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Organisation Européene pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

ESO - European Southern Observatory
Karl-Schwarzschild Str. 2, D-85748 Garching bei München

Very Large Telescope

HAWK-I
Calibration Plan

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Prepared by M. Kissler-Patig for the HAWK-I team . . . .
Date Signature

Approved O.Hainaut . . . .
Name Date Signature

Released A. Kaufer . . . .
Name Date Signature

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Contents

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.

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 describe 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: it 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

HAWK-I – Calibration Plan

TO BE UPDATED COMM1

Calibration	number	frequency	comments / purpose
Darks	10 exp. / DIT-NDIT	daily	for all pairs with DIT$\times$NDIT $\leq$ 120
Darks	5 exp. / DIT-NDIT	daily	for all other DIT-NDIT pairs taken during the night
Twilight Flat-fields	1 set / filter	daily	for broad-band filters
	1 set / filter	as needed	for narrow-band filters
Zero points	1 set / (broad-band) filter	daily	zero points only
Illumination frames	1 set	monthly	zero point variations across the field
Astrometric calibration	$1+1$ sets	monthly	plate scale, distortions
Detector characteritics	1 set	monthly	RON, dark current, linearity, ...

2.2 Darks

- **Responsible:** Science Operations
- **Phase:** Day time
- **Frequency:** Daily with a standard setting and as required for every DIT/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/NDIT setting used during the night. Ten Darks are taken for each DITxNDIT setting $<$ 120 s. Five Darks are taken for each DITxNDIT pair $>$120 s.
- **Outputs:** pipeline products:
  ◦ Master dark frame
  ◦ Hot pixel map
  QC parameters:
  ◦ Readout Noise: mean/median/rms
- **Prepared OBs:** calobbuild based on template `HAWKI_img_cal_Darks`
- **OT queue:** N/A
- **Duration:** variable, experience showed it to be from 45 min to 2h.
- **Pre-requisites:** none
- **See also:**

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 neighbor); 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 solution 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. Zero point variations across the field are corrected by the illumination calibrations (see Sect. 2.7).

- **Responsible:** Science Operations
- **Phase:** Night time (morning and evening twilight)
- **Frequency:** Daily, depending on filter used. It is probably not strictly necessary to take flats every day, twilight flats might typically be used over several days.
- **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 several NB filters and all BB filters in a twilight. However, the window of opportunity for obtaining these flats lasts only a few minutes.

  No preset is done and the telescope is left pointing to Zenith (no tracking!). The instrument is set in imaging mode with the minimum DIT and with the filter wheels in close position, so that the detector does not see light.

  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,Y about 12 minutes after sunset. Typically 2-3 filters are flat-fielded "simultaneously", cycling through the filters. OBs are prepared for the optimal combinations.

  In the evening it is important to set up the desired filter before removing the close position, so as not to saturate the detector by going through filter positions which will receive more light and which could saturate the detector.

  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 takes between 15 to 25 exposures.

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

- **Outputs:** pipeline products:
  ○ Master flat-field frames
  ○ Cold pixel map
  QC parameters:

- **Prepared OBs:** TBD, based on the template `HAWKI_img_cal_TwFlats`

- **OT queue:** `HAWK-I.Nighttime.Calibration`

- **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 Zero points

2.5 Daily

Every night, the photometric zero points are determined.

- **Responsible:** Science Operations
- **Phase:** Night time
- **Frequency:** Nightly (visitor and service), 1 star. 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. Note that the checking for variations of the zero point across the field is not the purpose of this calibration but of the illumination frames (see Sect. 2.7).
- **Procedure:** The pre-defined OBs will position the photometric standard star at the center of the each detector. I.e. 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 (UKIRT Faint standards) shall be used.

  Always check the magnitude of the object. Stars with magnitudes fainter than 11.5 are preferred. If the counts in the central pixel are much higher than 25.000 ADU, then degrade the image quality (i.e. do a onecal, or badAO, instead of full active optics), or choose a fainter star.
- **Outputs:** pipeline products:
  ◦ Reduced standard star image
  QC parameters:
  ◦ Zero points
- **Prepared OBs:** TBD, based on the templates `HAWKI_img_acq_Preset`and `HAWKI_img_cal_StandardStar`
- **OT queue:** `HAWK-I.Nighttime.Calibration`
- **Duration:** Typically 30 min for 1 star in all 4 quadrants for all 4 filters.
- **Pre-requisites:** Photometric 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:** Illumination frames, Sect. 2.7

2.6 Monthly

Once per month, colour terms and extinction coefficients are monitored.

- **Responsible:** Science Operations
- **Phase:** Night time
- **Frequency:** Monthly (in service in bad seeing conditions). The 4 broad band filters should be calibrated.
- **Purpose:** Zero point, colour term and extinction coefficient determination of the photometric calibration.
- **Procedure:** The procedure is exactly the same as for the Daily zero point determination - except that the calibration is repeated three or four times throughout the night to follow the standard star from an airmass of ∼1 down to an airmass of ∼2.
- **Outputs:** pipeline products:
  ◦ Reduced standard star image
  QC parameters:
  ◦ Zero points
  ◦ Color terms
  ◦ Extinction coefficients
  The latter two are not products of the pipeline, but of the QC trending.
- **Prepared OBs:** TBD, based on the templates `HAWKI_img_acq_Preset` and `HAWKI_img_cal_StandardStar`
- **OT queue:** `HAWK-I.Nighttime.Calibration`
- **Duration:** Three of four times 30 min through the night.
- **Pre-requisites:** Photometric conditions.
- **See also:** Illumination frames, Sect. 2.7

2.7 Illumination Frames

The illumination frames are used to correct for large scale variations of the zero point across the field.

Only broad-band filters are supported in the calibration plan.

