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Chapter 1

Introduction

1.1 Scope

HARPS is a spectrograph dedicated to the search for extra-solar planets by means of the technique of precise radial velocity measurement. HARPS is developed by a consortium headed by the Geneva Observatory. It is installed at the Coudé room of the 3.6-m ESO telescope at La Silla, with an optical fiber link to the Cassegrain focus.

The present document describes the Data Reduction Software (DRS) as well as its current architecture and configuration. The reader is supposed to be familiar with all the applicable documents listed below. Chapter 2 describes the Hardware and Software environment of the DRS. Chapter 5 describes programs, modules and functions of the DRS. Chapter 4 describes the data used and produced by the DRS.

1.2 Applicable Documents

The following documents, of the exact issue shown, form a part of this document to the extent specified herein.

[4] 3M6-TRE-HAR-33110-0006 1.0 09/06/2001 HARPS DRS Design Description
### 1.3 Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D</td>
<td>Two Dimension</td>
</tr>
<tr>
<td>AFPO</td>
<td>Average Flux per order</td>
</tr>
<tr>
<td>CCD</td>
<td>Charge-Coupled Device</td>
</tr>
<tr>
<td>CCF</td>
<td>Cross Correlation Function</td>
</tr>
<tr>
<td>CDB</td>
<td>Calibration Database</td>
</tr>
<tr>
<td>DAU</td>
<td>Data Archiving Unit</td>
</tr>
<tr>
<td>DFS</td>
<td>Data Flow System</td>
</tr>
<tr>
<td>DRS</td>
<td>Data Reduction Software</td>
</tr>
<tr>
<td>E2DS</td>
<td>Extracted 2 Dimension Spectra</td>
</tr>
<tr>
<td>ESO</td>
<td>European Southern Observatory</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>ICDP</td>
<td>Instrument Configuration Data Pool</td>
</tr>
<tr>
<td>LED</td>
<td>Light-Emitting Diode</td>
</tr>
<tr>
<td>LSO</td>
<td>ESO Chile (La Silla)</td>
</tr>
<tr>
<td>MS</td>
<td>Maintenance Software</td>
</tr>
<tr>
<td>OG</td>
<td>Observatoire de Genève</td>
</tr>
<tr>
<td>OS</td>
<td>Observing Software</td>
</tr>
<tr>
<td>QC</td>
<td>Quality Control</td>
</tr>
<tr>
<td>QE</td>
<td>Quantum Efficiency</td>
</tr>
<tr>
<td>RMS</td>
<td>Root Mean Square</td>
</tr>
<tr>
<td>RON</td>
<td>Read-Out Noise</td>
</tr>
<tr>
<td>RV</td>
<td>Radial Velocity</td>
</tr>
<tr>
<td>RVPO</td>
<td>Radial Velocity per order</td>
</tr>
<tr>
<td>S1D</td>
<td>Extracted 1 Dimension Spectra</td>
</tr>
<tr>
<td>SNR</td>
<td>Signal to Noise Ratio</td>
</tr>
<tr>
<td>SW</td>
<td>Software</td>
</tr>
<tr>
<td>TBD</td>
<td>To Be Defined</td>
</tr>
<tr>
<td>TBC</td>
<td>To Be Completed</td>
</tr>
<tr>
<td>VLT</td>
<td>Very Large Telescope</td>
</tr>
</tbody>
</table>
2.1 Overview

The DRS runs on-line on a dedicated HP-UNIX Workstation whadr
s. The DRS deals with all the aspects of the scientific reduction of the raw data, as well as the processing of these reduced data to extract the radial velocities. The DRS does not interfere with the operation of the instrument, i.e. observations are independent from the Data Reduction activity. The DFS configuration is illustrated on Fig. 2.1 and the DRS architecture on Fig. 2.2.

The DRS is designed to run automatically (no user interaction) like a batch process controlled by the Trigger (see [3]) right after the end of each exposure or at the completion of a sequence of exposures. It is also possible to use a DRS off-line to display and analyze reduced data.

2.2 Architecture of the data on WHADRS

The raw frames are automatically stored on the directory: /data/raw/YYYY-MM-DD/ where YYYY-MM-DD is the night directory automatically created at noon. All these directories are automatically created by the DFS system at noon.

The reduced frames are automatically stored in the directory: /data/reduced/YYYY-MM-DD/

The calibration frames are copied in the calibration Data Base directory: /data/calibDB/

The log files of the DRS are stored in the directory: /data/msg/

2.3 Execution of the On-line DRS

On-line DRS is executed by a set of system commands (recipes) send automaticaly by the Trigger. These recipes need two parameters:
Figure 2.1: DFS configuration

Figure 2.2: DRS architecture. The DRS is control by the Trigger. Products of the DRS are stored in "Reduced Data". A calibration data-base ("Calibration DB") is dynamically maintained by the DRS. Performances and config files are static databases (read-only by the DRS) where all relevant parameters useful for the DRS are stored. "CONFIG" is used to stored parameters of algorithms and "PERFORMANCE" to store QC parameters.
<table>
<thead>
<tr>
<th>Exposures type</th>
<th>Templates</th>
<th>Reduction program</th>
</tr>
</thead>
<tbody>
<tr>
<td>HARPS_ech_ [...] (Recipes)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Calibration

<table>
<thead>
<tr>
<th></th>
<th>cal_bias</th>
<th>cal_BIAS</th>
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</thead>
<tbody>
<tr>
<td>CCD BIAS</td>
<td>cal_dark</td>
<td>cal_DARK</td>
</tr>
<tr>
<td>Geometry of orders</td>
<td>cal_tun</td>
<td>cal_loc_ONE</td>
</tr>
<tr>
<td>Flat-field sequence</td>
<td>cal_tunAB</td>
<td>cal_FF</td>
</tr>
<tr>
<td>Wavelength calibration</td>
<td>cal_thoAB</td>
<td>cal_TH</td>
</tr>
<tr>
<td>$I_2$ spectrum measurement</td>
<td>cal_tunA_I2cell</td>
<td>cal_I2</td>
</tr>
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</table>

## Science Observations

<table>
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<th>obj_TH</th>
</tr>
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<tbody>
<tr>
<td>Accurate RV measurement</td>
<td>acq_I2cell</td>
<td>obj_ONE</td>
</tr>
<tr>
<td>Spectroscopy + $I_2$</td>
<td>acq_objA</td>
<td>obj_ONE</td>
</tr>
<tr>
<td>Spectroscopy for object only</td>
<td>acq_objAB</td>
<td>obj_TWO</td>
</tr>
</tbody>
</table>

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>

Table 2.1: List of on-line data reduction programs.

