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Published version information:

Citation: P. Di Marcantonio et al., ANDES, the high-resolution spectrograph for the ELT: project management for the preliminary design phase, Proceedings Volume 13099, Modeling, Systems Engineering, and Project Management for Astronomy XI; 130991W

DOI: https://doi.org/10.1117/12.3018067

ANDES, the high-resolution spectrograph for the ELT: project management for the preliminary design phase

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ABSTRACT

The ESO/ELT ANDES (ArmazoNes high Dispersion Echelle Spectrograph) project successfully completed the system architecture review and is currently finalizing its preliminary design phase. ANDES is the high-resolution spectrograph for the ELT (ESO Extremely Large Telescope) capable of reaching a resolution of R~100,000 simultaneously, in a wavelength range between 0.35-2.4 μm (goals included), characterized by high-precision and extreme calibration accuracy suitable to address a variety of flagship scientific cases across a wide range of astronomical domains.

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Modeling, Systems Engineering, and Project Management for Astronomy XI,
edited by Sébastien Elias Egner, Scott Roberts, Proc. of SPIE Vol. 13099,
130991W · © 2024 SPIE · 0277-786X · doi: 10.1117/12.3018067

To fulfill the required specifications the proposed design adopts a modular approach where the instrument is split in four individual spectrographs, each fiber-fed, and thermally and vacuum stabilized. A dedicated front-end which hosts a single conjugated adaptive optics module, collects either the light from the telescope or from a calibration unit feeding in turn the individual spectrographs. To master the described complexity the same modularity is reflected also at the project management level: each of the 9 subsystems (counting also the software as a standalone subsystem) is under direct responsibility of different teams coordinated by the ANDES project office. The high distribution and the large community involvement, consisting of 24 institutes from 13 countries, represent certainly a challenge from the project management point of view.

In this paper we present the project management approach we envisaged to master successfully all the ANDES project phases from the finalization of the preliminary design up to commissioning on-sky; in particular we will describe in detail the risk management and PA/QA activities we have foreseen to assure appropriate risk mitigation and an overall high-quality standard required for the ANDES project.

Keywords: ANDES, astronomical instruments project management, risk management, product assurance, quality assurance, high-resolution spectrograph, high-precision spectrograph, ELT instrumentation

1. THE ANDES INSTRUMENT AND THE PROJECT

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. The baseline concept foresees 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. Detailed technical description of the instrument and the presentation of its main scientific capabilities are outside the scope of the present paper and can be found in [1].

The Contractor Consortium, formed for the realization of the ESO/ELT ANDES instrument is composed by 24 signatory parties from 13 countries (Brasil, Canada, Denmark, France, Germany, Italy, Poland, Portugal, Spain, Sweden, United Kingdom, United States of America); these "parties" are in various cases actually governmental organizations that coordinate multiple individual research centers (as is the case of INAF, the Italian National Institute for Astrophysics or of CNRS, the French Centre National de la Recherche Scientifique) thereby effectively leading to a large consortium of 35 distinct institutes, research centers, and universities. In terms of human resources, ANDES sees the participation of more than 300 scientists involved in technological and scientific aspects reflecting the large interest in such high-resolution spectrograph for the ELT, worldwide. This of course poses challenging in its management looking ahead towards its construction.

The ANDES project has already completed multiple initial project phases. As described in [2], it started with an initiative known as HIRES, acronym for High RESolution Spectrograph, in 2014, which resulted from merging of two Phase A studies, CODEX and SIMPLE, conducted in the framework of "ESO instrumentation roadmap for ELT construction proposal". Through this initiative, the consortium was formed and an initial pre-design study was completed, enabling the Phase A Study to be successfully completed in 2018. ESO council approved afterwards (2021) the HIRES construction, soon renamed ANDES, following an internal ballot, particularly to avoid confusion thinking to future scientific papers, as a high-resolution spectrograph of the same name already exists at Keck.

At the time of writing this paper, ANDES is in its preliminary design phase and in this paper, we will outline our proposed approach to effectively manage this technically and scientifically demanding instrument also in view of the preliminary review preparation. Section 2 presents the ANDES organisation and breakdown structure, section 3 the management approach we intended to pursue, sections 4, 5 and 6 describe in greater detail the configuration and risk management and product assurance program, section 7 and 8 conclude the paper presenting the resource, funds and schedule.

