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HARPS

DRS USER MANUAL

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Contents

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.

[1]	3M6-SPE-HAR-33100-0002	2.0	31/05/2002	HARPS Tech. Requirements Spec.
[2]	3M6-PLA-HAR-33100-0005	1.4	11/06/2001	HARPS Oper., Calib. and Maint. Plan
[3]	3M6-TRE-HAR-33110-0005	1.1	10/07/2001	HARPS DFS Design Description
[4]	3M6-TRE-HAR-33110-0006	1.0	09/06/2001	HARPS DRS Design Description
[5]	3M6-TRE-HAR-33110-0019	1.0	12/12/2002	HARPS DRS Test and Progress Report
[6]	3M6-TRE-HAR-33110-0008	1.31	22/01/2002	Templates Reference Guide

1.3 Abbreviations and Acronyms

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

Chapter 2

DRS Hardware and Software Environment

2.1 Overview

The DRS runs on-line on a dedicated HP-UNIX Workstation `whadrs`. 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:

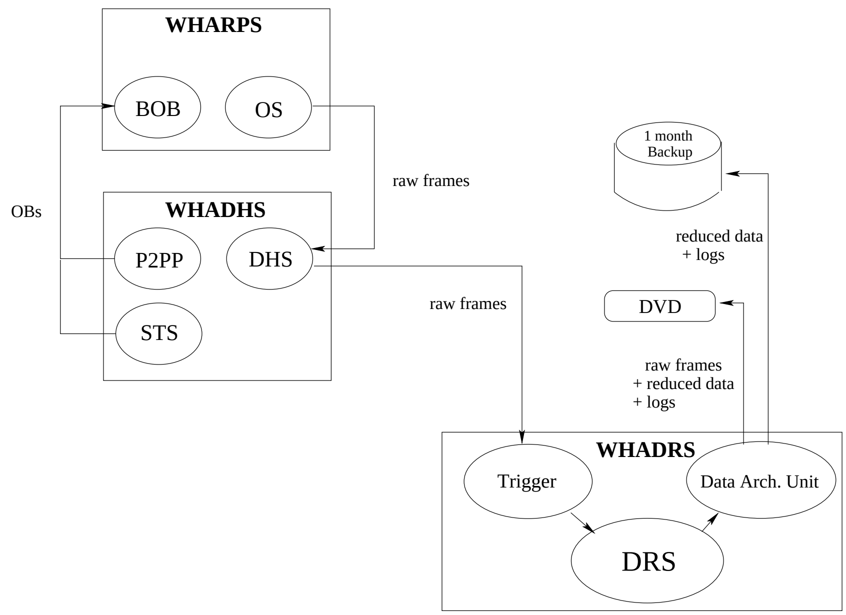

Figure 2.1: DFS configuration

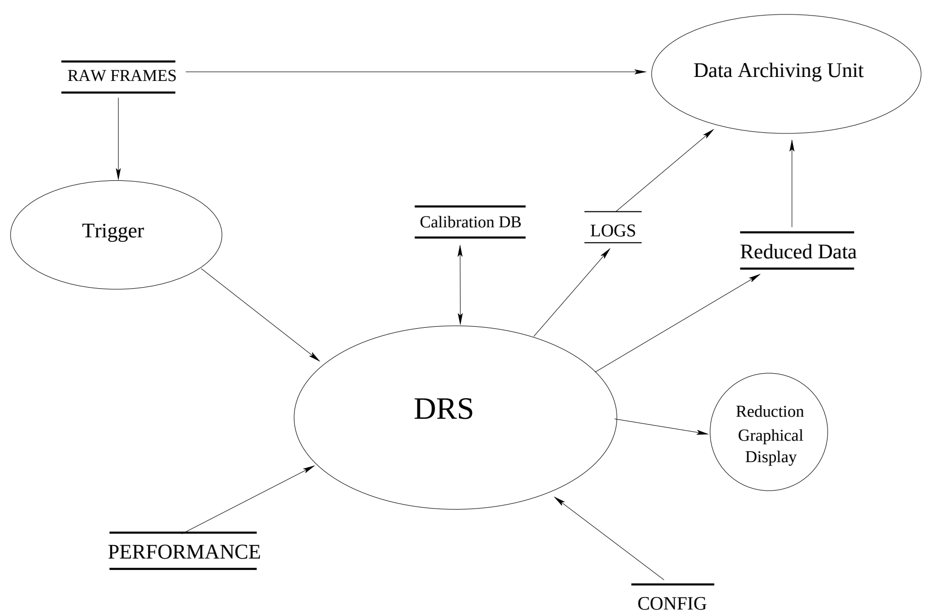

Figure 2.2: DRS architecture. The DRS is control by the Trigger. Products of the DRS are stored in "Reduced Data". A calibration data-base ("Calibration DB") is dynamically maintained by the DRS. Performances and config files are static databases (read-only by the DRS) where all relevant parameters useful for the DRS are stored. "CONFIG" is used to stored parameters of algorithms and "PERFORMANCE" to store QC parameters.

Exposures type	Templates HARPS_ech_[...]	Reduction program (Recipes)
Calibration		
CCD BIAS	cal_bias	cal_BIAS
CCD Dark	cal_dark	cal_DARK
Geometry of orders	cal_tun	cal_loc_ONE
Flat-field sequence	cal_tunAB	cal_FF
Wavelength calibration	cal_thoAB	cal_TH
I_2 spectrum measurement	cal_tunA_I2cell	cal_I2
Science Observations		
Accurate RV measurement	acq_thosimult	obj_TH
Spectroscopy + I_2	acq_I2cell	obj_ONE
Spectroscopy for object only	acq_objA	obj_ONE
Spectroscopy object and sky	acq_objAB	obj_TWO

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`