- night directory name [YYYY-MM-DD]
- raw frame name(s) [HARPS.YYYY-MM-DDTHH:MM:SS.SSS.fits]
(for some recipes a list of raw frame names is needed)

For example, the command:

```
cal_loc_ONE.py 2002-02-11 HARPS.2002-02-11T20:13:45.768.fits
```

reduces the raw frame HARPS.2002-02-11T20:13:45.768.fits with the reduction program cal_loc_ONE. The raw frame is read in the directory /data/raw/2002-02-11/ and all DRS products are stored in the directory /data/reduced/2002-02-11/. The logs of the DRS are stored in the file /data/msg/DRS-whadrs.2002-02-11. The list of the raw frames obtained on a night is stored in the file /data/msg/2002-02-11.r.

The reduction programs are executable files (actually python scripts) that contain all relevant information to carry out the reduction. No other parameters nor options are needed for the reduction. Parameters specific to the exposure are in the FITS descriptors of the raw frame.

The Trigger runs automatically the appropriate reduction program of each frame or set of frames as soon as the exposure is archived and available on the DRS machine. The reduction programs associated to each template types are listed in the table 2.1.

The on-line trigger is executed on the WHADRS workstation (under user harps) with the command:

```
trig.csh online
```
<table>
<thead>
<tr>
<th>Description</th>
<th>Reduction program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display one order of the E2DS spectrum</td>
<td>off_visu_e2ds</td>
</tr>
<tr>
<td>Display a domain of the S1D spectrum</td>
<td>off_visu_s1d</td>
</tr>
<tr>
<td>Display SNR per orders</td>
<td>off_visu_SN</td>
</tr>
<tr>
<td>Display the CCF and its parameters</td>
<td>off_visu_ccf</td>
</tr>
<tr>
<td>Display the RV per orders</td>
<td>off_visu_rvo</td>
</tr>
</tbody>
</table>

**Radial velocity re-computation**

Compute the CCF | off_newccf

Table 2.2: List of off-line data reduction programs.

## 2.4 Execution of the Off-line DRS

The Off-line DRS is used to display and analyze reduced data. Off-line DRS is executed by a set of system commands (recipes) send manually through a dedicated GUI or directly from the prompter. The reduction programs associated to reduced datas are listed in the table 2.2.

## 2.5 Programming language

The programming language is Python, a powerful, object-oriented, interpreter programming language that is easy to extend, freely distributed, and available for most computer platforms (see [http://www.python.org/](http://www.python.org/) and [http://www.vex.net/parnassus/](http://www.vex.net/parnassus/)).

The following python modules are needed by the DRS:

- Mathematical and Numerical (Numeric)
- Graphical and visualization (Gnuplot)
- FITS format manipulation (pcfitsio, fitsio)
- User interface (Tkinter)
- system and files (sys,time,shutil,os)
- string manipulation (string)
- Fortran program interface (f2py)

Most of these modules are part of the python 2.1.1 distribution version. DRS is currently running on this version.

Some specific algorithm of the DRS are written in Fortran in order to increase the DRS execution.
They are included in Python library through the Fortran program interface \texttt{f2py}.

### 2.6 Architecture of the DRS

All the directories and files related to the Data Reduction Software of HARPS are stored on the directory: \texttt{/home/harmgr/INTROOT/DRS/}

From this point:

- `./config`: Contains all the Instrument Configuration Data files used by the DRS.
- `./docs`: Contains all useful documents, notes and manuals related to the DRS.
- `./scripts`: Contains all the executable programs or their links.
- `./fortran`: Contains all the fortran sources \texttt{name.f} and their associated python modules \texttt{namemodule.sl}.
- `./python`: Contains the python executable \texttt{python.csh} and two initialization file \texttt{startup.py} and \texttt{startup_recipes.py}.
- `./python/f2pymodule`: Contains all the modules based on fortran code and their test python scripts.
- `./python/Recipes`: Contains all the python reduction programs.
- `./python/Modules`: Contains all the python modules used by the reduction programs.

### 2.7 Architecture of the DRS Modules

All the functions used by the reduction programs are grouped in modules related to a specific application. Table 2.3 describes all the modules used by the Data Reduction programs and their field of application.
<table>
<thead>
<tr>
<th>module name</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>hadmrBIAS</td>
<td>Bias Measurement and Correction</td>
</tr>
<tr>
<td>hadmrCDB</td>
<td>Calibration Database access functions</td>
</tr>
<tr>
<td>hadmrDARK</td>
<td>Dark Measurement and correction functions</td>
</tr>
<tr>
<td>hadmrEXTOR</td>
<td>Extraction of Orders</td>
</tr>
<tr>
<td>hadmrFITS</td>
<td>Manipulate FITS</td>
</tr>
<tr>
<td>hadmrFLAT</td>
<td>Flat field Measurement and correction functions</td>
</tr>
<tr>
<td>hadmrLOCOR</td>
<td>Localization of orders</td>
</tr>
<tr>
<td>hadmrRV</td>
<td>Calculation of velocity (Earth, drift, stellar)</td>
</tr>
<tr>
<td>hadmrTHORCA</td>
<td>Thorium Calibration</td>
</tr>
<tr>
<td>hadrgdCONFIG</td>
<td>Configuration Panel Function of the RGD</td>
</tr>
<tr>
<td>hadgtVISU</td>
<td>Graphical functions</td>
</tr>
<tr>
<td>hadgtMATH</td>
<td>Mathematical functions</td>
</tr>
</tbody>
</table>

Table 2.3: List of the modules used by the Reduction programs.
Chapter 3

On-line DRS Description

3.1 Overview

The On-line Data Reduction is automatically executed with the *Trigger* which can be started by typing the command: `trig.csh online` on the *whadrs* (under user *haprs*).

