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# ELT High Resolution Spectrograph: Phase-A software architecture study

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**ABSTRACT**

High resolution spectroscopy has been considered of a primary importance to exploit the main scientific cases foreseen for ESO ELT, the Extremely Large Telescope, the future largest optical-infrared telescope in the world. In this context ESO commissioned a Phase-A feasibility study for the construction of a high resolution spectrograph for the ELT, tentatively named HIRES. The study, which lasted 1.5 years, started on March 2016 and was completed with a review phase held at Garching ESO headquarters with the aim to assess the scientific and technical feasibility of the proposed instrument. One of the main tasks of the study is the architectural design of the software covering all the aspects relevant to control an astronomical instrument: from observation preparation through instrument hardware and detectors control till data reduction and analysis. In this paper we present the outcome of the Phase-A study for the proposed HIRES software design highlighting its peculiarities, critical areas and performance aspects for the whole data flow. The End-to-End simulator, a tool already capable of simulating HIRES end products and currently being used to drive some design decision, is also shortly described.

**Keywords:** ELT instruments, control software, PLC, COTS

## 1. INTRODUCTION

ELT HIRES (acronym for Extremely Large Telescope HIgh REsolution Spectrograph, temporary name to be changed in the next project phases) is the high-resolution, high-efficiency, ultra-stable, optical-infrared spectrograph proposed for the ELT (the future ESO 39-m worldwide largest ground-based telescope). The requirement for an ELT instrument with such characteristics dates back to 2007 when ESO started defining the ELT instrumentation roadmap.

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High-resolution precision spectroscopy is indeed the only technique capable of fulfilling some of the flagship science cases for the ELT such as the detection of life signatures in Earth-like exoplanets and the direct detection of the cosmic expansion and re-acceleration, among others. A detailed description of the initial project phases and consortium organization leading to the Phase A HIRES feasibility study has been already reported in great detail in [1] and will not be repeated in this paper. Here we will present software aspects of the successful Phase A, 1.5-year lasting study, which emerged after the final review held at ESO HQ in December 2017.

It is important to recall that the HIRES operational scheme has been developed with the final goal of providing the astronomer with high-level products (e.g. radial-velocity measurements or other astronomical observables) as complete and precise as possible in a short time (within minutes) after the end of an observation. This will allow to maximize the overall efficiency in producing scientific outputs making HIRES a "science-grade products generating machine" following the philosophy already adopted in ESPRESSO (see[2] and references therein). In this paper we will present the proposed architecture of the specific HIRES software packages that will constitute the overall HIRES data flow system (DFS). They are shown with red labels in Figure 1, superimposed on the foreseen ESO night-time operation packages product tree (acronyms are explained in the caption of Figure 1).

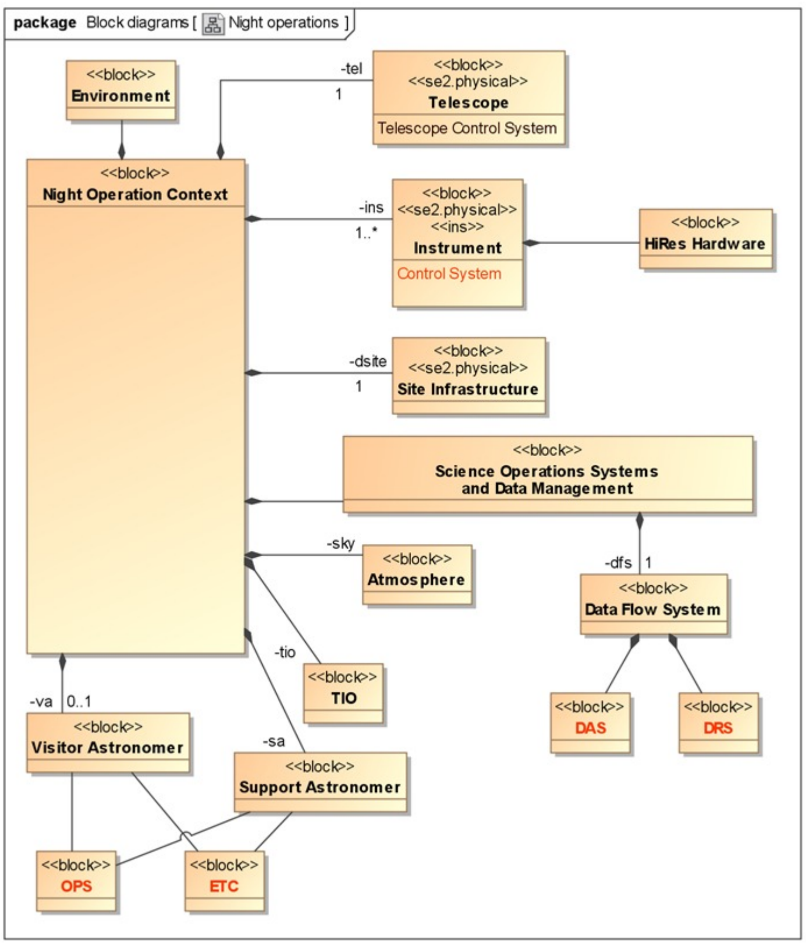


Figure 1. ELT night operations product tree with specific HIRES DFS packages (shown in red) superimposed. Black labels refer to packages outside the scope of the present study and are under ESO responsibility. OPS = Observation Preparation Software; ETC = Exposure Time Calculator; DAS = Data Analysis Software; DRS = Data Reduction Software

