliness

Contamination of the CCDs is avoided by applying the FPA Contamination Control Plan. Only personnel trained in the applicable protocols are involved in CCD and FPA activities.

Exposure time of the CCDs is minimized through the use of dedicated covers, one for use during integration and another for transport, in addition to ESD bags.

Clean facility environments and FPA sub-systems are continuously monitored for molecular (MOC) and particulate (PAC) contamination; and solvents are never sprayed in the direction of the CCD location, to avoid contaminating the devices with solvent droplets.

For more details of Particulate and Molecular Cleanliness control of the FPA, see [5].

4. CLEANING METHODS [11]

The presence of particles on the CCD sensor surface is unacceptable, since affected pixels may become unable to produce a valid image (particles can cause shadows, dark spots, blemishes, or a reduction in sensitivity). ISO 5 working conditions are used to minimize particle deposition, but a residual deposition rate remains, which makes a controlled cleaning procedure necessary.

Only one cleaning method is currently approved by ESA for use at INTA on the PLATO FPAs: N₂ blowing. When a significant number of particles is present, an ionized, grade 4 filtered N₂ flux is applied to the CCD surface, generating an airflow that removes them. The airflow from the blowing gun is used in conjunction with an ionizing blower; the ioniser fan configuration at INTA has been adapted accordingly to maximize its effectiveness. The entire area was analyzed by personnel external to the project to verify the effectiveness of the ionizers and ionizing air guns.

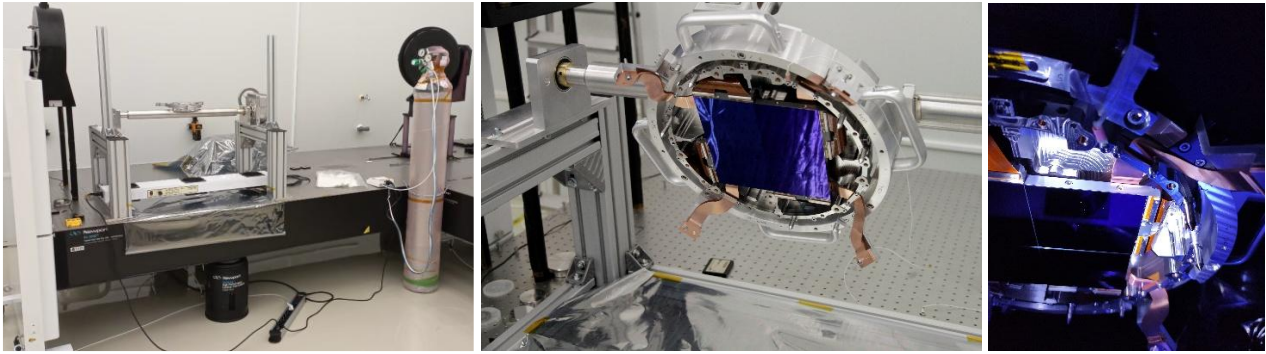


Figure 4. From left to right: Flipping jig; FPA mounted on flipping jig ambient light on; FPA mounted on flipping jig ambient light off.

The cleaning area is built around a flipping jig, a structure that supports the FPA (integrated in its cradle, the mechanical support structure used to handle the FPA) and allows rotation around two axes, complemented by an ionizer covering the FPA location to prevent ESD damage, and a blowing system consisting of quality nitrogen bottles and an ionizing blowing gun located alongside the area.

Every cleaning campaign shall comply with the following operational rules:

- at least two operators (one handling the nitrogen gun and another a vacuum cleaner) plus the PA manager, must be present;
- contamination witnesses are closed during cleaning and cleaned following the same procedure as the flight model;
- grounding and cleanliness status of the cleaning area is verified before any actuation;
- where a particle cannot be removed, the operator should proceed carefully rather than forcing the process, to avoid causing damage;
- FPA covers must be kept on as much as possible, and removed only at the moment of cleaning.

