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LA SILLA OBSERVATORY

HARPS project
3.6m-HARPS fibre adapter
Requirement Specifications

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1 INTRODUCTION

1.1 Purpose

The present document contains the requirement specifications (RS) for the fibre adapter of the HARPS instrument to the Cassegrain focus of the 3.6m telescope. This fibre adapter shall also be usable with other fibre-coupled instruments of the 3.6m (see Section 3.1), but will be referred to as the HARPS Cassegrain fibre adapter (HCFA) in this document.

Following the announcement of apportunity by ESO for the construction of a new instrument enabling a measurement precision for differential radial velocities (RV) of 1 ms^{-1} a proposal was received by a consortium consisting of the “Observatoire de Genève”, the “Observatoire de Haute-Provence”, the “Universität Bern”, and the “Service d'Aeronomie du CNRS (SA)” [1][2][3]. The decision was made by ESO that the HARPS instrument be built by this consortium.

One of the responsibilities of La Silla observatory in the HARPS project will be the realization of the coupling of the instrument fibres to the Cassegrain focus of the 3.6m telescope by constructing the HCFA. The here presented RS for the HCFA will be jointly evaluated by ESO and the HARPS consortium. The design of the HCFA will then be made in a collaboration of OHP and ESO La Silla.

The primary goal of HARPS is the achievement of a long-term precision of 1 ms^{-1} for differential RVs on slowly rotating G-dwarfs; long-term means a three-year baseline. As a main construction feature this high-resolution Echelle spectrograph will be a sealed instrument kept in an absolutely stable configuration. All requirements at the instrument end are dictated by the primary goal of HARPS. The same is true for part of the requirements at the adapter end presented in this document.

However, the HCFA holds the opportunity to add to the instrument a number of features that can be used for a variety of scientific applications additional to the the use for planet search, thereby making HARPS attractive for a larger community of users. As HARPS will be a regular ESO instrument that will be offered to the scientific community as a whole, ESO wishes to exploit these possibilities for a wider range of applications.

There is clear agreement, however, that any such additional features shall in no way compromise the primary scientific goal of HARPS, i.e. the achievement of a measurement precision of 1 ms^{-1} for differential RVs. Also, the specific requirements related to the achievement of this goal shall be set by the HARPS consortium.

The realisation of the additional requirements may in some cases be quite demanding and it has to be established whether they are technically feasible in all cases; e.g. limited space in the Cassegrain plane may be a concern. All proposed additional features will have to undergo an acceptance process.

1.2 Reference Documents

The following documents contain additional information and are referenced in the text.

References

[1] HARPS-Sys-Mag-ObsGe-1001 29/01/99 — HARPS Management plan

[2] HARPS-Sys-Prop-ObsGe-0101 01/02/99 — HARPS Scientific Proposal

[3] HARPS-Sys-Prop-ObsGe-0102 29/01/99 — HARPS Technical Proposal

[4] 3p6-SPE-ESO-006-001, 26/08/96 — User Requirements for 3.6m Cassegrain adapter and calibration unit

[5] 3p6-SPE-ESO-045-02, 18/09/96 — User Requirements for CES fibre link

[6] Internal Memorandum, 19/03/1999 — Properties of the UVES iodine cells #1 and #2.

1.3 Abbreviations and Acronyms

The following abbreviations and acronyms are used in this document:

3.6m	ESO 3.6m Telescope
ADC	Atmospheric Diffraction Compensator
CES	Coude Echelle Spectrograph
CFHT	Canada France Hawaii Telescope
EFOSC2	ESO Faint Object Spectrograph 2
ESPaDOnS	Echelle Spectropolarimetric Device for the Observation of Stars
HARPS	High Acuuracy Radial Velocity Planet Search
HCFA	HARPS Cassegrain Fibre Adapter
ICS	Instrument Control Software
OHP	Observatoire de Haute Provence
RS	Requirements Specifications
RV	Radial velocity
UVES	Ultraviolet Visual Echelle Spectrograph
VLT	Very Large Telescope

2 OVERVIEW

2.1 Document overview

The remainder of this document is structured as follows: Section 3 contains the requirement specifications for the HCFA with details on eight different functions. Section 4 contains the justifications for these features and is subdivided into justifications for reasons of relevance for the primary goal of HARPS, additional scientific reasons, operational reasons, and reasons of the improvement of the performance of other fibre-fed instruments at the 3.6m (currently the CES). Some of the functions have more than one type of justification. A concise overview of the functions and their justification is provided by Table 2 at the end of this document.