Note that during the present Phase A study a detailed design of the OPS package has been put on hold since its need will be defined in the next project phases according to the major scientific HIRES programs and the availability of ESO-specific tools. Therefore, design efforts have been put in developing a working prototype of an End-To-End simulator (E2E) which even if does not strictly belong to the final DFS it is crucial to predict the overall instrument performance and requirements as well as to drive the design of DFS packages in the early project phases. This paper is thus organized as follows: section 2 describes the HIRES instrument in terms of sub-systems and devices highlighting those aspects that are more relevant to the software, section 3 presents the major use cases and requirements, section 4 describes the proposed design for the control software and section 5 does the same for DAS and DRS. Last sections introduce some of the products developed in the design phase, in particular the HIRES ETC (section 6) and HIRES E2E (section 7), whereas section 8 highlights the main HIRES critical areas and challenges.

## 2. HIRES SYSTEM DESCRIPTION

HIRES is a modular fibre-fed cross-dispersed echelle spectrograph that will operate both at a Nasmyth and at Coudé focus of the ELT. The baseline solution (see Figure 2) consists of two separate spectrographs operating in the visible (BVRI) and infrared (ZYJH) bands. A more complete solution consisting of four separate spectrographs with the addition of the U and K bands respectively is also taken into account in the design (and handled by the software) even though this solution is currently termed as "*add-on*" due to the cost cap.

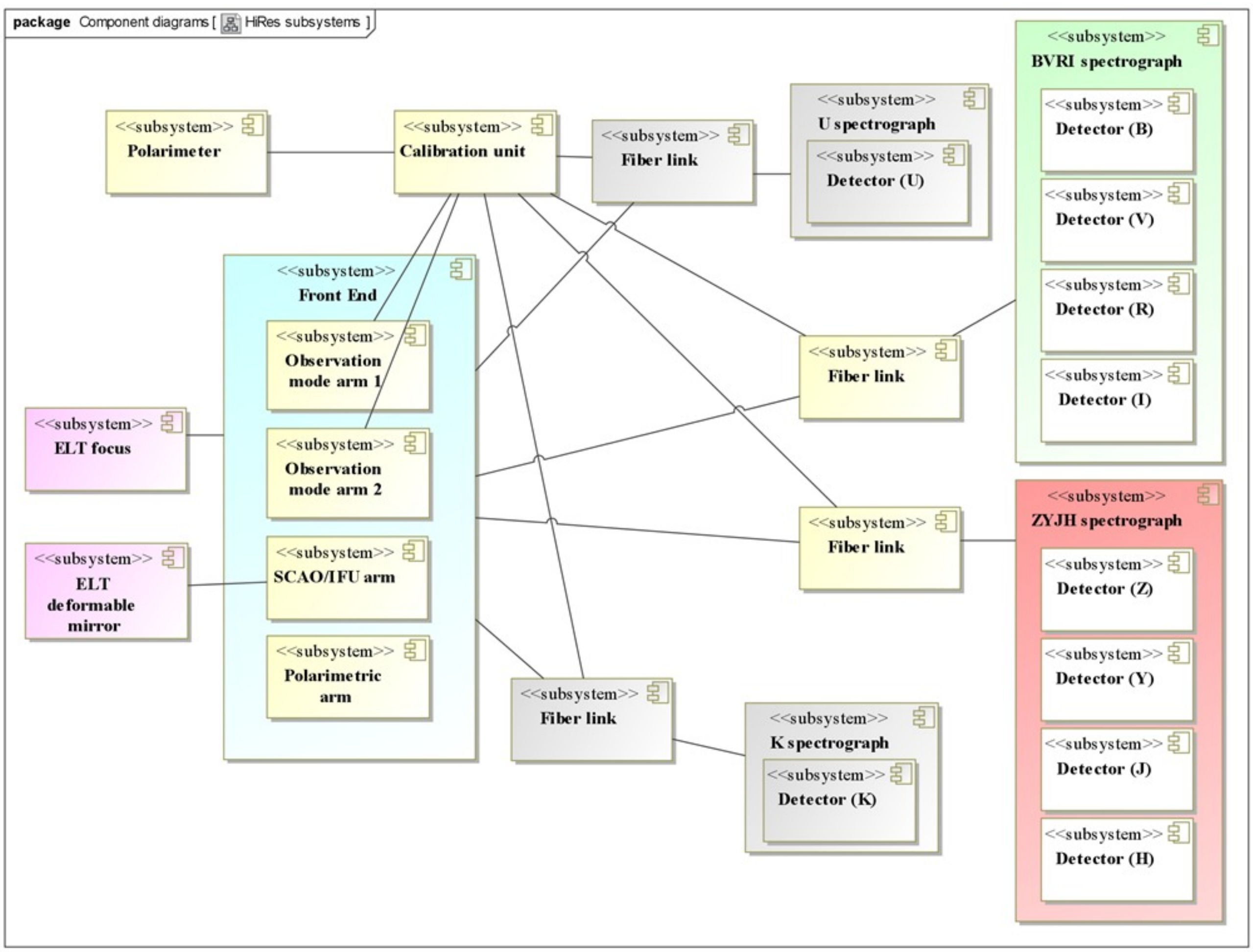


Figure 2. HIRES sub-systems. The grey boxes show the U and K spectrographs currently considered "*add-on*" due to cost cap imposed by ESO to all ELT second-generation instruments (see text for detailed description).

