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HARPS

High Efficiency Mode Upgrade: Users requirements and Implementation Plan.

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CHANGE RECORD

ISSUE	DATE	SECTION/PAGE AFFECTED	REASONS/INITIATION DOCUMENTS/REMARKS
1.0	27.11.03	all	new document
1.1	30.01.04	Scientific Drivers	address J. Melnick's comments
1.2	24.02.04	all	address S. D'Odorico's comments
1.3	05.03.04	4.1	add flux ratio table

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1 Scope

This document describes the scientific drivers, the user requirements and the conceptual solution fot the upgrade intended to provide the HARPS spectrograph with a powerful high-efficiency mode.

2 Introduction

HARPS is a spectrograph built for the search for extrasolar planets using the radial velocity (RV) method with unprecedented accuracy (1 m/s). In the course of the development it became apparent that the optical efficiency of the system could be significantly improved by (1) using a thicker fiber ($100\mu m$ in diameter rather than the $70\mu m$ of the "high accuracy" fiber), allowing more light to enter even in mediocre seeing conditions, and (2) avoiding the use of the image scrambler, reducing the light loss intrinsic to this optical component.
However, these modifications will decrease the spectral resolution by approximately 30% and likely also the final accuracy in the RV determination (in the case of bright sources, where the photon noise is negligible), compared to the baseline mode , or "high accuracy" (HA).
The upgrade to a "high efficiency" mode (HE) is therefore not considered as an alternative to the baseline mode which will not be impaired in any way.
At the time of the installation of HARPS (December 2002 - January 2003), the high efficiency fiber link was installed in the instrument. The problem which was left open was the implementation of a new exposure shutter. The exposure shutter of HARPS, in its present configuration (HA), is an integral part of the image scrambler. The new HE mode does not use the scrambler, therefore a new shutter is required which naturally must be located before the fiber entrance, i.e. in the HCFA.

3 Scientific drivers

The main scientific drivers for the high efficiency fiber upgrade are:

1. Doppler follow up of transiting objects orbiting faint stars detected with the existing or future photometric surveys (e.g. from OGLE, COROT, KEPLER)

2. asteroseismology of faint objects (down to a magnitude of 17) for which large amplitude modes are expected and high RV accurcay is not strictly needed;

3. fast and accurate asteroseismology observations (up to a repetition period of 1 minute, 30s integrating + 30s readout time);

4. identify evolved stars in clusters through their pulsation signature;

5. Extragalactic astronomy: QSOs, variation of the fine structure constant (Webb et al. 2001 PhRvL 87, 1301)

The limiting magnitude of HARPS in high accuracy mode is about 16.5. At such faint magnitude, the RV uncertainty is dominated by photon noise. Although the larger fiber will decrease the spectral resolution with impact on the RV accuracy, the higher throughput will finally result in a better RV determination. The high efficiency system would move the limiting magnitude of the instrument almost one unit up, to 17.5.
During the first commissioning HARPS could confirm the existence of a RV modulation of OGLE-TR-56, a star of magnitude 16.6 with a detected transit by the OGLE III program. A RV accuracy of 30m/s was obtained in one hour exposure time. The event might be interpreted as a hot Jupiter

(ESO Messenger 114, December 2003). The RV accuracy is clearly dominated by photon noise. A higher efficiency system like the one we are proposing would improve the RV accuracy to better than 20m/s for such an object, opening the door to observations of hot Saturns in systems whose central star has a magnitude as faint as 17.
After the planet identification the subsequent spectroscopic studies of its atmosphere (by absorption of the parent star's light) during the transit (Schneider 1994, Schneider and Doyle 1995, Coustenis et al. 1996) would be unprecedented and would benefit from the increased instrument efficiency.

4 Expected performance

4.1 Improved transmission

Transmission should improve by about 20% due to the absence of the scrambler .
The overall gain in efficiency can be up to almost one magnitude as compared to the baseline, depending on the seeing. This is clearly seen in the following table, where the gain in flux between the HE and HA modes are given as a function of the seeing. The geometrical gain has been multiplied by the expected gain of 1.2 (20%) given by the absence of the scrambler. We must also take into account that:
- the seeing values reported by the seeing monitor are reduced to airmass one,
- to this, the image quality of the telescope has to be added.

