MOSAIC on the ELT: Front-End and instrument AITV planification

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ABSTRACT

MOSAIC is the Multi-Object Spectrograph for the ESO-ELT (European Southern Observatory-Extremely Large Telescope). The Laboratoire d'Astrophysique de Marseille (LAM) is in charge of the "Assembly, Integration, Test and Verification (AIT/V)" activities for both the Front-End channel level and the instrument level in Europe (LAM) and at the Telescope. AITV for AO instruments, in laboratory as well as at the telescope, always represent numerous technical challenges. We already started the preparation and planning for the Front-End and instrument AIT activities, from identification of needs, challenges, risks, to defining the optimal AIT strategy.

In this paper, we present the state of this study and describe the MOSAIC AITV organization, give an overview of the Front-End and the Instrument MAIT flows. We also describe the visible and near-infrared channels MAIT flows as well as the different AITV responsibilities during the AITV phases both in Europe and in Chile.

Keywords: Extremely Large Telescope, Multi-object spectrograph, ELT-MOS, MOSAIC, AITV.

1. INTRODUCTION

LAM is highly involved in the development of ELT instruments: for example, as the PI of MOSAIC [1], the ELT Multi-Object Spectrograph [2] which will tackle several important aspects of contemporary astrophysics from resolved stars up to the most distant galaxies or still, as deputy-PI of HARMONI [3], an ELT visible and near-infrared integral field spectrograph (IFS).

The MOSAIC scientific and technical teams have recently revised the phase A conceptual study and proposed a new viable architectural design concept in terms of optical, mechanical and electronic designs, fiber cabling, VIS&NIR [4, 5] spectrographs, as well as a Ground Layer Adaptive Optics (GLAO) system [6] for image correction. The project was approved to start the Preliminary Design phase in early 2023 and has passed recently its System Requirement Review (June 2024).

In this framework, the Laboratoire d'Astrophysique de Marseille (LAM) is responsible of defining the front-end channel & instrument-level assembly, integration, tests and verification (AIT/V) activities, both in Europe and at the telescope in Chile.

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In this work, we first briefly introduce the MOSAIC instrument (capabilities, concept and systems, development timeline) and present the front-end channel (main functions and sub-systems). Then, we describe the front-end and instrument AITV activities (AITV organization by channels) and present preliminary MAIT flows. We also discuss some preliminary thoughts on integration strategies that take into account sustainable development aspects [7].

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2. MOSAIC OVERVIEW

ESO is building the 39m telescope (ELT), the world's largest eye on the sky which will be operational around 2028. Then, and in order to exploit the signal collected by the telescope, advanced and various instruments (cameras, spectrographs) will be needed: as such, four first generation instruments (HARMONI, METIS, MICADO, MORFEO) and 2 others following are planned (ANDES, MOSAIC).

MOSAIC is built on the legacy of earlier ELT instrument concept studies, OPTIMOS-EVE [8, 9], OPTIMOS-DIORAMAS [10] and EAGLE [11, 12], leading to a versatile Multi-Object Spectrograph combining fibers, Integral Field Unit and adaptive optics (Ground Layer) and using the full resolution of a 39 m telescope for a sensitivity never seen before. With such characteristics, MOSAIC will be the most powerful instrument in the world to address many astronomy and cosmology science cases [1]. Also, MOSAIC design inherits mainly known instruments, as for example, MOONS [13] for its near-infrared channel or still 4MOST for the visible one [14].

MOSAIC capabilities

As a summarized in Figure 1, MOSAIC will use the widest field-of-view provided by the ELT (credit ESO) and three observing modes: Multi-Object Spectroscopy in the visible (MOS-VIS) and infrared (MOS-NIR) as well as multi-Integral Field Unit (multi-IFU) capability.

Figure 1. MOSAIC observing parameters. MOS mode includes VIS and NIR bands

As illustrated in Figure 2, MOSAIC will have three operating modes that permit observations for more than a hundred sources simultaneously.