They complement the zero point calibration (see Sect. 2.4) and use the UKIRT faint standard star.

In the future the procedure might be replaced by observing 2MASS standard fields (avoiding multiple pointings). The photometric accuracy of 2MASS is typically 1.5% and sets the limit on the illumination correction.

- **Responsible:** Science Operations
- **Phase:** Night time
- **Frequency:** Once every month (frequency can be decreased if the stability is confirmed), or after intervention on the instrument.
- **Purpose:** modeled the zero point variations across the field
- **Procedure:** A standard field is typically dithered in a 5×5 pointing pattern with (automatically determined) ∼400 pix offsets. The grid can be varied in the template. The variations in zero point across the field are measured and modeled.

  The prepared OB will run through a set of pre-defined telescope offsets. Ensure that the number of counts and DIT/NDIT settings are such that the S/N is around a few hundreds on the star.
- **Outputs:** pipeline products:
  ◦ Illumination correction map
  QC parameters:
  ◦ Illumination statistics (min, max, mean, rms)
- **Prepared OBs:** TBD, based on the template `HAWKI_img_tec_IlluFrame`
- **OT queue:** `HAWK-I.Nighttime.Calibration`
- **Duration:** The 5x5 grid in each quadrant was timed to need 1h40 per filter.
- **Pre-requisites:** Photometric, any seeing
- **See also:** Zero points, Sect. 2.4

2.8 Astrometry

The average distortion solution across the field is determined following the method outlined in Anderson et al. (2006, A&A 454, 1029) .

- **Responsible:** Science Operations
- **Phase:** Night time
- **Frequency:** Once every month (frequency can be decreased if the stability is confirmed), or after intervention on the instrument.
- **Purpose:** to determine the average distorsion solution
- **Procedure:** to obtain a set of "dithered" images, observed in a regular grid of 5∼5 large (∼ 200 pix) offsets. At each offset position,five exposures of 60s in (typically) Y or J are obtained.
- **Outputs:** pipeline products (supported in the future):
  ◦ distortions
  QC parameters:
- **Prepared OBs:** TBD based on the templates `HAWKI_img_acq_Preset`and `HAWKI_img_tec_Astrometry`
- **OT queue:** `HAWK-I.Nighttime.Calibration`
- **Duration:** 45–60 min
- **Pre-requisites:**
- **See also:** Flexure and Plate Scale, Sect. 3.4.

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 is 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 K 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
  - Persistence
  - Relative Contamination
- **Procedure:** Take a series of flats, darks for the standard detector modes
- **Outputs:** pipeline products:
  ◦ ...
  QC parameters:
  ◦ RON
  ◦ Dark current
  ◦ Conversion factor / Gain
  ◦ Bad pixel/columns map
  ◦ Linearity
  ◦ Persistence
  ◦ Relative Contamination
- **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

3.3 Filter position monitoring

This calibration is used to exercise the filter wheel. The data taken are then used to monitor some of the internal "flat fields". Since HAWK-I does not have a calibration's unit, the "internal flats" correspond to long integrations on the Nasmyth shutter. They cannot be used to calibrate science data (they are not flat) but are useful to monitor the instrument's transparency (throughput).

- **Responsible:** Science Operations
- **Phase:** Daytime
- **Frequency:** Monthly
- **Purpose:** to exercise the filter wheel and to determine the stability of the "internal flats"
- **Procedure:** One can give a list of filters for both filter wheel (FW) 1 and FW2. The template starts working through the list given for FW1. It sets a filter (e.g. J) and takes an image then move back to the filter defined as first in that list and moves back (i.e to J) and takes another image. It was originally meant to test the filter wheel reproducibilty but not having e.g. a pinhole array, it is not possible. Instead we use this to take "internal flats" to monitor the transparency of the optics. Once the OB ran through the list of FW1, it then repeats the same procedure for FW2.
- **Outputs:** Median flux for a given filter (over the full field and some pre-defined sub-windows).
- **Prepared OBs:** TBD, based on `HAWKI_FW_test_daily`
- **OT queue:** `HAWK-I.Daytime.Calibration`
- **Duration:** $\sim$ 30 min
- **Pre-requisites:** At most lower lights in the dome
- **See also:** Twilight Flat-fields

3.4 Flexure and Plate Scale

This calibration complements the first step of the astrometric calibration (see Sect. 2.8).

The absolute scale and flexures are determined. Note that the flexures are currently measured to be negligible (<1pix over 180 deg rotation; while typical rotations over one hour are <30 degrees when not crossing meridian close to zenith).

- **Responsible:** Science Operations
- **Phase:** Night time
- **Frequency:** Monthly
- **Purpose:** to measure the instrument flexures and determine the absolute plate scale
- **Procedure:** to points towards a standard astrometric field, configures the instrument, and acquires one image per position angle of the telescope adapter/rotator, while the later scans over 400 degrees in steps of 30 degrees (TBD).

  Use standard astrometric fields from the approved lists.
- **Outputs:** pipeline products:
  ◦ center of rotation
  ◦ flexure measure
  ◦ plate scale
  ◦ rotator offset
  ◦ WCS
  QC parameters:
- **Prepared OBs:** TBD based on the templates `HAWKI_img_acq_Preset`and `HAWKI_img_tec_Flexure`
- **OT queue:** `HAWK-I.Nighttime.Calibration`
- **Duration:** $\sim$ 30 min
- **Pre-requisites:** science calibrations and average distortion map
- **See also:** Astrometry, Sect.2.8

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
Filter Wheel check	all filters		30 min

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 star / quad / filter	30 min before astronomical twilight
Zero points +	as above at 3-4 airmasses	30 min per airmass; 2h in a night
Illumination frames	1 set / filter	100 min per filter
Astrometric calibration	1 set of 25 images	45–60 min

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