

ANDES, the high resolution spectrograph for the ELT: project management and system engineering approaches for mastering its preliminary design phase

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ABSTRACT

At the end of 2021, the ESO council approved the start of the construction phase for a High Resolution Spectrograph for the ELT, formerly known as ELT-HIRES, renamed recently as ANDES (ArmazoNes high Dispersion Echelle Spectrograph). The current initial schedule foresees a 9-years development aimed to bring the instrument on-sky soon after the first-generation ELT instruments. ANDES combines high spectral resolution (up to 100,000), wide spectral range (0.4 μm to 1.8 μm with a goal from 0.35 μm to 2.4 μm) and extreme stability in wavelength calibration accuracy

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(better than 0.02 m/s rms over a 10-year period in a selected wavelength range) with massive optical collecting power of the ELT thus enabling to achieve possible breakthrough groundbreaking scientific discoveries. The main science cases cover a possible detection of life signatures in exoplanets, the study of the stability of Nature’s physical constants along the universe lifetime and a first direct measurement of the cosmic acceleration. The reference design of this instrument in its extended version (with goals included) foresees 4 spectrographic modules fed by fibers, operating in seeing and diffraction limited (adaptive optics assisted) mode carried out by an international consortium composed by 24 institutes from 13 countries which poses big challenges in several areas.

In this paper we will describe the approach we intend to pursue to master management and system engineering aspects of this challenging instrument focused mainly on the preliminary design phase, but looking also ahead towards its final construction.

Keywords: ANDES, astronomical instruments project management, astronomical instruments system engineering ELT instrumentation, high-resolution spectrograph, high-precision spectrograph

1. ANDES CONCEPT AND ITS SCIENTIFIC OBJECTIVES

ANDES (ArmazoNes high Dispersion Echelle Spectrograph) is the high-resolution optical-infrared spectrograph for the ESO/ELT (European Southern Observatory/Extremely Large Telescope) thought to study astronomical objects that require highly sensitive observations. It will be used to search for signs of life in Earth-like exoplanets, find the first stars born in the Universe, test for variations of the fundamental constants of physics, and measure the acceleration of the Universe's expansion (more details can be found in [1]). ANDES baseline concept is a modular fiber-fed cross dispersed echelle spectrograph composed by four ultra-stable modules (called in our Project terminology, *subsystems*), namely UBV, RIZ, YJH and K, capable of providing a simultaneous spectral coverage (goals included) of 0.35-2.4 μm at a resolution of 100,000 with several, interchangeable, observing modes ensuring maximization of either accuracy or throughput (as shown schematically in Figure 1). Further detailed technical description is outside the scope of this paper and can be found in [1], [2] and references therein.

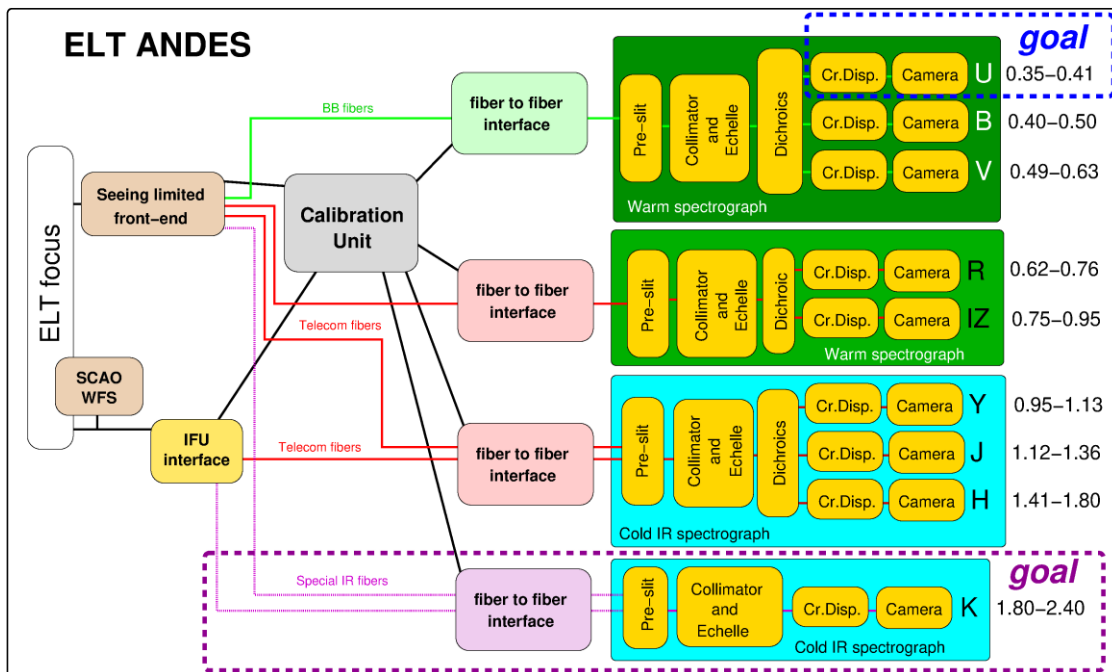


Figure 1: Schematic view of functional architecture of overall ANDES instrument with the modular splitting concept highlighting the goals and wavelength coverage achievable by respective modules (units are microns).

1.1 ANDES history

The steps that led to the organization of ANDES project as described in this paper can be briefly summarized as follows:

- ESO commissioned two phase-A studies for high-resolution spectrographs, CODEX and SIMPLE, in the framework of “ESO instrumentation roadmap for ELT construction proposal” (successfully completed in 2010)
- HIRES initiative: merging of CODEX and SIMPLE with a preparation of community white paper (2013) [3]
- HIRES Phase A study: started 2016, successfully concluded beginning 2018 [4]
- the “waiting-for-approval phase”: new partners (USA and Canada) joined the consortium, modified baseline design adopted, new organisation of consortium developed, preparation of agreements
- ESO Council approves HIRES Construction (December 2021)
- New name adopted: **ANDES** (ArmazoNes high Dispersion Echelle Spectrograph)

1.2 ANDES scientific objectives

During the course of the phase-A study, the HIRES Science Advisory Team, chaired by the Project Scientist, has defined the science priorities and determined the corresponding Top-Level Requirements which applies now to ANDES. As for the technical concept, detailed description of the science goals is outside the scope of this paper. Here we would like just to recall that the key science cases cover:

- Exoplanets and Circumstellar disks
- Stars and Stellar populations
- Galaxies (formation and evolution) and Intergalactic Medium
- Cosmology and Fundamental Physics

Needless to say that the concept of the instrument is enough versatile to cover a huge number of many more science cases and the ones reported are just the ones identified as top priority considering that their fulfilment actually enables to cover a much wider science (see [5]).