3 Requirement Specifications for the HCFA

3.1 Multi-instrument fibre adapter

The HARPS fibre adapter is to be constructed in such a way that it can simultaneously host the fibre heads of HARPS and the CES. In addition, space should be foreseen for a third fibre head. This will open the possibility for a future installation of yet another fibre-fed instrument at the 3.6m telescope.

One possibility for the technical realisation are

1. a common multi-fibre head for all instruments, or
2. individual fibre heads mounted on a movable carriage.

The second possibility is currently favoured as it makes it easier to separate the fibres of the different instruments. The La Silla mechanics workshop has the know-how to produce carriages with a positioning stability and reproducibility of a few microns, i.e. on the order a few percent of the fibre diameter.

The requirement for stability and reproducibility of the fibre head carriage depends on the adopted star acquisition and guiding procedure (Sect. 3.7). If acquisition and guiding is made in a flexible way that identifies the position of the fibre hole(s) rather than working with fixed predefined positions, then the reproducibility and stability requirements for the fibre carriage itself are not very demanding.

The final requirements for method and accuracy of star acquisition and guiding should come from the HARPS consortium. The requirements for reproducibility and stability of the fibre carriage will then follow from them. Note in this respect that for a fibre aperture diameter of 0.9 arcsec on the sky and an image scale of 0.25 arcsec per guide camera CCD pixel of size 15 micron, an uncertainty of 1 micron correpsonds to a spatial offset of the object of 1.9% of the fibre aperture diameter.

3.2 Calibration unit

The design of the calibration unit must ensure a beam from both the flatfield lamp and the ThAr lamp that matches as close as possible the beam (f/8) from a star as seen through the 3.6m telescope.

Possible considerations:

1. An integrating sphere if sufficient flux levels (see below) can be assured.
2. The usage of the calibration screen to simulate the f/8 telescope beam (as used with EFOSC2). This has already proven inefficient for the CES, but may be reconsidered if the efficiency can be enhanced.

With HARPS flux levels should be kept high enough to permit short calibration exposures, i.e. no more than 1 min for ThAr and no more than 30 sec for flatfield exposures with 50,000 ADU at maximum.

The simultaneous ThAr exposure will require a rotable neutral density filter with continuously varying density to be mounted in the light path from the ThAr lamp in order to get predefined ThAr exposure levels for all science exposures independent from exposure times within the interval $1 - 60$ min.

Table 1 lists the object/calibration modes that are to be foreseen according to these requirements outlined in this document (upper part of table) and according to the requirements given by the HARPS consortium in[3] (lower part). Note that the latter does not differentiate between the types of lamp, but it is implicit that a combination of 2 different lamps is not meant. Also, the latter requires that each fibre can be object fibre.

3.3 Atmospheric diffraction compensator

The HCFA is to be equipped with an atmospheric diffraction compensator (ADC). This is a unit that is to be inserted in front of the object fibre in the telescope beam in order to compensate for atmospheric diffraction (dispersion) up to zenith distances of 60°, i.e. the maximum zenith distance for the 3.6m telescope.

Typically, an ADC consists of two counter-rotating prisms which, e.g., is the case for the ADC in use with UVES. As it is mostly the primary goal of HARPS that requires the ADC it should be designed by the HARPS consortium to maximize its benefit (see Chapter 7.2 of [3]).

Following the HARPS technical proposal[3] the ADC should correct both longitudinal and lateral chromatic aberrations within
$\oslash < 0.04$ arcsec for $Z = 0°$
$\oslash < 0.07$ arcsec for $Z = 45°$
$\oslash < 0.14$ arcsec for $Z = 60°$, where Z is the zenith distance.