2. PROJECT AND WORK ORGANISATION

The organisation of the ANDES project is explained in great detail in [2], is unchanged in this Phase B (Preliminary Design), and we will only summarize the main roles and their relationships here. The Organisation Breakdown Structure (OBS) follows the typical organisation chart common in other astronomical projects. The consortium is represented by the *Principal Investigator* (prof. A. Marconi) who has the ultimate responsibility of the project and is the formal contact point between ESO and the Consortium. The ANDES PI is assisted by a board of Co-Is which together 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, composed of one representative for each Partner, does not take scientific or technical decisions, but its role is to ensure that adequate level of funding, personnel and infrastructures necessary to the ANDES Project are obtained. It is worth in fact mentioning that ANDES, being an ELT second generation instrument, will be entirely self-founded by the consortium partners and, according to the current agreement, ESO will not be providing any specific financial support.

Additional key roles in the project include the *Project Scientist* that leads the development of the science program and top-level requirements, the *Project Manager* who oversees the management of the overall project, the *System Engineer* (SE) and the *Software System Engineer* (SSE) who supervise the overall system design, assisted by the *Instrument Scientist* who makes sure that the adopted technical solutions are constantly aligned with the foreseen science expectations. The PI, PM, SE, SSE, PS and IS form the *Project Office* which ultimately and collegially encompass all programmatic activities of the project.

To master the complexity of ANDES the scientific/technical work is organized modularly as shown in the Work Breakdown Structure (WBS) chart, Figure 1.

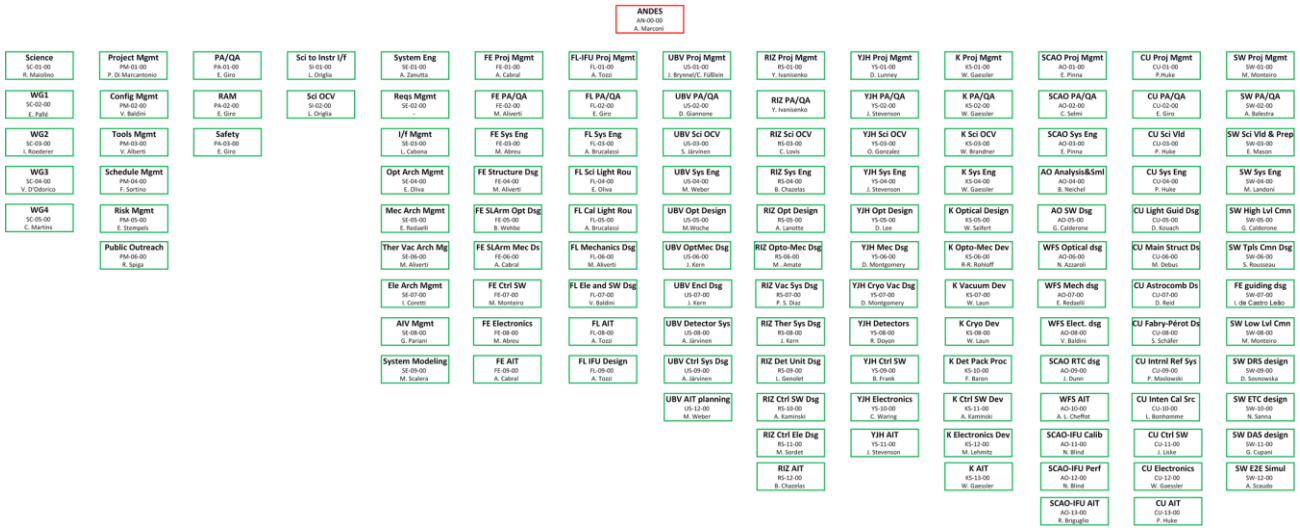

Figure 1:ANDES level-1 Work Breakdown Structure

The PS is heading the *Science Team* (ST), whose task is to develop major ANDES scientific cases and provide scientific guidance to accomplish the main ANDES goals (see [1] for a comprehensive summary of the primary ANDES science objectives). The ST is organized into four Working Groups (WGs) made up of renowned worldwide experts in the respective scientific domains:

- 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 and assisted by co-chair(s), as shown in Figure 1.

Technical work is organized in **9 separate subsystems**:

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

which are coordinated at system level, by a Project management, a System engineering and an Instrument Scientists team. We will only discuss the project and system teams in the following subsections because they are unique to ANDES.

Project management team

To promote capillary information spread and representativeness of all parties, the ANDES Project management team is organized into three levels, as shown in Figure 2:

- the *core team*: consists of the ANDES PM and his deputy, with assistance from the configuration, schedule manager and tools manager
- the *subsystems PMs*: the PMs for each of the nine ANDES subsystems;
- the *local PMs*: all the other PMs (country or institute-based) not represented in the previous two teams.