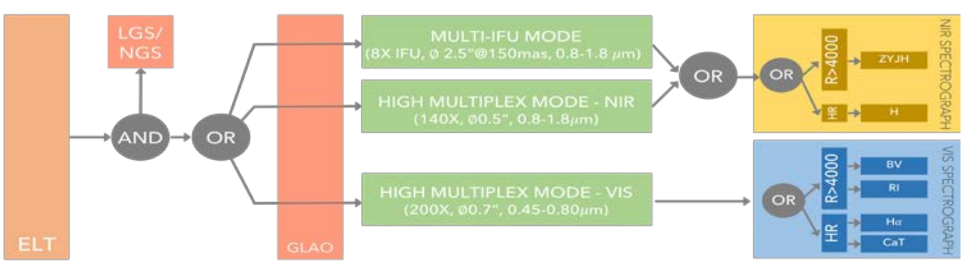
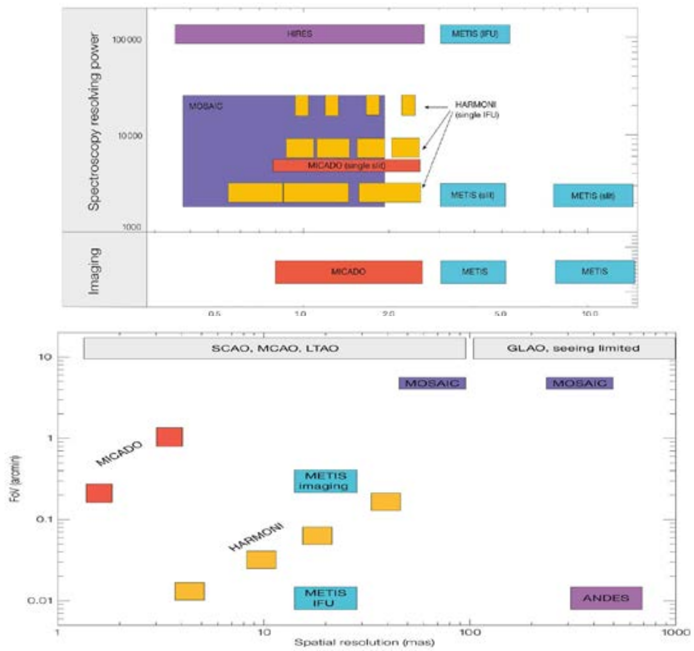


Figure 2. MOSAIC observing modes both in the visible and Near-Infrared ranges.

MOSAIC in the ELT instruments landscape

As shown the Figures below, illustrating the observing parameters space, MOSAIC is compared with other ELT instrument and presents very high performances with:

- Unique spectral coverage & spectral resolution, as shown in Figure 3 (a).
- Unique Field-of-View & spatial resolution, as shown in Figure 3 (b).



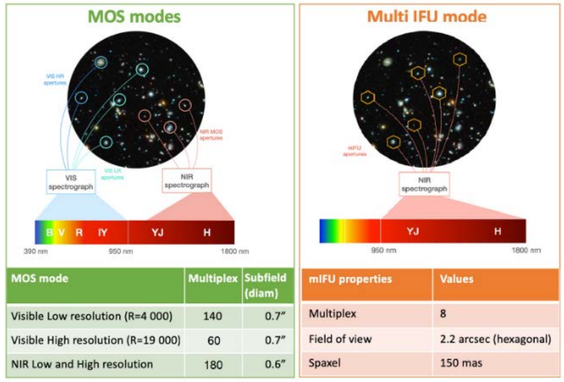
(a) (b)

Figure 3: MOSAIC spectral coverage and spectral resolution (a) and MOSAIC Field-of-View and spatial resolution (b).

MOSAIC concept

The figures below illustrate the MOSAIC concept using three observational modes:

- Figure 4 (a) showing two MOS modes:
  - The MOS-VIS (0.39-0.95 µm) mode will provide integrated spectra for ~140 objects at the same time in a single shot. The spectra will be obtained using on-sky apertures of diameter 0.7 arcsec, with spectral resolving power R>4000. Alternatively, it will possible to observe ~60 (goal 65) objects at higher spectral resolution R~19000 within four narrower windows of specific interest.
  - The MOS-NIR (0.95-1.8 µm) mode will provide integrated spectra for ~180 objects at the same time in a single exposure. The spectra will be obtained using on-sky apertures of diameter 0.6 arcsec, with spectral resolving power R>4000. Alternatively, it will be possible to observe ~180 at higher spectral resolution R~18000 within one narrower window of specific interest.
- Figure 4 (b): the mIFU mode will offer Integral Field Units for parallel observations of up to 8 extended objects, covering the same wavelength range as the MOS-NIR mode. The individual FoV of each IFU will be ~2.2 arcsec in diameter, with hexagonal shape. Each spaxel (also hexagonal) will be 150mas on-sky, providing coarser spatial resolution compared to HARMONI, but optimized to reach higher surface brightness sensitivity for faint extended sources.