Description	Reduction program
Visualization	
Display one order of the E2DS spectrum	`off_visu_e2ds`
Display a domain of the S1D spectrum	`off_visu_s1d`
Display SNR per orders	`off_visu_SN`
Display the CCF and its parameters	`off_visu_ccf`
Display the RV per orders	`off_visu_rvo`
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/` and `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 `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: `/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 `name.f` and their associated python modules `namemodule.sl`.
`./python`	Contains the python executable *python.csh* and two initialization file *startup.py* and *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.

module name	description
hadmrBIAS	Bias Measurement and Correction
hadmrCDB	Calibration Database access functions
hadmrDARK	Dark Measurement and correction functions
hadmrEXTOR	Extraction of Orders
hadmrFITS	Manipulate FITS
hadmrFLAT	Flat field Measurement and correction functions
hadmrLOCOR	Localization of orders
hadmrRV	Calculation of velocity (Earth, drift, stellar)
hadmrTHORCA	Thorium Calibration
hadrgdCONFIG	Configuration Panel Function of the RGD
hadgtVISU	Graphical functions
hadgtMATH	Mathematical functions

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 stoppped.
- 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 skeem 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 staturation 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_tunAI2 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`

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

3.2.8 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_A.tbl`
Fits files *[generic name]*_`ccf_mask_B.fits`
Fits files *[generic name]*_`ccf_mask_B.tbl`
Quality control
- Warning if saturation level reached

Chapter 4

DRS Data Product Description

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 begining 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]

