HIRES: The High Resolution Spectrograph for E-ELT

F. M. Zerbi*[a], F. Bouchy[b], J. Fynbo[c], R. Maiolino[d], N.Piskunov[e], R. Rebolo Lopez[f], N. Santos[g], K. Strassmeier[j], S. Udry[h], L. Vanzi[k], M. Riva[i], A.Basden[l], I. Boisse[b], X. Bonfils[m], D. Buscher[d], A. Cabral[n], P. Dimarcantonio[o], I. Di Varano[h], D. Henry[p], M. Monteiro[g], T. Morris[l], G. Murray[l], E. Oliva[q], I. Parry[r], F. Pepe[h], A. Quirrenbach[s], J.L. Rasilla[f], P. Rees[p], E. Stempels[e], L. Valenziano[t], M. Wells[p], F. Wildi[h], L. Origlia[u], C. Allende Prieto[f], A. Chiavassa[v], S. Cristiani[o], P. Figueira[g], B. Gustafsson[e], A. Hatzes[w], M- Haehnelt[r], K. Heng[x], G. Israelian[f], O. Kochukhov[e], C. Lovis[h], A. Marconi[y], C.J.A.P. Martins[g], P. Noterdaeme[z], P. Petitjean[z], T. Puzia[aa], D. Queloz[d], A. Reiners[ab] M Zoccali[k]

[a]Scientific Directorate of INAF – Viale del Parco Mellini 84, I-00036 Roma (Italy); [b]Laboratoire d'Astrophysique de Marseille – CNRS – Rue Frédéric Joliot Curie, 13013 Marseille, France; [c]Dark Cosmology Center – Juliane Maries Vej 30, 2100 Copenhagen O- Denmark; [d]Cavendish Laboratory – University of Cambridge, 19 JJ Thomson Ave, Cambridge CB3 0HE– United Kingdom; [e]Department of Physics and Astronomy – University of Uppsala - Regementsvägen 1 SE-752 37 Uppsala, Sweden; [f]Instituto de Astrofisica de Canarias (IAC) – C/ Vía Láctea, s/n E38205 - La Laguna (Tenerife). España; [g]Centro de Astrofisica – Universidade do Porto - Rua das Estrelas, 4150-762 Porto - Portugal; [j]Astrophysical Institute Potsdam, An der Sternwarte 16, 14482 Potsdam, Germany; [h]Observatoire Astronomique – Université de Geneve - Chemin des Maillettes 51, Sauverny, CH-1290 Versoix, Switzerland; [k]Centro de Astro Ingenieria – Pontificia Universidad Catolica de Chile – Avda. Libertador Bernardo O'Higgins 340 - Santiago de Chile; [i]INAF-Osservatorio Astronomico di Brera – Via Bianchi 46, I-23807 Merate, Italy; [l]Department of Physics University of Durham – South Road, Durham DH1 3LE – UK; [m]Observatoire de Science de l'Univers de Grenoble - France; [n]Faculdade de Ciencias – Universidade da Lisboa - 1749-016 Lisbon, Portugal; [o]INAF Osservatorio Astronomico di Trieste – Via Tiepolo Giambattista, 11, 34131 - Trieste Italy; [p]UK Astronomy Technology Centre – Blackford Hill Edinburgh EH9 3HJ – UK; [q]INAF-Osservatorio Astrofisico di Arcetri – Largo Enrico Fermi, 5, 50125 - Firenze Italy; [r]Institute of Astronomy – University of Cambridge – Madingley Road, Cambridge CB3 0HA, UK; [s]Landessternwarte Heidelberg – Koenigstuhl 69117 Heidelberg - Germany; [t]INAF-IASF Bologna – V.Piero Gobetti, 101 - 40129 , Bologna – Italy; [u]INAF-Osservatorio Astronomico di Bologna – Via Ranzani, 1, 40127, Bologna, Italy; [v]Observatoire de la Cote d'Azur – Boulevard de l'Observatoire, 06300, Nice – France; [w]Thuringer Landessternwarte, Sternwarte 5, 07778 Tautenburg - Germany; [x]Center for Space and Habitability – University of Bern – Sidlerstrasse 5, CH-3012, Bern - Switzerland; [y]Dipartimento di Fisica ed Astronomica, Università di Firenze, Via G. Sansone 1, I-50019 Sesto Fiorentino (Fi), Italy; [z]Institute d'Astrophysique de Paris – 98bis Boulevard Arago, 75014 Paris- France; [aa]Institute of Astrophysics, Pontificia Universidad Catolica de Chile – Avda. Libertador Bernardo O'Higgins 340 - Santiago de Chile; [ab]Institute for Astrophysics University of Göttingen – Friedrich-Hund-Platz 1 37077 Göttingen Germany;

ABSTRACT

The current instrumentation plan for the E-ELT foresees a High Resolution Spectrograph conventionally indicated as HIRES. Shaped on the study of extra-solar planet atmospheres, Pop-III stars and fundamental physical constants, HIRES is intended to embed observing modes at high-resolution (up to R=150000) and large spectral range (from the blue limit

Ground-based and Airborne Instrumentation for Astronomy V, edited by Suzanne K. Ramsay, Ian S. McLean, Hideki Takami, Proc. of SPIE Vol. 9147, 914723 · © 2014 SPIE · CCC code: 0277-786X/14/$18 · doi: 10.1117/12.2055329

to the K band) useful for a large suite of science cases that can exclusively be tackled by the E-ELT. We present in this paper the solution for HIRES envisaged by the "HIRES initiative", the international collaboration established in 2013 to pursue a HIRES on E-ELT.

Keywords: Extra-solar Planet Atmospheres, High Resolution Spectroscopy, Extremely Large Telescopes

1. INTRODUCTION

The exploitation of the large collecting area of the EELT to explore the High Spectral Resolution domain has been considered and studied since the early phases of the E-ELT program. Out of the Phase-A Instrument studies[1] two have been dedicated to the spectral high resolution domain: CODEX[2], an ultra-stable optical (0.37-0.710 μm) high resolution (R=120,000) spectrograph and SIMPLE[3], a Near-IR (0.84-2.5 μm) High Resolution (R=130,000) AO-assisted spectrograph.

