The MUSE Project Face to Face with Reality

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ABSTRACT

MUSE (Multi Unit Spectroscopic Explorer) is a second generation instrument built for ESO (European Southern Observatory) to be installed in Chile on the VLT (Very Large Telescope). The MUSE project is supported by a European consortium of 7 institutes.

After the critical turning point of shifting from the design to the manufacturing phase, the MUSE project has now completed the realization of its different sub-systems and should finalize its global integration and test in Europe.

To arrive to this point many challenges had to be overcome, many technical difficulties, non compliances or procurements delays which seemed at the time overwhelming. Now is the time to face the results of our organization, of our strategy, of our choices. Now is the time to face the reality of the MUSE instrument.

During the design phase a plan was provided by the project management in order to achieve the realization of the MUSE instrument in specification, time and cost. This critical moment in the project life when the instrument takes shape and reality is the opportunity to look not only at the outcome but also to see how well we followed the original plan, what had to be changed or adapted and what should have been.

Keywords: MUSE instrument, project management, development, PBS, WBS, IFU, Integral Field, 3D spectroscopy,

1. INTRODUCTION

Since March 2009 and a successful Final Design Review (FDR), the MUSE project has started the most critical phase of its development which is the Manufacturing Assembly Integration and Testing (MAIT) Phase. This phase will be punctuated by the Preliminary Acceptance in Europe (PAE) and followed by the Preliminary Acceptance in Chile (PAC) occurring after installation and commissioning of the instrument on the Nasmyth platform B of the VLT Unit Telescope 4 (UT4).

2. RECALL ON THE ORIGINAL GOALS AND 2010 STATUS

As the aim of this paper is to give an update on the project and compare the real progresses with regards to the expected ones, it is worth recalling what was the goals and status presented in 2010 in our previous paper "The MUSE Project from the dream towards reality" [1]

2.1. MUSE Instrument Original Dreamed Performance

MUSE is an innovative Integral Field Spectroscope which has been imagined to enable direct spectroscopic exploration of the universe and beside many other scientific cases the study of the progenitors of normal nearby galaxies out to high redshift. As described in R. Bacon et al. paper "Probing unexplored territories with MUSE" [2] the tremendous scientific potential of MUSE instrument is based on crucial and of course very challenging top level specifications which are given hereafter:

- **Wide & Integral Field of View**
  - 1×1 arcmin² in Wide Field Mode (WFM)
  - 7,5x7,5 arcsecond² in Narrow Field Mode (NFM)
  - Integral Field of View (FoV) with less than 5% field loss
- **High Spatial Resolution**
  - 0.19 arcsecond² spatial sampling in WFM
  - 0.025 arcsecond² spatial sampling in NFM
- **Broad Spectral bandwidth**
  - Large visible and near IR spectral range from 465 to 930 nm of wavelength
- **High Spectral Resolution**
  - R1750 at 465 nm up to R3750 at 930 nm
- **High Efficiency**
  - From 20% of minimum average transmission in NFM for 465- 570 nm wavelengths
  - To 40% in WFM for 600- 800 nm wavelengths

One shall note that the high spatial resolution can only be achieved when using the associated ground layer adaptive optics system named GALACSI which is developed by ESO as part of the VLT Adaptive Optics Facility (AOF).

2.2. MUSE Instrument Expected Performance In June 2010

After the Design phase in 2010, the MUSE design presented was not only fully compliant with its specified functionalities such as FoV and spectral range but had also comfortable margins:

- 24% to 41% in image quality, thus ensuring spatial and spectral resolution
- 4% to 17% in throughput, thus ensuring limiting magnitude sensitivity
- No field loss
- Less than 25% light loss on only 17% of the pixels

The MUSE performance is given by its optical scheme (See Figure 1) as the results of individual sub-systems and critical components performance. In 2010 the numbers provided were mostly based on the Integral Field Unit (IFU) measurements, the other sub-systems performance being calculated.