3.2 Recipes

Recipes are made of specific functions available in the Modules specifically developed for the HARPS DRS (see Table 2.3) or part of the distribution of python modules (see in section 2.5). Dependencies between recipes and modules can be found in the DRS design document. We present in this chapter a description of the reduction task carried out by each recipes.

3.2.1 cal_BIAS - CCD BIAS

**Inputs**
Raw fits frame obtained with the HARPS_ech_cal_bias template

**Description**
- Read keywords related to the CCDs parameters (readout mode, readout noise, gain)
- Correction of the bad columns of the CCDs (average of adjacent columns)
- Measurement of the mean level and the dispersion of the 4 overscan areas
- Measurement of the mean level and the dispersion of the 4 CCD ports
- Print and Display of the results
- Store results on the file `cal_BIAS_result.tbl`

**Outputs**
- Ascii file `cal_BIAS_result.tbl`
Quality control
- Quality control with warning message when bias level > 500 ADU or bias noise > 10 e-

3.2.2 cal_DARK - CCD Dark

**Inputs**
Raw fits frame obtained with the HARPS_ech_cal_dark template

**Description**
- Read keywords related to the CCDs parameters (readout mode, readout noise, gain)
- Correction of the bad columns of the CCDs (average of adjacent columns)
- Mean level and dispersion of the Bias on the 4 overscan areas
- Mean level and dispersion of the 4 CCD ports with sigma clipping of the cosmic hits
- Calculation of the mean dark level (e-/hour)
- Calculation of the number of cosmic events (event/cm2/mn)
- Store result on the file cal_DARK_result.tbl

**Outputs**
Ascii file cal_DARK_result.tbl

**Quality control**
- Error message if the exposure time is shorter than 5 minutes, DRS stopped.
- Warning if dark level > 10 e-/hour or cosmic events > 10 event/cm2/mn

3.2.3 cal_loc_ONE - Geometry of orders of One fiber

**Inputs**
Two raw fits frames obtained from a sequence of two successive Tungsten exposures with the HARPS_ech_cal_tun template for each fibers A and B.

**Description**
- Retrieve from calibDB previous last full calibration sets - Read keywords related to the CCDs parameters (readout mode, readout noise, gain)
- Read keywords related to the exposure type in order to determine the illuminated fiber
- Correction of the bad columns of the CCDs (average of adjacent columns)
- Correction of the BIAS determined in the 4 overscan areas. The bias is determined for each of the 4096 rows by average of the 50 columns. This skeme allow to conserve and correct the possible structure of the bias when the CCDs are illuminated.
- Resize of the raw frame and cut through all the spectral orders on the central row of the CCD
- Renormalization the central row in order to put all orders at the same level
- Find all orders in the normalized central row greater than 0.15. This first step allow to find the 72 orders of fiber A and the 71 orders of fiber B listed in Table 6.1. - From these starting points order position are searched and located by 20 pixel steps. At each point, profile of each order is fitted by a
gaussian in order to measure its center and fwhm. On the whole frame centers and FHWM of each order are determined on 200 points.

- A 4th degrees polynome is fitted for each order to constrain the center and to measure its FWHM. The typical RMS of the fit is 25 mpixels for the centering (75 mpixels for the fwhm). The FWHM ranges of orders from 3 to 4 pixels.

- The position x of the center of each orders for each rows y is stored in a FITS file with the suffix loco
- The FWHM of each orders for each rows y is stored in a FITS file with the suffix fwhm-order
- Parameters of 3 orders are appended in the file cal_loc_ONE_result.tbl
- Quality control on the number of orders identified, dispersion of the center and FWHM.
- If passed the Quality control updates the Calibration Data Base.

**Outputs**

Ascii file cal_loc_ONE_result.tbl

Fits files [generic name]_loco_A.fits and [generic name]_loco_B.fits

Fits files [generic name]_fwhm-order_A.fits and [generic name]_fwhm-order_B.fits

**Quality control**
- Error if flux level on the central row (65000 ADU > Flux > 15000 ADU), DRS stops
- Quality control on the number of orders (72/71) dispersion of the fit both on center and FWHM values of order profiles (< 0.1[pix]). If Quality control fails calibDB is not updated

### 3.2.4 cal_FF - Flat-field measurement

**Inputs**

Several raw fits frames obtained from a sequence of Tungsten exposures on the two fibers with the HARPS_ech_cal_tunAB template or HARPS_ech_cal_tunUSER (at least 5 frames in order to reach the photon noise level above the flat-field noise).

**Description**

- Retrieve from calibDB previous last full calibration sets - Sum of the raw frame delivered
- Correction of the bad columns of the CCDs (average of adjacent columns)
- Correction of the BIAS as described previously
- Read the last localisation in the Calibration Data Base
- Horn optimum extraction of orders
- A box window is used to smooth the tungsten flux along the orders to determine a "pseudo"-blaze response.
- Divide the extracted tungsten spectrum by this blaze response to obtain the flat field spectrum.
- Computation of the SNR at the blaze center and the dispersion of the flat field
- The Blaze for each orders is stored in a FITS file with the suffix blaze
- The Flat for each orders is stored in a FITS file with the suffix flat
- Parameters of 3 orders are appended in the file cal_FF_result.tbl
- If passed Quality control update the Calibration Data Base.
Outputs
Ascii file cal_FF_result.tbl
Fits files [generic name]_blaze_A.fits and [generic name]_blaze_B.fits
Fits files [generic name]_flat_A.fits and [generic name]_flat_B.fits

