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ASTRO MBSE: MODEL BASED SYSTEM ENGINEERING SYNTHESIZED FOR THE ITALIAN ASTRONOMICAL COMMUNITY

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ABSTRACT

Systems Engineering requires the involvement of different engineering disciplines: Software, Electronics, Mechanics (often nowadays together as Mechatronics), Optics etc. Systems Engineering of Astronomical Instrumentation is no exception to this. A critical point is the handling of the different point of view introduced by these disciplines often related to different tools and cultures. Model Based Systems Engineering (MBSE) approach can help the Systems Engineer to always have a complete view of the full system. Moreover, in an ideal situation, all of the information resides in the model thus allowing different views of the System without having to resort to different sources of information, often outdated. In the real world, however, this does not happen because the different actors (Optical Designers, Mechanical Engineers, Astronomers etc.) should adopt the same language and this is clearly, at least nowadays and for the immediate future, close to impossible.

In the Italian Astronomical Community, we are developing methodologies and tools to share the expertise in this field among the different projects. In this paper we present the status of this activity that aims to deliver to the community proper tools and template to enable a uniformed use of MBSE (friendly name Astro MBSE) among different projects (ground and space based, …). We will analyze here different software and different approaches. The target and synthesis of this work will be a support framework for the MBSE based system Engineering activity to the Italian Astronomical Community (INAF).

Keywords: MBSE strategies, templates, architectures for system engineering, ELT, SPACE projects, ASTROMBSE.

1. INTRODUCTION

The aim of this paper is to describe the AstroMBSE initiative that aims at acting as reference point for projects in INAF that intend to adopt MBSE technologies and techniques. This idea has been initiated in 2020 creating a so called "*scheda INAF*", a form submitted to INAF Scientific Directorate stating the existence of such initiative and listing aims and people interested. This paper, in a sense, goes one step further making the initiative official and known to the whole astronomical community.

The initiative has been born based on the experiences made by authors in several projects, both ground and space based. In particular, the authors have recognized the need of sharing experiences in the domain of MBSE and, also, the need to make MBSE techniques compatible and accepted in the world of Systems Engineering where different views (mechanical, electronic, software) exist with different (and quite "conservative") approaches.

2. GOAL AND RESULTS

The projects that Systems Engineering in general, and in particular in INAF, will face in the coming years will be bigger, more expensive and more complex.

Already now projects such as, for example, MAORY, HIRES, ATHENA, PLATO, EUCLID are managed by geographically distributed consortia, which move huge financial masses and face extreme technological challenges.

Systems Engineers find themselves interacting with the development team, often geographically scattered and with different working approaches. New projects are frequently not only complicated but also extremely complex. Using

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traditional methodologies may no longer be enough. Model-Based Systems Engineering (MBSE) allows both to rationalize and improve the quality of information relating to a project and to simplify the management of stresses by optimizing communication between the different teams. The MBSE also makes it possible to effectively address and reduce the complexity of projects, also reducing technical risks and increasing efficiency and effectiveness at the same time and in the development phase. The system model is created using a formal language (typically SysML) with the use of a tool (e.g. Cameo or Enterprise Architect) and becomes the only “Source of Truth” of the project. The relative documentation, when required, is therefore produced directly from the model.

The program envisaged here foresees to include, at INAF level, a group that collects all the experiences and can act as a reference point during the whole life of a reference project, expertise and help as far as the MBSE is concerned. Off course it refers to the sections of the Scientific Direction of INAF which presents itself as Systems Engineering. Currently this methodology is applied in INAF within the MAORY, CUBES and MAVIS projects with respect to round instrumentation and PLATO and EUCLID with respect to pace instrumentation.

From a technical point of view, Cameo (https://www.nomagic.com/products/cameo-systems-modeler) is used for terrestrial projects and Enterprise Architect (https://sparxsystems.com/) for space ones. The choice was determined by the fact that the first tool is used in the ESO environment, in particular for what concern software projects, while the second is the tool chosen for MBSE applications in ESA concerning the PLATO and EUCLID projects. The results obtained so far are very promising:

- A MAORY SysML model has been created where all the system requirements are traced, a model for CUBES based on MAORY's experience is being developed and we are actively participating in the modelling of MAVIS.
- A collaboration was also initiated with the PA / QA group to both insert information such as the Bill of Materials (BOM) into the model, connecting it to the rest of the model and integrate SQA information and activities in the model.
- A collaboration with ESA is also underway within PLATO (see PLATO data sheet).
- A collaboration has also begun with the *Politecnico di Milano* and the *University of Insubria* on issues related to the MBSE.