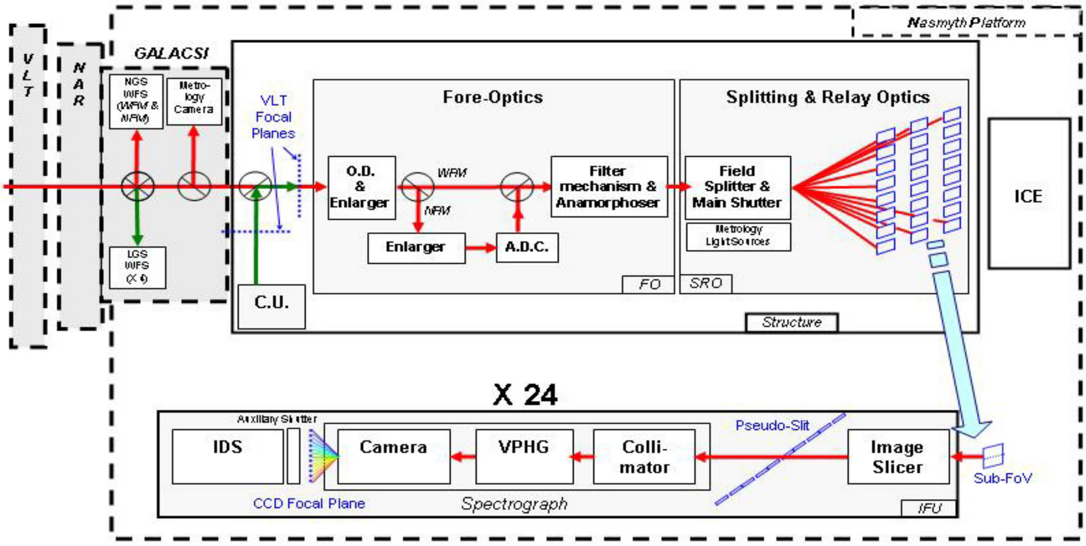

Figure 1: MUSE Optical Schematic

2.3. Initial Resources To Complete The Project

- **Manpower**
  - 180 Full Time Equivalent (FTE) or Men-years of total manpower was estimated at MUSE Kick off
  - Skilled staff from MUSE Consortium (See Figure 2) to take in charge the different tasks of different competencies
- **Budget**
  - Initial instrument hardware cost estimate of ~8,4 M€
  - MUSE Total Budget of 4,985 M€ for the instrument hardware without the Instrument Detector System (IDS)
  - Additional direct participation of ESO with the hardware delivery of the IDS
  - Additional funding of national agencies to support the different institutes in their participation

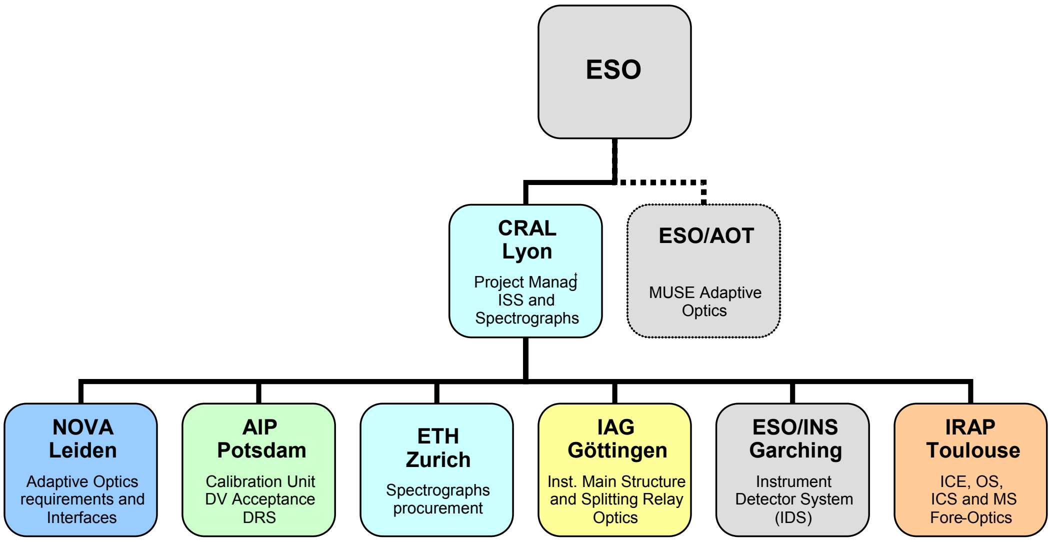

Figure 2: MUSE Consortium Organization

2.4. MUSE Manpower & Financial Status In June 2010

- **Manpower**
  - 104 men-years were already spent and 54 were foreseen to be needed to complete the instrument.
  - The total expected manpower was therefore estimated to 158 which gave at that time some margin compared to the 180 initially expected.
- **Budget**
  - The cost spent/engaged was 2,4 M€ with a remaining foreseen of 2,4 M€
  - The contingency for risks was evaluated to 300 k€
  - The total expected cost was therefore 5,1 M€ with contingency and 4,8 M€ without

Globally the manpower & financial situation of the project was pretty good. The risk of budget overrun needed to be followed but wasn't critical.