Quality control
- check saturation level, stop DRS if saturated
- check FF parameters (rms < 0.033[e-]; S/N > 100), CalibDB is not updated if failed

3.2.5 cal_TH - Thorium Calibration

Inputs
Raw fits frame obtained with the HARPS_ech_cal_thoAB template

Description
- Retrieve from calibDB previous last full calibration sets
- Correction of the bad columns of the CCDs (average of adjacent columns)
- Correction of the BIAS as described previously
- Fit on raw frame a small set of thorium lines and save parameters in a tbl file with suffix spot_thAB
- Read the last localisation and flat field in the Calibration Data Base
- Horn optimum extraction of orders
- Flat field correction
- Compute the RV drift from the last Th Calibration in the Calibration Data Base.
- Identify lines using calibration provided by calibDB (if calibration is not available: "first wavelength calibration" procedure must be used)
- Fit each thorium emission line - Adjust a polynomial solution for each order with a sigma-clipping scheme
- Compute the Littrow first and second order deviation and computes the granulation of the global solution - Save E2DS Thorium spectrum in FITS file with the suffix e2ds with all descriptors.
- Save an image of the wavelength solution (wavelength of each orders for each pixels) in FITS file with the suffix wave.
- Parameters of the Thorium wavelength calibration are appended in the file cal_TH_result.tbl.
- Listing of all Thorium lines detected are stored in a tbl file with suffix th_lines.
- If passed Quality control update the Calibration Data Base.

Outputs
Ascii file cal_TH_result.tbl
Ascii file [generic name]_spot_thAB.tbl
Ascii file [generic name]_th_lines_A.tbl
Ascii file [generic name]_th_lines_B.tbl
Fits files [generic name]_e2ds_A.fits and [generic name]_e2ds_B.fits
Fits files [generic name]_wave_A.fits and [generic name]_wave_B.fits

Quality control
- Check if Littrow solution has rms granulation less than 50m/s. if found greater calibDB is not updated

3.2.6 cal_I2 - $I_2$ spectrum measurement

**Inputs**
Raw fits frame obtained with the HARPS_ech_cal_tunAl2 template

**Description**
- Retreive from calibDB previous last full calibration sets - Correction of the bad columns of the CCDs (average of adjacent columns)
- Correction of the BIAS as described previously
- Read the last localisation, flat field and wavelength solution in the Calibration Data Base
- Horn optimum extraction of orders
- Flat field correction
- Save E2DS Thorium spectrum in FITS file with the suffix e2ds with all descriptors.

**Outputs**
Fits files [generic name]_e2ds_A.fits

**Quality control**
- Error if saturation level reached on $I_2$ spectrum, DRS stops

3.2.7 obj_TH - Accurate RV measurement

**Inputs** Raw fits frame obtained with the HARPS_ech_acq_thosimult template

**Description**
- Retreive from calibDB previous last full calibration sets - Correction of the bad columns of the CCDs (average of adjacent columns)
- Correction of the BIAS as described previously
- Read the last localisation, flat field, wavelength solution and Thorium reference spectrum in the Calibration Data Base
- Horn optimum extraction of orders
- Flat field correction
- Save E2DS Thorium spectrum in FITS file with the suffix e2ds with all descriptors.
- Compute the rebinned and merged spectrum S1D and save it with the suffix s1d.
- Compute the instrumental drift with the Thorium spectrum relative to the last Thorium reference in the Calibration Data Base and save the result in the file drift_result.tbl.
- Compute the Barycentric Earth Radial Velocity.
- Compute the cross correlation function with a template mask driven by the spectral type and save the average CCF on the fits file [generic name]_ccf_mask_A.fits, the RV for each orders in the table [generic name]_ccf_mask_A.tbl, and the summary of results on the table CCF_result.tbl.

**Outputs**
Ascii file drift_result.tbl
3.2.8 obj_ONE - Spectroscopy using One fiber

Inputs
Raw fits frame obtained with the HARPS_ech_acq_objA template

Description
- Retrieve from calibDB previous last full calibration sets - Correction of the bad columns of the CCDs (average of adjacent columns)
- Correction of the BIAS as described previously
- Read the last localisation, flat field, wavelength solution and Thorium reference spectrum in the Calibration Data Base
- Horn optimum extraction of orders
- Flat field correction
- Save E2DS Thorium spectrum in FITS file with the suffix e2ds with all descriptors.
- Compute the rebinned and merged spectrum S1D and save it with the suffix s1d.
- Compute the Barycentric Earth Radial Velocity.
- Compute the cross correlation function with a template mask driven by the spectral type and save the average CCF in the fits file [generic name]_ccf_mask_A.fits, the RV for each orders in the table [generic name]_ccf_mask_A.tbl, and the summary of results on the table CCF_result.tbl.

Outputs
Ascii file CCF_result.tbl
Fits files [generic name]_e2ds_A.fits
Fits files [generic name]_e2ds_B.fits
Fits files [generic name]_s1d_A.fits
Fits files [generic name]_s1d_B.fits
Fits files [generic name]_ccf_mask_A.fits
Fits files [generic name]_ccf_mask_A.tbl

Quality control
- Warning if saturation level reached
3.2.9  obj_TWO - Spectroscopy using Two fibers

**Inputs** Raw fits frame obtained with the HARPS_ech_acq_objAB template

**Description** - Retrieve from calibDB previous last full calibration sets - Correction of the bad columns of the CCDs (average of adjacent columns)
- Correction of the BIAS as described previously
- Read the last localisation, flat field, wavelength solution and Thorium reference spectrum in the Calibration Data Base
- Horn optimum extraction of orders
- Flat field correction
- Save E2DS Thorium spectrum in FITS file with the suffix e2ds with all descriptors.
- Compute the rebinned and merged spectrum S1D and save it with the suffix s1d.
- Compute the Barycentric Earth Radial Velocity.
- Compute the cross correlation function with a template mask driven by the spectral type for both fibers and save the average CCF on the fits file [generic name]_ccf_mask_A.fits, the RV for each orders in the table [generic name]_ccf_mask_A.tbl, and the summary of results on the table CCF_result.tbl.