In this paper we will describe the approach to master management and system engineering aspects of this scientifically and technically challenging instrument. Section 2 presents the ANDES organisation breakdown structure and describes the way the project and system teams are organized. Section 3 depicts the management approach adopted for ANDES with a description of the major project phases, management tools we intend to use and monitoring strategy we intend to adopt. Product breakdown structure and work organisation are presented in section 4, whereas section 5 introduces the model-based system engineering approach as a mean to effectively master ANDES complexity. In section 6 the ANDES project timeline is eventually presented.

2. PROJECT ORGANIZATION

This section describes the organization of the Contractor Consortium, formed for the realization of the ESO/ELT ANDES instrument. The Consortium is composed by 24 institutes from 13 countries (Brasil, Canada, Denmark, France, Germany, Italy, Poland, Portugal, Spain, Sweden, United Kingdom, United States of America); note that in many cases, these institutes are in reality “high-level” (often governmental) organizations that coordinate several individual research centers such that the real number of involved institutes is much higher – around 35 (this is for example the case of the leading organization INAF, the Italian National Institute for Astrophysics, which coordinates activities of 16 geographically distributed astronomical observatories and institutes across Italy). The large number of institutes involved in the Consortium reflects the large scientific and technical interest in a high-resolution spectrograph for the ELT in the astronomical community worldwide and clearly represents a challenge for its successful mastering.

The ANDES Organisation Breakdown Structure (OBS) follows the typical organisation chart common in other astronomical projects and at ESO in particular. To tackle the complexity of a large number of involved institutes a

“modular” and “team” approaches have been adopted where roles and subsystems (see below for their description) are managed by coordinated teams with a clear identified responsibility. At the same time, a centralized Project Office ensures coordination and a clear reporting line to the Principal Investigator and to ESO.

The consortium is represented by the *Principal Investigator* who has the ultimate responsibility of the project and is the formal contact point between ESO and the Consortium. For ordinary project activities, the Consortium is structured at a country-basis. Each Country contributes to the scientific and technical activities with the participation of one or more institutes within each single country. Each country is represented by a single Co-I, member of the board of Co-Is, representing all institutes in her/his country. The ANDES PI and the board of Co-Is constitute the *Executive Board (EB)*.

To ensure a proper connection with the funding agencies and a proper representativeness of each consortium partner a *Steering Committee (SC)* has been further appointed. The SC does not take scientific or technical decisions but operates by approving documents proposed by the PI in collaboration with the Executive Board. It provides a general oversight of the Project with particular attention to costs and to the use of financial and human resources within the Project. As mentioned, the SC is composed of one representative for each Partner and ensures that adequate level of funding, personnel and infrastructures necessary to the ANDES Project are obtained.

The *Project Scientist* leads the development of the science program and top-level requirements, working in close contact with the *Project Manager* (and his team) who takes on the responsibility for the management of the overall project. The project manager is supported by a *System Engineer (SE)* and the system team (composed by the *Software System Engineer - SSE* and *System Architects - SA*) who supervise the overall system design. SE and SSE work in close contact with the *Instrument Scientist* (and her team) who makes sure that the adopted technical solutions match the foreseen scientific needs. The PI, PM, SE, SSE, PS and IS form the *Project Office* which ultimately and collegially encompass all programmatic activities of the project.

Technical work is organized following a modular approach where ANDES is seen as composed by **9 subsystems**:

1. Front end (FE)
2. Fiber Link – Integral Field Unit (FL-IFU)
3. UVB spectrograph
4. RIZ spectrograph
5. YJH spectrograph
6. K spectrograph
7. Single Conjugated Adaptive Optics module (SCAO)
8. Calibration Unit (CU)
9. Software (SW)

For each subsystem, a *subsystem* Project Manager and a *subsystem* System Engineer have been appointed with similar responsibilities of the PM and SE even though limited to the subsystem level.

All matters that concern science cases and GTO scientific program for ANDES are responsibility of the PS and the *Science Team (ST)*. The Science Team composition ensures the scientific return for each of the partners and is thus directly linked to the investment each partner makes for the construction of the project. A Consortium Agreement states the rules for the science team constitution, competences and rights and the corresponding scientific return. The ST is organized in four Working Groups (WGs) following the key ANDES scientific objectives reported in section 1.2:

- WG1: Exoplanets and Circumstellar disks
- WG2: Stars and Stellar populations
- WG3: Galaxies (formation and evolution) and Intergalactic Medium
- WG4: Cosmology and Fundamental Physics

Each WG is led by a chair, assisted by co-chair(s) and composed by a number of scientists from the participating countries selected by appointment from the PI, following indications of the EB and of the PS and ultimately approved by the SC.

The overall OBS of ANDES (Phase B) is summarized in Figure 2.