As shown in Figure 2 HIRES can be considered physically composed of the following parts:

- Front End, located at the Nasmyth focus B2 of the ELT;
- Fibre Links;
- Spectrographs (two for the baseline, visible one located at the Nasmyth focus, infrared one located in the Coudé room; four for the complete solution);
- Calibration Unit;
- Polarimeter;
- Single-Conjugated Adaptive Optics / Integral Field Units (SCAO/IFU) module

### 2.1 Front End

The task of the Front End, located at the Nasmyth focus B2, is to collect the light coming from the ELT focus, split it in different bandwidths, stabilize the light beams and feed the output fibres for the selected observing mode. The Front End is composed of four arms: two Observation Modes (OM) arms (for simultaneous observations of object and sky or two simultaneous objects), one SCAO/IFU arm and one Polarimetric arm. Each arm can translate and the whole Front End can rotate in order to select the target (object/sky) and to follow the sky rotation.

### 2.2 Spectrographs

The baseline solution foresees two spectrographs, a visible (BVRI) and an infrared one (ZYJH). A more complete solution foresees two more spectrographs (U and K). The BVRI and U spectrographs are located on the Nasmyth platform B, close to the Front End. The cryo-cooled spectrographs, ZYJH and K are located in the Coudé room. At the entrance of each spectrograph there is the input slit. The input slit is composed of the spectrograph fibres and associated micro-lenses. Each observing mode has an associated bundle of fibres in the input slit.

Each spectrograph contains scientific detectors:

- BVRI: four cameras, one for each band
- ZYJH: four cameras, one for each band
- U: one camera
- K: one camera

### 2.3 Calibration Unit

The Calibration Unit, located in the Coudé room, is connected via fibres to the Front End and to the Fibre Links. A shutter in the Calibration Unit enables the transmission of the calibration light into a Light Distribution Point (LDP) where its intensity is controlled via optical density filter(s). The LDP distributes the light to the Front End, the Polarimeter and the Fibre Links. The foreseen calibration sources are intensity calibration sources (laser driven light source, halogen lamps, light emitting diodes, light bulbs) and spectral sources for simultaneous calibration (AstroComb, Faby-Perot, single wavelength laser, hollow-cathode lamps).

### 2.4 Polarimeter

The HiRes Polarimeter is composed of two modules:

- Intermediate Focus Polarimetric Module (IFPM). It is located in the Adaptive Optics Tower of the telescope and is in charge of splitting the incoming beam into the ordinary and extraordinary rays via a birefringent prism (double Wollaston). This module uses also the calibration light via a fibre bundle coming from the Calibration Unit.
- Front End Polarimetric Module (FEPM). Once the target in the IFPM is acquired and tracked, it is picked-up by the FEPM. Besides the parallactic angle derotation provided by the Front End Unit, the image needs to be derotated for the linear polarizer (dW) rotation. This latter functionality is provided by a Dove prism located at

the entrance of the Polarimetric arm and must be remotely synchronized with the IFPM. The incoming beam separated into the two ordinary and extraordinary rays have different PSFs, and for this reason two dichroics split each ray into two different optical paths, replicating the modules BVRI and ZYJH. Then, along the optical path of each of the four resulting beams, there is an ADC and a field stabilization mirror controlled by a guiding camera. At the end, each beam is injected into the proper fibre bundle.

### 2.5 SCAO/IFU

The SCAO/IFU arm is composed of two modules: the SCAO module, that will provide guiding on the reference star and the analysis of the incoming wavefront and the IFU module that will transform the incoming light beam into appropriate f/numbers to feed the fibre bundles corresponding to different observing modes. The two modules are placed one above the other (the SCAO is above) and are separated by a dichroic.

## 3. HIRES REQUIREMENTS AND MAJOR USE CASES

The requirements of the HIRES Software are both of scientific and technical nature and originate from the instrument characteristics and the software requirements imposed by ESO for ELT Instruments. They depend also on the ESO adopted hardware and software solutions, termed *ESO standards,* and on the ESO standard organization of the instrument software. Although from an operational/control point of view HIRES could be considered a relatively standard instrument here we give an example of the work done during Phase A for the special case of technical CCD (TCCD) operations, which are particular challenging to guarantee the necessary HIRES performance.

