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Very Large Telescope

HAWK-I
Calibration Plan

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1 Introduction

1.1 Scope and content

This document describes the calibration procedures for the HAWK-I instrument at the VLT.

The document is intended for observatory staff and interested users. Users not interested in all the details of the operations can simply refer to the calibration summary in the HAWK-I User Manual.

The basic calibration of science data requires a set of calibrations obtained shortly before or after the observations and covering the specific instrument set-up used. The calibration and monitoring of the entire instrument, on the other hand, requires a large set of calibrations covering all offered set-ups and obtained periodically.

In practice, for instruments like HAWK-I which offer only few standard set-ups both tasks are combined. The science data are calibrated during night and day time, typically in a 24h window of the science observations. In addition, a standard set of calibrations is performed regularly (daily to weekly depending on their nature). Combined, these calibrations allow to monitor and calibrate the entire instrument. Finally, a few monitoring calibrations are obtained on a monthly basis to observe long range trends of the instrument.

The Calibration plan and strategy did not change with the use of the Ground-Layer Adaptive Optics module : GRAAL with HAWK-I.

For each calibration task this document defines the:

- **Responsible** group to carry out the calibrations,
- **Phase** when the calibrations have to be carried out (e.g. day or night time),
- **Frequency**, i.e., how often the calibration task has to be carried out,
- **Purpose** of the calibration,
- **Procedure** or the way how the calibration task is carried out,
- **Outputs**, i.e. the Pipeline data products, the Quality Control (QC) parameters, and/or the keywords entered into the VLT engineering data stream ("FITSLOG") that are being produced by the calibration task,
- **Prepared OBs** to carry out the task (and their location in a corresponding **OT queues**),
- **Prepared Templates** to carry out the task (if no prepared OB exists)
- **Duration**, i.e. the estimated time to execute the calibration task,
- **Pre-requisites**, i.e. the possible dependencies on instrumental or sky conditions, or other calibration tasks.

The appendix of the document provides an estimate of the expected typical daily calibration times for HAWK-I .

1.2 Absence of internal calibration unit

The experience with ISAAC and WFCAM (UKIRT) showed that the calibration of NIR imaging mode data does not necessarily require an internal calibration source. Accordingly, HAWK-I, a pure NIR imager, was not designed to include a calibration unit. None of the calibrations described in this document require internal lamp exposures. However, some calibrations use exposures of the uniform (thermal) illumination of the Nasmyth screen.

The issue of flat-fielding on sky is addressed in Sect. 2.3.

1.3 References

none

1.4 Glossary

Day/Night time Calibrations: usually calibrations are done during day time following the night of observations. This implies a typical delay between science observations and day time calibrations of a few hours. Upon request, night time calibration can be provided. Their execution time is charged against the time allocated to the science program, unless explicitly listed in the calibration plan.

Template: is a set of instructions for the set-up of the instrument and detector followed by the performance of a specific standard operation. The templates are specially devised sequences used to simplify the execution of frequently performed instrument operations and calibrations.

Template Signature File: is a file describing for a given template its parameters, their default values and their allowed range of values.

Observation Block: is a collection of templates to be executed as a single block in order to obtain a coherent set of data. It consists of the potential target information, a set of templates, parameter files (if needed) for the templates, a list of execution conditions/requirements, and, potentially, comments. Constructing Observation Blocks is part of the Phase II Proposal Preparation Process.

2 SCIENTIFIC DATA CALIBRATIONS

This section of the HAWK-I calibration plan summarizes the HAWK-I calibrations that have to be collected (and with which frequency) in order to allow to remove the instrumental signatures from the scientific data.

These calibrations are accessible as standard calibrations to the user.

2.1 Summary: Science Data Calibrations

Table 1: BB = broad band filter; NB = narrow band filter; ZP= zero-point; EC= extinction coefficient; FF= flat field.