ANDES Organisation Breakdown Structure

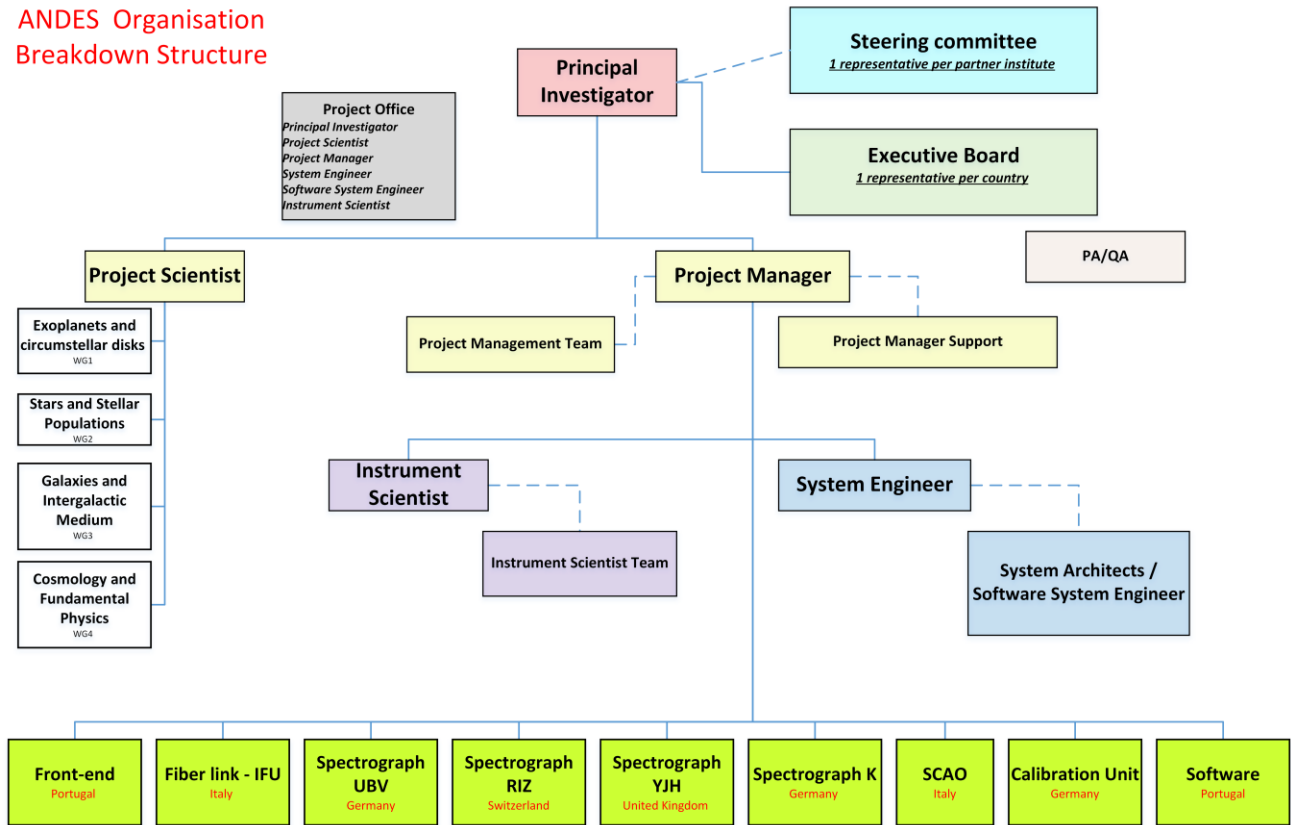


Figure 2: ANDES Phase B Organisation Breakdown Structure

2.1 Project management team

Due to organizational complexity of ANDES, the PM is assisted by a team of local PMs which represents, where possible, all the institutes belonging to a country or individual institute when a shared representativeness is not possible. The ANDES PM team is divided into three levels:

- the *core team* is composed of the ANDES PM, his deputy, and of the configuration manager, schedule manager and tools manager
- the *subsystems PMs* team is composed of one PM per major ANDES subsystem
- the *local PMs* composed by all the other PMs (country or institute-based) not represented in the previous two teams

The main task of the PM core team is to support the PM in all management and day-by-day activities as described above, help in keeping close contacts with ESO follow-up team and assure that communication with all the team is constant and efficient. The main tasks of the PM team are also the definition of the Project Plan, the Schedule and the Financial Plan (with the help of SE, SSE to be approved by the SC).

Following the modular approach foreseen for ANDES, each ANDES subsystem is coordinated and managed by the respective project manager, the subsystem PM who will have the same duty of the system PM, but at subsystem level. In particular the subsystem PM is responsible for the successful execution of the subsystem she/he represents within an agreed time, budget and within the scientific, managerial, and technical frame defined by the system PM and PS. Tasks of the subsystem PM are: to prepare progress reports as specified in the SoW, participate to the system project meetings, prepare and conduct the subsystem reviews and for the final subsystem document delivery as detailed in signed SoW.

A third level is foreseen (the local PMs) to ensure proper spread of information to all partners that are not represented by any project manager in the previous two sub-teams and guarantee that the work is coordinated and managed also for work packages which do not belong to subsystem leading institutes. As for the previous cases, local PMs are responsible for delivering work packages under their control within given budget and schedule. They shall report to the subsystem PM on schedule and any cost aspects that fall within the remit of the subsystem they work with. The subsystem PM, in turn, reports the overall subsystem status to the core PM team and PM.

Overall PM team composition is shown in Figure 3.

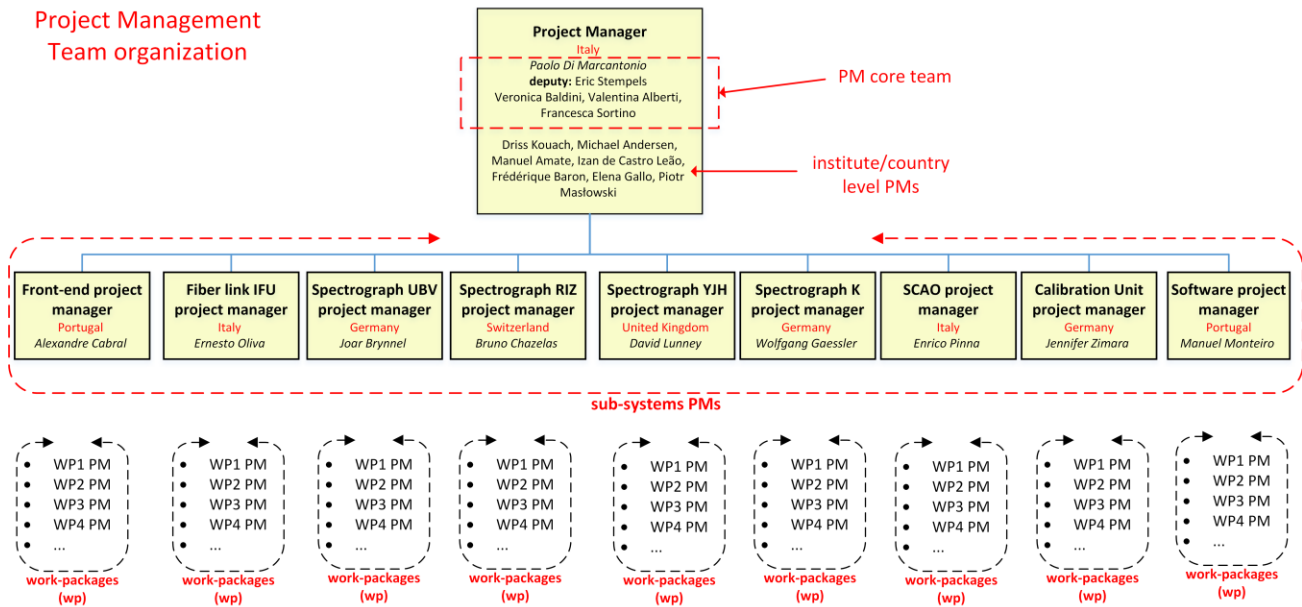


Figure 3: ANDES PM team organization

2.2 System engineering team and System Architects

Following the modular approach foreseen for ANDES and following the same philosophy of the PM team, each ANDES subsystem is coordinated and managed by the respective subsystem engineer, the subsystem SE which will have the same duty of the system SE, but at subsystem level.