2.5. The Initial Schedule And Status in June 2010

Is given hereafter the main contractual milestones of the project indentified at the time of the signature in July 2006 versus the real review dates or updated expected date at the time with an (*).

Milestone	Planned Date	2010 Status
Optical Preliminary Design Review (OPDR)	-	July 2006
Preliminary Design Review (PDR)	January 2007	July 2007
Optical Final Design Review (OFDR)	-	December 2007
Final Design Review (FDR)	July 2008	March 2009
MAIT Progress Meeting 1	July 2009	Feb 2010
Preliminary Acceptance Europe (PAE)	July 2011	January 2012*
Preliminary Acceptance Chile (PAC)	December 2012	December 2012*
Final Acceptance	December 2014	December 2014*

Table 1: MUSE Planning in June 2010

In June 2010, already an eight months delay was acknowledged. This delay was foreseen to be reduced by 2 months for PAE and completely catch-up for PAC.

3. PROJECT ORGANISATION EVOLUTION

3.1. INITIAL PROJECT ORGANIZATION

The initial organization of the MUSE Project was based on one hand on the consortium members' expertise and competencies and on the other hand on the detailed needs of tasks to be performed. This organization has then been built on the main following principles. As for the 2010 status some more detail on the project organization are available in our previous paper [1].

- **A Product Breakdown Structure (PBS)**
  Defining the different sub-systems and associated responsible institute (See Figure 3)
- **A Work Breakdown Structure (WBS) for the Design Phase and MAIT Phase**
  Defining the work packages & tasks to be performed, associated responsible institute, manpower and costs (See Figure 4 & Figure 5)
- **A Project Office**
  Addressing the global tasks and performance of the instrument
- **7 Local Project managers**
  Addressing the tasks and performance of their associated sub-system
- **An Internal Development Process**
  Defining validation reviews from design to manufacture and test at the system and sub-system level.