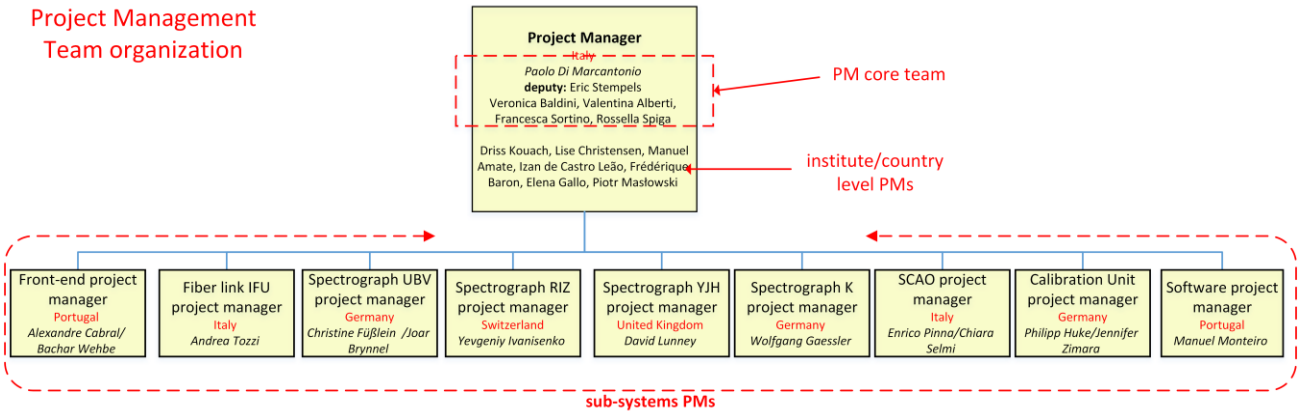

Figure 2: ANDES Project management team organisation

This modularity and separation of responsibilities proves to work well and has made it possible to manage the project smoothly thus far. The *core team* is in charge for the successful execution of the overall project within the agreed time and budget and within the scientific, managerial, and technical frame defined by the scientific program, the Statement of Work, and the top-level Technical Requirement Specifications. It collaborates closely with the PI, reports to PO and EB

and is the contact point for ESO management. Similarly, albeit one level below, the *subsystem PMs* are responsible for the subsystem they represent, track subsystem progresses, take part in system project meetings, lead subsystem reviews and ensure that the necessary subsystem documentation pack is delivered as requested. Additionally, the *local PMs* guarantee that work is coordinated and managed for work packages that do not belong to subsystem leading institutes. They act as the contact point for all partners who were not represented by a project manager in the previous two sub-teams.

System engineering team

The modular approach taken in structuring the WBS and the project management team is also reflected in the system engineering team. ANDES's technical lead, the System Engineer, is assisted by a team of *System Architects* who are responsible for specific disciplines. This role was first introduced in the Phase A of ANDES to aid handling communalities among different subsystems in a centralized way, in defining the overall instrument architecture and to uniform the adherence to ESO applicable and reference documents.

The following system architects' role has been maintained from the Phase A (order follows the work packages division shown in Figure 1):

- *Requirement's architect*: deals with flow-down of top-level requirements from 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
- *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
- *Thermal and Vacuum architect*: similarly, deals with the definition of the main parameters and constraint 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 Assembly-Integration-Testing-Validation strategy
- *System modelling architect*: responsible for developing and maintaining the overall ANDES system model following the Model Based System Engineering (MBSE) approach

3. PROJECT MANAGEMENT APPROACH

As described in section 2, one of the key aspects of the management approach for ANDES involves delegating responsibilities to several actors and dividing the work with granularity in order to adequately master ANDES complexity. As is common in other projects, overall work is organized into work packages which are the activities to be performed. There will be only one responsible per work package, named *Work Package Manager* (WPM) who is in charge of organizing tasks, resource allocation, interfaces, dependencies and budgeting of the respective work package. The difference from the typical approach is that each WPM reports to the subsystems PM (and not to the system PM) who integrates information with the goal of obtaining a complete overview of the subsystem in terms of cost, manpower and work performed. It is the subsystem PM who 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.

ANDES, like any other instrumental project at ESO, follows the stage-gate paradigm: construction is divided into phases, and the transition from one phase to the next is only possible after a review has been passed (the gate). Although the review process conducted by a board of experts in various disciplines is critical for certifying that an instrument meets scientific needs, is mature at the level needed for the phase at which it is reviewed and complies with all required (ESO) standards, it is a fact that the current reviews at ESO have some shortcomings. One weak aspect is that the

documentation set provided for the reviews has grown in size as a result of instrument complexity, with documents often containing varying, non-uniform, levels of detail, making it difficult to find information, to understand the true level of advancement reached and consequently, to provide a thorough technical analysis. This is especially critical for the case of ANDES and its division in 4 spectrographs since each of which can be viewed as a separate instrument with a comparable complexity of a single instrument currently installed at the VLT. This means that in the case of ANDES, reviewers can expect an overall documentation pack, drawings included, four times larger if compared to a typical VLT review!