**Outputs**

Ascii file CCF_result.tbl
Fits files [generic name]_e2ds_A.fits
Fits files [generic name]_e2ds_B.fits
Fits files [generic name]_s1d_A.fits
Fits files [generic name]_s1d_B.fits
Fits files [generic name]_ccf_mask_A.fits
Fits files [generic name]_ccf_mask_B.fits
Fits files [generic name]_ccf_mask_A.tbl
Fits files [generic name]_ccf_mask_B.tbl

**Quality control**

- Warning if saturation level reached
4.1 Data naming rules

The raw frames are stored on FITS format by the DFS with the ESO-VLT standard naming rules:
HARPS.YYYY-MM-DDTHH:MM:SS.SSS.fits with YYYY-MM-DD and HH:MM:SS.SSS being respectively the date and time of the beginning of observation.

Image products of the DRS are stored on FITS format with the same generic names plus a additional suffix describing its format (see next section for details) and the specific fiber name (A or B). For example: HARPS.YYYY-MM-DDTHH:MM:SS.SSS_e2ds_A.fits is an E2DS format image of the fiber A product by the DRS from the HARPS.YYYY-MM-DDTHH:MM:SS.SSS.fits raw frame.

Tables in ASCII format are also produced by the DRS. See in Table TBC for a list and a description of the content of tables.

The relevant log-books of the DRS is named DRS-whadrs.YYYY-MM-DD.

4.2 Data formats

4.2.1 Raw frames

The raw frame corresponds to a 4296 x 4096 integer (35’242’560 bytes) matrix written on disk in FITS format (see Fig. 4.1). This images includes a 4096x4096 sensitive zone plus 4 over and prescan zone of 50 pixels each. The following generic descriptors are used by the DRS:

- **DATE-OBS**: Date and Time of beginning of observation [string]
- **RA**: RA of the target [float]
- **DEC**: DEC of the target [float]
The DRS needs as well the following **HIERARCH ESO** descriptors:

- **DET READ SPEED**  
  CCD Readout mode (speed, port and gain) [string]

- **DET OUT2 RON**  
  Readout noise (e-) of Linda (Blue) [float]

- **DET OUT2 CONAD**  
  Conversion from ADUs to electrons of Linda (Blue) [float]

- **DET OUT4 RON**  
  Readout noise (e-) of Jasmin (Red) [float]

- **DET OUT4 CONAD**  
  Conversion from ADUs to electrons of Jasmin (Red) [float]

- **DET WIN1 DIT1**  
  Actual sub-integration time (s) [float]

- **DET WIN1 DKTM**  
  Dark current time (s) [float]

- **DET DPR CATG**  
  Observation category [string]

- **DET DPR TYPE**  
  Exposure type [string]

- **INS DET1 TMMEAN**  
  Normalised mean exposure time [float]

- **INS DET1 CMMEAN**  
  Average count PM on fiber A [float]

- **INS DET2 CMMEAN**  
  Average count PM on fiber B [float]

- **OBS TARG NAME**  
  Target name [string]

- **TEL TARG EQUINOX**  
  Equinox [float]

- **TEL TARG PMA**  
  Proper motion alpha (arcsec/year) [float]

- **TEL TARG PMD**  
  Proper motion delta (arcsec/year) [float]

- **TEL TARG RADVEL**  
  Radial velocity of target (km/s) [float]

- **TEL AMBI FWHM START**  
  seeing at start [float]

- **TEL AMBI FWHM END**  
  seeing at end [float]

- **TEL AIRM START**  
  air mass at start [float]

- **TEL AIRM END**  
  air mass at end [float]

- **TPL NEXP**  
  TPL Number of exposures [integer]

- **TPL EXPNO**  
  TPL Exposure number within template [integer]

- **TPL NAME**  
  TPL NAME [string]
4.2.2 Localization frames _loco_ and _fwhm-order_

Centers and FWHM of orders are stored in two 4096 x (n\textsubscript{order}) real matrix written on disk in FITS format with the suffix _loco_ and _fwhm-order_ added to the generic name. Each lines corresponds to an order and each column to a line of the CCD raw frame. The localization frame _loco_ contains the position of the center positions of orders. The localization frame _fwhm-order_ contains the FWHM of orders. Pay attention to the orientation of the raw frame by comparison with the E2DS format described below. The FITS descriptor includes all descriptors of the raw frame. In addition, the order position are stored with the following HIERARCH ESO DRS fits descriptor:

- CAL LOC NBO number of orders localized [int]
- CAL LOC DEG degree of the polynomial fit [int]
- CAL LOC CTRi Coeffi for center order (i = NBO x DEG) [float]
- CAL LOC FWHMi Coeffi for fwhm order (i = NBO x DEG) [float]

4.2.3 Flat field frames _flat_

The Flat field frame is a 4096 x (n\textsubscript{order}) real matrix written on disk in FITS format with the _flat_ suffix added to the generic name. Each lines contains the normalized flat field spectrum of the orders. The row numbering of the matrix corresponds to the inverse of the column of the raw frame in order to have wavelength increasing with pixels (see on Fig. 4.1). The FITS descriptor includes all descriptors.
4.2.4 Blaze frames _blaze_

The Blaze frame is a 4096 x (norder) real matrix written on disk in FITS format with the \_blaze\_ suffix added to the generic name. Each line contains the pseudo blaze reponse of the orders. The row numbering of the matrix corresponds to the inverse of the column of the raw frame in order to have wavelength increasing with pixels (see on Fig. 4.1). The FITS descriptor includes all descriptors of the raw frame.