Later, following the recommendation of the EELT Science Working Group and the ESO Scientific Technical Committee, one single High Resolution Spectrograph was scheduled to start a phase-A study in 2014. This instrument is expected to digest and merge, were possible, the science cases and technical solutions proposed in the former phase-A studies. In addition is expected to explore new synergic concepts and features to provide the community with the best possible performance.

An instrument of this kind and size is a relevant effort both in terms of human and financial resources. For this reason in early 2013 a number of Entities belonging to 9 countries (Chile, Denmark, France, Germany, Italy, Portugal, Spain, Sweden, Switzerland and United Kingdom) joined efforts in the “HIRES Initiative” and elected as spoke-person the first author of this paper. The “HIRES Initiative” gathers into a single scientific and technical team any expressed interest about High Resolution Spectroscopy for the E-ELT. The Initiative also coordinates actions at Agencies level with the purpose of granting the required support to bring the project forward until the end of construction.

In late 2014 ESO is expected to issue a call for a phase-A for a HIRES-like instrument. The Initiative will at this time transform itself into a Consortium for the study and possibly procurement of HIRES for the E-ELT.

2. THE SCIENCE CASE

The Science case for HIRES at EELT has been built on the experience of the high-resolution community with the suite of VLT high-resolution spectrographs, which has been tremendously successful. The Science Team of the HIRES Initiative coordinated the effort of a larger community to outline the case[3] for a high-fidelity, high-resolution spectrograph with wide wavelength coverage optimized for the E-ELT.

Flagship science drivers include:

- The study of exo-planetary atmospheres with the prospect of the detection of signatures of life on rocky planets.
- The chemical composition of planetary debris on the surface of white dwarfs.
- The spectroscopic study of protoplanetary and proto-stellar disks.
- The extension of Galactic archaeology to the Local Group and beyond.
- Spectroscopic studies of the evolution of galaxies with samples that, unlike now, are no longer restricted to strongly star-forming and/or very massive galaxies.
- The unraveling of the complex roles of stellar and AGN feedback for the supply and retention of the baryonic component of galaxies across the full range of galaxy masses, morphologies and a wide range of redshift, with the help of IGM tomography at high spatial resolution,.
- The study of the chemical signatures imprinted by population III stars on the IGM during the epoch of re-ionization.
- The exciting possibility of paradigm-changing contributions to fundamental physics due to the precision afforded by Laser Frequency Comb (LFC) calibrated high-fidelity spectroscopy.

The characterization of **exo-planets** is one of the outstanding key science cases for HIRES. The focus will be on characterizing exo-planet atmospheres over a wide range of masses, from Neptune-like down to Earth-like including those in the habitable zones, in terms of chemical composition, stratification and weather. The ultimate goal is the detection of signatures of life. The extremely high signal-to-noise required to detect the exo-planet atmospheric signatures has paradoxically pushed this area into the "photon-starved" regime with current facilities, making the collecting area of the E-ELT essential for achieving the ambitious goals.

The key requirements for this science case are a spectral resolution R~100,000 (primarily to disentangle the exoplanet atmospheric features from the telluric absorption lines of our atmosphere and to increase detection capability by allowing the detection of narrow lines, but also to trace different layers of the atmosphere and exoplanet weather), 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. Similar capabilities (especially in the blue part of the spectrum) are required for enabling the detection of planetary debris on the surface of white dwarfs, which is an alternative exciting and rapidly growing technique to trace the composition of exoplanets. In the ELT era, radial velocity studies will not only focus on the detection of exo-Earths, but also on the detection of weak and rare time-limited signals, like the Rossiter-McLaughlin effect. The latter will require a stability of the spectrometer of 10 cm s^{-1}.

HIRES, as discussed here, has also the unique capability of revealing the dynamics, chemistry and physical conditions of the inner regions of the **accretion disks and proto-planetary disks of young stellar objects**, hence providing unprecedented constraints on the physics of star formation, jet launching mechanisms and planet formation. To achieve these goals we propose here that in the near-IR the instrument’s high resolution (R~100,000) is exploited with spatially resolved information (possibly with an IFU mode) at the diffraction limit of the E-ELT. This science case would also benefit from a polarimetric mode, which would provide information on the magnetic field in the inner regions of the accretion disk.

On the front of **stellar spectroscopy** HIRES will deliver for the very first time the high-resolution and high-quality spectra (S/N>100) required to trace in detail the chemical enrichment pattern of solar-type and cooler dwarf stars out to distances of several kpc, thus sampling most of the Galactic disk and bulge, or sub-giants and red giants in the outer Galactic Halo and in neighboring dwarf galaxies. With a spectral resolution R~100,000 and a broad spectral coverage (0.37-2.5 µm), the detailed chemical mapping of multiple elements and isotopes, through HIRES spectra, will reveal the origin and the formation history of ancient stars belonging to different Galactic components. This will be crucial for the extremely low metallicity stars, whose photospheres may trace the chemical abundances resulting from the enrichment of the first population of stars (**PopIII**).

HIRES will also be an extremely efficient machine to trace the metal enrichment pattern and dynamics of **extragalactic star clusters** and resolved stellar populations, hence tracing the star formation history in other galaxies, if enabled with some multiplexing capability (~5-10 objects over a FoV of a few arcmin) with intermediate spectral resolution (R~20,000) sampling the full spectral range from 0.37 µm to 2.5 µm.

In the context of galaxy formation and cosmology, one of the most exciting prospects for HIRES is the detection of elements synthesized by the first stars in the 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. These observations will reveal the nature and physical properties of the first stars that populated the Universe. The high spectral resolution of HIRES will also allow astronomers to trace in detail the history of the reionization process of the Universe and the subsequent thermal history of the IGM. To reach these exciting science goals with HIRES requires a spectral resolution R>50,000 and a spectral coverage extending from about 6000Å to 2.5 µm.