For reference, image quality of the telescope at zenith is about 0.5 arcsec, while at airmass 1.2 is of the order of 0.7 arcsec. Long time scale statistics (few years) performed during EFOSC2 runs show that a minimum seeing on the CCD images of about 0.8 arcsec is obtained at the 3.6m telescope. A realistic, long "on source" observation (which is typical of faint object observations or of seismological studies) may require fairly high airmasses and therefore high values of the seeing.

Seeing (arcsec)	0.8	1.	1.2	1.4	1.6	2
Flux ratio HE/HA	1.68	1.78	1.93	2.0	2.05	2.2

4.2 Scrambling properties

At the moment it is not possible to predict with certainty how well the scrambling by the fiber itself will work in the proposed configuration. It will have to be tested. Experience gained so far with ELODIE on the OHP 1.93m telescope (which has no scrambler) is however encouraging because of the very good RV results obtained there ($\pm$ 15m/s) (F. Pepe, private communication).

4.3 Impact on radial velocity measurement

The increased diameter of the fibre (1.4") will naturally decrease the spectral resolution by about 30%. This implies the spectral element should increase from about 3 to about 4 pixels and the attaianble RV accuracy from 1 to about 1.35m/s due to the degraded spectral resolution only and assuming a rough scaling. However, based on the experience with CES and UVES, we expect the major source of error coming from the larger star area sampled. This might introduce an error as large as 10m/s. In one hour exposure time on a 15 magnitude G0 star the photon noise limits the RV accuracy of the HA mode to 10m/s. This implies that for stars fainter than magnitude 15 the HE method could achieve a better RV accuracy than the HA method, in a fixed integration time of 1 hour.
The precise effect is however very difficult to predict and will only be known when tests will have been done.

5 Description of the upgrade

The HARPS shutter in the present (HA) configuration, is located just outside the vacuum vessel, upstream of the image scrambler. The driving reason for this positioning is to avoid moving and breakable parts inside the vacuum vessel, in order to minimize intervention on the spectrograph. The following options were considered for the location of the shutter:

1. cutting the fiber: results in 20-30% light loss due to FRD thus limiting the HE gain only to the geometrical factor compared to the HA mode. A loss in efficiency of up to 5-10% could still be considered as acceptable;
2. using the mode selector HARPS/CES: this function is too slow, and it was never designed for the frequent use as a shutter ($\approx 10^6$ operations in 5 years);
3. nodding the telescope: this is too slow;
4. not to use a shutter at all: this solution is not acceptable as it would imply that a) the system is still collecting photons while reading; b) pixels closer to the read out electronics will be exposed 23s less than pixels far away from the electronics; c) one of the scientific drivers for this mode is fast time series, for which the 23s readout time is a significant fraction of the exposure time.
5. **insert a shutter between the front mirror of the fiber head and the coupling lens of the fiber.**

The proposed solutions 2,3 and 4, all suffer the long time needed to "close the shutter", of the order of few seconds. This would inhibit the use of this mode for fast asteroseismology time series, one of the main scientific drivers of the upgrade. The time needed for the "shutter" to close should be negligible in comparison to the period exepcted for the stellar oscillations under study. Moreover even a slight (few percent) polllution of the profile of the spectral lines might severly impact the precision of the RV determination. For reference, a 1m/s RV accuracy corresponds to a 1/1000 of a pixel error in the determination of the line profile.
The only possible solution seems to be the last one, despite the fact that the available space is only $770\mu m$**.**

5.1 User requirements

5.1.1 Impact on instrument stability

It is mandatory that there should not be any impact on the baseline instrument stability. This requirement is spelled out in the following points:

- the high efficiency fibers are already installed in the spectrograph and full installation would not require to open the vacuum vessel;
- the fiberhead will be installed in the available slot in the fiber carriage of the HCFA, this does not require to dismount the high accuracy HARPS fiber at any time;
- in case of failure of the shutter only the high efficiency observation mode would be compromised;
- the coupling between the fiberhead and the HCFA is through fixation points which fix the fiber head on the HCFA fiber carriage;
- the only change of the instrument operation with respect to the high RV accuracy mode is the position of the fiber carriage in the HCFA.