To try to mitigate the weak aspects mentioned above, while retaining and strengthening the reviews' positive aspects, two major changes were made to the ANDES review process with the addition of:

1. the System Architecture Review (SAR)
2. and the Subsystem Reviews

The primary goal of the SAR is to examine the technical specifications as derived from top level requirements, the external interfaces towards the observatory, the proposed system architecture and formally endorse them. This allows to identify early on that the instrument's primary scientific goals have been broadly met and that the architecture is feasible, responsive to the functional and performance requirements, does not contain showstoppers and follows overall ESO standards. ANDES SAR took place on October 17 and 18, 2023 and was the first milestone of the construction of the ANDES instrument. The outcome of the review was very positive, with only very few actions left open for the upcoming project phases, certifying that all objectives were successfully met.

The second novelty introduced in ANDES project management are the subsystem reviews. The rationale behind is that by dividing up large reviews into smaller, more focused ones, the size of the large (system) reviews can be significantly reduced. This allows for improved engineering quality to be achieved on particular topics (mainly optics, mechanics, control, risk and safety) and helps to overcome all the drawbacks that come with a large review, as discussed above. Seven independent subsystem reviews are currently scheduled in accordance with the ANDES technical concept:

1. Front End
2. Fiber Link – Integral Field Unit
3. UBV and RIZ spectrographs: a single review for both spectrograph due to similarity of the two modules and to take advantage of communalities
4. YJH spectrograph
5. K spectrograph: review limited in scope since the addition of the K module is currently a goal
6. Calibration Unit
7. Single Conjugated Adaptive Optics module

According to the current schedule, reviews will be carried out by an external board of experts from a variety of disciplines in October and November of 2024. ESO has the right to participate as reviewer and/or observer, but will not be directly involved in review organisation and execution. Role of the observers is to provide technical and management advice, have access to the data package, but there is no direct involvement of observers in the review process itself. To ensure that reviews are conducted consistently and that adhere to project technical guidelines, a chair appointed from among the ANDES PO members oversees each subsystem review and is in charge of preparing the Review Conclusion Report which includes the board's final recommendation for the review's results.

Software (both control and science, i.e., data reduction and data analysis) will also be reviewed in a separate, subsystem-specific review, but not under ANDES project responsibility; instead, ESO will organize and carry it out. The main reason is that software is quite specific, follows very strict ESO ELT software standards and guidelines and as such requires a board composed of reviewers with appropriate knowledge, which only ESO has. The software review will take place after all the others review are completed, most likely in the first quarter of 2025.

The successful completion of subsystem reviews will enable the preliminary design review at system level which is under ESO responsibility. In this approach, the system PDR becomes much more manageable: it focuses on system aspects (interfaces, compliances, risks and safety), but no technical review of sub-systems is performed again thus

simplifying the entire process (except of course for the case of critical issues arising from the subsystem reviews which has to be addressed).

ANDES construction path is divided in four phases:

- Phase B = Preliminary design phase closed by the Preliminary Design Review
- Phase C = Final design phase closed by the Final Design Review
- Phase D = Manufacture, Assembly, Integration and Test phase closed by the Instrument Preliminary Acceptance Europe
- Phase E = Transport phase / Incoming inspection / Installation and commissioning phase closed by the Instrument Provisional Acceptance Chile (PAC)

The PDR-like process (i.e. the division in several subsystem reviews) repeats at every phase. Technical review is mostly demanded to subsystems whereas system-level reviews look at compliances, interfaces, safety and risk given the sub-system review outcomes. By emphasizing system-level compliance at PDR and FDR the focus remains on delivering a working instrument to the telescope, rather than focusing on details of implementation.

In addition to this process, specifically for ANDES, an important gate applies: the *Funding Review*. On the specified date after the PDR and before the FDR begins, the Consortium shall confirm at this review the available funding vs cost prediction and demonstrate the secured funding (either available or formally committed) of the total expected ANDES hardware costs including contingencies and integration cost up to PAC. The successful completion of this review will be required prior to the launch of any procurement contracts for instrument hardware.

