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T-REX OU4 HIRES: the high resolution spectrograph for the E-ELT

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Abstract. The goal of this unit was to consolidate the project for the construction of the high resolution spectrometer of the E-ELT (HIRES). The task included the development of scientific cases and tools to predict the instrumental performances. From the technical point of view it included several R&D activities in collaboration with highly specialized Italian companies; it culminated with the detailed design of a highly modular instrument based on well established technologies. From the management point of view it lead to the consolidation of a large international consortium that spans over 12 countries and includes most of the European and ESO-related institutes interested in high resolution spectroscopy. This consortium is led by INAF; its formal creation is awaiting the official call by ESO for the phase-A study for the HIRES instrument of the E-ELT.

Key words. Instrumentation: spectrographs – Techniques: high resolution spectroscopy – Telescopes: Extremely Large Telescopes

1. Introduction

The Italian astronomical community has always demonstrated great interest in high-resolution spectroscopy both from the scientific and technical points of view. Different groups of INAF astronomers played crucial roles in the projects for the construction of spectrometers for the TNG (SARG, GIANO) and for ESO-VLT (UVES-FLAMES, XSHOOTER, ESPRESSO, CRIRES). INAF was deeply involved in the early (2007-2010) phase-A studies for the high resolution spectrographs for E-ELT. INAF led the international consortium that presented the infrared high-resolution spectrograph (SIMPLE), and was a major contributor to the consortium that studied CODEX, the visual high-resolution spectrometer. Within the re-organization of the E-ELT project, ESO published in 2011 a detailed proposal for the construction of the telescope and instruments. In this document ESO identified two first-light instruments (ELT-CAM/MAORY and ELT-IFU) and other three instruments with equal scientific priority, namely ELT-MIR (a middle-infrared camera and spectrometer), ELT-MOS (a multi-objects spectrograph) and ELT-HIRES (a HR spectrograph covering the optical and infrared λ-ranges). The ESO road-map originally foresaw a call for proposals for ELT-MOS and ELT-HIRES in 2013; this date was later on shifted forward in time. Given the widespread interest of the Italian scientific community towards spectroscopy, a dedicated operative unit (OU4) for the study of ELT-HIRES was included in the TREX project.

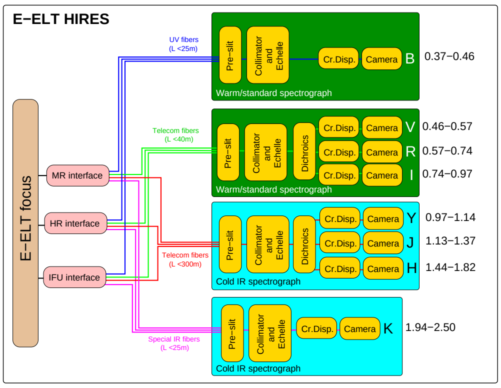

Fig. 1. Possible HIRES architecture with spectral separation in four spectrometers.

2. Science cases and requirements

HIRES is conceived to be a versatile instrument capable of pursuing a range of key science cases most of which can only be achieved through high spectral resolution with the photon collecting area provided by the E-ELT. In the following we give a very concise summary of the main science cases and requirements, extracted from the HIRES white paper (1). The characterization of exoplanets is one of the outstanding key science cases for HIRES. The focus will be on characterizing exoplanet atmospheres over a wide range of masses, from Neptune-like down to Earth-like including those in the habitable zones. The ultimate goal is the detection of signatures of life. The key requirements for are a spectral resolution R$\sim10^5$ (primarily to disentangle the exoplanet atmospheric features from the telluric absorption lines of our atmosphere) a wide wavelength range (0.37-2.5 μm), high stability of the PSF on the detector during planetary transits and high flat-fielding accuracy. A polarimetric mode would further enhance the exoplanet diagnostic capabilities of HIRES, especially for the detection of bio-signatures. HIRES will also provide the unique capability of revealing the dynamics, chemistry and physical conditions of the inner regions of the accretion disks and protoplanetary disks of young stellar objects, hence providing unprecedented constraints on the physics of star and planets formation. To achieve these goals the instruments high spectral resolution should be accompanied with spatially resolved information (IFU mode) at the diffraction limit of the E-ELT. This science case would also benefit from a polarimetric mode for the measurement of magnetic fields in the accretion disk. In the field of stellar abundances HIRES with broad spectral coverage and R$\sim10^5$ will reveal the origin and the formation history of ancient stars belonging to different Galactic components, by studying chemical enrichment pattern of solar-type and cooler dwarf stars out to distances of several kpc (i.e. sampling most of the Galactic disk and bulge) or subgiants and red giants in the outer Galactic