3.4 Polarimetric mode

Following the recommendation by the La Silla 2000+ report to install a spectropolarimentric facility at a high-resolution spectrograph, a polarization analyser should be foreseen in the HCFA. Ideally, this device can be equally used with HAPRS and the CES.

An interesting design that should be considered is that of ESPaDOnS for the CFHT which is also a polarimeter to be used in conjunction with a fibre-fed instrument. It enables to measure all four Stokes parameters, i.e. linear polarization and circular polarisation.

Table 1: Illumination modes for the two HARPS fibres

From present requirements:	
Fibre 1	Fibre 2
ThAr	ThAr
Flat	Flat
Flat through polarizer	Flat through polarizer
Flat through iodine cell	Flat through iodine cell
Object	ThAr
Object through polarizer (pol. direction 1)	Object through polarizer (pol. direction 2)
Object through iodine cell	ThAr
Object through iodine cell	Flat through iodine cell
From HARPS technical proposal:	
Fibre 1	Fibre 2
Dark	Dark
Lamp	Dark
Dark	Lamp
Lamp	Lamp
Star	Dark
Dark	Star
Star	Lamp
Lamp	Star
Star	Sky
Sky	Star

In short, the design consists of a pinhole, two rotating halfwave Fresnel rhombs, a quarterwave fresnel rhomb, and a Wollaston prism. Fresnel rhomb retarders were chosen because they are highly achromatic and very efficient over a wide spectral range. The two output beams from the Wollaston are simultaneously imaged into two fibres.

See the preliminary optical design from the Donati group for ESPaDOnS,
`http://webast.ast.obs-mip.fr/magnetisme/espadons.html` ,
`http://webast.ast.obs-mip.fr/people/donati/pub/espadons.html` ,
and especially
`http://webast.ast.obs-mip.fr/magnetisme/espadons/polarimeter.html`.

3.5 Self-calibration mode: iodine gas absorption cell

The HCFA shall have an iodine gas absorption cell for self-calibration potential in the wavelength range $\approx 5000-6500$ Å. Inserted into the telescope beam this absorption cell superimposes absorption lines of molecular iodine onto the starlight or the light from the flatfield lamp. The cell permits the accurate determination and monitoring of the spectrograph instrumental profile and provides very accurate calibration possibilities over both wide and narrow regions of the spectrum. It can also be used as a corrector to any instrumental instabilities that may limit the achievable RV precision.

The iodine cell is a sealed evacuated glass cylinder which is temperature controlled to contain a stable atmosphere of melocular iodine. Its useful range starts at ≈ 5000 Å almost independent from temperature, its extent into the red part of the spectrum depends on the iodine filling temperature and the operational temperature.

If the same quality iodine cell as used with UVES can be obtained, an operational temperature of 70° C will give iodine line depths of up to 80% (at ≈ 5200 Å) and useful lines up to Hα 6563 with a depth of up to 8% . See [6] for details.

Requirements are:

1. The whole beam from a star must pass through the iodine cell.
2. It must be possible to obtain pure iodine spectra using a flatfield source.
3. The whole beam from the flatfield lamp must pass through the iodine cell.
4. Temperature control at 70° C should be stable to within 0.5° C.

3.6 Tip-tilt correction optics

There has been quite some discussion about the insertion of a tip-tilt correction optics in HARPS with as yet no definitve outcome in favour of it[3]. The HARPS consortium is not requiring tip-tilt correction as necessary for the primary goal. Reasons are that stability of the spectrograph input beam is mostly achieved by image scramblers and that the expected gain in efficiency is small and only achieved at the expense of a more complicated optical system at fibre entrance.

A substantial gain in efficiency (around 30%) would result, if the image scrambler could be dismissed and its function to stabilize the spectrograph input beam could be taken over by the tip-tilt system by already stabilizing the input beam into the fibre. However, the performance of a tip-tilt system with respect to spectral stability has not yet been demonstrated in pratice. Therefore, the HARPS consortium opts to retain the image scrambler. E.g. at the ELODIE spectrograph at OHP an improvement by a factor of 2 in the RV precision resulted after installing an image scrambler.