HAWK-I – Calibration Plan

Calibration	Exp. number	frequency	comments / purpose
Darks	10 / DIT-NDIT	daily	for each combination of DIT and maximum associated NDIT $<$ 120 s
Darks	5 . / DIT-NDIT	daily	for each combination of DIT and maximum associated NDIT $>$ 120 s
Twilight FF	1 set / filter	daily	BB filters (best effort basis)
	1 set / filter	as needed	for NB filters
ZPs	1 set / (BB) filter	daily	ZPs only when CLR or PHO
ZPs and ECs monitor	2 set / (BB) filter	daily	ZPs and ECs when PHO
Colour terms	1 set	monthly	BB filters only (best effort basis)
ECs reference values	1 set	monthly	BB filters only (best effort basis)
Illumination frames	1 set	monthly	ZPs across the field
Astrometric calibration	$1 + 1$ sets	monthly	plate scale, distortions
Detector characteristics	1 set	monthly	RON, dark current, linearity, gain, fixed pattern noise, inter-pixel capacitance correction

2.2 Darks

- **Responsible:** Science Operations
- **Phase:** Day time
- **Frequency:** Daily with several standard settings and as required for every DIT and associated maximun NDIT combination used during the previous night.
- **Purpose:** Calibration, read-out noise checks, hot pixel detection
- **Procedure:** Run the template, check results, report in night log. Darks are taken for each DIT and associated maximun NDIT . Ten Darks are taken for each DIT and associated maximun NDIT setting $<$ 120 s. Five Darks are taken for each DIT and associated maximun NDIT setting $>$120 s. Windowed darks are provided in case FastPhot is used.
- **Outputs:** pipeline products:
  ◦ Master dark frame
  ◦ Hot pixel map
  QC parameters:
  ◦ Readout Noise: mean/median/rms
- **Prepared OBs:** calob based on template `HAWKI_img_cal_Darks`
- **OT queue:** N/A
- **Pipeline support:** Recipe hawki_dark_combine can be used to produce a master dark frame. See pipeline manual for details.
- **Duration:** Variable, experience showed it to be from 45 min to 2h.
- **Pre-requisites:** none
- **See also:** none

2.3 Twilight Flat-fields

Flat-fielding is necessary to correct for several effects: to correct for pixel-to-pixel variations (each pixel of the array has a slightly different quantum efficiency than its neighbours); to correct for large scale variations of the quantum efficiency of the detectors; and in the case of HAWK-I to correct for the varying efficiency between the 128 read-out channels of the four arrays. The flat-field can also be used to compensate for vignetting of the optics, filter defects or dust on the optical elements. All above effects are multiplicative, and can ideally be removed by dividing a scientific exposure by the processed flat-field calibration frame.

Further additive effects exist (scattered light, fringing due to night sky emission lines, ...) but they do not change the signal of the astronomical object under study, i.e. do not need to be corrected for. They are, however, often difficult to disentangle from the multiplicative component and can thus limit the achievable correction.

Ideally, if the illumination would be homogeneous, flat-fielding would correct for all the multiplicative effects. For this purpose, the flat-field frames should be of a much higher S/N than the science images in order not to add noise to the latter.

Flat-fields for wide-field NIR imager are difficult to obtain given the restricted possibilities to homogeneously illuminate the field of view of the instrument. Wide-field imagers on 4m-class telescopes (WIRC/Palomar, OMEGA2000/Calar Alto, FLAMINGOS/KPNO, ISPI/CTIO) all use Dome flat-fields in addition of twilight flat-fields. However, ISAAC (with a ten times smaller field-of-view than HAWK-I), as well as WFCAM (UKIRT) only rely on twilight flat-fields in imaging mode and achieve $\sim$3% flatness over their fields.

For HAWK-I, the possibility to illuminate the Nasmyth calibration screen has been considered. The location relatively close to the focal plane would require a very homogeneous illumination of the screen if it was aimed at correcting for the large scale variations. No affordable technical solutions exist to realize this. Lower constraints on the homogeneity of the illumination of the screen would allow to use 'internal' flat-fields to correct for small scale variations, but these are also well corrected by twilight flat-fields.

Thus, HAWK-I only relies on twilight flat-fields. These are sufficient to correct (up the $\sim$ 3% level) for any pixel-to-pixel and small scale variations. The twilight flat-fields are also used to determine dead pixels and to adjust (harmonize) the gain between the four detectors of the mosaic.

- **Responsible:** Science Operations
- **Phase:** Night time (morning and evening twilight)
- **Frequency:** Twilight flats has 21 validated days to date of the science data taken
- **Purpose:** To correct for pixel-to-pixel gain variations and small scale variations, to compute a bad pixel map and to harmonize the gain between the four detectors.