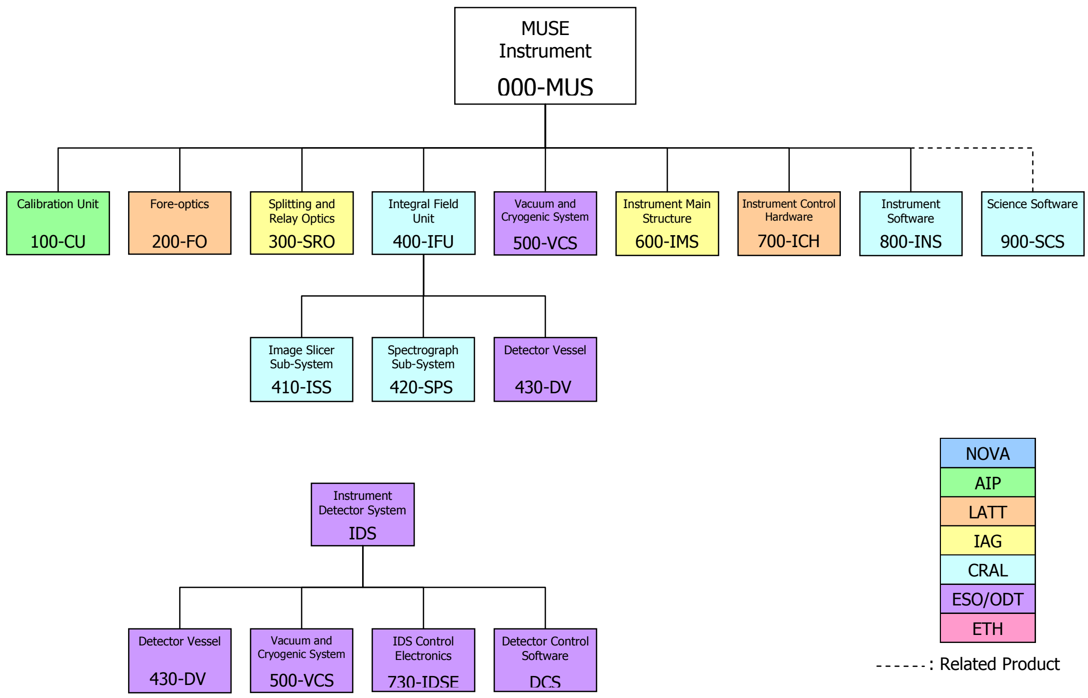

Figure 3: MUSE Product Breakdown Structure

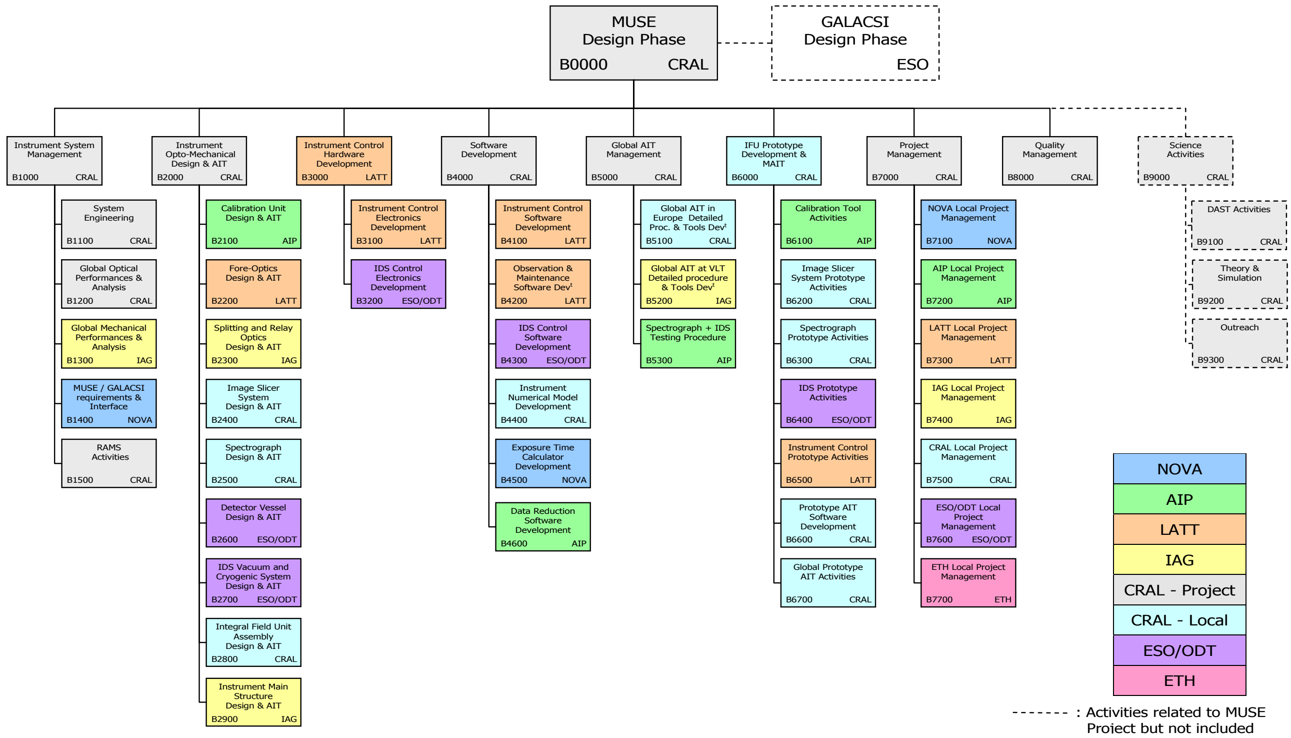

Figure 4: MUSE Design Phase WBS

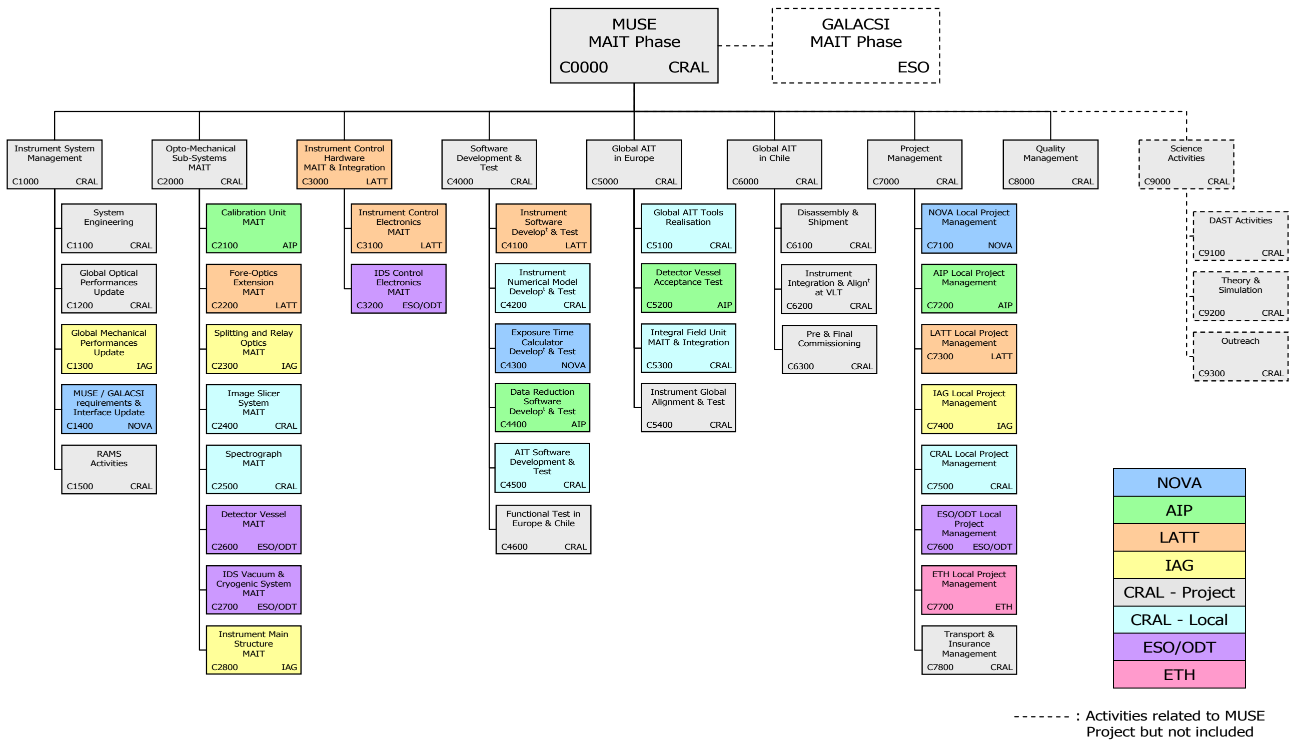

Figure 5: MUSE MAIT Phase WBS

3.2. GLOBAL AIT A CHANGE OF PARADIGM

In September 2011, the MUSE Project had to face an important turning point in the MAIT phase. This important milestone was the shifting from sub-system AIT to the global system integration and test. This evolution had many consequences on the AIT conditions which are listed below:

- All activities are converging toward one point : CRAL integration Hall
  - All sub-systems are delivered on the same integration site, same building
  - One location but multiple simultaneous actions going on
  - The number of interactions and risk of conflicts is therefore increasing
- Participation of different teams of different institute to common tasks
  - Sub-systems Institute's Teams
  - Global Integration Technical Staff
  - The Project Office
- More Stressful Working Conditions
  - Home straight to PAE (final step) but a long lasting finish
  - Stronger Pressure (Almost every task becomes critical)
  - Shrinking of time scales

This change in AIT conditions was a real challenge which required also a change in our ways of working and ways to address problems and goals. The following challenges and associated necessary evolutions were identified as following:

- To pass the PAE in performance and schedule
  - To converge in direction of one common and global goal
  - To change from a sub-system focus to the whole system and its integration steps.
  - To include and rely on all competent staff
- To manage the integration on different time scales
  - Unforeseen events / Day to day organization
  - Important decisions & mean term organization ~2/3 weeks
  - Follow-up, preparation and strategy up to PAE
- To keep up motivation and efficiency
  - Maintain everyone informed and working synchronized
  - Allow flexibility while still staying organized
  - React quickly but in proportion

3.3. A NEW ORGANIZATION FOR GLOBAL AIT

To address the new challenges and necessary evolutions given above a change in the project organization was clearly necessary. But at first glance some of the goals would appear opposite: to address short and long time scale, to focus on the whole system but also on some specific integration task… The initial organization had also no real reason to be completely renewed as most of the instrument and sub-system performance responsibilities remained unchanged.