The Technical Detectors Control System (TDCS) will provide HIRES with the necessary functionality to manipulate all the TCCDs: acquire technical images, provide images to a GUI (Graphical User Interface) or publish them in external data servers, configure and perform recipes (algorithms to be executed on data), configure and calibrate technical cameras and start-up/shutdown cameras.

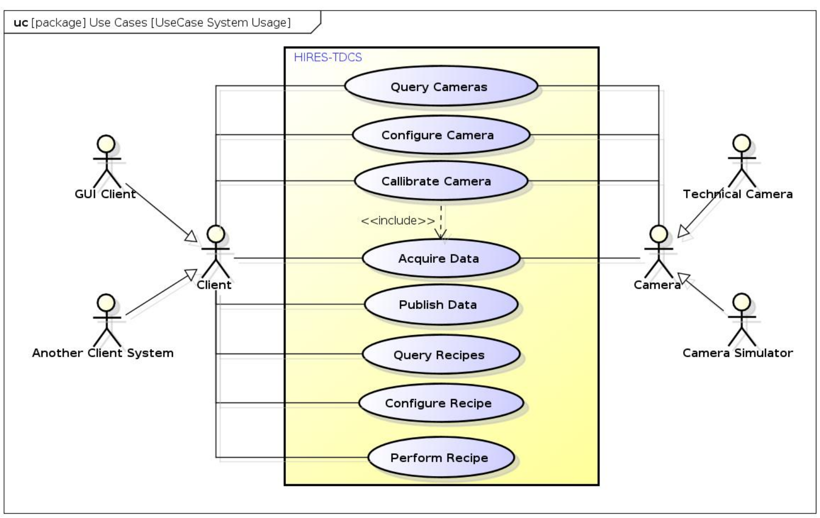


Figure 3. TDCS major use-cases shown on an use cases UML diagram.

This system was planned to be operated by two kinds of actors (external entities): a generic client, which can be a GUI or another Client system, and generic camera, which can be represented by a real Technical Camera or a Camera Simulator (although not depicted, the multiplicity of clients and cameras can be one or more). These actors were defined in order to fulfill the HIRES requirements and it is envisioned that they will operate with TDCS in a client-server fashion: through an appropriate interface, the actors follow a protocol state machine in order to execute the services provided by the TDCS system. Thus, there is flexibility on choosing the concrete kinds of actors since they obey the same protocol defined for the most generic kinds of actor planned to interact with the system: Client and Camera. The TDCS major use cases are summarized below (see Figure 3):

- Query Cameras: it is initiated by the Client actor in order to get all the available Cameras and their current configurations and status;
- Configure Camera: it is initiated by the Client actor in order to configure a Camera device;
- Calibrate Camera: it is initiated by a Client when it needs to calibrate a specific Camera;
- Acquire Data: it is initiated by a Client when it needs to acquire data from an external Camera;
- Publish Data: it is initiated by a Client when it needs to publish data acquired from a Camera;
- Query Recipes: it is initiated by a Client when it needs to know the recipes that are stored in the system;
- Configure Recipe: it is initiated by the Client actor in order to configure a recipe (create, read, update or delete recipe);
- Perform Recipe: it is initiated by the Client actor in order to perform a recipe on input data that was previously stored from an acquisition process.

# 4. CONTROL

The architecture of the HIRES control software follows the design defined in the "E-ELT Instrument Control System Conceptual Architecture" (see[4]), where the Supervision System of the high-level software will coordinate the functionalities of the low-level control software.

## 4.1 High-level control software

The main purpose of the High Level Control Software is to coordinate a scientific exposure. In the planned ELT Instrument Control System architecture, the software component in charge of performing this task is the Supervision System. This component manages the execution of the exposures of the individual spectrographs, according to the given observation mode, and implements the interfaces to the external sub-systems. The Supervision System is composed of the following components:

- Observation Sequencer. It executes the templates contained in the observation scripts. The commands specified in the templates are sent to the Observation Coordination Manager;
- Observation Coordination Manager. It coordinates and supervises the scientific exposure, handling simultaneously the data acquisitions of the individual spectrographs;
- Configuration Manager. It is used for the internal configuration of the Supervision System software components;
- Data Product Manager. It is used to merge the metadata coming from the instrument sub-systems with the scientific images and send them to the archive system.

## 4.2 Low-level control software

The HIRES low-level control software is in charge of monitoring and controlling the electronic devices located in the instrument sub-systems. Its main responsibility is to redirect the light coming from the target sources to the scientific detectors and keep the system stable during an exposure. The functionalities of the low-level software are grouped under the concept of the Functional Control System (FCS). In HIRES, the architecture was designed having in mind the concept of "high cohesion and loose coupling", which means to keep related functionalities inside a FCS, and separate different functionalities that don't depend on each other, in separated Functional Control Systems (FCSs). This concept will facilitate the development of the control software in different institutes, since changes introduced during the development phase will mostly affect a single sub-system (located at the same institute) and won't affect functionalities that are already stabilized and validated in another institute.

Figure 4 shows an overview of the low-level software architecture where we foresee to have 7 FCSs (9 if U and K spectrographs would be present) to ensure the required modularity of this project.