The experience acquired so far has also allowed us to understand how the optimal strategy is to make the model the only Source of Truth of a project where information can be exported or imported even using consolidated and widely used tools such as Word or Excel. The Use of the latter tools is also strategical in integrating with consolidated procedures used by domain engineers (e.g. mechanical, electronic…) wo may be reluctant to abandon well known and effective procedures and opens up a promising area of research in the field of SysML model synchronization methodologies with more “traditional” tools such as the aforementioned Word or Excel, with tools for CMS or with specialized engineering design tools such as CAD. The goals are therefore:

- Consolidate expertise in INAF in the field of MBSE to allow you to better face the challenges of new, large projects and to remain at the technological forefront in the field of Systems Engineering, thus allowing INAF personnel to have both managerial and technical leadership roles in international level.
- Research and develop new technologies and new modalities in the field of MBSE, allowing the synchronization of the model with other "visions" of the system (eg with the CAD files of the mechanical engineers or supporting the methodologies related to PA / QA) or by participating to international initiatives in this field, such as OpenMBEE (https://www.openmbee.org/).
- Further develop existing collaborations with scientific organizations dealing with MBSE such as NASA and ESA.
- Integrate MBSE approach in Combined Design Facilities like e.g. COMET by ESA.
- Develop collaborations with other non-scientific organizations but representative of the Systems Engineering world such as INCOSE and AISE where similar initiatives in the field of MBSE are active.
- Develop synergies with the world of universities to train Systems Engineers for astronomical (and other) projects of tomorrow.

The goal is to establish an efficient and stable service within the Systems Engineering section of the Scientific Management of INAF.

3. ACTIVITY PLANNING

In Figure 1 is shown the team organization (any member is identified with a real person, we prefer to not include the names here as it is out of the scope of the paper.

The coordinator and its deputy define the guidelines of the overall project, identifying the model strategy and the proper use cases to be analysed in depth. They also handle the relationship with external partners, like the agencies (as possible stakeholders of INAF projects), and universities (for partnerships and collaborative developments, through thesis and similar).

There will be several collaborators that will take care of the development of the various standardized models, starting from their experience and system engineering all day life needs. They will be organized per topics (Behaviour, Structure, Analysis, and Requirement) and by application (Space and Ground). Obviously, there will be also focus onto the identification and development of commonalities among all the activities. All the collaborators are working as system engineers of astronomical instruments (or subsystems).