4.2.5 Wavelength frames _wave_

The wavelength frame is a 4096 x (norder) real matrix written on disk in FITS format with the \_wave\_ suffix added to the generic name. Each line contains the wavelength calibration of the orders. The row numbering of the matrix corresponds to the inverse of the column of the raw frame in order to have wavelength increasing with pixels (see on Fig. 4.1). The FITS descriptor includes all descriptors of the raw frame.

4.2.6 Extracted two-dimensional spectra _e2ds_

The extracted two-dimensional spectra (E2DS) is a 4096 x (n\_order) real matrix written on disk in FITS format with the \_e2ds\_ suffix added to the generic name. Each line contains the extracted flux of one spectral order in photo-electrons unit. The line numbering of the matrix corresponds to the inverse of the column numbering of the raw frame in order to have wavelength increasing with pixels on E2DS format. The FITS descriptor includes all descriptors of the raw frame. The following extra descriptor HIERARCH ESO DRS related to the localization, flat-field, Barycentric Earth Radial Velocity, Instrumental drift and wavelength calibration are included:

- CAL LOC FILE: Localization file used [string]
- CAL EXT OPT: Option extraction [integer]
- CAL EXT SIG: Size extraction zone [float]
- CAL EXT COSM: threshold cosmic detection [float]
- CAL EXT SNi: S_N order center i [float]
- CAL EXT NBCOSi: NbCos detected order i [integer]
- CAL FLAT WIN: half size blaze window [integer]
- CAL FLAT FILE: Flat file used [string]
CAL FLAT NBFILES  Nb of Flat files used [integer]
CAL FLAT RMSi    FF RMS order i [float]
CAL ADDED NBRFILES Nb of raw files processed [integer]
CAL ADDED FILES  Files name of raw files used [string]
BERV             Barycentric Earth Radial Velocity [float]
BJD              Barycentric Julian Day [float]
BERVMX          Maximum BERV [float]
CAL TH FILE      Wavelength file used [string]
DRIFT REF FILE   Th Drift ref file used [string]
DRIFT VR         Th RV Drift (m/s) [float]
DRIFT NBCOS      Th Drift Nbr cosmic detected [integer]
DRIFT RFLUX      Th Drift Flux ratio [float]
DRIFT NBORDKILL  Th Drift Nb orders killed [integer]
DRIFT NOISE      Th Drift photon noise (m/s) [float]
CAL TH ORDER NBR  nbr of orders in total [int]
CAL TH ORDER START numbering of the first blue order [int]
CAL TH ORDER NBLUE nbr of blue orders [int]
CAL TH ORDER NGAP nbr of orders in the gap [int]
CAL TH ORDER NRED nbr of red orders [int]
CAL TH GUESS ORDER nbr of the first guess order [int]
CAL TH GUESS LINES file name for first guess lines [string]
CAL TH LINES     file name for tbl of cal lines [string]
CAL TH DEG LL    degre polyn fit ll(x,order) [int]
CAL TH DEG X     degre polyn fit x(ll,order) [int]
CAL TH COEFF LL  coeff for ll(x,order) [dbl precision]
CAL TH COEFF X   coeff for x=(ll,order) [dbl precision]
The wavelength calibration $\lambda = f(x, \text{order})$ is related to the coefficient with the following equation:

$$
\lambda(x, o) = \sum_{i=0}^{d} A(i + o(d + 1)) x^i,
$$

where $d = \text{ESO DRS CAL TH DEG LL}$, $bf.A = \text{ESO DRS CAL TH COEFF LL}$ and $o$ the internal numbering of the order (raw number in the e2ds frame).

For thorium spectrum an extension \_wave\_ is also produced by the DRS. It is a e2ds format image where the matrix stores the wavelength value of each pixel instead of the flux of the spectrum.

### 4.2.7 Extracted one-dimensional spectra \_s1d\_

The extracted one-dimensional spectra (S1D) is a real vector written on disk in FITS format with the \_s1d\_ suffix added to the generic name. This vector contains the rebinned and merged spectral orders in relative flux corrected from the instrumental respond and stretched to the barycentric referential. The wavelength step is 0.01 Angstrom.

### 4.2.8 Cross-correlation function \_ccf\_

The cross correlation function is stored with the suffix \_ccf\_\_[template\_name\] with \template\_name\ the file name of the corresponding template (also called coorelation mask) used to compute it. The matrix is made of $n_{\text{order}}$ CCF spectrum corresponding to the CCF computed for each order. The following extra descriptor HIERARCH ESO DRS related to CCF are included:

- **CCF MASK**: template filename
- **CCF MAXCPP**: max count/pixel in the continuum of the CCF (e-)
- **CCF FWHM**: FWHM of CCF (km/s) [gaussian fit]
- **CCF RV**: Baryc Rad vel (km/s) [gaussian fit]
- **CCF LINES**: nbr of lines used by the template
- **CCF CONTRAST**: Contrast of CCF (%) [gaussian fit]
- **BERV**: Barycentric Earth Radial Velocity correction
- **BJD**: Barycentric Julian Day
- **BERVMX**: Maximum BERV along the year
- **DRIFT REF FILE**: Th Drift ref file used [string]
- **DRIFT VR**: Th RV Drift (m/s) [float]
### 4.3 Summary tables

The DRS produces a set of summary table for performance tracking of calibration exposure. The tables have ASCII format with a TAB for separator:

- `cal_BIAS_result.tbl` for BIAS
- `cal_DARK_result.tbl` for DARK
- `cal_loc_ONE_result.tbl` for the order localization
- `cal_FF_result.tbl` for Flat-Field
- `cal_TH_result.tbl` for thorium calibration
- `drift_result.tbl` for instrumental drift
- `CCF_result.tbl` for CCF