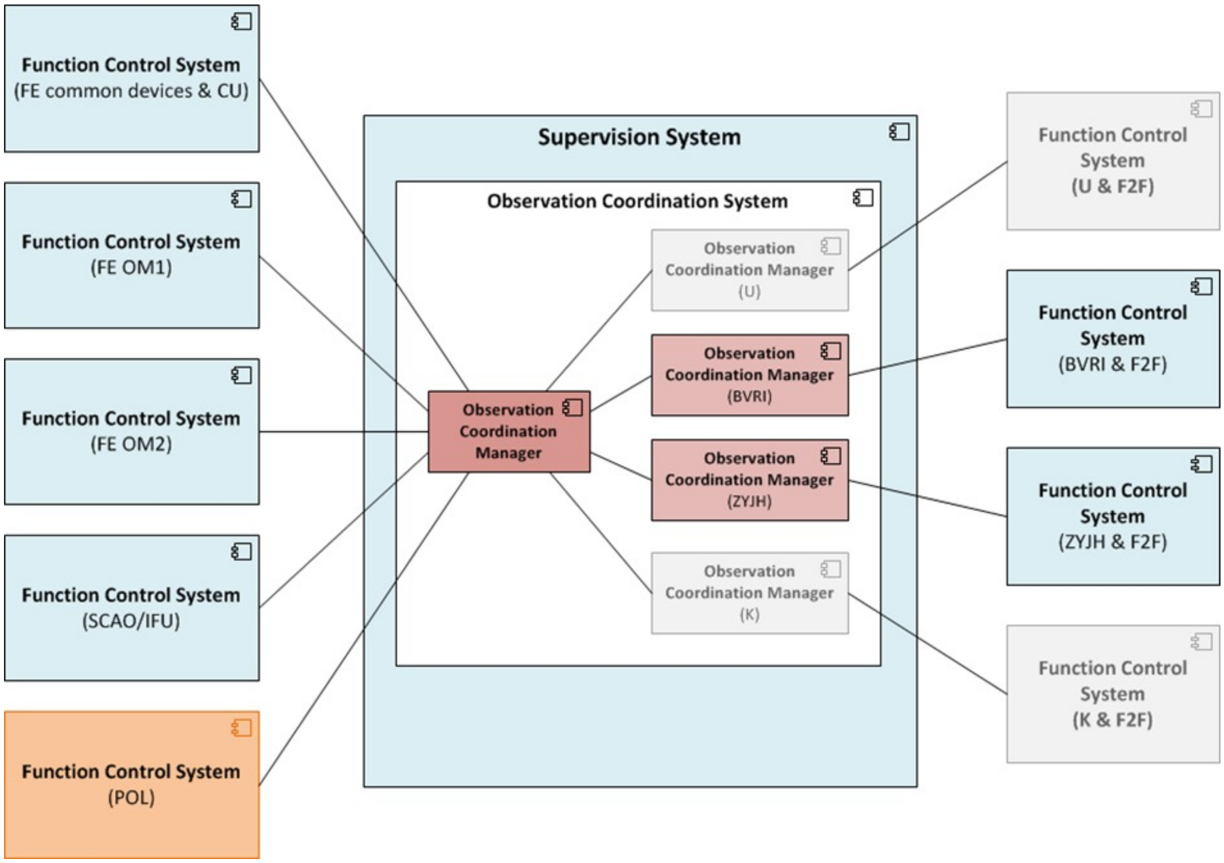


Figure 4. Overview of the HIRES low-level software architecture (see text for a detailed description)

The control of the Front End hardware will be divided into four FCSs:

a. the Front End common devices and Calibration Unit: it will control the Front End de-rotator, the movement of the arms, and the devices in the Calibration Unit;

b. the Front End Observation Mode Arm 1 (OM1): it will control the Tilt-Tip mirrors, ADC, technical cameras, focusing mechanism, shutters, and fibre bundle mode selectors;

c. the Front End Observation Mode Arm 2 (OM2): same as OM1, but for the OM2;

d. the SCAO/IFU arm: it will control the devices of the SCAO sub-system.

A dedicated FCS will be used for the Polarimetry sub-system; it will control both the respective Front End arm and the devices in the telescope tower. In addition, a dedicated FCS will be used per spectrograph and corresponding fibre-to-fibre box. The interface to the electronic devices follows ESO specification, in which the local hardware controllers will be based on commercial off-the-shelf industrial Programmable Logic Control (PLC) units.

In each FCS, based on the System Configuration interface, it is possible to route the control and monitor messages to simulators for the development and testing of the high-level control software without the hardware. In addition each FCS provides an engineering interface which allows verifying the electronic hardware without the high-level software. Although still depending on the future implementation of the ELT common software, we expected that most of the devices defined in HIRES should fall in the category of an "ESO standard device". Therefore, no additional software is required except for the configuration of the specific parameters of each device.