(a) (b)

Figure 4. Main parameters for: both MOS-VIS and MOS-NIR observing modes (a) and for multi-IFU observing mode (b).

MOSAIC instrument overview

The Figure 5 shows an optomechanical overview of MOSAIC actual design with three main channels (systems):

- The Front-End channel, itself made from five sub-systems (see paragraph 3).
- The VIS channel containing the visible spectrograph and corresponding fiber links (high and low resolution)
- The NIR channel with two near infrared spectrographs and &multi-IFU fiber links.

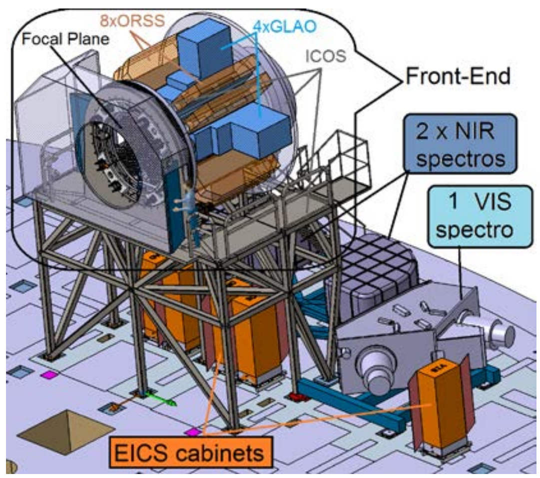


Figure 5. Optomechanical view of MOSAIC on ELT platform with 3 main blocks: Front-End, containing five sub-systems (Calibration Unit not represented, see paragraph 3 for details), two NIR spectrographs and one VIS spectrograph. EICS (electronics) cabinets are also shown.

MOSAIC development timeline

The Table 1 summarizes the actual instrument development timeline the main ESO milestones.

ESO milestones	Planned dates	Comments
Kick-off	Q1-2023	MOSAIC was agreed to start the Preliminary Design phase. The project has passed recently its System Requirement Review (June 2024)
SAR	Q1-2024	Specification Architecture Review to freeze the baseline for design
PDR	Q4-2025	Preliminary Design Review
FDR	Q4-2028	Final Design Review
MAIT	Q4-2031	Manufacturing, Assembly, Integration and Test phase.
PAE	Q4-2032	Preliminary Acceptance in Europe
PAC	Q4-2034	Preliminary Acceptance in Chile