Halo and in neighbouring dwarf galaxies. In the context of galaxy formation and cosmology, one of the exciting prospects is the detection of elements synthesized by the first stars in the early Universe. HIRES will probably be the first facility that will detect the fingerprint of PopIII stars by measuring the chemical enrichment typical of this population in the Inter-Galactic (IGM) and Inter-Stellar Medium (ISM) in the foreground of Quasars, GRBs and Super-Luminous Supernovae at high redshift, probing in this way the epoch of reionization. With some MOS capabilities (i.e. simultaneous spectroscopy of 5-10 objects at R ~20,000) HIRES will also be able to obtain a three-dimensional map of the cosmic web and of the distribution of metals in the IGM at high red-shift, by probing absorption systems towards multiple lines of sight on scales of a few arc-minutes. The same MOS capabilities are also required to investigate the processes driving the evolution of massive early type galaxies, during the epochs of their formation and assembly (z∼1-3). HIRES with an IFU sampling the ELT diffraction limit will be the only instrument able to measure the low mass end of super-massive black hole in galactic nuclei, which bears signature of primordial black hole seeds. Perhaps most exciting, HIRES will be an instrument capable of addressing issues that go beyond the limited field of Astronomy, breaking into the domain of "fundamental physics". In particular, HIRES will provide the most accurate constraints on a possible variation of the fundamental constants of nature, and in particular of the fine structure constant α and of the proton-to-electron mass ratio μ. By measuring the red-shift drift-rate dz/dt of absorption features in distant QSOs, HIRES will be the only instrument capable of obtaining a direct and completely model-independent measurement of the Universes expansion history. This should be regarded as the beginning of a legacy experiment lasting several decades.

3. Instrument design

Designing a high resolution spectrograph with wide spectral coverage for the E-ELT represents a challenge for two main reasons. The immense AΩ of a 40-meters class telescope operated in seeing-limited mode requires some level of AΩ splitting in order to contain the design in sizes for which the optics can be manufactured. In addition, operating the instrument from the blue to the K band requires different detector and opto-mechanical technologies, e.g. a cryogenic environment for the IR optics. A modular fiber-fed cross-dispersed echelle spectrograph is considered as a viable baseline solution. The overall concept is summarized in Figure 1. The light from the telescope is split, via dichroics, into four wavelength channels. Each wavelength channel includes several telescope optical interfaces that feed, through groups of fibers, a dedicated spectrograph module. Each telescope-interface and fiber-bundle corresponds to an observing mode. Our study indicates that the instrument can be most conveniently divided in four spectrograph modules as shown in Figure 1. The splitting in wavelengths approximately matches the photometric bands, i.e. B, VRI, YJH and K. The shortest wavelength is 0.37 μm but could be extended to the ultraviolet by adding a U (0.33-0.37 μm) channel to the B module. The split in λ's among the modules is influenced, among all other parameters by the optical transparency of the different types of fibers available on the market. Therefore, the different modules can be positioned at dif-

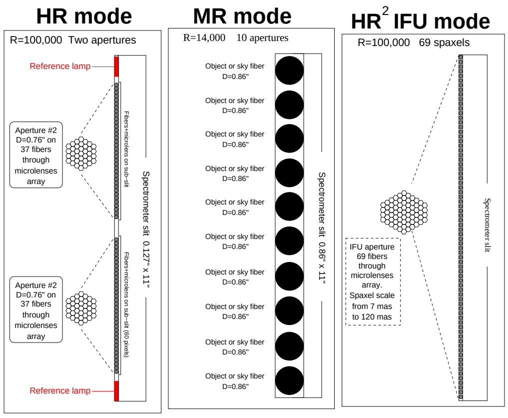

Fig. 2. Schematic view of the slit illumination in the main observing modes of HIRES.

Table 1. Main parameters of the observing modes of HIRES

Parameter	HR mode	MR mode	HR^2 IFU mode
Resolving power ($\lambda/\Delta\lambda$)	100,000	14,000	100,000
# of simultaneous objects	2 + λ_{ref} lamp	10	69 spaxels
Aperture on sky	D=0.76"	D=0.86"	7–120 mas/spaxel$^{(1)}$
	per object	per object	58–1000 mas f.o.v.
Slicing/dicing	37 fibers/object	1 fiber/object	1 fiber/spaxel
Diameter of each fiber core	0.085 mm	0.57 mm	0.085 mm
Projected fiber size on detector	3×2 pix	20×11 pix	3×2 pix
(see note 2 below)	5×3 pix	37×20 pix	5×3 pix

$^{(1)}$ The scale and f.o.v. of the IFU mode can be changed in the telescope interface optics.
$^{(2)}$ First entries for for IR detectors, second entries are for optical CCDs.

ferent distances from the telescope focal plane. All spectrometer modules have a fixed configuration, i.e. no moving parts. They include a series of parallel entrance slits, each generated from a separate set of fibers that, in turn, determines the observing mode (see Figure˜reffig2). Observing modes are selected at the level of the telescope interface. The three basic observing modes (HR, MR, HR^2-IFU) are shown in Figure 2; their parameters are listed in Table 1. A fourth mode, namely UHR, can be added in order to provide even higher resolution i.e. R∼150,000. With such a modular approach one could also increase the number of observing modes by adding other sets of fibers and telescope interfaces.

4. Conclusions

The study demonstrated that a high-resolution spectrometer (R∼10^5) for E-ELT covering a wide λ-range (0.37 to 2.5μm) can reach unprecedented scientific goals and can be built with currently available technology. The widespread interest in this project led to the creation of a large international collaboration that started as "HIRES initiative" (Zerbi et al. 2014).

The modularity of the HIRES concept can guarantee the best use of time and resources. The project can be developed with different time-lines for the various sub-systems, depending on the available funds. It is reasonable to consider an early delivery of one or two spectrograph modules, with a limited front end. The other spectral modules and full interface capabilities (polarimetry, MR and HR^2-IFU modes) can be added later on. Being a fiber-fed instrument designed for seeing limited observations, the main performances of HIRES will not depend on external adaptive optics nor variations of pupil illumination (e.g. missing segments from primary mirror).

References

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