# 5. DATA REDUCTION AND ANALYSIS

As described in section 2, the entire HIRES software (control and scientific), is being developed with the final goal of providing the astronomer with high level products as complete and precise as possible in a short time (within minutes) after the end of an observation. To this purpose, beside the "classical" Data Reduction Software (DRS) package aimed at removing the instrument signature and extract the final spectrum in a way as optimal as possible, a fully integrated Data Analysis Package (DAS) has been also conceived, able to perform scientific measurements on data as soon as they are reduced. Both packages will be fully integrated in the ESO context, i.e. written in C, using CPL and other ESO tools like EsoRex and Reflex[5].

## 5.1 Data reduction

The HIRES DRS will be a data reduction library for both visible and near-infrared parts of the spectrograph. The visible part will be inspired by the ESPRESSO pipeline and the NIR part by the CRIRES+ pipeline. It will follow the usual scheme of spectroscopic data reduction: the detector characterization, orders definition, wavelength calibration, different additional calibrations and finally the science reduction. An outline of the reduction cascade envisaged for HIRES is shown in Figure 5.

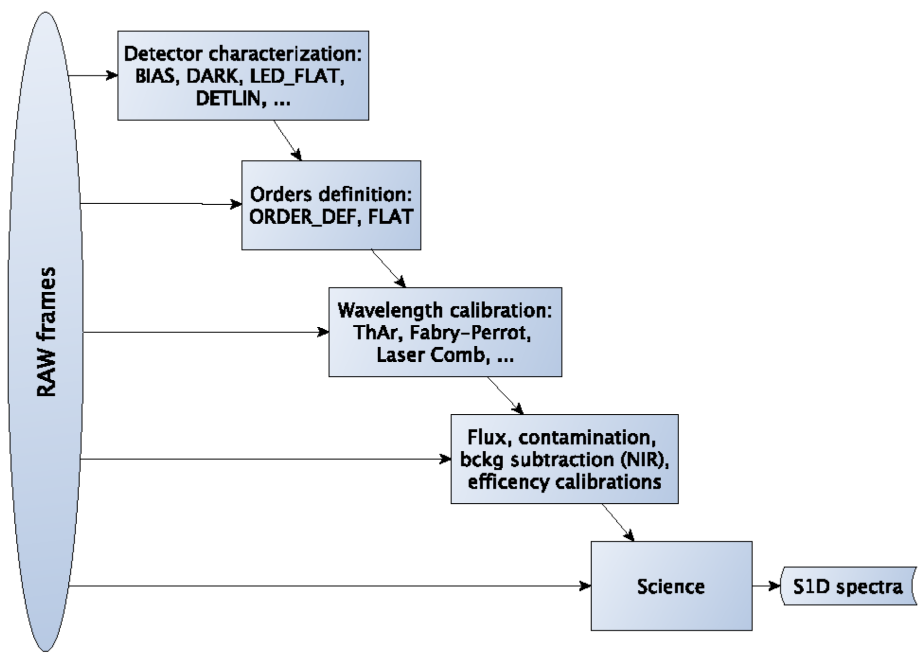


Figure 5. HIRES data reduction cascade.

For proof-of-principle and despite the early project phase, beta recipes of the CRIRES+ DRS have been applied on images produced by the HIRES End-To-End simulator (E2E; see section 7). Although HIRES is fibre-fed and CRIRES+ is a true slit spectrograph, they do share enough similarities in the echellograms (high-resolution, cross dispersed, inclined and curved slits) so that the recipes could be applied without modification. A successful order tracing, i.e. finding the spectral orders and fitting them with polynomials, allowed us to optimally extract (applying robust algorithms) the simulated spectrum from the first available E2E science frame with simultaneous etalon-calibration on either side of the slit (see Figure 6 and 7).

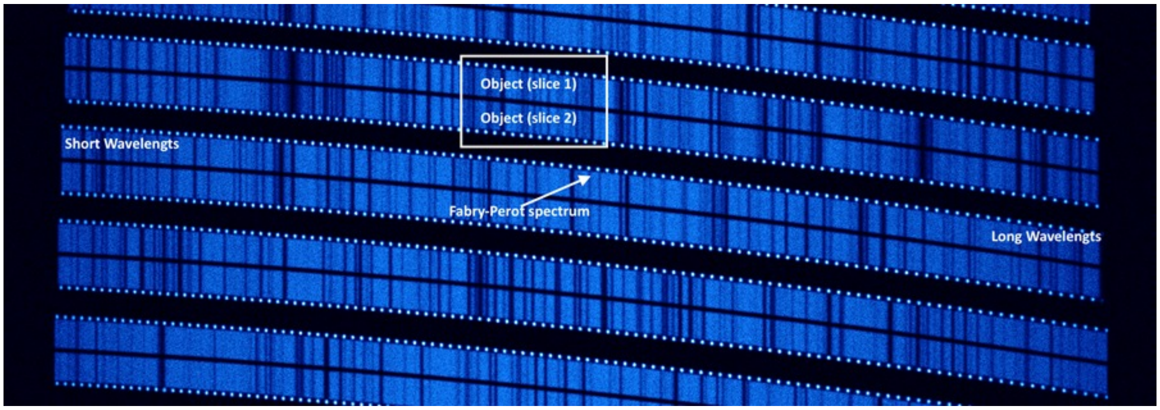


Figure 6. Simulated science spectrum with simultaneous etalon-calibration.