Besides the subsystems SEs the SE is assisted also by the *system architects*. This role has been introduced already in Phase A of ANDES to help handle communalities of different subsystems in a centralized way, to define the overall instrument architecture as a whole and to uniform the adherence to ESO applicable and reference documents. The following system architect's role has been maintained from Phase A:

- *Software System Engineer* (acts also as a *Software Architect*): counterpart of the SE for software related issue; is responsible for the various interfaces between the control software and the science software, and ensures proper level of homogenization among all subsystem software WPs
- *Requirements architect*: deals with flow-down of requirements from ESO and system level to subsystems

- *Interface architect*: deals with interfaces both external (e.g. versus telescope and the Observatory) and internal (in cooperation with subsystem SEs)
- *Optical architect*: deals with the definition of the system optical architecture (which is used by subsystem SEs and their teams to develop their own optical designs)
- *Mechanical and Vacuum architect*: deals with the definition of the main parameters and constraint of each sub-system (e.g. mass, volume) which are used by subsystem SEs and their teams to develop their own mechanical designs. He will also be in charge with the provision of guidance for thermal and vacuum architecture
- *Electrical architect*: deals with the definition of the system electrical and network architecture
- *AIV architect*: deals with the definition of the overall ANDES AIV strategy

ANDES system management is summarized in Figure 4 where the various roles are shown in a matrix view.

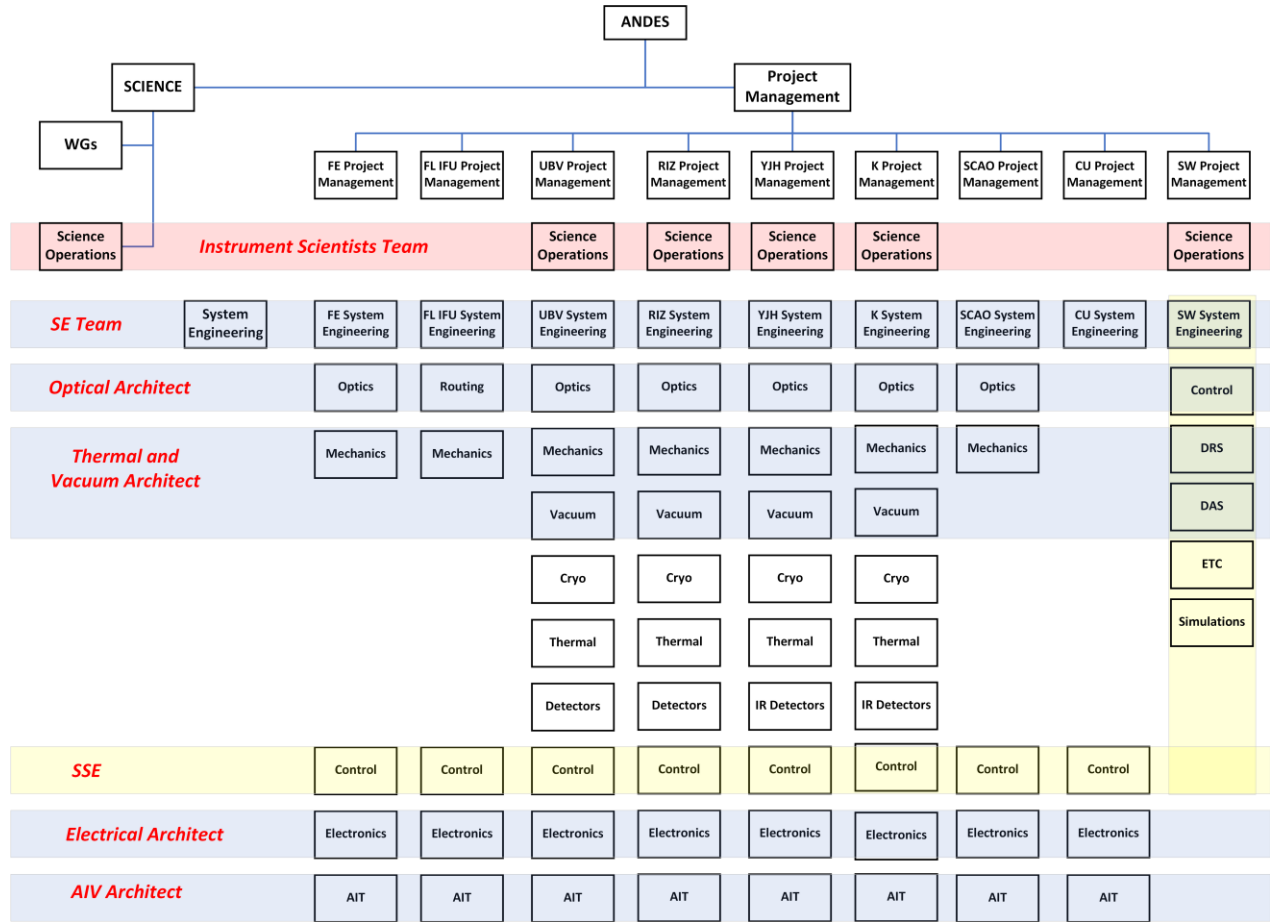


Figure 4: ANDES system management matrix view

3. PROJECT MANAGEMENT APPROACH

The management approach for ANDES project is based on a combination of requirements agreed with ESO, guidelines provided by the Project Management Body of Knowledge (PMBOK) framework, and experience of the consortium members with previous ESO instrumentation projects. The PM and his team are in charge of initiating, planning, controlling and monitoring all the project phases (in the spirit of PMBOK). The PM prepares the management and project plan and organizes the work in subsystems and work packages.