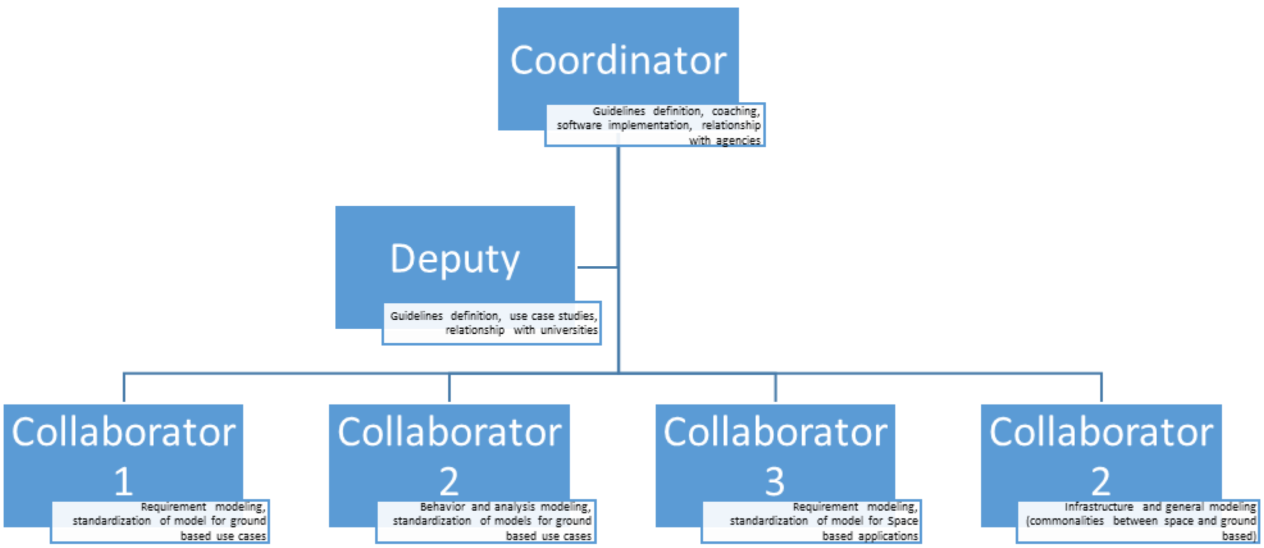

Figure 1 Team organization

A first phase of development of new tools is envisaged that can solve the problems of interfacing with "traditional" Systems Engineering and where the methodology is consolidated. At the same time, based on the accumulated experience, support activities will continue to projects that already use MBSE such as MAORY and CUBES and the collaboration with ESA will be deepened within PLATO. It is expected to have a stable system for the second quarter of 2022 and consolidated for the second quarter of 2023.

Finally, in order to have both visibility and a collection point of information/templates etc., a web site is under development.

4. MORFEO (AKA MAORY) GROUND BASED USE CASE

MORFEO is the ELT-MCAO system providing first-light wide-field correction for the near infrared imager and spectrograph MICADO and a second ELT instrument. A CAMEO model has been deployed to manage all system engineering activities [1] including also RAMS and PAQA ones [3]. MORFEO is used in the *astroMBSE* context as test bench for the development of ground based tuned approach. The choice of cameo has been led by its adoption by most of the ground based astronomical customer (ESO, LSST, GMT, ...)

In the following we show some extract of the model as example of possible standardization.

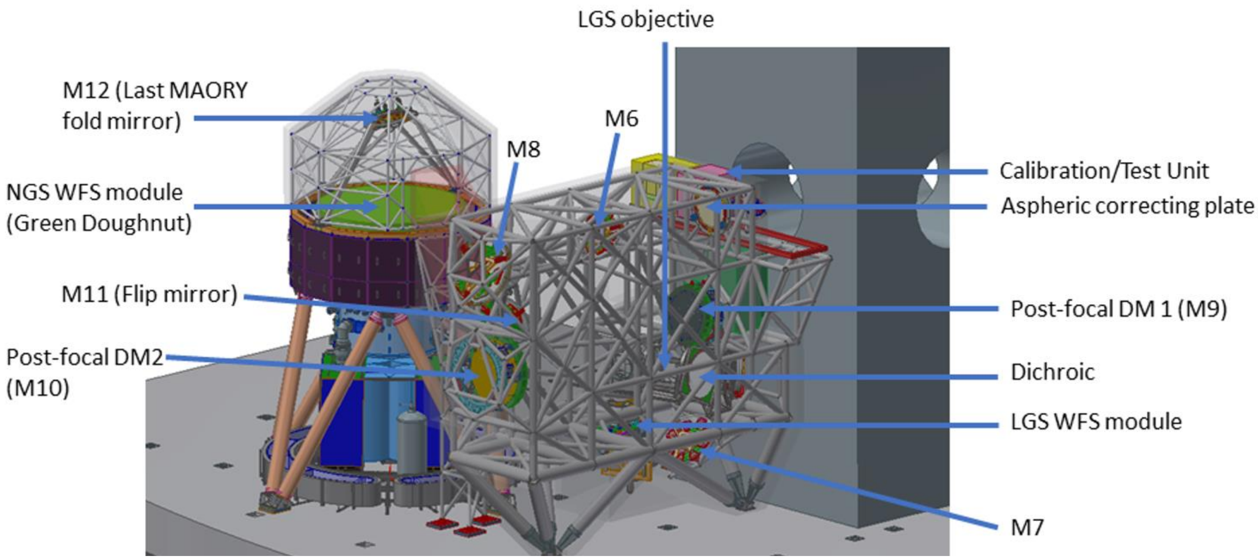

Figure 2 Morfeo schematic view

The model is organized in a fractal way. From Figure 2 is possible the context as entry point. Then at System level are modelled:

- Requirements
- Structure
- Use cases
- Analysis

This approach is then replicated inside each subsystem, and potentially could be replicated in lower levels. The interface management is kept at system level as imply agreement between subsystems