Management tools

A number of software tools support the ANDES project management process, assisting with team organization, information flow (in both directions, from PO to subsystem and vice versa), mutual information exchange among subsystems and programmatic and technical progress monitoring.

Minutes of meetings, shared discussions, actions assignment and their follow-up, project advancements monitoring are performed by *Atlassian Confluence* and *Jira*:

- *Confluence* is a knowledge sharing tool that makes the information accessible in a wiki-like style. It allows to create and edit content on-the-fly and supports offline discussions as well as retrieving of previously shared material
- *Jira* is a well-known 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.

Documentation storage and long-term archiving is managed via *ownCloud* and *Xerox DocuShare:*

- *ownCloud* is a free and open-source software project for content collaboration and sharing and syncing of files in distributed systems
- *DocuShare* is a content management platform that supports document versioning and the definition of workflows to track the document lifecycle and the acceptance process

In addition, ANDES utilizes "standard" Microsoft products such as Word, Excel, Project Pro and SharePoint (for concurrent document editing), as a result of ESO's adopted standards for document delivery.

4. CONFIGURATION MANAGEMENT

The purpose of the configuration management (CM), in a nutshell, is to make sure that the hardware, software, and documentation deliverables are configured consistently throughout the project, accurately tracked, and compliant with established guidelines.

Specifically, for ANDES, the configuration management process must ensure that:

- each document or drawing produced by the project is correctly and uniquely identified through type of document identification and numbering rules and is produced using CM released templates in precise file format
- each product is correctly and uniquely named and identified and is listed in a Configuration Item List
- the Bill Of Material (BOM) is produced for each configured item
- the Product Breakdown Structure (PBS) is structured according to the functional decomposition of products
- the software components are correctly handled, delivered and documented
- the procedure to perform a Change Request is correctly followed
- the documents are signed, approved and verified before being delivered to ESO
- the documents are stored in an organized and maintained in the Consortium Central Archive System and, once released, orderly uploaded also in ESO archive system

Each ANDES product (e.g., Document, Drawing, Model, etc.) is uniquely identified by rules agreed within the PM team. The reference code identification system adopted for all documentation is the following:

E-AND-aa-bbb-cc-cc-nnn

where

- **E**: represents the ELT telescope
- **AND** : represents the ANDES project
- **aa**: are two letters, corresponding to the first two letters of the subsystem (e.g. FE or CU)
- **bbb**: second string of characters, identifies the type of document (e.g. PLA for planning's, DER for design reports)
- **cc-cc**: are the WP identification numbers of the WBS (e.g. 02-00 for the Configuration Management WP, 03-00 for FE System Engineering WP, etc.)

nnn: sequential number. This numeric value is related to the "subsystem+type" of document (i.e. linked to the alphanumerical part, E-AND-aa-bbb). The numbering starts from 001 for each "subsystem+type" and is progressive in the same "subsystem+type" range.

The drawings numbering (e.g. for mechanical or electronics drawings) follows the rule below, considering the product number of the leading element of the drawing:

E-AN-AA_oo_pp_qq_rr_nnn-DWG _v

where

- **E**: ELT
- **AN**: is the project name ANDES
- **AA**: are the two letters that identifies the main work package
- **oo**: level 2 of the Product Tree (PT) (digits from 00 to 99 to ZZ)
- **pp**: level 3 of PT (from 00 to 99 to ZZ)
- **qq**: level 4 of PT (from 00 to 99 to ZZ)
- **rr**: level 5 of PT (from 00 to 99 to ZZ)
- **nnn**: incremental digits (from 000 to 999)

- **v**: version number (integer for released dwg)

5. RISK MANAGEMENT

Risk Management is an important process to improve the probability of successful completion of the project by continuously identifying, assessing and reassessing potential problems and weaknesses of the project. Especially important is to identify potential issues well ahead of possible occurrence, do a quantified assessment and plan for appropriate mitigation actions. No project is ever without risks, and some risks will eventually lead to occurrences; for a project as large and expensive as ANDES appropriate and active risk management is mandatory. Within ANDES risk management is carried out within the activities of the Risk Management team by a dedicated ANDES Risk Manager.

The ANDES project is organized in clearly identifiable instrument and software subsystems, each with its own challenges and working environments. In addition, a considerable planning effort, both in terms of engineering and overall project management, is concentrated at the level of the Risk Management team. This requires the process of Risk Management to be semi-devolved, with some risks entirely with subsystem control, while others affect the entire project. Risk identification is for a large part performed at a per-subsystem basis, but since there is a considerable interaction between subsystems and the overall project, risk impact analysis and risk response planning are performed by the ANDES Risk Manager.