Blowing is performed at a regulated pressure of approximately 2 bar, not exceeding 2.1 bar (30 psi), following the direction of the wire bonds. The activity is performed with ambient lights switched off, inspecting the area under white or UV light to locate the particles to be removed. Only the two bottom CCDs are blown, allowing particles to be expelled from the FPA. A single 180° rotation of the assembly is preferred over multiple rotations, exposing the remaining CCD locations for cleaning while minimizing handling operations.

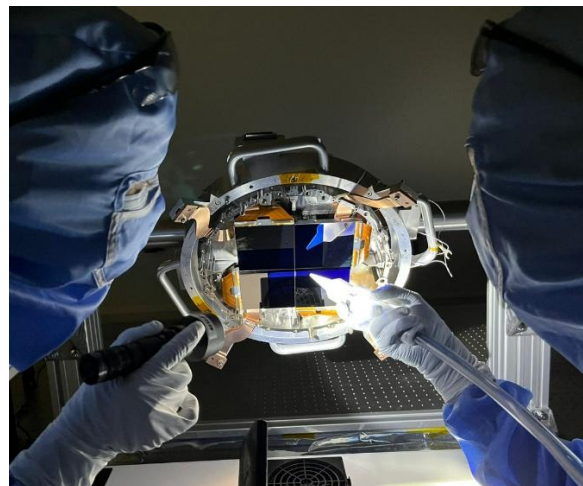


Figure 5. CCD cleaning by N2 blowing.

Cleaning is highly critical and carries significant risk, and therefore must be carried out with great care and only by trained personnel.

5. INSPECTION [11]

Two distinct environments are used for cleaning, inspection, integration or testing activities. Cleaning is performed in an ISO 6 open environment: the N2 blowing activity benefits from an open area that allows the nitrogen jet to dissipate, although ISO 5 laminar-flow panels are also available for a higher-quality environment.

Inspection, by contrast, is always performed in a closed ISO 5 environment (laminar flow cabinet), using white and UV lights. The CCD surface can be observed while remaining ESD-protected by an ionizer fan, ensuring that visual inspection does not itself introduce an electrostatic risk.

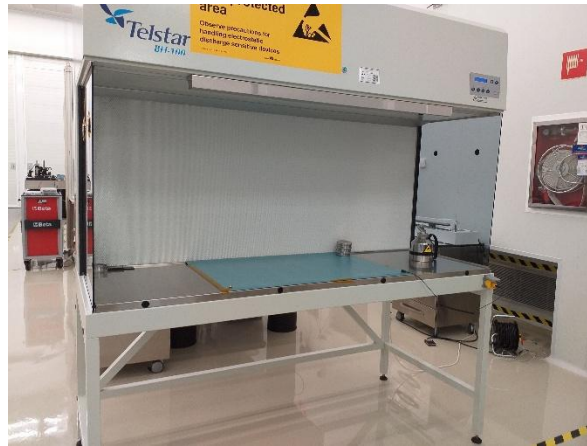


Figure 6. ISO 5 Laminar flow cabinet used for inspections.

6. FPA INTEGRATION, TEST AND TRANSPORT ACTIVITIES

The FPA integration procedure incorporates all the guidelines described in this paper. For testing activities, the same ESD precautions and cleanliness controls are stressed throughout the applicable test procedures; the FPA is kept bagged for as much as possible, with the use of ESD bags being mandatory.

During external transport, the FPA is double-bagged and N2-filled to prevent contamination and water condensation, and is assembled into its Mechanical Ground Support Equipment (MGSE [6][7]) to ensure safe transport without structural damage. A dry nitrogen flush is performed on the inner bag prior to sealing, after which the outer bag is filled with N2 and sealed.

For storage, the FPA is kept under positive pressure inside double-sealed ESD bags filled with dry, filtered, high-purity nitrogen, following the same philosophy applied during transport.