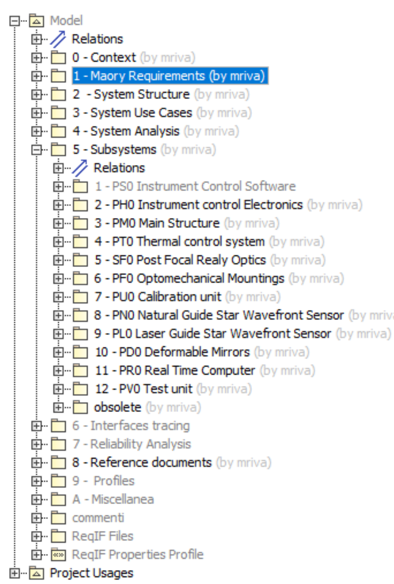

Figure 3 Backbone of the System model

The modeling of the context shown in Figure 4 has been the very first step to identify all the relation of the Modeled system (Morfeo) with the other systems (stakeholder and environment).

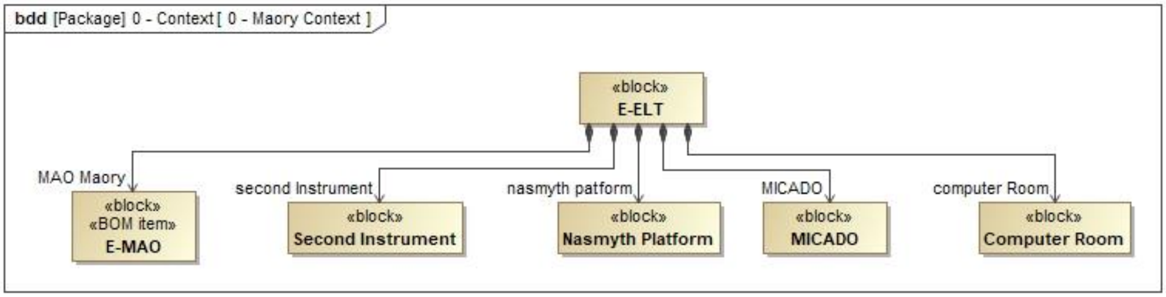

Figure 4 Morfeo context BDD

The system structure has been deployed thanks to block element at different levels. In Figure 5 is shown a typical subsystem requirement tree. The main root is made by the subsystem tech-specs. The main root branches out to subsystem requirements of different type:

- Physical
- Functional
- performance
- operational
- interfaces

This root branches also to set of requirements like the one derived by ESO documents (dark pink block in Figure 5).

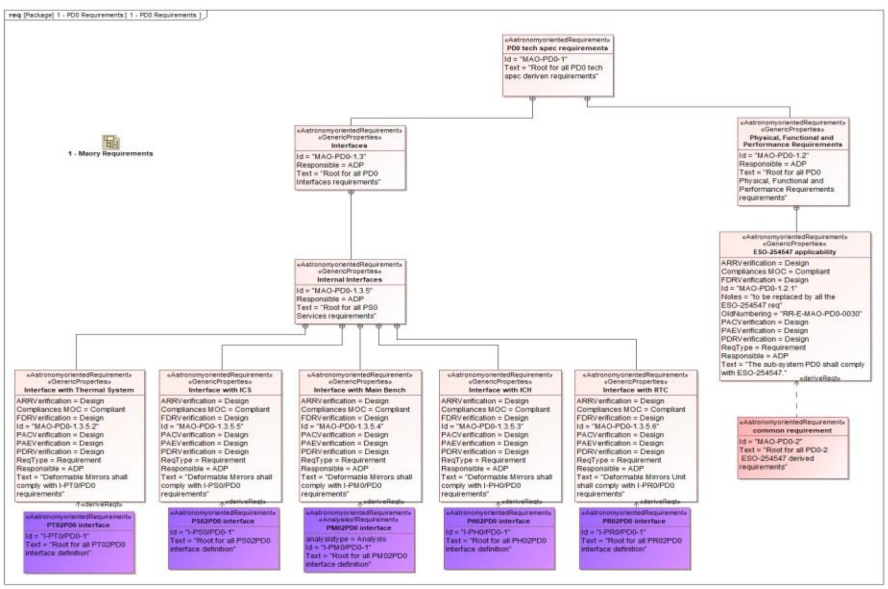

Figure 5 subsystem req tree

In order to define proper procedures and keep control of the relevant activities to be done on MORFEO, four main families of use cases have been defined.