- **Procedure:** The acquisition of twilight flats with HAWK-I is similar to the NACO ones. It is usually possible to do one NB filters and a few BB filters in a single twilight. However, the window of opportunity for obtaining these flats lasts only a few minutes. Because star trails affect the flats we recommend to have 20 frames per filter, thus reducing the number of filters that can be done in a single twilight.

Skyflats for almost all filters are taking tracking at empty field. The only exception are red NB filters (see below.) The corresponding OBs are named SkyFlat-HHMM-BB for BB filters and SkyFlat-HHMM-NB for the NB filters and are located in the HAWKI TWILIGHT FLATS queue.

Red NB filters (BrG, H2 and NB2090) skyflats are taking without preset and tracking. The corresponding OB is named Flat-sequence-NB- red and is also located in the HAWKI TWILIGHT FLATS queue.

The user will then be prompted to set up the instrument. It is usually possible to start the twilight flats in NB 30 minutes before sunset, in Ks about 2 minutes after sunset, and in H, J, and Y about 12 minutes after sunset. In the evening, the procedure is to measure the number of counts on the RTD, and start when the counts reach ~ 25.000 ADU. The template is to be aborted when the number of counts is no longer decreasing. This will usually take between 15 to 25 exposures.

In the morning, the procedure is the reverse one to the night – only H,J, and Y can be flat-fielded before the telescope is closed (10 min before sunrise).

Special care has to be taken for Fast Photometry skyflats. There are two Fast Photometry templates for flats : Windowed Skyflats and Windowed Twilight flats which will be offered for P100. The read-out mode is set to *DoubleRdRstRd* and the window configuration need to be adjusted to the one of the users.

- **Outputs:** pipeline products:
  ○ Master flat-field frames
  ○ Cold pixel map
  QC parameters:
- **Prepared OBs:** see above, depending on the filter.
- **OT queue:** `HAWK-I TWILIGHT FLATS`
- **Pipeline support:** Recipe hawki_twilight_flat_combine can be used to produce a flat field frame. See pipeline manual for the details.
- **Duration:** Start $\sim$ 1h before sunset, ends $\sim$ 20 min after sunset
- **Pre-requisites:** Clear / Photometric. Cloudy conditions do not allow to take proper twilight flats
- **See also:**

2.4 Photometric calibrations

2.4.1 HAWK-I 2MASS calibrator fields

We are observing, on a best effort basis, a set of 2MASS fields so that we can cross-calibrate the HAWK-I photometry. These fields are adapted - in terms of field covearge and magnitude - from the 2MASS touchstone fields (http://www.ipac.caltech.edu/2mass/releases/allsky/doc/sec3$_{2d}$.html).

The following are intended as guidelines for the observations of the HAWK-I fundamental standard fields.

- At the beginning of the night one standard field is chosen to control the night quality. Basically a measure of the zero-point is obtained, and compared with previous nights. If the night is found to be photometric, a second standard at high airmass is taken to confirm the zeropoint and get an estimate of the extinction.
- In poor seeing photometric nights star fields at different airmasses are observed (instead of going idle)
- The 2MASS fields are observed for a proper determination of the transformation between 2MASS and HAWKI system.

Field	RA	Dec	mag range	Comment
S90021	00 24 25.0	-02 00 10.6	10.56-13.54	
S90301	02 26 51.0	-39 32 33.6	10.78-11.54	
S90013	05 57 13.0	+00 19 08.0	10.01-12.01	
S90067	08 51 24.0	+11 52 24.8	9.76-12.66	include FS 16
S90217	12 01 59.0	-50 21 47.3	10.13-11.14	
S90868	15 00 29.0	-00 28 28.3	10.20-13.41	include T868-5385
S90547	18 51 18.0	-04 12 29.6	10.21-11.34	
S90813	20 41 20.0	-05 06 36.2	10.49-12.17	

2.4.2 Daily: Zero points and extinction coefficients monitor

Every night, the photometric zero points are determined.

- **Responsible:** Science Operations
- **Phase:** Night time
- **Frequency:** Nightly (visitor and service), 1 or 2 standard fields. Irrespective of the filters used during the night, the 4 broad band filters should be calibrated. **Zero points for the narrow band filters are NOT foreseen in the calibration plan**.
- **Purpose:** Zero point determination of the photometric calibration. If the condition are CLR we observe only 1 standard field. In case the conditions are declared photometric, we provide a second standard field at high airmass to monitor the extinction coefficients, ideally soon after the OB which needs photometric conditions

- **Procedure:** The pre-defined OBs will position the photometric standard field at the center of the field of view. Small offsets are made and four images are obtained per filter.