5.1.2 Design, installation and operation

Area:	the two HE fibers have a diameter of $100\mu m$ each. This defines the smallest area the shutter should close. The shutter should close both fibers at the same time.
Exposure time:	$> 5s$.
Speed:	$< 0.1s$; the whole pupil should be symmetrically free in this amount of time
Accuracy:	the start of the exposure should be known within $< 0.1s$
Reproducibility:	the shutter should never cover only part of the fiber-hole once in an "open" or "closed" state. It should always be fully opened or fully closed.
Heat dissipation:	the shutter should not dissipate while open
Reliability:	10^6 exposures expected over 5 years
Scattered light:	the shutter shall be black on both sides (not painted) and light tight
Working conditions	temperature: 0°C 70°C (the upper limit is for use with the iodine cell, given its proximity). orientation: the shutter should work on all the different orientations it can assume while at the telescope.
Status report:	feedback about open/close status should be available
Control:	the shutter shall be controlled by the DCS via PULPO
Instrument mode:	it should be possible to use the high efficiency fiber and its shutter in any instrument mode (included with the iodine cell)
Accessibility:	the shutter should be easily accessible and it should be possible to change it in less than a day (ideally less than 2 hours) of work.
Fiber installation:	it should be easy and safely duable in no more than twenty minutes of work in the Cassegrain cage of an experienced person. The HE fiber installation should not disturb the HA fiber which should never be removed from its slot in the fiber carriage. The HE fiber will share the same position in the fiber carriage as the CES fiber; it should be straightforward to change from the CES fiber to the HE fiber.
Maintenance:	the mechanical part of the shutter should run dry (i.e. no lubricant) and should require a minimum amount of maintenance.
Spares:	at least one spare, preferably two, should always be available in La Silla.

5.2 Shutter control - Electronics

The shutter, located in the HCFA, should be controlled via PULPO, located in the HARPS room, 38 meters away. This implies that a standard driver / receiver system for the PULPO signals shall be implemented. At the moment PULPO cannot control two shutters. Therefore a mechanical switch shall be implemented to redirect the PULPO commands to either the HE or the HA shutter.

5.3 Shutter control - Software

New software will be required:

- new templates; (Developed by Geneva in collaboration with ESO-La Silla)
- adjustment of the definition of "instrument modes"; (developed by ESO-La Silla)

5.4 Data reduction software

Fine tuning of the data reduction pipeline will be needed. It will be carried over by the HARPS consortium as already agreed.

5.5 Commissioning

All functioanlity tests of the new mode will be made in daytime, with no interference on observing programs. The instrument does not need to be installed at the Cassegrain focus in this phase.
Night time will be requested for final commissioning. A total of five nights (already scheduled starting July 29th 2004) is estimated to be necessary to collect data for the following measurements:

- system functionality in night operations
- system efficiency and limiting magnitudes
- RV accuracy.

A detailed commissioning plan will be supplied at a later stage, in advance of the observing period.

6 Implementation

The new system should be implemented with a low cost, in terms of capital cost and manpower.

6.1 ESO-La Silla Manpower

Estimated 0.2 FTE : mechanical design and workshop;
0.1 FTE : electronic design and implementation;
0.1 FTE : software desing and implementation. (template development by Geneva)

6.2 Budget

Estimated capital cost $< 10k$EURO (available from 2003 Garching carryover).

6.3 Optimum schedule

April 2004:	design ready;
May 2004:	prototype ready;
June 2004:	start testing the final unit in the lab;
July-August 2004:	installation and commissioning (technical time requested and approved);
September 2004:	offered in CfP for period 75.

7 List of Acronyms

CES	Coude Echelle Spectrograph
ESO	Europen Southern Observatory
FRD	Focal Ratio Degradation
HA	High Accuracy
HARPS	High Accuracy Radial velocity Planetary Spectrograph
HCFA	HARPS Cassegrain Fibre Adapter
HE	High Efficiency
PU	PolyUrethane
RV	Radial Velocity
DCS	Detector Control System
TBC	To Be Confirmed
TBD	To Be Decided
EGGS	Extra Good General Spectroscopy