Ideally, the HCFA should be designed and constructed in such a way that space is available for a later installation of tip-tilt correction optics, should a clear demand for it arise.

3.7 Autoguiding

Autoguiding is currently achieved with the so-called "slit viewer camera" (which would better be called "fibre viewer camera"). Stable autoguiding is possible between V=0 mag and V=16 mag. Guiding corrections are currently ≤ 0.05 arcsec rms per coordinate over time scales of ≥ 30 min for a star of V=5.4 mag. (A more detailed determination of the accuracy of the autoguiding as a function of atmospheric or seeing conditions and for various stellar magnitudes is not yet available.)

However, there is a limit to the above caused by a mechanical instability in the guide camera mirror which probably is at its mechanical limit within the current design. This occasionally leads to sudden jumps of the guide camera image on its CCD of typically $1-2$ arcsec with the effect that the fibre hole and the reference position in the CCD do no longer coincide, and the star is no longer guided on the fibre.

To solve this problem the mechanical design of the guide camera mirror needs inspection and revision or redesign in order to strongly reduce this effect. Requirement goal is an stability comparable to the guiding errors, i.e. 0.05 arcsec rms in both coordinates and for all telescope positions.

It must be acknowledged, however, that this mechanical stability may be very demanding. In addition to the required mechanical improvement there is a practical guiding strategy that further enhances the achieved stability of the centering of the object in the fibre. This strategy should be borrowed from UVES where it is called 'co-guiding'. There guiding is always done with the guide probe, but the distribution of light around the fibre (or for UVES around the slit) is evaluated in order to redetermine the reference position for guiding, i.e. the center of the fibre hole. Corrections are sent to the guide probe (combined offset of telescope and guide probe) at a frequency sufficiently low to ensure stability. This way small mechanical imperfections in the guiding system are overcome. Note that this approach also optimizes object acquisition in a natural way.

In practice, the following three guiding modes should be available:

1. UVES-type co-guiding as described above.
2. Plain guiding on the fibre hole.
3. Plain guiding on the guide probe.

Their usage will depend on the final evaluation of the performance of the guiding system.

3.8 VLT compliant control software

The control of the HARPS functions should be made under the VLT compliant software standard. As a matter of control strategy the HCFA should be treated as part of the instrument. To a large extent the HARPS instrument control software (ICS) will be able to build on the existing ICS for EFOSC2 and the CES.

4 Justification of HCFA features

4.1 Relevance for the primary goal of HARPS

4.1.1 Calibration unit

The two-fibre approach for the achievement of precise RVs requires in particular that both fibres can serve as object and calibration fibes in any combination, especially ensuring simultaneous object and calibration spectra. The rotable neutral density filter with continuously varying density for the ThAr lamp is required to ensure optimal ThAr exposures for every science exposre.

4.1.2 Atmospheric diffraction compensator

The ADC is mostly needed for reasons of maximizing the efficiency and to keep the spectral format constant.

Without an ADC the relative flux at the blue and red ends of the recorded spectrum is a function of zenith distance leading to variable contributions of different spectral regions which directly influences the determined radial velocities.

4.1.3 Tip-tilt correction optics

No final justification given so far.

4.1.4 Autoguiding

Stability of the input beam is required for reasons of maximising the recoreded stellar flux and also keeping the input beam into the spectrograph stable. The latter is largely achieved by the image scrambler, but also benefits from a stable centering of the star on the fibre.

4.2 Additional scientific reasons

4.2.1 Polarimetric mode

The La Silla 2000+ report recommends the implementation of a spectro-polarimetric capacity at a La Silla spectrograph. Spectro-polarimetric facilities are currently not foreseen in the VLT instrumentation. The scientific applications comprise:

- Magnetic surface fields of active stars (Zeeman Doppler imaging).
- Magnetic fields in young cluster stars.
- Magnetic dipole fields (circular polarization) in the emission lines of T Tauri stars.
- Magnetic fields in accretion disks of young stars and cataclysmic variables.
- Magnetic fields in hot stars with azimuthally structured stellar winds (O-stars, Herbig Ae/Be-stars, Wolf-Rayet, or Be-stars).
- Magnetic fields in chemically peculiar A and B stars (both circular and linear polarisation).
- Geometry and chemistry of circumstellar scattering matter (both linear and circular polarisation).