What appeared was that a dedicated organization was then necessary to address the new needs of global AIT but the main project organization based on sub-systems, project office and local project manager which was working well had also to be kept. At the end, the choice was therefore taken to implement a specific organization for global AIT with the following limitation:

- To address the realization of dedicate AIT task going on in the Integration Hall only
- To manage and coordinate these tasks on a short time scale (week scale)

To do so it was proposed to create autonomous AIT teams which would be supervised by a Main Instrument Coordinator and composed as following:

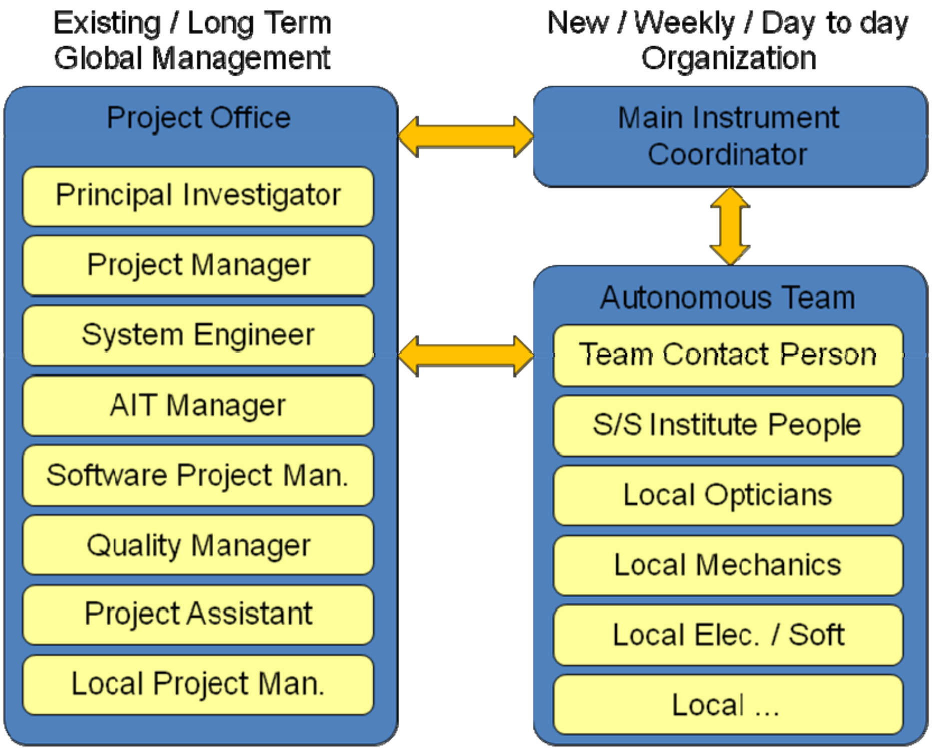

Figure 6: MUSE Global AIT organization

As suggested in the above figure, some tight communication was necessary between the teams and not only the Main Instrument Coordinator (MIC) but also the Project Office (PO). It seemed therefore also necessary that the team would have a dedicated contact person to ease and ensure a good communication inside but also outside the team.

Autonomous teams were created and defined as following:

- Self directed teams without clearly identified manager but including a contact person
- Mission clearly set and assigned collectively to the group
- Multi-competencies, multi-institutes, multi-cultural teams
- Shall embedded all knowledge & competencies to complete the mission
- Team defined by a stable core of people…
- But can be reinforced in case of urgency or need

The designed Contact Person for the team has a specific role:

- Interact with other teams, the MIC and the PO
- To bring in local support to the team people from other institutes
- To bring in global vision / knowledge of the system
- Can be member of the PO but not preferably

Main Instrument Coordinator was given the following role and responsibility:

- Manages and supervise the different teams working on MUSE global AIT
- Control the access to the instrument from the physical and operational (Work Station) point of view as well as to the main common tools and equipments
- Organize daily points and manages the weekly planning
- To be present in the Integration Hall or always near & reachable
- Ensures (but not alone) that safety, cleanliness and quality rules are applied
- Define priorities and immediate actions in case of conflict or unexpected course of event
- Identifies & triggers the analysis & resolution of important reported problems requiring the intervention of PO or other consortium members.