If enabled with some multiplexing capability (5-10 objects), HIRES will also be able to obtain a three-dimensional map of the cosmic web of the **IGM at high redshift**, by probing absorption systems towards multiple lines of sight on scales of a few arcminutes. Most importantly, if the simultaneous wavelength coverage extends from 4000Å to 2.5µm, HIRES will have the unique and exceptional capability of obtaining a three-dimensional map of the distribution of metals in the

IGM, which would be a unique probe of the enrichment process of the Universe. The same capabilities (i.e. intermediate spectral resolution, wide simultaneous spectral coverage and multiplexing of 5-10 over a field of view of a few arcminutes) 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), which is still a major unsolved puzzle beyond reach of current facilities.

If equipped with an IFU sampling the ELT diffraction limit, HIRES, with its high spectral resolution (R~100,000) will be the only tool to measure the **low mass end of supermassive 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, some of the most exciting topics in physics. The latter measurement in particular will be enabled by a spectral resolution R~100,000, and high efficiency in the blue part of the spectrum.

HIRES will also deliver the most accurate measurement of the **deuterium abundance** that, compared with the value obtained from the CMB measurements (from Planck), will provide stringent constraints on models of non-standard physics. By measuring the redshift drift-rate dz/dt of absorption features in distant QSOs, HIRES will be the only instrument capable of obtaining a direct, non-geometric, completely model-independent measurement of the Universe's expansion history (the "Sandage test"). This should be regarded as (the beginning of) a legacy experiment, lasting several decades. However, in addition to high-spectral resolution (R~100,000), this measurement requires a very accurate absolute wavelength calibration of about 2 cm s-1 (which can be achieved with laser comb technology and high fiber scrambling efficiency) as well as excellent stability, of the order of 2 cm s-1, over the duration of an observing night.

3. TOP LEVEL REQUIREMENTS AND DESIGN DRIVERS

In summary, the various science cases result in the following set of requirements:

- A primary high-resolution observing mode with **R~100,000** and a simultaneous wavelength range **0.37-2.5 μm** (although the extension to 0.33 μm is desirable for some cases).
- For most science cases a stability of about **10 cm s^{-1}** and an accuracy of the relative wavelength calibration of 1 m s^{-1} are sufficient. The exo-planet radial velocity cases also require a wavelength accuracy down to 10 cm s^{-1}.
- The Sandage test requires a stability as good as **2 cm s^{-1}** over the duration of a night and also an absolute wavelength calibration of 2 cm s^{-1}. These numbers are at the date considered as desirable goals more than design drivers.
- The science cases of mapping the metals in the IGM, galaxy evolution and extragalactic star clusters would greatly benefit from having, within the same wide spectral coverage (**0.37-2.5 μm**), a **moderate multiplexing capability** (5-10 objects within a FoV of a few arcminutes) with a **moderate spectral resolution** mode (R~10,000-50,000).
- Most of the extragalactic, high-z science cases require an accurate **subtraction of the sky background, to better than 1%**.

Table 1: Summary of the Top Level Technical Requirments for HIRES

	HR Single Obj. Mode	MR Multiplexed Mode	HR AO-assisted IFU
Spectral Resolution	100,000	10,000 -20,000	100,000
Multiplexing	1	1-10 (few arcmin FoV)	IFU
Wavelength Range [μm]	0.37-2.5	0.37-2.5	0.37-2.5
Accuracy	10 cms^{-1} (goal 2 cms^{-1})	n.a.	10 cms^{-1}
Stability (over 1 night)	10 cms^{-1} (goal 2 cms^{-1})	n.a.	10 cms^{-1}
Throughput	> ESPRESSO	> ESPRESSO	> ESPRESSO
Polarimetry	YES	n.a.	n.a.

4. GENERAL CONCEPT

Designing a High-Resolution wide-spectral-coverage Spectrograph for the E-ELT represents a challenge to state-of-the-art opto-mechanical manufacturing. In the first place operating the Instrument from the blue U band to the K band requires different detector technologies to be encompassed in the design, not to mention the different required temperature regimes, e.g. cryogenic environment in the K band. Secondly the immense AΩ of a 40-mt class telescope operated in seeing mode requires some level of AΩ splitting or repartition in order to contain the design in sizes for which the optics (e.g. Echelle gratings) can effectively be manufactured.

4.1 Wavelength Repartition

HIRES will be made of a number of modules, each of which optimized for a part of the wavelength range. The number of modules is driven by the need to accommodate in the focal plane of each arm an echellogram with the dispersion and cross/dispersion required by the TLR. The exact wavelength repartition is instead driven by technological issues such as the detectors QE, the need of cooling the optics and, particularly, the transmission of the optical fibers (Figure 1).

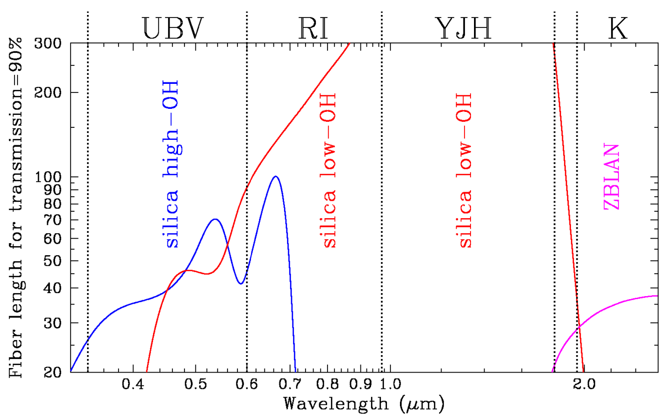

Figure 1: Transmision of current state-of-the-art optical fibres in use in Astronomy

The transmission of the optical fibers determines the location of each potential HIRES module. High transmission fibers can be used for longer bundles with acceptable efficiency losses, allowing one to locate the corresponding module far away from the E-ELT focal plane, e.g. in the Coudé area. Low transmission fibers require the corresponding module to be located close to the focal plane, i.e. on the E-ELT Nasmyth Platform.

4.2 Dicing and Slicing

The entrance aperture of a spectrograph on a telescope can be quantified in terms of its AΩ product, i.e. the product of the solid angle Ω (in steradians) which is the FOV of the fibre or slit and the aperture area (in m^2) of the telescope. AΩ determines both the size of the pupil required to achieve the given spectral resolution R and the size of the resolution element on the detector.