6.1 Electrical verification

Electrical verification is performed at several discrete points of the flow rather than continuously, in order to minimize the exposure time during which the CCD is not protected by its shorting connectors. Shorting connectors are fitted to the device by default and are removed only for the duration of the test, being refitted immediately afterwards; this practice confines the period of increased ESD vulnerability to the shortest interval strictly necessary to obtain the required measurements.

The performed DC test is a series of two wire tests, which check whether connections between package pins are as expected.

DC checks are performed at incoming inspection, prior to integration into the FPA, at intermediate and final inspection points of the FPA assembly, after test and before packing, so that any performance drift or damage introduced by a given handling step can be attributed to that step rather than discovered only at the end of the production flow. Every verification is carried out inside the ESD Protected Area (EPA), with the workbench and test equipment grounded and the operator wearing a wrist strap checked with the ESD tester before donning the final gloves, consistent with the precautions described in Section 3.1.

7. LESSONS LEARNED AND DISCUSSION

The scale of the PLATO FPA production (116 flight detectors integrated into 26 flight FPAs plus 3 spares) has exposed the handling flow to a much larger number of repetitions than is typical for space instrumentation, and has therefore been a valuable stress test of the procedures described above. Several lessons learned have emerged from this experience.

First, ESD protection and humidity control had to be considered together: while low humidity reduces the corrosion risk of the Invar parts, it simultaneously increases the risk of electrostatic discharge, so the two constraints must be actively balanced rather than optimized independently. In practice, this balance was not difficult to maintain, since all activities were carried out in a clean room with controlled relative humidity. Even so, clear stop criteria (such as halting activities and contacting the PA manager [11] when relative humidity drops below 45%, or bagging with dry nitrogen when relative humidity is above 65%) have been essential to avoid conflicting requirements being resolved ad hoc by operators.

The ionizer fan configuration was adapted in the several working areas, and ad hoc ground handling procedures were defined, rather than relying solely on generic ESD and contamination control standards.

The use of a dedicated flipping jig, with a well-defined and versioned step-by-step sequence has been key to achieving repeatability across the many cleaning campaigns performed on different FPA units, and to limit the dependence of the outcome on individual operator experience. This is particularly relevant given that only personnel with specific experience and training have been authorized to handle the flight hardware.

It is also important to highlight the significance of documentation and its control: every modification or incident occurring during the AIT/AIV process, however minor, has been recorded and controlled, and operators have been thoroughly trained and familiarized with the procedures.

Visual inspections performed between the intermediate steps of all AIT/AIV activities have played a key role in achieving and maintaining the required level of quality throughout the entire integration and verification process.

Finally, the consistent application of double-bagging, nitrogen-filled storage and transport, and dedicated covers throughout every stage of the flow (from incoming inspection to final delivery) has allowed contamination and corrosion risks to be kept under control despite the CCDs and FPAs moving repeatedly between storage, integration, test and transport configurations over an extended production campaign.

8. CONCLUSION

The production of the PLATO flight hardware (26 FPAs plus 3 spares, integrating a total of 116 CCD detectors) has required an unusually high level of serial manufacturing for a space optical instrument. Ensuring consistent performance across every unit has depended on strict, repeatable control of handling, integration and verification activities throughout the CCD and FPA production lifecycle at INTA.

The methodologies presented in this paper (covering ESD mitigation, corrosion control of Invar parts, protection of the brittle SiC package and wire bonds, contamination control, N₂ blowing cleaning, and dedicated inspection and transport procedures) have been successfully implemented across the full flight production.

Thanks to the implementation of the measures presented in this paper, all CCDs have remained within the required contamination limits (despite these limits being particularly stringent), demonstrating the robustness and effectiveness of the procedures developed for this project. Considering the large number of CCDs handled throughout the project, the number of issues encountered has been remarkably low relative to what could have been expected. It is noteworthy that only two Non-Conformances (NCs) have been opened due to significant damage to CCDs [11].

The results demonstrate the feasibility of large-scale, high-reliability CCD handling for space applications, and provide a robust framework that can be adapted to future missions with similar industrial scale and performance requirements.

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