#### 4.3.1 `cal_BIAS_result.tbl`

<table>
<thead>
<tr>
<th>column</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>night_name</code></td>
<td>name of the night directory</td>
</tr>
<tr>
<td><code>file_name</code></td>
<td>name of the corresponding raw frame</td>
</tr>
<tr>
<td><code>ccd_mode</code></td>
<td>CCD read out mode</td>
</tr>
<tr>
<td><code>mean_bias1</code></td>
<td>mean bias in zone 1 (prescan Linda) (ADU)</td>
</tr>
<tr>
<td><code>rms_bias1</code></td>
<td>rms bias in zone 1 (prescan Linda) (ADU)</td>
</tr>
<tr>
<td><code>mean_bias2</code></td>
<td>mean bias in zone 2 (overscan Linda) (ADU)</td>
</tr>
<tr>
<td><code>rms_bias2</code></td>
<td>rms bias in zone 2 (overscan Linda) (ADU)</td>
</tr>
<tr>
<td><code>mean_bias3</code></td>
<td>mean bias in zone 3 (prescan Jasmin) (ADU)</td>
</tr>
<tr>
<td><code>rms_bias3</code></td>
<td>rms bias in zone 3 (prescan Jasmin) (ADU)</td>
</tr>
<tr>
<td><code>mean_bias4</code></td>
<td>mean bias in zone 4 (overscan Jasmin) (ADU)</td>
</tr>
<tr>
<td><code>rms_bias4</code></td>
<td>rms bias in zone 4 (overscan Jasmin) (ADU)</td>
</tr>
</tbody>
</table>
4.3.2 cal_DARK_result.tbl

column description:

- **night_name**: name of the night directory
- **file_name**: name of the corresponding raw frame
- **ccd_mode**: CCD read out mode
- **dark_time**: dark exposure time (s)
- **mean_dark**: mean dark level (e-/hour)
- **cosmic**: number of cosmic events (event/cm²/mn)

4.3.3 cal_loc_ONE_result.tbl

column description:

- **night_name**: name of the night directory
- **file_name**: name of the corresponding raw frame
- **fiber**: fiber name (A or B)
- **posx_161**: location of the center of the order 161 [pixel]
- **err_posx_161**: error on order location [pixel]
- **fwhm_161**: width of the center of the order 161 [pixel]
- **err_fwhm_161**: error on the width of the center of the order 161 [pixel]
- **posx_114**: same than above for order 114
- **err_posx_114**: same than above for order 114
- **fwhm_114**: same than above for order 114
- **err_fwhm_114**: same than above for order 114
- **posx_89**: same than above for order 89
- **err_posx_89**: same than above for order 89
- **fwhm_89**: same than above for order 89
- **err_fwhm_89**: same than above for order 89
4.3.4  cal_FF_result.tbl

column description:

<table>
<thead>
<tr>
<th>Column</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>night_name</td>
<td>name of the night directory</td>
</tr>
<tr>
<td>file_name</td>
<td>name of the corresponding raw frame</td>
</tr>
<tr>
<td>nbfiles</td>
<td>number of frame coadded</td>
</tr>
<tr>
<td>fiber</td>
<td>fiber name (A or B)</td>
</tr>
<tr>
<td>FFrms_161</td>
<td>rms on the flat-field at center of order 116</td>
</tr>
<tr>
<td>S_N_161</td>
<td>S/N ratio per extracted pixel at center of order 161</td>
</tr>
<tr>
<td>FFrms_114</td>
<td>same than above for order 114</td>
</tr>
<tr>
<td>S_N_114</td>
<td>same than above for order 114</td>
</tr>
<tr>
<td>FFrms_89</td>
<td>same than above for order 89</td>
</tr>
<tr>
<td>S_N_89</td>
<td>same than above for order 89</td>
</tr>
</tbody>
</table>

4.3.5  cal_TH_result.tbl

column description:

<table>
<thead>
<tr>
<th>Column</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>night_name</td>
<td>name of the night directory</td>
</tr>
<tr>
<td>file_name</td>
<td>name of the corresponding raw frame</td>
</tr>
<tr>
<td>fiber</td>
<td>fiber name (A or B)</td>
</tr>
<tr>
<td>mean</td>
<td>mean value of the final solution in mpixel</td>
</tr>
<tr>
<td>rms</td>
<td>rms on the final solution in mpixel</td>
</tr>
<tr>
<td>N_lines</td>
<td>number of lines used in the final solution</td>
</tr>
<tr>
<td>err</td>
<td>internal error in the final solution in mpixel</td>
</tr>
<tr>
<td>rms_L0</td>
<td>rms on Littrow at cut #1 in mpixel</td>
</tr>
<tr>
<td>rms_L1</td>
<td>rms on Littrow at cut #2 in mpixel</td>
</tr>
<tr>
<td>rms_L2</td>
<td>rms on Littrow at cut #3 in mpixel</td>
</tr>
<tr>
<td>drift</td>
<td>drift in m/s compared to previous wavelength solution</td>
</tr>
</tbody>
</table>
**Rflux** flux ration by comparison with the previous solution

**Ccosmic** number of corrected cosmic

**ll1ref** wavelenth of reference line #1

**ampl1ref** amplitude in (e-) of the reference line #1

**ll2ref** wavelenth of reference line #2

**ampl2ref** amplitude in (e-) of the reference line #2

**error_spe** estimate of the velocity photon noise error of the spectrum

### 4.3.6 drift_result.tbl

column description:

- **night** name of the night directory
- **e2ds_file_name** name of the corresponding thorium e2ds spectrum
- **reference** name of the thorium e2ds spectrum used as reference
- **exp_time** exposure time (s)
- **VR_drift** Instrumental Drift (m/s) (To Add to the CCF result)
- **Nbcosmic** Nb cosmic corrected
- **Flu_ratio** Flux ratio between thorium spectrum and reference
- **Norders_killed** Nb order killed by the process

### 4.3.7 CCF_result.tbl

column description:

- **night_name** name of the night directory
- **file_name** name of the corresponding thorium e2ds spectrum
- **fiber** fiber 'A' or 'B'
- **mask** Name of the ccf template
- **maxccp** Maximum of count per pixel in the CCF
4.4 Databases

Several Databases are accessed by the DRS. The DRS uses Calibrations Databases to store and to retrieve calibrations. Its needs a Reduction Performance List for the quality control. The DRS main engine uses the Instrument Configuration Data Pool as input reference to carry on the reduction.