For an HIRES on the E-ELT, with an entrance of about 1 as, for R=100,000, if we use a single aperture, i.e. fibre, we will need a grating of a length of about 10 mt and will record the resolution element on a detector patch of 190x190 µm which is about 11x11 pixels (assuming a rather challenging a camera F/# of 1.0 and a pixel size of 18um). Such a grating does not exist and it is very difficult, if ever possible, to achieve its feasibility in the time-frame of HIRES development, not to mention the cost and complexity of the opto-mechanical system to accommodate such an hypothetical grating.

One way to get round this problem is to rearrange the AΩ of the entrance aperture and this is what is meant by the term AΩ-dicing: a single, large AΩ is broken up into several smaller AΩ pieces but the total AΩ is preserved. This idea was studied in both the early phase-A studies for CODEX[2] and SIMPLE[3], pointing to two different solutions: a) The anamorphic pupil slicing concept (CODEX) and b) the fibre-based focal plane slicing (SIMPLE). Both solutions, or the combination of the two, are currently considered for HIRES.

As regards the implementation of the above concepts the HIRES Team incorporates the experience gained in ESPRESSO[5], designed with a sliced anamorphic pupil, and SPIRAL[6], COHSI[7] and CIRPASS[8], which implemented AΩ-dicing using macro-lenses and fibres.

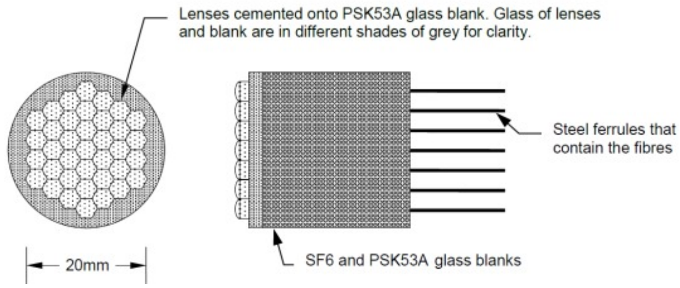

Figure 2: The 37 element macro-lens array and fibers from SPIRAL

The AΩ-dicing can be equivalently performed on a pupil plane (so that each fiber appears to be fed by a smaller telescope aperture) or on the sky focal plane (so that each fiber appears to have a narrower on-sky projected FoV). The great advantage of dicing is that any existing high resolution spectrograph design, E.G. ESPRESSO@VLT or PEPSI@LBT, can be used on the E-ELT provided that it is manufactured in the sufficient number of units to collect the whole AΩ.

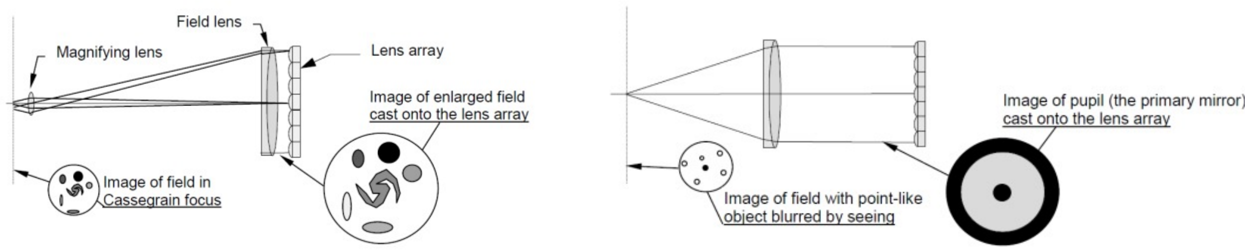

Figure 3: The SPIRAL Lens array used as IFU or field slicer (left) and uses as pupil slicer (right)

A side advantage of AΩ-dicing is the possibility to implement additional observing modes in HIRES entirely at font/end level by simply using differently arranged fiber-bundles. Some of the additional observing modes considered for HIRES and its possible implementation are reported in Figure 4.

The primary High Resolution Mode (left panel of Figure 4) is obtained via dicing the seeing spot of the target into a long entrance slit to the spectrograph. Two bundles of fibers are deployed, one for the object and one for the sky. Simultaneous reference calibration can be added using a third fiber of reduced dimensions. The Medium Resolution mode (central panel of Figure 4) is obtained by grouping a less extreme dicing of the seeing spot. Finally the IFU mode (right panel) is implemented using the AΩ-dicing macro-lenses array to scan an AO-corrected FoV (few milliarcsecs) using each macro-lens as spaxel. The spectrograph entrance slit is arranged to separate each spaxel spectrum from the neighboring one.