  The usual procedure (adopted by the calibration plan) is to measure the zero points at the beginning of the night, after the twilight flats, when the sky is still too bright for science observations, or at the end of the night. **Should the user require a good photometric calibration throughout the night, special calibration (charged against the user's time) need to be requested.**

  Standards from the approved lists shall be used.

- **Outputs:** pipeline products:
  ○ Reduced standard star image
  QC parameters:
  ○ Zero points

- **Prepared OBs:** Many, based on the templates `HAWKI_img_acq_Preset`and `HAWKI_img_cal_StandardStar`

- **OT queue:** `HAWK-I TOUCHSTONE FIELDS`

- **Pipeline support:** Recipe hawki_standard_process

- **Duration:** Typically 30 min for 1 standard field for all 4 filters.

- **Pre-requisites:** Photometric or clear conditions. (It might be useful under some clear/cloudy conditions (light uniform cirrus) to obtain zero points in order to get an idea of the cloud extinction.)

- **See also:**

3 MAINTENANCE CALIBRATIONS

3.1 Summary: Technical Calibrations

This section of the HAWK-I calibration plan summarizes the HAWK-I *technical* calibrations that are being collected to complement the science data calibrations. They are used by ESO to compute instrument characteristics that are then provided to the user (e.g. field distortions, zero point variations, ...). These calibrations are performed less frequently than the science data calibrations. They are normally NOT accessible as special calibrations to the user.

Monitoring data are normally made available as QC parameters through QC web pages and FITSLOG keywords through the Paranal Autrep database with standard plots created on a daily basis.

3.2 Detector Characterization and Monitoring

The characteristics (read-out noise, dark current, bad pixels, linearity, persistence, ...) of the detector mosaic are monitored periodically.

This is partly achieved with the calibrations listed above (in particular with Darks, see Sect. 2.2). Yet, several characteristics (linearity, conversion factor, ...) require a set of internal flat-fields with various illumination in order to be determined. This is the purpose of this calibration. Note, however, that HAWK-I has no internal calibration source, i.e. the images are acquired on the dark Nasmyth screen in the Ks band.

- **Responsible:** Science Operations
- **Phase:** Daytime
- **Frequency:** Monthly
- **Purpose:** Characterize the Detector via the following parameters:
  - RON as a function of read-out mode
  - Dark current
  - Conversion factor
  - Bad pixel/columns map
  - Linearity
  - Gain
  - Fixed Pattern Noise
  - Inter-pixel capacitance correction
- **Procedure:** Take a series of flats, darks for the standard detector modes
- **Outputs:** pipeline products and associated template:
  QC parameters:
  ◦ RON (`HAWKI_img_cal_Darks`)
  ◦ Dark current (`HAWKI_img_cal_Darks`)
  ◦ Bad pixel/columns map (`HAWKI_img_cal_TwFlats`)
  ◦ Linearity (`HAWKI_img_tec_DetTest`)
  ◦ Gain (`HAWKI_img_tec_DetTest`)
  ◦ Fixed pattern noise (`HAWKI_img_tec_DetTest`)
  ◦ Inter-pixel capacitance correction (`HAWKI_img_tec_DetTest`)
- **Prepared OBs:** TBD, based on `HAWKI_img_cal_Darks`, `HAWKI_img_cal_TwFlats`, and `HAWKI_img_tec_DetTest`
- **OT queue:** `HAWK-I.Daytime.Calibration`
- **Duration:** $\sim 2h$
- **Pre-requisites:** Detectors have stabilized, i.e. been online for > 6 h.
- **See also:** Darks and Flats, Sects. 2.2, 2.3

A Daily Calibration Time Estimates

Typical calibration times will first be recorded during commissioning. More detailed estimates for this section are expected from experience collected during the dry run and operations.

Overall, the time for daytime calibration is expected to be short. An estimate for daytime calibrations is:

Type	Set-ups	Estimated time per set-up	Total time
Darks	each DIT/NDIT combination	<1000s	45 min to 2h
Detector Monitoring	Ks filter	2h	

An estimate for night time calibrations is:

Type	Set-ups	Estimated total time
Twilight Flat-fields	all filters/twilight	80 min (from 1h before, until 20 min after sunset)
Zero points	1 field / quad / filter	15 min

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