- AIV
- Calibrations
- Operations

- Maintenance

This organization is applied to the instrument and in the same way to the subsystems.

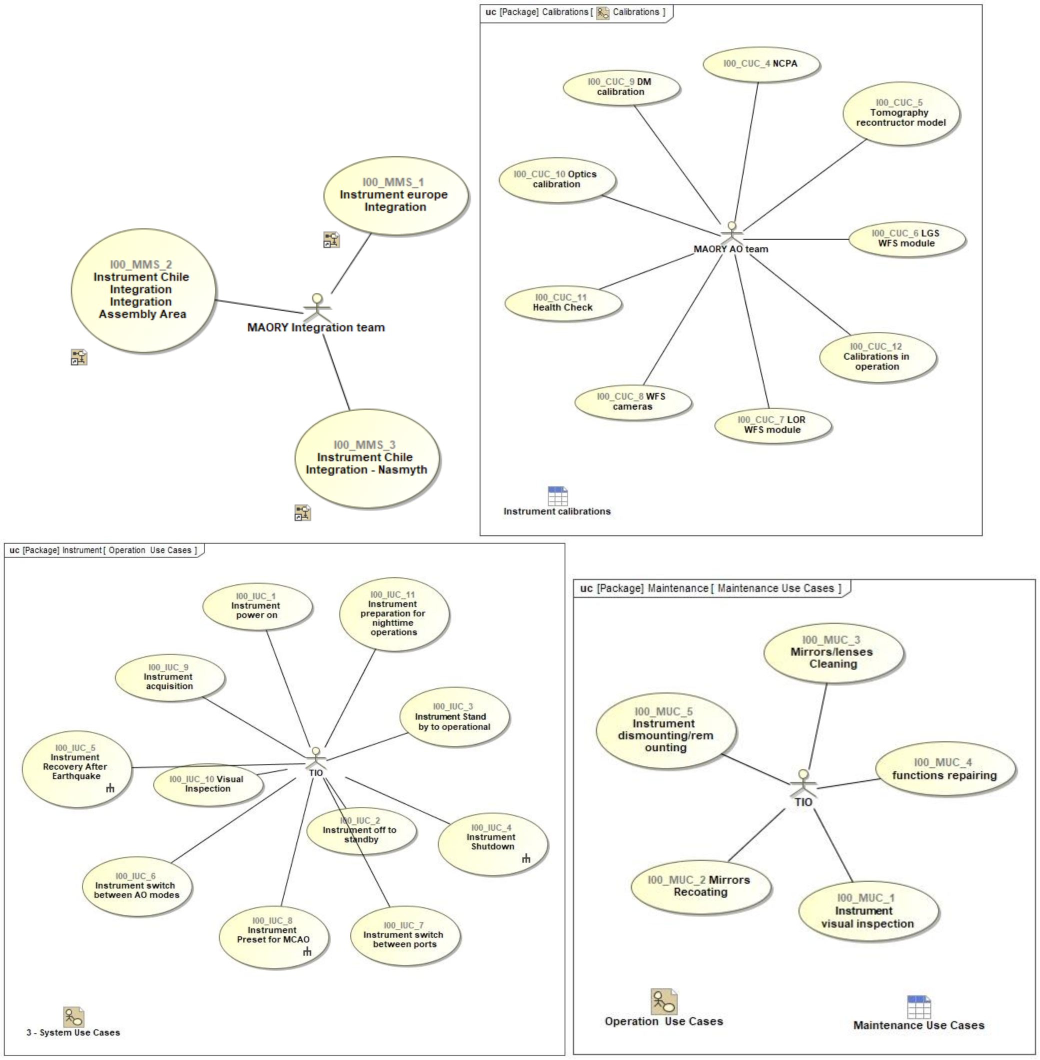

Figure 6 MORFEO use case diagrams: AIV (top left), Calibration (top right), Operation (Bottom left), Maintenance (bottom right)

In Figure 7 are schematized all the external interfaces of Morfeo.