4.2.2 Self-calibration mode

There is considerable interest in the scientific community to include a self-calibration mode in HARPS based on an iodine gas absorption cell. Areas for which this is important are:

- Asteroseismology: An example is studying the non-radial pulsations (NRP) of rapidly oscillating Ap stars (roAp stars). The analysis consists of measuring the RV displacements caused by the oscillations for individual lines or classes of lines which have their particular behaviour different from each other, e.g. different pulsation phases and amplitudes. High RV precision on individual lines is difficult with conventional ThAr calibration due to the sparseness of ThAr lines. The high line density of iodine lines is required. Other examples are stars pulsating in high radial orders where surface velocities are predominantly horizontal. The γ Dor variables are prime targets for such RV studies.

- Long term stability of RV measurements. Should the stability of the cross-correlation technique prove to degrade on long time scales, about which concerns have been raised, regular calibration monitoring with an iodine cell will permit a correction even if the self-calibration mode is not regularly used in RV programs.

- Cross-calibration between instruments. As the best type of modelling of data taken with an iodine cell is based on high-resolution iodine spectra taken with a Fourier Transform Spectrometer (FTS) of the iodine cell (as the main reference standard), data from various instruments can be combined if they are taken with the same iodine cell. This has been successfully demonstrated by the Marcy group. This means that in long-term projects on can change from one generation of instrument to the next by using the same iodine cell. Even if different iodine cells are involved their FTS spectra can be more easily and precisely cross-calibrated than the regular spectra taken with this instrument.

4.3 Operational reasons

4.3.1 Multi-instrument fibre adapter

A multi-instrument fibre adapter will substantially ease the operational load in the 3.6m team as changing from one instrument to the other will be very quick and possible at any time. If properly designed, all fibre-fed instruments at the 3.6m can share functions of the adapter such as the calibration lamps, the polariser, and the iodine cell.

4.3.2 Self-calibration mode

An iodine gas absorption cell permits the reconstruction an regular monitoring of the instrumental profile (IP) as part of the instrument calibration plan. This is an attractive way to identify optical degradation in the instrument at a seismically active loaction as La Silla. The iodine cell provides a stable reference and calibrator over a long time baseline.

Due to the richness and stability of its absorption lines the iodine cell can give superior wavelength calibration in its applicable range (5000–6500 Å) also on short pieces of spectrum.

In contrast to ThAr lamps which degrade with time and need to be replaced by another lamp with somewhat different characteristics of its spectral emission lines, changes in the absorption spectrum of a sealed iodine cell are practically absent even on long time scales.

4.3.3 VLT compliant control software

Maintaining the instrument control software and training in instrument operation is substantially facilitated when a common standard is adopted for as many instruments as possible. With two instruments at the 3.6m already under VLT compliant control software, the natural choice is the VLT standard.

4.4 Improvement of performance of the CES and future instruments

4.4.1 Calibration unit

The current design of the CES calibration unit has the shortcoming that flatfielding is not properly possible, because of structure in the flatfield exposures. This is due to the lack of proper imitation of the telescope beam together with sufficient exposure levels.

If the newly designed calibration unit (Sect. 3.2) can also be used by the CES (and hypothetical other fibre-fed instruments at the 3.6m) instrument calibration would be considerably improved.

4.4.2 Requirements for autoguiding

The outlined requirements for autoguiding (Sect. 3.7) would also be of substantial value for the CES (and other fibre-fed instruments), especially because of the measures taken against sudden image movements in the guide camera (machanical stabilisation and UVES-type co-guiding).

Table 2: HCFA features

Function	Justification
Multi-instrument adapter	operational
Calibration unit	primary goal + performance improvement
Atmospheric diffraction compensator	primary goal
Polarimetric mode	additional scientific
Self-calibration mode	additional scientific + operational
Tip-tilt correction	primary goal ?
Autoguiding	primary goal + preformance improvement
VLT compliant software	operational

5 Summary of HCFA features

The HCFA features and their justification are summarized in Table 2.