However, due to the complexity of the instrument, once a first work organization is implemented, a bottom-up approach has to be considered too. Overall work is organized in work packages which are the ultimate tasks to be performed. There will be only one responsible per work package, named *Work Package Manager* who is in charge of organizing tasks, resource allocation, interfaces, dependencies and budgeting of the respective work package. The subsystems PMs integrate information provided by each WPM to obtain a complete overview of the subsystem in terms of cost, manpower and work performed. The subsystems in turn collegially works with PM and his core team to perform all the project management commitments at system level, monitoring constantly the advancement of the project.

As baseline, the stage-gate paradigm applies. Important points of decision are project milestones (gates of the project) and which mark transition into a new stage. Specifically, the ANDES construction project shall be developed in four phases and a guarantee period:

- Phase B = Preliminary design phase, from Kick-Off Meeting with the Instrument Specification and Architecture Review, subsystems Preliminary Design Reviews and closed by the Preliminary Design Review
- Phase C = Final design phase, subsystems Final Design Reviews and closed by the Final Design Review
- Phase D = Manufacture, assembly, integration and test phase with the subsystems and system Integration Readiness Review, the system Test Readiness Review and closed by the Instrument Preliminary Acceptance Europe
- Phase E = Transport phase / Incoming inspection / Installation and commissioning phase closed by the Instrument Provisional Acceptance Chile
- Guarantee period closed by the Instrument Final Acceptance Completion

In addition, for ANDES an important milestone applies, the *Funding Review*. On the defined date after the PDR and before the FDR starts, the Consortium shall confirm at this review the available funding vs cost prediction and shall demonstrate the secured funding (either available or officially committed) of the complete expected ANDES hardware costs including contingencies and integration cost up to PAC. The successful outcome of this review will be a prerequisite to any procurement contract launch of the instrument hardware.

To keep reviews affordable in terms of overall documentation and reviewers' efforts, reviews are foreseen to be conducted first at subsystems level. These are at minimum subsystems Preliminary Design Review, subsystems Final Design Review, subsystems Manufacturing Readiness Review and subsystems Acceptance. They are performed under the Consortium's authority, but the associated review packages form a formal delivery for the formal System reviews.

In ANDES the PM is supported by the PA/QA manager, whose role is to manage and coordinate the overall Product Assurance activities of the Consortium work, a Risk Manager that cover the activities of the risk management process, a Configuration Manager responsible to master the process of establishing and maintaining a consistent record of a product's functional and physical characteristics and a Scheduler Manager which deals with all schedule related issues. A detailed description of their roles is outside the scope of this paper and will not be reported here.

3.1 Management tools

It is foreseen to use several tools to support project management activities in ANDES. The starting point will be a project/consortium web page where all the relevant information is stored for a quick and easy retrieval, shortly, a portal for ANDES project.

There is a Consortium password protected shared area for document sharing managed by ownCloud:

Project management process is assisted by Atlassian Confluence and Jira:

- Confluence is a knowledge sharing tool that makes the information accessible to everyone with an account. It allows to create and edit content and supports offline discussions as well as retrieving of previously shared material.
- Jira is a ticketing system that allows for tracking the progress of the project through the ticket's status workflow. It provides a powerful filtering system and the ability to create dashboards to quickly visualize statistics on the project development.

Jira and Confluence are very well integrated and can be extended with plug-ins if additional functionalities are needed.

The chosen Document Management System is Xerox DocuShare

- It is a content management platform that supports document versioning and the definition of workflows to track the document lifecycle and the acceptance process. Along with a broad spectrum of other functionalities, it also allows to add a simple signature to the documents.

The project plan is prepared in Microsoft Project (version 2019). Freedom is left to communication and real-time collaboration tools, while concurrent document sharing will be provided through Microsoft SharePoint.

3.2 ANDES progress monitoring

The evolution of programmatic, technical and PA/QA aspects of the ANDES project will be monitored in several steps:

- Periodic meetings
- Issue of periodical progress as part of ESO formal progress reports (with quarter cadence)
- Jira tickets status monitoring
- Microsoft Project status monitoring

4. PRODUCT AND WORK BREAKDOWN STRUCTURE

The work breakdown structure (WBS) contains the structured breakdown of the whole project activities based on the analysis of the requirements and the products identified in the ANDES PBS. To define each work package within ANDES WBS, a dedicated template has been prepared at the system level and distributed to all the subsystem PMs to allow to define objectives, needed inputs and expected outputs for each major task (in a homogeneous way) together with foreseen resources and costs needed to complete it within the project schedule.

The work and responsibilities foreseen for Phase B are distributed among countries as follows (not exhaustive):

- Italy, specifically INAF, is the leading institute, holds the PI-ship, project management, science to instrument I/f, system engineering, fiber link-IFU, SCAO and participate as WPM in other subsystems. The PM is collocated in the same institute of the PI (INAF)

(In alphabetical order)

- Brasil participates to software WPs (end-to-end simulator and TCCDs)
- Canada leads the IR detectors/camera WPs (under YJH) and SCAO subsystem (real-time controller)
- Denmark participates in spectrograph (grating and other optics) and TCCDs activities
- France participates in SCAO, CU and SW subsystems
- Germany leads UVB, K and CU subsystems
- Poland participates to FL-IFU and CU
- Portugal leads FE and SW subsystems
- Spain participates to spectrograph subsystems (benches and mounts)
- Sweden participates to PM (deputy), FL-IFU and SW subsystems
- Switzerland leads RIZ and participates in SCAO and SW subsystems
- UK leads science and YJH spectrograph
- US has no specific WPs (will contribute to the project with funds).

Following the modular philosophy of ANDES each subsystem has the freedom to organize internally the work to better suit the respective institute and the partner expertise.

Having “product” and “work” related views of the plan is very useful in completeness validation. This allows to deliver only products in the PBS that are required and do only necessary work to achieve the outcome of the project.

The Product Breakdown Structure (PBS) is a hierarchical structure of things that the project will deliver. It decomposes the "Main Instrument" into its constituent parts in the form of a hierarchical structure. The products can be “internal”, those built by the project, or “external”, those either supplied by another project or bought in. The PBS is supported by Product Descriptions that describe individual products in more detail. This enables quality expectations and responsibility for approval to be clearly identified at an early stage in the project life cycle.

From the PBS, a Product Flow Diagram can be produced to represent the order in which subsystems integrate into the main project product, helping to define the logic of the delivery plan.

An example of ANDES PBS can be seen in Figure 5. The central block ANDES represents the whole instrument at level 0. The blocks at level 1 are the subsystems, e.g., the Calibration Unit or the K-band Spectrograph. Each block can be further decomposed in its constituents and eventually associated to a sub-work-package.