ANDES Risk Management follow the traditional scheme of risk identification, severity and probability assessment according to predefined criteria, scoring the impact in terms of effect on schedule, cost and reputation, and the definition of possible actions to deal with the risk. Risks can be avoided, mitigated, transferred, accepted, or a contingency plan can be prepared, all depending on the associated cost of the proposed action in terms of time and or money. Existing risks, their status, action, progress and evolution are documented in a centralized risk management table.

The typical workflow (also described in Figure 3) is that the ANDES Risk Manager periodically asks the subsystem managers to actively identify new risks, which are then reported together with a first estimate of the impact of the risk and a proposed mitigation mechanism. Final risk assessment and the assignment of the appropriate risk action and due dates is then performed by the Risk Manager, who then adds the risk to the Risk Register, either as system-wide, or subsystem specific; cross-listing of risks affecting several subsystems is possible. Risks that are reported by subsystems, but with large impacts or similar impacts as identified in other subsystems will be upgraded to system-wide risks. Typical examples of system-wide risks concern uncertainties in scheduling, long-lead item procurement, overall design challenges and financial uncertainties. In addition to active risk monitoring, risks may also be assessed reactively, for example when unexpected problems appear. Depending on the assigned actions, revisions may be required to project planning at the system or subsystem level.

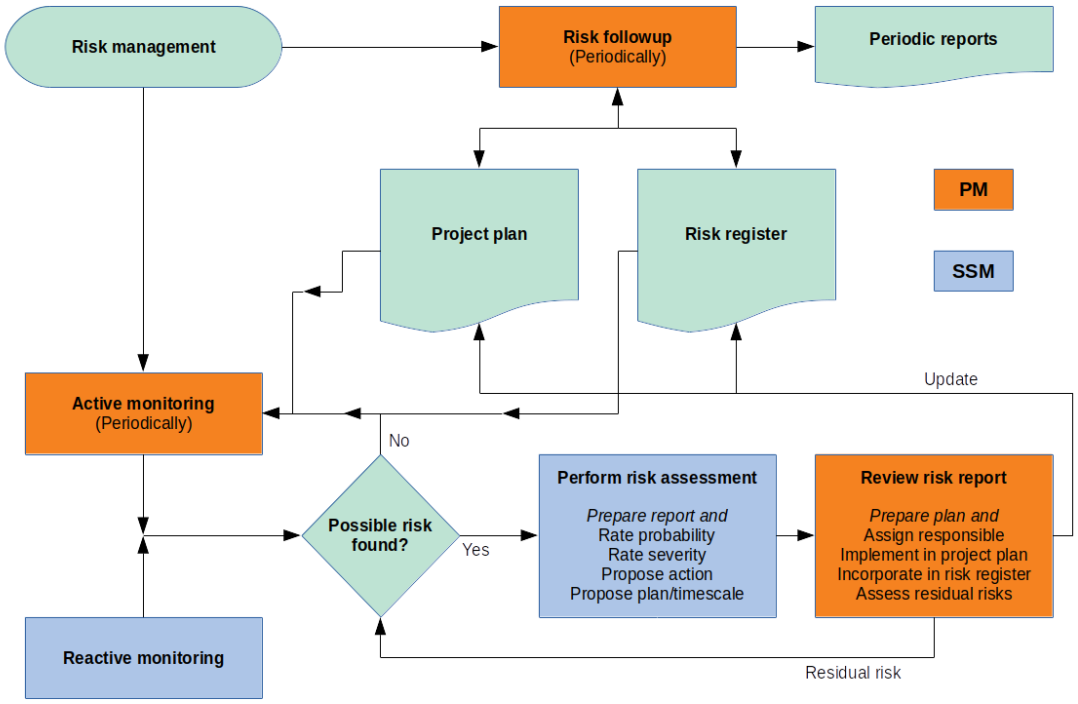

Figure 3: Flow diagram of the risk management process as adopted in the ANDES project. Actions in orange are handled by the ANDES Risk Managers, and actions in blue are handled by subsystem managers.

The risk workflow is complemented by periodic follow-up, often in connection with periodic reporting within the ANDES project. After risk review, possibly with the help of subsystem managers, risk impact and exposure may be adjusted depending on the progress of the assigned actions. Continuous adjustments to the risk impact scoring will guarantee that the focus of project management stays with those risks that have the largest probability and severity. Risk review also occurs routinely as part of the regular reviews with ESO, at which point any risks with high impact will be subjected to scrutiny and additional risk-reducing actions may be demanded.