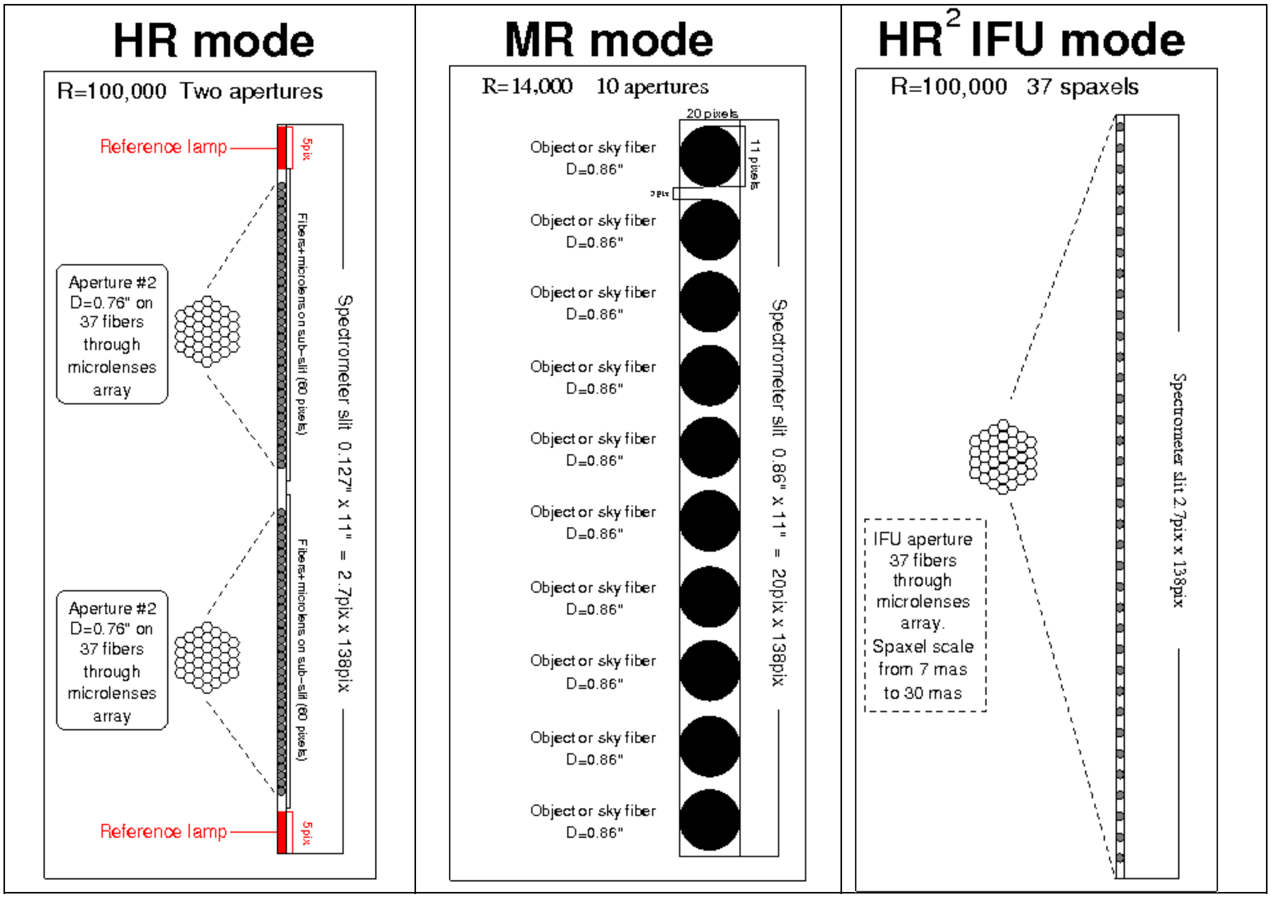

Figure 4: Possible HIRES Observing Modes implemented thorough a suited fiber arrangement.

5. HIRES INSTRUMENT CONCEPT

The preliminary instrument concept encompasses wavelength repartition and AO-dicing in the way schematically represented in Figure 5. The light from the telescope is split, via dichroics, into 4 wavelength channels, namely (U)BV, RI, YJH and K. The U band will be included if the reflective coating of the E-ELT mirrors will be sufficiently efficient in the 0.33-0.36 microns range. 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 and observing mode.

The split-wavelengths between the modules and the maximum length of the fibers will be chosen taking into account the optical transparency of the different types of fibers available on the market. According to fibers currently available (Figure 1) HIRES will need four spectrometers to meet the TLR, positioned at the following distances:

- The YJH module can be at large distances (>300 meters, i.e. anywhere in the ELT building).
- The RI module can be conveniently positioned within ~100 meters of the focal plane.
- The (U)BV and K modules must be within ~25 meters of the ELT focus.

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.

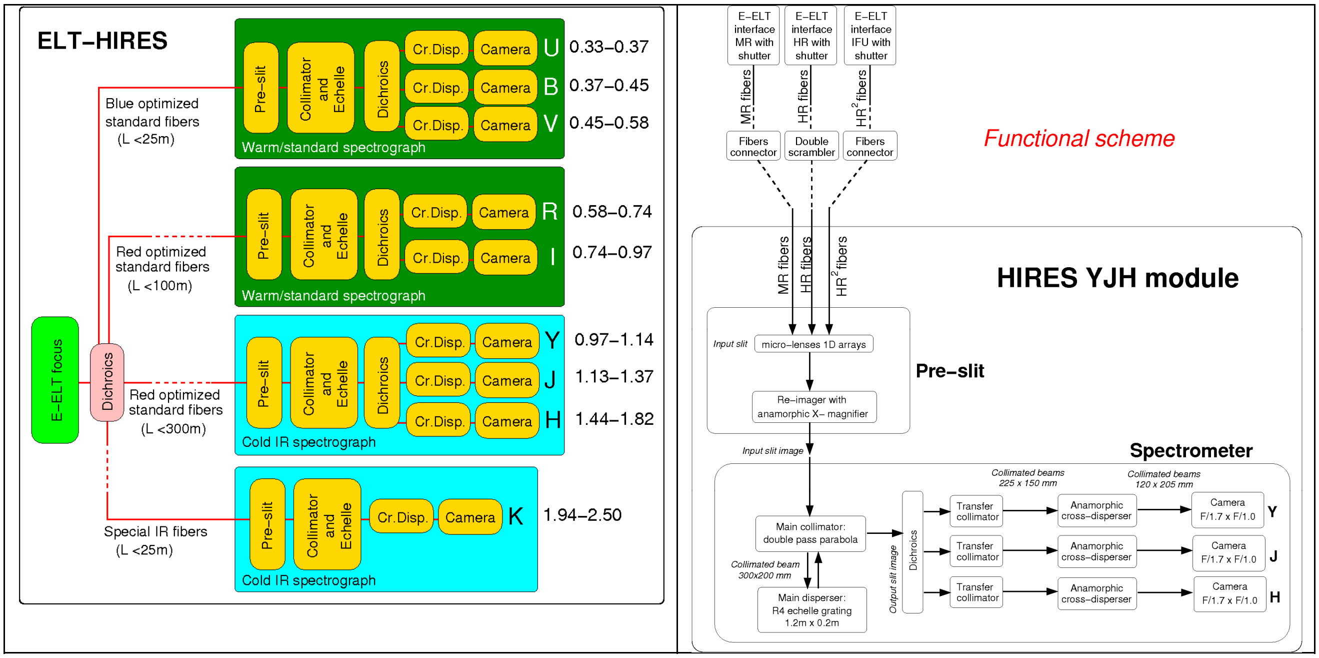

Figure 5: HIRES Instrument Concept and Functional Scheme

5.1 The Front/End module

Each set of fibers (i.e. observing mode) has a dedicated interface to the E-ELT telescope. A preliminary layout of the interface for a seeing-limited observing mode is shown in Figure 6.