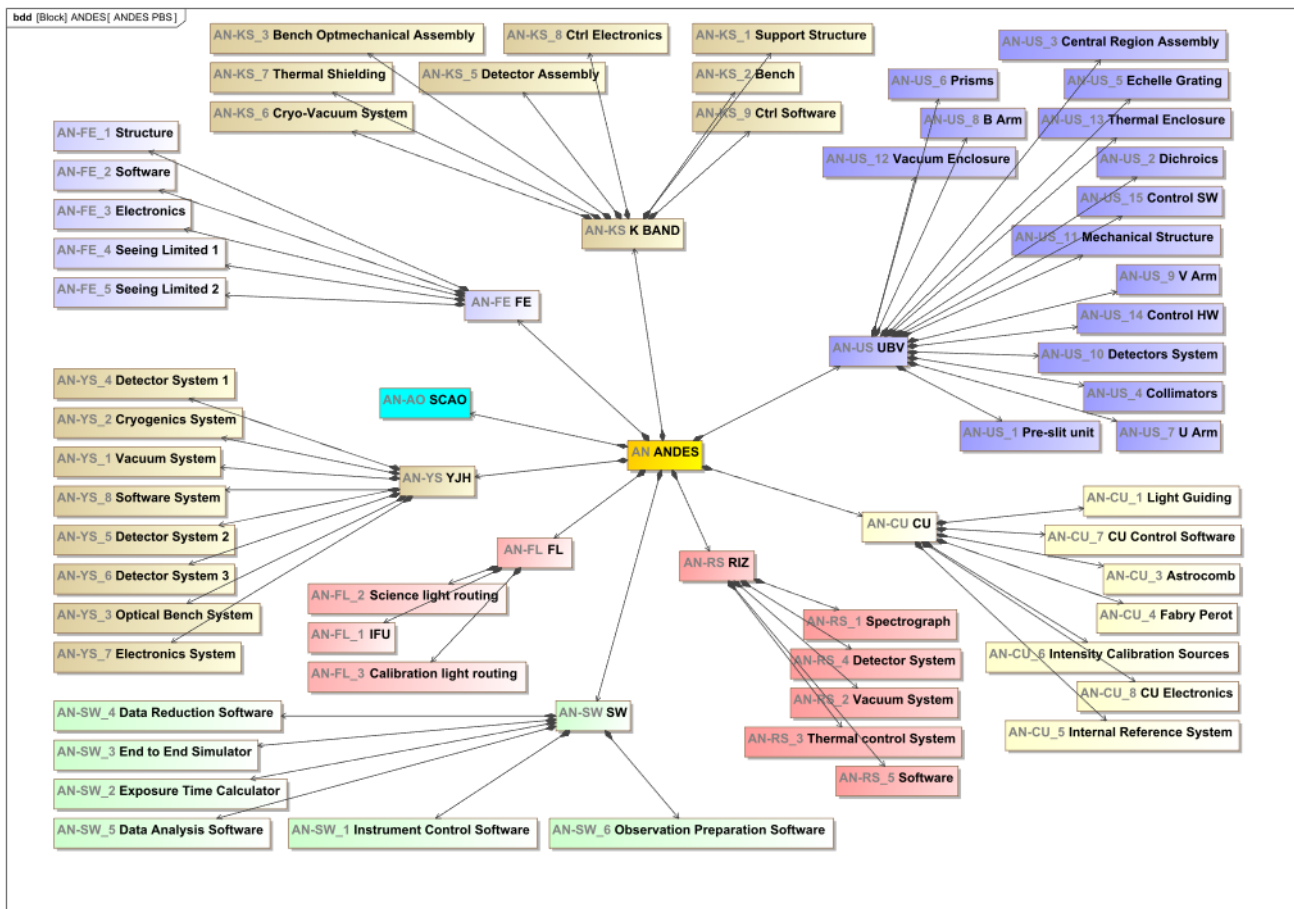


Figure 5: Product Breakdown Structure of the ANDES instrument.

5. MBSE APPROACH

The Model Based System Engineering (MBSE) approach [6] can help the SE keep control of complex projects using the Model as primary "Source of Truth" for all SE-information related to the instrument. This approach requires the adoption of specific tools and a modeling language (e.g., Cameo and SysML in our case [7]) that can create associations between the different aspects of the projects, such as products, actions, requirements, simulations and verifications, etc. MBSE generates and manages tables and diagrams that represent the system in all its possible developing aspects; those can be very simple or expanded like fractals depending on the detail level that the user needs and can show links between every part or use case.

MBSE, however, faces difficult challenges in projects that are document-centric like in the case of ESO related projects, therefore we also developed customizations to produce the ESO required documents and deliverables, directly from the model.