Table 1. MOSAIC actual timeline

3. FRONT-END OVERVIEW

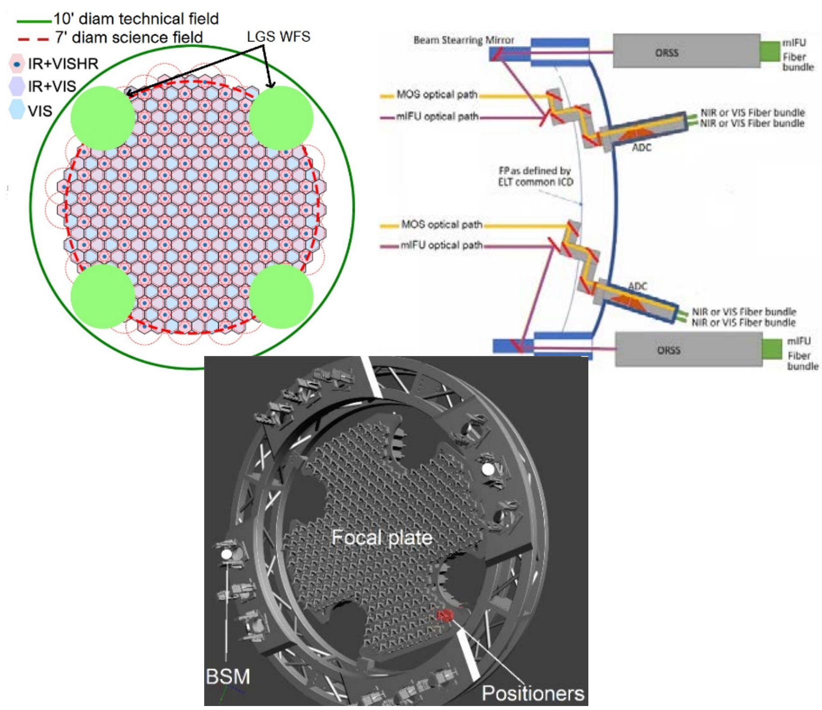
3.1 Front-End Sub-Systems

The MOSAIC Front-End channel is a system extending from the acquisition of the light of the target objects in the focal plane, its shaping and correction until its delivery to the fibers feeding the spectrographs. It contains five sub-systems:

- FP - Focal Plane: acquires the field with 300 positioners and relays to ORSS with 8 BSM (Beam Steering Mirrors)
- ORSS (x8) - Optical Relay Sub-System: adapts for the mIFU NIR optical path length
- GLAO (x4) - Ground Layer Adaptive Optics: ensures guiding with NGS (Natural Guide Star) and wavefront sensing with LGS (Laser Guide Star).
- CALEMOS: provides flat and spectral illumination for instrument daytime calibration.
- ICOS - Instrument Core Structure: constitutes the main instrument structure (Static Structure Module + Rotating Structure Module) and holds all the other sub-systems along with cables, optical fibers and cooling pipes.

In order to satisfy the different observing modes described above, the MOSAIC target object acquisition is made from a stepped and tiled focal plane design to compensate for the telescope non-telecentricity:

- Figure 6 (a): 300 tiles (100 for VIS, 100 for NIR+VIS and 100 for NIR+VISHR) are placed in the focal plan to pick-up the light from the target and feed ~500 fiber bundles to transport it to the spectrographs. The overall MOSAIC wide field-of-view allows about 7' diameter for science and 10' diameter for technical fields.
- Figure 6 (b): In the details of the optical architecture, at the focal plane, the light is picked-up by either microlens-fiber or mirror, then:
    - The mIFU mode is probed using a Pick-Off Mirror (POM) & Beam Steering Mirror (BSM) and an optical relay (ORSS) to re-image on a microlens array/fibers that will feed the spectrograph using mIFU fiber bundles.
    - The MOS modes are directly probed by microlens/fibers. This arm includes an ADC (Atmospheric Dispersion Compensator) through NIR or VIS fiber bundles.
- Figure 6 (c): Opto-mechanical of the focal plan illustrating the focal plate holding 300 positioners and the beam steering mirrors (BSM) to direct the light toward optical relays for multi-IFU operation.



(a) (b) (c)

Figure 6. (a) Focal plane design showing 300 tiles (100 blue + 100 purple+ 100 dotted pink), Laser Guide Star footprint (green). (b) illustration of the MOS (with AC) and mIFU (with BSM and ORSS) optical paths. (c) Opto-mechanical view of the designed the focal plan.

3.2 Front-End functions

The main front-end functions are to:

- Ensure Field Acquisition (provided by GLAO & ICOS)
- Pick-off light from multiple subfields of the instrument FoV (provided by Focal Plane & ORSS)
- Maintain target position within pick-off apertures during exposure (provided by ICOS, GLAO & Focal Plane).
- Increase ensquared energy within sub-fields (provided by GLAO).
- Move sky position on subfields during observations (provided by Focal Plane & GLAO).
- Illuminate science path with calibration light (provided by CALEMOS).
- Minimize sources of external light contamination (provided by all).

4. FRONT-END AIT

The front-end AIT (Assembly, Integration and Test) is one of the most challenging in MOSAIC. Indeed, this channel concentrates some of the main functions of the instrument, with numerous sub-systems and interfaces to manage, leading to a number of technical challenges.

For the current baseline, a preliminary MAIT flow for the front-end is shown in Figure 7 where the main steps are:

- Manufacturing, Integration, Verification and Acceptance of:
    - Each sub-system [ICOS, ORSS, Focal Plane (including Focal plate, Positioners & BSM), GLAO, CALEMOS).
    - + all EICS cabinets (electronics SW & HW) for different sub-systems.
    - + all Fiber Links (VIS, IFU and NIR).
- Front-End Integration, Verification and Acceptance at LAM with

- o All Interfaces Verification.
- o Functional test and verification.
- o Performance Verification.