At the end 9 autonomous teams with created as following:

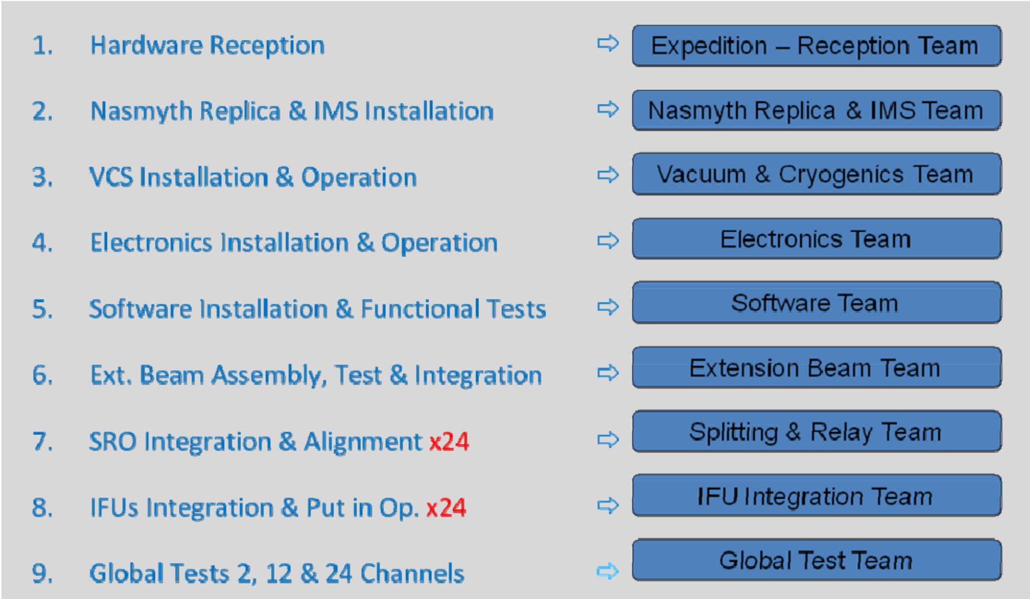

Figure 7: MUSE Autonomous Teams List

The proposed organization could then address the numerous and challenging new constrains of global AIT but one remaining drawback is to be noted. This point is related to the number of local personnel available for MUSE on the integration site which is more or less around 15. This meant that many the AIT teams had overlapping personnel and also with the project office. The consequence would be that a given team was rarely fitted to its full capacity and that some trade-offs on personnel were often to be done between teams. The risk of confusion or priority in roles was also an issue for the member of the project office.

4. 2012 OUTCOMES

4.1. Preliminary Successes

As described in the previous chapter a transition from local sub-system AIT to global AIT was quite challenging. The global AIT ramped up during summer 2011 to really start in the beginning of fall with the delivery of the most important sub-systems.

Due to missing components or failed validation items some of the sub-systems were accepted to be delivered to the CRAL but with a partial compliance. This decision was taken in order not to delay the global AIT phase. The first main target of the global AIT first phase was to obtain the instrument first calibration light in an end to end configuration on one of its 24 channels. This goal was achieved in December 2011 and was a big success for the project. As one can see in the related papers “MUSE instrument global performance test” [3] and “MUSE Optical Alignment Procedure” [4], this first step enabled the validation of a number a key performance and functionalities. This first step also enabled identifying some issues which would have to be corrected.

4.2. Some difficulties

As previously mentioned during the first phase some items were missing, some being replaced by prototypes. The second phase of the global integration and test was therefore a retrofit period to complete the instrument and solve the issues encountered during the first phase. This second phase was conducted from February 2012 till June 2012 and enabled the instrument to be partly disassembled and reintegrated with its Narrow Field Mode and with 2 more channels. Some stability issues on the relay optics were also to be solved during this period with design improvements.