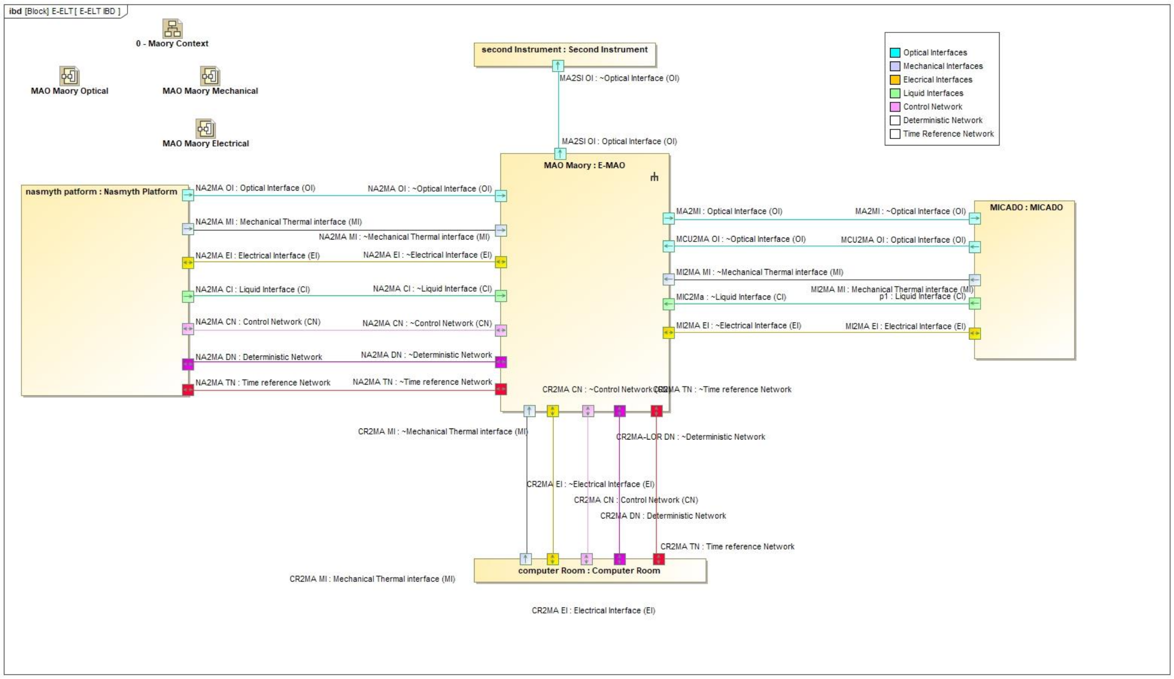

Figure 7 Morfeo External Interfaces

5. PLATO CAMERA: SPACED BASED USE CASE

In the case of PLATO, external support has been given to software engineering team of the Camera subsystem (in particular Francesco Santoli and Giacomo Dinuzzi).

In the context of PLATO Camera Subsystem development, it has been decided to take advantage MBSE methodologies using Enterprise Architect by Sparx Systems as tool. The choice of EA relied also on the fact that the same tool has been used by ESA to develop the main PLATO mission model. In particular, focus has been put on the interaction between the model and the Engineers of the different domains (i.e. not System Engineers) who may not be proficient in SysML and/or may find it unsuitable for their work. On the other hand, Excel templates are widely used and accepted in the Engineering community and are therefore well accepted. For this reason, we developed a so called “Excel Profile” to import data to the model from Excel templates. Another Excel profile allows then the export of data realizing the role of the SysML Model as “Single Source of Truth”.

A Local SysML Camera model for PLATO mission has thus been built from different Excel spreadsheets, i.e. Verification Control Matrices, released by Subsystem teams during CDRs. In this framework, a dedicated Excel template provided by ESA has been used in order to match “ad hoc” profile created to import VCMs into the model. Same approach has been used for the Camera-System itself. From PLATO Camera Subsystem perspective, fields of main interest to be considered are Requirement ID, Requirement Text, Verification Method, Statement of Compliance, Test Block, Execution and Reporting Document. The Excel Profile also allows to define information about “connectors” i.e. to describe relations among objects in the SysML model. The complete flow-down of requirements from System to Subsystem level has been created in order to easily identify and monitor any impact on the design due to changes, deviations and non-compliances, e.g. as result of manufacturing process and test performed. In this regard, a verification diagram has been developed for each requirement at System and Subsystem level by taking into account proper relationships between parent and child requirements, verification documents across external link to Eclipse and Confluence, and requirement deviations raised, i.e. RFDs-RFWs. This is an iterative process constantly evolving during the development of the project; indeed, Verification Control Boards are still on-going and consequently diagrams will change based on further discussions.