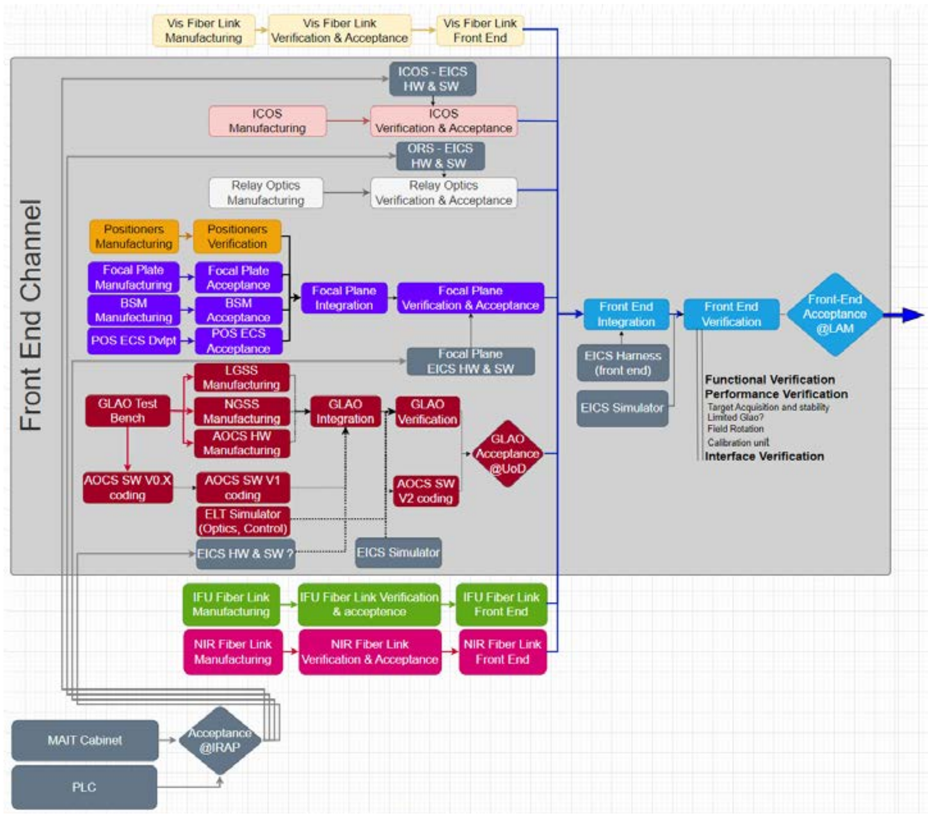


Figure 7. MOSAIC AITV organization chart (CALEMOS not represented).

5. INSTRUMENT AIT/V

The instrument AITV has been structured from instrument to channel and to workpackage levels, as shown in the MOSAIC AITV organization chart below (Figure 8) with:

- AIT (different institutes and countries in Europe)
  - o Instrument level: different AIT responsibilities (overall AIT, EICS – Electronic Instrument Control System and SSO – Science Software Operation)
  - o Channel level: Front-End AIT (at LAM, France), VIS AIT (at ASTRON, Netherlands) and NIR AIT (at UCM, Spain).
  - o Workpackage level: at different institutes (flags indicating countries).
- AIV in Chile.

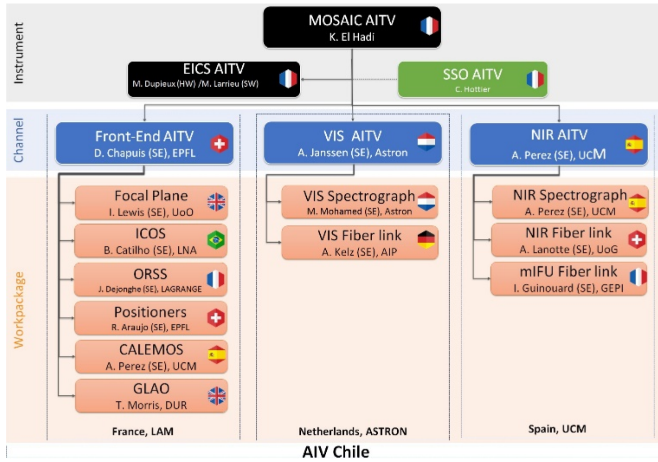


Figure 8. MOSAIC AITV organization chart.