6. QUALITY ASSURANCE PROGRAM

The Quality Assurance program for ANDES is organized into three different branches controlling several aspects related to Quality and defined in the Quality Assurance Plan, as shown in Figure 4 and described in great detail in [3]. These processes are:

- PA/QA control;
- Reliability Analysis;
- Safety.

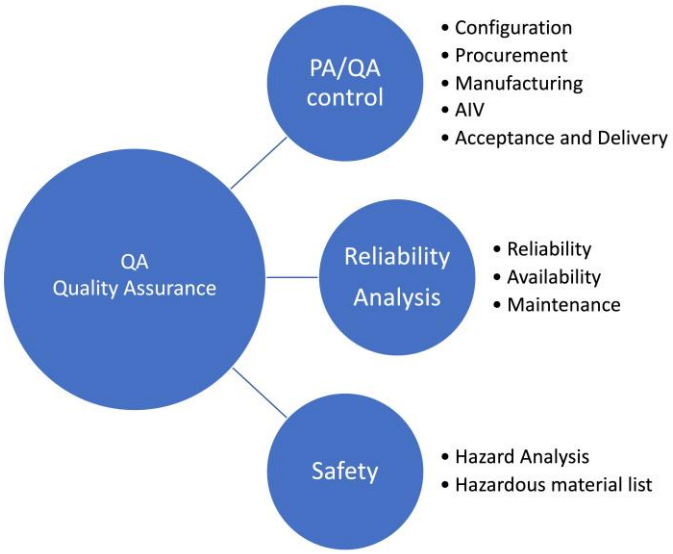

Figure 4: Schematic description of the ANDES Quality Assurance program

PA/QA Control

This process started during the PDR phase and along with all the other phases covers all the aspects of the configuration since the design phase to ensure that the hardware and the instrument will be delivered as designed. In particular, it controls the configuration during the design (PBS and BoM), the procurement during the preparation of the call of tenders, the manufacturing during the production of the hardware, the AIT in which it controls the process to assembly, integration and testing/validation of the instrument and the final acceptance and delivery. All the activities and resources are described in the PA/QA plan which is the reference document that all the actors involved in the project must follow.

Reliability Analysis

This process is related to the activities devoted to guaranteeing that the operations and maintenance resources are well-identified and compliant with requirements accepted at the kick-off of the instrument design. During the PDR, a reliability model of the instrument describing how the instrument will be maintained will be set up. During FDR, this model will be verified based on laboratory data and datasheets collected for all the instrument components. A list of spares at the observing site is proposed as a by-product of this activity. The maintenance plan and manuals will identify and report all preventive and corrective maintenance procedures, clearly reporting needed resources. Moreover, the model will demonstrate that the required availability of the instrument is assured.

Safety

This process must start at the PDR phase and it aims to identify all possible hazards arising during AIV, Operations and Maintenance activities of the instrument. Provisions applied like EU directives and standards such as ISO 12100 or IEC 62061 must be reported in the Hazard identification and mitigation. It is a top-down approach that starts from system

level to identify the hazards, propagate them down to the subsystems and subassemblies, identify consequences in terms of effects to Humans, Products, and Operations. An accurate mitigation must be proposed and applied to keep the effects inside acceptable levels. This is an iterative approach that must be consolidated at the FDR level and applied since AIV phase. The Hazard Analysis and the Hazardous material list are delivered documentation as a by-product of this activity.

7. RESOURCES, HARDWARE COSTS AND FUNDS

ANDES is a resource-intensive project, even for an ELT-sized focal plane astronomical instrument. Its construction involves approximately 300 scientists and technologists over the course of more than a decade. Current estimates indicate an overall personnel effort of more than 700 FTEs, with nearly 110 already foreseen for the Phase B study. Precise estimation is made at the end of each major milestones for the next one (at the same time the subsequent ones are also estimated, but only as a best approximation). In this respect a reassessment of the overall efforts for the final design phase will be carried out at the system PDR milestone.

Monitoring the progress of such large cumulative efforts, therefore, presents some challenges. Nonetheless, an accurate monitoring is essential for tracking the project's progress, spotting early-on possible staffing shortages and for the final scientific return computation, also in terms of Guarantee Time Observation (GTO). Several attempts have been made in the initial phase of the design study to figure out the best way to accomplish this while also making the whole reporting process easier. We eventually adopted quarterly reporting on a shared excel sheet, where each subsystem PM reports the FTEs of her/his subsystem, but indicating only deviations from what was originally planned. This proves to be quite effective, relatively easy to fill and offers a quick way to show possible deviations. Excel's computation capability also allows it to recalculate the partner's share immediately after numbers are entered, providing an always-updated view of each partner's overall cumulative effort.