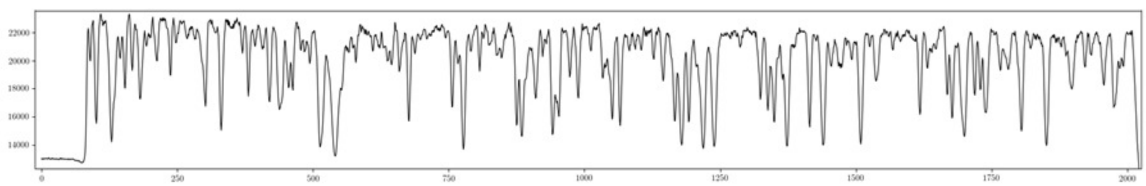

Figure7. Extracted HIRES science spectrum from the 2-D frame shown in Figure 6.

### 5.2 Data Analysis

The concept of the DAS is modelled on the Data Analysis Software of VLT ESPRESSO as a set of self-standing modules ("recipes") performing interdependent operations. In the case of ESPRESSO, recipes were written in ANSI-C as plugins of the standard VLT Data Flow System. They were meant to be run individually through the EsoRex command-line interface, or in a cascade-like fashion through the EsoReflex workflow environment. The EsoReflex workflows included a set of Python scripts to interactively inspect the data and set up the recipe execution.

The solutions to be adopted for the ELT Data Flow System are obviously still unknown. The DAS design is aimed to be as portable as possible, to allow for easy implementation to whichever environments will be chosen. Based on the lessons learned from ESPRESSO, we have set the following guidelines for the early development phase:

- the granularity of the analysis operations will be increased with respect to ESPRESSO, to accommodate more complex (and possibly unforeseen) analysis tasks;
- the list of modules will be left open to include further operations at a later time (either developing new algorithms or porting existing solutions into the DAS);
- the early development of the code will be done in Python, to easily test different solutions in a mature environment with several available tools, specifically designed for astronomical analysis.

A full prospective list of HIRES science cases to be addressed by the DAS is outside the scope of this paper. However we highlight that they will be mainly focused on the analysis of stellar and quasar spectra aiming to address some of the top-priority HIRES science cases (e.g. variation of fundamental constants, detection and investigation of near pristine gas, characterization of cools, pristine stars and their atmospheric parameters etc.).

## 6. ETC

The ETC is a tool to predict the global performance of the spectrograph, given a number of instrumental and environmental input parameters. The input parameters can be modified to allow quantification of their effect on the spectrograph performance. The ETC computes the limiting magnitude and the limiting surface brightness achievable for a point source and an extended object, respectively, at a given wavelength, for a given exposure time and signal to noise ratio (SNR). The ETC can also predict the SNR that is achievable at a given wavelength, in a given exposure time and at a given magnitude (for a compact object) or at a given surface brightness (for an extended source).

During the Phase A, a web-based ETC has been designed and implemented (see[3] and references therein). It is based on an HTML GUI interfaced with a PHP program that invokes an executable FORTRAN program with the chosen set of input parameters. The output information generated by the FORTRAN code is written subsequently in the output web page by the PHP program and shown to the user. A detailed description of the adopted algorithms and parameters together with the current telescope and instrument specifications can be found, by the interested reader, following the link referenced in [3].

It is worth noticing that ESO developed, before HIRES Phase A, an ETC prototype dedicated to ELT high resolution spectroscopy. However the two tools operate differently: the HIRES ETC works wavelength by wavelength and, differently from the ESO ELT ETC, it does not take into account the target flux distribution. Nevertheless the two tools behave very similarly and we verified that both predict consistent results. An example is shown in Table 1 where we computed, as an example, the SNR ratio for a compact source assuming similar parameters.

| **HIRES ETC** | **ESO ELT ETC** |
|---|---|
| WL = 0.55 | WL = 0.55 |
| AB mag = 15 | AB mag = 15 |
| EXPTIME = 1800 | |
| NDIT = 1 | NDIT = 1800 |
| | target source = power law with index eq. 0 |
| airmass = 1 | airmass = 1 |
| R = 100000 | R = 100000 |
| DAPE (sky projected angular diameter of the spectrometer aperture) = 0.8 | radius of SNR reference area=400 |
| | number of pixels in SNR reference area=96 |
| dark current = 2 | |
| RON = 2 | |
| **SNR=385.9** | **SNR=372** |

Table 1. Input parameters set for the two ETCs to determine the SNR ratio (last row, bold) in case of a compact source. For the other input parameters we have used the default values. Note that the instrument efficiency in the HIRES ETC is set appropriately to obtain the total efficiency = 0.25, as in the case of ESO ELT ETC.

# 7. E2E

The End-to-End (E2E) simulator, as described in a separate paper of this same proceeding, is a modular tool capable of predicting the science raw data as collected at the telescope, starting from an input theoretical spectral energy distribution related to a specific scientific target object. The main goal of this simulator is the physical modeling of the light propagation form the astrophysical source to the raw data produced by the instrument. In case of HIRES, the E2E simulator comes in two versions. The first (the parametric version) adopts the paraxial approximation to characterize each optical element. The second (the ray tracing version) uses commercial optical design software (e.g. ZEMAX®) to predict the combined effects of each optical element.