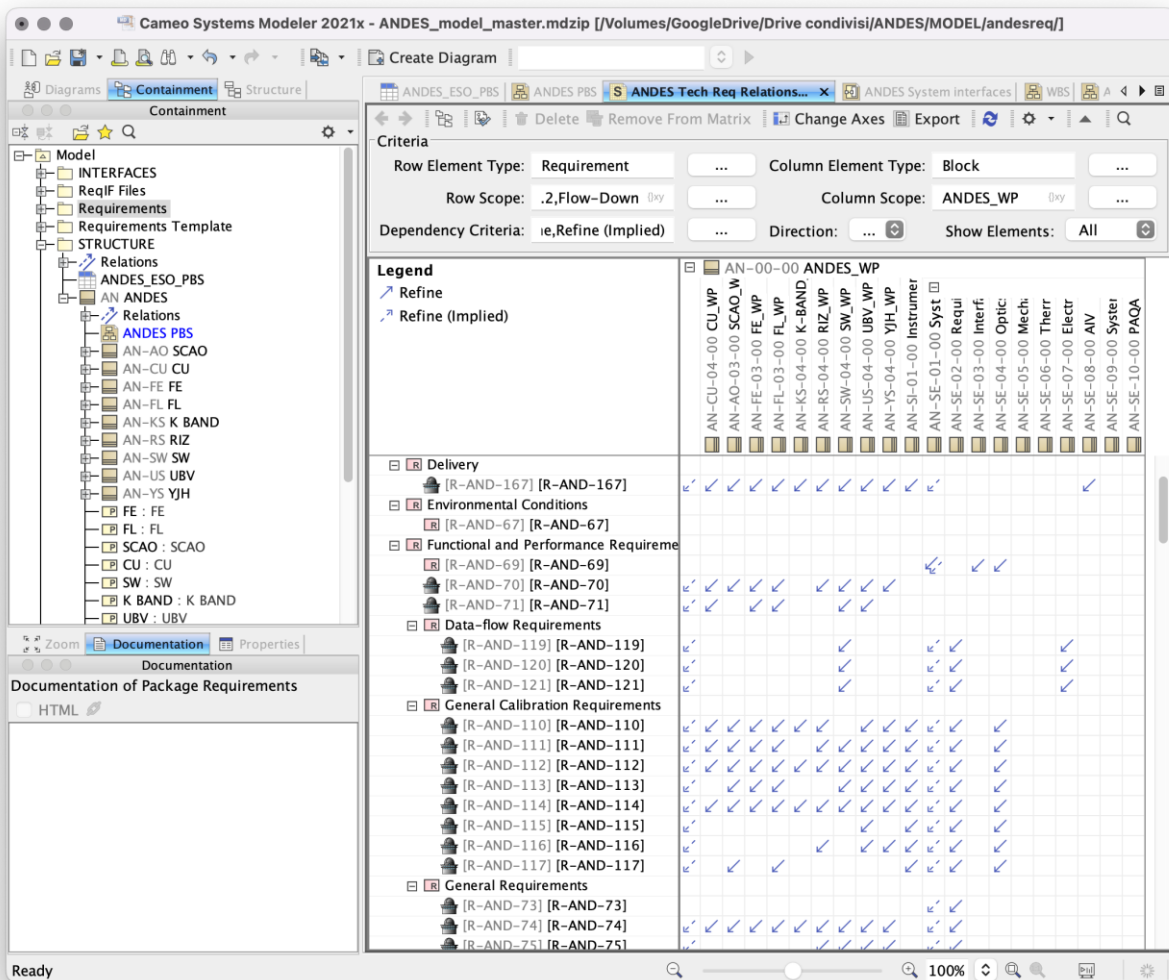


Figure 6: Example of the model showing on the left the structure of the instrument (PBS) and on the right the requirement refinement matrix. In this example each requirement is associated (arrows) and delivered to a specific work-package by the Requirement Manager.

Another challenge derives by the interaction with the various "cultures" of the engineering disciplines that take part of the project: Software, Electronic, Mechanical Engineers, etc., are all used to different tools and languages to describe

their discipline. The Model can filter and automatically interpret each input depending on the domain, but in order to avoid hastily impose MBSE to everyone, which may look like an attempt to centralize and bureaucratize the project, we decided to keep the modeling environment restricted to the SE-team while interacting with the other engineers using traditional Excel files that are normally well accepted. This approach allowed us to both exploit the advantages of MBSE while not "disturbing" other engineering domains. Also, the Excel file can be used in syncing mode allowing to enter data in the model through them; it should be however stressed that the model remains the only "Source of Truth".

Top level requirements and Technical Specifications of the Instrument, contained in the official ESO DOORS [8] database are part of the agreement documents, however, they have been also imported in Cameo model using reqIf format (Requirements Interchange Format) to take advantage of one of the most fundamental tasks of MBSE: the requirements analysis. Such inspection and flow-down of the requirements have then been performed using the SysML rules inside the model and gave birth to one of the fundamental deliverables for the project: the Compliance and Verification Matrix. Here, all the simulations and verifications are automatically brought together, highlighting the requirements that still need attention or refinement, with huge benefit for the SE-team (Figure 6).

A formal description in SysML of the requirement analysis process has been developed to also ease the flow-down of requirements to the different subsystems. Development of different sets of use cases (calibration, AIV etc.) added then more functional requirements to the subsystems, without fear of losing track of their dependency or the analysis that generated them.

Another critical point of the design process, of course, is to tackle efficiently interfaces relating the different subsystems. Taking advantage of all features provided by Cameo and SysML, the SE can represent those ports between parts and associate them to specific simulations and constrains. If properly established, this can warn the user if, during the design process something has to be updated or is not compatible with the related subsystems.

The MBSE approach today is still evolving, but we can clearly appreciate the advantages of it in big astronomical projects such as ANDES. This will for sure lay foundations for further applications in future astronomical instruments. The experience accumulated in this project will be conveyed in a general SysML profile (AstroMBSE) that will be made available to the community.

In Figure 7 the AstroMBSE model is shown, integrated in Cameo, which is composed by different sections (dashed areas). On the left there is the "Requirements Managing" area, the blocks inside serve to customize the requirement analysis and to be able to specify the mandatory fields in the ESO environment (such as project phases, verification types or achieved values). On the right top, the "Numbering Scheme" customizes the way to assign the unique ID to each type of block inside the project, differentiating between PBS items, requirements and WPs. Lastly, on the right bottom, new specifications and labels for the PBS are defined so that we can follow the guidelines required by ESO (e.g., differentiate between item and instance, assign and show IDs or OEM numbers, etc.).