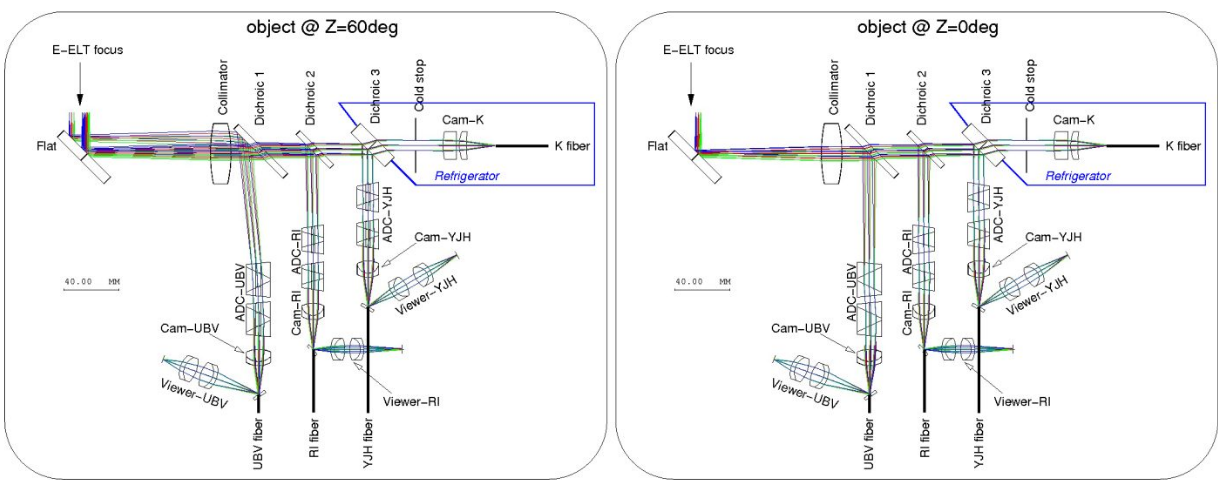

Figure 6: Layout of the Front/End Optics

The interface includes the following elements

- One collimator (a singlet lens).
- Three dichroics, which separate the wavelengths to the four spectrometer modules.
- Three atmospheric dispersion compensators, made using two counter-rotating Amici prisms. No ADC is needed for the K channel.
- Four cameras, that feeds the fibers. The cameras or the fibers are mounted on a X-Y stage used to separately optimize the centering in each channel.
- Four viewers, used to verify the correct centering of the image on the fiber. Each viewer is made by a folding mirror with a central hole which feeds a camera and a small detector. Alternatively, the mirror could be

substituted with a beam splitter that reflects ~2% of the light. The error-signal from the viewers will be used to control the X-Y moving stage described above.

- A refrigerator which cools the pupil stop and the camera feeding the K channel to temperatures ~240 K, necessary to abate the thermal emission.

5.2 ADCs

Even if telescope pointing and guiding is perfect at a given reference wavelength, atmospheric dispersion will shift the image centroid at different wavelengths. Moreover such effect will vary during acquisition with the observation zenith angle. Depending on the requirements on the maximum acceptable loss, an Atmospheric Dispersion Compensator (ADC) might be necessary, namely when visible wavelengths are considered, as they introduce a larger dispersion when compared to IR. HIRES concept relies on having the spectral coverage split in several spectral bands. Each spectral band will have, if required, a specific ADC.

The ADC will be designed for a collimated beam, less critical in terms of aberrations, and following two major drivers: a) Variable dispersion to compensate that of the atmosphere at a given zenith angle, b) zero-deviation at a reference wavelength, within the range of interest for all zenith angles.

Two counter-rotating prisms are sufficient to satisfy the variable dispersion driver but they cannot satisfy the zero-deviation condition. This requires each prism to be itself a zero-deviation unit, i.e. made of a pair of prisms with different dispersions and oppositely directed apex angles (Figure 7). In order to minimize ADC size, a pupil is materialized in the middle of the two prisms.

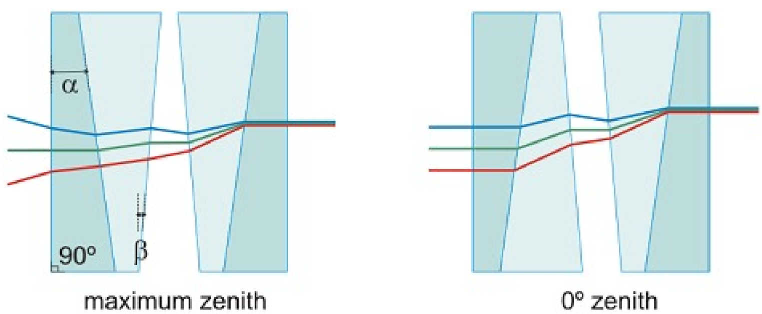

Figure 7: Scheme of the ADCs of HIRES

5.3 Calibration

Aside of the ordinary calibration needs, any High Resolution spectrograph requires to determine the wavelength reference with great precision. Such a precision relies on an accurate determination of the wavelength solution, i.e. a precise mapping of the detector physical coordinates to the wavelength domain.

Many modern High Resolution Spectrographs, e.g. HARPS-S, HARPS-N, ESPRESSO, rely on Laser Frequency Combs as optimal wavelength calibration source. LFCs, unlike other sources e.g. gas Cells, provide unblended, unresolved and equidistant spectral lines which allow to determine directly the instrumental profile. Unfortunately existing LFCs do not yet cover broad wavelength ranges. A range extension can be obtained coupling the LFC with FP-Etalons opportunely tailored, nevertheless a system covering the entire HIRES range has is not available yet. LFCs are currently object of many R&D studies to widen their application in Astronomy. At this early phase of HIRES development we consider that, by the time a the calibration strategy will have to be decided, suited LFCs will be available.

HIRES, at least in the primary High Resolution mode, is expected to have simultaneous reference capabilities. Unlike ESPRESSO where the simultaneous reference light (LFC) uses the sky fiber and is therefore alternative to sky recording, in HIRES we foresee a third fiber, smaller in core, carrying the simultaneous reference light into the spectrograph.