4.3. Feedback on the New Organization

The new organization implemented was clearly successful in addressing the first step of the global AIT tasks. It was well fitted when many teams from the different institutes were present on the integration site. During the second step and the return of the consortium teams to their institutes some of drawbacks started to appear. The global AIT tasks were now concentrated on a limited number of people. As a consequence the role of the project office was minimized in favor of the global AIT tasks. Finding the balance between these two important roles is not a simple task. Some actions had therefore to be taken in order to re-equilibrate things and find this optimum sweet spot between short and long term, between integration, test and analysis. Nonetheless even if not perfectly optimal the project organization issues were, at the end, far from being the biggest problem …

4.4. The Hard Point

Among the different difficulties which the MUSE project had to face the most critical one is related to one specific component which is the Field Splitting Optics (FSO). This optical component has the particularity to be common to all channels and is therefore mandatory to do global alignment and test. It was initially supposed to be delivered by mid 2010 but had already been delayed once in 2011 and a prototype with 5 active channels was provided in order to start global integration.

The final complete delivery was supposed to happen in March/April 2012 but at the end of a lingering painful process nothing inside specification or up to an acceptable level of quality could be delivered. The drastic conclusion had to be drawn that a complete remanufacturing of the FSO by a new supplier was necessary.

This dramatic event had of course important consequences on the schedule and on the financial budget but moreover, it imposed a complete reorganization of the Global AIT phase. Luckily, even if limited to 5 channels and not up to specification, the FSO prototype was still useable to validate a large fraction of the instrument performance. It was therefore proposed to carry on the global integration and test phase with the FSO prototype and validate it completely as the final instrument would. The retrofit of the FSO and final re-integration and alignment would then happen after this full validation in a minimum of time.

4.5. MUSE Instrument Performance In June 2012

As shows in “MUSE instrument global performance test” [3], the preliminary results on the first channel indicate that, even if not perfectly aligned, the image quality is in into specification with a margin of 12 to 18% (regarding the different bandwidth). The 2010 expected margins of 24% to 41% could therefore still be reachable after an improved alignment. Those margins will be refined as final measurements are done.

On the throughput performance, the situation has been dramatically improved. As detailed in the paper “MUSE Optical Coatings” [5] the MUSE throughput margin increased from 4-17% to 31-70% (with regards to the different applicable bandwidths).

Final field and light loss is still to be assessed a bit later with the final FSO but is still expected to be at least as good as expected in 2010.

4.6. MUSE Manpower & Financial Status In June 2012

- **Manpower**
  - 139 men-years have been spent and 31 are foreseen to be needed to complete the instrument.
  - The total expected manpower is therefore estimated to 170
- **Budget**
  - The cost spent/engaged is 4,3 M€ with a remaining foreseen of 0,7 M€
  - The contingency for risks is evaluated to 200 k€
  - The total expected cost is therefore 5,2 M€ with contingency and 5 M€ without
  - The total project budget as slightly been increased to 5 M€

As expected the global manpower & financial situation of the project has degraded compared to 2010 situation. The risk of manpower and cost overrun is more present but is however still limited to a few percents of the global budget.

4.7. THE SCHEDULE STATUS IN JUNE 2012

Is given hereafter the main remaining contractual milestones of the project with an updated status at June 2012.

Milestone	Planned Date	2010 Status	2012 Status
Preliminary Acceptance Europe (PAE)	July 2011	January 2012	May 2013
Preliminary Acceptance Chile (PAC)	December 2012	December 2012	December 2013
Final Acceptance	December 2014	December 2014	December 2015

Table 2: MUSE Planning in June 2012

The comparison of the schedule in 2012 with the initial contractual schedule is somehow cruel. This planning status is however also the result of the balance with the need to decommission the existing instrument NACO which MUSE will replace on the UT4 Nasmyth Platform of the VLT. Today the operation of NACO had been extended by 2 periods of 6 months.

5. CONCLUSION

During the 2010-2012 period the MUSE project had to face many changes and challenges. The new organization enabled the consortium to meet the targets of global AIT and achieve a number of successes. Unfortunately the missing of a critical component has jeopardized the achievement of all our goals. Nevertheless the outcome of this period is also that MUSE is still to reach a performance which is not only well within specifications but which is expected to set a new standard in 3D spectroscopy.

At the end, this face to face with reality can be harsh on certain aspects but it also highlights the capacity and will of the MUSE consortium to overcome any obstacle which could be set in its way toward its main goal:

To provide the scientific community a unique instrument enabling
unprecedented spectroscopic exploration of the universe.

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