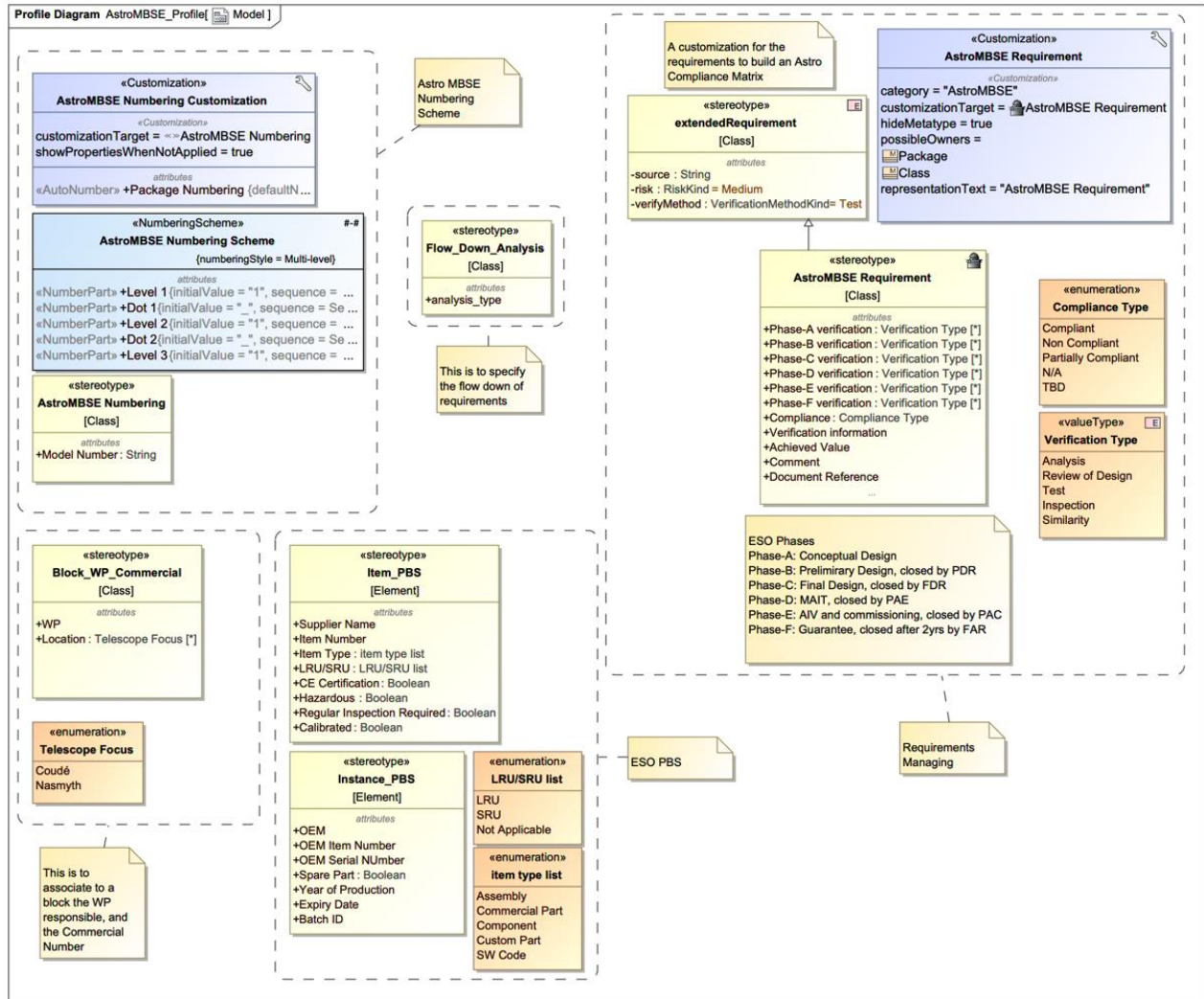


Figure 7: AstroMBSE profile used to customize the ANDES model and to tailor it to the astronomical needs.

6. ANDES PROJECT RESOURCES AND SCHEDULE

Overall staff efforts required for the ANDES construction has been estimated as part of the pre-phase B activities by the system and project management teams following the results of Phase A study. Current estimations points to an overall staff effort of the order of 700 FTEs on a time span of 10 years whereas Figure 8 shows the percentage share per country.

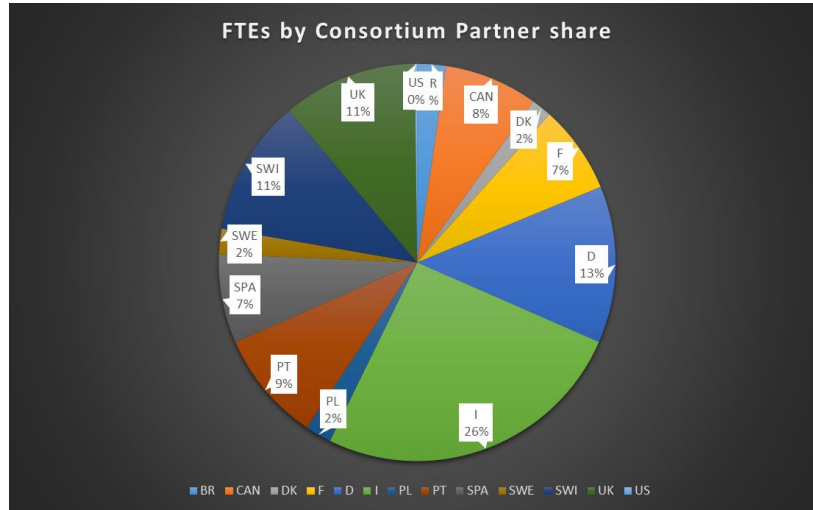


Figure 8: Partner share (per country) for ANDES construction (all phases).

Construction of ANDES will be divided into several Phases as described in section 3. Table 1 details the ANDES timeline up to commissioning in Chile, estimated by the system and project management team following the results of Phase A study and subsequent activities.

Table 1: Overall ANDES project timeline

Project timeline			
Project phases	Milestones	Duration	Name
Phase B	KM.1	T0	Kick-off (KO)
	KM.2	T0 + 9 months	System architecture completion (SAR)
	KM.3	T0 + 22 months	Preliminary design completion (PDR)
		T0 + 26 months	Funding review (FR)
Phase C	KM.4	T0 + 48 months	Final design completion (FDR)
Phase D	KM.5	T0 + 80 months	Integration readiness completion (IRR)
	KM.6	T0 + 88 months	Test readiness completion (TRR)
	KM.7	T0 + 108 months	Preliminary acceptance Europe completion (PAE)
Phase E	KM.8	T0 + 120 months	Provisional acceptance Chile completion (PAC)
Phase F	KM.9	PAC + 2 years	Final acceptance completion (FAC)

7. CONCLUSIONS

In this paper we have described the approach we intend to pursue to master management and system engineering aspects for the ESO/ELT ANDES spectrograph, the forthcoming high-resolution, high-precision spectrograph for the ELT.

ANDES is a challenging instrument in several aspects: it is actually a multi-instrument composed by several modules (subsystems) where each one is an instrument by itself already exceeding dimensions of current largest spectrographs of such kind, worldwide. At the project management level main challenges are represented by its large consortium, the needs of huge efforts and funds' investments for its construction within a not negligible time frame to reach on-sky operations. In order to master ANDES complexity, a modular approach has been adopted both at project and system level: 9 major subsystems have been identified with their own project managers and system engineers which are responsible for their respective subsystems and, at the same time, are also part and support the project manager and system engineer at the system level. The model-based system engineering approach allows furthermore to overcome the typical document-centric view allowing to handle the requirements, interfaces, product breakdown, design and verification (among others) in a consistent model-centric way. Both, modularity and MBSE, should eventually allow to master ANDES complexity such to reach in an affordable way and within the set time frame, all the foreseen ANDES scientific objectives.

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