5.4 Spectrograph Unit Concept Design

The AΩ-dicing operated at Front/End level somewhat simplifies the concept of the unit spectrograph and allows to use existing designs, e.g. ESPRESSO@VLT or PEPSI@LBT, as starting points and templates. The preliminary optical design of the YHJ module, chosen as an example, is given in Figure 8. This design has been adapted by the ESPRESSO@VLT design. Relevant parameters of both configurations are compared in Table 2.

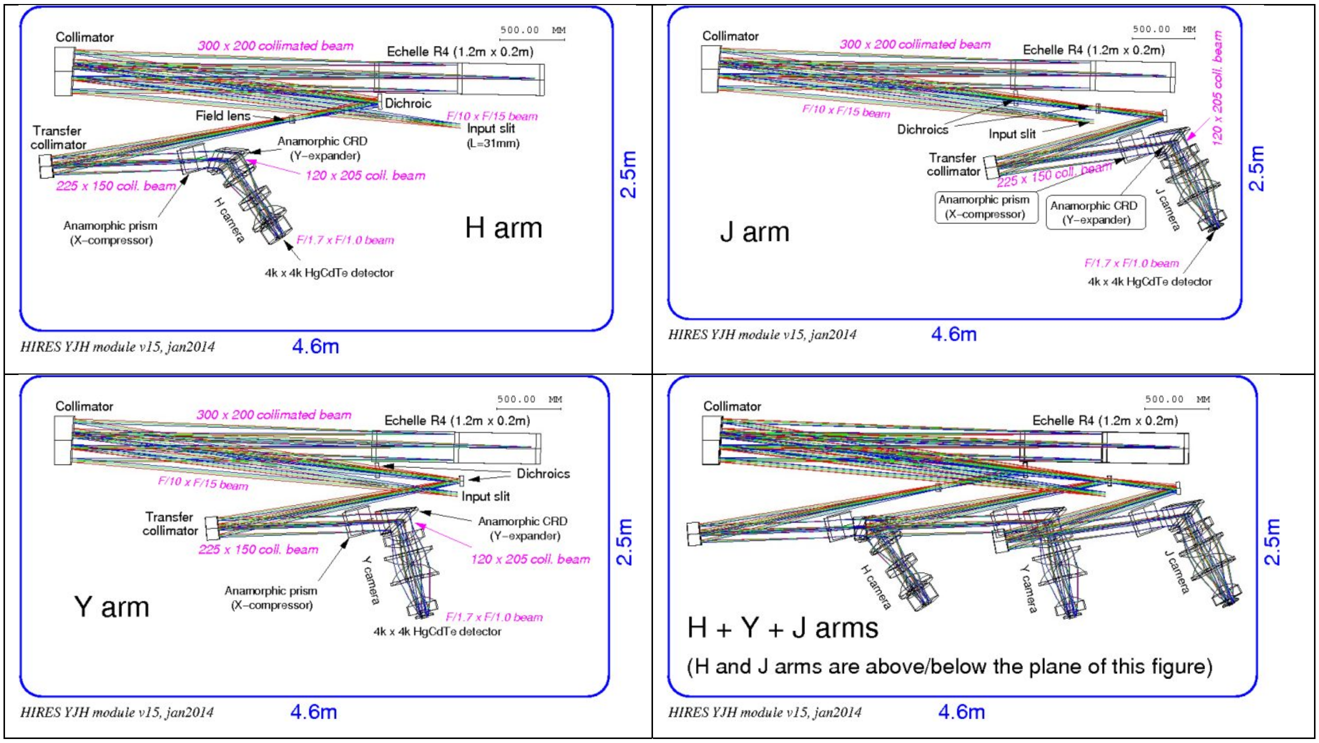

Figure 8: Preliminary Optical Layout of the YJH arm of HIRES

The YJH arm consists in a common path where the beam is anamorphically collimated and the pupil sliced in order to fit on a single large-format R4 echelle grating (1.2 m x 0.2m – same size of ESPRESSO grating). The collimator is used in double-pass and compacts the dispersed beam. A set of dichroics separate the bands feeding the optimized camera channels (Y, J, H).

Table 2: Comparison between the HIRES-YJH Module relevant parameters and the equivalent in ESPRESSO

Parameter	ESPRESSO-VLT	HIRES YJH
Input slit length	31 mm	10 mm
Beam aperture at slit	F/10 x F/15	
Main collimator	Parabola f=3m double pass	
Collimated beam on main disperser	300mm x 200mm	
Main disperser	R4 echelle, 1.2m x 0.2m	
Dichroics and field lenses/mirrors	Close to the intermediate focus	
Transfer collimator	Sphere f=1.5m	Parabola f=2.25m
Collimated beam after transfer collimator	150mm x 100mm	225mm x 150mm
Collimated beam after cross-disperser	150mm x 150mm	120mm x 205mm
Beam on detector	F/2.6 x F/2.6	F/1.7 x F/1.0 (IR) F/2.2 x F/1.3 (VIS)
Detector	10k^2 9cm x 9cm	4k^2 6cm x 6cm (IR) 10k^2 9cm x 9cm (VIS)

6. EXPECTED PERFORMANCES

The expected performance evaluation of this early concept of HIRES relies on a preliminary Exposure Time Calculator. The ETC computes the achievable limit magnitude (AB) at a given wavelength, in a given exposure time and at a given SNR.

Beside the above entrance parameters ETC also uses: a) Number of separate read-outs to achieve the requested exposure time, b) Resolving Power, c) Total throughput of the instrument, d) Sky projected angular size of the spectrometer aperture, e) Sky background at the selected wavelength, f) Total emissivity of the Telescope and Instrument, g) Physical size of the detector pixel, h) Focal apertures of the cameras, i) Dark and RON, l) Slit Efficiency.

The ETC also uses Telescope Constructional Parameters like M1 diameter and central obscuration, and meteo data like local humidity, pressure and temperature. In Table 3 we report a template case of the ETC computation for a set of reasonable parameters for HIRES.