The model can be updated at any time importing Excel spreadsheet while it can be used as source to export documentation needed during formal reviews, both as Word and Excel files. One of the key points is the flexibility of the tool given that custom scripts can be implemented based on project phase needs. In particular, a series of JavaScript scripts have been developed to organize the model adding functionalities that are not present in the EA Excel import mechanism. More functionalities are foreseen to be added as the need arise.

In addition, Model architecture and constraints have been created through Block Definition Diagram and Internal Block Diagram so that structure, external and internal interfaces as well as interaction including Flow Properties between different items, can be easily identified and monitored at both System and Subsystem level particularly when design is affected by deviation raised from suppliers.

All the information needed to keep under control System model design and feasibility at different stages of the project are thus collected together within a single place: the EA SysML Model. The EA Model is based on EA toolbox version 3 and can be integrated with PLATO mission main SysML model developed and maintained by ESA. Work is in progress to streamline the process of integration of the models.

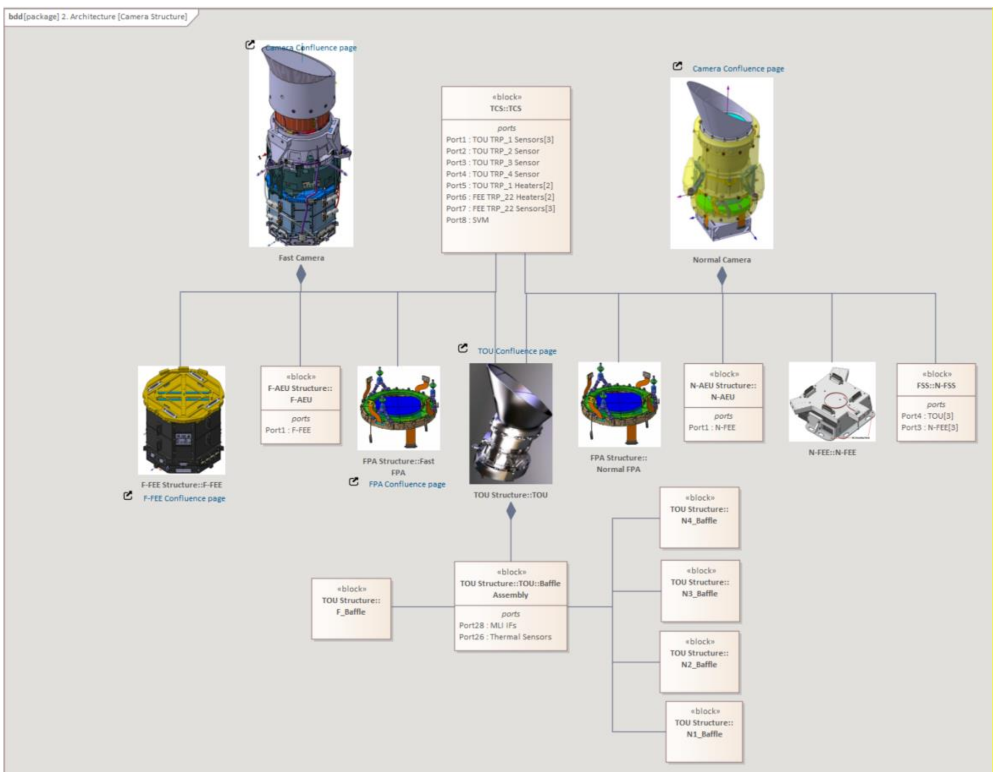

Figure 8 PLATO Camera Architecture

6. CONCLUSIONS

With this activity which is transversal to the whole INAf community, we are offering a permanent service within the System engineering department of INAF. We are developing standard to be used within the community gathering heritage from senior System engineering offered to everyone.

Having a flexible approach, we are able to provide MBSE related support, almost independently from the tools adopted by different projects. Considering both ground and space based, and forcing the two members to confront, we aim also to find some commonalities that could be useful for the definition of MBSE for any kind of astronomical instrument.

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