A similar method is used to estimate the total cost of ANDES hardware. A shared excel file allows each subsystem to fill out a specific sheet contextually. Excel calculation capability allows the grand total of ANDES hardware costs to be calculated as soon as any entry (at the subsystem level) is inserted (also simultaneously). This ensures that the instrument's global cost is constantly updated and visible to all PMs and project office. This is especially important given that ANDES is a fully self-funded instrument (i.e., funded solely by consortium members). Funds will be obtained only as a result of grant applications submitted by consortium members, and the ability to constantly compare the actual cost by monitoring what is actually submitted or obtained allows for careful planning to ensure the project's success.

8. PROJECT SCHEDULE

ANDES overall construction phase is divided into several sub-Phases as described in section 2. Table 1 details the ANDES timeline up to commissioning in Chile, estimated by the system and project management team following the results of the SAR review.

Table 1: ANDES project timeline

Project timeline			
Project phases	**Milestones**	**Schedule**	**Name**
Phase B		(11.08.2022)	Phase B-One signature
	KM.1	T0 (02.09.2022)	Kick-off (KO)
	KM.2	T0 + 12 months (done on 17.10.2023)	System architecture completion (SAR)
		T1	Full construction agreement
	KM.3	T1 + 12 months	Preliminary design completion (PDR)
	KM.4	T1 + 18 months	Funding review (FR)
		T2	Authorization to proceed

Phase C	KM.5	T2 + 18 months	Final design completion (FDR)
Phase D	KM.6	T2 + 74 months	Test readiness completion (TRR)
	KM.7	T2 + 92 months	Preliminary acceptance Europe completion (PAE)
Phase E	KM.8	T2 + 102 months	Provisional acceptance Chile completion (PAC)
Phase F	KM.9	PAC + 2 years	Final acceptance completion (FAC)

Note that the dates of KM.4 (*Funding review*) and subsequent *Authorization to proceed* are tentative and represent the consortium's best guess at this time of writing the paper based on the suggested submission dates of various partner grants. This is mostly because it is unknown in advance when a proposal will be approved.

9. OUTREACH

The ANDES Communication and Outreach Working Group (WG) is developing a strategy for outreach from a very early stage of the project in order to help the organization to connect with its target audience by using various communication channels. From conception to completion, there are many occasions in which the team must communicate with non-specialists about milestones and progress of the work. Potential audiences include decision makers, the media and the general public.

The ANDES outreach strategy is decided by the WG according to the governance of the project (PI and PM) and it includes:

- developing and maintaining the website (https://andes.inaf.it/) with regular news on construction/project progress. The website shows sections aimed at different audiences (during the early stages: consortium, press, scientists, team; later: decision makers, general public, schools);
- building media awareness of the project gradually through briefings, releases and press packs in according with the press offices of the Institution member of the Consortium;
- producing materials, both printed ones (leaflets, posters, etc.) and multimedia ones (interviews, ppt, video, infographics, images, etc.);
- attending exhibitions, science fairs and public events;
- other communication channels such as social media will be implemented.

The Communication and Outreach WG includes at least one representative per major subsystem/country. A very close collaboration with the Project Office is useful to produce a coherent and effective outreach strategy and to correctly involve all the subsystems in order to have a full coverage for all consortium partners.

10. CONCLUSIONS

This paper describes the management strategy being implemented for the ESO/ELT ANDES spectrograph, the ELT's upcoming high-precision, high-resolution spectrograph. The main challenging aspects for ANDES project management are the large consortium, the significant efforts and funds invested in its construction, and the inherent technical complexity because, ultimately, ANDES, is a multi-instrument composed of several modules (subsystems), each of which is an instrument in its own right, already exceeding the dimensions of the world's largest spectrographs of this type. 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 paper also outlines configuration, risk, and PA/QA management approaches, which we believe are

critical components of the management activities required to achieve the goal of bringing ANDES to the telescope in the most optimal way possible.

ACKNOWLEDGEMENTS

The Portuguese team is supported by Fundação para a Ciência e a Tecnologia (FCT) through the research grants UIDB/04434/2020 DOI: 10.54499/UIDB/04434/2020 and UIDP/04434/2020 DOI: 10.54499/UIDP/04434/2020. The Portuguese team thanks the Portuguese Space Agency for the provision of financial support in the framework of the PRODEX Programme of the European Space Agency (ESA) under contract number 4000143136.

The Swiss participation is partially funded by the SNSF, Swiss National Science Foundation.

AIP received financial support by the German Federal Ministry of Education and Research (BMBF/DESY-PH: 05A23BAB).

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