Table 3 Limiting AB-magnitudes for spectra at R = 105 with 2 hours of integration time for a point-like source

Band (λ)	10	20	50	100	300	1000
U (0.36 µm)	21.22	20.41	19.26	18.25	16.28	13.76
B (0.44 µm)	21.22	20.41	19.26	18.25	16.28	13.76
V (0.55 µm)	21.20	20.40	19.24	18.24	16.28	13.76
R (0.64 µm)	21.39	20.59	19.43	18.43	16.48	13.96
I (0.80 µm)	21.33	20.53	19.39	18.40	16.46	13.96
Y (1.05 µm)	21.45	20.65	19.51	18.54	16.62	14.12
J (1.25 µm)	21.28	20.49	19.37	18.43	16.58	14.12
H (1.65 µm)	21.28	20.49	19.37	18.42	16.58	14.12
K (2.20 µm)	20.43	19.66	18.61	17.77	16.23	14.05

7. ADDITIONAL MODES

7.1 AO for HIRES

HIRES is optimized for seeing mode operations. However HIRES is a multi-mode instrument where the modes are defined by feeding with a suite fiber bundle a fixed-format spectrograph(s). It is of limited impact to add a fiber bundle to implement an AO-assisted IFU mode (right panel of Figure 4).

The performance of the AO-assisted IFU mode has been evaluated via a Monte-Carlo simulation analyzing the PSFs of a model of the fiber, spectrograph and contamination by background/foreground light sources. The conclusion is that Observations at longer wavelengths, observations in crowded fields and high spatial resolution observations benefit of AO assistance, whereas single targets with no background contamination and the shorter wavelength range don't gain much from AO assistance.

At this level it is still not clear how and where HIRES will be interfaced with E-ELT. However it is not foreseen to be fed via a post-focal-AO module (e.g. MCAO or LTAO). HIRES will have to rely on the correction performed by M4 and with either a loop closure provided by the telescope itself (if available) or via HIRES-driven wave-front sensing. The AO-mode will be subject of further study and trade-offs in the Phase-A about to begin.

7.2 MOS with HIRES

As a baseline HIRES is not conceived as an optimized MOS spectrograph. However the possibility to obtain simultaneous intermediate resolution spectra of a limited number of objects in a field of view of a few arcmin and in the wide spectral range of HIRES, allows one to study science cases not covered elsewhere in the current E-ELT instrumentation plan.

The MOS-mode is statically implemented as an intermediate solution between the MR mode and IFU Mode illustrated in Figure 4, by using larger core fibers. The resulting spectrograph entrance slits will be larger along the dispersion direction (lower resolution) and shorter along the cross-dispersion direction allowing more than an object-spectrum to be recorded through the fixed-format spectrographs.

The MOS mode also relies on the fact that the entire pre-slit optics coupled to the single fiber bundle, including the ADC, is sufficiently compact to fit into a mechanical arm deployable across the EELT focal plane. The evident drawback of the MOS mode is the added complexity inherent to the installation of the arm positioner and the more complicated interfaces with the EELT infrastructure. The MOS mode will be object of further study and trade-off during the about-to-begin HIRES phase-A study.

7.3 Polarimetry with HIRES

The possibility to feed the HIRES spectrographs with fibers carrying polarization information opens a variety of interesting science cases. Nevertheless a post-focal polarimetric mode in a five-mirror telescope does not appear to be the optimal solution due to the instrumental polarization introduced by the telescope.

For this reason, as a baseline, HIRES is optimizing the concept of "Spectropolarimetric focal station for the ESO's E-ELT" developed a few years ago[9], and based on the PEPSI@LBT design. The concept makes use of the intermediate f/4.4 focus, the only symmetric focus of the telescope. A dual channel, full Stokesvector polarimeter provides on-axis light for the wavelength range 380-1600nm, suited to feed the relate modules of the HIRES spectrograph.

As a secondary option we are investigating the possibility to locate at the intermediate focus a polarimetric calibration source to facilitate the measurement of the instrumental polarization at the Nasmyth Focus as it was studied for SIMPLE.

8. CONCLUSIONS AND NEXT STEPS

The HIRES initiative, set-up in early 2013, built a Community Science Case for a High Resolution Spectrograph for the E-ELT, derived a set of Top Level Requirements and developed a preliminary technical concept responding to them. These are presented in this paper. Later this year ESO is expected to issue a call for a Phase-A study of an Instrument of this kind. The HIRES initiative is ready to answer to the call and submit a proposal and bring HIRES to life in the early observing days of E-ELT.

REFERENCES

[1] Ramsay, S., D'Odorico, S.; Casali, M., Gonzalez, J.C., Hubin, N., Kaeufl, H.U., Kissler-Patig, M., Marhetti, E., Pafique, J., Pasquini, L., Siebenmorgen, R., Richichi, A., Vernet, J., Zerbi F.;., "An overview of the E-ELT instrument programme", Proc. SPIE 7735 art.id 773524 15pp (2010)

[2] Pasquini, L., Cristiani, S., Garcial Lopez, R., et al. "Codex", Proc SPIE 7735, art.id 77352F, 12pp (2010)

[3] Origlia, L., Oliva, E., Maiolino, R., et al "SIMPLE: a high-resolution near-infrared spectrometer for the E-ELT", Proc. SPIE 7735, art.id 77352B, 9pp. (2010)

[4] Maiolino, R., Haehnelt, M., Murphy, M., et al, "A Community Science Case for E-ELT HIRES", arXiv:1310.3163, (2013).

[5] Mégevand, D., Zerbi, F.M., Cabral, A., et al. "ESPRESSO: the ultimate rocky exo-planets hunter for the VLT", Proc. SPIE 8446 p. 1R, (2012)

[6] Kenworthy, M., Parry, I., Taylor, K., "SPIRAL Phase A: Prototype Integral Field Spectrograph for the Anglo-AustralianTelescope", PASP 113, p. 215 (2001).

[7] Ennico, K., Passy, I., Kenworthy, M., et al., "Cambridge OH suppression instrument (COHSI): status after first commissioning run", Proc. SPIE 3354 p. 668 (1998).

[8] Parry, I., Bunker, A., Dean, A., et al. "CIRPASS: description, performance and astronomical results", Proc. SPIE 5492, p. 1135 (2004).

[9] Strassmeier, K., Di Varano, I., Ilyin, I., et al., "A spectro-polarimetric focal station for the ESO E-ELT", Proc. SPIE 8444, art. Id 844435, (2012)