The modules and units constituting the E2E simulator include the major components of the instrument (Calibration Unit, Front End unit, fibre-link, spectrographs, detectors, etc.) as well as external modules, which provide the necessary information at the instrument entrance window (e.g. the theoretical source spectrum, atmospheric absorption and emission, the telescope PSF, among others). A high level program, currently implemented in Matlab®, controls and coordinates the action of each module as well as the interface and data exchange between different modules. As properly described in[6], the simulator has been designed to achieve high computational performance by adopting the proper state-of-the-art technologies. Specifically, the adoption of Cloud-Computing and massive parallel computing architectures allow to speed up by various orders of magnitude the computational time.

The tool has multiple purposes: 1) help the instrument design phase, 2) facilitate the development of other instrument software (e.g. data reduction and data analysis tools), and 3) allow the timely verification of the science requirements. Figure 6 shows one of first science frame simulated by HIRES E2E.

## 8. CHALLENGES AND CRITICAL AREAS

The design of HIRES as emerged from the Phase A identifies no particular showstoppers or critical areas. Considering only the baseline solution, for HIRES the following scientific detectors are foreseen:

- BVRI: four cameras, 4k x 4k - 15 µm, or 6.3k x 6.3k – 10 µm, or 10k x 10k – 6.3 µm, one for each band (physical dimension 63 x 63 mm)
- ZYJH: four cameras, 4k x 4k - 15 µm, one for each band (physical dimension 63 x 63 mm)

Taking into account the most demanding scenario (i.e. 10k x 10k detectors) and roughly estimating the engineering data produced by TCCDs the data size of one exposure involving all the spectrographs amounts to ~ 1 TB, well within current archive capabilities.

The maximum data rate foreseen (theoretical) is linked to the shortest duty cycle of exposures which amounts to several seconds. Based also on ESPRESSO results, software overhead and detector read-out implies a little bit less than one exposure (all bands) per minute i.e. 400 exposures on an 8 hours night. The required data storage amounts therefore to roughly 400 TB per night. This is anyway purely theoretical (real observation will not be done with such cadence) and does not impose actually significant problems: current storage capacities are well able to cope with such amounts.

For the control performance aspects the more demanding areas are the stabilization loops and the SCAO system. The frequency for stabilization loops are of the order of Hz or slightly more which is well inside the capabilities of a typical standard workstation with multi-core CPUs. SCAO requirements in terms of performance are obviously more demanding. Computationally, the key component will be represented by a dedicated real-time computer (RTC) able to perform the required reconstruction operations. Specifically, it will be in charge to compute the wavefront deformation and command the M4 adaptive mirror with a frequency of the order of 1 kHz (goal 2 kHz) considering 90x90 sub-apertures. The expected computational power is about 100 GFlops not unrealistic already with present day SCAO systems.

## 9. PROJECT NEXT PHASES

In this paper we have presented the outcome of the software design activities developed in the framework of the ELT HIRES Phase A study for the entire data flow. In response to the high level of modularity and parallelism in the development of the HIRES instrument, the HIRES Consortium has agreed to propose an aggressive schedule, aiming at bringing the instrument to the telescope as soon as possible after the first-light ELT instruments. The current schedule, foresees to achieve first light 7 years after the kick-off of the Phase B. Note that the HIRES project phases follow the standard approach for all ESO instruments. Phase B, which will follow the current Phase A, will start with signing a memorandum of understanding for the construction phase between ESO and the Consortium. It will last until the successful conclusion of the instrument Preliminary Design Review (PDR). Subsequent phases (final design review and MAIT - manufacture, assembly and integration) will eventually lead to the Preliminary Acceptance in Europe (PAE), scheduled currently in 2026 (provided Phase B will start in 2019). The software design work done during the Phase A, presented in this paper and reviewed at the final review, has been considered well in advance and without major showstoppers. The consortium is therefore quite confident that despite the aggressive schedule the software packages, control and science, can be developed in time and at required level of excellence to allow to fully exploit the groundbreaking scientific cases foreseen for the HIRES instrument.

## REFERENCES


[1] Di Marcantonio, P., et al., "Software and Cyberinfrastructure for Astronomy III," Proc. SPIE 9913, 99133R-1 (2016).

[2] Cupani, G., et al., "Software and Cyberinfrastructure for Astronomy III," Proc. SPIE 9913, 99131T (2016).

[3] "http://www.arcetri.astro.it/~hires"

[4] Kiekebusch, M., et al., "E-ELT Instrument Control System Conceptual Architecture," ESO Tech. Doc. ESO-205917, issue 1 (2013).

[5] Freudling, W., et al., "Automated data reduction workflows for astronomy The ESO Reflex environment," A&A 559, A96 (2013).

[6] Genoni, M., et al., "The end-to-end simulator for the EELT HIRES high resolution spectrograph," Proc. SPIE 10329, 103290Z-1 (2017).