Hereafter, we remind the different level responsibilities and places for AIT/V activities:

- **AIT in Europe (LAM-France)**
  - Sub-system level (responsibility of WP / takes place at the WP institute)
    - Component testing
    - Assembly and testing of all sub-assemblies, assemblies, modules, sub-systems and systems
    - Sub-system Test and Verification Tools (STVT) validation,
    - Sub-System delivery to channel place, with their associated STVT
    - Participation to integration and testing of the sub-system at system place
  - System / channel level (responsibility of LAM-France for front-end, ASTRON-Netherlands for VIS and UCM-Spain for NIR)
    - Assembly and testing of different sub-systems/systems
    - System functional and performance validation
    - Participation to integration and testing of the system at instrument level in Europe and in Chile
  - Instrument-level AIT (responsibility of LAM-France)
    - Integration of systems into the instrument structure, interface validations
    - Functional testing of the system within the instrument
    - Functional testing of the instrument
    - Performance verification of the instrument
    - Instrument dismounting (as parts or assembled modules when possible)
    - Instrument shipping to Chile (with respect of ESO standards: size, Nasmyth Platform access,).
- **AIV in Chile (LAM-France)**
  - Instrument-level AIV
  - Reintegration of the instrument at the telescope
  - Functional testing of the instrument
  - Performance verification of the instrument
  - Functional testing of the instrument within the telescope system
  - Performance verification of the instrument on sky

For the actual baseline architecture, an overall preliminary instrument MAIT flow is presented below (Figure 9) with:

- VIS channel MAIT flow (preliminary)
- Front-End MAIT flow (preliminary)
- NIR channel MAIT flow (preliminary)
- Particular AIT aspect with the “Virtual MOSAIC”. The idea is to perform a number of devices test with a remote

control from three main control stations (LAM-France, UCM-Spain and NOVA-Netherlands). The possibility of this "Distributed AIT concept" is still to be demonstrated during Phase B.