4.4.1 Calibration Database

The Calibration Databases includes all relevant calibrations which have passed properly the quality control tests. It contains BIAS frames, DARK frames, localization images, flat-fields, and thorium calibrated spectra. A master_calib.tbl file keeps track of all the calibration frames. All calibration frames needed and accessed by the DRS during the reduction process are automatically copied on the directory where all data product of the DRS are stored. This allow the observer to have a self-consistent set of data products if he wants to reprocess his observations.

Calibration Database stores a full calibration set made of:

- order localisation (A and B)
- flat-field and blaze spectrum (A and B)
- wavelenth solution (A and B)
- reference thorium spectrum (B)

4.4.2 Reduction Performance list

The reduction performance list contains all the DRS parameters that are checked by the Quality Control process. This list is stored on the /config/ directory.

4.4.3 Intrument Configuration Data Pool

All the fixed parameters needed by the DRS are in the file hadmrICDP.py on the directory /config/. In this file, one finds the characteristics of the CCD, mapping of the FITS descriptor to DRS
variable, and all the parameters of DRS algorithms optimized for HARPS.

4.4.4 Instrument Performance Database

All DRS outcome helpful to track instrument performance are stored on the table files cal_BIAS_result.tbl, cal_DARK_result.tbl, cal_loc_one_result.tbl, cal_FF_result.tbl, and cal_TH_result.tbl, [generic name]_spot_thAB.tbl, [generic name]_th_lines_A.tbl, [generic name]_th_lines_B.tbl.
Chapter 5

Off-line DRS Description

5.1 Overview

The Data Reduction Off-line corresponds to a set of tools offer to the user through a Graphical User Interface to display and analyze the reduced data provided by the On-line DRS. The outputs of the Off-line DRS are generated in the local directory. Unfortunately the GUI of the Off-line DRS has not been tested during the third commissioning and will not be available before January 2004. However users can send manually the off-line recipes like commands following by parameters as described in the next section. Note that these tools are not essential to analyze reduced data since their format is completely compatible with Midas or other tools.

5.2 Recipe

5.2.1 off_visu_e2ds - Display E2DS order

off_visu_e2ds.py [night] [e2dsfits] [order_number] [ps]

[night] Night directory (2002-02-11)
[e2dsfits] E2DS fits file (HARPS.2002-02-11T20:13:45.768_e2ds_A.fits)
[order_number] Order number (0-71) default value = 49
[ps] Poscript file output option (0/1) default value = 0

5.2.2 off_visu_s1d - Display S1D spectrum

off_visu_s1d.py [night] [s1dfits] [lambda_start] [lambda_end] [ps]
5.2.3 off_visu_ccf - Display CCF

off_visu_ccf.py [night] [ccffits] [ps]

[night] The night directory (2002-02-11)


[ps] Poscript file output option (0/1) it default value = 0

5.2.4 off_visu_SN - Display S_N per orders

off_visu_SN.py [night] [e2dsfits] [ps]

[night] The night directory (2002-02-11)

[e2dsfits] CCF fits file (HARPS.2002-02-11T20:13:45.768_e2ds_A.fits)

[ps] Poscript file output option (0/1) it default value = 0

5.2.5 off_visu_rvo - Display RV per orders

off_visu_rvo.py [night] [ccftbl] [ps]

[night] The night directory (2002-02-11)

[ccftbl] Table CCF file (HARPS.2002-02-11T20:13:45.768_ccf_G2_A.tbl)

[ps] Poscript file output option (0/1) it default value = 0
5.2.6  off_newccf - Re-process CCF

off_newccf.py [night] [e2dsfits] [maskfilename] [targetRV] [widthccf] [stepccf]

[night]    The night directory (2002-02-11)
[e2ds]     E2DS fits file (HARPS.2002-02-11T20:13:45.768_e2ds_A.tbl)
[maskfilename]     Template of correlation (K0.mas) default is G2.mas
[targetRV]  Target Radial Velocity (km/s) default is 0.
[widthccf]  Windows of the CFF (km/s) default is 20 km/s
[stepccf]   Step of the CCF (km/s) default is 1 km/s

The new CCF is saved in the file [generic name]_newwccf_mask_A.fits
This appendix describes the use of the Data Archiving Unit (DAU). This unit allows the VA to write his/her data (raw and reduced) to DVD.

In order to archive the data of one night the following has to be done:

1. Launch the Data Archiving Unit on the wharch machine as harps user with the command 
   dau.csh (do not send it in a background process).

2. Indicate the night date in the “Night” field (the only one which is white); pressing “Enter” key 
   validates the entered value. The process scan the corresponding night directory in the whadrs 
   workstation and compute the size in MB.

3. Select the Backup buttons of the data files you want to archive and click on the “Go” button 
   to start the backup. Files are then copied in the wharch workstation under the /BACKUP/ 
   directory.

4. De-select the backup button and check that the Size is less than 4400 MB.

5. Put a writable DVD in the burner.

6. Select the Prepare DVD and Write DVD button.

7. Click the “Go” button to start archiving.

If the total data size is too big for one DVD (more than 4.4 GBytes), the raw files will be automatically 
compressed (by about 50%; approximately 170 gzipped FITS files fit on one DVD). If the volume is 
still too large the user has to split the night in two, e.g < night > _a and < night > _b directories. 
To archive both directories the complete name of the directory has to be put in the “Night” field. Both 
directories have to be archived separately. The “Compute size” button computes the total size of the 
data saved in the BACKUP under the < night > directory.
### Table 6.1: Order identified and extracted by the DRS

<table>
<thead>
<tr>
<th>Fiber A order</th>
<th>Fiber B order</th>
<th>Grating order</th>
<th>Central wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>161</td>
<td>3802 Å</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>160</td>
<td>3826 Å</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>159</td>
<td>3850 Å</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>44</td>
<td>44</td>
<td>117</td>
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