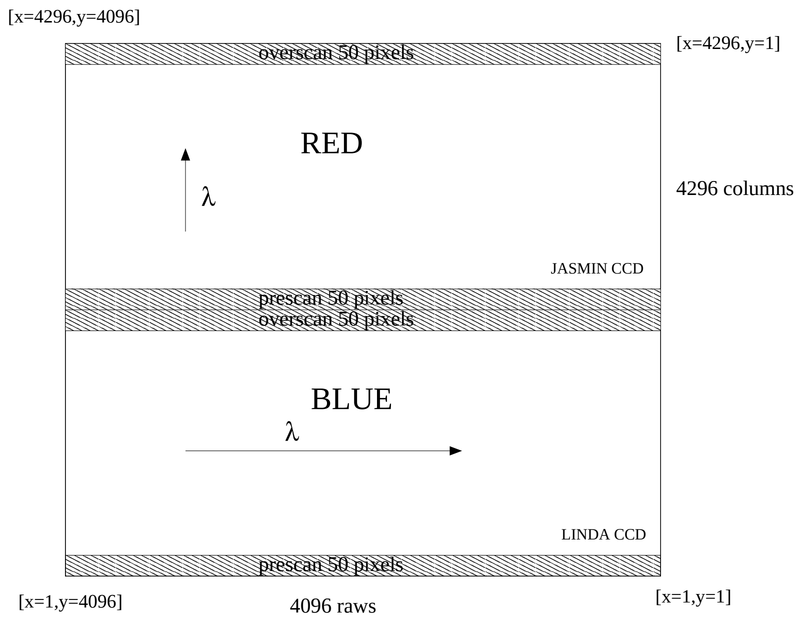

Figure 4.1: Raw frame format. The raw image is oriented in order to correspond to the CCD orientation in focal plane when looking at the detector from the spectrograph.

4.2.2 Localization frames _loco_ and _fwhm-order_

Centers and FWHM of orders are stored in two 4096 x (n_{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 (norder) 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 of the raw frame.

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 lines 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 lines 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 $\lambda = f(x, order)$ is related to the coefficient with the following equation:

$$\lambda(x,o) = \sum_{i=0}^{d} A(i + o(d+1))x^i, \tag{4.1}$$

where **d** = `ESO DRS CAL TH DEG LL`, bf A = `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_{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]

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]

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

column description:

night_name name of the night directory

file_name name of the corresponding raw frame

ccd_mode CCD read out mode

mean_bias1 mean bias in zone 1 (prescan Linda) (ADU)

rms_bias1 rms bias in zone 1 (prescan Linda) (ADU)

mean_bias2 mean bias in zone 2 (overscan Linda) (ADU)

rms_bias2 rms bias in zone 2 (overscan Linda) (ADU)

mean_bias3 mean bias in zone 3 (prescan Jasmin) (ADU)

rms_bias3 rms bias in zone 3 (prescan Jasmin) (ADU)

mean_bias4 mean bias in zone 4 (overscan Jasmin) (ADU)

rms_bias4 rms bias in zone 4 (overscan Jasmin) (ADU)

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:

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

4.3.5 cal_TH_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)
mean	mean value of the final solution in mpixel
rms	rms on the final solution in mpixel
N_lines	number of lines used in the final solution
err	internal error in the final solution in mpixel
rms_L0	rms on Littrow at cut #1 in mpixel
rms_L1	rms on Littrow at cut #2 in mpixel
rms_L2	rms on Littrow at cut #3 in mpixel
drift	drift in m/s compared to previous wavelength solution

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
Nborders_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

lines	Number of spectral lines used in the CCF
contrast	Contrast of the CCF (%)
RV	RV (km/s) corrected from BERV
FWHM	FWHM of the CCF (km/s)

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 Confi guration 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 Intrument 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)
[e2dsfi ts]	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]
```

[night]	Night directory (2002-02-11)
[s1dfi ts]	S1d fits file (HARPS.2002-02-11T20:13:45.768_s1d_A.fits)
[lambda_start]	First wavelentgh (Angstrom) *default value 3780*
[lambda_end]	Last wavelentgh (Angstrom) *default value 6912*
[ps]	Poscript file output option (0/1) it default value = 0

5.2.3 off_visu_ccf - Display CCF

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

[night]	The night directory (2002-02-11)
[ccffi ts]	CCf fits file (HARPS.2002-02-11T20:13:45.768_ccf_G2_A.fits)
[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)
[e2dsfi ts]	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)

[maskfi lename] Template of correlation (K0.mas) *default is G2.mas*

[targetRV] Target Radial Velocity (km/s) *defaut 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`

Chapter 6

Use of the Data Archiving Unit

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.

APPENDIX

Fiber A order	Fiber B order	Grating order	Central wavelength
0	0	161	3802 Å
1	1	160	3826 Å
2	2	159	3850 Å
...	...	...	...
44	44	117	5232 Å
45	GAP	116	5277 Å
GAP	GAP	115	5318 Å
46	45	114	5370 Å
47	46	113	5417 Å
...	...	...	...
70	69	90	6801 Å
71	70	89	6877 Å

Table 6.1: Order identified and extracted by the DRS .