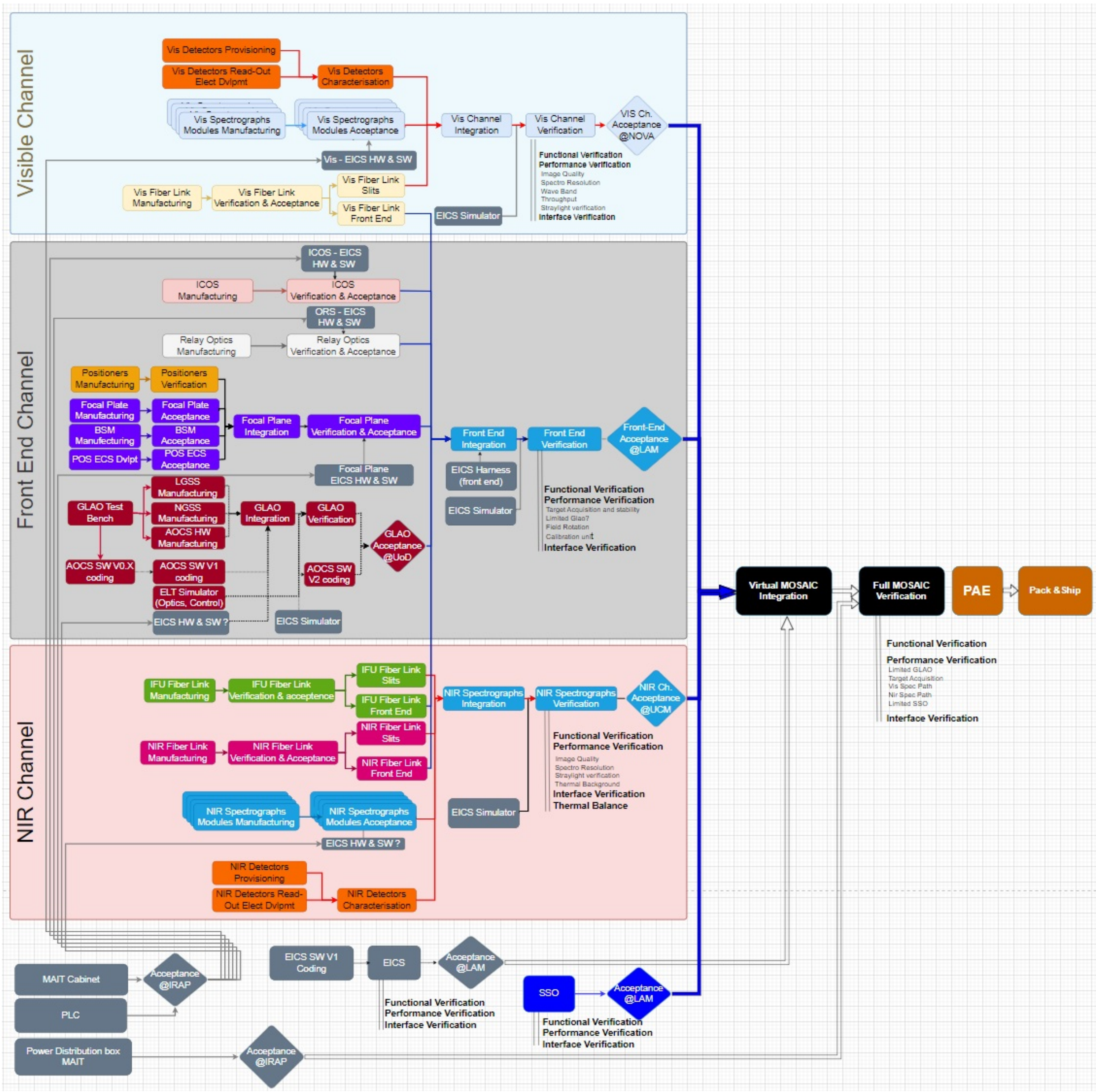


Figure 9. MOSAIC overall MAIT flow.

6. CONCLUSION AND DISCUSSION

MOSAIC concept is a heritage mainly from known instruments such as MOONS (for its NIR part) or still 4MOST (for its VIS part), both instruments are now ahead of commissioning. Therefore, it presents no technological lock, except the complexity of the focal plane, with the positioner robots (~300). But the MOONS front-end constitutes a real (small size) prototype of MOSAIC's one with a number of lessons to take from (900-1000 motors, cable wrap, fibers and cables routing, AIT tools, etc.)

To build MOSAIC, the consortium has a long expertise in building high multiplex/high definition instruments based on the same concepts (IFU, Seeing limited, GLAO) such as: FORS@VLT, FLAMES@VLT, MOONS@VLT, WEAVE@WHT or still GIRAFFE@VLT, KMOS@VLT and MUSE@VLT.

To lead the MOSAIC AIT/V activities, LAM has all the required facilities, tooling and manpower to perform the AIT work with a new ELT integration hall, state-of-the-art equipment, high technical skills and, in particular, a long experience and expertise in leading AIT/V activities for different (space and ground) projects, including several MOS instruments or still ELT Instruments (MOSAIC & HARMONI). To perform the instrument level AIT/V, LAM has presented (Phase A) and is still investigating few scenarios.

In this paper, we have presented and overview of the instrument concept and its systems with a focus on the main one: the front-end on which the instrument's performance is mainly based. For the actual baseline architecture, preliminary MAIT flows for the MOSAIC front-end, VIS, NIR and instrument were also presented. This work will be further developed during phase B.

On the other hand, knowing that:

- MOSAIC has requirements from ESO to estimate and reduce the carbon footprint of its development.
- MAIT can be responsible for 40-60% (average estimate from various space and ground instruments development) of this impact, because these phases are very consuming in human resources, team trips, number of tests on the different elements, etc.

we have already started to think about environment oriented strategies during MAIT and AIV phases, such as:

- Distributed AIT concepts where a number of devices test is made by a remote control from different places. The possibility of this concept will be demonstrated during Phase B.
- When technically possible, the different parts should be always shipped pre-assembled (sub-systems to systems, systems to instrument, instruments parts to telescope).
- Shipping mode (air, sea, train), always when possible, should be optimized.
- In Chile, AITV strategies should optimize time to re-build and resources.

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